

User Manual

# BEAMGAGE® USER GUIDE

## LASER BEAM ANALYZER

### FOR WINDOWS 10®

BEAMGAGE STANDARD EDITION VERSION 6.X  
BEAMGAGE PROFESSIONAL EDITION VERSION 6.X

OPHIR-SPIRICON, LLC  
3050 NORTH 300 WEST  
NORTH LOGAN, UTAH 84341  
(800) 383-0814 OR (435) 753-3729

FAX: (435) 753-5231  
E-MAIL SERVICE: [SERVICE.OPHIR.USA@MKSINST.COM](mailto:SERVICE.OPHIR.USA@MKSINST.COM)  
E-MAIL SALES: [SALES.OPHIR.USA@MKSINST.COM](mailto:SALES.OPHIR.USA@MKSINST.COM)  
[WWW.OPHIROPT.COM](http://WWW.OPHIROPT.COM)



Dear Ophir-Spiricon Customer,

Thank you for your recent purchase of the BeamGage system.

At Ophir-Spiricon we strive to provide the highest level of leading edge photonic measurement technology and service possible. We hope that your experience with us is a pleasant one, and anticipate the relationship we build will serve your photonic measurement needs for years to come.

As a valued customer, your comments and opinions are always very important to us. If you have any concerns, questions, or comments, bring them to our service department's attention. We are ready to help with everything from basic setup to working with you to find solutions for your most complex photonics measurement needs.

Please let us know if there is any way we can be of service. Thank you once again for your business.

Sincerely,

Ophir-Spiricon, LLC

Ophir-Spiricon, LLC  
3050 North 300 West  
North Logan, UT 84341, USA

Tel 435-753-3729  
Fax 435-755-5231

[www.ophiropt.com/photonics](http://www.ophiropt.com/photonics)

# How to Use this Guide

## Introduction

Read this user guide before setting up your BeamGage system. Become familiar with the laser beam analysis theory and acquire a basic understanding of how BeamGage operates. Insights gained through this review facilitate achieving a correct system setup, and help with interpreting results.

## Chapter Outline

### **Chapter 1 Equipment Setup**

Provides instruction on getting started, and describes how to utilize pre-canned setups that can speed up collecting useful beam data for the first time user.

### **Chapter 2 BeamGage Operating Controls**

Describes the various displays, control panels, menus, and dialog boxes in detail, along with configuration considerations and optimization techniques.

### **Chapter 3 Displays**

Explains how to employ the many display controls that are used to launch, dock, float, pin, and hide the various display components.

### **Chapter 4 Files, Formats, and Privileges**

Describes the types of file formats generated by BeamGage and some of the things that can be done with them. Also how to lockout controls for restricted users.

### **Chapter 5 Computations**

Presents background information on the theory behind the laser beam measurements and the ISO measurement methods, as well as the BeamMaker modeling feature.

### **Chapter 6 Partitioning**

Presents instructions on how to use the BeamGage Partitioning feature available only in Professional edition.

### **Chapter 7 Custom Calculations**

Presents instructions on how to use the BeamGage Custom Calculations Server available only in Professional edition.

### **Chapter 8 Automation Interface**

Presents instructions on how to use the BeamGage Automation Server available only in Professional edition.

## Symbol Notation



Indicates general information that poses no risk.



Indicates important information about the product with little or no risk.



Indicates warning information. Failure to follow instruction may result in harm to the user or product damage.

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# Safety

While BeamGage itself does not present the user with any safety hazards, this instrument is intended for use with laser systems. Therefore, the user should protect from any hazards that the laser system may present. The greatest hazards associated with laser systems are damage to the eyes and skin due to laser radiation.

## Optical Radiation Hazards



Use of this instrument requires the operator to work near the optical path of lasers. Exposure to radiation from these lasers may be sufficient to warrant the use of protective equipment.

Unless the laser's optical path is enclosed, the operator, and any other personnel should be protected against accidental exposure. Hazards include direct beam exposure and reflected radiation.

When working with an unenclosed beam path, it is advisable to do so while the laser is powered down or at reduced power levels. Whenever there is a risk for dangerous exposure, protective eye shields and clothing should be worn.

## Electrical Hazards



BeamGage utilizes only low voltages, derived from the USB bus and camera power supplies. Thus, there is little risk of electrical shock presented to the user.

Always disconnect the power to the computer when installing or removing hardware from a PC.

Always operate the computer with its covers in place and in accordance with its manufacturer's recommendations.

Always operate the computer with a properly grounded AC power cord.



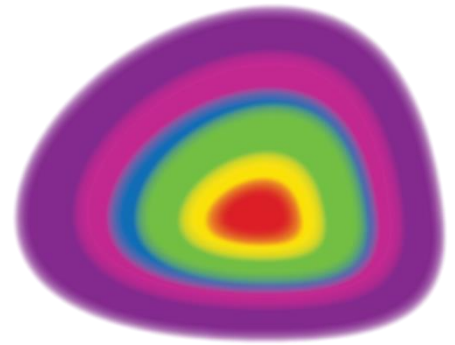
# Information

## Introduction to BeamGage

BeamGage is a low cost, PC-based product for use in modern multi-core advanced personal computers running Windows 10 operating system.



*Ophir-Spiricon no longer verifies or certifies operation with Windows 7 or with 32-bit machines.*



*BeamGage 6.17.0 is the last version of BeamGage that provides a 32-bit installation package. Future versions will provide a 64-bit installation package only. For those users that must maintain 32-bit legacy systems, BeamGage 6.17.0 will continue to be available for download from our website.*

### Industry standard results:

- ISO plus expanded Gauss fit capabilities for both 1D and 2D
- Full ISO Top-Hat results
- All ISO beam width and diameter methods supported
- Industry standard data file formats, HDF5 and CSV

### Accurate and powerful measurements:

- High-speed high-resolution false color beam intensity profile displays in both 2D and 3D
- Numerical beam profile analysis employing advanced patented calibration algorithms
- Extensive set of ISO quantitative measurements
- Three Divergence measurement techniques, one ISO method
- Expanded **Positional Stability** results in the form of strip charts and scatter plots
- Statistical Analysis of all measured parameters
- Pass/fail testing available on most all measured parameters

### Powerful software features:

- **BeamMaker** beam simulator for algorithm self-validation
- Video Playback console for review and post processing
- Continuous zoom scaling in both 2D and 3D
- Both Manual and Auto Aperture for isolating beam data
- Off axis aspect ratio image correction
- Histogram display and results
- Integrated automatic Help linked into this User Guide

### Intuitive and simple to use customization features:

- Enhanced window layout tools to get the most out of the desktop display area, including satellite windows that can span multiple monitors
- .NET Automation interface that allows for third party remote control

- The ability to program Custom Calculations results
- Both Results and Data logging capabilities with multiple logging methods
- Configurable Report Generator that allows cut and paste of results, images, and settings from .PDF file types

#### Versatile hardware support:

- Operates in Windows 10 (64-bit) operating systems
- Support for USB, Gig-E, and Pyrocam
- Results synchronized to select models of Ophir power/energy meters
- Camera **ROI** support on USB and Gig-E cameras

## Equipment

The equipment included varies by camera purchased.

#### A complete BeamGage system requires:

- BeamGage software
- BeamGage licensed camera with associated hardware
- Windows PC

#### Optional equipment:

- A printer with appropriate Windows compatible drivers
- LBS-300, LBS-100, or other Laser Beam Attenuator
- USB-TTL Pass/Fail signaling option (SP90060)



#### System Requirements:

<b>Operating System</b>	Windows 10 (64-bit)
<b>Processor</b>	A multi-core style (2.00 GHz or better) or equivalent
<b>Main Memory</b>	4 GB minimum
<b>Hard Disk Memory</b>	50 GB
<b>Monitor</b>	High resolution 1920x1080 minimum
<b>Graphics</b>	Advanced Graphics chip set with 256MB of dedicated graphics memory
<b>Inputs</b>	USB 2.0, USB3, or GigE



*All latest Microsoft updates and service packs must be installed prior to BeamGage installation to ensure successful operation.*

# Chapter 1 Equipment Setup

Read the previous section to see system requirements for BeamGage operation.

## 1.1 BeamGage Software Installation



*Do not connect the camera to the computer until after the BeamGage software is installed.*

### Install the BeamGage Software Application:

There are two ways to install the software from the provided DVD. All installations must be performed with Administrator privileges.

- A. If the computer is setup to Auto Play DVDs do the following:
  1. Insert the supplied DVD into the DVD drive and wait for the **Spiricon Software Auto Install** screen to appear.
  2. Select **Software Install**.
  3. Follow the directions on screen.
- B. If the computer does not have the Auto Play feature enabled:
  1. Insert the supplied DVD into the DVD drive and open **Windows Explorer**.
  2. Select **My Computer** and right-click on the DVD drive with Ophir-Spiricon DVD. Select **Autoplay** and wait for the **Spiricon Software Auto Install** screen to open.
  3. Select the **Software Install** button.
  4. Follow the directions on screen.



*Certain Drivers are required when installing BeamGage and the installation of these drivers may be interrupted by StarLab. Refer to the Ophir-Spiricon Driver Manager User Guide for details.*



*Ophir-Spiricon no longer verifies or certifies operation with Windows 7 or with 32-bit machines.*

## 1.2 Connect the Camera



*Some cameras require additional installation steps. Please refer to the appropriate camera appendix for additional information.*

Connect only one camera to the PC with the provided USB or GigE cable.

Some cameras, such as the Pyrocam, Xeva, and L11059, require an external power supply. Be sure to connect the camera to its provided power supply and connect it to a compatible AC power source as applicable.



*Cameras must be licensed in order to operate in BeamGage, and only those sold with Ophir-Spiricon products can be licensed.*

## 1.3 Launch BeamGage

To start the BeamGage application, go to the Windows taskbar and select **Start -> All Programs -> BeamGage [edition]**

On startup BeamGage attempts to connect to a camera in the following order:

1. With a saved Setup file
  - a. Find the camera used in the last saved setup—*Fastest*
  - b. Find a camera of the same model used in the last saved setup—*Faster*
  - c. Connect to the first compatible camera it can find—*Slowest*
2. No saved setup is found
  - a. BeamGage looks for the first compatible camera—*Fast*





*Review the remaining chapters to become familiar with BeamGage before taking measurements.*

## 1.4 Camera Setup

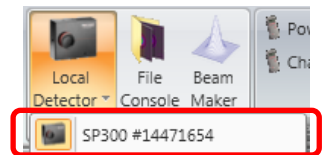
The first time BeamGage is opened it connects to the first camera found, loads the default configuration, and displays camera data in the 2D display window. The default setup assumes a CW laser application and is useful as an initial starting point. The 2D image indicates the presence of light striking the camera imager as the camera is exposed to room light.

Select the **Source** ribbon tab to view the controls for the camera.



Select the **Pause**  and **Start**  button to stop and start data collection.

If a camera is connected after launching the software, select **Local Detector** from the **Source** ribbon tab. Available cameras appear in the drop-down by model and serial number. Select the camera to connect; the camera controls display in the ribbon bar and the camera begins collecting data.



*When an unlicensed camera is connected, controls are locked and a license entry box displays in the ribbon. Users upgrading from LBA, BeamStar, or BeamMic are provided a license key. Enter the license key in the entry box and follow the instructions on screen.*

Become familiar with the camera controls and features associated with the attached camera. Some cameras have unique capabilities depending upon the make and model.

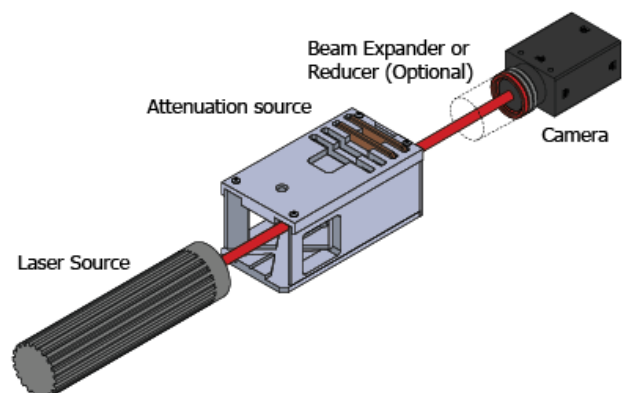
## 1.5 Equipment Setup

BeamGage can be used in various setups depending on the needs of the user. The following diagrams are concepts which can be used to meet the needs of specific applications. Devices may vary in appearance.

### 1.5.1 Direct to Camera

Direct to Camera is the most common setup. This setup directs the beam straight into the camera. Beams should be properly attenuated and reduced, expanded, or converted as needed.

This setup is best used with beams with lower power densities, collimated beams, or when the beam can be accessed by a beam splitter to sample or direct the beam directly into the imaging optics.



The beam is properly attenuated and sized if the image is not saturated and the beam does not exceed 2/3 of the camera imager size.

## 1.5.2 Camera Off Axis

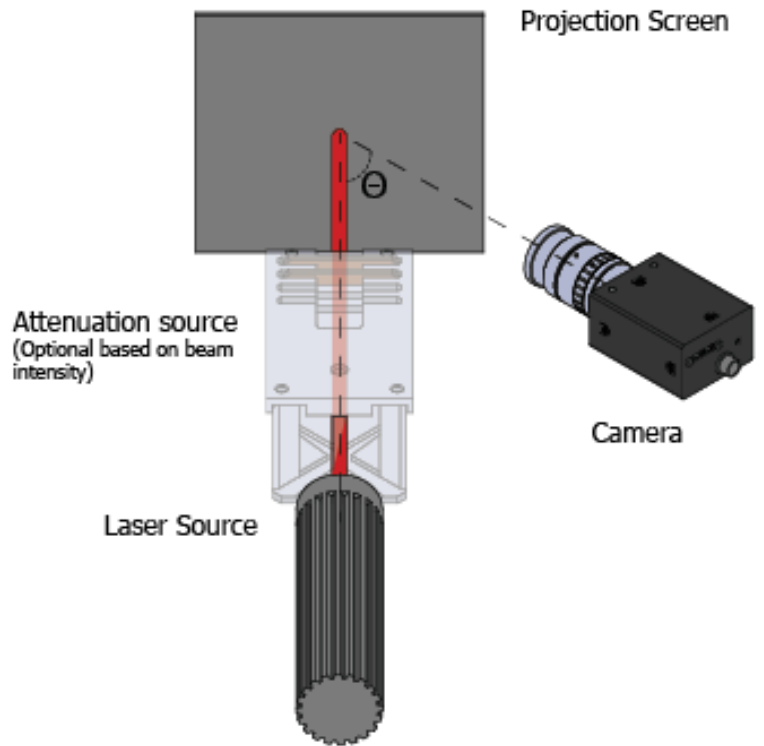
In this setup the beam is cast directly on a projection screen and the camera images the beam projection from an angle (see 2.5.7).

High intensity beams should be attenuated before the projection screen to eliminate the risk of damage.

Best used when:

- The beam is converging or diverging and cannot be accessed by a beam splitter
- Cannot be shone directly into imaging optics
- The power density is too high for the imaging optics.

The beam is properly attenuated when the image on the camera is not saturated.



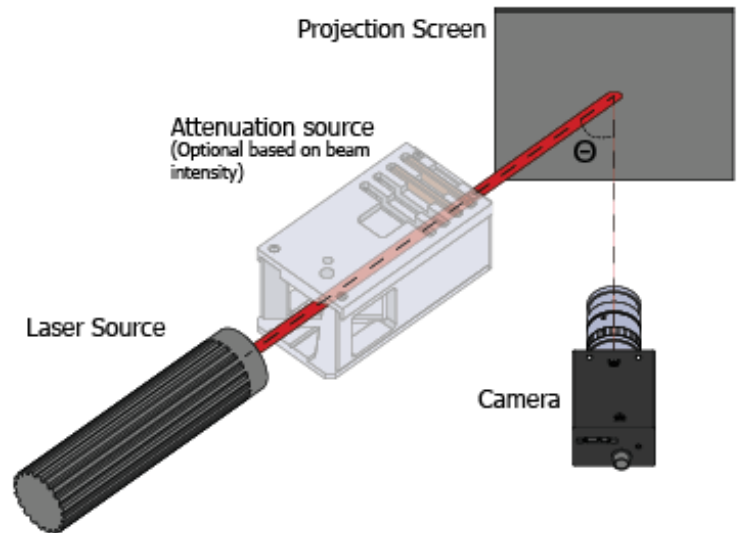
## 1.5.3 Laser Off Axis

In this setup the beam is cast at an angle onto a projection screen and the camera images the beam projection directly (see 2.5.7).

High intensity beams should be attenuated before the projection screen to eliminate the risk of damage.

This is the least desirable approach and should only be used if mechanically placing the camera off axis does not allow the image to be viewed by the camera.

The beam is properly attenuated when the image on the camera is not saturated.



## 1.6 Attenuation

Most laser beams require significant amounts of attenuation before application to the camera sensor. Attenuation requirements vary greatly depending upon the application. Ophir offers optional equipment for beam attenuation. Consult an Ophir Representative or call the Ophir Sales Department for further information.

Most Ophir supplied cameras ship with a basic set of ND filters able to



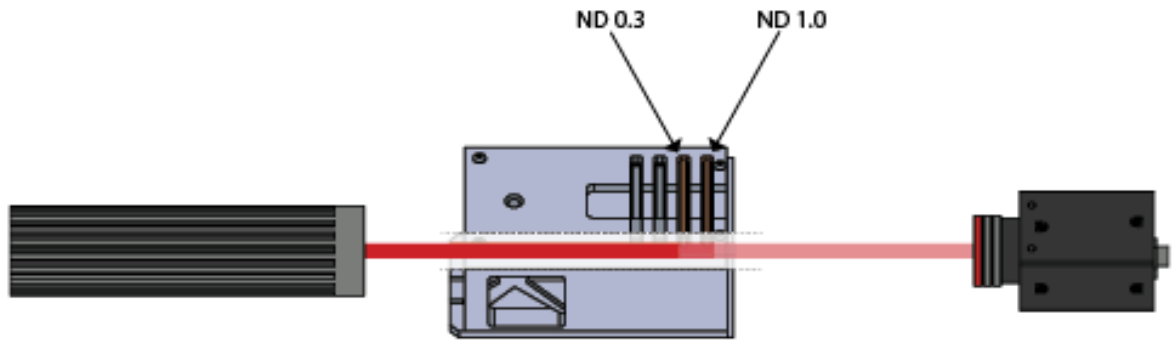
Stackable ND Filters

attenuate lasers up to approximately 5 Watts/cm<sup>2</sup>. Greater power levels require additional beam attenuating devices to prevent damage.

Before collecting data with the camera, insert the necessary amount of beam attenuation devices between the camera input and the laser beam output and then align the camera with the laser beam.



*Always order ND filters from weakest to strongest with the strongest closer to the camera. Beams that are not filtered in the proper order can damage the ND filters.*



*Camera imagers can be easily damaged. Be sure to read and do not exceed the damage specifications of the supplied camera. Replacing camera imagers is time consuming and costly.*

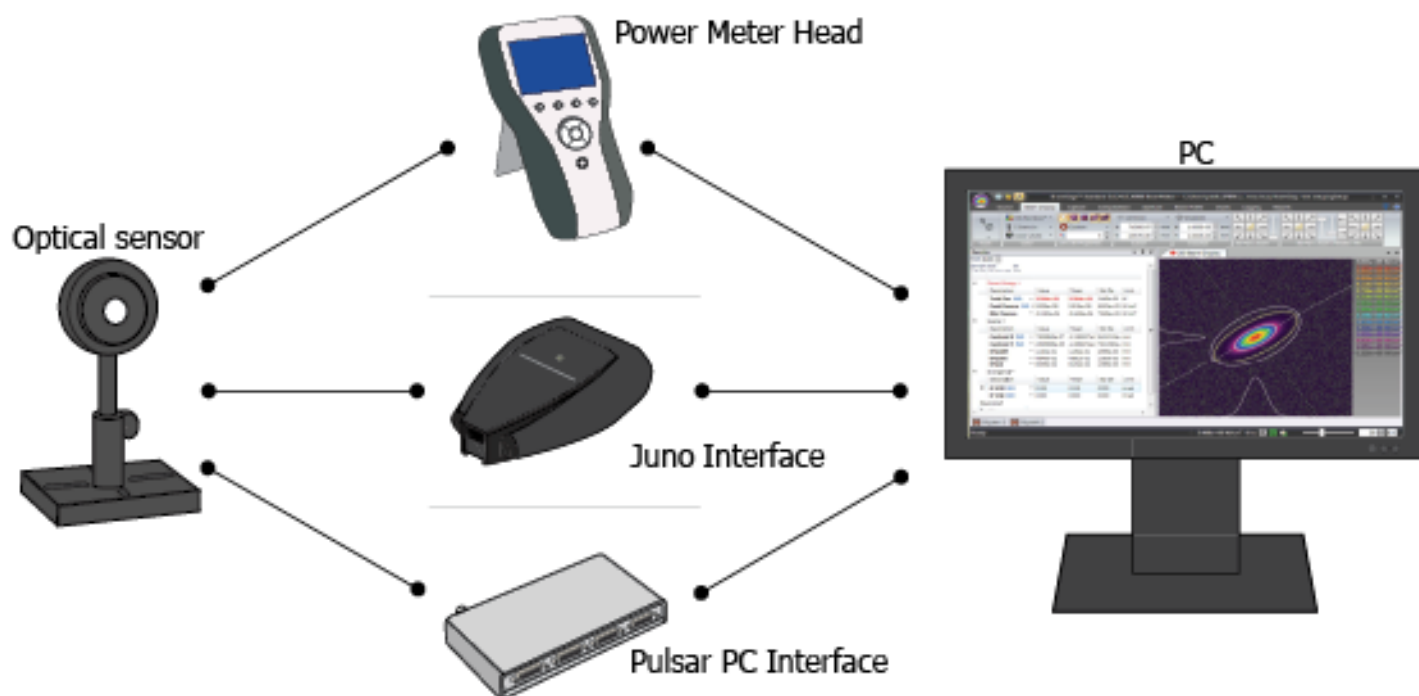
## 1.7 Connect a Power/Energy Measurement Device (Optional)

BeamGage has the ability to utilize an external Ophir power/energy meter for real-time reporting of the lasers total power/energy. Current supported Ophir products include:

- USBI and Pulsar -1, -2, and -4 channel USB models
- Vega, Nova II, StarLite, StarBright, and Centauri displays, via USB cable
- Juno single channel USB model

Vega, Nova II, StarLite, StarBright, and Centauri displays must first be setup locally to set the wavelength, range, pulse width, etc. The Pulsar and Juno models must be setup via StarLab.

1. Connect the optical sensor to the measurement device then connect the measurement device to the PC with BeamGage installed.
2. Select the device from the **Power Meter** panel found on the **Source** ribbon. Multiple connected measurement devices populate here by serial number.



*Power meters connected to BeamGage are no longer recognized by StarLab. Meters must be properly configured before connecting to BeamGage. Disconnect the meter and reconnect to StarLab to make adjustments for wavelength, range, pulse width, etc.*

## 1.8 Load a Setup File

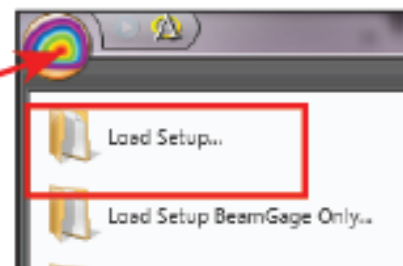
The BeamGage application ships write protected pre-canned setup files (marked with a tilde '~') that can aid in beginning to collect meaningful data.

1. Select the **File Access** button
2. Select **Load Setup**
3. Select the setup file that seems to be a best fit for the desired type of operation.

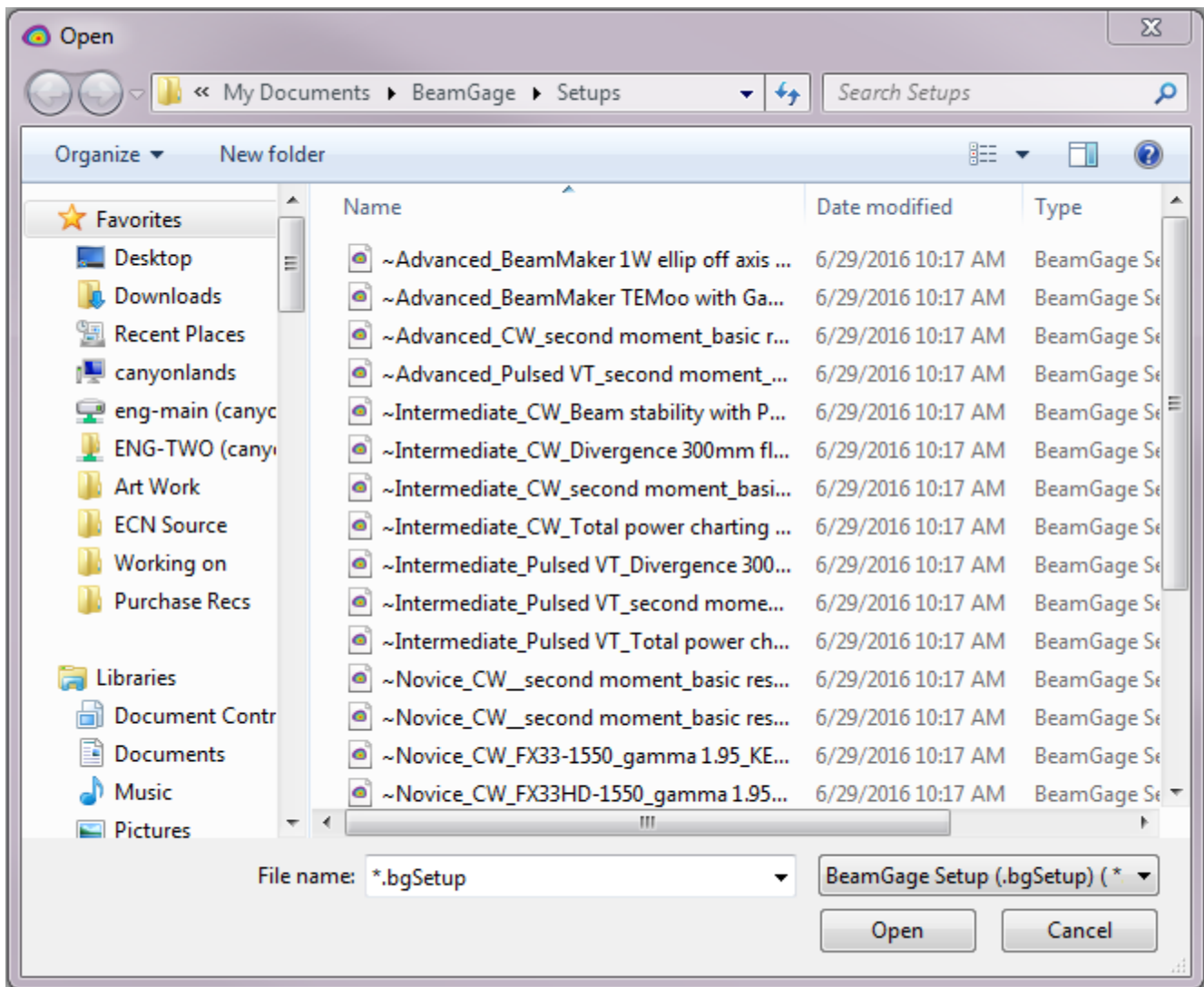
Setup files are organized by level of expertise within BeamGage:

- **Novice** — Many operating features are hidden with only the most common visible. Get up and running quickly with minimum decision making.
- **Intermediate** — For users with more experience who need to perform more advanced operations such as image processing.
- **Advanced** — For the most advanced users who want all BeamGage has to offer.

Once selected, BeamGage begins collecting data.







## 1.8.1 CW Laser Setup

Select a [...CW...] style canned setup file for continuous wave lasers. This is the most basic type of setup.

Lasers with a high rep rate pulsed output (much faster than the camera frame rate) may appear more like a CW output to the camera. In this case a CW setup may be successful.



*A user friendly, low power, HeNe style laser can be used to become familiar with BeamGage.*

## 1.8.2 Pulsed Laser Setup

Select a [...Pulsed...] style setup file for pulsed lasers. Pulsed setup files employ the **Video Trigger** capture mode which syncs the input with the pulse rate of the laser. In this mode a data frame is buffered when the camera outputs a frame where the intensity exceeds the Video Trigger programmable threshold.

Video Trigger may produce lower image quality, especially if the temporal pulse width is long compared to the camera's exposure setting. If the laser pulse duration exceeds a few microseconds, the camera may occasionally not integrate the entire temporal pulse. This may cause the pulse-to-pulse intensity of the beam profile to be unstable.



**Camera Trigger** mode can improve data collection reliability. Most BeamGage cameras support electronic triggering. These cameras ship with trigger cables. The **Trigger** panel in the **Source** ribbon contains the controls for setting up the trigger mode (see 2.3.1.7).



*Applying more than 5 Volts to the input triggers of USB cameras may cause damage.*

## 1.9 Saving a Setup

Setups can be saved and reused later.

1. Select **File Access**
2. Select **Save Setup As...**
3. Enter a new name for the setup file and select **Save**.

The last saved or used setup opens as the default the next time BeamGage is launched. This feature is user specific; meaning the last used or last saved file by one user does not affect other users.

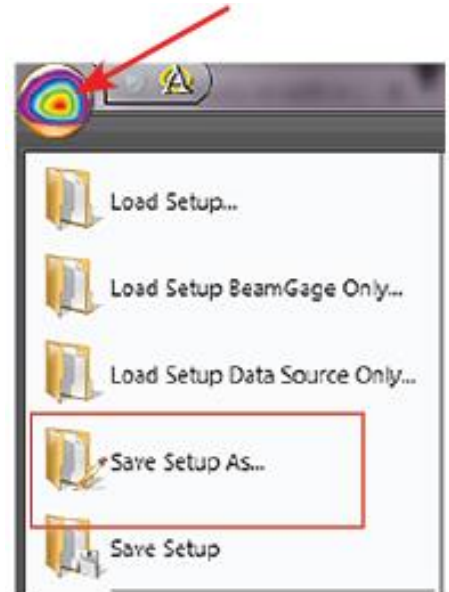
BeamGage creates two folders when installed:

**C:\Users\<user\_name>\Documents\BeamGage\Data**

**C:\Users\<user\_name>\Documents\BeamGage\Setup**

The default location for data, log files, and reports is the ...Data folder.

The default location for setup files is the ...Setup folder.



*If a setup change is detected when BeamGage is closed, a prompt to save the setup appears.*

# Chapter 2 BeamGage Operating Controls

This chapter describes the various screen and window features as well as the controls provided both within the ribbon panels and inside the various display windows.

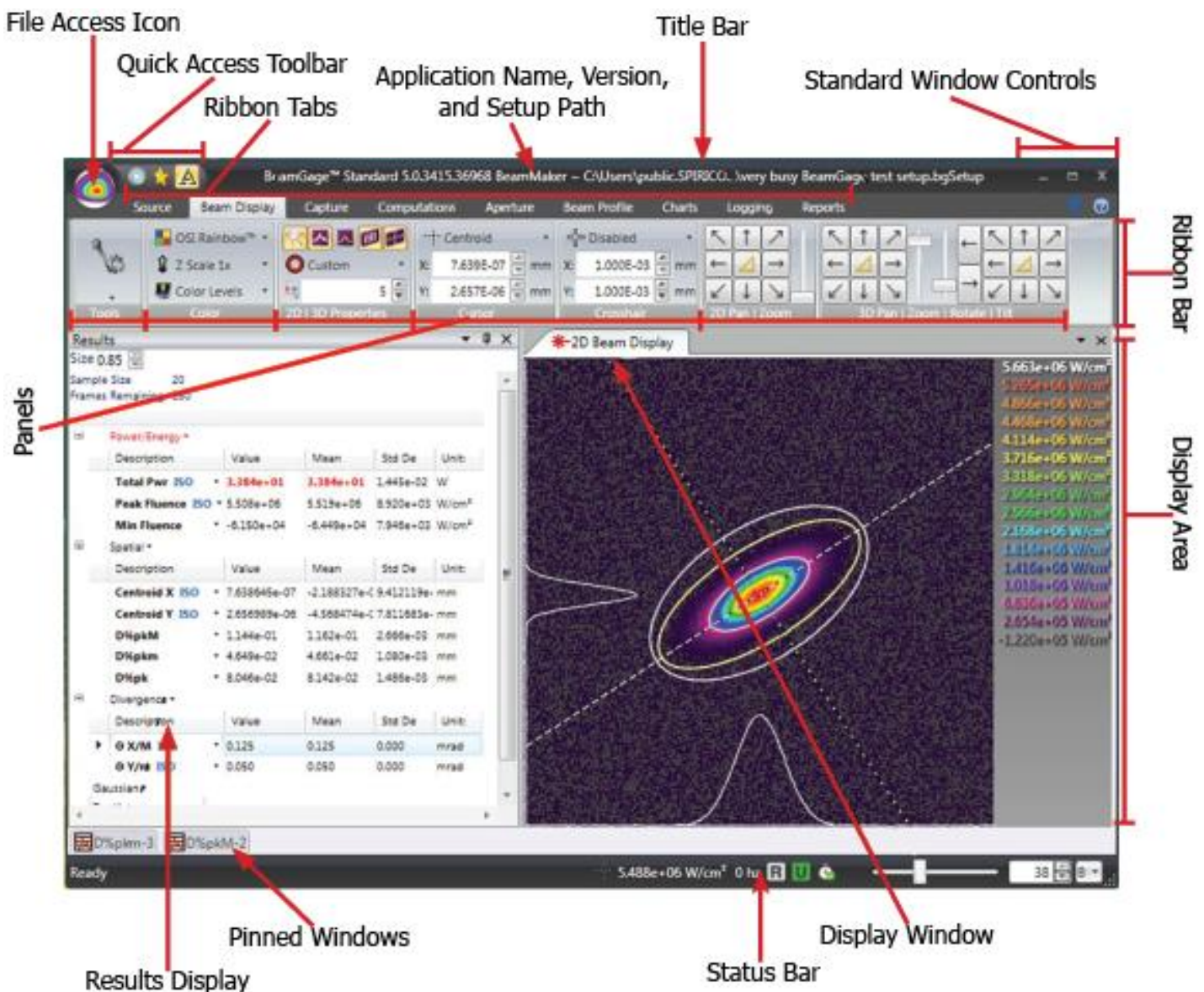
## 2.1 Display Terminology

BeamGage employs a ribbon control motif. This format provides intuitive access to control functions with the ability to hide the controls for better screen utilization.

The terminology used in this guide may be new to some users. This section provides definitions of terminology used in the software.

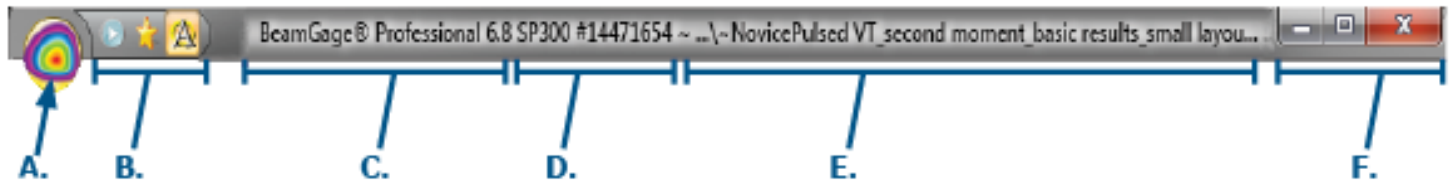


*There may be variation in naming conventions in the ribbon motif used in BeamGage. Terms selected are used for consistency.*



## 2.2 Window Information and Controls

### 2.2.1 Title Bar



#### A. File Access Button

Provides access to Save, Load, Export, and Print (see Chapter 4)

#### B. Quick Access Toolbar

The buttons shown are, from left to right:

- Start/Pause data collection or replay control
- Perform an Ultracal
- Enable/Disable Auto Aperture

#### C. Application Information

Displays the currently installed software version and application name

#### D. Source Information

Displays the Model and Serial number of the selected input source

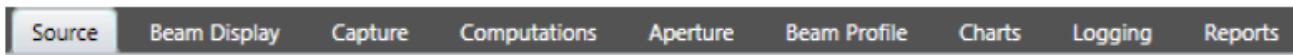
#### E. Setup Information

Displays the name and path of the last loaded or saved setup file

#### F. Window Controls

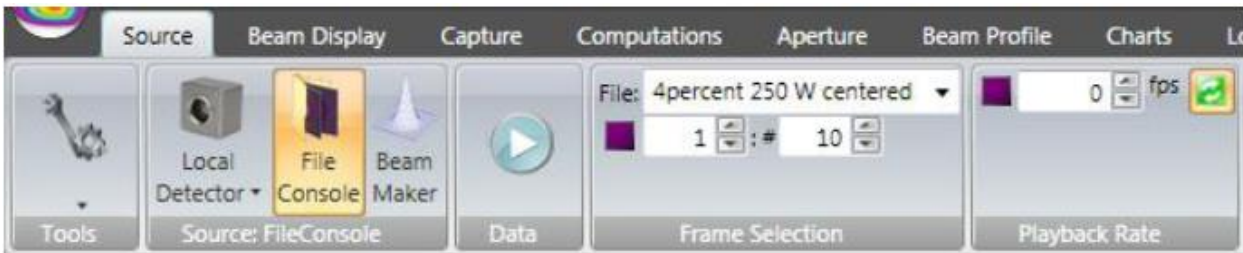
Standard Windows Minimize, Maximize, and Close buttons

### 2.2.2 Ribbon Tabs



The Ribbon tabs define the current ribbon control being accessed. Double-click any Tab to open and close the entire ribbon bar display area. A single click temporarily opens a closed ribbon bar until it is clicked off.

### 2.2.3 Ribbon Bar



Displays the current set of control panel options available within the selected Ribbon Tab. Panels contain the most common program controls.

## 2.2.4 Panels



Expansion Button

Individual groups in the Ribbon Bar containing drop-down lists, edit controls, etc. Some panels have a small expansion button located in the lower right corner of the panel. This button reveals additional, less frequently accessed controls that fall under the function title of the panel. Hovering over most controls and result items brings up tool tips.

## 2.2.5 Display Area


The Display area contains active Display windows. It is highly customizable to fit your application needs. Windows can be side-by-side, within each other, or even satellite across multiple monitors. See Chapter 3 for more information on the Display area.

## 2.2.6 Status Bar

The bottom bar of the BeamGage application contains a number of display items that will convey a variety of current operating conditions and states. The content of this bar is explained in more detail in section 3.2.

## 2.2.7 Help/What's This?

**Help**  provides quick access to this User Guide.

Select the **What's This**  button, then click on any featured item in BeamGage. This opens the User Guide, or if already open, goes to the section describing that feature or result.

### 2.2.7.1 Default PDF Viewer

Many different programs allow PDF viewing (Adobe Reader, Adobe Acrobat, etc.). The BeamGage **What's This** links work best with Adobe Reader as your default PDF viewer. If Adobe Reader is not your default viewer, follow these steps to change it.

1. Navigate to **Start -> Default Programs -> Associate a file type or protocol with a program**

Choose the programs that Windows uses by default



Set your default programs

Make a program the default for all file types and protocols it can open.



Associate a file type or protocol with a program

Make a file type or protocol (such as .mp3 or http://) always open in a specific program.



Change AutoPlay settings

Play CDs or other media automatically

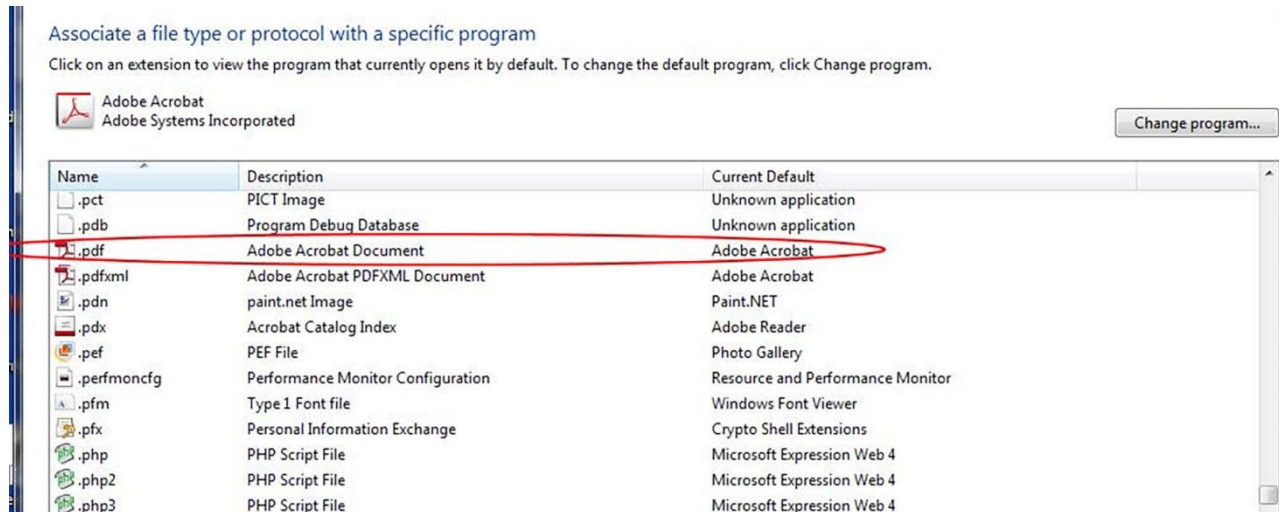


Set program access and computer defaults

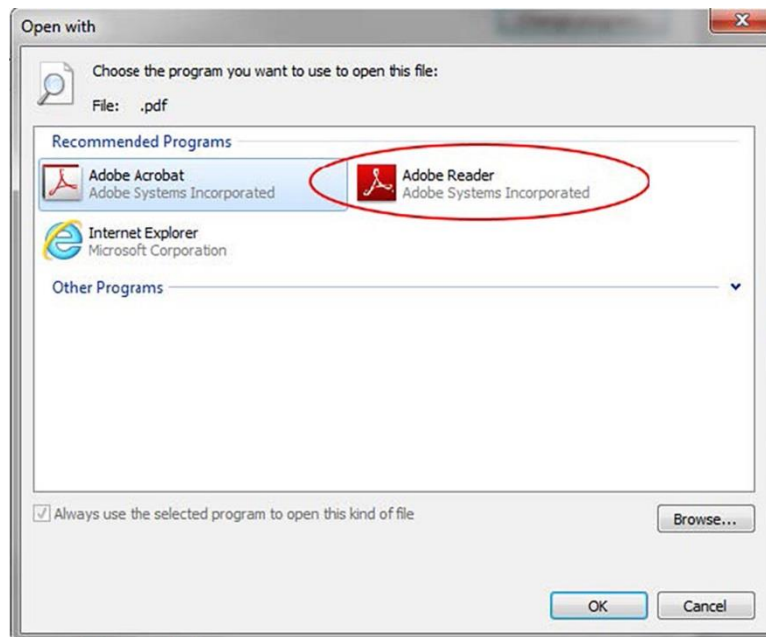
Control access to certain programs and set defaults for this computer.



- Find and select the line that has the **.pdf** extension.



- Select **Change program...**
- Select **Adobe Reader** and click **OK**.

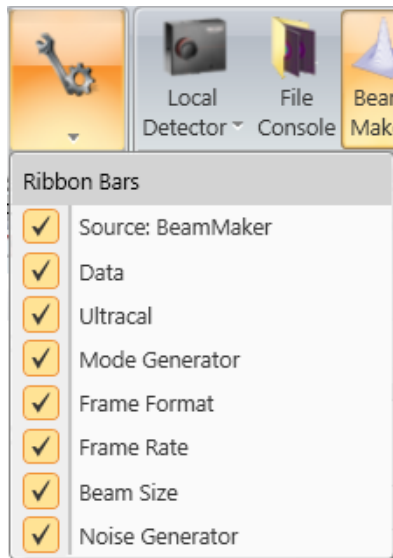


## 2.2.7.2 Adobe Reader XI Problem

The **What's This** feature may not always work in Adobe Reader XI or later. This is due to an added security feature. For **What's This** to operate correctly, make the following change to the Properties section in Adobe Reader XI:

- Open Adobe Reader XI
- On the Menu bar click **Edit**
- Click on **Preferences...**
- In the Categories list click on **Security (Enhanced)**
- Uncheck the **Enable Protected Mode at startup** item, and answer **Yes**
- Click **OK**

## 2.3 Source Ribbon and Panel Options

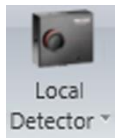


The **Source** ribbon controls which type of input is assigned to run in the current application. There are three standard input choices.

After a Source is selected the ribbon bar reconfigures to provide controls that apply to the selected source.

The Source Ribbon **Tools** panel provides options to hide or display panels for the connected source. The options within the toolbar vary by source and camera.

### 2.3.1 Source Ribbon: Local Detector



This control displays a list of available connected cameras. Available devices are listed by model and serial number. Select a device to connect to the application. On startup, BeamGage attempts to connect cameras in the following order:

1. The camera model and serial number specified in the currently applicable setup file.
2. If not found, it connects to a similar model.
3. If multiple similar cameras are connected, a list appears to select an available camera.
4. If no camera is available, BeamGage opens in an off-line state with no source selected.

Once a camera is selected camera specific controls open in the **Ribbon** Bar; including common controls that affect how BeamGage collects data.

The following sections describe the operation of both common and camera related controls. Camera specific features are not included.

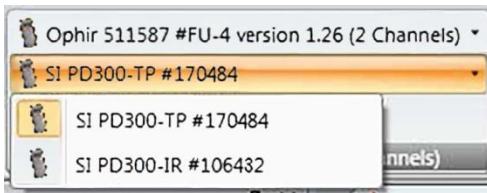


*Specialized camera controls are described in the Appendices at the end of this guide.*

#### 2.3.1.1 Source Ribbon: Power Meter



BeamGage can interface directly with select Ophir power/energy meters to collect real-time power/energy results. Whenever an Ophir power/energy meter is selected, the power readings in BeamGage will reflect the value and units from the meter. This allows the BeamGage power/energy results to be as accurate as a NIST referenced power or energy head. This also eliminates the need to manually calibrate BeamGage based on ever changing setup conditions. Any manually calibrated settings will be ignored during data frames collection.



When multiple Ophir power meters are connected to the local machine, the **Power Meter** drop-down control will display the ID of the connected meters. Select the Ophir product that is to be connected to BeamGage.

If the meter has a multiple head feature (such as the Pulsar product line) then the **Channel** drop-down control will become active and the output from one of the available heads can be selected.



Values from the Ophir meter device may not be scaled correctly if a beam sampler/attenuator is in the power sensor's path. To have BeamGage scale the results to reflect true laser power/energy you may enter a scaling factor or a beam sample percentage.



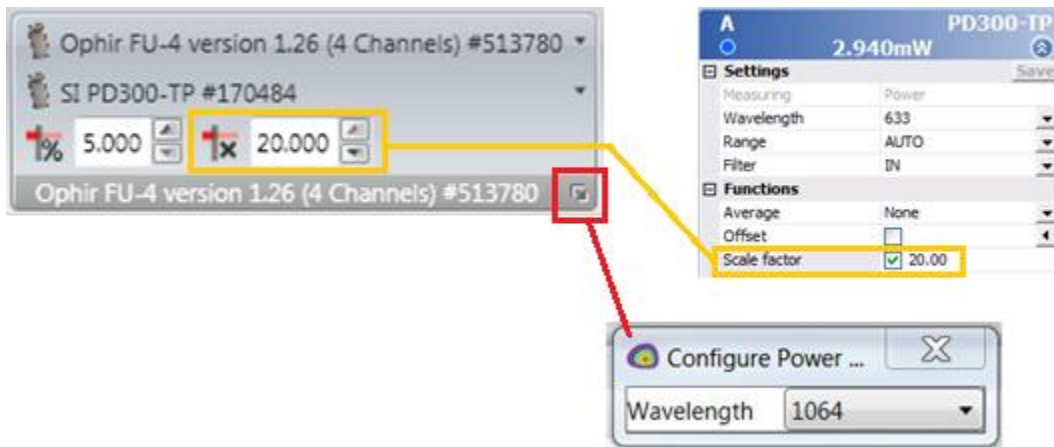
### Beam Sample Percentage

The beam sample percentage ranges from 0.1% to 100% and follows the same approach used in the Nova II and Vega. For example, if entering a 5% beam sample in a Nova II, enter 5% in the **Beam Sample Percentage** edit control.



### Scale Factor

The scale factor ranges from 1000.000 to 1.0000 and follows the same approach used in StarLab, see below. For example, if entering a scale factor of 20 in StarLab enter a scale factor of 20.000 in BeamGage.



BeamGage gives you the option to change the wavelength setting. Select the icon at the bottom right of the power meter panel to alter the settings.



*BeamGage always configures the power/energy sensor interface to the **AUTO** Intensity Sensitivity Range setting.*

## 2.3.1.2 Source Ribbon: Data



Select **Data** to start or stop data collection. The icon changes when the program is running or paused.

This function is repeated in the Quick Access Toolbar



### 2.3.1.3 Source Ribbon: Ultracal



**Ultracal** performs an accurate baseline calibration on the camera and removes small amounts of light that may leak into the camera image. It preserves both positive and negative noise floor, and in conjunction with **Auto Aperture** (see section 2.7) results in the most accurate beam width calculations possible with camera based technology.

Before performing an Ultracal, **Exposure** and **Gain** must be adjusted in the **Exposure/Gain/Black Level** panel. Use these settings to remove saturation in the beam profile (white pixels in the normal OSI Rainbow color palette).




After setting up the camera and the laser input with appropriate attenuation, block the beam somewhere between the camera and laser then select **Ultracal**. Do not block the camera input aperture, this can prevent Ultracal from subtracting ambient light contributing to the camera baseline.

Once the baseline correction cycle completes, the Ultracal check box turns ON and the camera's signal-to-noise ratio (SNR) is computed and displayed in RMS dB.



Select the check mark to toggle Ultracal on/off.

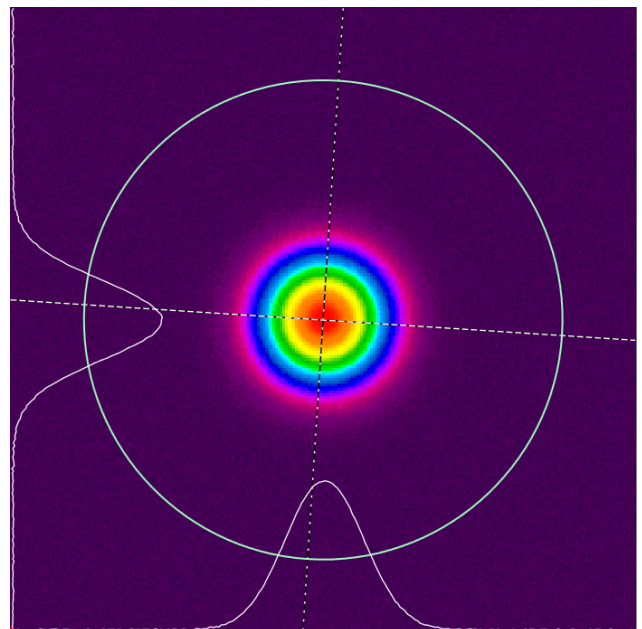
A Green  illuminates in the status bar at the bottom of the screen when **Ultracal** is active. When a camera setting changes that can compromise the setup, the "U" indicator turns Red, and Ultracal processing is suspended. Hover over this indicator to see what changed to cause the suspension.

To demonstrate the necessity of Ultracal, consider the following example:

The green aperture represents the calculated beam widths using the beam width method listed in the **Beam Width** panel in the **Computations** tab.

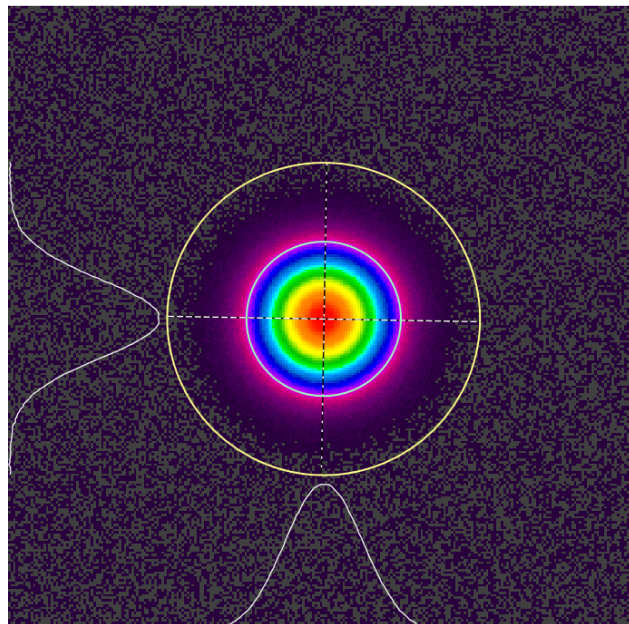
The aperture is picking up noise and the diameter is noticeably larger than the visible beam profile.

An image of what happens after an Ultracal is found below.





After an Ultracal is performed notice how tight the green circle gets to the beam profile. Ultracal balances the baseline noise about zero reducing the noise impact.



## 2.3.1.4 Source Ribbon: Auto Exposure



The **Auto Exposure** panel provides tools for a quick setup that are not as meticulous as using Ultracal. However, the accuracy may be reduced if the setup conditions are not ideal.



### Auto Setup

Automatically adjusts the camera **Exposure** and **Gain**, then performs an **Ultracal** cycle. During the **Ultracal** cycle, it prompts you to block the beam. Once run, the beam should appear scaled in the beam display window with an accurate baseline computed and applied to the processed image.

The accuracy and stability of **Auto Setup** relies on modulating the camera by attenuating the beam until the most intense portions of the profile are at or around 90% saturation when the **Exposure** setting is maximized.

The final **Exposure** and **Gain** levels can indicate the accuracy of **Auto Setup**. A large increase in **Gain** raises the camera noise and contributes rapidly to a reduced SNR. A low **Exposure** setting may cause smearing where a vertical stripe is visible through the most intense portion of the beam profile. See section 2.5.8 for more information on smearing.

After an **Auto Setup** cycle, you should only need to run additional **Ultracal** cycles periodically if the baseline drifts.



### Auto X

An **Auto-Xposure** mode which puts the **Exposure**, **Gain**, and **Black Level** into an auto tracking mode. Previous Ultracal processing is disabled and a new automatic baseline subtraction method takes effect. If you change the **Black Level** while **Auto X** is running, then it will no longer automatically adjust, however the **Exposure** and **Gain** will continue to adjust.

This mode tracks the changes of the laser beam's intensity and attempts to display the beam over a wide range of changing input conditions. Baseline correction still occurs, but the precision and amount is constantly changing as input conditions change.

Under the best input conditions, the beam width results obtained in this mode can be nearly as accurate as those from an **Ultracal** setup. Observing the **Exposure** and especially the **Gain** control sliders can show degradation. As more **Gain** is applied, the results degrade and become noisier and less accurate. Adjusting the input attenuation to minimize the **Gain** setting can improve accuracy.

### Limitations to Auto Setup and Auto X

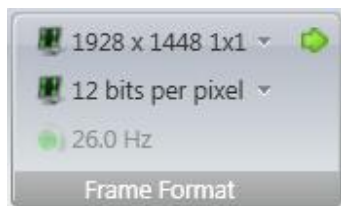
The best performance is always achieved with a precise setup of the system and **Ultracal** baseline processing. The Auto methods allow convenience with a possible reduction in accuracy. The user must decide on which tradeoff is appropriate for their application.

There are some limitations in these features when operating with a pulse laser and **External Triggering** or **Video Triggering**. With slow rep-rate pulsed lasers, the **Exposure** control is only usable to split out single laser pulses. As a result, the **Auto Exposure** features are not useful in changing the camera sensitivity. In triggered modes, the only effective automatic control is the **Gain** control. Due to the drawbacks, the benefits of the Auto features in single pulse exposure triggered modes are limited.

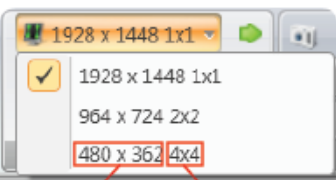


*The Auto X mode does not adjust for a manual power/energy calibration and thus cannot be relied upon to accurately track beam power/energy changes. This mode is best used with an external power/energy meter.*

## 2.3.1.5 Source Ribbon: Frame Format



Frame Format is used to set how camera data frames are formatted. The **Frame Format** panel and options available vary by camera.



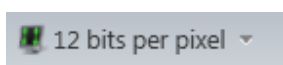
ROI

Binning  
format

### Frame Format

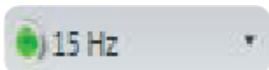
Reveals a drop-down with preset Region of Interest (ROI) selections and Binning formats for the connected camera. Formats are normally centered in the camera imager and allow for quick modification of the camera settings.

A smaller ROI usually results in higher camera frame rates. Some formats employ pixel binning that can speed up the camera frame rate while preserving the field of view of the imager. When binning is used, the camera sums the pixel intensity of each binned pixel leading to brighter images. For most cameras bad pixel correction does not operate when a binned format is selected.



### Bits per Pixel

Sets the camera output format in number of bits per pixel. The lowest setting is 8, and the highest is 16. The available settings vary by camera. Some cameras run faster with lower bits per pixel settings. Using too few bits may compromise accuracy with cameras with a lower SNR.



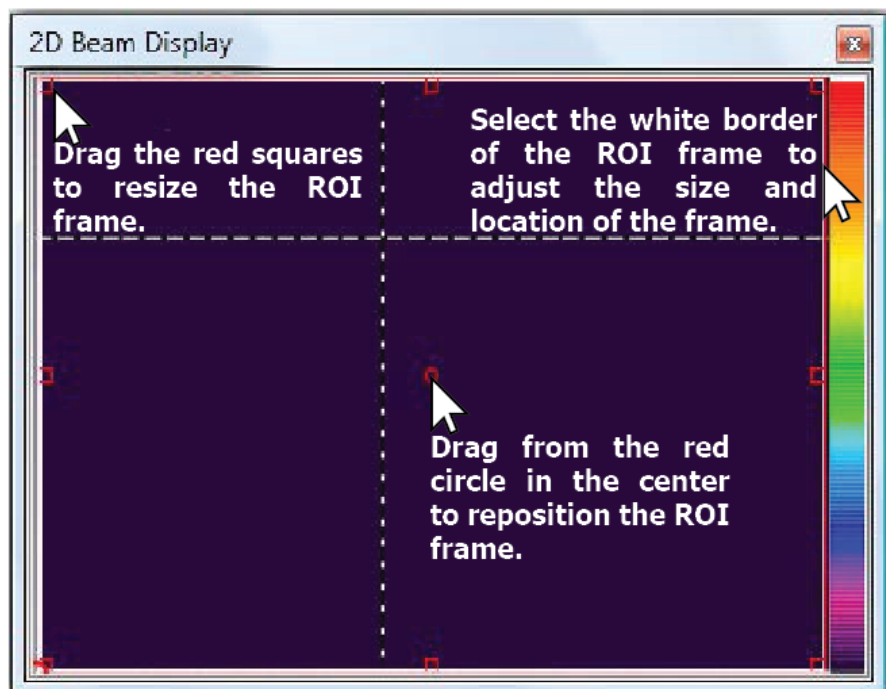
### Frame Rate

Sets the default camera frame rate in Hz. Available rates change based on the camera and selected Frame Format.



### Custom ROI

This button is available with specific cameras. Select it to reveal the custom **ROI** controls shown below.



When the **ROI** controls are activated, the captured image becomes full frame and a White aperture window appears in the **2D Beam Display**. Select this aperture to highlight its red control handles as shown.

This special **ROI** aperture can be used to define the new region of interest for the camera to output.



### ROI Size and Offset

These edit controls indicate the pixel **X** and **Y Offset** of the upper left corner and the **Width** and **Height** of the image in pixels. These can be used as an alternative to changing the ROI in the **2D Beam Display**.



### Horizontal Centering

Locks the **ROI** frame along the horizontal axis allowing it to only move vertically.



### Vertical Centering

Locks the **ROI** frame along the vertical axis allowing it to only move horizontally.

Enabling both the **Horizontal** and **Vertical Centering** controls locks **ROI** in the center of the imager.

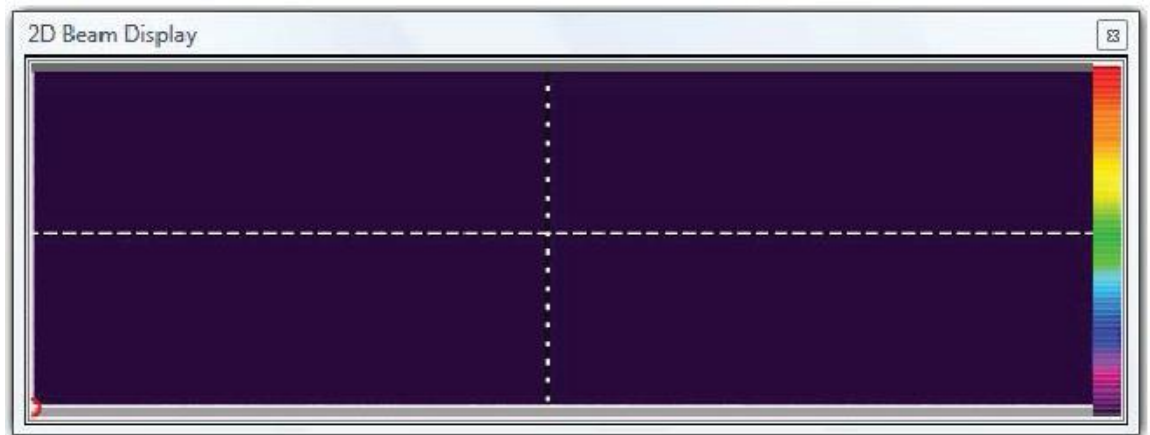
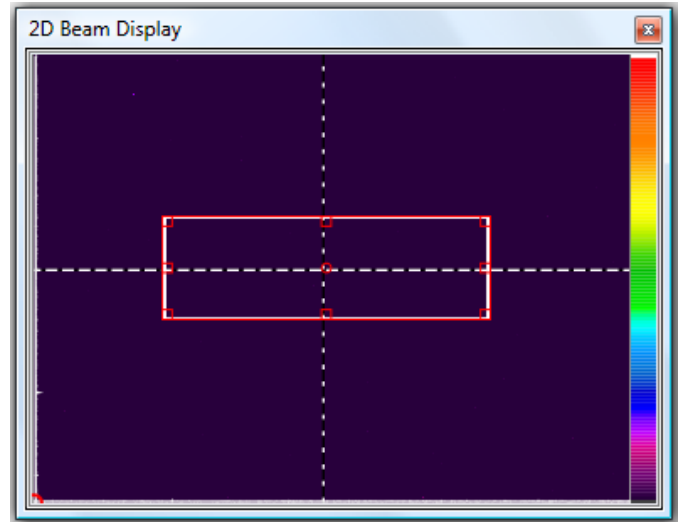
Binning: 1x1

### Binning

Can be applied to speed up the capture rate while covering the same area on the detector as indicated by the ROI window. May not be acceptable for all applications.

Once the custom **ROI** settings are configured, select **Set** ☒ to apply. The **2D Beam Display** changes to the size set by the custom **ROI** controls. In this example, the 2D display adjusts to the image shown below.

Only one custom **ROI** setup is available at a time. The panel's **Bits per Pixel** and **Frame Rate** drop-down edit controls may be disabled when an **ROI** is enabled. This can vary depending upon the camera type. Some cameras' frame rates are locked to their max value.



*The L11059 model cameras respond differently with and without the application of the **Horizontal Centering** feature. The camera can run faster with the **ROI** centered horizontally.*

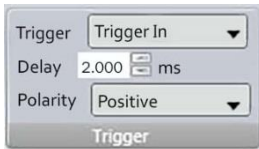
## 2.3.1.6 Source Ribbon: Exposure | Gain | Black Level



Make manual adjustments to camera settings that determine the intensity and quality of the output image.

In Auto modes, these controls are automatically adjusted to the input beam intensity conditions. **Ultracal** only adjusts the **Black Level**.

## 2.3.1.7 Source Ribbon: Trigger



Trigger: Trigger In  
Delay: 2.000 ms  
Polarity: Positive

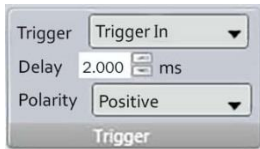
Control the electronic trigger features in the selected camera. The camera must be provided with a low voltage TTL/CMOS input trigger pulse to activate the external trigger feature. Trigger options are described below.



Trigger: None

### None

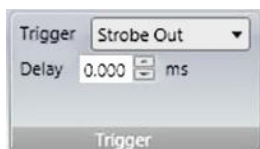
No trigger present. Camera operates in CW mode and outputs frames continuously.



Trigger: Trigger In  
Delay: 2.000 ms  
Polarity: Positive

### Trigger In

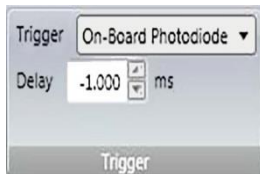
Sets the camera to start to expose and transmit a frame of data when a trigger pulse is sent to the camera.



Trigger: Strobe Out  
Delay: 0.000 ms

### Strobe Out

**Strobe Out** is a low voltage TTL/CMOS output signal that can be used to trigger a laser. The camera runs in CW mode, but issues a Strobe output pulse at the start of each frame exposure time. Some cameras also offer a Strobe **Delay** and a Strobe **Pulse Width** setting feature.




Trigger: On-Board Photodiode  
Delay: -1.000 ms

### On-Board Photodiode

The legacy cameras SP503U and SP620U have a built-in photodiode detector that can be used to sync pulsed lasers without providing an external signal to the camera. When this option is selected the camera begins a calibration cycle setting the photodiode detector to the room ambient lighting conditions. Make sure the laser is not active during this calibration cycle. When the cycle completes the camera should be able to detect the laser flash and trigger in sync with the laser pulses.

If a change in lighting conditions stops the camera from triggering reliably, then change the **Trigger** setting to **None**, and then back to **On-Board Photodiode** to recalibrate.

Because the location of the on-board detector is fixed on the front of the camera, it may not always be able to detect the laser pulse under all operating conditions. If it fails to perform reliably, connect a trigger cable to the camera from the laser and use **Trigger In** or use the remote photodiode detector option, **Photodiode In**.



Trigger: Photodiode In  
Delay: -1.000 ms  
Polarity: Positive

### Photodiode In

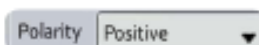
Some legacy cameras can be operated with an external photodiode trigger probe. These included the SP503 and SP620 cameras.



Delay: 2.000 ms

### Delay

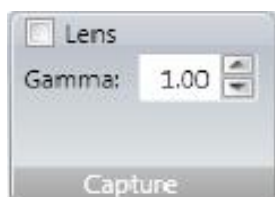
Set a delay time in milliseconds for the start of **the** exposure if needed. The delay can be either positive or negative depending upon the duration of the laser pulse. If the pulse is short (<100µs) set a negative **Delay** of at least -1.0ms, and a set the **Exposure** to at least 2ms. If the laser pulse width is long, set a **Delay** of 0ms and the **Exposure** slightly longer than the pulse width.



### Polarity

Set the TTL edge polarity to Positive or Negative.

## 2.3.1.8 Source Ribbon: Capture

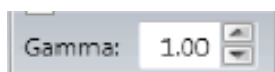


These controls do not affect the camera electronically, but do enable image processing options with the BeamGage application.



### Lens

Check this box if the camera is fitted with an imaging lens. When enabled, the 2D image orientation is adjusted to depict the image as if the observer is standing and viewing the scene from behind the camera. When disabled, the 2D image is oriented as if the observer is standing in front of the camera looking at the surface of the detector.



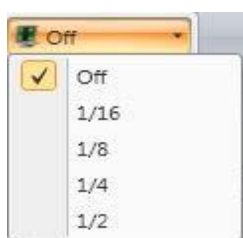
### Gamma

Solid state CCD or CMOS style detectors respond linearly to monochromatic light. For linearly responding cameras the **Gamma** setting should be set to 1.

For cameras that employ phosphors or other wavelength conversion materials the gamma of the material should be entered here to convert the nonlinear response back to a linear one.

Ophir-Spiricon's Phosphor coated cameras (i.e. SP920s-1550, Lt665-1550, etc.) require **Gamma** to be set to 1.95.

## 2.3.1.9 Source Ribbon: Video Trigger



Enable and set the threshold for the **Video Trigger**. The trigger threshold value in the drop-down sets the sensitivity of the trigger based on the camera bits per pixel. Only permits frames of data with a laser pulse to be captured.

For example: a camera set to 12 bits per pixel, 4095 counts full scale, and a threshold of  $\frac{1}{4}$  will trigger on a beam that has a peak amplitude  $>1023$  counts.

## 2.3.1.10 Source Ribbon: Camera/Firmware Info



Info panels provide basic information on the camera source. The type of information displayed depends on the source connected. The panels shown here display the camera's **Pixel Scale** (pixel pitch) as well as the current firmware version.



*Some cameras have a combined camera/firmware info panel.*



## 2.3.2 Source Ribbon: File Console

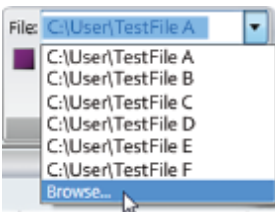


**File Playback Console** allows you to playback and view a BeamGage **Data File**. Various processing features can be applied to the input data when the re-played frames are processed into the **Frame Buffer**.

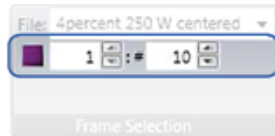


*When data is loaded through the **File Console** the data is treated as if it is being seen for the first time. All results obtained depend on the current settings, not on the settings in place when originally captured.*

### 2.3.2.1 Source Ribbon: Frame Selection



The **Frame Selection** panel allows you to select a file for playback and adjust the frames to view. To open a file for playback, select a recent file from the **File** drop-down, or select **Browse** to locate a file.



Enter the starting frame in the first field, and enter the number of frames to playback in the second field. When a file loads these values default to 1 and the total number of frames in the file, respectively.

### 2.3.2.2 Source Ribbon: Playback Rate



Files playback as fast as possible when set to zero. Setting the **fps** value greater than zero decreases the playback rate.

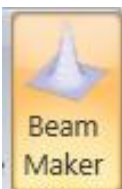


Select  to loop playback continuously.



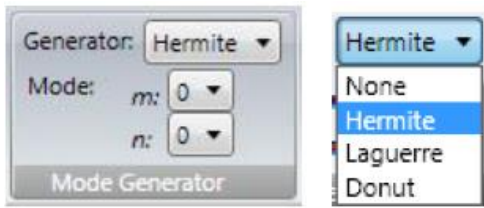
*Frames may be skipped if running playback at max speed. A low **fps** can ensure all frames are loaded and processed.*

## 2.3.3 Source Ribbon: BeamMaker™



**BeamMaker** is a proprietary embedded modeling tool that allows users to create synthetic beams. This can be used to assess and validate Ophir-Spiricon's beam measurement algorithms, ISO algorithms, and specialized user algorithms. It also provides convenient tools that can help model a particular measurement environment to determine what degree of accuracy is possible under a variety of conditions. See 5.27 for examples.

### 2.3.3.1 Source Ribbon: BeamMaker Mode Generator



Sets what type of beam mode is to be modeled. Choose from a **Hermite**, **Laguerre**, or the mixed **Donut** mode (TEM<sub>01\*</sub>). The M<sup>2</sup> value of a modeled mode is defined as shown below:

$$M_x^2 = 2m + 1$$

$$M_y^2 = 2n + 1$$

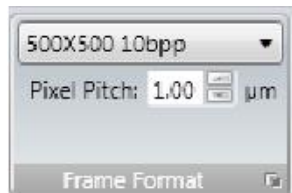
For the **Hermite** mode, program the TEM<sub>mn</sub> m and n values, where:

For the **Laguerre** mode, program the TEM<sub>pl</sub> p and l values, where:

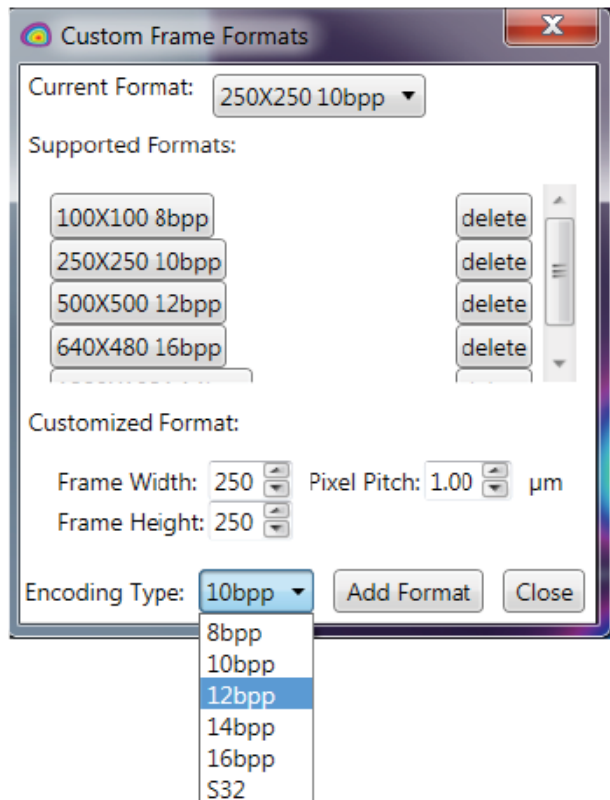
$$M^2 = 2p + l + 1$$

The **Donut** mode, TEM<sub>01\*</sub>, consists of two superimposed Hermite TEM<sub>01</sub> and TEM<sub>10</sub> beams. This pure Donut mode has an M<sup>2</sup> value of 2.

### 2.3.3.2 Source Ribbon: BeamMaker Frame Format



In **BeamMaker**, the **Frame Format** panel lets you customize the frame specifications. This allows you to mimic cameras by matching the frame to a specific camera imager. Select from the preset formats in the drop-down list. Match the imager **height** and **width**, **Encoding Type**, and **Pixel Pitch**. **Pixel Pitch** defines the size of the pixels on the camera imager. **BeamMaker** considers all pixels to be square. You can also customize the frame format by selecting the expansion button.



**Current Format** displays the active format. You can switch formats from the drop-down list.

Saved formats are shown in the **Supported Formats** list. You can also select a format in this list to switch to it.

To delete a format select **delete** adjacent to the format description.

To add a custom format enter the new **Frame Width** and **Height**, **Pixel Pitch**, and select the **Encoding Type**; then select **Add Format**. Select the new format from the list or the drop-down menu, and then select **Close**.

Changes take effect after you select **Start** in the data panel, or run an **Ultracal**.

The **Encoding Type** defines the number of bits per pixel used to model the beam. Ophir-Spiricon currently ships cameras that support formats from **8bpp - 14bpp**. **16bpp** format cameras exist but are not very common. The **S32** format is a signed 32-bit format. No known camera supports this large of a dynamic range. It is provided here only as an



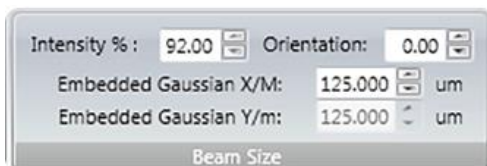
example to demonstrate how accurately a measurement could be made under nearly ideal input conditions.

### 2.3.3.3 Source Ribbon: BeamMaker Frame Rate

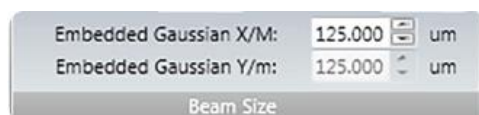


**BeamMaker** attempts to run at the set frame rate. The final speed is dictated by the computations loading on the processor and by the **Results/Frame Priority** setting in the **Capture** ribbon. Larger frame sizes with larger beams take longer to model. Adding noise also takes additional time.

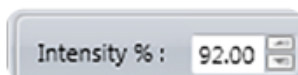
### 2.3.3.4 Source Ribbon: BeamMaker Beam Size



Define the size, intensity, and orientation of modeled beams. **BeamMaker** defines the size of the embedded TEM<sub>00</sub> Gaussian mode of the beam. This embedded mode is transformed into the higher modes that are specified in the **Mode Generator** panel. For example, an embedded TEM<sub>00</sub> beam with a 100µm beam width results in a modeled beam width M times larger than the embedded size. If the beam M<sup>2</sup> value is equal to 2, the M value equals 1.414 so the modeled beam width is 1.414 times larger than the embedded size, resulting in a 141.4µm beam width.



Set embedded beam widths in microns (µm) with these edit controls. These values automatically scale if the **Pixel Scale** setting in the **Frame Format** panel is modified.



Control the intensity of the modeled beam as a percentage of the model's full dynamic range. Never set values near 100% when noise and **Ultracal** are used as a part of the modeling process. Like with real cameras the noise component is part of the dynamic range. Thus, when a baseline is computed and subtracted from the model's dynamic range, the maximum beam intensity cannot be 100% of the original full scale counts, but is now lowered by the mean baseline offset.

Typically values of 90-95% can be used to indicate full signal amplitude under most realistic noise scenarios. If the SNR is reduced to a level where noise constitutes a large percentage of the signal, the intensity may need to be decreased.



If modeling an off axis elliptical beam, set the orientation of the modeled beam with respect to the X axis. The X/M axis should be larger than the Y/m axis if comparing the **BeamMaker** settings to the reported **Orientation** result.

### 2.3.3.5 Source Ribbon: BeamMaker Noise Generator



Allows you to add a **Gaussian** RMS noise signal to the modeled beam profile. If no noise model is required select **None**.

The **Signal to Noise Ratio** (SNR) is specified in dB. If the camera you want to model has a known SNR the value can be entered here.

It is also possible to model the effects induced by a camera's DC offset bias. Enter the offset, positive or negative, as a % of the camera's full scale digitized output range. For example, a **% DC Offset** of -0.1% on a 12 bit (0-4095 counts) camera creates an offset of -4 counts. This subtracts 4 counts from the input signal, clipping at zero. Conversely an increase in offset of 0.1% adds 4 counts to the input signal.

In BeamGage, a camera's black level is raised to preserve the full noise floor. This means both the positive and negative noise can be used to compute a more accurate baseline. You can program the offset higher or lower to simulate the effect on computed beam widths due to baseline offset errors.

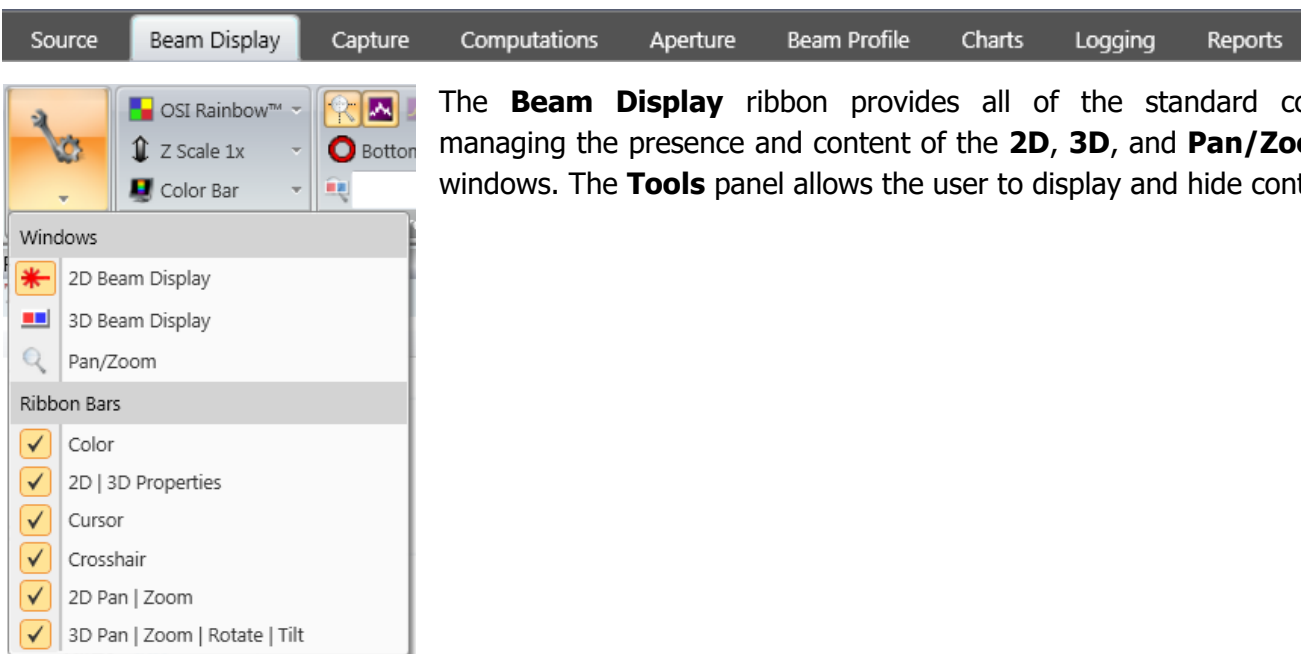
If no DC offset is applied, and noise is present, only the positive noise is available when beam widths are computed, having a net effect of increasing the measured beam size.

Conversely, lowering the noise floor to suppress the baseline noise leads to a reduced beam width measurement. The degree of the errors can be minor or significant depending on other conditions present; such as the use of an aperture, or the size of the beam relative to the imager if no aperture is used.



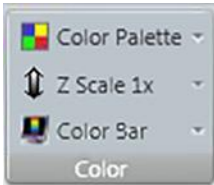
*Once a beam model is constructed, perform an **Ultracal** cycle to compute an accurate beam width. This simulates the adjustment of the black level, treating **BeamMaker** as if it is a real camera. In effect, this cancels the programmed % DC Offset since **Ultracal** resets the offset to achieve a best case baseline adjustment.*

## 2.4 Beam Display Ribbon and Panel Controls

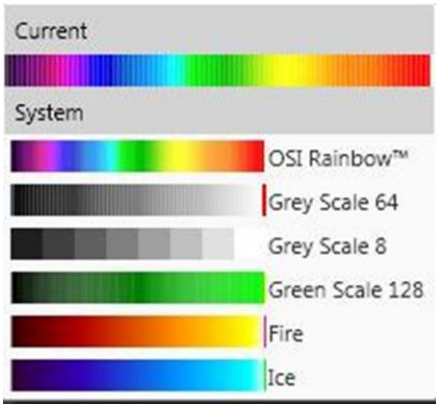


The **Beam Display** ribbon provides all of the standard controls for managing the presence and content of the **2D**, **3D**, and **Pan/Zoom** display windows. The **Tools** panel allows the user to display and hide control items.

## 2.4.1 Beam Display Ribbon: Color

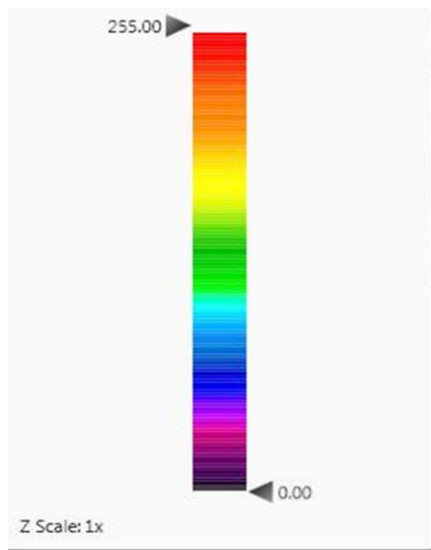


Sets the color display options for the **2D**, **3D**, and **Pan/Zoom** windows.



### Color Palette

Displays a set of color palettes for the beam intensity profiles. Select the desired display palette.



### The Z Scale

Opens a vertical palette with dual slider controls that scale the colors into a smaller region of the Z axis beam intensity profile. Most useful when trying to resolve the lowest intensity features often present in the wings of the beam.

Grab the top arrow and slide it downwards to observe the false color detail expand at the bottom of the beam profile displays.

Grab the center and slide the entire palette up and down inside of the beam profile.

The numerical values indicate the location of the palette boundaries and the actual amount of Z Scaling factor that is compressing the color scale.



### Color Bar Drop-down

Toggles the color bar display found on the right side of the **2D Beam Display** on/off.



The **Color Bar** display is a solid vertical bar that displays the distribution of the colors from the lowest to the highest beam intensity.



The **Color Levels** display is a numerically coded display that translates the colors into non-calibrated pixel counts or calibrated pixel Fluence values.

## 2.4.2 Beam Display Ribbon: 2D | 3D Properties



Control display features in the **2D** and/or **3D Beam Display** windows.



### Zoom to Cursor

Sets the **2D Beam Display** to zoom to the **Cursor** location (see 2.4.7). Disables and sets zoom to center when the **Cursor** is turned off.



### Beam Profiles

Displays a 1D slice through the beam intensity profile along the bottom and left side of the **2D Beam Display** based on the location of the **Cursors**.



### Reference Profiles

Only available when a **Reference Frame** is selected (see 2.5.5). Displays a 1D slice through the Reference Frame's intensity profile along the bottom and left side of the **2D Beam Display** based on the location of the **Cursors**.



### 3D Backplanes

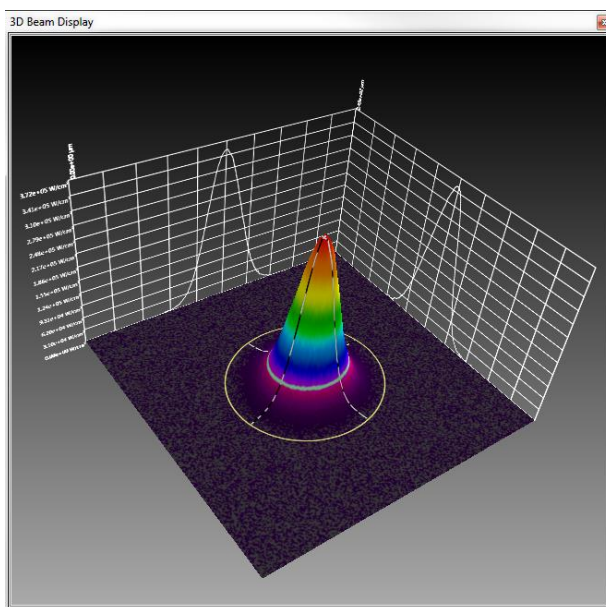
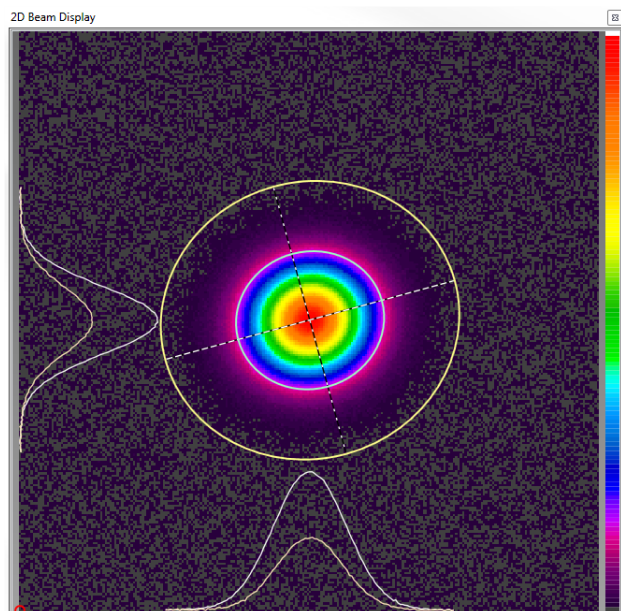
Sets 3D Backplane visibility. Useful to view the beam profile slices in the **3D Beam Display** window.



### 2D Elements in 3D

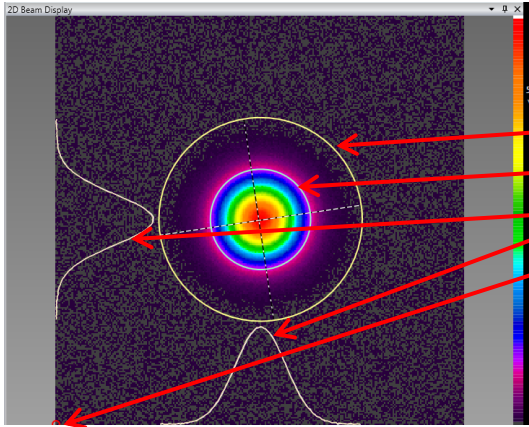
Sets visibility for projections of the **Manual**, **Auto**, and **Beam Width Apertures** onto the surface of the 3D beam profile.

The following figures depict the views of the **2D** and **3D Beam Display** windows with all of the above properties enabled with both **Cursor** and **Reference Frame** slice profiles.





## 2.4.3 Beam Display Ribbon: 2D Beam Display Window

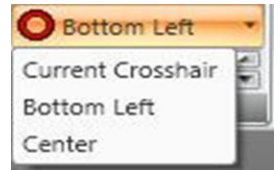


The image displays a typical **2D Beam Display** view.

The active properties are:

- Auto Aperture (Yellow)
- Beam Width (Lt Green)
- Beam Profiles (White)
- Origin Location (Red)

The **Origin Location** (indicated by a red circle) can be placed in the **2D Beam Display** at the bottom left corner, center, or snapped to the **Crosshair** location. Select the location from the drop-down in the **2D/3D Properties** panel.



See the **Crosshair** panel in section 2.4.8 for information on how to position it.

## 2.4.4 Beam Display Ribbon: 2D Pan | Zoom



Panning and zooming in the **2D Beam Display** window can be accomplished either with the controls in the panel or with the mouse. The arrows pan the beam and the slider is a zoom control. The center button re-centers and resizes the beam to fit the window.

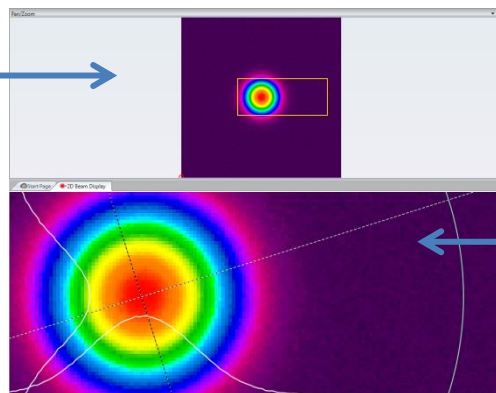
The simplest way to pan and zoom the **2D Beam Display** is to position the mouse pointer into the window, then pan by holding down the left button and dragging the display to its final destination and zoom with mouse wheel control.



### Pan/Zoom Window

Enable in the **Tools** panel. The Yellow box in the **Pan/Zoom** window indicates the region of the imager displayed in the **2D Beam Display** window.

Pan/Zoom Window

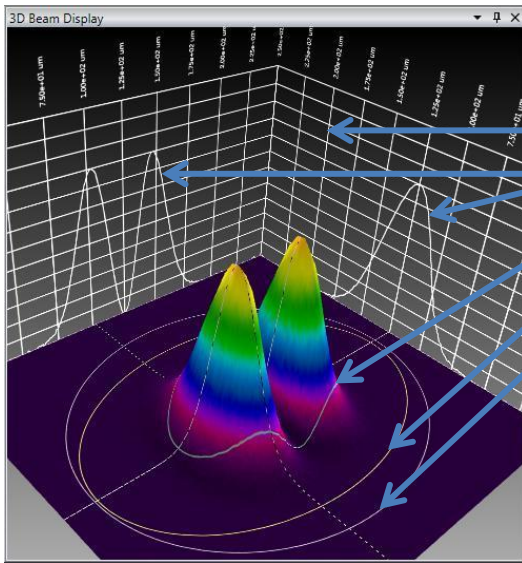


2D Beam Display Window



*The **Pan/Zoom** window indicator has no relationship with the ROI setting in the camera or with the regions defined by the apertures. It is only a display tool.*

## 2.4.5 Beam Display Ribbon: 3D Beam Display Window



The image displays a typical **3D Beam Display** view.

The active properties are:

- 3D Backplane
- Beam Profiles (White)
- Beam Width (Lt Green)
- Auto-aperture (Yellow)
- Manual Aperture (Lt Grey)



*The beam slice profiles are not visible unless the 3D Backplane is active.*



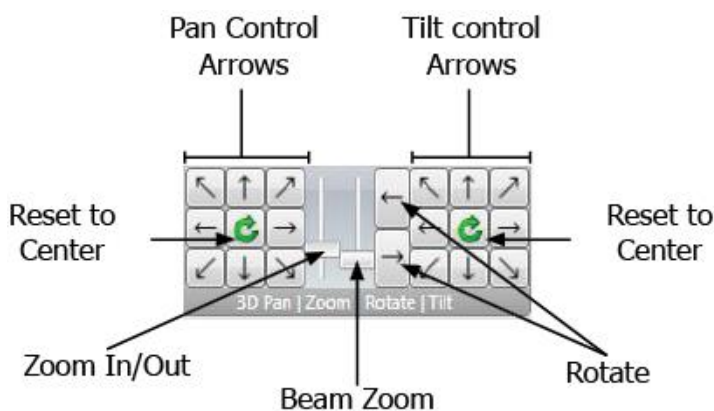
### 3D Resolution

Located in the **2D/3D Properties** panel, this control determines the amount of detail rendered in the **3D Beam Display** on a scale from **1** (finest resolution with slower data frame update rate) to **10** (a more grainy display with a faster data frame update rate).



*The **3D Beam Display** utilizes the maximum amount of graphics drawing resources that the PC and Graphics card can provide. This causes the acquisition rates to run significantly slower, especially noticeable with higher resolution cameras.*

## 2.4.6 Beam Display Ribbon: 3D Pan | Zoom | Rotate | Tilt



Pan, Zoom, Rotate, and Tilt in the **3D Beam Display** can be controlled from the panel or the mouse.

### Pan Control Arrows

Controls the view along the X and Y axes.

### Tilt Control Arrows

Controls the pitch of the view.

### Rotate

Turns the view around the beam profile image.

### Reset to Center

Reverts the view to its default position and zoom level.

### Zoom In/Out

Magnifies the image in reference to the center of the window.

### Beam Zoom

Magnifies the image in reference to the beam profile.

3D View Mouse Controls	
<b>Pan</b>	Hold Left mouse button and drag
<b>Tilt</b>	Hold Left and Right mouse buttons and drag
<b>Rotate</b>	Hold Right mouse button and drag
<b>Zoom In/Out</b>	Roll Scroll Wheel forward to increase magnification and back to decrease magnification

## 2.4.7 Beam Display Ribbon: Cursor



The **Cursor** is a reference point that displays profile information across its axes. Use the drop-down to set the visibility and mode of **Cursor** in the **2D** and **3D Beam Display** windows. The location dictates the data plotted in the **Beam Profile** display windows. **Cursors** can operate in three modes:

### Manual

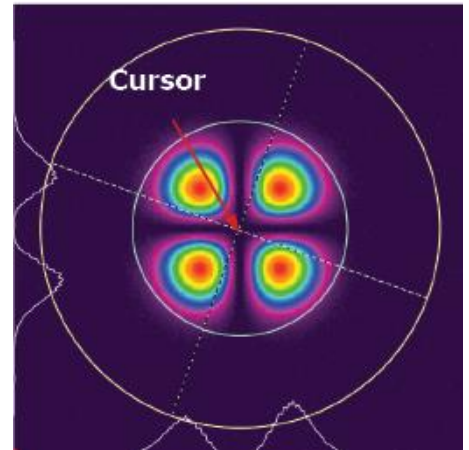
Position the **Cursors** anywhere within the **2D Beam Display Window** either by dragging and dropping with the mouse (grab at the intersection), or by entering exact **X** and **Y** coordinates in the edit controls in the panel. The displayed spatial units follow the units setting in the **Computations** ribbon.

### Peak

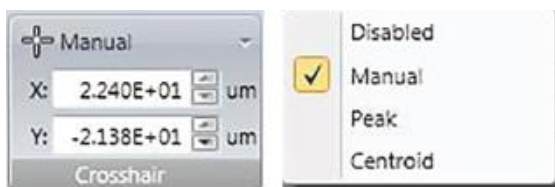
Set the **Cursors** to automatically track the peak fluence of the input beam. If two identical peaks are present, the peak closest to the top left corner is indicated.

### Centroid

Set the **Cursor** to automatically track the location of the computed beam centroid.



## 2.4.8 Beam Display Ribbon: Crosshair



The **Crosshair** is a reference point that can be used to manually set the origin location or to get distance measurements to the Cursor or Centroid. Use the drop-down to set the visibility and mode of **Crosshair** in the **2D Beam Display** window (not visible in the **3D Beam Display**). The **Crosshair** can operate in three modes:



## Manual

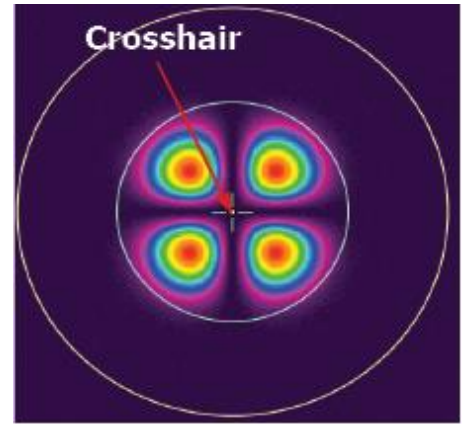
Position the **Crosshair** anywhere within the **2D Beam Display** window either by dragging and dropping with the mouse (grab at the intersection), or by entering exact **X** and **Y** coordinates in the edit controls in the panel. The displayed spatial units follow the units setting in the **Computations** ribbon.

## Peak

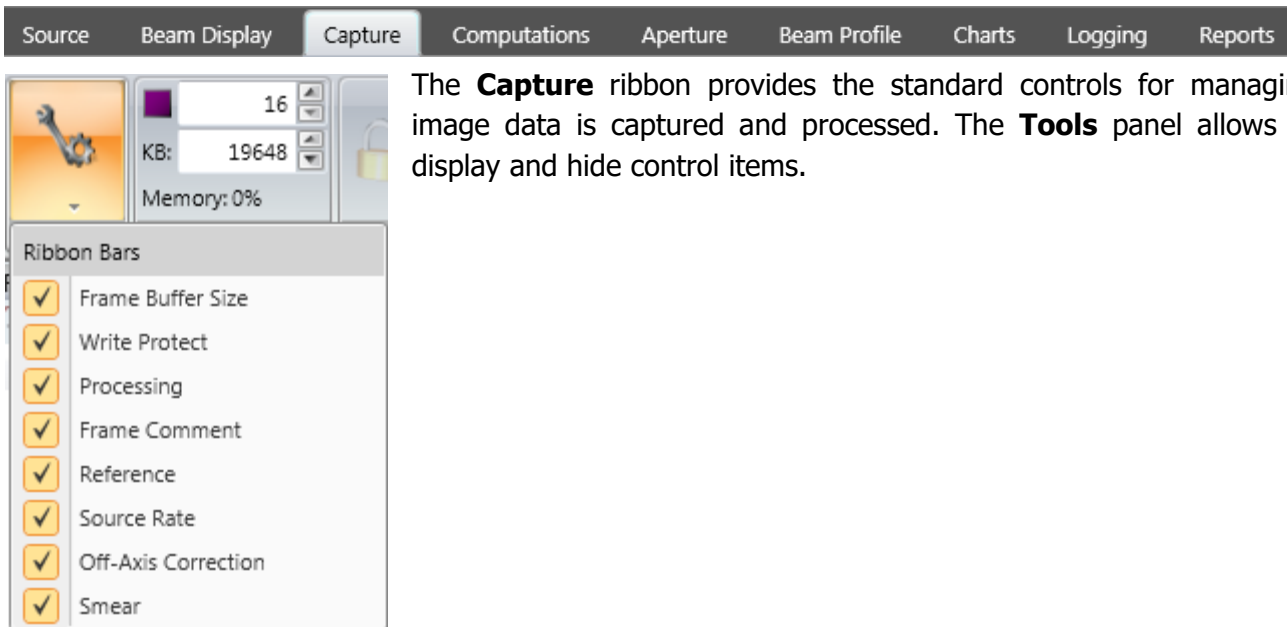
Set the **Crosshair** to automatically track the peak fluence of the input beam. If two identical peaks are present, the peak closest to the top left corner is indicated.

## Centroid

Set the **Crosshair** to automatically track the location of the computed beam **Centroid**.

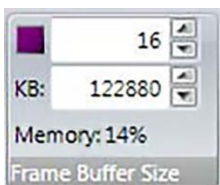


## 2.5 Capture Ribbon and Controls



The **Capture** ribbon provides the standard controls for managing the way image data is captured and processed. The **Tools** panel allows the user to display and hide control items.

### 2.5.1 Capture Ribbon: Frame Buffer Size



Set the size of the image capture buffer. BeamGage reports how much memory is needed in KB, and what percent of the total virtual memory space is consumed.

Slide to view different frames.



Select arrows to view different frames.

The **Frame Buffer** is a cycling temporary data storage space. For example a **Frame Buffer** set to 16 temporarily saves the last 16 frames. Once frame 17 is collected it overwrites frame 1, and so on.

The current frame position in the buffer is displayed in the **Frame Buffer Indicator** on the status bar.

The amount of memory required for each frame depends on the frame size of the camera. Larger imagers require more memory space per frame than smaller formats. The camera **ROI** feature can be used to reduce memory demands (see 2.3.1.5).

BeamGage employs a dynamic memory allocation algorithm that decreases the size of the **Frame Buffer** as total system memory demand increases. This means the **Frame Buffer** size shrinks if other applications are open that draw a greater amount of the total memory available. Modern PCs have 2 or more GB of RAM memory so this is not common. However, if additional applications are open you may notice that the **Frame Buffer** has reduced in size to allow these other applications to be accommodated.



*Always use the smallest buffer size possible.*

## 2.5.2 Capture Ribbon: Write Protect



The **Write Protect** controls prevent buffered data frames from being overwritten by new data. Toggle the frame protection state of a single frame or of the entire contents of the **Frame Buffer**.



Lock **Write Protect** for current frame



Lock **Write Protect** for entire **Frame Buffer**



Unlock **Write Protect** for current frame

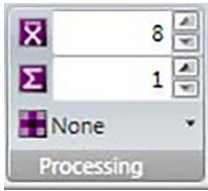


Unlock **Write Protect** for entire **Frame Buffer**



Locked frames are displayed with a padlock in the status bar

## 2.5.3 Capture Ribbon: Processing



Control various types of image processing for collected frames of data.



### Frame Averaging

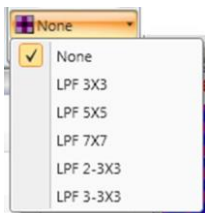
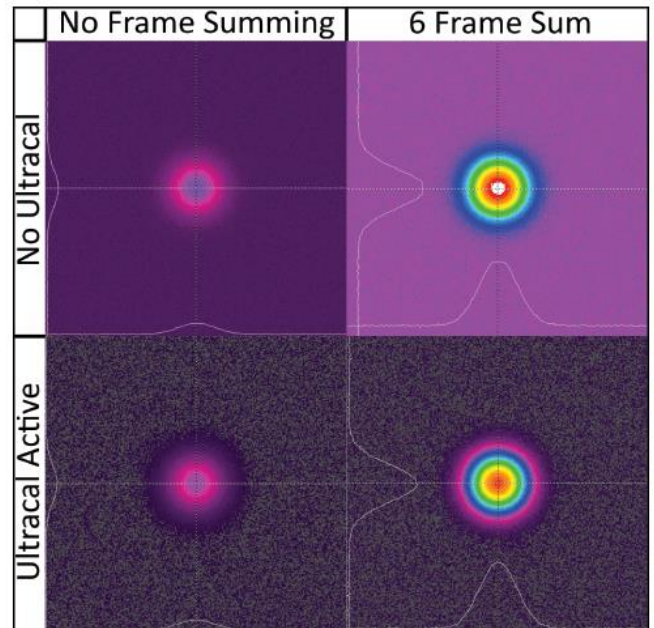
Enter the number of frames to be averaged while collecting data. In this example, 8 frames are averaged and the resulting single frame is placed into the **Frame Buffer**. **Frame Averaging** can be a convenient method to improve SNR when observing low signals where noise is a significant problem. The SNR is improved by the square root of the number of frames averaged.



### Frame Summing

Enter the number of frames to be summed. The summed results are saved in the **Frame Buffer**. In this example, frame summing is set to 1, which disables summing. **Frame Summing** can be used to increase the amplitude of weak signals. Always have **Ultracal** processing enabled so a positive baseline offset doesn't artificially inflate the noise of the resulting data frame as shown.

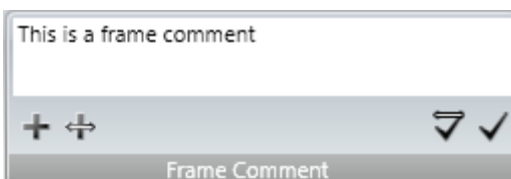
The beam used in this example is the same in each frame. Notice how summing without performing an Ultracal results in a noisier frame and the beam is saturated.



### Convolution

Use to smooth the image noise using various Low Pass Filter (LPF) Convolution algorithms. **Convolution** can help turn a beam with a lot of spatial noise into an ideal beam image.

## 2.5.4 Capture Ribbon: Frame Comment



Enter frame specific comments. Saved comments are displayed in this panel, under the **Frame Info** section in the **Results** window, and at the top of a **Report**. Comments cannot be applied to write protected frames. Comments can be attached four different ways:



### Comment Current

Attaches the comment to the current frame only. It is recommended to save these comments to a data file as they are lost once the **Frame Buffer** is overwritten.



### Comment All

Attaches the comment to all non-write protected frames in the **Frame Buffer**. It is recommended to save these comments to a data file as they are lost once the **Frame Buffer** is overwritten.



### Comment New

Attaches the comment to the current and all future collected frames. Select again to stop commenting on future frames.



### Comment All and Future

Attaches the comment to all previous non-write protected frames and all future collected frames. Select **Comment New** to stop commenting on future frames.



*Adding a comment to all frames overwrites any existing comments.*

## 2.5.5

## Capture Ribbon: Reference Subtraction



**Reference Subtraction** is a special data processing mode that stores a reference frame to a special frame buffer location and then subtracts it from the incoming data frames.

Only one reference frame can be saved at a time. To view the currently saved reference frame set the special buffer mode control to **R** (see 3.2).



### Current Frame

Select to store the currently displayed frame into the **Reference Frame Buffer**.



### Gauss Fit to Current Frame

Select to store a Gaussian fit of the currently displayed frame into the **Reference Frame Buffer**.



### Enable/Disable Reference Subtraction

Toggle **Reference Subtraction** processing. When enabled, newly acquired frames of data have the **Reference Frame** subtracted with the results stored in the **Frame Buffer**, and a green **R** indicator illuminates in the status bar.



**Reference Subtraction** can only be enabled when a data frame of the same format as the incoming data format has been stored into the **Reference Frame Buffer**.

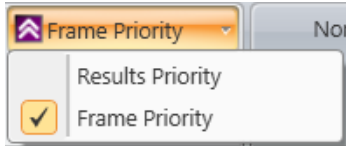


The **R** indicator turns red and **Reference Subtraction** is suspended when a camera setting changes that can compromise the setup. Hover over the indicator for an explanation of what changed to cause the suspension.

## 2.5.6 Capture Ribbon: Source Rate



Sets the data frame collection method. Data is collected in either **Frame Priority** mode or **Results Priority** mode and the **Frame Sampling** rate can be specified.



### Frame Priority

Attempts to capture data frames and store them in the **Frame Buffer** as quickly as possible. Results are computed and posted as fast as the remaining bandwidth allows. Results posting will be skipped if the rate of incoming data cannot be maintained. In this mode it may still be possible for the camera to output frames faster than BeamGage can process them.

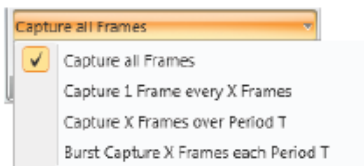
### Results Priority

Makes the computing and posting of results more important than how fast frames are placed into the **Frame Buffer**. Use this mode if observing the results is the main focus of operation.



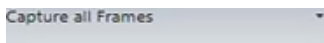
### Stop After

Sets data collection to stop after a specified number of frames. When set to zero this feature is disabled and frame collection is not affected by this control.



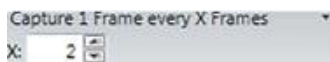
### Frame Sampling

Use the drop-down to select more complex data acquisition modes. These modes can work in parallel with the previous settings, but use with caution. Unanticipated results can occur when many of these types of controls are enabled simultaneously. Each setting is discussed below.



### Capture all

The default setting for frame sampling. Captures all frames in the run and contains no custom settings in the panel.



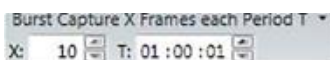
### Periodic Sampling

The value set in the X edit control determines the periodic sample rate. In this example, the capture rate is set to 1 frame out of every 2 frames transmitted by the input device.



### Timed Sampling

Collect X frames over a T second period. In this example, 2 frames will be collected every 1 second, for a capture frame rate of 2Hz.

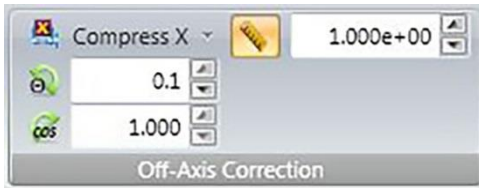


### Burst Sampling

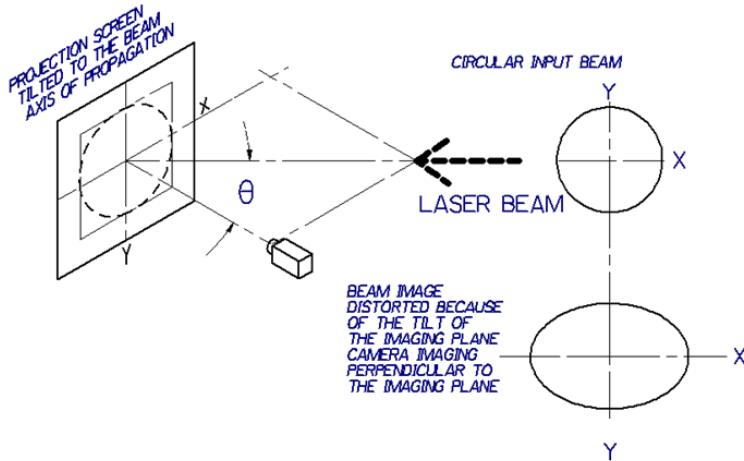
This mode acquires X number of frames each time the period T elapses. Enter the time in HH:MM:SS. In this example, 10 frames will be collected as quickly as possible every 1 hour and 1 second of elapsed time.

All of the above sampling sessions begin by clicking the **Start** button. Clicking **Pause** will end the previous cycle. Clicking the **Start** button again will begin a new cycle. The acquisitions run until stopped by the operator or by a user defined stop condition.

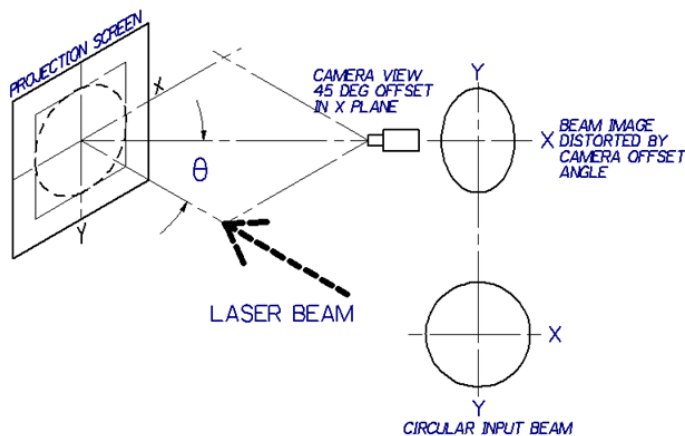
## 2.5.7 Capture Ribbon: Off Axis Correction



The **Off Axis Correction** panel, only available in BeamGage Professional, allows corrections for beam image aspect ratio distortion by compressing it in either the X or Y axes.



**Laser off axis**



**Camera off axis**

**Off-Axis Correction** can be used either when the laser (shown left) or camera (shown below) is off axis, as long as one of the two is perpendicular to the projection screen. In these off axis examples, the input beam is circular but the beam imaged by the camera appears compressed in the X or Y axis.

Beam compression on one axis can be employed to restore the beam's aspect ratio. BeamGage employs a Bresenham smooth scaling image compression algorithm.

In the **Laser off axis** example the beam aspect ratio can be restored by compressing the data on the X axis. In the **Camera off axis** example the beam aspect ratio can be restored by compressing the data on the Y axis. Continue reading for examples.

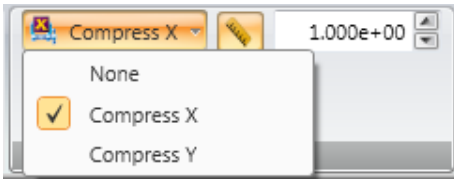


*BeamGage cannot perform image expansion, only image compression.*



## 2.5.7.1 Correction in Two Steps

When working with an off axis imaging system you can correct the beam image and results by following a two step process.

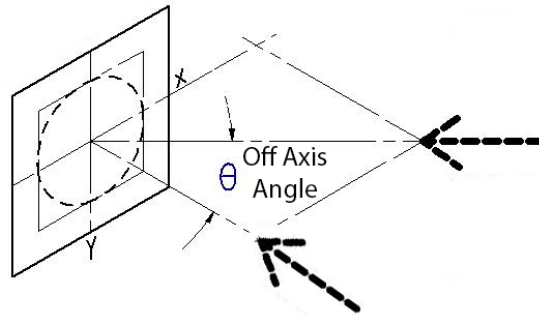


### Step 1, Correct the Image

Select which axis needs to be compressed. If the X axis appears stretched select **Compress X**. If the Y axis appears stretched select **Compress Y**. Select **None** to turn image correction off.



In the **Off Axis Angle** edit box enter the off-axis angle of the camera or laser in relation to the Z axis of the projection screen (represented in image below), or enter the **Off Axis Ratio** (the cosine of the angle). These values are linked and will change in relation to each other. An **Off Axis Angle** of 45.0° (the maximum) has an **Off Axis Ratio** of 0.707 (the minimum).



### Step 2, Scale the Image

After compressing, the image needs to be accurately scaled. The **Optical Scaling** panel is native to the **Computations** ribbon (see section 2.6.3); however the **Optical Scale Factor** control is duplicated here so the needed inputs for correcting and scaling the image are available in one location. Select the ruler icon to activate scaling and enter the scaling factor in the edit control.



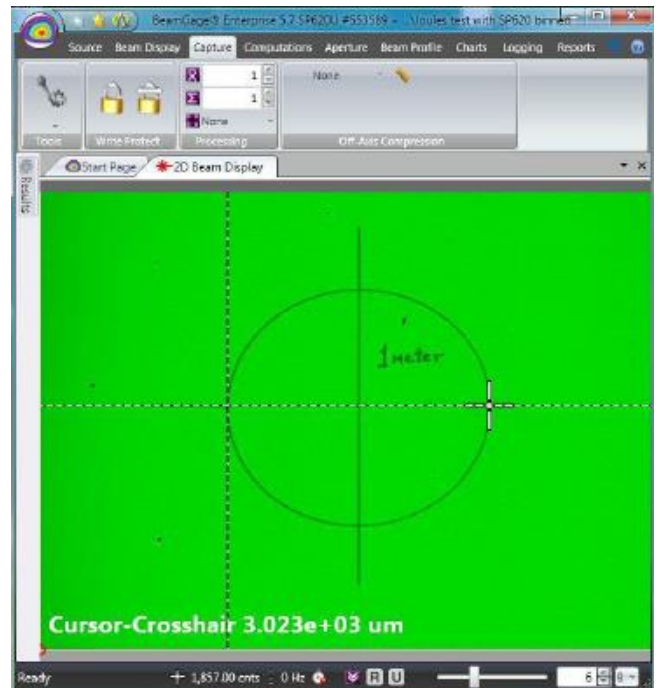
### 2.5.7.1.1 Correction Example

The following example describes a common application of off-axis image correction.

In this example the camera is imaging a projection screen with a temporary 1 meter target circle drawn on, and is placed low in the Y axis of the target, compressing it in the Y axis. It will be used to align, correct, and scale the final image. The original image (shown right) is the target before correction.

The camera is focused on the target and the **Cursor** and **Crosshair** are enabled. The **Cursor-Crosshair** distance result is overlaid in the 2D display to show the target width before and after compression.

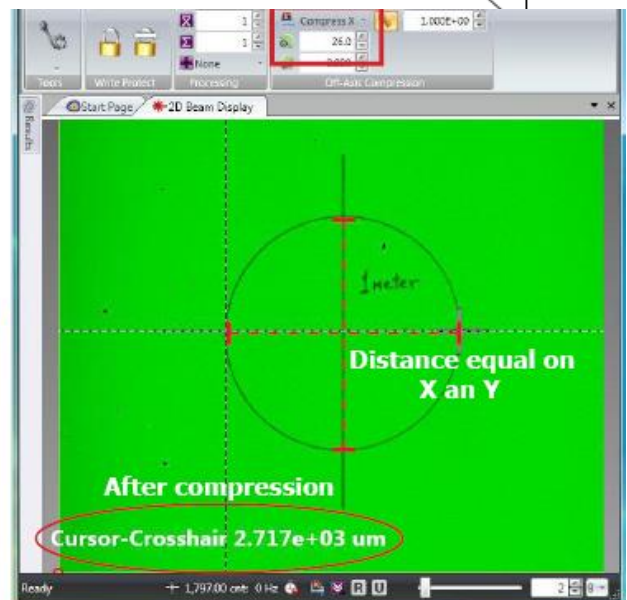
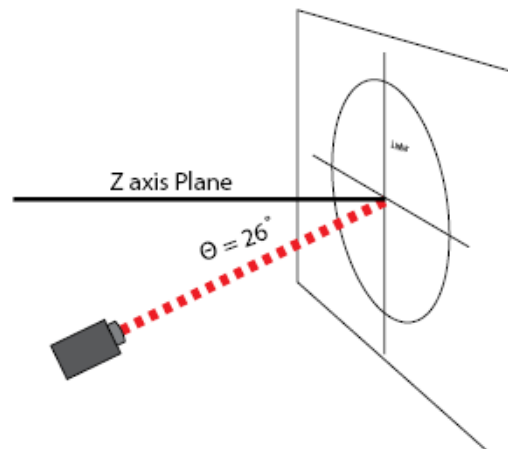
The current **Scale Factor** is 1x so the distances are based on the pixel pitch of the camera.



The first step in correcting the image is to apply image compression in the X axis.

In this example the camera's angle in the Y axis was measured as 26 degrees. **Compress X** was enabled and an **Off Axis Angle** of 26.0 degrees is entered.

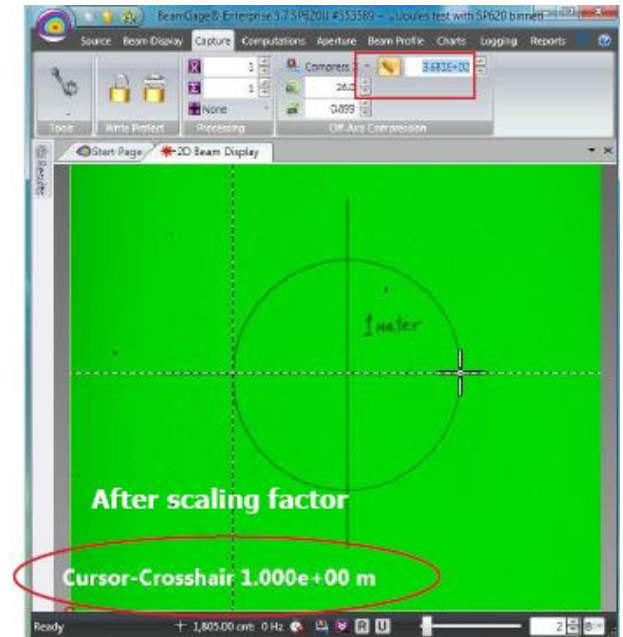
After compression, the image was measured using the **Cursor-Crosshair** distances in both the X and Y axes and found to be the same.



The final step is to set the scaling factor so the resulting circle measures 1 meter.

The image right shows the **Scale Factor** modified to a value of 368.1, resulting in a **Cursor-Crosshair** distance of 1.000+00 m, or 1 meter, the actual size of the physical target.

The setup can be saved if it may be needed again in the future (see 1.9).



## 2.5.7.1.2 Correction Induced Errors

The Bresenham compression algorithm is designed for speed at the expense of accuracy. One consequence is that small compressed images may experience some image distortion. To keep the measurement errors low, the user should make the imaged beam fill as much of the camera's imager as possible without overfilling the frame. Since most cameras have wider X axis, it is beneficial to orient the camera with the elongated image axis aligned with the camera's X axis. This will require compression in the X axis making the final image aspect ratio squarer.



*To prevent overfilling the imager the beam width should be no greater than half the imager in height and width.*

The table below indicates the typical degree of induced second moment beam width error as the original imaged beam is compressed in size for various offset angles. Pixels and beam widths are normalized to unit pixel values. BeamMaker was employed to create an elongated Gaussian beam, and then the compression feature was used to correct it. The user may employ BeamMaker to replicate their beam size and measurement method to determine error based on a specific measurement scenario.

Beam Size in Pixels vs. ⊙	10°	20°	30°	45°
10px	+1.5%	+4.3%	+1.1%	+1.0%
15px	+1.6%	-0.3%	-0.3%	+0.5%
30px	+1.5%	-0.4%	0%	0%
60px	-0.2%	+0.1%	0%	0%
100px	-.4%	0%	0%	0%

**Typical Second Moment Beam Width Compression Measurement Error, Corrected Beam Width vs. Offset Angle**

As illustrated above, beam widths > 60 pixels suffer little error effects due to the compression algorithm. Error effects only become significant if the beam approaches 10 pixels, which is the recommended minimum spot size for beams even without applying compression.

### 2.5.7.1.3 Correction Alters the Image Data Format

When image compression is applied the resulting image data format is permanently modified from the original format generated by the camera. This modified data format can be processed, saved, and reloaded just as if it originated from a camera with the same horizontal and vertical format resulting from the compression process. In other words, this new image is forever linked to the resulting image size.

The pixel scaling is made permanent for these data sets and is reapplied if the data is viewed later. Frames that have been compressed cannot be uncompressed at a later time.

In order to process this image against another, such as using image reference subtraction, both the source and the reference images must have matching formats.

### 2.5.7.1.4 Optical Considerations

In all instances the user is required to apply a properly designed optical imaging system. The system must take into account the depth of field of the applied lens. Beams imaged off-axis may also experience additional distortion if the beam is not collimated (i.e. rapidly diverging or converging) and the projection plane is tilted to the beam axis. Control of background light, scatter, diffusion in the projection plane, and wavelength filters should also be taken into account.

#### Rear Surface Projections

The projection plane can also be made of a diffuse material that allows the image to be viewed on its rear surface. Rear surface imaging is often performed off-axis. All of the above scenarios that apply to front surface distortion can also apply to rear surface imaging.

#### Projection Directly on the Camera Imager

It should be noted that **Laser off axis** can also be applied if the camera imager is substituted for the projection plane. While this is a less common application, it is corrected the same way.


## 2.5.8 Capture Ribbon: Smear Correction

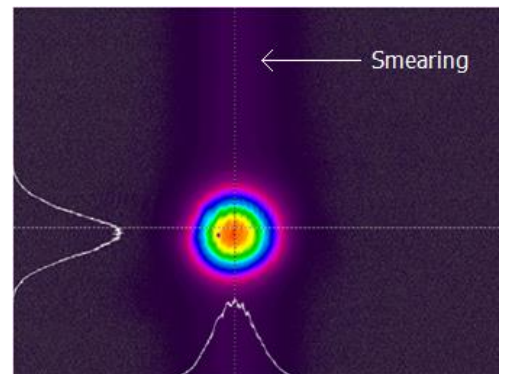


Smearing manifests as a vertical streak in the camera image. It is caused by an excessive amount of incident power on the sensor, typically as a result of a poor match between the laser wavelength and the camera sensor's quantum efficiency. Silicon-based sensors have high quantum efficiency at visible wavelengths and tend to experience smearing in the NIR and IR ranges ( $>1000\text{nm}$ ).

The best way to avoid smearing is to increase the camera exposure above 10ms and add attenuation until the beam is not saturated. If this is not feasible, **Smear Correction** can be enabled to correct for the smearing mathematically.

**Smear Correction** is only available on CCD cameras. Some multi-tap cameras will not correct the image unless the camera is put in single tap mode.

If **Smear Correction** is applied successfully, a green  indicator illuminates in the status bar.



**Smear Correction** should not be enabled if smearing is not present. Doing so may create a loss of accuracy.

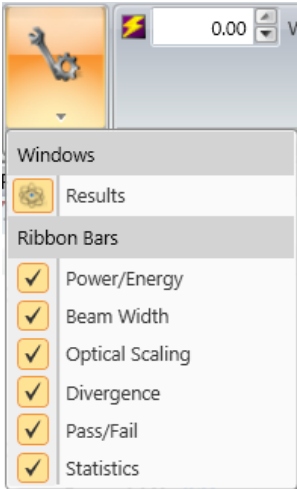


**Smear Correction** makes the background look similar to having performed an **Ultracal**. For accurate measurements **Ultracal** must still be enabled.



The **S** indicator turns red and **Smear Correction** is suspended if the beam is saturated or if **MultiTap** is enabled. Hover over the indicator for an explanation of what caused the suspension.

## 2.6 Computations Ribbon and Controls

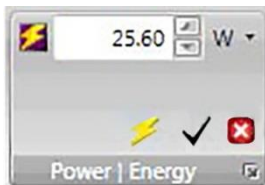


The **Computations** ribbon provides many basic setup controls for the computed values that can be enabled in the **Results** window as well as other display windows that depict numerical values either directly or in graphical form. The **Results** window and panels are enabled in the **Tools** panel.



The **Results** button in the **Tools** menu opens/closes the **Results** display window. Section 2.6.7 describes the **Results** display window and all of its controls.

### 2.6.1 Computations Ribbon: Power/Energy



Manually calibrate the beam power/energy based on an external reference source. When an external Ophir meter is connected to the local PC and has been selected as a calibration source, the values entered here have no effect.



#### Calibration Value

Enter calibration values based on a measurement from an external power/energy meter. Until the calibration is applied, results are not calibrated and the beam intensity is reported in counts.



#### Calibration

To apply the entered Power/Energy value with the selected units, click **Calibration**. The current frame is assigned the calibration value entered. If the calibration value has been changed but not applied, the value displays red.



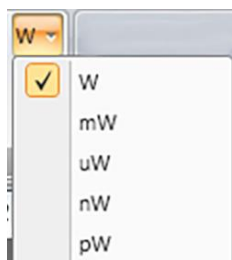
#### Clear Calibration

Select to clear the calibration. The last entered calibration value remains but the calculated units revert to processed digitized counts (cnts) and are dimensionless.



#### Power Meter Indicator Icon

This icon only appears when a power meter is connected and giving results. Any values entered in this panel are ignored.

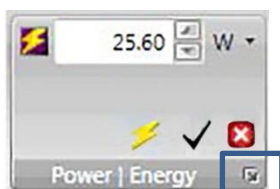


### Power/Energy Units

Set the units of measurement for Power/ Energy.

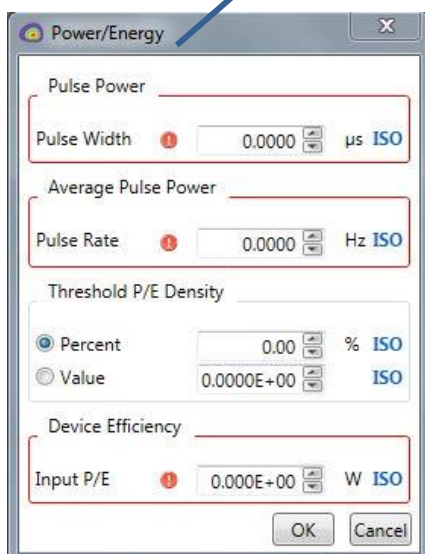


*If the units of measurement are changed after calibration has processed, the results automatically update. However the units cannot be changed from Power to Energy or vice versa without the current calibration being cleared, and then recalibrating with the correct units.*



### Power/Energy Settings

Select the expansion button in the lower right corner to open the **Power/Energy** dialog box. These additional entries are needed to compute additional power/energy results items. They are described below and reviewed mathematically in Chapter 5.



### Peak Pulse Power

The **Peak Pulse Power** of a single laser pulse can be computed by entering the laser's pulse width in the associated edit control.

### Average Pulse Power

The **Average Pulse Power** of a pulsed laser can be computed by entering the pulse repetition rate in the associated edit control.


### Threshold P/E Density

The **Top Hat Threshold Power/Energy Density** can be computed by entering the known threshold effective fluence value needed to perform the work of the Top Hat beam. This result can also be computed based on a **% of Peak** setting.

### Device Efficiency

Enter the input power or energy of the laser to compute the laser's overall **Device Efficiency**. Enter the laser's input power/energy in the same units that are being used to measure the output power/energy, i.e. Watt units or Joule units for the input and output.



*If an entry is not applicable with the current calibration, an error appears around the option. Place your cursor over the warning sign  for an explanation as to why the option is not applicable.*

The blue **ISO** indicates that the result is computed using an ISO defined method. However, if other settings are inappropriately configured, the ISO result may not be achieved. This topic is covered in more detail in Chapter 5.



## 2.6.2 Computations Ribbon: Beam Width



**Beam Width Basis** is one of the most important settings for obtaining accurate ISO results in many areas. Selections here define the beam width methods used in computing all other results items that require and rely on the **Beam Width** or **Diameter** as an input. Many of the ISO results rely heavily on the use of the second moment beam width or diameter definition to yield correct results. ISO Divergence calculations are one such example.

The **Beam Width Basis** selects which method is used to draw the **Beam Width Aperture** in both the 2D and 3D displays. It also impacts which clip level method is employed when computing a beam's rotational orientation.



### Beam Width Method

Select the **Beam Width Basis** from the drop-down list. **D4σ** is the preferred Second Moment calculation method.



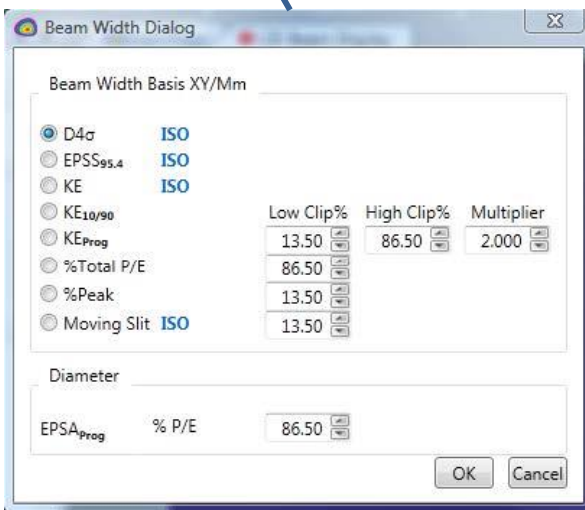
### Beam Width Units

Choose the primary spatial display units in the right drop-down control.



### Beam Width Settings

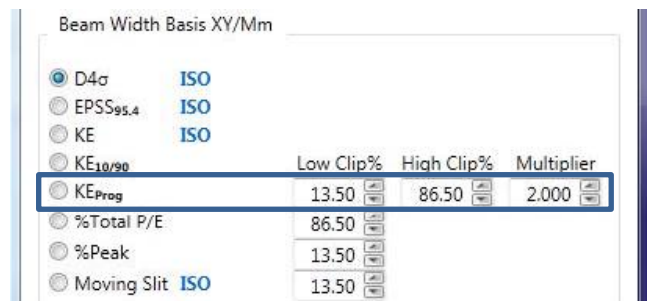
Select the expansion button in the lower right corner to open the **Beam Width** dialog box. Some beam width choices require additional input parameters to be correctly and meaningfully applied. The required input parameters are entered here. The factory default settings are shown.



A description of these Beam Width and Diameter setting notations is contained in Chapter 5.

### 2.6.2.1 Programmable Knife Edge, KE<sub>Prog</sub>, KE Clip %

These are the settings for the user programmable Knife Edge Clip level entries. Specify a **Low** and a **High** % of power clip level and a **Multiplier** correction factor. 13.5% and 86.5% with a 2x multiplier is the default setting and represents the second moment settings for a TEM<sub>00</sub> Gaussian beam.



## 2.6.2.2 Programmable % of Total Power/Energy, %P/E, Clip %

Enter the percent of power/energy contained to set the clip level for computing the beam widths and diameters using this method. 86.5% is the default setting and represents the second moment setting for a TEM<sub>00</sub> Gaussian beam.

Beam Width Basis XY/Mm	Low Clip%	High Clip%	Multiplier
<input checked="" type="radio"/> D4σ ISO			
<input type="radio"/> EPSS <sub>95.4</sub> ISO			
<input type="radio"/> KE ISO			
<input type="radio"/> KE <sub>10/90</sub>			
<input type="radio"/> KE <sub>Prog</sub>	13.50	86.50	2.000
<input checked="" type="radio"/> %Total P/E	86.50		
<input type="radio"/> %Peak	13.50		
<input type="radio"/> Moving Slit ISO	13.50		

## 2.6.2.3 Programmable % of Peak, %Peak, Clip %

The Ophir-Spiricon legacy version of this result is based on a 1D analysis of the data lying along the X/Y or M/m axis running through the centroid of the beam. Enter the percent of the beam's peak fluence that defines the clip level for computing the beam widths and diameters using this method. 13.5% is the default setting and represents the second moment setting for a TEM<sub>00</sub> Gaussian beam. To obtain a Full Width Half Max (**FWHM**) result set this value to 50%.

Beam Width Basis XY/Mm	Low Clip%	High Clip%	Multiplier
<input checked="" type="radio"/> D4σ ISO			
<input type="radio"/> EPSS <sub>95.4</sub> ISO			
<input type="radio"/> KE ISO			
<input type="radio"/> KE <sub>10/90</sub>			
<input type="radio"/> KE <sub>Prog</sub>	13.50	86.50	2.000
<input type="radio"/> %Total P/E	86.50		
<input checked="" type="radio"/> %Peak	13.50		
<input type="radio"/> Moving Slit ISO	13.50		

## 2.6.2.4 Programmable Moving Slit % of Peak, D%ms, Clip %

This result mimics the moving slit method as defined by **ISO 11146-3**. Enter the percent of the beam's peak fluence that defines the clip level for computing the beam widths and diameters using this method. 13.5% is the default setting and represents the second moment setting for a TEM<sub>00</sub> Gaussian beam. This method assumes the beam is TEM<sub>00</sub> (M<sup>2</sup>=1). To obtain a **FWHM** result set this value to 50%.

Beam Width Basis XY/Mm	Low Clip%	High Clip%	Multiplier
<input checked="" type="radio"/> D4σ ISO			
<input type="radio"/> EPSS <sub>95.4</sub> ISO			
<input type="radio"/> KE ISO			
<input type="radio"/> KE <sub>10/90</sub>			
<input type="radio"/> KE <sub>Prog</sub>	13.50	86.50	2.000
<input type="radio"/> %Total P/E	86.50		
<input type="radio"/> %Peak	13.50		
<input checked="" type="radio"/> Moving Slit ISO	13.50		

## 2.6.2.5 Diameter EPSA % of Power/Energy

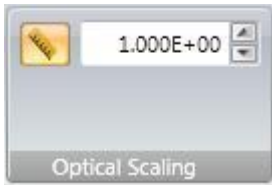
This is the Diameter Encircled Power Smallest Aperture (**EPSA**) method, also commonly called the encircled power or power in a bucket method. Enter the percent of the total power for the reported beam diameter to encircle. 86.5% is the default setting and represents the second moment setting for a TEM<sub>00</sub> Gaussian beam.

Diameter	Value
<input type="radio"/> %Peak	13.50
<input type="radio"/> Moving Slit ISO	13.50
<input checked="" type="radio"/> EPSA_Prog % P/E	86.50

OK Cancel



## 2.6.3 Computations Ribbon: Optical Scaling



Apply a pixel scaling factor to correct for optical expansion or reduction when using an imaging optic, e.g. a beam expander or reducer.

Select the ruler icon to activate optical scaling and enter a scaling expansion or reduction factor in the edit field.

Values greater than 1 indicate a larger field of view projected onto the imager. Use with beam reducers or standard C-mount lenses.

Values less than 1 indicate a smaller field of view projected onto the imager. Use with beam expanders or microscope objectives.

## 2.6.4 Computations Ribbon: Divergence



BeamGage supports three different methods for measuring Divergence.

- The ISO Focal Length method
- The Point Source Far-Field Wide Angle method
- The Far-Field 2 point method

Divergence		
$\theta$ X ISO	0.384	mrاد
$\theta$ Y ISO	0.383	mrاد
$\theta$ ISO	0.383	mrاد
Radiant Intensity	19,320,648,520	cnts/sr

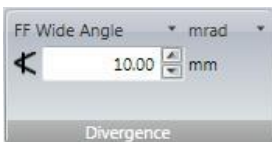
Each method determines how the Divergence results are calculated. All are described in more detail in Chapter 5.

### 2.6.4.1 Focal Length Method



The **Focal Length** divergence method provides a means for finding the far-field beam divergence at any point in the beam propagation path. This method is for small divergence angles and is best displayed using the **mrاد** units. Enter the **Focal Length**, in mm, of the plano-convex lens being employed.

### 2.6.4.2 Far-Field Wide Angle Method



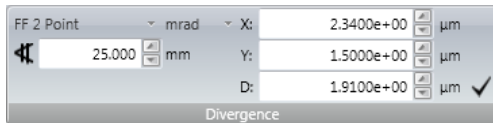
This method assumes the laser beam emanates from a point source. This is a good approximation for measuring the divergence of a laser diode in **degrees**.

1. Set the camera imager at a location in the beam far-field where it still contains the entire beam profile. This is usually quite close to the laser source.
2. Measure the distance from the laser source to the camera imager.
3. Enter the value in the **Detector Distance** edit control









As the resulting beam widths are measured, the corresponding divergence angles are computed.

### 2.6.4.3 Far-Field Two Point Method



This method is only accurate when the measurements are made in the far-field of a small diameter laser beam. Use for small divergences with the units best suited for **mrاد** dimensions.

The beam must be measured at two separate locations, with each in the far-field of the caustic.

1. Set the camera imager to a location in the far field of the beam with a smaller beam width.
2. Select **Start**  to collect at least one frame for the imager to be able to populate the beam width dimensions.
3. **Pause**  the data acquisition.
4. Select the  button to populate the beam widths directly into the **X**, **Y**, and **D** fields, or enter beam widths manually.
5. Note the position of the camera imager.
6. Move the imager to a second, distant location in the far field with a larger beam width.
7. Enter the distance the camera imager moved, in mm, in the **Far-Field Two Point** edit control  25.000 
8. Select **Start**  to begin collecting **Divergence** results based on the angle subtended by the two beam widths.

For most accurate results use a second moment **Beam Width Basis** and be sure to **Ultracal** before making each measurement.

### 2.6.5 Computations Ribbon: Pass/Fail



Set master **Pass/Fail** controls. **Pass/Fail** boundary conditions are set in the various **Results** display windows (2.6.7.3.4). The controls that enable the **Pass/Fail** indicators and the consequences of a Pass or a Fail event are determined here.



*If any Pass/Fail item is active in the results, the **Master Enable Pass/Fail** box is automatically checked.*



#### Master Enable Pass/Fail

Toggle ON to allow **Pass/Fail** limits to be applied to bounded results items. **Pass/Fail** testing is disabled when OFF.



#### Pass/Fail Action

Select which **Pass/Fail** condition to perform an action on: Pass, Fail, or no Action. The possible actions are:



#### TTL Pulse

Output a TTL pulse from a USB adapter on each actionable event. Order this adapter as an option (SP90060).



### Beep

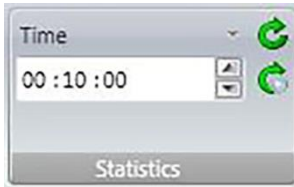
The PC's Beep tone will sound when an actionable event occurs.





### Stop

Stop data collection when an actionable event occurs.

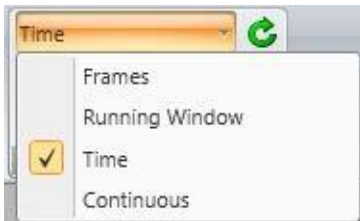
## 2.6.6 Computations Ribbon: Statistics



Configure the master control for the **Results** window Statistical calculations. Set the number of samples to use in computing the statistical results values. The stats can be set to reset each time data collection is started , or can be manually reset at any time, even while running .

A typical stats display with all statistical measurement types (Mean, Std Dev, Max, Min, and Sample Size) will look like the results display shown below.

Name	Value	Units	Mean	Std Dev	Max	Min	Sample Size
Power/Energy ▾							
Total Power ISO	3.749e+02	W	3.749e+02	7.493e-02	3.751e+02	3.748e+02	100
Avg Pwr Density ISO	3.486e+06	W/cm <sup>2</sup>	3.488e+06	3.341e+03	3.496e+06	3.482e+06	100
Peak Fluence ISO	1.299e+07	W/cm <sup>2</sup>	1.300e+07	2.729e+04	1.307e+07	1.294e+07	100
Spatial ▾							
Centroid X ISO	1.249938e+02	pixels	1.249868e+02	1.437e-02	1.250306e+02	1.249492e+02	100
Centroid Y ISO	1.250022e+02	pixels	1.249855e+02	1.350e-02	1.250190e+02	1.249567e+02	100
D%pkX	0.000e+00	pixels	0.000e+00	0.000e+00	0.000e+00	0.000e+00	100
D%pkY	0.000e+00	pixels	0.000e+00	0.000e+00	0.000e+00	0.000e+00	100
D%pk	1.990e+01	pixels	1.993e+01	1.859e-01	2.037e+01	1.951e+01	100

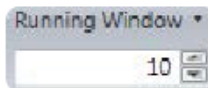


There are four running modes for collecting Statistics. The mode selected here also interacts with the **Source Rate** settings in the **Capture** ribbon. After setting up one of these modes, make sure the **Capture** setup is compatible with the objectives of the statistical mode setup.



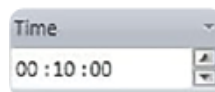
### Frames

Sets the number of frames used to calculate statistics. Data collection will continue running but statistics calculation will stop after collecting the specified number of frames. This is one of the simpler and most common methods for collecting statistics.



### Running Window

Sets statistics and data collection to run continuously, but only calculate statistics on the last specified number of frames.



### Time

Sets data collection to run continuously but statistics calculation ends after a set period of time (HH:MM:SS). The display counts down during data collection and statistics stop calculating when the count reaches zero. The number of frames processed in the final count is determined by other factors e.g. the **Capture Source Rate**.

Continuous

### Continuous

Sets statistics to compute continuously until manually stopped or reset.



### Reset on Start

When enabled, this control resets all statistics when the Start button is selected, and can assist in keeping statistics in sync.



### Reset

Select to reset all statistics manually.



*When collecting statistics over an extended period of time, the camera baseline may drift due to changes in the camera's temperature. For best results allow the camera to reach thermal equilibrium and then try to maintain the temperature while collecting data frames.*

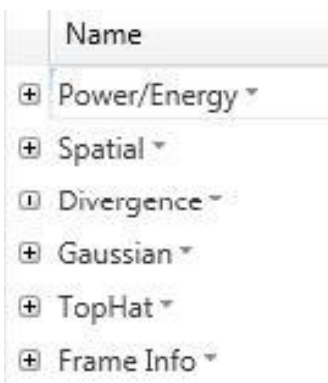
## 2.6.7 Results Display Controls

The **Results** display window is the only window with a great number of embedded controls. Results groups and individual Results items have drop-down controls that select which results items are to be enabled/computed as well as other related features such as:

- Collapse/expand a group
- Enable Statistical results, applied to groups or to individual items
- Drag and Drop a result item in another display window
- Configure the Pass/Fail limits for a selected results item
- Open a Strip chart on a selected results item
- Set the font size and color for a selected results item



*Only enabled results are computed.*



The Results Items are grouped into self-descriptive and logical divisions.

Click on a group name to open a drop-down selector of the results within the group. The + control expands the group and shows the enabled results items.

For example, the **Power/Energy** group contains the results items shown below. The items checked in the group appear in the expanded results.

Name	Value	Units
Power/Energy ▾		
Statistics ▸		
Select All Results		
<input checked="" type="checkbox"/> Total Power		
<input checked="" type="checkbox"/> Avg Pwr Density		
<input checked="" type="checkbox"/> Peak Fluence		
Minimum Fluence		
Peak Pulse Power		
Avg Pulse Power		
Efficiency		
% in Aperture		

Name	Value	Units
Power/Energy ▾		
<b>Total Power ISO</b>	3.750e+02	W
<b>Avg Pwr Density ISO</b>	3.490e+06	W/cm <sup>2</sup>
<b>Peak Fluence ISO</b>	1.305e+07	W/cm <sup>2</sup>

## 2.6.7.1 Group Statistics

Name	Value	Units	Mean
Power/Energy ▾			
Statistics ▸			
Select All Results			
<input checked="" type="checkbox"/> Total Power			
<input checked="" type="checkbox"/> Avg Pwr Density			
<input checked="" type="checkbox"/> Peak Fluence			
Minimum Fluence			
Peak Pulse Power			
Avg Pulse Power			
Efficiency			
% in Aperture			

<input checked="" type="checkbox"/> Select All Statistics	
<input checked="" type="checkbox"/> Mean	
<input checked="" type="checkbox"/> Std Dev	
<input checked="" type="checkbox"/> Max	
<input checked="" type="checkbox"/> Min	
<input checked="" type="checkbox"/> Sample Size	

To enable the statistics within a group click on the Statistics drop-down option as shown. Check on the statistical item(s) to be computed and displayed.

The **Sample Size** must be enabled for each item. When each item is enabled, the sample size for that item resets. The easiest way to get all results in sync is to enable the desired results and then reset all statistics in the **Computations** ribbon.

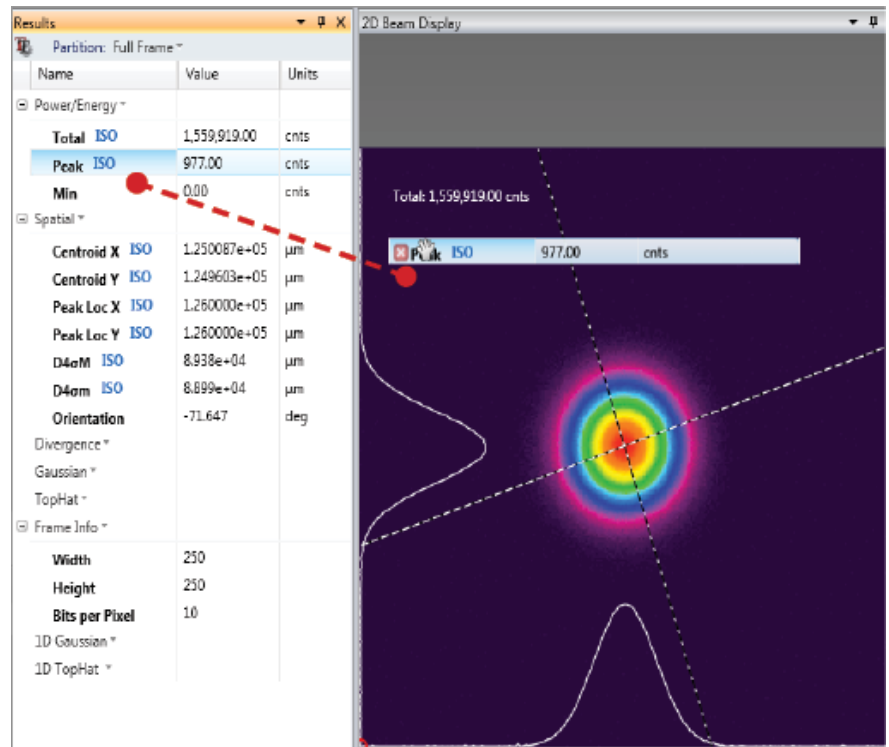
A full set of statistics is displayed in the image below.

Name	Value	Units	Mean	Std Dev	Max	Min	Sample Size
Power/Energy ▾							
<b>Total Power ISO</b>	3.749e+02	W	3.749e+02	7.493e-02	3.751e+02	3.748e+02	100
<b>Avg Pwr Density ISO</b>	3.486e+06	W/cm <sup>2</sup>	3.488e+06	3.341e+03	3.496e+06	3.482e+06	100
<b>Peak Fluence ISO</b>	1.299e+07	W/cm <sup>2</sup>	1.300e+07	2.729e+04	1.307e+07	1.294e+07	100
Spatial ▾							
<b>Centroid X ISO</b>	1.249938e+02	pixels	1.249868e+02	1.437e-02	1.250306e+02	1.249492e+02	100
<b>Centroid Y ISO</b>	1.250022e+02	pixels	1.249855e+02	1.350e-02	1.250190e+02	1.249567e+02	100
<b>D%pkX</b>	0.000e+00	pixels	0.000e+00	0.000e+00	0.000e+00	0.000e+00	100
<b>D%pkY</b>	0.000e+00	pixels	0.000e+00	0.000e+00	0.000e+00	0.000e+00	100
<b>D%pk</b>	1.990e+01	pixels	1.993e+01	1.859e-01	2.037e+01	1.951e+01	100

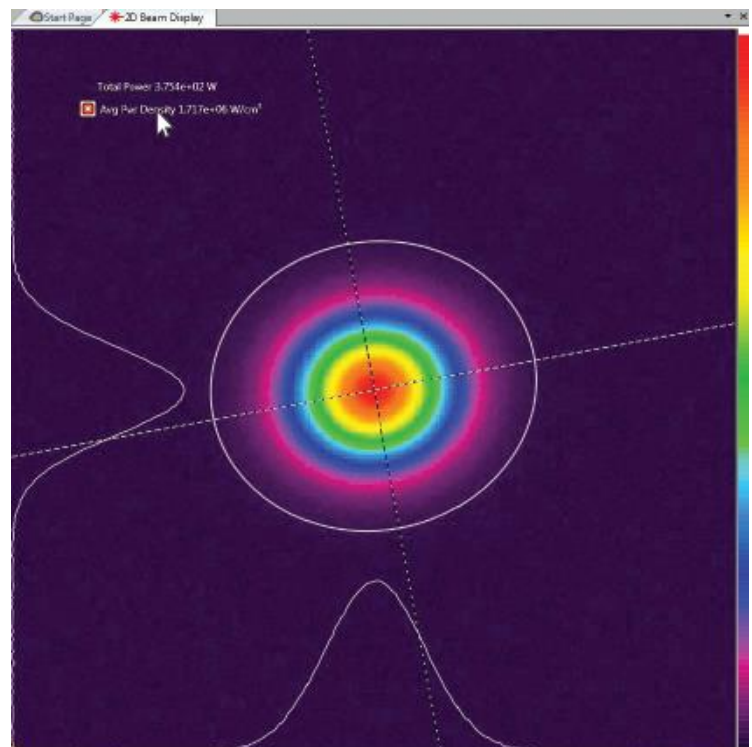
## 2.6.7.2 Drag and Drop

The Drag and Drop feature allows selected results to float in any display window, providing the ability to strip off only the results items that are needed and display them within another display window with a transparent background.

Enabled statistic values also are displayed in the display window. Statistics values can be enabled/disabled for the selected result while it is in the display window the same way they are enabled when in the **Results** window.



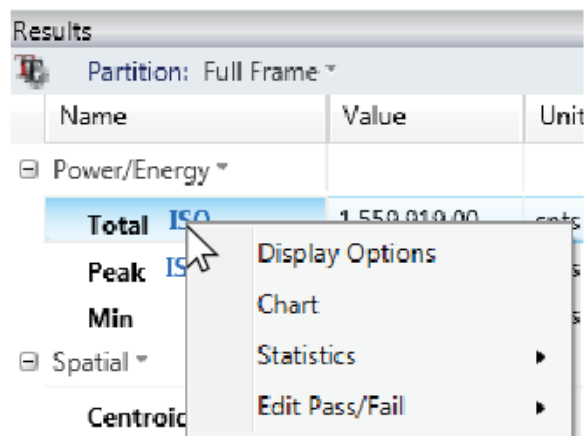
To reposition the location of the item, use the mouse to drag and drop it to a new location. To delete the floating item, hover the mouse over the item and click the cancel box that appears.



*If a result item is copied and displayed in another window, hiding it in the results window will not remove it from the display window. It must be removed separately.*

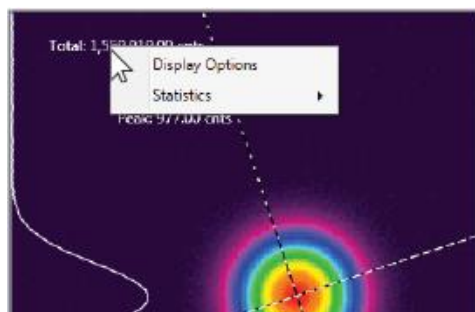


## 2.6.7.3 Results Options



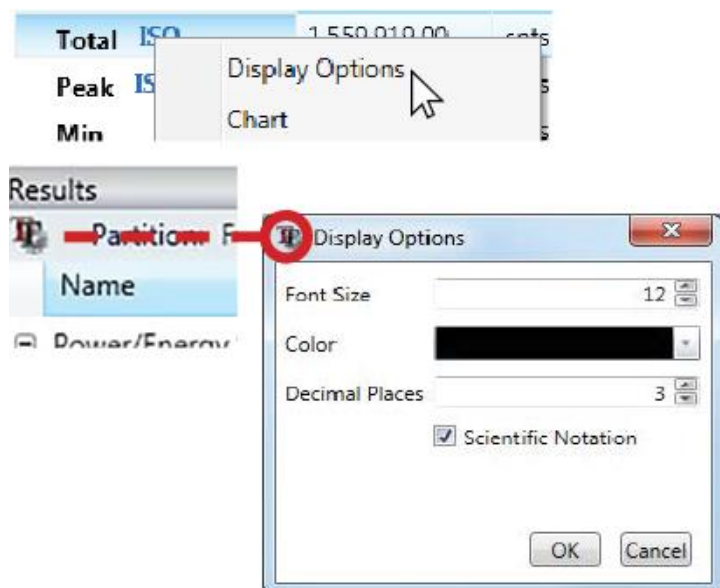
\*Result item options vary for each setting.

Each result item has its own drop-down list of statistics and results options which can be accessed by right-clicking the result item. **Display Options**, **Chart**, and **Edit Pass/Fail** open separate dialog boxes that contain additional choices.



Only **Display Options** and **Statistics** can be accessed for an item that has been dropped in a separate display. To access all options, right click the item in the **Results** window instead.

### 2.6.7.3.1 Display Options



The font size, color, and display notation for results can be changed using the **Display Options** dialog box. Right-click a results item and select **Display Options** to open the dialog box.

**Display Options** can be changed for all results at once by clicking the **Display Options** icon at the top of the **Results** window.

Set the font size, color, the number of decimal places to be displayed, and whether scientific notation is enabled for the all results.

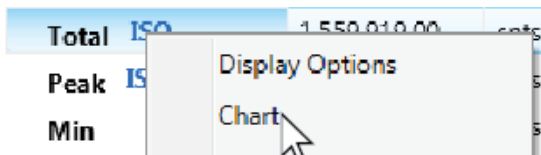
Results dropped in a different display maintain their settings, but can be changed manually by right-clicking the result and selecting display options.



*Enabled Pass/Fail colors overwrite the color set here (see 2.6.7.3.4).*



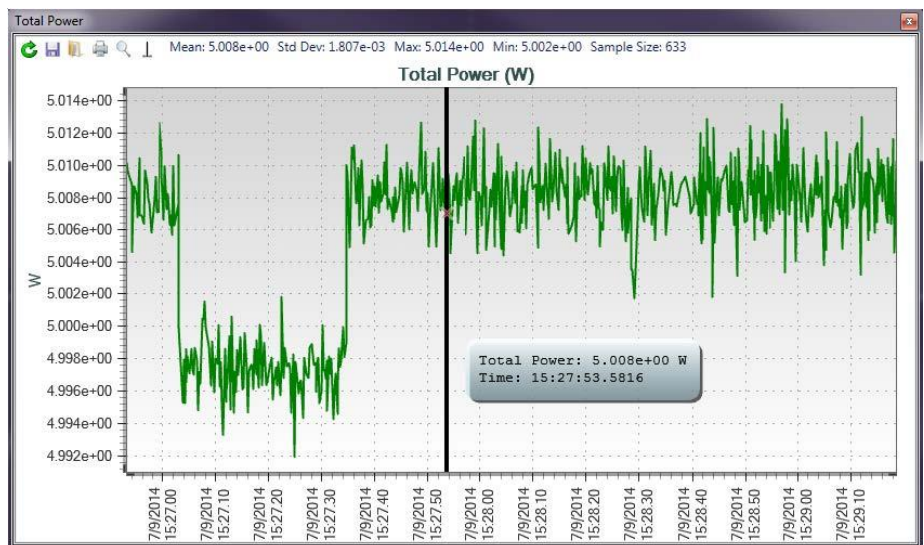
## 2.6.7.3.2 Chart



The **Chart** option opens a **Strip Chart** window that plots the result item over time. The **Charts** ribbon and the **Strip Chart** contain important controls that may need to be modified for charting operation to perform as expected.

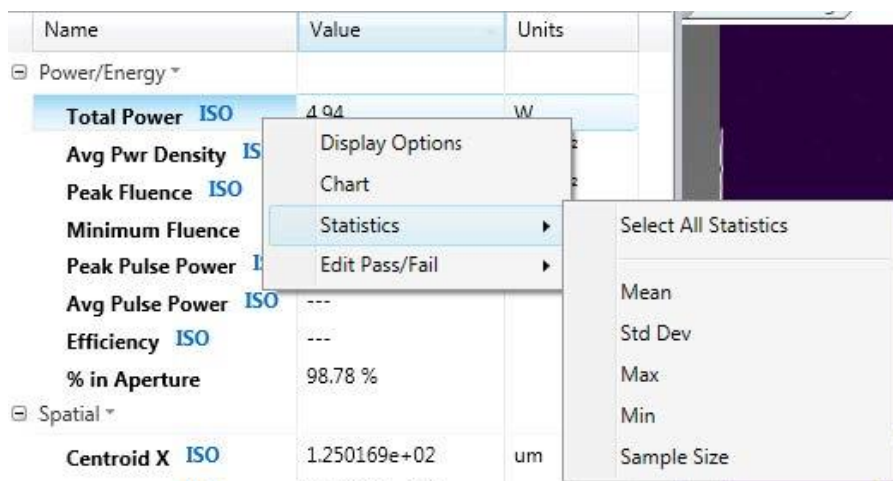
The **Strip Chart** window opens in a Primary Dock tab and may need to be repositioned.

The figure below shows a typical **Strip Chart** display window for Total Power. See 2.9.2 for information on all **Strip Chart** controls.



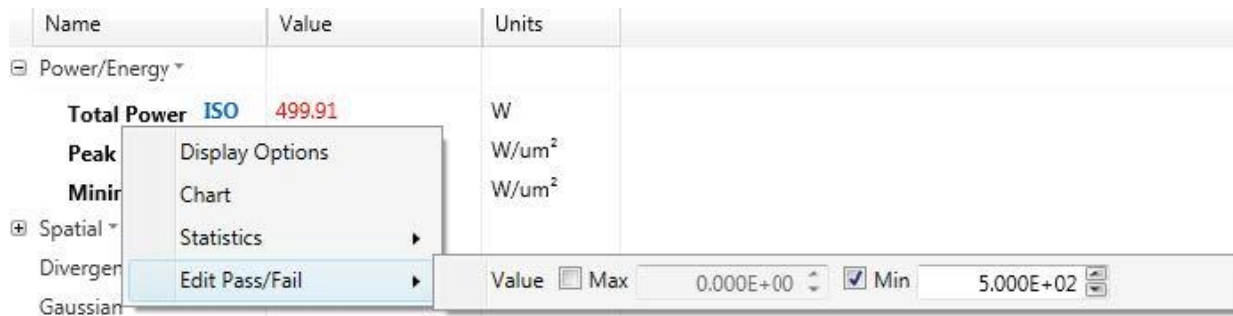
## 2.6.7.3.3 Individual Statistics

Statistics values can be enabled/disabled for each result individually. Right-click a result to see the options and select the statistics values.



## 2.6.7.3.4 Edit Pass/Fail

Enable and define **Pass/Fail** parameters on individual Results items. Right-click a Results item, select **Edit Pass/Fail**, enable the max/min condition(s) to be applied, and enter the limit values that define the boundary conditions.



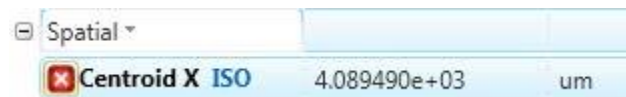
In the example above, the pass condition requires the Total Power to be greater than or equal to 500 Watts. The units selected define the pass/fail units.

Results that pass conditions appear **Green** and values that fail appear **Red**.

Additional Pass/Fail settings may need to be set in the **Computations Pass/Fail** panel.

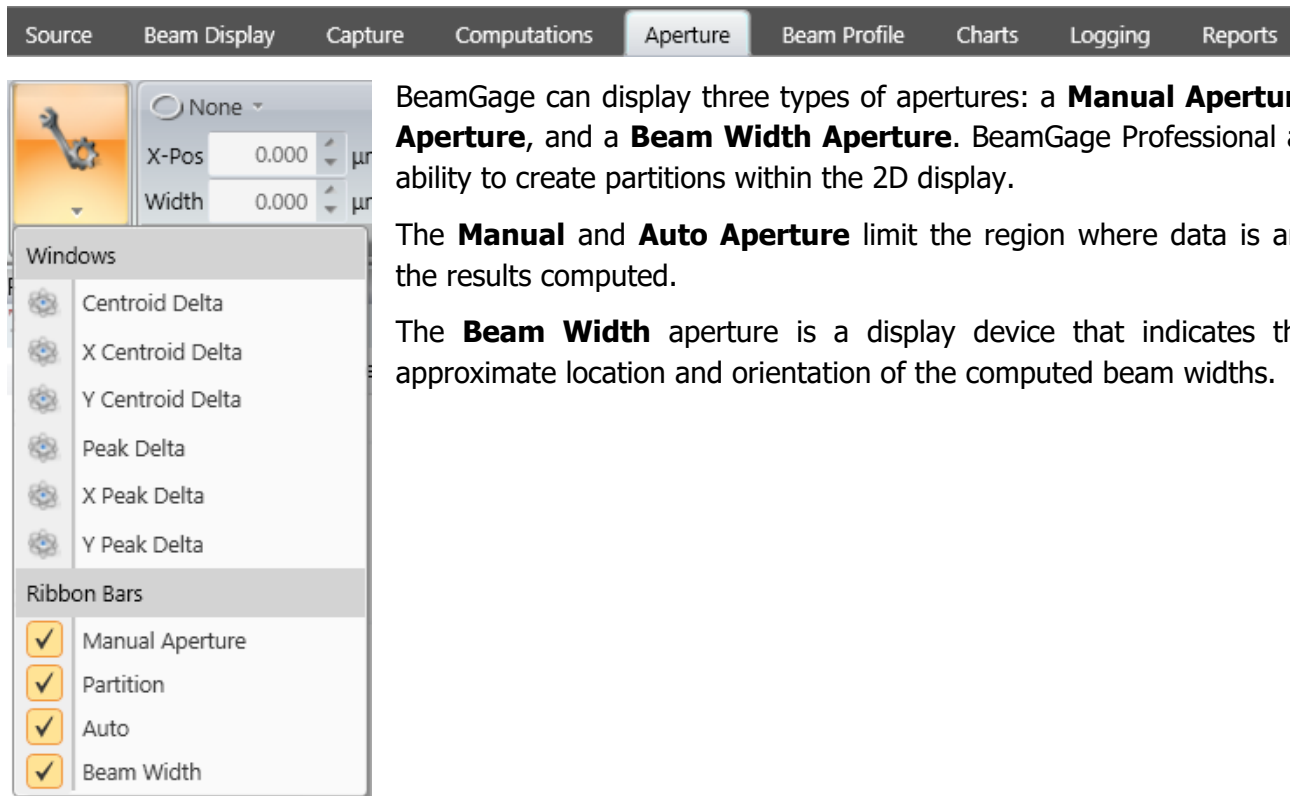
Name	Value	Units
Total Power ISO	4.974e+02	W
Peak Fluence ISO	1.396e+05	W/cm <sup>2</sup>
Minimum Fluence	-1.169e+06	W/cm <sup>2</sup>

## 2.6.7.3.5 Hide



Hover your mouse on a result item and select the **Hide** icon to disable it. Hiding a result item in either the results window, or a window that it has been dropped in does not close the other.

## 2.7 Aperture Ribbon and Controls

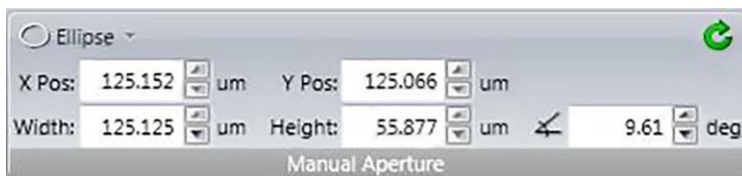


BeamGage can display three types of apertures: a **Manual Aperture**, an **Auto Aperture**, and a **Beam Width Aperture**. BeamGage Professional also has the ability to create partitions within the 2D display.

The **Manual** and **Auto Aperture** limit the region where data is analyzed and the results computed.

The **Beam Width** aperture is a display device that indicates the size and approximate location and orientation of the computed beam widths.

### 2.7.1 Aperture Ribbon: Manual Aperture

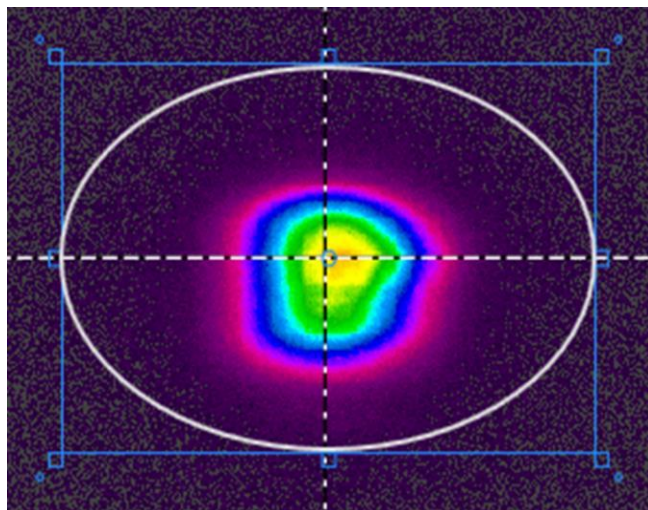


Use the drop-down to select the shape of the aperture.

The aperture size, position, and orientation can be controlled by entering numerical values in panel edit boxes, or can be manipulated by the mouse.

Select the perimeter of the aperture to bring up a set of handles that provide grab points for moving, sizing, and reorientation.

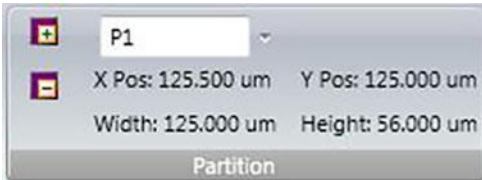
- Drag and drop anywhere inside the blue box to move the aperture.
- Drag the small blue boxes to resize.
- Drag the small blue circles just outside of the corner to rotate.
- Click outside of the blue box to release and hide the handles.



#### Reset Aperture

Resizes and positions the aperture in the event that the **ROI** changes and the aperture is no longer in image space.

## 2.7.2 Aperture Ribbon: Partition



Partitions are only available in BeamGage Professional. This feature and all **Delta Tables** are covered in more detail in Chapter 6.



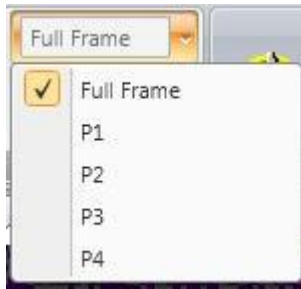
### Add Partition

Creates a partition with the current size and location of the **Manual Aperture**. This option is only available when the **Manual Aperture** is enabled. Partitions are always square or rectangular and oriented on axis.



### Remove

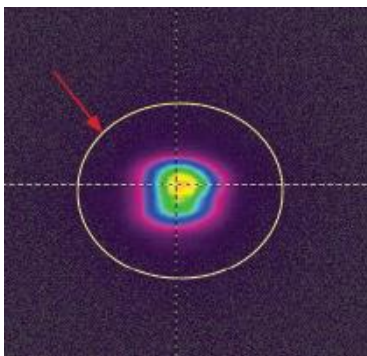
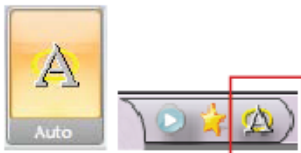
Removes the current partition selected from the **Name** drop-down list. This option is only available when a partition is selected.



### Name

Drop-down list to select a partition. **Full Frame** selects the full detector area or the enabled **Manual** or **Auto Aperture**.

## 2.7.3 Aperture Ribbon: Auto Aperture



The **Auto Aperture** is one of the most important computational aids and should be used whenever possible. This feature is so important that it is also provided in the **Quick Access Toolbar**.

The **Auto Aperture** is especially important to apply when making second moment measurements as it can aid in reducing the impact of noise in the wings of the beam. Wing noise can cause the computed second moment results to become very unstable. Enabling the **Auto Aperture** becomes even more important when the beam is small relative to the size of the display area.

The figure left shows a beam with the resulting **Auto Aperture** surrounding the region of the beam that is included in the results calculations. Note how it isolates the noise in the outlying area from inclusion in the calculations.

The **Auto Aperture** is always drawn as an ellipse and orients off axis when one of the off-axis results (Orientation, Ellipticity, or Eccentricity) is enabled.

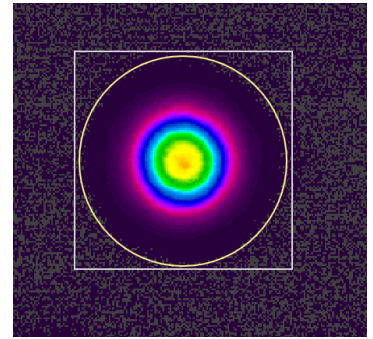


*Because both the **Manual** and the **Auto Apertures** isolate regions of the display for computational purposes, a precedent needs to be established on the order in which they are applied. If the **Manual Aperture** is applied it can affect the outcome of the **Auto Aperture** location, size, and shape. Once the **Auto Aperture** is established, only its boundary settings determine the outcome of the final results, i.e. an **Auto Aperture** takes precedence over a **Manual Aperture** when computing results.*

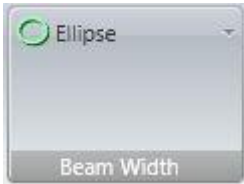




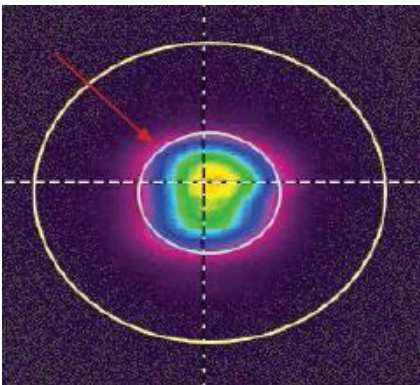
With the release of BeamGage v6.15 the algorithm that places the **Auto Aperture** has changed. This new algorithm makes it much easier for the aperture to locate the beam, especially when the beam is small compared to the frame size or there is a lot of noise present. Under some conditions, the **Auto Aperture** alone may cause degraded accuracy. In these cases, it is recommended to use both the **Manual Aperture** and the **Auto Aperture**, with the **Manual Aperture** sized to be approximately the size of the **Auto Aperture**.



## 2.7.4 Aperture Ribbon: Beam Width Displayed Aperture



The displayed **Beam Width Aperture** (displayed in Lt Green) can be used to provide a view of the computed beam shape and orientation overlaid on top of the beam profile. This overlay is drawn in both the **2D** and **3D Beam Displays**.

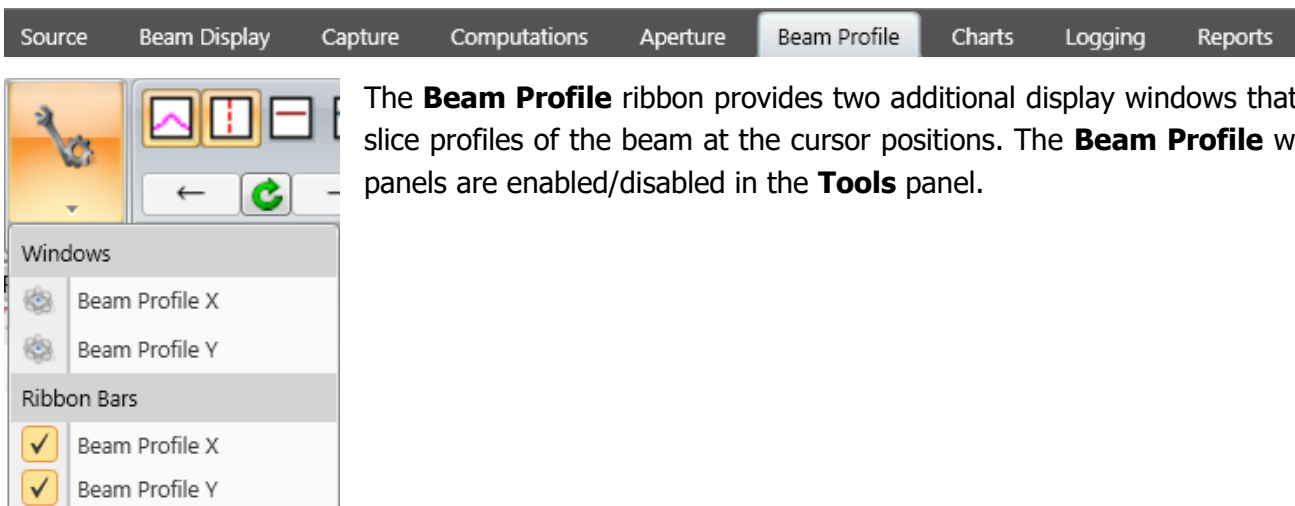


Use the drop-down in the panel to select the shape of the **Beam Width Aperture**.

The assigned **Beam Width Basis** defines the size of this aperture.

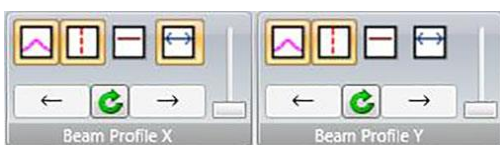
The figure shows both the **Auto Aperture** and the **Beam Width Aperture** drawn in the **2D Beam Display**.

## 2.8 Beam Profile Ribbon and Controls







The **Beam Profile** ribbon provides two additional display windows that display 1D slice profiles of the beam at the cursor positions. The **Beam Profile** windows and panels are enabled/disabled in the **Tools** panel.

### 2.8.1 Beam Profile Ribbon: Beam Profile




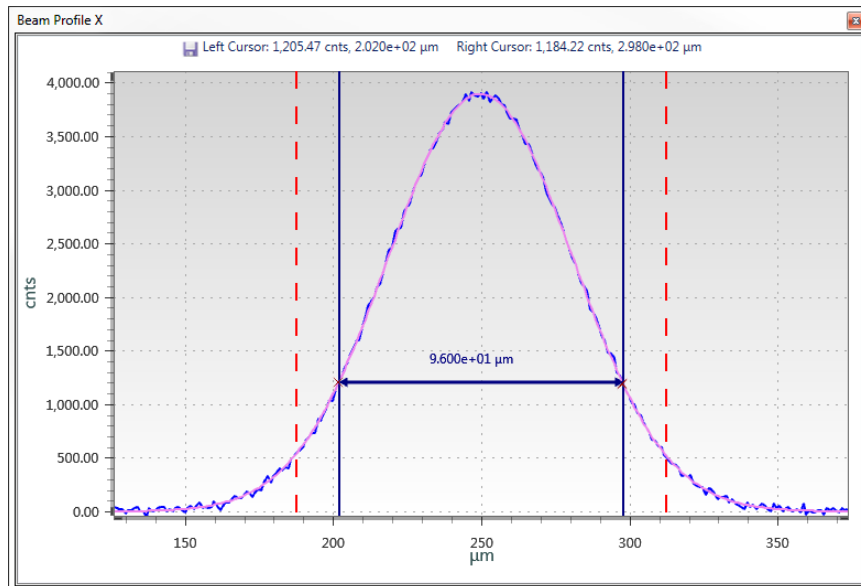
Because the **Beam Profile X** and **Y** panels are identical, they are discussed as one below.

-  Enable/Disable the display of the **Gauss Fit** profile.
-  Enable/Disable the display of the **1D Beam Width** markers.
-  Show the **Top-Hat Threshold** marker.
-  Enable/Disable the **Caliper** to display a second cursor.



The 1D profile can be panned and zoomed with the Arrow and Slider controls in the panels, or by dragging the mouse in the display window and using the mouse wheel to zoom. The center button resets the view to full width.

**Beam Profile** displays are similar to the embedded profiles drawn in the **2D** and **3D Beam Display** windows, except they are drawn with scales and tools that provide more visual information. The cursor must be enabled for the **Beam Profile** displays to update correctly. The figure below shows a typical 1D profile plot at one of the cursor locations. Save the profile data to a \*.csv file by selecting the  icon.

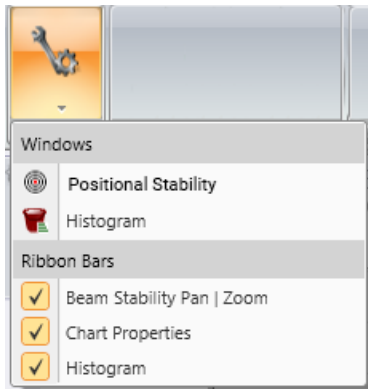


*When the cursors are on axis the position locations are the same as in the X or Y positions relative to the 2D origin. When the cursors are off axis, the locations are specified as the distances from the Cursor intersection.*



*It is recommended to have the cursors track the centroid when off axis.*

## 2.9 Charts Ribbon



BeamGage has two main types of charts: **Positional Stability** and **Strip Charts**. BeamGage Professional also includes a **Histogram** chart. The **Positional Stability** and **Histogram** charts are enabled in the **Tools** panel. **Strip Charts** are enabled via the individual result item that is to be graphed.

All charts can be printed using the **Reports** feature and can also be saved as \*.csv files.

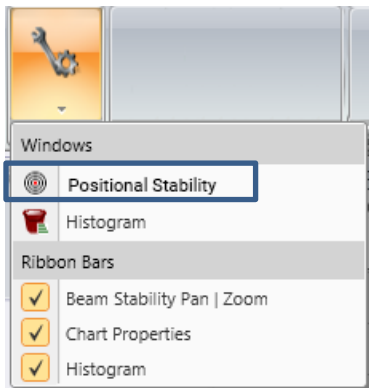
**Positional Stability** is a 2D histogram scatter plot depicting the movement of the laser beam centroid location over time. It does not include a time axis. The **Positional Stability** chart also includes a set of computed ISO results. See below for more information on the **Positional Stability** display.

**Strip Charts** are plots of selected result items as they change over time. Charts also display statistics that apply to the region of the plot.

Both the **Positional Stability** and **Strip Charts** show a **Sample Size** value indicating how many frames were collected to yield the displayed results.

The **Histogram** charts the population distribution of a single data frame. The number of pixels included in the Histogram chart is defined by the aperture and follows the aperture priority rules.

### 2.9.1 Charts Ribbon: Positional Stability

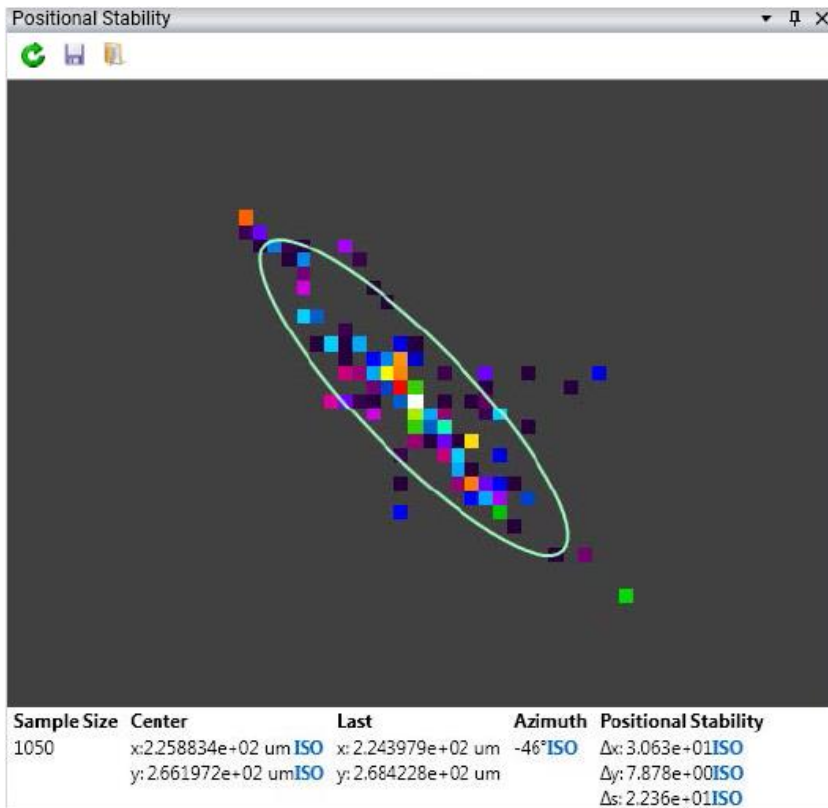


Select **Positional Stability** from the **Tools** in the **Charts** ribbon to open the **Positional Stability** window.

Some laser beam centroids drift over time. In some applications there is a need to know how much the beam drifts. The **Positional Stability** chart can convey the relative motion of the beam in space but not over time.

The resolution is based on the camera pixel size. The colors indicate the number of times the computed centroid falls inside the area of that pixel. The color palette is the same as the **2D Beam Display**, however the palette is automatically ranged such that the highest color intensity is always applied to the pixel with the greatest population (usually white) with lower valued populations proportionally spread across the lower colors.





This figure shows the **Positional Stability** histogram for a beam that displays negative angular movement in relation to the camera's X-axis.

The **Positional Stability** window has a set of controls that operate only on the data located in this window.



#### Reset

Clear the chart and the results



#### Save

Save the chart to an ASCII \*.csv file



#### Load

Open a previously saved **Positional Stability** file

The results below the chart are ISO defined calculations and tell the mathematical movements of the centroid.

- **Sample Size**

The total number of data points in the chart. A minimum of 1000 samples is required to satisfy the ISO requirement for the results items.

- **Center**

The coordinate position of the centroid of the chart.

- **Last**

The coordinate of the last centroid plotted.

- **Azimuth Angle**

The angular direction of movement.

- **Positional Stability**

The computed  $4\sigma$  of the displacement in the axis of the beam distribution **Azimuth Angle** where  $\Delta x$ ,  $\Delta y$ , and  $\Delta s$  are the positional results along the direction of the azimuth angle, orthogonal to the axis of the azimuth, and radially when the distribution of the motion is random and lacks a clearly definable Azimuth direction.

The displayed aperture (Lt Green) is a graphical plot of the Azimuth,  $\Delta x$ , and  $\Delta y$  results plotted superimposed over the histogram distribution.




*The lowercase  $x$  and  $y$  notations define the axis of the motion of the centroid per ISO 11670. The Laboratory system is always the upper case letters  $X$  and  $Y$ .*



### Positional Stability Pan | Zoom

A control that allows panning and zooming in the **Positional Stability** 2D plot window. The same control functions can be performed with the mouse by dragging and dropping the view and by using the mouse wheel for zooming.

Select **Automatic Pan and Zoom**  to enable automatic panning and zooming. This feature scales the display dynamically to show the best view of all the plotted points.

## 2.9.2 Charts Ribbon: Chart Properties



The controls in this panel are common to both **Positional Stability** and **Strip Charts**. They set the running and reset properties of the charts.



### Reset on Start

When enabled, this control resets all charts when the **Start** button is selected. This can ensure all charts stay in sync.



### Charts Reset

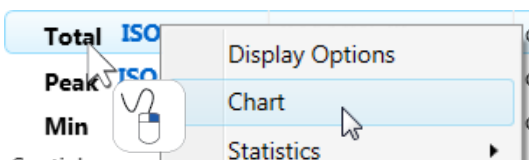
Select to manually reset all open data charts. Charts do not have to be in view to be reset (e.g. a pinned chart).



### Sample Size

The button and the edit control limit the charting displays to a fixed running sample size. In this example, the charts run until 1200 samples are plotted then they maintain only the last 1200 samples collected. The data of the deleted samples is lost. The displayed statistics cover only the retained samples. If the **Sample Size** check is disabled the charts will continue collecting frames until they reach the maximum sample size of 10,000, then maintain only the last 10,000 samples collected.

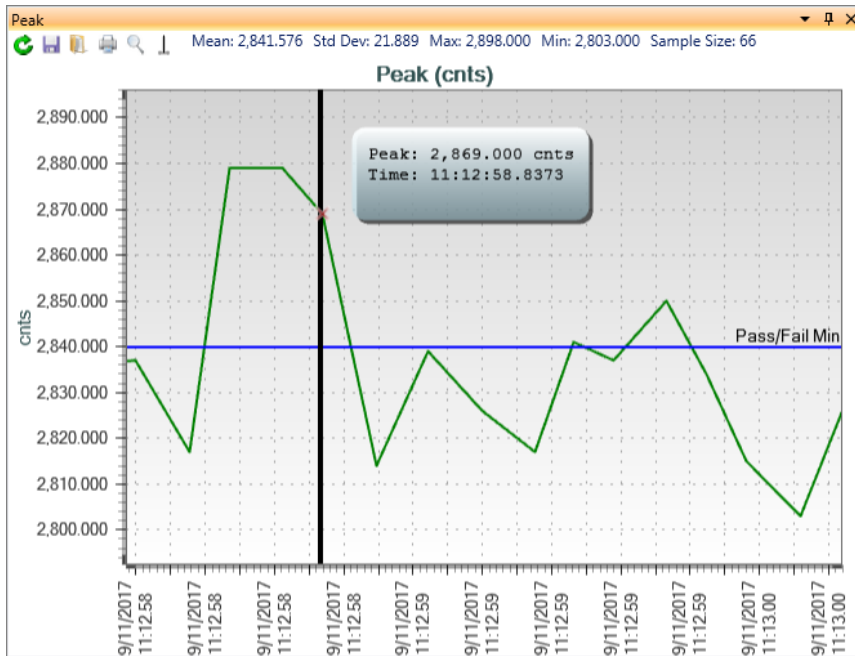
## 2.9.3 Charts Ribbon: Strip Charts



Open **Strip Charts** by right-clicking a result and then selecting **Chart**. This opens a chart in the Primary Dock Window. Each result can be charted. In the example shown below, a **Peak** chart has been launched.



*It is possible that a particular calculation will produce a non-valid result. When this type of result occurs, it is not plotted in the chart.*



In this example the vertical axis is displaying the Peak in raw digitized counts and the horizontal axis is Time. The cursor (vertical Black bar) can be moved to any location and the time and Peak value can be seen in a readout box that follows the cursor. A Red X is shown at the point where the cursor and the data point intersect. If the cursor is not visible select **Center Cursor** to bring the cursor to the center of the chart.

If the charted value has a **Pass/Fail** limit applied, a limit line is drawn in the strip chart. **Pass/Fail** values can be quickly changed by dragging the line in the chart.

Statistical results covering the data in the chart are displayed along the top edge of the window. These stats do not require statistics to be enabled in the **Results** display window.

Pan the data by clicking and dragging the mouse and zoom using the mouse wheel. Zooming is centered on the mouse location. The axes can also be panned by clicking and dragging the tick marks of the axis.

Within each chart are controls that allow the user to perform actions on the individual chart.



#### Reset

Click to clear the chart data



#### Save

Click to save the chart data to an ASCII \*.csv results file



#### Load

Click to open a chart from either a saved chart or log file



#### Print

Click to print the chart



#### Reset Pan/Zoom

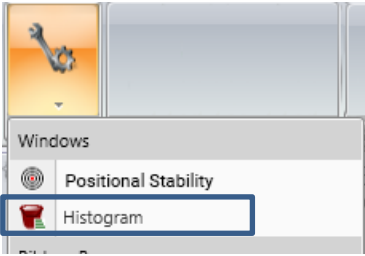
Click to show all collected data points



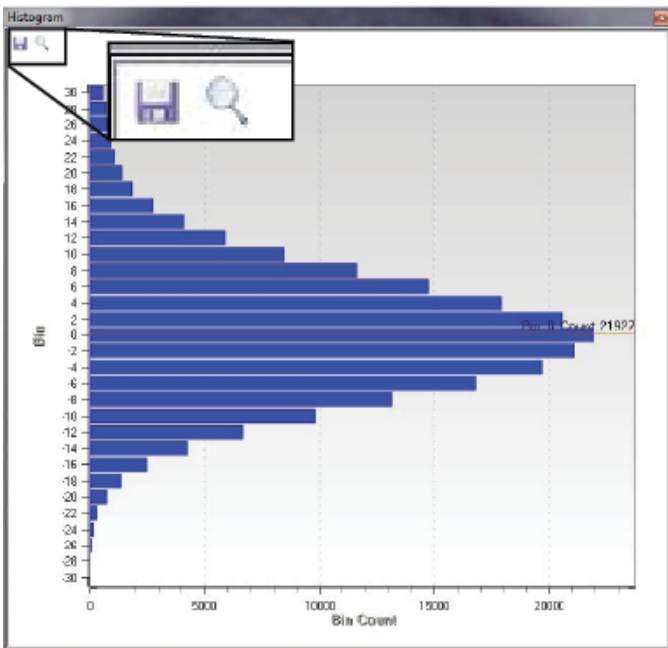
#### Center Cursor

Click to position the cursor in the center of the chart

## 2.9.4 Charts Ribbon: Histogram Chart



This feature is only available in BeamGage Professional. Select **Histogram** from the **Tools** panel in the **Charts** ribbon to open the **Histogram** window. The Histogram charts the population distribution of a single captured data frame. The number of pixels included in the **Histogram** chart is defined by the aperture and follows the aperture priority rules. The **Histogram** display ignores **Partitions** and only represents the full frame and the content of either a **Manual** or **Auto Aperture** operating in the full frame.



The **Histogram** display automatically scales to the range of pixel values available in the data frame. The finest resolution for the bin is 1 pixel count. When operating in calibrated power/energy mode the displayed bin value is converted to the equivalent power/energy value. The values along the left side of the histogram display are the mean count/power/energy value for each bin.

The orange cursor displays the current bin and the number of pixels observed in that bin. This cursor can be moved to any bin in this display.

The histogram plot shown is what a typical Gaussian noise distribution looks like for a 12 bit camera with a signal-to-noise ratio of 55dB. The cursor is placed on the "0" bin.

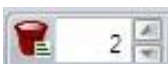
To save this data in a comma delimited \*.csv file, click the **Save** button. This type of file can be imported into Excel and many other types of mathematical analysis tools.



*The entire histogram data set gets saved at the set bin size.*

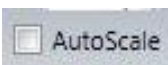


The following is a description of the histogram viewing controls. The **Histogram** panel has specialized controls to allow the user to zoom and scroll through the data and set the displayed binning size.



### Bin Size

Sets the binning population size in integer raw digitized counts. Values are assigned to the bins with their value rounded to the nearest bin integer. For example if the bin size is set to 2, a pixel with a count of 1.000 to 2.999 is assigned to the "2" bin; a pixel with a value -1.000 to +.999 will be assigned to the "0" bin.



### AutoScale

When enabled, the histogram max and min populated bins are automatically sized to fit the

current Histogram data. When disabled, the histogram max and min bins are based on the total counts available in the data frame.



### Histogram Panning

When zoomed into the **Histogram** display the up/down arrows pan the window. This operation can also be performed by clicking and dragging the mouse inside the window. The mouse operation is limited to the current display region and is best used for fine adjustments. Select the **Reset** button to reset the pan and zooming operations to the full histogram window.



### Histogram Zooming

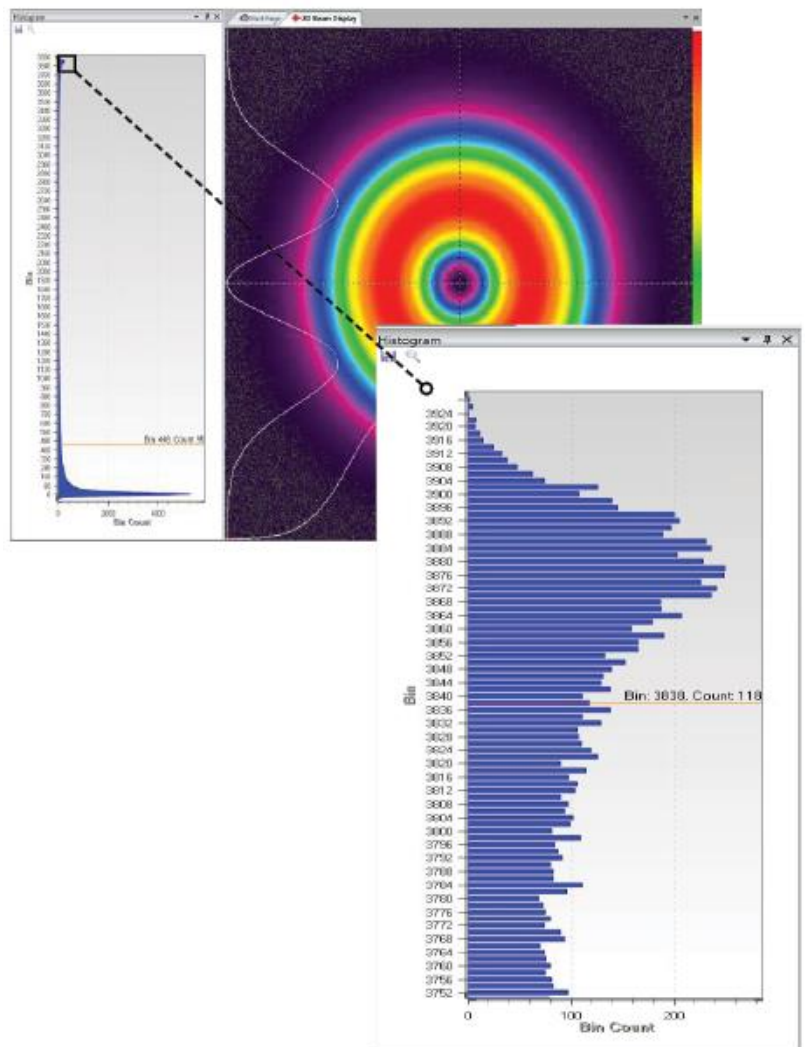
Controls the horizontal and vertical zoom in the **Histogram** display. Vertical zooming can also be performed by placing the cursor inside the histogram window and then rolling the mouse wheel. Zooming is centered on the mouse location.

Example: A histogram of the displayed donut beam is shown. The bin size in this histogram is set to 2. The full histogram range is displayed in the first view. The power/energy is uncalibrated.

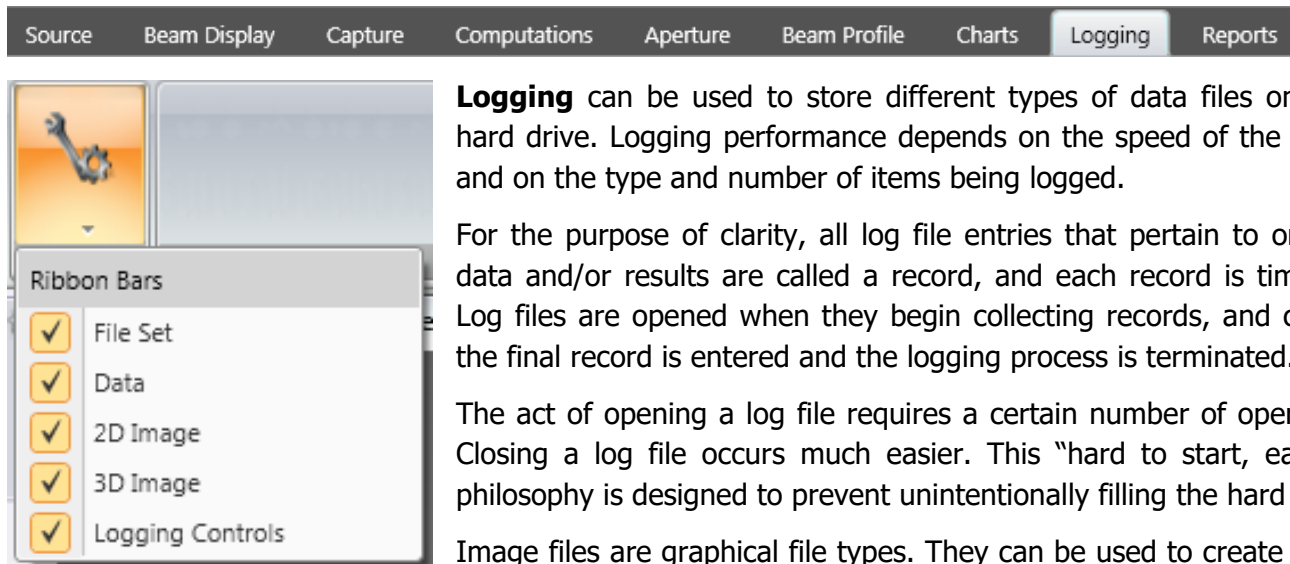
In order to view a specific region of the histogram in more detail, use the special histogram viewing controls. For example, to view the upper distribution indicated by the black rectangle, use the controls as follows:

1. Disable **AutoScale**
2. Place the mouse in the middle of the region to zoom into
3. Use the mouse wheel to zoom into the region of interest
4. Use the right slider to expand the distribution

After performing the above operations, the histogram display will look something like the lower image.



## 2.10 Logging Ribbon and Controls



**Logging** can be used to store different types of data files onto the PC's hard drive. Logging performance depends on the speed of the PC platform and on the type and number of items being logged.

For the purpose of clarity, all log file entries that pertain to one frame of data and/or results are called a record, and each record is time stamped. Log files are opened when they begin collecting records, and closed when the final record is entered and the logging process is terminated.

The act of opening a log file requires a certain number of operator inputs. Closing a log file occurs much easier. This "hard to start, easy to stop" philosophy is designed to prevent unintentionally filling the hard drive.

Image files are graphical file types. They can be used to create images that can be imported into third party document tools such as Adobe or MS Word. These files cannot be used to recreate the actual data of the frame and are mostly relegated to more artistic pursuits such as AVI or other types of video replay images.

Only a basic explanation of the various logging types is described here. See Chapter 4 for more details about the file formats created by BeamGage as well as exported image and ASCII data files which are the same as the file types logged in this section. Use the export feature (see 4.2.1) to create single or small groups of image files when logging is not appropriate.

### Binary Logging

Binary frame data files are usually large file types, often many megabytes per frame record. They also contain additional display details, such as the setup, which take up space on a per frame basis. These files are saved in the industry standard HDF5 file format and can be reloaded into BeamGage with the **File Console** playback feature.

### Results Logging

Numerical results logs are the fastest because they are ASCII files with limited amounts of data in each record.

### Column/Row Sum Logging

A special Column and Row summed log file allows for the exporting of the summing of all the rows and then all the columns into an ASCII file. This is a rather small file type and does not generally impact performance. Each record contains the results of the column summation and the results of the row summation, in that order.

### ASCII Logging

The ASCII data file is an actual copy of the image's processed data, minus any graphical overlays. Thus this type of image faithfully reproduces the processed pixel values. If the data is calibrated the ASCII is in the calibrated power/energy value at each pixel. If uncalibrated, the data is in counts. **Ultracal** data and **Auto-X** data is processed and contain negative noise values as well as positive signal content. ASCII files can be quite large especially if the frame is large and the data is power/energy calibrated.

Unlike the previous data formats, the ASCII data stores the entire frame unless a **Manual** or **Auto Aperture** is present. Using an aperture can reduce the amount of data to just the region that is involved in results calculations. The X and Y extents of a square or rectangular **Manual Aperture** will limit the image region



logged into the ASCII file. If the aperture is not a rectangular shape drawn on axis, the pixels that lie outside of the aperture are exported as empty values.

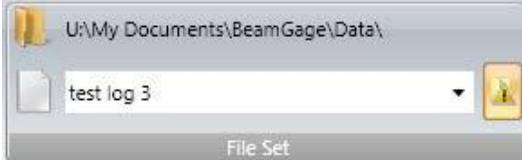


A **Manual Aperture** also limits the area where data gets analyzed, not just the region copied into an ASCII image file. Use the **Manual Aperture** with this in mind.



In order to keep the logged region stable, use the **Manual Aperture** and turn off **Auto Aperture**.

## 2.10.1 Logging Ribbon: File Set



Multiple types of log files can be generated simultaneously. To begin the process, a file path and name must be entered in the **File Set** panel. This file name is common to all of the resulting log files. Different file extensions are added to the file name to designate the file type. The default file extensions are:

- **.bgData** for Binary BeamGage HDF5 data files
- **.csv** for BeamGage ASCII comma delimited log files
- **.bmp, .gif, .jpg, .png, and .tif** formats for image files


The upper line of text displays the current path leading to the log file folder. The second line is where the log file name is entered.

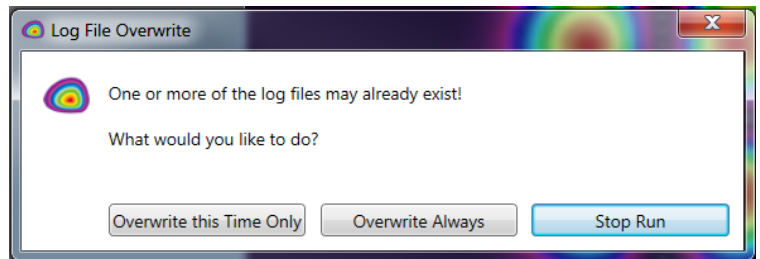
When installed, BeamGage creates two folders in the installers user account:

**C:\Users\<user\_name>\Documents\BeamGage\Data**

**C:\Users\<user\_name>\Documents\BeamGage\Setup**

The default location for data, log files, and reports is the ...Data folder.

The  button in the corner enables the overwrite file warning. It is recommended to leave this on to avoid accidentally overwriting a log file with the same name.



*Logging operations can quickly fill the hard drive with many hundreds to thousands of data and/or image files. Use care and tightly control logging operations to not log unnecessary data. Image logging cannot be reloaded so use cautiously. ASCII data logging is primarily for export to third party applications. These files can be extremely large when saving power/energy calibrated frames.*



## 2.10.2 Logging Ribbon: Logging Data



The types of data files to log are controlled here.



### Binary Logging

Enable frame data logging in HDF5 format. These binary data files can contain multiple records (frames) per file and can be reloaded in BeamGage through the **File Console**.



### Results Logging

Enable logging results in ASCII format. If partitions are present use the drop-down to select which partitions and/or the full frame to include in the log. The full frame selection is governed by the **Manual** or **Auto Aperture** if enabled. These files contain the results per frame with a time stamp. Each file can contain multiple record entries.



### Column/Row Sum Logging

Enable **Column/Row Sum** logging in ASCII format. These files contain the results per frame with a time stamp. Each file can contain multiple record entries.



### Cursor Logging

Enable **Cursor** data logging in ASCII format. These files contain the results per frame with a time stamp. Each file can contain multiple record entries.



### ASCII Logging

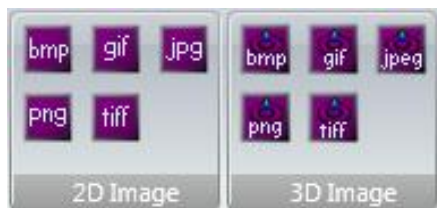
Enable Frame data logging in ASCII format, bounded by the **Manual** or **Auto Aperture** if enabled. Each frame will be recorded into a separate file.



*Partition frame data cannot be separately logged; only the full frame data will be logged. The partition apertures are ignored.*

Whenever the logging process is stopped the above logging buttons are automatically disabled. To begin a new Logging cycle the selection(s) must be re-enabled.

## 2.10.3 Logging Ribbon: Logging 2D/3D Images



Sets the image file type(s) to log. Each frame is recorded into a separate file sharing a common name with a frame number and the appropriate file type extension.

For correct operation, you must be in **Results Priority** capture mode or frame images may be skipped and the resulting number of frames may be less than the number specified.

All logged images contain the exact 2D or 3D display window in a What You See Is What You Get (WYSIWYG) format.

## 2D 3D



Enable logging \*.bmp image files



Enable logging \*.gif image files



Enable logging \*.jpeg image files



Enable logging \*.png image files



Enable logging \*.tiff image files



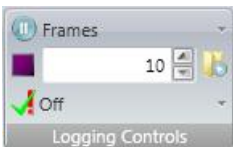
*If while logging the 2D or 3D image window you grab it to move or resize, the image will stop updating and logging will be suspended until you release the window.*



*Image files are not able to reproduce the numerical data used to create the viewed image. Use **Data** file types to extract real numerical information from the frames.*

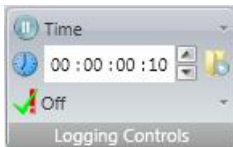
## 2.10.4 Logging Ribbon: Logging Controls

These controls allow automatic termination of the logging cycle.



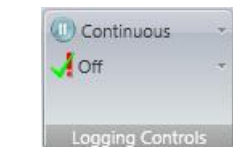
### Frames

Set the logging duration to a specified number of frames.



### Time

Set the logging duration to a specified amount of time.



### Continuous

Set the logging duration to run until manually stopped.



*If not manually stopped the log will run until the hard drive is full.*





### Stop or Continue Data Capture

When in a **Frame** or **Time** logging mode, data collection stops when the logging requirements of time or number of frames is met. Enable this control to continue capturing data frames after the logging process terminates.

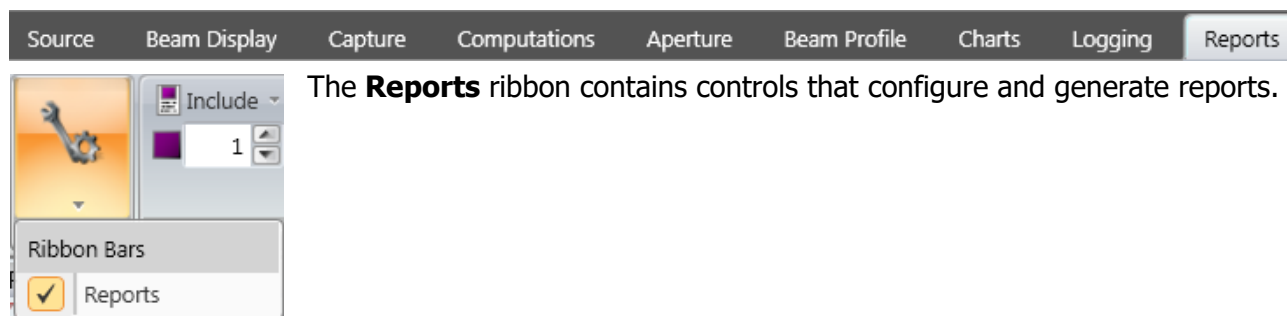


### Log Pass/Fail

The user can apply a **Log Pass/Fail** filter that determines which files are logged. If **Pass** is checked, then only the frames that pass the enabled **Pass/Fail** criteria are logged. Similarly, if **Fail** is checked, only the failed frames are logged.

Once all logging settings have been configured, begin logging by clicking **Start** . Logging will either stop automatically based on the set logging controls, or manually by clicking **Pause** .

## 2.11 Reports Ribbon

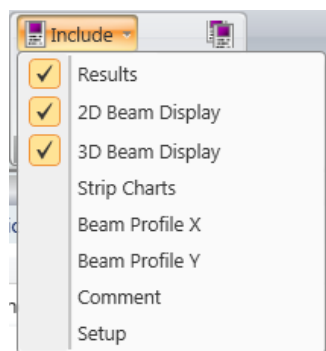


The **Reports** ribbon contains controls that configure and generate reports.

### 2.11.1 Reports Ribbon: Reports



**Reports** consist of user defined printouts or savable PDF files that can be created from the various display windows and results enabled in BeamGage. The basic rule is that items are printed in a What You See Is What You Get (WYSIWYG) style. If certain displays are pinned, they are automatically opened for the purpose of printing or saving to a PDF file.



#### Include Options

Use the **Include** drop-down to choose which items appear in a report. The choices in the drop-down are based on the active windows.

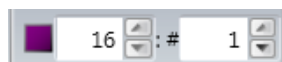


If **Strip Charts** is checked, all active charts, not just those visible, are included in the report. To print a single chart, use the local **Print** button in the chart display window. If **Setup** is checked, images of all the panels with their settings are added to the report to help with replication.



#### Separate Pages

To keep everything neatly sorted, enable this and each item will be printed on a separate sheet of paper.



#### Frames

This value is the current **Frame Buffer** display location and indicates at which frame the report process will start. To print more than one frame, enter the number to report in the **# of Frames** edit box. The number of frames always counts up in the **Frame Buffer** and the maximum number is the **Frame Buffer** size.



#### Save

Select **Save** to generate a PDF report. This opens a standard Windows **Save As** dialog. Specify a location, enter a file name, and click **Save**.



#### Print Preview

Select **Print Preview** to create a temporary PDF file. This is a good way to verify what is being printed and how it will appear. The PDF can be printed or saved using the Adobe controls. Once the PDF is closed, the temporary file is deleted.



*If used carelessly, printed Reports can over-utilize extreme amounts of paper. Whenever printing multiple numbers of frames, make it a habit to confirm the **Include** choices and check the generated PDF file to ensure that a lot of paper is not wasted.*

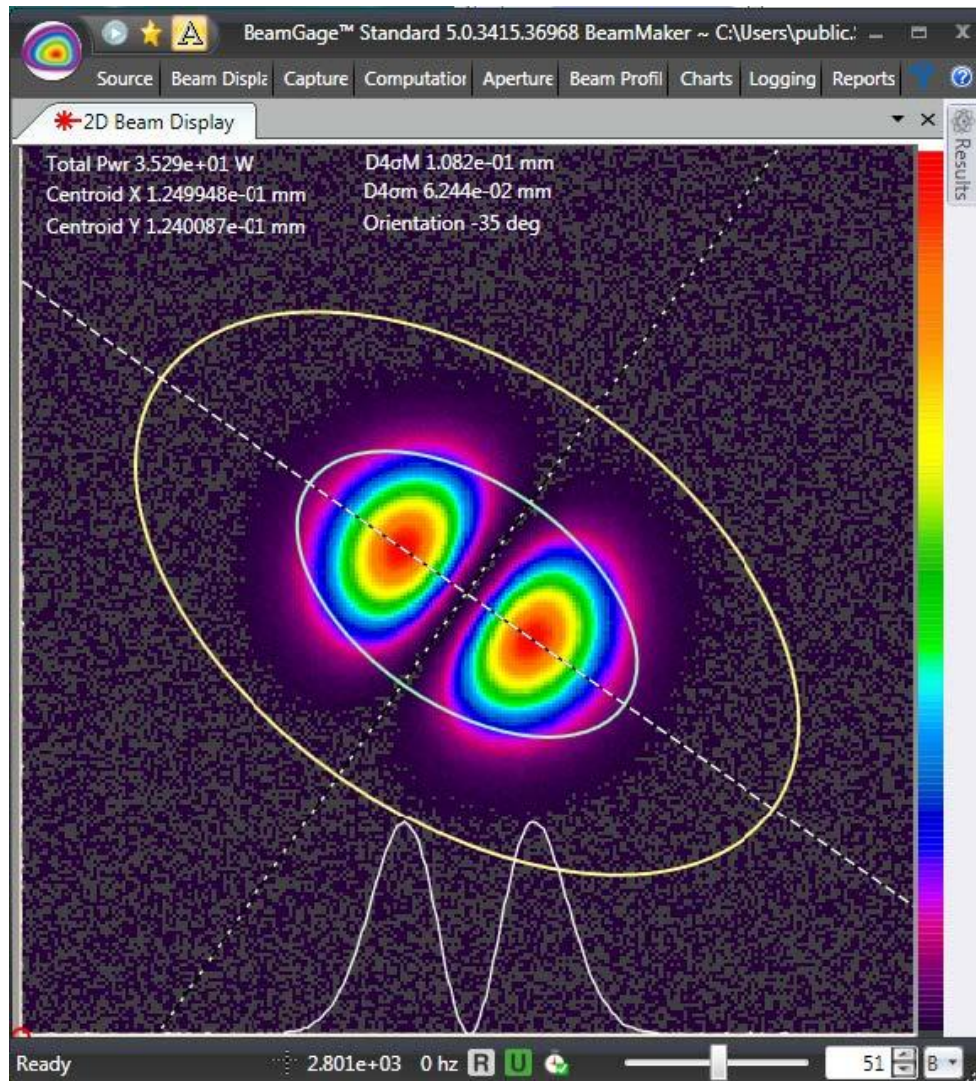
# Chapter 3 Displays

## 3.1 Display Options

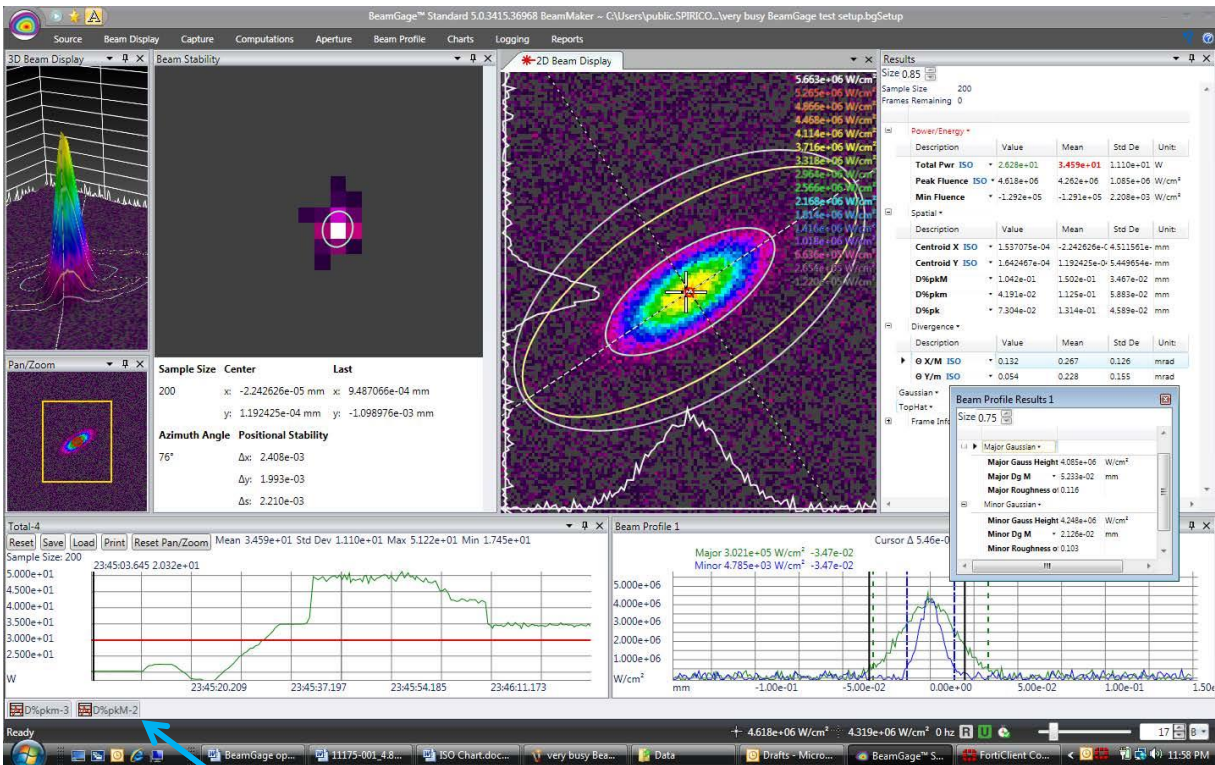
One of the most versatile features in BeamGage is the ability to create a flexible display environment to meet your needs. From a simple beam display window with specific items, to a highly complex multi-tasking displays with pop-out on demand display elements, floating desktop windows, and displays across multiple screens.

This chapter describes the tools that control the screen layouts.

The two examples below display a very basic example of BeamGage and a more complex example.



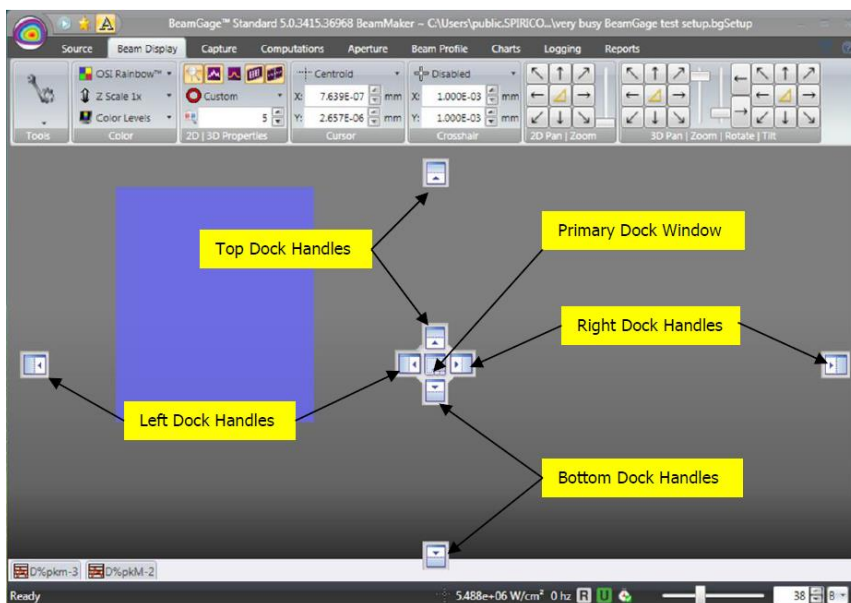




In this example some features are hidden within tabs. Selecting these tabs allows you to temporarily open these display windows.

### 3.1.1 Primary Dock Window and Dock Handles

The first time a new window opens, it appears as a tab in the primary dock window. This is a tabbed window located in the main display. Each new primary dock window displays on top of the previous one. This stacked layout is one type of display option but has a limited view of each window. The **Start Page** tab is a permanent primary dock site that cannot be removed.



#### Docking Handles

All display windows can be dragged and docked to the four sides of the application window.

All windows can be grabbed with the mouse in their Title Bar or Tab region and dragged onto a dock handle. When being moved, the window turns blue and a set of docking handles appear as shown.

If the window is not released on one of the docking handles, it becomes a floating window and can be positioned anywhere on the screen.

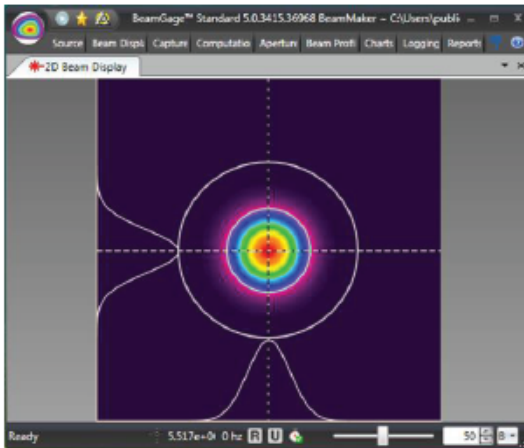




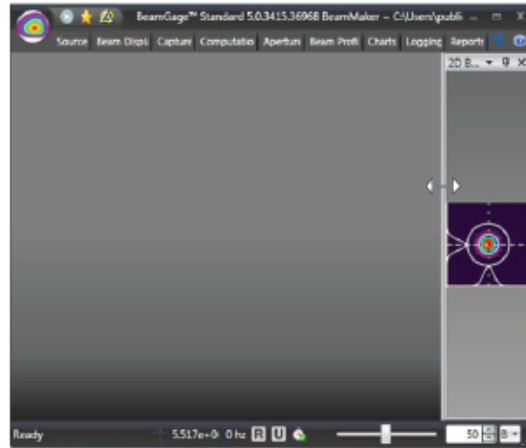
*Floating windows do not appear as separate items in the Windows task bar and can be inadvertently lost. Use them prudently.*

After positioning, windows can be resized into a more useful display. Simply grab the edge and drag the window open.

2D Beam Display in Primary Dock window  
before relocating



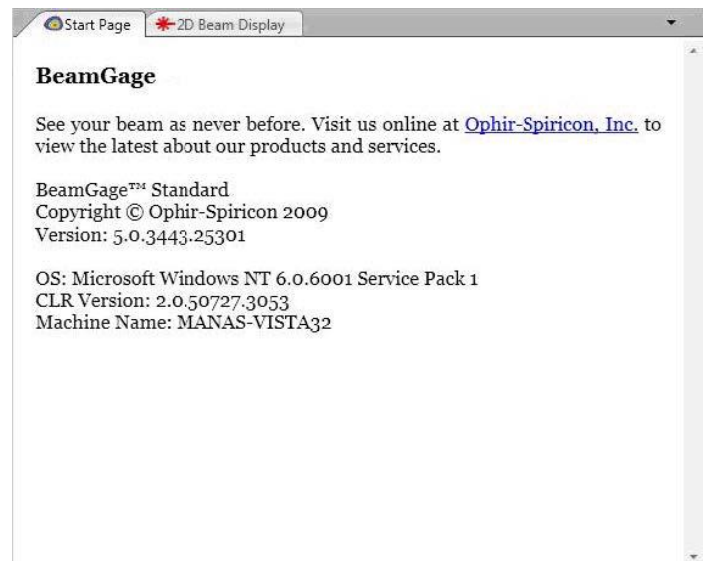
2D Beam Display after relocating to the  
Right Dock Handle



*Once a window has been repositioned, BeamGage remembers the placement so that the next time the window is opened it displays in the last docked location, not in the Primary Dock Window.*

In order for this window docking scheme to operate correctly there must always be a window in the Primary Dock. This makes manipulating the other windows much easier as each parent window's docking handles remain more accessible during the screen layout process.

To ensure the presence of the primary dock window, a permanent tab called the **Start Page** is always present. Usually this window is covered by another display window, such as the **2D Beam Display**. The **Start Page** contains basic information about the software.



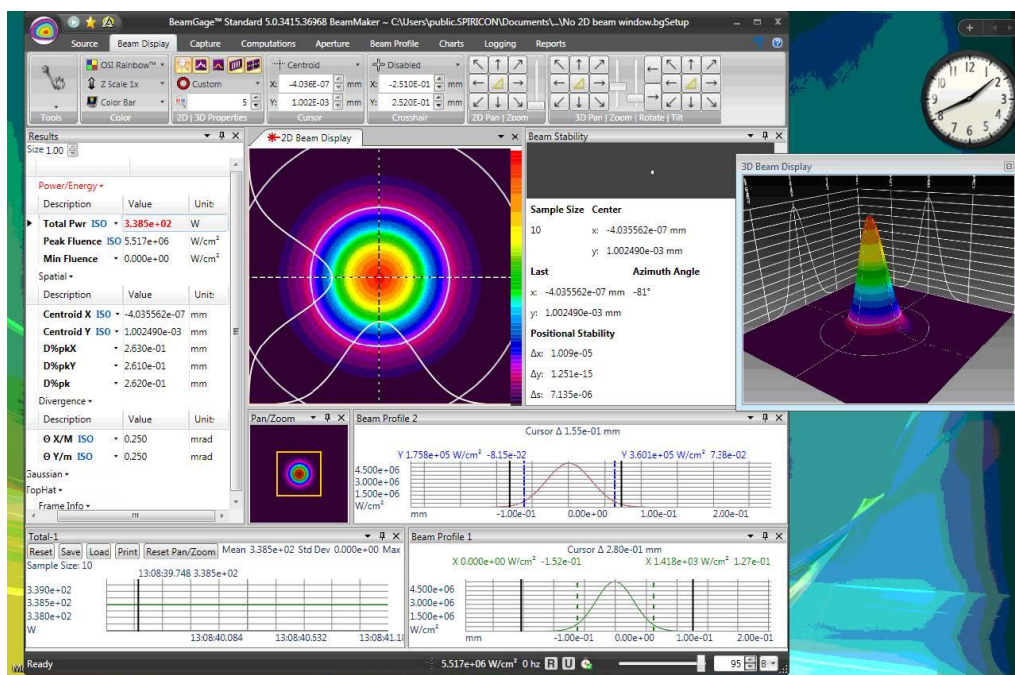
### 3.1.2 Dock Handle Cloning

Each docked window has its own set of dock handles, thus each time a window is docked it clones its own set of handles allowing more windows to be docked within it. This permits placing windows side by side, and over and under each other.

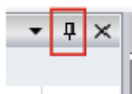


*Floating windows do not clone the docking handles. Thus they cannot be combined with other child windows. Floating windows are separated from the main application and have no features beyond what appears in their window. A floating window can be re-docked into the main application by dragging its title bar back into the main display window and dropping on a dock handle.*

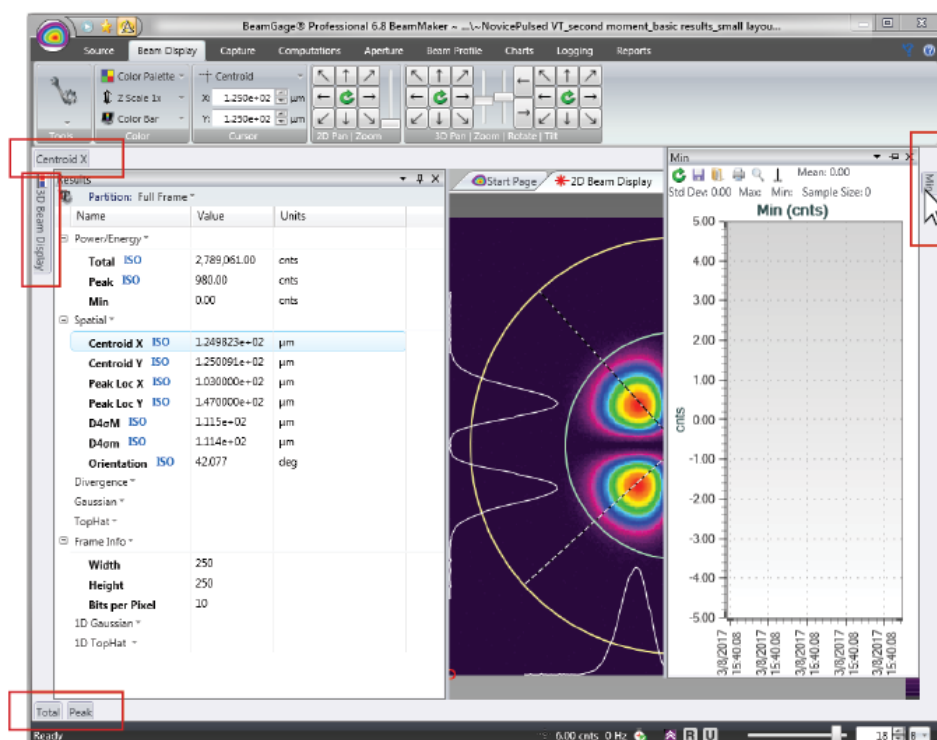
Below is an example of many windows. Some docked inside of other docked windows and one floating outside of the main BeamGage application. Experiment with using the dock handles to find the layout that works best for your needs.



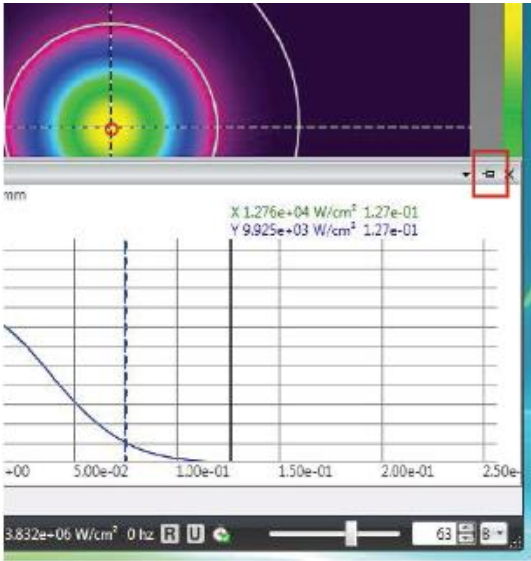
### 3.1.3 Pin



The Pinning feature minimizes any display to a tab. Select a window's Pin control, shown left, to collapse the window into the dock frame. Pinned items appear in the top, left, bottom, or right frame depending on where they are docked respectively. The figure below shows five separate windows pinned to the edges of the BeamGage main window.



Hover over or click on a pinned tab to open the display. Click on an open tab to close it.



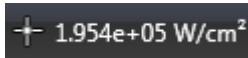
### Un-pin

Click on the Un-pin tool to restore a pinned window to its former docked condition.

## 3.2 Status Bar

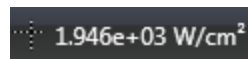


The right most section of the **Status Bar** contains information at a glance. Each is described below.



### Crosshair Fluence

This value is the measured beam fluence at the position of the **Crosshair**. When not calibrated, the units are in raw or processed counts (cnts).



### Cursor Fluence

This value is the measured beam fluence at the position of the **Cursor**. When not calibrated, the units are in raw or processed counts (cnts).



### Frame Rate

The frame rate is calculated and updated as data frames are received from the camera in real time. When stopped the rate displayed is 0Hz.



### Dropped Frame

The **Dropped Frame** indicator has a **Green** check-mark when BeamGage is collecting frames at the camera output rate. If frames are being dropped the check-mark turns or flickers **Red**. The input frame rate can be an important detail if attempting to collect laser pulses at a fixed and guaranteed rate. Adjust some display parameters to ensure a high capture rate.



### Capture Priority

This indicator signifies if the **Source Rate** is set to **Frame Priority** (up arrow) or **Results Priority** (down arrow). See 2.5.6 for more information on the different source rates.



### Smear Correction

This indicator changes color based on the current status of Smear Correction processing. The meanings are:

**Grey**: Smear Correction disabled

**Green**: Smear Correction enabled and active

**Red:** Smear Correction has been disabled because of a change that may make it no longer reliable, such as the image is saturated or camera is in **MultiTap** mode



### Reference Subtraction

This indicator changes color based on the current status of reference subtraction processing. The meanings are:

**Grey:** Reference Subtraction disabled

**Green:** Reference Subtraction enabled and active

**Red:** Reference Subtraction has been disabled because of a change that may make it no longer reliable, such as the camera settings have changed



### Ultracal

This indicator changes color based on the current status of Ultracal processing. The meanings are:

**Grey:** Ultracal disabled

**Green:** Ultracal enabled and active

**Red:** Ultracal processing has been disabled because of a change that may make it no longer reliable, such as the camera settings have changed



### Auto-X

When operating in auto exposure mode, the **Ultracal** indicator becomes the **Auto-X** indicator. When **Green**, the collected data frame is expected to yield accurate results and should have a good baseline correction. When **Red**, the results may be compromised.



### Bloom Correction

This indicator appears based on the current status of Bloom Correction processing. The meanings are:

**Grey:** Bloom Correction disabled or unavailable

**Green:** Bloom Correction enabled and active



### Frame Buffer Indicator/Selector

The slider and edit control indicate the current **Frame Buffer** location. To navigate in the **Frame Buffer**, either edit the frame number or run the slider to the desired location. The letter edit control allows the user to view special **Frame Buffer** locations. When indicating a **B**, the display is following the buffer edit controls. Setting it to an **R** forces the display to show the currently saved **Reference Frame**. Setting it to a **U** displays the current Ultracal frame.

# Chapter 4 Files, Formats, and Privileges

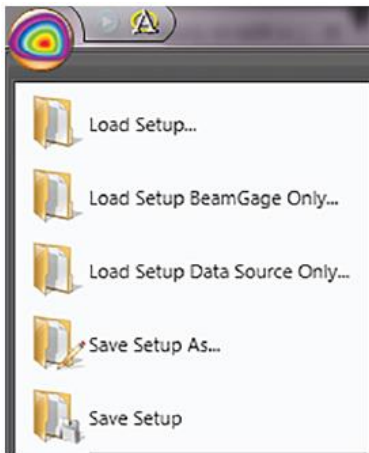
## 4.1 BeamGage File Types

BeamGage produces four different types of files. The list of file types and their naming extensions are as follows:

Extension label	BeamGage Application	Format
.bgSetup	Setup file type	HDF5, proprietary content
.bgData	Data files that are loadable and playable by the File Console source	HDF5, compatibility with Matlab and many other 3 <sup>rd</sup> party applications
.csv	Results, Log files, and Charts files	Comma delimited ASCII
.pdf	Report file format	Adobe compatible

### 4.1.1 Setup Files, .bgSetup, HDF5

Setup files are used to define the configuration states of BeamGage. The user can configure BeamGage into as many setups and layouts as needed to suit their application needs. To ensure the precise return of the settings use the **Save Setup As...** file choice via the **File Access** button. There are five different setup file actions possible.



#### Load Setup

Open Windows Explorer directed at the folder where the setup files are saved. Select the file to be loaded and click **Open**. Note that the default folder will always be the last folder used.

#### Load Setup BeamGage Only

Performs the same functions as **Load Setup**, but only applies the settings not dealing with the Source selection. The Source settings remain unmodified by this load operation.

#### Load Setup Source Only

Performs the same functions as **Load Setup**, but only loads the Source selection and settings. The remaining settings are unmodified by this load operation.

#### Save Setup As

Open the standard Windows file save dialog box directed at the folder where the setup files are saved. Enter the name of the new setup file and click **Save**. Note that the default folder is always the last folder used.

#### Save Setup

Immediately overwrite the loaded setup with the current settings under the same file name.



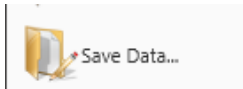
## 4.1.2 Data Files, .bgData, HDF5

Data files contain the processed beam data with setup information. Each file contains one or more frames of data, known as records. One or more records can be saved at a time and are saved from and loaded into the **Frame Buffer**.

Data files can also be created using the Logging feature. A Logged data file contains multiple records saved in real time.

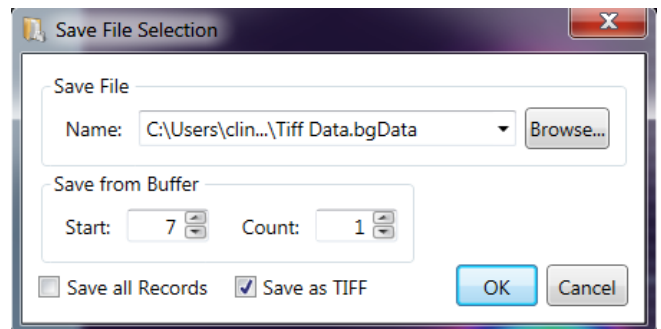
Data files can be played back and post-processed using the **File Console**.

Data files contain all necessary information needed to reload as when the data was originally captured. They can be loaded with or without restoring the setup conditions.



### Save Data

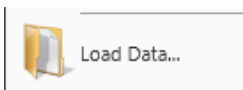
Opens a specialized Windows file save dialog box directed at the folder where the data files are saved. Specify which frames in the **Frame Buffer** are to be saved by entering the **Start** frame and frame **Count** value, or check the **Save all Records** box. Check the **Save as TIFF** box to save images in a tiff format (see 4.1.2.2 for more information). If unchecked the data remains as an integer array.



- The default **Start** value is the current frame
- The default **Count** is 1
- **Save all Records** is unchecked by default
- **Save as TIFF** is unchecked by default

Select **Browse** and enter the name of the new file. Select **Save** and then **OK** to save the data file.

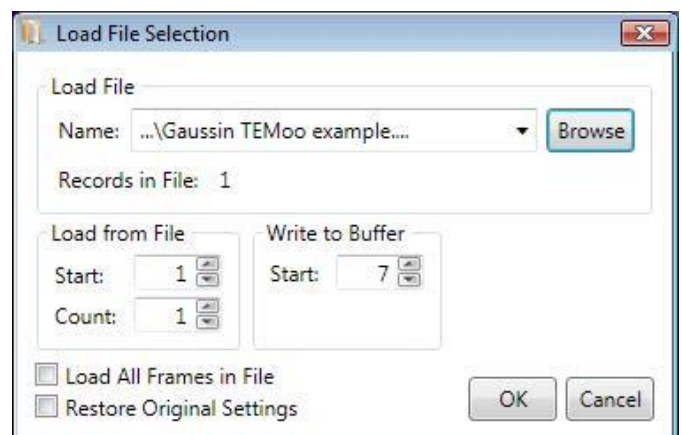
Note that the default folder is always the last folder used.



### Load Data

Opens a specialized Windows file load dialog box directed at the folder where the data files are saved.

Specify which frames in the data file to load by entering the **Load from File: Start** frame and frame **Count**. Specify where to begin depositing the data within the Frame Buffer with **Write to Buffer: Start**. Checking **Load All Frames in File** loads the entire file and all its records starting at the designated **Frame Buffer** position.





To ensure that the reloaded data loads in exactly as when it was originally collected, check the **Restore Original Settings** check-box.

- The default **Start** value is the 1<sup>st</sup> record in the file
- The default **Count** is 1
- **Write to Buffer: Start** defaults to the current Frame Buffer location
- **Load All Frames in File** is unchecked by default
- **Restore Original Settings** is unchecked by default

Click the **Browse** button and enter the name of the file. Click **Open** and then click **OK** and the data file records will be loaded.

Note that the default folder is always the last folder used.



*Loading a data file that is larger than the frame buffer size causes the data to wrap and overwrite the frame buffer with the last frames loaded remaining in the buffer.*

### 4.1.2.1 HDF5 Format

The HDF5 format is compatible with many third party applications, one of which is MATLAB. See the following web link to learn more about the HDF5 format. <http://www.hdfgroup.org/HDF5/>

The .bgData file format contains the processed image output from BeamGage. The HDF5 file contains a 2D array of the frame image that can be loaded into MATLAB so that third party computations can be performed on the data. The image and pixel data formatting is directly readable and follows standard HDF5 formatting rules.

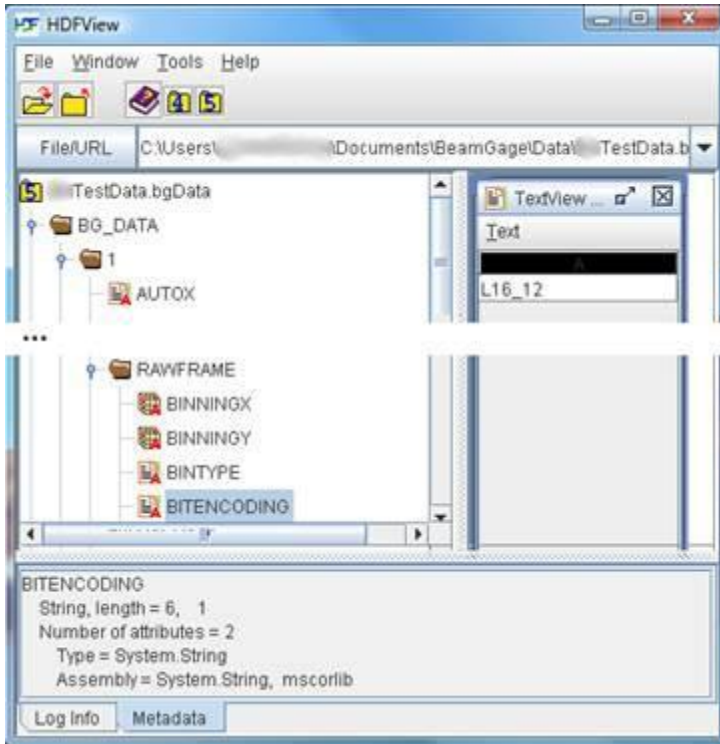
An example that reads an HDF5 file into MATLAB is supplied and installed into the following folder location:

[C:\Program Files\Spiricon\BeamGage <edition>\Examples\MatLab\...](#)

#### 4.1.2.1.1 Image Data Access

Pixel data is stored in the HDF5 file at folder node **1, DATA**. All pixel data is in an S32 bit signed binary fixed point format that is described below. Data is stored in packed 32-bit words loaded left to right, top to bottom, as it appears in the **2D Beam Display** window. To determine the width and height of the data frame, access node **1, RAWFRAME, WIDTH** and **1, RAWFRAME, HEIGHT**.

## 4.1.2.1.2 Image Data Description



The input camera native source may be 8, 10, 12, 14, or 16 bits per pixel. BeamGage employs a normalized (signed 32-bit) fixed point format for storing pixel values in HDF5 data files. The acquired and processed camera pixel data is converted to a 32-bit signed value and stored. The most significant bit of the camera's native data is shifted to the bit position just behind the sign bit (assuming bit positions 0 [lsb] -31 [msb] this would be position 30). The empty bits below the native format are then available for additional precision and are utilized via frame averaging, background subtraction, or other image processing activities.

This format has several advantages. One key advantage is that frame averaging or baseline subtraction allows the lower order bits to be populated with fractional values thus allowing greater precision.

In order to utilize the normalized data, the native format must be known or determined. The data format is stored in one of the HDF5 file's nodes. The window above shows an HDF viewer that is accessing the string that describes the native format of the data in the file. The string, see image above, is found in a folder on node **1**, **RAWFRAME**, **BITENCODING** and is described as **L16\_12**.

This means that the original or raw data format was from a **12** bit camera and was shipped left justified in a **16** bit word. The **L**, **R**, or **S** denote if the data was left or right justified within the word sized (pixel) packet or if it was a signed format. All signed formats are left justified with the sign bit in the left most position. BeamGage can support any one of the following native formats:

L8	x x x x x x x x	unsigned 8-bit
L16	x x x x x x x x x x x x x x	unsigned 16-bit
L16_8	x x x x x x x x _ _ _ _ _ _ _ _	
L16_10	x x x x x x x x x x _ _ _ _ _ _	
L16_12	x x x x x x x x x x x x _ _ _ _	
L16_14	x x x x x x x x x x x x x x _ _	
R16_8	_ _ _ _ _ _ _ _ x x x x x x x x	
R16_10	_ _ _ _ _ _ _ x x x x x x x x x x	
R16_12	_ _ _ _ _ x x x x x x x x x x x x	
R16_14	_ _ x x x x x x x x x x x x x x	
S16	s x x x x x x x x x x x x x x	Note: Only 15 bits of precision
S16_13	s x x x x x x x x x x x x x _ _	
S16_14	s x x x x x x x x x x x x x x _	
S32	s x x x ...                      ... x x x	31 bits of precision*

s = signed bit; x = used bit; \_ = unused bit

\* All BeamGage data files are stored in S32 regardless of the native format. However, you must know the native format in order to correctly position the decimal point. To return to the original native pixel values you need to divide by a normalization factor.



*Not all of these formats are in common use by camera manufacturers.*

If the data is processed, such as with calibrated frames, the original raw camera data becomes unrecoverable.

### 4.1.2.1.3 Calibrated Data Conversion

BeamGage always stores pixel data in the S32 signed binary fixed point format. If the frames were saved as power/energy calibrated images, the HDF5 file will contain a power/energy conversion factor that can be used to convert each pixel value into power/energy units. To read the conversion factor, access the content of the string in the folder on node **1, RAWFRAME, ENERGY, POWER\_CALIBRATION\_MULTIPLIER**.

To determine what units to apply, access the folder on node **1, RAWFRAME, ENERGY BASE, and ENERGY QUANTIFIER**. The units will be whatever was in effect when the data was collected and calibrated. Examples are WATTS, MILLIWATTS, JOULES, MILLIJOULES, etc.

To determine the power or energy value of a given pixel, multiply the S32 binary value by the **POWER\_CALIBRATION\_MULTIPLIER** and assign the **ENERGYUNITS**.

## 4.1.2.2 TIFF Image Format

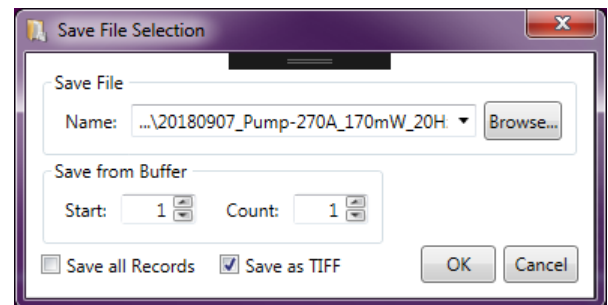
TIFF files are an encoded, compressed data file format that produces smaller data files and can be easily loaded into third party applications, such as MATLAB. Files saved as TIFF retain the \*.bgData extension but can be manually loaded into other applications that support TIFF formats.

TIFF data is stored using the gray32bppFloat pixel format. This format uses a single color channel with 32 bits of precision. The pixel count is stored as a normalized floating-point value between -1 and 1. The value is calculated using the minimum and maximum values of a signed 32-bit integer, namely  $\pm 2,147,483,647$ . The original per pixel values of the collected data can be obtained by multiplying the floating-point value obtained from the tiff image by 2,147,483,647.

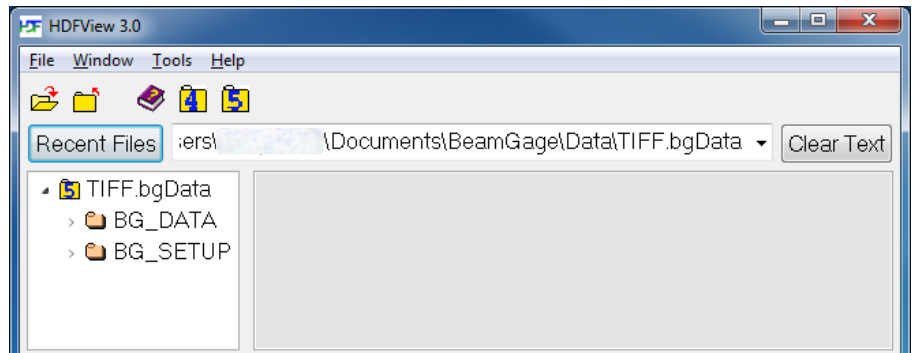
### 4.1.2.2.1 Exporting TIFF Images for use with HDF5

TIFF images can be exported for use with HDF5.

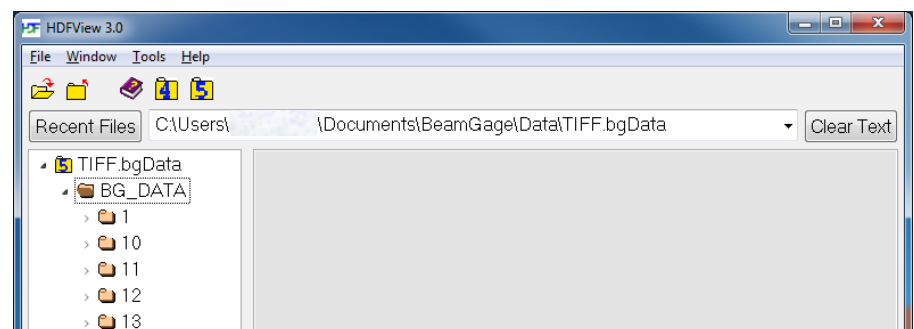
1. Select **File->Save Data**. Save the data with the TIFF compression enabled.



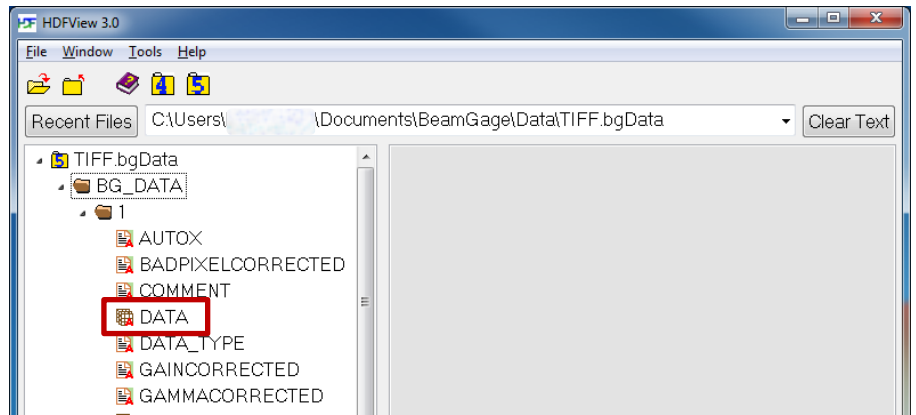
2. Download and install HDFView.
3. Run HDFView.
4. Open the BeamGage data file.



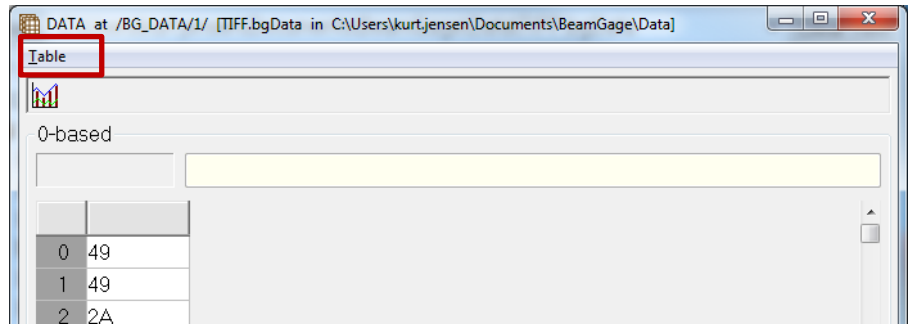
5. Click and expand **BG\_DATA**.



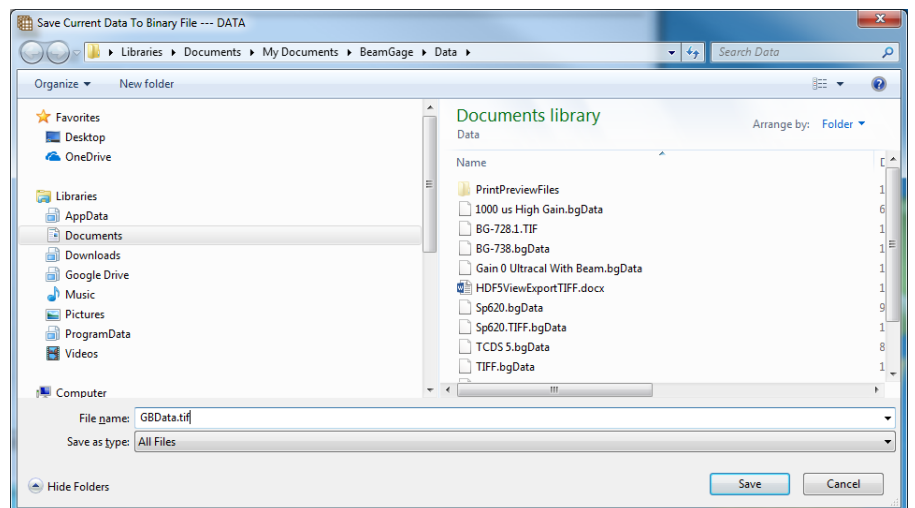
6. Click and expand the desired frame number.
7. Right-Click on **DATA**, select **Open**.



8. Select **Table->Export Data to Binary File->Native Order**.

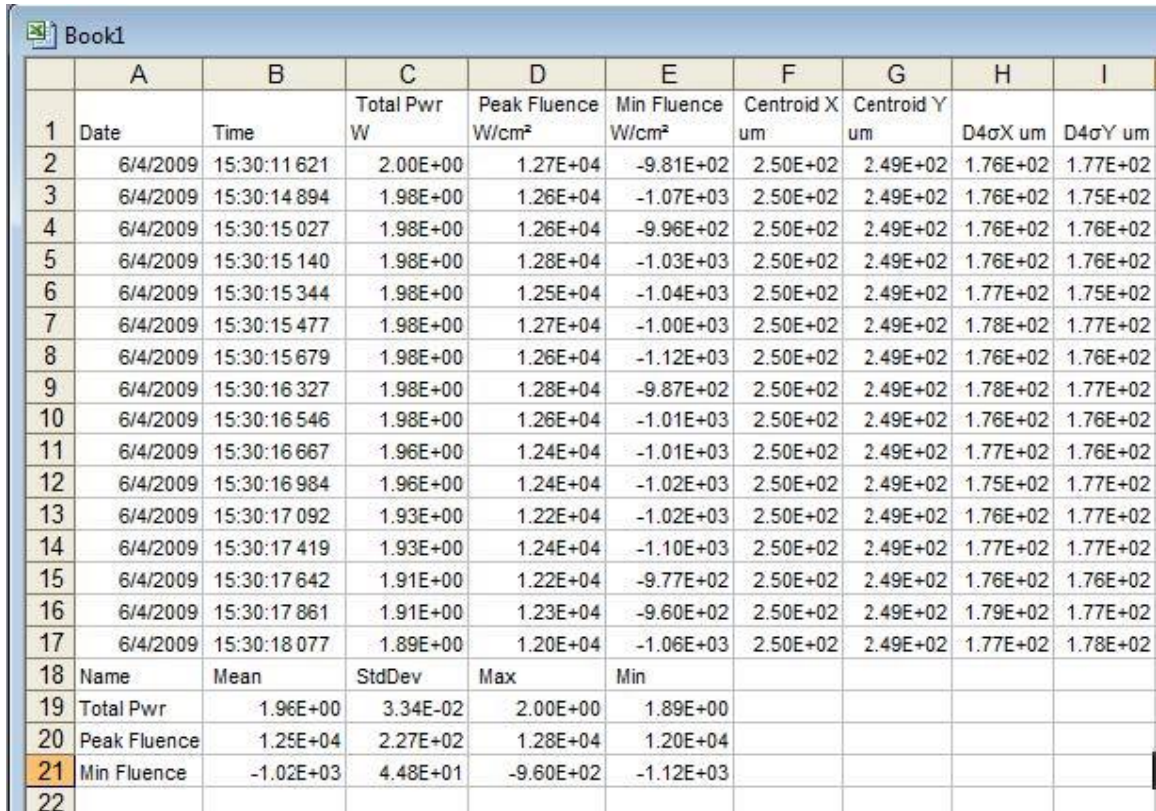


9. Locate and open the TIFF file with desired software.



### 4.1.3 Log Result and Chart Files, .csv, ASCII

Log results files are ASCII comma delimited text files that contain entries for Date, Time, and each enabled result item. These file types can be imported into Excel and other third party applications. The first row entry in a log file is a header describing the results items posted in the following entries. The logged items appear in the following rows. The end entries contain the statistical results if enabled. The example below shows what a log file looks like after importing the log data into an Excel spreadsheet.



	A	B	C	D	E	F	G	H	I
1	Date	Time	Total Pwr W	Peak Fluence W/cm²	Min Fluence W/cm²	Centroid X um	Centroid Y um	D4σX um	D4σY um
2	6/4/2009	15:30:11 621	2.00E+00	1.27E+04	-9.81E+02	2.50E+02	2.49E+02	1.76E+02	1.77E+02
3	6/4/2009	15:30:14 894	1.98E+00	1.26E+04	-1.07E+03	2.50E+02	2.49E+02	1.76E+02	1.75E+02
4	6/4/2009	15:30:15 027	1.98E+00	1.26E+04	-9.96E+02	2.50E+02	2.49E+02	1.76E+02	1.76E+02
5	6/4/2009	15:30:15 140	1.98E+00	1.28E+04	-1.03E+03	2.50E+02	2.49E+02	1.76E+02	1.76E+02
6	6/4/2009	15:30:15 344	1.98E+00	1.25E+04	-1.04E+03	2.50E+02	2.49E+02	1.77E+02	1.75E+02
7	6/4/2009	15:30:15 477	1.98E+00	1.27E+04	-1.00E+03	2.50E+02	2.49E+02	1.78E+02	1.77E+02
8	6/4/2009	15:30:15 679	1.98E+00	1.26E+04	-1.12E+03	2.50E+02	2.49E+02	1.76E+02	1.76E+02
9	6/4/2009	15:30:16 327	1.98E+00	1.28E+04	-9.87E+02	2.50E+02	2.49E+02	1.78E+02	1.77E+02
10	6/4/2009	15:30:16 546	1.98E+00	1.26E+04	-1.01E+03	2.50E+02	2.49E+02	1.76E+02	1.76E+02
11	6/4/2009	15:30:16 667	1.96E+00	1.24E+04	-1.01E+03	2.50E+02	2.49E+02	1.77E+02	1.76E+02
12	6/4/2009	15:30:16 984	1.96E+00	1.24E+04	-1.02E+03	2.50E+02	2.49E+02	1.75E+02	1.77E+02
13	6/4/2009	15:30:17 092	1.93E+00	1.22E+04	-1.02E+03	2.50E+02	2.49E+02	1.76E+02	1.77E+02
14	6/4/2009	15:30:17 419	1.93E+00	1.24E+04	-1.10E+03	2.50E+02	2.49E+02	1.77E+02	1.77E+02
15	6/4/2009	15:30:17 642	1.91E+00	1.22E+04	-9.77E+02	2.50E+02	2.49E+02	1.76E+02	1.76E+02
16	6/4/2009	15:30:17 861	1.91E+00	1.23E+04	-9.60E+02	2.50E+02	2.49E+02	1.79E+02	1.77E+02
17	6/4/2009	15:30:18 077	1.89E+00	1.20E+04	-1.06E+03	2.50E+02	2.49E+02	1.77E+02	1.78E+02
18	Name	Mean	StdDev	Max	Min				
19	Total Pwr	1.96E+00	3.34E-02	2.00E+00	1.89E+00				
20	Peak Fluence	1.25E+04	2.27E+02	1.28E+04	1.20E+04				
21	Min Fluence	-1.02E+03	4.48E+01	-9.60E+02	-1.12E+03				
22									

Strip charts in BeamGage can be saved into ASCII log files. The data in log files can also be loaded into appropriate BeamGage chart displays. To load a strip chart, the log file must contain the result item that the chart window is setup to plot, i.e. if the chart plots Total Power/Energy, the log file must contain a Total Power/Energy result column.

A Chart File is similar to a general-purpose results log file except that the only results in the file are of the type plotted in the chart. For example, a Total Power strip chart plots Total Power vs. Time. Thus only the Date and Time stamp plus the Total Power results comprise entries in this chart file.

### 4.1.4 Report Files, .PDF

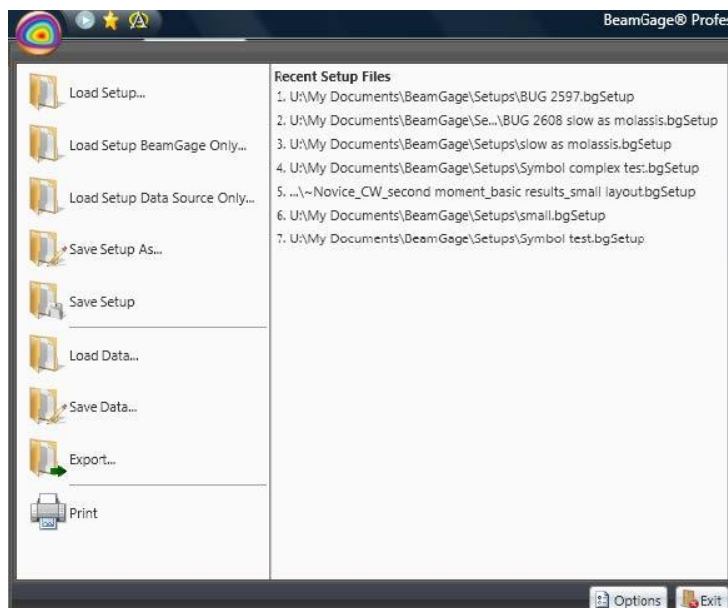
Reports can be configured to contain the various results and displays that are part of BeamGage. A report can either be a printed document or can be saved into an Adobe .PDF file format.

## 4.2 File Access Window



Data and Setup files are saved and loaded via the **File Access** button, shown left. Below is an example of the **File Access** window. The files listed on the right are a list of the last saved or opened setup files. To perform a quick reload from the list, click once on the desired file name.

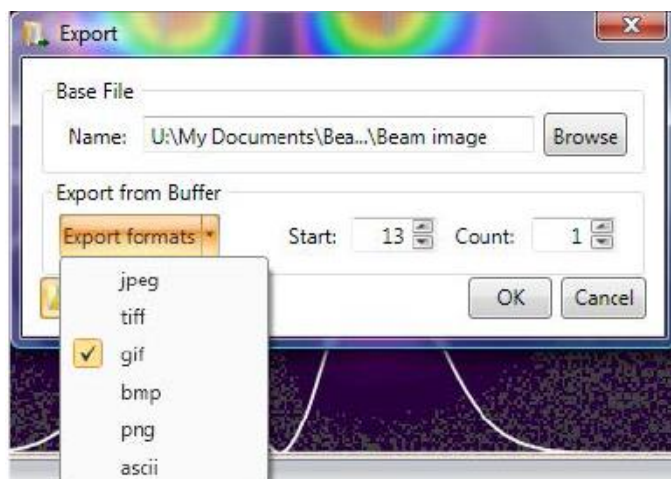




## 4.2.1 Export

To capture the 2D or 3D displayed image into an image file format, click on the **Export...** folder. This will open the **Export** dialog box shown below.

Select an image formats to create. Enter the buffer location to start and how many frames to export. Enter a file name or click **Browse** to select an existing file. Then click **OK**.



*2D or 3D image exports need to be performed with the display fully visible. Closing the display or hiding it behind another displayed item causes all overlays, such as results, apertures, profile slices, etc., to disappear from the exported file image.*



*Image files such as jpeg, tiff, gif, bmp, and png do not accurately preserve the data content of the source information. These files contain an image exactly as displayed.*

The ASCII data file is an actual copy of the processed data image, minus any graphical overlays. This type of image faithfully reproduces the processed pixel values. If the data is calibrated the ASCII is in the calibrated power/energy value at each pixel. If uncalibrated, the data is in counts. **Ultracal** data and **Auto-X** data is processed and contain negative noise values as well as positive signal content. ASCII files can be quite large especially if the frame is large and the data is power/energy calibrated.

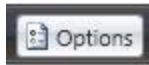
See section 2.10.3 for information on Logging images in real time.

## 4.2.2 Print Preview

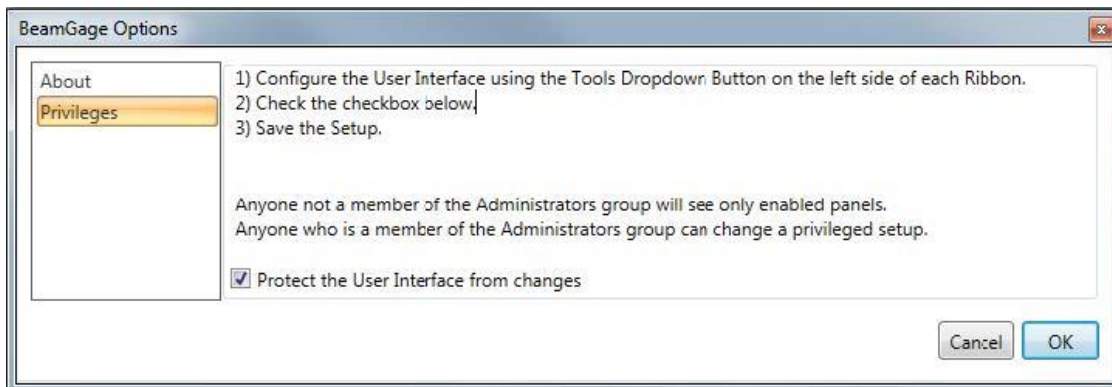


Use the **Print Preview** button to produce a printed report without accessing the **Reports** ribbon. The settings in the **Reports** ribbon are applied as preconfigured. A temporary PDF file is created which can be printed or saved using the Adobe controls. Once the PDF is closed, the temporary file is deleted.

## 4.2.3 Options Privileges



Select the **Options** button and then the **Privileges** item to open the following dialog box. In order to access this privilege control, the user must be assigned Administrator privileges on the local machine. This feature allows an administrator to **Protect** (lock) the controls.



Privileges can be used to restrict non-administrator users from accessing certain controls.

For example, the administrator may want to setup BeamGage for a specific operator, and restrict that operator from changing the setup.

The instructions shown in this dialog box describe the basic procedure that is followed to hide features from non-administrator users.

The Administrator needs to login as the target user and load the setup file the first time BeamGage is launched under the new user's login account. After configuring BeamGage for its intended user/application, save a setup file and then copy that setup file into the following location for the target users:

**C:\Users\<user\_name>\Documents\BeamGage\Setup\**

Be sure to set the **Attributes** of setup files to **Read Only** in order to ensure that they cannot be deleted or overwritten.

This makes this setup file, along with any other protected access setup files, the only setups that the restricted user can load and run.



*This locking capability does not extend to every area in BeamGage. However, it does cover the vast majority of operating controls.*

The following feature items are blocked from the user when the **Protect** box is checked:

- The Panels enabled or hidden in the **Tools** panels are locked. Panels cannot be added or removed from view.
- The Ribbon Bars sections of the **Tools** panels are disabled and not accessible.

- Exposed results items cannot be deleted and new ones cannot be added. The results drop-down controls with their associated features are not accessible. Only those items enabled by the administrator are available.

The following items cannot be blocked from the user and are always accessible:

- Displayed windows can be opened/closed and repositioned on the desktop.
- The BeamGage application window can be resized and positioned.
- The Save and Load data file functions are accessible.
- The Save and Load setup file functions are accessible.
- The **Run/Pause**, **Ultracal**, and **Auto Aperture** buttons in the **Quick Access Toolbar** are always accessible.
- The **Frame Buffer** position slider and edit controls are always active.
- Ribbon tab open/close behavior is preserved.

# Chapter 5 Computations

## 5.1 Computational Accuracy

The degree of accuracy of the computed results is based primarily on two factors. The first, and most significant, is the correct nulling of the camera background signal. The second deals with optimizing the presentation of the beam display within the detector and/or within a properly sized aperture.

The background nulling operation establishes the zero reference from which all computed results are based. Failure to correctly null and periodically monitor the background energy yields inconsistent results. Excessive background energy levels yield oversized beam diameters and reduced magnitudes when energy relationships are compared. The opposite effects result if the background levels are excessively suppressed.

BeamGage is equipped with a patented auto calibration feature called Ultracal. Ultracal performs a nulling operation that is significantly more accurate than can be achieved manually. The Ultracal algorithm also compensates for background noise, imager point defects, and camera shading.

### 5.1.1 What is Ultracal?

The Ultracal processing feature should be used in the place of any manual energy nulling techniques. Ultracal employs a sophisticated proprietary algorithm that yields greatly improved accuracy over various operating conditions and signal dynamic range. In addition, it can quickly be rerun if changes in setup or conditions occur as required by modifications to experimental conditions.

Before performing an Ultracal, it is recommended that the beam's presentation be optimized. Any changes to camera settings (Gain, Exposure, ROI, etc.) invalidate the current Ultracal. Auto and Manual apertures are not locked by the calibration cycle and may be manipulated by the user at any time.

Ultracal fails if there is excessive noise in the signal. This can be improved by decreasing the gain. If Ultracal continues to fail, there may be a "dark" pixel. If this is the case, a bad pixel correction is needed. For a Pyrocam IIIHR or Pyrocam IV, see section I.1. All other cameras must be corrected at the Ophir-Spiricon facility.

The Ultracal cycle can be run at any time. The beam must be blocked from the camera detector. After completion of the Ultracal cycle, the subsequent results remain accurate as long as the setup conditions remain the same and the camera black level, shading, and noise conditions do not change.

Since some cameras can drift with temperature, it is recommended to perform an Ultracal cycle every 10 to 15 minutes, or whenever the camera may have strayed. This drift can be observed as changes to the background noise image. Un-illuminated areas appear as gray and dark violet (almost black) random noise. If the background starts to look too gray, then the baseline is drifting negative; if too dark, then the baseline is drifting positive.



*These colors apply to the OSI Rainbow color palette. The color shading changes depending on the palette selection, but the principle remains the same.*



*Allow the camera to warm up and reach thermal equilibrium before performing calibrations. One hour is usually sufficient as a warm-up period. If the ambient air temperature is changing, then periodically recheck the background energy levels to make sure they have not been significantly altered.*

## 5.2 Beam Presentation Affects Results

Effective beam presentation is essentially an attempt to improve accuracy by increasing the signal-to-noise property of the digitized data. Since the camera and the digitizing process primarily fix the noise level, most efforts concentrate on increasing the signal content.

Always try to optimize the beam's amplitude into the camera's dynamic operating range. Whenever possible, use external optical attenuation to bring the beam's peak signal levels into the upper half of the camera's dynamic range. If optical attenuation results in low signal amplitude, use the camera's gain control to restore some of the loss.



*Increasing gain also increases noise, so use it sparingly.*

To isolate the laser beam profile from unwanted background effects BeamGage has both Manual Aperture and Auto Aperture capabilities. Ophir-Spiricon recommends always using the Auto Aperture feature to ensure elimination of background noise effects, which are detrimental when making second moment measurements.

If beam intensity is low and/or covers only a small fraction of the display window, use a Manual Aperture to eliminate the background energy noise in the wings. Use external optical magnification if the beam begins to approach only a few pixels in width. Widths of at least 10 pixels are required to obtain a reliable beam width measurement.

## 5.3 ISO Standards Compliance

Ophir-Spiricon has adopted the current versions of the International Organization for Standardization (ISO) that pertains to the measurements of laser beam characteristics. At the same time, Ophir-Spiricon has preserved other legacy measurement techniques that have found general favor within the industry. Some of these legacy techniques have been incorporated into ISO standards while others remain outside.

Computational methods that follow the ISO mathematical models are indicated in BeamGage's results and in other areas by having the suffix **ISO** as part of the results identifier. However, this marking does not mean that the computed result meets all the necessary ISO criteria. In particular, an ISO result may depend upon certain prerequisites. Such a prerequisite might be the need to utilize as an input the second moment beam width. If the user were to choose a different beam width basis, such as a 50% of Peak, then it is likely that the final results will not yield an ISO compliant answer.

Another area where one may fail to achieve a good ISO result could be in the application of proper baseline correction. While Ophir-Spiricon's Ultracal technique is an ISO compliant method, it could be improperly applied or not monitored for thermal drift or ambient light effects. All of which could lead to an incorrect result even though the computations are performed according to ISO equations.



*The ISO standards referenced here are an ongoing work in progress. Ophir-Spiricon will attempt to update BeamGage as they evolve. As of this writing, the definition of "Goodness of Fit" is being challenged and has been withdrawn from ISO 13694. The Goodness of Fit result that is currently reported is based on our current interpretation of this algorithm and is subject to change in the future.*

See Appendix A for a table of BeamGage supported ISO results and a reference to the applicable ISO standards.

## 5.4 Clip Level

The clip level is a processed power/energy pixel value. Various input dialog box entries apply to these results items. Only those pixel values that exceed the clip level are used in computing the following results:

- Certain Beam Width methods that have programmable clip levels, such as those shown.

<input type="radio"/> KE <sub>10/90</sub>	Low Clip	High Clip	Multiplier
<input type="radio"/> KE <sub>Prog</sub>	13.50	86.50	2.000
<input type="radio"/> %Total P/E	86.50		
<input type="radio"/> %Peak	13.50		
<input checked="" type="radio"/> Moving Slit <b>ISO</b>	13.50		

- Top-Hat results that rely on a programmable **Threshold P/E Density**. Enter the threshold clip level into the following dialog. Note that the value entered here is also the one used in the 1D profile and results.

Threshold P/E Density			
<input type="radio"/> Percent	0.00	%	<b>ISO</b>
<input checked="" type="radio"/> Value	0.0000e+00	cnts	<b>ISO</b>

Depending on the Beam Width Method selected, the clip level value is determined as follows:

- With the **Percent of Power/Energy** method, BeamGage totals the pixel energy values in descending order until it finds the pixel that causes the sum to exceed the set Clip% of the total energy value. The energy value of this pixel becomes the clip level.
- With the **Percent of Peak** method, BeamGage sets the clip level to the value that is equal to the set Clip% of the current peak energy value.

The number of pixels with values above the clip level establishes the Effective Area of the beam. In some cases, the selected Beam Width Basis determines which Clip Level is used in the calculation of the Orientation for elliptical beams. These are shown in the table below.

Beam Width Basis	Clip Level used for Orientation
D4Sigma	None
Smallest Slit	None
Knife Edge 16/84	None
Knife Edge 10/90	Total Energy Clip
Knife Edge Prog	Total Energy Clip
% Energy	Total Energy Clip
% Peak	Peak Clip
Moving Slit	None



## 5.5 Total Power/Energy

The cameras used with BeamGage are not calibrated to directly provide the power/energy of a laser beam. The **Computations Power/Energy** panel allows the user to calibrate to the power/energy of the laser using an external measuring device. The value entered must be the total power/energy of the beam for the frame currently displayed. For accurate results, the beam must fit inside of the current ROI.

If a calibrated value of **zero** or a units setting of **counts** (cnts) is displayed, then all power/energy related results will be displayed as processed digitizer values. Any entry other than zero immediately translates to the power/energy results items. The **Units** entry determines the energy units that appear to the right of various energy displays (i.e., W, J, mW/cm<sup>2</sup>, etc.).

When using a Manual Aperture (without an Auto Aperture), the Total Power/Energy is the amount of power/energy inside the Manual Aperture.

When using an Auto Aperture (with or without a Manual Aperture), the Total Power/Energy is the amount of power/energy inside the Auto Aperture. An Auto Aperture takes precedence over a Manual Aperture.



*When an Ophir power/energy meter is being used as the source for the Total results values, the **Power/Energy** panel does not have an effect on the Total results. See section 5.26.*

## 5.6 Peak and Min

These are the Peak and Minimum power/energy density values in the displayed frame, or within the Manual or Auto Aperture if present. The Minimum value most often is negative, and is therefore not meaningful except as an indication of the amount of noise or baseline drift present in the video data. An Auto Aperture takes precedence over a Manual Aperture.

## 5.7 Peak Location

This is the first location where the peak intensity value was found. The Peak Location is found by scanning the pixel data from left to right, top to bottom. If a Manual or Auto Aperture is present, then the scanning is confined to the pixels inside the aperture. An Auto Aperture takes precedence over a Manual Aperture.

## 5.8 Centroid Location

The Centroid location is found by calculating the first moment (center of mass) of all the selected pixels to be analyzed. The selection process is controlled by the aperture settings. When no apertures are enabled the centroid is computed over the entire area of the imager. When a manual aperture is present, the centroid calculation only involves the data contained within the manual aperture. When Auto Aperture is enabled, it defines the region of the centroid calculation. An Auto Aperture takes precedence over a Manual Aperture.

The following equations describe the X and Y centroid locations from the collection of data points that satisfy the above criteria:

$$x \text{ centroid} = \frac{\sum(X \times z)}{\sum z}$$

$$y \text{ centroid} = \frac{\sum(Y \times z)}{\sum z}$$

Where:

- $X$  The x locations of selected pixels
- $Y$  The y locations of selected pixels
- $z$  The value of selected pixels

## 5.9 Beam Widths and Diameters

To some extent, beam width is a term that describes how the user has decided to measure the size of a laser beam. BeamGage is designed to provide a set of measurement tools that allow the user to make this measurement as they see fit. The ISO standards have created a consensus regarding a standard definition of beam width. This definition has grown out of laser beam propagation theory and is called the Second Moment, or D4-Sigma beam width. The "D" stands for Diameter but is also used to denote Beam Widths. Sigma refers to the common notation for standard deviation. Thus, an X-axis beam width is defined as 4 times the standard deviation of the spatial distribution of the beam's intensity profile evaluated in the X transverse direction. A measurement taken in the Y transverse direction will yield the Y-axis beam width.



*For a  $TEM_{00}$  (Gaussian) beam, 2-Sigma is the  $1/e^2$  radius about the centroid.*

The term **Diameter** implies that the beam is radially symmetric or circular in shape. The term **Width** implies that the beam is non-radially symmetric, but is axially symmetric and characterized by two principal axes orthogonal to each other. Beams that are asymmetric, distorted, or irregularly shaped fail to provide significantly meaningful or repeatable beam width results using any of the standard methods.

When measurements of the beam widths are performed on the camera's X and Y axes, results are denoted with the letters **X** and **Y**. When a rotated elliptical beam is being measured, the notations **X/Y** become **M/m** to denote the beam widths in the orthogonal **Major** and **minor** axes, respectively.

The absence of either the X/Y or M/m notation indicates when a **Diameter** result is being designated.

According to ISO, when the ratio of the Beam Widths exceeds 0.85, then the beam can be described as circular and the Diameter result is appropriate.

### 5.9.1 D4-Sigma Method

#### **D4σX/M, D4σY/m, D4σ**

Second moment method: ISO 11145, ISO 11146-1, and ISO 11146-3.

From laser beam propagation theory, the Second Moment, or D4-Sigma, beam width definition is found to be of fundamental significance. It is defined as 4 times the standard deviation of the energy distribution evaluated separately in the X and Y transverse directions over the beam intensity profile.

$$D4\sigma X: d_{\sigma x} = 4 \cdot \sigma_x$$

$$D4\sigma Y: d_{\sigma y} = 4 \cdot \sigma_y$$

Where:

- $d_{\sigma}$  The 4-Sigma beam width
- $\sigma$  The standard deviation of the beam intensity

The standard deviations are derived from the distribution variances and are equal to the square roots of the variances. The variances are:

$$\sigma_x^2 = \frac{\sum_x \sum_y (x - \bar{x})^2 \cdot Z(x, y)}{\sum_x \sum_y Z(x, y)}$$

$$\sigma_y^2 = \frac{\sum_x \sum_y (y - \bar{y})^2 \cdot Z(x, y)}{\sum_x \sum_y Z(x, y)}$$

Where:

$Z$  The intensity of the pixel at  $(x, y)$

$\bar{x}$  The x coordinate of the centroid

$\bar{y}$  The y coordinate of the centroid

For the second moment diameter of a circular beam:

$$D4\sigma: d_\sigma(z) = 2\sqrt{2\sigma(z)}$$

Where:

$$\sigma^2 = \frac{\iint r^2 \cdot E(r, \varphi, Z) \cdot r \cdot dr d\varphi}{\iint E(r, \varphi, Z) \cdot r \cdot dr d\varphi}$$

Where:

$r$  The distance from the centroid  $(\bar{x}, \bar{y})$

$\varphi$  The azimuth angle

The first moments give the coordinates of the centroid:

$$\bar{x} = \frac{\iint xE(x, y, z) dx dy}{\iint E(x, y, z) dx dy}$$

$$\bar{y} = \frac{\iint yE(x, y, z) dx dy}{\iint E(x, y, z) dx dy}$$

Only beam propagation factors based on second moment beam widths/diameters, and divergence angles derived from the second moments of the energy density distribution function allow one to predict how a beam will propagate. Other definitions of the beam widths/diameters and divergence angles may be used, but they must be shown to be equivalent to the second moment definitions for computing the correct beam propagation.

To make an accurate measurement of the beam widths, establish an aperture for the beam inside a Manual or Auto Aperture. The aperture must be approximately 2x the size of the beam. The Auto Aperture feature automatically provides such an aperture under most operating conditions. It can be used in combination with a Manual Aperture if needed. If the beam size is already equal to about 1/2 the beam display window, a manual aperture may not be necessary. In such an event, be sure to center the beam in the window.

## 5.9.2 Knife Edge Method

DkeX/M 10/90, DkeY/m 10/90, DKE 10/90

DkeX/M 16/84, DkeY/m 16/84, DKE 16/84

DkeX/M prog, DkeY/m prog, DKE prog

Knife Edge beam widths are computed using special algorithms that simulate knife-edge techniques. The methods employed in BeamGage borrow from two sources:

1. ISO 13694 defines a method based on a 16/84 clip level method.
2. Ophir-Spiricon's legacy 10/90 clip level method, which we feel is superior to the ISO 16/84 technique. (Reference: IEEE Journal of Quantum Electronics, Vol. 27, No. 4, April 1991 Choice of Clip Levels for Beam Width Measurements Using Knife-Edge Techniques by Siegman, Sasnett, and Johnston.)
3. A user programmable method is also provided for users that wish to tune the process to best model their beam's mode content.

The ISO 16/84 method presets the Clip% values to 16% and 84%, respectively, and the Multiplier to 2.0; best for beams that are mostly TEM<sub>00</sub>.

The 10/90 method presets the Clip% values to 10% and 90%, respectively, and the Multiplier to 1.561. These are the recommended values based on the above Siegman, et al. paper, and are very compatible with CCD camera noise figures. These values are perfectly correct for computing an equivalent second moment width for TEM<sub>00</sub> beams, and are a good approximation for many beams of mixed modes.

The third Knife Edge selection allows programming the Clip% and Multiplier values. Use of this option successfully requires advanced knowledge of the beams modal content.

All Knife Edge Diameters are the computed average of the orthogonal beam widths.

When rotated beam results are disabled, the computed beam widths are aligned with a pair of simulated knife-edges, cutting one in each of the X and Y directions. Hence, the displayed beam widths are indicated in the results window as X and Y. If the laser beam is not radially symmetric but does contain two axes of symmetry, rotate the beam so the beam's axes align with the X and Y axes of the display.

When rotated beam results are enabled, the computed beam widths are aligned with a pair of simulated knife-edges, cutting one in each of the Major and Minor axial directions. Hence, the displayed beam widths are indicated in the results window as **M**/Major and **m**/minor. The implication is that the displayed values represent the major and minor widths of an elliptically shaped laser beam.



*Rotated beam results are enabled whenever one of the following results items are enabled: Orientation, Ellipticity, Eccentricity.*

## 5.9.3 Percent of Total Power/Energy Method

D%tX/M, D%tY/m, D%t

With the **Percent of Power/Energy** method, BeamGage totals the pixel energy values of all pixels in descending order until it finds the pixel that causes the sum to exceed the set Clip% of the total energy value. The energy value of this pixel becomes the clip level.

BeamGage determines the beam widths by separately looking out along the lengths of two orthogonal lines that pass through the beam centroid and counts all the pixels that are greater than the set clip level. The reported beam widths are the number of pixels greater than the clip level multiplied by the pixel pitch.

When rotated beam results are disabled, the computed beam widths are the measure of the pixels in the row and column that pass through the centroid. The beam widths in the results window are labeled **X** and **Y**.

When rotated beam results are enabled, the computed beam widths are the measure of the pixels along the Major and Minor axes that pass through the centroid. The beam widths in the results window are labeled **M**/Major and **m**/minor.

The **Percent of Total** diameter result is derived by taking the area of all pixels above the clip level, and computing the diameter of a circle that contains that amount of area. The Diameter beam width in the results window is labeled without axis labels.

## 5.9.4 Percent of Peak Method

**D%pkX/M, D%pkY/m, D%pk**

With the **Percent of Peak** method, BeamGage sets the clip level to the value that is equal to the set Clip% of the current peak energy value.

BeamGage determines the beam widths by separately looking out along the lengths of two orthogonal lines that pass through the beam centroid and counting all the pixels that are greater than the set clip level. The reported beam widths are the number of pixels greater than the clip level multiplied by the pixel pitch.

When rotated beam results are disabled, the computed beam widths are the measure of the pixels in the row and column that pass through the centroid. The beam widths in the results window are labeled **X** and **Y**.

When rotated beam results are enabled, the computed beam widths are the measure of the pixels along the Major and Minor axes that pass through the centroid. The beam widths in the results window are labeled **M**/Major and **m**/minor.

The **Percent of Peak** diameter result is derived by taking the area of all pixels above the clip level, and computing the diameter of a circle that contains that amount of area. The Diameter beam width in the results window is labeled without axis labels.

## 5.9.5 Moving Slit Percent of Peak Method

**D%msX/M, D%msY/m**

BeamGage emulates a moving slit by summing the rows and columns of data in either the X/Y or the M/m axial directions. The beam widths are determined by separately looking out along each line and counting the sums that are greater than the set clip level of the peak sum. The reported beam widths are the number of sums greater than the clip level multiplied by the pixel pitch or the pixel pitch adjusted by the orientation angle. The default clip level is 13.5% which yields an accurate second moment beam width for a TEM<sub>00</sub> beam.

ISO 11146-3 section 10.4.3 describes this method. It is assumed that  $M^2=1$  and thus the summed data is from a perfect TEM<sub>00</sub> Gaussian distribution. As a result, the moving slit method returns an accurate second moment beam width for a TEM<sub>00</sub> beam. For higher mode mixes, the accuracy is, at best, a second moment approximation. In many cases, this is not very accurate.

## 5.9.6 Encircled Power Methods

**Depss(X/M) 95.4, Depss(Y/m) 95.4, Depsa86.5, Depsa-prog**

The encircled power (ep) methods come in two versions, the smallest slit (ss) method for measuring beam widths, and the smallest aperture (sa) method for measuring beam diameters. The smallest aperture method is often referred to as a “power-in-a-bucket” method, where the size of the aperture is the bucket diameter.

For the epss method, a symmetrically adjustable slit centered at the beam centroid, and sized in both the X/Y or M/m axis, is found that contains 95.4% of the beam power/energy. The separation distance between the slit edges is the reported beam widths.

For the epsa method, a circular adjustable aperture is placed on the beam and centered on the beam centroid. The diameter is adjusted until it contains 86.5% of the beam power/energy. The epsa-prog method allows the percent of power in the aperture to be set by the user.

The above fixed percentages return an accurate second moment beam width result for a TEM<sub>00</sub> beam. For higher mode mixes, the accuracy is, at best, a second moment approximation. In many cases this is not very accurate.

## 5.10 Rotated Beams

**Orientation, Ellipticity, Eccentricity**

BeamGage can compute and display the Orientation, Ellipticity, and Eccentricity of beams rotated with respect to the normal X and Y axes. This includes elliptical or rectangular shaped beams. When any of these three result items is activated, the cursors change to a rotated mode of operation. In this mode, the cursors align to the orientation of the input beam.

If the beam is more circular than elliptical, the beam axes gyrate uncontrollably indicating that the elliptical results items should probably be turned off.

The Orientation is defined as the angle formed between the Major axis and the horizontal, pointing to the right. If the Major axis points above the horizontal, the angle is positive (+); below the horizontal is negative (-). The Major and Minor axes are perpendicular to each other. The method for computing the orientation is effected by the chosen beam width basis. To achieve an ISO orientation result, one of the ISO indicated beam widths must be chosen as the beam width basis. Choosing a non-ISO (legacy) beam width as a basis applies the various clip level criteria for analysis of the orientation.

Beam Width Basis	Orientation Algorithm
D4Sigma	Azimuthal (ISO)
Smallest Slit	Azimuthal (ISO)
Knife Edge 16/84	Azimuthal (ISO)
Knife Edge 10/90	Legacy
Knife Edge Programmable	Legacy
% Energy	Legacy



% Peak	Legacy
Moving Slit	Azimuthal (ISO)

The **Ellipticity** result is the ratio of the computed beam widths. The Minor (smaller) beam width is always divided by the Major (larger) to produce a result less than or equal to one. Thus, beams with Ellipticity values close to 1.000 are nearly circular.

$$\xi(z) = \frac{d_{\sigma m}}{d_{\sigma M}}$$

The **Eccentricity** result approaches zero as the beam becomes more circular.

$$e(z) = \frac{\sqrt{d_{\sigma M}^2 - d_{\sigma m}^2}}{d_{\sigma M}}$$

## 5.11 Cross-Sectional Area

The cross-sectional area of the beam is the area contained by the computed beam width. The applicable beam width for this calculation is the one chosen as the Beam Width Basis. Note that in BeamGage only beam widths, not beam diameters, can be used to compute the cross-sectional area result.

$$A_{\sigma} = \pi \frac{d_{\sigma x} d_{\sigma y}}{4}$$

## 5.12 Crosshair Measurements

### Cursor-Crosshair, Centroid-Crosshair

These two results are the straight line distances measured between the **Crosshair** and the **Cursor** or the **Crosshair** and the computed **Centroid**. For this result to operate correctly, the **Crosshair** must be enabled, and in the first case, the **Cursor** must also be enabled.

## 5.13 Average Power Density

The average power density is the total power of the beam divided by its cross-sectional area.

## 5.14 Peak Pulse Power

In ISO this is simply called the Pulse Power, but common usage has added the term “peak” to denote the peak power present in a single pulse. Not to be confused with “peak power,” this denotes the maximum of the power-time function.

This result is computed by dividing the energy of a single pulse by the pulse period. The pulse period is defined as the time interval between the half peak power points at the leading and trailing edges of the pulse.

To compute this result the input Total P/E units must be set to an energy value, such as Joules, and the pulse period must be entered into the **Pulse Width** edit control. This edit control is in the **Computations Power/Energy** expansion dialog box. In this

Pulse Power

Pulse Width

10.0000

μs

ISO

example the pulse width is set to 10 $\mu$ s.

## 5.15 Average Pulse Power

The average pulse power is the time average power based on the pulse repetition rate in Hertz and the energy per pulse. This result is computed by multiplying the energy per pulse by the pulse rate in Hz.

To compute this result, the input Total P/E units must be set to an energy value, such as Joules, and the pulse rate must be entered into the **Pulse Rate** edit control. This edit control is in the **Computations Power/Energy** expansion dialog box. In the example shown, the pulse rate is set to 30Hz.

Average Pulse Power  
Pulse Rate 30.0000 Hz ISO

## 5.16 Device Efficiency

The efficiency result describes how well the laser converts input power/energy into output power/energy. The output value is divided by the input and multiplied by 100%.

In order to perform this calculation the input power/energy of the laser needs to be measured or known to some reasonable accuracy. Some laser manufactures provide input pump power/energy while others do not. If a mains power meter is available, this figure may be useful as the input power/energy value.

To compute this result the input and output P/E units must be the same. Manually enter the input power/energy value in the **Device Efficiency** edit control. This edit control is in the **Computations Power/Energy** expansion dialog box. In the example shown, the input power is set to 1000 Watts.

Device Efficiency  
Input P/E 1.0000e+03 W ISO

## 5.17 Percent in Aperture

When a Manual Aperture is placed in the beam display, the percentage of the total energy of the frame that lies inside of the Manual Aperture is computed.

If an Auto Aperture is present, then the value represents the total energy contained within the Auto Aperture.

If no aperture is present, then this result displays 100%.

## 5.18 Divergence

⊖ X/M, ⊖ Y/m, ⊖

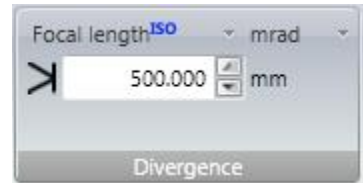
BeamGage supports three different methods for computing beam divergence. Each is useful under different operating conditions. Only the Focal Length method is recognized as ISO compliant. However, the other two methods should be just as accurate when properly applied. Only one method can be employed at a time.



*Divergence measurements that follow beam propagation theory are based on second moment beam width measurements. The beam widths used in these calculations are selected by the Beam Width Basis setting. If a basis other than second moment or a second moment approximation is chosen, then the divergence results will be affected accordingly.*

### 5.18.1 Focal Length Method

This method is based on the beam width of a focused beam's spot size and the focal length of the focusing optic. If off axis results are disabled Divergence results are computed in the X and Y aligned axes of the beam; Major and Minor axes are used if off axis is enabled. Enter the focal length of the optic into the divergence panel as shown.



The Focal Length divergence method provides a means for finding the far-field beam divergence at any point in the beam propagation path. As shown below, the calculation performed by BeamGage is quite simple; however, the optical setup must be done with great care. The user must provide the optic to suit their particular application. The focusing optic must be large enough to accommodate the input beam without introducing diffraction effects. Either a refracting or reflecting focusing optic can be used, but in either case the camera's detector must be placed at the exact focal length of the optical element. The Divergence result is based on the focused spot size as described in the equation below.

$$divergence = \frac{W_f}{f}$$

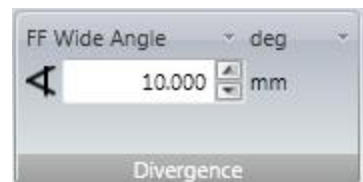
Where:

$W_f$  The width of the beam at distance  $f$  from the optic

$f$  The focal length of the imaging optic at the wavelength of the laser

### 5.18.2 Far-Field Angle Method

This method is designed to measure the divergence angles of devices, such as laser diodes, where the divergence angles tend to be large and are best measured in degrees rather than mrad. This method assumes that the laser output is essentially a point source. Enter the distance from the laser to the camera imager into the divergence panel as shown.



Position the camera imager a known distance from the source and ensure that the entire beam does not overfill the imager area. Because these sources are often diverging rapidly in one axis and slower in the other, it is recommended that the rapidly diverging axis be aligned with the wide axis of the camera imager.

The Divergence result is computed as follows:

$$divergence = 2 \cdot \tan^{-1} \left( \frac{W_c}{2 \cdot S} \right)$$

Where:

$W_c$  The width of the beam at location  $S$

$S$  The distance from the beam source to the imager

### 5.18.3 Far-Field Two Point Method

This method is based on the actual measured increase in laser beam width as it expands in the far-field region. Before using this method, be sure that the measurements will be made in the beam's far-field region

and that the size of the beam does not grow larger than the camera's ability to contain it. Divergence results will be computed in the X and Y aligned axes of the beam.



*We recommend not using the off axis Elliptical mode when using the Far-Field method, but rather rotate the camera to bring the axes of the laser into X and Y alignment. This will eliminate any errors possibly caused by uncertainty in determining the orientation angles at the two measurement locations.*

Position the camera in the beam path to acquire a first beam width sample. It is assumed that this first sample is nearest the beam waist, but still in the far-field region, and thus the smaller sample size. With this measurement held in the results display, select the check mark to transfer this first sample results into the **X**, **Y**, and **D** beam width/diameter entries as shown.

Parameter	Value	Unit
X	2.3400e+00	μm
Y	1.5000e+00	μm
D	1.9100e+00	μm

These values can also be manually entered into the three edit boxes.

Next, move the camera a distance further from the beam waist. Enter the distance the camera has traveled as the **Separation Distance** in the edit box. Now measure the beam widths at this new location and observe that the divergence results are being calculated based on the geometric expansion of the beam from the first and the second sample locations.

The Divergence result is computed as follows:

$$divergence = 2 \cdot \tan^{-1} \left( \frac{W_c - W_1}{2 \cdot S} \right)$$

Where:

$W_1$  The width of the beam at the first sample (nearer to the waist) location

$W_c$  The width of the beam at the current (further from the waist) location

$S$  The separation distance between the two beam width sample locations

## 5.18.4 Far-Field Radiant Intensity

When placed at the focal length of a lens, the intensity distribution on the imager is proportional to the angular distribution of the beam in the far field (at infinity).

The far field radiant intensity is the average power/energy per steradian (sr) contained within the propagating second moment beam width. This calculation is intended for use on a circular beam and is computed using only the divergence result. If the beam is not circular, the result is an approximation of the mean or actual radial second moment calculation.

The expanding cone of laser power/energy, expressed in watts or joules per steradian, is independent of position. Once the far field divergence is known, independent of the method employed, it becomes possible to compute the Radiant Intensity.

$$J(\theta) = \frac{P_\sigma}{2\pi \left[ 1 - \cos\left(\frac{\theta}{2}\right) \right]}$$

Where:

$P_{\sigma}$  The total second moment power/energy of the beam

$\Theta$  The circular full angle divergence of the beam in rad

## 5.19 Gaussian Fit

BeamGage can perform a least squares bivariate normal equation (Gaussian equation) fit using all of the data when doing a 2D whole beam fit. Or it can perform two univariate normal equation fits using orthogonal lines of data defined at the Cursor location.

The whole beam fits are performed on the 2D beam profile and its results items are available in the main Results window. 2D fits can be performed either on or off axis.

The 1D fits are performed on the beam data plotted in the X/Y, M/m 1D beam profile displays. The results of the 1D fits are displayable in the Results window beneath the 1D Gaussian heading.

Of all the results items available from the fits, presently only one is an ISO defined item: **Roughness of Fit**. A result item called **Goodness of Fit** has been temporarily dropped from the ISO standard because of confusion in understanding how it is to be calculated. We have computed it based on our current interpretation of the method, however our results may change when ISO settles onto an agreed upon calculation.

The following table describes the available results items for both the 2D and 1D Gauss fits:

2D Whole Beam Fits	1D Line Fits computed at Cursor Location	
Gauss Height	X/M Gauss Height	Y/m Gauss Height
Gauss Width X/M	X/M Gauss Width X/M	Y/m Gauss Width Y/m
Gauss Width Y/m		
Gauss Centroid X	X/M Gauss Centroid X/M	Y/m Gauss Centroid Y/m
Gauss Centroid Y		
Goodness of fit*	X/M Goodness of fit*	Y/m Goodness of fit*
Roughness of fit	X/M Roughness of fit	Y/m Roughness of fit
$\Delta$ Centroid X		
$\Delta$ Centroid Y		
$\Delta$ Centroid	X/M $\Delta$ Centroid	Y/m $\Delta$ Centroid

\*The **Goodness of Fit** results are based on our interpretation of the ISO method. Once the ISO definition becomes settled we will replace it with the agreed upon algorithm.

Note that all fits are least square fits, meaning that the algorithm minimizes the sum of the square of the differences between the data and the fitted surface or line, as described in the following equation.

$$A_{min} = \sum_x \sum_y (Z_{xy} - S_{xy})^2$$

Where:

$Z_{xy}$  Amplitude of the pixel data at  $(x, y)$

$S_{xy}$  Amplitude of fitted surface at  $(x, y)$

### 5.19.1 Whole Beam Fit Equations

The bivariate normal equation is used to fit data in two locked directions, X and Y or Major and minor. The Whole Beam selection assumes the beam is circular or elliptical. The definition of the bivariate normal equation and the displayed results are as follows:

$$J = J_0 e^{-2 \left[ \left( \frac{x - \bar{x}}{w_x/2} \right)^2 + \left( \frac{y - \bar{y}}{w_y/2} \right)^2 \right]}$$

Where:

$J$  Amplitude at the point  $(x, y)$

$J_0$  \* Amplitude at the Gaussian center

$x$  The x location of the pixel

$\bar{x}$  \* The x location of the Gaussian center

$w_x$  \* Horizontal width at  $1/e^2$  of energy

$y$  The y location of the pixel

$\bar{y}$  \* The y location of the Gaussian center

$w_y$  \* Vertical width at  $1/e^2$  of energy

**Parameters marked with an asterisk (\*) are the variables fitted.**

### 5.19.2 X/Y or Major/Minor Line Fit Equations

The univariate normal equation is used to fit data in one direction. The definition of the equation and the displayed results are shown below.

For the X or Major cursor position:

$$J = J_M e^{-2 \left( \frac{M - \bar{M}}{w_M/2} \right)^2}$$

Where:

$J$  Amplitude at the point  $M$

$J_M$  \* Amplitude at the Gaussian center

$M$  Location of the pixel

$\bar{M}$  Location of the Gaussian center



$w_M$  \* Width at  $1/e^2$  of energy

**Parameters marked with an asterisk (\*) are the variables fitted.**

For the Y or Minor cursor position:

$$J = J_m e^{-2\left(\frac{m-\bar{m}}{w_m/2}\right)^2}$$

Where:

$J$  Amplitude at the point  $m$

$J_m$  \* Amplitude at the Gaussian center

$m$  Location of the pixel

$\bar{m}$  M location of the Gaussian center

$w_m$  \* Width at  $1/e^2$  of energy

**Parameters marked with an asterisk (\*) are the variables fitted.**

### 5.19.3 2D Whole Beam Gauss Fit Results

The Gauss Fit results are defined as follows:

**Gauss Height:** the peak fluence of the Gauss fit result.

**Gauss Width(s):** The second moment width(s) of the Gauss fit, either X/Y or M/m.

**Gauss Centroid:** The X and Y coordinates of the fitted centroid.

**Δ Centroid X/Y:** The X and Y displacement of the fitted centroid from the X and Y coordinate values of the input beam centroid.

**Δ Centroid:** The straight line linear displacement of the fitted centroid to the centroid of the input beam.

**Roughness of Fit:** Maximum deviation of the theoretical fit to the measured distribution.

$$R = \frac{|E_{ij} - E_{ij}^f|_{max}}{E_{max}}$$

Where:

$E_{ij}^f$  The fitted theoretical distribution

$E_{ij}$  The input beam distribution

Note:

$0 \leq R \leq 1$ , as  $R \rightarrow 0$  the fit becomes better

### 5.19.4 1D Gauss Fit Results

The Gauss Fit results are defined as follows:

**Gauss Height:** the peak fluence of the Gauss fit result

**Gauss Width:** The second moment width of the Gauss fit on the cursor data

**Gauss Centroid:** The location of the fitted centroid on the cursor data

**Δ Centroid:** The displacement of the fitted centroid to the centroid of the input data on the cursor

**Roughness of Fit:** Maximum deviation of the theoretical fit to the measured distribution

$$R = \frac{|E_i - E_i^f|_{max}}{E_{max}}$$

Where:

$E_i^f$  The fitted theoretical distribution

$E_i$  The input beam distribution

Note:

$0 \leq R \leq 1$ , as  $R \rightarrow 0$  the fit becomes better

1D Gauss fits can be either X/Y aligned where the fits will be performed upon the cursor data in the X & Y directions, or the fits can be off axis Major/minor axes aligned with the fits performed upon the cursor data parallel with the Major and Minor axes passing through the Centroid.

When the off axis Major/minor mode is enabled the cursor intercepts become the origins for the 1D profile plots.

## 5.20 Top-Hat Results

ISO 13694 defines a large number of beam measurements that are typically applied to beams with a Top-Hat profile. This 2D Top-Hat profile is characterized by beams that have a flat-topped energy distribution with steeply sloped sides. The 2D Top-Hat results are found in the main Results display window. These results are not confined to the Top-Hat shape, but because of their frequent association with this shape they are collectively referred to as Top-Hat results.

A subset of the Top-Hat results can be computed on the 1D beam profiles and these results items are located in the Beam Profile Results window.

The Top-Hat results include the following set of computed items:

2D Top-Hat Results	*1D Top-Hat Results computed at Cursor Location	
Flatness	X/M Flatness	Y/m Flatness
Effective Area		
Effective Power	X/M Effective Power	Y/m Effective Power
Fractional Power	X/M Fractional Power	Y/m Fractional Power
Effective Avg Fluence		
Uniformity	X/M Uniformity	Y/m Uniformity

Plateau Uniformity	X/M Plateau Uniformity	Y/m Plateau Uniformity
Edge Steepness	X/M Edge Steepness	Y/m Edge Steepness

\*The calculations applied to 1D results will have different meanings than those defined in ISO. It is up to the user to find utility in these results, and not to expect any special correlation between the 2D ISO values and the 1D values, even though they have similar names.

Top-Hat results introduce the concept of a threshold fluence value. Most appropriately this threshold value defines a minimum specification where the power/energy density of the beam is intense enough to do work; such as ablating a surface material, melting a target material, etc. Thus this threshold setting is used to define the effectiveness of the laser beam to perform a certain task.

The **Threshold P/E Density** is programmed in the **Computations Power/Energy** expansion dialog box.

In the example here, the threshold fluence is set to 2000 W/cm<sup>2</sup>. This value can also be programmed based on the percent of the peak fluence observed in the beam.

Threshold P/E Density

☐ Percent
 ☐ Value

50.00 % ISO  
 2.0000e+03 W/cm<sup>2</sup> ISO

The threshold value is given the notation  $E_{\eta T}$

## 5.21 2D Whole Beam Top-Hat Calculations

The following sections describe each of the Top-Hat results items as defined for 2D spatial analysis.

### 5.21.1 Effective Irradiation Area

$A_{\eta}^i(z)$  Irradiation area at location  $z$  for which the power/energy density exceeds the threshold density. This is the sum of all pixel areas that are equal to or greater than the threshold fluence.

### 5.21.2 Effective Average Power/Energy Density

Spatially averaged power/energy density of the distribution at location  $z$ , defined as the weighted mean.

$$E_{\eta}(z) = \frac{P_{\eta}}{A_{\eta}^i}$$

Where:

$P_{\eta}$  The total power/energy above the threshold

$A_{\eta}^i$  The area containing the above power/energy

### 5.21.3 Flatness Factor

Flatness is defined as the ratio of the effective average power/energy density to the maximum power/energy density at location  $z$ .

$$F_{\eta}(z) = \frac{E_{\eta}}{E_{max}}$$

Where:

$E_\eta$  The effective average power/energy density

$E_{max}$  The peak power/energy density in the beam

### 5.21.4 Effective Power/Energy

$P_\eta(z)$  The Effective power/energy is the total power that is contained in the area above the threshold fluence.

Evaluated by summing only over locations  $(x, y)$  for which:

$$E(x, y) > E_{\eta T}$$

### 5.21.5 Fractional Power/Energy

The fractional power/energy is the ratio of the power/energy above the threshold divided by the beam total power/energy.

$$f_\eta(z) = \frac{P_\eta(z)}{P(z)}$$

Where:

$$0 \leq f_\eta(z) \leq 1$$

### 5.21.6 Beam Uniformity

The normalized RMS deviation of the power/energy density from its average value at location  $z$ .

$$U_\eta = \frac{1}{E_\eta} \sqrt{\frac{1}{A_\eta^i} \iint [E(x, y) - E_\eta]^2 dx dy}$$

Note:

$U_\eta = 0$  for a perfect flat top beam with vertical edges

### 5.21.7 Plateau Uniformity

For distributions having a nearly flat-top profile.

$$U_P(z) = \frac{\Delta E_{FWHM}}{E_{max}}$$

$\Delta E_{FWHM}$  is the full-width at half-maximum (FWHM) of the peak near  $E_{max}$  of the power/energy density histogram  $N(E_i)$ , i.e. the number of  $(x, y)$  locations at which a given power/energy density  $E_i$  is recorded.

Note:

$$0 < U_p(z) < 1; \quad U_p(z) \rightarrow 0 \text{ as distributions become more flat-topped}$$

## 5.21.8 Edge Steepness

Normalized difference between effective irradiation areas of 10% and 90% of peak with power/energy density values of 10% of peak.

$$s(z) = \frac{A_{0.1}^i(z) - A_{0.9}^i(z)}{A_{0.1}^i(z)}$$

Note:

$$0 < s(z) < 1; \quad s(z) \rightarrow 0 \text{ as the edges of the distribution become more vertical}$$

## 5.22 1D Top-Hat Calculations

The following sections describe each of the Top-Hat results items as defined for 1D spatial analysis.

### 5.22.1 1D Flatness Factor

Flatness is defined as the ratio of the effective average power/energy density to the maximum power/energy density at location  $z$ .

$$F_{1\eta}(z) = \frac{\bar{E}_{1\eta}}{E_{1max}}$$

Where:

$E_{1\eta}$  The average effective power/energy density above the threshold

$E_{1max}$  The peak power/energy density in the 1D beam profile

### 5.22.2 1D Effective Power/Energy

$P_{1\eta}(z)$  The Effective power/energy is the total power that is contained in the area above the threshold fluence.

Evaluated by summing only over locations  $(x)$  for which:

$$E(x) > E_{\eta T}$$

### 5.22.3 1D Fractional Power/Energy

The fractional power/energy is the ratio of the power/energy above the threshold divided by the beam total power/energy.

$$f_{1\eta}(z) = \frac{P_{1\eta}(z)}{P_1(z)}$$

Where:

$$0 \leq f_{1\eta}(z) \leq 1$$

### 5.22.4 1D Beam Uniformity

Normalized RMS deviation of power/energy density from its average value at location z.

$$U_{1\eta} = \frac{1}{E_{1\eta}} \sqrt{\frac{\int [E_1(x) - E_{1\eta}]^2 dx}{d_{1\eta}^i}}$$

Note:

$$U_{\eta} = 0 \text{ for a perfect flat top beam with vertical edges}$$

### 5.22.5 1D Plateau Uniformity

For distributions having a nearly flat-top profile.

$$U_{1P}(z) = \frac{\Delta E_{1FWHM}}{E_{1max}}$$

$\Delta E_{1FWHM}$  is the full-width at half-maximum (FWHM) of the profile peak near  $E_{1max}$  of the power/energy density histogram  $N(E_i)$ , i.e. the number of (x) locations at which a given power/energy density  $E_i$  is recorded.

Note:

$$0 < U_{1P}(z) < 1; \quad U_{1P}(z) \rightarrow 0 \text{ as distributions become more flat-topped}$$

### 5.22.6 1D Edge Steepness

Normalized difference between effective irradiation amplitudes of 10% and 90% of peak with power/energy density values of 10% of peak.

$$s_1(z) = \frac{d_{0.1}^i - d_{0.9}^i}{d_{0.1}^i}$$

Note:

$$0 < s_1(z) < 1; \quad s_1(z) \rightarrow 0 \text{ as the edges of the distribution become more vertical}$$



## 5.23 Beam Positional Stability

The **Positional Stability** results are defined in ISO 11670. The implementation performed in BeamGage assumes that the laser axis of propagation is parallel with the camera's Z axes and the measurement is made directly in the plane of the camera imager.

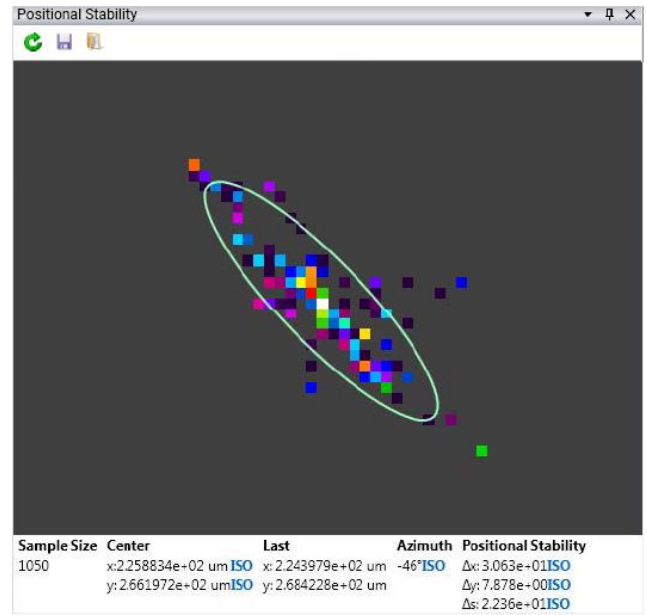


*BeamGage does not compute Beam Angular Stability.*

To meet the ISO requirement for beam **Positional Stability** the laser beam must be sampled at least 1000 times during the measurement interval.

ISO also defines three stability recoding time periods as:

- Short-term, within a time period of 1 second
- Medium-term, within a time period of 1 minute
- Long-term, within a time period of 1 hour



With camera technology, the ability to capture 1000 frames in 1 second is not practical as the fastest cameras typically capture at rates of 60-100 fps. In addition, BeamGage would not be capable of computing the stability results at such high rates of speed. The ability to capture 1000 frames in about 1 minute may be possible under optimum conditions. Above 1 minute the possibility of satisfying the 1000 frame sample becomes more doable.

### 5.23.1 Center

#### Center

x: 2.258834e+02 um ISO  
y: 2.661972e+02 um ISO

The x/y Center results define the mean centroid position. This is the mean of the centroid position over time and is the center of mass of the Positional Stability spatial histogram. The results given here only match the centroid mean values in the results screen if they are configured with the same sample size.

### 5.23.2 Last Center

#### Last

x: 2.243979e+02 um  
y: 2.684228e+02 um

The x/y Last result is the centroid of the last frame of data collected. It provides an indication of where the current beam centroid is located. This result is the same as the Centroid X/Y values that are reported in the main Results display window.

### 5.23.3 Azimuth Angle

Azimuth  
-46° ISO

The angle that the major axis (x) of the asymmetric centroid histogram plot makes with respect to the laboratory (camera) axial system.

As the spatial histogram of the beam centroid motion is plotted, the movement often takes on an asymmetrical shape. Quite often this shape will point in a specific direction as the centroid wanders back and forth over time. The shape of this movement will often be rotated with respect to the camera's X/Y axes. The

long axis of the motion is defined as a rotated coordinate system x/y with respect to the camera's coordinate system. The angle of the rotated x axis formed with the camera's X axis is called the Azimuth angle. Similar to the manner that an elliptical beam's orientation is calculated, the Azimuth is limited to a rotation of +90°/-89°.

## 5.23.4 Beam Positional Stability

$\Delta x, \Delta y, \Delta s$

### Positional Stability

$\Delta x$ : 3.063e+01ISO

$\Delta y$ : 7.878e+00ISO

$\Delta s$ : 2.236e+01ISO

The **Positional Stability** of the beam in the x/y axial directions is four times the standard deviation of the distribution of the centroids histogram of movement.

The 2D histogram display uses a binning size equal to the current camera pixel scale. The center of the pixel defines the bin's absolute location and each centroid falling within the pixel is assigned to that pixel's bin location. The positional standard deviations are computed based on the bin coordinates, thus some rounding of the reported stability values does result.

The  $\Delta s$  standard deviation represents the radial **Positional Stability** value when the histogram plots a radially symmetric or random scatter plot having no meaningful azimuth angle.

In the **Positional Stability** scatter plot, a displayed aperture is drawn that indicates the position and size of the ellipse defined by the scatter histogram. The major axis of this ellipse is aligned with the x axis or azimuth rotation. The minor axis of the ellipse is aligned with the orthogonal y axis. The size of the ellipse is based on the computed standard deviation of the histogram spatial distribution and is referred to as the beam **Positional Stability**.

## 5.24 Gamma Correction

Gamma 1.00

If the camera has a gamma value less than or greater than 1, BeamGage can be set to correct for the camera's non-linear response. Enter the gamma of the camera in the **Gamma** field located in the **Capture** panel found in the **Source** ribbon. Each pixel of each new frame of data will be automatically corrected as defined in the equation shown below. An entry of "1.0" disables gamma correction.

$$z = \left( \frac{Z}{P} \right)^{1/g} \times P$$

Where:

- $z$  The gamma corrected pixel intensity
- $Z$  The uncorrected pixel intensity value
- $g$  Gamma
- $P$  The maximum value for a pixel (255 for 8-bit cameras, 1023 for 10-bit cameras, 4095 for 12-bit cameras, etc.)



Be sure of the Gamma correction value. If necessary, run a response curve on the camera. Standard published gamma values are usually averages for particular camera types and may not always be adequate for obtaining the desired accuracy. Also, be wary of gamma values less than 1 published for CCD cameras. These values are usually approximations obtained by using two-piece linear fits to an exponential gamma curve. Whenever possible, use CCD cameras which allow for a gamma setting of 1.0 and do the gamma correction in BeamGage.

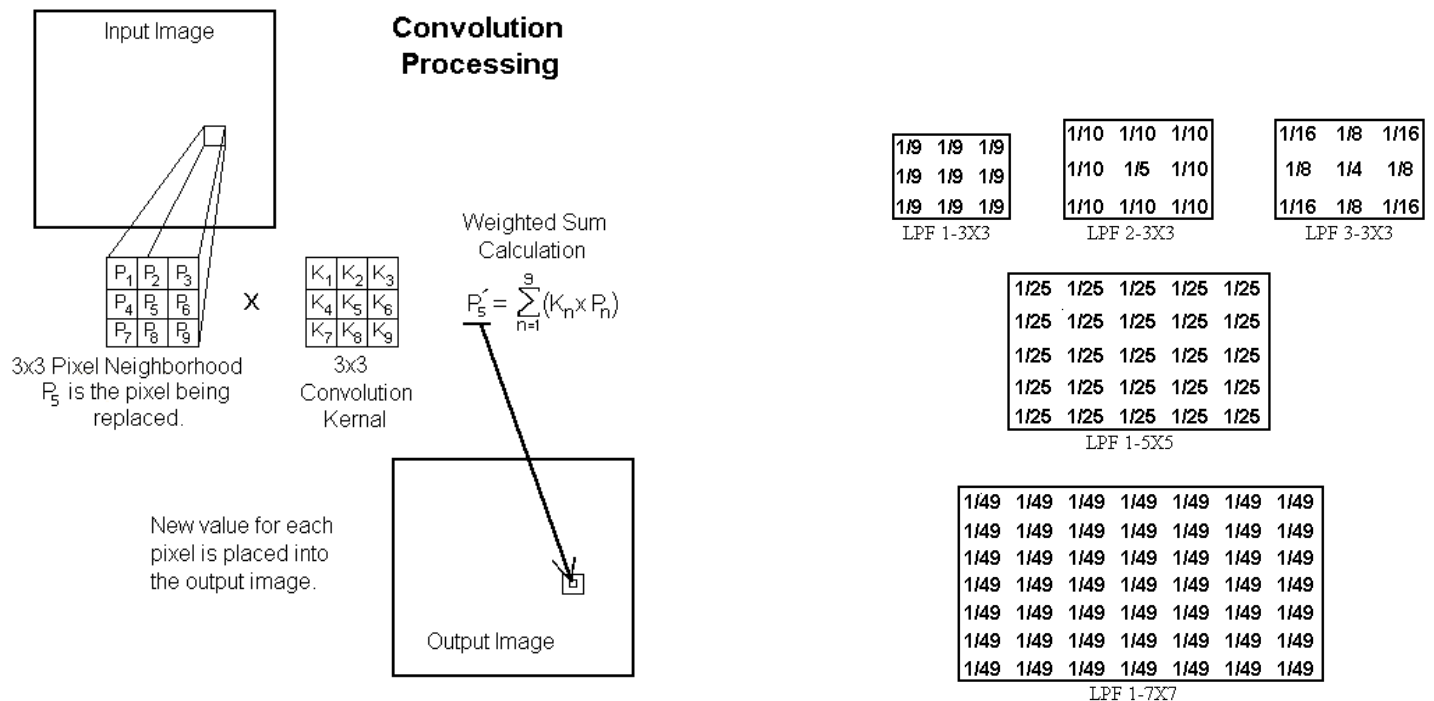
## 5.25 Convolution

Convolution algorithms in BeamGage may take on a number of forms. In the broadest sense, convolution refers to a general-purpose algorithm that can be used in performing a variety of area process transformations. One such general-purpose algorithm is described here.


For the purpose of this description, the best way to understand a convolution is to think of it as a weighted summation process. Each pixel in an image becomes the center element in a neighborhood of pixels. A similarly dimensioned convolution kernel multiplies each pixel in the neighborhood. The sum of these products is then used to replace the center pixel.

Each element of the convolution kernel is a weighting factor called a convolution coefficient. The size and arrangement of the convolution coefficients in a convolution kernel determines the type of area transform to apply to the image data.

The figure on the left shows a 3x3 neighborhood and convolution kernel. The tables on the right give the convolution coefficients (K values) for some of the included low-pass spatial filters.



## 5.26 Power/Energy Meter Operation

Power/Energy manual calibration settings no longer take effect when a meter is connected. A  icon appears in the **Power/Energy** panel to indicate that a meter reading is being used for the power/energy results display and related computations.

The reported meter values are synchronized to the frame captures performed by BeamGage. However, it is important to understand that the values reported by the power meter and BeamGage may be asynchronous or synchronous depending upon the type of equipment in use and the way the equipment is configured. This means that the results assigned to each frame may or may not be temporally accurate. The next sections describe how these various scenarios can affect the validity of the reported results versus the data image associated with the results.

## 5.26.1 Thermopile Head Operations

Ophir high power heads are based on thermopile technology which, by design, has relatively slow response times. Generally, the larger the total power capability of the head, the slower the response, which can vary from approximately one second to tens of seconds, depending on the head.

Camera based beam profilers are generally faster in response, especially as the camera frame rate increases. As a result, values reported by the meter lag behind data collected by the camera. The faster and greater the magnitude of the power input change, the more noticeable the delay is between the meter and the camera display. Once a steady state condition is reached, the head and the camera can be said to be in close agreement.

Ophir power meters employ speedup algorithms that improve this response time significantly. However, the lag can still be a factor under the best of conditions.

If attempting to have BeamGage report accurate real-time power fluctuations, it is better to use the meter to manually calibrate BeamGage and use a well Ultracal'd setup. This type of setup remains quite accurate for power fluctuations in a range near 50:1.

If a larger dynamic range is needed, BeamGage can be run in Auto-X mode at the cost of 1:1 correlation of the data frames vs. the power reading, without trying to infer a temporal match between the image results and the precise power results being reported.

## 5.26.2 Photodiode Head Operations

As a purely electronic device, photodiodes can respond in near real time. Used in a power meter application they respond more slowly, as a trade-off between speed and dynamic range. Photodiodes have a much larger dynamic range than CCD cameras, and as a result the rate data is output from a typical meter is about 15-16 Hz. Like a camera, running at about the same frame rate, the recorded power readings should be a fairly close temporal match.

## 5.26.3 Pyroelectric Head Operation

Joule meter heads operate on short pulse widths and can record pulse energies at very high rep-rates. An energy meter can significantly outperform a BeamGage camera system when it comes to collecting pulse to pulse energy readings.

The meter can be either self-triggered (by the head) or externally triggered.

The camera must be externally triggered to collect stable images and the exposure time must be long enough to contain the entire pulse width.

The ability for a camera to split out laser pulses and record them in real time is limited by the camera frame rate. Some of the fastest cameras run at 60-100 Hz frame rates. However, not all can be triggered this fast.

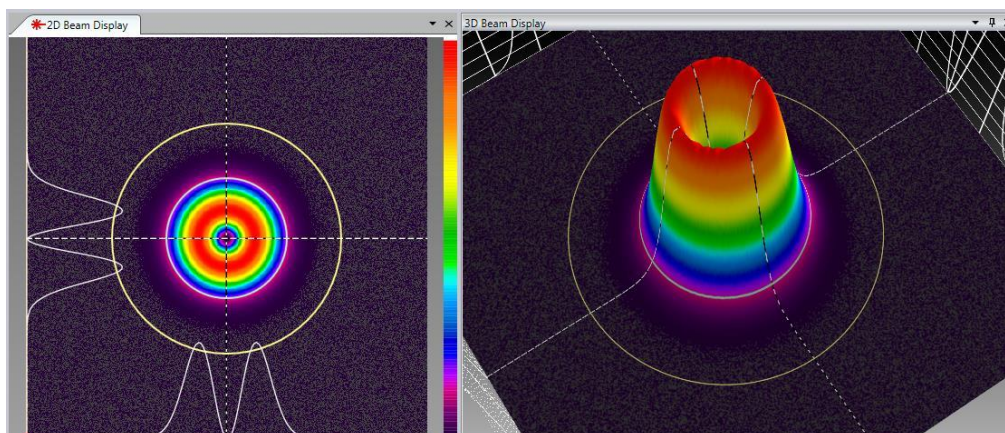
At pulse rates that exceed the camera frame rate, the exposure time can be set short enough so that only one pulse can be split out per captured frame. Of course, this means that not all pulses are being collected.

The opposite choice is to allow the camera to collect multiple pulses per frame. This has the effect of pulse summing a certain number of shots in the displayed frame. If the trigger rate is unstable, it could be possible that some frames may contain a different number of shots.

BeamGage can precisely match the output from a Pulsar to the exact camera frame up to about 100 Hz, or the frame rate of the triggered camera, whichever is less, but it cannot match rates of the Vega and Nova II if the pulse rates are much more than approximately 10 Hz. Even at these rates the syncing is not always a perfect match.

## 5.27 BeamMaker™ Application

The following example demonstrates how a Donut TEM<sub>01</sub>\* beam profile produces different beam width results using the different methods available in BeamGage. In this model, the SNR is set to 60dB which is a value that matches most of the better cameras running with well optimized beam attenuation. Beam intensity is set to 95% and no offset is applied. The beam shown below has an embedded Gaussian set to 100µm in both the X and the Y axial directions. An Auto aperture is employed to reduce noise effects in the wings by limiting the calculations to only the area inside the aperture. As a result, the correct second moment beam width/diameter for this beam is 141.42µm.



Only the X axis beam width, or the diameter, is shown in the following results.

As seen in these results, the second moment **D4σX** value is computing the second moment accurate to 4 significant digits. Some of the other methods are less accurate. Even those described as ISO methods can be seen to perform poorly. The **DkeX 16/84** method measures the beam larger, while the **DepssX 95.4** and **Depsa 86.5** methods report smaller beam widths/diameters, respectively.

Description	Value	Units
<b>D4σX ISO</b>	1.414e+02	um
<b>DkeX 10/90</b>	1.438e+02	um
<b>DkeX 16/84 ISO</b>	1.519e+02	um
<b>DkeX prog</b>	1.329e+02	um
<b>D%pk</b>	1.492e+02	um
<b>D%t</b>	1.314e+02	um
<b>Depss(X) 95.4 ISO</b>	1.294e+02	um
<b>Depsa 86.5 ISO</b>	1.325e+02	um

The **DkeX prog** result yields a very accurate result because the programmed settings for this have been set to 16/84 with a 1.86 multiplier, making it equivalent to the second moment for this pure donut mode input. Of course, a different setting would be optimum for a different mode or mode mix.



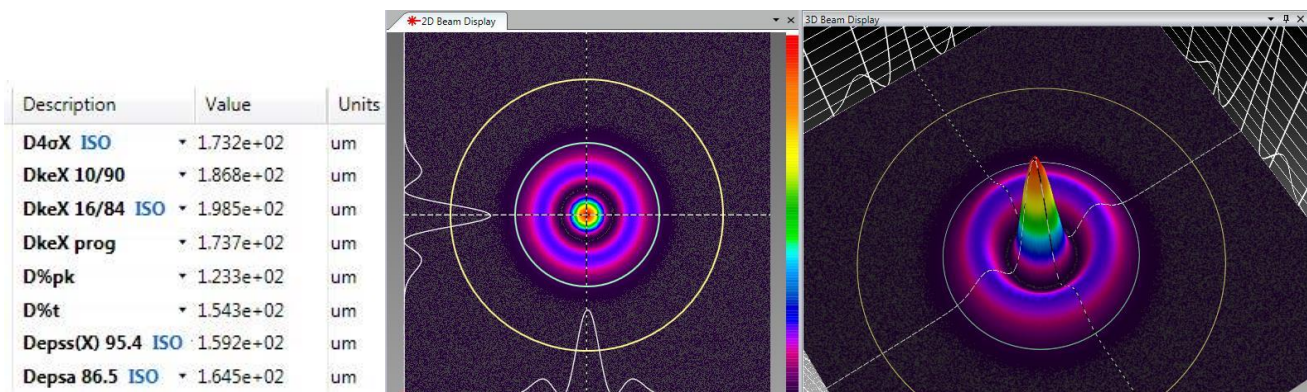
Method	Width/Dia.	% Error
<b>D4σX ISO</b>	141.4	---
<b>DkeX 10/90</b>	143.8	1.7
<b>DkeX 16/84 ISO</b>	151.9	7.4
<b>DkeX prog</b>	141.3	-.01
<b>D%pk</b>	149.2	5.5
<b>D%t</b>	131.4	-7.1
<b>D%msX ISO</b>	141.6	0.0
<b>DepssX 95.4 ISO</b>	129.4	-8.5
<b>Depsa 86.5 ISO</b>	132.5	-6.3

### Donut Beam Results

The accuracy of each of the above results is listed as compared to the second moment. Observe that the Ophir-Spiricon legacy 10/90 result is very close to the true second moment value, being high by about 1.7% in this example. This is why Ophir-Spiricon has employed this method in the past as it works well for many mode mixes.

Here's another example showing how results can vary based on the beam width method being employed. This beam model is of a Laguerre TEM<sub>10</sub> mode. The basic settings are as in the previous example. The multiplier for the **DkeX prog** has been changed to 1.75 in order to compute an equivalent D4σ result.

The M<sup>2</sup> of this mode is 3, resulting in a beam width of 173.2μm (3<sup>-2</sup> x 100μm). Observe the results shown below the beam profile.





Method	Width/Dia.	% Error
<b>D4σX ISO</b>	173.2	---
<b>DkeX 10/90</b>	186.8	7.9
<b>DkeX 16/84 ISO</b>	198.5	14.6
<b>DkeX prog</b>	173.7	.28
<b>D%pk</b>	123.3	-28.8
<b>D%ot</b>	154.3	-10.9
<b>D%msX ISO</b>	166.5	-3.9
<b>DepssX 95.4 ISO</b>	159.2	-8.1
<b>Depsa 86.5 ISO</b>	164.5	-5.0

#### Laguerre TEM<sub>10</sub> Results



*All BeamMaker data frames can be saved as .bgData files in the HDF5 format. They can be power/energy calibrated and exported into 3rd party applications to be used to perform additional analysis. The data file can be modified and reloaded into BeamGage as long as critical header parameters are not destroyed in the process.*

# Chapter 6 Partitioning

The Partitioning feature is available only in BeamGage Professional edition. Partitioning allows you to subdivide the camera imager into separate regions, called partitions, and compute separate beam results within each partition. When using partitioning, special results items can be displayed that relate to delta values between the computed centroids of each partition. When using partitions, some normally computed results may no longer have a useful meaning.

## 6.1 Partitioning Definitions and Rules

The full frame is the original input frame. Additional partitions can be created within the full frame. When partitions are created, special rules apply to both the content of each partition and to the full frame. The following apply when one or more partitions are created:

- The Origin location is set in the full frame and is global for all partitions.
- Partitions are always square or rectangular in shape and are always orientated on axis.
- Partitions appear as Orange apertures in the **2D Beam Display** window.
- Partitions are not visible in the **3D Beam Display** window or the 2D **Pan/Zoom** window.
- Partitions can overlap and be nested inside each other.
- The **Results** display window can only display the results of one partition at a time. The selected partition is highlighted in RED.
- The **Manual Aperture** is applied only to the full frame and has no effect on the results computed within the partitions.
- The **Auto Aperture** is applied only to the selected partition.
- The **Cursor** and **Crosshair** operate in the selected partition.
- **Power/Energy** calibration values are always applied to the data in the full frame.
- Computed results items are enabled on a global basis, i.e. a result item enabled/disabled in any partition is enabled/disabled in all partitions.
- Statistical results can be computed in partitions.

## 6.2 Partitioning Features and Results

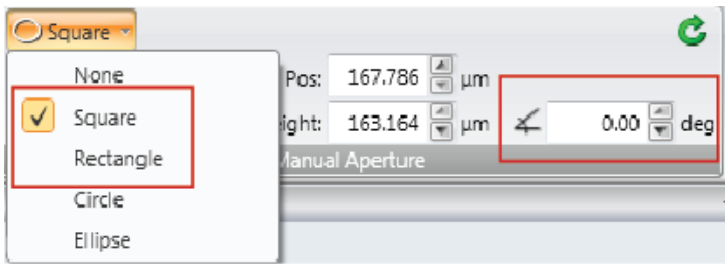
Results are individually computed for the content of each partition. Delta table results items are displacement measurements between either Centroids or Peaks located within each partition.

- Results from any partition can be dragged and dropped onto the display window.
- Individual Pass/Fail rules can be applied to partition results items.
- Linear Centroid to Centroid Deltas between partitions can be displayed in a Partition table.
- Linear Peak to Peak Deltas between partitions can be displayed in a Partition table.



*The number of partitions and the number of computations being performed within each partition has a slowing effect on the overall performance. The worst case scenario would occur if whole beam Gauss fits were being performed within each partition.*

## 6.3 Partition Creation



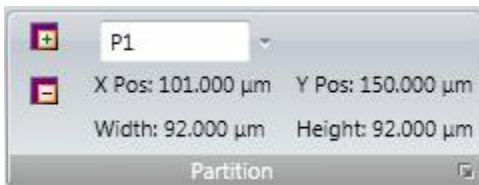
All partitions begin as a drawn manual aperture. Partitions must be either square or rectangular in shape. Also, since partitions must be drawn on axis, the rotation angle for the manual aperture should always be set to 0 degrees.


If the position of the aperture is important relative to a defined origin location then be sure to set the Origin to the desired location. This can be changed later, but if you want to locate centroids relative to a fixed spatial position, it may be a good idea to fix this position at the start of the process.

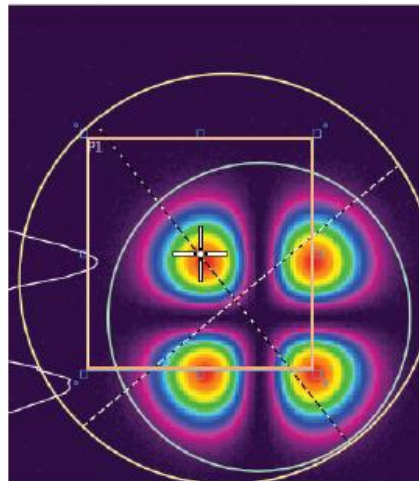
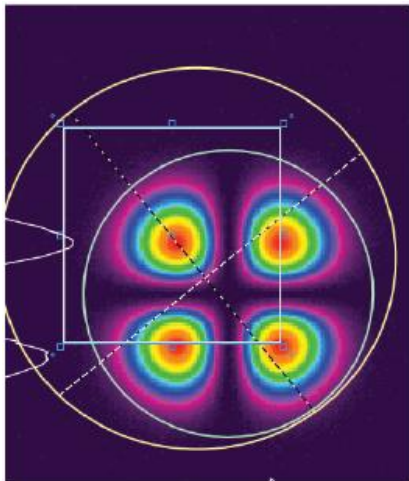
To create a partition, begin by using the **Manual Aperture** Design tool. Create the aperture with the location and size required. For precise placement vs. a fixed origin position, use the numerical edit controls in the **Manual Aperture** panel.



*For the most accurate beam width measurements, set the apertures to  $\sim 2x$  the expected beam width size.*




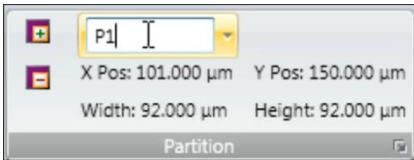
Use the **Partition** panel to convert the Manual Aperture into a Partition by clicking on the **Add Partition**  button.



An orange partition is created with the same location and size as the manual aperture and a partition label appears in its upper left-hand corner. The Manual Aperture is active and can be repositioned to create the next partition. Repeat the above process until all partitions have been created.

Partitions are assigned labels starting with P1, P2, P3 ...etc. There is no limit to the maximum number of partitions that can be created.

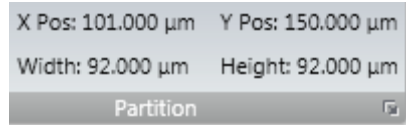
Partitions cannot be revised once created so it is important to use care and define them correctly. The only way to correct a partition is to delete it and recreate it. To delete a partition select it from the drop-down, and select the **Remove Partition**  button.



The **Partition** labels may be replaced with a user assigned alias. Select the partition that you wish to rename from the drop-down list. Click the partition name, type in the new name, and hit the **Enter** key.

The new partition name appears as the partition label and at all locations where the partition is identified. Brevity in selection of the alias is its own reward. Partitions cannot have the same name. The list shows the partitions in the order they were created.

The location and size of the selected partition is displayed as shown where X Pos and Y Pos are the center coordinates of the partition.



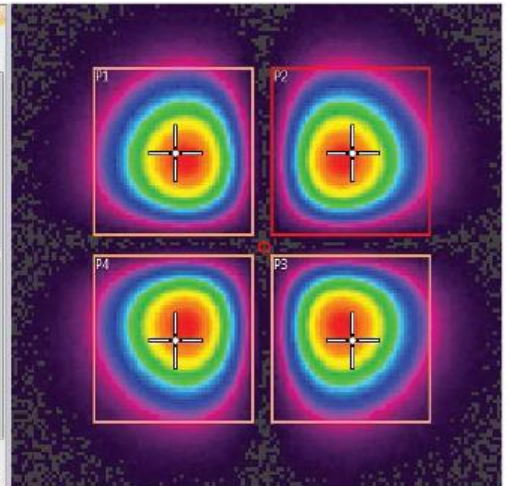
To place the partition crosshair at the center of the partition, copy the X/Y values into the crosshair table explained in the following section.

## 6.4 Partition Results

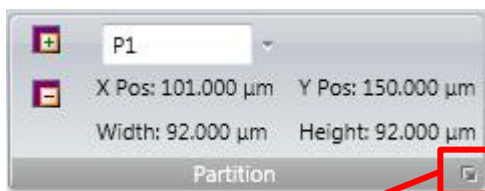
The **Results** window can only display the computed results of one partition at a time. This constraint is due to space restrictions, especially if a large number of partitions are in use and more so when statistics are being computed. Select which partition is displayed using the **Partition** panel.

This example shows the results for partition P2 and its related display frame.

Name	Value	Units
Power/Energy ~		
Total Power ISO	2.235e+00	W
Peak Fluence ISO	3.356e-03	W/um <sup>2</sup>
Minimum Fluence	2.475e-06	W/um <sup>2</sup>
Spatial ~		
Centroid X ISO	2.421452e+01	um
Centroid Y ISO	2.507711e+01	um
D4σX ISO	3.826e+01	um
D4σY ISO	3.788e+01	um
D4σ ISO	3.807e+01	um
Divergence ~		
Gaussian ~		
TopHat ~		
Frame Info ~		
1.D Gaussian ~		
1.D TopHat ~		



Notice the selected partition is highlighted in RED. The crosshair in each partition is user controlled. The crosshair can be moved to a new position with the mouse or can be numerically positioned using the expanded controls option that appears when a partition is created.



To numerically position the crosshair, click on the expand button. A coordinate table of the displayed Partition Crosshairs appears as shown. You can use the check box to turn the individual partition crosshairs ON or OFF, and manually enter the position that you want the crosshair to occupy.

Partition	X-Pos	Y-Pos	Units
<input checked="" type="checkbox"/> P1	-4.017e+01	4.048e+01	um
<input checked="" type="checkbox"/> P2	3.958e+01	3.987e+01	um
<input checked="" type="checkbox"/> P3	3.885e+01	-4.088e+01	um
<input checked="" type="checkbox"/> P4	-3.847e+01	-4.088e+01	um

OK Cancel



*A partition's crosshair cannot be located outside of the partition boundary.*

## 6.5 Partition Delta Results

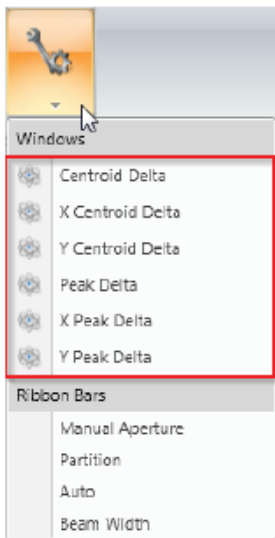
Peak Delta				
	P4	P3	P2	P1
P4	-----	6.401e+01	8.981e+01	6.503e+01
P3	6.401e+01	-----	6.400e+01	9.055e+01
P2	8.981e+01	6.400e+01	-----	6.203e+01
P1	6.503e+01	9.055e+01	6.203e+01	-----

One of the most common applications for partitioning is to compare the alignment of multiple beam spots to a fixed set of spatial coordinates and/or to each other. This is usually done by checking the spacing between the partitioned spot centroids or peaks.

To make this easier, a new type of results window is provided. These are called **Delta Centroid** and **Delta Peak** tables and are enabled by using the **Tools** panel in the **Aperture** ribbon. They can display either straight line distance deltas or X/Y axis deltas. All values in the table are the results of subtracting the values found in each partition with the values in all the other partitions. This example shows the linear distance displacements between Peak values in each of the partitions found in the image in the previous section.

The number format of the values is the same as selected in the **Display Options** for the entire **Results** window. See section 2.6.7.3.1 for more details.

Six possible variations can be computed and displayed based on the user's preference:



### Centroid Delta

Straight line centroid to centroid delta values

### X Centroid Delta

X axial direction centroid to centroid delta values

### Y Centroid Delta

Y axial direction centroid to centroid delta values

### Peak Delta

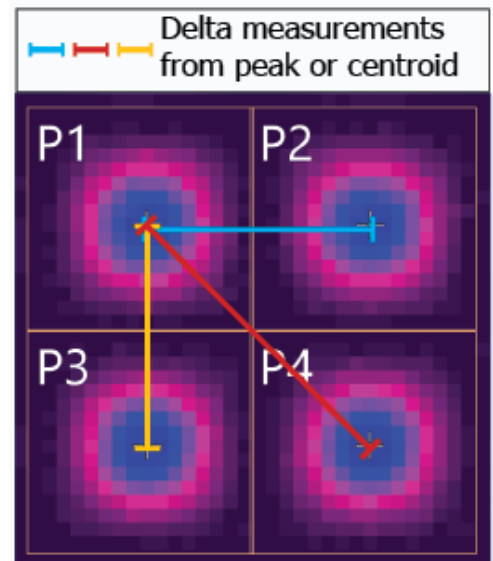
Straight line peak to peak delta values

### X Peak Delta

X axial direction peak to peak delta values

### Y Peak Delta

Y axial direction peak to peak delta values







*All X/Y Delta distances are computed on axis and are not compatible with using one of the off-axis features in BeamGage. To achieve stable and meaningful results, all of the off-axis results items (Orientation, Ellipticity, and Eccentricity) should remain disabled. Straight line delta distances are not affected if off-axis results are enabled.*


Y Centroid Delta (Pixels)				
	P2	P1	P3	P4
P2	-----	0.003179	15.981217	15.967329
P1	0.003179	-----	15.978037	15.964150
P3	15.981217	15.978037	-----	0.013887
P4	15.967329	15.964150	0.013887	-----

X Centroid Delta (Pixels)				
	P2	P1	P3	P4
P2	-----	15.976576	15.967618	0.004595
P1	15.976576	-----	0.008958	15.971981
P3	15.967618	0.008958	-----	15.963023
P4	0.004595	15.971981	15.963023	-----

Centroid Delta (Pixels)				
	P2	P1	P3	P4
P2	-----	1.598e+01	2.259e+01	1.597e+01
P1	1.598e+01	-----	1.598e+01	2.258e+01
P3	2.259e+01	1.598e+01	-----	1.596e+01
P4	1.597e+01	2.258e+01	1.596e+01	-----

## 6.6 Partitions and Logging

When logging results with partitions, the results of each partition can be separately entered into its own log file.

Click on the **Logging** control panel's **Log Results**  drop-down to see a list of partitions to enable for logging. When statistics are enabled they appear at the end of the log file in the normal fashion.

## 6.7 Partition Cautions

Because all the features are not cloned within partitions, some results items and displays may not work in as meaningful a manner as before. A few of these are discussed in this section.

### 6.7.1 Partitioning and Cursor/Crosshair Operations

The 2D and 3D main display window cursors and crosshair operate in the selected partition. If the mode of operation is to track the peak or centroid, it does so within the boundary of the selected partition. If an **Auto** and/or **Manual Aperture** is enabled, however, it follows the normal aperture application rules for the full frame.

### 6.7.2 Partitioning with Beam Profiles

While the beam profile displays continue to be available, there is only one set of common cursors for all the partitions. The beam profiles are created from the cursor and are restricted to the boundaries of the enabled partition. However, if partitions overlap, the usefulness of the beam profiles may be limited.

### 6.7.3 Partitioning with Positional Stability

**Positional Stability** results are also available when partitioning. However, the stability plot and result are performed on the content of the full frame and is not assignable to the content of any one partition.



You may apply a manual aperture onto one of the partitioned regions, and this limits the stability results to just that one region. However, this also reduces all of the full frame results to this one region, which may complicate your ability to calibrate power/energy and monitor the entire frame.

## 6.7.4 Partitioning with Histogram

As with Positional Stability, the Histogram display operates only upon the content of the full frame. Adding a **Manual** or **Auto Aperture** further restricts the data content of the histogram, but this may adversely affect other full frame results calculations.

# Chapter 7 Custom Calculations

BeamGage Professional provides a custom calculation ability which allows users to program their own set of calculations. Because of the high technological background required to successfully operate custom calculations, it is recommended that the user has the following minimum skill set:

- A minimum BS degree in Computer Science, Computer Engineering, or equivalent.
- Demonstrated proficiency in writing programs in Microsoft Visual Basic, and/or C++ and/or C#
- Review Ophir-Spiricon's Automation Documentation (see 8.4 below). If you do not know immediately what this means and how to use it, we strongly recommend that you contract a consulting LabVIEW developer to design your company's automation client.

## 7.1 Documentation

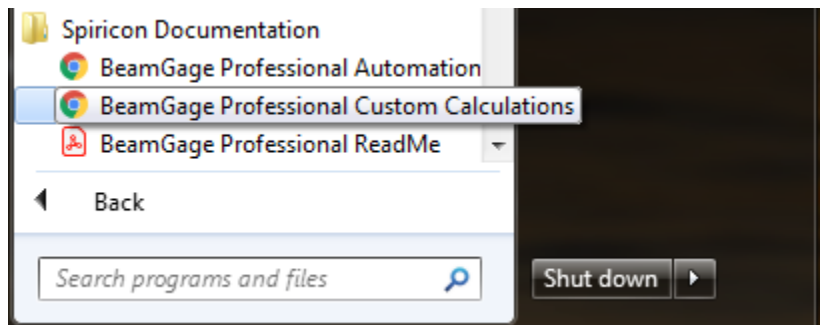
The custom calculations reference documentation is presented via html. The html provides cross-referenced access to all interfaces, functionality, and examples provided for custom calculation development and application. The **BeamGage Custom Calculations** may be accessed via the following link:

[Custom Calculations Documentation](#)

-or-

Via the start menu shortcut as shown:

**Start -> All Programs -> Spiricon  
Documentation -> BeamGage  
Professional Custom Calculations**



# Chapter 8 Automation Interface

BeamGage Professional provides an automation interface via .NET components to allow customers the ability to build custom applications that incorporate the laser beam analysis and processing power of BeamGage. The BeamGage automation interface allows developers to control BeamGage programmatically via a set of “puppet strings” known as the automation interface. The automation interface was developed to provide the ability to base control decisions for a second application on results and behaviors recognized by BeamGage. With this ability, users can quickly and efficiently meet their manufacturing/analysis goals with minimum human interaction.

## 8.1 Introduction

The BeamGage automation interface was designed to achieve two main goals. First, to allow the BeamGage user to programmatically do what they could otherwise do via the graphical user interface (GUI). Second, to expose stable interfaces to the user that will not change, causing breaks to their dependent code. In order to facilitate these goals, it is important that the user be given stable abstractions to program against. It is likewise important to allow BeamGage to evolve as new features are added. Ophir-Spiricon is dedicated to protect users from changes in underlying implementation as BeamGage evolves. To this end, the BeamGage automation interface is presented as a set of interfaces that collectively expose the functionality of the application. Access to these various interfaces is provided by creating one concrete class known as AutomatedBeamGage. From AutomatedBeamGage, the user can create and destroy several instances of the BeamGage application.

## 8.2 Automation Design Skill Set

Over the years, Ophir-Spiricon has learned that to design a proper automation client for products similar to BeamGage requires a skill level comparable to that of a degreed and experienced computer programmer. Even with this background, a learning curve is necessary to achieve an acceptable level of competency. Very often Ophir-Spiricon’s service and engineering departments are contacted by individuals that are assigned to design an automation interface, but lack a sufficient technical background. To assist your company in making a good employee fit for this type of work, we offer the following guidelines for the minimal skill sets needed.

### **To interface with LabVIEW you need:**

- An understanding of .NET programming methods.
- An understanding of LabVIEW .NET Connectivity objects.
- Prior, and recent, experience designing and deploying National Instruments LabVIEW VI’s in an automation environment.
- Review Ophir-Spiricon’s Automation Documentation (see 8.4 below). If you do not know immediately what this means and how to use it, we strongly recommend that you contract a consulting LabVIEW developer to design your company’s automation client.

### **To interface with a program written in Visual Basic (VB), C++, or C# you need:**

- A minimum BS degree in Computer Science or Computer Engineering, or equivalent.
- Three (3) or more years of software design experience using Microsoft Visual Studio design and debugging tools.
- Demonstrated proficiency in writing programs in Microsoft Visual Basic, and/or C++, and/or C#
- A background in .NET programming methods

- Review Ophir-Spiricon's Automation Documentation (see 8.4 below). If you do not know immediately what this means and how to use it, we strongly recommend that you contract a consulting software engineer to design your company's automation client.

## 8.3 Evolution of Ophir-Spiricon's Automation Interface

Ophir-Spiricon's older products used COM and ActiveX to provide an automation interface. More recent technologies, like .NET, provide more fully featured functionality. Recent developments in remoting technologies allow nearly transparent interaction between machines on the same domain. This allows the user to leverage more than one machine while using BeamGage for analysis. COM remote operation is more difficult to use and setup when compared to its .NET counterpart. For this reason, the BeamGage automation interface was developed using Microsoft's .NET infrastructure. Any .NET application should easily integrate and be able to interact with the core functionalities provided by BeamGage.

## 8.4 Documentation

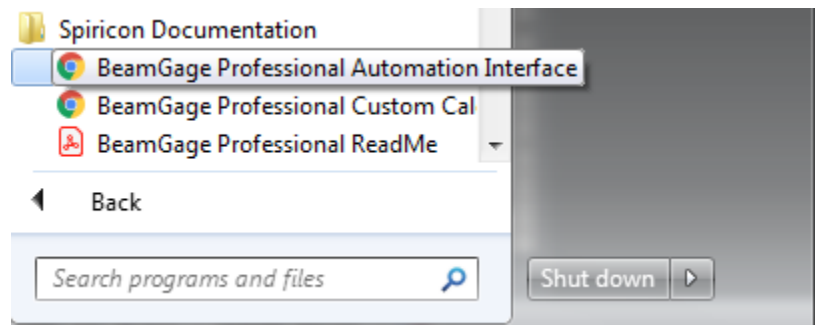
The Automation API reference is presented via html. The html reference provides cross-referenced access to all interfaces and functionality provided for automation application development. The **BeamGage Automation API** may be accessed via the following link:

[Automation Documentation](#)

-OR-

Via the start menu shortcut as shown:

**Start -> All Programs -> Spiricon Documentation -> BeamGage Professional Automation Interface**



### 8.4.1 Examples

Examples of simple automation applications in LabVIEW and Visual Basic .NET are provided. For step-by-step walkthroughs click on the appropriate link:

[Setup \(LabVIEW\)](#)

[Setup \(VB\)](#)

-OR-

By navigating to the files located at:

**C: -> Program Files -> Spiricon -> BeamGage Professional -> Automation -> Documentation**

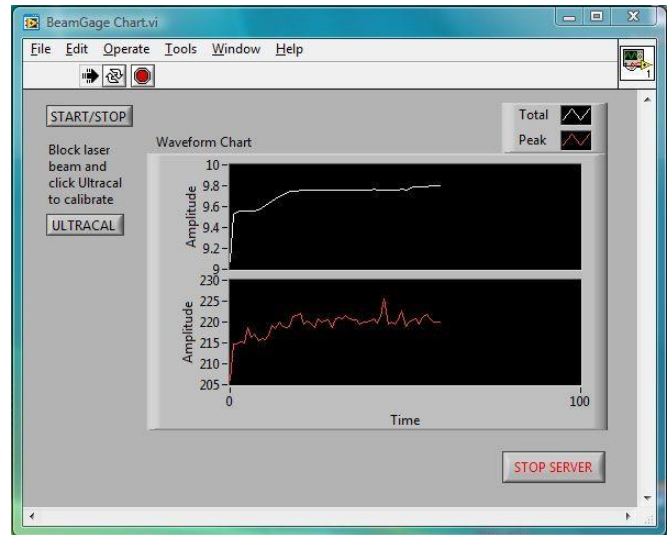
## 8.4.2 Operating the LabVIEW Example

The **TotalPeakExample** opens with the shown LabVIEW VI, and it will also open, connect to, and run BeamGage. When BeamGage opens it starts with the setup file last saved. If that setup connects to an available source, the **Total Power** and **Peak Fluence** values will plot in the displayed charts.

The **START/STOP** button will cause BeamGage to start and stop collecting data. The **ULTRACAL** button will cause BeamGage to perform an **Ultracal** cycle.

To close the LabVIEW example and BeamGage you must, in the following order:

1. Click on the **Stop Server** button to close BeamGage.
2. Close the VI.



*BeamGage must be closed using the **Stop Server** button. It cannot be closed normally once this VI is closed. If you close the VI without first closing BeamGage with the **Stop Server** button, then the only way you will be able to close BeamGage will be by rebooting the PC.*



*When BeamGage is launched from an automation client, it can only be properly closed by that same client. Thus, it must be closed before the client is closed. Keep this in mind when designing your own client application.*

# Chapter 9 Troubleshooting

System Troubleshooting		
Symptoms	Cause	Resolution
General Errors		
Error Message: "The Spiricon Console Service is unavailable on the computer."	The service is not running.  Spiricon.ConsoleService.exe is a required service process for all BeamGage products.	If possible, restart the service with the Windows Service Manager, otherwise reboot the computer to restart the service.
	The console service communication ports are in-use or blocked.	Ensure that TCP ports 10100-11100 are available. If in use by another application, the port range may be customized by modifying PortFinder.config.xml (found in the BeamGage installation directory) and restarting the service.
	The environment required to run the service may be corrupt. In some cases this may happen due to a failed installation/upgrade of the software.	Uninstall all BeamGage products and install the latest version.
Error Message: "Data Source Unavailable"	If received when selecting a data source, BeamGage was unable to connect to the camera.	Please contact Ophir-Spiricon Customer Service for assistance.
	If received after selecting a data source, e.g. during data acquisition or changing camera settings, then the data source process has or will likely crash.	Please contact Ophir-Spiricon Customer Service with details of the behavior that caused the crash.
What's This Help doesn't open to the correct topic in Adobe Reader.	In Adobe Reader X and later, a security feature called "Protected Mode", can prevent an external application from accessing a PDF document's bookmarks correctly.	Disable Protected Mode in Adobe reader.  For more details, go to <a href="http://www.ophiropt.com/laser-measurement-instruments/beam-profilers/knowledge-center/tech-tips/beamgage-adobe-reader">http://www.ophiropt.com/laser-measurement-instruments/beam-profilers/knowledge-center/tech-tips/beamgage-adobe-reader</a>  If the behavior persists, try opening the User Guide separately and making the selection with the <b>What's This</b> cursor a second time.



# System Troubleshooting

Symptoms	Cause	Resolution
<b>SP Model Cameras</b>		
<b>CANNOT</b> connect to an SP620U or SP503U camera, <b>CAN</b> connect to the BeamMaker or File Console data sources.	Camera may not be connected or USB cable is defective.	<p>Verify cable connection between the camera and the computer.</p> <p>Verify that the device is recognized in Windows Device Manager.</p>
	A powered USB 2.0 high-speed port and cable may not be in-use.	Ensure camera is connected to a USB 2.0 high-speed port, power savings modes are disabled, and the cable in use is certified for use with USB 2.0 high speed devices.
	A conflicting webcam may be installed.	<p>Disable the webcam hardware in the system BIOS.</p> <p>If disabling the webcam hardware did not solve the problem on its own, locate and uninstall the preloaded software/drivers used to operate the webcam.</p>
<b>Pyrocam Model Cameras</b>		
Cannot find the Pyrocam III in BeamGage using Windows 7.	The proper FireWire Bus Host Controller driver may not be installed.	<p>The Pyrocam III camera driver requires the Windows 7 "1394 OHCI Compliant Host Controller (Legacy)" driver. If using the FireWire adapter card supplied with the camera system then this should be installed automatically by the Spiricon Camera Driver Manager found in the start menu.</p> <p>If using a FireWire adapter card other than what is supplied, please go to:</p> <p><a href="http://www.ophiropt.com/laser-measurement-instruments/beam-profilers/knowledge-center/tech-tips/installing-the-pyrocam-iii">http://www.ophiropt.com/laser-measurement-instruments/beam-profilers/knowledge-center/tech-tips/installing-the-pyrocam-iii</a></p>

System Troubleshooting		
Symptoms	Cause	Resolution
Other Camera Models		
Cannot find the camera when selecting a Local Detector.	Camera may not be connected or USB cable is defective.	<p>Verify cable connection between the camera and the computer.</p> <p>Verify that the device is recognized in Windows Device Manager.</p>
	Ensure the proper drivers are installed for the camera you are using.	<p>Locate the shortcut for the Spiricon Camera Driver Manager in the Windows Start Menu. Run the driver manager and follow the instructions to install the drivers for your camera.</p>

# Appendix A ISO Computations Table

This table of ISO computations follows the labeling and notions found in the ISO standards. Where differences exist within the standards, no particular preference is given to any one notation. The information contained here may not always agree with the latest releases of the individual standards; however Ophir-Spiricon will update it from time to time as the ISO standards evolve. The Section numbers in the list may also break when ISO standards are reformatted. The ordering of the items follow no particular sequence and no importance should be attached to the item #.



*The symbols and names listed here may or may not agree with the notations used in BeamGage. These notations may be slightly modified for the purpose of maintaining consistency in labeling within BeamGage and standard industry and legacy usage. Not all listed results are currently provided in BeamGage.*

( ) shall contain one of the following symbols<sup>1</sup>

u = a measurement based upon a percentage of power/energy, usually an encircled amount or contained by a smallest slit. The value u shall be replaced with an amount, such as 90 to represent 90%.

$\sigma$  = a measurement based on second moment definitions

k = a measurement based on a Knife Edge measurement, usually a 10/90 percent of energy<sup>2</sup>

Item #	Symbol	Name	ISO 11145	ISO 11146	ISO 11670	ISO 13694	ISO 15367	Section	Definition
1	$A_{()}$ $A_{\sigma}(z)$	beam cross-sectional area	x			x		3.2.1 3.2.2 3.2.6	Area bounded by the beam width definition ( ) for circular beams $A_{\sigma} = \pi \frac{d_{\sigma}^2}{4}$ for elliptical beams $A_{\sigma} = \pi \frac{d_{\alpha} d_{\sigma}}{4}$
2	$d_{()}$	beam diameter	x	1				3.3.1 3.3.2 3.3	Smallest aperture or second moment diameter of a circular beam. beam diameter (second moment) $d_{\sigma}(z) = 2\sqrt{2\sigma(z)}$ where :

<sup>1</sup> The ISO procedures typically refer to two types of beam diameter/width measurements; second moment, and encircled energy. When dealing with elliptical beams, the encircled energy method is modified to a minimum slit technique, where for a circular Gaussian distribution, 95.4% of the energy contained in a slit is equal to the second moment width. Also in dealing with elliptical beams, the direction of variable slit orientation is described as being in the "preferential directions"... see ISO 11145 sec 3.5.1. While the "preferential directions" are rather loosely defined, one can surmise that the later described azimuth directions can be used in its place... see ISO 11146-1 sec 7.2.

<sup>2</sup> The Knife Edge measurement technique is mentioned in ISO 13694 sec 3.2.4 d. It is not given much attention in the ISO documentation. However, it is a valuable measurement technique when correctly applied.

Item #	Symbol	Name	ISO 11145	ISO 11146	ISO 11670	ISO 13694	ISO 15367	Section	Definition
									$\sigma^2 = \frac{\iint r^2 \cdot E(r, \varphi, z) \cdot r \cdot dr d\varphi}{\iint E(r, \varphi, z) \cdot r \cdot dr d\varphi}$ <p>where  r is the distance from the centroid  <math>(\bar{x}, \bar{y})</math>  <math>\varphi</math> is the azimuth angle  and where the first moments give the coordinates of the centroid</p> $\bar{x} = \frac{\iint x E(x, y, z) dx dy}{\iint E(x, y, z) dx dy}$ $\bar{y} = \frac{\iint y E(x, y, z) dx dy}{\iint E(x, y, z) dx dy}$
3	$w()$	beam radius	x					3.4.1 3.4.2	Half a beam diameter. See above.
4	$d_{\sigma x} \ d_{\sigma y}$ $d_{x,k} \ d_{y,k}$ $d_{x,u} \ d_{y,u}$	beam widths... second moment  knife edge  smallest aperture	x	1		x		3.5.2 3.5.1  3.2  3.2.4	Second moment, knife edge, or smallest slit methods beam widths (second moment) $d_{\sigma x}(z) = 4\sigma_x(z)$ $d_{\sigma y}(z) = 4\sigma_y(z)$ knife edge, 90/10% method smallest slit method
5	$M^2$	beam propagation ratio	x	1				3.7  3.4	Measure of how close the beam is to the diffraction limit of a perfect Gaussian beam. $M^2 = \frac{\pi d_{\sigma 0} \Theta_{\sigma}}{4\lambda}$
6	$d_{0,u} \ d_{\sigma 0}$	beam waist diameter	x					3.11.1	Beam diameter measurements performed at the waist.
7	$d_{x0,k} \ d_{y0,k}$ $d_{\sigma x0} \ d_{\sigma y0}$	beam waist widths	x					3.13.1 3.13.2	Beam width measurements performed at the waist.
8	$\eta_T$	device efficiency	x					3.17	Ratio of the total power/energy in the beam to the total input power/energy.
9	$\Theta_{()} \ \Theta_{x()}$ $\Theta_{y()}$	divergence angle	x	1				3.18  5.2	Full angle of the far-field envelope formed by the increasing beam diameter or widths. $\Theta_{\sigma} = \frac{d_{\sigma, fl}}{fl}$ <p>Where <math>fl</math> is the focal length of a focusing optic and <math>d_{\sigma, fl}</math> is the beam diameter at the</p>

Item #	Symbol	Name	ISO 11145	ISO 11146	ISO 11670	ISO 13694	ISO 15367	Section	Definition
									focus.
10	H <sub>0</sub>	average energy density	x					3.20	Total energy of a beam divided by its cross sectional area.
11	Q Q(z)	pulse energy	x			x		3.21 3.1.4 9.2.2	Energy in one pulse... at location z.    Joules $Q(z) = \iint H(x, y, z) dx dy$
12	H(x,y) H(x,y,z)	energy density	x			x		3.22 3.1.2	Energy impinging on a specified area x,y at location z, divided by the area δA. Often referred to as fluence at a specific pixel location, and peak fluence. $H(x, y, z) = \int E(x, y, z) dt$
13	E <sub>0</sub>	average power density	x					3.43	Total power of a beam divided by its cross sectional area.
14	P P(z)	CW power	x			x		3.44 3.1.3 9.2.2	Power output of a CW laser... at location z.    Watts $P(z) = \iint E(x, y, z) dx dy$
15	E(x,y) E(x,y,z)	power density	x			x		3.45 3.1.1	Power impinging on a specified area x,y at location z, divided by the area δA. Often referred to as fluence at a specific pixel location, and peak fluence.
16	P <sub>H</sub>	pulse power	x					3.46	Ratio of the pulse energy Q to the pulse duration τ <sub>H</sub> .
17	P <sub>av</sub>	average power	x					3.47	Product of the average pulse energy Q and the pulse repetition rate.
18	P <sub>pk</sub>	peak power	x					3.48	Maximum of the power-time function.
19	τ <sub>H</sub>	pulse duration	x					3.49	Time between the half peak power points at the leading and trailing edges of the pulse.
20	τ <sub>10</sub>	10% pulse duration	x					3.50	Same as above except at the 1/10 <sup>th</sup> of peak levels.
21	η <sub>Q</sub>	quantum efficiency	x					3.52	Ratio of the energy of a single laser photon to the energy of a single pumping photon.
22	z <sub>R</sub> ,    z <sub>Rx</sub> z <sub>Ry</sub>	Rayleigh length	x					3.53	Distance from the waist where the beam is √2 times larger than at the waist. for the Gaussian fundamental mode: $z_R = \pi \frac{d_{\sigma 0}^2}{4\lambda}$ Generally the formula $z_R = \frac{d_{\sigma 0}^2}{\Theta_{\sigma}}$ is valid.
23	z <sub>0</sub> ,	beam waist		1				3.1	Position where beam widths reach their

Item #	Symbol	Name	ISO 11145	ISO 11146	ISO 11670	ISO 13694	ISO 15367	Section	Definition
	$Z_{0x} \ Z_{0y}$	location							minimum values along the axis of prop.
24	$M_{eff}^2$	effective beam propagation ratio		1				3.5	For simple astigmatic beams $M_{eff}^2 = \sqrt{M_x^2 M_y^2}$
25	$\varphi$	azimuth angle		1 3				4.3 7.2 9.3	The angle that the beam's axis system (major axis) makes with respect to the laboratory (camera) axis system. (see equations in ISO reference sections)
26	$\alpha_x$ $\alpha_y$	angular movement			x			3.1	Angular movement of the beam in the x-z and y-z planes. Requires a focusing element.
27	$\delta\alpha_x$ $\delta\alpha_y$	beam angular stability			x			3.2 8.2	Twice the standard deviation of the measured angular movement. $\delta\alpha_x = \frac{2s_{\zeta_x}}{fl}$ $\delta\alpha_y = \frac{2s_{\zeta_y}}{fl}$ $\delta\alpha = \frac{\sqrt{2}s_{\zeta}}{fl}$ <p>Where <math>s</math> is the angular standard deviation of the energy/power distribution and <math>fl</math> is the focal length of the focusing optic.</p>
28	$a_x$ $a_y$	transverse displacement			x			3.4	Distance of transverse displacement of the beam in the x and y directions.
29	$\Psi$	azimuth angle <sup>3</sup>			x			4.2 8.1c	The angle that the major axis of the asymmetric centroid histogram plot makes with respect to the laboratory (camera) axial system. (see Figure 1 in the ISO reference)
30	$\Delta(z')$ $\Delta_x(z')$ $\Delta_y(z')$ $\Delta(z)$ $\Delta_x(z)$ $\Delta_y(z)$	beam positional stability			x			3.5 8.1	Maximum transverse displacement and/or angular movement of the beam away from an average, steady-state position. $\Delta(z) = 2\sqrt{2}s$ $\Delta_x(z) = 4s_x$ $\Delta_y(z) = 4s_y$ <p>Where <math>s</math> is the standard deviation of the energy/power distribution.</p>
31	$x' \ y' \ z'$	laboratory system			x			4.2	The orthogonal coordinate system of the laboratory (camera) system.
32	$x \ y \ z$	beam axis system			x			4.2	A second coordinate system that defines the axes of the laser beam.

<sup>3</sup> The asymmetric beam axis distribution should not be confused with the asymmetric beam power/energy distribution function.



Item #	Symbol	Name	ISO 11145	ISO 11146	ISO 11670	ISO 13694	ISO 15367	Section	Definition
33	$E_{\max}(z)$ $H_{\max}(z)$	maximum power/energy density				x		3.1.5	Maximum of the spatial power/energy density distribution function $E(x,y,z)/H(x,y,z)$ at location $z$ . Peak fluence.
34	$(x_{\max}, y_{\max}, z)$	location of the maximum				x		3.1.6	Location of $E_{\max}(z)/H_{\max}(z)$ in the x-y plane at $z$ .
35	$E_{\eta T}(z)$ $H_{\eta T}(z)$	threshold power/energy density				x		3.1.7	A fraction $\eta$ of the max power/energy density at location $z$ . for CW-beams: $E_{\eta T}(z) = \eta E_{\max}(z)$ for pulsed beams: $H_{\eta T}(z) = \eta H_{\max}(z)$ where: $0 \leq \eta < 1$
36	$P_{\eta}(z)$ $Q_{\eta}(z)$	effective power/energy				x		3.2.1	Evaluated by summing only over locations $(x,y)$ for which: $E(x,y) > E_{\eta T}$ $H(x,y) > H_{\eta T}$
37	$f_{\eta}(z)$	fractional power/energy				x		3.2.2	Fraction of the effective power/energy to the total power/energy at location $z$ . $f_{\eta}(z) = \frac{P_{\eta}(z)}{P(z)}$ $f_{\eta}(z) = \frac{Q_{\eta}(z)}{Q(z)}$ where: $0 \leq f_{\eta}(z) \leq 1$
38	$(\bar{x}, \bar{y})$	centroid position				x		3.2.2	First linear moments at location $z$ .
39	$\xi(z)$ $e(z)$	beam ellipticity/eccentricity				x		3.2.5	Method for quantifying the circularity or squareness (aspect ratio) of a distribution at $z$ . ellipticity: $\xi(z) = \frac{d_{\sigma y}}{d_{\sigma x}}$ eccentricity: $e(z) = \frac{\sqrt{d_{\sigma x}^2 - d_{\sigma y}^2}}{d_{\sigma x}}$
40	$A_{\eta}^i(z)$	effective irradiation area				x		3.2.7	Irradiation area at location $z$ for which the power/energy density exceeds the threshold density.
41	$E_{\eta}(z)$	effective avg.				x		3.2.8	Spatially averaged power/energy density of

Item #	Symbol	Name	ISO 11145	ISO 11146	ISO 11670	ISO 13694	ISO 15367	Section	Definition
	$H_{\eta}(z)$	power/energy density							<p>the distribution at location z, defined as the weighted mean. effective average power:</p> $E_{\eta}(z) = \frac{P_{\eta}}{A_{\eta}^i}$ <p>effective average energy:</p> $H_{\eta}(z) = \frac{Q_{\eta}}{A_{\eta}^i}$
42	$F_{\eta}(z)$	flatness factor				x		3.2.9	<p>Ratio of the effective average power/energy density to the maximum power/energy density at location z. flatness factor:</p> $F_{\eta}(z) = \frac{E_{\eta}}{E_{\max}}$ $F_{\eta}(z) = \frac{H_{\eta}}{H_{\max}}$ <p>for: <math>0 &lt; F_{\eta} \leq 1</math></p>
43	$U_{\eta}(z)$	beam uniformity				x		3.2.10	<p>Normalized RMS deviation of power/energy density from its avg. value at location z. beam uniformity for CW-beams:</p> $U_{\eta} = \frac{1}{E_{\eta}} \sqrt{\frac{1}{A_{\eta}^i} \iint [E(x, y) - E_{\eta}]^2 dx dy}$ <p>beam uniformity for pulsed beams:</p> $U_{\eta} = \frac{1}{H_{\eta}} \sqrt{\frac{1}{A_{\eta}^i} \iint [H(x, y) - H_{\eta}]^2 dx dy}$ <p>Note: <math>U_{\eta}=0</math> for a flat top beam.</p>
44	$U_p(z)$	plateau uniformity				x		3.2.11	<p>For distributions having a nearly flat-top profile. plateau uniformity for CW-beams</p> $U_p(z) = \frac{\Delta E_{FWHM}}{E_{\max}}$ <p>plateau uniformity for pulsed beams</p> $U_p(z) = \frac{\Delta H_{FWHM}}{H_{\max}}$ <p>Note: <math>0 &lt; U_p(z) &lt; 1</math>; <math>U_p(z) \rightarrow 0</math> as</p>

Item #	Symbol	Name	ISO 11145	ISO 11146	ISO 11670	ISO 13694	ISO 15367	Section	Definition
									distributions become more flat-topped.
45	s(z)	edge steepness				x		3.2.12	<p>Normalized difference between effective irradiation areas of 10% and 90% of total and power/energy density values of 10% of peak. edge steepness</p> $s(z) = \frac{A_{0.1}^i(z) - A_{0.9}^i(z)}{A_{0.1}^i(z)}$ <p>Note: <math>0 &lt; s(z) &lt; 1</math>; <math>s(z) \rightarrow 0</math> as the edges of the distribution become more vertical.</p>
46	R	roughness of fit				x		3.3.1	<p>Maximum deviation of the theoretical fit to the measure distribution. roughness of fit:</p> $R = \frac{ E_{ij} - E_{ij}^f _{\max}}{E_{\max}}$ <p>where: <math>E_{ij}^f</math> is the fitted theoretical distribution. Note: <math>0 \leq R \leq 1</math>, as <math>R \rightarrow 0</math> the fit becomes better.</p>
47	G	goodness of fit				x		3.3.2	<p>Parameter based upon Kolomogorov-Smirnov statistical test characterizing the fit between measured and theoretical distributions. goodness of fit:</p> $G = \frac{1}{1 + \Delta\sqrt{N}}$ <p>where: N is the total number of data points in the measured distribution, <math>\Delta</math> is the maximum deviation between measured and theoretical distributions of apertured powers/energies truncated at <math>n \geq 10</math> random locations <math>(x_i, y_j)</math> in the distribution:</p> $\Delta = \frac{ P_{ij} - P_{ij}^f _{\max}}{P}$ <p>Note: <math>0 \leq G \leq 1</math>, as <math>G \rightarrow 1</math> the quality of the fit becomes better.</p>
48	d <sub>x</sub> , d <sub>y</sub>	grid spacing					2	3.1	Partition of detector area into orthogonal grid of apertures.
49	A <sub>ij</sub>	area of sub-aperture					2	3.2	Area of a sub-aperture may be either square or round.
50	L <sub>H</sub>	focal length					2	3.3	Distance from the sub-aperture screen to the

Item #	Symbol	Name	ISO 11145	ISO 11146	ISO 11670	ISO 13694	ISO 15367	Section	Definition
									detector array.
51	$d_p$	pinhole diameter					2	3.5	Diameter of the holes in a Hartmann screen
52	$N_{Fr}$	Fresnel number					2	3.6	<p>The ratio of the pinhole spacing to the radius of the projected spot on the detector. Fresnel number:</p> $N_{Fr} = \frac{d_x}{\rho_{ij}}$ <p><math>\rho_{ij}</math> = radius of the projected spot</p>
53	$\rho_{ij}$	spot radius					2	3.6	<p>The spot radius is measured to the location of the first minimum in the point-spread function. for square pinholes:</p> $\rho_{ij} = \frac{L_H \lambda}{d_x}$ <p>for round pinholes:</p> $\rho_{ij} = 1.22 \frac{L_H \lambda}{d_p}$
54	$\beta_{max}$	angular dynamic range					2	3.7	Maximum usable angular range of the Hartmann sensors.
55	$w_{s,rms}$	wavefront statistical uncertainty					2	3.8	Average uncertainty of estimating the wavefront over the entire aperture.
56	$w(x,y)$	wavefront shape					1	3.1.1	
57	$w_c(x,y)$	corrected wavefront shape					1	3.4.2	

## Appendix B BeamGage Supported Cameras

BeamGage supports a variety of cameras to best suit your measurement application. We will add support for new cameras as technology continues to evolve. This table displays all the cameras that are supported in BeamGage. Click on the model name to access the camera specifications.

All cameras currently available have additional information provided in subsequent sections of this user guide. Please read over the information carefully before attempting to use the camera.

Model	BeamGage Standard	BeamGage Professional	Section
<a href="#">SP920s</a>	X	X	C.4
SP932U <b>NEW</b>	X	X	C.5
<a href="#">SP920G</a>	X	X	Appendix D, Appendix E
<a href="#">LT665</a>	X	X	Appendix C
<a href="#">L11059</a>		X	Appendix G
<a href="#">SP920s-1550</a>	X	X	C.4
<a href="#">LT665-1550</a>	X	X	Appendix C
<a href="#">Xeva XC-130</a>		X	Appendix H
<a href="#">Pyrocam IIIHR</a>		X	Appendix D, Appendix I
<a href="#">Pyrocam IV</a>		X	Appendix D, Appendix I
<a href="#">SP1201</a>		X	Appendix D, Appendix F
<a href="#">SP1203</a>		X	Appendix D, Appendix F

Legacy Products			
SP928	X	X	
SP907	X	X	
SP300	X	X	
SP920	X	X	
SP620	X	X	
SP503	X	X	
Gras20	X	X	
SP928-1550	X	X	
SP907-1550	X	X	
SP620-1550	X	X	
SP503-1550	X	X	
Gras20-1550	X	X	

# Appendix C USB 3.0 Cameras

## C.1 Multi-Tap Sensor Behavior

The Sony ICX694 sensor in the LT665 utilizes the EXview HAD II CCD Multi Tap sensor technology. There are some differences in behavior from traditional single tap sensors.

- Multi-tap sensors read out each tap individually and allow for faster frame rates in CCD sensors.
- Each tap has its own A/D converter and amplifier and thus must be factory matched.
- Factory matching ensures a uniform background response for a wide variety of conditions.
- A tap mismatch appears as a visible seam between taps.

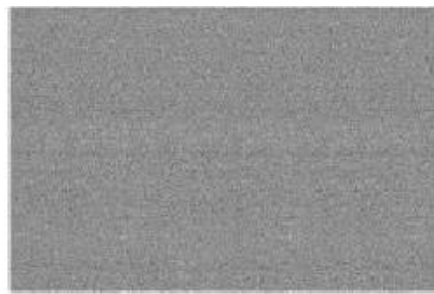
Slight mismatching is possible under some operational conditions but does not typically affect laser beam measurement.

The color palettes available in BeamGage are designed to maximize visibility across the dynamic range of the sensor and can greatly exaggerate tap mismatching to the human eye. The significance of a tap mismatch on a beam measurement is a function of the delta of the intensity across the mismatch and the peak intensity of the beam.

If conditions that encourage a tap mismatch cannot be avoided, then adjusting the peak intensity of the beam to 80-95% of saturation ensures that the effect of the mismatch is statistically minimized.



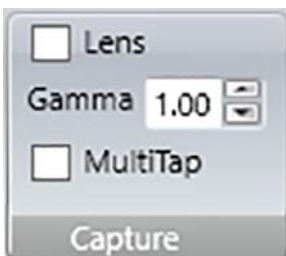
*Quad Tap Mismatch*



*Quad Tap Matched*

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## C.2 Multi-Tap Camera Formats



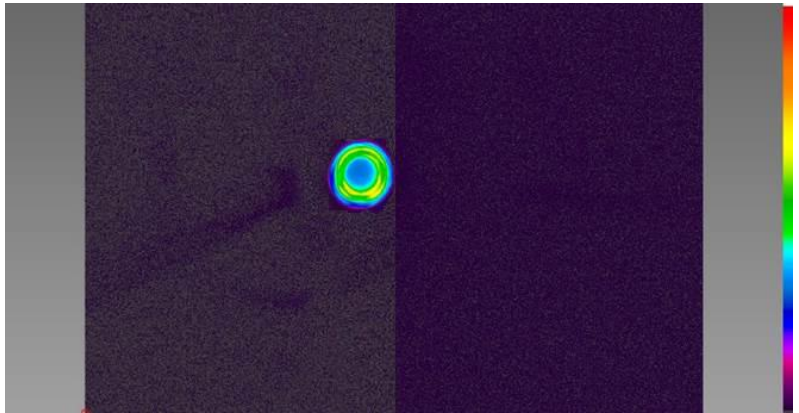
The **MultiTap** feature can be found in the **Source** ribbon in the **Capture** panel. It is only available with certain cameras. Multi-tap cameras enable faster frame rates by splitting the image frame into two or more areas read out in parallel. Multi-tap cameras may display faint lines in the image where the image frame splits which can be seen in the Quad Tap Mismatch image above.

The tap balance of each camera is factory calibrated by adjusting the gain offsets of each ADC. Under most circumstances, small imbalances may be easily visible in BeamGage particularly when Ultracal background correction is active. It is rare however, for small imbalances to affect laser beam measurement to a measurable degree.



In the L11059 and LT665 camera models, there is an additional dynamic tap balance algorithm running in the camera electronics when a multi-tap format is selected. This feature utilizes several rows and columns along the boundaries of each tap to monitor the balance.

There are conditions where a laser spot may cause the dynamic balance to drastically unbalance the taps. This occurs when the edge of a laser spot is within the monitor rows/columns on one tap edge but it has not entered the monitor rows/columns on the other side of the tap edge. **In this condition, laser beam analysis is not possible.** The issue resolves itself as the laser spot is translated across both sides of the tap boundary.



This issue can be avoided by using one of the following techniques:

- Ensure the laser spot does not transit the tap boundary during measurement.
- Ensure that the laser spot is measured on one tap only.
- Disable the **MultiTap** control.  
(Note: Disabling Multi-tap results in slower frame rates.)

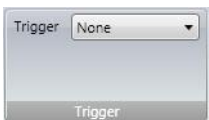
## C.3 LT665 Camera Specifications

### C.3.1 Supplied Accessories

The LT665 is a quad-tap camera and is supplied with the following accessories:

- 5 volt AC power adapter, 2 Amp minimum, Center Positive
- Pre-wired 8-pin GPI/O cable (Hirose HR1824-ND adapter)
  - Pins 1 & 8 – External Power, DC Coaxial socket: 2.1mm (ID) x 5.5mm (OD)
  - Pins 6 & 7 – External Trigger, SMA Bulkhead, Female
  - Pins 2, 3, 4, 5 – Unused, Insulated, see reference table

### C.3.2 External Trigger



The LT665 camera is supplied with an external trigger input cable. The input to this cable should be a standard TTL level positive going pulse. The camera triggers, and begins integrating light on the rising edge. A trigger pulse should be at least 5 $\mu$ s in duration.

To operate in external trigger mode you must set this control to **Trigger In**. Select **None** when operating in CW mode.

### C.3.3 GPI/O Connector Description

For all non-isolated GPO/GPI pins, the voltage swing is as follows:

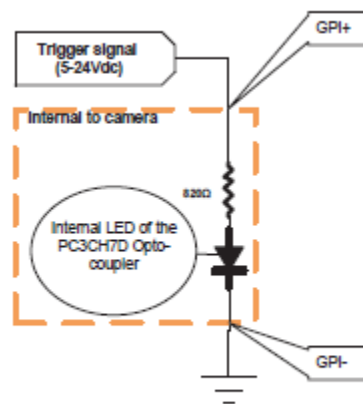
- For a LOW value: 0.0 to 0.1 V
- For a HIGH value: 3.0 to 3.3 V
- The typical forward current ( $I_f$ ) is 20mA with maximum of 50mA.



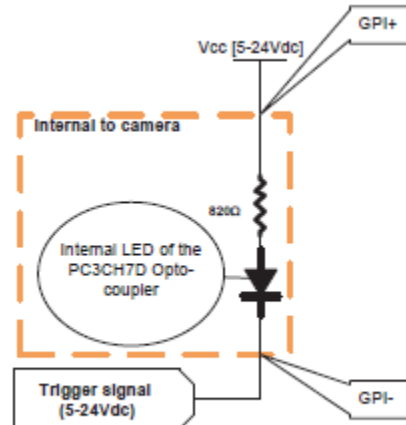
Pin #	Function	Wire color	Description
1	V-External	RED	External power input terminal (+5Vdc)
2	GPO1+	GREEN	Optically isolated output positive terminal
3	GPO1-	ORANGE	Optically isolated output negative terminal
4	GPI02	BLUE	Bi directional general purpose I/O
5	GPI03	BROWN	Bi-directional general purpose I/O
6	GPI1-	YELLOW	Optically isolated input negative terminal
7	GPI1+	GREY	Optically isolated input positive terminal
8	GND	BLACK	External power ground reference terminal

### C.3.4 Optically Isolated inputs

The optically-isolated input pins are designed to operate from 5V to 24V at a typical current of 20mA and must not exceed 50mA. Greater input voltages are supported with use of an external resistor. When current flow from GPI1+ to GPI1- it is seen as a level 1 from the camera otherwise the camera sees it as a level 0. A simple usage is to apply the signal (active high) on GPI1+ and then have GPI1- connect to the ground plane of the input signal (illustrated below). In some applications the trigger may need to be active low, and then Vcc (5-24V) from the trigger circuit should be applied at GPI1+ and the signal at GPI1- as illustrated below. The internal resistor value on these pins is 820Ω. Therefore,  $V_{input} = (0.02 \text{ A}) * (820\Omega + R_{external})$ .



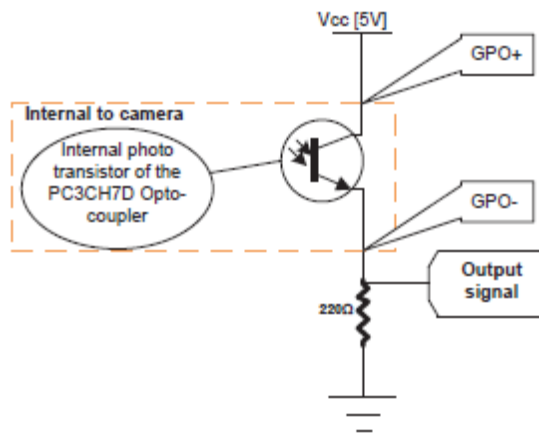
Active High Example



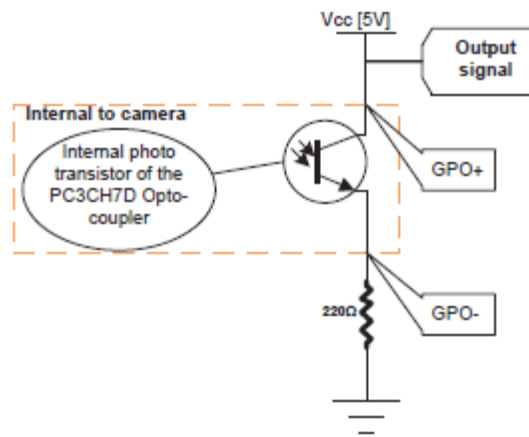
Active Low Example

### C.3.5 Optical Isolated Outputs

The optically-isolated output requires an external resistor and biasing current. The current flow between collector and emitter should nominally be 20mA and must not exceed 50mA. For example, for biasing with a 5V supply (output referenced to 5V), use a 220Ω series resistor. For a 12V supply, use 560Ω. There are 2 common configurations that can be used for outputs, active high or active low output signal. Active high output produces an output level to VCC when the LED in the opto-coupler is on, alternatively for active low output, configure the GPO1 to output 0 when the signal is active (illustrated below).



Active High output



Active Low Output

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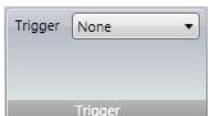
## C.4 SP920s Camera Specifications

### C.4.1 Supplied Accessories

The SP920s is a single tap camera and is supplied with the following accessories:

- USB3.0 Certified Standard-A to Micro-B cable
- Coax External Trigger Cable – Hirose HR10A-7P-6S(73) to BNC
  - Pins 2 & 5 – External Trigger, SMA Bulkhead, Female
  - Pins 1, 3, 4, & 6 – Not connected, see reference table

### C.4.2 External Trigger Control

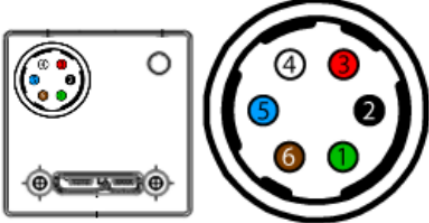


The SP920s camera is supplied with an external trigger input cable. The input to this cable should be a standard TTL level positive going pulse. The camera triggers and begins integrating light on the rising edge. A trigger pulse should be at least 5μs in duration.

To operate in external trigger mode you must set this control to **Trigger In**. Select **None** when operating in CW mode.

## C.4.3 GPIO Connector Description

The camera is equipped with a 6-pin GPIO connector on the back of the case. The connector is a Hirose HR10A-7R-6PB, the mating connector is a Hirose HR10A-7P-6S(73).

Diagram	Color	Pin	Function	Description
	Green	1	V <sub>EXT</sub>	+12 V DC Camera Power
	Black	2	I/O	Opto-isolated input (GPIO 0)
	Red	3	NC / +3.3 V	+3.3 V output. Current 120 mA (nominal). Firmware enabled
	White	4	O1	Opto-isolated output (GPIO 1)
	Blue	5	OPTO_GND	Ground for opto-isolated I/O, not connected to camera ground
	Brown	6	GND	DC camera power ground

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## C.5 SP932U Camera Specifications

### C.5.1 Supplied Accessories

The SP932U is a single tap CMOS camera and is supplied with the following accessories:

- USB3.0 Certified Standard-A to Micro-B cable
- Coax External Trigger Cable – JST NSHR-09V-S to SMA
  - Pins 7 & 9 – External Trigger, SMA Bulkhead, Female
  - Pins 1-6 & 8 – Not connected, see reference table
- 1/4-20 tripod adapter

### C.5.2 External Trigger Control



The SP932U camera is supplied with an external trigger input cable. The input to this cable should be a standard TTL level positive going pulse. The camera triggers and begins integrating light on the rising edge. A trigger pulse should be at least 5μs in duration.

To operate in external trigger mode you must set this control to **Trigger In**. Select **None** when operating in CW mode.

### C.5.3 GPI/O Connector Description

The camera has a 9-pin GPIO connector on the side of the case; refer to the diagram below for wire color-coding. The header connector is JST part number BM09B-NSHSS-TBT and the wire plug connector is JST part number NSHR-09V-S. The wire contacts are SSSL-003T-P0.2.

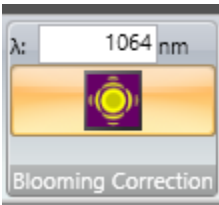
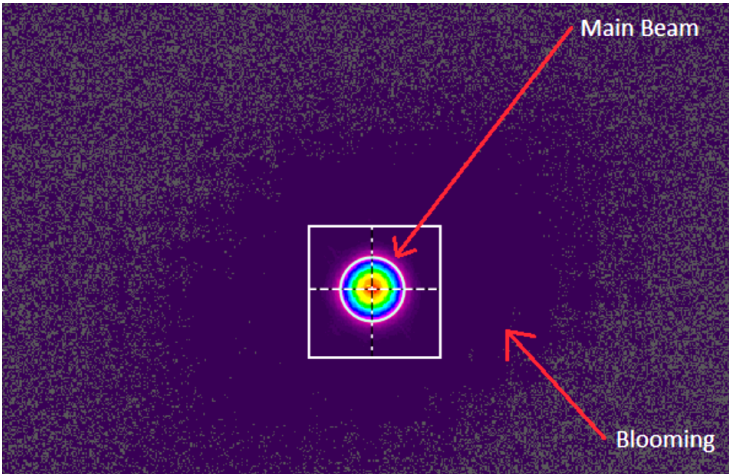
Diagram									Pin #	Color	Function	Description
9	8	7	6	5	4	3	2	1	1	Red	V-External	External power input terminal (5V +/- 7.5%, 2A) Takes priority over USB3 power
Opto In	Opto Out	Opto Ground	Ground	GPIO3	GPIO2	3.3VDC Out	Ground	5VDC In	2	Black	GND	External power ground reference terminal
									3	Grey	3.3 Vdc Output	Output supplying a maximum of 150 mA
									4	Blue	GPIO2	Bi-directional general purpose I/O #2 terminal
									5	Purple	GPIO3	Bi-directional general purpose I/O #3 terminal
									6	Black	GND	External power ground reference terminal
									7	Brown	Opto GND	External ground reference for Opto signal
									8	Orange	Opto Output	Optically isolated output
									9	Yellow	Opto Input	Optically isolated input

### C.5.4 Blooming Correction

Blooming manifests as an outspread region of positive signal around the beam profile. It is caused by longer wavelengths (>1000nm) of light that partially scatter on periodically placed pixels, traverse the silicon-based sensor, reflect off the sensor back plane, and get absorbed by the sensor on the second pass.

Both silicon CCD and CMOS cameras have a blooming effect. As the new CMOS camera sits optical sensors on a thinner silicon wafer, blooming artifacts become more prevalent. Blooming not only affects the image visually, it significantly impacts the computed results. In some cases, the  $D4\sigma$  beam widths could measure as much as 30% larger.

The best way to avoid any blooming artifacts is to use a sensor that is not silicon-based, such as InGaAs. If changing to a different sensor is not possible, BeamGage provides a mathematical Blooming Correction algorithm with the SP932U camera. The algorithm is based on the physical model of the light diffraction, transmission, and reflection.




Blooming Correction is unnecessary for wavelengths shorter than 1000nm. In the **Blooming Correction** panel in the **Source** ribbon, enter the laser wavelength. If the wavelength is in the correctable range (1000nm to 1100nm), enable the correction.



**Blooming Correction** may not be suitable for all applications and should only be enabled if blooming is present.



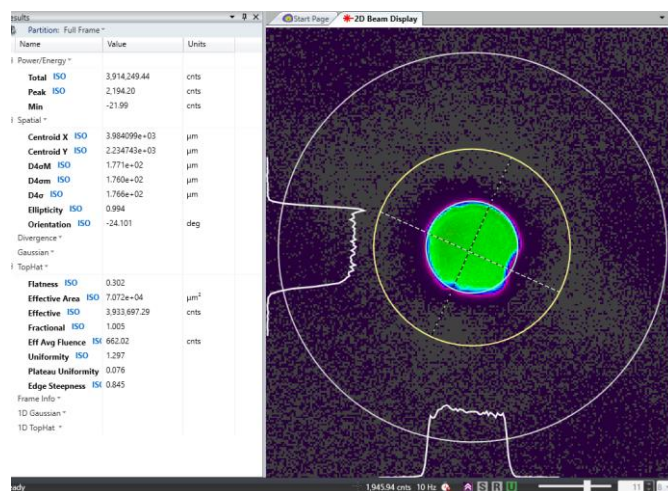
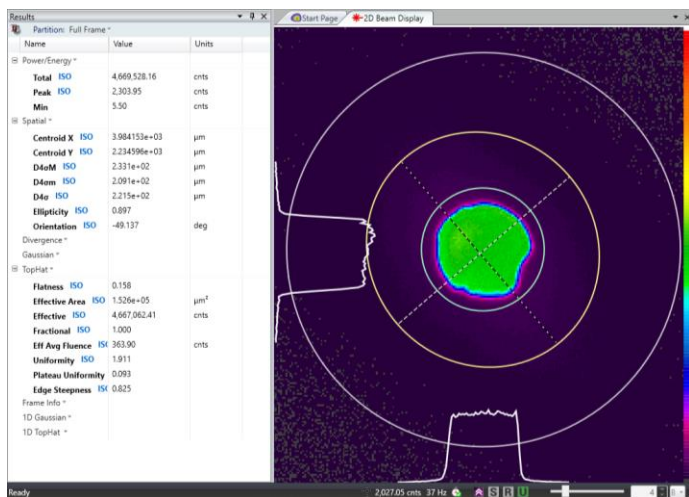
**Blooming Correction** can only be enabled for live data collection. When viewing saved data, a  in the status bar indicates that the frame was corrected for blooming when originally acquired.





**Blooming Correction** is computationally intensive, require approximately 100ms per frame at full resolution and may therefore slow down the data collection frame rate. For beam widths above 300 $\mu$ m, Frame Rate can be improved by applying the binning option. For smaller beam widths, an ROI can be used for faster calculations.

Below is a comparison of results when blooming correction is off and when engaged.





# Appendix D Gig-E Camera Information

## D.1 Gig-E Camera Installation



*The Gig-E camera installation must be performed in the following order to ensure a proper connection with BeamGage.*

Most Gig-E cameras are supplied with a USB 3.0 to Gigabit Ethernet adapter and a Cat6 Ethernet cable.

Most any commercially available Gig-E rated Ethernet card works, so long as it has Jumbo packet capability. In general, Ophir-Spiricon has found that Intel PRO/1000 series Ethernet PCI-Express cards and Realtek 8168/8111 chipsets in PCI-Express/34 cards, work trouble free. Only use a network interface card (NIC) that supports Jumbo packets.

It is recommended that one Gig-E rated Ethernet port on your computer be reserved for connection to the Gig-E camera. BeamGage does not support a camera connected to your Local Area Network as a standalone device.

## D.2 Installing the Ethernet Adapter



*Must be performed with Administrator privileges.*

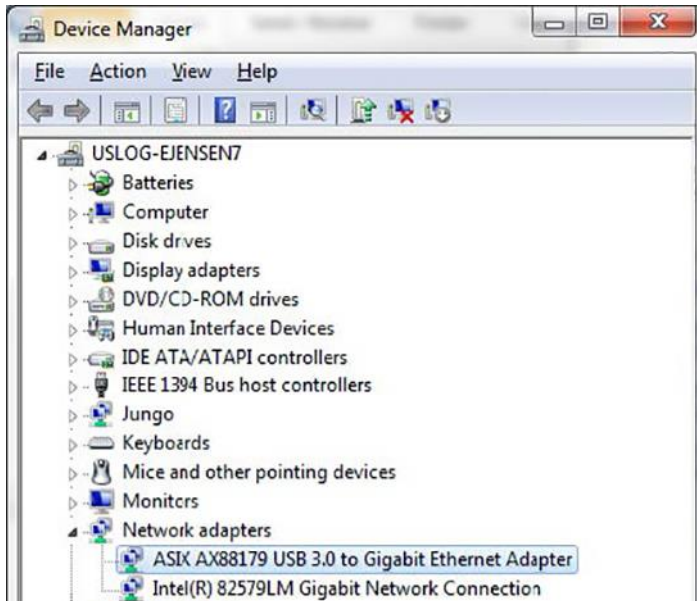
The following steps instruct how to install and configure the USB 3.0 to Gigabit Ethernet Adapter. However, it may be possible to employ an unused Ethernet port already built-in or installed in your PC. The following instructions can be used for either case.



*Use of standard PCI style NIC cards is not recommended unless they are truly operating at 66MHz bus speed. Slower 33MHz cards will perform poorly, if at all.*

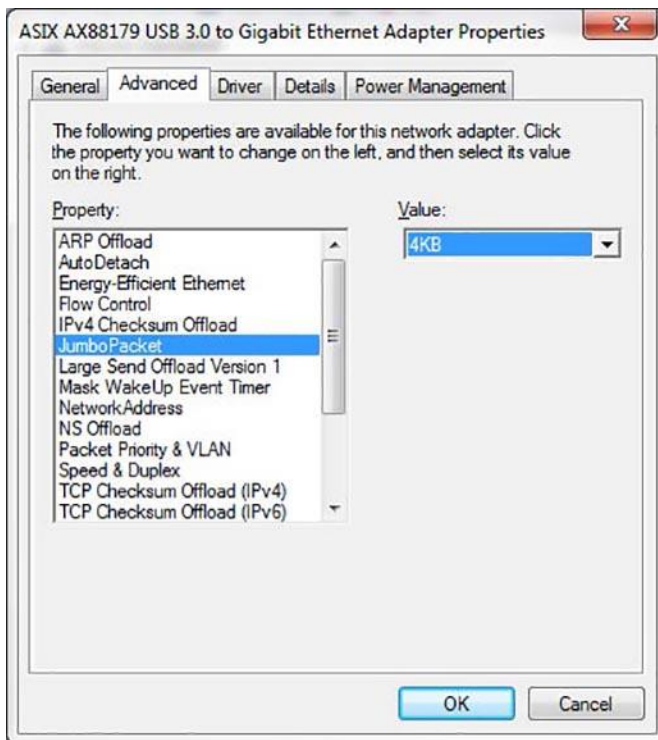
### **DO NOT POWER OR CONNECT THE CAMERA UNTIL DIRECTED TO DO SO.**

1. Plug the USB connector into a USB 3.0 port. When the adapter is plugged into a USB 2.0 port the camera may not work, at a minimum the image capture rate from the camera will be reduced.
2. The plug and play feature of Windows will assign a driver to the newly found hardware.



3. Once the NIC and its driver are installed, open the Windows **Device Manager** and locate the new card in the **Network adapters** node. See the example of the ASIX AX88179 USB 3.0 to Gigabit Ethernet Adapter. Be especially careful that you select the new card and not the NIC connected to your network. Changing the settings on your network card may cause you to be disconnected from your network.

4. Double click on the new adapter to open the properties window. Then select the **Driver** tab. If needed use the **Update Driver** button to search for and install the latest driver.



5. Select the **Advanced** tab. In the **Property** list locate and click on the item containing the word **Jumbo**. Set the value on this to the largest size available.

6. Click OK.

7. This completes the NIC setup.



*If your NIC does not support Jumbo packets, it will not be suitable for operation with Gig-E cameras. Lack of Jumbo support may be an indication that the installed driver is old and a newer one may need to be installed.*

## D.3 Connecting Gig-E to BeamGage

The Gig-E camera can now be connected to the PC and to BeamGage. The camera is pre-licensed for the edition of BeamGage supplied with the camera.



*The first time a Gig-E camera is connected to BeamGage with a newly installed NIC, you must do so with Administrator privileges. Thereafter it can be run with lower privileges.*

Do the following:

1. Connect the Cat6 cable between the camera and the NIC.
2. Connect the power supply to the camera then apply AC power to the power supply.
3. Launch BeamGage with **Administrator** privileges by right clicking on the application icon and selecting "Run as administrator".
4. In the **Source** tab select **Local Detector**.
5. Observe that the camera appears for selection displayed as:
  - a. (Pyrocam\_IIIHR#<serial number>)
  - b. (Pyrocam\_IV #<serial number>)
  - c. (SP920g #<serial number>)
6. Click the camera to select it.
7. Begin collecting data.

# Appendix E SP920G Camera Information

## E.1 SP920G Camera Operation

This section describes the camera controls that are unique to the SP920G camera. Common controls are covered in other sections of this manual. **What's this** help is available on all of the special SP920G controls.

### E.1.1 External Trigger Control



The power supply connector to the SP920G camera has an external trigger input cable split out from the connector housing. The input to this cable should be a standard TTL level positive going pulse. The camera triggers and begins integrating light on the rising edge. A trigger pulse should be at least 5 $\mu$ s in duration.

To operate in external trigger mode you must set this control to **Trigger In**. Select **None** when operating in CW mode.

In most cases, it is best to select the maximum frame rate available on the camera when operating in pulsed mode with external triggers. The laser pulse should start no sooner than a few  $\mu$ sec after the rising edge of the trigger pulse. The exposure time should be set just long enough to contain the entire pulse width, and short enough to exclude pulses that may start before the imager has had time to be read out. This prevents laser pulse doubling in the captured image.

### E.1.2 Bad Pixel Correction


Bad Pixel correction is automatically enabled whenever the camera is operating in full resolution mode. Windowless imagers are more prone to developing bad pixels over time. If new bad pixels present a problem, you can send the camera back to Ophir-Spiricon to be serviced as part of our camera recertification program. Part of that service attempts to locate and add new bad pixels to the bad pixel correction map embedded in the camera.

### E.1.3 GPIO Connector Description

The camera has an 8-pin GPIO connector on the back of the case; refer to the diagram for wire color-coding.

The connector is a Hirose HR25 8 pin connector (Mfg P/N: HR25-7TR-8SA).

The GPIO pins are TTL 3.3V pins. When configured as inputs, the pins are internally pulled high using weak pull-up resistors to allow easy triggering of the camera by simply shorting the pin to ground (GND). Inputs can also be directly driven from a 3.3V or 5V logic output. The inputs are protected from both over and under voltage. It is recommended, however, that they only be connected to 5V or 3.3V digital logic signals. When configured as outputs, each line can sink 10mA of current.

Diagram	Color	Pin	Function	Description
	Black	1	I0	Opto-isolated input (default Trigger in)
	White	2	O1	Opto-isolated output
	Red	3	IO2	Input/Output/serial transmit (TX)
	Green	4	IO3	Input/Output/serial receive (RX)
	Brown	5	GND	Ground for bi-directional IO, $V_{EXT}$ , +3.3 V pins
	Blue	6	OPTO_GND	Ground for opto-isolated IO pins
	Orange	7	$V_{EXT}$	Allows the camera to be powered externally
	Yellow	8	+3.3 V	Power external circuitry up to 150 mA
To configure the GPIO pins, consult the General Purpose Input/Output section of your camera's Technical Reference Manual.				

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# Appendix F SP1201 and SP1203 Camera Information

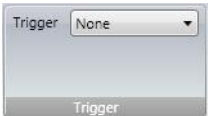
## F.1 SP1201 and SP1203 Camera Operation

This section describes the camera controls that are unique to the SP1201 and SP1203 cameras. Common controls are covered in other sections of this manual.

## F.2 Connection Information

These cameras are PoE (Power over Ethernet). This requires the GigE port on the PC to be powered. If it is not, the power side of the supplied Power/Trigger cable must be used. The cameras can be triggered for pulsed lasers by using the BNC connector on the Power/Trigger cable.

## F.3 External Trigger Control



The cameras have an external trigger input cable. The input to this cable should be a standard TTL level positive going pulse. The trigger cable does not provide external power, only triggering. The camera triggers and begins integrating light on the rising edge. A trigger pulse should be at least 5 $\mu$ s in duration.

To operate in external trigger mode you must set this control to **Trigger In**. In most cases, it is best to select the maximum frame rate available on the camera when operating in pulsed mode with external triggers. The laser pulse should start no sooner than a few  $\mu$ sec after the rising edge of the trigger pulse. The exposure time should be set just long enough to contain the entire pulse width, and short enough to exclude pulses that may start before the imager has had time to be read out. This prevents laser pulse doubling in the captured image.

## F.4 NUC Files

Cameras with InGaAs imagers require a significant amount of image correction in order to get a useful output. The SP1201 and SP1203 cameras employ special nonuniformity correction (NUC) files that are loaded into the camera. These correction files are supplied by the manufacturer and are unique to each camera. NUC files provide gain, offset, and bad pixel correction, as well as specific operating settings, e.g. exposure, gain, black level, imager temperature, etc. The camera loads these files automatically based on the selected settings.

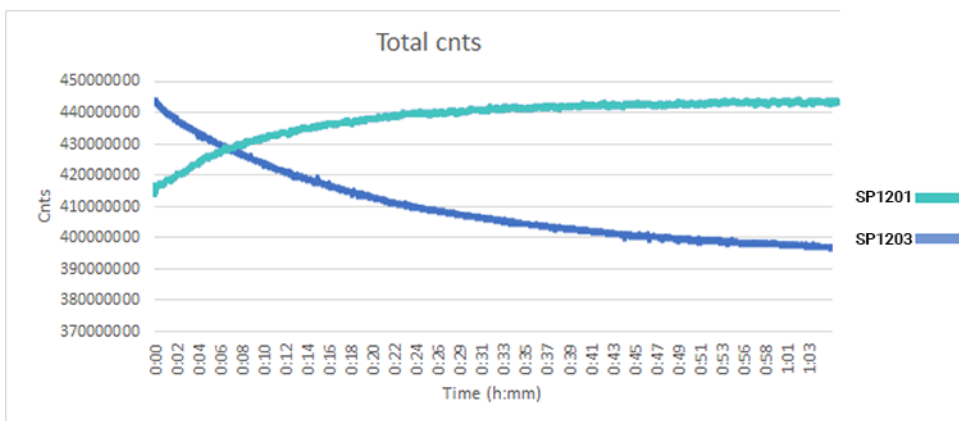
## F.5 Bad Pixel Correction

Bad Pixel correction is automatically enabled whenever the camera is operating in full resolution mode. If new bad pixels present a problem, you can send the camera back to Ophir-Spiricon to be serviced as part of our camera recertification program. Part of that service attempts to locate and add new bad pixels to the bad pixel correction map embedded in the camera.

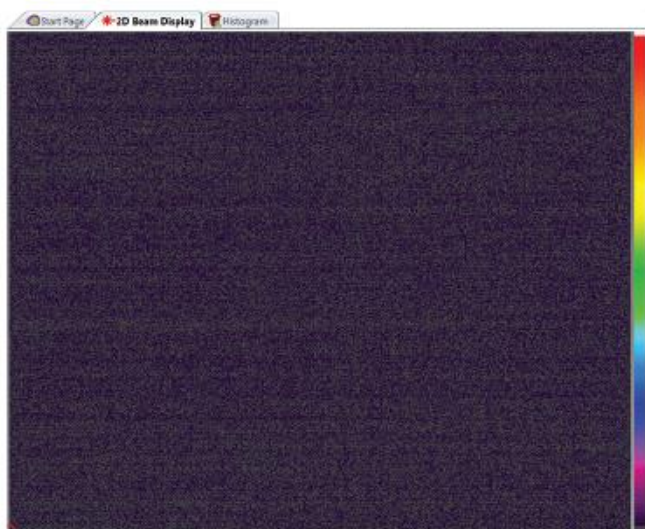


## F.6 Thermal Equilibrium

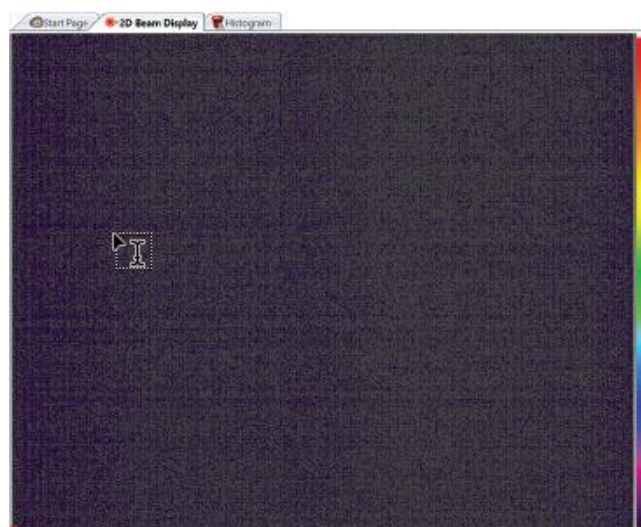
As the camera runs, it progressively gets warmer until it reaches its Thermal Equilibrium. For the SP1201 and SP1203 this takes approximately 55 minutes. As the temperature changes the number of pixel counts changes. This change is different for each camera: the SP1201 increases and the SP1203 decreases. The change in pixel counts can be seen as a change in the background noise.



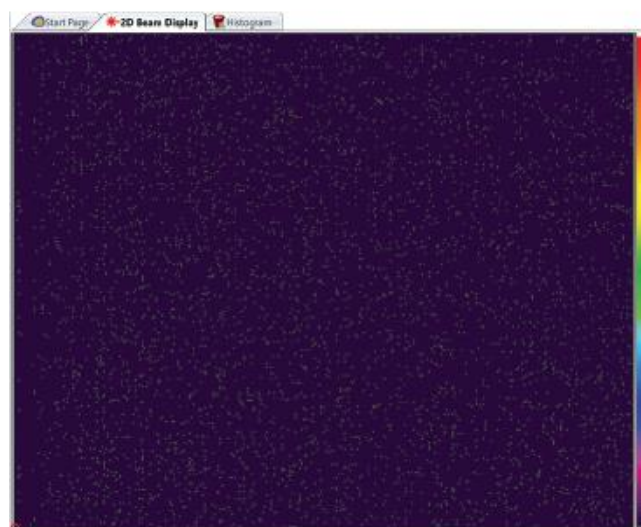
The changes in background can affect almost every result so this must be fixed frequently until thermal equilibrium is reached. The best way to combat this change is to perform a new Ultracal when the change in background noise is visible. A good background can be seen below. Perform an Ultracal if the image begins to look similar to the images on the right.



**Good Background**



**SP1203 Background Low**



**SP1201 Background High**

## F.7 GPI/O Connector Description

The camera has a 12-pin GPIO connector on the back of the case; refer to the diagram for wire color-coding and line information.

Diagram	Pin	Function	Level	Description
	1	In/Out	GND for RS232 and external power	External Ground
	2	In	10.8 V to 3	Power Supply
	3	Out	N/A	Video Iris
	4	In	$V_{in}$ (low) 0.0 V to 0.8 V $V_{in}$ (high) 2.0 V to 5.0 V	Input 1 non-isolated
	5	Out	Open emitter, max 20 mA	Output 3 opto-insolated
	6	Out	TTL (5 V, max. 20 mA)	Output 1 non-isolated
	7	In	Common GND for opto-isolated inputs	Camera Common Input Ground
	8	In	RS232	Terminal Receive Data
	9	Out	RS232	Terminal Transmit Data
	10	In	Common supply voltage for outputs max. 30 VDC	External Power Input for Digital outputs
	11	In	$V_{in}$ (low) 0.0 V to 1.0 V $V_{in}$ (high) 3.0 V to 24.0 V	Input 2 opto-insolated
	12	Out	Open emitter, max. 20 mA	Output 2 opto-insolated

# Appendix G L11059 Camera Information

## G.1 L11059 System Considerations

To operate BeamGage at maximum full frame resolution with the L11059, it must be operated with Windows 10 64-bit OS, with at least 8GB of RAM memory.



*Ophir-Spiricon no longer verifies or certifies operation with 32-bit machines.*

## G.2 Upgrading from LBA-USB to BeamGage

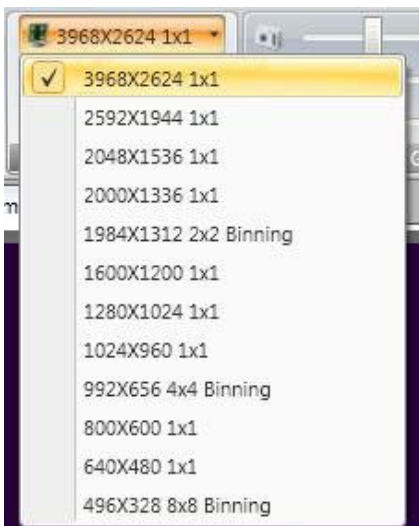
With the release of BeamGage v5.5, which included the L11058 and L230 cameras, new Lumenera drivers are deployed. These drivers are not compatible with LBA-USB, and replace the older drivers that LBA-USB relies upon. As a result, LBA-USB will cease to operate with any of the Lumenera style cameras including the L11059.

To maintain operation of LBA-USB, you must either relocate it to another PC or install BeamGage onto a different PC. Since BeamGage is designed around higher performance PC platforms, it is advised that it be installed on more modern equipment than what LBA required.

## G.3 First Time Connection

The first time an L11059 camera is connected to BeamGage the format defaults into a full frame 4x4 binning mode, in order to allow the camera to capture frames at a faster rate than if launched in the full 11 Mega-pixel format. This binned mode gives a better operating environment with which to setup and align your laser and prepare for final operation. Once the system is configured, proceed to change the format to the one desired and make any last minute adjustments. Save the configuration. Depending on other settings in BeamGage, this camera may run slower at full resolution.

## G.4 Operation



To view the L11059 features in BeamGage navigate to **Source**, then the **Frame Format** panel. Click on the format item to see the list of the provided preset formats as shown.

The list is quite extensive. In addition, there are full frame formats that utilize 2x2, 4x4, and 8x8 binning modes. These binning modes allow for much higher full image format frame rates. In 8x8 bin mode, the camera can output full frames of data in excess of 20 fps. This is the fastest full image format possible with this model of camera. Of course, binning also reduces pixel to pixel resolution so measuring small spots with high precision suffers accordingly.

BeamGage also offers user configurable **ROI's** (see 2.3.1.5).

Be aware when using the binning modes: Bad pixel correction is not supported when operating in binned modes. This is true for most all cameras. However, L11059 imagers often have a large number of bad pixels when compared to much smaller format imagers. The Ultracal operation baseline corrects most of the defects. However, unstable pixels, referred to as twinklers, may still randomly appear even after performing an Ultracal. The best method to eliminate their effects is by using a manual

aperture to exclude them from the measurement region. Normally bad pixels do not significantly affect measurement results unless you are monitoring Peak level or Peak location and the twinkler rises above your signal peak.

Strobe Out is not supported in BeamGage.

## G.5 External Triggering

The L11059 can be triggered from an external source. The cameras are supplied with an external trigger cable with BNC connectors. The drive for the trigger is positive TTL compatible 5VDC logic level pulses. The pulse should have a minimum pulse width of at least 5 $\mu$ s.

When operating in external trigger mode, the maximum frame rate is 1/2 the CW rate. For example, if the selected camera format can collect 20fps in CW mode, it will only be able to collect 10fps when in external triggered mode.

Trigger mode is also equipped with a **Delay** feature that can be used to help isolate pulses that may occur within a burst of pulses.

# Appendix H    XenICs InGaAs Camera Information

## H.1    Installation



*To use a XenICs USB XEVA camera install the BeamGage software supplied on Ophir-Spiricon's DVD and the Xeneth software supplied on the XenICs USB flash drive. The order of installation is irrelevant.*

Run the XenICs USB flash drive and follow the directions for installing Xeneth. You cannot successfully use the XenICs camera in BeamGage unless the camera driver and calibration pack NUC files are available for BeamGage. The XEVA camera cannot be connected to both Xeneth and BeamGage at the same time.



*You must install the correct version of Xeneth for proper BeamGage operation. On the XenICs USB flash drive is a folder named Xeneth-Software containing four Xeneth EXE installation programs. For 32-bit operating systems, you must install Xeneth-Setup-Advanced. For 64-bit operating systems, you must install Xeneth-Setup-Advanced64. Xeneth-API-Setup and Xeneth-API-Setup64 are for those who wish to write their own software to control the camera and collect images.*

The operating controls for the XEVA model cameras are simplified for use with BeamGage. This is necessary to ensure the cameras operate under conditions that yield the best accuracy. Cameras with InGaAs imagers require a significant amount of image correction in order to get a useful output. XenICs cameras employ special non-uniformity correction (NUC) files that must be downloaded into the camera. These correction files are supplied by the manufacturer and are unique to each camera. NUC files provide gain, offset and bad pixel correction, as well as specific operating settings, e.g. exposure, gain, black level, imager temperature, etc. BeamGage provides a control panel that allows the user to select the necessary NUC file.

There are two (2) types of NUC files, TrueNUC files and standard NUC files.

All types of NUC files can be used with Xeneth.

NUC files end with a file extension of .xca and are also referred to as "calibration packs" or "camera correction" files. XenICs provides a USB flash drive with each camera. This flash drive contains the factory generated NUC and TrueNUC files as well as a utility called **Xeneth** that allows the user to test the camera and make additional NUC files if necessary.

NUC and TrueNUC files fall into 2 general classes, High Gain (HG) and Low Gain (LG). For laser beam analysis the High Gain NUC files will be the ones most frequently employed. High Gain NUC files give exceptional response linearity. Low Gain NUC files will not produce good response linearity.

TrueNUC files can be used over a broad exposure range and will maintain good pixel correction. **The TrueNUC\_HG file is recommended for use with BeamGage.**

Regular NUC files are specified for operation at or very near the preset exposure that was in effect when the NUC file was created. Using them outside of their set value will degrade the cameras image correction performance.

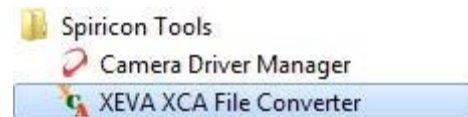
## H.1.1 Converting X-Control XCA Files to Xeneth



*X-Control NUC files are not compatible with BeamGage v6.0 and above. You must convert NUC files supplied with cameras purchased prior to October 2013.*

Follow these instructions to convert X-Control XCA files for use with BeamGage v6.0 and above:

1. Copy the X-Control XCA files to the Xeneth calibration folder located at "C:\Program Files\Xeneth\Calibrations"
2. **Before** applying power to the camera, plug in the USB cable from the camera to the PC
3. Apply power to the camera
4. Start the Xeneth software
5. Select the camera and set "Calibration data" to "(none)"
6. In the File menu select "Settings"
7. Select the calibration file to convert
8. Click OK
9. In the Calibration menu select "Export calibration data"
10. Select a path. This can be any path, not necessarily the calibration folder.
11. Enter an appropriate file name by including Xeneth in the name
12. Click Save
13. Because of a bug in the Xeneth software, the converted calibration file will cause the camera background noise to be suppressed. This defeats the BeamGage Ultracal process and may cause inaccurate results. In order to correct for this problem you must perform a final conversion for use in BeamGage.
  - a. Open the XEVA XCA File Converter utility installed with BeamGage.
    - i. **Start Menu -> All Programs -> Spiricon Tools -> XEVA XCA File Converter**
  - b. Click the Browse button. A file selection dialog will open to the Xeneth\Calibrations directory from Step 1.
  - c. Select the NUC file that has been processed by the Xeneth software in the previous steps.
  - d. Click OK.
  - e. Click Convert.
14. Repeat steps 6-13 for each NUC file.



When loading a calibration pack in BeamGage be sure to specify the Xeneth converted NUC file. If you attempt to load an X-Control NUC file then BeamGage will display "Invalid Calibration!" in the Camera Correction File text box.



## H.2 Getting Started with a Xeva Camera

Once you have installed all of the above required software do the following:

1. **Before** applying power to the camera, plug in the USB cable from the camera to the PC
2. Apply power to the camera
3. Open BeamGage
4. Go to the **Source** panel and click on **Local Detector**, select the camera, and a prompt to enter a Camera License Key appears.



*If the camera was shipped from Ophir-Spiricon it may already have the license key loaded and steps 4 through 6 can be skipped*

5. Locate the camera license key supplied with the BeamGage DVD or camera and enter this code. Enter the license on each computer where the camera is used
6. Cycle the **Source** selector to **File Console** and then back to **Local Detector**
7. It should startup running and collecting frames from the camera
8. In the **Source** ribbon click on the **Pause** button
9. Go to the **Camera Correction File** panel and click on the drop-down arrow
10. Select Browse...
11. Go to the folder: C:\Program files\X-Control\CalibrationPacks\
12. Click on an .xca file name that contains **TrueNUC\_HG** and click **Open**
13. Click **Start** on the **Source** tab
14. The camera should now be collecting data frames with a well corrected image with a raised black level baseline
15. The preset cooling temperature will normally be 17°C. Wait for the readout temperature to stabilize at this setting
16. Once stabilized, block the imager from stray radiation and perform an **Ultracal**
17. You are now ready to collect laser beam images in **CW** mode
18. Attenuate the laser and adjust the **Exposure** time to an appropriate setting, you will need to re-Ultracal when the exposure time changes



*To disconnect a XEVA camera always first remove power to the camera, then unplug the USB cable.*



*There is a known bug with the XEVA camera regarding unplugging the camera's USB cable with the camera under power. Doing so will crash the camera firmware. You must now power cycle the camera to restart it. When you re-plug the USB cable into the PC the camera will once again ask you to supply the Camera License Key in order to restore its operation with BeamGage. XenICs has indicated that they are not going to fix this bug.*

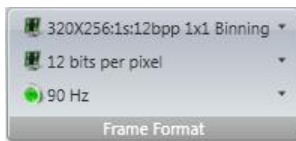


*Custom NUC files created with Xeneth will operate correctly when used by BeamGage.*

## H.3 Operation

This section describes the camera controls that are unique to the XenICs XEVA camera. Common controls are covered in other sections of this manual. **What's this**  help is available on all of the special XEVA controls.

### H.3.1 Frame Format

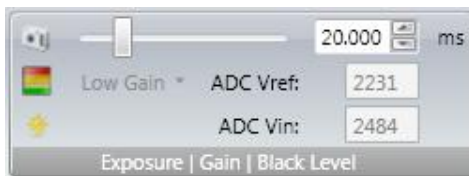


Many options are displayed on the Frame Format panel when working with a Xeva camera, but few need to be altered. The XEVA camera does not support binning, and because the imager has a small 320X256 format, there is little need for **ROI** adjustments. Due to this **ROI** controls are not included with XEVA cameras.

This camera only operates in 12 bits per pixel mode.

The XEVA camera model most commonly supplied or supported by BeamGage has a specified frame rate of 100Hz. With NUC, the rate drops to about 90Hz. Unless there is a need for longer integration times it is recommended to set the rate to 90Hz.

### H.3.2 Exposure | Gain | Black Level



The following settings are preset in the TrueNUC or NUC file to optimize the camera dynamic range for best beam measurement accuracy using BeamGage. Only the **Exposure** setting can be altered by the user and saved into a BeamGage setup file.

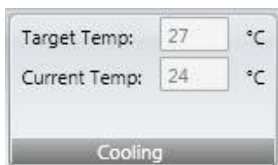
The **Exposure** control operates much like any other type of camera. It sets the exposure duration in milliseconds. When operating in external trigger mode, the exposure time begins upon receipt of the electronic trigger pulse. When using a regular NUC file (not a TrueNUC) the exposure setting should not be changed.

The **Gain** indicator follows the setting pre-programmed into the TrueNUC/NUC file. The setting can be either **High** or **Low**.

The **Black Level** indicator is also preset to the value that corresponds to the TrueNUC/NUC file. In Xeneth, this setting is called ADC Vin. It is displayed here only for verification purposes.

The **ADC Vref** indicator is also preset to the value that corresponds to the TrueNUC/NUC file. It is displayed here only for verification purposes.

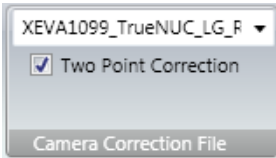
### H.3.3 Cooling



The XEVA camera has a cooler that is used to stabilize the imager. The InGaAs type of imager is very sensitive to changes in temperature. To ensure a stable baseline the temperature should be set to a value below the room temperature and below the detector's nominal operating temperature. Since 300° Kelvin is a nominal room temperature, and an operating camera will warm somewhat above this, all TrueNUC files force a temperature value of 17°C. If the environment is naturally colder, e.g. 12°C, then contact XenICs and order from them new TrueNUC/NUC files with a lower preset temperature value.

The camera has a cooler that can lower the imager temperature, but relies on normal heating of the camera to raise it. The readout from the camera indicates that the cooler is functioning and tracking to the present value. There is a nominal error between the set and the reported value from the camera. This error is compensated for in the TrueNUC/NUC file.

### H.3.4 Camera Correction File



To successfully use an InGaAs camera, such as the XEVA, a camera correction file must be downloaded to the camera. The file must match how the camera is setup for use. When the Xeneth software that came with the camera was installed, it copied the camera correction NUC files into a folder called:

**C:\Program files\Xeneth\CalibrationPacks\...**

This folder contains two or more .xca NUC files specific to each camera's serial number. The name of the file provides details about when it should be applied. A file that contains the letters LG or HG are for low gain/high gain settings respectively.

To load a NUC file click on the drop-down arrow and browse to the folder shown above. Select the appropriate TrueNUC/NUC .xca file and click **Open**.

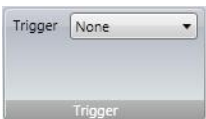
The **Two Point Correction** box should also always be checked. If unchecked you can observe what the camera output looks like w/o NUC.

This file name is saved in a setup file and automatically applied to the camera upon opening the setup if the camera is already attached. If the camera was not connected then it may need to be manually restored.



*Use of the NUC file reduces the maximum frame rate of the camera by an amount corresponding to the impact of the NUC effort required. Typically this yields a 10-20% reduction in maximum frame rate.*

### H.3.5 External Trigger Control



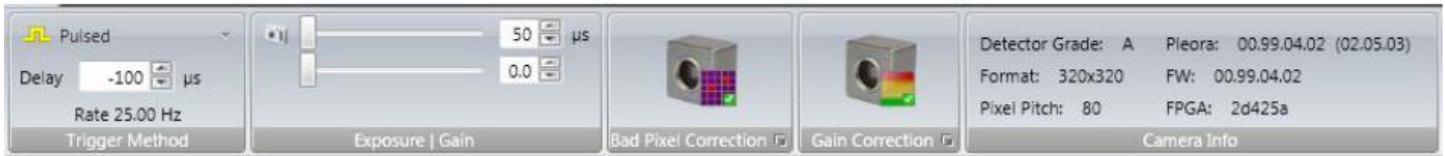
The XEVA camera is supplied with an external trigger input cable. The input to this cable should be a standard TTL level positive going pulse. The camera will trigger and begin integrating light on the rising edge. A trigger pulse should be at least 5µs in duration.

To operate in external trigger mode you must set this control to **Trigger In**. Select **None** when operating in CW mode.

# Appendix I Pyrocam IV and IIIHR Information

## I.1 Special Controls

The Ophir-Spiricon Pyrocam IV and IIIHR cameras do not operate like traditional CCD or CMOS devices and therefore require specially designed controls. All features for the Pyrocam IV and IIIHR are found in BeamGage. The unique Pyrocam IV and IIIHR panels are shown and described below.

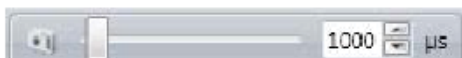


### Chopped (CW) vs. Pulsed

To operate in CW mode, the Pyrocam employs a rotating chopper that can operate at one of two different chopping rates, 25Hz and 50Hz. We recommend always using the 50Hz rate in order to obtain good response linearity. The 25Hz rate should only be used in combination with maximum gain and frame averaging to extract the very weakest of images.

When operating in pulsed mode, the Pyrocam must be externally triggered and the delay for the pulse width should be set to a value just slightly longer than the actual laser pulse.

The Rate value indicates either the current chopper frequency or the input trigger pulse rate in Hz.



### Exposure Control

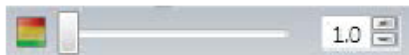
In Pulsed mode, the Pyrocam must be externally triggered and the **Exposure** control must be set to a value slightly larger than the input pulse width. The exposure range is from 50 to 65,535μs.



*The Exposure control has no effect in chopped mode and there is no Auto setup or Auto-X features for the Pyrocam IV or IIIHR.*



*Always remember to re-Ultracal after changing the **Exposure** setting.*



### Gain Control

The Pyrocam has a video gain control to help with viewing lower power lasers. The control will have different ranges in chopped and pulsed modes.



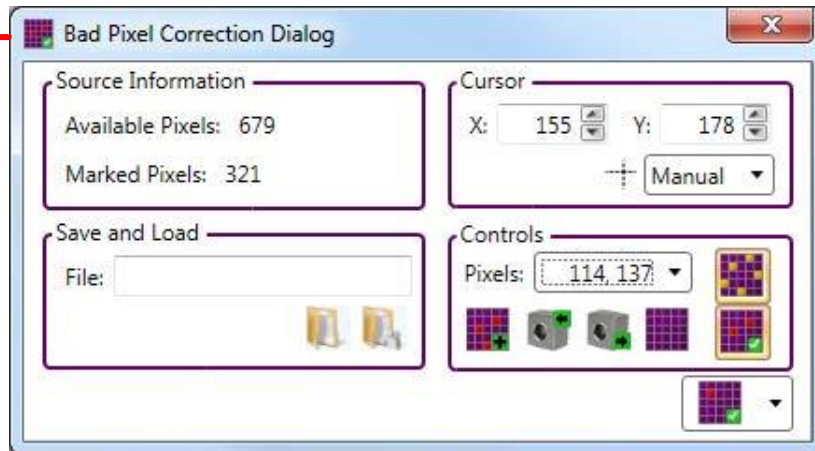
*Always remember to re-Ultracal after changing the **Gain** setting.*



### Bad Pixel Correction

Click this control to enable/disable bad pixel correction in the Pyrocam. **Bad pixel Correction** defaults to ON and should always be enabled. If this control is deactivated, it indicates that the Pyrocam does not have a Bad Pixel map programmed. Note that the Pyrocam has separate Bad Pixel Correction maps programmed for pulsed vs. chopped operation.

Select the expansion button to customize your own bad pixel correction map.



The **Source Information** group shows how many more pixels you can mark and how many pixels have already been marked. The **Save and Load** group allows you to save a different Bad Pixel maps for each Pyrocam. In the **Cursor** group, set the cursor to either **Manual** or **Peak** to locate the bad pixels. The X and Y values show the pixel value of the current cursor location.



### Add Pixel to List

Click to add the pixel at the current cursor location to the pixel correction list.



### Remove Pixel from List

Click to remove the pixel selected from the **Pixels** drop-down from the pixel correction list.



### Write Pixel List

Click to write the current pixel list to the camera.



### Read Pixel List

Click to read the current pixel list from the camera. This replaces the list currently displayed in BeamGage.



### Clear Pixel List

Clears all marked pixels from the correction list.



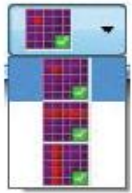
### Software Bad Pixel Correction

Enables/Disables the bad pixel correction built into the BeamGage software.



### Bad Pixel Correction Map

Highlights the pixels currently in the correction list.



### Pixel Selection Type

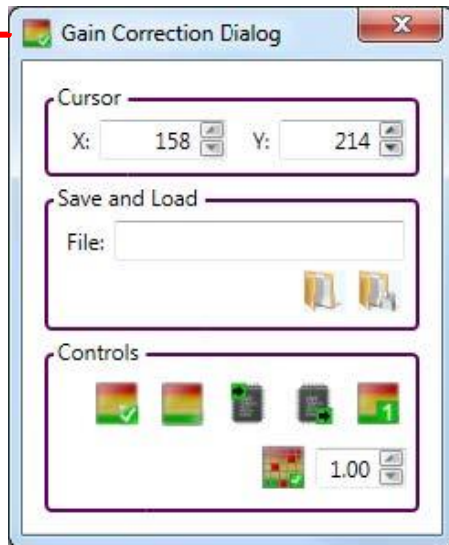
Selects whether to affect a single pixel, row of pixels, or column of pixels when adding or removing pixels from the correction list.



### Gain Correction

Click this control to enable/disable gain correction in the Pyrocam. **Gain Correction** defaults to ON and should always be enabled. If this control is deactivated, it indicates that the Pyrocam does not have a gain correction table programmed. Note that the Pyrocam has separate gain correction tables programmable for pulsed and chopped operation. Many Pyrocam units ship with a valid 50Hz chopped gain correction table installed at the factory. Pyrocam units almost never ship with a pulsed gain correction table.

Select the expansion button to customize your own **Gain Correction** table.



The X and Y values show the current pixel location of the cursor. The **Save and Load** group allows you to save a different Gain Correction table for each setup of your Pyrocam.



### Software Gain Correction

Enable/disable the built in software gain correction.



### Create Gain Table

Click to create the table of gain correction values.



### Write Flash

Click to write the gain correction values to the camera.



### Read Flash

Click to read the gain correction values from the flash.



### Set Gain Frame to Default

Click to set the gain frame to the default value of 1.0 for each pixel.





### **Pixel Gain Value**

Select the gain value for the pixel at the current cursor position. Available options are between 0.33 and 3.00.



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