

**User Guide**

# BEAMPEEK™

## BEAM PROFILER AND POWER METER FOR THE ADDITIVE MANUFACTURING INDUSTRY



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# 1 Warnings and Safety

While BeamPeek itself does not present the user with any safety hazards, this instrument is intended for use with laser systems. Therefore, the user should be protected 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.

## 1.1 Safety Procedures and Precautions

The following general safety precautions must be observed during all phases of operation of this instrument. Failure to comply with these precautions or with specific warnings elsewhere in this guide violates safety standards of intended use of the instrument and may impair the protection provided by the equipment. MKS Instruments, Inc. and its subsidiaries assume no liability for the customer's failure to comply with these requirements.

### 1.1.1 Do Not Substitute Parts or Modify Instrument

Do not install substitute parts or perform any unauthorized modification to the instrument. Return the instrument to an Ophir Calibration and Service Center for service and repair to ensure that all safety features are maintained.

### 1.1.2 Optical Radiation Hazards



BeamPeek is designed for use with high power lasers and therefore safety precautions must be taken. Users must be protected against accidental exposure. Exposure to personnel other than the user must also be considered.

Unless the laser's optical path is enclosed, the operator, and any other personnel must 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 must be worn.

### 1.1.3 Electrical Hazards



BeamPeek utilizes only low voltages. BeamPeek derives its power from the USB cable connected to a PC. Thus, there is little risk of electrical shock.

When installing or removing hardware from a PC, the power to the computer should always be disconnected.

The computer should always be operated with its covers in place and in accordance with its manufacturer's recommendations.

The computer should always be operated with a properly grounded AC power cord.

## 1.2 Symbols Used in this User Guide

Definitions of NOTE, CAUTION, and WARNING messages used throughout the guide.

### **NOTE**

The NOTE sign denotes important information. It calls attention to a procedure, practice, condition, or the like, which is essential to highlight.

### **CAUTION**

The CAUTION sign denotes a hazard. It calls attention to an operating procedure, practice, or the like, which, if not correctly performed or adhered to, could result in damage to or destruction of all or part of the product.

### **WARNING**

The WARNING sign denotes a hazard. It calls attention to a procedure, practice, condition, or the like, which, if not correctly performed or adhered to, may result in injury to personnel.

## 2 Introduction

### 2.1 What is BeamPeek?

The Ophir BeamPeek Beam Profiler and Power Meter is designed to analyze laser beams up to 1kW. The optical design enables measurement of both 532nm and NIR wavelength lasers. BeamPeek is designed for use inside Additive Manufacturing (AM) chambers and can simultaneously measure power as well as profile the laser beam. Thanks to the innovative design, the BeamPeek can measure continuously for up to two minutes at maximum power, and even longer by swapping the replaceable beam dump. BeamPeek is intended to provide a complete solution for beam analysis inside AM machines.

### 2.2 Principles of Operation

The beam enters the device through the aperture on the top of the instrument (1). As the beam passes through optical wedges, it is attenuated and profiled by the camera. A beam sampler further splits approximately 4% of the beam and reflects it to the power sensor where the power is measured. The remaining 96% is directed to the beam dump. This design maintains the low operating temperature necessary for accurate power and beam profile measurement. Note that high density beams must be further attenuated before contacting the camera. To accommodate this, there are three fixed ND filters and three interchangeable ND filters (2) in the camera's path to allow image intensity control together with camera exposure.

#### NOTE

The BeamPeek must be operated with one of three interchangeable ND filters inserted to maintain the integrity of the optical path between the entrance and the camera.

The lens tray (3) holds one of three interchangeable lenses. These are intended to increase beam size to lower the power density on the beam dump.

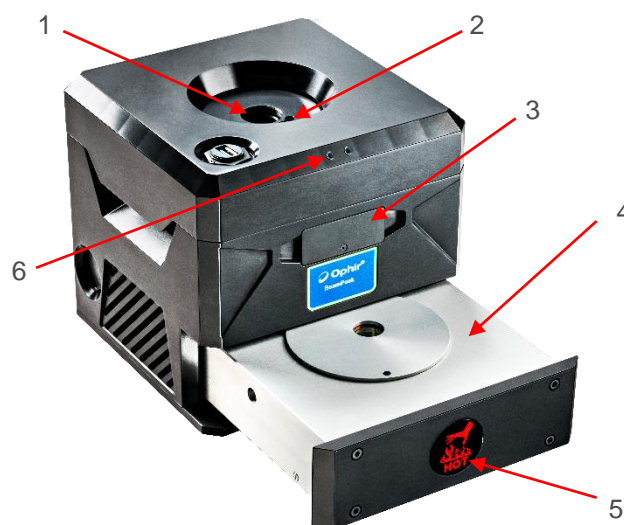


Figure 1: BeamPeek Detailed View

**CAUTION**

Failure to use the proper lens for the beam's wavelength can lead to incorrect power readings, beam dump damage, and large back reflections into the AM chamber.

Typical AM machines are equipped with high power lasers which could heat the measurement equipment enough to interfere with the accuracy of measurements. To contain it, BeamPeek includes a beam dump (4) designed to remove the excess heat from the measurement system. The heat warning sticker (5) will turn red when the beam dump reaches high temperatures.

An additional beam dump cartridge can be ordered as an accessory (P/N SP98005).

**NOTE**

The beam dump cools passively. It is not a water or fan cooled system. Users can extend the measurement duration by using two beam dumps, interchanging them when one gets too hot. One beam dump can be used for up to 2 minutes at 1000W and handled without need for thermal protection.

The device contains two LEDs (6). The green LED indicates when power is supplied. The red LED is a warning light that blinks when the temperature sensors are nearing the safe operating limit and remains lit when the temperature reaches or exceeds the safe operating limit.

The main body and the camera are both monitored by temperature sensors. The status is displayed in the BeamPeek application as annunciators (see section 4.5 Status Bar). There is no temperature sensor on the beam dump, only the heat warning sticker.

**WARNING**

At temperatures exceeding the safe operating limit, the camera measurements lose accuracy and the device may become too hot to handle.

## 3 Setup

### 3.1 Software installation

The BeamPeek device is licensed to operate with both the BeamPeek software and BeamGage Professional. Only details for the BeamPeek software are explained here. For information on use with BeamGage Professional see Appendix A.

Install the BeamPeek software from the Ophir website. Software installation must be performed with Administrator privileges.

- Navigate to the Ophir software download page:
  - <https://www.ophiropt.com/laser--measurement/software-download>
- Select the BeamPeek software package to start the download.
- Extract the contents of the zip folder to a local destination on the PC.
  - Do not extract the files to a Network location as this may cause the installation to not execute properly.
- Open the extracted folder and select the file "BeamPeek.Setup.exe"
- Follow the directions on screen.
- The BeamPeek shortcut icon (Figure 2) appears on the desktop.

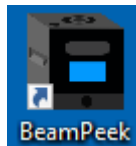


Figure 2: BeamPeek Shortcut Icon

### 3.2 Hardware setup

The device comes from the factory calibrated and ready to measure.

1. BeamPeek ships with two M6 hex locking screws at the bottom of the unit (Figure 3). These secure the beam dump during transportation and must be removed before first use. After screw removal, the beam dump remains secured by the quick-release pins, found on both sides of the device.



Figure 3: Beam Dump Locking Screws on the Bottom of the Unit

2. Verify that the replaceable lens is correct for the laser in use (refer to section 3.3 Lens Selection).
  - a. F20/532nm/700W



- b. F20/1030-1080nm/700W
- c. F12.7/1030-1080nm/1000W

**CAUTION**

Inserting the lens incorrectly will cause damage to the unit when the main beam is applied! The screw must be oriented towards the bottom of the unit.



Figure 4: Correct Lens Orientation

3. Place the BeamPeek so the guide beam is centered on the supplied target cap (Figure 5).



Figure 5: Target Cap

**CAUTION**

Dust particles on the optical elements may damage the optics when contacted by the focused beam. Protect the BeamPeek internal optics from contamination by keeping the target cap, ND filter, and lens installed between uses.

4. Connect the provided USB 3.0 cable to the BeamPeek and to the PC. The green LED will illuminate when connected.

- Open BeamPeek software. If only one BeamPeek device is found the software will automatically connect. If multiple BeamPeek devices are found, select the desired unit from the **Data Source** panel.

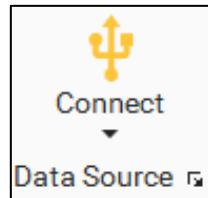


Figure 6: Data Source Panel

- Lower the AM machine bed by the **Focal Plane Offset** distance. This places the camera sensor at the build plane. The **Focal Plane Offset** is printed on the BeamPeek calibration sticker and can be found in the **Hardware** group of the **Results** window in the BeamPeek software (Figure 8).

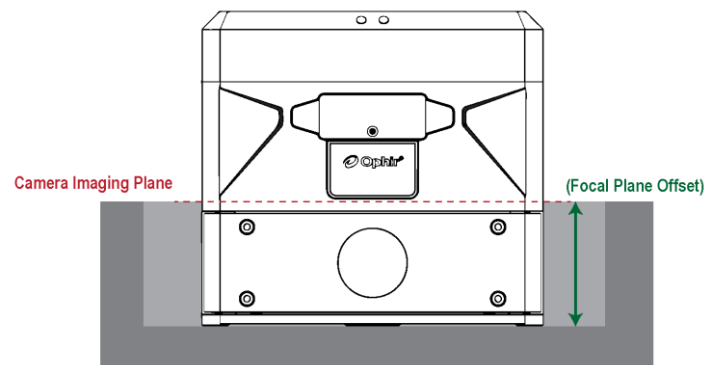


Figure 7: Camera Image Plane

Hardware		
Focal Plane Offset	76.830	mm

Figure 8: Focal Plane Offset in the Results Window

## CAUTION

Take care not to place the BeamPeek more than 5mm past the Focal Plane Offset, 10mm when beam power is less than 300W. Failing to do so may damage the beam dump and optical elements.

Lowering the BeamPeek a distance less than the Focal Plane Offset will not cause any damage.

- In BeamPeek, enter the laser wavelength in the **Settings** panel (Figure 9).

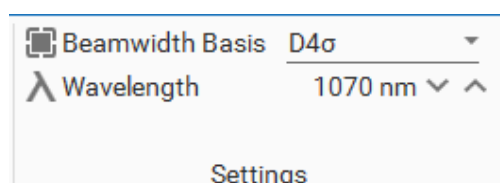


Figure 9: Settings Panel



8. With only the guide beam emitting, remove the target cap and the ND filter.
9. Verify that the guide beam is in the center of the optical axis of the device. This is defined by the **X** and **Y Alignment** results being:
  - a. Within 500µm of the calibrated optical axis position when using an F=20mm lens
  - b. Within 300µm of the calibrated optical axis position when using an F=12.7mm lens

▼ Frame (Quantitative)			▼ Frame (Quantitative)		
D4σ ISO	125.695	µm	D4σ ISO	101.411	µm
Z Location	—	mm	Z Location	—	mm
X Alignment	11.636	µm	X Alignment	677.688	µm
Y Alignment	-14.951	µm	Y Alignment	918.829	µm
Total Power ISO	43.100	W	Total Power ISO	42.600	W
Avg Pwr Density ISI	347,816.275	W/cm²	Avg Pwr Density ISI	527,469.359	W/cm²

Figure 10: X and Y Alignment Results

**NOTE**

Power measurement accuracy will degrade if the beam is not aligned to the calibrated optical axis.

The calibrated optical axis position may not be in the center of the camera imager. If the beam centroid is more than 500µm from the calibrated position, the X Alignment and/or Y Alignment results will turn red.

10. Based on initial laser data, select and install the proper ND filter (see section 3.4 ND Filter Selection).
11. Turn on the laser at minimum power and begin to gradually increase until a beam is visible and power measurements are received. The power reading should stabilize after 3-5 seconds and be within 10% of the expected value. If not, verify that the BeamPeek is set up correctly (steps 2-10 above).

**CAUTION**

If encountering unexpected behavior or results, confirm the following:

- System is aligned to the calibrated Optical Axis Position.
- Correct lens is inserted in the proper orientation.
- There is no obstruction to the optical path, including contamination on optics.

If unexpected behavior continues, turn off the laser and contact Product Support. Continued operation may damage the unit.

12. BeamPeek is now ready to start taking measurements.

It is advised to review the remainder of this guide to become familiar with the controls, displays, and procedures before attempting to operate the BeamPeek system.

### 3.3 Lens Selection

BeamPeek is equipped with three lenses:

- F=20mm (for 532nm)
- F=20mm (for 1030nm–1080nm)
- F=12.7mm (for 1030nm–1080nm)

Ensure that the correct diffusing lens is in place. Use the F=20mm lens for divergence greater than 20mrad (full angle) and power up to 700W, or for divergence greater than 30mrad for Single Mode lasers up to 1kW. Use F=12.7mm lens for beam divergence under 20mrad.

The information in Table 1 will help select an appropriate lens and the associated measurement cycles.

Cycle times are determined by the amount of time the beam can be continuously emitted before a pause is required. This pause allows the heat in the BeamPeek to dissipate effectively for longer overall measurements. Number of cumulated cycles is determined based on beam dump, body, and camera temperatures.

Table 1: Lens Selection

Lens Selection				
Lens Type	F=20mm		F=12.7mm	
Wavelength	532nm; 1030nm – 1080nm		1030nm – 1080nm	
Beam Divergence (Full Angle)	Min=20mrad Max=100mrad		Min=10mrad Max=40mrad	
Laser Type	Multi-Mode	Single Mode	Multi-Mode	Single Mode
Power Levels [W]	CW cycle[s]/Pause[s]			
5-500	no limit	no limit	no limit	no limit
500-700 (up to 6 cycles)	60/5	30/5	no limit	45/5
700-1000 (up to 4 cycles)	30/5	30/5*	45/5	30/5

\* For divergence greater than 30mrad only, otherwise use F=12.7mm lens

**NOTE**

- Always examine the inserted lens before taking measurements to confirm the desired wavelength, focal length, and cleanliness.
- An incorrect lens will yield incorrect power readings (>10% error) and increase the temperature of the main body.
- F=20mm lens allows larger X-Y positioning error and is the preferred selection whenever possible.

### 3.4 ND Filter Selection

Attenuation is modified by replacing the ND filter. Reference the information in Table 2 to select an appropriate filter. For other power and spot diameter values, evaluate by interpolation using the power density. There may be multiple ND filters that provide sufficient attenuation for a given setup.

For caustic measurement, select the lowest ND value that does not show saturation when viewing the minimum beam diameter.

Table 2: ND Filter Selection

Power (W)	Spot size (µm)	ND
1000	35	ND4
100	70	ND4
500	150	ND2.5
20	200	ND2.5
10	200	ND1

**NOTE**

- Values are for single mode lasers ( $M^2 \sim 1.0$ ).
- For NIR beams with diameters smaller than 150µm, higher ND values are preferred to increase the stability and accuracy of the measurement.
- Always examine the inserted ND filter before taking measurements to confirm the desired ND and cleanliness.

## 4 User Interface

BeamPeek follows the Windows ribbon control motif which provides intuitive access to control functions as well as the ability to hide the controls for better screen utilization. The following sections describe the various control features available in BeamPeek.

Figure 11 contains all main display windows.

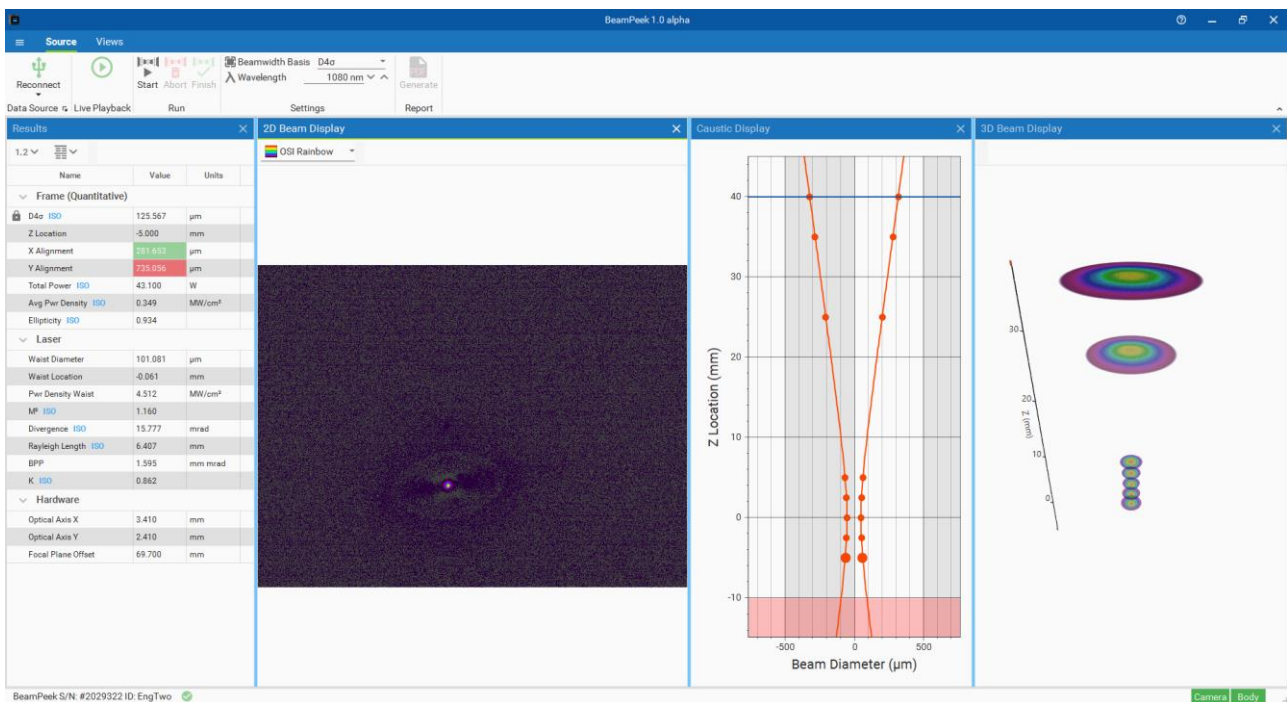


Figure 11: BeamPeek User Interface

### 4.1 User Interface Customization

BeamPeek software provides the ability to create flexible display environments to meet your preferences. All windows can hide, float, and reposition on the screen. The application opens with the same configuration as when it was closed.

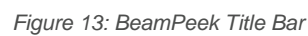
#### 4.1.1 Docking Handles

To undock a window, click and drag anywhere in the title bar with the mouse. When dragged, a set of docking handles appear. In Figure 12 the **2D Beam Display** window is being dragged. Drag the display over one of the docking handles and release to place the window in that position. If the window is not released on one of the docking handles, it floats. All windows can be docked to any of the display handles or left to float anywhere on the screen or on secondary displays.



Floating windows can be maximized to fill the screen. They can also be re-docked into the main application by dragging the title bar into the main display window and dropping on a dock handle.

## 4.2 Title Bar



### System Menu Button

## Application Information

**Help**

## Standard Windows Controls

13 | BEAMPEEK

## 4.3 File Menu

Select  to access the **File Menu** (Figure 14).

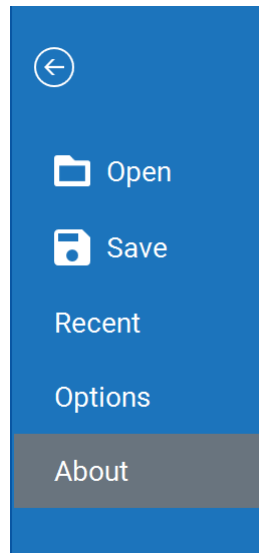


Figure 14: File Menu

### 4.3.1 Open

Opens Windows Explorer to navigate to a specific file to open for review.

### 4.3.2 Save

Opens Windows Explorer to navigate to a location to save the current data set.

### 4.3.3 Recent

Stores quick links to recent data files.

### 4.3.4 Options

Contains options to customize the application UI (Figure 15).

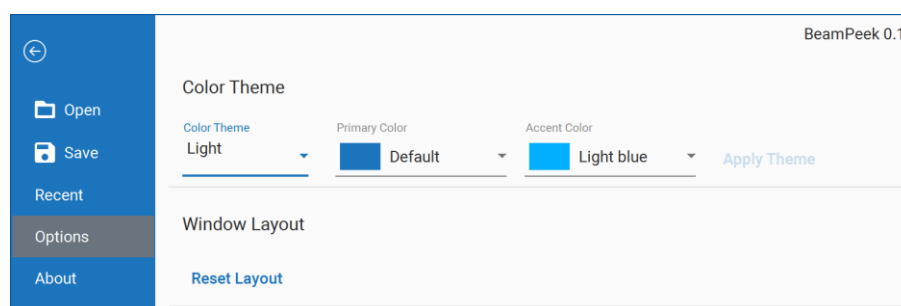


Figure 15: BeamPeek Options

**Color Theme** allows customization of the color scheme of the user interface. Choose a combination of a light or dark theme, a primary color, and secondary color. Select **Apply Theme** to accept changes.



**Windows Layout** allows you to restore all windows to a docked location within the primary window.

### 4.3.5 About

Displays the current software version, copyright information, a link to this user guide, and contact information for Product Support.

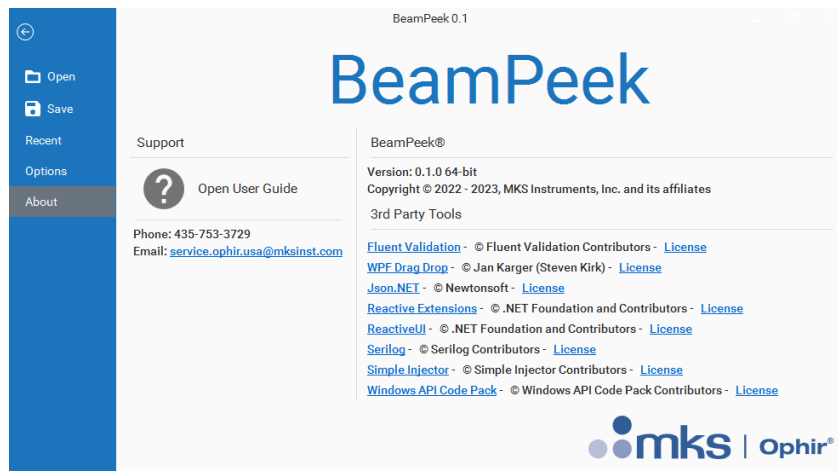


Figure 16: BeamPeek About Page

## 4.4 Ribbon bar

The **Ribbon** bar displays the current set of panel control options available within a selected **Ribbon** tab (Figure 17). These panels contain all common control items.

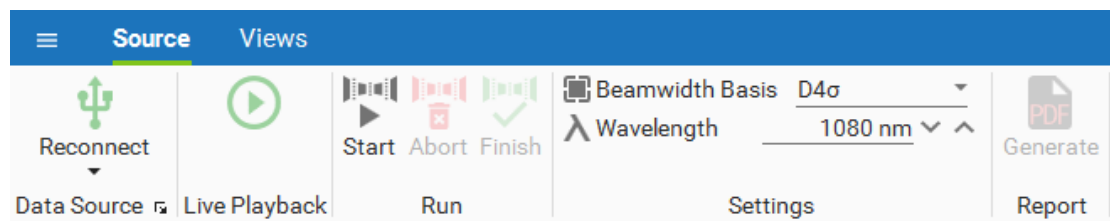



Figure 17: BeamPeek Ribbon Bar

### 4.4.1 Show/Hide Ribbon Bar

Select  in the bottom-right corner of the **Ribbon** bar to minimize the ribbon bar. Click the icon again to restore to full size.

Double-click any ribbon tab to fully hide the ribbon bar. A single click will open the ribbon until you click off the ribbon. Double-click a ribbon tab again to restore the ribbon to full size.

## 4.5 Status Bar

The **Status** bar contains useful information about the connected device and state of the system (Figure 18).



Figure 18: Source Info and Annunciators in the Status Bar

### Source Info

**Source Info** displays the BeamPeek model, serial number, and device alias when a camera is connected or when viewing a loaded file.

### Annunciator

The **Annunciator** monitors the temperature of the BeamPeek body and camera and notifies if the device is overheating. As the respective temperature readouts near or exceed permissible limits, the annunciators change from green (okay), to yellow (warning), to red (overheated). The body temperature sensor is placed close to the optical aperture and can indicate misalignment of the laser beam. **If misaligned, the device could overheat in 10-15 seconds.**

## CAUTION

If the **Body** annunciator turns red, immediately remove the device from the chamber and allow it to cool to prevent damage to the device.

## NOTE

The **Camera** temperature is read from the camera housing inside the BeamPeek device. As the camera heats, the dynamic range will decrease and the imager noise will increase, thus reducing result accuracy.

## 4.6 Panels

Panels are the divisions of the **Ribbon** bar that contain buttons, drop-down lists, edit controls, etc. Hover the mouse over a control to view the tooltips which are available on most items.

## 4.7 Source

### 4.7.1 Data Source

On startup the BeamPeek software automatically connects to the first system found. If a BeamPeek hardware device is plugged in after the software launches, select **Connect** (Figure 19) to find the device. The software can only connect to one BeamPeek at a time.

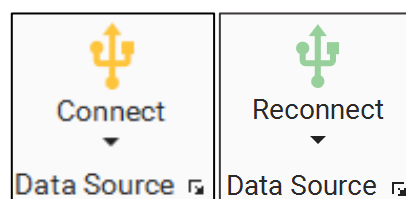


Figure 19: Data Source Panel

The **Data Source** panel has an expansion button in the bottom-right corner that opens the **Source Info** window (Figure 20). This window displays the serial number of the connected device and allows adding an alias to the device in the **Edit Alias Name** field. Only alphanumeric characters are accepted, no spaces or special characters are allowed. This alias appears in the **Data Source** list and in the **Status Bar**.

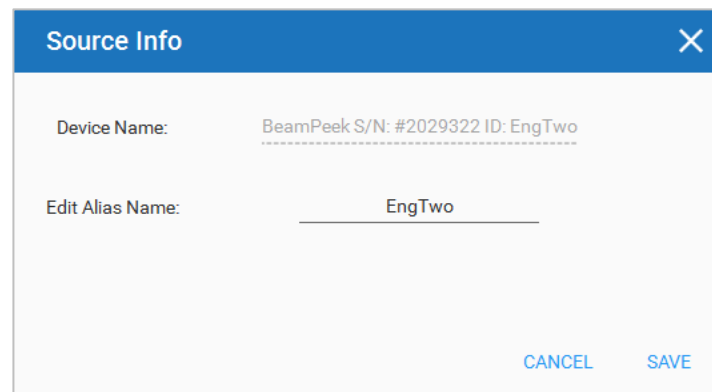


Figure 20: Source Info Window

#### 4.7.2 Live Playback

When **Live Playback** (Figure 21) is enabled, all active displays and results update in real time.

Data collected in live mode is not stored and therefore cannot be saved or loaded. Only results in the **Frame (Quantitative)** group are computed.

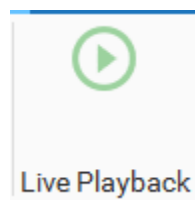


Figure 21: Live Playback Button

#### 4.7.3 Run

The **Run** panel (Figure 22) features buttons to start, abort, or finish a caustic measurement.

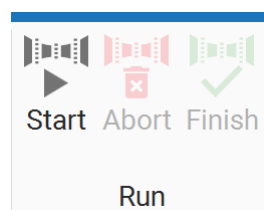


Figure 22: Run Panel

##### Start

The **Start** button is used to begin a caustic measurement run. When you start a run, the **Run** wizard appears. Use the wizard to take measurements at various points along the caustic. BeamPeek needs at least five measurement points to create a caustic, but ten or more are recommended for accurate results. See section 5.1 for instructions on using the wizard.

**NOTE**

If a caustic measurement has already been completed when **Start** is selected, a pop-up window appears asking if you would like to save or discard the data or cancel the **Start Run** operation.

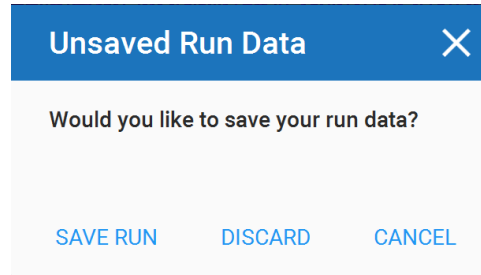


Figure 23: Unsaved Run Data pop-up

**Abort**

The **Abort** button can be used to end an in-progress caustic measurement. Aborting the process discards all collected data. You can also abort the run using the **Abort Run** button in the wizard.

**Finish**

The **Finish** button can be used finish and accept the caustic measurement data. It is greyed out and cannot be selected until at least five measurement points have been collected. You can also finish the run using the **Finish Run** button in the wizard.

**NOTE**

ISO recommends at least 10 measurement points to achieve accurate results.

## 4.7.4 Settings

The **Settings** panel (Figure 24) contains the settings for beam measurement.

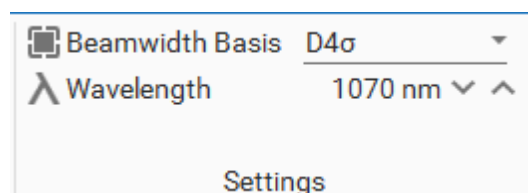


Figure 24: Settings Panel

**Beam Width Basis**

**Beam Width Basis** defines the beam width method used in computing all results items that require and rely on the Beam Width as an input.

Use the drop-down menu to select the desired beam width basis for measurement. Choose from the following options:

- D4σ
- % Peak (13.5% clip level)
- EPSA (86.5% clip level)

Only diameter results are computed. Details about each method are found in Chapter 7.

### Wavelength

Enter the wavelength of the beam in nm. This value is used to configure the power meter and to calculate **Beam Quality** results.

## 4.7.5 Report

The report feature generates a PDF file with data from the previous run, an image of the **Caustic Display**, and the **3D Beam Display**.

When clicked, a Windows Explorer dialog box opens. Enter a file name and select the save location, then select **Save**. The report will save and open automatically using your default PDF viewer program.

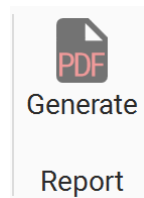


Figure 25: Report Panel

## 4.8 Views

The panels in the **Views** ribbon allow turning on and off all the display windows (Figure 26).

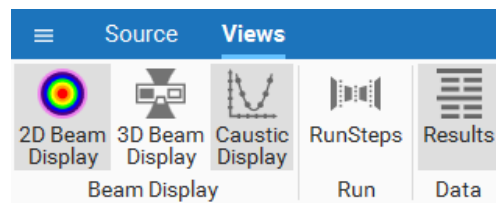


Figure 26: Views Ribbon

### 4.8.1 2D Beam Display

The **2D Beam Display** (Figure 27) presents the real-time data from the camera or the selected frame if a run has completed or a saved file is open.

Scroll the mouse wheel to zoom and left click and drag to pan the display area.

The color palette drop-down (top left) displays color palette options for the beam profiles. Palettes are designed to work with a variety of laser safety eyewear.

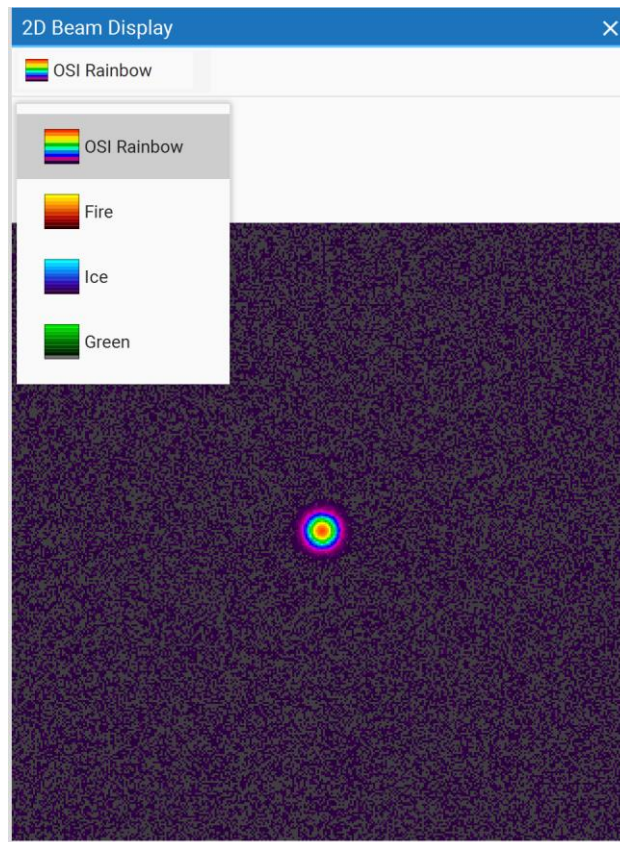


Figure 27: 2D Beam Display

#### 4.8.2 Caustic Display

The **Caustic Display** (Figure 28) shows the X and Y beam widths plotted against the Z axis locations. An estimated curve appears as soon as enough data accumulates, stabilizing as the run progresses. The results also update as the collection process continues.

Scroll the mouse wheel to zoom and left-click and drag to pan the display area.

Single-click a data point to view the **Frame** results and the **2D Beam Display** saved at that location.



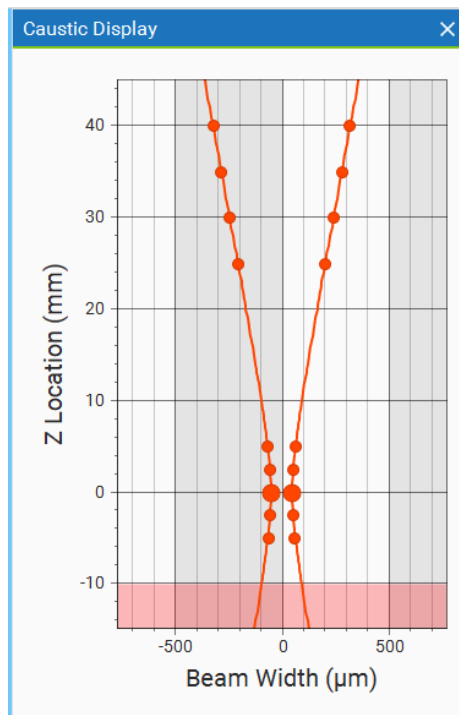


Figure 28: Caustic Display

The red region at the bottom of the display represents the danger zone for the BeamPeek device. If the device is lowered to this region while the main beam is emitting, damage may occur to the beam dump and optical elements. The location of this shaded region shifts based on the beam power and waist location. The BeamPeek cannot be lowered more than 5mm past the Waist Location, 10mm if the power is less than 300W.

### 4.8.3 3D Beam Display

The **3D Beam Display** (Figure 29) provides a 3D representation of the beam made up of the frames saved during a run. Each slice represents a data point in the **Caustic Display**.

Left click and drag anywhere in the display to rotate the image. Right click and drag anywhere in the display to pan the image. Zoom by scrolling the mouse wheel.

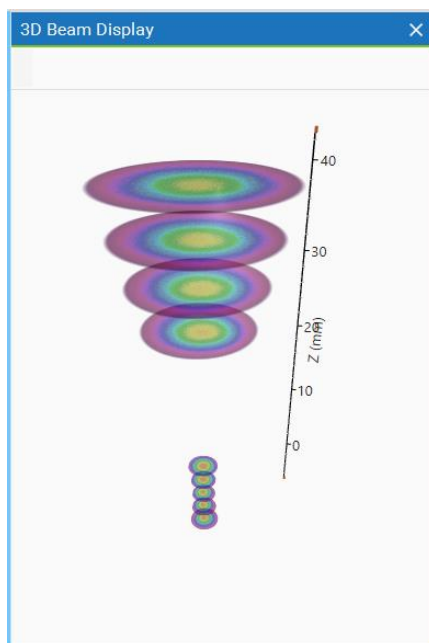


Figure 29: 3D Beam Display Window

#### 4.8.4 Results

The **Results** window (Figure 30) displays all enabled result items. Result items can be customized to display only the parameters that are relevant for each user.

Results			
1.2			
Name	Value	Units	
Frame (Quantitative)			
D4σ ISO	125.567	μm	
Z Location	-5.000	mm	
X Alignment	11.653	μm	
Y Alignment	-14.944	μm	
Total Power ISO	43.100	W	
Avg Pwr Density ISO	0.349	MW/cm²	
Ellipticity ISO	0.934		
Laser			
Waist Diameter	101.081	μm	
Waist Location	-0.061	mm	
Pwr Density Waist	4.512	MW/cm²	
M² ISO	1.160		
Divergence ISO	15.777	mrاد	
Rayleigh Length ISO	6.407	mm	
BPP	1.595	mm mrad	
K ISO	0.862		
Hardware			
Optical Axis X	3.140	mm	
Optical Axis Y	1.660	mm	
Focal Plane Offset	76.830	mm	

Figure 30: BeamPeek Results window

## Results Settings

**Results** settings are found at the top of the **Results** window and allow you to customize how results are displayed. The options are described below from left to right.

### Notation

Click the drop-down to choose between **Scientific** or **Decimal** notation.

### Results Filter

Select the drop-down and hover over a results group to select which results are active or inactive.

- An empty check box shows that no results are enabled. Select to enable all results.
- A blue dash shows that some results are enabled. Select to enable all results.
- A blue checkbox shows that all results are enabled. Select to close all results.

## Definition of Results

A brief description of all available results is given here. See Chapter 7 for a detailed explanation of most calculations.

### Frame (Quantitative)

- **Beam Width**—Measured beam diameter based on the selected beam width basis.
- **Z Location**—The BeamPeek location when the sample point was generated, measured from the build plane.
- **X Alignment**—The distance between the beam centroid and the calibrated optical axis position in the X axis.
- **Y Alignment**—The distance between the beam centroid and the calibrated optical axis position in the Y axis.
- **Total Power**—The total power of the beam for the current frame.
- **Average Power Density (Avg Pwr Density)**—The total power of the beam divided by the current cross-sectional area.
- **Ellipticity**—The computed ratio of the major and minor beam widths. Beams with Ellipticity greater than 0.87 are considered circular by ISO standards. If the result is less than 0.86 the value highlights red.

### Laser

- **Waist Width ( $W_0$ )**—The diameter of the beam waist based on the selected beam width basis.
- **Waist Location ( $Z_0$ )**—The location of the beam waist measured from the build plane.
- **Power Density at Waist (Pwr Density Waist)**—The total power of the beam divided by the cross-sectional area of the beam at the waist location.
- **M2**—A wavelength dependent measure of beam focusability compared to a TEM<sub>00</sub> Gaussian beam ( $\geq 1$ ).
- **Divergence ( $\Theta_0$ )**—The far field full angle divergence of the laser
- **Rayleigh Length ( $Z_R$ )**— The distance from the waist to where the area of the beam cross-section is 2 times larger than the area at the waist.
- **Beam Parameter Product (BPP)**— A wavelength independent measure of beam focusability.
- **K**— A wavelength dependent measure of beam focusability compared to a TEM<sub>00</sub> Gaussian beam ( $>0$  and  $\leq 1$ ).

**Hardware Settings**

- **Focal Plane Offset**—The calibrated offset distance between the measurement plane and the camera sensor. This value represents the distance the BeamPeek must be lowered for the sensor to be imaging at the work surface.
- **Optical Axis X**—The location of the device optical axis center in the X direction relative to the bottom left corner of the camera sensor.
- **Optical Axis Y**—The location of the device optical axis center in the Y direction relative to the bottom left corner of the camera sensor.

## 5 Operation

BeamPeek is designed to measure beams with diameters down to 35µm at focus and up to 10mm at the entrance aperture, and divergence angles above 10mrad. Like with all beam profiling systems, appropriate attenuation and correct alignment is required to ensure measurement accuracy.

The beam dump can absorb and dissipate energy up to 2 minutes at 1000W and still be handled without need for protection. For lower powers, this can be spread out over a longer period. For faster cooling, remove the beam dump and place it on a metallic or granite surface.

### NOTE

**Increase measurement time by turning off the beam while the build plate location is adjusting.**

### 5.1 Run Wizard

To take measurements:

1. Click **Start** in the **Run** panel. The first time a run is started, a **Pre-Run Checklist** is shown (Figure 31). Carefully review the setup of the BeamPeek before starting a run to avoid damaging the device. Select **Cancel** to abort starting a run or select **Continue** to open the **Run** wizard (Figure 32). Selecting **Don't Show Again** will also proceed to open the **Run** wizard but the software will not show the checklist again the next time a run is started.

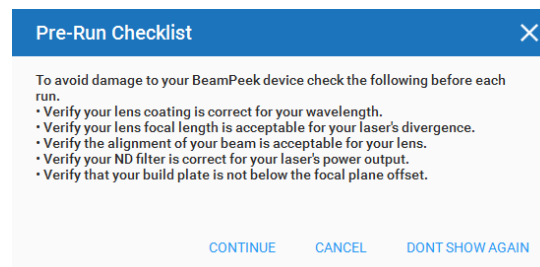


Figure 31: Pre-Run Checklist

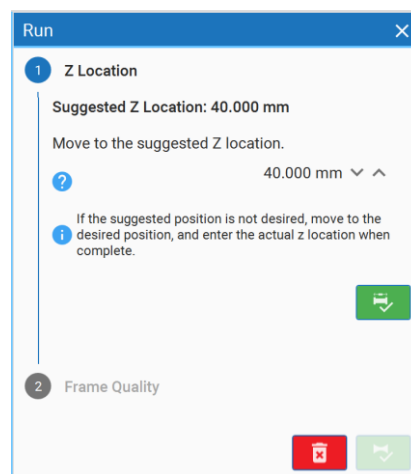


Figure 32: Z Location Step in the Run Wizard

## NOTE

At any point during the run, you can select the red Abort Run button at the bottom to end the run without saving.

2. Move the build plate to the suggested Z Location or to a different desired location for the first measurement point. Distances are determined by the Focal Plane Offset value, where lowering the build plate exactly by the Focal Plane Offset distance is 0, positive values are up (towards the beam delivery system), and negative values are down (away from the beam delivery system).

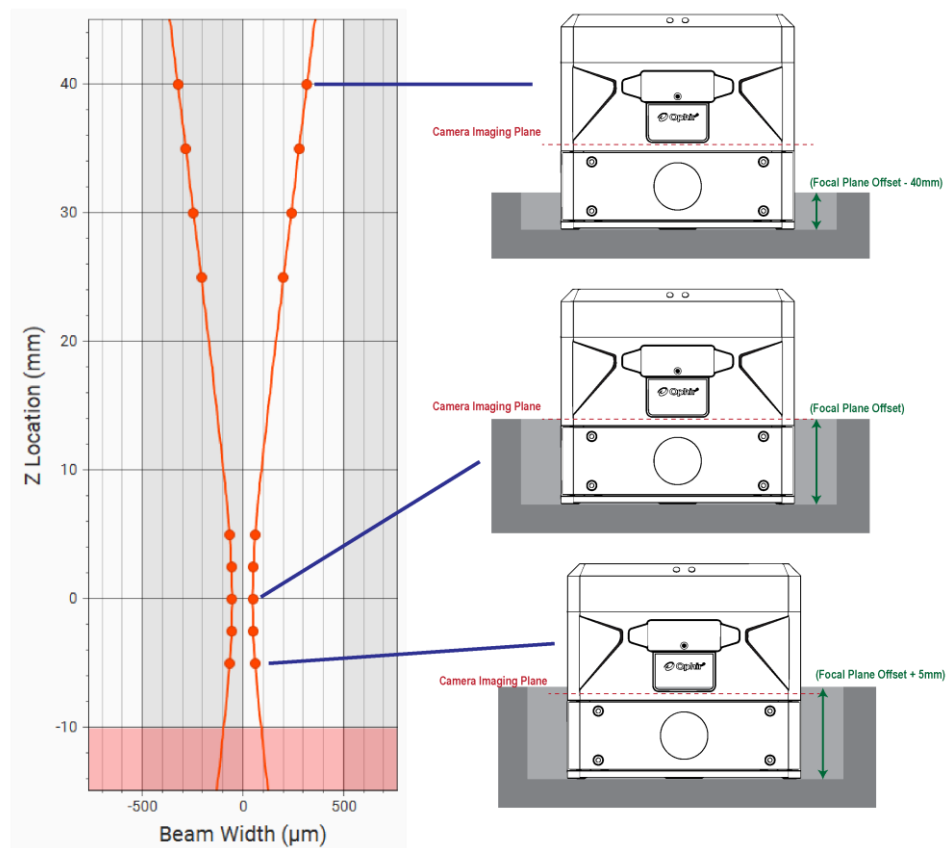


Figure 33: Device Position Relative to Caustic Display

## NOTE

If you move to a measurement location other than the suggested location, ensure that you enter it in the actual position field. If you do not, your results will be inaccurate.



## CAUTION

Moving the AM machine bed down too far beyond the Waist Location may damage the optics. The BeamPeeK cannot be lowered more than 5mm past the Waist Location, or 10mm when power is less than 300W.

If a Z location is entered that is beyond the safe operating space, a warning is displayed in the Run Wizard (Figure 34).

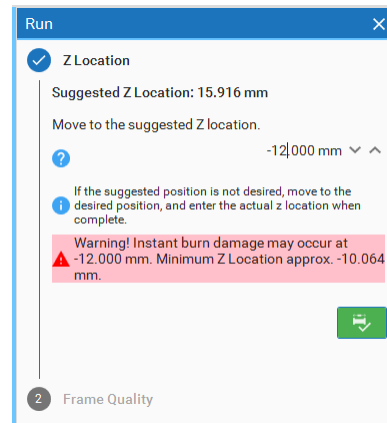


Figure 34: Z Location Warning

3. After moving the build plate, click **Accept Z Location**. The wizard will advance to the **Frame Quality** check.
4. **The beam must be emitting during the Frame Quality check.** The software performs an image quality check and indicates if there are any recommended corrections. A frame that has quality issues can still be accepted but doing so is discouraged. Possible warnings are:



**Adjusting** – The camera exposure and black level settings are automatically adjusted to produce the best image quality. Please wait while adjustments are being made.



**Misaligned** – The edge of the beam has reached at least one edge of the sensor. Measurement accuracy could be degraded. Accept frame or Abort Run, adjust the setup, and take a new measurement.



**Too big** – The edges of the beam have reached the edges of the sensor. Measurement accuracy could be lost. Accept frame or Abort Run, adjust the setup, and take a new measurement.



**Too small** – The calculated beam diameter is below 10 pixels (34.5µm). Measurement accuracy could be lost. Accept frame or Abort Run, adjust the setup, and take a new measurement.



**Too bright** – The peak beam energy is above 95% of the camera's dynamic range and the auto adjustment was unable to resolve the image. Change the ND filter to a higher value, Accept frame, or Abort Run.



**Too dim** – The peak beam energy is below 50% of the camera's dynamic range and the auto adjustment was unable to resolve the image. Change the ND filter to a lower value, Accept frame, or Abort Run.

As soon as a good frame is found, live playback stops. You then have the following options (Figure 36):



**Live Playback** – Re-enable live playback to view the beam in real-time.



**Single Frame** – Collect a single new frame from the camera.



**Accept Frame** – Accept the current frame and move on to the next Z location. If the beam has quality issues, this icon turns yellow. A frame cannot be accepted if live playback is running.

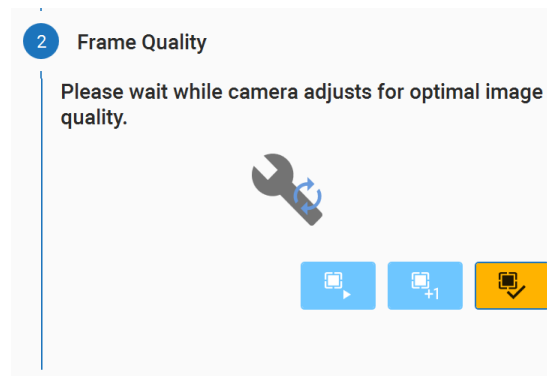


Figure 35: Frame Quality Step in the Run Wizard

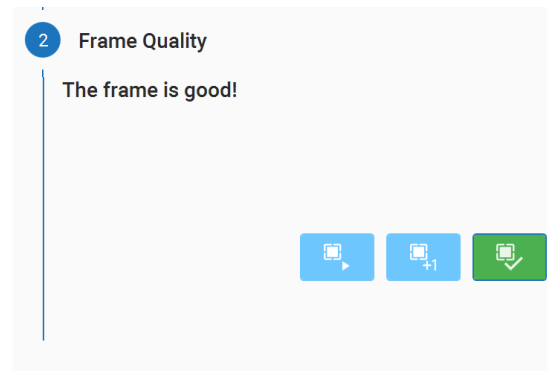


Figure 36: Good Frame Detected in the Run Wizard

- Each accepted data point appears in the **Caustic Display** window. Repeat the steps above to collect the remaining number of points. A caustic will begin to draw from the measurement points and refine as more points are collected. The results also update as the collection process continues.
- Once five points have been saved, the **Finish Run** button at the bottom-right becomes selectable. When you have taken enough points for your requirements, Select **Finish Run** to end the run.

## NOTE

ISO recommends at least 10 measurement points to achieve accurate results.

The **Run** wizard closes and data can be reviewed in the **Results** window.

## 6 Measurement Considerations

The BeamPeek software measures beam size, power, and caustic information in one application. For accurate measurements, follow setup steps outlined in the previous sections in this guide. Take the following comments under consideration while gathering measurements:

- During measurements, watch power values closely. They should be within 10% of the expected value.
  - If measured power values are different than expected, double-check the following:
    - The beam is correctly positioned relative to the optical axis within the recommended limits as described in section 3.
    - The correct diffusing lens is used.
    - The correct wavelength is entered in the **Settings** panel.
- Do not exceed the recommended exposure of 30 seconds continuous operation with 5 second pauses at 1000W, or equivalent for power levels of 500W or higher, and up to 2 minutes or equivalent cumulated use. Keeping to these limits allows removal and replacement of the beam dump without the need for protective gloves.
  - As a reference, 1 minute exposure (two 30/5 cycles) at 1000W increases the beam dump temperature by 14°C and body temperature by 2°C. Beam dump temperature will be close to 80°C after 4 minutes at 1000W or equivalent.
- To avoid long exposure at high power, start by adjusting alignment and finding the focus position at a lower power.
- Note that many high-power lasers exhibit a thermal lensing effect which may cause the beam waist location to change at different powers.
- Use the F=20mm lens whenever possible. The F=12.7mm lens requires more accurate positioning.
- Use a thermal camera to determine actual temperatures after intense use or warning.
- Wait a few minutes after powering on the device to allow the internal components to thermally stabilize before starting a measurement.
- After three seconds of beam emission the power measurements are at least 95% of the nominal value.
  - Higher accuracy power measurements can be attained after 15s.
  - Power measurement specifications refer to measurements taken within one Rayleigh length of the beam waist.
- Always take caution not to move the bed down more than 5mm past the Waist Location of the beam, 10mm if power is less than 300W. Before the actual Waist Location is known, the **Focal Plane Offset** can be used as the reference.

For more information consult the BeamPeek specifications.

## 7 Computations

This section describes the basic calculations used in the BeamPeek product. No attempt is made to disclose every possible feature of the algorithms employed, but rather to convey the techniques used which allow the reader to verify conformity to the ISO procedures.

Computational methods that follow the ISO mathematical models are indicated in the **Results** window with 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. Some ISO results depend on certain prerequisites. One such prerequisite might be the need to utilize the second moment beam width as an input. If the user were to choose a different beam width basis, such as EPSA, then it is likely that the final results will not yield an ISO compliant answer.

### 7.1 Beam Diameters

Beam width is a term that describes how the user has decided to measure the size of a laser beam. BeamPeek employs a limited selection of beam width methods which provide the most common techniques. The ISO procedures have defined the Second Moment, or D4-Sigma beam width to be the standard for beam width definition.

BeamPeek calculates only diameter beam widths. The term *Diameter* implies that the beam is radially symmetric or circular in shape. According to ISO, when the ratio of the Beam Widths exceeds 0.87, then the beam can be described as circular and the Diameter result is appropriate.

#### 7.1.1 D4-Sigma Method, 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.

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

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:

- $Z$      The intensity of the pixel at  $(x, y)$
- $r$      The distance from the centroid  $(\bar{x}, \bar{y})$
- $\varphi$      The azimuth angle
- $\bar{x}$      The x coordinate of the centroid
- $\bar{y}$      The y coordinate of the centroid

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 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 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.

### 7.1.2 Percent of Peak Method, D%pk

The Percent of Peak diameter result is derived by taking the area of all pixels above the 13.5% clip level and computing the diameter of a circle that contains that amount of area.

### 7.1.3 Encircled Power Method, Depsa

The encircled power smallest aperture (EPSA) method is often referred to as a “power-in-a-bucket” method, where the size of the aperture is the bucket diameter.

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. This percentage returns 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.

## 7.2 Ellipticity

The Ellipticity result is the ratio of the computed beam widths along the Major (M) and Minor (m) axes of the beam using the selected Beam Width Basis. The Minor beam width is always divided by the Major to produce a result less than or equal to one. ISO defines beams with an Ellipticity greater than or equal to 0.87 as circular.

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

## 7.3 Curve Fitting

The collected data points are fit to the hyperbolic beam propagation equation using a non-linear least squares technique.

$$W(z)^2 = W_0^2 + \theta^2(z - Z_0)^2$$

Where:

- $W_0$  The beam width at the waist (the minimum focused spot size)
- $Z_0$  The waist location (measured from the reference plane)
- $\theta$  The far field full angle divergence

The results of the fit yield the  $W_0$ ,  $Z_0$ , and  $\Theta$  results.

## 7.4 $M^2$ , K Factor, and BPP

The  $M^2$  or K factor is computed from the values obtained from the curve fit as:

$$M^2 = \frac{1}{K} = \frac{W_0 \Theta \pi n}{4\lambda}$$

Where:

$\lambda$  The laser wavelength in a vacuum

$n$  The index of refraction of the medium (assumed to be ~1)

BPP is computed from the  $M^2$  results.

$$BPP = \frac{M^2 \lambda}{\pi}$$

## 7.5 Rayleigh Range

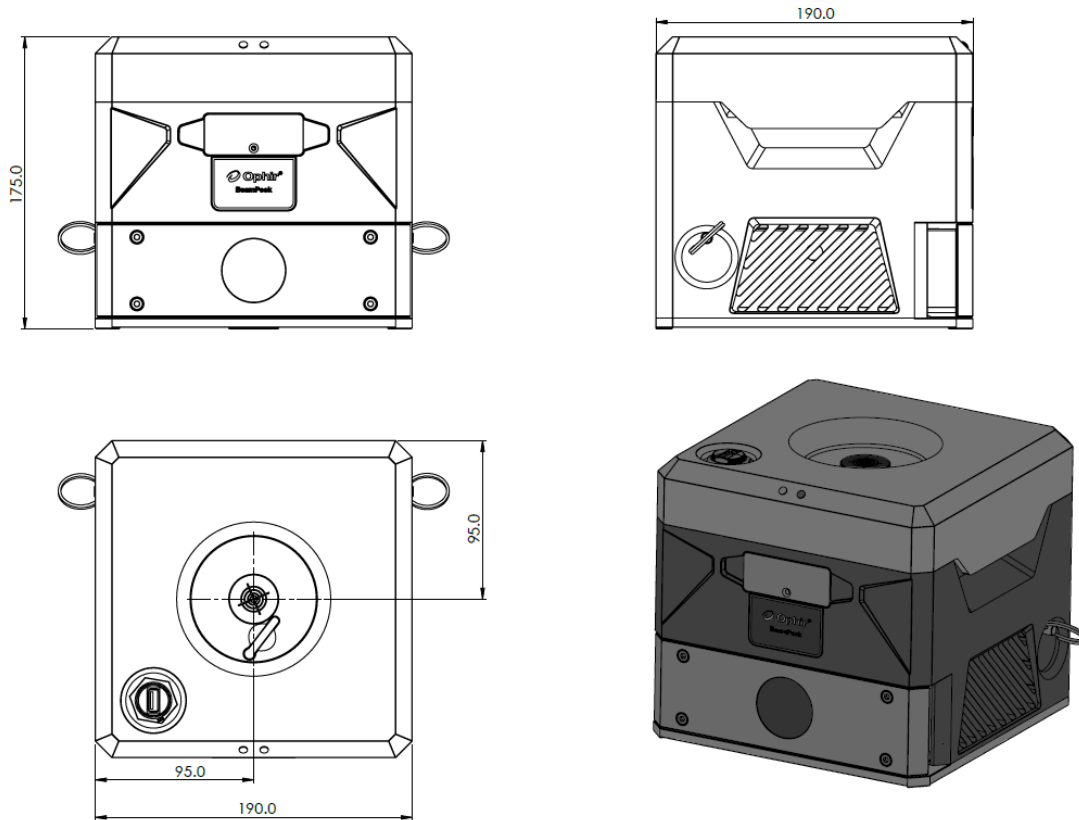
The Rayleigh range is the distance from the waist where a beam of a circular diameter increases to twice the area at the waist, or in other words where the diameter increases by  $\sqrt{2}$ . This is also the distance where the wavefront radius of curvature reaches its minimum value. The Rayleigh range value is used to describe a region where a laser is generally regarded as being collimated.

The Rayleigh range,  $Z_R$ , is computed by:

$$Z_R = \frac{W_0}{\Theta}$$



## 8 Dimensions



## Appendix A Secondary Applications

The BeamPeek software is intended to assist users in obtaining a quick diagnostic view of their beam. Some users may require more advanced analysis than what BeamPeek currently provides. For these situations, BeamGage Professional and BeamPeek Tools can be used.

### NOTE

BeamPeek software and BeamGage Professional cannot connect to the same BeamPeek device simultaneously. BeamGage Professional and BeamPeek Tools do allow simultaneous connection.

### A.1 Software Installation

Install BeamGage Professional and BeamPeek Tools from the Ophir website. Software installations must be performed with Administrator privileges.

- Navigate to the Ophir software download page:
  - <https://www.ophiropt.com/laser--measurement/software-download>
- Select the BeamGage Professional software package and the BeamPeek Tools software package to start the downloads.
- Extract the contents of the zip folders to a local destination on the PC.
  - Do not extract the files to a Network location as this may cause the installations to not execute properly.
- Open the respective extracted folders and select the files "BeamGageProfessional.Setup.exe" and "BeamPeekTools.exe"
- Follow the directions on screen.

### A.2 BeamGage Professional

BeamGage Professional has multiple functions available for advanced analysis. All features in BeamGage Professional are available when a BeamPeek device is connected. BeamGage Professional can be used to collect data directly using the BeamPeek device, or load BeamPeek data files for post processing analysis.

#### A.1.1 Collecting Data in BeamGage Professional

A pre-defined setup file is available for download from the Ophir website which may be beneficial for first-time use (BeamPeek Start Setup for BeamGage Professional.bgSetup). This setup file configures many of the BeamGage controls to be similar to the setup that is used in BeamPeek.

The **Power Meter** settings must be configured to receive accurate measurements from the embedded power sensor. Select **Ophir Juno** for the power meter and select the appropriate wavelength in the **Configure Power Meter** menu (Figure 37). The power sensor is calibrated inside the BeamPeek housing so the scaling factor should remain at 1.000.

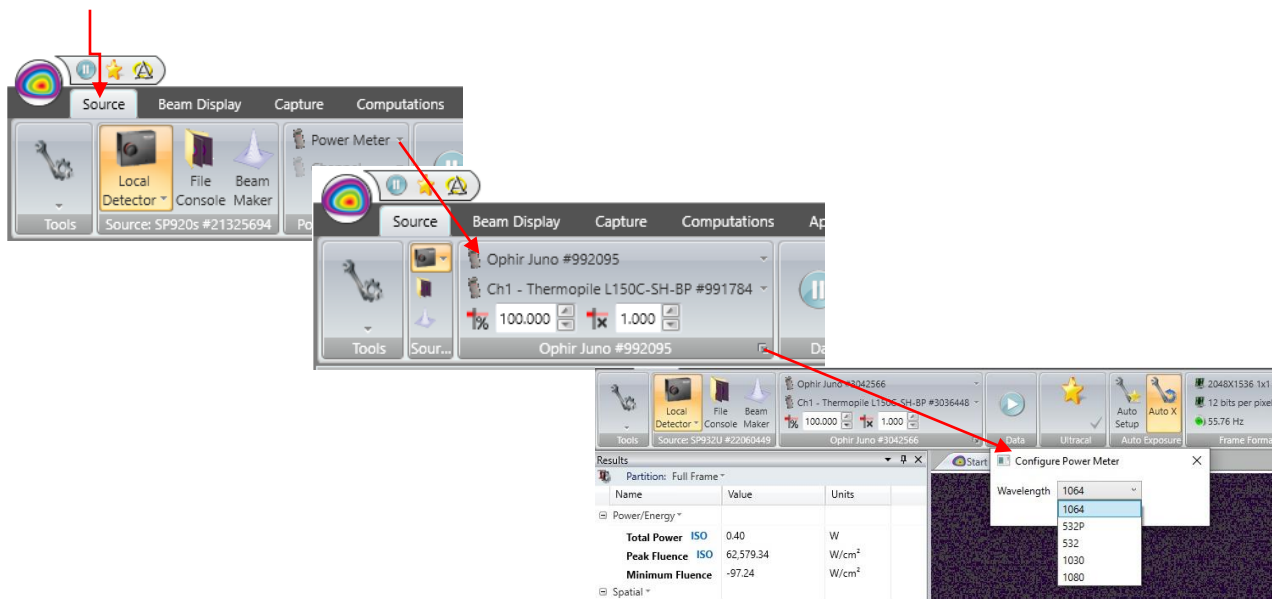


Figure 37: Configure the Power Meter in BeamGage

BeamGage software features such as **Auto Aperture**, **AutoX**, and **Blooming Correction** can be used to get stable and reproducible results. Refer to the *BeamGage User Guide* for further details on the BeamGage application.

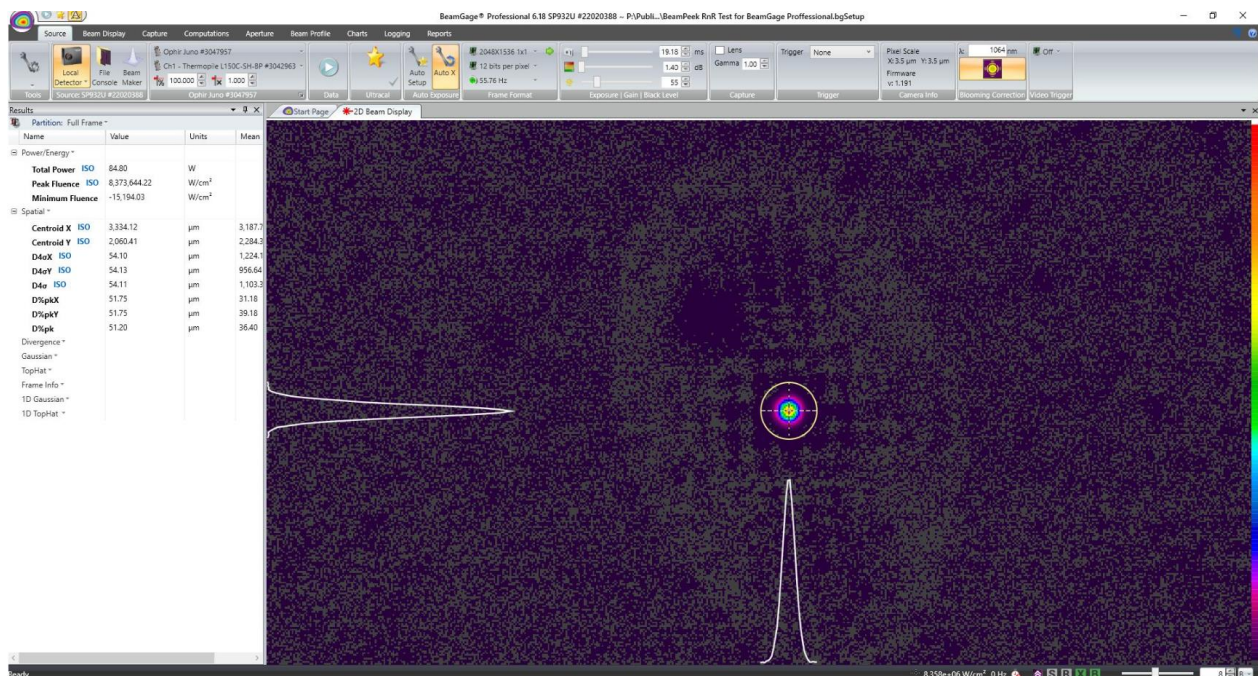


Figure 38: Typical BeamGage Setup

## A.1.2 Loading BeamPeeK Data into BeamGage Professional

Data files saved using BeamPeeK application can be manually loaded into BeamGage Professional for review and advanced post-processing analysis.

Reviewing data files enables many options available in BeamGage Professional such as results computation and 1D, 2D, and 3D profile views. To load the data for review:

1. Open BeamGage Professional and select **File > Load Data...**

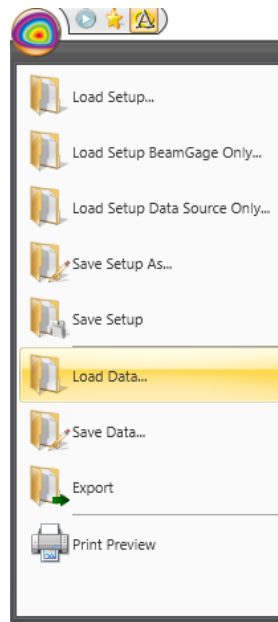


Figure 39: BeamGage Load Data

2. In the **Load File Selection** dialog box select **Browse...** and set the file type filter to **All Files (\*.\*)**. Locate the desired .bpData file.

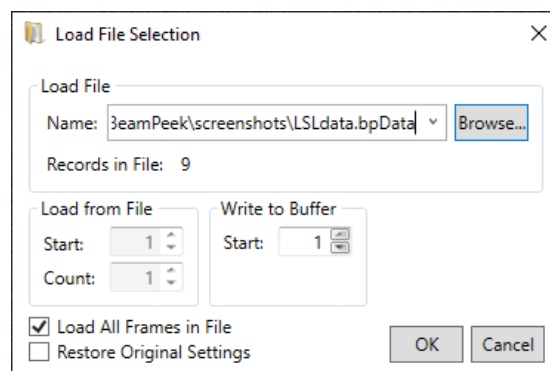


Figure 40: Load File Selection

3. Set the **Write to Buffer Start** to 1 and enable **Load All Frames in File**. Select **OK** and the BeamPeek data will load into the BeamGage frame buffer.

## NOTE

BeamGage will load frames until the Frame Buffer is full. Reference the BeamGage User Guide for information on changing the frame buffer size if needed.

4. Scroll through the Frame Buffer to review each caustic cross-section. Ensure **Auto Aperture** is enabled for the most accurate results.

Post-processing analysis is also available in BeamGage Professional. This option allows playing through a data file as if the frames were streaming directly from a camera which enables more analysis options such as Positional Stability and Logging. To load data for post-processing analysis:

1. Open BeamGage Professional and select **File Console**.

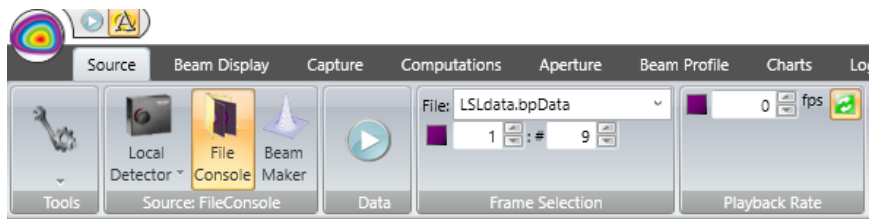


Figure 41: BeamGage File Console

2. In the File name dropdown select **Browse...** and set the file type filter to **All Files (\*.\*)**. Locate the desired .bpData file.
3. Select **Start** to play through all the frames in the file. Ensure **Auto Aperture** is enabled for the most accurate results.

### A.3 BeamPeek Tools

The BeamPeek Tools software (Figure 42) can be used to monitor temperature of the BeamPeek body and the camera. The respective temperature readouts turn orange and subsequently red as the temperature increases close to or over permissible limits. The calibrated **Focal Plane Offset** and **Optical Axis Position** values are also shown.

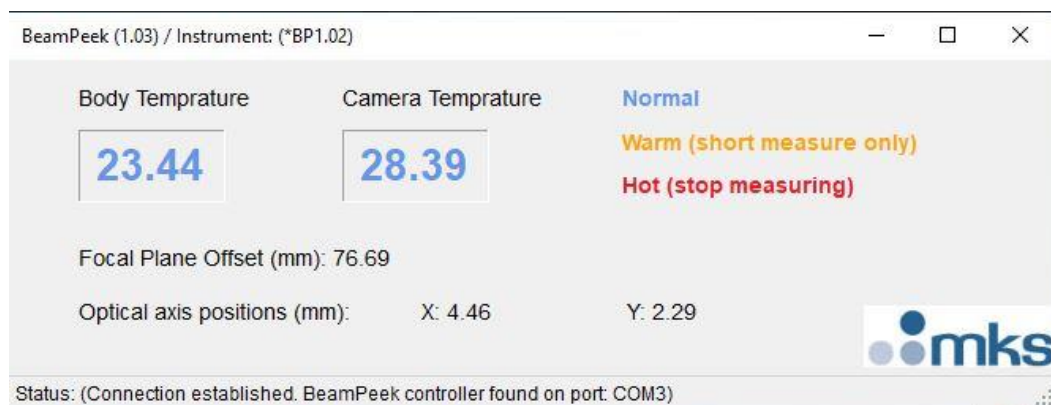


Figure 42: BeamPeek Tools



## Notes:

This image shows a full page of blank, lined paper. It features approximately 20 evenly spaced horizontal black lines across its entire width, providing a template for writing or drawing. The margins are consistent on all sides.

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