22/Jun/2026

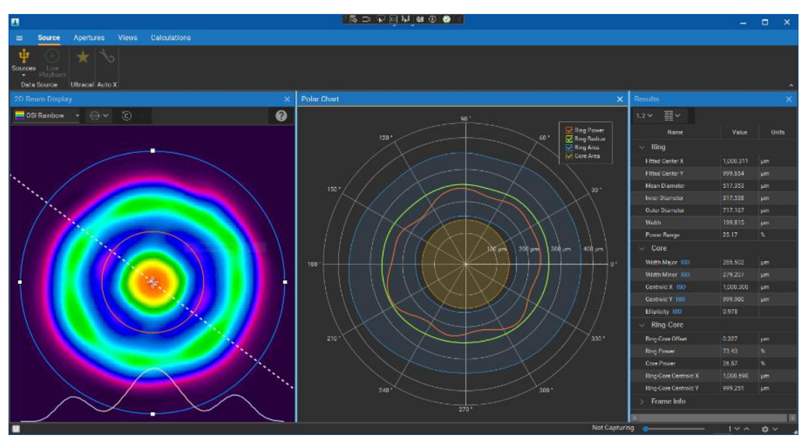
User Guide

BEAMGAGE® RING-CORE

LASER BEAM ANALYZER

FOR WINDOWS 11®

VERSION 1.0



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Dear Customer,

Thank you for your recent purchase of BeamGage® Professional and its accompanying Ring-Core analysis system.

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,

MKS Ophir USA

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1 Warranty

All terms and conditions of software licensing agreement and product warranty are provided during software installation. A full text copy is available upon request.

2 Safety Information

BeamGage® Ring-Core does not present the user with any safety hazards directly. Although 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 enough to warrant the use of protective equipment.

Unless the laser 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 of dangerous exposure, protective eye shields and clothing should be worn.

Electrical Hazards

BeamGage Ring-Core 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.

2.1 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 manual violates safety standards of intended use of the instrument and may impair the protection provided by the equipment. MKS, Inc. assumes no liability for the customer's failure to comply with these requirements.

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 MKS Calibration and Service Center for service and repair to ensure that all safety features are maintained.

SERVICE BY QUALIFIED PERSONNEL ONLY

Operating personnel must not remove instrument covers. Component replacement and internal adjustments must be made by qualified service personnel only.

2.2 Symbols Used in This Instruction Manual

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

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, on the like, which, if not correctly performed or adhered to, could result in injury to personnel.**
DANGER	**The DANGER sign Indicates an imminently hazardous situation that, if not avoided, will result in death or serious injury.**

3 Introduction

3.1 Product Description

BeamGage Ring-Core is designed to analyze laser beams with concentric ring (annular) beam and core beam elements. Its patent pending algorithms enable isolation of the ring and core beam elements and measurement of the characteristics of each. A range of specialized ring and core results are provided for measuring size, alignment, power distribution, and quality of ring-core beams.

3.2 Principles of Operation

BeamGage Ring-Core is a standalone analyzer application with specialized features and algorithms uniquely suited to the challenges of ring-core beam analysis while using existing camera-based beam profiling technologies.

All principles of operation for BeamGage camera-based beam profilers apply, including isolation of the beam signal via Ultracal™ baseline calibration, isolation of the beam from the full frame using software apertures, and reducing ambient light using attenuation. BeamGage Ring-Core features a new Automatic Ring-Core Aperture which isolates the ring beam from the core beam allowing novel measurements of all aspects of ring-core laser systems. A Polar Chart enables analysis of complex ring-core modes and geometry.

Some elements of operation and best practice are not repeated in this user guide. Learn more about these methods in the BeamGage User Guide.

3.3 Product Licensing

Users with existing BeamGage® Professional licensing are granted access to all Ring-Core analysis features.

Contact MKS Ophir Product Support (service.ophir.usa@mksinst.com) to obtain a license.

https://www.ophiropt.com/en/c/beamgage-profilers

3.4 Software Installation

Install the BeamGage Ring-Core software:

All installations must be performed with an account that can elevate to administrator privileges.

1. Navigate to the MKS Ophir software download page:
    a. https://www.ophiropt.com/en/g/software-download
2. Select the desired software package to start the download.
3. Extract the contents of the zip folder to a local destination on the PC.
    a. Do not extract the files to a network location as this may cause the installation to not execute properly.
4. Open the extracted folder and select the file ending in “Setup.exe”

5. Follow the directions on the screen.

To download additional user guides, datasheets, and related information, visit the MKS Ophir website: https://www.ophiropt.com

3.5 Camera Setup

The first time BeamGage Ring-Core is opened it will connect to the first licensed camera found, load the default configuration, and display camera images in the 2D Beam Display view. The default setup assumes a continuous wave laser application.

Select the Source ribbon tab to view camera controls.

Use the Pause/Start button to stop and start data collection.

If a camera is connected after launching the software, select the Sources menu from the Source ribbon. Available cameras appear in the drop-down by model and serial number. Select the camera to connect; camera controls will display in the ribbon and data collection begins.

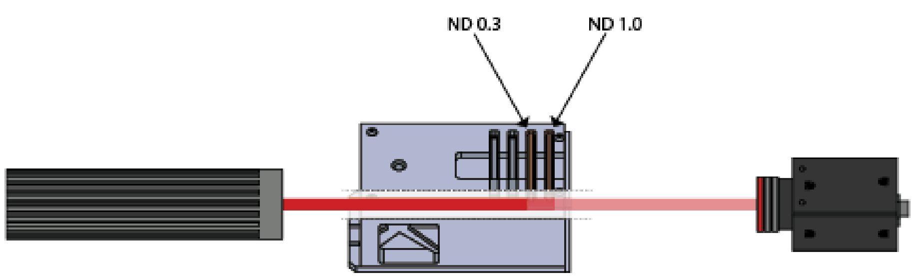
When an unlicensed camera is connected, controls are locked, and a license entry box is displayed in the ribbon. Enter the license key in the entry box and follow the instructions on the screen.

3.6 Attenuation

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

Most MKS Ophir supplied cameras ship with a basic set of ND filters able to attenuate lasers up to approximately 5 Watts/cm². Greater power levels require more 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.



CAUTION	**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.**

4 Software Operation

4.1 Layout

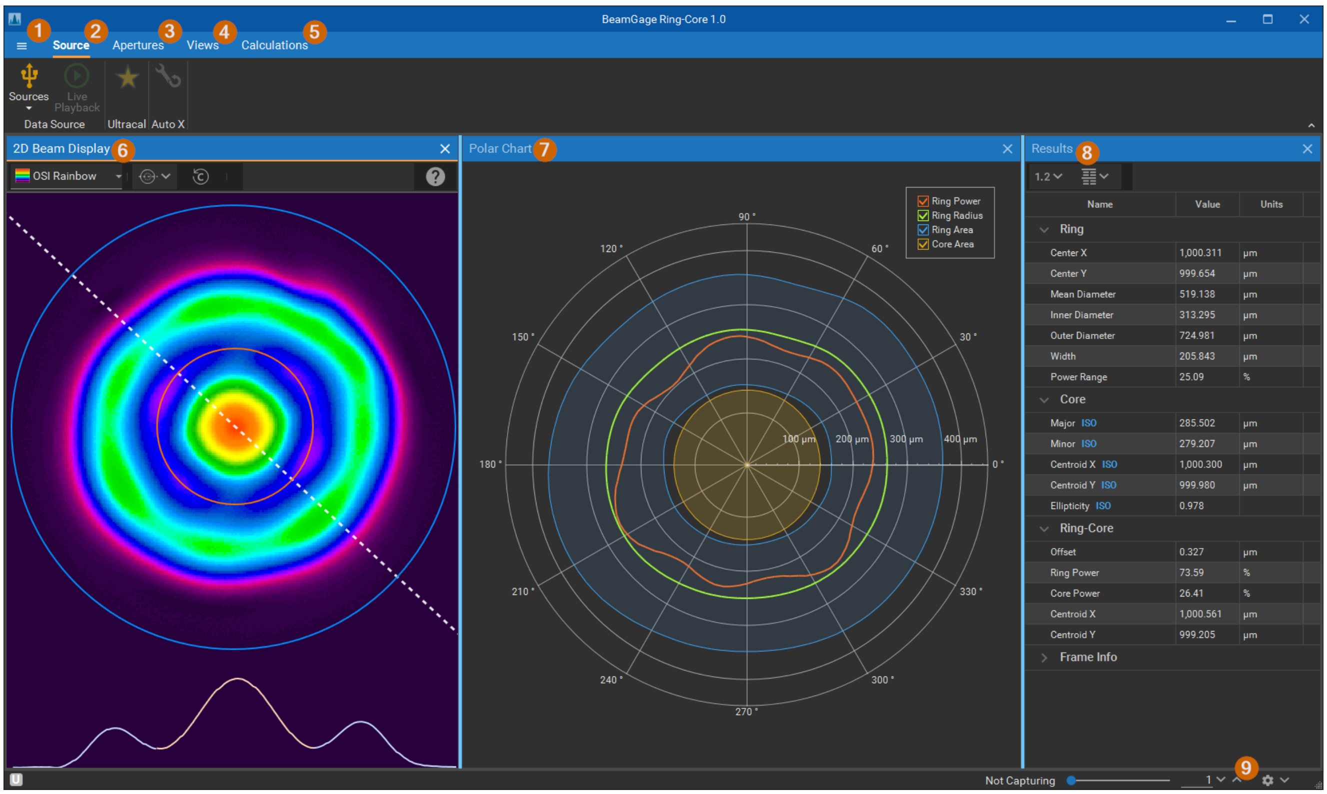
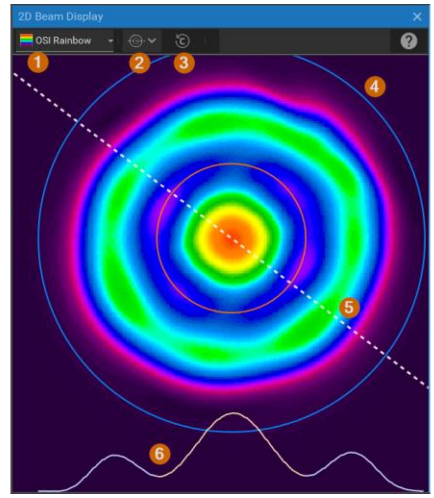


Figure 1 BeamGage Ring-Core UI

1. ***Backstage***: Data file load/save and theme selection. Save and load BeamGage Ring-Core data files (.rcData) or load BeamGage Data files (.bgData).
2. ***Source tab***: Source selection and camera controls.
3. ***Apertures tab***: Aperture controls and information.
4. ***Views Tab***: Controls what views are visible: 2D Beam Display, Polar Chart, and Results views.
5. ***Calculations Tab***: Adjust calculation settings: Heat Sim, and Optical Scaling.
6. ***2D Beam Display***: Displays 2D beam data, aperture location, and 1D beam profile.
7. ***Polar Chart***: Depicts deviations in the ring and core. Shows qualitative results.
8. ***Results***: Lists results separated into Ring, Core, Ring-Core, and Frame Info.
9. ***Frame Buffer***: Frame Buffer controls and information. Use the slider to select past frames. Use the gear icon to select how many frames are kept before being overwritten.

4.2 Views

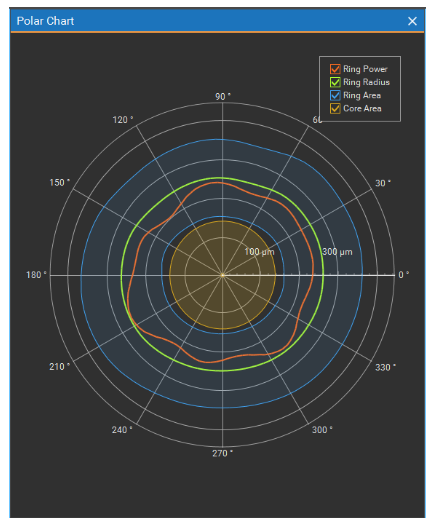
4.2.1 2D Beam Display



The 2D Beam Display shows the most recently captured frame or the selected frame. Use the scroll wheel to zoom into the frame image. Hold right-click and drag the image to pan around the zoomed-in frame.

1. ***Color Palettes***: Select from OSI Rainbow or other palettes.
2. ***Profile Mode***: Select placement mode for profile or disable profile. In Manual Profile Mode drag the control point to set a new pivot.
3. **Reset Profile**: Set the profile line back to horizontal.
4. ***Apertures***: Both apertures can be moved when *Auto Ring-Core Aperture* in the Apertures tab is disabled. Drag apertures with left-click and resize by dragging the control points at the cardinal edges of the apertures. Shift + drag points to resize and stay circular
5. ***Profile Line***: Shows where the 1D Profile samples the frame. Drag and rotate to a new angle with left-click.
6. ***1D Profile***: The cross section of the beam's intensity, colored by aperture.

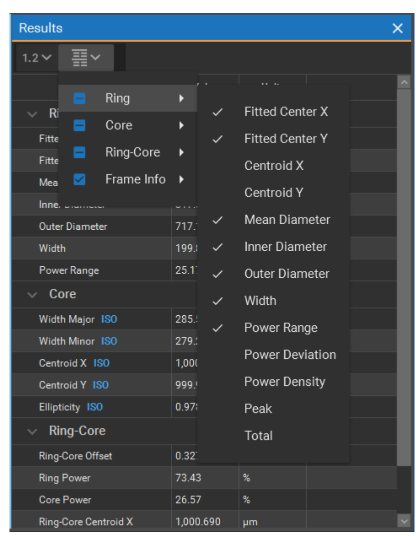
4.2.2 Polar Chart



The Polar Chart shows deviations in the ring and alignment. This display provides many qualitative results not shown in the Results view.

Use the scroll wheel to zoom into the Polar Display. Use the legend in the top right to see what color represents each result and click the legend's checkmarks to disable unused results. Each result set is explained in Section 5.2.

4.2.3 Results



The Results view holds all the numerical information calculated from the current frame. The top bar settings adjust how and what results are displayed. The results are grouped into:

Ring: Results that measure properties of the ring between the Core and Ring Aperture. See Section 5.3.

Core: Results that measure the beam inside the Core Aperture. These results can also be found in BeamGage. See Section 5.4.

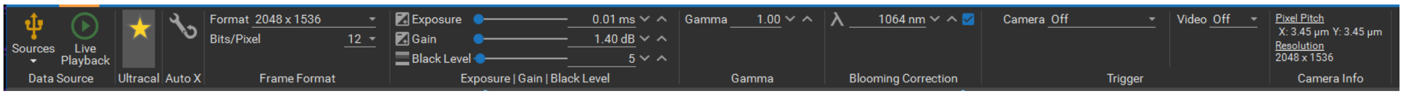
Ring-Core: Results from the full beam or comparing Ring and Core results. See Section 5.5.

Frame Info: Basic context about the frame captured. See Section 5.6.

4.3 Tabs

The Tabs are different toolboxes and settings to control BeamGage Ring-Core.

4.3.1 Source



Data Source: Select a data source, such as a beam profiling camera or the BeamMaker™ simulated data source.

Ultracal™: Creates a background subtraction frame to neutralize electronic noise and ambient light in the baseline of the frame. Ultracal provides isolation of the beam signal from bias caused by such signals and is recommended for accurate ring-core beam measurement.

AutoX: Dynamically adjusts the Exposure, Gain, and Black Level settings and subtracts the remaining baseline of the frame. AutoX is best used as an alternative to Ultracal when dynamic patterns in the baseline signal cannot be neutralized with Ultracal.

Frame Format: Set the size, format, and bit depth of the raw frame provided by the camera.

Exposure | Gain | Black Level: Adjust in order of Exposure, Gain, then Black Level to improve measurement quality. In Auto modes, these controls are automatically adjusted to the input beam intensity conditions.

> **Exposure**: Set the integration time of sensor response. Recommend use is to set to the shortest exposure interval possible without saturating the image.
>
> **Gain**: Set the amplification of the sensor response. Recommended use is to set to the lowest settings required to obtain a measurement to limit the electronic noise added to the frame.
>
> **Black Level**: Set the dark or zero level of the frame. Set by Ultracal to elevate the entirety of the camera noise profile into an accessible range to be subtracted.

Gamma: Set a gamma correction for non-linear sensor response. A value of 1.0 is used for most cameras as BeamGage camera models adhere to strict linearity specifications. Gamma should rarely be adjusted to avoid invalid measurements.

When using camera models with a phosphor-coated sensor, this value is automatically set to 1.55 to compensate for the response curve of the phosphor.

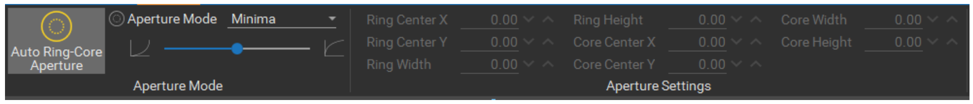
Blooming Correction: Enables/disables a correction for sensor response artifacts unique to some camera models.

Trigger: Set the trigger mode for receiving a frame. Used for synchronization with pulsed laser sources.

> **Camera Trigger**: Set the electronic trigger mode in the camera. The camera must be supplied with a low voltage TTL pulse via its GPIO connector to activate the external trigger.
>
> **Video Trigger**: Set the peak intensity threshold for software trigger. Video Trigger only permits frames of data with a laser pulse to be received into the frame buffer.

See the BeamGage User Guide for more information on camera settings.

4.3.2 Apertures

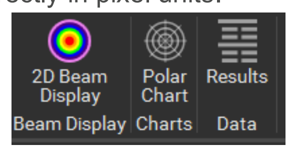


Aperture Mode: Control Aperture settings.

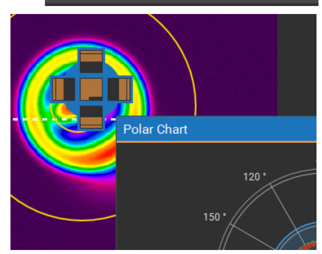
> **Auto Ring-Core Aperture**: Enable Auto Ring-Core Aperture (shown yellow) to use the placement method described in Section 5.1.
>
> **Minima**: Recommended and the default. Places aperture in the dim region between the ring and core.
>
> **Curvature**: For beams with poor separation of ring and core, change Aperture Mode to Curvature.
>
> **Aperture Gamma**: If neither aperture mode will suffice use the Aperture Gamma slider to adjust what beam structures are prioritized.

Aperture Settings: Disable Auto Aperture (changes to grey) to manually adjust apertures in the 2D Beam Display (Section 4.2.1) with the mouse. Aperture location can also be adjusted by typing values directly in pixel units.

4.3.3 Views



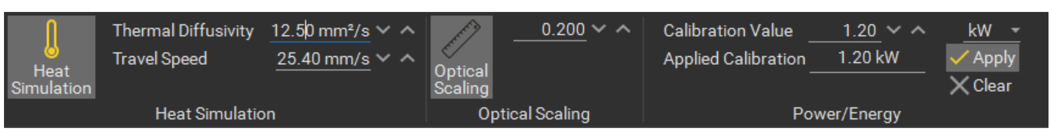
Select what views are shown in the UI. Select if 2D Beam Display, Polar Chart, and Results views are visible.



Docking Views: All views can be dragged and docked to locations within the application window by clicking and dragging the top of the view onto a dock handle. When moving the view, a set of docking handles appear as shown.

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

4.3.4 Calculations

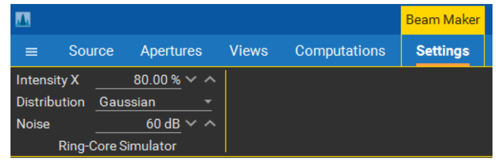


Heat Simulation:
Settings provided to adjust ring power distribution results. Only ring beam errors that would affect the beam's performance are calculated by simulating how much heat moves around the material under the ring beam. See section 5.7.

Optical Scaling: Adjusts the scaling of spatial results for beams that have been expanded or condensed. For example, use 0.2 Optical Scaling for a 5x beam expander for results scaled to the original beam.

Power/Energy: Calibrate Power/Energy results with an assumed or separately measured wattage/joules. Input a value, select your units, and click *Apply*. You must *Clear* your calibration to switch from a power unit to an energy unit. Relevant results will automatically be displayed in the Results tab. A fresh Ultracal can significantly improve relevant result accuracy if Ring or Core Totals are lower than expected.

4.3.5 BeamMaker® Settings



BeamMaker is a proprietary beam modeling tool in BeamGage Ring-Core which can provide example ring-core data to test results and measure results' sensitivity to noise. To generate more complex ring-core beams use BeamMaker provided in BeamGage Professional. Data files from BeamGage can be opened in BeamGage Ring-Core.

When the BeamMaker data source is selected, an extra ribbon is provided to control the parameters of the simulated beam.

Ring-Core Simulator:

Intensity X: Adjust the peak intensity of the simulated beam to a percentage of the max A/D range of the frame.

- Setting to 100% will cause the peak of the beam to saturate the simulated camera.
- A range of 80-95% will simulate a beam that is attenuated optimally for an accurate measurement.
- Set to zero to simulate blocking the beam.

Distribution: Select a **Gaussian** noise distribution to simulate the electronic noise profile of a camera or disable noise by setting to **None**.

Noise: Adjust the Signal to Noise ratio (SNR) of noise added to the frame. 55-60db simulates nominal, real-world camera noise. Lower values simulate more noise.

5 Ring-Core Calculations

5.1 Automatic Ring-Core Aperture

Placing apertures correctly is critical to the accuracy of Ring-Core measurement. Our patent pending Auto Ring-Core Aperture provides a robust and accurate placement of both the Ring and Core apertures isolating the measurement data from each other.

The Aperture Mode setting in the Apertures tab provides either a Minima or Curvature setting for the Automatic Core aperture. The Minima setting is the default, as it is considered the most accurate way to place the Core aperture. The Curvature setting is more robust, handling a wider range of ring-core beams with acceptable results. It is useful for dim rings where the core may bleed into the ring and vice versa, hiding the minima between the beams.

The Aperture Gamma setting provides fine tuning for the Auto Aperture. Aperture Gamma does not affect the raw data or other calculations. A high gamma setting will increase contrast in the dimmest parts of the image, enhancing dim structures. When the core aperture is placed it will prefer dim valleys over bright structures in the ring or core. A low gamma setting will increase contrast in the brightest parts of the image to place the core aperture using bright structures. The new sampled intensity is $I' = (I/I_{max})\text{^}2^{-\gamma}$ where γ is Aperture gamma.

The Auto Apertures are placed by:

1. Many radial samples, or spokes, are taken from an estimated center of the beam outward (depicted as green lines in Figure 2) to find 1D profiles of the beam.
2. Aperture Gamma correction is temporarily applied to the spoke samples.
3. Depending on which algorithm is selected by the user:
    a. ***Minima:*** Locates the dimmest point between the ring peak and the core peak, measured along each spoke, by prominence (Figure 3).
    b. ***Curvature:*** Measures the brightness curvature of each spoke with a Laplace of Gaussians filter and finds the point at the base of the core with strongest upward curvature.
4. Both algorithms produce a set of points (Figure 2, red) that are fitted to a core circle creating the Core aperture for beam separation.
5. The core region, any smoothing, and gamma correction are removed from the spoke samples. A centroid is found from the remaining intensity of each spoke.
6. The Ring Center and estimated ring radius are calculated by fitting the radial centroids to another circle (Figure 2, blue).
7. The Ring Aperture radius is two times the estimated ring radius and is placed at the Ring Center.

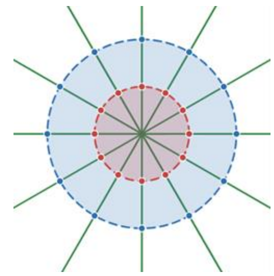


Figure 2: Sampling to place apertures

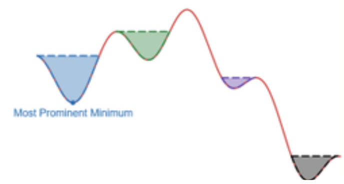


Figure 3: Prominence by depth

NOTE	**The Ring Aperture is highly sensitive to elevated background signals, especially for low intensity ring beams. Ultracal background correction is required for accurate ring-core measurement.**

5.2 Polar Results

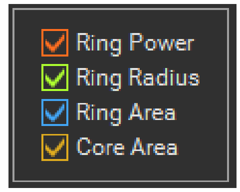
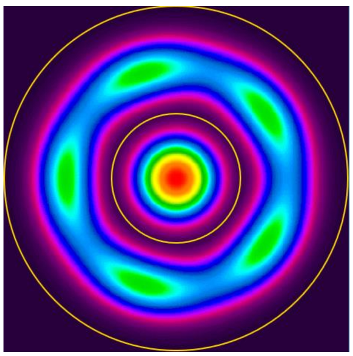
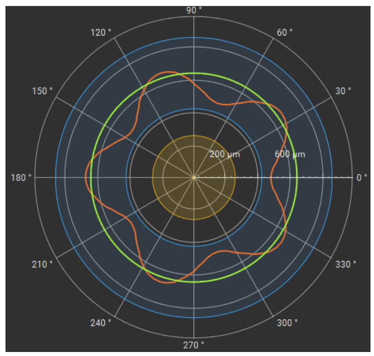


Figure 4: Results in Polar Display legend

The Polar Chart provides a set of visualizations of angle-dependent results to assist in aligning, grading, and measuring the beam at a glance. The Ring Center is used as the basis for all Ring calculations, so it is always placed at the center of the chart. The Polar Chart shows the beam in polar coordinates, with an angle axis and a radial axis. The radial axis measures distance from the Ring Center for each part of the beam.

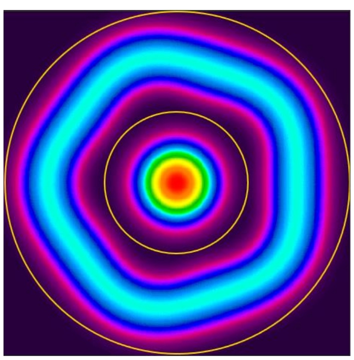
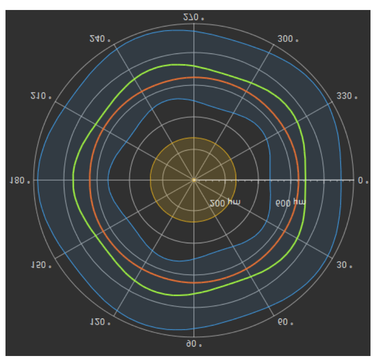
5.2.1 Fourier Results

A discrete Fourier transform converts the ring image into functions that describe power, radius, and thickness. 5.9

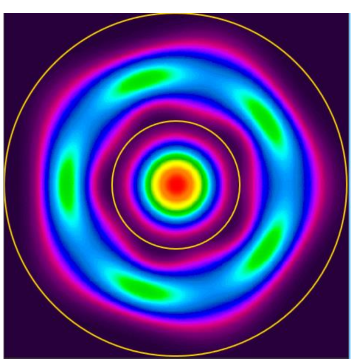
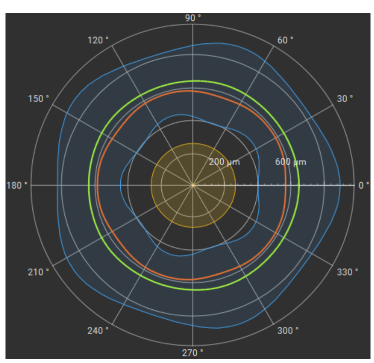
Ring Power

The orange Power line shows the relative power by angle. It is calculated as a percentage of the ring average and not as a radius. In the Polar Chart the orange line representing the ring's power distribution shows five lobes. Those five lobes correspond to five bright spots around the ring.

Ring Radius

The green Ring Radius line represents the radial centroid of the ring. In the Polar Chart the green Ring Radius line follows the pentagon shape of the ring. Note how the blue Ring Area follows the green Ring Radius line.

Ring Area

The blue Ring Area represents four radial standard deviations of ring thickness. In the Polar Chart the blue area changes thickness while the orange Power line stays constant. This reflects that the beam's bright spots are the thinnest ring sections while the dim spots are the widest for an even power distribution.

5.2.2 Core Area

The yellow area representing the core beam uses the core's Centroid X/Y, Width Major/minor, and Orientation to draw an ellipse depicting the shape and location of the core beam. Overlap of Ring and Core areas indicate poorly separated beams, confounding ring and core result accuracy. Improving the beam's focus may improve accuracy.

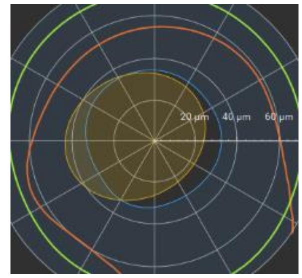


Figure 5: Polar Chart showing misaligned, elliptical core

5.3 Ring Results

The Ring Results are calculated from the pixels outside the Core Aperture but within the Ring Aperture. All Ring spatial results (not including Centroid X/Y and Total Power) apply the Ring Radial Intensity Correction. See section 5.8.

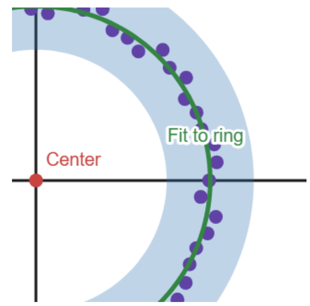


Figure 6: Ring Center

Center X/Y: The center of the Ring Auto Aperture and the point equidistant to each ring radius found in 5.1 step 6. The center of a circle fit to the ring. This point is used as the center basis for all spatial Ring Results.

Centroid X/Y: The centroid of the ring based on the ring's power distribution. Does not use the Radial Intensity Correction .

Mean Diameter: Two times the mean distance from the Ring Center to the ring's radial centroids. The average distance from the ring's radial centroid to the opposite radial centroid.

Inner Diameter: Ring Mean Diameter minus the Ring Width. The inner edge to the opposite inner edge.

Outer Diameter: Ring Mean Diameter plus the Ring Width. The outer edge to the opposite outer edge.

Width: The thickness of the ring beam. Four times the radial standard deviation of the ring beam's power.

Power Range: Measures how evenly the ring distributes power. The maximum to minimum power by angle in the ring as a percentage of average power. This result is based on the Ring Power polar result and is affected by the Heat Simulation.

Power Deviation: Measures how evenly the ring distributes power. 2.83 standard deviations of power distribution error by angle as a percentage of average power. This result is based on the Ring Power polar result and is affected by the Heat Simulation.

$$\sqrt{8}\sigma = 2\sqrt{\sum_{n=1}|a_n|^2}$$

Where a_n are complex Fourier coefficients of power.

NOTE **Why √8σ or 2.83? To compare the Power Range and the Power Deviation results a sine wave is used as a reference. From peak to trough a sine wave is √8σ or 2.83 standard deviations tall. If Power Range > Power Deviation the ring power distribution contains sharp peaks and valleys.**

Power Density: The ring power/energy per square centimeter using the area between Inner and Outer Diameter.

Peak: The highest power/energy density in the ring beam.

Total Power/Energy: The total power/energy in the ring beam.

5.4 Core Results

Core Results are calculated from pixels inside the Core Aperture. They are calculated the same as their corresponding BeamGage result.

NOTE **Additional core results can be obtained by analyzing the beam in BeamGage with a manual aperture in the same position as the core aperture. Please contact us if there are any such results desired in BeamGage Ring-Core.**

Major/Minor [ISO]: The core beam's four standard deviation widths measured off-axis.

Centroid X/Y [ISO]: Coordinate location of the core beam's centroid or center of fluence.

Ellipticity [ISO]: The ratio of Minor / Major. Always ≤ 1.

Total Power/Energy: Total power/energy within the core aperture.

5.5 Ring-Core Results

The Ring-Core results are calculated either from Core and Ring Results or are calculated from the combined pixels within the Ring and Core aperture.

Offset: Misalignment. The distance from the Ring Center to the Core Centroid.

Centroid Offset: The distance from Ring Centroid to Core Centroid.

Ring Power: The percentage of energy in the ring.

Core Power: The percentage of energy in the core.

Centroid X/Y: The combined, weighted centroid of the ring and core. The center of fluence for the entire beam.

5.6 Frame Info

Frame Info results provide metadata for the selected frame. See the BeamGage User Guide for more information on each result.

Frame ID: The unique identifier to differentiate frames.

Width/Height: The size of the current frame in pixels.

Timestamp: The moment the frame was received from the camera.

Bits per Pixel: The number of bits per pixel. The precision of a pixel's intensity.

Pixel Scale: The width and height of a single pixel. μm/pixel

Exposure/Gain/Black Level: The camera's settings when the frame was taken.

5.7 Heat Simulation

Understanding how the ring distributes power is important to measuring the quality of a ring beam. When small beam defects are measured, the ring power distribution could appear poor despite acceptable beam performance. Heat Simulation attempts to measure only defects in the ring large enough to affect performance.

The effect of the Heat Simulation can be seen in the orange Power result in the Polar Display. Power distribution is then quantified by Ring Power Range and Ring Power Deviation.

5.7.1 Settings

Thermal Diffusivity: The rate that heat transfers across a material measured in mm^2/s. Refer to the table provided for some common materials, an online reference, or measure the thermal diffusivity for the specific alloys in use. A powder bed's diffusivity can be around 1/20th of the solid material's diffusivity.

Travel Speed: The maximum speed the beam travels across the work surface. Travel speed is used to calculate heat diffusion time.

Material	Thermal Diffusivity
Copper	111 mm^2/s
Aluminum 6061	64 mm^2/s
Steel 1010	18.8 mm^2/s
Steel A36	12.5 mm^2/s
Titanium	9.3 mm^2/s
Stainless 304A	4.2 mm^2/s
Stainless 310	3.35 mm^2/s
Inconel 600	3.43 mm^2/s
Nylon	0.09 mm^2/s

Figure 7: Thermal Diffusivity of common materials

Source: Wikipedia

5.7.2 Calculation

Heat Simulation can predict the spread of heat in the material after the Ring Width has passed over an area. The simulation describes a loop of material with the starting energy of the beam, allowed to diffuse for the time it takes the Ring Width to pass over a point on the surface. The real temperature, travel direction, and melt pool are not simulated. The Ring Fourier Power coefficients are used to calculate the end state of the heat simulation. These coefficients represent structures in the ring's power distribution at different scales. Thin power deviations diffuse faster than wide deviations. Therefore, the heat simulation simply scales each coefficient by a heat transfer function before reconstructing the power distribution of the ring beam. Each Fourier Power coefficient a_n is scaled by

$$a_n = a_n \mathrm{e}^{-\alpha(\pi n/L)^2 t}$$

where α is the Thermal Diffusivity in mm²/s, n is the coefficient index or 1/structure scale, L is circumference of the ring beam in mm ($L = \pi d$), and t is seconds to traverse the ring thickness ($t = W/v$). Any coefficients that would be scaled down below 2% (e^{-4}) are set to 0.

5.8 Ring Radial Intensity Correction

This correction is applied before almost every ring result is calculated except the Ring Centroid and Total.

The Ring section contains more pixels at further radii than closer. Without correction, those outer pixels are overrepresented, skewing the ring's spatial results. To correct this skew, each pixel's intensity is divided by its radius or distance from the Ring Center. This correction ensures the results match expectations of a 1D cross-section. By using all pixels, not a 1D cross-section, the Ring Results are more accurate, and the Radial Intensity Correction makes the results more consistent and intuitive.

$$r = \sqrt{(x - C_x)^2 + (y - C_y)^2}\ , \qquad I'(x,y) = \frac{I(x,y)}{r}$$

where (x, y) is the pixel location, (C_x, C_y) is the Ring Center location, and $I'(x, y)$ and $I(x, y)$ are the corrected and uncorrected pixel intensities, respectively.

5.9 Ring Discrete Fourier Transform

The Fourier Transform algorithm is generally used to convert repeating signals into harmonic frequencies. For a ring beam the Fourier Transform is used to turn a loop of pixels into different sizes of deviation represented by a maximum of 12 complex coefficients. The conversion from pixels to coefficients creates three continuous, differentiable functions representing the ring's properties. These functions are used to create the most accurate Ring Results possible. The ring's Power Discrete Fourier Transform is described below, however the ring's. Radius, and Width transforms are proprietary.

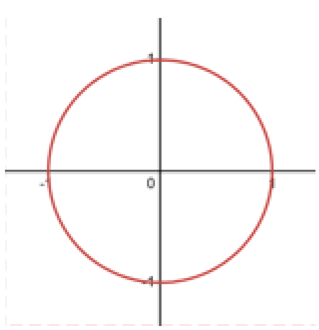


Figure 8: 0th coefficient is average value

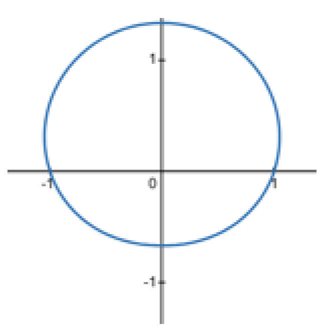


Figure 9: 1st coefficient adds a balance shift

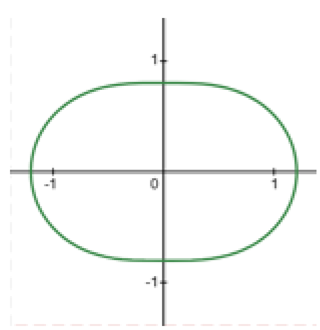


Figure 10: 2nd coefficient similar to ellipticity

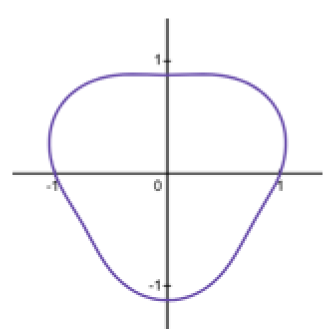


Figure 11: 3rd+ coefficient adds higher order structure.

5.9.1 Calculation

The input is an image of the ring's intensity profile, and a chosen center (C) to measure the ring from. The Ring Center result is used for C.

First each pixel $I(x, y)$ is converted to its polar form where r and θ are a property of each pixel

$$r = \sqrt{(x - C_x)^2 + (y - C_y)^2}\ , \qquad \theta = atan2(y - C_y, x - C_x)$$

Then the Ring Radial Intensity Correction is applied. See 5.8 Ring Radial Intensity Correction.

Each power distribution coefficient T_k is calculated by

$$T_k = \sum_{x,y=0}^{N} I'(x, y)\ e^{-ik\theta}$$

Then each coefficient is divided by the image total, the real component of T_0, to get coefficients scaled to 1 so the resultant Fourier series represents a percentage of average power.

$$t = R(T_0), \qquad T_k = T_k/t$$

5.9.2 Inverse Tranform

To turn coefficients back into radii for display on the polar chart the following calculation is used to calculate the power percentage for a given angle φ.

The power distribution percentage r_T by angle φ is calculated by

$$r_T = \sum_{k=0}^{K} T_k\ e^{ik\varphi}$$

6 Supported Cameras

BeamGage Ring-Core provides support for a selection of BeamGage cameras. The table below details the supported models and their primary features. Click on the model name to access the camera specifications.

For full documentation of the supported models, refer to the BeamGage User Guide appendices.

Supported Camera Models						
Model	**Sensor Type**	**Spectral Range**	**Format**	**Effective Pixel Pitch**	**Beam Size**	**Interface**
SP932U	Silicon CMOS	190-1100 nm	2048 x 1536	3.45µm	27µm-12.3 mm	USB 3.0
SP204S	Silicon CMOS	190-1100 nm	2472 x 2064	2.74µm	27.4µm-5.7mm	USB 3.1
SP402S	Silicon CMOS	190-1100 nm	4512 x 4512	2.74µm	34.5µm-5.3mm	USB 3.1
SP504S	Silicon CMOS	340-1100nm	5120 x 5120	4.5µm	45µm-23mm	Gig-E

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