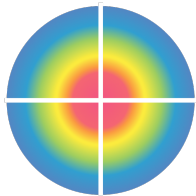
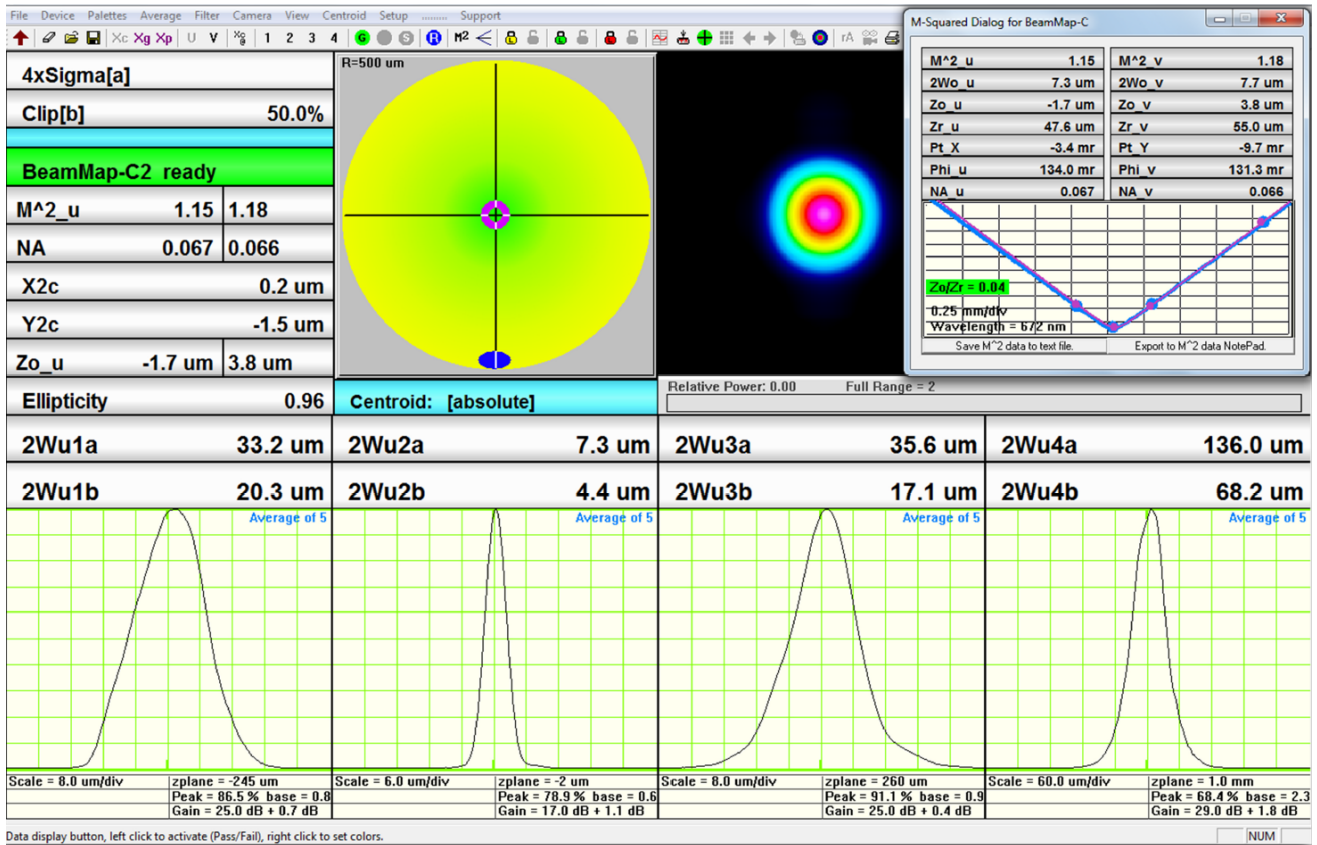


Scanning Slit Beam Profilers

DataRay Inc.



DataRay Inc.

Advancing the Technology of Laser Beam Analysis

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Chapter 1

Introduction

Welcome to DataRay Beam Profiling. These innovative products define state-of-the-art, feature-rich, real-time, scanning slit/knife-edge beam profiling in accordance with the ISO 11146 Standard¹. They are designed as research, development, QA and manufacturing test tools that can be easily customized to your application. The program combines easy-to-use intuitive software and proven beam profiling algorithms. This manual covers the BeamMap2 and Beam'R2 series instruments.

The [DataRay website](#) is always the best source for the most current versions of Software, Manuals, Application Notes, Specifications, etc. At any time, you may download the latest version of the software, manual updates and application notes for free. Visit the website in order to determine whether an update is available.

Custom Products: The BeamMap, BeamMap Collimate, and LensPlate product lines originated in response to OEM requests for production line instruments to measure focal position. We welcome requests for custom hardware configurations.

1.1 Theory of Operation

The Beam'R2 and BeamMap2 are both scanning slit profiling devices with the same principle of operation. A rotating disk or puck carries a pair of slits. A photodetector sits behind the puck. The slits are oriented such that they are orthogonal to each other. When a beam is input to the device, the amount of power allowed through the rotating puck will vary as the slit passes across the beam. The large photodetector measures this power as the puck rotates and this data is used to create X and Y profiles, and calculate various beam parameters. Figure 1.1 presents a simplified interpretation of how the beam profile is constructed as the slit transverses through the beam from left to right. These profiles are commonly referred to as integrated intensity or summed energy profiles as all of the energy allowed through the slit at a single location is integrated into a single summed intensity point on the profile.

The Beam'R2 uses two pairs of x-y slits, one pair with 2.5 μm slit width and one pair with 25 μm slit width. (5 and 50 μm for InGaAs). These are referred to as standard and knife-edge slits respectively. The knife-edge slits are used to measure very small beams ($<8 \mu\text{m}$ diameter for Si, $<17 \mu\text{m}$ for InGaAs). All 4 slits are nominally located on the same plane.

¹ International Organization for Standardization. ISO 11146: Test methods for laser beam parameters: Beam widths, divergence angle and beam propagation factor.

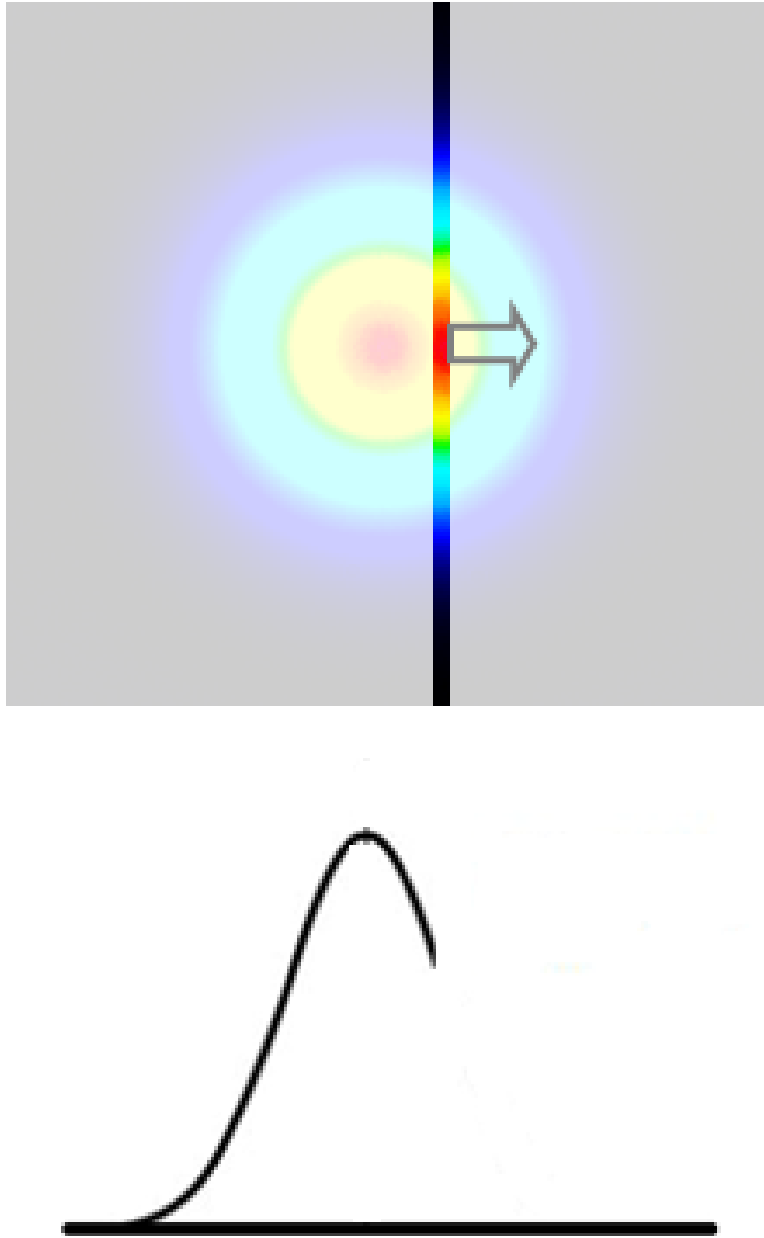


Fig. 1.1: Construction of profile as slit transverses through beam

The BeamMap2 extends this concept in unique, patented ways. The puck for the BeamMap2 allows 4 pairs of slits to be mounted in different z-axis locations which allows for real-time, multi-plane measurements. Figures 1.2 and 1.3 illustrate the difference between the two pucks.

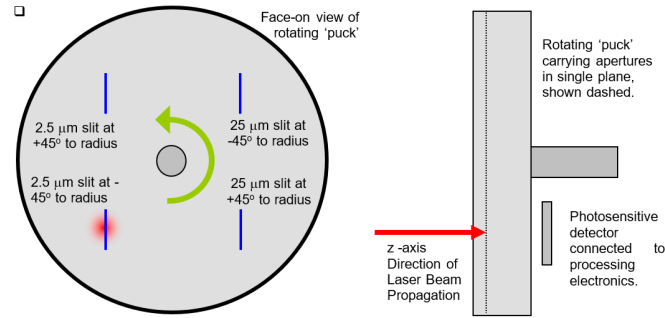


Fig. 1.2: Beam'R2 Slit Scan Sequence Schematic & Detail

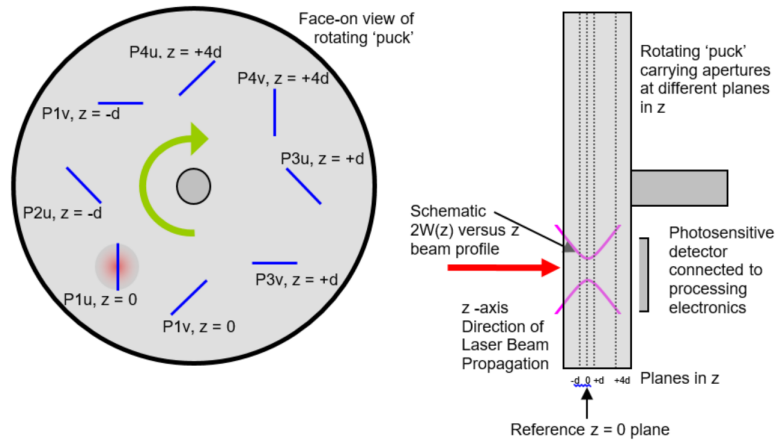


Fig. 1.3: BeamMap2-C schematic puck configuration

1.1.1 Knife-edge Slits

For very small beams, the width of a normal slit is large relative to the beam diameter. The wide slit will cause significant smoothing of the profile causing inaccurate measurements. In this case, a knife-edge slit should be used. A knife-edge slit is much larger than the beam diameter. As the knife-edge slit transverses through the beam, the response of the photodetector starts at 0 and then reaches a peak once the entire beam is within the knife edge. The profile plateaus at this peak until the slit moves enough that the beam is no longer entirely contained. The diameter of the beam can be determined by analyzing the rise of the photodetector response. These profiles are often referred to as differentiated intensity profiles. Figure 1.4 illustrates this concept. The slope of the profile on the left-hand side determines the beam diameter.

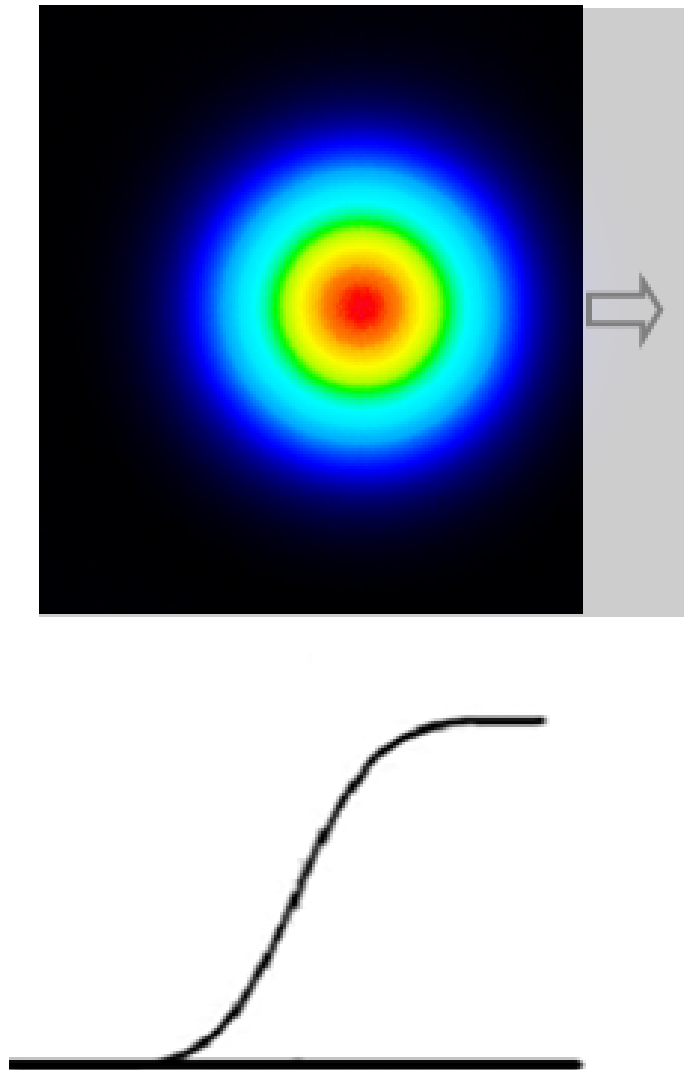


Fig. 1.4: Construction of profile as a knife-edge slit transverse through beam

1.1.2 Comparison to Camera Systems

It is important to understand the differences between camera-based beam profiling instruments and scanning slit instruments. While both types of instruments can accurately profile a variety of sources, their methodology is significantly different. A camera consists of a 2-dimensional array of photosensitive pixels. This allows the accompanying software to generate a complete 2-dimensional image of the source. The software can then generate a profile by reading off a line of pixels. This is often referred to as an intensity or energy profile. This is significantly different from a scanning slit instruments whose profiles are the integrated intensity or summed energy profiles. To get the equivalent integrated intensity profile from a camera, you would need to sum every pixel in one column for each point in the x-profile. You would need to sum up every pixel in

a row to get a single point in the integrated intensity y-profile. On a perfect Gaussian (TEM_{00}) laser, the integrated intensity profile will match the intensity profile.

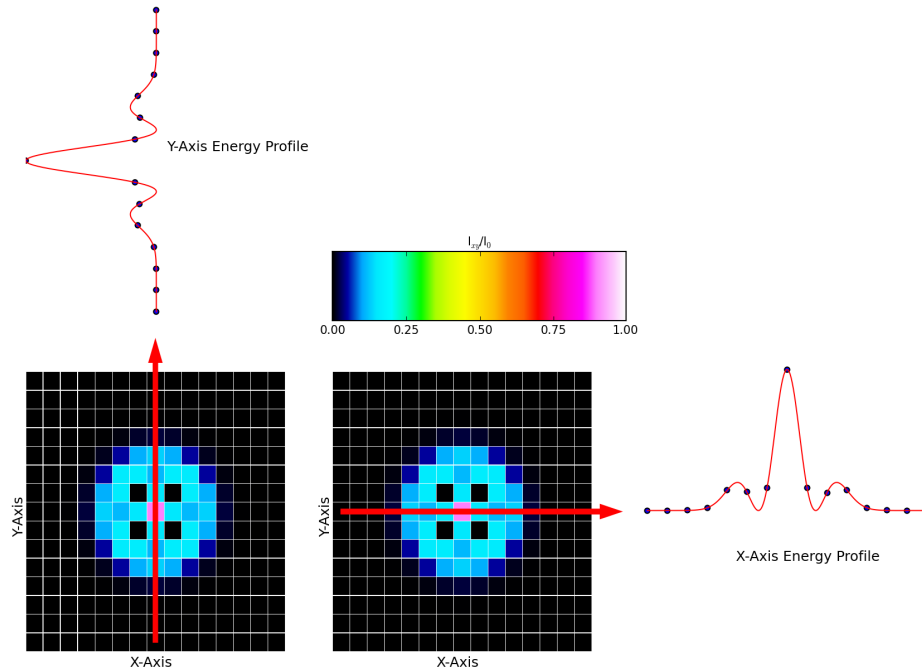


Fig. 1.5: Energy or Intensity profiles of Non-Gaussian Beam

As the beam becomes less Gaussian, the discrepancy between the integrated intensity and intensity profile increases. Figure 1.5 shows the intensity profile of a non-Gaussian beam. Figure 1.6 shows the integrated intensity profile. In this figure, the gray arrows represent the portion of the beam that is summed together to represent each point of the profile. The summed energy profiles in Figure 1.6 accurately represent the results from a scanning slit instrument.

As this example demonstrates, camera-based systems have a significant advantage over scanning slit instruments when profiling non-Gaussian or multi-mode sources. Scanning slit instruments obfuscate some of the 2-dimensional data of these beams. It is not possible to extract an energy profile from a summed energy profile. However, scanning slit instruments have several advantages that offset this. The first advantage a scanning slit has over a camera based detector is higher resolution. Currently, the smallest pixel size offered by laser profiling sensors is around $3\ \mu\text{m}$, so that the beam under measurement must be at least $30\ \mu\text{m}$. However, a scanning slit device delivers a significantly better resolution of $0.1\ \mu\text{m}$ and allows beams down to $2\ \mu\text{m}$ to be profiled. Thus, when measuring very small beams, a scanning slit device is preferred. Fortunately many sources that can be focused to this small size are very close to Gaussian.

In addition to profiling small beams, scanning slit devices have a large wavelength range. The silicon detectors in cameras have difficulty imaging wavelengths above $1200\ \text{nm}$, but scanning slit devices can use both silicon and InGaAs photodetectors. This significantly extends the wavelength range of the device.

Cameras have another significant advantage over scanning slit instruments in terms of suitability for pulsed laser measurement. Many cameras have global shutters which allows all of the pixels to be exposed to the source simultaneously. This enables a single pulse to be captured and analyzed. Scanning slit instruments

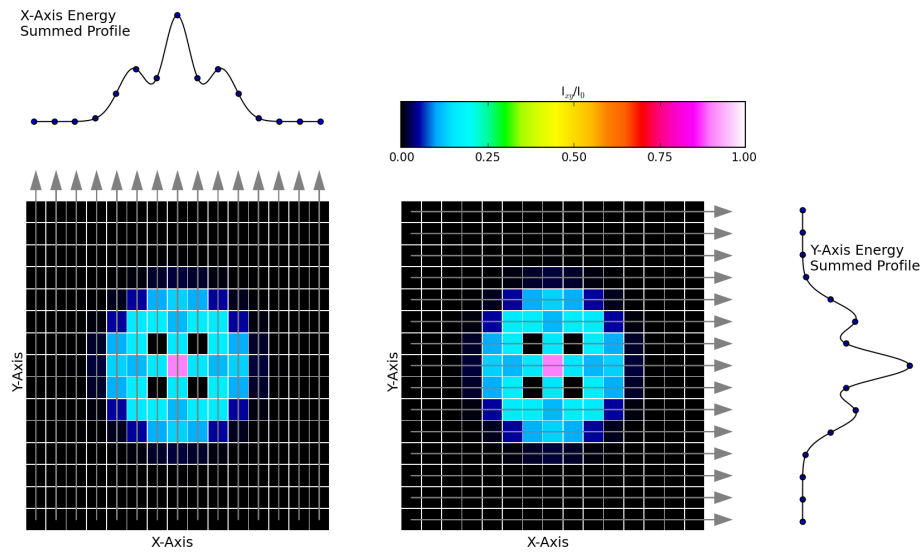


Fig. 1.6: Summed Energy or Integrated Intensity profiles of Non-Gaussian Beam

cannot capture individual pulses since scanning is a physical motion that takes time. Only time averaged measurements are possible. If the pulse repetition rate is high enough, a pulsed source can appear as a CW signal to a scanning slit detector.

1.2 BeamMap2 Series

BeamMap2 represents a radically different approach to real-time X,Y,Z, Θ , Φ beam profiling. A patented, multi-plane real-time slit scanning system is coupled to True2DTM thin multilayer metallic film on sapphire slit technology. If you have ever used a single plane beam profiler to measure a tightly focused beam, you will appreciate the problems that DataRay set out to solve.

1.2.1 Application: Aligning and measuring tightly focused beams.

A focused, aligned in-spec. beam should have the classic hyperbolic $w(z)$ (diameter) versus z profile shown right. Prior to alignment and focusing, the beam:

- May not be focused at $z = 0$
- May meet neither the beamwaist diameter nor the irradiance specifications.
- May have M^2 (Beam Quality) greater than specification

An instrument with a single plane of measurement gives just one plane of information. With only a single plane of measurement, finding the focus can be a truly frustrating exercise. Setting multiple assemblies to the identical focus in a production environment can be time consuming and costly. If the assembly will not

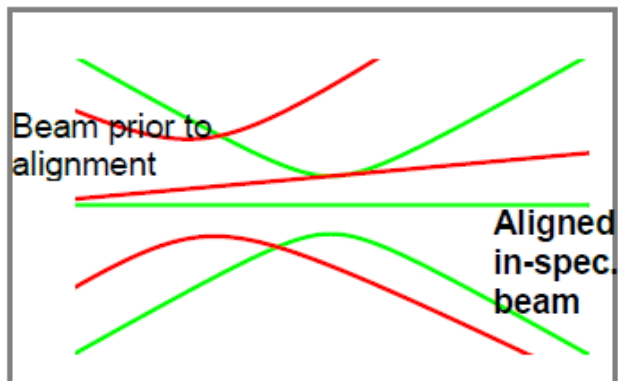


Fig. 1.7

adjust correctly, you have no real-time indication of what the problem might be. BeamMap2 enables you to measure and correct these beam focus and alignment errors. It measures the beam in multiple planes². If these planes are around the focus position, even when not at the focus, BeamMap2 can:

- Measure the axial misalignment (pointing).
- Indicate the current focus direction.
- Estimate the beamwaist diameter at the focus.
- Estimate the off-axis distance of the focus.
- Estimate M^2 and/or beam divergence.

in real-time. When the central measurement plane is positioned in the focal plane, these estimates become measurements of:

- Focus position in z .
- X-Y position and θ_{xz} angle.
- Beam-waist diameter and irradiance.
- M^2 Beam Quality and/or beam divergence.

with sub-micron repeatability, a 5 Hz update rate for real-time adjustment .

The BeamMap2 is the only commercially available multi-plane instrument for tightly focused laser beams. It saves setup time and ensures accurate, repeatable results. If the BeamMap2 is moved in z , it can give unambiguous indication of when the beam waist position is at the central measurement plane. If all assemblies are to be set to the same focus, place the central measurement plane at the design focus (or at the focus of a 'golden' (reference) unit) and adjust all assemblies to the same focus quickly and easily.

1.2.2 Application: Measuring very short focus beams

The Rayleigh Range (the distance from the focus at which the beam increases its diameter by $\sqrt{2}$) of a tightly focused laser beam can be as low as $2.0 \mu\text{m}$. The actual slits in standard slit scanners can actually

² The standard unit has $250 \mu\text{m}$ plane spacing; 50, and $100 \mu\text{m}$ spacing is available for very tightly focused beams, 500 and $750 \mu\text{m}$ for diverging beams, 3 or 4 planes at several mm spacing for collimated beams.

have a large depth in the z direction, they are three-dimensional slits with partially reflective sidewalls. The 'air' slits conventionally employed are 12.5 or 25 μm thick in the z direction, or 6 μm thick for the best available air slits. To a tightly focused beam, they look like a reflective tunnel rather than a two-dimensional slit. This reduces the accuracy of the focus determination.

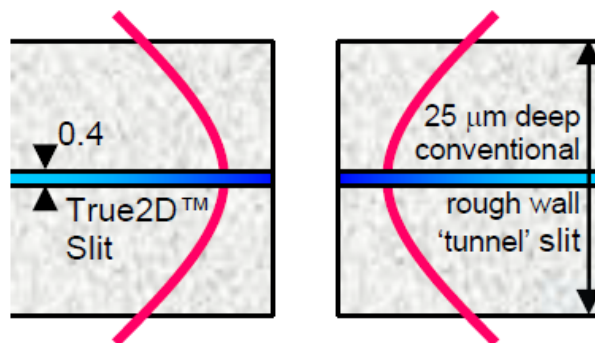


Fig. 1.8

Custom-developed, thin True2DTM slits allow accurate profiling of very tightly focused beams. These new metallic film slits, defined using high resolution optical lithography, comprise multiple opaque layers deposited on a sapphire substrate. The total slit thickness is ~ 0.4 microns, an order of magnitude thinner than the best air slits. The thermally conductive sapphire substrate allows for high irradiance performance.

1.2.3 Application: Measuring Beam Collimation/Divergence/Pointing

If you have ever used a single plane profiler to measure and adjust a collimated beam, then you know how time consuming the procedure can be. Measure once, move the profiler along the z axis, measure in the second plane, calculate beam divergence, readjust, start again, etc.

The BeamMap2 ColliMate uses widely spaced planes to extend multi-plane BeamMap2 profiler technology to beam divergence and pointing measurement, achieving an accuracy of better than 1 mrad. The measurement plane spacing in a BeamMap2 Collimate is 5 mm. They dramatically simplify the measurement of collimation and the alignment and the adjustment of multiple assemblies to the same axes.

1.3 Model Your BeamMap Beam

The plane spacing on a BeamMap2 instrument cannot be changed. It is important to select the correct plane spacing for your intended application. Download the [BeamMap Series Choice Excel Sheet](#) (see Fig. 1.9) from the website to model your beam with respect to your BeamMap2 Series unit. The spreadsheet is self-explanatory. Within the first 30 days, if you find that you may have the wrong plane spacing, contact Technical Support.

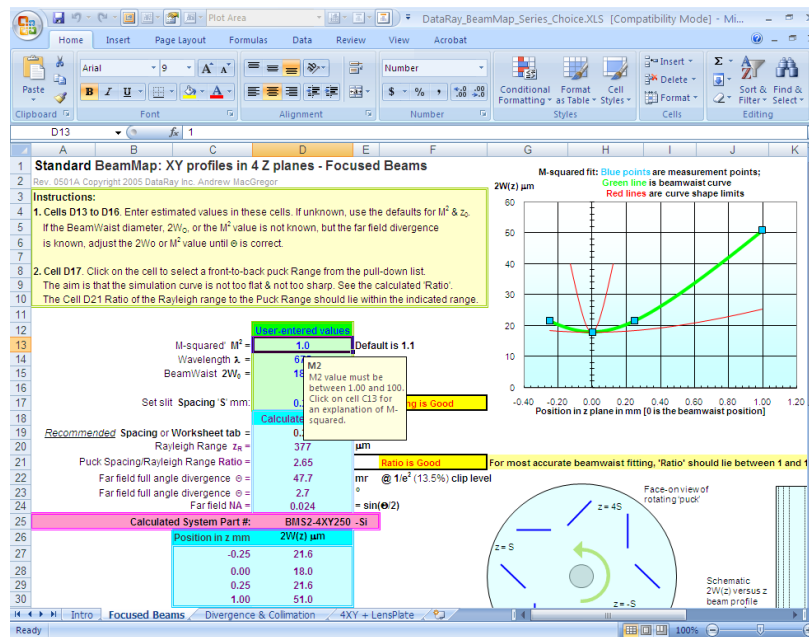


Fig. 1.9

1.4 Manual and Copyright Notice

This manual describes the operation of DataRay scanning slit Beam Profilers. DataRay Inc. reserves the right to make changes to this manual and to the equipment described herein without notice. DataRay has made considerable efforts to ensure that the information in this manual is accurate and complete. However, DataRay will not be liable for any technical or editorial errors or omissions or for any incidental, special or consequential damages of any nature resulting from the furnishing of this manual, or for the operation and performance of equipment in connection with this manual.

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Windows XP and Vista are trademarks of Microsoft Corporation.

LabVIEWTM and LabWindows are trademarks of National Instruments.

Chapter 2

Installation

This chapter will guide you through the initial setup and installation of your DataRay device.

2.1 Unpack the Hardware

Please check your purchase. Locate and identify all items. If any items appear damaged or missing or you have any other questions, please immediately contact Product Support or your local Distributor. A system shipment should include:

- Instrument
- 3 meter USB 2.0 A to mini-B5 cable.
- Software on USB drive (includes user manual)
- Any accessories ordered.

Part number questions? Visit dataray.com for the current datasheets and part numbers.

2.2 System Functional Configuration

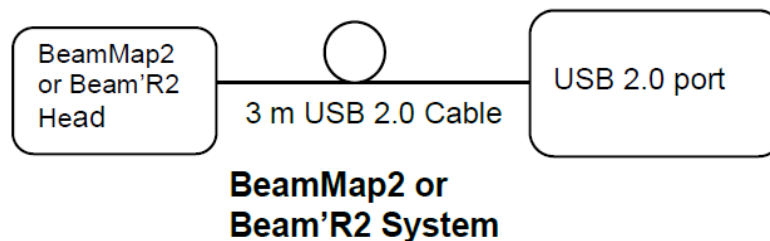


Fig. 2.1: BeamMap2/Beam'R2 Diagram



Fig. 2.2: Beam'R2 Scanning Slit Beam Profiler

2.3 Minimum Computer Requirements

- Windows versions: Windows Vista, 7, 8, and 10 supported; both 32-bit and 64-bit are supported
- A 1 GHz Processor or faster.
- 1024 x 768 display with ≥ 256 colors
- USB 2.0 port with 500 mA capability (the standard except on unpowered hubs).
- ≥ 512 MB of RAM. 1 GB if you are to use the M2DU Stage.
- A hard drive with 10 MB or more available space.

2.4 Installation

In order to ensure successful installation and use of DataRay products, please closely follow the software and hardware installation instructions detailed in this chapter.

IMPORTANT: INSTALL THE SOFTWARE BEFORE THE HARDWARE. The software can be used to view data whether or not the camera is installed.

You must install the software as 'Administrator'. 'User with Administrator Rights' is not enough. [Windows requires that hardware drivers be installed by an Administrator. If you cannot even install the software, it may be that your Administrator (i.e. the actual IT person) has restricted your software installation rights, and must therefore be called in to install the software.]

Not sure what your User Profile covers? Go to Start, Control Panel, User Accounts, click on your account name, click on Change my account type, and verify that Computer Administrator is checked.

Software upgrades are free for the life of the product. The absolutely latest software is not necessarily the version that arrived with the hardware. Always visit Software Upgrades at the website in order to determine whether a more recent version is available for download. Check the version and the date. If you do not already have it, download and install the latest version from the website.

2.4.1 Software Installation Instructions

1. Be sure to meet the minimum computer requirements outlined in Section 2.3.
2. Insert the installation USB drive in the computer's USB port. It should AutoRun. If it does not, it can be manually started by navigating to the drive in Windows Explorer and running iDataRayXXYZZ.exe

[If installing from downloaded software saved to your hard drive, in Windows Explorer, from C:\Downloads, or whichever temporary directory you put the software in, extract the zip file then double-click iDataRayXXYZZ.exe to begin the installation.]

3. Choose Install as Administrator.
4. Choose Yes if asked Do you want to allow this software to make changes to your PC?. You must have administrator rights to install the DataRay software/drivers
5. Accept the Installation & Use Agreement to begin the installation. Wait for installation to complete.
6. Press OK if a pop up window appears; this will install the DataRay driver.
7. Connect the hardware per the diagram in Figure 2.1. Follow through the New Hardware found procedure., but do not allow Windows to search on the web. If necessary, direct it to look in c:\Program Files\DataRay.

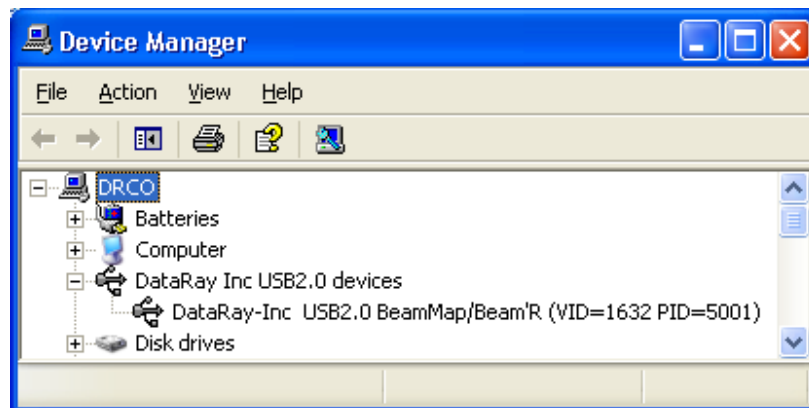



Fig. 2.3: BeamMap in Windows Device Manager

2.4.2 Connecting the unit

1. Connect the BeamMap/Beam'R2 to the computer's USB 2.0 compatible port using the 3 m USB 2.0 cable
2. Booster cables or hubs are required for cable lengths greater than 5m (16ft); look under Accessories at the [DataRay](#) website
3. Start the software. The LED will sequence through: Off, Red, Green. To start taking data, click on the Go , or press F1 or g on the keyboard. Problems? Contact Technical Support at support@dataray.com.

2.5 Software Interfacing

For interfacing to LabVIEW™, Visual Basic, Visual C++, MATLAB, etc., we do provide an OCX. Instructions and sample code are available at <http://www.dataray.com/interfacing.html>. Contact [Technical Support](#) as necessary.

2.6 Firmware Upgrades

- What is firmware? Firmware is software programmed into the permanent memory of the hardware that controls the hardware's behavior. Upgrades may be required to improve performance, add features, and/or to correct a bug.
- How frequent are upgrades? Firmware upgrades may happen during the year following introduction of a new product or a major upgrade. Subsequently they are rare events.

Chapter 3

Quickstart

3.1 Overview

Our current scanning slit line of beam profilers include the Beam'R2 and BeamMap2 series of products. The scanning slit and knife-edge profiling techniques used by these devices allow for real-time direct measurement of X/Y summed profiles with sub-micron resolution. The BeamMap2 series can also provide real-time M2, divergence, and pointing measurements.

3.2 Beam Limitations and Safety

3.2.1 Safety

Always follow proper laser safety protocol when working with lasers of any power, refer to ANSI Z136.1. Be sure to understand the light's path, including every reflection/transmission through any surfaces.

3.2.2 Beam Power/Energy Limitations

Rule of thumb:

- Slit damage threshold $\approx 0.2 \text{ mW}/(\mu\text{m diam.})^2$
 - (e.g. $\approx 20 \text{ mW}$ at $10 \mu\text{m}$ diameter.)

Please refer to Section [5.4](#) for complete damage thresholds and beam size limitation information.

3.3 Setup and Use

3.3.1 Software Installation

1. Identify your device product series and firmware version. The product series will either be Beam'R2 or BeamMap2 and can be found on the front faceplate of the device.
2. Identify your device firmware version. The Firmware version is marked on the device back label. Current devices will be Firmware Rev. 4.
3. Download the corresponding software package for your product and firmware version from <https://www.dataray.com/downloads.html>
 - You may use the software on the USB drive included with your device, but it is a good idea to check the website to ensure you have the latest software available.
4. Extract the ZIP file and run the installation executable.
 - Follow the on-screen instructions to install the software.
 - Choose "Yes" if prompted with a User Account control dialog asking whether to allow changes to your system.

3.3.2 Hardware Installation

1. Be sure to have installed the correct version of software.
2. Open the DataRay software.
3. Attach the USB-A end of the included cable to an available USB port on the computer.
 - If a USB hub is used, it may need to be a powered hub in order to work properly since the profiler is USB powered.
4. Attach the USB Mini-B end of the cable to the beam profiler.
 - The puck in the device will begin to spin
 - The green bar in the Left Panel of the software will show Initializing for a few seconds
 - The green bar will then show your device model, firmware number, and display Ready

3.3.3 Beam'R2 Measurements

1. Follow the Software and Hardware installation instructions.
2. Ensure your beam is below the maximum irradiance limits. (Refer to Section 5.4).
3. Ensure you have (at least) X and Y alignment adjustments available for beam location.
4. Click on the green button that says Beam'R2.[FW version] Ready to start the camera. At first it will just read background noise until a beam is aligned correctly.
5. Turn on the beam and roughly align to the center of the input aperture of the device.
 - Some models have two detectors and two input apertures. The primary detector is behind the left input aperture. The alternate detector is behind the right input aperture. Choose Setup→Select alternate detector input to choose which detector is active.

6. If the beam is aligned well, the circular shape in the Alignment panel that marks the beam centroid location will no longer be on the edge of the alignment target. The 2D reconstruction window will begin to display the shape of the measured beam once it is aligned well.
7. Continue to adjust the alignment of the beam by observing how the centroid marking moves with small X/Y alignment adjustments. The centroid location should be stable and well inside the alignment target.
8. Beam diameter and other measured parameters can now be read from the various software panels.

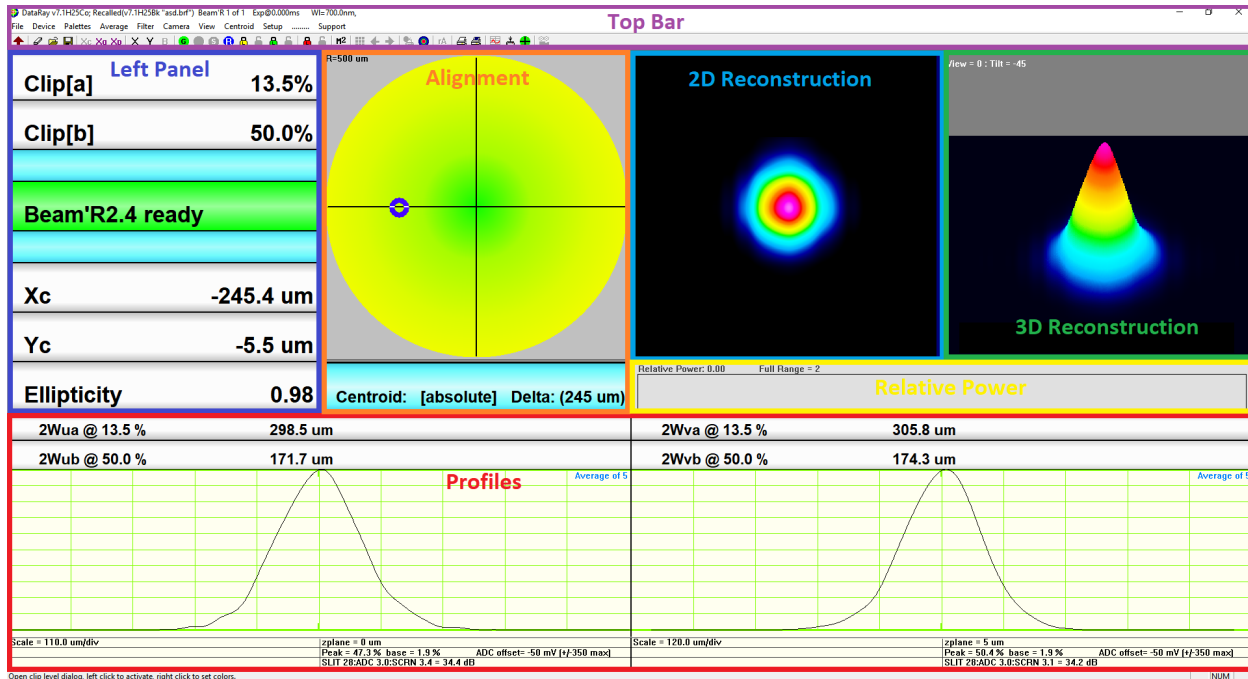


Fig. 3.1: Beam'R2 Software Panels

3.3.3.1 Beam'R2 Software Panels

This provides a quick overview of the Beam'R2 software panels. For more detailed information, please refer to Section 4.

- Left Panel (Section 4.1.2.4 and 4.1.2.5)
 - Clip Levels
 - Camera Status
 - Centroid Readings
 - Ellipticity
- Alignment Panel (Section 4.1.2.8)
 - Visually display centroid location

- 2D Reconstruction Panel (Section 4.1.2.9)
 - Visually display 2D reconstruction of the beam in accordance with X/Y profiles
- 3D Reconstruction Panel (Section 4.2.1)
 - Visually display 3D reconstruction of the beam in accordance with X/Y profiles
- Profiles Panel (Section 4.1.2.6)
 - Displays profile plots and diameter measurements in accordance with chosen Clip[a] and Clip[b] settings
 - The X profile is shown on the left, the Y profile is shown on the right.
- Relative Power Panel (Section 4.2.5)
 - Left click to setup relative power measurements
- Top Bar
 - Title Bar displays capture settings for currently shown data (Section 4.1.2.1)
 - Menu Bar contains several dropdown menus with various options (Section 4.3)
 - Toolbar contains clickable icons for quick options and additional tools (Section 4.4)

3.3.4 BeamMap2 Measurements

1. Follow the Software and Hardware installation instructions
2. Be sure the beam is below the maximum irradiance limits. To measure M2, it must be a focused beam.
3. Be sure to have X, Y, Z, Θ , and Φ alignment adjustments available.
4. Click on the green button that says BeamMap2.[FW version] Ready to start the camera. At first it will just read background noise until a beam is aligned correctly.
5. Turn on the beam and roughly align to the center of the input aperture of the device. The beam focus should be roughly positioned on the rotating puck.
 - Some models have two detectors and two input apertures. The primary detector is behind the left input aperture. The alternate detector behind the right input aperture. Choose Setup→Select alternate detector input to choose which detector is active.
6. The beam centroid, pointing (boresight), and focus position must be aligned.
 - The alignment panel displays the centroid location of the beam at the Z=0 plane as a circular marker. The beam should be adjusted in X/Y to center this marker on the target. If the beam is aligned well, the circular marker in the Alignment panel that marks the beam centroid location will no longer be on the edge of the alignment target and the 2D reconstruction window will begin to display the shape of the measured beam.
 - The elliptical marker in the alignment panel tracks the focus position of the beam. This marker will move left/right to indicate whether the beam waist is positioned before/after the z=0 plane. The beam should be adjusted in Z in order to center this elliptical marker as shown in Figure 3.2. At this position, the beam waist will lie on the Z=0 slit plane.
 - If you are measuring the linear region of a beam rather than around a focus, you will not have to worry about aligning the focus location. The Divergence dialog can be opened by clicking the Divergence button on the toolbar (Section 4.4.2) for linear fit information.

- The beam should be incident normal to the face of the device (approximately). The M2 dialog (Section 4.4.4.1) can be opened to check the pointing (boresight) and visualize the beam caustic. Pointing is ideally minimized, but should at least be good enough so that each slit plane provides a full profile without clipping.
 - When the beam is well aligned with the focus on the $Z=0$ plane, the plot in the M2 dialog will show two Green boxes for Z_0/Z_r and M2 measurements will now be valid.
 - The M2 dialog is opened by clicking the M2 button on the toolbar.
 - If the beam is aligned and focused correctly but these boxes are still Red or Yellow, then the plane spacing of your device may not be correctly chosen for your beam waist size. You may save a *.bcf file and send to support@dataray.com for further assistance.
7. Continue to adjust the alignment of the beam by observing how the centroid marking moves with small X/Y alignment adjustments. The centroid location should be stable and near the center of the alignment target.
 8. Beam diameter and other measured parameters can now be read from the various software panels.

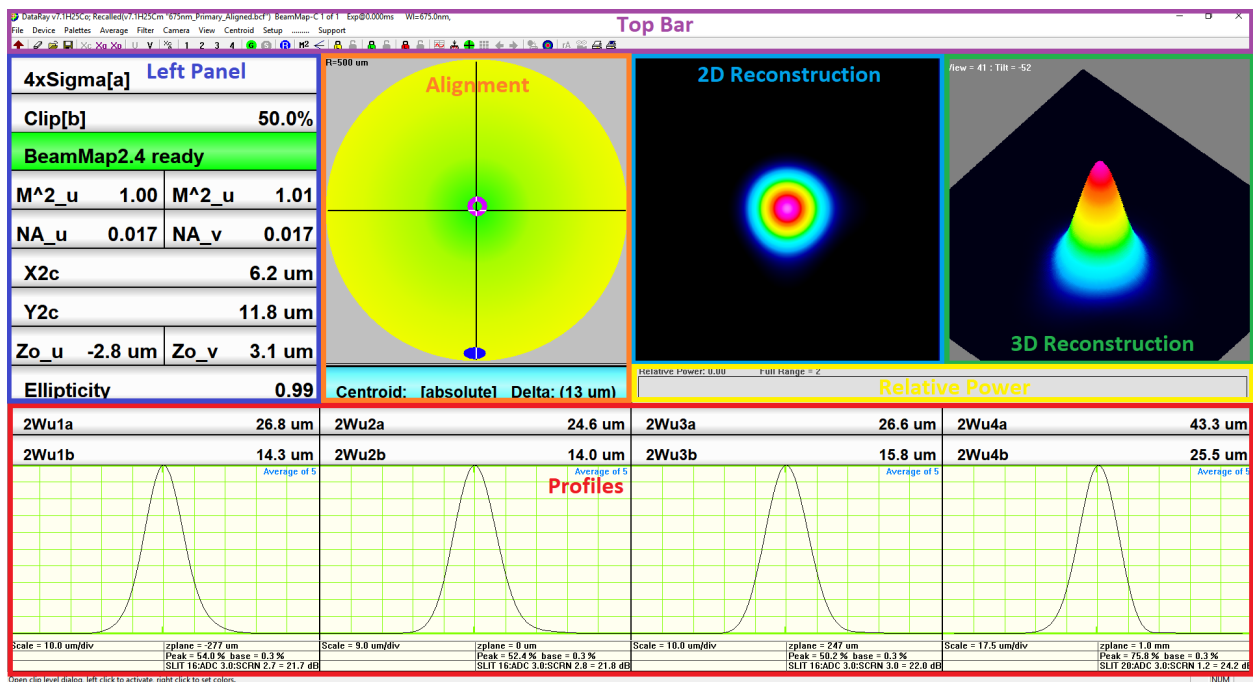


Fig. 3.2: BeamMap2 Software Panels

3.3.4.1 BeamMap2 Software Panels

- Left Panel (Section 4.1.2.4 and 4.1.2.5)
 - Clip Levels
 - Camera Status

- M2 Readings
 - NA Readings
 - Centroid Readings
 - Focus positions readings (relative to Z=0 plane)
 - Ellipticity
- Alignment Panel (Section [4.1.2.8](#))
 - Visually display centroid location with circular marker
 - Visually display beam waist location with elliptical marker which only moves left and right. When the ellipse is centered at the bottom of the alignment panel, as shown in [Figure 3.2](#), the beam waist is located at the Z=0 slit plane.
- 2D Reconstruction Panel (Section [4.1.2.9](#))
 - Visually display 2D reconstruction of the beam in accordance with X/Y profiles
- 3D Reconstruction Panel (Section [4.2.1](#))
 - Visually display 3D reconstruction of the beam in accordance with X/Y profiles
- Profiles Panel (Section [4.1.2.6](#))
 - Displays profile plots and diameter measurements in accordance with chosen Clip[a] and Clip[b] settings
 - By default, the X profiles at each slit plane are shown. The toolbar icons can be used to see the four Y profiles instead (Y), or the X and Y profiles for each slit plane individually (1, 2, 3, 4).
- Relative Power Panel (Section [4.2.5](#))
 - Left click to setup relative power measurements
- Top Bar
 - Title Bar displays capture settings for currently shown data (Section [4.1.2.1](#))
 - Menu Bar contains several dropdown menus with various options (Section [4.3](#))
 - Toolbar contains clickable icons for quick options and additional tools (Section [4.4](#))


Chapter 4

Software Tutorial

4.1 Software Tutorial

This section will provide a detailed tutorial on using the software and can be used to become familiarized with the features provided by the DataRay software before connecting any hardware.


4.1.1 Start the Software

Double-click the DataRay icon  on the desktop to start the software. Click Device in the pull-down menu bar and select the appropriate product. For simplicity in this tutorial, start with Beam'R2 which has orthogonal slits and measures in a single z plane.

Greek letters, subscripts, and superscripts are not used on DataRay screens because some non-English versions of Windows do not display them properly. Instead the following is used:

- um rather than μm
- Xc rather than X_c
- y rather than γ

4.1.1.1 Examine Previously Saved Data

Click on the  button or choose File→Open... to open the Open dialog box. Navigate to the previously saved file or open a sample file from the DataRay installation folder (usually located at C:\Program Files (x86)\DataRay).

When you simply capture or open image data, it does not change the current settings of the various display and measurement options. It is possible to do this by previously saving specific display settings as a *.ojf (ocx job file) file and then opening this file which contains display and analysis settings. See Section 4.3.1.

To see other device screens, under Device select a different product then Open a sample file, or simply select a different file in the Open dialog from Files of type:. Have a look, and then return to Sample.brf via the recently opened file list at the bottom of the File menu.

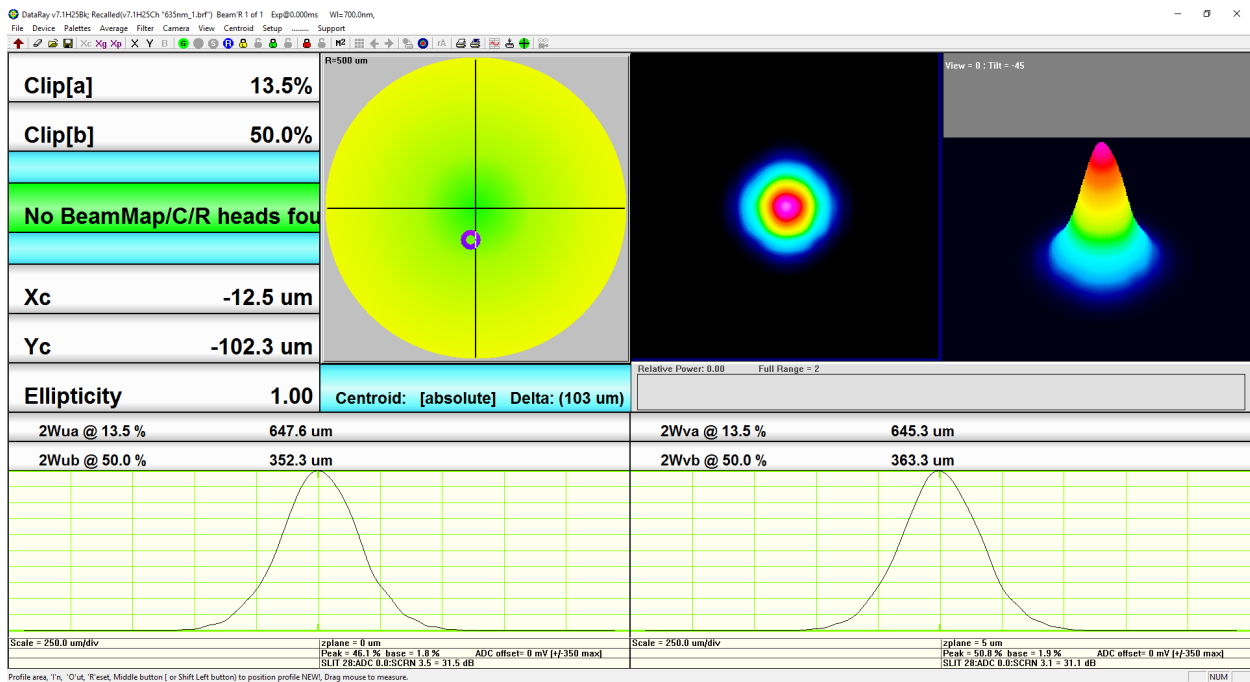


Fig. 4.1: DataRay interface after opening *.brf data file

4.1.2 Main screen

Note the Main screen areas for default settings, starting at the top left:

4.1.2.1 Title Bar

- Live Mode: DataRay v7.1H25Bk: Live = image 0 of 0 Wl=700.0nm,
- Recalled file mode: DataRay v7.1H25Bk; Recalled(v7.1H25Ch "635nm_1.brf") Beam'R 1 of 1 Exp@0.000ms
 - DataRay version 7.1H25Bk: The software version installed on your PC
 - Live or Recalled (v7.1H25Ch). The current software operating mode and the Rev. of the software employed to save the recalled file
 - 1 of 1: The profile number "i of n"

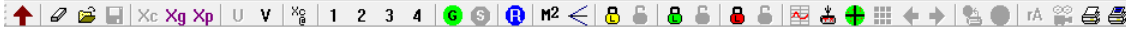
4.1.2.2 Pull-down Menu Bar

File Device Palettes Average Filter Camera View Centroid Setup Support

- Section 4.3 describes menus in detail.

4.1.2.3 Toolbar

- Accesses frequently used functions. Section 4.4 contains detailed descriptions.
- BeamMap2



- Beam'R2



- If you have no hardware installed and are simply evaluating the software, or if they are inapplicable to your hardware, some buttons will be grayed out.
- Hover the mouse over any button to see a description of its function. If additional buttons appear in later software revs, hover the mouse over them to determine their function.

4.1.2.4 Clip Levels

- User set profile clip levels that determine 2W_a and 2W_b, see Section 4.2.2. A clip level is the percentage of peak signal at which the diameter is measured during clip width measurements.

Clip[a]	13.5%
Clip[b]	50.0%

Fig. 4.2: Left-click in the box to change clip level

4.1.2.5 Unit Status and Results

- The green background bar shows the current unit type and status.
- X_c and Y_c are the beam centroid positions calculated as the 'center of mass' intensity-wise for the beam levels above the current centroid clip level. (This defaults to 13.5% and may be changed from the Menu Bar in Setup→Set centroid clip level.)
 - Note that X_c & Y_c, [Absolute] or [Relative] are the running average of four measurements as long as the individual readings are within 2 μm of the running average. If the change is >2 μm, then a new running average is immediately started.
- BeamMap2 screens add M2 & Z_c and the X_c & Y_c values change to X1_c & Y1_c, X2_c & Y2_c, X3_c & Y3_c, or X4_c & Y4_c, depending on the selected 1, 2, 3 or 4 z-plane, or defaults to X2_c & Y2_c when the u or v set of profiles is selected from the Toolbar.
- Note that all BeamMap2 z related calibrations and measurements are referenced to the Plane 2, which is why in it is referred to interchangeably as the 'zero plane'.
- Ellipticity is the ratio of the minimum beam diameter to the maximum for the selected Clip[a] level

No BMap/R heads			
M^2_u	0.00	M^2_u	0.00
NA_u	0.000	NA_v	0.000
X2c	0.0 um		
Y2c	0.0 um		
Zo_u	0.0 um	Zo_v	0.0 um
Ellipticity	0.00		

Fig. 4.3: Results Box for BeamMap2

4.1.2.6 Default Profile Detail

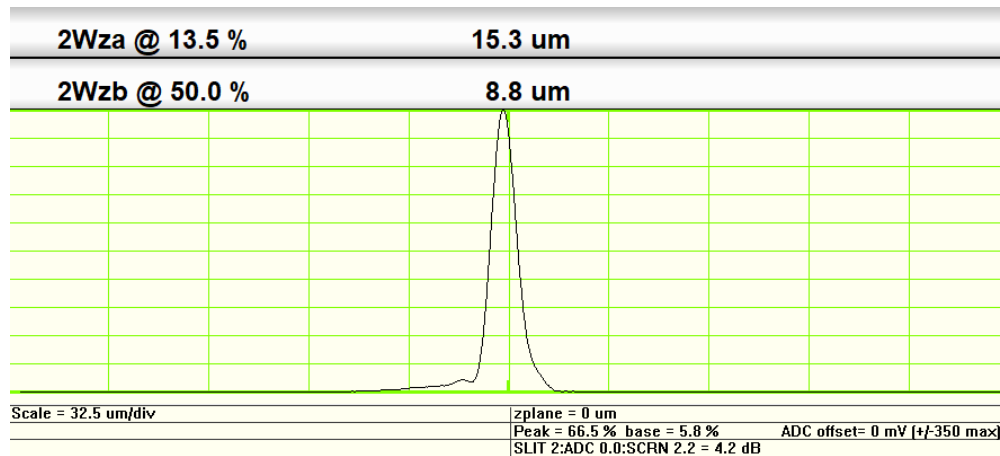


Fig. 4.4: Profile display

- Zero Level. Note first that the zero level is a three pixel wide line, the center of which is the actual zero as set by the software after subtraction of the baseline. This zero level line is set five pixels above the base of the graph area so that 'negative' (electrical) noise remains visible.
- 2Wua and 2Wub: Profile widths at the Clip[a] and Clip[b] levels, expressed as a % of peak.
- Zoom = 2X. Indicates horizontal zoom on this profile. (Blank if not selected)
- Scale = xx.x um/div for the current zoom setting
- zplane = xxx um. The plane on the Beam'R2 or BeamMap2 puck at which the profile was taken. A negative number indicates a plane closer to the front of the unit.

Beam'R2 takes all measurements in the same nominal z plane, therefore zplane = is invariably within a few tens of microns (or better) of 0 um.

- Peak = xx.x% indicates the peak value of the (un-normalized) profile as a percentage of the display height, which is also the percentage of the 12-bit (4096 levels) ADC range.

- Base = xx.x % indicates the subtracted base. In a dark area this will be low. Next to a sunny window it can be high.
- G = xx.x dB + yy.y dB. The amplifier (hardware and software) xx.x dB gain on this channel + the yy.y dB software gain required for the (default) normalized profile display in optical dB.

Why should you care what the gain is? If the amplifier is saturated at 0 dB Gain, or the signal is too low at the maximum gain, the numbers will turn orange as a warning. If you need to increase or attenuate the beam irradiance, knowing the current gain is important. [Optical dB are half the value of electrical dB. A factor of 10 dB corresponds to a change of x10 in the peak intensity. Some competitors' specs deal only in electrical dB]

- BeamMap2/Beam'R2: Hardware gain steps 0 to 30 dB, 4 dB steps, 12-bit ADC.

4.1.2.7 Status Bar Help Hints

- Almost every area of the screen is a 'Button' which you may left-click or right-click to cause something to happen. Instructions for using the current function appear just below the profiles in the bottom status bar of the DataRay software window. Watch the Status Bar Help Hints change as you move the cursor across the screen. If at any time you are not sure how to do something, move to the relevant area of the screen, look at the Help Hints bar, and you will often find your answer.

Open clip level dialog, left click to activate, right click to set colors.

Fig. 4.5: Example of a status bar hint while the mouse cursor is hovering over the Clip Level box in the software

4.1.2.8 Centroid Position

- The large yellow-green target has a 500 um default diameter shows the region around the Relative centroid (user defined) or the Absolute centroid (unit defined), based upon the Xc, Yc values.
- X & Y are the conventional axes, where X is horizontal and Y is vertical. The U, V axes are the axes measured by the slit pair(s), identical to X and Y for all profilers in this manual when the unit is mounted in a normal configuration.
- Centroid 'ring' or 'donut'. The 30 pixel diameter outer circle of the donut shows the beam centroid in relation to the absolute unit 0,0 centroid reference established at the time the instrument was calibrated.
- The 15 pixel diameter inner circle shows the beam centroid in relation to the last selected relative centroid.
- When the beam is outside the current radius the indicator will appear to be stuck on the appropriate edge or corner.
- The circles and the ellipse are always the inverse color to the part of the target on which they sit. i.e., they change color as they move over the target.
- Clicking on Toggle Centroid: [absolute] toggles it to Toggle Centroid: [relative] , & vice versa. Pressing z or a on the keyboard gives the same result. If you select [relative], it resets the relative centroid origin to the current centroid position, whatever that might be.

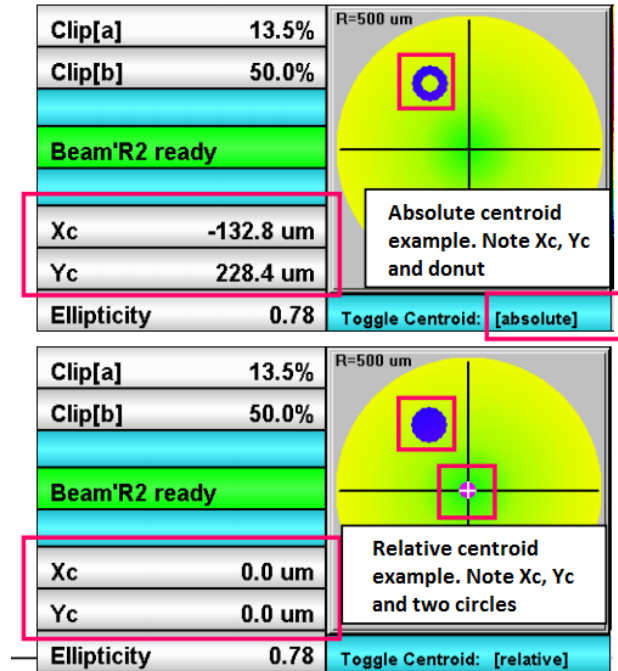


Fig. 4.6: In absolute centroid mode, the 15 pixel inner circle lies within the 30 pixel outer circle.

For the specification accuracies, you should try to work with the centroid close to the absolute centroid of the instrument. i.e. The centroid should normally lie within the 500 um radius screen. The further that you move from here, the greater the possibility that energy in the edge of the beam may fall off the edge of the detector and affect the measurement.

When are you in this danger region? It is simple to tell. If the dB gain increases when you move the beam further from the center, then energy is falling off the detector.

- BeamMap2 series Multiple z plane units.

When a multi-plane unit is in use, a blue ellipse on the bottom line will move left/right to indicate the calculated distance of the actual focus from the zero plane of the instrument. The scale is the same as that of the centroid display.

Right-click on the target area to open the box shown in Figure 4.7. The defaults are as shown. To lock the centroid display to a particular radius, select a specific Wander display radius = XX microns. This may be useful if you are using relative centroid and fine adjusting the centroid position.

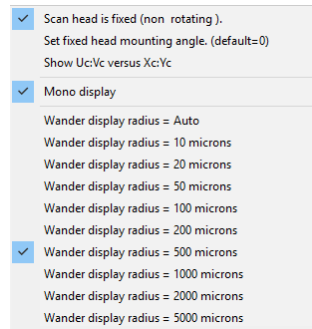


Fig. 4.7: Right-click on the target area to display options to change the wander display radius.

4.1.2.9 2D Profile Display

For all scanning slit profiles this is a visualization tool. The 2D Profile display is not a picture of the beam. It displays a derived 2D plan view interpretation of the beam profiles.

The display algorithm assumes the only reasonable reconstruction of the information contained in two orthogonal scans. I.e. it assumes that: The measured X profile is identical for all values of Y. The measured Y profile is identical for all values of X

- A Gaussian beam will therefore appear like a true Gaussian.
- An elliptical beam with orthogonal Gaussian profiles will appear like an elliptical beam.
- A beam with a 'tail' on one profile will appear to have a tail in that direction.
- A beam with extended tails on both sides of both profiles will appear like a four point star.
- A square beam will appear square.
- A circular 'Top Hat' beam will appear close to square.
- A beam with complex structure will show complex structure in the 2D image, but only as much as can be derived from summed X/Y profiles.

Right-click on the 2D area to open the context menu shown in Figure 4.9. Most of which is self explanatory. This allows you to change the palette selection and to zoom the 2D profile area. If a rectangular selection region [white box] for the 3D display has been selected, then the 2D zoom also zooms the 3D area.

Ink saver option is used for inkjet printing to avoid the floppy wet paper effect when a lot of black background is printed.

Export to Paint opens Paint and allows the user to save that area of the screen in any of the Paint Save As formats.

4.2 Manipulate the Image and the Profile Analysis

This section takes you beyond the defaults described in Section 4.1.2.

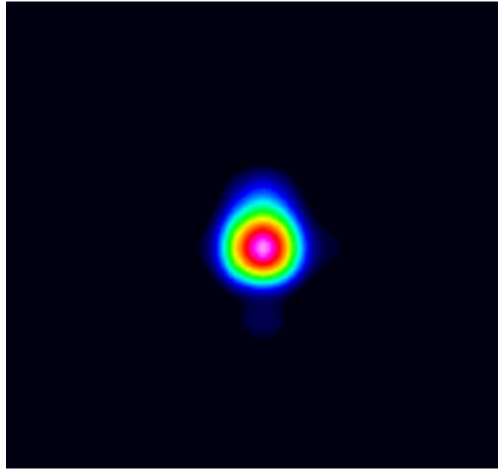


Fig. 4.8: 2D representation of the X and Y summed profiles obtained from orthogonal slits

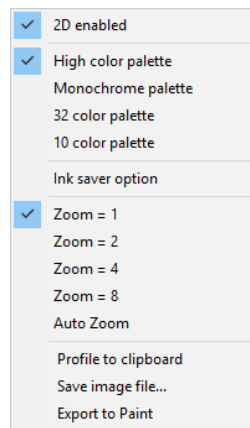


Fig. 4.9: Right-click on the 2D profile to access various display options

4.2.1 2D & 3D Display & Manipulation

- Right-click on the 2D image area to bring up the Zoom and color palette options shown in Figure 4.9. Choose a higher Zoom setting to zoom the 3D image. The sample file is shown above at Zoom = 1.
- Click and drag in the 3D box to change the view of the 3D image. Side-to-side cursor motion rotates the image. Up-down changes the tilt angle

4.2.2 Clip Level Entry – Choose a Beam Width Definition

- Click on the Clip[a] or Clip[b] 'button' (Figure 4.10) to open a Clip level entry dialog box (Figure 4.11) that allows you to choose a Beam Diameter/Width definition.

Clip[a]	13.5%
Clip[b]	50.0%

Fig. 4.10: Clip level buttons

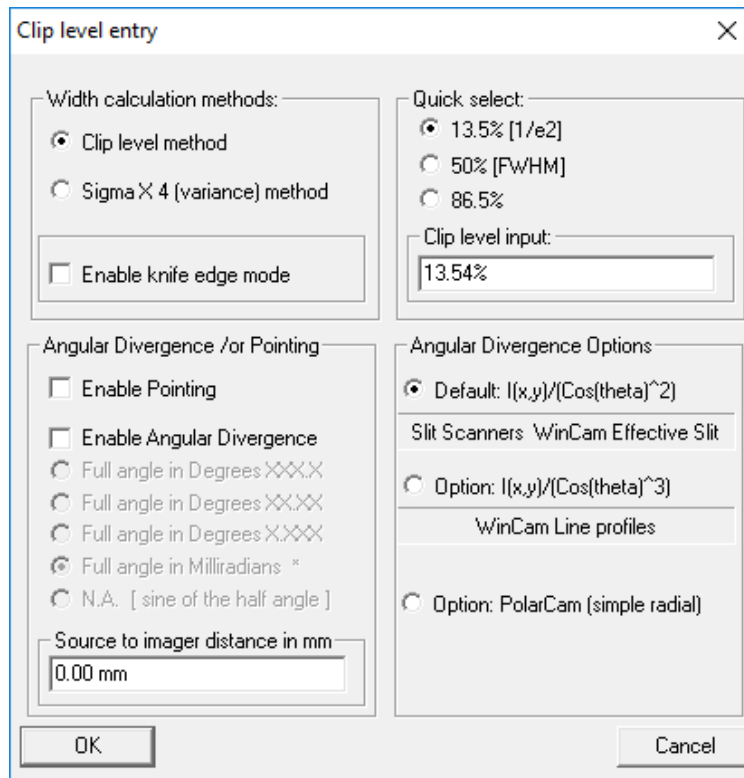


Fig. 4.11: Left click on the Clip[a] or Clip[b] button to open the Clip level entry dialog box.

4.2.2.1 Width Calculation Methods

- Clip Level Method
 - Clip Level set at 13.5% [$1/e^2$] is the commonly employed 'de facto' standard. (Actually 13.53%).
 - Additional menu selections are 50% [FWHM] (Full Width Half Maximum) and 86.5%.
 - Any user set value percentage between 0.5 and 99.5 can be entered in the Clip level input box.
- Sigma X4 (Variance) Method
 - If ISO 11146 compliant Sigma X4 (variance) method (Second Moment) is selected, the clip level is ignored. With a beam profile that is a pure Gaussian, the Variance definition of diameter is exactly the same as selecting a 13.5% Clip Level, but if your beam is non-Gaussian, as many beams are, the Variance method may be more appropriate. An exception to this general rule is that the presence of a significant background level above zero or background noise will skew the Variance reading to larger values.

- In accordance with Section 6.2 of the ISO 11146 Standard, the Second Moment calculation integrates over 99% of the total energy in the profile. In order to allow for any baseline tilt, the zero levels on either side of the center are treated separately and integration from the centroid is separately performed for 99% of the energy on each side of the centroid.
- If you select the Sigma X4 (variance) method option, a Warning box will appear to suggest setting averaging to a minimum of 5 frames.

4.2.2.2 Baseline Zero

The software automatically determines the peak level and the outer crossings of the raw 13.5% width. It then scans a width approximately four times greater than this raw 13.5% width. The actual baseline is then calculated as the average of the values at either end of the scan (5% of the scan length at each end). This baseline is then subtracted to create the zero level displayed. The calculated baseline value is also displayed below the profile.

If your beam has wide low level 'wings', best seen using log mode, (see section 4.2.4), then the zero level may be incorrectly set. See section 4.2.4 also for how to set a wider scan region.

4.2.2.3 Enable Knife Edge (KE) Mode

Knife Edge Processing. On a beam narrower than the slit, the slit acts as two opposed knife-edges. As the slit scans the profile, this gives first the integral of the actual beam profile, then a flat top while the beam energy is totally within the slit width, and then the inverse integral of the profile.

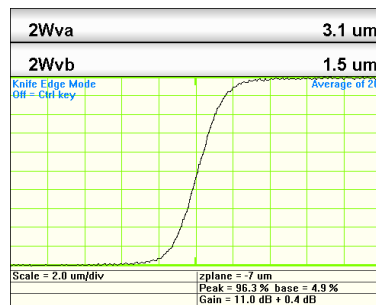


Fig. 4.12: Knife Edge Profile

- If you check this option, when the beam's FWHM (Full Width Half Maximum) is smaller than the width of the alternate slit (normally 50 μm wide), the software will automatically display the integral waveform from the leading edge of the slit.
- The displayed 2W values assume that the beam is Gaussian and that:
 - For the 13.5% diameter, the intercepts on the integral power curve are at 2.28 & 97.72%
 - For the 50% diameter, the intercepts on the integral power curve are at 11.95 & 88.05%

IMPORTANT: The focus position for KE mode will be different to that for the standard slits. When switching between the two modes, you must refocus in z.

Select an appropriate level of Average or Filter from the pull-down menu to reduce the noise at the expense of resolution. See Section 4.3.4.

4.2.2.4 Angular Divergence

Estimates the divergence based on the diameter of the beam and distance from the source waist.

- First enter a Source to slits distance in mm, 'd', then you can select the Angular Divergence option, in which case the diameter readouts will full angle Θ in terms of the angular units selected and at the clip levels selected. [Not valid for Variance.]
- The irradiance varies as distance from the source (for a slit scanner, which integrates along the slit). The angle of the slit to the source changes with distance 'x' from the beam centroid. In order to correct for these two $\cos(\theta)$ dependencies, the profile intensities are multiplied by $1/(\cos(\theta))^2$ before the diameters are calculated, where $\tan(\theta) = x/d$, where x is the distance along the profile from the beam centroid.

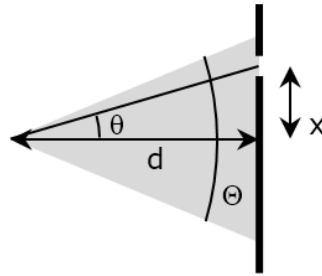


Fig. 4.13: Angular Divergence is calculated with the user input 'd' distance and the measured beam dimensions.

4.2.3 Set Pass-Fail Criteria

Pass/Fail parameters can be specified so that any user of the DataRay program can easily determine whether a measurement meets certain specifications.

4.2.3.1 Pass-Fail Parameters

- Left-click on any result area of the screen to open a Pass/Fail parameters dialog box. You may set an Upper Limit and a Lower Limit for the particular parameter.
- Check the Enable Test box to enable the test.
- When the test is enabled, the numbers will be displayed onscreen in the chosen Pass/Fail colors. The default colors are Green for Pass and Red for Fail.
- Check the Lock w/ Password box to lock the criteria. Left-click on the result again to enter and set the password. The master password peanuts can be used as a backdoor.

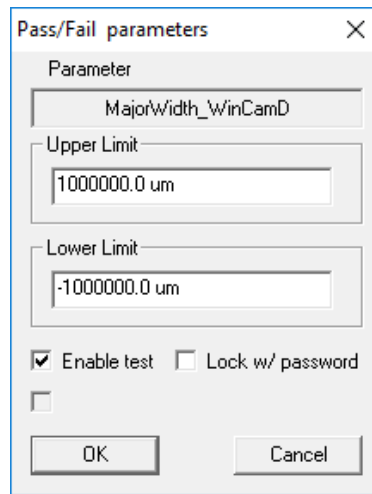


Fig. 4.14: Pass/Fail parameter dialog

4.2.3.2 Button Color Settings

- Right-click on any result area of the screen to open Button colors settings. Unless you have good reason, or good color sense, it is suggested that you stay with the default values. You may change them to work with (e.g.) laser safety goggles or to simplify the screen by making results of no interest invisible by setting the Normal Text color to the same color as BackGround. If you do this, save the settings as a *.ojf job file, (See Section 4.3.1).
 - If the software determines or 'suspects' a result to be invalid for any reason, the numbers will appear in orange. E.g. when the profile peak is greater than the linear full well (saturated) or <10% the results will appear orange as a warning.
 - If you wish to highlight a particular set of numbers, change the background color. Ensure that it is not a color that is too close to the text colors, or the visual contrast will 'wash out'.

4.2.4 Change Profile Display

These options are found by clicking directly on the profile or right-clicking on the profile to access the context menu.

- Center profile. In order to center the profile in the profile area in which the cursor lies, press 'c' for 'Center' on the keyboard
- Pan profile. For zoomed profiles, to pan the profile in the profile area in which the cursor lies, press 'P' for 'Pan' on the keyboard and the current cursor position in the profile box will be centered in the window. E.g. place the cursor to the left of the center of the graph and when you press 'p' that point will move to the center.

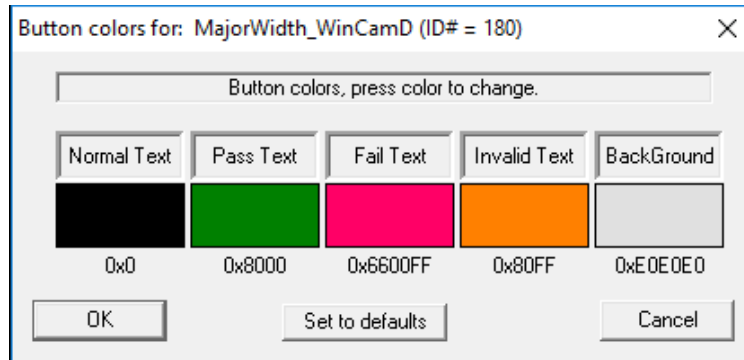


Fig. 4.15: Button Color Settings

- Measure any distance on a profile. Click & drag a line between two features in the profile, in order to determine the (horizontal) distance between these features. This is shown as Dist. = xx.x um on the bottom left of the table below the profile. Left click in the profile area to delete the line and the measurement.
- Right-click on any 1D profile area to open the selection box shown in Figure 4.15. Default settings are as shown. The range of options allows you to control how 'busy' the display appears.
- Check Global selections (On by default) to apply selections to all profiles.
- Choose Linear or Logarithmic profile display modes. Both linear modes set the baseline to zero to compensate for ambient light and amplifier offset on a dynamic basis. Linear normalized normalizes the profile peak to 100% and is the default mode.
 - Log modes are useful for assessing structure and 'ghosts' in the wings. Digitization of noise below 0.1% implicit in the 12-bit ADC's 4096 samples may be observed.
- Choose Thin or Thick Line and Fill mode to choose how the profile is displayed. The latter modes are useful when observing the display monitor from across the test bench, or when saving the screen data for a presentation.
- Enter intensity multiplier opens a dialog box that allows you to multiply the display profile by up to 200 in order to see detail in the wings. It only changes the display, not the amplifier gain. To change the gain, see below.
- Enter new gain value allows you to set a specific gain value if Auto range (default is on) is unchecked.
- Set um/div, scale value opens: This allows you to set the scale/value if Auto range (default is on) is unchecked. (May be unavailable)
- Enter over scan ratio allows you to change the default (scan range/beam diameter) ratio for the unit being measured. Useful if the beam has an extended 'wings' such that the baseline is not reached in the default scan range.
 - The 50% intensity level for a Gaussian is at a diameter of 1.18w
 - The 1% intensity level for a Gaussian is at a diameter of 3.03w.
 - The 0.5% intensity level for a Gaussian is at a diameter of 3.26w.
 - The 0.1% intensity level for a Gaussian is at a diameter of 3.72w.
 - The ISO standard specifies that the beam diameter measurement should use 99% of the power in the beam. For a Gaussian scanned by a slit this is out to a diameter of 2.576w, the point at which the Gaussian intensity has fallen to 3.625% of peak.

- Show clip levels displays the variable clip levels in blue on the profile Clip[a], Clip[b]. You may drag and click the levels in 0.5% increments. If Clip[a] or Clip[b] is 4σ , the applicable level is locked at 13.5%.
- To measure a distance on a profile, left click and drag a line across a profile. The Distance and the Enclosed power (% of total) values will appear in the box below the profile.
- Show Gaussian fit. A Gfit results line appears over the 2W results and a red line Gaussian appears superimposed over the profile. The Gaussian fit is based upon the following:
 - Determination and subtraction of the baseline. (True for all modes of operation.)
 - The iterated least squares fit starts from the actual 13.5% diameter
 - The centroid remains the same as that of the portion of the actual beam above 13.5%, unless you have reset the default in the Setup pull-down menu.
 - The area under the fitted Gaussian always equals the area under the actual beam profile. i.e. an equal power requirement.

If the area under the curve is A , defined as the baseline-corrected total of the individual ADC values for each sample, and the actual 13.5% diameter is $2W$, then the initial height in ADC units is set to $H = A * (2/2W) * (2/\pi)^{0.5} = 1.596 * (A/2W)$.

- Fitted over the profile width that includes 99% (default) of the power in the profile. [As with the 4σ diameter, Ctrl Alt S allows you to set a different percentage for the included power.]
 - The fit algorithm, whilst keeping the area under the curve constant, iteratively adjusts the height and width of the Gaussian until the Least Squares difference between the actual profile and the Gaussian profile is minimized.
 - G 2W is the calculated diameter of the fitted Gaussian.
 - Gfit in % is calculated as: $100 * [1 - ((\text{Sum of absolute differences}) / (\text{Gaussian profile area}))]$
- Show Top-Hat fit. The Top Hat fit:
 - Determines and subtracts the baseline. (True for all modes of operation).
 - Determines the '50% of peak' edges of the profile. Defines the center (as opposed to centroid) of the beam as the midpoint between these two points.
 - Determines the Least Squares level of the central 80% of this region. It plots a straight line at this mean level, and defines it as 100% for the purpose of subsequent TopHat fit calculations.
 - Shows the Top-Hat fit in % as: $100[1 - (\text{Total area of } |\text{deviations}| / \text{Area under line})]$.
 - Show max deviation. For both the Gaussian and Top Hat fits, a vertical red line appears on the graph at the point of maximum deviation, and the Max Deviation = xx.x% and Std. Deviation = xx.x% are overwritten in red on the graph.

TIP: On slower PCs, to speed up the processing, do not show these options.

Additional information is given by the alternative 'Gaussian Fit Coefficient' and the 'Gaussian Roughness coefficient', defined as follows:

- Find the average difference between the Actual point, P_j , and the fitted Gaussian, G_j . (N is the # of points)

$$A = [\text{Sum}(P_j - G_j)]/N \quad (4.1)$$

- For each point determine the difference, D_j , from the average of the deviation:

$$D_j = (P_j - G_j) - A \quad (4.2)$$

- Determine the sum of D_j^2 :

$$S = \text{Sum}(Dj^2) \quad (4.3)$$

– Determine the Gaussian Fit Coefficient, C , as follows:

$$C = 1((S/N^{0.5})/N) \quad (4.4)$$

– Determine the Gaussian Fit Roughness, R %, as follows:

$$R = 100 * [Max(Pj - Gj)] / [Max(Pj)] \quad (4.5)$$

- Show scale grids defaults on. You may turn them off.
- The Zoom 1X to 16X allows you to zoom the profile area on which the cursor is currently sitting. If Global selections is checked, then all profiles will change.

TIP: Pressing 'i' and 'o' on the keyboard zooms the profile 'in' or 'out' respectively, and is much faster than accessing the menu.

- Profile to Clipboard sends the profile on which the cursor is sitting to the Clipboard, including the diameter lines above the profile.
- Save image as Bitmap file does precisely that.
- Export to Paint opens Paint which allows you to save the profile in a variety of formats.
- Export profile data to Excel opens Excel, exports the profiles & plots a graph of the profiles. It can be slow into Excel 2007.
- Save Profile data as text opens NotePad and exports the profile data to it.
- Beam Profile Fit to Excel is found by right-clicking in the profile area.
Profile fit values in spreadsheet may be changed by editing cells F30 to H40 in Form1.xls found in the C:/Program files/DataRay directory.

4.2.5 Power Bar

The auto-scaling Power bar function gives an indication of relative power as a scrolling ten-sample histogram. Click on the bar to open the dialog box shown in Figure 4.17. Enter the power as measured by a calibrated power meter, and the unit of measurement. The power bar will then display relative to the measurement entered. If you enter dB or dBm, it will recognize these terms and work in logarithmic mode. You may also enter 100 as the number and % as a label to give answers in %.

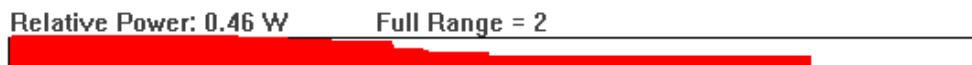


Fig. 4.16: Relative power and histogram of last 10 power measurements.

4.3 Pull-down Menu Bar

The majority of the pull-down menus are only applicable to live sessions, but it is important to take a look at them and read the brief description to understand the versatility and intuitive nature of the software.

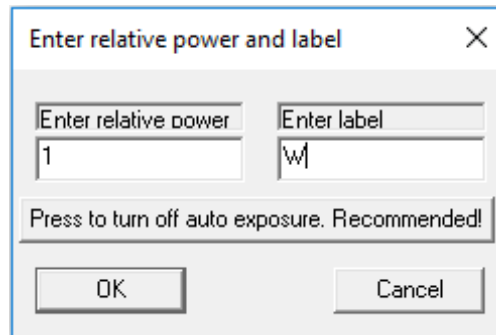


Fig. 4.17: Left-click the power bar to access the relative power dialog box.

4.3.1 File

Where there is a corresponding button on the button bar, it is illustrated below.

- Open... (Ctrl+O) Opens the Open dialog box for files.
- Save (Ctrl+S) Opens the Save As dialog box for files.
 - Save current data saves the current on-screen profile.
 - Select data from data buffer opens a Beam Select Dialog box that allows you to select which profiles to save. E.g. A sequence to send to Tech Support to show some misbehavior. (Tip: to save a few from the array, choose Select None and then click on the ones that you want.)
 - Select all data from data buffer saves all the profiles in the buffer.
- Screen to Clipboard sends the screen area between the Toolbar and the Status bar to the clipboard, allowing import into reports generated in other software.
- Save current screen as bitmap file opens a Save as dialog for the screen area between the Toolbar and the Status bar to the clipboard.
- Export Screen to Paint sends the screen area between the Toolbar and the Status bar into a Paint window that opens automatically. This allows saving in a variety of formats:

Saving Images as *.jpg or *.gif files. Within Paint, use the Save As... then Save as type

- Print... (Ctrl P), Print Preview and Print Setup... are self-explanatory. The software will print the current screen, plus the date and a screen plot title. The profiles are deliberately printed with vertical elongation for greater visibility. The header includes the software version number, and the day and date of printing. To avoid soggy black paper with ink-jet printers, go Palettes & choose Inksaver.

Print...w/Notes allows the addition of notes to the printout, and shows previous notes for editing. A dialog will open that you can fill in. When you save the file the notes will be saved with it, and will also be saved for future editing next time you select Print...w/Notes.

- Load Defaults does precisely that, useful if things seem screwed up. Holding the Shift key down while starting the software has the same effect.
- Load Job and Save Job... A Job file allows saving and opening particular software setups. It is especially useful when testing a variety of laser assemblies on a regular basis. Saving a complex setup with specific Pass/Fail criteria is a very effective way of saving time and establishing parameters for repeatable results. Multiple *.ojf (ocx job file) files can be saved, each with a different set of settings.

- The next block shows the six most recent files that have been saved and/or opened.
- Exit will close the program.

4.3.2 Device

Select the hardware unit that you are working with. If you recall a file for a different unit, the software will automatically change the screen to the appropriate unit type, but will display Head not found and/or the unit type present.

4.3.3 Palettes

Select the palette that you require.

- High color palette is set/limited by the Windows Display Settings.
- Monochrome palette is 128 level gray scale.
- 16 color palette is precisely that
- 10 color palette is precisely that
- Ink Saver mode, changes the black and blue-black background (the lowest 2% of the levels after background subtraction) to a white background. This does what it says. It saves ink when you print, and minimizes that soggy floppy paper feeling.

4.3.4 Average

- Choose either a running average based upon a specific number of profiles, Average 5 to 100, or choose Continuous (accumulation) averaging of the profiles. An averaging mode indication will appear in blue on the profile graphic.
- The displayed results are derived from the averaged profile.
- Reset average [ESC]. Press the Esc button to restart the averaging.
- Enable Average or [CTRL A]. [To be added in a future version.] If this is checked (the default), CTRL A toggles averaging on and off.

4.3.5 Filter

Filter selects a triangular weighting smoothing function performed as a running smooth of the profile. Select Filter = 0.X% Full Scale. The actual FWHM of the triangular filter may be calculated as:

$$\text{FWHM} = [\% \text{ of full scale} * \text{Scale } \mu\text{m/div} * \text{Zoom factor}] / 10 \quad (4.6)$$

- Since smoothing causes an increase in the width of the smoothed profile, the displayed value for the beamwidth is corrected using the same algorithm as is used for slit width correction. See Section 5.4.3.

Tip: How much filtering is safe to use? Default is 0.2%. On very small beams set it to No Filtering. On large beams, you may increase it until the detail that you seek is being lost or the beam diameter starts to increase. Then go back one step on the filtering.

4.3.6 View

Almost redundant unless you wish to eliminate the Toolbar and/or Status Bar in order to 'clean up' the screen. The Log and M2 dialog are also accessible from the Button Bar.

4.3.7 Setup

- Capture setup dialog. Only applies to cameras rather than scanning slit devices.
- Enter Magnification Factor. Compensates displayed results values for the LensPlate magnification, if present, object to image.
Important: If the Magnification factor is set to other than 1, the software assumes that the beam is being inverted by the optic and reverses the Xc, Yc readings accordingly.
- Enter wavelength... in nm. Must be set if you wish the M2 value to be correct. You cannot change wavelength in a saved file, so set it first. If you forgot to set the wavelength and need to interpret some saved files, remember that the M2 value is proportional to $(1/\lambda)$.
- Numeric Display Modes...
 - XXX.Y um is the default
 - XXX.YY um The second decimal place is 10% of the smallest sample spacing and is essentially meaningless...but the option is here due to customer request
- Set centroid clip level. Default is 13.5%. You may set a different value.
- Set geo-centroid clip level. Default is 13.5%. You may set a different value.
- Setup trigger. Only applies to WinCamD and other camera-based profilers.
- Enable auto-naming. If you select this option, when you Save a file, a name will be suggested in the format: BX_YY_MM_DD_HH_MM_SS.bxf
 - A device abbreviation (BC, BM, BR or BS) followed by the international date and time (24 hour clock) read off your computer's clock. [In the future this may change to a shorter version: BXYM-MDD_HHMMSS.bxf]
- Use ISO 11146 compliant diameters and angles. Only applies to WinCamD and other camera-based profilers.
- Turn off motor at exit. Only applies to older PCI based Beam'R and BeamMap systems.
- Device eeprom programming opens a box with the data held in the unit's EEPROM.

NEVER ATTEMPT TO REPROGRAM THE EEPROM

This calibration file is an accessible diagnostic that you can read out to DataRay if things go wrong. Before you ever do anything with it, click on Save as file to save the original as a text file. If lost, you cannot reset to any defaults.

4.4 Toolbar Buttons

Hover over any button to reveal its function. This is useful to know if new buttons appear in later revisions.

A grayed out button is either the current selection or an unavailable selection.

4.4.1 BeamR'2



Fig. 4.18: For BeamR'2 and BeamScope-P7U/P8, the profile options are X, Y, or B for Both



- The X button displays the X profile in the software
- The Y button displays the Y profile in the software
- The B button displays both the X and Y profiles in the software

4.4.2 BeamMap2

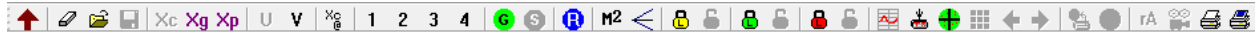


Fig. 4.19: For BeamMap2 devices, the profile options are U, V, 1, 2, 3, and 4



- The U or the V button selects the set of four U or V profiles in the sequential planes.
- The Xc@ button selects which centroid to use when U or V is selected.
- The 1, 2, 3, and 4 buttons select the first, second, third and fourth pairs of u,v slits seen by the beam as it propagates through the instrument. The zero plane, as defined in calibration is plane 2.

M2 Button

- Open the M2 dialog to perform a least squares hyperbolic fit to the data and calculate M2 and related values. See section 4.4.4.1 for more info about the M2 dialog.

Divergence Button

- Open the Divergence dialog to perform a least squares linear fit to the data and calculate divergence and related values. See section 4.4.4.2 for more info about the Divergence dialog.

4.4.3 All Products



Data Handling

- Put the screen to the clipboard
- Clear the data from the screen
- Open a previously saved file
- Save data to a file



Start/Stop Measurement

- The G button starts the capture of profiles by the unit, or press F1 on the keyboard.
- The S button stops the capture of profiles by the unit, or press F2 on the keyboard.



Stored Data Selection

- Opens the Select Beam Set Dialog which allows you to select a beam from the stored data. Move the cursor over the array and click the beam that you wish to view.
- The left-right arrows allow you to scroll through the beams without first opening the dialog. The caption line at the top tells you which beam you are looking at. Page Up, Page Down has the same effect.



Recall Mode and Live Mode

- These buttons allow you to toggle between live mode and saved data.



Range Lock

- This pair of buttons allows you to lock the range to it's current value and unlock.



Baseline Lock

- This pair of buttons allows you to lock the baseline to it's current value and unlock.



All Lock

- This pair of buttons allows you to lock the range, position, and gain to it's current value and unlock.



Print Buttons

- This pair of buttons allows you to print just the screen or the screen with additional notes. In either case the header includes the software version number, and the day and date of printing.
- Any notes that you enter are saved for use/modification on the next occasion that you print.
- If using an inkjet printer, remember to go to Palette and select Ink Saver mode to avoid soggy paper and wasted ink cartridges.

4.4.4 Dialog Boxes

4.4.4.1 M2 Dialog for BeamMap2

The Clip[a] beam diameter definition must be set to Sigma x4.

The Average should be set to at least Average 5.

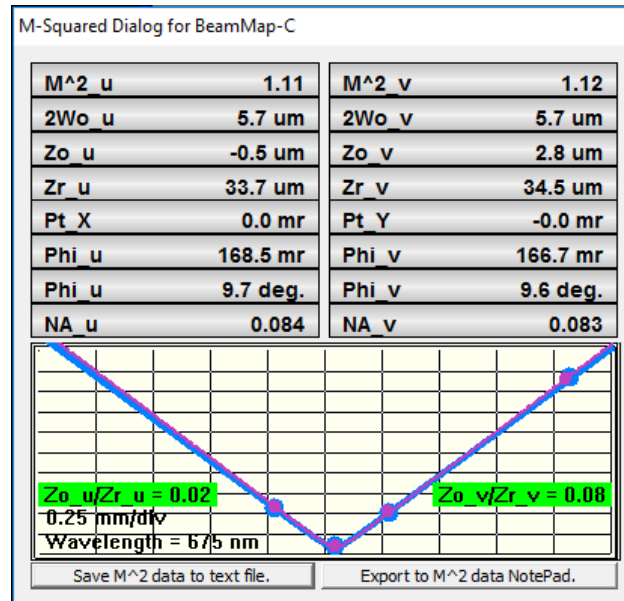


Fig. 4.20: BeamMap2 M2 Dialog

The Wavelength must have been correctly entered in the Setup menu. It cannot be changed at a later time on a saved file.

The beamwaist must lie closest to the 'zero' plane, (plane 2), with $Z_o/Z_r < 0.20$.

The results for the two axes are:

- M2: A dimensionless number, equals 1.0 for a perfect TEM00 Gaussian beam, >1.0 for imperfect beams and higher order beams.
- 2Wo: The beamwaist diameter
- Zo: The beamwaist position in z relative to the zero plane of the instrument. Negative values imply a beamwaist closer to the front of the instrument.
- Zr: The beam's Rayleigh Range
- Pt: The beam Pointing Angle in mrad with respect to the unit, sometimes termed Boresight
- Phi: The beam's far-field divergence
- NA: The beam's far-field Numerical Aperture. $NA = \sin(\phi/2) = 1/2(F/\#)$

The software calculates and tabulates these values for the beam. The hyperbolic curve fit uses un-weighted 2W values. The wider blue points and lines are for the u diameters. The thinner purple line is for the v diameters.

The tabulated M2 and 2Wo values are used to generate the displayed continuous curves. The 2W data from the z planes is displayed on the graph as points, together with the hyperbolic lines which are the least squares fit to the best hyperbolic curve.

The horizontal scale is dependent on the plane separation of the unit being used. The vertical scale is normalized to show the highest measured diameter at 80%. The vertical scale therefore varies as each result is taken. The center of the horizontal plane is the zero plane of the instrument.

Focusing: The Z_0 value is the calculated distance of the zero plane from the focus. It is frequently different for u and v.

The calculated Z_0/Z_r , for the u axis only, is displayed in a bar which changes color. For accurate M2 estimates, the bar should be green, indicating $Z_0/Z_r < 0.20$. [2 W_0 within 2% of its nominal value.] It is yellow for $0.20 < Z_0/Z_r < 0.40$. It is red for $Z_0/Z_r > 0.40$.

When the focus is not in the zero plane, the bottom of the curve will be off-center, the Z_0/Z_c value will be in red, and the M2 values are not valid.

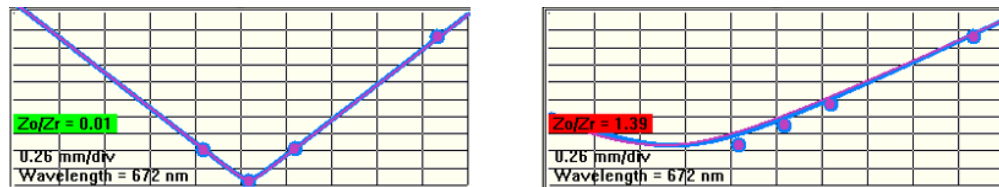


Fig. 4.21: (Left) The M2 measurement is valid because the second slit plane falls at the waist. (Right) The M2 measurement is invalid because the waist is not at the second slit plane.

The ISO 11146 standard calls for measurements in at least ten planes in z, and we do not pretend that BeamMap2 meets this requirement (though we do have products which do). However, they do allow you a real-time estimate of M2, and in particular can give you a good feel for relative M2 between different laser assemblies.


When optimizing focus position, we recommend:

- Turn off averaging
- Look at the fitted curve to set the minimum in the center of the graph. Remember, the blue ellipse at the bottom of the centroid screen is a left-right coarse indicator of focus on a default +/- 500 micron scale in z.
- Once focused, reset the Average to at least Average = 5.

Having trouble? Common reasons are:

- The beamwaist is too far from the zero plane. The Z_0/Z_r box is not green.
- Beam is not centered in x,y and 'falls off' the detector edge
- Clip [a] is not set to 4xSigma.
- The beam is noisy or has 'wings' & the 4xSigma value is corrupted by the noise or wings. Try 13.5% instead.
- The beamwaist diameter is too small for the unit plane spacing, such that $Z_r < (\text{Plane Spacing}/12)$. The graph will be too V-shaped to give a good fit.
- The beamwaist diameter is too large for the unit plane spacing such that $Z_r > (\text{Plane Spacing}/1.5)$. The graph will be too flat to give a good fit.
- You are working in the far-field of the beam. See right image in Figure 4.21.

4.4.4.2 Divergence Dialog for BeamMap2

The Divergence function performs a least squares linear fit to the beam diameter and centroid versus measurement plane values in order to determine the angular divergence u , & v and the Pointing (boresight) x & y of the beam. The Divergence Dialog is opened by clicking the  button in the toolbar.

This unweighted least squares fit assumes a straight-line divergence, generally applicable in the far field more than about three Rayleigh Ranges from a focus.

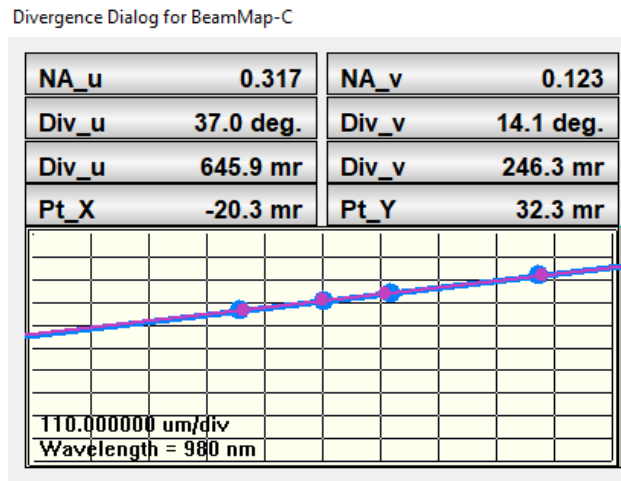


Fig. 4.22: Example of a good divergence measurement because the measurement points all fall on the least squared linear fit.

The Clip[a] and Clip[b] results are displayed in terms of Numerical Aperture NA [$=\sin(\Phi/2)$], full divergence angle Φ in degrees and mr (milliradians), and the calculated distance Z_c (in the centroid values display area) from the zero plane of the puck to the source.

NA for optical fibers is frequently defined at the 1% level, so if this is what you are measuring, set the Clip[a] level appropriately. Check in log mode profile display that the noise level is sufficiently low to give reasonable results with a 1% clip level. The peak noise should be at least -25 dB, or use profile averaging in order to reduce the noise to this level.

Nonsense results. If you are working with a focused beam rather than a divergent or collimated beam, then the Divergence results are calculated correctly mathematically, but are nonsense. They are nonsense because the algorithm performs a straight line fit to the results, but the actual results around a beam focus should be fit to a hyperbola. Use the M2 dialog for a correct calculation of the far field divergence when you are working in the near field.

4.4.4.3 Beam Wander Dialog

Relative zero: If, as is commonly the case, you require Relative zero rather than Absolute zero, don't forget to first press Toggle Centroid to choose [relative].

- Time interval allows you to set the time interval between samples.
- Samples to be recorded allows you to set the number of samples, up to 8192.
- Clear restarts the plot, after a warning.
- Normalize recenters the plot.
- Replay or Replay Fast replays the beam position history.
- Sequence off Press this button and use the + and - buttons on the numeric keypad to scroll through the data for the deviation data for the individual points. Holding down the buttons continuously replays the sequence.
- To Clipboard puts Beam Wander to the Windows Clipboard.
- To Excel exports the data to Excel, automatically opening an Excel spreadsheet with the Xc, Yc data imported.
- Save as bitmap opens a Save As dialog box.
- Export to Paint opens the image in Paint

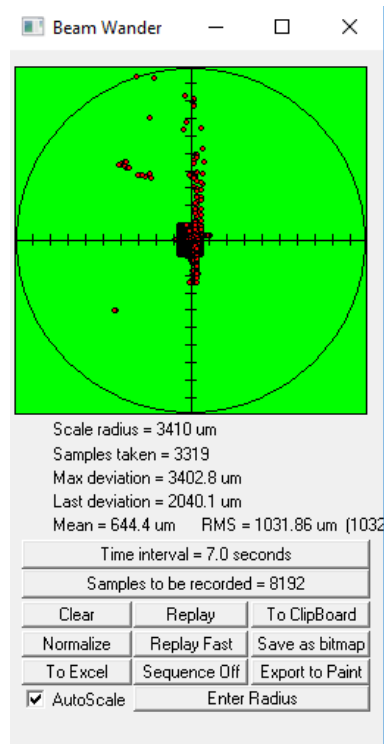


Fig. 4.23: The Beam Wander dialog tracks the movement of the centroid across many measurements.

4.4.4.4 Log Data

Logs all measured data values to a log file at specified intervals for the chosen amount of time. There is also an option to log only "Enabled data" which can be chosen in the Setup Logging dialog box. "Enabled data" is chosen by left-clicking a result button in the software and choosing "Enable test".

The following data can be logged:

- Sample #
- Time in seconds
- 2Wua
- 2Wub
- 2Wva
- 2Wvb
- Eff_2W
- Xc
- Yc
- Ellipticity
- Relative Power
- Orientation
- Major diameter
- Minor diameter
- Mean diameter
- ADC Peak %
- Plateau Uniformity
- SetClipLevel1
- SetClipLevel2
- Crosshair
- Rc

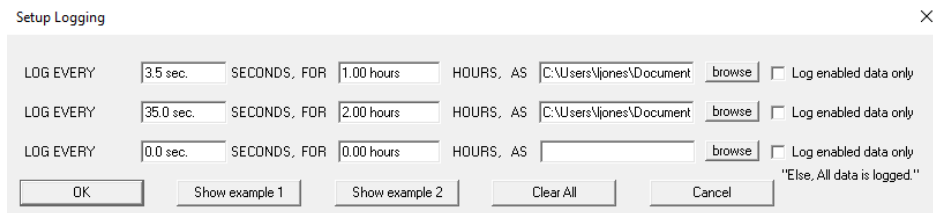


Fig. 4.24: Setup Logging Dialog

Chapter 5

BeamMap, BeamR2 Description and Use

The Beam'R2 and BeamMap2 are both scanning slit beam profiling devices with similar principles of operation, as such they are both covered in this chapter. Sections 5.2 and 5.3 will cover each device individually, and the remaining sections will apply to both devices. This section assumes that you have already successfully installed the hardware. If not, see section 2.4.2.

5.1 Precautions and Safety Warnings

Do not skip this. If you do not take these precautions, you may damage the equipment or your eyes.

- Always measure the beam power and try to estimate the beam diameter before analyzing a laser beam for the first time. Ensure that it meets the maximum irradiance and maximum power limits in the specifications in section 5.4.2.
- If you are unsure of the power, walk the beam on from above or below.
If the label is burning, the power is too high.
If the numbers are orange and the profiles are flat-topped, the power is too high.
- Be aware of the laser beam path and its reflections. As necessary, always use beam blocks/dumps and Wear Proper Eye Protection for the wavelength being analyzed.

5.2 Beam'R2 Description and Operation

5.2.1 Beam'R2 Principle of Operation

- A rotating disk or 'puck' carries four slits, one 2.5 μm pair, and one 25 μm pair. (5 & 50 μm pairs with InGaAs units). The slits are precisely located in a single plane. Slits at $+45^\circ$ and -45° to the radial direction scan through the beam in order to determine beam centroid and to give orthogonal 'x-y' profiles. Due to the 45° inclination, the effective slit widths for such scans are $\sqrt{2}$ greater than the actual slit width, i.e. 3.5 and 35 μm respectively (7 & 70 μm pairs with InGaAs units).
- When the beam diameter goes below 10 μm , the user may choose KE (Knife-Edge) mode using the 35 μm effective width slits. (20 and 70 μm for InGaAs). If the beam is too large for KE mode, then the

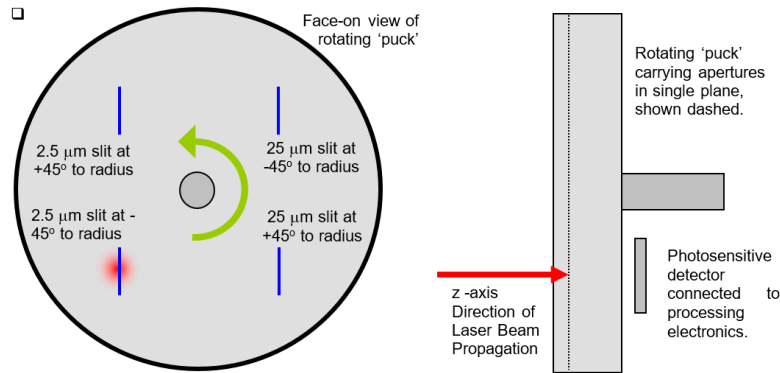


Fig. 5.1: Beam'R2 Slit Scan Sequence Schematic & Detail

mode will not engage, instead you get the extra sensitivity provided by wider slits, though smoothed by the wide slit.

- Rotating about an axis parallel to the z-axis, satisfies the orthogonal linear scan requirements of the ISO 11146 beam profiling standard.

5.2.2 Beam'R2 Specifications

See Table 5.1

5.2.3 Start BeamR Units

1. Respect the beam power limits in section 5.4.2.
2. Note that the capture region diameter is 5 mm diameter Beam'R2. [3 mm for InGaAs detectors.] Since the sensitive area is only a few mm in diameter, ensure that either the unit or the source assembly can be adjusted in x, y and z –and in angle if appropriate. Mount the unit in a rigid manner such that the unit will intercept the laser beam in a plane perpendicular to the beam axis. If you don't aim the beam properly, it will not be captured.

In many cases, it helps to install the unit or the assembly to be measured on an X-Y-Z stage with one micron resolution.

As with any measurement with sub-micron resolution, always allow several minutes of warm-up before attempting to take measurements for the most accurate results.

Be aware that inadequate vertical stage preload can lead to vertical drift in the measured diameter on tightly focused beams.

3. Start the PC if it is not already started

Beam'R2 Product Specifications

Parameter	Specifications
Wavelengths	190 to 1050 nm Silicon detector
	675 to 1750 nm InGaAs detector
Dimensions of capture region (x, y)	5 mm diameter for Silicon detectors
	3 mm diameter for InGaAs detectors
	1.5 mm diameter for extended InGaAs detectors
Waist diameters ($2W_0$)	0.5 to $\sim 1500 \mu\text{m}$, [At all plane spacings]
Waist diameter resolution	Resolution: 0.2% of beam diameter
	0.1 μm best resolution
	Accuracy: $\pm < 0.5 \mu\text{m} \pm \leq 2\%$ of diameter
Waist diameter measurements (x) & (x,y)	'Second moment' 4σ diameter to ISO 11146
	$1/e^2$ (13.5%) Gaussian width
	Knife-Edge algorithm for beams $< 50\%$ of slit diameter
	User selectable % of peak
	Simultaneous display of two beam diameters per profile
Waist centroid position error (x,y)	$\pm \leq 2 \mu\text{m}$ rms, with centroid averaging after warm-up
Uniformity across measurement region	$\pm \leq 2\%$ relative error for beams that fall totally within the measurement region
Maximum Beam Power/Irradiance	Max Total: $\sim 1\text{W}$ @ $\lambda > 400\text{nm}$ Lower @ $\lambda < 400\text{nm}$
	Max Irradiance: $\sim 0.25\text{mW}/\mu\text{m}^2$ @ $\lambda > 400\text{nm}$ Lower @ $\lambda < 400\text{nm}$
	(To add external sampling/attenuation, contact factory)
Displayed Profiles	All profiles from all slits may be displayed
	2-D plot (10,16 or 256 colors, gray scale)
	3-D plot (10,16 or 256 colors, gray scale)
Displayed Graphics	Xc,Yc Centroid position
	Zoom profiles x1 to x16
Relative Power measurement	Unlimited relative to a reference measurement input by the user. User may enter units such as mW, %, etc.
	Rolling bar histogram of last 10 measurements

Table 5.1: Beam'R2 Specifications (Continued in Figure 5.2)

Beam'R2 Product Specifications (continued)

z Parameter	Specifications
Auto Gain Range	10,000:1 (40 dB). [30 dB optical switched gain plus 10 dB software gain]
Update rate, all measurements	5 Hz. See minimum PC requirements, below.
Source to first plane distance	3 mm for standard Beam'R2 units. .
<u>Measurement Analysis</u>	
Pass/Fail:	On-screen, on values & graphics, in selectable colors
Averaging:	User selectable running average (5 - ∞ samples)
Statistics:	Min., Max., Mean, Standard Error in the Mean
Unit Dimensions, see Figure 5.4	Across axis width x Height x Along axis depth 51 x 100 x 90 mm (2.65 x 2.4 x 2.7 inches)
Mounting	1/4-20 threaded mounting holes
Weight	450 g (1.0 lb) for standard units
Temperature: Operating	18° to 30° C.
Temperature: Storage	5° to 55° C. Non-condensing atmosphere
Cable	3 m (10 ft.) standard length: USB 2.0 A to mini-B5
Minimum PC requirements	See section 2.3

Table 5.2: Beam'R2 Specifications (Continued from Figure 5.1)

4. Double-click the icon to start the software. Click Device in the pull-down menu and select the Beam'R2 device type.
5. The puck will go through a start sequence and will eventually rotate at 5 Hz, at which stage the green box will change from Initializing to Beam'R2.X ready where X indicated the device's firmware version.
6. To start taking data you may: press F1, click on the Go button or the green Beam'R2.X Ready box, or press g on the keyboard.
7. While capturing data, adjust the unit or source to center the beam
 - $X_c[\text{abs}]$, and $Y_c[\text{abs}]$ measure the beam centroid. The beam should be centered according to these values, preferably so that each are $<250 \mu\text{m}$.
 - The blue "donut" shown in Figure 5.3 indicates graphically where the beam is centered, this must be near the middle of the cross-hairs after centering the beam.

- Review Chapter 4 to learn about how to use the DataRay software, this is important in order to ensure valid results.

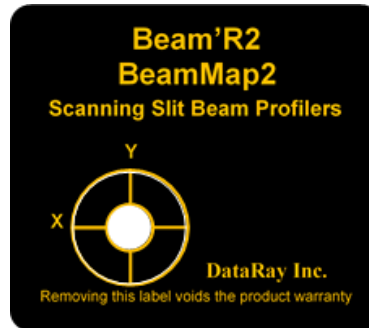


Fig. 5.2: Beam'R/BeamMap2 Label

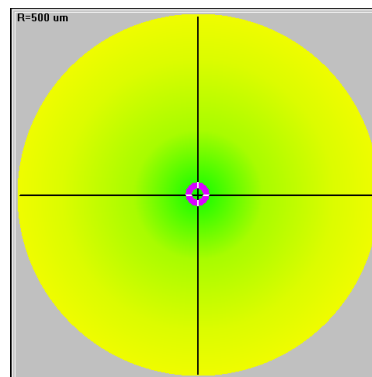


Fig. 5.3: The circular disc indicates the centroid position.

5.2.3.1 Troubleshooting

- Go to File, Load defaults to reset the software to default settings
- Make sure the beam is correctly centered according to the absolute centroid readings, the blue "donut" should be near the middle of the cross-hairs in the software centroid target
- Read the relevant manual section
- Contact [DataRay Support](mailto:support@dataray.com) at support@dataray.com. Phone support is available weekdays 9am-5pm PT.

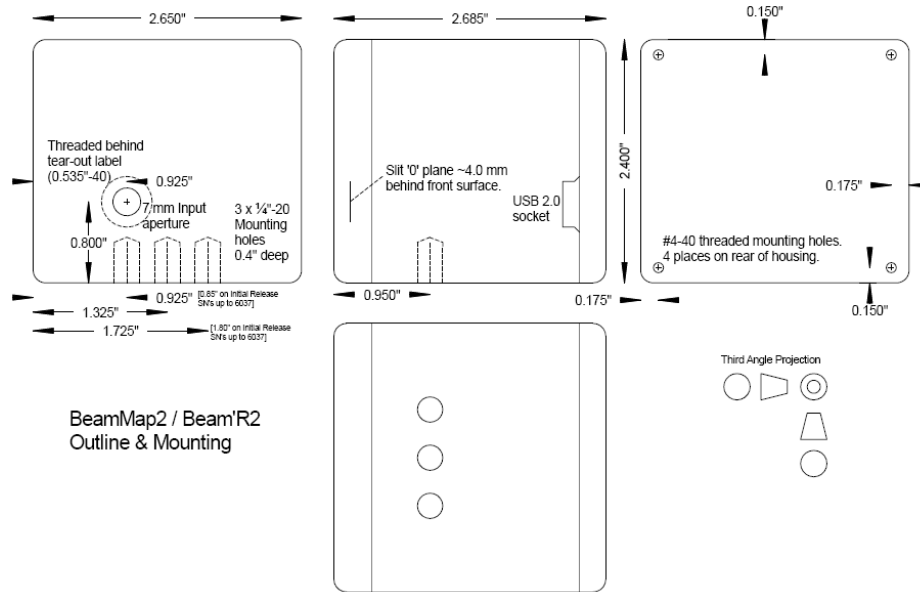


Fig. 5.4: BeamMap2/Beam'R2 Outline and Mounting

5.3 BeamMap2 Description and Operation

5.3.1 BeamMap2 Principle of Operation

- A disk [‘puck’] carrying multiple XY slit pairs rotates about an axis parallel to the z-axis, This satisfies the orthogonal linear scan requirements of the ISO 11146 standard.
- The slits are precisely located in multiple planes separated in z in the focal region.
- Slits are placed at ± 4.5 degrees to the local radial direction. Effective slit width is $\sqrt{2}$ greater than actual slit width.
- On the first scan, the software detects the 13.5% outer limits of the profile and then sets an overscan of the profile width by a factor of approximately three times the $1/e^2$ profile width. The scanned width is digitized as 2048 equally spaced samples. The intensity is digitized by a 12-bit (4096 level) ADC (Analog-to-Digital Converter).
- The software determines the zero level in the digitized profile and then processes for display and data logging. It feeds back intensity information to the AGC. (Automatic Gain Control).
- The user configures screen functions to implement the measurements as desired.
- User-set Pass/Fail criteria, plus real-time results facilitate its use as a development and production alignment tool.
- The BeamMap2 is uniquely suited to the active alignment focusing and verification of tightly focused laser beams.

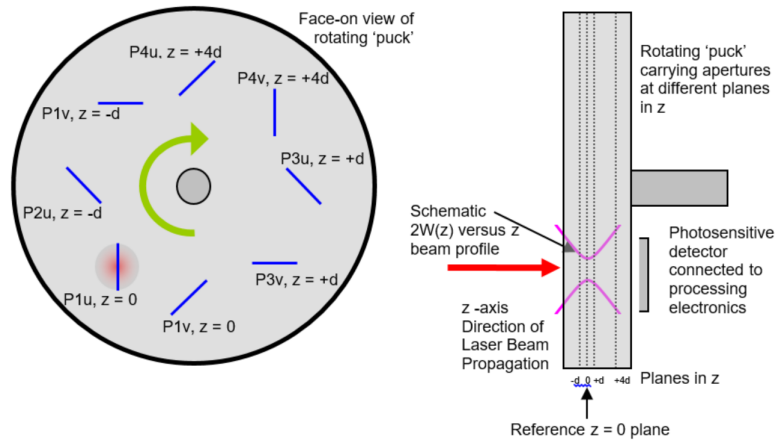


Fig. 5.5: BeamMap2 schematic puck configuration

5.3.2 BeamMap2 Specifications

See Table 5.3

5.3.3 Mount & Start BeamMap

1. Respect the beam power limits in section 5.4.2.
2. Note that the capture region diameter is 5 mm diameter for BeamMap2 & Beam'R2. [3 mm for InGaAs detectors.] Since the sensitive area is only a few mm in diameter, ensure that either the unit or the source assembly can be adjusted in x, y and z—and in angle if appropriate. Mount the unit in a rigid manner such that the unit will intercept the laser beam in a plane perpendicular to the beam axis. If you don't aim the beam properly, it will not be captured.

In many cases, it helps to install the unit or the assembly to be measured on an X-Y-Z stage with one micron resolution.

As with any measurement with sub-micron resolution, always allow several minutes of warm-up before attempting to take the most accurate results.

Be aware that inadequate vertical stage preload can lead to vertical drift in the measured diameter on tightly focused beams.

3. If you are using a BeamMap2 Collimate with its longer front to back distance, additionally allow for some θ_{x-z} and θ_{y-z} adjustment.
4. Start the PC if it is not already started
5. Double-click the icon to start the software. Click Device in the pull-down menu and select the BeamMap-C device type.
6. The puck will go through a start sequence and will eventually rotate at 5 Hz, at which stage the green box will change from Initializing to BeamMap.X ready where X indicated the device's firmware version.

BeamMap2 Product Specifications

Parameter	Specifications
Wavelengths	190 to 1050 nm Silicon detector
	675 to 1750 nm InGaAs detector
Dimensions of capture region (x, y)	5 mm diameter for Silicon detectors
	3 mm diameter for InGaAs detectors
	1.5 mm diameter for extended InGaAs detectors
Waist diameters ($2W_0$)	0.5 to $\sim 1500 \mu\text{m}$, [At all plane spacings]
Waist diameter resolution	Resolution: 0.2% of beam diameter
	0.1 μm best resolution
	Accuracy: $\pm < 0.5 \mu\text{m} \pm \leq 2\%$ of diameter
Waist diameter measurements (x) & (x,y)	'Second moment' 4σ diameter to ISO 11146
	$1/e^2$ (13.5%) Gaussian width
	Knife-Edge algorithm for beams $< 50\%$ of slit diameter
	User selectable % of peak
	Simultaneous display of two beam diameters per profile
Waist centroid position error (x,y)	$\pm \leq 2 \mu\text{m}$ rms, with centroid averaging after warm-up
Uniformity across measurement region	$\pm \leq 2\%$ relative error for beams that fall totally within the measurement region
Z-axis waist position relative accuracy	$\pm \leq 2 \mu\text{m}$ best for BeamMap2 units (Beam quality and NA dependent)
	$\pm \leq 100 \mu\text{m}$ typical for BeamMap2 Collimate units.
Beam divergence:	± 1 mrad over ± 100 mrad range (Beam and unit dependent)
Beam pointing:	± 1 mrad over ± 100 mrad range (Beam and unit dependent)
Beam M^2 (See graphs at website)	$\pm < 5\%$, $M^2 = 1.0$ to > 20 [$2W_0 \leq 2[1000M^2\lambda/\pi]^{(0.5)}$]
Maximum Beam Power/Irradiance	Max Total: $\sim 1\text{W}$ @ $\lambda > 400\text{nm}$ Lower @ $\lambda < 400\text{nm}$
	Max Irradiance: $\sim 0.25\text{mW}/\mu\text{m}^2$ @ $\lambda > 400\text{nm}$ Lower @ $\lambda < 400\text{nm}$
	(To add external sampling/attenuation, contact factory)

Table 5.3: BeamMap2 Specifications (Continued in Figure 5.4)

BeamMap2 Product Specifications (continued)

Displayed Profiles	All profiles from all slits may be displayed
	2-D plot (10,16 or 256 colors, gray scale)
	3-D plot (10,16 or 256 colors, gray scale)
Displayed Graphics	Xc,Yc Centroid position
	Zoom profiles x1 to x16
z Parameter	Specifications
Relative Power measurement	Unlimited relative to a reference measurement input by the user. User may enter units such as mW, %, etc.
	Rolling bar histogram of last 10 measurements
Auto Gain Range	10,000:1 (40 dB). [30 dB optical switched gain plus 10 dB software gain]
Update rate, all measurements	5 Hz. See minimum PC requirements, below.
Source to first plane distance	3 to 5 mm for standard BeamMap2 units. 9.1 mm for BeamMap Collimate
<u>Measurement Analysis</u>	
Pass/Fail:	On-screen, on values & graphics, in selectable colors
Averaging:	User selectable running average (5 - ∞ samples)
Statistics:	Min., Max., Mean, Standard Error in the Mean
Unit Dimensions, see Figure 5.4	Across axis width x Height x Along axis depth
	51 x 100 x 90 mm (2.65 x 2.4 x 2.7 inches)
	Collimate: 66.7 mm (2.65 inches) deep
Mounting	1/4-20 threaded mounting holes
Weight	450 g (1.0 lb) for standard units
Temperature: Operating	18° to 30° C.
Temperature: Storage	5° to 55° C. Non-condensing atmosphere
Cable	3 m (10 ft.) standard length: USB 2.0 A to mini-B5
Minimum PC requirements	See section 2.3

Table 5.4: BeamMap2 Specifications (Continued from Figure 5.3)

7. To start taking data you may: press F1, click on the Go button or the green BeamMap.X Ready box, or press g on the keyboard.
8. While capturing data, adjust the unit or source to center the beam
 - $Xc[abs]$, and $Yc[abs]$ measure the beam centroid. The beam should be centered according to these values, preferably so that each are <250 μm .
 - The blue "donut"-shaped icon shown in Figure 5.7 indicates graphically where the beam is centered, this must be near the middle of the cross-hairs after centering the beam.
9. The blue ellipse icon as shown in Figure 5.7 indicates the location of the waist of the laser along the optical axis (z -axis). When measuring a focused beam, the waist is located on the $z=0$ plane slit when the blue ellipse is centered. Otherwise the ellipse will move left/right depending on whether the beam waist is located before/after the $z=0$ plane slit.
10. Review Chapter 4 to learn about how to use the DataRay software, this is important in order to ensure valid results.

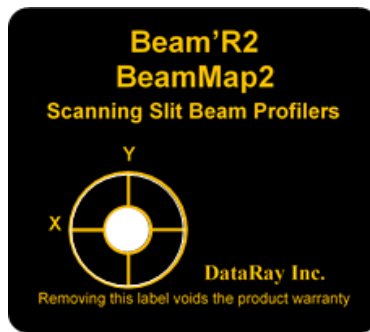


Fig. 5.6: Beam'R/BeamMap2 Label

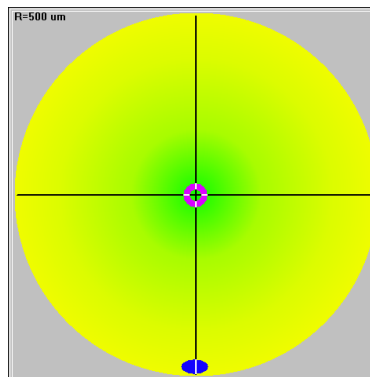


Fig. 5.7: The circular shape indicates the beam centroid location for the selected slit plane. The ellipse shape indicates the location of the beam waist.

5.3.3.1 Troubleshooting

- Go to File, Load defaults to reset the software to default settings
- Make sure the beam is correctly centered according to the absolute centroid readings, the blue "donut" should be near the middle of the cross-hairs in the software centroid target
- Read the relevant manual section
- Contact [DataRay Support](#) at support@dataray.com. Phone support is available weekdays 9am-5pm PT.

5.4 Scanning Slit Series Limits

5.4.1 Beam Acquisition and Measurement Region

5 mm diameter for Silicon

3 mm diameter for InGaAs

1.5 mm diameter for InGaAsx.x extended λ response detectors

For the most accurate profile measurement, the beam to be measured must lie totally within the Acquisition & Measurement region. [If part of the beam lies outside the region, the centroid position reading may be absent or invalid.]

- For the most accurate measurements, center the beam at $[x,y] = [0,0]$. Errors will increase towards the edges of the region. An easy way to determine if measurement errors are likely is if the Peak = xx.x % (see Section 4.1.2.6) has decreased by more than 5% from its value on-axis at $[0,0]$.
- For the most accurate measurement of beams at the 13.5% clip level ($1/e^2$) the beam diameter should be $\leq 60\%$ of 50% of the beam measurement region dimension.
- For true 4σ (Variance) measurement to the ISO 11146 standard, the beam diameter at the 13.5% clip level should be a maximum of half the measurement regions shown. The ISO standard also requires that five-sample averaging should be performed.

The 4σ measurement integral is truncated by the software at 99% of the energy in the beam. This approach is less sensitive to amplitude noise than the alternative approach of truncating the integral at a certain low clip level.

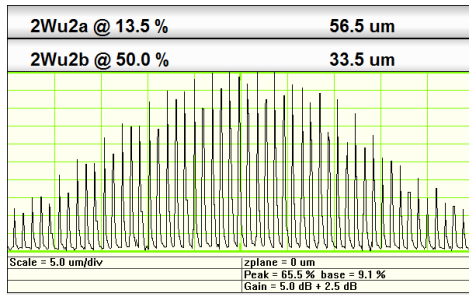
5.4.1.1 CW & Pulsed Beams

The unit operates with CW lasers and with pulsed lasers on beam diameters $\geq (5000/\text{PRR in kHz}) \mu\text{m}$ if you use Filter and Average. Figure 5.8a shows a 50 micron beam with No Filtering and with Filter = 1.0%.

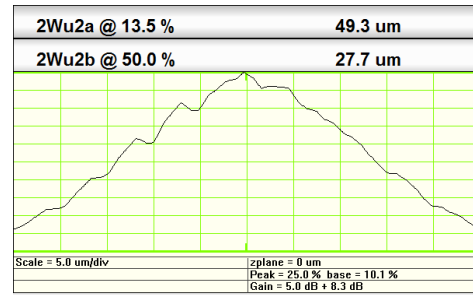
5.4.2 Beam Power Limits

Measure your beam with a calibrated power meter before letting power fall on the unit.

If you permanently need a higher saturation power (below the damage limit), ask for a /ND2 version with



(a) Profile Plot With No Filtering



(b) Profile Plot With 1% Filtering

an ND2 filter between the slits and the front of the detector.

If you temporarily need a higher saturation power and higher damage limit, a variety of screw-on attenuators/samplers are available, up to ND4 (0.01%). Contact the factory.

Under any circumstances the following maxima apply.

The following slit and unit damage limits always apply:

- Total power on the unit must not exceed 1 W, or unit/slit damage may occur.
- Total irradiance (power density) at any $\lambda > 500$ nm must not exceed $0.5 \text{ mW}/\mu\text{m}^2$ (mm of beam diameter), or slit damage may occur.
- Total irradiance (power density) at any $\lambda < 500$ nm must not exceed $0.25 \text{ mW}/\mu\text{m}^2$ times the relative value given on the graph below, or slit damage may occur.
- Beware of back reflections from the slits. Always employ appropriate eye protection.

Power Saturation limits versus beam diameter

- The graphs on the pages that follow show the approximate upper and lower power limits for reference wavelengths of 675 nm for the Silicon units and 1310 nm for the InGaAs units.
- For other wavelengths multiply the values indicated by the factor shown in Figure 5.9. The damage limits given above still apply.

e.g. At 1550 nm multiply by ~ 0.85 to get the applicable limits, i.e. it hardly makes any difference from 1064 to 1600 nm. Similarly for the Silicon units, the change is negligible between 450 and 1050 nm.

- The graphs which follow show as a range enclosed by a line, the approximate range of powers versus beam diameter that the BeamMap2/Beam'R2 products can measure without additional external attenuation.
- The graphs which follow show as a range enclosed by a line, the approximate range of powers versus beam diameter that the BeamMap2/Beam'R2 products can measure without additional external attenuation.

For BeamMap2/Beam'R2, the lines are not straight for the following reasons:

Upper Limit

- The one Watt total forms a horizontal upper bound.
- Down to around $10 \mu\text{m}$, preamplifier saturation is the upper bound on allowed power through slit. It is proportional to beam width until the beam diameter is a few times the slit width.
- However as the beam size decreases to a few μm , one hits the slit damage threshold limit and the upper limit then decreases, proportional to (beam diameter)².

Right Hand Vertical Limit

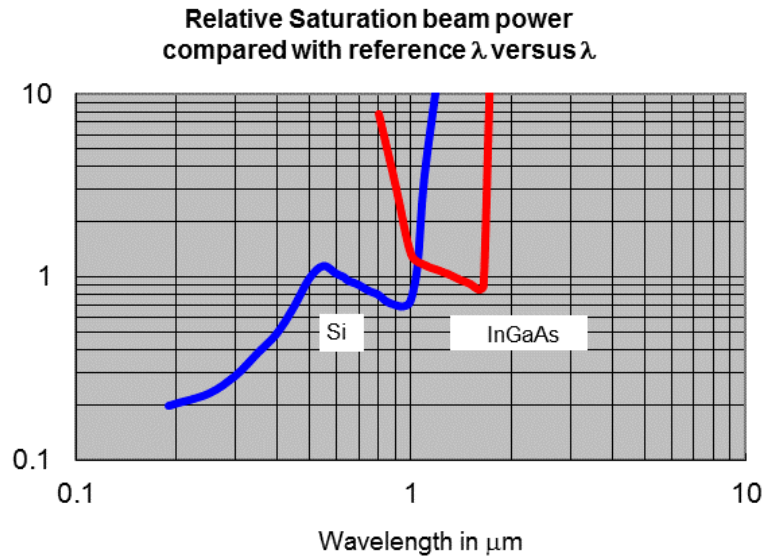


Fig. 5.9: Relative Saturation beam power compared to reference λ of 675 nm for Silicon units or 1310 nm for InGaAs

- This limit depends upon the detector size and, for BeaMap2 Collimate units, the distance from the front plane to the detector as well as the wavelength.

Higher Maximum Irradiance Limits: Lower sensitivity units can be made to special order. The dashed lines show /ND2 for silicon units and /ND1.5 for InGaAs, showing the higher maximum limits. This can be at a fixed internal ND filter or as an external screw-on ND filter or sampler, up to ND4 (0.01%).

At the lower beam diameters due to slit irradiance limits, the higher irradiances can only be achieved with the external filter/sampler.

Lower Irradiance Limits: Higher sensitivity may be achieved by using the KE mode on beams which are too large for the KE algorithm.

For a Silicon detector the sensitivity increases by x20.

For an InGaAs detector the sensitivity increases by x10.

5.4.3 Beam Waist Diameters

A standard formula for the minimum beamwaist for a focused laser beam with $M2 = 1$ is:

$$2w \approx 1.3(f/\#)(\lambda) \approx 8.7\mu m @ 670nm, f/10 \quad (5.1)$$

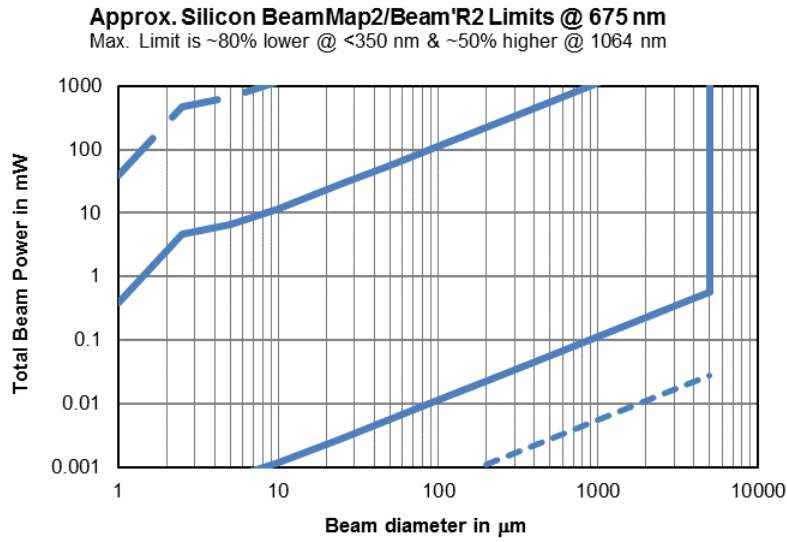


Fig. 5.10: Approximate Silicon BeamMap2/Beam'R2 Limits at 675 nm

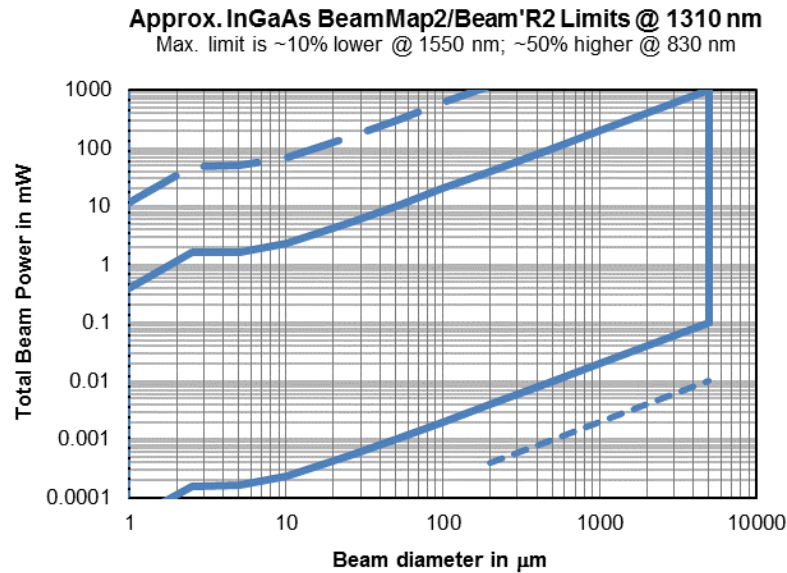


Fig. 5.11: Approximate InGaAs BeamMap2/Beam'R2 Limits at 1310 nm

For a beam of minimum possible divergence but higher M2, this would become:

$$2w \approx 1.3(f/\#)(\lambda)(M^2) \quad (5.2)$$

From this you may estimate the lowest possible beam waist diameter for your beam. You may measure beam diameters up to the beam measurement limits in 4.4 above.

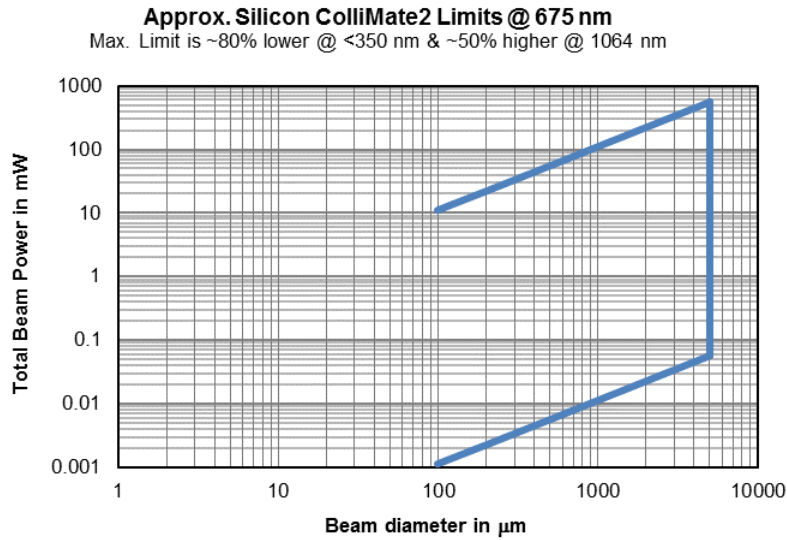


Fig. 5.12: Approximate Silicon BeamMap Collimate Limits at 675 nm

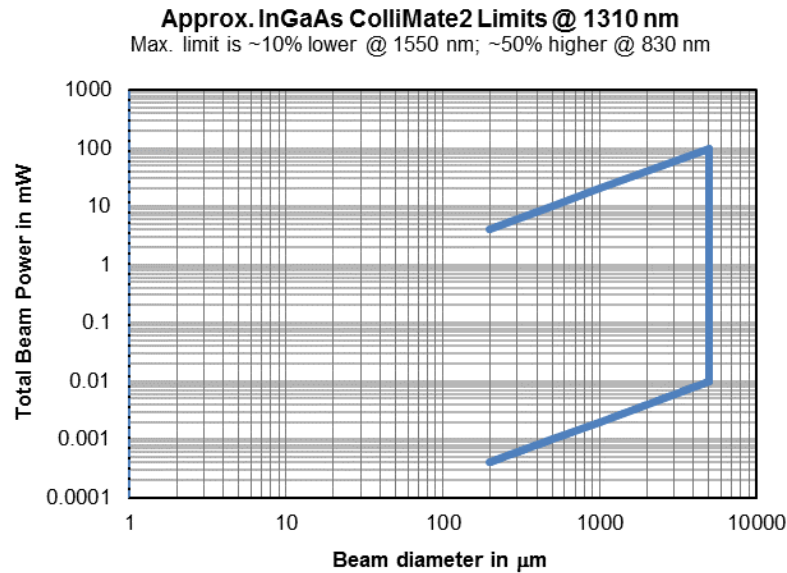


Fig. 5.13: Approximate InGaAs BeamMap Collimate Limits at 1310 nm

5.4.4 Slit Dimension and Beam Waist

For 'Slit mode' measurements, the de facto industry standard is that the 13.5% Clip Level beam diameter should be at least a factor of three greater than the slit width, and preferably a factor of five. To strictly meet the ISO 11146 Standard requires a factor of twenty. [Paragraph A.3.3 of the Standard.] In addition,

the slit length should be twice the beam diameter [per the ISO Standard].

In 'Knife-edge mode', the beam diameter should be at least a factor of three less than the slit width. In this mode the effective slit width is the sample spacing of $0.087 \mu\text{m}$.

When the slit width approaches the beam diameter, software correction should be made for the slit width. DataRay automatically compensates the diameter readings for slit diameter. If this is not done, the error is nearly 5% for Gaussian beams when the slit width to beam diameter ratio, $(s/2w)$ is 25% of the $1/e^2$ beam diameter. A simple correction (difference of squares) for slit width reduces this error to 1.35%. DataRay's algorithm reduces the error to $<0.1\%$, and to 1% at $(s/2w)$ ratios as high as 0.70.

This compensation has been modeled as the movement of a slit across two-dimensional Gaussian beams and 'top-hat' distributions. The three graphs show the compensation error as a function of [beam diameter/slit width] for a simple compensation algorithm (square root of the difference of the squares, clip level independent), and for the more complex, clip-level dependent, algorithm employed by DataRay. The first two graphs are for Gaussians. The third is for 'Top-hat' circular beams.

5.4.5 Beam Numerical Aperture and $f/\#$

Based on a maximum measured beam diameter of 3 mm and a minimum inner slit pair to detector separation of 6 mm, the absolute maximum measurable NA in optimum conditions is >0.5 . This corresponds to an $f/\#$ of $< f/2$. [$NA = 1/(2(f/\#))$]

5.4.6 Beam M^2 Limits

M^2 is calculated as a weighted least squares fit of beamwaist diameter $2W(z)$ at three or four z positions.

$$M^2 = \frac{\pi W_0^2}{\lambda z} \sqrt{\left(\frac{2W(z)}{2W_0}\right)^2 - 1} \quad (5.3)$$

In order to accurately measure M^2 it is preferable to measure the beamwaist $2W_0$ at $z < 0.5z_R$ and beam divergence at $z \geq 2z_R$.

$$z_R = \frac{2W_0}{\Theta} = \frac{\pi W_0^2}{M^2 \lambda} \quad (5.4)$$

With available slit plane separations of $d = 50, 100, 250, 500, 750 \mu\text{m}$ and 10 mm, the criterion the front to back plane separation ($5d \mu\text{m}$) to be $\geq 2.5Z_R$.

5.5 LensPlate2

The detachable LensPlate2TM screws to the front of the Beam'R2 or BeamMap2 in order to reimage or create a waist. E.g. to reimage a lensed fiber output or a waveguide, or to create a waist inside the instrument

from a collimated beam. It employs diffraction limited aspheric or other lenses coated for the wavelengths of interest. These lenses are designed for use with the small beams typical of fiber optics. The magnification M of the actual unit is determined during calibration and marked on the unit. The software can be set to correct displayed values for M . Standard configurations are 1:1 within NA of 0.68 or 0.33, and 1:4.5 with an NA of 0.68. For more information see the [LensPlate2 application note](#)

5.6 Calibration

- Units come with a Calibration Certificate. Annual recalibration is offered but is not considered necessary unless the unit has experienced significant physical shock. The only moving part is the 'puck' on a ball bearing motor. The calibration is held in an EEPROM in the unit.

Where possible we recommend that customers measure and keep a 'golden' or reference test beam appropriate to their measurement requirements. By measuring this beam on a regular basis they can establish whether or not the device is showing any drift for any reason.

- Calibration of the actual slit positions & angles on the individual pucks is essential to correct operation. For this reason pucks are not interchangeable in the field.
- Calibration does not assume that the slits are perfectly positioned on the puck, nor does it consider the puck to be square on the motor shaft. Instead the individual slits are assumed to lie in skew planes. The planes of each individual slit are accurately measured.
- Calibration does not assume that the beam is always at its nominal radius. As the beam moves away from the calibrated 0,0 position, measurement of the actual centroid position X_c , Y_c allows determination of the actual radial distance 'r' of the beam centroid from the rotation axis, and hence allows the calibration of the measured beam diameters.

Appendix A

Beam'R2 M^2 Measurements

A guide to performing M^2 and divergence measurements using a Beam'R2 beam profiler and M2DU stage. Applies to: Software Ver. 7.1H25Bk or higher, running under Windows 7, 8, or 10.

A.1 Description

The USB 2.0 M2DU accessory converts DataRay's Beam'R2 beam profiler into a compact, fully ISO 11146 compliant M^2 measurement system. The M2DU system is comprised of an achromatic lens fixed to the front of a travel stage on which the WinCamD is carried. The lens refocuses an input beam to a waist within the stage's travel range. While DataRay provides a spreadsheet (see Section A.3) to simplify the choice of the achromatic lens, we will also work with each customer to recommend and supply the correct lens.

ASRTM auto-sampling measures the beam diameter both in the near-field (the hyperbolic region about the waist) and in the far-field ($z > 2z_R$) in accordance with the ISO 11146 standard. A least squares hyperbolic fit to the second moment diameter data allows calculation of the M^2 value and related parameters for both the focused beam and the source beam.



Fig. A.1: (a) Beam'R2 on M2DU-50 stage (side view). (b) Beam'R2 on M2DU-50 stage (isometric view).

A.1.1 Applications

- M^2 measurement of CW & pulsed lasers with minimum repetition rate of $[500/(\text{Beam diameter in microns})]$ kHz
- M^2 measurement of focused beams
- Focus position of laser assemblies

A.1.2 Features

- Auto Scan Range (ASRTM) for ISO 11146 compliant scan
- USB 2.0 for field service applications
- Fast, Compact, Portable system
- Field-replaceable lens options

A.1.3 Specifications

- Maximum beam diameter: See Fig. [A.2](#)
- 400 to 800 nm with standard lens
- 266 to 2500 nm with optional lenses and detector options
- M^2 Range* 1 to >50
- M^2 Accuracy* $\pm 5\%$ typical
- M^2 Repeatability* $\pm 2\%$ typical

* Beam dependent. Achieving absolute accuracy better than $\pm 5\%$ is possible, but can be difficult.

A.1.4 Parts List

- Beam'R2 Scanning Slit Beam Profiler
- M2DU-50 system comprising moving stage, lens mount and Beam'R2 mount
- LNZ–UV, –VIS, –NIR, or –TEL lens system, with focal length options as shown in Table. [A.1](#) (may change)

A.2 M^2 Beam Quality Factor and Measurement

The Beam Quality Factor M^2 is a dimensionless parameter that characterizes the degree of imperfection of a real-world laser beam. The closer the M^2 value is to 1.0 (i.e. the closer the beam is to TEM₀₀ Gaussian perfection) the closer the beam can be focused to its diffraction limited spot size.

Due to limitations of the optical cavity, the lasing medium, and/or the output/ancillary optics, most beams

Stage	Lens focal length options	Wavelength options
M2DU-WCD	75-75 mm focal length (22 mm aperture)	UV Fused silica singlet for 250-450 nm
	100-100 mm focal length (22 mm aperture)	
	150-150 mm focal length (22 mm aperture)	VIS Achromat for 400-800 nm
	250-250 mm focal length (22 mm aperture)	NIR Achromat for 630-1100 nm
	250-50-250 mm focal length (47 mm aperture)	TEL Achromat for 1000-1800 nm
	500-50-500 mm focal length (47 mm aperture)	

Table A.1: Standard lens focal length options.

are not the ‘perfect’, diffraction-limited, Gaussian profile, pure TEM_{00} mode described in textbooks. Complex beams can contain multiple TEM_{xy} contributions leading to high values of M^2 .

A.2.1 M^2 Definition

At its simplest M^2 may be defined as: the ratio of the divergence of the actual beam, to that of a theoretical, diffraction limited TEM_{00} beam with the same waist diameter.

$$M^2 = \frac{\Theta}{\theta} \quad (\text{A.1})$$

Where Θ is the measured, far-field, full-angle divergence of the actual beam and θ is the theoretical far-field divergence of a ‘perfect’ TEM_{00} Gaussian beam, which has the same waist diameter as the measured beam.

$$\theta = \frac{2\lambda}{\pi W_0} \quad (\text{A.2})$$

Where λ is the beam wavelength, and W_0 is the second moment beam waist radius (2σ). The shape of the M^2 curve is hyperbolic and defined by

$$2W(z) = 2W_0 \sqrt{1 + \left(\frac{z}{z_R}\right)^2} \quad (\text{A.3})$$

Where z_R is the Rayleigh Range, defined as the distance at which the beam diameter is $\sqrt{2}$ greater than the diameter at the waist. z_R may be shown to be:

$$z_R = \frac{2W_0}{\Theta} = \frac{\pi W_0^2}{M^2 \lambda} \quad (\text{A.4})$$

A definition of M^2 in terms of a measured diameter is

$$M^2 = \left(\frac{\pi}{4\lambda} \right) 2W_0 \Theta \quad (\text{A.5})$$

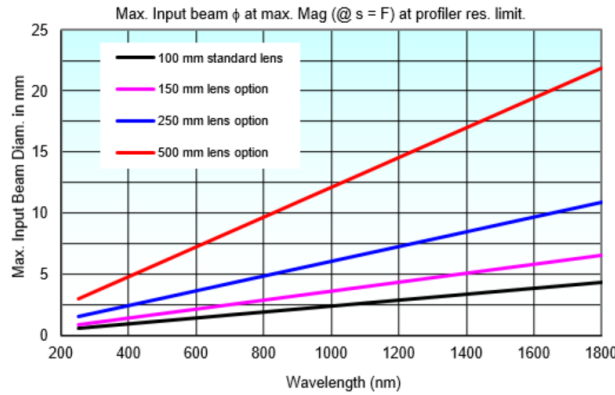


Fig. A.2: Maximum input beam diameter for various wavelengths.

A.2.2 M^2 Measurement

“Test methods for laser beam parameters: Beam widths, divergence angle, and beam propagation factor” (Available from the [ANSI Standards store](#)), requires:

- Use of the Second Moment (4σ or Variance) definition of the beam diameter.
- Averaging of 5 samples at each position in z .
- A minimum of ten samples in z . “...half of them shall be distributed within one Rayleigh length on either side of the beam waist and half of them should be distributed beyond two Rayleigh lengths from the beam waist.” (DataRay offers from 10 to 60 samples in z). Although this statement is slightly ambiguous, we interpret “within one Rayleigh length” as $|z| < z_R$, and “beyond two Rayleigh lengths” as $|z| > 2z_R$.

For equi-spaced samples in z , and an initially unknown beam waist position, these sample position requirements of the standard are met by a minimum of 18 samples at $z_R/3$ intervals about the waist, e.g. from $-3z_R$ to $+2.67z_R$. To ensure that we spatially sample the actual beam waist diameter within 1% requires the z samples around the beam waist to be spaced at $z_R/3.5$ intervals. (For equi-spaced samples, the samples in the $\pm z_R$ to $\pm 2z_R$ region are additional to the specific requirements of the Standard, but may still be used in the calculation.) See Table A.2

ISO 11146 requirements can also be met by more samples at a higher sampling frequency in z_R .

- A least squares hyperbolic fit to the data.

z position	Beam Diameter	Percentage Greater
0 (beam waist)	$2W_0$	0%
$\pm 0.14z_R$	$2.02W_0$	1%
$\pm 0.2z_R$	$2.04W_0$	2%
$\pm z_R$	$2.83W_0$	41.4%
$\pm 2z_R$	$4.47W_0$	123.6%
$\pm 2.5z_R$	$5.38W_0$	169.2%
$\pm 3z_R$	$6.32W_0$	216.2%

Table A.2: Beam diameter near waist.

A.2.2.1 Notes:

1. With a beam profile that is a pure Gaussian, the Variance (Second moment) definition is exactly the same as selecting a 13.5% Clip Level, but if your beam is non-Gaussian—which is most beams—the Variance method is more consistent. An exception to this general rule is that the presence of a significant background level above zero or background noise will skew the Variance reading to larger values.
2. In accordance with Section 5.1 of the ISO 11146 Standard, the Second Moment calculation integrates over 99% of the total energy in the profile.
3. If the beam waist profile in the propagation direction—the z direction—is either too flat or too 'V' shaped, the fit will be poor.
4. With the lens provided/recommended, the system will measure the M^2 of collimated lasers. If you already have an appropriate beam waist and can position it within the range of travel of the stage, you can measure the M^2 of the beam directly.

A.3 Beam Modeling for Lens Selection

An intuitive Excel spreadsheet simplifies lens selection. You may have already received this spreadsheet during the purchase process. If not, download the [lens choice spreadsheet](#). from the Documentation section at the website and model your beam in order to ensure that it can be correctly measured with the received system.

Enter the values for your beam in the light-blue shaded cells. The results of the Gaussian optics calculations appear in the dark pink shaded cells and a curve appears below. The output data fields show several factors and highlights in yellow the required lens diameter plus the length of spacers required to place the beam waist within the range of the stage. The lines on the (auto-scaled) graph show:

- The estimated post-lens beam waist profile.
- The calculated flattest acceptable beam waist (maximum Rayleigh Range) for this stage.
- The minimum allowed beam waist for the chosen profiler.

If the beam waist is too small for the device or the curve is too flat, warnings with advice will appear next to the values. You may need to be in the far field of the laser in order to form a beam waist within the range of travel of the stage.

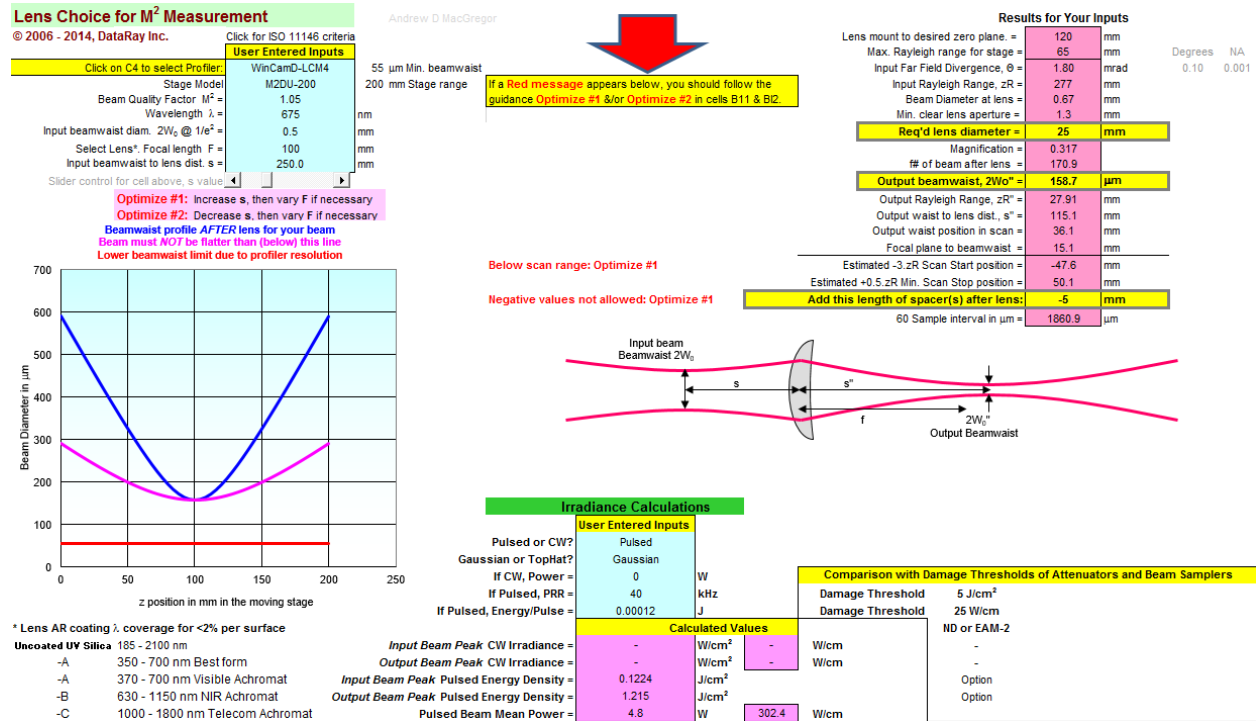


Fig. A.3: Lens Choice for M^2 Measurement Spreadsheet

A.3.1 Avoiding Profiler Damage

Verify the lens incident power with a power meter. For the calculated value of $2W_0''$ shown as output beam waist in Fig. A.3, use the curves in section 5.4.2 to determine whether you will need to add additional sampling/attenuation in order to avoid damage to the slits. Add the required attenuation before proceeding. DataRay offers several solutions for beam attenuation which can be found on our website.

A.4 Getting Started

A.4.1 Install Software

Make sure the latest DataRay software has been installed on your computer and learn to use the software and Beam'R2 together before working with the M2DU stage. The latest software downloads may be found on our [website](#). If you do not have an M2DU stage and wish to perform an M^2 measurement using a different stage see Section [A.13](#).

A.4.2 Hardware Assembly

A.4.2.1 Parts List

The M2DU system consists of the following parts:

- (1) M2DU stage
- (1) 3 m USB 2.0 cable
- (1) 12V-PSU Power supply with power cord
- (1) LNZ-XXX-YYY Achromatic lens in holder plus spacers.
- (1) Beam'R2 Mount
- (1) Lens Mount Bracket
- (1) 9/64" Hex Allen Wrench
- (1) 3/16" Hex Allen Wrench
- (1) 2.5mm Hex Allen Wrench
- (1) Socket Head Cap Screw, 8-32 Thread, 3/8"
- (2) Socket Head Cap Screw, 1/4"-20 Thread, 3/8" Length
- (6) Socket Head Cap Screw, M3 Thread, 8MM Length, 0.50MM Pitch

A.4.2.2 Assembly Instructions

Use the following instructions for correct assembly:

1. Attach the BeamR'2 series head to the mounting block a using the #8-32 screw. Use a 3/32" or 2.5 mm hex key.
2. Attach the M2DU-WC Mounting Block to the moving platform on the M2DU stage using two M3-0.50×8 screws.
3. Attach the M2DU-WC-LMB lens mount bracket to the front of the M2DU stage using two M3-0.50×8 screws as shown in Fig. [A.4](#).
4. Optional: Attach the M2DU-WC-LMB lens mount bracket to an optical table, breadboard or other hardware using two 1/4"-20×0.5" screws (imperial, not supplied) or M6×12.5 mm cap-head screws (metric, not supplied).
5. Optional: To mount it higher, attach either through these holes or to the 1/4"-20 threaded holes in the base of the M2DU. **IMPORTANT:** If you use the threaded base holes, screw length inside the unit must never exceed 0.375" (10 mm).
6. Add the LNZ-XXX-YYY lens assembly as shown in Fig. [A.5](#).

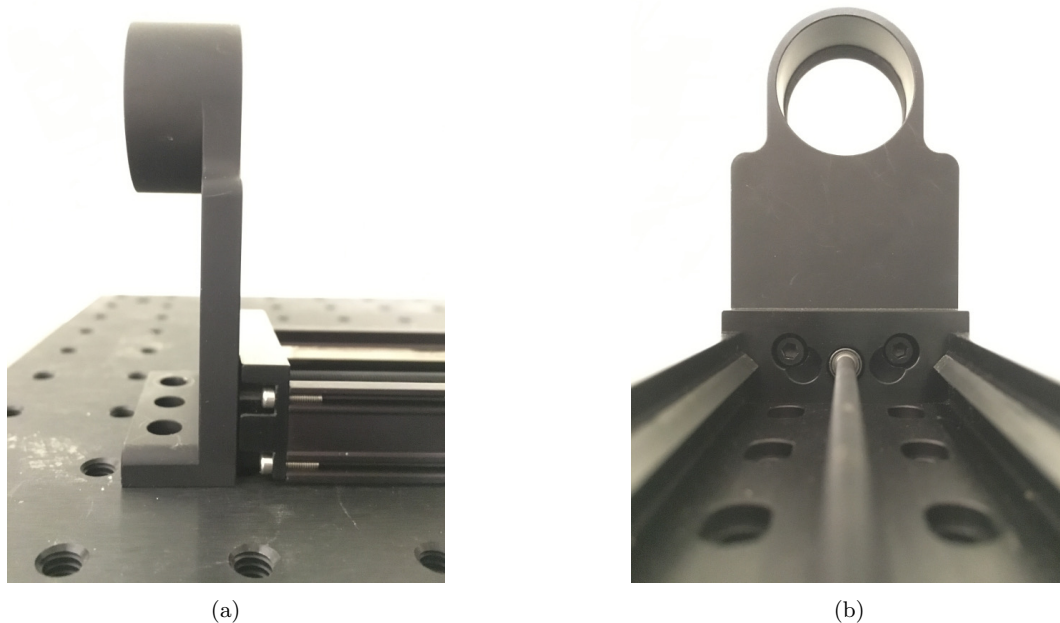


Fig. A.4: (a) Lens mount bracket attaches to end of stage (b) Two M3-0.50×8 screws are used to attach the lens mount bracket

7. Connect the 12V power supply to the M2DU.
8. Connect a USB 2.0 cable between the M2DU and the PC. After finding the hardware and installing the drivers the Device Manager should show them as shown in Fig A.7a. Note: If connecting to the USB through a hub, it must be a powered hub.

A.5 Start the Software

Start the software, choose Beam'R from the Device menu dropdown. Click the **M²** button. A warning dialog will advise to set the clip mode to Sigma4. Allow all the offerings by clicking Yes. You will then see the M-squared Setup box as shown in Fig. A.7b where you will enter some values:

1. Enter Wavelength in nm and Lens Focal Length in mm.
2. LPPSO: If you require that the software calculate the source beam characteristics, you need to measure this critical distance. The flexible lens focal length, wavelength and spacer options means that lens Principal Plane to scan stage position is not fixed and must be entered manually.

Use a mm scale/tape to measure LD, the distance from the front of the lens flange (with dust cap removed) to the back of the Lens Mount Bracket—the red double arrow in Fig. A.6. LD must then be corrected for the distance between the front of the lens and its Principal Plane, the Zo Delta value from the lens label, and for the distance A between the rear of the lens bracket and the sensor in the camera.

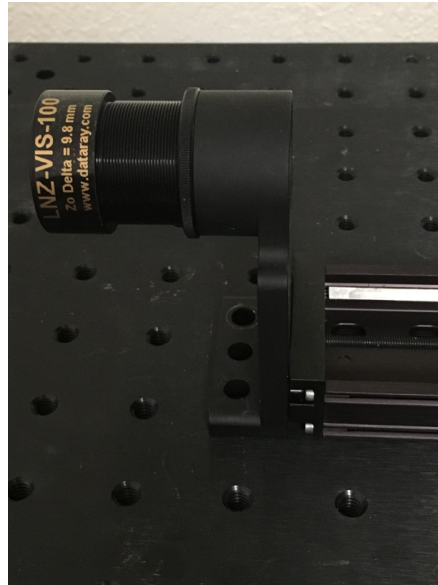


Fig. A.5: The LNZ-XXX-YYY lens assembly attaches to the lens mount bracket. The properly chosen lens will create a beam waist within the range of the M2DU stage

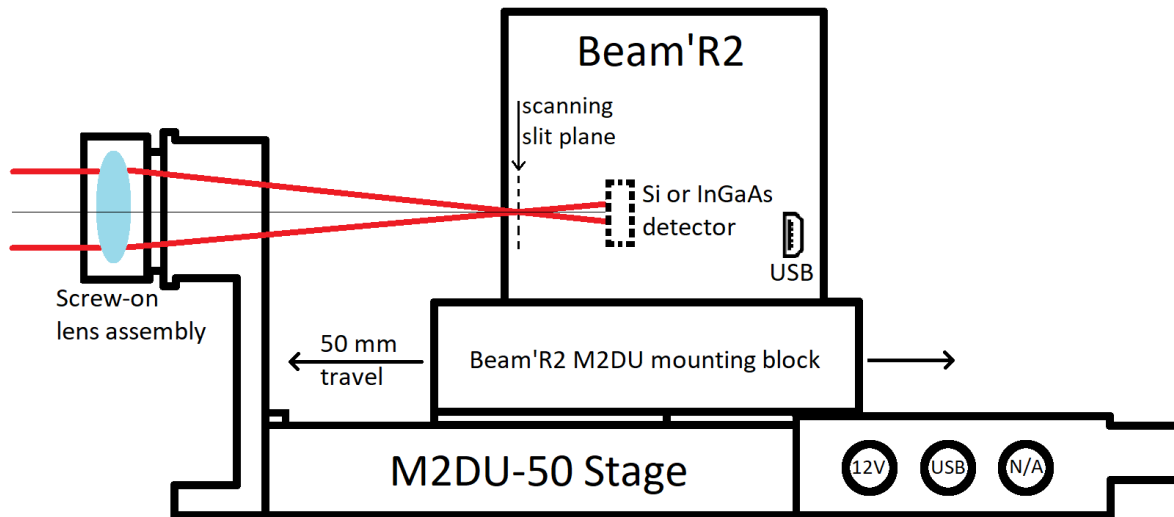


Fig. A.6: M2DU Assembly Diagram.

- Add LD to A-Zo Delta, and enter this value as the LPPSO (Lens Principal Plane to Sensor at 0) entry in the dialog. The value of A depends on the camera and mount position, the distance from the front of the camera to the sensor for each camera can be found in the drawings on the [DataRay website](http://www.dataray.com).
3. Enter the Zo Delta value from the lens label in the M-squared dialog.

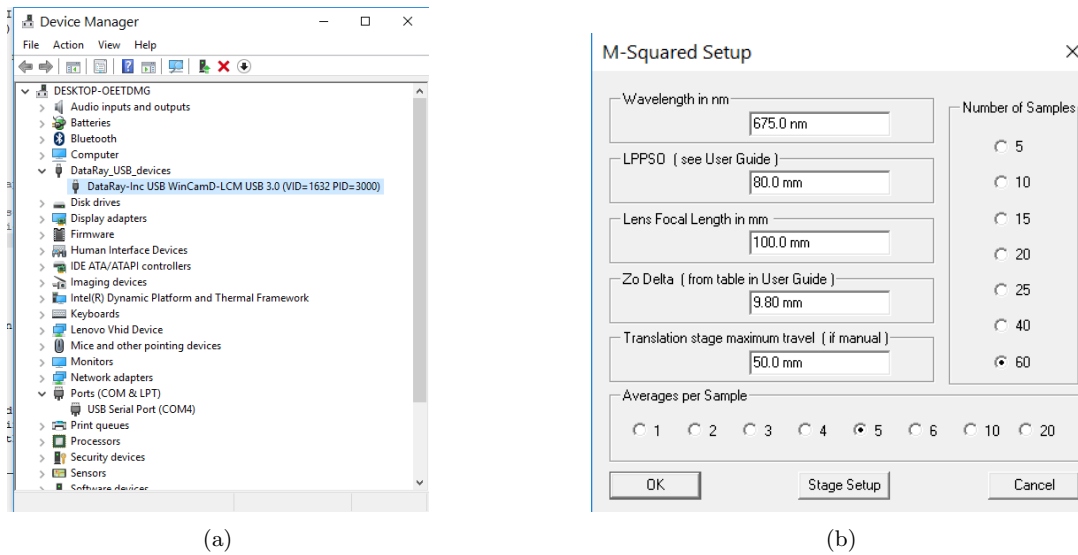


Fig. A.7: (a) WinCamD-LCM in Device Manager, with the M2DU detected as a USB Serial Port. (b) M-squared Setup Dialog Box.

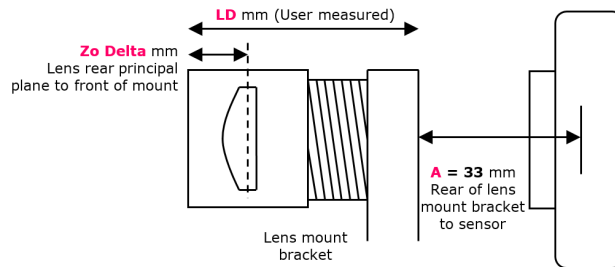


Fig. A.8: Required known distances with M2DU setup.

4. Copy LPPSO and Zo Delta to the front page for your future convenience.

Lens focal length (LNZ-XXX-YYY)	LD (User measured)	(A-Zo Delta)	LD+(A-Zo Delta)=LPPSO (Enter in M ² dialog)	Zo Delta (Enter in M ² dialog)

Table A.3: Chart to enter your lens setup details.

Let's double-check: You did all your calculations in mm and to ±1 mm or better, correct?

Translation Stage maximum travel is automatically read from the stage EEPROM when a stage is present.

Click OK, and the M Squared Dialog as shown in Fig. A.9 will appear.

Particularly on smaller displays, to stop it from blocking the screen, you may resize the main screen away from its default full screen setting. .

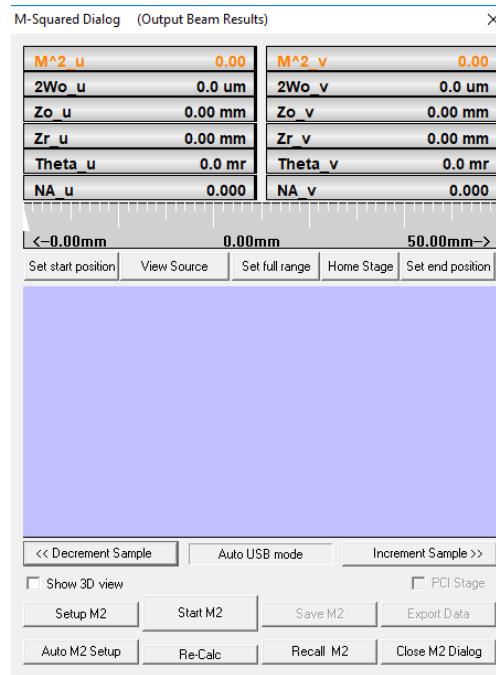


Fig. A.9: M-Squared Measurement dialog box.

A.6 Align the Beam

Correct alignment is critical to successful operation. A misaligned beam can lead to astigmatism and to overestimation of the M2 value. You are aiming for on-axis to $\sim \pm 2$ mm max.

The M2DU stage sets the optical axis at a height of 2.5" (63.5 mm) above the base.

The small circular ring in the alignment window indicates the beam's centroid location.

With these covers in place:

1. Click on the right hand edge of the gray scale to move the stage to the end closest to the motor.
2. Align the beam on the target with a hole in it on the front of the lens.
3. Rotating about the front lens cap center as pivot point, adjust the laser or the rear of the M2DU to center the laser beam on the camera target.

4. Lock down the laser and the M2DU stage.
5. Remove the lens & camera covers.
6. Press **G** or click on the green highlighted cell as shown in Fig. A.12 to start a capture. Verify that Peak ADC is <90%. If it is not, the beam may require additional attenuation.
7. Press **S** or click on the green highlighted cell again to stop this capture.

A.7 Perform a Coarse Scan

1. Press Go **G** to let the exposure adjust.
2. Press Auto Setup to perform a coarse scan of 20 equally spaced points in z using the full length of the stage, with an average of 5 scans per z position.
3. At the conclusion of the scan, the software performs a hyperbolic weighted least squares fit to the data to calculate the approximate position of the beamwaist, Z_0 , and the Rayleigh Range, Z_r . This is shown in Fig. A.10a
4. Select Use ISO major/minor to get true M^2 values.
The Use Clip Width (x/y) option will calculate the beam dimensions using the Clip A clip level. Please note that the clip width option will not provide a valid ISO 11146 M^2 measurement.
5. Based on these values, the software produces estimates of the full results. More importantly the ASR™ Auto Scan Range software module sets upward pointing white tick marks on the scale at the suggested Start and End positions for an ISO 11146 compliant scan.
6. A series of warnings will appear if there was an error in the coarse scan. The warnings that can appear are as follows:
 - **Warning: Beam waist too shallow** If the scan is too flat for an accurate M^2 fit because the far-field is not adequately reached within the range of the scan in accordance with the Standard
 - **Warning: More attenuation recommended** If the exposure dips below 0.25 ms this warning will appear in the Exposure area.
 - **Warning: Less attenuation recommended** If the exposure rises above 200 ms this warning will appear due to the risk of dark noise contribution to the ISO diameter.

Orange Data- During the scan through a beam waist, the software changes the Exposure to accommodate the change in the irradiance as the beam diameter changes. During Exposure iteration, before the correct Exposure is determined, the Peak % will sometimes go to 100% and the numbers will turn orange to warn of this saturation. Do not worry. The software only uses data taken when the exposure has stabilized and the Peak % is below 100%. If the numbers remain orange, then a valid image could not be obtained. Please see the Troubleshooting section A.15 to resolve this issue.

A.8 Perform a Final Scan

Unless you have reason to disagree with the proposed scan range, press Start in the M2 Measurement dialog. The software automatically performs a scan of 60 equally spaced points in z over the set range, with an average of 5 scans per z position. The number of samples and averages per sample can be modified in the M-Squared Setup dialog box (Fig. A.7b). At the conclusion of the scan, the software performs a weighted

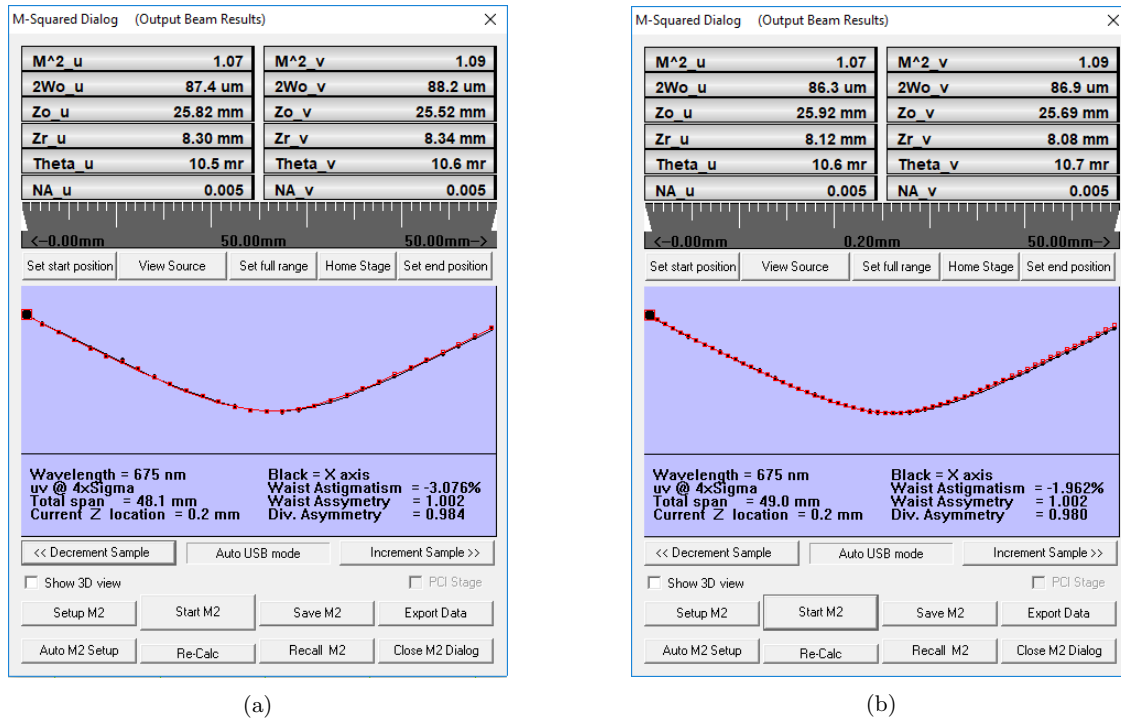


Fig. A.10: (a) M² Measurement dialog box after Auto Setup. (b) M² Measurement dialog box after final scan.

least squares hyperbolic fit to the data to calculate the final results (see Fig. A.10b)¹. Descriptions of the various results are explained below. Each result will be explained along only one axis. For instance M²_u and M²_v are the same measurement, but on orthogonal axes.

- M²_u: The M^2 value along one of the axes with accuracy² $\pm 5\%$ and repeatability³ $\pm 2\%$.
If your beam M^2 is actually 1.03, the value that you see may vary from 0.98 to 1.08. If it is less than 1.0 it will show in orange, as 0.98, but this does not necessarily mean that it is a bad result.
- 2Wo_u The beamwaist diameters.
- Zo_u The beamwaist positions with respect to the zero position of the sensor.
- Zr_u The beams Rayleigh range.
- Div_u The far-field divergence of the focused beam in mrad.
- Div_{NA_u} The far-field divergence of the focused beam in NA.

¹ The ISO 11146 Standard calculations, even when used to find the beam waist of a perfect Gaussian beam, result in a beam waist diameter that is smaller than expected. DataRay has a proprietary correction factor, enabled by default, to correct this discrepancy. This can be disabled in the ISO Clip Level & Correction Setup dialog box (Fig. A.15).

² Beam dependent. Absolute accuracy better than $\pm 5\%$ is possible, but can be difficult.

³ See Footnote 2

A.9 Source Beam Characteristics

Press the View Source button below the dialog to toggle between the output beam and the source beam. The software uses Gaussian beam calculations to calculate the position and dimensions of the source beam. Below the curve (Fig. A.10b) are calculations of:

- **Waist Relative Astigmatism** The difference between the calculated source waist Z_o distances from the lens principal plane divided by the average Z_r distance.

$$\text{Waist Relative Astigmatism} = \frac{(Z_{o_u} - Z_{o_v})}{(Z_{r_u} + Z_{r_v})/2} \% \quad (\text{A.6})$$

- **Waist Asymmetry** The ratio of the calculated source diameters

$$\text{Waist Asymmetry} = \frac{2W_{o_u}}{2W_{o_v}} \quad (\text{A.7})$$

- **Divergence Asymmetry** The ratio of the calculated source divergence angles.

$$\text{Divergence Asymmetry} = \frac{\text{Div_u}}{\text{Div_v}} \quad (\text{A.8})$$

Important: The source Z_{o_u} , Z_{o_v} values are given as measured from the front of the lens holder, not from the lens principal plane.

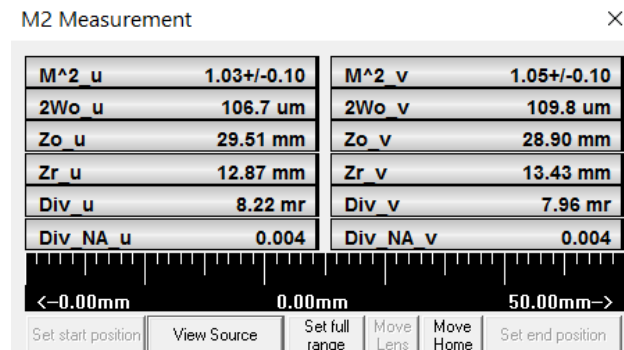


Fig. A.11: Press View Source to toggle Source/Output beam characteristics.

A.10 Further Options

Below the image of the beam waist, the following options are given:

- **Save** Save the results as a *.wcf file. If you forget to do so, a warning will appear before you start another M^2 scan.
- **<<Decrement Sample/Increment Sample>>** Scan through the planes of the individual measurements. Saved files contain the original images, so you may switch between Use clip widths and Use major/minor widths.

- Use ISO 11146 compliant diameters and angles Uses the ISO 11146 Standard calculations. This option is automatically selected and any clip level is ignored⁴.
- Use clip widths (x/y) The software will use clip levels to calculate the beam diameter instead of ISO 11146 compliant calculations.
- Show 3D view To see a visually more satisfying 3D view.
- Export Data to export the data to an M2data.txt file in Notepad, which may be saved for subsequent analysis, and from which the data may be exported into Excel.
- Recall M2 Browse for and open previously saved .m2_wcf files.

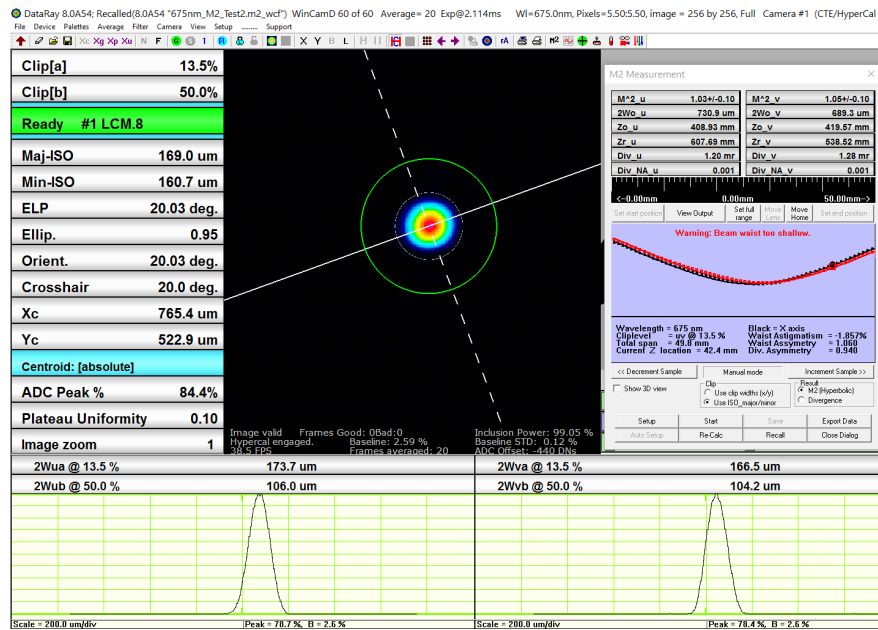


Fig. A.12: Save data using Save in the M2 Measurement dialog.

A.11 Second Time Around

When the software is closed, it saves the current settings. If the laser power and alignment have not changed substantially, all you need to do is rerun the software. If anything has changed revisit that section only.

A.12 Support

If you get a result which makes no sense, and rechecking the procedure did not help, then:

⁴ If the beam waist profile in the propagation direction—the z direction—is either too flat or too 'V' shaped, the fit may be poor.

1. Scan through the saved images to see whether or not you have a dirt, dust, exposure time or Capture block issue affecting the image.
2. If the previous step showed nothing that explained the problem, then save a *.m2_wcf file ⁵ or at least an *.wcf image saved from the data set. Email the file with comments to support@dataray.com.


A.13 Manual M^2 (with a different translation stage)

If you have a WinCamD camera but no M2DU unit, the procedure is identical, particularly with respect to alignment, exposure, laser safety, capture block, etc. Before trying to perform a Manual M^2 , you must first read and understand the full document carefully except for items relating specifically to the parts list and assembly of/with the M2DU unit. Exceptions to the procedure are as follows:

- Stage Travel Determine the length of travel of your stage (motorized or manual).
- Stage Readout: The stage must have a readout in mm (digital or manual).
- Source diameter and location. To additionally determine the waist diameter & z location of the source beam:
 - Lens: You need to know the focal length (mm), and back focal length (mm) of your lens. Enter the value in Table A.4.
 - Lens mount: You need to determine the distance Zo Delta (mm) from the front of your lens mount to the rear principal plane of the lens. Enter in Table A.4.
 - Lens mount: You need to determine the distance LPPSO (mm) from the lens rear principal plane to the sensor plane when at 0 mm on your measurement scale. Enter in Table A.4.

Lens focal length	Lens back focal length	=LPPSO (Enter in M^2 dialog)	Zo Delta (Enter in M^2 dialog)

Table A.4: Lens setup details for manual stage.

- Move the camera in z and determine that the beam waist is located between near the midpoint of the stage. Some variation is allowed (i.e. make sure the beam waist is located between 1/4-3/4 of the stage length).
- When the M-Squared Setup dialog screen opens (Fig. A.7b), enter the listed parameters, plus the Translation stage maximum travel.
- When you start the software with no M2DU stage connected the M-Squared Dialog will say Manual mode below the graphic area of the dialog.
- Set the camera to your start position, which need not be zero on the scale. Press Go  and let the image and exposure stabilize. Press Start⁶. The dialog shown in Fig. A.13a will appear:

⁵ The *.m2_wcf files can be large (ten's of MB). We can receive large files, but your email server may restrict attachment size. In that case, either put them to an FTP location on your server and tell us how to download them, or try using <http://www.sendthisfile.com>.

⁶ Auto M2 Setup is grayed out if you do not have an M2 stage.

1. The position highlighted in blue is the software's best guess at what the position will be based upon the entered stage range and the number of steps. You may choose to use these values or you may ignore them. Enter the actual z position (no need to include mm) rather than blue value. Then press OK.
 2. The screen in Fig. A.13b will appear. You may use the recommended position or one of your choosing. Once the position is set, press OK and after the image exposure has stabilized, the next reading will be taken.
 3. The screen in Fig. A.13a will reappear and the current position should be entered.
 4. Follow through the sequence until the requested number of samples have been entered, at which stage the results will appear instead of a dialog box.
- As you read about using the M2DU stage, you will probably have to iterate the positioning and the number of samples until the curve looks right and there are no warnings.

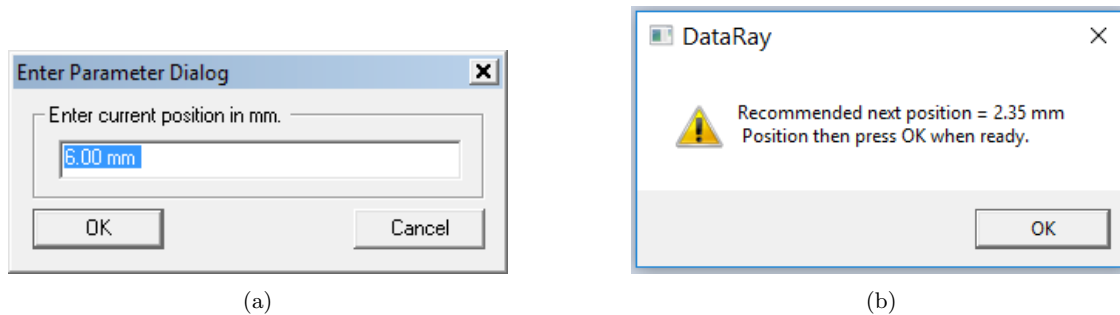


Fig. A.13: (a) Manually enter current position in mm. (b) Move the stage to the desired position, then press OK.


A.14 Divergence Measurement

The M2DU stage can also be used to measure the divergence of a beam without the need of forming a beam waist within the travel of the stage. The same steps for the setup of the M^2 measurement should be followed, but the focusing lens used to create the new beam waist within the travel of the stage is no longer needed. For most cases, this divergence measurement will be performed on a collimated source. A few caveats are as follows:

- The travel of the camera sensor should be within the linear region of the beam's expansion (at least 1 Rayleigh length from the beam waist).
- The size of the beam should not exceed the capture region at either end of the stage (see Table 5.1 for beam limits).

Follow the steps below to perform the divergence measurement:

- Be sure to first perform all the steps for the M^2 measurement up to and through the 'Check Exposure' section. Only the LNZ-XXX-YYY focusing lens will be omitted.

- When checking the exposure, the beam diameter should be at a minimum when the camera is closest to the beam source.
- On the M2 Measurement dialog box —within the Result options— choose Divergence instead of M2 (Hyperbolic). The dialog box will update for divergence measurements (Fig. A.14) and the fit will change from hyperbolic (for M^2 measurements around the beam waist) to linear (for divergence measurements outside the beam waist in the linear expansion region).
- Press Go  to let the exposure adjust and make sure a valid image can be obtained.
- Press Start to begin the divergence measurements. The software automatically performs a scan of 60 equally spaced points in z over the entire stage, with an average of 5 images per z position. The number of samples and averages per sample can be modified in the M-Squared Setup dialog box (Fig. A.7b)
- At the conclusion of the scan, the software performs a linear fit to the data to calculate the final results as shown in Fig. A.14.
 - Div_u/Div_v The far-field divergence of the focused beam in mrad, deg.
 - Div_NA_u/Div_NA_v The far-field divergence of the focused beam as NA.
 - Pt_X/Pt_Y: Pointing with respect to x and y.
 - Zo_u/Zo_v: Estimated beam waist positions with respect to the principal plane of the lens.
- The divergence measurements can be saved and exported with the same method as for the M^2 data as shown in the ‘Save the Data’ section.

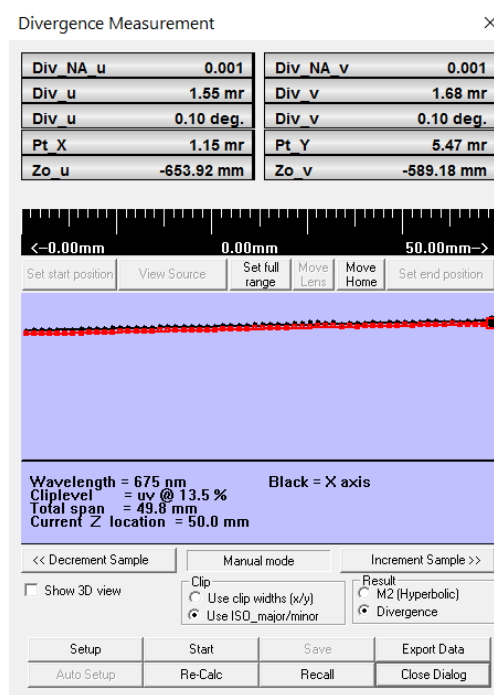
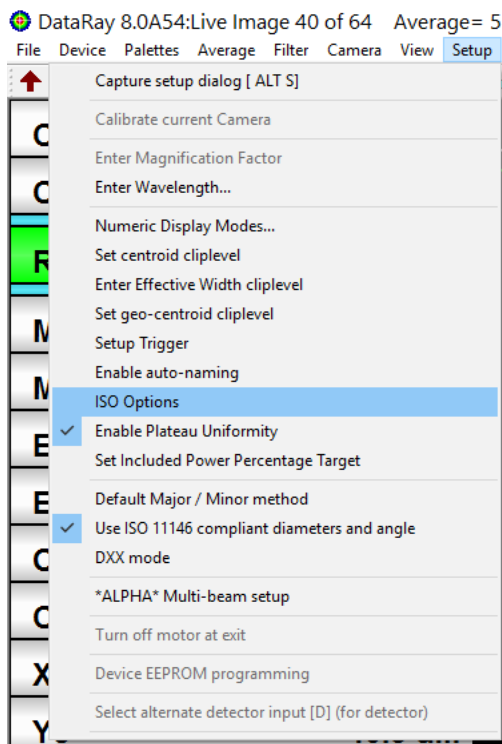


Fig. A.14: The M2 Measurement dialog box changes to the Divergence Measurement dialog box when the Divergence option is chosen instead of M2.

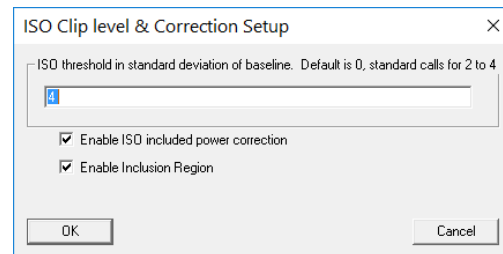
A.15 Troubleshooting

The main display says **Image invalid**. This may be caused by a number of reasons. For example, in order to satisfy ISO 11146 compliance, the Inclusion Power must be greater than 99%. The following list provides common problems and solutions.

- HyperCal may not function when the intensity of the beam is too high which can cause a very low exposure time. Try more attenuation to allow for an exposure time of at least 0.5 ms.
- The ADC Peak % may be too low. Try increasing the power of the beam, decreasing the attenuation, or increasing the exposure time.
- The ISO threshold defines which pixel values can be ignored based on a factor of the standard deviation of the baseline. The ISO threshold option can be accessed by choosing ISO Options from the Setup menu (Fig. A.15a). The ISO standard calls for a factor from 2 to 4, so try changing this value from 2 to 4 or vice versa in the ISO Clip Level and Correction Setup dialog box (Fig. A.15).



(a)



(b)

Fig. A.15: (a) Choose ISO Options to change the ISO threshold value. (b) ISO Clip Level and Correction Setup dialog box.

M2DU Stage Not Recognized

- Current versions of DataRay software will scan the computer's COM ports for stages up to COM26. If Windows assigns a number higher than COM26 for the stage, then the DataRay software will not

recognize the stage. This is a rare occurrence, but can sometimes happen with computers that have previously used many COM accessories. To fix the issue, open the Device Manager in Windows. Click on the dropdown arrow next to Ports for a list of the currently attached COM Ports. If there are several COM ports recognized, then unplug the stage to identify which port disappears; reattach the stage and the port will reappear. If the COM port number is above COM26, right-click on it and choose Properties as shown in Figure A.16. Go to the Port Settings tab and click the Advanced... button. Change the COM Port Number to a lower port number as shown in Figure A.17, then press OK to close each dialog. Start the DataRay software, which should now be able to recognize the stage.

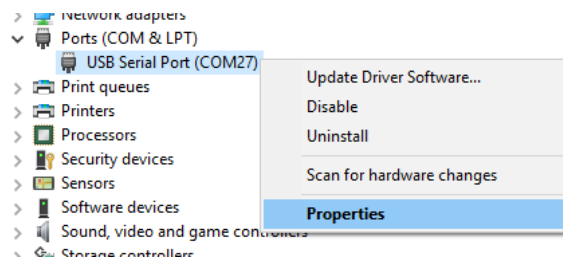


Fig. A.16: Right-click to choose Properties

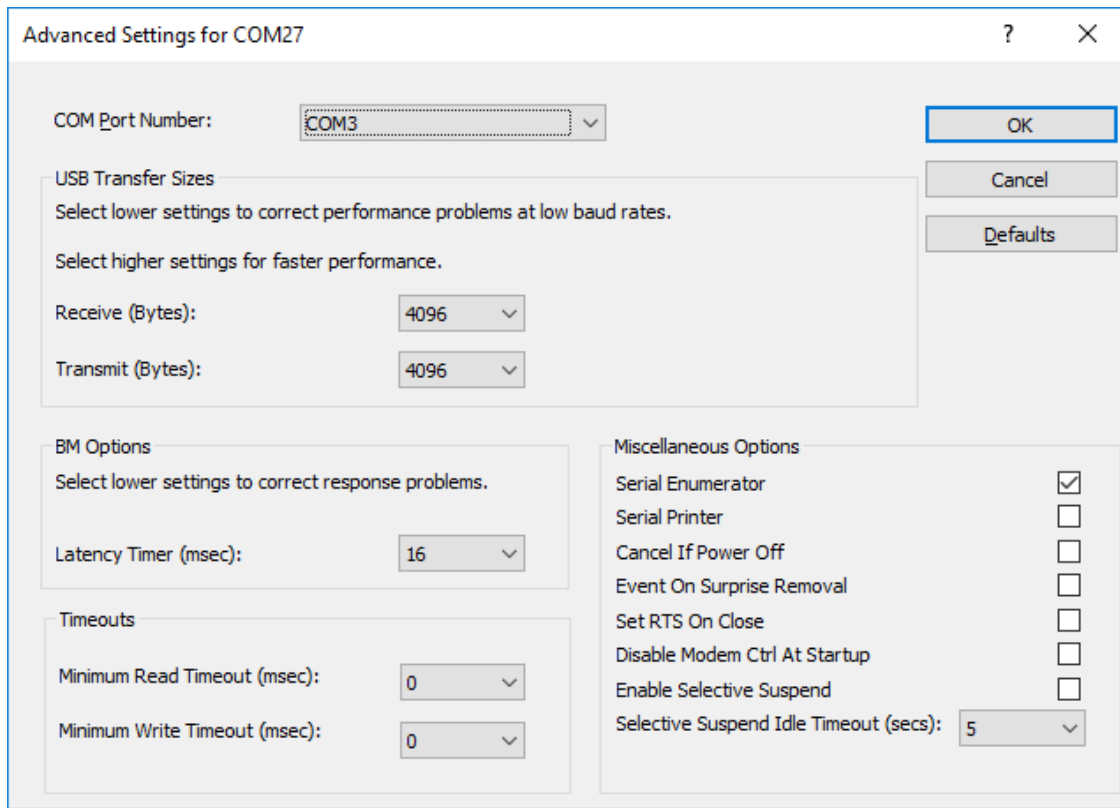


Fig. A.17: Change the COM port to a lower number

Appendix B

Sales, Support, and Returns

DataRay maintains a network of knowledgeable, non-exclusive, Distributors and Representatives, and also offers direct product support. Contact names and telephone numbers can be found at <https://www.dataray.com/where-to-buy.html>.

We are experts in beam profiling and strive to offer the best technical support to our customers. We can be contacted by email or phone for assistance in choosing the right system for your application, or for other technical support. We are available Monday-Friday from 9AM-5PM PT. Please refer to the [Technical Support](#) page on our website for more information.

For the current procedure for returning product go to the website and under Support look for [RMA](#).

Appendix C

Calibration

Dataray offers annual recalibration on all BeamMap2 and Beam'R2 products. Contact the factory or your local distributor for current pricing.

Calibration is based upon:

1. Averaging across multiple periods of a Ronchi ruling with a NIST traceable period.
2. Movement of the centroid measured by the instrument as compared with a micron resolution digital micrometer.

BeamMap2 series: Annual recalibration is offered but is not considered necessary unless the head has been damaged. The only moving part is the puck on a stepper motor. The ball bearing motor is good for 5 years continuous operation, and to date we have yet to see a system where motor wear is an issue. The calibration is held in an EEPROM in the head. More detail is available at the website.

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