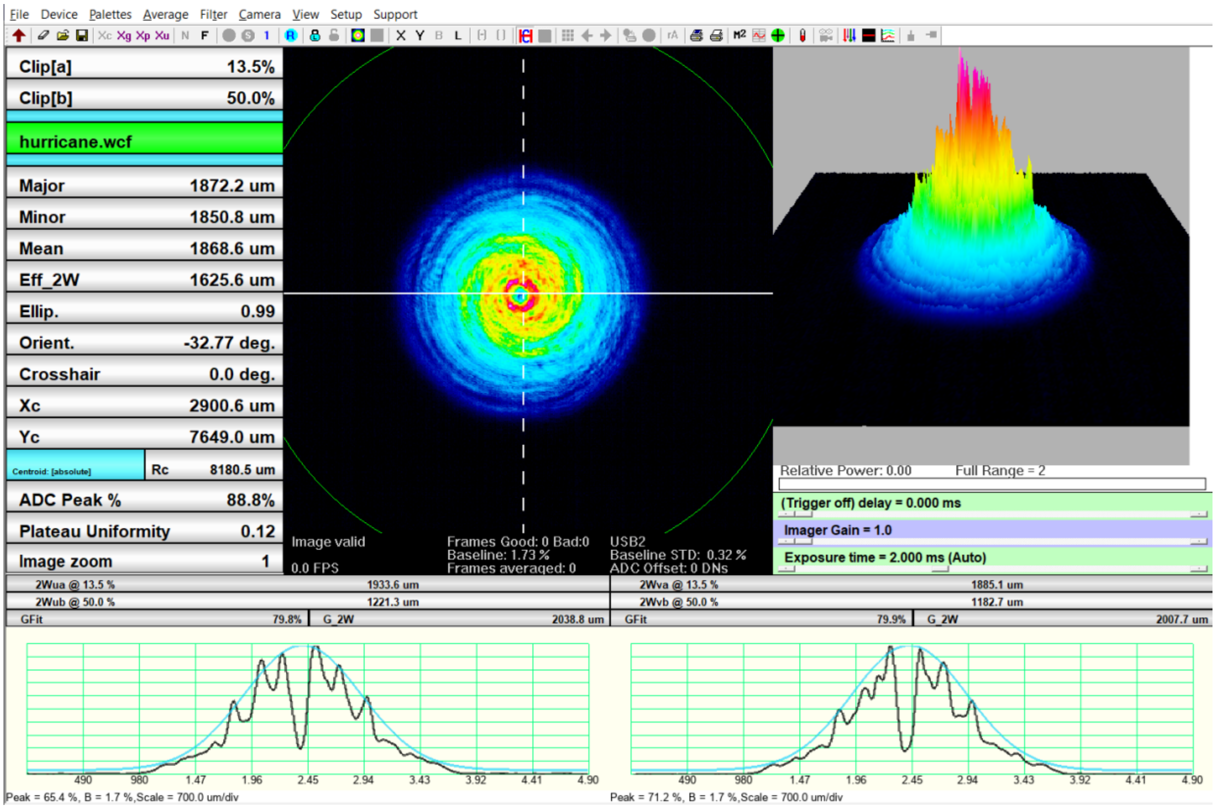
Beam Profiling Camera User Manual



Contents

List of Figures

List of Tables

Manual and Copyright Notice

This manual describes operation of BladeCam2, TaperCamD, and WinCamD Series cameras. We reserve the right to make changes to this manual and to the instruments described herein without notice. We have taken considerable effort to ensure that information in this manual is accurate and complete. However, we will not be liable for technical or editorial errors, omissions, or for any incidental, special or consequential damages of any nature resulting from the furnishing of this manual, or from the operation and performance of the instruments described herein.

Chapter 0

Very Important

Read this entire section first

- **Register** your product at https://dataray.com/resources/product-registration
- **Very Quick Start**
  1. Minimum PC requirements? See Section 3.
  2. Install the software before connecting the camera from included USB drive or from the website.
  3. Connect USB cable to profiler using locking screws where available. Connect the camera to your PC, preferably to a USB 3.0 port of any compatible device.
  4. **Start the software**. Depending on the profiler, the camera LED will go from red to green. If it stays red, the port is not reporting itself as USB 3.0/2.0. In the pull-down menu verify **Device** shows **WinCamD:**. If the software detects the camera type. Remove the dust cap.
  5. Press Go G to begin capturing data. Measurements will update live. The text color will be black for measurements that are suspected by the software to be valid or orange if they are suspected to be invalid.
  6. To avoid camera damage, **observe the power/energy limits** described in section 1. Damaged image sensors are replaceable but at customer expense.
- **Centering**. Stay within the imaging area for accurate measurements. If energy spills outside the imaging area, erroneous measurements may result.
- **Save files for future reference**: Press Stop S , then in the top menu bar choose **File** → **Save** → **Save Current Data as WCF** to save the current single profile/image. Or choose **Save all data in data buffer as WCF** to save the entire data sequence, particularly if you are seeing instability. The saved file (*.wcf format) includes setup data and image data, so it can be opened again on any PC to display the data exactly as seen when saved.

- TaperCamD, Industrial Laser Monitoring System (ILMS), Large Beam Profiling System (LBPS), LensPlate2 (LP2), UV converter, or CamIR adapter: Click **Setup** → **Capture Setup Dialog** and confirm the **Pixel Multiply Factors** (**PMF**) are set to the appropriate values printed on the profiler and/or included calibration sheet. In some cases, only one PMF value is provided, in which case the **Y=X** box should be checked.

- **Help us help you.** If you are getting strange results, e.g. corrupted screen layout, press Stop. In the menu bar, choose **File** → **Load defaults** to reset to default settings. You may also restart the software. If the problem persists, save a ***.wcf** file (see above) and email it to support@dataray.com or to your distributor. Include your commentary and the S/N found on your camera. You may then wait for an answer or call support at +1-831-215-2200, Option 2.

- By default, all BladeCam2 and most WinCamD cameras come with the sensor window removed. See Appendix B for instructions on cleaning the ND filter and, *in extreme situations*, the sensor chip.

- **Read the manual**. Please familiarize yourself with each section of the manual. Reading the manual will allow you to properly and fully use the beam profiler and software features.

- **Software Bugs?** We attempt to deliver bug-free software, but it is difficult to test all permutations and combinations of beam size, capture block, processing option, etc. Some error messages are warnings only. Some require the software to be restarted. Take a screenshot (**Alt PrtSc** to put the message to the Windows internal clipboard). Then press **OK** and see whether you can continue to use the software.

- **Additional Information**. Our website provides additional documentation including many Application Notes and blog posts that may be helpful.

- **If you have a problem**, please note the details. *Wherever possible* capture a relevant ***.wcf** data file, and email the file along with the details of the PC, the problem, and the camera S/N to support@dataray.com. We will attempt to resolve the issue as soon as possible.

Chapter 1

Introduction

Welcome to the world of laser beam profiling. DataRay's innovative products set the standard for state-of-the-art, feature-rich, real-time, camera-based beam profiling in compliance with ISO 11146. They serve as powerful tools for research and development, quality assurance, and process design, combining intuitive, easy-to-use software with proven beam-profiling algorithms.

This manual covers all DataRay camera beam profilers including the WinCamD, BladeCam2, and TaperCamD series of products. This manual also pertains to all specialized systems that utilize WinCamD profilers such as the Large Beam Profiling System (LBPS), Industrial Laser Monitoring System (ILMS), and Line Laser Profiling System (LLPS).

Visit our website for the most recent versions of software, manuals, application notes, specifications, and other documentation. You will find download links for the latest version of the software for free here.

Need something you don't see? Many software features are based on customer feedback. If you need a software feature that is not currently offered, our team can work with you to determine if it can be added or if a workaround exists. Please contact us at support@dataray.com for more information.

About WinCamD, TaperCamD, and BladeCam2 Series

WinCamD, TaperCamD, and BladeCam2 profilers are state-of-the-art, real-time, USB or GigE cameras optimized for beam profiling.

These profilers use high-resolution CMOS, quantum dot, or microbolometer sensors with small, square pixels. BladeCam2 and CMOS WinCamD models offer windowless sensors to prevent fringing while the WinCamD models with quantum dot sensors (WinCamD-QD series), offer a wedged window to mitigate fringing. TaperCamD profilers use an optical taper mounted directly to the sensor to effectively increase the sensor active measurement area.

WinCamD profilers are also the heart of other specialized systems including the Large Beam Profiling System (LBPS), Industrial Laser Monitoring System (ILMS), and Line Laser Profiling System (LLPS).

System Configuration and Description

WinCamD, BladeCam2, and TaperCamD profiling systems are shipped ready to install on any PC with the minimum requirements (see Section 3) and consist of the following components:

- **Camera beam profiler**

- **Cable:** Screw-locking 3 meter USB 3.0 cable (longer cables up to 5 meters are possible with extensions, or 25 meters with booster cables/hubs). GigE cameras will include an Ethernet cable.

- **Power Supply:** WinCamD-QD series profilers and GigE profilers include a power supply. Other profiling systems use a single USB cable for power and data.

- **USB drive:** Includes software, manual, and documentation. For WinCamD-QD profilers, the USB drive also includes critical calibration files that must be installed (see Section 3).

- **Neutral Density (ND) Filters:** Standard OD = 1, 2, and 4 filters included with most WinCamD, BladeCam2, and TaperCamD profilers. WinCamD-IR-BB only includes an OD = 1 and 2 filter.

The user can:

- Define the **Capture Block**, the area of the sensor from which the data should be taken.
- Use **Fast** mode —half of **Full** resolution— for large beams and initial alignment.
- Automatically set the correct exposure time for CW lasers.
- Vary the pre-ADC gain for pulsed lasers.
- Accept an external trigger or output a trigger to a pulsed laser via the BNC/SMB port (if using a profiler with an external trigger port).
- Automatically synchronize to the pulses from lasers with a Pulse Repetition Rate (PRR) between 100 Hz and $\sim$25 kHz.
- Advance or delay the capture timing with respect to an external trigger.
- Process and log acquired images.

Calibration

Dimensional beam calibration of a WinCamD or BladeCam2 Series profilers is an intrinsic calibration based upon the traceable precision of sensor photolithography. The nominal dimensions of the chips and pixels are used in all calculations. The accuracy is believed to be much better than $\pm$ 0.5%, and probably better than 0.1%. Calibration and certificates are available upon request.

Camera Profiler Product Specifications

Specifications apply to all cameras in the series unless otherwise noted, and are subject to change without notice. For the specifications relating to the WinCamD-LCM, WinCamD-GCM, WinCamD-QD, and WinCamD-IR-BB see Table 1.1. For the specifications relating to the BladeCam2-HR, and the BladeCamd2-XHR see Table 1.2. Finally, for specification relating to the TaperCamD-LCM see Table 1.3. For appropriate wavelengths ranges of these products, see Table 1.4. For a list of the measurements that can be made with DataRay cameras and software, see Table 1.5. For more information about camera hardware and mounting, see Table 1.6. Finally, drawings and models of each profiler are available in Appendix C.

Specification	WinCamD-LCM	WinCamD-GCM	WinCamD-QD	WinCamD-IR-BB
Image Area (mm):	11.3×11.3		9.6×7.7 19.2×15.4 (L) 28.8×16.2 (XL)	10.8×8.2
Sensor:	1" CMOS		1/1.8" QCD	2/3" Microbolometer
Resolution:	2048×2048		640×512 1280×1024 (L) 1920×1080 (XL)	640×480
Pixel Count (MPixel):	4.2		0.33 1.3 (L) 2.1 (XL)	0.31
Pixel dimensions: (μm):	5.5×5.5		15×15	17×17
Wavelength range:	355 - 1150 nm		400 - 1700 nm (QD-1550) 350 - 2000 nm (QD-2000)	2 - 16 μm
Interface:	USB 3.0 Port-powered	GigE Vision with PSU	USB 3.0 or GigE with PSU	USB 3.0 Port-powered
CW or Pulsed:	CW, Pulsed			CW, Pulsed (PRR > 1 kHz)
Shutter type:	Global			Rolling
Single pulse capture PRR (kHz):	12.6		3.3	N/A
Min. beam diameter (10 pixels, μm):	55		150	170
Max. frame rate (Hz):	60		25	7.5 (International) 30 (United States)
Signal to RMS Noise:	2,500:1		$\geq$2100:1	$\geq$1000:1
Electronic Shutter Dynamic Range:	USB 2.0: 12,600:1 (41 dB) USB 3.0: 25,000:1 (44 dB)	50,000:1 (47 dB)	100:1 (20dB)	Fixed Exposure

Specification	WinCamD-LCM	WinCamD-GCM	WinCamD-QD	WinCamD-IR-BB
ADC:	12-bit	14-bit	16-bit	14-bit
Opt./Elec. dB:	34/68		33/66	30/60
Max full frame rate (Hz):	∼12.5		25	7.5 (International) 30 (United States)
Max. 'every pulse' PRR (Hz):	≥12.5		25	N/A
Beam Diameter Accuracy:	±2%			

Table 1.1: The product specifications for the WinCamD-LCM, WinCamD-GCM, WinCamD-QD, and WinCamD-IR-BB.

Specification	BladeCam2-HR	BladeCam2-XHR
Image Area (mm):	6.6×5.3	6.5×4.9
Sensor:	1/2″ CMOS	1/2″ CMOS
Resolution:	1280×1024	2048×1536
Pixel Count (MPixel):	1.3	3.1
Pixel dimensions: (μm):	5.2×5.2	3.2×3.2
Wavelength range:	355 - 1150 nm	
Interface:	USB 3.0 Port-powered	
CW or Pulsed:	CW and Quasi-CW (PRR $\sim$>50kHz)	
Shutter type:	Rolling	
Single pulse capture PRR (kHz):	NA	
Min. beam diameter (10 pixels, μm):	52	32
Max. frame rate (Hz):	20+	
Signal to RMS Noise:	1,000:1	
Electronic Shutter Dynamic Range:	12,500:1 (41dB)	25,000:1 (44 dB)
ADC:	10-bit	10-bit
Opt./Elec. dB:	30/60	
Max full frame rate (Hz):	$\geq$9	$\geq$6
Max. ‘every pulse’ PRR (Hz):	N/A	
Beam Diameter Accuracy:	±2%	

Table 1.2: Product specifications for the BladeCam2-HR and BladeCam2-XHR.

Specification	TaperCamD-LCM
Image Area (mm):	25×25
Sensor:	1” CMOS
Resolution:	2048×2048
Pixel Count:	4.2 M Pixel
Effective Pixel dimensions (μm):	12.5×12.5
Wavelength range:	355 - 1150 nm
Interface:	USB 3.0 Port-powered
CW or Pulsed:	CW, Pulsed, Auto Trigger
Shutter type:	Global
Single pulse capture PRR:	USB 2.0: 6.3kHz USB 3.0: 12.6kHz
Min. beam (10 pixels)(μm):	125
Max. frame rate (Hz):	60+
Signal to RMS Noise:	2,500:1
Electronic Shutter Dynamic Range:	USB 2.0: 12,600:1 (41 dB) USB 3.0: 25,000:1 (44 dB)
ADC:	12-bit
Opt./Elec. dB:	30/60 dB
Max full frame rate:	$\sim$12
Max. ‘every pulse’ PRR (Hz):	$\geq$12.5

Table 1.3: The product specifications for the TaperCamD-LCM.

Camera Option	Wavelength Range
WinCamD-LCM, WinCamD-GCM, BladeCam2	355 - 1150 nm
-UV*	190 - 1150 nm. Includes Reflective filters for use from 190 - 355 nm
-1310*	355 - 1350 nm. Residual silicon response. Includes long pass filter to block ambient light.
-TEL*	1480 - 1610 nm. IR Phosphor coating. 10% non-uniformity. 40 μm FWHM
UV Converter	Converter for λ <355 nm are available from DataRay with options down to X-ray.
CamIR Adapter	1480 - 1610 nm. IR Phosphor. 10% non-uniformity. 180 μm FWHM

*When ordering, add suffix to WinCamD-LCM, WinCamD-GCM, and BladeCam2 part numbers to expand wavelength range.

Table 1.4: Shows the wavelengths that can be covered by various cameras, camera options, and accessories.

Measured and Displayed	Descriptions
Profile parameters	Raw and smoothed profiles Triangular running average filter up to 10% FWHM
Beam diameter	Diameter at two user-set clip levels Gaussian and ISO 11146 Second Moment beam diameters Equivalent diameter above a user defined clip level Equivalent slit and jnife Edge diameters
Beam fits	Gaussian and top hat profile fit and percent fit Equivalent slit profile
Beam ellipticity	major, minor, and mean diameters. Auto-orientation of axes.
Centroid position	Relative and absolute Intensity weighted centroid and geometric center Beam wander display and statistics
Pass/fail display	On-screen selectable pass/fail colors. Ideal for QA and production.
Log data and statistics	Min., max., mean, standard deviation. Up to 4096 samples (to be added shortly)
Relative power measurement	Rolling histogram based on user's initial input. Units of mW, μJ, dBm, (relative to a reference measurement input)
Fluence	Fluence within user defined area

Table 1.5: Parameters and values that are measured with DataRay software.

Physical Dimensions	BladeCam2-HR/XHR	46.0×46.0×12.8 mm
	TaperCamD-LCM	57.2×57.2×54.0 mm
	WinCamD-LCM	46.0×46.0×20.7 mm
	WinCamD-GCM	72.6×72.6×54.2 mm
	WinCamD-QD	61.0×61.0×100.9 mm
	WinCamD-IR-BB	73.0×73.0×51.9 mm
Sensor Depth (Approx.)	BladeCam2-HR/XHR	5.25 mm
	TaperCamD-LCM	7.5 mm (taper depth)
	WinCamD-LCM	7.5 mm
	WinCamD-GCM	8.5 mm
	WinCamD-QD	17 mm (with c-mount flange), 7 mm (without)
	WinCamD-IR-BB	15.5 mm
Mass	BladeCam2-HR/XHR	85 g (3.0 oz)
	TaperCamD-LCM	387 g (13.7 oz)
	WinCamD-LCM	100 g (3.5 oz)
	WinCamD-GCM	272 g (9.6 oz)
	WinCamD-QD	407 g (14.4 oz)
	WinCamD-IR-BB	422 g (14.9 oz)
Mounting	BladeCam2-HR/XHR	#6-32 threaded holes
	TaperCamD-LCM	1/4”-20 threaded holes
	WinCamD-LCM	#8-32 threaded holes
	WinCamD-GCM	1/4”-20 threaded holes
	WinCamD-QD	1/4”-20 threaded holes and M3x0.5 threaded holes
	WinCamD-IR-BB	1/4”-20 threaded holes

Table 1.6: Specifications on BladeCam2 and WinCamD products and mounting.

Saturation Power/ Energy

Measure your beam with a calibrated power or energy meter before aiming it at your profiler. Beware of back reflections from ND filters or the profiler sensor surface. Always employ appropriate eye protection.

ND filter or sensor damage may occur if:

- Beam power exceeds the recommendations in this chapter.
- Beam power exceeds the recommended values in the DataRay Attenuation Calculator (calculator instructions can be found here starting on page 5).
- Beam Power > 1 W

However, the limit is lower for some pulsed lasers (especially nanosecond and femtosecond lasers). Use Fig. 1.2 or the DataRay Attenuation Calculator to determine estimates for wavelengths other than those shown in Fig. 1.1. The variation is due to a combination of detector response versus wavelength and ND 4.0 filter actual transmission versus wavelength. For additional information on attenuation, see Chapter 5.

Above the saturation limits, the profiler will no longer provide valid results. DataRay does not recommend operating above the saturation limits outlined in this section.

CW Lasers

Fig. 1.1 shows saturation optical power that the standard camera configuration with ND4 filter can measure versus beam diameter and wavelength. The **Saturation Limit** assumes:

- The ND 4.0 filter is in place.
- The electronic shutter is set at 40 μs.
- The gain is set at 1.

Additionally we can use the Saturation Limit to define the Lower Limit

$$\text{Lower Limit} \approx \left(5 \times 10^{-3}\right)\left(\text{Saturation Limit}\right). \tag{1.1}$$

Pulsed Lasers

See Chapter 6 for instructions on pulse laser capture. It may also be helpful to review the blog articles below.

- Pulsed Lasers and Auto-Trigger Mode
- Pulsed Lasers and External Trigger Mode
- Pulsed Lasers: Pulse Energy & Imager Gain

Generally, for pulsed beams:

- PRR > 25 kHz: Treat the laser as CW based on the mean power (for example mJ/pulse x PRR), then consult Fig. 1.1, Fig. 1.2, or the attenuation calculator.

- PRR ≤ 25 kHz: Consult Fig. 1.3, Fig. 1.2, or the attenuation calculator.
- To avoid multiple pulse capture, set the Exposure time at 0.95/PRR.
- If you set an Exposure time $>$1/PRR, you will capture more than one pulse and the saturation limit will reduced in proportion to the number of pulses captured.

The **Saturation Limit** assumes:

- The ND 4.0 filter in place.
- Single pulse capture with the electronic shutter set at < 0.95/PRR.
- The gain is set at 1.

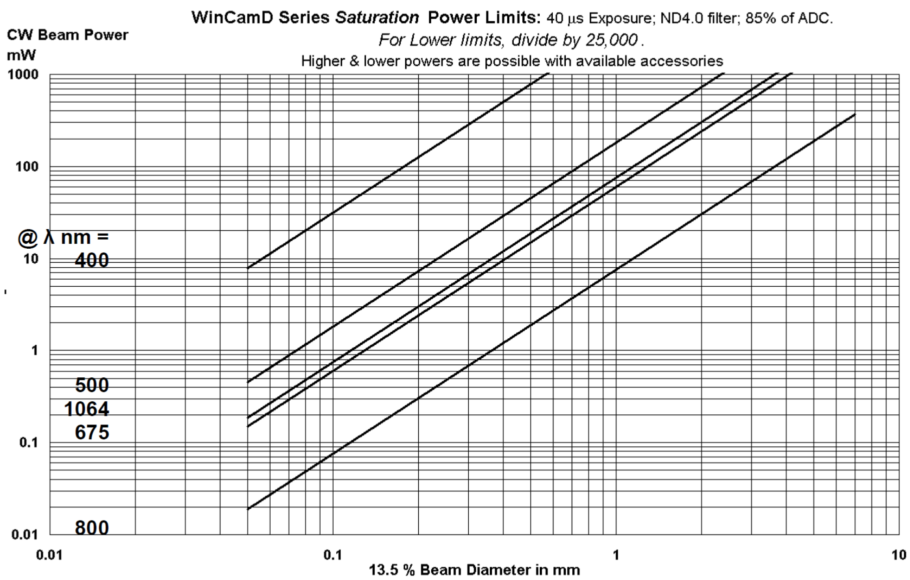


Figure 1.1: Graphs for WinCamD-UCD12. Other sensors will be within a factor of 2.

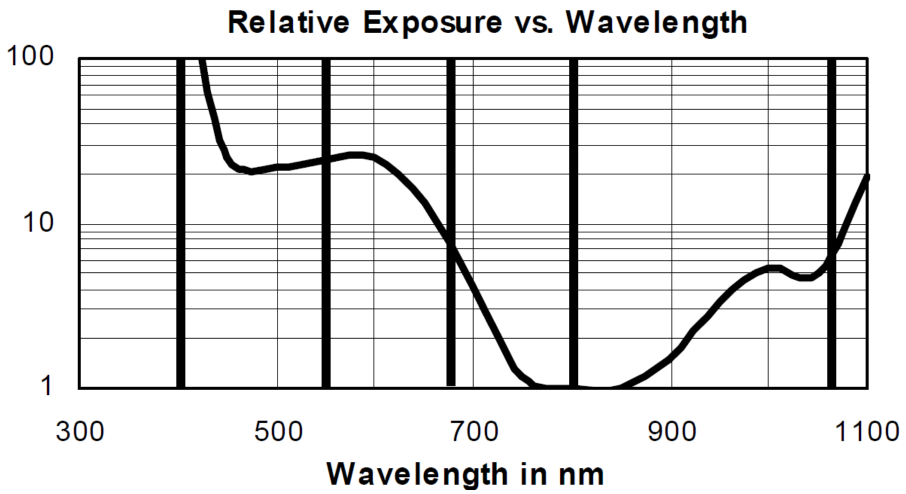


Figure 1.2: Graphs for WinCamD-UCD12. Other sensors will be within a factor of 2.

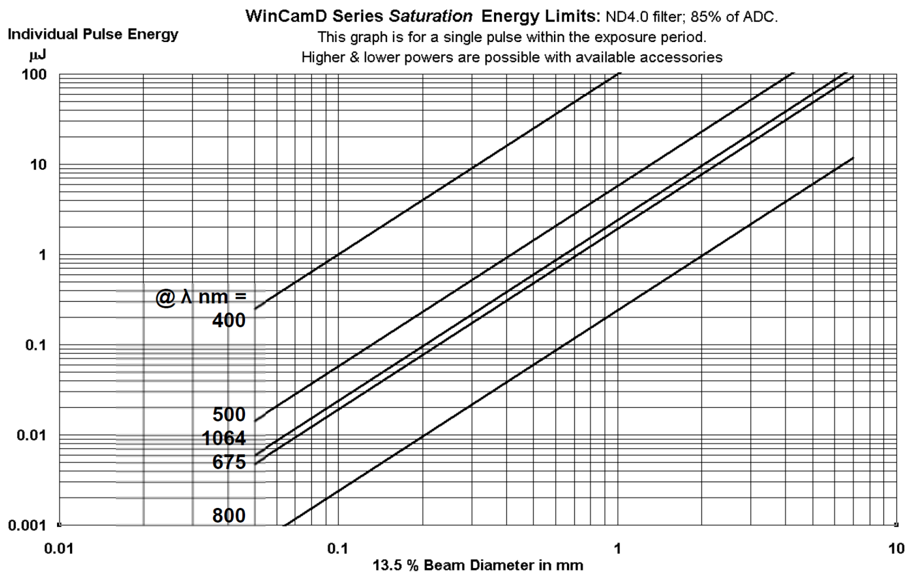


Figure 1.3: Graphs for WinCamD-UCD12. Other sensors will be within a factor of 2.

The -1310 versions of the cameras come with a long pass IR filter which has:

- < 0.1% transmission at $<\sim 1240$ nm
- ~ 50% transmission at ~ 1250 nm
- > 97% transmission from $>\sim 1283$ nm to ~ 2200 nm

Thermal Lensing

In addition to the power limit to avoid ND filter damage, there is also a power limit to avoid thermal lensing. Thermal lensing occurs when the energy from the laser absorbed by the ND filter glass is enough to cause a change of temperature in the material. Since the refractive index of the ND filters is slightly temperature dependent, the temperature gradient can induce a thermal lensing effect. To avoid the thermal lensing effect, we recommend not exceeding $1W/cm^2$ through the ND filter.

Chip Surface Height-Standard and Options

While the standard WinCamD-LCM has a sensor depth of 7.5 mm below the front case, options are available to move the sensor closer to the surface of the profiler, especially useful for profiling highly divergent beams. Add **-S1** or **-S1.5** to the WinCamD-LCM part number for sensor depths of 5 mm or 2.5 mm below the front case, respectively (for example, part number WinCamD-LCM-S1). Add **-S2** to the WinCamD-LCM part number for a sensor that protrudes approximate 0.9 mm from the front case. There is an additional charge for these options.

Keep in mind, c-mount filters are only compatible with standard and S1 versions. For S1.5 and S2 versions, the sensor will interefere with c-mount accessories. ND filters for the S2 version must be mounted separately from the camera to accommodate the protruding sensor.

TaperCamD Taper Information

The TaperCamD series uses an optical taper mounted directly to the camera sensor to increase the sensor active area to 25 x 25 mm. Tapers are fused coherent fiber bundles, heated, drawn round to rectangular, and polished to give an output end the size of the imager chip. The image is demagnified (M< 1) from the faceplate input to the imager end.

- NA at the imager end is 1.0; NA at the input faceplate is a factor of M smaller.
- Individual fibers at the input end are 6 um pitch with a 50% core/cladding area ratio.
- Refractive index is 1.81, leading to a front surface reflectivity of 8.3%.
- These taper ends are bonded to the surface of the imager chip.
- These tapers do not transmit in the UV. They have low transmission (TBA) at 355nm.

Phosphor coated sensors (-TEL)

DataRay offers -TEL versions of our CMOS and CCD sensors that include a phosphor coating directly applied to the sensor. This coating converts IR to visible light to produce an economical solution to profiling beams in the Telecom C & L bands. BladeCam2-HR-TEL and WinCamD-LCM-TEL are economical alternatives to expensive InGaAs cameras for the TEL wavelengths 1480-1610 nm. The granular nature of the phosphor coating introduces a $\approx$25 µm FWHM point spread function, increasing the minimum beam size to $\approx$250 µm. Phosphor coatings also may contain minor defects that should not significantly affect parameters calculated by the software.

- 1480 to 1610 nm, IR to visible conversion phosphor on Silicon CMOS sensor
- $\approx$25 µm FWHM point spread function due to phosphor
- Sensitivity down to 20 µW for 1 mm diam. 1550 nm

- Gamma (γ) correction is included in the software.
  - The phosphor provider recommends setting Gamma = 2.0
- Comes with 3 ND filters and a 1290 nm long pass filter to block ambient light

Beam Limits

Beam Measurement Region

For accurate beam measurement, the beam must lie totally within the area shown in Table 1.7. For the most accurate measurements on the TaperCamD-LCM, center the beam fairly well. For true 4σ (Variance) measurement to the ISO 11146 standard, a Gaussian beam diameter at the 13.5% clip level, should be a maximum of 55% of the imager size.

Camera	Image Area (mm)	Actual Image Area
BladeCam2-HR	6.6×5.3	
BladeCam2-XHR	6.9×4.9	
WinCamD-LCM	11.3×11.3	
WinCamD-GCM	11.3×11.3	
WinCamD-QD (Standard)	9.6×7.7	
WinCamD-QD (-L Versions)	19.2×15.4	
WinCamD-QD (-XL Versions)	28.8×16.2	
WinCamD-IR-BB	10.8×8.2	
TaperCamD-LCM	25×25	

Table 1.7: List of cameras with their respective sensor sizes.

Chapter 2

WinCamD Series Quick Start Guide

Precautions and Safety Warnings

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

- Always look-up or 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.
- Be aware of the laser beam path and its reflections. Where appropriate use beam blocks and wear proper eye protection for the wavelength being analyzed.

Installation and Initialization

- Download and install the latest software for your camera from DataRay's website or included USB drive.
- Connect the profiler to the workstation using the included USB 3.0 cable (or Ethernet cable if using a GigE profiler).
- If using a WinCamD-GCM or WinCamD-QD, plug in the power supply.
- Open the DataRay application.
- Turn on the beam source.

Configuration

- From the DataRay application menu bar click **Setup** ⟶ **Capture Setup Dialog** or press **Alt + S**. A sample profile of your beam will be displayed (see Fig. 2.1). The capture block is the square/rectangular shape within this frame (with squares in each corner). If the capture block size matches the maximum pixel dimensions, the capture block edges will coincide with the edges of the frame.
- Orient the capture block by dragging it until the beam is centered.

- Resize the capture block by changing the **camera pixels** resolution. The corners of the capture block (shown as yellow boxes in Fig. 2.2a) should be entire dark. If the corners of the capture block are illuminated, increase the **camera pixels** resolution.

  NOTE: A baseline intensity calculation is made by averaging the intensity across these sample regions, so they must remain dark.

- Select the desired **Capture Resolution**. **Full** resolution returns every pixel. **Fast** resolution returns every other pixel on both the x and y axes (thereby returning only one fourth of the total pixels). **4X BINNING** bins each 4x4 square of pixels into a single value. While **Fast** mode can increase frame rate, **4X BINNING** is performed in software and does not. It should be used when trying to reduce the amount of data being processed.

- Select **OK** and return to the main window.

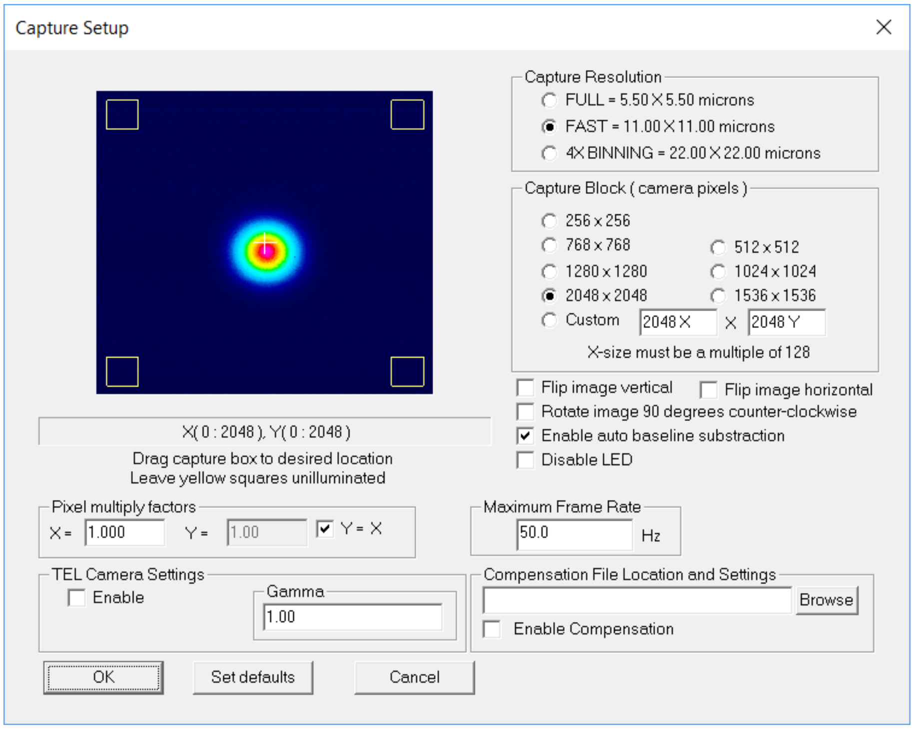


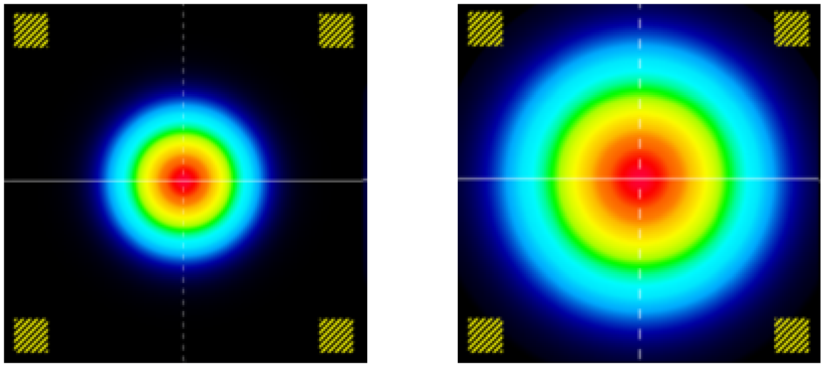
Figure 2.1: Capture setup dialog box.

Capturing Live Stream or Single Image

DataRay software allows capture of a single frame of data or a buffered series of frames. The duration of each frame is controlled by the exposure time slide bar in the main window. Exposure time is automatically adjusted by default. To disable automatic adjustment right click the exposure time button and deselect **Enable auto exposure adjustment**.

- Press **F1**, click the green **Ready** button, or click the **Green Start Capture** button (see Fig. 2.3a) to begin Live Stream capture.

- Press **F2**, click the green **Running** button, or click the **Red Stop Capture** button (see Fig. 2.3b) to stop the capture



(a) (b)

Figure 2.2: (a) Proper size and location of beam. (b) Capture block too small.

(a) (b) (c)

Figure 2.3: Menu buttons for capturing a live stream or a single image.(a) The green button is used to start capture, while the "1" captures a single image. (b) The red button is used to stop capture. (c) The array button is used to show the all of the images in the Live Stream buffer. The two arrows allow the user to step through the Live Stream buffer image one image at a time.

process.

- Press the **Capture Single Image** button (denoted by a "1," see Fig. 2.3a and Fig. 2.3b) to capture a single frame of the current profile.
- The Live Stream buffer can be accessed using the buttons shown in Fig. 2.3c. The left and right arrows cycle through frames in the buffer, while the grid view allows you to view all the frames in the buffer simultaneously, selecting the frame you wish to see in more detail.

Saving Data

The complete buffer, partial buffer, or a single frame of the current DataRay Live Stream can be saved in the WinCamD File Format (.wcf) by pressing **Ctrl + S** or clicking **File** ⟶ **Save** and selecting the desired option. The Current Frame data can also be saved as 8 or 16 bit TIFFs .

Data Points

DataRay software captures the beam profile with clip level measurement by default. Click **Setup** ⟶ **ISO 11146 compliant diameters and angles** if ISO 11146 compliant measurements are desired. For more information on beam diameter definition, see Appendix 7

Profiling Modes

Any data displayed in orange is considered unreliable and invalid. This is due to one or more of the following:

- Turned on but not done initializing
- ADC saturation
- Input signal below threshold
- Improper capture block size.

If the text does not turn black (denoting valid data) after a few moments, recheck configuration as outlined in Section 2. A chart with the application's different buttons (which display relevant calculations and data) can be seen in Table 2.1.

2D View Data

The 2D View section shows an image of the sensor as well as nine data points about the current status (see Table 2.3).

Profile Display

The Profile Display shows the power intensity and gives data about each crosshair axis (see Fig. 2.4). The **u** axis is the solid crosshair axis, while the **v** axis falls along the dotted crosshair axis. Specific data is listed alongside these graphs (see Table 2.4). Right clicking on the graphs allows independent modification

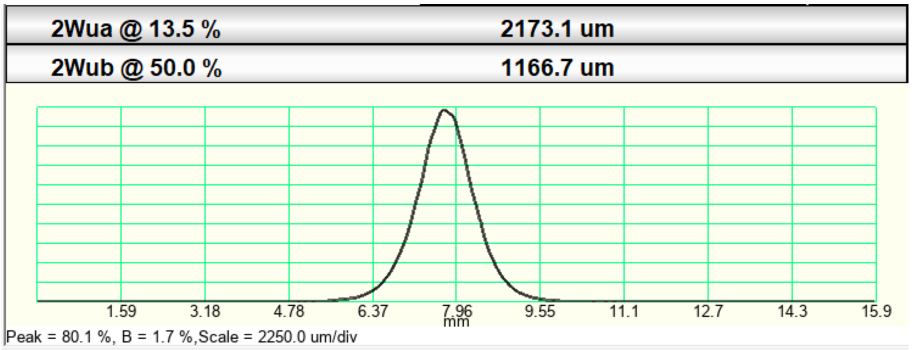


Figure 2.4: Axis Profile. For a detailed explanation of each message see Table 2.4

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Further Support

For further information, as well as documentation on the BladeCam2, TaperCamD, and WinCamD series of cameras, visit our website. For support, email DataRay at support@dataray.com or call +1-831-215-2200, Option 2.

Button	Description
Clip[a]/Clip[b]	**Clip levels** (percentage) compare the intensity of a pixel to the peak intensity to determine the cutoffs for the beam diameters **2Wa** (**Clip[a]**) and **2Wb** (**Clip[b]**).
Camera Status	The current camera status, either **Not Present**, **Ready**, or **Running**. Clicking on a **Ready** or **Running** head status will start and stop sampling.
Major/Minor	**Minor** The data is first clipped at **Clip[a]** and then the ISO 11146 method used to determine the orientation of the beam. Once the orientation has been found, the diameter of the beam along the **Major** and **Minor** axes is determined using the clip level method (see APPENDIX 7.
ISO-Maj / ISO-Min	**Major** and **Minor** diameters calculated according to ISO 11146. These are not shown outside of ISO 11146 mode.
Mean	**Mean** is the mean diameter of the beam, based on the Major and Minor diameter. The Major and Minor diameters are weighted in the calculation such that the mean is also valid for elliptical beams. $$Mean = 0.83114 * (\text{Major Diameter}) + 0.16886 * (\text{Minor Diameter}) \quad (2.1)$$
Eff_2W	$= \sqrt{\frac{4N_pA_p}{\pi}}$ where N_p is the number of pixels with an intensity above a set clip level (13.5% default) and A_p is the pixel area. In the **Setup** menu, choose **Enter Effective Width cliplevel** to change the clip level from its default value of 13.5%.
Ellipse	Ellipticity = **2W**[**minor**] / **2W**[**major**].
Orientation	The angle between the horizontal x-axis and the **major** or **minor** axis closest to the horizontal x-axis.
Crosshair	The angle between the horizontal x-axis and the solid crosshair line.

Table 2.1: Descriptions of the various result buttons.

X_c, Y_c **X_g, Y_g** **X_p, Y_p** **X_u, Y_u**	Location of the crosshair center (μm) in Cartesian coordinates from the center of the full sensor. There are four different modes available to determine the crosshair position. **X_c** (default) uses the weighted intensity of the pixels. **X_g** sets the position to the geometric centroid of all points whose intensity falls above the geometric clip level. **X_p** sets the position to the pixel with the highest intensity. **X_u** sets the position to a user selected coordinate; this is chosen by mouse click and can be refined using arrow keys.
R_c **R_g** **R_p** **R_u**	Radial distance from the center of the full sensor to the center of the current crosshair position. There are four different modes available to determine the crosshair position. **X_c** (default) uses the weighted intensity of the pixels. **X_g** sets the position to the geometric centroid of all points whose intensity falls above the geometric clip level. **X_p** sets the position to the pixel with the highest intensity. **X_u** sets the position to a user selected coordinate; this is chosen by mouse click and can be refined using arrow keys.
Centroid	Clicking **Centroid** toggles the origin position for the crosshair center measurement between **[absolute]** and **[relative]** (only in **X_c** mode). **[absolute]** defines the origin as the center of the image, whereas toggling to **[relative]** sets the origin to the last crosshair center value recorded in **[absolute]** mode.
ADC Peak %	The image peak level as a percentage of the ADC range, determined as the peak value for the average of any 'L' shaped group of three pixels within the image. It represents the raw level, calculated before any background subtraction.
Plateau Uniformity	Value between 0 and 1 denoting how closely the beam resembles a theoretically perfect flat-top beam.
Image Zoom	The current 2D screen zoom.

Table 2.2: Descriptions of the various result buttons (continued).

Title	Description
Image validity	Denotes whether the image shown is valid or invalid.
Good/Bad Frame Count	The number of good and bad frames taken since sampling began.
HyperCal status	Shows whether HyperCal is turned on.
Baseline	The level of input power subtracted by the algorithm.
Baseline STD	Standard deviation of the baseline.
Frame Rate	The number of frames per second.
Frames averaged	The number of frames averaged.
ADC Offset	Adjustment to ADC input range for reduced noise in the output.

Table 2.3: Gives explanations behind the different descriptors in the 2D area.

Title	Description
2Wua 2Wub **2Wva 2Wvb**	The beam diameters **2Wa** and **2Wb** along the solid crosshair axis (**u**) and the dotted crosshair axis (**v**).
Scale (μm/div)	The scale of the current x-axis block division. Right click the graph and choose the desired zoom level (**1X** default) to adjust. Additionally, the cursor can be placed over the graph and **i** pressed to zoom in or **o** to zoom out. Hold down the mouse center button and move the cursor in the desired direction to pan left/right.
Peak = xx.x%	The peak value of a (unnormalized) profile as a percentage of the levels of the ADC range. There are 16384 levels for 14-bits, 1024 levels for 10-bits, and 65536 levels for the 16-bit CMOS. Cameras with less than 14 bits are bit shifted to fill 14 bits.
B = x.x%	The level of input power subtracted by the algorithm as a percentage of the peak.
Filter=0.2%	The baseline intensity level (percentage of peak) subtracted by the software.
Zero level	The zero level is calculated by taking the maximum filled level of the histogram of intensities below 25% of peak. Default mode is baseline subtraction. The zero level is displayed as a line placed slightly above the graph zero so that negative noise may still be seen.

Table 2.4: Explains the different text messages associated with the axis profile area (see Fig 2.4).

Chapter 3

Installation

Unpack the Hardware

Please locate and identify all items ordered. If any items appear damaged or missing or you have any other questions, please contact us. Camera beam profilers include the following:

- Camera profiler
- 3 meter USB 3.0 (or 1.5 meter Ethernet cable for GigE devices)
- USB drive with software, manual, and documentation
- Neutral density (ND) filters with most models
- For GigE and WinCamD-QD profilers, an external power supply
- For WinCamD-LCM, WinCamD-GCM, WinCamD-QD and TaperCamD-LCM profilers, a BNC trigger adapter

Now register your product on DataRay's website. A few notes:

- Some models include an SMB trigger port. This is not an analog video output.
- For both UV converters and CamIR adapters, remove any ND filters on the camera before attaching the converter/adapter. Then, ensure that the Pixel Multiply Factors (PMF) values on the converter/adapter label are entered in the **Capture Setup** dialog window (**Setup** → **Capture Setup Dialog**). In some cases, only one PMF value is provided, in which case the **Y=X** box should be checked.
- When using a LensPlate2, Industrial Laser Monitoring System (ILMS), Large Beam Profiling Systems (LBPS) or TaperCamD, ensure the Pixel Multiply Factors (PMF) values on the calibration certificate are entered into the the **Capture Setup** dialog window (**Setup** → **Capture Setup Dialog**). In some cases, only one PMF value is provided, in which case the **Y=X** box should be checked.
- Photographs, datasheets, and documentation are available on our website for the following products:

Profiling Systems:

- WinCamD-LCM / WinCamD-GCM
- BladeCam2-HR / BladeCam2-XHR
- TaperCamD-LCM
- WinCamD-QD
- WinCamD-IR-BB
- Industrial Laser Monitoring System (ILMS)
- Line Laser Profiling System (LLPS)
- Large Beam Profiling System (LBPS)

Profiling Accessories:

- Polarization Preserving Beam Sampler (PPBS)
- M2DU Automated Translation Stages
- CamIR Adapters / UV Converters
- Beam Reducers
- Lens Assemblies for M2 Measurements

Minimum Computer Requirements

- Windows Vista, 7, 8/8.1, 10, or 11 required. 32 and 64-bit are supported (WinCamD-GCM requires 64-bit). Additionally, USB 2.0 cameras will also run on Windows Vista.
- A 2 GHz Processor
- A processor or graphics card which supports OpenGL 3.1
- $\geq$ 1366 x 768 display with $\geq$256 colors. Software will run on smaller resolution displays, but some visual elements may be cut off.
- USB 3.0 / 2.0 port with 500 mA capability (the standard except on unpowered hubs).
- $\geq$1 GB of RAM.

Installation

IMPORTANT: INSTALL THE SOFTWARE BEFORE PLUGGING IN YOUR PROFILER.

You must install the software as an administrator. If you cannot install the software, the administrator may have restricted your software installation rights and must therefore be consulted before proceeding.

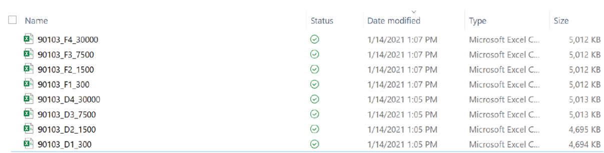
Software upgrades are free for the life of the product. The latest software is not necessarily the version that was originally included with your hardware. Visit our download page to check if a newer software version is available.

Installation Instructions:

1. Run the iDataRay.exe file (either from the included USB drive or downloaded from the DataRay website).

2. The driver should be installed by the software installer automatically.

3. **NOTE:** If installing a WinCamD-QD profiler, eight calibration files must be copied from the USB drive included with your profiler to the **My Documents\DataRay** directory. Each of the eight files should begin with the serial number listed on your profiler. These files are shown in Fig. 3.1 for serial number 90103. See the WinCamD-QD application note for more details.



Name	Status	Date modified	Type	Size
90103_F4_30000		1/14/2021 1:07 PM	Microsoft Excel C...	5,012 KB
90103_F3_7500		1/14/2021 1:07 PM	Microsoft Excel C...	5,012 KB
90103_F2_1500		1/14/2021 1:07 PM	Microsoft Excel C...	5,012 KB
90103_F1_300		1/14/2021 1:07 PM	Microsoft Excel C...	5,012 KB
90103_D4_30000		1/14/2021 1:05 PM	Microsoft Excel C...	5,013 KB
90103_D3_7500		1/14/2021 1:05 PM	Microsoft Excel C...	5,013 KB
90103_D2_1500		1/14/2021 1:05 PM	Microsoft Excel C...	4,695 KB
90103_D1_300		1/14/2021 1:05 PM	Microsoft Excel C...	4,694 KB

Figure 3.1: QD Calibration Files.

4. **For USB profilers:** Connect the camera by plugging the camera into a USB port. Follow the prompts provided by the **"New Hardware Found" Wizard**. When prompted, do not allow Windows to search the web for drivers. The driver should then install automatically. If the profiler does not install automatically, go to Section 3.

5. **For USB profilers:** To check that the device was correctly installed, go to **Device Manager** and click **+** next to **DataRay USB Devices**, then double-click the driver (see Fig. 3.2). If necessary, select **Drivers** and then click on **Update Drivers** to access the **Update Device Driver Wizard** again.

6. **For GigE profliers:** Consult our WinCamD-GCM application note for additional guidance and best practices.

NOTE: The software can be used to view data whether or not the camera is installed.

Connecting the Camera

Mounting the Camera

It is recommended that you mount the profiler before connecting it.

1. Most DataRay camera profilers utilize mounting holes in line with the sensor for easy alignment. WinCamD-GCM, TaperCamD-LCM, WinCamD-IR-BB, and WinCamD-QD all use $\frac{1}{4}$"-20 mounting holes. WinCamD-LCM series use #8-

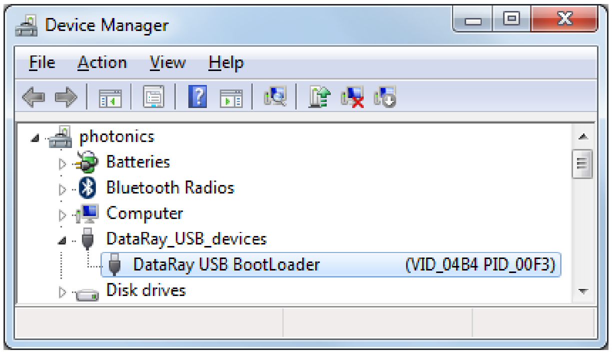


Figure 3.2: Device Manager and Installation.

32 threaded holes. BladeCam2-HR / BladeCam2-XHR use #6-32 threaded holes. Please consult individual product drawings for a full description of mounting options.

2. Since the active measurement area of some profilers is on the order of millimeters in size, ensure that the profiling system or the source assembly can be adjusted in x, y, and z as necessary. For LensPlate2 and the Industrial Laser Monitoring System (ILMS), tip and tilt adjustment may also be required for proper alignment.

3. If present, remove the protective cap covering the profiler aperture and install ND filters and attenuation accessories where needed. See chapter 5 for more information about attenuation.

Connecting the Camera

1. Start the PC.

2. **For USB profilers:** Connect the USB cable between the camera and the PC. For WinCamD-QD profilers, ensure the profiler is powered by the provided external power supply. Active repeater USB cables are required for cable lengths $>$5m [~16ft]. For options, please see our website.

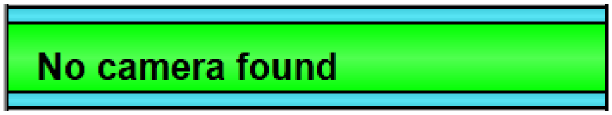
3. **For GigE profilers:** Ensure the device is powered with the included external power supply and connect the Ethernet cable between the camera and PC network adapter. Consult our WinCamD-GCM application note for additional guidance and best practices.

4. Open the software. The camera LED will sequence through to green. The software will automatically determine the camera type. To start taking data, click on the **Go** button, the green **Ready** button, or press **"F1"** or **"g"** on your keyboard.

5. If using a profiling system that requires Pixel Multiply Factors (PMF) such as a TaperCamD, Industrial Laser Monitoring System (ILMS), Large Beam Profiling System (LBPS), LensPlate2 (LP2), UV converter, or CamIR adapter, navigate to the **Capture Setup** dialog window to ensure the PMF values are entered correctly. This is accessed through **Setup** $\rightarrow$ **Capture Setup Dialog** or by pressing **Alt** + **S**.

NOTE: You can safely 'hot' plug or unplug the profiler without causing damage.

NOTE: If no camera is connected, the software will display the text **"No camera found"**. If the camera is connected to a USB 1.1 port or there is any problem with your USB port (e.g. low current), the LED will change to red and stay red. If using a USB hub, trying plugging the profiler directly into the PC USB port to rule out issues with the hub.



Firmware Upgrades

- **What is firmware?** Firmware is software code that resides in the hardware rather than running on the PC. Firmware updates may be required to improve performance, add features, or resolve issues.

- **How frequently are firmware updates released?** Firmware updates may be released after introduction of a new product or after a major software update. Subsequent firmware releases are generally uncommon events.

- **How do I know if a necessary firmware update is available?** Contact us for information on the newest firmware updates.

Chapter 4

Software

Main Screen Overview

This is the standard main screen configuration.

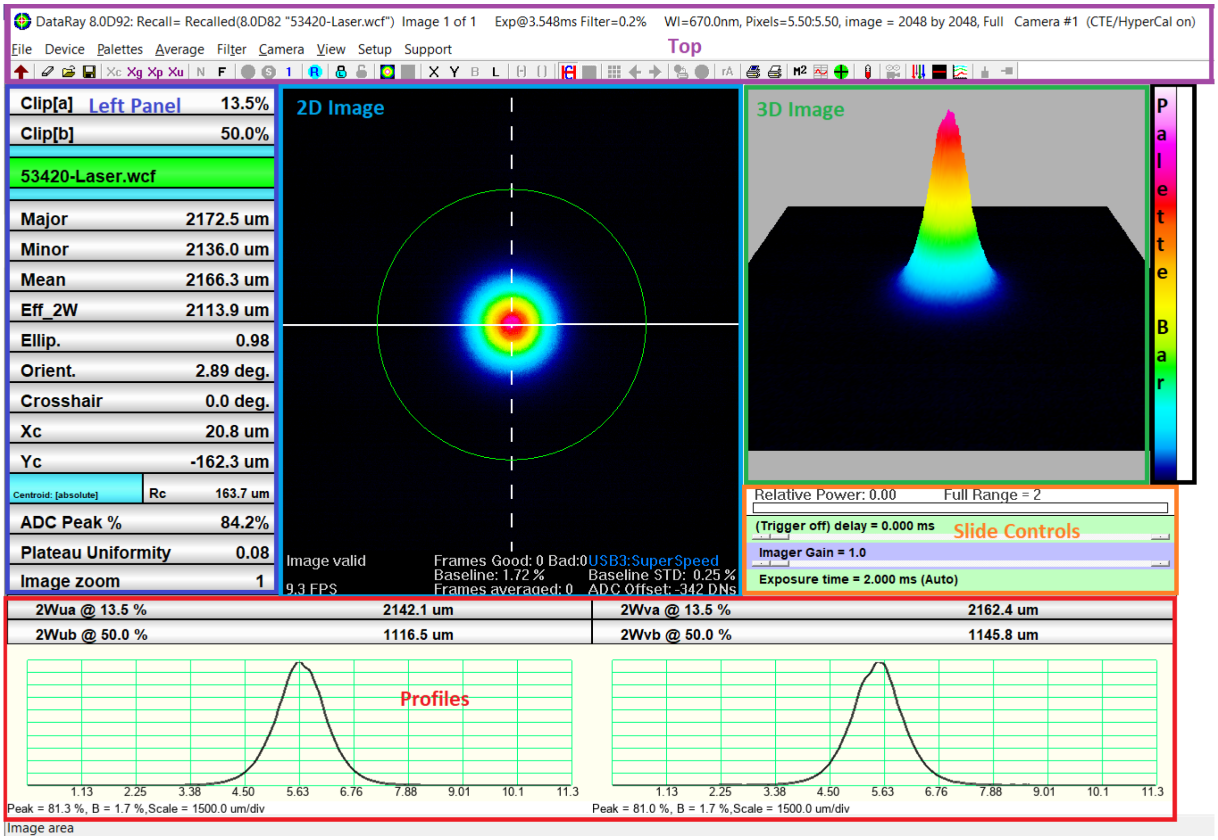


Figure 4.1: Note the seven areas: top, left panel, 2D Image, 3D image, palette bar, slide controls and profiles.

Label	Description
DataRay gvx.yyz	The sofware version on your PC.
Live Image x of xx	The software version on which the file was saved.
Average=x	The number of data samples used in average mode.
Exp@x.xxxms	The exposure time of the saved image.
Filter=0.2%	Filter=0.2%
Wl=670.0nm	The set wavelength.
Pixels=xx.x μm:xx.xμm	The effective pixel pitch (twice the actual pixel pitch in the default **Fast** mode).
Full/Fast	Displays whether the camera is in Full or Fast mode.
Camera #x	Denotes which camera is being displayed if multiple cameras are in use.
(HyperCal on)	This text will be displayed when HyperCal is on, but will disappear when HyperCal is off.

Table 4.1: Explains the different labels associated with the caption bar (see Fig 4.2).

General Tips

- **File⟶Load Defaults** will reset the software to its default settings
- **Tooltips** If you hover your mouse over an item, it will display helpful information.
- **Left-click** or **right-click** to display settings or information about a component

Top

Software Status Header

The blue/gray streak of the Caption bar (see Fig. 4.2) at the top of the screen displays information about the software (see Table 4.1).

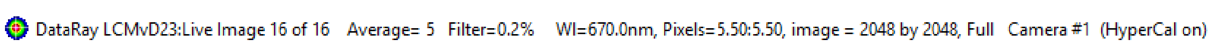


Figure 4.2: The Caption bar displays useful information (for a description of each label see Table 4.1)

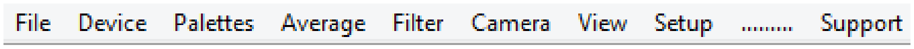


Figure 4.3: The menu bar containing the various dropdown menus.

Dropdown Menus

File

Opening WinCamData (.wcf) files To open a previously saved .wcf file, use the following steps:

- Click on the open file button **File**⟶**Open** or enter **Ctrl+O** to open the **Open** dialog box.
- Select the sample .wcf file, and click **ok** to display the saved file. The image of a beam will appear [1].

Saving WinCamData (.wcf) files Click on the open disk button **File**⟶**Save** or enter **Ctrl+S** to save the current image/images. There are various options for saving files in various formats:

- **Save current data as wcf** Saves the current image into a .wcf file.
- **SELECT data from data buffer as wcf** Select images to save into a .wcf file (see Fig. 4.4).
- **SAVE ALL data in data buffer as wcf** Save all images into a .wcf file.
- **Save data as text** Save file as text with columns delimited by commas and rows delimited by semi-colons.
- **Save current data as 8 bit TIFF** Saves picture as an 8 bit TIFF.
- **Save current data as 16 bit TIFF** Saves picture as a 16 bit TIFF.

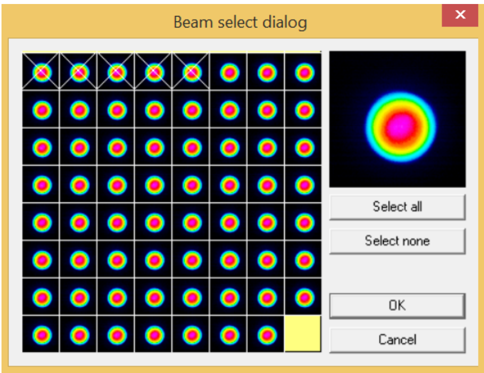


Figure 4.4: Images may be individually selected for inclusion in the .wcf file.

Saving and loading software settings (.ojf) job files Software settings can be saved and loaded with .ojf job files. This enables users to keep settings between sessions with the DataRay software.

- **Save Job file** Saves the current settings into a job file.

[1] Opening an image does not change the current display settings and measurement options.

- **Load Job file** Changes the settings the settings to those of a job file.

Reset settings to default with Load Defaults To load software's default settings click **File⟶Load Defaults**. If you are seeing unexpected results, reloading the default settings will often fix the problem.

Device

The device dropdown menu is used to select devices and device configurations. Although options exist for other DataRay devices, four options can be used with the WinCamD.

- **WinCamD:** Used to look at data from one WinCamD camera.
- **WinCamD: Two Cameras** Used to look at data from two WinCamD cameras.
- **WinCamD: Three Cameras** Used to look at data from three WinCamD cameras.
- **WinCamD: Four Cameras** Used to look at data from four WinCamD cameras.

Palettes

Default Palette Options This dropdown menu lets you select a color palette that will be used for both the 2D image and 3D image. There are currently four palette options:

- **High color palette** The default DataRay palette.
- **Monochrome palette** A black and white palette.
- **32 color palette** A palette utilizing only 32 colors.
- **10 color palette** A palette utilizing only 10 colors.

Custom Palette Option

Selecting a Custom Palette The **Import file** option allows the user to import a new file for use as an alternate color palette. To import a file, select this option and navigate to the directory containing a correctly formatted CSV file and select it.

If an error occurs in reading the selected file, an error message should appear. Note the given reason for the error (RGB values too large, greater than 3 values per row, etc.) and verify that the selected file meets all related requirements listed in the following section. When such an error occurs, the program will automatically revert to the default color palette, which is generated solely in the software and does not rely upon an external palette file. The original color palette will also be restored if the user reloads default settings or if any option in either palette dropdown menu is selected other than **Import from file** or **Ink saver**.

Creating a New Palette The requirements for a file that is to be read in as a color palette are as follows:

- The file must be a .csv file

- The file must contain exactly 3 columns and 16384 rows
- The value of each entry must be between 0 and 255 inclusive for proper RGB display values

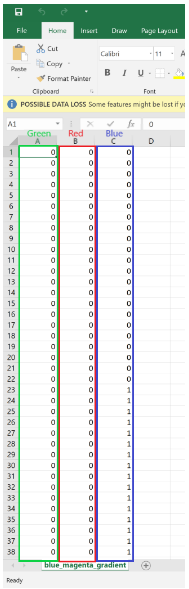


Figure 4.5: Properly formatted CSV file

The easiest way to create a properly formatted file is through Excel, making sure to follow the requirements above. Each row in the CSV file contains an RGB triad that corresponds to a digital intensity reading from the camera equivalent to the line number in the file (1-16384). In other words, the lower the line number of a specific RGB value, the lower the corresponding intensity reading from the camera. The RGB triads are to be formatted such that the first column contains Green values, the second column contains the Red values, and the third column contains the Blue values (shown in Fig. 4.5). Fig. 4.6 shows the final result of a custom palette that fades from black [0,0,0] to blue [0,0,255] to magenta [0,255,255] and finally to white [255,255,255] as intensity readings increase.

Additional Palette Options The Palette dropdown menu also allows for ink-saver mode. If **Ink saver** is selected, the entire image excepting the beam will be whited out to save ink when printing. Additionally, the button panels' backgrounds will be changed to white. This option can be applied with either the original software generated palette or a custom palette imported from a file.

Average

This dropdown menu lets you select various averaging methods:

- **No Averaging** No averaging is done.
- **Average 2** Averages two images.
- **Average 5** Averages five images.
- **Average 10** Averages 10 images.

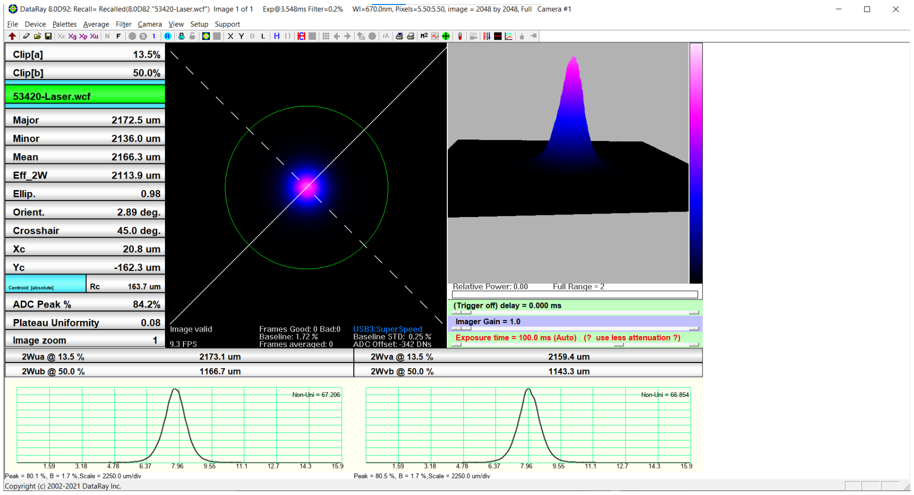


Figure 4.6: Final result of palette customization

- **Average 20** Averages 20 images.
- **Continuous** Produces frames which represent the average of all captured images, even beyond the size of the image buffer.
- **Max Hold** Produces frames in which a pixel is only updated when a new frame with a higher value at that pixel is detected. This can be useful when measuring pulsed lasers with a camera that has a rolling shutter.

Filter

The filter dropdown menu offers three options:

- No Filtering
- Percentage Filtering
- Area Filtering

For beams below 20 times the pixel dimensions, the filter should be set to **No filtering**.

Percentage Filtering A triangular weighting smoothing function performed as a running smooth of the profile. There are seven selectable settings:

- Filter = 0.1% Full Scale
- Filter = 0.2% Full Scale
- Filter = 0.5% Full Scale
- Filter = 1.0% Full Scale

- Filter = 2.0% Full Scale
- Filter = 5.0% Full Scale
- Filter = 10% Full Scale

The default settings use Filter = 0.2% Full Scale. The FWHM of the triangular filter may be calculated as as the percentage times the length of the profile.

Area Filtering Area filtering applies a convolution to the pixels. Currently they average a number of neighboring pixels, the number denoted by the following options:

- Area filter 1 pixel (Default)
- Area filter 3 pixel
- Area filter 5 pixel
- Area filter 7 pixel
- Area filter 9 pixel

Outlier Filter Turns on the outlier filter. If a pixel differs in value by more than 10% from the average of its 8 neighbors, set that pixel to the average value.

Camera

This selects the camera to use. You may specify a custom ordering of a group of cameras by pressing **Alt+N** to open the Numeric Identifier Dialog. Cameras are ordered by their numeric identifiers in ascending order.

View

This menu has four options:

- **Toolbar** When selected the toolbar is displayed.
- **Status Bar** When selected the status bar is displayed.
- **Open/Close Log Dialog [CTR L]** Opens the Data Logging Control & Status dialog box.
- **Open M2 Dialog** Opens the M2 dialog box.

Setup

Capture setup dialog The Capture Setup Dialog may be opened by selecting it from the setup menu or by pressing **Alt+S**. It can be used to adjust capture settings for the camera currently selected in the **Camera** dropdown menu.

Additional Setup Options In the **Setup** dropdown menu, there are several options to adjust software settings (for a full description of each option see Table 4.3).

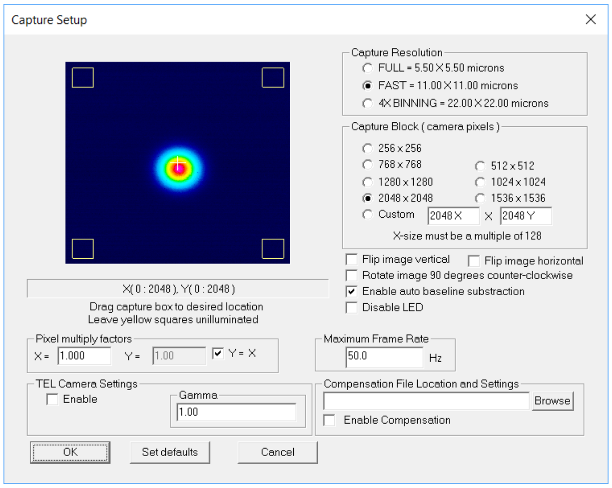


Figure 4.7: The Capture Setup menu allows the user to control the capture and display of images. The many options (see Table 4.2) herein allow the settings to be tailored to the user's beam.

Support

Provides convenient, up-to-date links to the following:

- DataRay.com
- Software Updates
- Register Product
- Technical Support
- WinCamD Manual
- Slit Device Manual

Additionally, the support dropdown menu has an option to install the USB 2.0 and USB 3.0 drivers.

Toolbar/Button Bar

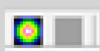
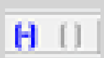
The Toolbar (see Fig. 4.8) provides quick access to several items. If a toolbar item cannot be used, it is grayed out. Some buttons are grayed out until you press Stop. Some will be grayed out if they are inapplicable to your device or to your current mode of operation. The Toolbar buttons are described in Table 4.4, while the following subsections describe the dialog boxes resulting from selecting the various toolbar buttons.

Figure 4.8: Toolbar menu

Label	Description
Capture resolution	**FULL** resolution returns readings for every pixel on the imager, whereas **FAST** returns the value of every other pixel in both directions for a higher frame rate.
Capture block	Selects the image capture size and position. You may drag-and-click the capture block to put it into the desired position or input coordinates in the box below the image.
Flip image vertical	Flips the image along the horizontal axis to ensure positive Y is up.
Flip image horizontal	Flips the image along the vertical axis to ensure positive X is left.
Rotate image 90 degrees counter-clockwise	Rotates image 90 degrees count-clockwise.
Disable LED	Turns off the LED on WinCamD-LCM and TaperCamD-LCM cameras.
Pixel multiply factor	Allows you to adjust for ancillary optical elements that may change the scale between the object plane and the image sensor plane. For TaperCamDs this number is on the label on the back of the camera. The Pixel multiply factor (PMF) value is now held in the camera EEPROM, and will not change unless you specifically change it.
Maximum Frame Rate	Sets a maximum frame rate for the camera.
Gamma	Allows you to change the Gamma value for Phosphor-coated sensors that have a non-linear response. Typically Gamma will be 2 for Phosphor coated sensors. All other sensors have a linear response so Gamma should remain equal to 1.

Table 4.2: Explains the options associated with the Capture Setup dialog box (see Fig 4.7).

Button	Figure	Description
Select Centroid Mode		This determines the X,Y position of the crosshairs by one of several methods: • **Xc** The centroid for all points above the cliplevel with weighting by power. • **Xg** The geometric centroid for all points above the set centroid level without any weighting by power. • **Xp** Sets the crosshairs to the peak. • **Xu** Allows the user to set the crosshairs by clicking any location on the 2D image.

Normal and Fast Mode		Normal (**N**) and fast Mode (**F**) allow display in Normal or Fast mode for LCM cameras. When the **N** button is grayed out you operate in normal mode; standard and user requested calculations are performed for the beam. This limits the speed of the screen update. You may select **F** to tell the software to simply update the screen as fast as possible, but Fast mode is not recommended. Fast mode triggers the capture of an image before the current image is readout; this may cause glitches.
Go, Stop, Single Shot and Refind Cameras		The following buttons are used to acquire images: • **G** This button starts the capture of images. • **S** This button stops the capture of images. • **1** This button starts the single capture mode. Once initialized, you may take single images by clicking this button again. • **R** This button re-finds the cameras and other devices.
Lock Baseline		The **Lock** and **Unlock** buttons allow you to lock and unlock the baseline. This is useful for the measurement of beams larger than the sensor.
Normalized and Regular Images		To normalize the 2D and 3D displays to 100%, click the left-hand button. The right-hand button displays the actual values. This does not work with recalled files.
Display Modes		These are various layouts: • **X** Display the X profile only. • **Y** Display the Y profile only. • **B** Display both profiles. • **L** Remove profiles and 3D image to display a large 2D image.
Background Subtraction		• Right-click the left-hand button to enable background subtraction and the right-hand button to disable it. • To effectively use background subtraction, right-click on the Exposure time box and disable auto-exposure. As appropriate, set Average=20, especially if the background to be subtracted is noisy. • Click the button to initiate background subtraction. The captured back-ground is subtracted from subsequent images. If Average is still engaged, subtraction will be gradual. • Holding down Control+Spacebar while the window is in focus will display the current subtracted background frame.

HyperCal		To engage and disengage HyperCal, click on the HyperCal button. HyperCal is a type of background subtraction technique to remove unwanted background patterns from measurements. A dark frame with the lowest possible exposure time will be captured every 16 frames during live data capture and is continuously averaged with previous dark frames up to a 5 frame average. This continuously updated dark frame is subtracted from each full exposure during live data capture to remove unwanted background patterns. HyperCal also has the benefit of removing blooming or comet tailing on CCDs; the option was historically called Comet Tail Elimination. There is a minimum exposure time below which HyperCal is automatically disabled to ensure that it does not remove an appreciable amount of the actual beam. This exposure time is approximately 2.5X the minimum exposure time of the camera. Holding down Control+Spacebar while the window is in focus will display the current subtracted dark frame.
Image Selection		The matrix button opens a dialog that allows you to select an image from the buffer. The forward and backward arrows increment and decrement the currently displayed image.
Reset Averaging		Resets the average if the averaging option is engaged.
M^2		This button starts the M^2 measurement which is detailed in Appendix 9.
Log Data		Selecting this button will open up the Data Logging Control & Status dialog box (see Fig. 4.9 and Section 4). This allows you to set up and recall the logging of data in various formats (e.g. text and Excel). The Data Logging Control & Status dialog box has several options: **Setup Log..**, **Start log**, and **Recall Log file**.
Beam Wander		Opens the Beam Wander dialog box (see Fig. 4.11 and Section 4).
Fluence		The fluence button will open the Fluence dialog box (see Fig. 4.12a and Section 4). You must have relative power set in order to use the Fluence dialog.
Image log		Saves a specified number of frames up to 64 images at intervals specified from 1 to 5,000s and combines them into a .wcf file.
Line laser dialog		Opens the line laser dialog for use with DataRay's Line Laser Profiling System (LLPS).
Strip chart		Opens the strip chart dialog to plot data over time.
Shutter Control		Allows manual control of WinCamD-IR-BB shutter.

Table 4.4: Toolbar Button Descriptions.

Toobar Button Dialog Boxes

Data Logging Control & Status The Data Logging Control & Status dialog box (see Fig. 4.9) offers the following options:

- **Setup Log..** Opens the **Setup Log** dialog box (see Section 4).
- **Start Log** Starts the logging
- **Show log file as text** Displays log as text.

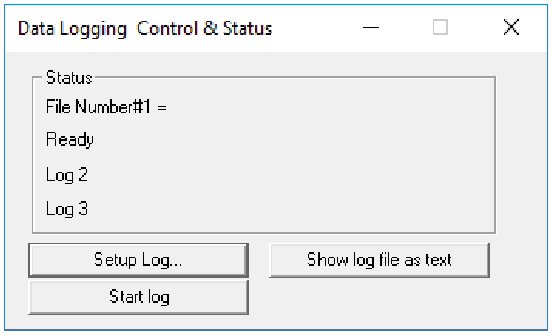


Figure 4.9: Data Logging Control and Status Dialog Box.

Setup Log After clicking **Setup Log**, the Setup Logging dialog box will open (see Fig. 4.10). You will be able to set up at most three logging intervals in the Setup Logging dialog, all of which may have a different logging rates and log files. As a default, all data is logged, but by selecting **Log enabled data only**, you may log only those values which have **Pass/Fail** parameters.

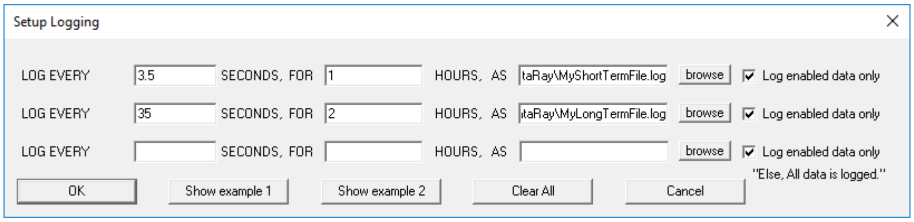


Figure 4.10: Example 1 of the dialog shows two logging intervals with different settings.

Wander Dialog The Beam Wander dialog (see Fig. 4.11) tracks the centroid position over time. The results it displays are as follows:

- **Scale radius** The current size of the circle shown in the dialog box.
- **Samples taken** The number of samples used in the current display.
- **Max deviation** Maximum difference between a centroid position and the first centroid position.
- **Last deviation** The difference in position between the first centroid position and the last centroid position.
- **Mean** The average difference between the first centroid position and the subsequent centroid positions.

- **RMS** The root mean square defined as:

$$\textbf{RMS} = \sqrt{\frac{1}{N}\sum_{n=1}^{\mathrm{N}} X_n^2 + Y_n^2} \tag{4.1}$$

where N is the number of samples and X_n and Y_n are the x and y positions relative to the first point plotted.

- **[xx.x]** The number in brackets after the RMS is the standard deviation of the centroid positions compared to the first centroid position.

The Beam Wander dialog allows for the following user inputs:

- **Time interval** Opens a dialog box to set the time between samples.
- **Samples to be recorded** Opens a dialog box to set the maximum number of samples (up to 8192).
- **Clear** Restarts the plot.
- **Replay** Replays the position history.
- **To clipboard** Saves a picture of the Beam Wander dialog to the clipboard.
- **Normalize** Re-centers the plot on the average centroid position.
- **Replay Fast** Replays the position history quickly.
- **Save as bitmap** Saves a screenshot of the current DataRay software as bitmap.
- **To Excel** Opens up an Excel workbook with all the beam position's coordinates listed.
- **Sequence off** Allows you to explore the data by using + and - on your numeric keypad.
- **Export to Paint** Opens a screenshot of the current DataRay software in the Paint application.

Fluence Dialog The Fluence Dialog allows you to view the calculated fluence results (see Fig. 4.12a). Values for Average Fluence, Defined Fluence, Peak Fluence, and Power Contained are displayed as buttons, so that clicking on the button enables you to set pass/fail limits on the results. In Fig. 4.12a, the green text displaying the Average Fluence shows that it passes the set limits, while the pink text displaying the Defined Fluence shows that it fails.

Setup Fluence The Fluence Setup Dialog will enable you to adjust settings for several fluence measurements (see Fig. 4.12b):

- **Peak Fluence Aperture** allows you to select pixels, from a minimum of four, surrounding the peak to measure. **Save** will save a custom setup to be reloaded with **Restore**. **Clean** will revert to the standard 4 pixel setup.
- **Defined Fluence Array** designates a region around the peak in which to measure fluence.

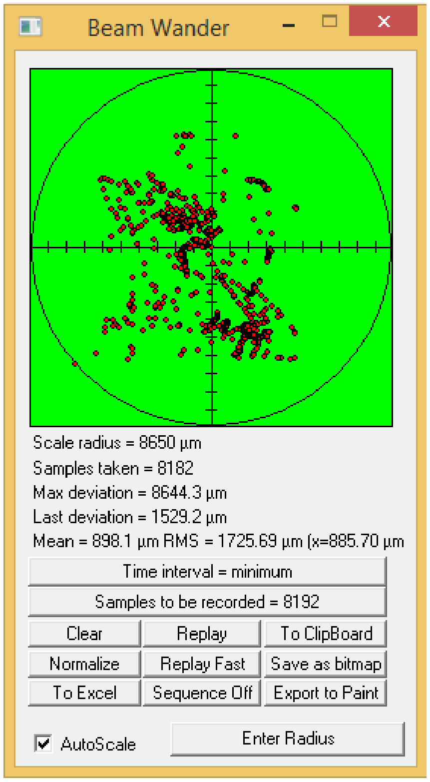


Figure 4.11: The Wander Dialog with several recorded points.

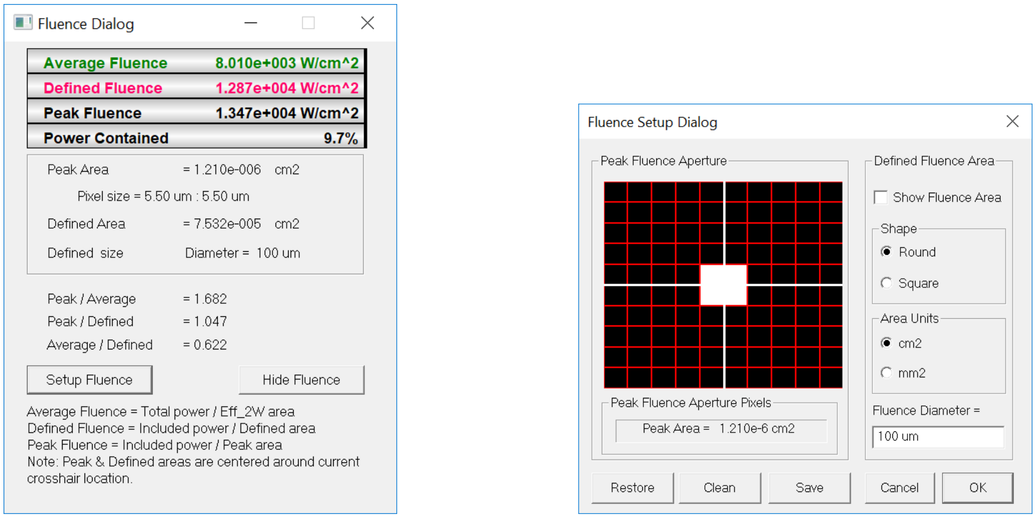
Strip Chart Dialog The Strip Chart dialog allows the user to track and plot any of the metrics that are displayed in the results buttons on the left hand side of the main screen. This application records the trend of the selected results over time, while constantly calculating and updating the mean, standard deviation, minimum, and maximum values of the current set of data. Each chart supports the recording of up to three metrics at a time. If allowed to run, the chart will draw up to 2000 points of data for each metric. Once 2000 points have been drawn, the data begins to undergo First in, First out processing, where the oldest data is removed at the same rate that the newest data is added. In addition, the user can define the number of frames or amount of time to wait between recording each point of data. The user can also limit the recording period to a defined number of points or amount of time. The data displayed on the chart may also be exported to Excel or CSV.

Left Panel

Hover the mouse over any button to see a description of its function (see Fig. 4.13). Additional buttons may appear in newer software releases and various modes.

Clip Level Buttons: Clip[a] / Clip[b]

Clip levels (percentage) compare the intensity of a pixel to the peak intensity to determine the cut offs for the beam diameters **2Wa** (**Clip[a]**) and **2Wb** (**Clip[b]**) (see Fig. 4.14). Left clicking on either the **Clip[a]** or **Clip[b]** button will open the Clip Level Entry dialog box which allows changes to the clip level selected.



(a) (b)

Figure 4.12: (a) Fluence analysis results dialog box. (b) The menu to set up fluence analysis.

Clip-level entry dialog

The Clip level entry dialog box allows the user to adjust the following settings:

- **Width calculation method** Allows the user to select one of two width calculation methods.
  - **Clip level method** the standard method.
  - **Sigma X 4 (variance) method** The ISO 11146 compliant measurement method utilizing second moments.
- **Quick select** allows you to set any clip level > 0.5%.
  - **13.5% [1/e^2]** the industry standard.
  - **50% [FWHM]** the full-width half-maximum.
  - **86.5%** another commonly used clip level.
- **Angular Divergence /or Pointing** Contains the following settings to measure either the Angular Divergence or Pointing angle:
  - **Enable Pointing** Calculates the pointing/boresight of a beam from a point source based on the **Source to imager distance** and centroid distance from the center of the sensor.
  - **Enable Angular Divergence** Calculates the angle of a beam from a point source based on the **Source to imager distance** to the current centroid.
  - Choose the unit of measurement from the following:

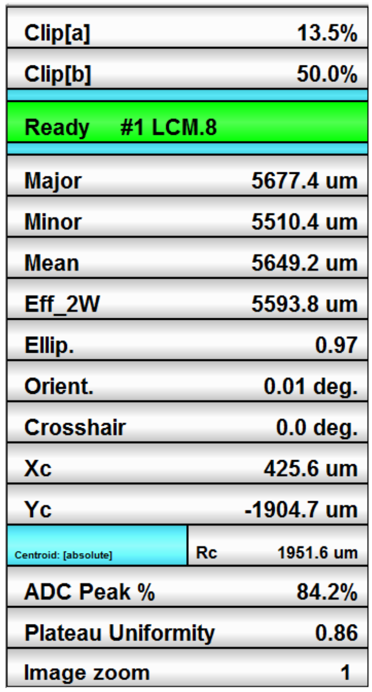


Figure 4.13: From top to bottom: The top two buttons are **Clip[a]** and **Clip[b]** clip level buttons (see Section 4). Following the clip level buttons is the green camera status button (see Section 4). Below the camera status button are the result buttons (see Section 4 and Table 4.5).

    * Full angle in Degrees XXX.X
    * Full angle in Degrees XX.XX
    * Full angle in Degrees X.XXX
    * Full angle in Milliradians *
    * N.A. [sine of the half angle]

  - **Source to imager distance in mm** Uses this value to calculate the Angular Divergence and Pointing. Remember that the imaging sensors generally sit $\approx$ 7.5 mm below the surface of the camera body; you may find schematics on the DataRay website for your model.

- **Angular Divergence Options** Errors in intensity values may arise as measurements spread outward from the beam centroid. This is due to the increasing distance from the source and higher angle of incidence on the sensor the farther measurements are taken from the centroid. The software can automatically perform a correction that is applied to the beam diameter calculations (**2Wa** and **2Wb**) and the Profile Displays (see Fig. 4.25 and Table 4.8) without affecting any other data. An example of the profile data correction can be seen in Fig. 4.15. This correction can be performed with the following options:

  - **cosine2** (for Use 'effective slit' profiles)

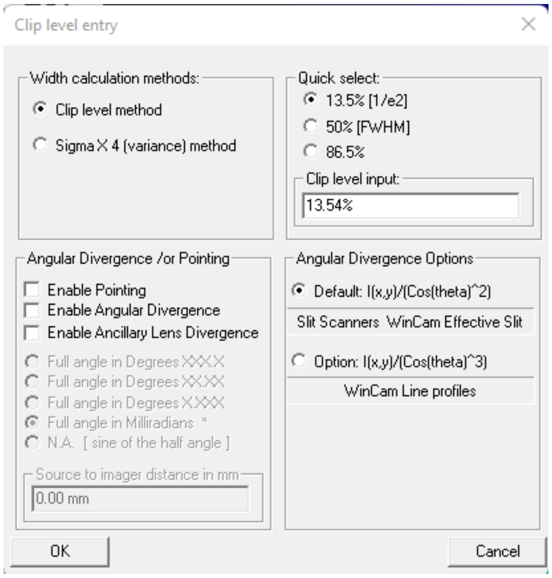


Figure 4.14: The clip level dialog allows you to change the settings for a single clip level.

- **cosine3** (for the default line profiles) the data to allow for the use of a flat measurement plane to measure a spherically diverging beam

Use ISO 11146 compliant diameters and angles

DataRay software enables the user to take ISO 11146 compliant data. A full description of the ISO 11146 calculations can be found in Section 7. For full ISO 11146 compliance select **Average 5** from the Average dropdown menu. To select settings, use **Setup** $\rightarrow$ **ISO options** and the ISO Clip level & Correction Setup dialog box will open (see Fig. 4.16).

ISO Clip level & Correction Setup dialog The ISO Clip level & Correction Setup dialog box (see Fig. 4.16) allows the user to modify the following ISO 11146 compliant settings:

- **ISO threshold** In ISO mode, the clip level determines which pixels are used in the second moment beam diameter calculation. The ISO threshold determines the clip level based on

$$\text{clip level} = n \times \sigma_{\text{Baseline}} \tag{4.2}$$

  Where n is a user defined input in the dialog box and σ_{Baseline} is the standard deviation of the baseline. The mean and standard deviation and mean of the baseline are calculated using the unilluminated four corners of the capture block.

- **Enable ISO included power correction** Due to systematic error inherent in the ISO 11146 measurement method, DataRay's proprietary correction factor may applied for more accurate results. For more information see our blog post on systematic error in ISO 11146 calculations.

- **Enable Inclusion Region** Provides a data aperture that eliminates noise in the wings of the sensor.

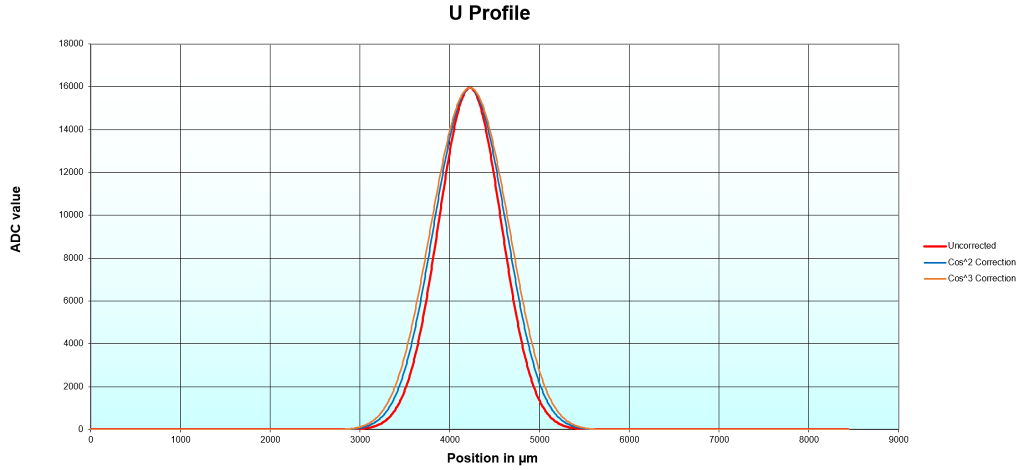


Figure 4.15: This figure shows the differences in the profile data with varying angular divergence options. This includes profile plots with correction disabled (red), $\cos^2$ corrected data (blue), and $\cos^3$ corrected data(orange).

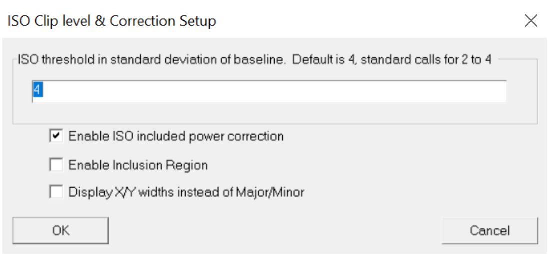


Figure 4.16: ISO Clip level & Correction Setup dialog box.

Power Meter Dialog

Opens up the Power Meter Dialog which allows you to connect to DataRay supported laser power meters.

Set WinCamD-GCM Bandwidth Limit

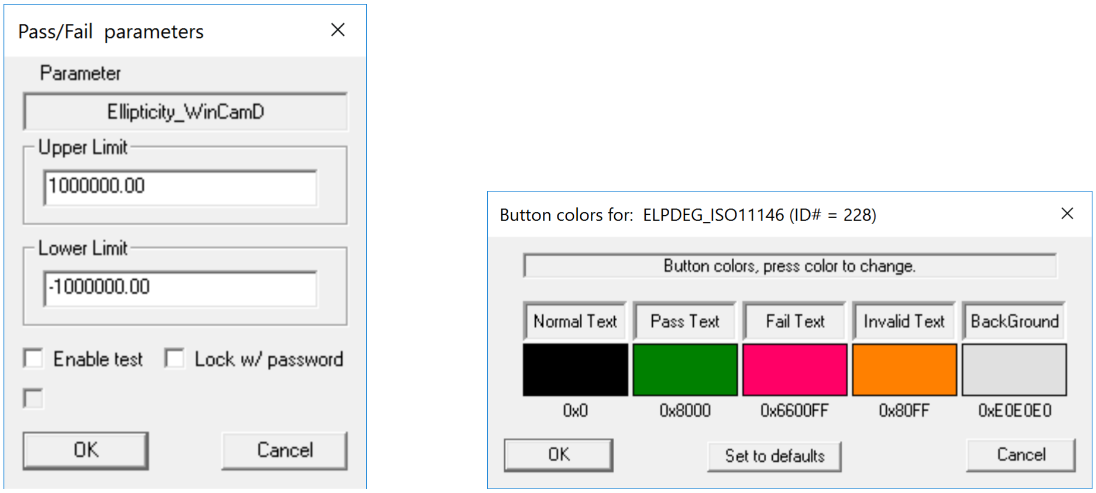
Opens up dialog to allow the user to set a limit to the amount of bandwidth the WinCamD-GCM will try to use on a network (default 60 MBPS).

Camera Status and Firmware Version

The current camera status (see Fig. 4.13) is either **Not Present**, **Ready**, or **Running**. Clicking on a **Ready** status will start and stop sampling. The number to the left of the camera name designates its camera number while the number to the right designates its firmware version.

Result buttons

Results are also displayed with buttons (see Fig. 4.13 and Table 4.5). If the software determines or suspects that a result is invalid it will change the button font color will change from black to orange (default). Right clicking on a Result button will open the Button Colors Dialog box for the button (see Fig. 4.17b), whereas left-clicking on a Result button will open the



(a) (b)

Figure 4.17: (a) The Pass/Fail parameters dialog box allows the user to put pass/fail limits on each button. (b) The Button Colors Dialog box enables the user to change the font colors used in the results buttons.

Pass/Fail parameters dialog box for the button (see Fig. 4.17a).

Pass/Fail Parameters Dialog Box

You may enable Pass/Fail settings for a button which displays results by left-clicking on it.

- **Enable test** By clicking "Enable test," you will enable the data to be logged by **Log Data** and the display of Pass/Fail colors. If the result is not between the lower and upper limits, the button will display the fail color, default red. Otherwise, it will display the pass color, default green.
- **Lock w/ Password** locks the test limits with a password. After setting a password, the settings cannot be changed without it. As of this writing, the master password is "peanuts", all lower-case. Contact support if you need help.

Button Colors Dialog Box

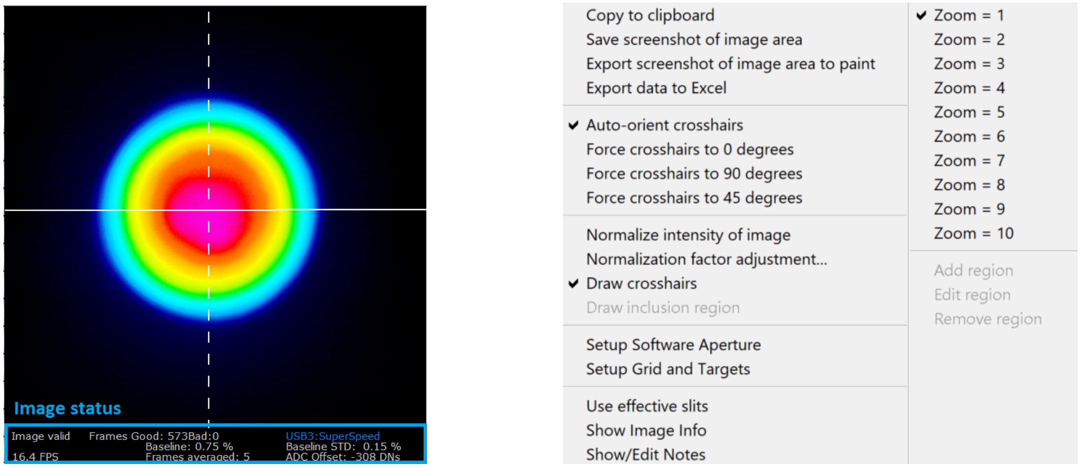
You may select the colors for all buttons by right-clicking on it and selecting the respective color square. The software either determines or suspects that a value is Invalid. For example, the software determines that the peak is invalid if it is > 100 or < 10. As with all settings, display colors can be saved in a job file.

2D Image

2D Image Display

Besides the 2D image and crosshairs, there is a label below the image (see Fig. 4.18a) which displays information (see Table 4.7 for label descriptions) about the current image and vital settings. The image status in orange text means the image is invalid.

If the capture block (Section 2) is rectangular, the unused portion of the 2D image area will be a gray color.



(a) (b)

Figure 4.18: (a) The image status is displayed at the bottom of the 2D image. (b) Right-click the 2D image for these options.

2D Image Settings

There are several ways to interact with the 2D Image.
Left-click options include:

- **CTRL** Left-Click: allows the user to draw a line and view the X, Y, and radial delta between the end points.

Middle-click on the 2D area allows you to:

- Pan the image.

Right-click on the 2D area to access further options (see Fig. 4.18b). This allows you to:

- The first four options are various ways of saving the data:
  - **Copy to clipboard**
  - **Save screenshot of image area**
  - **Export screenshot of image area to paint**
  - **Export data to Excel**
- The second area gives four options for the crosshair orientation:
  - **Auto-orient crosshairs** Programatically sets the crosshair orientation,
  - **Force crosshairs to 0** Manually sets the crosshair orientation to 0 degrees.
  - **Force crosshairs to 90** Manually sets the crosshair orientation to 90 degrees.

- **Force crosshairs to 45 degrees** Manually sets the crosshair orientation to 45 degrees.

- **Draw crosshairs** When checked the crosshairs will appear overlayed on the 2D image.
- **Draw inclusion region** Sketches a circle which contains 99% of the beams energy. This is consequently available in ISO and DXX mode only.
- **Setup Software Aperture** Opens the Setup Inclusion dialog box (see Section 4).
- **Setup Grid and Targets** Opens the Grid and Target Setup dialog box (see Section 4).
- **Use effective slits** Approximates a scanning slit device by summing up all the values along the orthogonal axis to place one value on the profile axis.
- **Show Image Information** Opens a box with the data shown right for a live or recalled image.
- **Zoom** Zooms in on the position of the crosshairs. **i** and **o** zoom in and out respectively.

Setup Inclusion

The Software Aperture dialog (see Fig. 4.19) allows you to set up a region of pixels to be included in the software's calculations, see Fig. 4.20a. There are various modes:

- **Major Width x 3.0 (DEFAULT** A circle around the center with radius three times the major width
- **Major Width X** A circle around the center with a user-specified radius
- **Fixed diameter circle** Diameter is specified in μm
- **Rectangle** A rectangular region around the center.
- **Turn off** Turns off the software aperture.

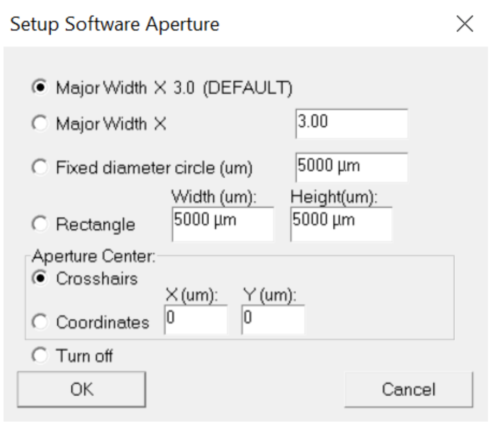
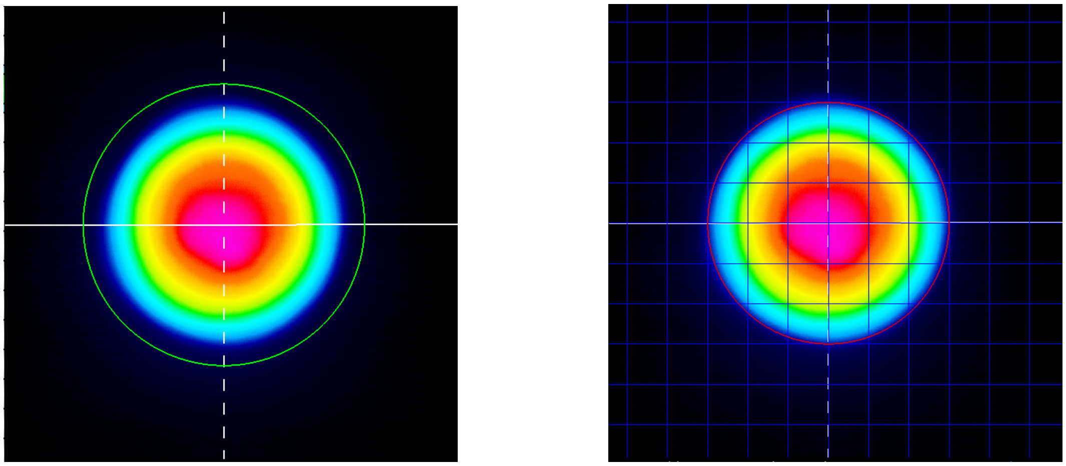


Figure 4.19: The Setup Inclusion dialog box.



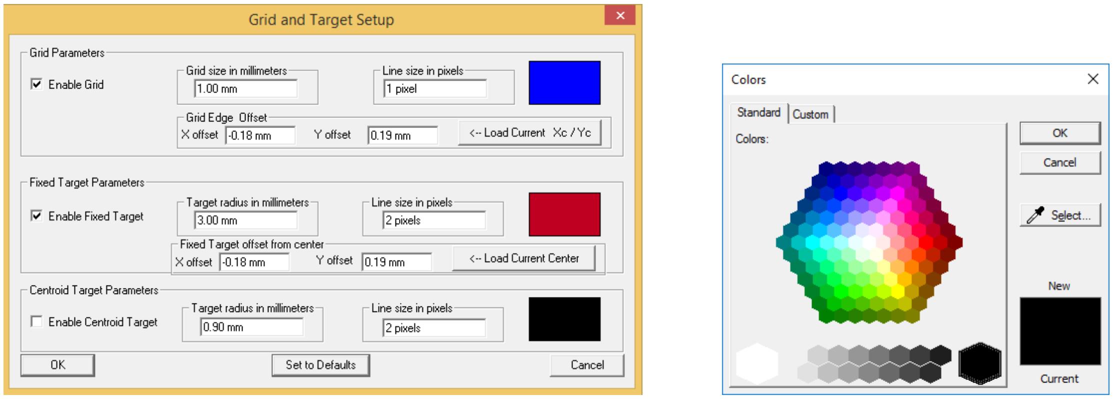
(a) (b)

Figure 4.20: (a) An image with Software Aperture enabled. Only pixels inside the ring will be used in calculations. (b) An image with the grid and fixed target set to the beam's centroid.

Grid and Target Setup

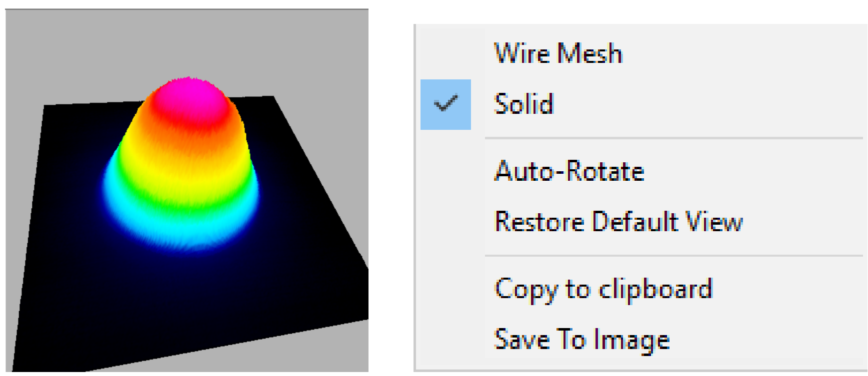
This dialog box (see Fig. 4.21a) enables the users to overlay a grid or a beam target over the 2D image. There are three different options that may be adjusted:

- **Grid Parameters** Overlays a grid onto the 2D image. This setting itself has several different options:
  - **Enable Grid** Toggles the grid on/off.
  - **Grid size in millimeters** Sets the spacing of the grid.
  - **Line size in pixels** Sets the size of the grid line.
  - **Grid Edge Offset** Provides an offset to the grid based on entered X and Y coordinates. Furthermore, the Load Current XC/YC button can be pressed to provide and automatic offset corresponding to the current centroid center.
- **Fix Target Parameters** Places a circular target around a specified position with the following options:
  - **Enable Fixed Target** Toggles the fixed target on/off.
  - **Target radius in millimeters** Sets the radius of the target.
  - **Line size in pixels** Sets the size of the target line.
  - **Fixed Target offset from center** Sets the center of the target. Furthermore, the Load Current XC/YC button can be pressed to automatically set the target to the current centroid center.
- **Centroid Target Parameters** Places a circular target around the centroid with the following options:



(a) (b)

Figure 4.21: (a) The coordinates of the grid and fixed target are relative to the center of the image sensor. (b) The menu that appears after clicking on the color boxes in (a).



(a) (b)

Figure 4.22: (a) A 3D image rotated and tilted. (b) The menu that appears after right clicking on the 3D image.

- **Enable Centroid Target** Toggles the centroid target on/off.
- **Target radius in millimeters** Sets the radius of the target.
- **Line size in pixels** Sets the size of the target line.

• **Set to Defaults** Resets all the options to their default.

For each of the above options, a colored box is shown. By clicking on the box, a dialog box appears (see Fig. 4.21b) which allows the user to edit the color of the item.

3D Image

Click and drag in the 3D box to change the view of the 3D image. Side-to-side motion rotates the image. Up-down motion changes the tilt angle. Right-click the 3D image and a floating menu (see Fig. 4.22b) appears with the following options:

- Two different options for rendering the 3D image:
  - **Solid** better quality more processor intensive.
  - **Wire Mesh** lesser quality, less processor intensive.
- **Auto-Rotate** rotates the 3D image, but slows the update rate.
- Two different export options:
  - **Copy to Clipboard** copies the image to the clipboard.
  - **Save To Image** opens up a dialog box with options to save the image to a directory.

Slide Controls

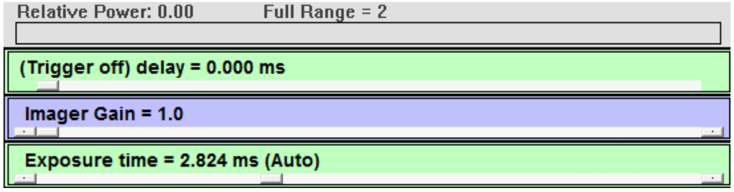


Figure 4.23: The slide controls from top to bottom: power bar, trigger, image gain, and exposure.

Power Bar

The auto-scaling Power bar function gives an indication of relative power as a scrolling ten sample histogram. The power is calculated as the integral of the energy in the image at a fixed exposure. It is not a calibrated power meter. Left-click the Power bar to access the Enter relative power and label dialog box (see Fig. 4.24).

Enter Relative Power and Label Dialog Box

Enter the power as measured by the calibrated power meter and the unit of measurement. The power bar will display relative power to the measurement entered. If you enter *dB* or *dBm*, it recognizes these terms and works in logarithmic mode. You may also enter *100* as the number and *%* as the label to display the results as a percentage.

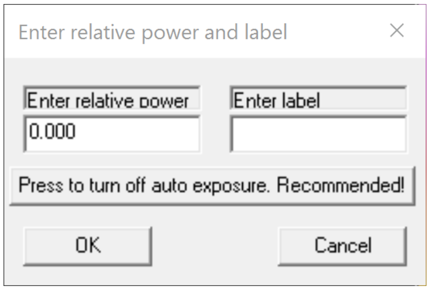


Figure 4.24: Relative Power Dialog Box.

Trigger

See Chapter 6.

Image Gain

The image gain is additional gain that can be applied to the signal. This is only recommended for use with pulsed lasers where increasing exposure time is not an effective way of increasing the signal strength. Increasing the gain will also increase the noise present in the signal. The gain control range varies on a per camera basis.

Exposure control

This allows the control and display of exposure time. You may right-click this control for more options

- **Apply to all cameras** applies the setting to all cameras
- **Enable auto exposure adjustment** has the software find an exposure time that approaches 90 % ADC Peak; this is enabled by default
- **Exposure limits** allows minimum and maximum exposure times for auto exposure.

Profiles

The two Profile Displays give information about the beam along each crosshair axis (see Fig. 4.25 and Table 4.8). Right-clicking on either of the profile displays will open the Profile Settings dialog box (see Section 4).

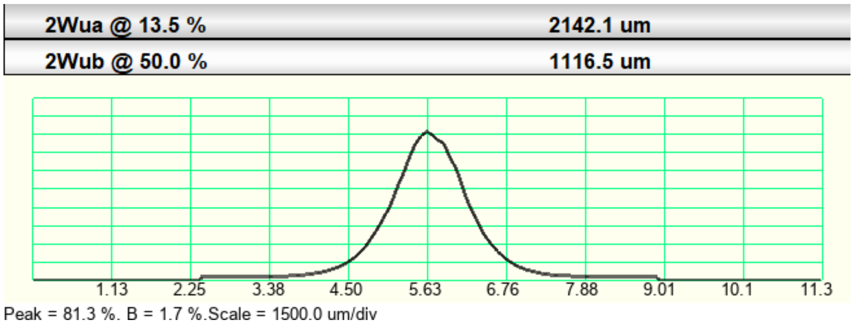


Figure 4.25: The profile displayed for one of the axes (Major or Minor). Top: Clip levels; bottom-left: peak and baseline; bottom-right: scale . Descriptions of each label can be found in Table 4.8.

Profile Settings Dialog Box

The Profile Settings dialog box (see Fig. 4.26) allows the user to modify the profile display settings. If *****GLOBAL SELECTIONS***** is checked, the settings will apply to both profile displays. If unchecked the settings will apply only to the profile selected with the right click. Table 4.9 describes the various options in the Profile Settings dialog box. Dialog boxes opened as a result of a Profile Settings selections will be described in subsequent subsections.

Fitting Algorithms

DataRay software offers two types of fitting algorithms in the profile display. The first is the Gaussian fit and the second is the Top-Hat fit. For both of the fitting algorithms, the deviation D_j is needed. D_j is defined at each position j $(0 \leq j \leq S)$

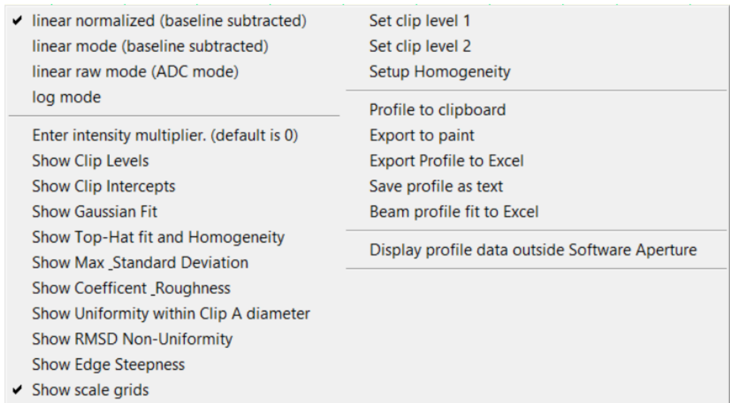


Figure 4.26: The options displayed when you right-click the profile.

on the profile, relative to the Gaussian fit or the Top-Hat fit —depending on the fit chosen— as

$$D_j = 100\left(\frac{P_j - F_j}{F_j}\right) \tag{4.4}$$

Where F_j is the fitted value and P_j is the profile value. For example, If $P_j = F_j$, D_j is 0% and if $P_j = 2F_j$, D_j is 100%.

Show Gaussian fit

The Gaussian fit is based upon a fit algorithm that —keeping the power under the curve constant and the centroid the same as that calculated for the profile— iteratively adjusts the height and width of the Gaussian until the Least Squares difference between the actual profile and the Gaussian profile is minimized. A **GFit** result appears under the **2W** results and a red line Gaussian appears superimposed over the profile. Some degradation of performance is to be expected due to the demands of these calculations. With the Gaussian fit, the software subtracts the baseline. Specifically the software steps for the Gaussian fit are:

1. Set the centroid position of the fitted Gaussian the same as that of the actual profile

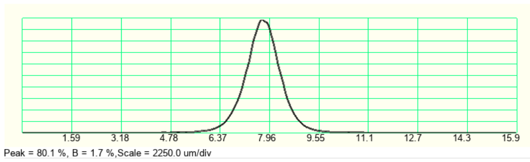
2. Set the area under the fitted Gaussian equal to the area under the actual beam (i.e. an equal power requirement).

   If the area under the curve is 'A' and the actual 13.5% diameter is 2, then the first iteration's Gaussian height is set to

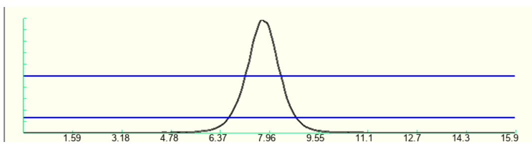
$$H = A\left(\frac{2}{2W}\right)\sqrt{\frac{2}{\pi}} = 1.596\frac{A}{2W} \tag{4.5}$$

3. The least squares fit iteration starts from the actual 13.5% diameter.

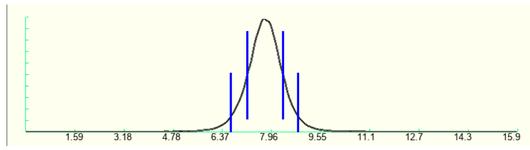
4. **G 2W** is the calculated diameter of the least squares fitted Gaussian which can be substituted into Eq. 4.5 for $2W$ to find the height.



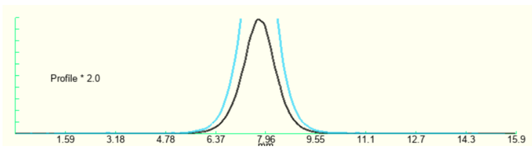
(a)



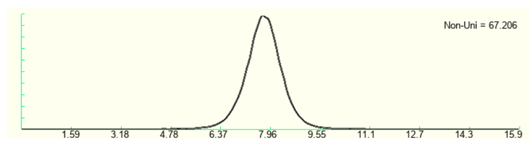
(b)



(c)



(d)



(e)

Figure 4.27: Profile Display with the various options available. (a) Show scale grids option. (b) Show clip. (c) Show Clip Intercepts. (d) Enter intensity multiplier. (e) Show Uniformity with Clip A diameter.

5. The equation for **GFit** is as follows

$$\textbf{GFit\%} = 100\left(1 - \frac{\sum_{j=1}^{S} |D_j|}{A}\right) \tag{4.6}$$

Show Top-Hat fit

1. Determines 50% of peak outer edges of the profile. Defines the center (as opposed to centroid) of the beam as the midpoint between these two points.

2. Determines the mean level of the central 80% of this region. It plots a straight line at this level, and defines it as 100% for the purpose of subsequent **Top-Hat** fit calculations.

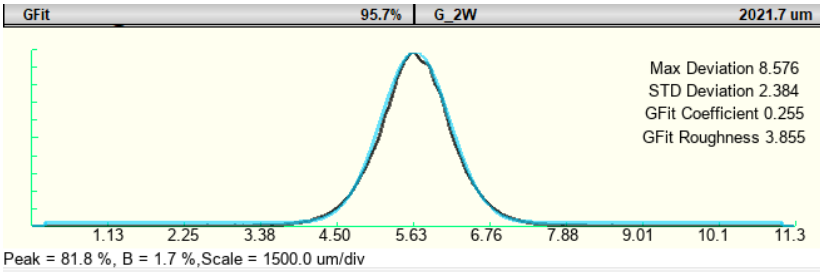
3. The **Top-Hat** % is calculated with the following equation

$$\textbf{Top-Hat\%} = 100\left(1 - \frac{\sum_{j=1}^{S} |D_j|}{\sum_{j=1}^{S} \text{If } (D_j < 0) \text{ Then } (D_j)}\right) \tag{4.7}$$

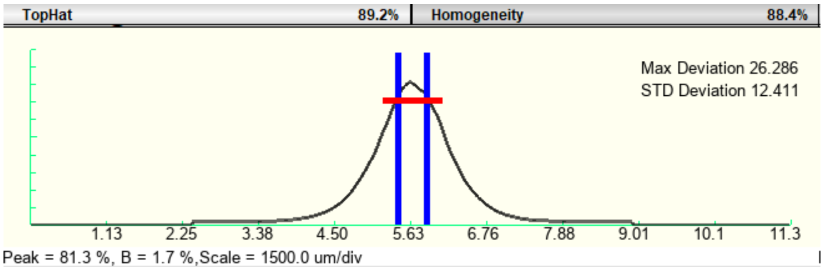
Show Max & Standard Deviation

A vertical red line (see Fig. 4.28a) appears on the graph at the point of maximum deviation of the profile from the fit. Additionally, the **Max Deviation** and **Std. Deviation** are written in red on the graph (see Fig. 4.28a and Fig. 4.28b).

The **Max Deviation** is defined as the maximum value of the $|D_j|$.



(a)



(b)

Figure 4.28: (a) Gaussian Fit mode with the **Show Max & Standard Deviation** and **Show Coefficient & Roughness** options selected. (b) Top-Hat Fit mode with the **Show Max & Standard Deviation** option selected.

$$\textbf{Max Deviation} = \max |D_j| \tag{4.8}$$

The **Std. Deviation** is the standard deviation of the deviation D_j for all j

$$\textbf{Std. Deviation} = \sqrt{\frac{1}{S}\sum_{j=1}^{S}\left(D_j - \bar{D}\right)^2} \tag{4.9}$$

where $\bar{D}$ is defined as

$$\bar{D} = \sum_{j=1}^{S} D_j \tag{4.10}$$

Show Coefficient & Roughness

Additional information is given for the Gaussian fit by the alternative **Show Coefficient & Roughness** selection. However, these values are not available for the Top-Hat fit. The following expressions are needed to calculate the **Coefficient** and the **Gaussian Roughness**. We define δ_j as the difference between P_j and F_j

$$\delta_j = P_j - F_j \tag{4.11}$$

so that the average difference $\bar{\delta}$ is given by

$$\bar{\delta} = \frac{1}{S}\sum_{j=1}^{S}\delta_j \tag{4.12}$$

Next we find the deviation Δ_j for each point

$$\Delta_j = \left|\bar{\delta} - \delta_j\right| \tag{4.13}$$

Finally the **Coefficient** is defined as

$$\textbf{Coefficient} = 1 - \frac{1}{S^{\frac{3}{2}}}\sum_{j=1}^{S}\Delta_j^2 \tag{4.14}$$

whereas the **Roughness** is given by

$$\textbf{Roughness} = 100\left[\frac{\text{max}(\delta_j)}{\text{max}(P_j)}\right] \tag{4.15}$$

Show Uniformity within Clip A Diameter

Determines the Clip A edges of the profile and displays the Non-uniformity value. For the central 90% of this region, it calculates the **Non-uniformity**% value as follows

$$\textbf{Non-uniformity} = \frac{100 - \text{min}}{100 + \text{min}} \tag{4.16}$$

The non-uniformity value is displayed on the profile display (see Fig. 4.27e).

Show RMSD Non-Uniformity

Calculates and displays the normalized Root Mean Square Deviation(RMSD) of power.

$$\text{U}_\eta = \frac{1}{E_\eta}\sqrt{\frac{1}{A_\eta^i}\int\int[E(x,y) - E_\eta]^2\text{d}x\text{d}y)} \tag{4.17}$$

NOTE $U_\eta = 0$ indicates a beam with completely vertical edges and a flat top.
For more information see ISO+13694-2000

Show Edge Steepness

Calculates the Edge Steepness based off the normalized difference between the effective irradiation areas at 90% and 10% respectively.

$$s(z) = \frac{A_{0,1}^i(z) - A_{0,9}^i(z)}{A_{0,1}^i(z)} \tag{4.18}$$

$0 < s(z) < 1$

NOTE $s(z)$ approaches zero as the edges become more vertical
For more information see ISO+13694-2000

Shortcuts

See Table 4.11 for keyboard shortcuts.

Additional Notes

We use the FreeType library for rendering fonts on OpenGL plots.

Numeric display modes	This sets the display of numeric values in the software. XXX.Y um is the default choice.
Set centroid cliplevel	This allows you set a default other than the 13.53% which corresponds with 1/e^2
Set centroid cliplevel	This allows you set a default other than the 13.53% which corresponds with 1/e^2. The centroid is calculated for all pixels with % level above the centroid clip level. Currently, the level may be set between .5% and 99.5%.
Setup trigger	See Chapter 6 on Pulsed Lasers.
Enable auto-naming	When you save a file, a unique name will be suggested in the format WC_YY_MM_DD_HH_MM_SS_WC followed by the date and time read off your computer's clock.
ISO options	Adjusts settings for ISO compliant measurements such as σ (see Section 4).
Default Major / Minor method	Calculates major and minor axes based on the clip level method.
Use ISO 11146 compliant diameters and orientation	Calculates 4σ diameter and beam orientation based upon analysis of the whole image, rather than simply the line profiles along the crosshairs. See Appendix 7 for equations and explanations.
DXX mode	With a percentage of power designated with **Set Included Percentage Power Target**, D_{XX} mode calculates beam major, minor & mean diameters in mm, and area A_{XX} mm^2 of the ellipse centered about the centroid containing the specified % of the total energy in the beam (Per the requirements of IEC 60825). Entering the total beam power as measured by a calibrated power meter gives the power P in watts in A_{XX} and the irradiance I_{XX} W/cm^2.
Multi-beam setup	This is detailed in Appendix 11.

Table 4.3: Explains the options associated with the Setup dropdown menu.

Button	Description
Major/Minor	**Minor** The data is first clipped at **Clip[a]** and then the ISO 11146 method used to determine the orientation of the beam. Once the orientation has been found, the diameter of the beam along the **Major** and **Minor** axes is determined using the clip level method (see APPENDIX 7.
ISO-Maj / ISO-Min	**Major** and **Minor** diameters calculated according to ISO 11146. These are not shown outside of ISO 11146 mode.
Mean	**Mean** is the mean diameter of the beam, based on the Major and Minor diameter. The Major and Minor diameters are weighted in the calculation such that the mean is also valid for elliptical beams. $$Mean = 0.83114 * (\text{Major Diameter}) + 0.16886 * (\text{Minor Diameter}) \quad (4.3)$$
Eff_2W	$= \sqrt{\frac{4N_pA_p}{\pi}}$ where N_p is the number of pixels with an intensity above a set clip level (13.5% default) and A_p is the pixel area. In the **Setup** menu, choose **Enter Effective Width cliplevel** to change the clip level from its default value of 13.5%.
Ellipse	Ellipticity = **2W**[**minor**] / **2W**[**major**].
Orientation	The angle between the horizontal x-axis and the **major** or **minor** axis closest to the horizontal x-axis.
Crosshair	The angle between the horizontal x-axis and the solid crosshair line.
X_c, Y_c **X_g, Y_g** **X_p, Y_p** **X_u, Y_u**	Location of the crosshair center (μm) in Cartesian coordinates from the center of the full sensor. There are four different modes available to determine the crosshair position. **X_c** (default) uses the weighted intensity of the pixels. **X_g** sets the position to the geometric centroid of all points whose intensity falls above the geometric clip level. **X_p** sets the position to the pixel with the highest intensity. **X_u** sets the position to a user selected coordinate; this is chosen by mouse click and can be refined using arrow keys.

Table 4.5: Descriptions of the various result buttons.

Button	Description
R_c R_g R_p R_u	Radial distance from the center of the full sensor to the center of the current crosshair position. There are four different modes available to determine the crosshair position. X_c (default) uses the weighted intensity of the pixels. X_g sets the position to the geometric centroid of all points whose intensity falls above the geometric clip level. X_p sets the position to the pixel with the highest intensity. X_u sets the position to a user selected coordinate; this is chosen by mouse click and can be refined using arrow keys.
Centroid	Clicking **Centroid** toggles the origin position for the crosshair center measurement between **[absolute]** and **[relative]** (only in X_c mode). **[absolute]** defines the origin as the center of the image, whereas toggling to **[relative]** sets the origin to the last crosshair center value recorded in **[absolute]** mode.
ADC Peak %	The image peak level as a percentage of the ADC range, determined as the peak value for the average of any 'L' shaped group of three pixels within the image. It represents the raw level, calculated before any background subtraction.
Plateau Uniformity	Value between 0 and 1 denoting how closely the beam resembles a theoretically perfect flat-top beam.
PkToAvg	Peak-to-Average measurement. A circle large enough to contain all of the illuminated pixels (defined as pixels with intensity above the effective width clip level) is generated. The PkToAvg value is the ratio of the peak pixel's power compared to the average power within the circle.
Image Zoom	The current 2D screen zoom.

Table 4.6: Descriptions of the various result buttons (continued).

Title	Description
Image validity	Denotes whether the image shown is valid or invalid.
Good/Bad Frame Count	The number of good and bad frames taken since sampling began.
HyperCal status	Shows whether HyperCal is turned on.
Baseline	The level of input power subtracted by the algorithm.
Baseline STD	Standard deviation of the baseline.
Frame Rate	The number of frames per second.
Frames averaged	The number of frames averaged.
ADC Offset	Adjustment to ADC input range for reduced noise in the output.

Table 4.7: Gives explanations behind the different descriptors in the 2D area.

Title	Description
2Wua 2Wub 2Wva 2Wvb	The beam diameters **2Wa** and **2Wb** along the solid crosshair axis (**u**) and the dotted crosshair axis (**v**).
Scale (μm/div)	The scale of the current x-axis block division. Right click the graph and choose the desired zoom level (**1X** default) to adjust. Additionally, the cursor can be placed over the graph and **i** pressed to zoom in or **o** to zoom out. Hold down the mouse center button and move the cursor in the desired direction to pan left/right.
Peak = xx.x%	The peak value of a (unnormalized) profile as a percentage of the levels of the ADC range. There are 16384 levels for 14-bits, 1024 levels for 10-bits, and 65536 levels for the 16-bit CMOS. Cameras with less than 14 bits are bit shifted to fill 14 bits.
B = x.x%	The level of input power subtracted by the algorithm as a percentage of the peak.
Filter=0.2%	The baseline intensity level (percentage of peak) subtracted by the software.

Table 4.8: Explains the different text messages associated with the axis profile area (see Fig 4.25).

Option	Description
Display mode	• **Linear normalized (baseline subtracted)** Normalizes the profile to 100%. It is the default setting. • **Linear mode (baseline subtracted)** Displays the profile data with baseline subtraction. • **Linear raw mode (ADC mode)** Displays the profile data without baseline subtraction. • **Log mode** displays the profile at a logarithmic scale. This is useful for assessing low-level structure.
Intensity Multiplier	Allows you to superimpose a magnified profile over the current profile. The multiplier may be anywhere between 2 and 200 (see Fig. 4.27d).
Show clip levels	Provides horizontal lines on the profile plot corresponding to Clip Level A and Clip Level B (see Fig. 4.27b).
Show Clip Intercepts	Displays vertical lines where the profile crosses the intercepts (see Fig. 4.27c).
Show Gaussian fit	Displays a Gaussian fit (see Section 4).
Show Top-Hat fit	Displays a Top-Hat fit (see Section 4).
Show Max & Standard Deviation	Will display the Max and Standard Deviation values if either Show Gaussian fit or Show Top-Hat fit is also selected.
Show Coefficient & Roughness	Will display the Coefficient and Roughness values if Show Gaussian fit is also selected.
Show Uniformity within Clip A diameter	Will display the Non-uniformity value (see Fig. 4.27e).
Show RMSD Non-uniformity	Will display the Root Mean Square Deviation value.
Show Edge Steepness	Will display the edge steepness.
Show scale grids	Will display a grid along the profile plot (see Fig. 4.27a).

Table 4.9: Explains the different options associated with the Profile settings dialog box (see Fig 4.26).

Zoom	Allows you to zoom into the profile area with the following magnification values: 1×, 2×, 4×, 8×, 16×. Pressing **i** while hovering over the profile display will zoom in, whereas pressing **o** will zoom out.
Set clip level 1	Opens the clip level entry dialog box (see Section 4) for Clip Level A.
Set clip level 2	Opens the clip level entry dialog box (see Section 4) for Clip Level B.
Profile to clipboard	Saves the current profile image to the clipboard.
Export to Paint	Opens and places a screenshot of the current DataRay program in the paint application.
Export Profile data to Excel	Exports both the data from both profiles to Excel with a graphs showing the fit.
Save Profile data as text	Opens Notepad and places data from both profiles in a text document.
Beam Profile Fit to Excel	Opens Excel and places beam fit information in a spreadsheet along with graphs.
Display profile data outside Software Aperture	Allows including data outside the software aperture set in the 2D control

Table 4.10: Explains the different options associated with the Profile settings dialog box (see Fig 4.26)(continued).

Shortcut Keys	Description	Shortcut Keys	Description
F1 or **g**	Start camera capture	**F2** or **s**	Stop camera capture
b	Displays both profiles	**x** or **u**	Displays X profile
y or **v**	Displays y profile	**l**	Displays large 2D view
i	Zooms in	**o**	Zooms out
Ctrl+o	Opens the open dialog	**Ctrl+s**	Opens the save dialog
Ctrl+t	Opens the trigger dialog	**Ctrl+w**	Opens the wander dialog
Page Up	Increments the image index	**Page Down**	Decrements the image index

Table 4.11: Software shortcuts.

Chapter 5

Laser Attenuation

Introduction

This chapter addresses appropriate attenuation/beam sampling techniques and the measurement of large diameter beams. Where a recommendation not covered by this chapter is required, please email a description of your problem, together with a diagram and full laser beam details, to support@dataray.com. Although DataRay sells some laser attenuation equipment on our websites accessories page.

Cameras are designed to be sensitive to low light levels. Lasers are high intensity sources. If the beam irradiance (W/cm^2 or J/cm^2) exceeds the Damage Threshold (Minimum signal/unit area which causes damage) of the camera, irreparable damage may result.If the laser beam **Irradiance** (W/cm^2 or J/cm^2) exceeds the **Saturation Irradiance** (Saturation signal/unit area) of the camera, a saturated image results. If the beam overfills the active area, inaccurate measurement of the beam will result. Typical attenuation factors required between the laser beam and the camera are factors of 10^3 to 10^{10} or more (ND 5.0 to $>$ND 10.0).

WinCamD-LCM, WinCamD-GCM, and BladeCam2 Series cameras feature as standard:

- ND-1, ND-2, and ND-4 attenuating filters set at 3° to the optical axis in order to avoid interference fringes.
- Electronic shutter giving effectively ND4.5 (45 dB or 32,000:1) for CW beams.
- **Imager Gain** variation for pulsed beams

This makes achievement of the required levels of beam attenuation as simple as possible, but it is still important to understand what the considerations are, and how to address beam attenuation and large diameter beam measurement.

Although the WinCamD software offers background subtraction, for best dynamic range and Signal-to-Noise Ratio (SNR), it is better to reduce the ambient background to black level on the camera. Measurements under typical lab conditions require a reduction of the ambient level of around 10,000. The ND4 filter provided with WinCamD cameras provide suitable levels of ambient attenuation.

Attenuation	ND Value	Color Code
3	0.5	
10	1.0	
100	2.0	
1000	3.0	
10,000	4.0	
100,000	5.0	
LP1290	See Fig. 5.1	

Table 5.1: Gives the ND filter attenuation, name and color.

Important Terms

- **Irradiance**–Power Density. For a Gaussian beam the peak Irradiance I_0 may be calculated with Eq 7.2:
- **Signal-to-Noise Ratio (SNR)**–Peak Signal/RMS noise
- **Pulse Repetition Rate (PPR)**–Pulses per second for a pulsed laser.
- **Neutral Density** (**ND**)–A commonly used logarithmic approach to define the attenuation factor provided by a neutral filter (approximately wavelength independent). It has the advantage that logarithmic numbers may be added and subtracted, whereas attenuation factors must be multiplied and divided. The ND filters are supplied in color coded holders (see Table 5.1). ND is defined as:

$$\text{ND} = \log_{10}(\text{Attenuation Factor}) \tag{5.1}$$

- **Electronic shutter**–Most CCD cameras offer a manual, pull-down menu or software controlled 'electronic shutter' mode in which the **Exposure time** per frame (integration) may be set, effectively acting as an attenuator for CW inputs. For WinCamD Series cameras, the software interacts directly with the electronic shutter controls on the CCD chip, allowing on-screen shutter control in small steps from 40 μs to 1000 ms. For CW beams, the exposure automatically adjusts to the beam intensity. The use of an electronic shutter does not change the **Damage Threshold** in W/cm^2 for either CW or Pulsed lasers, the **Saturation Level** in W/cm^2 for CW lasers, or the **Saturation Level** in J/cm^2 for Pulsed lasers, unless the pulse-width is greater than the minimum electronic shutter period of 40 μs.

Attenuation of Your Beam

1. Using a suitable calibrated power or energy meter, measure the laser beam total power P in watts or energy per pulse E in joules, preferably at the point at which you wish to measure the beam profile.
2. By viewing the beam on a diffuse screen, or by using an IR Display Card or IR viewer for IR lasers, or by calculation,

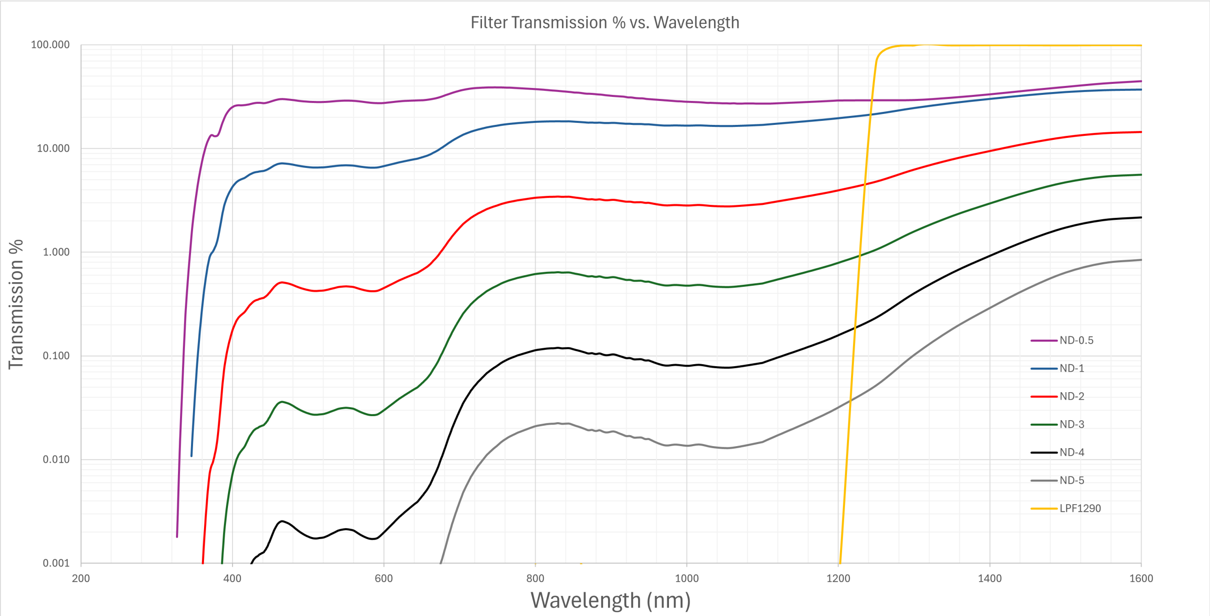


Figure 5.1

Figure 5.2: WinCamD filter transmissions % and ND vs. λ

or by some other means, estimate the laser beam diameter (the '1/e^2' diameter estimate, denoted as 2w). If you are using a lens or a microscope objective to magnify or demagnify the beam onto the WinCamD, then the beam diameter will vary as magnification M, and the irradiance will vary as 1/M^2. This should be less than the dimensions shown in Section 1.

3. Go the graphs in Section 1. If your beam is less than the saturation limits, then no further attenuation is required. If it is above the limits, carry on reading.

4. Calculate any additional attenuation required.

Additional Beam Sampling/Attenuation

Choose between the beam sampling/attenuation approaches given below. Note that since wave front aberration, diffraction and interference results from the inclusion of any optical component in a coherent beam. Schemes that introduce the minimum number of reflections, optical surfaces, optical media, and dust and fibers on surfaces are preferred. The catalog optics companies list a range of suitable accessories. Techniques for beam attenuation/sampling may fall into the following categories:

- **Absorbing Neutral Density (ND) filters**

  - Attenuation factors up to ND5.0 are available with single absorbing ND filters. As standard we offer stackable ND filters, 5 mm stack height, each in a circular housing with male and female Cmount threads. Filters are tilted by a few degrees to avoid interference fringes. Standard values are ND 0.5, 1.0, 2.0, 3.0, 4.0. Each filter assembly adds an additional 5.7 mm (0.22”) in depth in front of the CCD chip.

- Neutral density filters are not truly neutral since ND values are normally quoted at 546 nm. See Figure 5.1 for how transmission varies with wavelength.

- Power $> 2.5\times$ (Beam diam in mm) W, or $>$10 W total, may damage the ND filter. The limit is lower for pulsed lasers, especially ns and fs lasers.

- Do not attempt to attenuate high powers or power densities (irradiance) with absorbing ND filters. Absorbed power $> 2.5\times$ (Beam diam in mm) W, or $>$10 W total can cause the filters to shatter, presenting danger of injury and camera damage.

- **Metallic Neutral Density filters**

  Attenuation factors up to ND 4.0 (1/10,000) are available with single metallic ND filters. Avoid reflecting the beam back into the laser. Care must also be taken to direct the reflected beam to a beam dump. Above ND 2.0, metallic ND filters are highly wavelength dependent. For these reasons, metallic ND filters are not normally recommended.

- **Reflection Off a Window, Prism or Wedge Front Surface**
  Sampling factors from $\approx$4% for an uncoated window to $<$1% for an AR coated window (ND 1.4 to $>$ND 2.0). An issue with any such reflection is the degree of polarization sensitivity as a function of angle of incidence. Catalog optics companies also offer suitable wedged windows. Note that fused silica damage thresholds can be as high as 1 kW/cm^2, so this can be a very effective way of dumping power.

- **Multiple reflections in a wedge beamsplitter**
  Sampling factors of 1/1,000,000 are attainable, but multiple internal reflections may lead to interference if the beam divergence is comparable to the beam deviations in the wedge prism. Since the angular separation of the beams is 2ϕ, if the beam is large and ϕ is small, it can be hard to determine which beam is being sampled.

  The **Polarization Preserving Beam Sampler (PPBS)** (see Fig. 5.3) will sample a small percentage of a beam's power for measurement applications where the original beam's power density would otherwise damage the measurement instrument or standard absorptive ND filters. The PPBS samples the reflections from two orthogonal wedge windows to safely reduce the power of high intensity light while preserving the original polarization of the input beam and eliminating the effects of multiple reflections from each air-glass interface. It consists of a pair of glass windows that each transmit a large percentage of the input beam's energy to be discarded or trapped in a beam trap, and reflect a small percentage of the input beam's energy at each window surface for measurement. Two reflections occur at each window–one per surface. This results in 4 beams exiting the PPBS from the output face. The beam of interest is the result of the reflections off the first surface of each window. The three other beams exiting the PPBS are displaced due to the wedge design of the windows so that they do not hit the beam profiler's imaging area.

UV Lasers

DataRay offers screw-on UV converters. Download the UV Profilers Datasheet from the website. The WinCamD-LCM sensor has been testes down to 190 nm without degradation (See WinCamD-LCM UV detection).

Figure 5.3: TThe PPBS mounted to a WinCamD-LCM. A beam trap (BT-50) is used to trap the majority of the input beam's power

Figure 5.4: The WinCamD-LCM with screw-on UV Converter accessory

Chapter 6

Capturing Pulsed Lasers

WinCamD and TaperCamD series cameras make capturing pulsed beams as simple as possible. However, we recommend learning to operate the software with a simple CW beam before you try to operate with a pulsed beam.

WinCamD-LCM, WinCamD-GCM, WinCamD-QD, and TaperCamD-LCM series cameras feature:

- A input trigger via SMB or BNC
- Comprehensive Auto Trigger capability.
- Synchronizing to a positive 5V input pulse (preferably TTL). There is 200 ns delay between the trigger pulse and the shutter opening.
- Output of a 5 V TTL sync pulse to trigger a laser.
- Advance/delay of the electronic shutter with respect to the input/output trigger.
- The ability to vary the shutter exposure time allowing beam 'attenuation' on pulsed beams with pulse widths greater than 40 μs.
- The ability to vary the LCM gain up to 3.2:1.

Important: The BladeCam2-HR, BladeCam2-XHR, and WinCamD-IR-BB beam profiling cameras have a rolling shutter and as such are only suitable for CW or quasi-CW lasers.

Terms and Features

See Table 6.1 for a list of terms and pertaining to pulsed beam capture.

Term	Description
Synchronous Camera Trigger	The camera is triggered by a TTL pulse from the laser.
Exposure/Electronic Shutter	The light falling on the array leads to a proportional integrated signal while the electronic shutter is open.
PRR	The Pulse Repetition Rate of the laser.
SNR	The Signal to (rms) Noise Ratio

Table 6.1: Pulse Capture Terms and Features.

Notes

- The electronic shutter opens once per frame. The *Exposure time* (integration time) can be changed in small steps for the WinCamD-LCM, WinCamD-GCM, WinCamD-QD, and TaperCamD-LCM series cameras
- Imagers perform "energy in a bucket" integration. All photo-electrons [pulse(s) plus background] incident within the electronic shutter period are integrated.

  An ideal situation is that a single laser pulse falls within the period when the shutter is open, and that the background is zero. It is therefore important to use a logical procedure to systematically adjust settings to correctly capture beams. Consider a laser pulse train. A pulse will only be captured when it falls within an open shutter period. The pulse train and the imager exposure period must coincide.
- The frame transfer timing pulse reads out all charge accumulated on the pixels, essentially clearing the imaging area.
- Imager gain may be increased in order to increase signal closer to saturation (85% of Peak on the ADC is ideal) at the expense of slightly degraded SNR.

Pulsed Beam Capture Initial Setup

Capturing pulsed beams may require some trial and error to obtain the best results. Read the following advice to avoid damaging the camera and/or your eyes.

1. Read and apply Chapter 5 for your personal safety and to set the power falling on the camera head to acceptable levels. If you are unsure, move the beam in slowly from the edge to first pick-up the edge of the beam.
2. Start in CW mode. Press **File, Load defaults**. It is highly recommended that you initially treat the beam as if it were CW, with the camera shutter on auto, watching and centering the occasional captured pulses on the screen. If you see nothing in untriggered mode, you will see nothing in any of the triggered modes. At this stage you are concerned with ensuring that the beam is not too faint to observe and is centered on the imager.
3. Note that the **Gain** may be increased using the on-screen slider located just below the 3D display areas. Higher gains assist in setting the signal level (**Peak = xx.x %**) to its optimum value of 90% (% of ADC saturation) but at the expense of somewhat degraded SNR.

4. Next, minimize the 'dead' space around the beam by redefining the Capture Block (See Section 2) to be as small as possible while still fully capturing the beam (Fig. 6.1). If this is not done, a residual un-subtracted integrated image background may be a significant percentage of the pulsed signal, and may compromise correct capture and analysis. (The software automatically subtracts the baseline value, based upon the lowest signal level in the capture region.)

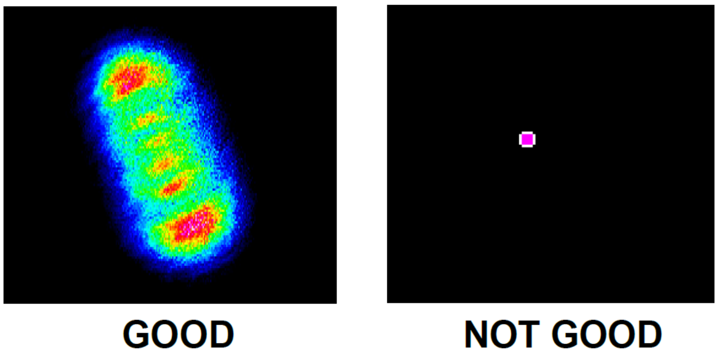


Figure 6.1: The capture block should contain the beam without excessive 'dead' space.

In order to access the **Trigger Setup** dialog (Fig. 6.3), right-click on the trigger delay box (Fig. 6.2) located below the 3D area or press **Ctrl T**.

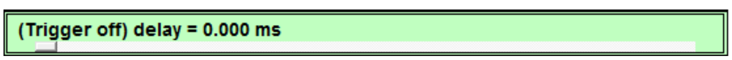


Figure 6.2: Right-click this trigger delay box to access the Trigger Setup dialog.

Trigger Modes

There are two triggered modes of operation provided by the WinCamD and TaperCamD series cameras and the DataRay software:

- **Auto Trigger**-no 'formal' laser synchronization occurs
- **Synchronized mode**-the laser provides a trigger output or input.

Auto Trigger Mode

In Auto Trigger mode, WinCamD automatically captures and displays pulses that lie within the intensity limits set by the user. Auto Trigger is attractive to many users of the WinCamD and TaperCamD series. It works well in many circumstances. Auto Trigger may require some trial and error experimentation to get consistent results. It may require a level of knowledge of what is "good data", based upon a level of experience with the WinCamD and the laser being tested. Even if your laser driver provides a TTL trigger output or accepts a trigger input, try Auto Trigger before trying Synchronized mode.

A few notes on Auto-trigger:

- Auto-trigger is totally ungated and untriggered, with a simple upper and lower intensity level criteria to accept or reject images each time a frame is captured.

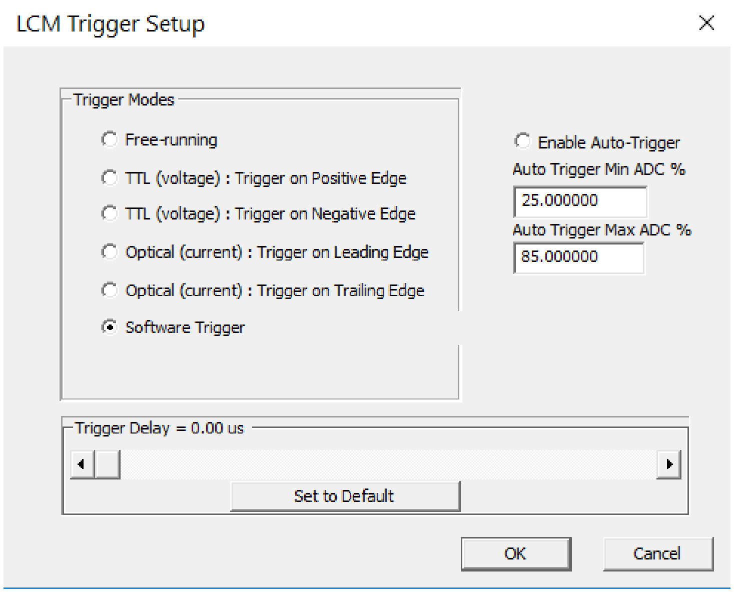


Figure 6.3

Figure 6.4: Trigger Setup Dialog for WinCamD-LCM

- Capture status messages are displayed in the box on the left hand side immediately below the button bar.

Auto-Trigger Mode Operation

1. As previously advised, first set up in CW mode.

2. Press **Ctrl T**, or right-click on the non-slider area of the **Trigger Control** box (Fig. 6.2), to open the dialog box shown in Fig. 6.3, and select **Enable Auto-Trigger**.

3. Unless you have a reason to select otherwise, start with the defaults of **25%** and **85%** for the **Auto Trigger Min ADC %** and **Auto Trigger Max ADC %** respectively. The % is expressed as a proportion of the saturation level of the ADC, as shown on the screen. If the **Auto Trigger Max ADC %** is set to 100%, then beams with intensity above 100% will also be captured. Setting to any value below 100% (e.g. 99%) excludes such beams. If the **Auto Trigger Min ADC %** is set at 0%, then the software triggers on noise as well as real beams.

4. Pulse Repetition Rate dependencies.

   - **PRR $<$25 kHz**. Capture single pulses by manually setting the exposure (see next).

   - **PRR $\geq$25 kHz**. Treat as a CW beam, and ignore pulsed laser operation. The number of pulses n captured per exposure is defined by

   $$n = \tau \times f \tag{6.1}$$

   where τ is the exposure period in millisecond and f is the PRR in kHz.

5. If **Auto-Trigger** mode is enabled, a dialog box will alert the user after pressing **OK** on the **Trigger Setup** dialog box that Auto-exposure will be disabled. This is so the user can manually select an exposure time to help control the

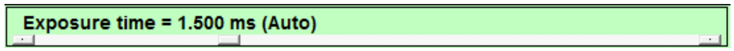


Figure 6.5: Right-click the exposure time box to open the Exposure Control dialog. If Auto-exposure is disabled, the scroll bar at the bottom of this box can be dragged to change the exposure time.

beam saturation.

'Control' can mean attenuating a single wide pulse beam by capturing only a part of that beam (e.g. a pulsed LED) or sampling a string of high PRR laser pulses by capturing a larger or smaller number of pulses during each exposure.

Normally, set **Exposure** $\approx$ 0.95/PRR, to capture single pulses. Any longer exposure time will capture one or more pulses. The exposure time can be set using the scroll bar shown in Fig. 6.5. (E.g. For PRR = 200 Hz, set **Exposure time** to just below 5 ms (1/200) in order to capture nearly every pulse.) If background illumination levels are a problem, set the exposure time to a lower value, but at the expense of probability of pulse capture.

The camera will repeatedly capture beam images, as fast as the set **Exposure**, the software & the PC will allow. Pulses with an ADC % within the set levels will be captured and displayed. However, pulses which do not meet the criteria will not be displayed.

6. Begin capturing images by pressing Go. Images that are not within the set Min and Max ADC % from the Trigger Setup dialog will be ignored. Keep this in mind if images are not returning (Setting the Min to 0% and Max to 100% will return every exposure including exposures that happened to collect more, or less, than one pulse).

7. **Intensity Variations**. Because the Auto-Trigger mode is asynchronous with the pulsing laser, the intensity can fluctuate to a greater or lesser extent as one or more pulses fully or partially overlaps the exposure period, and one or more pulses gets included.

   To restrict the captured images to unsaturated images of reasonable intensity, set the **Auto Trigger Max ADC %** to 90%, and increase the **Auto Trigger Min ADC %**. Then adjust the external attenuators and/or the CCD gain until pulses are being captured. A narrow ratio between the **Maximum** and **Minimum** levels ensures that only single pulses will be captured.

Note: If you use an Exposure below the laser pulsewidth and the pulse spatial distribution changes during the pulse, then a single pulse image will not fully represent the pulse. Instead use External Trigger mode.

External Trigger Mode

In this mode, WinCamD captures and displays pulses by laser synchronization.

1. **Ctrl T** opens the **Trigger Setup** dialog box. Select one of the TTL (voltage) trigger modes if you are using TTL input pulses. Select one of the Optical (current) trigger modes if you are using an optical trigger. Make sure **Enable Auto Trigger** is unchecked. Then press OK.

2. After pressing Go, each trigger input to the camera will begin an exposure.

   Attach a 50 Ω or 75 Ω BNC cable to the BNC connector on the camera head. The WinCamD-LCM and TaperCamD-LCM impedance is 75Ω. The WinCamD-QD and WinCamD-GCM impedance is 50 Ω. If it does not work, verify the electrical pulse shape on an oscilloscope.

3. The camera will repeatedly capture images as fast as the software, the PC and the **Capture Block** settings will allow. In this setting the shutter is open continuously. As requested by the software, the accumulated image is moved to the interline transfer register for readout.

4. Disable Auto-exposure in the Exposure Control dialog (Fig. 6.6) which is accessed by right-clicking the exposure time box (Fig. 6.5) and set an appropriate **Exposure time** as discussed earlier in section 6 by using the scroll bar slider in the green exposure time box.

5. Advance or delay the **Trigger Control** slider (Fig. 6.2) to change the timing of the capture in relation to the trigger pulse, until the whole pulse is captured.

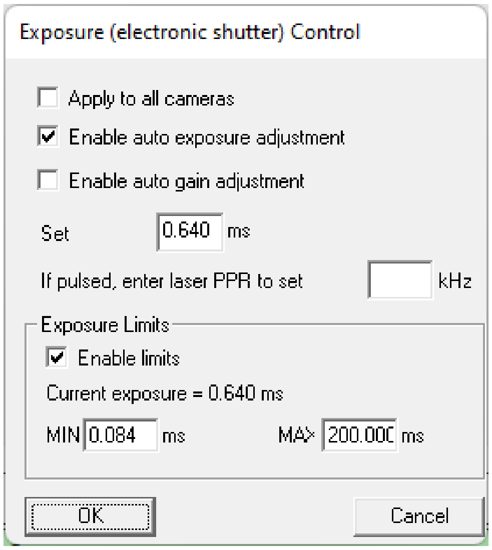


Figure 6.6: The Exposure Control dialog box is used to disable Auto-exposure.

Chapter 7

Beam Diameter Parameters and Measurement

Gaussian Beams

Gaussian beams are one of the most commonly measured laser beans. They derive their name from the Gaussian function in the equation for both the electric field and irradiance. The equations for the electric field of a laser are found by solving the wave equation. When the wave equation is solved in Cartesian coordinates, the resulting solution is the Hermite-Gaussian modes (see Fig. 7.2), whereas the solution when solving in polar coordinates is the Laguerre-Gaussian modes (see Fig. 7.3). The Hermite-Gaussian (0,0) mode equation is the same as the Laguerre-Gaussian equation for the (0,0) mode. The (0,0) mode is known as the Transverse Electromagnetic Mode 00 (TEM_{00}) or the fundamental Gaussian (see Fig. 7.1). The equation for the irradiance of the TEM_{00} mode is

$$I\left(r,z\right) = I_0 e^{\frac{-2r^2}{w^2(z)}} \tag{7.1}$$

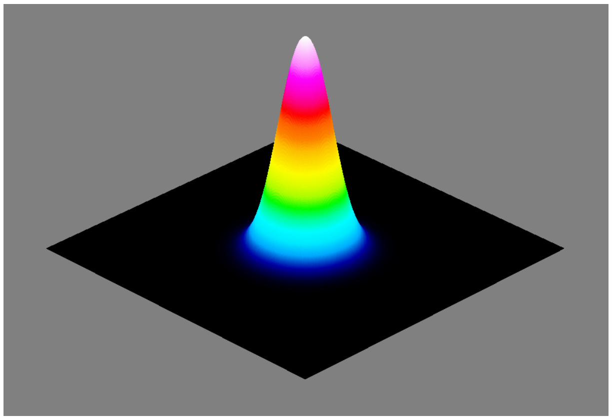


Figure 7.1: 3D Image of a fundamental Gaussian beam (TEM_{00}).

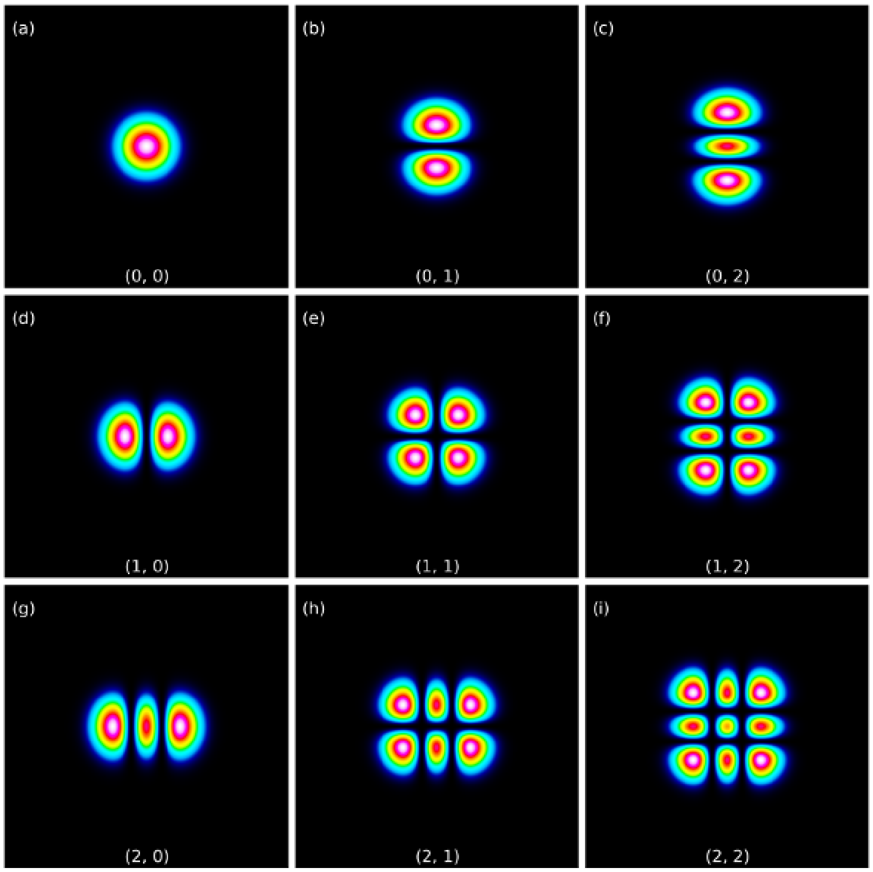


Figure 7.2: An array of subplots containing the various Hermite-Gaussian modes. Notice that the definition of beam width becomes fairly abstract in the higher-order modes.

where r is the radius, $w(z)$ is the radius when the intensity has fallen to $\frac{1}{e^2}$ (13.5%) of the peak value, and P is the total power of the beam. I_0 is described by

$$I_0 = \frac{2P}{\pi w^2} \tag{7.2}$$

Since the fundamental Gaussian is often the desired laser output, it is used to set the definition for many beam measurement techniques in this chapter.

Beam Irradiance

In order to assess whether the irradiance (power per area, for example, mW/cm^2) from a given laser might overload a beam profiler, it is useful to be able to calculate the peak irradiance (see Eq. 7.1). Using the on-axis irradiance at $r = 0$ and Eq. 7.1

$$I\left(0\right) = \frac{2P}{\pi w^2} \tag{7.3}$$

while for $r = w$

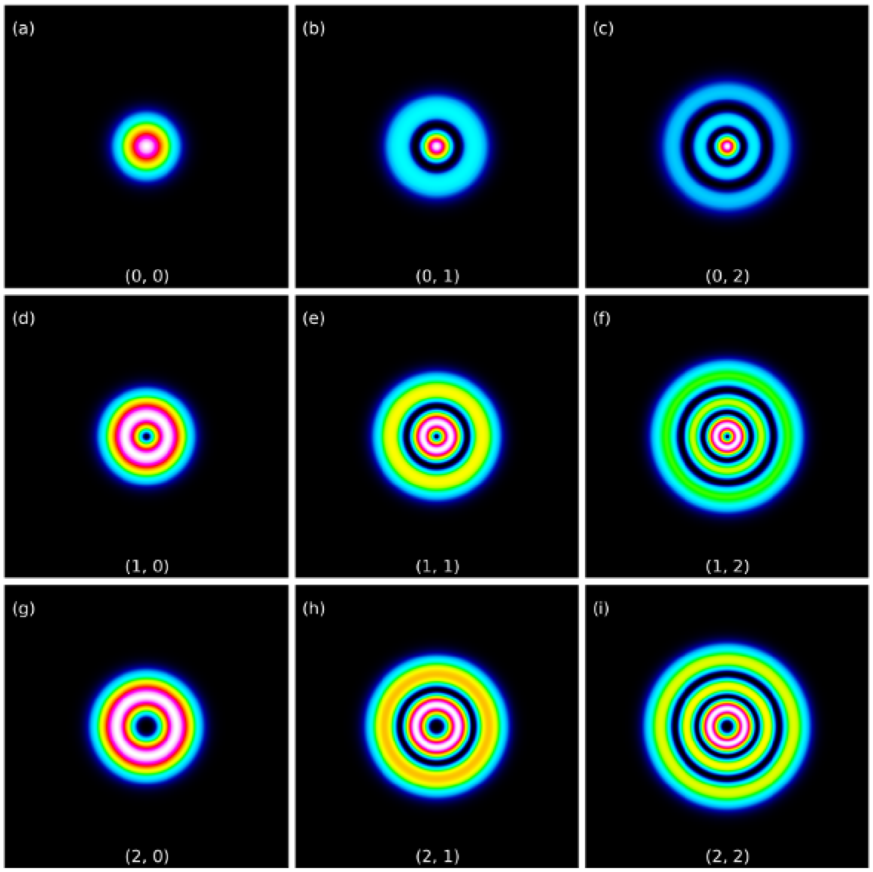


Figure 7.3: An array of subplots containing various Laguerre-Gaussian modes.

$$I(w) = \frac{2P}{\pi w^2}\frac{1}{e^2} \tag{7.4}$$

For example:

- The peak irradiance from a 1 mm diameter, 10 mW HeNe is 26 mW/mm^2.
- The peak irradiance from a 5 mm diameter, 5 W Nd:Yag is 520 mW/mm^2.

Beam Width Measurement Techniques

Although there are multiple ways to determine the diameter of a laser beam, two of the most common are the clip level method and the second moment method.

Clip Level Width

The clip level method uses a set percentage of the beam's peak intensity to determine the edges of the beam. We list the steps in the clip level method:

1. First a clip level is set. DataRay uses 13.5% and 50% as the default clip levels. 13.5% corresponds to the beam width where the intensity falls to 1/e^2 of the peak while 50% corresponds to the Full Width Half Maximum (FWHM). These clip levels can be modified by by clicking the **Clip A** and **Clip B** buttons.
2. Next, the DataRay software finds the profile of the beam along the solid and dashed crosshairs in the 2D profile. By default, these crosshairs are fixed to the major and minor axes (see Fig. 7.4).
3. The position where the beam intensity is equal to the clip level is then found for each profile (major and minor). Since most beams are fairly Gaussian, there will be two positions where this occurs.
4. The distance between these two positions is then calculated as the beam width.

The clip level method is often used with scanning slit sensors as they only return axis profile data. Even with camera sensors —which take a two dimensional array of data— the clip level method is often used, as it provides a less computational intensive beam width measurement. However, since only the axis profiles are utilized, subtleties in the beam's composition can be lost. Additionally, clip level diameters do not take into account the edges or "tails" of the beam profile where intensity is low.

Second Moment Beam Diameter

Camera profilers generate true 2D beam profiles, allowing more complex and accurate techniques than the clip level method to be used. The second moment method provides the most accurate beam width measurement technique and is formally defined in the international standard for beam measurement techniques —the ISO 11146 Standard [1]. For perfectly Gaussian beams, the second moment definition of beam diameter produces identical results to the clip level method with the default 1/e^2 (13.5%) clip level. For radial coordinates the beam width is defined as

$$d_\sigma(z) = 2\sqrt{2}\sigma(z) \tag{7.5}$$

where the variance $\sigma^2(z)$ is calculated as

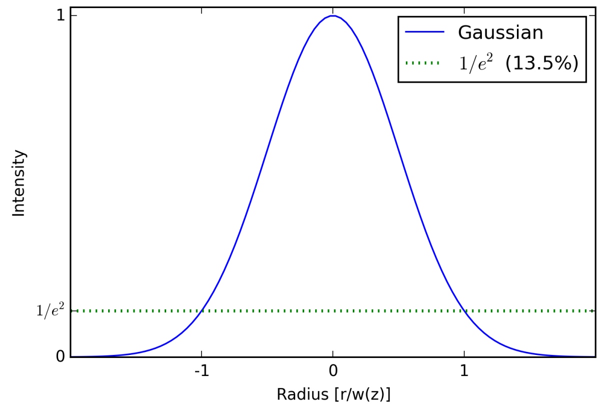


Figure 7.4: Axis profile for a (TEM_{00}).

$$\sigma^2(z) = \frac{\iint r^2 I(r,\phi,z)\, dr\, d\phi}{\iint I(r,\phi,z)\, dr\, d\phi} \tag{7.6}$$

where r is the distance to the centroid ($\bar{x}$, $\bar{y}$) given by the first moments

$$\bar{x} = \frac{\iint x I(x,y,z)\, dx\, dy}{\iint I(x,y,z)\, dx\, dy} \tag{7.7}$$

$$\bar{y} = \frac{\iint y I(x,y,z)\, dx\, dy}{\iint I(x,y,z)\, dx\, dy} \tag{7.8}$$

and $I(r,\phi,z)$ is the radial intensity distribution versus angular position ϕ, along propagation axis z. In more useful x and y terms (which actually get measured)

$$\sigma_x^2(z) = \frac{\iint (x-\bar{x})^2 I(x,y,z)\, dx\, dy}{\iint I(x,y,z)\, dx\, dy} \tag{7.9}$$

$$\sigma_y^2(z) = \frac{\iint (y-\bar{y})^2 I(x,y,z)\, dx\, dy}{\iint I(x,y,z)\, dx\, dy} \tag{7.10}$$

so that the beam widths $d_{\sigma x}$ and $d_{\sigma y}$ are given by

$$d_{\sigma x} = 4\sigma_x(z) \tag{7.11}$$

$$d_{\sigma y} = 4\sigma_y(z) \tag{7.12}$$

Furthermore, the orientation of the beam (angle ϕ) is given by

$$\phi = \frac{2\sigma_{xy}^2}{\sigma_x^2 - \sigma_y^2} \tag{7.13}$$

The ISO 11146 [1] standard actually terms the quantity $E(x, y, z)$ rather than $I(x, y, z)$. Additionally, we have used the $d_{\sigma x}(z)$ and $d_{\sigma y}(z)$ notation given in the standard rather than the $2W_{\sigma x}(z)$ and $2W_{\sigma y}(z)$ used elsewhere in this manual.

Although the second moment method is useful, the integrals weight noise heavily and can compromise the accuracy of the measurements. Most commercial second moment beam diameter software first automatically determines and subtracts the background noise, and then truncates $I(x, y, z)$ to the zeroed background level at a predetermined distance from the 1/e^2 diameter. This distance defines the software aperture, the diameter of which is set to three times the major diameter of the beam in the DataRay software. To override this diameter, right-click the 2D profile, select **Setup Software Aperture**, and choose one of the software aperture options.

Chapter 8

Accuracy, Precision and Resolution

This section describes the error that can arise to discretization and quantization of the beam by the sensor's pixel array. Users sometimes ask the following questions:

- What is the beam measurement accuracy/error of my camera profiler?
- How can you justify listing accuracy values smaller than the pixel size?
- How does the accuracy depend on the beam size?

They may feel frustration when the answers are somewhat ambiguous, since the answer always depends on the actual measured beam.

Definitions - Accuracy vs. Precision vs. Resolution

The **accuracy** of a reading describes how close the reading is to the absolute value of the parameter being measured. The absolute value is the value that would be read by a perfect measurement system in perfect calibration with zero errors.

The **precision** of an instrument refers to the repeatability of the value obtained. An otherwise perfect measurement instrument that was incorrectly calibrated could be described as inaccurate but precise.

The **resolution** of an instrument refers to the smallest increment (i.e. above the noise level) that the instrument can measure.

Readout resolution is the smallest increment that can be read on the screen or via the software interface. DataRay software offers several **Numeric Display Modes**. The default is **XXX.Y μm**. The user may choose other options, but changing the **Numeric Display Mode** does not change measurement accuracy.

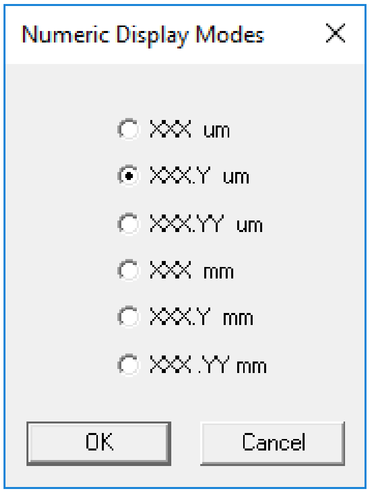


Figure 8.1: Numeric Display Modes.

Pixel Size/Pitch Quantization

The pixel pitch of DataRay profilers is shown in Chapter 1. Keep in mind, in **Fast** and **4X BINNING** modes, the pixel pitch is doubled.

While it may seem that all measurements are 'quantized' in terms of the pixel dimension, this is not the case as explained below.

Beam Diameter Based on Clip Level

DataRay camera profilers rely on inter-pixel linear intensity interpolation to clip level diameter measurements.

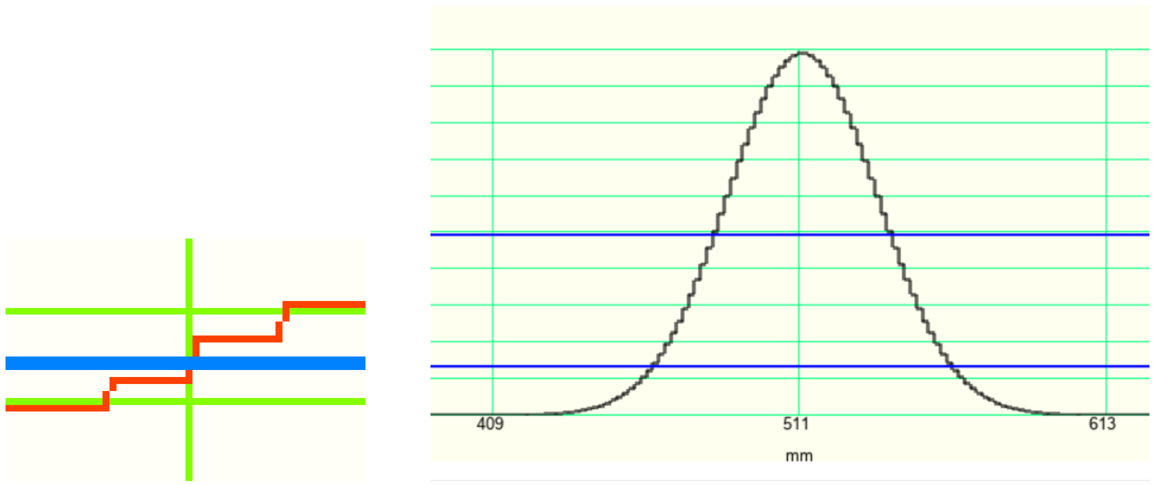
In Fig. 8.2a, the magnified orange profile portion, shown against the light green grid, shows the profile intensity (y-axis) versus position (x-axis) for the left hand edge of a profile. There are pixels above and below, but not on, the blue line indicating the requested clip level.

Rather than simply taking the outer pixel as a diameter basis, the profiler determines the position of the two (adjacent) pixels above and below the requested clip level, and performs a linear interpolation between these two values. It then makes the same determination for the right hand side of the full profile. The difference between these two interpolated positions determines the diameter for the specified clip level.) Since these interpolated values are not quantized by the pixel location, the measured beam diameter is not quantized by the pixel size.

Smallest Beam Size

Understanding this inter-pixel intensity interpolation leads to an understanding that accuracy will degrade as we move to smaller beams.

Fig. 8.2b shows the profile of a 100 μm diameter Gaussian beam. Even with 4.65 μm pixels, the validity of linear interpolation starts to break down as we go to smaller beams. This is because the two adjacent pixels start to lie on a curve rather than a straight line segment. Generally, we recommend that the user ensures that they cover at least 10 camera



(a)

(b)

Figure 8.2: (a) Interpolation of quantized levels. (b) Full beam profile quantization and clip level interpolation.

pixels along each axis to get a good measurement. The rest of this section will examine why we provide this guideline, discuss the theory behind it, and use measured data gathered from several DataRay cameras to validate this theory. We will also provide approximate error values to expect when covering a small numbers of pixels.

The ADC values of the illuminated pixels are proportional to the intensity and power (we assume the intensity is constant across the pixel and thus the power is a scalar multiple of the intensity) and thus we can plot the intensity against the pixel position to obtain a profile of the beam. The simplest way of determining the width from the beam profile is the clip level method. First, the maximum intensity (α) of the beam profile is determined and a certain percentage cutoff (γ) is set (we use 13.5%). An algorithm searches to find where the beam intensity is equal to α and returns the pixel coordinates. For almost all beams, there are two such pixel coordinates and by determining the distance between them the beam width can be found.

The error in the width of the beam being profiled by the clip level method is directly proportional to the number of pixels that are illuminated. With an infinite number of illuminated pixels (requiring infinitely small pixels), the true profile of the beam would be represented. However, camera sensors have finite pixel dimensions which cause a discretization of the returned beam profile. The discretization causes errors in the beam diameter measurement. Therefore, the beam must illuminate a minimum number of pixels for an accurate beam width measurement. To determine the minimum amount of pixels that must be illuminated, DataRay created a theoretical model and tested it against experimental data.

Theoretical model

First, the profile of a perfect Gaussian beam was generated to represent the profile of a beam incident on a sensor (see Fig. 8.3). The beam width can be analytically determined by using the Gaussian formula

$$I(r) = I_0 e^{\frac{2}{w^2(z)} r^2} \tag{8.1}$$

Where I_0 is the peak intensity of the Gaussian, $w(z)$ is the beam width when the intensity falls to 1/e^2 and r is the radius. By setting $I(r) = \gamma I_0$, where $0 \leq \gamma \leq 1$, and then solving for the r, the beam's width is found to be

$$\Delta r = r_2 - r_1 = \left(w(z)\sqrt{\frac{1}{2}\ln\left(\frac{1}{\gamma}\right)}\right) - \left(-w(z)\sqrt{\frac{1}{2}\ln\left(\frac{1}{\gamma}\right)}\right) = w(z)\sqrt{2\ln\left(\frac{1}{\gamma}\right)} \tag{8.2}$$

To approximate how the sensor reads the beam intensity, a number of equally sized bins m along the x-axis were created. A bin represents one pixel; therefore, m represents the number of pixels illuminated. The beam intensity was then integrated across the width of each bin and the values normalized by setting the maximum bin value equal to the maximum of the Gaussian beam. The bins were then plotted alongside the Gaussian. After quantizing the Gaussian, the quantized beam's width was determined. The percentage error was calculated by comparing the quantized beam's width against the analytically determined width (see Fig. 8.3).

We experimented with different values of m, from $m = 5$ to $m = 100$. As the number of pixels illuminated increased, the quantized beam provided a better approximation of the Gaussian, and the average error of the quantized beam's width measurement decreased. We also randomly offset the Gaussian beam such that the center of the Gaussian did not always fall in the exact center of a pixel. If the beam is perfectly aligned on the pixels, then a symmetric quantization will be seen (see Fig. 8.3a). However, if the beam is shifted slightly, then an asymmetric quantization will be seen (see Fig. 8.3b). A variety of different alignments for each m value were simulated and the percentage errors recorded (see Fig. 8.3c-Fig. 8.3f). The error for different alignments at the various levels m were averaged to provide a better estimation of the true error. Finally, the percentage errors were fitted to a decaying exponential curve (see Fig. 8.4a).

Experiment

To prove the validity of our theoretical model, we devised an experiment to find the percentage error vs. pixels illuminated. The beam waist of a focused 675 nm Gaussian beam was measured with six different pixel sizes and two lenses for a total of twelve different measurements. Furthermore, each measurement included an x and y axis for a total of twenty-four data points. The measured width of the beam was divided by the pixel size to give the number of pixels illuminated. The percentage error of the beam width was calculated by comparison with the Beam'R2 control width. Finally, the percentage error vs. the pixels illuminated was plotted with a decaying exponential curve fitted through the data. The experimental results followed the theoretical results and we see similar decaying exponential curves in both the experimental and theoretical data (see Fig. 8.4). From the theoretical model, ten illuminated pixels corresponds to approximately a 10% error, while the experimental data shows that a 5% error was achieved.

Second Moment Diameter

The second moment diameter of an image is based upon an area integral weighted by the square of the distance from the beam centroid. As such it does not include a specific clip level (see Chapter 7 for a full description and the formulae).

Since second moment diameter is a total image based calculation, then, at least to a first order, it is not subject to pixel dimension quantization limits.

In accordance with the ISO 11146 standard, DataRay cuts off the calculation at 99% of the included energy. For a pure Gaussian beam 99% of the energy corresponds to curtailing the calculation at a clip level of 1%, corresponding to a beam diameter 1.54 times greater than the 13.5 % clip level diameter. For typical beams that are not pure Gaussians these numbers are different.

Centroid

The Centroid (Xc,Yc) of an image is the intensity weighted arithmetic mean position of all pixel intensities above the centroid clip level (default value 13.5%). It is the 'center of gravity' of the beam.

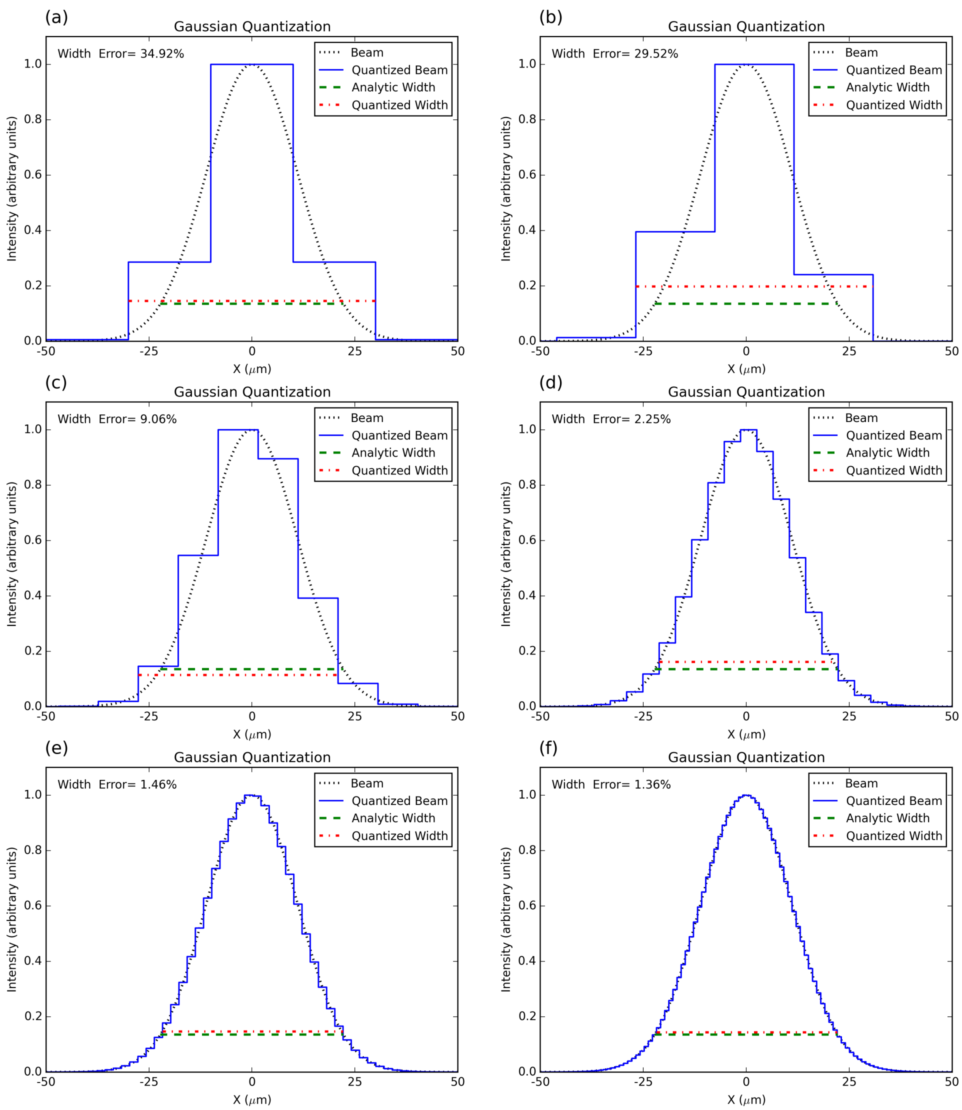


Figure 8.3: (a) The Gaussian beam (dotted) is approximated by the quantized beam (solid). The quantized beam has pixels=5. The analytic width (dashed) is compared to the quantized width (dash-dot) to give the Width Percentage error listed. Note the quantized beam is symmetric. (b) Although is still equal to 5, by changing the alignment of the beam on the pixels, the quantized beam becomes asymmetric. (c) =10. (d) =25. (e) =50. (f) =100. Note that as the number of pixels illuminated grows larger, the quantized beam better approximates the Gaussian and the error decreases.

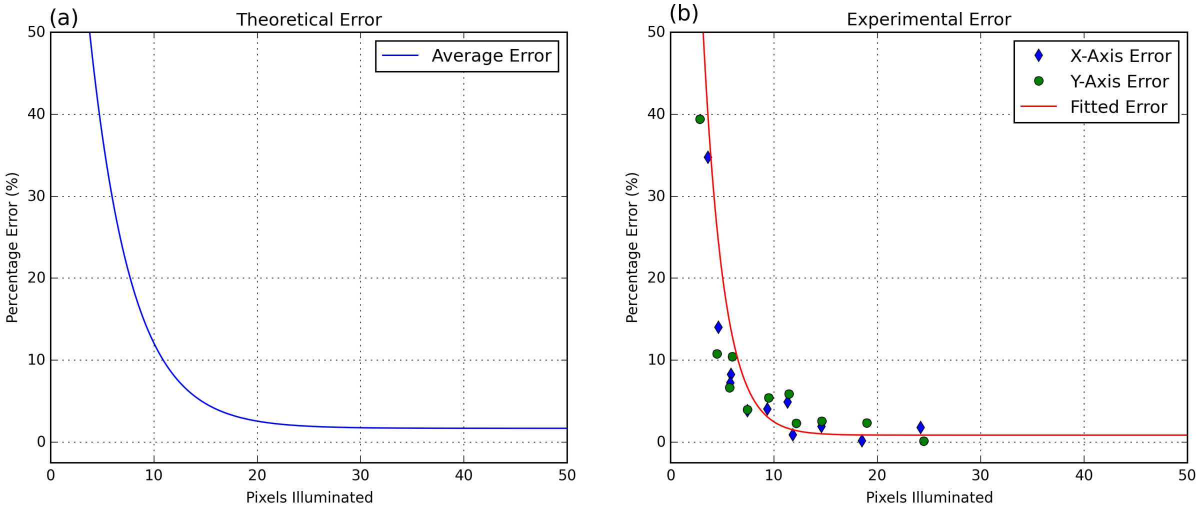


Figure 8.4: (a) The percentage error of the beam width as a function of the number pixels illuminated. This was a numeric simulation. (b) The percentage error of the beam width as a function of the number pixels illuminated. This was tested with a number of different DataRay devices and lenses.

As noise moves pixels above and below the centroid clip level, and hence in or out of the centroid calculation, the centroid value may change by an amount lower than the pixel size. For large beams the 'quantization' is barely visible. For smaller beams, it may become significant.

Chapter 9

M2 and Divergence Measurements with M2DU

A guide to performing M^2 and divergence measurements using a WinCamD camera and M2DU stage. Applies to: Software Ver. iDataRayLCMvA30.exe or higher, running under Windows 7, 8, 10, or 11.

Description

The USB 2.0 **M2DU** accessory converts WinCamD and BladeCam2 beam profiling cameras into a compact, fully ISO 11146 compliant M^2 measurement system. The M2DU system is comprised of an achromatic or plano-convex lens fixed to the front of a travel stage on which the profiler is carried. The lens refocuses an input beam to a waist within the stage's travel range. While DataRay provides a spreadsheet (see Section 9) to simplify the choice of lens, we will also work with each customer to recommend and supply the correct lens.

ASR™ 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.

Applications

- M^2 measurement of CW & pulsed lasers
- Focus position of CW & pulsed lasers
- Pointing angle of CW & pulsed lasers
- Divergence angle of CW & pulsed lasers

Features

- Auto Scan Range (ASR™) for ISO 11146 compliant scan
- USB 2.0 & 3.0 for field service applications
- Fast, Compact, Portable system

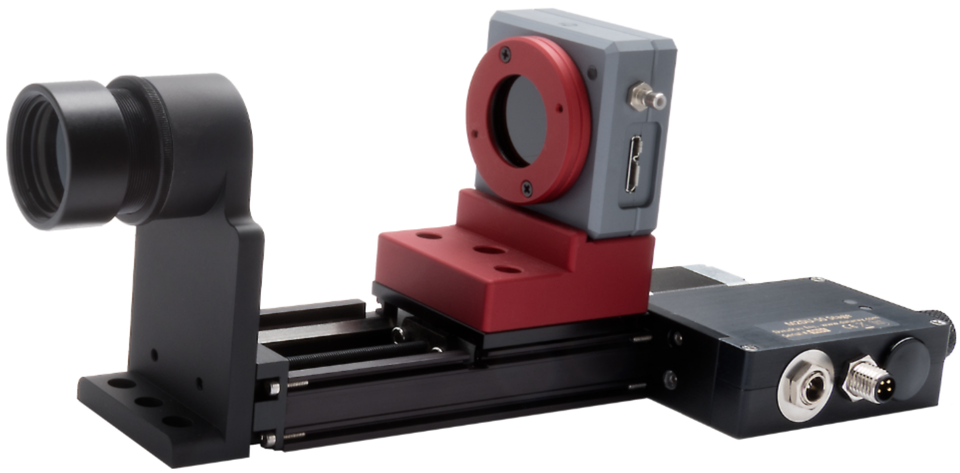


Figure 9.1: WinCamD-LCM on M2DU-50 stage.

- Swappable lens assemblies

Specifications

- **Maximum beam diameter:** See Fig. 9.2
- **190 nm to 16 μm** wavelengths (dependent on profiler and lens)
- **High power** attenuation accessories available
- M^2 **Range*** 1 to $>$50
- M^2 **Accuracy*** ±5% typical
- M^2 **Repeatability*** ±2% typical

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

Parts List

- **WinCamD** or **BladeCam2** series head. Compatible profilers include:
  - **WinCamD-LCM**
  - **WinCamD-GCM**
  - **WinCamD-QD series**
  - **WinCamD-IR-BB**

– **BladeCam2-HR**

– **BladeCam2-XHR**

- **M2DU** system consisting of moving stage, lens mount, and camera mount. Stage options shown in Table 9.1.
- **LNZ** focusing lens. Lens options shown in Table 9.2. Lens part numbers are of the form **LNZ-(wavelength option)-(focal length option)**. For example, LNZ-VIS-100 is a f=100mm lens for 400-800 nm. By default, LNZ lens assemblies use 1” optics. For 2” optics, add **-50** to the end of the part number.

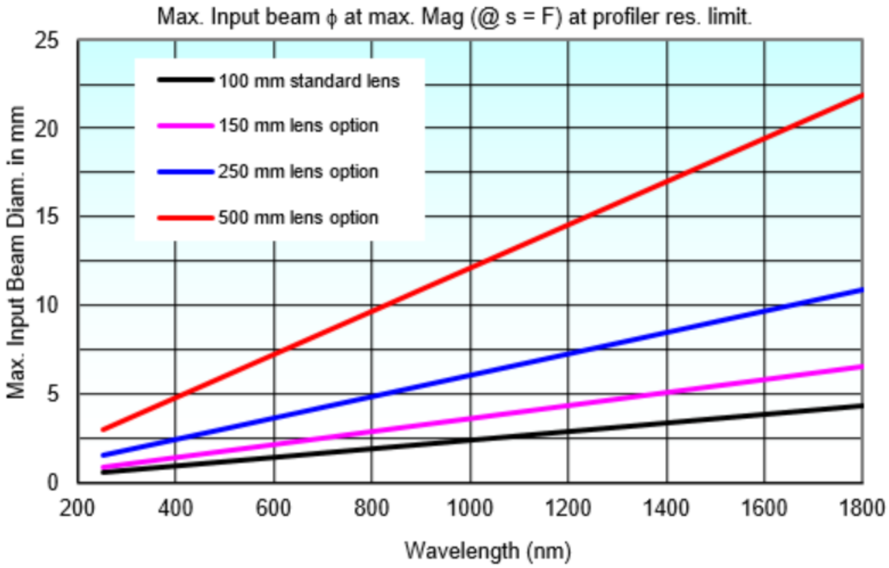


Figure 9.2: Maximum input beam diameter for various wavelengths.

Profiler	Stage Travel Length	Stage Part Number
WinCamD-LCM	50 mm 200 mm 500 mm 1000 mm	M2DU-50-WCD M2DU-200-WCD M2DU-500-WCD M2DU-1000-WCD
WinCamD-GCM	50 mm 200 mm 500 mm 1000 mm	M2DU-50-WCD-GCM M2DU-200-WCD-GCM M2DU-500-WCD-GCM M2DU-1000-WCD-GCM
WinCamD-QD series	50 mm 200 mm 500 mm 1000 mm	M2DU-50-WCD-QD M2DU-200-WCD-QD M2DU-500-WCD-QD M2DU-1000-WCD-QD
WinCamD-IR-BB	50 mm 200 mm 500 mm 1000 mm	M2DU-50-WCD-IR-BB M2DU-200-WCD-IR-BB M2DU-500-WCD-IR-BB M2DU-1000-WCD-IR-BB
BladeCam2-HR/XHR	50 mm 200 mm 500 mm 1000 mm	M2DU-50-BC2 M2DU-200-BC2 M2DU-500-BC2 M2DU-1000-BC2

[H]

Table 9.1: Stage part numbers.

Lens focal length options	Wavelength options
75 mm 100 mm 150 mm 200 mm 250 mm 500 mm 750 mm 1000 mm	**UV** Fused silica singlet for 250-450 nm **VIS** Achromat for 400-800 nm **NIR** Achromat for 630-1100 nm **TEL** Achromat for 1000-1800 nm **MWIR** Plano-convex for 1800 nm - 8 μm **FIR-G** Plano-convex for 7 μm - 12 μm

Table 9.2: Lens options.

M² 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 TEM_{00} 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 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.

M² Definition

At its simplest M^2 may 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.

$$M^2 = \frac{\Theta}{\theta} \tag{9.1}$$

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.

$$\theta = \frac{2\lambda}{\pi W_0} \tag{9.2}$$

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

$$2W(z) = 2W_0\sqrt{1 + \left(\frac{z}{z_R}\right)^2} \tag{9.3}$$

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:

$$z_R = \frac{2W_0}{\Theta} = \frac{\pi W_0^2}{M^2 \lambda} \quad (9.4)$$

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

$$M^2 = \left(\frac{\pi}{4\lambda}\right) 2W_0 \Theta \quad (9.5)$$

M^2 Measurement

ISO 11146, "Test methods for laser beam parameters - Beam widths, divergence angle, and beam propagation factor" 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 9.3. 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.

Notes:

1. For a perfectly Gaussian beam, the variance (second moment) definition is exactly the same as selecting a 13.5% clip Level. However if the 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. See Chapter 7 for beam diameter definitions.
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 without an additional lens.

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

Table 9.3: Beam diameter near waist.

5. For non-collimated beams with an inadequately accessible beam waist, DataRay recommends first appropriately collimating the beam, then refocusing along the stage using a suitable lens.

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 Worksheet for M2DU Stages from the Documentation section of our website to model your beam and ensure it can be accurately profiled with the received system.

Create a beam waist (focus) within the travel of the M2DU stage and with an output Rayleigh length (z_R) such that the stage can measure the diameter around the waist from -z_R to $3z_R$ or ideally -$3z_R$ to $3z_R$. The waist diameter should not be smaller than the minimum beam diameter the profiler can accurately measure.

1. Enter the beam parameters **wavelength**, **estimated** M^2(use 1.1 if Gaussian), and **beamwaist diameter**.

2. Choose the **beam profiler model** and **stage length** (options are 50, 200, 500, and 1000 mm). The 200 mm stage is more versatile because it can measure M^2 of beam waists with longer Rayleigh lengths.

3. Check if a **lens accessory** is required. A lens is not required if the beam waist is already the right size and has enough working distance.

    (a) If a lens accessory is not required, choose "No" and enter the **working distance**. If the working distance is long enough, a lens is not required.

    (b) If a lens accessory is required, choose "Yes". Choose a lens **focal length** that satisfies the M^2 measurement conditions and enter the **input beamwaist to lens distance**. If the beam is collimated, then the beamwaist distance may be unknown. If so, enter 100 mm.

4. There are a number of M^2 conditions that the spreadsheet automatically checks. If a condition is not satisfied, the

products box will be highlighted red and striked through. There will be an explanation below this box about what is wrong and how it can be fixed.

The bottom plots show the simulated beam diameter in red across the stage travel. The dotted and dashed curves are limits that should not be crossed. The + data points are the 60 locations where the stage will move the camera to measure the beam and fit an M^2 curve to these 60 measurements.

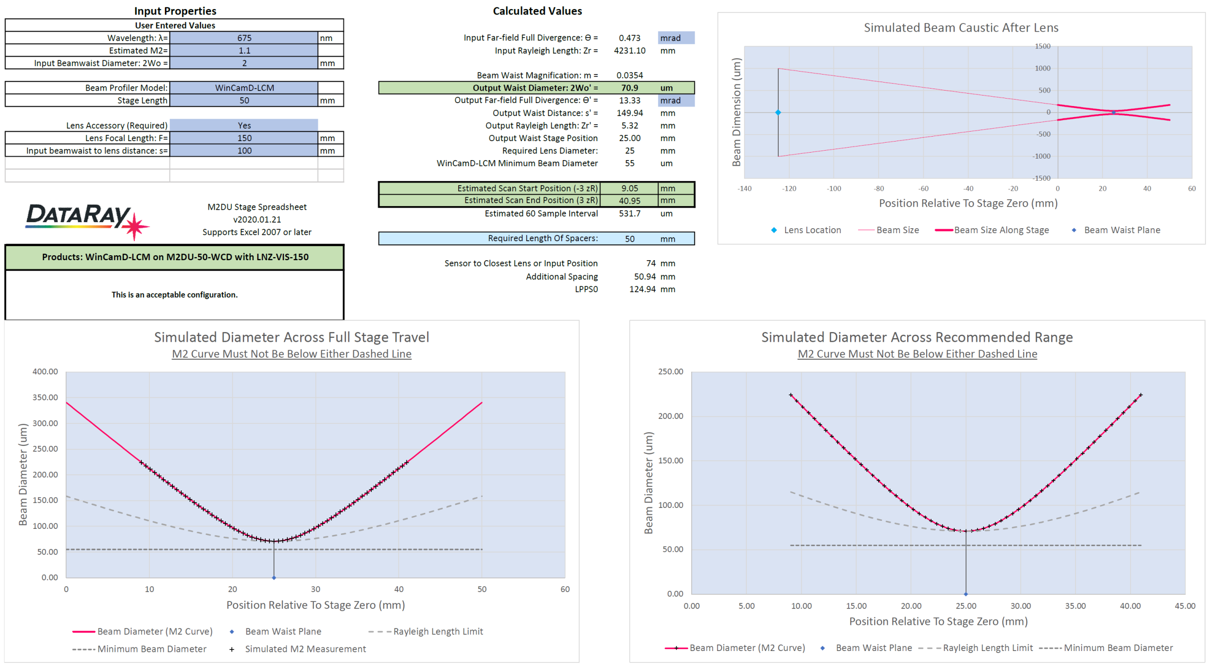


Figure 9.3: Lens Choice for M^2 Measurement Spreadsheet

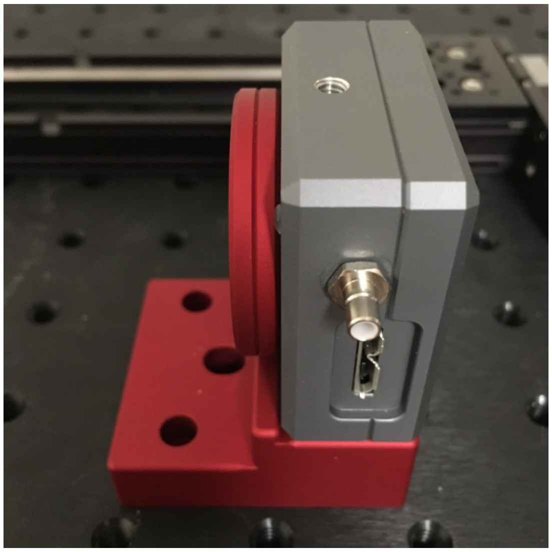
Avoiding Camera Sensor Damage

Verify the lens incident power with a power meter. For the calculated **output waist diameter** highlighted in green in Fig. 9.3, use the curves in Fig. 1.1 (for CW) and Fig. 1.3 (for pulsed), or use our attenuation calculator to determine whether additional sampling/attenuation is required. Add the required attenuation before proceeding. DataRay offers additional ND filters and wedge samplers to assist you. For additional information on attenuation, see Chapter 5.

Getting Started

Install Software

Make sure the latest DataRay software has been installed on your computer and learn to use the software and camera 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 —manual or automatic— see Section 9.



(a)

Figure 9.4: LCM positioned on the textbfM2DU camera mount, attached with #8-32 screw

Hardware Assembly

Parts List

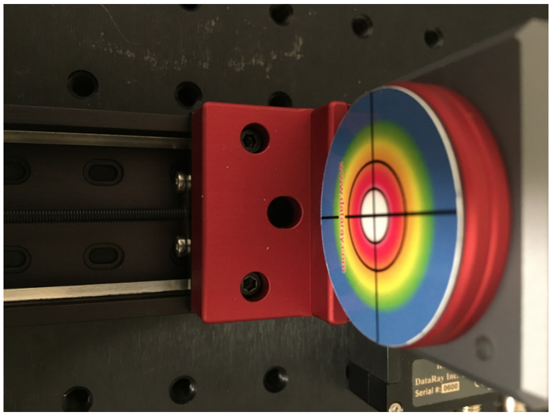
The M2DU system consists of the following parts:

- (1) M2DU stage
- (1) 3 m USB 2.0 cable
- (1) 24V-PSU power supply with power cord
- (1) LNZ lens assembly (purchased separately), including tube spacers for longer focal length lenses.
- (1) camera mount
- (1) lens mount bracket
- Appropriate hex allen wrenches for hardware
- Appropriate screws to secure mounts and brackets

Assembly Instructions

Use the following instructions for correct assembly:

1. Attach the **WinCamD** or **BladeCam2** series head to the red **M2DU** camera mount as shown in Fig. 9.4 for the WinCamD-LCM. Other profilers may utilize slightly different mounts.



(a)

Figure 9.5: Camera mount attaches to moving platform with two screws

2. Attach the red **M2DU** camera mount to the moving platform on the M2DU stage using two M3-0.50×6 mm screws. See Fig. 9.5.

3. Attach the **M2DU** lens mount bracket to the front of the M2DU stage using two M3-0.50×8 mm screws as shown in Fig. 9.6.

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** lens assembly as shown in Fig. 9.7.

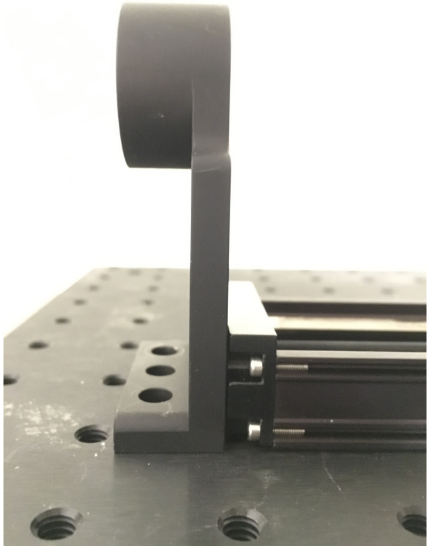
7. Connect the 24V power supply to the **M2DU**.

8. Connect the 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 9.9a. Note: If connecting to the USB through a hub, it must be a powered hub.

Start the Software

Start the software and click the  button. A series of warnings advise that the software will in turn:

- Set Full resolution
- Turn off the filter
- Allow change to 'Use ISO Major' (Recommended)



(a)

(b)

Figure 9.6: (a) Lens mount bracket attaches to end of stage (b) Two M3-0.50×8 mm screws are used to attach the lens mount bracket

Allow all the offerings by clicking Yes. You will then see the **WinCam M-squared Setup** box as shown in Fig. 9.9b where you will enter some values:

1. Enter **Wavelength in nm** and **Lens Focal Length in mm**.

2. **LPPS0** (**L**ens **P**rincipal **P**lane to **S**ensor at **0**): 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.

   If you just need M2 and do not need to calculate other source properties, there is no need to measure or enter accurate LLPS0 or Zo Delta values. These are only necessary for back-calculating the source waist size and properties and do not effect the M2 value. By default, the measurements in the M2 dialog apply to the output beam (after the lens) and do not use the LLPS0 or Zo Delta values. If the **View Source** button is clicked, then the measurements apply to the source beam (before the lens) and *require* accurate LLPS0 and Zo Delta values.

   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. 9.8. **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.

   Add **LD** to **A**–**Zo Delta**, and enter this value as the **LPPS0** (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 Appendix C or on our website.

3. Enter the **Zo Delta** value from the lens label in the M-squared dialog.

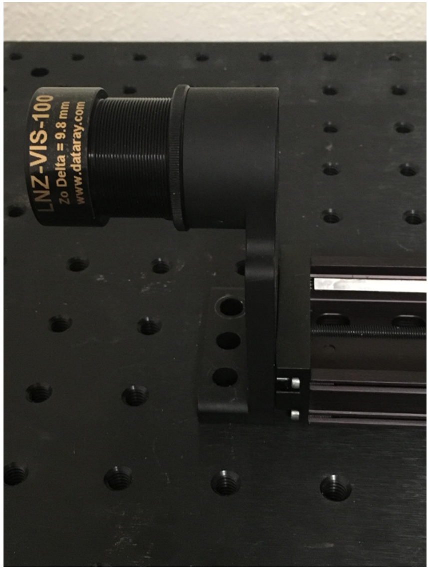


Figure 9.7: The **LNZ** lens assembly attaches to the lens mount bracket. The properly chosen lens will create a beam waist within the range of the M2DU stage.

4. Copy **LPPS0** and **Zo Delta** to the front page for your future convenience.

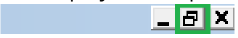
Lens focal length (LNZ–XXX–YYY)	**LD** (User measured)	(**A-Zo Delta**)	**LD**+(**A-Zo Delta**)=**LPPS0** (Enter in M^2 dialog)	**Zo Delta** (Enter in M^2 dialog)

Table 9.4: Chart to enter your lens setup details.

Double check that all your calculations are in mm and to ± 1 mm or better.

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. 9.11 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. 

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.

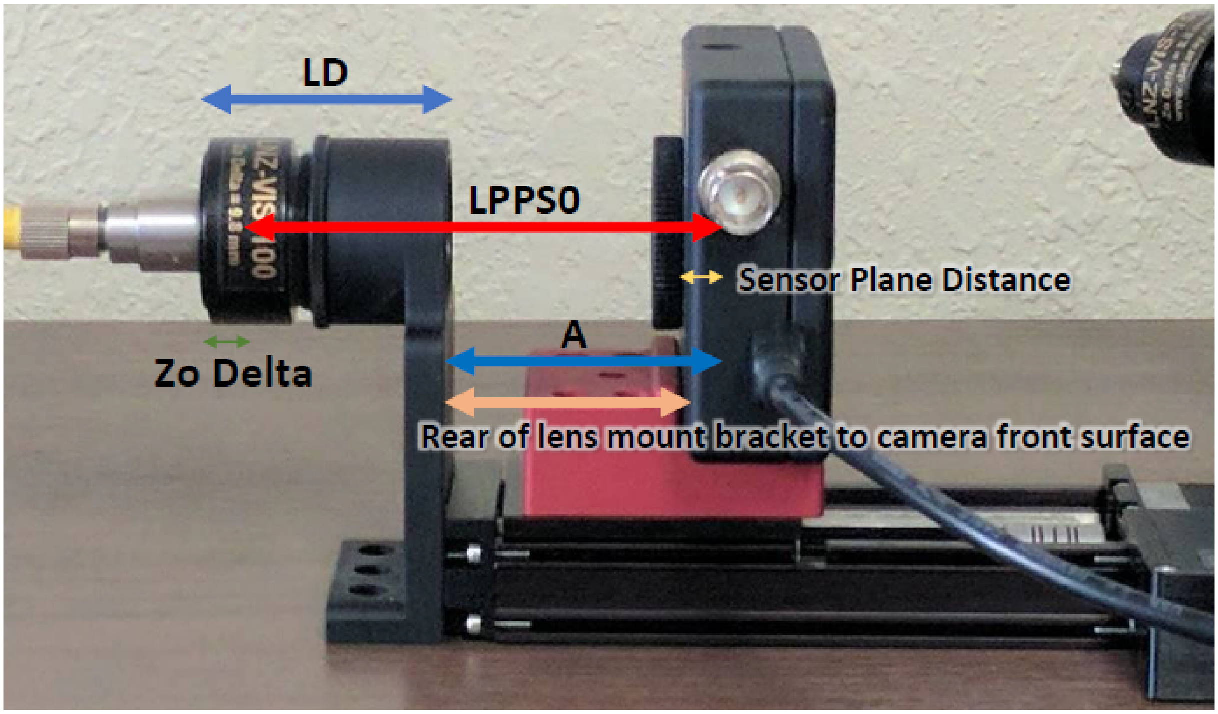
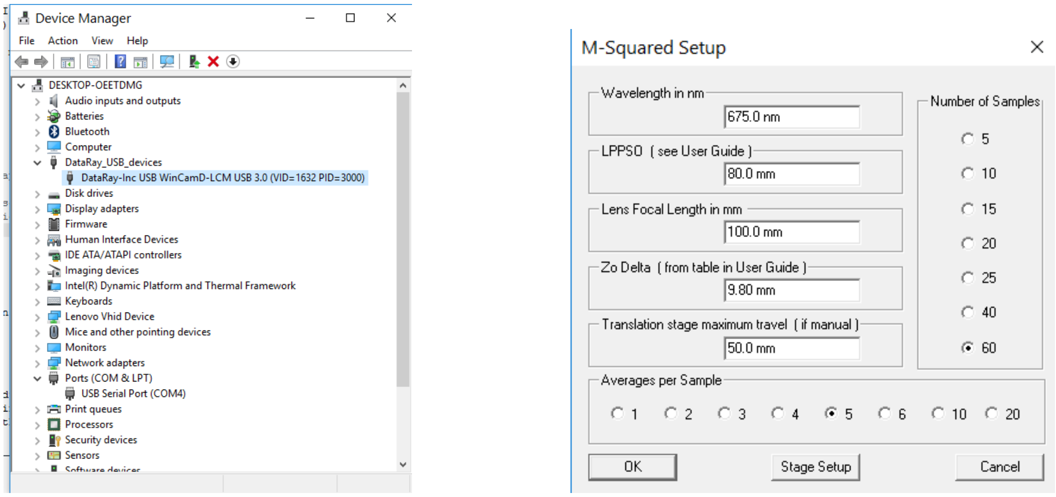


Figure 9.8: M2DU Assembly and important measurements.



(a) (b)

Figure 9.9: (a) WinCamD-LCM in Device Manager, with the M2DU detected as a USB Serial Port. (b) M-squared Setup Dialog Box.

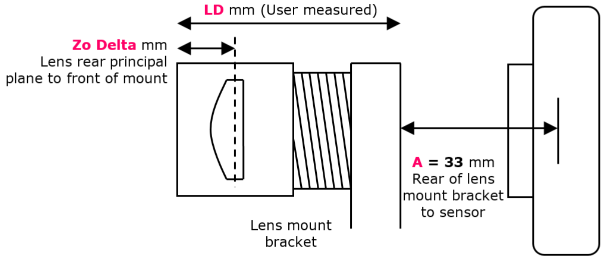


Figure 9.10: Required known distances with M2DU setup.

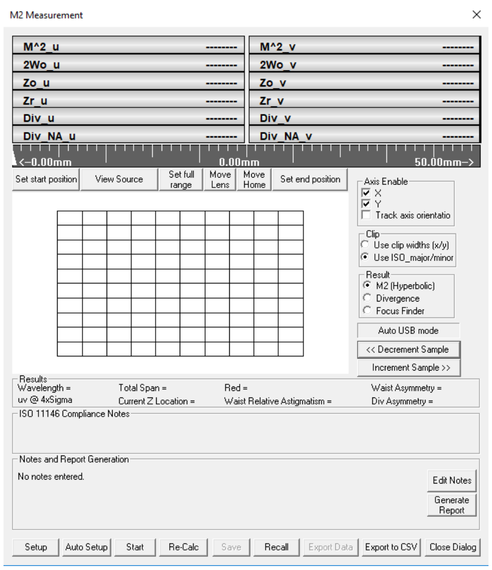


Figure 9.11: M-Squared Measurement dialog box.

The lens and camera covers have black on white beam target cross-hairs with 5 and 10 mm circles. These are useful for visible lasers.

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 onto the lens. Remove the lens cap.
3. Rotating about the end of the lens assembly, 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 camera cover.
6. Press G or click on the green highlighted cell as shown in Fig. 9.15 to start a capture. Verify that Peak ADC is $<$90%. If it is not, revisit Chapter 5.

7. Press or click on the green highlighted cell again to stop this capture.

Set the Capture Block

In order to minimize the size of saved M^2 files, it is recommended that you minimize the Capture Block. A properly sized capture block will better achieve ISO-compliant measurements. We suggest a 512×512 Capture block initially.

Press **Alt** + **S** to open the **Capture Setup** box as shown in Fig. 9.12. In the **M-Squared Dialog** box, click at the extreme ends of the gray scale and watch the image in the Capture Setup box. The image will update each time the stage stops moving.

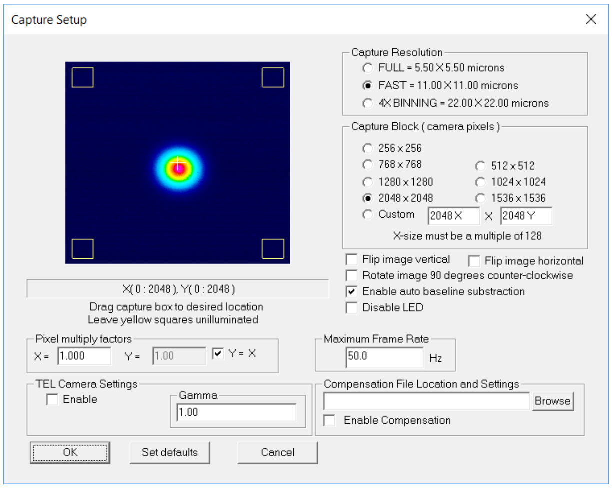


Figure 9.12: Capture Setup dialog box to select Capture Block.

If the image moves more than 25% of the capture block, readjust your beam alignment until it moves less than this. With the stage at the lens end, select a Capture Block around five times the visible beam size. In most cases, 512×512 should suffice. Click **OK**.

Check Exposure

For CW lasers, Auto-exposure sets correct exposure for all z values.

- **Check Exposure** Move the stage in z by clicking on the scale until the beam diameter is at or close to minimum.
- **CW beams** Adjust any attenuation/sampling until the **Peak ADC** is $<$90% and that, at the beamwaist: 0.25 ms $\leq$ **Exposure time** $\leq$5 ms. If it is not, revisit Chapter 5.
- **Pulsed laser beams** Currently the software averages multiple pulses and varying the Exposure time effectively varies the number of pulses averaged. The minimum pulse repetition rate (PRR) for which the system will work reliably in default mode is around 1000 Hz. Ensure that at the beamwaist, both 0.2 ms and (10,000/PRR) ms $\leq$ **Exposure time** $\leq$ 20 ms. A later release may extend these limits[1].

[1] Setting the maximum exposure limit to 1,000 ms instead of 200 ms can extend the upper exposure limit to 200 ms, but the increase in dark current spikes will affect the M^2 accuracy.

Perform a Coarse Scan

1. Press **Go** 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 2 images 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, **Zo**, and the Rayleigh Range, **Zr**. This is shown in Fig. 9.13a

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. The **Use Effective Slits** option will calculate the beam dimensions using the **Clip A** clip level with effective slits enabled. Please note that ***neither*** the clip width option ***nor*** the effective slits option will 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 the 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.

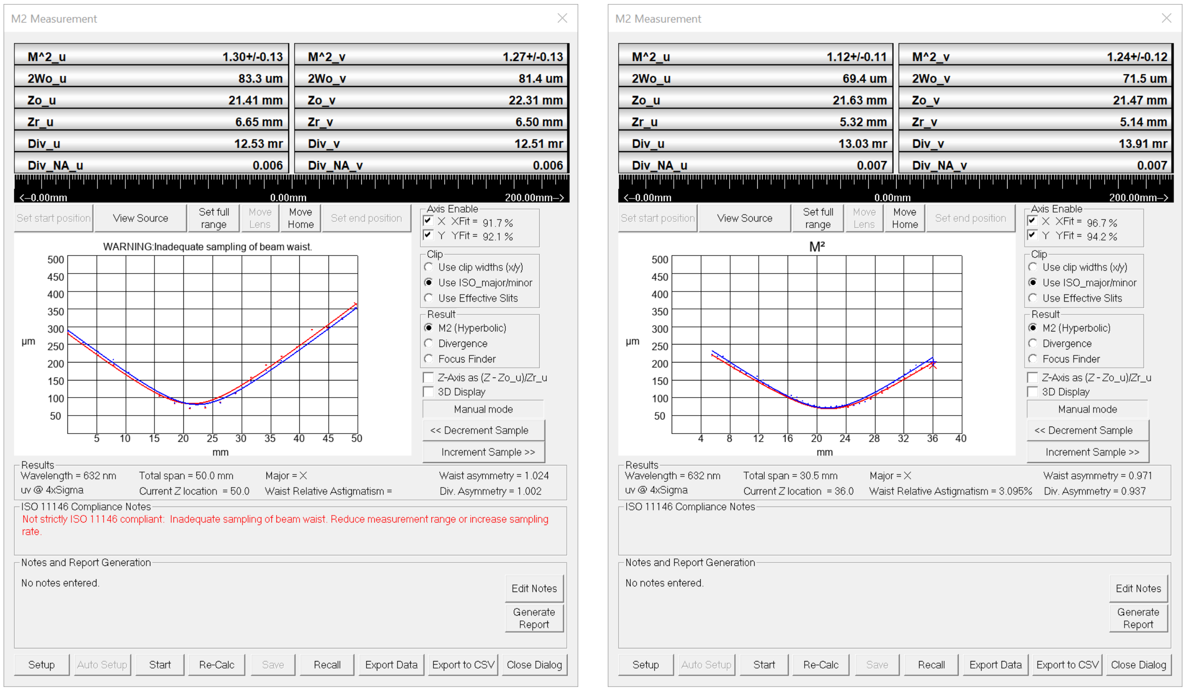
   - Warning: Less attenuation recommended If the exposure rises above 200 ms this warning will appear due to the risk of dark noise contribution to the ISO diameter.

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 9 to resolve this issue.

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 images per z position. The number of samples and averages per sample can be modified in the M-Squared Setup dialog box (Fig. 9.9b). At the conclusion of the scan, the software performs a weighted least squares hyperbolic fit to the data to calculate the final results (see Fig. 9.13b)[2]. Descriptions of the various results are explained below. Each result will be explained along only one axis. For instance M^2_u and M^2_v are the same measurement, but on orthogonal axes.

[2]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. 9.18).



(a) (b)

Figure 9.13: (a) M2 Measurement dialog box after Auto Setup. (b) M2 Measurement dialog box after final scan.

- **M^2_u**: The M^2 value along one of the axes with accuracy[3] $\pm 5\%$ and repeatability[4] $\pm 2\%$.

  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.

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 in accordance with your entered values in the M-squared setup dialog. Below the curve (Fig. 9.13b) are calculations of:

[3] Beam dependent. Absolute accuracy better than $\pm 5\%$ is possible, but can be difficult.
[4] See Footnote 3

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

$$\textbf{Waist Relative Astigmatism} = \frac{\text{(Zo\_u - Zo\_v)}}{\text{(Zr\_u - Zr\_v)/2}}\% \tag{9.6}$$

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

$$\textbf{Waist Asymmetry} = \frac{\text{2Wo\_u}}{\text{2Wo\_v}} \tag{9.7}$$

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

$$\textbf{Divergence Asymmetry} = \frac{\text{Div\_u}}{\text{Div\_v}} \tag{9.8}$$

Important: The source Zo_u, Zo_v values are given as measured from the front of the lens holder, not from the lens principal plane.

The accuracy of the source beam characteristics are highly dependent on a correct measurement of ***LPPS0****.*

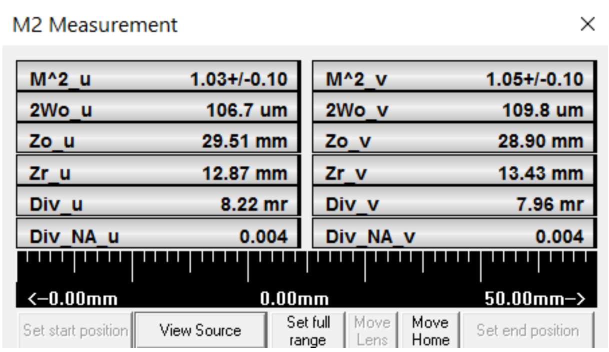


Figure 9.14: Press View Source to toggle Source/Output beam characteristics.

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 ignored[5].

[5] 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.

- **Use clip widths (x/y)** The software will use clip levels to calculate the beam diameter instead of ISO 11146 compliant calculations.

- **Use Effective Slits** The software will use effective slits 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.

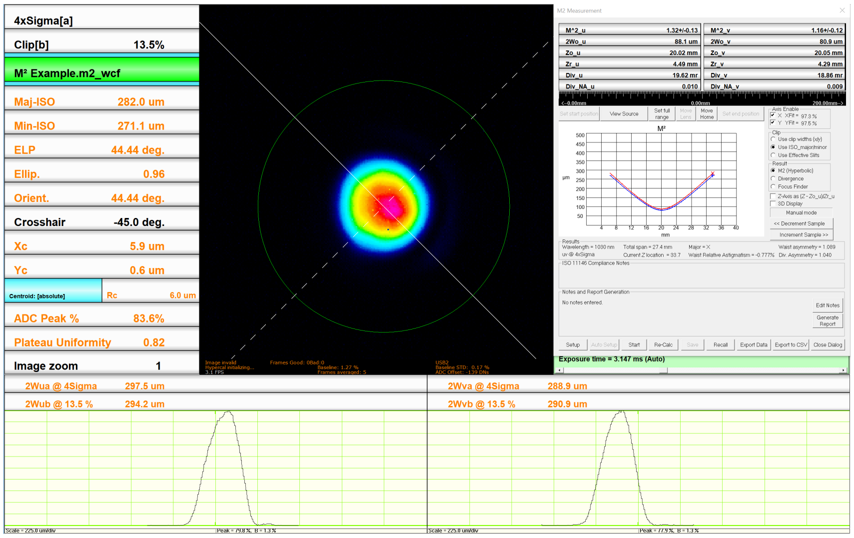


Figure 9.15: Save data using Save in the M2 Measurement dialog.

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.

Support

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

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 [6] or at least an ***.wcf** image saved from the data set. Email the file with comments to support@dataray.com.

[6] **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.

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:

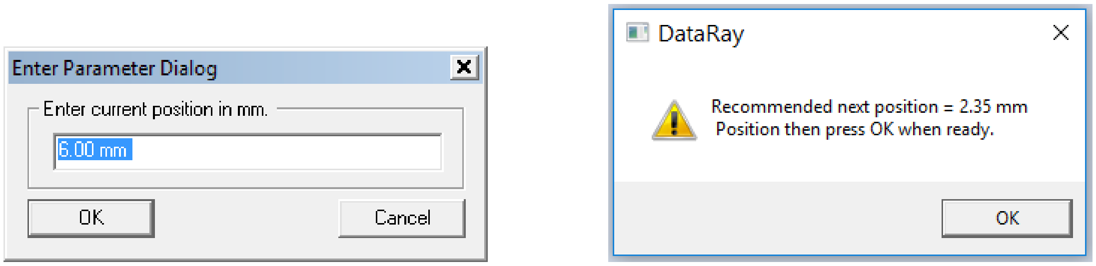
- **Stage Travel** Determine the length of travel of your stage (motorized or manual).
- **Stage Readout**: The stage must have a readout in mm (digital or manual).
- **Source diameter and location**. To additionally determine the waist diameter & z location of the source beam:
  - **Lens**: You need to know the focal length (mm), and back focal length (mm) of your lens. Enter the value in Table 9.5.
  - **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 9.5.
  - **Lens mount**: You need to determine the distance **LPPS0** (mm) from the lens rear principal plane to the sensor plane when at 0 mm on your measurement scale. Enter in Table 9.5.

Lens focal length	**Lens back focal length**	=**LPPS0** (Enter in M^2 dialog)	**Zo Delta** (Enter in M^2 dialog)

Table 9.5: 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. 9.9b), 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** G and let the image and exposure stabilize. Press **Start**[7]. The dialog shown in Fig. 9.16a will appear:
  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. 9.16b 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.

[7] Auto M2 Setup is grayed out if you do not have an M2 stage.



(a) (b)

Figure 9.16: (a) Manually enter current position in mm. (b) Move the stage to the desired position, then press **OK**.

3. The screen in Fig. 9.16a 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.

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 2 Rayleigh lengths from the beam waist.
- The size of the beam should not exceed the sensor size at either end of the stage (see Section 1 for beam limits).
- Directly measuring the divergence provides divergence within the region of measurement, this may be different than the nominal divergence of the beam if the customer is not in the linear expansion region.

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. 9.17) 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. 9.9b)
- At the conclusion of the scan, the software performs a linear fit to the data to calculate the final results as shown in Fig. 9.17.
  - **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.

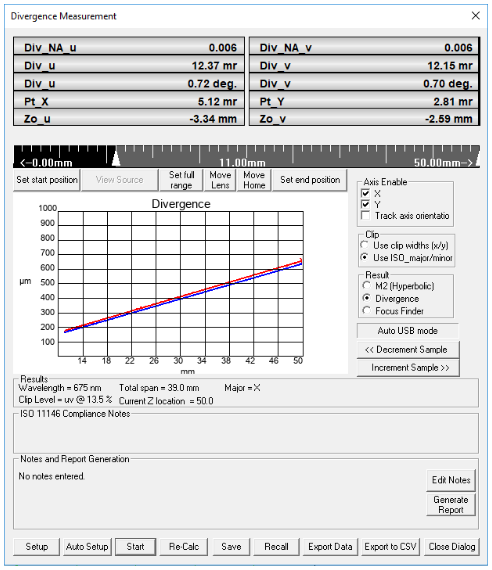
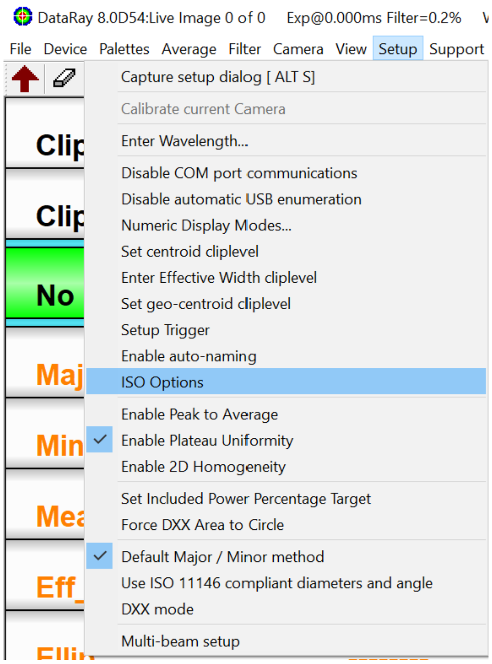


Figure 9.17: The M2 Measurement dialog box changes to the Divergence Measurement dialog box when the Divergence option is chosen instead of M2.

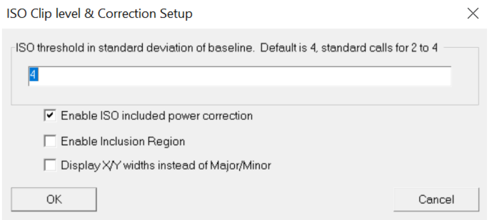
Troubleshooting

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.

- The capture block may be too large, and should be adjusted to the proper size (See section 9).
- Make sure **HyperCal** is toggled on to help cancel out background noise.



(a)



(b)

Figure 9.18: (a) Choose ISO Options to change the ISO threshold value. (b) ISO Clip Level and Correction Setup dialog box.

- 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. 9.18a). 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. 9.18).

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 9.19. 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 9.20, then press OK to close each dialog. Start the DataRay software, which should now be able to recognize the stage.

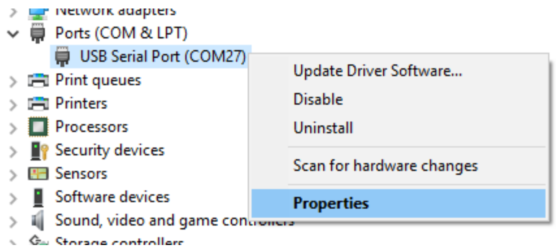


Figure 9.19: Right-click to choose **Properties**

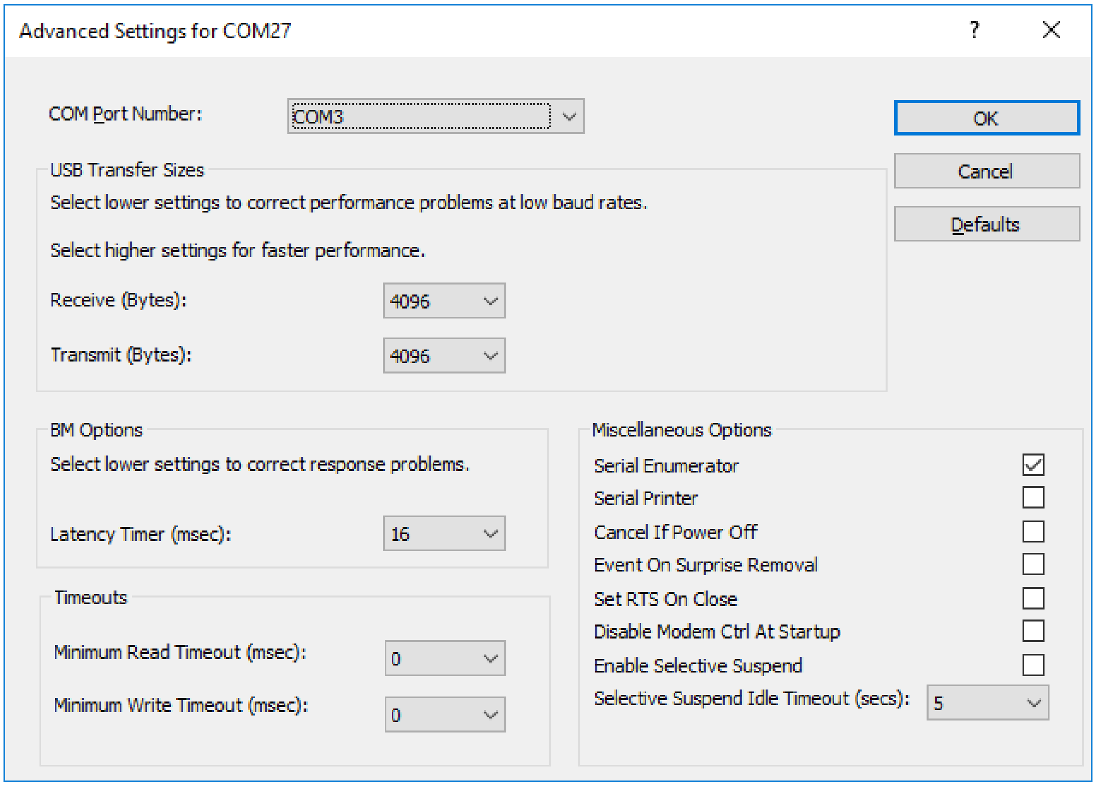


Figure 9.20: Change the COM port to a lower number

Chapter 10

Gaussian Beam Divergence Measurement with Ancillary Lens

Gaussian beams do not follow the same rules as incoherent beams described by geometric optics.

For a Gaussian beam, it may be shown that: When a Gaussian beam passes through a lens, the far field divergence of the input beam may be determined by measuring the second moment beam diameter **at the back focal distance from the lens**. This is true irrespective of the distance of the source from the lens. Note that this is not the position of the beam waist formed after the lens, though it may be very close.

It obviously assumes that the lens does not introduce additional aberrations, normally achieved by using a long focal length achromat coated for the wavelength(s) of interest.

The far field divergence of the input beam, θ mrad, is calculated as:

$$\theta = \frac{2W}{F} \tag{10.1}$$

Where $2W$ (μm) is the measured second moment (4σ) beam diameter in the Measurement plane and F is the focal length (mm) of the lens at the length of interest.

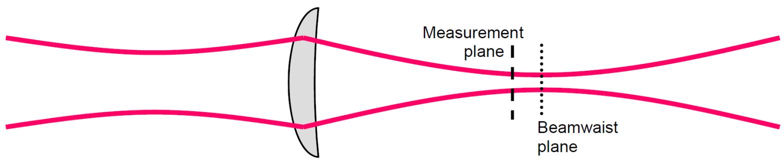


Figure 10.1

Modeling

DataRay offers a simple calculator to model these lens systems. See the Gaussian Beam Divergence Measurement Excel spreadsheet at our website.

This technique requires an appropriate lens and a beam diameter measurement instrument.

- The instrument may be a WinCamD or BladeCam2 series camera.
- The lens must have a known focal length, preferably AR coated for the wavelength(s) of interest, and be at least 1.5 times, and preferably twice the $1/e^2$ beam diameter at the lens.
- Errors in the lens focal length value or positioning of the instrument with respect to the back focal length will lead to errors in the divergence measurement. The spreadsheet models these errors.
- The beam must be centered on the lens.
- The beam centroid in the measurement plane does reflect the beam pointing.

The lens and instrument may be supplied by DataRay as a prealigned system or may be mounted on an optical bench or table. Use the spreadsheet or contact us for lens suggestions for your application.

Typically an accuracy of 0.1 to 0.05 mrad should be achievable. To simply adjust an input beam assembly for best collimation, minimize the value of 2W in the measurement plane. Contact us for accuracy and misalignment sensitivity calculations for your beam.

Software Setup

The DataRay software is capable of automatically calculating divergence for these systems. To enable this feature, navigate to **Clip A** or **Clip B** $\rightarrow$ **Enable Ancillary Lens Divergence**. Then in the **Enter lens focal length in mm** field, enter the lens focal length in mm. The software will now show the measured divergence in the main software window under either the Clip A or Clip B field, whichever was chosen above.

Acknowledgments: Parts of this section draws on Johnston's work [2], and we have used the same notation wherever possible.

Chapter 11

Multi-Beam User Guide

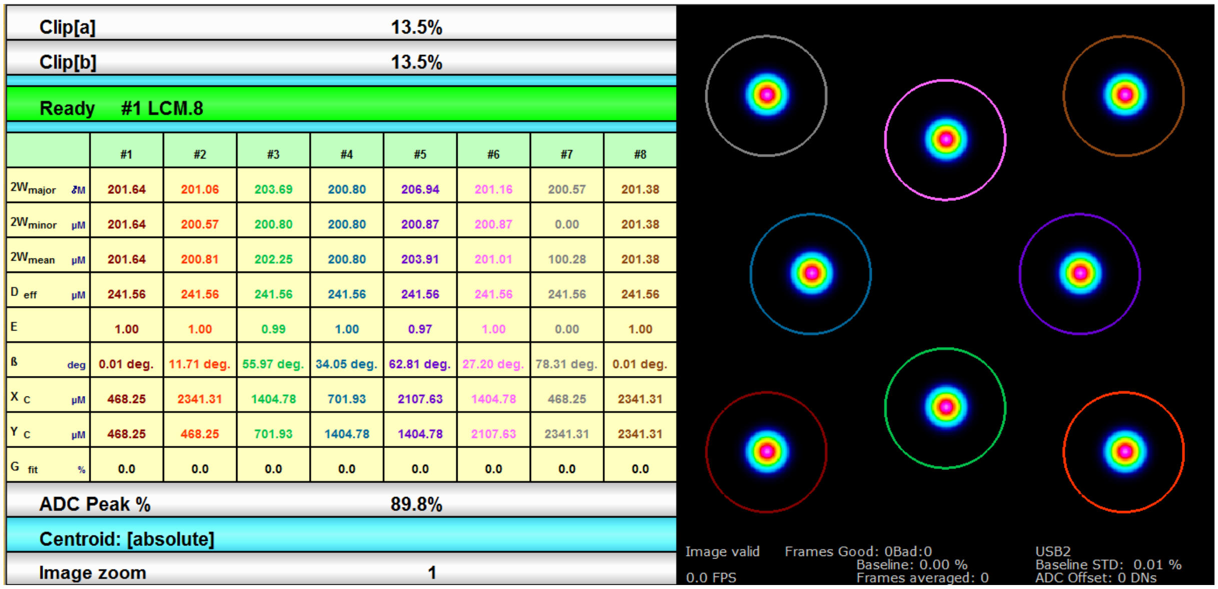


Figure 11.1: The multi-beam mode can track up to 8 beams.

Multi-Beam Description

DataRay is offering a version of software incorporating multi-beam analysis. The new mode was created to support analysis of beams that vary in size and number. Instead of expecting a group of uniform beams, the multi-beam mode uses a heuristic approach to define the regions including beams

Using the multi-beam mode

By clicking **Setup**→**Multi-beam setup**, you will open the Multi-beam settings dialog. Regardless of whether you use the automatic or manual modes, the heuristic approach depends on the number of regions expected and the expansion threshold. Starting at the highest peak with no regions defined, the program keeps expanding outward from the peak as long as each additional section has a total power greater than the threshold. In general, a higher threshold makes regions fit tightly around beams and a lower threshold makes regions expand farther out. Ideally, it is best to have regions expand out as far as possible without overlapping because a significant percent of the power is included in the tails of a Gaussian beam. Expansion thresholds can range from 0.01 to 99. If the automatic mode is selected, regions will be added by starting at peaks outside of already defined regions.

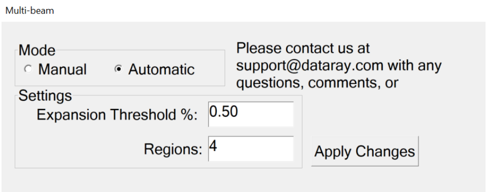


Figure 11.2: The multi-beam setup menu.

If in manual mode, the user will need to specify where the beams are located by right-clicking on the location of the beam in the 2-D image and the selecting **Add region** from the popup menu shown in Fig. 11.3

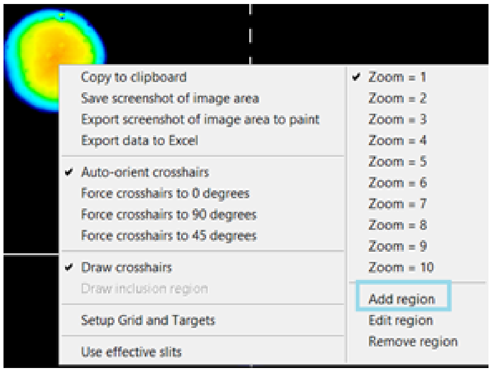


Figure 11.3: The **Add region** button adds a new region for another beam.

We can see the results from the automatic mode with an Expansion Threshold of 0.5 in Fig 11.4. The beams are numbered by the vertical position of their peak first, lowest to highest, and then by their horizontal position, left to right when they are added. The region around beam #1 was generated too tightly around its peak in Fig. 11.4.

We can correct this by overriding this definition with manual input. As with the manual addition of beams, the user right-clicks with the cursor completely within the region on the image and then left-clicks Edit Region. In the Edit Region dialog, Fig. 11.5, the user can specify the center and diameter of the region. Currently, only circular regions are supported and the center will move towards the calculated centroid of a beam. If a region encompasses two beams, the user will want to delete that region and manually specify two new regions.

The guidelines for taking good images still apply. Users who place beams at the edges of the imager, especially the four corners, will negatively impact their results. The four, nominally 'dark', corners of the image are used to calculate the baseline whose value is displayed below the 2D image. In most cases, a baseline below 4% and a baseline standard deviation

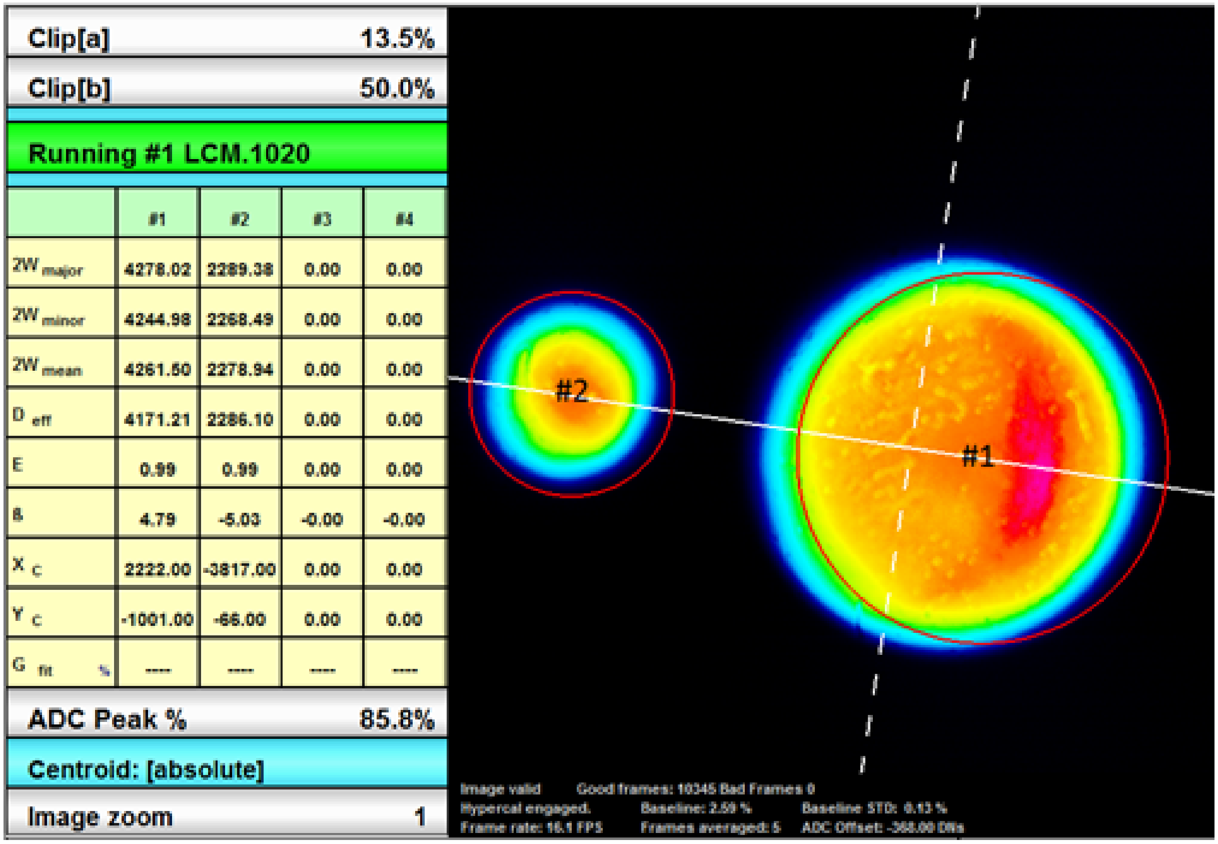


Figure 11.4: Multi-beam mode can capture beams of various sizes.

0.40% are ideal.

As we receive feedback from customers, we will improve performance and add features. Please send any questions, requests, or comments to support@dataray.com.

Interfacing to the multi-beam mode

In order to receive results from the multi-beam mode in an interface, the interface must have an instance of one of the multi-beam buttons. The user must use the GetData.GetOcxResult(#id for each beam and value) method if they wish to programmatically access the results. The numbers below represent the relative ordering of data types. Given the current maximum beam value of 8, a user accesses the values as follows: $1000 + 8 \times \#data\_type + \#beam\_index$. For example, the OCX value for the major axis of the third beam is $1000 + 8 \times 0 + 3 = 1003$ while the OCX value for its minor axis is $1000 + 8 \times 1 + 3 = 1011$. These access values do not depend on the number of beams located.

Term	Description
MB_MAP_2W_Major_1	0
MB_MAP_2W_Minor_1	1
MB_MAP_2W_Mean_1	2
MB_MAP_Deff_1	3
MB_MAP_E_1	4
MB_MAP_B_1	5
MB_MAP_Xcs_1	6
MB_MAP_Ycs_1	7
MB_MAP_Xcg_1	8
MB_MAP_Ycg_1	9
MB_MAP_Xcp_1	10
MB_MAP_Ycp_1	11
MB_MAP_Gfit_1	12
MB_MAP_Ig_1	13
MB_MAP_Nu_1	14

Table 11.1: Multi-beam OCX identifiers

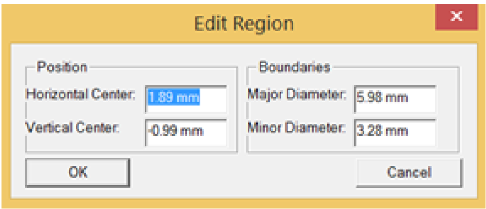


Figure 11.5: The edit region menu allows the user to edit the centroid of the beam and the boundaries of the beam.

Chapter 12

Support, Returns, Distributors, Reps

The **Support** pull-down menu has hyperlinks to:

- DataRay.com
- The software upgrade page.
- Product registration information.
- Technical support.
- Manual for your profiler.
- USB drivers.

DataRay maintains a network of knowledgeable distributors and representatives and also offer direct product support. Visit our website for more information.

Service, Returns, Repairs, Equipment Problems, Recalibration

If you did not receive the product directly from DataRay, contact your vendor directly. If you did receive the product directly from DataRay, see up-to-date procedures for returning products for repair here. The steps below are designed to address your issue as a quickly as possible.

Remember:

- There is a three-year product warranty on all standard DataRay manufactured products (see our warranty for more details). Third party manufactured items normally carry a one-year warranty. Outside the warranty period, DataRay can often repair products for a fee as long as replacement parts are still available.
- Repair turnaround time target is 5-10 working days excluding shipping.
- If you purchased the product via a distributor and obtain their permission, you may be able to ship the product

directly to DataRay for repair.

When contacting support:

1. Clearly outline the problem and note the name, contact number, and email address of the person with direct experience of the issue. Providing relevant WCF files of the issue may expedite resolution (saved under the **File** menu).

2. If purchased through a distributor, contact them directly. If purchased directly from DataRay, contact our support team. Provide the detailed outlined in step one.

3. After speaking with your distributor or directly to DataRay, if a return or repair is necessary, you will receive important RMA information and instructions from DataRay or your distributor.

   NOTE: All RMAs must be accompanied by an RMA form. Shipments originating outside of the United States require additional documentation. Please review the RMA instructions you receive carefully.

4. Pack it properly.

   - Where possible, use the original packaging.
   - Always ensure that all boards and hardware with electrical connections are first wrapped in static dissipative foam (pink or mauve) or bag (metallic silver/gray).
   - DataRay is not responsible for damage caused in transit.
   - Include the cables.

5. Return the equipment to the address on the RMA form, clearly marking your RMA case number on the package.

6. If the return package originates outside of the United States, carefully follow the instructions provided. Additionally, a Foreign Shippers Declaration and Importer's Declaration of Goods are required. These should be included in the pouch on the outside of the package. If RMA instructions are not followed, it may result in additional delays, duties, and fees which are the end user's responsibility.

Bibliography

[1] International Organization for Standardization. Lasers and laser related equipment - test methods for laser beam parameters - beam widths, divergence angle and beam propagation factor. Standard, International Organization for Standardization, Geneva, CH, March 1999.

[2] Thomas F. Johnston. Beam propagation (m2) measurement made as easy as it gets: the four-cuts method. *Appl. Opt.*, 37(21):4840–4850, Jul 1998.

Appendices

Appendix A

Spatial Response Variation Compensation

You may use this approach to compensate for any spatial non-uniformity in the response of the array. Camera sensors are nominally uniform to around $\pm$1% (according to the manufacturer). We have noted that for **ADC Peak** % above 80% of the camera non-uniformity is higher (under investigation). This note reports on experiments performed in **Fast** resolution mode.

Setting Up Compensation File

1. Under the File pull-down menu, **Load job file** to load the **LCM4_Fast CompFileSetup.ojf** job file that accompanies this App. Note. This job file sets:
   - **Fast** resolution
   - **Average** = **20**
   - Disables Auto-exposure
   - Sets crosshair orientation to zero
   - Sets crosshair to center of screen (**Xu**)
   - Sets **Filter** to **No filtering**
   - Disables background subtraction (in **Capture setup dialog**)
   - Sets the Profile display to **Linear raw mode (ADC mode)**
   - Turns off **HyperCal**
2. (a) Remove any filter and set a C-mount tube, minimum 100 mm long, on the camera. 200 mm is recommended and was used here. Tube should be ridged or matte finish internally.

   (b) If the system will be used with a filter, the Compensation file generation should be performed with the (cleaned) filter in place. See page Fig. A.10.

(c) Set a diffuser on top of the tube and illuminate it with a tungsten filament or halogen light source from a distance. See Fig A.1 (100 mm tube shown).

(d) Suitable diffusers are ground glass and/or high quality printer paper. (These tests use two layers of Staples Bright White Inkjet paper).

(e) Important: Check the effectiveness of your diffuser + tubes arrangement. If you move the source and adjust the exposure, does the gradation in the illumination change?

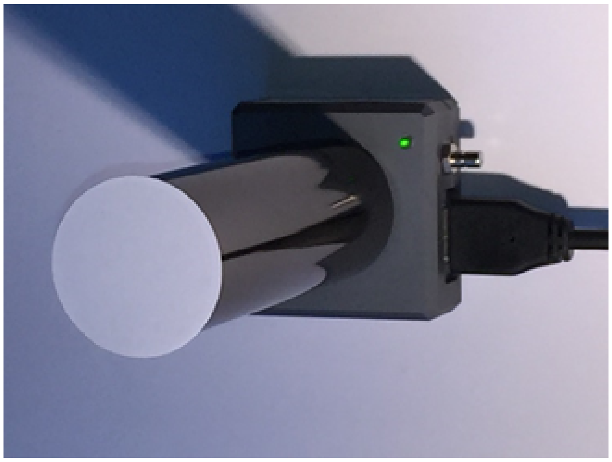


Figure A.1: Camera and C-mount tube for compensation setup.

3. Adjust the illumination and the Exposure until the ADC Peak % reads 75 to 80% at an Exposure in the range 10 to 50 ms. Allow the signal to stabilize and Save a wcf file as #####_FastCompFile.wcf, where ##### is the camera Serial #.

4. Use **Alt** + textbfS to open the Capture Setup dialog. Check the Enable compensation box and Browse to the #####_FastCompFile.wcf file location. Click **OK**.

5. Click **Go** to run the software and the screen image will be compensated for the residual non-uniformity.

Measurement of a Stripe

Adhesive backed thin optical velvet and sized washers were employed to generate a roughly rectangular optical aperture that sat barely above the sensor surface (see Fig. A.6-A.10). There are some fall-off end effects on the illumination due to

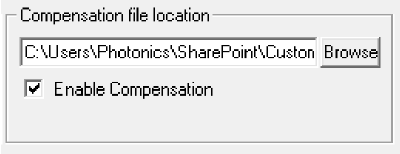


Figure A.2: Camera Setup dialog box compensation options.

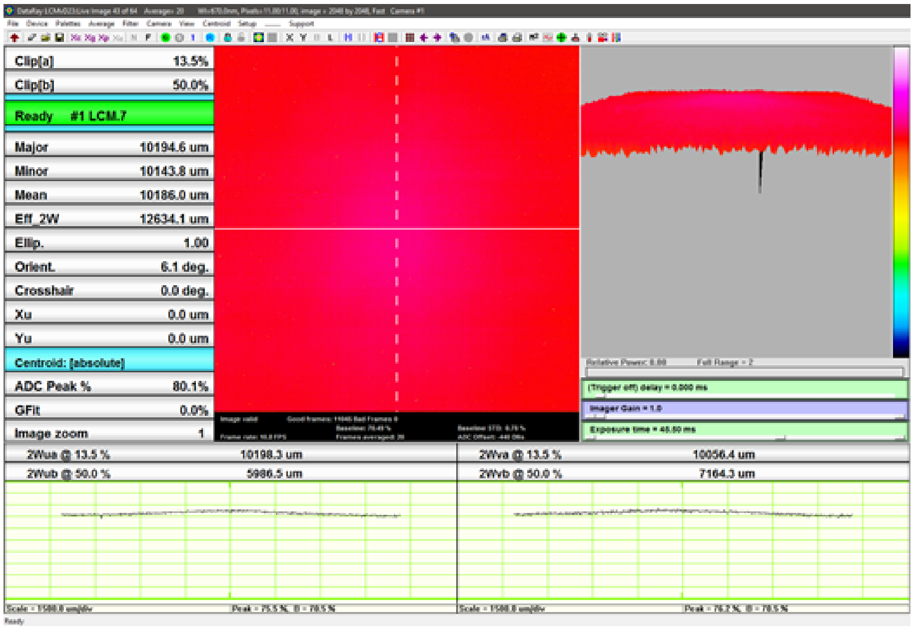


Figure A.3: Uncompensated. Around 7% peak to peak variation on the line profiles at 67% of ADC, which means 10% relative peak-to-peak variation. Some bright pixels due to minor 'specks' of dust on the sensor surface that would not blow off. (Ignore the edge noise in the 3D area display which is due to the way that this part of the display is baseline adjusted and normalized.)

this assembly. Press **Xc** in the tool bar to place the crosshairs at the centroid of the image.

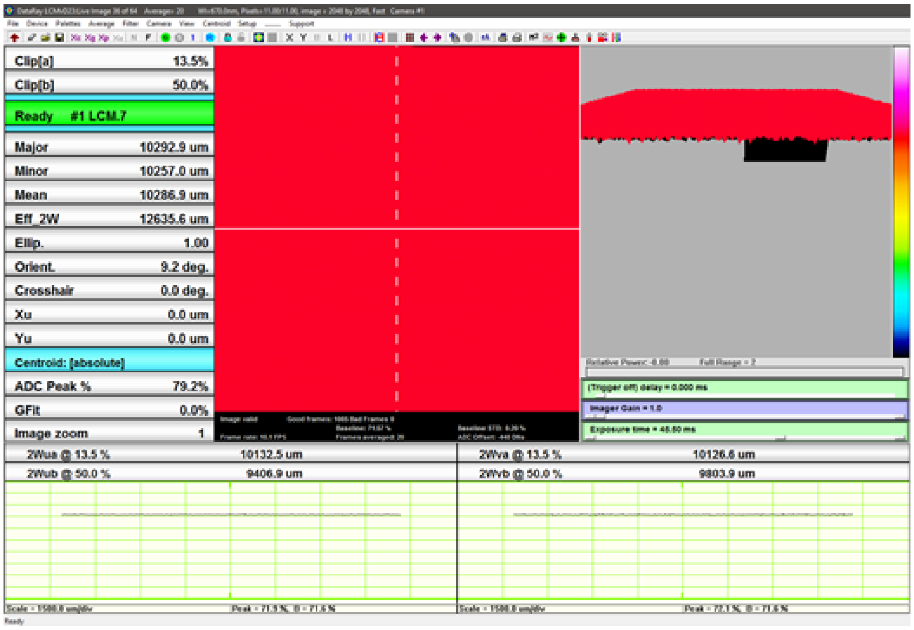


Figure A.4: Compensated. Peak-to peak noise measures around 1.5%.

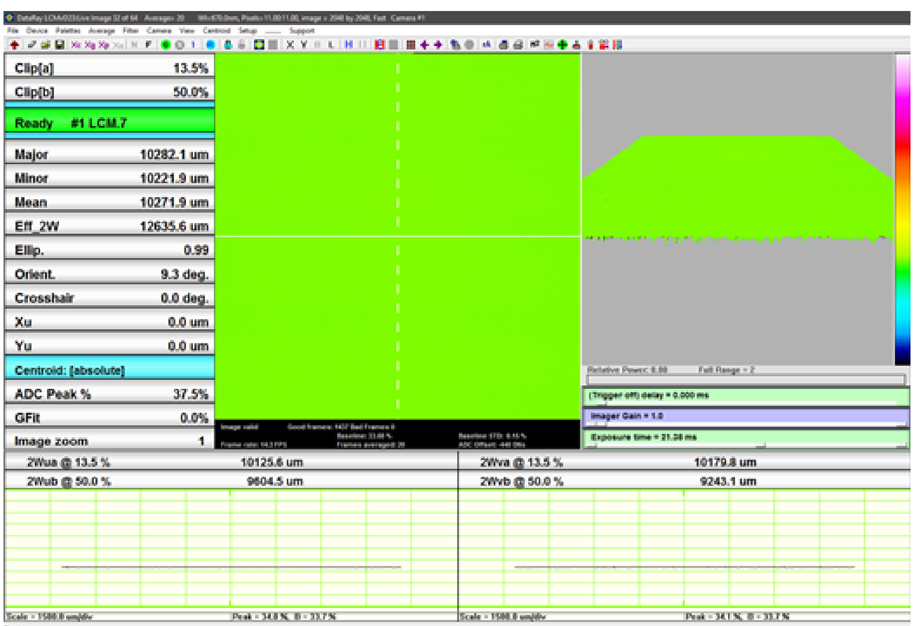


Figure A.5: Compensated at a different irradiance.

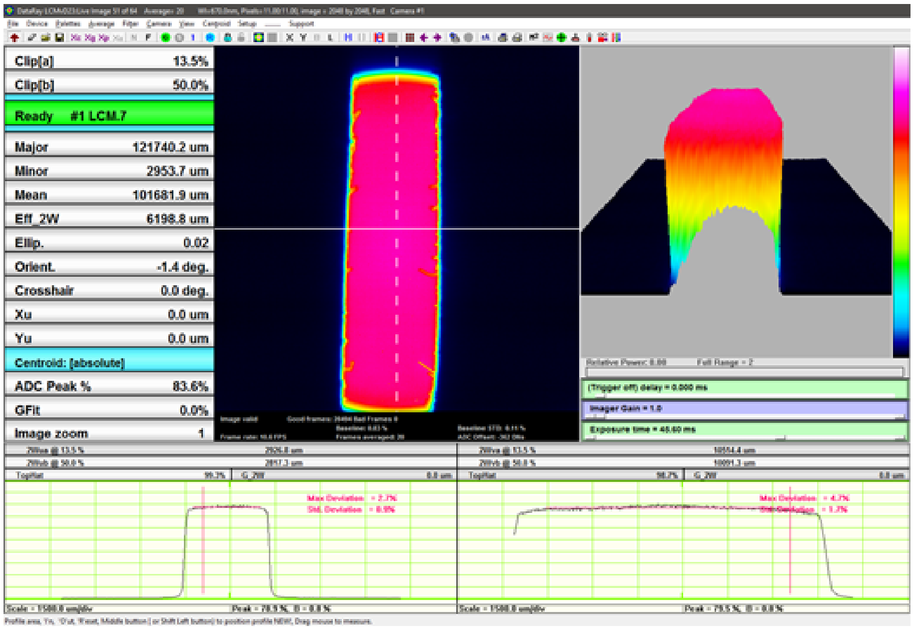


Figure A.6: Uncompensated. The Max and Standard Deviation are for the central 80% of the Tophat distribution.

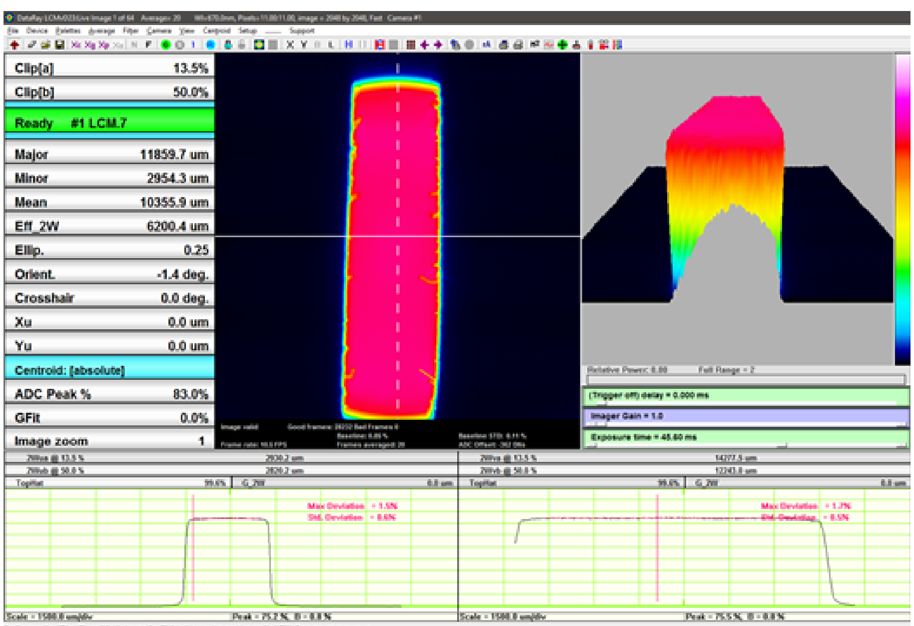


Figure A.7: Compensated. The Max and Standard Deviation are for the central 80% of the Tophat distribution.

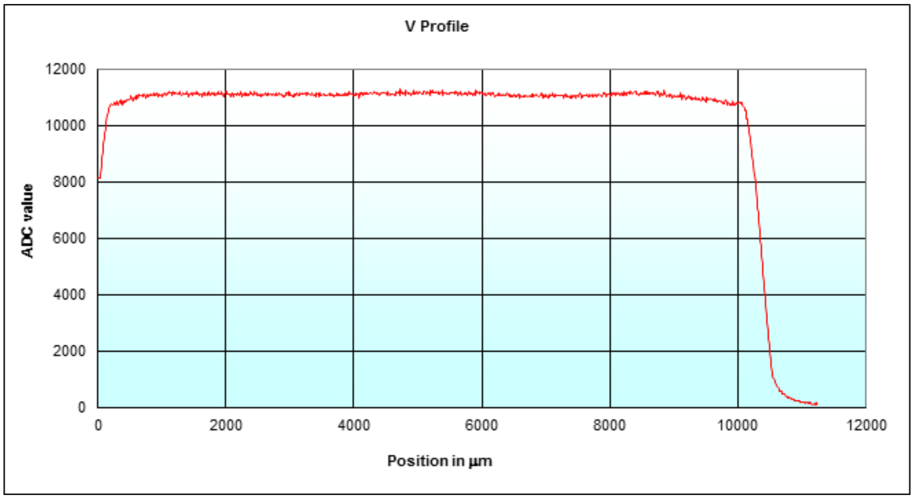


Figure A.8: Exported Y profile data.

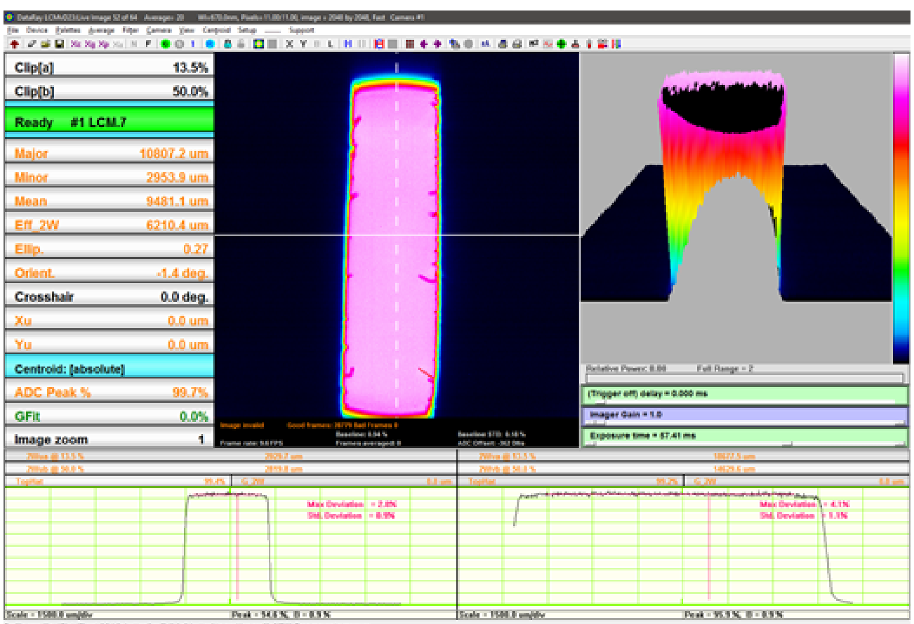


Figure A.9: Compensated but peak irradiance too high.

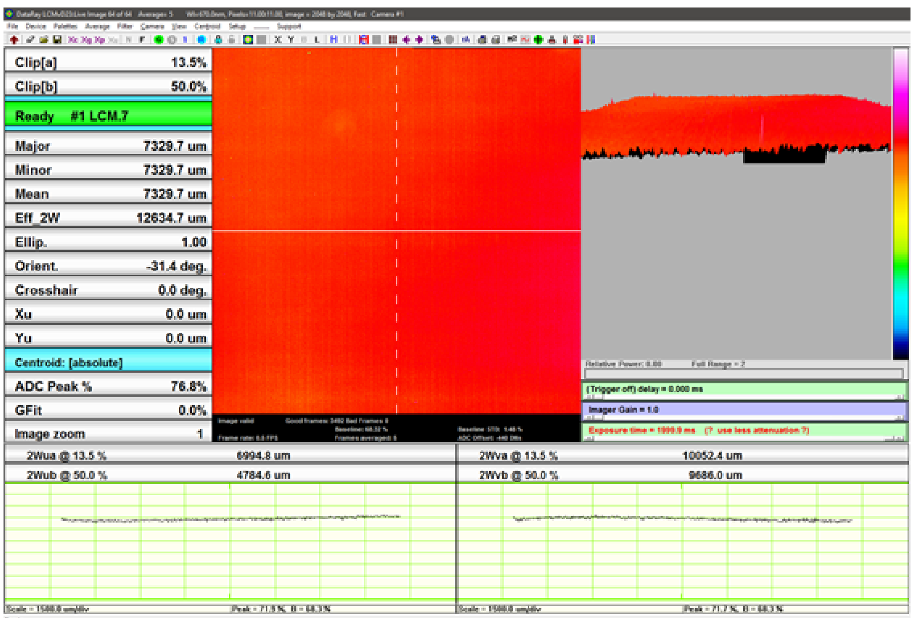


Figure A.10: Flat field illuminated sensor with ND4 filter compensated by a compensation file taken without the filter in place. This emphasizes the necessity to generate compensation files with the filter that will be used in the orientation in which you intend to use it. The variations are due to variation in the Schott NG glass melt.

Appendix B

Image Degradation Diagnosis and Filter/Sensor Cleaning

Although DataRay does not recommend cleaning the beam profiling camera sensors due to the delicacy of the parts, cleaning may become necessary if dirt is interfering with the quality of laser beam profiling measurements. If the user decides to clean the sensor, we recommend extreme caution as user-damaged sensors are not covered by the camera's three-year warranty.

There are three different places that image degradation can occur. First, the optics preceding the DataRay beam profiling camera (source optics) can have flaws (e.g. dirt on preceding lenses, problems with the source output). These source optic problems must be addressed by the user as each setup varies. Second, the ND filter covering the sensor may be dirty or scratched. Dirty ND filters can be cleaned, but scratched or damaged ND filters must be replaced. Lastly, the sensor itself can be dusty or damaged. A dusty sensor can be cleaned, while a damaged sensor must be replaced. If the problem lies in the source optics or a dirty ND filter, then a diffraction pattern should be seen (see Fig. B.1). If the problem lies with a dirty sensor, then small dark spots will be seen (see Fig. B.2). Scratched sensors will generally show a dark line running across the image.

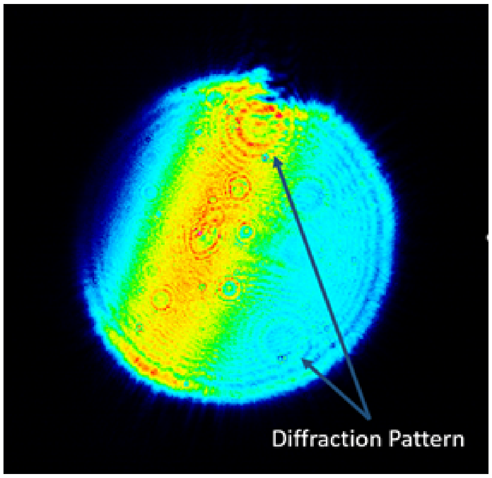


Figure B.1: Shows the diffraction pattern caused by dirt on the ND filter.

Diffraction pattern

If a diffraction pattern is seen, then the problem most likely lies in the source optics or the ND filter attached to the DataRay beam profiling camera. Distinguish between them as follows:

Source Optics

Move your source so that the source's motion can be seen on the DataRay beam profiling software. If the diffraction spots move with the source, then the issue is the source optics. Solutions to this problem are not addressed in this blog post as they are user specific.

ND Filter

If the diffraction pattern does not move when the source moves, the most likely explanation is dust or other marks on the ND filter or sampling/attenuation optics. If the problem is dust, then the filter can be cleaned with an oil free air-duster. However, if the problem is finger prints, the ND filter or sampling attenuation optic must be physically cleaned.

To clean the filter of dust, first try only air-dusting the front surface of the filter. If this does not work, carefully unscrew the ND filter from the profiling camera. Next with an oil free air-duster, blow off both sides of the ND filter (see air-duster section under the Black Spots heading).

To clean finger prints from the ND filter or sampling attenuation optics, first remove the filter by carefully unscrewing it from the DataRay profiling camera. Next, clean the filter by rubbing it down with a small amount of laboratory grade methanol on a lint-free cloth. We use cloth cleaning wipes. After wiping down the filter, blow off the filter with an oil free air-duster. If the mark is particularly stubborn, two alternate methods can be tried. The first is an alcohol wash with a cotton bud followed by an edge to edge blow-dry. Secondly, since some marks are not alcohol soluble but rather water-soluble, the marks must be rubbed off with a water-dampened, lint-free cloth.

Black Spots

If you see small black spots on the image that do not move with the source image, or when you rotate the filter, then this is dust on the chip. A small amount of dust is inevitable, so avoid cleaning the sensor unless the dust is interfering with measurements. We reiterate that user-damaged sensors are not covered by the warranty. However, to clean the sensor first carefully remove the ND filter or sampling/attenuation optics. With the filter removed, the ambient illumination of the imager typically shows the dust spots (see Fig. B.2). Avoid touching the surface of the sensor chip at any time during the cleaning process. Ultimately, the sensor surface will be blown off with an oil free air-duster, but first a couple of important things must be noted:

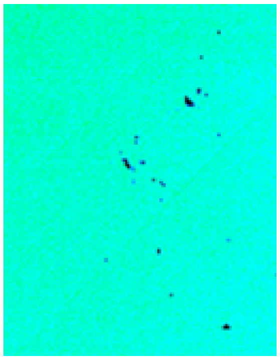


Figure B.2: Black spots on sensor.

Bond Wires

Bond wires connect the sensor to the rest of the electronics; they are extremely small and delicate (see Fig. B.3). Should they be damaged, the sensor cannot be repaired. Avoid blowing directly on the fragile bond wires by instead blowing off the chip at an angle (air-dusters addressed below). The ambient light on the sensor should show when the dust spots have been removed.

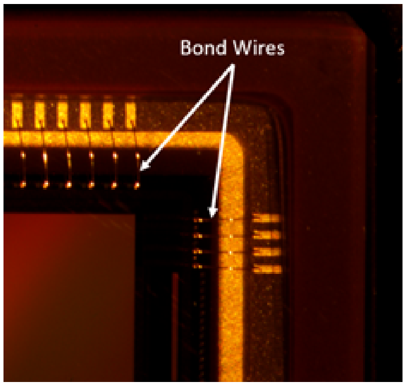


Figure B.3: Delicate bond wires on the sensor.

Figure B.4: Left: Incorrect way to use air duster. Liquid exits canister because of its horizontal orientation.
Right: Correct vertical orientation of air duster canister. Air is blown at an angle by bending the attached nozzle.

Air-Dusters

Air-dusters often spray a visible film when they are used at an angle (see B.4). Always make sure that the air-duster is completely vertical and upright when blowing off the sensor. The film will irreparably contaminate the sensor surface. We recommend doing a test blow away from the sensor with the air-duster to make sure the duster isn't blowing oil. When blowing off the sensor with the air-duster, the air stream should make approximately a 30-degree angle with the sensor surface. Either hold the sensor at an angle or angle the plastic nozzle attached to the duster (but leave the air-duster can upright, see B.4). Avoid touching the surface of the sensor. We use the Dust-Off and Dust Destroyer brand products which are available at both Amazon and Staples in the USA.

Sensor Replacement

Most cameras have user-replaceable imager chips. User-damaged chips are not covered under warranty, but can still be replaced. Often times, replacing the sensor is more cost effective than buying a new camera. Additionally, most sensors are field replaceable (instructions available), which can save on RMA shipping time.

For questions on sensor cleaning not addressed in this document feel free to contact us. For more information on image sensor replacement please contact your local Rep or Distributor.

Appendix C

Drawings and Models

About Drawings and Models

This section includes drawings and links to models for BladeCam2, TaperCamD, and WinCamD profilers. For the most updated versions of these drawings and models, please visit the product pages on our website.

BladeCam2

BladeCam2-HR/XHR drawing is shown in Fig. C.1. Visit our website for downloadable copies of the drawing, step model, and eDrawings assembly.

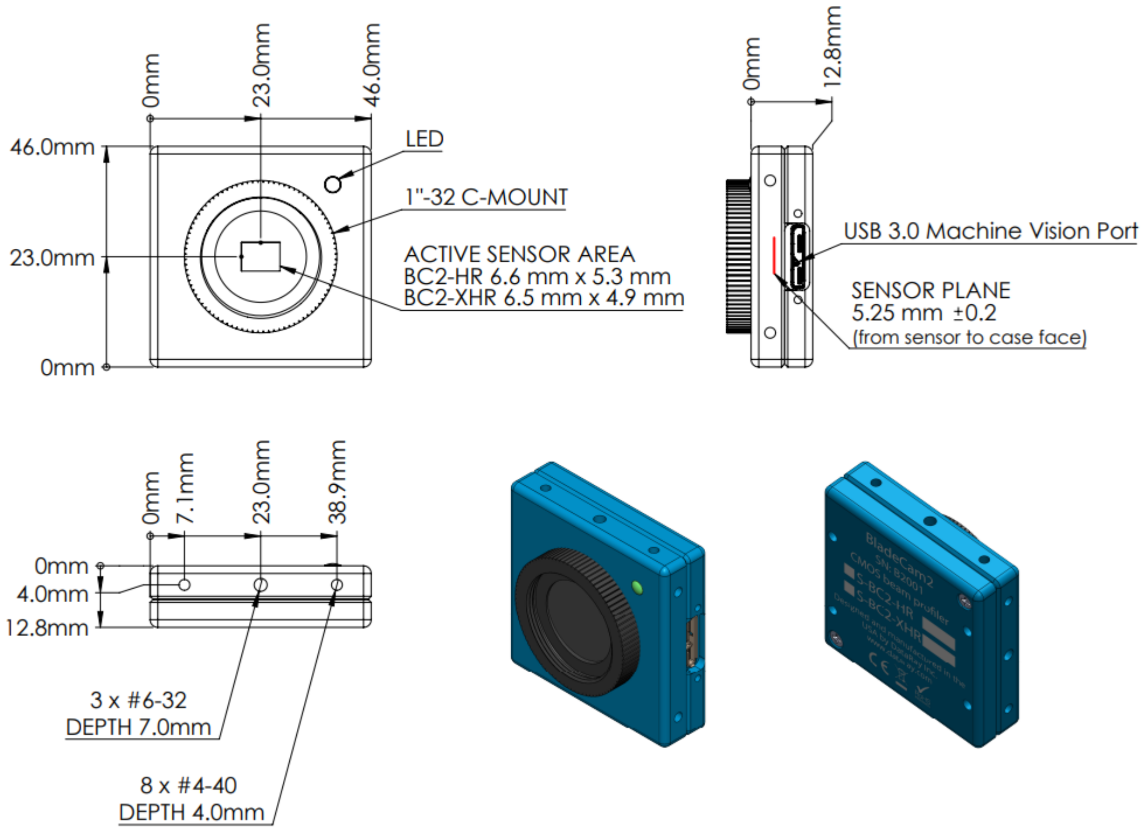


Figure C.1: BladeCam2-HR/XHR Drawing.

TaperCamD-LCM

TaperCamD-LCM drawing is shown in Fig. C.2. Visit our website for downloadable copies of the drawing, step model and eDrawings assembly.

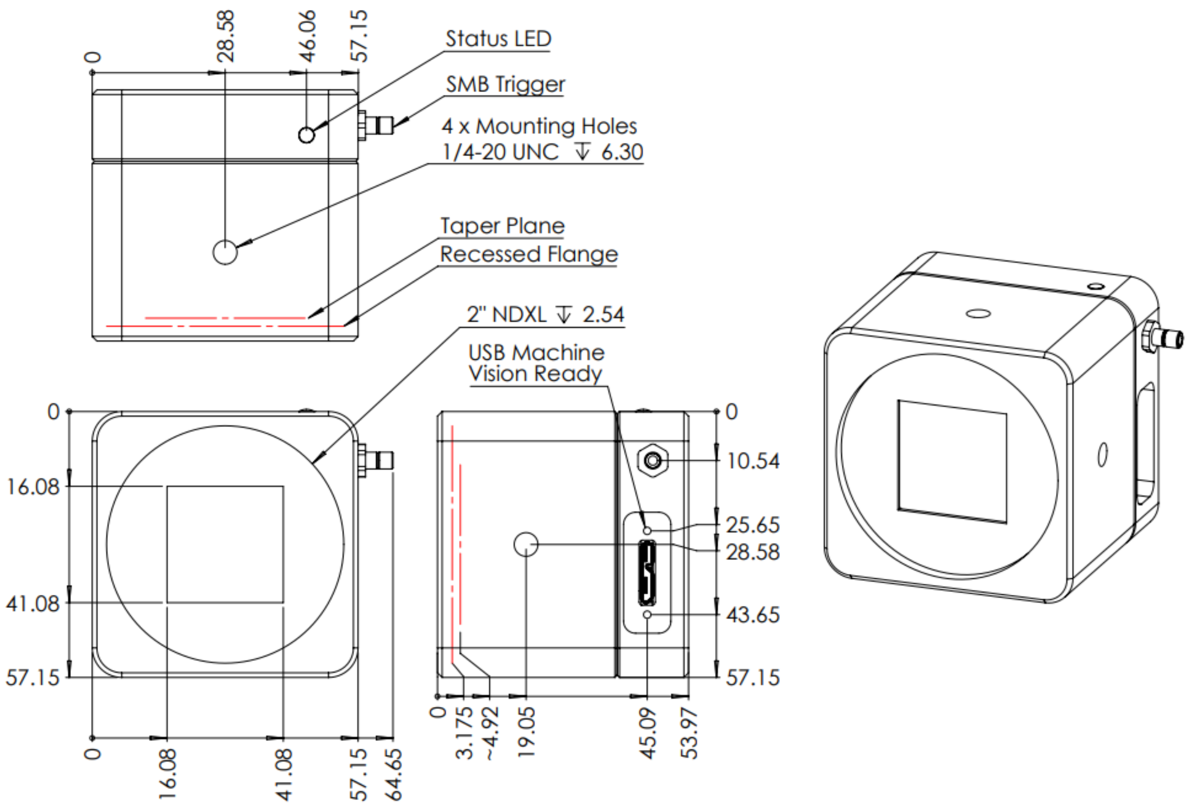


Figure C.2: TaperCamD-LCM Drawing.

WinCamD-LCM

WinCamD-LCM drawing is shown in Fig. C.3. Visit our website for downloadable copies of the drawing, step model, and eDrawings assembly.

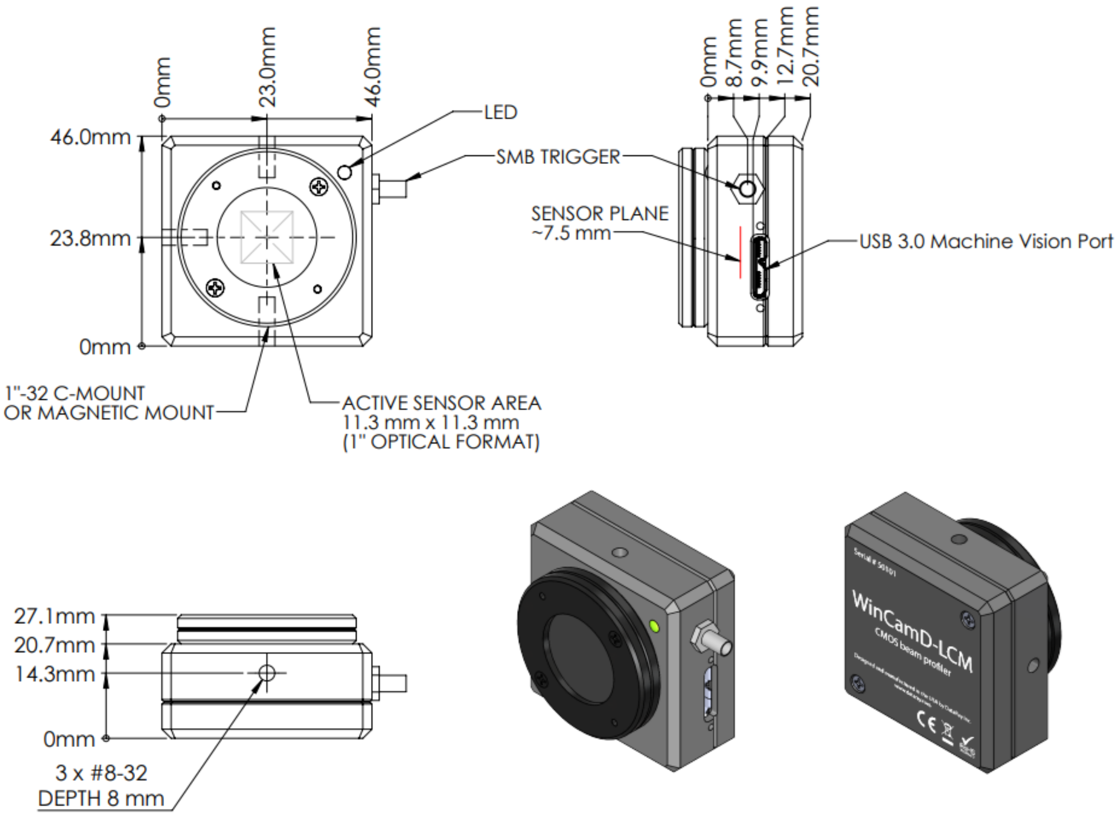


Figure C.3: WinCamD-LCM Drawing.

WinCamD-GCM

WinCamD-GCM drawing is shown in Fig. C.4. Visit our website for downloadable copies of the drawing, step model, and eDrawings assembly.

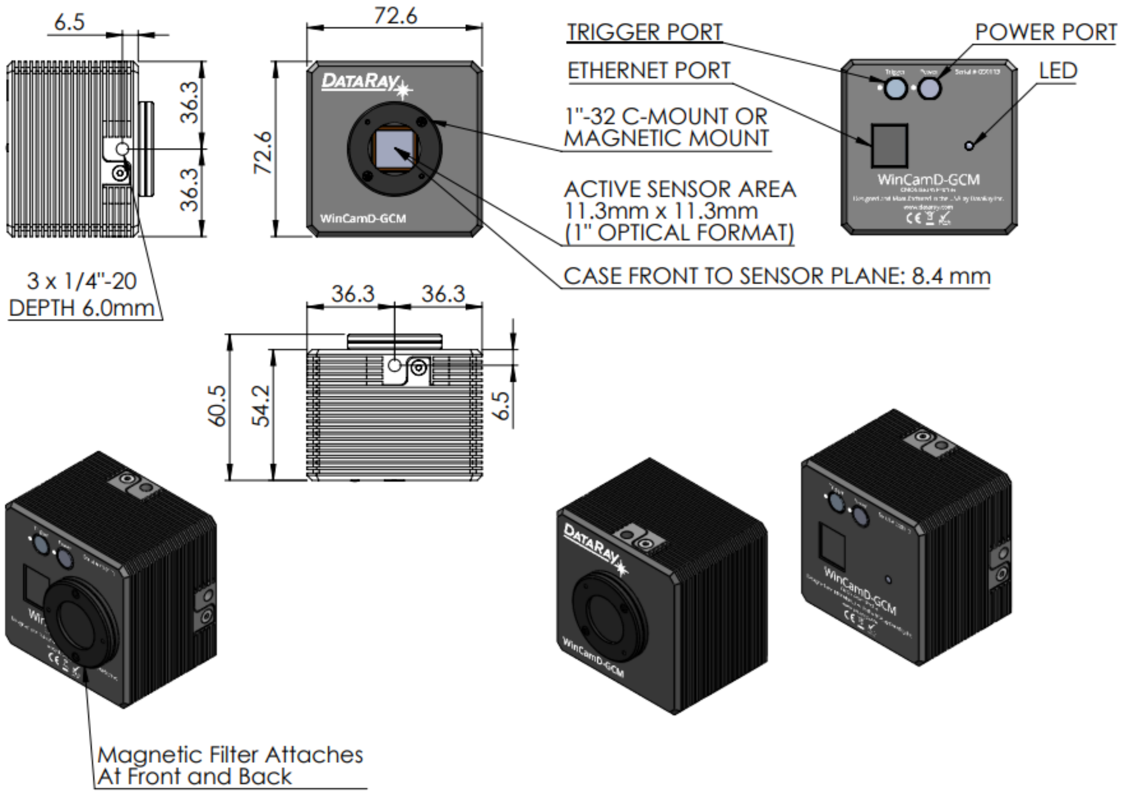


Figure C.4: WinCamD-GCM Drawing.

WinCamD-QD

WinCamD-QD drawing is shown in Fig. C.5. Visit our website for downloadable copies of the drawing, step model, and eDrawings assembly.

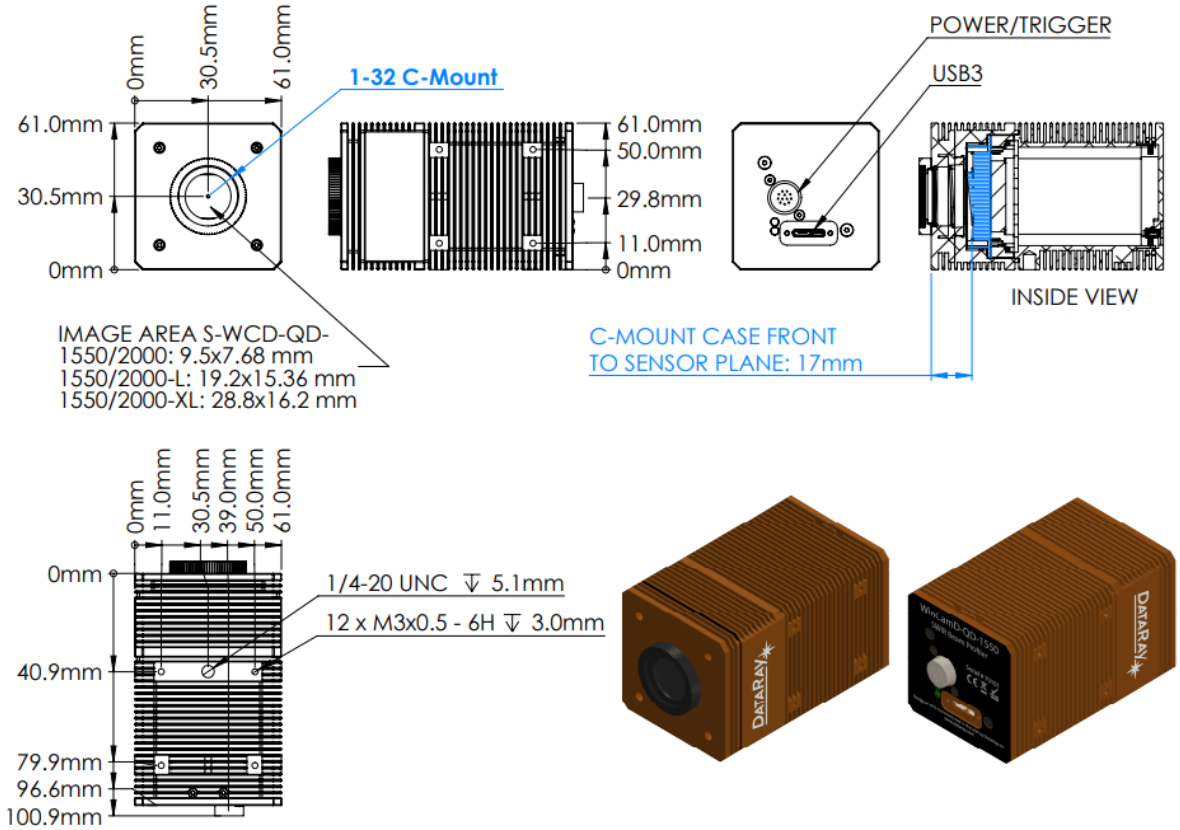


Figure C.5: WinCamD-QD Drawing.

WinCamD-IR-BB

WinCamD-IR-BB drawing is shown in Fig. C.6). Visit our website for downloadable copies of the drawing, step model, and eDrawings assembly.

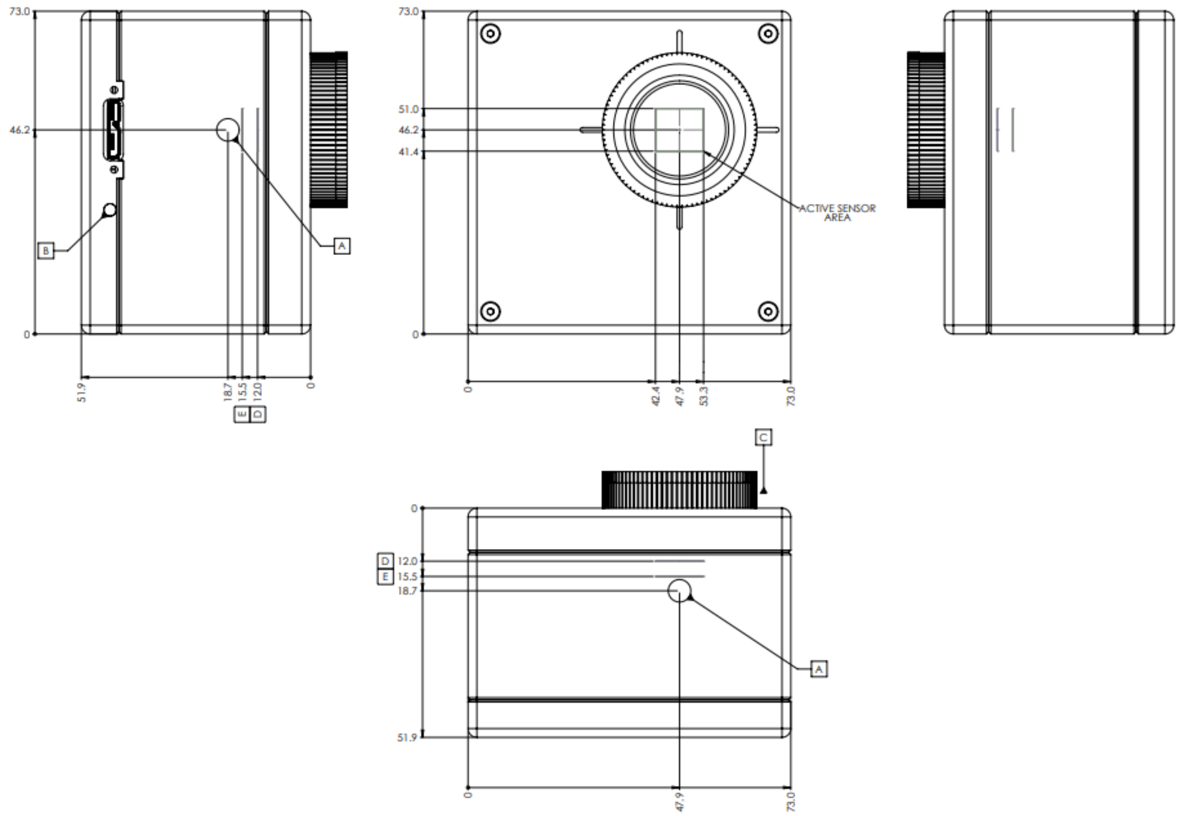


Figure C.6: WinCamD-IR-BB Drawing.

Appendix D

Quick Reference Guide

Attenuation	ND Value	Color Code
3	0.5	
10	1.0	
100	2.0	
1000	3.0	
10,000	4.0	
100,000	5.0	
UG11	See Fig. 5.1	
LP1290	See Fig. 5.1	

Table D.1: Gives the ND filter attenuation, name and color.

Shortcut Keys	Description	Shortcut Keys	Description
F1 or **G**	Start camera capture	**F2** or **S**	Stop camera capture
b	Displays both profiles	**x**	Displays X profile
y	Displays y profile	**l**	Displays large 2D view
i	Zooms in	**o**	Zooms out
Ctrl+O	Opens a file	**Ctrl+S**	Opens a save dialog
Ctrl+t	Opens the trigger dialog	**Ctrl+w**	Opens the wander dialog
page up	Increments the image index	**page down**	Decrements the image index

Table D.2: Software shortcuts.

Specification	WinCamD-LCM	WinCamD-GCM	WinCamD-QD	WinCamD-IR-BB
Image Area (mm):	11.3×11.3		9.6×7.7 19.2×15.4 (L) 28.8×16.2 (XL)	10.8×8.2
Sensor:	1" CMOS		1/1.8" QCD	2/3" Microbolometer
Resolution:	2048×2048		640×512 1280×1024 (L) 1920×1080 (XL)	640×480
Pixel Count (MPixel):	4.2		0.33 1.3 (L) 2.1 (XL)	0.31
Pixel dimensions: (μm):	5.5×5.5		15×15	17×17
Wavelength range:	355 - 1150 nm		400 - 1700 nm (QD-1550) 350 - 2000 nm (QD-2000)	2 - 16 μm
Interface:	USB 3.0 Port-powered	GigE Vision with PSU	USB 3.0 or GigE with PSU	USB 3.0 Port-powered
CW or Pulsed:	CW, Pulsed			CW, Pulsed (PRR > 1 kHz)
Shutter type:	Global			Rolling
Single pulse capture PRR (kHz):	12.6		3.3	N/A
Min. beam diameter (10 pixels, μm):	55		150	170

Table D.3: The product specifications for the WinCamD-LCM, WinCamD-GCM, WinCamD-QD, and WinCamD-IR-BB.

BladeCam2	-HR	-XHR
Image Area (mm):	6.6×5.3	6.5×4.9
Sensor:	1/2″ CMOS	1/2″ CMOS
Resolution:	1280×1024	2048×1536
Pixel Count:	1.3 M Pixel	3.1 M Pixel
Pixel dimensions: (μm):	5.2×5.2	3.2×3.2
Wavelength range:	355 - 1150 nm	
Interface:	USB 2.0 Port-powered	
CW or Pulsed ?:	CW	
Shutter type:	Rolling	
Single pulse capture PRR:	NA	
Min. beam (10 pixels, μm):	~52	~32
Max. frame rate (Hz):	20+	
Signal to RMS Noise:	1,000:1	
Electronic Shutter Dynamic Range:	44	
ADC:	10-bit	110-bit
Opt./Elec.* dB:	30/60 dB*	
Max full frame rate:	$\sim 5 - 10$	
Max. 'every pulse' PRR:	$\sim 5 - 10$	

Table D.4: Product specifications for the WinCamD-UHR, and WinCamD-XHR.

Index