



USER MANUAL

Beamage-M2 | Automated M² Measurement System



121-203554

gentec-eo
PARTNERS for ACCURACY

WARRANTY

First Year Warranty

The Gentec-EO Beamage series beam profiler carries a one-year warranty (from date of shipment) against material and/or workmanship defects, when used under normal operating conditions. The warranty does not cover damages related to battery leakage or misuse.

Gentec-EO Inc. will repair or replace, at Gentec-EO Inc.'s discretion, any Beamage that proves to be defective during the warranty period, except in the case of product misuse.

Any attempt by an unauthorized person to alter or repair the product voids the warranty.

The manufacturer is not liable for consequential damages of any kind.

Contacting Gentec Electro-Optics Inc.

In case of malfunction, contact your local Gentec-EO distributor or nearest Gentec-EO Inc. office to obtain a return authorization number. The material should be returned to:

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Fax: (418) 651-1174
E-mail: service@gentec-eo.com
Website: gentec-eo.com

CLAIMS

To obtain warranty service, contact your nearest Gentec-EO agent or send the product, with a description of the problem, and prepaid transportation and insurance, to the nearest Gentec-EO agent. Gentec-EO Inc. assumes no risk for damage during transit. Gentec-EO Inc. will, at its discretion, repair or replace the defective product free of charge or refund your purchase price. However, if Gentec-EO Inc. determines that the failure is caused by misuse, alterations, accident, or abnormal conditions of operation or handling, it would therefore not be covered by the warranty.

SAFETY INFORMATION

Do not use a Beamage-M2 if the device or the detector appears damaged, or if you suspect that a Beamage-M2 is not operating properly.

Note: This equipment has been tested and was found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses, and can radiate radio frequency energy. If not installed and used in accordance with the instructions, it may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, try to correct the interference by taking one or more of the following steps:

- Reorient or relocate the receiving antenna.
- Increase the distance between the equipment and receiver.
- Connect the equipment to an outlet that is on a different circuit than the receiver.
- Consult the dealer or an experienced radio/TV technician for help.

Caution: Changes or modifications not expressly approved in writing by Gentec-EO Inc. may void the user's authority to operate this equipment.

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1. BEAMAGE-M2

1.1. INTRODUCTION

Gentec-EO's Beamage beam profiler now has a powerful ally in its quest towards M^2 measurement: The Automated M^2 Measurement System, Beamage-M2. With its low profile and smart hardware, Beamage-M2 is easy to setup on any optical table. Intended for use with a Beamage camera, equipped with a rapid translation stage, and integrated in the PC-Beamage software, an M^2 measurement can be done in less than 1 minute. It comes with a complete set of 2" optics, the only one on the market allowing you to directly measure $>1"$ beams. No need to add uncertainties by further shrinking the beam!

The M^2 factor can be considered a quantitative indicator of laser beam quality. In terms of propagation, it is an indicator of closeness to an ideal Gaussian beam at the same wavelength. Paired with a Beamage-4M beam profiling camera, the Beamage-M2 module provides a very quick M^2 measurement directly in the PC-Beamage software.

1.2. SPECIFICATIONS

M2 System	Beamage-M2
Wavelength Range	350-1100 nm
Attenuation Range	ND0 - ND0.5 - ND1 - ND2 - ND1.5 - ND2.5 - ND3 - ND3.5
Beam Diameter Range	55 μ m to 11.3 mm (at Beamage)
Damage Threshold	See Specifications for Beamage-4M
Translation Stage	
Travel Range	200 mm
Effective Optical Path	180 – 587 mm
Lens Focal Length	200 mm 300 mm 250 mm
Optical Axis Height	86 mm
Typical Estimated M^2 Accuracy (depending on beam quality and optical configuration)	5% 2% repeatability
Applicable Light Sources	CW and pulsed
Typical Measurement Time	45 sec

Camera Specification		See Beamage-4M manual
Sensor Technology		CMOS without cover glass
Pixel Dimension		5.5 μm
Pixel Count		4.2 MPixels
ADC		12 bit (default) or 10 bit
Frame Rate		See Beamage-4M Manual
Minimum and Maximum Exposure Time		0.06 ms - 200 ms
USB Port		USB 3.0 port for optimal performance USB 2.0
General Specification		
Size		602 mm (L) x 193 mm (W) x 172 mm (H)
Weight		6.8 kg (15 lb)
Power Supply		48V DC, 1.25A out
Environmental		
Storage Temperature		10°C to 60°C
Storage Humidity		RH< 90%
Operating Temperature		15°C to 28°C
Operating Humidity		RH< 80% (without condensation)
Measurements		
M-Square		M_x^2, M_y^2
Beam Parameter Product		BPP_x, BPP_y
Width At Waist		w_x, w_y
Divergence angle		θ_x, θ_y
Waists Location and Offset		$Z_x, Z_y, \Delta Z$
Rayleigh Length		Z_{Rx}, Z_{Ry}
Astigmatism		

1.3. MECHANICAL DESCRIPTION

1.3.1. Schematic

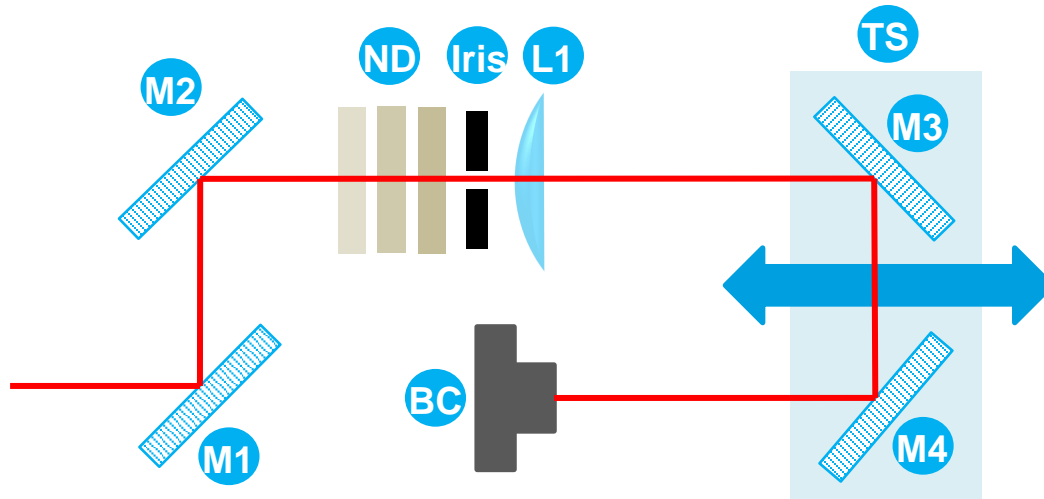


Figure 1-1 : Automated M-Squared Measurement System schematic

M1

Alignment mirrors

M1 and M2 allow the user to align the beam through the lens and on the Beamage. M1 is mounted on a translation stage that allows a better centering on the mirror pair, while M2 is mounted on a fixed post. They both allow the usual “x” and “y” angle alignment.

M2

ND

Variable neutral density filters (ND)

Three ND filters are held in separate toggle mounts, allowing the user to rapidly change the beam attenuation factor. A sufficient attenuation factor set for the far field will usually be too weak around the focal spot for the camera to adjust its exposure time. The variable density filter eliminates the hassle of setting a cage system or multiple posts-mounted ND filters during the measure.

L1

Lens

Three cage-mounted 2” lenses of different focal lengths are supplied with every M² system: 200 mm, 250 mm, and 300 mm. The cages screw onto SM2 female thread.

TS

Translation stage

A 200 mm motorized rail allows a computer controlled position of the folding mirrors (M3 and M4), which in turn allow a 400 mm beam path difference. The automation of the translation stage allowed by the software is the key to a fast measurement.

M3

Folding mirrors

M3 is glued to the TS while M4 allows an angular adjustment. This enables the best possible beam alignment inside the translation chamber. M4 is factory-aligned.

M4

BC

Beamage camera

A Beamage profiling camera is held in a smooth borehole by a set screw and can easily be removed when the M² measurement is done.

Iris

Iris aperture

An iris aperture is used in order to facilitate the alignment.

1.3.2. Mechanical properties

The overall appearance of the fully assembled Beamage-M2 is shown below. A casing covers the moving parts to protect them from dust and to prevent accidental misalignment of the factory-adjusted mirror (M4).

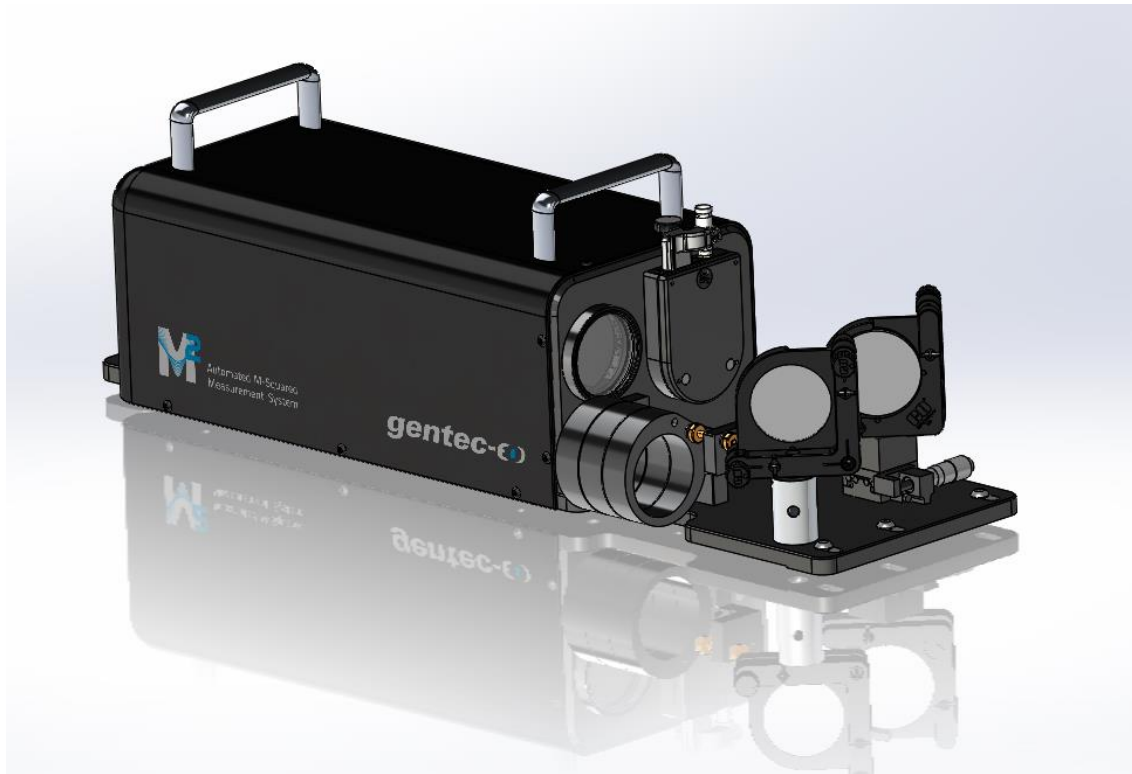


Figure 1-2 : Assembled Automated M² Measurement System

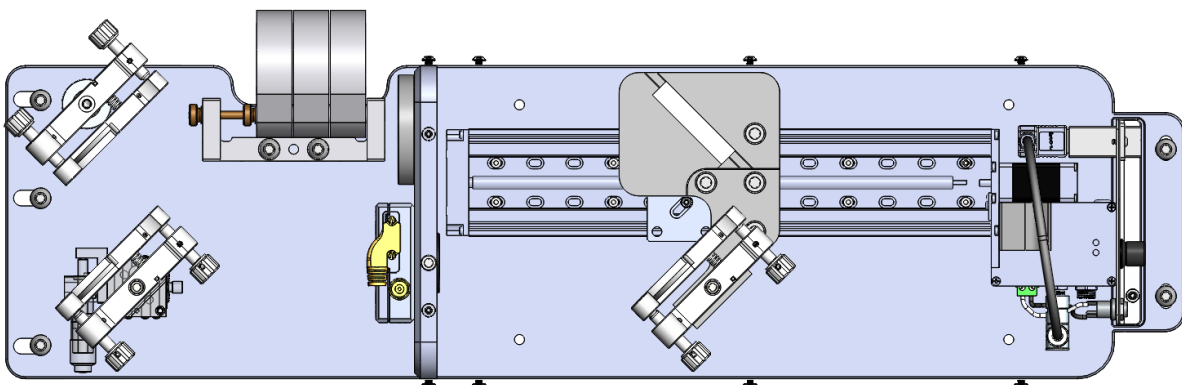


Figure 1-3 : Complete mechanics top-view
Automated M² Measurement System with the casing removed. CAD version of **Figure 1-1**.

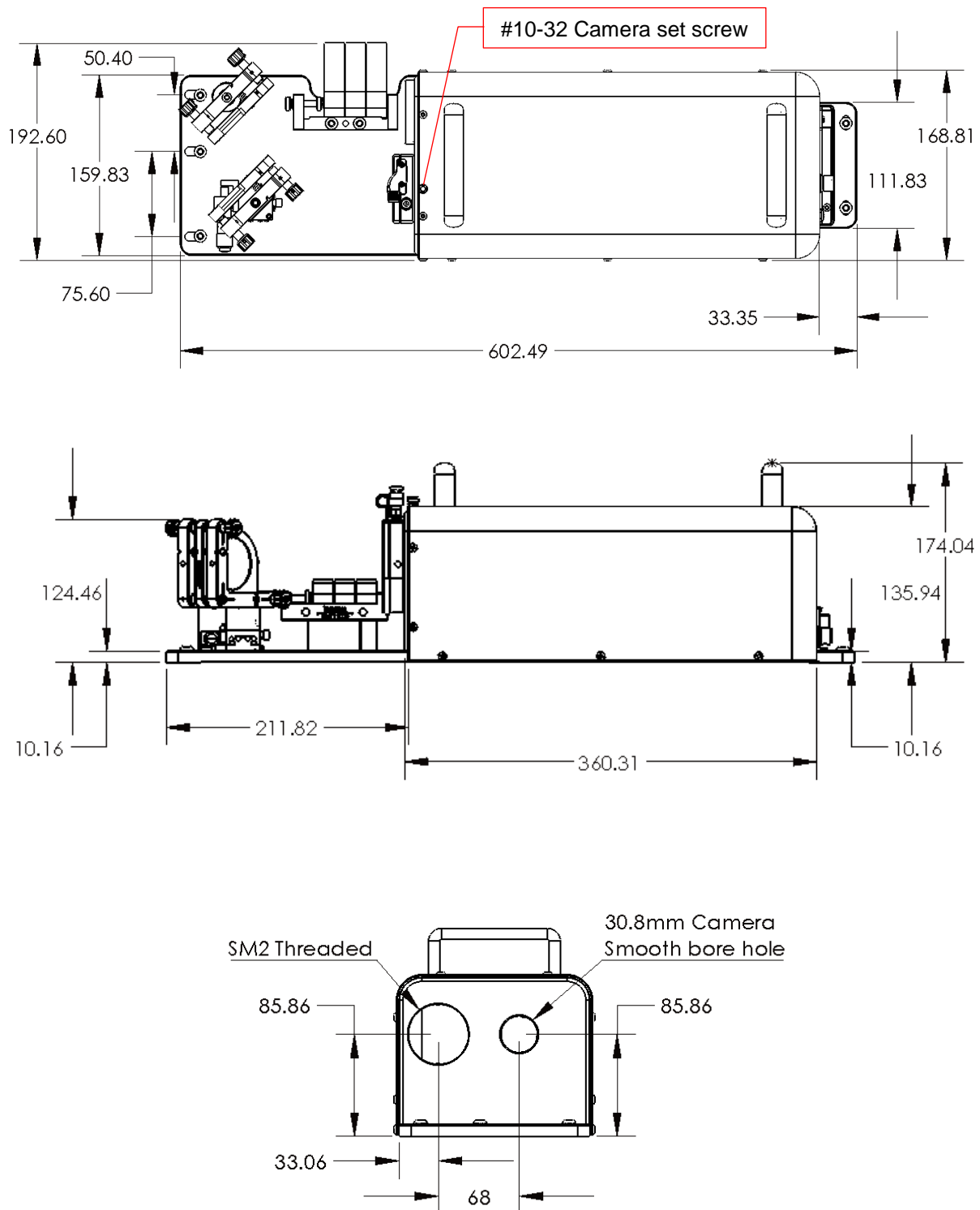


Figure 1-4 : Beamage-M2 module top, side and front view

2. BEAMAGE-M2 SETUP

Before a measurement, make sure that the entire device is in good condition and ready to work. This section shows how to perform the set up and verify that each component is working properly.

2.1. MECHANICAL AND ELECTRICAL SETUP

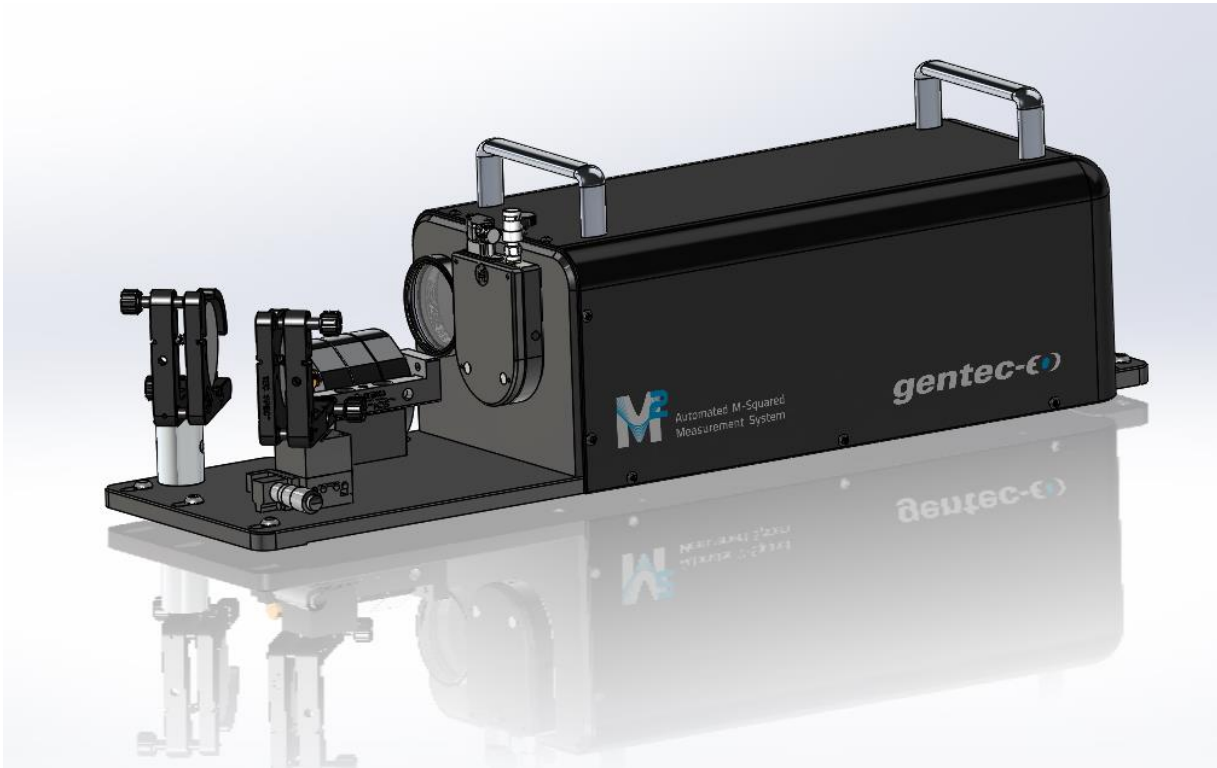


Figure 2-1 : Completely assembled Beamage-M2 setup

1. Make sure the Beamage-4M camera is in place as shown in the image above. The connectors must be facing upwards.
2. Verify the focal length of the lens placed into the SM-2 threaded hole.
3. Plug the camera into a USB-3 port on your computer equipped with the latest PC-Beamage software version.
4. Connect the Beamage-M2 rail to a USB-2 or USB-3 port. Note that the translation stage will only work with the provided USB cable.
5. Connect the power cable to a power outlet. Upon connection, the rail should run by itself for a few seconds.
6. Verify that the translation stage is in good working condition by turning the translation knob towards the “far” and “near” positions, respectively. “Far” and “near” refer to the position of the stage relative to the lens. Be sure to return the stage to the end of the “far” position prior to laser alignment.

2.2. LASER ALIGNMENT

The first time the Beamage-M2 is being used, the laser must be aligned correctly to ensure that the beam fits completely on the camera's sensor.

The mechanics simplify this task by putting all the optics at the same height. Mirrors on the moving stage are factory-aligned so that the user should never need to adjust them. The only adjustment remaining is the entry angle, controlled by M1 and M2.

The beam must be centered on the lens and the Beamage camera at the same time; these are our success criteria.

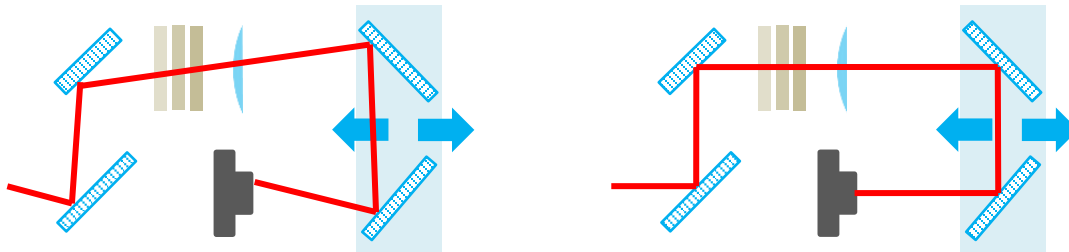


Figure 2-2 : Bad alignment vs. good alignment.

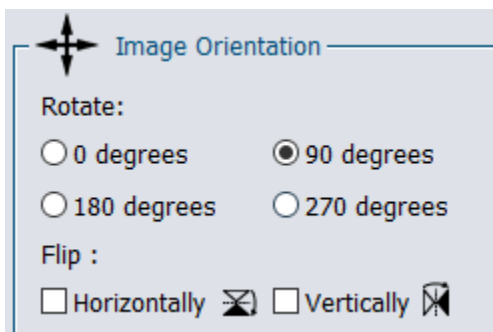
Left side: Bad alignment, causes the beam to shift a great distance on the sensor when the stage moves.

Right side: Good alignment, the beam is centered on both the lens and the camera.

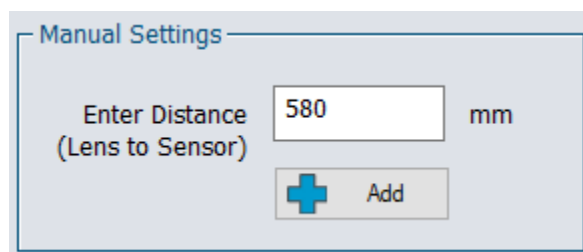
1. Alignment:

- a. Place the Beamage-M2 on an optical table
- b. Fix at least two of the 5 anchoring points to the optical table in order to keep the module from moving during or after alignment
- c. Install the Alignment Tube in front of the Iris (i.e. screw the tube on the Iris)
Note : the orange surface on the disk is fluorescent from 800nm to 1700nm
- d. Make sure the Beamage-M2 mirrors are parallel to their mount prior to alignment, it will make it easier
- e. Block the output of the laser you wish to measure with the detector card or with a suitable beam blocker then turn it on
- f. Be sure not to damage the system :
 - i. If your laser beam has a power higher than 100mW, put some attenuation in the beam path before mirror M1
 - ii. Use ND-Filters for beams with a power lower than 1W
 - iii. Use a Beam Splitter for beams with a power higher than 1W
- g. Align the beam towards the center of M1 while trying to have it as parallel as possible to the optical table. Use the detector card to help you align the beam from now on
- h. Use M1 to align the beam on the center of M2
- i. Make sure the beam reaches the first disk of the alignment tube. Use M1 to target the center of P1 (see **Figure 2-3**)
- j. Once the beam passes through P1, look through the tube's slot to find where it hits P2
- k. Use M2 to center the beam on P2.
- l. Repeat steps 8 to 11 until the beam is centered and passes through both P1 and P2
- m. Remove the alignment tube while keeping the iris in place
- n. Turn on the PC-Beamage software, press « Start Capture » and click on « 2D Display »

- o. Under the “Setup” tab, change the image orientation to 90°:



- p. In the “Advanced” tab, click the “M2” button. 2 new tabs open, then go to the “M2 Setup” tab and click “Connect the stage”
- q. Once connected, click “Cancel” in the pop-up box and type 580 in the Manual Settings then press enter



- r. Observe the beam in the Display screen and Use M2 to center the beam on the sensor
- s. Type 185 in the Manual Settings, press enter and center the beam using M1
- t. Repeat steps q. to s. if needed

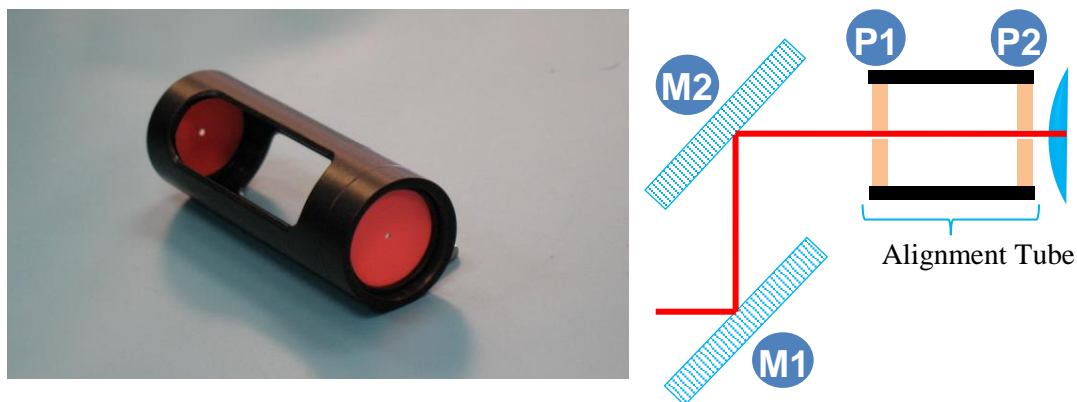


Figure 2-3: Alignment tube

On the left, the alignment tube mounted with its 2 fluorescent pinholes. On the right, schematics of the alignment tube with M1 and M2 aligning a laser beam.

2.3. SOFTWARE AND DRIVERS SETUP

The automatic control of the M² module requires at least the 1.04.00 version of PC-Beamage but some features only appear in version 1.04.04. Here, we will guide you through the software update/installation procedure.

1. If you already have PC-Beamage installed on your computer, jump to Step 4. Otherwise, go to Gentec-EO's website under the "Downloads" content:
<https://www.gentec-eo.com/downloads>
2. Download the latest PC-Beamage software.

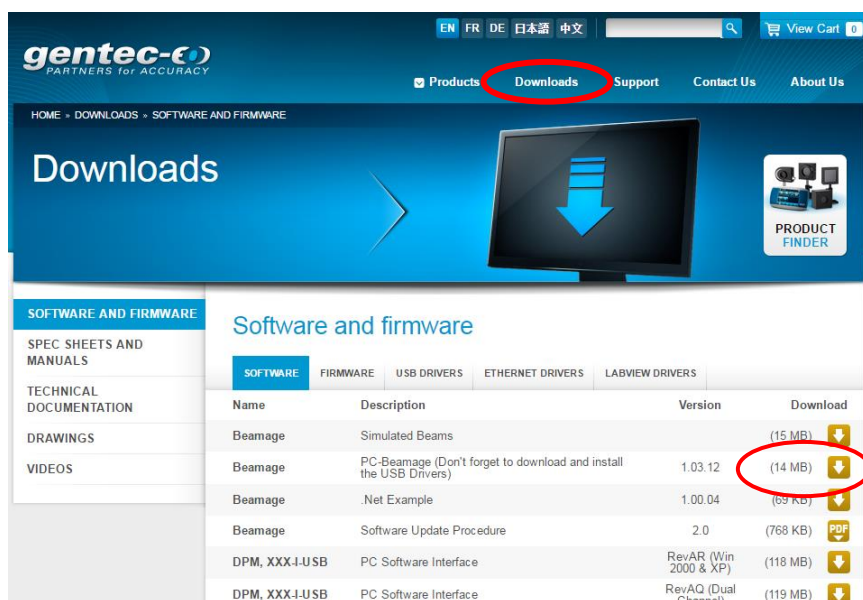


Figure 2-4 : PC-Beamage download web page

3. Install and run the software.
4. Under the "Advanced" tab, click "About" and a window will pop up:

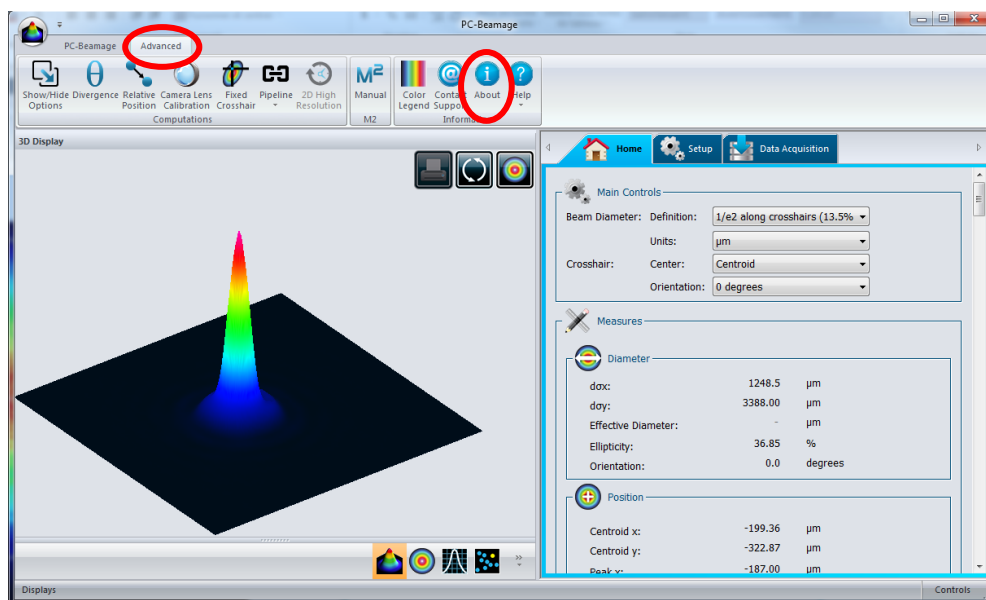


Figure 2-5 : PC-Beamage version verification

The pop-up window shows the current version of PC-Beamage.

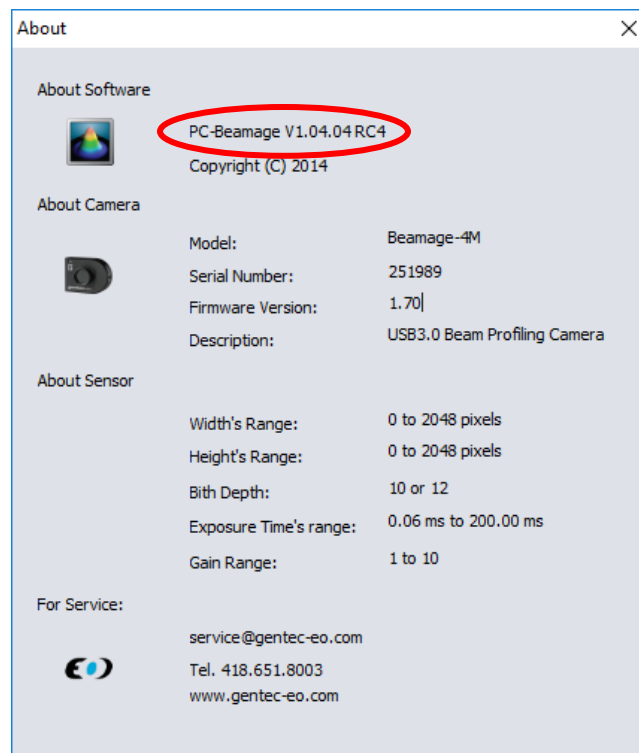


Figure 2-6 : PC-Beamage version

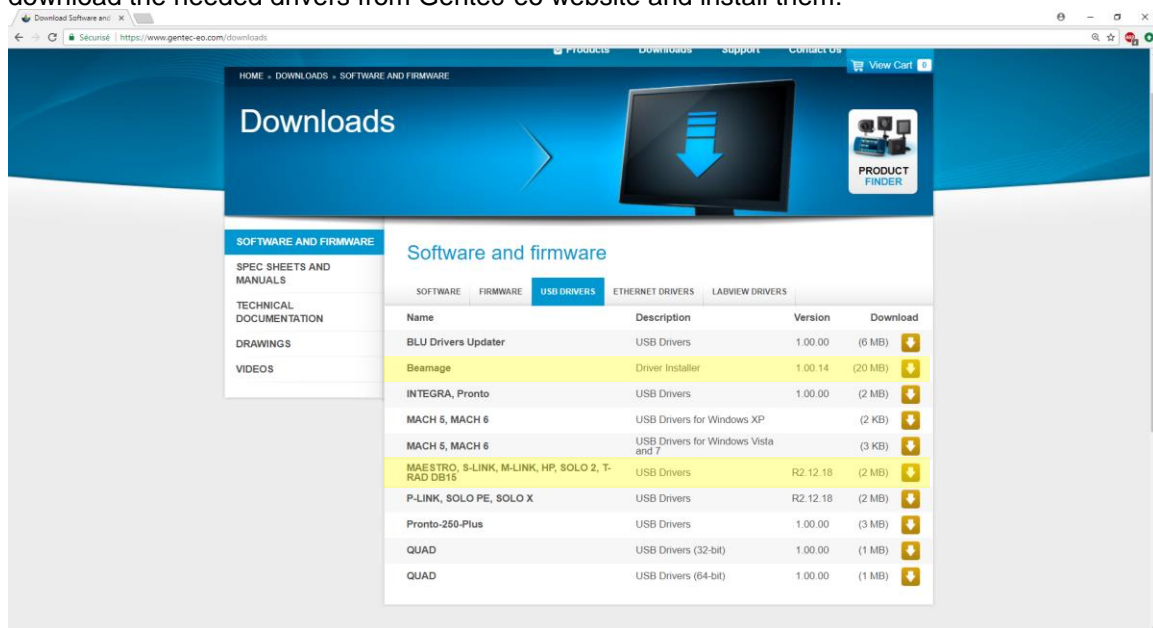
5. If your software version is not at least V1.04.04 RC4, then uninstall your current version of PC-Beamage from the Windows's Control Panel, and install the latest version (see steps 2 and 3).



Tip

This guide contains the software information needed to operate the Beamage-M2 automation. More information about the PC-Beamage software and interface can be found in the "Beamage user manual."

6. In case your camera and/or the translation stage is not able to communicate with the computer, download the needed drivers from Gentec-eo website and install them:



The required drivers are highlighted in yellow in the image above:

- Beamage driver installer (for the beamage camera)
- MAESTRO, S-LINK, M-LINK, HP, SOLO 2, T-RAD DB15 (for translation stage)

3. QUICK M² MEASURE

1. Start up PC-Beamage software.



Figure 3-1 : PC-Beamage logo

2. Select the serial number of the camera recognized on the “Beamage Selector” pop-up, click “OK.”

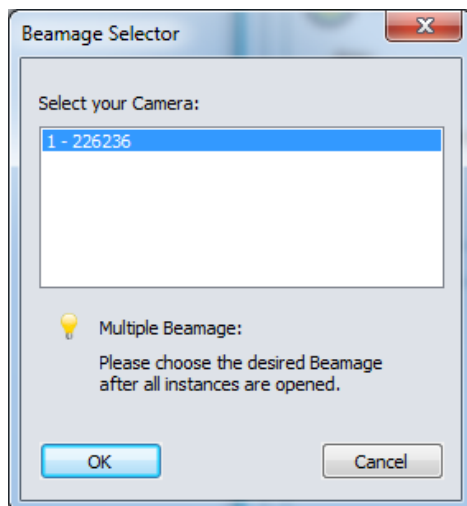


Figure 3-2 : Beamage camera selector pop-up

3. Switch to 2D Display and press “Start Capture.”

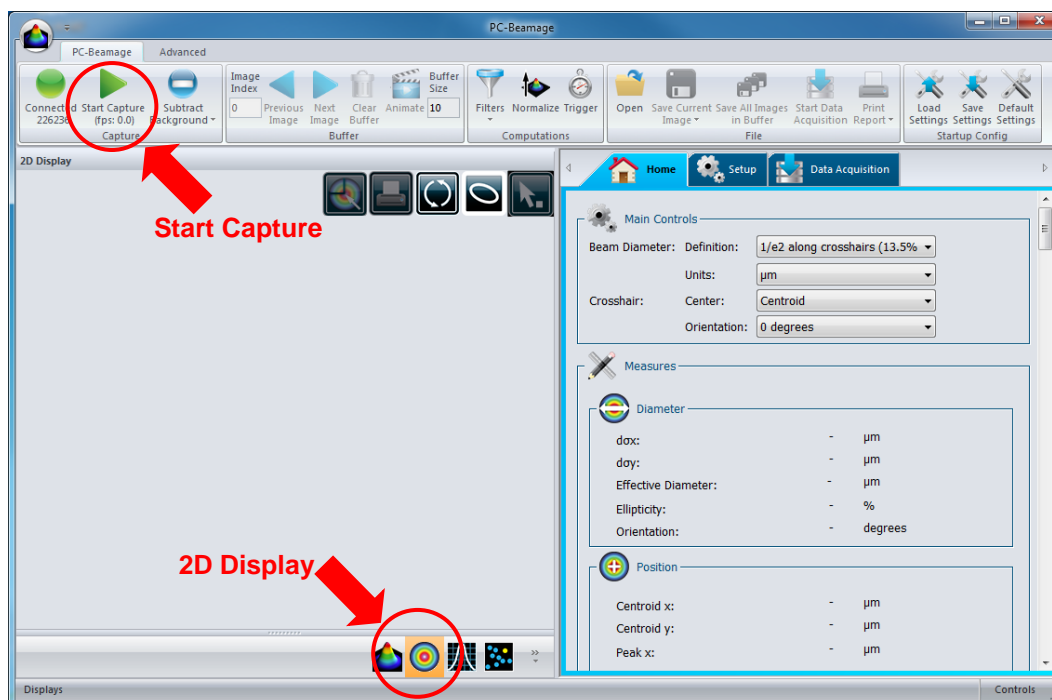


Figure 3-3 : Software setup Step 1

4. In “Setup” tab, under the “Image Orientation” box, select “Rotate: 90 degrees”. This ensures that the position of the beam on the sensor in reference to the user is as shown on the interface.

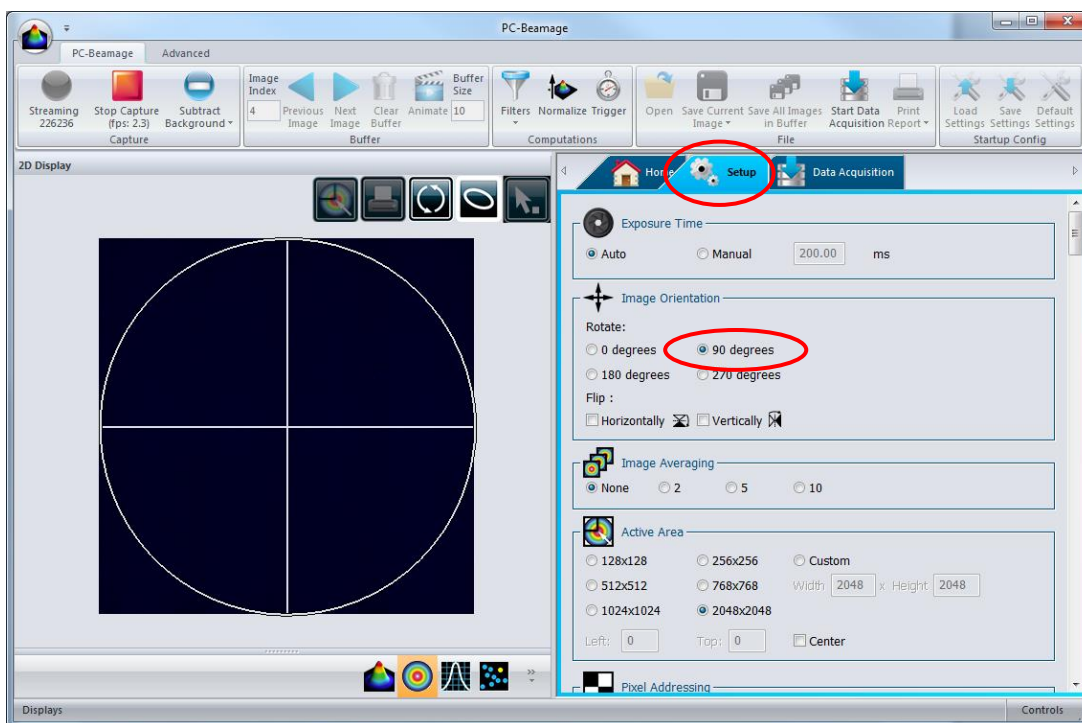


Figure 3-4 : Software setup Step 2

5. Make sure that the “Active Area” is set at the maximum.
6. Subtract background.

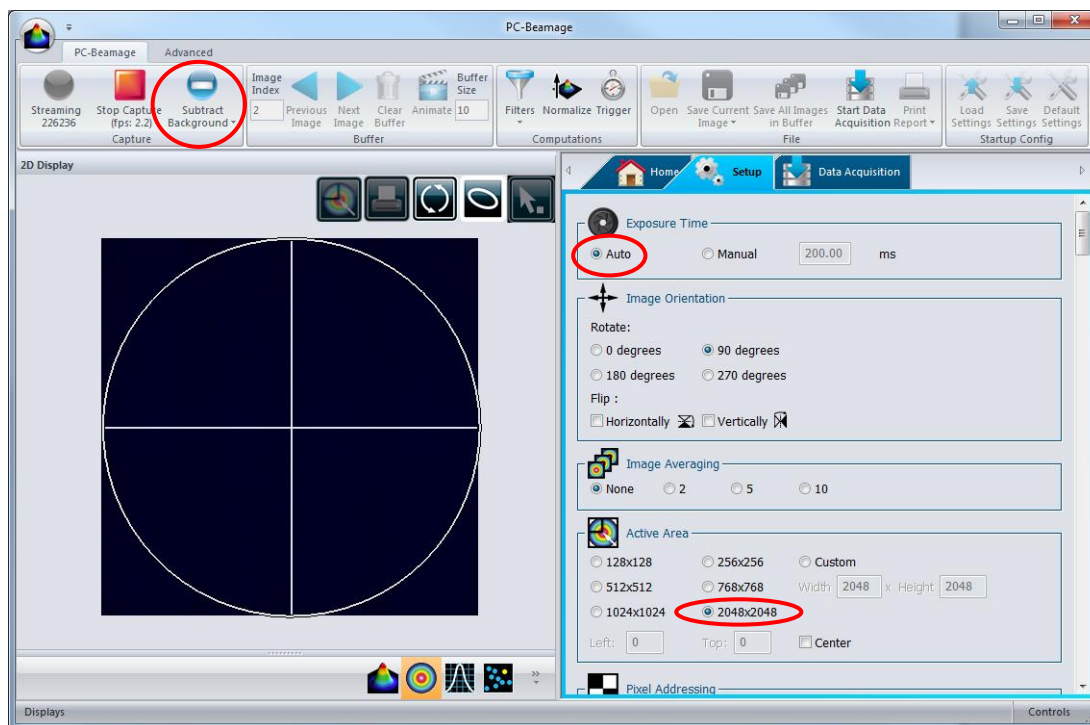


Figure 3-5 : Software setup Step 3

7. In the “Home” tab, under “Main Controls,” verify the parameters:
 “Beam Diameter: Definition: 4 sigma (ISO),”
 “Crosshair: Center: Centroid,” and
 “Crosshair: Orientation: Auto Orient.”

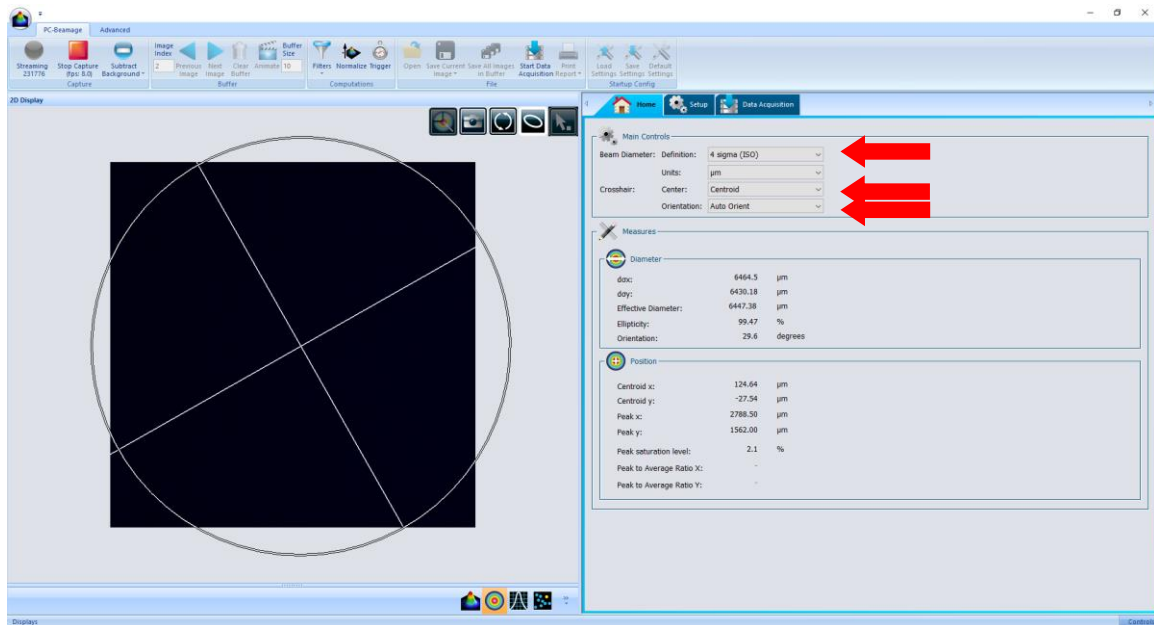


Figure 3-6 : Software setup Step 4

8. Turn on the laser you want to measure and direct it towards the center of M1.
9. Use M1 and M2 to align the laser. The beam must pass through the center of the lens AND be measured approximately on the center of the Beamage sensor in order to be properly aligned.
10. In the software, under the “Advanced” tab, select “M2” This will open two new tabs: “M² M2 Results” and “M² M2 Setup.”

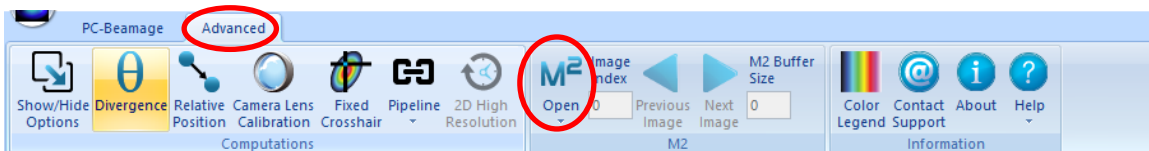


Figure 3-7 : Software setup Step 5

11. Under “M2 Setup,” fill in the “Laser Wavelength” and “Focal Length” fields.

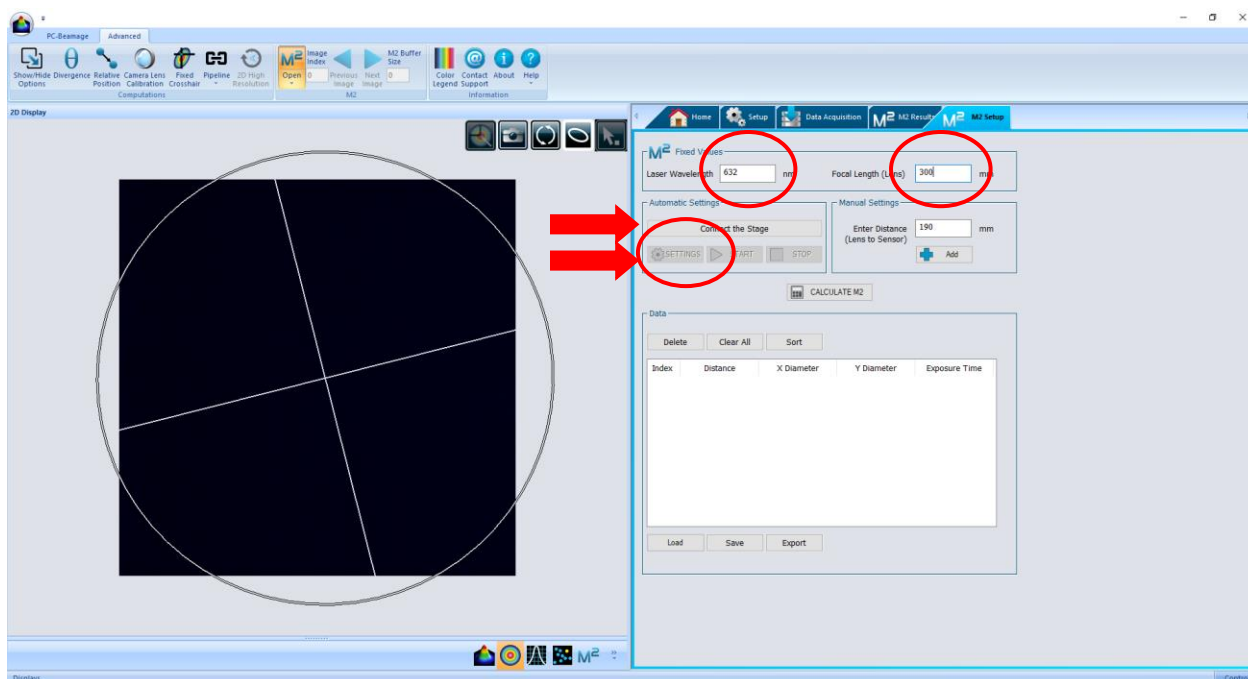


Figure 3-8 : Software setup Step 6

12. Click “Connect the Stage.”
13. In the “Automatic Settings” box, click “SETTINGS” and a window pops up.

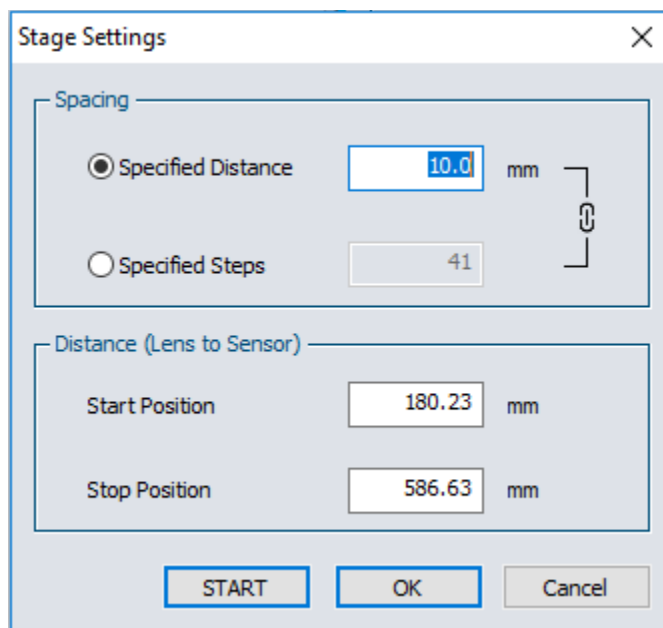


Figure 3-9 : Software setup Step 7

14. Enter the value 20 in the field “Specified Steps,” leave the “Start Position” and “Stop Position” fields at their default values (which are set to the maximum) then click “START”

15. The software automatically turns to 2D Display and the stage starts moving to take data.
16. When the routine is done, a window pops up. Press "Calculate M²" to reach the results tab.

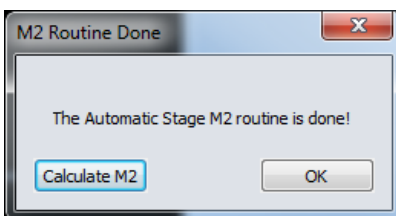


Figure 3-10 : Calculate M² prompt

This first scan gives you an idea of the position of the focal spot and an approximate Rayleigh Length. If the waist position (Z_0) or the Rayleigh length lacks definition, scan with more steps.

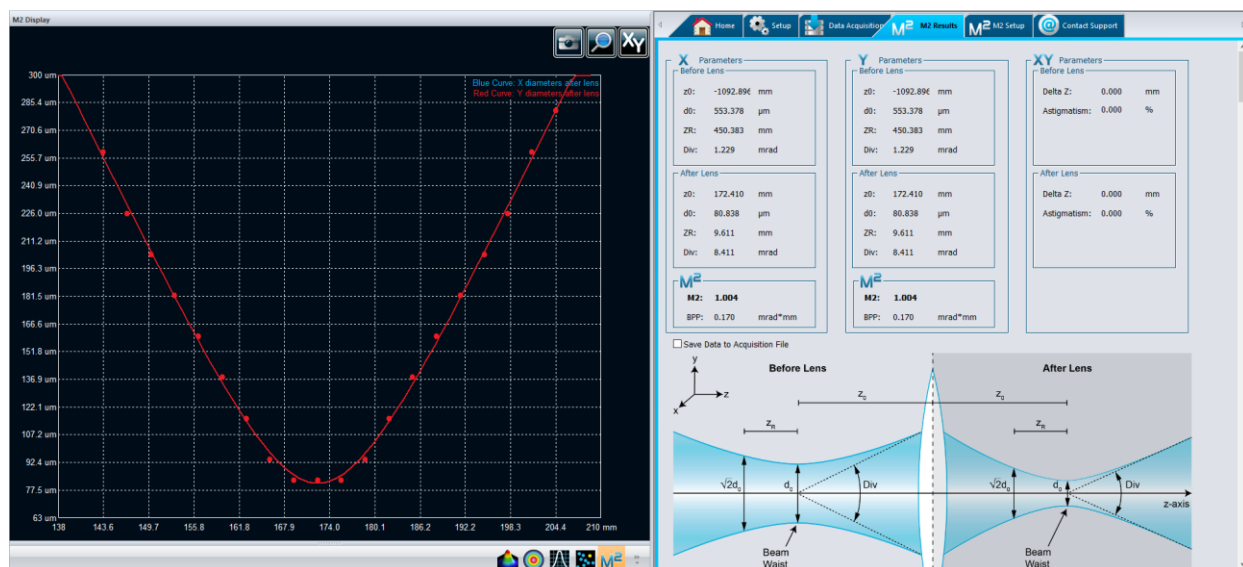


Figure 3-11 : Preliminary results

17. If needed, use the " Z_0 " and " Z_R " under the "After Lens" box in the "M2 Results" to define new parameters for a more precise M² measurement.

In the above example, Z_0 is approximately 172 mm and Z_R is approximately 9.6 mm. Therefore, we want to measure diameters from position $(Z_0 - 3Z_R) = 143$ mm to $(Z_0 + 3Z_R) = 200.8$ mm. Taking 20 measurements within $[Z_0 - 3Z_R; Z_0 + 3Z_R]$ produced enough valid data points to return an ISO M² measurement.

4. THEORY

4.1. UNDERSTANDING THE M^2 FACTOR

The M^2 factor, which is unit-less, can be considered a quantitative indicator of laser beam quality. It indicates the deviation of the measured beam from a theoretical Gaussian beam of the same wavelength. It can be mathematically defined as the ratio between the Beam Parameter Product (beam waist radius w_0 multiplied by divergence half-angle θ) of the measured beam with the theoretical Gaussian beam. Thus, for a single mode ideal TEM₀₀ theoretical Gaussian beam, the M^2 factor is exactly one. Since an ideal Gaussian beam diverges more slowly than any other beam, the M^2 value is always greater than one. An M^2 value very close to 1 indicates an excellent beam quality. This is associated with a low divergence and a good ability to focus. Multimode lasers have higher M^2 factors.

4.1.1. Propagation Parameters

In the following equations, “th” refers to theoretical values and “exp” to experimental or real values.

The beam waist is defined as the location along the beam propagation axis where the beam radius reaches its minimum value (see **Figure 4-1**). For a theoretical Gaussian beam, the beam radius $w_{th}(z)$ at any position z along the beam axis is given by the following equation¹:

$$w_{th}(z) = w_0 \sqrt{1 + \left(\frac{\lambda z}{\pi w_0^2} \right)^2}$$

where λ is the laser wavelength and w_{0th} the theoretical beam waist radius.

As depicted in **Figure 4-1**, the theoretical Rayleigh Length z_{Rth} is the distance (along the propagation axis) between the beam waist and the position where the beam radius is $\sqrt{2}$ times larger than the beam waist (doubled cross-section).

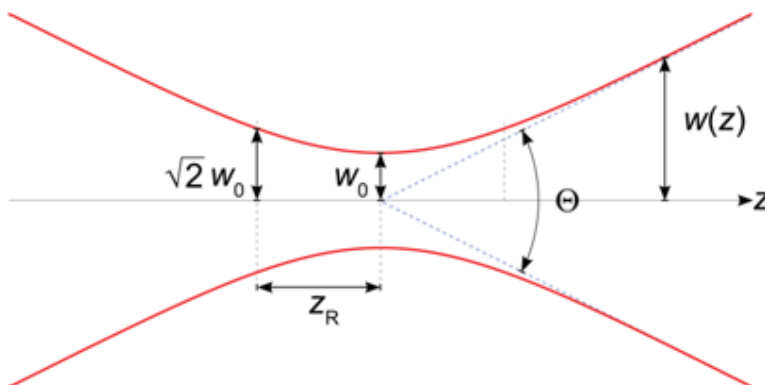


Figure 4-1 : Gaussian beam parameters

¹ Siegman, A. E., 1993. Defining, measuring, and optimizing laser beam quality. *Proceedings of SPIE*, Volume 1868, pp. 2-12.

Mathematically, it is given by the following equation:

$$z_{Rth} = \frac{\pi(w_{0th})^2}{\lambda}$$

Far from the beam waist, the beam expansion becomes linear and the theoretical divergence half-angle θ_{th} (half of the angle shown in **Figure 4-1**) can be obtained by evaluating the limit of the beam radius's first derivative as the position tends towards infinity:

$$\theta_{th} = \lim_{z \rightarrow \infty} \frac{dw_{th}(z)}{dz} = \lim_{z \rightarrow \infty} \frac{d}{dz} w_{0th} \sqrt{1 + \left(\frac{\lambda z}{\pi(w_{0th})^2} \right)^2} = \frac{\lambda}{\pi w_{0th}}$$

For a laser beam that passes through a focusing lens of focal length f , the theoretical radius of the beam w_{fth} at the focal spot of the lens can be obtained by multiplying the beam divergence half-angle with the focal length f :

$$w_{fth} = f\theta_{th} = \frac{f\lambda}{\pi w_{0th}}$$

As mentioned, all of the equations above describe theoretical ideal Gaussian beams. However, they can describe the propagation of real laser beams if we modify them slightly using the M^2 factor, which can be mathematically defined by the following equations:

$$M^2 = \frac{\pi\theta_{exp}w_{0exp}}{\lambda} = \frac{\theta_{exp}w_{0exp}}{\theta_{th}w_{0th}} > 1 \quad \text{because} \quad \theta_{exp}w_{0exp} > \frac{\lambda}{\pi} = \theta_{th}w_{0th}$$

With the mathematics, it is easy to understand why small M^2 values correspond to low experimental divergences and small experimental beam waist radiuses.

The experimental beam waist radius $w_{exp}(z)$, the experimental half-angle divergence θ_{exp} , and the experimental beam radius at the focal spot of the lens w_{fexp} are therefore given by the following equations:

$$w_{exp}(z) = w_{0th} \sqrt{M^2 + M^2 \left(\frac{\lambda z}{\pi(w_{0th})^2} \right)^2}$$

$$\theta_{exp} = \frac{M^2 \lambda}{\pi w_{0exp}}$$

$$w_{fexp} = f\theta_{exp} = \frac{fM^2 \lambda}{\pi w_{0exp}}$$

We can now easily understand why small M^2 values correspond to low divergence beams with small focus spots.

4.1.2. Practical Measurement

In order to measure the M^2 factor, multiple slices of the beam within and beyond one Rayleigh Length along the propagation axis must be considered (see **Figure 4-2**). For each one, the second order spatial moment beam radius $w(z)$ is measured. A hyperbola, which recalls the beam radius equation, is then fitted with the results. The M^2 value is derived from that fit.

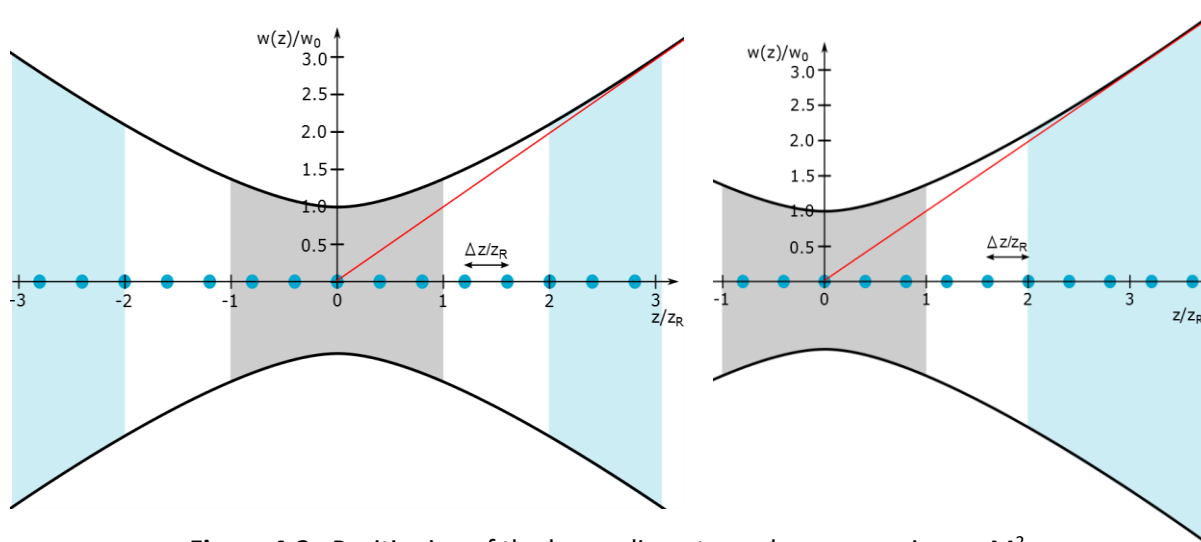


Figure 4-2 : Positioning of the beam diameters when measuring an M^2 .

Left: 5 diameters are taken in the focal region and 3 diameters are taken at the far field on each side of the caustic. **Right:** 5 beam diameters are taken in the focal region and 5 more beyond $2z_R$ on one side only. The grey zone is the focal region, between $-z_R$ and $+z_R$, the blue zones are for far field measurements and the white regions are the non-essential measurement zones. Blue dots represent the position along the "z" axis where beam diameters are measured.

Since the distance range within which the measures must be taken is too large (could be several meters), the use of a focusing lens is mandatory. It is also mandatory to comply with ISO standard. It helps to compress the slices of interest around the focal spot of the lens.

Please refer to ISO-11146 for more information.

5. M² MEASUREMENT CONTROLS

The controls allowing an M² measurement are toggled by clicking on the “M² Manual” button, under the “Advanced” tab. It also adds an “M²” display button.

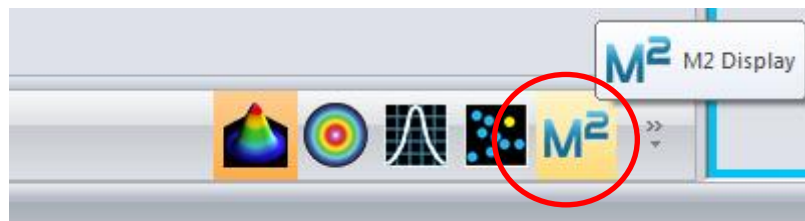
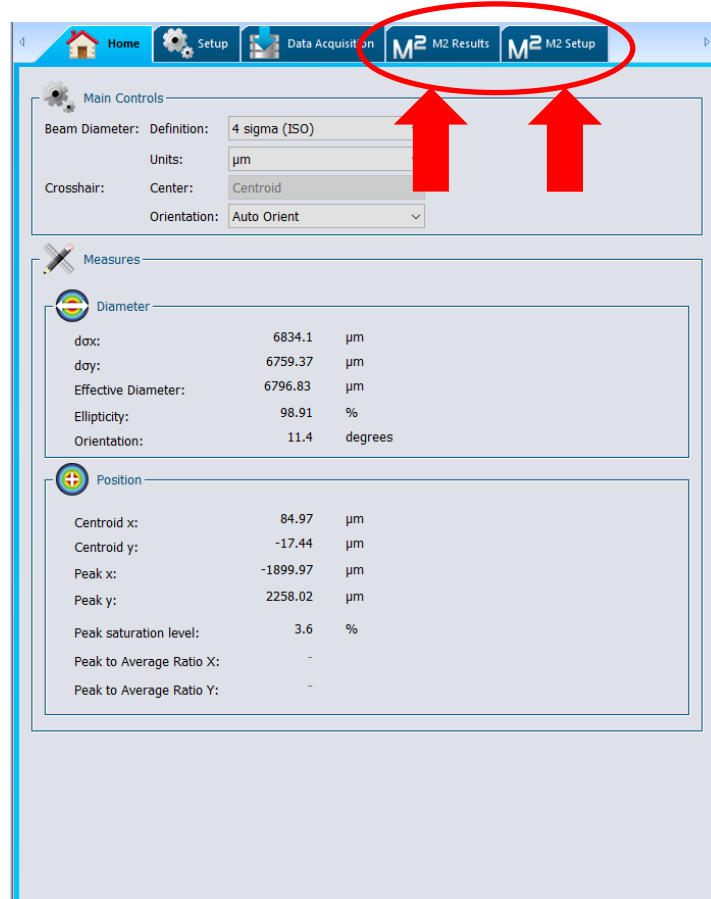
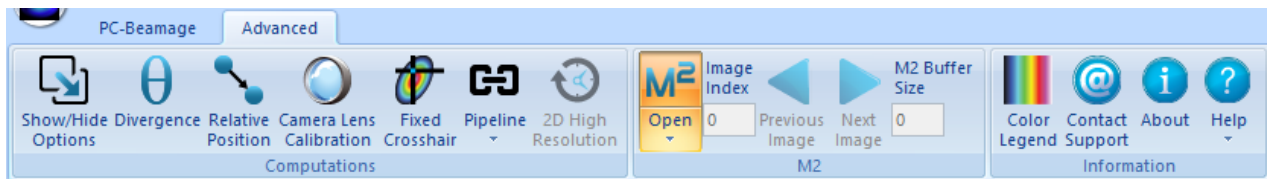


Figure 5-1 : M² main control buttons

5.1. M² M2 SETUP TAB

The “Setup” tab allows you to control the beam path length for every spot size you need to measure.

The screenshot shows the M2 Setup tab interface. At the top, there is a navigation bar with tabs: Home, Setup, Data Acquisition, M2 M2 Results, and M2 M2 Setup. The M2 M2 Setup tab is selected. Below the navigation bar, the interface is divided into several sections:

- Fixed Values:** Contains input fields for "Laser Wavelength" (632 nm) and "Focal Length (Lens)" (200 mm).
- Automatic Settings:** Includes a "Connect the Stage" button, a "SETTINGS" button, a "START" button, and a "STOP" button.
- Manual Settings:** Includes an "Enter Distance (Lens to Sensor)" field (190 mm) and an "Add" button.
- Central Button:** A "CALCULATE M2" button.
- Data Section:** Includes "Delete", "Clear All", and "Sort" buttons, and a table with columns: Index, Distance, X Diameter, Y Diameter, and Exposure Time.
- Bottom Buttons:** "Load", "Save", and "Export" buttons.

Figure 5-2 : M2 Setup tab

- **M² Fixed Values** : Input fields required for identifying the laser and lens used in order to obtain correct calculations
- **Automatic Settings** : Communication with the translation stage, allows you to connect and control the stage, set the range over which you want the beam to be scanned, and the number of points needed.
- **Manual Settings** : Allows a manual data collection and/or provides you with a method of adding points that were not in the automatic scan.
- **CALCULATE M2** : After a data collection, this button switches the display to show the data and curves on a graphic.
- **Data** : Section used to manage the data. You can delete some or all of the current data, then sort, import, or export it.

5.1.1. M² Fixed Values

As seen in Section 4 (Theory), the wavelength of the laser plays a crucial role in the calculation of the waist position and minimal beam radius (w_0). Note that if you change the laser and/or the lens, it is necessary to update manually these values.

To do so, just click the fields and change the required values, keeping in mind that the wavelength is expressed in nanometers (10^{-9} m) and the focal length in millimeters (10^{-3} m)

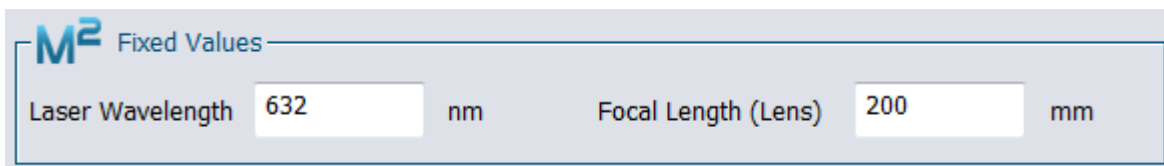


Figure 5-3 : Fixed parameters

5.1.2. Automatic Settings

When the translation stage is connected to your computer, the communication must be started. To do so, click on the “Connect the Stage” button. Upon successful connection, the stage will move the carrier to the “far” end of the rail (far from the lens), and the other buttons will become clickable.

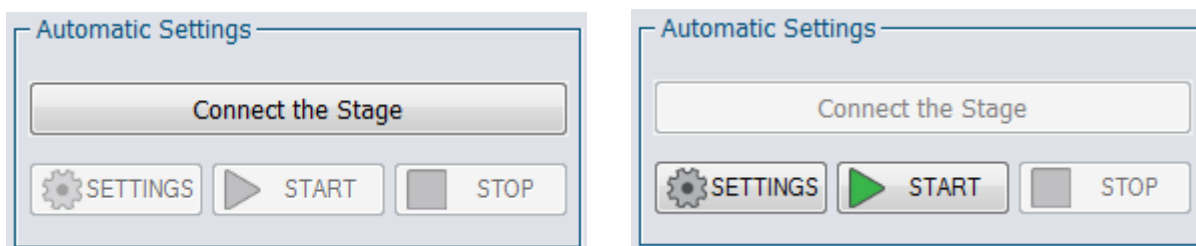


Figure 5-4 : Translation stage controls

SETTINGS button displays the “Stage Settings” window:

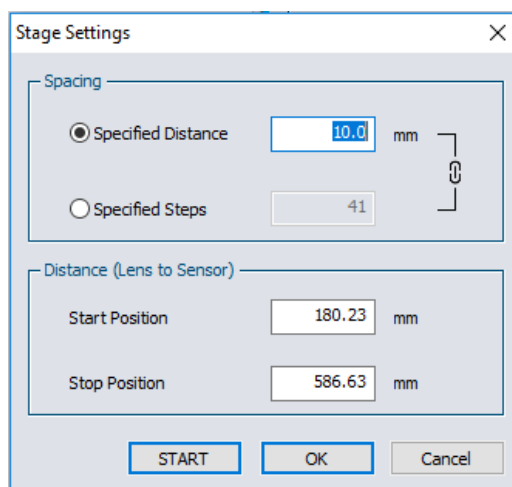


Figure 5-5 : Stage Settings

Spacing options let you choose whether you prefer to have a **Specified Distance** between two measurements or a specific number of **Steps** in the chosen interval.

Distance (Lens to Sensor) determines the limits of the carrier's travel and is expressed in millimeters. When a " Z_R " is short, bring the **Start position** and the **Stop position** nearer from the beam waist position " Z_0 " in order to make a "zoomed" measurement. It prevents problems such as a highly diverging beam being too big for the sensor.

When you are done with the **SETTINGS**, press **START** to have the stage running and scan over the chosen span. At the end of a scan, a window pops up asking to calculate M^2 . The **Calculate M2** button forces the calculation of the beam parameters based on the acquired data and makes PC-Beamage switch to **M2 Results** tab and M^2 display.

Pressing **OK** just closes the pop-up window.

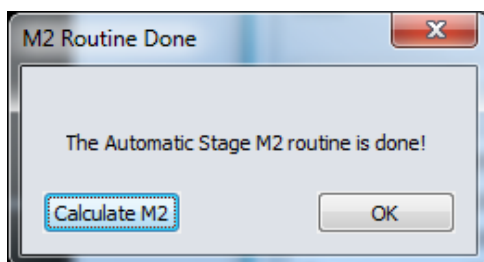


Figure 5-6 : Routine done pop-up

At any moment during the scan, press **STOP** to interrupt it.

5.1.3. Manual Settings

In case you wish to add points at specific beam path lengths, write the distance, in millimeters, at which the data must be taken and click "Add" button. This can be done many times if needed.

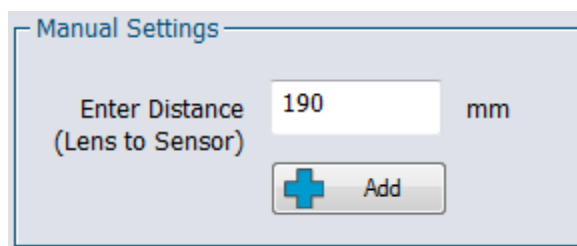


Figure 5-7 : Manual distance setting

5.1.4. Calculate M2

Clicking this button forces the calculation of the beam parameters based on the acquired data and makes PC-Beamage switch to **M2 Results** tab and M^2 display.

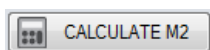


Figure 5-8 : "Calculate M2" button

5.1.5. Data

Data box allows visualization and manipulation of the data.

Click on any data of the list to select it. When the camera is not running, the corresponding beam measurement will be shown in the Display panel.

Delete removes the selected row(s) from the data box. The same action can be done by pressing “DELETE” key on your keyboard.

Clear All removes all the data from the data box.

Sort can be used to refresh the *Index* numbers (left row) and rearrange the rows by *Distance* (propagation axis).

For example, upon deleting row 5 and manually adding a data point around the center of distribution, the only indexed numbers remaining will be “1, 2, 3, 4, 6, 7,...” and the last row’s *Distance* will not match its position. Pushing **Sort** reallocates the numbers to the remaining rows and places them in increasing *Distance* order.

Load allows you to recall a previously saved set of data with a “.m2man” file format.

Save allows you to save the current data set as a unique “.m2man” file to use them again later.

Export is the option to save the current data as a usable sorted list in a “.txt” file.

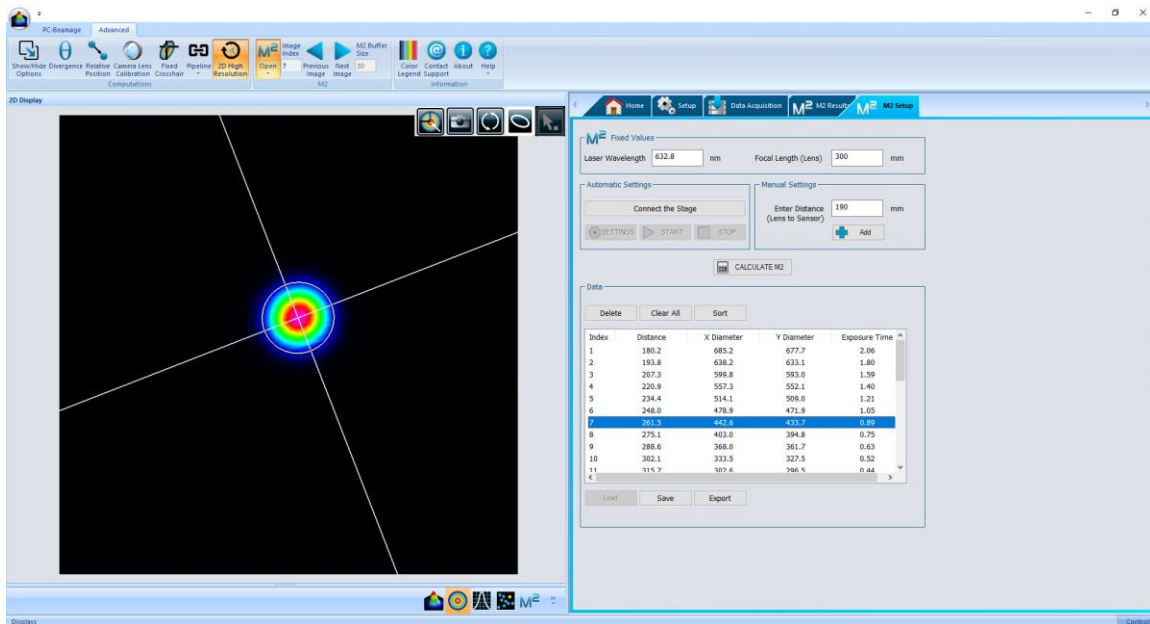


Figure 5-9 : Data section

When the camera is not running, click any data in the list and the corresponding beam image will show in the Display panel.

5.2. M² M2 RESULTS

Calculations made from the acquired data are centralized in the “M2 Results” tab.

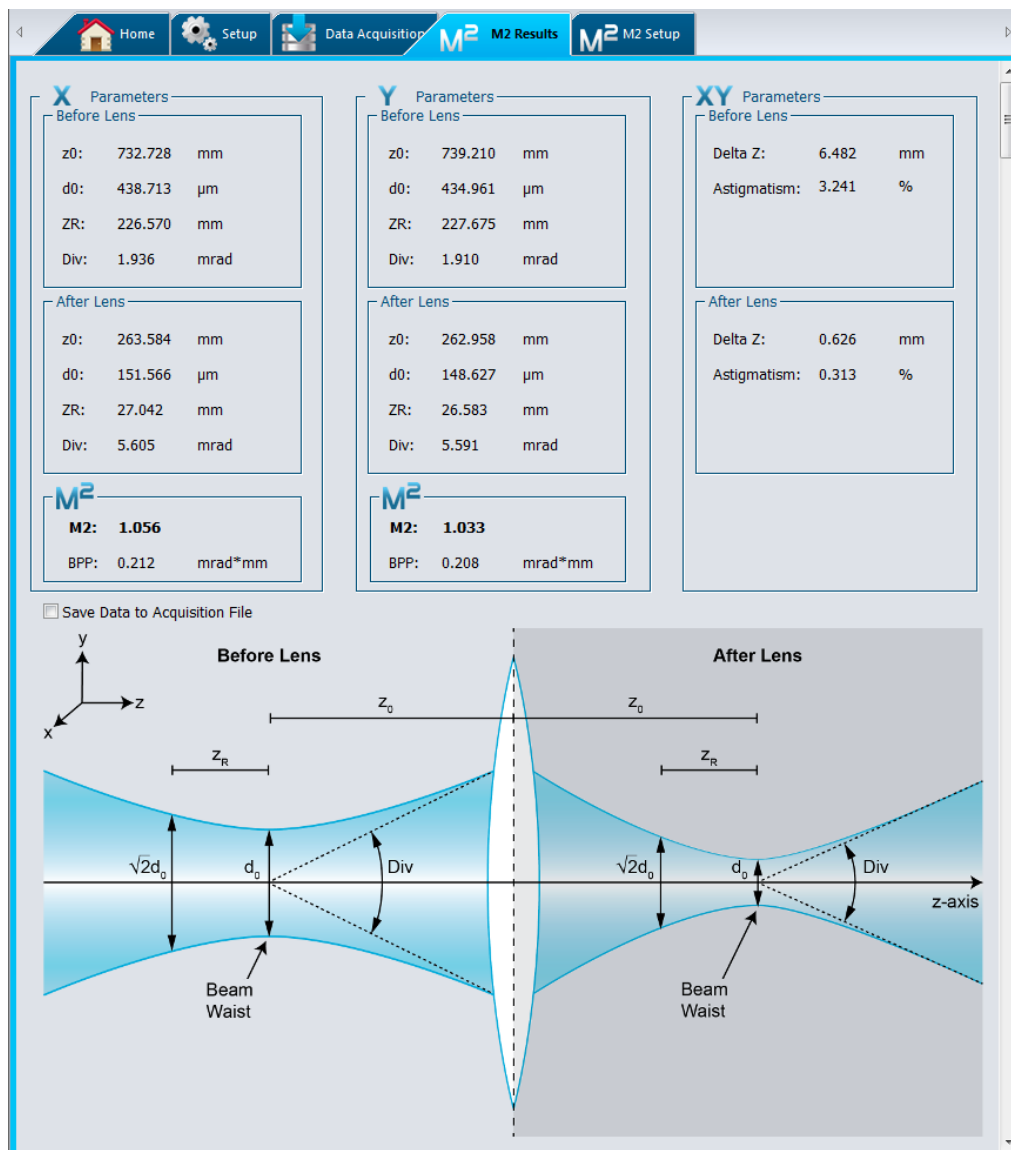


Figure 5-10 : M2 Results tab

- **X Parameters** : Results of the calculations for the beam profile on the “X” axis.
- **Y Parameters** : Results of the calculations for the beam profile on the “Y” axis.
- **XY Parameters** : Summary of the comparisons between data on “X” and “Y” axis
- **M²** : Value of the M² and the Beam Propagation Parameter obtained from data
- **Graphic** : A reminder of the meaning of every parameter shown above

5.2.1. Before lens

These are the beam parameters derived from those measured and calculated in the “**After Lens**” box in either “**X**” or “**Y**” axis:

z0: Position of the “natural” beam waist relative to the lens

d0: Diameter of the “natural” beam waist where $d_0 = 2w_0$

ZR: Rayleigh Length of the “natural” beam

Div: Divergence of the original beam

The section beneath “**XY Parameters**” is slightly different as it shows a comparison of the parameters on “**X**” and “**Y**”.

Delta Z: Distance between z_{0x} and z_{0y} on the propagation axis

Astigmatism: How far apart the **X** and **Y** waists are, compared to the focal length f : $\frac{|z_{0x}-z_{0y}|}{f}$

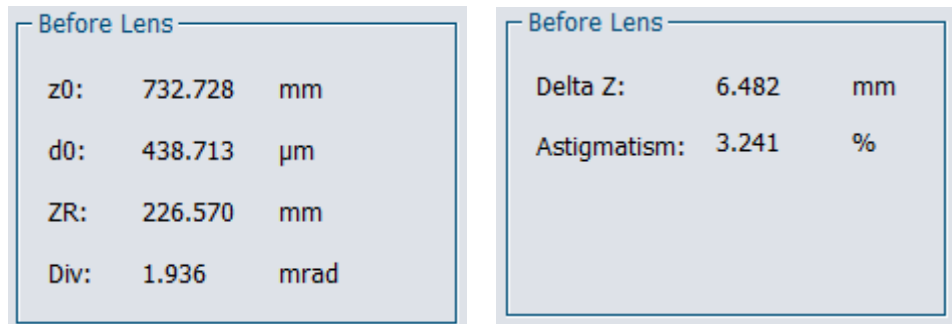


Figure 5-11 : Calculation results before lens

5.2.2. After Lens

Calculated parameters of the beam past the lens:

z0: Position of the focused beam waist relative to the lens

d0: Diameter of the focused beam waist where $d_0 = 2w_0$

ZR: Rayleigh Length of the focused beam

Div: Divergence of the focused beam

“**XY Parameters**” shows a comparison of the “**X**” and “**Y**” parameters.

Delta Z: Distance between the focused z_{0x} and z_{0y} on the propagation axis

Astigmatism: Value of the focused **Delta Z** compared to focal length f : $\frac{|z_{0x}-z_{0y}|}{f}$

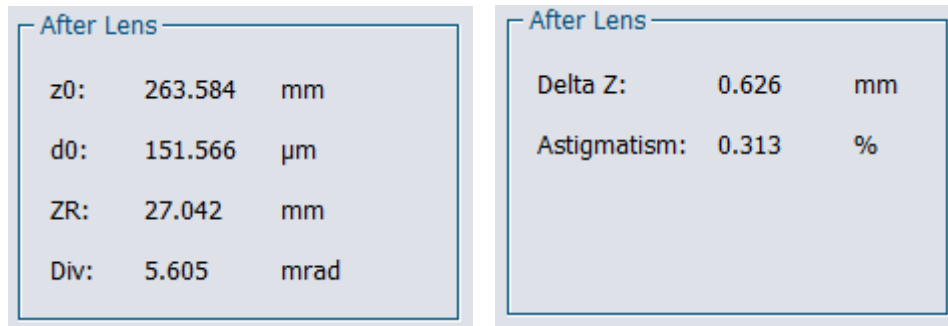


Figure 5-12 : Calculation results after lens

5.2.3. M^2

M2: Beam's calculated M^2 value as defined in section 4

BPP: Beam Parameter Product, defined as the product of the measured divergence by the waist diameter size: $BPP = \theta * w_0 = \frac{Div}{2} * \frac{d_0}{2}$

Figure 5-13 : M^2 and BPP results

5.2.4. Definitions scheme

Illustration detailing the values found in the **M^2 M2 Results Tab.**

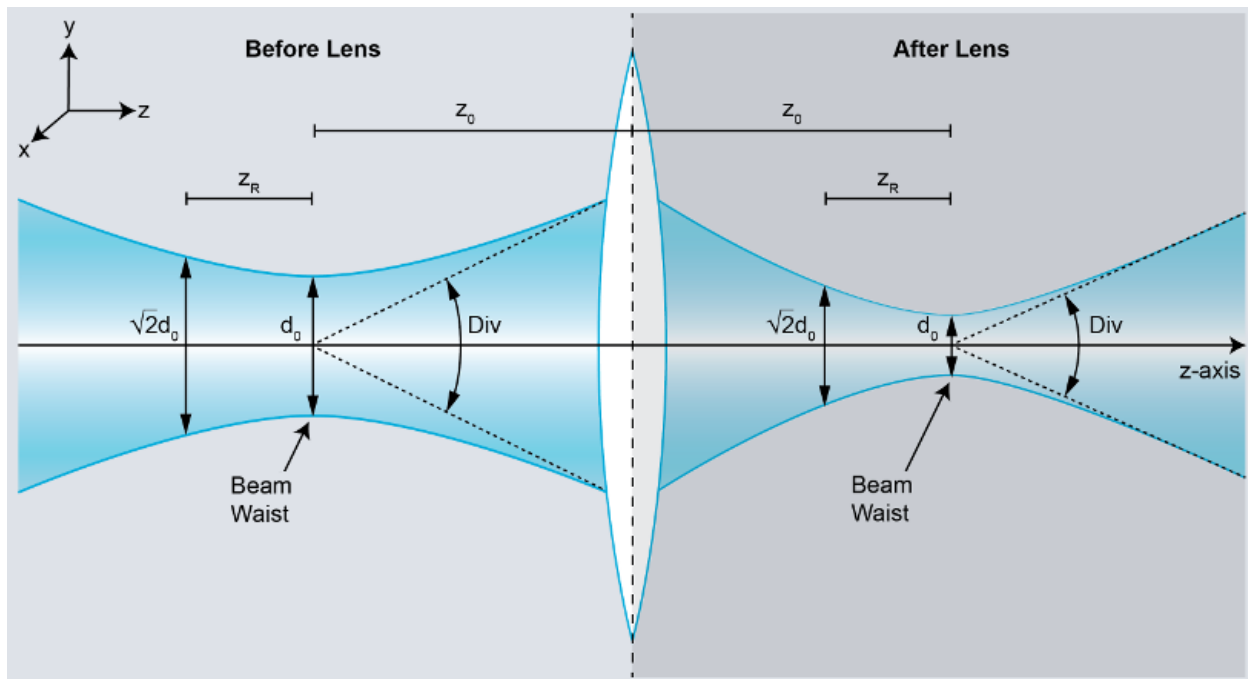


Figure 5-14 : Gaussian beam parameters schematic before and after lens

5.3. DISPLAY WINDOW

After an acquisition, the data points and the paraboloids approximating them appear in the M^2 display window. The graphic shows beam diameters (μm) as functions of the lens to sensor distances (mm).

It automatically generates itself when you press the **Calculate M^2** button.



Save an image of the current graph as a bitmap (.bmp) file.



Use mouse pointer to zoom over an area.



Toggles between data and “after lens curves” / “before lens” approximation curves.

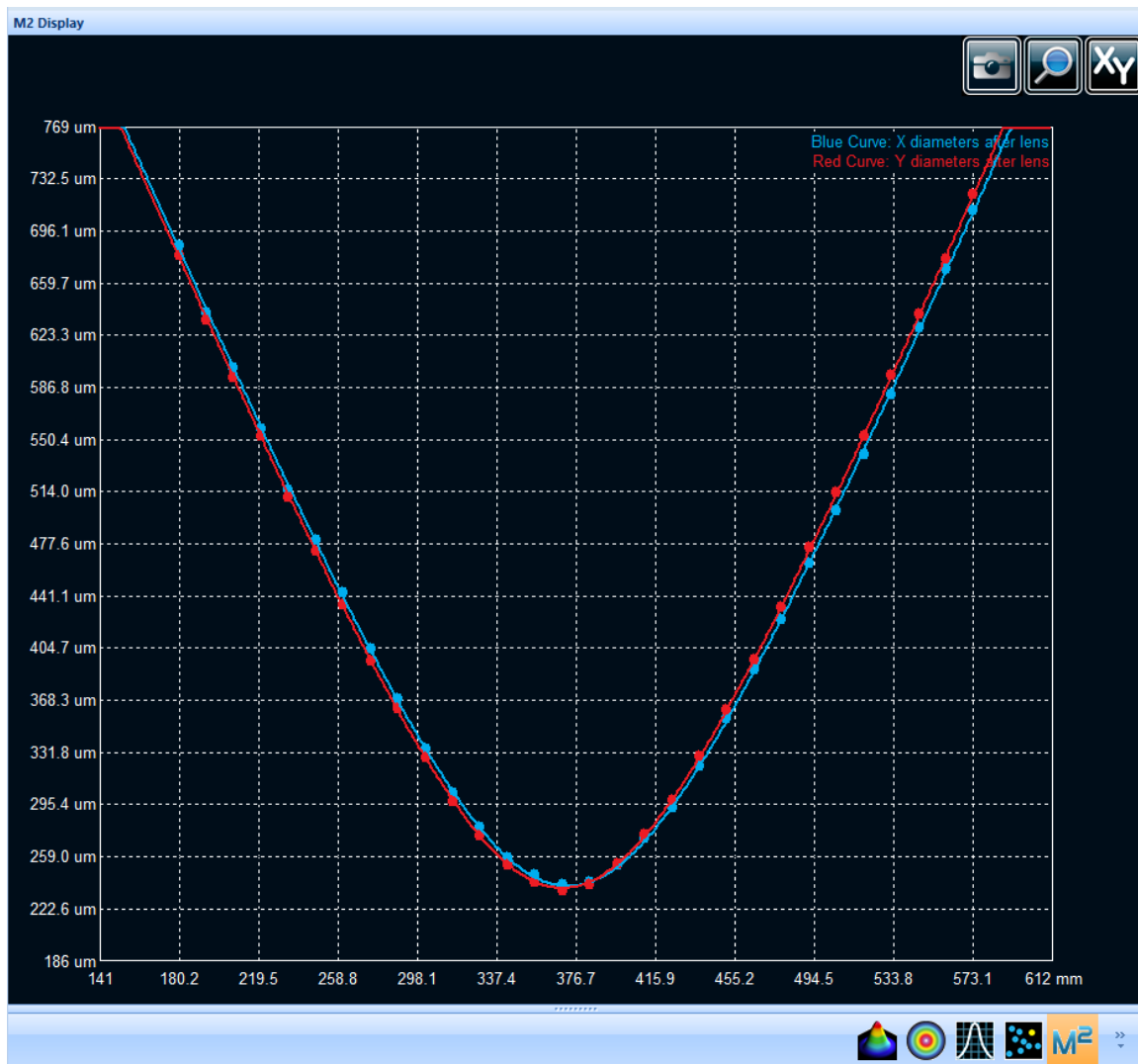


Figure 5-15 : Display window showing data and their Gaussian fit

5.4. PRINT REPORT

A customized print report has been made for the **M²** mode. To use the Print Report function, press the **Print Report** button in the main menu

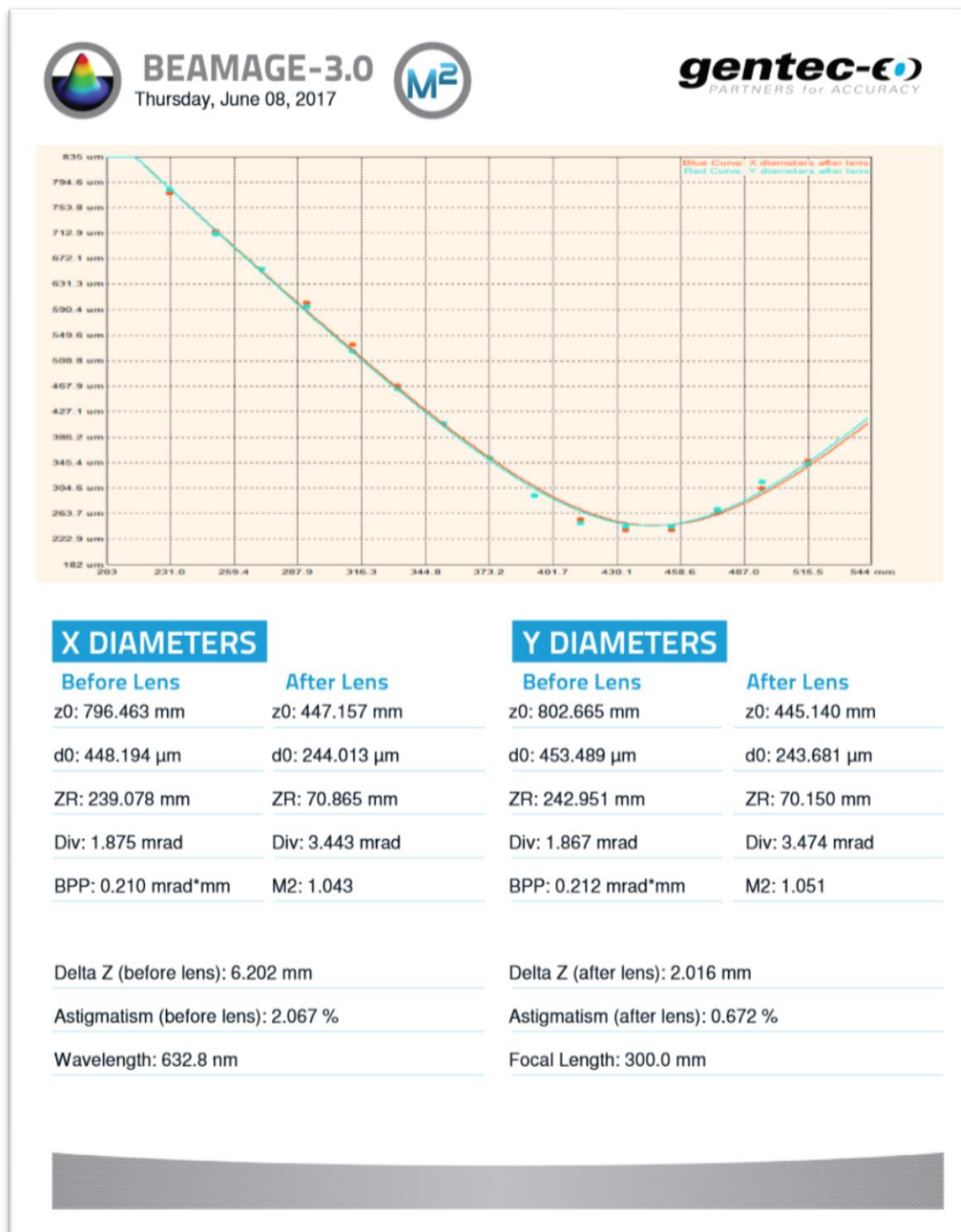


Figure 5-16 : Printed Report

6. TROUBLESHOOTING AND TIPS

1) While trying to install PC-Beamage, the following message appears: The program cannot start because msvcr100.dll is missing [...]

You must download the missing dll from Microsoft software and install it on your computer:

32 bit: <http://www.microsoft.com/download/en/details.aspx?id=5555>

64 bit: <http://www.microsoft.com/download/en/details.aspx?id=14632>

2) Beamage is not detected

Make sure the Beamage is connected to a USB 3.0 Super Speed port. The Beamage will work if plugged directly into a USB 2.0 port at a slower transfer rate.

Close the software application, disconnect and reconnect the USB 3.0 to the Beamage, then reopen the software application. The LED indicator on the Beamage should blink green and then red before turning green. If the LED does not turn on upon software startup, or if it does not turn on completely, please contact your Gentec-EO representative or contact us at service@gentec-eo.com.

3) The display area is completely white

Press the “Refresh” button and the display should return.

4) There is no serial number displayed in the camera

- Please close the PC-Beamage software program, wait a couple of seconds, then reopen the PC-Beamage.
- If the problem persists, please verify in Window's Task Manager if there is only one PC-Beamage.exe instance running. If more than one is running, end all processes and reopen PC-Beamage.
- If the problem persists, please disconnect the Beamage and connect it again.
- If the problem persists, please contact your Gentec-EO representative or contact us at service@gentec-eo.com.

5) Do not disconnect the Beamage while it is streaming

The Beamage must not be disconnected when it is streaming.

6) Tips to increase the frame rate

The Beamage's frame rate greatly depends upon the computer's performance. Here are a few tips to increase the frame rate:

- Use a USB-3.0 port
- Use a computer with high performance (Beamage manual, PC Requirements, section 1.2)
- Use Windows 7, Windows 8, or Windows 10
- Follow the PC operating state for optimal conditions (Beamage manual, refer to section 1.2)

- Use the smallest attenuation possible (refer to Beamage manual)
- Do not use Image Averaging (refer to Beamage manual)
- For a large beam, use Pixel Addressing (refer to Beamage manual)
- For a small beam, use an Active Area (refer to Beamage manual)
- Make sure you have a short exposure time
- Do not stream multiple Beamage units simultaneously

7) The beam disappears from the sensor

When the beam disappears from the sensor, it must be re-aligned. The conditions for a good alignment on the whole carrier travel are:

- While the carrier is in farthest position, the beam must be centered on the Beamage's sensor
- The beam must be centered on the lens

Make sure your laser does not move relative to the Beamage-M2 setup during the experiment.

For more details about the Beam alignment, see section 2.2 Laser alignment.

8) Actual settings do not allow an M^2 measurement

Measuring the M^2 of a diverging laser may pull the beam waist position beyond the reach of the system. In this case, using a lens with a shorter focal length will bring the waist closer to the measured span and therefore allow the M^2 measurement.

In case you find Z_0 to be out of the range or Z_R to be too high, you will need to change the lens. Here is the procedure to follow to replace a lens. See different cases of bad focal length choice right after.

1. Changing the lens:
 - a. Lower all the ND-filters
 - b. Unscrew the iris and the iris adapter
 - c. Unscrew the lens tube and put it in a clean plastic bag
 - d. Take the lens you need from the transport case and screw it in place of the one you just took away
 - e. Screw the iris and the adapter in front of the new lens

Lens choosing guide

Here is a quick guide to help you choose a suitable lens.

In case you get:

1. $Z_0 < 186\text{mm}$
 - a. The focal length is too short, change for a longer focal length
2. $Z_0 > 580\text{mm}$
 - a. The focal length is too long, change for a shorter focal length
3. $Z_R > 100\text{mm}$
 - a. The Rayleigh length is too long to return an ISO M^2 value
 - b. This means the divergence is too low
 - c. Change the lens for a shorter focal length to raise divergence
4. $Z_R > 58\text{mm}$
 - a. The Rayleigh length is too long to return a Gentec approved commercial M^2 measurement (7 Z_R must fit in the stage's range)
 - b. This means the divergence is too low
 - c. Change the lens for a shorter focal length to raise divergence

Here are a few possible issues with the system :

1. Curve fit passes below 0
 - a. The measurement is made too far away from the waist
 - i. We have too many points beyond $-3.5Z_r$ and $3.5Z_r$
 - ii. We do not have enough points between $-Z_r$ and Z_r
 - iii. Solutions :
 1. Remove points far from the waist, one by one and then recalculate
 2. Note the values of Z_0 and Z_r , clear all results and re-measure a set of points expanding ONLY from $-3.5Z_r$ to $+3.5Z_r$, not beyond
 3. Take more points around the waist
 - b. The software cannot find the waist
 1. See the “lens choosing guide” above
2. M2 is below 1
 - a. The system (not laser) affects the beam
 - i. Check and clean every mirror and ND filter
 - ii. Dust can change drastically M2 measurement
 - iii. Broken optic or mirror can change drastically M2 measurement
 - iv. Look and ask for collimator adjustment
 - b. ISO minimum requirements are not respected
 - i. Look in the M2 display for ISO minimum requirement
 - ii. If not respected, add more points (MORE THAN REQUIRED BY ISO)
 - c. The measurements were made too far away from the waist
 - i. See the “lens choosing guide” above
3. The software continually asks to change attenuation and take no measurement
 - a. The laser beam might be so intense that it saturates the sensor near the focus.
Possible solutions:
 - i. Change the lens for a longer focal length, this will make w_0 wider
 - ii. Add attenuation before M1; a beam that has a power beyond 100mW might have some attenuation issues near the focus
 - b. The computer might be too slow (very low frame rate)
 - i. See the “Make my measurement faster” section below
 - ii. Use the “Image averaging” to stop the flickering
4. Other things to double check
 - a. Mirrors are set well
 - b. Camera is securely fastened
 - c. Filter on the camera is completely screwed
 - d. Moving stage is plugged with **special** USB cable
 - e. Measurement has enough attenuation
 - f. Drivers and software are up to date
 - g. In case of uncertainty, uninstall everything with Windows control panel and install last versions
5. Make my measurement faster
 - a. Make sure you are using a USB-3 port for the camera
 - b. Turn-off “2D High Resolution” under “Advanced” tab
 - c. Use 10 bits ADC
 - d. Make a region of interest (ROI) around the camera’s center
 - e. Use “Decimate 2x2” function under “Pixel Addressing”

9) The beam is too weak to start an automatic acquisition

There may be many causes for a weak beam: Too much attenuation in the optical path, a measurement taken too far from the waist, and more.

Some beams will lose too much intensity to be correctly measured when they get far from the waist. In those cases, stream the camera output in PC-Beamage, set 2D view, and turn the translation stage knob to find the waist. From there, start an acquisition and use the software to find the maximum measurement range. Repeat in the other direction and verify that $6Z_R$ fits in the measured zone. Otherwise, use a lens with a shorter focal length or remove attenuation.

If you turned off the 3 ND filters already and the beam continues to be too weak, you can change or remove the ND filter mounted directly on the Beamage camera. Refer to the Beamage Manual for changing the Beamage's ND filter.

7. DECLARATION OF CONFORMITY

Application of Council Directive(s): 2014/30/EU The EMC Directive



Manufacturer's Name: Gentec Electro Optics, Inc.
 Manufacturer's Address: 445 St-Jean Baptiste, suite 160
 (Québec), Canada G2E 5N7

European Representative's Name: Laser Components S.A.S.
 Representative's Address: 45 bis Route des Gardes
 92190 Meudon (France)

Type of Equipment: Laser Beam Diagnostic Equipment.
 Model No.: Beamage-M2
 Year of test & manufacture: 2017

Standard(s) to which Conformity is declared:
 EN 61326 :2005/EN 61326 : 2006/ Emission generic standard

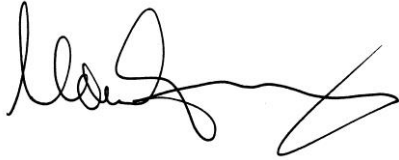
Standard	Description	Performance Criteria
CISPR 11 :2009 +A1 2010	Industrial, scientific, and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement	Class A
EN 61326 :2005/EN 61326 : 2006	Limits and methods of measurement of radio interference characteristics of information technology equipment. Testing and measurements of radiated emission	Class A
IEC 61000-4-2:2001	Electromagnetic compatibility (EMC) – Part 4: Testing and measurements techniques - Section 2: Electrostatic discharge.	Class B
IEC 61000-4-3:2002	Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques - Section 3: Radiated, Radio Frequency immunity.	Class A
IEC 61000-4-4:2012	Electromagnetic compatibility (EMC) - Part 4-4: Testing and measurement techniques - Electrical fast transient/burst immunity test	Class B
IEC 61000-4-5:2014	Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test	Class B
IEC 61000-4-6:2013	Electromagnetic compatibility (EMC) - Part 4-6: Testing and measurement techniques - Immunity to conducted disturbances, induced by radio-frequency fields	Class A
IEC 61000-4-8:2009	Electromagnetic compatibility (EMC) - Part 4-8: Testing and measurement techniques - Power frequency magnetic field immunity test	Class B
IEC 61000-4-11:2004	Electromagnetic compatibility (EMC) - Part 4-11: Testing and measurement techniques - Voltage dips, short interruptions, and voltage variations immunity tests	Class C

I, the undersigned, hereby declare that the equipment specified above

conforms to the above Directive(s) and Standard(s).

Place: Québec (Québec)

Date : July 14, 2017

A handwritten signature in black ink, consisting of a series of loops and a long horizontal stroke ending in a sharp diagonal line.

(President)

APPENDIX A. ISO11146 AND ISO11670 DEFINITIONS

The beam centroid coordinates are given by:

$$\bar{x}(z) = \frac{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E(x, y, z) x dx dy}{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E(x, y, z) dx dy}$$

$$\bar{y}(z) = \frac{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E(x, y, z) y dx dy}{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E(x, y, z) dx dy}$$

The beam widths are defined as an “*extent of a power density distribution in a cross section of beam based on the centered second order moments of the power density distribution.*”

The second order moments of power density distribution are given by:

$$\sigma_x^2(z) = \frac{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E(x, y, z) (x - \bar{x})^2 dx dy}{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E(x, y, z) dx dy}$$

$$\sigma_y^2(z) = \frac{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E(x, y, z) (y - \bar{y})^2 dx dy}{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E(x, y, z) dx dy}$$

$$\sigma_{xy}^2(z) = \frac{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E(x, y, z) (x - \bar{x})(y - \bar{y}) dx dy}{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E(x, y, z) dx dy}$$

The beam widths are given by:

$$d_{\sigma_x} = 2\sqrt{2} \left\{ (\sigma_x^2 + \sigma_y^2) + \gamma \left[(\sigma_x^2 - \sigma_y^2)^2 + 4(\sigma_{xy}^2)^2 \right]^{\frac{1}{2}} \right\}^{\frac{1}{2}}$$

$$d_{\sigma_y} = 2\sqrt{2} \left\{ (\sigma_x^2 + \sigma_y^2) - \gamma \left[(\sigma_x^2 - \sigma_y^2)^2 + 4(\sigma_{xy}^2)^2 \right]^{\frac{1}{2}} \right\}^{\frac{1}{2}}$$

where:

$$\gamma = \frac{\sigma_x^2 - \sigma_y^2}{|\sigma_x^2 - \sigma_y^2|}$$

The major axis is the width's maximum whereas the minor axis is the width's minimum.

The effective diameter of the beam is an “*extent of a circular power density having an ellipticity greater than 0.87. [...] If the ellipticity is larger than 0.87, the beam profile may be considered to be of circular symmetry at that measuring location and the beam diameter can be obtained from:*”

$$d_{\sigma} = 2\sqrt{2}(\sigma_x^2 + \sigma_y^2)^{1/2}$$

The beam ellipticity is the “*ratio between the minimum and maximum widths*”

The beam orientation is the “*angle between the x-axis [...] and that of the principal axis of the power density distribution which is closer to the x-axis.*” From this definition, the angle is comprised between 45° and -45°.

$$\varphi(z) = \frac{1}{2} \arctan \left(\frac{2\sigma_{xy}^2}{\sigma_x^2 - \sigma_y^2} \right)$$

The beam's divergences transformed by an aberration-free focusing element of focal length f are given by the following equations:

$$\theta_x = \frac{d\sigma_x}{f}$$

$$\theta_y = \frac{d\sigma_y}{f}$$

$$\theta_\sigma = \frac{d\sigma}{f}$$

In the laboratory or usual system of coordinates (X', Y', Z'), the coordinates of the latest calculated position of the centroid for both X' and Y' axes are given by the following equations:

$$\bar{x}'(z) = \frac{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E(x', y', z') x' dx' dy'}{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E(x', y', z') dx' dy'}$$

$$\bar{y}'(z) = \frac{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E(x', y', z') y' dx' dy'}{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} E(x', y', z') dx' dy'}$$

The coordinates of the mean position of all computed centroids for both X' and Y' axes are thus defined by the following equations, which are simple arithmetic means:

$$\bar{x}'_M = \frac{\sum_i \bar{x}'_i}{n}$$

$$\bar{y}'_M = \frac{\sum_i \bar{y}'_i}{n}$$

Where $\bar{x}'_i(z)$ and $\bar{y}'_i(z)$ are the centroid coordinates for X' and Y' axes already saved in the buffer, and n the number of computed centroid positions saved in the buffer.

The azimuth angle, which is the angle between the usual X' axis and all computed centroids, is given by the following equation:

$$\psi = \frac{1}{2} \arctan \left(\frac{2s_{\bar{x}\bar{y}}^2}{s_{\bar{x}}^2 - s_{\bar{y}}^2} \right)$$

where we have the following definitions:

$$s_x = \sqrt{\frac{\sum_i \bar{x}'_i^2}{n-1}}$$

$$s_{\bar{y}}^2 = \frac{\sum_i (\bar{y}'_i - \bar{y}'_M)^2}{n-1}$$

$$s_{\bar{x}\bar{y}}^2 = \frac{\sum_i (\bar{x}'_i - \bar{x}'_M)(\bar{y}'_i - \bar{y}'_M)}{n-1}$$

In the beam axis coordinate system (X, Y, Z), the beam positional stability values in the azimuth direction (X) and perpendicularly to the azimuth direction (Y), which are 4 times the standard deviations of all computed centroid values, are given by the following equations:

$$\Delta_x(z) = 4s_x$$

$$\Delta_y(z) = 4s_y$$

The overall positional stability is given by:

$$\Delta(z) = 2\sqrt{2}s$$

In the previous 3 equations, the standard deviations are defined by the following equations:

$$s_x = \sqrt{\frac{\sum_i \bar{x}_i^2}{n-1}}$$

$$s_y = \sqrt{\frac{\sum_i \bar{y}_i^2}{n-1}}$$

$$s = \sqrt{\frac{\sum_i \bar{x}_i^2 + \bar{y}_i^2}{n-1}}$$

\bar{x}_i^2 and \bar{y}_i^2 are derived from $\bar{x}_i'^2$ and $\bar{y}_i'^2$ by transformation of coordinates. (X',Y',Z') is the usual or laboratory coordinate system and (X,Y,Z) is the beam axis coordinate system.

The RMS standard deviation value of the centroid position, which is not an ISO standard, is given by the following equation:

$$RMS = \sqrt{\left(\frac{\sum_i x_r^2 + y_r^2}{n}\right)}$$

where x_r^2 and y_r^2 are relative values.

APPENDIX B. RECYCLING AND SEPARATION PROCEDURE FOR WEEE

This section is used by the recycling center when the Beamage-M2 reaches its end of line. Breaking the calibration seal or opening the Beamage's case will void the warranty.

The complete Beamage-M2 contains:

- 1 Beamage-4M camera
- 1 USB 3.0 cable with screw locks
- 1 BNC to SMA connector
- 1 Software USB key
- 3 Circular 2" Al-coated mirrors
- 1 Square 2" Al-coated mirror
- 2 Moving stages
- 1 48V Power Supply
- 1 USB 2 cable
- 3 2" ND filters
- 4 Mirror mounts
- 1 Aluminum housing with mounting pieces
- 3 Lenses, 2"
- 3 Lense holding tubes, 2"

SEPARATION

Plastic: Aperture cap, SMA cap, USB key housing

Metal: Beamage case, screws, SMA connector, BNC to SMA connector, ND filter holders, mirror holders, Beamage-M2 casing, connector plate, mirror posts, lense holding tubes

Wires: USB cables, Power supply

Printed circuit board: Inside the Beamage-4M and inside the electrical moving stage

Glass: ND filters and Mirrors

DISMANTLING PROCEDURE

Remove every housing screw.

Separate the round mirrors from their mounts by un-screwing their holding screws.

Remove the square mirror by sliding a fine flat head screwdriver behind it.

Remove the 2" ND filters and the 2" lenses with a spanner wrench.

Use a Philips screwdriver to unscrew the electrical moving stage's circuit housing.

Remove the PCB and motor.

Unscrew the #8-32 set screw to remove the Beamage-4M camera.

Unscrew every other screw to completely unmount the assembly.

For the Beamage camera:

Remove the 3 screws on the BEAMAGE's back cover with an Allen key.

Remove the 1 screw holding the PCBs with a flat screw driver.

Cut the wire between the PCB and the SMA connector.

Remove the ND filter and remove the glass with a spanner wrench.

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BEAM PROFILING



THZ MEASUREMENT

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