Thorlabs Beam
Beam Analyzing Software

BC106-VIS
BC106-UV
Operation Manual

2011

Version: 4.0
Date: 11.04.2011

Table of Contents

We aim to develop and produce the best solution for your application in the field of optical measurement technique. To help us to come up to your expectations and develop our products permanently we need your ideas and suggestions. Therefore, please let us know about possible criticism or ideas. We and our international partners are looking forward to hearing from you.

Thorlabs GmbH

WARNING

Sections marked with this heading explain dangers that might result in personal injury or death. Always read the associated information carefully before performing the indicated procedure.

ATTENTION

Paragraphs preceeded by this symbol in the manual explain hazards that could damage the instrument and connected equipment or may cause loss of data.

NOTE

This manual also contains "NOTES" and "HINTS" written in this form.

1 General Information

This chapter contains general information about the Beam Profiler's safety, warranty and waste treatment.

1.1 Safety

Attention

All statements regarding safety of operation and technical data in this instruction manual will only apply when the unit is operated correctly as it was designed for.

Before applying power to your PC system used to operate the Beam Profiler, make sure that the protective conductor of the 3 conductor mains power cord is correctly connected to the protective earth contact of the socket outlet! Improper grounding can cause electric shock with damages to your health or even death!

The Beam Profiler must not be operated in explosion endangered environments!

The instrument must only be operated with a duly shielded and low resistance USB cable delivered by Thorlabs.

Do not cover the Beam Profiler in order to prevent heating the instrument.

Changes to single components may be carried out or components not supplied by *Thorlabs* be used. Only with written consent from *Thorlabs* may

This precision device is only transportable if duly packed into the complete original packaging. If necessary, ask for a replacement package.

Be very carefully when removing one of the four filter holders on the filter wheel, they act also as dust protection cover. Prevent any kind of dust entering the entrance aperture!

Do not stick anything into the Beam Profiler aperture, you may damage the image sensor chip because there is no protective glass in front of it.

2 Getting Started

This section is provided for those interested in getting the Beam Profiler up and running quickly. The more detailed description and advanced features are described in the following sections.

2.1 Ordering Codes and Accessories

Ordering code	Short description
BC106-UV	CCD Camera Beam Profiler, 190 - 350 nm*
BC106-VIS	CCD Camera Beam Profiler, 350 - 1100 nm

*Design range of Lumigen coating, sensitivity is given throughout 1100 nm but shows increased non-uniformity and noise compared to uncoated BC106-VIS.
Wavelength range of supplied UV ND filters start at 220 nm.

For beam quality (M^2) measurement, extension sets including a translation stage and mounting adapter for the beam profiler are available:

Extension Set Model	**BC1M2-150**	**BC1M2-300**
Length of translation stage	150 mm	300 mm

Please visit our homepage http://www.thorlabs.com for further information.

2.2 Unpacking

Inspect the packaging for damage. If the shipping container seems to be damaged, keep it until you have inspected the contents and you have inspected the Camera Beam Profiler mechanically and electrically.

Verify that you have received the following items:

- 1 BC106 Camera Beam Profiler instrument with mounted filter wheel containing
  - 4 Attenuation filters, see Filter Wheel 9
  - 4 Filter caps in front of filters
- 1 USB 2.0 Cable A to Mini B, length 2 m
- 1 Distribution CD-ROM
- 1 BC106 Operation Manual
- 1 SM1BC Adapter

2.3 Preparation

1. Install the Thorlabs Beam software to your computer as described in Software Installation 13.
2. Connect the camera using the supplied USB cable to the PC as described in Connection to the PC 23.
3. Remove the filter caps screwed on the attenuation filters.
4. Rotate the filter wheel to set the highest loss optical ND filter (40 dB) in front of the

camera aperture which is behind the bottom attenuation filter. This prevents damage to the camera sensor.

5. Mount the Camera Beam Profiler instrument so that its optical aperture is exposed to the optical beam you like to measure.
6. Switch on your light source but be sure to not exceed the max. allowed optical power to the instrument. See Power Ranges 75 for details.

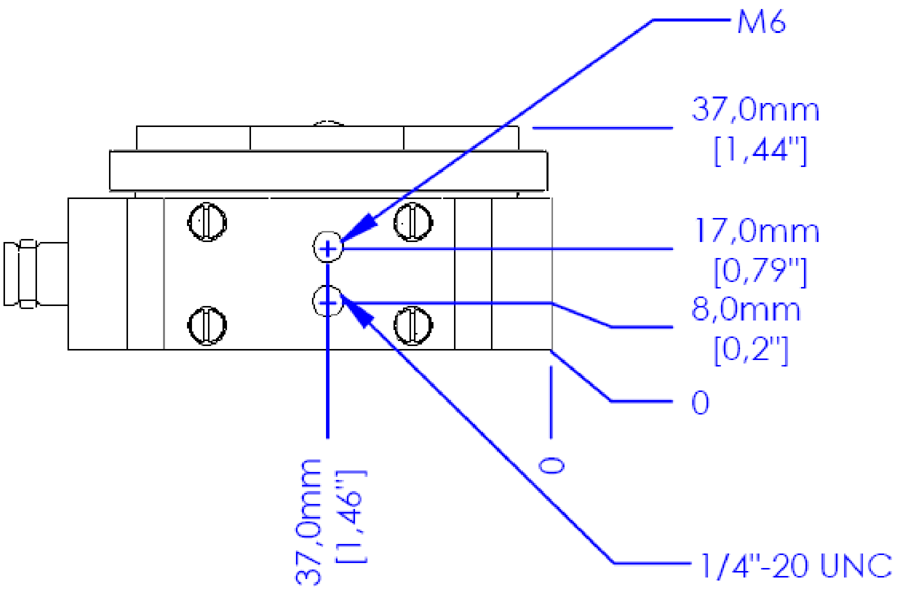
Attention

Please, install the software prior to connect the instrument to your PC via USB interface. Use only the supplied high speed (USB 2.0) cable, not full speed (USB 1.1) cables or thin profile cables with increased resistance, this can cause transmission errors and improper instrument operation!

2.4 Operating Elements

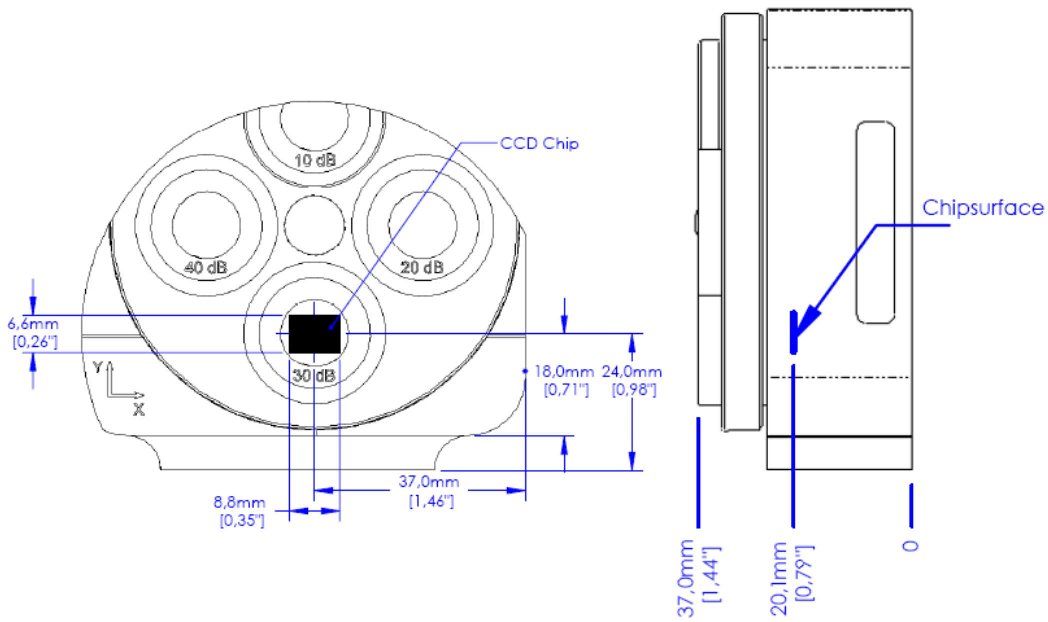
2.4.1 Mounting and Sensor Position

The Beam Profiler provides at the bottom side a mounting plate with 2 holes and different thread - M6 (ahead) and UNC8-32 (rear).



Mount the Beam Profiler on your optical board using Thorlabs post, post holder and base. See Accessories 154.

The following drawing shows the sensor position with respect to the Beam Profiler housing edge:



The sensor is centered with respect to the holes in the mounting base, its depth measured from the front surface of a filter holder is 16.5 mm [0.65 inches].

2.4.2 Filter Wheel

The Thorlabs BC106 Camera Beam Profiler is equipped with a filter wheel containing four different neutral density (ND) optical attenuation filters. The filter types and its nominal losses are model dependent. These filters are designated for a quick and easy adaptation of the light source power (which may exceed the saturation power of the camera) to a power level within the dynamic range of the CCD camera. The following image shows the BC106-UV filter wheel.

The following table gives you an overview:

Model	BC106-UV	BC106-VIS
Attenuation filters	1x 20 dB UV, reflective 1x 20 dB VIS, absorptive 1x 40 dB UV, reflective 1x 40 dB VIS, absorptive	1x 10 dB VIS, absorptive 1x 20 dB VIS, absorptive 1x 30 dB VIS, absorptive 1x 40 dB VIS, absorptive

Model BC106-VIS is equipped with four absorptive neutral density (ND) filters made from glass, that's why they are applicable only for the visible and near infrared wavelength range 350 - 1100 nm.
Model BC106-UV offers a wavelength range of 190 - 350 nm and therefore is equipped also with reflective filters made from fused silica. Two absorptive filters are similar to the VIS model and two filters for the UV are added. Because these filters are AR coated they are only applicable for the UV range (220 - 350 nm). See chapter Wavelength Response 151 for detailed data.

Attention

Be sure to have selected the appropriate ND filter corresponding to the actual operating wavelength! Keep attention to the light reflected from reflective UV filters!

The nominal filter loss and also the appropriate wavelength range (UV / VIS) is engraved to the filter housing. Note that the filter loss is wavelength dependent and may diverge largely from its nominal value, especially for operating wavelengths at the border of the Beam Profiler wavelength range. See chapter Wavelength Response151 for details.

Which attenuation to choose?
To adapt a light source with unknown power level to the Camera Beam Profiler it is highly recommended to use the automatic exposure control (see chapter Device Settings50) of the camera. In addition, it is advisable to start with the highest loss attenuation filter (40 dB) in order to prevent damage to the camera.
In case the Beam Profiler software displays an error "Power too high, camera saturated!" the light intensity exceeds the maximum detectable power of the BC106 Beam Profiler. In this case additional means for external beam attenuation are required.

In case the Beam Profiler software doesn't show a "Power too high" error you can work with this setting and the measurement results are reliable. But, in order to minimize beam distortions by the ND filters you should work with the lowest possible attenuation.
Rotate the filter wheel a quarter revolution to bring the nearest lower attenuation filter in front of the camera aperture. Whether now a "Power too high" error appears, rotate the filter wheel back to the previous filter which was optimal. If no error appears, rotate the wheel further until the lowest attenuation filter is in use.

If the optical beam power is low enough you can operate the Beam Profiler camera also without any attenuation filter in front of it. For this, unscrew a filter holder out of the filter wheel.

Attention

Be very carefully when operating the Beam Profiler without a protective filter in front of it! Since the CCD camera sensor is freed from its protective window it is extremely vulnerable! It is absolutely required to prevent dust and other contaminations from entering the Beam Profiler aperture. See Cleaning133 chapter for details.

When using a high loss attenuation filter in conjunction with a low power light source the software will display a "Power too low" warning. This means the source is attenuated too much so that the camera's gain and exposure regulation is not able to achieve an evaluable signal level. In this case reduce the optical attenuation down to the lowest available filter loss (10 dB) or remove one filter completely.

Attention

You need to enter the actually chosen ND filter loss in dB into the Beam Profiler software as a precondition for proper power measurement results! See Device Settings50 chapter.

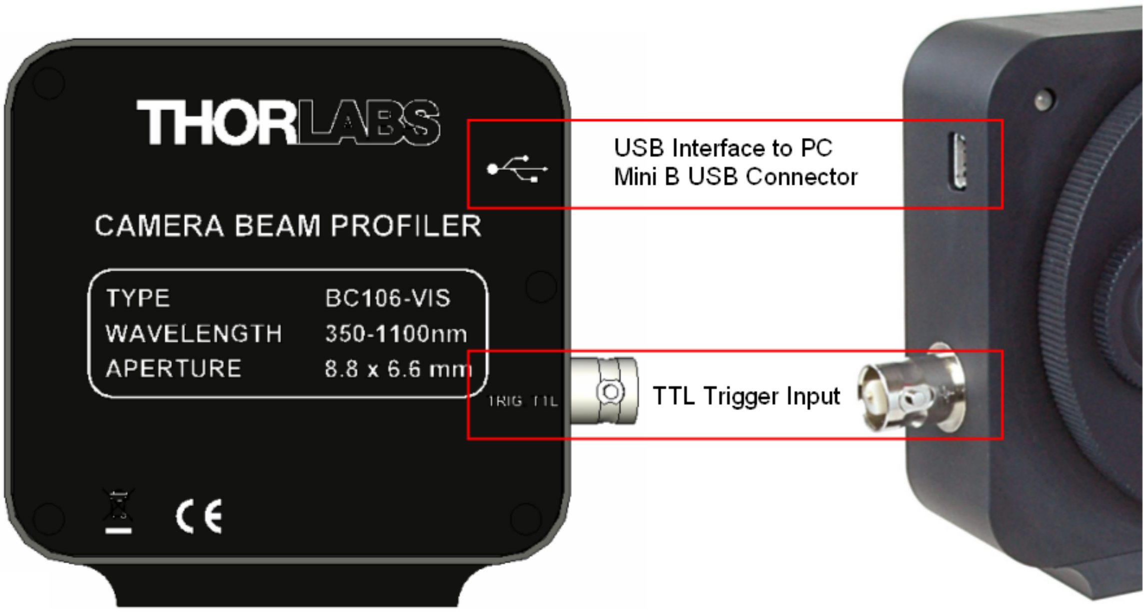
For correct beam profiling results it is highly recommended to shield ambient light from entering the Beam Profiler aperture. Using attenuation filters provided within the filter wheel will attenuate ambient light but will also absorb power of the light source by the same amount so that the ratio between both remains unchanged. Increasing the laser power will help to increase the dynamic between wanted and unwanted light portions.

2.4.3 Connectors

The BC106 Camera Beam Profiler provides two connectors at its left side of the instrument body.

- Mini B USB connector, labeled with USB symbol
  For connection to your PC, see chapter Connection to the PC [23]

- TTL Trigger input, labeled with **TRIG TTL**
  For synchronizing a Pulsed Laser Sources [76] to the Beam Profiler, see Trigger Input [12] for specifications.



2.4.4 Trigger Input

An electrical TTL trigger input is provided for synchronizing the Camera Beam Profiler's global shutter to Pulsed Laser Sources 76. The appropriate BNC connector is situated on the left side of the instrument body, see Connectors 11. The following table summarizes important electrical data for a compatible signal source.

Parameter	Value
Save static voltage level	-0.5V ≤ U ≤ 6.5V
Max. low level	1.5 V
Min. high level	3.5 V
Input impedance	> 100 kΩ
Min. pulse width	10 µs
Min. slew rate	5 ns/V
Applicable safety standards	IEC 61000-4-2 (ESD 15kV air, 8kV contact) IEC 61000-4-5 (Lightning 12A 8/20µs) IEC 61000-4-4 (EFT 40A 5/50ns)

Attention

Be sure to enter only a TTL compatible signal to the BNC jack not exceeding the range (-0.5 V … +6.5 V). Higher or lower voltages may damage the Beam Profiler input!

Note

Use shielded coaxial cables for connecting the trigger source only. Do not connect a trigger cable without a signal source because it may capture disturbing trigger pulses.

3 Operating the Beam Profiler

This section gives a more detailed description for operating the Thorlabs Beam Profiler.

3.1 Requirements

To operate the Beam Profiler on a PC your system needs to fulfill the following

Minimum hard- and software requirements:

- Operating system: Windows XP® SP2 (32bit), Windows Vista®, Windows 7® (32 or 64 bit)
- USB 2.0 high speed port
- Monitor resolution minimum 800 x 600 pixel (>= 16 bit color depth)
- Processor: Pentium 4 ≥ 2,6 GHz, 3,0 GHz Intel or A64 3000+ AMD, 1,0 GB RAM
- OpenGL (specification GLX 1.3 up) compatible graphics adapter:
    - Radeon (X100 series ≥ X850, X1000 series ≥ X1600, HD series ≥ 2400)
    - Geforce 7 series ≥ 7600, 8 series ≥ 8500, 9 series ≥ 9600
    - Quadro FX series ≥ FX770M

For optimal performance Thorlabs suggests to follow these

Recommended hardware features:

- USB 2.0 high speed port
- Processor: Core 2 Duo E4300 or A64 X2 3800+ AMD, 2,0 GB RAM
- OpenGL (specification GLX 1.3 up) compatible graphics adapter:
    - Radeon HD series ≥ 3870
    - Geforce 8 series ≥ 8800, 9 series ≥ 9800, GTX series ≥ 260
    - Quadro FX series ≥ 2700M

3.2 Installation

3.2.1 Software Installation

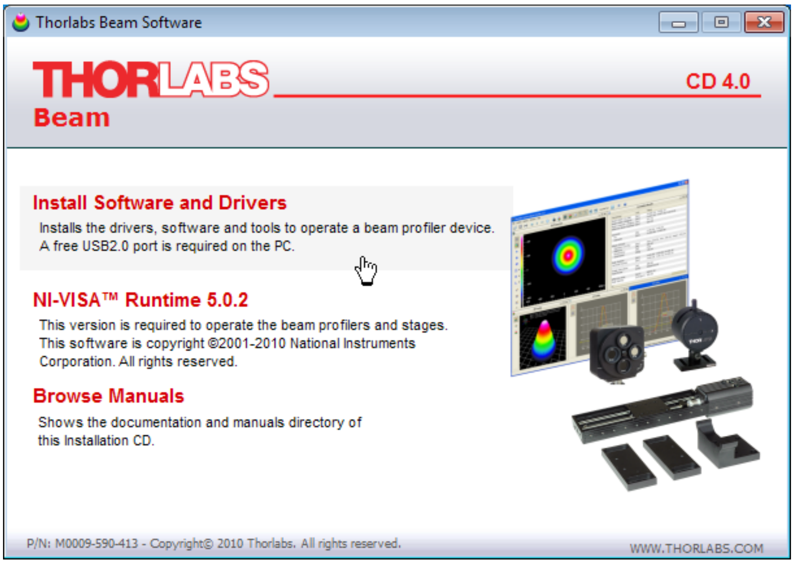
Insert the "**Thorlabs Beam CD 4.0**" (or higher) CD-ROM in your CD/DVD drive. It automatically starts up and displays the installation start screen.

In case this 'auto start' feature is disabled on your computer please execute the "Autorun\Autorun.exe" file on the CD.

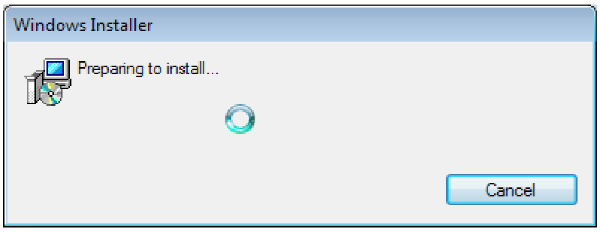
Quick Overview
The installation CD contains of 3 parts - Software and Drivers, NI-VISA Runtime and Manual. Starting with the Topic"Install Software and Drivers", the Beam software is being installed to your computer, with a subsequent check for NI-VISA Runtime: If no NI-VISA Runtime is installed to your computer, or the installed version is older than 4. x, you will be prompted to install it. Therefore you may use the appropriate installer on the CD 4.0 (NI-VISA Runtime 5.0.2).
Finally, you can find this manual in PDF format on the CD.

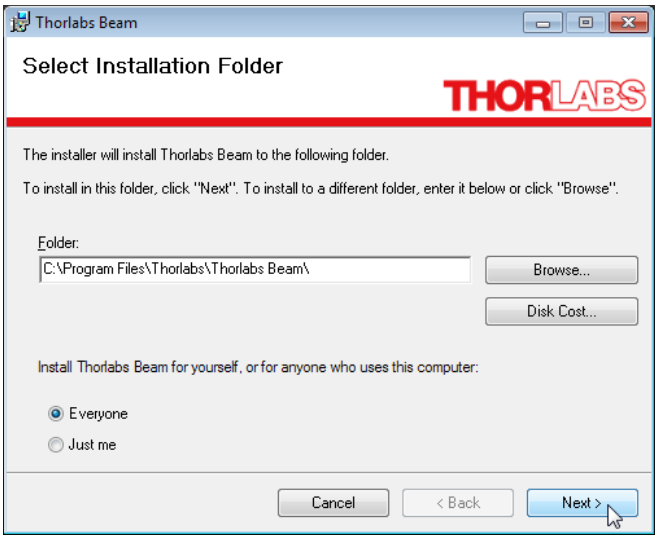
Installation

The following procedure is described for installation to a Windows 7® operating system.

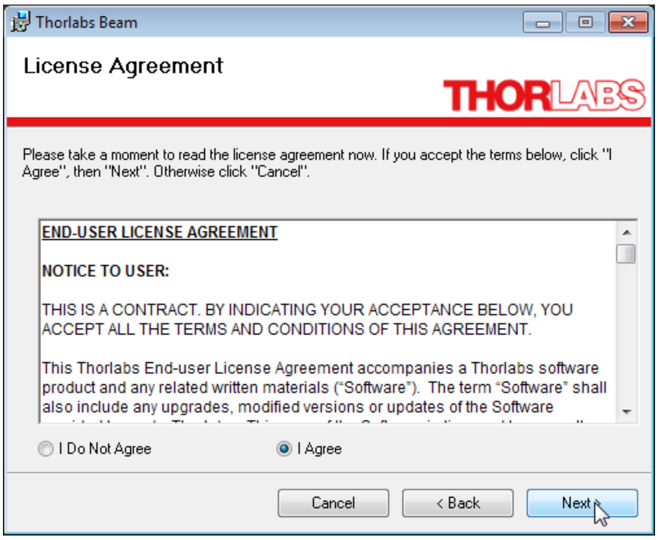


Click to the first topic.

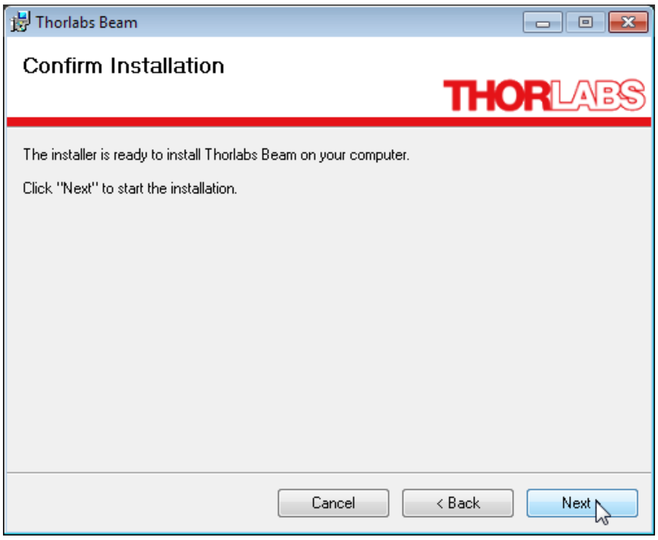




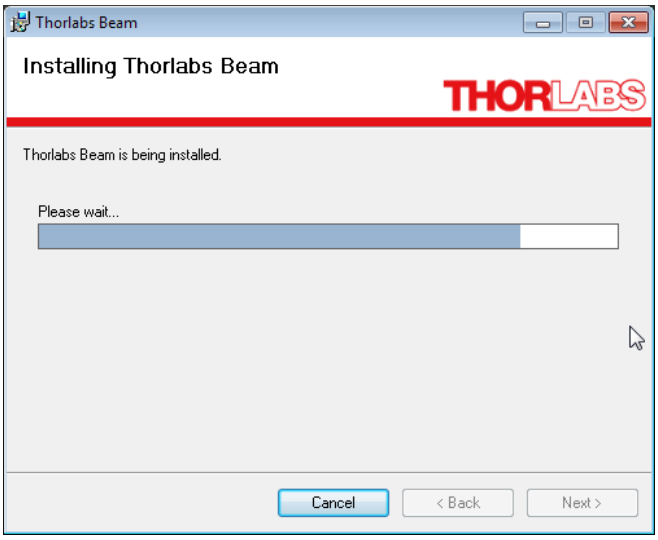
It is recommended to follow the recommended path, click Next.

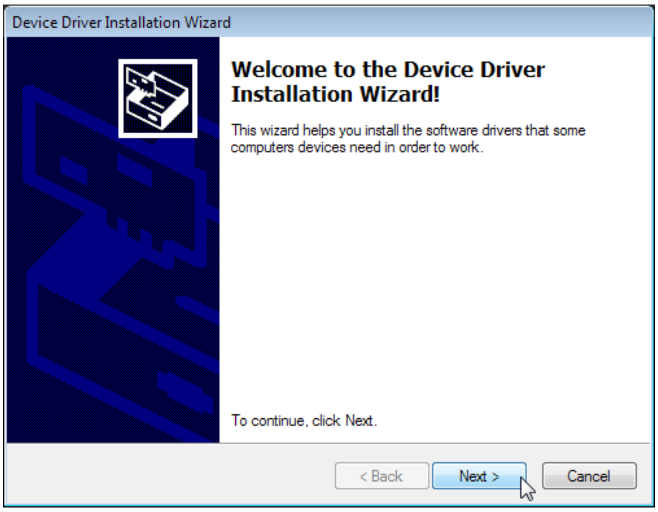


Please read this license agreement carefully, choose "I agree" and click 'Next'.



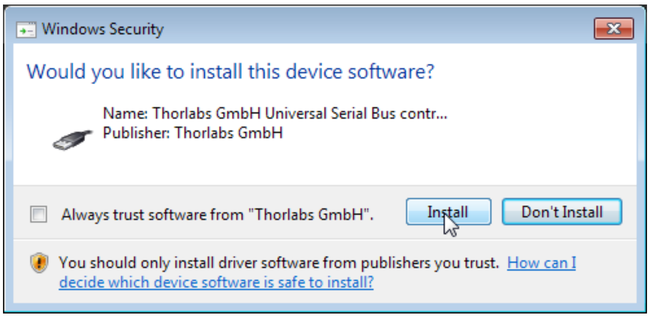
Click "Next", the software installation starts.



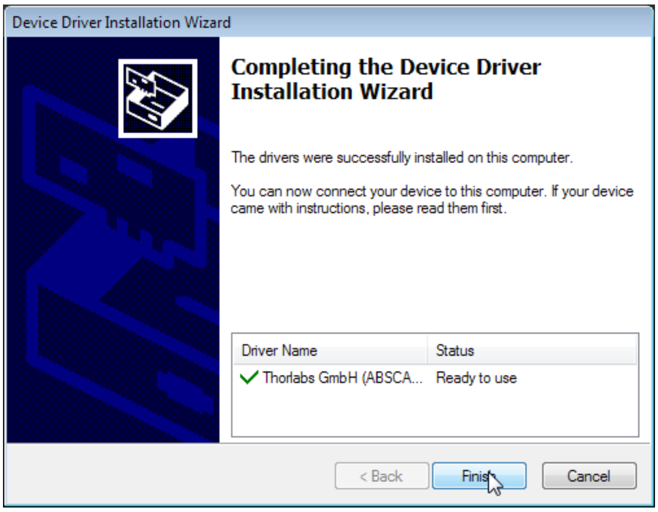


A new window appears, click "Next" to continue.

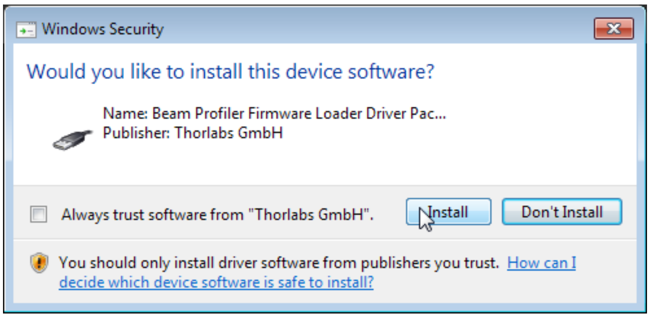
Windows Security will ask your confirmation to install the Thorlabs USB driver.

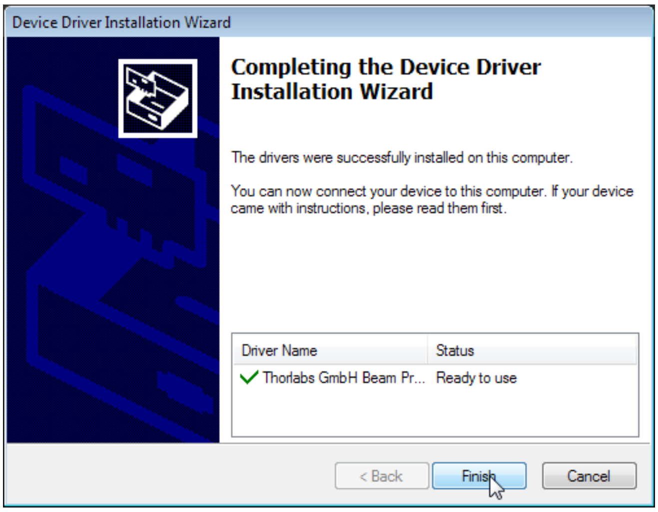


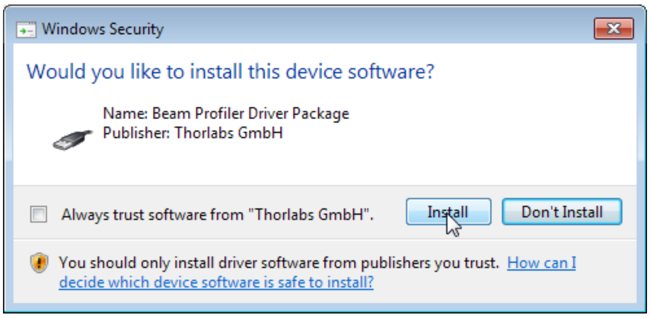
You may check the box "Always trust software from "Thorlabs GmbH", this will shorten the installation. However, if you do not want to do that, please click the "Install button.

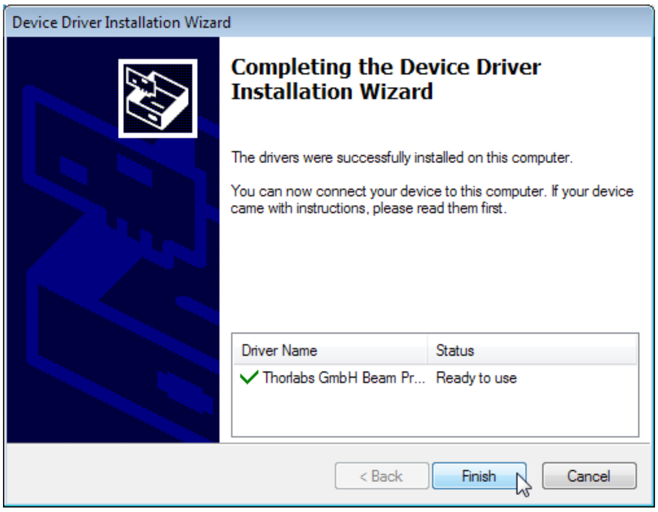


Thorlabs USB driver is now installed. Further, you will be asked to confirm the installation of another two device software. Please proceed as described above.

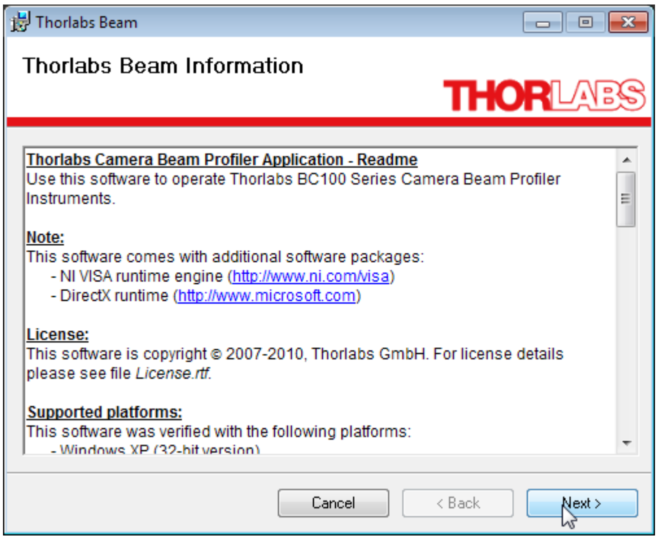




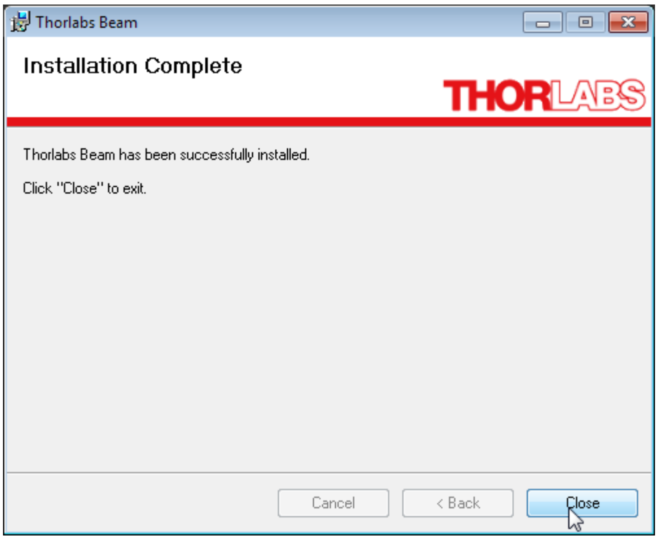




Now, the Beam software including device drivers is installed to your computer.

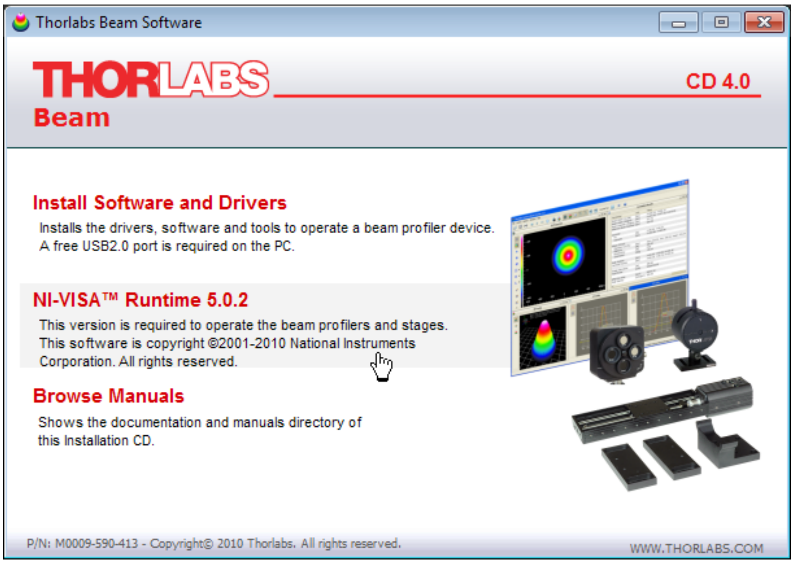


Click "Next",



and "Close" to complete the software installation.

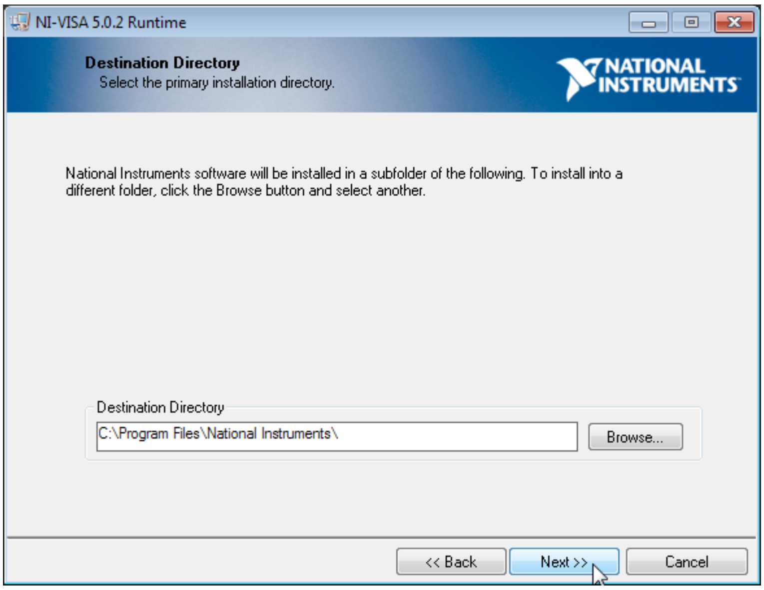
After finishing, the installer runs a check for installed NI-VISA Runtime. If you have a Version 4.x up already installed to your computer, you can proceed immediately with Connection to the PC 23, else please proceed with second topic as per the screenshots below.



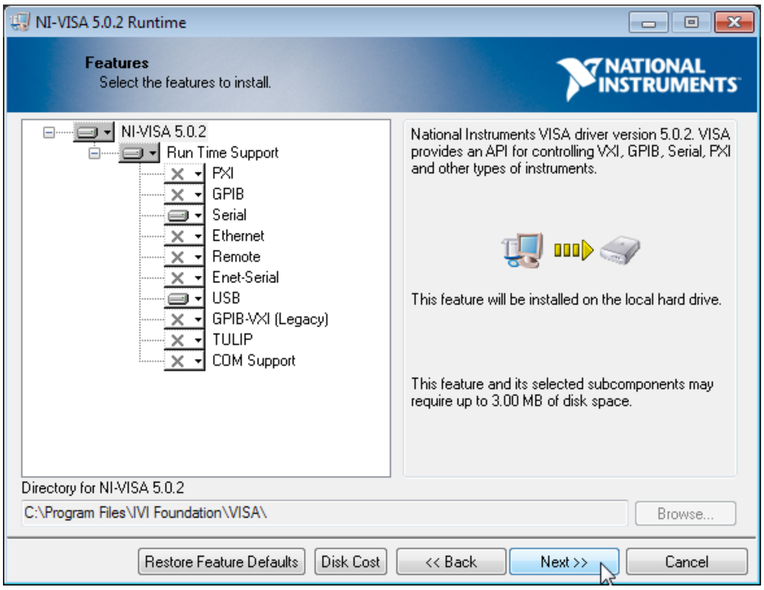
Click to "NI-VISA Runtime 5.0.2."

The NI Installer comes up.

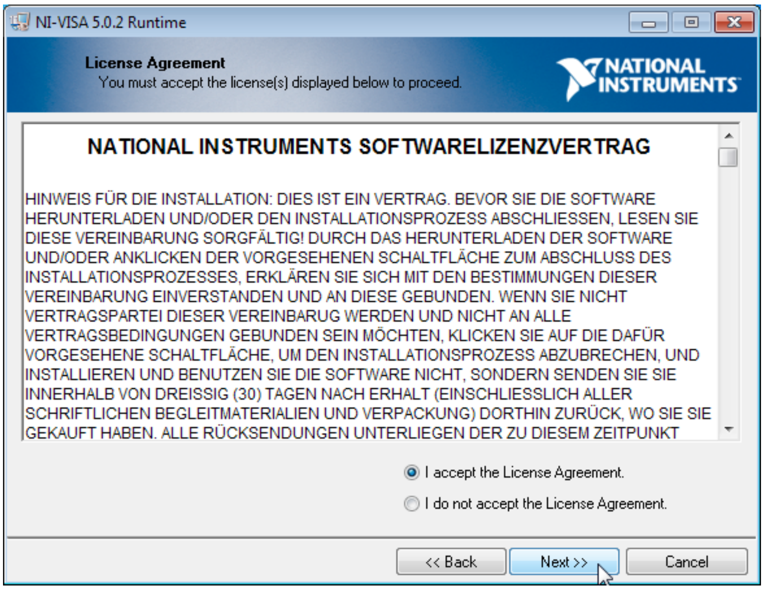
Click "Next"



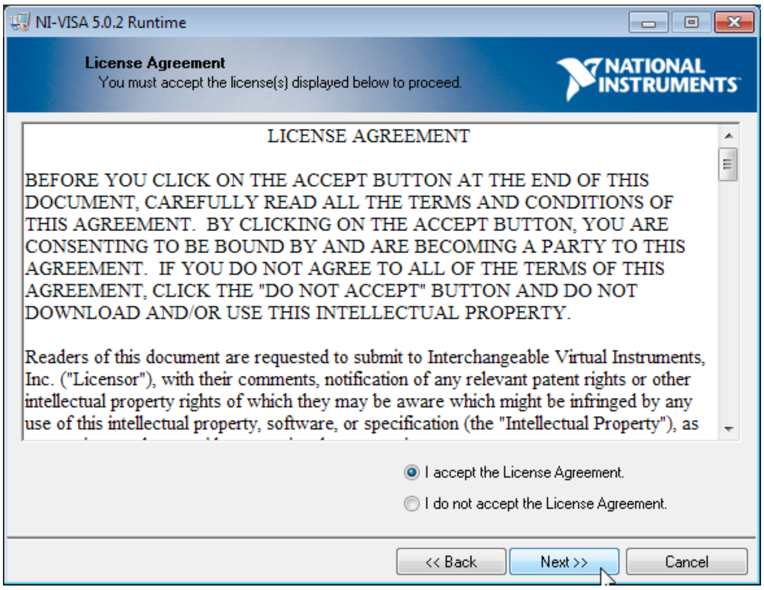
It's recommended to install NI-VISA to the proposed folder, click "Next"



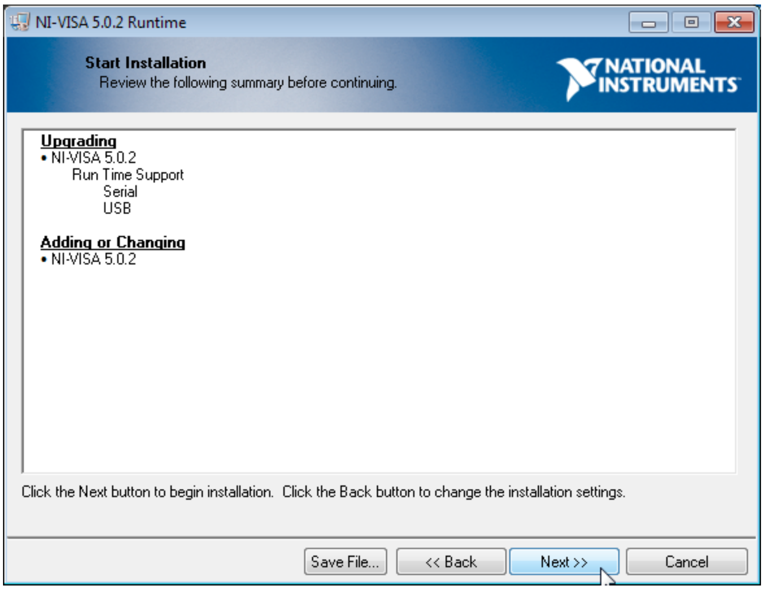
In this screen the required components are being selected. USB is required for the Beam Profiler control, Serial (RS232) for control of the translation stage used for M² measurements.



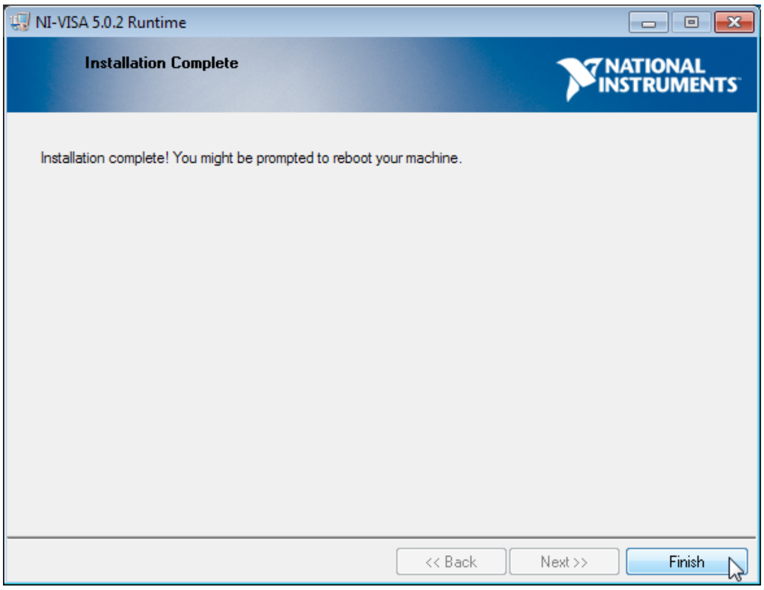
Please read the Software License Agreement carefully, choose "I accept" and click "Next"



Please read the License Agreement carefully, choose "I accept" and click "Next"



Click "Next", the software installation starts and may take a few minutes.



Click 'Finish'. The installation has completed successfully.

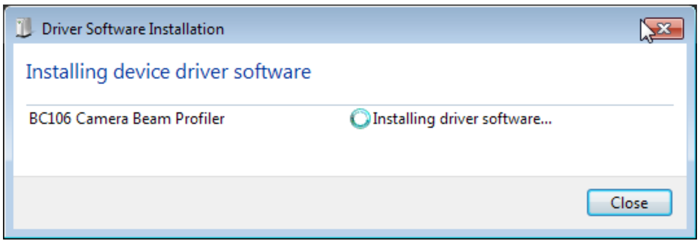
3.2.2 Connection to the PC

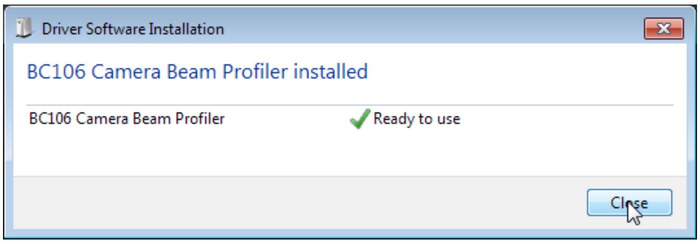
Connect the Beam Profiler to a USB 2.0 high speed port of your computer. Use only the cable that comes with the Beam Profiler or a cable qualified for high speed USB2.0 standard.

Attention

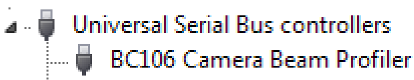
Do not use low speed USB cables as this can cause transmission errors and improper instrument operation!

After connecting the instrument to the PC the Windows 7® operating system will load the appropriate USB drivers for the Beam Profiler instrument.
After connection, in the task bar will appear an icon, indication that the driver installation is in progress. If click to this icon, the window below appears:





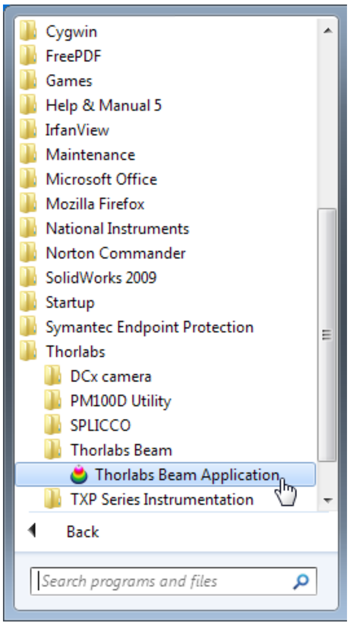
For verification purposes you might check the existence of this instrument in the Device Manager of your computer.
From the Start button select Control Panel → Device Manager
The following entry under the USB-Devices group indicates that the Thorlabs Camera Beam Profiler device is properly installed.



If you cannot see such an entry please check the troubleshooting 135 chapter.

3.2.3 Start the Application

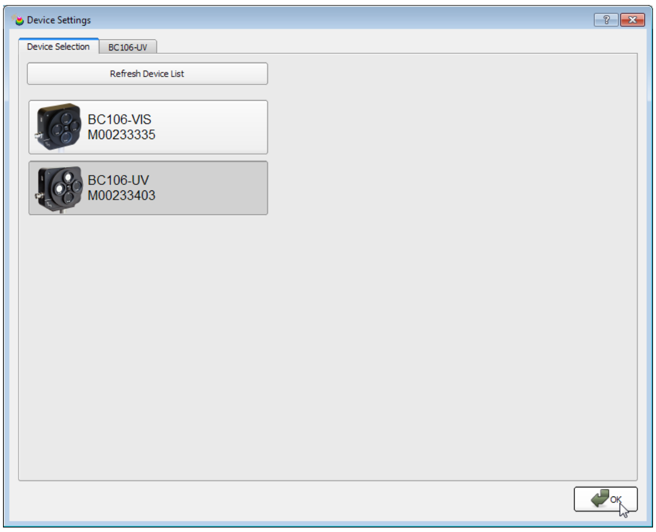
Access the Application Programs from the START button. Click the "Programs" → "Thorlabs" → "Thorlabs Beam Application" entry.



Or simply click the appropriate 

symbol added to your desktop.

When the application is started the first time or if the last used camera is not connected to your system the following 'Device Selection' dialog will appear:



Usually the Beam Profiler connects automatically to the first connected camera. If you want to use another connected camera click onto an entry of the instrument to mark it and click 'OK'.

With the next start of the Beam software and if the last used instrument is connected with your system, the 'Device Selection' dialog is skipped and the Beam Profiler is automatically used. When opening the 'Device Selection' dialog you will be forwarded directly to the "BC106" settings tab.

Click on 'Refresh Device List' for an update in case you have very recently connected to or removed a Beam Profiler instrument from your PC. If an expected instrument is still missing check if the USB driver is properly installed (see chapter Troubleshooting135).
After selecting a Beam Profiler instrument the tab "Device Settings" is enabled so that all available settings and adjustments to the Beam Profiler can be done. See chapter Device Settings50 for a detailed description.
It is advisable to read the steps described in chapter Measurement with the Beam Profiler48 carefully in order to setup your Beam Profiler device properly.

In case you do not have a Beam Profiler hardware available you may click on 'Load Stored Image ...' to load a previously stored Beam Profiler image for interrogation. Browse for an image in the "Image Selection" box.

Click 'OK' to confirm your selection and the 'Device settings' panel will be closed.

When the Beam Profiler application is started the first time, three preselected windows are opened and arranged automatically. Otherwise, the arrangement of the last session (selected windows and its position) will be recovered. See chapter Child Windows31 for a detailed description of each window.

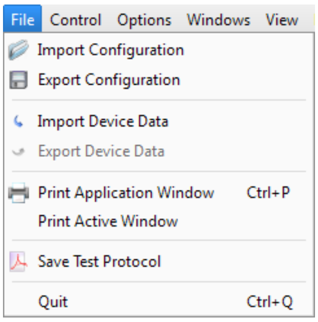
3.3 The Graphics User Interface (GUI)

3.3.1 GUI Overview

The main window consists of a menu bar, a tool bar, a status bar and common frame for displaying several child windows.

A: Menu bar
All user activities can be done with items in the menu bar.

1. File
These menu entries deal with files or printing.



The first two entries **Import and Export Configuration** files (XML format) which contain information about the chosen Beam Profiler device and its settings, file export parameters and application settings. In order to copy the GUI appearance and Beam Profiler settings to another PC you need to save the configuration file, copy it and load it on the target system.

The second part allows you to import and export originally retrieved from the camera beam profiler data:

Export

- RAW format: This is a product specific bitmap with additional information, here pixel pitch (distance between 2 pixels) and exposure time.
- BMP format: This is the standard, uncompressed bitmap image retrieved from the camera.
- CSV format: Intensity values are saved to a text matrix. This matrix saves values according to selected precision mode (8 or 12bit - see Device Settings 56). The 1st value in the 1st line represents the intensity of the left upper pixel in the 2D projection .
- TIFF (8bit), PNG and JPG formats: Standard picture formats for easy integrating of measurement results into external documents

Import

The import is limited to Device Data allowing reconstruction of the original measurement result with the Beam software.

- RAW format: Along with the bitmap, saved from the camera, pixel pitch and exposure time are used for calculation, so the imported beam profile will reproduce the true size and also the optical power.
- BMP format: Only the bitmap will be shown. The dimensions in X and Y direction are not the original ones (pixel pitch will be considered as 1)

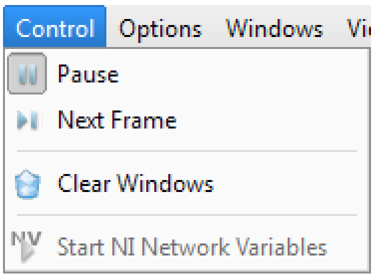
The third block exports the currently displayed window content of the child windows.

With the **Print Application Window** a screenshot of the Beam Profiler application is printed.
The **Print Active Window** entry prints the current active child window of the Beam Profiler application. This function gives you the opportunity to print a specific child window.

The **Save Test Protocol** opens a dialog window, where individual data can be entered. Clicking to "Save" and then "Close", a test report with the calculation results and the current projection image is saved to the indicated location. If the 3D Profile window is opened, a screenshot of the 3D Profile is also included into the test report.
See the some detailed examples for data export in chapter Save Measurement Results 70.

2. Control

Use the two first menu entries to start and pause the continuous operation of the Beam Profiler device including retrieving measurement data, performing calculations and displaying graphs and numerical results to the output windows. 'Next Frame' starts a single measurement and goes to the pause state.



When the GUI is started or the active Beam Profiler instrument was changed, the application will start continuous operation automatically. Pausing the consecutive operation is advantageous for detailed analysis of a single image. User interactions will show increased performance on such a frozen image. The paused Beam Profiler can be restarted at any time.

The "**Clear Windows**" function resets the content of all windows, including child windows. With the receive of the next measurement result from the instrument, the window content is filled. This function may be useful in combination with a trigger mode while waiting for the next image orfor a synchronous restart of all plots and time-based measurements.

Start NI Network Variables

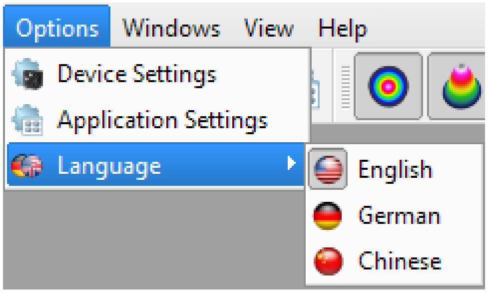
Note

In order to use this command, you need to have installed additional National Instrument® software (Distributed System Manager, NI Runtime Engine). This feature is a data interface handing over the parameters

saturation
total Power
centroid Position X
centroid Position Y
4-sigma width X
4-sigma width Y

to an external program environment.

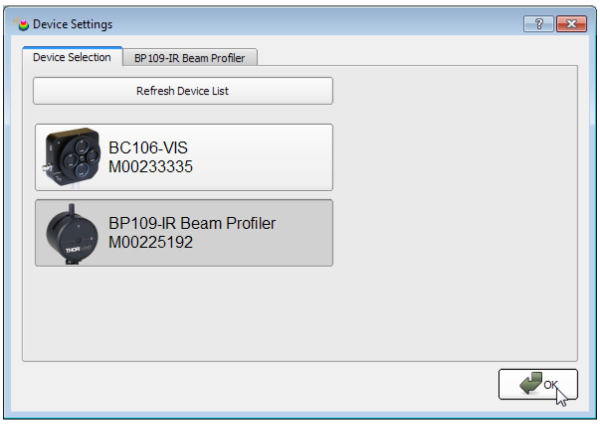
3. Options



These entries allow changing the device (Beam Profiler) and application (GUI) specific settings and let you choose a language.

Device Settings

The *Device Settings* window contains two tabs - *Device Selection* and a tab with instrument specific settings. The second tab is disabled if the current device is a image from the disk. It will be enabled if the device changes to a recognized beam profiler.

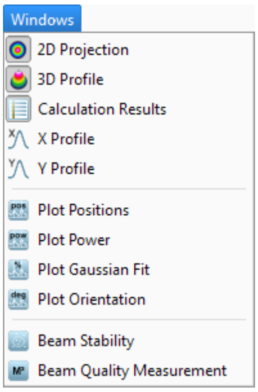


On panel 'Device Selection' choose a connected Beam Profiler instrument from the list and click 'OK' for its activation. Use 'Refresh Device List' to see also instruments very recently connected to your PC.
See chapter Start the Application 24 for details.
See chapter Device Settings 50 for a detailed description of all specific instrument settings.

Application Settings
See Application Settings 59 for detailed settings of the software.

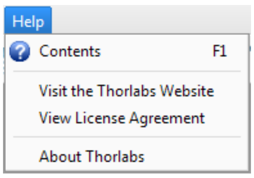
Language
The current language of your operating system is selected.

4. Windows
When the GUI is started the first time, the 2D projection , 3D Model and the Calculations windows are opened by default. To close and open the windows, toggle the corresponding entry in the windows menu. The following list shows all available windows.



An open child window can also be closed by pressing the X in the upper right corner of the child window.

5. Help
The first entry 'Contents' within the help menu or Key 'F1' will open the online help file which contains the complete information of this manual.



With a click on the link *Visit the Thorlabs Website* the Thorlabs website is opened in the standard browser.
View License Agreement will open the license file of the installer package.
About Thorlabs opens the about dialog panel which displays device information and software versions details:

If you have trouble with the software, please submit the version of the application to Thorlabs. This is helpful for resolving your problem.

B. Toolbar

For the most important menu entries there are also symbols provided in the tool bar.

Clicking on a toolbar symbol will have the same effect as clicking on the original menu entry. Moving the mouse over the icons, a tool tip will be displayed.

The toolbar symbol have the following meaning:


Open the online help file


Pause and start the continuous device operation, take a single measurement and clear the content of each window


Open the device settings panel concerning the Beam Profiler instrument


Open the application settings panel concerning the GUI and calculation settings


Open or close the GUI window 2D Profile, 3D Profile, Calculation Result, X-Y Profiles, Plot Position and Plot Power, Beam Stability and Beam Quality Measurement.

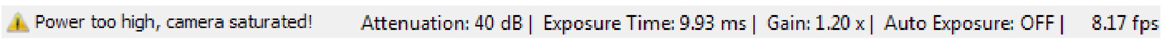

Toggle Auto Exposure On/Off


Toggle Auto Scale To Peak On/Off


Toggle Max Hold On/Off


Change ROI (Region Of Interest) dimensions

C. Status bar



The status bar is used to display important status information about the Beam Profiler concerning

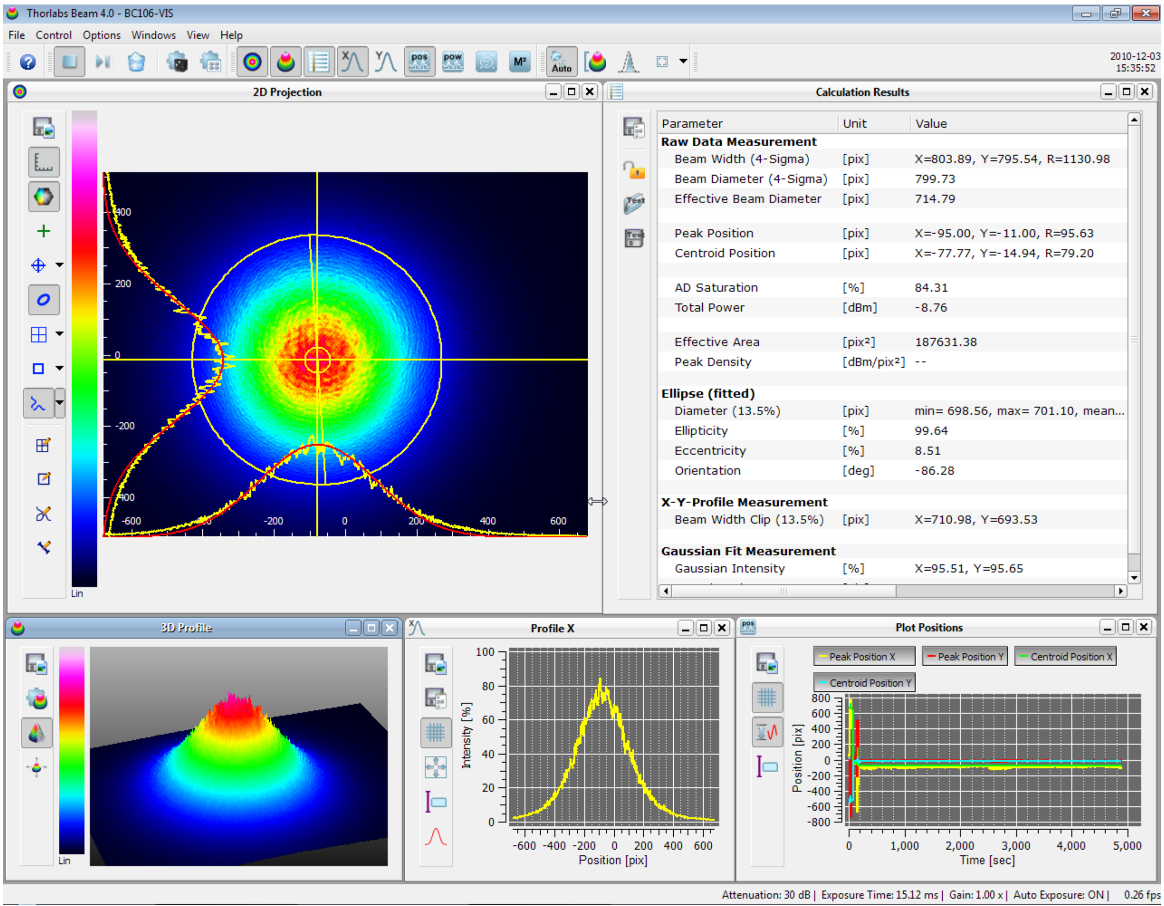
- Errors and warnings, see chapter Warnings and Errors 132
- Attenuation setting (by Filter Wheel 9 or external attenuator)
- Camera settings like Exposure Time and Gain
- Current refresh rate of the application in frames per seconds (fps)
- Alternatively, if stored Device Data are loaded, the location of the file is displayed

3.3.2 Child Windows

If the application starts the first time, three child windows are opened and arranged automatically: "2D Projection 33", "3D Profile 36" and the "Calculation Results 39". The application provides further windows: "X Profile 37", "Y Profile 37", "Plot Positions 41", "Plot Power 43", "Plot Gaussian Fit 44", "Beam Stability 46" and "

Beam Quality (M²) 81". All these windows can be opened and closed with the symbols in the toolbar or via the entries in the menu "Windows".

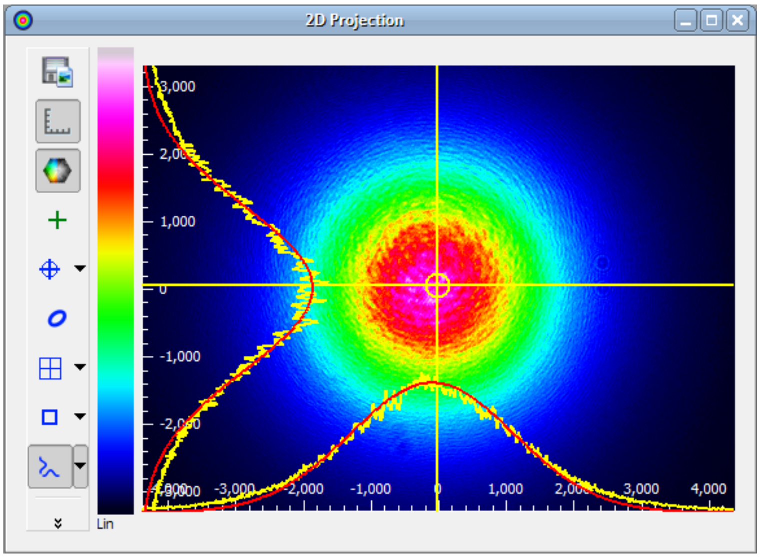
The appearance of the Thorlabs Beam software can be arranged according to somebody's requirements and taste. All child windows can be sized and positioned very flexible. Here is an example of arranging some child windows:



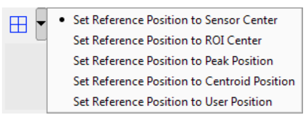
To close a child window deselect the menu entry or the appropriate toolbar symbol or click the close button "X" in the upper right corner of the child window.
Each child window can be moved and resized. If a child window is closed its settings are stored so that it will have the same position and size when it is reopened.
When the GUI application is closed and reopened also the main panel will have the same child panels open at the former positions. To arrange the windows automatically use the function "Tile View" from the menu.

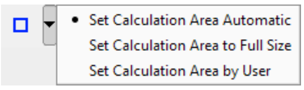
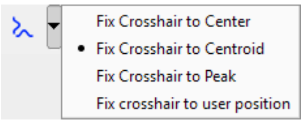
3.3.2.1 2D Projection

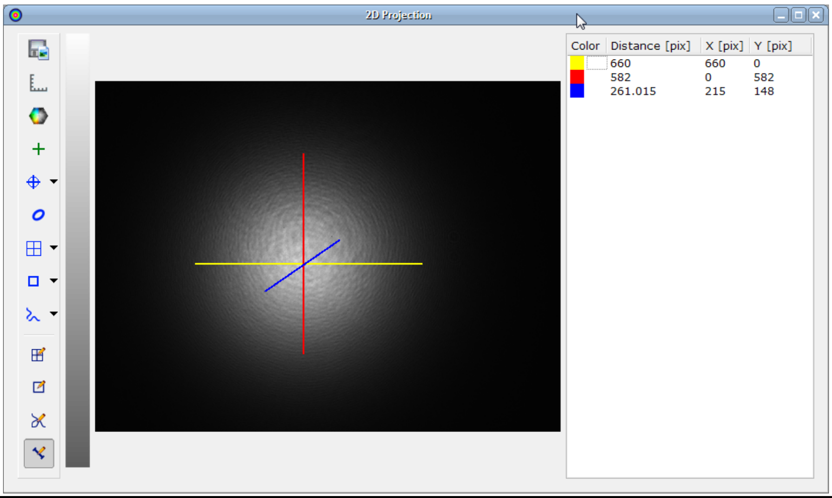
The 2D Projection graph shows the image from the Beam Profiler indicating the power intensity distribution within the selected Region of Interest (ROI).
This window can be opened and closed via the menu item "2D Projection" in the window menu or via the toggle button in the toolbar. The window can also be closed via the X button in the upper right corner of the child window.



On the left side of the 2D Projection window a toolbar is located with the following toggle buttons:

Toolbar Icon	Associated Action
Save diagram or data	Opens a dialog box to specify the properties of the saved screenshots / diagrams.
Scale	Show or hides the x and y scale
Color	Changes the color of the image from grayscale to color (see Display Settings 62)
Peak	Marks the Peak Position using a green cross
Centroid	Marks the Beam Centroid using a blue cross within a blue circle; resets the centroid indicators
Ellipse	Displays the approximated Beam Ellipse in yellow color. The ellipse is drawn corresponding to fitted or unfitted numerical data. See Application Settings 59 to enable/ disable the ellipse fit.
	The reference position influences the calculation results; peak and centroid positions refer to the reference position. The reference position can be either the center of the sensor, the center of the region of interest, the peak position, the centroid position or a user defined position which can be set in reference position edit mode.

Toolbar Icon	Associated Action
	Defines the Calculation Area which is a subarea of the visible camera image which is itself defined by the ROI (see Device Settings 50). Only pixels within this Calculation Area are interrogated and recognized for beam data calculation. • **Set calculation area automatic:** The software calculates the area for each new camera image, see Application Settings 59. This is also the default setting. • **Set calculation area to full size:** The calculation area spans the whole image ROI. Note that the Calculation Area is set to "full size" as soon as a new ROI is set. • **Set calculation area by user:** the last user defined calculation area is used. If no calculation area was defined or the calculation area is outside the current image roi, a error message occurs and calculation area returns to the last selection. The calculation area can be set with the calculation area edit mode.
	Draws X and Y Profiles into the 2D graph displaying the power distribution within a horizontal and a vertical cross section. The positions of these X and Y cross sections can be defined by either intensity peak, centroid, image center or a user defined position. By default **'Fix cross hair to centroid'** is selected. If no user position is defined by the editor, the user position is the centroid.
 Reference Position Editor	Set a user defined reference position with a click with the left mouse button inside the projection image.
 Calculation Area Editor	You are expected to draw a rectangle of the desired size onto the 2D Graph thereafter. Press the left mouse button at the upper left corner and drag the yellow rectangle into the image. It should be large enough to cover the desired beam spot. Release the mouse button at the lower right corner. Press and hold the right mouse button to move the drawn rectangle over the display area.
 Profile Cross Editor	To select a user defined position simply click left onto the image position. The selected pixel row will be the source for the diagram in the X Profile windows and the selected column for the diagram in the Y Profile window.
 Distance Editor	The distance measurement editor opens a table beside the projection image. When drawing lines into the projection image, the distance is inserted into the table. A maximum of 10 distances can be drawn. Remove a distance entry by selecting the entry and pressing the "DEL" key or select the entry and choose the "Delete Distance" entry from the context menu.

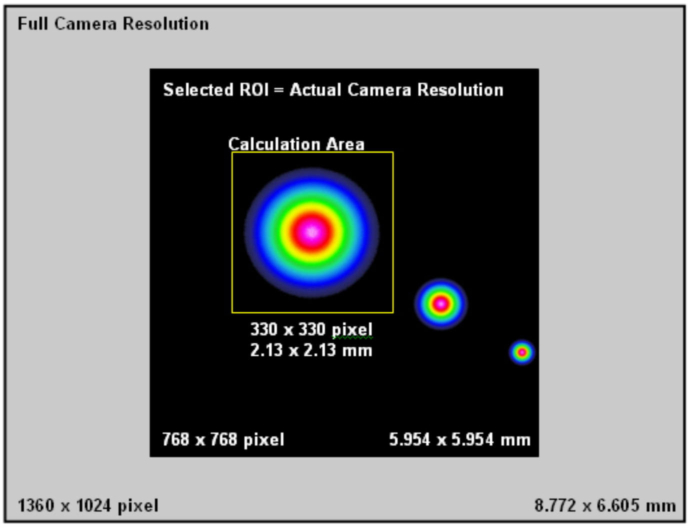
Toolbar Icon	Associated Action
	

If the window height is smaller than the full toolbar, the lower symbols are packed into a context menu which is accessible via a arrow button on the bottom of the toolbar.

Attention

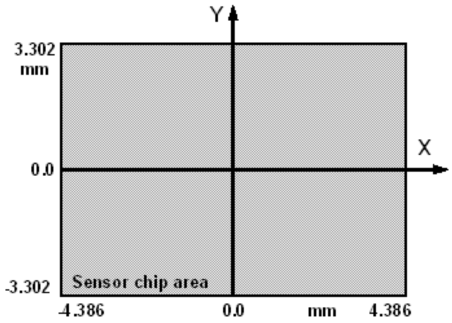
The calculation area must not cut off also lower intensity parts of the beam profile. This may cause improper calculation results!

The following graph shows an example of chosen ROI and Calculation Area:



Example:
A beam is entering the Beam Profiler once directly and in addition multiple reflections of it. The ROI is selected to 768 x 768 pixels so that all 3 beams are visible within the 2D Projection window. But, in order to limit the image interrogation to the main beam the calculation area was chosen much smaller.

Within this 2D Projection panel, coordinates X and Y are defined as follows:



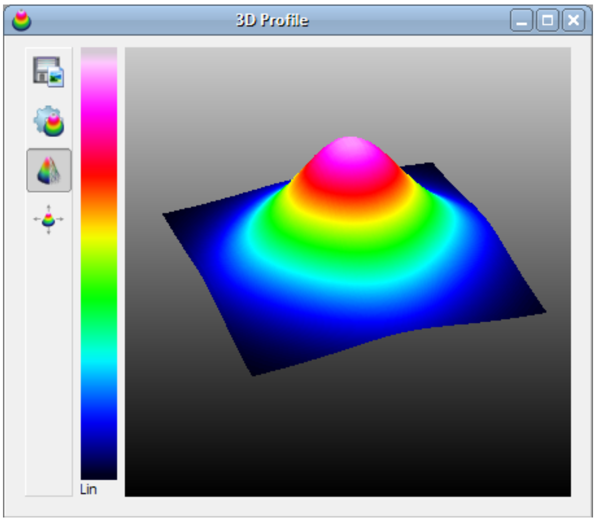
Independent of the selected unit (pixel or µm) within the Application Settings panel (see Application Settings 59) the origin of the coordinate system is the selected reference position. Horizontal axis is X and vertical axis is Y. Both axes are also labeled onto the Beam Profiler housing.

3.3.2.2 3D Profile

The 3D Profile illustrates the power density distribution of the measured optical beam. Whereas the beam's cross-section is parallel with the x-y-plane the relative power intensity is shown in the z direction (Pseudo 3D).
This window can be opened and closed via the menu item "3D Profile" in the window menu or via the toggle button  in the toolbar. It can be closed via the X button in the upper right corner of the child window.

The 3D profile can be moved, rotated and zoomed with the mouse interaction in the window. Instructions how to manipulate the displayed graph within the window

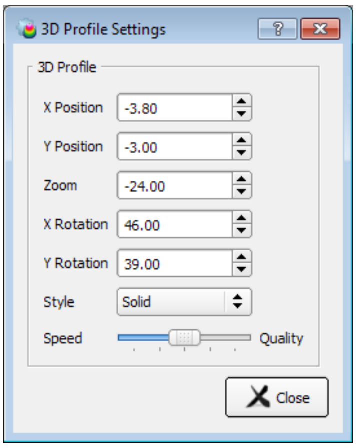
Rotate: Press right mouse button and move mouse
Move: Press left mouse button and move mouse
Zoom: Scroll mouse wheel



The following table summarizes the toolbar symbols available within the 3D Profile window and its appropriate action.

Toolbar Icon	Associated Action
	Opens a dialog box to specify the properties of the saved screenshots / diagrams.
	Opens the 3D Profile Settings dialog box.
	Toggles the appearance of the profile between solid to wired (default).
	Resets the manipulations of translation, rotation and zoom to the default view.

Position, size and rotation angle are also displayed within the 3D Profile Settings dialog box. Here you can input numerical values to define the 3D Profile appearance:

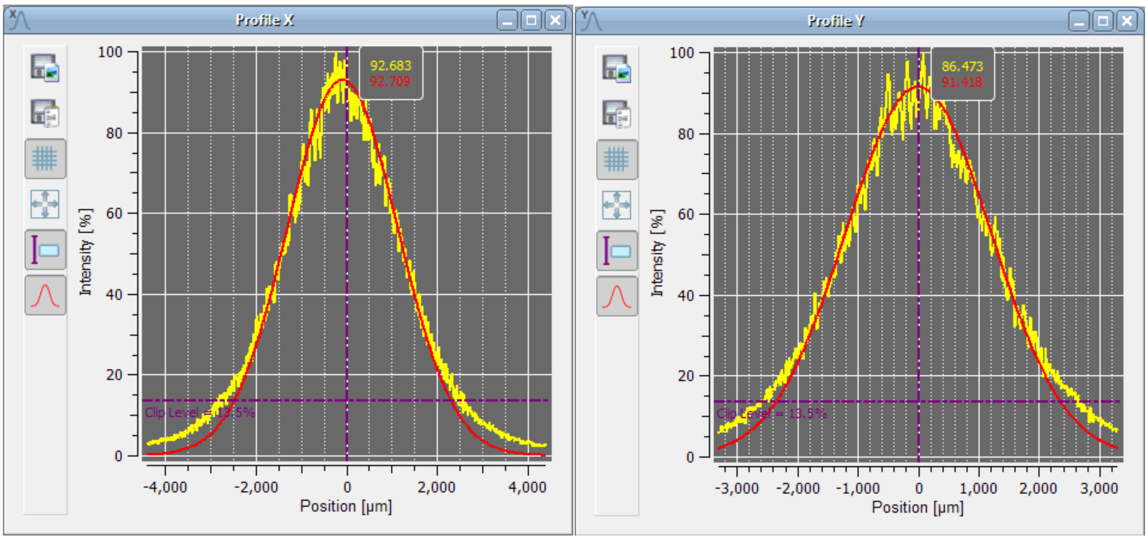


Note

- If the slider "Speed - Quality" is in the very right position, the 3D image is displayed with highest quality, i.e., with full resolution.
- The higher the 3D image quality is set, the more system resources are used. Depending on the system capabilities, the software may slow down.

3.3.2.3 X,Y Profiles

Each of the two windows can be opened and closed via the menu item "X Profiles" or "Y Profiles" in the window menu or clicking on the appropriate toolbar symbols. The windows can also be closed via the X button in the upper right corner of the child window.



The X profile displays a single pixel row taken from the received camera image, whereas the Y profile shows a single pixel column. The column and row is defined by the position of cross hair within the 2D Projection 33 graph.

The yellow graph shows the measured profile, while the red curve shows the approximated Gaussian fit function. If "Autoscale to Peak" is enabled and in 2D projection the cross hair is fixed to peak, the measured curve shows relative intensities from 0 to 100%, where 100% denotes the maximum value in the selected row / column. The amplitude of the Gaussian fit curve may be lower or even higher than the peak intensity of the measured curve.
The selected clip level (default 13.5%) is displayed, if the "Auto Scale to Peak" function is enabled (button).
The horizontal scale is displayed in pixels or µm and its range refers to the selected Region of Interest 53. The unit of the scale can be changed with the Application Settings 59 dialog.

Toolbar Icon	Associated Action
	Opens a dialog box to specify the properties of the saved screenshots / diagrams.
	Opens a dialog box to save measurement data to XLS or CSV file.
	Toggle button to display grid in the diagram. Default: grid is shown.
	Zoom Home button
	Toggle button to show or hide the cursor.
	Toggle button to show or hide the Gaussian curve fit. Default: curve fit is shown.

Zoom Mode

To zoom in the diagram, draw a rectangle with the left mouse button pressed.
Right click to the diagram undoes last zoom action.
"Home" button returns to display of the complete diagram.

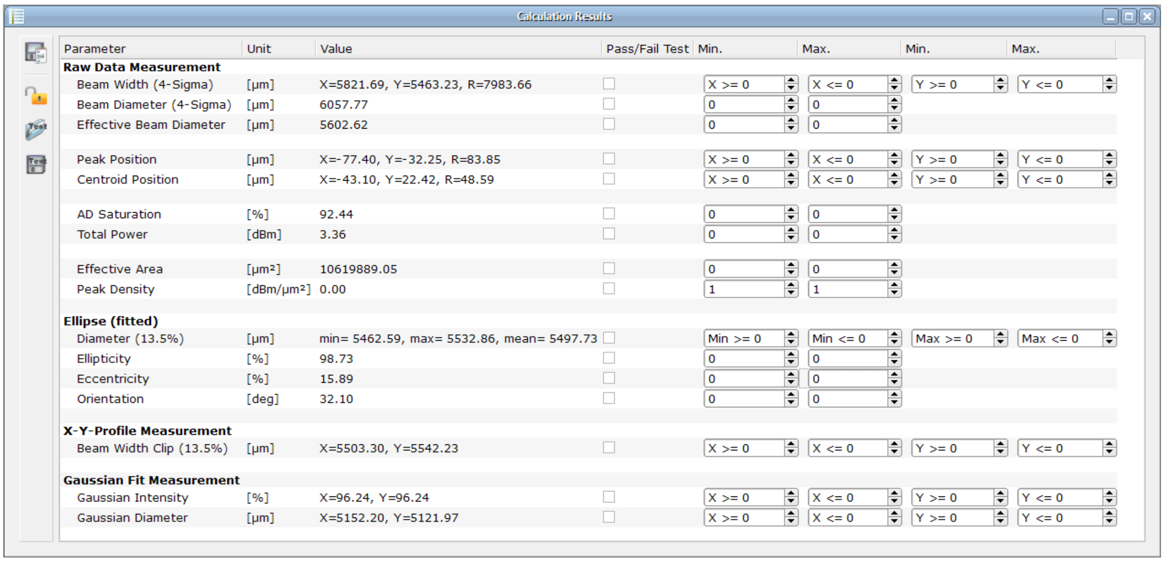
Cursor Mode

Move the the mouse pointer close to the vertical cursor line, the mouse pointer changes to ⫲. The cursor line can be moved with the left mouse button pressed to a position inside the diagram. The current values at the cursor position are shown in a rectangle next to the cursor in the colors of the plotted curve.
If the locate the mouse pointer over vertical or horizontal diagram axis and press left mouse button, the mouse cursor changes to ↕ or ↔ . Hold left mouse button pressed and move the mouse, this will scroll through the diagram.
Return to default view using the Zoom Home button.

3.3.2.4 Calculation Results

In this window the result of the calculations are displayed. It can be opened and closed via the menu item "Calculation Results" in the window menu or via the toggle button in the toolbar and closed via the X button in the upper right corner of the child window.

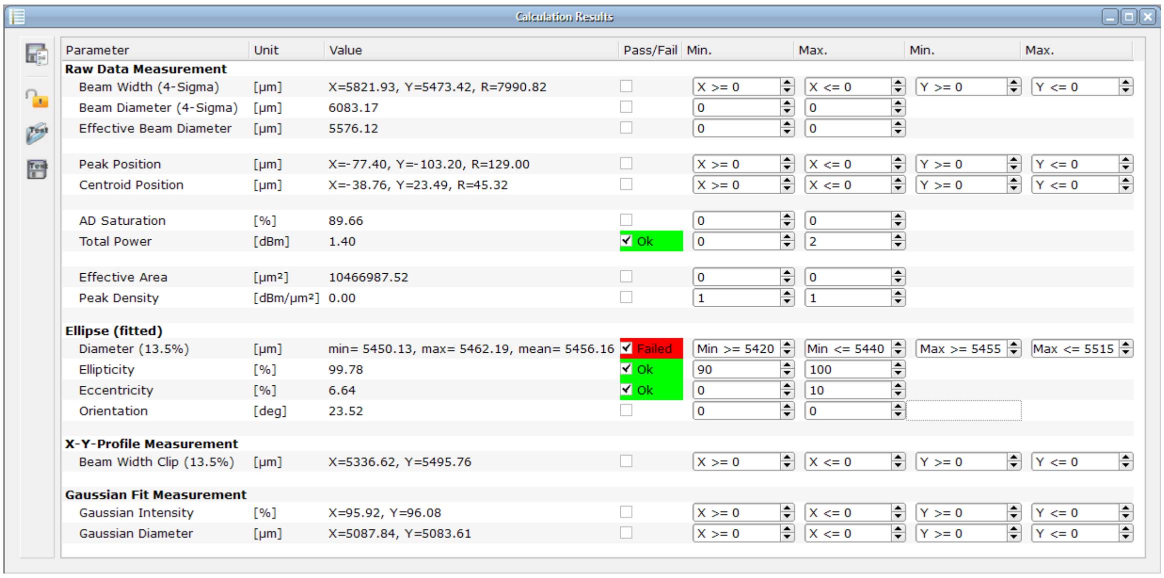
Use the Application Settings 59 dialog to define the output parameters which will be calculated and displayed here. There is also the possibility to change the units for the calculations.



The width of the columns is predefined but can be resized.
All measurement parameters are described in chapter Measurement Results 69.

3.3.2.4.1 Pass/Fail Test

The Calculation Results panel includes a pass/fail test.



For each parameter a minimum and maximum can be set.
Pass/Fail test result will be displayed only for those parameters, where the appropriate box in Pass/Fail column is checked.
The test result status will be displayed beside the check box verbally and by red/ green color.

Note

Please note the following explanations to the parameter
Ellipse (fitted), Diameter (13.5%):
As per definition, the beam ellipse has a minor and a major axis, also known as minimum and maximum ellipse diameter.
For pass/fail testing, for both diameters can be entered an upper and lower margin.
In the given above example, the "pass" ranges are:
- **Min:** minor axis (**Min**. diameter) must be between 5240 and 5440µm
- **Max:** major axis (**Max**. diameter) must be between 5455 and 5515µm
Only if both conditions are fulfilled, the test has been passed.

Toolbar Symbol	Associated Action
	Save diagram (screenshot) or measurement data (TXT, CSV and XLS formats available)
	Lock or unlock the test parameter
	Load the test parameter configuration
	Save the test parameter configuration

Save diagram or measurement data opens a dialog box to enter file properties (name, format, comments)

Lock By default, pass/fail test parameters are unlocked. They can be locked in order to prevent manipulation of margins and parameters included in pass/fail test. Optionally, the lock can be secured by entering a password.

Note

A password can be entered only once and cannot be changed! In case of troubles, please contact Thorlabs 161 for a solution.

Load / Save test parameter configuration

The **Load** and **Save** buttons in the **Calculation Results** toolbar allow to save and load configuration of the pass/fail test.
In order to reconstruct a pass/fail test configuration automatically with the next session, save the parameter to a test parameter configuration file. This file will be loaded with the next start of the application. If there is saved more than one configuration file, the most recently save file will be loaded automatically.
To load test parameter from a file push the "Load Test Parameter" button and select the test parameter configuration file.

3.3.2.5 Plots

Thorlabs Beam software offers several additional plot windows to show the beam behaviour:

Plot Positions
Plot Power
Beam Stability
Plot Gaussian Fit
Plot Orientation

All plot windows are accessible via the "**Windows**" menu, the first 3 child windows have also buttons in the toolbar.
The diagram can be cleared using the "Clear Windows" command (Menu Bar -> Control or button).

Comfortable view functions allow a detailed analysis of the parameter's behaviour over time.

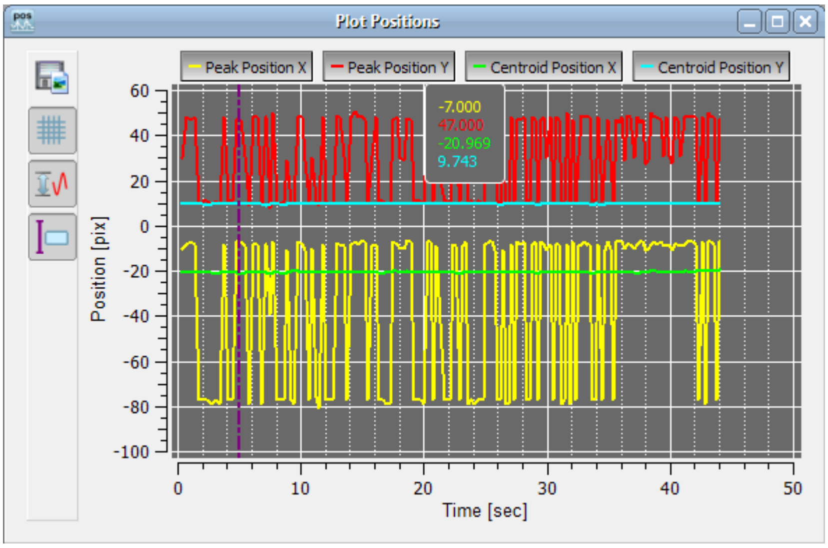
- **Display/hide a certain parameter**: Above the diagrams appropriate buttons are located.
- **Zoom**: hold left mouse button pressed and mark the desired diagram area.
- **Undo zoom**: right click to the diagram - the previous zoom status will be reproduced
- **Scroll**: Move the mouse pointer over time or parameter axis, the mouse pointer changes to ↕ or ↔, hold left mouse button pressed and scroll through the diagram
- **Autoscale**: This button in the left toolbar returns the diagram to default view (auto scaled)

- **Cursor mode**: If the mouse position is near to the vertical cursor line, the mouse cursor changes to ⟛. The cursor line can be moved with the left mouse button pressed to a position inside the diagram. The current values at the cursor position are shown in a rectangle next to the cursor in the colors of the plotted curve.

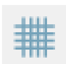
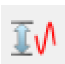
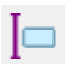
Below the individual plot windows are explained in detail.

3.3.2.5.1 Plot Positions

Toolbar:
Menu bar: Windows -> Plot Positions



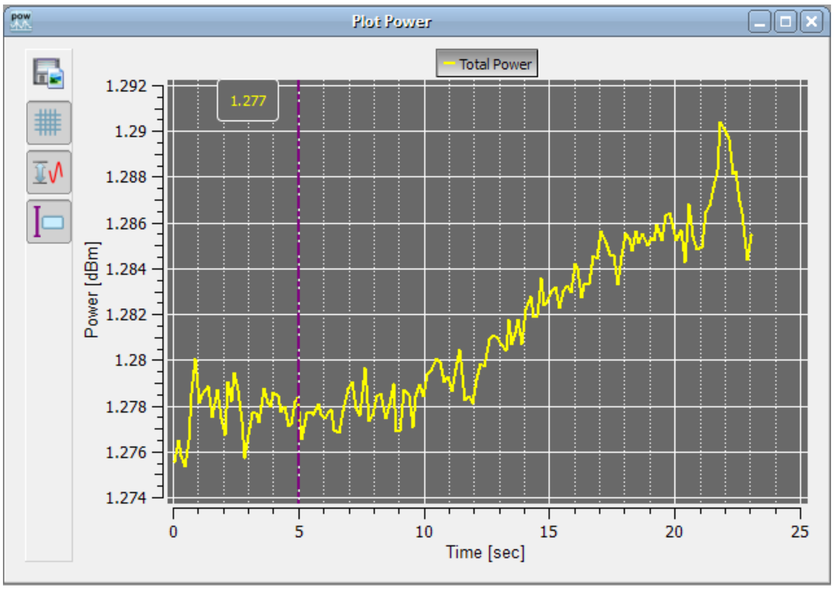
The positions of X and Y peak and of X and Y centroid positions can be displayed vs. time.

Toolbar Icon	Associated Action
	Opens a dialog box to specify the properties of the saved screenshots / diagrams.
	Toggle button to display grid in the diagram.
	Auto scale
	Show or hide the cursor

3.3.2.5.2 Plot Power

Toolbar: 

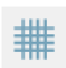
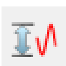
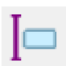
Menu bar: Windows -> Plot Power



The total power measured by the beam profiler vs. time can be displayed.

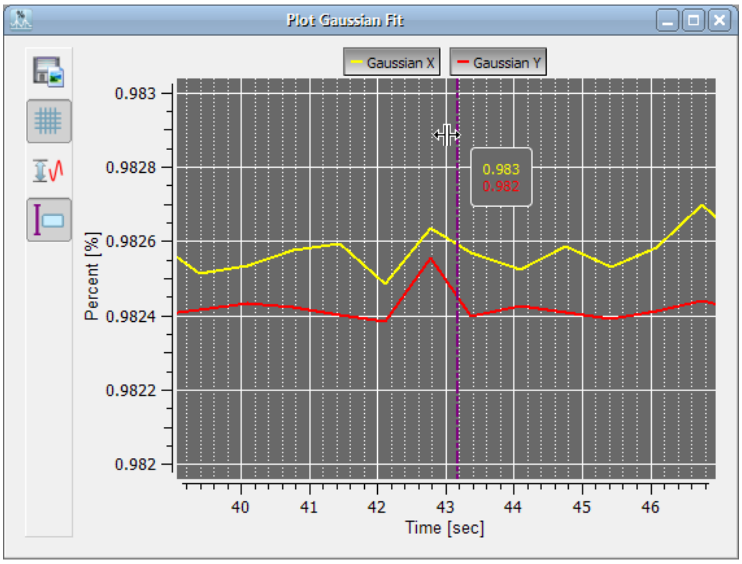
Note

Thorlabs Beam Profiler instruments are not calibrated for power wavelength dependent. The power calculation is based on a typical responsivity curve of the used sensor and manually entered wavelength (see Device settings 50)

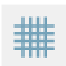
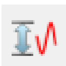
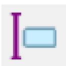
Toolbar Icon	Associated Action
	Opens a dialog box to specify the properties of the saved screenshots / diagrams.
	Toggle button to display grid in the diagram.
	Auto scale
	Show or hide the cursor

3.3.2.5.3 Plot Gaussian Fit

Menu bar: Windows -> Plot Gaussian Fit

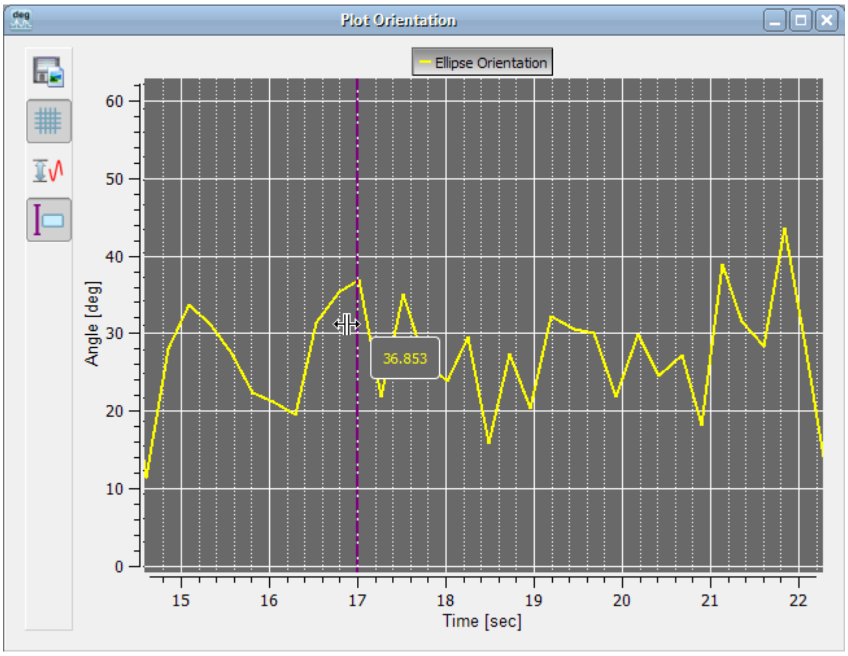


This window plots the Gaussian Intensity value (see Calculation Results 39) which shows the coefficient of determination of the fit.

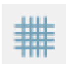
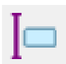
Toolbar Icon	Associated Action
	Opens a dialog box to specify the properties of the saved screenshots / diagrams.
	Toggle button to display grid in the diagram.
	Auto scale
	Show or hide the cursor

3.3.2.5.4 Plot Orientation

Menu bar: Windows -> Plot Orientation

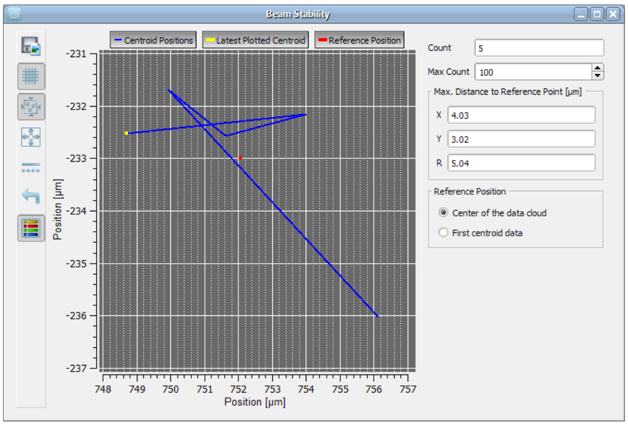


This windows plots the orientation (in degrees) of the ellipse, see Calculation Results 39.

Toolbar Icon	Associated Action
	Opens a dialog box to specify the properties of the saved screenshots / diagrams.
	Toggle button to display grid in the diagram.
	Auto scale
	Show or hide the cursor

3.3.2.5.5 Beam Stability

Toolbar: 
Menu bar: Beam Stability

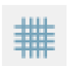
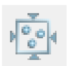
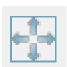


Count: The actual count of displayed measurement results.

Max Count: Max count limits the number of displayed measurement points. If the actual count reached the entered max count value (here: 100), in the diagram will be displayed the recent 100 measurement results, previous results will be deleted.

Max. Distance to Reference: is given in distance (X), distance (Y) and as radial distance (R)

Reference Position The reference point can be set either to the center of the data cloud or the first measured centroid data is the reference.

Toolbar Icon	Associated Action
	Opens a dialog box to specify the properties of the saved screenshots / diagrams.
	Toggle button to display grid in the diagram.
	Scale to all points are located in the diagram area
	Zoom out to see the sensor dimension
	Display results as dots or wired
	Reset Data Counter
	Show / hide legend

3.3.3 Save Settings

The actual settings of the GUI including configurations of the graphical displays and the instrument setup are automatically saved when you exit the program. When starting the Beam software again, the most recent settings are automatically loaded. Exception: Actual zoom settings of 3D graphs, the rotation and translations are not stored. This is to see the full aperture range and full amplitude range on every start of the GUI.

Note

The stop state of the previous measurement will be ignored at a new start of the Beam software because it always starts in continuous mode.

3.4 Measurement with the Beam Profiler

General guidelines for operating the Camera Beam Profiler BC106

You should follow these basic guidelines to achieve correct and reliable measurement results.

1. Provide stable Mounting 8 to the Beam Profiler using the appropriated threads on its base plate.
2. Ensure to operate the instrument within the allowed Power Range 75 of the instrument.
3. Choose a neutral density (ND) filter out of the Filter wheel 9 which is suited for the operating wavelength (UV / VIS) of your light source.
4. Select a filter attenuation which is adapted to the applied laser power.
5. Align the beam to be measured perpendicular to the front face of the BC106 Camera Beam Profiler.
6. Minimize ambient light entering the Beam Profiler aperture, use a high loss ND filter for its attenuation.
7. Perform a Ambient Light Correction 66 in case of weak light sources compared to the ambient power level.

Attention

Do not stick anything into the Beam Profiler aperture, you may damage the windowless image sensor chip!
Prevent dust or other contaminations from entering the aperture!
Keep beam power below the allowed limit, otherwise you may damage the instrument!

For accurate power measurements you should:

1. Enter the correct operating wavelength.
2. Enter the chosen ND filter loss.
3. Perform a User Power Calibration 65 to achieve best power accuracy.

Performance Optimization

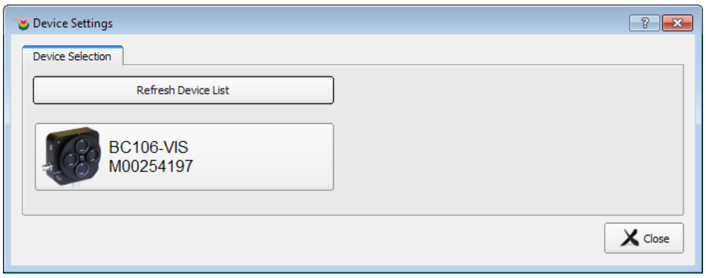
As soon as a BC106 device is selected within the 'Device Selection' panel the measurement starts in the continuous mode. It may be advantageous to stop the continuous measurement for a detailed analysis of a beam profile captured with the last camera image. Also, user interactions with the GUI will work more fluently when the continuous flow of image data is stopped.

Measurement speed of the Camera Beam Profiler is depending on various device settings like Fast/Precision mode, image resolution (ROI) and the selected exposure time. Also the number of open child windows used to visualize the measured results and the number of activated numerical parameters to be calculated may reduce the available measurement speed, depending on the performance of your PC.

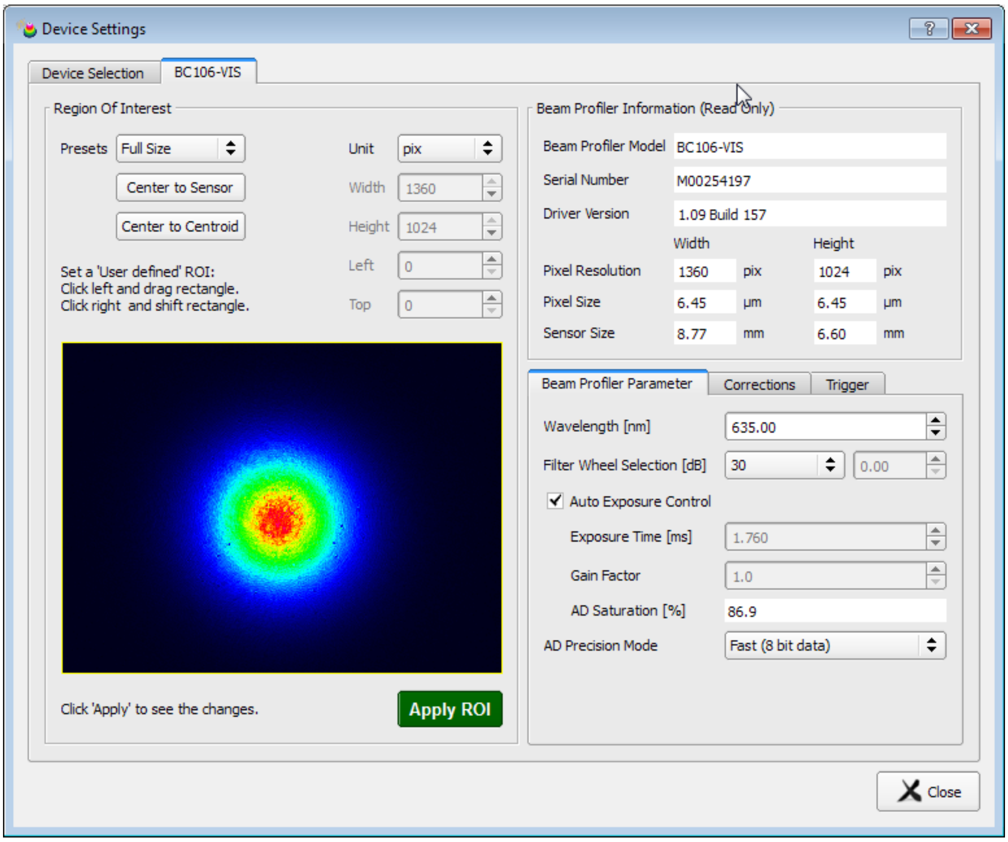
3.4.1 Operating the Instrument

Be sure that the Camera Beam Profiler is connected to the PC and the driver is installed properly as described in chapter Connection to the PC 23. During initial program start a Device Selection panel will be displayed.

On tab "**Device Selection**" mark the instrument "BC106-UV" or "BC106-VIS" within the device list you want to work with. Use the device type (UV/VIS) as well as the Serial Number for device identification.

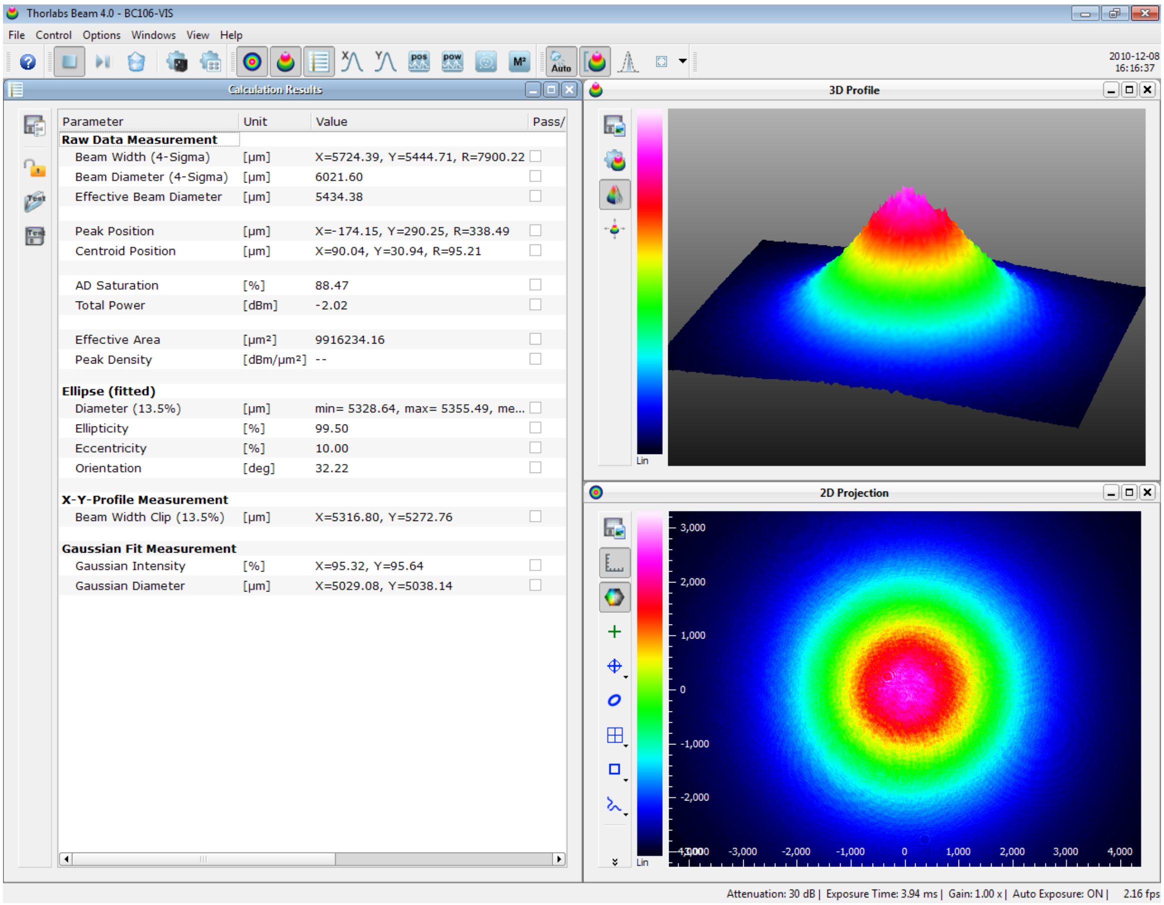


See chapter "Start the Application 24" for a detailed description of the further device options.
After selecting the instrument, the tab **BC106-xxx** is displayed.



Make sure, the correct **Wavelength** is entered, and click "Close" to work immediately with the selected instrument. For details on Beam Profiler Settings, please see section Device Settings 50.
After clicking "Close" the measurement starts immediately in continuous mode. If the

application is started the first time, three child windows are opened and arranged automatically. The user can open and close child windows via the entries in the menu "Window" or via the symbols in the toolbar of the main window.

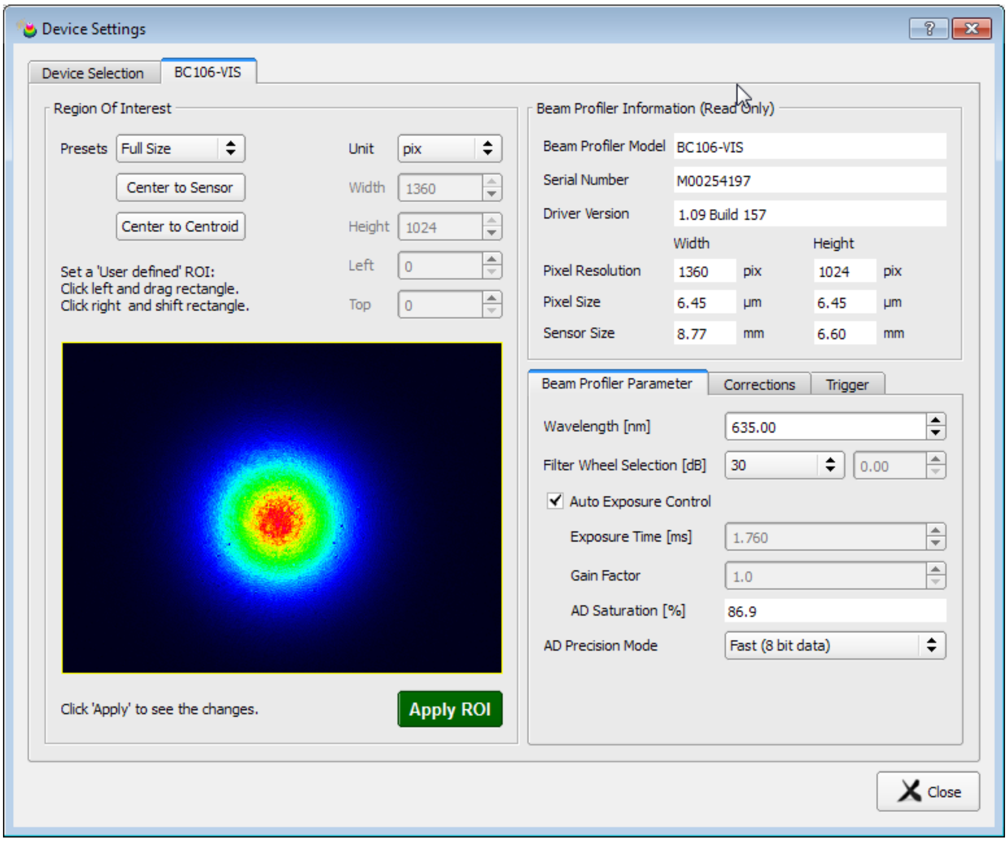


Window 2D projection 33 shows the measured intensity distribution across the sensor area in gray or color scale whereas the 3D Profile 36 is obtained by converting beam intensity into the 3rd dimension (Z scale). Numerical calculation results are displayed in the appropriate Calculation Results 39 window. The number of calculated parameters can be controlled in the Application Settings 59 panel. All contents of the child windows including available options are explained in chapter Child Windows 31.

3.4.2 Device Settings

Prior to take proper measurements with the BC106 Camera Beam Profiler some instrument settings should be checked to fit your measurement application.

Open 'Options' → 'Device Settings ...' from the Menu or click on  within the toolbar to open the Device Settings Panel. Select the right tab 'BC106-xxx'.



1. On the lower left side you will see a **preview image** of the camera. In case your laser beam is much smaller than the available sensor area simply drag a rectangle into the preview area in order to define a **Region of Interest (ROI)**. The Beam Profiler camera will transmit then only this selected area.

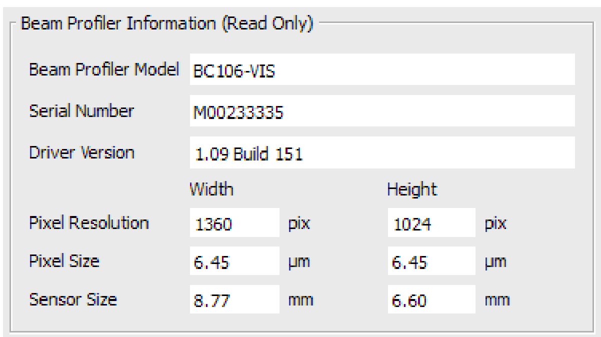
2. In the upper right corner enter the correct **wavelength** of the laser beam and the attenuation of the selected ND filter within the Filter Wheel 9 (the nominal attenuation value is written on the filter holder).

3. If this camera is connected the first time, the following default values are set for the camera parameters:

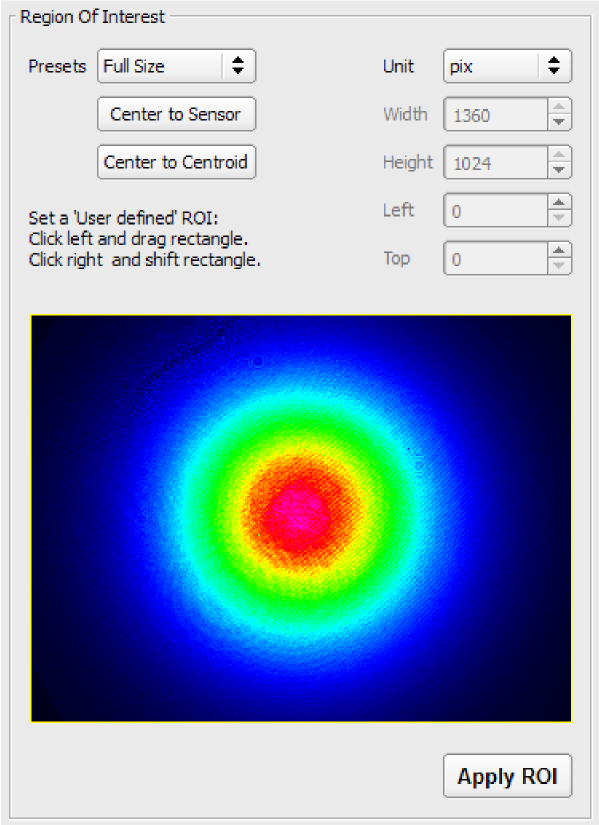
Parameter	Default value
Region Of Interest	Full Size
Tab Beam Profiler Parameter	
Wavelength	635nm
Filter Wheel Selection [dB]	No Filter (0 dB)
Auto Exposure Control	ON
Gain	1.0 (minimum)
AD Precision mode	FAST (8 bit data)
Tab Corrections	
Hot Pixel Correction	ON
Power Correction	OFF, factory calibration active
Ambient Light Correction	OFF
Tab Trigger	
No Trigger	ON
Software Trigger	OFF, 50% min AD saturation
Hardware Trigger	OFF, Rising Edge
Single Pulse	100ms Target Delay
Repetitive Pulses	1.000kHz Rep. Rate

These values are chosen to enable proper conditions for most applications. Below is a detailed description of all settings and additional features.
This panel contains a number of important camera settings which are accessible to the user. Please become familiar with the meaning of these controls in order to prevent improper adjustments which may lead to erroneous measurement results. All visible controls explained below:

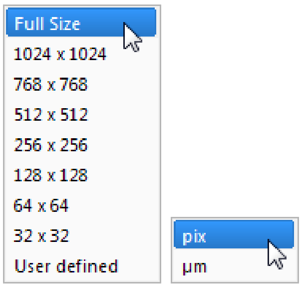
Beam Profiler Information (Read Only)
These data are read out from the BC106 instrument and cannot be changed.
Beside general information (Beam Profiler model, serial number and driver version), other important sensor information are stated:
- max. camera resolution of the Region of Interest (ROI) in pixels
- pixel size
- max. available physical sensor size.



Region of Interest (ROI)
The ROI defines a subarea within the maximum available camera sensor surface, whereas the maximum ROI is 1360 x 1024 (full size) and the smallest 32 x 32 pixel. Only image data of the selected ROI are transmitted from the Camera Beam Profiler to the PC so that a narrowed ROI size reduces bandwidth requirements and therefore increases measurement speed (frames per second, fps)



There are some predefined ROIs which can be selected by clicking to the appropriate control entry.



By selecting a predefined ROI it is automatically centered to the sensor center. See the **preview image** for visualizing the adjusted size which is displayed as a yellow rectangle. To shift the selected ROI within the available sensor area click right into this rectangle and drag the mouse.

You may also chose a user defined ROI. Just draw a rectangle into the preview image by clicking left while dragging the mouse from the upper left corner to the lower right corner. The last preset value is replaced automatically by "**User defined**" and the chosen ROI size and position is displayed within the controls on the right. These values can also be modified by entering the desired Width, Height, Left and Top values into the appropriate controls. Its unit can be switched between pixels or mm.

Note

The ROI point of origin (0,0) is located in the upper left corner of the entire sensor area so that 'Left' and 'Top' describe the upper left ROI borders with respect to this corner.
In contrast to that, measurement coordinates X and Y are defined with respect to the center of the ROI, see below.

Click **'Center'** for centering the actual chosen ROI with respect to the entire image area.

Correct ROI adjustment

In case the measured beam is considerably smaller than the Camera Beam Profiler aperture it is advisable to limit the area captured by the camera. Reduce the image area by determining a ROI so that it is filled well.
However, it's not recommended to narrow ROI too much - lower intensity areas surrounding the laser beam will be cut off! This may lead to incorrect numerical results (for instance Beam Centroid position) or even prevent calculation of the beam width because the selected clip level (default 13.5% of the peak intensity) is not reached within the ROI.
When the beam under test does not fit to the selected ROI area, you need to increase field of viewing by enlarging the ROI. The ROI height and width should be at least two times the beam width.

Note

The Beam Profiler's point of origin (X = 0, Y = 0) is always fixed to the center of the entire sensor area so that X and Y coordinates have a bipolar range. Shifting the ROI off-center will maintain the calculated beam position because this data is bound to the entire sensor area and not to the relative ROI coordinates.

Tab Beam Profiler Parameter

On the right side of the BC106 device settings tab are listed some important controls for the Beam Profiler operation. Please take care about the essential for your application settings.

Wavelength

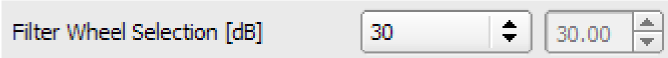
Enter your operating wavelength in nm as a precondition for proper measurement of the Total Power. It enables consideration of the known response curve stored within the Beam Profiler instrument. No other result than Total Power is influenced by this setting.

The available range is limited to 190 - 350 nm for BC106-UV and 350 - 1100 nm for

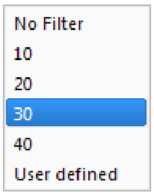
BC106-VIS, respectively.

Filter wheel selection

There are in total 4 different neutral density (ND) filters available by rotating the filter wheel in front of the Beam Profiler aperture. See chapter Filter Wheel 9 for details.
You need to enter the **nominal attenuation** of the chosen ND filter in order to be recognized for calculating the Total Power.



Select the filter in operation from the pull down list.



Select **'No Filter'** in case you have removed the filter in front of the entrance aperture so that no attenuation (0 dB) is present. In case you are using external attenuation filters or beam splitters select **'User Filter'** and enter its attenuation value into the control on the right.
Only values between 0 and 100dB can be entered.

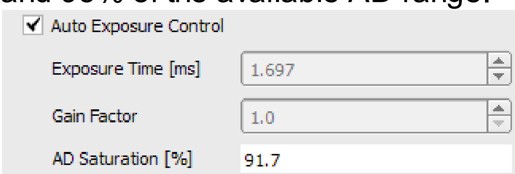
Note

The correct selection of this attenuation value is a precondition for a proper power measurement and function of Ambient Light Correction.

Exposure Control

Auto Exposure Control

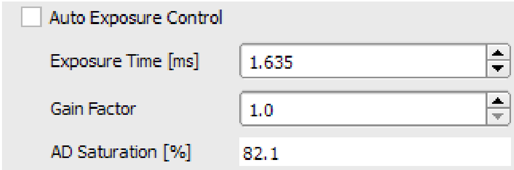
The exposure control of the Beam Profiler camera include adjustments for Exposure Time and electrical Gain. Both settings determine the sensitivity of the camera and need to be adapted to the actual beam power in order to ensure a nearly full scale amplitude measured by the camera's AD converter.
By default, both settings are automatically controlled in order to achieve an Image Saturation between 80 and 95% of the available AD range.



It is highly recommended to use this automatic exposure control by enabling the 'Auto Exposure Control' checkbox. If activated, the Beam Profiler software will automatically adapt both, the exposure time and the additional gain in an optimal manner. Both controls become gray and will only display the actually chosen parameters. The Target is to keep the brightest pixel of the selected ROI at a high saturation level but prevent saturation (100%) due to the limited range of the AD converter digitizing the image.
However, in case of unstable or pulsed laser power it might be advantageous or

even required to disable the automatic exposure control and set the optimal values manually. For this, remove the 'Auto Exposure Control' check mark.

Manual Exposure Control



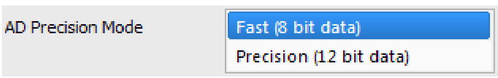
Exposure time is the period of time in which the global shutter is open and the image sensor is exposed. For CW sources there is a linear dependency between exposure time and mean image brightness. Increase the exposure time to increase brightness and vice versa.
Exposure time ranges from 0.020 ms to 1000 ms with a step width of 0.063 ms whereas lowest exposure times 20µs, 43µs, 74µs, 136µs, ... are separated by smaller steps.
Use the up and down arrows in order to increase and decrease the exposure time stepwise, respectively. Step size is automatically adapted to the actual value so that a change of about 20% is achieved. To enter a certain value just overwrite the present one.

Gain Factor denotes the linear amplification factor of the electrical amplifier between the CCD sensor and the AD converter. Higher gain increase image brightness but also image noise. Therefore, it is highly recommended to mainly use the exposure time control for brightness adjustments.
Gain settings higher than 1.0 should be used only when

- Exposure time is already set to its maximum value or
- Exposure time below 1 ms is set and fine gain adjustment is helpful to fill the gap in brightness between two successive exposure times.

AD Saturation
AD (Analog-to-Digital Converter) saturation is related to the intensity of the brightest pixel within an image and is given in % of the available range between the dark level and saturation of the AD converter at its full scale value. It is recommended to keep the Image Saturation at a high level in order to use the full resolution of the AD converter (4095 digits for 12 bit, 255 digits for 8 bit image data). The actual image saturation level is displayed as a numerical value. A value between 80% and 95% is recommended.

AD Precision Mode
AD Precision Mode controls the number of bits used for digitization of each single camera pixel.



	Fast Mode	Precision Mode
Used ADC resolution	8 bit	12 bit
Available Digits	0 - 255	0 - 4095
Quantization noise	medium	low
Achievable frame rate	maximum	reduced

By default, Fast Mode is selected in order to enable a maximum frame rate. For low-noise and highly accurate measurement results it is required to switch to Precision Mode.

Tab Corrections

Power Correction

This Power Correction is provided to align the total beam power measured by the Beam Profiler to the power level measured by a reference power meter. After this calibration the Beam Profiler can be used as a power meter which is reading correct values.
Click 'Start' to perform this power correction.

See chapter User Power Calibration 65 for detailed instructions.

Hot Pixel Correction

Hot pixels appear as an unwanted property of CCD sensors and are due to different charge leakage rates between individual pixels. Hot pixels appear as points of high intensity particularly at long exposure time and their intensity depends on temperature as well.
See chapter Hot Pixel Correction 67 for detailed instructions

Ambient Light Correction

It is highly recommended to shield ambient light from entering the entrance aperture best possible because it cannot be distinguished from beam power. Accordingly, an offset level will add up to the measured beam profile which leads to inaccurate beam parameters. Therefore, this correction of the remaining ambient light level is provided and should be carried out in case of measurable ambient light level (far-off wings of the X Y profiles do not go down to zero intensity level).
Click 'Start' to perform this ambient light correction.

See chapter Ambient Light Correction 66 for detailed instructions.

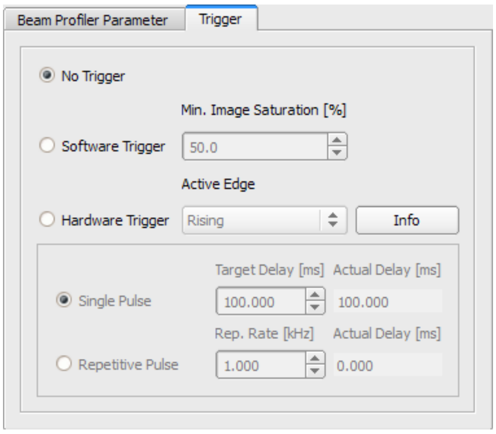
Camera's Dark Level

It was not necessary to provide means for proper dark or black level adjustment because the camera itself is equipped with an automatic black level compensation which works perfectly and ensures that zero beam intensity is measured without parasitic offsets yielding to zero measured intensity. Therefore a manual or automated black level adjustment is dispensable.
Since an increased sensor's dark level would have the same effect like uniformly distributed ambient light, the provided ambient light correction (see above) will also

eliminate a remaining dark level.

Trigger

The electrical TTL level trigger input is used to synchronize laser pulses to the camera exposure time. See chapter Pulsed Laser Sources 76 for a detailed description of the implemented trigger functionality.



By default 'No Trigger' is chosen for continous caption of CW light sources.

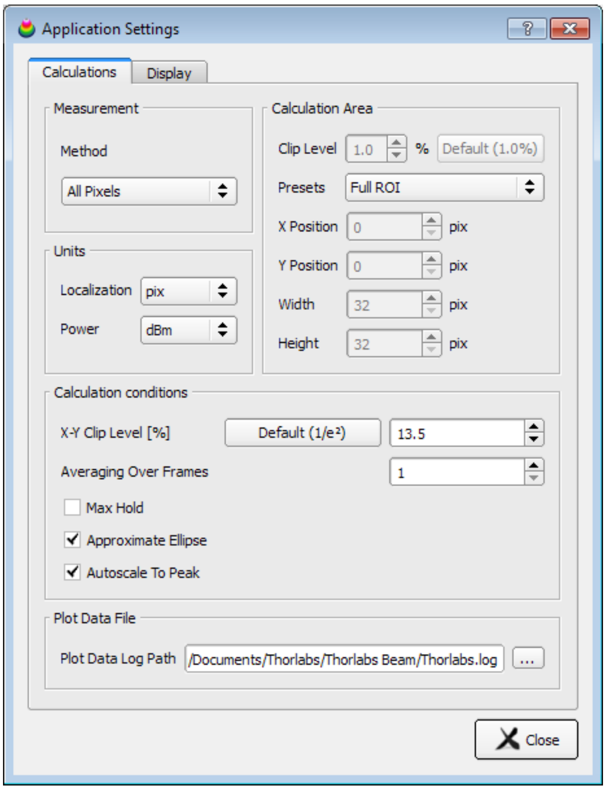
3.4.3 Application Settings

Separated from the Device Settings 50 these Application Settings are concerned to calculation and graphical presentation options.

Open 'Options' → 'Application Settings ...' from the Menu or click on in the toolbar to open the Applications Settings Panel. Select the left tab 'Calculations'.

Calculations Settings

Select tab 'Calculations' to display options influencing the numerical calculations.



Measurement Method

Switch between the normal mode where all calculations are calculated with every single pixel ("All Pixels") or the slit emulation mode ("Slit Emulation") where some calculation results (e.g. Beam Width with clip level and the Gaussian fit) depend on the row and column sum.

Calculation Area

Calculation Area defines a rectangular area within the already selected Region of Interest (ROI), see Instrument Settings 50. Whereas the ROI determines the image area that is retrieved from the camera and displayed, the Calculation Area can be equal to or smaller than the ROI and defines the image area used for all numerical calculations. That is, pixels inside the ROI, but outside the Calculation Area are displayed but not used for calculations!

Such a limitation is especially advantageous for:

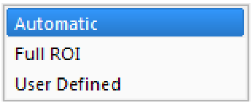
- Selecting and analyzing only a single beam spot among multiple beams
- Rejecting ambient or stray light

- Reducing measurement noise
- Increasing performance

Note

It is advisable to set the camera ROI to the smallest feasible area instead of working with a large ROI and shrinking the Calculation Area afterwards. This will increase measurement speed.

Three Presets are provided to chose a Calculation Area.

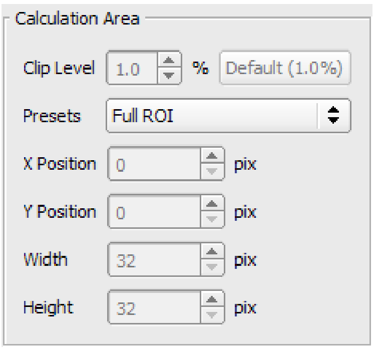


Automatic: The software will analyze every image from the camera automatically and determine the area in which a measurable amount of power is present. Areas with a lower power level than the clip level with will be excluded from further calculations. The clip level can be set up in the Application Settings.

Full ROI: The entire image area defined by the ROI is involved into beam calculations.

User defined: A rectangular area set by user input is defined as Calculation Area. Enter pixel values which describe the Calculation Area position and size or simply drag a rectangular area into the 2D Projection window.

When 'User defined' is selected you need to enter size and position of the Calculation Area numerically. All values are in pixels, whereas the point of origin is situated here in the upper left corner of the entire sensor area. *X Position* describes the left border and *Y Position* the upper border position.



The Calculation Area can also be set and visualized within the 2D_Projection 33 window. See the appropriate chapter for details.

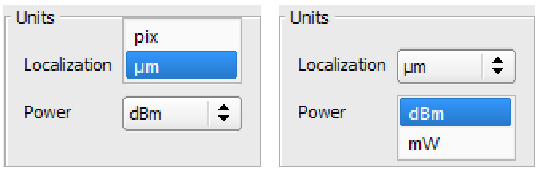
Attention

The calculation area must not cut off lower intensity parts of the beam profile. This may cause improper calculation results!

Note
When the ROI size or position is changed and the Calculation Area was not set to 'Automatic' and does not fit into the new ROI, the Calculation Area will be reset to 'Full Size', by other words, to the new ROI.

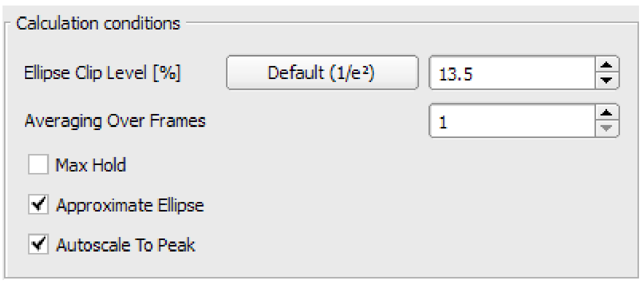
Clip Level of Calculation Area
The borders of the Calculation Area in all four directions are defined by the Clip Level. The border in one direction is set when all pixel values fall (seen from the peak) below the Clip Level. Decreasing the Clip Level increases the Calculation Area which in return increases for example the 4-Sigma diameters, but also increases the noise. For a steep beam profile, 1.0% are an optimal clip level value. If the beam profile is rather flat, it might be advantageous to lower the clip level.
The calculation area's clip level can be set between 0.1 and 13.5%.
In order to quickly return to the recommended 1.0% clip level, just click to the box *Default (1.0%)*.

Units
On the right the units for all calculation results expressing a location, distance or width can be chosen to either **pixel or µm**. The unit of Total Power result can be displayed either in **mW or dBm**.



Note that the power result depends also on the wavelength setting, the selected attenuation of the ND filter and a power correction value calculated during the power correction. See chapter User Power Calibration 65 for details.

Calculation Conditions



The **Ellipse Clip Level** defines a relative intensity level between dark level (0%) and peak level (100%) of the measured beam profile used to measure the beam width, the default value $1/e^2$ =13.5% of the peak intensity is recommended by ISO11146. You may define other clip levels by entering the appropriate value in %.
Input values are valid from 5% to 95%. Click on *Default (1/e²)* to set the default Clip Level of 13.5%. See Appendix Application Note 137 for details.

Set **Averaging over frames** to numbers higher than 1 to enable noise reduction.

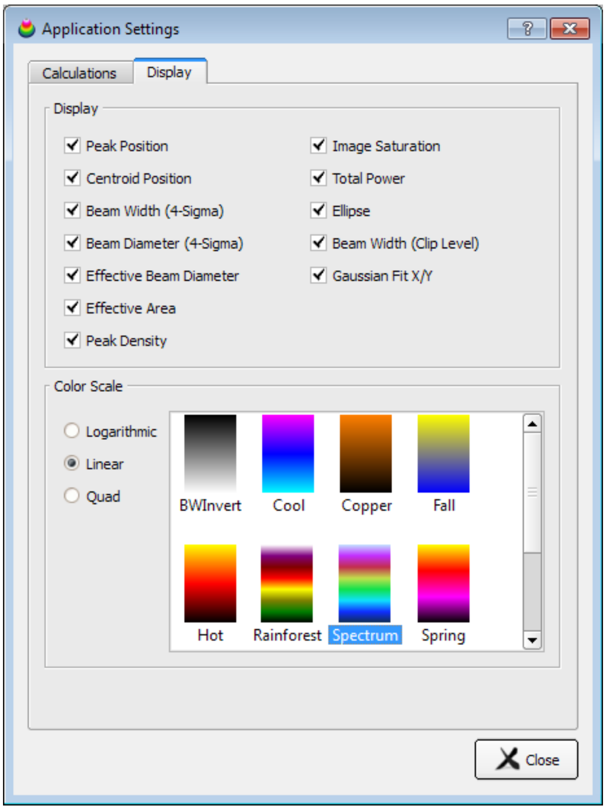
The chosen number of frames are averaged and only the averaged frame is displayed and calculations are applied to it.
This option is helpful under instable light sources with fluctuating intensity or beam shape and if the update rate on the screen is too high for easy data readout. Also use this option to suppress Beam Profiler camera noise in case of low intensity. Average numbers between 1 and 25 frames are valid.

The **Max Hold** feature is recommended for pulsed laser sources. In all subsequent scans for each pixel only the maximum values are stored, displayed and used for calculation.

Enable the **Approximate Ellipse** checkbox in order to get the best fitted beam ellipse.
This setting provides more stable and reliable ellipse results. Otherwise, ellipse data are retrieved from single minimum and maximum diameters of the elliptical beam cross section. These results are more noisy and therefore less reliable than the fitted results.

Enable the '**Autoscale To Peak'** checkbox to scale the x-y-profiles to the peak of the selected row / column.
Unchecking the checkbox will scale the x-y-profiles to the maximal possible intensity of a pixel.

Display Settings
Select tab **Display,** check or uncheck beam parameters that shall be displayed within the 'Calculation Results' window, see Measurement Results 69
In the lower part a number of different styles for **2D** and **3D Display** is listed for selection.



There are 3 different color scale types available:
- Logarithmic is recommended to view lower intensity values with a good resolution
- Linear
- Quad offers a better resolution for higher intensity values.

User-made Color Scales

If a certain color scale is required it is possible to create an own color scale which can be loaded automatically by starting the application. To do so a few things have to considered.

The application loads valid *.lut files from the folder
...\My Documents\Thorlabs\Thorlabs Beam\LUT

A valid *.lut file is an ordinary text file with nine columns and 256 rows. Values have to be tab-separated. The first three columns have 256 entries, the last six columns only 128. Each value represents a 8 bit intensity (0- 255) of R(ed), G(reen) and B (lue), respectively.

The first three column represent the linear scale of a user-made color scale, the next three columns the logarithmic scale and the last three columns the quadric scale.

Such a color scale could look like this (ignore the first two rows):

linear scale			logarithmic scale			quadric scale		
R	**G**	**B**	**R**	**G**	**B**	**R**	**G**	**B**
0	255	0	0	255	0	0	255	0
1	255	0	1	255	0	3	255	0

2	255	0	2	255	0	10	255	0
...	...	...	...	...	...	...	...	...
127	255	0	255	255	0	255	255	0
128	255	0						
129	255	0						
...	...	...						
255	255	0						

... stands for the intermediary values.

3.4.4 Power Correction

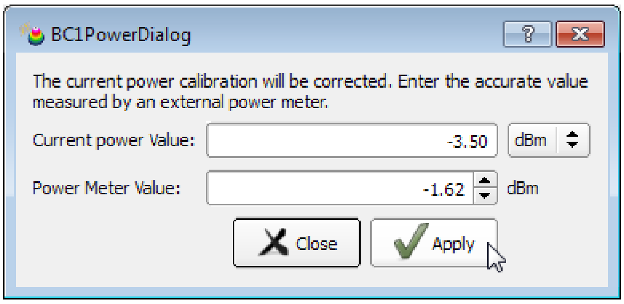
The Power Meter Correction is used to align the total beam power measured by the Beam Profiler to a known power level measured by a reference power meter.

Open 'Options' → 'Device Settings ...' from the Menu or click on within the toolbar to open the Device Settings Panel. Select the right tab 'BC106 Settings'.

Preconditions:
Be sure to have set the following settings accurately within the Beam Profiler software:

- Operating wavelength
- Nominal loss of the selected ND filter

Click 'Start Correction' and the BC1 Power Dialog panel will appear.

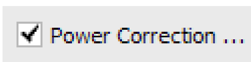


It displays the 'Current power value' measured by the Beam Profiler and you need to input the correct value into the 'Power meter value' control. Click 'Apply' and both values will coincide. To manage this, an internal power correction offset is calculated and recognized within each Total Power calculation. This offset (in dBm) is stored within the Beam Profiler and will be read out and activated automatically each time after connecting the instrument. Click 'Close' to leave the panel.

Note

The user calibrated power reading will loose accuracy when going to another wavelength or changing the selected ND filter so that a recalibration may be required in these cases.

An activated Power Correction is indicated by the check mark and can be deactivated by removing the mark.



When such a Power Correction was performed once successfully the appropriate calibration value is stored within the Beam Profiler instrument so that the check mark will become active as soon as the instrument is initialized new.

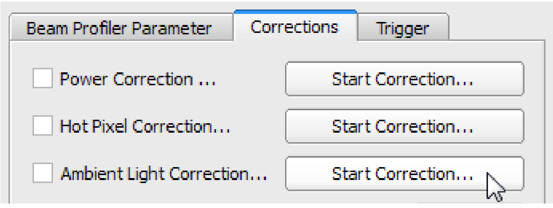
3.4.5 Ambient Light Correction

In general, it is highly recommended to shield ambient light from entering the entrance aperture and use the supplied ND attenuation filters.
However, a considerably high ambient light level may occur within the camera image. In such case, the interfering ambient light can be compensated.

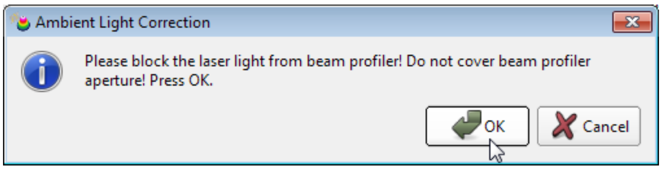
Note

It is recommended to proceed with the ambient light correction after a 30min warm-up time and repeat it if needed (e.g., ambient light conditions changed).

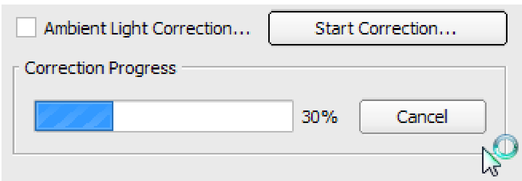
Open 'Options' → 'Device Settings ...' from the Menu or click on  within the toolbar to open the Device Settings Panel. Select the right tab 'BC106 Settings' and there the tab "Corrections"

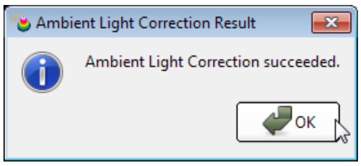


Click "Start Correction", a dialog opens:



Make sure the laser is blocked, but not the ambient light, click "OK"; the correction starts.





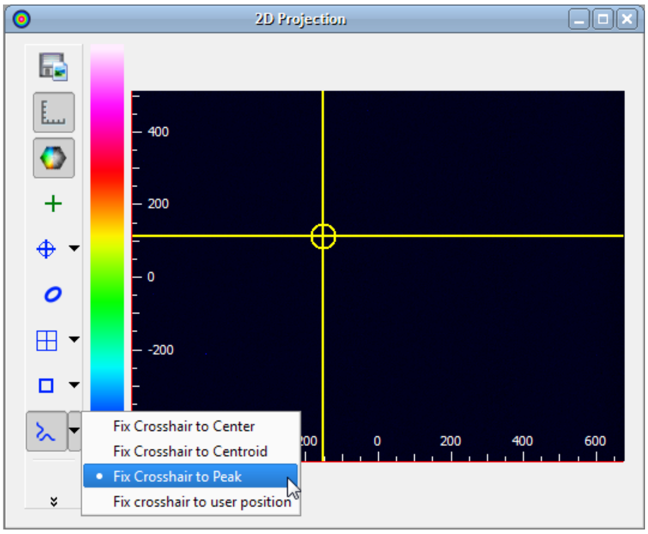
Note

- Thorlabs Beam software uses a unique approach for Ambient Light Correction - please see details in section Application Notes 137.
- When ambient light power is changed or a different ND filter is used, a new correction is required, otherwise beam profiles are displayed using an unreal (positive or negative) offset and accuracy of measurement data can be highly reduced.
- Any software restart, reconnect of a camera beam profiler or change of the ND filter settings in the software disables ambient light correction.

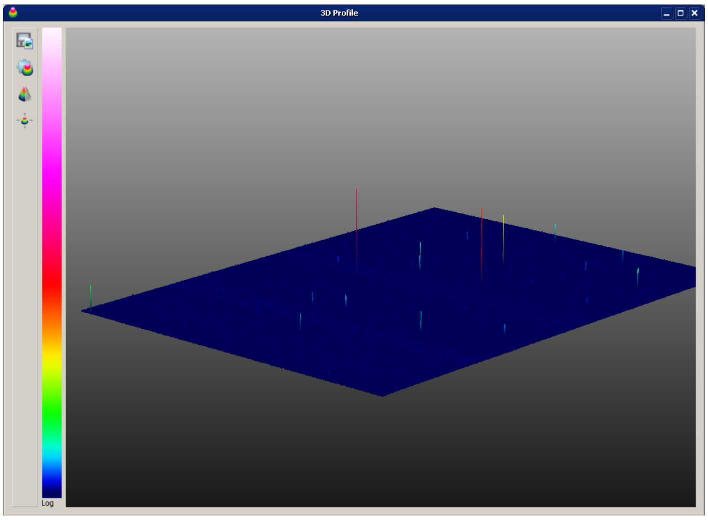
3.4.6 Hot Pixel Correction

Hot pixels appear as an unwanted property of CCD sensors and are due to different charge leakage rates between individual pixels. They appear as points of high intensity particularly at long exposure time and their intensity depends on temperature as well.
Hot pixel may cause measurement errors, particularly in 4σ measurements, which is important for M² beam quality measurements and may impact the baseline definition during ambient light correction.

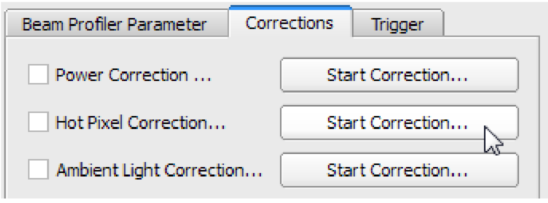
Hot pixels can be displayed in the software, using 2D projection and fixing the crosshair to peak. Darken the aperture and set exposure control to Auto. The crosshair will go to the hot pixel with the highest intensity:

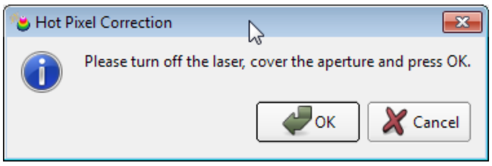


Hot pixels can be displayed in 3D view (auto scale to peak disabled), either:

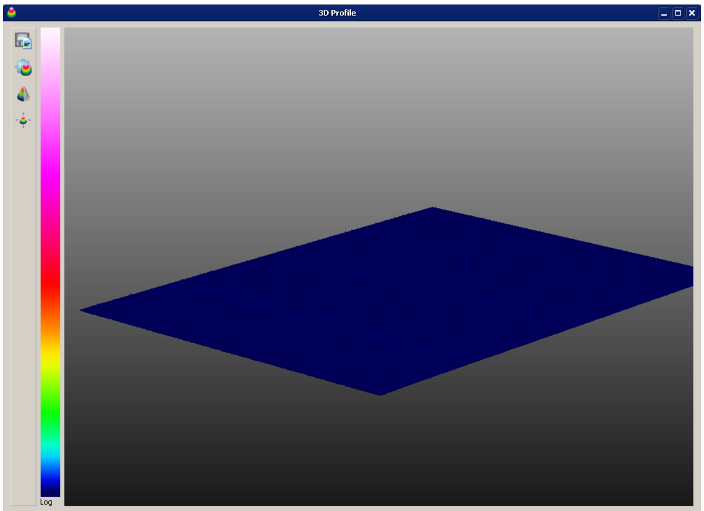


Thorlabs Beam offers a hot pixel correction feature. Start the Device settings from Menu "Options" or from the appropriate icon. From the right tab choose Corrections and start hot pixel correction by clicking the Start Correction button:



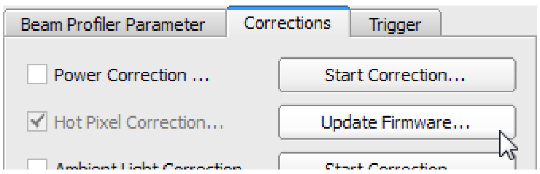


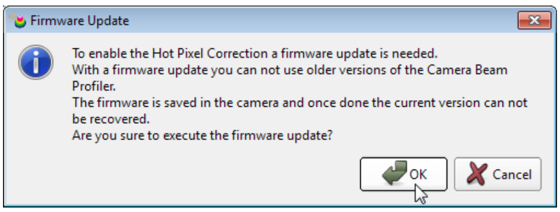
The correction starts; hot pixels are being smoothed by interpolation to adjacent pixels and a maximum of 100 hot pixel can be saved.
After completing, the box "Hot Pixel Correction" will be checked.
Hot pixel correction data are saved to the camera's internal non-volatile memory and remain there unless overwritten with the next hot pixel correction.
Below is the 3D projection of the same camera as above, but after correction - indeed, no hot pixels can be seen anymore.



Note

- Hot pixel correction is possible only if your BC100 firmware is of V13.20 up. In case your device firmware is older, hot pixel correction is disabled and you are offered to update the firmware.

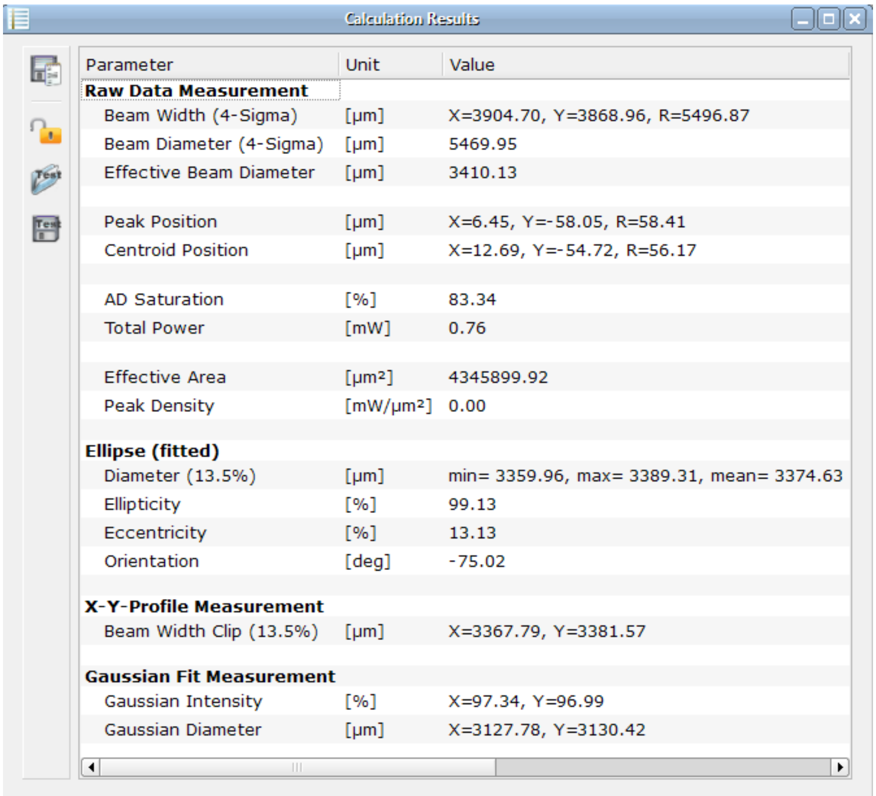




After confirming, the firmware update is executed and you can start the correction.
- Note that with firmware V13.20 and later Camera Beam Profiler software versions V3.1 and older cannot be used anymore.

3.4.7 Measurement Results

The results of the Camera Beam Profiler measurements are displayed in the Calculation Results window.


Calculation Results

Parameter	Unit	Value
Raw Data Measurement		
Beam Width (4-Sigma)	[µm]	X=3904.70, Y=3868.96, R=5496.87
Beam Diameter (4-Sigma)	[µm]	5469.95
Effective Beam Diameter	[µm]	3410.13
Peak Position	[µm]	X=6.45, Y=-58.05, R=58.41
Centroid Position	[µm]	X=12.69, Y=-54.72, R=56.17
AD Saturation	[%]	83.34
Total Power	[mW]	0.76
Effective Area	[µm²]	4345899.92
Peak Density	[mW/µm²]	0.00
Ellipse (fitted)		
Diameter (13.5%)	[µm]	min= 3359.96, max= 3389.31, mean= 3374.63
Ellipticity	[%]	99.13
Eccentricity	[%]	13.13
Orientation	[deg]	-75.02
X-Y-Profile Measurement		
Beam Width Clip (13.5%)	[µm]	X=3367.79, Y=3381.57
Gaussian Fit Measurement		
Gaussian Intensity	[%]	X=97.34, Y=96.99
Gaussian Diameter	[µm]	X=3127.78, Y=3130.42

All available Calculation Parameters are inserted into this table with the first start of the Camera Beam Profiler. To reduce the number parameters, uncheck the parameter in the Application Settings 59. This will also increase speed performance.

Note

- If the "Gaussian Fit" calculation is disabled for display within this results panel, the appropriated fit curves are still shown in the X,Y Profile windows, if enabled there.
- Centroid Position:This parameter is very sensitive to ambient light which may shift the calculated centroid! See Ambient Light Correction 66.

The units of the calculations are divided into 3 categories:

- Location: units pix and µm are available
- Quantization: digit, mW or dBm are available
- Units specified for the calculation (e.g. Gaussian fit is always in per cent, degree for angles)
  Change the units in the appropriate Application Settings 59.

Overview on all available units:

Unit	Description
pix	Location, width or distance in camera pixels. The origin of the coordinate system (X=0, Y=0) is the sensor center not the image center!. Positive X values go to the right, positive Y values to the top of the image.
µm	Location, width or distance in µm, calculated from the camera pixels. 1 pixel = 6.45 µm The origin of the coordinate system (X=0, Y=0) is the sensor center not the image center! Positive X values go to the right, positive Y values to the top of the image.
mW	The Total Power of the beam is calculated from the integral intensity of the image using the wavelength dependent sensor response, the Exposure Time and Gain of the camera as well as the filter attenuation and the power correction value.
dBm	The Total Power translated from mW into dBm: 10 * log(P/mW)
%	Relative level between 0 and 100%
deg	Angle in degree with respect to the X axis, range -90 to +90 deg

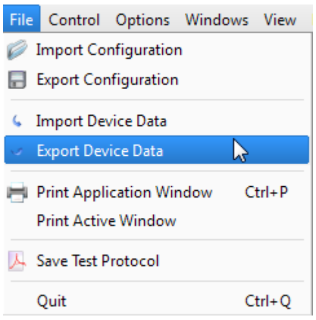
If a calculation failed the value turns to "--".
The columns can be resized by moving the column separators.

For details on these parameters, please see section "Application Note 137"

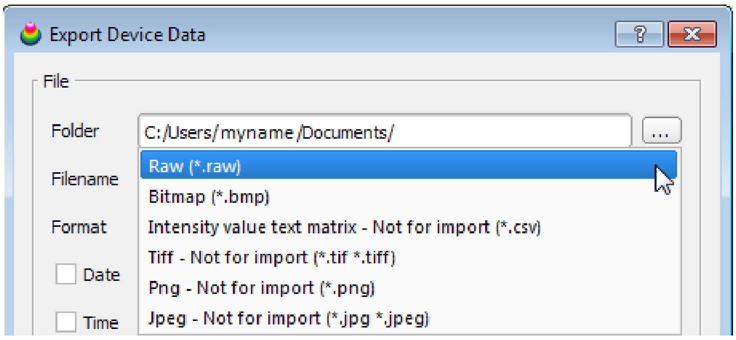
3.4.8 Save Measurement Results

1. Data Export

To export the data into a delimiter separated text document or into an excel sheet select **'File→Export Data ...'** from the Menu.



A dialog opens and asks for the type of file and the path where to save the file.



Select the desired path and file name and choose the export format.

Raw is the true image from the camera (intensity value per pixel), with an additional header, including information on pixel pitch and exposure time. Raw data can be loaded to the Beam software and allow to reconstruct the exact image; the data on exposure time allow to reconstruct total power. Raw data format cannot be used for import to standard Windows applications.

Bitmap standard uncompressed RGB 24bit bitmaps. As this is an uncompressed image format, *.bmp files can be imported by the Beam software.

Tiff 8bit; compressed 24 bit image
Png compressed 32bit image
Jpeg compressed 24bit image

Note

Compressed images cannot be imported by Beam software.

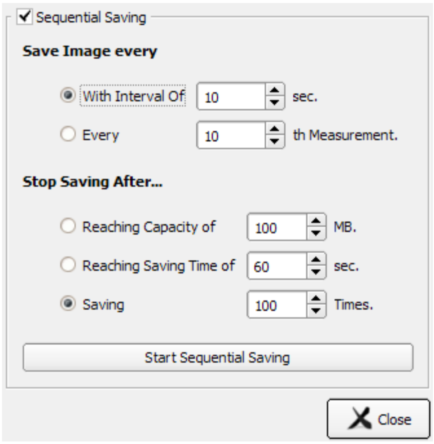
Intensity value text matrix

This is a CSV (comma separated variables) file format. The comment "Not for import" is related only to Beam Software: A data file cannot be imported in order to reconstruct a beam profile.
Intensity values are saved to a text matrix with a header:

Thorlabs Beam				
Version: 4.0 Build 127				
Date: 2011-02-15				
Time: 15:06:38				
Device: BC106-VIS				
S/N: M00233335				
0	1	1	4	9
2	9	2	2	2

The 1st value in the 1st line represents the intensity of the left upper pixel in the 2D projection.

Sequential Saving



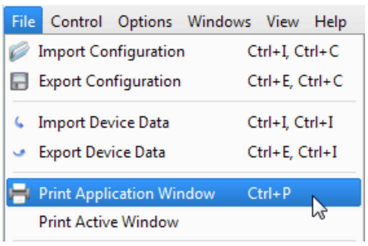
By checking the **Sequential Saving** box, a series of measurement data can be saved.
The same data formats can be chosen as for Export of Device Data 71.
The saving can be proceeded with a defined time interval (0 to 100.00 sec) or for each n^{th} measurement - here the value range is from 1 (saving every single measurement) to 100.000 (99.999 measurements are being skipped).

The saving can be stopped by fulfilling one of three possible criteria: reaching a max. memory space (0 to 100.000 MB), a max. saving time (0 to 100.000 sec, if 0 only 1 measurement is being saved) or a max. number of savings (up to 100.000 files).

The file name must be set in the appropriate box; a date and/or time stamp can be added. In order to avoid doublets, a counter "_#xxx" is appended. This counter is reset at each software restart.

Print screenshots

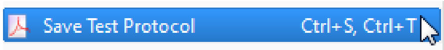
Select **'File→ Print Application Window'** or **'File→Print Active Window'** to print screenshots of the appropriate window.



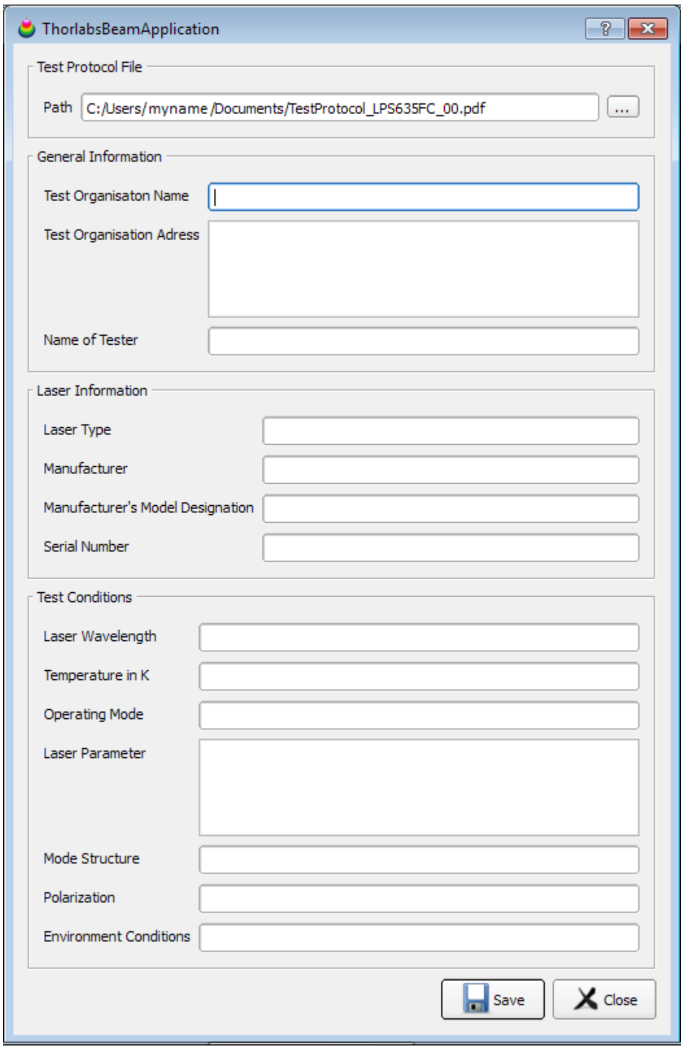
If a PDF creating software is installed as a printer, the screenshot can be printed also as a PDF file.

3. Export a PDF Test Protocol

To save a test protocol in pdf format select **'File → SaveTest Protocol'**.



A dialog box opens:



Here, additional information can be entered in order to save together with the test report.

The results of the measurement are saved to a compact test protocol. It contains the Beam Profiler data and settings, numerical calculation results as well as the 2D Projection and the 3D Profile windows, so far these windows were displayed.

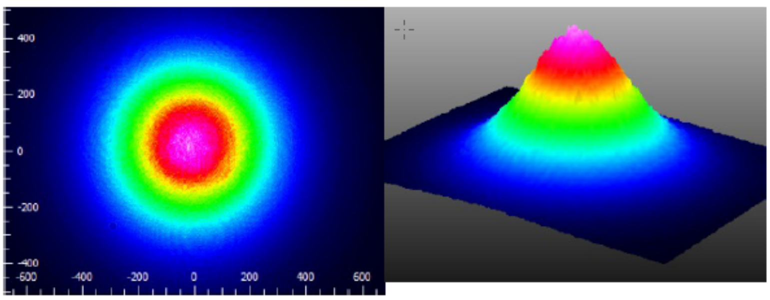
Example:

Laser Beam Measurement Test Protocol

Measurement Instrument:	Thorlabs Beam, version 4.0 Build 98
Date:	12-14-2010 10:35:46
Test Organisation Name:	Thorlabs GmbH
Test Organisation Adress:	Hans-Boeckler-Str. 11
	D-85221 Dachau
	Germany
Name of Tester:	Max Mustermann
Laser Type:	Fiber coupled FP laser
Manufacturer:	Thorlabs, Inc
Manufacturer's Model Designation:	LPS-635-FC
Serial Number:	090319-03
Laser Wavelength:	635nm
Temperature in K:	294
Operating Mode:	Constant current
Laser Parameter:	I LD = 69.5mA
	P LD = -1.26dBm
Mode Structure:	single mode
Polarization:	n.a.
Environmental Conditions:	45% rel. hum.

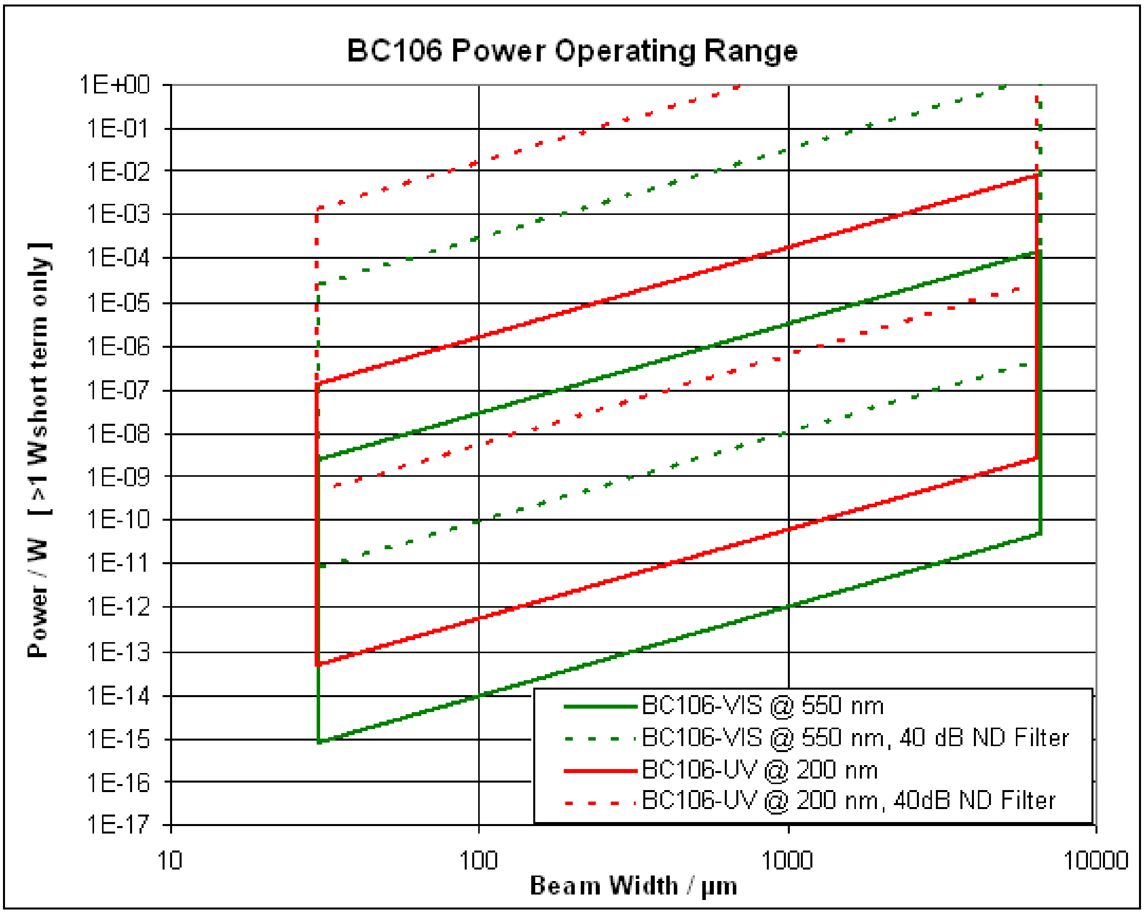
Model:	BC106-VIS	
Serial Number:	M00233335	
Attenuation:	[dB]	30
Exposure Time:	[ms]	10.00
Gain:		1

Parameter:	Unit:	Result:
Beam Diameter (4-Sigma)	[pix]	943.10
Beam Width (4-Sigma)	[pix]	X=852.89, Y=799.08
Beam Width Clip	[pix]	X=757.90, Y=755.90
Centroid Position	[pix]	X=-11.66, Y=19.91
Eccentricity	[%]	17.00
Effective Area	[pix²]	208366.61
Effective Beam Diameter	[pix]	765.31
Diameter	[pix]	X=746.69, Y=757.72
Ellipticity	[%]	98.54
Gaussian Diameter	[pix]	X=703.78, Y=711.70
Gaussian Intensity	[%]	X=96.34, Y=96.16
AD Saturation	[%]	84.50
Orientation	[deg]	-72.45
Peak Density	[dBm/pix²]	-0.00
Peak Position	[pix]	X=-19.00, Y=14.00
Total Power	[dBm]	-3.92



3.4.9 Power Ranges

Both BC106-VIS and BC106-UV models offer a different input power range. Maximum and minimum applicable power depends on beam diameter and the selected optical filter and wavelength.
The wavelength of maximum response is chosen: for BC106-VIS 550 nm, for BC106-UV 200 nm.



Both unbroken lines indicate the BC106 power range without any filter applied. When an attenuation filter is applied the appropriate power range is shifted towards higher values. Displayed dashed lines stand for 40 dB filters only, the highest value available in the supplied within the filter wheel. Intermediate filter settings are not displayed but are located between drawn through and dashed lines.

Since the max. and min. applicable power depends on the actual beam diameter you need to read out the diagram by selecting the beam diameter first. Choose the diameter on the horizontal scale and go up to the power range curve representing your Beam Profiler model. Then go left and read out the power level.

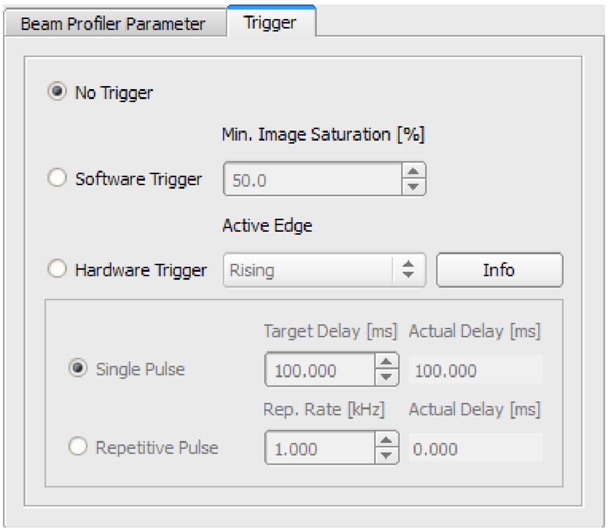
Note

The power readings are exemplary for the wavelength 550 and 200 nm, respectively, and need to be modified according to the wavelength depending response curve.

3.4.10 Pulsed Laser Sources

Overview

The BC106 Camera Beam Profiler is able to capture beam profiles in different trigger modes. Basically, you can work using a continuous or single shot mode. Use these control buttons in the toolbar to enable one of these modes and click to pause image acquisition.
In order to capture beam data of pulsed light sources various modes to trigger exposure time with respect to the laser pulse occurrence are offered.
Open the 'Device Settings' panel and look at the area controlling the 'Trigger' capabilities of the Beam Profiler.



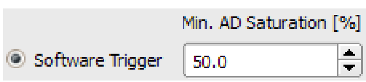
There are three excluding trigger modes.

3.4.10.1 No Trigger

This mode is dedicated mainly for CW sources. A constant beam power is expected so that image capturing can start at any time.This mode should be used also for pulsed sources with high repetition rates above 50 kHz - such pulse trains appear as CW signal to the camera.

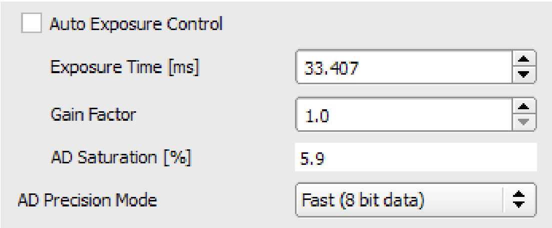
3.4.10.2 Software Trigger

Software trigger can be used for pulsed light sources which do not provide an electrical trigger signal for synchronization to the Beam Profiler. Also rarely or irregularly occurring optical pulses can be captured. In this case the Beam Profiler is restricted to trigger on the captured image brightness.
Activate the Beam Profiler's continuous measurement mode by clicking in the toolbar. Then define a 'Min. Image Saturation' level in % as a software controlled brightness trigger level.



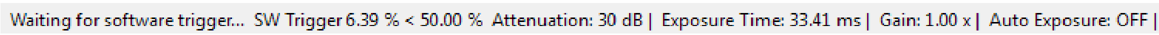
A default value of 50 % indicates that only images with a half scale maximum brightness are triggered, captured and interrogated afterwards. Dark images taken by the camera with a maximum brightness lower than the selected ‘Min. AD Saturation’ level will be ignored and not displayed. Only the detected ‘AD Saturation’ level in % will be displayed within the Exposure Control field.

As soon as ‘Software Trigger’ is selected the ‘Auto Exposure Control’ is switched off automatically and the desired ‘Exposure Time’ and the ‘Gain Factor’ must be entered manually.



Adjust both controls so that a low ‘AD Saturation’ (in % of full scale brightness) results when no laser pulse is captured. Increase ‘Exposure Time’ and ‘Gain Factor’ so that a detected laser pulse exceeds the ‘Min. AD Saturation’ threshold. Decrease both controls in case the detected pulse reaches the limiting 100% saturation because its real intensity may be considerably higher.

The status bar informs you about the activated software trigger function.
The Beam Profiler is waiting for an image reaching the selected saturation threshold. In case the actual AD saturation level is below the threshold, the status bar informs you about a waiting software trigger event.



For frequently occurring pulses it is recommended to adjust the Exposure Time slightly shorter than the pulse period so that only a single pulse is captured. Prevent ambient light from entering the input aperture and use one of the neutral density filters for its attenuation.

Note that the image brightness of a captured single optical pulse isn’t adjustable by the ‘Exposure Time’ control in case the single optical pulse is shorter than the adjusted exposure duration. Use the supplied ND filters of the filter wheel and the ‘Gain Factor’ control to adjust image brightness. In order to ensure a minimum noise level it is recommended to keep the gain value as low as possible.

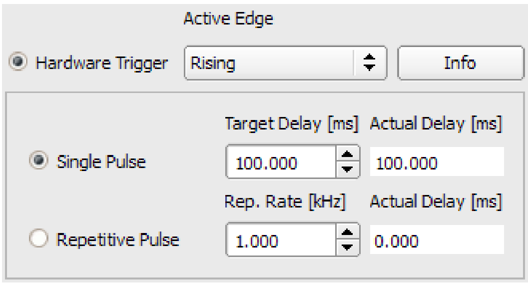
You also may activate the Beam Profiler’s single shot measurement mode by clicking  in the toolbar in combination with this Software Trigger. Although a continuous image capturing is performed in the background, the first image fulfilling the software trigger condition will stop this process and the appropriate image is displayed and interrogated.

3.4.10.3 Hardware Trigger

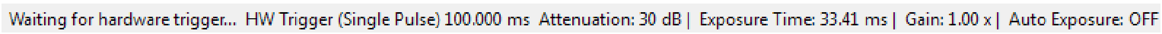
Hardware Trigger is suited for pulsed light sources which provide an electrical trigger signal for synchronization to the Beam Profiler. An additional trigger delay can be programmed to align the profiler’s exposure time exactly to the occurrence of a single or a repetitive light pulse. This trigger mode is suited for pulsed light sources which provide an electrical TTL level trigger output signal for synchronization to the Beam Profiler. Feed the TTL level trigger signal from your laser source or from the appropriate driving pulse generator into the BNC connector of the Beam Profiler.

Attention

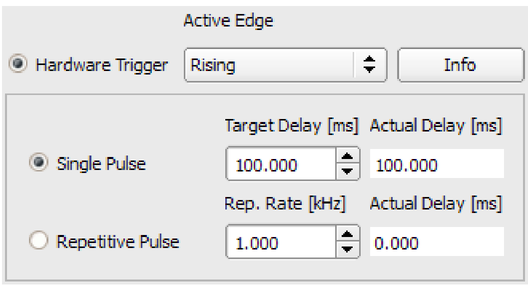
Be sure to enter only a TTL compatible signal to the BNC jack not exceeding the range (-0.5 V … +6.5 V). Higher or lower voltages may damage the Beam Profiler input, see chapter Trigger Input 12**!**



Activate the ‘Hardware Trigger’ mode and select the active edge of the trigger signal to '**Rising**' or '**Falling**'.
The **'Info'** button will open the online help manual.
The status bar informs you about the activated hardware trigger. The Beam Profiler is waiting for a trigger pulse on its BNC input.



Single Pulse

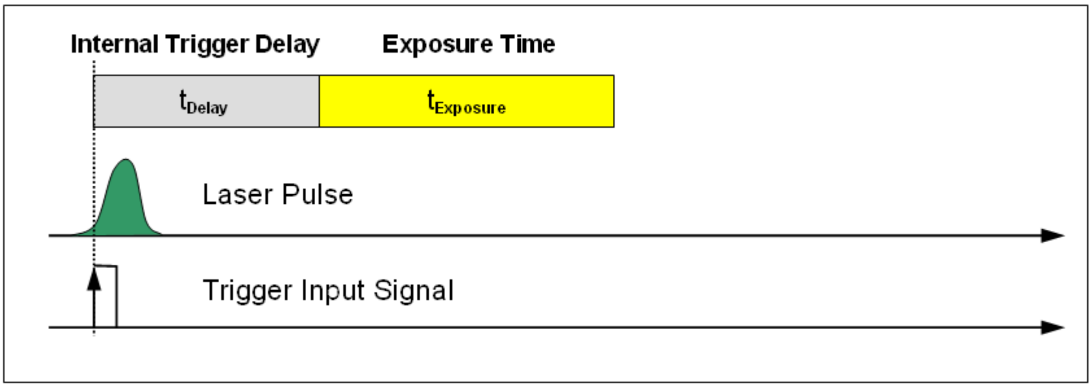


Check the ‘Single Pulse’ option and the camera will capture images after the selected trigger edge has been detected. You might also enter a ‘Target Delay’ which is useful to postpone the start of the exposure time in case the optical pulse is delayed by the same amount.

Note

The BC106 camera TTL trigger circuit has an internal delay (t_{Delay}). This internal

delay is inevitable.
As a result, the camera cannot start exposure before the internal trigger delay time has expired. An optical pulse that is received during this time span (t_{Delay})cannot be detected. The following figure illustrates this situation:



The internal trigger delay t_{Delay} depends on the selected exposure time:

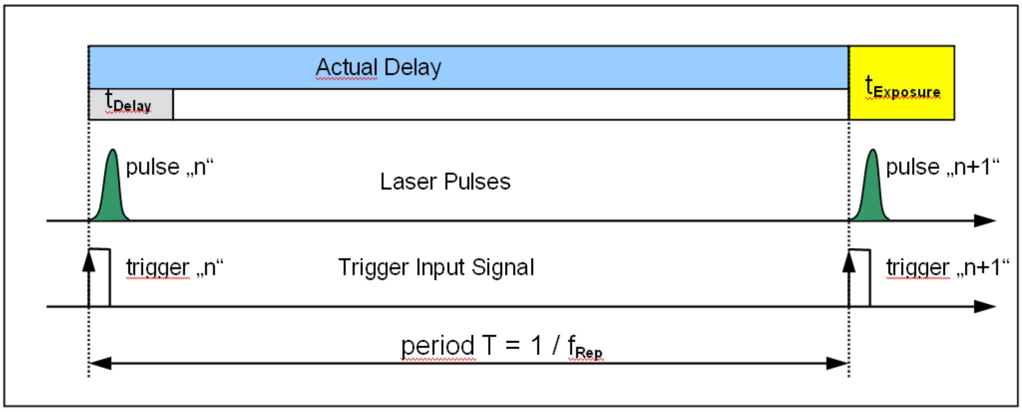
Exposure time	Internal trigger delay
20 µs	96 µs
43 µs	73 µs
≥ 74 µs	42 µs

When entering a desired delay to the box 'Target Delay', the software displays the resulting 'Actual Delay' as the closest possible value.
Example for exposure time = 0.020ms (20µs):

Target Delay	Actual Delay
0.000 ms	0.096 ms
0.050 ms	0.096 ms
0.100 ms	0.100 ms

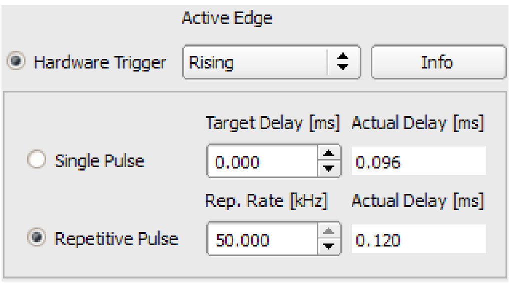
Repetitive Pulses

This Trigger mode is helpful suited for pulsed light sources which
- provide an electrical TTL level trigger output signal
- generate **pulses with duration shorter than the internal trigger delay** of the Beam Profiler
- have a constant repetition frequency, i.e. constant time interval between two consecutive pulses,



Above diagram illustrates this case.
The laser source outputs a trigger signal "n" (rising edge) when the optical pulse "n" is released. The pulse duration is shorter than the internal trigger delay, that's why the appropriate laser pulse cannot be captured.
Entering the laser's repetition rate, software calculates a delay (displayed as 'Actual Delay') to capture the next possible laser pulse - this can be the pulse "n+1" or, for high repetition rates, "n+2", "n+3" etc.

Check ‘Repetitive Pulse’ and enter the repetition frequency in kHz within the available range 0.001 to 50 kHz. The optimal trigger delay is calculated and displayed.



If the repetition rate is significantly higher than 50kHz, a number of subsequent pulse will be captured, as for this reason beam profiles of successive pulses cannot be resolved anymore. In such cases the pulsed light source appears more and more like a CW source. In such cases the trigger functionality can be disabled by checking ‘No Trigger’ and the external trigger signal can be omitted. In order to achieve a constant beam power set a suitably long exposure time that performs an average over a high number of laser pulses.

3.5 Beam Quality (M^2) Measurement

3.5.1 General

In laser science, the parameter M^2 is the ratio of the beam parameter product (BPP) of an actual beam to that of an ideal Gaussian beam at the same wavelength. It is often referred to as the beam quality factor, since its value can be used to quantify the degree of variation the actual beam is from such an ideal beam. M^2 is a better guide to beam quality than Gaussian appearance, however, since there are many cases in which the beam can look Gaussian, yet have an M^2 value far from unity. As well, a beam can appear very "un-Gaussian", yet have an M^2 value close to unity. For a single mode TEM00 Gaussian Laser beam, M^2 is exactly one.
The value of M^2 can be determined by measuring 4σ diameter or "second moment" width. Unlike the beam parameter product, M^2 is unitless and has no variance with wavelength.
In laser science, the beam parameter product (BPP) is the product of a laser beam's divergence angle (half-angle) and the radius of the beam at its narrowest point (the beam waist).
The M^2 value is an important measure of beam quality. It is widely used in the laser industry as a specification, and its method of measurement is defined in ISO 11146 standard. It is especially useful for determining the degree of beam divergence of real laser beams and the minimum focussed spot size.

The Camera Beam Profilers Series BC100 are camera-based instruments to measure the beam quality factor M^2. For the measurement, the beam profiler is mounted to a software controlled translation stage, moved step by step along the propagation axis of a focussed beam and the beam diameter is measured at each position in order to find the beam waist.

The associated extension set for the Camera Beam Profilers Series is the **BC1M2-xxx** 89 consisting of a linear translation stage of two selectable lengths and a mounting adapter kit for BC100 beam profiler.

BC1M2 extension set features:

- Accurate M^2 measurements
- Measures divergence, waist diameter, Rayleigh range and astigmatism
- Flexible design
- Compatible with CW and Quasi-CW pulsed laser sources
- Short measurement cycles
- fully ISO11146 compliant

Motivation

Many laser applications require maximum optical power density at minimum beam diameter. Not only the focusing optics but mainly the quality of the light source itself has influence to the focusability. A high beam quality is a pre-condition for optimal focusability.

What is Beam Quality

Beam Quality and its direct influence to focusability is a very important feature of lasers.

Beam Propagation Measurements according to **ISO 11146 standard** disclose beam quality and describes it as a single value either the **Times-Diffraction-Limit Factor M^2** (also known as *beam quality factor* or *beam propagation factor*) or its reciprocal **Beam quality $K = 1/M^2$** whereas the beam quality K is direct proportional to the quality level (K=1 optimal, decreasing for worse quality), its reciprocal value M^2 (M^2=1 optimal, increasing for worse quality) is used more often.
Please do not confuse beam quality (K≤1) and times-diffraction-limit factor (M^2≥1).

Diffraction Limit
Depending on wavelength λ and beam divergence angle θ there is a limit for minimum beam waist diameter d_0 called **diffraction limit** which cannot be decreased further more by theory.

M^2 is an expression of how close the beam parameter product d_0*θ is to the diffraction limit of a perfect Gaussian beam. For beams of worse quality the product d_0*θ is increased by the factor M^2

$$d_o\theta \rightarrow M^2\, d_0\theta$$

where d_0 is beam waist at the focus point of the focussing lens.

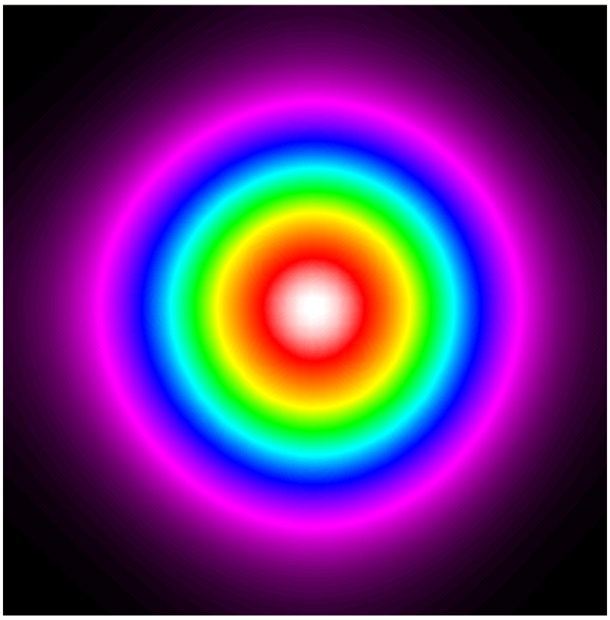
M^2 is also known as

- the ratio of the waist diameter d_0 of the measured beam to that of an ideal Gaussian beam (TEM_{00}) at same divergence angle θ.
- the ratio of the divergence angle θ of the measured beam to that of an ideal Gaussian beam (TEM_{00}) at same waist diameter d_0,

Worse beam quality is a result of laser imperfections like inhomogeneities which lead to appearance of higher transversal modes.

How to measure Beam Quality
If only the fundamental mode TEM_{00} (which has an ideal Gaussian shape) is existing - this ensures an ideal beam quality (K=1, M^2=1) with diffraction limited waist size. The existence of higher modes decrease beam quality which leads to larger waist diameters. Often, such distortions can be easily discovered by looking at the non Gaussian beam profile.
But in many cases, several higher modes are distributed in a way that generate a nearly Gaussian shape but the beam itself suffers from a bad beam quality.

The following example shows a beam with nearly perfect Gaussian shape but having a multi-mode origin leading to bad quality M^2 = 1.79.

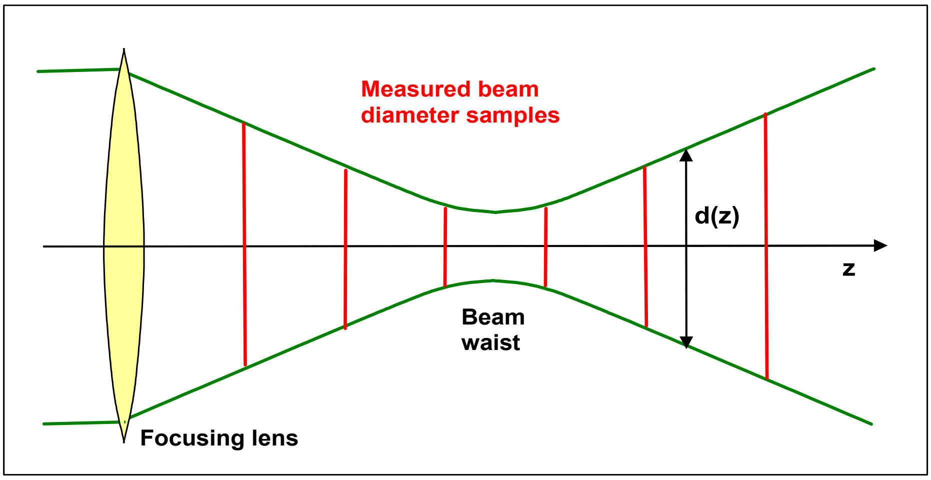


Note

A nearly Gaussian shape is not an indicator for high beam quality!
Therefore, a single beam shape shot measured by a Beam Profiler does not allow a statement about beam quality.

Although a single Beam Profiler result is not a measure if beam quality, the Thorlabs Camera Beam Profiler Series can be used to measure beam quality in a sophisticated manner.

Beam Propagation Measurement is carried out according to ISO 11146 standard.
The key idea is to measure the course of beam diameter d(z) along the axis of beam propagation z.



The Beam Profiler is mounted on a translation stage which is controlled by the Beam Profiler software too.
At several z positions the beam diameter and other parameters are measured and stored.

Besides determination of the **times-diffraction-limit factor M^2** the Thorlabs Beam Propagation measurement determines the following parameters of an optical beam:

- beam waist width d_{0x}, d_{0y}
- beam waist z-position z_{0x}, z_{0y}
- Rayleigh range z_{Rx}, z_{Ry}
- divergence angle θ_x, θ_y
- beam pointing direction
- waist asymmetry
- divergence asymmetry
- astigmatism

Note

The Thorlabs Beam Quality measurement tool handles cw sources and some pulsed sources only! For more information about pulsed laser sources read chapter Pulsed Laser Sources 76.

3.5.2 M² Application recommendations

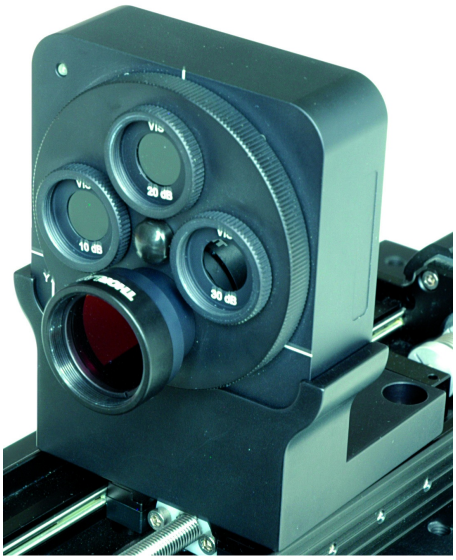
This section describes exemplary needs which are useful for some applications.

The BC106 Beam Profiler is delivered with a SM1BC adapter which allows to mount 1 inch threaded extensions to the Beam Profiler. The following examples give an idea how to realize special needs and how to personalize the Beam Profiler setup.

Using anti-reflection (AR) coated filters

In some cases it can be advantageous to use AR coated filters instead of the uncoated filters on the Filter wheel 9. These uncoated filters might allow reflections from the camera CCD sensor to the filter and back to the sensor. Under certain circumstances (like not perfectly aligned optical elements in the optical path) these reflection tend to walk over the sensor while driving the camera over the translation stage.

This effect can be avoided by using AR coated filters - reflected light from the CCD sensor is not reflected from the filter surfaces. Stackable AR coated filters can be found on our website www.thorlabs.com.

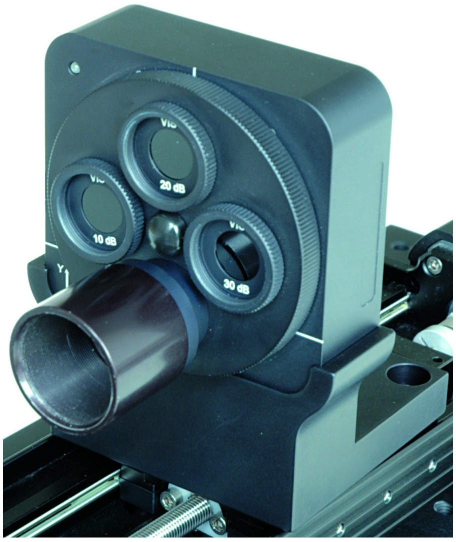


Suppressing ambient light

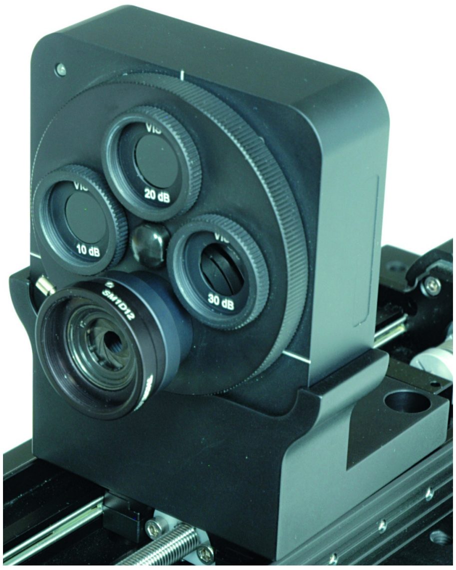
In a M^2 measurement the beam width on the CCD sensor varies. At constant laser power the beam intensity increases when approaching the beam waist. In this case, the exposure time is adapted in order to avoid saturation of the camera.
Though the Ambient Light Correction 66 is able to eliminate influence of ambient light, particularly at extended exposure time, it is recommended to shield the BC106 input aperture from ambient light, for example using SM1Lxx lens tubes with SM1BC adapter. Lens tubes can be found on our website www.thorlabs.com.

Attention

Make sure that a mounted to the BC106 camera beam profiler lens tube won't collide with other parts of the optical setup!



Alternatively, an iris diaphragm can be mounted to the SM1BC adapter. This avoids unwanted ambient light as well. But keep in mind not to cut the beam - this could take influence on the measurement. It is useful to set the size of the aperture at the position with the largest beam width.



3.5.3 Selecting Focal and Stage Length

Since the BC1M2 Extension Set does not include focusing elements, it has to be selected and ordered separately.
The following guideline should help selecting the optimal focal length of the lens as well as the optimal length of the translation stage.

Selecting the focal length

The following diagram A helps selecting the optimal focal length *f* depending on the operating wavelength λ and the unfocussed beam diameter. See Focal and stage length calculation 145 for details.

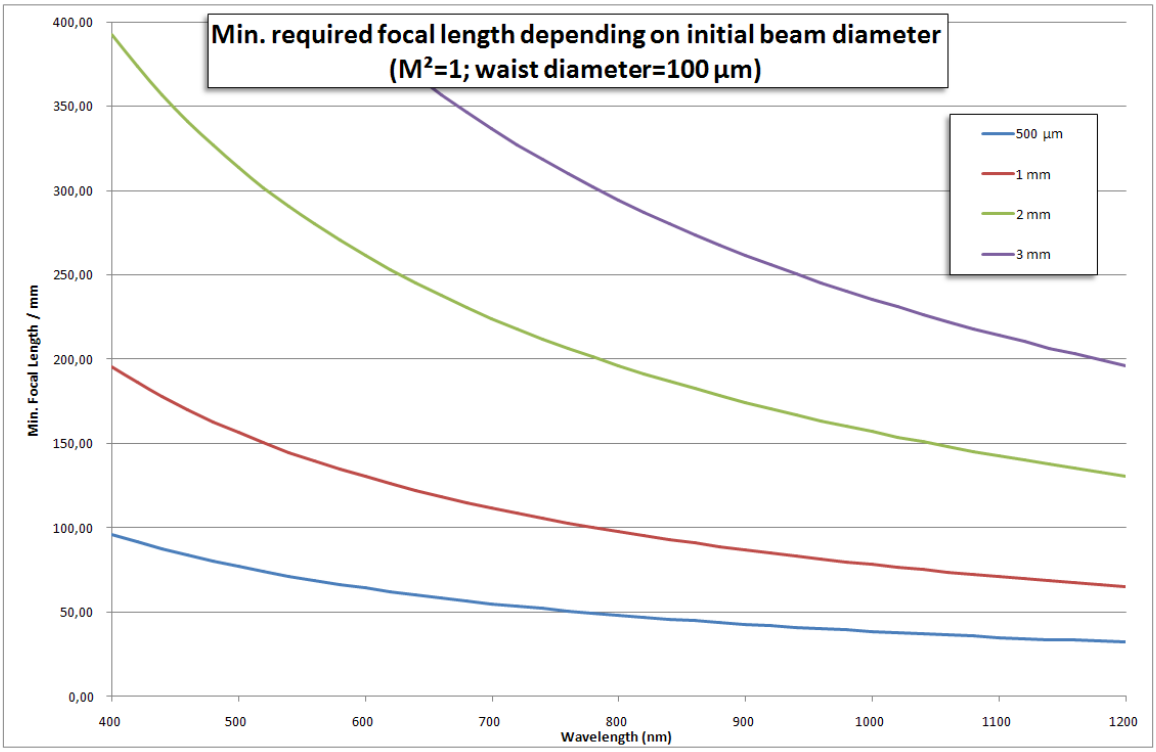


Diagram A

Select your operating wavelength at the x-axis of diagram A and go up to the curve representing your initial (unfocussed) beam diameter. Then read out the minimal required focal length at the vertical axis. Round it up to the next available focal length (100 mm, 150 mm, 200 mm, ...). Longer focal lengths generate waist diameters above 100 µm and relax the measurement requirements to the Beam Profiler.
Refer to the 'Accessories' tab for recommended focusing lenses. Be sure to order the appropriate AR-coating for your wavelength range of interest.

Selecting the translation stage length

It is advisable but not necessary to choose the translation stage length at least as long as the focal length of the focusing lens. For a correct M^2 measurement the translation range has to be at least 5 times the Rayleigh length of the focused beam to cover both the beam waist and the neighboring divergent beam propagation. The Rayleigh length depends strongly on the generated waist diameter and also linearly

increases with M^2. Therefore, the translation range needs to be longer for bad beam quality ($K<<1$, $M^2>>1$).
See Focal and stage length calculation 145 for details.

Diagram B shows the minimal required stage length for $M^2=1$ depending on the expected waist diameter:

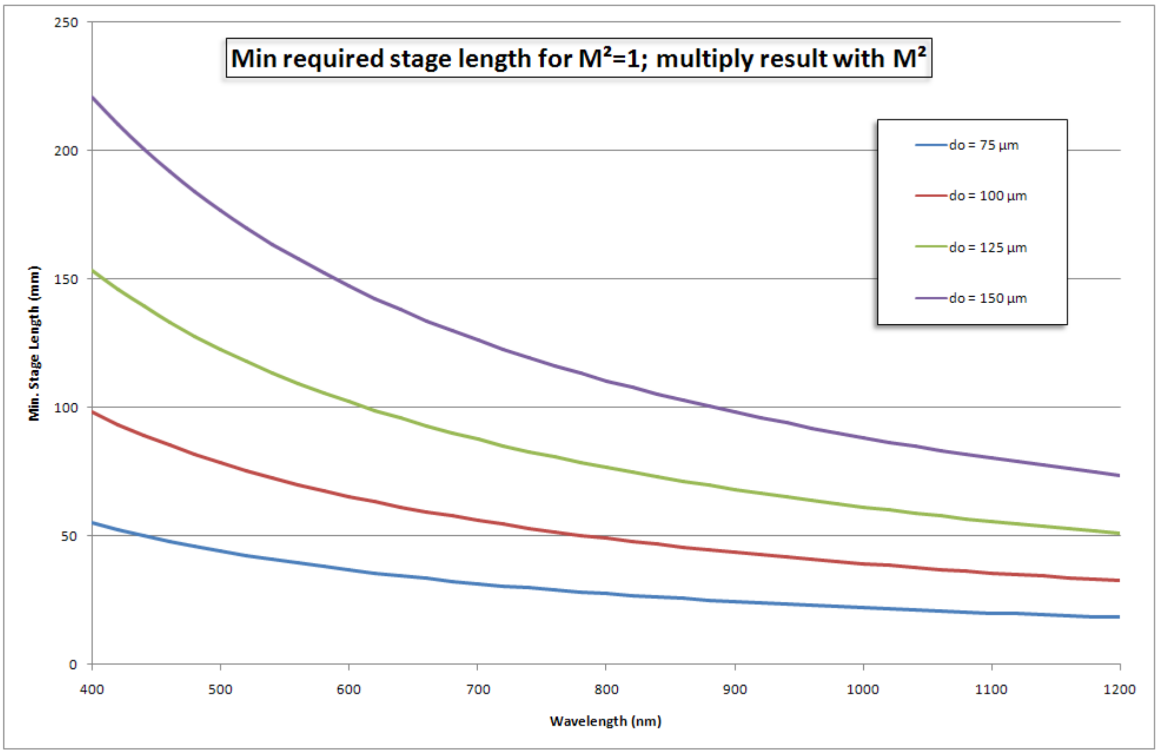


Diagram B

Select your operating wavelength at the x-axis of the diagram B and go up to the curve representing your expected waist diameter. Then read out the minimal required translation range at the vertical axis. Multiply this result with the highest expected M^2 value of your laser source and round it up to the next available translation stage length (150 or 300 mm). Please note this length is a minimum requirement for M^2 detection.

As a disadvantage, for each application the short stage carrying the Beam Profiler needs to be well positioned according to the beam waist position. Therefore, the longer stage length of 300 mm is advisable for universal setups which are ready to use for various laser types, beam diameters, wavelengths, M^2 values and focal lengths. Also, the entire diverging process on both sides of the beam waist can be analyzed without the need to relocate a shorter stage to the new focus position.

3.5.4 Extension Hardware

3.5.4.1 BC1M2 Extension Set for M² measurement

The BC1M2 M^2 Analysis Extension Set is comprised of a motorized Translation Stage of selectable length, plus mounting accessories to be used with the BC106 Beam Profiler. The Beam Profiler itself and required means for beam alignment and focusing are not supplied with the Extension Set and need to be ordered separately.

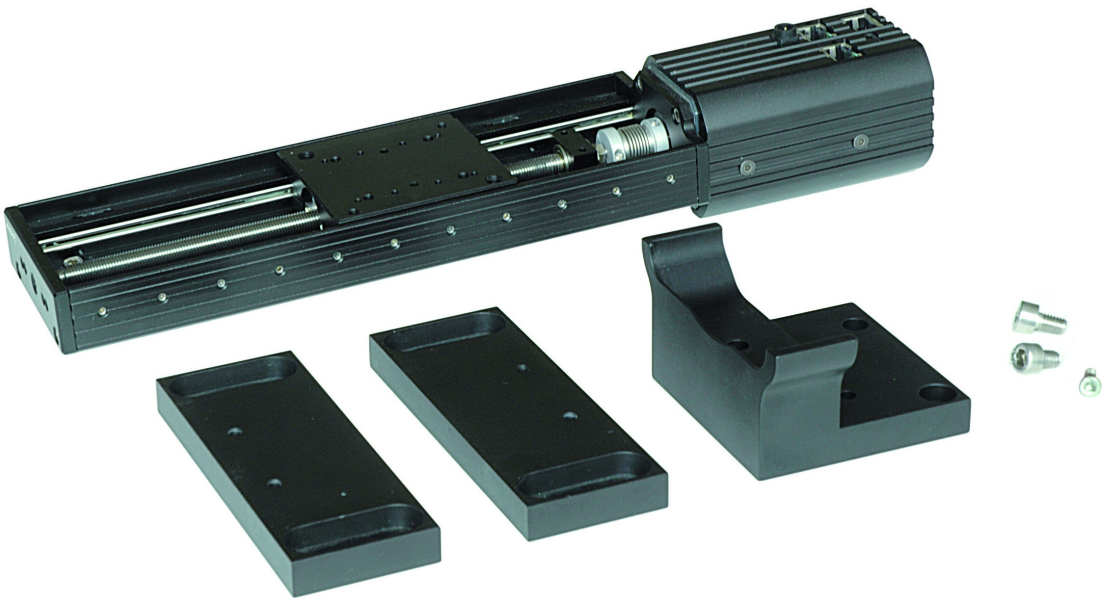
Two different models with different translation stage lengths are available:

Extension Set Model	**BC1M2-150**	**BC1M2-300**
Length of translation stage	150 mm	300 mm

Required Travel Length of the M² Extension Set

Please see the Selecting Focal and Stage Length 87 chapter for information on selecting the model with a suited travel length for your particular application.

The following picture shows the 150 mm translation stage and controller, two mounting base plates (left) and a mounting plate for the Beam Profiler (2 parts, right). The supplied screw set, power supply and cables are not shown. See Translation Stage drawing 158 for a detailed drawing.



BC1M2-150 Extension Set

The stage movement is fully controlled by the software module (included in BC106 software package V3.0 or newer) of the BC106 which allows it to take measurements at different stage positions and perform a complete M^2 analysis. This is done taking multiple measurements of the beam diameter of the collimated beam at different positions along the beam propagation axis. A hyperbolic curve fit to the measured data yields reliable and repeatable values for beam waist diameter and position, Rayleigh range, divergence angle, beam pointing direction, waist asymmetry, divergence asymmetry and astigmatism.

Extension set contains

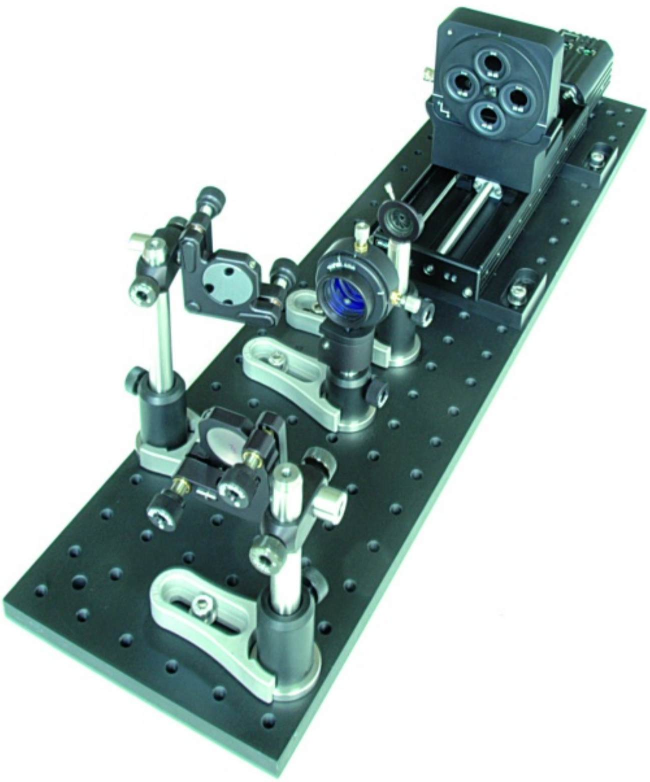
- Translation Stage of selectable length incl. controller
- Power Supply
- RS232 Cable
- USB to RS232 converter
- 2 Mounting Base Plates
- Adapter Plate to Beam Profiler
- Latest Beam Profiler Software CD
- Manual

Note

The BC100 Series Beam Profiler as well as beam focusing and alignment means are not included in the BC1M2 Extension Set and are sold separately. See Mechanical Setup 93 for optional equipment.

3.5.4.2 Recommended Accessories

The mentioned in previous section components are mandatory for a M^2 measurement.
Additional accessories are recommended to adapt the M² measurement system to the laser beam height and it's axis. The following example gives you an idea how to realize a well-proven and easy-to-build construction for adjusting the beam height and the beam pointing.



All required components can be purchased at **Thorlabs.com**. The following tables give an overview about the single components used in the given example.

Imperial version

Item	Part number	Quantity
Kinematic Mirror Mounts	KM100	2
Protected Silver Mirror	PF10-03-P01	2
Right Angle Clamp	RA90	2
1/2" Post 1.5"	TR1.5	2
1/2" Post 4"	TR4	2
1/2" Pedestal Post Holder 1.5"	PH1.5E	3
Small Clamping Fork	CF125	4
Aluminium Breadbord 8" x 24" x 1/2"	MB824	1
Translating Lens Mount	LM1XY	1
1/2" Pedestal Post Holder 1"	PH1E	1
1/2" Post 3/4"	TR075	1
Mounted Iris Diaphragm	ID15	1

Metric version

Item	Part number	Quantity
Kinematic Mirror Mounts	KM100	2
Protected Silver Mirror	PF10-03-P01	2
Right Angle Clamp	RA90	2
1/2" Post 30 mm	TR30/M	2
1/2" Post 100 mm	TR100/M	2
1/2" Pedestal Post Holder 43 mm	PH1.5E	3
Small Clamping Fork	CF125	4
Aluminium Breadbord 200 x 600 x 12.7 mm	MB2060/M	1
Translating Lens Mount	LM1XY/M	1
1/2" Pedestal Post Holder 30 mm	PH1E	1
1/2" Post 20 mm	TR20/M	1
Mounted Iris Diaphragm	ID15/M	1

Note

In these packages are neither screws nor washers included.

Note

Depending on the application different components like larger posts or different mirrors could be more useful than the suggested ones. If you have any questions contact us 161.

There are no focussing elements listed because the necessary lens depends on the given laser beam diameter. Finding the right lens is just a short calculation away.

Assuming that the beam diameter should not drop below 100 microns at the focus point to ensure a reliable measurement the following formula gives the least focal length of the lens:

$$f = \frac{d_{\text{beam}}}{2 \cdot \sin\left(\frac{2 \cdot \lambda}{\pi \cdot 100 \cdot 10^{-6}\text{m}}\right)}$$

where d_{beam} is the beam diameter of the laser system and λ the operating wavelength.

Round it up to the next available focal length (e.g. 50, 100, 150, 200, 300 mm). Longer focal lengths generate waist diameters above 100 microns and relax the measurement requirements to the Camera Beam Profiler.

In general a focussing lens with 100 mm to 150 mm (4" - 6") is quite common for the desired use. This is a good choice for laser beam diameters between a few hundred microns and a few millimeters (0.2" to a few inches).

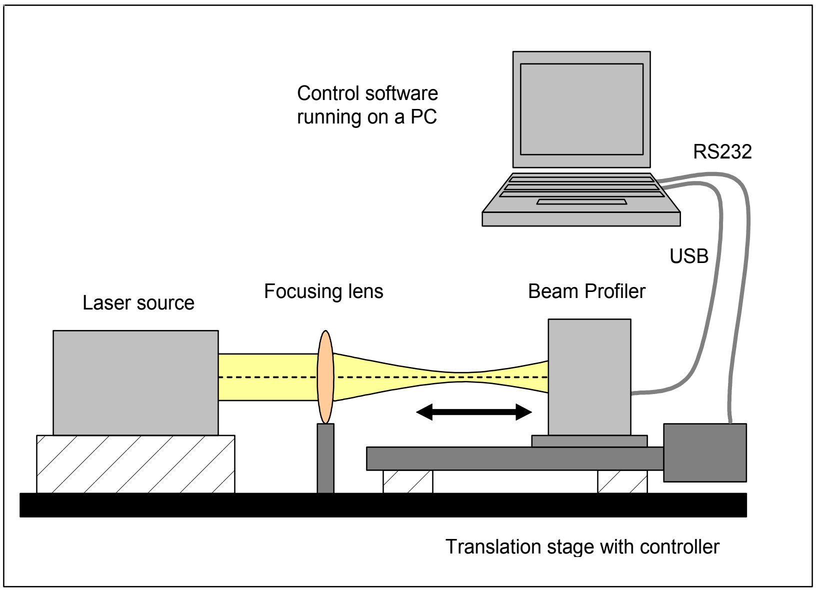
Be sure to order the appropriate AR-coating for your wavelength range of interest. You can find a find a broad selection of different lenses at Thorlabs.com.

3.5.5 Setting up

3.5.5.1 Mechanical Setup

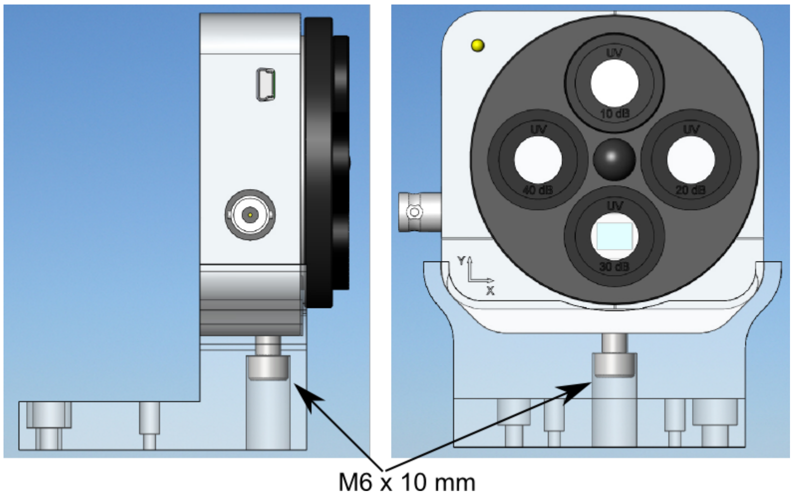
The Thorlabs BC1M2 Extension set for M^2 measurements is not a compact instrument but consists of separate components which are built together. In addition, means for beam alignment and focusing need to be ordered separately.

The following sketch gives an example of a M^2 measurement setup.

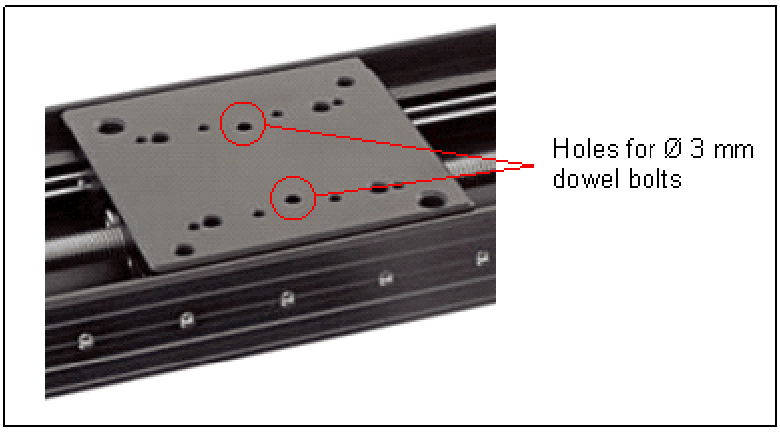


Mounting the translation stage on a table
It is highly recommended to mount the translation stage onto a table to ensure a fixed position and repeatable measurements.
Use the **base plates** delivered with the BC1M2 Extension Set to mount the stage onto an optical table.

Mounting the BC106 Beam Profiler to the translation stage
First mount the Beam Profiler onto the adapter plate by using the appropriate M6x10 screw delivered with the BC1M2 Extension Set. Therefore put the BC106 Beam Profiler into the designated bracket and push it slightly against the stop at the front. This guarantees orthogonal to the moving direction of the translation stage adjustment of the camera sensor. Then fix the screw.



Now insert both dowel bolts into the mounting plate of the translation stage.

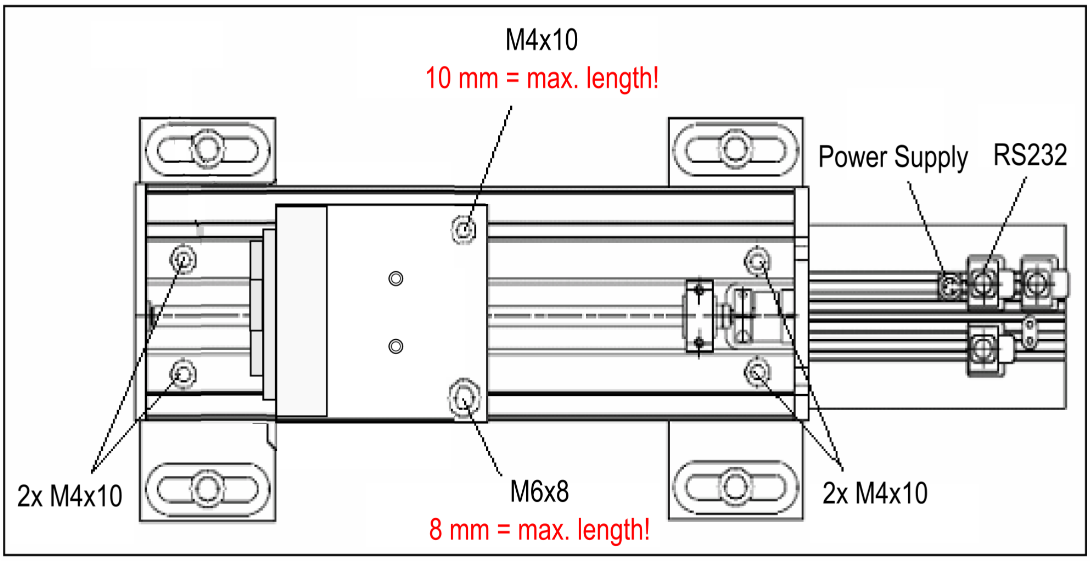


Put the adapter plate with the Beam Profiler mounted on it onto the mounting plate of the translation stage so that the two dowel bolts guarantee a nearly free from play connection. Fit both plates with 2 screws near the back plate of the Beam Profiler.

Attention

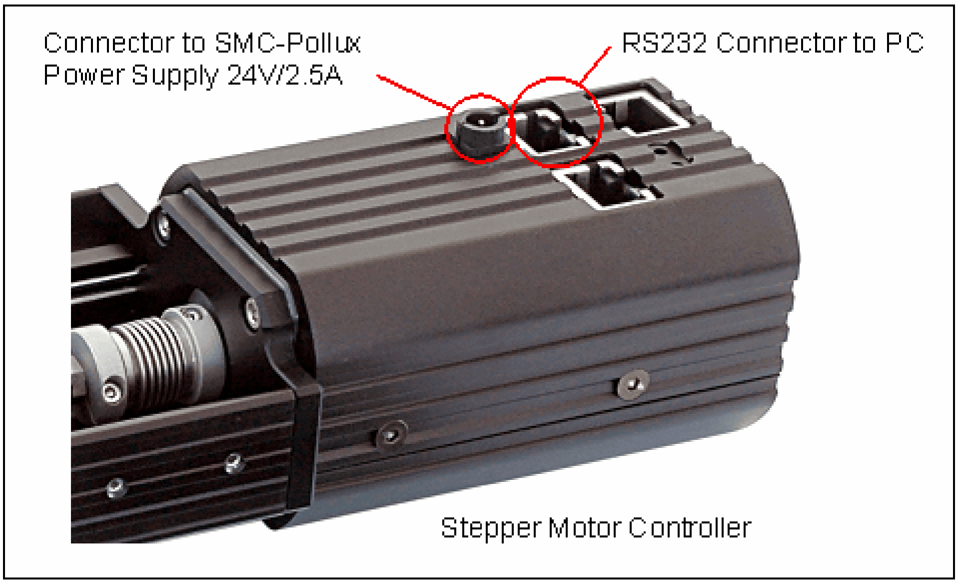
Be sure to mount the Beam Profiler's adapter plate with the designated cap screws M4x10 and M6x8 only! Longer screws will block or even damage the translation stage!
Be sure to mount the translation stage with the Beam Profiler on it in a way that prevents any contact to ambient mechanical parts!
Lasers, lenses, holders or other mechanics may damage the Beam Profiler and Translation Stage!

The following figure shows the fully assembled BC1M2 Extension Set.



3.5.5.2 Electrical Connections

The Pollux controller includes also the stepper motor driving the VT-80 translation stage.
It needs to connect to the appropriate power supply and to the computer via RS232. Use the cables supplied with your BC1M2 Extension Set package.

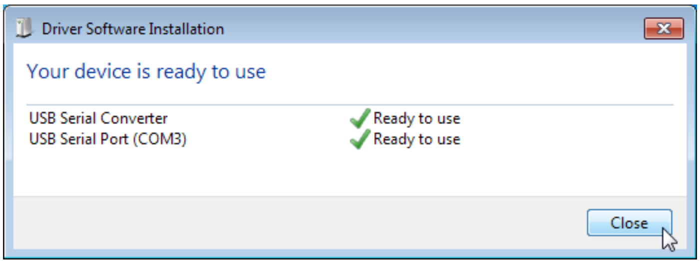


As soon as the power supply is connected to the controller a LED starts to blinking. This indicates normal operation.

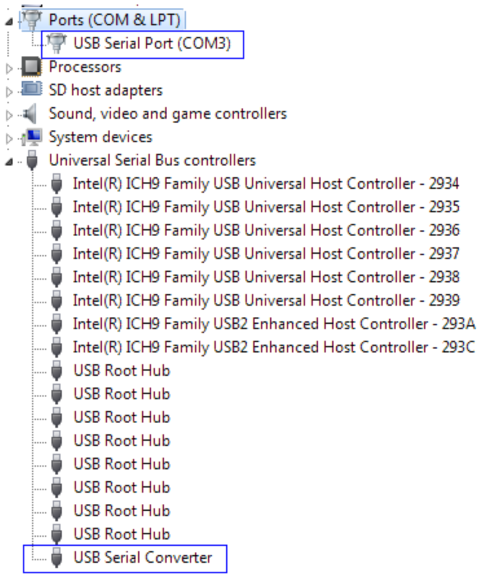
3.5.5.2.1 Installation of USB to RS232 Converter

The M² translation stage controller interfaces with the control PC via a COM port (serial RS232 interface). The connecting cable has a RJ45 connector on the translation stage's end and a 9pin female DSUB connector on the other end.

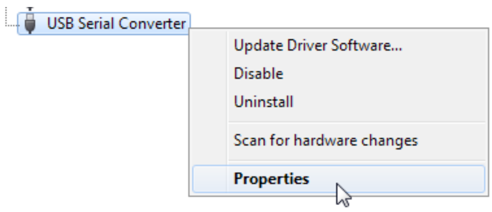
If your computer does not have available a COM port, please use the supplied with the M² meter package USB to Serial converter. The driver for this converter is installed automatically to your system with the software installation, so upon first connection it's being recognized and installed:



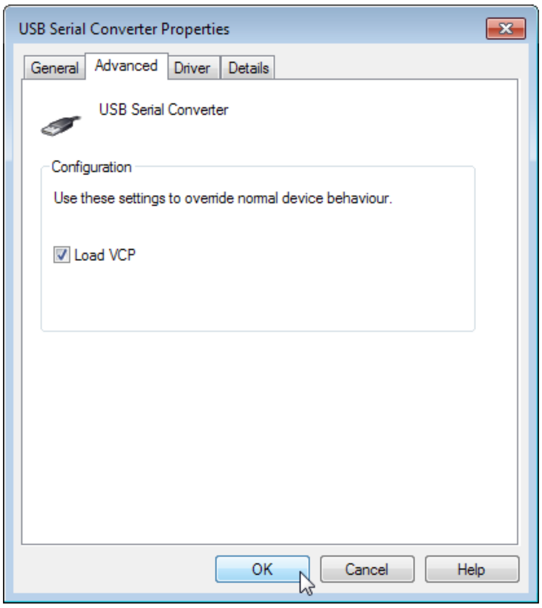
If you wish to verify the correct installation, please open the Device Manager of your PC. The USB-to-Serial Converter appears in both the **Ports** and **USB controllers** lists:



If it does not appear in Ports list, right click to "**USB Serial Converter**" and in the following dialog, select "**Properties**"



Select the tab "**Advanced**" and make sure, the **Load VCP** (Virtual COM Port - this driver forces a USB device to appear as an COM port to the operating system) box is checked:



Unplug the USB converter and connect it again - now it works as intended.

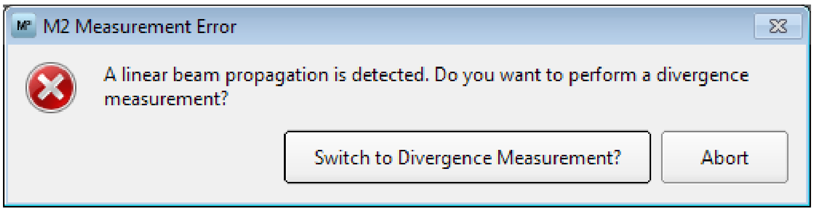
3.5.6 M² Measurement

Click on symbol in the toolbar or select **'Windows → Beam Quality Measurement**' from the menu to enter the M^2 measurement feature.

The **Beam Quality Measurement** window is the central control for the M^2 measurement. The windows consists out of three tabs

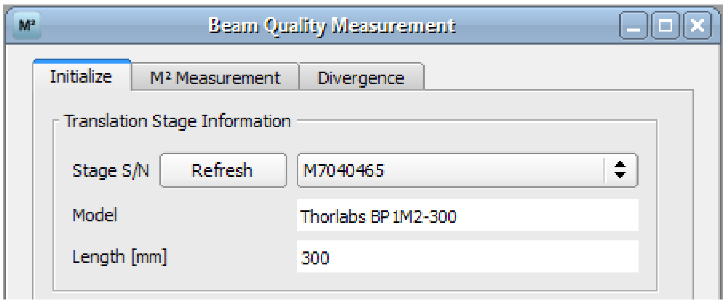
- Initialize
- M^2 Measurement
- Divergence

Initialize provides translation stage initialization and a manual stage control, necessary for beam direction alignment prior to start M² measurements.
M^2 Measurement allows to measure beam quality of a focussed beam.
If the beam is unfocussed (diverging or converging without a beam waist), Thorlabs Beam software offers the **Divergence** measurement feature:

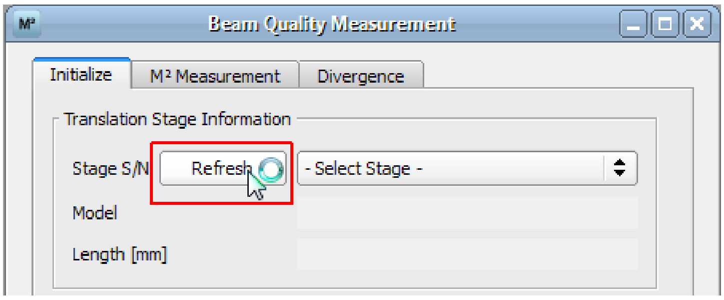


3.5.6.1 Initialize

Make sure a stage is connected and powered.
Starting Thorlabs Beam software, the translation stage is being initialized and zeroed automatically. This means, it's recognized in the tab **Initialize** and moves to the Zero position, so far it's not yet there.

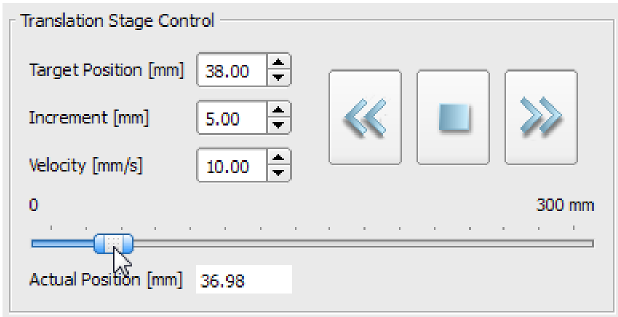


If connect the stage after starting software, it must be initialized manually.



Click to Refresh, then Select Stage.

Manual translation stage control
The controls are located in the lower part of the **Initialize** tab:



Velocity can be set between 1 and 13mm/s and remains valid for all subsequent operations. Default: 10mm/s.
Target position and **Increment** are parameters for manual move of the stage for use with the « and » buttons. The slider below shows the actual stage position. Alternatively, the slider can be moved using the mouse pointer: Click and hold left mouse button, move to the desired position and release - the stage will move to the new target position. Movement can be stopped by clicking the ■ button.

Troubeshooting: Translation Stage cannot be found

- Be sure to have the translation stage powered on and connected to your PC via RS232 cable.
- Ensure that the selected port is not used by a different application at the same time.

Attention

Once the translation stage has been initialized a program restart re-initializes the stage automatically when it is connected to the computer system.

Be sure to have the translation stage with the Beam Profiler on it mounted in a way that prevents any contact to ambient mechanical parts while driving over the entire stage length! Otherwise lasers, lenses, holders or other mechanics may be damaged!

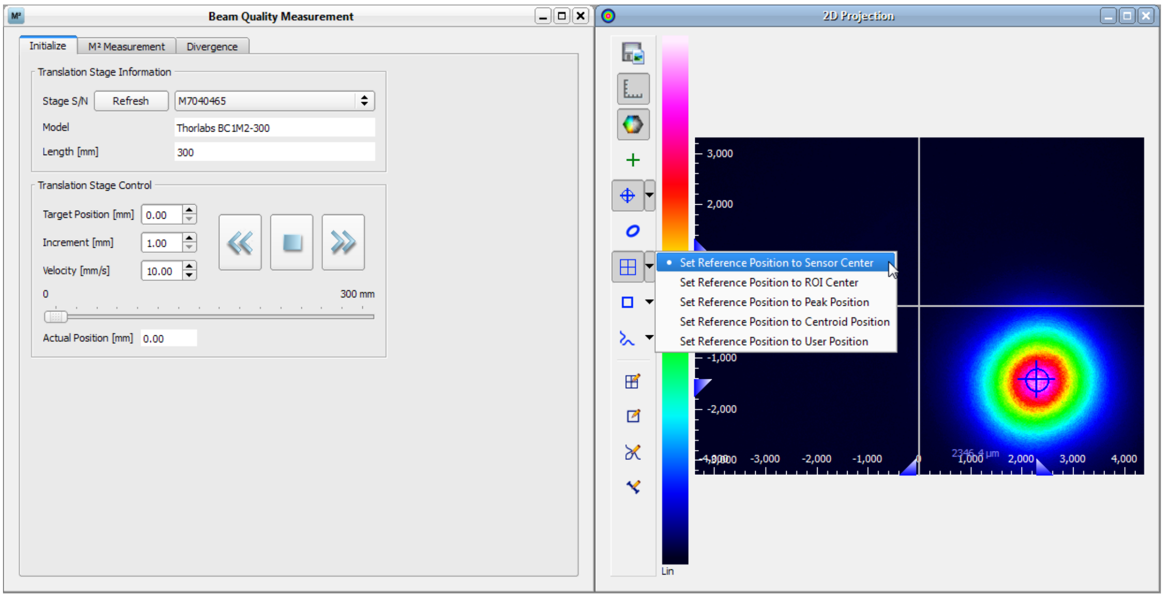
3.5.6.2 Beam Alignment

Why Beam Alignment?

The Beam Profiler has a defined input aperture, so when moving it along the translation stage's axis it must be ensured that the laser beam remains within the aperture. Ideally, the beam centroid remains centered within the aperture during movement of the beam profiler.
So prior to start M² measurement, the beam must be aligned parallel to the movement axis of the stage and should hit the aperture in the center.

It is highly recommended to do the alignment procedure precisely in order to obtain accurate measurement results.

Open the Initialize tab of M² measurement panel and additionally the 2D Projection as shown below:



For beam alignment, the manual Translation Stage Control 99 is used, while the beam position is observed in the 2D Projection panel. For more convenience, enable the Reference Position crosshair (set to sensor center) and enable the centroid cross.

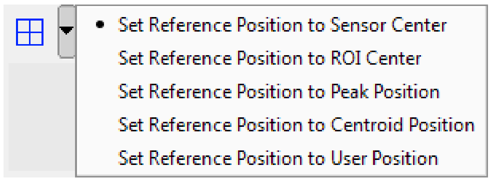
Preconditions

Prior to start beam alignment and measurement take care of these points:

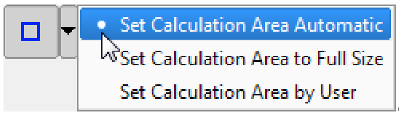
- avoid reflections, interferences, ambient light
- check that entire laser beam is entering the Beam Profiler aperture
- warm up laser system 1 hour
- ensure that laser output is spatially and temporally stable
- set the camera beam profiler to **Auto exposure** mode.
- the camera must not enter saturation at any time!

Hints

It's helpful to enable the **Reference Position,** set to sensor center:

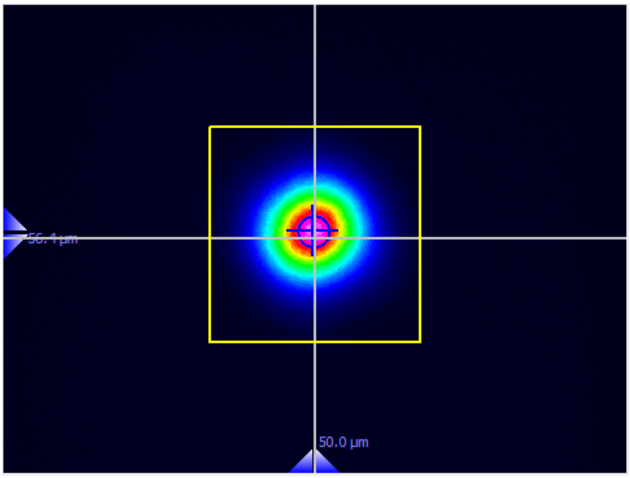


This displays the centered to the beam profiler's aperture crosshair.
For this measurement the **Automatic Calculation Area** should be enabled:

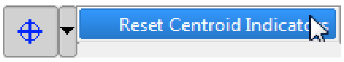


.

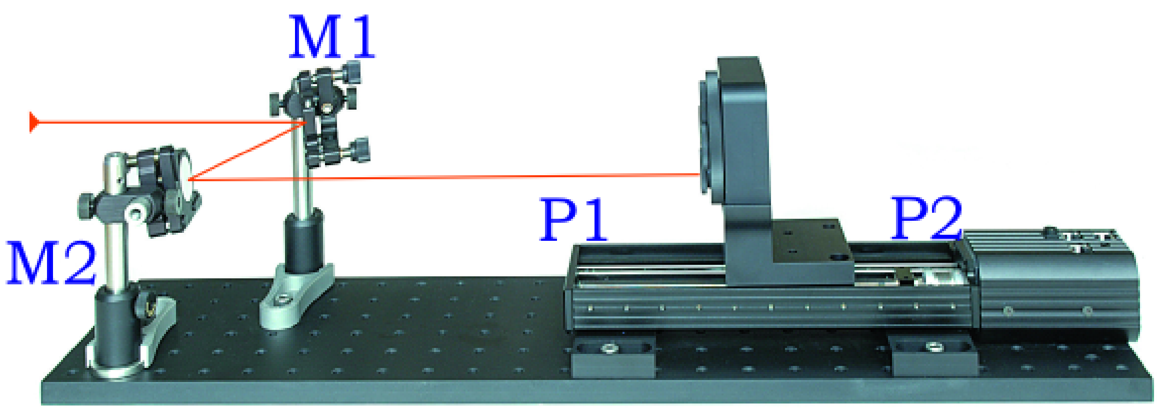
Together with the enabled **Centroid Cross** it's easy to observe beam centricity.



The triangular centroid position indicators then will show how much the centroid was shifted during the move. They can be "zeroed" (reset):



Mechanical Setup
For the mechanical setup at least two mirrors are required to allow positioning the laser beam in any direction. The following picture gives an idea of a possible setup.



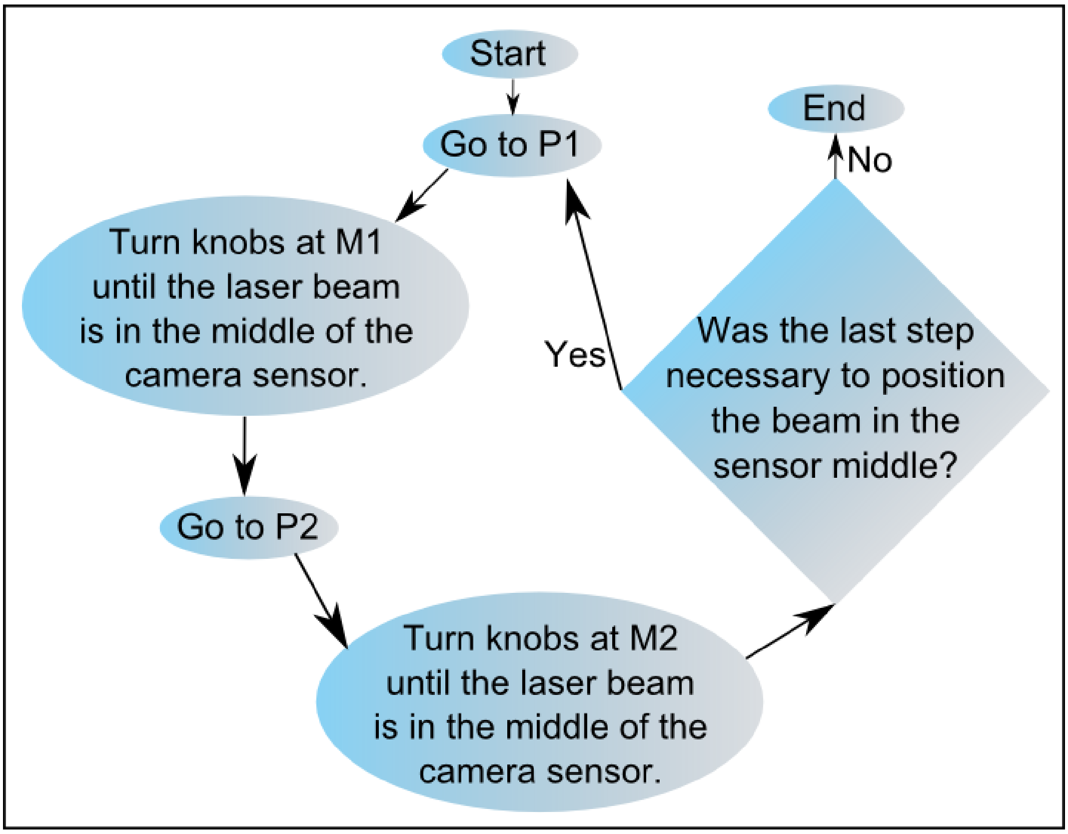
Note

When mounting the mirrors ensure to keep some space between the second mirror and the translation stage. Mind that you might like to add a lens and/or an iris diaphragm.

Doing The Beam Alignment

If the laser beam is already led over the two mirrors to the beam profiler a convinient way to align the laser beam is described in the following.

Assuming that the stage position at the beginning of the drive is position **P1** (0 mm) and the position at the end is **P2** (150 or 300 mm). And assume that the two mirrors in front of the translation stage are **M1** and **M2** (see picture above).



First the stage has to be positioned at P1, then the knobs of the mirror M1 have to be turned for positioning the laser beam in the middle on the camera sensor. If this is done drive the stage to position P2. Here the knobs of mirror M2 have to be set up till the beam is centered again. Repeat these steps as long as the beam moves clearly when the stage moves from P1 to P2.

It is important to turn only one mirror for the corresponding stage position. Then this method will lead to a laser beam parallel to the translation stage axes. The beam should be in the middle of the sensor for any stage position.

Note

For aligning a beam the entire camera sensor should be used. The **Region of Interest** (ROI) can be changed to **Full Size** in the **Device Settings**. For more information see chapter Device Settings 53.

Lens alignment

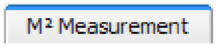
For a M2 measurement a focussing element like a lens is necessary. If the laser beam is set up parallel to the translation stage axes adding a lens into the beam pathway is quite easy.

When inserting a lens the Beam Profiler should rather be at the end of the stage than at the front. If the beam was centered before the lens was added the lens has to be positioned in X and Y direction so that the beam in centered again. In doing so it is crucial to avoid any tilt of the lens.

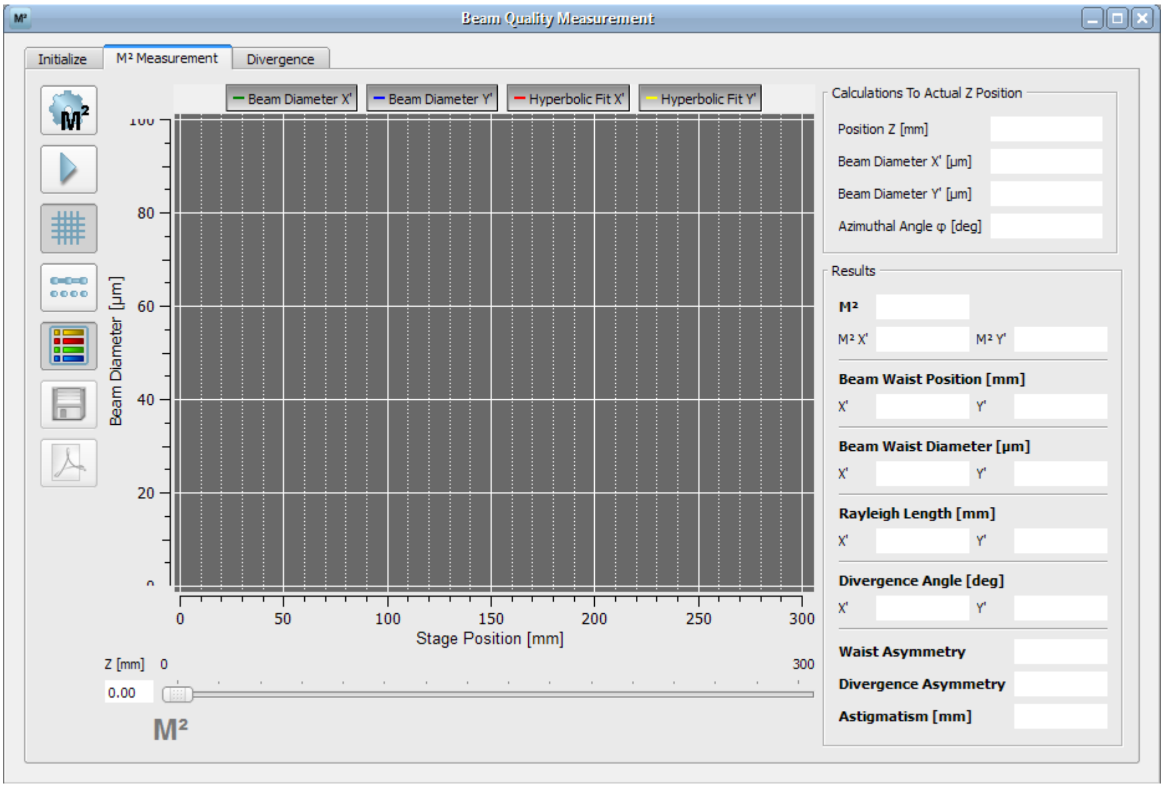
During the lens alignment please make sure, that the camera never enters saturation. Therefore observe during movement the status bar. The closer the BC106 moves to the focus (beam waist), the higher beam intensity and the shorter exposure time becomes. When the BC106 is located close to the beam waist, select the correct ND filter from the filter wheel in order to avoid saturation.

When the beam is still centered at all stage position the lens is well-aligned into the optical path.

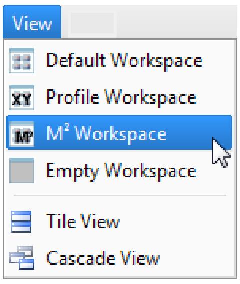
3.5.6.3 M² Panel

This section concerns the M^2 measurement and its settings. Click to 

in the **Beam Quality Measurement** window to enter the **M^2 Measurement** section.



Via Menu "View" -> M² Workspace"



can be accessed a convenient display, consisting of the Beam Quality Measurement panel and 2D profile For more information about the 2D Projection window, see section 2D Projection 33 . Both windows should be arranged that they can be observed and controlled well.

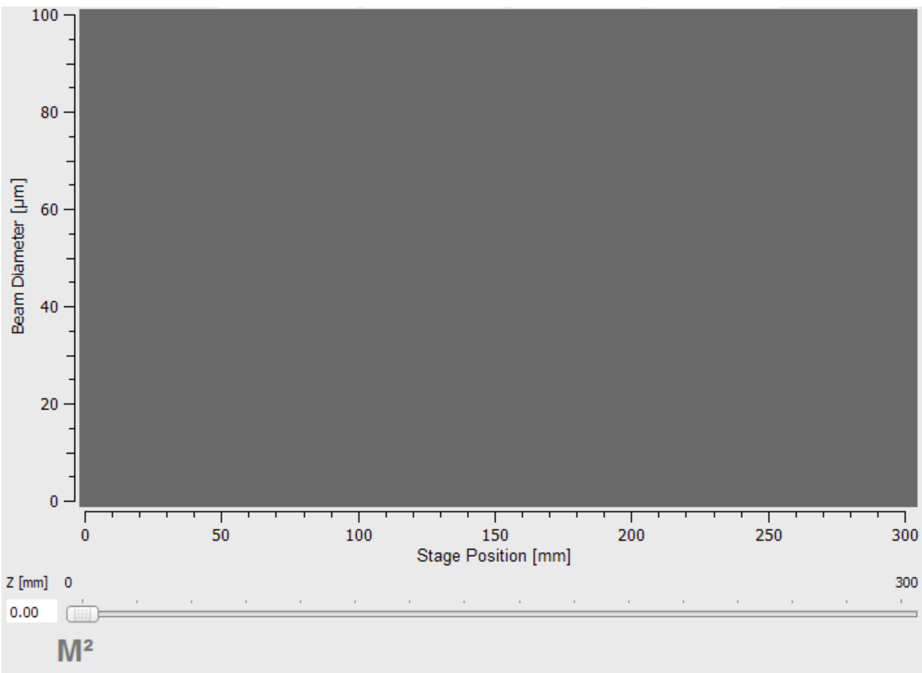
4 buttons above the M² diagram allow to choose the displayed beam diameter (X, Y) and the type of fit to be applied to the measured data. By default, both the X and Y beam diameter will be displayed, and to both parameters, the hyperbolic fit will be applied.
In the example below the "Hyperbolic Fit Y" is disabled.

In the case of a focussed beam, the hyperbolic data fit is recommended. In addition to this fit selection the program is able to identify a coarse beam gradient. If the M² measurement is chosen but the beam shows a linear slope with a beam width variation of less than 50% the Beam software will suggest a linear fit.
If the program detects a (unfocussed) linear beam propagation instead of a (focussed) hyperbolic one the software will recommend to proceed with **Divergence** measurement perform a linear fit to the data points.

Toolbar

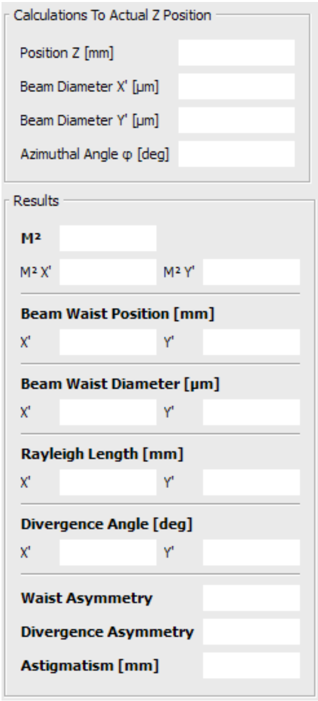
Button Name		Function
	M^2 Settings	Opens the settings for the M^2 measurement
	Play/Stop	Starts / stops a M^2 measurement
	Grid	Disables/Enables the grid in the diagram
	Dots/Line Display	Toggles between a line and dots diagram for the plotted data
	Legend	Opens a window extension with a legend and results panels
	Save Data	In the case of a successful M2 measurement this button enabled and saves plot data.
	PDF Test Protocol	Saves the results of a M^2 measurement into a PDF file

In the diagram (which is of course empty at the beginning) the measured data are plotted.

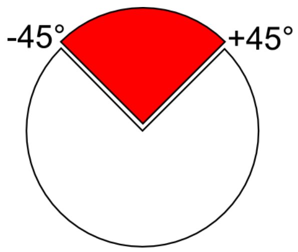


The **Position Bar** at the bottom shows the actual position of the translation stage as seen before in the **Initialize** tab.

On the right side of the diagram the **Calculation To Actual Z Position** and the **Results** of the M^2 measurement are displayed; the boxes are empty so far no measurement has been made yet.



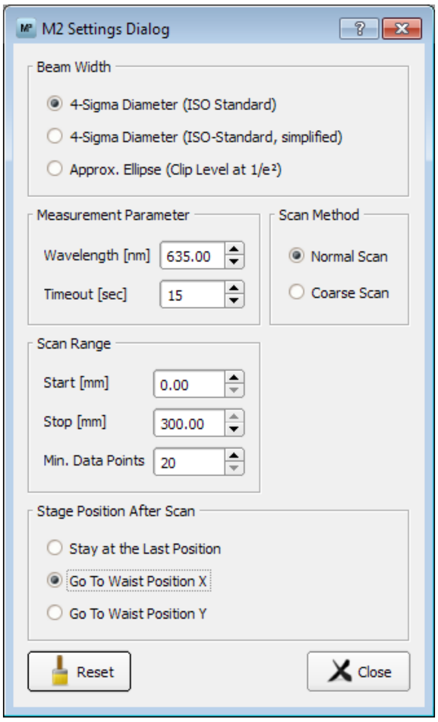
The panel **Calculation to Actual Z Position** contains the following information:

Parameter	What does it show?
Position Z [mm]	Shows the actual Z position of the translation stage in mm.
Beam Diameter X' [µm]Beam Diameter Y' [µm]	In case of 4-sigma beam widths this panel shows the ISO11146 compliant 4-sigma beam diameter in the transformed coordinate system (not lab system) for the actual Z position. In case of ellipse clip level beam widths the shown value equals the min. or max. value of the ellipse.
Azimuthal Angle [deg]	In case of 4-sigma beam widths the azimuthal angle is the absolute azimuthal angle obtained by the 4-sigma beam widhts. The calculation follows the ISO11146-1 standard. Note that the rotation range is not identical with the Orientation 69 used for the ellipse. Rotation angle range:  In case of ellipse clip level beam width the azimuthal angle shows a difference angle to a reference angle. Latter is calculated out of ten frames at the beginning of each beam quality measurement.

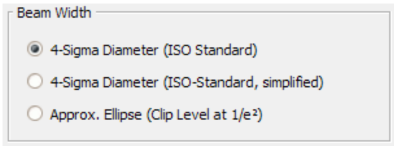
3.5.6.4 M² Settings

For a successful and reliable measurement it is essential to adapt the measurement settings.

Click on [M² icon] to enter the **M² Measurement Settings** dialog.



Beam Width



The calculation of the **4σ Diameter** follows the ISO 11146-1:2005 standards. According to ISO11146-1, if the ellipticity 140 is larger than 0.87, the beam profile may be considered to be of circular symmetry at the measuring location - in this case a 4σ simplified calculation can apply.

It is strongly advisable to select the 4σ option to ensure that the M² measurement is in conformity with ISO11146-1.

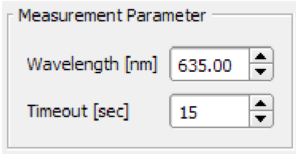
Note
There are two different types of 4σ diameters considered:
When measuring the Beam Profile, in the Calculation Results 39 window the 4σ diameters are related to X and Y direction (lab system - see Coordinate systems) 137

When measuring the M² beam Quality, 4σ diameters are calculated for X' and Y' of the transformed coordinate system, which have in general an non-vanishing angle to the lab system.For more information see the ISO11146-1:2005 standard.

The **Approximated Ellipse** beam width is based on the 13.5% clip level. At the beginning of a measurement a reference angle is determined by averaging over 10 frames. This angle is then used to evaluate all following frames and ellipses.

Since the clip level width suffers from more noise and unsteadiness than the 4σ diameter you should only use this option with well-justified reasons.

Measurement Parameters



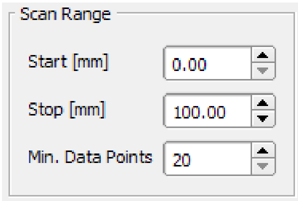
Setting the wavelength is mandatory for correct measured M². If the lasing wavelength is unknown, measure the wavelength using a spectrometer.

Attention

Do not use the nominal wavelength but the actual (measured) wavelength of the laser! Accuracy of this input determines the measurement accuracy.

Timeout is the max. waiting time for a valid camera image. This is to allow the Autoexposure function to obtain a valid camera image

Scan Range

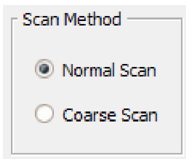


The **Scan Range** determines the range from where to where sleigh of the translation stage is driven during a measurement. **Start** has to be at least 5 mm smaller than **Stop** and greater-than-or-equal to 0 mm. Valid values for Stop are

5 mm < Stop < stage length.

The number of **Min. Data Points** give the (minimum) number of Z positions. The actual number also depends on the **Scan Method**.

Scan Method



The software provides two different kinds of scan methods, the **Normal Scan** and the **Coarse Scan**.

The **Coarse Scan** just takes the sleigh of the translation stage from **Start** to **Stop** (or vice versa depending on the position of the sleigh before starting the measurement). The number of recorded beam widths equates exactly to entered number of **Data Points**.

The **Normal Scan** is in the first instance equal to the Coarse Scan but can add a series of further data points if some conditions for an ISO compliant measurement are not yet given. The ISO standard requires that

"at least 10 measurements shall be taken. Approximately half of the measurements shall be distributed within one Rayleigh length on either side of the beam waist, and approximately half of them shall be distributed beyond two Rayleigh lengths from the beam waist."

This means the first run of the Normal Scan calculates a temporary Rayleigh length and evaluates if enough data points are already measured. If yes a hyperbolic fit is applied. If not a second run adds additional measurements within the Rayleigh length on both sides and/or beyond two Rayleigh lengths.

For a M^2 measurement the Normal Scan is highly advised. Only, for example, for a first estimation position of the beam waist position or other simple applications the Coarse Scan should be used.

Reset

Restores the default settings for M^2 settings:

Option	Default
Beam Width	4-Sigma Diameter (ISO-Standard)
Wavelength	635 nm
Timeout	15 sec
Start	0 mm
Stop	150 / 300 mm (depending on the stage length)
Min. Data Points	20
Scan Method	Normal Scan

Calculation Area

The settings for the **Calculation Area** can be made in the Application Settings 59.
During a Beam Quality Measurement (M^2 or Divergence) the Automatic Calculation Area is enabled by default for effective noise reduction. Reflections and artefacts from filters, lenses or other optical elements can be suppressed as well using the automatic Calculation Area which is close to the beam profile.
This setting can be changed to manual, but this may affect the measurement.
By default the Clip Level of the Calculation Area is set to 1%. This is a reasonable value for most applications and measurements. Lowering the clip level leads to increased calculation area and noise level, this way increasing the measured the beam width.
For some beams it might be useful to adjust the Clip Level to cover the whole intensity.

Initial settings

Independently from the user-defined settings the following options are set automatically for every beam quality measurement.

Setting	Parameter
Calculation Area	Automatic
Auto Exposure	On
Ambient Light Correction	remains as set
Ellipse clip level	13.5%
Approximate Ellipse	On

Note

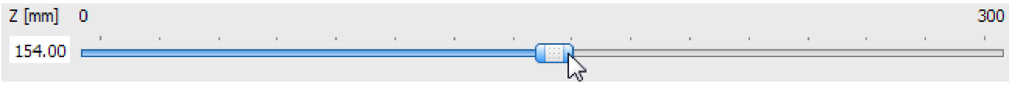
It is strongly recommended to run an ambient light correction 66 prior to any measurement, and then enable Ambient Light Correction. This ensure the most accurate measurement.
Please be aware of the fact that ambient light correction is disabled any time the Beam software is started and/or the settings for attenuation (filter wheel) are changed in the software (see Device settings 50).

3.5.6.5 Running The Measurement

Prior to start measurement, make sure that

- the beam is aligned properly. This means that the beam is completely on the CCD sensor over the whole scan range. If not see chapter Beam Alignment 100 for aligning the beam.

- the right focal length is chosen. When driving the slider of the translation stage from start to stop the beam width minimum should be approximately in the middle of the scan range. Position the sleigh with help of the Position Bar to check this.



- the ambient light is turned off or dimmed as far as possible. Ambient light may disturb the measurement and should be avoided. See M² Application Notes 85 to learn how ambient light can be reduced in a non-dark environment.

- reflections and interferences are avoided as far as possible.

- the laser system is warmed up - depending on the source this might last up to 1 hour.

- the laser output is spatially and temporally stable.

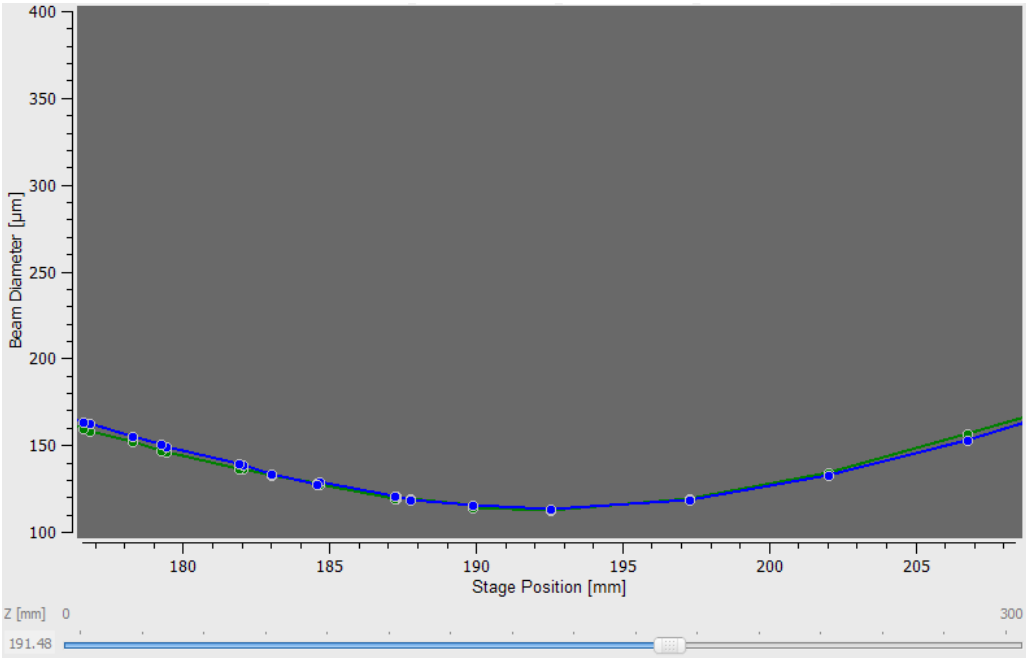
Start the measurement by clicking on the **Start** button .

While running the measurement most of the buttons and options are disabled, e.g.

the M² measurement settings and the toolbar. This prevents the modification of settings during a measurement.

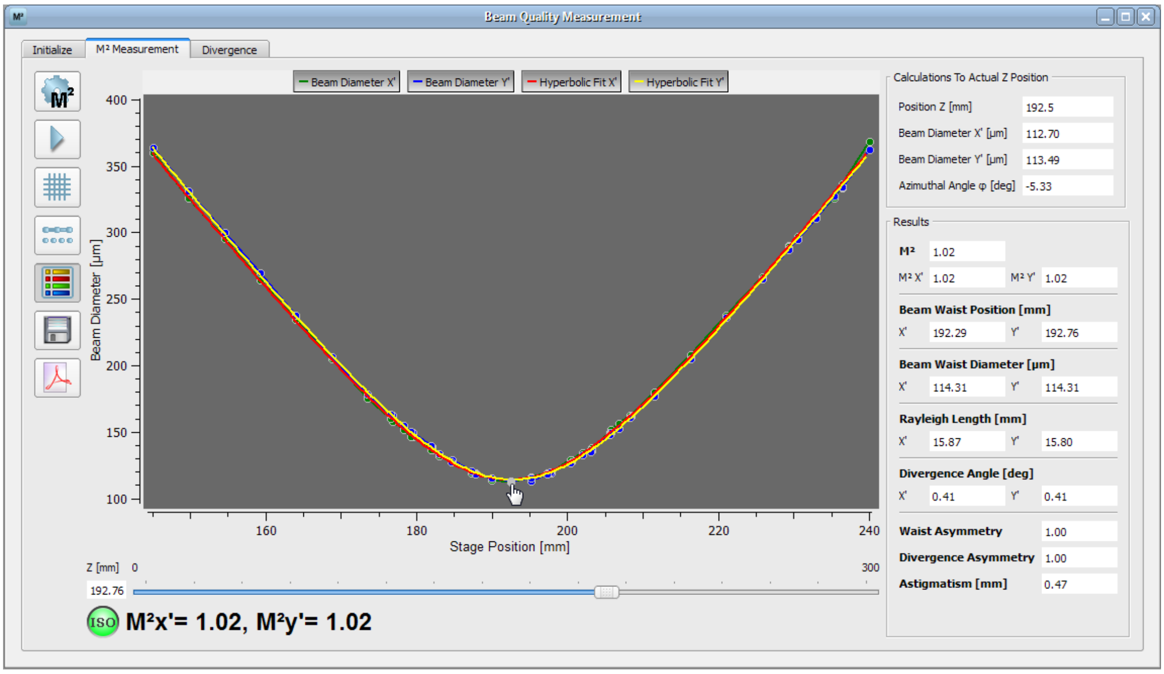
If necessary, the measurement can interrupted by clicking the **Stop** button .

After starting the measurement the X axis of the diagram is adapted to the user-defined scan range, for example from 0 to 120 mm. The Y axis scales automatically to the recorded beam widths.
If the **Normal Scan** is applied the diagram is zoomed in when the fine scanning adds additional data points. After this step (at the end of the measurement) the full scan range is shown again.

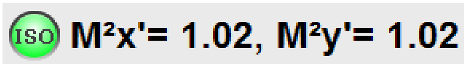


3.5.6.6 Numerical Results

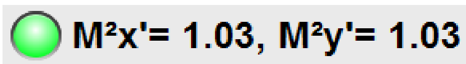
If a M^2 measurement was successful the **Beam Quality Measurement** window looks like the one below.



The green bulb indicates that the measurement was successful and fulfills the ISO 11146 standards.

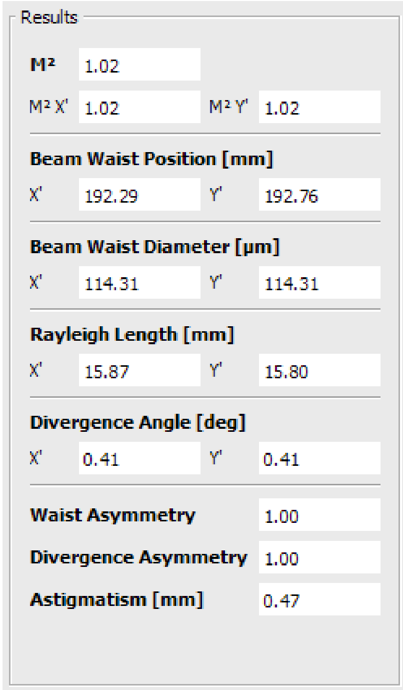


In the case of a non ISO compliant measurement (not 4σ diameters but elliptical approximation was selected, see M² Settings 108) a successful measurement is shown without the ISO indication.



In general the axes X' and Y' do not coincides with the lab system which is described by the axes X and Y. Furthermore the M² value for X' is independently from the one of Y'. For highly elliptical beams like from semiconductor lasers M^2X' and M^2Y' differ much more as in this example.

These values can also be found in the listing of the complete **Results**.



M^2
Mean M^2 value (arithmetic average of M^2 X' and M^2 Y')

M^2 X' and M^2 Y'
M^2 value for X' or Y' axis, respectively, calculated from hyperbolic fit.

Beam Waist Postion X' (Y')
Z position of the beam waist (smallest beam diameter). This is the calculated beam waist position in mm derived from the curve fit. This value may differ from the position where the smallest beam width was measured.

Beam Waist Diameter X' (Y')
Beam diameter in X' and Y' direction in focal point. This is the calculated minimum beam diameter in µm derived from the curve fit. This value may differ from the smallest measured beam width.

Rayleigh Length X' (Y')
Rayleigh length is the calculated distance from the beam waist position in mm derived from the curve fit where the beam diameter is $\sqrt{2}$ times wider than the waist diameter. See also chapter M2 Theory 142.

Divergence Angle
Divergence angle of the focused beam is explained in chapter M2 Theory 142.

Waist Asymmetry
Waist asymmetry stands for the ellipticity at the waist position. It results from the waist diameters in both X' and Y' directions. A waist asymmetry of 1.0 indicates a round beam spot.

$$waist\ asymmetry = \frac{d_{0y}}{d_{0x}}$$

Divergence Asymmetry

Divergence Asymmetry is the quotient of divergence angles in Y and X scan directions. Values differing from 1.0 indicate that the beam ellipticity is changing with z position, for instance an elliptical beam is focussed to a round spot.

$$divergence\ asymmetry = \frac{\theta_y}{\theta_x}$$

Astigmatism

Astigmatism is known as the effect that the beam waist in X and Y scan direction is not at the same z position. So there is a difference between the positions of minimal spot diameters z_{0y} and z_{0y}.

$$astigmatism\_abs = z_{0y} - z_{0x}$$

Note

All results are calculated from the applied fit!

Save Test Results

Save measurement data as ASCII file (*.txt) or as EXCEL spreadsheet (*.xls).

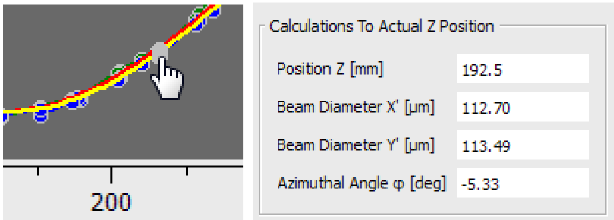
Save measurement data as *.pdf file.

Zooming and panning the display

Both axes in M² measurement result display can be zoomed and also panned.
Panning: Place the mouse pointer onto the axis to be shifted. Press and hold **left mouse button** - the pointer changes to ⇔ or ⇕ depending on the axis direction. Move the mouse as the mouse pointer arrows indicate in order to move through the entire measurement data range for stage position resp. beam diameter.
Zoom: Place the mouse pointer onto the axis to be shifted. Press and hold **right mouse button** - the pointer changes to ⇔ or ⇕ depending on the axis direction. Move the mouse as the mouse pointer arrows indicate in order to zoom in or out the measurement data range for stage position resp. beam diameter.

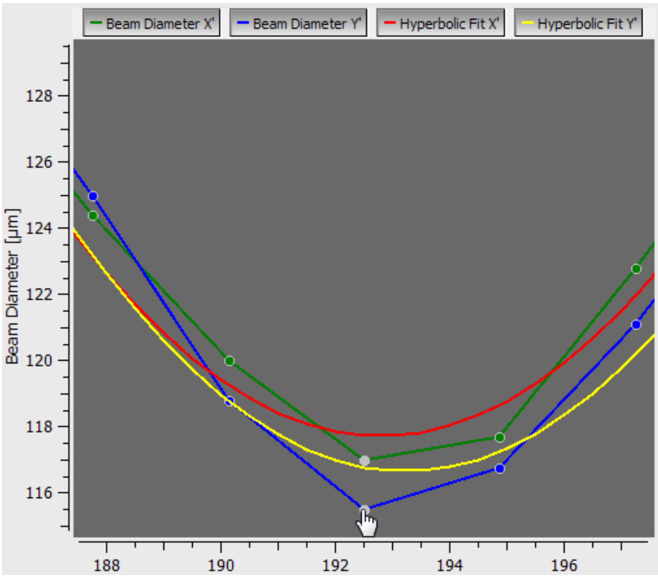
Display of results at a certain Z position

After measurement is finished, the calculated data for Beam Diameter (X') and Beam Diameter (Y') as well as Azimuthal Angle can be retrieved from the curve. Therefore, move the mouse pointer over the M² curve. As soon as it hits a measurement point, it's shape changes to .
Then click to this point. In the Calculations to Actual Z Position panel will appear the position according to the clicked point and the calculated values.



Note

Different from the **Results** pane, here results are calculated from the measured data without hyperbolic fit. So it may happen, that in the waist position, at the actual position are displayed diameter values less that the waist X' (Y') diameters.



In above example, the fitted Y' beam diameter (yellow) is larger than the measured Y' diameter (blue); same is for X' diameters.

3.5.6.7 Troubleshooting

Some typical problems which might occur are discussed in the following.

The beam does not hit the CCD sensor of the camera for all stage positions.
Aligning the beam is necessary, see section Beam Alignment 100.

A timeout occurs during a measurement.
A timeout always occurs when the Beam Profiler camera does not get a valid image. This may happen

- if the camera is saturated. Since the beam is focussed the intensity increases for small beam widths. This may lead to a saturation of the camera. Attenuate the laser beam with additional ND filters or decrease the laser output power. Alternatively increase the focal length (which increases the spot size of the beam) when possible.
- if Normal Scan is applied and the Fine Scan shall add data points then the exposure time has to change from long exposure times to small ones. This can take more time than the timeout allows. Set the timeout to a greater value to solve this problem (M² Settings 107).
- if the beam power is too low. Remove ND filters or increase output power of the laser.
- if the beam size is too small and no ellipse could be calculated (if **Clip Level Ellipse** is selected as beam width). Use a longer focal length to avoid beam size which are too small.
- if the beam is outside the CCD chip. Align the beam, see section Beam Alignment 100.

Parasitic reflections walk over the CCD sensor during the measurement.
These reflections are due to the reflections of the laser light from the CCD to a filter and back to the CCD sensor. This happens when the beam is not perfectly aligned and/or the filters are not parallel to the CCD chip.

The detection of these reflections can be improved by using the logarithmic color scale. A logarithmic scale pronounces smaller intensities which helps to observe reflection with low intensities.
The scale can be switched from **linear** to **logarithmic** by clicking on the color scale. An effective way to avoid these reflections is to use anti-reflection coated ND filters.

See section M² Application recommendations 85 to learn more about AR coated filters and how to mount them.

The M² value differs extremely from the expected value.
For example, the beam has a nearly Gaussian intensity distribution and M² values are larger than 1.1:

- check set wavelength (see M² Settings 107)
- check Clip Level of the **Calculation Area**.
  If the selected Clip Level is too high, the beam might be cut and will be measured too small. This results in a too small beam waist and a too small

M^2 (even below 1).
If the selected Clip Level is too small, this increases the Calculation Area, captures noise around the beam and this way the measured beam width is larger. This leads to an increased M^2.

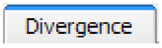
M^2 is smaller than 1.0 - How can this be?
M^2 values < 1.0 are non-physical but may be due to

- a too small Calculation Area (Clip Level too high - see M2 Settings 107)
- the accuracy of the measured result. A error of 5% should be considered.
- incorrect wavelength setting. Set the wavelength to the correct value; M^2 results will be corected without running a new measurement.

The beam profile looks distorted (particularly, at the end positions of the stage).
Even if a laser is expected to produce a Gaussian beam with $M^2 = 1.0$, the beam still can be influenced by every optical element between laser and Beam Profiler. For instance, a focussing lens could be mounted with a tilt or could produce a height distortion which results in optical aberrations.This reduces the beam quality.
Filters and mirrors may impact on the beam profile as well in the case that surfaces are contaminated. Clean surfaces according to manufacturer's instructions.

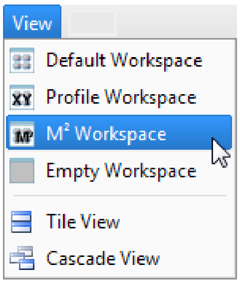
3.5.7 Divergence Measurement

The following section concerns the **Divergence Measurement** and its settings.

Click on  in the **Beam Quality Measurement** window to enter the corresponding section.
For an unfocussed beam the **Divergence** tab has to be chosen for measuring the divergence angle of the beam (which could - of course - converge as well). In this case a linear fit is applied to the measured data.

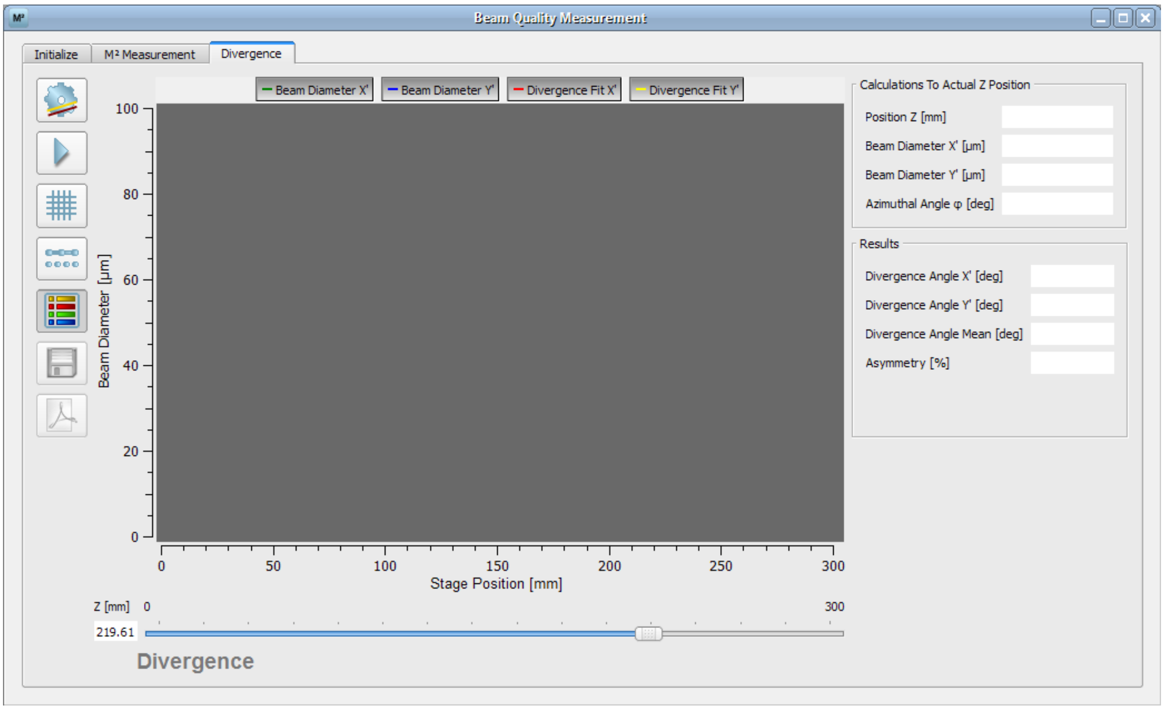
3.5.7.1 Divergence Measurement Panel

If you have selected the M² workspace



you can find two child windows on your program environment, the **Beam Quality Measurement** and the 2D **Projection** window. For more information about the 2D Projection window, see section 2D Projection 33. Both windows should be arranged that they can be observed and controlled well.

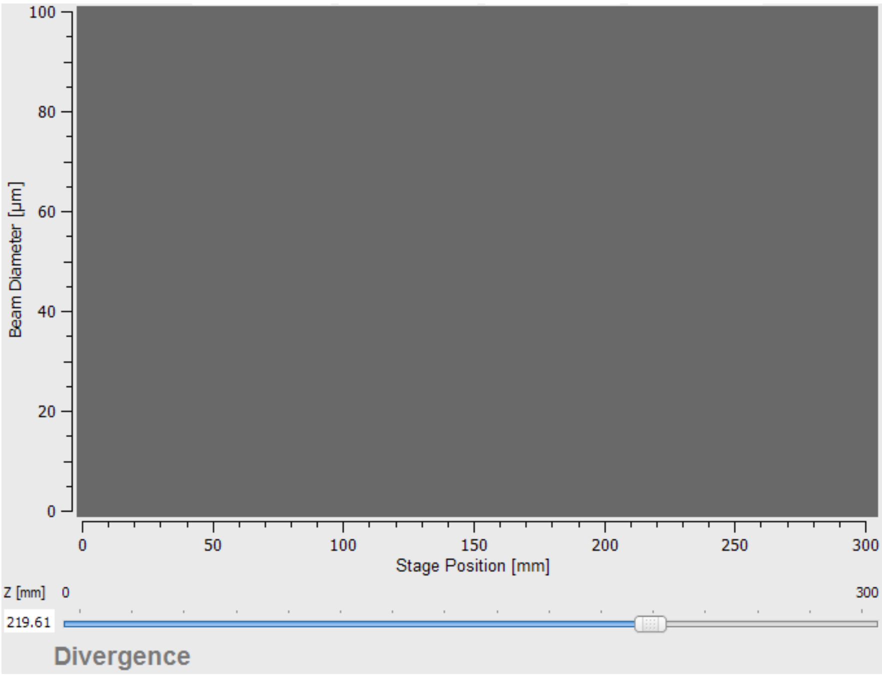
Divergence tab:



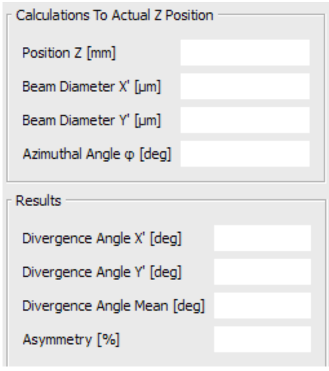
Same as in the M² Measurement tab you find on the left hand side a **Toolbar** which provide the following functionality.

Button	Name	Function
	Divergence Settings	Opens the settings for the Divergence measurement
	Play/Stop	Starts / stops a Divergence measurement
	Grid	Disables/Enables the grid in the diagram
	Dots/Line Display	Toggles between a line and dots diagram for the plotted data
	Legend	Opens a window extension with a legend and results panels
	Save Data	In the case of a successful divergence measurement this button enabled and saves plot data.
	PDF Test Protocol	Saves the results of a divergence measurement into a PDF file

In the diagram (which is of course empty at the beginning) the measured data are plotted.



The **Position Bar** at the bottom shows the actual position of the translation stage as seen before in the **Initialize** tab.
On the right side of the diagram the **Calculation To Actual Z Position** and the **Results** of the M^2 measurement are displayed; the boxes are empty so far no measurement has been made yet.

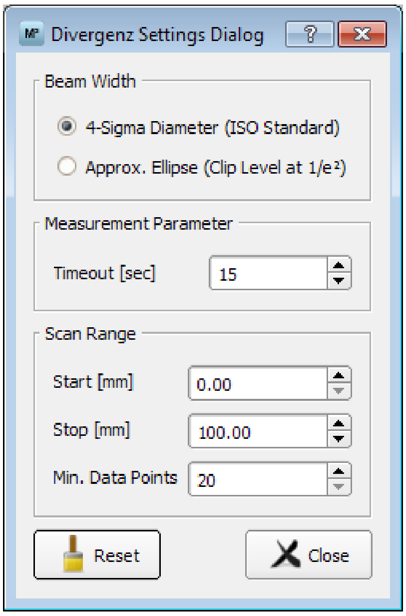


The panels of the **Calculation To Actual Z Position** and **Results** are described in the M² Measurement 104 section.

3.5.7.2 Divergence Measurement Settings

For a successful and reliable measurement it is essential to adapt the settings of the software.

Click on  to enter the **Divergence Measurement Settings**.



Beam Width

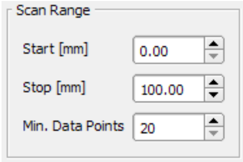
The Beam Width can be selected from the two already known methods.
The calculation of the **4σ Diameter** follows the ISO 11146-1:2005 standard.

The **Approximated Ellipse** beam width is based on the 13.5% clip level. At the beginning of a measurement a reference angle is determined by averaging over 10 frames. This angle is then used to evaluate all following frames and ellipses.

Measurement Parameters

Timeout is the max. waiting time for a valid camera image. This is to allow the Autoexposure function to obtain a valid camera image
Wavelength is not relevant for divergence measurement.

Scan Range



The **Scan Range** determines the range from where to where sleigh of the translation stage is driven during a measurement. **Start** has to be at least 5 mm smaller than **Stop** and greater-than-or-equal to 0 mm. Valid values for Stop are
5 mm < Stop < stage length.

Note

It is advisable to set up a larger scan ranges than 40 mm to ensure higher accuracy. A scan over the entire translation length is often the best choice.

Reset

Restores the default settings for M^2 settings:

Option	Default
Beam Width	4-Sigma Diameter (ISO-Standard)
Timeout	15 sec
Start	0 mm
Stop	150 / 300 mm (depending on the stage length)
Min. Data Points	20

Calculation Area

The settings for the **Calculation Area** can be made in the Application Settings 59.
During a Beam Quality Measurement (M^2 or Divergence) the Automatic Calculation Area is enabled by default for effective noise reduction. Reflections and artefacts from filters, lenses or other optical elements can be suppressed as well using the automatic Calculation Area which is close to the beam profile.
This setting can be changed to manual, but this may affect the measurement.
By default the Clip Level of the Calculation Area is set to 1%. This is a reasonable value for most applications and measurements. Lowering the clip level leads to increased calculation area and noise level, this way increasing the measured the beam width.

Note

Setting the Clip Level of the Calculation Area for divergence measurements is not as critical as for M^2 measurements. Increasing the Clip Level will give smaller beam widths but might cut the beam profile.

Initial settings

Independently from the user-defined settings the following options are set automatically for every beam quality measurement.

Setting	Parameter
Calculation Area	Automatic
Auto Exposure	On
Ambient Light Correction	remains as set

Note

It is strongly recommended to run an ambient light correction 66 prior to any measurement, and then enable Ambient Light Correction.
Please be aware of the fact that ambient light correction is disabled any time the Beam software is started and/or the settings for attenuation (filter wheel) are changed in the software (see Device settings 50).

3.5.7.3 Running The Measurement

The divergence measurement is thought to measure low divergent or convergent beam propagations. Therefore, it is required to remove any focussing elements which produce a beam waist within the scan range.

Prior to start measurement, make sure that

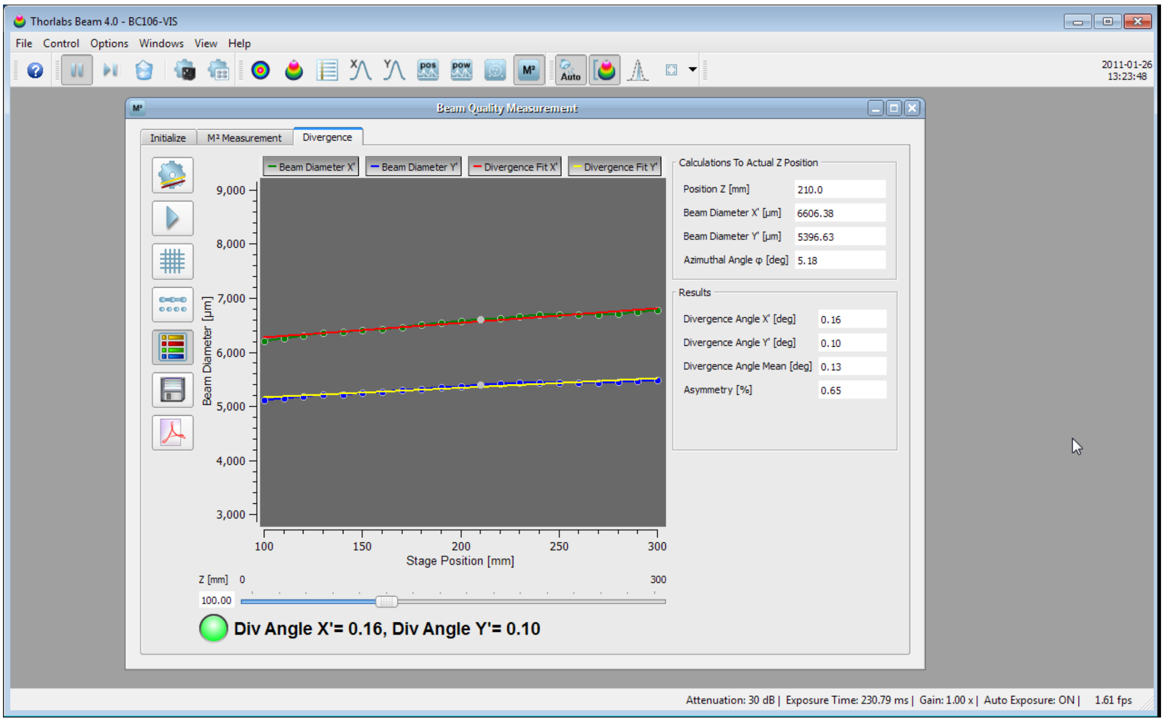
- the beam is aligned properly. This means that the beam is completely on the CCD sensor over the whole scan range. If not see chapter Beam Alignment 100 for aligning the beam.
- the ambient light is turned off or dimmed as far as possible. Ambient light may disturb the measurement and should be avoided. See M² Application Notes 85 to learn how ambient light can be reduced in a non-dark environment.
- reflections and interferences are avoided as far as possible.
- the laser system is warmed up - depending on the source this might last up to 1 hour.
- the laser output is spatially and temporally stable.

Start the measurement by clicking on the **Start** button .
While running the measurement most of the buttons and options are disabled, e.g. the Divergence measurement settings and the toolbar. This prevents the modification of settings during a measurement.

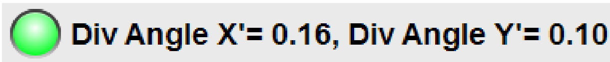
If necessary, the measurement can interrupted by clicking the **Stop** button .
After starting the measurement the X axis of the diagram is adapted to the user-defined scan range, for example from 0 to 120 mm. The Y axis scales automatically to the recorded beam widths.

3.5.7.4 Numerical Results

If a divergence measurement was successful the **Beam Quality Measurement** window looks like the one below.

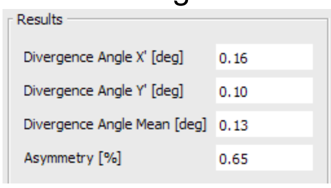


The green bulb indicates that the measurement was successful.



In general the axes X' and Y' do not coincides with the lab system which is described by the axes X and Y. Furthermore the divergence angle for X' is independent from the one of Y'. For highly elliptical beams like from semiconductor lasers the divergence angles of X' and Y' could differ much more as in this example.

These values can also be found in the listing of the complete **Results**.



Note

All results are calculated from the applied fit!

Divergence Angle X' (Y')

Divergence angle is explained in chapter M2 Theory 142.

Asymmetry

Asymmetry is the quotient of divergence angles in Y and X scan directions. Values differing from 1.0 indicate that the beam ellipticity is changing with z position, for instance an elliptical beam is focussed to a round spot.

$$divergence\ asymmetry = \frac{\theta_y}{\theta_x}$$

Save Test Results

 Save measurement data as ASCII file (*.txt) or as EXCEL spreadsheet (*.xls).

 Save measurement data as *.pdf file.

Zooming and panning the display

Both axes in M^2 measurement result display can be zoomed and also panned, see M^2 Measurement results 115.

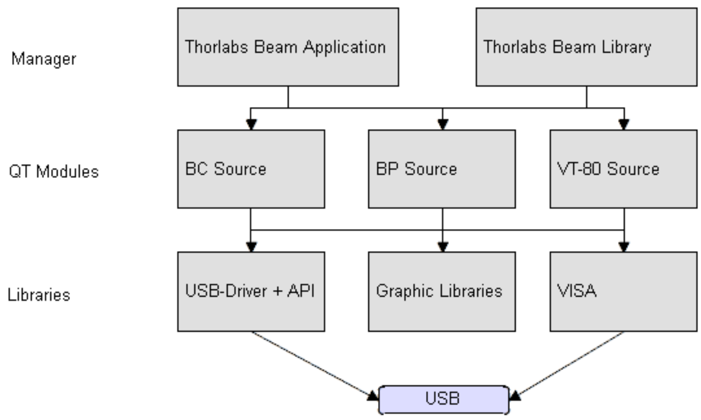
4 Computer Interface

Thorlabs Beam software is a 32 bit Windows® application capable to recognize, initialize and control scanning slit and camera beam profiler instruments. This software was created in Visual Studio 2008 and uses QT libraries.
Instrument control via device drivers or VISA is executed in separated from the software modules, located in dynamic libraries.
Upon start of Thorlabs Beam software the installation directory is being scanned for libraries with a certain QT plug-in interface. If such libraries were found, the software loads them in order to communicate with the device via this interface.
Individual applications can directly access the interface via the device modules by loading the appropriate libraries using the QT plug-in procedure. Alternatively, the ThorlabsBeamLibrary administrates these modules and this way enables a QT independent access to connected beam profiler instruments.

4.1 Libraries

Thorlabs Beam software is split into 3 levels:

- 3rd party components (USB drivers, VISA)
- QT/C++ libraries (device modules directly accessing device drivers)
- Thorlabs Beam application (loads the modules and communicates with them via QT plug-in interface) and Thorlabs Beam Library (shifts the functionality of the Thorlabs Beam application into a C++ library)



For individual applications, there are two levels to set up:

- a QT application to communicate with the modules using the defined QT plug-in interface
- an application using the Thorlabs Beam Library
-

1. QT Application

A QT application can be created in a development environment like QtCreator or Visual Studio. QT libraries `qtmain.lib`, `QtCore4.lib` and `QtGui4.lib` must be included.

Device modules include the „IBeamProfiler“ interface for accessing the modules.

This interface must be included in your application:

```
#include "IBeamProfiler.h"
```

To load modules, a QPluginLoader is used. It looks up in all libraries in the addressed folder for QT plug-in interface and attempts to load the plug-ins:

```
QPluginLoader loader(fileName);
QObject *plugin = loader.instance();
```

If the plug-in has been loaded, the interface IBeamProfiler can be extracted from the module:

```
IBeamProfiler* deviceClass = qobject_cast
<IBeamProfiler*>(plugin);
```

Now, all functions can be accessed via the interface.
The function `deviceList()` generates a list of all connected devices:

```
const QList<DEVICE_SETTINGS>* deviceList =
deviceClass->deviceList();
```

Device Settings include the essential device parameters. Not all beam profiler devices support all Device Settings parameters. Some parameters are valid only for the Camera beam profiler BC106* (Trigger, Exposure, Gain, Corrections), other parameters only for the Scanning Slit beam profiler BP10x (Target Resolution, Scan Rate, Auto Gain, Bandwidth and DC).
A set of device parameters is required to initialize a connected device:

```
DEVICE_SETTINGS deviceSettings = deviceList->at
(0);
deviceClass->initializeDevice(&deviceSettings);
```

When terminate your own application, devices must be released:

```
deviceClass->releaseDevice();
```

2. Thorlabs Beam Library application
Thorlabs Beam Library is a library handling the device modules and providing simple functions for device access.
Prior to all, a library instance must be created. Device modules are searched and loaded:

```
CreateThorlabsBeamInstance();
```

The function below returns the number of connected devices:

```
GetConnectedDeviceCount();
```

A device is initialized with a device identifier. The ID is “0”, if only one device is connected, and 0 or 1, if two devices are present:

```
InitDevice( unsigned long deviceID);
```

Prior to terminate the application. the library instance must be released:

```
ReleaseThorlabsBeamInstance();
```

Retrieve measurement results:

```
GetMeasurement()
```

Measurement results are created in the library, user access only by reference.

```
GetMeasurementCopy()
```

First, a result variable must be created; then the function copies the results from library to the result variable. This function is required when a programming language handels the memory managemenent independently and cannot access results by refererence (e.g. LabVIEW®).

3. LabVIEW® application

For LabVIEW® programming VIs (converted from Thorlabs Beam Library functions) are supplied. These VIs allow to use all Thorlabs Beam Library functions.

4.2 Sample Programs

C++ program sample with MFC

Sample program „ThorlabsBeamSamplec++MFC“ is a standard MFC application with inserted Thorlabs Beam library functions. Modifications are bordered as below:

```
//*************** Thorlabs Beam ****************
[ …]
//**********************************************
```

First, the Thorabs Beam library is included and an instance created:

```
#include "ThorlabsBeamLibrary.h"
CreateThorlabsBeamInstance();
```

If at least one device is connected, it is being initialized with standard settings.

```
int deviceCount = GetConnectedDeviceCount();
if (deviceCount > 0)
{
InitDevice(0);
}
```

In the message loop the PaintEvent is used to trigger the measurement cycle. To keep it running, the PaintEvent is continously recalled:

```
InvalidateRect( msg. hwnd, &clientRect, false);
```

In PaintEvent a new result is requested:

```
CALCULATION_CLUSTER calcCluster;
                unsigned char* imageData = NULL;
                int width;
                int height;
                int lStride;
if( 0 == GetMeasurement( &calcCluster, &imageData, &width, &height,
&lStride))
{
[ …]
}
```

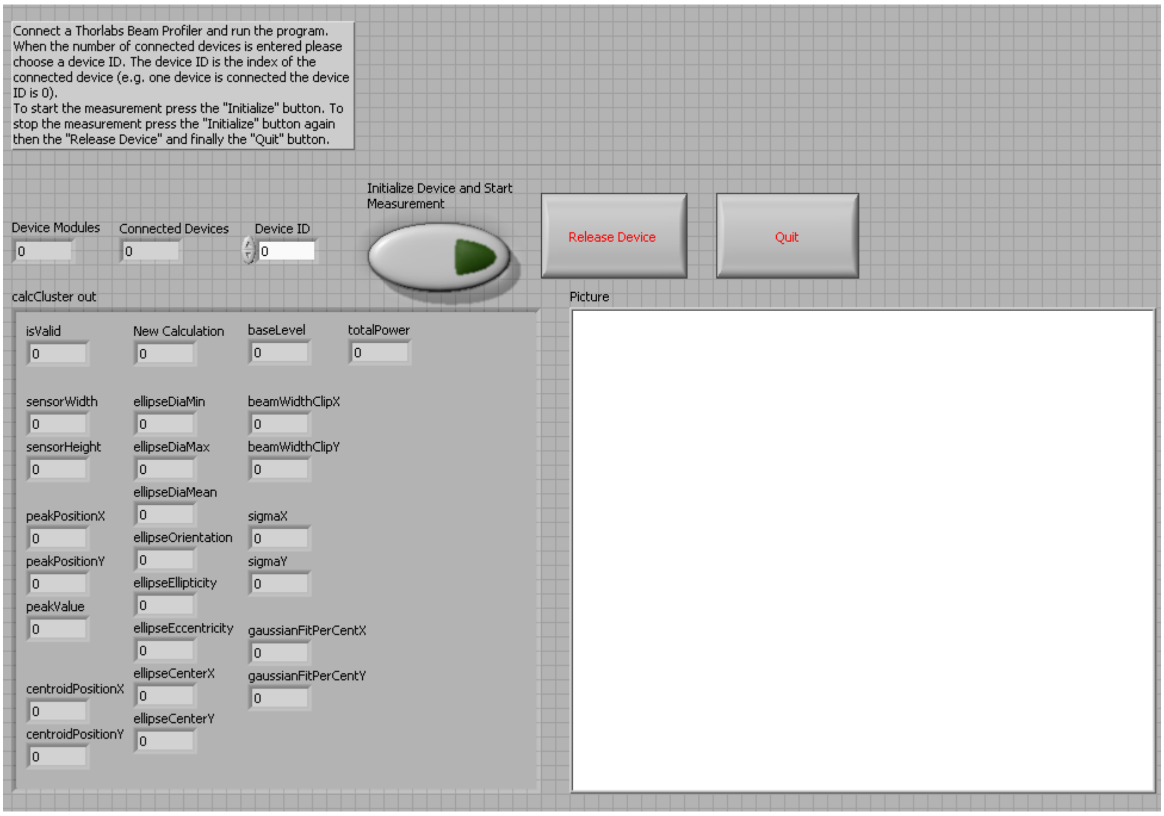
When terminate the program, devices and their drivers are being released:

```
ReleaseThorlabsBeamInstance();
```

LabVIEW® program sample

Here, the Thorlabs Beam library functions are used via VIs. These VIs are located in the „ThorlabsBeamLibrary.lvlib" library.
Description of „ThorlabsBeamLabViewSample.vi":

- at program start, the Thorabs Beam Library is initialized
- the number of connected devices is displayed in the „Connected Devices" box
- the index entered to „Device ID" box identifies which of the connected devices shall be used
- by clicking to the „Initialize Device and Start Measurement" button a measurement cycle is started, results are written to the „calcCluster" structure and the image of the camera (or reconstruction of the slit beam profiler) is displayed in the „Picture" box.
- to exit the program:
  switch off the button „Initialize Device and Start Measurement",
  click to „Release Device"
  click „Quit" button.



4.3 Thorlabs Beam Library

Function description of the Thorlabs Beam Library can be found in the file „ ThorlabsBeamLibrary.h“:

```
// load the device modules
// return: number of device modules found
THORLABSBEAMLIBRARY_API unsigned short  CCONV CreateThorlabsBeamInstance();

// collects the number of connected devices
// return: number of connected devices (number is deviceID)
THORLABSBEAMLIBRARY_API unsigned long   CCONV GetConnectedDeviceCount();

// initializes the device with default settings
// parameter deviceID: index of connected device
// return: success of initialisation (0 = success, -1 = failed)
THORLABSBEAMLIBRARY_API short   CCONV InitDevice(unsigned long deviceID);

// changes the clip level
// parameter clipLevel: value between 0.0 an 1.0 (e.g. 1/e² = 0.135)
THORLABSBEAMLIBRARY_API void    CCONV ChangeClipLevel(float clipLevel);

// changes the wavelength which have influence on the power
// parameter wavelength: wavelength depends on the device model from 190.0 to 2700.0
THORLABSBEAMLIBRARY_API void    CCONV ChangeWavelength(float wavelength);

// fills the calculation result and image parameter
// parameter calcCluster: reference on a CALCULATION_CLUSTER structure
// parameter pData: NULL pointer. The pointer refers to the internal buffer for the image data
// parameter pWidth: Width of the image
// parameter pHeight: Height of the image
// parameter pStride: Bytes of pixel data per image line (e.g. 1 od 2 byte per pixel = width or
twice the width)
// return: success of measurement (0 = success, -1 = failed)
THORLABSBEAMLIBRARY_API short   CCONV GetMeasurement(CALCULATION_CLUSTER* calcCluster, unsigned
char** pData, int* pWidth, int* pHeight, int* pStride);

// fills the calculation result and image parameter and copies the image data
// parameter calcCluster: reference on a CALCULATION_CLUSTER structure
// parameter pData: preinitialized data buffer where the image data is copied into (min. size is
2785280 Bytes)
// parameter pWidth: Width of the image
// parameter pHeight: Height of the image
// parameter pStride: Bytes of pixel data per image line (e.g. 1 od 2 byte per pixel = width or
twice the width)
// return: success of measurement (0 = success, -1 = failed)
THORLABSBEAMLIBRARY_API short   CCONV GetMeasurementCopy(CALCULATION_CLUSTER* calcCluster, unsigned
 char* pData, unsigned long* pWidth, unsigned long* pHeight, unsigned long* pStride);

// closes the device and releases all resources
THORLABSBEAMLIBRARY_API void    CCONV ReleaseThorlabsBeamInstance();
```

5 Maintenance and Repair

Protect the beam profiler from adverse weather conditions. The beam profiler is not water resistant.

Attention

To avoid damage to the instrument, do not expose it to spray, liquids or solvents!

The unit does not need a regular maintenance by the user.
The Camera Beam Profiler does not contain any modules that could be repaired by the user himself. If a malfunction occurs, the whole unit has to be sent back to Thorlabs. Do not remove covers!

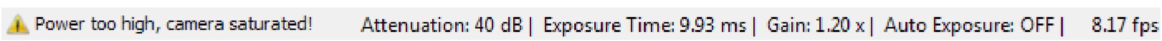
5.1 Version and other Information

The menu entry **Help → About Thorlabs** displays application relevant data.

In case of a support request, please submit the software version of the application. This will help to locate the error.
Visit Thorlabs website www.thorlabs.com to download the latest updates of the Beam Profiler Software.

5.2 Warnings and Errors

In order to prevent measurement errors the user will be informed about improper Camera Beam Profiler measurement conditions using error and warning messages within the status bar. In this case the user should take action immediately in order to eliminate bad measurement conditions. Example:



Possible errors and warnings:

Power too high, camera saturated!

Explanation

Some pixels within the selected ROI or Calculation Area are saturated because they reach the maximum digit value (255 in Fast Mode (8 bit data) and 4095 in Precision Mode (12 bit data)). Therefore, the local beam intensity may be even higher than displayed. Calculated beam parameters cannot be calculated correctly!

Resolving

Decrease Exposure Time and Gain settings or reduce the beam intensity using a higher attenuation ND filter of the Filter Wheel 9. You may also cascade two filters.

If automated Exposure Control is activated, a short appearance of this error is harmless because Exposure Time and Gain will be reduced automatically

Power too low!

Explanation

The brightest pixel values fall below 10% of the available saturation range. This means that 90% of the available range remains unused. Therefore, measurement noise is increased by digitizing noise.

Resolving

Increase Exposure Time and Gain settings or increase the beam intensity using a lower attenuation ND filter of the Filter Wheel 9. You may also remove the filter.

High ambient power level!

Explanation

The lowest pixel value within the selected camera ROI or Calculation Area is too high. Therefore, the beam edges cannot be detected or distinguished from a constant ambient light level. The reasons are either the laser beam diameter is wider than the chosen ROI or the ambient light is too high.

Calculated beam parameters cannot be calculated correctly!

Resolving

Choose a larger ROI so that its height and width is at least twice the beam diameter.

Reduce the influence of ambient light by proper shielding or select a higher attenuation out of the Filter Wheel 9 and increase the beam power.

Attention

Calculation results are not reliable as long as an error or warning is displayed within the status bar!

5.3 Cleaning

Since the protective glass window was removed from the camera sensor to prevent optical interferences it has become extremely vulnerable!

Removing dust from the naked sensor chip can only be done using compressed gas which is free from oil and water. Thorlabs duster spray (Tetrafluoroetane) can be recommended. Keep the gas nozzle at least at a distance of **4 inches (10 cm)** from the sensor surface, otherwise liquid gas drops may hit the sensor and leaving marks visible in the camera image!

Attention

The camera sensor cannot be cleaned by conventional methods using ethanol or cleaning tissue! Warranty will be violated when other cleaning methods are used.
Keep a distance of minimum 4 inches (10 cm) when cleaning using compressed gas.

In case a professional cleaning of the windowless CCD sensor is required, please return the instrument to Thorlabs, see the appropriate Addresses 161.

ND Filters
ND filters (see Filter Wheel 9)can be cleaned by conventional methods using pure ethanol and/or cleaning tissue. You may clean the front surface of the ND filters without unscrewing the appropriate filter holder. After tissue cleaning it is recommended to remove remaining lints using compressed air.
In case dust is still visible within the camera image, unscrew the filter holder and clean the ND filter's rear surface. In addition, remove dust from the sensor itself (compressed air only!).
The instrument itself may be cleaned using a wet lint-free cloth.

5.4 Troubleshooting

Software Installation failed

Be sure to have **administrative rights** on your computer which enables you to install software at all. Ask your system administrator to give you such rights or to do the installation himself. See Software Installation 13 for details.

No beam profiler recognized

If after starting of Beam software no instrument was recognized, the Device Settings button in the Menu bar will be  This will be the case also if no instrument is connected to the PC.

- Check the USB cable
- Check proper driver installation
- Check if the green LED lights up - LED off indicates that the Beam Profiler's firmware isn't loaded.

See section Connection to the PC 23 for details.

You may unplug and reconnect the Beam Profiler to a different USB port or use a different USB cable. Wait a few seconds, until the green LED lights up. Then click **'Refresh Device List'** within the Device Selection panel. See chapter Start the Application 24 for a detailed description.

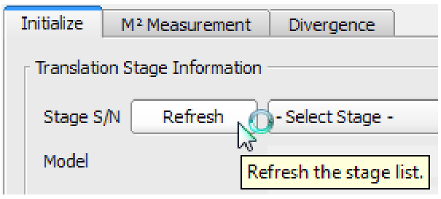
No translation stage recognized

If the M² translation stage was not initialized after Beam software start,

- check if the stage is powered up (red LED blinking)
- check the connection of the stage to the PC
- check for proper USB-to-Serial converter driver installation, if used

See section Electrical Connections 95 for details.

- Press the Refresh button



See section Initialize 98 for details.

Fixed sample image instead of live camera image

The Beam Profiler software selects automatically a stored camera image if no camera could be found during program start. This is indicated by the image path name in the status bar.
To operate a Beam Profiler instrument:

- Connect a BC106 Beam Profiler to the PC and wait a few seconds until its LED lights up green.
- Click **'Refresh Device List'** within the Device Selection panel.
- Select the instrument and click 'Close'

See chapter Start the Application 24 for a detailed description.

Erroneous or no measurement results

- Uncover the camera's filter caps.
- Direct the beam to be measured to the Beam Profiler aperture. Check it's power level is within the measurable Power Range 75.
- Check Exposure Time and Gain settings. Choose **'Auto Exposure Control'** in Device Settings.
- Check for **error messages** in the status bar. Ambient power may be too high or beam power too low or high. See Warnings_and_Errors 132.

No update of results and graphs

- The device is in the pause mode, resume the device: Press in Menu bar the Start button.
- The "**Average over frame**" rate might be high, check its value in the Application Settings 59.
- You may have selected the **'Software Trigger'** mode but the 'Min. Image Saturation' limit is not reached. Increase Exposure Time or even Gain to enable a sufficient high pulse intensity.
- A **'Hardware Trigger'** mode may be activated but no TTL trigger pulse is launched into the BNC input jack. Provide a trigger signal.

Menu, toolbar and setting controls do react lowly

- The graphics adapter of your PC may have too low graphical performance. Especially the 3D Profile window requires much capacity at high resolution which decreases its update rate extremely. See recommended system Requirements 13.
- The AD converter was set to Precision mode (12 bit data) - see Device Settings 56

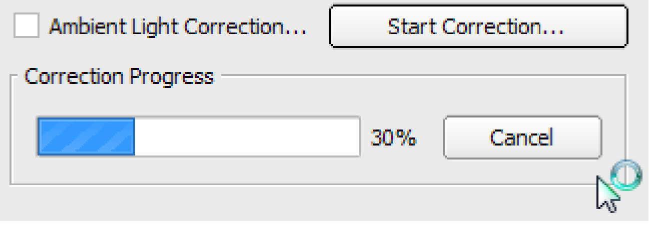
6 Application Note

This chapter contains the background knowledge about the measurement methods of beam profiles.

Beam profiles can be characterized by a number of different parameters. Our aim was to offer measurement of all usual beam parameters based on ISO11146-1.
In the following sections detailed explanations are given to the measured parameters.

6.1 Ambient Light Correction

Thorlabs Beam software implements a unique Ambient Light Correction (ALC) method.
You may have noticed, that the correction process takes a certain time, shown on the progress bar:



After the laser beam has been blocked, the ALC records a number of images at different exposures and averages them. Intermediate values are being interpolated. This allows a precise calculation of the camera's baseline with ambient light valid at different exposure times.
An outstanding property of the ALC is, that the baseline is determined as an average of the ambient light "noise" and does not clip negative intensity values. If the baseline is defined in a way, that negative values are possible, the ambient light sums up to a value close to Zero. This turns out in a significant advantage particularly for M^2 measurements - the 4σ values can be determined with a higher accuracy, as in this case the interference of ambient light is nearly eliminated.

6.2 Coordinate systems

Lab System
The lab system (AKA reference system) of coordinates is based on the true X and Y coordinate orientation of the CCD camera chip (X = lines, Y = columns).

Transformed System
The transformed system of coordinates is based on the calculated beam axes (minor and major axes for elliptical fit or for 4σ beam diameter).

6.3 Raw Data Measurements

Beam Width (4σ)
Width on **X** and **Y** axes (centroids), based on the second moment calculation

$$d_{\sigma x} = 4 * \sigma_x = 4 * \sqrt{\frac{\sum\left[(x - x_{centroid})^2 * p(x,y)\right]}{Sum\_Intensity}}$$

$$d_{\sigma y} = 4 * \sigma_y = 4 * \sqrt{\frac{\sum\left[(y - y_{centroid})^2 * p(x,y)\right]}{Sum\_Intensity}}$$

Beam width (4σ) can be calculated also based using radial distance (pixel - centroid; **R**).

According to ISO11146-1, if the ellipticity 140 is larger than 0.87, the beam profile may be considered to be of circular symmetry at that measuring location. In this case, ISO11146-1 allows to calculate only one common 4σ beam width (4σ simplified).

Beam Diameter (4σ)
Diameter based on second moment calculation on radial distance (pixel-centroid):

$$d_{\sigma} = 2 * \sqrt{2} * \sqrt{\frac{\sum\left[((x - x_{centroid})^2 + (y - y_{centroid})^2) * p(x,y)\right]}{Sum\_Intensity}}$$

Effective Beam Diameter
Circle diameter of equivalent beam area with pixel intensities above a level X% (clip level) down from the peak intensity:

$$D_{eff} = \sqrt{\frac{4 * N * A_{pix}}{\pi}}$$

with
N number of pixels with intensities above clip level
A_{pix} pixel size (for BC106 = 6.45*6.45µm²)

Peak Position
X, Y: position of the pixel with highest intensity (AD value) which is found first with respect to reference position.

R = $\sqrt{X^2 + Y^2}$ = radial distance of same pixel from reference position
Reference position is the sensor's center.

Centroid Position
X, Y and **R** position (first moment), calculated over all pixels with respect to the above reference position.

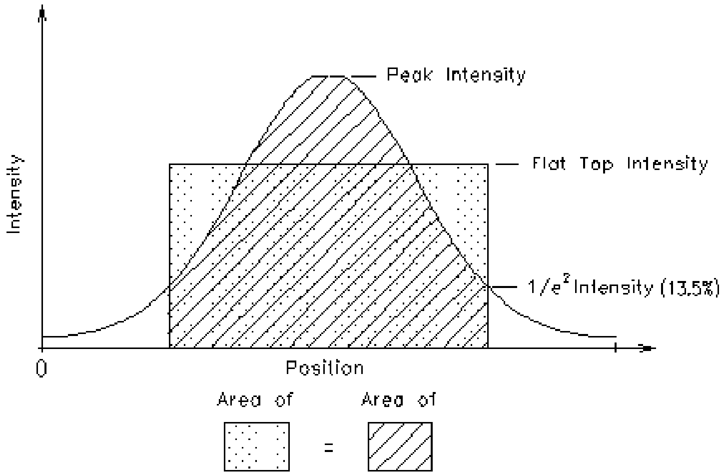
$X= SUM [x * p(x,y)] / I$
$Y= SUM [y * p(x,y)] / I$

where:
p(x,y) intensity at location (x,y);
I total intensity;
SUM of pixels taken taken over entire area

AD Saturation
Saturation level of the instrument's AD converter.

Total Power
Total power within the Calculation Area 59.

Effective Area
Area of an ideal flat top beam with same peak intensity:



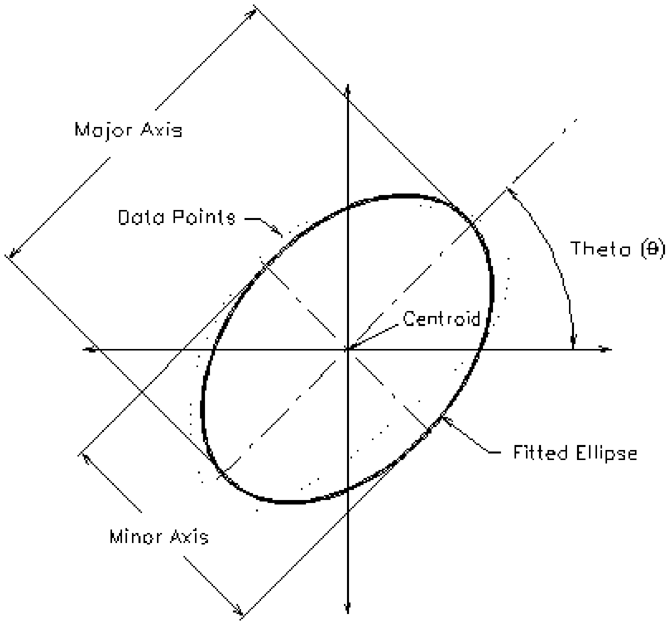
$$A_{eff} = \frac{SumAllPixels}{PeakIntensity} * PixelArea$$

For calculation into mm² , PixelArea is equal to 6,45*6,45 µm²

Peak Density
Power on peak pixel divided by its area

6.4 Ellipse (fitted)

The beam shape is being fitted to an ellipse using the set clip level (down from the peak).



Diameter (clip level) is given for the minor axis (**min**), major axis (**max**) and their arithmetic **mean** value.

Ellipticity and **Eccentricity** of the beam are defined in ISO 11146-1 as

$$Ellipticity = \frac{d_{min}}{d_{max}} \qquad Eccentricity = \frac{\sqrt{d_{max}^2 - d_{min}^2}}{d_{max}}$$

where d_{min} denotes the minor and d_{max} the major axes of the approximated beam ellipse, respectively.

Orientation denotes the angle θ of the major ellipse axis is with respect to the horizontal x axis and is within the range $-90° < \theta \leq 90°$.

6.5 X-Y-Profile Measurement

Beam Width Clip (xx%)

Beam width is the distance between two points on opposed edges of a captured beam profile in X and Y axis whereas its height is defined by a certain percentage of the peak power. This percentage is called clip level.

Preferred clip levels are for instance 50 % (Full Width at Half Maximum) and 13.53% (exactly $1/e^2$).

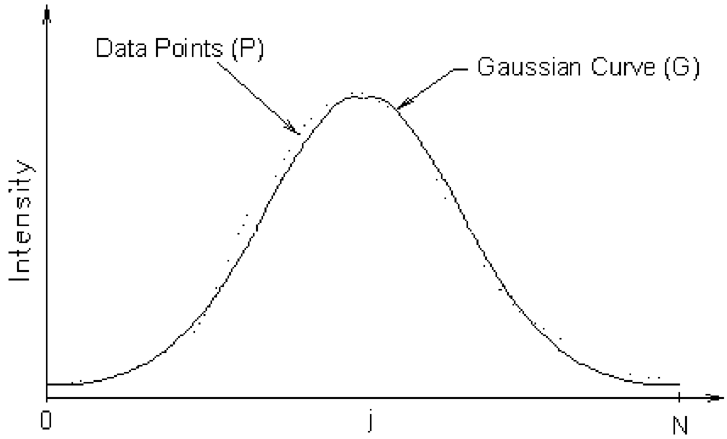
Since the Beam Profiler software supports a variable clip level, the beam width is always displayed with its clip level in brackets.

Note

Please note that 'Beam Width' is always the diameter, not the radius of the beam.

6.6 Gaussian Fit Measurement

Gaussian fit is a least-square fit of an ideal Gaussian curve to the X-Y Cross Section Profiles.



Gaussian Intensity
is the correlation between the beam profiles in a line (X) and column (Y) and its appropriate Gaussian curve fit

Gaussian Diameter
is the width of the Gaussian fit at the $1/e^2$ intensity level

6.7 M² Theory

The diameter d(z) of a focused laser beam of fundamental mode TEM_{00} increases with distance z from its waist position.

$$d(z) = d_0 \sqrt{1 + \left(\frac{z}{z_R}\right)^2}$$

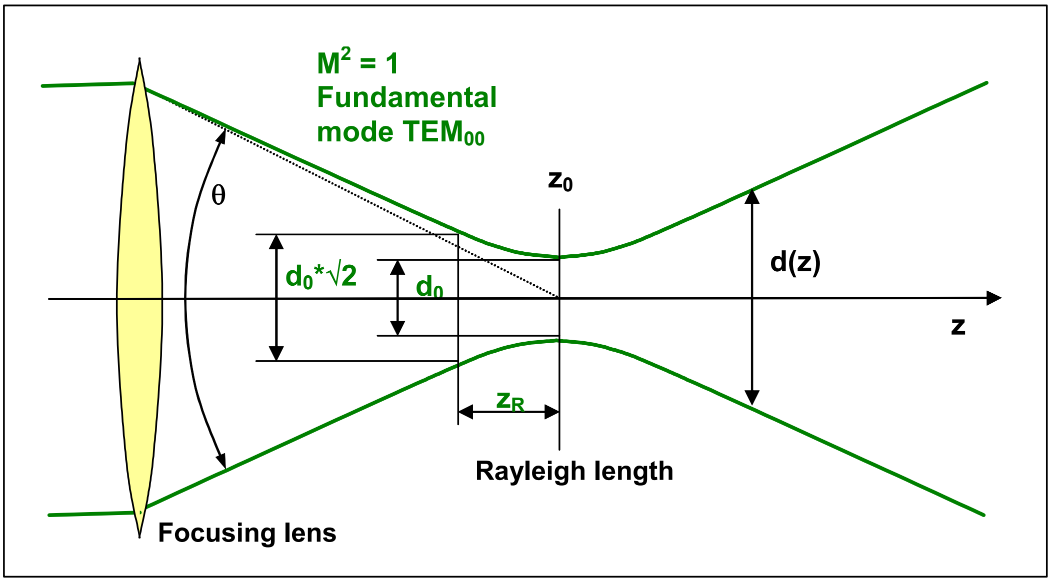
with

d_0 waist diameter

z_R Rayleigh length

λ wavelength

This formula is simplified. If the waist position z_0 is not zero, z has to be replaced with $(z-z_0)$.



The Rayleigh length z_R is defined by

$$z_R = \frac{\pi d_0^2}{4\lambda}$$

and determines the distance from the beam waist where the beam diameter has increased by a factor of √2 = 1,41 compared to the minimum diameter at the waist. This formula is valid for a Gaussian beam.

In the far field, ($z >> z_R$) beam diameter increases linearly with z which gives a constant divergence angle θ in the far field.

$$\theta = \frac{d_0}{z_R} = \frac{4\lambda}{\pi d_0}$$

The product of min. beam diameter at waist and divergence angle $d_0 * \theta$ is constant for a given wavelength.

$$d_0\theta = \frac{4\lambda}{\pi}$$

From this equation it is obvious that a smaller beam waist can only be achieved by increasing the divergence angle. This implies using a lens with short focal length. Also the wavelength determines the min. achievable spot size because beam waist d_0 is directly proportional to wavelength.

$$d_0 = \frac{4}{\pi\,\theta}\lambda$$

For higher modes than the fundamental mode TEM_{00} both the divergence angle θ and the beam waist diameter d_0 increase by a factor M.

$$d_o \rightarrow M\ d_0$$

$$\theta \rightarrow M\ \theta$$

Therefore the product d_0*θ increases by a factor of M^2.

$$d_o\theta \rightarrow M^2\ d_0\theta$$

$$d_0\theta = M^2\ \frac{4\lambda}{\pi}$$

Finally, the times-diffraction-limit factor M^2 is calculated by

$$M^2 = \frac{\pi}{4\lambda}d_0\theta$$

The reciprocal of this times-diffraction-limit factor M^2 is called the beam propagation factor or beam quality K.

$$K = \frac{1}{M^2}$$

The following table illustrates the relationship these parameters between a perfect Gaussian beam and non-perfect beam.

Parameter	**Gaussian beam**	**Bad quality beam**
Times-diffraction-limit factor M^2	1	> 1
Beam propagation factor = Beam quality K	1	< 1
Beam waist for given lens	minimal	broader
Divergence angle θ at given beam waist d_0	narrow	wider

Reasons for non-ideal Gaussian Beam with M^2 > 1

Gaussian beam is preferred to use because of its minimum divergence angle and the ability to get the minimal focus diameter.

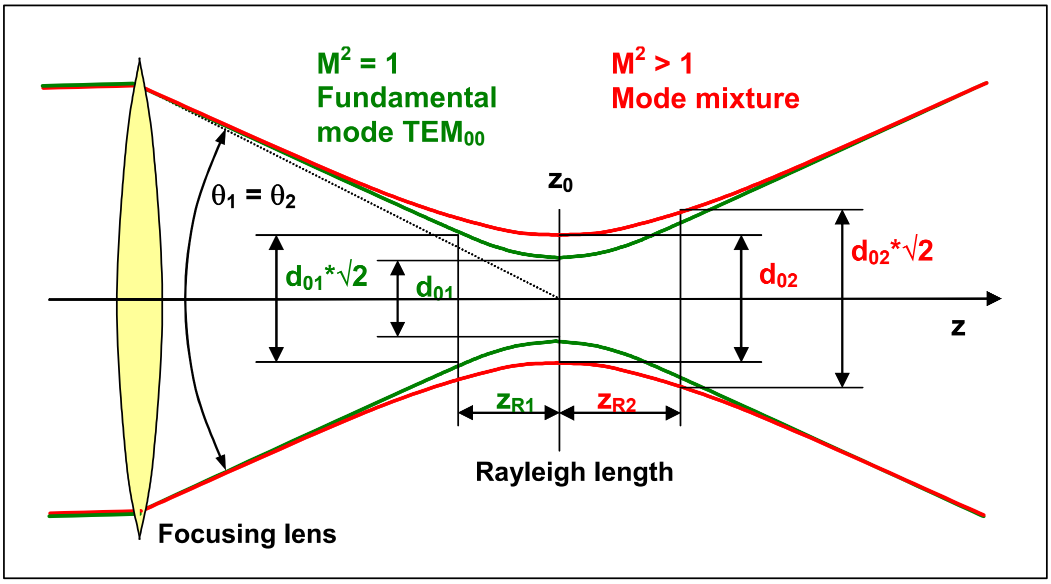
Differences to Gaussian shape can be due to

- existence of higher modes
- amplitude and phase distortions due to inhomogeneous gain medium in lasers
- occurrence of extraordinary beams

These distortions lead to higher divergence and wider beam waist compared to Gaussian beams when focused using the same lens. As a result the achievable max. power density is reduced.

Comparison of propagation between fundamental mode TEM_{00} (ideal Gaussian beam) and mode mixture beam

With a given divergence angle (i.e. knowing the focus of the lens) the fundamental mode alone produces the smallest (theoretical limited) beam waist (green curve). If beam quality gets worse (red curve) the beam waist becomes wider than before. If divergence is fixed, beam waist is enlarged by the factor M^2 and the appropriate power density at z_0 is reduced by a factor $(M^2)^2$.



The Rayleigh length may also be influenced due to the changed beam propagation curve.

6.7.1 Focal and stage length calculation

Focal length

The generated beam waist diameter d_0 must not decrease below the minimal measurable beam diameter of the Beam Profiler.
The beam waist diameter d_0 is:

$$d_0 = M^2 \frac{4 \cdot \lambda}{\pi \cdot \theta}$$

To fulfill this requirement for each wavelength and the highest focusability (M^2=1) the divergence angle θ must not exceed a maximum value θ_{max}.

$$\theta_{\max} = \frac{4 \cdot \lambda}{\pi \cdot d_{0,\min}}$$

Depending on initial beam size d_{init}, a minimal focal length *f* can be calculated.

$$f \geq \frac{d_{\text{init}}}{2 \cdot \tan\left(\frac{\theta_{\max}}{2}\right)}$$

Refer to diagram A for quick selection help.

Translation stage length

For optimal M^2 detection the translation range should be at least 5 times the Rayleigh length of the focused beam to cover both the beam waist and the neighboring divergent beam propagation.

Minimal translation stage length is:

$$L_{\min} \geq 5 \cdot z_R = 5 \cdot M^2 \frac{\pi \cdot d_0^2}{4\lambda}$$

where is:

L_{min}	minimum required stage length
z_R	Rayleigh length for a non-gaussian beam with fixed divergence angle
M^2	highest expected M^2 value
λ	operating wavelength
d_0	beam waist diameter

Refer to diagram B for quick selection help.
Besides this minimum requirement, more flexibility is added to the setup by selecting a longer stage.

7 Appendix

7.1 Certifications and Compliances

The Thorlabs GmbH, Hans-Böckler-Strasse 6, D-85221 Dachau, declares under it's own responsibility, that the products

Camera Beam Profiler
BC106-UV, BC106-VIS

fulfill the requirements of the following standards and therefore corresponds to the regulations of the directive.

Category	Standards or description	
EC Declaration of Conformity - EMC	Meets intent of Directive 2004/108/EC[1] for Electromagnetic Compatibility. Compliance was demonstrated to the following specifications as listed in the Official Journal of the European Communities:	
	EN 61326:1997 +A1:1998 +A2:2001 +A3:2003	Electrical equipment for measurement, control and laboratory use – EMC requirements: Immunity: complies with immunity test requirements for equipment intended for use in industrial locations[2]. Emission: complies with EN 55011 Class B Limits[2], IEC 610003-2 and IEC 61000-3-3.
	IEC 61000-4-2	Electrostatic Discharge Immunity (Performance criterion B)
	IEC 61000-4-3	Radiated RF Electromagnetic Field Immunity (Performance Criterion A)
	IEC 61000-4-4	Electrical Fast Transient / Burst Immunity (Perf. Criterion A)
EC Declaration of Conformity - Low Voltage	Compliance was demonstrated to the following specification as listed in the Official Journal of the European Communities: Low Voltage Directive 2006/95/EC[3]	
	EN 61010-1:2001	Safety requirements for electrical equipment for measurement, control and laboratory use.
[1] Replaces 89/336/EEC [2] Compliance demonstrated using a high-quality shielded USB cable shorter than 3 meters. [3] Replaces 73/23/EEC, amended by 93/68/EEC		

7.2 Warranty

Thorlabs GmbH warrants material and production of the BC106 for a period of 24 months starting with the date of shipment. During this warranty period Thorlabs GmbH will see to defaults by repair or by exchange if these are entitled to warranty.
For warranty repairs or service the unit must be sent back to Thorlabs GmbH (Germany) or to a place determined by Thorlabs GmbH . The customer will carry the shipping costs to Thorlabs GmbH, in case of warranty repairs Thorlabs GmbH will carry the shipping costs back to the customer.
If no warranty repair is applicable the customer also has to carry the costs for back shipment.
In case of shipment from outside EU duties, taxes etc. which should arise have to be carried by the customer.

Thorlabs GmbH warrants the hard- and software determined by Thorlabs GmbH for this unit to operate fault-free provided that they are handled according to our requirements. However, Thorlabs GmbH does not warrant a faulty free and uninterrupted operation of the unit, of the soft- or firmware for special applications nor this instruction manual to be error free.
Thorlabs GmbH is not liable for consequential damages.

Restriction of warranty

The warranty mentioned before does not cover errors and defects being the result of improper treatment, software or interface not supplied by us, modification, misuse or operation outside the defined ambient conditions stated by us or unauthorized maintenance.
Further claims will not be consented to and will not be acknowledged. Thorlabs GmbH does explicitly not warrant the usability or the economical use for certain cases of application.
Thorlabs GmbH reserves the right to change this instruction manual or the technical data of the described unit at any time.

7.3 Copyright

7.4 Technical Data

7.4.1 Technical Data BC106

All technical data are valid at 23 ± 5°C and 45 ± 15% rel. humidity

Operating Temperature	+ 5 ... + 35 °C
Storage Temperature	- 40 ... + 70 °C
Warm-up time	not required

Model	BC106-UV	BC106-VIS
Wavelength Range	190 - 350 nm 1)	350 - 1100 nm
Coating	Lumigen	none
Power Range	50 fW - 1 W 2)	1 fW - 1 W 3)
Sensor	2/3" EXview HAD™ CCD Sensor Sony ICX285AL, window removed	
Aperture Size	8,77 x 6,6 mm, max.	
Beam Diameter	30 µm - 6,6 mm	
Camera Resolution	1360 x 1024 pixel max., ROI selectable	
Pixel Size	6,45 µm x 6,45 µm	
Image Digitization	8 bit (0 - 255 digits) or 12 bit (0 - 4095 digits)	
Signal to Noise Ratio	≥ 62 dB	
Shutter	Global	
Exposure Range	20 µs – 1 s	
Gain Range	1x - 16x	
Frame Rate	max. 10 fps @ full resolution 4) >27 fps @ 640 x 480 pix 4) >43 fps @ 320 x 240 pix 4)	
Attenuation Filters (nominal values, on filter wheel)	20, 40 dB VIS 20, 40 dB UV	10, 20, 30, 40 dB VIS
Image Capture Modes	single frame, continuous, hardware triggered	
Sensor Distance to Surface	16.7 mm (6.65")	
Compatible Light Sources	cw, pulsed	
Pulse Frequency	1 Hz - 50 kHz (single pulse exposure), unlimited (multi pulse exposure)	
Trigger Input	TTL level , BNC jack 5)	
Trigger Delay	42 µs - 1 s, programmable	

Model	BC106-UV	BC106-VIS
Physical Size (H x W x D)	80 x 80 x 36.5 mm including base plate, filter wheel and filters	
Weight	310 g	
Mounting	UNC1/4-20 and M6 on base plate	
PC Interface	High speed USB2.0	
Power Supply	2.4 W, USB bus powered	

1) Wavelength range of supplied UV ND filters start at 220 nm, see chapters Filter Wheel 9 and Wavelength Response 151.

2) @ 200 nm, depending on beam diameter and ND filter

3) @ 550 nm, depending on beam diameter and ND filter

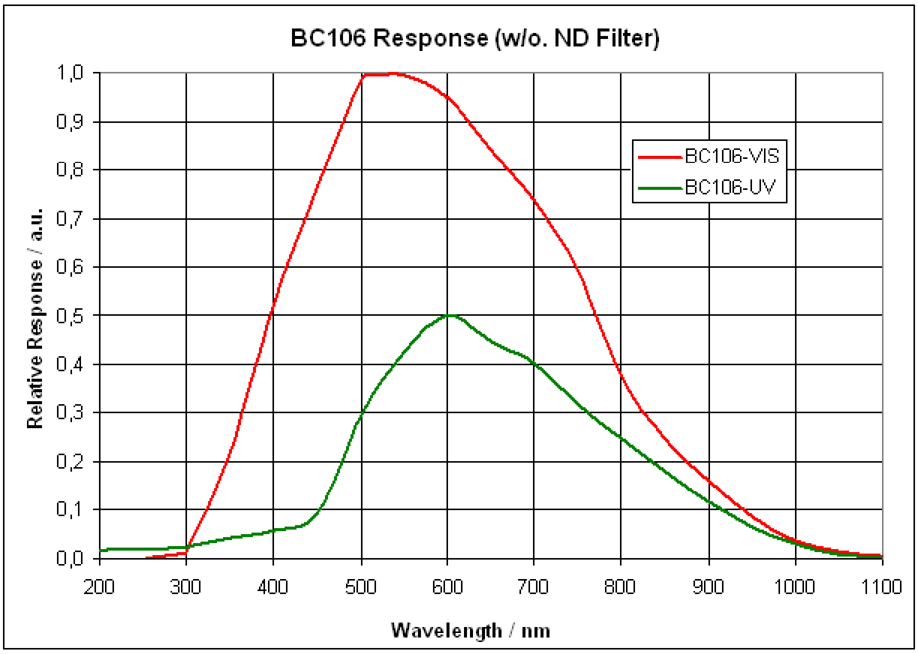
4) Highly depending on PC processor and graphic adapter performance.

5) See chapter Trigger Input 12 for detailed data.

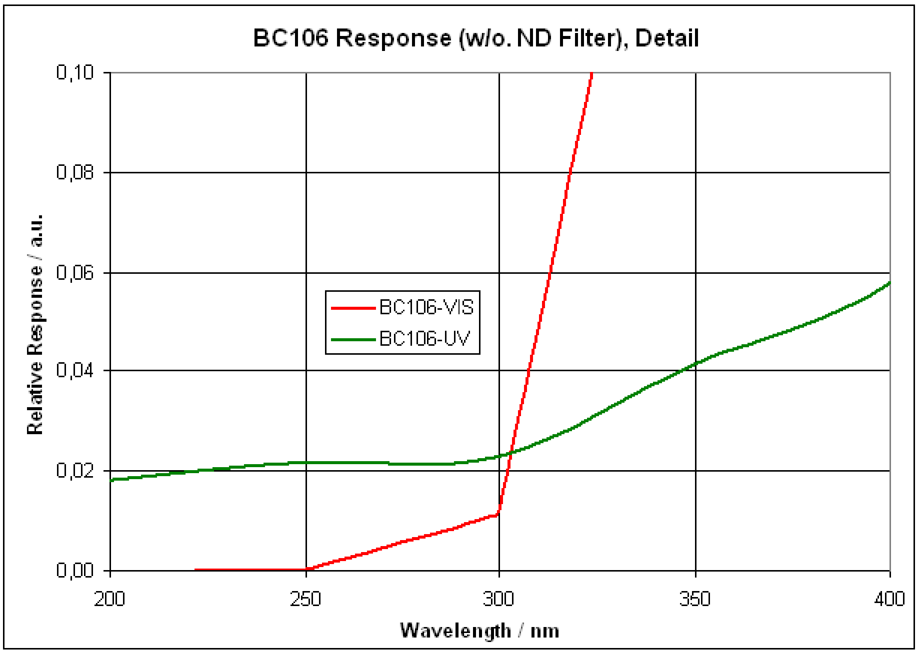
7.4.2 Wavelength Response

1. Wavelength Dependent Sensitivity of BC106 Models

Image sensors of both BC106 models show a wavelength depending response. The following diagrams show its relative response. Whereas model BC106-VIS offers about double sensitive in the visible wavelength range, it suffers from nearly zero sensitivity in the UV range below 300 nm.



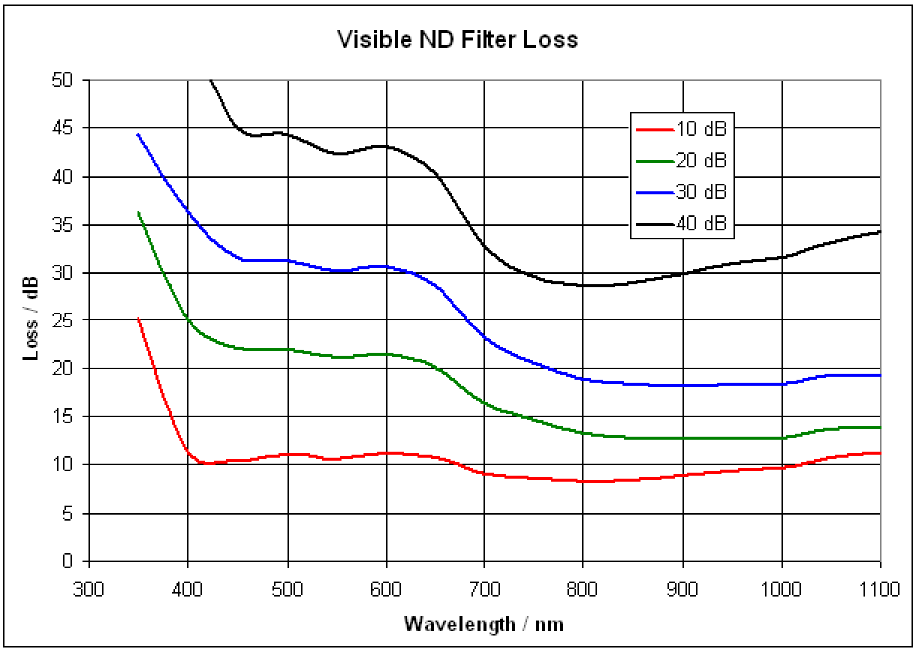
As shown here in detail the sensitivity of model BC106-UV considerable exceeds model BC106-VIS below 300 nm.



Both response diagrams are measured without any ND Filter.

2. Wavelength Dependent Loss of VIS ND Filters

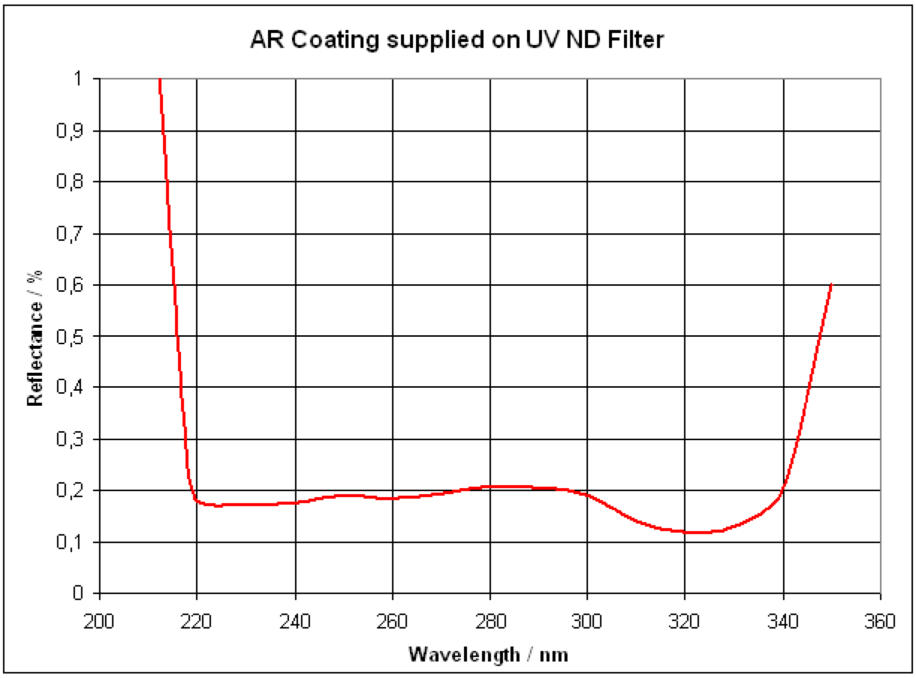
The following diagram shows the measured wavelength dependent loss of all four ND filters supplied with the BC106-VIS Camera Beam Profiler.



As seen, the ND filters keep their nominal loss values only coarsely within a limited wavelength range in the visible. Large deviations are outside this range will require a User_Power_Correction 65.

3. Wavelength Dependent Reflectance of AR Coating on UV ND Filters

This diagram shows the typical quality of the supplied reflective ND Filters for the UV wavelength range.



One surface of these reflective type ND Filters is metallized to obtain the 20 dB and 40 dB loss, respectively. The rear side of this fused silica substrate needs to be anti reflective coated to prevent interference effects due to multiple reflections. Therefore, the quality of this AR coating is important for a good image quality.
The displayed curve shows the remaining reflectivity of the AR coating supplied on the fused silica substrate. Between 220 nm and 340 nm is below 0.25 %.

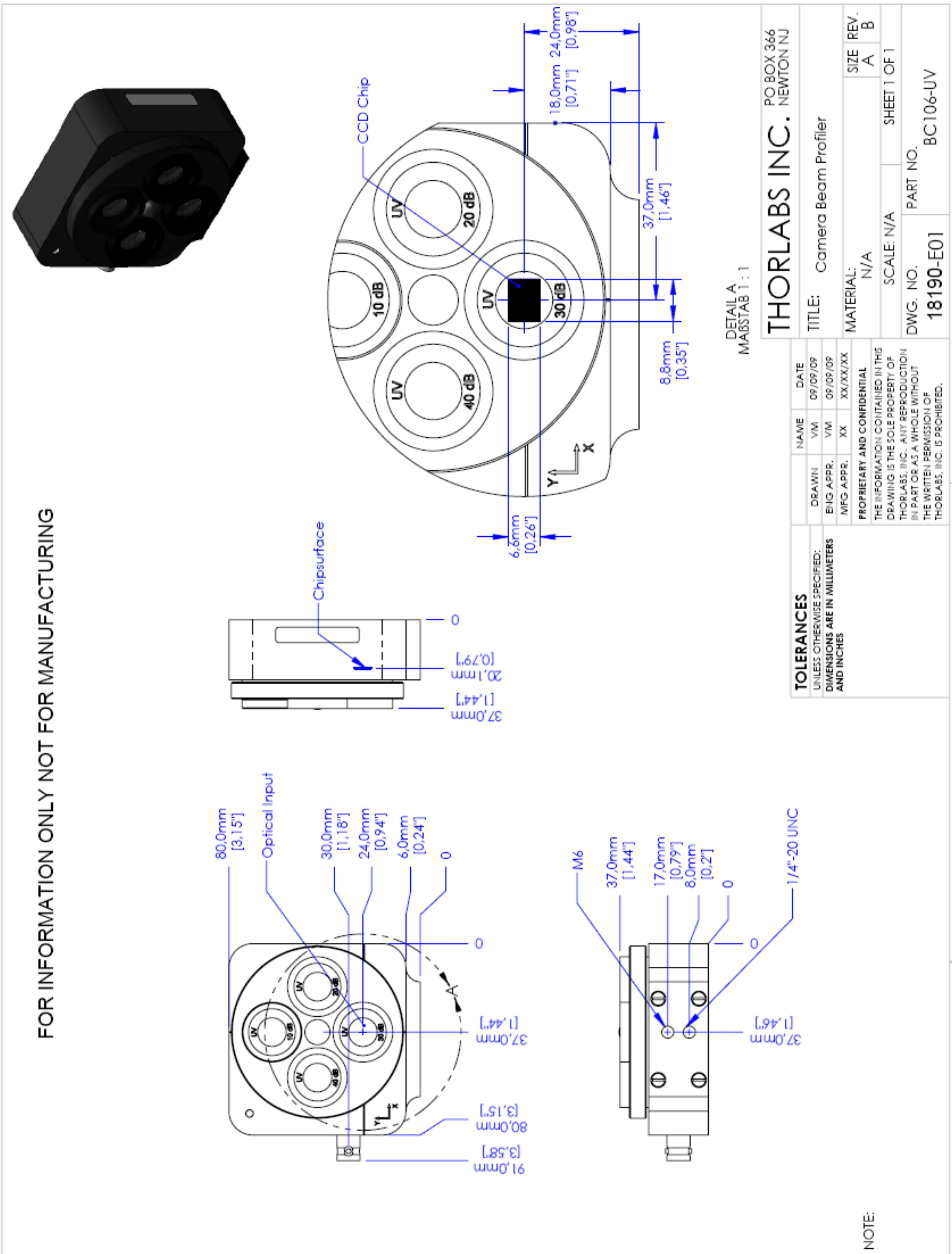
7.4.3 Accessories

The following accessory list may help mounting the instrument, increase the usable Power Ranges 75 and appoint suggested cleaning tools. This equipment does not belong to the BC106 scope of delivery but is available from the Thorlabs website http://www.thorlabs.com.

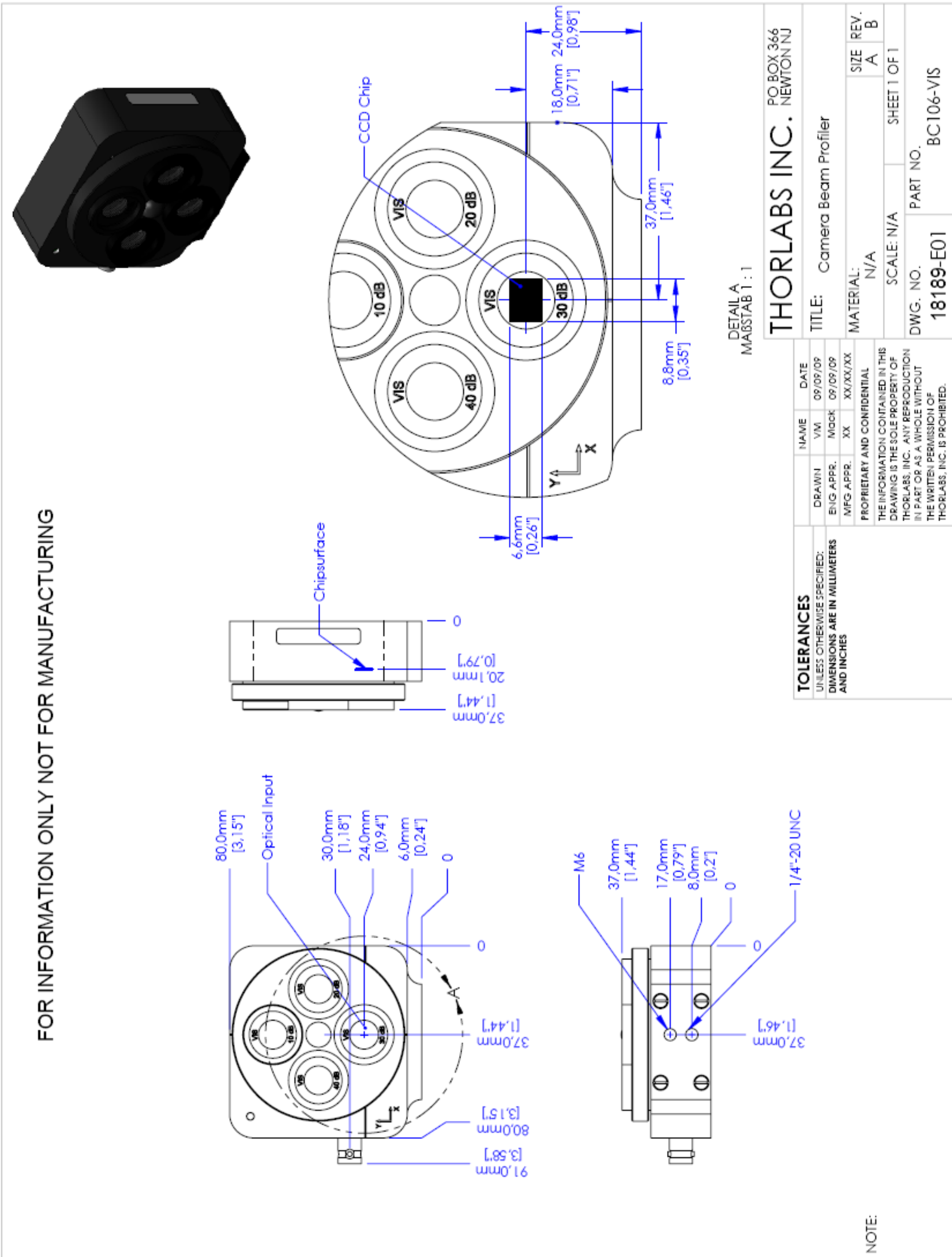
Part	Thorlabs item
BC106 Mounting	
Stainless optical post	TRxx (imperial), TRxx/M (metric) Series
Post Holder Ø 1/2 "	PHx (imperial), PHx/M (metric) Series
Base Plate	BAx (imperial), BAx/M (metric) Series
External Beam Attenuation	
Absorptive ND Filter	NExx Series
BK7 Reflective ND Filter	NDxx Series
Beam Splitter	Optical Beam Splitters (website seach key)
Cleaning	
Dusting Kits CA3	Optical Cleaning Supplies (website seach key)
Tissue MC-5, CP-100	

7.4.4 Drawings

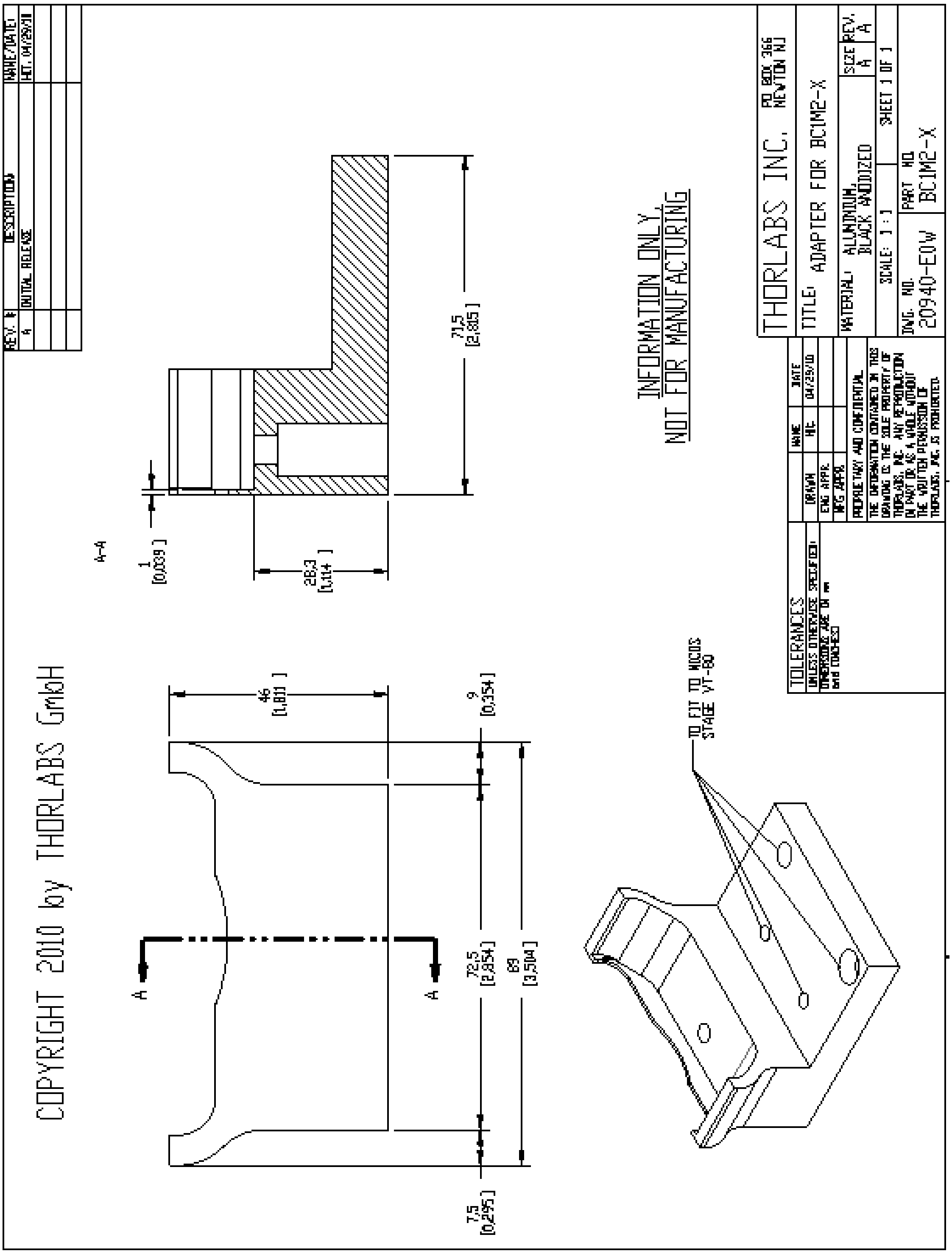
7.4.4.1 BC106-UV



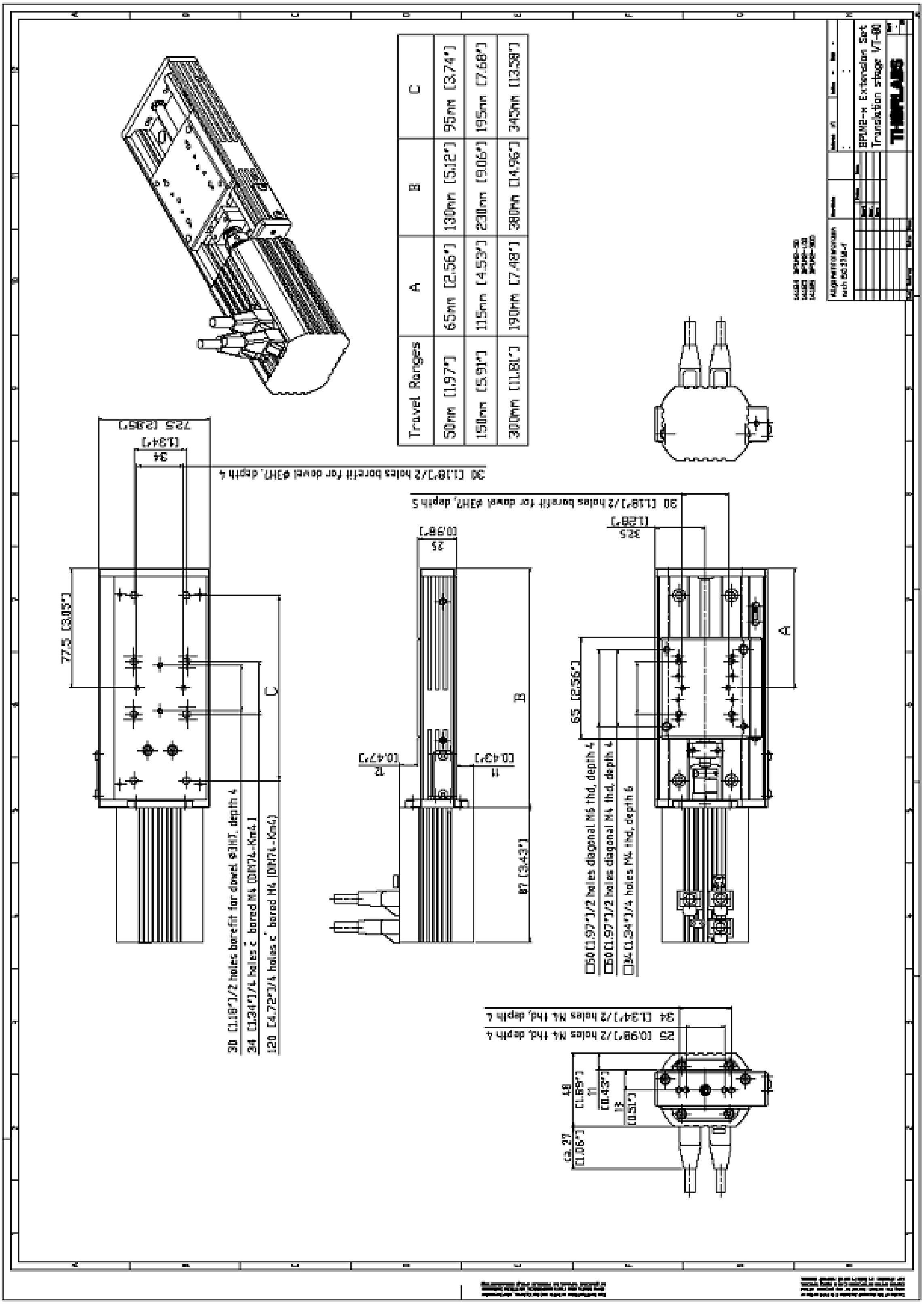
7.4.4.2 BC106-VIS



7.4.4.3 BC1M2 Mounting Adapter



7.4.4.4 Translation Stage VT-80



7.5 Thorlabs "End of Life" Policy (WEEE)

As required by the WEEE (Waste Electrical and Electronic Equipment Directive) of the European Community and the corresponding national laws, Thorlabs offers all end users in the EC the possibility to return "end of life" units without incurring disposal charges.

This offer is valid for Thorlabs electrical and electronic equipment

- sold after August 13th 2005
- marked correspondingly with the crossed out "wheelie bin" logo (see fig. 1)
- sold to a company or institute within the EC
- currently owned by a company or institute within the EC
- still complete, not disassembled and not contaminated

As the WEEE directive applies to self contained operational electrical and electronic products, this "end of life" take back service does not refer to other Thorlabs products, such as

- pure OEM products, that means assemblies to be built into a unit by the user (e. g. OEM laser driver cards)
- components
- mechanics and optics
- left over parts of units disassembled by the user (PCB's, housings etc.).

If you wish to return a Thorlabs unit for waste recovery, please contact Thorlabs or your nearest dealer for further information.

7.5.1 Waste Treatment on your own Responsibility

If you do not return an "end of life" unit to Thorlabs, you must hand it to a company specialized in waste recovery. Do not dispose of the unit in a litter bin or at a public waste disposal site.

7.5.2 Ecological Background

It is well known that WEEE pollutes the environment by releasing toxic products during decomposition. The aim of the European RoHS directive is to reduce the content of toxic substances in electronic products in the future.
The intent of the WEEE directive is to enforce the recycling of WEEE. A controlled recycling of end of live products will thereby avoid negative impacts on the environment.

Crossed out "Wheelie Bin" Symbol

7.6 Listings

7.6.1 List of Acronyms

The following acronyms and abbreviations are used in this manual:

2D	2 Dimensional
3D	3 Dimensional
ADC	Analog to Digital Converter
AR	Anti Reflection
BC	Beam Profiler Camera
CA	Calculation Area
cw	Continuous Wave (constant power source)
GUI	Graphical User Interface
ND	Neutral Density
PC	Personal Computer
FPS	Frames Per Second
ROI	Region Of Interest
USB	Universal Serial Bus
UV	Ultra Violet (wavelength range)
VIS	VISible (wavelength range)

7.6.2 List of Symbols

The following symbols appear on the BC106 Beam Profiler or within this manual:

Symbol	Meaning
	Universal Serial Bus (USB), a serial bus standard to interface devices to a host computer.
	The CE mark is a mandatory conformity mark on many products placed on the single market in the European Economic Area (EEA). By affixing the CE marking, the manufacturer asserts that the item meets all the essential requirements of the relevant European Directive(s). It does not certify that a product has met EU consumer safety, health or environmental requirements.
	Crossed out "Wheelie Bin" symbol. Waste Electrical and Electronic Equipment (WEEE) is a loose description of surplus, obsolete, broken or discarded electrical or electronic devices. See Ecological_Background 159

7.6.3 Thorlabs Worldwide Contacts

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Index

- R -

- S -

- T -

- U -

- V -

- W -

- X -

- Y -