THORLABS

Thorlabs Beam
Beam Analyzing Software

BP104-UV, -VIS, -IR, -IR2
BP109-UV, -VIS, -IR, -IR2
Operation Manual

2011

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Date: 22.02.2011

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 something into the aperture in the middle of the Beam Profiler front! You may damage the thin-skinned slits, spoil the bearings of the motor and/or blockade the rotating drum because there is no covering 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
BP104-UV	Slit Beam Profiler, 200 - 1100 nm, 4 mm aperture, 2.5 µm slit
BP104-VIS	Slit Beam Profiler, 400 - 1100 nm, 4 mm aperture, 2.5 µm slit
BP104-IR	Slit Beam Profiler, 700 - 1800 nm, 4 mm aperture, 2.5 µm slit
BP104-IR2	Slit Beam Profiler, 1000 - 2700 nm, 4 mm aperture, 2.5 µm slit
BP109-UV	Slit Beam Profiler, 200 - 1100 nm, 4 mm aperture, 2.5 µm slit
BP109-VIS	Slit Beam Profiler, 400 - 1100 nm, 9 mm aperture, 5.0 µm slit
BP109-IR	Slit Beam Profiler, 700 - 1800 nm, 9 mm aperture, 5.0 µm slit
BP109-IR2	Slit Beam Profiler, 1000 - 2700 nm, 9 mm aperture, 5.0 µm slit

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

Translation Stage Model	**BP1M2-50**	**BP1M2-150**	**BP1M2-300**
Travel range	50 mm	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:
- Beam Profiler instrument as an external measurement head with dust cover
- USB2.0 high speed cable
- CD-ROM with all software included like graphical user interface with NI-VISA® drivers and Beam Profiler driver to enable you to built your own application program
- Beam Profiler Operation Manual

2.3 Preparation

1. Install the Thorlabs Beam software to your computer as described in Software Installation 11.
2. Connect the Beam Profiler using the supplied USB cable to the PC as described in Connection to the PC 21.

3. Remove the dust cover.
4. Mount the Beam Profiler instrument so that its optical aperture is exposed to the optical beam you like to measure.
5. Switch on your light source but be sure to not exceed the max. allowed optical power to the instrument. See Power Ranges 60 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 Rotation mount

The BP104/BP109 Beam Profiler is an external optical beam measurement sensor, and was designed for applications with an open beam.
The BP104/BP109 comes with a rotation mount.
The rotation mount enables you to rotate the scan axis X and Y up to +/- 60° manually. Simply take the plug on the top and move it to the left or right (while keeping the mount fix) - the Beam Profiler rotates within its mount. For getting the desired angle use the short markers every 10° and the long markers at 0° and 45° on the rotation mount. So you are able to measure your beam profile at different directions very easy.

Note

For good measurement results adjust the forefront of the Beam Profiler perpendicular to your optical beam so that the beam nearly meets the middle of the Beam Profiler aperture.

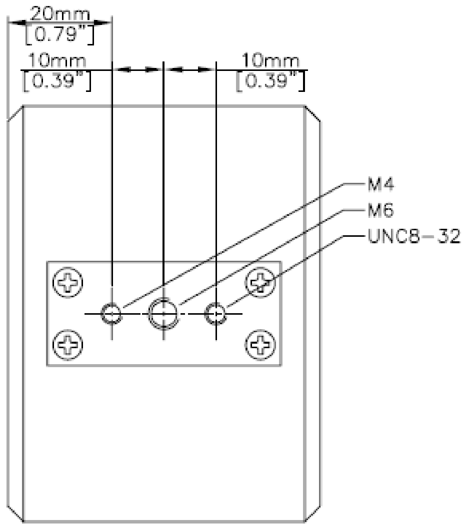
The rotation mount is essential for measurement the beam ellipticity, for instance. Since the major and minor axis of an elliptical beam may have arbitrary position in space, the scan axes of the Beam Profiler needs to be oriented to these axes in order to measure the real ellipticity.

Note

Without scan axes alignment the Beam Profiler will measure erroneous beam ellipticities!

2.4.2 Mounting plate

On the bottom side the Beam Profiler has a mounting plate with 3 holes. Every hole has a different thread - M6 midway, M4 rear and UNC8-32 ahead in the near of the front side of the Beam Profiler.
Fix the Beam Profiler on your optical bench using post, post holder and base from Thorlabs.



3 Operating the Beam Profiler

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

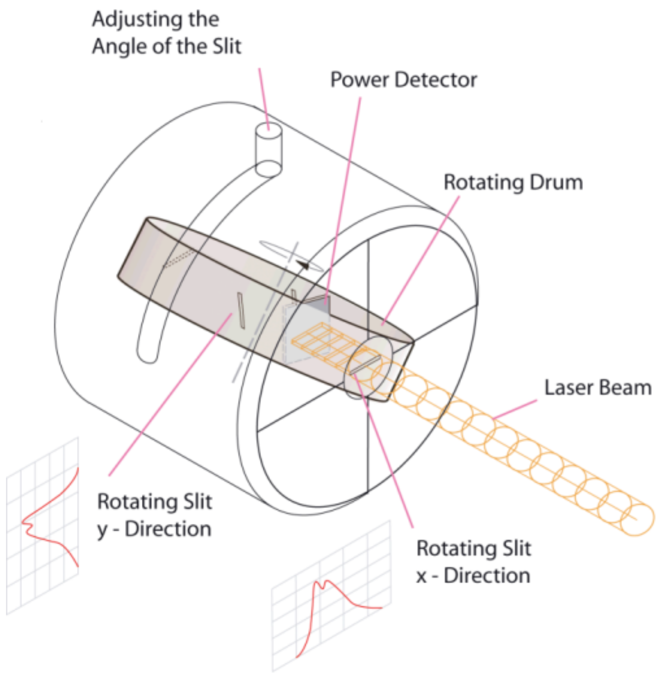
3.1 Requirements

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

- Operating system: Windows 2000®, Windows XP®, Windows Vista® (32 or 64 Bit), Windows 7® (32 or 64 Bit)
- USB 2.0 high speed port

3.2 Operation Principle

The BP104/BP109 uses the principle of scanning slits mounted on a rotating drum. This drum is equipped with a position encoder, which delivers exact information on the actual drum position to the analyzing software.
The slits are oriented orthogonal at angles +45° and -45° with respect to the rotation axis. This scanning axis is tilted at 45° so that the scanning directions of the slits appear as 0° (horizontal) and 90° (vertical), respectively. These scanning directions are marked as X and Y on the front of the instrument.
Using the rotation mount these scanning axes can be tilted to within +/- 60° in order to adapt it to the major and minor axes of an elliptical beam.
In addition there is a neutral density (ND) filter mounted on the drum which is used to take integral power measurements during every revolution. So this Beam Profiler can be used as a power meter too.
Note that the power meter readout is the result of a separate integral measurement and is not a result of mathematical integration across the scanned beam profile.



3.3 Installation

3.3.1 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.

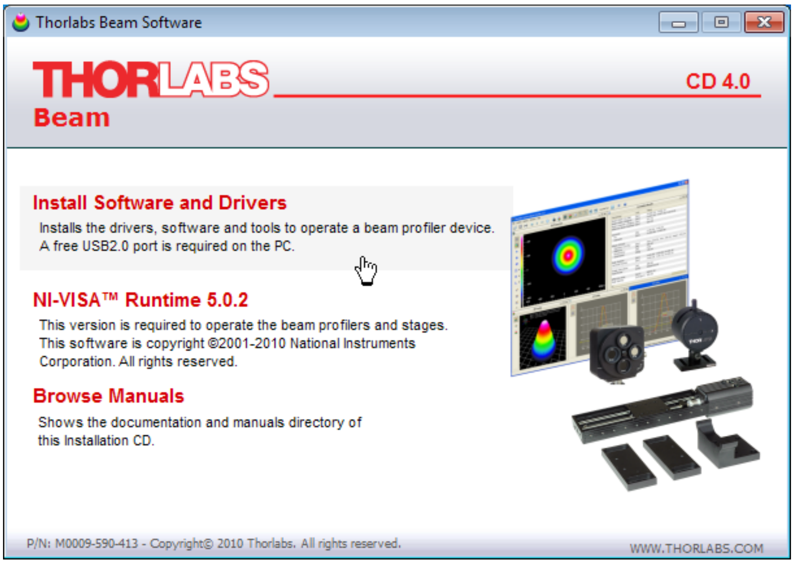
In case this 'auto start' feature is disabled on your computer please execute the "Autorun\Autorun.exe" file on the CD.

Quick Overview

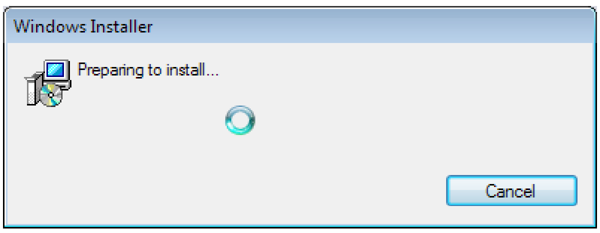
The installation CD contains of 3 parts - Software and Drivers, NI-VISA Runtime and Manual. Starting with the Topic"Install Software and Drivers", the Beam software is being installed to your computer, with a subsequent check for NI-VISA Runtime: If no NI-VISA Runtime is installed to your computer, or 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.

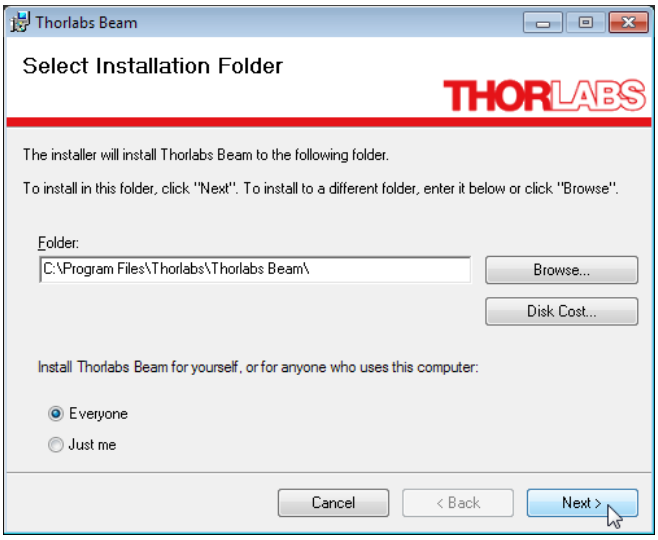
Installation

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

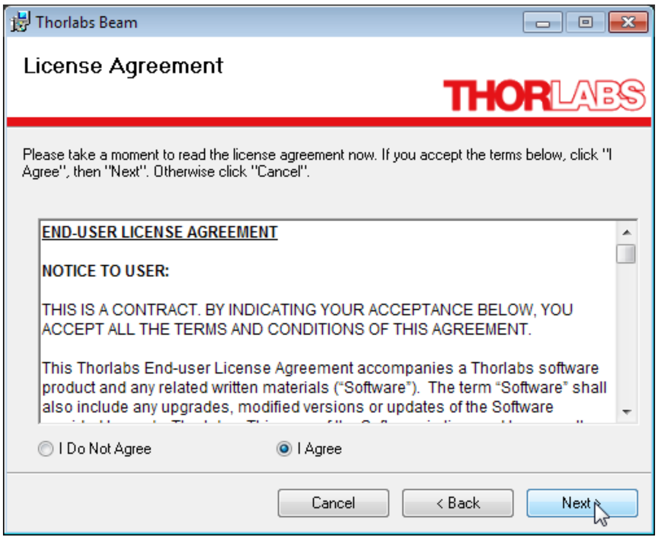


Click to the first topic.

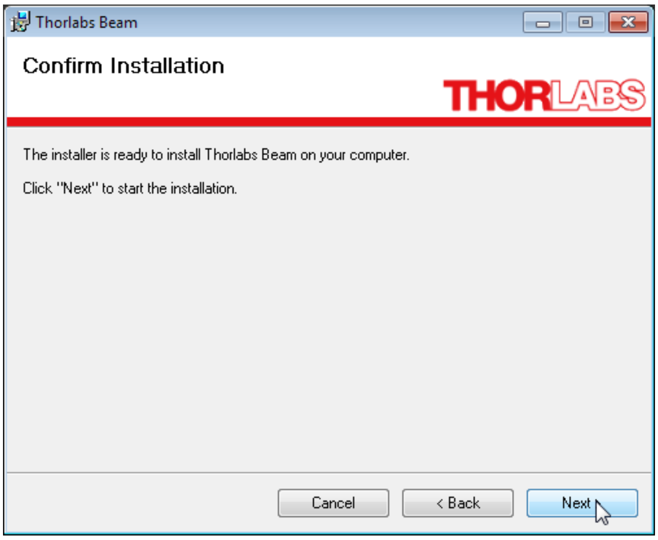




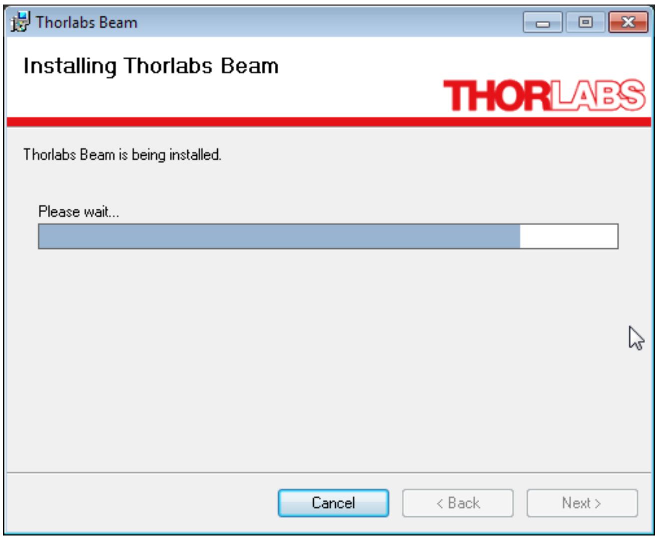
It is recommended to follow the recommended path, click Next.

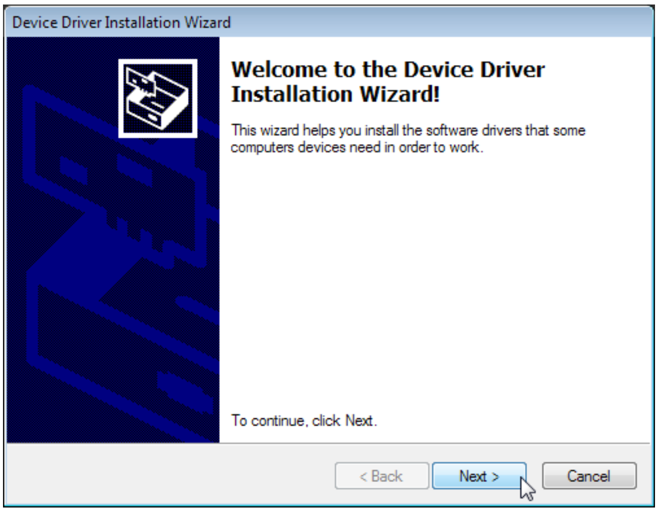


Please read this license agreement carefully, choose "I agree" and click 'Next'.



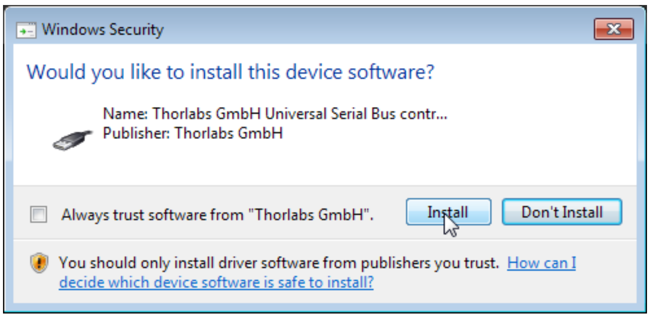
Click "Next", the software installation starts.



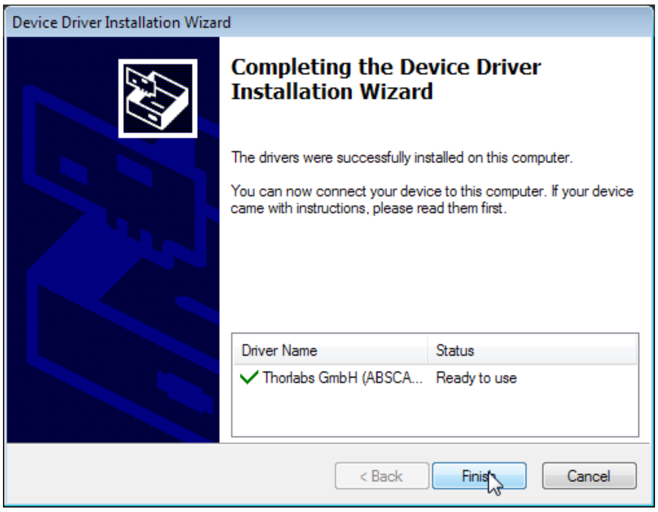


A new window appears, click "Next" to continue.

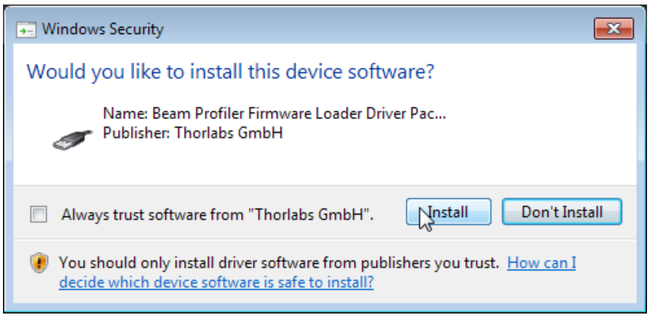
Windows Security will ask your confirmation to install the Thorlabs USB driver.

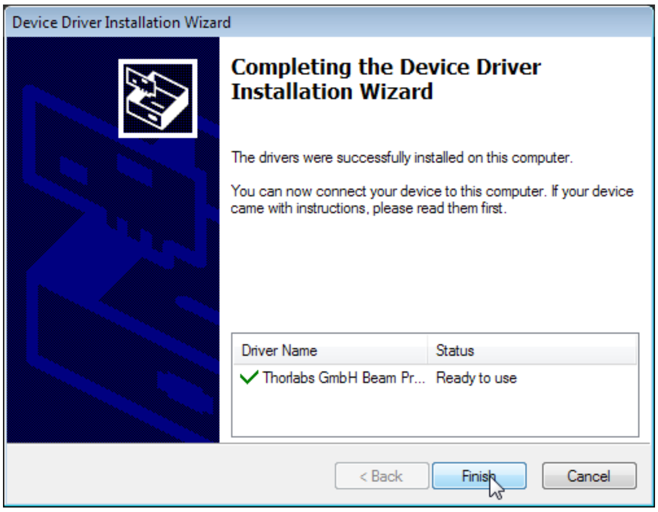


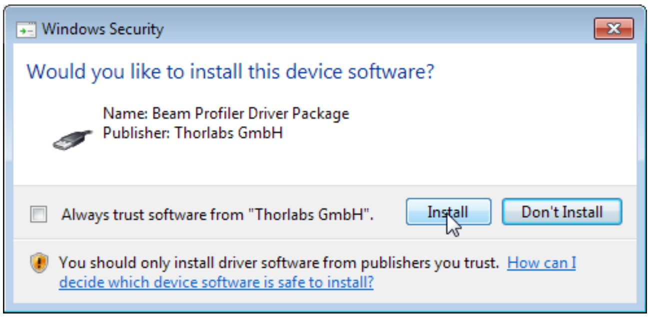
You may check the box "Always trust software from "Thorlabs GmbH", this will shorten the installation. However, if you do not want to do that, please click the "Install button.

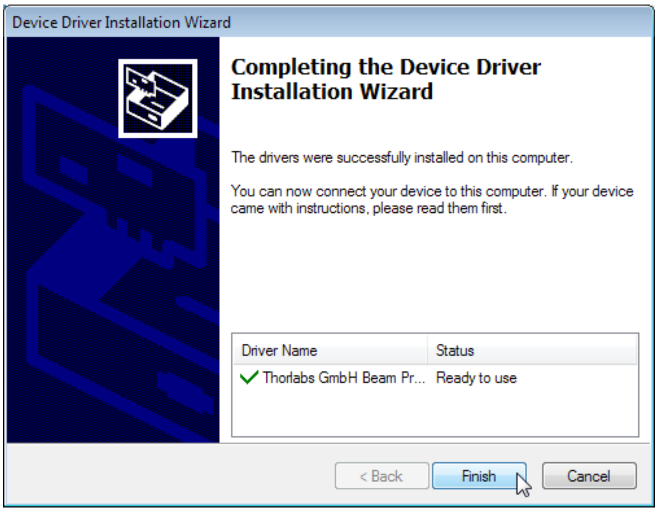


Thorlabs USB driver is now installed. Further, you will be asked to confirm the installation of another two device software. Please proceed as described above.

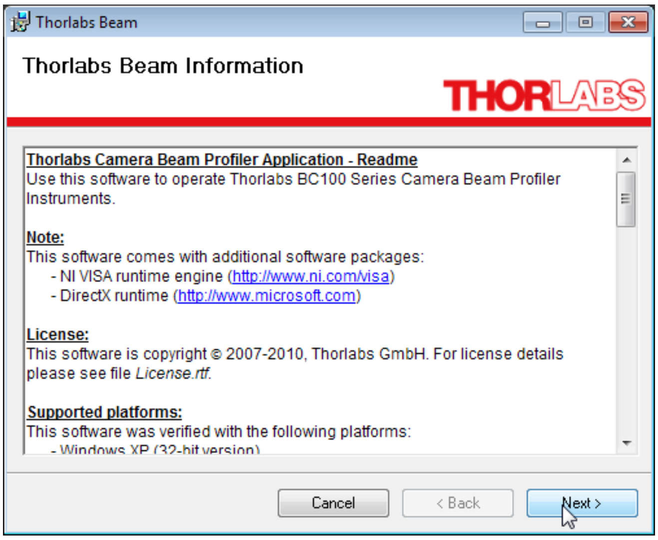




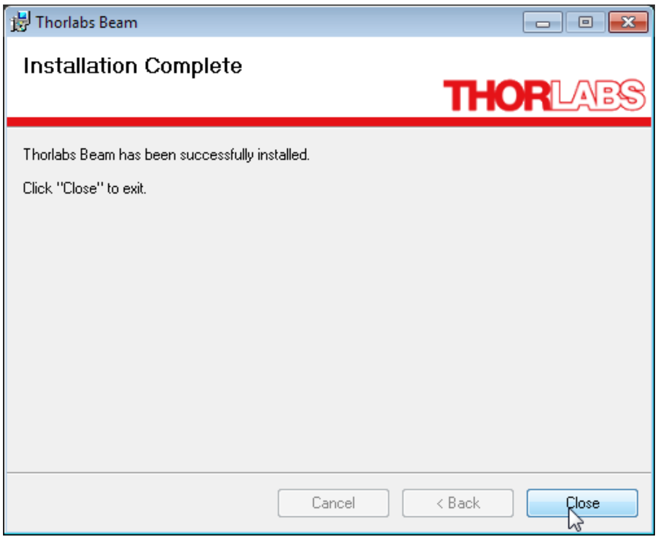




Now, the Beam software including device drivers is installed to your computer.

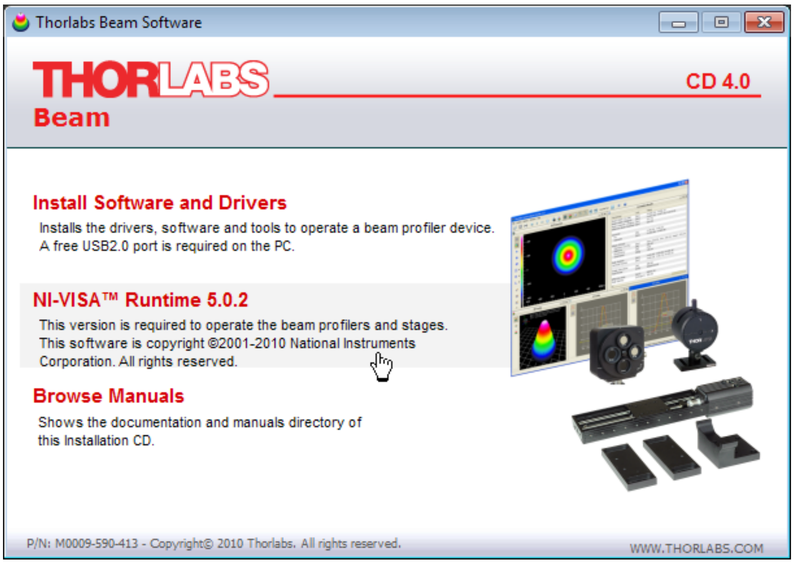


Click "Next",



and "Close" to complete the software installation.

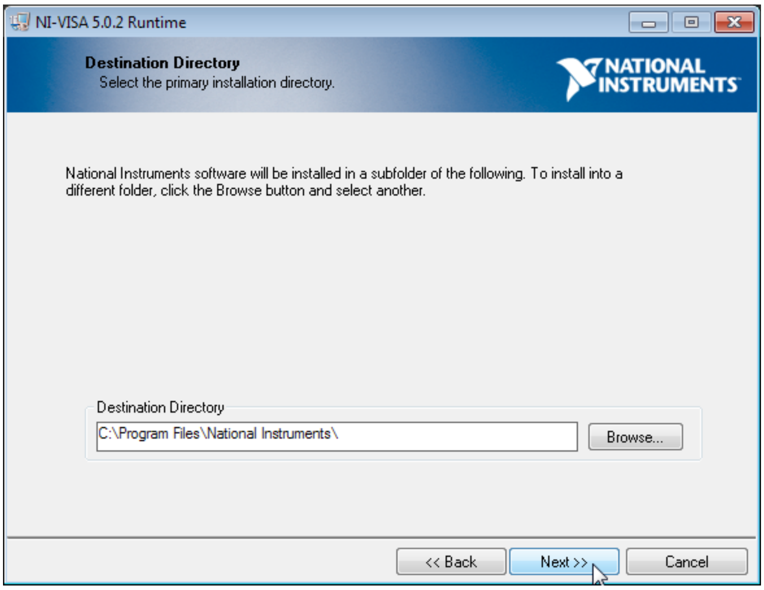
After finishing, the installer runs a check for installed NI-VISA Runtime. If you have a Version 4.x up already installed to your computer, you can proceed immediately with Connection to the PC 21, else please proceed with second topic as per the screenshots below.



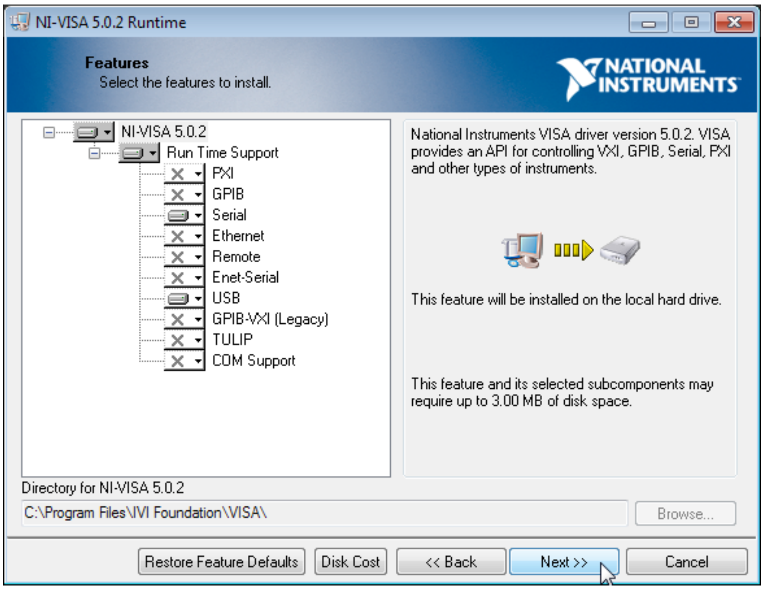
Click to "NI-VISA Runtime 5.0.2."

The NI Installer comes up.

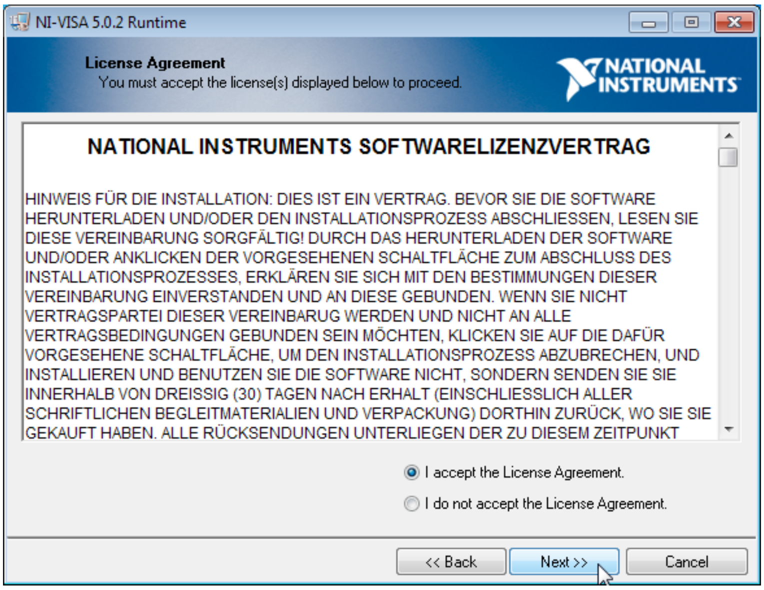
Click "Next"



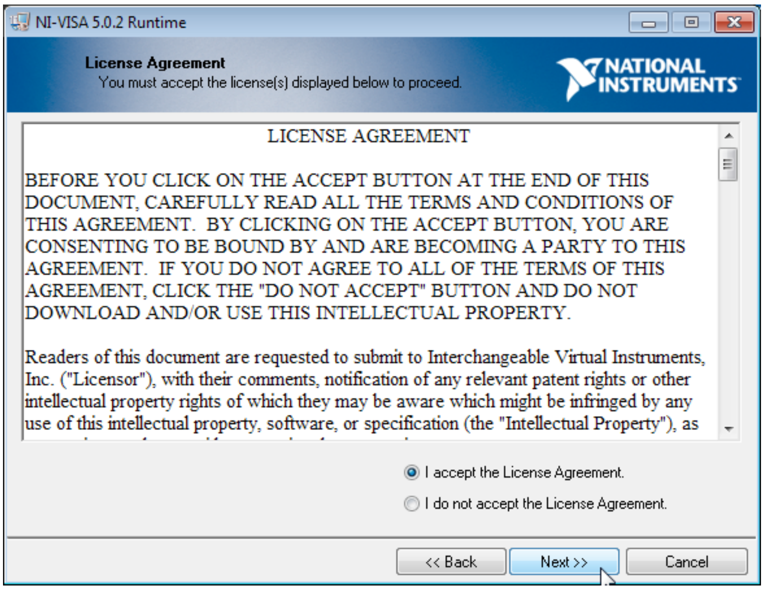
It's recommended to install NI-VISA to the proposed folder, click "Next"



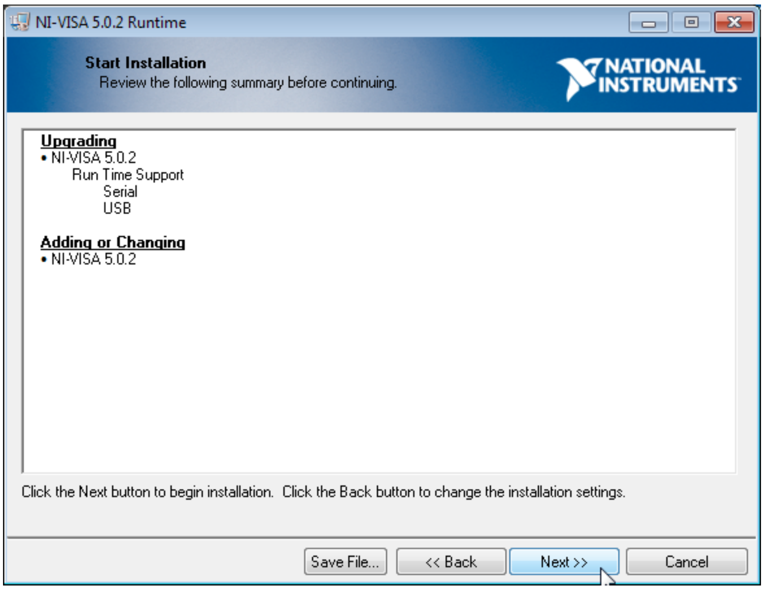
In this screen the required components are being selected. USB is required for the Beam Profiler control, Serial (RS232) for control of the translation stage used for M² measurements.



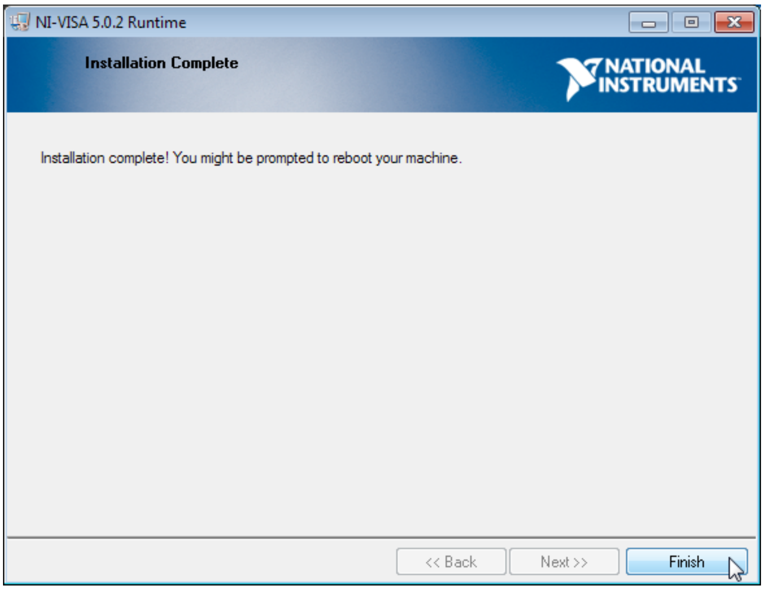
Please read the Software License Agreement carefully, choose "I accept" and click "Next"



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.

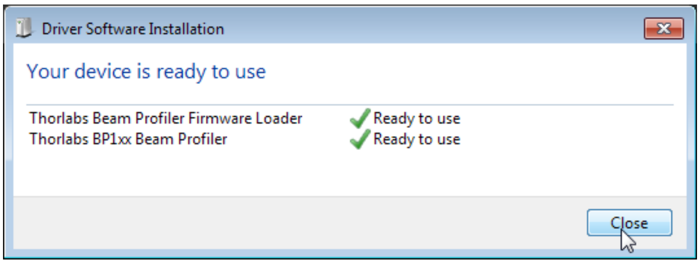
3.3.2 Connection to the PC

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.

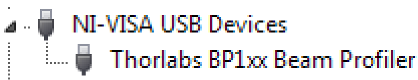
Attention

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:



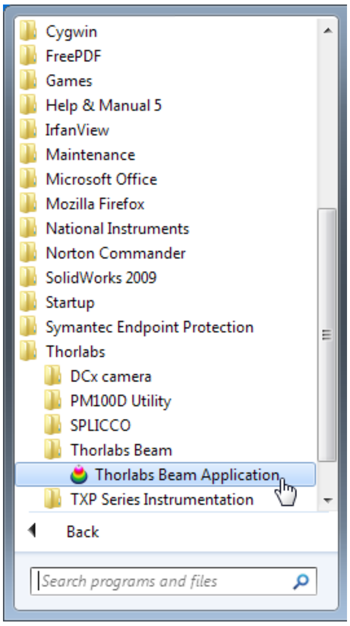
For verification purposes you might check the existence of this instrument in the Device Manager of your computer.
From the Start button select Control Panel → Device Manager
The following entry under the NI-VISA USB Devices group indicates that the Thorlabs Beam Profiler device is properly installed.



If you cannot see such an entry please check the troubleshooting 117 chapter.

3.3.3 Start the Application

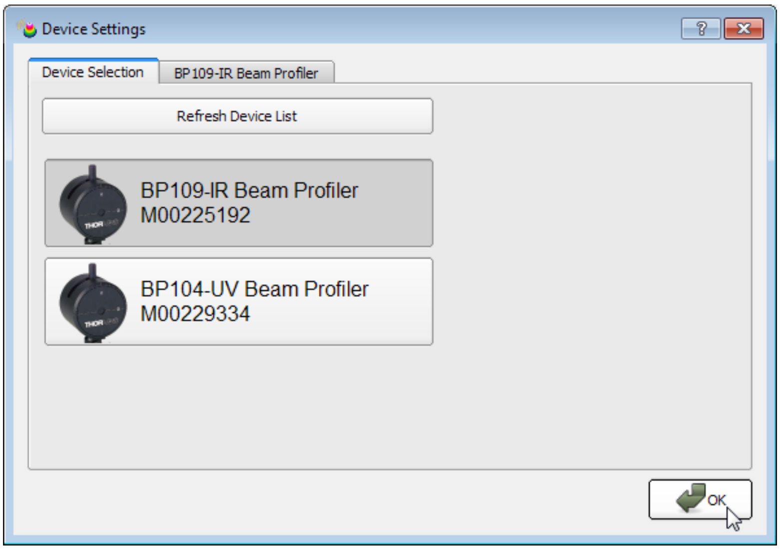
Access the Application Programs from the START button. Click the "Programs" → "Thorlabs" → "Thorlabs Beam Application" entry.



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 "BP10x Beam Profiler" 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 Troubleshooting 117).
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 Settings 46 for a detailed description.
It is advisable to read the steps described in chapter Measurement with the Beam Profiler 84 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 Windows 29 for a detailed description of each window.

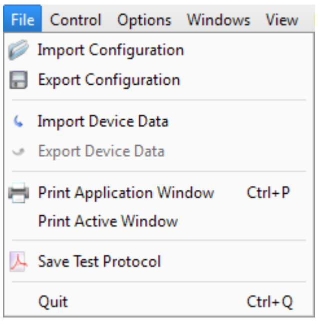
3.4 The Graphics User Interface (GUI)

3.4.1 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 beam profiler data in CSV format: Intensity values are saved to a text matrix.
There are 4 columns:

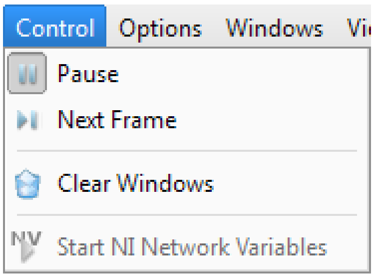
Column	Content
1	X position in µm
2	Intensity at X position
3	Y position in µm
4	Intensity at Y position

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 55.

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.

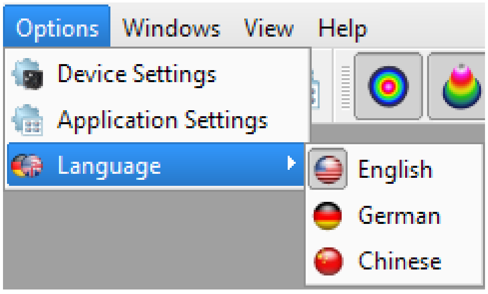
The "**Clear Windows**" function resets the content of all windows, including child windows. With the receive of the next measurement result from the instrument, the window content is filled. This function may be useful for a synchronous restart of all plots and time-based measurements.

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.

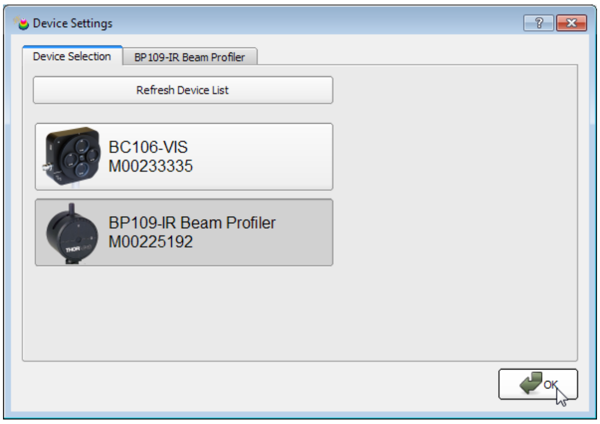
3. Options



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 22 for details.
See chapter Device Settings 46 for a detailed description of all specific instrument settings.

Application Settings

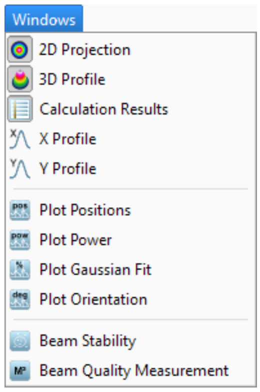
See Application Settings 49 for detailed settings of the software.

Language

The current language of your operating system is selected.

4. Windows

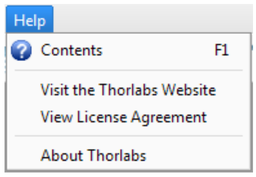
When the GUI is started the first time, the 2D reconstruction, 3D Model and the Calculations windows are opened by default. To close and open the windows, toggle the corresponding entry in the windows menu. The following list shows all available windows.



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.

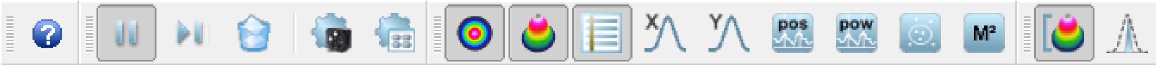


With a click on the link *Visit the Thorlabs Website* the Thorlabs website is opened in the standard browser.
View License Agreement will open the license file of the installer package.
About Thorlabs opens the about dialog panel which displays device information and software versions details:

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

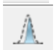

Pause and start the continuous device operation, take a single measurement and clear the content of each window


Open the device settings panel concerning the Beam Profiler instrument

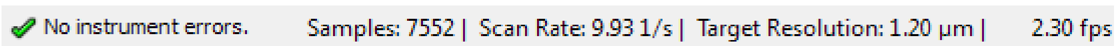

Open the application settings panel concerning the GUI and calculation settings


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 Scale To Peak On/Off


Toggle Max Hold On/Off

C. Status bar



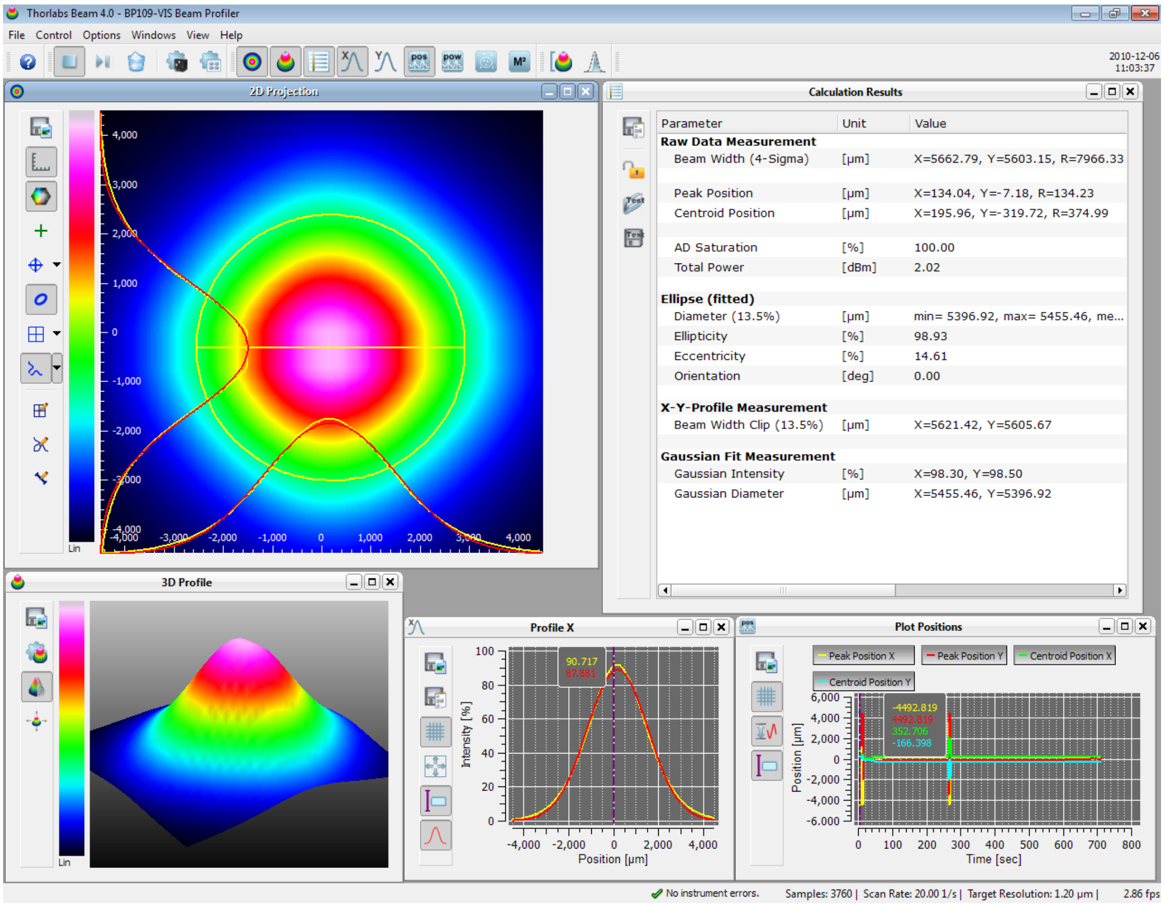
The status bar is used to display important status information about the Camera Beam Profiler concerning

- Errors and warnings, see chapter Warnings and Errors 115
- Instrument settings like taken samples, scan rate and target resolution
- Current refresh rate of the application in frames per seconds (fps)

3.4.2 Child Windows

If the application starts the first time, three child windows are opened and arranged automatically: "2D Reconstruction 30", "3D Profile 32" and the "Calculation Results 34". The application provides further windows: "X Profile 33", "Y Profile 33", "Plot Positions 37", "Plot Power 39", "Plot Gaussian Fit 40", "Beam Stability 41" and "Beam Quality (M²) 64". All these windows can be opened and closed with the symbols in the toolbar or via the entries in the menu "Windows".

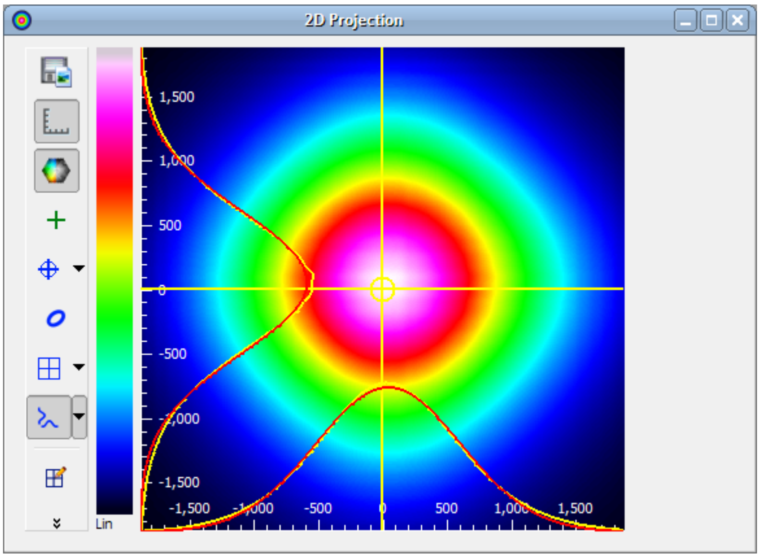
The appearance of the Thorlabs Beam software can be arranged according to somebody's requirements and taste. All child windows can be sized and positioned very flexible. Here is an example of arranging some child windows:



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.

3.4.2.1 2D Reconstruction

The 2D Reconstruction graph shows the image from the Beam Profiler indicating the power intensity distribution.
This window can be opened and closed via the menu item "2D Reconstruction" 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.



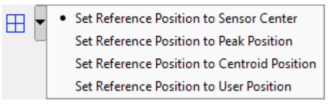
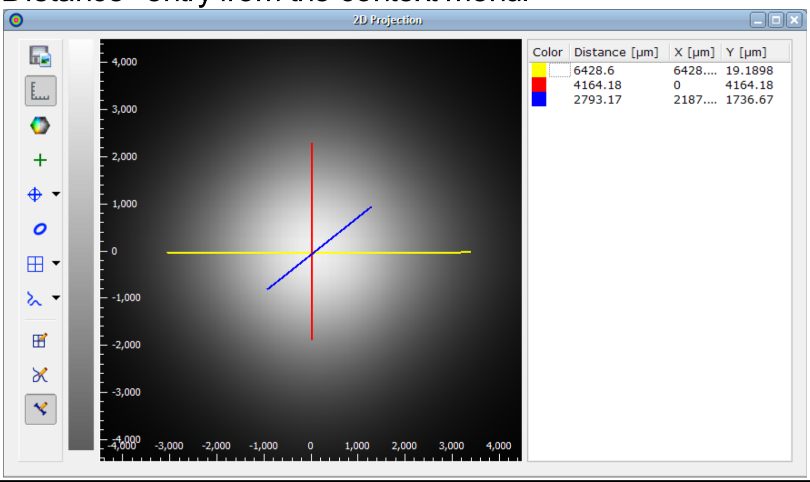
As the window name indicates the 2d image is based on a reconstruction since a slit beam profiler with two slits only provides two real cross section, i.e. x and y profile. The remaining pixel values are calculated by multiplying the normalized cross section values of the respective row and column. An additional bottom clipping is done for restraining amplied noise.

Note

Remember, this is only a reconstruction of an assumed Gaussian-like profile, it does not show a completely measured 2D cross section.

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

Toolbar Symbol	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 rainbow colors
Peak	Marks the Peak Position using a green cross
Centroid	Marks the Beam Centroid using a blue cross within a blue circle

Toolbar Symbol	Associated Action
Ellipse	Displays the approximated Beam Ellipse in yellow color. The ellipse is drawn corresponding to fitted or unfitted numerical data. See Application Settings [49] to enable/ disable the ellipse fit.
	The reference position has influence on the calculation results. The peak and centroid position refer to the reference position. The reference position can either be the center of the sensor, the peak position, the centroid position or a user defined position which can be set with the reference position edit mode.
Cross Hair	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 are fixed to the sensor center.
Reference Position Editor	Set a user defined reference position with a click with the left mouse button inside the projection image.
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. 

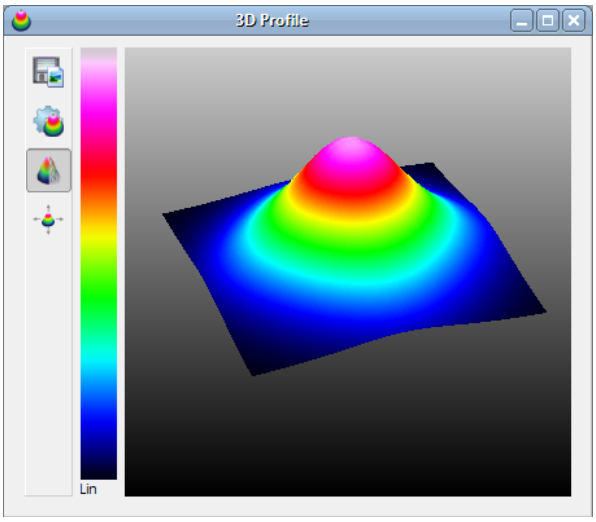
If the window height is smaller than the full toolbar, the lower symbols are packed into a context menu which is accessible via a arrow button on the bottom of the toolbar.

3.4.2.2 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

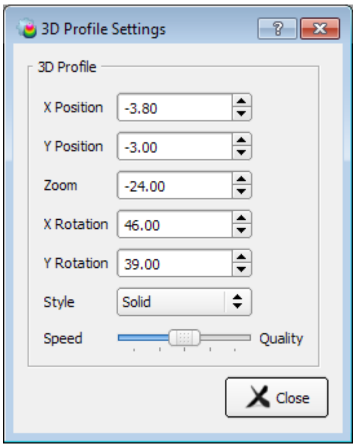
Rotate: Press right mouse button and move mouse
Move: Press left mouse button and move mouse
Zoom: Scroll mouse wheel



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:

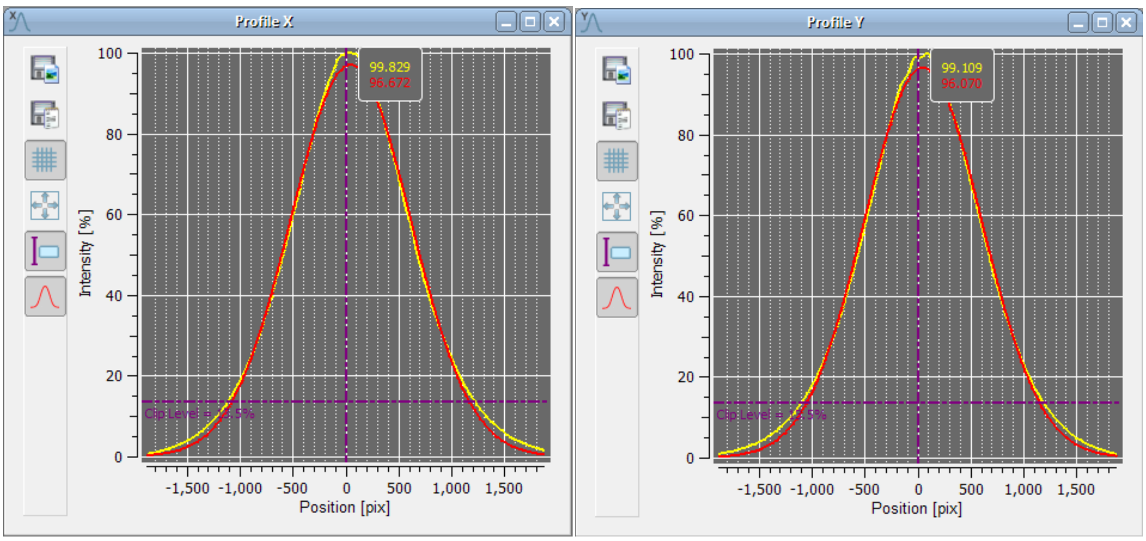


Note

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

3.4.2.3 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.



X and Y profiles display the intensity along the appropriate axes as marked on the front panel of the beam profiler.

The yellow graph shows the measured profile, while the red curve shows the approximated Gaussian fit function. If "Autoscale to Peak" is enabled , the measured curve shows relative intensities from 0 to 100%, where 100% denotes the maximum

value of intensity on X and Y axis. 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, where the number of pixels results from the settings of scan speed and target resolution, it is equal to the displayed vale of "samples" - see Device Settings 46). The unit of the scale can be changed with the Application Settings 49 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.

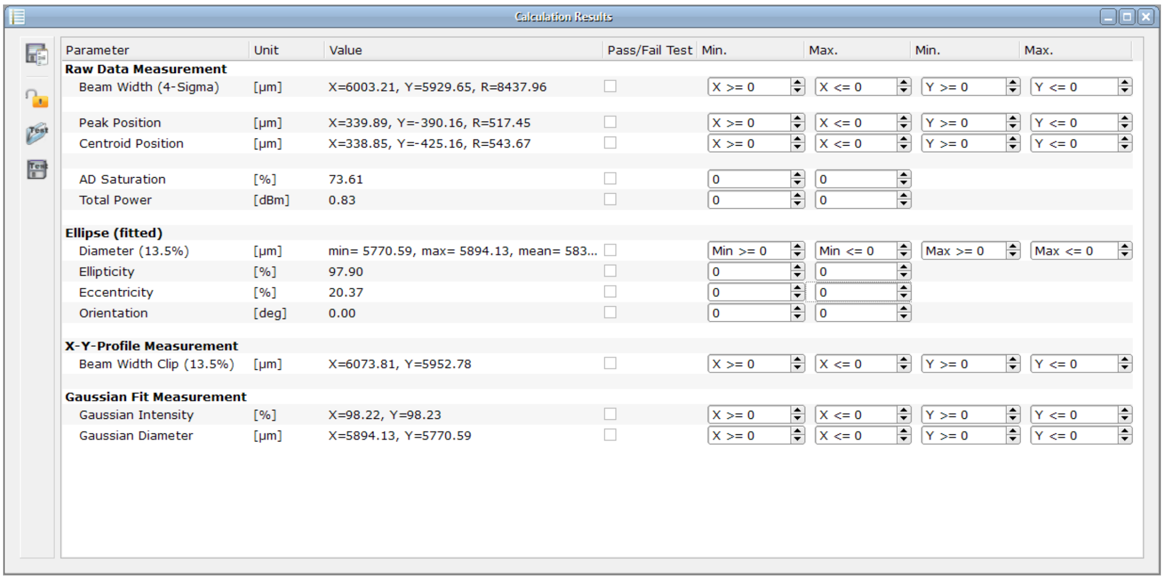
Zoom Mode
To zoom in the diagram, draw a rectangle with the left mouse button pressed.
Right click to the diagram undoes last zoom action.
"Home" button returns to display of the complete diagram.

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.

3.4.2.4 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.

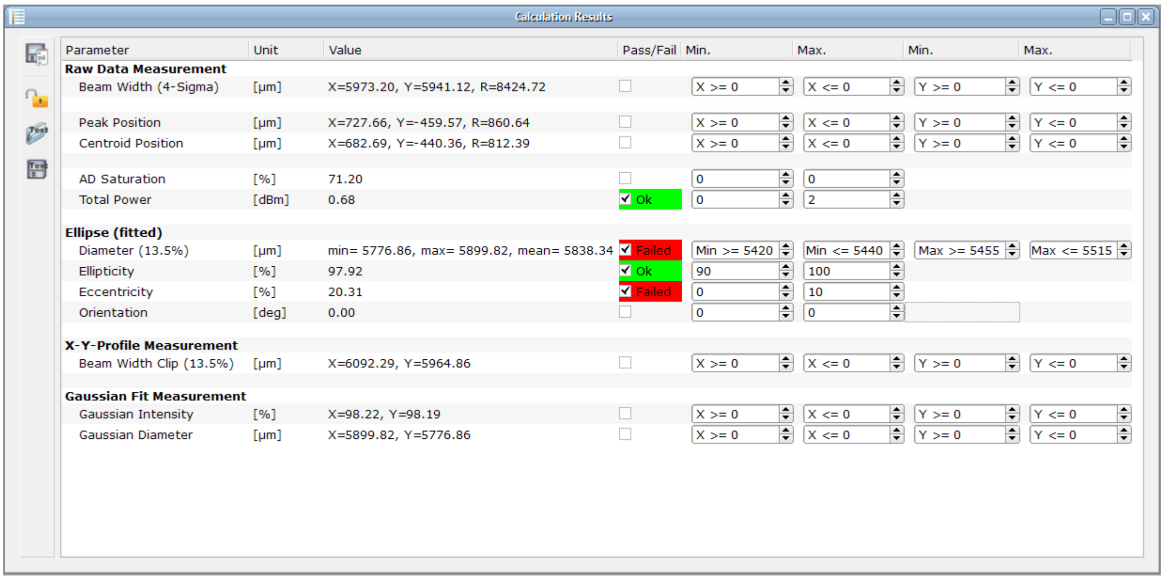
Use the Application Settings 49 dialog to define the output parameters which will be calculated and displayed here. There is also the possibility to change the units for the calculations.



The width of the columns is predefined but can be resized.
All measurement parameters are described in chapter Measurement Results 54.

3.4.2.4.1 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 142 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.

3.4.2.5 Plots

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

Plot Positions
Plot Power
Beam Stability
Plot Gaussian Fit

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

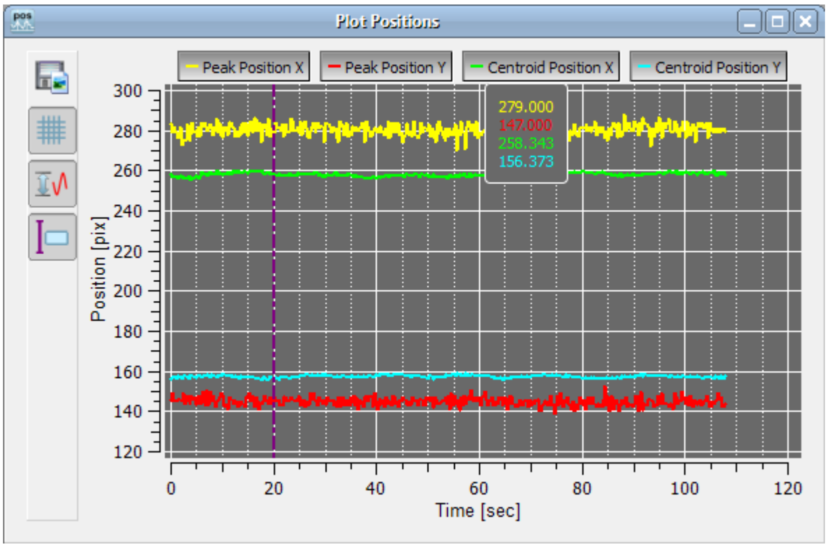
mouse cursor changes to . The cursor line can be moved with the left mouse button pressed to a position inside the diagram. The current values at the cursor position are shown in a rectangle next to the cursor in the colors of the plotted curve.

Below the individual plot windows are explained in detail.

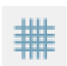
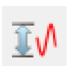
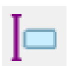
3.4.2.5.1 Plot Positions

Toolbar: 

Menu bar: Windows -> Plot Positions

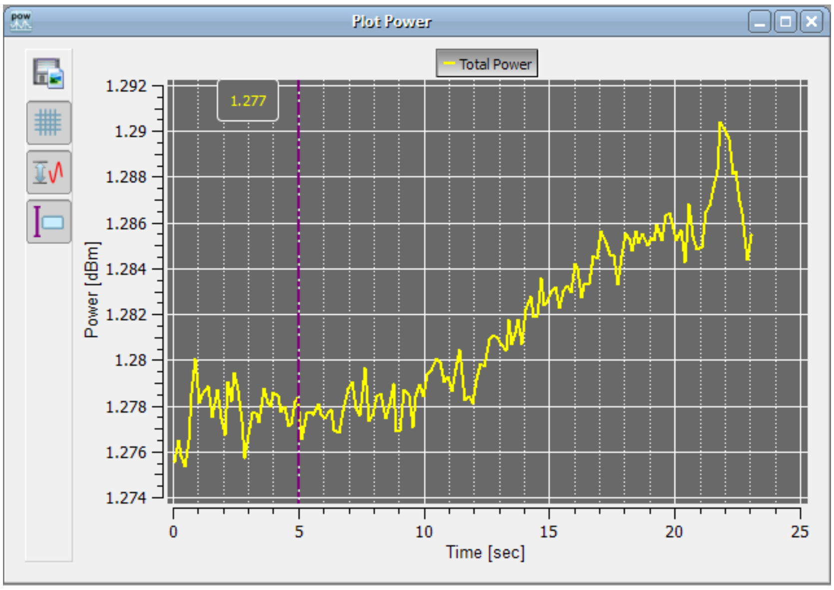


The positions of X and Y peak and of X and Y centroid positions can be displayed vs. time.

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

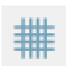
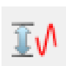
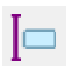
3.4.2.5.2 Plot Power

Toolbar: 
Menu bar: Windows -> Plot Power



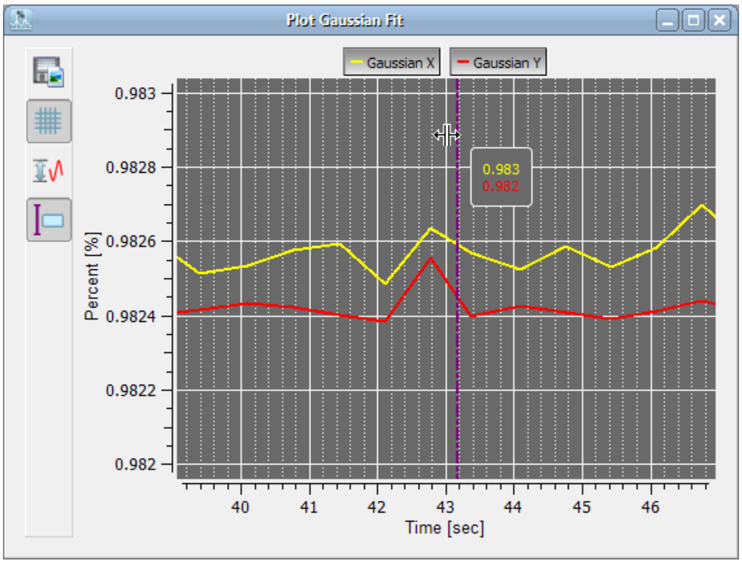
The total power measured by the beam profiler vs. time can be displayed.

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 46)

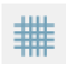
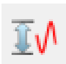
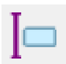
Toolbar Icon	Associated Action
	Opens a dialog box to specify the properties of the saved screenshots / diagrams.
	Toggle button to display grid in the diagram.
	Auto scale
	Show or hide the cursor

3.4.2.5.3 Plot Gaussian Fit

Menu bar: Windows -> Plot Gaussian Fit

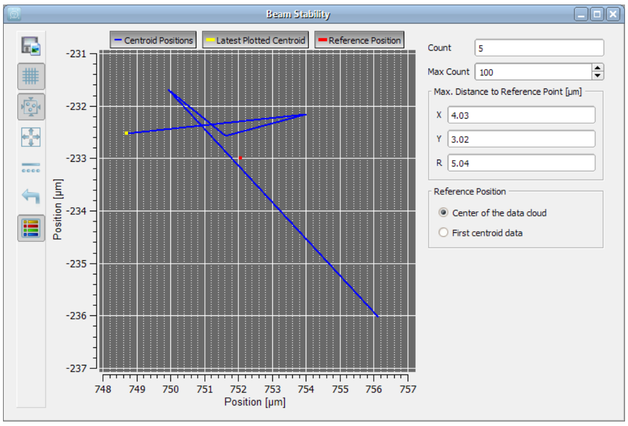


This window plots the Gaussian Intensity value (see Calculation Results 34) which shows the coefficient of determination of the fit.

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

3.4.2.5.4 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

3.4.3 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: Gain, bandwidth and DC offset are set to "Auto".

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.

3.5 Measurement with the Beam Profiler

General guidelines for operating the Slit Scanning Beam Profiler BP10x

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

1. Provide stable Mounting 9 to the Beam Profiler using the appropriated threads on its base plate.
2. Ensure to operate the instrument within the allowed Power Range 60 of the instrument.
3. Align the beam to be measured perpendicular to the front face of the Beam Profiler.
4. Minimize ambient light entering the Beam Profiler aperture.

Attention

Do not stick anything into the Beam Profiler aperture, you may damage the thin slit foils, spoil the bearings of the motor and/or blockade the rotating drum because there is no covering glass in front of it.
Higher beam power than the allowed power limit may damage the instrument.
Prevent dust or other contaminations from entering the aperture!

Performance Optimization

As soon as a Beam Profiler 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 Beam Profiler is depending on various device settings like scan rate (rotation speed of the scanning drum), target resolution, gain and bandwidth of the amplifier. 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.
The update rate of all values is synchronised to the measurement speed of the Beam Profiler. The display update rate is scan rate / average if standard average is selected and scan rate if rolling average is selected.

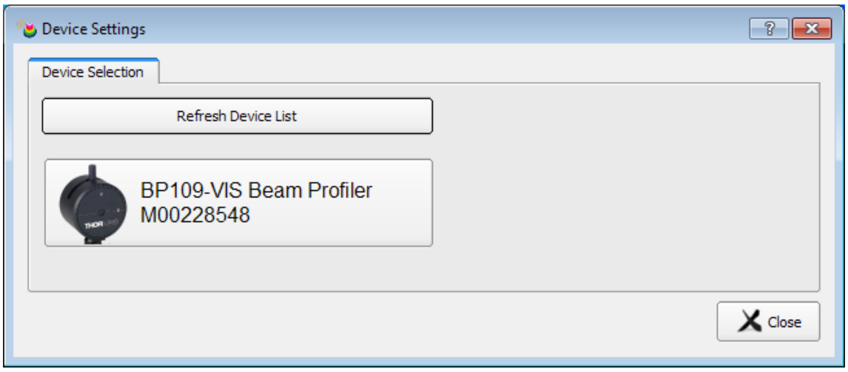
Note

1. For accurate measurement results (correct power values) you must enter the correct wavelength. Thorlabs Beam Profiler instruments are not calibrated for power with respect to the wavelength. The power calculation is based on a typical responsivity curve of the used sensor and manually entered wavelength (see Device settings 46)
2. Ensure to be within the allowed power range 60.
3. Align the laser beam perpendicular to the front panel.

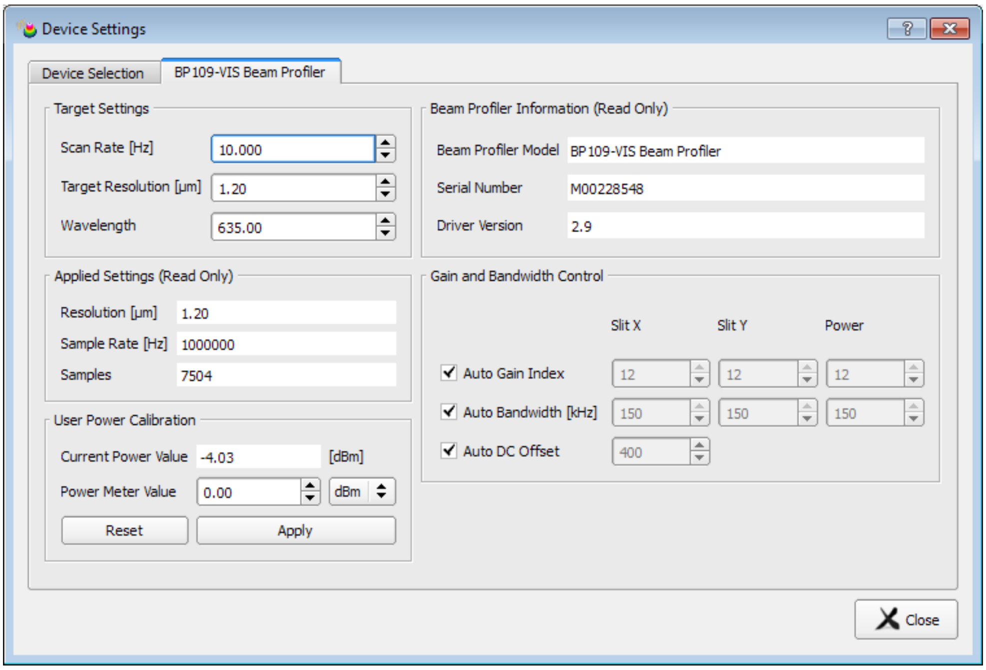
3.5.1 Operating the Instrument

Be sure that the Beam Profiler is connected to the PC and the driver is installed properly as described in chapter Connection to the PC 21. During initial program start a Device Selection panel will be displayed.

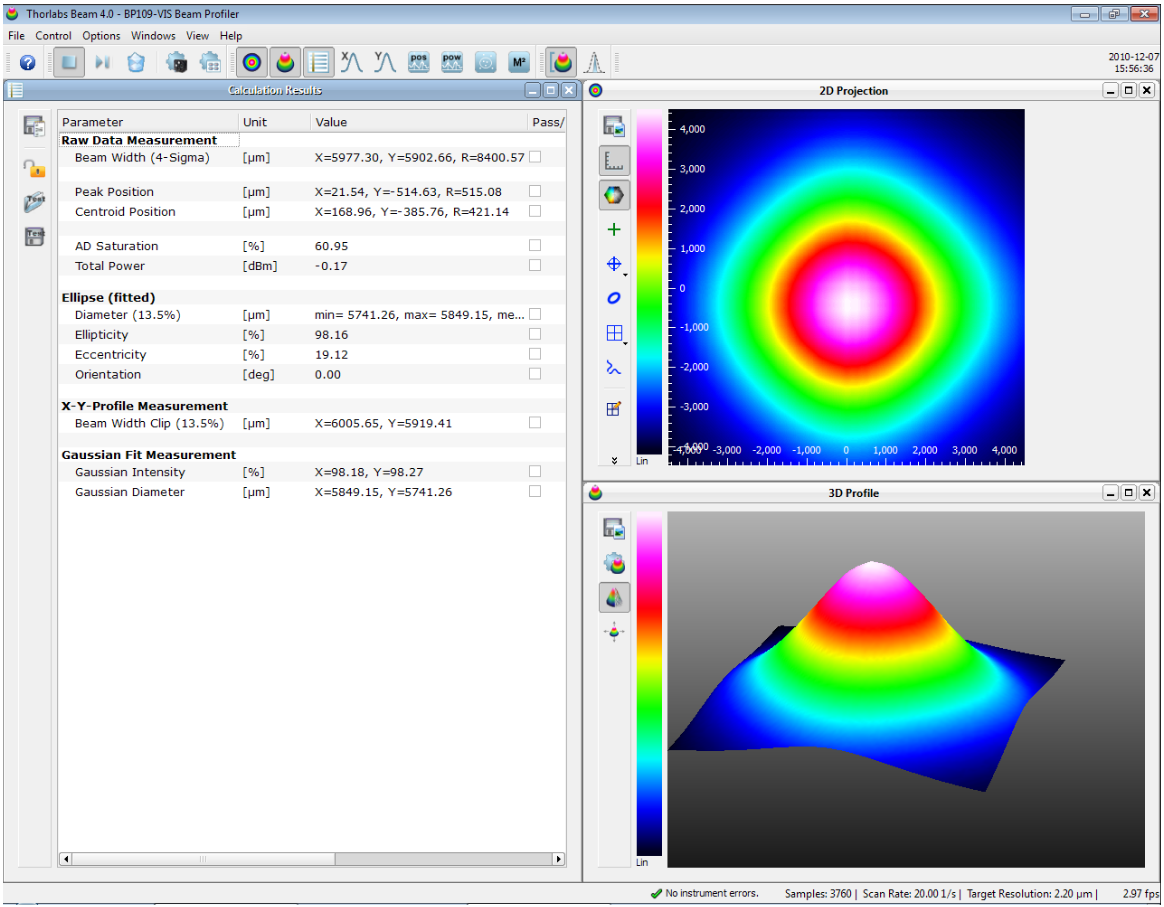
On tab "**Device Selection**" mark the instrument within the device list you want to work with. Use the device type as well as the Serial Number for device identification.



See chapter "Start the Application 22" for a detailed description of the further device options.
After selecting the instrument, the tab **BP10x Beam Profiler** is displayed.



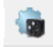
Make sure, the correct **Wavelength** is entered, and click "Close" to work immediately with the selected instrument. For details on Beam Profiler Settings, please see section Device Settings 46.
After clicking "Close" the measurement starts immediately in continuous mode.
If the application is started 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.

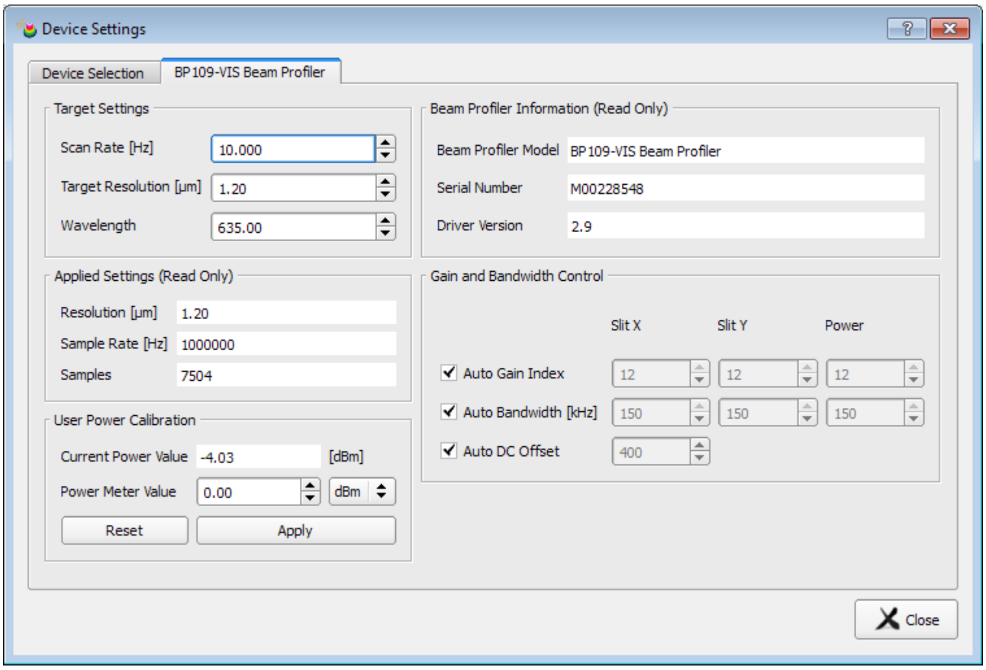


Window 2D Reconstruction 30 shows the measured intensity distribution across the sensor area in gray or color scale whereas the 3D Profile 32 is obtained by converting beam intensity into the 3rd dimension (Z scale). Numerical calculation results are displayed in the appropriate Calculation Results 34 window. The number of calculated parameters can be controlled in the Application Settings 49 panel.
All contents of the child windows including available options are explained in chapter Child Windows 29.

3.5.2 Device Settings

Prior to take proper measurements with the BP10x 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 'BP10x Beam Profiler'.



If this camera is connected the first time, the following instrument parameters are set as default:

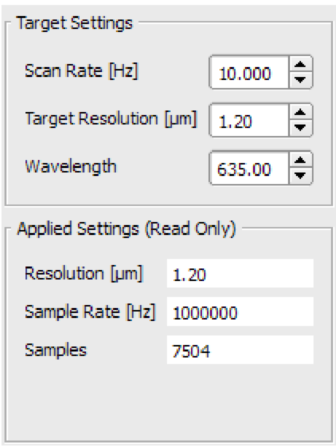
Parameter	Default value
Target Settings	
Scan Rate	10.000 Hz
Target Resolution	1.20 µm
Wavelength	635nm
User Power Calibration	
Factory Calibration in use	
Gain And Bandwidth Control	
Auto Gain Index	ON
Gain Index Slit X	12
Gain Index Slit Y	12
Gain Index Power	12
Auto Bandwidth [kHz]	ON
Bandwidth Slit X	150kHz
Bandwidth Slit Y	150kHz
Bandwidth Power	150kHz
Auto DC Offset	ON

This panel contains a number of important instrument 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 BP10x instrument and cannot be changed.

Target and Applied Settings



Scan Rate

This is the rotation speed of the drum in Hz (s^{-1}). Values between 1.5 and 20 Hz can be entered.

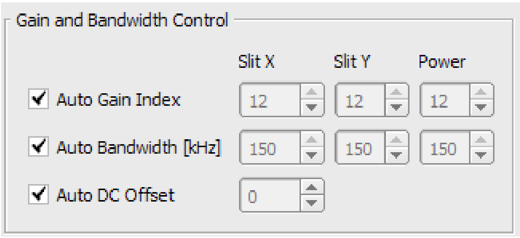
Target Resolution
The achievable resolution depends on the slit width (2.5µm for BP104 models, 5.0µm for BP109) and on the actual scan rate. A target value can be entered; depending on the recognized instrument and it's settings the software calculates the achievable resolution, which is displayed below in the box *Applied 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 (see Typical Photodiode Response Curve 131) stored within the Beam Profiler instrument. No other result than Total Power is influenced by this setting.
The range of allowed wavelength values is limited to specified range of the recognized beam profiler. Move the mouse pointer over the numeric box - a tooltip appears showing the valid range.

Sample Rate
is calculated based on the scan rate and the resolution.

Samples
is the number of displayed data points, calculated based on scan rate, resolution and slit width. The latter depends on the beam profiler type (BP104* -2.5µm; BP109* - 5.0µm)

Gain and Bandwidth control



Each time the software is started, gain, bandwidth and DC offset are set to Auto. This is the preferred setting for proper measurements. However, in some cases, e.g. measurement of pulsed lasers 61, it is recommended to change these settings manually.

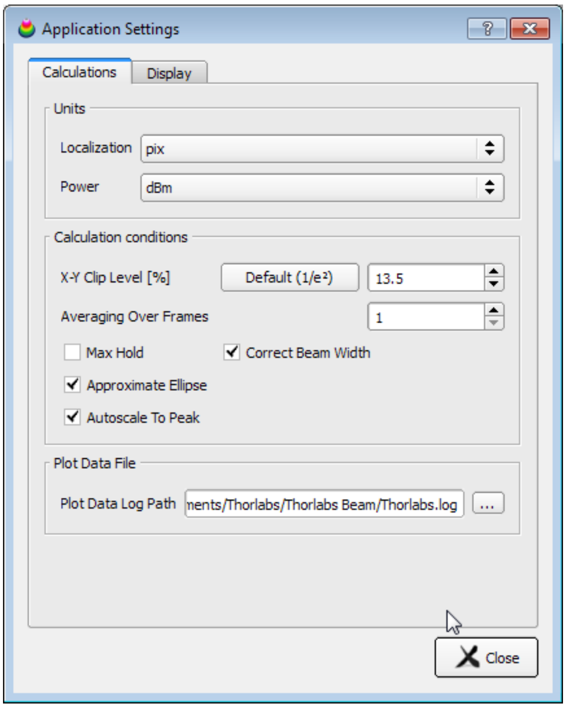
3.5.3 Application Settings

Separated from the Device Settings 46 these Application Settings are concerned to calculation and graphical presentation options.

Open 'Options' → 'Application Settings ...' from the Menu or click on [icon] 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.

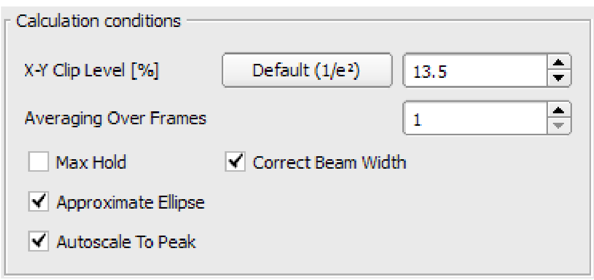


Units

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 and the user power calibration, see chapter User Power Calibration 53 for details.

Calculation Conditions



The **X-Y 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 118 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 noise in case of low intensity.
Average numbers between 1 and 25 frames are valid.

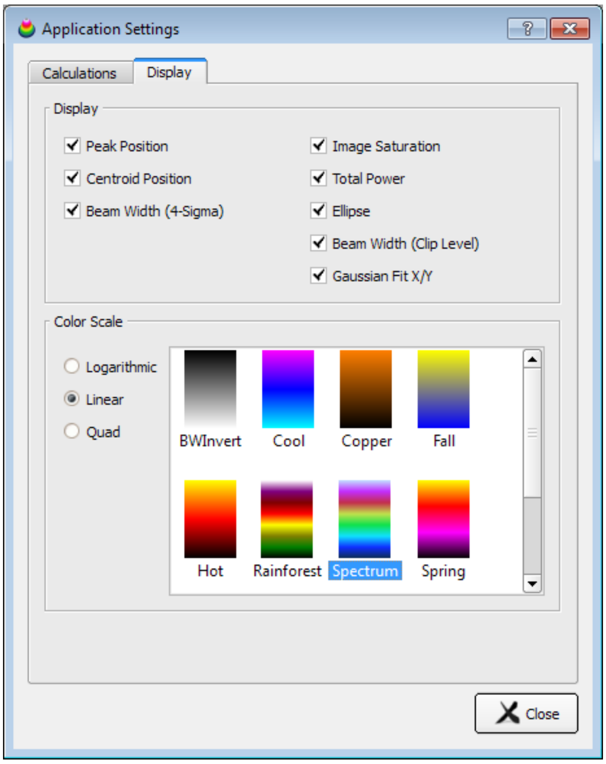
The **Max Hold** feature is recommended for pulsed laser sources. In all subsequent scans for each pixel only the maximum values are stored, displayed and used for calculation.

The **Correct Beam Width** option should be activated by default. It corrects for the measurement error due to the finite slit width for all methods (13.5% clip level with and without Gaussian fit). Since this convolution error is systematic it can be calculated and eliminated. Especially for narrow beams the beam width result will become smaller and closer to the real value.

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 54
In the lower part a number of different styles for **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						

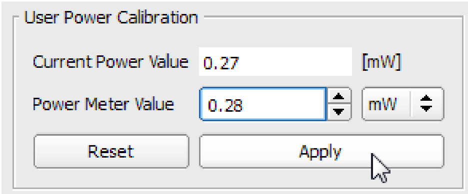
... stands for the intermediary values.

3.5.4 User Power Calibration

The User Power 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 'BP10x Beam Profiler'.

Enter the operating wavelength of your laser source.



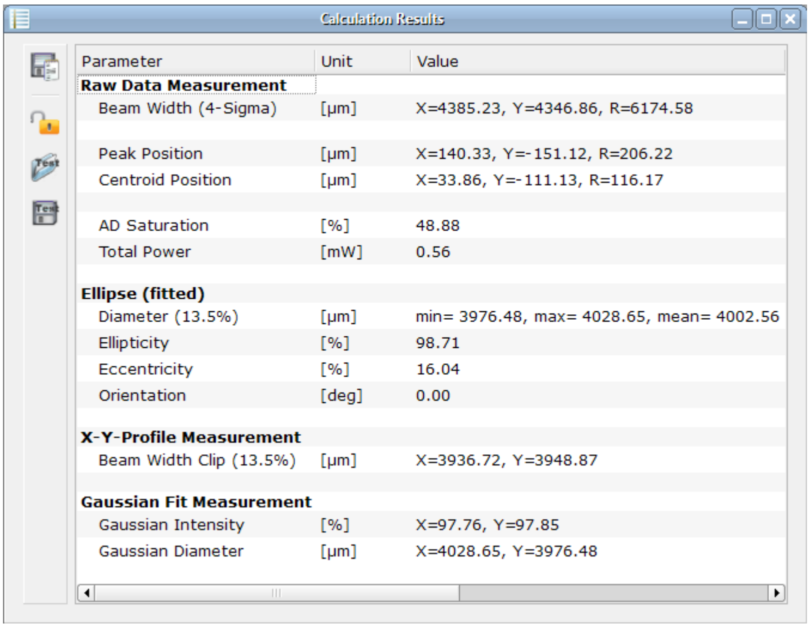
Enter the correct value into the 'Power meter value' control.
Click 'Apply' and both values will coincide. To manage this, an internal power correction offset is calculated and recognized within each Total Power calculation. This offset (in dBm) is stored within the Beam Profiler and will be read out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

Note

The user calibrated power reading will loose accuracy when going to another wavelength.

3.5.5 Measurement Results

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



Parameter	Unit	Value
Raw Data Measurement		
Beam Width (4-Sigma)	[µm]	X=4385.23, Y=4346.86, R=6174.58
Peak Position	[µm]	X=140.33, Y=-151.12, R=206.22
Centroid Position	[µm]	X=33.86, Y=-111.13, R=116.17
AD Saturation	[%]	48.88
Total Power	[mW]	0.56
Ellipse (fitted)		
Diameter (13.5%)	[µm]	min= 3976.48, max= 4028.65, mean= 4002.56
Ellipticity	[%]	98.71
Eccentricity	[%]	16.04
Orientation	[deg]	0.00
X-Y-Profile Measurement		
Beam Width Clip (13.5%)	[µm]	X=3936.72, Y=3948.87
Gaussian Fit Measurement		
Gaussian Intensity	[%]	X=97.76, Y=97.85
Gaussian Diameter	[µm]	X=4028.65, Y=3976.48

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 49. 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.

The units of the calculations are divided into 3 categories:

- Localization (widths, positions): units pix and µm are available
- Power: mW or dBm are available
  Change the units in the appropriate Application Settings 49.
- Units specified for the calculation (e.g. Gaussian fit is always in per cent, degree for angles)

Overview on all available units:

Unit	Description
pix	Location, width or distance in pixels. The max. number of pixels depends on scan rate and slit width and is displayed as "samples" in Device settings (see Device Settings 48) 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 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. Value range: BP104* = -2000 to +2000; BP109* = -4500 to +4500
mW	The Total Power of the beam is calculated from measurement of the total photo diode current, using it's typical wavelength dependent responsivity and the power correction value.
dBm	The Total Power translated from mW into dBm: 10 * log(P[mW]). 0 dBm = 1 mW
%	Relative level between 0 and 100%
deg	Angle in degree with respect to the X axis, range -90 to +90 deg

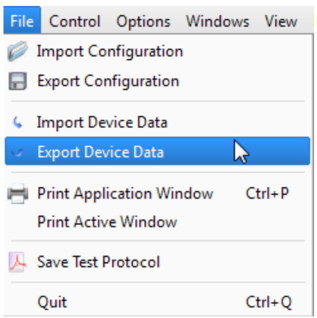
If a calculation failed the value turns to "--".
The columns can be resized by moving the column separators.

For details on these parameters, please see section "Application Note 118"

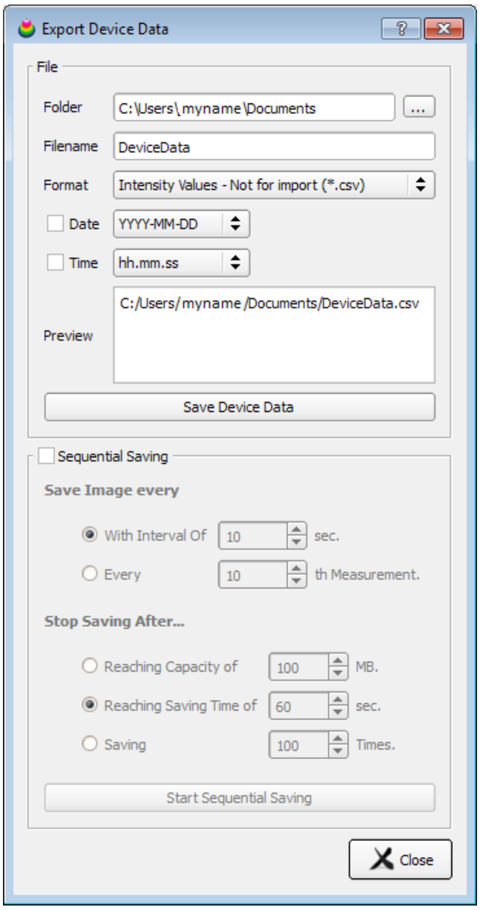
3.5.6 Save Measurement Results

1. Export Device Data

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



A dialog opens:

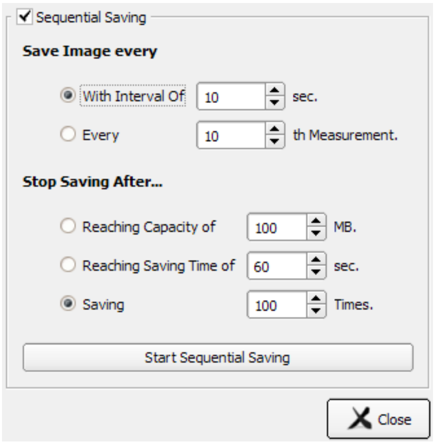


Only CSV (comma separated values) file format is available. Select the desired path and a file name.
The comment "Not for import" is related only to Beam Software: A data file cannot be imported in order to reconstruct a beam profile.

Thorlabs Beam			
Version: 4.0 Build 127			
Date: 2011-02-15			
Time: 15:32:21			
Device: BP109-VIS Beam Profiler			
S/N: M00228548			
Pos X [pix]	X	Pos Y [pix]	Y
-3752	5.19E-05	3752	2.53E-07
-3751	6.94E-05	3751	1.11E-05
-3750	4.82E-05	3750	-2.88E-06

The data file contents of the header with common data and a table stating X and Y positions with the appropriate relative intensity values.

Sequential Saving



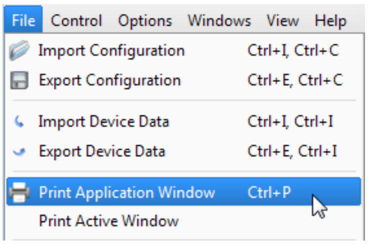
By checking the **Sequential Saving** box, a series of measurement data in *.csv file format can be saved.
The saving can be proceeded with a defined time interval (0 to 100.00 sec) or for each nth measurement - here the value range is from 1 (saving every single measurement) to 100.000 (99.999 measurements 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.

2. Print screenshots

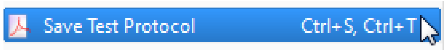
Select **'File→ Print Application Window**' or **'File→Print Active Window'** to print screenshots of the appropriate window.



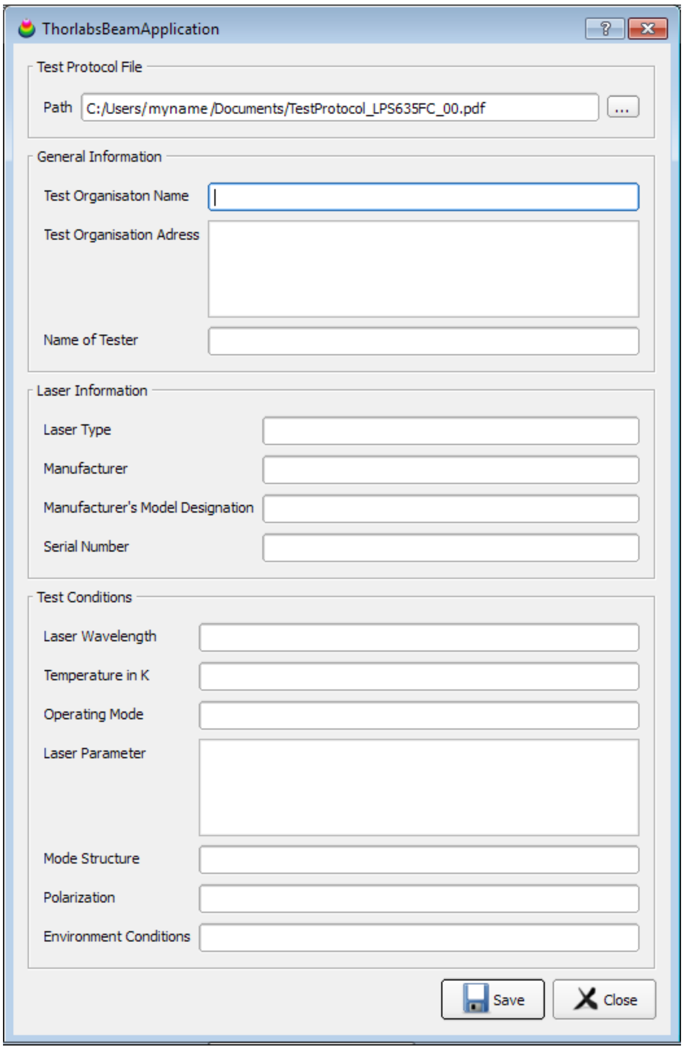
If a PDF creating software is installed as a printer, the screenshot can be printed also as a PDF file.

3. Export a PDF Test Protocol

To save a test protocol in pdf format select **'File → Save Test 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 Reconstruction and the 3D Profile windows, so far these windows were displayed.

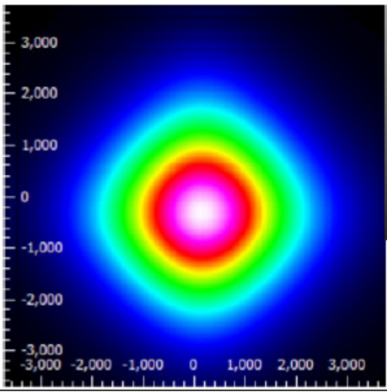
Example:

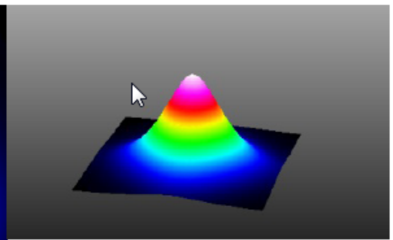
Laser Beam Measurement Test Protocol

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:	BP109-VIS Beam Profiler	
Serial Number:	M00228548	
Scan Rate:	[1/s]	10
Resolution:	[µm]	1.2

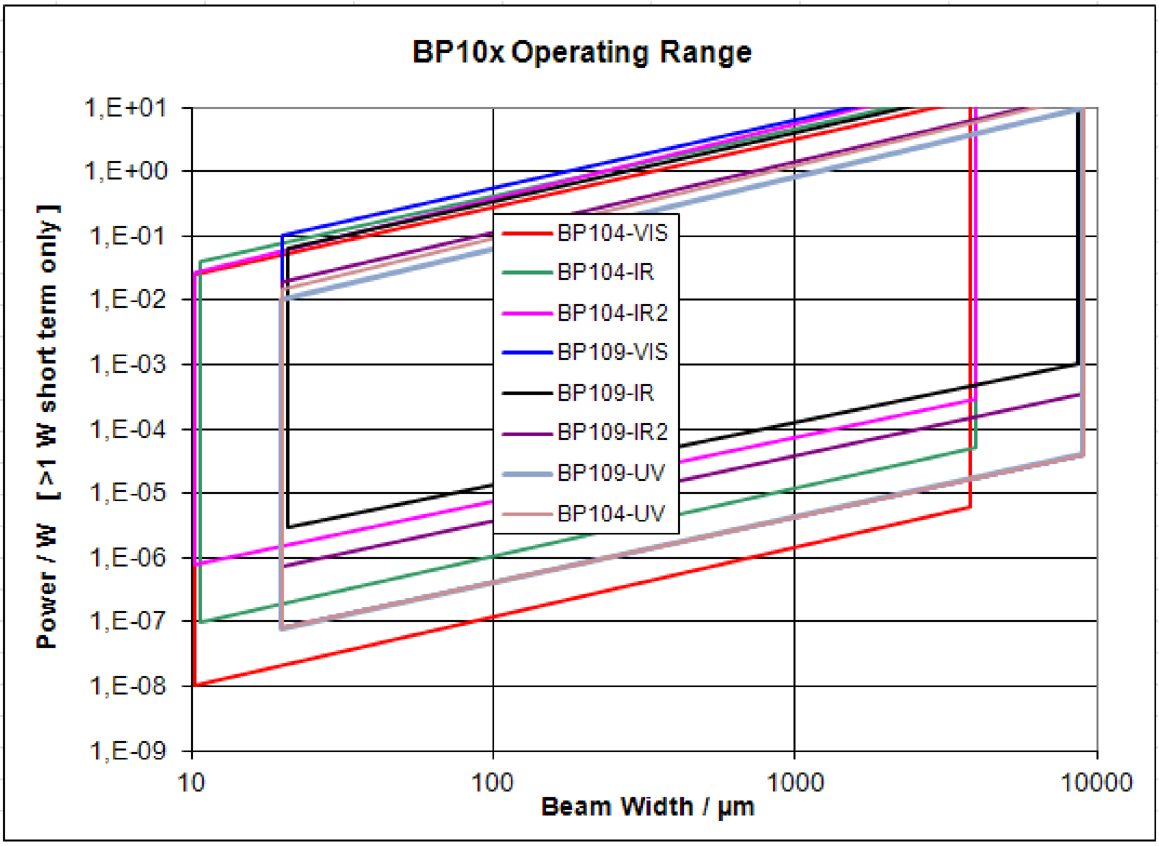
Parameter:	Unit:	Result:
Beam Diameter (4-Sigma)	[pix]	--
Beam Width (4-Sigma)	[pix]	X=3648.73, Y=3623.76
Beam Width Clip	[pix]	X=3474.61, Y=3429.18
Centroid Position	[pix]	X=159.61, Y=-277.69
Eccentricity	[%]	14.19
Effective Area	[pix²]	0.00
Effective Beam Diameter	[pix]	--
Diameter	[pix]	X=3311.76, Y=3345.63
Ellipticity	[%]	98.99
Gaussian Diameter	[pix]	X=3345.63, Y=3311.76
Gaussian Intensity	[%]	X=98.17, Y=98.18
AD Saturation	[%]	50.44
Orientation	[deg]	0.00
Peak Density	[dBm/pix²]	-1.00
Peak Position	[pix]	X=143.00, Y=-319.00
Total Power	[dBm]	-2.34





3.5.7 Power Ranges

Every Beam Profiler model has a different usable input power range (depending on aperture and wavelength range).
For a each Beam Profiler type the usable input power range depends on the actual beam with. As smaller the beam width as lower the maximum input power because of the maximum absorbable power density of the photodiode - see diagram below.



Note

Please note that this diagram shows limits for detecting the beam profile using the slits. The available power range for the power detector (total power) may be smaller. In the case of overdriven power measurement range an error message will be displayed in the status box but beam shape measurement are still feasible until the upper limits for the X and Y slit measurement windows are reached.

3.5.8 Pulsed Laser Sources

BP10x Beam Profilers can be used also to measure the profile of pulsed laser beams, although the better choice for such applications is the Thorlabs Camera Beam Profiler BC106x.

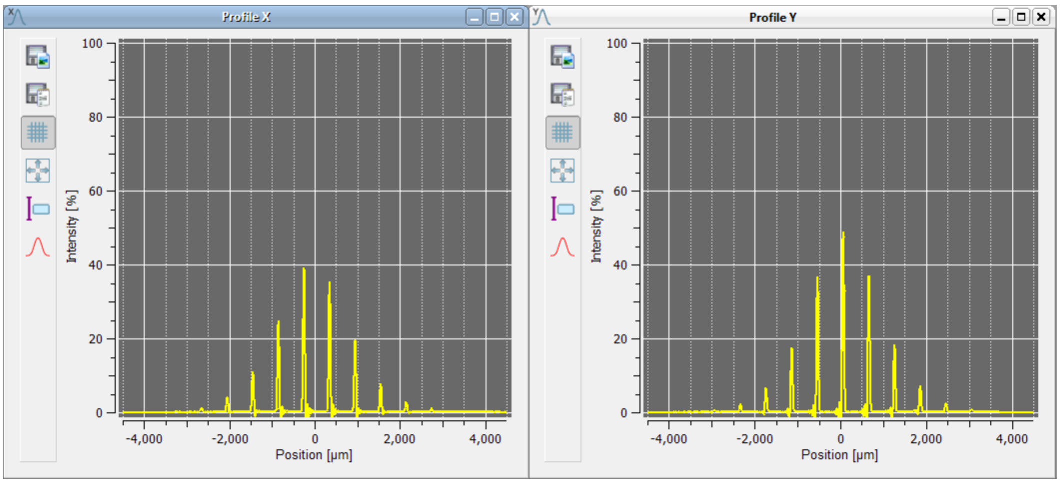
Pulsed lasers with high repetition rate and short pulse duration can be measured in the same way like a CW laser. Typical example is a femtosecond laser, having repetition rates of up to 100MHz and pulse durations below 100fs.
In such case, the photo diode current amplifier due to it's limited bandwidth "sees" not a pulse train, but virtually a CW signal.

The situation is different if the repetition rate is in the order of up to tens of kHz. In order to illustrate how to optimally setup the beam profiler, below are given two examples.

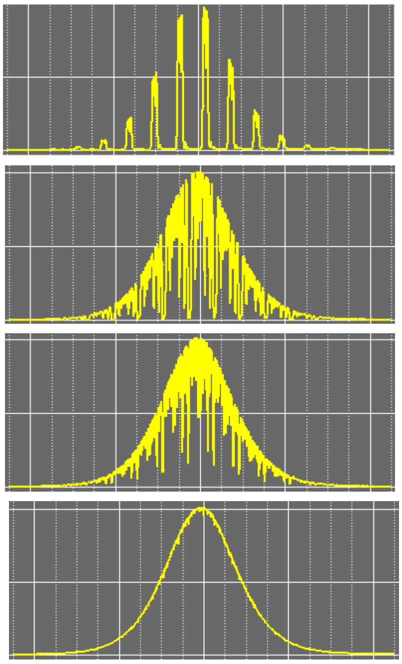
Used laser system
Thorlabs LPS-635-FC pigtailed laser diode with adjustable collimation package
Controller Thorlabs ITC4001 in QCW mode (f_{rep} = 1kHz, t_{pulse} = 100µs)

- **Scan rate setting**

The scan rate can be set between 1.5 and 20 Hz, so it cannot be set equal to the pulse repetition frequency. In the a.m. case, if set the scan rate to 10Hz, each 100th pulse will be scanned. Due to the high repetition frequency, also previous and following pulses will be displayed:



If set the scan rate in such way, that in X and Y profile the pulses move through the diagram (i.e., scan rate slightly differs from integer multiple), and activate the max hold function  function, the software will accumulate the peak intensities over a number of subsequent pulses, and finally, the beam profile will be displayed - however, this is the averaged profile over a number of subsequent pulses.



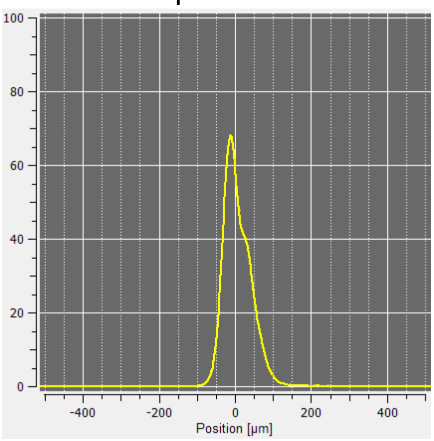
Note

The user should decide, when the envelope shape smoothing can be considered to be finished.

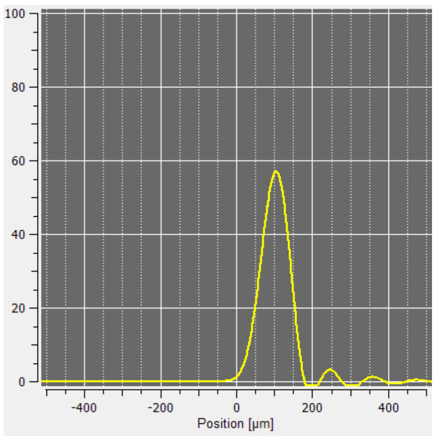
- **Bandwidth setting**

It is recommended to set bandwidth manually. The guideline is the same as for CW signals - the smaller the beam diameter, the higher the bandwidth is required: Small beam diameters cause short photo diode current pulses when the slit is scanning it. If the BW is set too low, the rising edge of the photo diode current is delayed, the falling edge causes overshoots and the peak amplitude is lowered.

The X profile of a 130µm beam illustrates this:

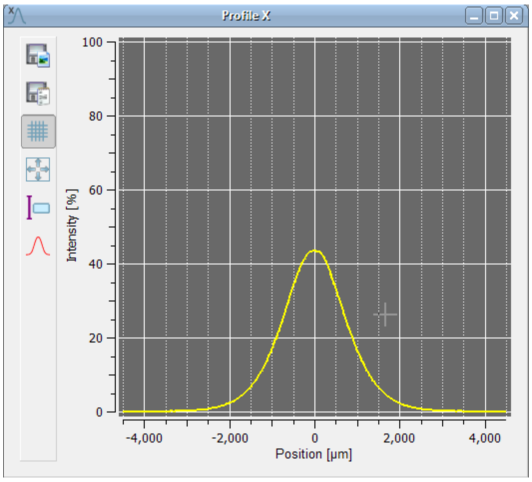


Bandwidth - 150 kHz

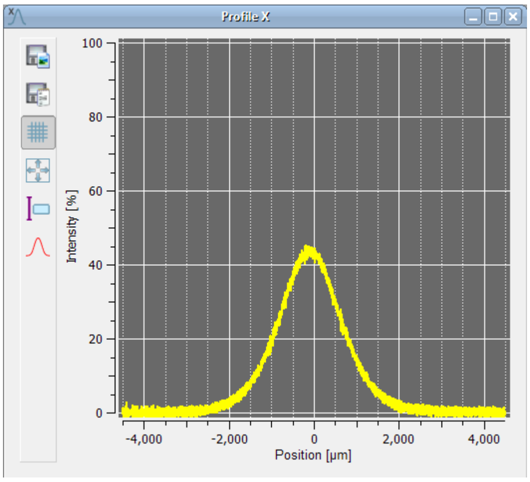


Bandwidth - 10 kHz

At larger beam diameters, higher bandwidth results in a higher noise level - as can be seen for a beam with of abt. 3mm:



Bandwidth - 10 kHz



Bandwidth - 150 kHz

- **Gain Index**
  For pulsed lasers, the gain index is recommended to be set manually in order to avoid saturation of the amplifier.

3.6 Beam Quality (M²) Measurement

3.6.1 General

In laser science, the parameter M² 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. M² 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 M² value far from unity. As well, a beam can appear very "un-Gaussian", yet have an M² value close to unity. For a single mode TEM00 Gaussian Laser beam, M² is exactly one.
The value of M² can be determined by measuring 4σ diameter or "second moment" width. Unlike the beam parameter product, M² 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 M² 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 Beam Profiler Series BP104 and BP109 are slit scanning beam profiler instruments to measure the beam quality factor M².
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.

There are two associated product groups

M2SET is a **complete ready to use M²-Meter instrument** that already contains the necessary equipment for beam alignment and focusing as well as the Beam Profiler which is already mounted on the translation stage. All components are mounted on a 600 x 150 mm (or 24 x 6 inch) breadboard in a pre-aligned state. The M²-Meter is available in both metric and imperial versions.

BP1M2 is just an **Extension Set** for an already existing Thorlabs Beam Profiler and contains a translation stage of selectable length and a mounting adapter for the Beam Profiler. Means for beam alignment and focusing are not supplied with the Extension Set.

M²-Meter M2SET and BP1M2 Extension Set feature

- Accurate M² Measurements
- Measures Divergence, Waist Diameter, Rayleigh Range and Astigmatism
- Flexible Design
- Compatible with CW and Quasi-CW Pulsed Laser Sources
- Short Measurement Times

- Includes Laser Focusability Test
- 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 ($M^2 \geq 1$).

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 $d_0 * \theta$ is to the diffraction limit of a perfect Gaussian beam. For beams of worse quality the product $d_0 * \theta$ 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.

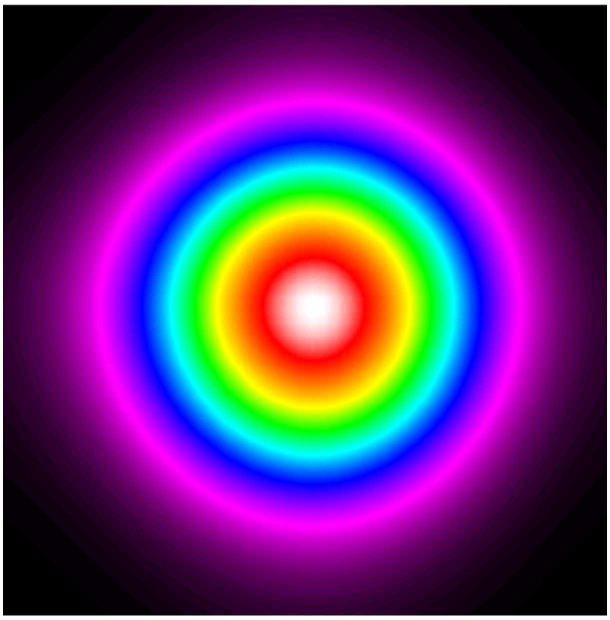
M^2 is also known as
- the ratio of the waist diameter d_0 of the measured beam to that of an ideal Gaussian beam (TEM_{00}) at same divergence angle θ.
- the ratio of the divergence angle θ of the measured beam to that of an ideal Gaussian beam (TEM_{00}) at same waist diameter d_0,

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.

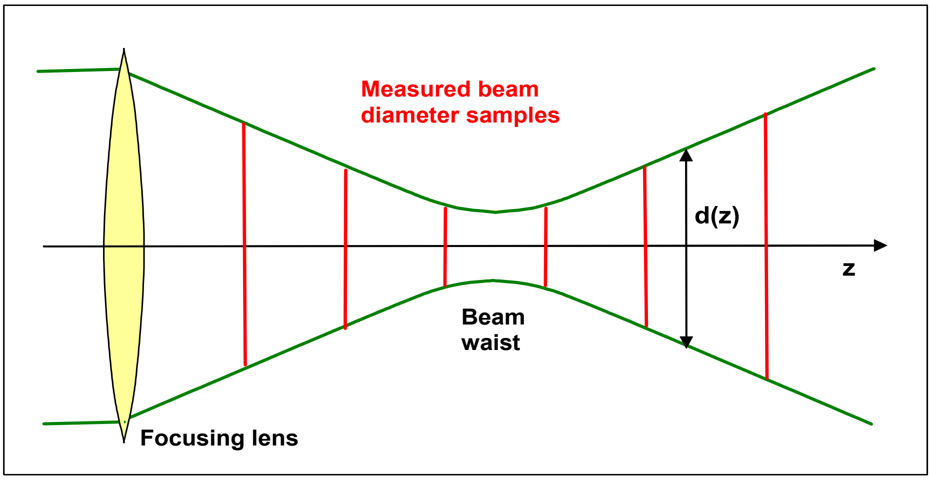


Note

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 61.

3.6.2 Selecting Focal and Stage Length

Since the BP1M2 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 124 for details.

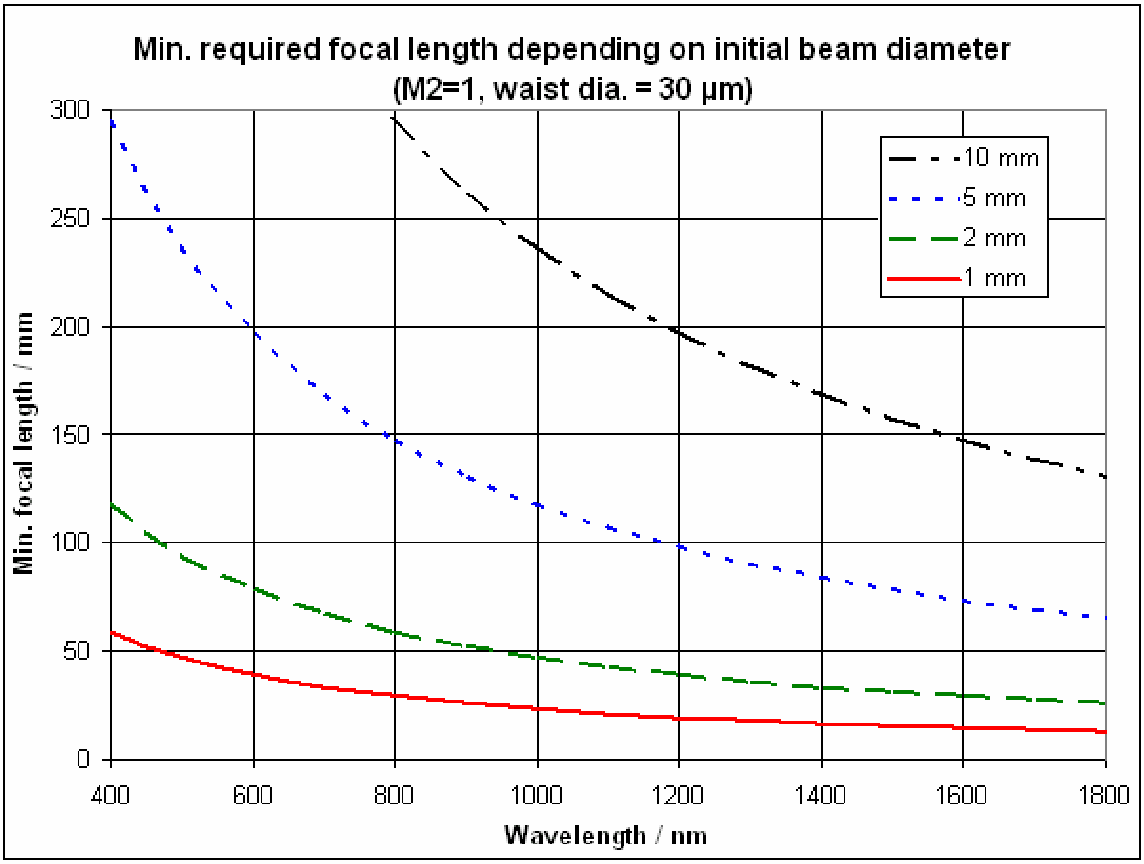


Diagram A

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 (e.g. 50, 100, 150, 200, 300 mm). Longer focal lengths generate waist diameters above 30 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 as long as the focal length of the focusing lens. For correct M² detection 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 M². Therefore, the translation range needs to be longer for bad beam quality (K<<1, M²>>1).
See Focal and stage length calculation 124 for details.

Diagram B shows the minimal required stage length for M²=1 depending on the expected waist diameter:

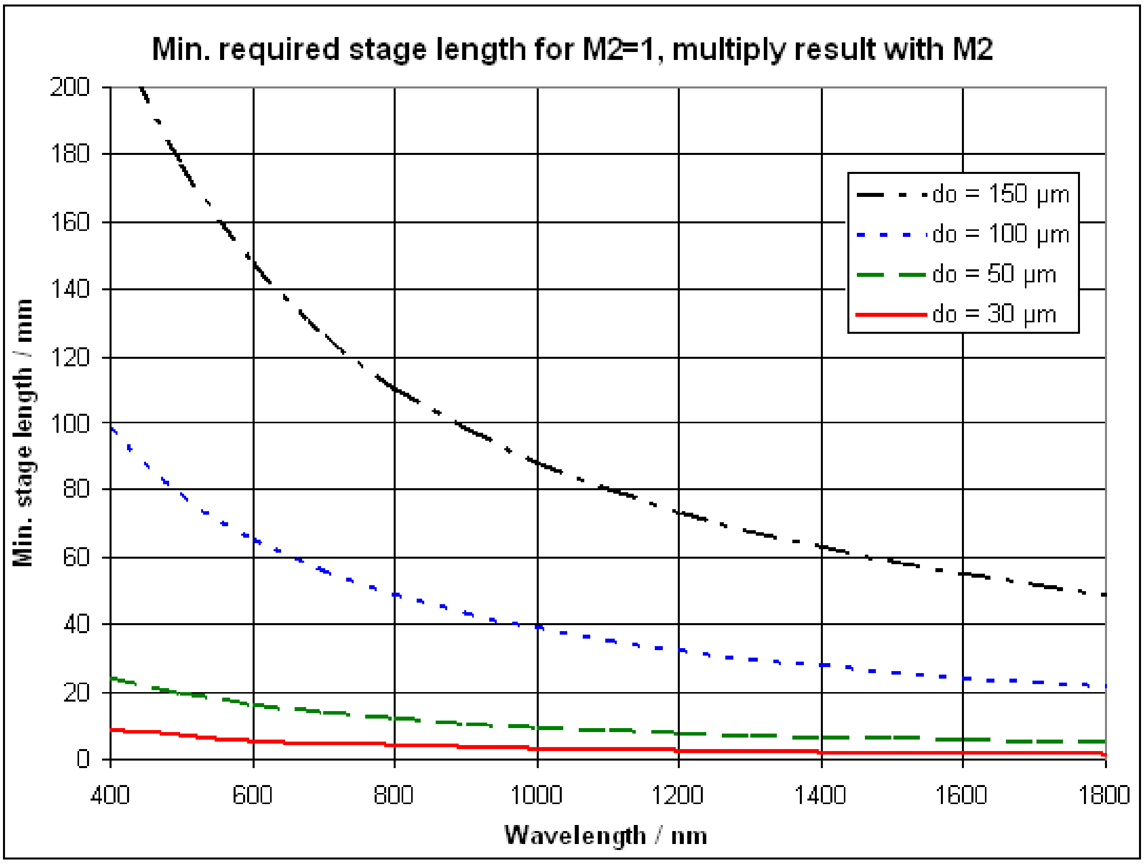


Diagram B

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 M² value of your laser source and round it up to the next available translation stage length (50, 150 or 300 mm). Please note this length is a minimum requirement for M² detection.

When a lens with the optimal focal length was selected according to diagram A, the resulting waist diameter of 30 µm keeps the required translation range below 50 mm even for M² values up to 5. 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, longer stage lengths of 150 mm or even 300 mm are advisable for universal setups which are ready to use for various laser types, beam diameters, wavelengths, M² 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.
For these reasons, Thorlabs recommends a translation stage length at least as long as the highest focal length that will be used in the setup.

3.6.3 Extension Hardware

3.6.3.1 BP1M2 Extension Set for M² Measurements

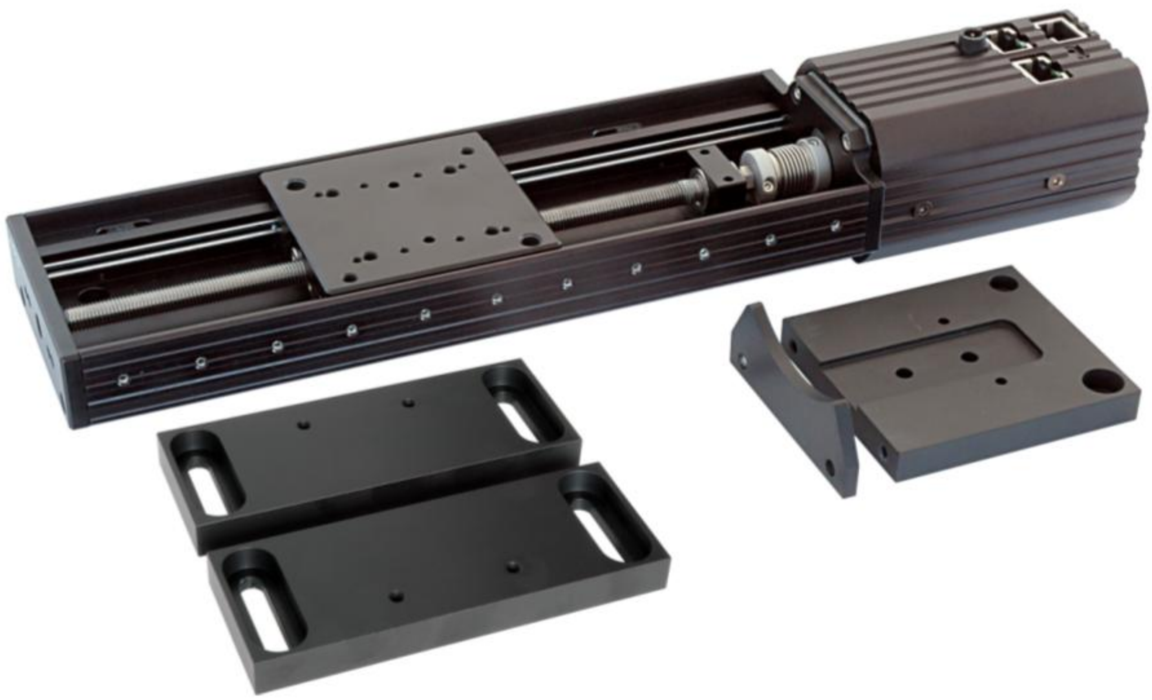
The BP1M2 M² Analysis Extension Set is comprised of a motorized Translation Stage of selectable length, plus mounting accessories to be used with the BP100 Beam Profiler. The Beam Profiler itself and required means for beam alignment and focusing are not supplied with the Extension Set and need to be ordered separately.

Three different models with different translation stage lengths are available:

Extension Set Model	**BP1M2-50**	**BP1M2-150**	**BP1M2-300**
Travel range	50 mm	150 mm	300 mm

Required Travel Length of the M² Extension Set
Please see the Selecting Focal and Stage Length 68 chapter for information on selecting the model with a suited travel length for your particular application.

The following picture shows the largest 300 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 138 for a detailed drawing.



The stage movement is fully controlled by the software module (included in BP100 software package V2.0 or newer) of the BP100 which allows it to take measurements at different stage positions and perform a complete M² 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 consists of:

- 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

BP100 Series Beam Profiler as well as beam focusing and alignment means are not included in the BP1M2 Extension Set and are sold separately. See Mechanical Setup 79 for optional equipment.

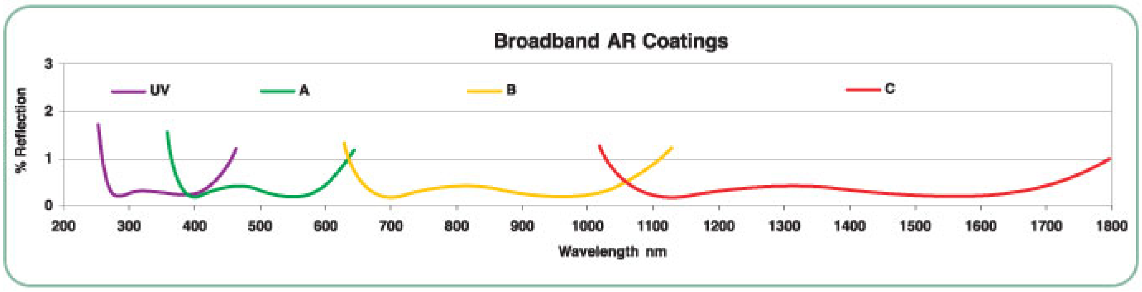
3.6.3.2 Recommended Accessories

Depending on existing lab equipment additional parts may be required to manipulate the laser beam for the M² measurements. To focus parallel laser beams you will need an appropriate focusing lens and holder. Additional beam alignment and redirection tools may be required to align your laser beam to the M² setup. The following table suggests some accessories for this.

Lenses

LB1471-λ	BK7 B Coated Bi-Convex Lens, DIA = 25.40, f = 50.00
LB1676-λ	BK7 B Coated Bi-Convex Lens, DIA = 25.40, f = 100.00
LB1945-λ	BK7 B Coated Bi-Convex Lens, DIA = 25.40, f = 200.00

AR coatings of lenses have to be selected according the wavelength range of the laser.
Suffix -λ needs to be replaced with -UV, -A, -B or -C.



Mechanical Accessories

(Metric parts versions - for imperial type delete "/M" appendix of the parts' name)

SM1L03	SM1 Lens Mounting Tube, 0.30" (7.6mm) Bore Depth
LMR1/M	Metric, Lens Mount for Ø 1" Optics

LM1XY/M	Translating Lens Mount
FM90/M	Flip Mount for easily inserting/removing a lens mount
K6X	6 Axis Kinematic Optic Mount (for lens alignment)
TR30/M	Post 30mm
PH1.5/M	Post Holder with Spring-Loaded Thumbscrew, L=40mm

For adapting the beam height and trajectory kinematic mirrors or a periscope assembly is useful:

KM100	Kinematic Mirror Mount for 1 inch Optics
KM100-E02	Kinematic Mirror Mount with Visible Laser Quality Mirror
KM100-E03	Kinematic Mirror Mount with Near IR Laser Quality Mirror
RS99/M	Complete Periscope Assembly, Metric
PF10-03-P01	Protected Silver Mirror, Dia= 25.4 mm, Thickness = 6mm, for periscope assembly

Attenuators might be required in case of high power optical beams.

ND20B	Unmounted Metallic ND Filter Ø 1", D=2.0
ND40B	Unmounted Metallic ND Filter Ø 1", D=4.0
LMR1/M	Metric, Mount for Ø 1" ND Filter

Other accessories:

MB1530/M	Breadboard 150 x 300mm
MB1560/M	Breadboard 150 x 600mm
TR30/M	Post 30mm
PH1.5/M	Post Holder

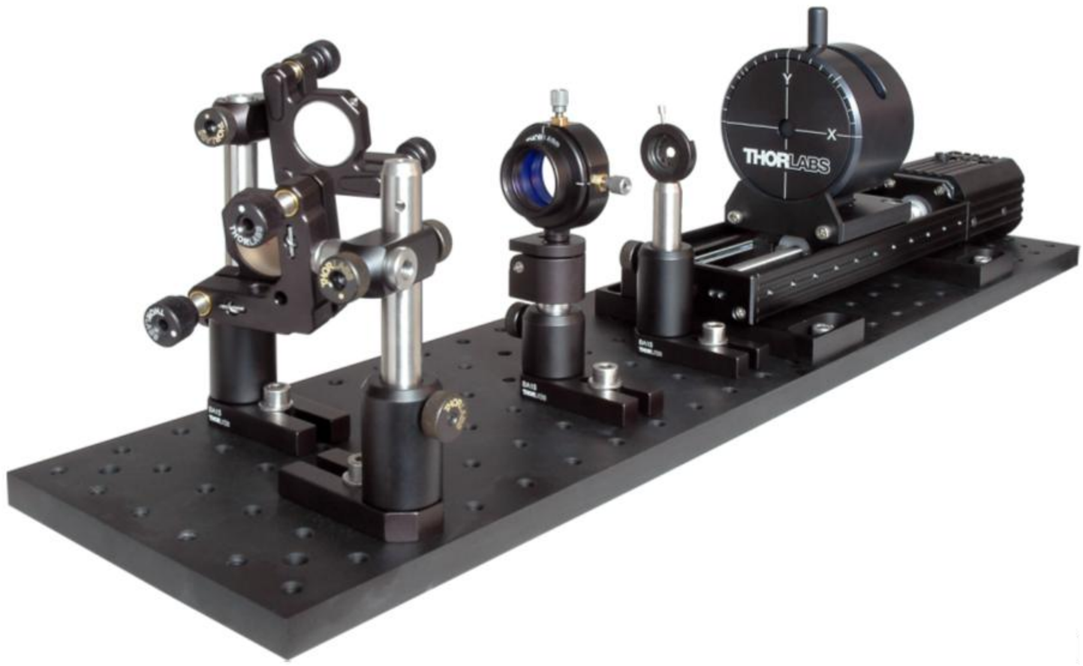
3.6.3.3 M2SET - M2-Meter

The M2SET M^2-Meter is comprised of a Beam Profiler mounted on a 150 mm long motorized translation stage as well as beam alignment and focusing tools mounted and pre-aligned on a breadboard. This complete M^2-Meter already brings along pre-selected and well suited optical and mechanical components. Thanks to its high degree of pre-alignment it saves time for setup and beam alignment considerably. All components of the M^2-Meter are available either in imperial or metric versions for compatibility to already existing lab components.

In total there are 4 different M^2-Meter models available:

	BP109-VIS	BP109-IR
Imperial components	M2SET-VIS	M2SET-IR
Metric components	M2SET-VIS/M	M2SET-IR/M

The following picture shows the ready to use M^2-Meter M2SET-VIS/M.



See Appendix M2SET M2-Meter 139 for dimensions and a drawing of the M^2-Meter.

The M^2-Meter contains

- Beam Profiler BP109-x incl. Mounting Adapter to Translation Stage
- Translation Stage 150 mm incl. Controller, Power Supply and RS232 Cable, Mounting Base Plates
- USB to RS232 converter
- Breadboard 600 x 150 mm (or 24 x 6 inch)
- Iris Diafragm ID12 for faster beam alignment
- Translating Lens mount LM1XY screwed on a Flip Mount FM90

- Two Lenses LB1945, f = 200 mm, AR coated for appropriate wavelength range
- Two laser quality Silver Mirrors in two KM100 Mirror Mounts on flexible post holders
- Latest Beam Profiler Software CD
- Manual

See a complete list of optical and mechanical M2-Meter Components 134 in appendix.

The stage movement is fully controlled by the software module (included in BP100 software package V2.0 or newer) of the BP100 which allows it to take measurements at different stage positions and perform a complete M² 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.

3.6.3.3.1 Setup and Electrical Connections

The Thorlabs M² Meter M2SET-x is delivered as a complete ready to use instrument. Mount its breadboard onto a table with a stable mechanical connection to the laser to be tested before you start beam alignment and measurement.
Do not direct the laser beam immediately to the Beam Profiler but use both alignment mirrors to adjust for optimal beam height and pointing direction.
Follow the alignment steps described in chapter Beam Alignment 86.

The M² Meter suited to adapt various beam properties:
- focussed beam, waist accessible
- divergent beam, waist not accessible
- parallel beam

Focussed beam, waist accessible
In case of measuring a focussed beam with accessible beam waist the focusing lens integrated in the M² Meter is not required and needs to be flipped aside. Using the applied tiltable mirrors the operator has to align the beam parallel to the translation axis so that the beam centroid is always in the middle of the Beam Profiler aperture for all z positions. The already existing beam waist needs to be positioned within the translation range.

Divergent beam, waist not accessible or
Parallel beam
In these cases the integrated lens within the M² Meter is required to generate an artificial beam waist within the moving range of the translation stage. Beam alignment is done first without the lens and subsequently the lens is flipped back into the beam and is also aligned for lowest beam displacement.

Selection of Focusing Lenses
Prior to start alignment and measurement with the M² Meter system check that the

wavelength range of the lens meets the wavelength of your beam under test. If the laser wavelength is outside the range you need to exchange it by unscrewing the lens tube out of the translating lens mount LM1XY and replace it with the appropriate lens.

Lenses provided with M2SET-VIS

LB1945-A	BK7 B Coated Bi-Convex Lens, DIA = 25.40, f = 200.00, AR coated 350 - 650 nm
LB1945-B	BK7 B Coated Bi-Convex Lens, DIA = 25.40, f = 200.00, AR coated 650 - 1050 nm*

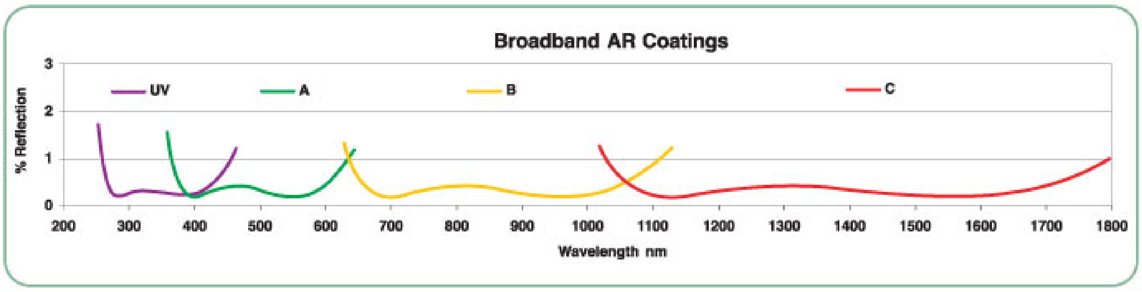
*Lens LB1945-B can be used up to 1100 nm with reflections below 1% to meet the maximum wavelength of BP109-VIS.

Lenses provided with M2SET-IR

LB1945-B	BK7 B Coated Bi-Convex Lens, DIA = 25.40, f = 200.00, AR coated 650 - 1050 nm
LB1945-C	BK7 B Coated Bi-Convex Lens, DIA = 25.40, f = 200.00, AR coated 1050 - 1620 nm*

*Lens LB1945-C can be used up to 1800 nm with reflections below 1% to meet the maximum wavelength of BP109-IR.

See the following graph for available AR coatings of lenses. Suffix -UV, -A, -B or -C specifies the wavelength range.



Note

Be sure your laser wavelength is covered by the wavelength range of the selected lens prior to start beam alignment and M² measurement. Otherwise, lens reflections may lead to increased measurement errors!

Electrical Connections

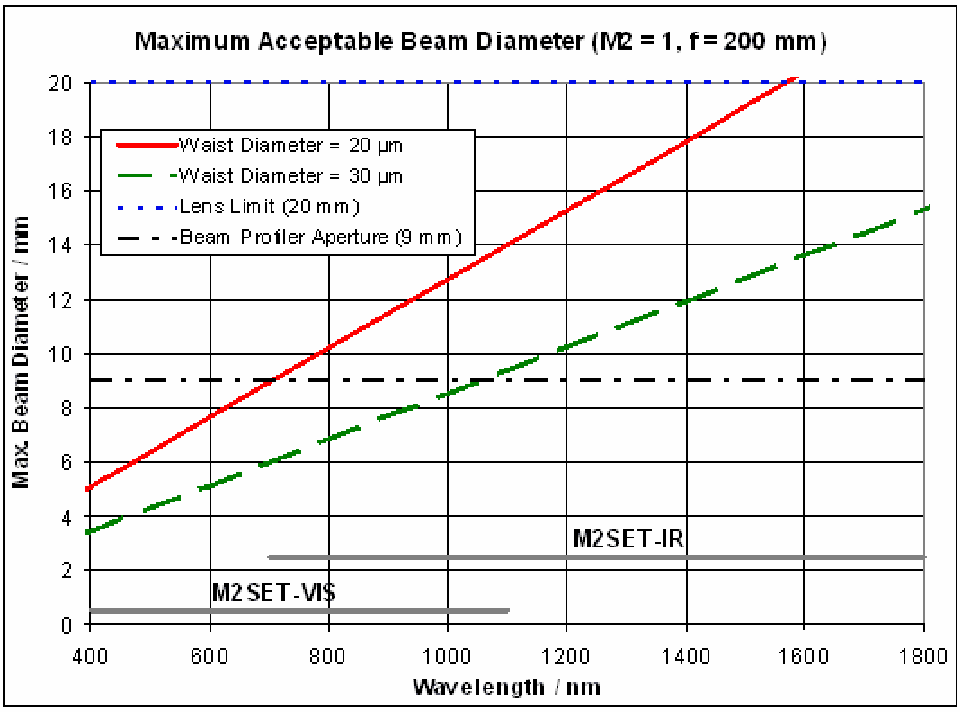
Connect the Beam Profiler to your computer using the supplied high speed USB cable as described in chapter Electrical Connections 82.

3.6.3.3.2 Acceptable Beam Diameters

Depending on the focal length (f = 200 mm) of the focusing lenses supplied within the M² Meter there is for a given wavelength a dependency between the applied initial beam diameter d_{init} and the resulting waist diameter $d_{0,min}$. The minimum waist diameter is achieved for large input beam diameters and at best beam quality (M²=1).

$$d_{init} \le 2 f \tan \frac{2 \lambda}{\pi \, d_{0,\min}}$$

Since the lowest measurable beam diameter for BP109-x Beam Profiler series is 20 µm the acceptable maximum beam diameter must not exceed the limit displayed in the following diagram.



Select your operating wavelength at the x-axis and go up to the curve representing waist diameter. Then read out the max. acceptable initial beam diameter at the vertical axis. For a waist diameter at the measurement limit (20 µm, red curve) an operating wavelength of 633 nm yields a max. beam diameter of 8.1 mm, whereas for 1064 nm the diameter can reach up to about 13.6 mm.
It is suggested to choose a somewhat higher waist diameter of (e.g. 30 µm, green curve) in order to relax the demands on the Beam Profiler so that it can operate at a higher measurement speed and achieves also better accuracy. As a drawback maximum allowed input beam diameters drop down to 5.4 mm at 633 nm and 9.0 mm @ 1064 nm, respectively.
Further limitation of the input beam diameters are given by the 20 mm usable lens diameter and the 9 mm Beam Profiler aperture.

To measure even larger beam diameters (above the red curve) the focusing lens needs to be replaced with a lens of longer focal length. In addition, the position of the lens mount needs to be shifted away from the translation stage so that the waist position will be located again within the traveling range of the Beam Profiler. See the Thorlabs catalog for suited lenses.

Note

The beam diameter applied to the M² Meter may exceed the input aperture diameter of the Beam Profiler since the focusing lens reduces the diameter continuously towards the beam waist and it is sufficient that the Beam Profiler only scans the section of the linear divergence region adjacent to the waist position. Here, beam diameters are much smaller than the Beam Profiler aperture and can be measured with high accuracy.

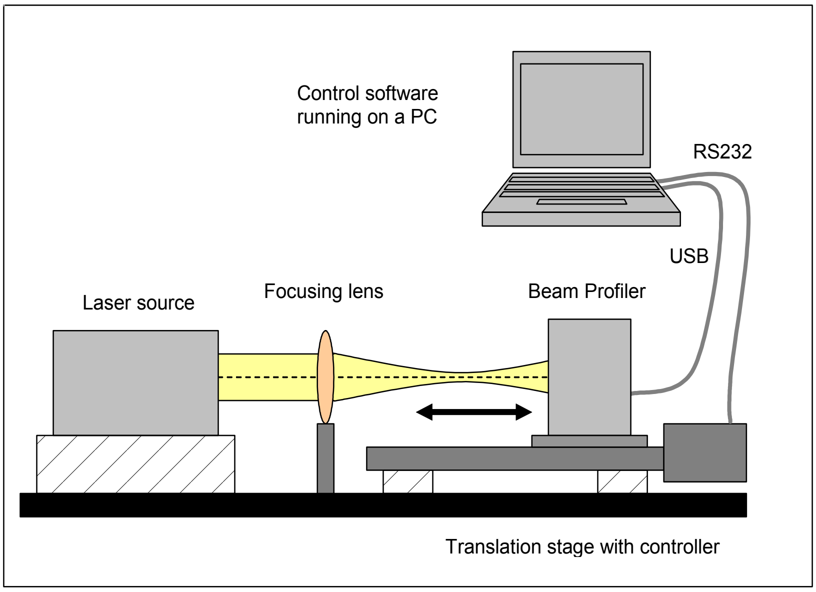
Since beam diameters wider than half the aperture already lead to measurable errors, the Beam software takes into account only beam diameters below 4.5 mm for its hyperbolic curve fit.

3.6.4 Setting up

3.6.4.1 Mechanical Setup

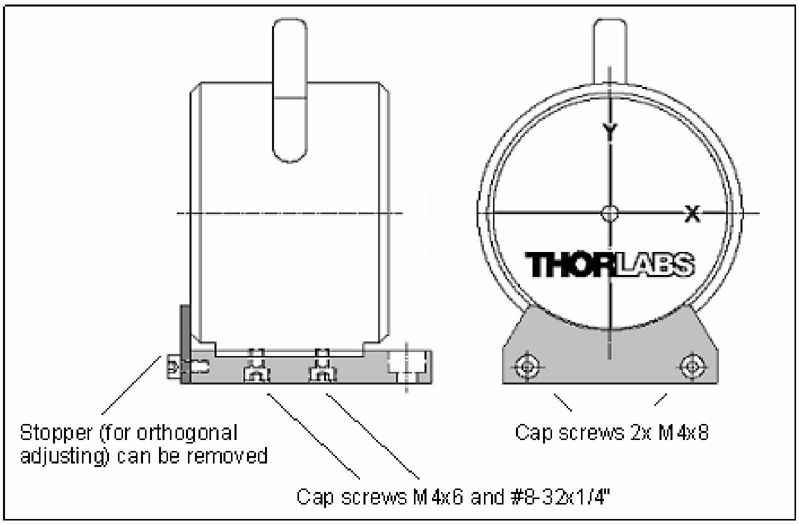
The Thorlabs BP1M2 Extension set for M^2 measurements is not a compact instrument but consists of separate components which are built together. In addition, means for beam alignment and focusing need to be ordered separately.

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



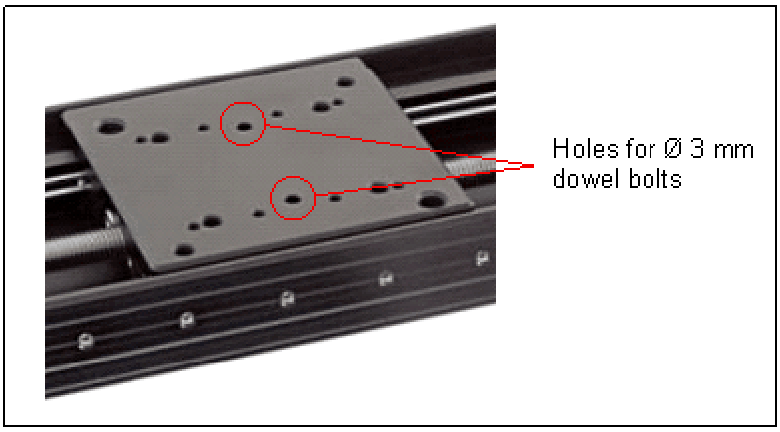
Mounting the translation stage on a table
It is highly recommended to mount the translation stage onto a table to ensure a fixed position and repeatable measurements.
Use the **base plates** delivered with the BP1M2 Extension Set to mount the stage onto an optical table.

Mounting the Beam Profiler to the translation stage
First screw together the mounting adapter plate and the stop plate delivered with the BP1M2 Extension set.
Then mount the Beam Profiler to the adapter plate by using the appropriate screws designated in the following figure.



See BP1M2 Mounting Adapter 137 for a detailed drawing of the adapter.
First mount the Beam Profiler onto the adapter plate by using the appropriate M4x6 and #8-32x1/4" screws, delivered with the BP1M2 Extension Set. Then push it slightly against the stop at the front. This guarantees orthogonal to the moving direction of the translation stage adjustment of the instrument. Then fix the screws.

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

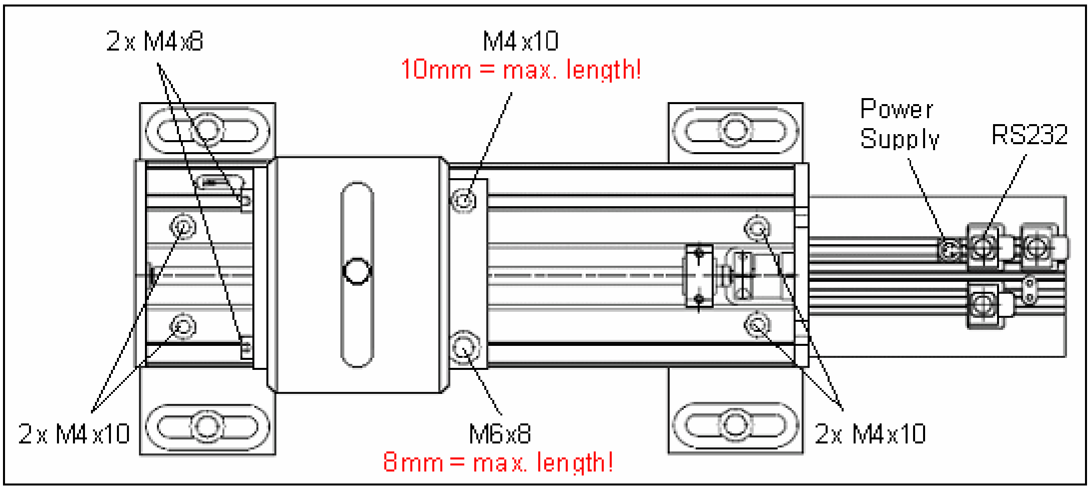


Put the adapter plate with the Beam Profiler mounted on it onto the mounting plate of the translation stage so that the two dowel bolts guarantee a nearly free from play connection. Fit both plates with 2 screws near the back plate of the Beam Profiler.

Attention

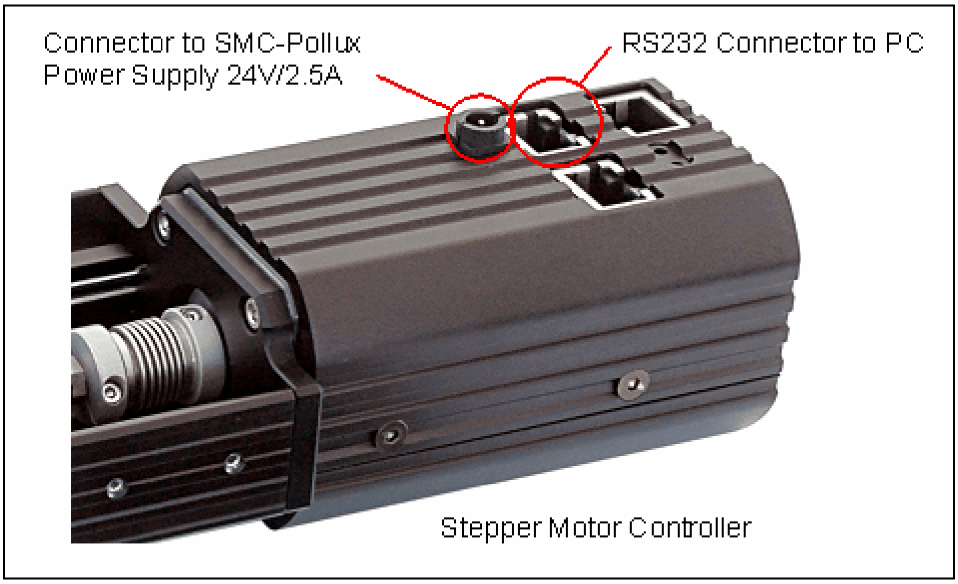
Be sure to mount the Beam Profiler's adapter plate with the designated cap screws M4x10 and M6x8 only! Longer screws will block or even damage the translation stage!
Be sure to mount the translation stage with the Beam Profiler on it in a way that prevents any contact to ambient mechanical parts!
Lasers,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

The following figure shows the fully assembled BP1M2 Extension Set.



3.6.4.2 Electrical Connections

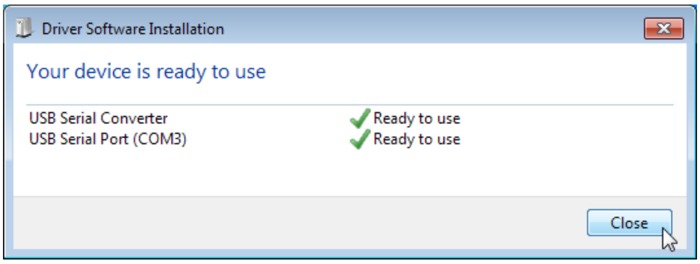
The Pollux controller includes also the stepper motor driving the VT-80 translation stage.
It needs to connect to the appropriate power supply and to the computer via RS232. Use the cables supplied with your BP1M2 Extension Set package.



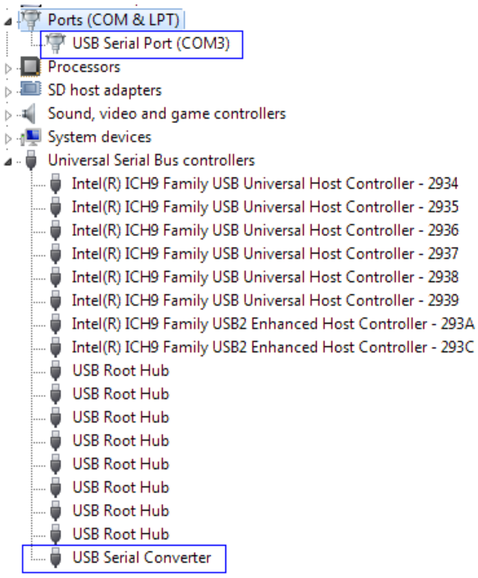
As soon as the power supply is connected to the controller a LED starts to blinking. This indicates normal operation.

3.6.4.2.1 Installation of USB to RS232 Converter

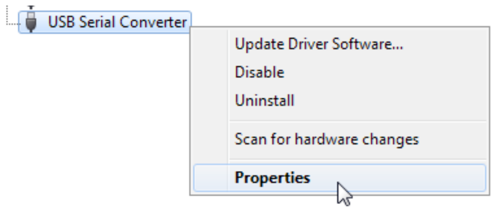
The M² translation stage controller interfaces with the control PC via a COM port (serial RS232 interface). The connecting cable has a RJ45 connector on the translation stage's end and a 9pin female DSUB connector on the other end.
If your computer does not have available a COM port, please use the supplied 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:



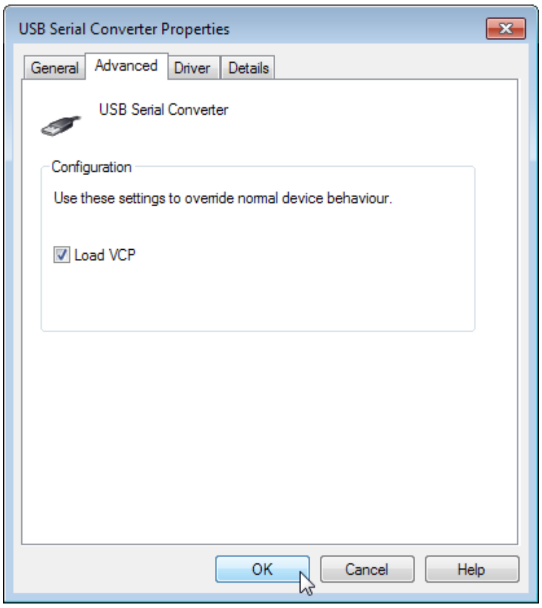
If you wish to verify the correct installation, please open the Device Manager of your PC. The USB-to-Serial Converter appears in both the **Ports** and **USB controllers** lists:



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.

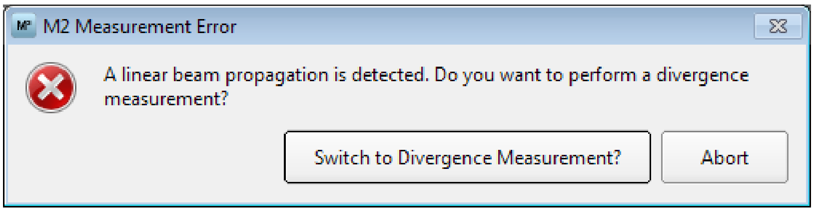
3.6.5 M² Measurement

Click on M² 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

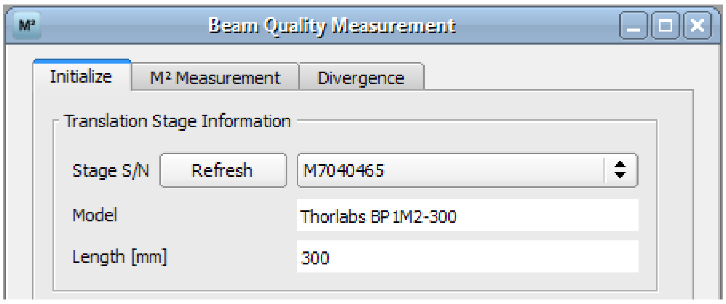
- Initialize
- M^2 Measurement
- Divergence

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:

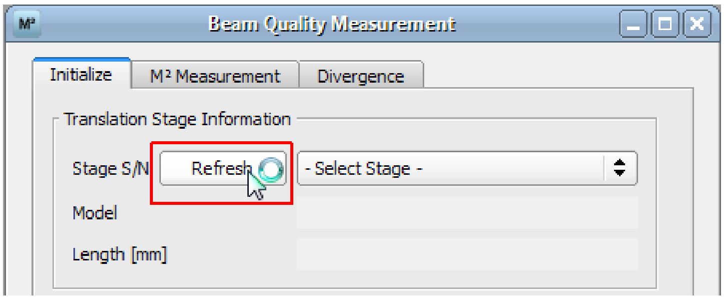


3.6.5.1 Initialize

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.

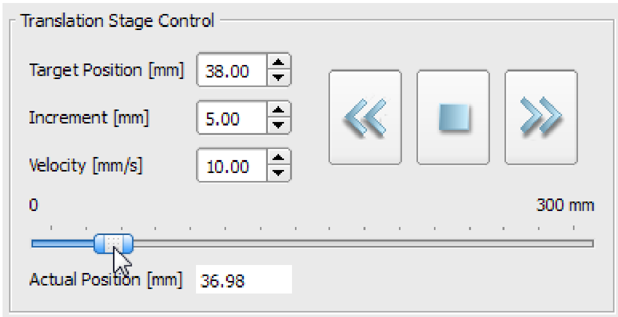


If connect the stage after starting software, it must be initialized manually.



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!

3.6.5.2 Beam Alignment

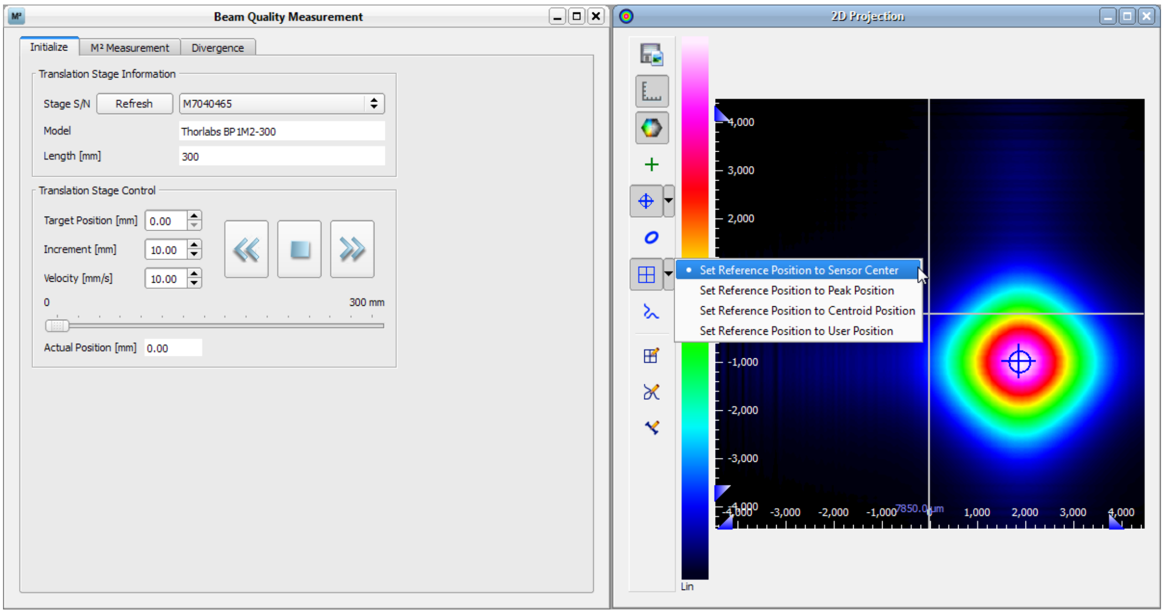
Why Beam Alignment?

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 Reconstruction as shown below:



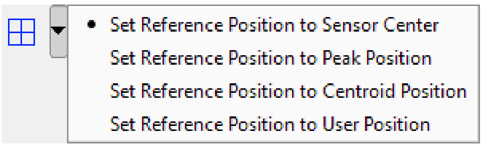
For beam alignment, the manual Translation Stage Control 85 is used, while the beam position is observed in the 2D Reconstruction panel. For more convenience, enable the Reference Position crosshair (set to sensor center) and enable the centroid cross.

Preconditions

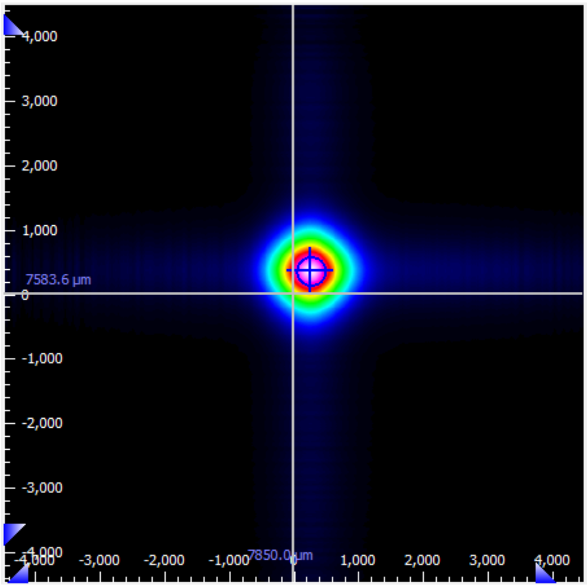
Prior to start beam alignment and measurement take care of these points:
- avoid reflections, interferences, ambient light
- check that entire laser beam is entering the Beam Profiler aperture
- warm up laser system 1 hour
- ensure that laser output is spatially and temporally stable

Hints

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



This displays the centered to the beam profiler's aperture crosshair.
Together with the enabled **Centroid Cross** it's easy to observe beam centricity.



Alignment Procedure for BP1M2 Extension Set

If the laser beam is already focussed a single alignment of position and angle is sufficient.

A proven alignment procedure is this:

1. Go to position A, for instance at 0 mm.
2. Align the beam to the aperture center using a **linear adjustment** in x and y direction.
3. Go to a position B at larger distance, for instance to the end of travel path.
4. Align the beam to the aperture center using the **angular adjustment** of the beam.
5. Repeat steps 1 to 4 until the beam is centered in both positions.

For parallel or divergent beams an extra focusing lens is required, see Mechanical Setup 79. In this case it is recommended to do this alignment without the lens first and to insert and align the lens in X and Y direction afterwards in order to get the focussed beam back into the center of the Beam Profiler's aperture. This procedure ensures that the optical axis runs through the geometrical center of the lens.

See Recommended Accessories 72 section for tools that enable to shift and tilt the laser beam to be measured.

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.

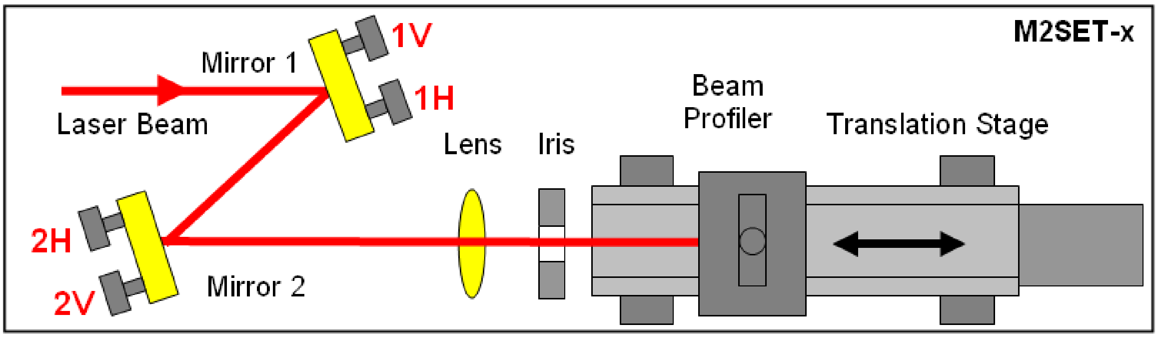
When the beam is still centered at all stage position the lens is well-aligned into the optical path and the system is ready for Beam Quality Measurement.

Alignment Procedure for M2SET M² Meter

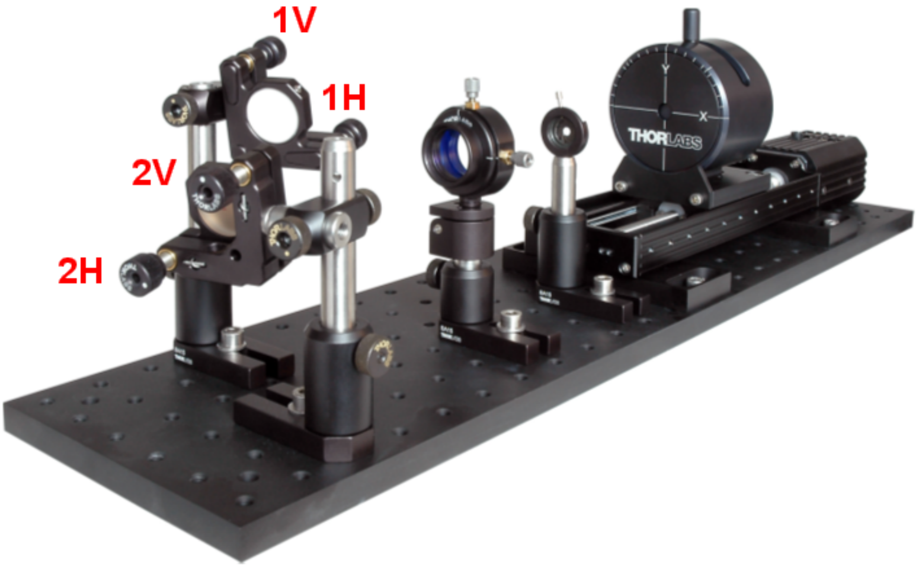
The test beam which is focused by the focusing lens needs to **constantly meet the center of the Beam Profiler aperture when it is moved along the beam propagation axis**. As a precondition, the unfocused beam direction needs to be adjusted first with the focusing lens flipped aside. Thereafter, the lens is flipped into the beam again and is centered to maintain the beam axis. In case the test beam is already focussed the lens remains flipped aside.

Alignment tools

Two widely adjustable mirrors and an iris diaphragm are integrated into the M²-Meter for making the beam alignment quick and easy. The following sketch illustrates their position on the breadboard.



The beam is reflected successively at mirror 1 and mirror 2 in order to adapt beam height and align its direction towards the Beam Profiler. Adjustment screws of both mirrors are labeled within this figure according to its influence on the horizontal (**1H, 2H**) or vertical (**1V, 2V**) beam position and direction. These four adjustment screws are labeled also in the following photograph:



All beam quality parameters including M^2 remain unchanged by this beam redirection using high quality mirrors.

Pre-Alignment of M^2-Meter

In order to ease beam alignment and minimize the required time, the M^2-Meter is shipped with a high level of pre-alignment. Height and horizontal position of the iris diaphragm, the focusing lens as well as the position of mirror 2 are already pre-aligned to the center of the entrance aperture of the Beam Profiler.

Note

Do not change height or position of these components accidentally.

Adjustment of a visible beam is easily done because its position is seen directly onto the partly closed iris and the entrance aperture of the Beam Profiler.

For infrared beams use a IR viewing card or alignment disk for visualization. In addition, the beam position is also displayed within the Beam Profiler software.

Follow these points for coarse beam alignment

1. Fix the laser under test and ensure a stable connection to the M^2-Meter breadboard.

2. Flip the lens mount aside to allow alignment of the unfocussed beam first.
3. Modify the height of mirror 1 so that the laser beam hits roughly its center. Direct the beam to the center of mirror 2. For coarse alignment loose the post clamps RA90 holding the KM100 mirror mounts and fix it in a suitable position. Set the adjustment screws of the mirror mount to a position that allows further fine alignment in both directions.
4. Align the angle of mirror 2 so that the beam is running centrically through the iris. Check this by partly closing the iris aperture. The outer beam regions will produce symmetrical pattern around the remaining hole.
5. Now check the beam position at the entrance aperture of the Beam Profiler which was positioned at z = 100 mm. Since the alignment of beam position and angle are coupled, it is required to align both mirror angles alternatively. Mirror 1 is used for determining the beam position at mirror 2 and mirror 2 is used for aligning the beam direction towards the Beam Profiler.
6. Repeat steps 4 and 5 until the beam running through the partly closed iris also roughly meets the center of the Beam Profiler's entrance aperture.

Fine Beam Alignment

It is advantageous to do alignment steps for horizontal and vertical directions separately. Use mirror adjustment knobs 1H and 2H for horizontal, screws 1V and 2 V for vertical beam alignment.

Lens Alignment

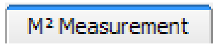
Now flip the lens back into the unfocussed beam. This leads to a reduce beam diameter but the beam position remains nearly unchanged because the lens holder is also pre-aligned. Use the alignment screws on the adjustable lens holders LM1XY to bring the beam position back to the Beam Profiler center accurately.

Congratulation, you have finished all alignment steps and you are ready to start the M^2 measurements described in the next chapter.

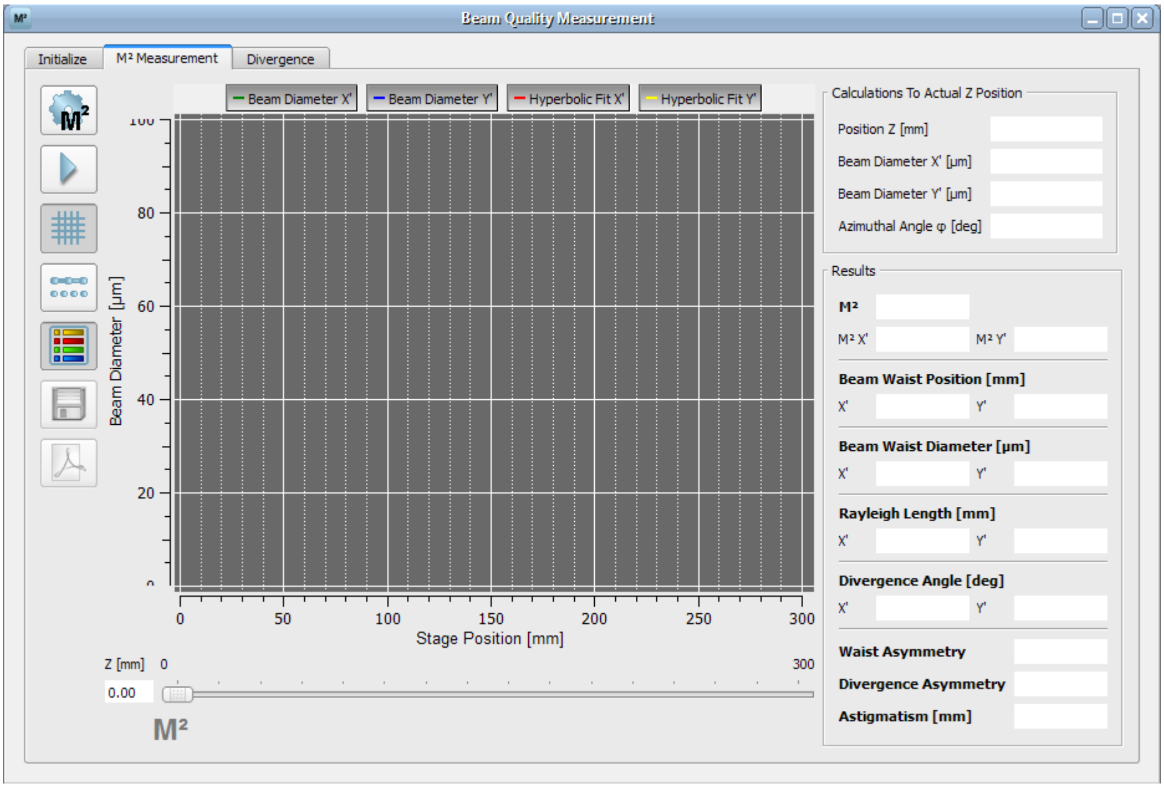
Note

Be sure to have the iris diaphragm completely open during all following measurements! It was just a helpful beam alignment tool.

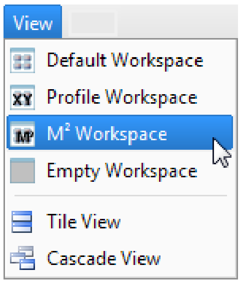
3.6.5.3 M² Panel

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 Reconstruction window, see section 2D Reconstruction 30. Both windows should be arranged that they can be observed and controlled well.

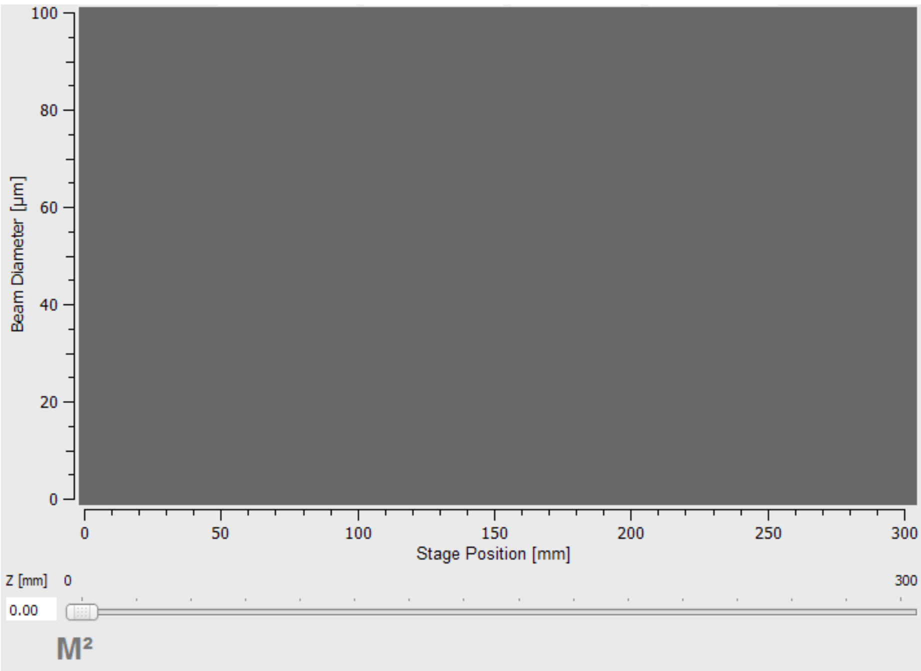
4 buttons above the M² diagram allow to choose the displayed beam diameter (X, Y) and the type of fit to be applied to the measured data. By default, both the X and Y beam diameter will be displayed, and to both parameters, the hyperbolic fit will be applied.
In the example below the "Hyperbolic Fit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

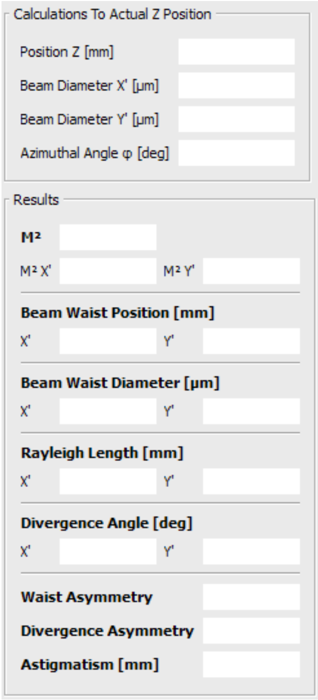
Button Name	Function
M^2 Settings	Opens the settings for the M^2 measurement
Play/Stop	Starts / stops a M^2 measurement
Grid	Disables/Enables the grid in the diagram
Dots/Line Display	Toggles between a line and dots diagram for the plotted data
Legend	Opens a window extension with a legend and results 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.



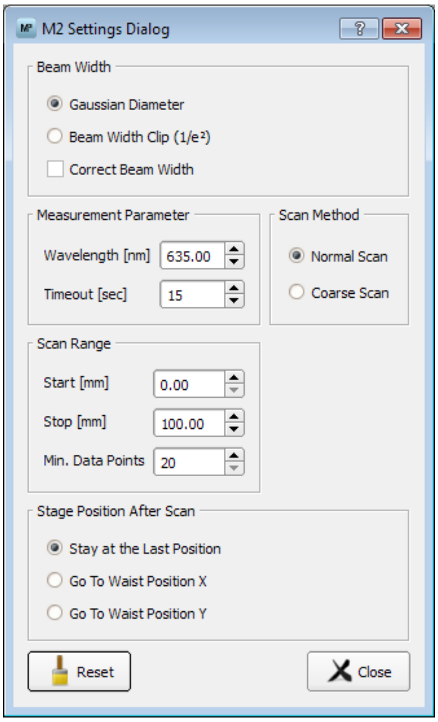
The panel **Calculation to Actual Z Position** contains the following information:

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]	Shown value equals the min. or max. value of the ellipse, where axes are identical to X and Y as marked on the front panel.
Azimuthal Angle [deg]	The displayed value is not relevant.

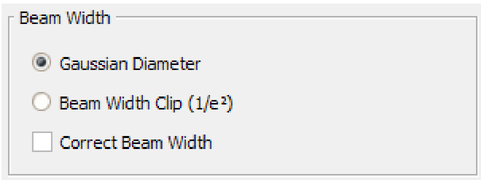
3.6.5.4 M² Settings

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

Click on  to enter the **M² Measurement Settings** dialog.



Beam Width

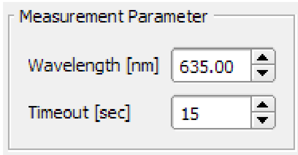


Beam Width Clip (1/e²): This is the value specified in ISO standard 11146. If a different clip level was used for normal Beam Profiler operation this will be overwritten by the M² measurement initialization.

Gaussian Diameter: The beam profile will be fitted using a Gaussian curve prior to determination of the beam width. A Gaussian fit can reduce the impacts of noise and/or unstable beam shape to the results.

Correct Beam Width: This option should be activated by default. It corrects for the measurement error due to the finite slit width for all methods (13.5% clip level with and without Gaussian fit). Since this convolution error is systematic it can be calculated and eliminated. Especially for narrow beams the beam width result will become smaller and closer to the real value.

Measurement Parameters



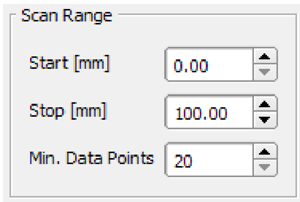
Setting the wavelength is mandatory for correct measured M^2. If the lasing wavelength is unknown, measure the wavelength using a spectrometer.

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 waiting time until valid data can be retrieved from the Beam Profiler (e.g. in case of slow travel speed)

Scan Range

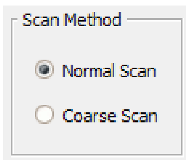


The **Scan Range** determines the range from where to where sleigh of the translation stage is driven during a measurement. **Start** has to be at least 5 mm smaller than **Stop** and greater-than-or-equal to 0 mm. Valid values for Stop are

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	Gaussian Diameter
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

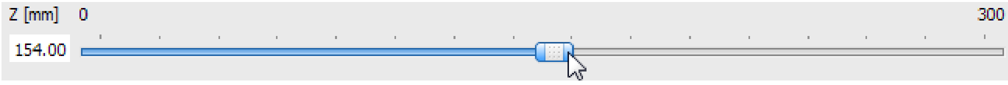
Device settings

It is important to set Gain and Bandwidth of the Beam Profiler (see Device Settings 46) to Auto.

3.6.5.5 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 86 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.

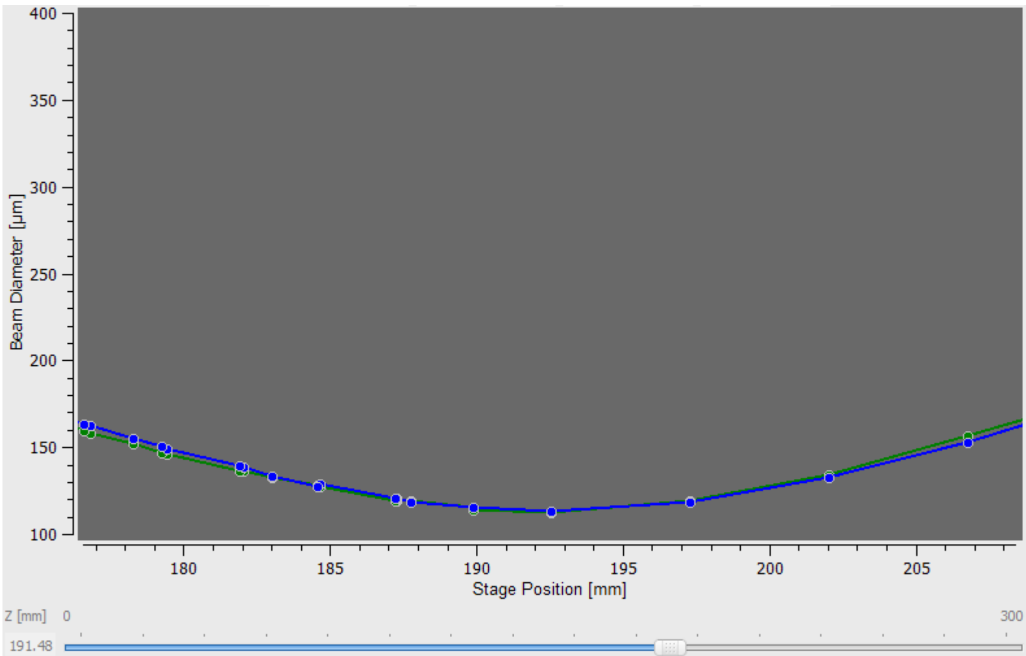


-
- reflections and interferences are avoided as far as possible.
- the laser system is warmed up - depending on the source this might last up to 1 hour.
- the laser output is spatially and temporally stable.

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

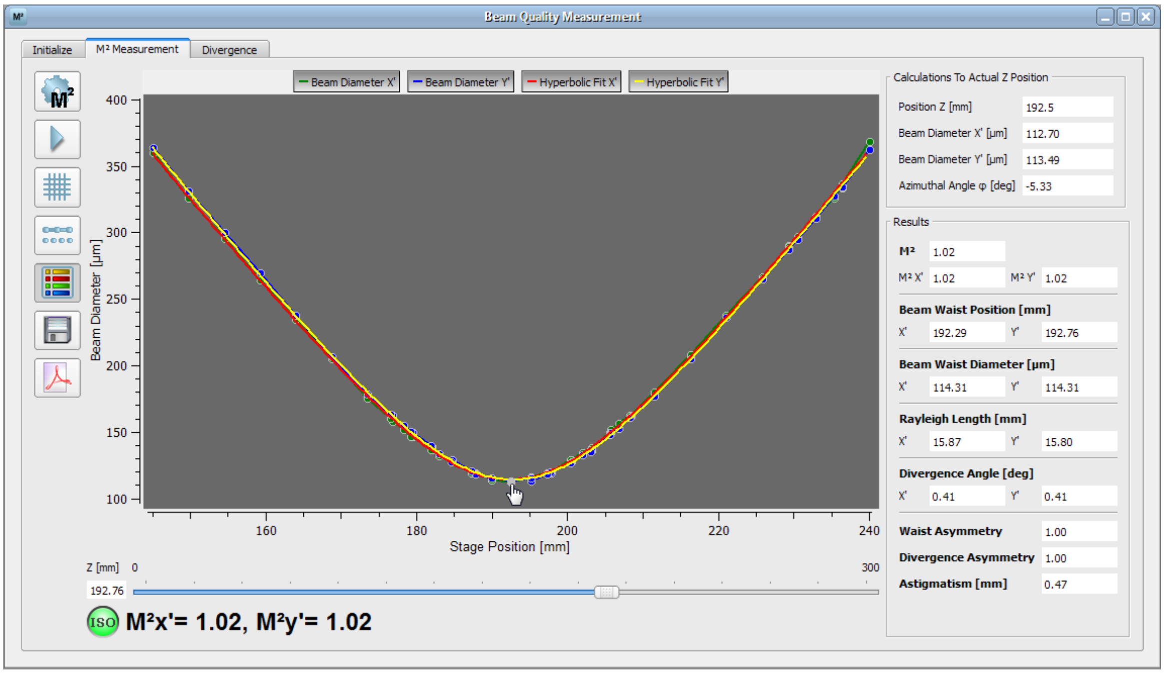
While running the measurement most of the buttons and options are disabled, e.g. the M² measurement settings and the toolbar. This prevents the modification of settings during a measurement.
If necessary, the measurement can interrupted by clicking the **Stop** button .

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.

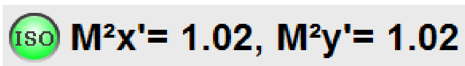


3.6.5.6 Numerical Results

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

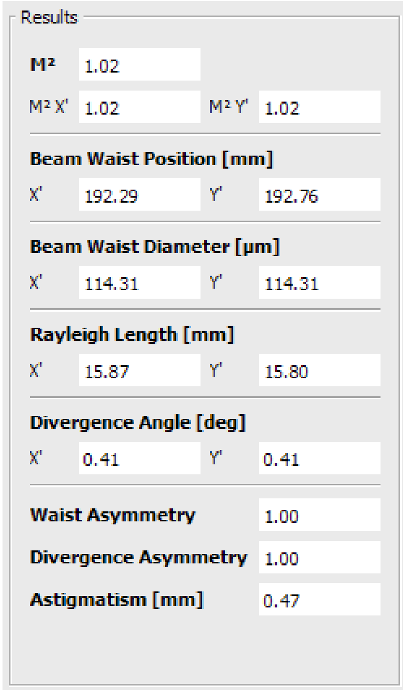


The green bulb indicates that the measurement was successful and fulfills the ISO 11146 standards.



In 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**.



M²
Mean M² value (arithmetic average of M² X' and M² Y')

M² X' and M² Y'
M² 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 √2 times wider than the waist diameter. See also chapter M2 Theory 121.

Divergence Angle
Divergence angle of the focused beam is explained in chapter M2 Theory 121.

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).

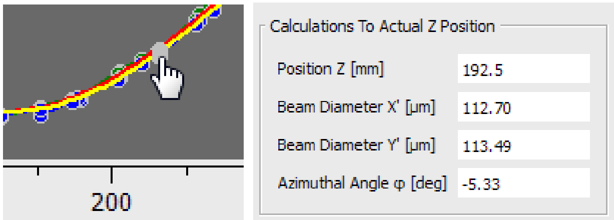
Save measurement data as *.pdf file.

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.

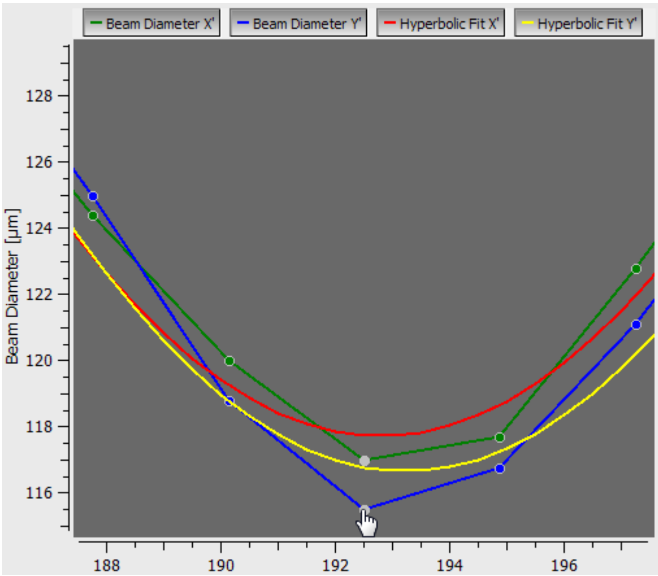
Display of results at a certain Z position

After measurement is finished, the calculated data for Beam Diameter (X') and Beam Diameter (Y') 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.

3.6.5.7 Troubleshooting

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

The beam does not hit the aperture for all stage positions.
Aligning the beam is necessary, see section Beam Alignment 86.

A timeout occurs during a measurement.
A timeout always occurs when the Beam Profiler does not deliver a valid image within the set timeout interval. This may happen

- if the photo diode of the beam profiler is saturated. Decrease incident optical power, alternatively increase the focal length (which increases the spot size of the beam) if possible.
- if the beam power is too low.
- 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 aperture. Align the beam, see section Beam Alignment 86.

M^2 measurement is carried out, but  **is displayed, no M^2 results**
Make sure for correct Device Settings 46.

The M^2 value differs extremely from the expected value.
For example, the beam has a nearly Gaussian intensity distribution and M^2 values are larger than 1.1:

- check set wavelength (see M^2 Settings 94)
- 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

- 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.

3.6.6 Divergence Measurement

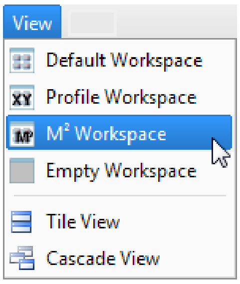
The following section concerns the **Divergence Measurement** and its settings.

Click on Divergence 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.

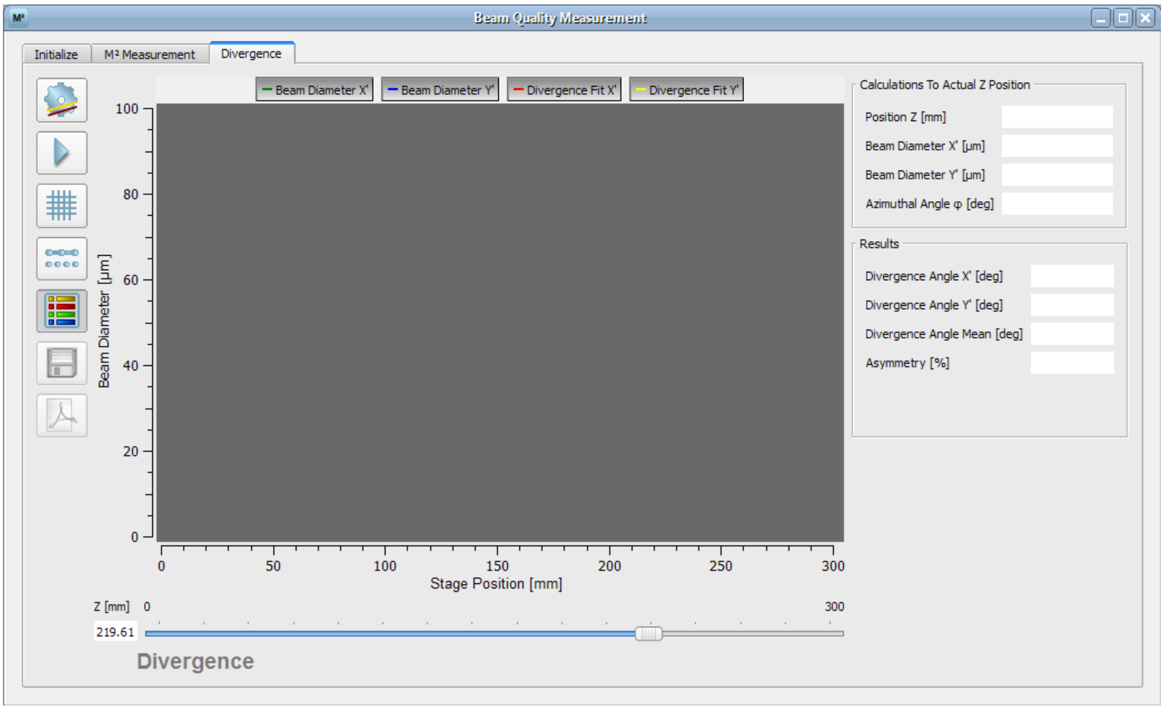
3.6.6.1 Divergence Measurement Panel

If you have selected the M² workspace



you can find two child windows on your program environment, the **Beam Quality Measurement** and the **2D Reconstruction** window. For more information about the 2D Reconstruction window, see section 2D Reconstruction 30. Both windows should be arranged that they can be observed and controlled well.

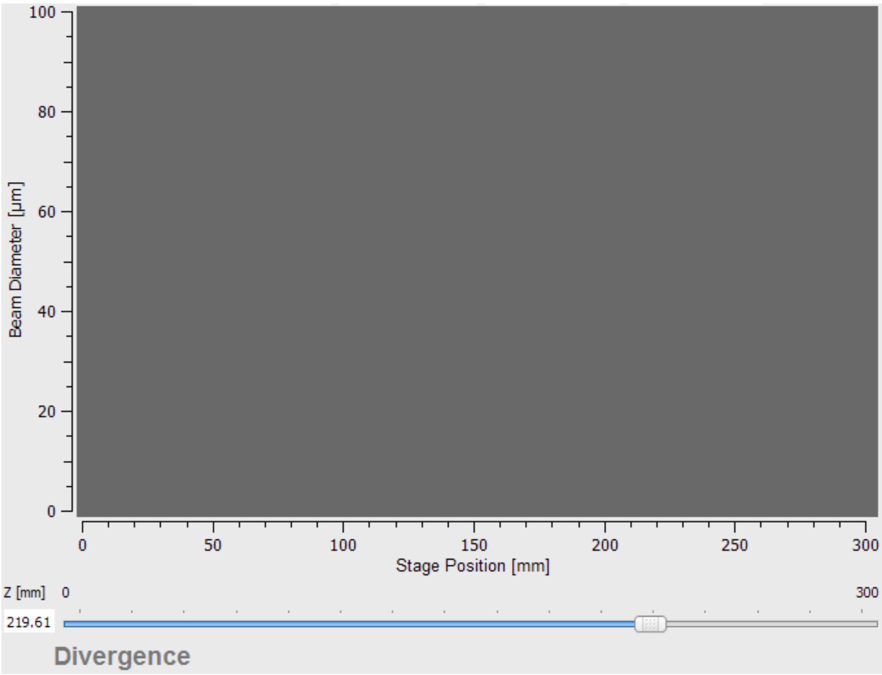
Divergence tab:



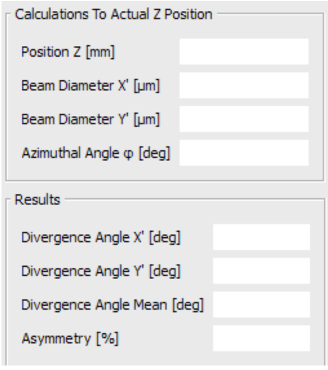
Same as in the M² Measurement tab you find on the left hand side a **Toolbar** which provide the following functionality.

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.

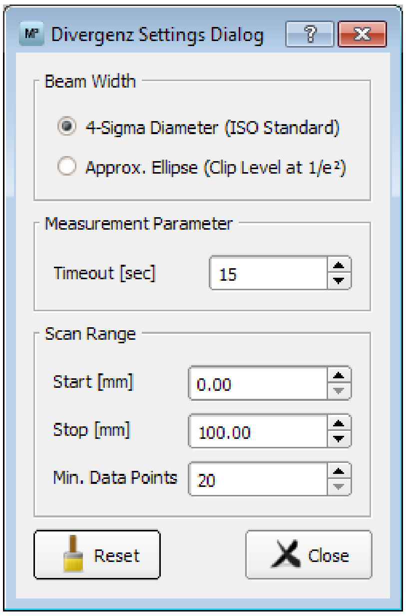


The panels of the **Calculation To Actual Z Position** and **Results** are described in the M^2 Measurement 91 section.

3.6.6.2 Divergence Measurement Settings

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

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



Beam Width

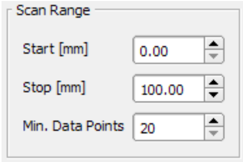
The Beam Width can be selected from the two already known methods.
The calculation of the **4σ Diameter** follows the ISO 11146-1:2005 standard.

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 waiting time until valid data can be retrieved from the Beam Profiler (e.g. in case of slow travel speed)
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 M² 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

Device settings

It is important to set Gain and Bandwidth of the Beam Profiler (see Device Settings 46) to Auto.

3.6.6.3 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 86 for aligning the beam.
-
- 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 .

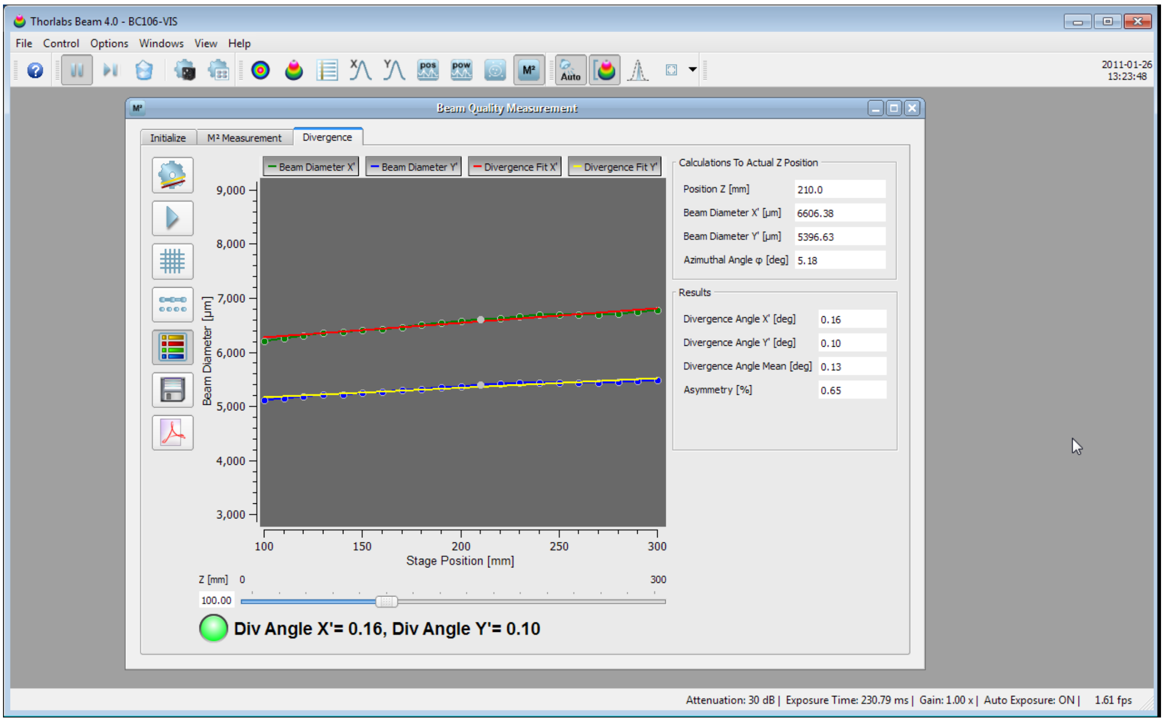
While running the measurement most of the buttons and options are disabled, e.g. the Divergence measurement settings and the toolbar. This prevents the modification of settings during a measurement.

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

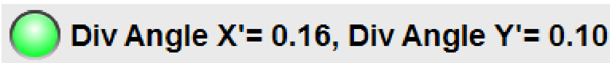
After starting the measurement the X axis of the diagram is adapted to the user-defined scan range, for example from 0 to 120 mm. The Y axis scales automatically to the recorded beam widths.

3.6.6.4 Numerical Results

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

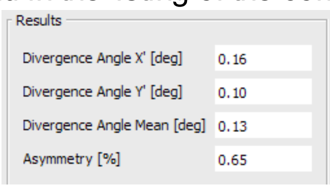


The green bulb indicates that the measurement was successful.



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 121.

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 M² measurement result display can be zoomed and also panned, see M² Measurement results 100.

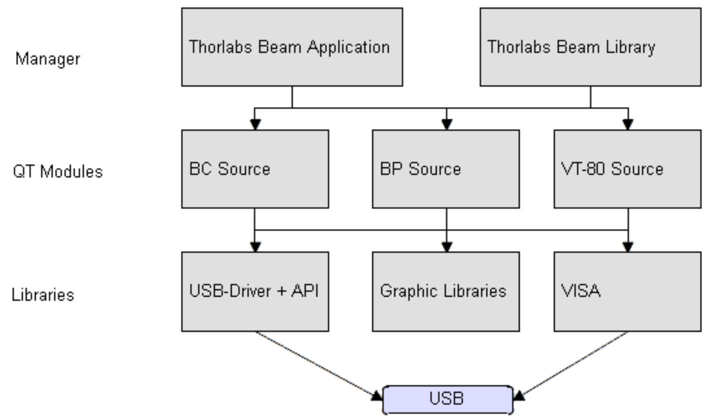
4 Computer Interface

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))
{
[ …]
}
```

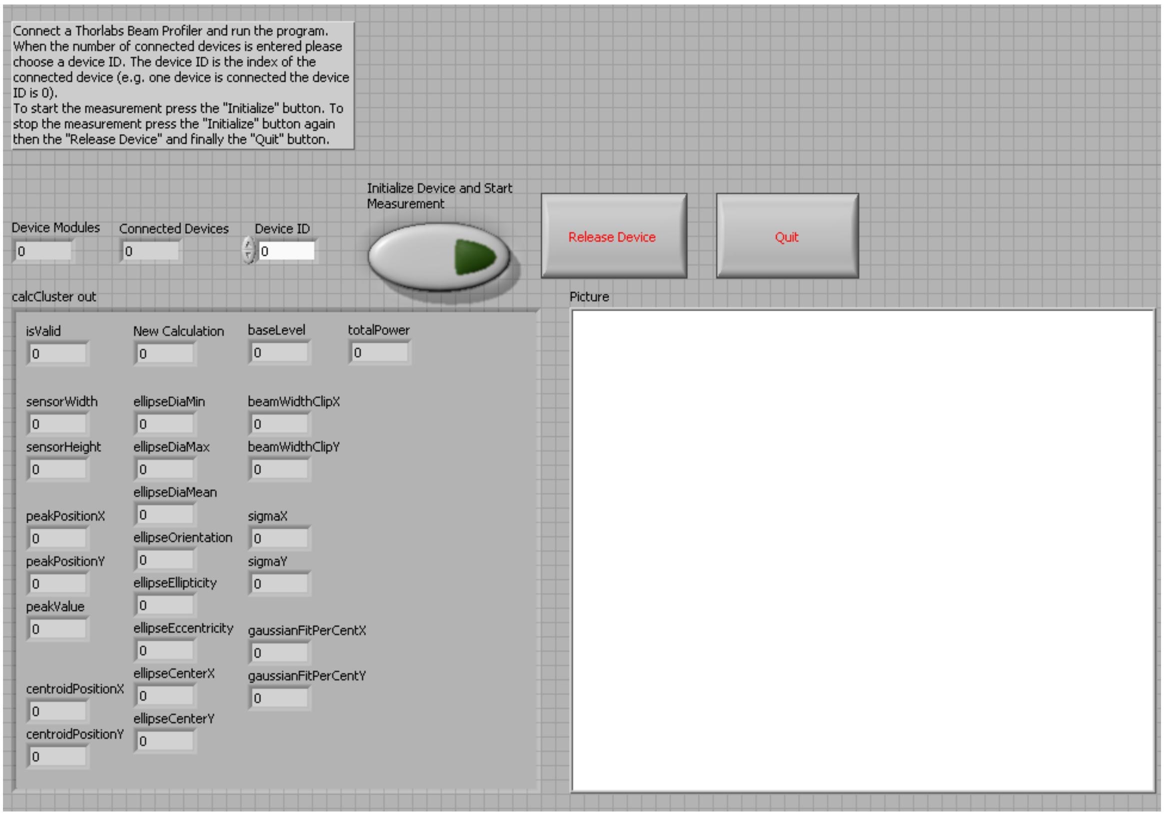
When terminate the program, devices and their drivers are being released:

```
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.

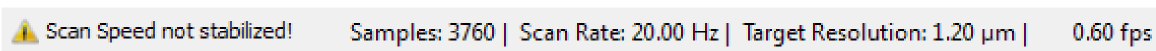
5.1 Version and other Information

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:

Scan speed not stabilized

Explanation

The detected drum rotation speed differs from the set value. Proper measurements are impossible.

Resolving

This warning may appear shortly after the Scan Rate has been changed - the drum's inertness causes a delay in reaching a new set value.
If this warning does not disappear, the Beam Profiler seems to be damaged and need factory repair - please contact Thorlabs [142] for return instructions

Device in Pause Mode

Explanation

In the Menu bar, the Pause or Next Frame button was pressed

Resolving

Press in Menu bar the Start button.

Attention

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

5.3 Cleaning

The Beam Profiler has sensitive to mechanical impacts parts (slits) mounted to the drum. Do not attempt to clean the slits using tissue, cotton buds or compressed air - the slit might be damaged. In case a visible contaminant is found, please return the instrument to Thorlabs, see the appropriate Addresses [142].
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 11 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 21 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 22 for a detailed description.

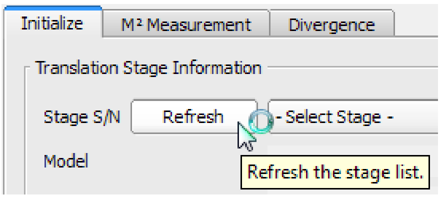
No translation stage recognized

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 82 for details.

- Press the Refresh button



See section Initialize 84 for details.

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 49.

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 Coordinate systems

Lab System
The lab system (AKA reference system) of coordinates is based on the true X and Y coordinate orientation of the drum in accordance with the marking on the front panel.

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).

6.2 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 119 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).

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*

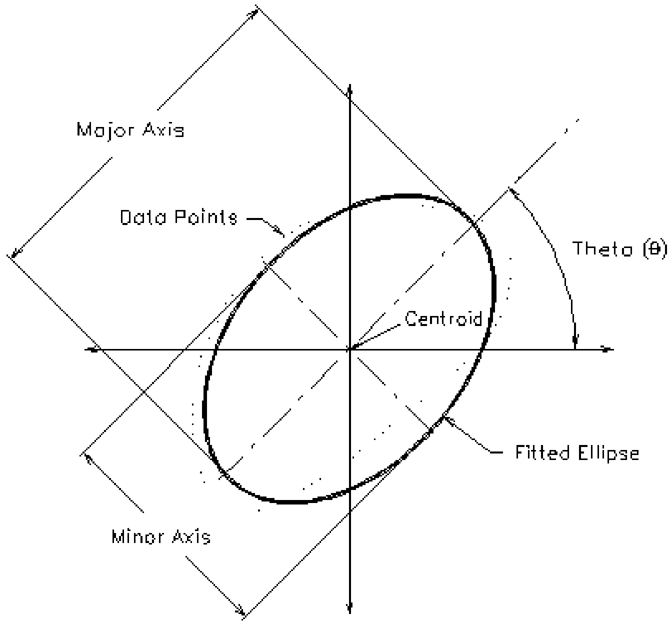
where:
p(x,y) intensity at location (x,y);
I total intensity;
SUM of pixels taken taken over entire area

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

Total Power
Total power measured through the ND filter 10 in the drum (photo diode current with respect to the typical wavelength dependant responsivity).

6.3 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 $-90° < \theta \leq 90°$.

6.4 X-Y-Profile Measurement

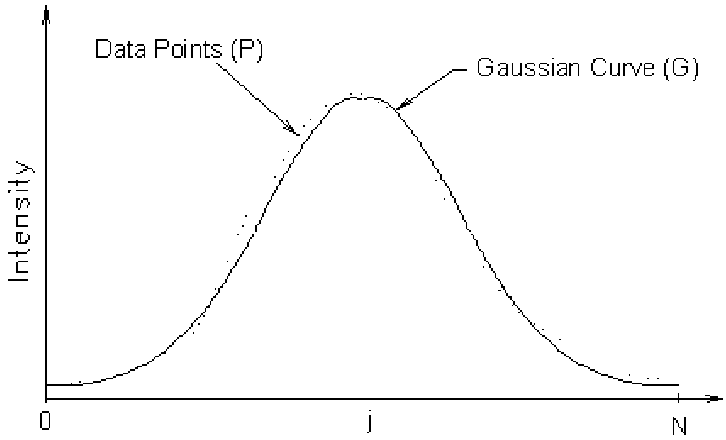
Beam Width Clip (xx%)
Beam width is the distance between two points on opposed edges of a captured beam profile in X and Y axis whereas its height is defined by a certain percentage of the peak power. This percentage is called clip level.
Preferred clip levels are for instance 50 % (Full Width at Half 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.

6.5 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

6.6 M² Theory

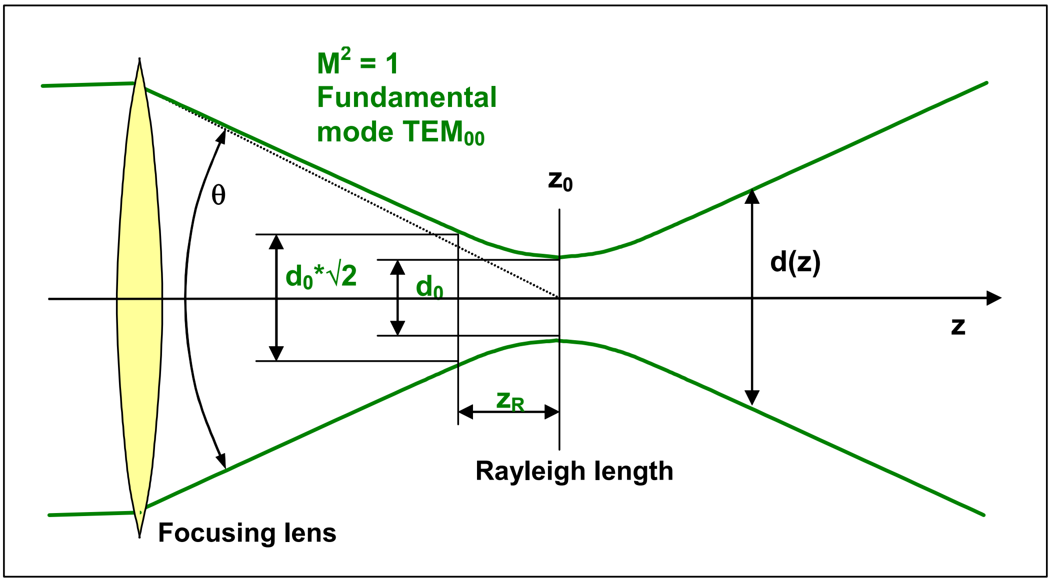
The diameter d(z) of a focused laser beam of fundamental mode TEM_{00} increases with distance z from its waist position.

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

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, ($z \gg z_R$) 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 $d_0 * \theta$ 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 $M^2 > 1$

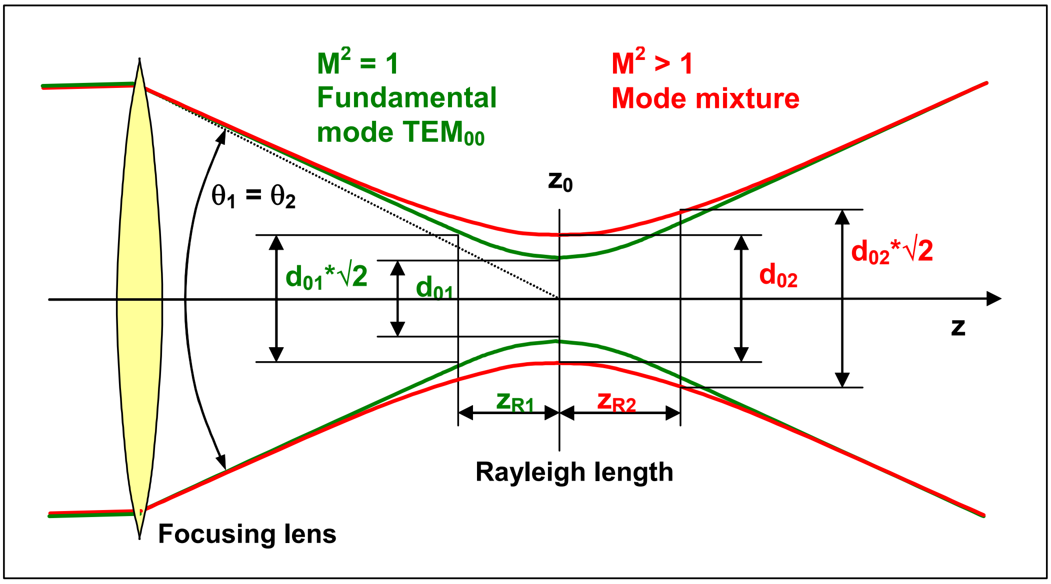
Gaussian beam is preferred to use because of its minimum divergence angle and the ability to get the minimal focus diameter.
Differences to Gaussian shape can be due to

- 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.

6.6.1 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}.

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

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

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

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:

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

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

Beam Profiler
BP104-UV, BP104-VIS, BP104-IR, BP104-IR2
BP109-UV, BP109-VIS, BP109-IR, BP109-IR2

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 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 (Performance Criterion A)
FCC EMC Compliance	Emissions comply with the Class B Limits of FCC Code of Federal Regulations 47, Part 15, Subpart B[2].	
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

Thorlabs GmbH has taken every possible care in preparing this Operation Manual. We however assume no liability for the content, completeness or quality of the information contained therein. The content of this manual is regularly updated and adapted to reflect the current status of the software. We furthermore do not guarantee that this product will function without errors, even if the stated specifications are adhered to.

Under no circumstances can we guarantee that a particular objective can be achieved with the purchase of this product.

Insofar as permitted under statutory regulations, we assume no liability for direct damage, indirect damage or damages suffered by third parties resulting from the purchase of this product. In no event shall any liability exceed the purchase price of the product.

Please note that the content of this User Manual is neither part of any previous or existing agreement, promise, representation or legal relationship, nor an alteration or amendment thereof. All obligations of *Thorlabs GmbH* result from the respective contract of sale, which also includes the complete and exclusively applicable warranty regulations. These contractual warranty regulations are neither extended nor limited by the information contained in this User Manual. Should you require further information on this product, or encounter specific problems that are not discussed in sufficient detail in the User Manual, please contact your local *Thorlabs* dealer or system installer.

7.4 Technical Data

7.4.1 Technical Data Beam Profiler

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 for rated accuracy	15 min

Beam Profiler

Model	BP104-UV	BP104-VIS	BP104-IR	BP104-IR2	BP109-UV	BP109-VIS	BP109-IR	BP109-IR2
Wavelength Range	200 - 1100 nm	400 - 1100 nm	700 - 1800 nm	1000 - 2700 nm	200 - 1100 nm	400 - 1100 nm	700 - 1800 nm	1000- 2700 nm
Detector Type	Si, UV enhanced	Si	Ge	InGaAs extended	Si, UV enhanced	Si	Ge	InGaAs extended
Aperture Diameter	4mm				9mm			
Slit Size	2.5µm				5µm			
Minimal Beam Diameter	10µm				20µm			
Maximal Beam Diameter	4mm				9mm*			
Sampling Resolution	0.5 … 38µm (depending on scan rate)				1.1 … 38µm (depending on scan rate)			
Scan Rate	1.0 ... 20.0 per s (continuously variable)							
Power Range	10nW ... 10W (depending on beam diameter and model)							
Amplifier Bandwidth	10, 20, ... , 150kHz (-1dB)							
Sample Frequency	0.0625 … 1.0MHz							
Dynamic Range	72dB (Amplifier Switchable)							
Signal Digitization	16bit							
Head Size	Ø 80mm x 60mm (Ø 70mm without rotation mount)							
Minimum Pulse Rate	10 Hz							

*BP109-UV, -VIS, -IR beam diameter error <10% at 9 mm Ø.
BP109-IR2 beam diameter error <20% at 9 mm Ø for beam divergence <5°

Additional data for M2SET M²-Meter

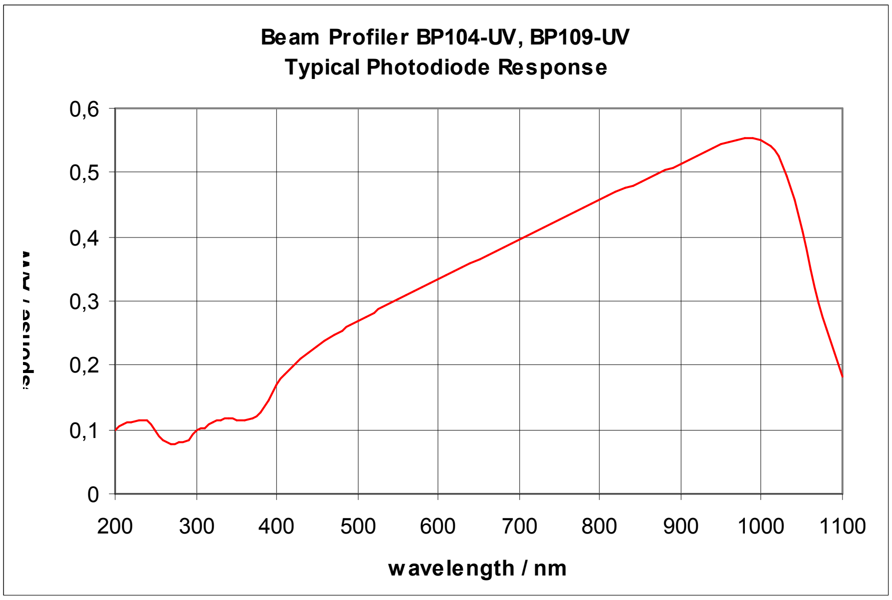
Model	M2SET-VIS	M2SET-VIS/M	M2SET-IR	M2SET-IR/M
Component Type	imperial	metric	imperial	metric
Breadboard Footprint	600 x 150 mm		24 x 6"	
Beam Profiler	BP109-VIS		BP109-IR	
Wavelength range	400 - 1100 nm		700 - 1800 nm	
Beam Diameter Range	20 µm - 9 mm (at Beam Profiler Input Aperture)			
Power Range	10 nW to 10 W, Depending on Beam Diameter			
Translation range	150 mm -100 mm to +50 mm from focal point			
Lens focal length	200 mm			
Optical axis height	50 - 120 mm, further extendable			
M^2 measurement range	1.0 - no upper limit			
Typical M^2 and K accuracy	± 5%, depending on optics and alignment			
Maximum Input Beam Diameter	14 mm depending on wavelength, see diagram		20 mm depending on wavelength, see diagram	
Accepted Beam Diameter for 5% Accuracy	20 µm - 4.5 mm (at Beam Profiler Input Aperture)			
Minimum Detectable Divergence Angle	<0.1 mrad			
Applicable Light Sources	CW and pulsed sources ≥ 300kHz			
Typical measurement time	20 - 40 sec. depending on beam shape and settings			

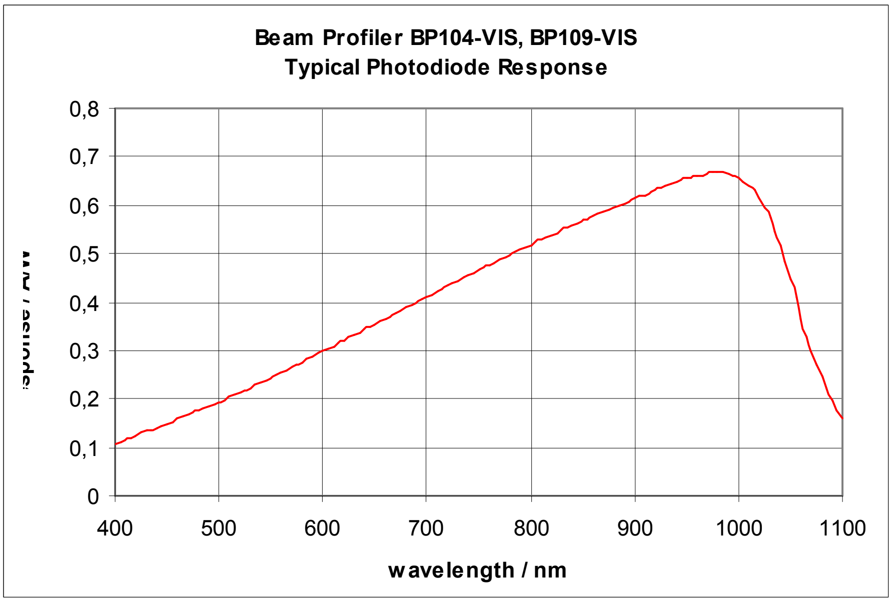
Additional data for BP1M2 Extension Set based M² Measurement

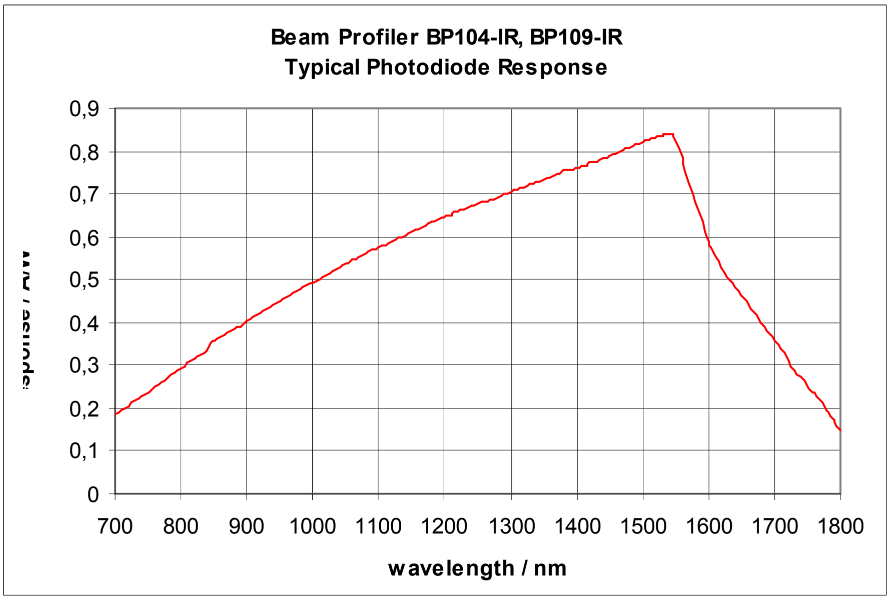
Model	BP1M2-50	BP1M2-150	BP1M2-300
Translation range	50 mm	150 mm	300 mm
Translation stage	VT-80 + Pollux controller		
Optical axis height	90 mm		
Wavelength range	see Beam Profiler range, extension around nominal range allowed		
M^2 measurement range	1.0 - no upper limit		
Typical M^2 and K accuracy	± 5%, depending on optics and alignment		
Accepted beam diameter for 5% accuracy	20µm - 2 mm (BP104) 20µm - 4.5 mm (BP109)		
Typical measurement time	20 - 40 sec. depending on beam shape and settings		
Applicable Light Sources	CW and pulsed sources ≥ 300kHz		

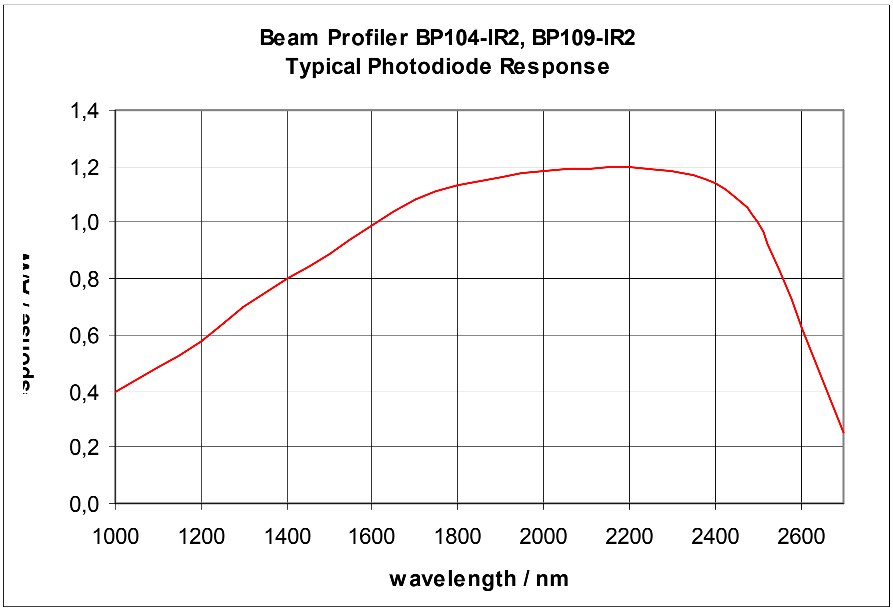
7.4.2 Typical Photodiode Responce Curves

The following diagrams showing typical response curves of UV-enhanced Silicon photodiodes used in BP104-UV and BP109-UV, Silicon photodiodes used in BP104-VIS and BP109-VIS, Germanium photodiodes used in BP104-IR and BP109-IR and extended wavelength Indium Gallium Arsenide (x-InGaAs) photodiodes used in BP104-IR2 and BP109-IR2.






Beam Profiler BP104-IR, BP109-IR
Typical Photodiode Response
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
wavelength / nm


Beam Profiler BP104-IR2, BP109-IR2
Typical Photodiode Response
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
1000
1200
1400
1600
1800
2000
2200
2400
2600
wavelength / nm

7.4.3 BP1M2 Extension Set Components

The following table lists all components supplied with the Thorlabs BP1M2-x Extension Set.

BP1M2-50	BP1M2-150	BP1M2-300	Part
x			Translation Stage 50 mm
	x		Translation Stage 150 mm
		x	Translation Stage 300 mm
x	x	x	Foot Plates for Translation Stage Mounting Adapters for Beam Profiler Power Supply RS232 Cable USB to RS232 Converter
x	x	x	BeamProfiler Software CD ROM incl. LabVIEW™ and LabWINDOWS™ /CVI Driver Set
x	x	x	Operation Manual

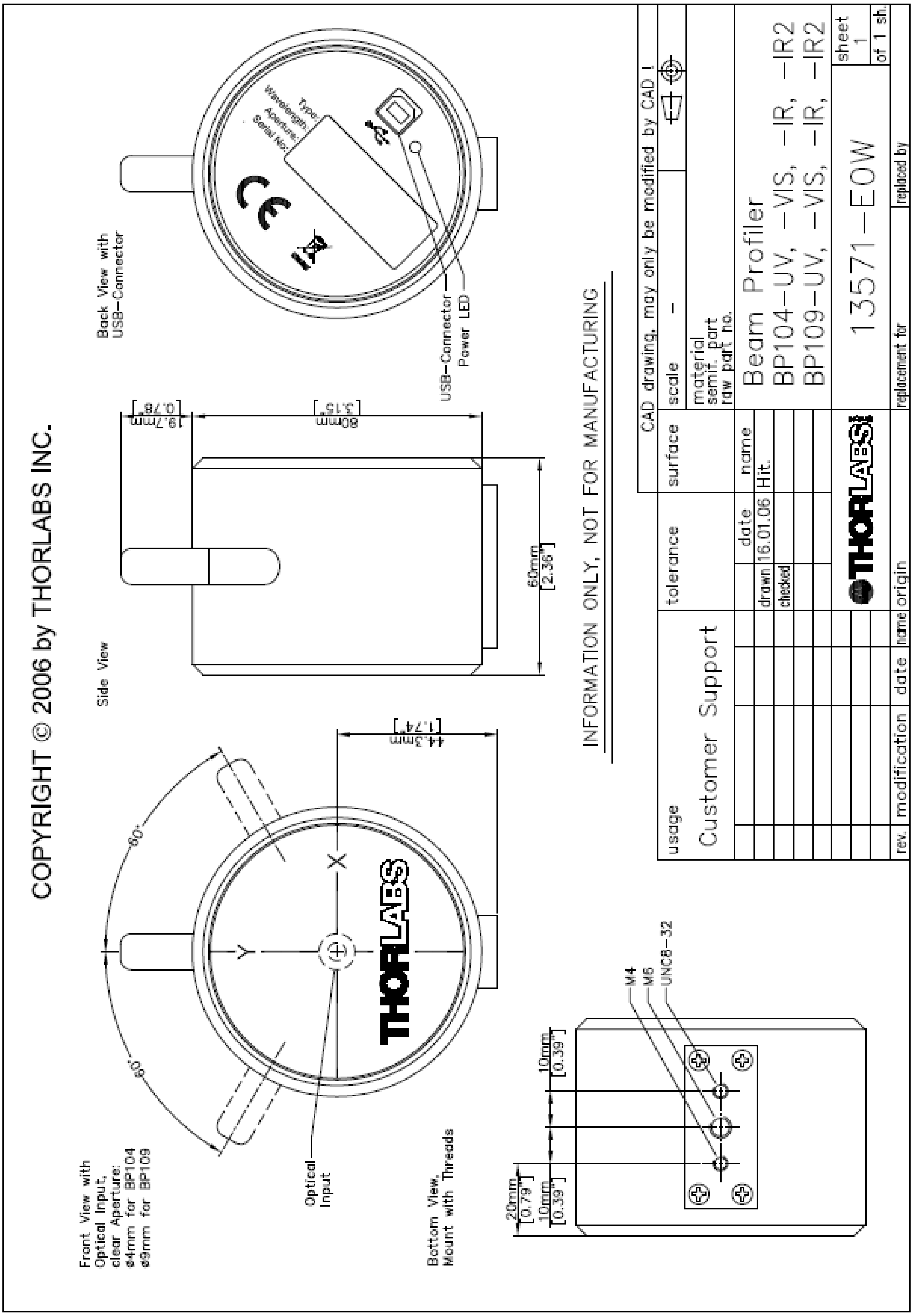
7.4.4 M2SET M2-Meter Components

The following table lists all components supplied with the Thorlabs M^2-Meter M2SET-x.

M2SET-VIS	M2SET-VIS/M	M2SET-IR	M2SET-IR/M	Part
x	x			Beam Profiler BP109-VIS, 400 - 1100 nm
		x	x	Beam Profiler BP109-IR, 700 - 1800 nm
x	x	x	x	USB 2.0 Connection Cable, 2m
x	x	x	x	Translation Stage 150 mm incl. Foot Plate and Mounting Adapters Power Supply RS232 Cable USB to RS232 Converter
x	x	x	x	BeamProfiler Software CD ROM incl. LabVIEW™ and LabWINDOWS™ /CVI Driver Set
x	x	x	x	Operation Manual
x	x			Biconvex Lenses 1" f=200 mm in SM1L03 Lens Tube 1x LB1945-A 1x LB1945-B
		x	x	Biconvex Lenses 1" f=200 mm in SM1L03 Lens Tube 1x LB1945-B 1x LB1945-C
x		x		1x MB624 Breadboard 24 x 6" 1x ID12 Iris Diafragm 1x LM1XY Translating Lens Mount 1x FM90 Flip Mpont 2x KM100 Kinematic Mirror Mount 2x PF10-03-P01 Protected Silver Mirror 2x RA90 Right Angle Post Clamp
x		x		3x PH1.5, 1x PH1 Post Holder 1x TR075, 2x TR1.5, 1x TR2, 2x TR4 4x BA1S Mounting Base Imperial Mounting Screws
	x		x	1x MB1560/M Breadboard 600 x 150 mm 1x ID12/M Iris Diafragm 1x LM1XY/M Translating Lens Mount 1x FM90/M Flip Mpont 2x KM100 Kinematic Mirror Mount 2x PF10-03-P01 Protected Silver Mirror 2x RA90/M Right Angle Post Clamp
	x		x	3x PH1.5/M, 1x PH1/M Post Holder 1x TR20/M, 2x TR30/M, 1x TR50/M, 2x TR100/M 4x BA1S Mounting Base Metric Mounting Screws

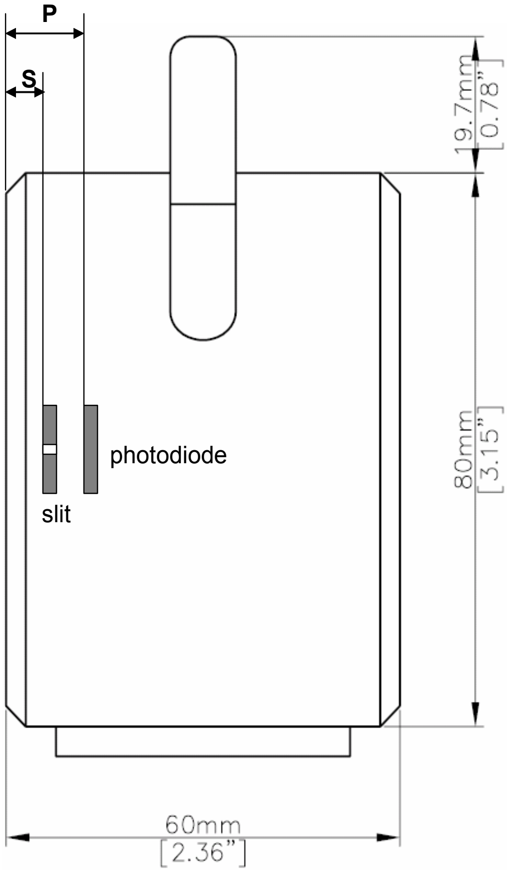
7.4.5 Drawings

7.4.5.1 Beam Profiler



7.4.5.2 Slit and Photodiode Position

Especially for highly divergent beams it is required that the entire beam power enters the entrance aperture, is scanned by the slit and is detected by the photodiode. To check for this condition the operator needs to know the positions and distances of these elements.

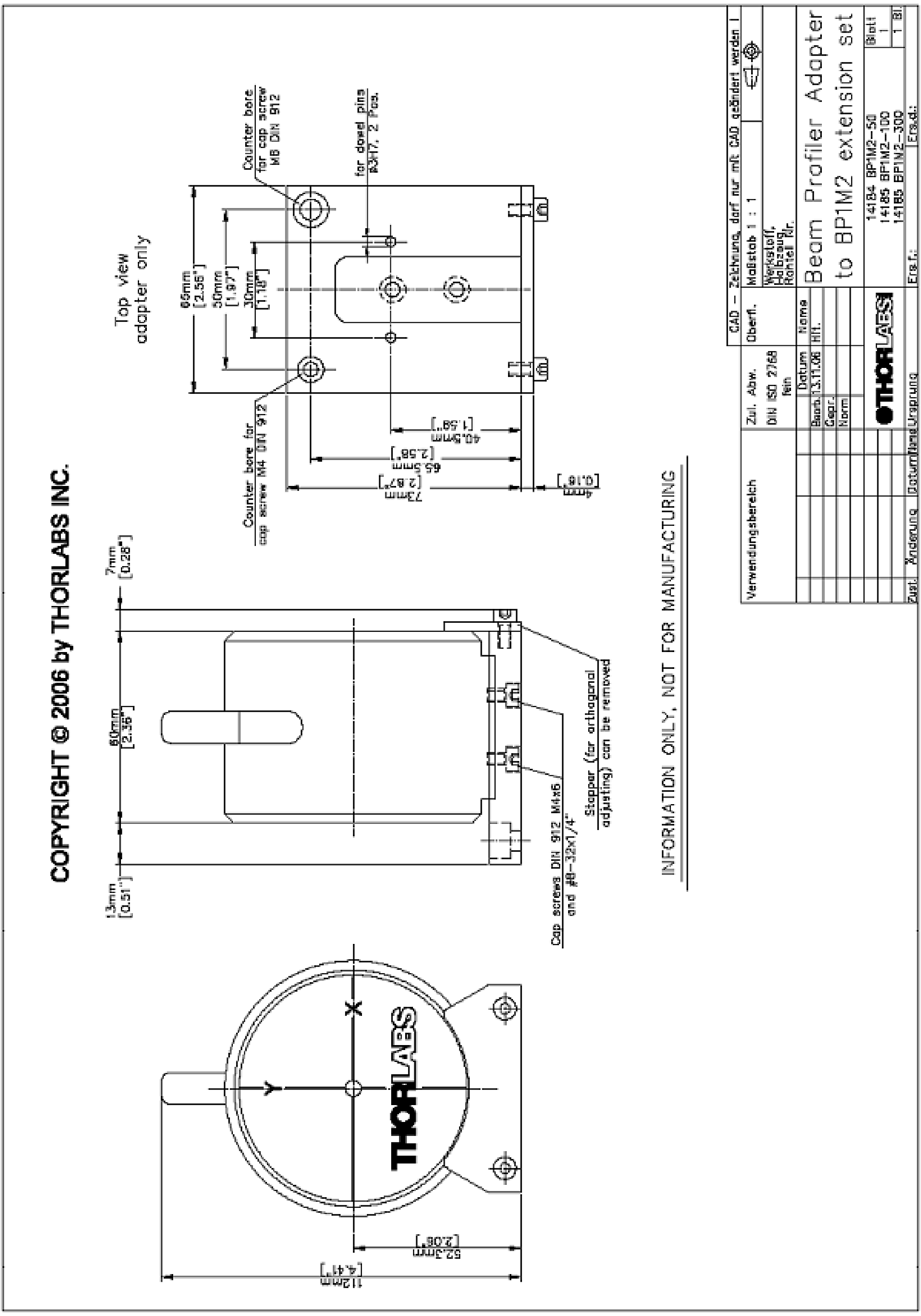


All dimensions are defined by design and may differ about 0.20 mm tolerance.

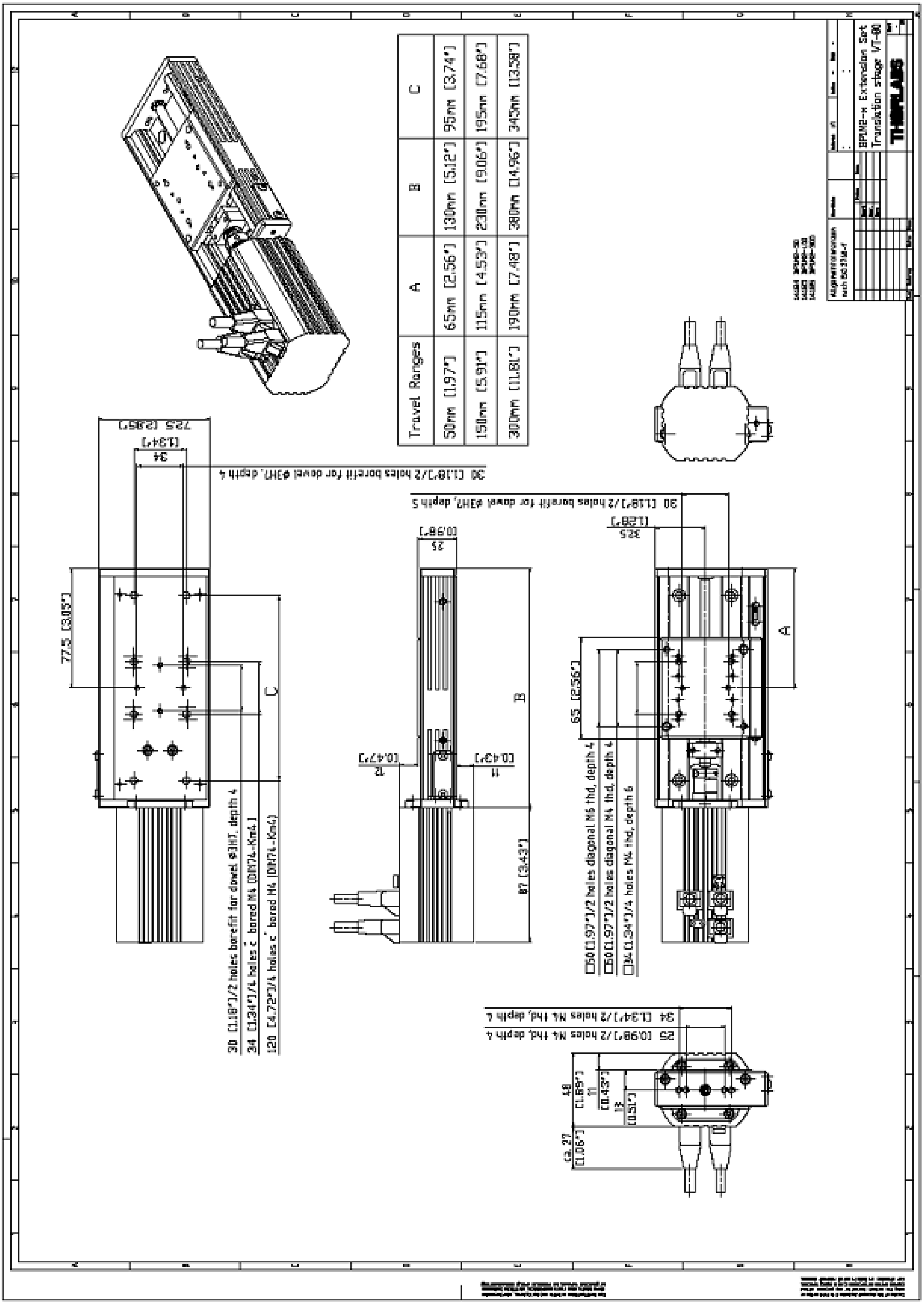
Model	Distance Front - Slit (S)	Distance Front - Photodiode (P)	Distance Slit - Photodiode
BP104-UV	1.87 mm	6.90 mm	5.03 mm
BP104-VIS	1.87 mm	5.90 mm	4.03 mm
BP104-IR	1.87 mm	7.40 mm	5.53 mm
BP104-IR2	1.87 mm	*	*
BP109-UV	1.87 mm	6.90 mm	5.03 mm
BP109-VIS	1.87 mm	6.90 mm	5.03 mm
BP109-IR	1.87 mm	6.90 mm	5.03 mm
BP109-IR2	1.87 mm	*	*

* Beam Profiler models BP104-IR2 and BP109-IR2 use an aspheric collimating lens behind the slit followed by a photodiode smaller than the entrance aperture.

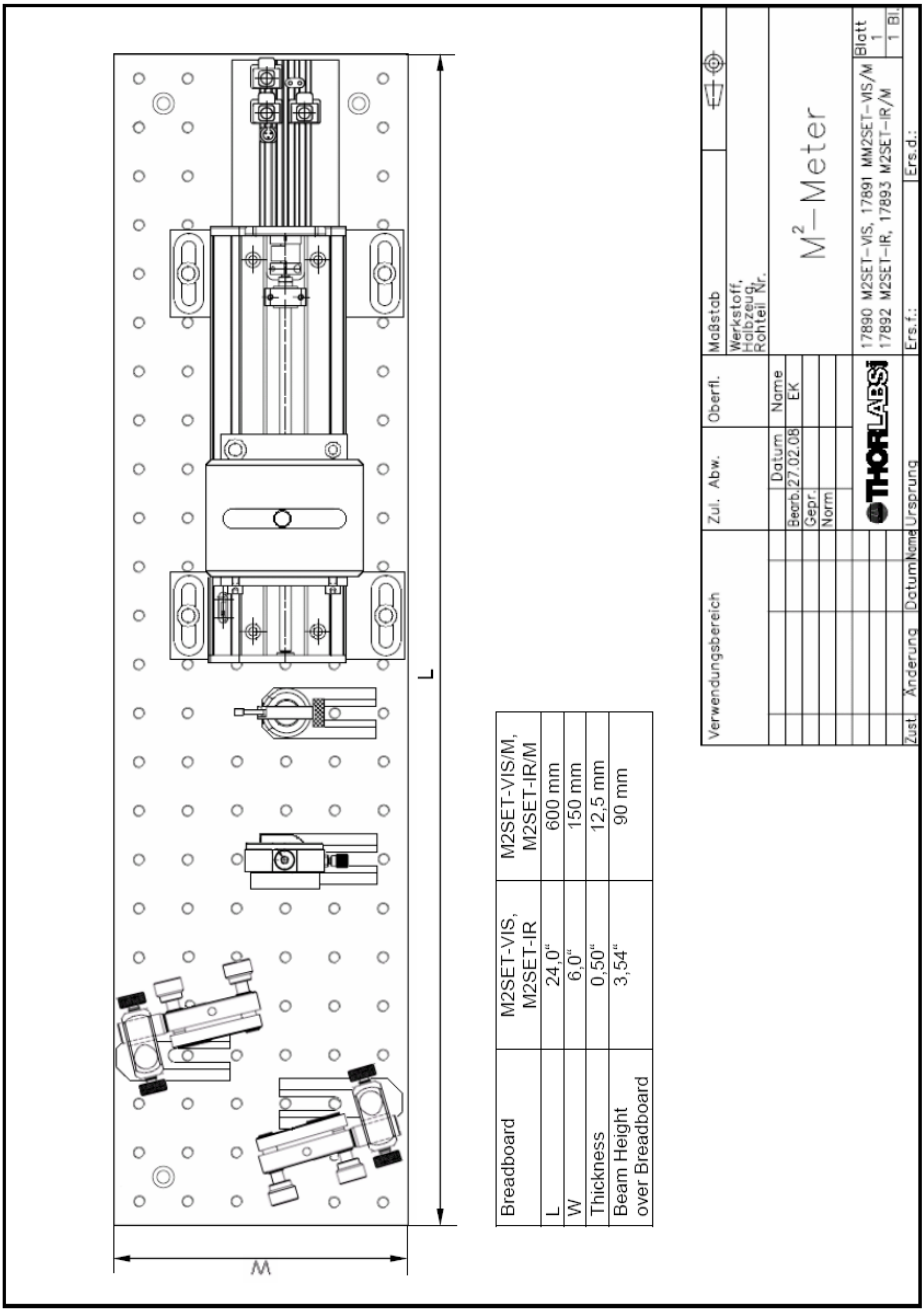
7.4.5.3 BP1M2 Mounting Adapter



7.4.5.4 Translation Stage VT-80



7.4.5.5 M2SET M2-Meter



Breadboard	M2SET-VIS, M2SET-IR	M2SET-VIS/M, M2SET-IR/M
L	24,0“	600 mm
W	6,0“	150 mm
Thickness	0,50“	12,5 mm
Beam Height over Breadboard	3,54“	90 mm

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 140

7.6.3 Thorlabs Worldwide Contacts

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