PRIMES

Original Instructions

LaserDiagnosticsSoftware LDS

Revision 03 EN – 02/2023

IMPORTANT!

READ CAREFULLY BEFORE USE.

KEEP FOR FUTURE USE.

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1 About this operating manual

The LaserDiagnosticsSoftware LDS is the control center for operating all PRIMES devices of the “+” generation and various power measurement systems (PowerMonitor, CompactPowerMonitor, ECPowerMonitor, Cube). Older devices (FM, LQM, MSM, BM-HQ) work with the previous version LDS 2.98.

This operating manual is for the basic version of LDS and describes software installation, file administration, and the display and analysis of measurement data.

A detailed description of installation and configuration of measuring devices and the performance of measurements is provided in the operating manuals for individual devices.

This operating manual describes the software version valid at the time of printing. This operating software undergoes continuous development.
It is therefore possible that a more recent version is available.

2 Technical support

For questions about LDS or the analysis of measurement results, please contact technical support:
- Email: support@primes.de
- Phone: +49 6157 9878 2500

3 Icons and conventions

The operating manual makes use of the following icons and conventions:

Here you will find useful information and helpful tips.

▶ Indicates a single action.
If multiple actions appear one below the other, then the order of their execution is immaterial, or they are alternative procedures.

1. A numbered list identifies a sequence of actions that must be executed in the specified order.
2.
...

→ Indicates the result of an action to explain processes that take place in the background.

Indicates an alert that calls attention to visual feedback from the device or software.
Such alerts help users check whether an action has been successfully executed. In many cases, they also lead to next action.

Indicates a control function that is to be pressed or clicked.

Indicates an element described in the text (e.g., an input field).

4 First steps

4.1 Install and run program

The basic version of LDS is included with the device. PRIMES will also be happy to provide you with a link to download the current version. To do so, contact your sales partner or contact us by email: **support@primes.de**

1. Please ensure:
- System requirements are met.
- You have administrator rights.

2. Close all programs on the PC.

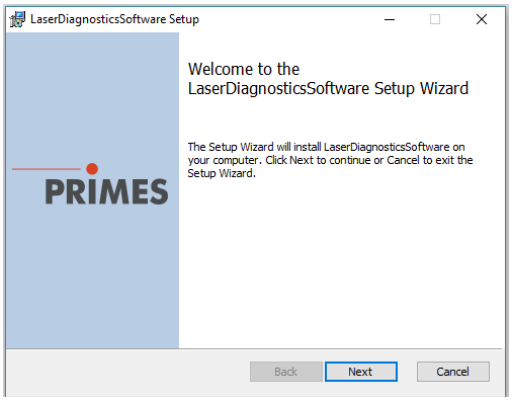
3. Insert the PRIMES thumb drive into the PC and open the directory. In the standard configuration, Windows automatically opens the removable storage device.

System requirements:

- Intel Pentium Core i3 or better
- Windows 10 (64-bit version)
- At least 4 GB RAM; 8 GB RAM recommended
- Display resolution: Full HD (1920x1080) at 100% scaling
- A USB or Ethernet interface for connecting the measuring device

4. Double-click on the file ***Setup LDS v.X.X.msi*** to start installation.
5. Follow the instructions on the screen.

➔ If no other location is specified, then the main program ***LaserDiagnosticsSoftware.exe*** will be copied to the directory ***C:\Programme\Primes\Software***.



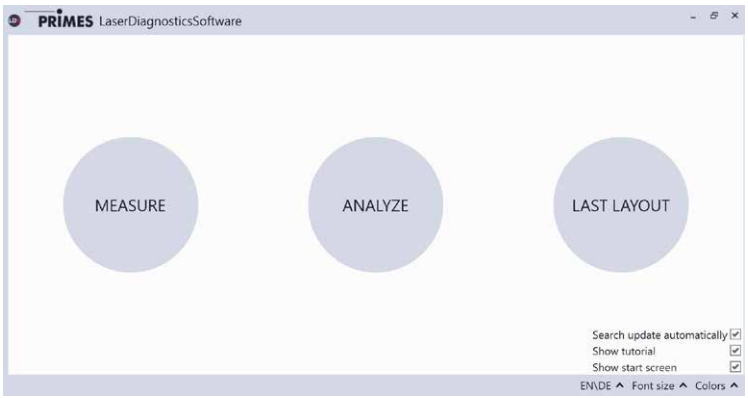
6. LDS can be launched in multiple ways:

▶ Double-click on the program icon in the start menu.

▶ Double-click on the desktop shortcut.

👁 The start logo appears briefly.

👁 The start screen appears.



4.2 Select mode of operation on the start screen

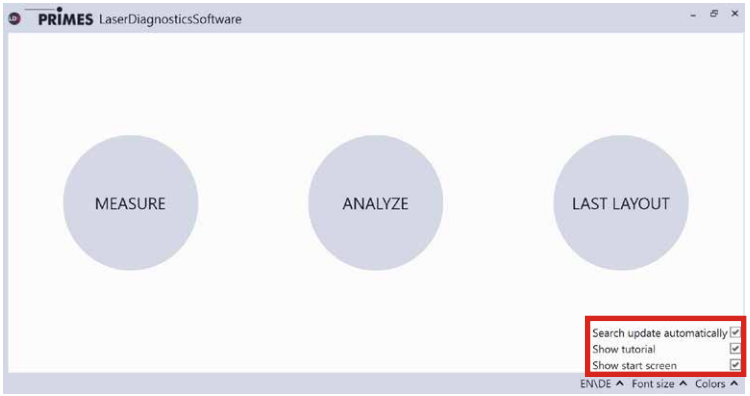
When the program is first started, the start screen appears. An operating mode can be selected here. Only then does the actual user interface open.

Set options

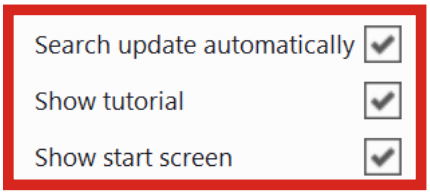
Before selecting the operating mode, various options can be set. These can be found in the bottom-right corner of the start screen.

▶ Set the options as required.

These options can also be set from within the user interface in the menu ***Extras > Options*** .



- ***Automatic search for update*** activates automatic notification of software updates.
- ***Show tutorial*** activates the tutorial function. The tutorial provides brief instructions, on a blue background, about the basic operating steps.
- ***Show start screen*** makes the start screen appears at every new start.

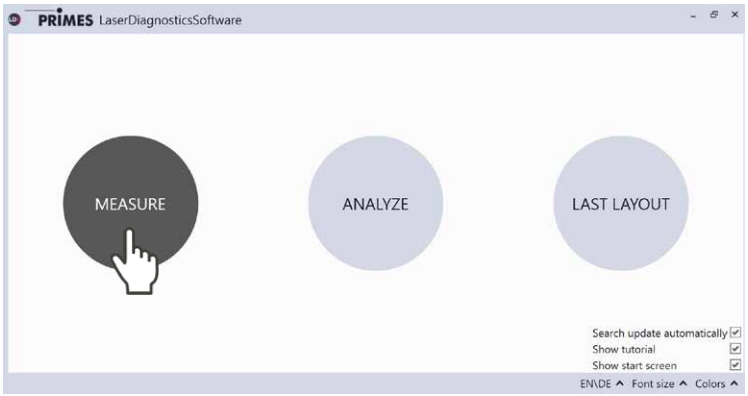


Select operating mode

When the program is first started, one of the following operating modes must be selected, along with the corresponding user interface: ***Measure / Analyze*** .
At each program restart, there is also the option to select the previous user interface by clicking ***Last layout*** (the following option must be activated: ***Show start screen***).

Operating mode *Measure*

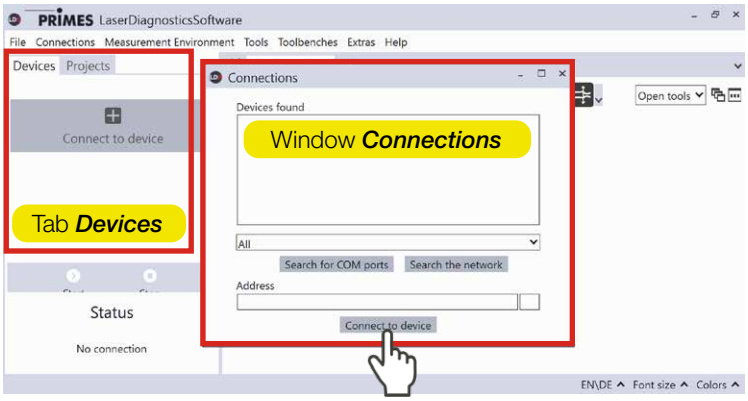
1. Select the ***Measure*** operating mode to connect the software to a measuring device in order to conduct a measurement.



The user interface is loaded.
The ***Devices*** tab appears in the foreground and the ***Connections*** window is open.

All PRIMES devices found in the network are listed in the window Connections.

2. Select one of the listed devices by clicking in the list.
3. Connect a measuring device via the ***Connect to device*** button. Observe also the information in the device operating manual.



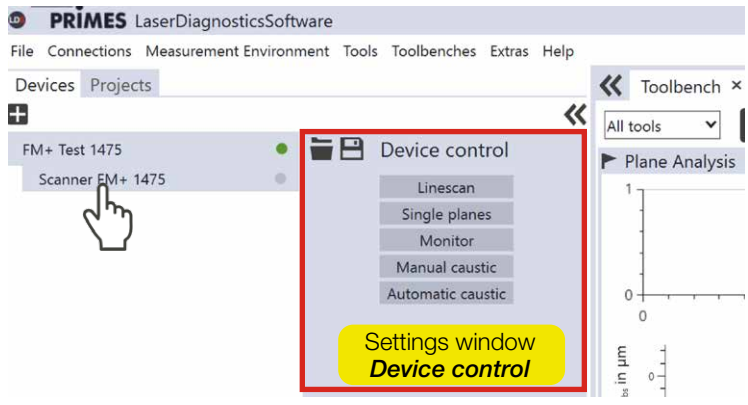
The connected device appears in the ***Devices*** tab.

4. Click on the desired device.

The settings window ***Device control*** appears.

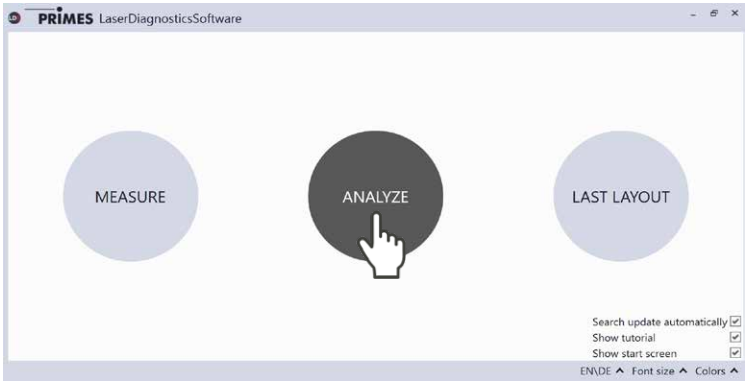
5. Select the appropriate measuring mode.

6. Enter the device and measurement parameters and start the measurement as described in the device operating manual.



Operating mode *Analyze*

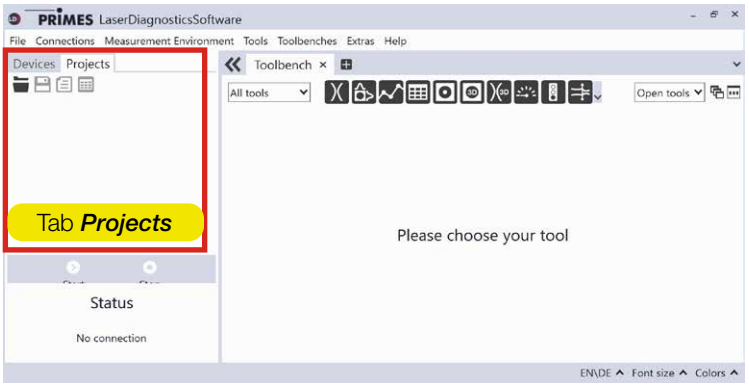
1. Select the ***Analyze*** operating mode to display and analyze measurements.



The user interface is loaded. The***Projects*** tab appears in the foreground. The toolbench is empty.

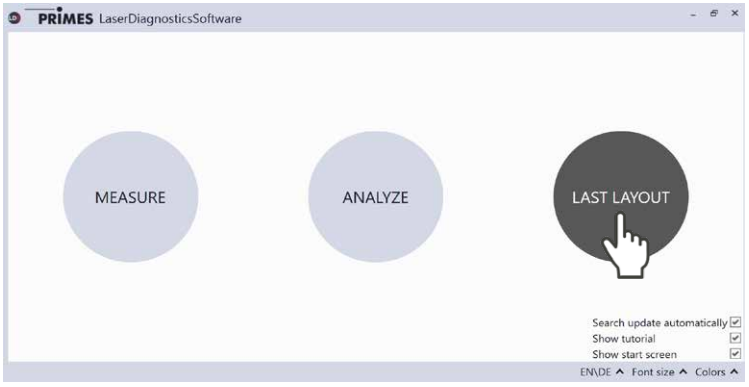
2. Load a project into the ***Projects*** tab, as described in Chapter 5.4.5 on page 19.

3. Open a measurement with a tool, as described in Chapter 6.1.2 on page 42.



Operating mode *Last layout*

▶ To load the user interface from the previously used layout, select the operating mode ***Last layout***.



5 The user interface

5.1 Layout and operation of user interface

The user interface is divided into functional areas, moving from left to right according to the sequence of operating steps:

- **Left**: Connect device and conduct measurements (operating mode ***Measure***) or load measurements (operating mode ***Analyze***).
- **Center**: Select a measuring mode in the ***Device control***. area to choose options and set parameters This settings window only appears if a measuring device with a corresponding measurement function has been selected in the ***Devices*** tab.
- **Right**: Display and analyze measurements in main window (operating modes ***Measure*** and ***Analyze***).

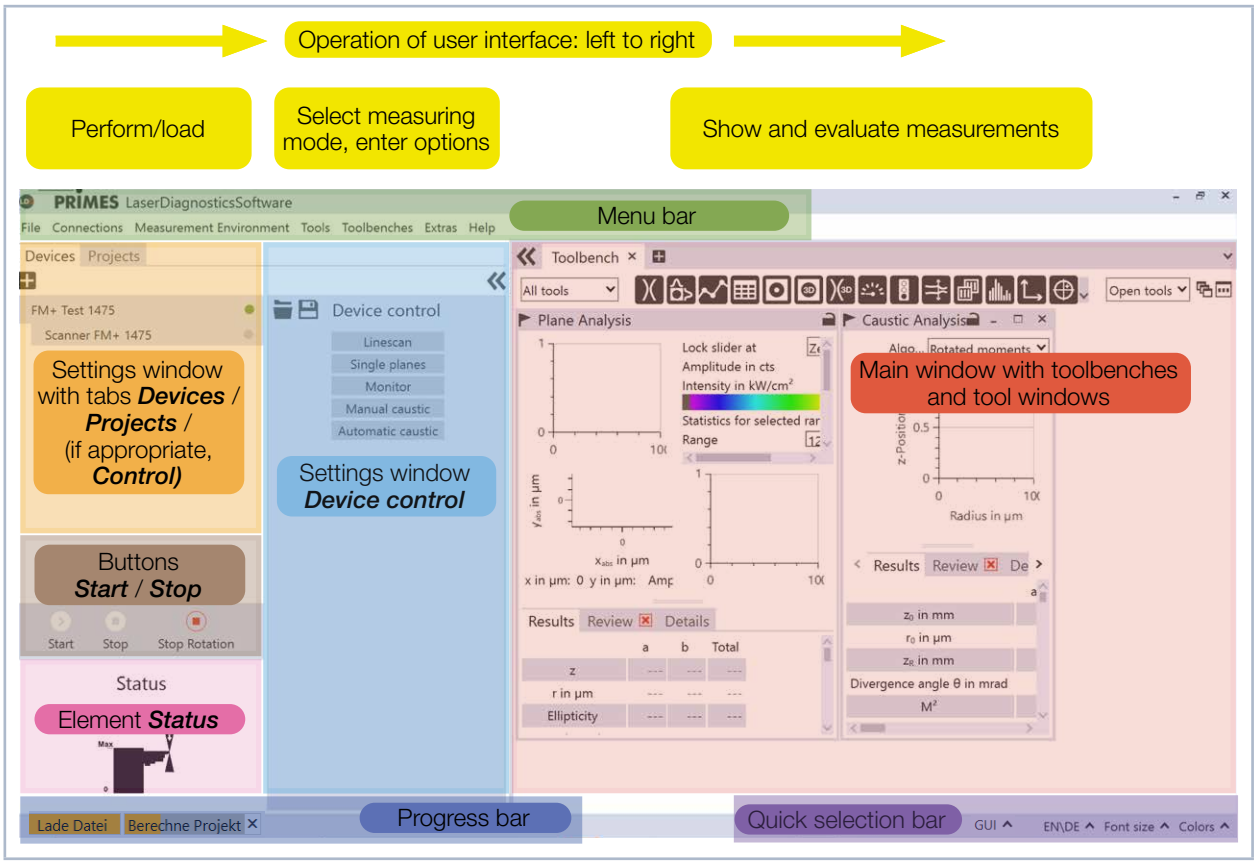


Fig. 5.1: Layout and operation of user interface

Elements	Explanation
Menu bar	The menu bar offers a wide range of operating and setting options. Further information can be found in Chapter 5.5 “The menu bar” on page 26.
Settings window with tabs ***Devices*** / ***Projects*** / (in some cases, ***Control)***	Clicking on the ***Devices / Projects*** tab brings this to the foreground. In this way, it is possible to switch between the ***Measure / Analyze*** operating modes. • In the ***Devices*** tab, measuring devices can be connected to LDS. All connected devices are listed along with their measurement functions. Further information can be found in Chapter “The “Devices” tab” on page 14. Once a connected device with a corresponding measurement function has been selected, the ***Device control*** settings window appears (see below for description). • Measurement projects are loaded into the ***Projects*** tab. The measurements in this tab can be opened with the tools in the main window. Projects in this tab are displayed in a hierarchically structured project tree. Further information can be found in Chapters “The “Projects” tab” on page 15 and “Show and evaluate measurements” on page 37.
Buttons ***Start*** / ***Stop***	The buttons in this window are used to start/stop a measurement. In the case of scanning devices, the rotation of the measuring tip can also be halted here. Further information can be found in the device operating manuals.
Element ***Status***	***Status*** displays the progress of a current measurement. Further information can be found in the device operating manuals.
Progress bar	Progress bars display the progress of measurement, saving, loading and calculating project tree elements.
Settings window ***Device control***	When a device is connected in the ***Devices*** tab and a corresponding measurement function has been selected, the ***Device control*** settings window appears. In the case of many devices, a measuring mode can also be selected here. The measuring mode contains all the setting options relevant for a measuring task, clearly arranged in a menu. Further information can be found in the device operating manuals. By clicking on the adjacent « icon, the settings window can be collapsed to form a dedicated tab. It then appears alongside the ***Devices / Projects*** tabs. Clicking on the gear icon ⚙ will return to the previous view.
Main window with toolbenches and tool windows	Measurement data can be displayed and analyzed in the main window of the user interface. A variety of tools are available for this purpose, all of which can be displayed in separate windows. For additional clarity and flexibility, these tool windows can be displayed in any number of tabs as toolbenches.
Quick selection bar	The user interface can be customized here: • Language: German/English • Color scheme: light/dark • Font size: M/L/ XL • GUI: Show/hide menu bar and script console (see ***Script editor tool*** in Tab. 6.1 on page 37).

Tab. 5.1: Elements of the user interface

5.2 Overview of control functions for all elements and windows

The elements and windows of the user interface contain different control functions in the form of icons.

Icon	Function
	In many elements and windows: ▶ To open/close a drop-down menu / drop-down list of the sub-elements of a project tree element, click on the arrow right/arrow down.
	In the top-right corner of a toolbench: ▶ For a cascaded/tiled arrangement of tool windows, click on the frame icon (left/right).
	In the main window: ▶ To add another toolbench, click on the plus symbol. In the ***Devices*** tab: ▶ To connect a device, click on the plus symbol. Further information can be found in the device operating manuals.
	In some graphic displays: ▶ To zoom in / zoom out in a graphic, click on the plus/minus symbol.
	In some elements and tool windows: ▶ To open a settings window, click on the gear icon. In the tool windows, the gear icon only appears when the mouse cursor is hovered over the window / the relevant element of the window.
	In the ***Device control*** settings window and the main window: ▶ To close the ***Device control*** settings window or the ***Devices*** / ***Projects*** tab, click on the double arrow.
	In the top-left corner of a tool window: ▶ To mark in a project tree the measurement data displayed in a tool, click on the flag icon. With this function, the measurement data displayed in a tool can be clearly identified in the project tree. This improves readability when a lot of tool windows are open in one toolbench simultaneously.
?	In the top-right corner of a tool window: ▶ To display help text for a tool, click on the question mark. The LDS operating manual then appears in a new window. The manual is open at the chapter for the tool in question.
	In some tool windows: ▶ To open an information window, hover the mouse cursor over the information icon. The information window provides relevant explanations or other help.
	In the top-right corner of a tool window: ▶ To lock/unlock the contents of a tool window, click on the lock icon (left/right). This function makes it easy to compare data sets in multiple tools. Further information can be found in Chapter 6.1.2 “Opening project tree measurements in tools” on page 42.
  	Lots of windows of the user interface can be adjusted for size by clicking and dragging the frames. In the top-right corner of many windows, there are also the standard icons to shrink, minimize and maximize the window. It may be necessary to activate the window before these control icons appear. If the window is maximized, there are the following options: ▶ To minimize the window, click on the underline icon. ▶ To shrink the window, click on the double-frame icon. ▶ To close the window, click on the cross symbol. If the window is neither maximized nor minimized, there are the following options: ▶ To minimize the window, click on the underline icon. ▶ To maximize the window, click on the frame icon. ▶ To close the window, click on the cross icon. If the window is minimized, there are the following options: ▶ To enlarge the window, click on the double-frame icon. ▶ To maximize the window, click on the frame icon. ▶ To close the window, click on the cross icon.

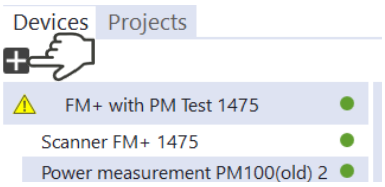
Tab. 5.2: Control icons for elements and windows

5.3 The “Devices” tab

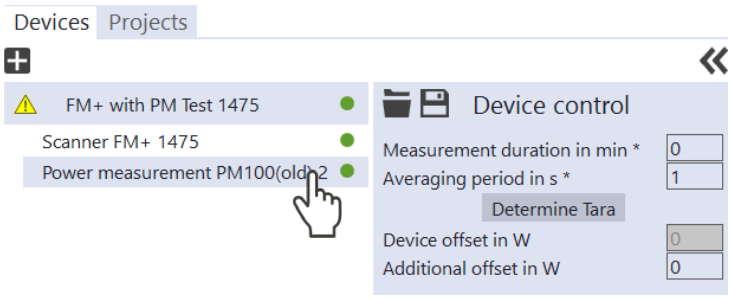
Clicking on the ***Devices*** tab brings this to the foreground and activates the operating mode ***Measure***.
In this tab, the following control options are available:

▶ To connect a device with LDS, click on the plus symbol.
The ***Connections*** window appears.

Further information can be found in the device operating manuals.

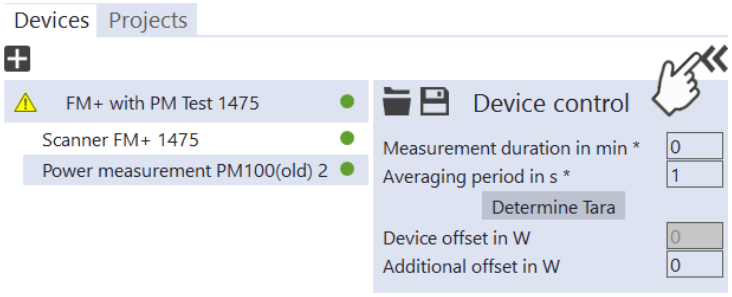


▶ To open the ***Device control*** settings window, click on the required device.



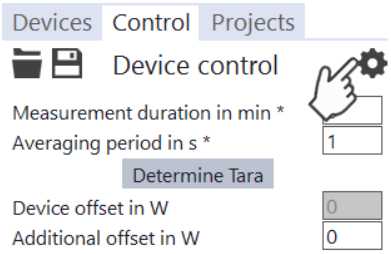
▶ To turn the ***Device control*** settings window into a dedicated tab, click on the double arrow.

Once settings have been made, this frees more space for displaying measurement data in the main window.



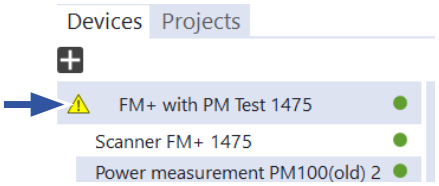
The tab then appears alongside the ***Devices*** / ***Projects*** tabs.

▶ To incorporate the ***Device control*** settings window in the ***Devices*** tab, click on the gear icon.



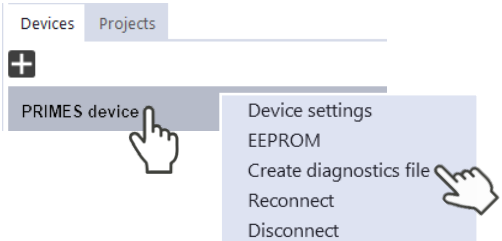
▶ To show warning information about the connected device,hover the mouse cursor over the warning triangle (if available).

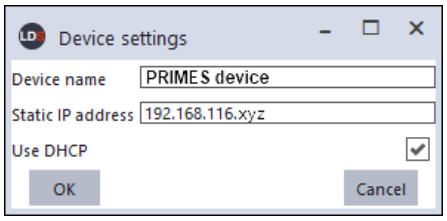
The warning triangle appears when, for example, the service interval of the device has expired.



▶ To display a device-related context menu, right-click on the device.

The options in the context menu are explained in Tab. 5.3 on page 15.



Option	Explanation
Device settings 	Opens the ***Device settings*** window. For communication within a network, an address is stored in the Static IP address field in the LDS and the Use DHCP function is activated. When connecting to the network, the device first waits to be provided with an IP address via DHCP. If this fails, it reverts to the static IP address. If ***Use DHCP*** is deactivated, the device reverts to the static IP address. This ensures faster network connection. 1. Enter a valid IP address or use the ***Use DHCP*** option. 2. Click ***OK*** to confirm. 3. Switch the device off and on again.
EEPROM	Here, adjustments can be made to PRIMES – e.g., for service requirements.
Create diagnostics file	Opens a Windows Explorer window for the purpose of saving a file with the LDS file extension ***.diagnose***. This file contains device status data for the purpose of troubleshooting. These can only be analyzed by PRIMES. This file does not contains any data from your PC or laptop.
Reconnect	Reconnects the device with LDS (e.g., after connection has been lost).
Disconnect	Disconnects the device from LDS. Further information can be found in the device operating manuals.

Tab. 5.3: Context menu options in the ***Devices*** tab

5.4 The “Projects” tab

Clicking on the ***Projects*** tab brings this to the foreground and activates the operating mode***Analyze***.

5.4.1 Project tree elements and their hierarchy

LDS categorizes measurement data in logical units. To enable clear and easy handling, these units are shown as elements in the project tree of the ***Projects*** tab.

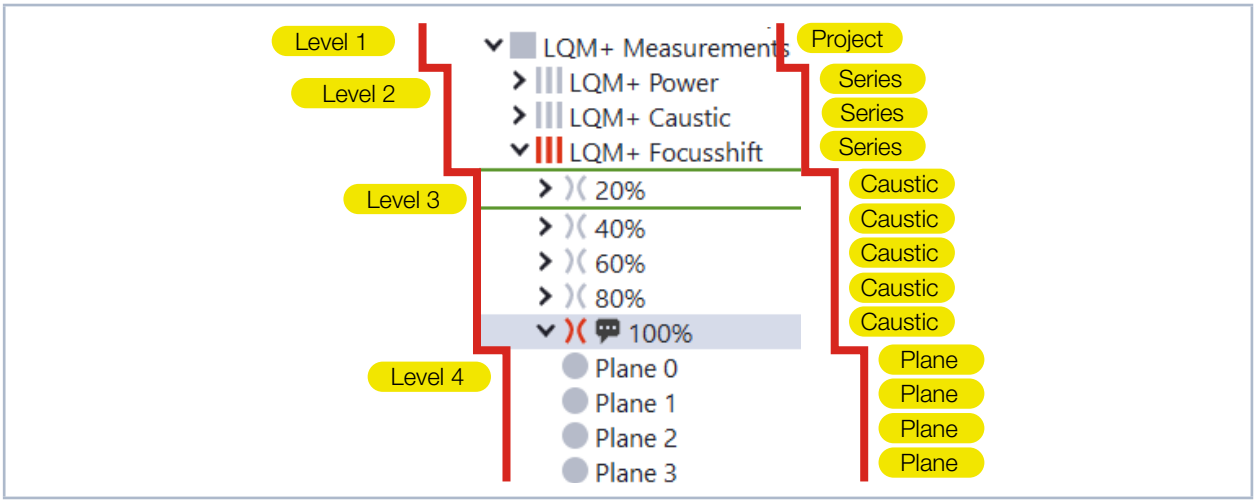


Fig. 5.2: Example of a project tree in the ***Projects***tab.

The project tree contains different types of element. These are assigned to a maximum of four hierarchy levels. Some of these elements have themselves sub-elements. Others are fundamental elements, which contain the basic measurement results.

1. Level	2. Level	3. Level	4. Level	
Project				***Project*** is an element of hierarchy level 1. It may occur repeatedly in the project tree and can be saved individually as a file with the LDS file extension ***.lpf***. This element can also contain one or more elements of the type ***Series***.
	Series			***Series*** is an element of hierarchy level 2. It may contain one or more sub-elements of the same kind; e.g., the element ***Caustic***.
		Caustic		***Caustic*** is an element of hierarchy level 3. It contains the results of a caustic measurement and one or more elements of the type ***Plane***.
			Plane	***Plane*** is a fundamental element of hierarchy level 4. It contains the results of a plane measurement.
	Series			***Series*** is an element of hierarchy level 2. It may contain one or more sub-elements of the same kind; e.g., the element ***Linescan***.
		Linescan		***Linescan*** is a fundamental element of hierarchy level 3. It contains the results of a linescan measurement.
	Series			***Series*** is an element of hierarchy level 2. It may contain one or more sub-elements of the same kind; e.g., the element **SFM vector series**.
		SFM vector series		**SFM vector series** is an element of hierarchy level 3. It contains one or more elements of the type **Vector**.
			Vector	**Vector** is a fundamental element of hierarchy level 4. It contains the results of a single vector measurement from the ***ScanFieldMonitor SFM*** device.
	Series			***Series*** is an element of hierarchy level 2. It may contain one or more sub-elements of the same kind; e.g., the element **SFM delay time**.
		SFM delay time		**SFM delay time** is an element of hierarchy level 3. It contains one or more elements of the type **Vector**.
			Vector	**Vector** is a fundamental element of hierarchy level 4. It contains the results of a single vector measurement from the ***ScanFieldMonitor SFM*** device.
	Series			***Series*** is an element of hierarchy level 2. It may contain one or more sub-elements of the same kind; e.g., the element **Cube series**.
		Cube series		**Cube series** is an element of hierarchy level 3. It contains one or more elements of the type **Cube measurement**.
			Cube measurement	**Cube measurement** is a fundamental element of hierarchy level 4. It contains the results of a single vector measurement from the ***ScanFieldMonitor SFM*** device.
	Series			***Series*** is an element of hierarchy level 2. It may contain one or more sub-elements of the same kind; e.g., the element ***Power measurement***.
		Power measurement		***Power measurement*** is a fundamental element of hierarchy level 3. It contains the results of a power measurement.

Fig. 5.3: Types of project tree elements and their hierarchical arrangement

5.4.2 About the project tree elements

When creating a project tree element, it is automatically assigned a name. If required, the element can also be assigned an alternative name via the context menu (see Chapter 5.4.6 “Context menus” on page 21). This alternative name should be different to the name automatically assigned by the system to the element type (see Chapter 5.4.1 “Project tree elements and their hierarchy” on page 15). PRIMES recommends giving the project tree elements a descriptive name.

In the project tree, further information about an element is displayed next to its name as follows:

- As graphical elements next to the name of the project tree element (icons, dashes, colors).
- As text in a window that appears when the mouse cursor hovers over the project tree element. This contains information such as the type of element, its name, saved measurement data, errors and instructions for solving these errors.

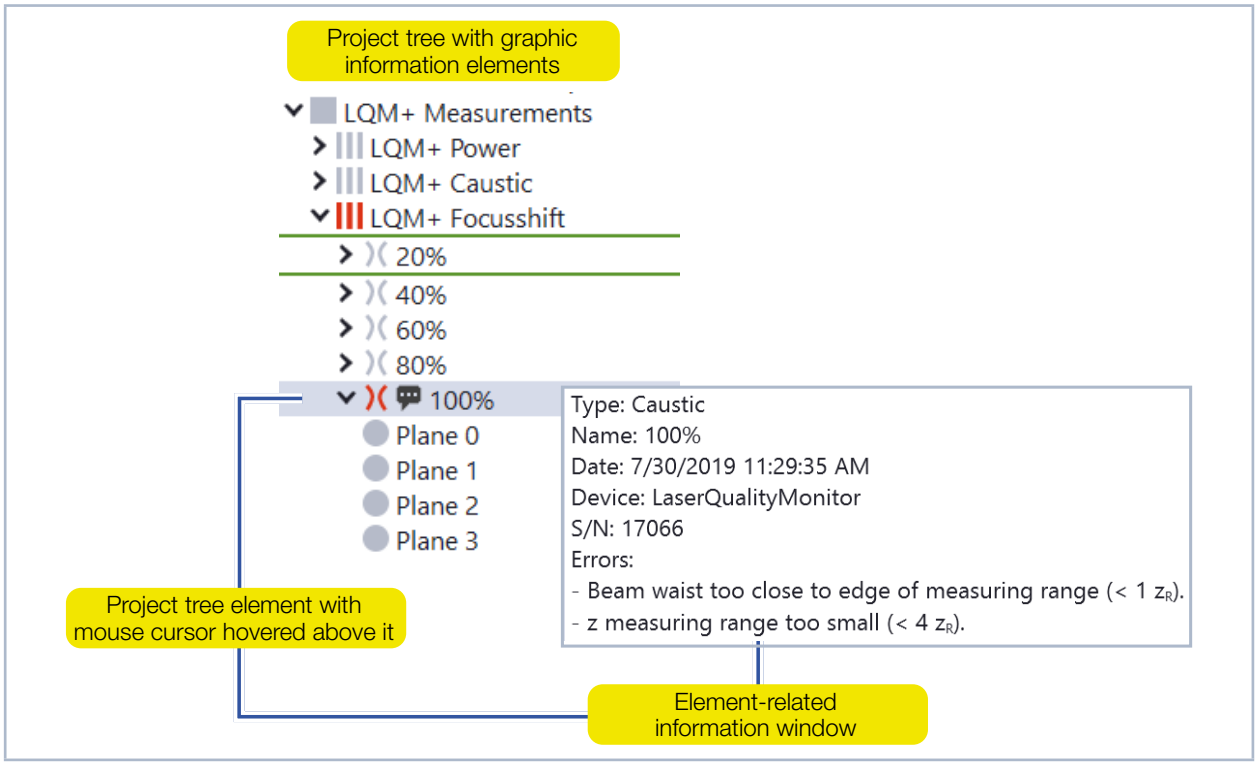
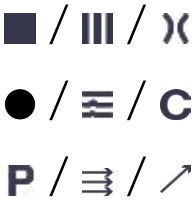


Fig. 5.4: About the elements in a project tree

Graphical representation	Information
	Arrow right/down: The element contains sub-elements. Clicking on the arrow shows/hides these sub-elements.
	Shows element type. Further information on element types can be found in Chapter 5.4.1 “Project tree elements and their hierarchy” on page 15. The icons can be gray or red. Further information can be found in Chapter 5.4.3 “Review of measurements in project tree” on page 18.
	Speech bubble: This element contains a comment. Users can assign comments to any elements. See the menu item ***Add comment*** in Tab. 5.6 on page 22.
*	Asterisk next to the name: The element or at least one of it sub-elements contains unsaved changes.
	Green lines above and below the element ***Caustic***: This element has been selected as a reference. Further information can be found in Chapter “Reference tab” on page 104
	Gray background: The element has been clicked or the mouse cursor is hovering over the element.

Tab. 5.4: Graphical display providing element-related information in project tree

5.4.3 Review of measurements in project tree

Element icons in a project tree may be gray or red (see Fig. 5.4 on page 17). Red indicates a warning in the following cases:

- The measurement was made outside device specifications.
- At least one of the measured parameters is invalid.
- At least one of the measured parameters lies outside of outside the permissible limits of the reference measurement set by the user (only for the element ***Caustic***; see chapter “Reference tab” on page 104).

The information window for a red-colored element contains a description of the error and, if applicable, instructions for correcting the error (see Fig. 5.4 on page 17).

If an element in a project tree is marked red, then so are all the other higher-level elements above it. Conversely, an element may be marked red without any of the elements below it also being marked red. For example, the element ***Caustic*** can be marked red although the elements below it all meet the required criteria. The reason for this is that only the limit values of caustic parameters were violated (e.g., because the minimum measurement area along the z-axis was not reached; see Fig. 5.4 on page 17).

In the project tree, the element ***Caustic*** is always reviewed on the basis of the default standard algorithm ***Invariant moments***. Conversely, in the ***Review*** tab of the ***Caustic analysis*** tool, this review is always based on the algorithm that is currently selected for that tool.
For this reason, the review in the ***Review*** tab may be different to the analysis in the project tree.
The default standard algorithm can be selected in the menu bar***Extras > Options > Software > Standard algorithm***.

Further reviews of the parameters of an element can be performed in the many tools in which the respective element can be opened.
Details are available in Chapter 8.2 “Review of parameters with colored markers” on page 140.

5.4.4 The toolbar above the project tree

Various command icons are arranged above the project tree. If a command is not available in a specific context, the respective icon is shaded gray.
Some of these commands can also be selected via the ***File*** menu.

Icon	*File* > menu	Function
	Open	Opens a Windows Explorer window for the purpose of opening a file with the LDS file extensions: • ***.lpf*** (LDS 1.3.1) • ***.foc*** (LDS 2.98) This file contains an LDS project. The file is loaded into the ***Projects*** tab.
	Save as	Opens a Windows Explorer window for the purpose of saving a file with the LDS file extension ***.lpf***. This file contains the LDS project that has been selected in the ***Projects*** tab.
	PDF export	Opens a Windows Explorer window for the purpose of saving a file with the file extensions: • ***.pdf*** • ***.png*** This file contains a report for the measurement that has been selected in the ***Projects*** tab. Before saving a measurement report, select the required document template (report template) from a drop-down list. Different templates are available depending on the type of measurement.
	CSV export	Opens a Windows Explorer window for the purpose of saving a file with the file extension ***.csv***. This file contains the numerical data of the measurement that has been selected in the ***Projects*** tab.
		Opens the context menu for a project tree. Further information can be found in Chapter 5.4.6 “Context menus” on page 21.

Tab. 5.5: Command icons above the project tree

5.4.5 Administration of projects

LDS projects are saved in a project file with the LDS extension ***.lpf***. Please note that the name shown in the project tree is not necessarily the name of the project file. The project name and file name may be different.

PRIMES recommends giving projects in the project tree a descriptive name. When saving the project file, the designated project name is also saved.

Open projects

A project file can be opened in a variety of ways:

▶ Select ***File > Open***in the menu bar or click on the icon above the project tree. This opens a Windows Explorer window. Now select a project file with the LDS extension ***lpf.***

▶ In a Windows directory, click on a project file with the LDS extension ***lpf***. Press down the left mouse button and drag the file to anywhere on the LDS user interface.

👁 The file is loaded into the ***Projects*** tab and the project data are calculated. Two progress bars in the bottom-left corner of the user interface display the state of progress. If required, calculation can be halted by clicking on the cross symbol ×.

Files from the predecessor version (LDS 2.98) can be opened.
These files have the LDS extension .foc. The following options are available:

- If no project is selected in the project tree, then a project with the name of the opened file will created in the project tree. The measurement is then saved as a sub-element of this project.
- If a project is selected in the project tree, then the measurement is stored as a sub-element of this project.

Create projects

1. Click on the free space beneath the project tree. Open the context menu by right-clicking or by clicking on the ☰ icon above the project tree.
2. Select the menu item ***New project*** (see Chapter 5.4.6 on page 21).

👁 A new project appears in the project tree with the name ***Project***.

3. If required, use the context menu to alter the project name in the project tree (see Chapter 5.4.6 on page 21). Give the project a descriptive name that meets your purposes.

If necessary, the project will be saved as described in Chapter Chapter “Saving projects as a new file” on page 20.

If no project is created or selected when a measurement is started, a new project is automatically created. The measurement is then saved as a sub-element in this new project.If a project is selected from a project tree, the measurement is then saved as a sub-element of this project.

Saving projects as a new file

1. Select the project in the project tree.
2. Select ***File > Save as*** in the menu bar.

👁 A Windows Explorer window opens. The project name of the selected project is displayed in thefile name field.

3. Select a storage location.
4. If necessary, alter the file name and then save the file.

👁 A progress bar in the bottom-left corner of the user interface displays the state of progress.

Save changes to projects

The asterisk * icon next to the name of a project tree indicates that an element or at least one of its sub-elements contains unsaved changes.

1. In the project tree, select the project that contains unsaved changes. Also select any sub-element of the project – in any case, the project is always saved.
2. Select ***File > Save*** in the menu bar.

👁 A progress bar in the bottom-left corner of the user interface displays the state of progress. Once saving has been completed, the asterisk icons * next to the project tree elements of a project disappear.

Delete projects

▶ Select a project in a project tree and press the Delete key or select ***Delete*** in the context menu (see Chapter 5.4.6 on page 21).
➔ The project is deleted from the project tree. The project file (if any) is not deleted from the file system.

Merge projects

Multiple projects can be merged into one via the context menu.

1. Load the relevant projects into the project window.
2. Click on the free space beneath the project tree. Open the context menu by right-clicking or by clicking on the ☰ icon above the project tree.
3. Select the menu item ***Merge projects*** (see Chapter 5.4.6 on page 21).

➔ The projects are merged into one project with the name “Merged project.” A comment is created that lists the names of the merged projects.

5.4.6 Context menus

Via the ***Projects*** tab, numerous functions can be selected via context menus:

Opening an element-related context menu

1. Click on the project tree element.
2. Then open the context menu by right-clicking or by clicking on the ☰ icon above the project tree.
3. Click on the relevant menu item.

Opening a tab-related context menu

1. Click on the free space beneath the project tree.
2. Then open the context menu by right-clicking or by clicking on the ☰ icon above the project tree.
3. Click on the relevant menu item.

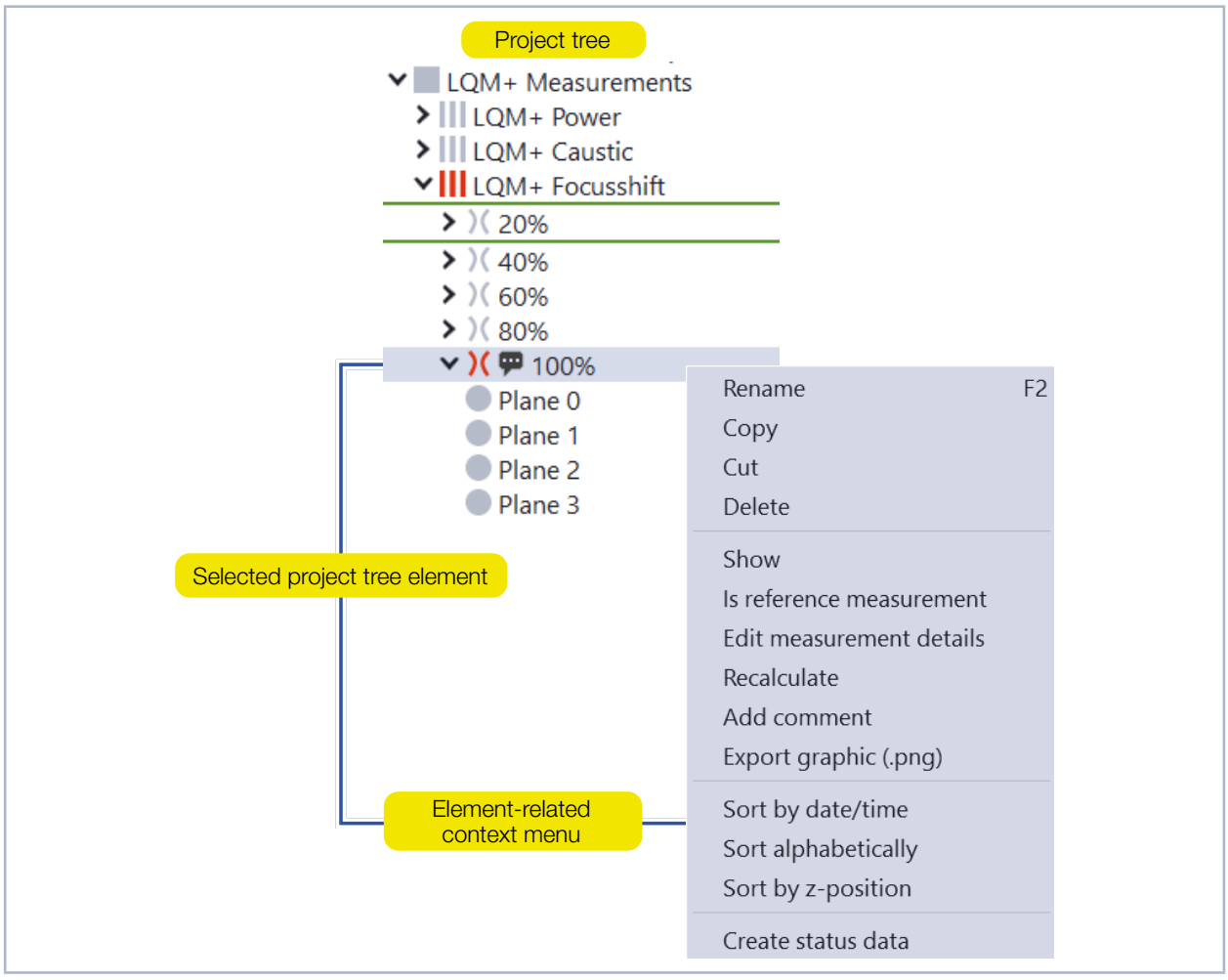


Fig. 5.5: Example of an element-related context menu

Menu item	Function
Show	Displays within a suitable tool the measurement data stored in the selected element.
Cut	Deletes the selected element and moves it to the clipboard.
Paste	Inserts an element from the clipboard as a sub-element of the selected element.
Export graphic (.png)	Opens a Windows Explorer window for the purpose of saving a file with the file extension ***.png***. This file contains the false-color views of the plane(s) of a caustic.
Show in Windows Explorer	Opens a Windows Explorer window containing the storage location of a saved project file.
Is reference measurement	Activates/deactivates the selected caustic as reference measurement. Further information can be found in Chapter “Reference tab” on page 104.
Add comment	Users can assign comments to any project tree elements. In order to enter a comment, proceed as follows: 1. Select menu item in the context menu of the element in question. 👁 The comments window opens. 2. Enter text. 3. To confirm a comment, click on the ***button***. 👁 A speech bubble indicates the presence of a comment in the project tree. In order to read/edit/delete a comment, proceed as follows: 1. Click on the relevant speech bubble icon in the project tree. 👁 The comments window opens. 2. Read or edit the text. To delete a comment, simply delete the text. 3. To confirm the change, click on the ***Save*** button. 👁 When all text has been deleted from a comment, the speech bubble icon disappears from the project tree. Any comment added to the elements ***Plane / Caustic*** is also displayed in the ***Details*** tab in the ***Plane analysis / Caustic analysis*** tools. (See Chapter 6.3.2 “Plane analysis” on page 74 / Chapter 6.3.6 “Caustic analysis” on page <?>).
Delete	Deletes a selected element from a project tree. 1. Call up menu item in the context menu of the element in question. 👁 The element is deleted and the asterisk icon * appears next to the name of the element above it. 2. If required, save the higher-level project by clicking on it and selecting ***File > Save*** in the menu bar.

Tab. 5.6: Menu items in the project tree context menu

Edit measurement details	This menu item appears with the elements ***Plane / Caustic / Series***. Calls up a toolbench for the purpose of editing measurement details. Proceed as follows: 1. Call ***Delete*** in the context menu of the element in question. 👁 Editable measurement details appear in a tab. 2. Edit a value. 3. Confirm by pressing the Enter key. 4. If required, edit further values. 5. If required, save the higher-level project by clicking on it and selecting ***File*** > ***Save*** in the menu bar.
Remeasure	This function appears for the elements ***Plane / Caustic***, when a device is connected. Further information can be found in Chapter “Remeasuring a caustic or a plane” on page 24.
Recalculate	Recalculates a measurement. This is relevant when a parameter is changed (e.g., ROI, wavelength).
New project	Creates a new, empty project when the mouse cursor is hovered above the empty space below a project tree.
New series	Creates a new, empty series in a project that has been selected in the ***Projects*** tab.
New caustic	Creates a new, empty caustic in a series that has been selected in the ***Projects*** tab. This presupposes that the series already contains at least one caustic.
Merge projects	Merges all open projects into one single project (see Chapter “Set options” on page 8).
Sort	Sorts the sub-elements of a selected element according to a named criterion.
Reverse sorting	Reverses the order in which the sub-elements of the selected element have been sorted.
Rename	Alters the name field of the element to write mode. Proceed as follows: 1. Call up menu item in the context menu of the element in question. 👁 In write mode, the element name appears in a frame and against a blue background. 2. Write over the former name. 3. Confirm by pressing the Enter key.

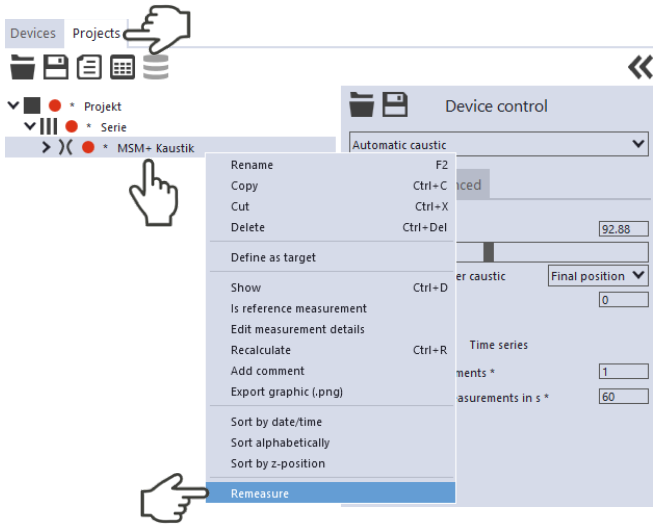
Tab. 5.6: Menu items in the project tree context menu

Remeasuring a caustic or a plane

When remeasuring a caustic, the existing measurement data are not overwritten. Instead, an additional caustic measurement is added to the project tree. When remeasuring a plane, LDS asks whether the plane selected in the project tree should be overwritten.

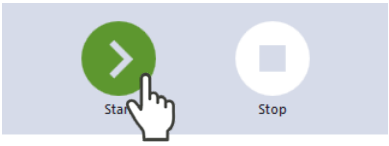
Proceed as follows (e.g., caustic measurement):

1. Click on the ***Projects*** tab.
2. In the project tree, click on the caustic measurement that is to be remeasured.
3. Select the context menu and the menu item ***Remeasure***.

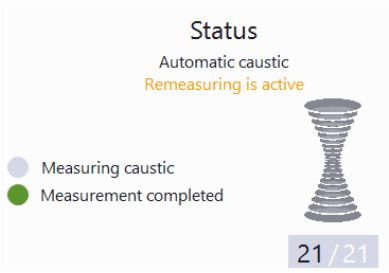


The settings of the selected measurement are applied and displayed in the ***Device control*** menu.

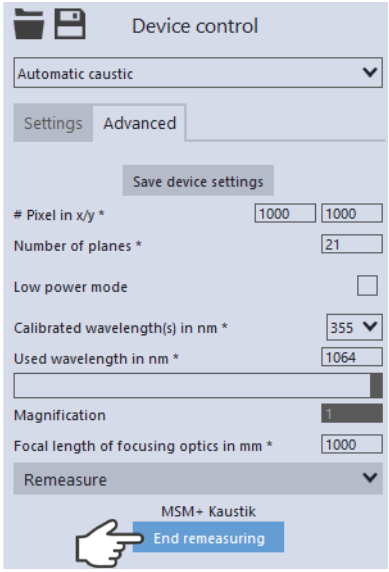
4. Start the measurement as described in the device operating manual.



The progress of the remeasurement is shown in the status display.



5. After measurement has been completed,click on the ***End remeasuring*** button in the ***Advanced*** tab.



5.4.7 Key combinations in the project tree

Key combination	Function
F1	Opens the LDS operating manual in a new window. The manual opens at the relevant chapter.
F2	Alters the name field of the selected element to write mode. The element can now be renamed: 1. Write over the former name. 2. Confirm by pressing the Enter key.
Delete	Deletes a selected element from a project tree The asterisk icon * appears next to the name of the higher-level element. ▶ If required, save the higher-level project by clicking on it and selecting ***File*** > ***Save*** in the menu bar.
Ctrl + O	Opens a Windows Explorer window for the purpose of opening a file with the LDS file extensions: • ***.lpf*** (LDS 1.3.1) • ***.foc*** (LDS 2.98) This file contains an LDS project. The file is loaded into the ***Projects*** tab.
Ctrl + S	Opens a Windows Explorer window for the purpose of saving a file with the LDS file extension ***.lpf***. This file contains the LDS project that has been selected in the ***Projects*** tab.
Ctrl + A	Selects all the elements of a project tree.
Crtl + V	Inserts an element from the clipboard as a sub-element of the selected element. This presupposes that the element to be inserted is compatible with the higher-level element
Crtl + X	Deletes the selected element and moves it to the clipboard.
Crtl + Y	Repeats the previous action (move, delete, rename).
Crtl + Z	Reverses the previous action (move, delete, rename).

Tab. 5.7: Key combinations in the project tree

5.5 The menu bar

The menu bar is at the top of the user interface. The menu items provide a wide range of control functions and settings.
In order to select a menu item, proceed as follows:

1. Click on the menu name in order to display the corresponding menu items. The name of the selected menu then appears in inverted form.
2. If required, move the mouse cursor over the other menus in order to view their menu items.
3. Click on a menu item in order to select it. The name of the selected menu then appears in inverted form.

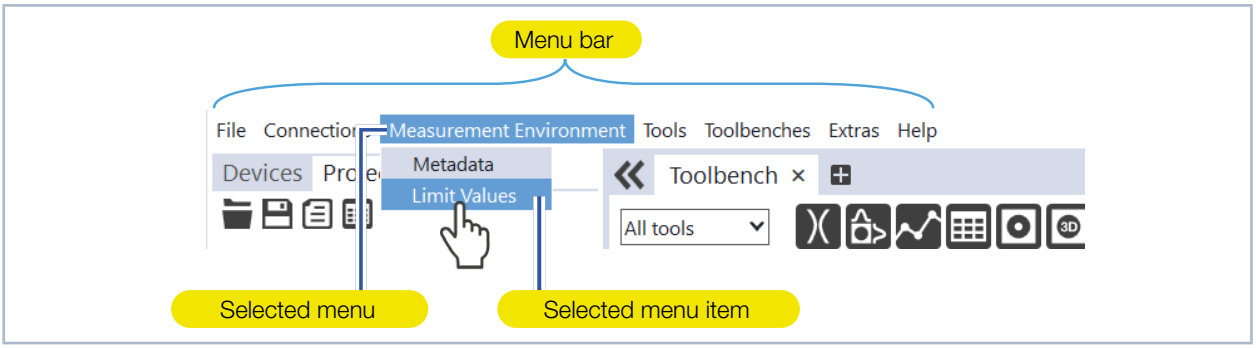


Fig. 5.6: Menu bar, menus and menu items

Menu items in the *File* menu	
Open	Opens a Windows Explorer window for the purpose of opening a file with the LDS file extensions: • ***.lpf*** (LDS 1.3.1) • ***.foc*** (LDS 2.98) This file contains an LDS project. The file is loaded into the ***Projects*** tab.
Selectively open	Opens a Windows Explorer window for the purpose of opening a project file with the LDS extension ***.lpf*** (LDS 1.3.1). When a partial project is selected in a preview dialog window, this partial project is then opened in the project tree. This function makes it easier to handle very large projects.
Save	Saves changes to a project that is selected from the ***Projects***tab and which has already been saved. If the selected project has never been saved, see menu item ***Save as***.
Save as	Opens a Windows Explorer window for the purpose of saving a file with the LDS file extension ***.lpf***. This file contains the LDS project that has been selected in the ***Projects*** tab.
PDF export	Opens a Windows Explorer window for the purpose of saving a file with the file extensions: • ***.pdf*** • ***.png*** This file contains a report for the measurement that has been selected in the ***Projects*** tab. Before saving a measurement report, select the required document template (report template) from a drop-down list. Different templates are available depending on the type of measurement.
CSV export	Opens a Windows Explorer window for the purpose of saving a file with the file extension ***.csv***. This file contains the numerical data of the measurement that has been selected in the ***Projects*** tab.
Files most recently loaded	Opens a list of the files most recently loaded (max. 10 files).

Tab. 5.8: Overview of the menu items in the menu bar

Imported settings	Opens a Windows Explorer window for the purpose of opening a file with the LDS extension ***.lof***. This file contains settings that are imported into the ***Extras*** > ***Options*** menu.
Exported settings	Opens a Windows Explorer window for the purpose of saving a file with the LDS file extension ***.lof***. The settings from the ***Extras*** > ***Options*** menu are saved in this file.
Quit	Quits the program.
Menu items in the *Connections* menu	
Connect	Opens the ***Connections*** window with all located devices.
Disconnect	Disconnects the device selected in the ***Devices*** tab.
Menu items in the *Measurement environment* menu	
Metadata	Opens a toolbench of the same name for viewing metadata in tabular form. ▶ Click on the project tree item in question and drag it into the toolbench window while pressing down the left mouse button. 👁 Metadata cannot be displayed for all project tree items. In this case, a prohibited sign appears in the position of the mouse cursor.
Limit values	Opens a toolbench of the same name for configuring global limit and warning values. Further information can be found in Chapter 8.2.1 “Limit and warning values” on page 140.
Menu items in the *Tools* menu	
Contains a listing of all tools in alphabetical order. Clicking on a tool name opens the corresponding tool in a toolbench of the same name. Information on all tools can be found in Chapter 6 “Show and evaluate measurements” on page 37.	
New toolbench	Creates a new, empty toolbench in a toolbench group.
Toolbenches >	This menu item only appears when toolbenches have already been saved. Opens a list of saved toolbenches. Clicking on an item in this list opens the corresponding toolbench.
Toolbenches as windows	Creates free-floating toolbench groups from the toolbenches in the main window.
Toolbenches as tabs	Arranges the free-floating toolbench groups as tabs in the main window.
Manage toolbenches	Opens the ***Manage toolbenches*** menu (see Chapter 5.6.3 on page 33).
Menu items in the *Extras* menu	
Options	Here, global settings can be made in the ***Software***, ***Device***, ***Plug-ins*** and ***Measurement*** tabs. Further information can be found in Chapter “Global settings in the Extras > Options menu” on page 28.
Menu items in the *Help* menu	
Instruction manuals	Opens a selection of operating manuals, including the current manual and PRIMES measuring device operating manuals. Clicking on a title opens the corresponding manual.
Beam information	Opens a window with information on the coordinate systems in use, the beam parameters and the evaluation algorithms. Further information can be found in Chapter 7 “Fundamentals of beam geometry analysis with LDS” on page 132.
List of key formulas	Opens a PDF that explains the key formulas for beam measurement.
About	Opens a window containing licenses and information on the version number and copyright of LDS.

Tab. 5.8: Overview of the menu items in the menu bar

Global settings in the Extras > Options menu

In the ***Extras*** > ***Options*** menu, global settings can be made in several tabs.

The ***Tools*** tab lists various tools. If the check box of a tool is disabled, then the tool does not appear in the ***All tools*** toolbar. The toolbar is displayed in the main window of the user interface (see Chapter 5.6 on page 30).

The ***Plug-ins*** tab lists installed plug-ins

Option (*Software* tab)	Function
Basic settings	
Show start screen	The start screen appears each time the software is restarted.
Show tutorial	Activates the tutorial. The tutorial provides brief instructions, on a blue background, about the basic operating steps.
Automatic search for update	Activates automatic notification of software updates.
Color contrast	Color contrast can be adjusted via a slider or numerically (-1 to 2).
Anti-aliasing	Prevents distortion artifacts in 3D images.
Standard algorithm	The algorithm for radius calculation can be preselected in a drop-down list. If a tool with a drop-down list for algorithm selection is opened, then the standard algorithm is set as default in the list (e.g., in the ***Caustic analysis*** tool; see Chapter 6.3.6 on page 97).
Display parameters for selected caustic algorithm only	Deactivates the drop-down list for algorithm selection in the relevant tools. These tools will then use the standard algorithm for radius calculation.
Standard false-color palette	The false-color palette can be preselected in a drop-down list. If a tool with a drop-down list for the selection of the false-color palette is opened, then the standard palette is set as default in the list (e.g., in the ***False-color view*** tool; see Chapter 6.3.1 on page 69).
Adaptive tool selection	The selection in the ***All tools*** toolbar is automatically adjusted. Only those tools that match the connected measuring devices and the loaded data types are displayed.
Open measurement toolbench	Opening a measuring mode automatically opens a customized toolbench. The toolbench is displayed in the main window of the user interface and contains the most important tools for display and evaluation of measurement results.
Display script console	Opens the script console. Outputs from the script can be displayed here.
Automatic update rate in ms	The interval for the automatic update of windows can be entered numerically.
Compression for project files	Choose in a drop-down list between different levels of compression for saving project files.
Use SI units	Values are displayed in SI units.
Temperatures in Fahrenheit	Temperature values are displayed in Fahrenheit.
Evaluation settings	
ROI fill factor	The ROI fill factor can be entered numerically. A value of 0.5 is set as default. After each new start of LDS, the ROI value is reset to 0.5. Further information on the ROI fill factor is available in the chapter“Fill factors” on page 136.
Use ROI	The value entered for the ROI fill factor is applied when calculating the measurement data.

Tab. 5.9: Global settings in the ***Extras > Options > menu, Software tab***

Option (*Software* tab)	Function
Export settings for plane data	
Automatic CSV export	Each time a project is saved, a file of the same name with the extension ***.csv*** is also automatically saved to the selected location. This file contains the numerical measurement data of all the planes contained in the project.
Localized decimal separator for CSV export	The decimal separator for CSV export is selected in line with the country setting for the operating system.
Separator for CSV export	The separator for CSV export can be selected in a drop-down list.
Export raw data as power density values	Raw data from the analog-to-digital converter (in cts = counts) are converted to power density (kW/cm²) during export. This presupposes that a power value was entered or measured during the measurement.
Add color legend to image export	During image export, a color legend is added with the corresponding color counts.
Communication	
Display connected devices only	This ensures that the ***Connections*** window displays only those Bluetooth devices that are actually connected. If not, devices that are not currently connected but were connected at an earlier time are also displayed.
Log device communication	Device communication is logged in the file ***lds_log***. This file is saved in the directory ***C:\Temp***.
Record device status values	The device status (e.g., axis travel) is logged in the file ***lds_log***. This file is saved in the directory ***C:\Temp***.
Additional settings for remote connections	
Directory for setting files	Directory path for the settings files that are used for data transfer according to the OPC UA automation standard.
Empty the project tree when disconnecting a device	The project tree is emptied when the device is disconnected via an automatic command.
OPC server address	OPC address with which a connection is to be established.
Device IP address	Device IP address to establish connection.
Device initialization time in s	Time until device is ready for operation. The device can be operated only once this time has elapsed.

Tab. 5.9: Global settings in the ***Extras > Options > menu, Software tab***

Option (*Measurement* tab)	Function
Remeasure: Adjust measurement settings	When remeasuring a plane, the device control settings are reset (e.g., beam search, exposure, size of measurement window). Otherwise, the settings from the selected measurement are applied. Further information can be found in Chapter “Remeasuring a caustic or a plane” on page 24.
Only with installed plug-in algorithms for radius calculation	
Calculate 1st/2nd power inclusion	The 1st/2nd power inclusion is calculated according to the percentage values in the fields below.
1st power inclusion in %	The percentage value for the calculation of the 1st power inclusion can be entered numerically.
2nd power inclusion in %	The percentage value for the calculation of the 2nd power inclusion can be entered numerically.

Tab. 5.10: Global settings in the ***Extras > Options > menu, Measurement tab***

5.6 Main window

Measurement data can be displayed and analyzed in the main window of the user interface. A variety of tools are available for this purpose, all of which can be displayed in separate windows.
For additional clarity and flexibility, these tool windows can be displayed in any number of toolbenches.

5.6.1 Structure of main window

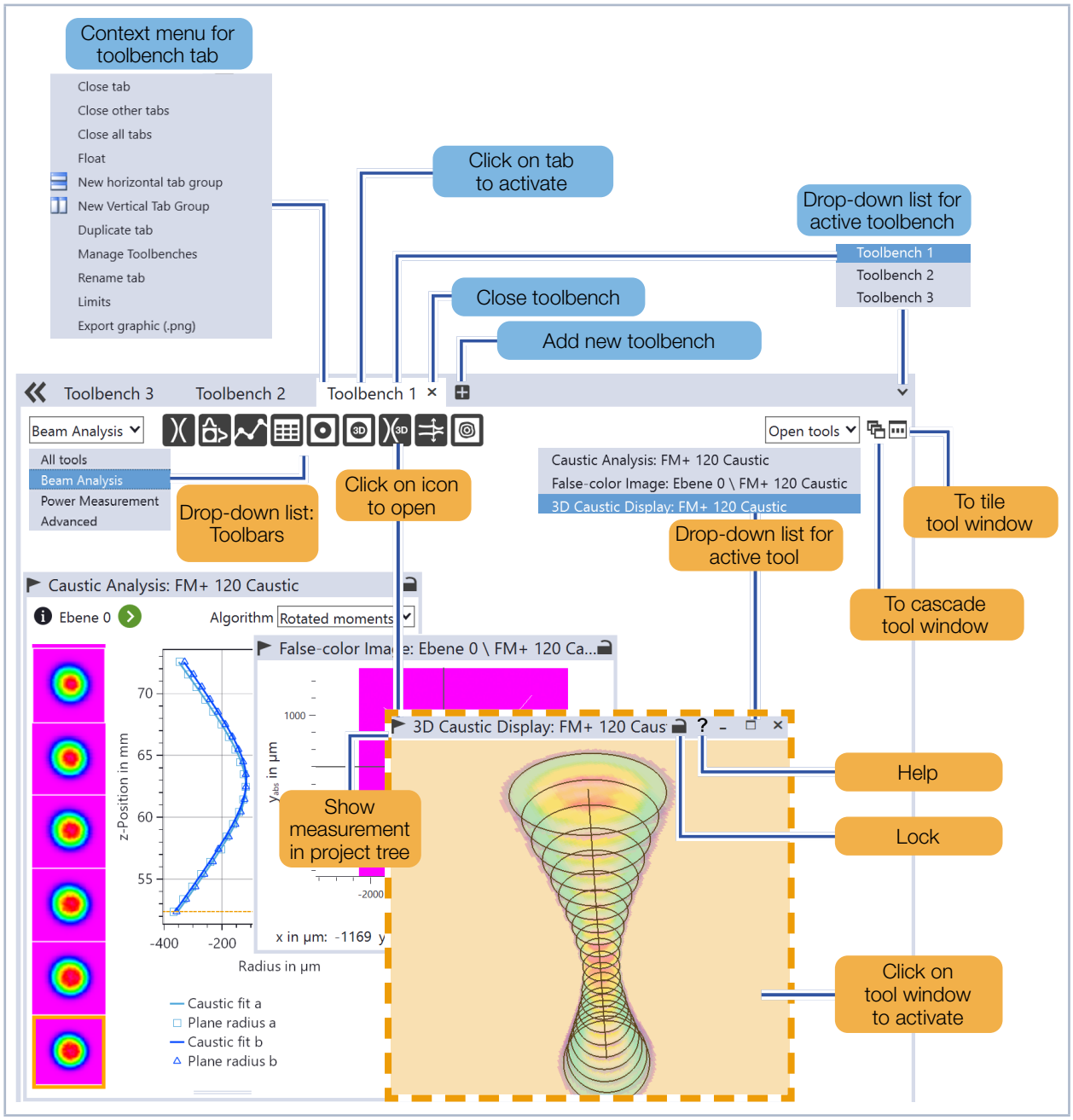


Fig. 5.7: Structure of main window

Operating elements	Explanation
Toolbench-related	When the program is first started, a toolbench appears in the main window. Any number of toolbenches can be added and individually named. The toolbenches are arranged as tabs in the main window. The active toolbench comes to the foreground. In the main window, the following control options are available: **Add a new toolbench:** ▶ Click on the plus symbol next to the toolbench tabs. **Close a toolbench:** ▶ Click on the cross symbol in the toolbench tab. **To activate a toolbench:** The following options are available: ▶ Click on the toolbench tab. ▶ Select the toolbench from a drop-down list of open toolbenches. ▶ Hold down the Ctrl key and press the Tab key repeatedly. 👁 The active toolbench comes to the foreground. **Open the context menu of a toolbench:** ▶ Right-click on the toolbench tab. Further information can be found in Chapter 5.6.2 “Context menu in the toolbench tab” on page 32. Note also the options in the ***Toolbenches*** menu (see Chapter 5.5 “The menu bar” on page 26).
Tool-related	In a toolbench, the following control options are available: **Select a toolbar:** ▶ Select a group from the drop-down list. Tools are thematically grouped in toolbars. **Opening a tool:** ▶ Click on the corresponding icon in the toolbar. **For cascaded/tiled arrangement of tool windows:** ▶ Click on the corresponding frame icon. **To activate a toolbench:** The following options are available: ▶ Click on the tool window. ▶ Select the tool window from a drop-down list of open tools. 👁 The active tool comes to the foreground. **To lock/unlock the contents of a tool window:** ▶ Click on the lock icon. **Calling up help for a tool:** The following options are available: ▶ Click on the question mark. ▶ Hover the mouse cursor over the tool window (but not over the header) and press the F1 key. 👁 The LDS operating manual then appears in a new window. The manual is open at the chapter for the tool in question. **Marking the measurement data displayed in a tool in the project tree:** ▶ Click on the flag icon. With this function, the measurement data displayed can be clearly identified in the project tree. This improves readability when a lot of tool windows are open in one toolbench simultaneously. Note also the alphabetic listing of tools in the ***Tools*** menu (see Chapter 5.5 “The menu bar” on page 26).

Tab. 5.11: Control functions in main window

5.6.2 Context menu in the toolbench tab

Option	Explanation
Close tab	Closes the corresponding toolbench.
Close other tabs	Closes all open toolbenches except from the one in use.
Close all tabs	Closes all open toolbenches. A new, empty toolbench is created in the main window.
Window	Detaches the toolbench from the tab and places it in a movable window.
New horizontal tab group	Creates a new horizontal toolbench group
New vertical tab group	Creates a new vertical toolbench group
Duplicate tabs	Creates an identical toolbench of the same name within a toolbench group. The number, arrangement and size of the tool windows are also replicated.
Manage toolbenches	Opens the ***Manage toolbenches*** menu (see Chapter 5.6.3 on page 33).
Change tab name	Calls up a window in which the name of the relevant toolbench can be changed.
Limit values	Opens a toolbench of the same name for configuring global limit and warning values. Further information can be found in Chapter 8.2.1 “Limit and warning values” on page 140.
Export graphic (.png)	Opens a Windows Explorer window for the purpose of saving a file with the file extension ***.png***. This file contains an image of the toolbench in question.
Copy graphic	Copies an image of the toolbench in question to the clipboard.

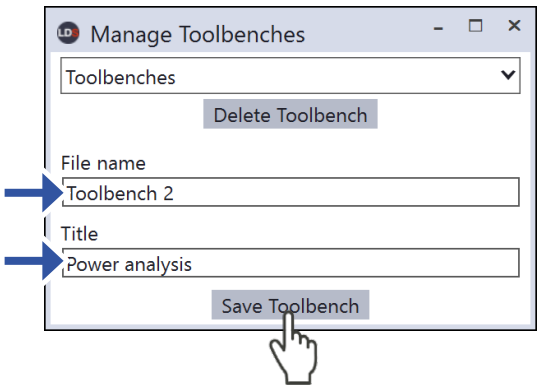
Tab. 5.12: Context menu options in the toolbench tab

5.6.3 Managing and loading toolbenches

A custom toolbench configuration can be saved as a file with the extension ***.xml*** at ***C:\ProgramData\Primes\LDS\customcontrols*** and loaded from there. This makes it easier to efficiently process recurring analysis tasks.

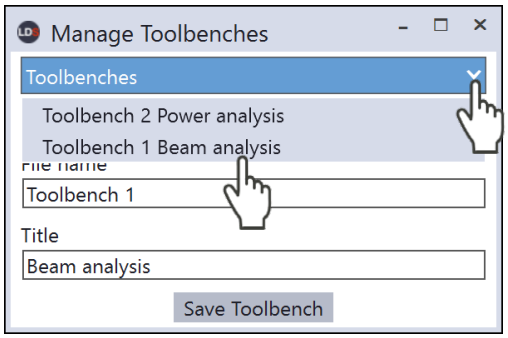
Saving a toolbench

1. Click on the workbench tab to activate the workbench to be saved.
2. Open the menu ***Manage toolbenches*** via the context menu of the toolbench tab or via the main menu ***Toolbenches > Manage toolbenches***.
3. Enter a file name and a title.
4. Click on the button ***Save toolbench***.



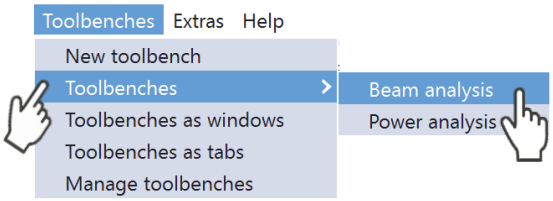
Delete a toolbench

1. Open the menu ***Manage toolbenches*** via the context menu of the toolbench tab or via the main menu ***Toolbenches > Manage toolbenches***.
2. Open the drop-down list.
3. Click on the toolbench to be deleted.
4. Click on the button ***Delete toolbench***.



Loading a toolbench

1. In the main menu, select ***Toolbenches > Toolbenches***.
2. Click on the name of the toolbench to be loaded.



5.6.4 Arranging the main window

By default, the main window contains only one toolbench group. For additional clarity and flexibility, tools can be divided into any number of toolbench groups. These can be placed either in a movable window or arranged as tiles.

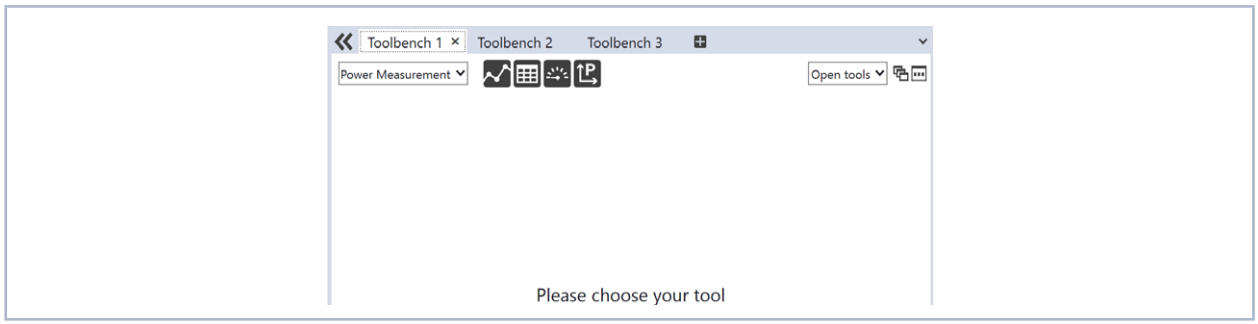


Fig. 5.8: Main window with a toolbench group

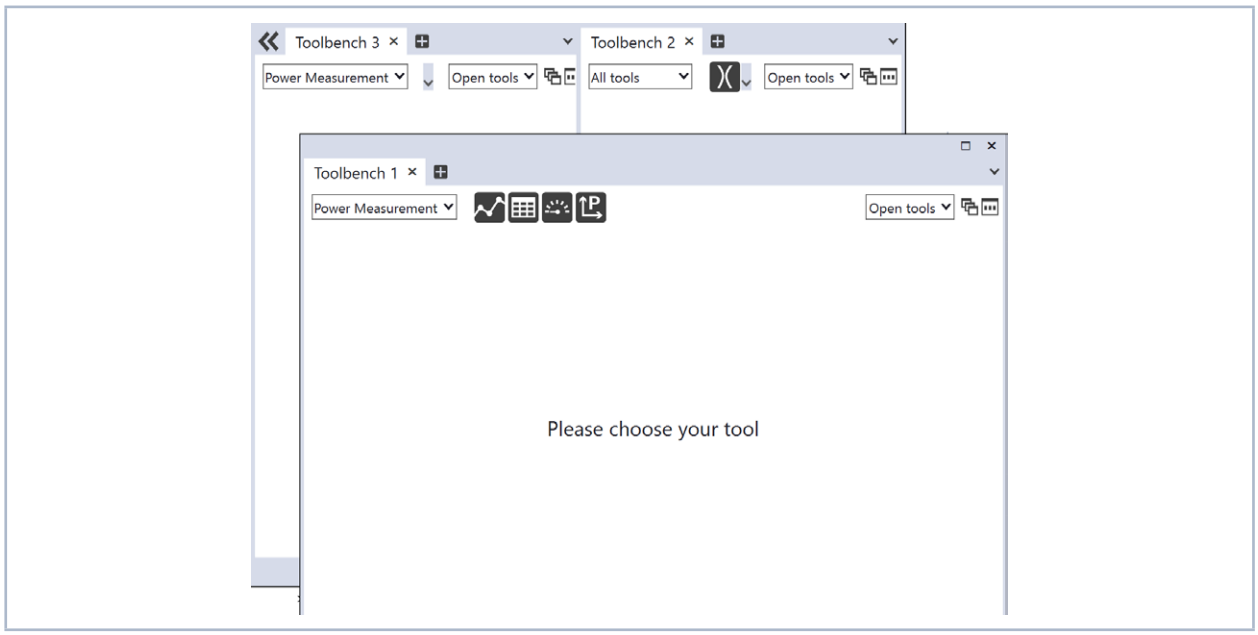


Fig. 5.9: Main window with a movable toolbench group

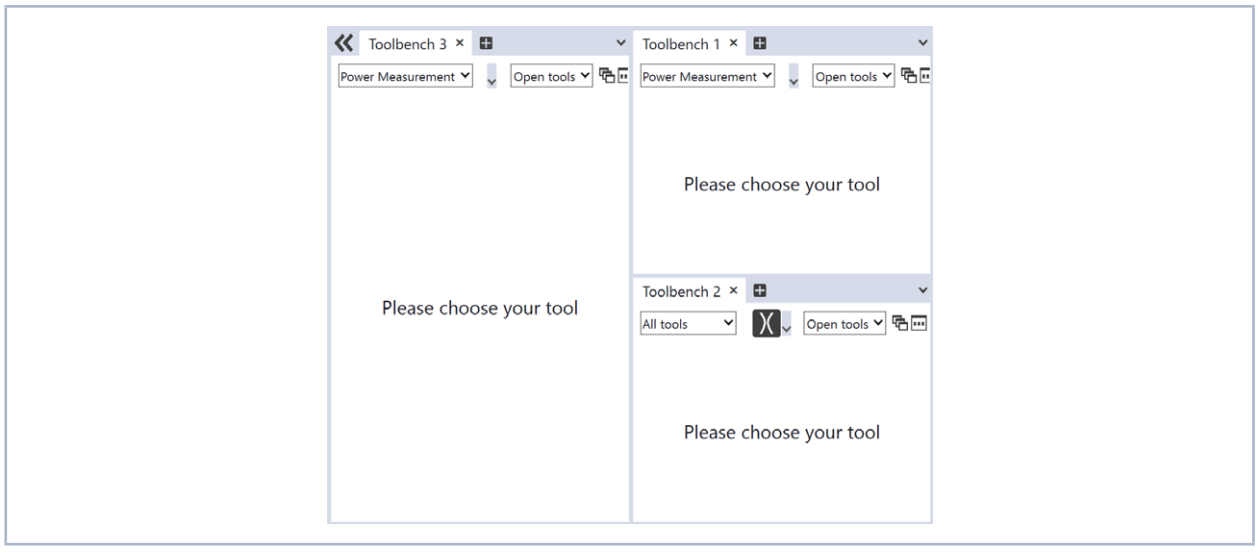
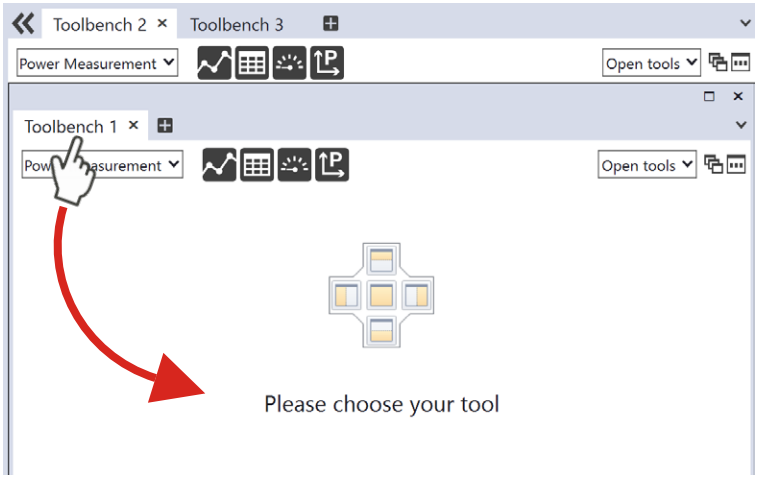


Fig. 5.10: Main window with tiled toolbench groups

Create a movable toolbench group

1. Click on a toolbench tab.
2. Hold down the left mouse button and drag the tab until a movable window appears and, in some cases, a positional cross.
3. Position the mouse cursor anywhere on the screen – but not over the positional cross.
4. Release the left mouse button when the window is positioned the way it is wanted.

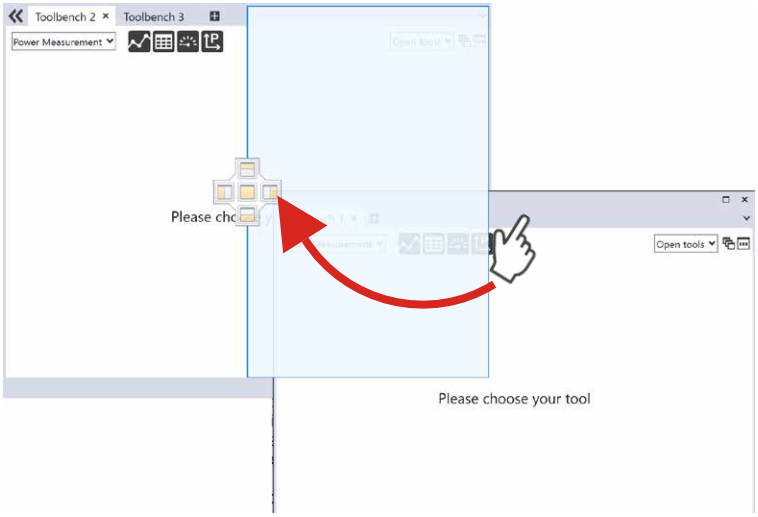


Create tiled toolbench groups

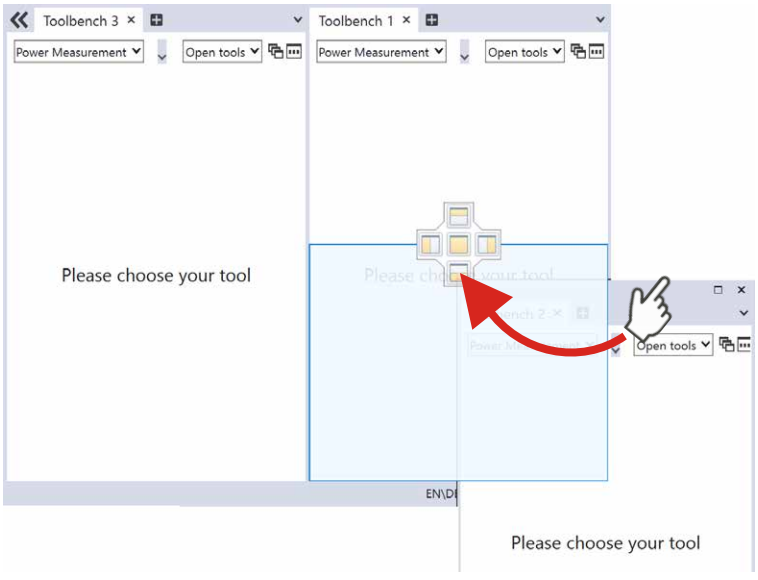
1. Create a movable toolbench group as described above.
2. Click on the header of the movable toolbench group.
3. Hold down the left mouse button and drag the cursor over the toolbench group until a positional cross appears.
4. Press and hold the left mouse button and position the mouse cursor above the positional cross – but not over its midpoint.

The toolbench group divides in two. The size and position of the newly created group is shown as a white area with a blue frame.

5. Release the left mouse button when the tile is positioned the way it is wanted.



6. To create more toolbench groups, repeat this process.

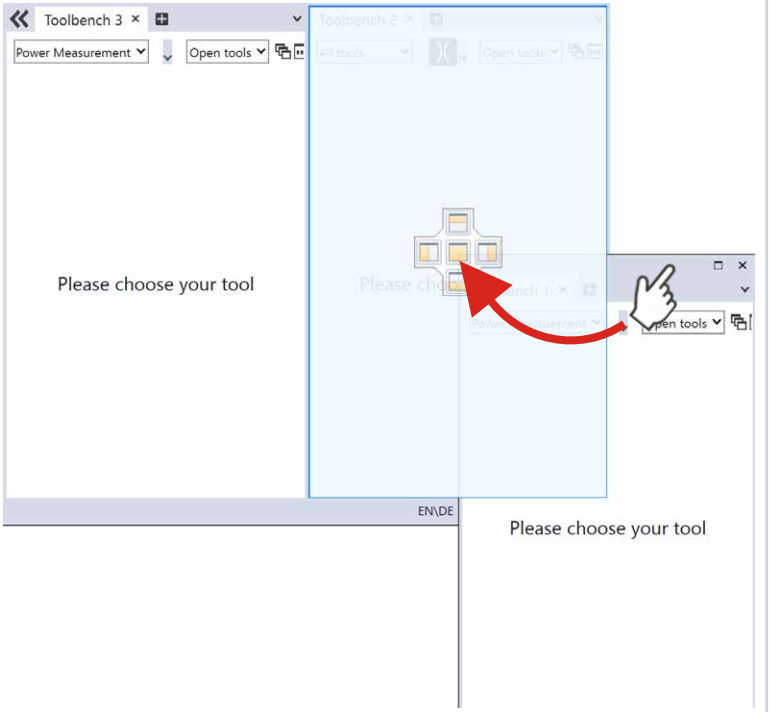


To add a toolbench to the tab of a toolbench group

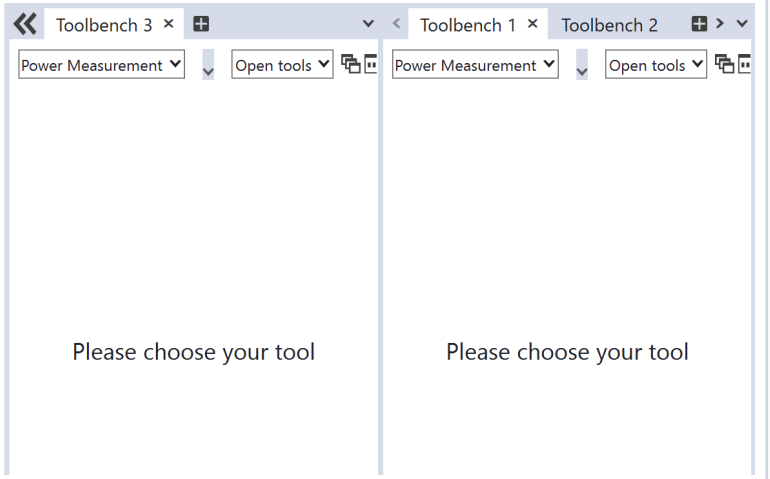
1. Create a movable toolbench group as described above.
2. Click on the header of the movable toolbench group.
3. Hold down the left mouse button and drag the cursor over the toolbench group until a positional cross appears.
4. Press and hold the left mouse button and position the mouse cursor over the midpoint of the positional cross

👁 The toolbench group is shown as a white area with a blue frame.

5. When the desired position has been achieved, release the left mouse button.
6. To add more toolbenches to toolbench groups, repeat this process.



👁 The toolbench in question has been added to the toolbench group tab.



6 Show and evaluate measurements

6.1 General information on the tools of LDS

6.1.1 Overview of tools

A variety of tools are available in LDS for showing and evaluating measurements. Tab. 6.1 on page 37 provides an overview of the tools available.

The background colors mean the following:

Green	Tools to show beam geometry data and power data
Red	Tools to show beam geometry data
Blue	Tools to show power data
Yellow	Other tools

Tool	Function
Results table	Table showing measurement results Special features: • Simultaneous display of several measurements in one tool window • Selection of any parameter; display in rows or columns • Display of limit value violations by means of colored markers Detailed information can be found in Chapter 6.2.1 on page 44.
Graph	Display of measurement results as graphs in a coordinate system Special features • Simultaneous display of several measurements in one tool window • Any combination of several measurement parameters for the y-axes • Selection of an x-parameter (including index, measurement duration and timestamp) • Axes divisible with respect to measurement parameters and measurement • Axes independently movable and scalable Detailed information can be found in Chapter 6.2.2 on page 46.
Measurement value display	Display of measurement parameters as single values in numerical form or on arc, linear or thermometer scale Special features: • Particularly suited for displaying a running measurement • Display of limit value violations by means of colored markers Detailed information can be found in Chapter 6.2.3 on page 50.
Histogram	Graphical display of categorized data Special features: • Simultaneous display of several measurements in one tool window • X-axis: equal category width (per measurement) • Y-axis: shows frequencies Detailed information can be found in Chapter 6.2.4 on page 53.

Tab. 6.1: Overview of tools and their functions

Tool	Function
Graphic data analysis	Display of measurement results as graphs in a coordinate system Special features: • Simultaneous display of several measurements in one tool window • View dependencies between any measurement parameters by selecting several y-parameters and one x-parameter • Axes divisible with respect to measurement • Axes independently movable and scalable • Display of limit value and warning values in the coordinates window Detailed information can be found in Chapter 6.2.5 on page 56.
Evaluation traffic light	Review of freely selectable parameters compared to limit and warning values, with result shown by a traffic light system. Special features: • Traffic light or tabular view • Particularly suited for displaying a running measurement Detailed information can be found in Chapter 6.2.6 on page 62.
Series analysis	Evaluation of large data volumes (several series or caustics) Special features: • Graphical and tabular display • Any combination of several measurement parameters for the y-axes • Selection of an x-parameter (including index duration and timestamp) • Axes independently movable and scalable Detailed information can be found in Chapter 6.2.7 on page 64.
False-color view	Gradated false-color view of power density distribution Detailed information can be found in Chapter 6.3.1 on page 69.
Plane analysis	Graphical and tabular display of a plane Special features: • Gradated false-color view of power density distribution with movable x-cross sections / y-cross sections • Tabular display of all measurement results • Review of the validity of a measurement, visually supported by colored markers Detailed information can be found in Chapter 6.3.2 on page 74.
3D plane display	Three-dimensional display of power density distribution, rotatable through all spatial axes Detailed information can be found in Chapter 6.3.3 on page 83.
Power inclusion	Calculation of the radius of a measuring plane at any given power inclusion (and vice versa) Special features: • Graphical and numerical display of results • Simultaneous display of several measurements in one tool window Detailed information can be found in Chapter 6.3.4 on page 86.

Tab. 6.1: Overview of tools and their functions

Tool	Function
Beam symmetry analysis	Graphical and tabular display of the different power inclusion levels of one plane Special features: • Graphical display, linear or polar • Adjustment of circle contours/histograms for better evaluation of beam symmetry Detailed information can be found in Chapter 6.3.5 on page 91.
Caustic analysis	Graphical and tabular display of a caustic Special features: • Graphical display of the measured planes as caustic cross sections (false-color views) and caustic longitudinal section • Tabular display of all measurement results • Review of the validity of a measurement, visually supported by colored markers • Comparison of the measured values with a reference caustic • Linking to open tools for the purpose of plane display: automatic application of the selected plane in the display of these tools Detailed information can be found in Chapter 6.3.6 on page 97.
3D caustic display	Colored, three-dimensional display of a caustic Special features: • View can be rotated through all spatial axes • Caustic planes in false colors Detailed information can be found in Chapter 6.3.7 on page 107.
Process volume	Display of z-section of a caustic at given minimum intensity (process volumes) Special features: • Tabular display • Comprehensive graphical display (graph, beam symmetry, 3D view) Detailed information can be found in Chapter 6.3.8 on page 110.
Focus shift	Graphical and numerical evaluation of a series of caustics in respect of a focus shift Detailed information can be found in Chapter 6.3.9 on page 114.
Raw beam analysis	Graphical and tabular display of the results of raw beam back calculation (only with ***LaserQualityMonitor LQM+***) Detailed information can be found in Chapter 6.3.10 on page 118.
Beam pointing stability	Display of monitor beam pointing stability (only with camera-based measuring devices) Detailed information can be found in Chapter 6.3.11 on page 122.
Preventive maintenance	Predictive calculation of when limit values will be reached (based on a trend analysis of previous measurement results) Special features: • Any parameters can be selected • Suitable for large data volumes (series) Detailed information can be found in Chapter 6.3.12 on page 126.

Tab. 6.1: Overview of tools and their functions

Tool	Function
SFM analysis	Display of measurements with ***ScanFieldMonitor SFM*** Further information can be found in the device operating manual.
SFM caustic	
SFM delay time	
SFM stitching	
Power measurement	Display of the measurement data of a project tree element ***Power measurement*** Special features: • Graphical and numerical display • Also suited for displaying a running measurement Detailed information can be found in Chapter 6.4 on page 129.
Script editor	This tool has an input field for program code in the scripting language ***Python***. This scripting language controls the device. Alternatively, program code can be loaded into the tool from a file with a ***.py*** extension. An explanation of the script commands for device control is available on request. The script is executed via a Start/Stop button. A script console can be opened via the menu ***Extras > Options > Software***. Outputs from the script are displayed here.

Tab. 6.1: Overview of tools and their functions

Tab. 6.2 on page 41 shows which project tree elements can be displayed in a specific tool. If a project tree element is dragged into an incompatible tool, a prohibited sign appears at the position of the mouse cursor.

		Series	Caustic	Plane	Linescan	Cube measurement	Cube series	Power measurement	Vector	SFM vector series	SFM delay time
Beam geometry and performance data	Results table	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Graph	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Measurement value display	⊘	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Histogram	✓	✓	✓	⊘	✓	✓	✓	⊘	✓	✓
	Graphic data analysis	✓	✓	⊘	⊘	✓	✓	✓	⊘	✓	✓
	Evaluation traffic light	⊘	✓	✓	⊘	✓	⊘	✓	⊘	✓	✓
	Series analysis	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘	✓	✓
Beam geometry data only	Plane analysis	⊘	✓	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘
	False-color view	⊘	✓	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘
	3D plane display	⊘	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
	Power inclusion	⊘	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
	Beam symmetry analysis	⊘	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
	Caustic analysis	⊘	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
	3D caustic display	⊘	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
	Process volume	⊘	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
	Focus shift	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘	✓	✓
	Raw beam analysis	⊘	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
	Beam pointing stability	⊘	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
	Preventive maintenance	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
	SFM analysis	⊘	⊘	⊘	⊘	⊘	⊘	⊘	✓	✓	✓
	SFM caustic	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘	✓	⊘
	SFM delay time	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	✓	✓
	SFM stitching	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘	✓	⊘
	Power measurement	⊘	⊘	⊘	⊘	⊘	⊘	✓	⊘	⊘	⊘

Tab. 6.2: Compatibility between project tree elements and tools

6.1.2 Opening project tree measurements in tools

The measurements listed in the project tree can be opened in tools in different ways. Some of the options shown may be limited to certain project tree elements / tools.

Opening a measurement without a suitable tool being already open

1. Activate the toolbench in which the measurement is to be opened.
2. Use one of the following options to open a measurement:

▶ Click on the measurement in the project tree. Then select ***Show*** in the context menu of this measurement.

▶ Double-click on the measurement in the project tree.

👁 A suitable tool is opened in the active toolbench. The measurement is displayed in this tool.

Drag a measurement into an open tool.

1. Activate the toolbench in which the measurement is to be opened.
2. Open a suitable tool via the toolbar.

👁 If a compatible measurement was clicked in the project tree before opening the tool, this will be shown in the tool.

3. In the project tree, click on the measurement that is to be opened.
4. Press and hold the left mouse button and drag the measurement into the tool.

👁 The measurement is now shown in the tool.

Opening different measurements in a single tool window in order to compare them

In some tools, multiple measurements can be displayed simultaneously.

1. Activate the toolbench in which the measurements are to be opened.
2. Click on one of the measurements. Press and hold the Crtl key and select further measurements. Alternatively, press and hold the Shift key and select successive measurements.
3. Open a suitable tool via the toolbar.

👁 The measurements are now shown together in the tool.

Further measurements can be dragged into the open tool:

4. Select one or more measurements in the project tree as described above.
5. Then press and hold down the left mouse button, drag the measurement(s) into the tool.

👁 A plus symbol appears in the tool.

6. Press and hold the left mouse button and drag measurements into the plus symbol until it grows in size.

Opening different measurements in multiple tool windows in order to compare them

If, in a particular tool, only one measurement can be displayed at any one time, it is still possible to compare measurements.

1. Activate the toolbench in which the measurements are to be opened.
2. Click on one of the measurements. Press and hold the Crtl key and select further measurements. Alternatively, press and hold the Shift key and select successive measurements.
3. Open a suitable tool via the toolbar.

👁 A tool window is opened for each measurement.

4. Arrange the tool windows in such a way that measurements can be easily compared. For this purpose, use the button to tile the tool windows (in the top-right corner of the toolbench).
5. If necessary, use the button (in the top-right corner of the window) to lock the contents of tool windows. This prevents the content from being updated as a result of double-clicking on another measurement in the project tree.

Opening a measurement in multiple tool windows in order to compare.

It is also possible to open a measurement in different windows for comparison purposes. This is useful when evaluating, for example, a caustic based on different algorithms and then comparing the results.

1. Activate the toolbench in which the measurement is to be opened.
2. Open a suitable tool repeatedly via the toolbar.

👁 If a compatible measurement was clicked in the project tree before opening the tool, this will be shown in the tool.

3. In the project tree, click on the measurement that is to be opened.
4. Press and hold the left mouse button and drag the measurement into toolbench tab.

👁 The measurement is now shown in all the open tool windows.

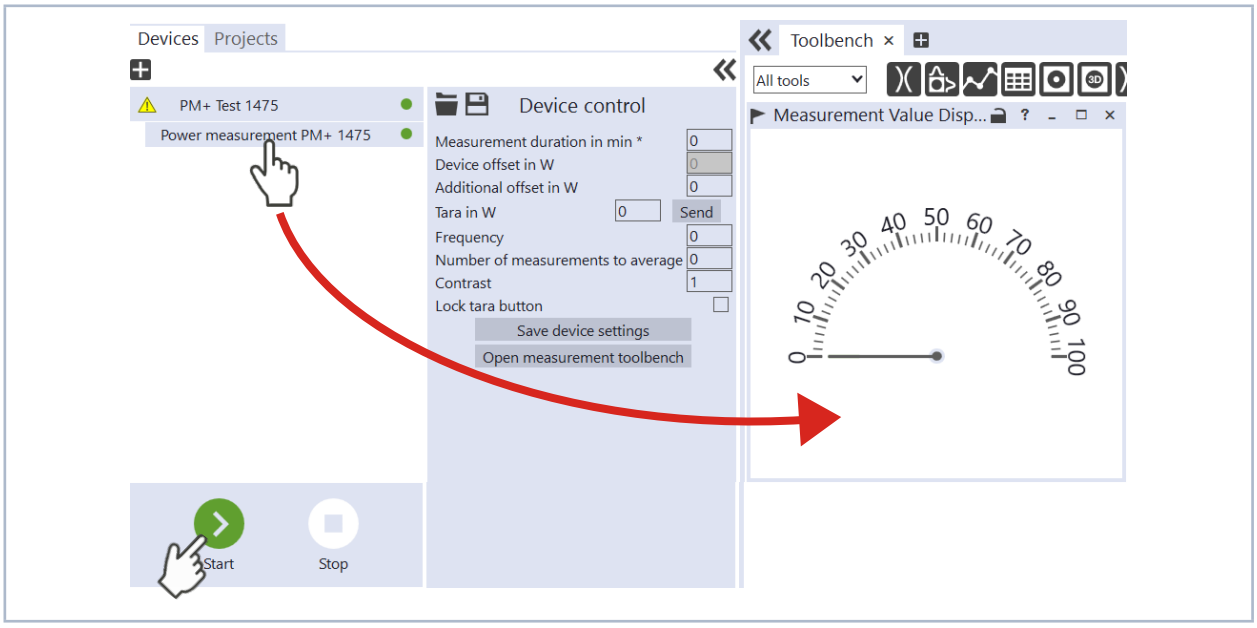
5. Arrange the tool windows in such a way that measurements can be easily compared. For this purpose, use the button to tile the tool windows (in the top-right corner of the toolbench).
6. Customize display mode, calculation method etc. in the individual tool windows as required.
7. If necessary, use the button (in the top-right corner of the window) to lock the contents of tool windows. This prevents the content from being updated as a result of double-clicking on another measurement in the project tree.

6.1.3 Display running measurements in a tool

Running measurements can be displayed in various tools. In this case, the display is continuously updated.

1. Switch on the measuring device and connect it to LDS as described in the device operating manual.
2. Activate the toolbench in which the measurement is to be opened.
3. Open a suitable tool via the toolbar.
4. Select a device function in the tab ***Devices***.
5. Press and hold the left mouse button and drag the function into the tool.
6. Start the measurement as described in the device operating manual.

👁 The measurement is now shown in the tool. The display is continuously updated.



6.2 Tools to show beam geometry data and power data

6.2.1 Results table

This tool displays measurement results in tabular form. It is suitable for displaying all project tree elements.

Multiple project tree elements of the same type can be simultaneously displayed in this tool window (see Chapter “Opening different measurements in a single tool window in order to compare them” on page 42).

Structure of the tool window

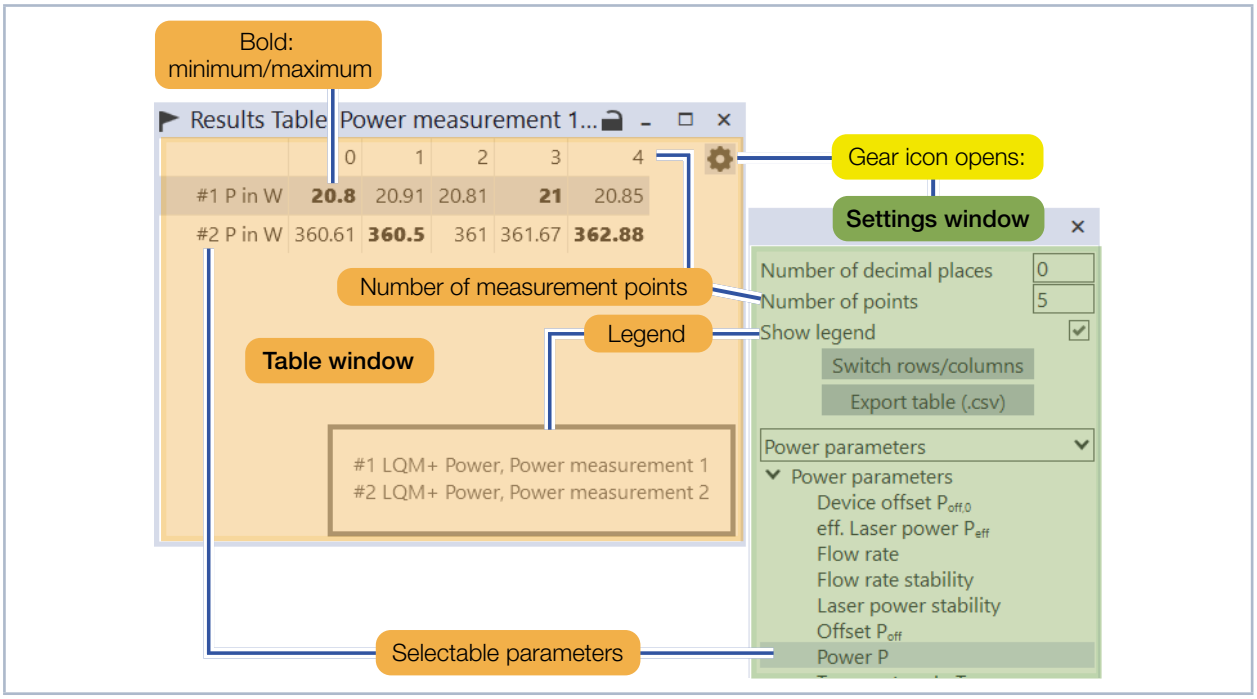


Fig. 6.1: Structure of the ***Results table*** tool

Elements	Description
Table window	The parameters selected in the settings window are displayed here. Rows and columns can be exchanged. Project tree elements of the same type can be displayed simultaneously. When data in the rows/columns are inscribed ***#1***, ***#2*** etc., then a legend can be displayed that assigns them to the corresponding project tree elements. If a displayed value violates a limit value, it is shown with a red background. Further information can be found in Chapter 8.2 “Review of parameters with colored markers” on page 140. Minimum/maximum values in the table on display are written in bold. Whenever the mouse cursor is hovered over the top-right corner of the table window, a gear icon appears. This is used to open the settings window.
Settings window	The settings window contains options for adjusting the table window and exporting data. Further information can be found in Tab. 6.4 on page 45.

Tab. 6.3: Elements of the ***Results table*** tool

Settings window

The table below lists all the options in order of appearance.

Option	Explanation
Number of decimal places	▶ Enter a value in the input field in order to determine the number of decimal places. ➔ Displayed values are rounded up or down.
Number of points	1. Enter a value in the input field in order to determine the maximum number of measurement points displayed. 👁 If, for example, the value 10 is entered, then the last 10 measurement points in the table are displayed. 2. If required, all measurement points can be displayed by entering 0.
Show legend	If data from different project tree elements are simultaneously displayed, a legend can be shown. This assigns the data to the corresponding project tree elements. ▶ Check the box to show the legend.
Exchange rows/columns	▶ Click on this button to exchange rows and columns.
Table export (.csv)	▶ Click on this button to save the table in its current state as a file with the extension ***.csv***.
List of parameters	Parameters can be selected from the category sublists of the parameter list on display. The parameter list on display depends on which project tree element is open. The following options are available: **Open/close a category sublist:** ▶ Click on the arrow right / arrow down. **Selecting all the parameters of a category sublist:** ▶ Click on the category sublist. **Selecting a parameter:** ▶ Click on the required parameter. **Selecting several parameters:** 1. Click on one parameter, 2. press and hold the Crtl key, and click on further parameters. **Selecting several consecutive parameters:** 1. Click on the top/bottom parameter. 2. Then press and hold the Shift key and click on the top/bottom parameter.

Tab. 6.4: Options in the settings window for the ***Results table*** tool

6.2.2 Graph

This tool displays measurement results as a graph in a coordinate system. It is suitable for displaying all project tree elements.
The y-axis is selected via the list of measurement parameters. For the x-axis, different parameters can be selected in a separate list (including index, measurement duration, time stamp). This is the essential difference to the ***Graphic data analysis*** tool, in which the x-axis is likewise selected via the list of measurement parameters (see Chapter 6.2.5 on page 56).

Multiple project tree elements of the same type can be simultaneously displayed in this tool window (see Chapter “Opening different measurements in a single tool window in order to compare them” on page 42).

Structure of the tool window

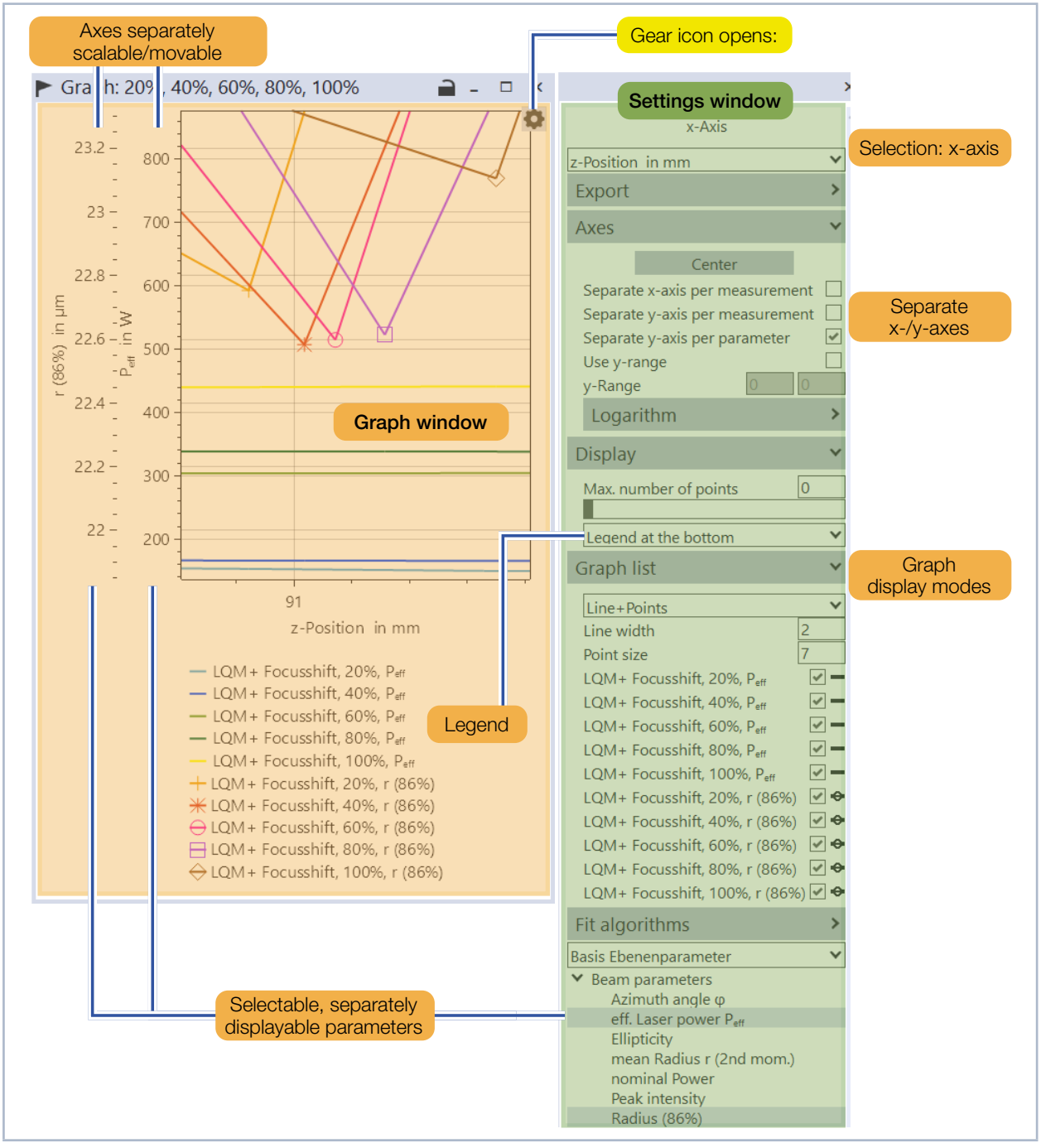


Fig. 6.2: Structure of the ***Graph*** tool

Elements	Description
Graph window	Information on the control options in this window can be found in Tab. 6.6 on page 47. A graph is shown in the coordinates window for each selected parameter / open measurement. The selected measurement parameters are plotted on the y-axis. For the x-axis, different parameters can be selected in a separate list . A legend can be displayed that assigns the displayed graphs to the corresponding project tree elements / parameters. Separate x-axes (per measurement) and y-axes (per measurement/parameter) can be displayed in the graph window. These can be moved and scaled independently of one another. The axes can also be displayed logarithmically. Whenever the mouse cursor is hovered over the top-right corner of the graph window, a gear icon appears. This is used to open the settings window.
Settings window	The settings window contains options for adjusting the graph window and exporting data. Further information can be found in Tab. 6.7 on page 48.

Tab. 6.5: Elements of the ***Graph*** tool

Control options in the graph window

Instead of the right mouse button, the left mouse button can also be used while holding down the Alt key.

Action	Procedure
Zoom to position of mouse cursor	1. Position the mouse cursor anywhere within the coordinates window. 2. Turn the mouse wheel.
Setting a zoom range	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Crtl key and the left mouse button. 3. Draw a square.
Change the scale of an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Turn the mouse wheel.
Shift the display along an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Press and hold the right mouse button and drag along the axis.
Shift the display in any direction	1. Position the mouse cursor anywhere within the coordinates window. 2. Use one of the following options: ▶ Press and hold the right mouse button and drag in the required direction. ▶ Use the arrow keys to incrementally move in the required direction.
Center all graphs in the coordinates window	▶ Double-click on the coordinates window, but not in the immediate vicinity of a graph. 👁 The axes are moved and scaled so that the graphs completely fill the coordinates window in all directions.
Display coordinate values at any position in a graph	▶ Click on the relevant area of the graph. 👁 The corresponding information is displayed.
Opening the settings window	1. Hover the mouse cursor over the coordinates window until the gear icon appears in the top-right corner. 2. Click on the gear icon to open the settings window.
Mark an area along the x-axis	Any number of areas can be marked along the x-axis. In this way, distances can be measured or fit algorithms applied to individual areas. To mark distances, proceed as follows: 1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Shift key and the left mouse button. 3. Mark an area along the x-axis. 4. If required, repeat to mark further areas along the x-axis.
Removing a marked area	1. Press and hold the Shift key. 2. Click on the area to be removed.

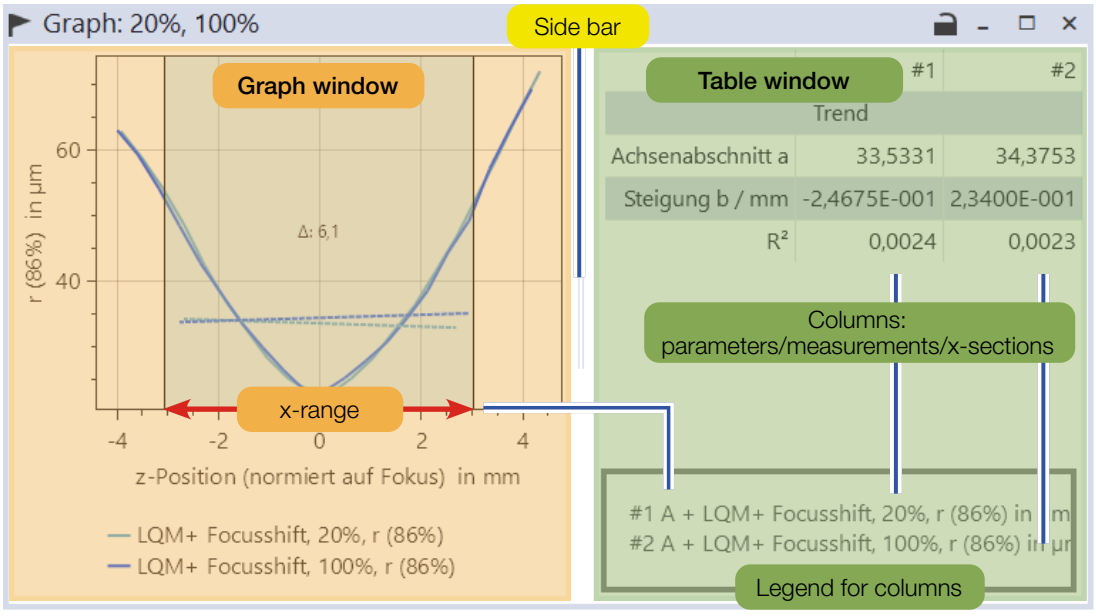
Tab. 6.6: Control options in the graph window

Settings window

The table below lists all the options in order of appearance. Some options / drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
X-axis	▶ Select an x-axis inscription from the drop-down list.
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save the graph data in numerical form as a file with the extension ***.csv***.
Export graphic (.png)	▶ Click on this button to save the graph in its current state as a graphics file with the extension ***.png***.
Copy graphic	▶ Click on this button to copy the graph in its current state to the clipboard.
Axes	Drop-down menu Separate x-axes (per measurement) and y-axes (per measurement/ parameter) can be displayed in the graph window. Multiple parameters, for example, can only be displayed simultaneously on a y-axis if they have the same unit of measurement. If not, the y-axis should be divided. Separate axes can also be useful when there is a large difference in magnitude between displayed parameters/measurements. The axes can be displayed logarithmically. A narrower section of the y-axis can be displayed.
Center	▶ Click on this button to center the graphic. 👁 The axes are moved and scaled so that the graphs completely fill the coordinates window in all directions.
Separate x-axis per measurement	▶ Check the box to display separate x-axes per measurement.
Separate y-axis per measurement	▶ Check the box to display separate y-axes per measurement.
Separate y-axis per parameter	▶ Check the box to display separate y-axes per parameter.
Apply y-range	▶ Check the box to activate the y-axis section as defined in the ***y-section*** fields.
Y-range	▶ In the left/right field, enter the minimum/maximum limit value of the y-axis section to be displayed.
Logarithm	Drop-down menu for logarithmic display of axes. A logarithmic display is particularly useful when the range of values spans many orders of magnitude. This makes it easier to see correlations in the range of small values.
X-axis logarithmic (log10)	▶ Check the box to display the x-axes logarithmically.
Y-axis logarithmic (log10)	▶ Check the box to display the y-axes logarithmically.
Display	Drop-down menu
Maximum number of points	The maximum number of measurement points displayed can be limited in the following way: ▶ Enter a value in the input field. ▶ Use the slider beneath the input field. 👁 In some instances, a slider appears beneath the graph. This is used to change the size of the section shown. Enter the value 0 to remove the restriction.
Legend	▶ Select in the drop-down list whether a legend is to be displayed – and, if so, in which position.

Tab. 6.7: Options in the settings window for the ***Graph*** tool

Option	Explanation
Graph list	Drop-down menu
Drop-down list: ***Line*** ***Line+points*** ***Points***	1. Select in the drop-down list a global display form for all graphs. 2. If necessary, alter the display form of individual graphs using the graph list below the graph.
Line width	▶ Enter a value in the input field.
Point size	The measurement points are displayed as circles, squares, triangles etc. ▶ Enter a value in the input field.
Graph list	The name of a graph contains the relevant parameter and, if applicable, the name of the project tree element and the higher-level project tree element. Determine for each graph if and how it will be displayed in the coordinates window: ▶ Check the box to display the graph. ▶ Click repeatedly on the icon to the right of the checkbox in order to toggle the display mode.
Fit algorithms	Drop-down menu Fit algorithms can be applied to the entire x-range of a graph as well as to individual sub-ranges. The results are displayed by means of fit graphs in the coordinates window. In addition, a table for the numerical display of important fit parameters is also displayed. The results are displayed in columns per parameter/ measurement/x-section. Window size can be altered via a side bar. Sub-ranges can be marked or removed as described in Tab. 6.6 on page 47.
	
Trend	▶ Check the box to apply trend algorithms.
Averaging	▶ Check the box to perform averaging.
Caustic fit	▶ Check the box to perform a caustic adjustment.
Wavelength	The parameter ***M²*** (fit algorithm***Caustic fit)*** is calculated as a function of wavelength. ▶ Enter a value in the input field.

Tab. 6.7: Options in the settings window for the ***Graph*** tool

Option	Explanation
List of parameters	Parameters can be selected from the category sublists of the parameter list on display. The parameter list on display depends on which project tree element is open. The following options are available: **Open/close a category sublist:** ▶ Click on the arrow right / arrow down. **Selecting all the parameters of a category sublist:** ▶ Click on the category sublist. **Selecting a parameter:** ▶ Click on the required parameter. **Selecting several parameters:** 1. Click on one parameter, 2. press and hold the Crtl key, and click on further parameters. **Selecting several consecutive parameters:** 1. Click on the top/bottom parameter. 2. Then press and hold the Shift key and click on the top/bottom parameter.

Tab. 6.7: Options in the settings window for the ***Graph*** tool

6.2.3 Measurement value display

In this tool, measurement parameters are displayed as single values in numerical form or as an analog scale (arc, linear or thermometer). This is suitable for displaying all project tree elements (except for ***Series***).

This tool is particularly suited for displaying a running measurement (see Chapter “Display running measurements in a tool” on page 43).

Structure of the tool window

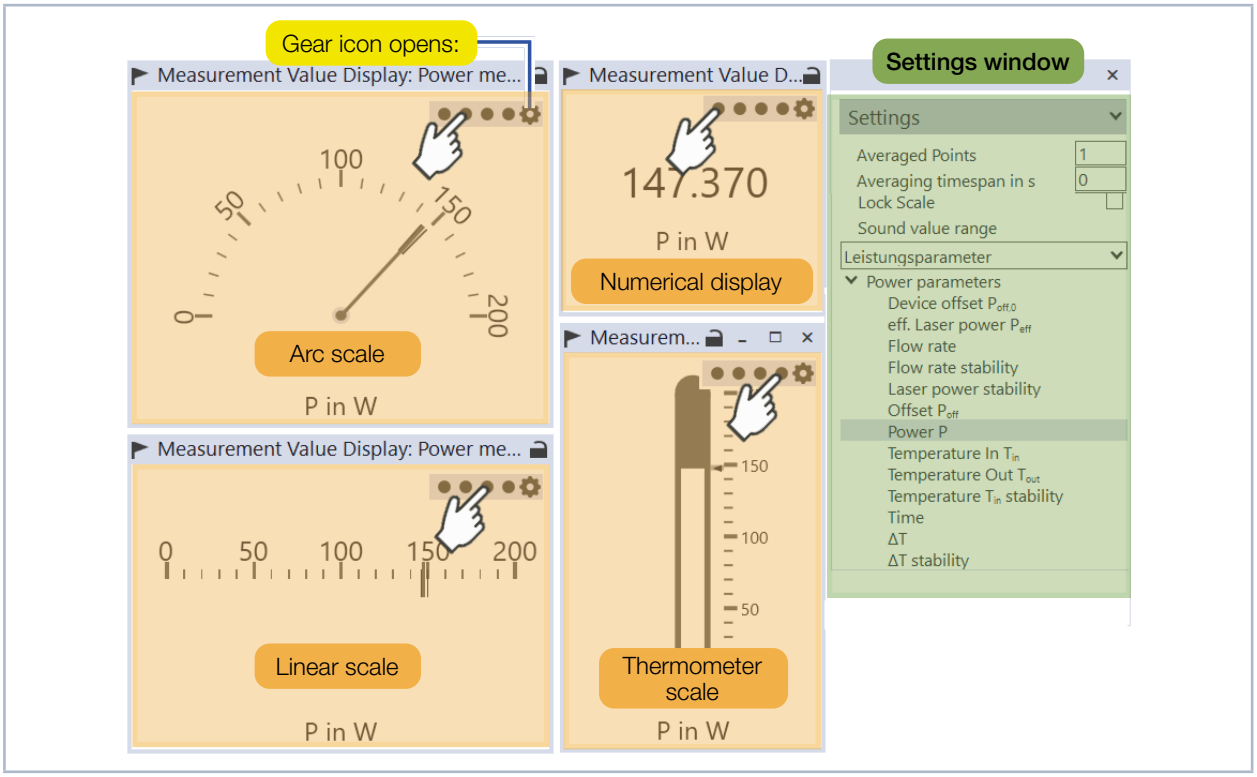


Fig. 6.3: Structure of the ***Measurement value display*** tool

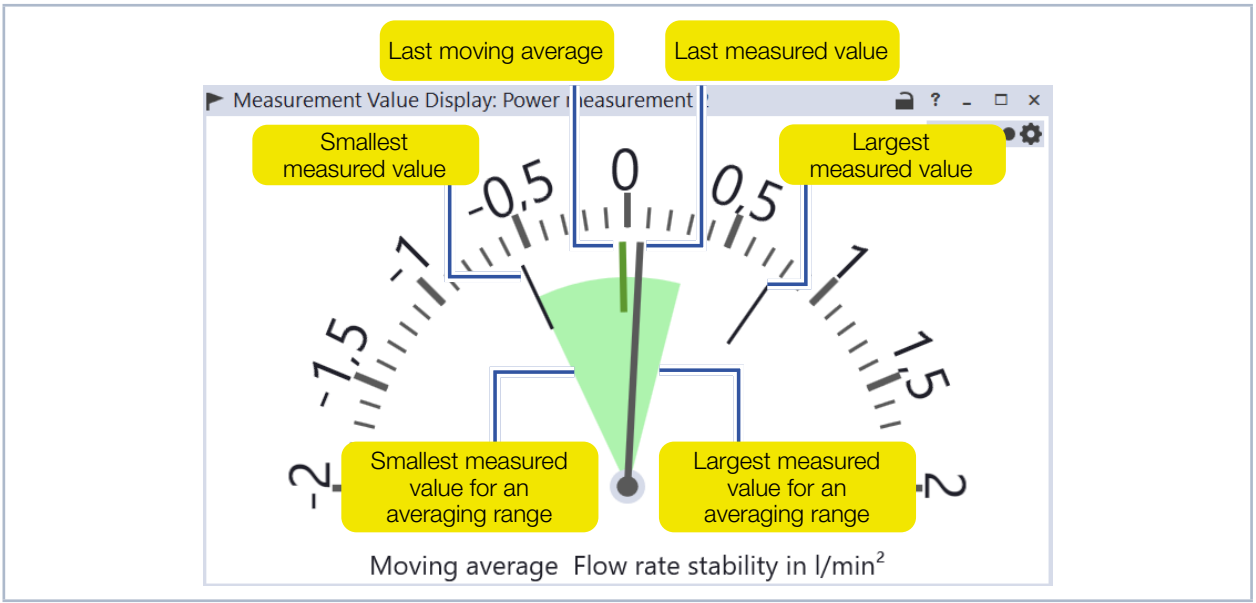


Fig. 6.4: Analog scale display (e.g., arc)

Elements	Description
Graph window	To toggle between different modes, click on the dots in the top-right corner of the measurement value display tool. The numerical display shows the last measured value / the last moving average of a series. The scale display modes are explained on the basis of an arc display; see Fig. 6.4 on page 51 (with display of moving averages).
Settings window	The settings window also contains options for specifying the averaged range and for selecting the displayed parameter. Further information can be found in Tab. 6.9 on page 52.

Tab. 6.8: Elements of the ***Measurement value display*** tool

Settings window

The table below lists all the options in order of appearance. Some options / drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
Settings	Drop-down menu
Number of averaged points	To calculate a moving average, the range in which averaging takes place must be set. ▶ Enter a value in the input field in order to set the number of averaged points.
Averaging timespan in s	To calculate a moving average, the timespan in which averaging takes place must be set. ▶ Enter a value in the input field in order to determine the averaging timespan.
Number of decimal places	This option appears only when the numerical display is selected. ▶ Enter a value in order to determine the number of decimal places. ➔ Displayed values are rounded up or down.
Font size	This option appears only when the numerical display is selected. ▶ Enter a value in the input field in order to set the font size of the numerical display.
Lock scale	If this option is selected, the scale of the measurement value display is locked. In this case, the scale display modes is no longer automatically adjusted when a new measurement is dragged into the tool. This makes it easier to compare different measurements. ▶ Check the box to activate this option.
List of parameters	Parameters can be selected from the category sublists of the parameter list on display. The parameter list on display depends on which project tree element is open. The following options are available: **Open/close a category sublist:** ▶ Click on the arrow right / arrow down. **Selecting a parameter:** ▶ Click on the required parameter.

Tab. 6.9: Options in the settings window for the ***Measurement value display*** tool

6.2.4 Histogram

In this tool, measurement data are categorized in a coordinates window. This tool is suitable for displaying the following project tree elements: ***Series, Caustic, Power measurement, Cube series*** and ***Cube measurement***.

Multiple project tree elements of the same type can be simultaneously displayed in this tool window (see Chapter “Opening different measurements in a single tool window in order to compare them” on page 42).

Structure of the tool window

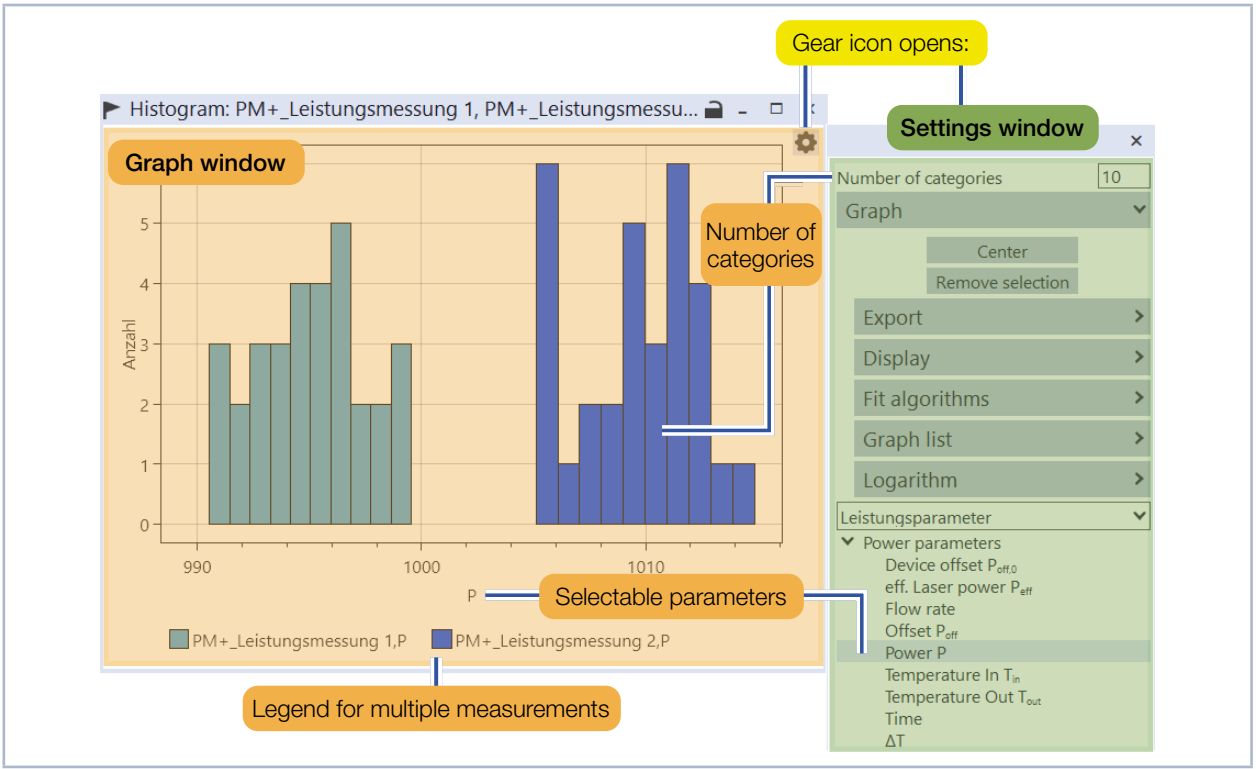


Fig. 6.5: Structure of the ***Histogram*** tool

Elements	Description
Graph window	Information on the control options in this window can be found in Tab. 6.11 on page 54. If several measurements are displayed in the tool simultaneously, then a legend can be displayed that assigns the squares to the measurements. In the coordinates window, the x-axis shows the categories (with equal width per measurement), and the y-axis shows their frequency. Whenever the mouse cursor is hovered over the top-right corner of the graph window, a gear icon appears. This is used to open the settings window.
Settings window	The settings window contains options for adjusting the graph window and exporting data. Further information can be found in Tab. 6.12 on page 55.

Tab. 6.10: Elements of the ***Histogram*** tool

Control options in the graph window

Instead of the right mouse button, the left mouse button can also be used while holding down the Alt key.

Action	Procedure
Zoom to position of mouse cursor	1. Position the mouse cursor anywhere within the coordinates window. 2. Turn the mouse wheel.
Setting a zoom range	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Crtl key and the left mouse button. 3. Draw a square.
Change the scale of an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Turn the mouse wheel.
Shift the display along an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Press and hold the right mouse button and drag along the axis.
Shift the display in any direction	1. Position the mouse cursor anywhere within the coordinates window. 2. Use one of the following options: ▶ Press and hold the right mouse button and drag in the required direction. ▶ Use the arrow keys to incrementally move in the required direction.
Center all squares in the coordinates window	▶ Double-click on the coordinates window. 👁 The axes are moved and scaled so that the squares completely fill the coordinates window in all directions.
Show the coordinate values of a square	▶ Click and hold on the square. 👁 The corresponding information is displayed.
Opening the settings window	1. Hover the mouse cursor over the coordinates window until the gear icon appears in the top-right corner. 2. Click on the gear icon to open the settings window.
Mark an area along the x-axis	Any number of areas can be marked along the x-axis. In this way, distances can be measured or fit algorithms applied to individual areas. To mark distances, proceed as follows: 1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Shift key and the left mouse button. 3. Mark an area along the x-axis. 4. If required, repeat to mark further areas along the x-axis.
Removing a marked area	1. Press and hold the Shift key. 2. Click on the area to be removed.
Removing all marked areas	▶ Press the ***Remove selection*** button in the settings window.

Tab. 6.11: Control options in the graph window

Settings window

The table below lists all the options in order of appearance. Some options / drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
Number of categories	
Graph	Drop-down menu
Center	▶ Click on this button to center the graphic. 👁 The axes are moved and scaled so that the squares completely fill the coordinates window in all directions.
Remove selection	▶ Click on this button to remove all the distances marked in the coordinates window.
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save the graph data in numerical form as a file with the extension ***.csv***.
Export graphic (.png)	▶ Click on this button to save the graph in its current state as a graphics file with the extension ***.png***.
Copy graphic	▶ Click on this button to copy the graph in its current state to the clipboard.
Display	Drop-down menu
Maximum number of points	The maximum number of measurement points displayed can be limited in the following way: ▶ Enter a value in the input field. ▶ Use the slider beneath the input field. 👁 In some instances, a slider appears beneath the graph. This is used to change the size of the section shown. Enter the value 0 to remove the restriction.
Legend	▶ Select in the drop-down list whether a legend is to be displayed – and, if so, in which position.
Fit algorithms	Drop-down menu
Averaging	▶ Check the box to perform averaging.
Graph list	Drop-down menu
Drop-down list: ***Line*** ***Line+points*** ***Points***	1. Select in the drop-down list a global display form for all graphs. 2. If necessary, alter the display form of individual graphs using the graph list below the graph.
Line width	▶ Enter a value in the input field.
Point size	The measurement points are displayed as circles, squares, triangles etc. ▶ Enter a value in the input field.
Graph list	Determine for each graph if and how it will be displayed in the coordinates window: ▶ Check the box to display the graph. ▶ Click repeatedly on the icon to the right of the checkbox in order to toggle the display mode.

Tab. 6.12: Options in the settings window for the ***Histogram*** tool

Option	Explanation
Logarithm	Drop-down menu for logarithmic display of axes. A logarithmic display is particularly useful when the range of values spans many orders of magnitude. This makes it easier to see correlations in the range of small values.
X-axis logarithmic (log10)	▶ Check the box to display the x-axes logarithmically.
Y-axis logarithmic (log10)	▶ Check the box to display the y-axes logarithmically.
List of parameters	Parameters can be selected from the category sublists of the parameter list on display. The parameter list on display depends on which project tree element is open. The following options are available: **Open/close a category sublist:** ▶ Click on the arrow right / arrow down. **Selecting a parameter:** ▶ Click on the required parameter.

Tab. 6.12: Options in the settings window for the ***Histogram*** tool

6.2.5 Graphic data analysis

This tool displays measurement results as a graph in a coordinate system. This tool is suitable for displaying the following project tree elements:

- ***Caustic***
- ***Series***
- ***Power measurement***
- ***SFM vector series***
- ***SFM delay time***
- ***SFM caustic***
- ***Absorber measurement***
- ***ADC measurement***
- ***Cube series***
- ***Cube measurement***
- ***Focustracker measurement***

In this tool, the parameters displayed on the x-axis and y-axis can be freely selected from the list of measurement parameters.
In this way, interdependencies between parameters can be observed.
This is the essential difference to the ***Graph*** tool, in which one or more measurement parameters can be displayed as a function of the timestamp, the measurement index or power (see Chapter 6.2.2 on page 46).

Multiple project tree elements of the same type can be simultaneously displayed in this tool window (see Chapter “Opening different measurements in a single tool window in order to compare them” on page 42).

Structure of the tool window

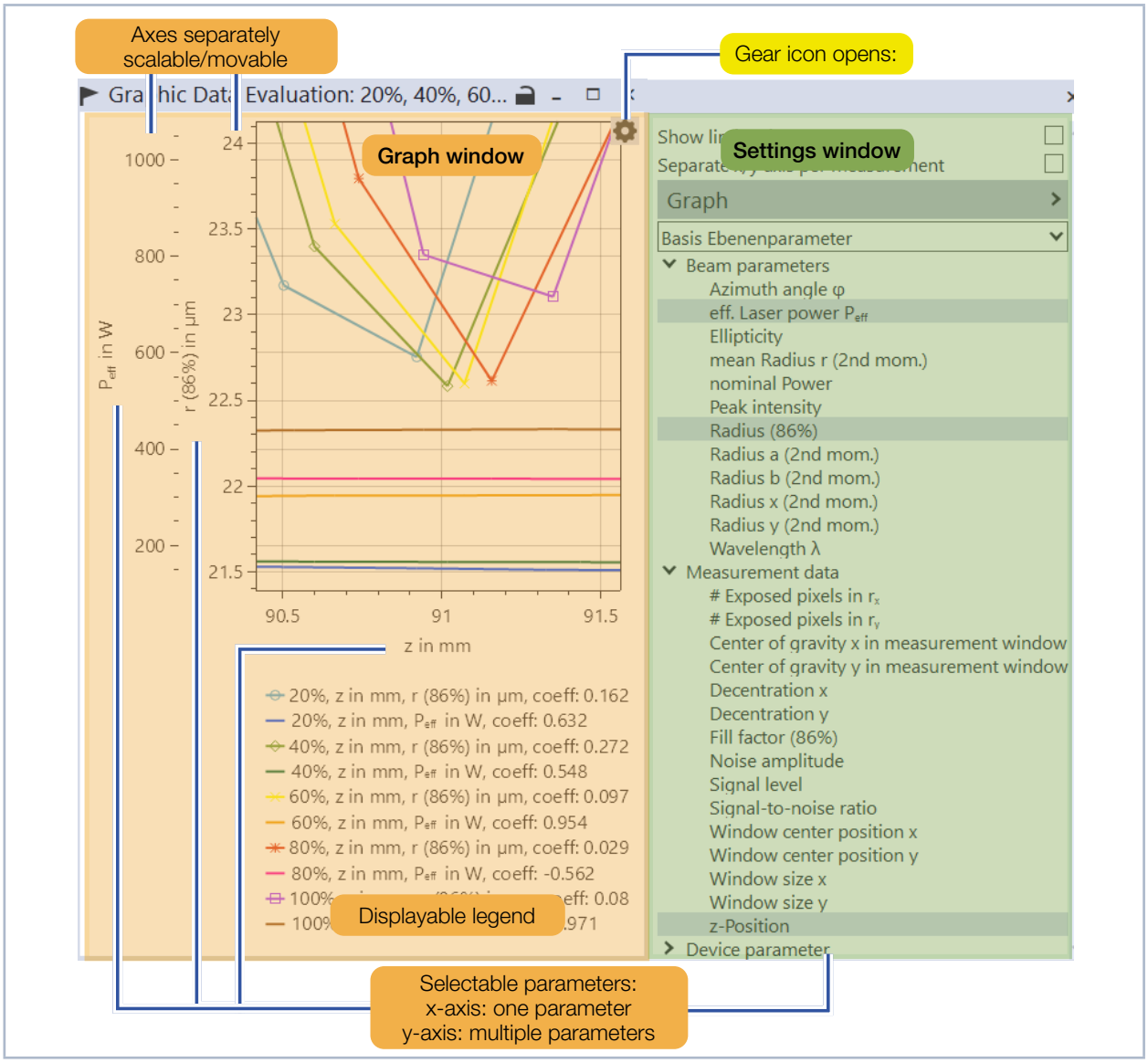


Fig. 6.6: Structure of the ***Graphic data analysis*** tool

Elements	Description
Graph window	Information on the control options in this window can be found in Tab. 6.14 on page 58. A graph is shown in the coordinates window for each selected measurement parameter / each open measurement. The first selected measurement parameter is plotted on the x-axis; the other measurement parameters are plotted on the y-axis (selection with Ctrl + left mouse button). A legend can be displayed that assigns the displayed graphs to the corresponding project tree elements / parameters. In the graph window, separate axes per measurement can be displayed. All axes can be moved and scaled independently of one another. The axes can also be displayed logarithmically. Whenever the mouse cursor is hovered over the top-right corner of the graph window, a gear icon appears. This is used to open the settings window.
Settings window	The settings window contains options for adjusting the graph window and exporting data. Further information can be found in Tab. 6.15 on page 59.

Tab. 6.13: Elements of the ***Graphic data analysis*** tool

Control options in the graph window

Instead of the right mouse button, the left mouse button can also be used while holding down the Alt key.

Action	Procedure
Zoom to position of mouse cursor	1. Position the mouse cursor anywhere within the coordinates window. 2. Turn the mouse wheel.
Setting a zoom range	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Crtl key and the left mouse button. 3. Draw a square.
Change the scale of an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Turn the mouse wheel.
Shift the display along an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Press and hold the right mouse button and drag along the axis.
Shift the display in any direction	1. Position the mouse cursor anywhere within the coordinates window. 2. Use one of the following options: ▶ Press and hold the right mouse button and drag in the required direction. ▶ Use the arrow keys to incrementally move in the required direction.
Center all graphs in the coordinates window	▶ Double-click on the coordinates window, but not in the immediate vicinity of a graph. 👁 The axes are moved and scaled so that the graphs completely fill the coordinates window in all directions.
Display coordinate values at any position in a graph	▶ Click on the relevant area of the graph. 👁 The corresponding information is displayed.
Opening the settings window	1. Hover the mouse cursor over the coordinates window until the gear icon appears in the top-right corner. 2. Click on the gear icon to open the settings window.
Mark an area along the x-axis	Any number of areas can be marked along the x-axis. In this way, distances can be measured or fit algorithms applied to individual areas. To mark distances, proceed as follows: 1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Shift key and the left mouse button. 3. Mark an area along the x-axis. 4. If required, repeat to mark further areas along the x-axis.
Removing a marked area	1. Press and hold the Shift key. 2. Click on the area to be removed.
Removing all marked areas	▶ Press the ***Remove selection*** button in the settings window.

Tab. 6.14: Control options in the graph window

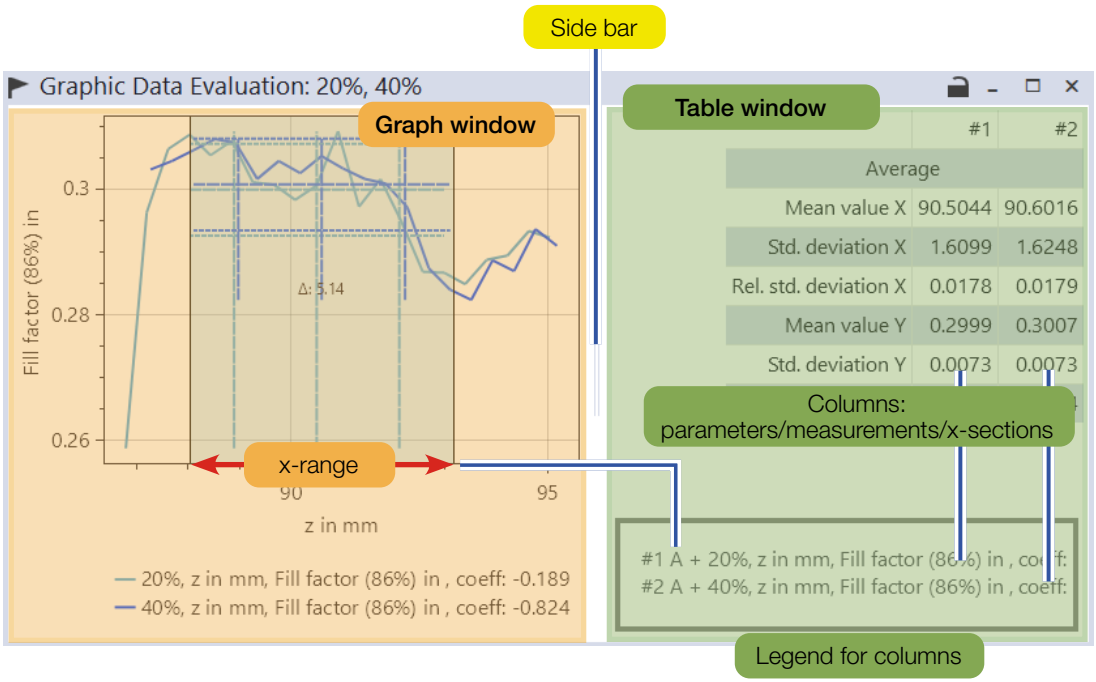
Settings window

The table below lists all the options in order of appearance. Some options / drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
Show limit values	1. Check the box to show limit values / warning values. 👁 If limit values / warning values are configured for the selected parameters, then these are displayed as dotted red/yellow lines (with inscriptions). 2. If necessary, zoom out of the display to see limit values / warning values.
Separate x-axes/y-axes per measurement	In the graph window, separate x-axes /y-axes can be displayed per measurement. Separate axes can be useful when there is a large difference in magnitude between displayed measurements. ▶ Check the box to display separate x-axes/y-axes per measurement.
Graph	Drop-down menu
Center	▶ Click on this button to center the graphic. 👁 The axes are moved and scaled so that the graphs completely fill the coordinates window in all directions.
Remove selection	▶ Click on this button to remove all the distances marked in the coordinates window.
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save the graph data in numerical form as a file with the extension ***.csv***.
Export graphic (.png)	▶ Click on this button to save the graph in its current state as a graphics file with the extension ***.png***.
Copy graphic	▶ Click on this button to copy the graph in its current state to the clipboard.
Display	Drop-down menu
Maximum number of points	The maximum number of measurement points displayed can be limited in the following way: ▶ Enter a value in the input field. ▶ Use the slider beneath the input field. 👁 In some instances, a slider appears beneath the graph. This is used to change the size of the section shown. Enter the value 0 to remove the restriction.
Legend	▶ Select in the drop-down list whether a legend is to be displayed – and, if so, in which position.

Tab. 6.15: Options in the settings window for the ***Graphic data analysis*** tool

Option	Explanation
Fit algorithms	Drop-down menu Fit algorithms can be applied to the entire x-range of a graph as well as to individual sub-ranges. The results are displayed by means of fit graphs in the coordinates window. In addition, a table for the numerical display of important fit parameters is also displayed. The results are displayed in columns per parameter/ measurement/x-section. Window size can be altered via a side bar. Sub-ranges can be marked or removed as described in Tab. 6.14 on page 58.



Trend	▶ Check the box to apply trend algorithms.
Averaging	▶ Check the box to perform averaging.
Caustic fit	▶ Check the box to perform a caustic adjustment.
Wavelength	The parameter ***M²*** (fit algorithm***Caustic fit)*** is calculated as a function of wavelength. ▶ Enter a value in the input field.
Graph list	Drop-down menu
Drop-down list: ***Line*** ***Line+points*** ***Points***	1. Select in the drop-down list a global display form for all graphs. 2. If necessary, alter the display form of individual graphs using the graph list below the graph.
Line width	▶ Enter a value in the input field.
Point size	The measurement points are displayed as circles, squares, triangles etc. ▶ Enter a value in the input field.

Tab. 6.15: Options in the settings window for the ***Graphic data analysis*** tool

Option	Explanation
Graph list	The name of a graph indicates the parameter in question. Determine for each graph if and how it will be displayed in the coordinates window: ▶ Check the box to display the graph. ▶ Click repeatedly on the icon to the right of the checkbox in order to toggle the display mode.
Logarithm	Drop-down menu for logarithmic display of axes. A logarithmic display is particularly useful when the range of values spans many orders of magnitude. This makes it easier to see correlations in the range of small values.
X-axis logarithmic (log10)	▶ Check the box to display the x-axes logarithmically.
Y-axis logarithmic (log10)	▶ Check the box to display the y-axes logarithmically.
List of parameters	Parameters can be selected from the category sublists of the parameter list on display. The parameter list on display depends on which project tree element is open. Proceed as follows: 1. Open the desired category sublist by clicking on the arrow to the left of the name. 2. Click on the parameter for the x-axis. 3. Press and hold the Crtl key, and click on one or more parameters for the y-axis/y-axes.

Tab. 6.15: Options in the settings window for the ***Graphic data analysis*** tool

6.2.6 Evaluation traffic light

This tools enables a review of freely selectable parameters in respect of limit and warning values. The selected parameters are automatically compared with limit and warning values and the result is shown by a traffic light system.
It is possible to toggle between a traffic light and tabular view. This tool is suitable for displaying the following project tree elements: ***Caustic***, ***Plane***, ***Cube measurement*** and ***Power measurement***.

This tool is particularly suited for displaying a running measurement (see Chapter “Display running measurements in a tool” on page 43).
Detailed information on the topic of review is available in the chapter8.2 on page 140.

Structure of the tool window

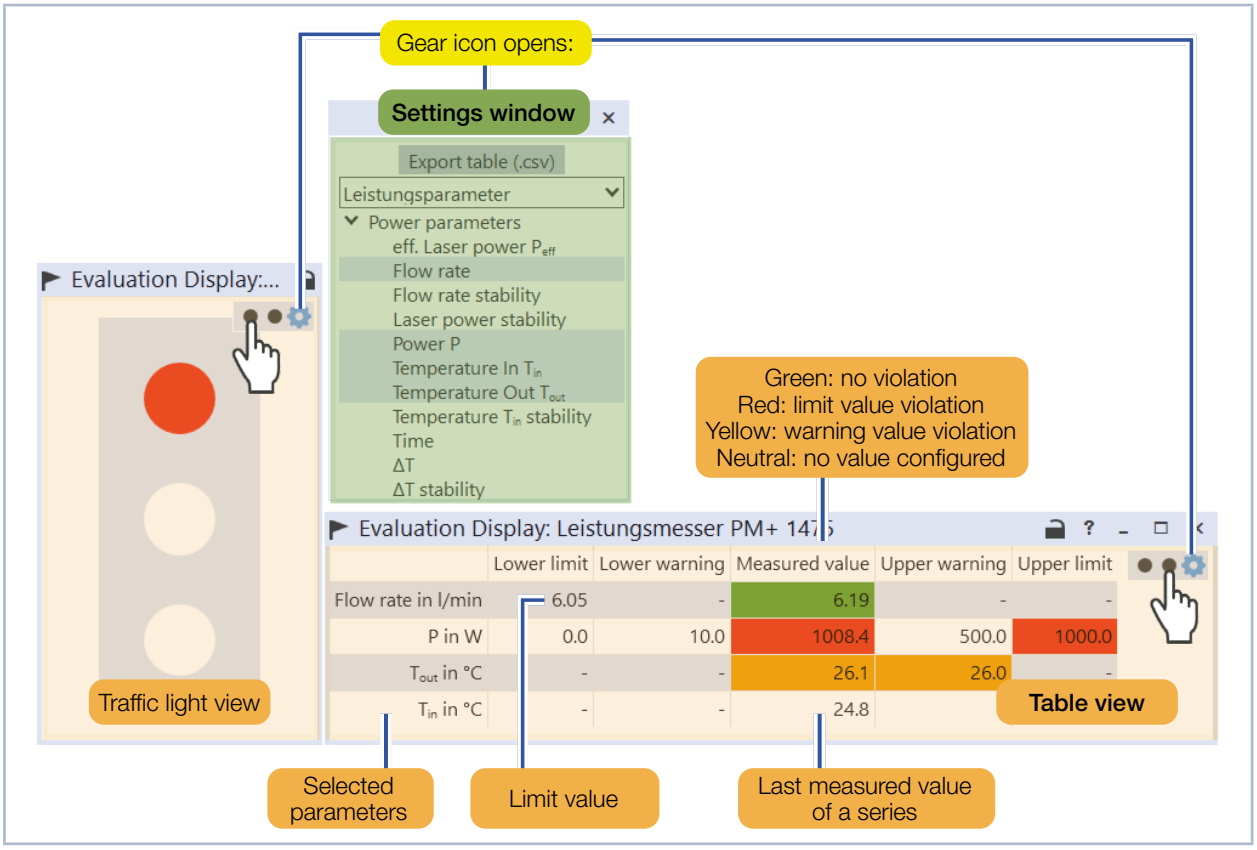


Fig. 6.7: Structure of the ***Evaluation traffic light*** tool

Elements	Description
Graph window	To toggle between different modes, click on the dots in the top-right corner of the measurement value display tool. The table also appears when the mouse cursor is hovered over the traffic light view. The traffic light view provides a snapshot review of selected parameters: Red — At least one factory or freely configured limit value has been violated. Yellow — No violation of a limit value, but violation of at least one factory or freely configured warning value. Green — No limit or warning values have been violated/configured. The tabular view shows the last measured value of a series for each selected parameter. This enables a direct review of the displayed parameters using background colors. In this way, it is possible to determine which parameters caused the change in traffic light color. In addition, the table lists the limit or warning values for each selected parameter. Red — A factory or freely configured limit value has been violated. Yellow — A factory or freely configured warning value has been violated. Green — The parameter lies within the configured limit or warning values. Neutral — No limit or warning values have been configured.
Settings window	The settings window features an option to export tables and parameter lists.
Table export (.csv)	▶ Click on this button to save the table in its current state as a file with the extension ***.csv***.
List of parameters	Parameters can be selected from the category sublists of the parameter list on display. The parameter list on display depends on which project tree element is open. The following options are available: **Open/close a category sublist:** ▶ Click on the arrow right / arrow down. **Selecting all the parameters of a category sublist:** ▶ Click on the category sublist. **Selecting a parameter:** ▶ Click on the required parameter. **Selecting several parameters:** 1. Click on one parameter, 2. press and hold the Crtl key, and click on further parameters. **Selecting several consecutive parameters:** 1. Click on the top/bottom parameter. 2. Then press and hold the Shift key and click on the top/bottom parameter.

Tab. 6.16: Elements of the ***Evaluation traffic light*** tool

6.2.7 Series analysis

This table enables the analysis of large data volumes. For this purpose, multiple project tree elements of the type ***Caustic / Series*** can be simultaneously displayed (see Chapter “Opening different measurements in a single tool window in order to compare them” on page 42).
The data from individual Caustics/Series measurements are mathematically aggregated. Various statistical indicators are available for this purpose. The results are shown in graphical and tabular form.

Structure of the tool window

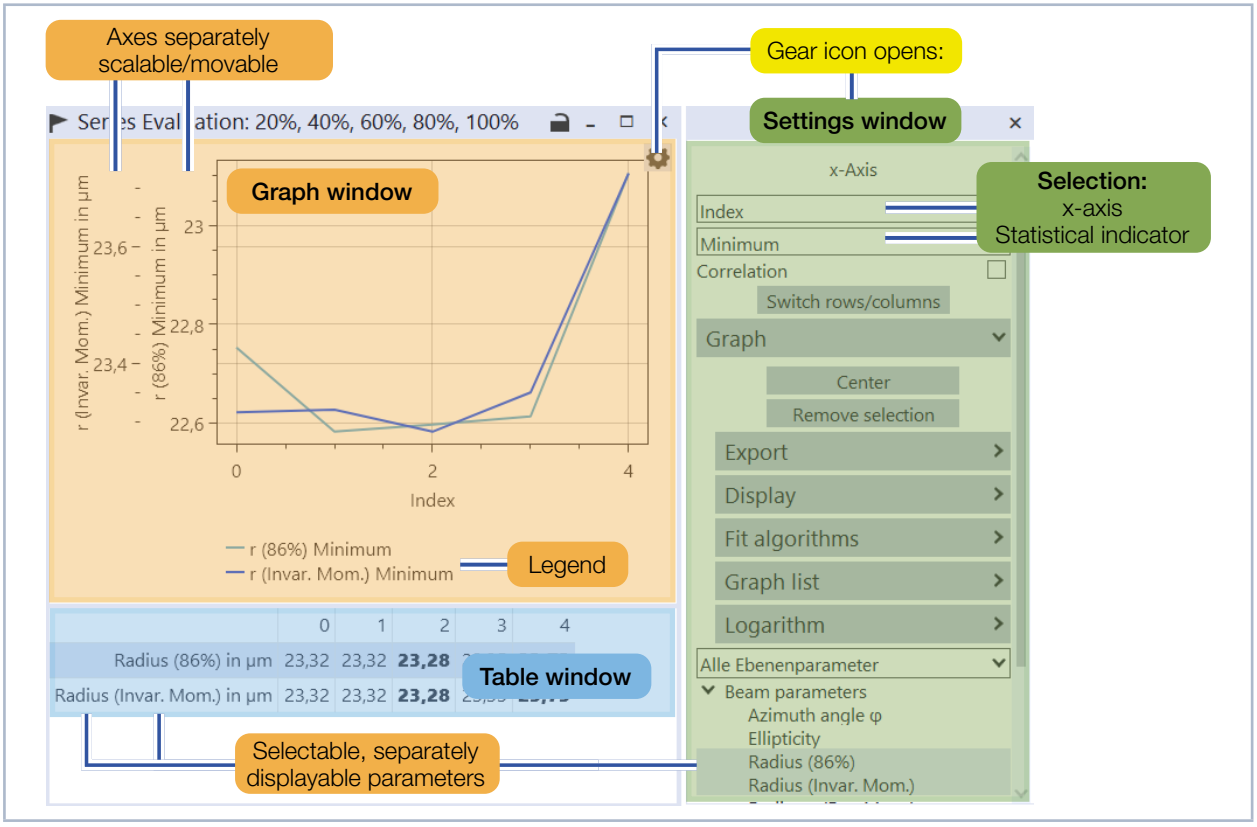


Fig. 6.8: Structure of the ***Series analysis*** tool

Elements	Description
Graph window	Information on the control options in this window can be found in Tab. 6.18 on page 65. A graph is shown in the coordinates window for each selected parameter. The selected measurement parameters are plotted on the y-axes. The y-axes can be moved and scaled independently of one another. A legend can be displayed that assigns the displayed graphs to the corresponding parameters. For the x-axis, the parameters ***Index*** and ***Timestamp*** can be selected in a separate list. The index numbering corresponds to the order in which the Caustics/Series are opened in the tool. The axes can also be displayed logarithmically. Whenever the mouse cursor is hovered over the top-right corner of the graph window, a gear icon appears. This is used to open the settings window.
Settings window	The settings window contains options for adjusting the graph window and exporting data. Further information can be found in Tab. 6.19 on page 66.
Table window	The parameters selected in the settings window are displayed numerically here. Rows and columns can be exchanged.

Tab. 6.17: Elements of the ***Series analysis*** tool

Control options in the graph window

Instead of the right mouse button, the left mouse button can also be used while holding down the Alt key.

Action	Procedure
Zoom to position of mouse cursor	1. Position the mouse cursor anywhere within the coordinates window. 2. Turn the mouse wheel.
Setting a zoom range	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Crtl key and the left mouse button. 3. Draw a square.
Change the scale of an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Turn the mouse wheel.
Shift the display along an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Press and hold the right mouse button and drag along the axis.
Shift the display in any direction	1. Position the mouse cursor anywhere within the coordinates window. 2. Use one of the following options: ▶ Press and hold the right mouse button and drag in the required direction. ▶ Use the arrow keys to incrementally move in the required direction.
Center all graphs in the coordinates window	▶ Double-click on the coordinates window, but not in the immediate vicinity of a graph. 👁 The axes are moved and scaled so that the graphs completely fill the coordinates window in all directions.
Display coordinate values at any position in a graph	▶ Click on the relevant area of the graph. 👁 The corresponding information is displayed.
Opening the settings window	1. Hover the mouse cursor over the coordinates window until the gear icon appears in the top-right corner. 2. Click on the gear icon to open the settings window.
Mark an area along the x-axis	Any number of areas can be marked along the x-axis. In this way, distances can be measured or fit algorithms applied to individual areas. To mark distances, proceed as follows: 1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Shift key and the left mouse button. 3. Mark an area along the x-axis. 4. If required, repeat to mark further areas along the x-axis.
Removing a marked area	1. Press and hold the Shift key. 2. Click on the area to be removed.
Removing all marked areas	▶ Press the ***Remove selection*** button in the settings window.

Tab. 6.18: Control options in the graph window

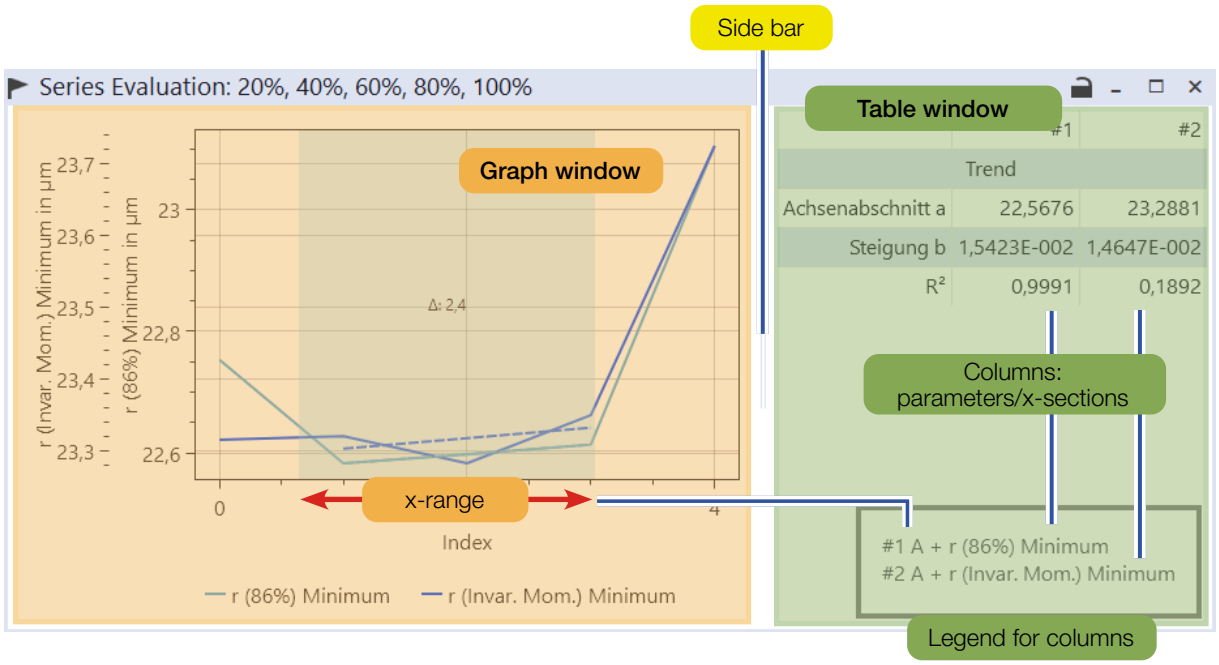
Settings window

The table below lists all the options in order of appearance. Some options / drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
X-axis	▶ Select an x-axis inscription from the upper drop-down list. ▶ Select a statistical indicator from the lower drop-down list.
Correlation	If at least two parameters are selected, the one first selected can be displayed on the x-axis. 1. Check the box. 2. Select the parameter for the x-axis at the bottom of the settings window. 3. Select further parameters for the y-axis.
Exchange rows/columns	▶ Click on the button to exchange rows and columns in the tabular view.
Graph	Drop-down menu
Center	▶ Click on this button to center the graphic. 👁 The axes are moved and scaled so that the graphs completely fill the coordinates window in all directions.
Remove selection	▶ Click on this button to remove all the distances marked in the coordinates window.
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save the data in numerical form as a file with the extension ***.csv***.
Export graphic (.png)	▶ Click on this button to save the graph in its current state as a graphic file with the extension ***.png***.
Copy graphic	▶ Click on this button to copy the graph in its current state to the clipboard.
Display	Drop-down menu
Maximum number of points	The maximum number of measurement points displayed can be limited in the following way: ▶ Enter a value in the input field. ▶ Use the slider beneath the input field. 👁 In some instances, a slider appears beneath the graph. This is used to change the size of the section shown. Enter the value 0 to remove the restriction.
Legend	▶ Select in the drop-down list whether a legend is to be displayed – and, if so, in which position.

Tab. 6.19: Options in the settings window for the ***Series analysis*** tool

Option	Explanation
Fit algorithms	Drop-down menu Fit algorithms can be applied to the entire x-range of a graph as well as to individual sub-ranges. The results are displayed by means of fit graphs in the coordinates window. In addition, a table for the numerical display of important fit parameters is also displayed. The results are displayed in columns per parameter/ x-section. Window size can be altered via the side bar. Sub-ranges can be marked or removed as described in Tab. 6.18 on page 65.



Trend	▶ Check the box to apply trend algorithms.
Averaging	▶ Check the box to perform averaging.
Caustic fit	▶ Check the box to perform a caustic adjustment.
Wavelength	The parameter ***M²*** (fit algorithm***Caustic fit)*** is calculated as a function of wavelength. ▶ Enter a value in the input field.
Graph list	Drop-down menu
Drop-down list: ***Line*** ***Line+points*** ***Points***	1. Select in the drop-down list a global display form for all graphs. 2. If necessary, alter the display form of individual graphs using the graph list below the graph.
Line width	▶ Enter a value in the input field.
Point size	The measurement points are displayed as circles, squares, triangles etc. ▶ Enter a value in the input field.

Tab. 6.19: Options in the settings window for the ***Series analysis*** tool

Option	Explanation
Graph list	Determine for each graph if and how it will be displayed in the coordinates window: ▶ Check the box to display the graph. ▶ Click repeatedly on the icon to the right of the checkbox in order to toggle the display mode.
Logarithm	Drop-down menu for logarithmic display of axes. A logarithmic display is particularly useful when the range of values spans many orders of magnitude. This makes it easier to see correlations in the range of small values.
X-axis logarithmic (log10)	▶ Check the box to display the x-axes logarithmically.
Y-axis logarithmic (log10)	▶ Check the box to display the y-axes logarithmically.
List of parameters	Parameters can be selected from the category sublists of the parameter list on display. The parameter list on display depends on which project tree element is open. The following options are available: **Open/close a category sublist:** ▶ Click on the arrow right / arrow down. **Selecting all the parameters of a category sublist:** ▶ Click on the category sublist. **Selecting a parameter:** ▶ Click on the required parameter. **Selecting several parameters:** 1. Click on one parameter, 2. press and hold the Crtl key, and click on further parameters. **Selecting several consecutive parameters:** 1. Click on the top/bottom parameter. 2. Then press and hold the Shift key and click on the top/bottom parameter.

Tab. 6.19: Options in the settings window for the ***Series analysis*** tool

6.3 Tools to show beam geometry data

6.3.1 False-color view

This tool shows a gradated false-color view of power density distribution.

In this tool window, not only the project tree element ***Plane*** but also the element ***Caustic*** can be opened by clicking and dragging. The plane that is closest to the focus is then displayed.
The ***Linescan*** element can also be opened. In this case, however, some areas / functionalities of the tool differ from the standard plane analysis.
For more information see the chapter “Analysis of a linescan” on page 81.

Structure of the tool window

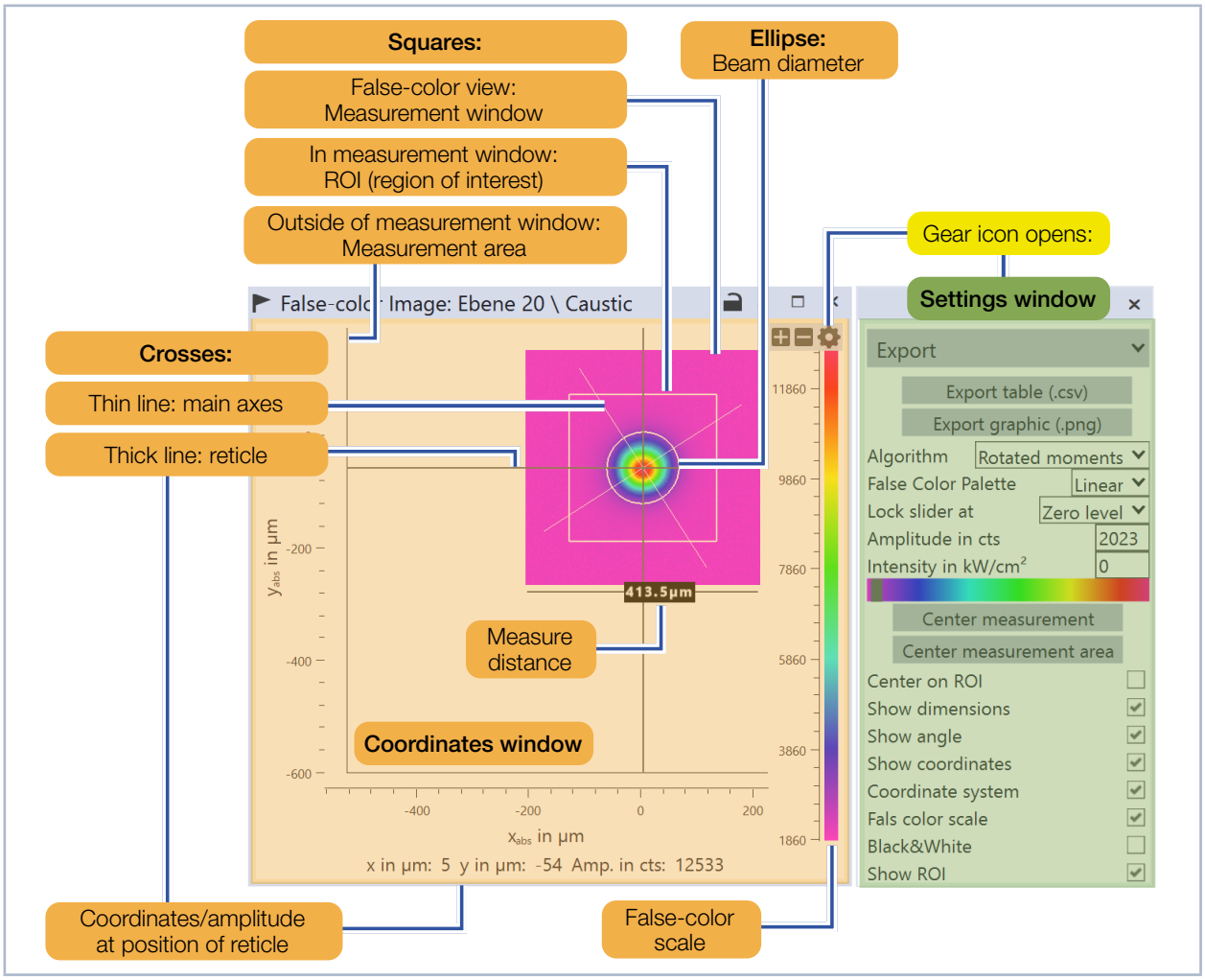


Fig. 6.9: Structure of the ***False-color view*** tool

Elements	Description
Coordinates window	The measuring plane is displayed graphically in the coordinates window. The complete measurable area (measurement area in the shape of a square) and the area recorded therein (measurement window in false-color view) can be displayed. Information on the control options can be found in Tab. 6.21 on page 70.
Settings window	The options in the settings window enable adjustments to the display, export of measurement data and algorithm selection for beam radius calculation. Further information can be found in Tab. 6.22 on page 71.

Tab. 6.20: Elements of the ***False-color view*** tool

Control options in the coordinates window

Action	Procedure
Zooming to the center of the coordinates window	1. Hover the mouse cursor over the coordinates window until the plus/minus buttons appear. 2. Press the buttons for incremental zooming.
Zooming to position of mouse cursor	1. Position the mouse cursor anywhere within the coordinates window. 2. Turn the mouse wheel for incremental zooming.
Adjusting zoom area to the size of the measurement window	1. Hover the mouse cursor over the measurement window. 2. Double-click. 👁 The zoom area is now set to the size of the measurement window. 3. To set the zoom area to the size of the measurement area, double-click once again on the measurement window.
Adjusting zoom area to the size of the measurement area	1. Hover the mouse cursor outside of the measurement window. 2. Double-click.
Moving the entire graphic	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the right mouse button and drag in the required direction.
Positioning the reticle (e.g., to show coordinates and amplitude at any one point)	To position the reticle, select one of the following options: ▶ Position the mouse cursor anywhere within the coordinates window and click the left mouse button. ▶ To continuously change the position of the reticle, drag while holding down the left mouse button. ▶ To incrementally change the position of the reticle, click on the arrow keys. 👁 The reticle (thick lines) is positioned at this point. The coordinates and intensity values are displayed beneath the coordinates window if the option ***Show coordinates*** is activated in the settings window.
Measuring a distance	To mark a distance, proceed as follows: 1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Crtl key and the left mouse button. 3. Mark with the mouse.
Removing a marked distance	1. Press and hold the Crtl key. 2. Click on the coordinates window.

Tab. 6.21: Control options in the coordinates window of the tool ***False-color view***

Settings window

The table below lists all the options in order of appearance. Some options / drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save all measurement plane data in numerical form as a file with the extension ***.csv***.
Export graphic (.png)	▶ Click on this button to save the coordinates window in its current state as a graphics file with the extension ***.png***.
Algorithm	The radii are calculated/recalculated according to the algorithm selected. Further information on calculation methods can be found in Chapter 7.5 on page 137. ▶ Select an algorithm from the drop-down list: • ***Device moments:*** Radii are calculated according to the second moment method in the device coordinates (x/y). This produces radii in x-/y-orientation. • ***Invariant moments:*** Radii are calculated according to the second moment method in the device coordinates (x/y). This produces the average of the radii in x-/y-orientation. • ***Rotated moments:*** Following conversion of the device coordinates (x/y) into beam coordinates (a/b), the radius calculation is performed according to the second moment method. This produces radii in a-/b-orientation. • ***86%:*** Radii are calculated according to the 86% method. This produces a radius.
False-color palette	For advanced analysis, different color palettes can be selected. Color palettes based on root functions provide a nuanced display of signal components with a very low intensity. This can be particularly useful when analyzing small variations near the zero level (e.g., for analyzing diffraction patterns). ▶ Select color palette from the drop-down list: • ***Linear:*** Linear color palette. • ***2nd root:*** Color palette based on the second root (colors assigned according to the second root of the power density values of each pixel). • ***4th root:*** Color palette based on the fourth root (colors assigned according to the fourth root of the power density values of each pixel). • ***Grayscale:*** Color palette in grayscale.
Amplitude in cts ***Intensity in kW/cm²***	A threshold value can be set to define a vertical section. ADC values / intensity values beneath the threshold are hidden in the false-color view. It only makes sense to display intensity when a power value has been entered or calculated for the purposes of a measurement. The ADC value (ADC = analog-digital count) corresponds to the raw data from the analog-to-digital converter. This is equal to intensity plus the zero level. In some instances, cts (counts) is given as the unit for the ADC value. To set a threshold, select one of the following options: ▶ Enter a value in one of the input fields. To confirm, press the Enter key. ▶ Use the color-palette slider beneath the input fields. ▶ Click on the color-palette slider. Move it by pressing the left/right arrow keys.

Tab. 6.22: Options in the settings window for the ***False-color view*** tool

Option	Explanation
Lock slider at	The color palette slider is used to set a threshold to define a vertical section. ADC values / intensity values beneath the threshold are hidden in the false-color view. The ADC value (ADC = analog-digital count) corresponds to the raw data from the analog-to-digital converter. This is equal to intensity plus the zero level. In some instances, cts (counts) is given as the unit for the ADC value. The slider can be locked in line with various criteria. This is useful when frequently switching back and forth between planes. ▶ elect a criterion from the drop-down list: • ***Power inclusion 86%:*** In the false-color view, starting from the beam center, only the values representing 86% of the power inclusion are shown. • ***Zero level:*** The zero level is the threshold value Only pixels with an ADC value above the zero level are shown. • ***Min. ADC:*** The minimum ADC value is the threshold value. • ***Current amplitude:*** The ADC value currently entered in the ***Amplitude in cts*** input field is the threshold value. • ***Current intensity*** The value currently entered in the ***Intensity in kW/cm²*** input field is the threshold value.
Center measurement	▶ Click this button to set the zoom area to the size of the measurement window and to center it. The measurement window contains this area as a false-color view.
Center measurement area	▶ Click this button to set the zoom area to the size of the measurement area and to center it. The measurement area corresponds to the complete measurable area (aperture).
Center on ROI	The ***ROI*** (region of interest) is the area of the measurement window that is used to calculate the beam radius. ▶ Click this box to set the zoom area to the size of the ***ROI*** and to center it.
Show dimensions	▶ Check this box to show the calculated diameter.
Show angle	▶ Check this box to show the lines representing the beam/device main axes. If these lines are not visible, click on the measurement area.
Show coordinates	▶ Check this box to show the coordinates and intensity values marked by the reticle. These are shown beneath the coordinates window.
Coordinate system	▶ Check this box to show the x-axis/y-axis scale.
False-color scale	▶ Check this box to show a false-color scale (in counts). 👁 The false-color scale is displayed to the right of the coordinates window.
Black & White	This setting gives a binary representation. If the value of a pixel is above/below the threshold of the color-palette slider, then the pixel is displayed in black and white. ▶ Check this box to show the graphic in black and white.
Show ROI	The ***ROI*** (region of interest) is the area of the measurement window that is used to calculate the beam radius. ▶ Check this box to show the ***ROI*** in the measurement window.

Tab. 6.22: Options in the settings window for the ***False-color view*** tool

Linescan display

The element ***Linescan*** can also be opened in this tool. A linescan is a repeated scan at short intervals of a linear section of a laser beam. Linescans can be performed with measuring devices such as **FM+** and **BM+**.

In this case, however, some elements/functionalities of the tool differ from the standard view. In the following, only the aspects specific to the Linescan view are described.

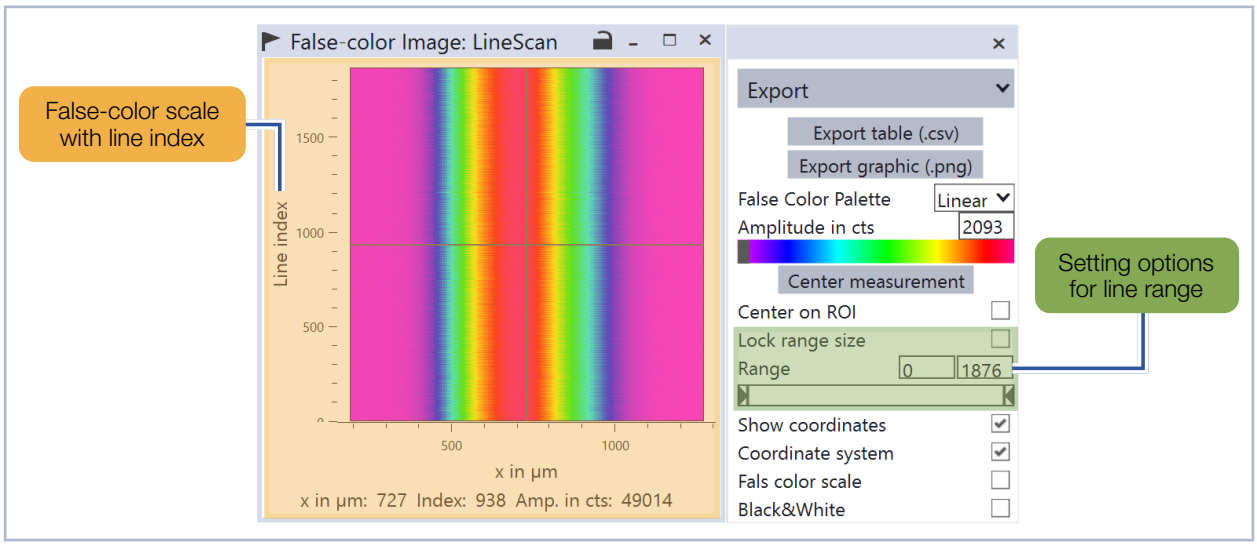


Fig. 6.10: A linescan in the tool ***False-color view***

Elements	Description
False-color scale with line index	In the false-color view, the line index forms the y-axis.
Setting options for line range	This settings window features options to select the line range that is to be displayed: ***Range*** The following options are available to select the Line range that is to be displayed. First, the option ***Lock range size*** must be deactivated: ▶ Enter the minimum/maximum limit value in the left/right input field. To confirm each entry, press the Enter key. ▶ Use the sliders beneath the input fields. ***Lock range size*** ▶ Check this box to lock the position of the slider. If one of the sliders is then moved, the other one will move with it while maintaining the set range.

Tab. 6.23: Elements of the ***False-color view*** tool

6.3.2 Plane analysis

This tool shows the results of a plane measurement in graphical and tabular form.

Tables are arranged as tabs in the lower part of the tool window. The area above is divided into quadrants that contain graphics and a settings window. The relative size of the quadrants can be altered by dragging their edges.

The graph window contains a false-color view and graphs of the x-cross section/y-cross section. The cross sections can be moved using the reticle in the false-color view.

In this tool window, not only the project tree element ***Plane*** but also the element ***Caustic*** can be opened by clicking and dragging. The plane that is closest to the focus is then displayed.
The ***Linescan*** element can also be opened. In this case, however, some areas / functionalities of the tool differ from the standard plane analysis.
For more information see the chapter “Analysis of a linescan” on page 81.

Structure of the tool window

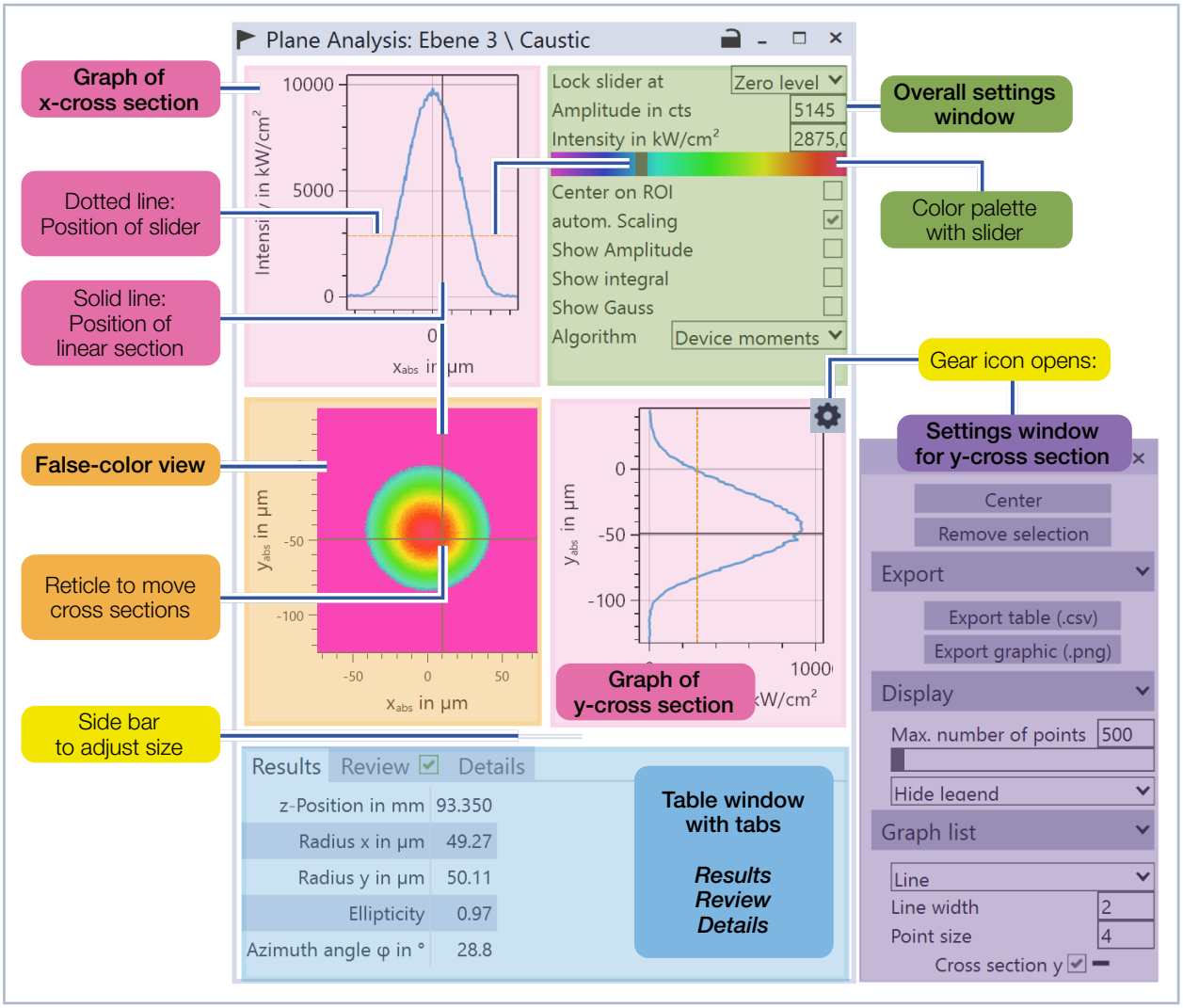


Fig. 6.11: Structure of the ***Plane analysis*** tool

Elements	Description
False-color view	The false-color view offers the same options as the ***False-color view*** tool. Further information can be found in Chapter 6.3.1 “False-color view” on page 69. The only difference is that with the ***Plane analysis*** tool, the reticle is used to move the cross sections in an x-/y-direction.
Graphs for x-cross section/ y-cross section	These coordinates windows display graphs in line with the position of the reticle. The coordinates windows also contain the following elements: • The **dotted orange line** shows the position of a vertical section. This corresponds to the position of the color-palette slider in the ***Overall settings window***. • The **solid line** shows the position of an x-cross section/y-cross section. • Whenever the mouse cursor is hovered over the top-right corner of the coordinates window, a **gear icon** appears. This is used to open the settings window. Information on the control options can be found in Tab. 6.25 on page 76.
Settings: Coordinates window for x-/y-cross section	This settings window features options for graphically adjusting the coordinates window and for exporting the contents of the window. Further information can be found in Tab. 6.27 on page 79.
Overall settings window	This settings window features options for adjusting the false-color view and cross sections. Further information can be found in Tab. 6.26 on page 77.
Table window	The tables for this area are included in the following tabs: • ***Results:*** Contains the parameters calculated for a plane. • ***Review:*** Contains the parameters that enable a review of a plane measurement. The review is visually supported by means of colored markers. Further information can be found in Chapter “The Review tab in the Plane Analysis tool” on page 80. • ***Details:*** Contains additional information on a measurement. If comments on a plane measurement have been created in the project tree, these are also displayed in this tab.

Tab. 6.24: Elements of the ***Plane analysis*** tool

Control options in the coordinates window for the x-/y-cross sections

Action	Procedure
Zooming to position of mouse cursor	1. Position the mouse cursor anywhere within the coordinates window. 2. Turn the mouse wheel.
Setting a zoom range	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Crtl key and the left mouse button. 3. Draw a square.
Change the scale of an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Turn the mouse wheel.
Shift the display along an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Press and hold the right mouse button and drag along the axis.
Shift the display in any direction	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the right mouse button and drag in the required direction.
Center graphs for false-color view	▶ To center a graph relative to the false-color view, double-click on the coordinates window – but not directly adjacent to the graph itself. 👁 This moves and scales the axis of intensity/amplitude.
Center graphs in the coordinates window	▶ Double-click on graphs. 👁 The axes are moved and scaled so that the graph completely fills the coordinates window in all directions.
Display coordinates and amplitude/ intensity at any position in a graph	▶ Click on the relevant area of the graph. 👁 The corresponding information is displayed. It is only possible to display the intensity when a power value has been entered or calculated for the purposes of a measurement.
Opening the settings window	1. Hover the mouse cursor over the coordinates window until the gear icon appears in the top-right corner. 2. Click on the gear icon to open the settings window.
Positioning a vertical section	1. Click on the dotted orange line. 2. Now press the left mouse button and drag along the axis of amplitude/intensity or press the corresponding arrow keys. 👁 The position of the false-color slider in the ***Overall settings window*** alters correspondingly. The vertical section can also be positioned by entering a number into the input field ***Amplitude in cts / Intensity in kW/cm²*** in the ***Overall settings window***.
Marking an area along the axis of amplitude/intensity	Any number of areas can be marked along the axis of amplitude/intensity This serves to measure distances. To mark distances, proceed as follows: 1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Shift key and the left mouse button. 3. Mark an area along the axis of amplitude/intensity. 4. If required, repeat to mark further areas.
Removing a marked area	1. Press and hold the Shift key. 2. Click on the area to be removed.
Removing all marked areas	▶ Press the ***Remove selection*** button in the settings window.

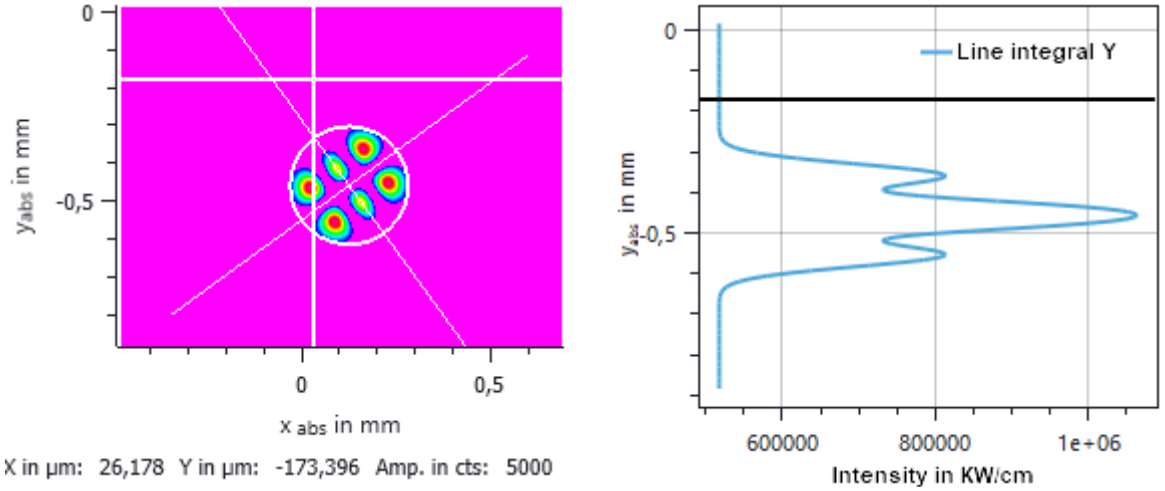
Tab. 6.25: Control options in the coordinates window for the x-/y-cross sections

Overall settings window

The table below lists all the options in order of appearance.

Option	Explanation
Lock slider at	The color palette slider is used to set a threshold to define a vertical section. ADC values / intensity values beneath the threshold are hidden in the false-color view. The ADC value (ADC = analog-digital count) corresponds to the raw data from the analog-to-digital converter. This is equal to intensity plus the zero level. In some instances, cts (counts) is given as the unit for the ADC value. The slider can be locked in line with various criteria. This is useful when frequently switching back and forth between planes. ▶ Select a criterion from the drop-down list: • ***Power inclusion 86%:*** In the false-color view, starting from the beam center, only the values representing 86% of the power inclusion are shown. • ***Zero level:*** The zero level is the threshold value Only pixels with an ADC value above the zero level are shown. • ***Min. ADC:*** The minimum ADC value is the threshold value. • ***Current amplitude:*** The ADC value currently entered in the ***Amplitude in cts*** input field is the threshold value. • ***Current intensity*** The value currently entered in the ***Intensity in kW/cm²*** input field is the threshold value.
Amplitude in cts ***Intensity in kW/cm²***	A threshold value can be set to define a vertical section. ADC values / intensity values beneath the threshold are hidden in the false-color view. It only makes sense to display intensity when a power value has been entered or calculated for the purposes of a measurement. The ADC value (ADC = analog-digital count) corresponds to the raw data from the analog-to-digital converter. This is equal to intensity plus the zero level. In some instances, cts (counts) is given as the unit for the ADC value. To set a threshold, select one of the following options: ▶ Enter a value in one of the input fields. To confirm, press the Enter key. ▶ Use the color-palette slider beneath the input fields. ▶ Click on the color-palette slider. Move it by pressing the left/right arrow keys.
Center on ROI	The ***ROI*** (region of interest) is the area of the measurement window that is used to calculate the beam radius. ▶ Click this box to set the zoom area of the false-color view to the size of the ***ROI*** and to center it.
Automatic scaling	In the coordinates windows of the graphs, the axis of intensity/amplitude can be automatically scaled according to the highest measured value. The axes of both coordinates windows are scaled equally, so that the displayed graphs are always comparable. ▶ Check the box to activate this option.

Tab. 6.26: Options in the Overall settings window for the ***Plane analysis*** tool

Option	Explanation
Show amplitude	▶ Check this box if amplitude (ADC value in counts) rather than intensity is to be displayed in the graphs. It is only possible to display the intensity when a power value has been entered or calculated for the purposes of a measurement.
Show integral	In the coordinates windows of the cross sections, the line integral can be displayed instead of the power density distribution. This means that for each x-value / y-value, the sum of all corresponding y-values / x-values is displayed. Using the line integral, it is easy to identify, for example, any holes in the power density distribution. The image below shows the y-line integral for a non-Gaussian beam.
	
Show Gauss	▶ Check this box if, in addition to graphs showing power density distribution, graphs showing the normal Gaussian distribution are to be displayed as well For this purpose, a Gaussian distribution is approximated to the actual power density distribution according to the smallest error square (Gaussian fit). 👁 Graphs of the power density distribution / line integrals are shown in light blue, Gaussian graphs in dark blue.
Algorithm	The radii are calculated/recalculated according to the algorithm selected. Further information on calculation methods can be found in Chapter 7.5 on page 137. ▶ Select an algorithm from the drop-down list: • ***Device moments:*** Radii are calculated according to the second moment method in the device coordinates (x/y). This produces radii in x-/y-orientation. • ***Invariant moments:*** Radii are calculated according to the second moment method in the device coordinates (x/y). This produces the average of the radii in x-/y-orientation. • ***Rotated moments:*** Following conversion of the device coordinates (x/y) into beam coordinates (a/b), the radius calculation is performed according to the second moment method. This produces radii in a-/b-orientation. • ***86%:*** Radii are calculated according to the 86% method. This produces a radius.

Tab. 6.26: Options in the Overall settings window for the ***Plane analysis*** tool

Settings windows for the coordinates window for the x-/y-cross sections

The table below lists all the options in order of appearance. Some options / drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
Center	▶ To center a graph relative to the false-color view, click on this button.
Remove selection	▶ Click on this button to remove all the distances marked in the coordinates window.
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save the graph measurement data in numerical form as a file with the extension ***.csv***.
Export graphic (.png)	▶ Click on this button to save the coordinates window in its current state as a graphics file with the extension ***.png***. If legends are hidden, they are not included in the exported graphic.
Display	Drop-down menu
Maximum number of points	The maximum number of measurement points displayed can be limited in the following way: ▶ Enter a value in the input field. ▶ Use the slider beneath the input field. 👁 In some instances, a slider appears beneath the graph. This is used to change the size of the section shown. Enter the value 0 to remove the restriction.
Legend	▶ Select in the drop-down list whether a legend is to be displayed – and, if so, in which position.
Graph list	Drop-down menu Different graphs are shown depending on the settings selected in the ***Overall settings window***. Instead of power density distribution, the line integral can be displayed. In addition, the graph of normal Gaussian distribution can also be displayed.
Drop-down list: ***Line*** ***Line+points*** ***Points***	1. Select in the drop-down list a global display form for all graphs. 2. If necessary, alter the display form of individual graphs using the graph list below the graph.
Line width	▶ Enter a value in the input field.
Point size	The points for power density distribution / line integral are shown as circles, the points for the Gaussian graph as squares. ▶ Enter a value in the input field.
Cross section / Line integral / Gauss	Determine if and how these graphs are to be displayed in the coordinates window: ▶ Check the box to display the graph. ▶ Click repeatedly on the icon to the right of the checkbox in order to toggle the display mode.

Tab. 6.27: Options in the settings window for the x-/y-cross sections of the ***Plane analysis*** tool

The *Review* tab in the Plane Analysis tool

To ease measurement routines, PRIMES has translated the requirements for an ISO 11146 measurement with LDS into individual, easily verifiable parameters. LDS rates the quality of each parameter with a traffic light system.
A red light means that a requirement according to ISO 11146 (or a related requirement pertaining to a measurement parameter) has been violated. As the number and severity of parameter violations increases, so too does the uncertainty of each measurement.
If all parameters are green, the measurement can be regarded as reliable and highly accurate.

The values displayed are marked red or green in the table:

- Red: one of the limit values factory configured as a criterion of validity has been violated
- Green: the limit values specified as a criterion of validity have been met

If one or more of the values displayed is marked red, then a red cross appears next to the title of the tab (if not, a green check mark appears).
A red cross indicates that the measurement should be repeated with optimized parameters.

Parameter	Explanation
Fill factor (86%)	Ratio of beam diameter to width of measurement window. If the fill factor is too small, this impacts the resolution of the recorded beam. If the fill factor is too large, there is a risk that the beam will be clipped. The automatic selection of an ROI by the LDS chooses optimal fill factors (target value: 0.33). Lower warning value: 0.30 Upper warning value: 0.60 Upper limit value: 0.75
SNR	Signal-to-noise ratio Lower warning value: 35 Lower limit value: 20
Signal level in %	Modulation related to sensor dynamics. Good values are in the range 40–90. Lower limit value 10 Upper limit value: 95
Percentage of overdriven pixels in %	Permissible number of overdriven pixels (modulation> 95%). Upper limit value: 0.2
Decentering x/y in %	Decentering of the beam's center of gravity with respect to the measurement window. Upper limit value: 5
# Illuminated pixels in r_x / r_y	A minimum number of pixels in the beam diameter is required in order to obtain a reliable measurement value for the diameter. Lower warning value: 30 Lower limit value: 10

Tab. 6.28: Review parameters of the ***Plane analysis*** tool

A systematic introduction to this topic and a detailed description of the tools used to review parameters is provided in Chapter 8.2 “Review of parameters with colored markers” on page 140.

Analysis of a linescan

The element ***Linescan*** can also be opened in this tool. A linescan is a repeated scan at short intervals of a linear section of a laser beam. Linescans can be performed with measuring devices such as **FM+** and **BM+**.

In this case, however, some elements/functionalities of the tool differ from the standard view. In the following, only the aspects specific to the Linescan view are described.

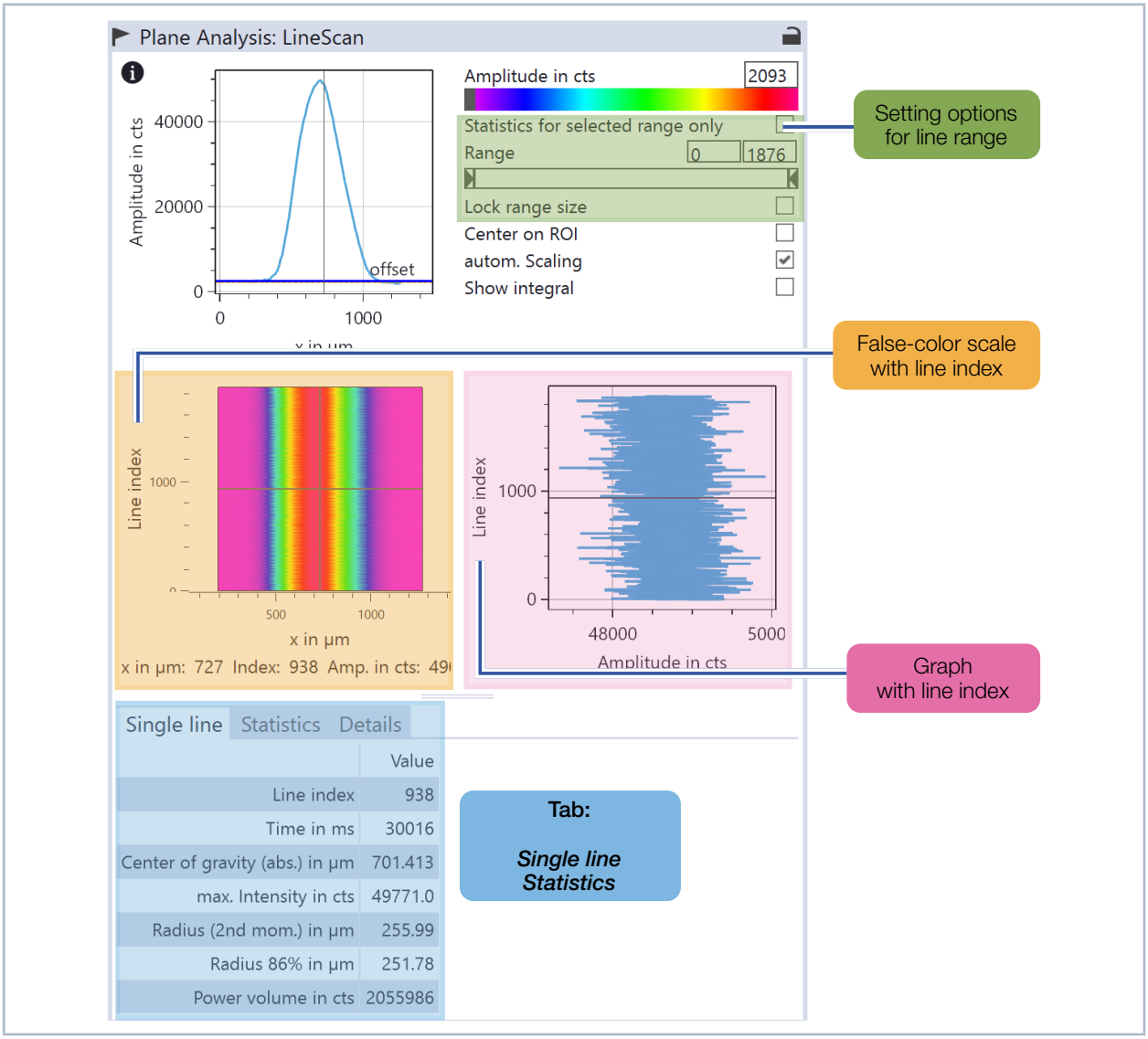


Fig. 6.12: A linescan in the tool ***Plane analysis***

Elements	Description
False-color scale with line index	In the false-color view, the line index forms the y-axis. The reticle marks the active line. The parameters calculated for the active line can be viewed in the ***Single line*** tab.
Graph with line index	In the coordinates window, to the right of the false-color view, the y-axis is replaced by the line index.
Setting options for line range	This settings window features options to determine the line range that is to be displayed: ***Statistics only for the selected area*** ▶ Check this box if only the values for the selected line range are to be calculated in the ***Statistics*** tab. ***Range*** The following options are available to set the Line range that is to be displayed. First, the option ***Lock range size*** must be deactivated: ▶ Enter the minimum/maximum limit value in the left/right input field. To confirm each entry, press the Enter key. ▶ Use the sliders beneath the input fields. ***Lock range size*** ▶ Check this box to lock the position of the slider. If one of the sliders is then moved, the other one will move with it while maintaining the set range.
Table window	This area contains two specific parameters: • ***Single line*** contains the parameters calculated for the selected line. • ***Statistics*** contains an averaged evaluation for all lines. If in the ***settings window*** the option ***Statistics for selected range only*** is activated, then the average will be calculated for this range only.

Tab. 6.29: Elements of the ***Plane analysis*** tool

6.3.3 3D plane display

This tool shows a gradated, three-dimensional false-color view of power density distribution.

In this tool window, both the project tree element ***Plane*** and the element itself can be opened ***Caustic*** by clicking and dragging. This shows the plane that is closest to the focus.

Structure of the tool window

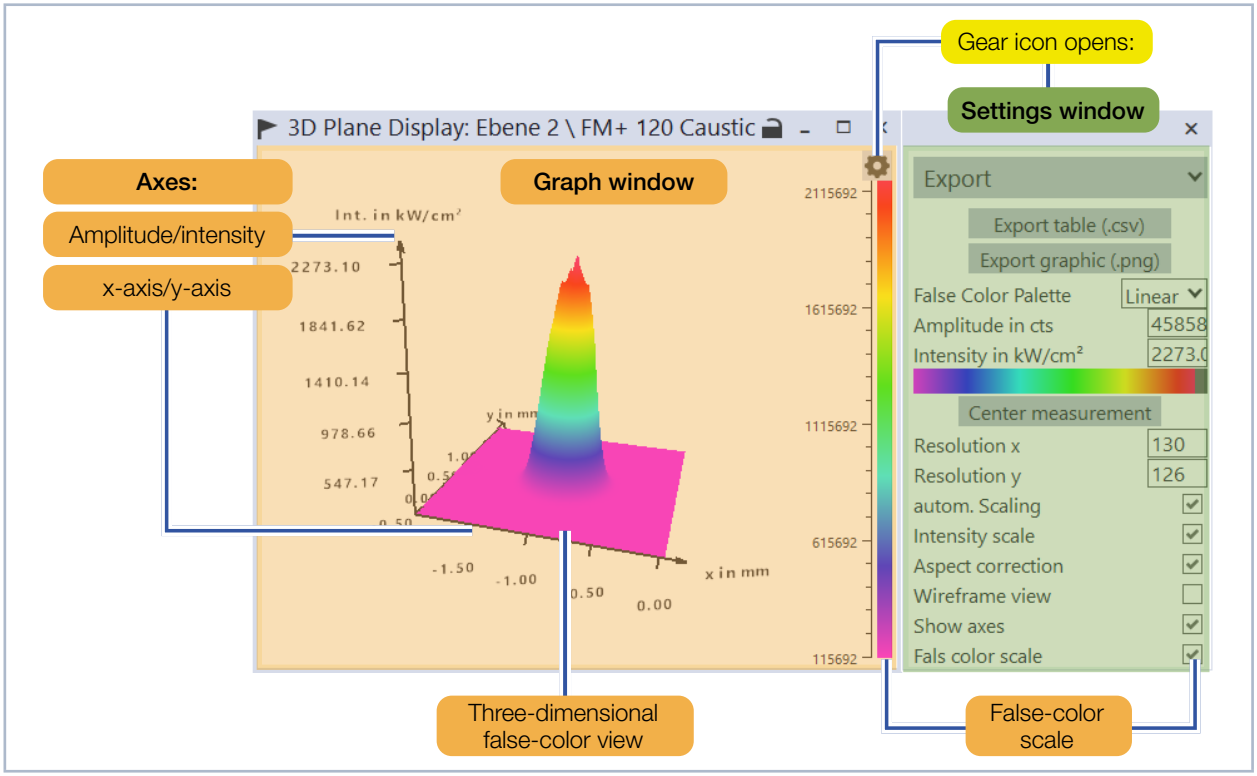


Fig. 6.13: Structure of the ***3D plane display*** tool

Elements	Description
Graph window	This three-dimensional view can be rotated through all spatial axes and is scalable to any size. When the mouse cursor is hovered over the graph window, the following controls options are available: **Opening the settings window:** ▶ Click on the gear icon in the top-right corner. **Zooming to the center of the graph window:** ▶ Turn the mouse wheel. **Rotating the view about its axes:** ▶ Press and hold the left mouse button and drag the graphic. **Moving the graphic:** ▶ Press and hold the right mouse button and drag the graphic. **Centering the graphic:** ▶ Double-click.
Settings window	The settings window contains options for adjusting the graph window and exporting measurement data. Further information can be found in Tab. 6.31 on page 84.

Tab. 6.30: Elements of the ***3D plane display*** tool

Settings window

The table below lists all the options in order of appearance. Some options / drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save all measurement plane data in numerical form as a file with the extension ***.csv***.
Export graphic (.png)	▶ Click on this button to save the graphic in its current state as a graphics file with the extension ***.png***.
False-color palette	For advanced analysis, different color palettes can be selected. Color palettes based on root functions provide a nuanced display of signal components with a very low intensity. This can be particularly useful when analyzing small variations near the zero level (e.g., for analyzing diffraction patterns). ▶ Select color palette from the drop-down list: • ***Linear:*** Linear color palette. • ***2nd root:*** Color palette based on the second root (colors assigned according to the second root of the power density values of each pixel). • ***4th root:*** Color palette based on the fourth root (colors assigned according to the fourth root of the power density values of each pixel). • ***Grayscale:*** Color palette in grayscale.
Amplitude in cts ***Intensity in kW/cm²***	A threshold value can be set to define a vertical section. ADC values / intensity values beneath the threshold are hidden in the false-color view. It only makes sense to display intensity when a power value has been entered or calculated for the purposes of a measurement. The ADC value (ADC = analog-digital count) corresponds to the raw data from the analog-to-digital converter. This is equal to intensity plus the zero level. In some instances, cts (counts) is given as the unit for the ADC value. To set a threshold, select one of the following options: ▶ Enter a value in one of the input fields. To confirm, press the Enter key. ▶ Use the color-palette slider beneath the input fields. ▶ Click on the color-palette slider. Move it by pressing the left/right arrow keys.
Center measurement	▶ Click on this button to center the graphic. 👁 This automatically rotates the graphic and scales it to size.
Resolution x/y	▶ To determine the resolution of the graphic, enter the required values in the relevant input fields. To confirm, press the Enter key. 👁 If the resolution thereby entered exceeds the resolution set during measurement, the latter is automatically selected.
Automatic scaling	▶ Check this box if the axis of intensity/amplitude is to be automatically scaled according to the highest measured value.

Tab. 6.31: Options in the settings window for the ***3D plane display*** tool

Option	Explanation
Intensity scale	▶ Check this box to display amplitude (ADC value in counts) rather than intensity. It is only possible to display the intensity when a power value has been entered or calculated for the purposes of a measurement.
Aspect correction	The x-axis and y-axis can be scaled in such a way as to produce a square. This makes it easier to view measurements with a large aspect ratio. ▶ Check the box to activate this option.
Wireframe view	▶ Check this box to display a pixel grid. Grid resolution is set according to the values entered in the ***Resolution x/y*** input fields.
Show axes	▶ Check this box to display axes.
False-color scale	▶ Check this box to show a false-color scale. This is shown to the right of the graphic.

Tab. 6.31: Options in the settings window for the ***3D plane display*** tool

6.3.4 Power inclusion

In this tool, the radius within a measurement plane can be calculated for any given power inclusion (and vice versa). The results are shown in graphical and numerical form.

Application example: Estimation of the power that is cut off by, or still passes through, an aperture of known diameter. This can be used, for example, to estimate losses in a beam guidance system or focusing unit.

Multiple measurement planes can be simultaneously displayed in this tool window (see Chapter “Opening different measurements in a single tool window in order to compare them” on page 42).
In this tool window, both the project tree element ***Plane*** and the element itself can be opened ***Caustic*** by clicking and dragging. This shows the plane that is closest to the focus.

Structure of the tool window

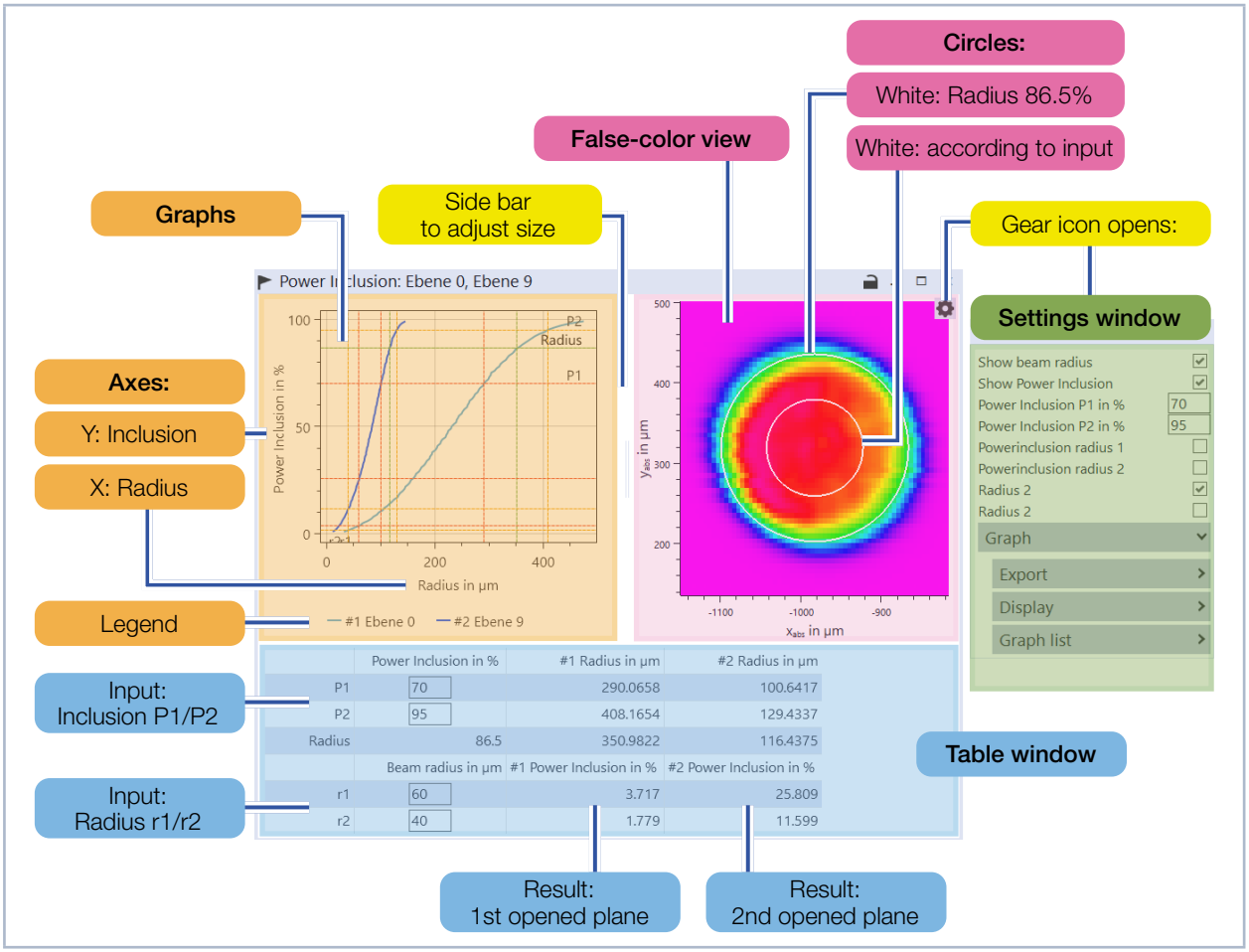


Fig. 6.14: Structure of the ***Power inclusion*** tool

Elements	Description
Coordinates window for graphs	**Control options** Information on the control options in this window can be found in Tab. 6.33 on page 88. **Coordinates window** For each measuring plane, a graph is shown in the coordinates window. The radius is plotted on the x-axis, the power inclusion on the y-axis. If multiple measurement planes are shown in the tool window, a legend can be displayed that assigns the graphs to the corresponding project tree elements and to the results columns in the table window. The coordinates window also contains the following inscribed lines (depending on the settings): • **Green:** Radius at a power inclusion of 86.5% (see Chapter “Radius calculation with the 86% method algorithm” on page 137) • **Red:** Radius / power inclusion according to input P1/r1 • **Orange:** Radius / power inclusion according to input P2/r2
Coordinates window for false-color view	**Control options** Information on the control options in this window can be found in Tab. 6.34 on page 89. **Coordinates window** The measuring plane is displayed graphically in the coordinates window. If several planes are open in the tool, the one most recently opened is displayed. The complete measurable area (measurement area in the shape of a square) and the area recorded therein (measurement window in false-color view) can be displayed. The coordinates window also contains the following elements (depending on the settings): • **White circles:** Radius according to input P1/P2 or r1/r2 • **White circle:** Radius at a power inclusion of 86.5% (see Chapter “Radius calculation with the 86% method algorithm” on page 137)
Settings window	The settings window contains options for adjusting the table window and graph windows. Further information can be found in Tab. 6.35 on page 90.
Table window	The input values for power inclusion P1/P2 and radius r1/r2 can be entered in the rows of the table window. The results are then shown in the columns. If multiple measurement planes are shown in the tool window, a legend can be displayed that assigns the columns to the corresponding project tree elements and to the graphs in the coordinates window. In addition, a beam radius at a power inclusion of 86.5% can be displayed (see Chapter “Radius calculation with the 86% method algorithm” on page 137).

Tab. 6.32: Elements of the ***Power inclusion*** tool

Control options for graphs in the coordinates window

Instead of the right mouse button, the left mouse button can also be used while holding down the Alt key.

Action	Procedure
Zooming to position of mouse cursor	1. Position the mouse cursor anywhere within the coordinates window. 2. Turn the mouse wheel.
Setting a zoom range	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Crtl key and the left mouse button. 3. Draw a square.
Change the scale of an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Turn the mouse wheel.
Shift the display along an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Press and hold the right mouse button and drag along the axis.
Shift the display in any direction	1. Position the mouse cursor anywhere within the coordinates window. 2. Use one of the following options: ▶ Press and hold the right mouse button and drag in the required direction. ▶ Use the arrow keys to incrementally move in the required direction.
Center graphs in the coordinates window	▶ Double-click on the coordinates window. 👁 The axes are moved and scaled so that the graphs completely fill the coordinates window in all directions.
Display coordinate values at any position in a graph	▶ Click on the relevant area of the graph. 👁 The corresponding information is displayed.
Mark an area along the x-axis	Any number of areas can be marked along the x-axis. This serves to measure distances. To mark distances, proceed as follows: 1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Shift key and the left mouse button. 3. Mark an area along the x-axis. 4. If required, repeat to mark further areas along the x-axis.
Removing a marked area	1. Press and hold the Shift key. 2. Click on the area to be removed.

Tab. 6.33: Control options for graphs in the coordinates window

Control options for false-color view in the coordinates window

Action	Procedure
Zooming to the center of the coordinates window	1. Hover the mouse cursor over the coordinates window until the plus/minus buttons appear. 2. Press the buttons for incremental zooming.
Zooming to position of mouse cursor	1. Position the mouse cursor anywhere within the coordinates window. 2. Turn the mouse wheel for incremental zooming.
Adjusting zoom area to the size of the measurement window	1. Hover the mouse cursor over the measurement window. 2. Double-click.
Adjusting zoom area to the size of the measurement area	1. Hover the mouse cursor outside of the measurement window. 2. Double-click.
Moving the entire graphic	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the right mouse button and drag in the required direction.
Measuring a distance	To mark a distance, proceed as follows: 1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Crtl key and the left mouse button. 3. Mark with the mouse.
Removing a marked distance	1. Press and hold the Crtl key. 2. Click on the coordinates window.

Tab. 6.34: Control options for false-color view in the coordinates window

Settings window

The table below lists all the options in order of appearance. Some options/drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
Show beam radius	▶ Check this box to show a radius at a power inclusion of 86.5% (see Chapter "Radius calculation with the 86% method algorithm" on page 137). 👁 The radius is shown in the following way: • In the coordinates window for graphs: as a dotted green line • In the coordinates window for false-color view: as a white circle • In the table window
Show power inclusion	1. Check this box to show power inclusion at a default radius r1/r2. 👁 The table window is enlarged to include rows for r1/r2. 2. Enter a value in the table for radius r1/r2. 3. Confirm by pressing the Enter key. 👁 The power inclusion at r1/r2 is displayed in the coordinates window for graphs and in the table window.
Power inclusion P1/P2 in %	1. Enter a value for power inclusion P1/P2. Alternatively, enter a value in the table. 2. Confirm by pressing the Enter key. 👁 The radius at P1/P2 is displayed in the table and in the coordinates window for graphs.
Power inclusion radius 1/2	▶ Check this box to show a radius at a power inclusion P1/P2. 👁 The radius at P1/P2 is displayed in the coordinates window for false-color view as a white circle.
Radius 1/2	▶ Check this box to show radius r1/r2. 👁 The radius r1/r2 is displayed in the coordinates window for false-color view as a white circle.
Graph	Drop-down menu
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save the data in numerical form as a file with the extension ***.csv***.
Export graphic (.png)	▶ Click on this button to save the graph in its current state as a graphics file with the extension ***.png***.
Copy graphic	▶ Click on this button to copy the graph in its current state to the clipboard.
Display	Drop-down menu
Maximum number of points	The maximum number of measurement points displayed can be limited in the following way: ▶ Enter a value in the input field. ▶ Use the slider beneath the input field. 👁 In some instances, a slider appears beneath the graph. This is used to change the size of the section shown. Enter the value 0 to remove the restriction.
Legend	▶ Select in the drop-down list whether a legend is to be displayed – and, if so, in which position.
Graph list	Drop-down menu
Line width	▶ Enter a value in the input field.
Point size	The points are displayed as circles and squares. ▶ Enter a value in the input field.
Graph list	Determine for each graph if and how it will be displayed in the coordinates window: ▶ Check the box to display the graph. ▶ Click repeatedly on the icon to the right of the checkbox in order to toggle the display mode.

Tab. 6.35: Options in the settings window for the ***Power inclusion*** tool

6.3.5 Beam symmetry analysis

This tool enables beam symmetry analysis on a measured plane. Contour lines to show the intensity values measured for different power densities are generated and approximated by circles. The results are shown in graphical and tabular form.

In the graph window, the contour lines are shown together with the approximated circles. Both a polar and a linear display can be selected. To aid evaluation of beam symmetry, the statistical deviation of measured values from generated values is calculated and displayed in the table window.

In this tool window, both the project tree element ***Plane*** and the element itself can be opened ***Caustic*** by clicking and dragging. This shows the plane that is closest to the focus.

Structure of the tool window

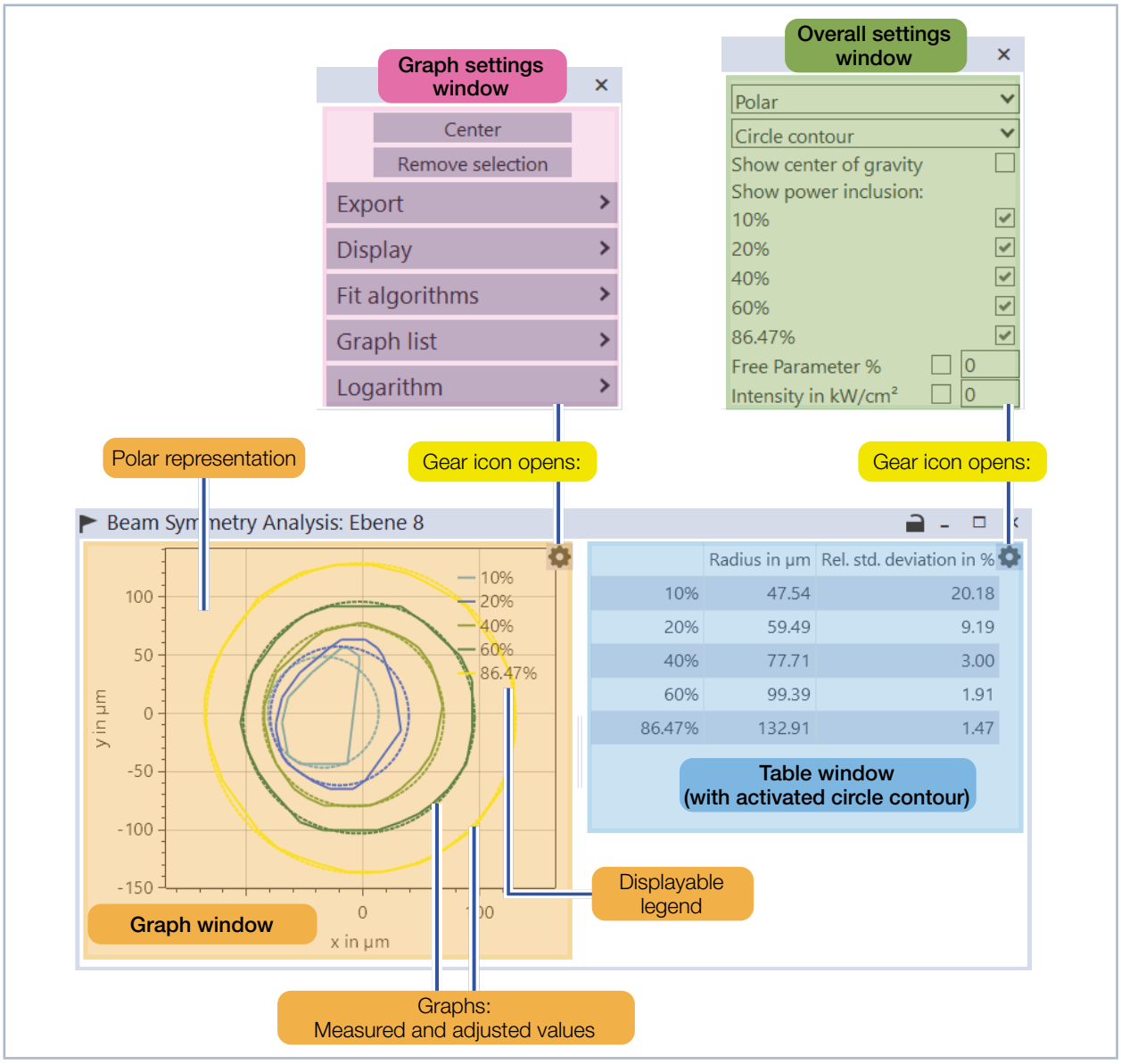


Fig. 6.15: Structure of the ***Beam symmetry analysis*** tool

Elements	Description
Graph window	Information on the control options in this window can be found in Tab. 6.37 on page 93. In the coordinates window, the results of the beam symmetry analysis can be displayed in either polar or linear mode. The following elements may be shown in the graph window (depending on the selected settings): • Whenever the mouse cursor is hovered over the top-right corner of the coordinates window, a **gear icon** appears. This is used to open the Graph settings window. • **Solid lines** show the intensity values measured. • **Dotted lines** show the mathematically approximated circles. • **Crosses** show two-dimensional centers of gravity (in polar views). • A **Legend** assigns the graphs to the corresponding power inclusion / minimum intensity values.
Overall settings window	The Overall settings window features a range of basic options. Further information can be found in Tab. 6.38 on page 94.
Graphics settings window	The Graph settings window features options for graphically adjusting the coordinates window and for exporting the contents of the window. Further information can be found in Tab. 6.39 on page 95.
Table window	The table window shows the following: • When the option ***Circle contour / histogram*** **is activated:** The radii of the mathematically approximated circles and the relative standard deviation of the measured intensity values. • When the options ***Circle contour / histogram*** and ***Show center of gravity*** are activated: The calculated two-dimensional centers of gravity and their relative deviation with respect to the beam center of gravity (calculated according to the first moment method; see Chapter “Calculation of beam position” on page 136).

Tab. 6.36: Elements of the ***Beam symmetry analysis*** tool

Control options in the graph window

Instead of the right mouse button, the left mouse button can also be used while holding down the Alt key.

Action	Procedure
Zooming to position of mouse cursor	1. Position the mouse cursor anywhere within the coordinates window. 2. Turn the mouse wheel.
Setting a zoom range	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Crtl key and the left mouse button. 3. Draw a square.
Change the scale of an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Turn the mouse wheel.
Shift the display along an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Press and hold the right mouse button and drag along the axis.
Shift the display in any direction	1. Position the mouse cursor anywhere within the coordinates window. 2. Use one of the following options: ▶ Press and hold the right mouse button and drag in the required direction. ▶ Use the arrow keys to incrementally move in the required direction.
Center all graphs in the coordinates window	▶ Double-click on the coordinates window, but not in the immediate vicinity of a graph. 👁 The axes are moved and scaled so that the graphs completely fill the coordinates window in all directions.
Display coordinate values at any position in a graph	▶ Click on the relevant area of the graph. 👁 The corresponding information is displayed.
Opening the graph settings window	1. Hover the mouse cursor over the coordinates window until the gear icon appears in the top-right corner. 2. Click on the gear icon to open the settings window.
Mark an area along the x-axis	Any number of areas can be marked along the x-axis. In this way, distances can be measured or fit algorithms applied to individual areas. To mark distances, proceed as follows: 1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Shift key and the left mouse button. 3. Mark an area along the x-axis. 4. If required, repeat to mark further areas along the x-axis.
Removing a marked area	1. Press and hold the Shift key. 2. Click on the area to be removed.
Removing all marked areas	▶ Press the ***Remove selection*** button in the Graph settings window.

Tab. 6.37: Control options in the graph window

Overall settings window

The table below lists all the options in order of appearance.

Option	Explanation
Drop-down list: ***Linear*** ***Polar***	▶ In the drop-down list, select the required mode of display for the graphs.
Drop-down list: ***No circle*** ***Circle contour*** ***Histogram***	▶ Select in the drop-down list whether circles should be mathematically approximated – and, if so, according to which method: • ***No circle:*** No generation of a circle. • ***Circle contour:*** A circle is approximated with a minimum deviation from the contours of the measured values. • ***Histogram:*** Circles are generated in a manner analogous to the 86% method (see Chapter “Radius calculation with the 86% method algorithm” on page 137). 👁 The mathematically approximated circles are shown in the coordinates window as dotted circle graphs. The table window shows their radii and the relative standard deviation of the points of a circle from the measured intensity values.
Show center of gravity	▶ Check this box to calculate the center of gravity of the circles. 👁 Crosses indicating the two-dimensional centers of gravity appear (only in polar view). The table window shows their coordinates and their relative deviation with respect to the beam’s center of gravity (calculated according to the first moment method; see Chapter “Calculation of beam position” on page 136).
Show power inclusion	▶ Check this box to show results in the graph and table windows.
Free parameters	1. Enter any value in the input field in order to determine the power inclusion in percent. 2. If required, check the box to display the results in the graph and table windows.
Intensity in kW/cm²	1. Enter any value in the input field in order to determine the minimum intensity. 2. If required, check the box to display the results in the graph and table windows.

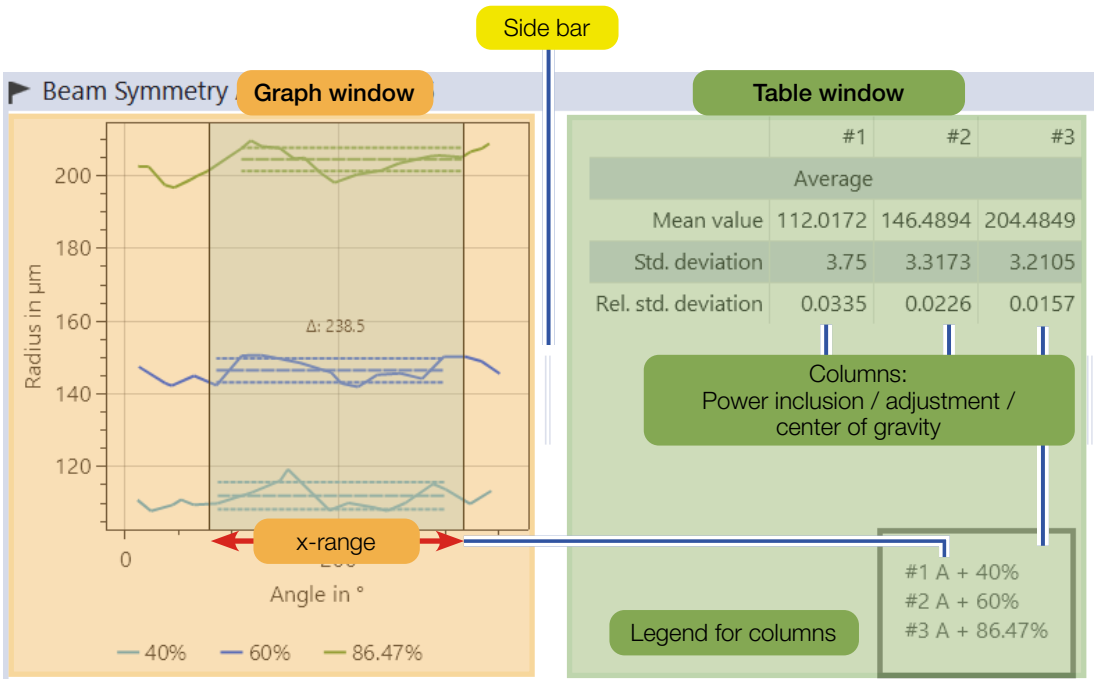
Tab. 6.38: Options in the Overall settings window for the ***Beam symmetry analysis*** tool

Graph settings window

The table below lists all the options in order of appearance. Some options / drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
Center	▶ Click on this button to center the graphic. 👁 The axes are moved and scaled so that the graphs completely fill the coordinates window in all directions.
Remove selection	▶ Click on this button to remove all the distances marked in the coordinates window.
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save the graph data in numerical form as a file with the extension ***.csv***.
Export graphic (.png)	▶ Click on this button to save the graph in its current state as a graphics file with the extension ***.png***.
Copy graphic	▶ Click on this button to copy the graph in its current state to the clipboard.
Display	Drop-down menu
Maximum number of points	This option refers to calculation points in the displayed graphs. The maximum number of points displayed can be limited in the following way: ▶ Enter a value in the input field. ▶ Use the slider beneath the input field. 👁 In some instances, a slider appears beneath the graph. This is used to change the size of the section shown. Enter the value 0 to remove the restriction.
Legend	▶ Select in the drop-down list whether a legend is to be displayed – and, if so, in which position.
Fit algorithms	Drop-down menu Fit algorithms can be applied to the entire x-range of a graph as well as to individual sub-ranges. The results are displayed by means of fit graphs in the coordinates window. In addition, a table for the numerical display of important fit parameters is also displayed. Window size can be altered via the side bar. Sub-ranges can be marked or removed as described in Tab. 6.37 on page 93.

Tab. 6.39: Options in the settings window for the ***Beam symmetry analysis*** tool

Option	Explanation
	
Trend	▶ Check the box to apply trend algorithms.
Averaging	▶ Check the box to perform averaging.
Caustic fit	▶ Check the box to perform a caustic adjustment.
Wavelength	The parameter ***M²*** (fit algorithm***Caustic fit)*** is calculated as a function of wavelength. ▶ Enter a value in the input field.
Graph list	Drop-down menu
Drop-down list: ***Line*** ***Line+points*** ***Points***	1. Select in the drop-down list a global display form for all graphs. 2. If necessary, alter the display form of individual graphs using the graph list below the graph.
Line width	▶ Enter a value in the input field.
Point size	The points are displayed as crosses. ▶ Enter a value in the input field.
Graph list	Determine for each graph if and how it will be displayed in the coordinates window: ▶ Check the box to display the graph. ▶ Click repeatedly on the icon to the right of the checkbox in order to toggle the display mode.
Logarithm	Drop-down menu for logarithmic display of axes. A logarithmic display is particularly useful when the range of values spans many orders of magnitude. This makes it easier to see correlations in the range of small values.
X-axis logarithmic (log10)	▶ Check the box to display the x-axes logarithmically.
Y-axis logarithmic (log10)	▶ Check the box to display the y-axes logarithmically.

Tab. 6.39: Options in the settings window for the ***Beam symmetry analysis*** tool

6.3.6 Caustic analysis

This tool shows the results of a caustic measurement in graphical and tabular form.

> In this tool window, both the project tree element ***Caustic*** and the element itself can be opened ***Plane*** by clicking and dragging. The higher-level caustic is then shown, and the selected plane marked in the filmstrip.

Structure of the tool window

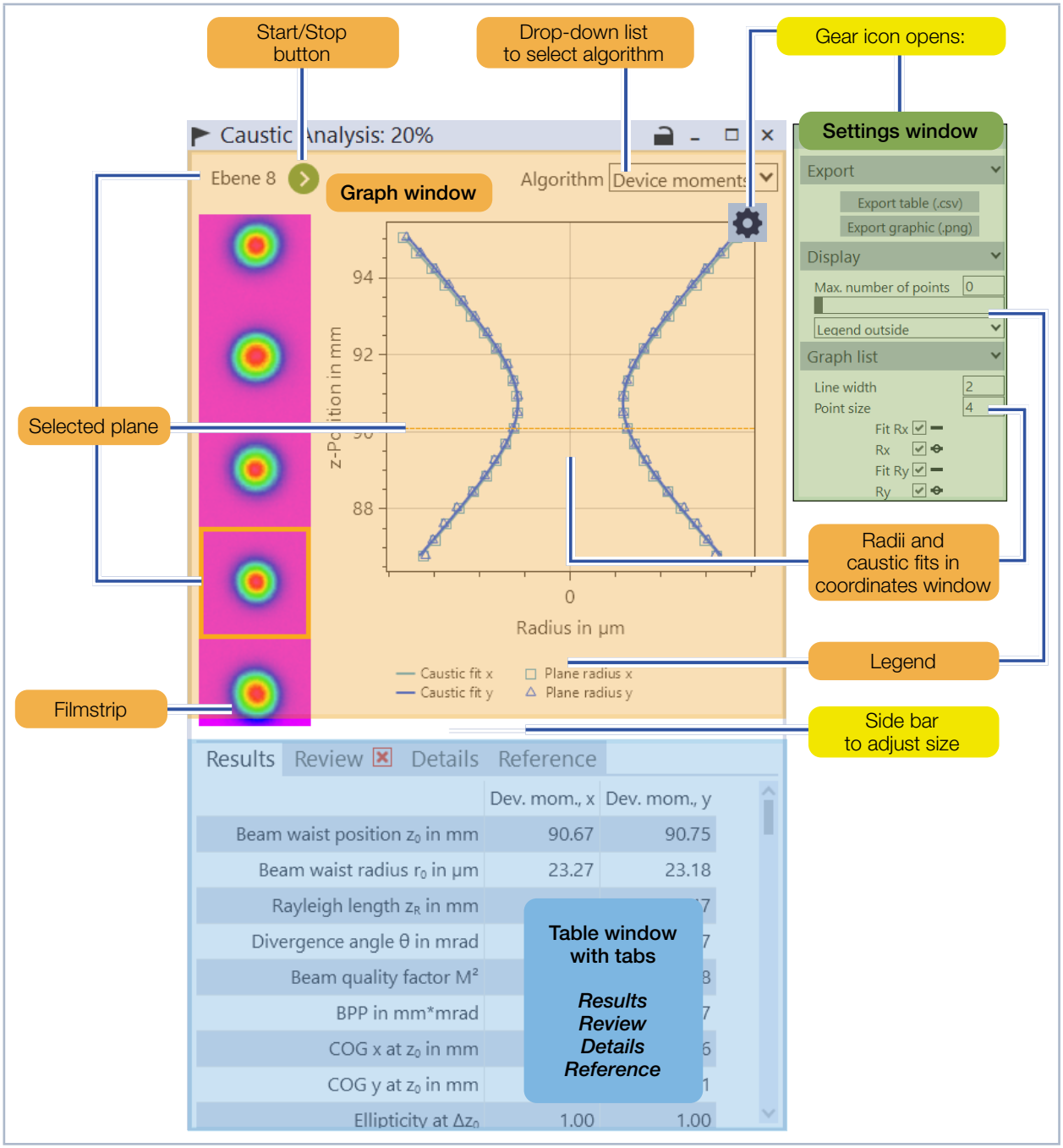


Fig. 6.16: Structure of the ***Caustic analysis*** tool

Elements	Description
Graph window	**Control options** Information on the control options in this window can be found in Tab. 6.41 on page 99. **Top left: Start/Stop button** Clicking on the green Start button causes the filmstrip to automatically spool through the individual planes, starting with the lowest plane of a caustic. To halt this process, click on the red Stop button. **Left-hand side: Filmstrip of the individual planes** The filmstrip shows a false-color view of the power density distribution of individual planes. The active plane is marked by a frame. The project tree name of the active plane is displayed above the filmstrip. **Right-hand side: Coordinates window** The coordinates window shows the caustic longitudinal section and a legend (depending on the settings selected). The calculated radius of the individual planes is plotted on the x-axis, the z-position on the y-axis. The following elements can be displayed in the coordinates window: • Whenever the mouse cursor is hovered over the top-right corner of the coordinates window, a **gear icon** appears. This is used to open the settings window. • The **dotted orange line** shows the z-position of the active plane. • **Blue elements** mark the measured radii and caustic fits. The radii and graphs to be displayed are selected in the separate settings window. In addition, the mode of display can be set here. **Top-right: Drop-down list to select algorithm** Further information can be found in Chapter “Drop-down list to select algorithm” on page 101.
Settings window	The settings window features options for graphically adjusting the coordinates window and for exporting the contents of the window. Further information can be found in Tab. 6.42 on page 100.
Table window	The tables for this area are included in the following tabs: • ***Results:*** Contains the parameters calculated for a caustic. • ***Review:*** Contains the parameters that enable a review of a plane measurement. The review is visually supported by means of colored markers. Further information can be found in Chapter “The Review tab in the Caustic Analysis tool” on page 103. • ***Details:*** Contains additional information on a measurement. If comments on a caustic measurement have been created in the project tree, these are also displayed in this tab. • ***Reference:*** Further information can be found in Chapter “Reference tab” on page 104.

Tab. 6.40: Elements of the ***Caustic analysis*** tool

Control options in the graph window

Range	Explanation
Filmstrip	**To activate a plane:** ▶ Click on the required plane. 👁 The dotted orange line in the coordinates window to the right of the filmstrip shows the z-position of the plane. 👁 If, within the same toolbench, plane data is displayed in other tools, the display is also updated there. This presupposes that these tools are not locked. **To toggle between planes:** ▶ Use the up/down arrow keys. **To open a plane in the *Plane analysis* tool:** ▶ Double-click on this plane. 👁 If the tool is not already open ***Plane analysis*** in the same toolbench, this will automatically occur.
Coordinates window	**Opening the settings window:** 1. Hover the mouse cursor over the coordinates window. 2. Click on the gear icon in the top-right corner. **To activate a plane:** ▶ With the mouse, drag the dotted orange line to the position of the desired plane. 👁 The action of moving the dotted line automatically displays the corresponding plane in the filmstrip.

Tab. 6.41: Control options in the graph window of the ***Caustic analysis*** tool

Settings window

The table below lists all the options in order of appearance. Some options/drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save in numerical form the radii and caustic fits of the coordinates window as a file with the extension ***.csv***. It is irrelevant which radii and caustic fits are currently displayed in the coordinates window. The values of all radii and caustic fits are always exported.
Export graphic (.png)	▶ Click on this button to save the coordinates window in its current state as a graphics file with the extension ***.png***. If legends are hidden, they are not included in the exported graphic.
Display	Drop-down menu
Maximum number of points	The maximum number of measurement points displayed can be limited in the following way: ▶ Enter a value in the input field. ▶ Use the slider beneath the input field. 👁 In some instances, a slider appears beneath the graph. This is used to change the size of the section shown. Enter the value 0 to remove the restriction.
Legend	▶ Select in the drop-down list whether a legend is to be displayed – and, if so, in which position.
Graph list	Drop-down menu for display options for measured radii and caustic fits. Depending on the algorithm selected, the radii and caustic fits are displayed either simply or separately according to main axes: • ***Rotated moments***: Beam main axes a/b • ***Device moments***: Device main axes x/y
Line width	▶ Enter a value in the input field.
Point size	The points for the radii are displayed as squares, the points for the caustic fits as circles. ▶ Enter a value in the input field.
Caustic fit	Determine if and how caustic fits are to be displayed in the coordinates window: ▶ Check the box to display the graph. ▶ Click repeatedly on the icon to the right of the checkbox in order to select the display mode.
Plane radius	Determine if and how these radii are to be displayed in the coordinates window: ▶ Check this box to display the radii. ▶ Click repeatedly on the icon to the right of the checkbox in order to toggle the display mode.

Tab. 6.42: Options in the settings window for the ***Caustic analysis*** tool

Drop-down list to select algorithm

In the top-right corner of the tool window there is a drop-down list to select the algorithm used to calculate the radius. Both the elements in the graph window and the values in the table window are calculated/ recalculated according to the selected algorithm (see Fig. 6.17 on page 102). Further information on calculation methods can be found in Chapter 7.5 on page 137.

PRIMES recommends always starting a caustic analysis with a well-considered choice of algorithm. Results can differ significantly depending on the choice of algorithm. In turn, the review of validity in the ***Review*** tab may also vary (see chapter “The Review tab in the Caustic Analysis tool” on page 103).

▶ Select an algorithm from the drop-down list:

- ***Device moments:***
  Radii are calculated according to the second moment method in the device coordinates (x/y). This produces radii in x-/y-orientation.
- ***Invariant moments:***
  Radii are calculated according to the second moment method in the device coordinates (x/y). This produces the average of the radii in x-/y-orientation.
- ***Rotated moments:***
  Following conversion of the device coordinates (x/y) into beam coordinates (a/b), the radius calculation is performed according to the second moment method. This produces radii in a-/b-orientation.
- ***86%:***
  Radii are calculated according to the 86% method. This produces a radius.

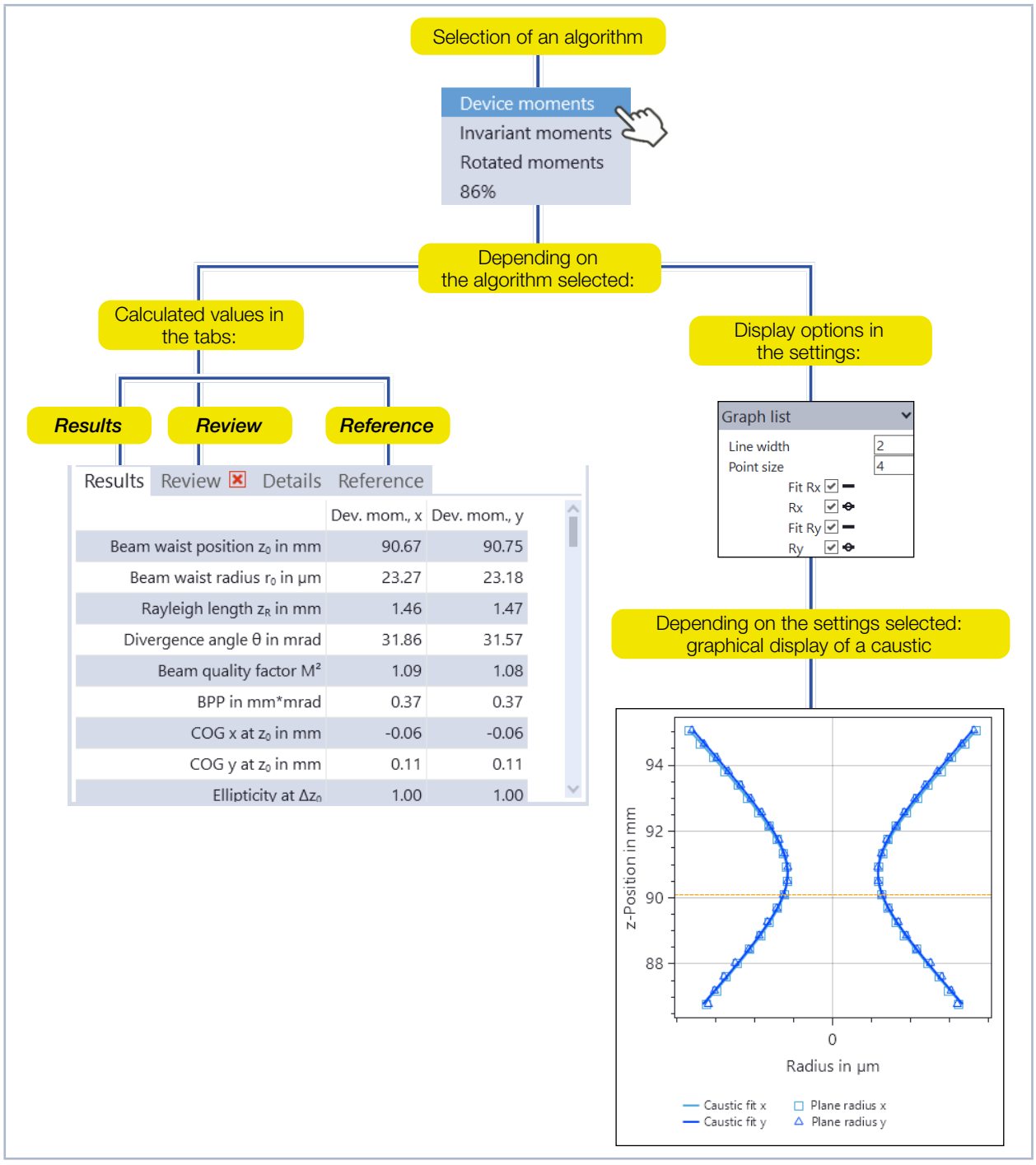


Fig. 6.17: Starting point of a caustic analysis: Selection of an algorithm

The *Review* tab in the Caustic Analysis tool

To ease measurement routines, PRIMES has translated the requirements for an ISO 11146 measurement with LDS into individual, easily verifiable parameters. LDS rates the quality of each parameter with a traffic light system. A red light means that a requirement according to ISO 11146 (or a related requirement pertaining to a measurement parameter) has been violated. As the number and severity of parameter violations increases, so too does the uncertainty of each measurement. If all parameters are green, the measurement can be regarded as reliable and highly accurate.

The values displayed are marked red or green in the table:
- Red: one of the limit values factory configured as a criterion of validity has been violated
- Green: the limit values specified as a criterion of validity have been met

If one or more of the values displayed is marked red, then a red cross appears next to the title of the tab (if not, a green check mark appears). A red cross indicates that the measurement should be repeated with optimized parameters. (see Fig. 6.18 on page 103).

The review of a caustic measurement in the ***Review*** tab can produce different results depending on which algorithm is selected for radius calculation (see Fig. 6.18 on page 103).

Please note: In the project tree, the element ***Caustic*** is always reviewed on the basis of the default standard algorithm. Conversely, in the ***Review*** tab of the ***Caustic analysis*** tool, this review is always based on the algorithm that is currently selected for that tool. For this reason, the review in the ***Review*** tab may be different to the review in the project tree.
The default standard algorithm can be selected in the menu bar ***Extras > Options > Software > Standard algorithm***.

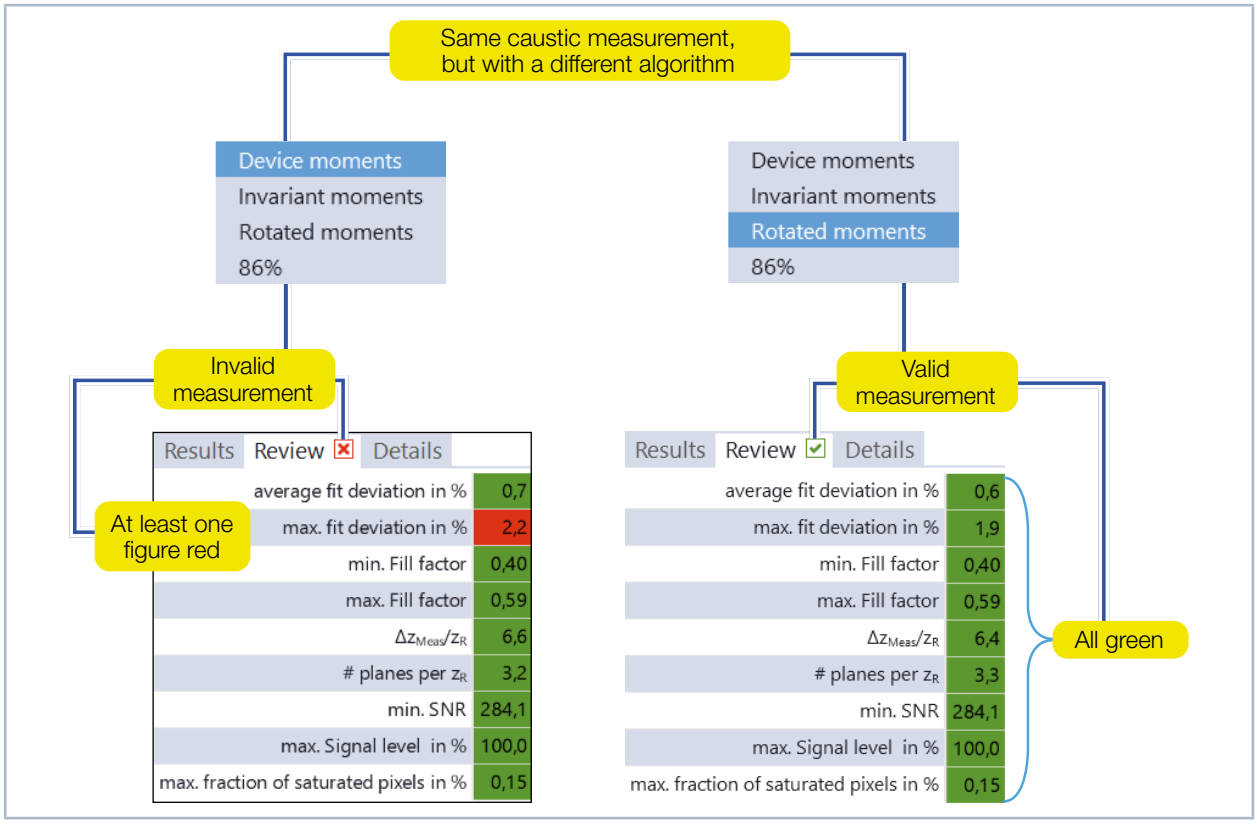


Fig. 6.18: Review of a caustic measurement in the ***Review*** tab

Parameter	Explanation
Averaged fit deviation in %	Averaged deviation of fit from data in percent. Upper warning value: 3.0 Upper limit value: 3.5
Fill factor	Ratio of beam diameter to width of measurement window. If the fill factor is too small, this impacts the resolution of the recorded beam. If the fill factor is too large, there is a risk that the beam will be clipped. The automatic selection of an ROI by the LDS chooses optimal fill factors (target value: 0.33).
Min. fill factor	Plane with the smallest fill factor. Lower warning value: 0.30
Max. fill factor	Plane with the largest fill factor. Upper warning value: 0.60 Upper limit value: 0.75
$\Delta z_{Meas}/z_R$	Ratio of the recorded z-length to the calculated Rayleigh length. The optimal value is 6.0. Lower limit value: 4
# planes per z_R	Number of measured planes per calculated Rayleigh length. The optimal value is 3.5. Lower limit value: 3
Min. SNR:	Value of the lowest signal-to-noise ratio. Lower warning value: 35 Lower limit value: 20
Max. signal level in %	Value of the largest modulation related to sensor dynamics. The optimal value is 75. Upper limit value: 95
Max. proportion of overdriven pixels in %	Value of the permissible number of overdriven pixels (modulation > 95%). Upper limit value: 0.2

Tab. 6.43: Review parameters of the ***Caustic analysis*** tool

A systematic introduction to this topic and a detailed description of the tools used to review parameters is provided in Chapter 8.2 “Review of parameters with colored markers” on page 140.

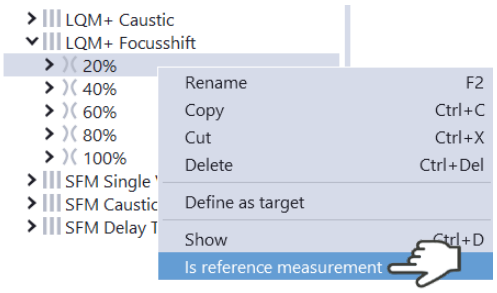
Reference tab

This tab only appears if one of the caustic measurements loaded in the project tree is marked as a reference measurement.

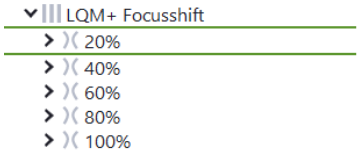
The ***Reference*** tab lists the same parameters as the ***Results*** tab. In this case, however, it is the deviation of the measurement results from those of the reference measurement that is calculated. In order to determine a reference range, a lower and upper threshold value are configured for each parameter. When a parameter deviates beyond this reference range, this is indicated by a red marking.

Proceed as follows in order to configure a caustic measurement as a reference measurement:

1. Right-click on the relevant caustic element in the project tree. This opens the corresponding context menu.
2. Click on the menu item ***Is reference measurement***.



👁 Green lines appear above and below the element. If applicable, these will be removed from the element that was previously marked as a reference measurement.



Proceed as follows in order to configure reference ranges:

1. Right-click on the reference measurement in the project tree. This opens the corresponding context menu.
2. Click on the menu item ***Edit measurement details***.

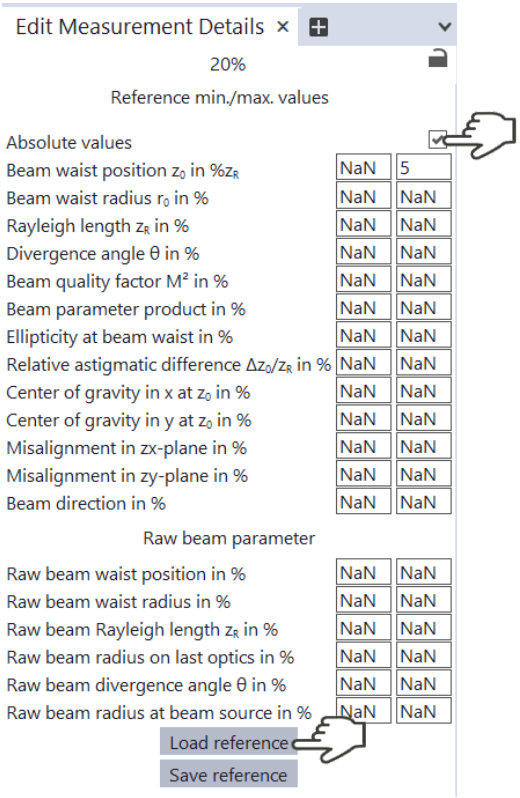
👁 A separate toolbench of the same name opens.

3. Use one of the following options to configure a reference range:

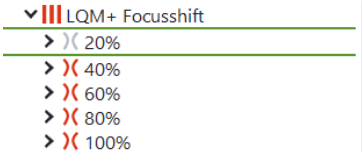
▶ Click the checkbox ***Absolute values,*** if absolute values are to be calculated instead of percentage ones. Enter the minimum/maximum threshold values in the left/right column. Confirm each value by pressing the Enter key.

▶ Click on the button ***Load reference*** in order to load a threshold value from a preconfiguration file with an ***.xml*** extension.

ℹ The default ***NaN*** (“Not a Number”) signifies that no value has been defined.
The area ***Raw beam parameter*** only appears when the reference measurement has been conducted with the ***LaserQualityMonitor LQM+*** measuring device.



👁 Following a configuration of reference ranges, other caustic elements in the project tree may also be marked red. This indicates that they deviate beyond the reference range.

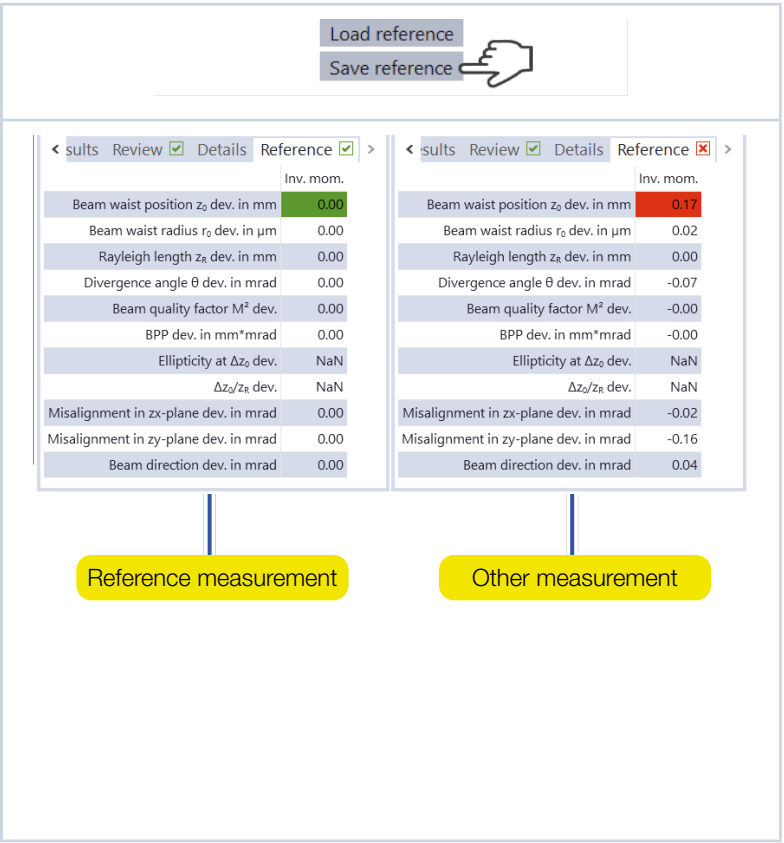


4. Click on the button ***Save reference*** in order to save as a preconfiguration file with an ***.xml*** extension.

5. Open the tool ***Caustic analysis*** in order to analyze the comparative results. To view deviations in a tool that is already open, drag the caustic measurement back into that tool.

> If reference ranges have been entered in the ***Raw beam parameter*** area, then the comparative results are displayed in the ***Raw beam analysis*** tool.

6. Click on the ***Reference*** tab:
- In the reference measurement tab, all the values are set to 0 (near right). Colored markers indicate that a reference range has been configured for the parameter.
- Values that deviate beyond a reference range are marked red (far right). If not, they are marked green
- If no threshold value has been defined (***NaN*** in each field), there are no colored markers.



6.3.7 3D caustic display

This tool generates a three-dimensional caustic display. The power density distributions of the planes are shown as false-color views.

In this tool window, both the project tree element ***Caustic*** and the element itself can be opened ***Plane*** by clicking and dragging. The higher-level caustic is then shown.

Structure of the tool window

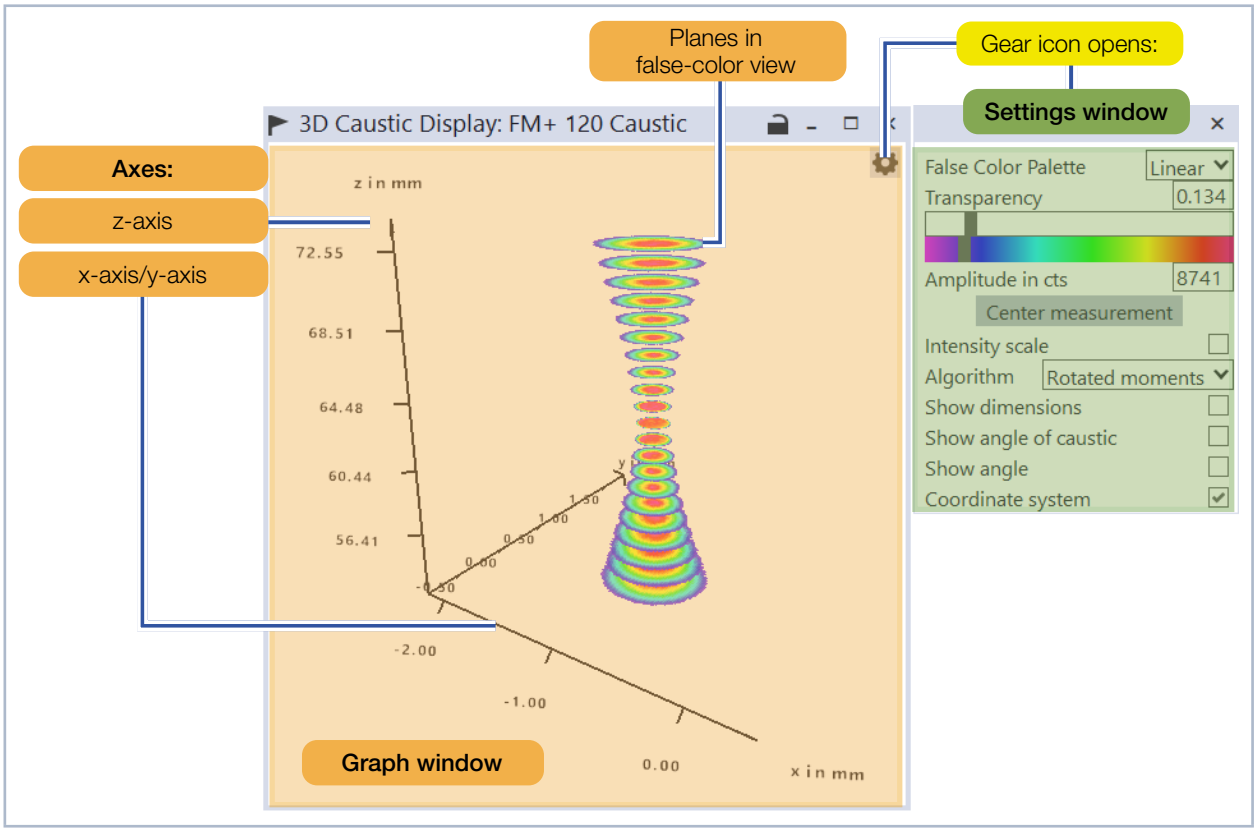


Fig. 6.19: Structure of the ***3D caustic display*** tool

Elements	Description
Graph window	This three-dimensional view can be rotated through all spatial axes and is scalable to any size. When the mouse cursor is hovered over the graph window, the following controls options are available: **Opening the settings window:** ▶ Click on the gear icon in the top-right corner. **Zooming to the center of the graph window:** ▶ Turn the mouse wheel. **Rotating the view about its axes:** ▶ Press and hold the left mouse button and drag the graphic. **Moving the graphic:** ▶ Press and hold the right mouse button and drag the graphic. **Centering the graphic:** ▶ Double-click.
Settings window	The settings window contains options for adjusting the graph window and a drop-down list to select the algorithm used to calculate the radius. Further information can be found in Tab. 6.45 on page 108.

Tab. 6.44: Elements of the ***3D caustic display*** tool

Settings window

The table below lists all the options in order of appearance.

Option	Explanation
False-color palette	For advanced analysis, different color palettes can be selected. Color palettes based on root functions provide a nuanced display of signal components with a very low intensity. This can be particularly useful when analyzing small variations near the zero level (e.g., for analyzing diffraction patterns). ▶ Select color palette from the drop-down list: • ***Linear:*** Linear color palette. • ***2nd root:*** Color palette based on the second root (colors assigned according to the second root of the power density values of each pixel). • ***4th root:*** Color palette based on the fourth root (colors assigned according to the fourth root of the power density values of each pixel). • ***Grayscale:*** Color palette in grayscale.
Transparency	The following options are available to determine the transparency of false-color views: ▶ Enter a value between 0 and 1 in the input field. ▶ Use the slider beneath the input field.
Amplitude in cts ***Intensity in kW/cm²***	Depending on whether the option ***Intensity scaling*** has been activated, a value for amplitude (ADC value) or for intensity in kW/cm² can be entered here. It only makes sense to enter a value for intensity, however, when a value for power has been entered or calculated for the purposes of a measurement. The ADC value (ADC = analog-digital count) corresponds to the raw data from the analog-to-digital converter. This is equal to intensity plus the zero level. In some instances, cts (counts) is given as the unit for the ADC value. The value entered serves as the threshold value for a section. ADC values / intensity values beneath the threshold are hidden in the false-color view. To set a threshold, select one of the following options: ▶ Enter a value in the input field. To confirm, press the Enter key. ▶ Use the color-palette slider beneath the input field. ▶ Click on the color-palette slider. Move it by pressing the left/right arrow keys.
Center measurement	▶ Click on this button to center the graphic. 👁 This automatically rotates the graphic and scales it to size.
Intensity scale	▶ Check this box to display amplitude (ADC value in counts) rather than intensity. It is only possible to display the intensity when a power value has been entered or calculated for the purposes of a measurement.

Tab. 6.45: Options in the settings window for the ***3D caustic display*** tool

Option	Explanation
Algorithm	The radii are calculated/recalculated according to the algorithm selected. Further information on calculation methods can be found in Chapter 7.5 on page 137. ▶ Select an algorithm from the drop-down list: • ***Device moments:*** Radii are calculated according to the second moment method in the device coordinates (x/y). This produces radii in x-/y-orientation. • ***Invariant moments:*** Radii are calculated according to the second moment method in the device coordinates (x/y). This produces the average of the radii in x-/y-orientation. • ***Rotated moments:*** Following conversion of the device coordinates (x/y) into beam coordinates (a/b), the radius calculation is performed according to the second moment method. This produces radii in a-/b-orientation. • ***86%:*** Radii are calculated according to the 86% method. This produces a radius.
Show dimensions	▶ Check this box to show the calculated diameters.
Show angle of caustic	▶ Check this box to show a line that represents the calculated direction of beam propagation.
Show angle	▶ Check this box to show the lines representing the beam/device main axes.
Coordinate system	▶ Check this box to display axes.

Tab. 6.45: Options in the settings window for the ***3D caustic display*** tool

6.3.8 Process volume

This tool is used to calculate the process volume of a laser beam at any given minimum intensity. To determine the process volume and other related parameters, planes that exceed the minimum intensity are used. The results are shown in graphical and tabular form.

In this tool window, both the project tree element ***Caustic*** and the element itself can be opened ***Plane*** by clicking and dragging. This will then calculate the process volume for the higher-level caustic.

Structure of the tool window

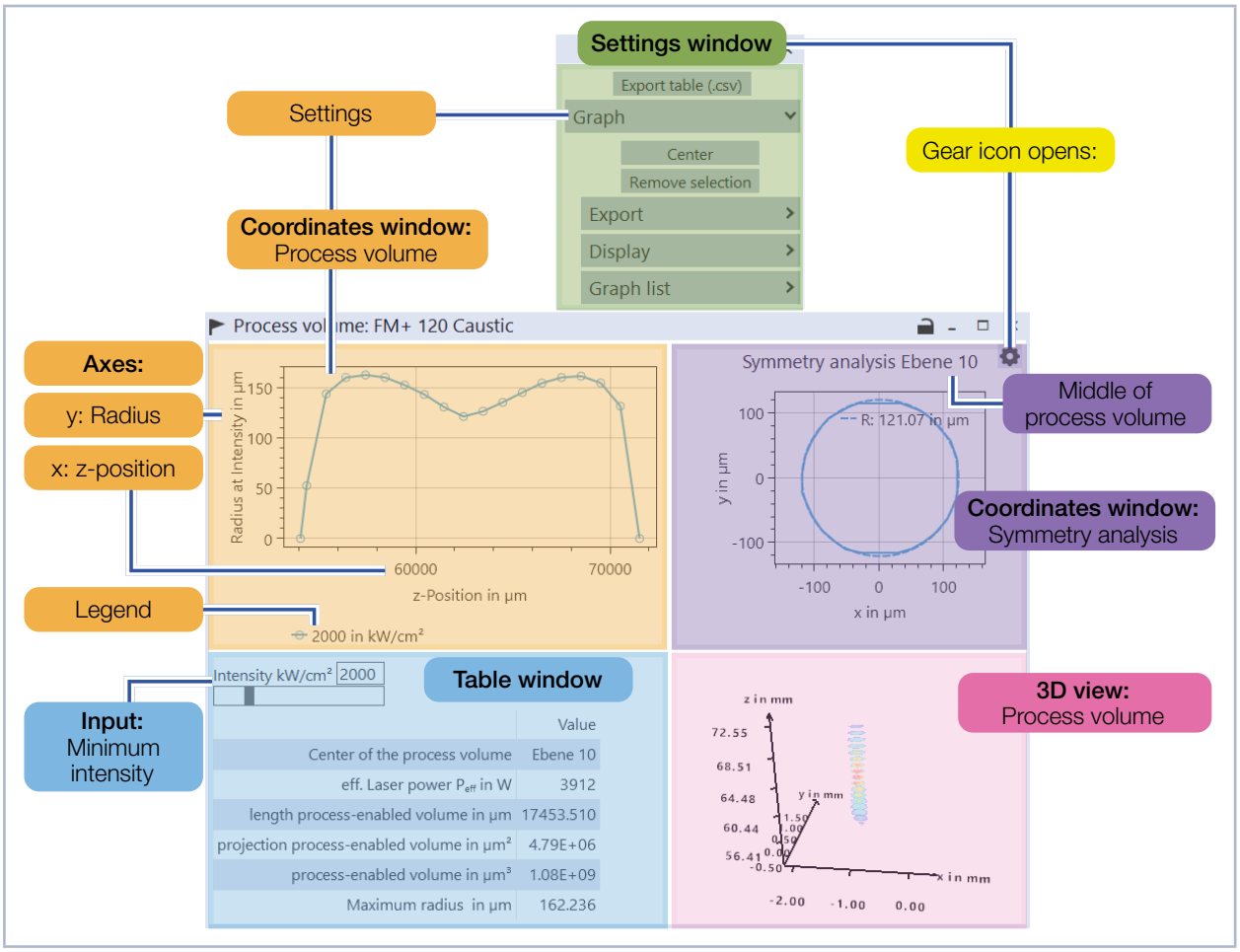


Fig. 6.20: Structure of the ***Process volume*** tool

Elements	Description
Coordinates window: Process volume	**Control options** Information on the control options in this window can be found in Tab. 6.47 on page 112. **Coordinates window** The coordinates window shows a graph of process volume at a given intensity. The z-position is plotted on the x-axis, the radius on the y-axis. A legend can be displayed to show the given intensity for the graph.
Settings window	The settings window contains options for adjusting the coordinates window showing process volume and for exporting data. Further information can be found in Tab. 6.48 on page 113. **Opening the settings window:** 1. Hover the mouse cursor over the tool window until the gear icon appears in the top-right corner. 2. Click on the gear icon to open the settings window.
Coordinates window: Symmetry analysis	**Control options** Information on the control options in this window can be found in Tab. 6.47 on page 112. The coordinates window displays the results of a beam symmetry analysis. This shows the measurement plane that lies approximately in the middle of the process volume. The following elements are plotted: • **Solid line** showing the outline of the measured intensity values. • **Dotted line** showing a circle mathematically approximated to the measured values. A circle is generated with a minimum deviation from the contours of the measured values.
Table window	At the top of the table window, a value for the minimum intensity can be entered. The values of the process volume calculated on this basis are displayed in the table below. To enter a minimum intensity value, select one of the following options: ▶ Enter a value in the input field. To confirm, press the Enter key. ▶ Use the slider beneath the input field. ▶ Click on the slider. Move it by pressing the left/right arrow keys.
3D view: Process volume	This three-dimensional view of process volume can be rotated through all spatial axes and is scalable to any size. When the mouse cursor is hovered over the graphic, the following controls options are available: **Zooming to the center of the graph window:** ▶ Turn the mouse wheel. **Rotating the view about its axes:** ▶ Press and hold the left mouse button and drag the graphic. **Moving the graphic:** ▶ Press and hold the right mouse button and drag the graphic. **Centering the graphic:** ▶ Double-click.

Tab. 6.46: Elements of the ***Process volume*** tool

Control options in coordinates windows

Instead of the right mouse button, the left mouse button can also be used while holding down the Alt key.

Action	Procedure
Zooming to position of mouse cursor	1. Position the mouse cursor anywhere within the coordinates window. 2. Turn the mouse wheel.
Setting a zoom range	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Crtl key and the left mouse button. 3. Draw a square.
Change the scale of an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Turn the mouse wheel.
Shift the display along an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Press and hold the right mouse button and drag along the axis.
Shift the display in any direction	1. Position the mouse cursor anywhere within the coordinates window. 2. Use one of the following options: ▶ Press and hold the right mouse button and drag in the required direction. ▶ Use the arrow keys to incrementally move in the required direction.
Center graphs in the coordinates window	▶ Double-click on the coordinates window. 👁 The axes are moved and scaled so that the graphs completely fill the coordinates window in all directions.
Display coordinate values at any position in a graph	▶ Click on the relevant area of the graph. 👁 The corresponding information is displayed.
Mark an area along the x-axis	Any number of areas can be marked along the x-axis. This serves to measure distances. To mark distances, proceed as follows: 1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Shift key and the left mouse button. 3. Mark an area along the x-axis. 4. If required, repeat to mark further areas along the x-axis.
Removing a marked area	1. Press and hold the Shift key. 2. Click on the area to be removed.
Removing all marked areas (only in the coordinates window for process volume)	▶ Press the ***Remove selection*** button in the settings window.

Tab. 6.47: Control options in coordinates windows

Settings window

The table below lists all the options in order of appearance. Some options / drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
Table export (.csv)	▶ Click on this button to save the measurement data for all caustic planes in numerical form as a file with the extension ***.csv***.
Graph	Drop-down menu ⓘ These options apply only to the coordinates window for process volume.
Center	▶ Click on this button to center the graphic. 👁 The axes are moved and scaled so that the graph completely fills the coordinates window in all directions.
Remove selection	▶ Click on this button to remove all the distances marked in the coordinates window.
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save the data displayed in the coordinates window in numerical form as a file with the extension ***.csv***.
Export graphic (.png)	▶ Click on this button to save the coordinates window in its current state as a graphics file with the extension ***.png***.
Copy graphic	▶ Click on this button to copy the coordinates window in its current state to the clipboard.
Display	Drop-down menu
Maximum number of points	The maximum number of measurement points displayed can be limited in the following way: ▶ Enter a value in the input field. ▶ Use the slider beneath the input field. 👁 In some instances, a slider appears beneath the graph. This is used to change the size of the section shown. Enter the value 0 to remove the restriction.
Legend	▶ Select in the drop-down list whether a legend is to be displayed – and, if so, in which position.
Graph list	Drop-down menu
Drop-down list: ***Line*** ***Line+points*** ***Points***	▶ In the drop-down list, select a display mode for the graph.
Line width	▶ Enter a value in the input field.
Point size	The points are displayed as circles. ▶ Enter a value in the input field.
Graph list	Determine if and how this graph is to be displayed in the coordinates window: ▶ Check the box to display the graph. ▶ Click repeatedly on the icon to the right of the checkbox in order to toggle the display mode.

Tab. 6.48: Options in the settings window for the ***Process volume*** tool

6.3.9 Focus shift

This tool enables an evaluation of a series of caustics in respect of a possible focus shift (see Chapter 8.4 “A focus shift and the temporal stability of measurement results” on page 144).

To achieve a meaningful assessment of focus shift, it is recommended to perform caustic measurements at substantially different laser powers.

Structure of the tool window

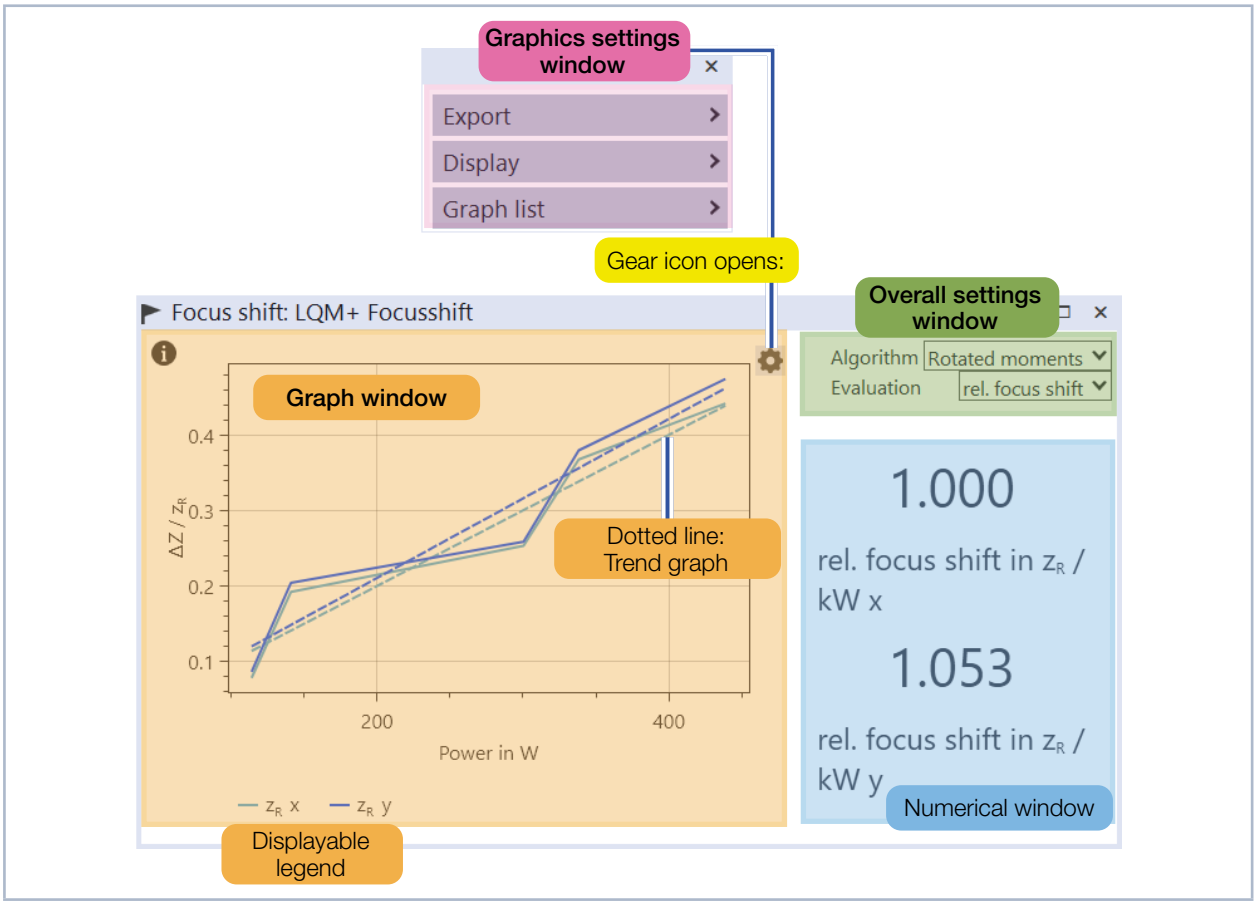


Fig. 6.21: Structure of the ***Focus shift*** tool

Elements	Description
Graph window	Information on the control options in this window can be found in Tab. 6.50 on page 116. The coordinates window shows graphs for $\Delta Z/z_R$ as a function of laser power and for the overall trend (dotted line). Depending on which algorithm is selected to calculate the radius, graphs are displayed either simply or separately according to main axes: • ***Device moments***: Device main axes x/y • ***Invariant moments:*** simple • ***Rotated moments***: Beam main axes a/b • ***86%:*** simple A legend can be displayed to assign the displayed graphs.
Overall settings window	The Overall settings window contains two drop-down lists for basic options. **Drop-down list *Algorithm*** The radii of the caustic planes are calculated/recalculated according to the algorithm selected. Further information on calculation methods can be found in Chapter 7.5 on page 137. ▶ Select an algorithm from the drop-down list: • ***Device moments:*** Radii are calculated according to the second moment method in the device coordinates (x/y). This produces radii in x-/y-orientation. • ***Invariant moments:*** Radii are calculated according to the second moment method in the device coordinates (x/y). This produces the average of the radii in x-/y-orientation. • ***Rotated moments:*** Following conversion of the device coordinates (x/y) into beam coordinates (a/b), the radius calculation is performed according to the second moment method. This produces radii in a-/b-orientation. • ***86%:*** Radii are calculated according to the 86% method. This produces a radius. **Drop-down list *Review*** ▶ Select an algorithm from the drop-down list: • ***Relative focus shift***: The relative focus shift is calculated in the Rayleigh length units z_R per kW. • ***Single mode***: The relative focus shift is calculated in the Rayleigh length units z_R per kW in single mode; i.e., adjusted for M^2. This allows for the fact that the value for M^2 may change during a focus shift.
Graphics settings window	The Graph settings window features options for graphically adjusting the coordinates window and for exporting the contents of the window. Further information can be found in Tab. 6.51 on page 117.
Numerical window	This shows the relative focus shift in the Rayleigh length units z_R per kW (depending on settings). Depending on which algorithm is selected to calculate the radius, values are displayed either simply or separately according to main axes: • ***Device moments***: Device main axes x/y • ***Invariant moments:*** simple • ***Rotated moments***: Beam main axes a/b • ***86%:*** simple

Tab. 6.49: Elements of the ***Focus shift*** tool

Control options in the graph window

Instead of the right mouse button, the left mouse button can also be used while holding down the Alt key.

Action	Procedure
Zooming to position of mouse cursor	1. Position the mouse cursor anywhere within the coordinates window. 2. Turn the mouse wheel.
Setting a zoom range	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Crtl key and the left mouse button. 3. Draw a square.
Change the scale of an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Turn the mouse wheel.
Shift the display along an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Press and hold the right mouse button and drag along the axis.
Shift the display in any direction	1. Position the mouse cursor anywhere within the coordinates window. 2. Use one of the following options: ▶ Press and hold the right mouse button and drag in the required direction. ▶ Use the arrow keys to incrementally move in the required direction.
Center all graphs in the coordinates window	▶ Double-click on the coordinates window, but not in the immediate vicinity of a graph. 👁 The axes are moved and scaled so that the graphs completely fill the coordinates window in all directions.
Display coordinate values at any position in a graph	▶ Click on the relevant area of the graph. 👁 The corresponding information is displayed.
Opening the graph settings window	1. Hover the mouse cursor over the coordinates window until the gear icon appears in the top-right corner. 2. Click on the gear icon to open the settings window.
Mark an area along the x-axis	Any number of areas can be marked along the x-axis. This serves to measure distances. To mark distances, proceed as follows: 1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Shift key and the left mouse button. 3. Mark an area along the x-axis. 4. If required, repeat to mark further areas along the x-axis.
Removing a marked area	1. Press and hold the Shift key. 2. Click on the area to be removed.

Tab. 6.50: Control options in the graph window

Graph settings window

The table below lists all the options in order of appearance. Some options / drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save the graph data in numerical form as a file with the extension ***.csv***.
Export graphic (.png)	▶ Click on this button to save the graph in its current state as a graphics file with the extension ***.png***.
Copy graphic	▶ Click on this button to copy the graph in its current state to the clipboard.
Display	Drop-down menu
Maximum number of points	The maximum number of measurement points displayed can be limited in the following way: ▶ Enter a value in the input field. ▶ Use the slider beneath the input field. 👁 In some instances, a slider appears beneath the graph. This is used to change the size of the section shown. Enter the value 0 to remove the restriction.
Legend	▶ Select in the drop-down list whether a legend is to be displayed – and, if so, in which position.
Graph list	Drop-down menu Depending on which algorithm is selected to calculate the radius, graphs are displayed either simply or separately according to main axes: • ***Device moments***: Device main axes x/y • ***Invariant moments:*** simple • ***Rotated moments***: Beam main axes a/b • ***86%:*** simple
Line width	▶ Enter a value in the input field.
Point size	The points are displayed as circles and squares. ▶ Enter a value in the input field.
Graph list	Determine for each graph if and how it will be displayed in the coordinates window: ▶ Check the box to display the graph. ▶ Click repeatedly on the icon to the right of the checkbox in order to change the display mode.

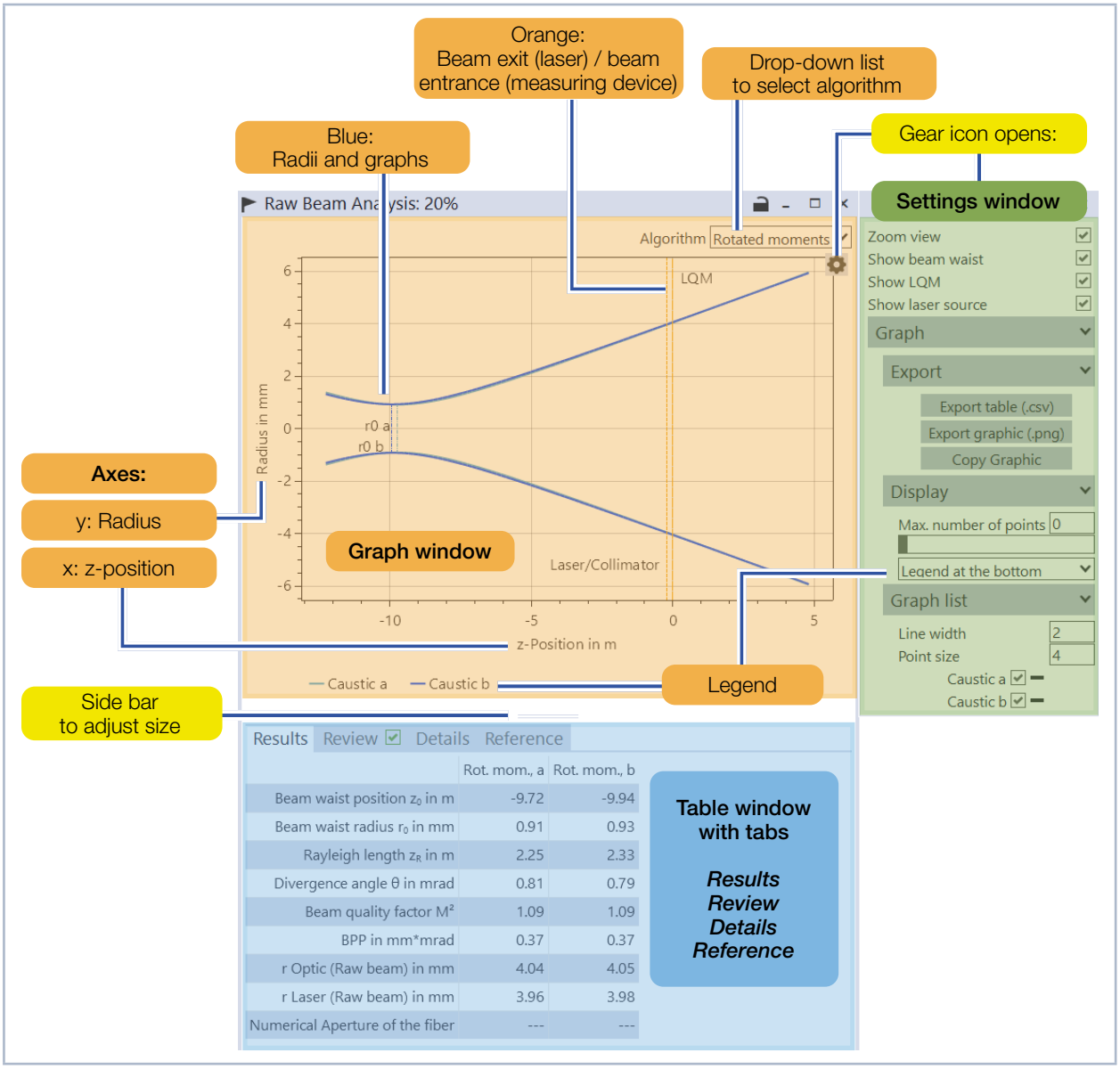
Tab. 6.51: Options in the settings window for the ***Focus shift*** tool

6.3.10 Raw beam analysis

This tool shows the results of a raw beam back calculation in graphical and tabular form. Calculation of raw beam parameters from a measured caustic is only possible for measurements with the LaserQualityMonitor LQM+ measuring device. This uses the formula described in ISO 11146.

The project tree element ***Caustic*** can also be opened in this tool window. However, measurement results are only displayed if the measurement has been performed with a suitable measuring device.
In addition, the element ***Plane*** can be opened by clicking and dragging. The back calculation is then based on the higher-level caustic.

Structure of the tool window



	Rot. mom., a	Rot. mom., b
Beam waist position z_0 in m	-9.72	-9.94
Beam waist radius r_0 in mm	0.91	0.93
Rayleigh length z_R in m	2.25	2.33
Divergence angle θ in mrad	0.81	0.79
Beam quality factor M^2	1.09	1.09
BPP in mm*mrad	0.37	0.37
r Optic (Raw beam) in mm	4.04	4.05
r Laser (Raw beam) in mm	3.96	3.98
Numerical Aperture of the fiber	---	---

Fig. 6.22: Structure of the ***Raw beam analysis*** tool

Elements	Description
Graph window	**Control options** Information on the control options in this window can be found in Tab. 6.53 on page 120. **Coordinates window** The coordinates window shows the caustic longitudinal section of the raw beam and a legend (depending on the graphic settings selected). The z-position is plotted on the x-axis, the back-calculated radius on the y-axis. The following elements can be displayed in the coordinates window: • Whenever the mouse cursor is hovered over the top-right corner of the coordinates window, a **gear icon** appears. This is used to open the settings window. • The **orange lines** show the z-position of the beam exit at the laser/collimator and of the beam entrance at the optics of the measuring device. The position of the beam exit is only displayed if a distance between the device and laser has been entered in the measurement details. • **Blue elements** show the radius/radii, as a function of the z-position, and the beam waist. The graphs to be displayed are selected in the separate settings window. In addition, the mode of display can be set here. **Drop-down list to select algorithm** In the top-right corner of the tool window there is a drop-down list to select the algorithm used to calculate the radii of the actual caustic. The results of the raw beam back calculation can differ substantially depending on the algorithm selected for the caustic calculation. Further information can be found in Chapter “Drop-down list to select algorithm” on page 101.
Settings window	The settings window features options for graphically adjusting the coordinates window and for exporting the contents of the window. Further information can be found in Tab. 6.54 on page 121.
Table window	The tables for this area are included in the following tabs: • ***Results:*** Contains the back-calculated raw beam parameters. The radius at the beam exit of the laser/collimator is only calculated if a distance between the device and laser has been entered in the measurement details. The numerical aperture of the fiber is only calculated if a focal length for the collimator has been entered in the measurement details. (Measurement details are called up via the context menu in the project tree; see Chapter 5.4.6 on page 21). • ***Review:*** Contains the relevant parameters of the actual caustic measurement; i.e., as in the similarly named tab of the tool ***Caustic analysis*** (see Chapter “The Review tab in the Caustic Analysis tool” on page 103). • ***Details:*** Contains additional information on a measurement. If comments on a caustic measurement have been created in the project tree, these are also displayed in this tab. • ***Reference:*** If a caustic measurement with raw beam back calculation is activated as a reference measurement, the deviation between the back-calculated raw beam parameters and the reference values are displayed here. Further information can be found in Chapter “Reference tab” on page 104.

Tab. 6.52: Elements of the ***Raw beam analysis*** tool

Control options in the graph window

Instead of the right mouse button, the left mouse button can also be used while holding down the Alt key.

Action	Procedure
Zooming to position of mouse cursor	1. Position the mouse cursor anywhere within the coordinates window. 2. Turn the mouse wheel.
Setting a zoom range	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Crtl key and the left mouse button. 3. Draw a square.
Change the scale of an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Turn the mouse wheel.
Shift the display along an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Press and hold the right mouse button and drag along the axis.
Shift the display in any direction	1. Position the mouse cursor anywhere within the coordinates window. 2. Use one of the following options: ▶ Press and hold the right mouse button and drag in the required direction. ▶ Use the arrow keys to incrementally move in the required direction.
Center graphs in the coordinates window	▶ Double-click on the coordinates window. 👁 The axes are moved and scaled so that the graphs completely fill the coordinates window in all directions.
Display coordinate values at any position in a graph	▶ Click on the relevant area of the graph. 👁 The corresponding information is displayed.
Opening the settings window	1. Hover the mouse cursor over the coordinates window until the gear icon appears in the top-right corner. 2. Click on the gear icon to open the settings window.
Mark an area along the x-axis	Any number of areas can be marked along the x-axis. This serves to measure distances. To mark distances, proceed as follows: 1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Shift key and the left mouse button. 3. Mark an area along the x-axis. 4. If required, repeat to mark further areas along the x-axis.
Removing a marked area	1. Press and hold the Shift key. 2. Click on the area to be removed.

Tab. 6.53: Control options in the graph window

Settings window

The table below lists all the options in order of appearance. Some options / drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
Zoom view	This view shows the area of the beam waist and the side of the raw beam adjacent to the measuring device. ▶ Check the box to activate this option.
Show beam waist	▶ Check the box to show the radii at the beam waist.
Show LQM	▶ Check this box to show the z-position of the beam entrance at the optics of the measuring device.
Show laser source	▶ Check this box to show the z-position of the beam exit at the laser/collimator.
Graph	Drop-down menu
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save the graph data in numerical form as a file with the extension ***.csv***.
Export graphic (.png)	▶ Click on this button to save the graph in its current state as a graphics file with the extension ***.png***.
Copy graphic	▶ Click on this button to copy the graph in its current state to the clipboard.
Display	Drop-down menu
Maximum number of points	In this case, points do not refer to measurement points – as here the radii of the raw beam are back calculated, not measured. Instead, it refers to the mode of display for the graphs. The maximum number of points displayed can be limited in the following way: ▶ Enter a value in the input field. ▶ Use the slider beneath the input field. 👁 In some instances, a slider appears beneath the graph. This is used to change the size of the section shown. Enter the value 0 to remove the restriction.
Legend	▶ Select in the drop-down list whether a legend is to be displayed – and, if so, in which position.
Graph list	Drop-down menu
Line width	▶ Enter a value in the input field.
Point size	In this case, points do not refer to measurement points – as here the radii of the raw beam are back calculated, not measured. Instead, it refers to the mode of display for the graphs. The points are displayed as circles and squares. ▶ Enter a value in the input field.
Graph list	Determine for each graph if and how it will be displayed in the coordinates window: ▶ Check the box to display the graph. ▶ Click repeatedly on the icon to the right of the checkbox in order to change the display mode.

Tab. 6.54: Options in the settings window for the ***Raw beam analysis*** tool

6.3.11 Beam pointing stability

With camera-based measuring devices, beam pointing stability can be monitored. For this purpose, the device performs plane measurements alternately at two z-positions of a beam. The points measured in this way show the position of the beam's center of gravity on the focal plane as well as the beam's angle of incidence to the z-axis. The measurement points are shown in the two coordinates windows of the tool ***Beam pointing stability***.

Only logged measurements and measurements saved as caustics can be displayed.
In this tool window, both the project tree element ***Caustic*** and the element itself can be opened ***Plane*** by clicking and dragging. The higher-level caustic is then analyzed.

Structure of the tool window

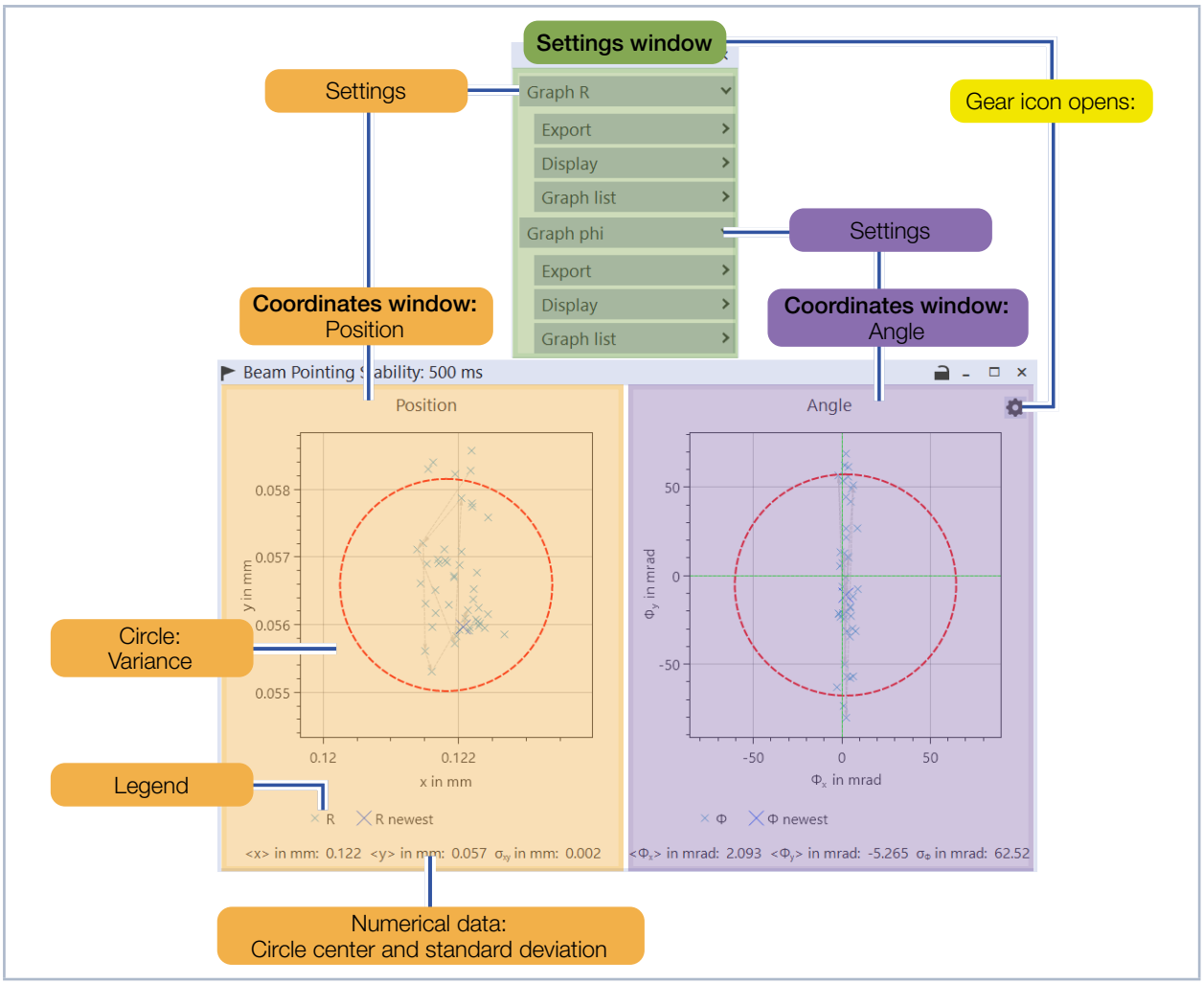


Fig. 6.23: Structure of the ***Beam pointing stability*** tool

Elements	Description
Coordinates window: Position	**Control options** Information on the control options in this window can be found in Tab. 6.56 on page 124. **Coordinates window** The coordinates window shows the position of the beam's center of gravity on the focal plane. The measurement points are displayed as crosses. The lines joining the points show the temporal sequence of the measurements. The final position of the laser beam is represented by a large cross, former positions by a small cross. The dotted circle shows the variance (spread of the probability density around its center of gravity) of the measurement points. Beneath the window, the following numerical information is shown: • **x/y coordinates:** Center of circle • **Sigma value**: statistical deviation A legend can be displayed.
Coordinates window: Angle	The coordinates window shows the angle between beam and z-axis. The measurement points are displayed as crosses. All other aspects are identical to those of the coordinates window **Position**.
Settings window	The settings window contains options for adjusting the coordinates window and for exporting data. Further information can be found in Tab. 6.57 on page 125. **Opening the settings window:** 1. Hover the mouse cursor over the tool window until the gear icon appears in the top-right corner. 2. Click on the gear icon to open the settings window.

Tab. 6.55: Elements of the ***Beam pointing stability*** tool

Control options in coordinates windows

Instead of the right mouse button, the left mouse button can also be used while holding down the Alt key.

Action	Procedure
Zooming to position of mouse cursor	1. Position the mouse cursor anywhere within the coordinates window. 2. Turn the mouse wheel.
Setting a zoom range	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Crtl key and the left mouse button. 3. Draw a square.
Change the scale of an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Turn the mouse wheel.
Shift the display along an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Press and hold the right mouse button and drag along the axis.
Shift the display in any direction	1. Position the mouse cursor anywhere within the coordinates window. 2. Use one of the following options: ▶ Press and hold the right mouse button and drag in the required direction. ▶ Use the arrow keys to incrementally move in the required direction.
Center graphs in the coordinates window	▶ Double-click on the coordinates window. 👁 The axes are moved and scaled so that the graphs completely fill the coordinates window in all directions.
Display coordinate values at any position in a graph	▶ Click on the relevant area of the graph. 👁 The corresponding information is displayed.
Mark an area along the x-axis	Any number of areas can be marked along the x-axis. This serves to measure distances. To mark distances, proceed as follows: 1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Shift key and the left mouse button. 3. Mark an area along the x-axis. 4. If required, repeat to mark further areas along the x-axis.
Removing a marked area	1. Press and hold the Shift key. 2. Click on the area to be removed.

Tab. 6.56: Control options in coordinates windows

Settings window

The table below lists all the options in order of appearance. Some options/drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
Graph R/phi	Drop-down menu for the coordinates window R/phi
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save the data displayed in the coordinates window in numerical form as a file with the extension ***.csv***.
Export graphic (.png)	▶ Click on this button to save the coordinates window in its current state as a graphics file with the extension ***.png***.
Copy graphic	▶ Click on this button to copy the coordinates window in its current state to the clipboard.
Display	Drop-down menu
Maximum number of points	The maximum number of measurement points displayed can be limited in the following way: ▶ Enter a value in the input field. ▶ Use the slider beneath the input field. 👁 In some instances, a slider appears beneath the graph. This is used to change the size of the section shown. Enter the value 0 to remove the restriction.
Legend	▶ Select in the drop-down list whether a legend is to be displayed – and, if so, in which position.
Graph list	Drop-down menu
Line width	▶ Enter a value in the input field.
Point size	The points are displayed as circles. ▶ Enter a value in the input field.
Graph list	Determine if and how this graph is to be displayed in the coordinates window: ▶ Check the box to display the graph. ▶ Click repeatedly on the icon to the right of the checkbox in order to change the display mode.

Tab. 6.57: Options in the settings window for the ***Beam pointing stability*** tool

6.3.12 Preventive maintenance

Using this tool, limit values can be specified for any parameter. An analysis of previous measurement results is used to calculate the future point in time at which limit values are forecast to be reached. This tool is suitable for displaying the following project tree elements: ***Series*** and ***Caustic***.
This forecast can serve as a basis for future maintenance schedules. If, for example, power is repeatedly measured at constant laser power, then falling measurement readings may well indicate increasing contamination of the optics. It can then be estimated when, at the latest, the optics should be cleaned in order to avoid a limit value violation.

Structure of the tool window

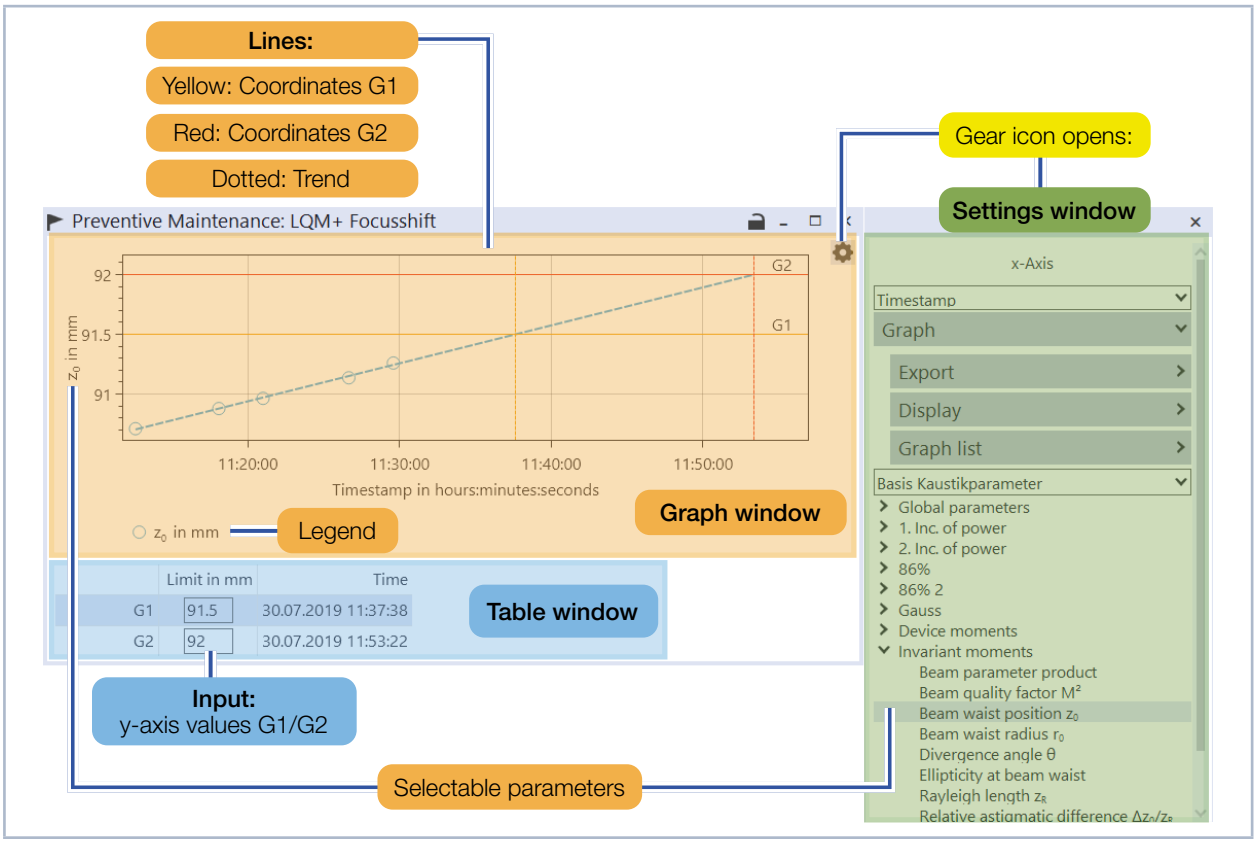


Fig. 6.24: Structure of the ***Preventive maintenance*** tool

Elements	Description
Graph window	Information on the control options in this window can be found in Tab. 6.59 on page 127. The parameter selected in the settings window is plotted on the y-axis. For the x-axis, the inscriptions ***Index*** and ***Timestamp*** can be selected in the settings window. The coordinates window shows graphs for the measurement points and for the trend. If the graphs are shown as lines (depending on settings), then the graph for the measurement points is plotted as a solid line and the graph for the trend as a dotted line. If a limit value G1/G2 is entered in the table window, then the coordinates will be shown as yellow/red lines. These coordinates are plotted on the trend graph. Whenever the mouse cursor is hovered over the top-right corner of the graph window, a gear icon appears. This is used to open the settings window.
Table window	The limit values G1/G2 for the y-axis can be entered in the rows of the table window. The corresponding values for the x-axis will then be calculated.
Settings window	The settings window contains options for adjusting the graph window and exporting data. Further information can be found in Tab. 6.60 on page 128.

Tab. 6.58: Elements of the ***Preventive maintenance*** tool

Control options in the graph window

Instead of the right mouse button, the left mouse button can also be used while holding down the Alt key.

Action	Procedure
Zooming to position of mouse cursor	1. Position the mouse cursor anywhere within the coordinates window. 2. Turn the mouse wheel.
Setting a zoom range	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Crtl key and the left mouse button. 3. Draw a square.
Change the scale of an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Turn the mouse wheel.
Shift the display along an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Press and hold the right mouse button and drag along the axis.
Shift the display in any direction	1. Position the mouse cursor anywhere within the coordinates window. 2. Use one of the following options: ▶ Press and hold the right mouse button and drag in the required direction. ▶ Use the arrow keys to incrementally move in the required direction.
Center all graphs in the coordinates window	▶ Double-click on the coordinates window, but not in the immediate vicinity of a graph. 👁 The axes are moved and scaled so that the graphs completely fill the coordinates window in all directions.
Display coordinate values at any position in a graph	▶ Click on the relevant area of the graph. 👁 The corresponding information is displayed.
Opening the settings window	1. Hover the mouse cursor over the tool window until the gear icon appears in the top-right corner. 2. Click on the gear icon to open the settings window.
Calculate a trend for a specific x-axis range	The trend algorithm can be selectively applied to a specific x-axis range. Proceed as follows: 1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Shift key and the left mouse button. 3. Mark an area along the x-axis. 👁 Measurement points within a range are marked. The trend for this range is then calculated.
Remove selection of an x-axis range	1. Press and hold the Shift key. 2. Click on the coordinates window.

Tab. 6.59: Control options in the graph window

Settings window

The table below lists all the options in order of appearance. Some options / drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
X-axis	▶ Select an x-axis inscription from the drop-down list.
Graph	Drop-down menu
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save the table in its current state as a file with the extension ***.csv***.
Export graphic (.png)	▶ Click on this button to save the graph in its current state as a graphics file with the extension ***.png***.
Copy graphic	▶ Click on this button to copy the graph in its current state to the clipboard.
Display	Drop-down menu
Maximum number of points	The maximum number of measurement points displayed can be limited in the following way: ▶ Enter a value in the input field. ▶ Use the slider beneath the input field. 👁 In some instances, a slider appears beneath the graph. This is used to change the size of the section shown. Enter the value 0 to remove the restriction.
Legend	▶ Select in the drop-down list whether a legend is to be displayed – and, if so, in which position.
Graph list	Drop-down menu
Line width	▶ Enter a value in the input field.
Point size	The measurement points are displayed as circles, the trend graph as a square. ▶ Enter a value in the input field.
Graph list	Determine for each graph if and how it will be displayed in the coordinates window: ▶ Check the box to display the graph. ▶ Click repeatedly on the icon to the right of the checkbox in order to change the display mode.
List of parameters	Parameters can be selected from the category sublists of the parameter list on display. The parameter list on display depends on which project tree element is open. The following options are available: **Open/close a category sublist:** ▶ Click on the arrow right / arrow down. **Selecting a parameter:** ▶ Click on the required parameter.

Tab. 6.60: Options in the settings window for the ***Preventive maintenance*** tool

6.4 The “Power measurement” tool to show power data

This tool shows measurement data as single values in numerical form and the complete measurement series as a graph. It is only suitable for displaying the project tree element ***Power measurement***.

This tool is also suited for displaying a running power measurement (see Chapter “Display running measurements in a tool” on page 43).

Structure of the tool window

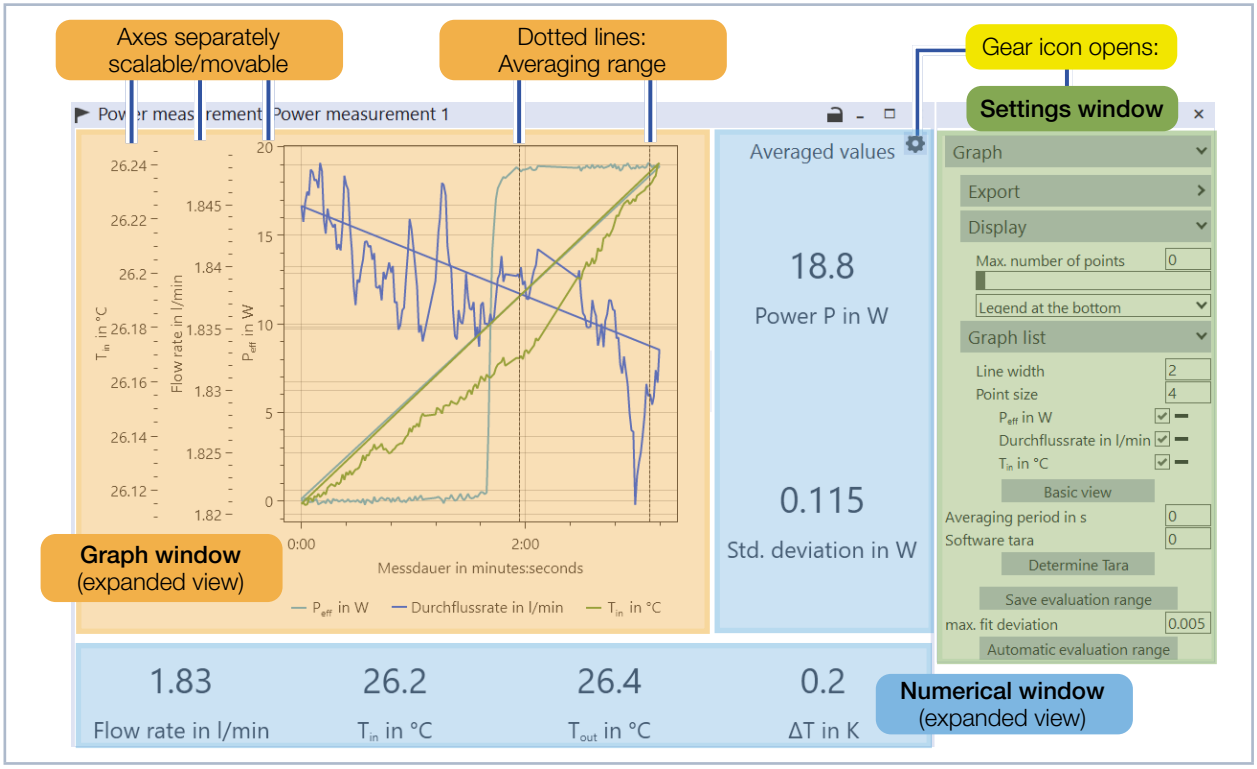


Fig. 6.25: Structure of the ***Power measurement*** tool

Elements	Description
Graph window	Information on the control options in this window can be found in Tab. 6.62 on page 130. The coordinates window shows a power graph. The expanded view shows the graphs of further parameters. A legend can be displayed that assigns the displayed graphs to the corresponding parameters. The y-axes can be moved and scaled independently of one another.
Numerical window	This shows the averaged power. The expanded view shows the averaged values for certain measurement parameters (e.g., flow rate). The range selected for averaging is displayed in the coordinates window. Permissible variations for specific background parameters are factory configured in the measuring devices (e.g., flow rate). If a background parameter moves beyond this permissible variation, then the corresponding value is shown against a yellow background. This may indicate that the device cannot be used safely or that the accuracy of measurement results is reduced.
Settings window	The settings window contains options for adjusting the graph window and for averaging data. Further information can be found in Tab. 6.63 on page 131.

Tab. 6.61: Elements of the ***Power measurement*** tool

Control options in the graph window

Instead of the right mouse button, the left mouse button can also be used while holding down the Alt key.

Action	Procedure
Zooming to position of mouse cursor	1. Position the mouse cursor anywhere within the coordinates window. 2. Turn the mouse wheel.
Setting a zoom range	1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Crtl key and the left mouse button. 3. Draw a square.
Change the scale of an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Turn the mouse wheel.
Shift the display along an axis	1. Position the mouse cursor anywhere along the x-axis/y-axis. 2. Press and hold the right mouse button and drag along the axis.
Shift the display in any direction	1. Position the mouse cursor anywhere within the coordinates window. 2. Use one of the following options: ▶ Press and hold the right mouse button and drag in the required direction. ▶ Use the arrow keys to incrementally move in the required direction.
Center all graphs in the coordinates window	▶ Double-click on the coordinates window, but not in the immediate vicinity of a graph. 👁 The axes are moved and scaled so that the graphs completely fill the coordinates window in all directions.
Display coordinate values at any position in a graph	▶ Click on the relevant area of the graph. 👁 The corresponding information is displayed.
Mark an area along the x-axis	An area can be marked along the x-axis. This serves to measure distances or to define a range for averaging. To mark an area, proceed as follows: 1. Position the mouse cursor anywhere within the coordinates window. 2. Press and hold the Shift key and the left mouse button. 3. Mark an area along the x-axis. 👁 The newly marked, unsaved area is given a background color. The previously marked area is no longer shown. 4. After use, remove this area or save it as described below.
Removing a marked area with a background color	1. Press and hold the Shift key. 2. Click on the area marked with a background color. 👁 The saved area reappears.
Saving a marked area with a background color	▶ In the settings window, click on the button ***Save evaluation range***. 👁 The background coloring and the distance value disappear. The saved range is indicated by vertical dotted lines.

Tab. 6.62: Control options in the graph window

Settings window

The table below lists all the options in order of appearance. Some options / drop-down menus are only visible when the higher-level drop-down menu is open. To open/close a drop-down menu, click on the blue bar.

Option	Explanation
Graph	Drop-down menu
Export	Drop-down menu
Table export (.csv)	▶ Click on this button to save the graph data in numerical form as a file with the extension ***.csv***.
Export graphic (.png)	▶ Click on this button to save the graph in its current state as a graphics file with the extension ***.png***.
Copy graphic	▶ Click on this button to copy the graph in its current state to the clipboard.
Display	Drop-down menu
Maximum number of points	The maximum number of measurement points displayed can be limited in the following way: ▶ Enter a value in the input field. ▶ Use the slider beneath the input field. 👁 In some instances, a slider appears beneath the graph. This is used to change the size of the section shown. Enter the value 0 to remove the restriction.
Legend	▶ Select in the drop-down list whether a legend is to be displayed – and, if so, in which position.
Graph list	Drop-down menu
Line width	▶ Enter a value in the input field.
Point size	The points are displayed as circles and squares. ▶ Enter a value in the input field.
Graph list	Determine for each graph if and how it will be displayed in the coordinates window: ▶ Check the box to display the graph. ▶ Click repeatedly on the icon to the right of the checkbox in order to toggle the display mode.
Normal/expanded view	▶ Click on this button to toggle between different views
Save evaluation range	▶ Click on this button to save a range marked with a background color in the coordinates window (see Chapter “Control options in the graph window” on page 130). 👁 The background coloring and the distance value disappear. The saved range is shown in the coordinates window by means of vertical dotted lines.
Automatic evaluation range	▶ Click on this button to automatically create an averaging range.

Tab. 6.63: Options in the settings window for the ***Power measurement*** tool

7 Fundamentals of beam geometry analysis with LDS

7.1 The beam geometry of rotationally symmetric laser beams

Fig. 7.1 shows schematic cross sections of a rotationally symmetric laser beam with the parameter designations used in LDS.

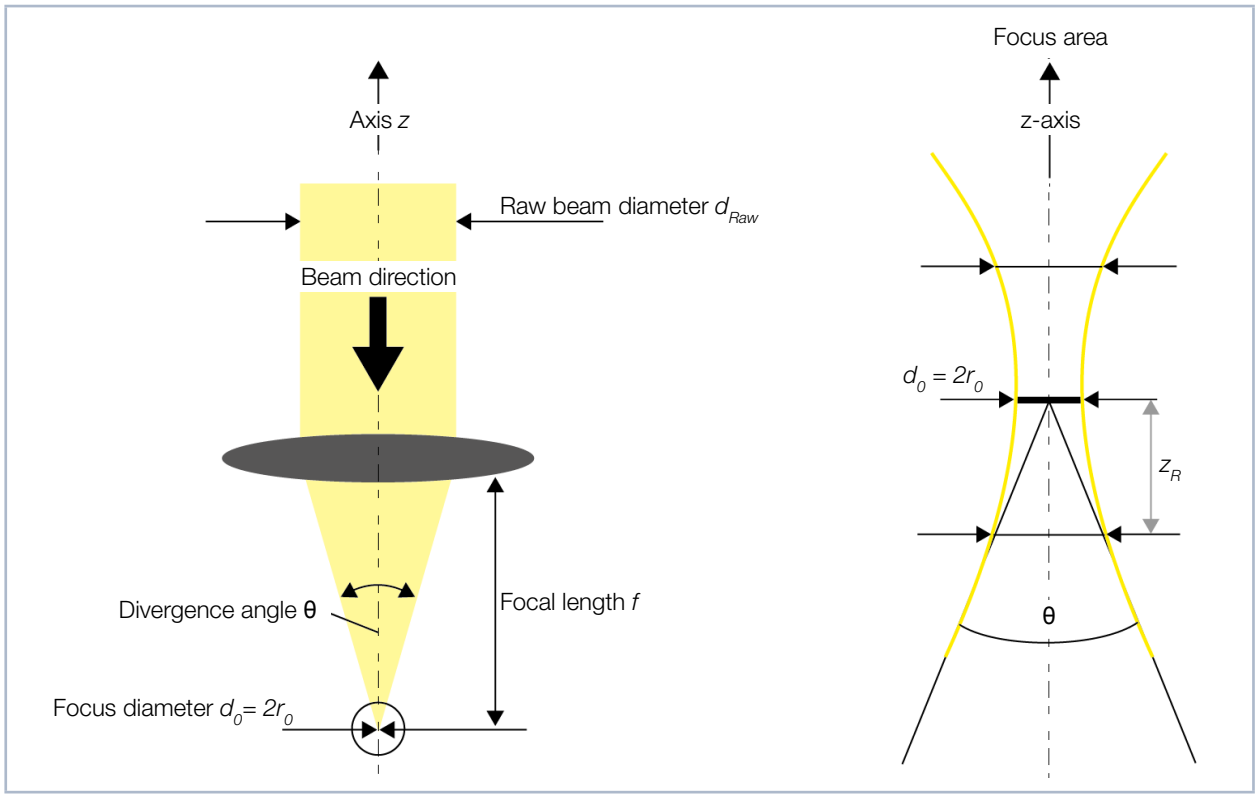


Fig. 7.1: Schematic beam cross sections along the propagation axis *z*

Beam focusing

The figure on the left shows beam transformation with focusing optics. The beam direction is from top to bottom. Above the focusing lens, the collimated raw beam runs approximately parallel. Below the focusing lens, the beam tapers until it reaches its narrowest point, the beam focal point. The beam edges describe – in simplified terms – the divergence angle θ (in LDS, this always means the full divergence angle). The focal length *f* determines the distance between the beam focal point and the focusing lens. The focal point has the original axial position z = 0 and the diameter $d_0 = 2r_0$ (in LDS, the index 0 signifies that a parameter refers to the focal point). After reaching its narrowest point, the beam widens again in the same way.

Focus area of beam caustic

The figure on the right shows the cross section of a focused beam in the focus area, the so-called near field. The beam caustic shows the typical longitudinal profile of a Gaussian beam. This can be interpreted as the rotation of a hyperbola around the axis of propagation. At the focal point, the beam radius is at its minimum r_0; with increasing distance from the focus, the radius increases non-linearly on both sides. In so doing, it asymptotically approaches the straight lines described by the divergence angle θ. At a greater distance from the focal point – the far field of the beam – the radius finally becomes approximately linear and the full divergence angle is obtained.

Rayleigh length

In the cross section shown on the right, two important planes are marked perpendicular to the axis of propagation *z*. Here, the cross-sectional area of the laser beam has increased by a factor of 2 and the radius by a factor of $\sqrt{2}$ (≈ 1.41), both with respect to the focal plane. The Rayleigh length z_R denotes the distance between these planes and the beam focal point. In the case of the ideal TEM_{00} laser beam, this is the quotient of double the focal radius r_0 and the divergence angle θ:

$$z_R = \frac{2r_0}{\theta} \qquad (1.1)$$

Elementary caustic parameters of rotationally symmetric beams

According to ISO 11145 and ISO 11146, the following parameters are required for the characterization of a rotationally symmetric beam:

- z-position of the beam focal point z_0
- Focal radius r_0
- Divergence angle θ

Using these three values, it is possible to determine the beam radius at any position along the direction of propagation, provided that the focal radius r_0 and the divergence angle θ have been calculated according to the second moment method.

$$r(z) = \sqrt{{r_0}^2 + \frac{1}{4}(z - z_0)^2 \cdot \theta^2} \qquad (1.2)$$

7.2 Parameters for laser beam focusability

A key determinant of the quality of a laser beam is how well it can be focused. Three related values are used to characterize this focusability:

- Beam parameter product *BPP*
- Beam quality factor M^2
- Beam quality *k*

Beam parameter product *BPP*

The focal radius r_0 and divergence angle θ of a laser beam are inversely proportional: if a smaller focal radius is required to achieve a higher power density, then a correspondingly wider divergence angle must be selected.

The product of the focal radius and half the divergence angle – the so-called beam parameter product (BPP) – is therefore a constant value:

$$SPP = \frac{r_0 \cdot \theta}{2} = const. \qquad (1.3)$$

In the case of the ideal TEM_{00} laser beam, the beam parameter product is the quotient of the laser wavelength λ and the mathematical constant π:

$$SPP_{Gauss} = \frac{\lambda}{\pi} \qquad (1.4)$$

The constancy of the beam parameter product can also be observed for real laser beams. Here, however, in contrast to the ideal TEM_{00} laser beam, both the focal radius r_0 and the divergence angle θ are bigger by the factor M:

$$SPP = \frac{r_0 \cdot \theta}{2} = M^2 \cdot \frac{\lambda}{\pi} \qquad (1.5)$$

On account of its minimal beam parameter product, the ideal TEM_{00} laser beam is therefore the benchmark for the focusability of real laser beams.

Beam quality factor M^2

Given the same divergence angle, real laser beams have a larger focal radius than the ideal TEM_{00} laser beam. The beam quality factor M^2 describes this correlation. Given the same divergence angle, the focal radius r_0 increases proportionally to M^2. In other words, the larger the value for M^2, the more difficult it is to focus a laser beam. An ideal TEM_{00} laser beam has a beam quality factor of 1. All real beams have a larger value.

$$M^2 = \frac{r_0 \cdot \theta \cdot \pi}{2 \cdot \lambda} \qquad (1.6)$$

For beam sources with higher laser power, the beam quality factor is generally smaller than for sources with lower laser power.

Beam quality *k*

The beam quality index *k* describes beam focusability inversely to M^2: the larger the value for *k*, the easier it is to focus a laser beam. An ideal TEM_{00} laser beam has a beam quality index of 1. All real beams have a smaller value.

$$k = \frac{1}{M^2} \qquad (1.7)$$

7.3 Simple astigmatic beams

So-called simple astigmatic laser beams are not rotationally symmetric. This results in different beam radii depending on orientation.

Coordinate systems

Calculation of beam parameters in line with orientation can be performed using either the laboratory coordinate system (x, y, z) or the beam coordinate system (a, b, z).

The term **laboratory coordinate system** generally refers to an external coordinate system that is independent of the beam geometry and therefore provides a fixed frame of reference. As a rule, the device coordinate system – defined by the orientation of the measuring device – is used for this purpose. For further information, please refer to the device operating manual.

The **beam coordinate system** is defined by the main axes of the beam ellipse. The axis with the smallest angle in relation to the x-axis is designated as the a-axis, and the other is designated as the b-axis. The angle between the x-axis and the a-axis is called the azimuth angle **φ**. Using a coordinate transformation, parameters calculated in x and y can also be converted to parameters in a and b, and vice versa.

Beam ellipticity

Beam ellipticity **ε** is a parameter for determining the circularity of a beam cross-section at a given point along the axis of propagation. It is determined as the ratio of the smaller to the larger diameter at this point. In line with ISO 11145 and ISO 11146, elliptical distributions **ε ≥** 0.87 can be regarded as circular.

Elementary caustic parameters of simple astigmatic beams

Since astigmatic beams have different parameters in the direction of the beam main axes (a and b), they do not, as a rule, have a common focal point. The following parameters are used to describe such a beam:

- The z-positions of the beam focal points z_{0a} and z_{0b}
- The focal radii r_{0a} and r_{0b}
- The divergence angle θ_{0a} and θ_{0b}
- The azimuth angle φ

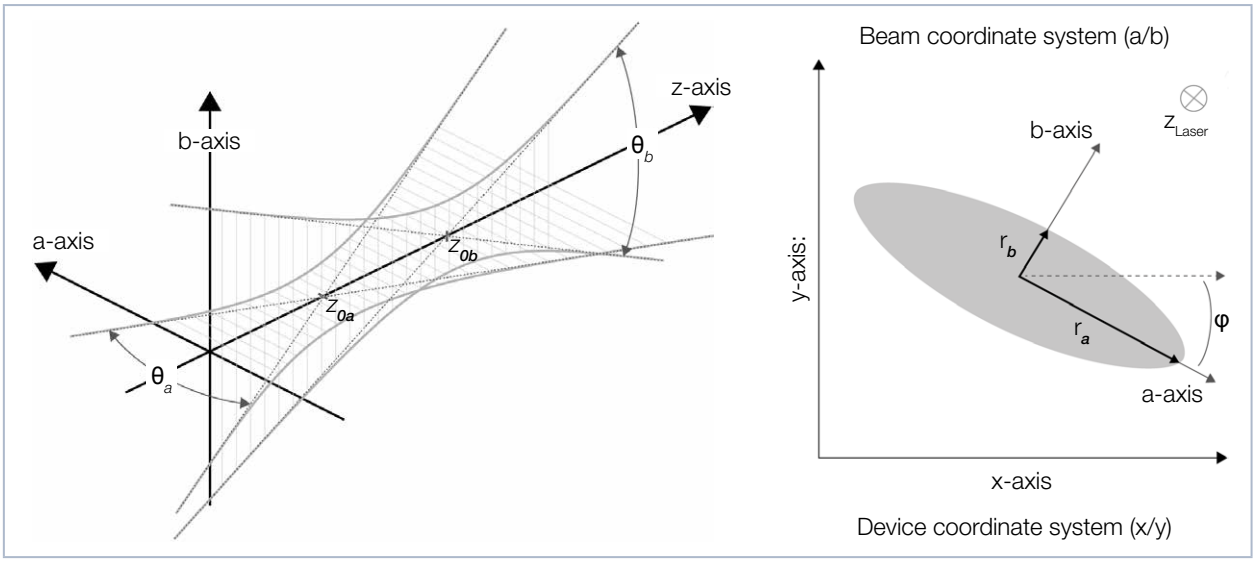


Fig. 7.2: Beam parameters of a simple simple astigmatic beam (left) and the relation between device coordinate and beam coordinate systems (right)

The above parameters can be used to describe all beams that can be characterized by two mutually perpendicular axes. Further beam parameters are calculated – also dependent on orientation – by means of the same equations that are used for rotationally symmetric beams. Therefore, there are always two parameters; e.g., k_a and k_b.

7.4 Determination of power density distribution for a plane measurement

To calculate the beam radius at any point along the axis of propagation, the two-dimensional power density distribution must first be measured. PRIMES systems measure power density distribution with either a CCD camera or a scanning device with a rotating pinhole.

Offset

To obtain a correct measurement, it is vital to ensure proper offset, since even small errors can lead to a significant change in the calculation volume. If offset is too high, for example, this reduces the intensity at the edges of the beam. As a result, the measured values are too low.

This is particularly noticeable when calculating the radius by means of the second moment method. The algorithm for this method is based on the product of power density and distance to the center of gravity, squared. Because of the square weighting, the edges of the beam must also be included in the measurement to a high degree of accuracy, otherwise this method does not work properly. Careful determination of offset is also essential when calculating the radius using the 86% method. By default, offset in LDS is determined by means of a “dark measurement” in the device (i.e., without a laser beam).

Fill factors

LDS distinguishes between measurement area, measurement window and ROI (region of interest). The **measurement area** is the complete area measurable by a device. The **measurement window** is the part of the measurement area for which intensity values are recorded during a measurement. The key to obtaining a correct measurement is the size and position of the measurement window, thereby ensuring that it contains the entire beam. The **ROI** is the area of the measurement window that is used to calculate the beam radius.

In LDS, the “fill factor” signifies the **measurement window fill factor**. This is the quotient of the beam diameter and the width of the measurement window. In LDS, this must lie between 0.25 and 0.75 in order for the measurement to be considered valid. The **ROI fill factor** is the quotient of the beam diameter and the ROI width. To minimize errors in determining offset, an ROI fill factor of 0.5 is ideal according to the quality criteria specified by PRIMES.

If measurement window size is set automatically for a measurement, the measurement window fill factor is approximately 0.3. This leaves enough of a margin for an ROI fill factor of 0.5 (default value). This default value be overwritten with another value in the menu ***Extras > Options***. Alternatively, the use of ROI can be deactivated (see Chapter “Global settings in the Extras > Options menu” on page 28).

Calculation of beam position

The beam position is calculated according to the first moment method; i.e., as the center of gravity of the power density distribution I(x,y,z):

$$x(z)_{COG} = \frac{\iint x \cdot I(x,y,z)dxdy}{\iint I(x,y,z)dxdy} \qquad y(z)_{COG} = \frac{\iint y \cdot I(x,y,z)dxdy}{\iint I(x,y,z)dxdy} \qquad (1.8)$$

The index **COG** stands for center of gravity.
Based on the beam position, the beam radius can now be calculated using the 86% method or the second moment of power density distribution.

7.5 Methods of radius calculation for a plane measurement

The basic version of LDS uses the following methods for radius calculation: second moment method and 86% method. These methods conform to ISO 11146. For the ideal TEM_{00} laser beam, both methods deliver the same result. For most real laser beams, however, the results of the two methods can differ significantly.

Radius calculation with the 86% method algorithm

The ***86%*** algorithm is used for experimental radius calculation according to the 86% method.

First of all, the volume of the power density distribution is determined. This is proportional to total power. Addition of all the power density values and multiplying them by the pixel dimensions gives the volume and thus the total power.

Based on this calculation of total power, a circular area is then observed that includes 86% of the total beam power. The beam power must lie within the beam radius. Integration starts at the center of gravity. The area of integration is then increased until it includes 86% of the total power. For the purposes of integration, the number of pixels is counted. This is then used to calculate the 86% area (and thereby the beam diameter). This is a very reliable method for circular, fundamental mode-like beams.

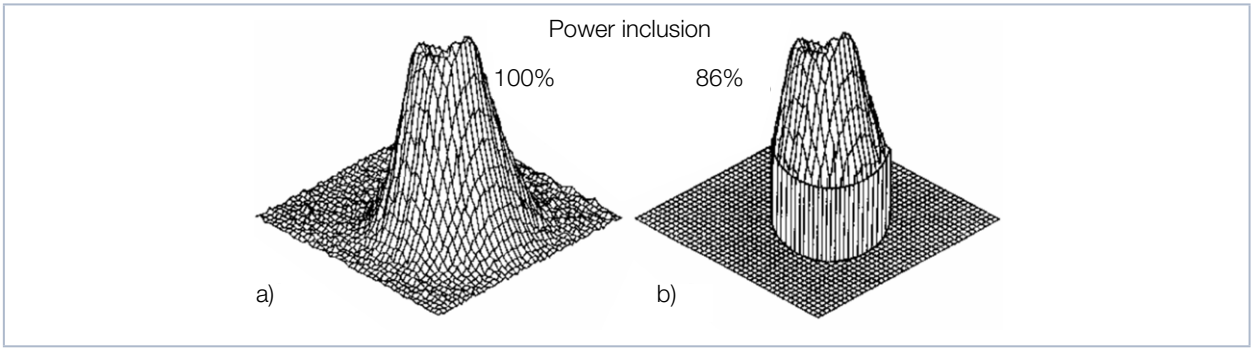


Fig. 7.3: Graphical representation of the calculation of 86% radius

Fig. 7.3 shows the power density distribution (a) and the pixels that together comprise 86% of the power (b). The pixels with lower power are set to zero for clarity.

Radius calculation with second moment method algorithms

The following algorithms are used for radius calculation according to the second moment method:

- ***Device moments:***
  Radii are calculated according to the second moment method in the device coordinates (x/y).
  This produces radii in x-/y-orientation.
- ***Invariant moments:***
  Radii are calculated according to the second moment method in the device coordinates (x/y).
  This produces the average of the radii in x-/y-orientation.
- ***Rotated moments:***
  Following conversion of the device coordinates (x/y) into beam coordinates (a/b), the radius calculation is performed according to the second moment method. This produces radii in a-/b-orientation.

The second moments are determined in the following way (in this example, for the device coordinates x/y):

$$\sigma_x{}^2(z) = \frac{\iint (x - x_{COG})^2 \cdot I(x,y,z,)dxdy}{\iint I(x,y,z)dxdy} \qquad \sigma_y{}^2(z) = \frac{\iint (y - y_{COG})^2 \cdot I(x,y,z,)dxdy}{\iint I(x,y,z)dxdy} \qquad \textit{(1.9)}$$

Based on the second moments, the beam radii are calculated in x-/y-orientation:

$$r_x(z) = 2 \cdot \sigma_x(z) \qquad r_y(z) = 2 \cdot \sigma_y(z) \qquad \textit{(1.10)}$$

Advanced algorithms for radius calculation as a plug-in option

Not all measuring devices for laser beam diagnostics show the same measurement result when used for comparative measurements on the same laser beam. Different measuring devices are validated in different ways. In addition, the measuring methods and the evaluation algorithms they use all have an influence on beam measurements.

Similarly, not all methods comply with standards but are nonetheless preferred in some spheres (e.g., in the scientific field). In concrete cases, it may be helpful to use alternative beam radius definitions (e.g., for the design of apertures or for correlation with machining results).

The ***Caustic algorithms*** plug-in adds the following methods for radius calculation to those included in the basic version of LDS (name of algorithm in brackets):

- Knife-edge method according to ISO 11146-3 (Knife)
- Slit method according to ISO 11146-3 (Slit)
- Gauss-fit method (Gauss)
- 86% 2 power density loss method (86% 2)
- Power inclusion method with freely definable 1st power inclusion (95%)
- Power inclusion method with freely definable 2nd power inclusion (99%)

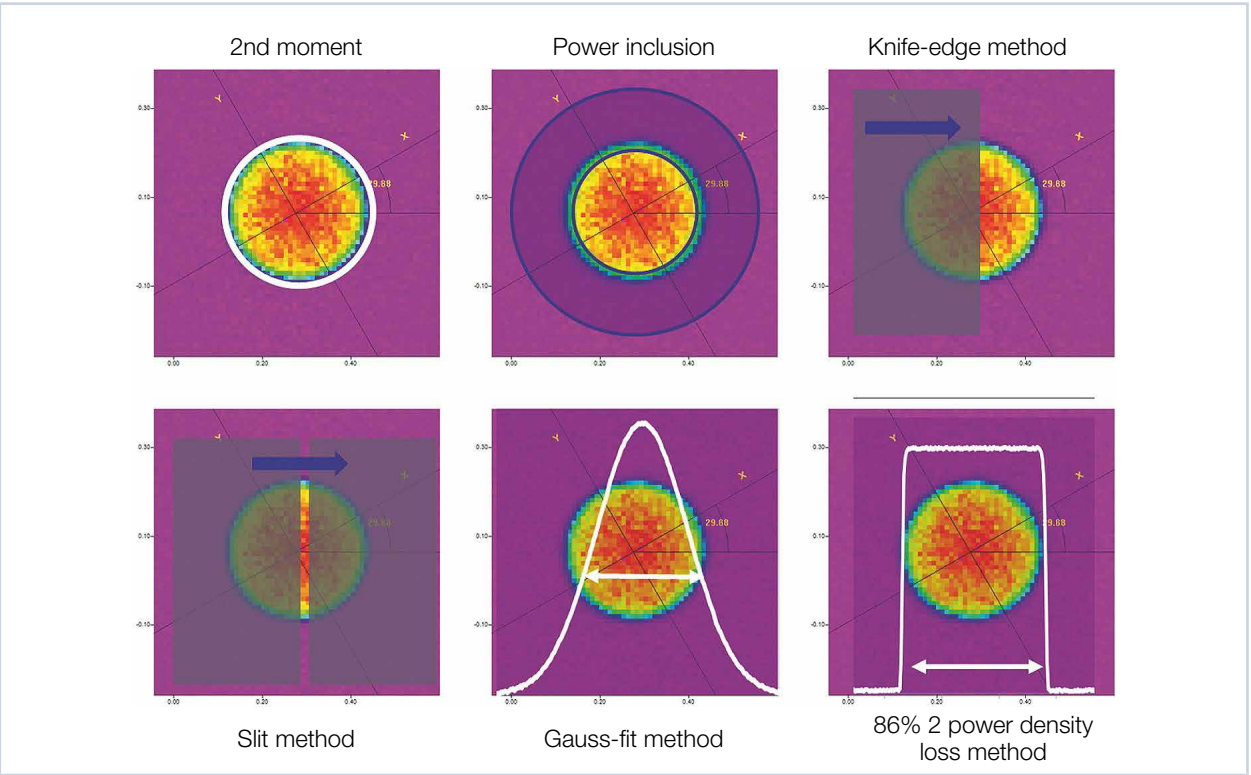


Fig. 7.4: Overview of the methods offered by the *Caustic algorithms* plug-in

7.6 Measuring a beam caustic

Number of plane measurements

To determine the elementary caustic parameters of a real laser beam, the radii of the cross-sectional areas must be measured at different points along the propagation axis. ISO 11146 stipulates that these radii must be determined for at least 10 points within a minimum of 4 Rayleigh lengths – 5 of them within 1 Rayleigh length of the focus and 5 planes more than 1 Rayleigh length from the focus. PRIMES recommends measuring at least 21 planes within 6 Rayleigh lengths.

PRIMES measuring devices with an integrated z-axis enable fully automatic measurement of beam caustics. Alternatively, beam caustics can be measured manually. In this case, the position of the focusing optics relative to the measuring device head must be manually adjusted before each plane measurement.

Calculation of caustic parameters by fitting

In this case, the elementary caustic parameters of the laser beam are determined mathematically by fitting a hyperbolic graph to the measured radii (caustic fit). Using these parameters, it is also possible to derive the parameters for the focusability of the beam that is to be measured.

Given that the caustic fit takes into account all measurement points, not all the beam waistlines determined by LDS are necessarily located at points along the propagation axis where the smallest radii were measured. As a rule, however, the focal radii thereby calculated are very close to the smallest measured radii.

8 Discussion of measurement results and troubleshooting

8.1 Inaccuracies with measurements beyond device specifications

If measurements are made beyond the limit values specified for a device, a reduction in measurement accuracy must be expected.

▶ Before measuring, be sure to read the device operating manual. To ensure safe use and accurate measurement results, observe all limit values specified therein.

In the case of some parameters (e.g., power, beam diameter, divergence angle), the measured value is compared with device-specific limit values. Any violation of limit values is saved with the measurement and displayed in the project tree as follows:

- Project tree element marked red (see Chapter 5.4.3 “Review of measurements in project tree” on page 18).
- Error message in element-related information window (see Chapter 5.4.2 “About the project tree elements” on page 17).

In some tools, a violation of a limit value is indicated by colored markers (see Chapter 8.2 on page 140).

8.2 Review of parameters with colored markers

In many instances, it is possible to review parameters on the basis of limit and warning values specially configured for this purpose. These parameters are automatically compared with limit and warning values and the result is shown by colored markers.

Here, parameter refers to all parameters displayed in LDS, regardless of whether they concern data for the purposes of measurement (e.g., flow rate, signal-to-noise ratio, fill factor) or the results of a measurement (e.g., laser power, M^2, average fit deviation).

The review of a parameter can be displayed either directly or indirectly. In many tools, numerically displayed parameters can be directly reviewed on the basis of their background color. By contrast, in a project tree or ***Evaluation traffic light*** tool, the use of color provides a general indication that at least one underlying parameter has violated a limit or warning value.

In addition, some of the tools used to create graphs feature an option to show limit and warning values in the coordinates window.

8.2.1 Limit and warning values

In LDS, all configured limit and warning values apply globally; i.e., to all open projects, including their sub-elements. However, the type of marking may differ from one area of LDS to another (tools and project trees).

General configuration of limit and warning values

Tab. 8.1 on page 140 provides an overview, with examples, of the configuration of limit and warning values in LDS. It is immaterial which and how many values are configured for a parameter. These values may be either factory configured or freely configured by the user. The < symbol shows the mandatory size relation between configured values. If a limit and a warning value are simultaneously violated, the warning value is marked.

Parameter		Lower values				Upper values		
Designation	Configuration	Limit value	<	Warning value	<	Warning value	<	Limit value
Ellipticity	Freely configurable	0.87		0.90				
Fill factor (86%)	Factory configured					0.60		0.75
P in W	Factory configured	0.0		10.0		500.0		1000.0

Tab. 8.1: General configuration of limit and warning values, with examples

Factory-configured values

In LDS, certain warning or limit values are factory configured. These settings may not be altered by the user. Based on the relevant reviews, it can be deduced whether and how the measurement setup or parameters must be altered in order to improve a measurement. Why are **limit values** factory configured?

- Factory-configured limit values provide **general criteria** for the validity of a measurement. By **validity**, we mean the conformity of a measurement with ISO 11146 and/or the quality criteria specified by PRIMES. If at least one such value is violated, then the measurement is considered invalid with respect to these criteria.

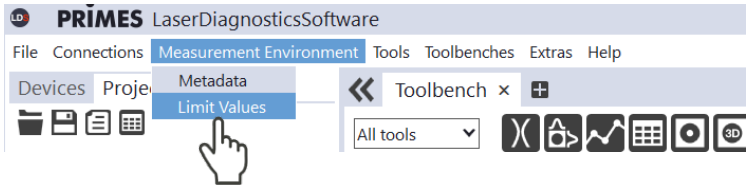
- Factory-configured limit values provide **device-specific criteria** for the **safety and quality** of a measurement. If measurements are made outside of device-specific limit values, devices may be damaged, or persons injured. At the very least, a reduction in measurement accuracy must be expected. Further information can be found in Chapter 8.1 on page 140.

On the other hand, the violation of factory-configured **warning values** indicates that the measurement setup or measurement parameters are not ideal. These warning values may be general or device specific.

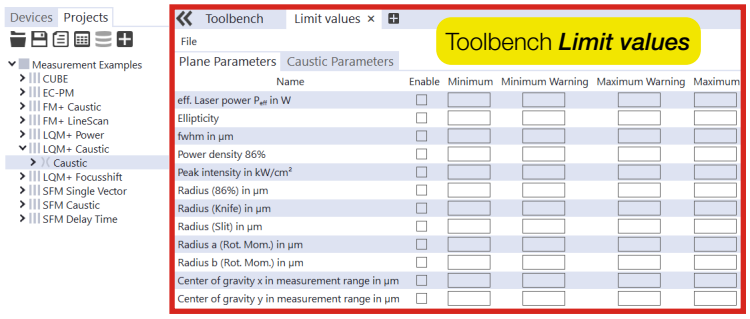
Freely configurable values for custom purposes

Limit or warning values that are not factory configured can be customized as required. If, for example, only the upper limit value for a specific parameter is factory configured, then the remaining values below this limit may be freely configured.

1. Select ***Measurement environment*** > ***Limit values*** in the menu bar.

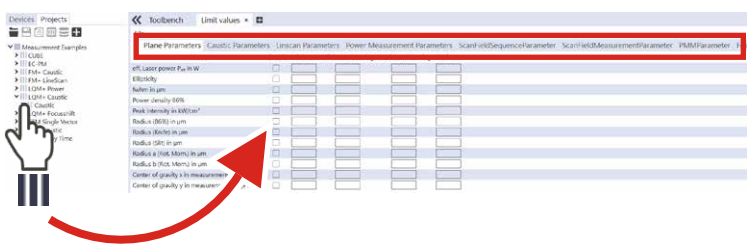


A toolbench of the same name opens. The choice of tabs depends on which project tree element is currently selected. If, for example, the element ***Caustic*** is selected, then the toolbench features the corresponding tabs ***Plane parameters*** and ***Caustic parameters***.



In LDS, all configured parameters apply globally, irrespective of which project tree element is selected; i.e., to all open projects, including their sub-elements.

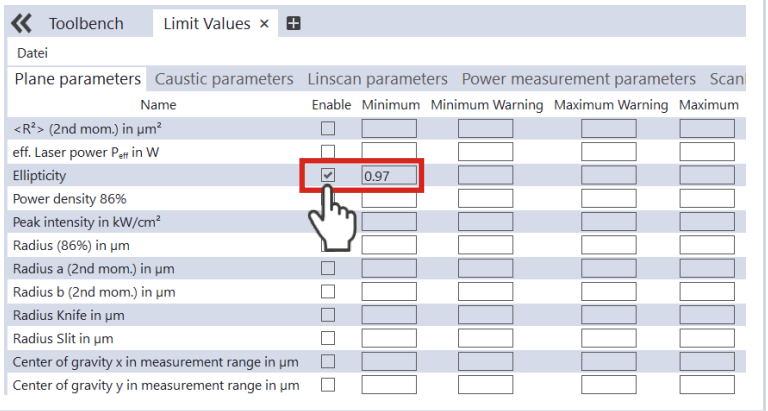
2. If required, open additional tabs by pressing and holding the left mouse button and dragging a suitable project tree element into the toolbench. In the case of the element ***Series***, all available tabs are shown.



3. Configure limit and warning values as required.

If, in the English user interface, a comma is entered, this is automatically replaced by a period (and vice versa).

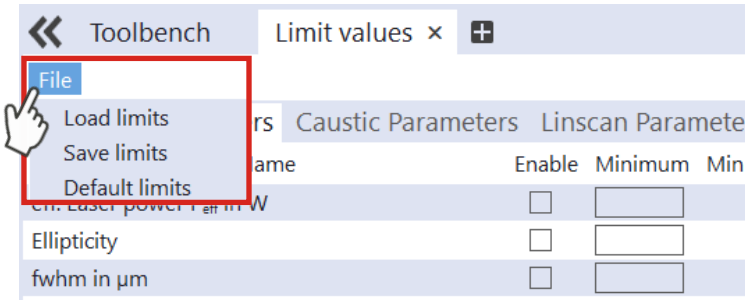
4. If required, click the checkbox of a parameter in order to activate the configured values.



▶ If required, select from the menu ***File*** one of the following items:

- ***Load limits*** opens a Windows Explorer window for the purpose of opening a file with the extension ***.xml***. This file contains a configuration of limit values.
- ***Save limits*** opens a Windows Explorer window for the purpose of saving a file with the extension ***.xml***. This file contains a configuration of limit values.
- ***Default limits*** deletes all configured values.

This applies to the configured values for parameters in all tabs! It is immaterial which tab is currently in the foreground when this command is executed.



8.2.2 Overview of tools with review functions

LDS area/tool	Description of review function
Project tree	Element review based on different colors for the element icon. Red — Indicates a warning in the following cases: • The measurement was performed outside of device specifications. • At least one of the measured parameters is invalid. • At least one of the measured parameters lies outside of the permissible limits for the reference measurement, as defined by the user (only for the element ***Caustic***). Gray — There is no warning. Further information can be found in Chapter 5.4.3 “Review of measurements in project tree” on page 18.
Caustic analysis Plane analysis Raw beam analysis	In the table of the ***Review*** tab: Review of the validity of a displayed parameter by means of different background colors. Red — The parameter is invalid. A limit value factory configured as a criterion of validity has been violated. Green — The parameter is valid. Further information: ***Plane analysis:*** Chapter “The Review tab in the Plane Analysis tool” on page 80. ***Caustic analysis / Raw beam analysis:*** Chapter “The Review tab in the Caustic Analysis tool” on page 103).

LDS area/tool	Description of review function
Results table	Review of a displayed parameter by means of different background colors. Red A factory or freely configured limit value has been violated. Neutral No limit valid has been violated. Further information can be found in Chapter 6.2.1 “Results table” on page 44.
Measurement value display	In numerical display mode: Review of a displayed parameter by means of different background colors. Red A factory or freely configured limit value has been violated. Yellow A factory or freely configured warning value has been violated. Further information can be found in Chapter 6.2.3 “Measurement value display” on page 50.
Evaluation traffic light	Indirect traffic light review of selected parameters in the background Red At least one factory or freely configured limit value has been violated. Yellow No violation of a limit value, but violation of at least one factory or freely configured warning value. Green No limit or warning values have been violated/configured.
	A table appears when the mouse cursor is hovered over the traffic light view. Direct review of a displayed parameter by means of different background colors. Red A factory or freely configured limit value has been violated. Yellow A factory or freely configured warning value has been violated. Green The parameter lies within the configured limit or warning values. Neutral No limit or warning values have been configured. Further information can be found in Chapter 6.2.6 “Evaluation traffic light” on page 62.
Graphic data analysis	When the option **Show limit values** is activated: Shows the limit and warning values of a selected parameter in the coordinate system. Red Display of minimum/maximum limit values with the inscription Minimum/Maximum Yellow Display of minimum/maximum warning values with the inscription Minimum warning / Maximum warning See also Chapter 6.2.5 “Graphic data analysis” on page 56.
Power measurement	Permissible variations for specific background parameters are factory configured in the measuring devices (e.g., flow rate). If a background parameter moves beyond this permissible variation, then the corresponding value is shown against a yellow background. This may indicate that the device cannot be used safely or that the accuracy of measurement results is reduced.

Tab. 8.2: Overview of tools with review functions

8.3 Low signal-to-noise ratio

A low signal level often results in a low signal-to-noise ratio. This in turn leads to increased unreliability in determining radii and the focus position. In this case, check the measured values carefully for consistency, or, if possible, improve the signal-to-noise ratio. In general, the signal-to-noise ratio can be improved by averaging during measurement.

8.4 A focus shift and the temporal stability of measurement results

Alongside the quality of individual measurements, the question often arises as to whether the results of different measurements are comparable with one another. In certain cases, measurement results that were carried out at different times but under otherwise seemingly identical conditions may differ from one another. Such discrepancies may be the result of a thermally induced focus shift.

A variety of factors may cause a focus shift. A significant factor is **laser power**. Transmissive laser optics absorb a certain part of the thermal energy of the laser beam. This has an impact on their expansion and refractive index. The greater the power of the laser beam, the more the focal length of an optical component changes. In order to evaluate a focus shift, therefore, it is often useful to compare caustics at low and at high laser power.

If laser power is adjusted by means of pulse-width modulation, a **modulation at the pulse frequency may** occur. This causes a periodic modulation of the measurement result. In some cases, superpositions may occur. Transmissive optics, such as out-coupling plates and lenses, may take some time to reach thermal equilibrium after the laser is switched on. During this time, the refractive index changes and, in some instances, the thickness of the optical material. A resulting focus shift should therefore be taken into account when evaluating the measurement results. Alternatively, the measurement should only be started after adequate thermalization time.
In order to measure the thermalization of the optics, a defined time interval must be selected between switching on the laser and starting the measurement.

Other factors may also favor a focus shift. These include the structure and absorption characteristics of the optics (e.g., the ratio of the focal lengths of focusing and collimating optics). Contamination of the optical elements can also be a key factor in causing a focus shift. These are largely the result of the laser processes themselves and, as a rule, cannot be avoided entirely, even with appropriate protective measures.

8.5 Evaluating a result in different versions of LDS

If identical beam geometry measurements are evaluated in different versions of the LDS, the results may differ slightly. This is especially the case when, in the current version of LDS (LDS 1.3.1, file extension ***.lpf***), measurement data are evaluated that were created with the previous version (LDS 2.98, file extension ***.foc***).

The following factors may lead to a difference in results:

- Radius determination according to the 86% method is performed experimentally. In general, deviations of up to 3% are possible and permissible.
- The current version of LDS uses enhanced algorithms compared to the previous version. This is enabled by general advances in PC computing power.
- In the current LDS, radius calculation is performed with an improved iterative process. In contrast to the previous version, not only the measurement window but also the **ROI** (region of interest) is defined. This is the area of the measurement window that is used for the actual calculation of the beam radius. Further information can be found in Chapter “Fill factors” on page 136.