

Original Instructions



MicroSpotMonitor MSM+

MSM+ 35, MSM+ 120

LaserDiagnosticsSoftware LDS

IMPORTANT!

READ CAREFULLY BEFORE USE.

KEEP FOR FUTURE USE.

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PRIMES - The Company

PRIMES manufactures measuring devices used to analyze laser beams. These devices are employed for the diagnostics of high-power lasers ranging from CO₂ lasers and solid-state lasers to diode lasers. A wavelength range from infrared through to near UV is covered, offering a wide variety of measuring devices to determine the following beam parameters:

- Laser power
- Beam dimensions and position of an unfocused beam
- Beam dimensions and position of a focused beam
- Beam quality factor M²

Development, production and calibration of the measuring devices is performed at PRIMES. This guarantees optimum quality, excellent service, and a short reaction time, providing the basis for us to meet all of our customers' requirements quickly and reliably.



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1 Basic safety notes

Intended use

The device has been designed exclusively for measurements in the beam of high-power lasers.

Use for any other purpose is considered as not intended and is strictly prohibited. Furthermore, intended use requires that you observe all information, instructions, safety notes and warning messages in this operating manual. The specifications given in chapter "17 Technical data" on page 90 apply. Any given limit values must be complied with.

If not used as intended, the device or the system in which the device is installed can be damaged or destroyed. In addition, there is an increased risk to health and life. Only use the device in such a way that there is no risk of injury.

This operating manual is an integral part of the device and must be kept in the immediate vicinity of the place of use, accessible to personnel at all times.

Every person who is responsible for the installation, start-up or operation of the device must have read and understood the operating manual and, in particular, the safety instructions.

If you still have questions after reading this operating manual, please contact PRIMES or your supplier for your own safety.

Observing applicable safety regulations

Observe the safety-relevant laws, guidelines, standards and regulations in the current editions published by the state, standardization organizations, professional associations, etc. In particular, observe the regulations on laser safety and comply with their requirements.

Necessary safety measures

The device measures direct laser radiation, but does not emit any radiation itself. However, during the measurement the laser beam is directed at the device. This produces scattered or directed reflection of the laser beam (laser class 4). The reflected beam is usually not visible.

Protect yourself from direct and reflected laser radiation while working with the device by taking the following measures:

- Never leave the device unattended when taking measurements.
- If the device is moved from its aligned position, increased scattered or directed reflection of the laser beam occurs during measuring operation. Fix the device in such a way that it cannot be moved by unintentional bumping or pulling on the cables.
- Connect the laser control's safety interlock to the device. Check that the safety interlock will switch off the laser properly in case of error.
- Install safety switches or emergency safety mechanisms that allow the laser to be switched off immediately.
- Use suitable beam guidance and beam absorber elements which do not emit any hazardous substances when irradiated.
- Wear **safety goggles** adapted to the power, power density, laser wavelength and operating mode of the laser beam source in use.
- Wear suitable **protective clothing** or **protective gloves** if necessary.
- If possible, also protect yourself from direct laser radiation and scattered radiation by using separating protective devices that block or attenuate the radiation.

Employing qualified personnel

The device may only be operated by qualified personnel. The qualified personnel must have been instructed in the installation and operation of the device and must have a basic understanding of working with high-power lasers, beam guiding systems and focusing units.

Conversions and modifications

The device may not be modified in terms of design or safety without the explicit consent of the manufacturer. The same applies to unauthorised opening, dismantling and repair. The removal of covers is only permitted within the scope of the intended use.

Liability disclaimer

Manufacturer and distributor exclude any liability for damages and injuries which are direct or indirect consequences of using the device not as intended or modifying the device or the associated software without authorization.

2 Symbols and conventions

Warning messages

The following symbols and signal words indicate possible residual risks in the form of warnings:



DANGER

Means that death or serious physical injuries **will** occur if necessary safety precautions are not taken.



WARNING

Means that death or serious physical injuries **may** occur if necessary safety precautions are not taken.



CAUTION

Means that minor physical injury **may** occur if necessary safety precautions are not taken.

NOTICE

Means that property damage **may** occur if necessary safety precautions are not taken.

Product safety labels

The following symbols are used on the device itself to indicate imperatives and possible dangers:



Hand injuries warning



Electrostatic sensitive devices



Read and observe the operating instructions and safety guidelines before startup!

Further symbols and conventions in this operating manual



Here you can find useful information and helpful tips.

- ▶ Indicates a simple instruction.
If several such instructions appear one below the other, then the order of their execution is irrelevant or they are alternative procedures.
- 1. A numbered list identifies a sequence of instructions 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 observation prompt to draw attention to visible feedback from the device or the software.
Observation prompts make it easier to check whether an instruction was executed successfully. Often they also guide to the next instruction.
- 👉 Points to a control element that is to be pressed / clicked.
- ← Points to an element described in the text (for example an input field).

3 About this operating manual

This manual describes the installation and operation of the device and how to perform measurements with the LaserDiagnosticsSoftware LDS 1.1.2.
For measurement operation with a PC, the LaserDiagnosticsSoftware LDS must be installed on the PC. The LDS is included in the scope of delivery.

The software description includes a brief introduction on using the device for measurements.
For a detailed description of the software installation, file management and evaluation of the measurement data, please refer to the separate instructions for the LaserDiagnosticsSoftware LDS.



This operating manual describes the software version valid at the time of printing. Since the user software is continuously being developed further, the supplied data medium may have a different version number.

If you have questions, please let us know the software version you are using. The software version can be found under the following menu item: Help > About LaserDiagnosticsSoftware.

4 Device description

4.1 Functional description

The device determines beam geometry data of focused laser beams with a diameter of 10 µm to 1 mm directly within the process zone. It is air-cooled and allows measurements in a power range from 1 mW to 200 W. A device version with water cooling for the power range up to 500 W is also available.

The device operates camera-based. The beam cross sections to be measured along the beam propagation axis are located outside the device. This non-contact measurement has the advantage that even very high

power densities can be measured. The beam cross sections are imaged on a CCD sensor in the device – enlarged by a measuring objective. Before hitting the sensor, the laser beam is attenuated by beam splitters and neutral-density filters inside the device. From the determined power density distribution of the beam cross-section, beam position and beam radius at this position are obtained.

The camera housing of the device can be moved by a motor on all axes of the device coordinate system. The travel range along the z-axis is 35 mm (MSM+ 35) or 120 mm (MSM+ 120). The travel range along the x-axis / y-axis is 2 mm. This allows fully automatic plane and caustic measurements.

The device uses interchangeable objectives with the magnification 3.3 / 5 / 10. The selection of the suitable measuring objective is essential for the quality of the measurement. The measuring objective should be optically matched to the wavelength, the numerical aperture and the radius to be measured.

The dynamic range of the integrated CCD sensor is amplified via an irradiation time control. This enables caustic measurements over more than four Rayleigh lengths, as demanded in the standard ISO 11146.

Optionally, the device can be equipped with a motor-driven filter wheel with neutral-density filters (OD1 to OD5). This filter wheel enables measurements of power densities between several W/cm² up to several MW/cm².

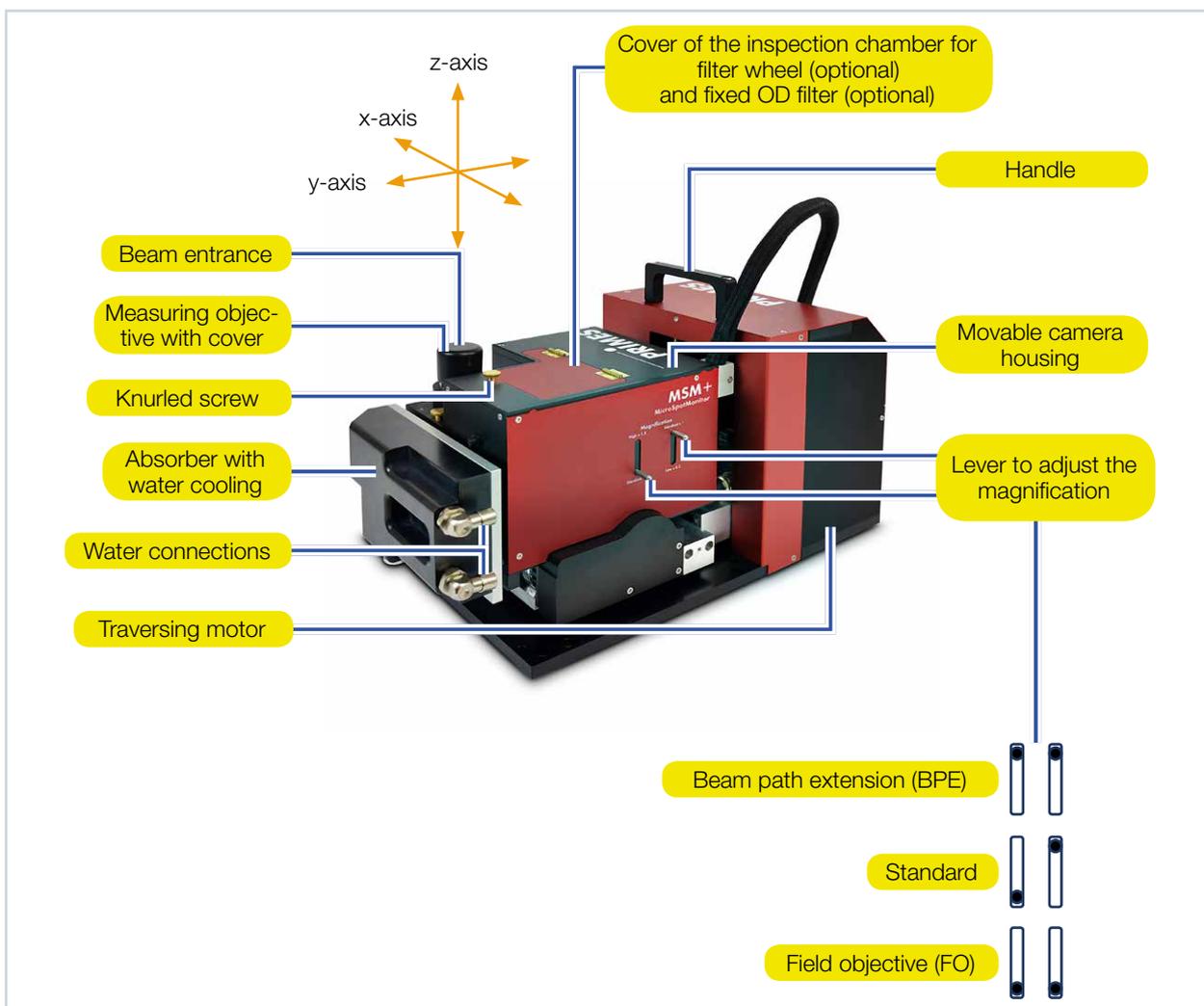


Fig. 4.1: System components (example: MSM+ 120, 500 W device version with water cooling)

4.2 Measuring principle

The device is a camera-based measuring system. Depending on the application, up to 7 different optical components can be placed within the beam path. The purpose and functionality of individual components are described in chapter 19.2, „Optical components“, on page 93.

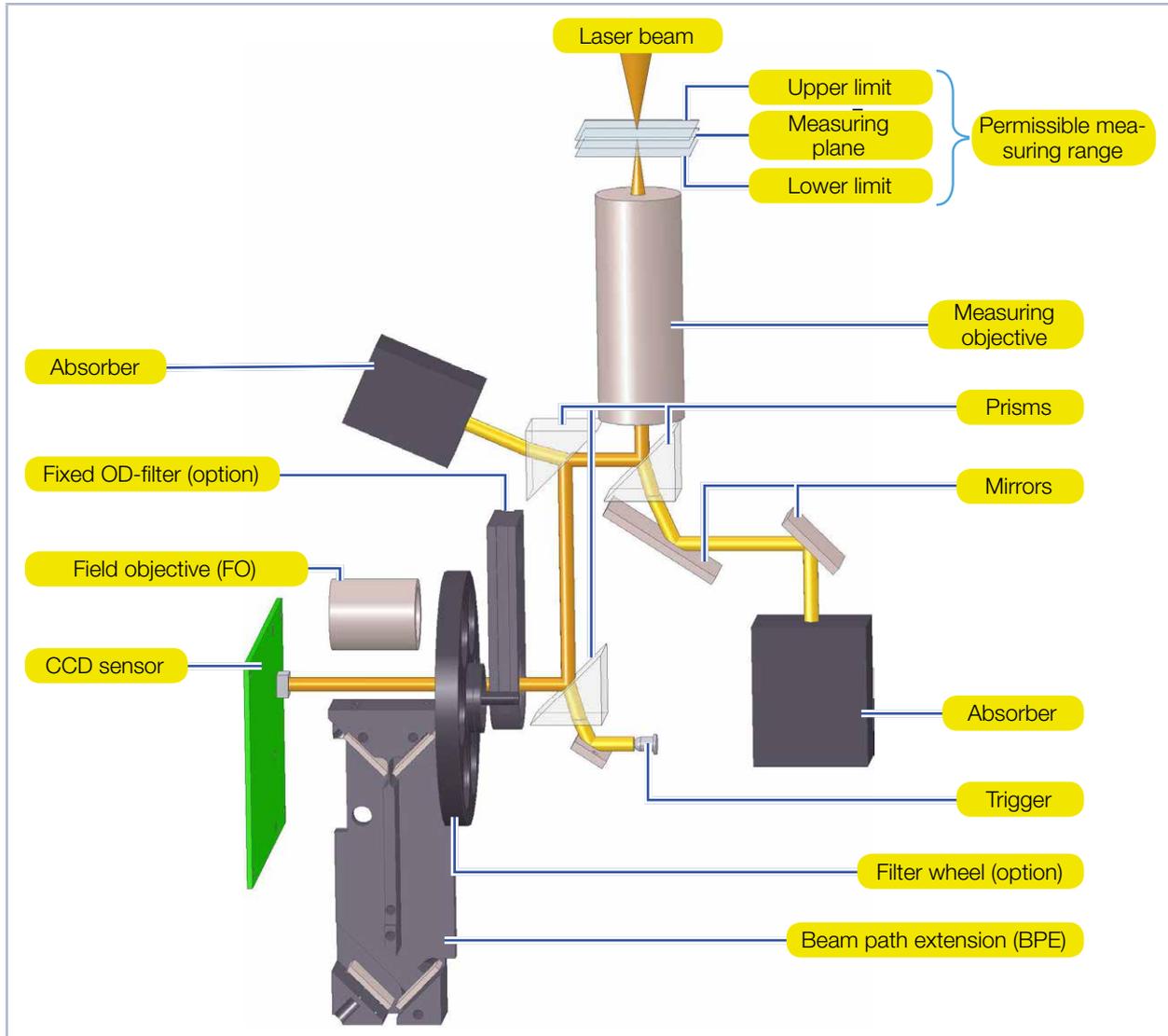


Fig. 4.2: Optomechanical design

5 Short overview installation

<p>1. Installing the LaserDiagnosticsSoftware LDS on the PC</p> <ul style="list-style-type: none"> • Software is part of the scope of delivery 	<p>See separate Operating Manual of the LaserDiagnosticsSoftware LDS</p>
<p>2. Taking safety precautions</p>	<p>Chapter 1 on page 8</p>
<p>3. Transport and storage</p> <ul style="list-style-type: none"> • Prepare device for transport / storage 	<p>Chapter 6 on page 14</p>
<p>4. Measuring objective</p> <ul style="list-style-type: none"> • Select appropriate measuring objective for the application • Insert / change measuring objective • Observe damage thresholds 	<p>Chapter 7 on page 16</p>
<p>5. Installation</p> <ul style="list-style-type: none"> • Make preparations • Set installation position • Align device manually • Mount device firmly 	<p>Chapter 8 on page 22</p>
<p>6. Connect the water-cooling (500 W version only)</p> <ul style="list-style-type: none"> • Connection diameter • Observe flow rate 	<p>Chapter 9 on page 28</p>
<p>7. Power supply</p> <ul style="list-style-type: none"> • Connect safety interlock • Connect power supply 	<p>Chapter 10 on page 31</p>
<p>8. Connection with the PC</p> <ul style="list-style-type: none"> • Via Ethernet or LAN 	<p>Chapter 10.4 on page 35</p>
<p>9. Measurement</p> <ul style="list-style-type: none"> • Observe warning messages • Select appropriate measurement mode for the measurement task • Perform measurement 	<p>Chapter 12 on page 37</p>

6 Transport and storage



WARNING

Injuries caused by lifting or dropping the device

Lifting and positioning heavy devices can lead, for example, to overstressed intervertebral discs and chronic changes in the lumbar or cervical spine. The device may fall down.

- ▶ If possible, use a lifting device or work in pairs to lift and position the unit.
-

NOTICE

Damaging / destroying the device

Contamination can damage or destroy the optical components. Components may be damaged if the device is subjected to hard shocks or is allowed to fall.

- ▶ Move the camera housing to home position before transporting / storing the device.
 - ▶ Handle the device with care when transporting it.
 - ▶ To avoid contamination, close the measuring objective with the supplied cover before transporting / storing the device.
 - ▶ If possible, transport / store the device in the original PRIMES transport case (optional).
-

NOTICE

Damaging / destroying the device

- ▶ Store the device in a closed room where it is protected from moisture and dirt.
 - ▶ Only store the device within the permissible environmental conditions specified in chapter "17 Technical data" on page 90.
-

NOTICE

Damaging / destroying the device

If the unit is water-cooled, it can be damaged by leaking or freezing cooling water. Even if the pipe system of the cooling circuit has been drained, a small amount of water always remains in the device. This can leak out and enter the interior of the device.

- ▶ Drain the pipe system of the cooling circuit thoroughly before transporting / storing the device. Do not use compressed air for draining.
 - ▶ Before transporting / storing the device, close the water connections of the cooling circuit with the sealing plugs provided.
-



The device only fits into the original PRIMES transport case (optional) when the camera housing is in home position.

To prepare the device for transport / storage:

1. Disconnect the device from the LaserDiagnosticsSoftware LDS and switch it off according to chapter 12.3 on page 41. Make sure that the camera housing is in home position before switching it off.
2. Close the measuring objective with the supplied cover.
3. Disconnect the electrical connections.
4. Only for water-cooled device versions: Drain the cooling circuit thoroughly. Close the water connections of the cooling circuit with the supplied sealing plugs.
5. Lift the device by the handle. If you are not using a lifting device, we recommend that two people lift the device.
6. If possible, pack the device in the original PRIMES transport case (optional).

7 Selection and change of measuring objectives

7.1 Selection of the measuring objective

The selection of the suitable measuring objective is essential for the quality of the measurement. The measuring objective should be optimally matched to the wavelength, the numerical aperture and the radius to be measured.

Furthermore, the possible fields of application are limited by the sensor- and pixel size (see chapter 19.2.2, „Measuring objective“, on page 95).

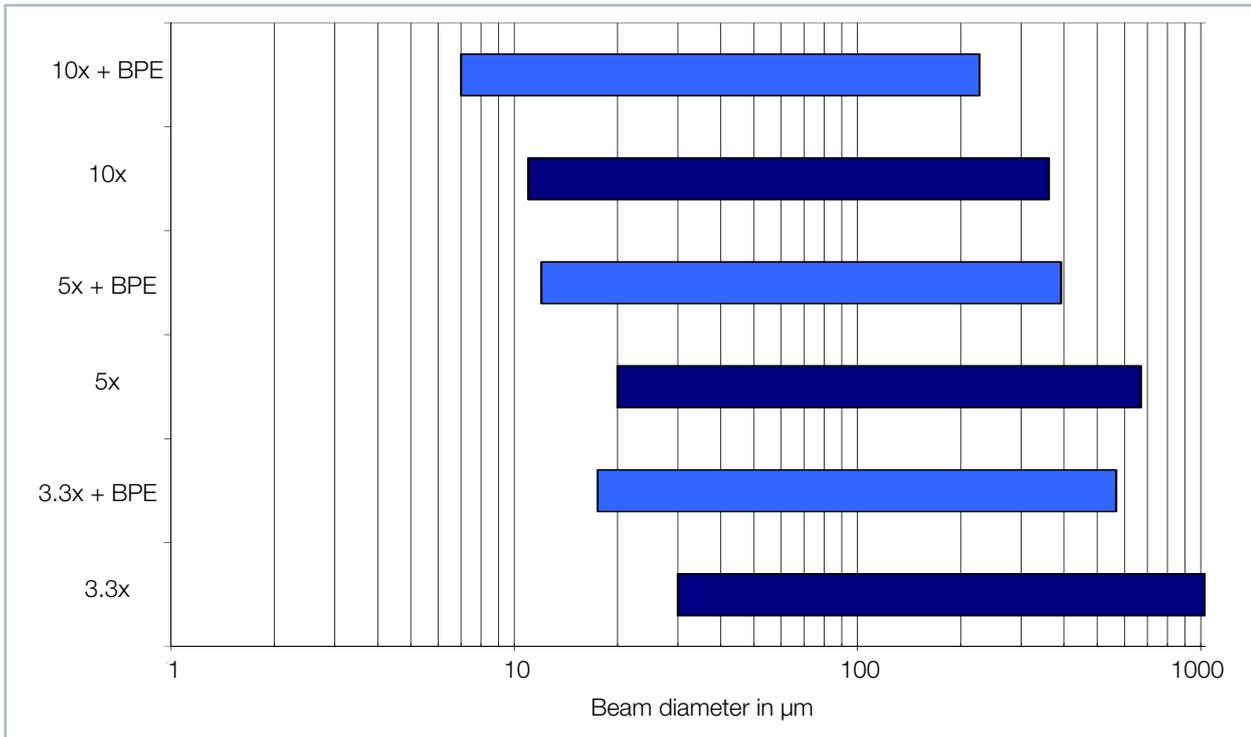


Fig. 7.1: Fields of application of the measuring objectives

Fig. 7.1 shows the field of application of different measuring objectives. The diagram enables a quick first selection of the suitable measuring objective.

The following table specifies the limits that apply to standard objectives. On the basis of this table, a suitable measuring objective can be selected. The values apply for a wavelength of 1 064 nm (the values are slightly different for other wavelengths).

Standard						
Objective	NA	F	Max. measuring window	Min. resolution	Min. beam diameter	Max. beam diameter
3.3x	0.11	5	1.4 mm	1.4 µm	30 µm	1 mm
5x	0.19		910 µm	0.9 µm	20 µm	650 µm
10x	0.24	2	510 µm	0.5 µm	11 µm	350 µm

With beam path extension (BPE)						
Objective	NA	F	Max. measuring window	Min. resolution	Min. beam diameter	Max. beam diameter
3.3x	0.11	5	800 µm	0.8 µm	17.5 µm	550 µm
5x	0.19		550 µm	0.5 µm	12 µm	380 µm
10x	0.24	2	320 µm	0.3 µm	7 µm	220 µm

With field objective (FO)						
Objective	NA	F	Max. measuring window	Min. resolution	Min. beam diameter	Max. beam diameter
3.3x	0.11	5	4 mm	3.9 µm	90 µm	2.8 mm
5x	0.19		2.75 mm	2.7 µm	60 µm	2 mm
10x	0.24	2	1.6 mm	1.6 µm	35 µm	1.1 mm

Tab. 7.1: Measuring objective data

NA = numerical aperture

F = focusing value (see Formula 7.2 on page 20)

7.2 Exchanging the measuring objective

1. Unscrew the two knurled screws.
2. Remove the measuring objective upwards. Note that the measuring objective is fixed by two dowel pins and will not tilt during removal.

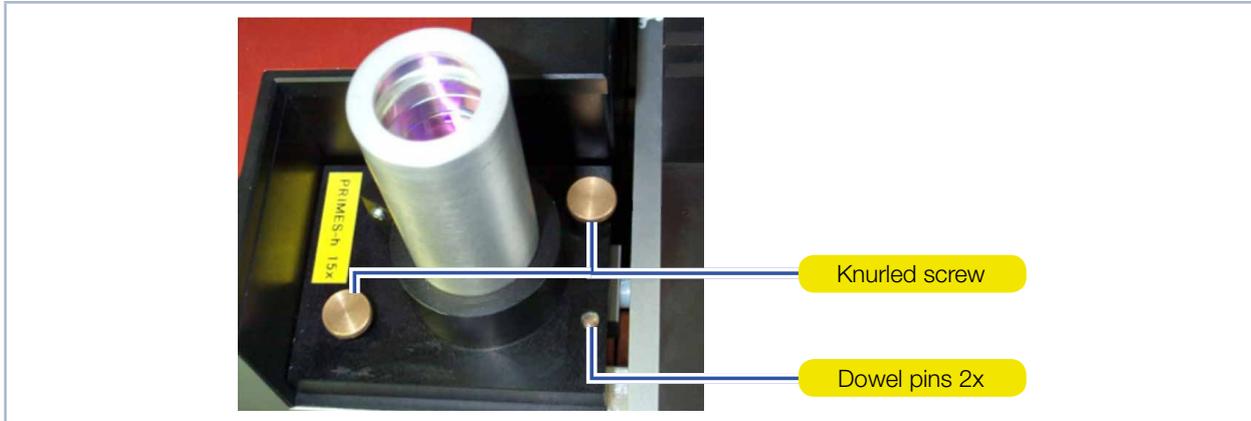


Fig. 7.2: Measuring objective inserted

NOTICE

Component susceptible to electrostatic discharge

The EEPROM can be destroyed by an electrostatic discharge.

- ▶ Do not touch the contacts of the EEPROM as well as the contact pin.
- ▶ Put on an ESD armband before changing the measuring objective.

There is an EEPROM in the mount of the measuring objectives, which contains all the objective data necessary.

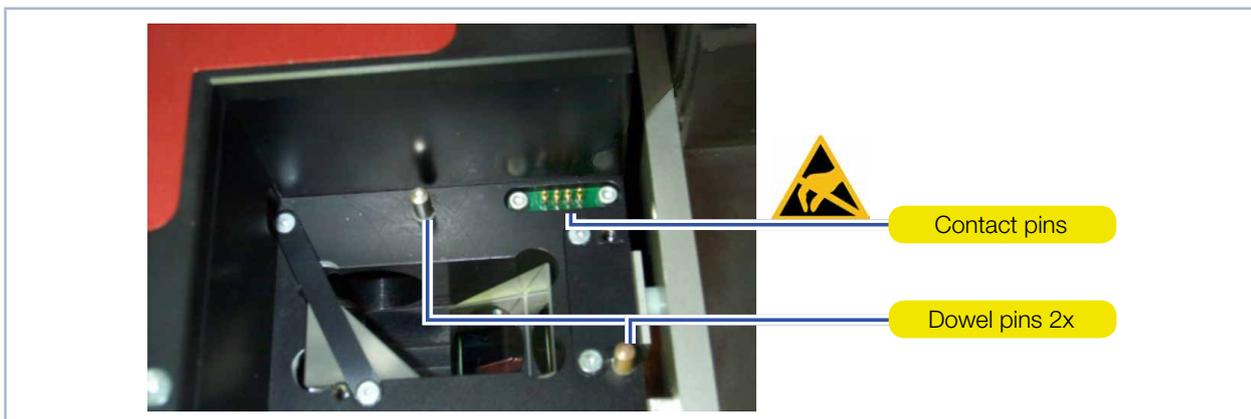


Fig. 7.3: Measuring objective removed

3. Place the measuring objective from above on the two dowel pins.
4. Press the measuring objective down vertically as far as it will go. When inserting, make sure that it does not tilt.

7.3 Damage thresholds

The operating limits of the device are determined by the damage thresholds of the optical components.

NOTICE

Damaging / destroying the measuring objective

Measuring objectives can be destroyed by an excessive power / energy density.

- ▶ **Observe the following maximum values on the first lens:**
 - **Max. power density with CW: 10 MW/cm²**
 - **Max. energy density at pulse length > 10 ns: 3 J/cm²**
- ▶ **The maximum average power for the wavelength range 1030 nm to 1090 nm (NIR) is 200 W (500 W for water-cooled device versions). The permissible power decreases for shorter wavelengths.**

The power density I is calculated according to the following formula:

$$I = \frac{P}{A} = \frac{P}{\pi \cdot r_{Spot}^2} \Rightarrow r_{Spot} \geq \sqrt{\frac{P}{\pi \cdot 10^6 \text{ bis } 7 \frac{W}{cm^2}}}$$

Formula 7.1: Formula for calculating the power density I

- If the beam focus is placed below the measurement range (too close to the measuring objective), the power density rises at the first lens of the measuring objective.
- If the focus is above the measuring plane, an intermediate focus develops inside the device. If the laser beam focus is too far above the measurement range, the intermediate focus can develop in areas in which the beam power has not been sufficiently decreased. This can damage the image-sided beam path.

The size and position of the area in which the beam focus is to be positioned before the first measurement depends on the choice of the measuring objective, the used wavelength as well as on the beam path.

The diagram in Fig. 7.4 on page 20 shows that the upper limits for high-magnification measuring objectives are much narrower than those with a 3.3-fold magnification.

The lower limit for convergent beams depends on the power density of the laser beam on the first lens. This is a function of laser power, amount of focusing, M^2 , as well as raw beam diameter.

The graphs in Fig. 7.4 and Fig. 7.5 can be used to estimate the minimum distance.

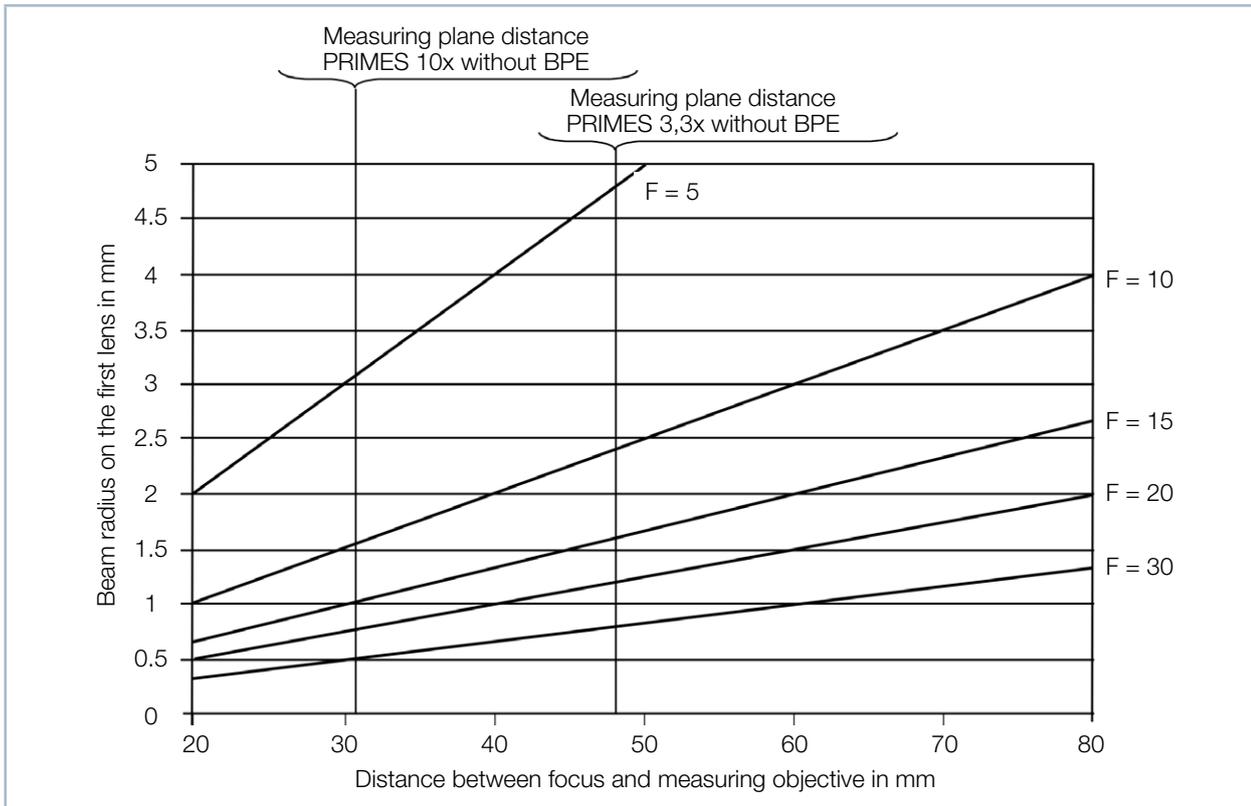


Fig. 7.4: Estimation by the focusing value F for 1 064 nm and 532 nm

The diagram in Fig. 7.4 shows the dependence of the beam radius on the first lens with the focusing value F and the distance of the focal plane to the first lens of the measuring objective.

The focusing value F can be determined by means of the following formula:

$$F = \frac{f}{d_s} = \frac{1}{2 \cdot \tan\left(\frac{\Theta}{2}\right)}$$

Formula 7.2: Formula for calculating the focusing value F

- f = Focal length of the focusing lens
- d_s = Raw beam diameter
- Θ = Full divergence angle

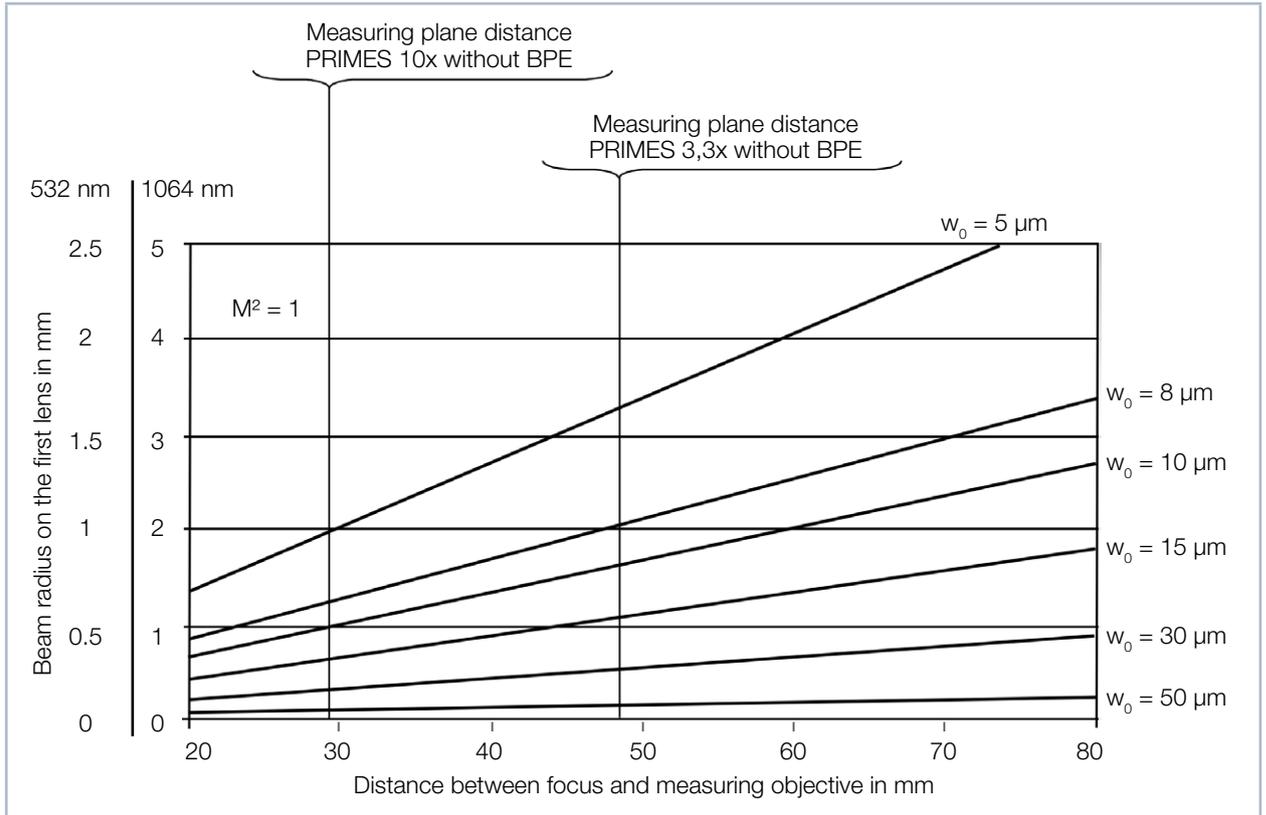


Fig. 7.5: Estimation by the focus radius for 1 064 nm and 532 nm

The diagram in Fig. 7.5 shows the dependence of the beam radius on the first lens with the wavelength, the focus radius, and the distance of the focal plane to the lens.

The beam radii are estimated by means of the beam parameter product BPP.

$$\frac{w_0 \cdot \Theta}{2} = \frac{\lambda}{\pi} \cdot M^2$$

Formula 7.3: Formula for calculating the beam radii by the beam parameter product BPP

- w₀ = Beam radius
- Θ = Full divergence angle
- λ = Wavelength
- M² = Beam quality factor

In Fig. 7.5 the beam quality factor M² was assumed to be 1.

The dependencies can be summarized as follows:

- When it comes to strongly divergent beams, for example with a focusing with small focal lengths, small focus radii develop. In order to be able to achieve a sufficient resolution on the camera chip, the 10-fold measuring objective is necessary. This objective also has a greater numerical aperture.
- When it comes to laser beams with a beam quality factor M² = 1-2, small focus radii also occur with small divergences. This may lead to damages of the entry lens when long focal length objectives are used.
- When it comes to laser beams with large beam quality factor M² values, high power values occur. They are, however, not so critical due to the large focus radii. The spot diameter on the entry lens should always be greater than 1 mm.

8 Installation



CAUTION

Crushing hazard

The camera housing of the device can be moved along the z-axis.

- ▶ **Never reach into the traversing range of the camera housing.**
-

Possible hazard spots are marked on the device as follows:



NOTICE

Damaging / destroying the device

Contamination can damage or destroy the optical components. Components may be damaged if the device is subjected to hard shocks or is allowed to fall.

- ▶ **Handle the device carefully when installing it.**
-

8.1 Conditions at the installation site

- The device must not be operated in a condensing atmosphere.
- The ambient air must be free of organic gases.
- Protect the device from splashes of water and dust.
- Operate the device in closed rooms only.

8.2 Preparation and mounting position

NOTICE

Damaging / destroying the device

The camera housing of the device can be moved along the z-axis. Obstacles in the traversing range of the device can lead to collisions and damage the device.

- ▶ **Always keep the traversing range of the camera housing free of obstacles.**
-

The device is intended for operation in horizontal position with beam incidence from above. An optional side plate enables operation with horizontal beam incidence (order number 801-004-060). The device must be set up stably and fastened with screws (see chapter 8.4 on page 27)).

- ▶ Check the space available before mounting the device. Special attention must be paid to the required space for the connecting cables and the traversing range of the z-axis (see chapterchapter 18, „Dimensions“, on page 91).

8.3 Manually aligning the device

8.3.1 Important conditions for the position of the focused laser beam

The device must be aligned to the laser beam both along the z-axis and on the x-y plane. Fig. 8.1 shows schematically the essential conditions for the manual alignment.

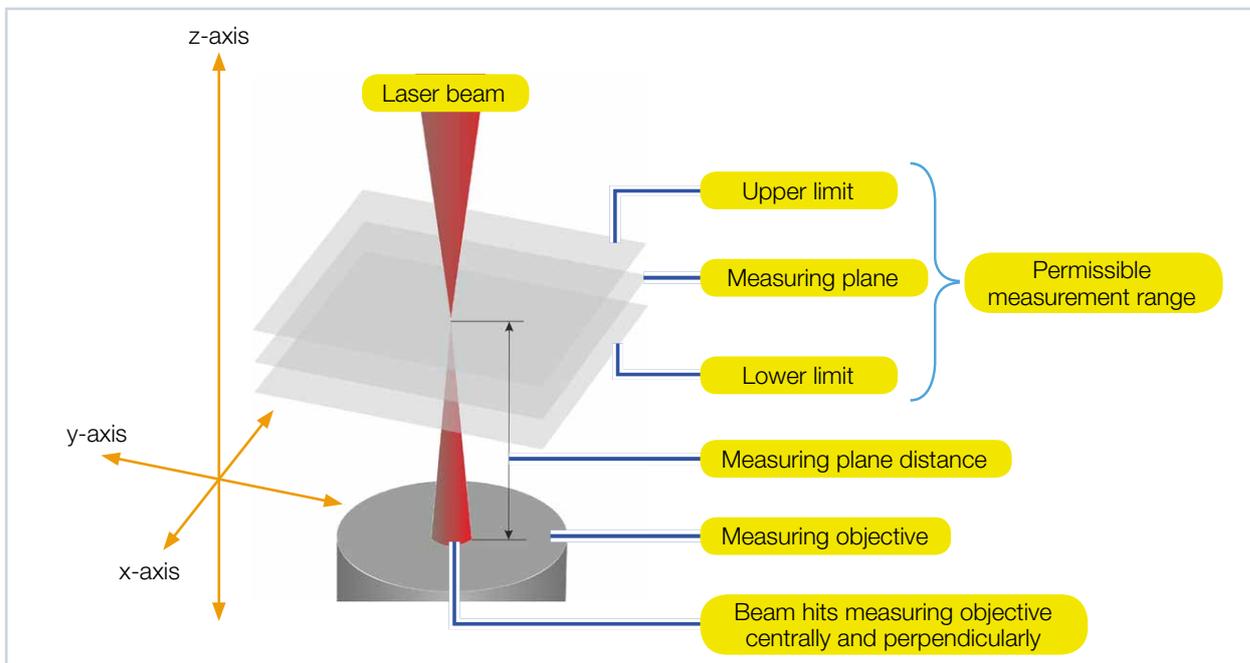


Fig. 8.1: Alignment along the device axes

Position of the measuring objective on the z-axis (measuring plane distance)

The measuring objective is designed to image a measuring plane onto the CCD sensor. The measuring plane is placed outside the measuring device. The beam must be aligned along the z-axis into the measuring plane.

Ideally, the beam focus is placed exactly on the measuring plane after alignment. In practical use, it is sufficient if the beam focus is placed within the limits of a permissible measurement range. Otherwise, the measuring objective can be damaged if beam intensities are too high.

The upper and lower limits of the permissible measurement range depend on the specific application. Selection of measurement objective, wavelength used and type of focusing of the laser are particularly important.

Before aligning, the specific measuring plane distance must be determined from Tab. 8.1. This is the distance between the measuring objective and the measuring plane. Tab. 8.1 shows that the measuring plane distance depends on the following factors:

- Magnification of the measuring objective
- Wavelength of the laser
- Use of additional optical components inside the device (beam path extension BPE or field objective FO)

The values listed in the table correspond to the distance between the measuring plane and the upper edge of the measuring objective.

Measuring objective	Measuring plane distance in mm		
	Standard	using beam path extension (BPE)	using field objective (FO)
3.3x			
1 064 nm	73	64.6	63.7
532 nm	70.5	62.6	61.5
355 nm	67.3	60.1	57.7
5x			
1 064 nm	51.1	47.1	46.7
532 nm	49.3	45.7	45.1
355 nm	47.2	43.8	42.7
10x			
1 064 nm	29.9	27.9	27.6
532 nm	—	—	—
355 nm	—	—	—

Tab. 8.1: Measuring plane distances in mm



If a 1.5 mm thick protective window is used, the measuring plane distance increases by approx. 500 µm. Due to manufacturing tolerances, the values of the measuring plane distance listed in Tab. 8.1 are subject to an error of ± 800 µm. However, it is possible to validate the measuring plane distance of the measuring objectives to an accuracy of ± 50 µm (TCP determination).

For detailed information on the damage thresholds of the optical components, refer to chapter 7.3, „Damage thresholds“, on page 19. In this chapter you will find diagrams for determining the limits of the permissible measurement range.

Position of the measuring objective on the x-y plane

Fig. 8.1 also shows the alignment of the device on the x-y plane: the laser beam must hit the measuring objective centrally and perpendicularly so that it is imaged centrally on the CCD sensor.

8.3.2 Moving camera housing to axis center position (optional)

- ▶ Before aligning and mounting the device, check the approximate z-position of the camera housing.

If the camera housing is in home position, it cannot be moved further down on the z-axis during measurement. We recommend moving the camera housing to the center position of the z-axis before alignment. If a caustic measurement is to be performed, the same amount of travel is available on both sides of the expected beam focus.



CAUTION

Crushing hazard

The camera housing of the device can be moved along the z-axis.

- ▶ Never reach into the traversing range of the camera housing.

NOTICE

Damaging / destroying the device

The camera housing of the device can be moved along the z-axis. Obstacles in the traversing range of the device can lead to collisions and damage the device.

- ▶ Always keep the traversing range of the camera housing free of obstacles.

Proceed as follows to move the camera housing to the axis center position:

1. Establish the electrical connections according to chapter 10 on page 31.
2. Switch on the device and connect it to the LaserDiagnosticsSoftware LDS according to chapter 12.2 on page 38.
3. Open the **Device control** menu according to chapter 12.4.1 on page 43.
4. Move the camera housing to the axis center position according to chapter 12.4.2 on page 43.

8.3.3 Selecting measuring objective and attaching associated alignment tool

To simplify the alignment of the device to the laser, suitable alignment tools are supplied.



Fig. 8.2: Alignment tools for direct placement on the measuring objective

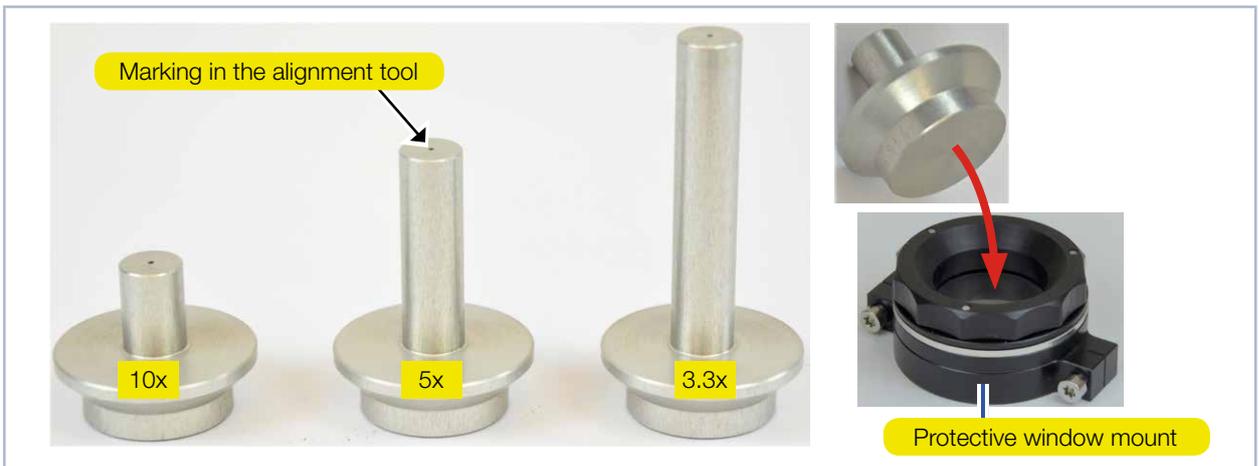


Fig. 8.3: Alignment tools for placement on the protective window mount

Special alignment tools are supplied for measuring objectives with a cyclone.

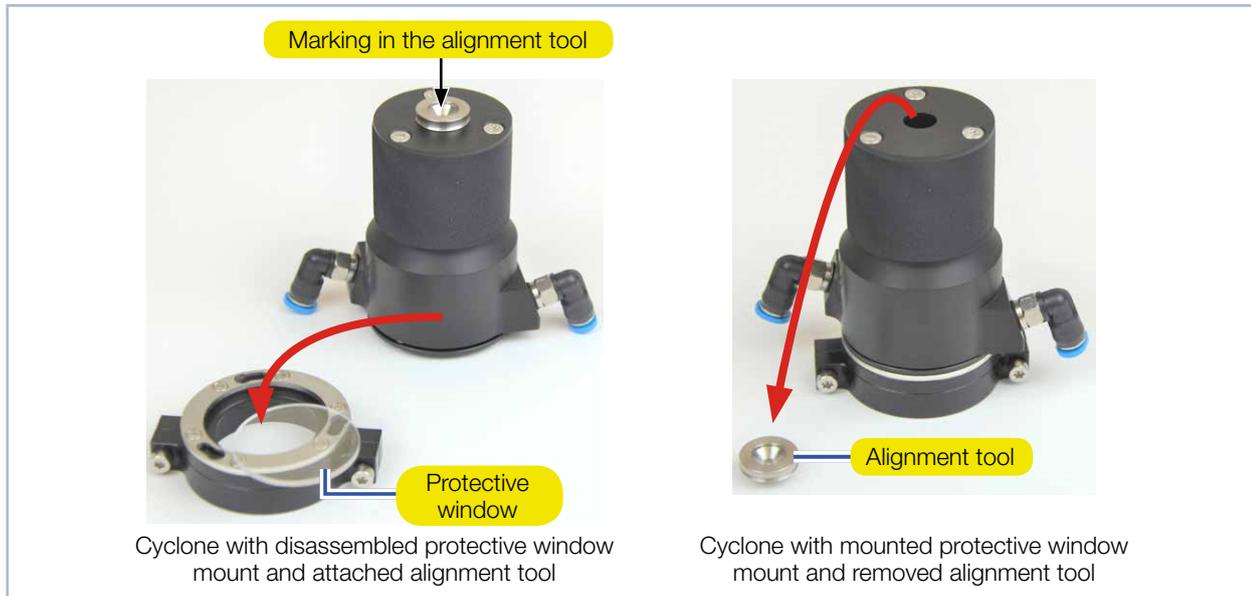


Fig. 8.4: Alignment tool for an optional cyclone (example: 3.3x measuring objective)

1. Depending on your specific application, select the appropriate measuring objective according to chapter 7 on page 16.
2. Insert the measuring objective into the device according to chapter 7.2 on page 18.
3. Place the appropriate alignment tool directly on the measuring objective (see Fig. 8.2), on the protective window mount (see Fig. 8.3) or on the cyclone (see Fig. 8.4).

8.3.4 Aligning device to laser beam

Proceed as follows to align the device with the alignment tool:

1. Switch on the pilot laser.
2. Align the device on the x-y plane in such a way that the laser beam hits the mark in the alignment tool perpendicularly.

NOTICE

Damaging / destroying the device

Excessive power densities can damage the measuring objective. The distance between the focal plane and the measuring objective must remain within the previously defined measurement range.

- ▶ **Align the device along the z-axis in a way ensuring that the beam focus is placed within the upper and lower limits of the permissible measurement range.**

3. Align the device along the z-axis in a way ensuring that the beam focus is placed within the upper and lower limits of the permissible measurement range (see Tab. 8.1 on page 24). The device is roughly aligned along the z-axis when the beam focus is on the mark of the alignment tool.

8.4 Mounting the device



DANGER

Serious eye or skin injury due to laser radiation

If the device is moved out of the aligned position, there will be increased scattered or direct reflection of the laser beam (laser class 4).

- Mount the device in such a way that it cannot be moved by unintentional bumping or pulling on the cables.

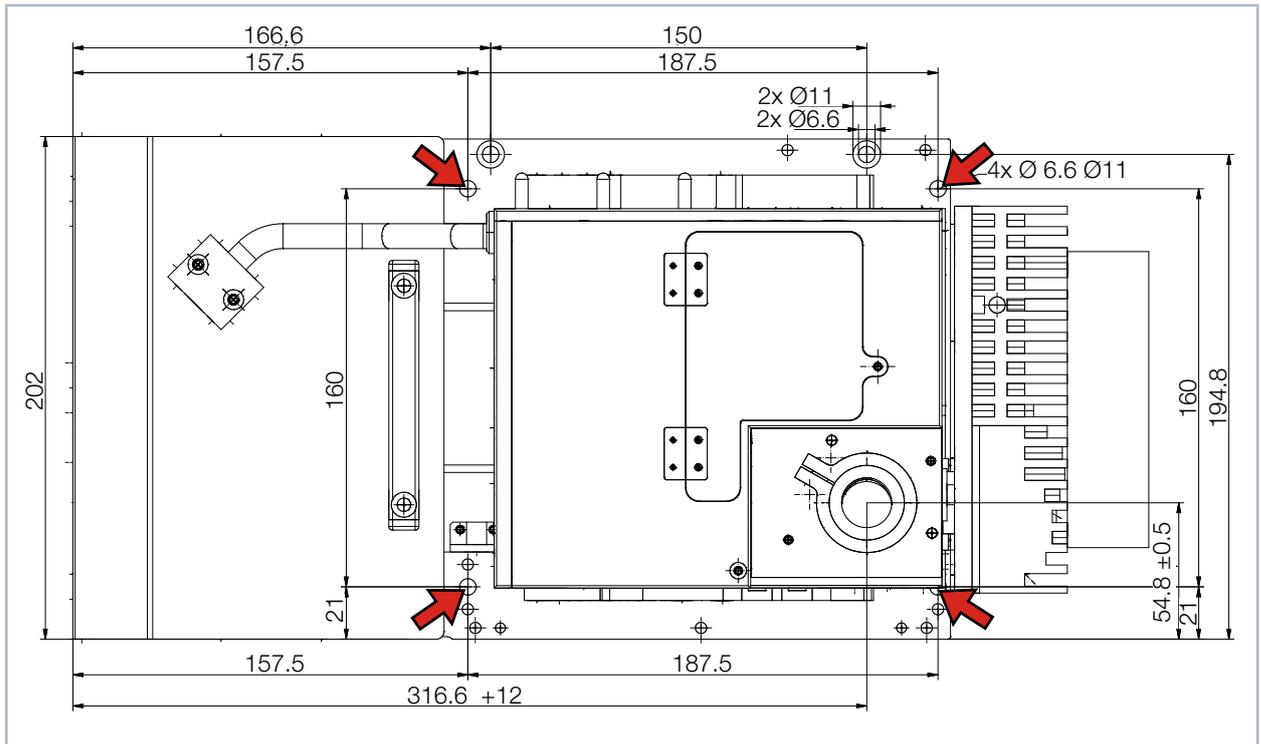


Fig. 8.5: Fastening bores, view from above (all dimensions in mm)

For the installation onto a holder provided by the customer, there are four mounting holes $\varnothing 6,6$ mm in the bottom plate. We recommend screws M6 (strength class 8.8; tightening torque 20 Nm). The total length of the screws depends on the dimensions of the customer's bracket.

- Fasten the housing with at least 4 M6 screws.

9 Cooling circuit (500 W device versions only)



DANGER

Fire hazard; Damage / Destruction of the device due to overheating

If there is no water cooling or an insufficient water flow rate, there is a danger of overheating, which can damage the device or set it on fire.

- ▶ Operate the device with a connected water cooling only and a sufficient water flow rate. Note that the flow rate is not monitored by the external safety circuit (interlock).
-

9.1 Water quality

NOTICE

Damage / Destruction of the device due to different chemical potentials

The parts of the device which get in contact with cooling water consist of copper, brass or stainless steel. Connecting the unit to a cooling circuit containing aluminum components may cause corrosion of the aluminum due to the different chemical potentials.

- ▶ Do not connect the device to a cooling circuit in which aluminum components are installed.
-

- The device can be operated with tap water as well as demineralized water.
- Do not operate the device on a cooling circuit in which aluminum components are installed. Especially when it comes to the operation with high powers and power densities, it may otherwise lead to corrosion in the cooling circuit. In the long term, this reduces the efficiency of the cooling circuit.
- Should the cooling fail, the device can withstand the laser radiation for a few seconds. In this case, please check the device as well as the water connections for damages.
- Large dirt particles or teflon tape may block internal cooling circuits. Therefore, please thoroughly rinse the system before connecting it.

9.2 Water pressure

Typically, 2 bar primary pressure at the inlet of the absorber with depressurized drain is sufficient to ensure the necessary flow rate.

NOTICE

Damage / Destruction of the device due to overpressure

- ▶ The maximum permissible water inlet pressure is 4 bar.
-

9.3 Humidity

- The device must not be operated in a condensing atmosphere. The humidity has to be considered in order to prevent condensates inside and outside the device.
- The temperature of the cooling water must not be lower than the dew point (see Tab. 9.1).

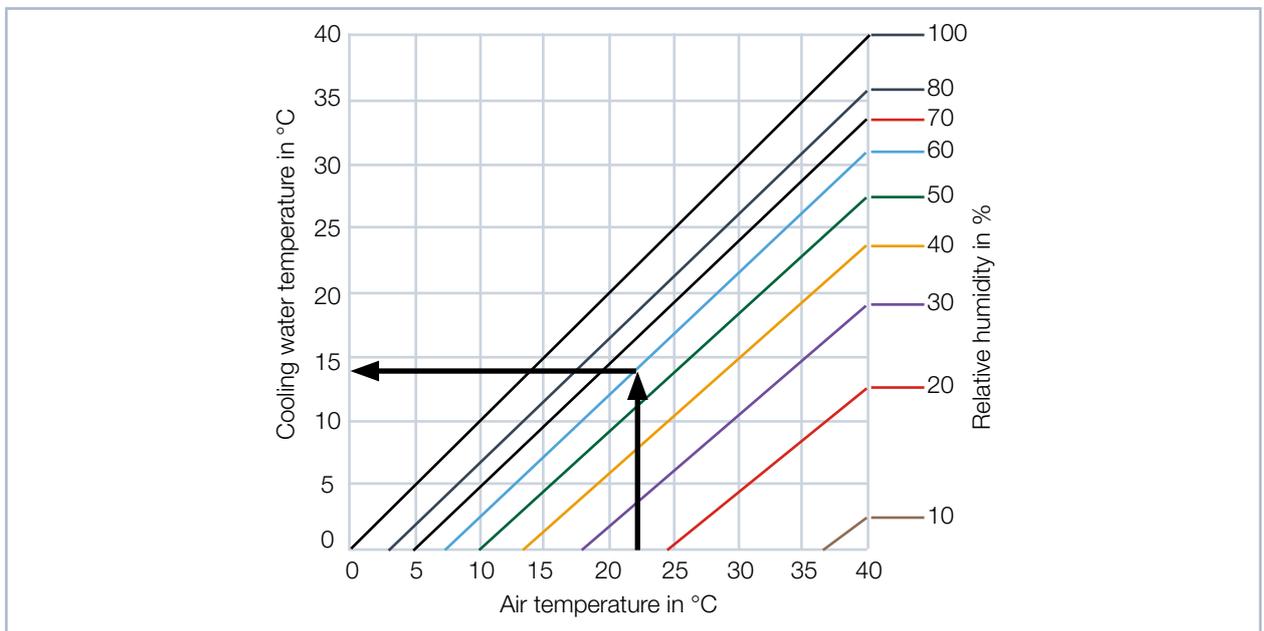
NOTICE

Damage / Destruction of the device due to condensing water

Condensation water inside of the device can lead to damage.

► **Mind the dew-point in Tab. 9.1.**

Only cool the device during the measuring operation. We recommend starting the cooling approx. 2 minutes before the measurement and terminating it approx. 1 minute after the measurement.



Tab. 9.1: Dew point diagram: The temperature of the cooling water must not be lower than the dew point

Example

Air temperature: 22 °C
Relative humidity: 60 %

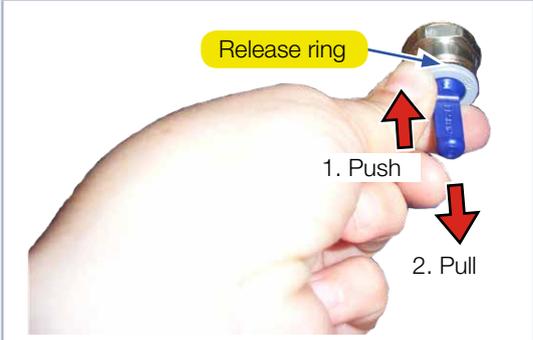
The cooling water temperature must not fall below 14 °C.

9.4 Water connections and water flow rate

Connection diameter	Recommended flow rate	Minimum flow rate
PE hoses 6 mm	1.5 l/min	not lower than 1.0 l/min

Tab. 9.2: Water connections and water flow rate

Removing the sealing plugs of the water connections



1. With two fingers of one hand, push down the release ring of the connection and pull out the plug with your free hand.
2. Remove both sealing plugs of the water connections and keep it in a save place.
3. Close the flow line (Water In) and the return flow (Water Out) of the device, by inserting the hose as far as possible (approx. 20 mm deep).

Fig. 9.1: Removing the sealing plugs of the water connections

10 Electrical connection

The device requires a supply voltage of 24 V \pm 5 % (DC) for operation. Power supply and connecting cables are provided.



Observe the correct sequence:
All electrical connections must be established before the device is switched on (see chapter 12.2 on page 38).



Only the provided PRIMES power supply and connecting cables are to be used.

10.1 Connections

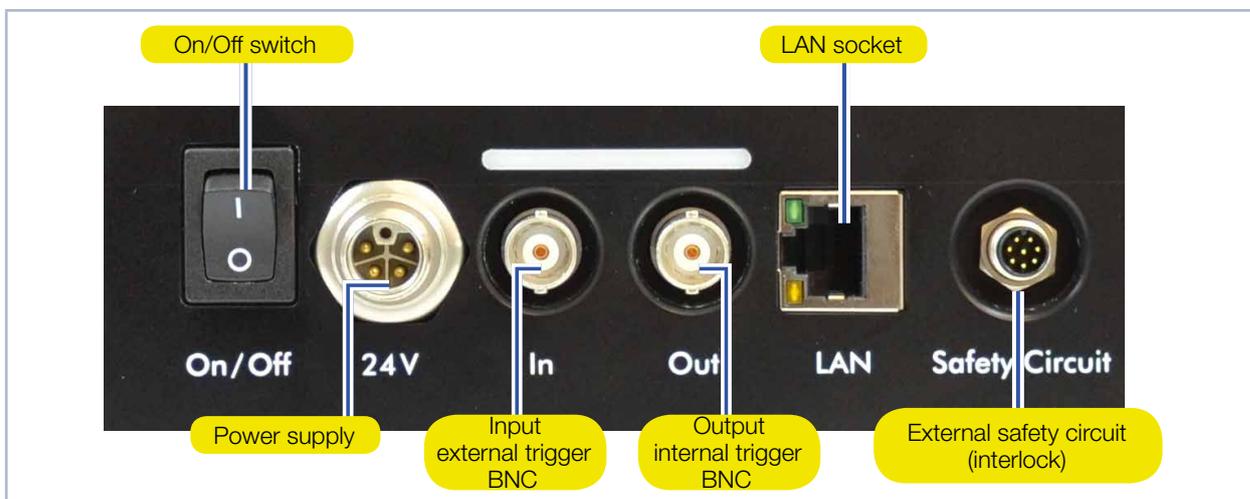
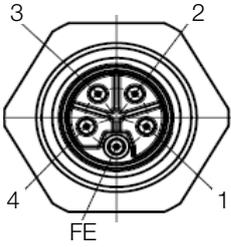


Fig. 10.1: Connections

10.2 Pin assignment

10.2.1 Power supply

Harting M12-P-PCB-THR-2PC-5P-LCOD-M-STR (view: connector side)		
	Pin	Function
	1	+24 V
	2	Not assigned
	3	GND
	4	Not assigned
	5	FE (functional earth)

Tab. 10.1: Connection socket for the PRIMES power supply in the connection panel

10.2.2 Input external trigger

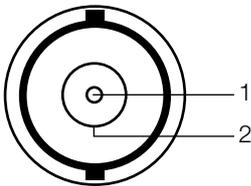
BNC connector (view: connector side)		
	Pin	Function
	1	+5 V (Trigger signal)
	2	GND

Fig. 10.2: Connection socket Inlet for an external trigger in the connection panel

10.2.3 Output internal trigger

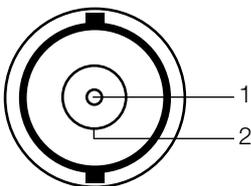
BNC connector (view: connector side)		
	Pin	Function
	1	+5 V (Trigger signal)
	2	GND

Fig. 10.3: Connection socket Outlet for the internal trigger in the connection panel

10.2.4 External safety circuit (interlock)

See chapter 10.3, „Monitoring of the inspection chamber by external safety circuit (interlock)“, on page 33.

10.3 Monitoring of the inspection chamber by external safety circuit (interlock)

The device has a connection for an external safety circuit (interlock), which monitors the cover of the inspection chamber during operation. If the cover is opened, the laser switches off.

The M8 device connector provides connections for two redundant safety circuits. A matching 8-pin cable socket is included in the scope of delivery.

DANGER

Serious eye or skin injury due to laser radiation

If the inspection chamber is open, reflected radiation (laser class 4) can escape from the device during measurement operation.

If the external safety circuit is not connected, the cover of the inspection chamber is not monitored.

- ▶ Only operate the device with the cover closed and the safety circuit correctly connected.
- ▶ Check that the safety interlock will switch off the laser properly in case of error.

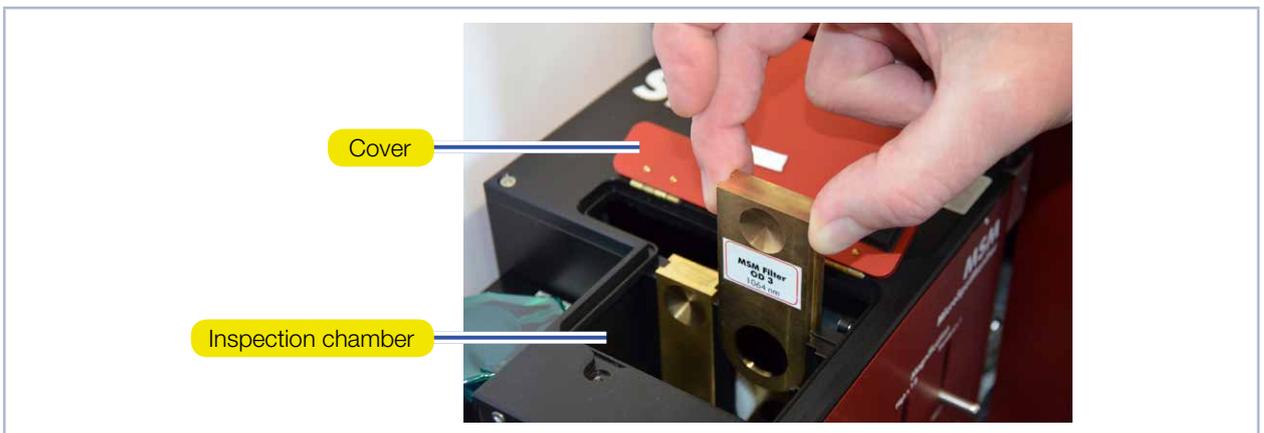


Fig. 10.4: Inspection chamber opened



Fig. 10.5: Device connector of the external safety circuit

- ▶ Connect the external safety circuit according to Tab. 10.2. If pin 1 and pin 3 (and pin 4 and pin 6) are connected, the laser is switched off.

i Pin 7 must be connected to pin 8 via an external switch or bridge so that the circuit to the interlock relay is closed.

i If the socket is not plugged in, the safety circuit is not active. In this case, a warning message is displayed in the LaserDiagnosticsSoftware LDS.

M8 connector 8-pin (view connector side)	
Pin	Function
1	Connected with pin 2 when ready for operation. Connected with pin 3 when not ready.
2	Connected with pin 1 when ready for operation.
3	Connected with pin 1 when not ready for operation.
4	Connected with pin 5 when ready for operation. Connected with pin 6 when not ready.
5	Connected with pin 4 when ready for operation.
6	Connected with pin 4 when not ready for operation.
7	Connection for switch or bridge
8	+ 24 V (applied), connection for switch or bridge

Matching ready-made cable: Binder 79-3808-52-08

Tab. 10.2: Pin assignment of the safety interlock connector

10.4 Connection to the PC and power supply

NOTICE

Damage / destruction of the device due to voltage peaks

Disconnecting the connecting cables during operation causes voltage peaks. This could destroy the communication modules of the device.

- ▶ Connect / disconnect all plugs only when the power is off.

1. Connect the device with the PC via a crossover cable or with the network via a patch cable.
2. Plug the power supply into the connector socket for the power supply.

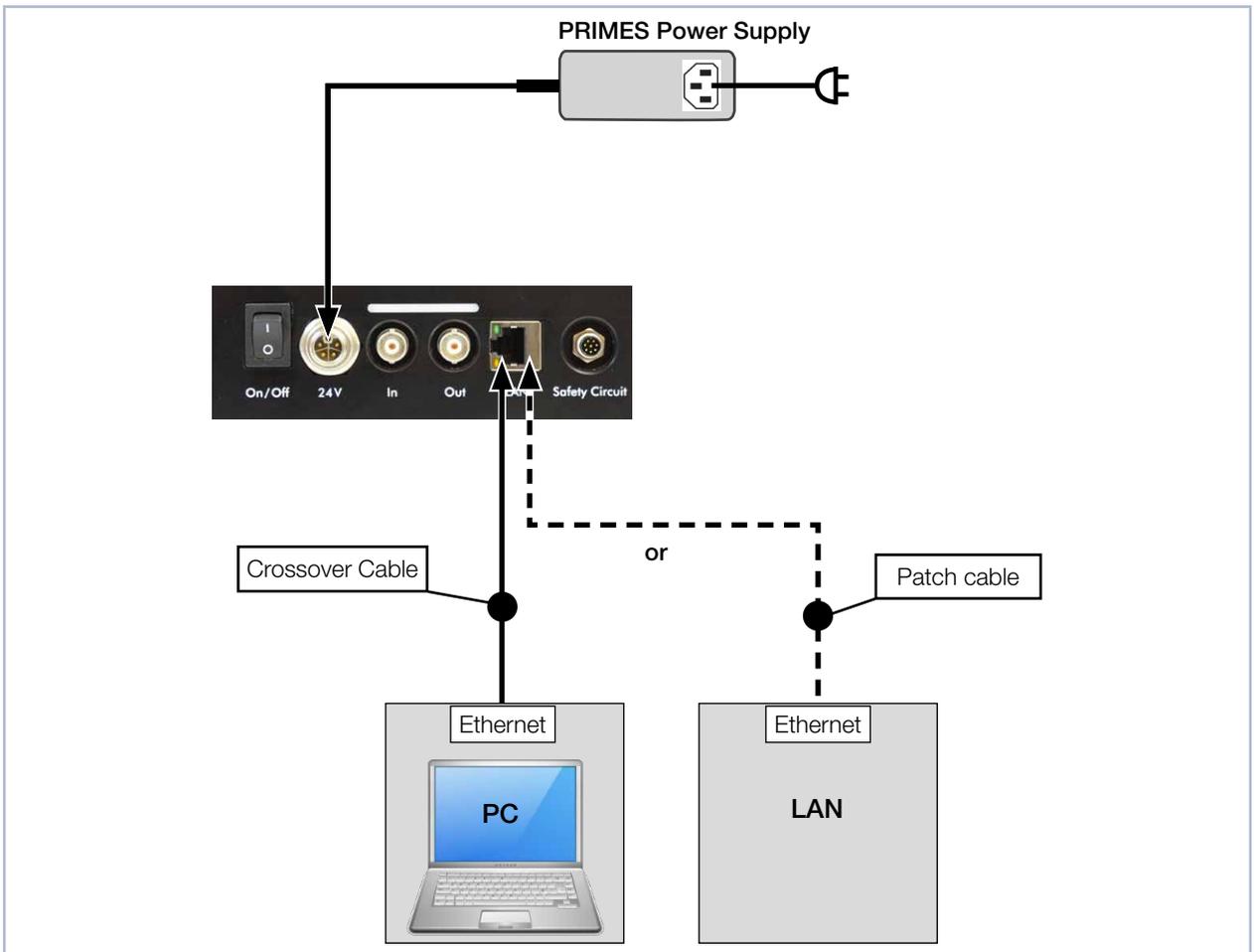


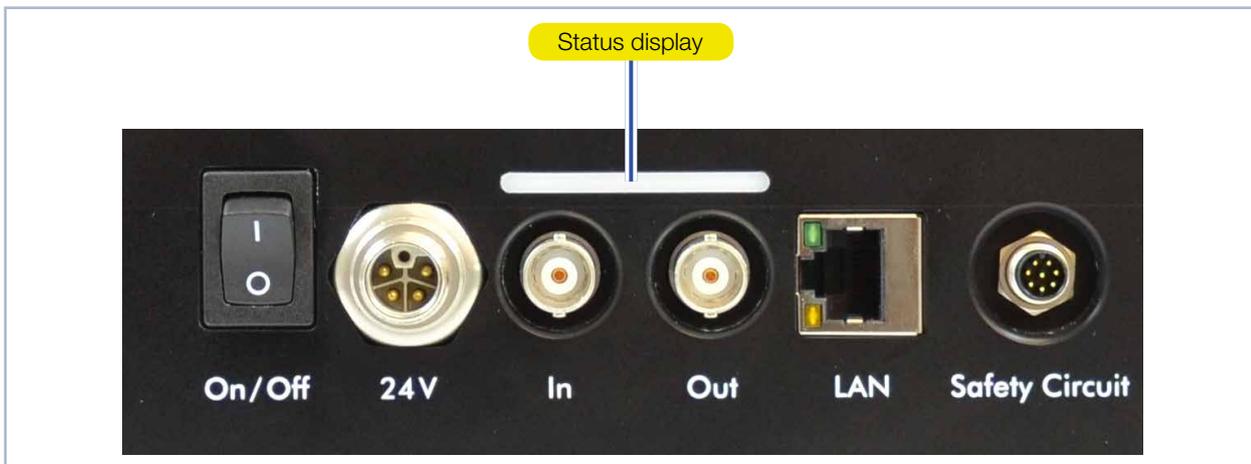
Fig. 10.6: Connection via Ethernet with a PC or a local network

11 Status display

The status display consists of an indicator field. The various device states are indicated by different lights.

Color	Meaning
White	The device is switched on and operational
Yellow	A measurement is running.
Red	Lights up briefly: a measuring plane is being recorded. Staying lit: a device error has occurred. The device error is shown in the LaserDiagnosticsSoftware LDS.

Tab. 11.1: Different lighting of the status display



Tab. 11.2: Status display

12 Measurement

This chapter describes measurements with the LaserDiagnosticsSoftware LDS. For a detailed description of the software installation, file management and evaluation of the measured data, refer to the separate operating manual LaserDiagnosticsSoftware LDS.

12.1 Warning messages



DANGER

Serious eye or skin injury due to laser radiation

The device measures direct laser radiation, but does not emit any radiation itself. However, during the measurement the laser beam is directed at the device. This produces scattered or directed reflection of the laser beam (laser class 4). The reflected beam is usually not visible.

- ▶ Connect the laser control's safety interlock to the device. Check that the safety interlock will switch off the laser properly in case of error.
- ▶ Wear safety goggles adapted to the power, power density, laser wave length and operating mode of the laser beam source in use.
- ▶ Wear suitable protective clothing or protective gloves if necessary.



CAUTION

Crushing hazard

The camera housing of the device can be moved along the z-axis.

- ▶ Never reach into the traversing range of the camera housing.

NOTICE

Damaging / destroying the device

Contamination and fingerprints on the protective window can lead to damage or shattering or splintering of the protective window.

- ▶ Do not touch the protective window.
- ▶ Regularly check the condition of the protective window and exchange it in case of pollution (see chapter 14.3, „Exchanging the protective window“, on page 85).
- ▶ Only operate the device with a clean protective window.

NOTICE

Damaging / destroying the device

The camera housing of the device can be moved along the z-axis. Obstacles in the traversing range of the device can lead to collisions and damage the device.

- ▶ Always keep the traversing range of the camera housing free of obstacles.

12.2 Switching on the device and connecting it to the LaserDiagnosticsSoftware LDS.

12.2.1 Switching on and connecting device



CAUTION

Crushing hazard

The camera housing of the device can be moved along the z-axis.

- ▶ Never reach into the traversing range of the camera housing.

NOTICE

Damaging / destroying the device

The camera housing of the device can be moved along the z-axis. Obstacles in the traversing range of the device can lead to collisions and damage the device.

- ▶ Always keep the traversing range of the camera housing free of obstacles.



If the camera housing was not in the home position when the device was switched off / disconnected from power source, then it moves to the home position after it is switched on / connected to power source. This happens even before the device is connected to the LaserDiagnosticsSoftware LDS. The axes are referenced to the home position.

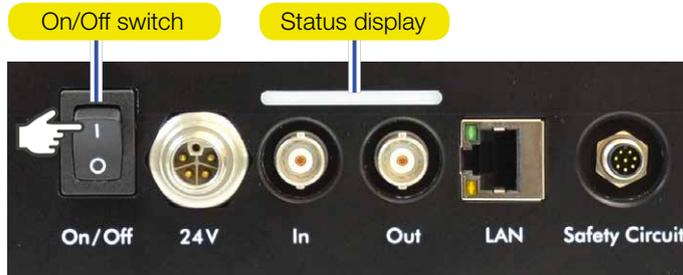


Observe the correct sequence:

- All electrical connections must be established before the device is switched on (see Kapitel "10 Electrical connection" on page 31).
- The device must be switched on before the LaserDiagnosticsSoftware LDS is started.

1. Switch on the device.

- 👁 The operating status is shown in the status display. If the device is ready for operation, the display lights up white.
- 👁 If necessary, the camera housing moves to the home position.



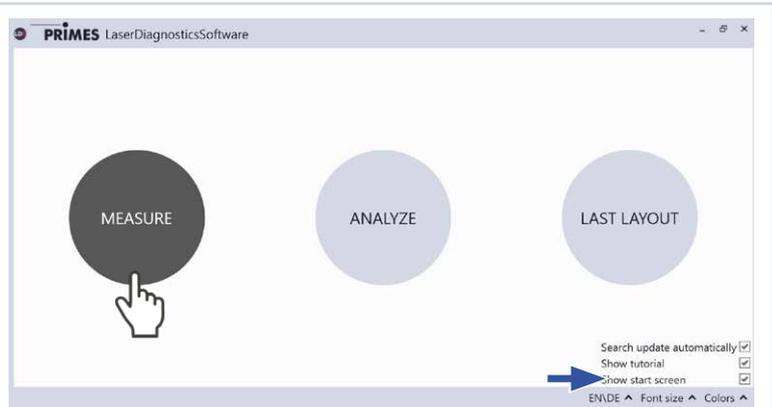
2. Use one of the following options to start the LaserDiagnosticsSoftware LDS:

- ▶ Double-click left on the program icon in the start menu group.
- ▶ Double-click left on the desktop shortcut.
- 👁 The start logo appears for a short time.



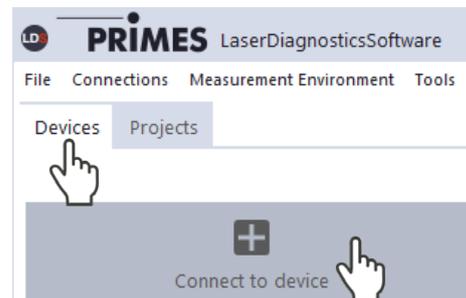
Only if the *Show start screen* option is enabled:

- 👁 The start screen appears.
- 3. Select the *Measure* operating mode.



Only if the *Show start screen* option is disabled:

- 4. Click on the *Devices* tab and then on the *+Connect to device* button.



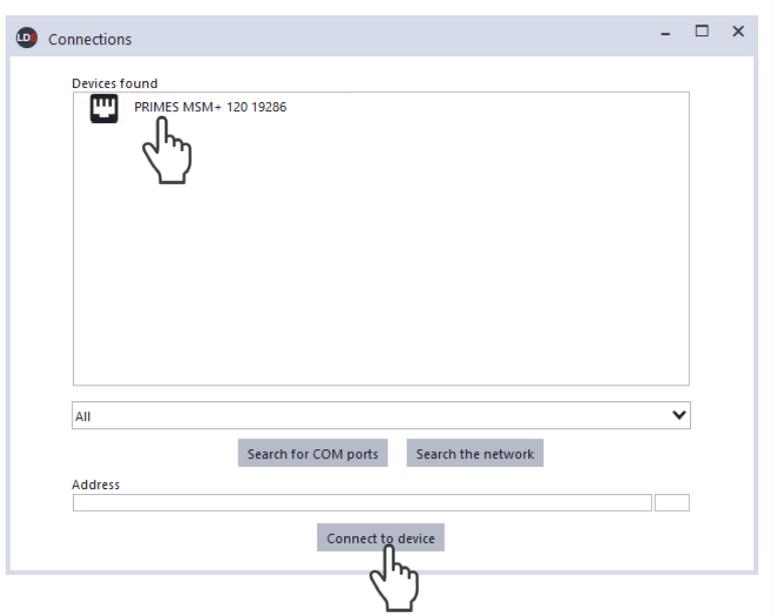
👁 The *Connections* window appears.

If the device appears in the *Connections* window:

- 5. Click on the desired device.
- 6. Click on the *Connect to device* button.

If the device does not appear in the *Connections* window:

- 7. Follow the instructions in chapter 12.2.2 on page 40.



12.2.2 If the device does not appear in the connections window

The connection of the device to the LaserDiagnosticsSoftware LDS may be blocked by the firewall:

- ▶ In **Windows > Control panel > Firewall**, enable the UDP port 20034

The UDP port should be enabled by a system administrator.

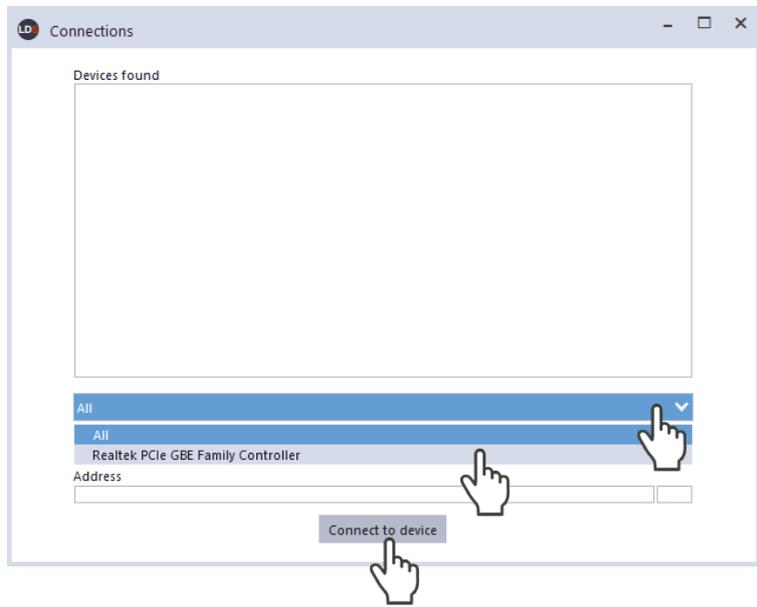
The network address of the PC is not within the range of the device.

- ▶ In **Windows > Control panel > Network and Sharing Center**, assign an IP address to your PC that is in the same address range as the device. The IP address of your device can be found on the identification plate.

The IP address should be entered by a system administrator.

If several network interface cards or a USB3-to-Ethernet card are installed in the PC, the connection of the device to the LaserDiagnosticsSoftware LDS may be blocked by the selection of the wrong network interface card.

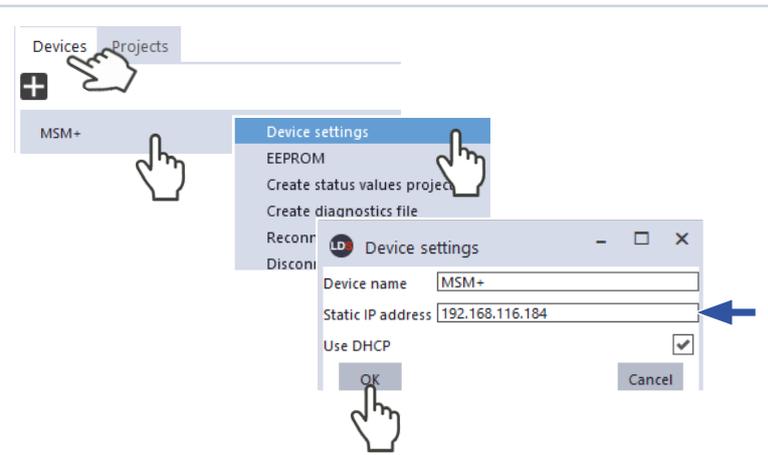
1. Select the appropriate network interface card in the **Connections > All** window.
- 👁 The device is displayed in the **Connections** window.
2. Click on the device.
3. Click on the **Connect to device** button.



12.2.3 Changing the network address of a connected device

Proceed as follows in order to assign a different IP address to a connected device:

1. Click on the **Devices** tab.
2. Right-click on the device and select the **Device settings** menu point.
3. Enter in the desired IP address or use the **Use DHCP** option and confirm the entry with **OK**.
4. Switch the device off and on again.



12.3 Disconnecting the device from the LaserDiagnosticsSoftware LDS and switching it off

When measurements are completed, the device must be disconnected from the LaserDiagnosticsSoftware LDS and switched off.



CAUTION

Crushing hazard

The camera housing of the device can be moved along the z-axis.

- ▶ Never reach into the traversing range of the camera housing.

NOTICE

Damaging / destroying the device

The camera housing of the device can be moved along the z-axis. Obstacles in the traversing range of the device can lead to collisions and damage the device.

- ▶ Always keep the traversing range of the camera housing free of obstacles.



Observe the correct sequence:

- The device must be disconnected from the LaserDiagnosticsSoftware LDS before it is switched off.
- The device must be switched off before the connecting cables are disconnected.

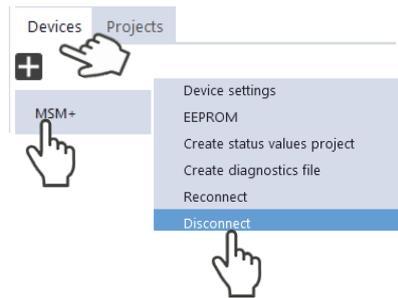


If the camera body was not in the home position when the device was switched off, it will move back to home position when it is switched on again (see chapter 12.2 on page 38).

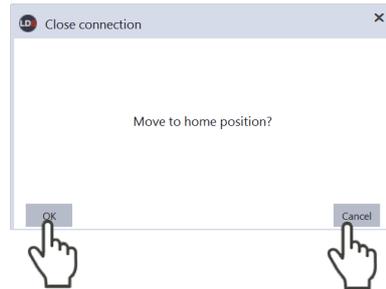


The camera housing must be in the home position before the device is transported or stored.

1. Click on the **Devices** tab.
2. Right-click on the device and select the **Disconnect** menu point.

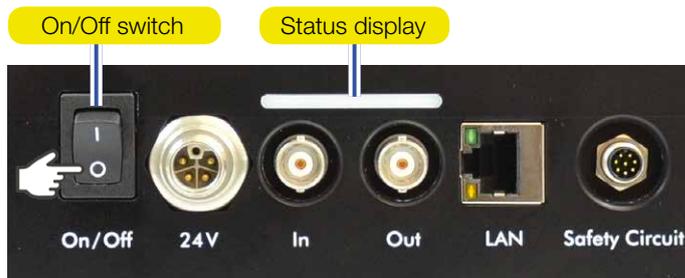


- 👁 The **Close connection** window appears.
3. Select one of the options offered:



- ▶ Confirm by clicking the **OK** button. Select this option to prepare the device for transport or storage.
- 👁 The device is disconnected from the LaserDiagnosticsSoftware LDS. The camera housing moves to home position.
- ▶ Click on the **Cancel** button.
- 👁 The device is disconnected from the LaserDiagnosticsSoftware LDS. The camera housing remains in the current axis position.

4. Switch off the device.
- 👁 The status display turns off.
5. Disconnect the electrical connections if necessary.



12.4 General procedure for measuring

This chapter describes in general which steps are necessary after connecting your device with the LaserDiagnosticsSoftware LDS to perform measurements and what you should pay attention to. Read this general information before you turn to the following chapters on the different measuring tasks.

12.4.1 Opening the „Device control“ menu

Immediately after connecting the device, the **Device control** menu must be opened:

1. Click on the **Devices** tab.
2. Select the device and click on the device function **CCD** below the device name.

The **Device control** menu with the **Adjustment** and **Measuring modes** sections opens.

12.4.2 Moving camera housing to desired z-position

The **Adjustment** area of the **Device control** menu offers various options for moving the camera housing.

Option	Explanation
<i>z-Position in mm</i>	▶ Enter the desired z-position in the input field or use the slider.
<i>Move to axis position</i>	▶ Click this button to move the camera housing to the z position specified in the <i>z-Position in mm</i> field.
<i>Move to axis center position</i>	<p>▶ Click this button to move the camera housing to the center position of the (unlocked) z-axis traversing range.</p> <p>Note that this does not have to be the maximum traversing range of your device. If a locked area of the z-axis was stored in the EEPROM during a previous use of the device, then this locked area is active. The camera housing then moves to the center position of the unlocked range.</p>

Tab. 12.1: Options in the **Adjustment** area of the **Device control** menu

12.4.3 Opening a measuring mode with adapted toolbench

In the **Device control** menu, a measuring mode can be selected. Here, all relevant settings for a measuring task are clearly arranged in a menu. For example, to measure individual planes, the **Single planes** mode provides all the options necessary.

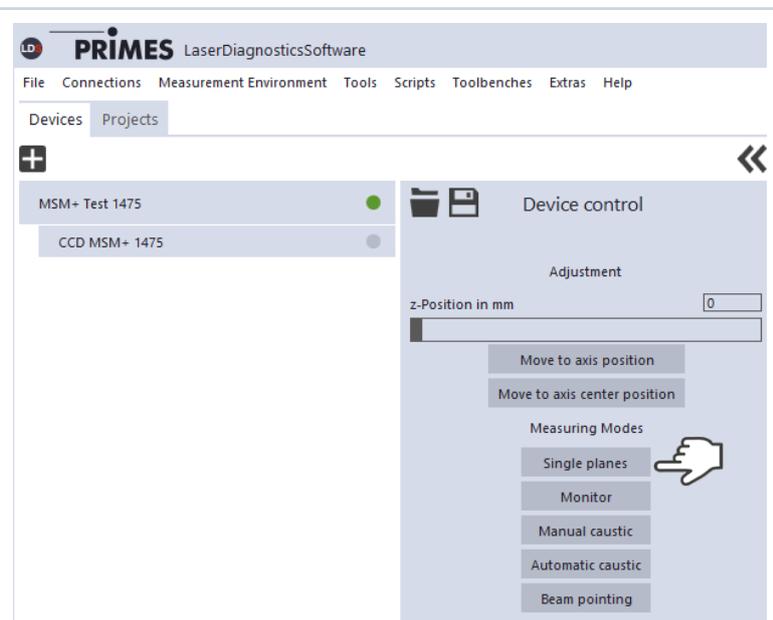
The following measuring modes can be selected:

- **Single planes** (see chapter 12.5, „Performing single plane measurement“, on page 51)
- **Monitor** (see chapter 12.6, „Performing continuous plane measurement“, on page 61)
- **Manual caustic** (see chapter , „“, on page 66)
- **Automatic caustic** (see chapter 12.8, „Performing automatic caustic measurement“, on page 73)
- **Beam pointing** (see chapter 12.9, „Monitoring beam pointing stability“, on page 79)

We recommend opening the adapted toolbench immediately after selecting a measuring mode. The toolbench is displayed in the main area of the user interface and contains the most important tools for displaying and evaluating measurement results.

Opening a measuring mode and the adapted toolbench

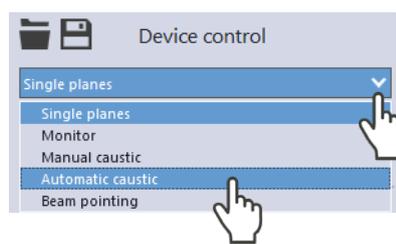
1. Open the **Device control** menu according to chapter 12.4.1 on page 43 .
2. After opening the **Device control** menu, click the button of the desired measuring mode, for example **Single planes**.



👁️ A drop-down list for changing the measuring mode appears in the upper area of the **Device control** menu.

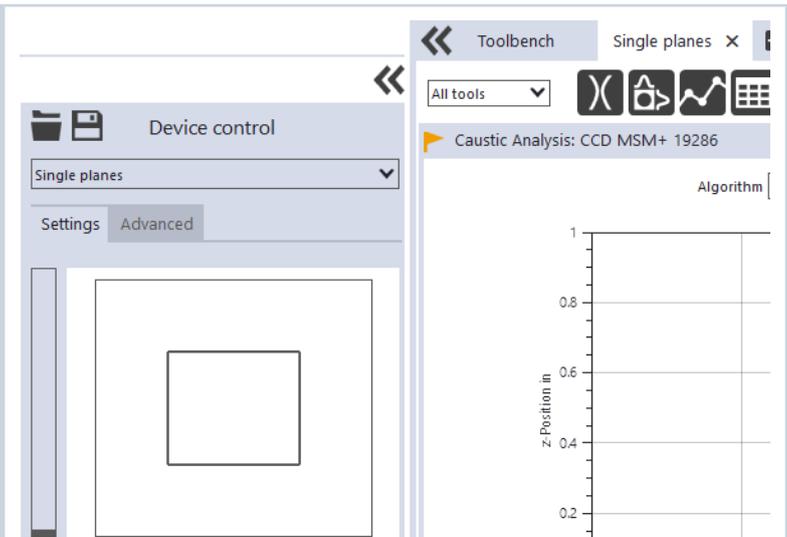
Optional:

3. Click on the arrow to open the drop-down list.
4. Click on the measuring mode to which you want to switch.



Only if the *Open measurement toolbenches* option is enabled in the *Extras > Options* menu:

- 👁 The toolbench adapted to the selected measuring mode is automatically opened in the main area of the user interface.

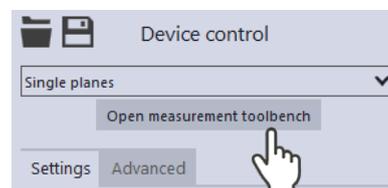


Only if the *Open measurement toolbenches* option is disabled in the *Extras > Options* menu:

- 👁 The *Open measurement toolbench* button appears in the upper area of the *Device control* menu.

This button also appears for the selected measuring mode whenever the customized toolbench had been closed.

- Click this button to open the adapted toolbench in the main area of the user interface.



12.4.4 Configuring and saving measurement settings

After selecting a measuring mode, numerous measurement and device settings in the **Settings** and **Advanced** tabs of the **Device control** menu can be configured. Which options exactly and what you need to know about them is described in the following chapters on the different measuring tasks. However, some operating steps in the **Device control** menu apply equally to all measuring modes. They are described in the following overview.

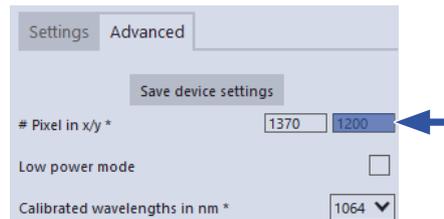
When configuring settings in one mode, note that some options may also be offered in other modes. For example, if a parameter is entered in the **Single planes** mode, it will automatically be applied to all other modes that have that same parameter field.

When saving / loading a configuration, note that although the command is made in a specific measuring mode, the saved / loaded data set also includes the settings of the other measuring modes.

Entering and activating parameters

To transfer a parameter value entered in the **Device control** menu to the active configuration, it must be confirmed with the Enter key.

1. Enter the desired value in the parameter field.
- 👁️ The background color of the parameter field changes to blue.
2. Confirm the entry by pressing the Enter key.
- 👁️ The field returns to its original background color.

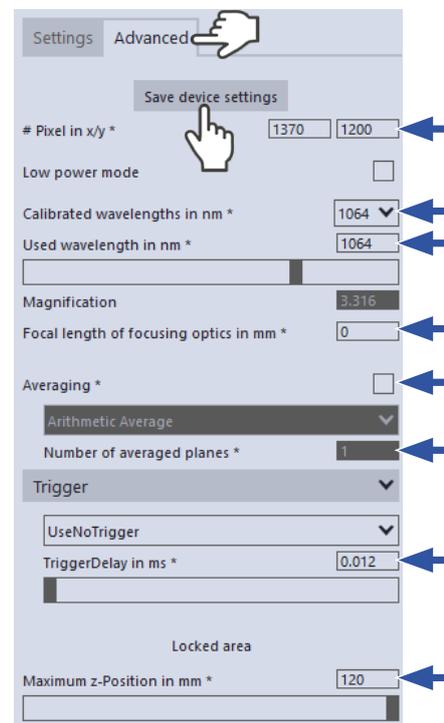


Saving a configuration in the device

All options marked with an asterisk in the **Device control** menu can be saved in the EEPROM in the device.

In this case, the settings are retained even if the device is switched off or disconnected from the power source.

1. Click on the **Advanced** tab.
2. Click on the **Save device settings** button.

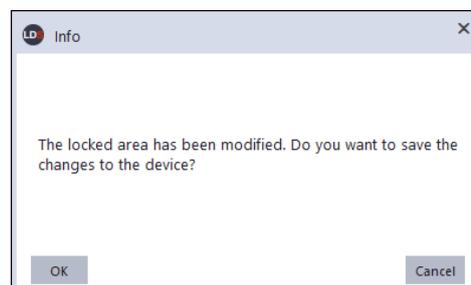


Saving a safety-relevant locked area

We recommend saving a configuration in the device especially if a safety-relevant locked area is configured in the **Advanced** tab.

- 👁️ If the locked area was configured but not saved via **Save device settings**, then a dialog box appears after clicking the **Start** button (to start a measurement).

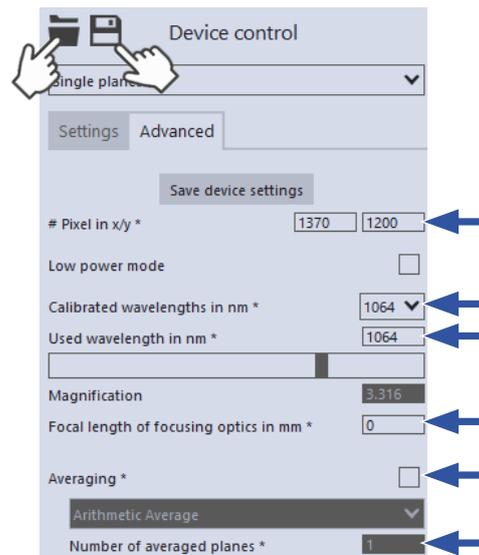
- ▶ If you now want to save the locked area (and the other options marked with an asterisk) in the device, click the **OK** button.
- ▶ Otherwise, click on the **Cancel** button.
- ➔ The settings are active during the measurement, but must be configured again when the device is switched off or disconnected from the power source.



Saving a configuration to a file / loading from a file

All options marked with an asterisk in the **Device control** menu can be saved to a preset file with the **.pre** extension.

- ▶ To save a configuration, click the  icon.
- ▶ To load a configuration, click the  icon.

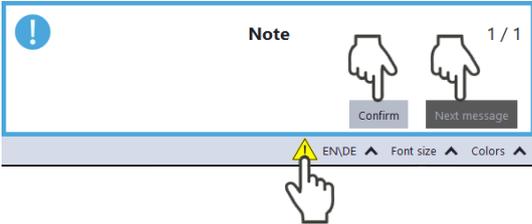
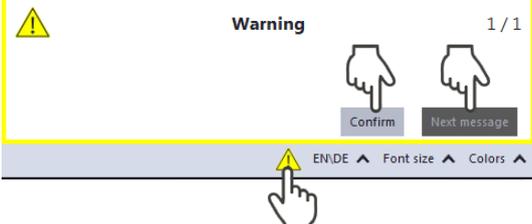


12.4.5 Performing a measurement

Once the measurement and device settings have been configured, a measurement can be performed. The corresponding procedures are described in the following chapters for the different measuring tasks.

12.4.6 Considering messages in the LaserDiagnosticsSoftware LDS during measurement

If problems occur during a measurement, the LaserDiagnosticsSoftware LDS displays them in different categories and different colors.

<p>Notes</p> <p>Notes provide assistance in interpreting the measurement results and are displayed in a blue window.</p> <p>Use one of the following options:</p> <ul style="list-style-type: none"> ▶ Click on the warning triangle in the footer to display / hide the window. ▶ If applicable, click the Next message button to display more messages of the same category. ▶ Click the Confirm button to remove the displayed message. 	
<p>Warnings</p> <p>Non-safety-critical problems that influence the quality of the measurement results, for example, are displayed in a yellow window.</p> <p>Use one of the following options:</p> <ul style="list-style-type: none"> ▶ Click on the warning triangle in the footer to display / hide the window. ▶ If applicable, click the Next message button to display more messages of the same category. ▶ Click the Confirm button to remove the displayed message. 	
<p>Safety critical device errors</p> <p>Safety-critical problems that can result in damage / destruction of the device are displayed in a red window.</p> <p>In this case, proceed as follows:</p> <ol style="list-style-type: none"> 1. Fix the problem immediately. 2. Click the Confirm button to remove the message. <p>👁 The message disappears. If the problem is not fixed, then the message appears again shortly afterwards.</p> <ol style="list-style-type: none"> 3. Do not proceed with the measurement until the problem is solved. 	

12.4.7 Checking the quality of the measurement results in the adapted toolbench

In the main area of the user interface, the measurement results are displayed in the tools of the adapted toolbench. We recommend checking the quality of the results immediately after a measurement. Depending on the results, it might be necessary to repeat the measurement with improved measurement setup or changed parameters.

In the project tree and in numerous tools, the LaserDiagnosticsSoftware LDS enables evaluating measurement results. The results are automatically compared with limit and warning values and are marked accordingly by colors. For a detailed description of the project tree, the tools and the evaluation of the measurement results, please refer to the separate operating manual of the LaserDiagnosticsSoftware LDS.

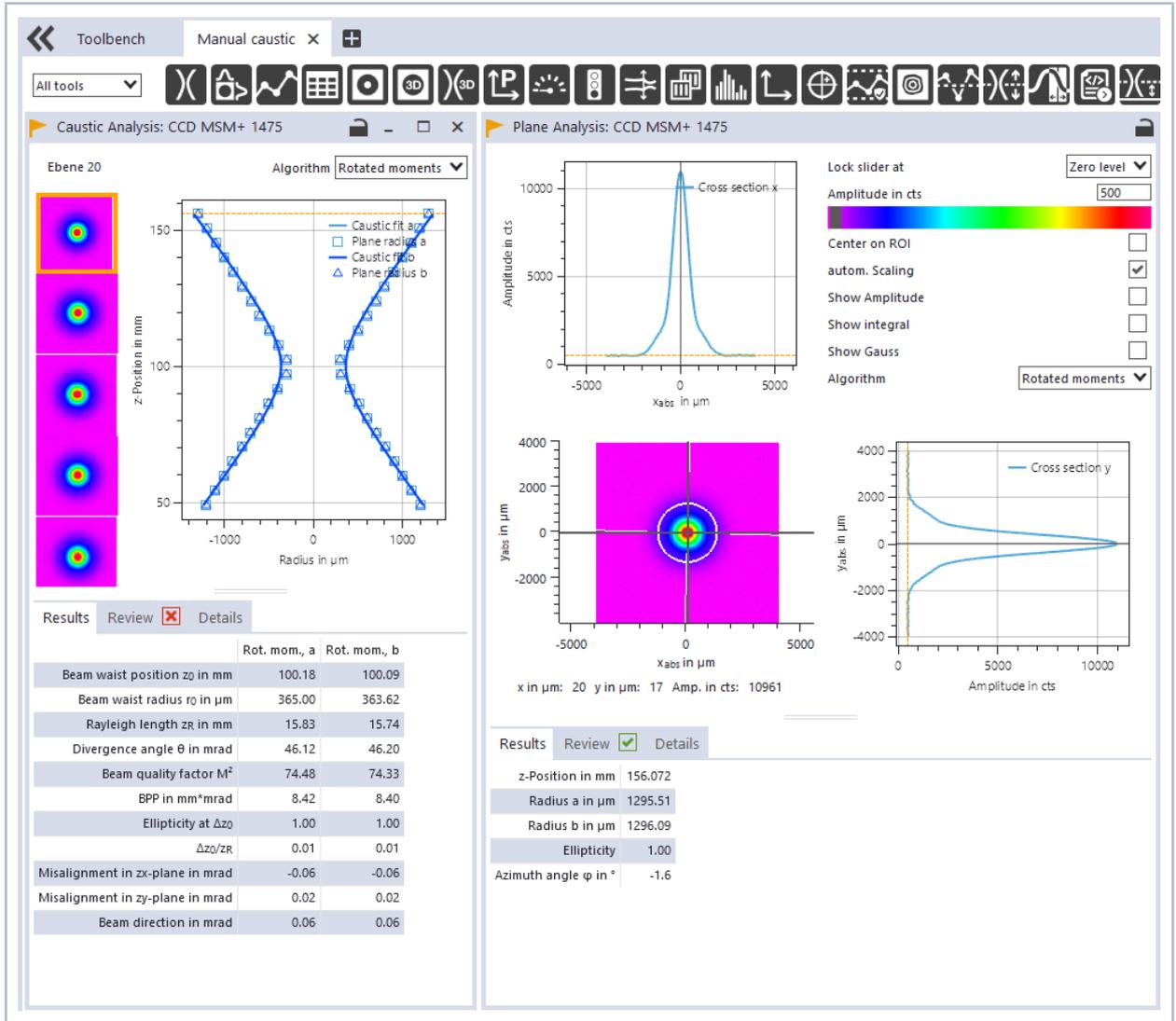


Fig. 12.1: Display of measurement results in the tools of the adapted toolbench (example)

12.4.8 Remeasuring a caustic or plane (optional)

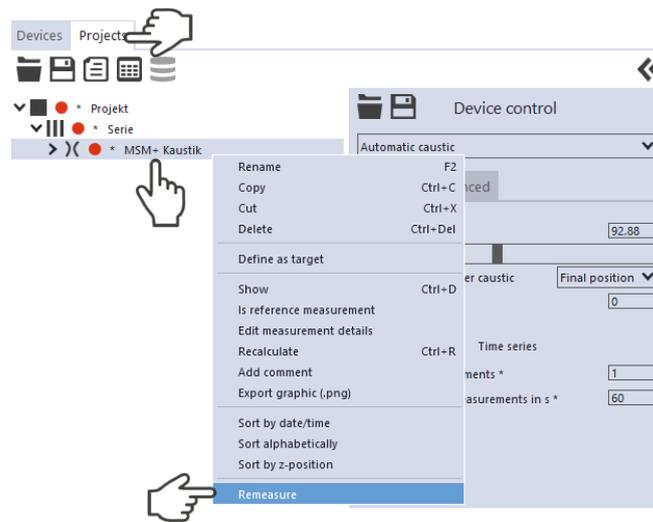
A caustic or plane can be remeasured using the **Remeasure** function. Note that this function is only available if a device is connected.

When remeasuring a caustic, the existing measurement data is not overwritten. Rather, an additional caustic measurement is created in the project tree. When remeasuring a plane, you will be asked beforehand if you want to overwrite the plane selected in the project tree.

For a detailed description of the project tree, please refer to the separate operating manual of the LaserDiagnosticsSoftware LDS.

**Proceed as follows
(Example caustic measurement)::**

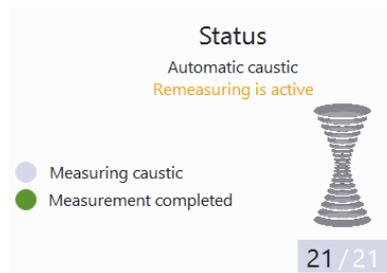
1. Click on the **Projects** tab.
2. In the project tree, select the caustic measurement that you want to remeasure.
3. Right-click to open the context menu and select **Remeasure**.
 ⦿ The settings of the selected measurement are applied and displayed in the **Device control** menu.



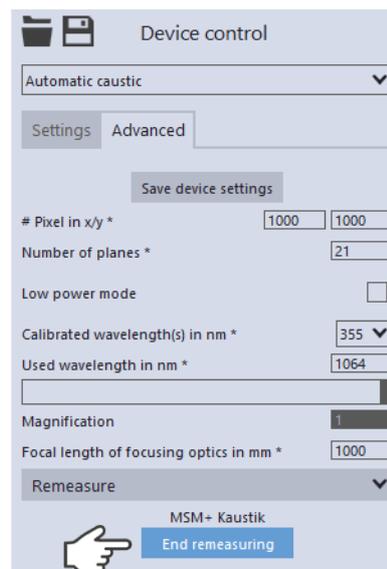
4. Start a measurement by clicking the **Start** button.



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



5. After you have finished the measurement, click on the **End remeasuring** button in the **Advanced** tab.



12.5 Performing single plane measurement

In the **Single planes** measuring mode, single planes are measured at selected z-positions. Measurement window size and exposure can be set automatically or determined freely. You can also have the software search the laser beam automatically in the entire measurement range.

To measure a custom caustic, several planes can be measured — either individually or by means of a series measurement. To define the caustic measurement, an increment along the z-axis can be configured. According to ISO 11146-1, at least 10 planes shall be measured. Approximately half of the measurements shall be distributed within one Rayleigh length on either side of the focus, and approximately half of them shall be distributed beyond two Rayleigh lengths from the focus.

By means of the variable integration time control, a large number of pulsed beams can be measured in quasi-cw operation in addition to cw laser beams. An exception are, for example, laser beams with a very low pulse frequency. Trigger operation is available for measuring such beams. If this is enabled, the device only measures within defined time periods. The laser pulse or the corresponding trigger signal marks the beginning of such a period and the (freely adjustable) integration time marks its end. A measurement can be triggered internally or externally. Internal signals are triggered by the photodiode integrated in the device. Externally triggered signals enter the device via a BNC socket. For detailed information on the measurement of pulsed laser beams and the trigger operation, please refer to chapter 19.3 on page 101.

12.5.1 Preparatory steps

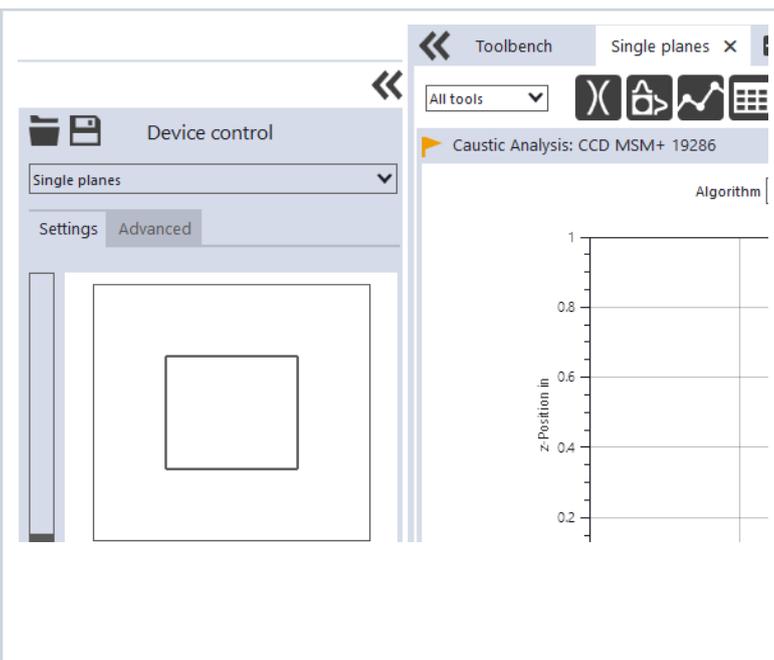
If you have not switched from another measuring mode to here:

1. Connect the device to the LaserDiagnosticsSoftware LDS according to chapter 12.2.1 on page 38.
2. Open the **Device control** menu according to chapter 12.4.1 on page 43.
3. Select the **Single planes** measuring mode and open the adapted toolbench according to chapter 12.4.3 on page 44.

👁️ The associated menu **Device control** is opened.

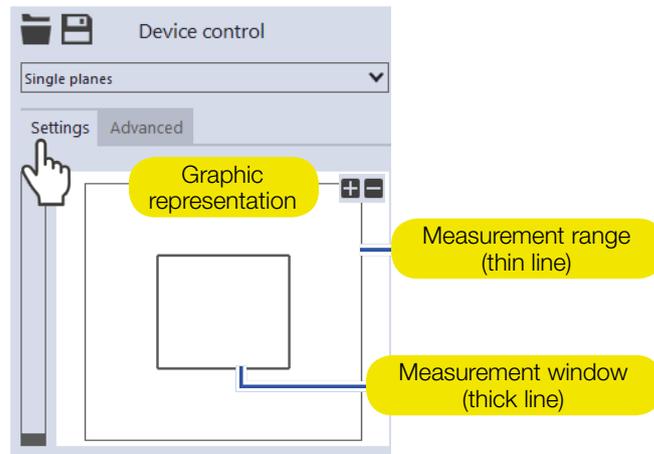
👁️ The **Single planes** toolbench with the following tools is opened:

- **Caustic Analysis**
- **Plane Analysis**



12.5.2 Configuring settings

1. Click on the **Settings** tab.
2. Maintain the options according to the explanations in Tab. 12.2.



Option	Explanation
Graphic representation	<p>In a window in the upper area of the Settings tab, the measurement plane is displayed graphically. Here you can see:</p> <ul style="list-style-type: none"> • the entire measurable area (measurement range, thin lines) • the area to be recorded (measurement window, thick lines) • after a measurement a false-color image of the recorded area <p>You can make changes in the graphic representation as follows:</p> <ul style="list-style-type: none"> ▶ To create a new measurement window, position the mouse pointer anywhere within the measurement range. Drag while holding down the left mouse button. Keep the mouse button pressed until the measurement window meets your requirements. The maximum size of the window depends, among other things, on the magnification of the measuring objective (see chapter 7.1 on page 16). ▶ To move the measurement window to another location, position the mouse pointer inside the measurement window. Drag while holding down the right mouse button. ▶ To zoom to the center of the graphic representation, first move the mouse pointer over the graphic representation until the plus / minus buttons appear. Then press the buttons. ▶ To zoom in on the position of the mouse pointer, position the mouse pointer anywhere within the graphic representation. Then turn the mouse wheel. ▶ To set the zoom section to the size of the measurement window, position the mouse pointer inside the measurement window. Then double-click left. ▶ To set the zoom section to the size of the measurement range, position the mouse pointer outside the measurement window. Then double-click left.
z-Position in mm	<p>Use one of the following options to set the desired z-position of the plane to be measured:</p> <ul style="list-style-type: none"> ▶ Enter a value in the input field. ▶ Use the slider on the left side of the graphic representation.
Reset measurement window	<ul style="list-style-type: none"> ▶ Click this button to maximize the measurement window and simultaneously center it in the measurement range.
z-Increment in mm	<ul style="list-style-type: none"> ▶ If you want to measure multiple planes with fixed spacing, enter the desired z-increment (see chapter 12.5.5, „Measuring further planes“, on page 60).

Tab. 12.2: Options in the **Device control** > **Settings** tab of the **Single planes** measuring mode

Option	Explanation
Power P in W *	<ul style="list-style-type: none"> ▶ Enter the laser power used during measurement. <p>Only if the power is entered, a calculation of the power density distribution can be performed. Otherwise, the measured amplitudes are given directly in counts.</p>
autom. Measurement window	<p>If this option is enabled, then the measurement window size will be set automatically.</p> <ul style="list-style-type: none"> ▶ Set the check mark to enable the option.
Window size in mm	<p>The maximum size of the measurement window depends, among other things, on the magnification of the measuring objective (see chapter 7.1 on page 16).</p> <p>If the autom. Measurement window option is disabled, the size of the measurement window can be adjusted manually. Use one of the following options:</p> <ul style="list-style-type: none"> ▶ Enter the length of a horizontal / vertical side in the input field on the left / right. ▶ Position the mouse pointer anywhere within the measurement range and drag while holding down the left mouse button. Keep the mouse button pressed until the measurement window meets your requirements.
Position in mm	<p>Use one of the following options to adjust the position of the measurement window:</p> <ul style="list-style-type: none"> ▶ Enter the x-position / y-position of the center of the measurement window in the input field on the left / right. ▶ Position the mouse pointer within the measurement window. Then drag while holding down the right mouse button.
Find beam	<p>This option enables a measurement in which the laser beam is automatically searched for in the entire measurement range. The plane at the defined z-position is then displayed in the graphic representation. Measurement window size, integration time, and filter level of the filter wheel (if available) are set automatically.</p> <ul style="list-style-type: none"> ▶ Click on the button to start the beam search. <p>Note that the determined measurement data will not be saved in the project tree of the Projects tab.</p>
autom. Exposure	<p>If this option is enabled, the integration time is set automatically.</p> <ul style="list-style-type: none"> ▶ Set the check mark to enable the option.
Integration time in ms	<p>If the autom. Exposure option is disabled, the integration time can be set manually.</p> <p>Use one of the following options:</p> <ul style="list-style-type: none"> ▶ Enter a value in the input field (0.006 ms to 225 ms). ▶ Use the slider below the input field.
Filter level	<p>This option is available if an optional filter wheel is installed in the device.</p> <ul style="list-style-type: none"> ▶ Select a filter level in the drop-down list. <p>The selected setting will only be active if the autom. filter adjustment option is disabled.</p> <p>The filter required for measurement depends on the wavelength and intensity of the laser beam to be measured. We recommend selecting a filter level that achieves a detector modulation of between 60 % and 80%.</p>

Tab. 12.2: Options in the **Device control > Settings** tab of the **Single planes** measuring mode

Option	Explanation
autom. filter adjustment	This option is available if an optional filter wheel is installed in the device. If this option is enabled, then the filter levels are set automatically. <ul style="list-style-type: none"> ▶ Set the check mark to enable the option.
Time series	A time series consists of several single plane measurements with the same settings.
Number of measurements *	<ul style="list-style-type: none"> ▶ Enter the desired number of single plane measurements of the time series.
Interval between measurements in s *	<ul style="list-style-type: none"> ▶ Enter the pause between the single plane measurements of the time series. This is the time gap between the end of one measurement and the start of the next.
Parameter settings	All settings in the Device control menu can be individually saved for each device. The saving location is the local installation of the LaserDiagnosticsSoftware LDS.
Save current parameters	<ul style="list-style-type: none"> ▶ Click this button to save all current settings of the connected device.
Load last parameters	<ul style="list-style-type: none"> ▶ Click this button to load the last saved device configuration.

 Tab. 12.2: Options in the **Device control > Settings** tab of the **Single planes** measuring mode

12.5.3 Configuring advanced settings

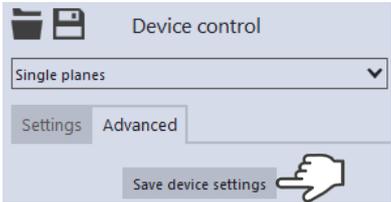
<ol style="list-style-type: none"> 1. Click on the Advanced tab. 2. Maintain the options according to the explanations in Tab. 12.3. 	
---	--

Option	Explanation
Save device settings	<p>All options marked with an asterisk in the Device control menu can be saved in the EEPROM of the device.</p> <p>These and other options for saving / loading configurations are described in chapter 12.4.4 on page 45.</p>
# Pixel in x/y *	<p>This option enables setting the resolution of the CCD sensor:</p> <ul style="list-style-type: none"> ▶ Enter the number of pixels in the x-direction / y-direction in the input field on the left / right.
Low power mode	<p>This option is only relevant when performing a beam search (Find beam option, see chapter 12.5.2 on page 52). We recommend activating it for low power laser beams (< 1 W).</p> <p>If this option is enabled, the following initial values are selected during beam search</p> <ul style="list-style-type: none"> • Filter level of the filter wheel (if available): 0 (instead of 1 otherwise) • Integration time: 10 ms (instead of 1 ms otherwise). <p>▶ Set the check mark to enable the option.</p>
Calibrated wavelength(s) in nm *	<p>▶ Select the calibrated wavelength in the drop-down list.</p> <p>The values displayed correspond to the calibration points of the measuring objective. The correct value should be selected before each measurement to enable high measurement accuracy.</p>
Used wavelength in nm *	<p>Use one of the following options to set the used wavelength of the laser:</p> <ul style="list-style-type: none"> ▶ Enter a value in the input field. ▶ Use the slider below the input field. <p>This parameter must be distinguished from the factory calibrated wavelength of the measuring objective. The exact value should be entered, because it is used for calculating the significant beam quality factor M^2.</p> <p>The wavelength used should approximately match the calibrated wavelength. To enable high measurement accuracy, a preconfigured acceptance range must be observed. For example, if the calibration point 1 064 nm is selected, measurements can be taken in a range between 1 030 and 1 100 nm with high measurement accuracy. Hence the value from the Calibrated wavelength in nm option is automatically adopted in the input field if a new selection was made there. If this value is replaced by an impermissible high / low value, the impermissible value is automatically overwritten with the maximum / minimum permissible value.</p>
Magnification	<p>This field displays the magnification of the measuring objective.</p>
Focal length of focusing optics in mm *	<p>▶ Enter the focal length used by the focusing optics of the laser system.</p> <p>If several planes of a caustic have been measured, the caustic fit and the entered focal length are used to calculate the raw beam diameter on the focusing optics.</p>

Tab. 12.3: Options in the **Device control > Advanced** tab of the **Single planes** measuring mode

Option	Explanation
Averaging *	<p>If this option is enabled, different algorithms for averaging a plane measurement can be selected in the drop-down list below. Averaging over several measurements can be useful, for example, when measuring a laser with significant power fluctuations.</p> <ol style="list-style-type: none"> Set the check mark to enable the option Select an algorithm from the drop-down list: <ul style="list-style-type: none"> Arithmetic mean: The measured values for each pixel are added together and divided by the number of planes. Max. intensity per pixel: The values from all the measurements are compared for each pixel and only the maximum value for each one is displayed. Max. lines: The values from all the measurements are compared for each line (meaning the line issuing from the measuring device in the x-direction for example) and only the maximum value for each one is displayed.
Number of averaged planes *	<p>▶ With the Averaging option enabled, enter the number of plane measurements for averaging.</p>
Trigger	<p>Drop-down area for displaying the options of the trigger operation.</p> <p>The trigger operation is suitable for measuring special pulsed beams. Detailed information on this topic can be found in the chapter 19.3 on page 101.</p>
Drop-down list for trigger selection	<p>This drop-down list is only visible if the drop-down area for displaying the options of the trigger operation is open.</p> <p>You can select from the following options:</p> <ul style="list-style-type: none"> UseNoTrigger: Switches to the default cw / quasi-cw operation. UsePhotoTrigger: Switches to a trigger operation in which the measurement is triggered internally. The signals come from the photodiode built into the device. UseExternalTrigger: Switches to a trigger operation in which the measurement is triggered externally. The trigger signals enter the device via the BNC socket.
TriggerDelay in ms *	<p>This drop-down list is only visible if the drop-down area for displaying the options of the trigger operation is open.</p> <p>The trigger delay specifies the period between the trigger signal and the beginning of the integration time. Use one of the following options to set the trigger delay time:</p> <ul style="list-style-type: none"> ▶ Enter a value in the input field (0.012 ms to 400 ms). ▶ Use the slider below the input field.
TriggerLevel *	<p>This drop-down list is only visible if the drop-down area for displaying the options of the trigger operation is open.</p> <p>The trigger level is the threshold value for triggering a signal via the internal photodiode. Use one of the following options to set the trigger level:</p> <ul style="list-style-type: none"> ▶ Enter a value in the input field. ▶ Use the slider below the input field. <p>You can determine the threshold value suitable for a measurement task as follows:</p> <ol style="list-style-type: none"> Set the trigger level to the maximum value. Decrease the value step by step until the device receives some trigger signals (lower trigger level). Increase the value until the device does not receive any trigger signals (upper trigger level). Calculate the trigger level as the arithmetic mean of the two limit values.

 Tab. 12.3: Options in the **Device control > Advanced** tab of the **Single planes** measuring mode

Option	Explanation
Locked area	Locked area means a restriction of the traversing range in the z-direction. The lower limit of the enabled traversing range is always home position. The upper limit can be set freely.
Maximum z-Position in mm *	<p>1. Use one of the following options to set the locked area:</p> <ul style="list-style-type: none"> ▶ Enter the upper limit of the permitted z-traversing range in the input field. ▶ Use the slider below the input field. <p>We recommend saving a locked area in the device, if it is safety-relevant:</p> <p>2. If you want to save the locked area (and the other options marked with an asterisk) in the device, click the Save device settings button.</p> <ul style="list-style-type: none"> ▶ The settings are retained even if the device is switched off or disconnected from the power source. <div data-bbox="895 705 1286 907" style="text-align: center;">  </div>

Tab. 12.3: Options in the **Device control** > **Advanced** tab of the **Single planes** measuring mode

12.5.4 Measuring a plane



DANGER

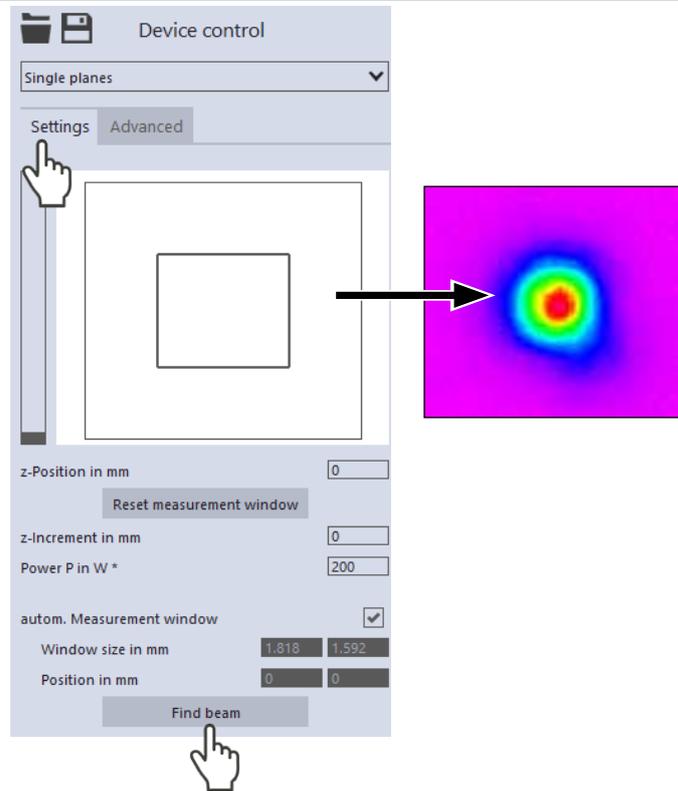
Serious eye or skin injury due to laser radiation

- Observe the warning messages in chapter 12.1 on page 37.

1. Switch on the laser.
2. Click on the **Settings** tab.
3. Click on the **Find beam** button.
 - The laser beam is automatically searched for in the entire measurement range. Measurement window size, integration time and filter level of the filter wheel (if available) are set automatically.
 - 👁 If the search is successful, the beam is displayed in the graphic representation.

If the beam is not displayed:

4. Select the **Low power mode** option or increase the integration time or select a weaker filter of the filter wheel (if available).
5. Select a different z-position.
6. Check again the correct alignment of the device on the x-y plane according to chapter 8.3.4 on page 26.
7. Increase the laser power (step by step).



As soon as the beam is displayed:

8. Click the **Start** button.
 - The measurement begins.
9. Optional:
If necessary, click the **Stop** button to end the measurement prematurely.



👁️ During the measurement, the progress is shown in the following indicators:

Measuring plane

While the indicator is rotating, the measurement is performed.

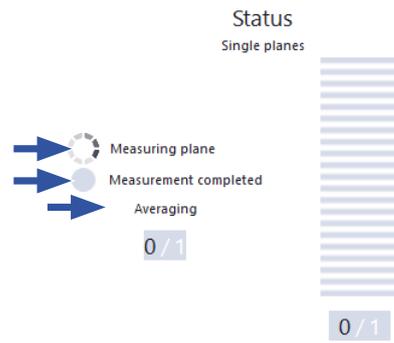
Measurement completed

After successful measurement, the indicator lights up green.

10. Switch off the laser after the measurement is completed, unless you want to perform further measurements.

Averaging (if enabled)

The indication shows the measured planes that are used to average a measured value.



Adjusting size and position of the measurement window (optional)

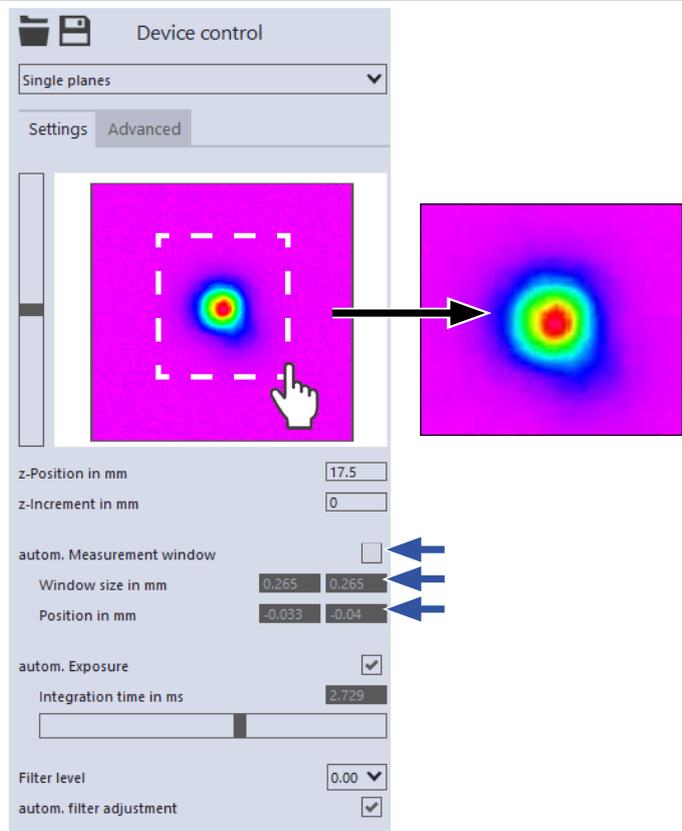
11. Make sure that the **autom. Measurement window** option is not enabled. Otherwise, the manual setting may be overwritten when starting a measurement.

12. Use one of the following options to adjust the size of the measurement window:

- ▶ Enter the length of a horizontal / vertical side in the input field on the left / right.
- ▶ Position the mouse pointer anywhere within the measurement range and drag while holding down the left mouse button. Keep the mouse button pressed until the measurement window meets your requirements.

13. Use one of the following options to adjust the position of the measurement window:

- ▶ Enter the x-position / y-position of the center of the measurement window in the input field on the left / right.
- ▶ Position the mouse pointer within the measurement window. Then drag while holding down the right mouse button.



14. Click the Start button to perform the measurement in the manually customized measurement window.

15. Switch off the laser after the measurement is completed, unless you want to perform further measurements.



12.5.5 Measuring further planes

Directly after a plane measurement, further measurements at other z-positions can be performed. In this way, a free caustic can be measured.

Single measurement at a specific z-position

1. Click on the **Settings** tab.
2. In the **z-Position in mm** field, enter the desired position of the next plane to be measured.
3. Start and stop the measurement according to chapter 12.5.4 on page 58.

Single measurements using z-increment spacing

1. Click on the **Settings** tab.
2. Enter the spacing for the further measurements in the **z-Increment in mm** field.
3. Start a measurement by clicking on the **Start** button and wait until the measurement is completed (see chapter 12.5.4 on page 58).
 - ➔ The measured plane is one z-increment away from the previously measured plane.
4. Click the **start** button again and wait until the measurement is completed (see chapter 12.5.4 on page 58).
 - ➔ The measured plane is one z-increment away from the previously measured plane.
5. Repeat the last step as often as you like.

Series measurement using z-increment spacing

The combination of the **Time series** and **z-Increment in mm** options enables measuring a free caustic in one run.

1. Click on the **Settings** tab.
2. Enter the spacing for the planes to be measured in the **z-Increment in mm** field.
3. In the **Number of measurements** and **Interval between measurements in s** fields, enter the number of measurements and the pause. The pause is the time between the end of one measurement and the start of the next. Start and stop the series measurement according to chapter 12.5.4 on page 58.

12.6 Performing continuous plane measurement

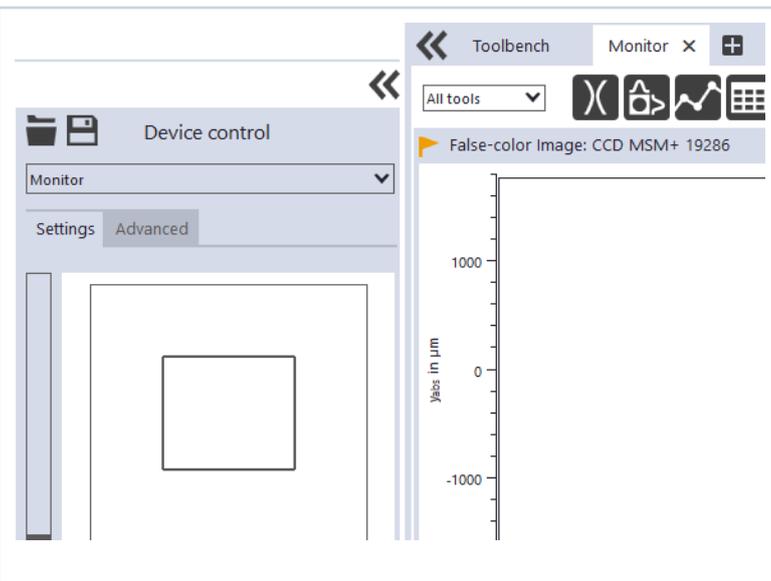
In the **Monitor** measuring mode, measuring planes can be continuously observed in a false-color image. The laser beam can be automatically searched by the software in the entire measurement range. After a successful search the measurement can be run as long as desired. During the measurement, data is continuously being read out and displayed in the graphic view with a high frame rate. The z-position of the camera housing can be changed during measurement. Measurement data is not saved in the project tree of the **Projects** tab.

12.6.1 Preparatory steps

If you have not switched from another measuring mode to here:

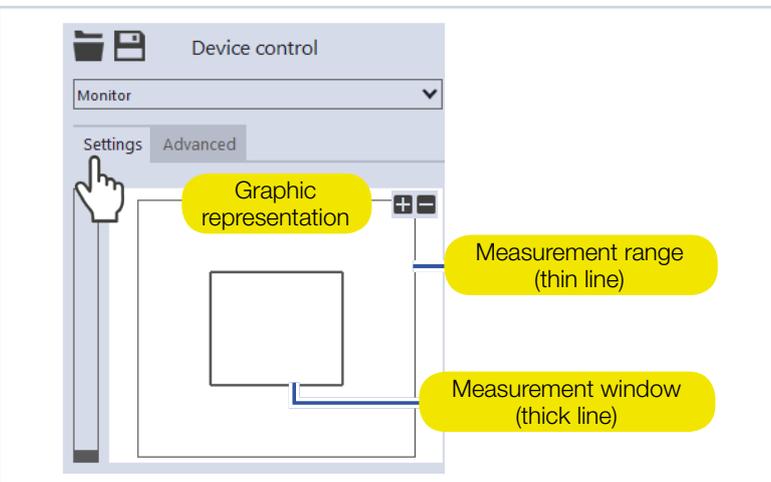
1. Connect the device to the LaserDiagnosticsSoftware LDS according to chapter 12.2.1 on page 38.
2. Open the **Device control** menu according to chapter 12.4.1 on page 43.
3. Select the **Monitor** measuring mode and open the adapted toolbench according to chapter 12.4.3 on page 44.

- 👁 The associated menu **Device control** is opened.
- 👁 The **Monitor** toolbench with the **False-color image** tool is opened.



12.6.2 Configuring settings

1. Click on the **Settings** tab.
2. Maintain the options according to the explanations in Tab. 12.4.



Option	Explanation
Graphic representation	<p>In a window in the upper area of the Settings tab, the measurement plane is displayed graphically. Here you can see:</p> <ul style="list-style-type: none"> • the entire measurable area (measurement range, thin lines) • the area to be recorded (measurement window, thick lines) • after a measurement a false-color image of the recorded area <p>You can make changes in the graphic representation as follows:</p> <ul style="list-style-type: none"> ▶ To create a new measurement window, position the mouse pointer anywhere within the measurement range. Drag while holding down the left mouse button. Keep the mouse button pressed until the measurement window meets your requirements. The maximum size of the window depends, among other things, on the magnification of the measuring objective (see chapter 7.1 on page 16). ▶ To move the measurement window to another location, position the mouse pointer inside the measurement window. Drag while holding down the right mouse button. ▶ To zoom to the center of the graphic representation, first move the mouse pointer over the graphic representation until the plus / minus buttons appear. Then press the buttons. ▶ To zoom in on the position of the mouse pointer, position the mouse pointer anywhere within the graphic representation. Then turn the mouse wheel. ▶ To set the zoom section to the size of the measurement window, position the mouse pointer inside the measurement window. Then double-click left. ▶ To set the zoom section to the size of the measurement range, position the mouse pointer outside the measurement window. Then double-click left.
z-Position in mm	<p>Use one of the following options to set the desired z-position of the plane to be measured:</p> <ul style="list-style-type: none"> ▶ Enter a value in the input field. ▶ Use the slider on the left side of the graphic representation.
Reset measurement window	<ul style="list-style-type: none"> ▶ Click this button to maximize the measurement window and simultaneously center it in the measurement range.
Window size in mm	<p>The maximum size of the window depends, among other things, on the magnification of the measuring objective (see chapter 7.1 on page 16).</p> <p>Use one of the following options to adjust the size of the measurement window:</p> <ul style="list-style-type: none"> ▶ Enter the length of a horizontal / vertical side in the input field on the left / right. ▶ Position the mouse pointer anywhere within the measurement range and drag while holding down the left mouse button. Keep the mouse button pressed until the measurement window meets your requirements.
Position in mm	<p>Use one of the following options to adjust the position of the measurement window:</p> <ul style="list-style-type: none"> ▶ Enter the x-position / y-position of the center of the measurement window in the input field on the left / right. ▶ Position the mouse pointer within the measurement window. Then drag while holding down the right mouse button.

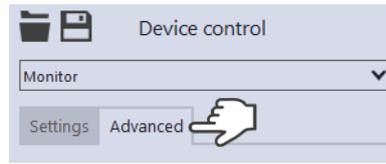
 Tab. 12.4: Options in the **Device control > Settings** tab of the **Monitor** measuring mode

Option	Explanation
Find beam	<p>This option enables a measurement in which the laser beam is automatically searched for in the entire measurement range. The plane at the defined z-position is then displayed in the graphic representation. Measurement window size, integration time, and filter level of the filter wheel (if available) are set automatically.</p> <ul style="list-style-type: none"> ▶ Click on the button to start the beam search. <p>Note that the determined measurement data will not be saved in the project tree of the Projects tab.</p>
autom. Exposure	<p>If this option is enabled, then the integration time is set automatically.</p> <ul style="list-style-type: none"> ▶ Set the check mark to enable the option.
Integration time in ms	<p>If the autom. Exposure option is disabled, the integration time can be set manually.</p> <p>Use one of the following options:</p> <ul style="list-style-type: none"> ▶ Enter a value in the input field (0.006 ms to 225 ms). ▶ Use the slider below the input field.
Filter level	<p>This option is available if an optional filter wheel is installed in the device.</p> <ul style="list-style-type: none"> ▶ Select a filter level in the drop-down list. <p>The selected setting will only be active if the autom. filter adjustment option is disabled.</p> <p>The filter required for measurement depends on the wavelength and intensity of the laser beam to be measured. We recommend selecting a filter level that achieves a detector modulation of between 60 % and 80%.</p>
autom. filter adjustment	<p>This option is available if an optional filter wheel is installed in the device. If this option is enabled, then the filter levels are set automatically.</p> <ul style="list-style-type: none"> ▶ Set the check mark to enable the option.
Fast Mode	<p>If this option is enabled, the plane is displayed with a higher frame rate. Note, however, that no corrective measurements are then performed. The measurement data may therefore be affected by measurement artefacts such as the readout noise "smear effect". In addition, no radii are displayed in the False-color image tool.</p> <ul style="list-style-type: none"> ▶ Set the check mark to enable the option.
Parameter settings	<p>All settings in the Device control menu can be individually saved for each device. The saving location is the local installation of the LaserDiagnosticsSoftware LDS.</p>
Save current parameters	<ul style="list-style-type: none"> ▶ Click this button to save all current settings of the connected device.
Load last parameters	<ul style="list-style-type: none"> ▶ Click this button to load the last saved device configuration.

Tab. 12.4: Options in the **Device control > Settings** tab of the **Monitor** measuring mode

12.6.3 Configuring advanced settings

1. Click on the **Advanced** tab.
2. Maintain the options according to the explanations in Tab. 12.5.



Option	Explanation
Save device settings	<p>All options marked with an asterisk in the Device control menu can be saved in the EEPROM of the device.</p> <p>These and other options for saving / loading configurations are described in chapter 12.4.4 on page 45.</p>
# Pixel in x/y *	<p>This option enables setting the resolution of the CCD sensor:</p> <ul style="list-style-type: none"> ▶ Enter the number of pixels in the x-direction / y-direction in the input field on the left / right.
Magnification	<p>This field displays the magnification of the measuring objective.</p>
Low power mode	<p>This option is only relevant when performing a beam search (Find beam option, see chapter 12.6.2 on page 61). We recommend activating it for low power laser beams (< 1 W).</p> <p>If this option is enabled, the following initial values are selected during beam search</p> <ul style="list-style-type: none"> • Filter level of the filter wheel (if available): 0 (instead of 1 otherwise) • Integration time: 10 ms (instead of 1 ms otherwise). <p>▶ Set the check mark to enable the option.</p>
Locked area	<p>Locked area means a restriction of the traversing range in the z-direction. The lower limit of the enabled traversing range is always home position. The upper limit can be set freely.</p>
Maximum z-Position in mm *	<ol style="list-style-type: none"> 1. Use one of the following options to set the locked area: <ul style="list-style-type: none"> ▶ Enter the upper limit of the permitted z-traversing range in the input field. ▶ Use the slider below the input field. <p>We recommend saving a locked area in the device, if it is safety-relevant:</p> <ol style="list-style-type: none"> 2. If you want to save the locked area (and the other options marked with an asterisk) in the device, click the Save device settings button. <ul style="list-style-type: none"> ➔ The settings are retained even if the device is switched off or disconnected from the power source.



Tab. 12.5: Options in the **Device control** > **Advanced** tab of the **Monitor** measuring mode

12.6.4 Measuring a plane continuously

DANGER

Serious eye or skin injury due to laser radiation

- ▶ Observe the warning messages in chapter 12.1 on page 37.

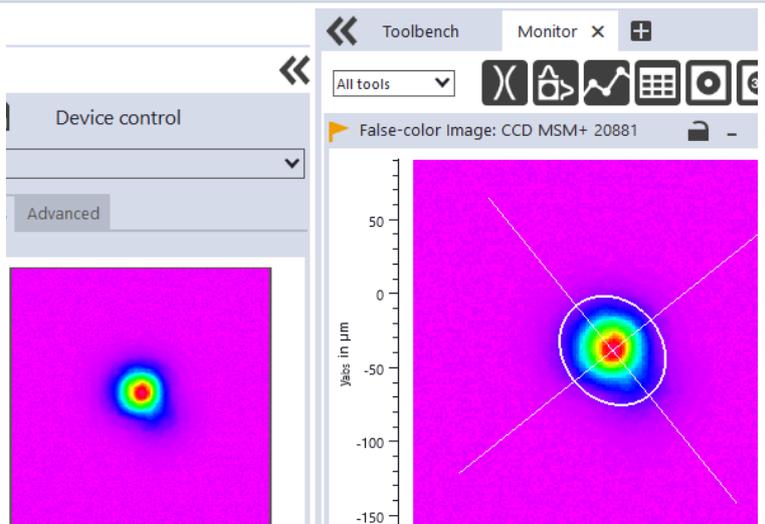
If you use continuous plane measurement to align the device, observe the following:

- ▶ Align the device using a pilot laser where no dangerous reflections can occur.
- ▶ Only align the device using a laser where dangerous reflections can occur (laser class 4) if the process is carried out remotely behind a separating protective equipment. The protective equipment must be suitable for blocking the radiation or attenuating it to a non-hazardous level.

<ol style="list-style-type: none"> 1. Switch on the laser. 2. Click on the Settings tab. 3. Click on the Find beam button. <ul style="list-style-type: none"> ▶ The laser beam is automatically searched for in the entire measurement range. Measurement window size, integration time and filter level of the filter wheel (if available) are set automatically. <p> If the search is successful, the beam is displayed in the graphic representation.</p> <p>If the beam is not displayed:</p> <ol style="list-style-type: none"> 4. Select the Low power mode option or increase the integration time or select a weaker filter of the filter wheel (if available). 5. Select a different z-position. 6. Check again the correct alignment of the device on the x-y plane according to chapter 8.3.4 on page 26. 7. Increase the laser power (step by step). 	
<p>As soon as the beam is displayed:</p> <ol style="list-style-type: none"> 8. Click the Start button. <ul style="list-style-type: none"> ▶ The measurement begins. 	

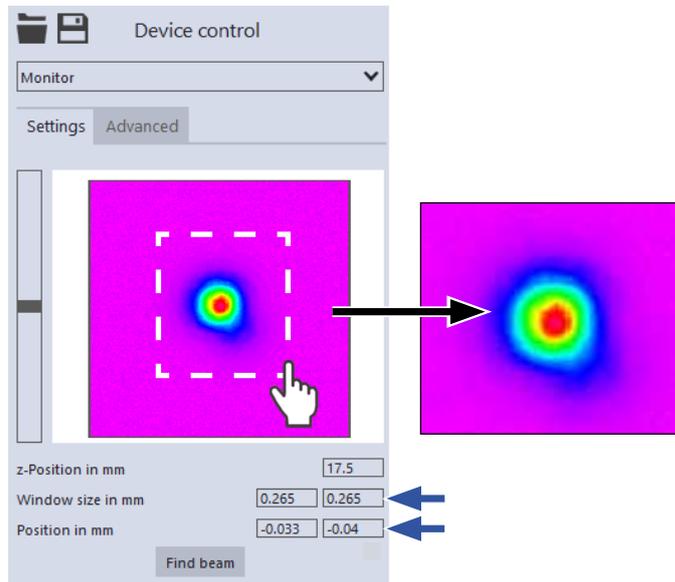
👁️ Data is continuously read out from the previously set measurement window and displayed with a high frame rate in the false-color image.

9. To stop the measurement, click on the **Stop** button.
10. Switch off the laser after the measurement is completed, unless you want to perform further measurements.



Adjusting size and position of the measurement window (optional)

11. Make sure that the **autom. Measurement window** option is not enabled. Otherwise, the manual setting may be overwritten when starting a measurement.
12. Use one of the following options to adjust the size of the measurement window:
 - ▶ Enter the length of a horizontal / vertical side in the input field on the left / right.
 - ▶ Position the mouse pointer anywhere within the measurement range and drag while holding down the left mouse button. Keep the mouse button pressed until the measurement window meets your requirements.
13. Use one of the following options to adjust the position of the measurement window:
 - ▶ Enter the x-position / y-position of the center of the measurement window in the input field on the left / right.
 - ▶ Position the mouse pointer within the measurement window. Then drag while holding down the right mouse button.



14. Click the **Start** button to perform the measurement in the manually customized measurement window.
15. To stop the measurement, click on the **Stop** button.
16. Switch off the laser after the measurement is completed, unless you want to perform further measurements.



12.7 Performing manual caustic measurement

In the **Manual caustic** measuring mode, only the z-range and the number of plane measurements have to be specified. All other required settings are automatically determined and adjusted. In addition, advanced settings can be applied.

According to ISO 11146-1, at least 10 planes shall be measured. Approximately half of the measurements shall be distributed within one Rayleigh length on either side of the focus, and approximately half of them shall be distributed beyond two Rayleigh lengths from the focus.

For two reasons, an odd number of measuring planes makes it more likely that the focal plane will be measured. First, the LaserDiagnosticsSoftware LDS always sets the spacing between the measuring planes equal. Second, the measuring range along the z-axis is almost always symmetrical around the focus. We recommend measuring at least 21 planes within 6 Rayleigh lengths.

By means of the variable integration time control, not only cw laser beams but also a multitude of pulsed beams can be measured in quasi-cw operation. An exception are, for example, laser beams with a very low pulse frequency. Trigger operation is available for measuring such beams. If this is enabled, the device only measures within defined time periods. The laser pulse or the corresponding trigger signal marks the beginning of such a period and the (freely adjustable) integration time marks its end. A measurement can be triggered internally or externally. Internal signals are triggered by the photodiode integrated in the device. Externally triggered signals enter the device via a BNC socket. For detailed information on the measurement of pulsed laser beams and the trigger operation, please refer to chapter 19.3 on page 101.

12.7.1 Preparatory steps

If you have not switched from another measuring mode to here:

1. Connect the device to the LaserDiagnosticsSoftware LDS according to chapter 12.2.1 on page 38.
2. Open the **Device control** menu according to chapter 12.4.1 on page 43.
3. Select the **Manual caustic** measuring mode and open the adapted toolbench according to chapter 12.4.3 on page 44.

👁️ The associated menu **Device control** is opened.

👁️ The **Manual caustic** toolbench with the following tools is opened:

- **Caustic Analysis**
- **Plane Analysis**



12.7.2 Configuring settings

1. Click on the **Settings** tab.
2. Maintain the options according to the explanations in Tab. 12.6.



Option	Explanation
Optimized measurement settings	<p>If this option is activated, the measurement takes shorter time. Fewer process steps are required, since the initial settings for a plane measurement are taken from the settings of the previous plane measurement.</p> <p>Please note, however, that beam artefacts may not be adequately detected in the single plane measurements due to the transfer of the settings.</p> <ul style="list-style-type: none"> ▶ Set the check mark to activate the option.
Number of planes *	<ul style="list-style-type: none"> ▶ Enter the number of planes to be measured.
z-Axis position (z1 / z2) in mm *	<p>This option enables configuring the z-range in which the measurement is to be performed.</p> <ul style="list-style-type: none"> ▶ Regarding the traversing range in which the measurement is to be performed, enter the lower limit z1 in the left field and the upper limit z2 in the right field. ▶ Alternatively, use the sliders.
Caustic suggestion	<p>When a caustic measurement is completed, a z-range is displayed in these fields. The limits of the suggested z-range have a distance of ± 3 Rayleigh lengths to the determined beam focus. This z-range is optimized according to Primes quality criteria.</p>
Use	<ul style="list-style-type: none"> ▶ Click this button to transfer the z-values displayed in the Caustic suggestion fields to the z-Axis position (z1 / z2) in mm fields.
Reset z-Axis position	<ul style="list-style-type: none"> ▶ Click this button to reset the z-axis position to the default values (z1 = 0 und z2 = 6).
Power P in W *	<ul style="list-style-type: none"> ▶ Enter the laser power used during measurement. <p>Only if the power is entered, a calculation of the power density distribution can be performed. Otherwise, the measured amplitudes are given directly in counts.</p>
Filter level	<p>This option is available if an optional filter wheel is installed in the device.</p> <ul style="list-style-type: none"> ▶ Select a filter level in the drop-down list. <p>The selected setting will only be active if the autom. filter adjustment option is disabled.</p> <p>The filter required for measurement depends on the wavelength and intensity of the laser beam to be measured. We recommend selecting a filter level that achieves a detector modulation of between 60 % and 80%.</p>
autom. filter adjustment	<p>This option is available if an optional filter wheel is installed in the device. If this option is enabled, then the filter levels are set automatically.</p> <ul style="list-style-type: none"> ▶ Set the check mark to enable the option.
Time series	<p>A time series consists of several caustic measurements with the same settings.</p>
Number of measurements *	<ul style="list-style-type: none"> ▶ Enter the desired number of caustic measurements of the time series.
Interval between measurements in s *	<ul style="list-style-type: none"> ▶ Enter the pause between the caustic measurements of the time series. This is the time gap between the end of one measurement and the start of the next.

 Tab. 12.6: Options in the **Device control > Settings** tab of the **Manual caustic** measuring mode

12.7.3 Configuring advanced settings

1. Click on the **Advanced** tab.
2. Maintain the options according to the explanations in Tab. 12.7.



Option	Explanation
Save device settings	All options marked with an asterisk in the Device control menu can be saved in the EEPROM of the device. These and other options for saving / loading configurations are described in chapter 12.4.4 on page 45.
# Pixel in x/y *	This option enables setting the resolution of the CCD sensor: ▶ Enter the number of pixels in the x-direction / y-direction in the input field on the left / right.
Averaging *	If this option is enabled, different algorithms for averaging a plane measurement can be selected in the drop-down list below. Averaging over several measurements can be useful, for example, when measuring a laser with significant power fluctuations. <ol style="list-style-type: none"> 1. Set the check mark to enable the option 2. Select an algorithm from the drop-down list: <ul style="list-style-type: none"> • Arithmetic mean: The measured values for each pixel are added together and divided by the number of planes. • Max. intensity per pixel: The values from all the measurements are compared for each pixel and only the maximum value for each one is displayed. • Max. lines: The values from all the measurements are compared for each line (meaning the line issuing from the measuring device in the x-direction for example) and only the maximum value for each one is displayed.
Number of averaged planes *	▶ With the Averaging option enabled, enter the number of plane measurements for averaging.
Low power mode	We recommend enabling this option for low power laser beams (< 1 W). If this option is enabled, the following initial values are selected during beam search <ul style="list-style-type: none"> • Filter level of the filter wheel (if available): 0 (instead of 1 otherwise) • Integration time: 10 ms (instead of 1 ms otherwise). ▶ Set the check mark to enable the option.
Calibrated wavelength(s) in nm *	▶ Select the calibrated wavelength in the drop-down list. The values displayed correspond to the calibration points of the measuring objective. The correct value should be selected before each measurement to enable high measurement accuracy.

Tab. 12.7: Options in the **Device control > Advanced** tab of the **Manual caustic** measuring mode

Option	Explanation
Used wavelength in nm *	<p>Use one of the following options to set the used wavelength of the laser:</p> <ul style="list-style-type: none"> ▶ Enter a value in the input field. ▶ Use the slider below the input field. <p>This parameter must be distinguished from the factory calibrated wavelength of the measuring objective. The exact value should be entered, because it is used for calculating the significant beam quality factor M^2.</p> <p>The wavelength used should approximately match the calibrated wavelength. To enable high measurement accuracy, a preconfigured acceptance range must be observed. For example, if the calibration point 1 064 nm is selected, measurements can be taken in a range between 1 030 and 1 100 nm with high measurement accuracy.</p> <p>Hence the value from the Calibrated wavelength in nm option is automatically adopted in the input field if a new selection was made there. If this value is replaced by an impermissible high / low value, the impermissible value is automatically overwritten with the maximum / minimum permissible value.</p>
Magnification	This field displays the magnification of the measuring objective.
Focal length of focusing optics in mm *	<ul style="list-style-type: none"> ▶ Enter the focal length used by the focusing optics of the laser system. <p>The caustic fit and the entered focal length are used to calculate the raw beam diameter on the focusing optics.</p>
Trigger	<p>Drop-down area for displaying the options of the trigger operation.</p> <p>The trigger operation is suitable for measuring special pulsed beams. Detailed information on this topic can be found in the chapter 19.3 on page 101.</p>
Drop-down list for trigger selection	<p>This drop-down list is only visible if the drop-down area for displaying the options of the trigger operation is open.</p> <p>You can select from the following options:</p> <ul style="list-style-type: none"> • UseNoTrigger: Switches to the default cw / quasi-cw operation. • UsePhotoTrigger: Switches to a trigger operation in which the measurement is triggered internally. The signals come from the photodiode built into the device. • UseExternalTrigger: Switches to a trigger operation in which the measurement is triggered externally. The trigger signals enter the device via the BNC socket.
TriggerDelay in ms *	<p>This drop-down list is only visible if the drop-down area for displaying the options of the trigger operation is open.</p> <p>The trigger delay specifies the period between the trigger signal and the beginning of the integration time. Use one of the following options to set the trigger delay time:</p> <ul style="list-style-type: none"> ▶ Enter a value in the input field (0.012 ms to 400 ms). ▶ Use the slider below the input field.

 Tab. 12.7: Options in the **Device control > Advanced** tab of the **Manual caustic** measuring mode

Option	Explanation
TriggerLevel *	<p>This drop-down list is only visible if the drop-down area for displaying the options of the trigger operation is open.</p> <p>The trigger level is the threshold value for triggering a signal via the internal photodiode. Use one of the following options to set the trigger level:</p> <ul style="list-style-type: none"> ▶ Enter a value in the input field. ▶ Use the slider below the input field. <p>You can determine the threshold value suitable for a measurement task as follows:</p> <ol style="list-style-type: none"> 1. Set the trigger level to the maximum value. 2. Decrease the value step by step until the device receives some trigger signals (lower trigger level). 3. Increase the value until the device does not receive any trigger signals (upper trigger level). 4. Calculate the trigger level as the arithmetic mean of the two limit values.
Locked area	<p>Locked area means a restriction of the traversing range in the z-direction. The lower limit of the enabled traversing range is always home position. The upper limit can be set freely.</p>
Maximum z-Position in mm *	<ol style="list-style-type: none"> 1. Use one of the following options to set the locked area: <ul style="list-style-type: none"> ▶ Enter the upper limit of the permitted z-traversing range in the input field. ▶ Use the slider below the input field. <p>We recommend saving a locked area in the device, if it is safety-relevant:</p> <ol style="list-style-type: none"> 2. If you want to save the locked area (and the other options marked with an asterisk) in the device, click the Save device settings button. <ul style="list-style-type: none"> ▶ The settings are retained even if the device is switched off or disconnected from the power source. <div data-bbox="895 1173 1286 1379" style="text-align: center;">  </div>

Tab. 12.7: Options in the *Device control* > *Advanced* tab of the *Manual caustic* measuring mode

12.7.4 Measuring a caustic manually



Serious eye or skin injury due to laser radiation

► Observe the warning messages in chapter 12.1 on page 37.

1. Switch on the laser.
 2. Click the **Start** button.
► The measurement begins.
 3. Optional:
If necessary, click the **Stop** button to end the measurement prematurely.
- 👁 During the measurement, the progress is shown in the following indicators:

Measuring caustic

While the indicator is rotating, the measurement is performed. The measurement parameters are optimized according to Primes quality criteria.

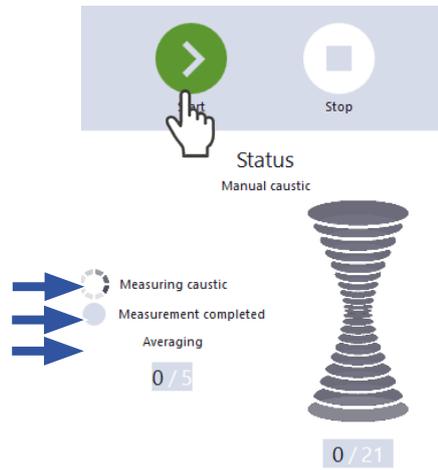
Measurement completed

After successful measurement, the indicator lights up green.

4. Switch off the laser after the measurement is completed, unless you want to perform further measurements.

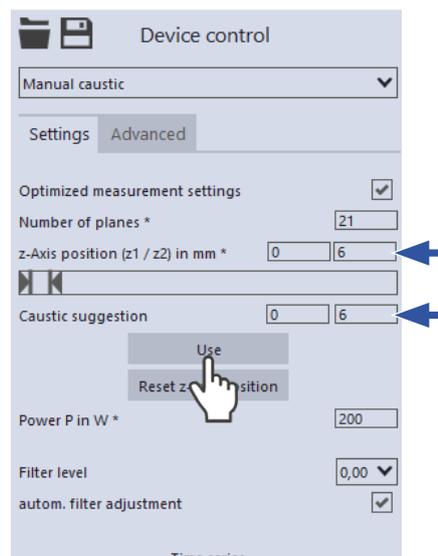
Averaging (if enabled)

The indication shows the measured planes that are used to average a measured value.



Applying a caustic suggestion (optional)

5. After the measurement is completed, a z-range is displayed in the **Caustic suggestion** fields. The limits of the suggested z-range have a distance of ± 3 Rayleigh lengths to the determined beam focus. This z-range is optimized according to Primes quality criteria.
6. If you want to apply this suggestion, click the **Use** button.
7. The suggested limit values z_1 / z_2 are transferred to the **z-Axis position (z1 / z2) in mm** fields.
8. Click the **Start** button again to perform the measurement in the suggested z-range.
9. Switch off the laser after the measurement is completed, unless you want to perform further measurements.



12.8 Performing automatic caustic measurement

In the **Automatic caustic** measuring mode, only the initial z-position of the pre-caustic measurement and the number of measuring planes of the actual caustic measurement are not selected automatically. The z-range as well as all other required settings are determined and adjusted automatically. In addition, advanced settings can be applied.

According to ISO 11146-1, at least 10 planes shall be measured. Approximately half of the measurements shall be distributed within one Rayleigh length on either side of the focus, and approximately half of them shall be distributed beyond two Rayleigh lengths from the focus.

For two reasons, an odd number of measuring planes makes it more likely that the focal plane will be measured. First, the LaserDiagnosticsSoftware LDS always sets the spacing between the measuring planes equal. Second, the measuring range along the z-axis is almost always symmetrical around the focus. We recommend measuring at least 21 planes within 6 Rayleigh lengths.

By means of the variable integration time control, not only cw laser beams but also a multitude of pulsed beams can be measured in quasi-cw operation. An exception are, for example, laser beams with a very low pulse frequency. Trigger operation is available for measuring such beams. If this is enabled, the device only measures within defined time periods. The laser pulse or the corresponding trigger signal marks the beginning of such a period and the (freely adjustable) integration time marks its end. A measurement can be triggered internally or externally. Internal signals are triggered by the photodiode integrated in the device. Externally triggered signals enter the device via a BNC socket. For detailed information on the measurement of pulsed laser beams and the trigger operation, please refer to chapter 19.3 on page 101.

12.8.1 Preparatory steps

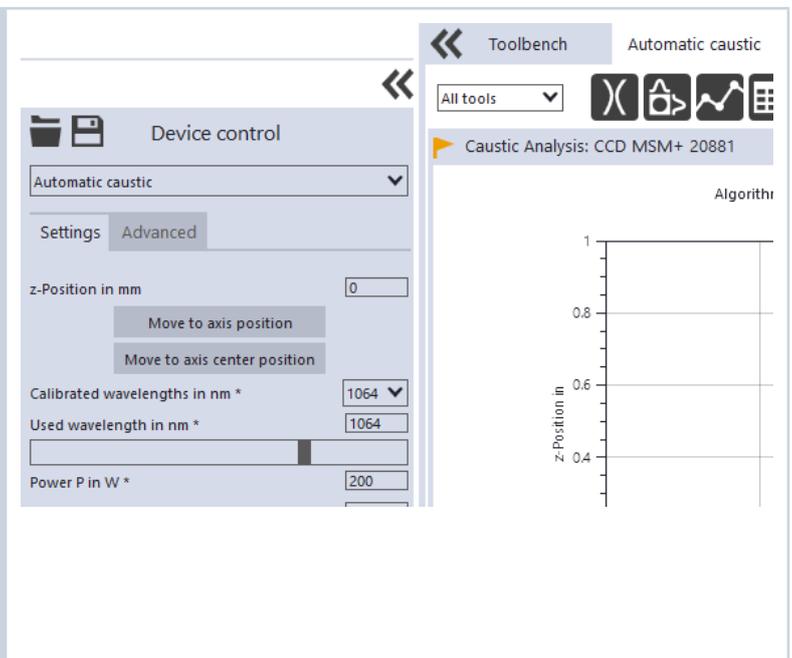
If you have not switched from another measuring mode to here:

1. Connect the device to the LaserDiagnosticsSoftware LDS according to chapter 12.2.1 on page 38.
2. Open the **Device control** menu according to chapter 12.4.1 on page 43.
3. Select the **Automatic caustic** measuring mode and open the adapted toolbench according to chapter 12.4.3 on page 44.

👁 The associated menu **Device control** is opened.

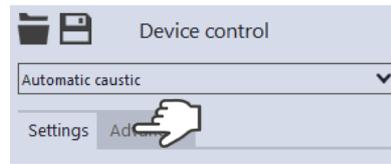
👁 The **Automatic caustic** toolbench with the following tools is opened:

- **Caustic Analysis**
- **Plane Analysis**



12.8.2 Configuring settings

1. Click on the **Settings** tab.
2. Maintain the options according to the explanations in Tab. 12.8.

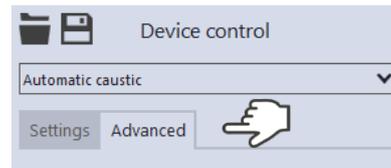


Option	Explanation
z-Position in mm	Use one of the following options to set the initial z-position for the pre-caustic measurement: <ul style="list-style-type: none"> ▶ Enter a value in the input field. ▶ Use the slider below the input field.
Parking position after caustic	<ul style="list-style-type: none"> ▶ In the drop-down list, select the parking position to which the camera housing will be moved after the caustic measurement. <p>You can select from the following options:</p> <ul style="list-style-type: none"> • Focus: The camera housing is moved back to the position of the determined beam focus. • Start position: The camera housing is moved back to the start position. • Final position: The camera housing remains in the final position. <p>The selected position is also the start position for the pre-caustic measurement of the next measurement (unless you enter a different value in the z-Position in mm field).</p>
Power P in W *	<ul style="list-style-type: none"> ▶ Enter the laser power used during measurement. <p>Only if the power is entered, a calculation of the power density distribution can be performed. Otherwise, the measured amplitudes are given directly in counts.</p>
Filter level	<p>This option is available if an optional filter wheel is installed in the device.</p> <ul style="list-style-type: none"> ▶ Select a filter level in the drop-down list. <p>The selected setting will only be active if the autom. filter adjustment option is disabled.</p> <p>The filter required for measurement depends on the wavelength and intensity of the laser beam to be measured. We recommend selecting a filter level that achieves a detector modulation of between 60 % and 80%.</p>
autom. filter adjustment	<p>This option is available if an optional filter wheel is installed in the device. If this option is enabled, then the filter levels are set automatically.</p> <ul style="list-style-type: none"> ▶ Set the check mark to enable the option.
Time series	A time series consists of several caustic measurements with the same settings.
Number of measurements *	<ul style="list-style-type: none"> ▶ Enter the desired number of caustic measurements of the time series.
Interval between measurements in s *	<ul style="list-style-type: none"> ▶ Enter the pause between the caustic measurements of the time series. This is the time gap between the end of one measurement and the start of the next.

Tab. 12.8: Options in the **Device control > Settings** tab of the **Automatic caustic** measuring mode

12.8.3 Configuring advanced settings

1. Click on the **Advanced** tab.
2. Maintain the options according to the explanations in Tab. 12.9.

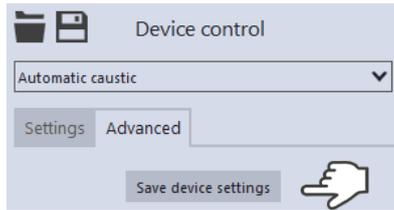


Option	Explanation
Save device settings	<p>All options marked with an asterisk in the Device control menu can be saved in the EEPROM of the device.</p> <p>These and other options for saving / loading configurations are described in chapter 12.4.4 on page 45.</p>
# Pixel in x/y *	<p>This option enables setting the resolution of the CCD sensor:</p> <ul style="list-style-type: none"> ▶ Enter the number of pixels in the x-direction / y-direction in the input field on the left / right.
Number of planes *	<ul style="list-style-type: none"> ▶ Enter the number of planes to be measured.
Low power mode	<p>We recommend enabling this option for low power laser beams (< 1 W).</p> <p>If this option is enabled, the following initial values are selected during beam search</p> <ul style="list-style-type: none"> • Filter level of the filter wheel (if available): 0 (instead of 1 otherwise) • Integration time: 10 ms (instead of 1 ms otherwise). <ul style="list-style-type: none"> ▶ Set the check mark to enable the option.
Calibrated wavelength(s) in nm *	<ul style="list-style-type: none"> ▶ Select the calibrated wavelength in the drop-down list. <p>The values displayed correspond to the calibration points of the measuring objective. The correct value should be selected before each measurement to enable high measurement accuracy.</p>
Used wavelength in nm *	<p>Use one of the following options to set the used wavelength of the laser:</p> <ul style="list-style-type: none"> ▶ Enter a value in the input field. ▶ Use the slider below the input field. <p>This parameter must be distinguished from the factory calibrated wavelength of the measuring objective. The exact value should be entered, because it is used for calculating the significant beam quality factor M^2.</p> <p>The wavelength used should approximately match the calibrated wavelength. To enable high measurement accuracy, a preconfigured acceptance range must be observed. For example, if the calibration point 1 064 nm is selected, measurements can be taken in a range between 1 030 and 1 100 nm with high measurement accuracy.</p> <p>Hence the value from the Calibrated wavelength in nm option is automatically adopted in the input field if a new selection was made there. If this value is replaced by an impermissible high / low value, the impermissible value is automatically overwritten with the maximum / minimum permissible value.</p>
Magnification	<p>This field displays the magnification of the measuring objective.</p>
Focal length of focusing optics in mm *	<ul style="list-style-type: none"> ▶ Enter the focal length used by the focusing optics of the laser system. <p>The caustic fit and the entered focal length are used to calculate the raw beam diameter on the focusing optics.</p>

Tab. 12.9: Options in the **Device control** > **Advanced** tab of the **Automatic caustic** measuring mode

Option	Explanation
Trigger	Drop-down area for displaying the options of the trigger operation. The trigger operation is suitable for measuring special pulsed beams. Detailed information on this topic can be found in the chapter 19.3 on page 101.
Drop-down list for trigger selection	This drop-down list is only visible if the drop-down area for displaying the options of the trigger operation is open. You can select from the following options: <ul style="list-style-type: none"> • UseNoTrigger: Switches to the default cw / quasi-cw operation. • UsePhotoTrigger: Switches to a trigger operation in which the measurement is triggered internally. The signals come from the photodiode built into the device. • UseExternalTrigger: Switches to a trigger operation in which the measurement is triggered externally. The trigger signals enter the device via the BNC socket.
TriggerDelay in ms *	This drop-down list is only visible if the drop-down area for displaying the options of the trigger operation is open. The trigger delay specifies the period between the trigger signal and the beginning of the integration time. Use one of the following options to set the trigger delay time: <ul style="list-style-type: none"> ▶ Enter a value in the input field (0.012 ms to 400 ms). ▶ Use the slider below the input field.
TriggerLevel *	This drop-down list is only visible if the drop-down area for displaying the options of the trigger operation is open. The trigger level is the threshold value for triggering a signal via the internal photodiode. Use one of the following options to set the trigger level: <ul style="list-style-type: none"> ▶ Enter a value in the input field. ▶ Use the slider below the input field. You can determine the threshold value suitable for a measurement task as follows: <ol style="list-style-type: none"> 1. Set the trigger level to the maximum value. 2. Decrease the value step by step until the device receives some trigger signals (lower trigger level). 3. Increase the value until the device does not receive any trigger signals (upper trigger level). 4. Calculate the trigger level as the arithmetic mean of the two limit values.
Locked area	Locked area means a restriction of the traversing range in the z-direction. The lower limit of the enabled traversing range is always home position. The upper limit can be set freely.

 Tab. 12.9: Options in the **Device control > Advanced** tab of the **Automatic caustic** measuring mode

Option	Explanation
<p>Maximum z-Position in mm *</p>	<ol style="list-style-type: none"> 1. Use one of the following options to set the locked area: <ul style="list-style-type: none"> ▶ Enter the upper limit of the permitted z-traversing range in the input field. ▶ Use the slider below the input field. <p>We recommend saving a locked area in the device, if it is safety-relevant:</p> <ol style="list-style-type: none"> 2. If you want to save the locked area (and the other options marked with an asterisk) in the device, click the Save device settings button. <ul style="list-style-type: none"> ▶ The settings are retained even if the device is switched off or disconnected from the power source. <div data-bbox="890 600 1284 810" style="text-align: center;">  </div>

Tab. 12.9: Options in the *Device control* > *Advanced* tab of the *Automatic caustic* measuring mode

12.8.4 Measuring a caustic automatically



DANGER

Serious eye or skin injury due to laser radiation

► Observe the warning messages in chapter 12.1 on page 37.

1. Switch on the laser.
 2. Click the **Start** button.
► The measurement begins.
 3. Optional:
If necessary, click the **Stop** button to end the measurement prematurely.
- 👁️ During the measurement, the progress is shown in the following indicators:

Pre-caustic

While the indicator is rotating, the measurement parameters are determined automatically (for example measurement window position, measurement window size, integration time, z-range). The measurement parameters are optimized according to Primes quality criteria. After successful pre-caustic measurement, the indicator lights up green.

Measuring caustic

While the indicator is rotating, the actual measurement is performed.

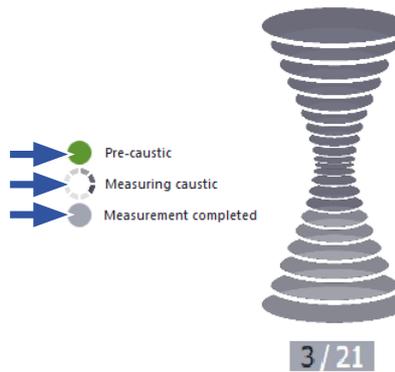
Measurement completed

After successful measurement, the indicator lights up green.

4. Switch off the laser after the measurement is completed, unless you want to perform further measurements.



Status
Automatic caustic



12.9 Monitoring beam pointing stability

In the **Beam pointing** measuring mode, the measuring points of a series of measurements are displayed in coordinates. The measuring points show the position of the beam center on the x-y plane as well as the angle of the beam incidence to the x-y plane. This display can be used to monitor the beam pointing stability.

During the measurement, the device alternately performs plane measurements at positions z1 and z2. These positions are determined automatically in a preparatory step, but can also be specified manually. Likewise, the number of measuring points displayed in the coordinates can be specified.

12.9.1 Preparatory steps

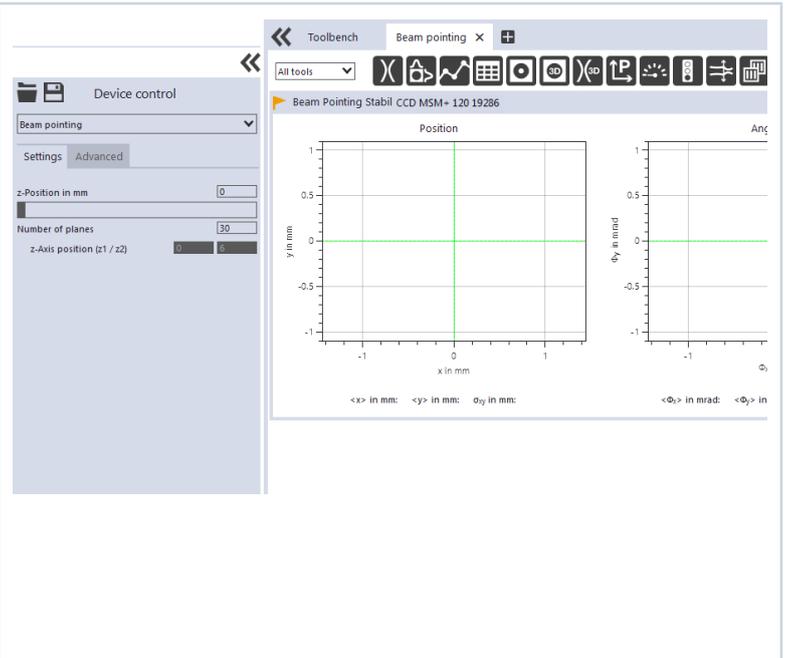
If you have not switched from another measuring mode to here:

1. Connect the device to the LaserDiagnosticsSoftware LDS according to chapter 12.2.1 on page 38.
2. Open the **Device control** menu according to chapter 12.4.1 on page 43.
3. Select the **Beam pointing** measuring mode and open the adapted toolbench according to chapter 12.4.3 on page 44.

👁 The associated menu **Device control** is opened.

👁 The **Beam pointing** toolbench with the following tools is opened:

- **Beam Pointing Stability**
- **False-color Image**



12.9.2 Configuring settings

1. Click on the **Settings** tab.
2. Maintain the options according to the explanations in Tab. 12.10.



Option	Explanation
z-Position in mm	Use one of the following options to specify the desired initial z-position of the camera housing for the pre-caustic measurement: <ul style="list-style-type: none"> ▶ Enter a value in the input field. ▶ Use the slider below the input field.
Number of planes	<ul style="list-style-type: none"> ▶ Enter the number of plane measurements. The default setting is 30 planes. <p>Specifying the number of plane measurements, you determine the number of measuring points that are displayed in the coordinates of the Beam Pointing Stability tool. To determine a measuring point, the beam cross sections are measured once at the positions z1 and z2. If, for example, 10 measuring points are to be displayed, enter the value of 20.</p>

Tab. 12.10: Options in the **Device control** > **Settings** tab of the **Beam pointing** measuring mode

Option	Explanation
z-Axis position (z1 / z2)	The measuring positions z1 and z2 determined during the pre-caustic measurement are displayed here.

Tab. 12.10: Options in the **Device control > Settings** tab of the **Beam pointing** measuring mode

12.9.3 Configuring advanced settings

<ol style="list-style-type: none"> 1. Click on the Advanced tab. 2. Maintain the options according to the explanations in Tab. 12.11. 	
--	--

Option	Explanation
Save device settings	<p>All options marked with an asterisk in the Device control menu can be saved in the EEPROM of the device.</p> <p>These and other options for saving / loading configurations are described in chapter 12.4.4 on page 45.</p>
# Pixel in x/y *	<p>This option enables setting the resolution of the CCD sensor:</p> <ul style="list-style-type: none"> ▶ Enter the number of pixels in the x-direction / y-direction in the input field on the left / right.
Low power mode	<p>We recommend enabling this option for low power laser beams (< 1 W).</p> <p>If this option is enabled, the following initial values are selected during beam search</p> <ul style="list-style-type: none"> • Filter level of the filter wheel (if available): 0 (instead of 1 otherwise) • Integration time: 10 ms (instead of 1 ms otherwise). <p>▶ Set the check mark to enable the option.</p>
Locked area	<p>Locked area means a restriction of the traversing range in the z-direction. The lower limit of the enabled traversing range is always home position. The upper limit can be set freely.</p>
Maximum z-Position in mm *	<ol style="list-style-type: none"> 1. Use one of the following options to set the locked area: <ul style="list-style-type: none"> ▶ Enter the upper limit of the permitted z-traversing range in the input field. ▶ Use the slider below the input field. <p>We recommend saving a locked area in the device, if it is safety-relevant:</p> <ol style="list-style-type: none"> 2. If you want to save the locked area (and the other options marked with an asterisk) in the device, click the Save device settings button. <p>➔ The settings are retained even if the device is switched off or disconnected from the power source.</p>

Tab. 12.11: Options in the **Device control > Advanced** tab of the **Beam pointing** measuring mode

12.9.4 Measuring beam pointing stability

DANGER

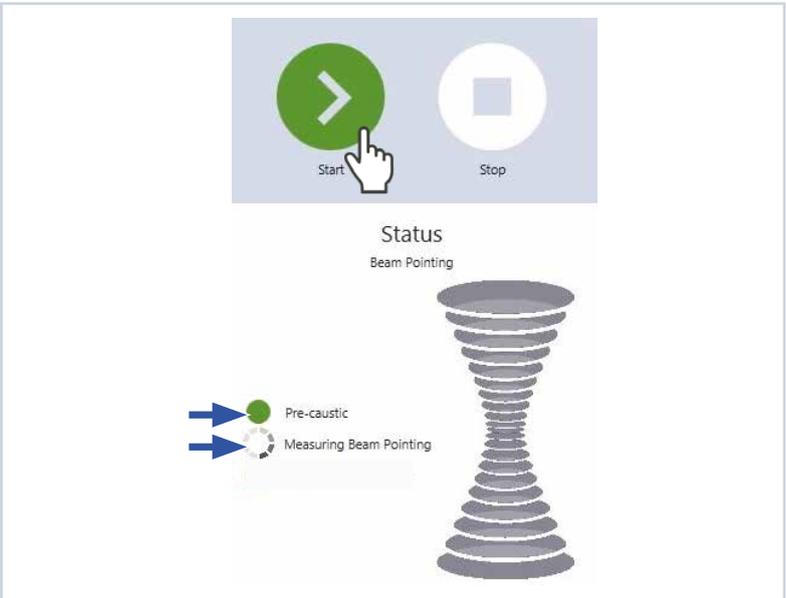
Serious eye or skin injury due to laser radiation

► Observe the warning messages in chapter 12.1 on page 37.

Starting measurement

1. Switch on the laser.
2. Click the **Start** button.
 - The measurement begins.

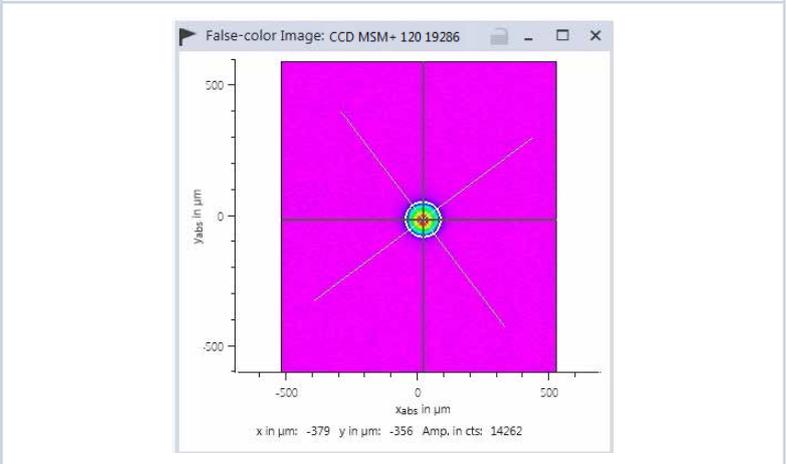
During the measurement, the progress is shown in the following indicators:



Pre-caustic

While the indicator is rotating, the z1 and z2 positions along the beam propagation are identified. The positions are optimized according to Primes quality criteria. After successful pre-caustic measurement, the indicator lights up green.

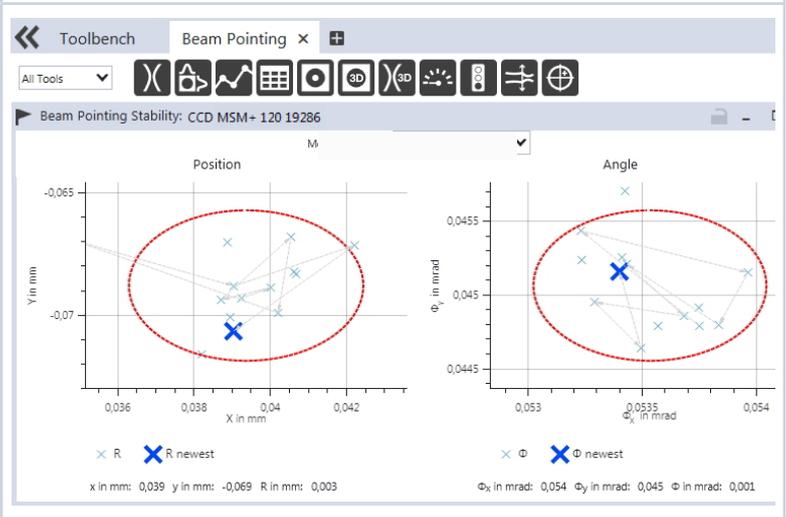
The process is visualized in the **False-color Image** tool.



Measuring beam pointing

While the indicator is rotating, the beam's centers of gravity are constantly recorded at the positions z1 and z2.

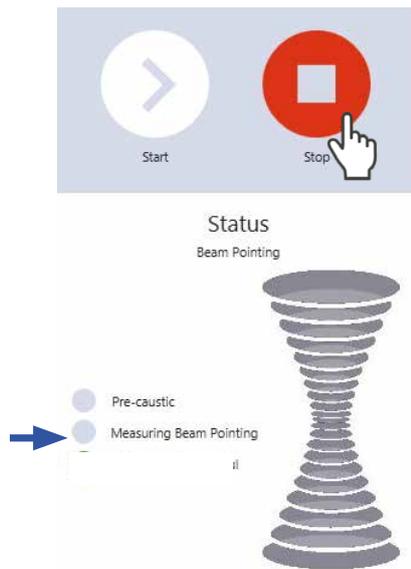
The determined measuring points are displayed in the coordinates of the **Beam Pointing Stability** tool. The current position of the beam is marked with a large X, previous positions are marked with a small x.



Completing measurement

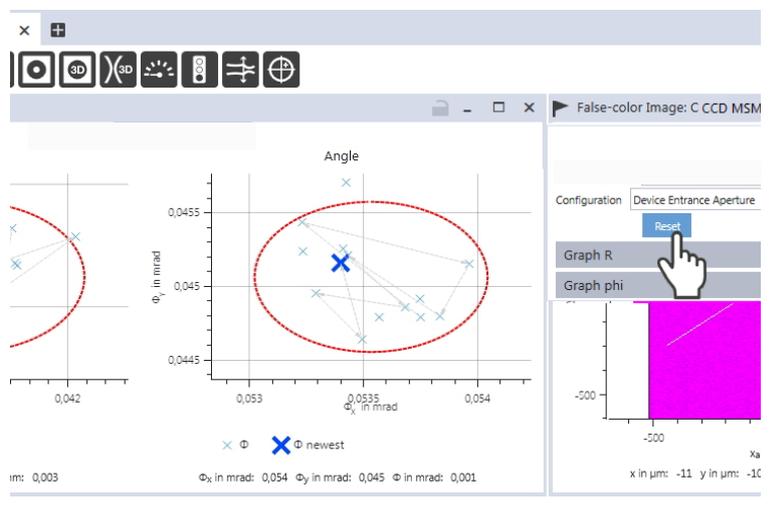
👁 When the beam pointing measurement is completed, the indicator **Beam Pointing** changes to green.

1. Click on the **Stop** button.
2. Switch off the laser.



You can reset the values for beam position stability in the **Position** and **Angle** windows by pressing the **Reset** button.

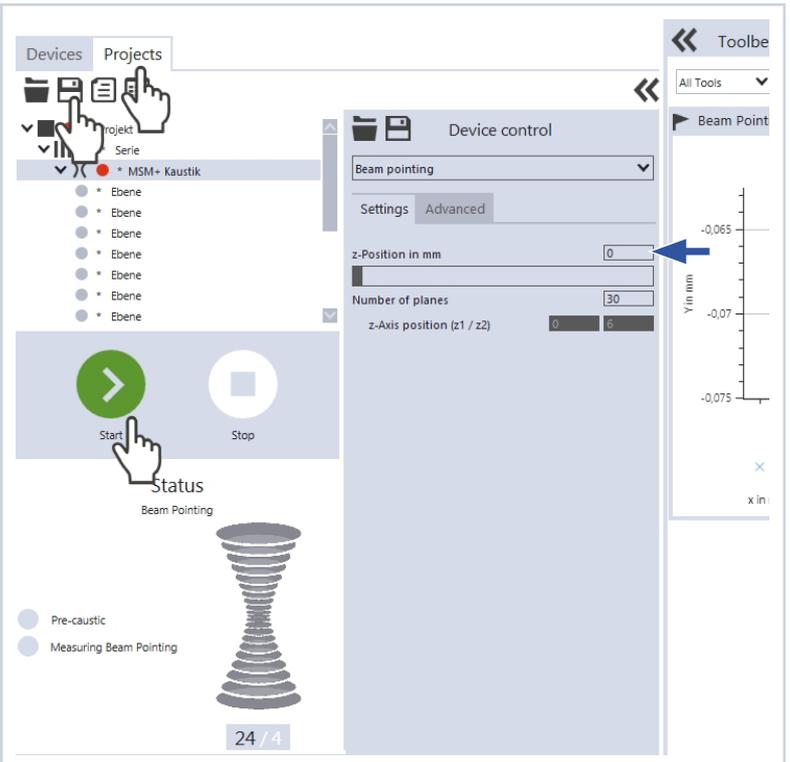
You can log the **Beam pointing stability** as described in chapter 12.9.5 on page 83.



12.9.5 Logging beam pointing stability

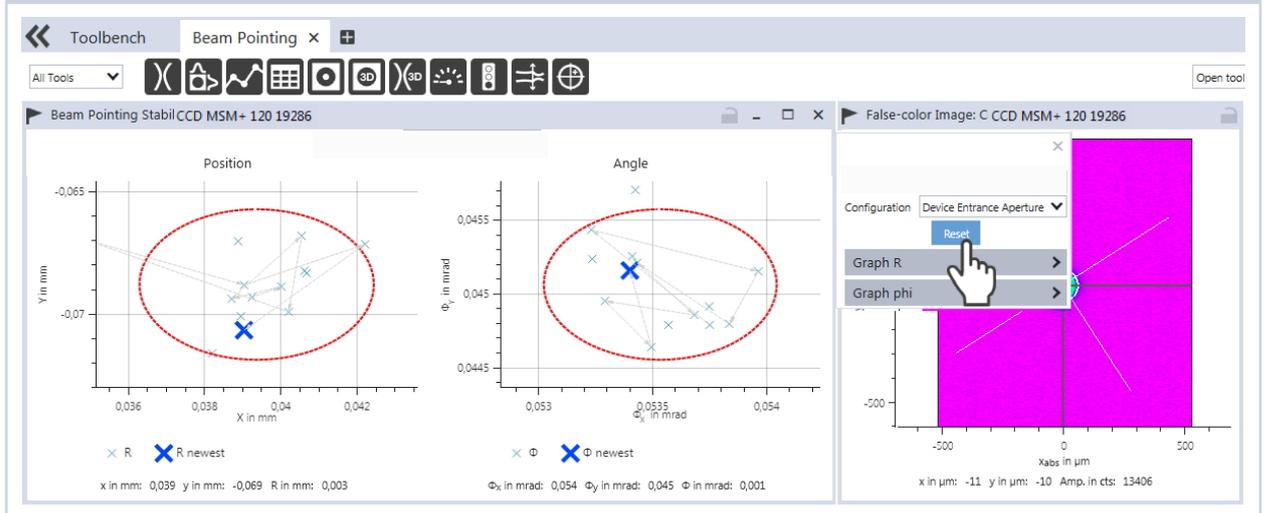
You can log the beam pointing stability under **Device control > Settings**:

1. Enter the value of 0 in the **Number of planes** field.
2. Click on the **Projects** tab.
3. Click on the **Start** button.
 - ➔ Continuous measurement data for beam position stability is generated in the project tree.
4. Click on the **Stop** button.
5. Click on the **Save** icon in order to save the measurement data.



👁 The measuring points in the **Position** and **Angle** windows can be deleted by clicking the gear icon ⚙ and the **Reset** button.

The measured data in the project tree is not deleted in the process.



13 Troubleshooting

Error	Possible cause	Remedy
There is no connection between the device and the PC.	The Network address of the PC is not within the range of the device.	In Windows > Control panel > Network and Sharing Center, assign an IP address to your PC that is in the same address range as the device.
	The connection may be blocked by the firewall.	Enable the UDP port 20034 according to chapter 12.2.2 on page 40.
	An incorrect network interface card is selected.	Select the appropriate network interface card according to chapter 12.2.2 on page 40.
Error during a measurement	<ul style="list-style-type: none"> Data transmission error Processor crash in the measuring system Program execution error 	<ol style="list-style-type: none"> Restart the software. Switch off the supply voltage, switch it on again, and start another reset cycle. Restart the computer.
Apart from the ambient noise and zero offset, no measuring signal is available.	The laser is not switched on.	Switch on the laser.
	The device is not aligned correctly.	Check the device alignment to the laser beam.
	The power density in the focus is too low.	Try the following actions in the order given: <ol style="list-style-type: none"> Enlarge the measurement window. Increase the integration time or select a weaker filter of the filter wheel (if available). Increase the laser power (step by step).
The safety interlock has been triggered.	The cover of the inspection chamber is not closed.	Close the cover.
Error messages in LaserDiagnosticsSoftware LDS	Possible cause	Remedy
Attention, the housing is open!	The cover of the inspection chamber is not closed.	Close the cover.
Measurement is not possible because no measuring objective has been detected.	The measuring objective is not / not correctly inserted.	Insert a measuring objective or check the position of the measuring objective.
The measuring objective used is not calibrated for this device, the measurement inaccuracy may be significantly increased.	A measuring objective from a different device may have been inserted.	Check the inserted measuring objective. PRIMES should calibrate the measuring objective for higher accuracy.
Measurement can't be taken, the connection with the camera head has been disrupted. Please switch the device off and on again.	The device wasn't able to initialize the camera head.	Switch the device off and on again.
Error in saving the user-defined device settings, the parameters must be reset.	It wasn't possible to save the device settings in the device.	Save the device settings again.
Internal device error. Switch the device off and on again. Device moves to the home position during this process.	The device is experiencing an internal error.	Switch the device off and on again.

14 Maintenance and service

14.1 Maintenance intervals

The operator is responsible for determining the maintenance intervals for the measuring device. PRIMES recommends a maintenance interval of 12 months for inspection and validation. If the device is used only sporadically, the maintenance interval can also be extended up to 24 months.

14.2 Cleaning

You can remove light contamination with compressed air. Make sure that all device openings are closed. For further cleaning, PRIMES recommends a mixture of distilled water and isopropanol in a ratio of approx. 5:1. Use lint-free cleaning cloths that do not scratch. This can be e.g. microfiber cloths or paper towels from the cosmetics sector.

If these measures are not sufficient, please contact PRIMES.

14.3 Exchanging the protective window

The measuring objective can optionally be delivered with a protective window or a combination of protective window and cyclone. The protective window in the beam entrance is a wearing part and can be replaced if necessary. Low levels of contamination of the protective window can be carefully removed with Isopropanol when it has cooled down (observe the manufacturer’s safety instructions). In case of heavy, non-removable contamination or damage, the protective window must be replaced with a new one.



The protective window is coated with an antireflex coating and has low reflection values of less than 1 %. To avoid increased reflection values, use only original PRIMES protective windows.

Order number	Suitable for the following spectra:			Diameter	Thickness
	NIR	VIS	UV		
801-004-054	✓	–	–	30 mm	1.5 mm
801-004-068	✓	✓	–	30 mm	1.5 mm
801-004-069	✓	✓	✓	30 mm	1.5 mm

14.3.1 Warning messages



DANGER

Severe eye or skin injury due to laser radiation

If the protective window is not correctly positioned, reflections can cause directional laser radiation.

- ▶ Make sure that the new protective window is settled flat in the groove of the protective window mount.



CAUTION

Burns due to hot components

After a measurement the protective window is hot!

- ▶ Do not replace the protective window directly after a measurement.
- ▶ Let the device cool down for an adequate period of time. The cooling time varies depending on the laser power and the irradiation time.

NOTICE

Damaging / destroying the device

Contamination and fingerprints on the protective window can lead to damage or shattering or splintering of the protective window.

- ▶ Only replace the protective window in a dust-free environment.
- ▶ Do not touch the protective window.
- ▶ When exchanging the protective window wear suitable gloves.

The protective window is located in the protective window mount of the measuring objective below the retaining ring / cyclone. The retaining ring / cyclone is attached to the protective window using a spring-loaded bayonet lock with three locking pegs.

14.3.2 Replacing the protective window

1. Observe the warning messages in chapter “14.3.1 Warning messages” on page 85.
 2. Push the retaining ring down against the protective window mount, turn it counterclockwise until it stops and lift the retaining ring up and off.
 3. Remove the old protective window from the protective window mount (for example with a suction cup) and dispose of it.
 4. Carefully place the new protective window into the protective window mount.
 5. Position the locking pegs of the retaining ring in the openings of the bayonet lock.
 6. Push the retaining ring down and turn it clockwise until it stops.
- ➔ The bayonet lock is locked.

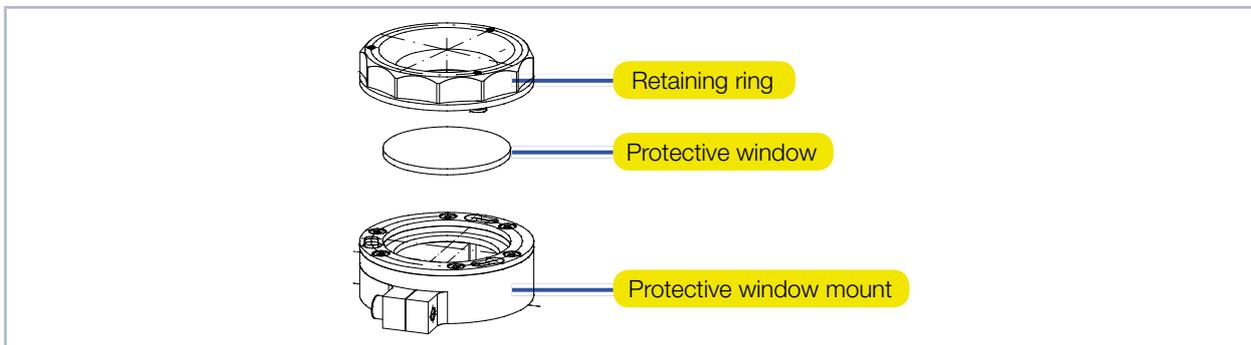


Fig. 14.1: Components of the protective window mount

14.3.3 Replacing the protective window for cyclone

1. Observe the warning messages in chapter “14.3.1 Warning messages” on page 85.
 2. Remove the compressed air hoses around the cyclone if necessary.
 3. Push the cyclone down against the protective window mount, turn it counterclockwise until it stops and lift it up and off.
 4. Remove the old protective window from the protective window mount (for example with a piece of adhesive tape) and dispose of it.
 5. Carefully place the new protective window into the protective window mount.
 6. Position the locking pegs of the cyclone in the openings of the bayonet lock.
 7. Push the cyclone down and turn it clockwise until it stops.
- ➔ The bayonet lock is locked.

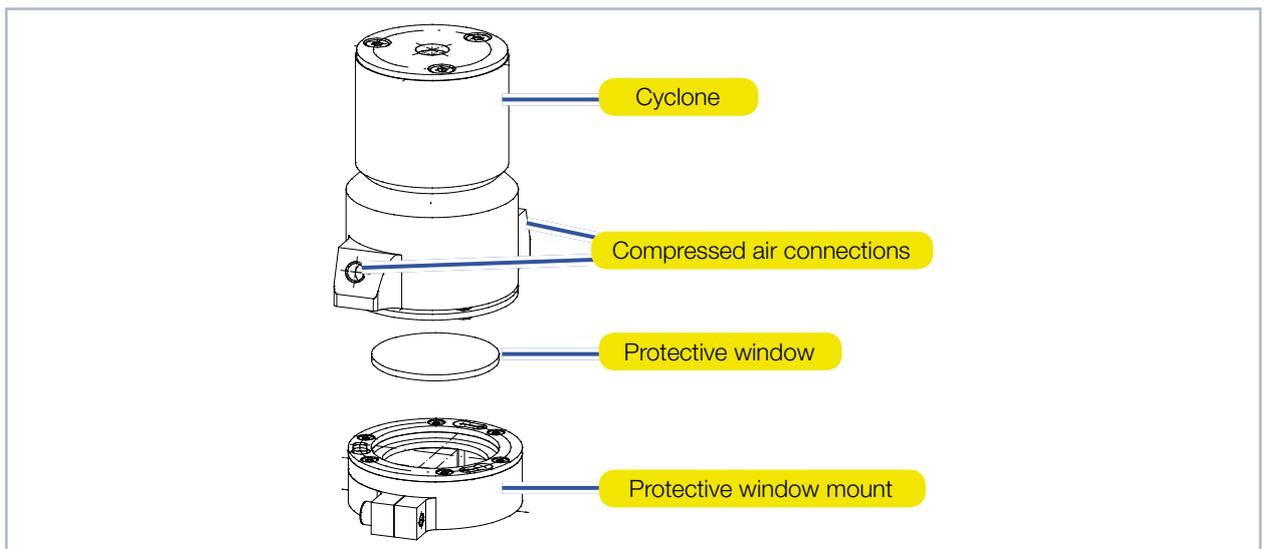


Fig. 14.2: Components of the protective window mount with cyclone

15 Measures for the product disposal

PRIMES gives you the opportunity to return your PRIMES measuring device for free disposal within the scope of the Waste of Electrical and Electronic Equipment (WEEE Directive). This service does not include shipping costs. You can send PRIMES measuring devices to be disposed of within the EU to our address:

PRIMES GmbH
Max-Planck-Str. 2
64319 Pfungstadt
Germany

If you are located outside the EU: please contact your local PRIMES distributor to discuss the disposal procedure.

PRIMES is a registered manufacturer in the German “Used Appliances Register“ stiftung elektro-altgeräte register (stiftung ear) with the number WEEE-reg.-no. DE65549202.

16 Declarations of conformity**Original EG Declaration of Conformity**

The manufacturer: PRIMES GmbH, Max-Planck-Straße 2, 64319 Pfungstadt, Germany,
hereby declares that the device with the designation:

MicroSpotMonitor (MSM)

**Types: MSM 35; MSM 120; MSM-HP
MSM+ 35; MSM+ 120; MSM+ HB10; MSM+ HB20**

is in conformity with the following relevant EC Directives:

- Machinery Directive 2006/42/EC
- EMC Directive EMC 2014/30/EU
- Low voltage Directive 2014/35/EU
- Directive 2011/65/EC on the restriction of the use of certain hazardous substances (RoHS) in electrical and electronic equipment
- Directive 2014/32/EC on measuring instruments

Authorized for the documentation:

PRIMES GmbH, Max-Planck-Straße 2, 64319 Pfungstadt, Germany

The manufacturer obligates himself to provide the national authority in charge with technical documents in response to a duly substantiated request within an adequate period of time.

Pfungstadt, August 5, 2020

Dr. Reinhard Kramer, CEO

UKCA Declaration of Conformity

The manufacturer: PRIMES GmbH, Max-Planck-Straße 2, 64319 Pfungstadt, Germany,
hereby declares that the device with the designation:

MicroSpotMonitor (MSM)

**Types: MSM 35; MSM 120; MSM-HP
MSM+ 35; MSM+ 120; MSM+ HB10; MSM+ HB20**

is in conformity with the following relevant EC Directives:

- Supply of Machinery (Safety) Regulations 2008
- Electromagnetic Compatibility Regulations 2016
- Electrical Equipment (Safety) Regulations 2016
- Directive 2011/65/EC on the restriction of the use of certain hazardous substances (RoHS) in electrical and electronic equipment
- Measuring Instruments Regulations 2016

Authorized for the documentation:
PRIMES GmbH, Max-Planck-Straße 2, 64319 Pfungstadt, Germany

The manufacturer obligates himself to provide the national authority in charge with technical documents in response to a duly substantiated request within an adequate period of time.

Pfungstadt, May 3, 2021



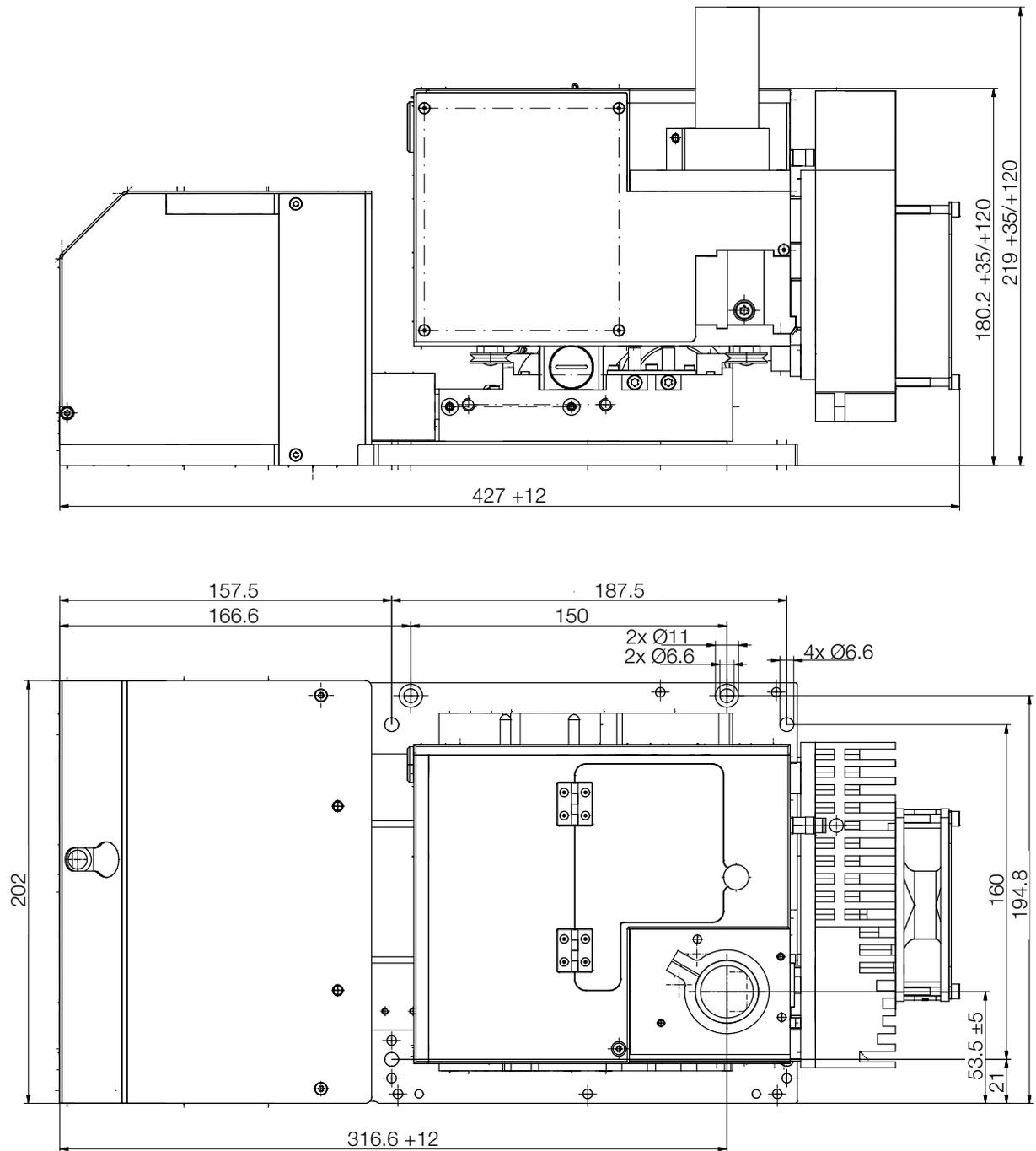
Dr. Reinhard Kramer, CEO

17 Technical data

Measurement parameters	
Power range	1 mW – 200 W (optional 500 W with water cooling)
Wavelength range	257 – 272 nm (on request)
	340 – 360 nm
	515 – 545 nm
	1 030 – 1 090 nm
Beam diameter	10 – 1 000 µm
Determined parameters	
Focus position x, y, z	yes
Focus radius x, y	yes
Beam quality factor M^2	yes
Raw beam diameter with focussing element	yes
Beam parameter product BPP	yes
Divergence angle	yes
Power density distribution	2D, 3D
Device parameters	
Traversing range x-y plane	2 × 2 mm
Traversing range z-axis	35 mm (MSM+ 35), 120 mm (MSM+ 120)
Measurement window sizes	0.02 – approx. 3.5 mm (depending on the measuring objective)
Integrated variable attenuation (option)	Filter wheel with 5 OD filter (OD 0 – 5)
Supply data	
Power supply	24 V DC ± 5 %, max. 1.8 A
Compressed air for cyclone (cleaned, free of water and oil)	0.5 – 1 bar
Specification of compressed air for the cyclone according to ISO 8573-1: 2010	6:4:4
Cooling water pressure (500 W device version only)	2 bar primary pressure with an unpressurized outflow, max. 4 bar
Min. Cooling water flow rate (500 W device version only)	1.5 l/min
Cooling water temperature $T_{in}^{1)}$ (500 W device version only)	Dew point temperatur $< T_{in} < 30$ °C
¹⁾ Please consult with PRIMES before working beyond this specification.	
Communication	
Interface	Ethernet
Dimensions and weight	
Dimensions (L x W x H)	Length: 427 mm +12 mm traversing range + connector Width: 202 mm Height: 181 mm + 35 / 120 mm traversing range + projection depending of the measuring objective used
Weight	15 kg

Environmental conditions	
Operating temperature range	10 – 40 °C
Storage temperature range	5 – 50 °C
Reference temperature	22 °C
Permissible relative humidity (non-condensing)	10 – 80 %

18 Dimensions



All dimensions in mm

19 Appendix

19.1 Insert fixed OD filter (option) in the inspection chamber

1. Switch off the laser source.
2. Ensure that moving parts, for example robot arms, etc. are at a standstill and that they cannot be set in motion unintentionally.
3. Switch off the device.

NOTICE

Damaging / destroying the optical components

Contamination can damage or destroy the optical components.

- ▶ **Only open the inspection chamber in a dust-free environment.**

4. Unscrew the knurled screw on the cover and open the cover.
5. Insert the fixed filter into the slot provided.
The insert has different guides so that the fixed OD filter can only be inserted in one position.
6. Close the cover and screw in the knurled screw.
7. Check the secure fit of the cover:
The cover must fit flush with the housing, so that no dust or dirt can get into the inspection chamber.

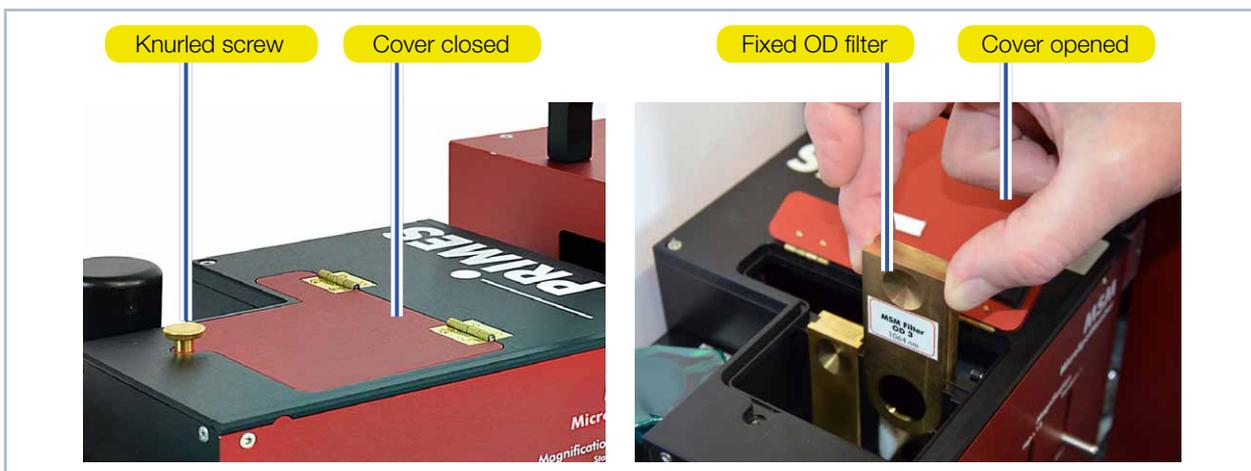


Fig. 19.1: Insert fixed OD filter into the inspection chamber

19.2 Optical components

The device is a camera-based measuring system. Depending on the application, up to 7 different optical components can be placed within the beam path. The purpose and functionality of individual components are described in the following chapters.

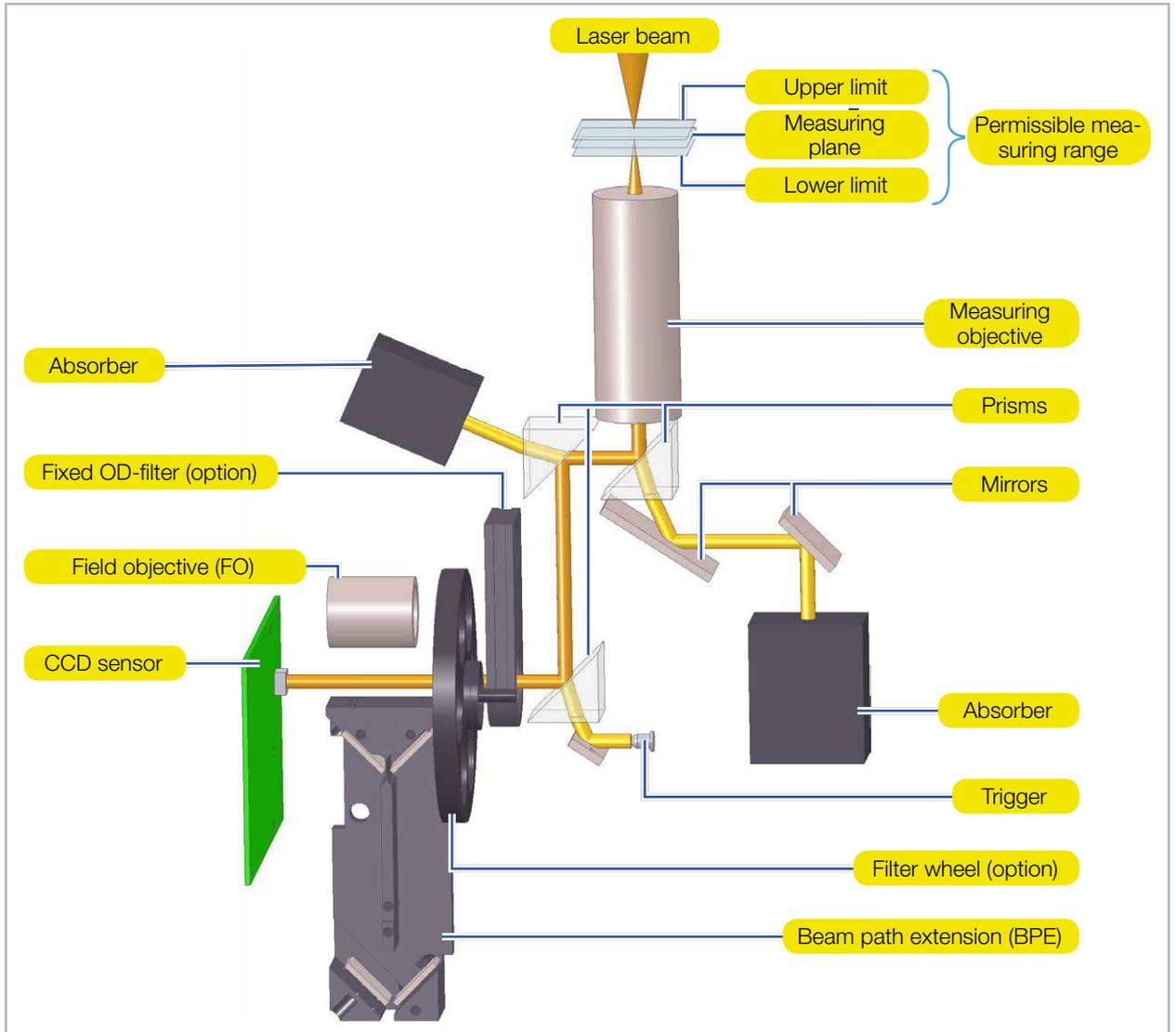


Fig. 19.2: Example of the optical design of the device

19.2.1 NA limit value, typical magnification and measuring plane distance

The interaction of the optical components makes it possible to image a measuring plane perpendicular to the z-axis and outside the measuring device onto the CCD sensor inside the device. Three important quantities must be considered in connection with this (see Tab. 19.1): the numerical aperture limit (NA limit), the typical magnification and the measuring plane distance.

The measuring plane distance is the distance between the measuring objective and the measuring plane. The values listed in Tab. 19.1 correspond to the distance from the measuring plane to the upper edge of the measuring objective. The measuring plane distance is essential for the manual alignment of the device along the z-axis (see 8.3.1 on page 23).

Measuring objective	NA limit values	Typ. magnification			Measuring plane distance in mm		
		Standard	with BPE	with FO	Standard	with BPE	with FO
3.3x							
1 064 nm	0.11	3.12	5.65	1.12	73	64.6	63.7
532 nm	0.1	3.23	5.81	1.11	70.5	62.6	61.5
355 nm	0.09	3.36	6.02	*)	67.3	60.1	57.7
5x							
1 064 nm	0.19	4.96	8.31	1.63	51.1	47.1	46.7
532 nm	0.18	5.15	8.6	1.59	49.3	45.7	45.1
355 nm	0.14	5.35	8.92	*)	47.2	43.8	42.7
10x							
1 064 nm	0.24	8.84	14.39	2.77	29.9	27.9	27.6
532 nm	0.24	9.17	14.91	2.72	-	-	-
355 nm	0.15	9.62	15.6	*)	-	-	-

Tab. 19.1: NA limit value, typical magnification and measuring plane distance

*) Only suitable for adjustment

FO = field objective

BPE = beam path extension



If a 1.5 mm thick protective window is used, the measuring plane distance increases by approx. 500 µm.

Due to manufacturing tolerances, the values of the measuring plane distance listed in Tab. 8.1 are subject to an error of ± 800 µm. However, it is possible to validate the measuring plane distance of the measuring objectives to an accuracy of ± 50 µm (TCP determination).

19.2.2 Measuring objective

The measuring objective is a lens system designed to image a measuring plane perpendicular to the z-axis and outside the measuring device onto the CCD sensor inside the device.

This non-contact measurement offers the advantage that even very high power densities can be detected. The measuring objective makes it possible to enlarge the beam and thus to image a sufficient resolution on the CCD sensor.

Fig. 19.3 shows a diagram of the measuring objective. It includes all important parameters.

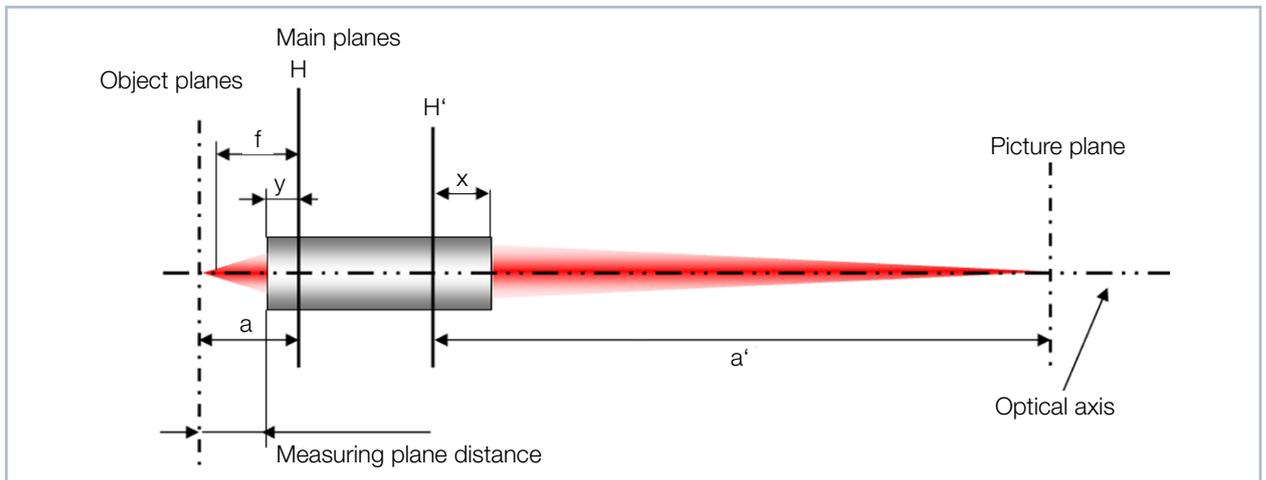


Fig. 19.3: Illustration of a defined measuring plane with a measuring objective

The main planes H and H' in the measuring objective or image space are auxiliary quantities in order to combine any number of optical components into one unit. The focal length f, offset distance a, and image distance a' are measured from the intersection of the main planes with the optical axis (cardinal point).

The dimensions x, y and the measuring plane distance are important auxiliary quantities. They establish the relationship between the optics and the socket edge.

The projection of the measuring objective is calculated according to the following formula:

$$\frac{1}{f} = \frac{1}{a} + \frac{1}{a'} \tag{1.1}$$

The focal length f is dependent on the wavelength and, as a result, the image distance a' is dependent on the object distance a.

The magnification of the measuring lens is calculated from the quotient of a and a':

$$\beta = \frac{a'}{a} \tag{1.2}$$

The combination of the two formulas gives β a dependence on the image size a' and the focal length f. The focal length is determined by selecting a measuring objective and the image distance is determined by the construction of the measuring device.

The choice of the measuring objective depends on the geometry and the beam parameters of the laser beam to be measured. The sensor area of the CCD sensor is 4.76 mm x 5.58 mm. According to ISO 11146, the measurement must be carried out for at least 4, more preferably 6 rayleigh lengths.

According to the following formula the sensor area must be at least 5 times larger than the expected focus diameter.

$$\omega_{\sigma(z)} = \omega_{a0} \cdot \sqrt{1 + \left(\frac{z}{z_{Ra}}\right)^2} \tag{1.3}$$

Once the appropriate measuring objective has been selected, the MicroSpotMonitor MSM recognizes the assembled measuring objective via an electronic coding on the holder of the measuring objective and adjusts the available measuring windows.

If, for example, the maximum square measurement window size in a 1:1 figure on the CCD sensor 4 mm x 4 mm, it should be reduced to 0.4 mm x 0.4 mm at a magnification of 10:1.

The inlet aperture of the device can easily be aligned with the optical axis of the laser beam within a range of 2 mm x 2 mm using an alignment tool (see chapter 8.3.3 on page 25). The path of movement of the x and y axis of 2 mm makes it possible to position the laser beam precisely on the CCD sensor.

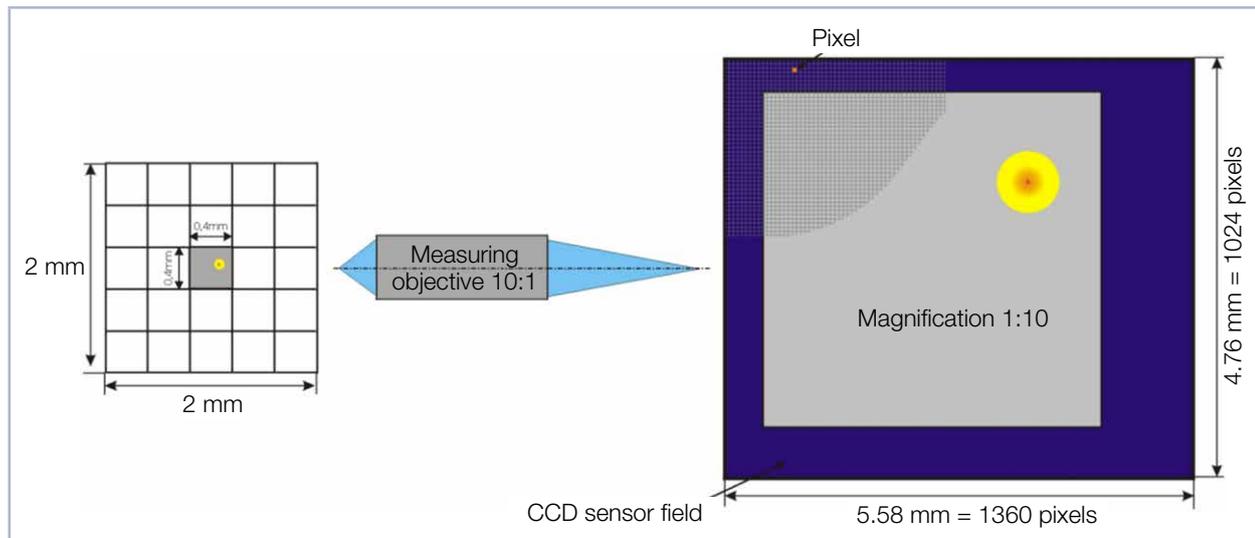


Fig. 19.4: Schematic illustration of a measuring plane on the CCD sensor

Fig. 19.4 shows schematically the projection of a measuring plane onto the CCD sensor. The reticule on the left shows the measuring area, which can be measured with the integrated x- / y-axis. This can also be done automatically.

Within the measuring area, a measuring window can be positioned (size depending on measuring objective). On the right, the CCD sensor field is displayed. The measuring window, which has an edge length of 0.4 mm (in the object level), is projected to the chip with a 10-fold magnification.

Equation (1.1) shows that the farther the focus is from the measuring lens (a_{fokus}), the shorter it is imaged behind the measuring lens (a'_{fokus}). Therefore, it is necessary to align the beam focus within a permissible range on the z-axis. Detailed information on this can be found in chapter 8.3, „Manually aligning the device“, on page 23.

19.2.3 Prisms

After the measuring objective, the laser beam hits three uncoated quartz glass prisms which attenuate the laser beam.

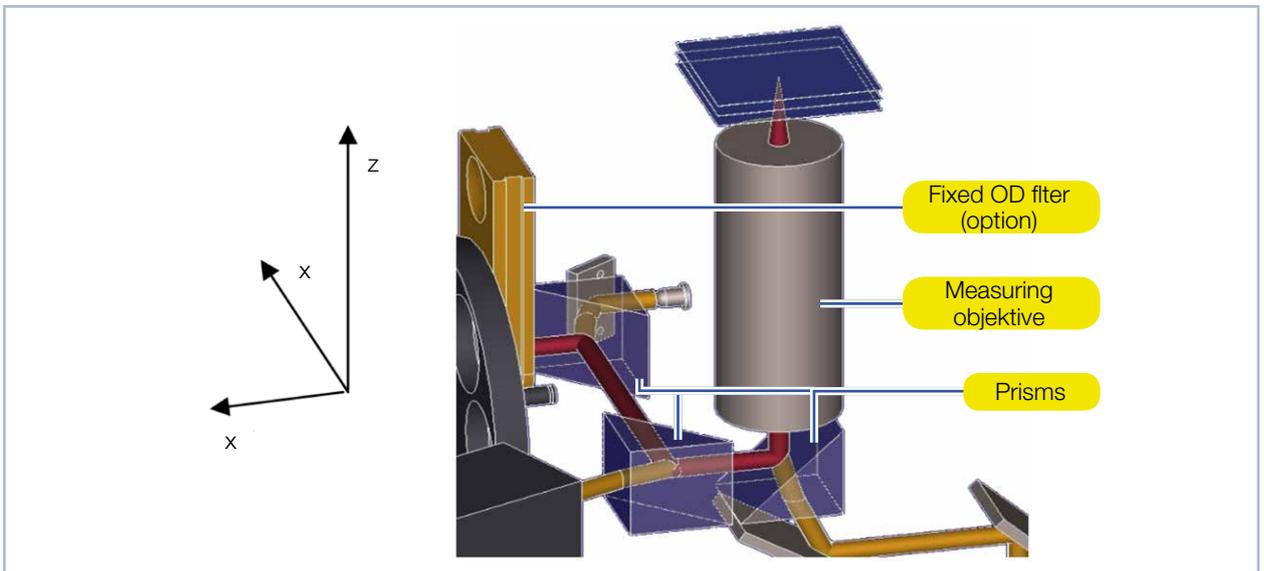


Fig. 19.5: Section of the beam path of the device

The reflection is described with the Fresnel formulas. They describe the so-called reflection respectively transmission ratio of light at surface boundaries.

$$\rho_{\perp} = \frac{-(\sqrt{n_{rel}^2 - \sin(\alpha)^2} - \cos(\alpha))^2}{n_{rel}^2 - 1} \quad (1.4)$$

ρ_{\perp} : Reflection ratio of vertically polarized light.

$$\sigma_{\perp} = \frac{2 \cdot \cos(\alpha) \cdot \sqrt{n_{rel}^2 - \sin(\alpha)^2} - 2 \cdot \cos(\alpha)^2}{n_{rel}^2 - 1} \quad (1.5)$$

σ_{\perp} : Transmission ratio of vertically polarized light.

$$\rho_{\parallel} = \frac{n_{rel}^2 \cdot \cos(\alpha) - \sqrt{n_{rel}^2 - \sin(\alpha)^2}}{n_{rel}^2 \cdot \cos(\alpha) + \sqrt{n_{rel}^2 - \sin(\alpha)^2}} \quad (1.6)$$

ρ_{\parallel} : Reflection ratio for parallel polarized light.

$$\sigma_{\parallel} = \frac{2 \cdot n_{rel} \cdot \cos(\alpha)}{n_{rel}^2 \cdot \cos(\alpha) + \sqrt{n_{rel}^2 - \sin(\alpha)^2}} \quad (1.7)$$

$\sigma_{||}$: Transmission ratio of parallel polarized light.

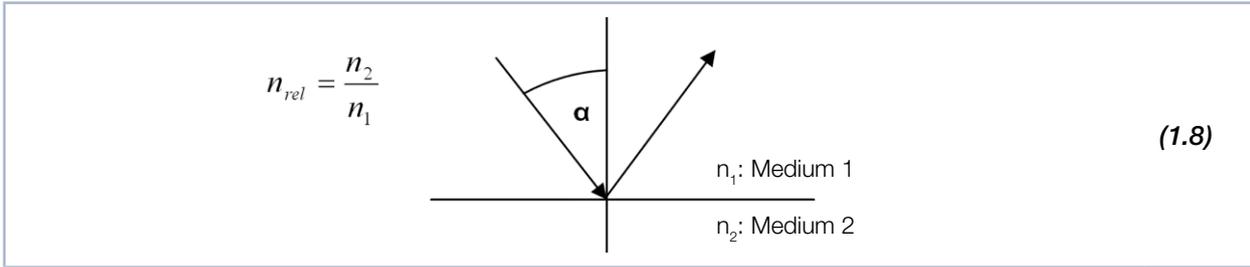


Fig. 19.6: Reflection of a beam at surface boundaries

The reflection respectively the transluence coefficients correspond to the squares of the respective ratios.

$$R_{[in\%]} = \rho^2 \cdot 100 ; T_{[in\%]} = \sigma^2 \cdot 100 \tag{1.9}$$

Plotted on a graph, the following curves are obtained:

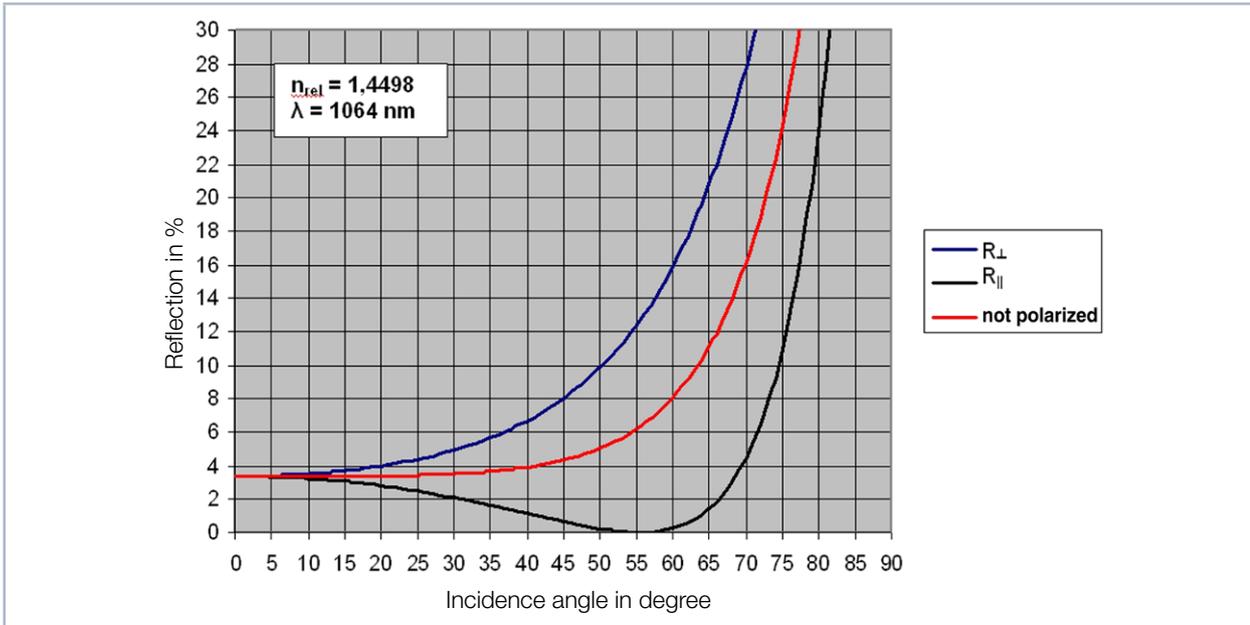


Fig. 19.7: Reflection of a laser beam at the prisms in % as a function of the angle of incidence

The curves in Fig. 19.7 were calculated for a wavelength of 1 064 nm. The refractive index n of quartz glass is wavelength-dependent. It varies from 1.4498 to 1.4766 in the wavelength range of 350 to 1 064 nm.

It can be clearly seen that the reflection characteristics depend on polarization. This also applies to an angle of incidence of 45° , the angle of incidence at which the beam passes through the device.

For this reason, the prisms are integrated in the device in such a way that the beam is diverted in all three spatial directions (see Fig. 19.5 on page 97). This ensures that always two of the three incidence planes of the prisms are perpendicular to each other and compensate the polarization effects.

Nevertheless, the attenuation of the prisms remains a function of the wavelength and polarization of the laser beam.

In the optimal case for reflection,

- the laser beam is attenuated by a factor of $1.7 \cdot 10^{-4}$ ($\lambda = 350$ nm; \perp polarized),
- in the worst case by the factor of $6 \cdot 10^{-5}$ ($\lambda = 1064$ nm; \parallel polarized).

For all other wavelengths (between 350 nm and 1 064 nm) and polarizations, the values are in between.

However, this only affects the measurements if the polarization changes over the beam profile. In this case, an additional prism can be mounted above the measuring objective. The radiation transmitted by the prisms is guided via mirrors to the absorber resp. to a trigger diode.

19.2.4 Fixed filter and filter wheel

For further attenuation of the beam, an arbitrary fixed OD filter (option) can be inserted into the beam path (see chapter 19.1 on page 92). Behind the retractable OD filter is a filter wheel (option). The filter wheel has 6 positions. It can be operated during the measurement via software control. The filter wheel is equipped with five filters with an optical density between 1 and 5. The 6th position remains empty in order to allow the laser beam to pass unfiltered.

Neutral-density filters have approximately the same transmittance over a wide wavelength range. The degree of weakening can be varied with the type of glass and the thickness of the filter.

However, the filters are only capable of handling 100 mW/cm², that's why they are not suitable to substitute the prisms.

The maximum average power for the wavelength range 1030 nm to 1090 nm (NIR) is 200 W (500 W for water-cooled device versions). Be sure to use the aperture of the measuring objective when operating in this power range.

The formula for converting the optical density into the transmission coefficient in % is:

$$D = \log \left(\frac{100}{T_{[\text{in}\%]}} \right) \quad (1.10)$$

The Filter wheel can be selected to weaken the laser beam by a factor of 10 to 10⁵. Taking both filter levels together results in a dynamic range of 200 dB.

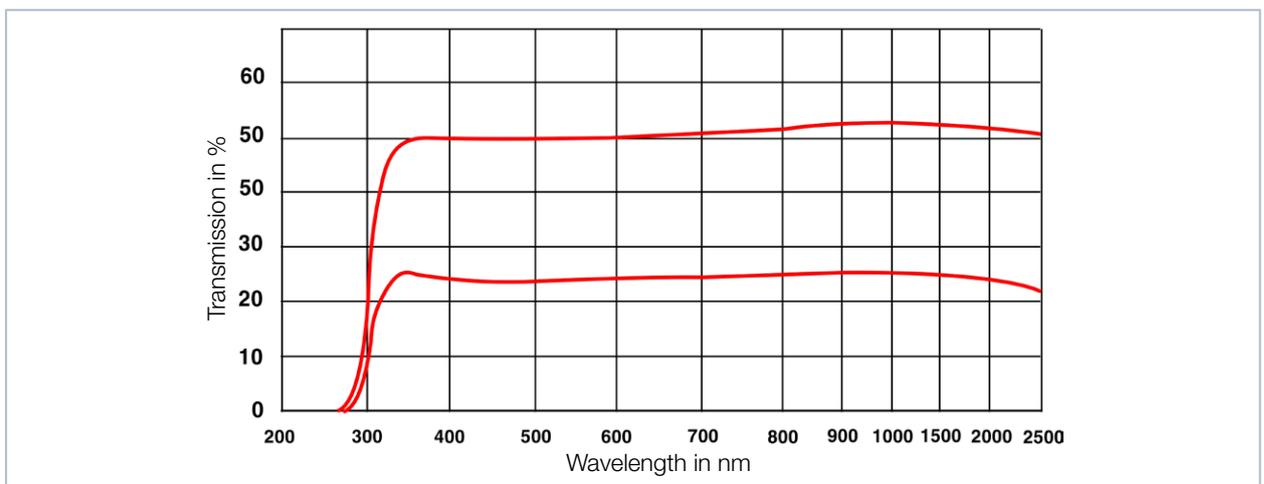


Fig. 19.8: Typical transmission curve of a neutral-density filter

19.2.5 Beam path extension (BPE)

The beam path extension allows the user to adjust the overall magnification of the system.

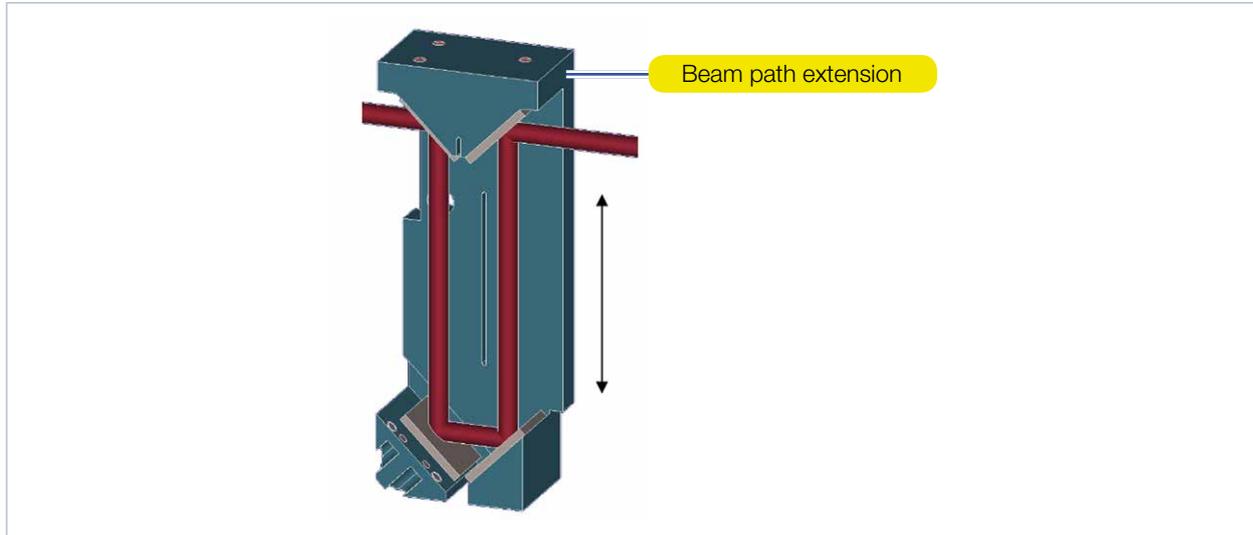


Fig. 19.9: Beam path extension of the device

The beam path extension consists of four mirrors. Using the levers to adjust the magnification (see Fig. 4.1 on page 11), it can be inserted in the beam path directly behind the filter wheel.

According to equation (1.1) for the measuring objective, this results in an enlargement of the overall image. The factor by which the magnification changes depends on the measuring objective and is approximately 1.5.



Note that the use of the beam path extension also changes the measuring plane distance. Therefore, the alignment of the device on the z-axis must be readjusted after activating / deactivating the beam path extension (see chapter 8.3, „Manually aligning the device“, on page 23).

19.2.6 Field objective (FO)

The field objective can be inserted into the beam path on the image side. Depending on the wavelength and the measuring objective used, this results in a reduction of the image by a factor of 2 to 3. This lens is particularly suitable for adjustment, because the device must be positioned less precisely to the laser beam due to the reduced imaging.

The reduced imaging of the measurement plane can also be seen as an enlargement of the active area of the camera chip. The sensor area of the CCD sensor is 4.76 mm x 5.58 mm. Using a 10x measuring objective means that in the standard case the device has to be positioned to approx. 0.5 mm in the x- / y-direction, for example in CCD mode. With the help of the field objective, this range can be extended to 1.5 mm.



The adjustment lens can be validated at wavelengths of 1064 nm and 532 nm. At the wavelength of 355 nm, it can only be used for alignment.

Note that the use of the field objective also changes the measuring plane distance. Therefore, the alignment of the device on the z-axis must be readjusted after activating / deactivating the field objective (see chapter 8.3, „Manually aligning the device“, on page 23).

19.2.7 Absorber

More than 99.8 % of the transmitted beam power is redirected by the first two prisms through a mirror system to an absorber.

The absorber is a channel in which the beam is completely absorbed by multiple reflections. The maximum average power for the wavelength range 1030 nm to 1090 nm (NIR) is 200 W (500 W for water-cooled device versions).

19.2.8 Trigger diode

With the aid of a sensor, the transmitted beam of the third prism is used as a triggering signal. The threshold at which the sensor sends a triggering signal can be set by the user or automatically. This signal can be used by the software to control delay and exposure time as well as better measure pulsed laser beams (see chapter 19.3).

19.3 Measuring pulsed irradiation

19.3.1 Trigger operation

The dynamic range of the CCD sensor in the camera housing is extended by means of a variable integration time control. The integration time can be freely determined in the range between 6 μ s and 225 ms, or it can be set automatically (for this purpose, activate the **Autom. exposure** option in the **Settings** tab of the **Single planes** measuring mode, see chapter 12.5.2 on page 52).

If the automatic exposure is enabled, then the software will automatically – using a series of pre-measurements – set the integration time at which the output signal of a pixel in the array is too high. The optimal integration time will then be a little below that.

By means of the variable integration time control, not only cw laser beams but also a multitude of pulsed beams can be measured in quasi-cw operation. An exception are, for example, laser beams with a very low pulse frequency. For measuring such beams, the trigger operation is available in the measuring modes **Single planes** / **Manual caustic** / **Automatic caustic** (see chapter 12.5 on page 51 / chapter on page 66 / chapter 12.8 on page 73). If this is enabled, the device only measures within defined time periods. The laser pulse or the corresponding trigger signal marks the beginning of such a period and the (freely adjustable) integration time marks its end.

Fig. 19.10 shows that in addition to the trigger signal and the integration time, a further variable intervenes in the sequential control of the CCD sensor: the trigger delay. It indicates the time period between the trigger signal and the start of the integration time.

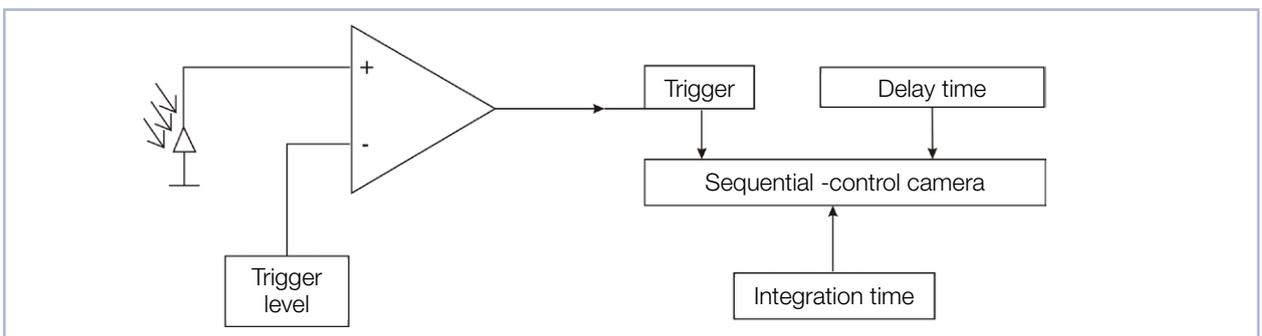


Fig. 19.10: Options for affecting the sequence control of the CCD sensor

A measurement can be triggered internally or externally. Internal signals are triggered by the photodiode integrated in the device. Externally triggered signals enter the device via a BNC socket. You can freely determine the threshold value of the internal trigger signal (trigger level).

Every measurement consists of a dark measurement and a measurement with photo transfer. This applies for trigger operation as well as cw / quasi-cw operation. This means that each measurement requires at least two trigger signals.

The following time constants apply:

Timeout:	2 sec (Standard)
Minimum integration time:	6 μ s
Maximum integration time:	225 ms
Minimum delay:	12 μ s
Maximum delay:	400 ms

19.3.2 Measuring configuration selection

There are various measuring options to differentiate between:

- Measuring a single plane or a caustic
- Measuring a complete pulse or just a single section
- Measuring with freely adjustable integration time or with automatic integration time control
- Measuring in trigger operation or quasi-cw operation
- Variations of optimal integration time caused by changing the attenuation

Combining these measurement options with the following pulse parameters provides numerous possibilities:

- Pulse duration: fs – ms
- Pulse frequency: 1 Hz – 1 kHz

The following merely describes a rough structure that is intended to help in choosing measuring settings.

19.3.3 Influence of the pulse parameters on the integration time control

The software-operated integration time control always assumes that there is a cw laser beam. This may cause quantization of the integration time for slow pulse lasers (< 500 Hz) or lasers with high pulse energy (integration time very short). Tab. 19.2 And the diagram in Fig. 19.11 on page 103 illustrates this.

Pulse frequency in Hz	Number of detected pulses	
	at maximum integration time 225 ms	at integration time 1 ms
1	0	0 – 1
5	1	0 – 1
10	2	0 – 1
50	11	0 – 1
100	22	0 – 1
200	45	0 – 1
500	112	0 – 1
1 000	225	1 – 2
2 000	450	2 – 3
5 000	1 125	5.00
10 000	2 250	10.00

Tab. 19.2: Number of detected pulses in correlation with the integration time and pulse frequency

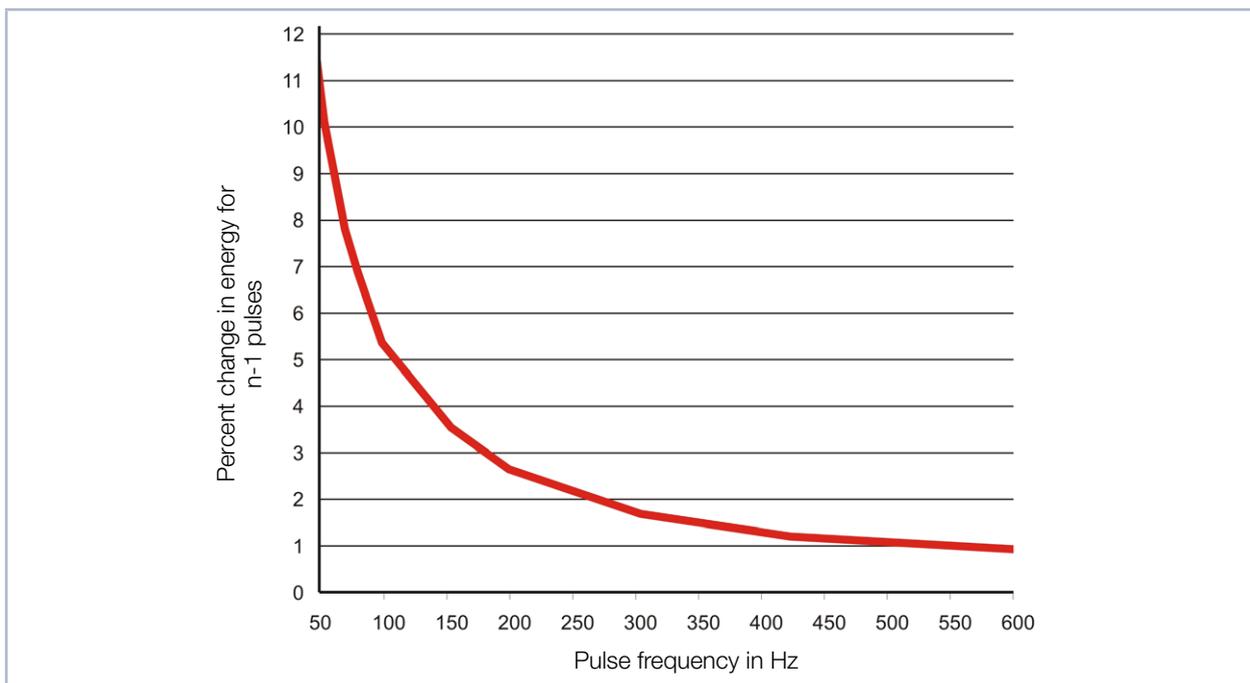


Fig. 19.11: Percentage of change in the detected energy when exactly one pulse is left out, in correlation with the pulse frequency

Tab. 19.2 shows the number of detected pulses during the maximum integration time and during an integration time of 1 ms for different pulse frequencies. Quantization with low pulse frequencies is clearly illustrated in the column for the maximum integration time. While 2 250 pulses are detected at a pulse frequency of 10 kHz, at 10 Hz there is only one or no more than two.

If the signal level is too high during a measurement at 10 Hz pulse frequency and the software tries to adjust the integration time, there are only three possible results. The energy application for a measurement remains the same, it decreases by 50 %, or it drops to zero. These increments are less significant at a pulse frequency of 10 kHz. This correlation is shown in general terms in Fig. 19.11 on page 103. It can be seen that from a pulse frequency of 500 Hz, the minimum jump with a reduction of the integration time is 1 %.

Small pulse frequencies aren't the only thing that will cause quantization though. If the pulse energy is very high and it isn't possible to further increase the attenuation, the integration times will be smaller. In Tab. 19.2, an integration time of 1 ms is added to the maximum integration time. In this case, a pulse frequency of 500 Hz is not sufficient in order to quasi continuously control the energy application for each measurement through integration time control.

A total of four states can always be differentiated on the way from low to high pulse frequencies or from short to long integration times. This is demonstrated by the following example for measuring pulsed irradiation during quasi-cw operation.

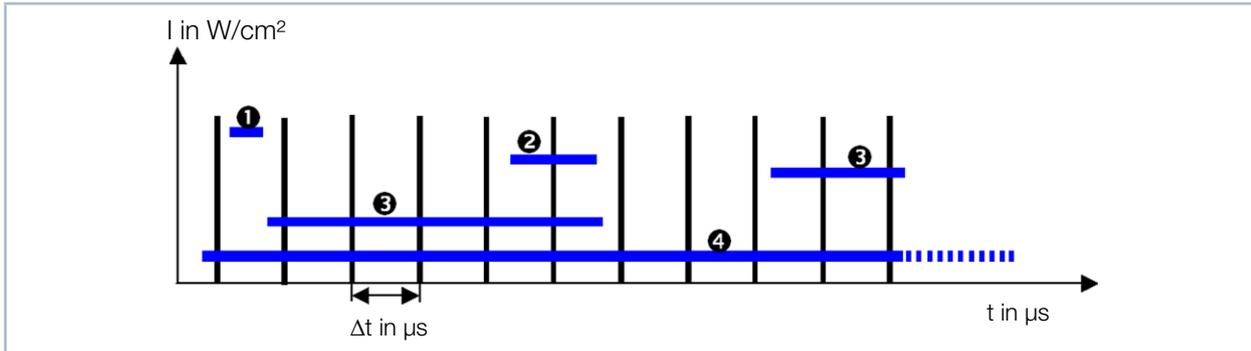


Fig. 19.12: Measuring with different integration times

- ❶ 12 – 200 µs: Sporadic measuring of pulses
- ❷ 200 – 400 µs: 1 pulse
- ❸ 200 – 2 ms: Quantization noise cause by a varied number of pulses
- ❹ 2 – 200 ms: Virtually continual integration time control

Fig. 19.12 shows pulsed irradiation. The pulse pauses are 200 µs. The required integration time of the sensor correlates directly with the intensity of the laser beam.

If it is smaller than the pulse pause as in case 1, statistically there is a maximum of 1 pulse in the measurement. The probability that a pulse is present during each measurement for integration time control as well as during the actual measurement is low.

If the optimal integration time falls exactly between the simple and double duration of the pulse pause, there will always be just one pulse in each measurement (case 2). This is the perfect state for measuring on one plane. The caustic can also be measured with this setup. Here it is important to make sure that the signal saturation for the measurement in the focus is as high as possible. Only then is it possible to ensure that there is a sufficient S/N ratio when measuring a plane far outside of the focus.

Case 3 describes the case in which the integration time ranges between the single and tenfold duration of the pulse pause. Within this range, every pulse is more or less noticeable as a clear signal jump during the integration time. Integration time control is only possible with quantization. The measuring results often have a bad S/N ratio or the signal level is too high.

If the integration time increases even more, the signal jumps become flatter. Integration time control operates quasi continuously (case 4). The laser being measured can now be measured as a cw laser.

The neutral-density filters, which can be inserted into the optical path, make it possible to always work within the desired range 1 to 4.

In addition, trigger operation is available for the device. Together with the integration time control and a delay time control, measurements can also be made reliably in case 1.

These four cases can generally be sorted into two groups. Case 1 and 2 must be measured in trigger operation. Case 4, however, is best measured in quasi-cw operation. Case 3 should be avoided altogether by choosing a suitable filter.

The diagram in Fig. 19.13 shows a classification of laser beams to be measured with regard to the suitable operation mode.

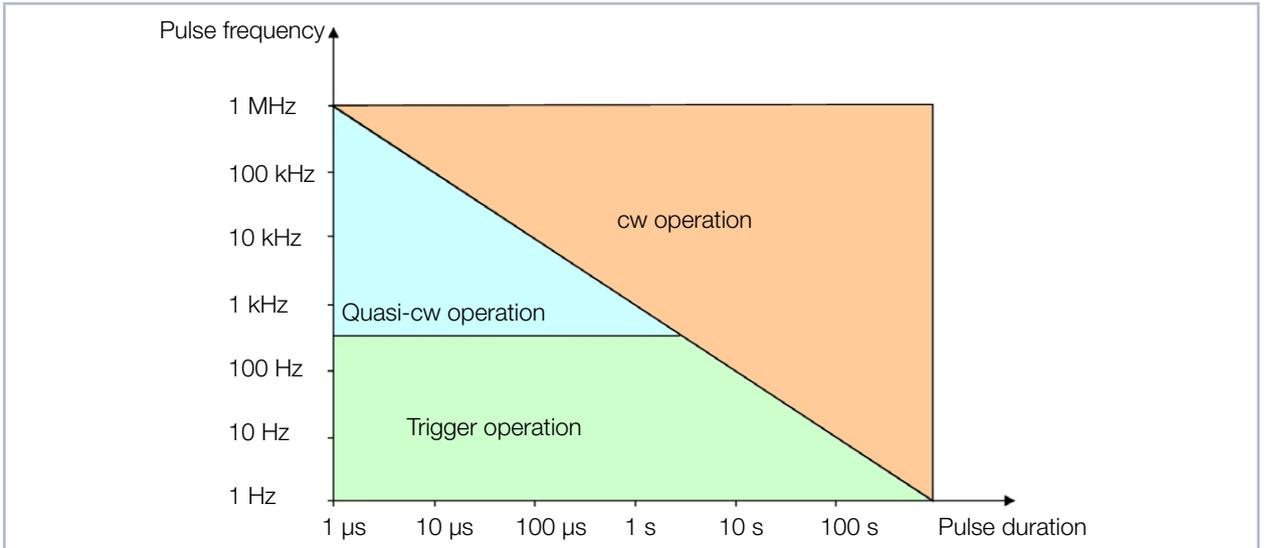


Fig. 19.13: Selection of the appropriate measurement mode based on laser parameters

For the blue field laser beams, the quasi-cw operation is most suitable. However, be aware that as the pulse frequency decreases, the required integration time increases to ensure the quasi-cw case. As a rule of thumb, the integration time of a focal plane measurement should be approximately the same as the time for 35 pulses. If the laser beam to be measured falls below a pulse frequency of approx. 500 Hz, you should switch to trigger operation.

While it is almost always possible to measure with the integration time control in the cw or quasi-cw operation, it only makes sense to use it for very long pulse durations (>1 ms) in trigger operation. With the help of the attenuation filters, the integration time is adjusted in such a way that it is only a fraction of the pulse duration. The trigger signal will then merely specify to the device the starting time for the measurement. The integration time may increase or decrease during the course of the caustic measurement without leaving the pulse path (see Fig. 19.14 and “Example 2: very long pulse duration” on page 106).

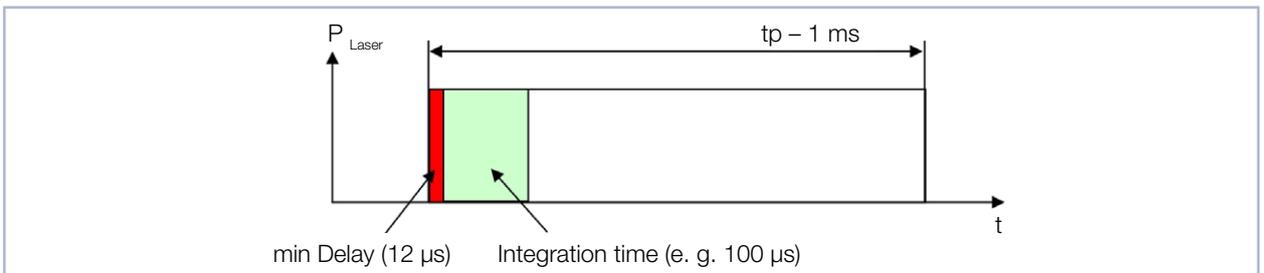


Fig. 19.14: Measuring parameters for pulsed laser systems with pulse duration greater than 1 ms

For all other cases, it is advisable to specify a fixed integration time in order to always measure a fixed number of pulses by cleverly selecting the filters and the delay and integration time (“Example 1: fixed integration time” on page 106).

19.3.4 Examples for trigger operation

Example 1: fixed integration time

With these settings, the device detects the second laser pulse after the trigger is released. Depending on how precisely it can be triggered, the integration time can also be varied.

Laser parameter	Device settings
Pulse duration: 50 ns	Delay: 950 μ s
Pulse frequency: 1 kHz	Integration time: 100 μ s
	Trigger channel: external trigger signal

Example 2: very long pulse duration

In this example, the first 12 μ s of the laser pulse are not measured.

Laser parameter	Device settings
Pulse duration: 1 ms	Delay: 12 μ s
	Integration time: 1 ms
	Trigger channel: internal trigger signal

19.3.5 Summary

If the laser is pulsing at a high frequency (> 500 Hz) or if the pulses last a long time (> 1 ms), it is best to measure with the automatic integration time control. This makes it possible to vary or optimize the integration time during a caustic measurement.

For the long pulse duration, choose the attenuation so that the integration time is smaller than the pulse duration even outside of the focal point.

When the pulse frequency is very high, however, the attenuation must be chosen so that enough laser pulses are integrated during the measuring cycle. If too few pulses occur during an integration time, the number of photoelectrons will change too much with each pulse. The regulating routines of the LaserDiagnosticsSoftware LDS will then lead to measurements with signal levels that are statistically too high.

It is important to make sure that the integration time is never shorter than the pulse pauses. If this is the case, it will no longer be possible to perform an untriggered measurement properly with the device.

So it sometimes makes sense to set the attenuation so that exactly one pulse is enough to expose the sensor at the focal point. You can then measure a caustic with a fixed delay and an integration time set when the focus was measured. The dynamic of the CCD sensor is sufficient to measure the entire caustic with an acceptable S/N ratio.