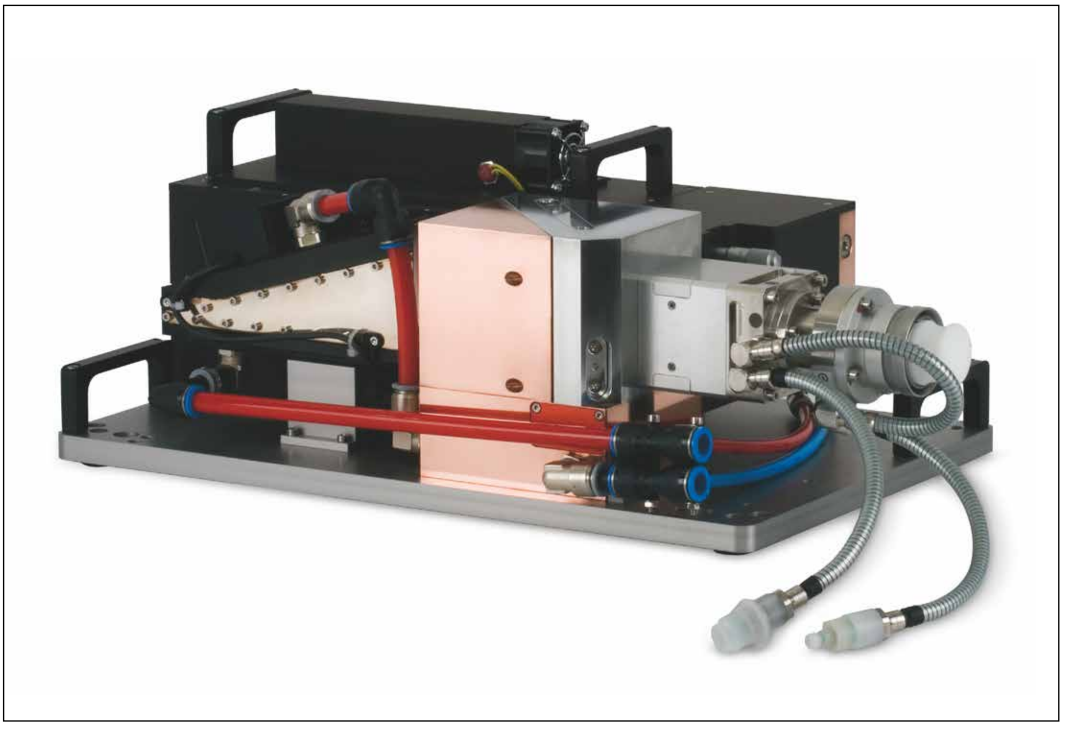
PRIMES

Operating Manual

Translation of the original instructions



LaserQualityMonitor LQM

LQM 20, LQM 200/500, HP-LQM II (10 kW)

LaserDiagnosticsSoftware LDS

Revision 02/2018 EN

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 CO_2 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 M^2

PRIMES is responsible for both the development, production, and calibration of the measuring devices. 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 instructions

Intended use

The LaserQualityMonitor LQM is exclusively intended for measurements which are carried out in or nearby the optical path of high power lasers. Please mind and adhere to the specifications and limit values given in chapter 18 „Technical data“ on page 102. Other forms of usage are improper. The information contained in this operating manual must be strictly observed to ensure proper use of the device.

Using the device for unspecified use is strictly prohibited by the manufacturer. By usage other than intended the device can be damaged or destroyed. This poses an increased health hazard up to fatal injuries. When operating the device, it must be ensured that there are no potential hazards to human health.

The device itself does not emit any laser radiation. During the measurement, however, the laser beam is guided onto the device which causes reflected radiation (**laser class 4**). That is why the applying safety regulations are to be observed and necessary protective measures need to be taken.

In measuring mode, the device’s safety circuit (interlock) must be connected with the laser control.

Observing applicable safety regulations

Please observe valid national and international safety regulations as stipulated in ISO/CEN/TR standards as well as in the IEC-60825-1 regulation, in ANSI Z 136 “Laser Safety Standards” and ANSI Z 136.1 “Safe Use of Lasers”, published by the American National Standards Institute, and additional publications, such as the “Laser Safety Basics”, the “LIA Laser Safety Guide”, the “Guide for the Selection of Laser Eye Protection” and the “Laser Safety Bulletin”, published by the Laser Institute of America, as well as the “Guide of Control of Laser Hazards” by ACGIH.

Necessary safety measures

⚠ DANGER

Serious eye or skin injury due to laser radiation

During the measurement the laser beam is guided on the device, which causes scattered or directed reflection of the laser beam (laser class 4).

The LaserQualityMonitor LQM cannot be operated in any of the available configurations without taking the following precautions. All precautions must be taken, even when the fiber is in the collimator or fiber adapter.

▶ **Please take the following precautions.**

If people are present within the danger zone of visible or invisible laser radiation, for example near laser systems that are only partly covered, open beam guidance systems, or laser processing areas, the following safety measures must be implemented:

- Connect the device’s safety circuit (interlock) to the laser control. Check that the safety circuit (interlock) will switch off the laser properly in case of error.
- Please wear **safety goggles** adapted to the power, power density, laser wave length and operating mode of the laser beam source in use.
- Depending on the laser source, it may be necessary to wear suitable **protective clothing** or **protective gloves**.
- Protect yourself from direct laser radiation, scattered radiation, and beams generated from laser radiation (by using appropriate shielding walls, for example, or by weakening the radiation to a harmless level).
- Use beam guidance or beam absorber elements that do not emit any hazardous substances when they come in to contact with laser radiation and that can withstand the beam sufficiently.
- Install safety switches and/or emergency safety mechanisms that enable immediate closure of the laser shutter.

- Ensure that the device is mounted securely to prevent any movement of the device relative to the beam axis and thus reduce the risk of scattered radiation. This in the only way to ensure optimum performance during the measurement.

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 must not be modified, neither constructionally nor safety-related, without our explicit permission. The device must not be opened e.g. to carry out unauthorized repairs. Modifications of any kind will result in the exclusion of our liability for resulting damages.

Liability disclaimer

The manufacturer and the distributor of the measuring devices do not claim liability for damages or injuries of any kind resulting from an improper use or handling of the devices or the associated software. Neither the manufacturer nor the distributor can be held liable by the buyer or the user for damages to people, material or financial losses due to a direct or indirect use of the measuring devices.

2 Symbol explanations

The following symbols and signal words indicate possible residual risks:

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.

The following symbols indicating requirements and possible dangers are used on the device:

Components susceptible to ESD

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

Further symbols that are not safety-related:

Here you can find useful information and helpful tips.

CE With the CE designation, the manufacturer guarantees that its product meets the requirements of the relevant EC guidelines.

▶ Call for action

3 About this operating manual

This documentation describes how to work with the LaserQualityMonitor LQM and operate it with the Laser-DiagnosticsSoftware LDS.
The software description includes a brief introduction on using the device for measurements.

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. Correct functioning of the device is, however, still guaranteed with the software.

Should you have any questions, please specify the software version installed on your device. The software version can be found under the following menu item: ***Help > About LaserDiagnosticsSoftware***.

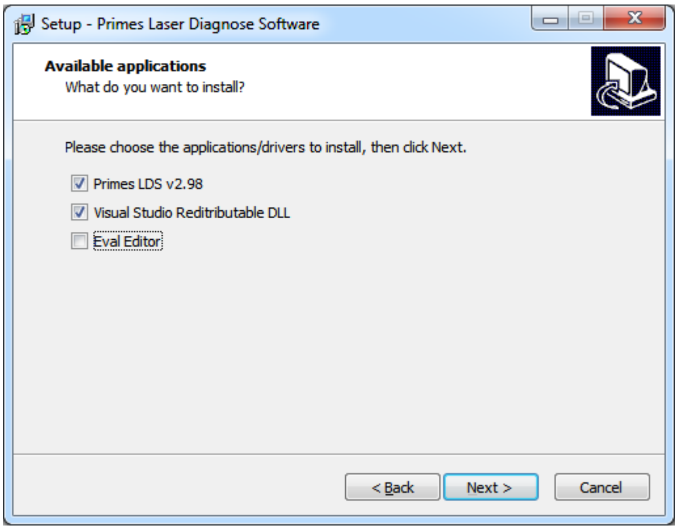


Fig. 3.1: Information regarding the current software version

4 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.

5 Introduction

5.1 Laser beam measurement

Laser beams in industrial applications, whether they be CO_2, Nd:YAG- diode or fibre lasers, work with invisible beams in the infra-red or near infra-red spectral range (NIR). Hence changes in beam quality or power cannot be detected visually, and only become evident from the outcome of their application. Under some circumstances, this results in very expensive rejects being produced.
If the deterioration in quality is not recognised in the manufacturing process, this usually results in the subsequent failure of the product in use, with consequences for the manufacturer of rectification, replacement and loss of image.

This is where PRIMES beam diagnostics devices for measuring beam quality, focusability and laser power come in. Process monitoring in production with laser beam diagnostics devices by PRIMES enables consistent quality assurance and allows the timely detection and elimination of malfunctions of laser beams.

PRIMES measuring devices allow the reliable recording of current beam parameters, and enable ongoing documentation of beam properties for quality assurance purposes. This is a requirement that should not be underestimated in many industrial areas, such as automotive or medical technology.

With PRIMES devices for beam diagnostics, troubleshooting of laser applications is simplified considerably. The beam intensity profile, beam diameter, beam caustic before and after focusing, and laser power to be applied are directly measured and analysed. Based on the readings and their evaluation, maintenance and servicing personnel can work in a targeted way on repair. Loss of time and system downtimes due to “trying out” possible causes of the problem are effectively avoided.

The same applies to process optimisation and approval of process windows in laser material processing. Only if the focal position and focal dimension and also the intensity profile of the laser beam are known, can processes such as laser beam cutting, welding or drilling be adjusted to the particular component geometry, materials be selected and the breadth of process windows be determined reliably.

5.2 System description

The LaserQualityMonitor LQM is used to measure the beam properties of a beam source either by measuring the open beam across several meters or with a fiber placed in a fiber holder or collimator.
Cw lasers can be measured and pulsed lasers can also be measured using an internal trigger.

The electronics and all optical components shown are installed in the basic device. The basic device can be supplemented by a front-end module with a beam splitter, an absorber and an alignment unit, which enables the use of the device even in the multikilowatt range. Fiber retainers, collimators, neutral-density filters as well as additional measuring objectives are available upon request.

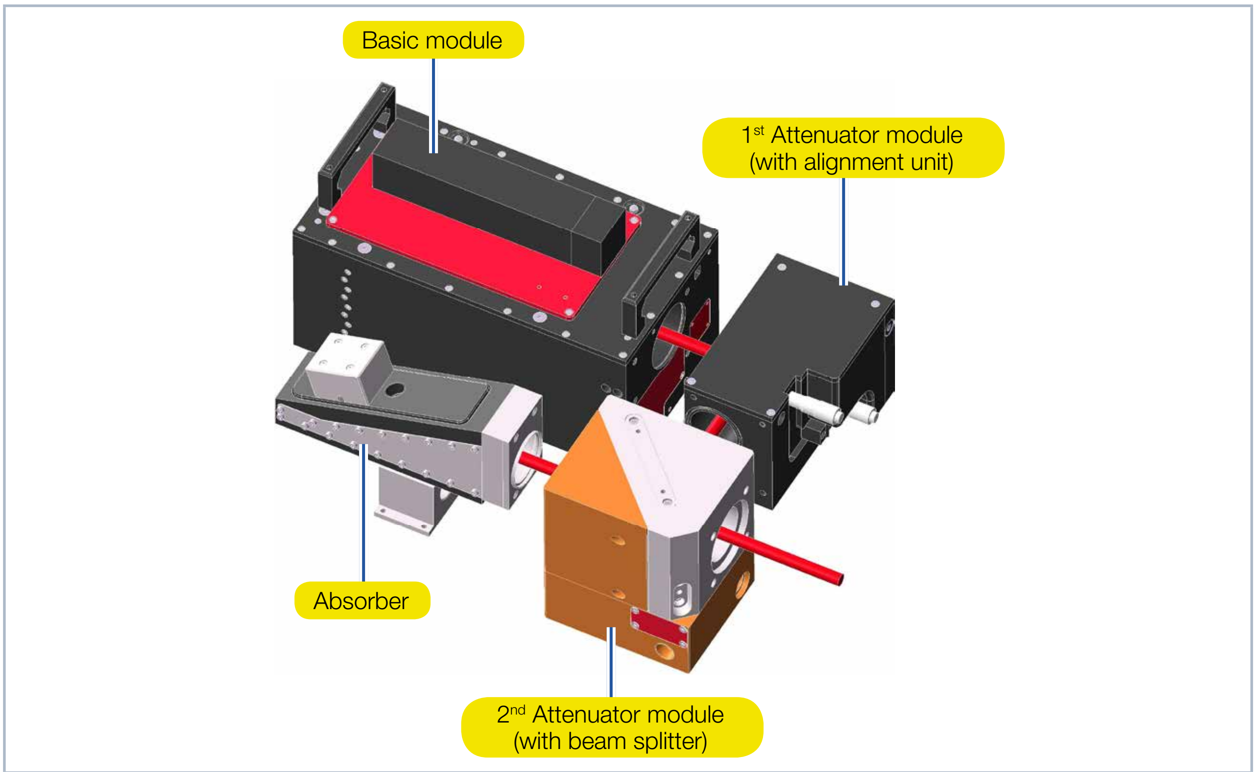


Fig. 5.1: Components using the example of LQM + HP

5.3 Measuring principle

Due to the very long measuring path of three to six Rayleigh lengths, a lot of measuring is needed to characterize a collimated laser beam. The LaserQualityMonitor LQM therefore generates a compact caustic inside the device by focusing the irradiated collimated laser beam with a focussing optic. In the process, the focused beam is weakened as it passes through an integrated absorber and OD filter and then appears on the CCD sensor, enlarged by a measuring objective.

The LaserDiagnosticsSoftware LDS software determines the radius, location, and orientation of the laser beam by moving the prisms inside the device and measuring the two-dimensional power density distribution repeatedly at various positions. The electronic integration time control of the CCD sensor expands the system's dynamic area. As a result of this, it generally isn't necessary to adjust the filter during a measurement.

The following laser sources can be measured:

- All cw and pulsed laser sources in the wave length area of 340-360 nm/515-545 nm/1030-1090 nm with medium power from approx. 1 mW up to multikilowatt ranges with an M² ranging from 1 to approx. 50.
- The beam diameter at the aperture of the measuring system can vary in the range of 1.5 mm to 15 mm, with divergence below 10 mrad.

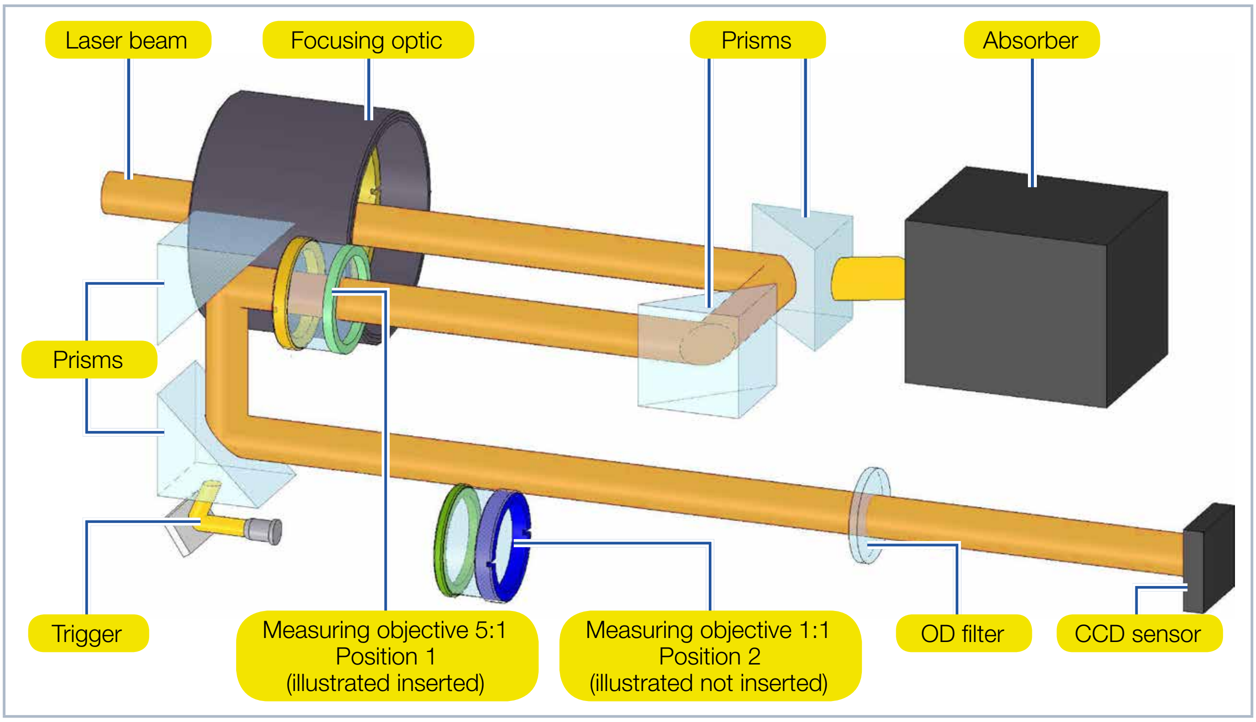


Fig. 5.2: Optical assembly of the LQM basic module

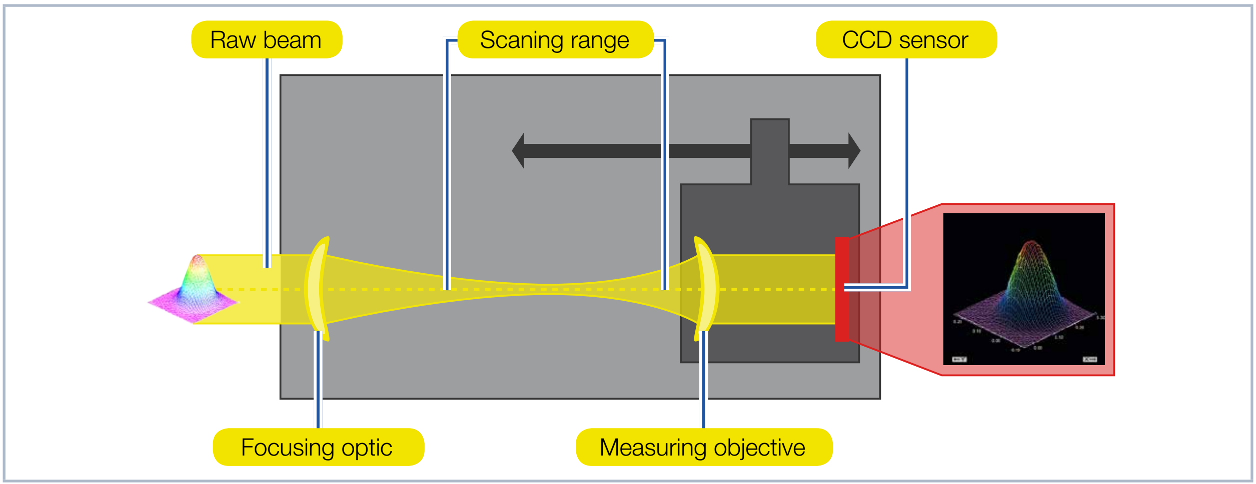


Fig. 5.3: Measuring principle

5.4 Short overview installation

1. Taking safety precautions	Chapter 1 on page 9
2. Prepare installation (only during open beam measurement) • Make preparations • Set the installation position • Align the device manually	Chapter 7 on page 17
3. Installing the water-cooling (HP-LQM II and LQM 500 W water-cooled version only) • Connection diameter • Note the flow rate	Chapter 8 on page 24
4. Power supply • Connect power supply • Connect external safety switch (interlock)	Chapter 9 on page 27
5. Connect with the computer • Via Ethernet or LAN	Chapter 9.4 on page 31
6. Install the LaserDiagnosticsSoftware LDS on the computer • The Software is part of the scope of delivery • Connect the LaserQualityMonitor LQM with the LaserDiagnosticsSoftware LDS	Chapter 11 on page 33
7. Complete installation (open beam measurement only) • Align the device with the LaserDiagnosticsSoftware LDS according to chapter 13.3 „Align the laser beam with the LaserDiagnosticsSoftware LDS“ on page 94 • Mount the device firmly in accordance with chapter 7 on page 17	Chapter 13.3 on page 94
8. Measure • Follow the safety instructions • Select and use the measuring objective and neutral-density filter • Check the device's alignment with the LaserDiagnosticsSoftware LDS • Perform a test measurement	Chapter 13.5 on page 98

6 Transport

WARNING

Risk of injury when lifting or dropping the device

Lifting and positioning heavy devices can, for example, stress intervertebral disks and cause chronic changes to the lumbar or cervical spine. The device may fall.

- ▶ **Use a lifting device to lift and position the device.**

CAUTION

Damaging/destroying the device

Optical components may be damaged if the device is subjected to hard shocks or is allowed to fall.

- ▶ **Handle the measuring device carefully when transporting or installing it.**
- ▶ **To avoid contamination, cover the apertures with the provided lid or optical tape.**
- ▶ **Only transport the device in the original PRIMES transport box.**

CAUTION

Damage/destruction of the device caused by leaking or freezing cooling water

Leaking cooling water can damage the device. Transporting the device at temperatures near or below freezing and without emptying the cooling circuit completely can damage the device.

- ▶ **Empty the lines of the cooling circuit completely.**
- ▶ **To empty the cooling circuit, the HP-LQM II/LQM 500 W can be flushed out with clean, dry compressed air.
The optional PowerLossMonitor PLM cannot be flushed with compressed air.**
- ▶ **Even when the lines of the cooling circuit have been emptied, a small amount of residual water will remain in the device at all times. This may leak out and end up inside the device. Close the connector plug of the cooling circuit with the included sealing plug.**

7 Installation

7.1 Preparation and mounting position

Check the space available before mounting the device, especially the required space for the connection cables. The device must be set up so that it is stable and fastened with screws (see chapter 7.3 on page 21).

The LaserQualityMonitor LQM can be mounted and operated in any position. During open beam measurement, the LaserQualityMonitor LQM must be aligned with the laser beam. The steps taken for installation can be found in chapter 5.4 on page 16.

7.2 Manually aligning the LaserQualityMonitor LQM

For an open beam measurement, the LaserQualityMonitor LQM must be aligned with the laser beam:

1. Align the LaserQualityMonitor LQM manually with a pilot laser and the alignment tool.
- The LaserQualityMonitor LQM is properly aligned when the pilot beam is centered through the holes in the alignment tool.
2. Check the alignment as specified in chapter 13.3 on page 94 with the alignment mode of the LaserDiagnosticsSoftware LDS.

7.2.1 Alignment tools

Depending on the LaserQualityMonitor LQM version, there are several alignment tools with different aperture diameters.

Aperture diameter in mm	LQM Version	Order No.
40	1st Attenuator • 200 W Air Cooling • 500 W Water Cooling	850-006-005
45	2nd Attenuator (HP Water Cooling)	850-006-006
54	Basic Module	850-006-001

Tab. 7.1: Alignment tools for different aperture diameters

The inlet aperture must be aligned centrally and at a right angle to the laser beam. Alignment tools for the various LQM versions help with alignment.

Fig. 7.1: Alignment tools for aligning the LQM versions with various apertures

7.2.2 Manual alignment of the basic device

In order to align the laser beam with the basic device, the alignment tool is mounted with a mounting plate and two knurled screws included in the scope of delivery (see Fig. 7.2 on page 19).

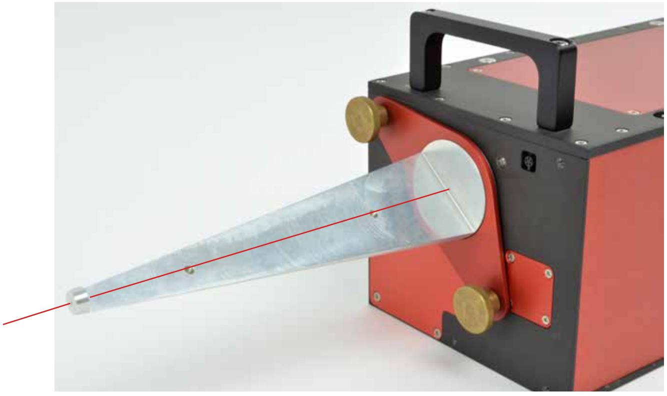


Fig. 7.2: Alignment tool mounted on the basic device

7.2.3 Manual alignment of the 1st attenuator module and fine adjustment

To align the laser beam with the 1st attenuator module, the alignment tool is mounted with a mounting plate and two knurled screws included in the scope of delivery (see Fig. 7.3 on page 19).

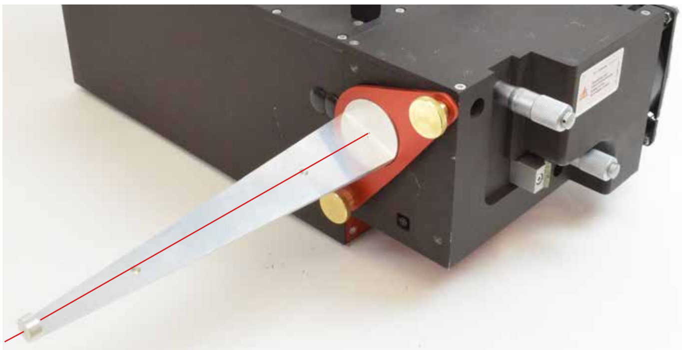


Fig. 7.3: Mounted alignment tool on the 1st attenuator module

With the 1st attenuator module, the angle of incidence of the laser beam can be corrected ± 3° by fine tuning the angle with two integrated micrometer screws (see Fig. 7.4 on page 19).

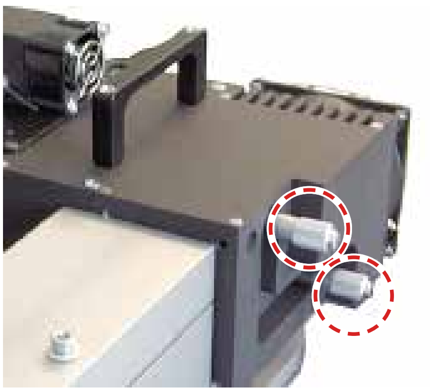


Fig. 7.4: Micrometer screws on the 1st attenuator module for fine adjustment

7.2.4 Manual alignment of the 2nd attenuator module

To align the laser beam with the 2nd attenuator module, the alignment tool is mounted with a mounting plate and two knurled screws included in the scope of delivery (see Fig. 7.5 on page 20).

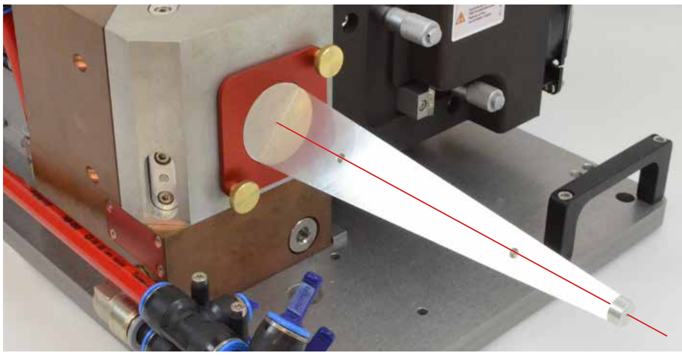


Fig. 7.5: Mounted alignment tool on the 2nd attenuator module

7.3 Install the LaserQualityMonitor LQM

DANGER

Serious eye or skin injury due to laser radiation

If the device is moved from its calibrated position, increased reflected radiation (laser class 4) may result during measuring operation.

- **When mounting the device, please ensure that it cannot be moved, neither due to an unintended push or a pull on the cables and hoses.**

7.3.1 Install the LQM 20/200 without bottom plate

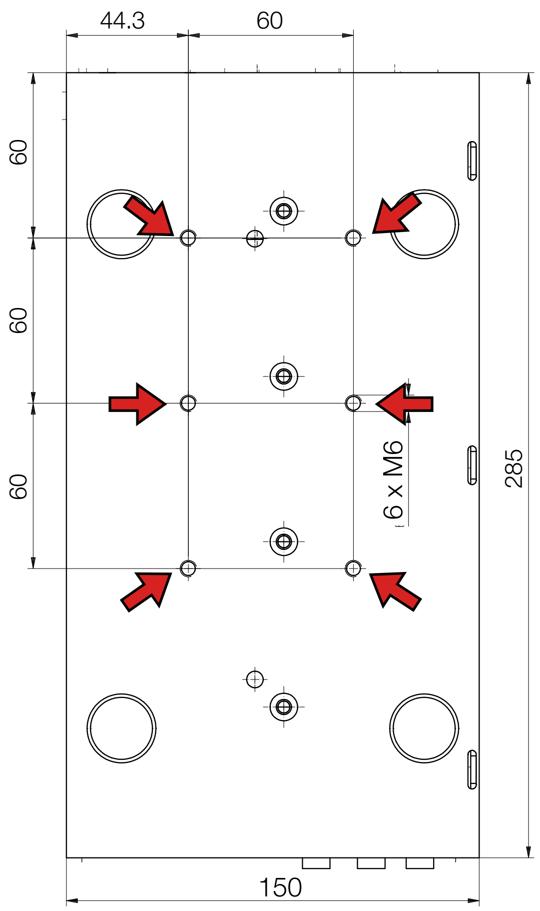


Fig. 7.6: Fastening threaded holes LQM 20/200 without bottom plate

There are six M6 mounting threads on the underside of the device for fastening it onto a holder provided by the customer. We recommend screws of the strength class 8.8.

➡ 6 threaded holes M6

7.3.2 Install the LQM 200/500 with bottom plate

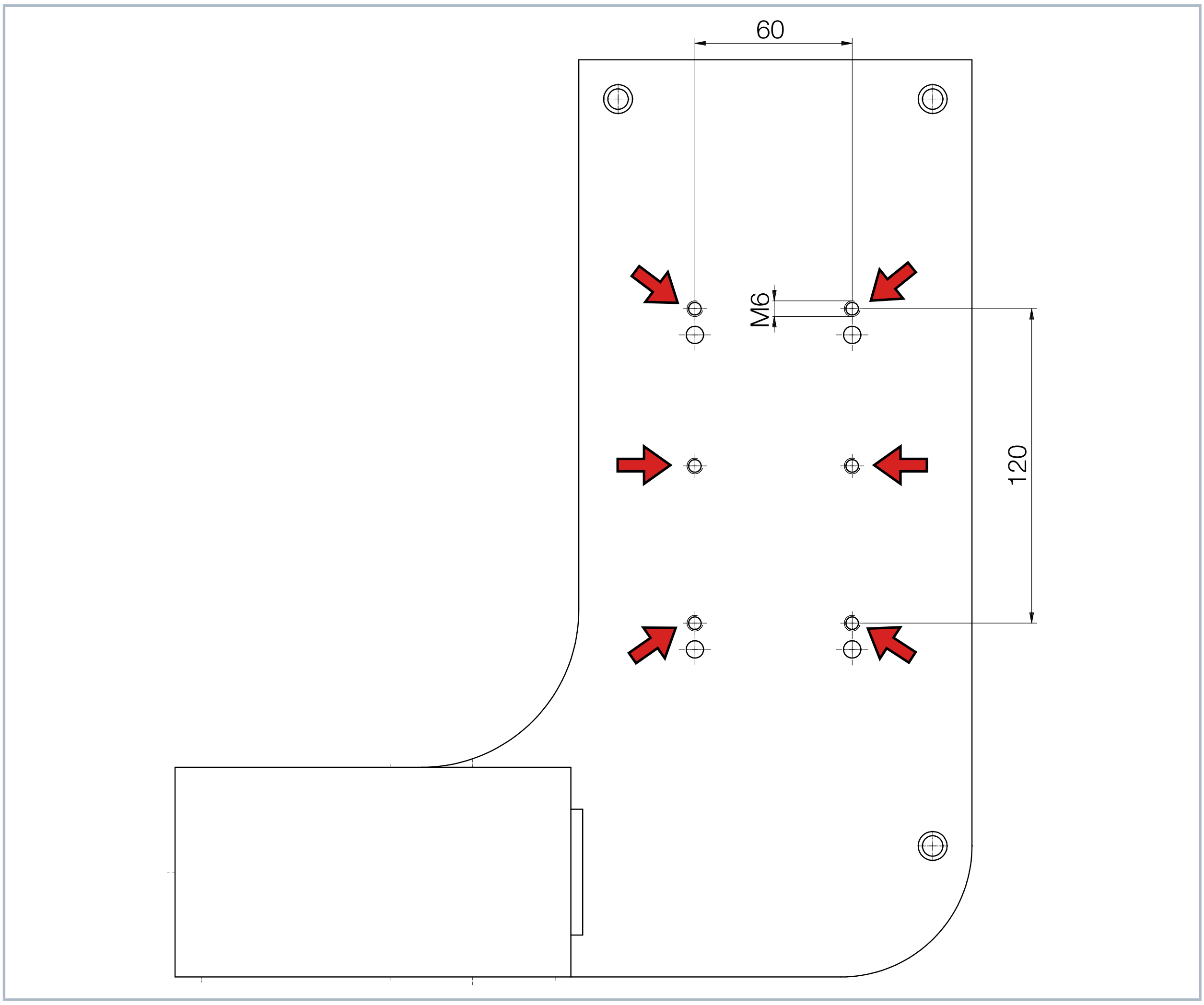


Fig. 7.7: Fastening threaded holes LQM 200/500 with bottom plate

For the connection of a customer specific part, there are six threads M6 in the bottom plate. We recommend screws of the strength class 8.8.

➔ 6 threaded holes M6

7.3.3 Install the HP-LQM II with bottom plate

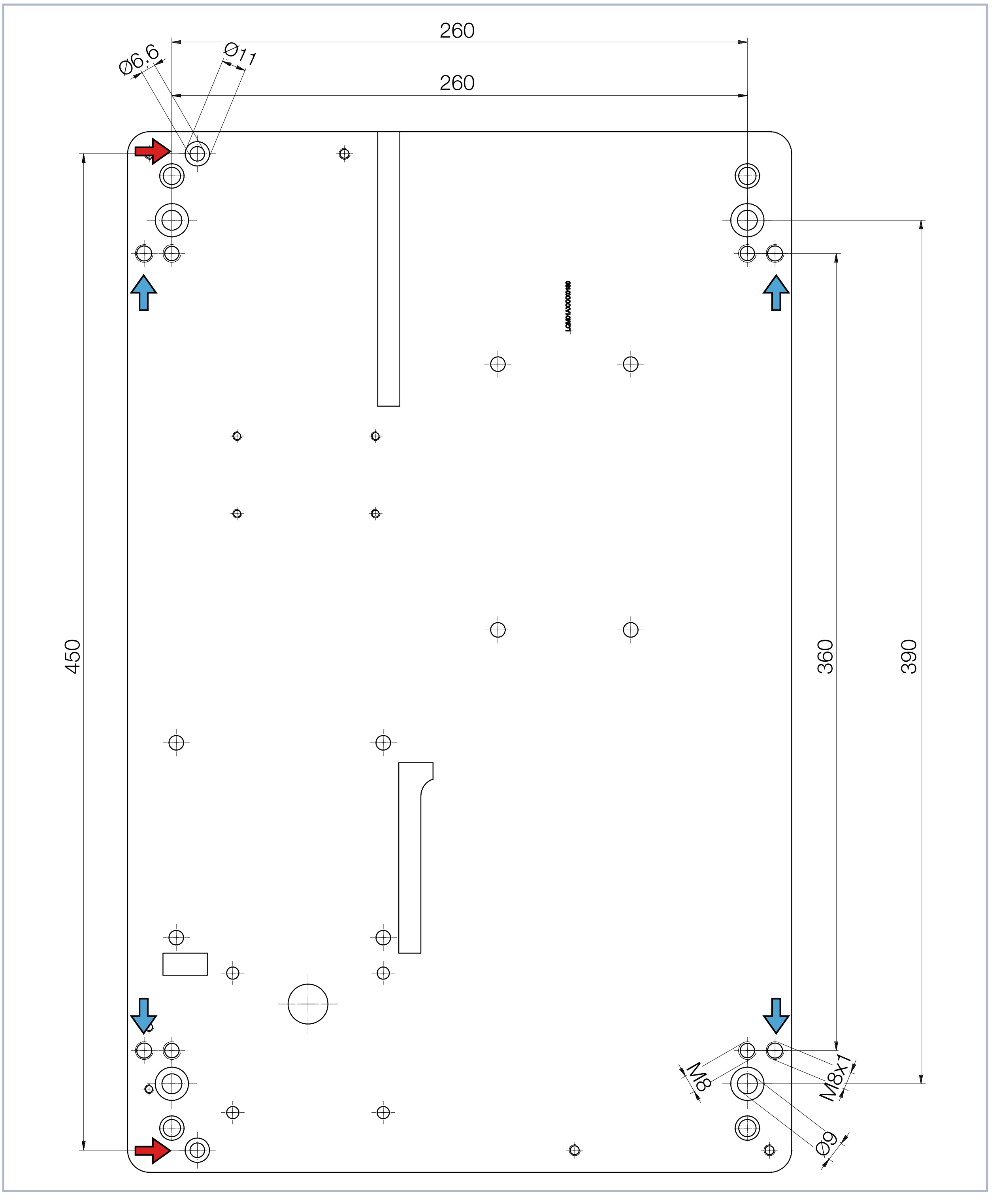


Fig. 7.8: Fastening bores and alignment threads HP-LQM II with bottom plate

2 mounting holes Ø 6.6 mm

4 threaded holes M8 for the alignment

8 Connect cooling circuit (HP-LQM II and 500 W water cooled version only)

DANGER

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

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

▶ **Do not operate the device without a connected water cooling. Ensure a sufficient water flow rate.**

8.1 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. This could lead to corrosion of the aluminium due to the different chemical potentials.

▶ **Do not connect the device with a cooling circuit made of aluminium.**

- The device can be operated with tap water as well as demineralized water.
- Do not operate the device on a cooling circuit containing additives such as anti-freeze.
- 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 and replace them if necessary.
- Large dirt particles or teflon tape may block internal cooling circuits. Therefore, please thoroughly rinse the system before connecting it.

8.2 Water pressure

Two bars of primary pressure applied at the absorber inlet during a pressureless procedure are normally sufficient to ensure the proper flow rate volume.

NOTICE

Damage/Destruction of the device due to overpressure

▶ **The maximum permissible water inlet pressure must not exceed 4 bar.**

8.3 Humidity

- The device must not be operated in a condensing atmosphere. The humidity has to be considered in order to prevent condensates within and outside the device.
- The temperature of the cooling water must not be lower than the dew point (see Tab. 8.1 on page 25).

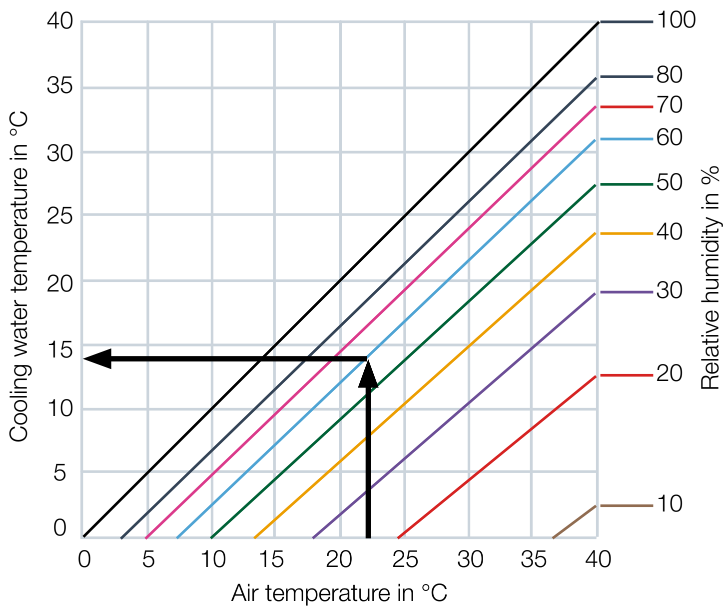
NOTICE

Damage/Destruction of the device due to condensing water

Condensation water inside of the objective will lead to damage.

▶ **Mind the dew-point in Tab. 8.1 on page 25.**

Do 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. 8.1: Dew point diagram

Example

Air Temperature: 22 °C
Relative Humidity: 60 %

The cooling water temperature cannot fall below 14 °C.

8.4 Water connections and water flow rate

8.4.1 HP-LQM II (10 kW)

HP-LQM II (10 kW)		
Connection diameter	**Recommended flow rate**	**Minimum flow rate**
PE hoses 12 mm	7 l/min – 8 l/min (1l/(min · kW)	Not lower than 4.5 l/min

8.4.2 LQM (500 W)

LQM II (500 W)	
Connection diameter	**Recommended flow rate**
PE hoses 8 mm	1,5 l/min (1l/(min · kW)

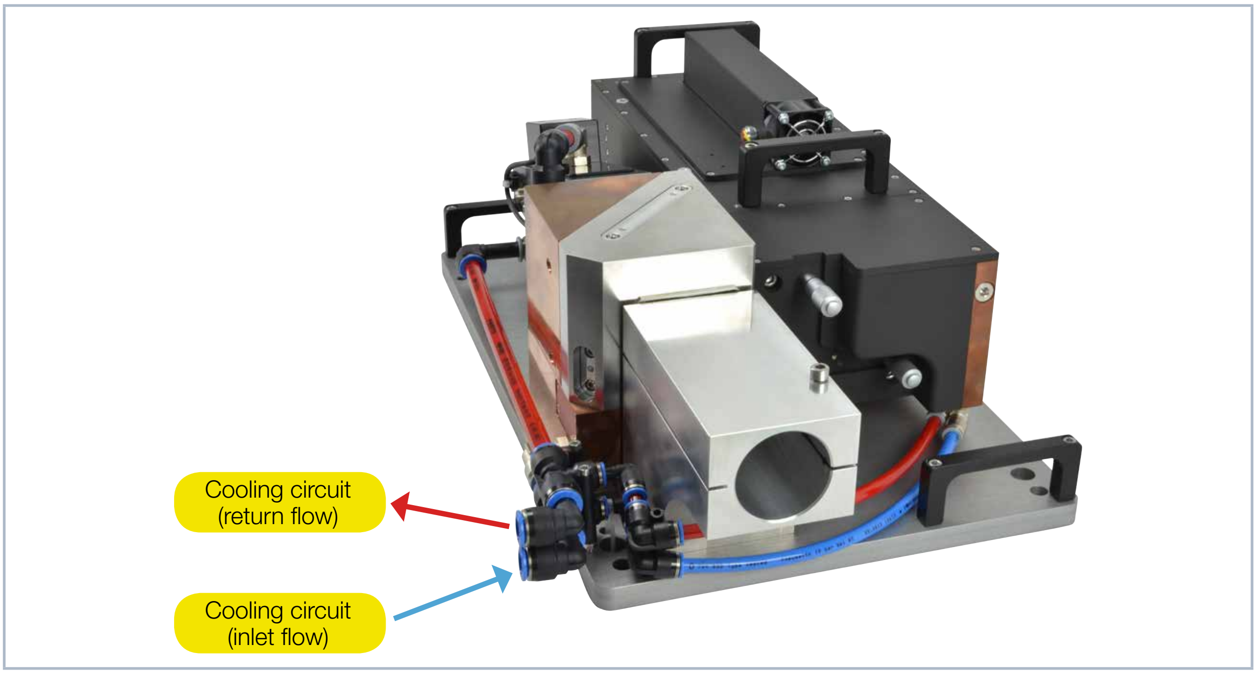
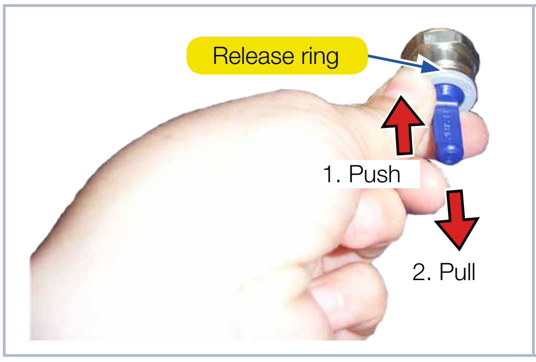


Fig. 8.1: Water connections of the HP-LQM II



1. Please push down the release ring of the connection and pull out the plug with your free hand.
2. Remove the 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. 8.2: Remove the sealing plugs of the water connections

9 Electrical connections

The LaserQualityMonitor LQM requires a supply voltage of 24 V ±5 % (DC) for the operation. A suitable power supply with an adapter is included in the scope of delivery. Please use only the provided connection lines.

Please ensure that all electrical connections have been established and switch the device on before starting the LaserDiagnosticsSoftware LDS.
The LaserQualityMonitor LQM serves as a dongle for the software on the computer in order to enable certain software functions.

9.1 Connections

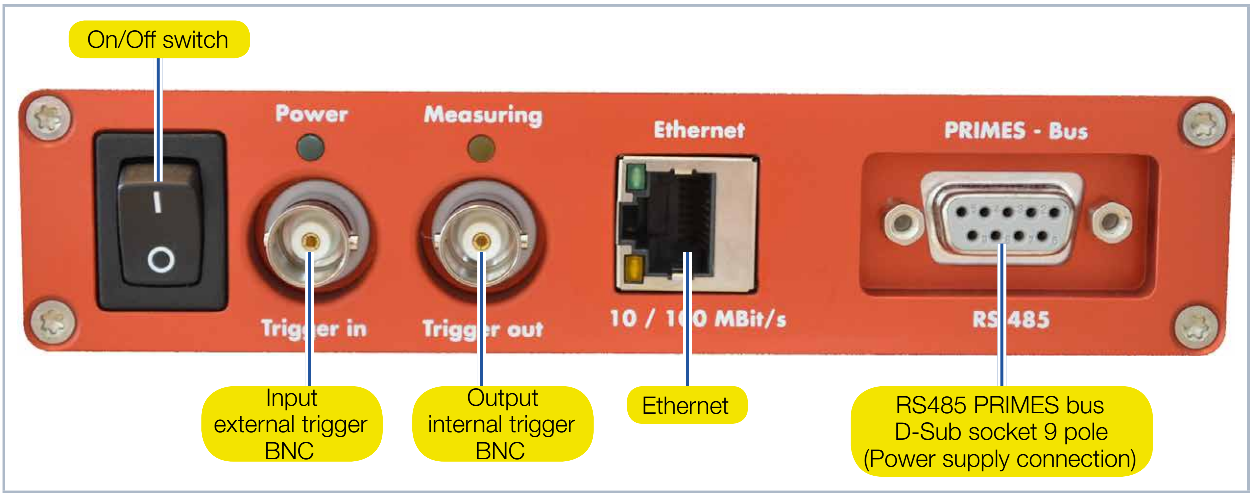
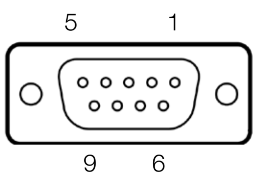


Fig. 9.1: Connections

9.2 Pin assignment

9.2.1 Power supply

D-Sub socket, 9-pin (view: connector side)		
	Pin	Function
	1	GND
	2	RS485 (+)
	3	+24 V
	4	Trigger RS485 (+)
	5	Not assigned
	6	GND
	7	RS485 (–)
	8	+24 V
	9	Trigger RS485 (–)

Tab. 9.1: D-Sub socket RS485

9.2.2 Inlet external trigger

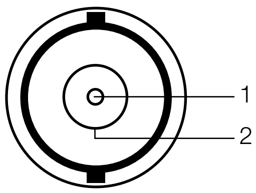
BNC connector (view: connector side)		
	Pin	Function
	1	+5 V (Trigger signal)
	2	GND

Fig. 9.2: Connection socket inlet for an external trigger in the connection panel

9.2.3 Outlet internal trigger

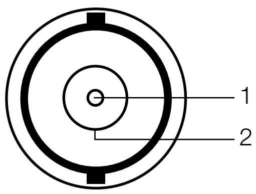
BNC connector (view: connector side)		
	Pin	Function
	1	+5 V (Trigger signal)
	2	GND

Fig. 9.3: Connection socket outlet for the internal trigger in the connection panel

9.3 Safety facilities

9.3.1 Temperature control

The 1st and 2nd attenuator module as well as the absorber and basic device each have a temperature switch. If the temperature exceeds 75 °C in one of these components, the LaserQualityMonitor LQM detects it and a warning message is issued in the LaserDiagnosticsSoftware LDS.

NOTICE

Damage/Destruction of the device

Due to the temperature control, an overtemperature of the device is indicated in the LaserDiagnosticsSoftware LDS, but the device is not protected against thermal damage.

- ▶ **Turn the laser off immediately upon receiving notification of excess temperature in the LaserDiagnosticsSoftware LDS.**
- ▶ **For this reason, the LaserQualityMonitor LQM should never be left unattended while taking measurements.**

9.3.2 External safety circuit (HP-LQM II with 2nd attenuator only)

An external safety switch (laser interlock) is integrated into the HP-LQM II with 2nd attenuator module. This switch must be connected to the laser safety circuit so that it can turn off the laser in case of error.

NOTICE

Damage/Destruction of the device

If the safety circuit is not connected, the device may be damaged by overheating in the event of a fault.

- ▶ **Connect the laser control to terminals 1 to 4 so that the laser shuts off when these connection is interrupted.**

Pin assignment (view: plug side)

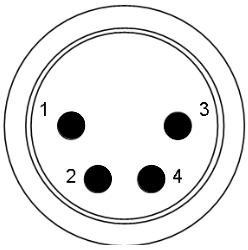


Fig. 9.4: Safety circuit device plug on the 2nd attenuator

Pin	Function
1	Interlock (potential free). Connected with pin 3 when ready for operation.
2	Connection Monitoring
3	Interlock (potential free). Connected with pin 1 when ready for operation.
4	Connection Monitoring

Tab. 9.2: Safety circuit device plug

When connecting the laser control with pin 1 and pin 3, it has to be ensured that the laser is turned off when this connection is interrupted.

To be able to identify a connected safety circuit, pin 2 and pin 4 have to be bridged in the cable socket. If the socket is not connected and the external safety circuit is thus not active, a warning message in the LaserDiagnosticsSoftware LDS is issued. A suitable 4-pole cable socket is part of the scope of delivery.

9.4 Connection to the PC and connect power supply

NOTICE

Damage/Destruction of the device

When the electrical cables are disconnected during operation (when the power supply is applied), voltage peaks occur which can destroy the communication components of the measuring device.

▶ **Please turn off the PRIMES power supply before disconnecting the cables.**

1. Connect the device with the PC via a crossover cable or with the network via a patch cable.
2. Use the adapter to connect the power supply to the 9-pin D-sub socket (RS485) of the device.

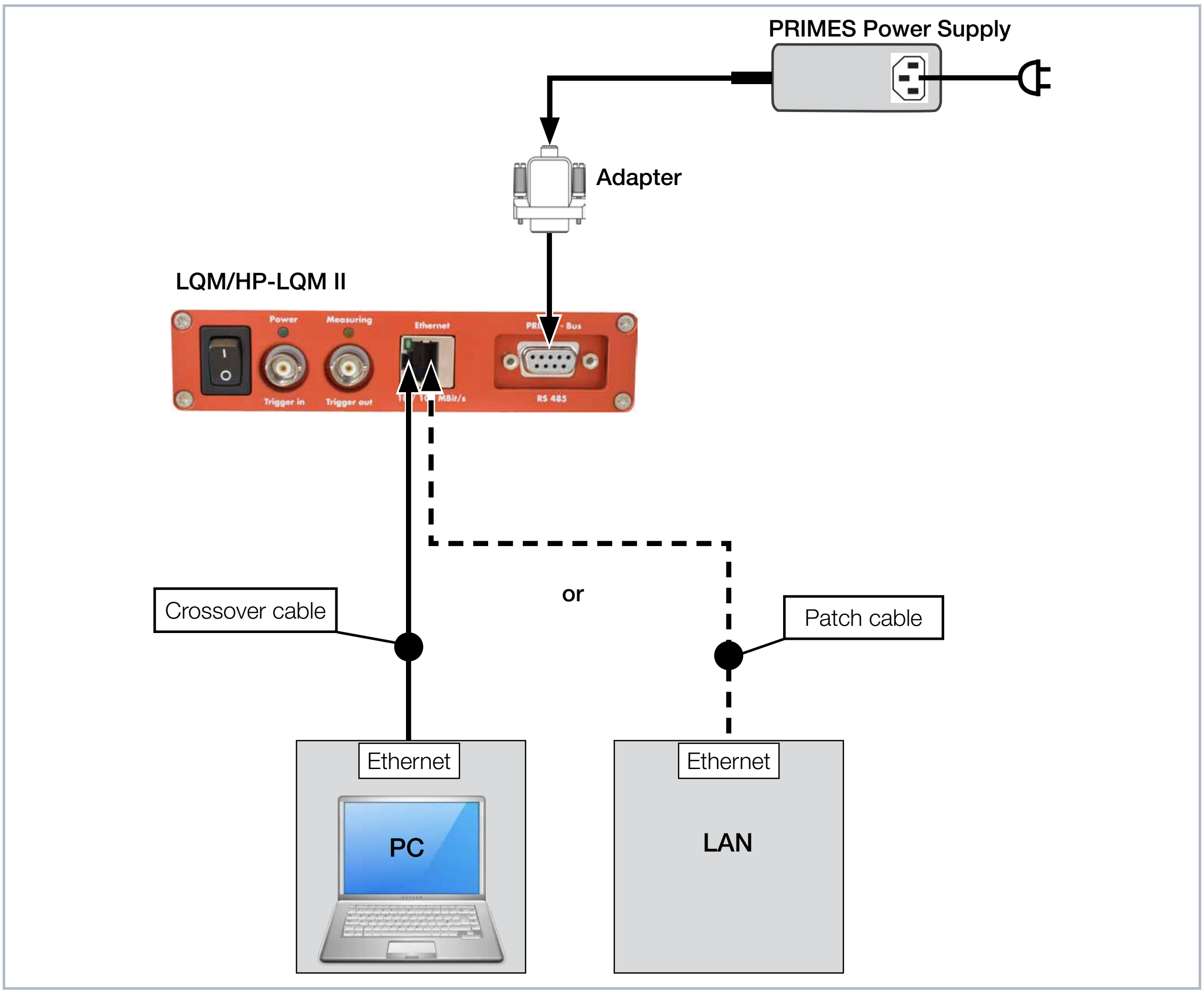


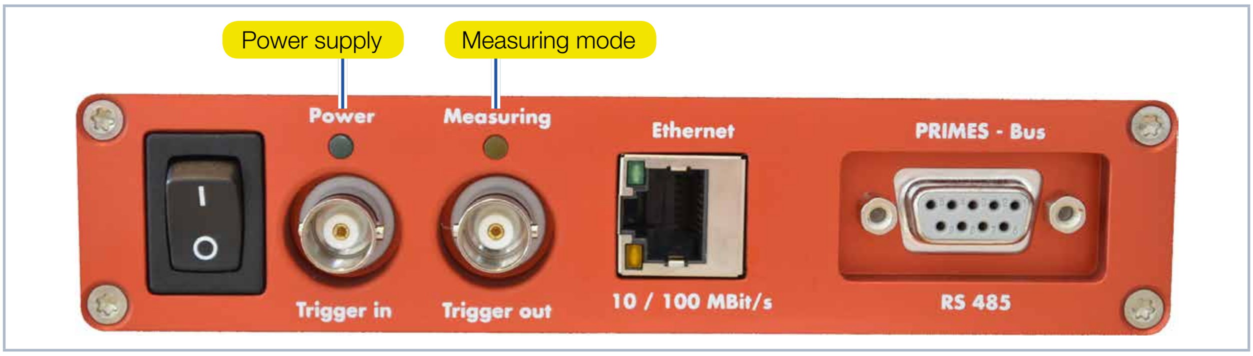
Fig. 9.5: Connection via Ethernet with a PC or a local network

10 Status LEDs

The device has two status LEDs.

Description	Color	Meaning
Power	green	The power supply is switched on
Measuring	yellow	A measurement is running

Tab. 10.1: Description of the status LEDs on the LaserQualityMonitor LQM



Tab. 10.2: Status LEDs on the LaserQualityMonitor LQM

11 Installation and configuration of the LaserDiagnosticsSoftware LDS

In order to operate the measuring device, the PRIMES LaserDiagnosticsSoftware LDS has to be installed on the computer. The program can be found on the enclosed medium.
You will find the latest version on the PRIMES website at: https://www.primes.de/en/support/downloads/software.html.

11.1 System requirements

Operating system:	Windows® XP/Vista/7/10
Processor:	Intel® Pentium® 1 GHz (or comparable processor)
Free disc space:	15 MB
Monitor:	19“ screen diagonal is recommended, resolution at least 1024x768
LDS-Version:	2.98 or higher

11.2 Installing the software

The installation of the software is menu driven and is effected by means of the enclosed medium. Please start the installation by double-clicking the file “Setup LDS v.X.X.exe” (X = placeholder for version number) and follow the instructions.

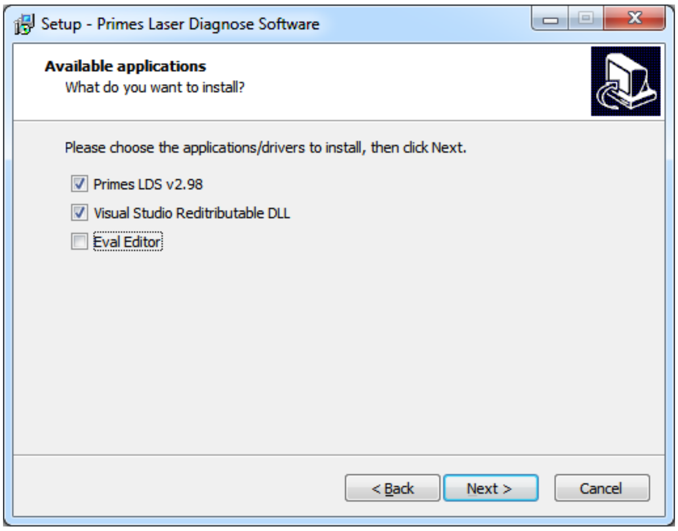


Fig. 11.1: Setup of the PRIMES LaserDiagnosticsSoftware LDS

If not stipulated differently, the installation software stores the main program “LaserDiagnosticsSoftware.exe” in the directory “Programs/PRIMES/LDS”. Moreover, the settings file “laserds.ini” is also copied into this directory. In the file “laserds.ini” the setting parameters for the PRIMES measuring devices are stored.

11.3 Ethernet configuration

11.3.1 Enter IP address

The LaserQualityMonitor LQM has a fixed IP address that is specified on the type plate:

- If the LaserQualityMonitor LQM is connected directly to the PC, enter the fixed IP address in the menu ***Communication > Free Communication*** (see chapter 11.3.2 on page 35).
- If the LaserQualityMonitor LQM is connected over a network, the LaserQualityMonitor LQM will spend about one minute pulling up a variable IP address in the network.
  You can read off this variable IP address with the provided software, “PrimesFindIp” and enter it into the ***Communication*** > ***Free Communication*** (see chapter 11.3.2 on page 35).
- If you want to connect the LaserQualityMonitor LQM to the network using the fixed IP address, first turn on the LaserQualityMonitor LQM and then connect the network cable to the LaserQualityMonitor LQM. Then enter the fixed IP address in the menu ***Communication*** > ***Free Communication*** (see chapter 11.3.2 on page 35).

The standard IP address of the LaserQualityMonitor LQM is:

IP Address: 192.168.116.84
Subnet mask: 255.255.255.0

The PC must also have an IP address in the same subnet, for example:

IP Address: 192.168.116.XXX
Subnet mask: 255.255.255.0

The first three blocks of the IP address must match the IP of the LaserQualityMonitor LQM.

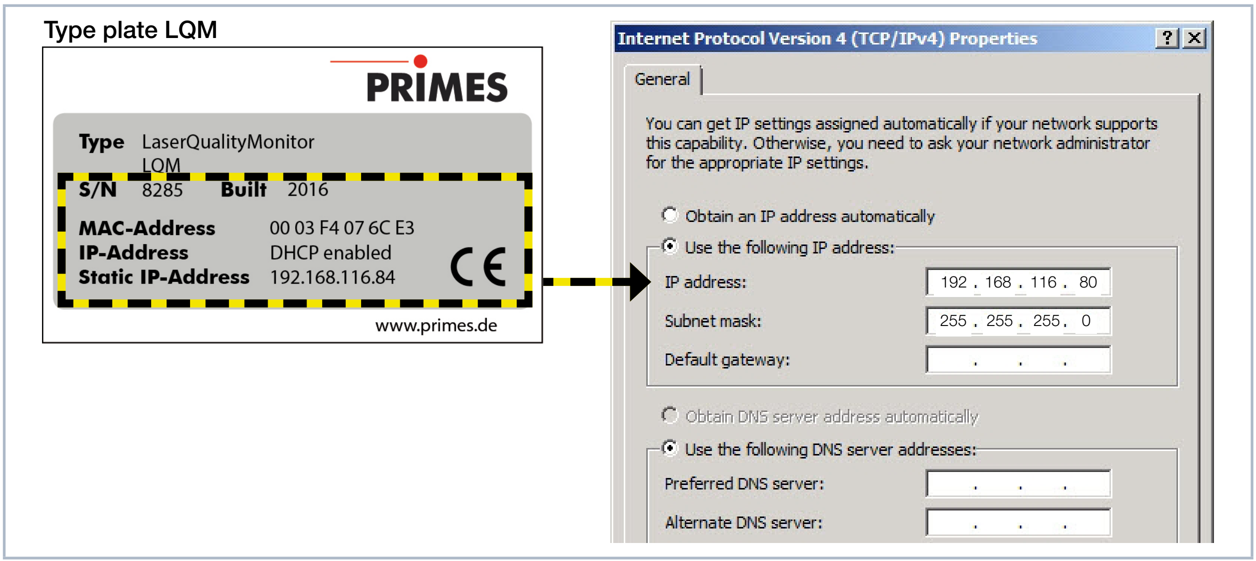


Fig. 11.2: Ethernet configuration in the dialogue window ***Ethernet***

11.3.2 Establishing a connection to PC (menu *Communication* > *Free Communication*)

1. Please start the LaserDiagnosticsSoftware LDS (see chapter 12 on page 38).
2. Open the dialogue window ***Communication > Free Communication***.
3. Choose in the field “Mode” ***TCP*** (the option “Second IP” must not be activated!).
4. Enter in the field “TCP” the IP Address.
5. Click on the ***Connect*** button (“connected” appears in the bus monitor).
6. Click on the ***Find Primes Devices*** button.
7. Click on the ***Safe Config*** button (the configuration is saved and does not need to be re-entered when starting the LaserDiagnosticsSoftware LDS again).

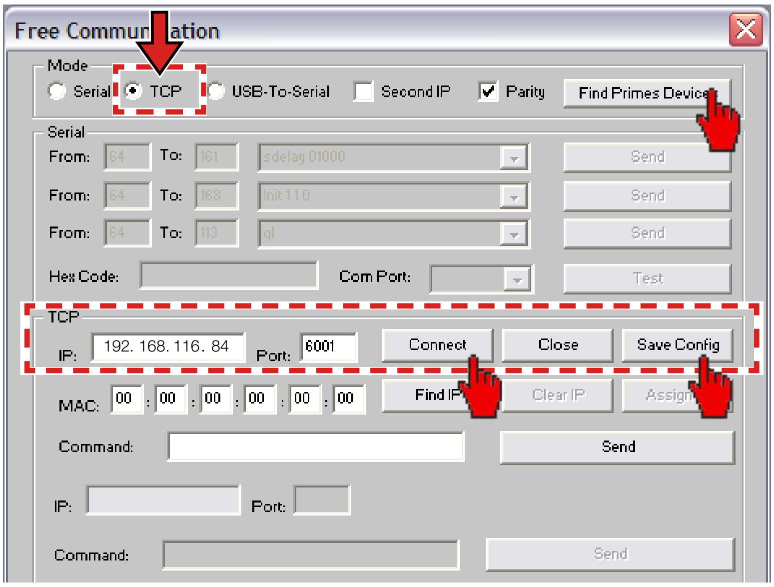


Fig. 11.3: Establishing a connection in the dialogue window ***Free Communication***

11.3.3 Changing the standard IP address of the device (menu *Communication* > *Free Communication*)

If the fixed IP address of the LaserQualityMonitor LQM conflicts with another device bearing the same IP address on the network, the fixed IP address of the LaserQualityMonitor LQM can be changed.

NOTICE

Device malfunction due to erroneous entries

While changing the IP address, it is possible that another EE cell might be overwritten by a mistype, for example, and the LQM could thus be rendered unusable.

- ▶ **Only very skilled users should attempt to change the IP address.**

You can change the preset IP address in the menu ***Communication*** **>** ***Free communication*** by means of the following commands:

IP-address (Sample address)	192.	168.	116.	85
	↑	↑	↑	↑
Commands	se0328✶xyz	se0329✶xyz	se0330✶xyz	se0331✶xyz

Tab. 11.1: Changing the IP address

In this case **xyz** are place holders of the four IP-address bytes (values 1 - 254) which always have to be entered with three digits!
For example, the number 84 has to be entered like this: 084.
For reasons of clarity the symbol ✶ marks a space.

Example: You will change the IP address from 192.168.116.**85** to 192.168.116.**86**.

1. Please start the LaserDiagnosticsSoftware LDS (see chapter 12 on page 38).
2. Open the dialogue window ***Communication > Free Communication***.
3. Choose in the field “Mode” ***TCP*** (the option “Second IP” must not be activated!).
4. Enter the current IP address in the “TCP” ***field***.
5. Click on the ***Connect*** button (“connected” appears in the bus monitor).
6. Activate the check box ***Write bus protocol*** (the protocol can be helpful in case of problems).
7. Enter the following in the field “Command”: **se0331✶086**
   (please make sure that the blank character ✶ is entered correctly):
8. Click on the ***Send*** button and wait for the confirmation in the bus monitor
   (see Fig. 11.4 on page 37 „-> Adr:0331 Wert: 086“)
9. Please turn off the device and turn it on again. After this restart the IP-address is updated.

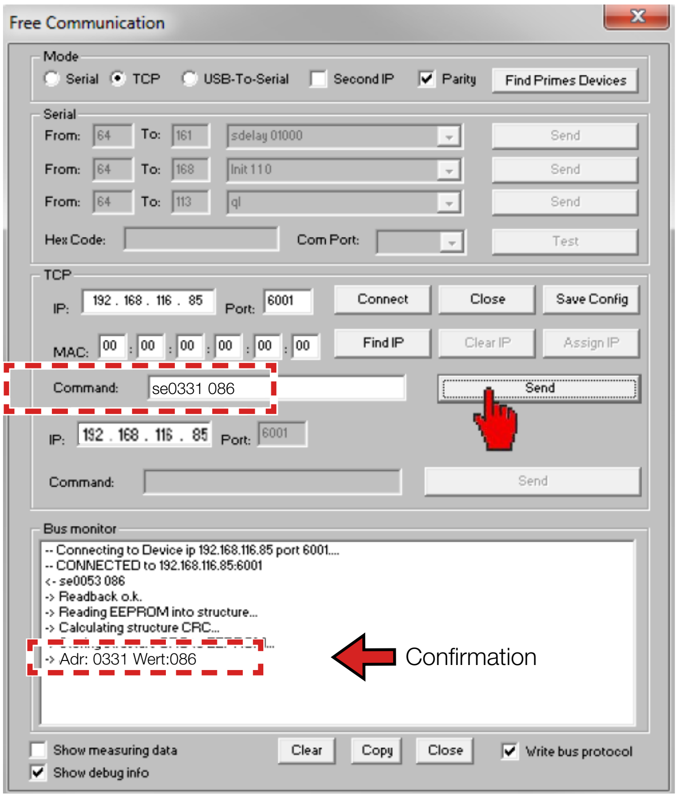


Fig. 11.4: Changing the IP address in the dialogue window ***Free Communication***

12 Description of the LaserDiagnosticsSoftware LDS

The LaserDiagnosticsSoftware LDS is the control centre for all PRIMES measuring devices which measures the beam distribution as well as focus geometries by means of which the beam propagation characteristics can be determined.
The LaserDiagnosticsSoftware LDS includes all functions necessary for the control of measurements and displays the measuring results graphically.
Moreover, the systems uses the measured data to carry out an evaluation in order to give the operator of the beam diagnosis an information regarding the reliability of the measuring results.

Please do not start the LaserDiagnosticsSoftware LDS before all devices are connected and turned on.

Please start the program by double-clicking the PRIMES symbol in the new start menu group or the desktop link.

12.1 Graphical user interface

Firstly, a start window is opened in which you can choose, whether you would like to measure or whether you would just like to depict an existing measurement (factory setting “measurement”).

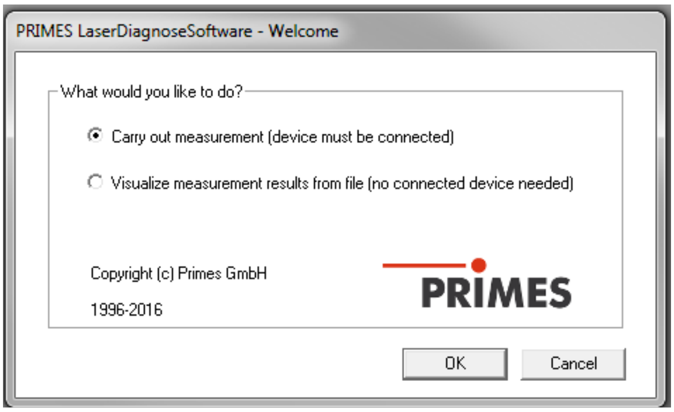


Fig. 12.1: Start window of the LaserDiagnosticsSoftware LDS

After the detection of the connected device, the graphical user interface and several important dialogue windows are opened.

In order to ensure that corresponding information can be assigned quickly, special markups for menu items, menu paths and texts of the user interface will be used in the following chapters.

Markup	Description
Text	Marks menu items. Example: Dialogue window ***Sensor parameters***
Text1 > Text2	Marks the navigation to certain menu items. The Order of the menus is depicted by means of the Sign “>” Example: ***Presentation > Caustic***
Text	Marks buttons, options and fields. Example: With the button ***Start***

Fig. 12.2: Special markups for menu items, menu paths and texts

The graphical user interface mainly consists of the menu as well as the toolbar by means of which different dialogue or display windows can be called up.

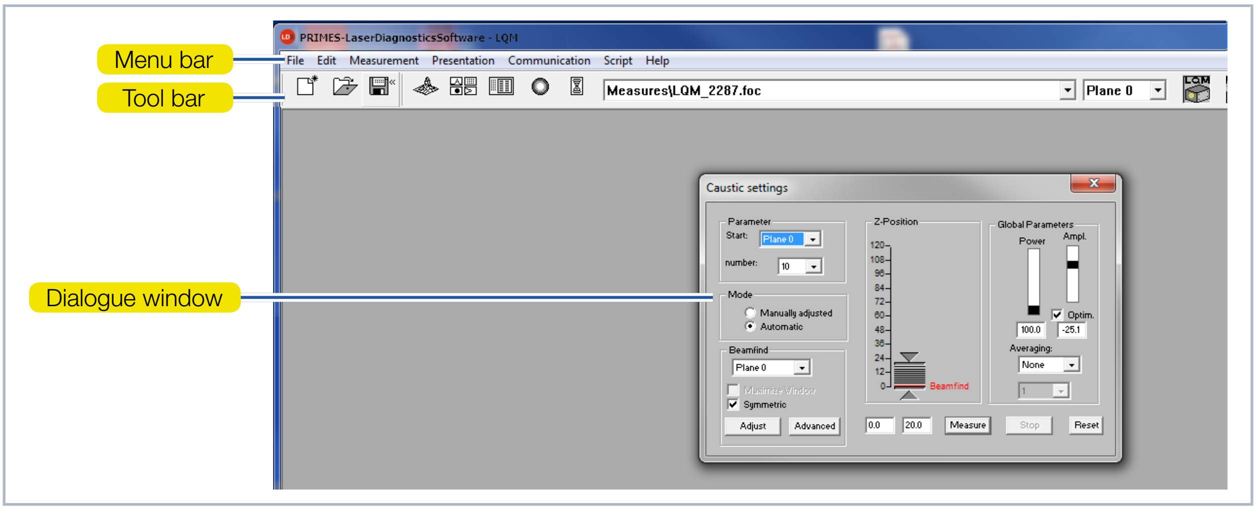


Fig. 12.3: The main elements of the user interface

It is possible to open several measuring and dialogue windows simultaneously. In this case, windows that are basically important (for the measurement or the communication) remain in the foreground. All other dialog windows fade into the background as soon as a new window opens.

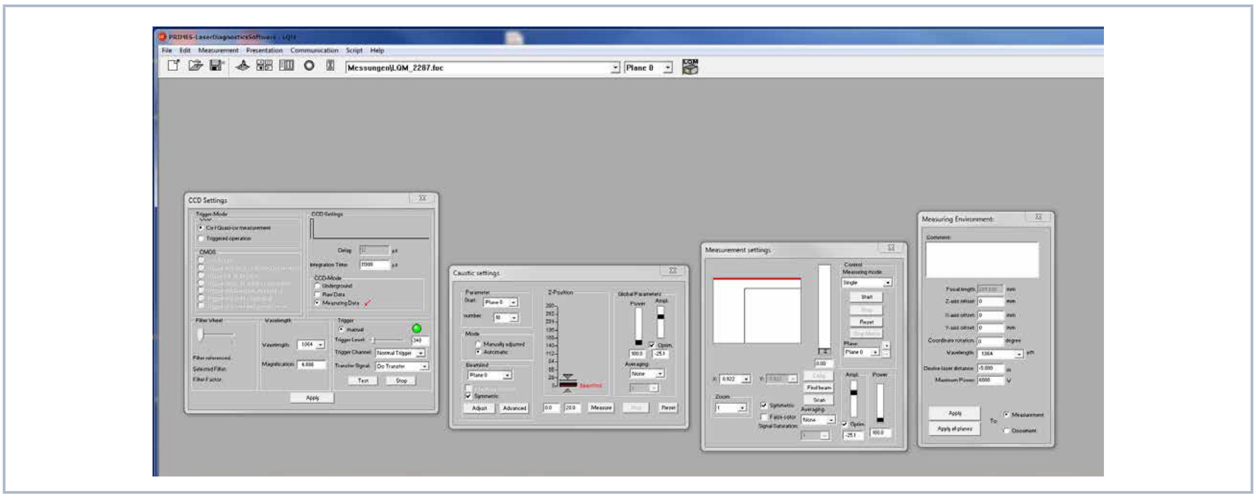


Fig. 12.4: The main dialogue windows

12.1.1 The menu bar

In the menu bar, all main and sub menus offered by the program can be opened.

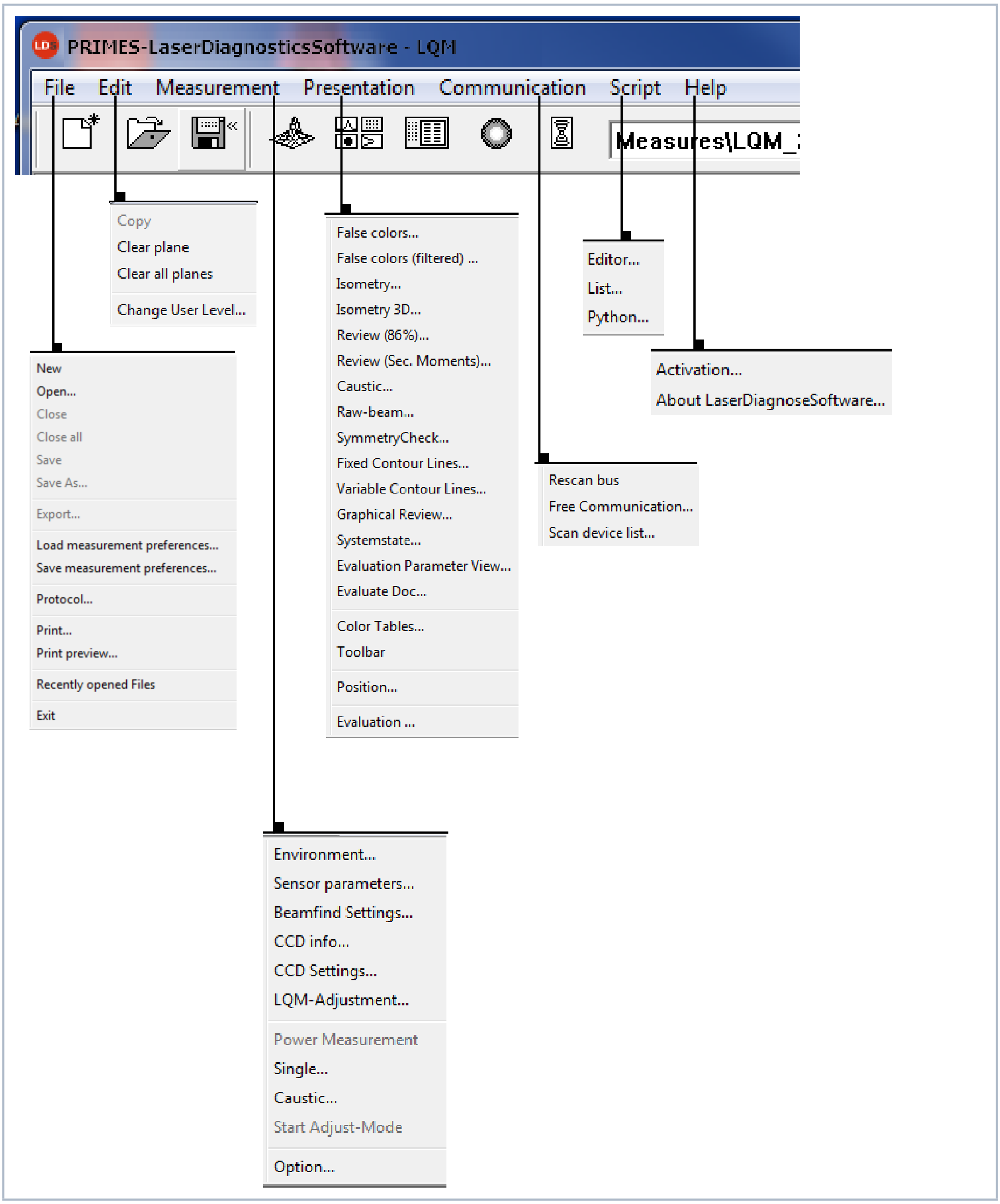


Fig. 12.5: Menu bar

12.1.2 The toolbar

By clicking the symbols in the toolbar, the following program menus can be opened.

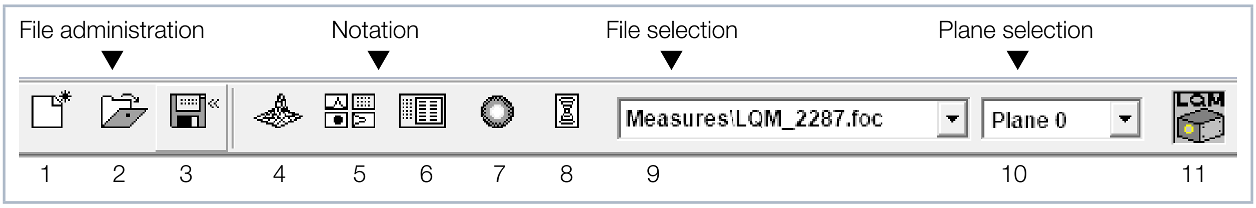


Fig. 12.6: Symbols in the toolbar

1 - Create a new data record
2 - Open an existing data record
3 - Save the current data record
4 - Open the isometric view of the selected data record
5 - Open the variable contours line view
6 - Open review (86%)
7 - Open false color depiction
8 - Caustic presentation 2D
9 - List with all data records opened
10 - Display of the selected measuring plane
11 - Display of the measuring devices available for the bus by means of graphical symbols

All measuring results are always written into the document selected in the toolbar.
It is only possible to display documents chosen here. After opening, the data set has to be explicitly selected.

12.1.3 Menu overview

File	
New	Opens a new file for the measuring data
Open	Opens a measuring file with the extensions ".foc" or ".mdf"
Close	Closes the file selected in the toolbar
Close all	Closes all files opened
Save	Saves the current file in foc- or mdf format
Save as	Opens the menu for the storage of the files selected in the toolbar. Only files with the extensions ".foc" or ".mdf" can be imported safely
Export	Exports all current data in protocol format ".xls" and ".pkl"
Load measurement preferences	Opens a file with measurement settings with the extension ".ptx"
Save measurement preferences	Opens the menu to save the settings of the last program run. Only files with the extension ".ptx" can be opened
Protocol	Starts a protocol of the numeric results. They can either be written into a file or a data base
Print	Opens the standard print menu
Print preview	Shows the content of the printing order
Recently opened files	Shows the file opened before
Exit	Terminates the program
Edit	
Copy	Copies the current window to the clipboard
Clear plane	Deletes the data of the plane selected in the toolbar
Clear all planes	Deletes all data of the file selected in the toolbar
Change user level	By entering a password a different user level can be activated.
Measurement	
Environment	Different system parameters can be entered, e.g. - Reference value for the laser power - Focal length (Not relevant for LaserQualityMonitor LQM) - Wavelength - Comment - Device offset (distance LQM - beam source)
Sensor parameters	The following device parameters can be e.g. set here: - The spatial resolution (32, 64, 128 or 256 Pixel) - The manual settings of the z-axis - Choosing the measuring devices connected to the bus - Deactivating the z-axis
LQM-Adjustment	Adjustment of the incident laser beam
Beamfind settings	Setting parameter for a beamfind procedure
CCD info	Provides information on device parameters
CCD settings	Special settings can be made, e.g.: - Trigger mode - Trigger level - Exposure time - Wave length

Power measurement	Not relevant for LaserQualityMonitor LQM
Single	This menu item enables the start of single measurements, of the monitor mode and the video mode
Caustic	Enables the start of a caustic measurement. Not only automatic measurements but also serial measurements of manually set parameters are possible. The automatic measurement starts with a beam search and then caries out the entire measuring procedure independently. Only the z-range that is to be examined as well as the desired measuring plane have to entered
Start adjustment mode	Not relevant for LaserQualityMonitor LQM
Options	Enables the setting of device parameters
Presentation	
False colors	False color display of the spatial power density distribution
False colors (filtered)	Usage of a spatial filtration (spline function) on the false color display of the power density distribution
Isometry	3-dimensional display of the spatial power density distribution
Isometry 3D	Allows a 3D display of caustic and power density distribution with spatial rotation as well as an optional isophote display
Review (86%)	Numerical overview of measuring results in the different layers basing on the 86% beam radius definition
Review (2. Moments)	Numerical overview of the measuring results in the different layers basing on the 2nd moment beam radius definition
Caustic	Results of the caustic measurement and the results of the caustic fit – such as beam quality factor M^2, focus position and focus radius
Raw beam	Information about the raw beam back calculation
Symmetry check	Analysis tool to check the beam symmetry especially for the alignment of laser resonators. No standard feature of the device
Fixed contour lines	Display of the spatial laser density distribution with fixed intersection lines for 6 different power levels
Variable contour lines	Display of the spatial power density distribution with freely selectable intersection lines
Graphical review	Enables a selection of graphical displays – among them the radius, the x- and y- position above the z-position and the time
System state	Not relevant for LaserQualityMonitor LQM
Evaluation parameter	Loading stored evaluation parameters
Color tables	Different color charts are available in order to analyse e.g. diffraction phenomena in detail
Toolbar	In order to display or to hide the toolbar
Position	Moving the device into a defined position
Evaluation	Comparison of the measured values with defined limit values and evaluation (optionally)
Communication	
Rescan bus	The system searches the bus for the different device addresses. This is necessary whenever the device configuration at the PRIMES bus was changed after starting the software.
Free Communication	Display of the communication on the PRIMES bus
Scan device list	Lists the device addresses of the single PRIMES devices

Script	
Editor	Opens the script generator, a tool, by means of which complex measuring procedures are controlled automatically (with a script language developed by PRIMES).
List	Shows a list of the opened windows
Python	Opens the script generator in order to control complex measuring procedures automatically (scripting language Python)
Help	
Activation	Enables the activation of special functions
About LaserDiagnostics-Software LDS	Provides information regarding the software version

Tab. 12.1: Menu overview

12.2 File

This menu includes – among others – the administration of measurement and setting data.

12.2.1 New (menu *File* > *New*)

By means of New a new file is created.

12.2.2 Open (menu *File* > *Open*)

By means of ***Open*** a selected file is opened.

12.2.3 Close/Close all (menu *File* > *Close/Close all*)

Close will close the file that is currently open. ***Close all*** will close all files currently open.

12.2.4 Save (menu *File* > *Save*)

The file currently opened is stored. The standard type of file is a binary file format with a minimal memory requirements. The file ending for a measuring file of this type is ".foc". As an alternative, it is possible to store the data in a ASCII format with the extension ".mdf". Information regarding the file format ".mdf" can be found enclosed. Only files with this formats can be opened by the program (see also chapter 20.5 on page 116).

12.2.5 Save as (menu *File* > *Save As*)

You have to assign a file name, choose the storage location and the file format.

Only save the measurement data with the extensions ".foc" or ".mdf". You can only view measurement data if the respective file was explicitly selected in the toolbar.

12.2.6 Export (menu *File* > *Export*)

Exports the pixel information of the power density distribution to a Excel table (*.xls). As an alternative, the numeric results from a ".foc" file can be stored in a tab-separated text file (*.pkl) which can be imported into Microsoft Excel. The pkl export function has a coordinate origin in the middle of the measuring area (yellow dot).

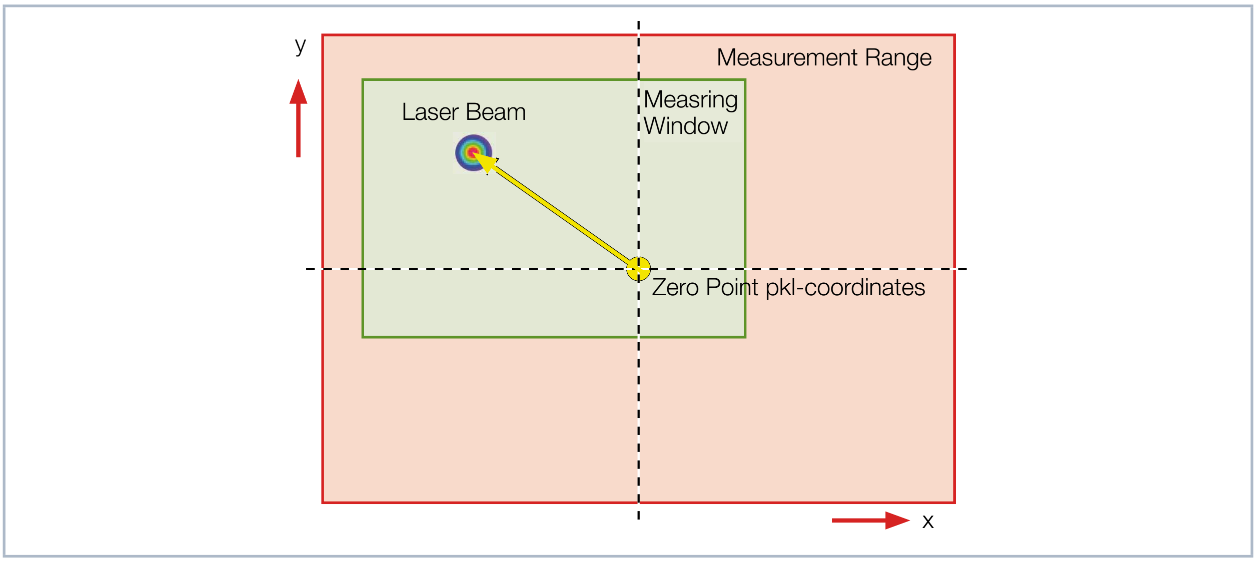


Fig. 12.7: Coordinates of the pkl-export function (the illustration is not to scale)

12.2.7 Load measurement preferences (menu *File* > *Load measurement preferences*)

Stored settings can be resorted to with ***Load measurement preferences***. The standardized extension for a setting file of the LaserQualityMonitor LQM is “.ptx”.

12.2.8 Save measurement preferences (menu *File* > *Save measurement preferences*)

The current measurement settings are stored (.ptx-file).

12.2.9 Protocol (menu *File* > *Protocol*)

The calculated measurement results from a single plane can directly be written into a text file.
The following is stored:

- Date and time of the measurement
- Beam position and beam radius (according to 86 %- and second moment definition)

Therefore please activate the check box ***Write***. Then you can directly enter the name in the field ***Filename*** or you can use the standard selection menu with the button ***Browse***.

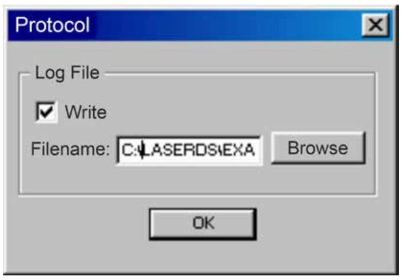


Fig. 12.8: Window ***Protocol***

12.2.10 Print (menu *File* > *Print*)

You can print directly from the program. The current window can be printed with the menu point ***Print*** in the menu ***File***. With the menu point ***Settings*** it is also possible to change the settings as far as the formats etc. are concerned.

12.2.11 Print preview (menu *File* > *Print preview*)

Shows a preview of your printing order.

12.2.12 Recently opened files (menu *File* > *Recently opened Files*)

Selection of the files processed before.

12.2.13 Exit (menu *File* > *Exit*)

Terminates the program.

12.3 Edit

12.3.1 Copy (menu *Edit* > *Copy*)

By means of the copy function a direct export of graphics to other programs is possible. In this case the content of the current window is transmitted to the Windows clipboard.

12.3.2 Clear plane (menu *Edit* > *Clear plane*)

The content of the actual displayed measurement plane of the measurement data set selected in the toolbar is deleted.

12.3.3 Clear all planes (menu *Edit* > *Clear all planes*)

The content of all measurement planes of the measurement data set selected in the toolbar is deleted.

12.3.4 Change user level (menu *Edit* > *Change User Level*)

By entering a password a different user level can be activated.

12.4 Measurement

12.4.1 Measuring environment (menu *Measurement* > *Environment*)

A description of the settings for the LaserQualityMonitor LQM can be found in chapter 13.4.2 on page 97

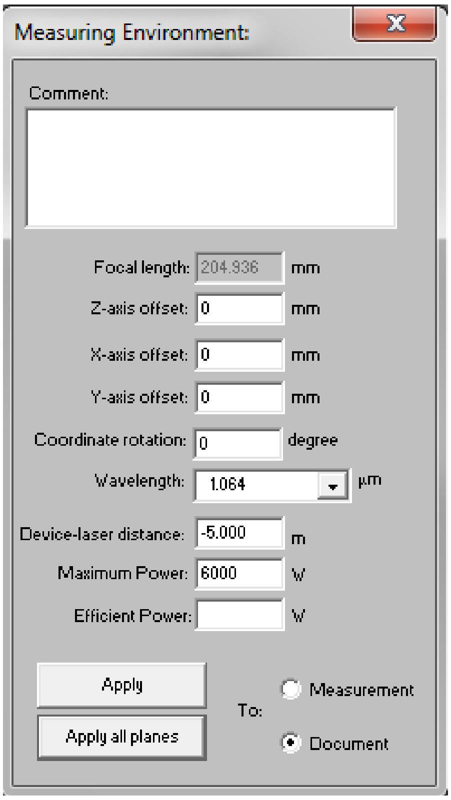


Fig. 12.9: Dialogue window ***Measuring Environment***

In the dialogue window ***Measuring Environment*** data such as the laser type, information on the collimator etc. can be stored. These data can be read via ***Presentation > Review***.

Please do not use the character # in the comment field “Comment”. This character is used as a separator in the software. If it is entered in the field “Comment”, problems could occur when it comes to storing or activating measuring data.
A line break can be enforced by means of the key combination: **<Ctrl> + <Enter>**.

Entering the laser power is a reference value for the relative power position in the menu point ***Single measurement*** or ***Caustic measurement***. Furthermore, a z-axes offset as well as a coordinate rotation angle can be entered. The wave-length is the basis for a correct determination of the beam quality factor M^2. There are the following options:

- 1.064 µm for Nd:YAG laser
- 0.532 µm for Green laser
- 0.355 µm for UV laser

A wavelength can also be typed in numerically.

By means of the button ***Apply*** the entries can also be changed after a measurement. With the button ***Apply all planes*** the entered values are inserted and settled, while the button ***Apply*** only refers to the value in the current plane.

12.4.2 Sensor parameters (menu *Measurement* > *Sensor parameter*)

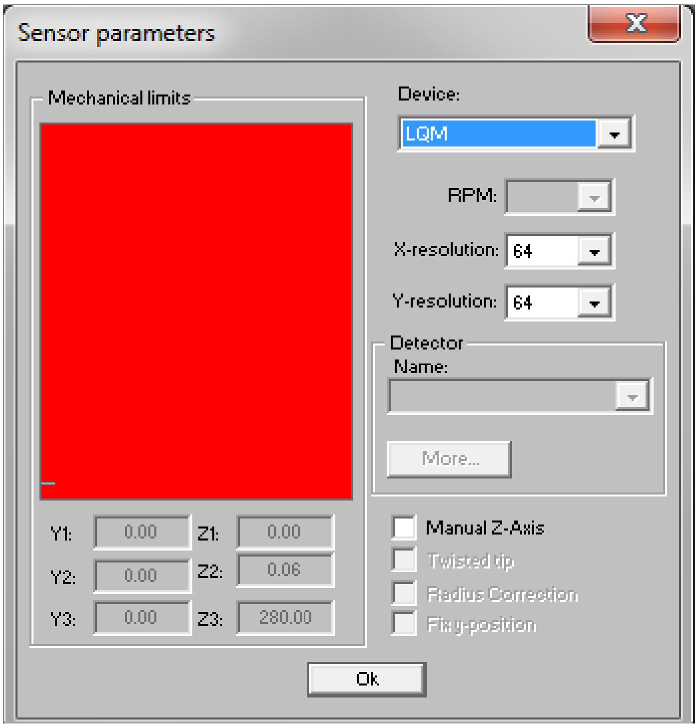


Fig. 12.10: Dialogue window ***Sensor parameters***

Mechanical Limits

Not relevant for LaserQualityMonitor LQM.

Device

By means of this option, you can select the device which is supposed to be operated. Depending on the number of devices connected, additional device numbers are assigned.

RPM

Not relevant for LaserQualityMonitor LQM.

Resolution

Here you can enter the number of pixels in the measuring window, ranging from 32 x 32 to 256 x 256 pixels. Generally, 64 pixels per line and a total of 64 lines is sufficient. Please keep in mind that the more pixels there are, the longer the measurement will take.

Detector

Not relevant for LaserQualityMonitor LQM.

Manual Z-Axis

Not relevant for LaserQualityMonitor LQM.

12.4.3 Beam find settings (menu *Measurement* > *BeamFind Settings: Beamfind*

Here, the parameters for the automated beam find are set. The general presetting is helpful for many standard applications.

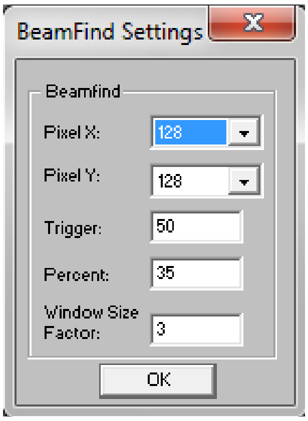


Fig. 12.11: Dialogue window ***BeamFind Settings: Beamfind***

The Beam find parameters can be set as follows:

Pixel X, Pixel Y

The selection of the spatial resolution.

Trigger

The signal threshold (Trigger) is dependant on the zero level of the measuring system.

Percent

The percentage value indicates by how much the signal has to exceed the zero level in order to be recognized as a beam. This value is determined by means of the signal-to-noise ratio of the detector.

Window size factor

The window size factor determines the size of the measuring window when it comes to the beam search. The factor indicates how big the measuring window has to be in relation to the beam diameter.

12.4.4 CCD info (menu *Measurement* > *CCD Info*)

The most important device data is shown in the menu ***Measurement > CCD Device Info***. Here you can see the magnification information for the measuring objective and also check which beam path is turned on.
If obvious default values (1:1) are shown instead of the actual magnification, then please check the mounting of the measurement objective.

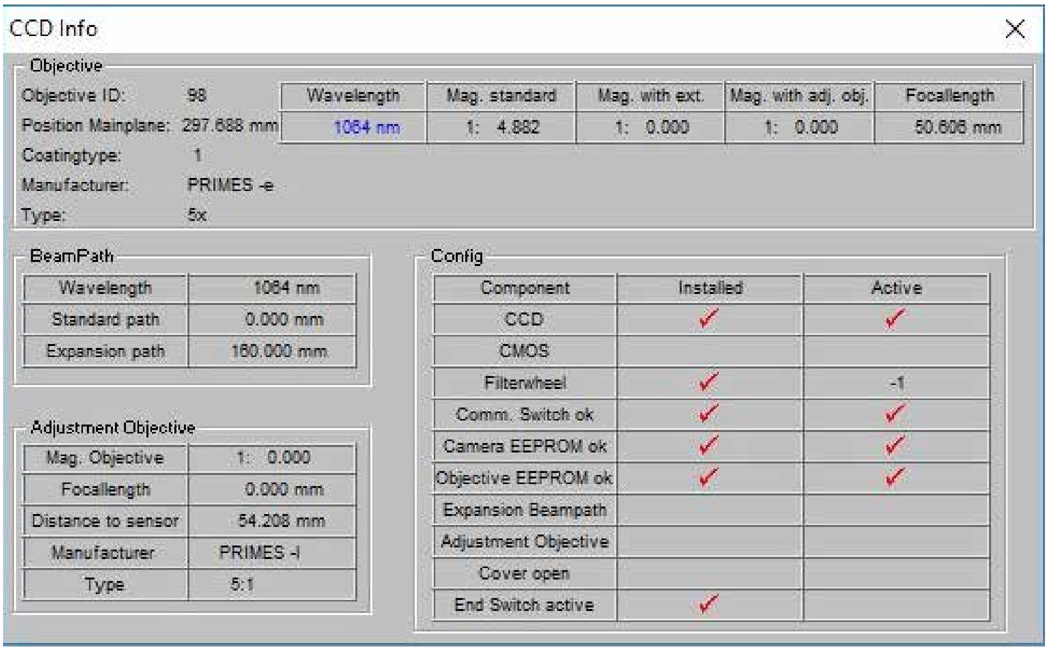


Fig. 12.12: Window ***CCD Info***

12.4.5 CCD settings (menu *Measurement* > *CCD Settings*)

A description of the settings for the LaserQualityMonitor LQM can be found in chapter 13.4.1 on page 96.

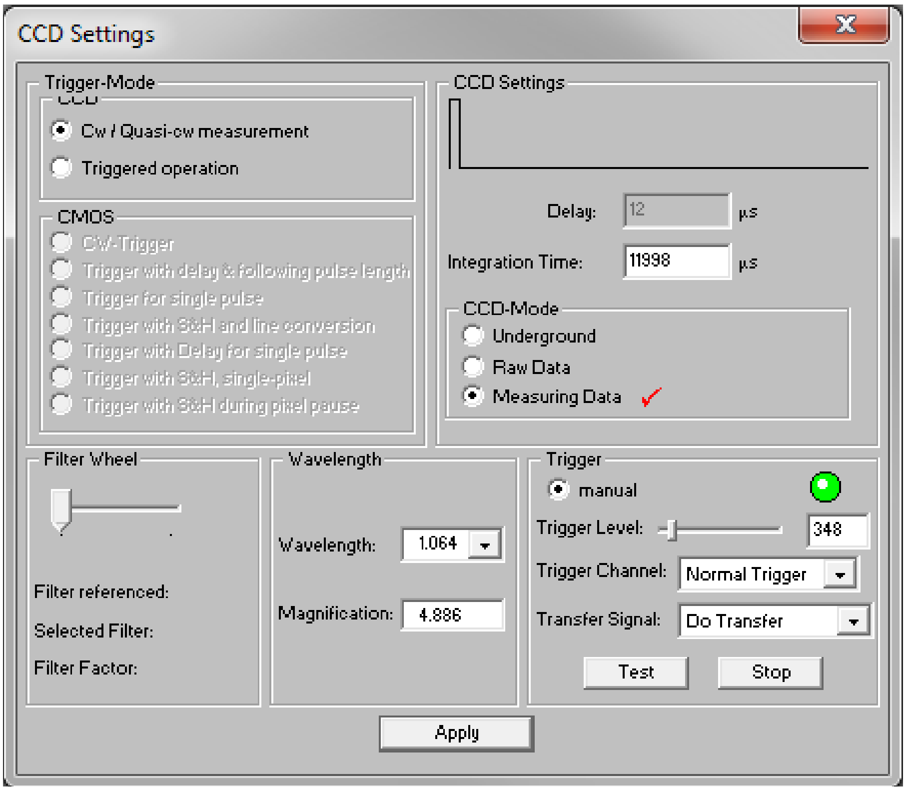


Fig. 12.13: Dialogue window ***CCD Settings***

The wavelength, attenuation, and operating mode are all set in the ***CCD Settings*** dialog window.

Trigger modes

The appropriate settings must be configured here in keeping with the operating mode of the laser to be measured. Here it is important to consider that pulsed lasers with a pulse frequency of more than 500 Hz can be measured in cw mode. If, however, the operating mode is set to pulsed and a cw laser system is involved, the measuring device will always display the error message “Error Black Pixel Measurement” or “Time Out During Measurement” in reaction to a measurement request.

Delay

This function can only be used with a “triggered operation” trigger mode. The time the measuring system should wait between when it detects the trigger pulse and the start of the measurement is set here. Together with the function “Integration Duration”, defined “Windows” from the plus cycles can be measured (e.g. exactly one pulse or parts of an ms pulse. The minimum delay is 12 µs.

CCD operating modes

Three different modes can be set here. If the raw data setting is activated, the measuring system will return the uncompensated data of the CCD when a measurement is requested. Especially with NIR irradiation, these can be riddled with measuring errors such as “smear” readout noise. Even the numeric beam data generated generated from this data will be affected by this.
If a background is selected as the operating mode, only correction data will be returned while measuring. Measuring data mode should always be the default setting here though. Only when this mode is turned on can the measuring system deliver reliable measuring values.

Integration duration

This function sets a defined integration duration. The optimizer must be deactivated before this can be accomplished, since otherwise the measuring device itself will optimize and thus change the integration duration. This function is also used mainly in measuring pulsed laser systems.

Filter wheel

Not relevant for the LaserQualityMonitor LQM.

Wavelength

Due to the wavelength-dependent overall magnification of the camera-based measuring system, it is important to check that the right selections have been made before each measurement. The wavelengths shown here represent the calibration points of the measuring objective. As a result of the achromatic properties of the measuring objective, a wavelength range between 1030 and 1100 can be achieved, for example, with a calibration point at 1064 nm without causing generating measuring errors.

Trigger

The trigger menu is only pertinent when measuring pulsed laser systems. A fixed value (2001) is generally specified for the trigger diode by default. This value describes the threshold value at which a trigger signal is emitted. If you switch the trigger to automatic, the trigger level will first be set to the maximum value. The ***Test*** button is renamed in ***Optimize***. In the optimize routine (laser must be turned on), the trigger threshold is lowered gradually until the MicroSpotMonitor starts receiving trigger signals (lower trigger level). The trigger level is then increased until the MicroSpotMonitor stops receiving trigger signals (top trigger level). The final trigger level is determined by calculating the arithmetic mean of the two limit values. External trigger entry can be activated via the menu point ***Trigger Channel*** . Transfer signal pertains to the transfer output of the MicroSpotMonitor. Here it is possible to define the CCD sensor state at which there should be a trigger signal (e.g. for turning on the laser).

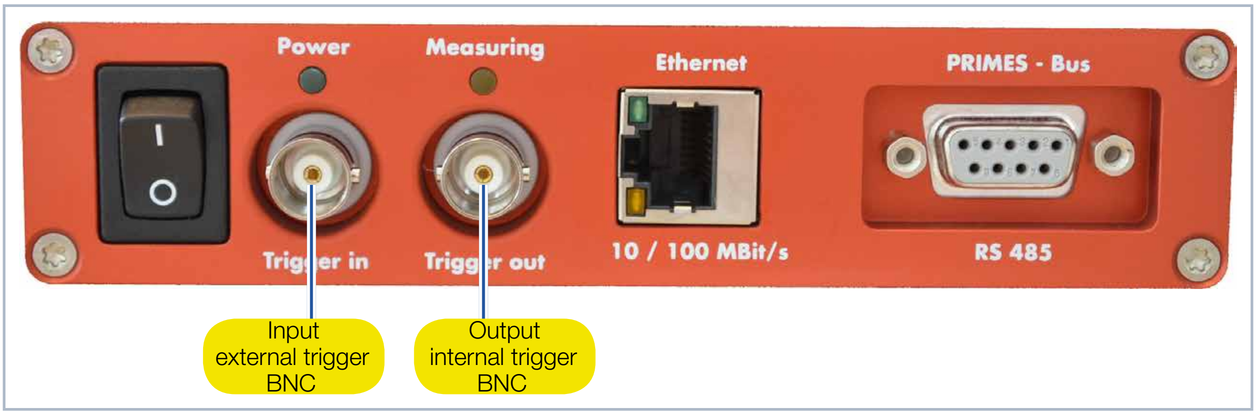


Fig. 12.14: Trigger connections

General sequence control

- Empty the CCD register
- Aim for the holding point in line a (line in which photo transfer takes place); if the trigger is set off during sub-pulse, repeat line a (-> NLC = NoLineChange)
- Wait for the trigger if necessary and repeat line a (NLC)
- Wait out the delay if necessary and repeat line a (NLC)
- Aim for the holding point in line a through sub-pulse (-> delete the charge in the photo diodes)
- Integration – no cycles (sliding the charges through the register) of CCD
- Cycles start again, a few AD cycles later: Photo transfer
- Read out the CCD register; when the addresses match (= desired pixels), the measuring value is forwarded to the AD transformer.

The various signals going through the transfer output mark certain points in time during the sequence control:

Transfer signals	Meaning
Do transfer	Is high when the CCD is at the holding point in line a (referred to in this way, since photo transfer also takes place in this line – when it isn't being suppressed by the NLC).
Do transfer & Xend	A short high-pulse, when we reach the end of line a.
Sub	Is high as long as a sub-pulse is running.
Start done	Is high when the CCD is ready for integration (or when waiting for the trigger) so when it is at the holding point in line a. Is low again when the CCD is read out. You could use the positive side to light the laser.
Wait for trigger	Is high when the CCD is at the holding point in line a and is waiting for the trigger signal. Is low as soon as the trigger is activated and the delay begins. Only a short high pulse occurs in untriggered operation. Could be used in addition to the trigger out connector to check triggering.
Integration done	Is high as soon as integration is complete. Is low again when the CCD is read out.
Photo cycle	Is high when the CCD is ready for integration. Is low as soon as integration is complete. During untriggered operation, the high phase returns exactly the integration time.

Tab. 12.2: Signals that can be sent through the transfer outlet

12.4.6 LQM adjustment (menu *Measurement* > *LQM Adjustment*)

A description of the settings for the LaserQualityMonitor LQM can be found in chapter 13.3 on page 94.

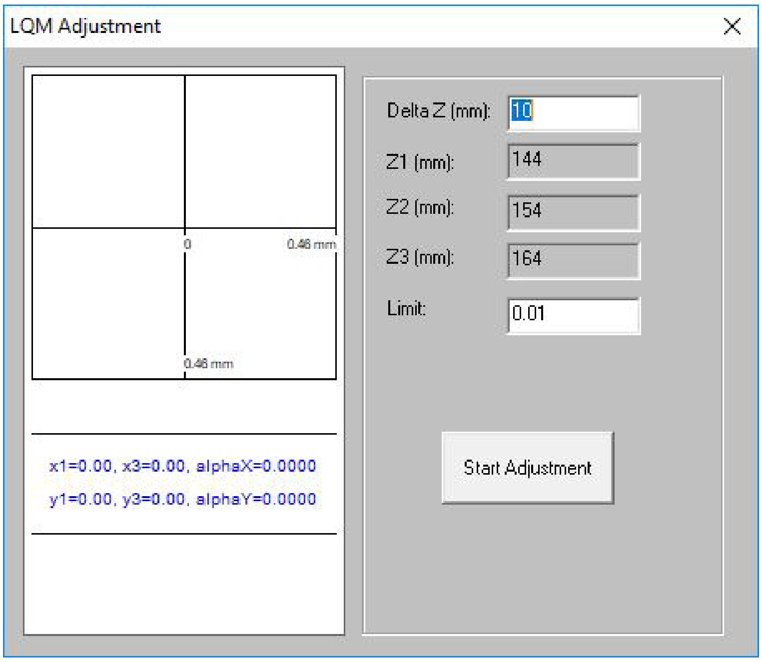


Fig. 12.15: Dialogue window ***LQM-Adjustment***

12.4.7 Power measurement (menu *Measurement* > *Power Measurement*)

Not relevant for the LaserQualityMonitor LQM.

12.4.8 Single (menu *Measurement* > *Single*)

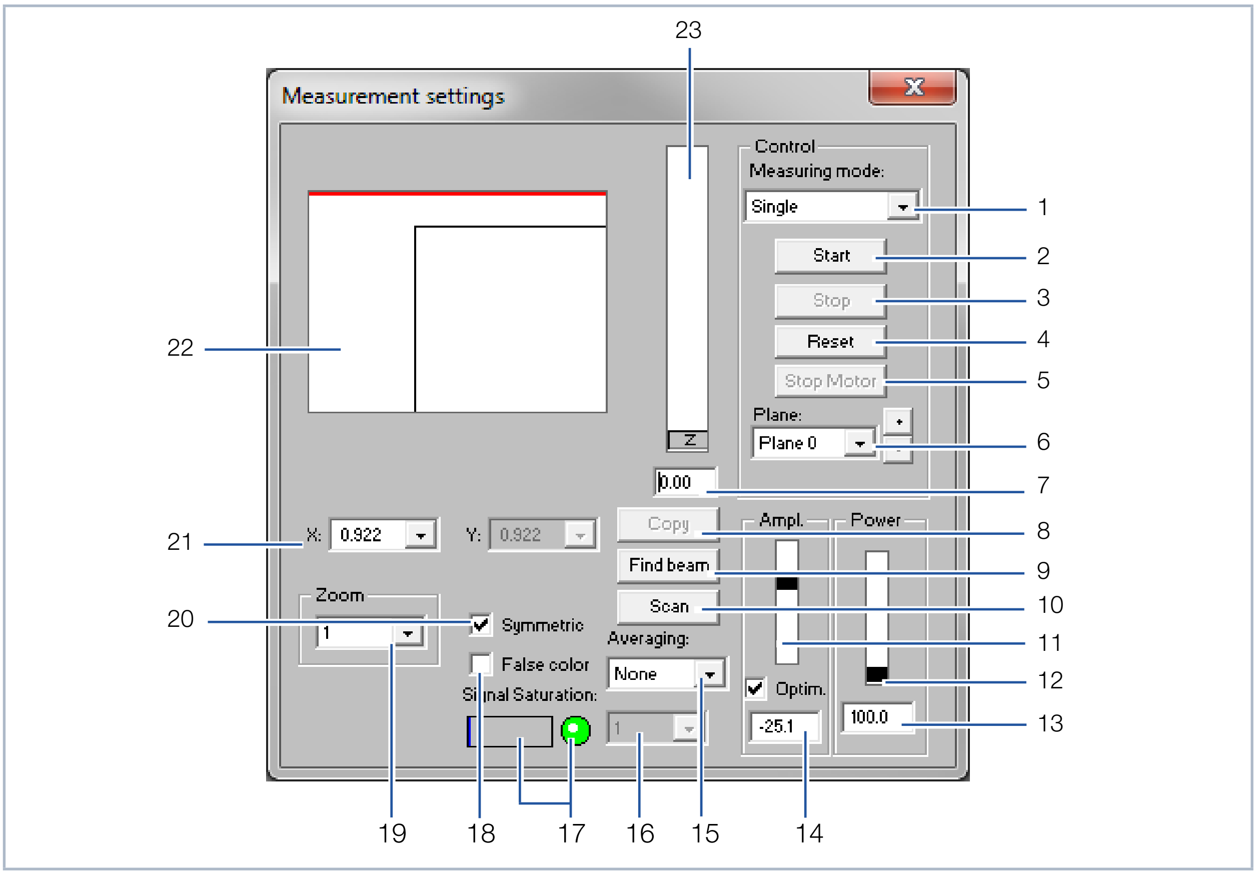


Fig. 12.16: Dialogue window ***Measurement settings***

1	Single Monitor Video Mode	Starts a measurement in the chosen plane Starts repeated measurements in the chosen plane automatically Repeated output of raw data in the chosen plane
2	Start	Starts a measurement in the currently chosen plane
3	Stop	Finishes the measurement in the currently chosen plane
4	Reset	The measuring device is reset
5	Stop Motor	Not relevant for LaserQualityMonitor LQM
6	Plane	Selection of the measuring plane (0-49) either explicit or by means of the buttons (+/-)
7	Entry field	Numerical entry of the z-position
8	Copy	Copies all settings (window size and window position; x, y, z; etc.) from the former plane to the current plane (e.g. 1>>2)
9	Find beam	Starts an automatic beam search in the current measuring plane
10	Scan	Starts an automatic beam search with the LaserQualityMonitor LQM. The algorithm works at a fixed z-position and searches only within the range of the specified measuring window.
11	Ampl.	Slide control in order to adjust the optical amplification (exposure time of the CCD)
12	Power	Slide control in order to adjust the laser power to save it in the software
13	Entry field Power	Numerical input of the laser power to save it in the software
14	Entry field Ampl.	Numerical input of the electrical amplification
15	Averaging	Not relevant for LaserQualityMonitor LQM
16	Averaging	Not relevant for LaserQualityMonitor LQM
17	LED symbol and bar graph display	Display for the degree of the signal saturation (LED green ≙ ok, red ≙ not ok)
18	False color	Activates the option of the false color presentation
19	Zoom	Magnification settings for the measuring window
20	Symmetric	This option enforces the usage of square measurement windows, whose size is only adjustable via x.
21	X/Y	Setting of the size of the measuring window for windows that are not square or rectangular
22	Display	Measuring window shows the current measuring result
23	Z	Slide control in order to set the z-position

Tab. 12.3: Explanation of input and setting elements

With the dialogue window ***Measurement settings*** either single measurements or repeated measurements can be carried out. The measuring window position can be set either manually or automatically.

Controlling measuring modes (individual measurement, monitor, and video mode)

There is a total of three different measuring modes that can be selected here. In the ***Individual Measurement*** and ***Monitor*** measuring mode, all necessary compensations (smear, diffusion) and lighting time adjustments are performed every time a new measurement is carried out. Valid measuring data is generated in this mode.

The ***Video Mode*** measuring mode only works with an Ethernet connection and doesn’t generate any valid measurement data. Unlike in the ***Individual Measurement*** and ***Monitor*** measuring modes, only raw data is conveyed in Video Mode measuring mode. If the CCD sensor gets overloaded during a measurement (indicated by the color red in the display field for signal saturation and/or an A/D transformer value of 4095 in the illustration ***Free Cuts***), you should use the ***opt. ampl.*** (optical amplification) slider to reduce the amplification and repeat the measurement.
Due to the “high” measuring frequency of about 5 Hz, this operating mode is particularly suited for use when aligning the device. The numeric results should not be interpreted absolutely, but rather always relative to each other.

Power

The slider sets the actual laser power, so the software algorithm can calculate the spacial power density. It can be set to any power up to the maximum.
The maximum power is entered in the menu under ***Measurement > Environment***. The power density is calculated in relation to the power values set here. Up to 50 individual measurements can be recorded in a measurement file. The results can be easily compared and analyzed with the various presentation functions of the LaserDiagnosticsSoftware LDS.

Optical amplification (opt. ampl.)

This function activates the automatic adjustment of the exposure time of the CCD for every measurement. The function must be activated in order to keep the signal/noise ratio consistently high for a caustic measurement.
For special measuring applications, however, it might make sense to deactivate this function and set the exposure time to a fixed value between 12 µs and 200 ms. It may also be necessary to increase the attenuation through another neutral-density filter.

Copy

Using the ***Copy*** button, you can apply the measurement settings for window size, window position, power, and amplification from the previous measuring plane.

Beam search

The ***Beam Search*** will initiate an automatic beam search. When this happens, the system will only search the area of the currently set window for the set z position.
If the beam search is completed successfully, a measuring window with the appropriate size and position will appear on the display screen. The beam can then be accepted using the ***Start*** button. The size of the measuring window depends on the magnification of the measuring objective. The measuring objective and the wavelength are the influencing variables here.

Scan

For devices such as the LaserQualityMonitor LQM, the measuring window is much smaller than the measuring area defined with the x- and y-axis (2 mm x 2 mm). The beam search is therefore supplemented with the ***Scan*** command. Once a scan is initiated, the LaserQualityMonitor LQM will automatically sense the measuring area. If a point of maximum intensity can be identified, the LaserQualityMonitor LQM will automatically zoom in on this area and adjust the measuring window size accordingly.

Size of the measuring window

During a manual beam search, you can define the location and size of the measuring window yourself in the dropdown menu within the mechanical limits. You can change the location of the measuring window by clicking on it and dragging the frame with the mouse.

Z-slider

The location of the window in the z direction (height) can be set by the z-slider or entering a numeric value.

Symmetrical

Once this function is activated, only rectangular measuring windows will be allowed. In cases where an elliptical or even a square laser beam is being measured, this function should be deactivated so that the measuring window can be optimally adjusted.

False color rendering

False color rendering is activated by clicking on the corresponding button. A measurement is initiated by clicking on the ***Start*** button. Selecting ***Monitor*** and pressing the ***Start*** button will initiate an ongoing, repeating measurement with the current settings. The repeat rate depends on the spacial resolution and the type of communication between the PC and the LaserQualityMonitor LQM.

Zoom function

The zoom function allows for detailed magnification of the measuring area.

12.4.9 Caustic measurement (menu *Measurement* > *Caustic*)

The caustic measurement is a serial measurement where the z position is varied. The results are stored in different planes. A different z-position is assigned to every measuring plane. As the beam radius as well as the power density change in every z position, the position as well as the size of the window and the signal strength can vary from plane to plane. The parameters are automatically adjusted in the process and can also be configured separately for each measuring plane.

Parameters (start number of the plane)

Under Start, the start number at which the measurement is initiated can be entered for the plane. By default, the start number is generally set to zero and should only be changed when you are measuring in an existing document and don't want the existing measurement data to be overwritten. If, for example, you have measured a caustic with 21 planes and want to magnify the measuring area to the smaller z-values, you can set the start plane to 21 and modify the measuring area appropriately. The new measuring values will then be written into the existing document starting with plane 21.

In the Quantity selection field, the number of planes to be measured in the specified z range is set. The following should be considered here:

- Since the LaserDiagnosticsSoftware LDS always sets the measuring plane distances so they are equidistant (equal spacing) and the measuring area is almost always situated symmetrically around the focal point, an odd number of measuring planes should be selected. This ensures that the focus plane is measured.
- Beam measurement norm DIN 11146 specifies that at least 10 measuring planes should be measured. Furthermore, five measurements should also be taken within a Rayleigh length and the other beyond 5 Rayleigh lengths. In order to meet all of the requirements with equidistant distribution, at least 17 measuring planes must be measured in a range of ± 3 Rayleigh lengths.

Mode (automatic and manual settings)

There are two different measuring modes for caustic measurement. In "Automatic" mode, the measuring system and the LDS determine the ideal measuring window position (x- and y-direction) for each measuring plane and the optimal measuring window size for the fill factor. Furthermore, the plane location in the z-direction is also calculated based on the specifications (number of measuring planes, measuring limits z-direction).

> Especially when adjusting the measuring window size and the measuring window position in the x- and y-direction, the number of iterations (max. three per plane) can result in an extended measurement duration.

It is therefore possible to change the measuring mode to "Manual Settings" for recurring measuring tasks and for repeating measurements. In this case, the measuring system will take the measuring window positions and measuring window sizes from the previous measurement or from a .ptx file. This reduces the measurement duration considerably, but does require that the location and parameters of the laser beam change only minimally.

Beam search

This selection field specifies which plane the caustic measurement should be started in. If the optional Beam Find function is activated in the Options dialog window, that is also the plane in which this function will be performed. When the Beam Find function is deactivated, this plane must be manually measured ahead of time to make sure that the laser beam is found.

The window can be adjusted under the ***Adjust*** menu point. The settings for spacial resolution of the beam search, the threshold value, and the minimum signal strength can be entered under the ***Details*** menu point.

Beam search can be turned off in the ***Measurement > Option (only for advanced users) menu*** by deactivating the checkbox ***Enable Beam Find Process***.

Automatic caustic measurement (menu *Measurement* > *Caustic* > *Automatic)*

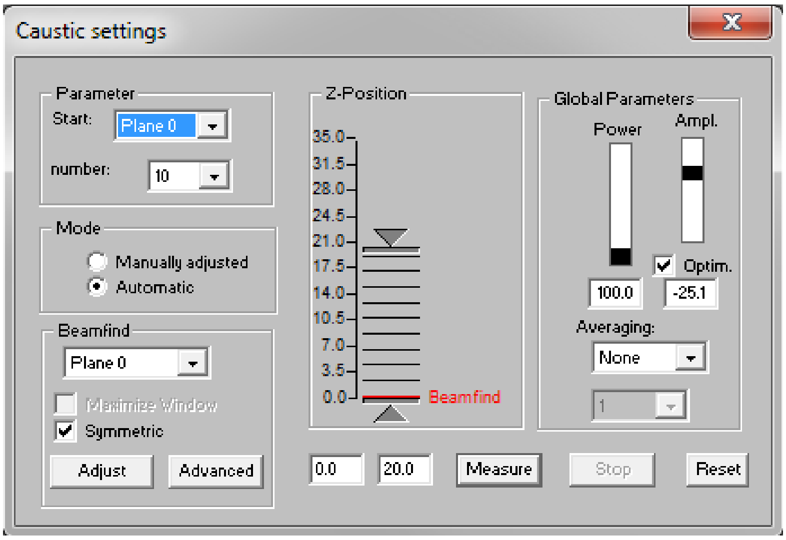


Fig. 12.17: Dialogue window ***Caustic settings***

During automatic caustic measurement, the minimum and maximum z-position is selected together with the number of measuring planes. The measurement cycle begins with an automatic beam search in the specified starting plane. The beam search only occurs within the area of the starting plane's measurement window.

Settings can be entered manually. After manually entering the settings for the measurement planes as described in the following section, the caustic measurement can be repeated automatically by choosing the ***Manually adjusted*** mode.

It is also possible to store measurement settings such as window size, position, etc. in a data file to be reloaded again if necessary (***File > Safe/Load measurement preferences***).

A measurement cycle is started by pressing the ***Measure*** button. All planes will be measured then one after the other during the measurement cycle.

Manual caustic measurement as time series (menu *Measurement* > *Caustic* > *Manually adjusted*)

The manual caustic measurement consists of a series of individual measurements at various z-positions, with the results being stored in their own planes.

For the manual caustic measurement the following steps are necessary:

1. Please choose the menu item ***File*** > ***New***.
2. Please choose the menu item ***Measurement*** > ***Single***.
3. Please choose the first plane.
4. Please adapt the z-position.
5. Please adapt the window size as well as the position.
6. Please click the button ***Start***.
7. Please choose the next plane, click the button ***Copy*** and continue with point 4.

Please repeat the steps 3 to 7 about 10 to 15 times.

Please choose the option ***Manually adjusted*** in the menu item ***Measurement*** > ***Caustic*** and click the button ***Measure***. Then the different planes are measured with the parameters set.

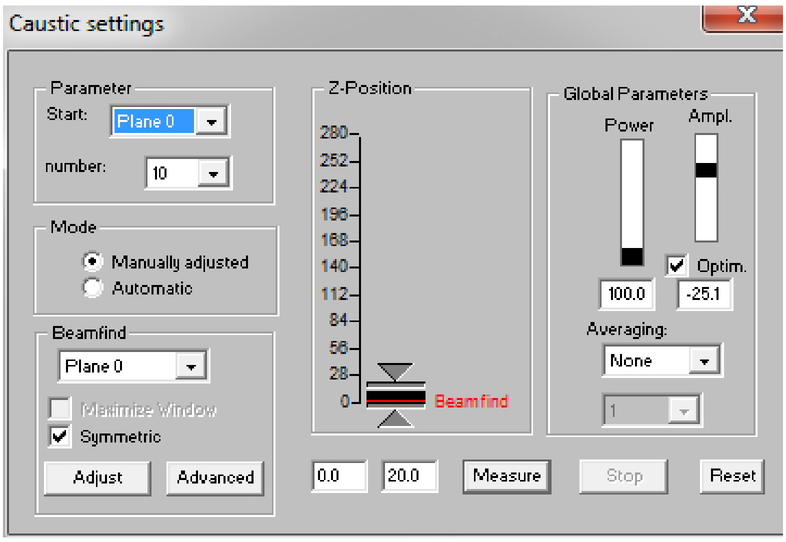


Fig. 12.18: Dialogue window ***Caustic settings***

The measuring parameters can be stored by means of the menu item ***File*** > ***Save measurement preferences*** and can be loaded again upon request.

12.4.10 Start adjust mode (menu *Messung* > *Start Adjust mode*)

Not relevant for LaserQualityMonitor LQM.

12.4.11 Option (advanced user only) (menu *Measurement* > *Option*)

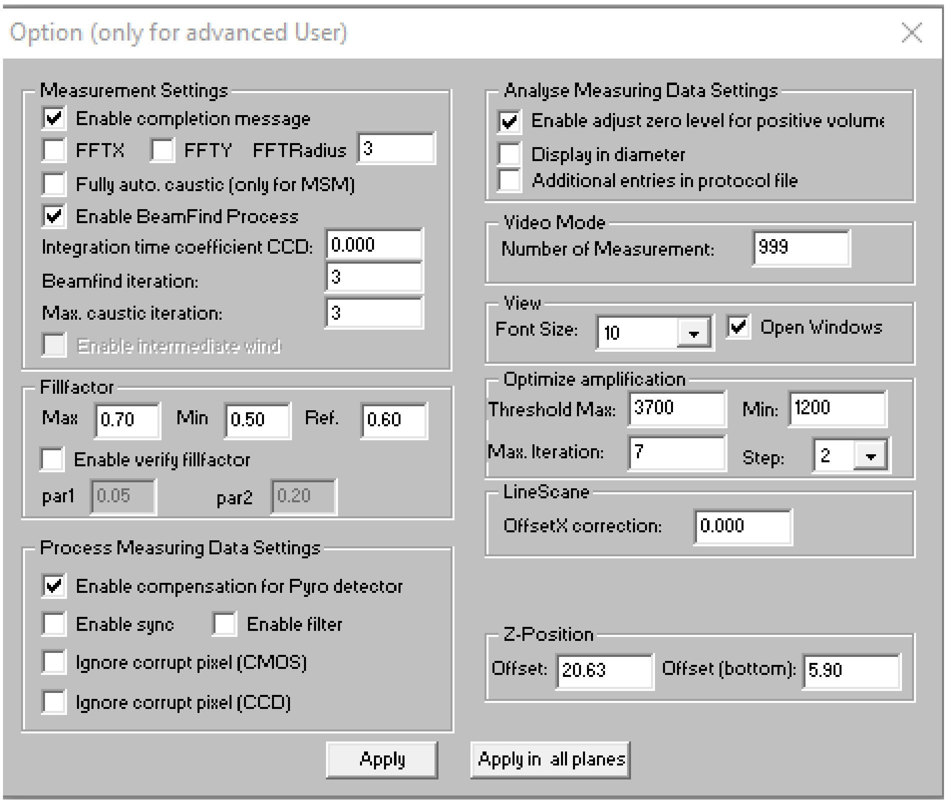


Fig. 12.19: Dialog window ***Option***

Enable beam find process

The Beam Find function must be used for caustic measurement. This involves an algorithm that separates the measuring signal from the measurement artifacts (e.g. noise) via an adjustable trigger threshold and adapts the size of the measuring window to this signal. This algorithm is only executed in the beam search plane (Dialog window ***Caustic***). On all other measuring planes, the measuring window size is determined using the fill factor.
If this function is deactivated, the beam search plane must be manually "premeasured" in the measuring system. Otherwise the measuring system might end up positioning the measuring window on the edge of the measuring area where there is no measuring signal. This makes it impossible to take a meaningful measurement.
If you turn the Beam Find function off and have the measuring measure the beam search plane system before each caustic measurement, you can save about 20 sec of measuring time per caustic measurement.

Summary: This function should be activated by default and only deactivated by experienced users. Turning off this function can shorten the time for caustic measurements by about 15 %.

Fillfactor

The fill factor is the quotient of the beam diameter and the length of the sides of the measuring window. As long as the measuring signal is not cut off and there are no noise components in the measuring result and now errors in the offset determination, the fill factor won't influence the accuracy at all. But since every real measuring signal is tainted with noise and since the precision with which the zero level of a measuring signal can be determined is finite, very small fill factors can lead to a high level of accuracy. Depending on how

substantial the RMS noise is and the errors in the zero level determination of a measuring plane, the optimal fill factor value to produce the best possible mathematical result will be different.
For TopHat and Gaussian beam shaped laser beams, the fill factor should range between 0.5 and 0.7. If the beam has diffraction rings, however, and if these are located completely within the measuring window, the optimal value for the fill factor can be between 0.5 and 0.6.

By default, the value should be set to: “Max 0.7 Min 0.5 Target 0.6”. For extremely deformed beams, the value may be changed to “Max 0.6 Min 0.4 Target 0.5”.

Font size

The font size for the most important display window can be changed here.
It is set to 10 points at the factory.

Open windows

When the window opening function is activated, some basic windows are opened when the LDS is started. If you don’t want this to happen, the function can be deactivated.

12.5 Presentation

This chapter describes the presentation, analysis and storage of measuring results.

In order to carry out comparisons between different measurements, the program can manage several measuring data sets simultaneously. The opened data sets are shown in the toolbar. In order to open one presentation, the data which is to be examined is selected in the list of the data selection and afterwards the desired kind of presentation is chosen.

File management functions as well as various display types can be pulled up directly with the symbols in the menu bar.

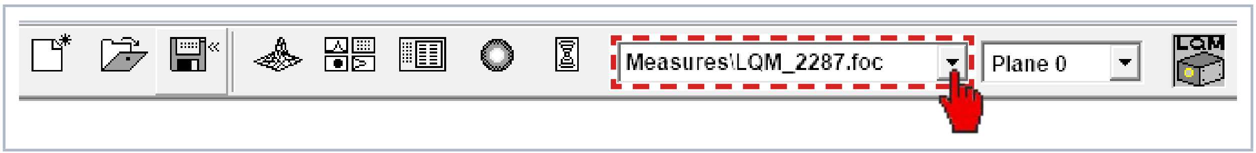


Fig. 12.20: Selection of a data set

On the selection plane, it is possible to switch back and forth between different image storages of the measuring series. When plane selection is activated, it is possible to move up or down by clicking the cursor. When plane selection is set to ***Global*** in the display menu, then it is also possible to move up/down with the cursor button.

In the menus for the notation of single measurements (***Presentation > Variable contour lines***, ***Presentation > Isometry*** and ***Presentation > False color presentation***) the option ***Autoscale*** effects the usage of the entire display range for the measuring values.

Moreover, you have the possibility of switching between different image memories of series of measurements by means of the ***Plane selection***. Switching is also possible by means of the cursor keys up/down if the plane selection is selected. If the plane selection in the display menus is set on ***Global***, switching simultaneously between the planes is possible via the selection in the toolbar.
The title of the dialogue window indicates the name of the data sets shown.

For the parallel evaluation of several measurements the program has 50 image memories which can record one measurement each. These image memories (measuring plane) can also be used in order to record changed measurement values in case of a parameter variation.

Due to the variation of the z-position in the different planes a caustic measurement is realized. Due to a change of the laser power it is possible to simulate, e.g. the thermal inflow-behavior of the system. Similarly, time series are possible. Respective displays are, for instance, possible by means of the menu item ***Presentation > Graphical review***.

12.5.1 False colors (menu *Presentation* > *False colors*)

Here, a false color presentation of the measured power density distribution is generated.

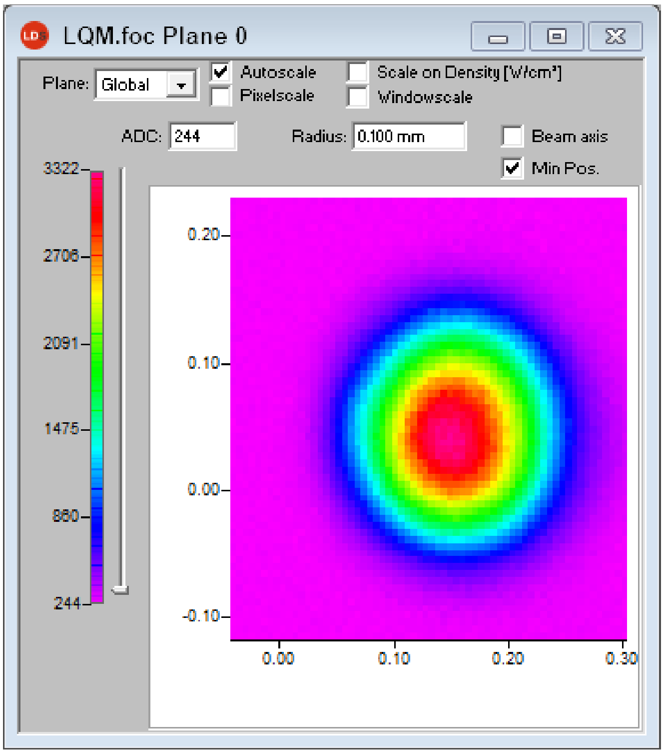


Fig. 12.21: Dialogue window ***False colors***

The used color scale is shown on the left. For a higher sensitivity, e.g. for the analysis of diffraction figures, it is possible to switch the used color scale in the menu ***Presentation > Color Tables***. By means of the slide control on the left hand side of the color scale you can display the sections of different ADC values with the corresponding radii.

Apart from the automatic scaling, there are three more types of scaling:

Scale on density

All planes of a caustic measurement are scaled on the maximum measured power density. This is supposed to help comparing the different planes more easily.

Pixel scale

This scaling is only interesting when it comes to the usage of asymmetric measuring windows. In this case the axis of the windows are no longer a function of the measuring window size but of the number of pixels measured.

Window scale

With regard to this function, all measuring windows of a caustic measurement are enlarged to the size of the maximum measuring window. This function, too, is supposed to help comparing the different measuring planes of a caustic measurement more easily.
The beam axes can be displayed in all types of scaling by activatng the check box ***Beam axis***.

Rule function

The beam can be measured in any direction by left-clicking on the image.

12.5.2 False colors (filtered) (menu *Presentation* > *False colors (filtered)*)

The special function of the filter is called spline – function. It is characterized by the fact that the position of the maximum is maintained. The single pixels in the matrix are weighed by means of a 1-2-1 filter in order to reduce the noise.
This filter can also be used multiple times without the position of the maxima being moved.

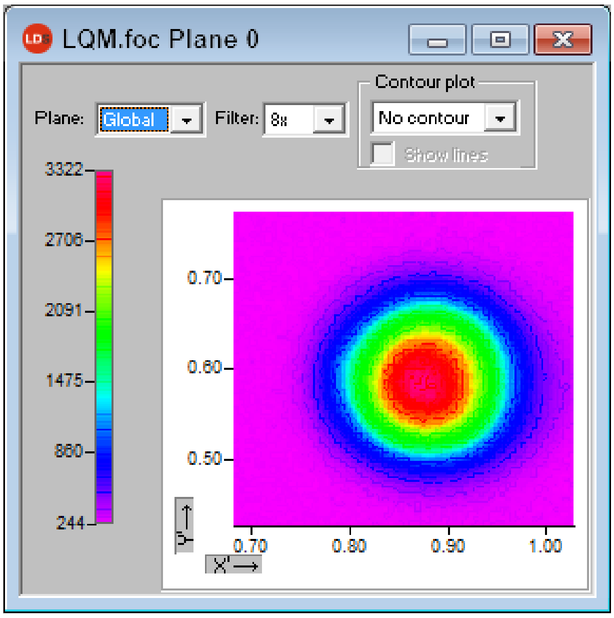


Fig. 12.22: Dialogue window ***False colors (filtered)***

12.5.3 Isometry (menu *Presentation* > *Isometry*)

This menu item generates a spatial display of the measured power density distribution of a plane. The false color display can be deactivated. A turn of the distribution by 90°, 180° and 270° each is possible.

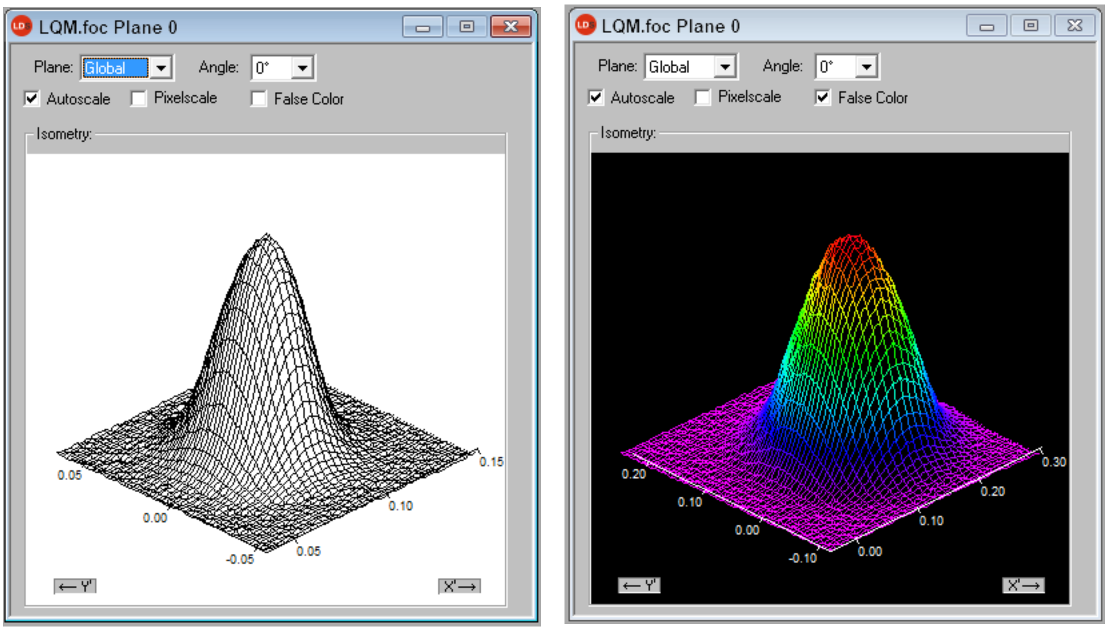


Fig. 12.23: Dialogue window ***Isometry*** (on the left with a deactivated color display)

12.5.4 Isometry 3D (menu *Presentation* > *Isometry 3D*)

This function generates three-dimensional displays of the power density distribution of a plane and all planes in false colors.
The presentation window is divided. On the left the caustic, on the right the power density distribution in a plane is displayed. The horizontal size of the single windows can be changed by drawing the separating bar by means of your mouse.
The graphics can be rotated along all three axis with the left mouse button and with the right mouse button they can be positioned in the window.

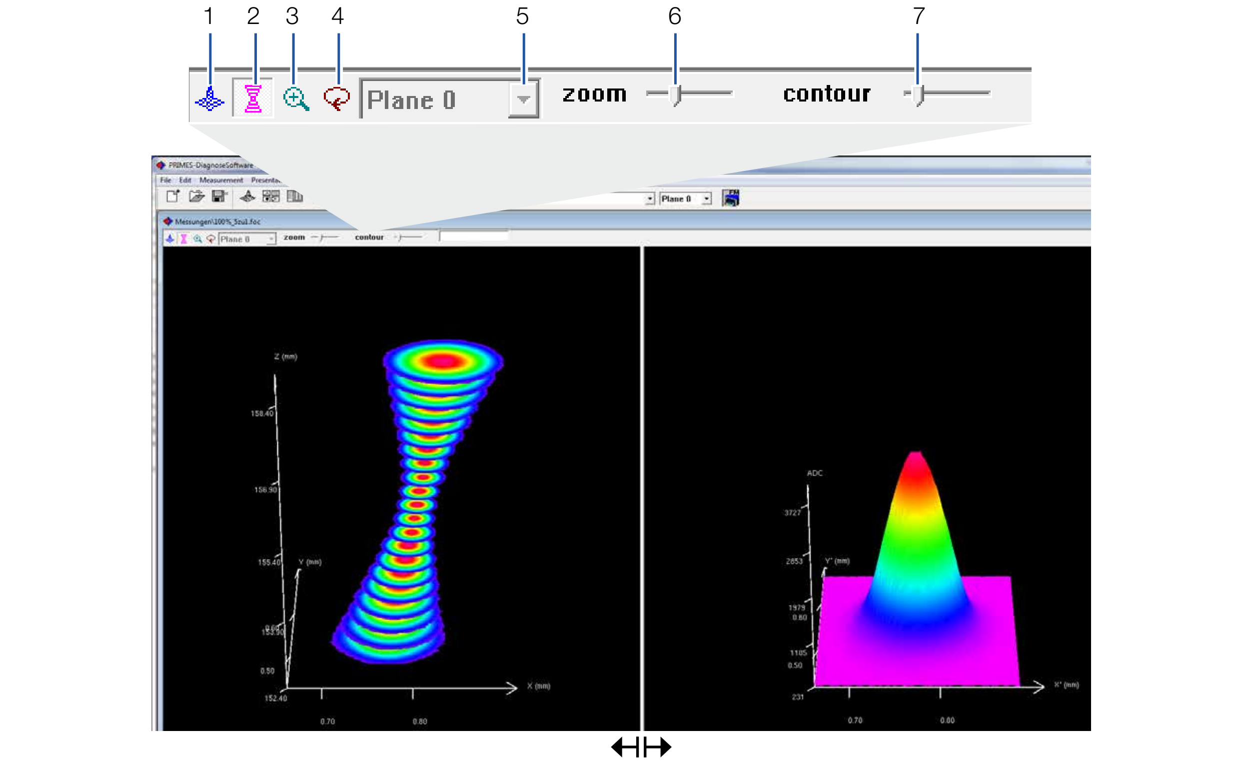


Fig. 12.24: Dialogue window ***Isometry 3D***

1	3D presentation of the plane	Inserts the 3D presentation of the power density distribution in the plane in the display window.
2	3D presentation of the caustic	Additionally inserts the 3D presentation of the caustic in the presentation window.
3	Magnification in the plane	In the left part of the presentation window a magnification of the plane displayed on the right is inserted (the desired area can be clicked by means of the left mouse button in the right window).
4	Rotation	Causes a rotation of both graphics along the z-axis.
5	Plane selection	Here the plane, which is to be displayed, can be chosen (you can also choose the desired plane in the 3D caustic by means of the left mouse button).
6	Zoom	Slide control for a continuous magnification of the presentation
7	Contour	Slide control for a contour trimming along the power density.

Tab. 12.4: Explanation of selection and setting elements

12.5.5 Review 86 % or 2nd Moment (menu *Presentation > Review (86%)/(Sec. Moments)*)

For the radius definition there are two basic determination possibilities:

- Determination of the beam radii according to the 86% - power definition, (see chapter 21.2.4 on page 130).
- Determination of the beam radii according to the 2nd moment method (ISO 11146), (see chapter 21.2.3 on page 129).

LQM.foc - 86% Review

Plane:	Plane 0	Plane 1	Plane 2	Plane 3	Plane 4	Plane 5	Plane 6	Plane 7	Plane 8	Plane 9	Plane 10
Radius [mm]	0.100	0.092	0.084	0.075	0.067	0.060	0.053	0.046	0.040	0.035	0.030
Position X [mm]	0.152	0.146	0.143	0.137	0.131	0.126	0.122	0.115	0.109	0.103	0.097
Position Y [mm]	0.043	0.040	0.033	0.032	0.028	0.023	0.021	0.017	0.012	0.010	0.006
Position Z [mm]	142.700	143.400	144.100	144.800	145.500	146.200	146.900	147.600	148.300	149.000	149.700
Zero level [A/D-Cnts]	261.750	260.000	265.000	264.750	264.750	264.500	258.750	262.000	258.750	259.000	261.000
Power [kW]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Radius inten. [kW/cm²]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Peak inten. [kW/cm²]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Date:	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014
Time:	10:26:56	10:26:59	10:28: 7	10:27: 9	10:27:11	10:27:13	10:27:17	10:27:19	10:27:22	10:27:25	10:27:28
Focal length [mm]	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000
Z-axis-offset	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
X-axis-offset	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Y-axis-offset	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Coord.rotation [deg.]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wavelength [µm]	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064
Fill Factor	0.577	0.528	0.483	0.645	0.582	0.516	0.604	0.534	0.686	0.601	0.519
Comment:											

Tab. 12.5: Result window ***Review (86%)***

LQM.foc - 2. Moments Review

Plane:	Plane 0	Plane 1	Plane 2	Plane 3	Plane 4	Plane 5	Plane 6	Plane 7	Plane 8	Plane 9	Plane 10
Radius [mm]	0.102	0.093	0.085	0.076	0.069	0.061	0.053	0.046	0.039	0.035	0.031
Radius X [mm]	0.101	0.094	0.085	0.075	0.068	0.060	0.052	0.045	0.038	0.034	0.030
Radius Y [mm]	0.102	0.093	0.086	0.076	0.069	0.062	0.054	0.047	0.040	0.036	0.032
Angle [°] (x/y-plane)	37.7	-44.5	40.2	24.3	16.8	10.5	5.5	1.1	2.7	-0.8	-3.6
Position X [mm]	0.153	0.147	0.144	0.137	0.131	0.125	0.121	0.115	0.108	0.103	0.097
Position Y [mm]	0.042	0.039	0.033	0.031	0.028	0.023	0.021	0.017	0.013	0.010	0.007
Position Z [mm]	142.700	143.400	144.100	144.800	145.500	146.200	146.900	147.600	148.300	149.000	149.700
Zero level [A/D-Cnts]	261.750	260.000	265.000	264.750	264.750	264.500	258.750	262.000	258.750	259.000	261.000
Power [kW]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Peak inten. [kW/cm²]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Date:	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014
Time:	10:26:56	10:26:59	10:28: 7	10:27: 9	10:27:11	10:27:13	10:27:17	10:27:19	10:27:22	10:27:25	10:27:28
Focal length [mm]	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000
Z-axis-offset	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
X-axis-offset	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Y-axis-offset	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Coord.rotation [deg.]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wavelength [µm]	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064
Radius X' [mm]	0.102	0.093	0.085	0.076	0.068	0.060	0.052	0.045	0.038	0.034	0.030
Radius Y' [mm]	0.102	0.093	0.085	0.076	0.069	0.062	0.054	0.047	0.040	0.036	0.032
Fill Factor	0.584	0.537	0.491	0.655	0.592	0.526	0.608	0.531	0.674	0.597	0.530
Ellipticity (Rmin/Rmax)	0.991	0.988	0.987	0.988	0.985	0.978	0.968	0.958	0.955	0.949	0.948
RadiusX/RadiusX'	0.997	1.006	0.994	0.998	0.999	0.999	1.000	1.000	1.000	1.000	1.000
RadiusY/RadiusY'	1.003	0.994	1.006	1.002	1.001	1.001	1.000	1.000	1.000	1.000	1.000
3*RadiusX'/WindowsizeX	0.876	0.806	0.735	0.978	0.883	0.781	0.897	0.779	0.987	0.872	0.774
3*RadiusY'/WindowsizeY	0.878	0.806	0.737	0.986	0.894	0.797	0.927	0.813	1.033	0.919	0.816
Comment:											

Tab. 12.6: Result window ***Review (Sec. Moments)***

The parameters and results of the current selected plane are highlighted in blue. When the measuring signal only exceeds the zero level by a little bit, the measuring results are not shown in black, but rather in gray. In this case, check to see if the measuring values are reliable or need to be thrown out and the measurement repeated with different settings.

The entries for power, focal length, and wavelength as well as any comments can also be changed after the fact. For this purpose there is the button ***Apply*** in the menu item ***Measurement > Environment***.

12.5.6 Caustic (menu *Presentation > Caustic)*

The results of the caustic measurement can be displayed by means of the menu item ***Presentation > Caustic***. On the left Fig. 12.25 on page 70 shows the measured beam parameter either on the basis of the 86%-radii or the 2nd Moment evaluation according to ISO 11146. In the middle of the picture the graphic shows the caustic profile. The beam radii are depicted on the beam spread direction. On the right is a false color presentation of the measurement plane selected with the mouse shown together with numerical results of this corresponding plane.

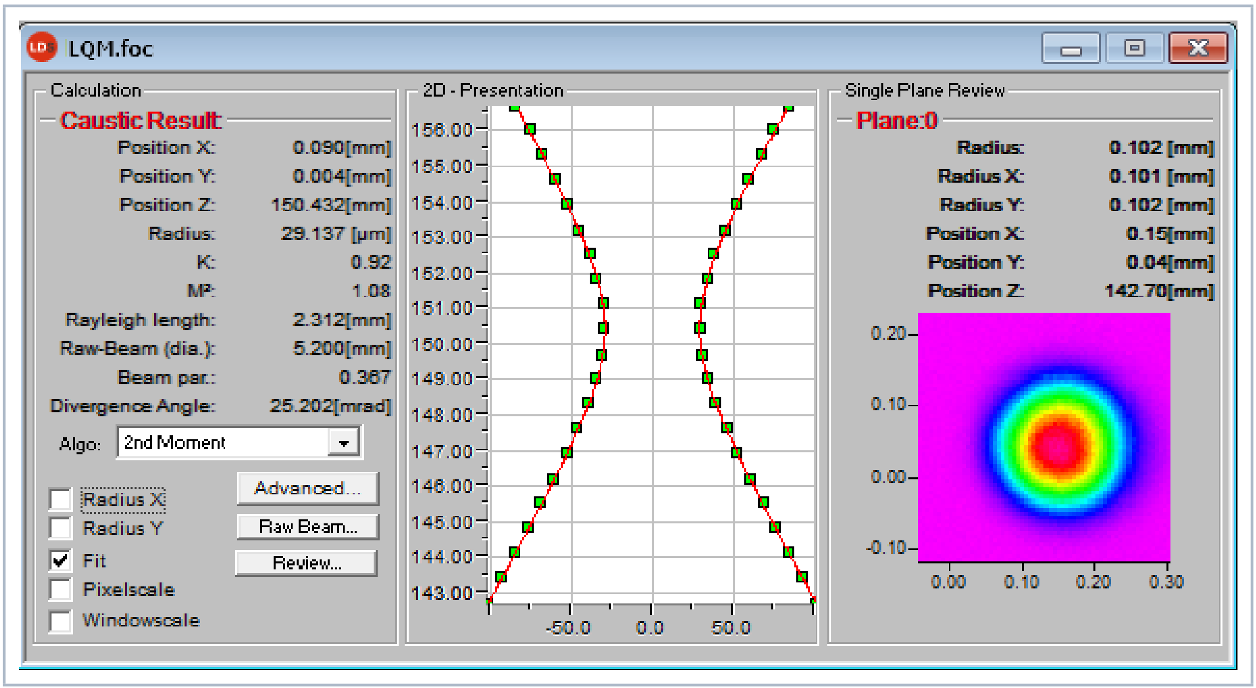


Fig. 12.25: Dialogue window ***Caustic***

The red line depicts a compensation curve according to the calculated fits which can be displayed via the check box ***Fit*** in the 2D presentation.

The raw beam diameter ***Raw Beam (dia.)*** corresponds to the beam diameter on the focussing optic, see Fig. 5.3 on page 15.

Compensating curve

In order to evaluate the caustic, a hyperbolic compensating curve (ISO 11146) is adapted to the measuring values. This compensating curve describes the propagation of an ideal laser beam mathematically. The development of the compensating curve is theoretically determined by means of the following parameters:

- Standardized beam quality factor M^2 or respectively beam propagation ratio K
- z-position
- focus radius
- rayleigh length

Standardized beam quality factor M^2 (or respectively the beam propagation ratio $K=\frac{1}{M^2}$)

The normed beam quality factor describes how well the affected laser beam can be focused in relation to the dominant mode. The basic mode represents the theoretically best possible beam and has a beam quality factor M^2 of 1. All other beams have higher M^2 values.

Z-position

This value provides the position of the focus points in the z-position. As the compensation curve takes the measurement points into consideration, the calculated z-position is not necessarily located at the position, which has measured the smallest radius.

Focus radius

The focus radius is the smallest beam radius in the caustic. Generally, this value is similar to the smallest value measured, but not necessarily.
Due to different reasons it may occur that the adaption to the measurement values was not carried out. This is the case if the compensation curve does not lie close to the measurement values. In this case the parameters of the adapted compensation curve are to be discarded.

Rayleigh length

The Rayleigh length is a derived parameter and describes the distance in z-direction with regard to which the beam radius has increased by the factor √2 (=1.41) and concerning which the beam area has increased by the factor 2. The Rayleigh length increases with the focal length of the focusing optics and the beam quality. The doubled Rayleigh length is an approximate point of reference, up to which material thickness (metal) a procession is possible with the optic employed.

In order to make sure that the adapted values have a high significance, the measurement is to be carried out in a z-range of at least ±2 Rayleigh-lengths. As demanded in the ISO 11146 5 to 6 Rayleigh-lengths would be ideal. However, this demand is often confronted with the problem of quickly sinking power densities of the laser beam which is to be measured. In case of a distance of 2 Rayleigh-lengths from the focus the power density has sunk to just a quarter.

In this case the caustic measurement consists of a compromise between the desired measurement range in z-direction and the power density (signal-to-noise ratio) necessary for a perfect measurement.

Cyclic caustic measurements

When performing cyclic caustic measurements, it is useful to store settings for various display parameters in a data file. This data is available anytime and can be reloaded for a new measurement. For a quick check of the beam or when it is necessary to measure only part of the caustic.

Cyclic measurements are normally performed over a period of 2 to 3 minutes; by Ethernet communication much quicker. For measurements after laser or system servicing, you should use more planes to achieve greater accuracy in the results.

To start a measurement, saved caustic data is loaded from the settings file. This is done through the menu item ***File > Load Settings***. The data is loaded after entering the desired file name.

Advanced (menu *Presentation* > *Caustic* > *Advanced)*

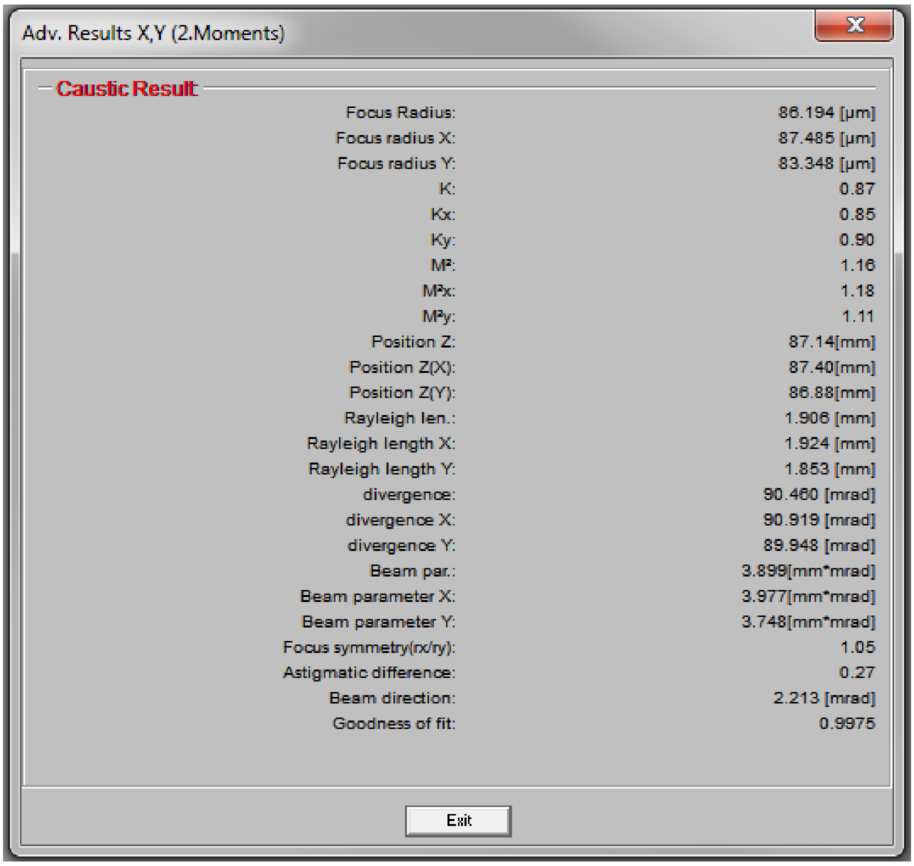


Fig. 12.26: Result window ***Results X,Y (2. Moment)***

For the examination of asymmetric beams the dimensions of the main axes of the beam can be determined. On the basis of these values the program also calculates direction dependent beam propagation factors as well as beam position values. The related curves are shown via the two check boxes radius x, y while the numerical values are provided by the result window.

Raw beam (menu *Presentation* > *Caustic* > *Raw Beam)*

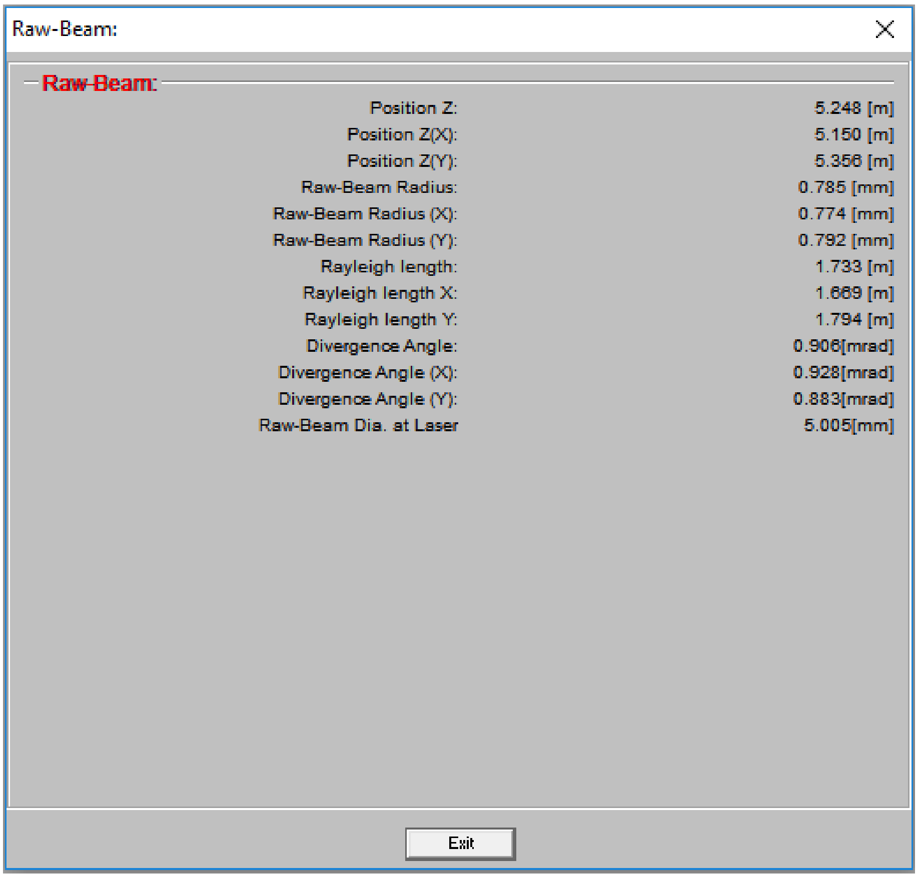


Fig. 12.27: Result window ***Raw Beam***

When measuring according to ISO 11146, the raw beam parameters can be recalculated from the internal caustic. The numeric values are also graphically displayed in the results window “raw beam”.

Review (menu *Presentation* > *Caustic* > *Review)*

This function checks whether the results and settings of the caustic measurement are within the reliable range.

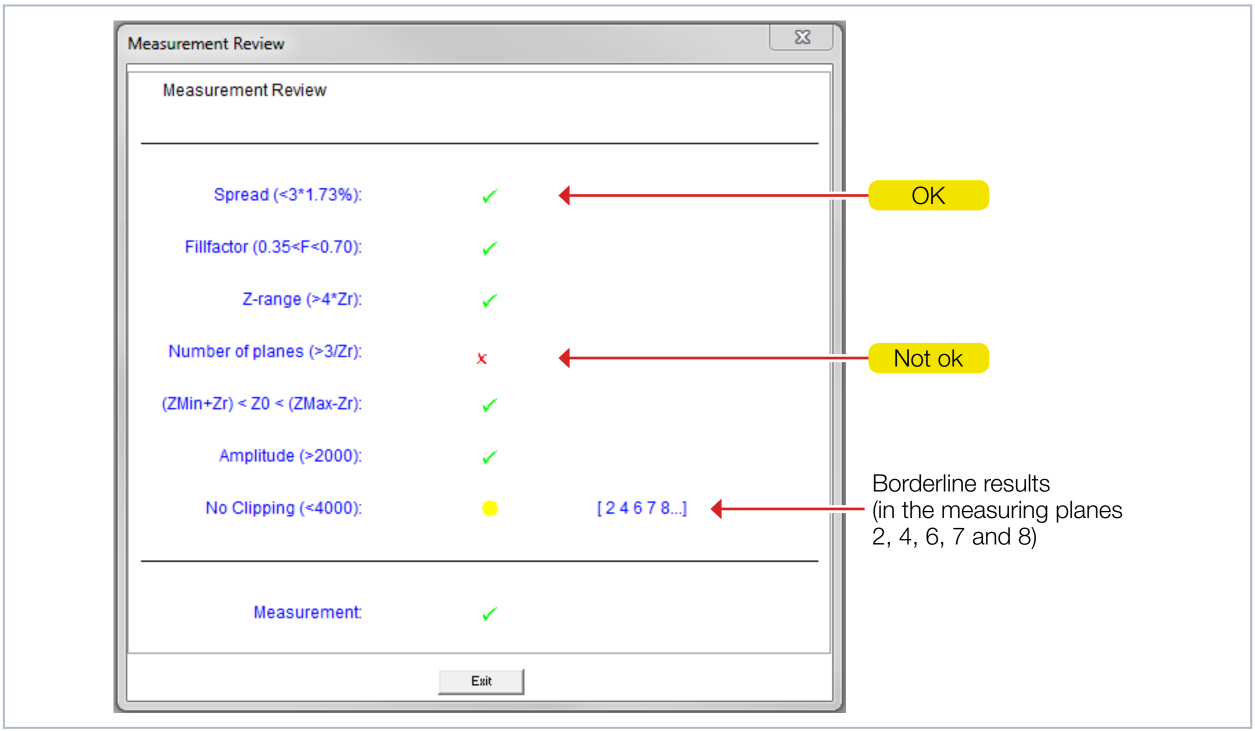


Fig. 12.28: Result window ***Measurement Review***

Under “spread” the average standard deviation of the caustic fit according to the 2nd moment method radii is stated. A “tick” (✓) is set if the standard deviation is smaller than 3.5 % and if all of the measuring values lie within a range of ± 3 % standard deviation.
When the divergence receives a negative assessment (**×**) the affected measuring planes are also displayed. The displayed planes are arranged from left to right, starting with the greatest divergence and working its way down. This means that the plane with the greatest divergence (see Fig. 12.28 on page 74 Plane 2) will be the first one in front.

Valued functions	Test criterion	Positive evaluation ✓
Spread	Average relative standard deviation of the caustic fit according to the 2nd moment method	Standard deviation < 3.5 %, all measurement values within a range of ± 3 % standard deviation
Fill factor	Describes the ratio of the beam diameter to the lengths of the sides of the measuring window	In the range 0.35 – 0.7
Z-range	Measuring range in z-direction	At least 4 Rayleigh-lengths
Measurement planes	Number of measurement planes per Rayleigh length	At least 3 measurement planes per Rayleigh length
$(Z_{Min}+Z_r) < Z_0 < (Z_{Max}-Z_r)$	Minimum measurement range above and below the focusing plane	The focus lies within the minimum measurement range and this range accounts for at least one Rayleigh length in every z-direction
Amplitude (>2000)	Signal control	Above 2000 counts
No Clipping (<4000)	Signal control	Below 4000 counts

Tab. 12.7: Criteria for the evaluation

If all criteria are fulfilled, the measuring results have a high reliability. The absolute accuracy can not be stated from the standard deviation from the fits as all the systematic measuring errors as well as the accuracy of the calibration are additionally taken into account when it comes to the absolute error.

12.5.7 Raw beam (menu *Presentation* > *Raw-beam)*

Actually, the parameter of the focussed beam is in the foreground during a measurement, but that is not the case with the LaserQualityMonitor LQM: recalculated data of the raw beam is the result of the measurement and therefore of note. For that reason an additional window can be found in the LaserDiagnosticsSoftware LDS.

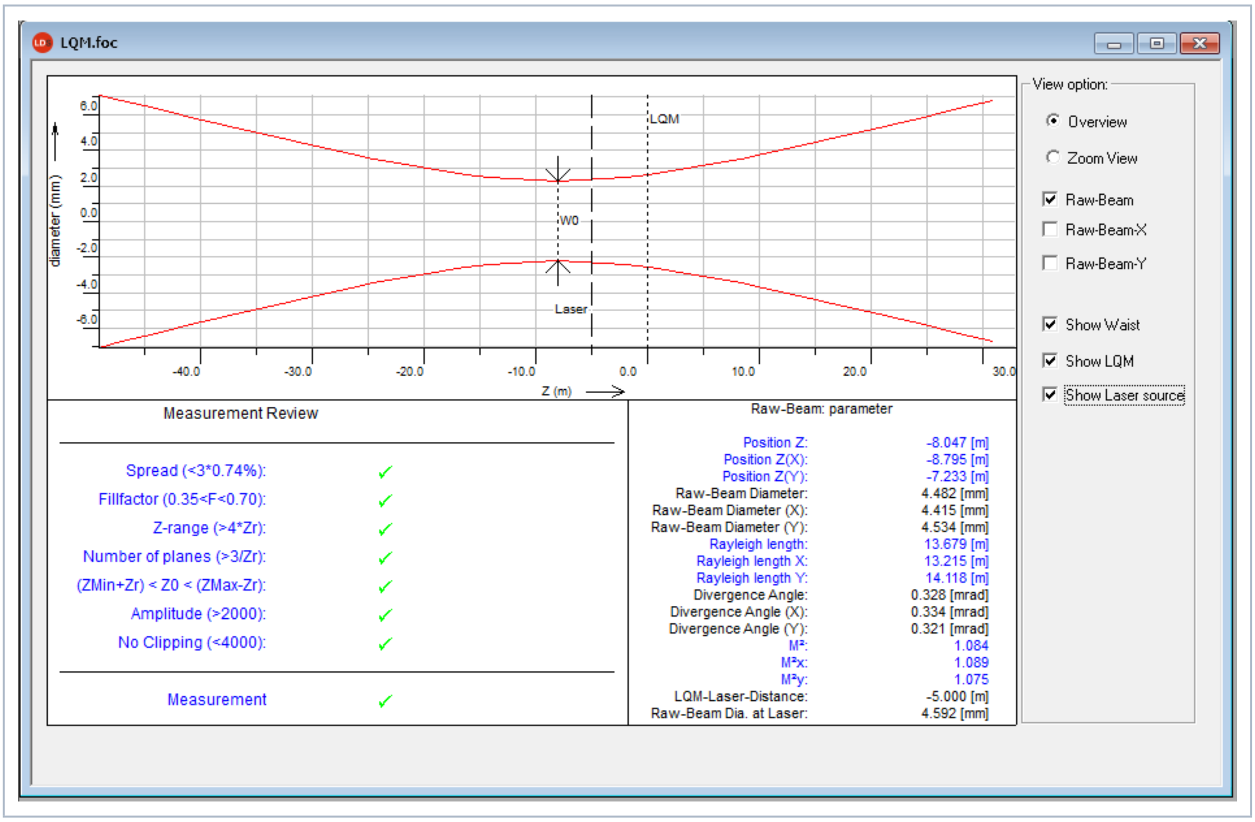


Fig. 12.29: Display of the recalculated data of a raw beam

The recalculated data of the raw beam regarding the measuring device is displayed in this window. Additionally, it is possible to enter a device offset in the window ***Measurement*** **>** ***Environment***. It calculates the distance between the measuring device inlet and the beam exit at the laser. This enables the user to get a fast overview of the beam waist's position regarding the measuring device or the beam exit at the laser. Furthermore, even any important beam parameter can be found in table form in that window.

The measuring planes in detail cannot be seen in this window. Thus, a direct, visual inference to the quality of the measurement is no longer possible. For this reason, not only raw beam parameters are shown, but even results of a numerical estimation of this measurement can be seen.

12.5.8 Symmetry check (menu *Presentation* > *SymmetryCheck*)

This display menu checks the rotational symmetry of the power density distribution of a laser beam. It can, for instance in connection with the monitoring operation (***Measurement > Single > Monitor***), be used for the alignment of laser resonators.
In the following, the figures Fig. 12.31 on page 76 and Fig. 12.32 on page 77 show two examples for the possible results of a symmetry check at an elliptic beam and a circular beam.

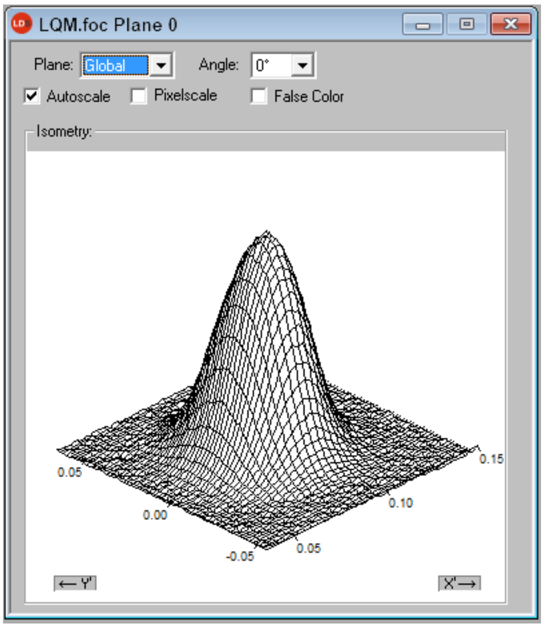


Fig. 12.30: Dialogue window (menu ***Presentation > Isometry***) power density distribution of an elliptic beam

The power density distribution of an elliptical beam as shown in Fig. 12.30 on page 76 together with the ***Symmetry check*** comes to the following results.

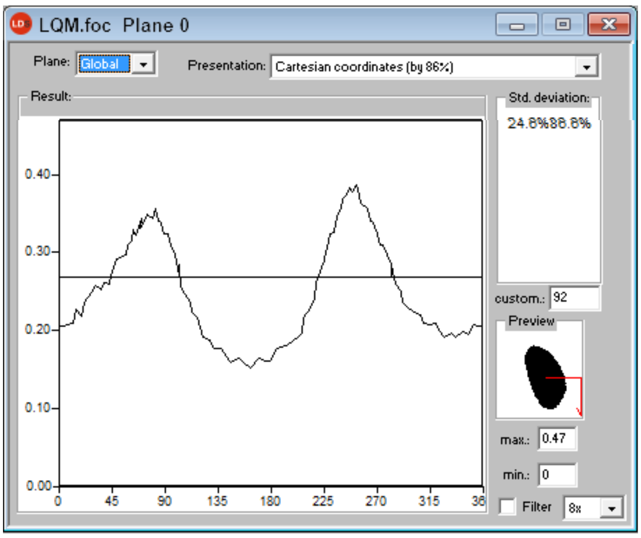


Fig. 12.31: Dialoque window ***Symmetry check*** in cartesian coordinates of an elliptic beam

The abscissa in Fig. 12.31 on page 76 shows the angle and the ordinate shows the beam radius with the intersection line at 86 % of the total power.

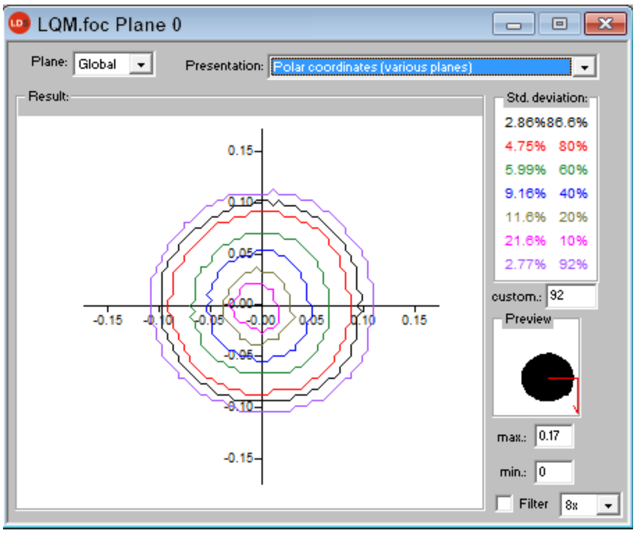


Fig. 12.32: Dialoque window ***Symmetry check*** in polar coordinates of an elliptic beam

On the screen the curves appear in different colors. The radius is indicated in pixel coordinates. The minimum as well as the maximum of the radius values can be chosen. On the right side the standard deviation of the different radius values are indicated. These values give detailed information on the symmetry of the beam distribution.

Well aligned resonators reach standard deviations in the range of 3 % to 5 %. Partially, values in a 1 % and 2 % range are possible.
A presentation in polar coordinates is also possible (Fig. 12.32 on page 77). The drawn in lines contain 86 % up to 10 % of the detected power. On the screen the graphs have different colors. X- and y-axis scale in pixel values.

12.5.9 Fixed contour lines (menu *Presentation* > *Fixed Contour Lines*)

The contour lines are displayed with different power levels. Intersection lines are selected with: 86 %, 80 %, 60 %, 40 %, 20 % and 10 % of the total power.
In this presentation it is also possible to measure distances by clicking the start and end points with the mouse.

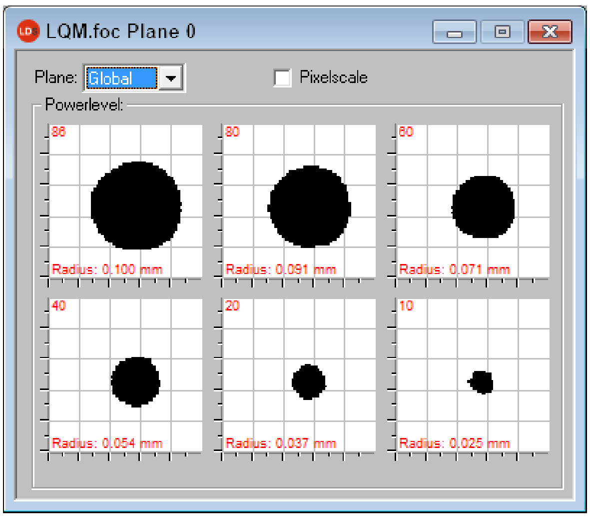


Fig. 12.33: Dialoque window ***Fixed contour lines***

12.5.10 Variable contour lines (menu *Presentation* > *Variable Contour Lines*)

Here the spatial power density distribution is displayed by means of freely selectable contour lines. Not only intersections in x- and y- direction but also in power density coordinates (A/D-converter-counts) can be carried out. The position of the intersections is settable by means of a slide control or the keyboard.

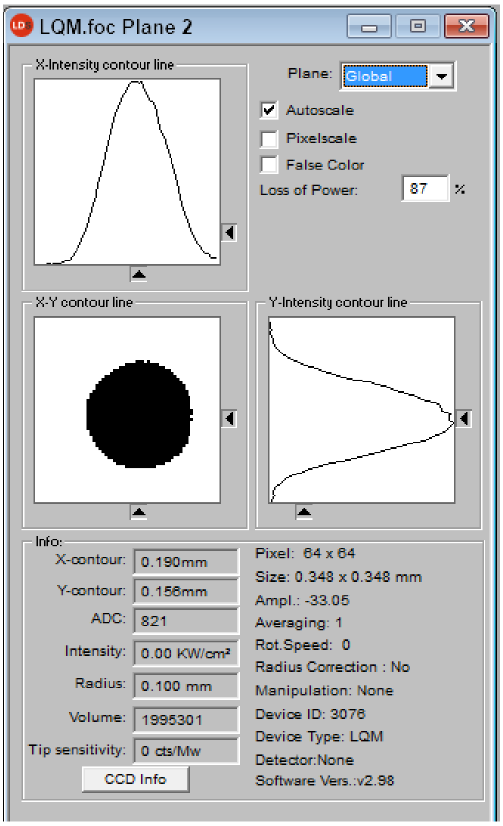


Fig. 12.34: Dialoque window ***Variable contour lines***

Setting by means of the keyboard:

- For the x-direction by means of the key ***x*** in order to increase the value and ***<shift> x*** in order to decrease it.
- For the y-direction by means of the key ***y*** in order to increase the value and ***<shift> y*** in order to decrease it.
- For the power density (intensity) by means of the key **i** in order to increase the value and ***<shift> i*** in order to decrease it.

In the range of the left hand lower corner the current intersection coordinates, the power densities, the radius generated by the intersection as well as the relative volume are displayed. The values are calculated basing on the correctly entered laser power.

In the right hand upper corner it is possible to switch the scaling. Below it, there is an input field where the desired power loss (-inclusion) can be entered. This value correlates to the given power levels in the window.

In addition to these functions, this window also offers plenty of additional information on the conditions under which measurements are taken. The amplification, resolution number, and the software version used for measuring are all displayed while measuring as well.

One click on the ***CCD Info*** button will open a window with additional information on the device parameters such as trigger mode, trigger delay, integration duration, magnification, and focussing optic type.

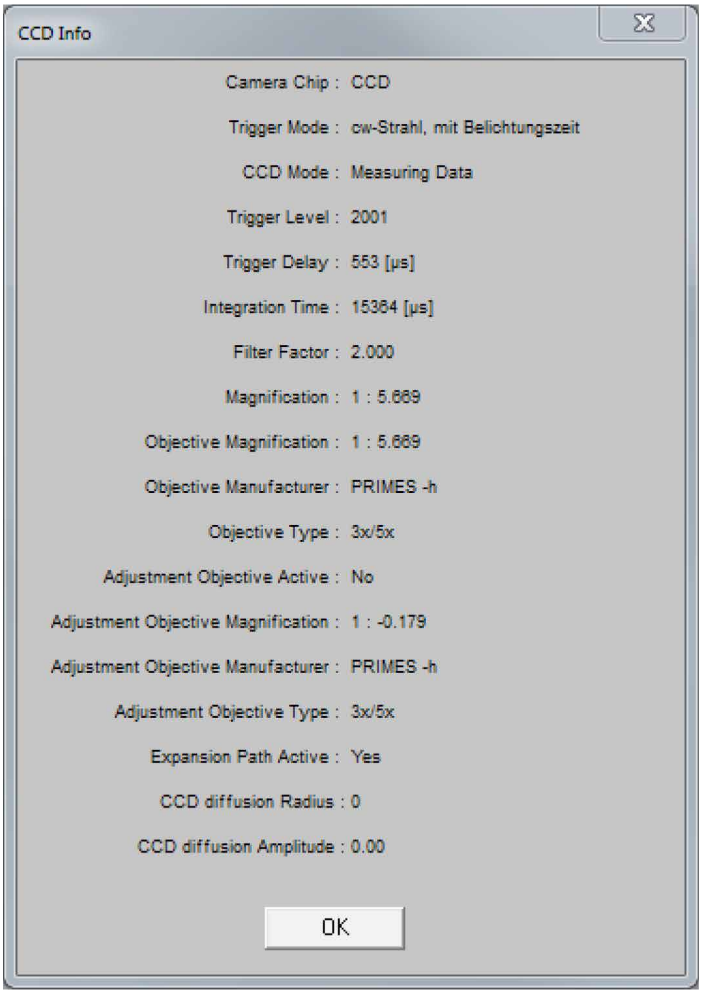


Fig. 12.35: Display window ***CCD Info***

12.5.11 Graphical review (menu *Presentation* > *Graphical Review*)

The display window ***Graphical review*** offers many possibilities to display the measurement values of the single measurement planes. In total this window can present 20 different graphs. The possible selections for the x- and y-coordinates are shown in the Tab. 12.8 on page 80.

y-axis	x-axis
Radius	Power
x-position	Time
y-position	Plane
Angle	Position
Ellipticity	

Tab. 12.8: Selections for the x/y coordinates

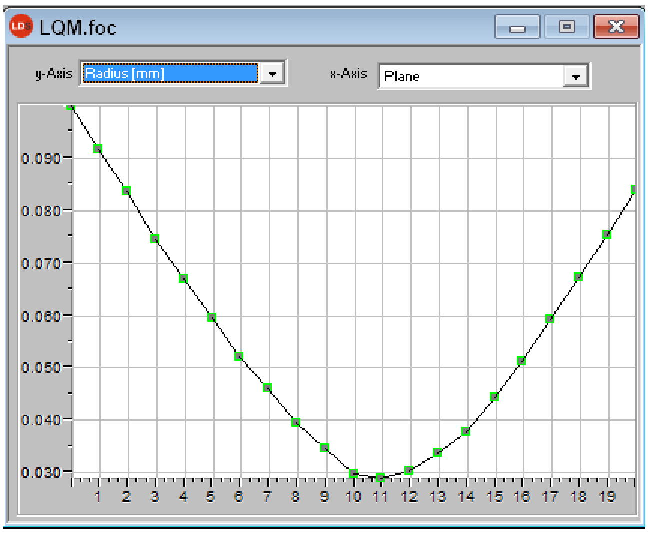


Fig. 12.36: Display window ***Graphical review*** – Example for assessment of a time series - radius/time

See chapter 12.4.9 on page 60, Section „Manual caustic measurement as time series (menu Measurement > Caustic > Manually adjusted)“.

12.5.12 Systemstate (menu *Presentation* > *Systemstate*)

Not relevant for LaserQualityMonitor LQM.

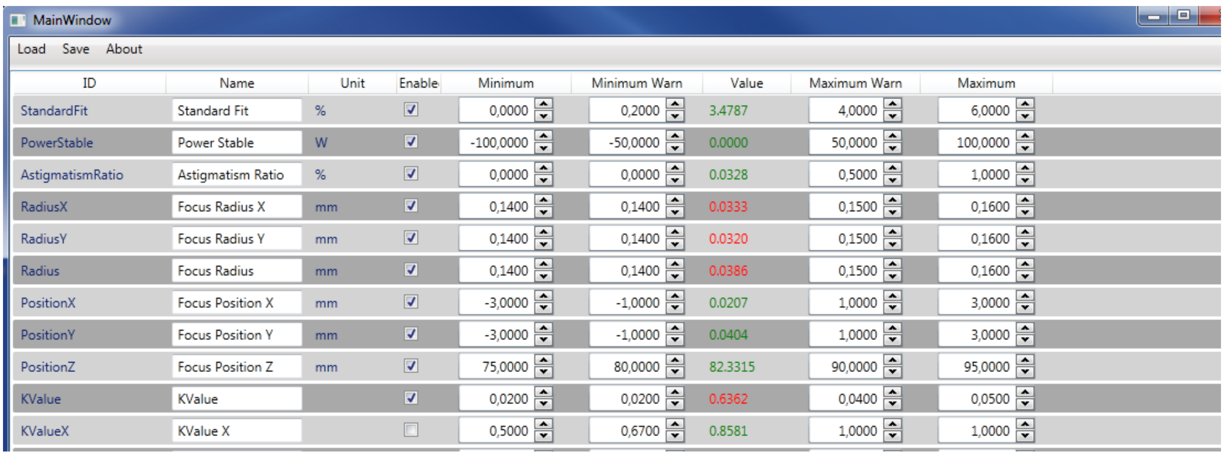
12.5.13 Evalution parameter view (menu *Presentation* > *Evalution Parameter View*)

In the directory “System“ in the LDS installation file (C:\Program\Primes\LDS2.98\System) you can find predefined parameter files for the raw beam retrograde calculation (RawBeamParams.eval) and the caustic evaluation (beamparams.eval). These can be pulled up under the menu point ***Presentation* > *Evaluation Parameter View***.

	Min	Warn	Actual	Warn	Max
Standard Fit [%]	0.00	0.50	3.48	3.00	5.00
Power Stable [W]	-100	-50	0	50	100
Astigmatism Ratio [%]	0.00	0.00	0.03	0.50	1.00
Focus Radius X [mm]	0.0100	0.0300	0.0333	0.0500	0.1000
Focus Radius Y [mm]	0.0100	0.0300	0.0320	0.0500	0.1000
Focus Radius [mm]	0.0100	0.0300	0.0386	0.0500	0.1000
Focus Position X [mm]	-0.200	-0.100	0.021	0.100	0.200
Focus Position Y [mm]	-0.200	-0.100	0.040	0.100	0.200
Focus Position Z [mm]	80.000	82.000	82.332	85.000	90.000
KValue	0.50	0.67	0.64	1.00	1.00
KValue X	0.50	0.67	0.86	1.00	1.00
KValue Y	0.50	0.67	0.90	1.00	1.00
Caustic Min Power [W]	50	100	0	10000	10000
Caustic Max Power [W]	0	0	0	7500	8000
Caustic Mean Power [W]	0	50	0	7500	8000
BPP	0.200	0.250	0.532	0.750	1.000
M²	1.00	1.00	1.57	1.50	2.00
M² X	1.00	1.00	1.57	1.50	2.00
M² Y	1.00	1.00	1.57	1.50	2.00
BeamDirection [°]	0.00	0.00	0.36	2.00	3.00
BeamDirection X [°]	0.00	0.00	0.36	2.00	3.00
BeamDirection Y [°]	0.00	0.00	0.36	2.00	3.00
Rayleigh Length [mm]	0.01	0.03	2.80	10.00	30.00
Divergence [mrad]	0.05	0.10	10.00	0.35	0.40

Fig. 12.37: Display window ***Evalution Parameter View*** with opened parameter file

The desired parameters and their limit values can be stipulated by means of the program PRIMES-EvalEditor and can then be saved in the evaluation parameter file (*.eval). The program is automatically installed when the LDS-setup is carried out.



ID	Name	Unit	Enable	Minimum	Minimum Warn	Value	Maximum Warn	Maximum
StandardFit	Standard Fit	%	☑	0,0000	0,2000	3.4787	4,0000	6,0000
PowerStable	Power Stable	W	☑	-100,0000	-50,0000	0.0000	50,0000	100,0000
AstigmatismRatio	Astigmatism Ratio	%	☑	0,0000	0,0000	0.0328	0,5000	1,0000
RadiusX	Focus Radius X	mm	☑	0,1400	0,1400	0.0333	0,1500	0,1600
RadiusY	Focus Radius Y	mm	☑	0,1400	0,1400	0.0320	0,1500	0,1600
Radius	Focus Radius	mm	☑	0,1400	0,1400	0.0386	0,1500	0,1600
PositionX	Focus Position X	mm	☑	-3,0000	-1,0000	0.0207	1,0000	3,0000
PositionY	Focus Position Y	mm	☑	-3,0000	-1,0000	0.0404	1,0000	3,0000
PositionZ	Focus Position Z	mm	☑	75,0000	80,0000	82.3315	90,0000	95,0000
KValue	KValue		☑	0,0200	0,0200	0.6362	0,0400	0,0500
KValueX	KValue X		☐	0,5000	0,6700	0.8581	1,0000	1,0000

Fig. 12.38: Dialoque window EvalEditor with loaded *.eval-file

The evaluation parameter file can only be displayed if the file **BeamControls.xsd** is located in the same directory (C:\Program\Primes\LDS2.98\System)!

12.5.14 Evaluate document (menu *Presentation* > *Evaluate doc*)

The evaluation function compares selectable beam parameters and their adjustable limit values with the results of a current or a saved measurement.
Under the menu point ***Presentation*** **>** ***Evaluate doc*** of the LDS, the following dialog window is opened:

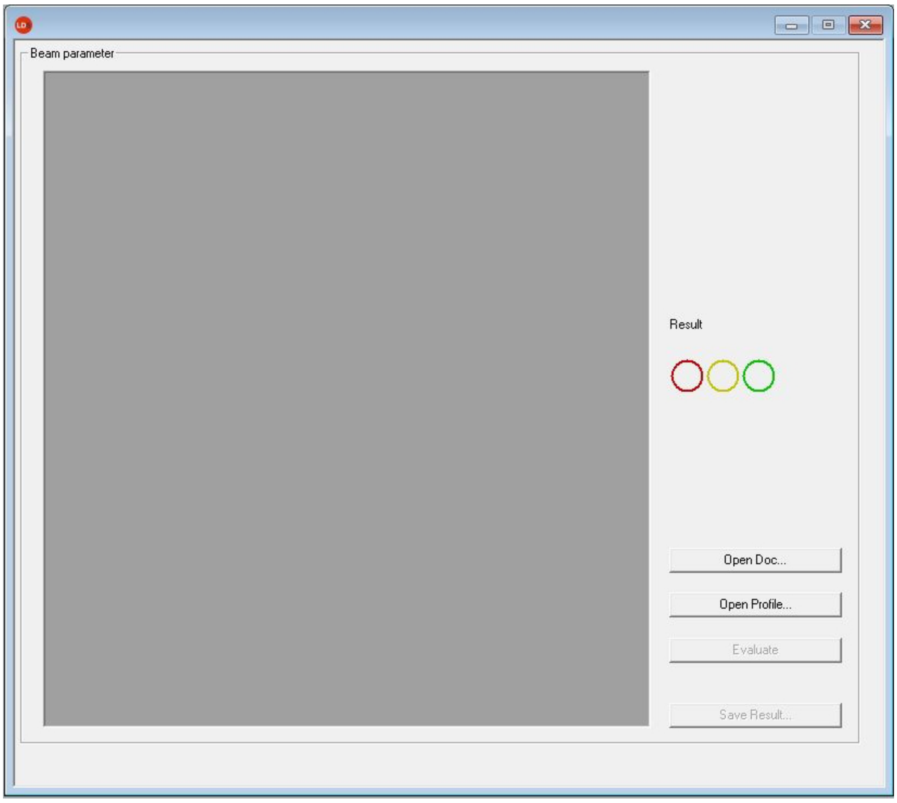


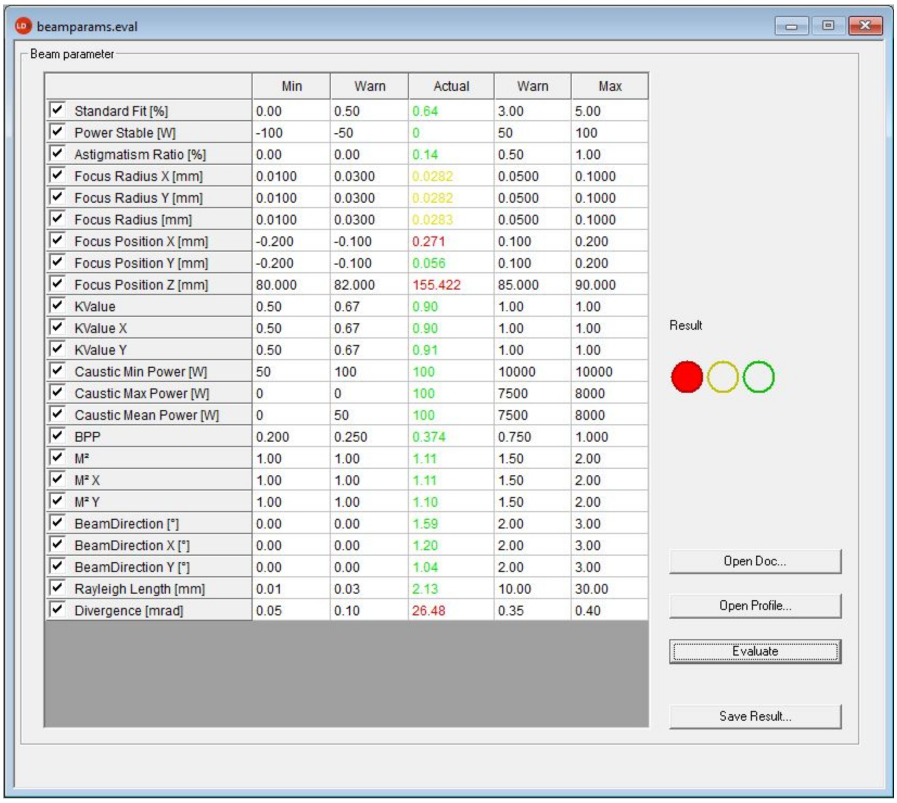
Fig. 12.39: Dialoque window ***Evaluate Document*** for loading an evaluation file

The button ***Open Doc*** opens a file selection window that allows to choose a saved measuring file (*.foc).

The button ***Open Profile*** opens a file selection window for choosing an evaluation parameter file (*.eval).

The button ***Evaluate*** triggers an evaluation (see Fig. 12.40 on page 83). The single evaluation parameters and the result of the evaluation are displayed. The overall evaluation (Result) of all results is displayed by means of a traffic light symbol.

Evaluation Criteria: Only if all single evaluations are ok, the overall evaluation is displayed in green in the traffic light symbol.



	Min	Warn	Actual	Warn	Max
Standard Fit [%]	0.00	0.50	0.64	3.00	5.00
Power Stable [W]	-100	-50	0	50	100
Astigmatism Ratio [%]	0.00	0.00	0.14	0.50	1.00
Focus Radius X [mm]	0.0100	0.0300	0.0282	0.0500	0.1000
Focus Radius Y [mm]	0.0100	0.0300	0.0282	0.0500	0.1000
Focus Radius [mm]	0.0100	0.0300	0.0283	0.0500	0.1000
Focus Position X [mm]	-0.200	-0.100	0.271	0.100	0.200
Focus Position Y [mm]	-0.200	-0.100	0.056	0.100	0.200
Focus Position Z [mm]	80.000	82.000	155.422	85.000	90.000
KValue	0.50	0.67	0.90	1.00	1.00
KValue X	0.50	0.67	0.90	1.00	1.00
KValue Y	0.50	0.67	0.91	1.00	1.00
Caustic Min Power [W]	50	100	100	10000	10000
Caustic Max Power [W]	0	0	100	7500	8000
Caustic Mean Power [W]	0	50	100	7500	8000
BPP	0.200	0.250	0.374	0.750	1.000
M²	1.00	1.00	1.11	1.50	2.00
M² X	1.00	1.00	1.11	1.50	2.00
M² Y	1.00	1.00	1.10	1.50	2.00
BeamDirection [°]	0.00	0.00	1.59	2.00	3.00
BeamDirection X [°]	0.00	0.00	1.20	2.00	3.00
BeamDirection Y [°]	0.00	0.00	1.04	2.00	3.00
Rayleigh Length [mm]	0.01	0.03	2.13	10.00	30.00
Divergence [mrad]	0.05	0.10	26.48	0.35	0.40

Fig. 12.40: Dialoque window ***Evaluate***

In case the warning or limit values are exceeded, this has an influence on the color display of the traffic light symbol. As soon as a warning value is exceeded or fallen short of, the yellow circle is filled. If the limit values (min/max) are exceeded or fallen short of, the red circle is filled. The actual values in the table of the evaluation window are marked in color as well.

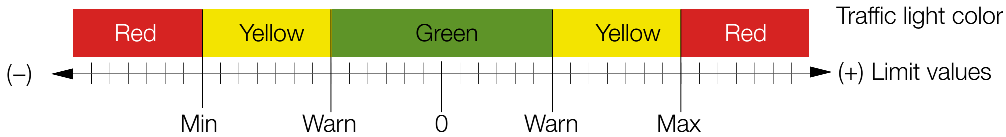


Fig. 12.41: Traffic light colors when warn- and limit values are exceeded

The overall result of the evaluation can be saved by means of the button ***Save***.

12.5.15 Color tables (menu *Presentation* > *Color Tables*)

Different color charts are available. It is possible to switch back and forth between the color charts. Thus the assignment of A/D converter values and different color scales can be varied. This is important for the false color presentation.

Three settings are possible:

- Linear color table (basic setting)
- Color table analogue to the root function
- Color table analogue to the fourth root function

These functions can especially be helpful as far as the analysis of slight variations near the zero level are concerned; e.g. the analysis of diffraction phenomena.

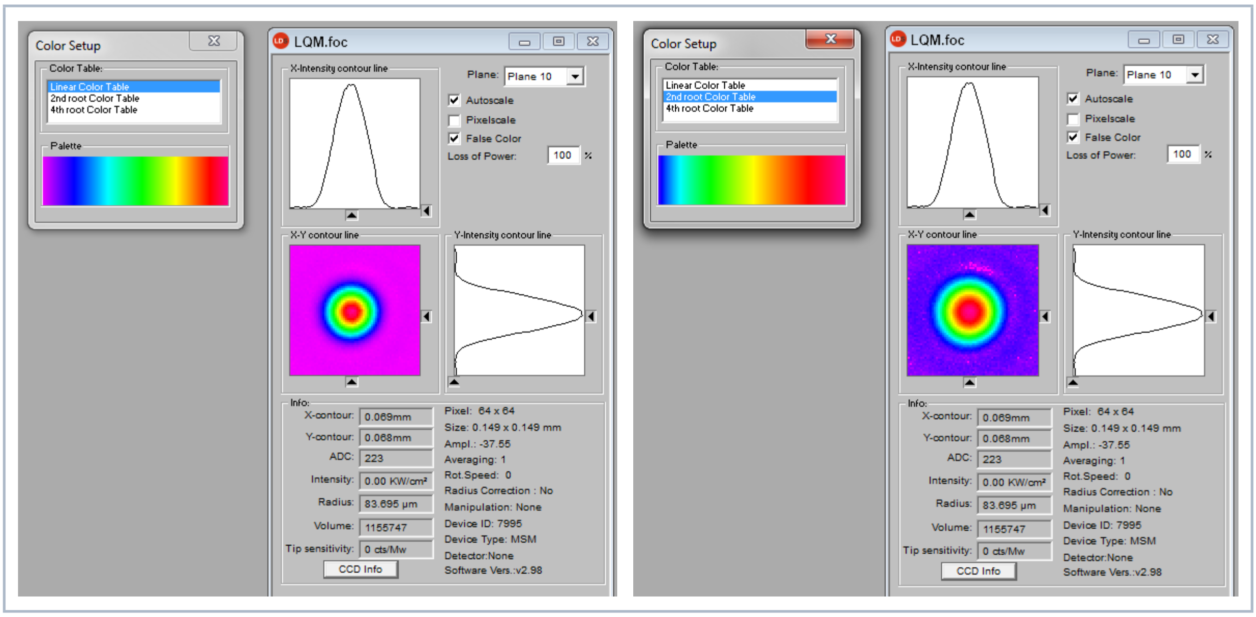


Fig. 12.42: Dialoque window ***Color Setup*** – Linear color table and 2nd root color table

12.5.16 Toolbar (Menu *Presentation* > *Toolbar*)

The toolbar can be shown or hidden by clicking ***Presentation*** **>** ***Toolbar*** in the menu.

Fig. 12.43: Showing or hiding the toolbar

12.5.17 Position (menu *Presentation* > *Position*)

This menu can be used to move the device to its parked position.

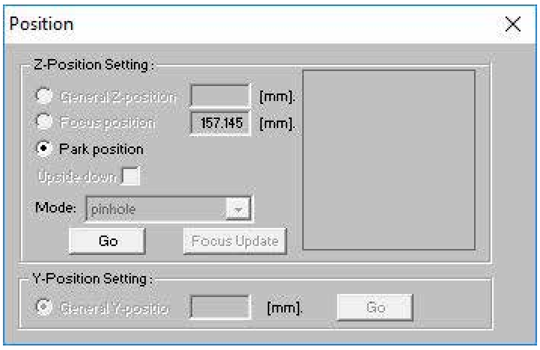


Fig. 12.44: Dialoque window ***Postition***

12.5.18 Evaluation (option) (menu *Presentation* > *Evaluation*)

By means of this evaluation function, you can compare and evaluate different parameters of the measured caustic (.foc-file) with specified limit values (.pro-file). The evaluation result is displayed optically with an LED symbol (red=bad, green=good). The overall result (field Conclusion) is only considered as good provided that all results are within the critical parameters (☆).

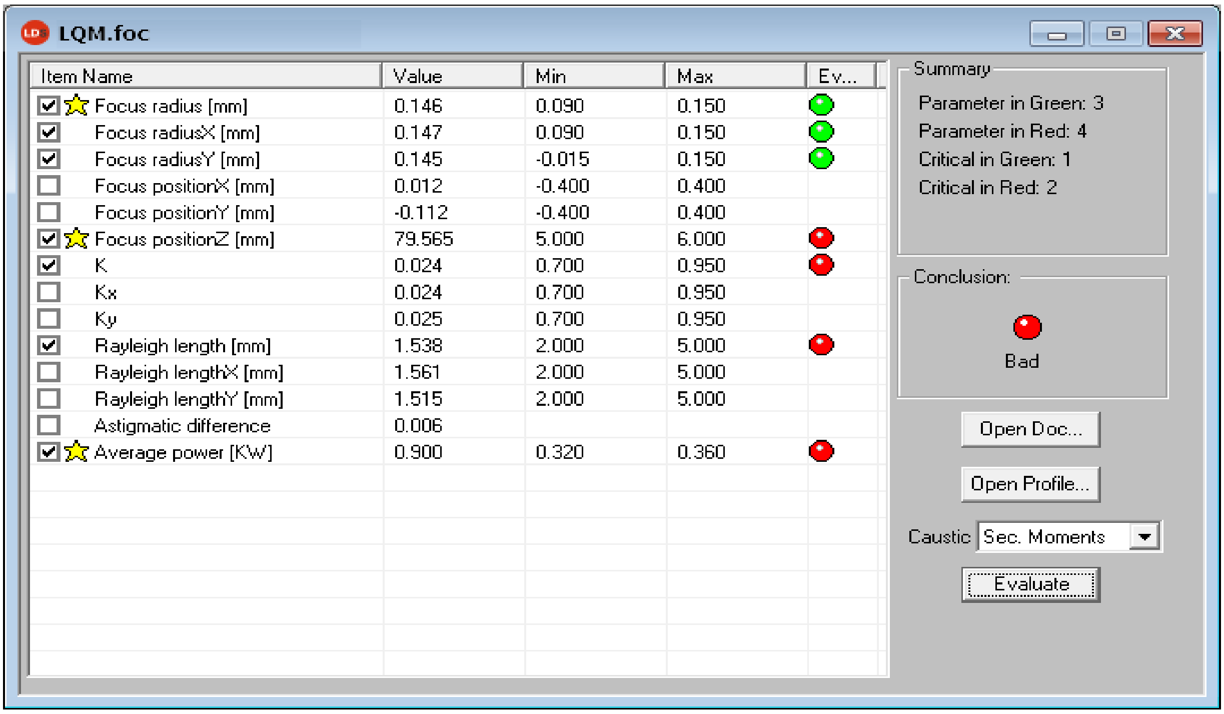
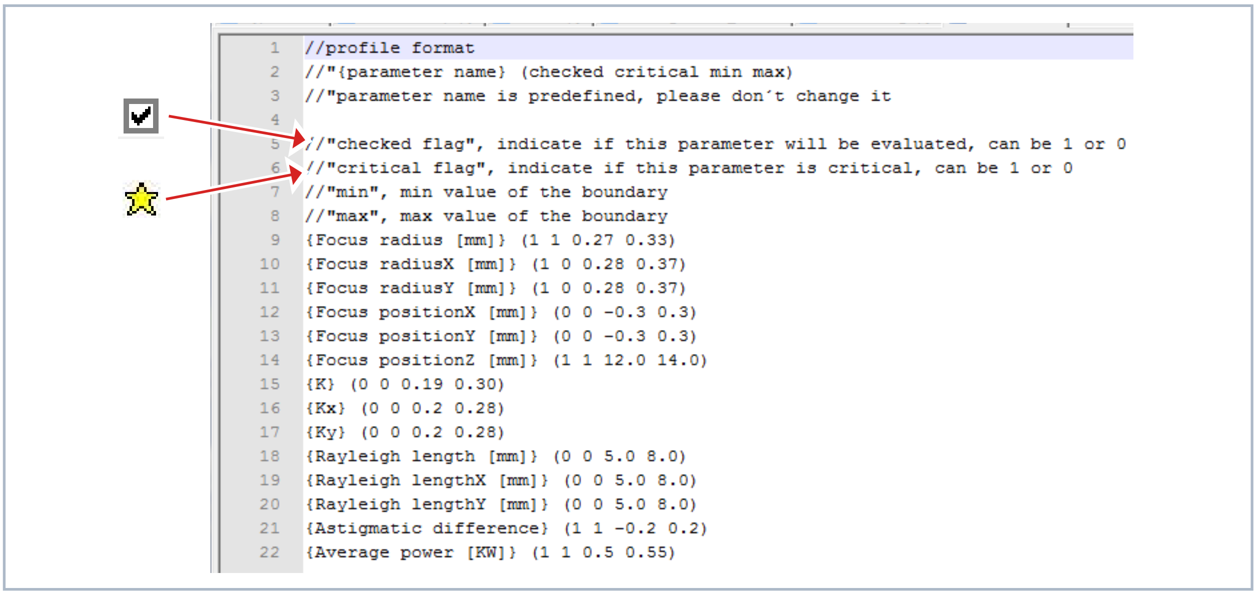


Fig. 12.45: Dialoque window ***Evaluation***

The parameters, the limit values and the identification of critical values are purported in a profile file (text file, please see the example file in Fig. 12.46 on page 86).



```
//profile format
//"{parameter name} (checked critical min max)
//"parameter name is predefined, please don´t change it

//"checked flag", indicate if this parameter will be evaluated, can be 1 or 0
//"critical flag", indicate if this parameter is critical, can be 1 or 0
//"min", min value of the boundary
//"max", max value of the boundary
{Focus radius [mm]} (1 1 0.27 0.33)
{Focus radiusX [mm]} (1 0 0.28 0.37)
{Focus radiusY [mm]} (1 0 0.28 0.37)
{Focus positionX [mm]} (0 0 -0.3 0.3)
{Focus positionY [mm]} (0 0 -0.3 0.3)
{Focus positionZ [mm]} (1 1 12.0 14.0)
{K} (0 0 0.19 0.30)
{Kx} (0 0 0.2 0.28)
{Ky} (0 0 0.2 0.28)
{Rayleigh length [mm]} (0 0 5.0 8.0)
{Rayleigh lengthX [mm]} (0 0 5.0 8.0)
{Rayleigh lengthY [mm]} (0 0 5.0 8.0)
{Astigmatic difference} (1 1 -0.2 0.2)
{Average power [KW]} (1 1 0.5 0.55)
```

Fig. 12.46: Example for a profile file

An evaluation is carried out as follows:

1. Click the button ***Open Doc*** and choose your measuring file (.foc-file).
2. Click the button ***Open Profile*** and choose your profile file (.pro-file).
3. Choose the desired radius definition in the selection ***Caustic***.
4. Click on the button ***Evaluate***.

12.6 Communication

12.6.1 Rescan bus (menu *Communication* > *Rescan bus*)

This menu can be used to reconnect a device that was connected previously.

12.6.2 Free communication (menu *Communication* > *Free Communication*)

By means of this menu you can control the communication via the PRIMES bus. Moreover, the settings for the communication are made here (see chapter 11.3.2 on page 35).

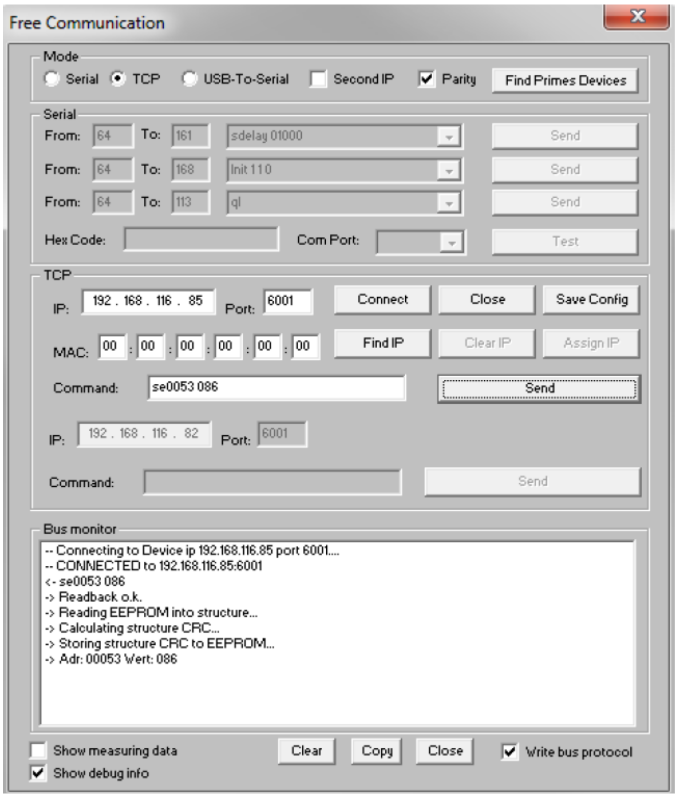


Fig. 12.47: Dialoque window ***Kommunikation*** > ***Freie Kommunikation***

12.6.3 Scan device list (menu *Communication* > *Scan device list*)

Every PRIMES device has a certain bus address. If a device is supposed to be controlled by means of the LaserDiagnosticsSoftware LDS, the address has to be entered here. Moreover addresses can also be added or deleted in this menu.

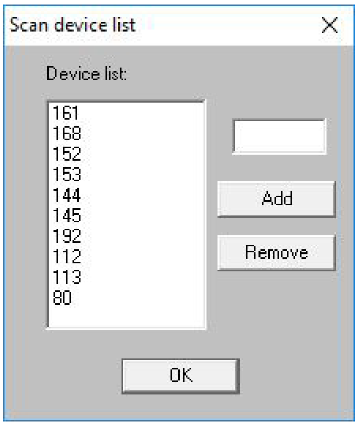


Fig. 12.48: Dialoque window ***Scan device list***

The following addresses for all PRIMES devices may be listed in the device list:
80, 92, 112, 113, 114, 144, 145, 152, 161, 168
For the LaserQualityMonitor LQM, the address 168 must be entered.

12.7 Script

By means of scripts complex measurement procedures can be controlled automatically. Scripts are programs which are written in several script languages. Scripts are almost exclusively provided as source files in order to enable an easy editing and adjustment of the program.

12.7.1 Editor (menu *Script* > *Editor)*

By means of the script editor you can draw up scripts which can control, for example, complex measuring procedures automatically. An example is given in Fig. 12.49 on page 89 – the beam find procedure with the LaserQualityMonitor LQM.
In order to open the script, the Open symbol has to be clicked, then a file can be chosen and played by using the button ▶. The button ❚❚ stops and ■ ends the script.

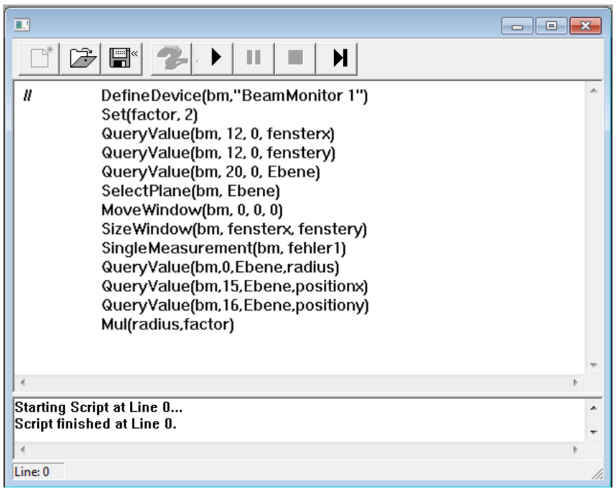


Fig. 12.49: Dialoque window ***Script*** – Script for the beam find procedure of the LaserQualityMonitor LQM

12.7.2 List (menu *Script* > *List)*

Here all available scripts are listed.

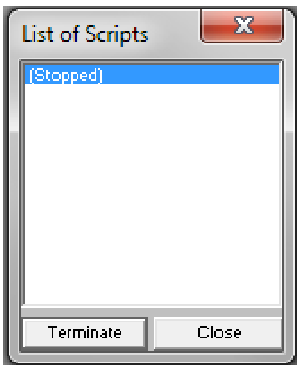


Fig. 12.50: Display window ***List of Scripts***

12.7.3 Python (menu *Script* > *Python)*

Starts the Python editor. The graphical user interface is identical to the one depicted in Fig. 12.49 on page 89. Python is a programming language with efficient abstract data structures and a simple but effective approach for an object-oriented programming. Python is not only suitable for scripts but also for a fast application development. For programming with Python a separate PRIMES documentation is available.

13 Measurement

13.1 Safety instructions

DANGER

Serious eye or skin injury due to laser radiation

During the measurement the laser beam is guided on the device, which causes scattered or directed reflection of the laser beam (laser class 4).

The LaserQualityMonitor LQM cannot be operated in any of the available configurations without taking the following precautions. All precautions must be taken, even when the fiber is in the collimator or fiber adapter

- ▶ Please 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 and protective gloves.
- ▶ Protect yourself from laser radiation by separating protective devices (e.g. by using appropriate shielding).

DANGER

Serious eye or skin injury due to laser radiation

If the device is moved from its calibrated position, increased reflected radiation (laser class 4) may result during measuring operation.

- ▶ When mounting the device, please ensure that it cannot be moved, neither due to an unintended push or a pull on the cables and hoses.

NOTICE

Damage/Destruction of the device (only in case of a HP-LQM II with 2nd attenuator)

If the safety circuit is not connected, the device may be damaged by overheating in the event of a fault.

- ▶ Connect the laser control to terminals 1 to 4 so that the laser shuts off when these connection is interrupted.

NOTICE

Damage/Destruction of the device

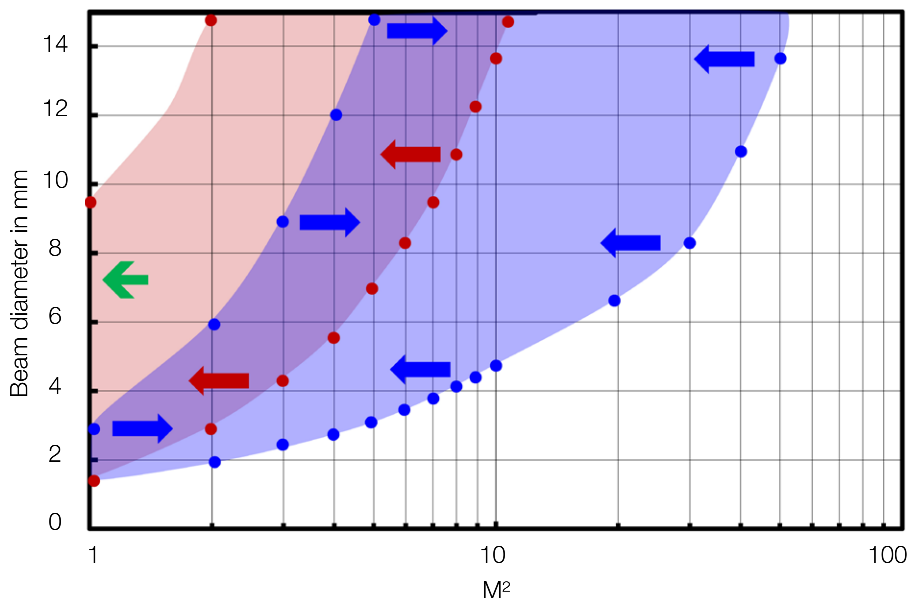
Due to the temperature control, an overtemperature of the device is indicated in the LaserDiagnosticsSoftware LDS, but the device is not protected against thermal damage.

- ▶ Turn the laser off immediately upon receiving notification of excess temperature in the LaserDiagnosticsSoftware LDS.
- ▶ For this reason, the LaserQualityMonitor LQM should never be left unattended while taking measurements.

13.2 Selection and change of the measuring objective and the neutral-density filter

13.2.1 Selection of the measuring objective

The selection of the correct measuring objective is of vital importance for the measurement quality. The limitation of use for the 1:1 or 5:1 measuring objectives is shown in the diagram Tab. 13.1 on page 91.



Tab. 13.1: Range of application of the LQM objectives

Blue area	→	1:1 measuring objective
Red area	→	5:1 measuring objective

$$d_{foc} = \frac{4 \cdot \lambda}{\pi} \cdot \frac{f_{200\mathrm{mm}}}{d_{rawbeam}} \cdot M^2$$

Example

The following example explains how a measuring objektiv is selected based on the minimum beam diameter in the LaserQualityMonitor LQM and the number of lit pixels to be achieved depending on the measuring objective (MOB).

λ = 1064 nm
M^2 = 1
$d_{rawbeam}$ = 7.3 mm

→ d_{foc} = 37.10 µm (d_{foc} = Focus diameter of the internal caustic)

For a fill factor of 35 % and a resolution of 64 pixel minimum 22 illuminated pixels are needed.

Quantity of illuminated pixels at 4.4 µm pixel pitch = $\frac{d_{foc}}{4.4\ \mu m} \cdot \beta$ (Magnification of the measuring objective 1 or 5)

MOB 1:1 --> 37.1 µm / 4.4 µm · 1 = 8 ✗
MOB 5:1 --> 37.1 µm / 4.4 µm · 5 = 42 ✓

13.2.2 Exchanging the measuring objective or the neutral-density filter

For changing a measuring objective or the neutral-density filter, the plate on the side of the LaserQualityMonitor LQM has to be opened:

1. Turn off the laser.
2. Press down two locking bolts (see Fig. 13.1 on page 92):
- The housing plate on the side will then jump out.

Optical components can be slid into the optical path of the LaserQualityMonitor LQM at three locations (see Fig. 13.1 on page 92, Positions 1, 2, 3).

Slot	Optical Component
1	5:1 Measuring objective
2	1:1 Measuring objective
3	Neutral-density filter (OD filter)
4, 5, 6	Storage slots for unused components

Tab. 13.2: Slot positions of the optical components

Important:
In order to prevent measurement errors, there should only ever be one measuring objective in the optical path at a time.

All insertions are coded differently via two dowels in order to keep the measuring objective and neutral-density filter from getting mixed up.

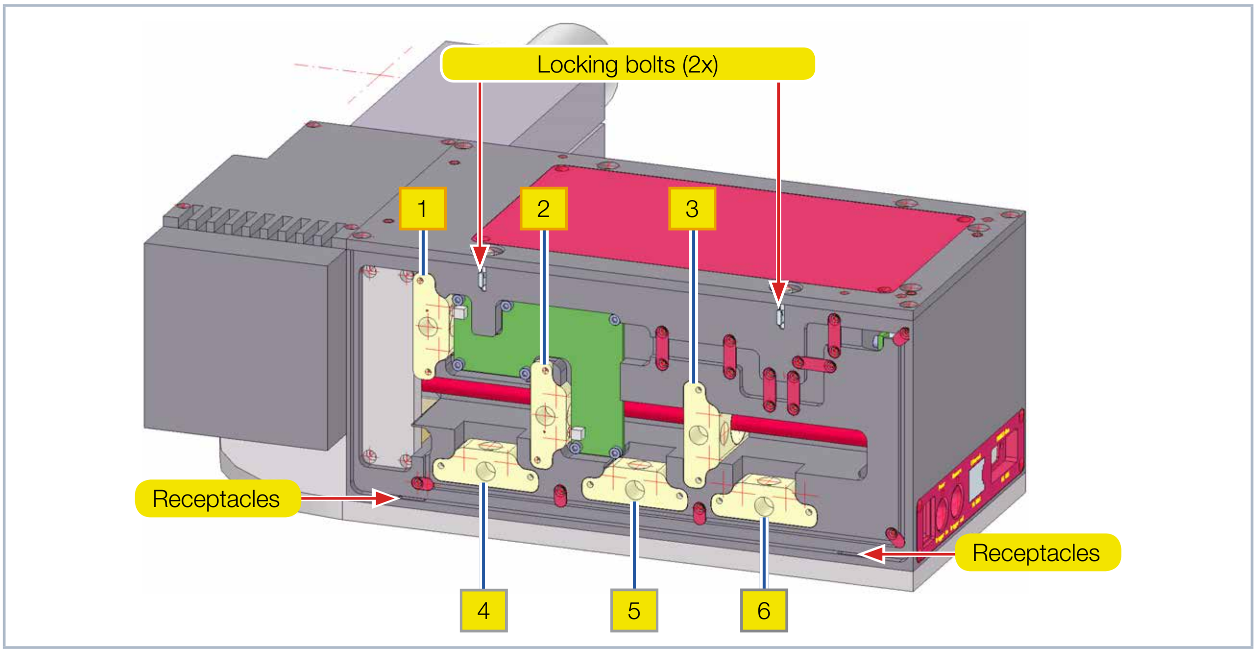


Fig. 13.1: Slot positions for the optical components

NOTICE

Damage of the device

Contamination in the device can damage the optical components.

▶ **Seal unused slots with the provided dummy inserts.**

Fig. 13.2: Dummy insert

DANGER

Serious eye or skin injury due to laser radiation

If the device is operated after the housing plate on the side has been removed, reflected beams (laser class 4) may leave the device in measuring mode.

▶ **Only operate the device with a mounted housing plate.**

3. Place the housing plate in the receptacles (see Fig. 13.1 on page 92) in the casing.
4. Flip the housing plate up until the two locking bolts clip into place.
5. Check that the housing plate is plan on the casing.

13.2.3 Neutral-density filter

Depending on laser beam source and configuration of the LaserQualityMonitor LQM, it can be necessary to reduce the power once more.
This is done with a neutral-density filter which is able to go into the beam path in front of the CCD sensor. The optical density of the filter can be varied between 1 (1:10) and 5 (1:100.000).

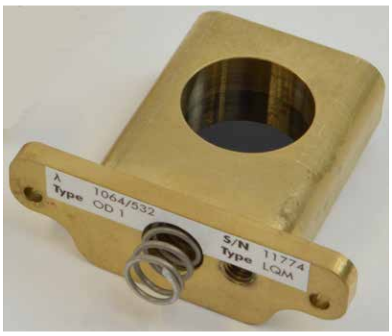


Fig. 13.3: Neutral-density filter

13.3 Align the laser beam with the LaserDiagnosticsSoftware LDS

After manually aligning the beam with the alignment tool, you can check the accuracy with a function of the LaserDiagnosticsSoftware LDS.

13.3.1 Align the laser beam at position z2 in the measuring window

1. Set the measuring objective to 1:1 at first so it's easier to detect the laser beam.
2. Open the dialog window ***Measurement > Individual Measurement*** and choose ***Video Mode*** in the ***Measuring Mode*** area (see Fig. 13.4 on page 94).
3. Enter the z-position under the slider
   (as an example for the LaserQualityMonitor LQM with 1:1 Measuring objective = 205 mm):
- LQM: 5:1 Measuring objective --->150 mm; 1:1 Measuring objective ---> 205 mm
- LQM UV: 5:1 Measuring objective ---> 55 mm; 1:1 Measuring objective ---> 61 mm
4. Choose the largest measuring window in the ***entry fields X and Y*** and arrange the section in the middle by holding down the left mouse button and dragging.
5. Click on the ***Start*** button.
- The LaserQualityMonitor LQM moves to the assumed focus position z2 of the caustic being measured and displays the constantly repeating measurements of the beam position in the measuring window.
6. Align the laser beam in such a way that the beam is positioned in the middle of the measuring window:
- For LaserQualityMonitor LQM with 1st attenuator module, slowly turn the micrometer screws and observe the changes to the beam position in the measuring window.
7. If the laser beam is oriented in the middle of the window, click on the ***Stop*** button.

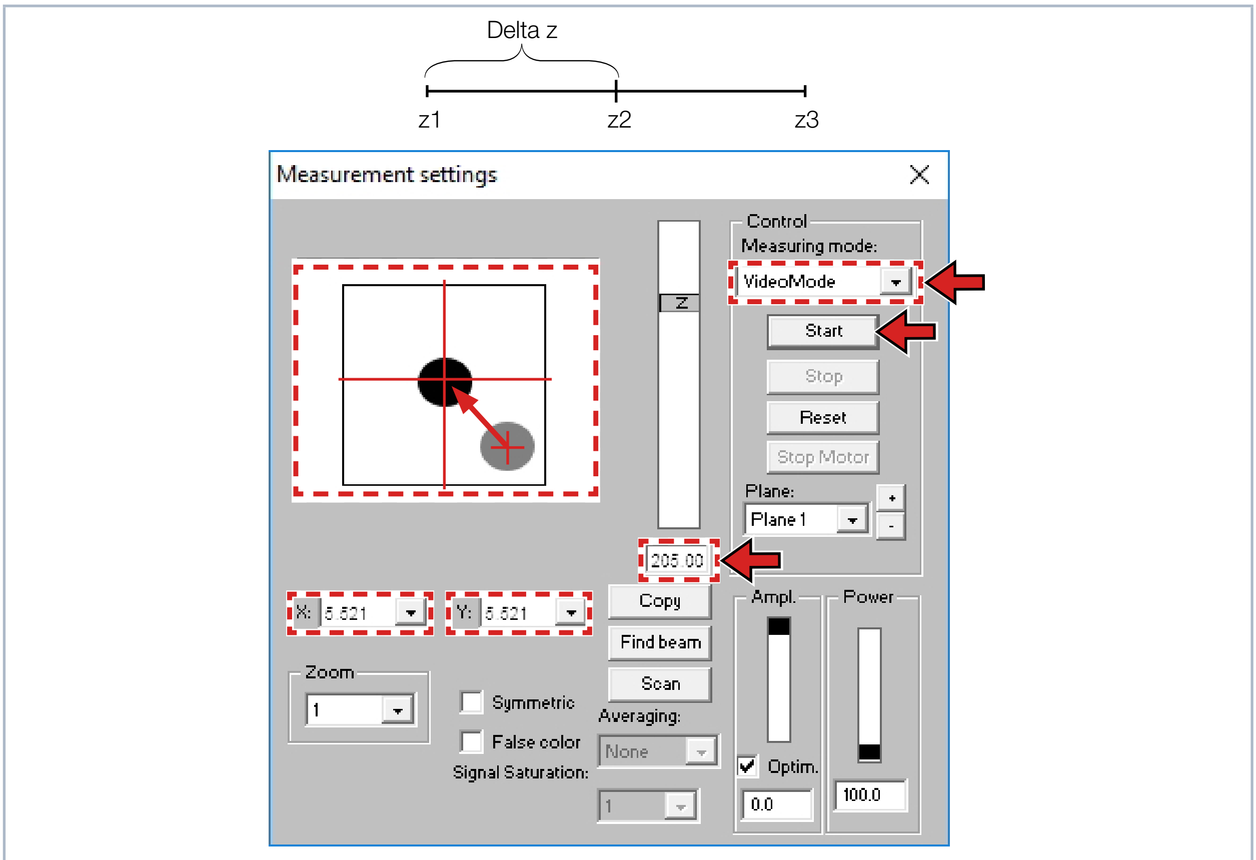


Fig. 13.4: Settings in the dialog window ***Measurement settings***

13.3.2 Display the misalignment angle of the laser beam via Position z1 and z3

1. Please open the dialogue window ***Measurement > LQM Adjustment***.
2. Click on the ***Start Adjustment*** button.
3. Check if the beam has an angular deviation (see Fig. 13.5 on page 95):

- If so, use the micrometer screws at the 1st attenuator module to align the beam.

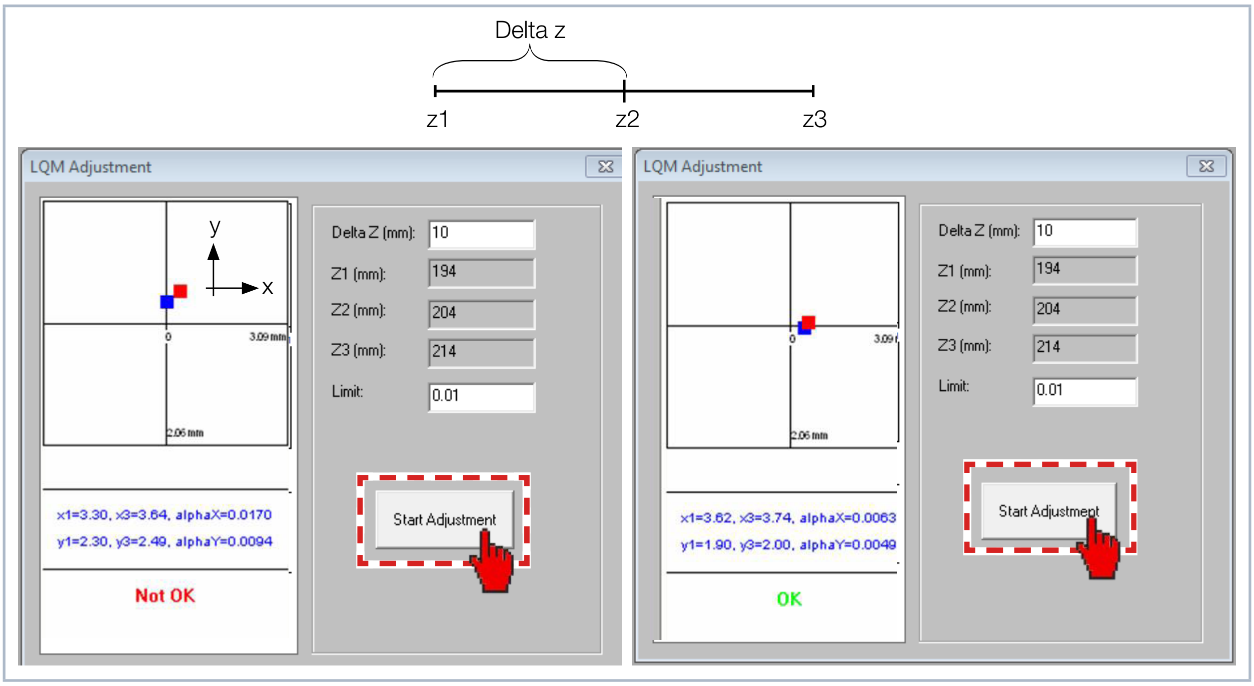


Fig. 13.5: Checking the alignment with the LaserDiagnosticsSoftware LDS

In the LaserDiagnosticsSoftware LDS, the values for the path of travel Delta Z (mm) and the limit value for the divergence can be freely selected.
Regardless of the assessment of the LaserDiagnosticsSoftware LDS for evaluating the misalignment angle, you should check the two planes 0 and 1 in the measuring window of the menu ***Measurement > Individual Measurement*** . The fill factor should show a value between 0.35 and 0.7.
If the laser beam is too large for the possible measuring window, you will need to cut the value for Delta Z (mm) in half. Once both measured laser beams are located at the center of the measuring window, the alignment process is complete.

The measuring mode ends with one of the following messages:

The device is adjusted sufficiently: • The real measurement can be started.	OK
This means, the beam has to be readjusted. The angular offset between the main axis of the LQM and the axis of the incoming laser beam is too large: • Repeat the alignment process with the LaserDiagnosticsSoftware LDS.	NOT OK PLEASE READJUST!
This means, the device is not adjusted properly. Thus, the beam cannot hit the CCD sensor: • Align the device again with the alignment tool. • Repeat the alignment process with the LaserDiagnosticsSoftware LDS.	NO BEAM! PLEASE READJUST!

Tab. 13.3: Messages from the LaserDiagnosticsSoftware LDS for aligning the LaserQualityMonitor LQM

13.4 Enter the measurement settings into the LaserDiagnosticsSoftware LDS

Due to the fact that the LaserDiagnosticsSoftware LDS is designed multifunctionally for all PRIMES devices, a few device-specific settings have to be made before a measurement. Moreover, the system and beam geometry provided by the customer are to be considered.

13.4.1 CCD settings (menu *Measurement* > *CCD Settings*)

1. Please start the LaserDiagnosticsSoftware LDS (see chapter 12 on page 38).
2. Please open the dialogue window ***Measurement > CCD Settings*** and choose in the field “Trigger Mode” ***Cw/Quasi-cw measurement***.

You can find information on operating the LaserQualityMonitor LQM with pulsed laser beams in chapter 20.6 on page 117.

3. Choose in the field “CCD Mode” ***Measuring Data***.
4. Choose in the field “Wavelength” one of the validated ***Wavelengths***.
5. Click on the ***Apply*** button.

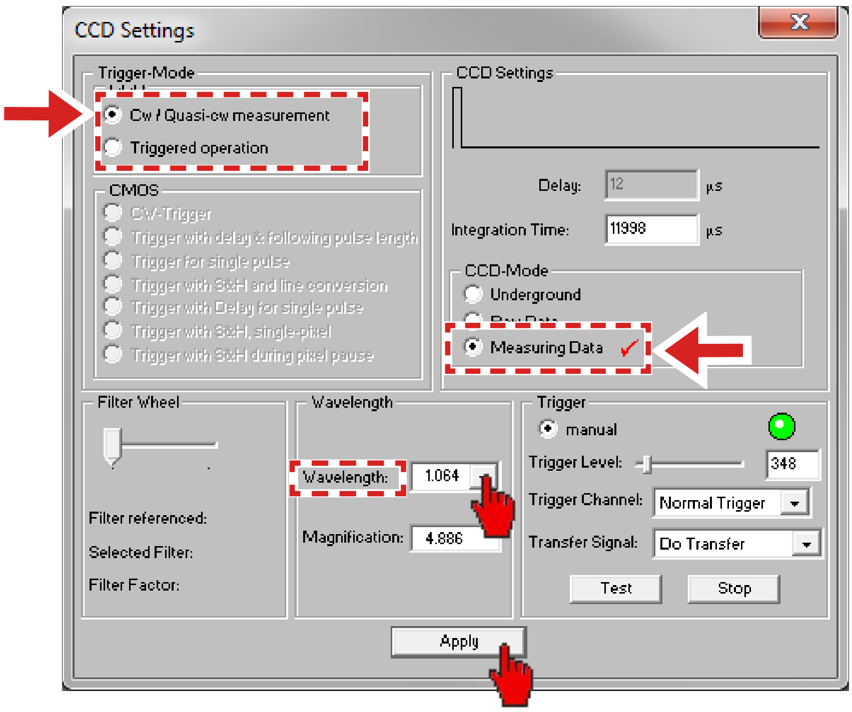


Fig. 13.6: Settings in the dialogue window ***CCD Settings***

Further information on the menu ***Measurement > CCD Settings*** can be found in chapter 12.4.5 on page 52.

13.4.2 Measuring environment (menu *Measurement* > *Environment*)

1. Please open the dialogue window ***Measurement*** **>** ***Environment***
2. Type in the field “Wavelength” the actual Wavelength.

- The current wavelength is needed in order to calculate the M^2 value.

The required distance is the distance between laser source/collimator to the aperture of the basic LaserQualityMonitor LQM. The distances between the basic LaserQualityMonitor LQM and the attenuator aperture are:
1st attenuator ≙ 94.3 mm
2st attenuator ≙ 196.8 mm
Eine Darstellung des Strahlengangs im LaserQualityMonitor LQM finden SIe in der Fig. 20.7 on page 115.

---

3. Type in the field “Device-laser distance” the actual distance from the LaserQualityMonitor LQM to the laser.
4. Type in the field “Maximum Power” the actual Maximum Power.
5. Type in the field “Efficient Power” (current power) the actual Efficient Power.
6. Click on the ***Apply*** button.

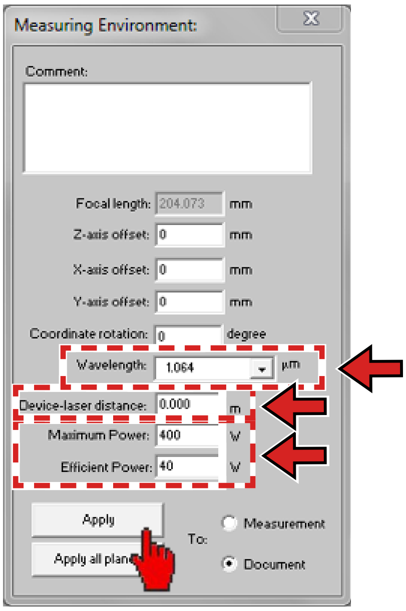


Fig. 13.7: Settings in the dialogue window ***Measuring Environment***

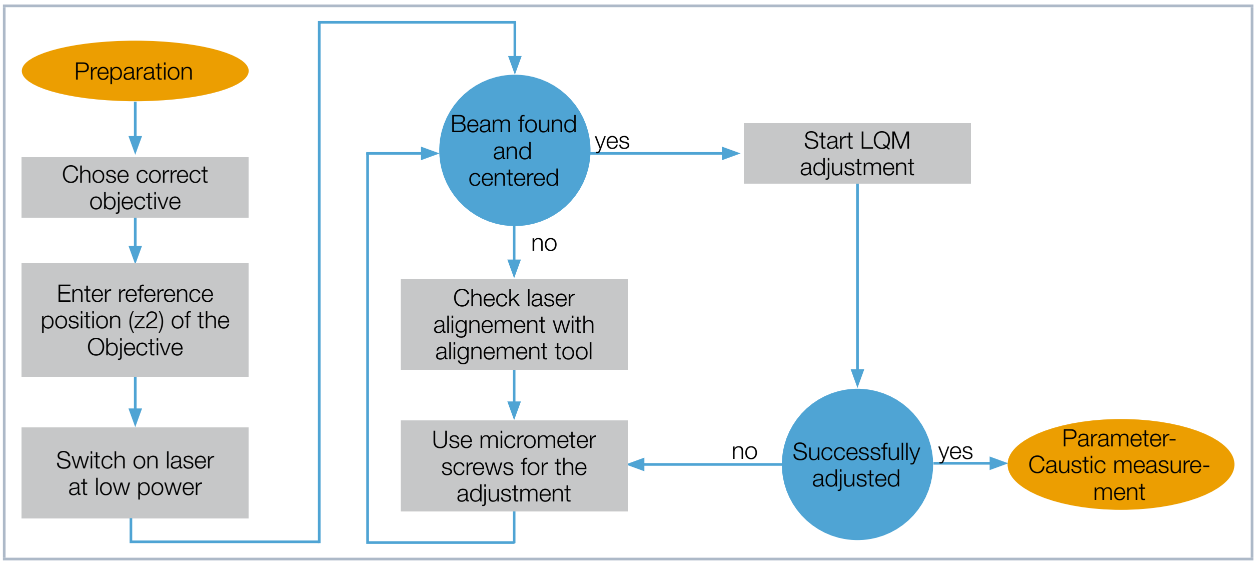
Further information on the menu ***Measurement*** **>** ***Environment*** can be found in chapter 12.4.1 on page 48.

13.5 Flowchart of a measurement

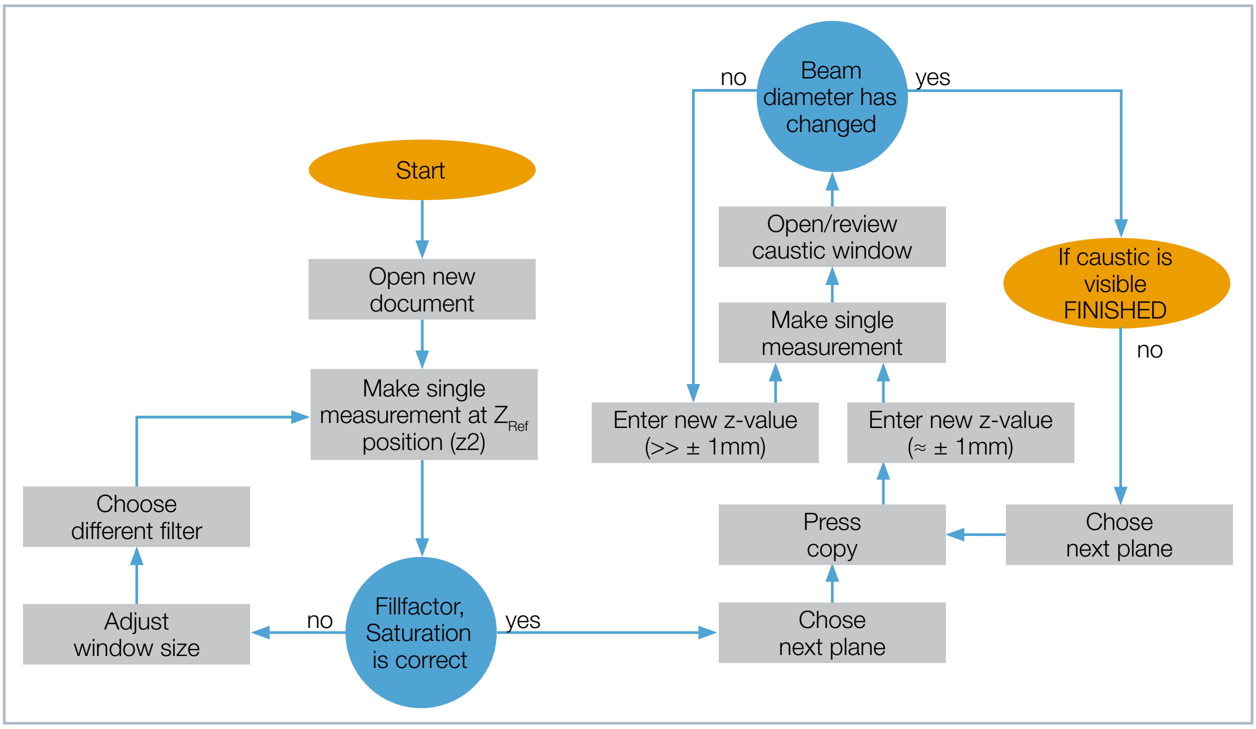
13.5.1 Align the laser manually and with the LaserDiagnosticsSoftware LDS

1. Choose the correct measuring objective according to chapter 13.2 on page 91 .
2. Reduce the laser power.
3. Align the LaserQualityMonitor LQM according to chapter 7.2 on page 18 manually to the laser beam.
4. Align the LaserQualityMonitor LQM with the laser beam according to the instructions in chapter 13.3 on page 94 and using the LaserDagnioseSoftware LDS.

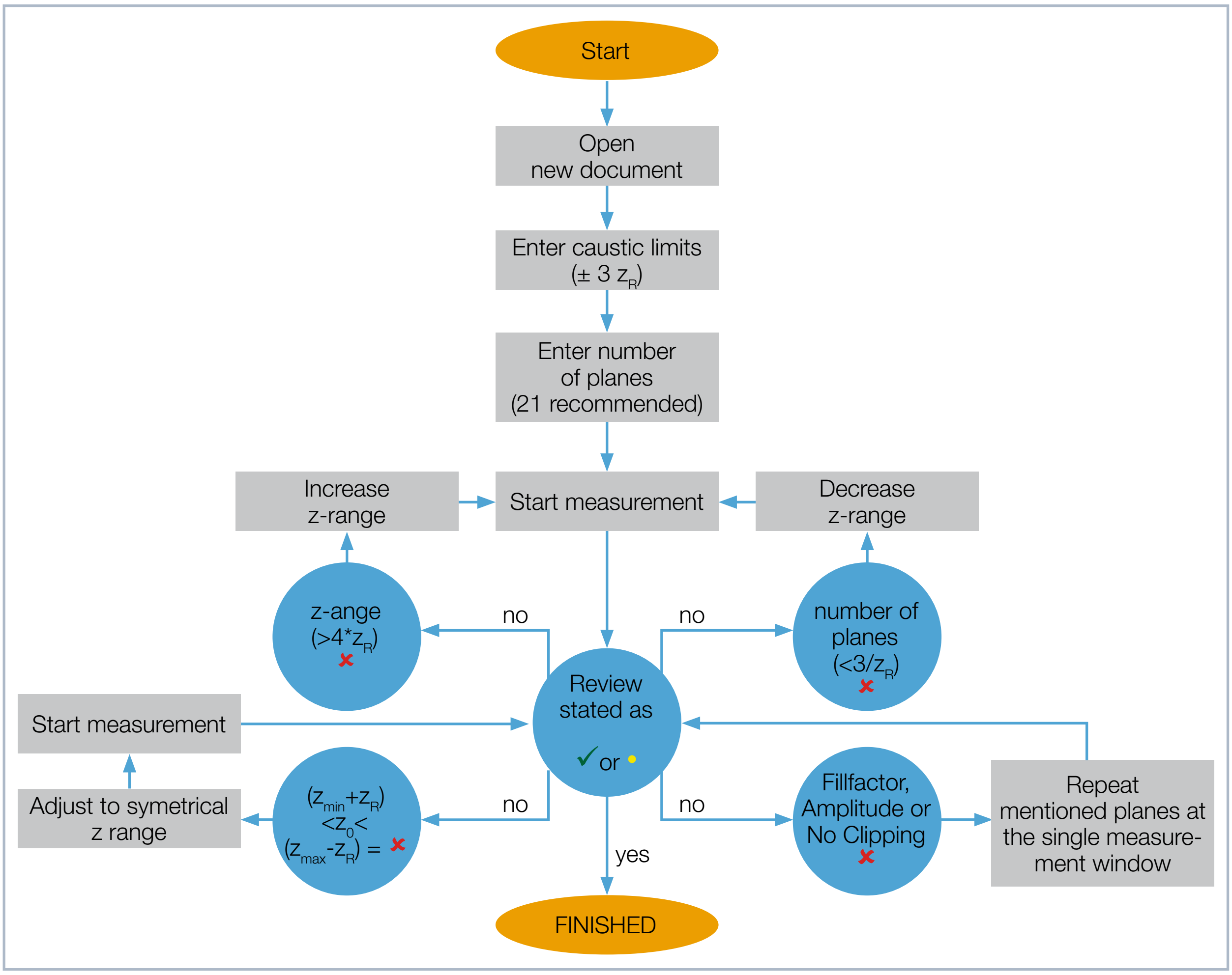
- The reference position (z2) is shown in the dialogue window ***LQM Adjustment***.



13.5.2 Set caustic limits



13.5.3 Perform caustic measurement



14 Maintenance and service

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 or calibration. If the device is used only sporadically, the maintenance interval can also be extended up to 24 months.

15 Storage and transport

Please note before storing devices with water cooling circuit:

NOTICE

Damage/destruction of the device caused by leaking or freezing cooling water

Leaking cooling water can damage the device. Storing the device at temperatures near or below freezing and without emptying the cooling circuit completely can damage the device.

- ▶ **Empty the lines of the cooling circuit completely.**
- ▶ **To empty the cooling circuit, the HP-LQM II/LQM 500 W can be flushed out with clean, dry compressed air.**
  The optional PowerLossMonitor PLM cannot be flushed with compressed air.
- ▶ **To avoid contamination, please cover the apertures with the provided lid or optical tape.**
- ▶ **Even when the lines of the cooling circuit have been emptied, a small amount of residual water will remain in the device at all times. This may leak out and end up inside the device. Close the connector plug of the cooling circuit with the included sealing plug.**
- ▶ **Store the device in the original PRIMES transport box.**

16 Measures for the product disposal

Due to the Electrical and Electronic Equipment Act (“Elektro-G“) PRIMES is obliged to dispose PRIMES measuring devices manufactured after August, 2005, free of charge.
PRIMES is a registered manufacturer in the German “Used Appliances Register“ (Elektro-Altgeräte-Register “EAR“) with the number WEEE-reg.-no. DE65549202.

Provided that you are located in the EU, you are welcome to send your PRIMES devices to the following address, where they will be disposed free of charge (this service does not include shipping costs):

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

17 Declaration 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:

LaserQualityMonitor (LQM)

Types: LQM 5; LQM 20; LQM 200; HP-LQM

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 2004/22/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, April 26, 2017

RKraemer

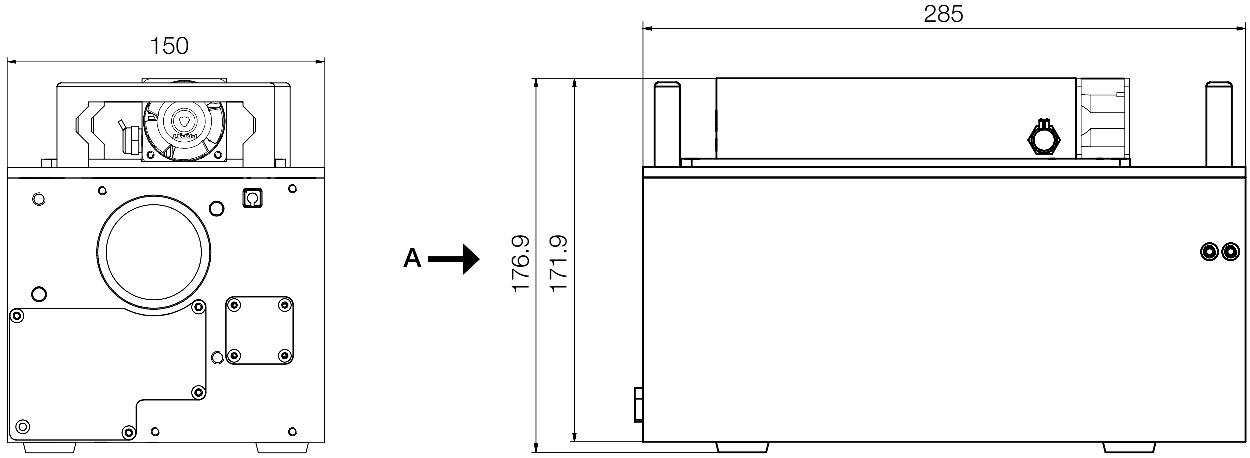
Dr. Reinhard Kramer, CEO

18 Technical data

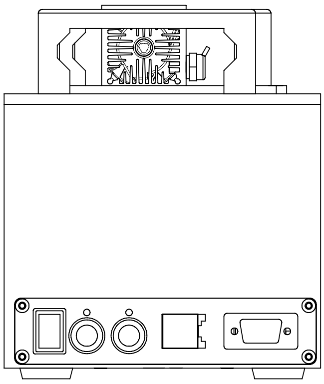
Measurement parameters	LQM 20	LQM 200/500	HP-LQM II
Power range (for 1064 nm)	20 W	200 W (opt. 500 W)	10 kW
Pulse duration	100 fs - cw		
Wavelength range	340 – 360 nm (UV) / 515 – 545 nm (Green) / 1030 – 1090 nm (NIR)		
Beam dimensions	1.5 – 15 mm		
Beam quality factor M^2	1 - 50		
Max. beam divergence	10 mrad		
Supply data			
Power supply	24 V DC ± 5 %, max. 1.8 A		
Cooling	Air cooling	Air cooling (opt. Water cooling)	Water cooling
Cooling water pressure	---	2 bar primary pressure with an unpressurized outflow, max. 4 bar	
Recommended Cooling water flow rate	––	1,5 l/min	7 – 8 l/min
Cooling water temperature T_{in} [1]	––	Dew point temperatur < T_{in} < 30 °C	
[1] Please consult with PRIMES before doing anything that does not comply with this specification.			
Communication			
Interface	Ethernet		
Dimensions and weight			
Dimensions (L x W x H)	285 x 190 x 180 mm	350 x 230 x 190 mm	480 x 300 x 190 mm
Weight	approx. 10 kg	approx. 18 kg	approx. 35 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 %		

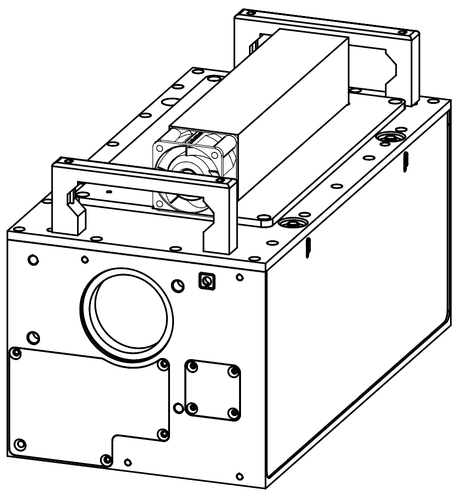
19 Dimensions

19.1 LaserQualityMonitor LQM 20 basic module



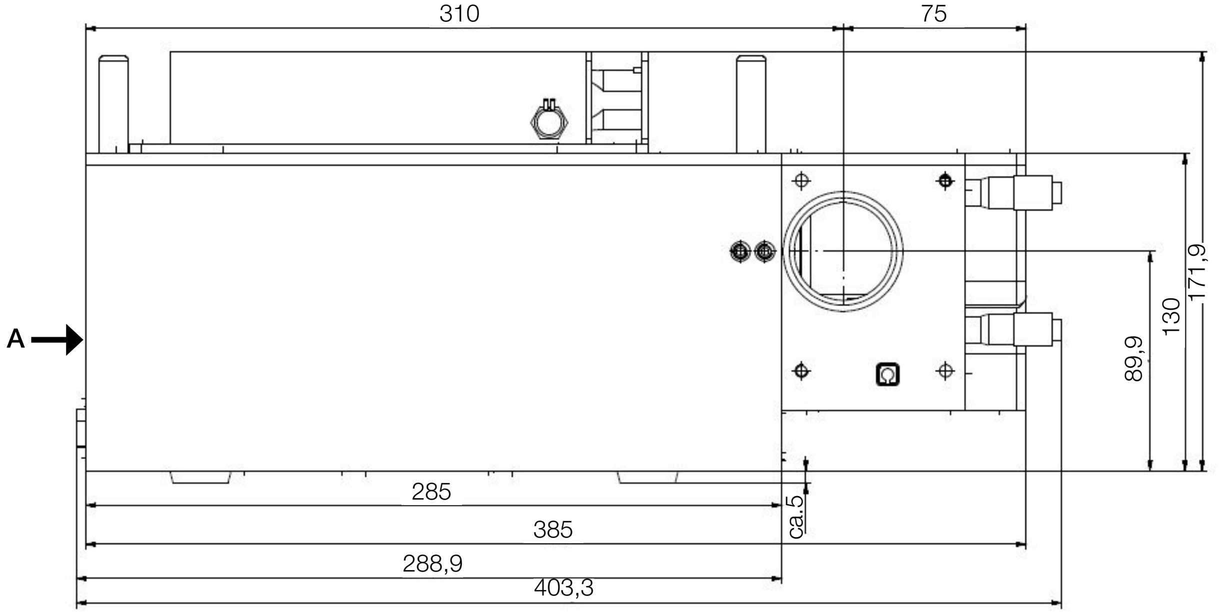
View A

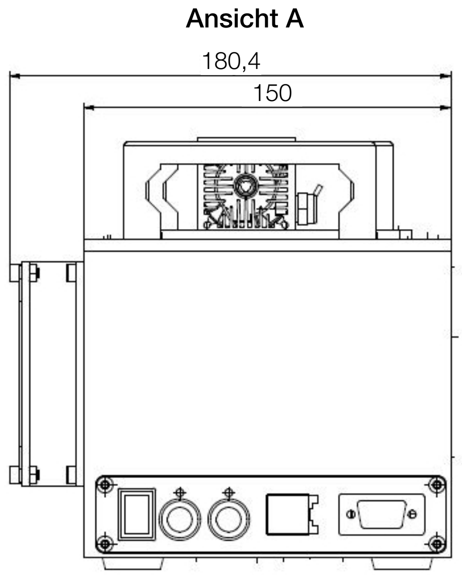


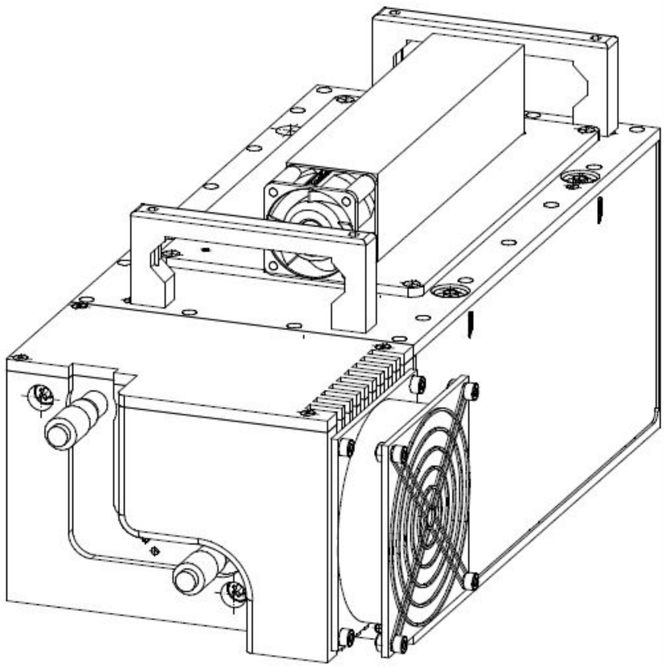


All dimensions in mm (general tolerance ISO 2768-v)

19.2 LaserQualityMonitor LQM 200/500 (without bottom plate)

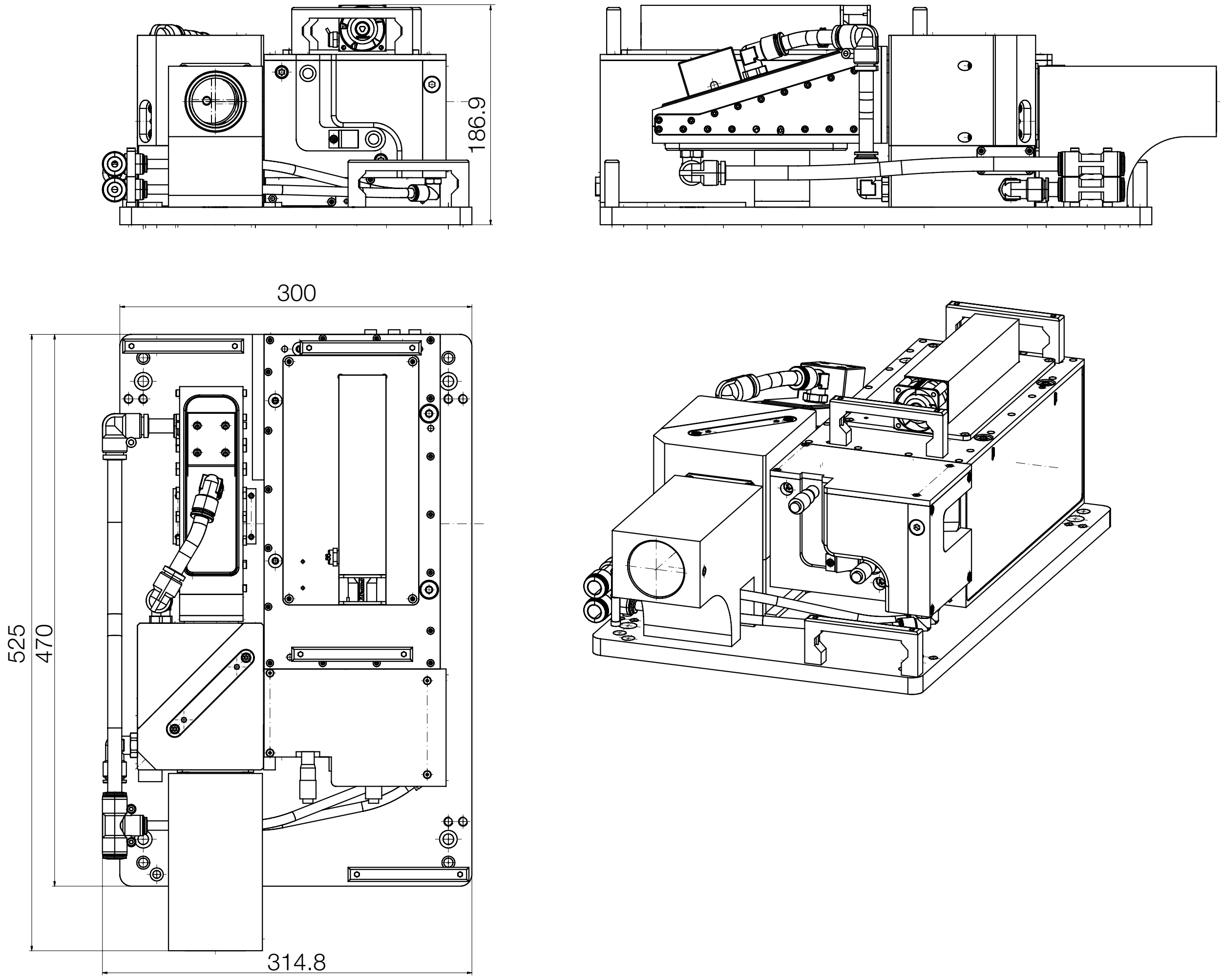






All dimensions in mm (general tolerance ISO 2768-v)

19.3 HighPower-LaserQualityMonitor HP-LQM II with optional fiber adapter



All dimensions in mm (general tolerance ISO 2768-v)

20 Appendix

20.1 Install a fiber adapter

DANGER

Serious eye or skin injury due to laser radiation

During the measurement the laser beam is guided on the device, which causes scattered or directed reflection of the laser beam (laser class 4).

The LaserQualityMonitor LQM cannot be operated in any of the available configurations without taking the following precautions. All precautions must be taken, even when the fiber is in the collimator or fiber adapter

- **Only attach the fiber adapter to the 2nd Attenuator module in conjunction with the adapter plate.**
- **Please 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 and protective gloves.**
- **Protect yourself from laser radiation by separating protective devices (e.g. by using appropriate shielding).**

1. Screw the adapter plate onto the 2nd attenuator module with four countersunk screws.
2. Insert the fiber adapter into the adapter plate.
3. Screw the fiber adapter onto the mounting plate with four cylinder head screws.

- Make sure that the fiber adapter is seated completely in the adapter plate.

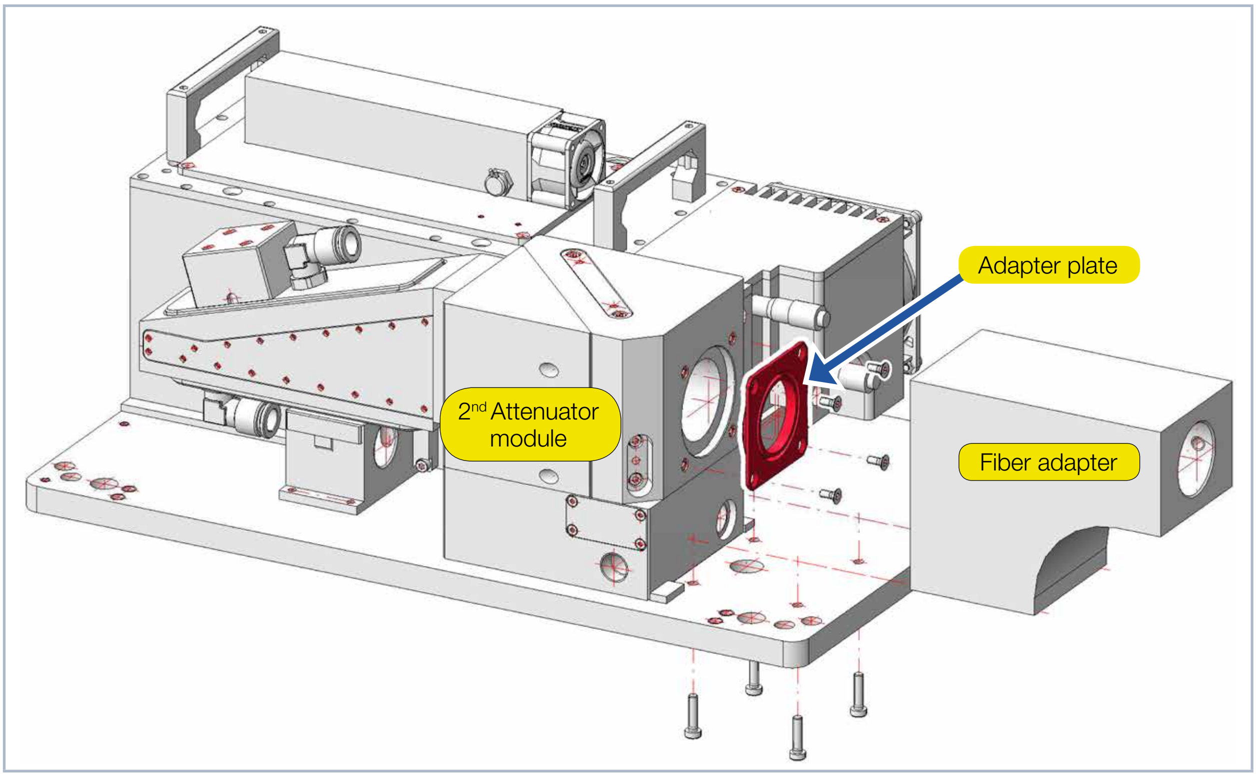


Fig. 20.1: Install a Fiber Adapter with the Adapter Plate

20.2 Changing the factory setting on the LQM UV

NOTICE

Damage/Destruction of optical components

Changing the factory settings may lead to damages to the device during the measuring operation.

▶ **Changing the factory settings for positioning range is only allowed by well trained and experienced personnel. In case of any doubt, please contact PRIMES service!**

The length of the internal beam path is influenced by the movement of prisms inside the device. Depending on the optical properties and the pulse parameters of a laser source, damages to the internal optical elements can occur. Especially in case of short pulsed UV-lasers the damages are foreseen.
To prevent the device from getting damaged and to avoid a positioning of a prism close to the internal focus, a shortened positioning range can be chosen.
The LaserQualityMonitor LQM UV is typically delivered with the shortened positioning range as a factory setting. Factory settings for standard and shortened positioning range are preset by a jumper, see picture below.

You can change the positioning range by replugging a jumper in the device.

DANGER

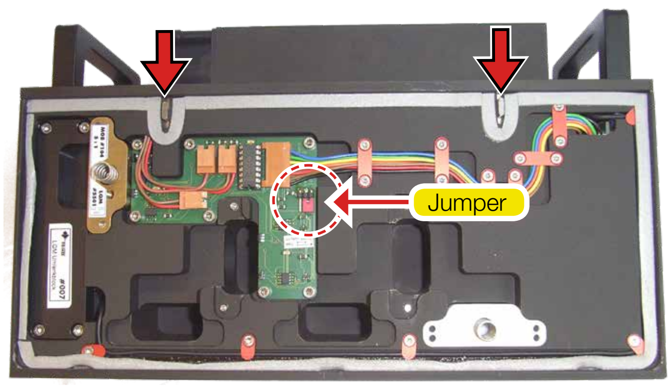
Serious eye or skin injury due to laser radiation

With the housing plate open and the laser on, reflected radiation (laser class 4) may leave the device.

▶ **Turn off the laser before removing the housing plate.**

1. Turn off the laser.
2. Turn off the power supply of the LQM.
3. Remove the housing plate on the side of the device by pressing down the two locking bolts (see red arrows).

The plate will then jump out.



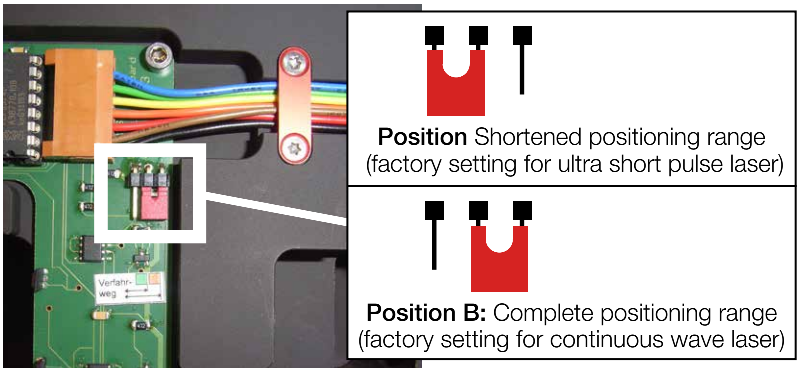
NOTICE

Component susceptible to electrostatic discharge

The circuit board could be destroyed by electrostatic discharge.

- **Before reconnecting the jumper, put on an ESD armband.**

4. Before switching the jumpers, put on an ESD armband.
5. On the now visible board you can find a jumper which has to be brought into the desired position.
6. Place the housing plate in the receptacles (see Fig. 13.1 on page 92) in the casing.
7. Flip the housing plate up until the two locking bolts clip into place.
8. Check that the housing plate is plan on the casing.



20.3 HighYAG collimation module

DANGER

Serious eye or skin injury due to laser radiation

During the measurement the laser beam is guided on the device, which causes scattered or directed reflection of the laser beam (laser class 4).

The LaserQualityMonitor LQM cannot be operated in any of the available configurations without taking the following precautions. All precautions must be taken, even when the fiber is in the collimator or fiber adapter

- ▶ **Please 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 and protective gloves.**
- ▶ **Protect yourself from laser radiation by separating protective devices (e.g. by using appropriate shielding).**

As an option PRIMES offers a 67 mm collimation module which can be mounted directly to the HP attenuator of the HighPower-LaserQualityMonitor HP-LQM II.

Specifications	
Focal length	67 mm
Max. Power	6 kW (multi mode) 3 kW (single mode)
Wave length range	1025 - 1080 nm
Design wave length	1064 nm
Acceptable divergence	160 mrad (half angle)*
Fibre core diameter	10 – 1000 µm
Fibre socket	LLK-D & QBH (LLK-B on request)
* If the 67 mm collimation module is operated with a high-power LaserQualityMonitor HP-LQM II the divergence (half angle) cannot be more than 110 mrad.	

Tab. 20.1: Specifications of the 67 mm collimation module

20.3.1 Key data for the cooling system for the HighYAG collimation module

Specifications	
Max. cooling water pressure	6 bar
Min. cooling water flow rate	2 l/min
Cooling water quality	Deionized water with corrosion inhibitor
Filter mesh	< 100 µm

Tab. 20.2: Specifications of the cooling system

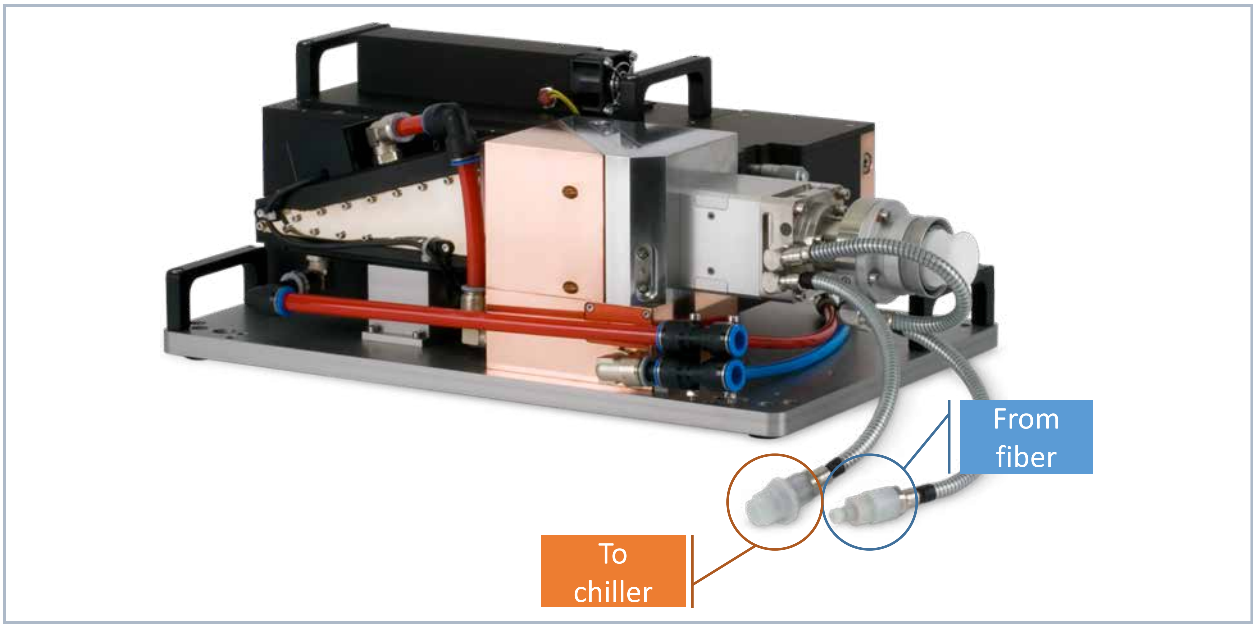


Fig. 20.2: Water connections

20.3.2 Schematic of the cooling system for the HighYAG collimation module

Important:
The collimator cannot be connected to the cooling circuit of the HP-LQM II, but rather to the cooling circuit of the fiber.

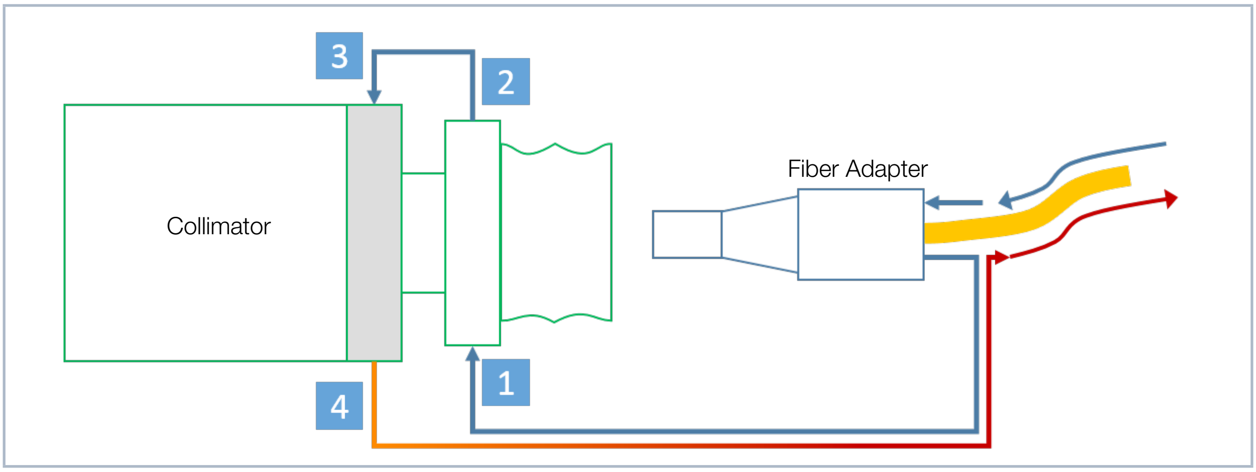


Fig. 20.3: Scheme cooling curcuit collimator

20.3.3 Schematic of the cooling circuit for the HP-LQM II

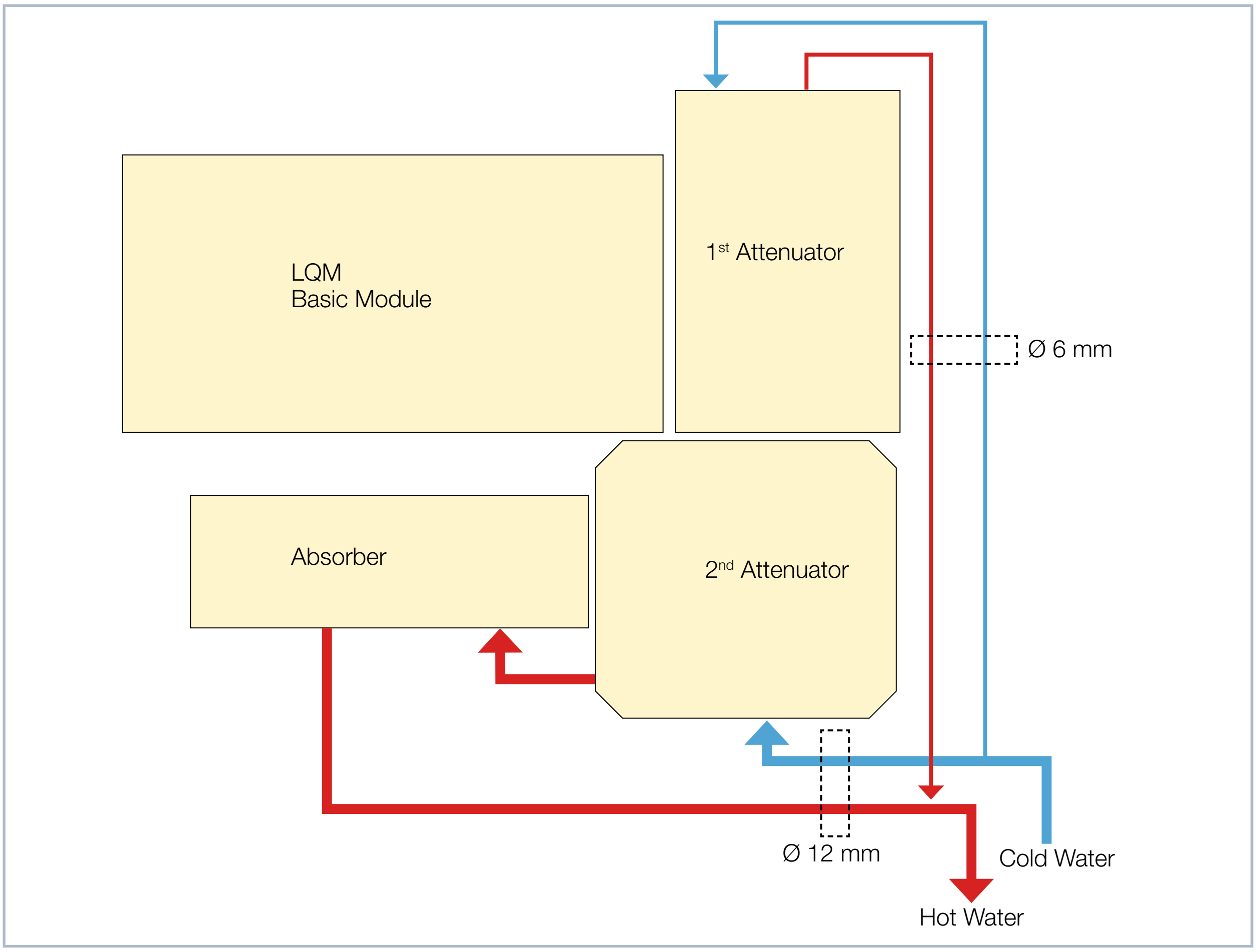


Fig. 20.4: Scheme cooling curcuit HP-LQM II

20.3.4 Remove HighYAG collimation module

Necessary tools:
- Allen key, a. f. 2.5 mm
- Allen key, a. f. 3 mm

NOTICE

Damage/Destruction of optical components

A contaminated focussing optic can heat up, change optical properties and potentially be damaged.

▶ **To avoid contamination, only perform work in a clean environment.**

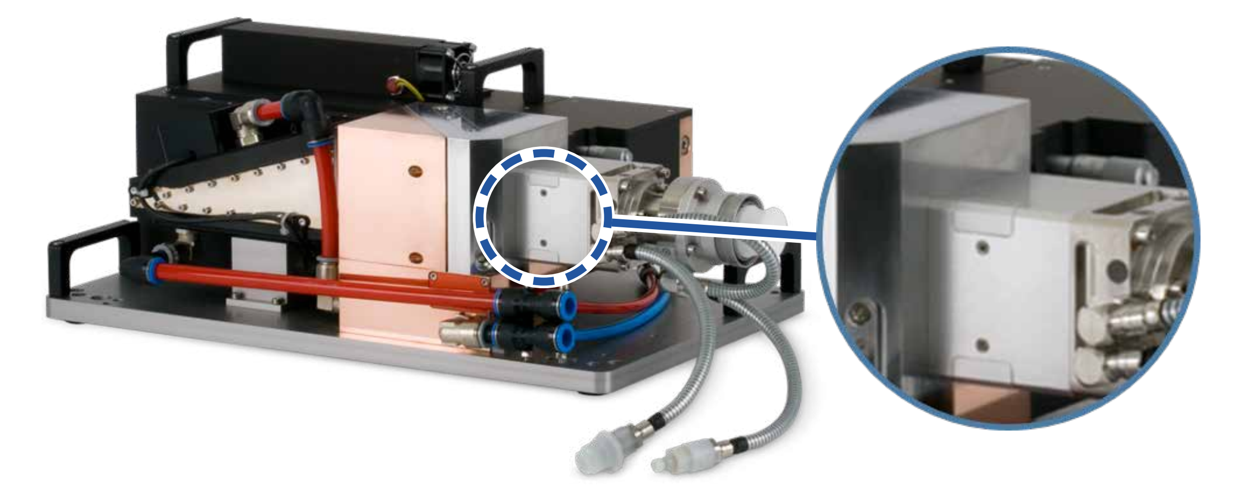
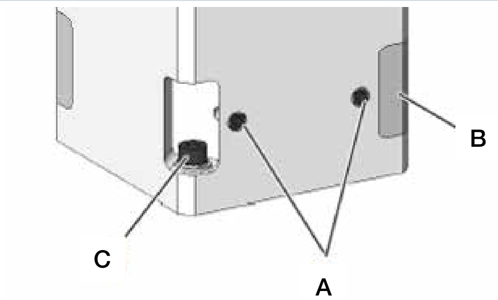
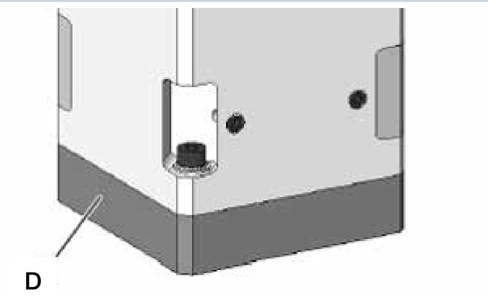


Fig. 20.5: Position of the collimator

1. Turn off the power supply of the LQM. 2. Loosen four set screws A (a. f. 2.5 mm). 3. Remove four covers B. 4. Remove four screws C by using the provided elbowed allen key (a. f. 3 mm)	
5. Use the protective cover D for storage. 6. After disassembling the collimator, the fiber adapter has to be mounted to the attenuator module again. 7. Close the aperture of the adapter with the red lid or with optical tape.	

20.3.5 Choosing the measuring objective with a HighYAG collimation module installed

Example 1:

λ = 1030 nm
M^2 = 12
$d_{fibercore}$ = 100 µm
f = focal length

$$d_{foc} = d_{fibercore} \cdot \frac{f_{LQM}}{f_{col}}$$

d_{foc} = 299 µm

To enable a measurement within ±3 z_R the estimated number of illuminated pixels at the focus should be less than 350.

Quantity of illuminated pixels at 4.4 µm pixel pitch = $\frac{d_{foc}}{4{,}4\ \mu m} \cdot \beta$ (Magnification of the measuring objective 1 or 5)

Measuring objective (MOB) 1:1 --> 299 µm / 4,4 µm x 1 = 68 ✓
Measuring objective (MOB) 5:1 --> 299 µm / 4,4 µm x 5 = 340 ✓

Example 2:

λ = 1064 nm
M^2 = 5.5
$d_{fibercore}$ = 50 µm

$$\Theta = \frac{4 \cdot \lambda \cdot M^2}{\pi \cdot d_{fibercore}}$$

Θ = 150 mrad

$$d_{rawbeam} = \frac{\Theta \cdot f_{col}}{1\ m}$$

$$d_{rawbeam} = \frac{150\ \text{mrad} \cdot 67\ \text{mm}}{1\ \text{m}} = 10.05\ \text{mm}$$

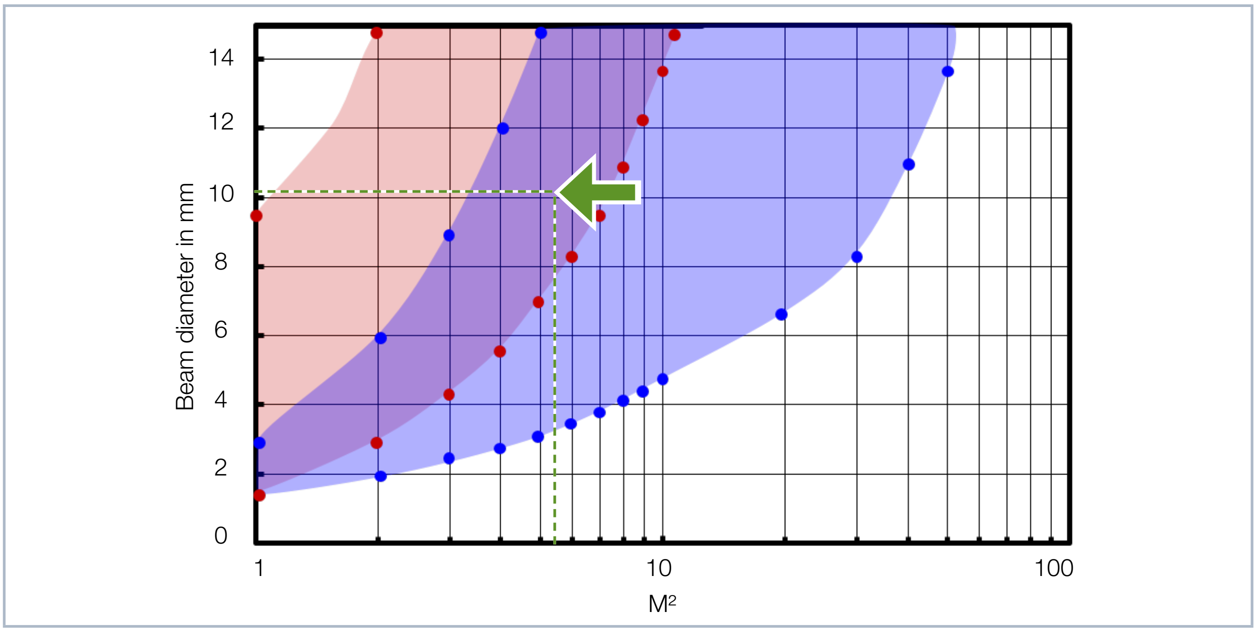


Fig. 20.6: Range of application of the LQM objectives

MOB 1:1 --> ✓
MOB 5:1 --> ✓

The two examples demonstrates the calculation of beam parameters based on a given collimator focal length. The calculation can also be done using other collimator focal lengths.

20.4 Optical path in the HP-LQM II (with collimator)

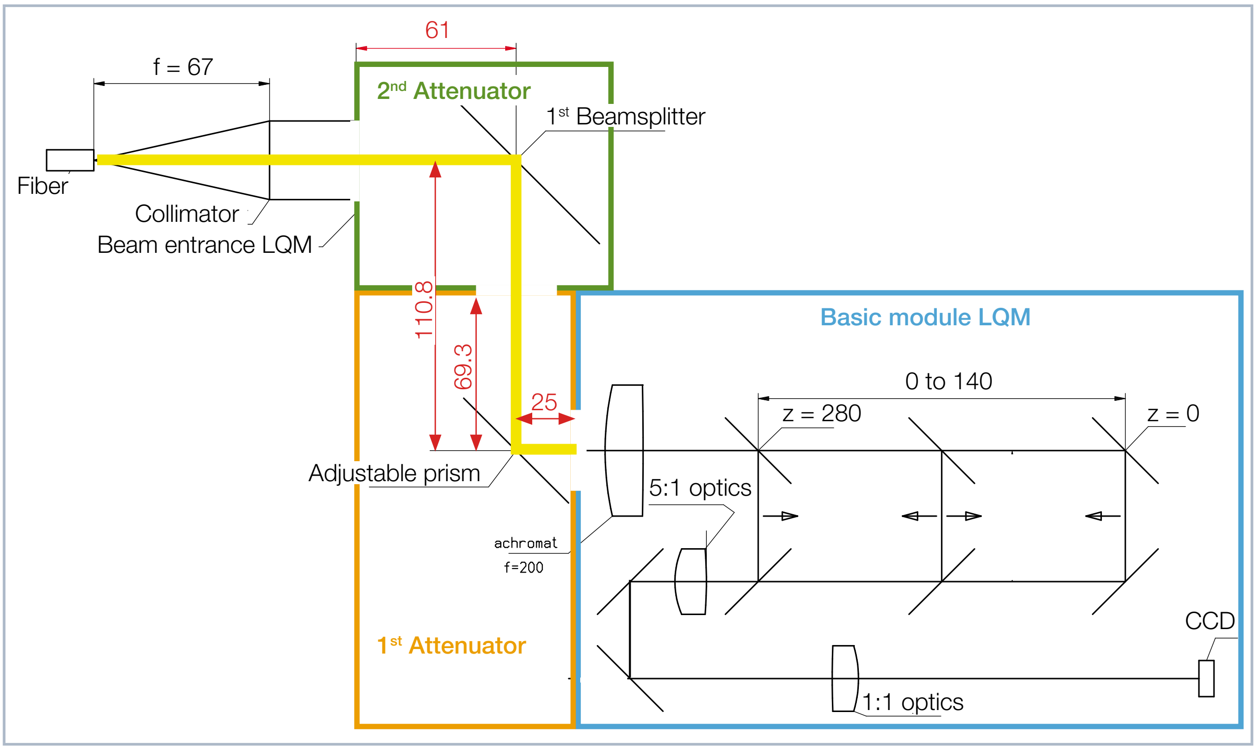


Fig. 20.7: Optical path in the HP-LQM II (with collimator)

Length of the optical path ( ):

1st Attenuator <--> LQM = 25 mm + 69.3 mm = 94.3 mm
2nd Attenuator <--> LQM = 25 mm + 110.8 + 61 mm = 196.8 mm

20.5 Description of the MDF file format

The MDF file format is a simple ASCII-format which includes the main data of a beam measurement – the spatial power density distribution. MDF stands for “mailable data format”.
By means of this standardized format conversion problems between different evaluation programs are supposed to be reduced and a safe data transmission, e.g. per e-mail, is supposed to be ensured.

The files are arranged as follows:

1st line:	MDF 100 (file identifier)
2nd line:	Number of image points: in x-direction in y-direction
3rd line:	Size of the measurement range: length in x (mm) length in y (mm)
4th line:	Position along the beam axis: z-position (mm)
5th line:	Transversal position of the center of the measurement range: x-pos y-pos (mm)
6th line:	Amplification of the measuring signal: enhancement (dB)
7th line:	Number of averages: number
8th line:	Offset value displayed by the measuring device: offset-value
9th line:	Wavelength-value
10th line:	Power value
11th line:	Focal length value
12th line:	Date, time value

In the following lines the data can be found.
There is a maximum of 80 characters per line.

Comments

Comments are inserted as additional lines, into the lines after the file identifier.
The comment lines each start with a semicolon.

Example:

```
MDF100
;This is an example.
;These lines are a comment.
64   64
2   2
11
...
...
1
10
10 10 10 10 10 10 10 10 10 10
11 12 13 14 15 16 17 18 19 20
20 20 20 20 20 18 16 14 12 10
....
```

20.6 Measuring pulsed irradiation

The CCD sensor of the LaserQualityMonitor LQM has a dynamic of 55 dB. An integration time control has been implemented in order to expand this. The integration time can be freely chosen within the range of 12 µs to 186 ms.
If the ***Optm. (Optimize)*** function is activated in the ***Single*** or ***Caustic*** dialog window, then the LaserDiagnosticsSoftware LDS 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.

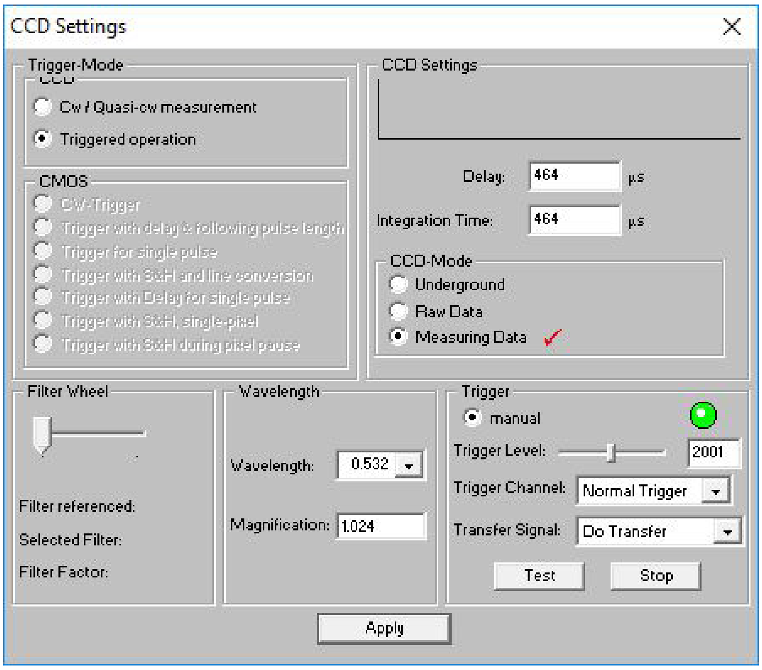


Fig. 20.8: CCD settings in the dialog window ***CCD Setting***

The integration time control magnifies the dynamics of the CCD sensor from 55 dB to over 130 dB. Once the ***Optim.*** Function is deactivated, a set integration time can be specified in the ***CCD Setting*** dialog window in the LaserQualityMonitor LQM (see Fig. 20.8 on page 117).

Integration time control alone isn't enough to be able to measure the full range of pulsed lasers. If, for example, it involves a pulsed laser with a very low pulse frequency (< 5 Hz), the maximum integration time of 186 ms will no longer be sufficient. This is why, in addition to the integration time control, a trigger option and delay time is also implemented.

In regards to triggering, there is an internal trigger and an external trigger.
A photo diode behind a prism functions as the internal trigger (see Fig. 5.2 on page 15). The user can determine the limit value of the trigger (0 ... 4096).
The trigger is preset to the value 2001 This setting works well for the majority of all applications.

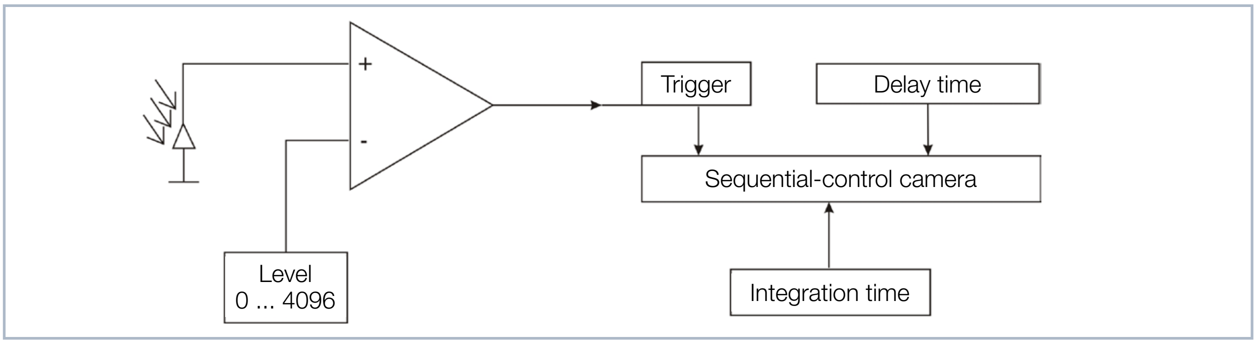


Fig. 20.9: Options for affecting the sequence control of the CCD sensor

Fig. 20.9 on page 118 Shows that the trigger, together with the adjustable delay and integration time, interferes with the sequence control of the CCD sensor. The user can now define discrete time frames in which the LQM is allowed to measure. The external trigger is connected via a BNC socket meant for this purpose. Similarly, it also interferes with the sequence control, meaning that it can be handled in the same way as the internal trigger.

The delay time and trigger type (external or internal trigger) settings are made in the ***CCD Settings*** dialog window of the LaserQualityMonitor LDS (Fig. 7.14).
When you enter a delay or integration time, you must always be sure to confirm these entries with the ***Update*** button.

There are the following time constants:

Timeout:	20 sec (Standard)
Minimum integration time:	12 µs
Maximum integration time:	186 ms
Minimum delay:	12 µs
Maximum delay:	186 ms

The long timeout time (20 sec.) also helps to measure lasers with a pulse that is manually triggered. If this is the case, a measurement must first be taken. The LaserQualityMonitor LQM will move to the desired position and run through a certain routine internally. Once the LaserQualityMonitor LQM is ready for a trigger, notification of this will be displayed in the ***Free Communication*** dialog window. Right after the measurement is initiated, a communication flow will be visible.

If this stops with the indication ***Waiting for Trigger***, then the LaserQualityMonitor LQM is waiting for a trigger. Every measurement of the LaserQualityMonitor LQM consists of a dark measurement and a measurement with photo transfer. This applies for triggered as well as untriggered operation. This means that each measurement requires at least two trigger signals or two laser pulses.

20.6.1 Measuring configuration selection

There are various measuring options to differentiate between:

- Measuring a single plane or a complete caustic
- Measuring a complete pulse or just a single section
- Measuring with a fixed integration time or with integration time control
- Measuring with triggered or untriggered operation
- Variations of optimal integration time caused by changing the attenuation

If you combine these measuring options with the pulse parameters:

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

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

20.6.2 Influence of the pulse parameters on the integration time control

The software-operated integration time control always assumes that there is a continual 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. 20.3 on page 119 And the diagram in Fig. 20.10 on page 120 makes this clear.

Pulse frequency	Number of pulses in	
in Hz	186 ms	1 ms
1	0	0 - 1
5	1	0 - 1
10	2	0 - 1
50	9	0 - 1
100	19	0 - 1
200	37	0 - 1
500	93	0 - 1
1000	186	1 - 2
2000	372	2 - 3
5000	930	5,00
10000	1860	10,00

Tab. 20.3: Number of detected pulses in correlation with the integration time and pulse frequency

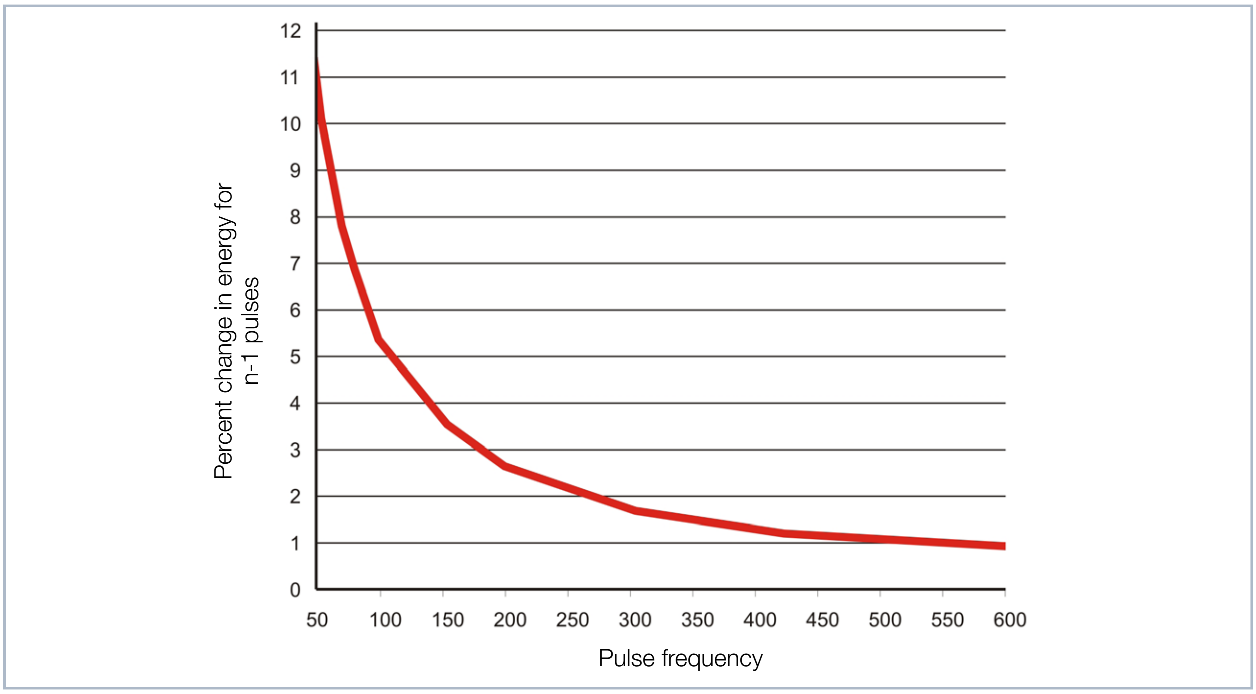


Fig. 20.10: Percentage of change in the detected energy when exactly one pulse is left out, in correlation with the pulse frequency

Tab. 20.3 on page 119 Shows the number of detected pulses during the maximum integration time (186 ms) and during an integration time of 1 ms for various pulse frequencies.
Quantization with low pulse frequencies is clearly illustrated in the column for the 186 ms integration time. While 1860 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. 20.10 on page 120. It is important to recognize that, starting from a pulse frequency of 500 Hz, the minimum jump when the integration time is shortened amounts to 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. 20.3 on page 119, 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 pretty much 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 untriggered operation.

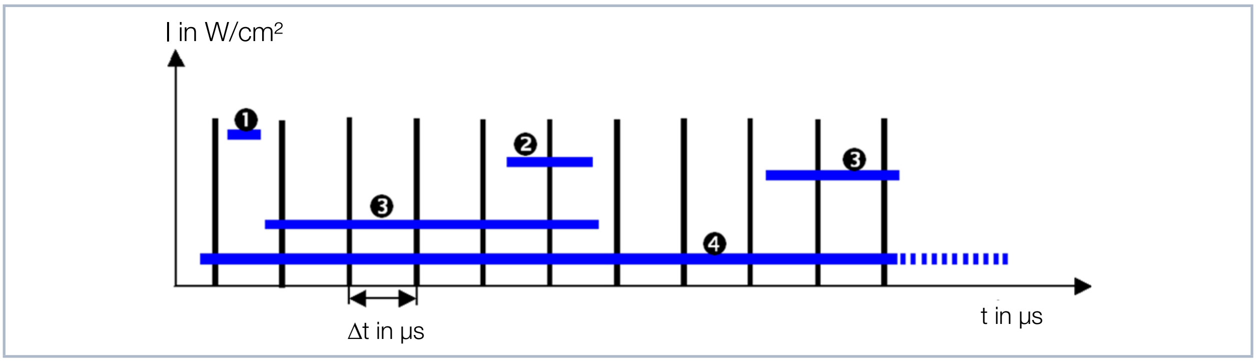


Fig. 20.11: Measuring with different integration times

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. 20.11 on page 121 Shows pulsed irradiation. The pulse pauses amount to 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, no more than one pulse will be in the measurement statistically speaking. The probability of there being one pulse during each measurement of integration time control as well as during the actual measurement is slim.

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 1). This is the perfect state for measuring on one plane. The caustic can also be measured with this setup, since the dynamics of the CCD sensors is 55 dB for a single pulse, with the intensity only varying by a factor of 5 in the relevant caustic range. Here it is important to make sure that the signal saturation for the measurement in the beam waist 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 a situation where the integration time falls between the simple duration and the duration times ten 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 pretty much operates 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 - 4.

Furthermore, as was mentioned in the initial consideration, the LaserQualityMonitor LQM is equipped with quite a few options for triggering. Combined with integration time control and delay time control, it is possible to take good measurements even in Case 1.

These four cases can generally be sorted into two groups. Case 1 and 2 must be measured in the triggered measuring mode. Case 4, however, is best measured in untriggered measuring mode cw. Case 3 should be avoided altogether by choosing a suitable filter.
The below diagram in Fig. 20.12 on page 122 should help with case classification for the laser beams to be measured.

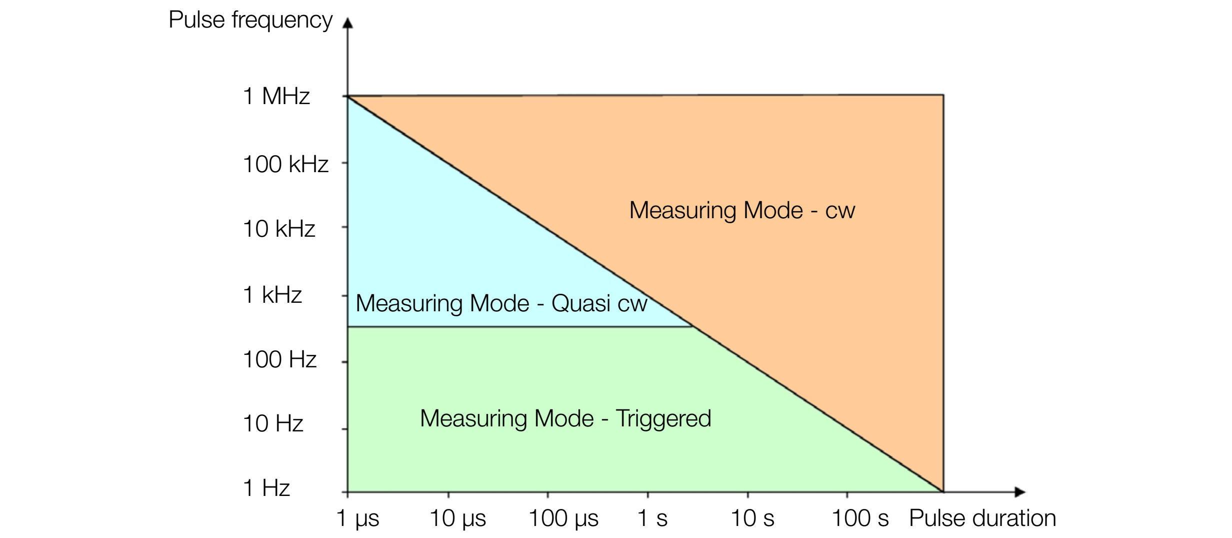


Fig. 20.12: Choosing the measuring mode through laser parameters

If the laser is in the blue range, it is best to choose measuring mode cw. It is, however, important to remember that the closer you get to the limit during triggered operation, the greater the integration time will be in order to achieve the virtual cw case. As a rule of thumb, the integration time within the focal point should amount roughly to the time for 35 pulses. If the laser being measured falls below the limit frequency of approx. 500 Hz, you should switch to triggered measuring mode.

While it is almost always possible to measure with the integration time control (optim. function) in the cw or virtual cw measuring mode, it only makes sense to use it for very long pulse durations (>1 ms) in triggered measuring mode. With the help of the attenuation filter, the integration time is thus set so that it only amounts to a fraction of the pulse duration. The trigger 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. 20.13 on page 122 or Example 2).

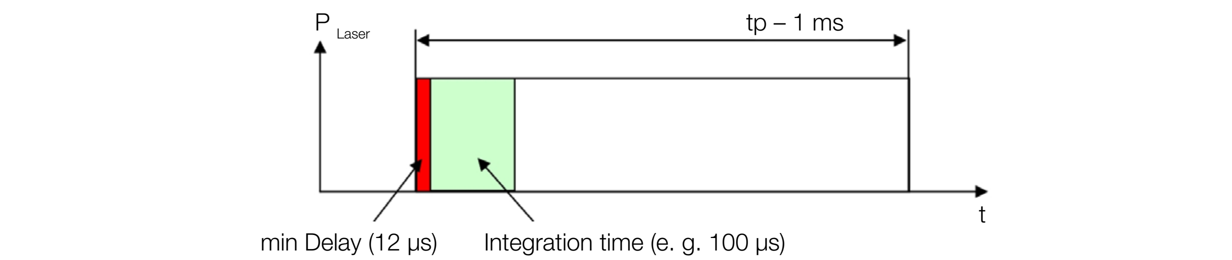


Fig. 20.13: Measuring parameters for pulsed laser systems with pulse duration greater than 1 ms

In all situations, it is advisable to specify a fixed integration time in order to, through the skilled selection of the filter as well as the delay and integration times, make sure that a fixed number of pulses is always measured (see Example 1).

20.6.3 Examples for triggered measuring mode

Example 1: Pulse duration 50 ns
Pulse frequency 1 kHz

LaserQualityMonitor LQM Settings:

Delay:	950
Integration duration:	0.1 ms
Trigger channel:	External trigger

Depending on how precisely you are able to set off the trigger, you can also extend or shorten the integration time.

Measure:
Initiate a measurement. You now have 20 sec. to set off a trigger.
As a result of the delay value of 0.95 ms and the fixed integration time of 100 µs, the LaserQualityMonitor LQM detects the second laser pulse after setting off the trigger.

Example 2: Pulse duration 1 ms

LaserQualityMonitor LQM Settings:

Delay:	12
Integration duration:	1 ms
Trigger channel:	Internal trigger

Measure:
Initiate a measurement. You now have 20 sec. to set off a laser pulse.
The LaserQualityMonitor LQM measures 12 µs after the trigger is set off.
In this example, the first 12 µs of the laser pulse are not measured:

Example 3: Measuring exactly one pulse
Trigger mode: Triggered operation

In the ***CCD Settings*** dialog window, there is a selection menu called ***CCD Operating Modes***. There you can choose between background, raw data, and measurement data.

When measuring in raw data mode, the CCD is read out quite normally. A second, dark measurement, is not performed though. Depending on the application case, wavelength, and integration time, there may be obvious errors in the background.

It makes sense to measure in this mode when exactly one pulse will be triggered. Since there won't be a second, dark, measurement, this single pulse is enough. Here the attenuation should be chosen so that the integration time is longer than the pulse duration. This makes it possible to avoid most background effects. If the integration time is too long though, more dark electrons will be generated.

If you would like to record the entire pulse, it must be triggered externally. In this case, the minimum delay between the trigger and start of the measurement should be 12 µs.

20.6.4 Summary

If the laser is pulsing at a high frequency (> 500 Hz) or if the pulses last a long time (> 1ms), it is best to measure with the ***Optim.*** option. 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 come during an integration time, the number of photoelectrons will change too much with each pulse. The regulating routines of the 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 smaller than the pulse pauses. If this is the case, it will no longer be possible to perform an untriggered measurement properly with the LaserQuality-Monitor LQM.

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 (55 dB) is sufficient to measure the entire caustic with an acceptable S/N ratio.

21 Basis of laser beam diagnosis

21.1 Laser beam parameter

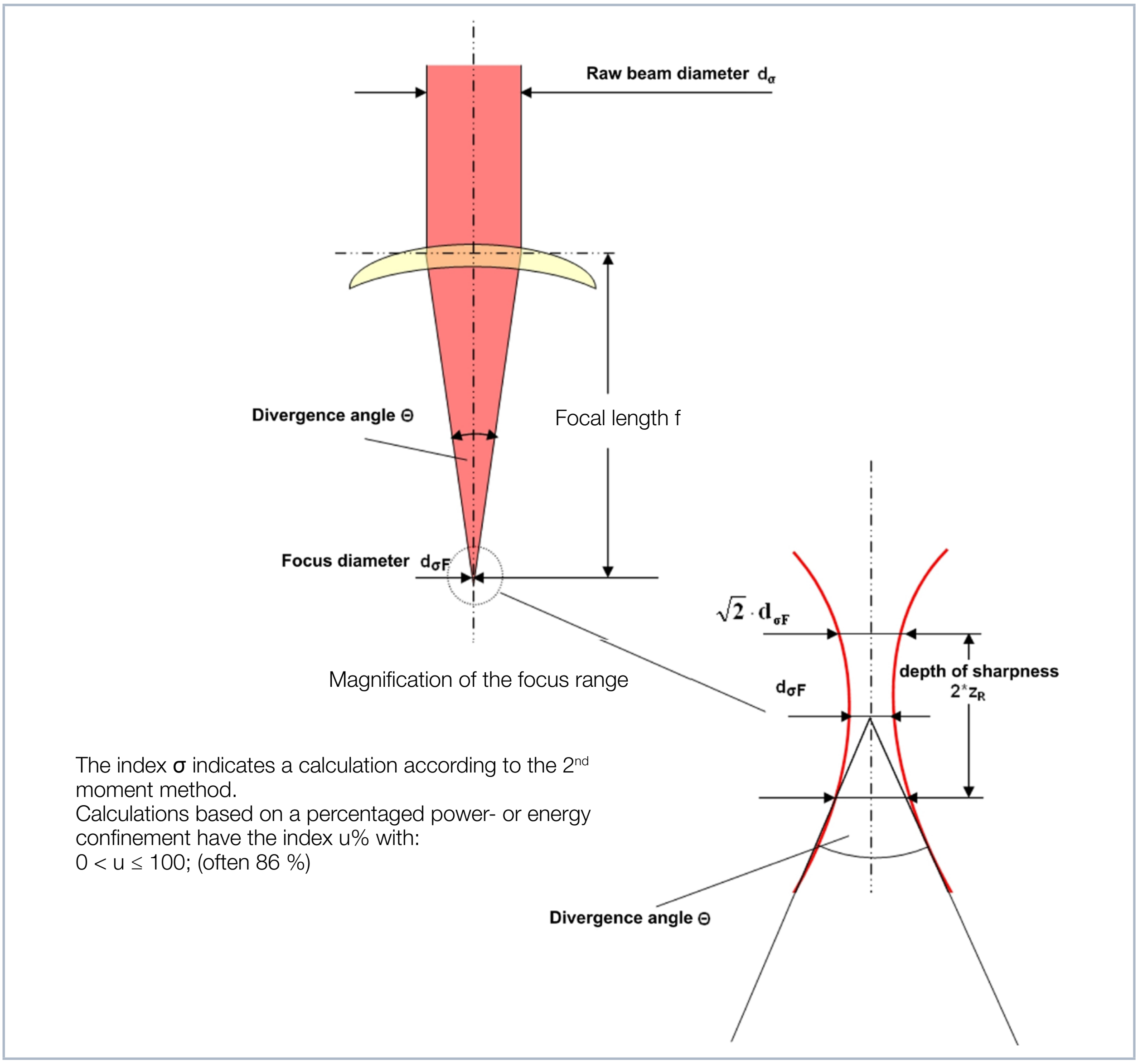


Fig. 21.1: Sketch for the definition of beam parameters

21.1.1 Rotationally symmetric beams

According to ISO 11145 as well as ISO 11146 three beam parameters are necessary for the characterization of a rotationally symmetric beam:

- the z-position of the beam waist (focus) z_0
- the diameter of the beam waist $d_{\sigma F}$
- the far field divergence angle Θ

By means of these three values it is possible to determine the beam diameter at every spot along the propagation direction. The following restriction is applicable: The divergence angle has to be smaller than 0.8 rad and the focus diameter and the divergence angle were determined with the 2^{nd} moment method.

$$d_\sigma(z)^2 = d_{\sigma 0}{}^2 + (z - z_0)^2 \cdot \Theta_\sigma^2 \qquad \textit{(1.1)}$$

Furthermore, the beam propagation is described by means of the so called beam propagation ratio K.

$$K = \frac{1}{M^2} = \frac{4 \cdot \lambda}{\pi} \cdot \frac{1}{d_{\sigma 0} \cdot \Theta_\sigma} \qquad \textit{(1.2)}$$

with:
K = beam propagation ratio
M^2 = beam propagation factor
λ = wave length in a medium with the refractive index n
Θ_σ = divergence angle
$d_{\sigma 0}$ = beam waist diameter

The derived beam parameter product, is a constant size as long as image defect free and aperture free components are used.

$$\frac{d_{\sigma 0} \cdot \Theta_\sigma}{4} = \frac{\lambda}{\pi \cdot K} \qquad \textit{(1.3)}$$

An important beam parameter is the Rayleigh length:

The Rayleigh length is the distance towards the propagation in which the laser beam has increased by $\sqrt{2}$. It can be calculated by means of the following formula:

$$z_R = \frac{d_{\sigma 0}}{\Theta_\sigma} = \frac{\pi \cdot d_{\sigma 0}{}^2}{4 \cdot \lambda \cdot M^2} \qquad \textit{(1.4)}$$

21.1.2 Non rotationally symmetric beams

In order to describe non rotationally symmetric beams, the following parameters are required:

- the z-position of the beam waist (focus) z_x and z_y
- the diameter of the beam waist $d_{\sigma 0x}$ and $d_{\sigma 0y}$
- the far field divergence angle $\Theta_{\sigma x}$ and $\Theta_{\sigma y}$
- the angle ϕ between the x´-axis of the measuring system and the x-axis of the beam (the x-axis of the beam is the one closest to the x-axis of the measuring system.)

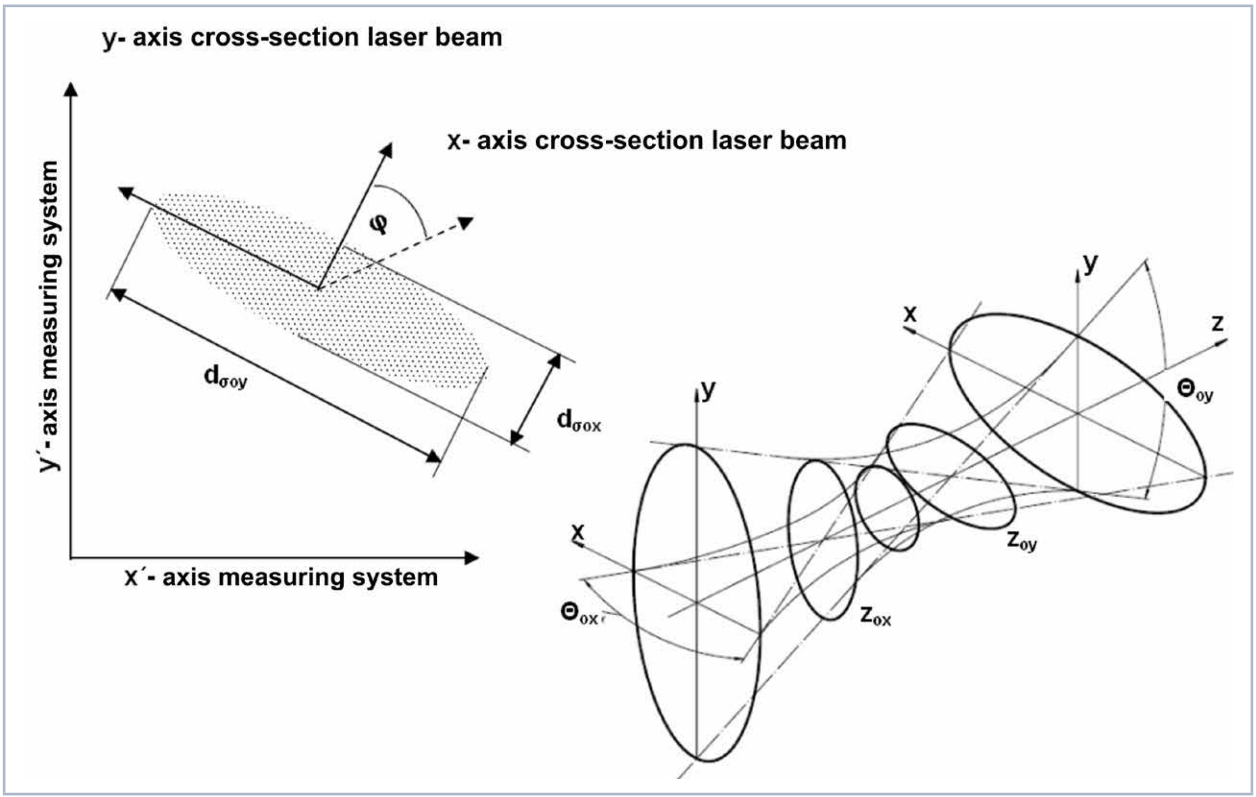


Fig. 21.2: Beam parameter of the not rotationally symmetric beam

All beams which can be characterized by two axes which are perpendicular to each other can be described by means of the above mentioned parameters.

Further beam parameter such as the K-figure or the beam propagation factor are calculated directionally by means of as the same equations as the rotationally symmetric beams. This always results in two parameters such as Kx and Ky.

21.2 Calculation of beam data

For the calculation of the beam data not only the algorithms for the 2nd moment method are implemented as demanded by the ISO standard 11145 but also the 86 % method which is widely-spread within the industry. For the Gaussian TEM00-mode both methods offer similar results whereas in case of the majority of other laser beams the 2nd moment method calculates bigger beam diameters than the 86 % method.
Laser radiation often is a mixture of different modes with different frequencies and coherent characteristics. All known measuring procedures only provide little information on the beam. Therefore the calculated beam parameters are always dependent on the measuring procedure. For the interpretation of the measuring results it is important to be aware of this fact.

The calculation of the beam radius requires the following to preparatory steps:

1. Measurement of the power density distribution
2. Determination of the zero level
3. Determination of the beam position

21.2.1 Determination of the zero level

The zero level can – for instance – be determined by means of a histogram by applying the frequency of the measured power density values (please see Fig. 21.3 on page 128).

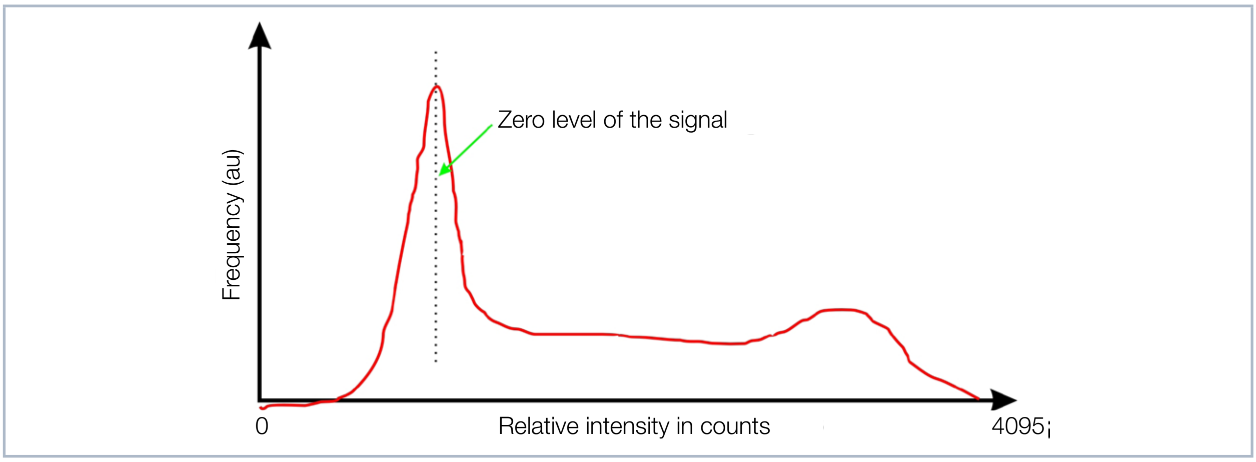


Fig. 21.3: Schematic histogram of the scanned measuring points

The histogram shows how frequently a certain power density was measured. The maximum of this curve indicates the power density of the zero level. The power density is deducted from all measured values of the power density distribution.

It is important to measure the zero level accurately because even the slightest error would lead to a drastic change as far as the volume is concerned. This in turn has a great impact on the measured beam radius.

21.2.2 Determination of the beam position

The beam position is determined by means of the 1st moment method. This means the moment of inertia of the power density distribution (E(x, y, z)) is determined.

$$\bar{x} = \frac{\int\int x \cdot E(x,y,z)dxdy}{\int\int E(x,y,z)dxdy} \qquad \bar{y} = \frac{\int\int y \cdot E(x,y,z)dxdy}{\int\int E(x,y,z)dxdy} \tag{1.5}$$

As mentioned at the beginning of the chapter, there are two possibilities how to determine the beam radius after the determination of the beam position.

21.2.3 Radius determination with the 2nd moment method of the power density distribution

The calculation of the beam radius according to the 2nd moment method of the power density distribution is effected as shown in equation ***(1.6)***.

$$\sigma_x^2(z) = \frac{\iint (x-\bar{x})^2 \cdot E(x,y,z)\,dxdy}{\iint E(x,y,z)\,dxdy} \qquad \sigma_y^2(z) = \frac{\iint (y-\bar{y})^2 \cdot E(x,y,z)\,dxdy}{\iint E(x,y,z)\,dxdy} \tag{1.6}$$

Based on equation ***(1.6)*** the beam diameter is determined as follows:

$$\begin{aligned} d_{\sigma x}(z) &= 4 \cdot \sigma_x(z) \\ d_{\sigma y}(z) &= 4 \cdot \sigma_y(z) \end{aligned} \tag{1.7}$$

This algorithm contains the product derived from the power density and the squared distance to the moment of inertia. It is only reliable when the zero level is determined correctly. The fill factor, the ratio of the beam diameter divided by the integration range/measuring window size is a further important quantity. It should always have a value between 0.35 and 0.7.

21.2.4 Radius determination with the method of the 86 % power inclusion

The first step is the determination of the volume of the power density distribution. It is proportional to the total power. The addition of all power density values and their multiplication with the pixel dimensions result in the volume and therefore the total power. A reliable zero level subtraction is the fundamental basis.
Based on this total power, the focus lies on the range which includes the 86 % of the total beam power. This beam power must lie within the beam radius.
The integration typically starts with the values of the maximum power density. Then the integration range is enlarged until 86 % of the total power lie within the radius. As far as the integration is concerned, the number of pixels is counted. By means of this the 86 % range which means the beam diameter can be determined. For circular beams similar to the fundamental mode beams the procedure works well.

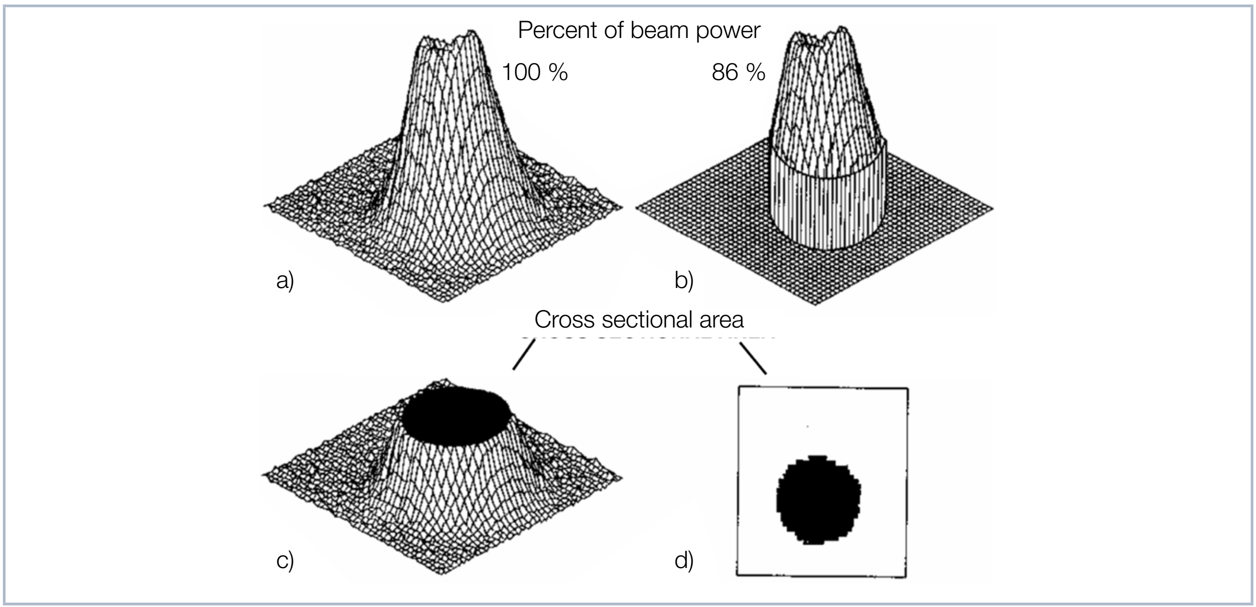


Fig. 21.4: Graphical presentation of the calculation of the 86% radius

- a) Shows the power density distribution.
- b) Shows the pixels which include 86 % of the power together.
  As a clarification the pixels with a low power are set to zero.
- c) Shows a section at the “86 % power density inclusion”.
  The level lies at 14 % of the maximum power.
- d) Shows the section through the distribution at 86 %.

21.2.5 Measurement errors

Regardless of the measuring principle, there are many sources of errors in determining beam radius.

- Determination of the zero level
- Finite size of the measurement window
- Resolution in x and y directions
- Intensity resolution

21.2.6 Error in determining zero level

Calculation of the beam waist radius is very strongly dependent on changes in the zero level. It doesn't matter if the 86% or 2nd moment method is used.

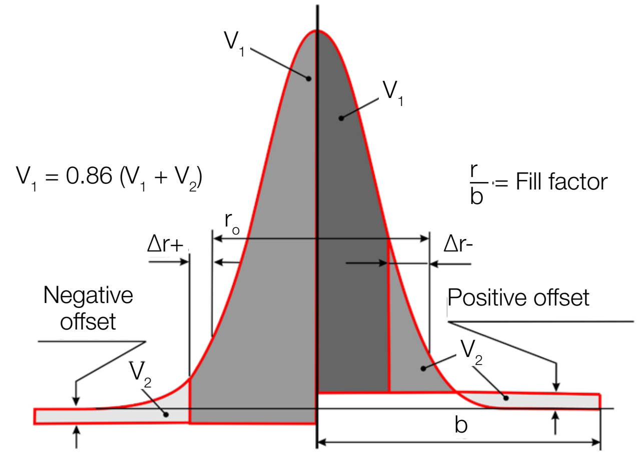


Fig. 21.5: Gaussian Intensity Distribution, zero level lowered (left) and raised (right)

Fig. 21.5 on page 131 illustrates this. When the zero level is lowered (left side), the total volume between the measurement values and the zero level increases. Because of this increase, a larger beam radius is calculated using the curve equation. Conversely, if the zero level is raised (right side), the volume decreases and the computed beam radius will be too small.

21.2.7 Saturating the signal

High signal amplitudes are clipped by the limited dynamics of the system. If the high power densities are missing from the calculation of beam geometry, the algorithm always computes a beam that is too large. This can be compensated for by increasing attenuation.

21.2.8 Errors from incorrect measurement window size

The entire laser beam must be within the measurement window for correct normalization of the volume of the measured distribution. Since the intensity distribution, in principle, extends infinitely, a fraction of the beam power is always outside the measuring range.
In the following, the normalization of beam radius is proportional by half to the window size. This size is defined as the Fill Factor (F).

$$F = \frac{2 \cdot r_s}{\textit{Width of the measuring window}} \tag{1.8}$$

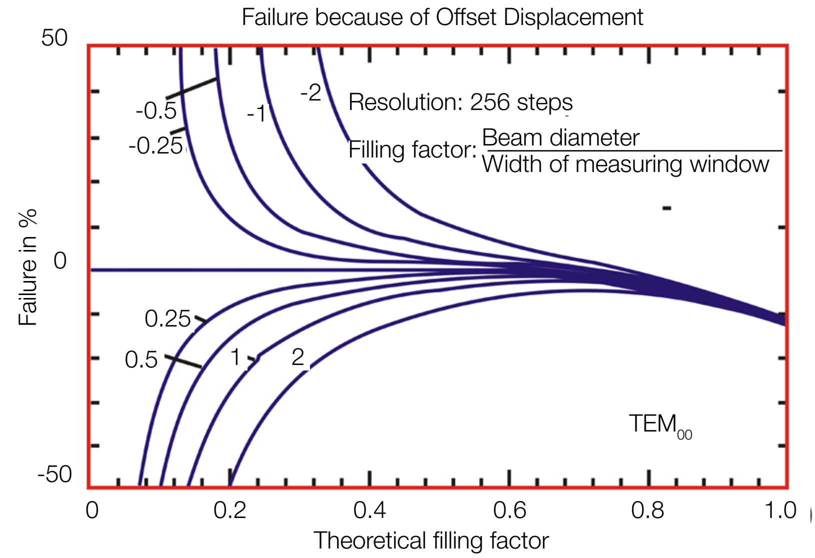


Fig. 21.6: Error During Beam Radius Calculation by Offset of the zero level Plane for Various Offset Values (Gaussian Intensity Distribution)

In Fig. 21.6 on page 132, the effect of a Fill Factor greater than 0.7 can clearly be seen. For Gaussian-like beams, the Fill Factor should be held between 0.4 and 0.6 to minimize errors. For Top-Hat distributions, the limit is around 0.9.

21.3 Formula and algorithms for raw beam back calculation of the LQM

To calculate the raw parameters from the measured beam parameters of the focus, the formula given in ISO11146 is used. Index F describes the beam parameters of the focus.

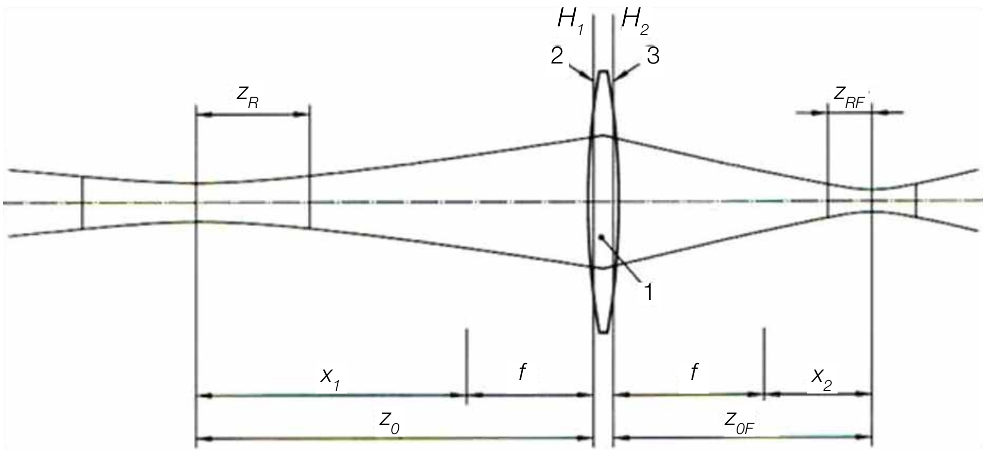


Fig. 21.7: Raw beam back calculation

Beam waist radius within the raw beam

$$w_0 = \frac{f}{\sqrt{z_{RF}{}^2 + \Delta^2}} \cdot w_{0F}$$

Far field divergence

$$\Theta = \frac{\Theta_F \cdot \sqrt{z_{RF}^2 + \Delta^2}}{f}$$

Position of beam waist within the raw beam

$$z_0 = \frac{f^2}{z_{RF}^2 + \Delta^2} \cdot \Delta + f$$

Rayleigh length within the raw beam

$$z_R = \frac{f^2}{z_{RF}^2 + \Delta^2} \cdot z_{RF}$$

With focus position difference

$$\Delta = z_{0F} - z_{ref}$$

Beam diameter onto the focussing optic

$$d_L = \Theta_F \cdot \left(f + z_{ref} - z_{0F} \right)$$