



Safety Aspects of Laser Processing in Laboratory

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OPTIMAL Workshop, 20 November 2025



LASER ZENTRUM HANNOVER e.V.

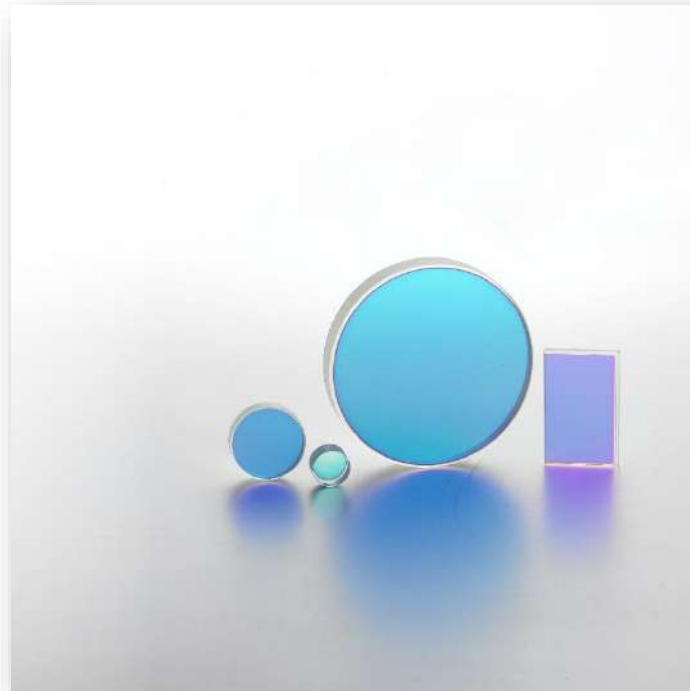


Extramural, independent and non-profit research institute

Interdisciplinary research and development in the field of photonics and laser technology



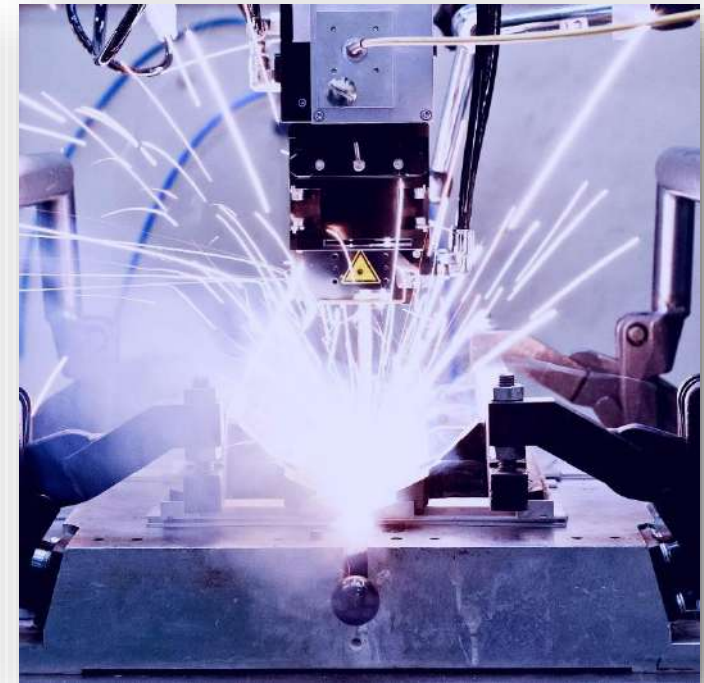
Development Along the Entire Value Chain



Optics and components



Laser

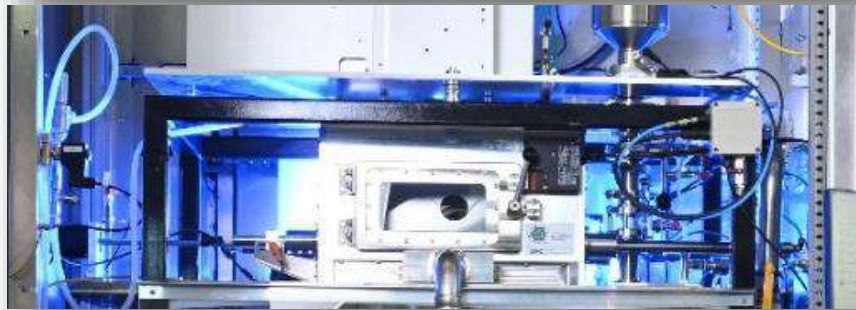


Processes and applications

Distinction of Responsibilities in Laser Safety

Regulations for distributors and users

Manufacturing / Placing on the market



Using (example: Germany)



Risk / hazard assessment

Machinery Directive 2006/42/EC
 Low Voltage Directive 2014/35/EU
 Regulation (EU) 2016/425 on PPE

Occupational Health and Safety 89/391/EEC
 "Artificial Optical Radiation" 2006/25/EC
 Individual Directive „Noise“ 2003/10/EC

Determination of general protection objectives

German Product Safety Act (ProdSG)
 1st Product Safety Ordinance (Low Voltage)
 9th Product Safety Ordinance (Machinery)

German Occupational Health and Safety Act
 Industrial Safety Ordinance
 Occupational Health and Safety Regulations on Artificial Optical Radiation

Determination of specific measures

EN 60825-1 EN ISO 11 553-1
 EN ISO 12100 EN ISO 60204-1
 EN ISO 13849-1

"TROS" Laser Radiation
 "TROS" Incoherent Optical Radiation (DGUV 11)

residual risk

Distinction of Responsibilities in Laser Safety

Regulations for distributors and users

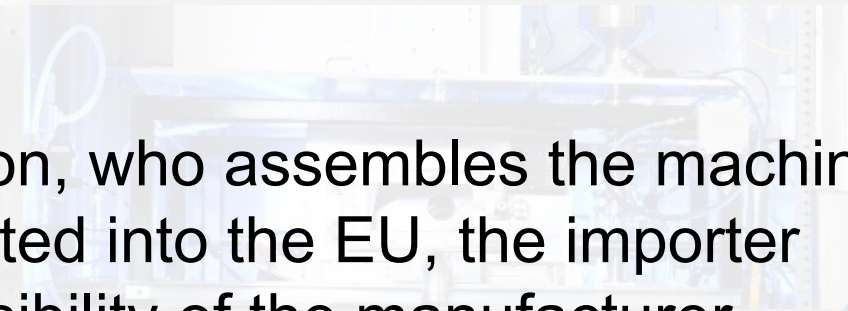
Manufacturer:

Person or organization, who assembles the machine.
If a machine is imported into the EU, the importer assumes the responsibility of the manufacturer.
The importer places the machine on the market.

A person or organization responsible for the modification of a machine is considered to be the manufacturer.

Determination of specific measures

Manufacturing / Placing on the market



Machinery Directive 2006/42/EC
Low Voltage Directive 2014/30/EU
Regulation (EU) 2016/425 on PPE

EN 60825-1
EN ISO 12100
EN ISO 13849-1
EN ISO 11 553-1
EN ISO 60204-1

Using (example: Germany)



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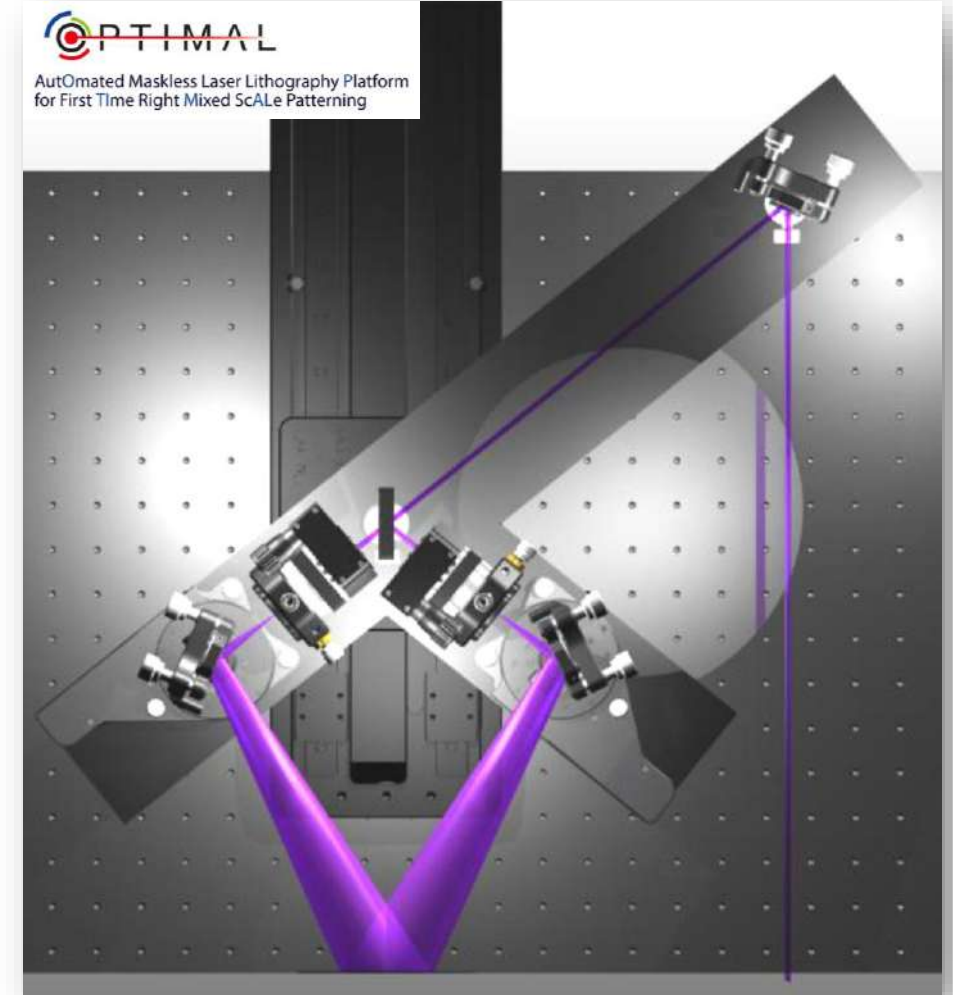
DLC HOLO-LITHO 405 (TOPTICA Photonics AG)

- cw laser @ 405 nm
- output power ≤ 1 W
- coherence length of > 100 m
- $M^2 = 1.15$



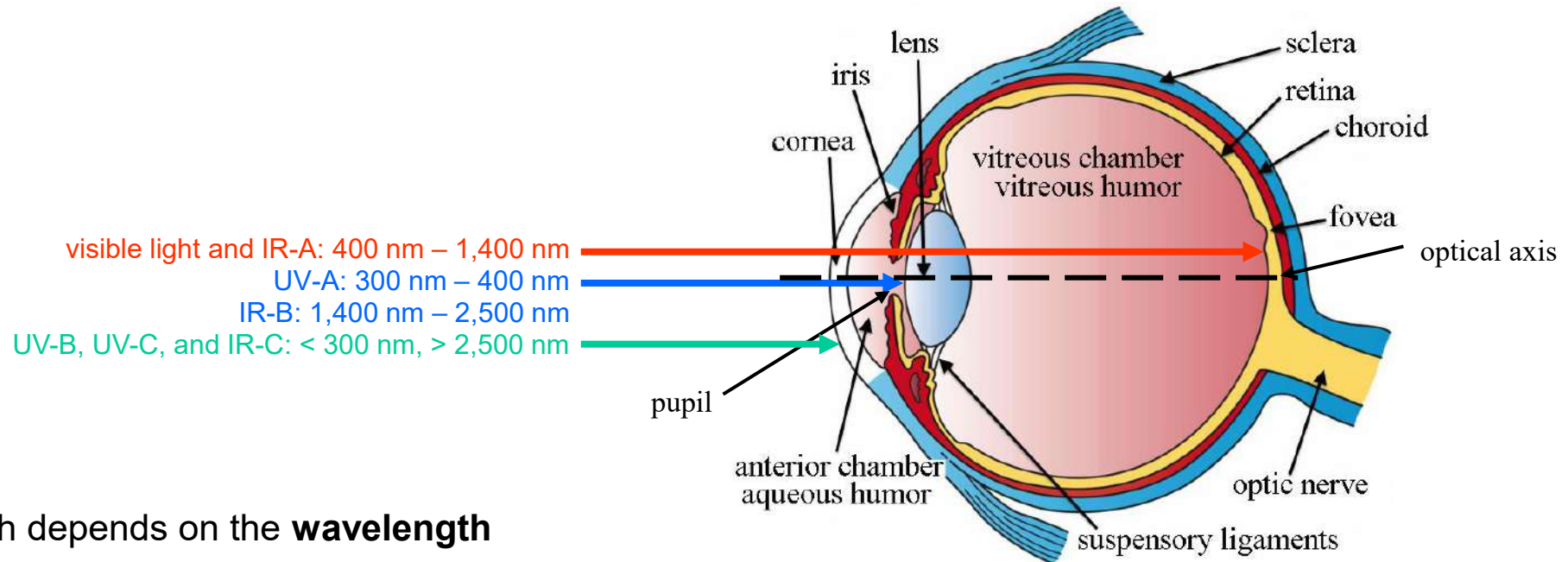
FemtoFiber ultra 780 (TOPTICA Photonics AG)

- fs laser (80 MHz) @ 780 nm
- pulse duration < 100 fs
- pulse width < 100 fs (sech² fit)
- average output power > 1 W
- $M^2 = 1.15$



Optical Properties of the Eye – Dependence on the Wavelength

- Structure of the human eye and wavelength ranges of transmitted radiation

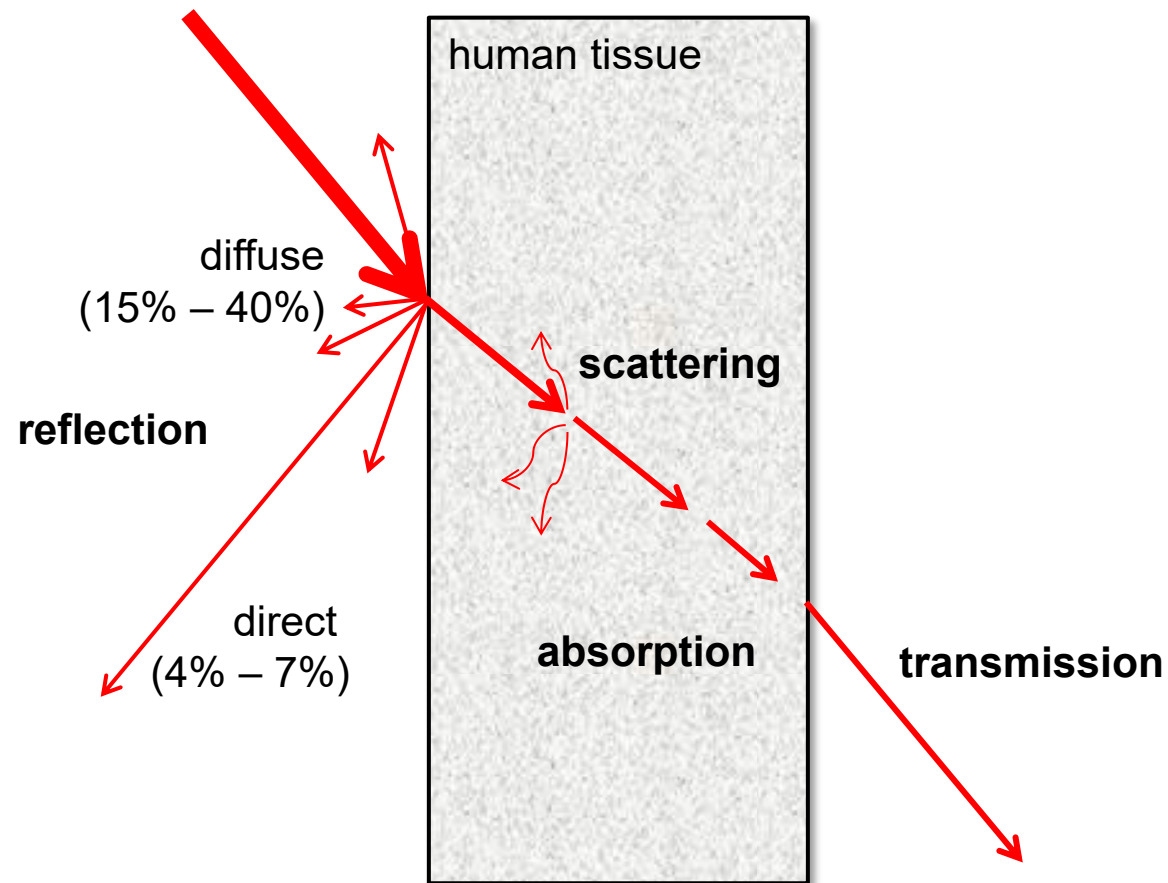


- Penetration depth depends on the **wavelength**
- Potential eye damage depends on the **irradiance** and the **exposure time**
- Intensity on the retina is **5 to 6 orders of magnitude higher** than on the cornea

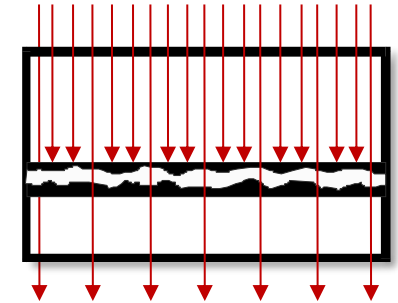
Artwork by Holly Fischer

– <http://open.umich.edu/education/med/resources/second-look-series/materials> – Eye Slide 3, CC BY 3.0, <https://commons.wikimedia.org/w/index.php?curid=24367145>, supplemented by the LZH with wavelength-dependent transmittance information

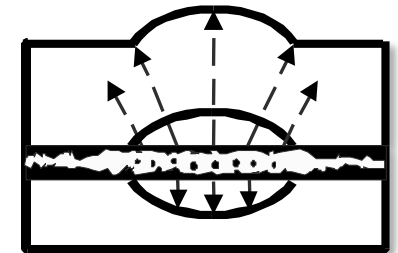
Light Propagation in Biological Tissue: Skin Injuries by NIR Laser Radiation



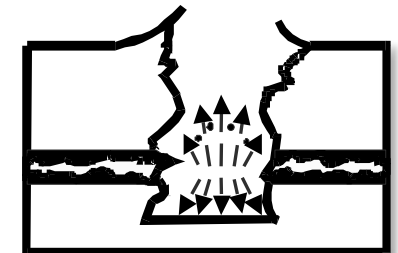
- Explosive evaporation of water in the tissue (popcorn effect)



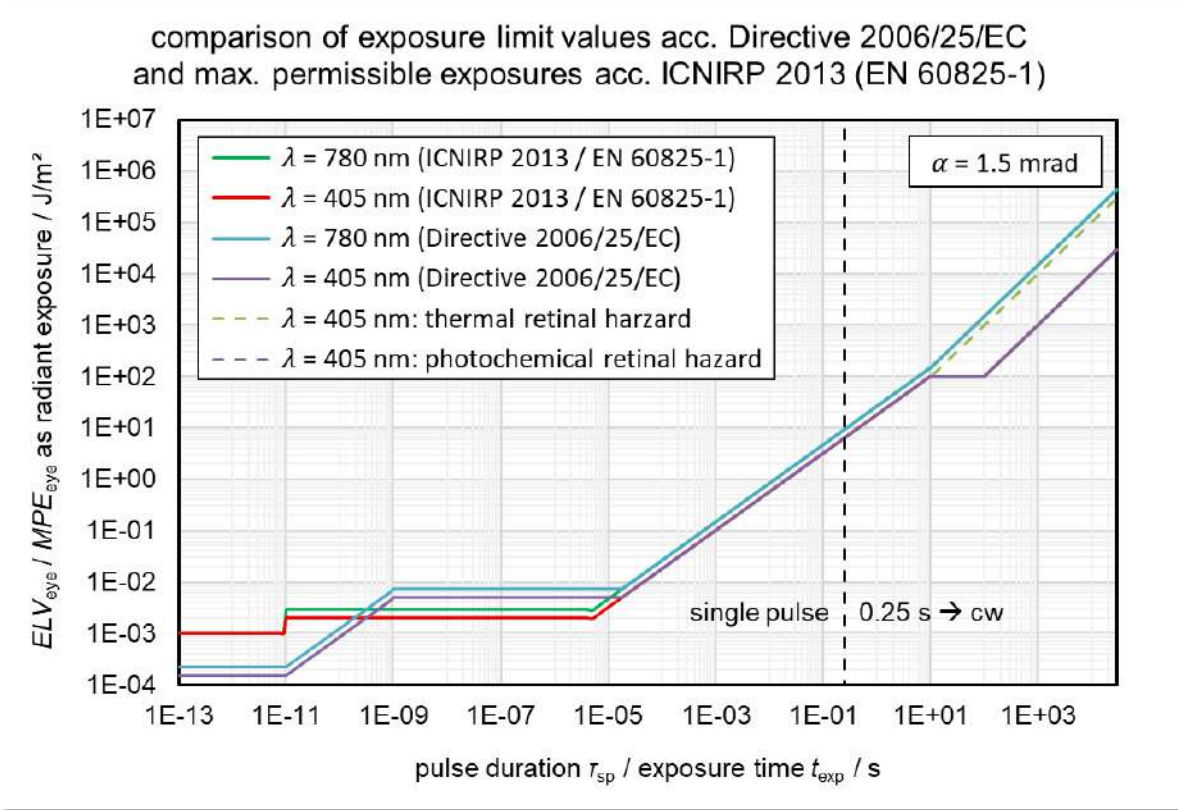
- Formation of shock waves



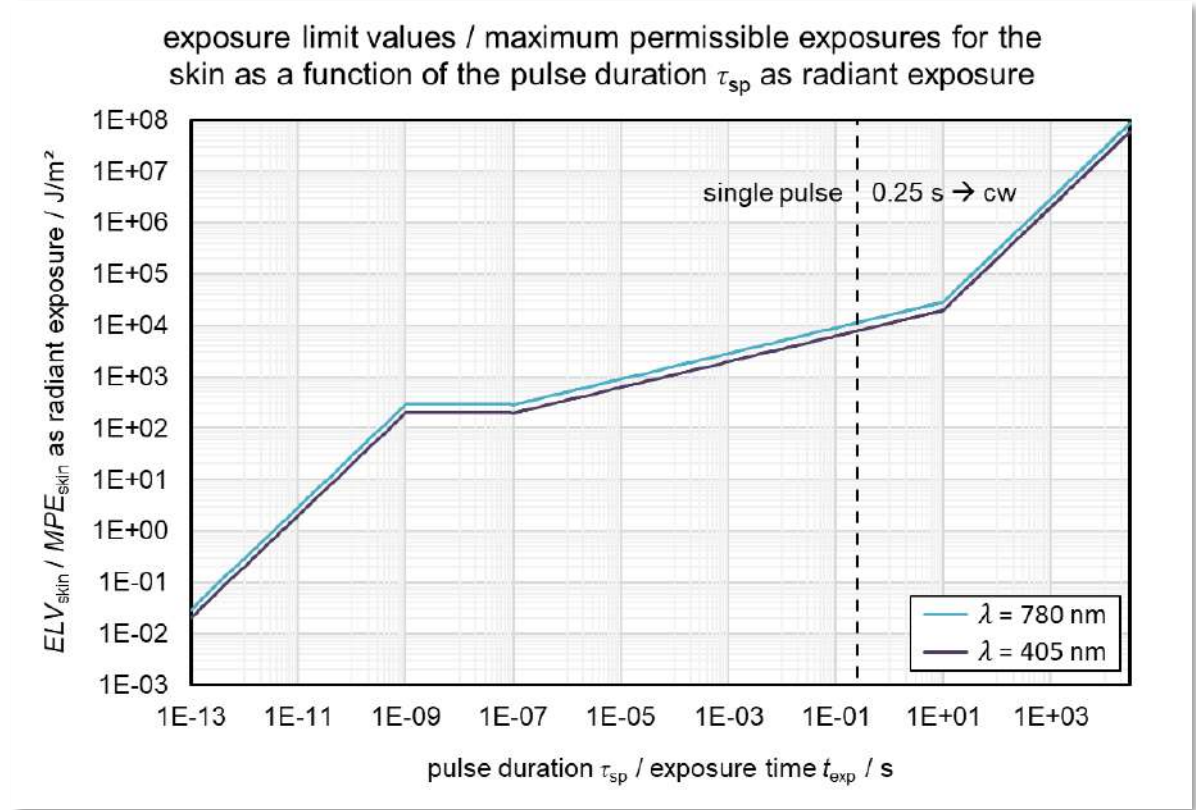
- Tissue is mechanically ruptured, particles ejected; pain, partially intense bleeding



Exposure Limit Values / Maximum Permissible Exposures

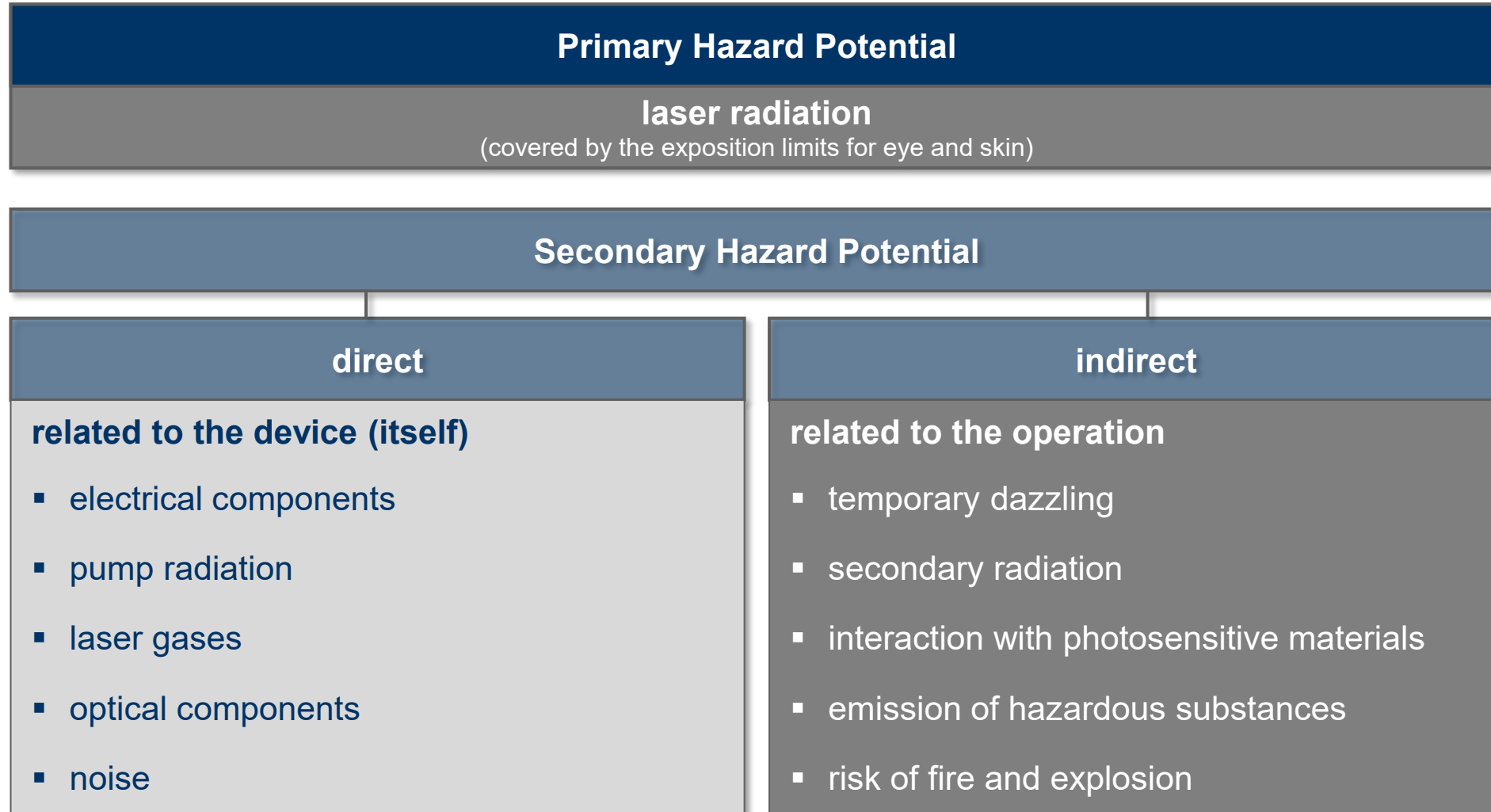


$ELV_{\text{eye}} / MPE_{\text{eye}}$



$ELV_{\text{skin}} / MPE_{\text{skin}}$

acc. Directive 2006/25/EC and ICNIRP Guidelines 2013 (EN 60825-1)



Primary hazard potential (laser radiation)

1. Direct (collimated) beam



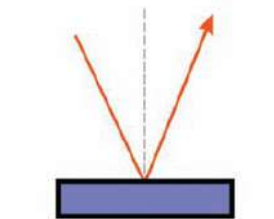
2. Direct (shaped) beam



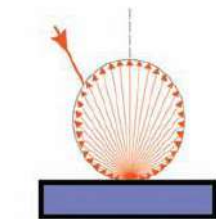
3. Directly reflected beam



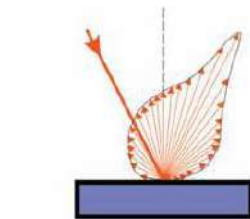
4. Diffusely reflected beam



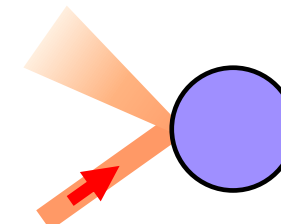
specular reflection



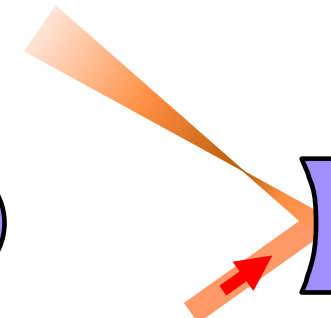
diffuse reflection



diffuse reflection with directed components



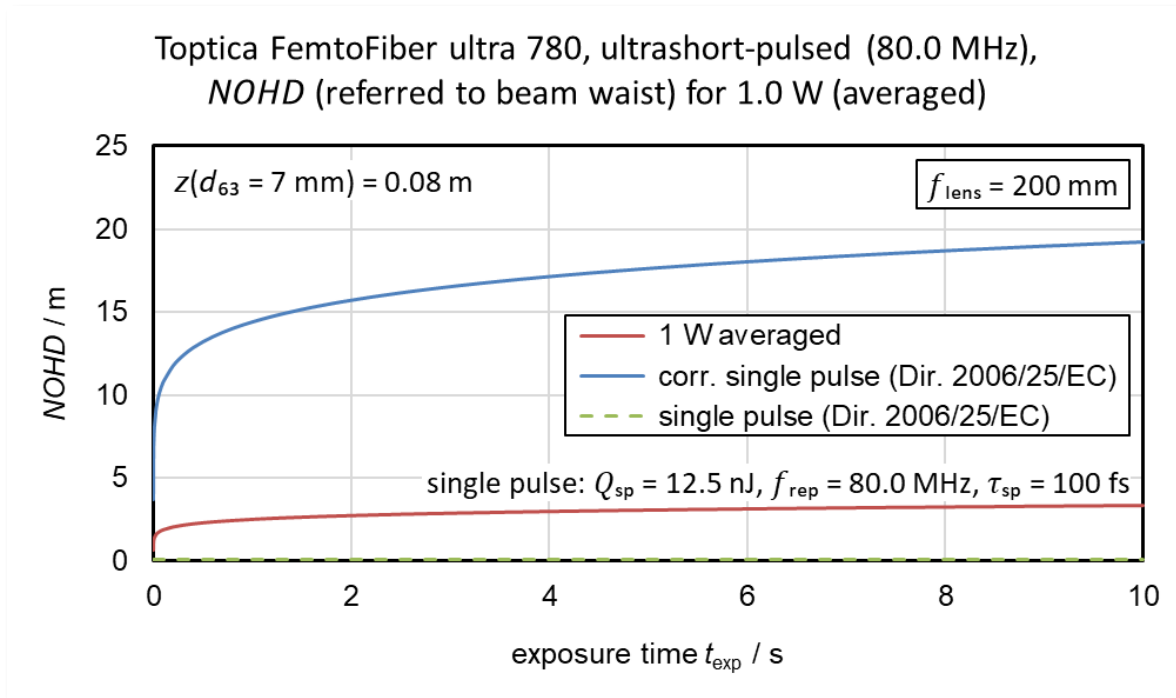
dispersion



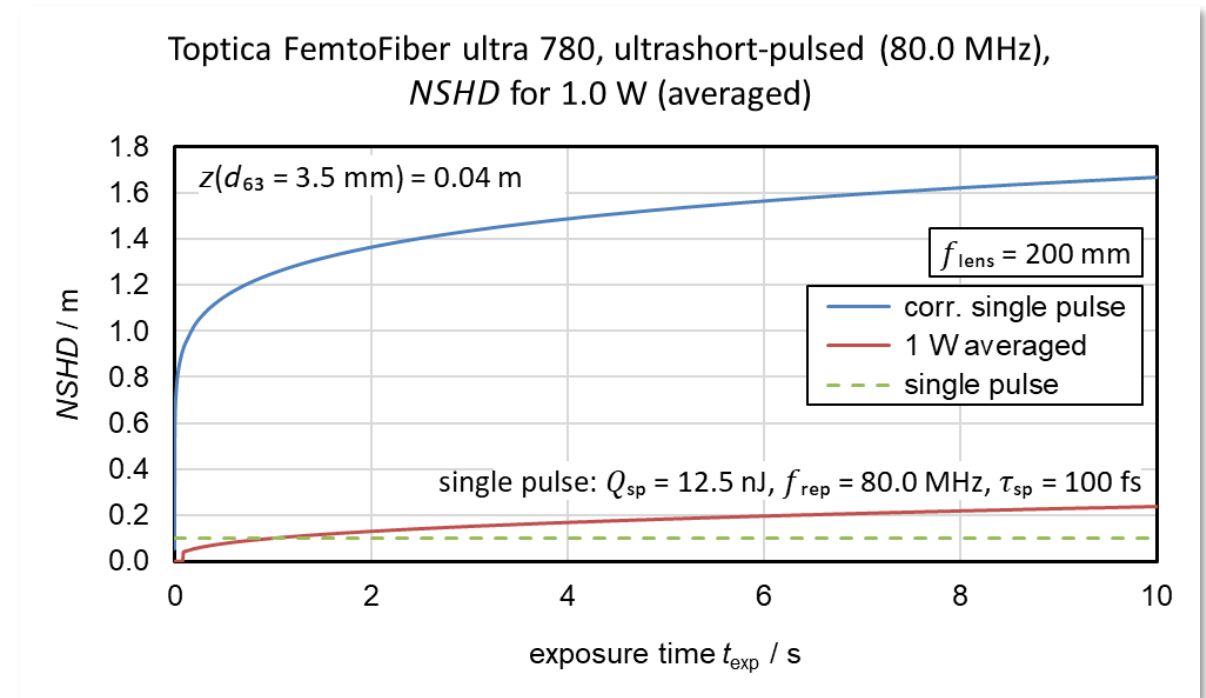
focusing

Nominal Ocular and Skin Hazard Distance (Toptica FemtoFiber)

- Assumptions: raw beam diameter $d_{R,86} = 25$ mm, focusing distance of the focusing lens $f_{\text{lens}} = 200$ mm



ELV_{eye}

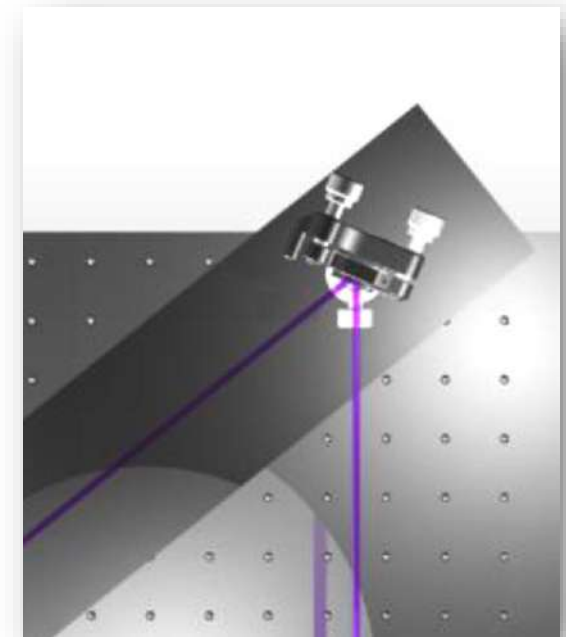


ELV_{skin}

acc. Directive 2006/25/EC

What Happens if Collimated Laser Radiation is Used?

- Collimated laser radiation is connected with extreme long ranges.
- Beam divergence is very low. Depending on the beam diameter, the power density / irradiance is constantly high.
→ *NOHD* calculation does not make sense.
- Example (FemtoFiber ultra 780, beam divergence neglected):
 - » assumed beam diameter: $d_{86} = 4.0 \text{ mm} \rightarrow d_{63} = 2.8 \text{ mm} \rightarrow$ beam area: $A_{63} = 6.3 \text{ mm}^2$
 - » average power: $P_{0,av} = 1.0 \text{ W} \rightarrow$ irradiance: $E_{av,63} = 159 \text{ mW/mm}^2 = 159 \text{ kW/m}^2$
 - » radiation not visible → time base: 10 s (according to wavelength)
 - » $ELV_{eye}(780 \text{ nm, cw}) = 14.45 \text{ W/m}^2 \rightarrow$ exceedance factor: **11,011**
 - » $ELV_{eye}(780 \text{ nm, single pulse}) = 217 \text{ μJ/m}^2 \rightarrow$ exceedance factor: **9**
 - » $ELV_{eye}(780 \text{ nm, corrected single pulse}) = 8 \text{ μJ/m}^2 \rightarrow$ exceedance factor: **360,731**



Estimation of the Possible Emission of Ionizing Radiation

There is a risk of an emission of laser-induced ionizing radiation, if the **maximum irradiance** E_{\max} in the spatial and temporal profile of the power-density distribution of a single laser pulse **exceeds** 10^{13} W/cm^2 (acc. StrlSchV, Germany).

Calculation using the following equation according to GMBI Nr. 5–6 2022, Appendix I, Part A (Germany):

$$E_{\max} = 4 \sqrt{\frac{4 \ln(2)}{\pi} \frac{Q_{\text{sp}}}{\tau_{\text{H}} \pi d_{63}^2}} \quad \left[\frac{\text{W}}{\text{cm}^2} \right]$$

- Q_{sp} : single-pulse energy [J]
- d_{63} : diameter of the **beam waist** referred to 63 % of the total laser power ($1/e$ diameter) [cm]
- τ_{H} : full width at half maximum of the temporal progression of the single pulse profile [s]
(assumption: $\tau_{\text{H}} = \tau_{\text{sp}}$)

→ $E_{\max} = 3.57 \cdot 10^{11} \text{ W/cm}^2$ → **No relevant emission to be expected!**

Provided by the manufacturer

Inherently safe design

Technical measures (constructive)

- Protective housing
- Safety interlocks
- Safety controls
- Beam dumps
- Warning devices
- Labelling
- Filter systems

Technical information

- Safety information
- Operating information

Provided by the operator

Technical measures (supplementary)

- Suitable space and accesses
- Suitable positioning of the laser
- Additional shields/guards
- Non-reflective instruments

Organizational Measures

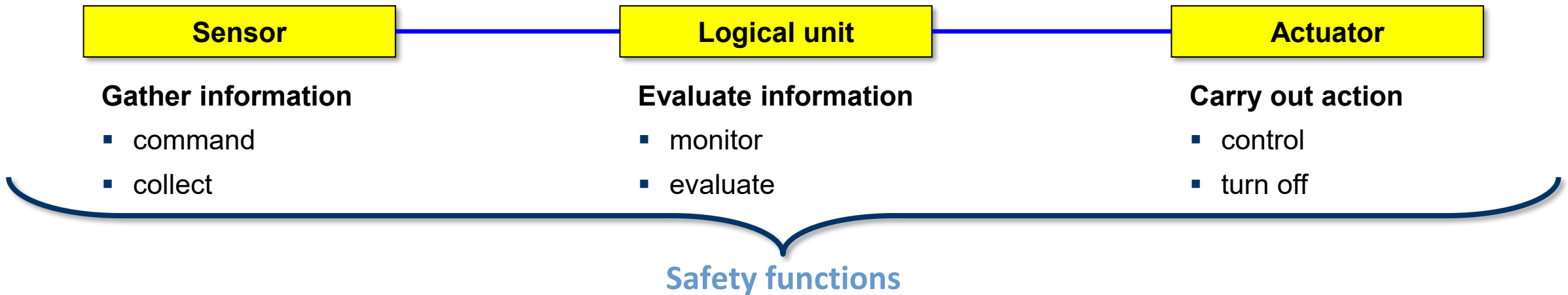
- Hazard assessment
- Operating directive
- Authorization measures
- Measures controlling access to the laser hazard area
- Selection of qualified workers
- Instructions/Training
- Accident prevention measures
- Appointment of a laser safety officer

Personal measures

- Protective clothing
- **Protective eyewear**
- Respiratory protection
- Ear/hearing protection

Technical standards

- **EN ISO 13849-1** Safety-related parts of the controls – General design principles
- **EN ISO 13849-2** Safety-related parts of the controls – Validation



Control categories

- B, 1, 2, 3, 4

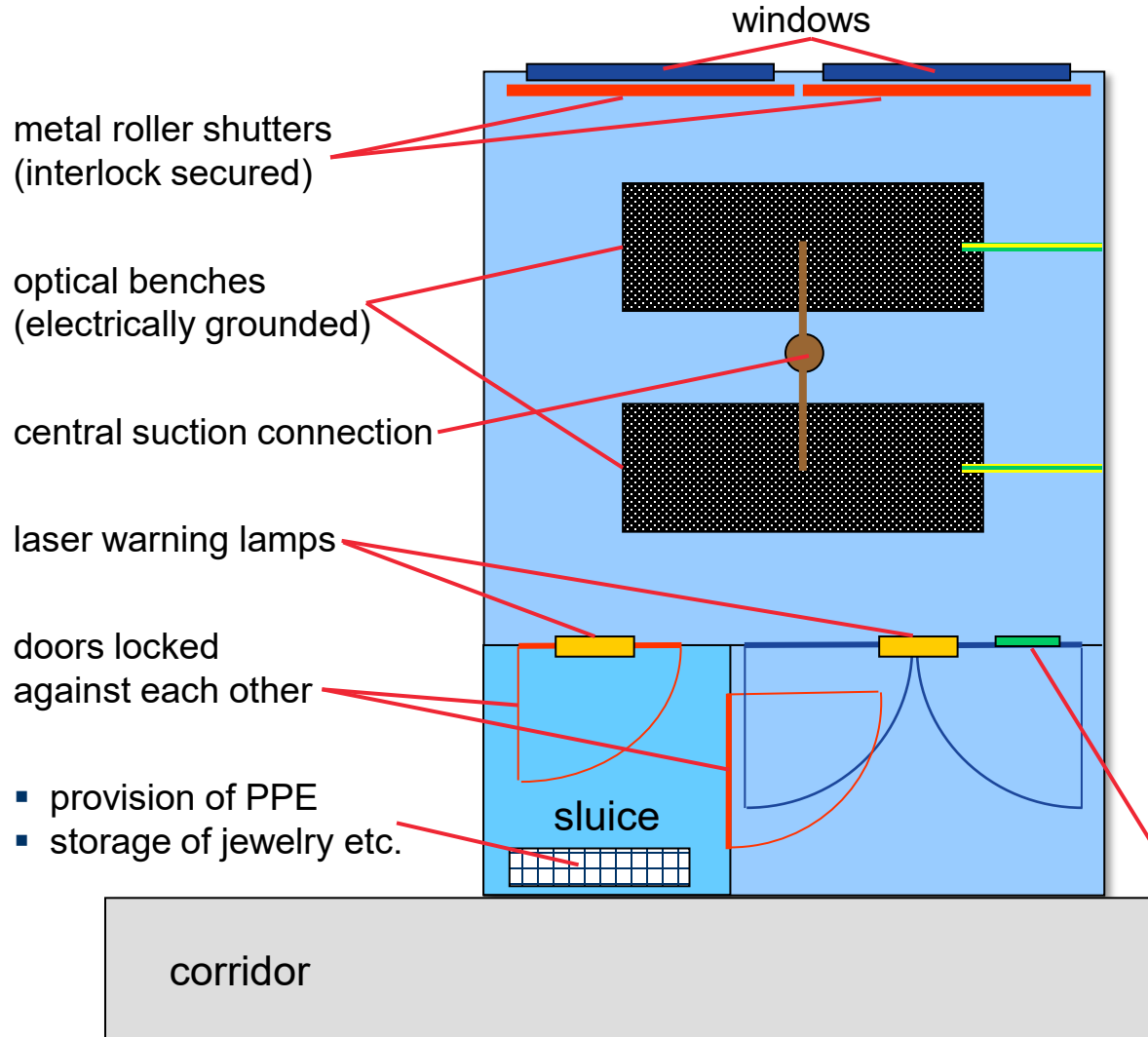
Laser class 1:

- Design of safety equipment
- failure safety
 - single fault condition



- Cat. 3: a single fault may not lead, under any conditions, to loss of the safety functions
- Cat. 4: an accumulation of faults may not lead to loss of the safety functions

Adequate Design of a Laser Laboratory



Advantages

- Doors all open in the direction of escape
 - Traffic route (corridor) is not restricted by opening doors
 - Large laboratory doors for loading the laboratory with equipment (laboratory tables), service/maintenance and, if necessary, rescuing people
 - Laser protection window in the loading door for observing people in the laboratory
 - Sluice for shielding the laser radiation and putting on PPE when the laboratory is being used as intended
 - Laser warning lamps at all laboratory entrances
 - Internal roller shutters (not blinds) in front of the windows for shielding the laser radiation
 - Central suction for extracting laser-generated air pollutants
- door (interlock secured, with guard locking if required, emergency release to be considered) with laser protection window (active if required)

Laser Laboratory for EU OPTIMAL Project at JOR



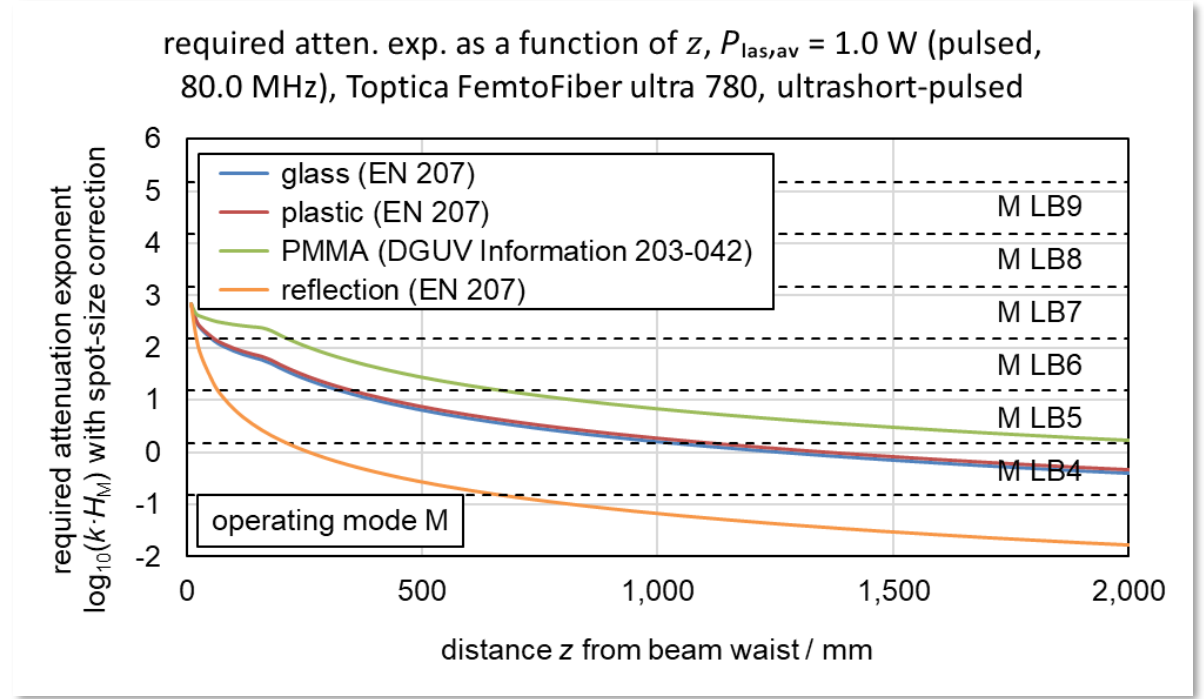
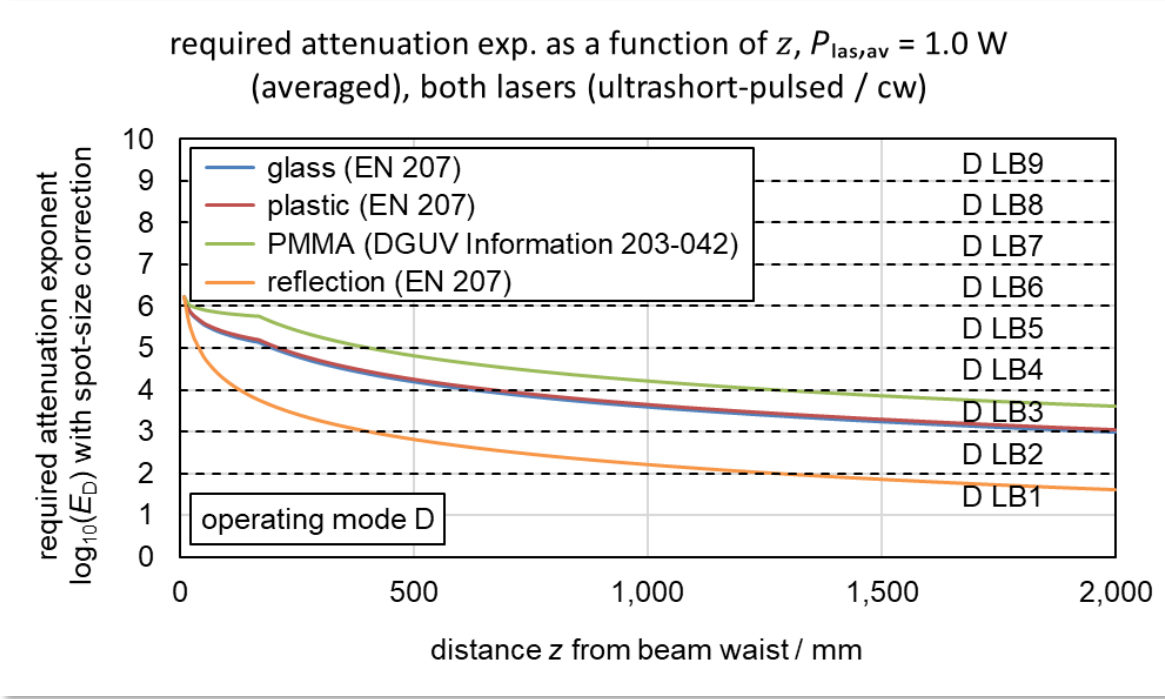
Types of laser filters used to protect the eyes



- absorption filters (glass/polymer)
- interference filters



Determination of Required Protection Level of Laser Goggles



- Assumptions: raw beam diameter $d_{R,86} = 25$ mm, focusing distance of the focusing lens $f_{lens} = 200$ mm
- Assumption of a collimated beam with $d_{86} = 4.0$ mm ($d_{63} = 2.8$ mm, corresponding to $z = 32$ mm)
 → **D LB5 / M LB6 – LB7** (depending on the filter material used)

acc. EN 207 / DGUV Information 203-042
(DGUV: German Statutory Accident Insurance)

- Risk analysis: primary hazards (laser radiation) as well as secondary hazards (direct: electrical components, pump radiation, laser gases, ... / indirect: hazardous substances, secondary radiation, risk of fire, ...) to be taken into account
- Foreseeable exposure limit *FEL* determined as a function of the distance from the process zone
- Nominal ocular / skin hazard distance (*NOHD* / *NSHD*) determined as a function of the exposure time t_{exp} :
NOHD in the order of 10 m – 20 m, *NSHD* in the order of 0,8 m – 1,7 m (ultrashort laser pulses acc. Directive 2006/25/EC)
- Technical measures to minimize risks for the operators, laser-safety control acc. EN ISO 13849-1 and -2
→ outside the laboratory: conditions of laser class 1 acc. EN 60825-1 required (no risk of injury)
- Laboratory setup requires usage of adequate PPE for the eyes, as the exposure limit values ELV_{eye} are exceeded by far
- Required protection level of laser protection goggles depending on the distance from the process zone and the filter material used (absorption filters or interference filters): levels in the range D LB2 – D LB5 / M LB3 – M LB6 acc. EN 207



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