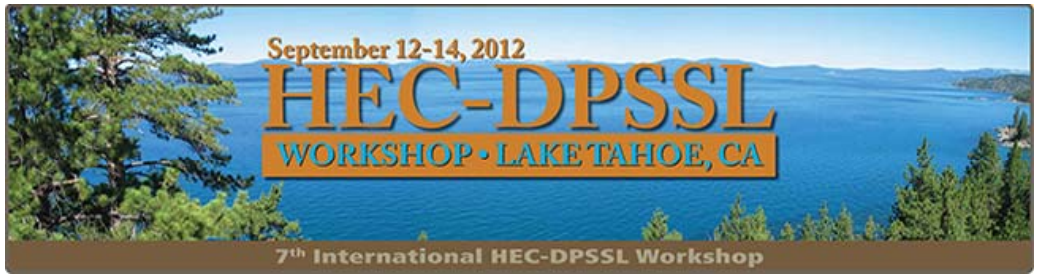


Comparison of large size Yb^{3+}:YAG ceramics and crystals

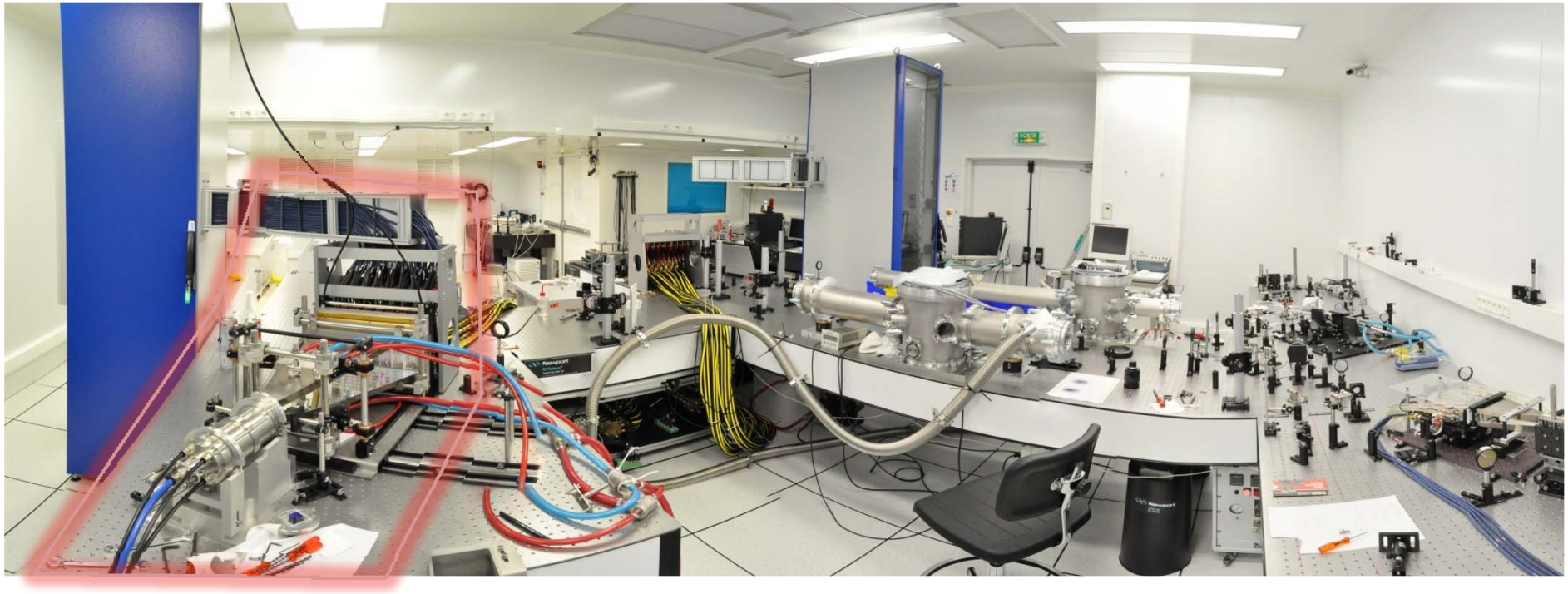
D. Albach, M. Arzakantsyan, T. Novo, B. Vincent and J.-C. Chanteloup

Laboratoire LULI, Ecole Polytechnique, Palaiseau, France

Lucia program, LULI, Ecole Polytechnique, France

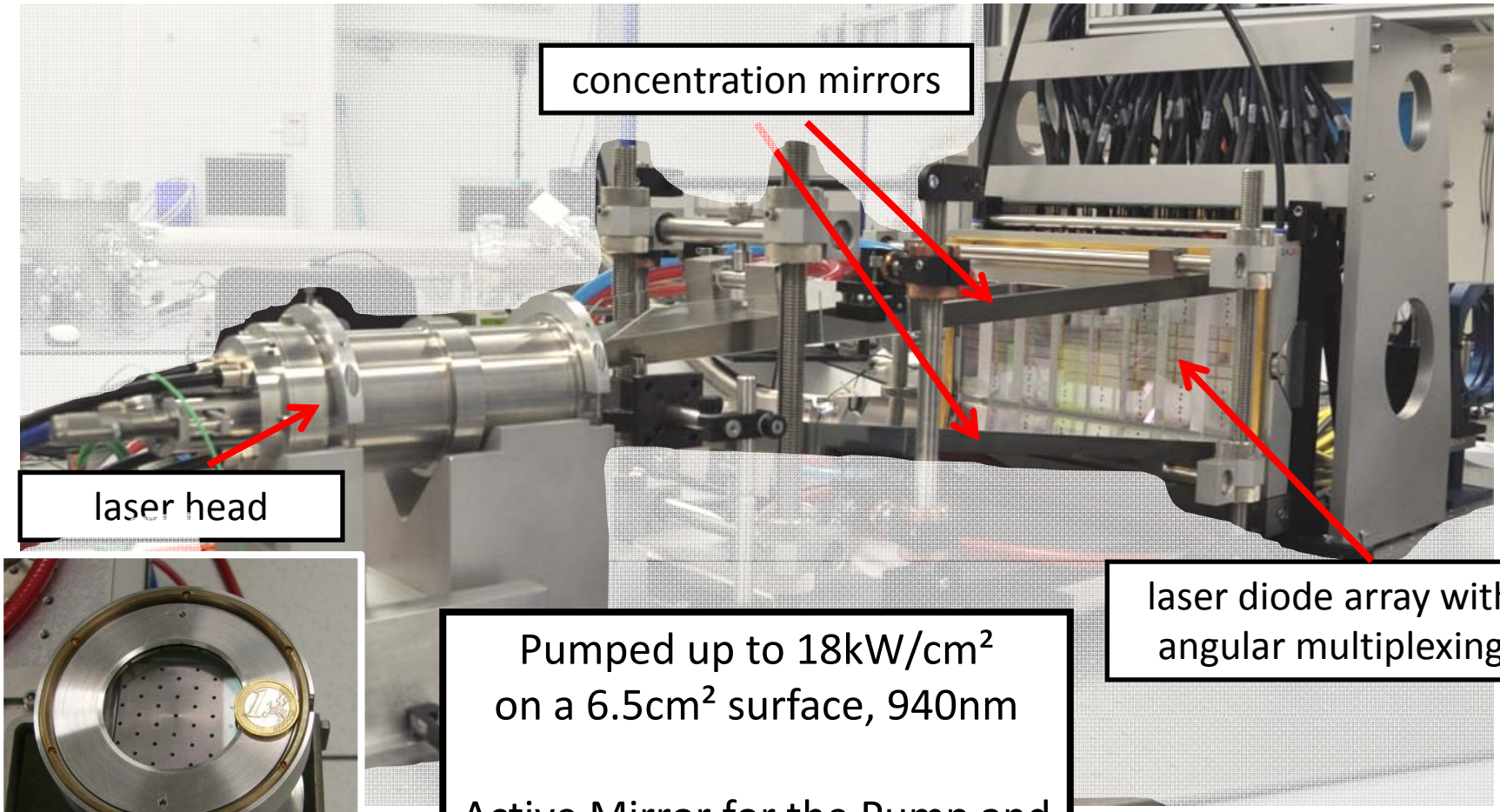
LULI DPSSL program goal : 100J / 10 Hz / 10 ns = **1kW average power**
Current laser performance :13.7 J / 2 Hz / 8 ns, 12% optical-to-optical efficiency

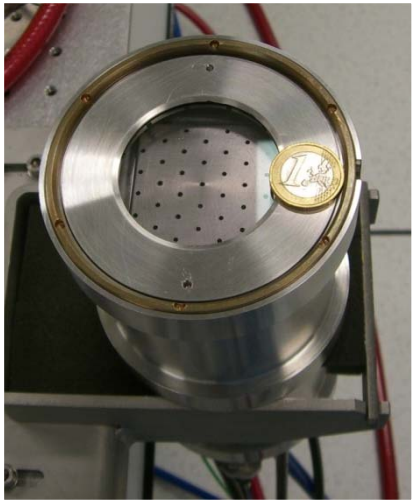
Crystalline Yb^{3+}:YAG is used, Ceramics are under assessment



Amplifier stage

Lucia main amplifier used for benchmarking



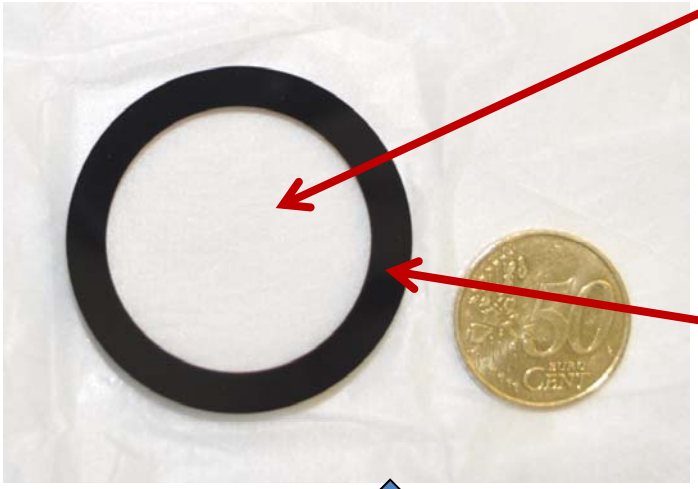


Pumped up to 18kW/cm²
on a 6.5cm² surface, 940nm

Active Mirror for the Pump and Extraction

Crystals and ceramics used in the Lucia amplifier setup

60mm diameter Yb^{3+}:YAG crystal, 7mm thickness, 2at.% doped



45mm diameter Yb^{3+}:YAG composite ceramics, 7mm thickness:

- 35mm Yb^{3+} doped center (2at.%)
- 5mm Cr^{4+} doped cladding (0.25at.%)

Comparison between crystal and ceramic

Crystal

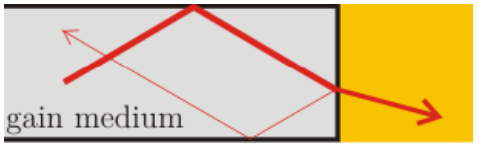
- High thermal conductivity (esp. at lower temperature operation)
- Good optical quality (possible)
- Specific orientation of the crystal possible ([111] instead of [100] e.g.)
- Difficult to add claddings, codoped volumes, bonding…
- Limited size, restricted geometries

Ceramic

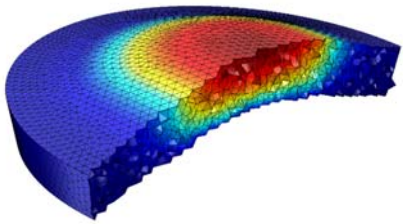
- Thermal conductivity almost similar to crystals at room temperature
- Scattering (grain boundaries)
- No impact of gain medium orientation (for most of the ceramics)
- Relative ease of adding differently doped volumes
- « unlimited » size

Main problems to solve for high average power DPSSL

- ASE and parasitic lasing

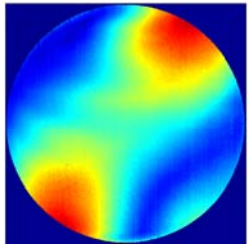


- Thermal management



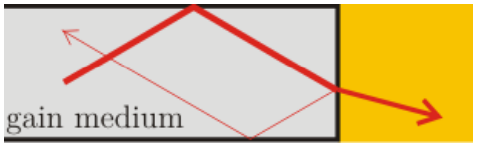
- Deformation

- Depolarization

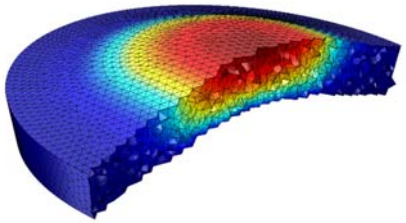


Main problems to solve for high average power DPSSL

- ASE and parasitic lasing

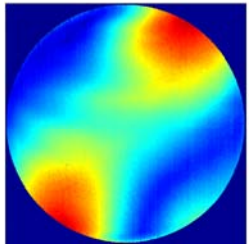


- Thermal management



- Deformation

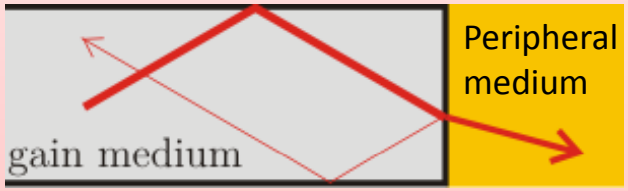
- Depolarization



Approached to avoid parasitic lasing at disk boundaries

Minimizing Reflectivity

Index Matching



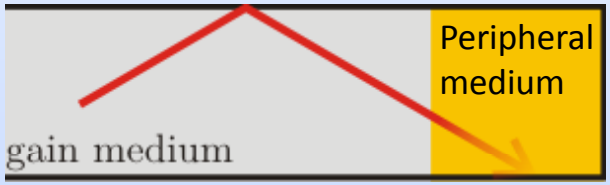
•Difficult for high refractive index combinations (Yb^{3+}:YAG n~1.82)

medium	index	refl.
air	1.0	8.5%
water	1.33	2.5%
diiodomethane	1.74	0.06%

•Not possible for low temperatures

Maximizing Absorption

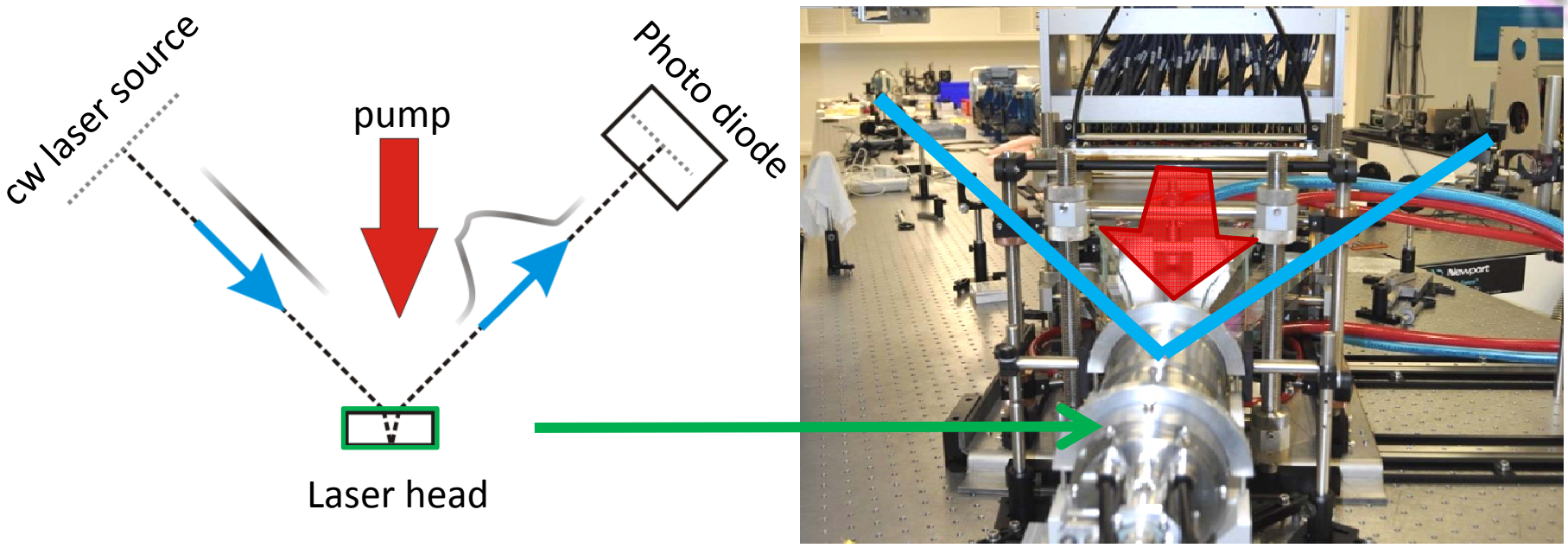
Absorbing Cladding



•Difficult to find an appropriate cladding

➔Laser quality ceramics

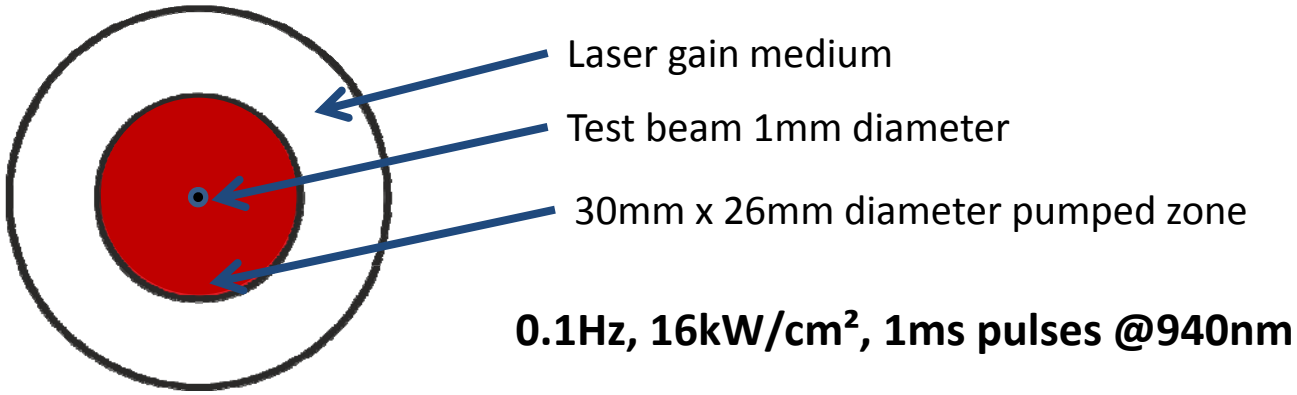
Small signal gain measurement on Lucia main amplifier



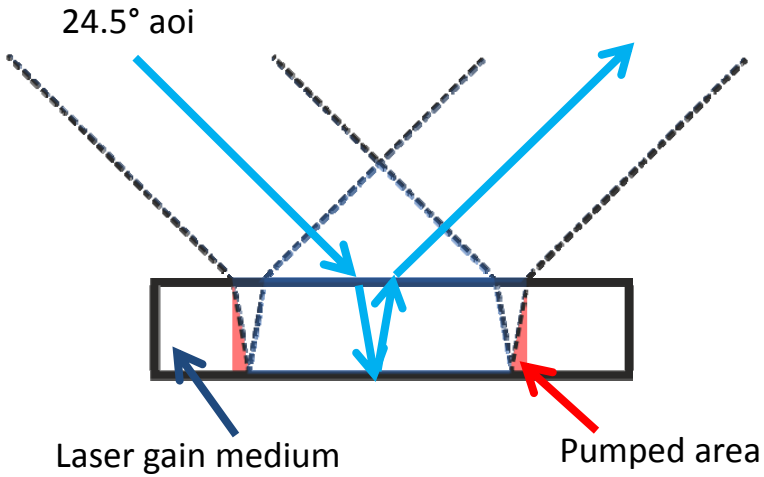
A cw laser beam at 1029.8 nm is imaged onto the gain medium and is recorded on a Photodiode.

By knowing the transmission of the system, the Small Signal Gain is deduced.

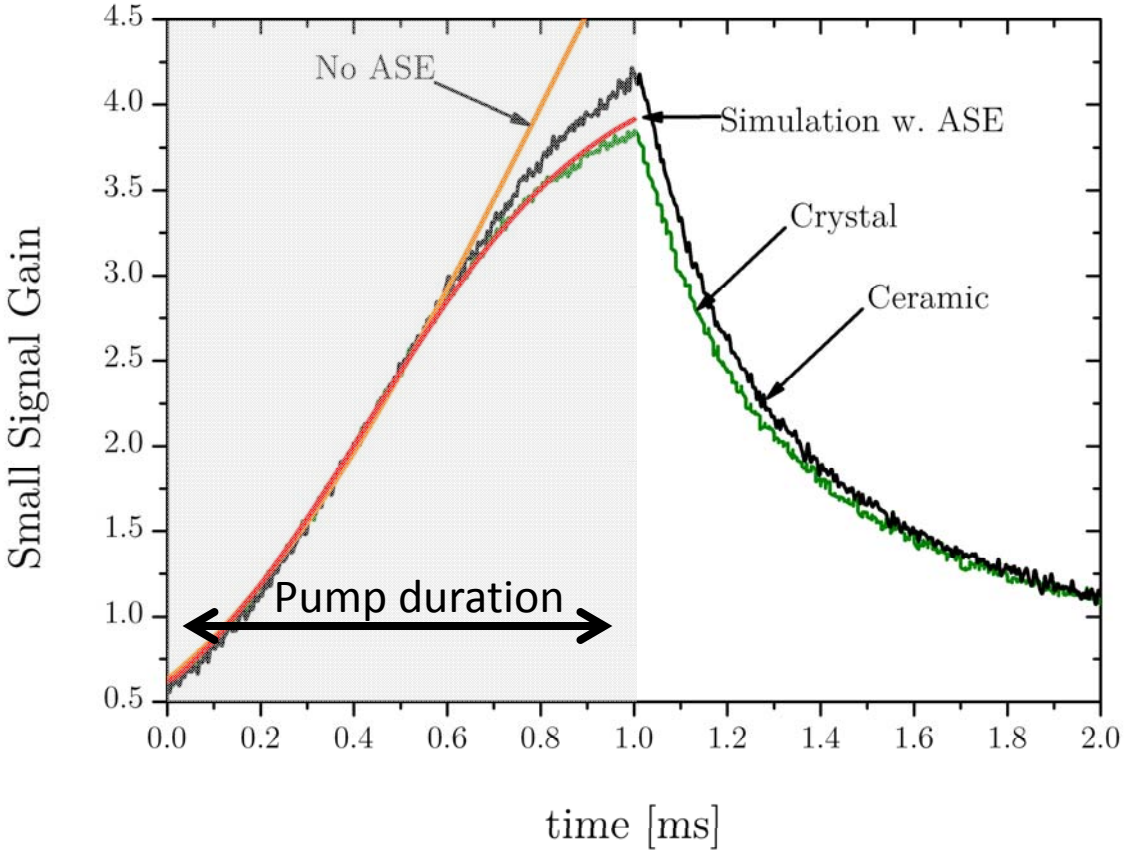
Single Shot Small Signal Gain measurement



0.1Hz, 16kW/cm², 1ms pulses @940nm



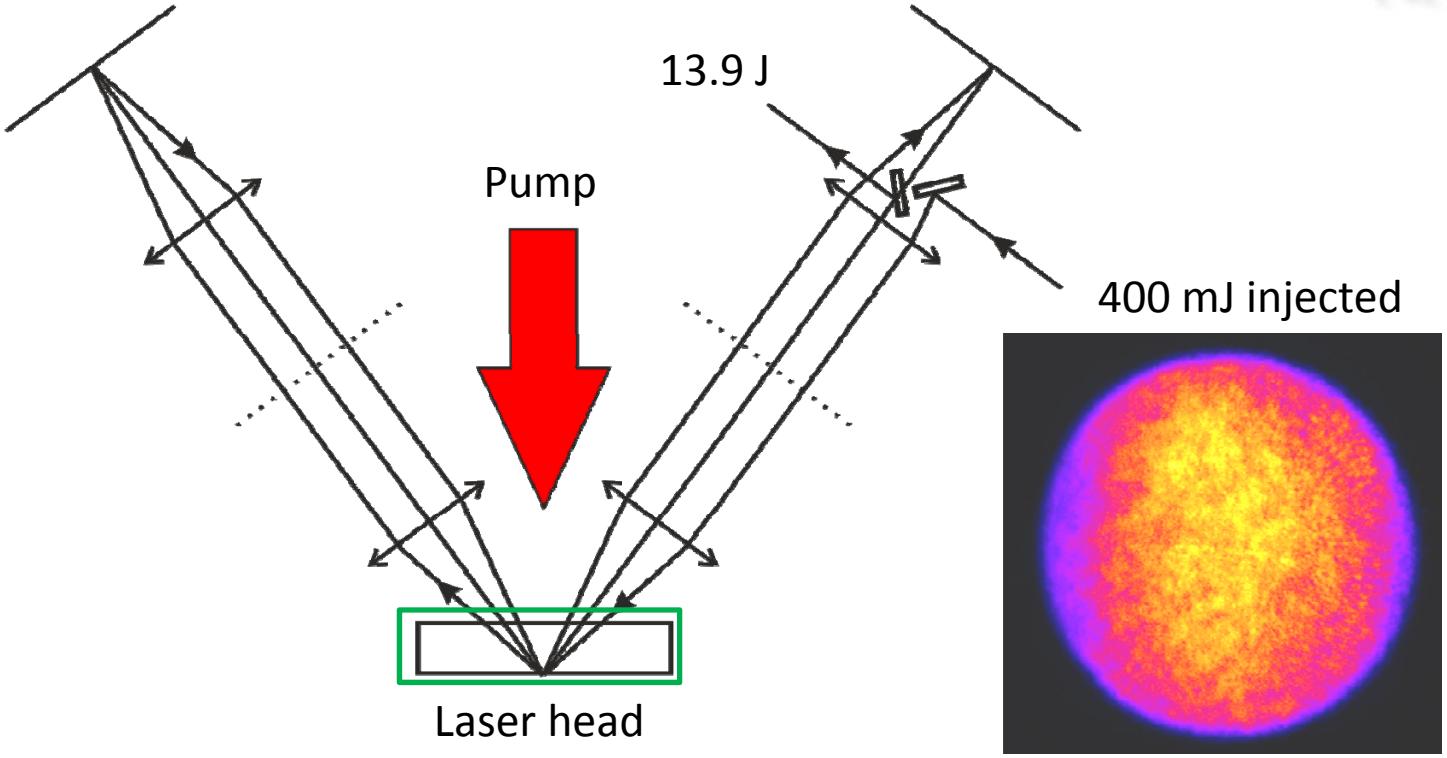
Crystal vs ceramic small signal gain, 16kW/cm², Single Shot



ASE simulation is in good accordance with the crystal case.

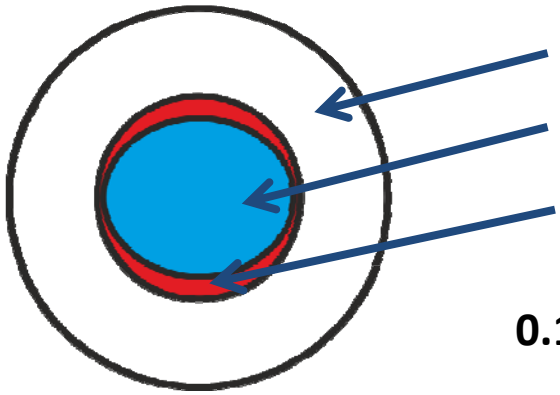
Ceramic cladding suppresses the onset of parasitic lasing succesfully.

4-passes single shot extraction with Main amplifier



4 fully image passes in the main amplifier

4-passes single shot extraction with main amplifier



Laser gain medium

Extracted area 25mm x 20mm

30mm x 26mm diameter pumped zone

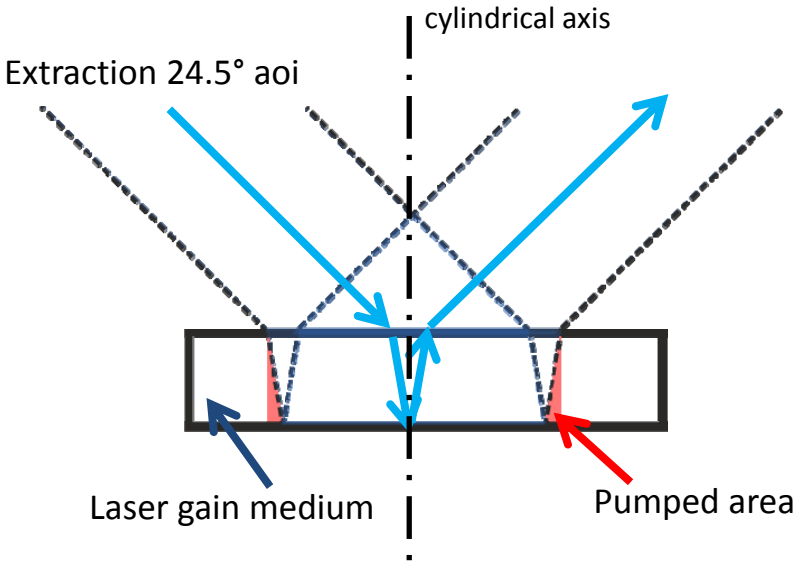
0.1Hz, 18kW/cm², 1ms pulses @940nm

20mm diameter « flat top » beam
4 passes, fully image relayed
24.5° angle of incidence

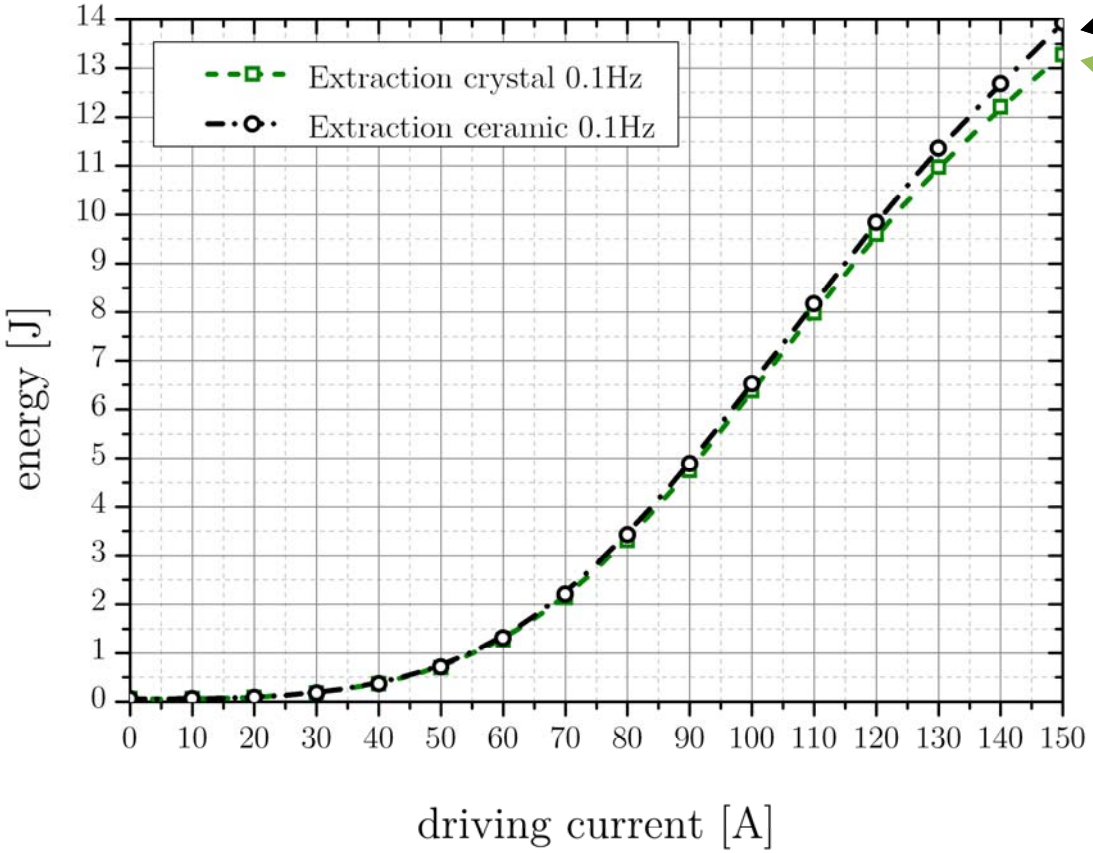
Angular multiplexing of 1.7°

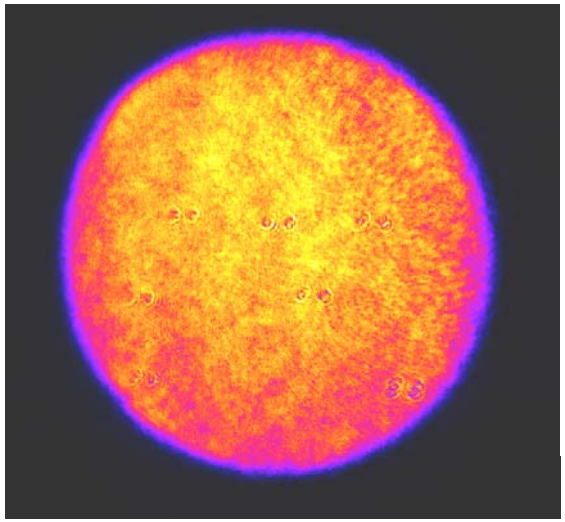
Only ~70% of the pumped volume used

Up to 400mJ, 8ns injected



Crystal vs ceramic extracted energy, (4-passes, 0.1 Hz)



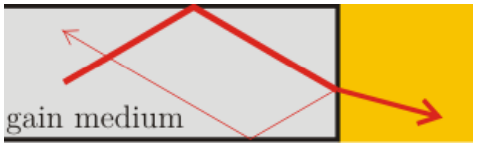


With 400mJ at the entry of the main amplifier and using about 70% of the available pumped volume, almost 14J are extracted in the ceramic case.

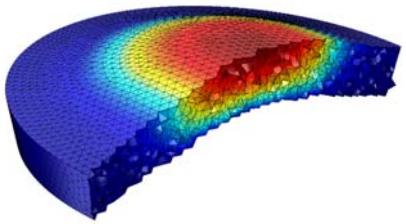
Damages caused by defective mirror

Main problems to solve for high average power DPSSL

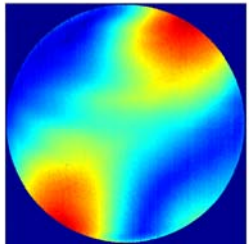
- ASE and parasitic lasing



- Thermal management



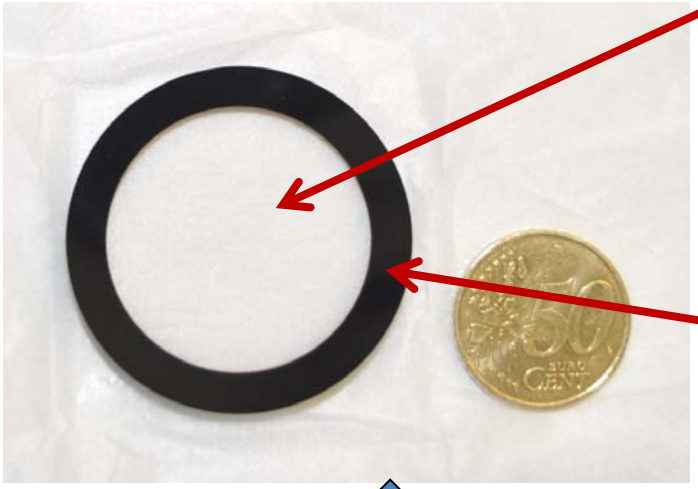
- Deformation



- Depolarization

Crystals and ceramics used in our experiments

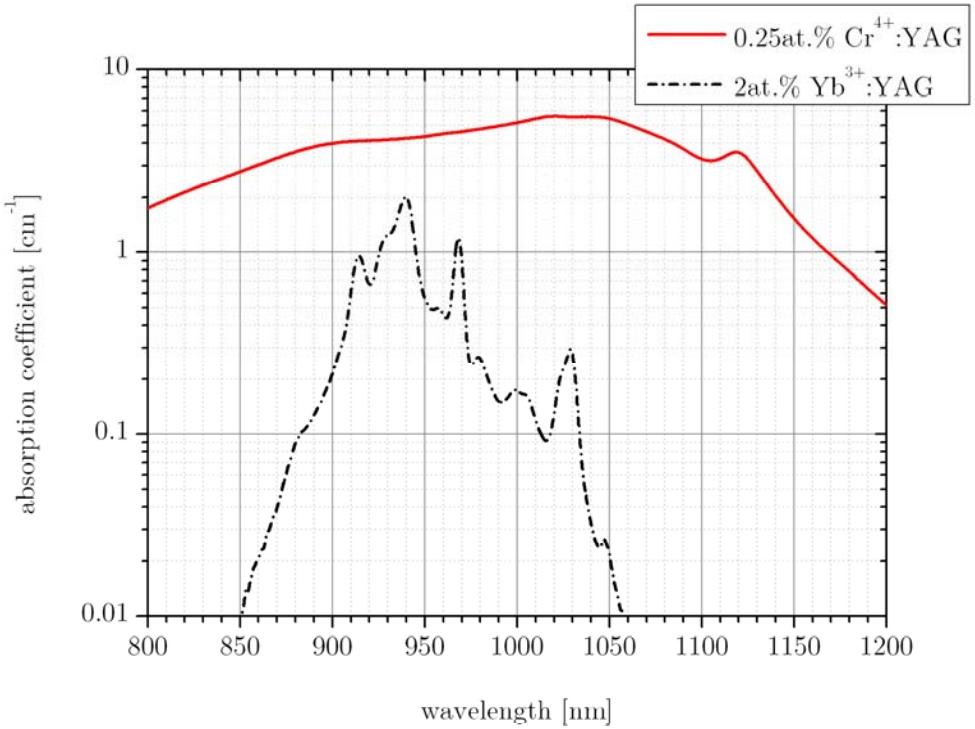
60mm diameter Yb^{3+}:YAG crystal, 7mm thickness, 2at.% doped



45mm diameter Yb^{3+}:YAG composite ceramics, 7mm thickness:

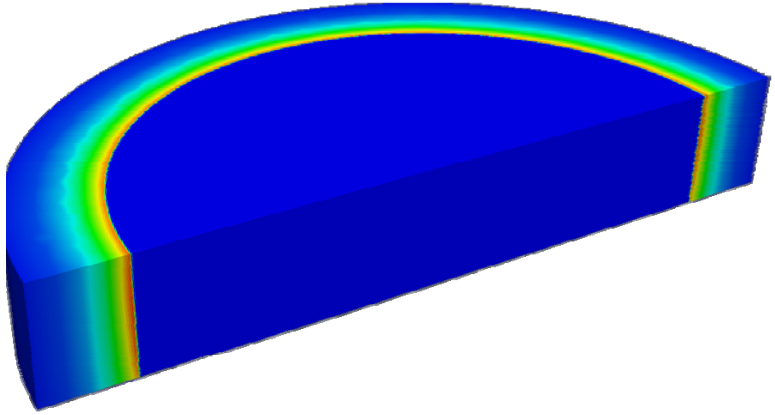
- 35mm Yb^{3+} doped center (2at.%)
- 5mm Cr^{4+} doped cladding (0.25at.%)

Absorption in cladding increases thermal load



Absorption coefficient of the of Yb^{3+} and Cr^{4+} doped YAG parts

Modeled Cr^{4+}/Yb^{3+} composite ceramic



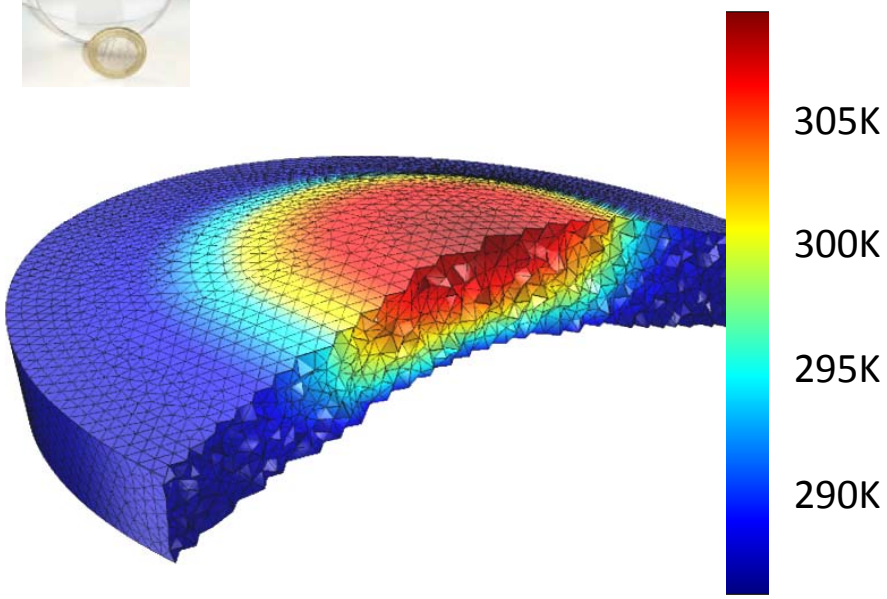
Energy distribution inside the cladding due to ASE transport

Additional energy deposition of ASE into the cladding:

➔ Increases total **heat load** to **~45%** (instead of ~15%)
➔ Increases deformation and depolarization losses

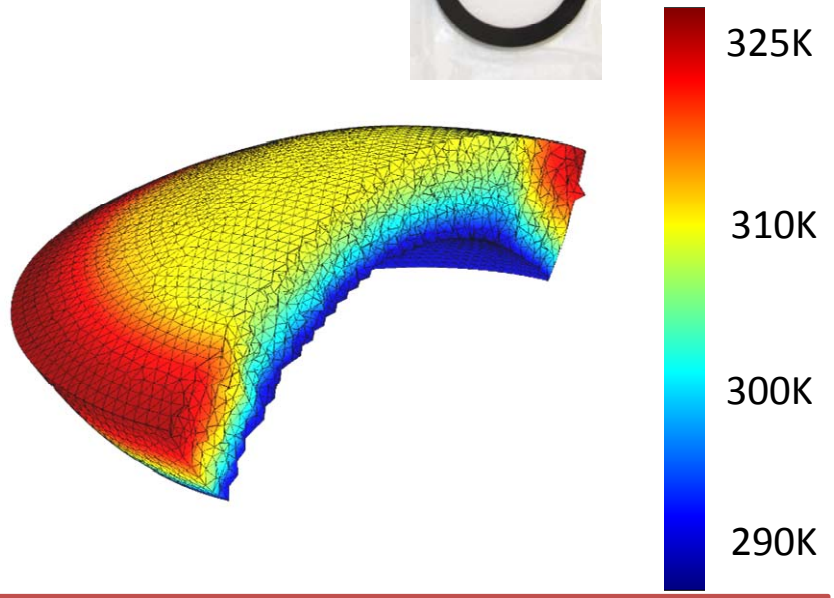
2Hz/16kWcm^{-2} illustrates temperature difference

Crystal



Thermal lens with **positive** focal length

Ceramic



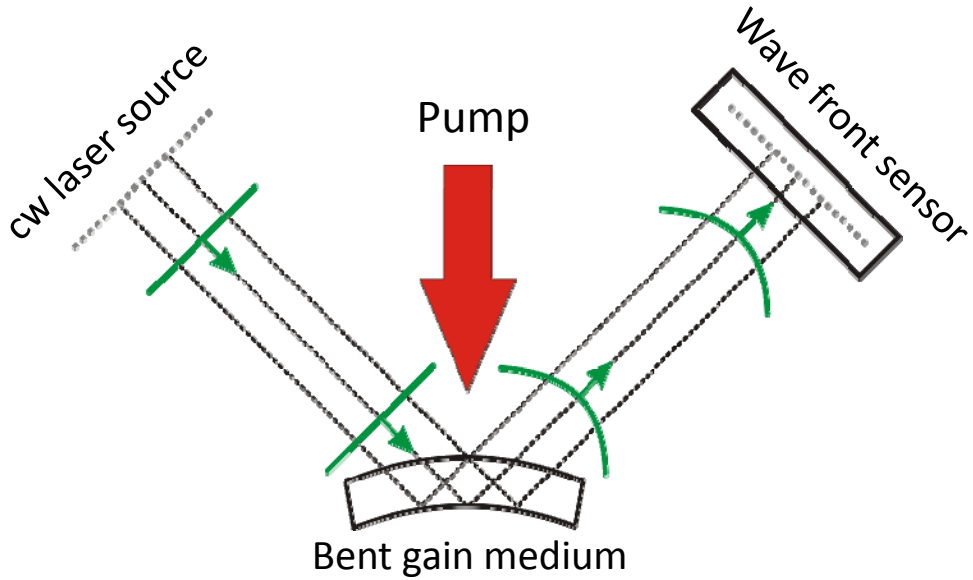
Low Thermal lens with **negative** focal length

Compensation of the **thermal lens** by gain medium **deformation** of the active mirror amplifier?

yes

no

Wave front analysis experimental setup



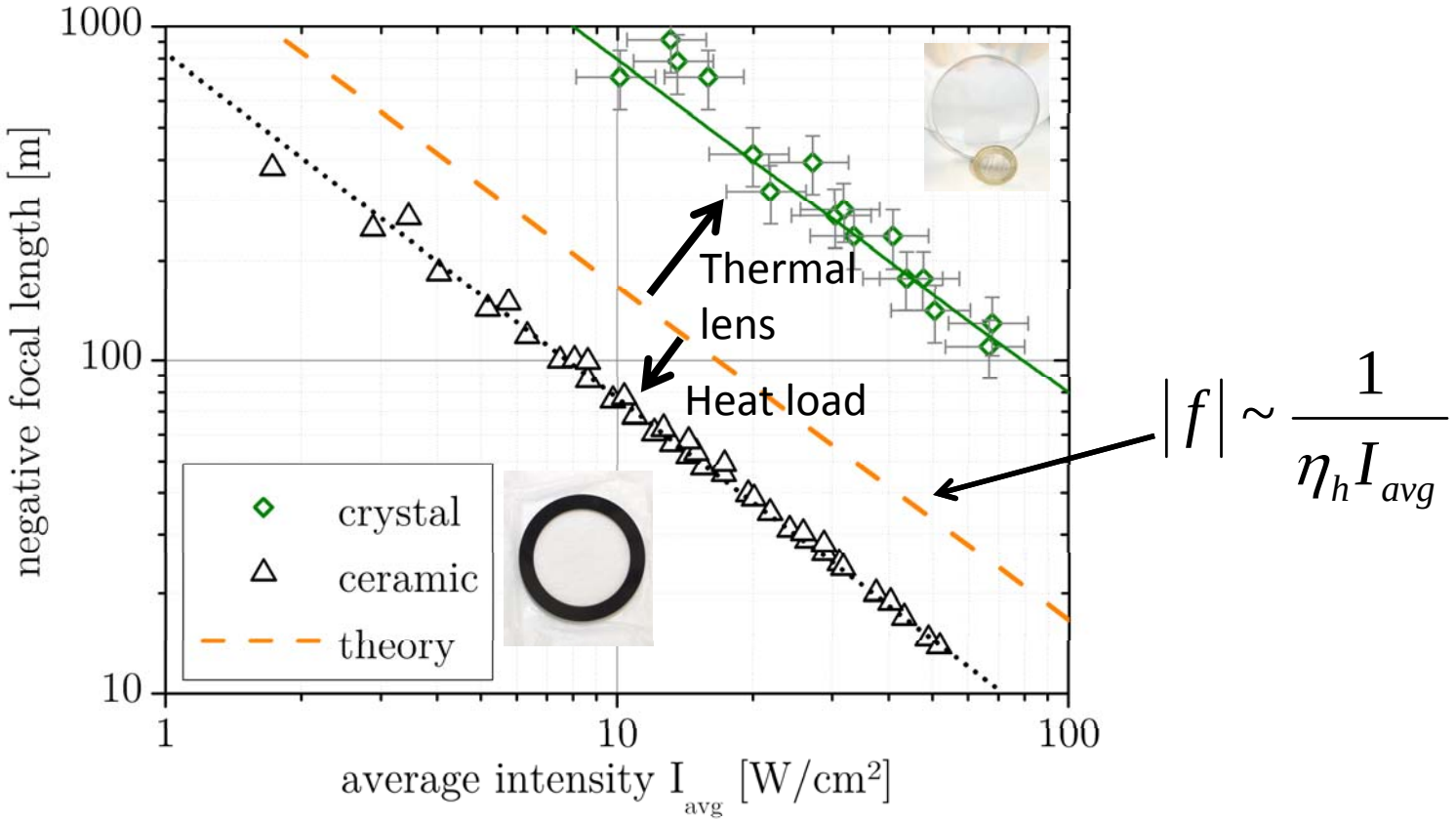
Gain medium deformation measurement by wave front analysis

Simple model: $$|f| \sim \frac{1}{\eta_h I_{avg}}$$

with

- I_{avg} incident intensity
- η_h fraction of absorbed energy transformed into heat

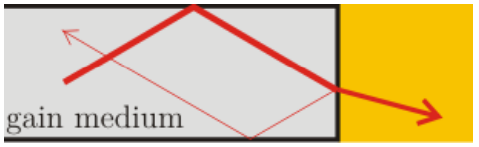
Ceramic shows stronger wave front deformation



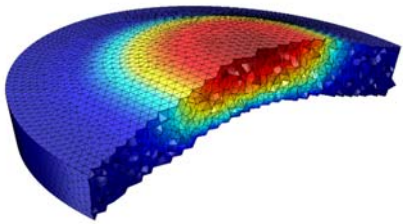
Optimized cladding design necessary to improve heat load distribution in the cladding

Main problems to solve for high average power DPSSL

- ASE and parasitic lasing

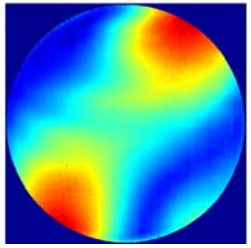


- Thermal management



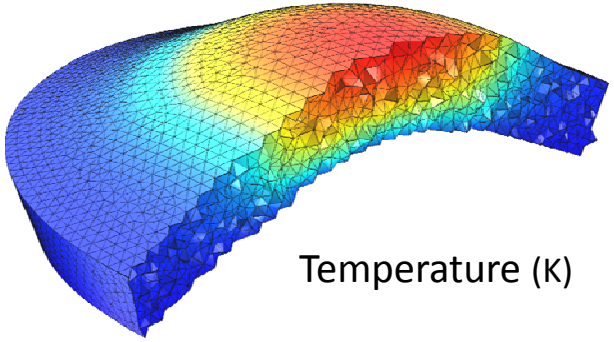
- Deformation

- Depolarization

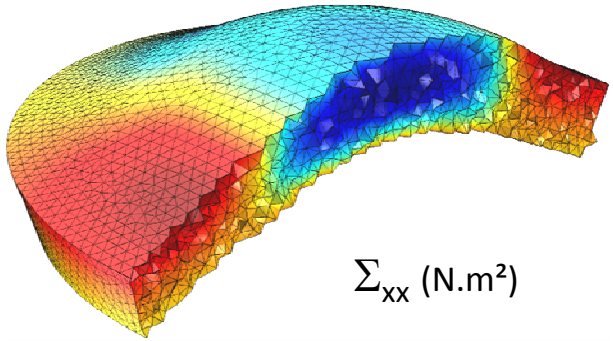


Nonuniform thermal load generates depolarization

Thermal load results in a deformation of the laser gain medium → **Stress**

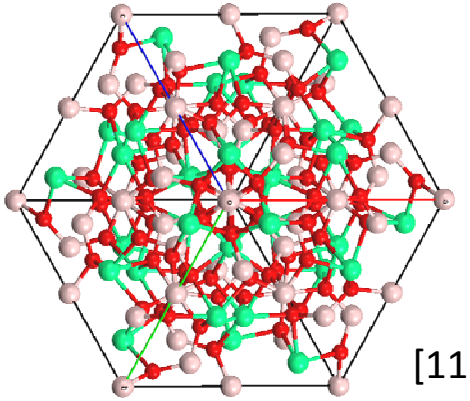


Temperature (K)

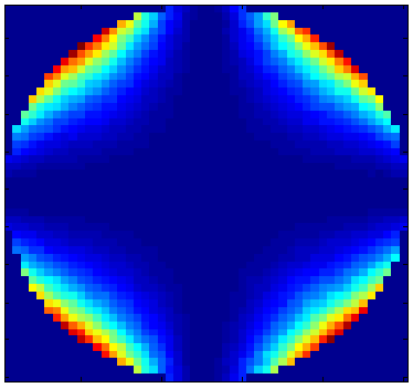


Σ_{xx} (N.m²)

Stress in combination with the material properties can yield **Birefringence**.



[111] oriented YAG



Depolarization losses

In the case of crystals, orientation axis plays a critical role

- [111] orientation is often used for YAG
- Other orientations could be of interest (optimization of depolarization losses)

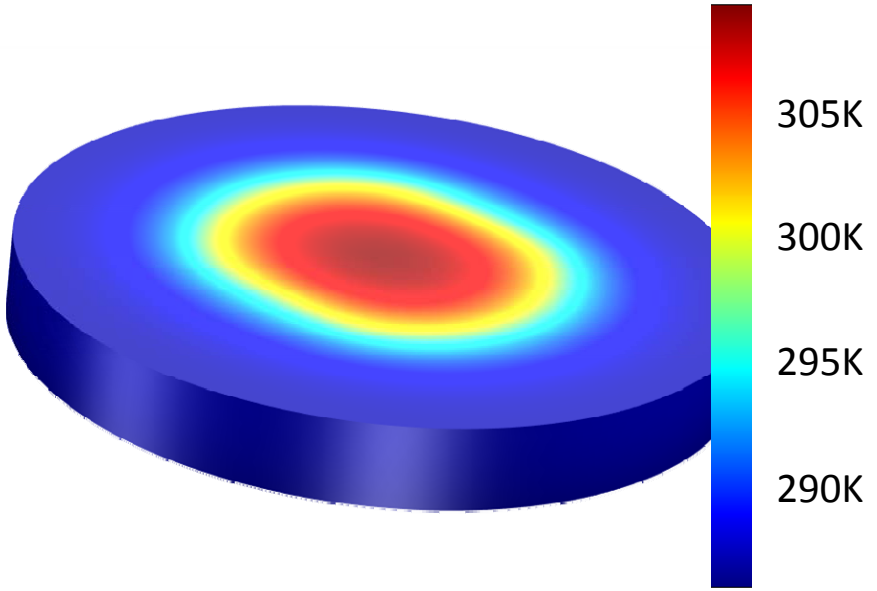
Impact of depolarization for disk amplifiers

Single side cooled disks exhibit a bi-metal type of deformation.

If the whole volume is pumped:

- no transverse temperature gradient
- no depolarization

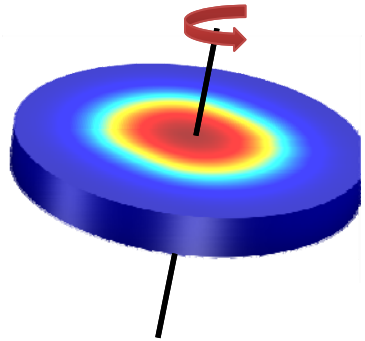
But the real setup carries **pump restrictions**
→**Transverse temperature gradient**
+ Edge effects

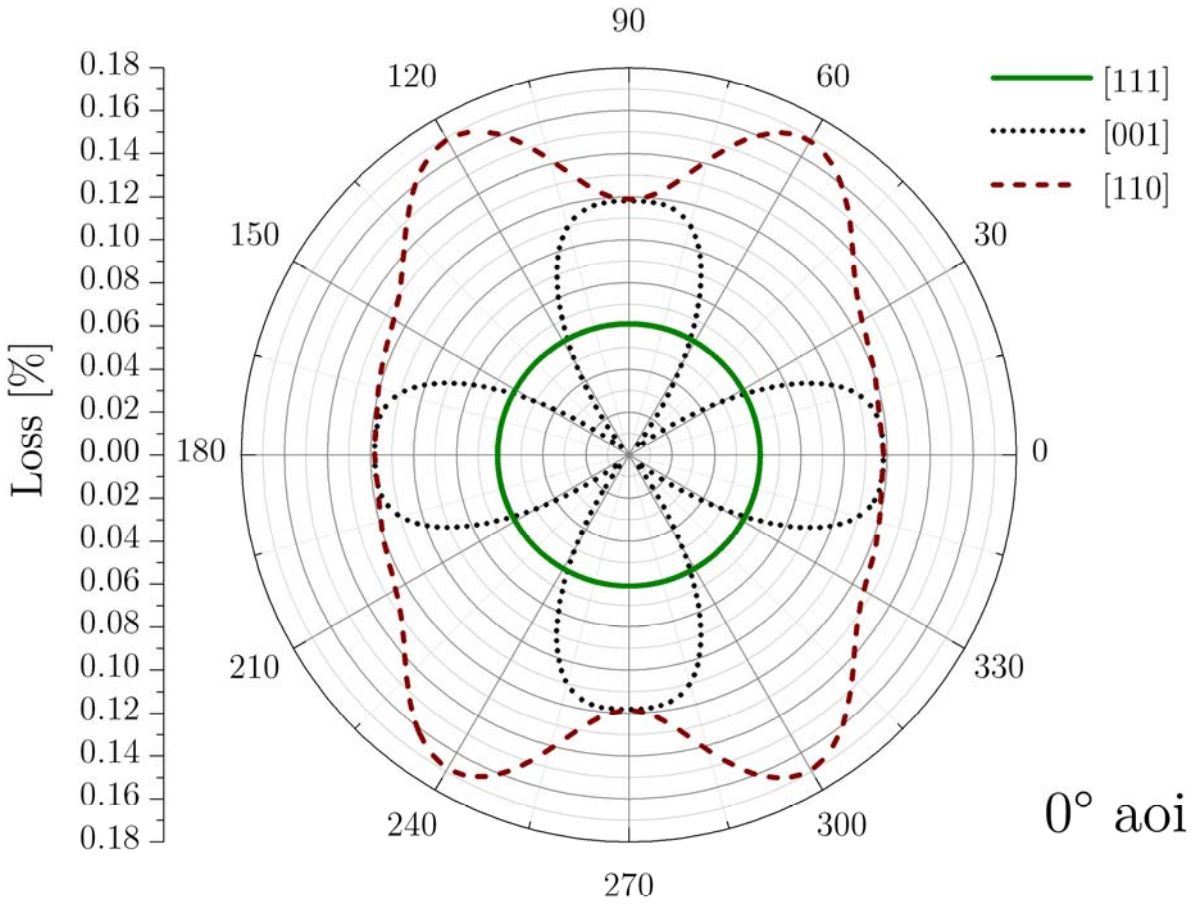


High average power laser systems with high efficiencies will most likely rely on disk architecture – depolarization control is different compared to rods.

LUCIA laser system is a high average power DPSSL prototype based on an active mirror concept (disks with internal reflection).

Depolarisation loss is a function of crystal orientation

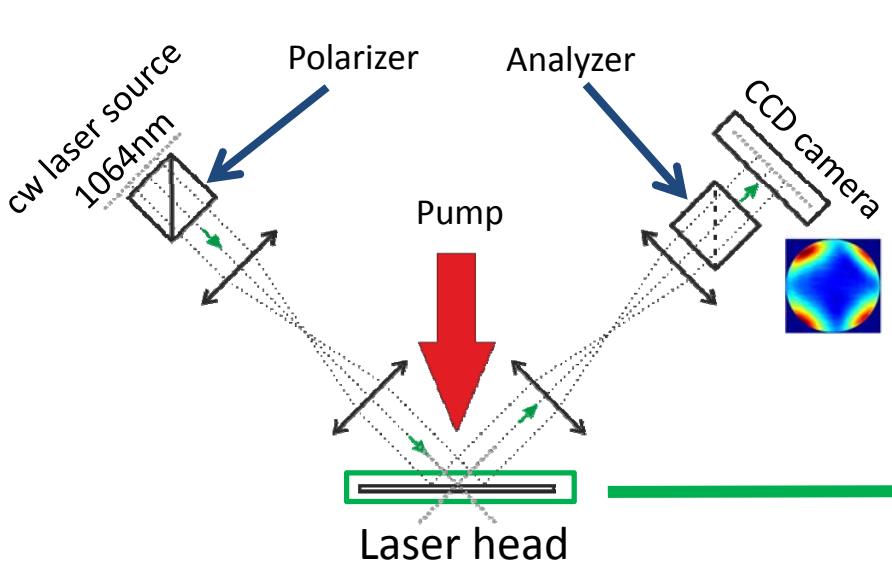


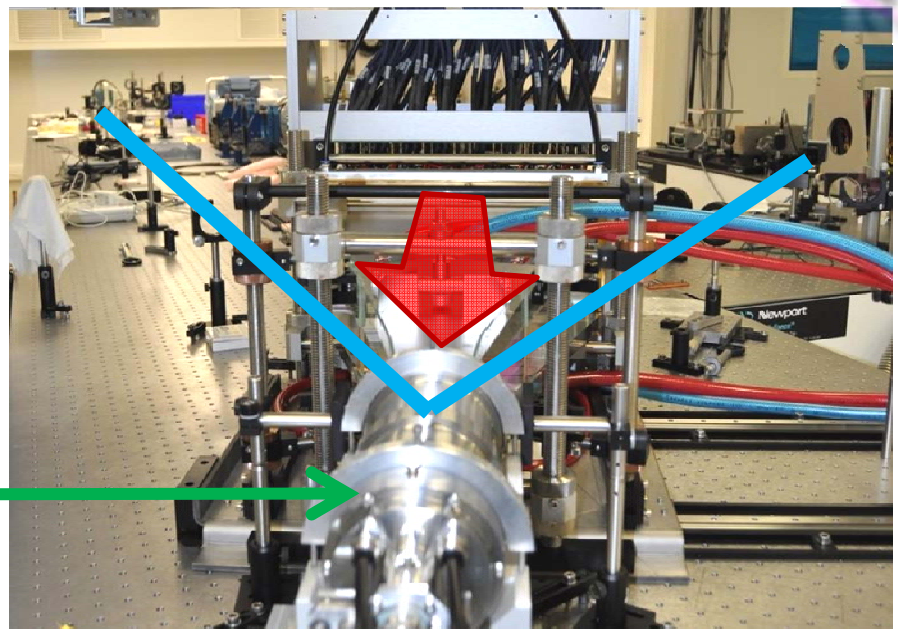


Different crystal axis orientations lead to different loss patterns under crystal rotation

Choice between no impact of rotation [111] or minimum depolarization losses e.g. [001]

Polarizer/Analyzer setup for depolarization measurement





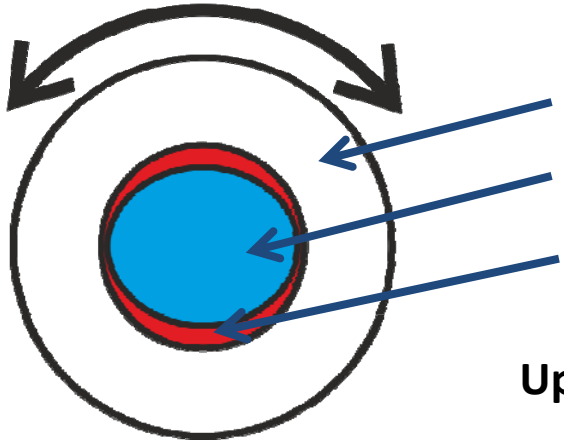
A polarized cw laser beam is imaged onto the gain medium, passes the analyzer and is recorded on a CCD.

CCD registers the energy passing the analyzer.

By rotating the analyzer, depolarization losses are estimated.

Large surface depolarization test

Rotation about the gain medium cylindrical axis

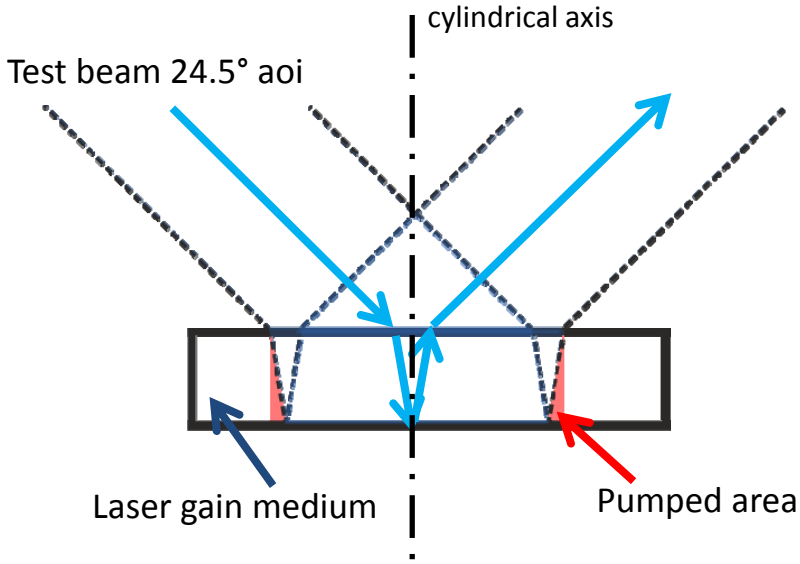


Up to 5Hz, 16kW/cm², 1ms pulses @940nm
➔ 80W/cm² on 6.5cm²

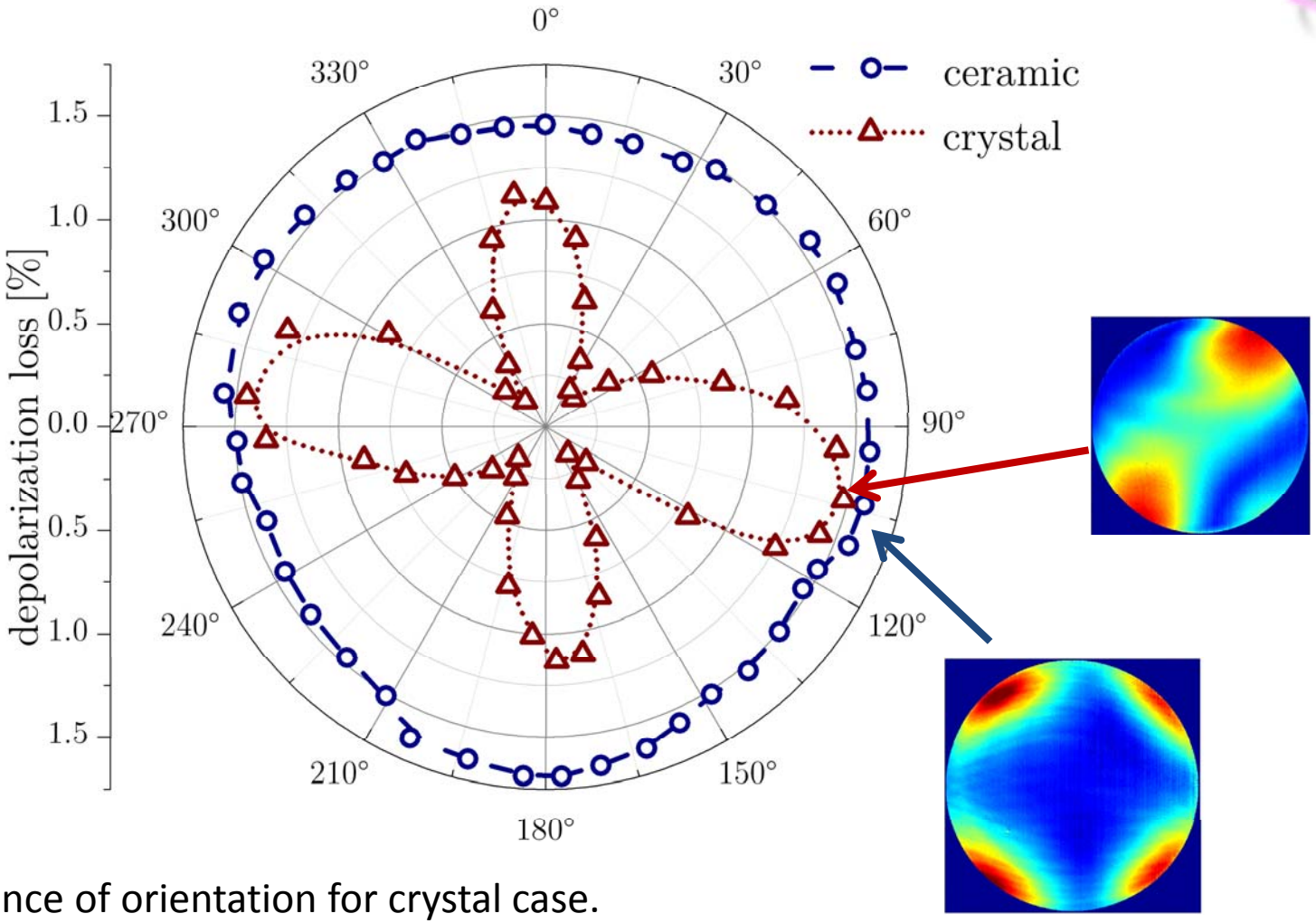
24mm diameter flat top test beam (1064nm)
24.5° angle of incidence

Ensures similar conditions compared to an extraction beam

Gain media can be rotated around the cylindrical axis



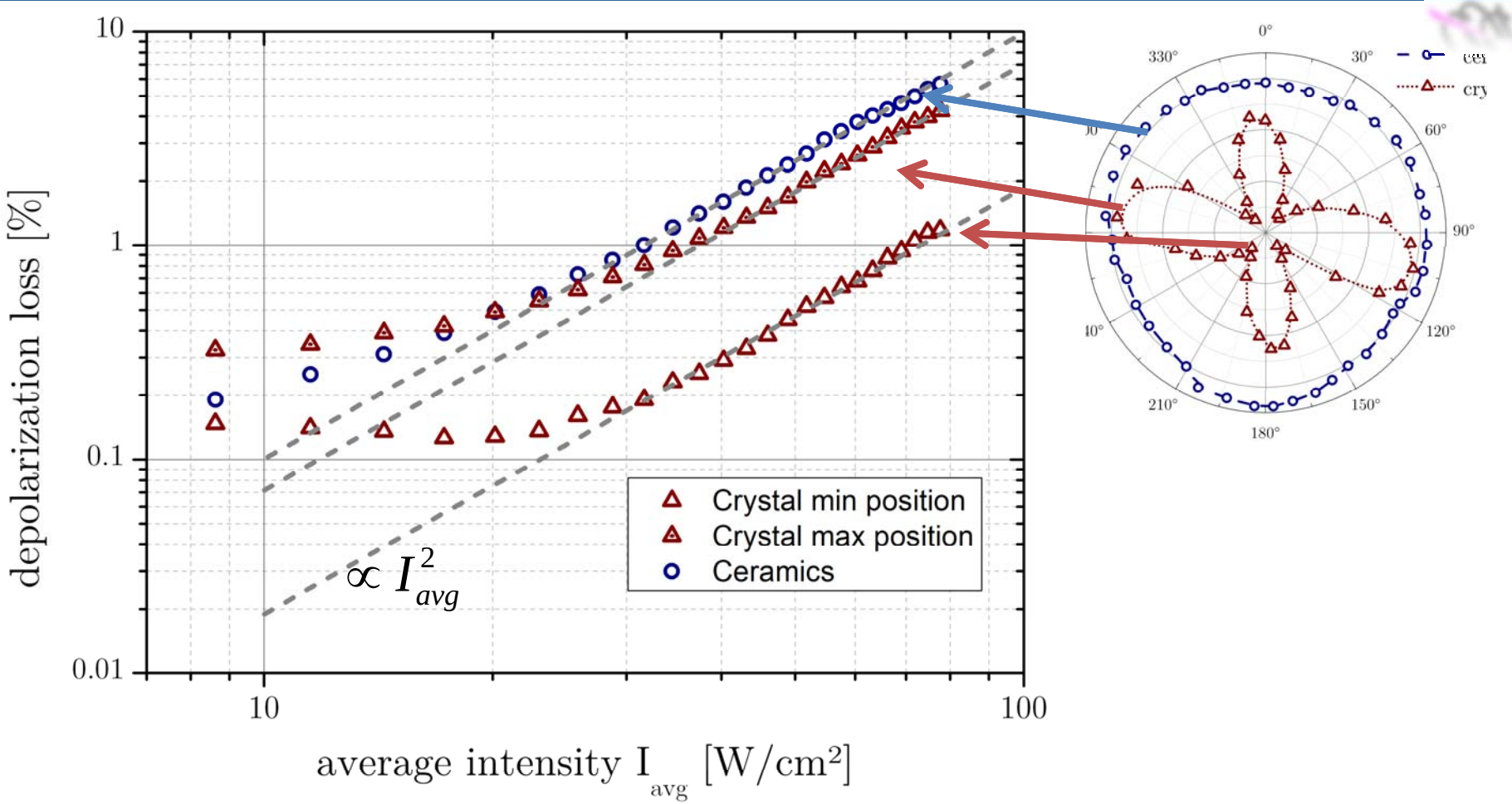
Difference crystal / ceramics pumped at 40W/cm²



Strong dependence of orientation for crystal case.

Ceramics show constant loss
(residual variations due to mount induced stress and intrinsic birefringence).

Scaling towards higher average intensities



Depolarization losses scale with I_{avg}^2

For low intensities, the intrinsic depolarization dominates

Pump induced depolarization quickly becomes dominant

Conclusion and Outlook

Ceramics are interesting candidates for high power DPSSLs

Cladding offers excellent parasitic lasing suppression
Proper optimization of the ceramic parameters necessary

High average power laser systems have to take depolarization issues into account.

Strong impact of cladding parameters (absorption, thickness…)
Compensation of depolarization losses is needed (active/passive)

Low temperature operation (100K – 300K)

Improved material properties at low temperatures
Cryostat for large size gain media under preparation
Strongly reduced depolarization losses expected