High-energy multi-pass amplifier design for the PEnELOPE laser project

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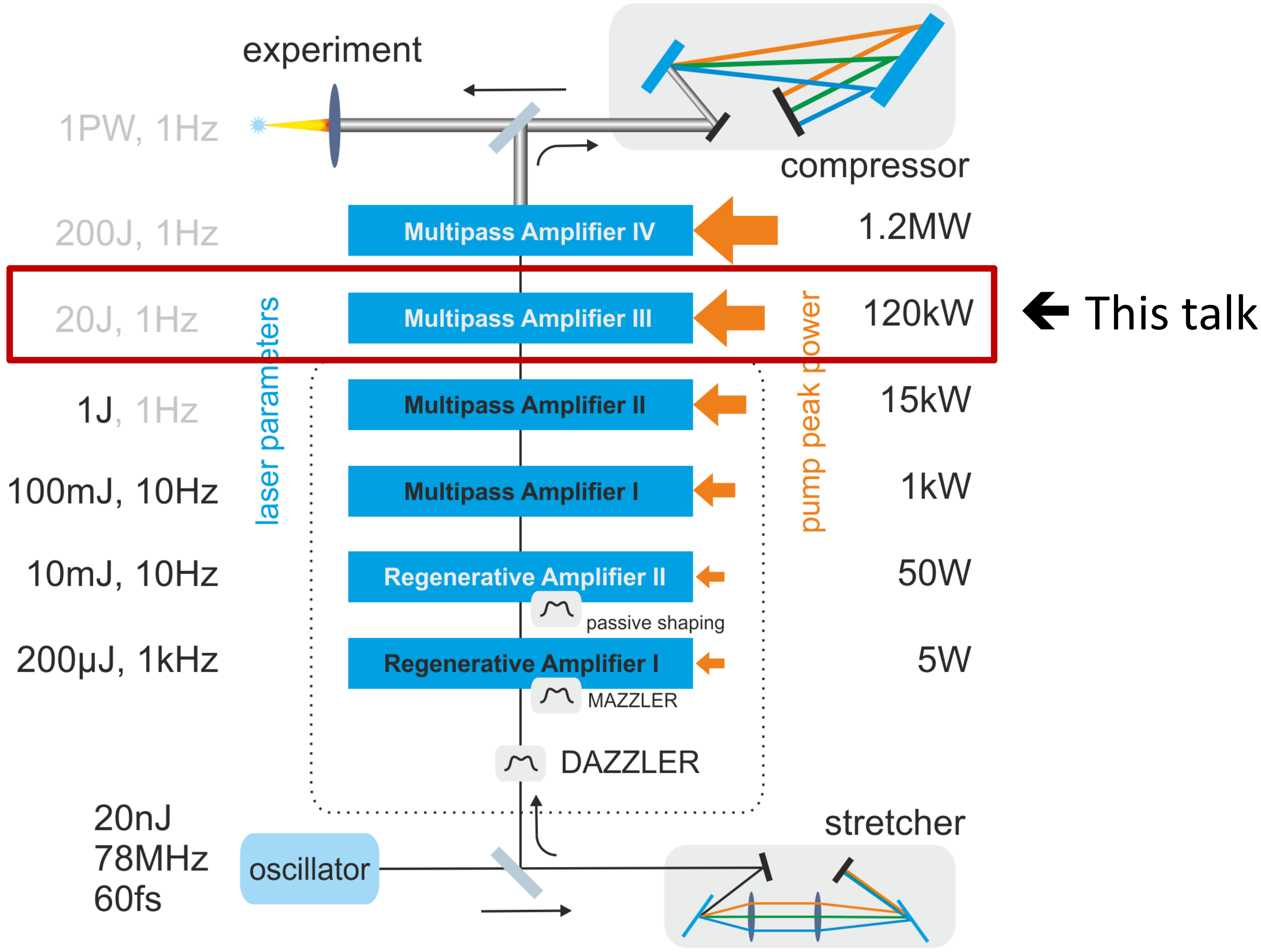
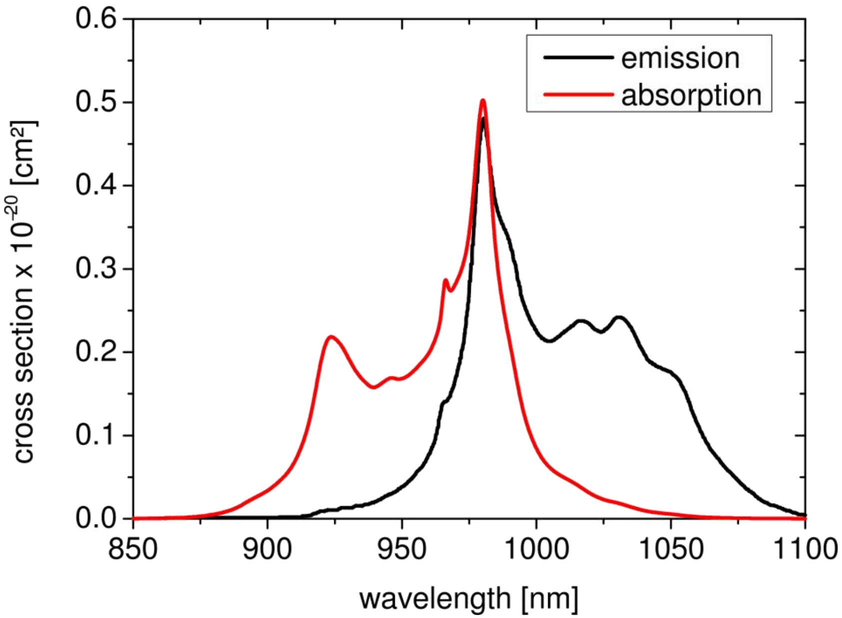
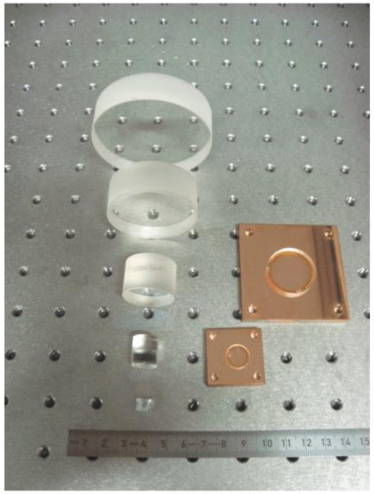
10J+ amplifiers in the main interest



Properties of $Yb^{3+}:CaF_2$





$$\tau_{rad} \approx 2.4ms$$

$$k \approx 9\ Wm^{-1}K^{-1}$$

$$n_0^{1\mu m} \approx 1.42$$

$$\left.\frac{dn}{dT}\right|_{300K} \approx -18\times 10^{-6}K^{-1}$$

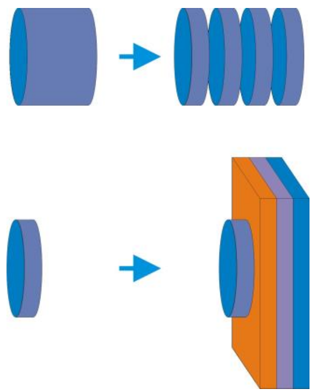
$$\left.\frac{dL}{dT}\right|_{300K} \approx 19\times 10^{-6}K^{-1}$$

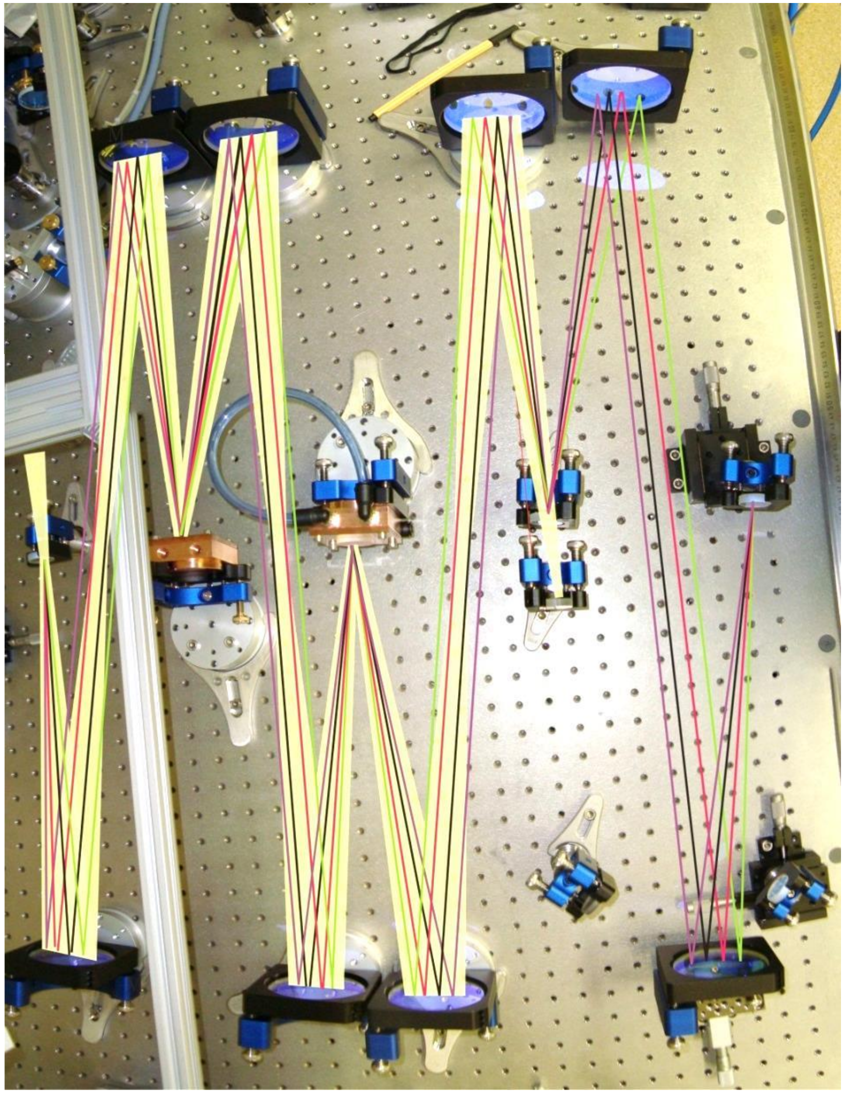
Yb^{3+} doped CaF_2 supports short pulse laser operation (100fs to 150fs on the 100J scale possible)

However : relatively small emission cross sections (small SSG)
many extraction passes needed

Small Signal Gain for 10J+ amplifiers < **1.3**

Design concept up to 1J active mirror





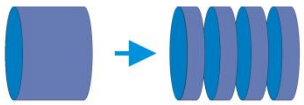
→ up to 1J, 10Hz possible

→ thermal abberations by
edge effects (1D → 2D)
(e.g. disc bending, stress birefr.)

→ scalability: *number of large aperture mirrors*

→ damage issues
(pulse overlap, glue, interferences)

→ MP pumping increases efficiency @ RT



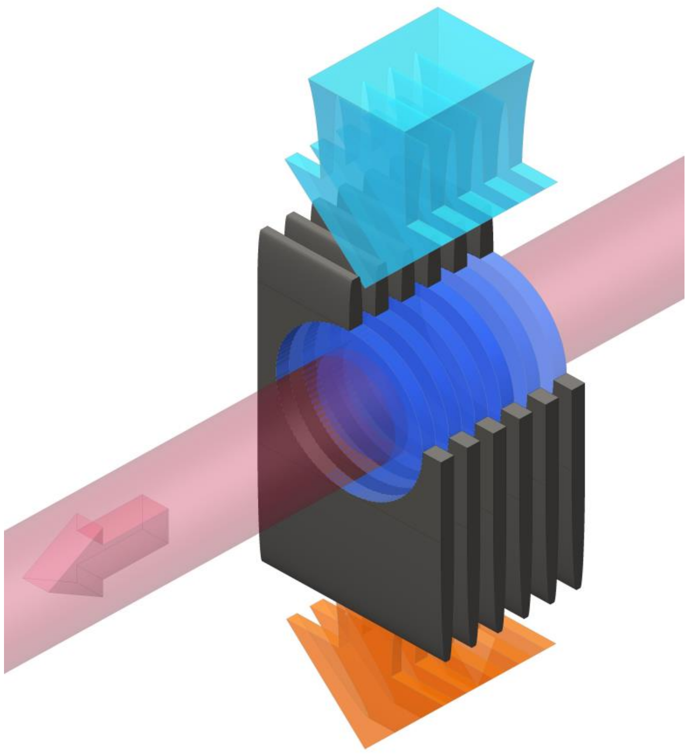
→ tested at 60J, 10Hz (LLNL) & 10J, 6Hz (RAL)

→ low thermal abberations

→ *operation at RT + MP pumping possible*

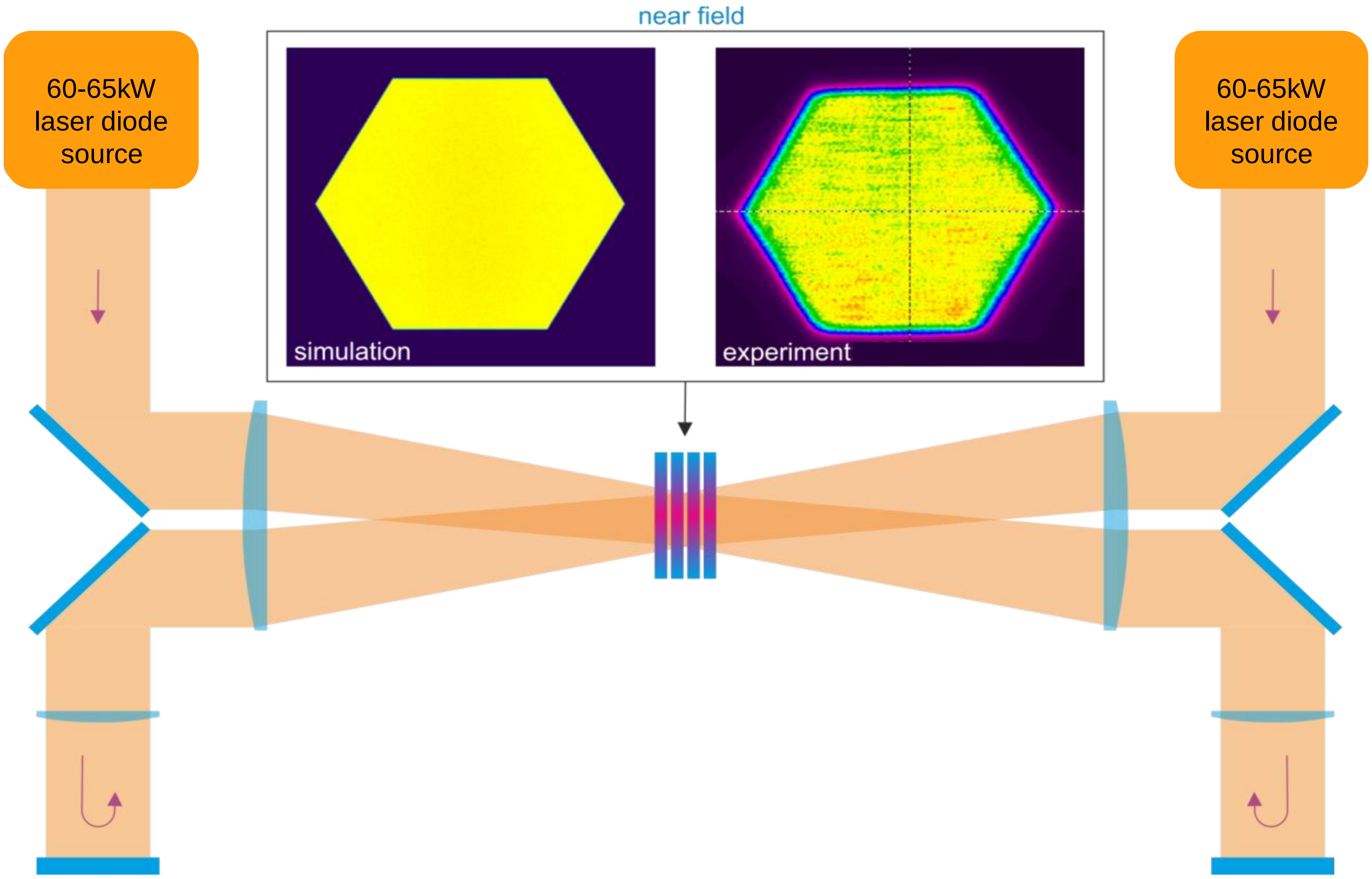
→ pump & extraction from both sides

→ 4 slabs 55/110 mm diameter, thickness: 5mm



Multiple slab amplifier design for 10J+ and 100J+ stage

Pumping scheme for 10J+ and 100J+

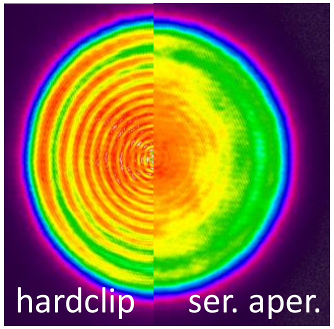


Beam size and Small Signal Gain (SSG) influence

- **Small beam** (e.g. <10mm) → „**Gaussian**“ beam (free propagation)

- **Larger beams** are **cost** intensive (large optics), so:
  - High SSG (> 3) → few passes, free propagation
  - Low SSG (< 2) → many passes, expensive obviously

- **PENELOPE** case: low SSG(**< 1.3**), **25mm** beam diameter
  - Reduce beam size to a minimum (serrated aperture)
  - Relay Imaging (4f-telescopes), magnification 1.35

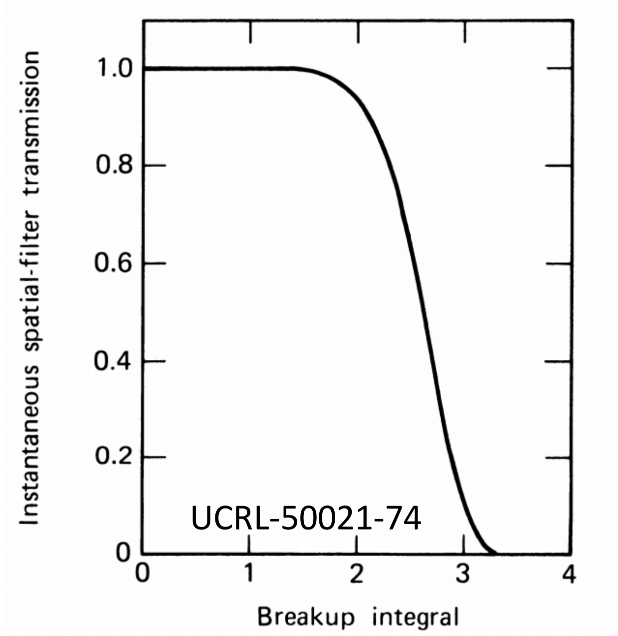


We need about **12 passes** – **B-Integral** important

Vacuum advantages

- **B-Integral**
  - Avoid high B (small ripple growth, uncompressed phase…)
  - Beam transport at air – no good idea (image relay foci)
  - Separate vacuum tubes for each pass → interfaces + material (B > 1.5)

➔ Put everything in **vacuum**



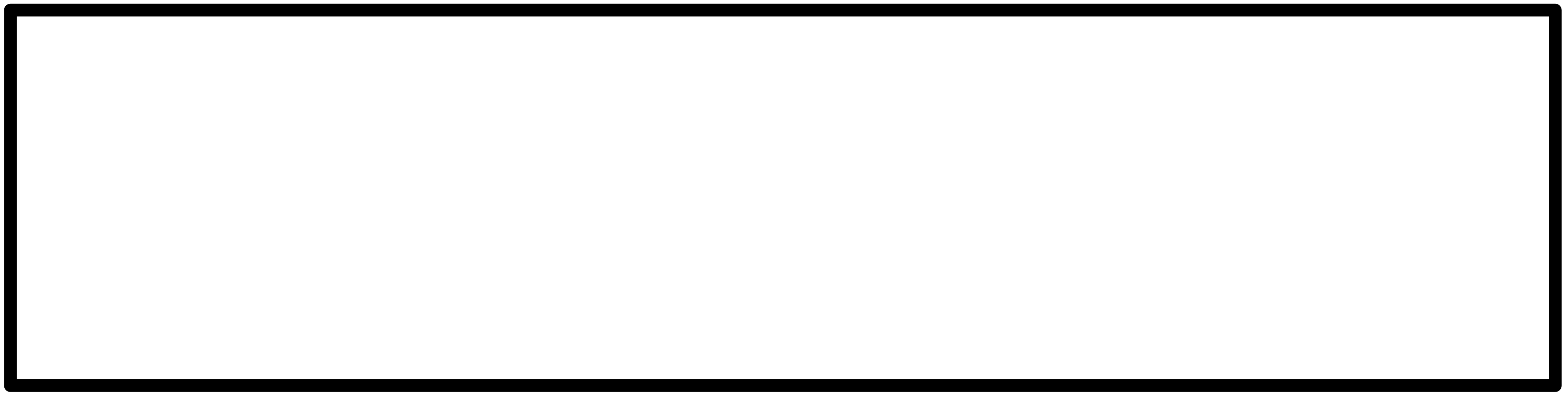
  - no separate windows for vacuum tubes
  - "no" **dust,** no air **fluctuations**

But: more bulky, less easy to manipulate,…

\+ **replace lenses by spherical mirrors**
  - less ghosts, less material

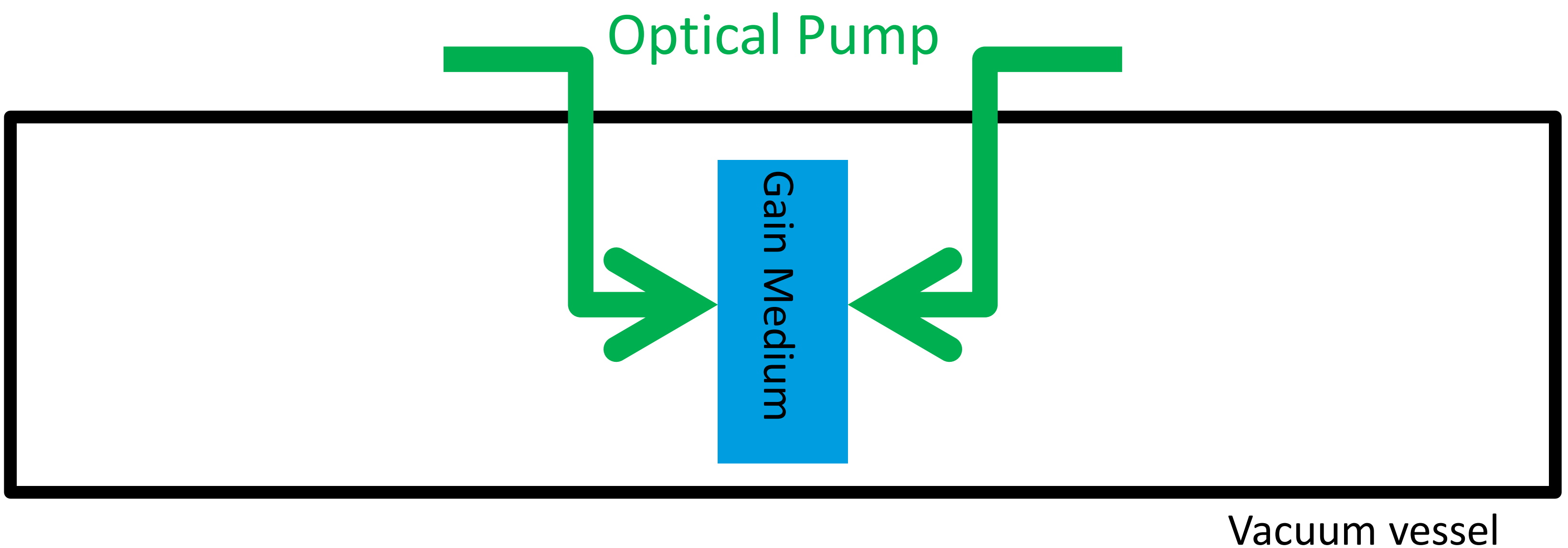
➔ B < 0.5

Simplified Layout I

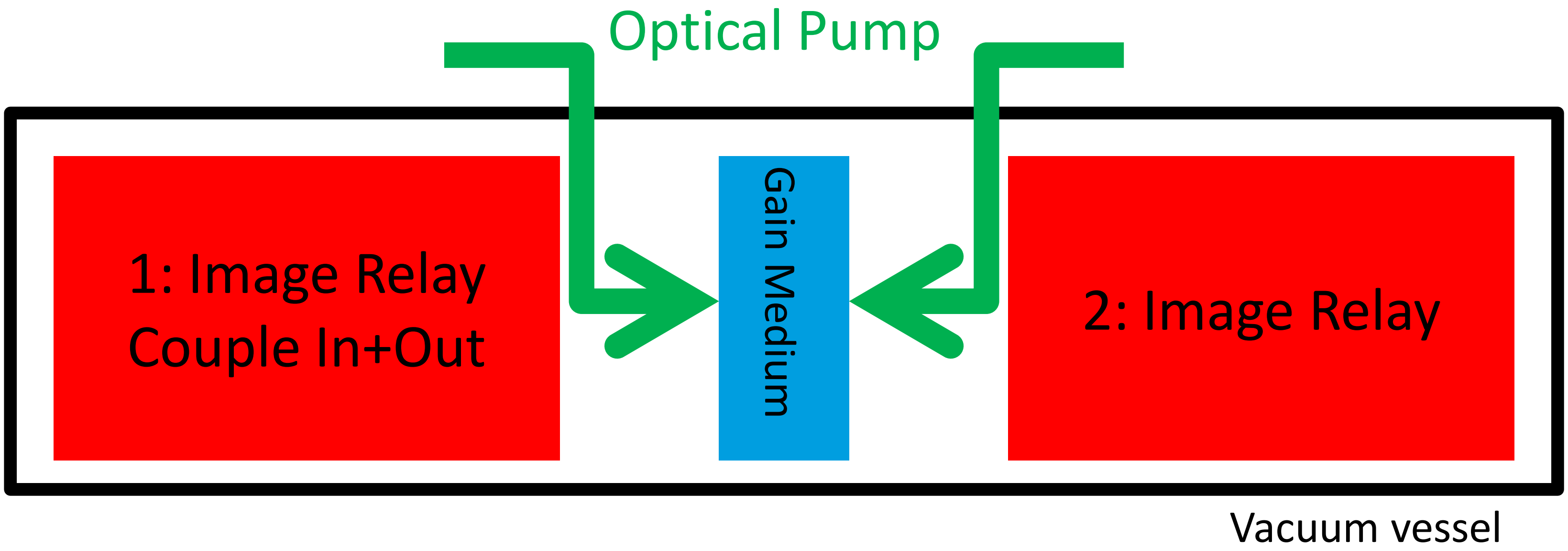


Vacuum vessel

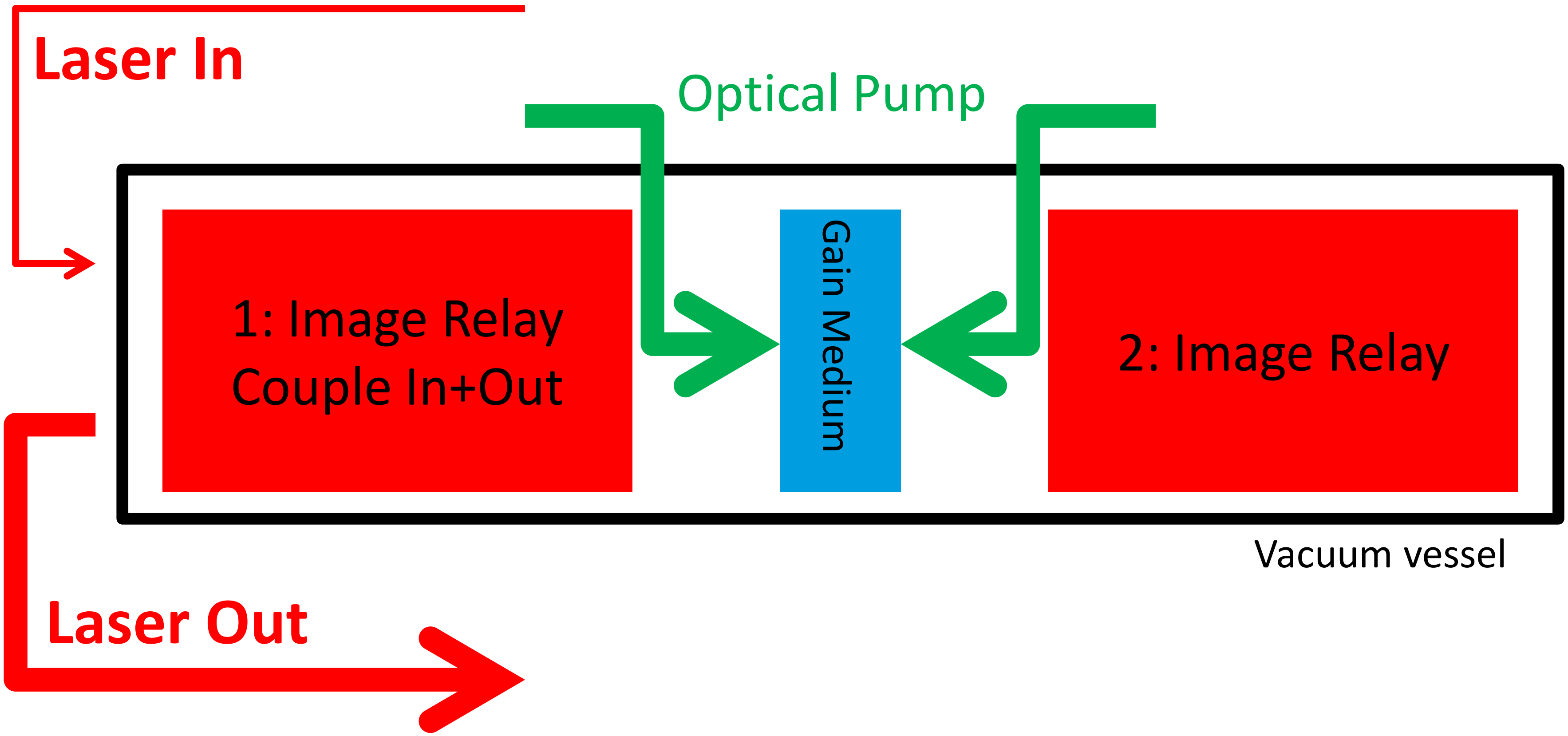
Simplified Layout I



Simplified Layout I

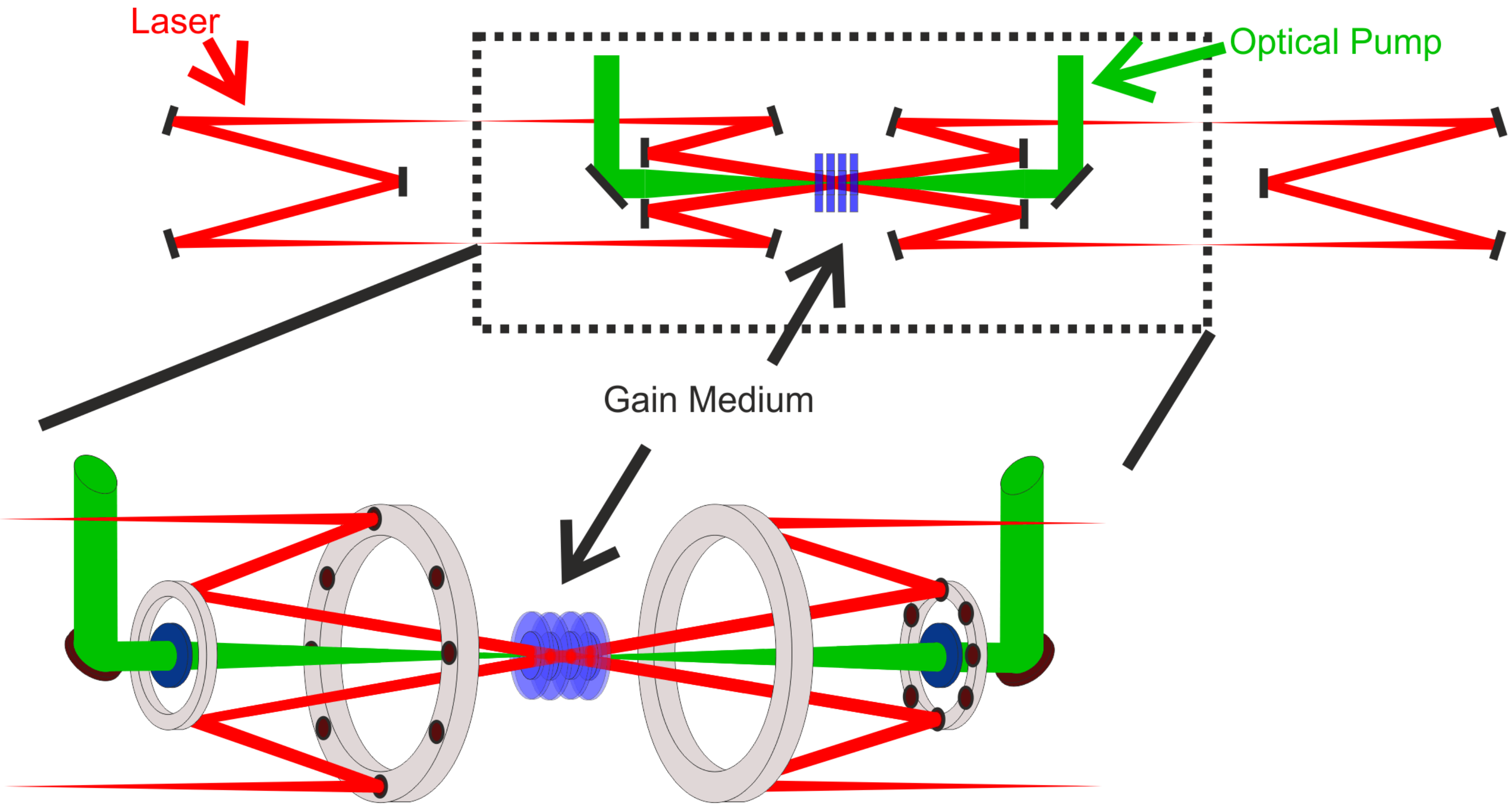


Simplified Layout I



All reflective transport optics setup

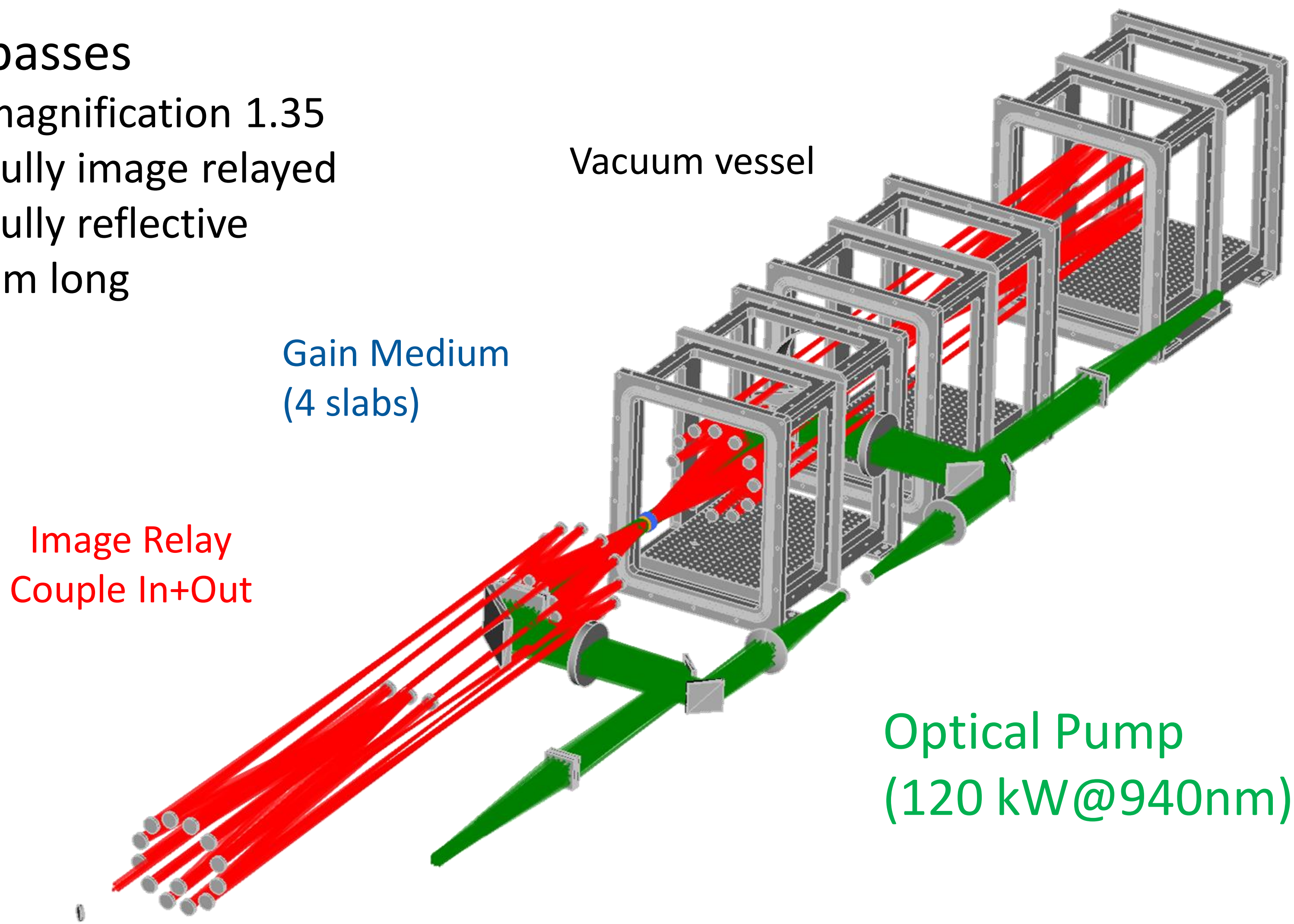
- less surfaces
- no material dispersion
- no ghosts



10 J Amplifier – modeling

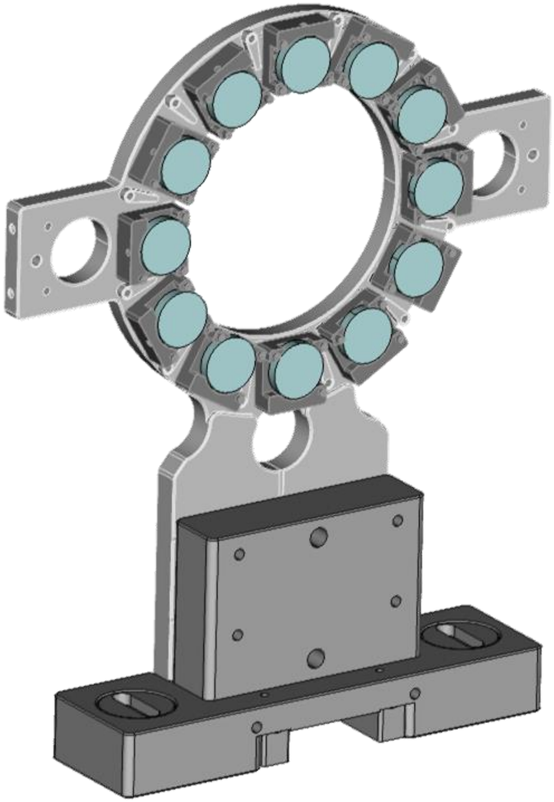
12 passes

- magnification 1.35
- Fully image relayed
- Fully reflective
- 6m long



Mirror mounts on a ring

Sketch

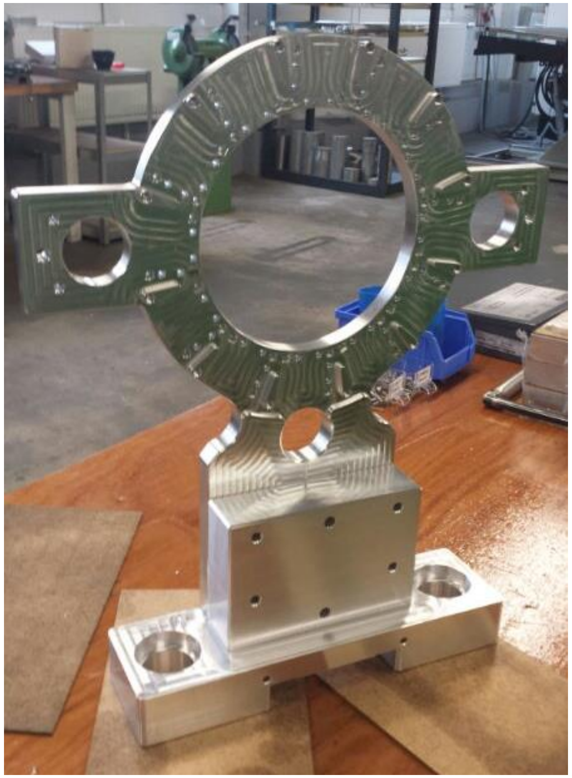


6 Rings

75 mirrors in total

Custom tailored

Workshop



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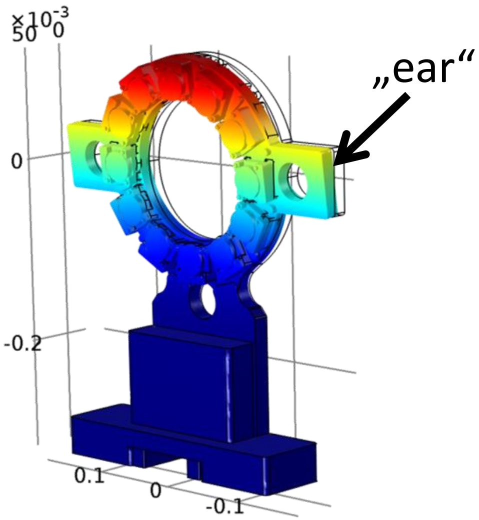
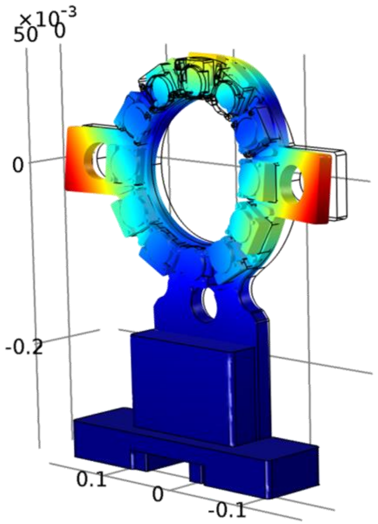
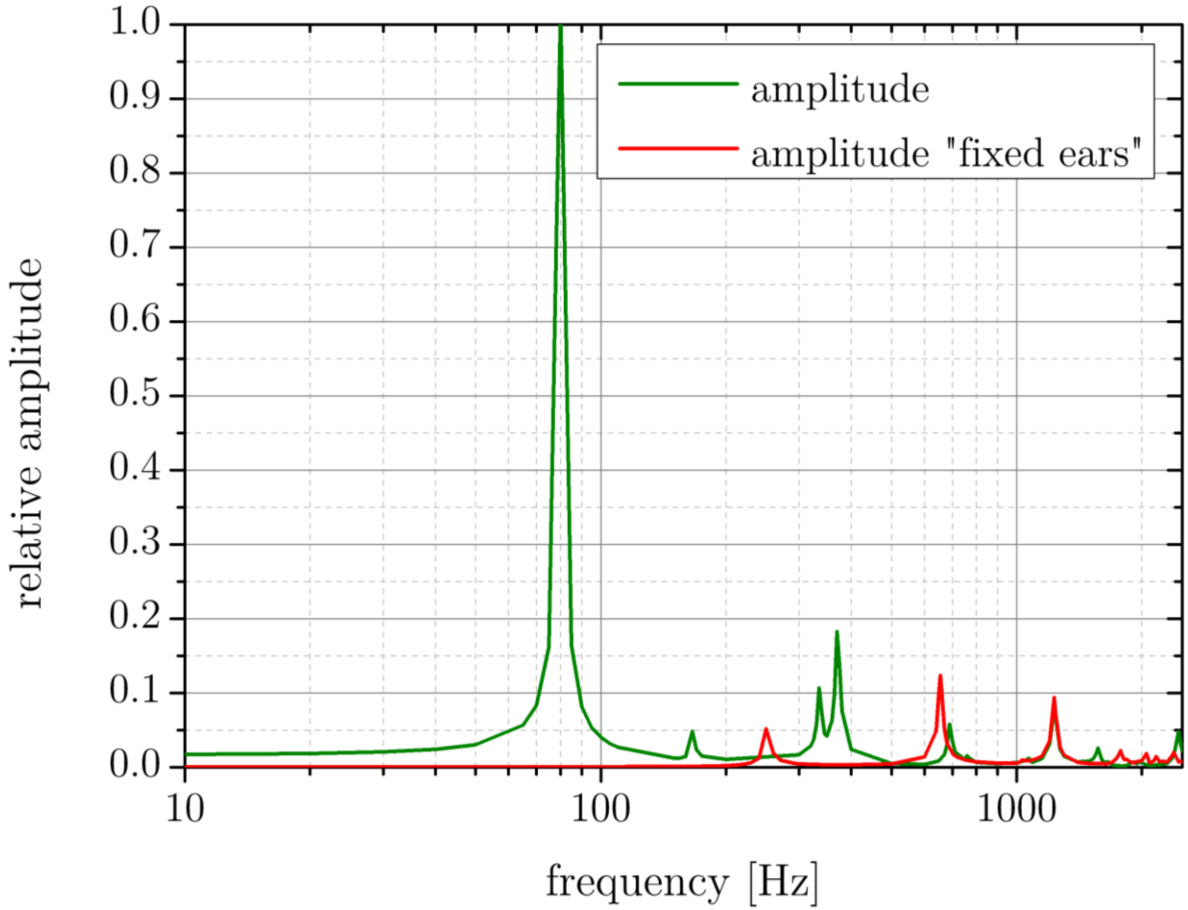
Vibrational analysis shows no critical Efrq.







No low frequency eigenmodes <50Hz

Fixing is foreseen → reduction in vibration amplitude

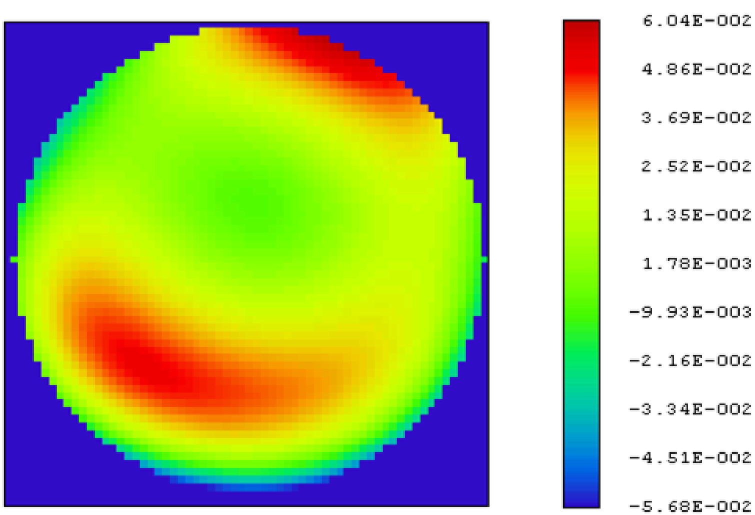
Strehl Ratio >0.98 after 12 passes

- Astigmatism is added with each pass
  - due to spherical mirrors + coupling in and out
  - added components turn with the rotation angle with each pass
  - after full rotation on the ring → defocus component

- Second arm is pure image relay
  - detuning the distance used to introduce defined defocus

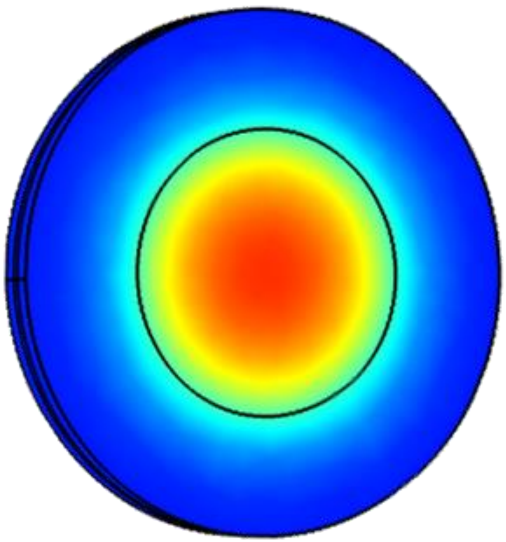
  → defoc „0“

- Full amplifier w. 12 passes
  - Transmission ~80% (coating)
  - Wavefront error <0.12 waves PtV
  - Strehl ratio >0.98
  - adaptive optics?



Focal power compensated for CaF_2

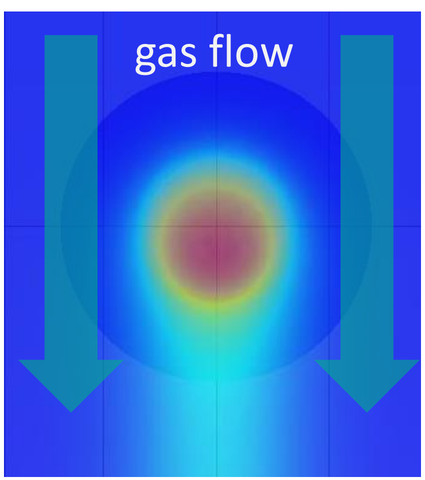
Partial pumping will lead to a transverse thermal gradient



- thermal lens $$f_{th} = \frac{p^2}{2d \frac{dn}{dT} \Delta T}$$
- mechanical $$f_{mech} \simeq \frac{p^2}{2d \frac{dL}{dT} \Delta T}$$

$$\frac{dn}{dT} \approx -\frac{dL}{dT}$$

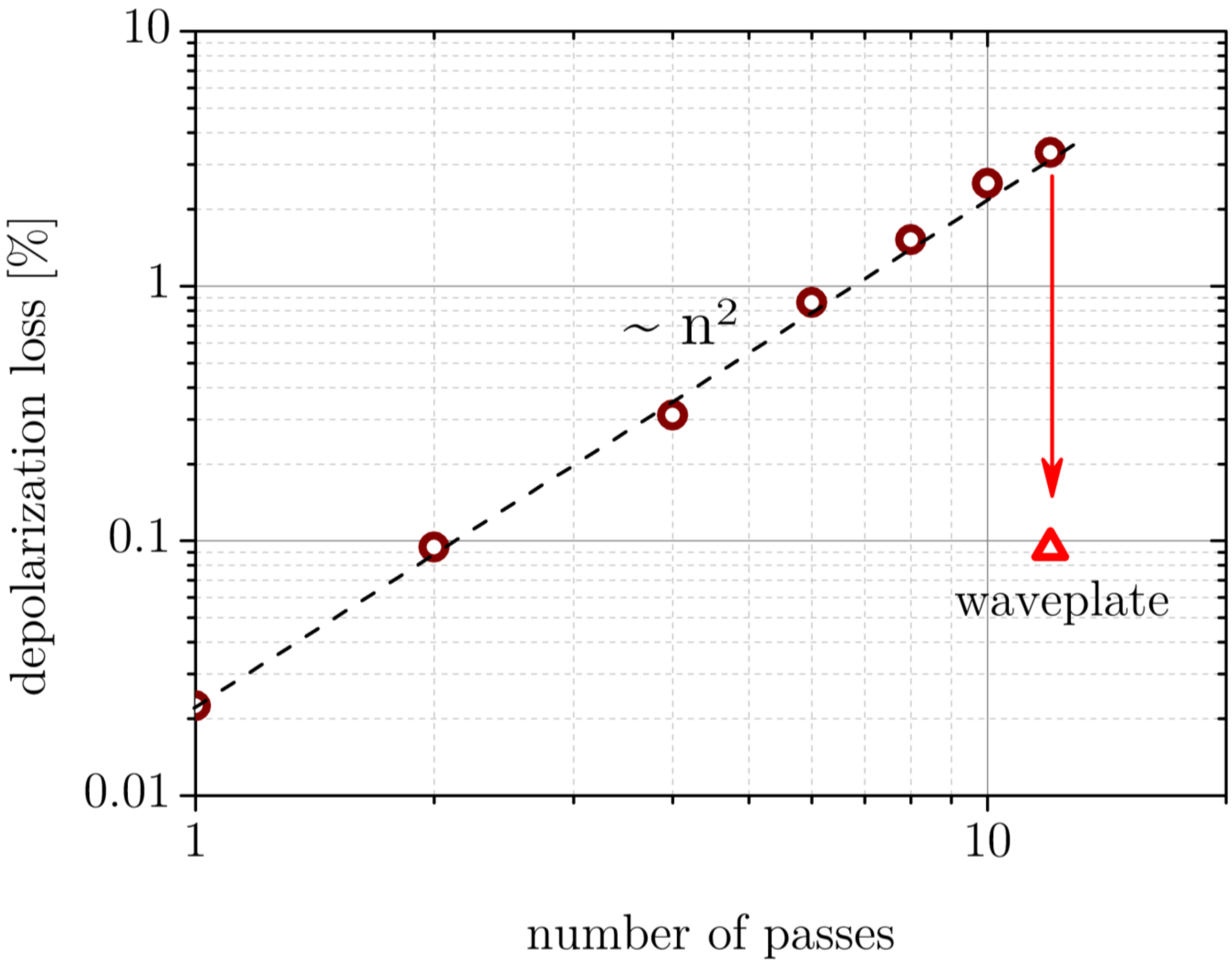
➔ partial compensation is possible



Gas flow drags heat with it

→ temperature distribution more complicated
→ under observation

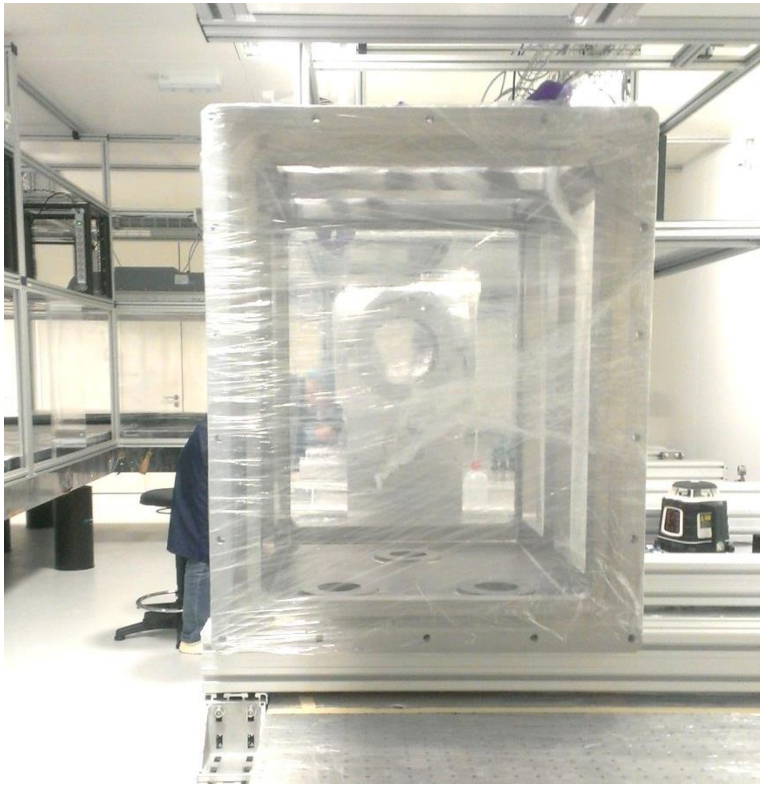
Depolarization simulation shows <10% loss



Depolarization loss increases with pump power and number of passes
→sufficiently compensated using a wave plate

10J+ amplifier in the lab under construction

lower frame construction



first chamber test

Currently: put it on the table + vacuum tests

10J+ amplifier – 3 of 6 modules ready

3 of 6 modules on the table

Finishing vacuum installation during April

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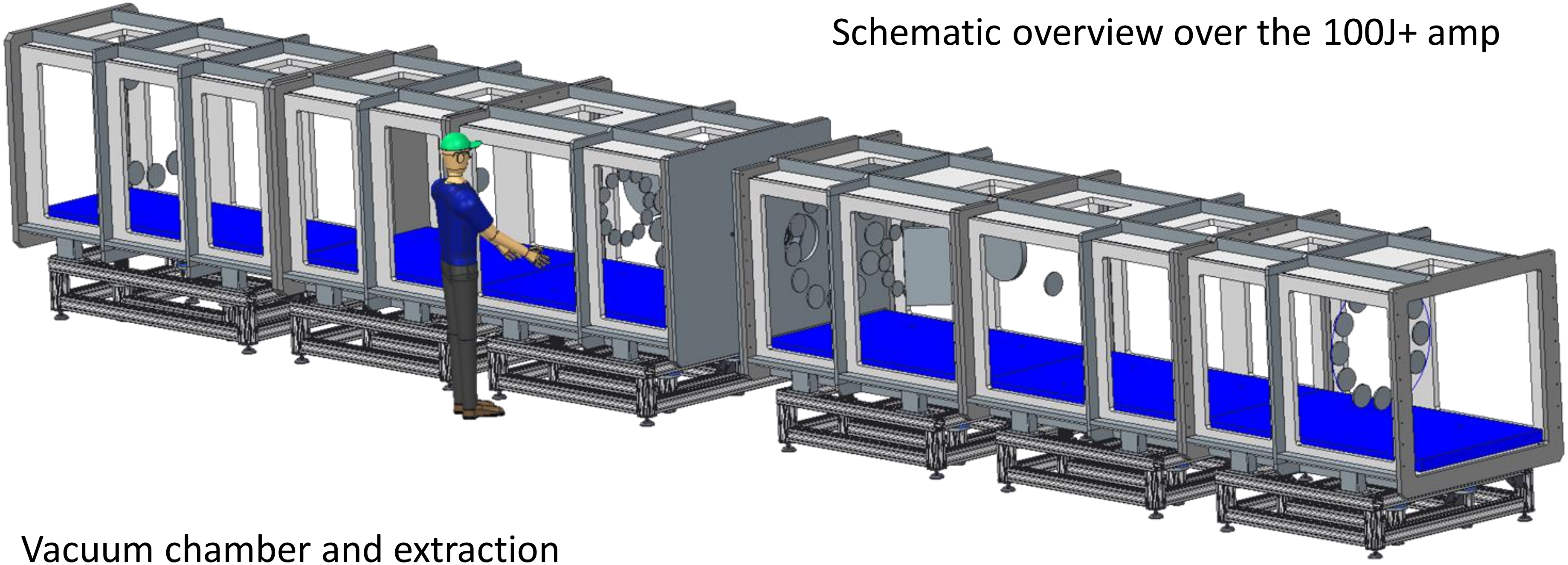
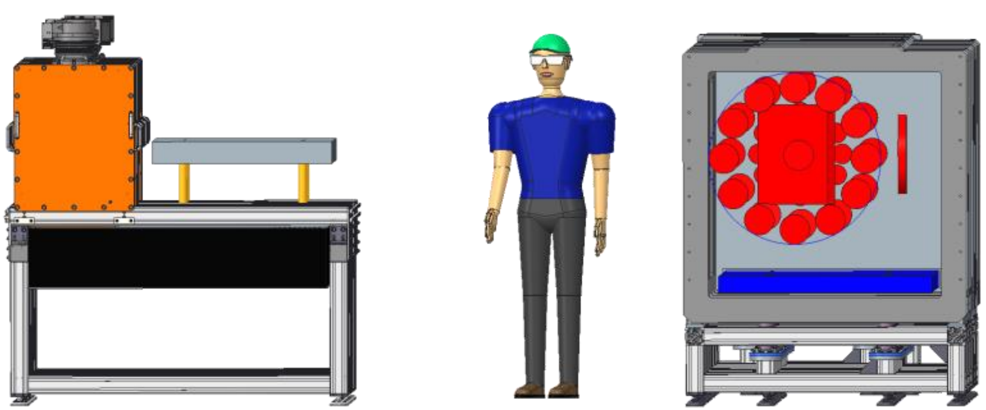
Outlook 100J+



Schematic overview over the 100J+ amp

Vacuum chamber and extraction scheme designed by HZDR:

1.2 MW pump peak power @ 980nm
80mm laser beam diameter
1:1.5 magnification
12 passes
13m, 20m³ vacuum chamber



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Conclusion

10J+ amplifier section :

25mm laser beam diameter
4 slabs, He gas cooled
SSG <1.3 per pass
SR 0.9+
Fully image relayed 12 passes in vacuum

Vacuum installation currently under construction (end of April)
First extraction (single shot) scheduled end of 2014

100J+ amplifier section :

80mm laser beam diameter
same parameters as 10J+ stage

Currently in design phase - Installation 2015


26/27/28/ March 2014
HEC-DPSSL
Lady Margaret Hall, Oxford