Cryogenically Cooled Laser Amplifiers

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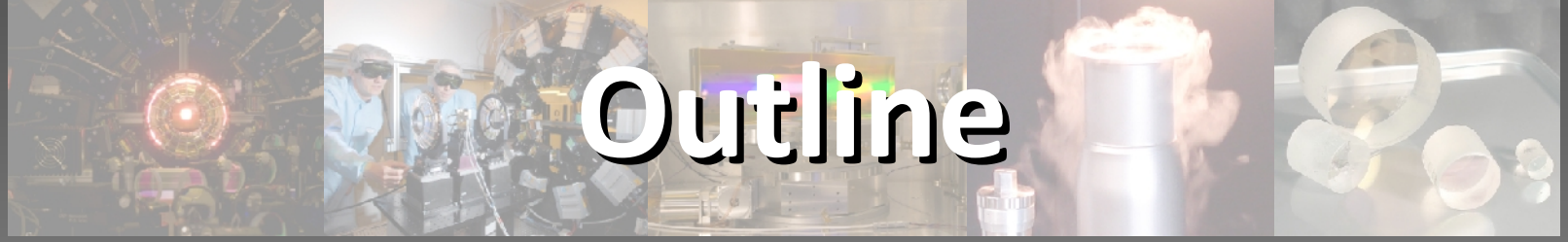
HEC-DPSSL, Lake Tahoe, Sept.12th – Sept. 14th



Outline

Introduction:

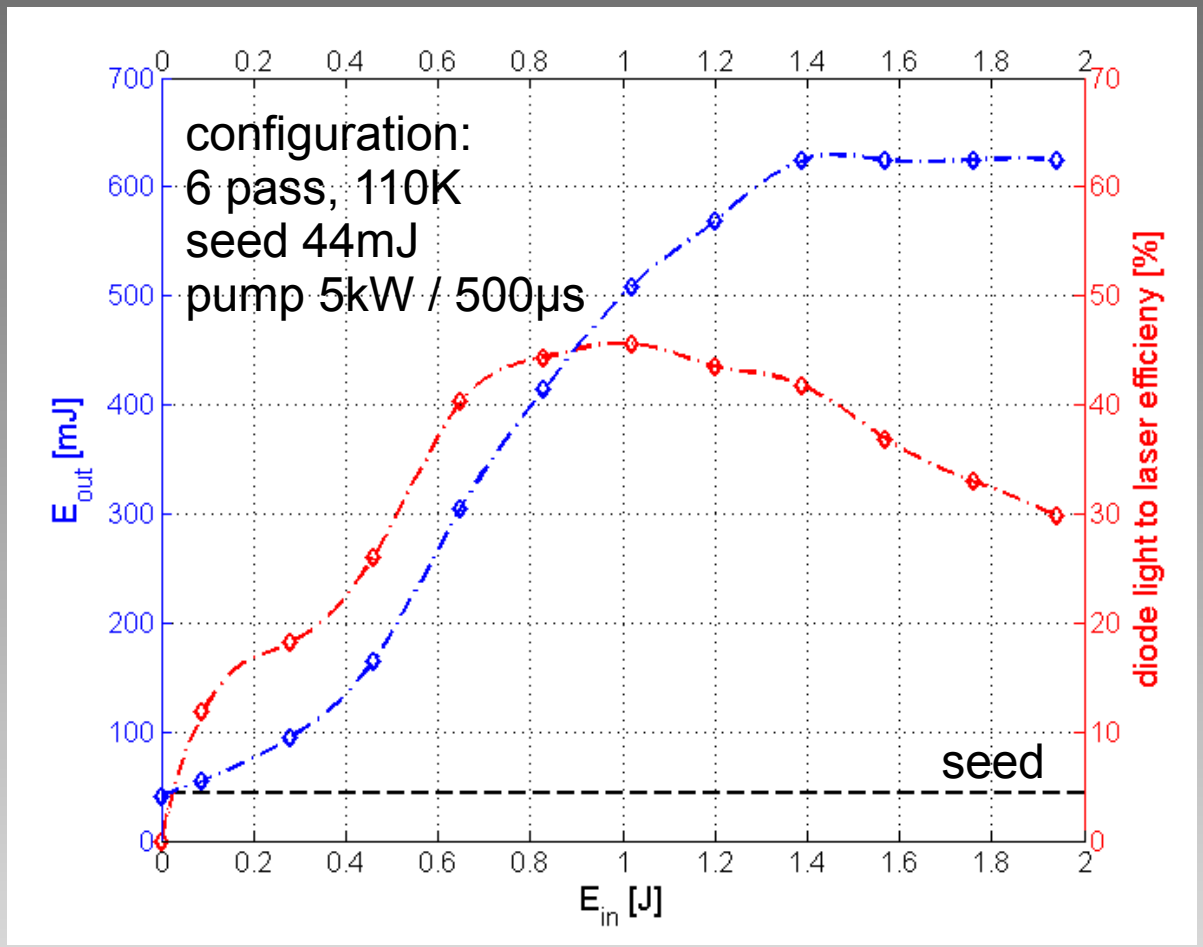
- *Why cryogenic cooling?*
- *Yb:CaF_2 @ cryogenic temperatures*
- *Burst mode?*

Burst Mode Laser system:

- *General layout*
- *Frontend*
- *Amplifiers*

Conclusion

Why cryogenic cooling?



J. Koerner et al., "High Efficiency Nanosecond Pulse Amplification Based on Diode-Pumped Cryogenic-Cooled Yb:YAG," ASSP, 2011, paper ATuE2.

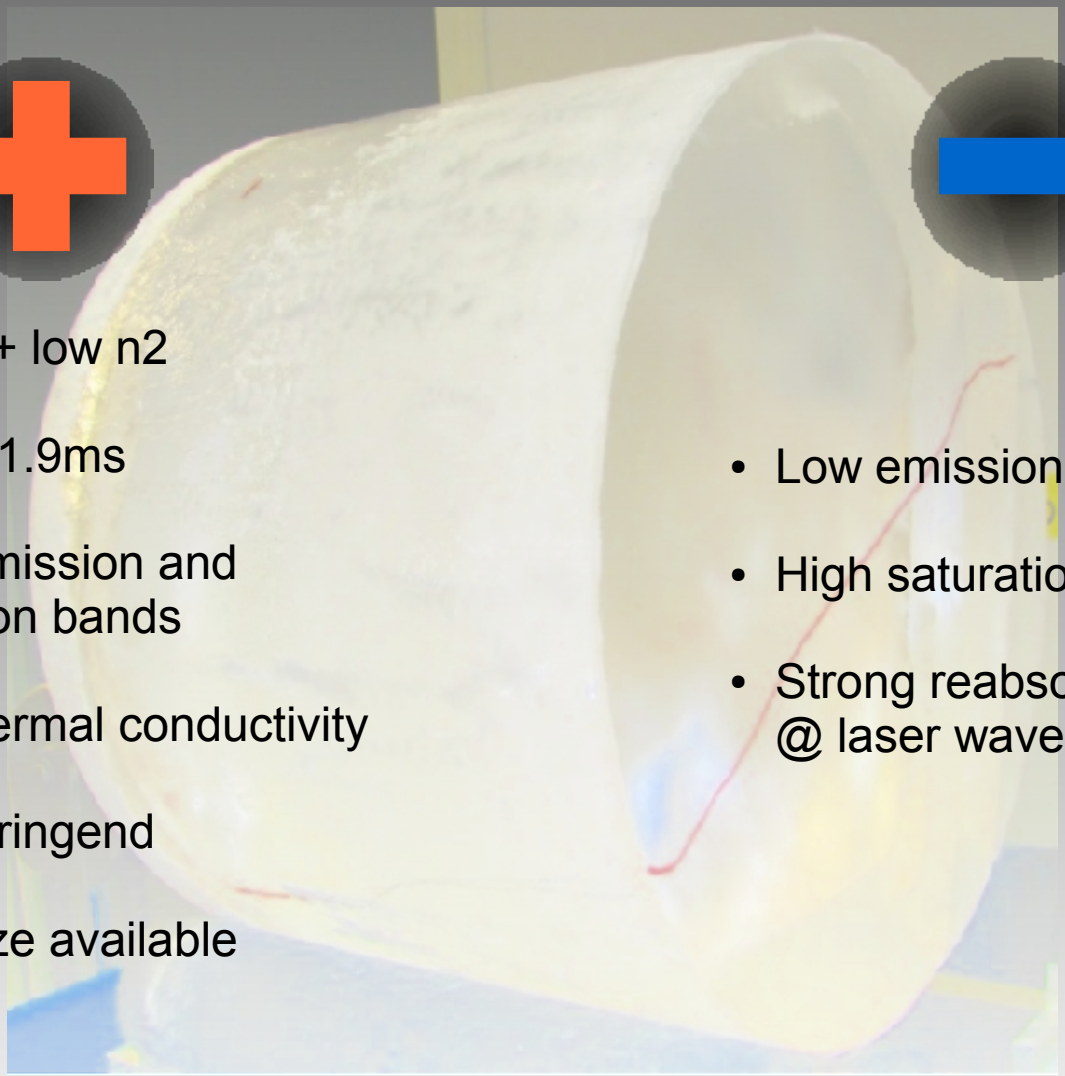
In case of Yb^{3+} doped media cryogenic cooling yields (typically):

- Higher efficiency
- Higher gain

e.g. Yb:YAG

Why?
Lower laser levels are thermally depopulated!

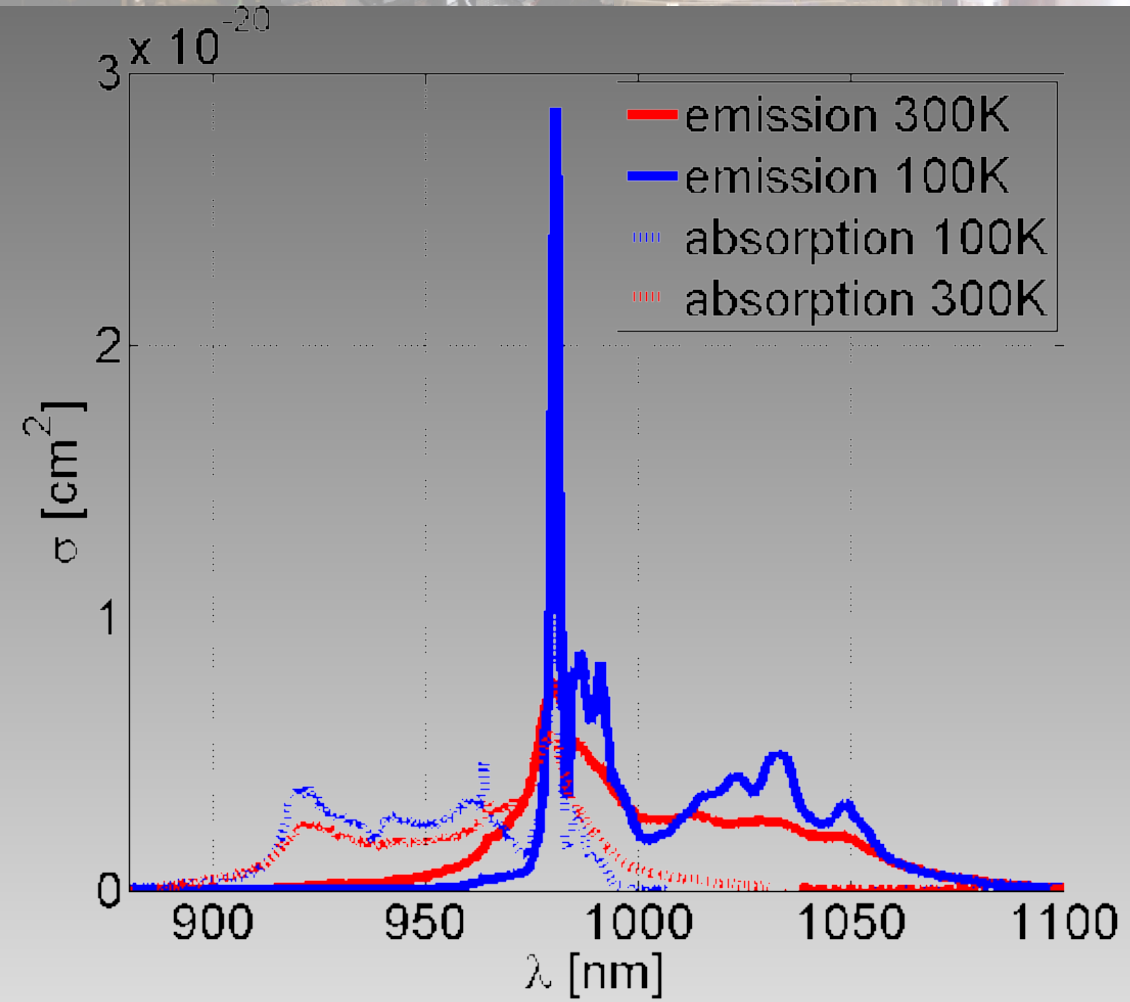
Yb:CaF_2 @ 300K



- n = 1.4 + low n2
- Lifetime 1.9ms
- Broad emission and absorption bands
- Good thermal conductivity
- Not birefringend
- Large size available

- Low emission cross sections
- High saturation fluence (74J/cm²)
- Strong reabsorption @ laser wavelength

Yb:CaF_2 @ 100K



- Higher σ_e @ 1030 nm
- Bandwidth nearly maintained but structured
- Absorption arround 940 nm nearly unaffected
- Reabsorption @ 1030 nm negligible
- **BUT:**
  still not high gain material
  still moderate saturation fluence (approx. 40 J/cm²)

J. Koerner et al., "Temperature dependent measurement of absorption and emission cross sections for various Yb^{3+} doped laser materials," Proc. SPIE 8080 808003–808007 (2011).

Yb:CaF_2 @ 100K

Further Improvement is achieved for mechanical properties in case of cryogenic cooling:
e.g. higher thermal conductivity (x4 for undoped material between 300 and 100 K!)

Yb:CaF_2 @ 100K

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Cryogenic cooling improves the amplification properties, but there are still challenges to face for efficient operation:

1. Yb:CaF_2 is still rather a low gain material

2. The saturation fluence is still high compared to LIDT values for Pulses in the nanosecond range

Yb:CaF_2 @ 100K

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1. Yb:CaF_2 is still rather a low gain material

→ ***Advanced multipass imaging schemes***

2. The saturation fluence is still high compared to LIDT values for Pulses in the nanosecond range

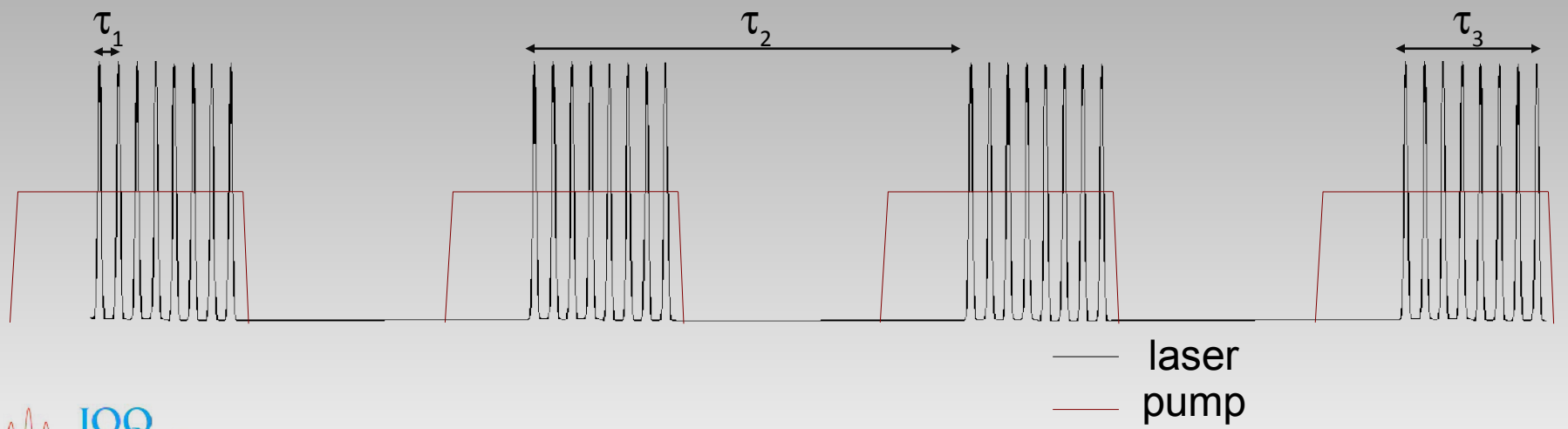
→ ***other pulse modes***

Burst mode

Amplification of multiple pulses within one amplification cycle

- Fluence for single pulse stays low
  - ➔ reduced LIDT issue
- Total extraction fluence of burst is high
  - ➔ efficient extraction

burst parameters for our system	
reprate within burst τ_1	1 – 10 µs (0.1 – 1 MHz)
reprate of bursts τ_2	100 ms (10 Hz)
pulses per burst	typically 500
burst length τ_3	typically 500 µs
length of single pulse	150 (300) fs



What is offered by bursts?

diode pumped high energy fs lasers

gain saturation of broadband materials is typically well above LIDT in CPA Yb-doped systems

- limited efficiency
- rather low average power

fs - burst mode amplifier

LIDT for bursts is way higher even at lower stretching

- good efficiency possible
- medium avarage power

medium peak power

diode pumped high power fs lasers

very high average power, but rather low peak power

good efficiency

Applications

fs – bursts applications

interaction with particle beams from accelarators

- matched pulse mode
- higher energy as CW pumped

other

- materials processing
- combustion diagnostics
- plasma diagnostics
- …

dose and energy sensitive experiments

- X-ray source
- electron acceleration
- HHG
- spectroscopy

Burst laser system

Frontend amplitude satzuma + pulse compression

1MHz, 1W, 150fs

Stretcher

1MHz, 200ps

S0
50W CW diode pumped

1MHz, 10W

Pulse Picker

x mJ bursts

S1 (cryogenic)
2.5 kW Diode pumped

mJ range, e.g ns pulse

alternative Frontend

up to 200 mJ, 10Hz
achieved >300 mJ, 0.5Hz

S2 (cryogenic)
16kW Diode pumped

up to 5J, 10Hz

compression

Experiment

Implementation in progress
Installed + running
under development

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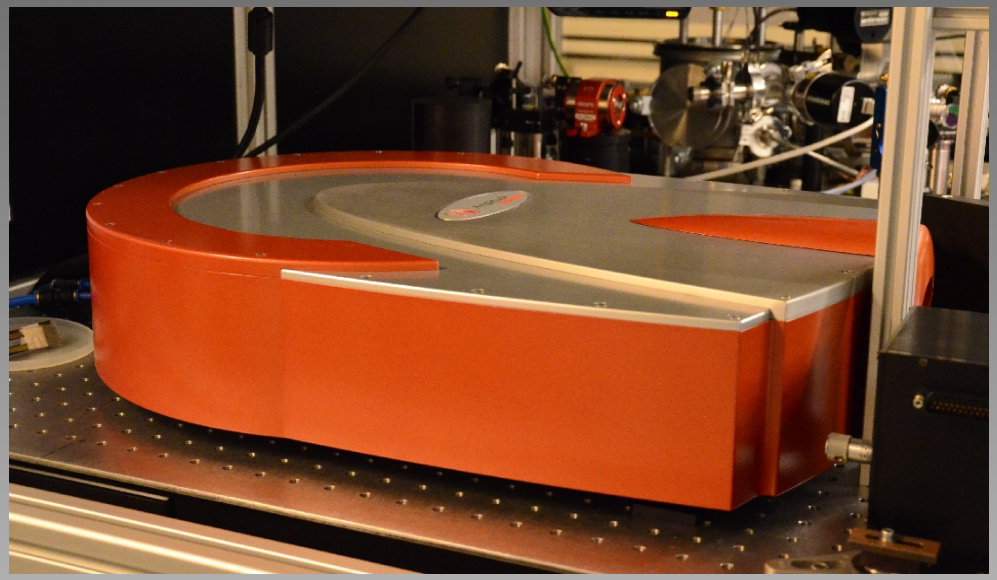
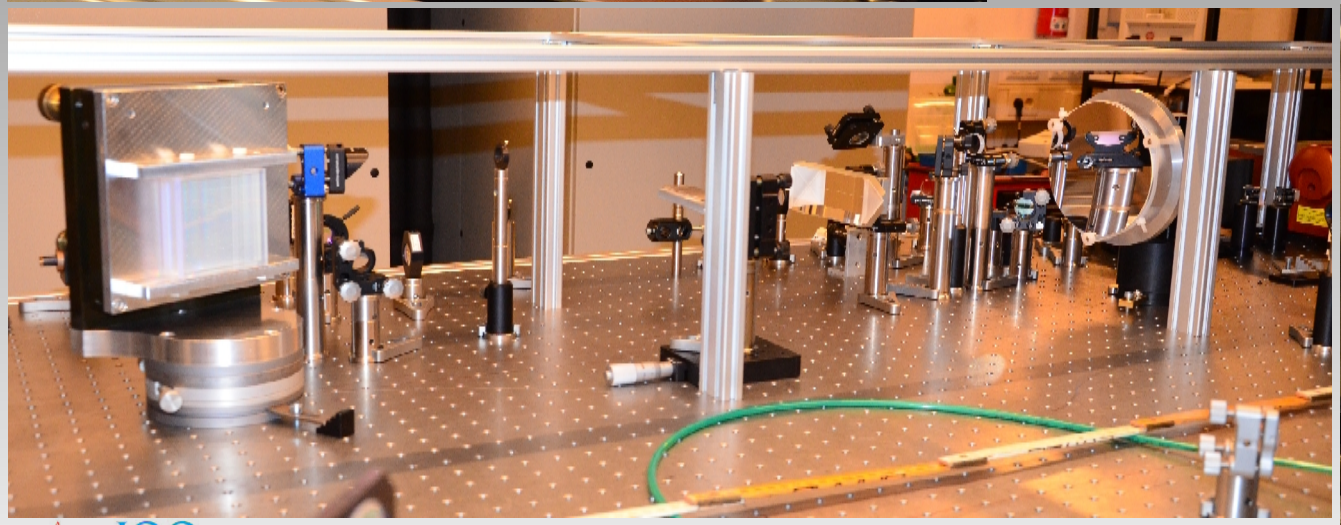
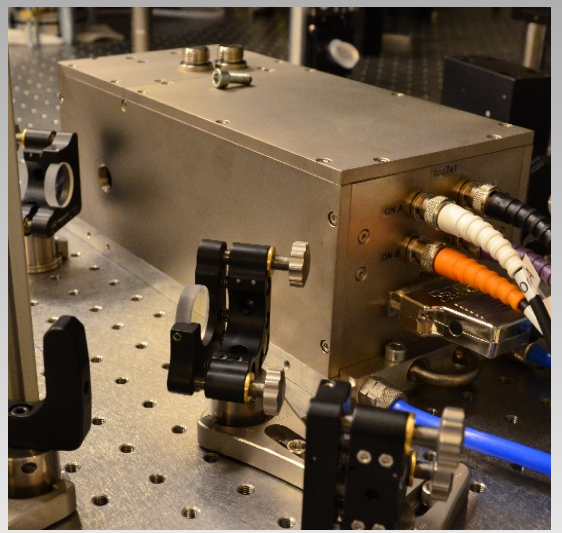
Frontend



- Amplitude Satsuma generates 300 fs, 1 MHz, 1 W
- Stretched to ca. 50 ps
- BME Pockels-cell cuts out bursts of 500 pulses, 1Mhz
- Burst reprate 10 Hz

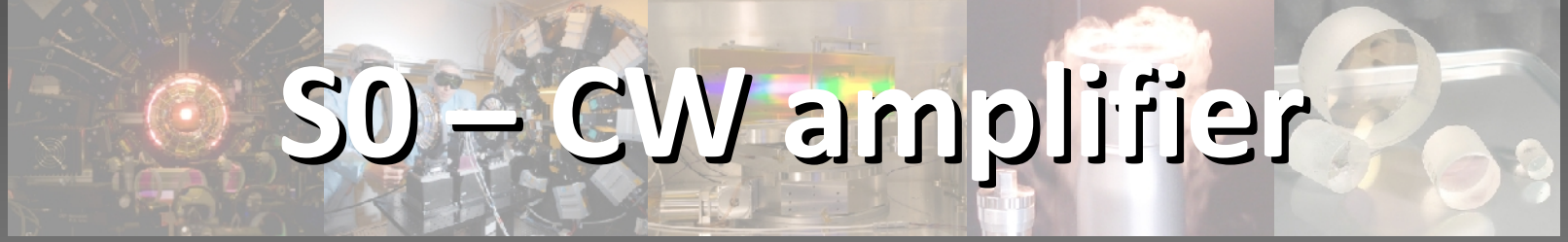




Burst laser system

	S0	S1	S2
Output	10W, 0.1-1MHz	200mJ, 10Hz	up to 5J,10Hz
pump	50W CW fiber coupled (105µm)	2.5 kW laser diode stack (ms pulses)	17 kW laser diode module (ms pulses, homogenized)
cooling	water	LN2	LN2
special	average power booster for fs	high gain multi pass	high energy +efficiency very compact
	relay imaging		

S0 – CW amplifier



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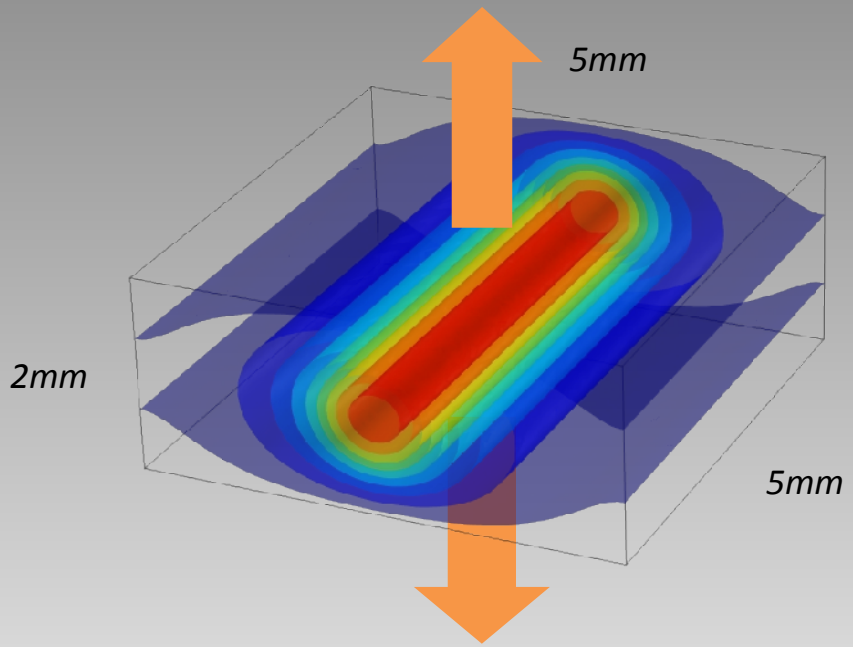
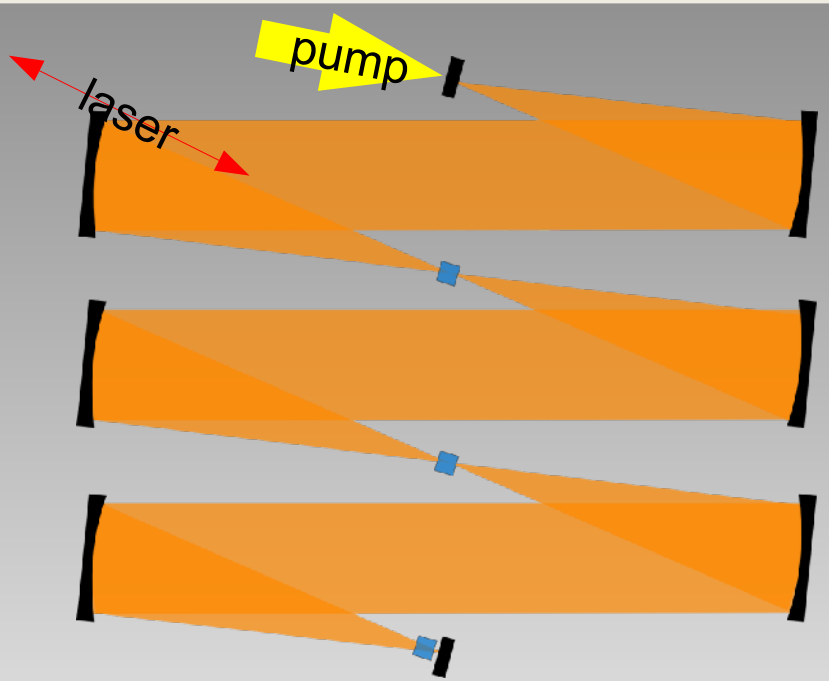
S0 – CW amplifier

- 4f imaging scheme, copropagating pump and extraction beam
- Heat splitted on two or more Yb:CaF_2 crystals in the image planes
- Pumped with 50W fiber coupled laser diode

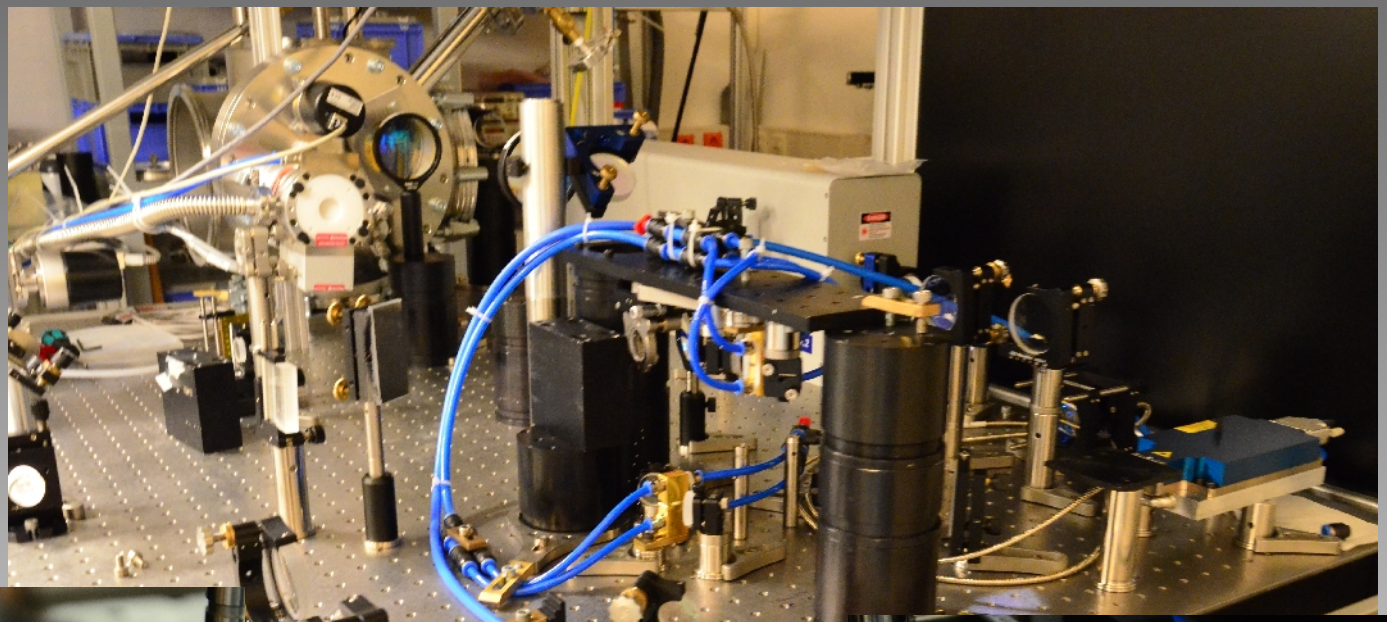


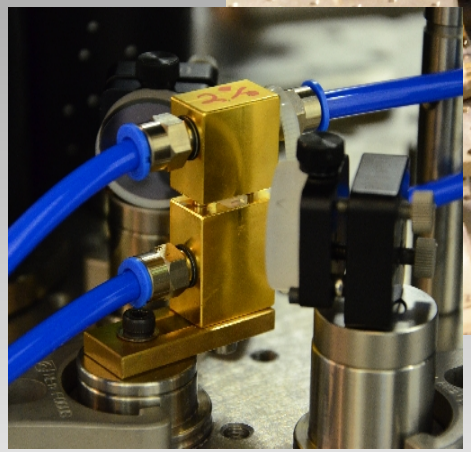
thermal model of single laser crystal

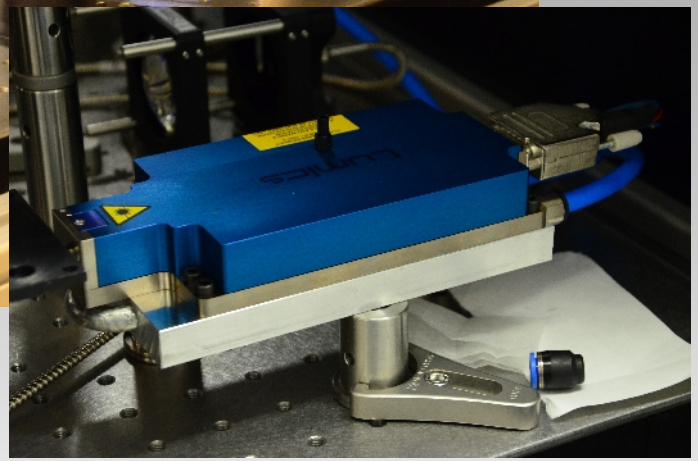


Principal setup with multiple image planes

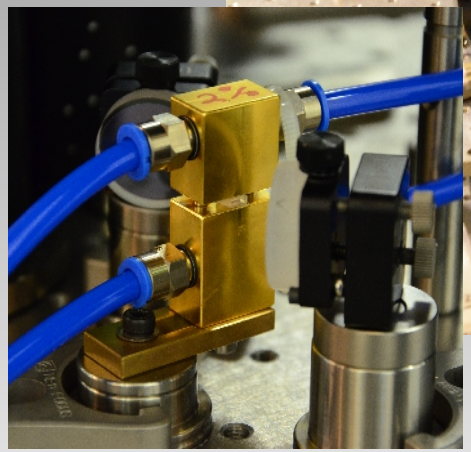
S0 – CW amplifier

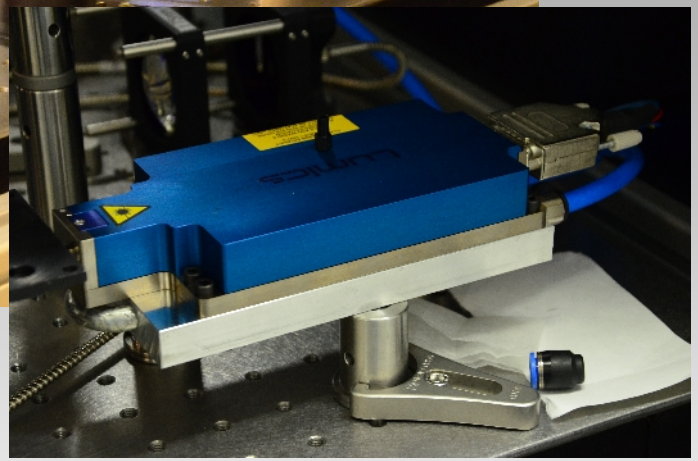


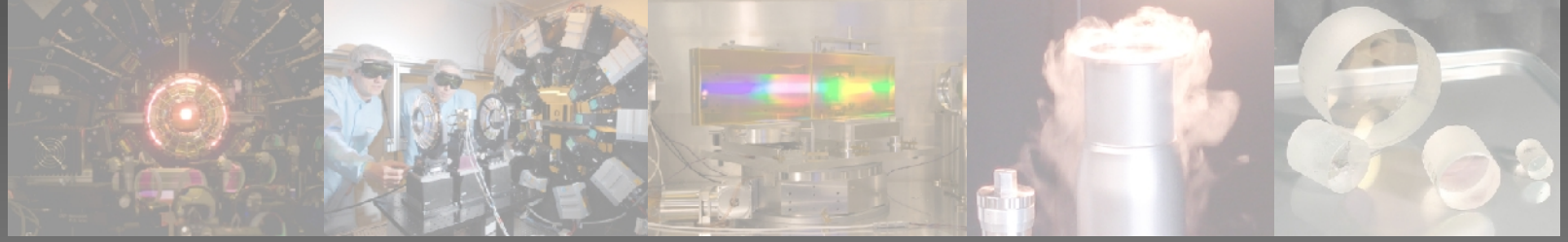




S0 – CW amplifier







Frontend amplitude satsuma + pulse compression

1MHz, 1W, 150fs

Stretcher

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50W CW diode pumped

1MHz, 10W

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x mJ bursts

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mJ range, e.g ns pulse

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up to 5J, 10Hz

compression

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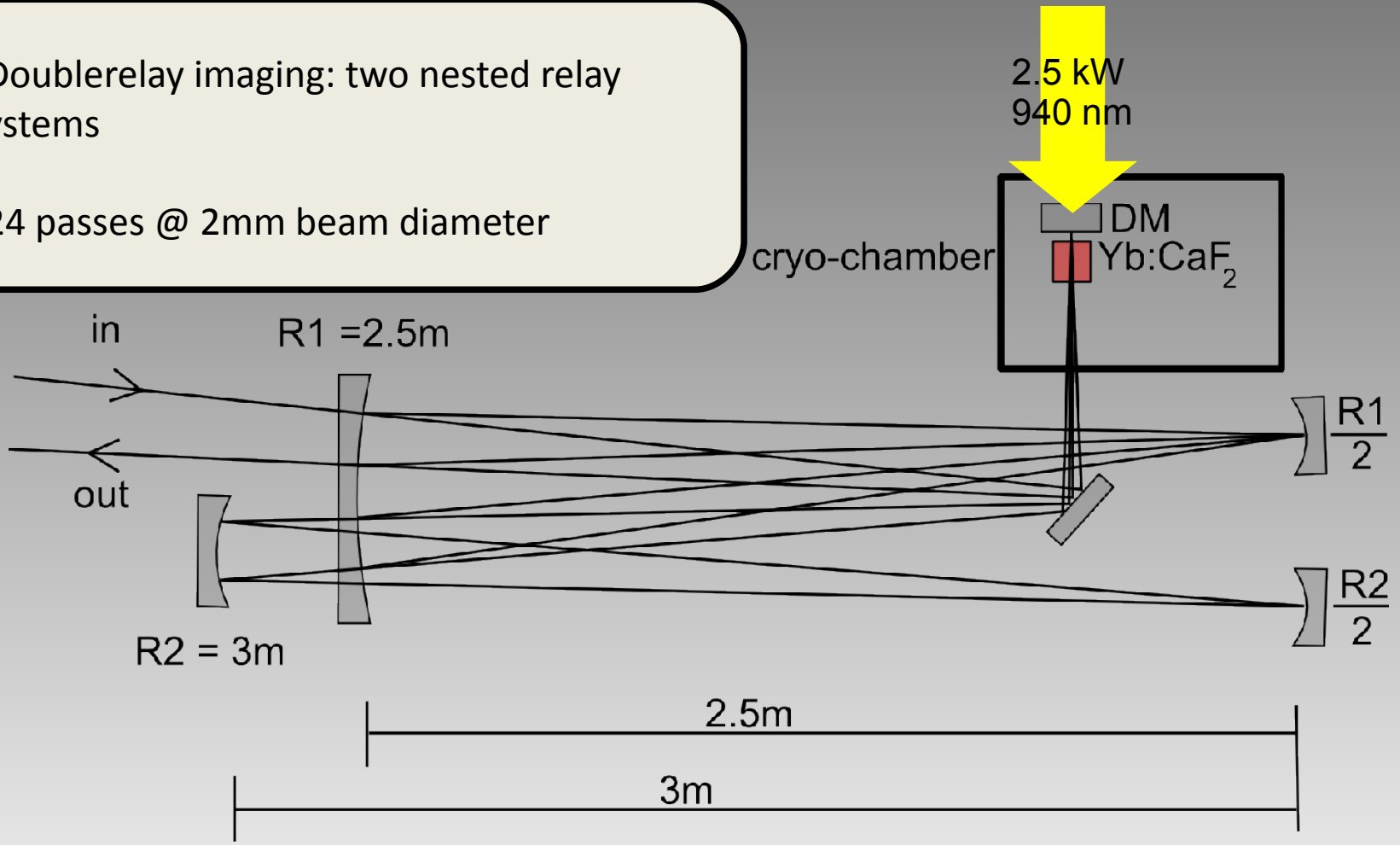
Amplifier S1 - setup

- Doublerelay imaging: two nested relay systems
- 24 passes @ 2mm beam diameter



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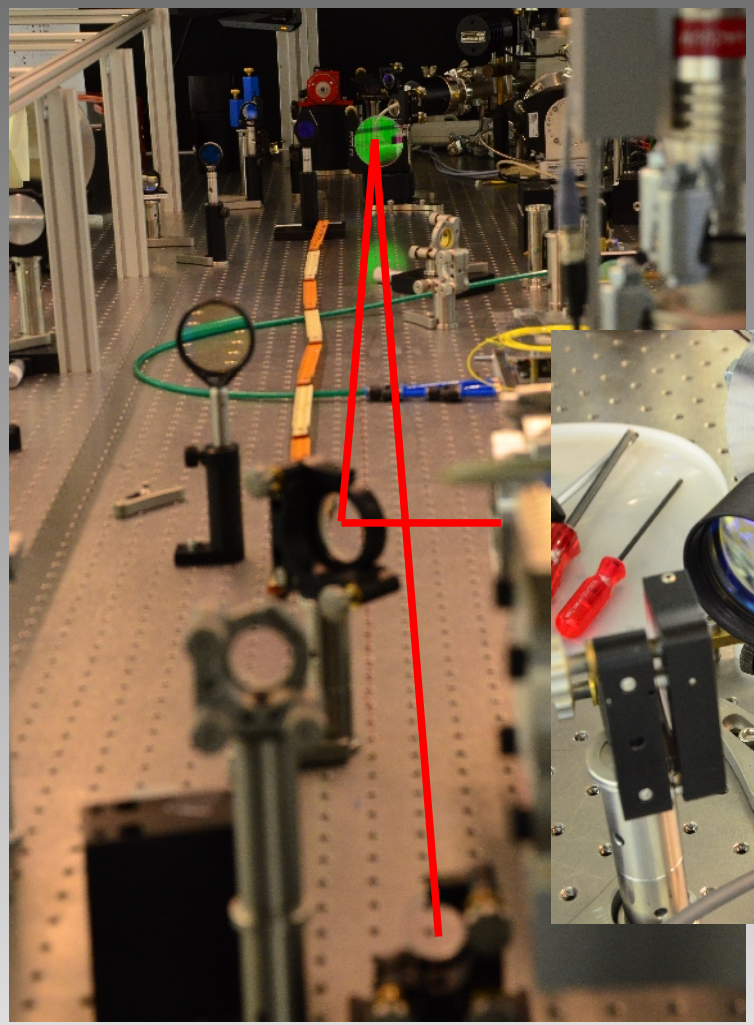
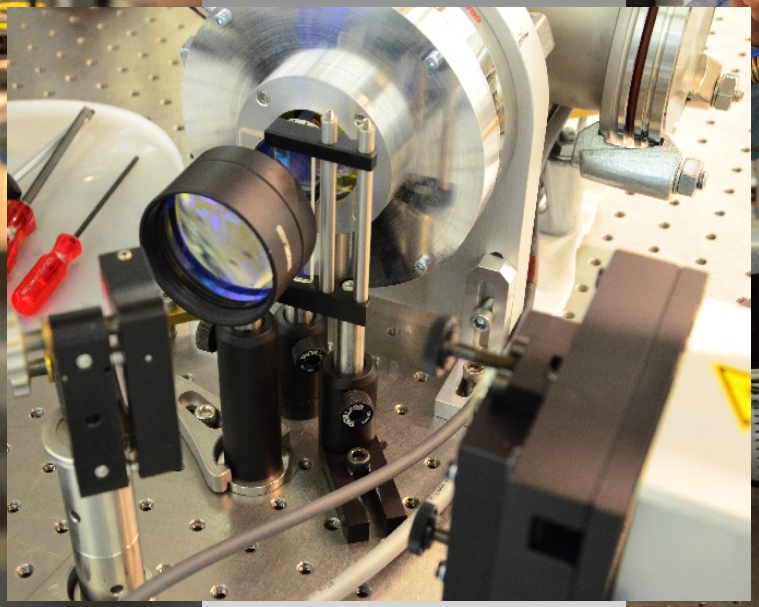
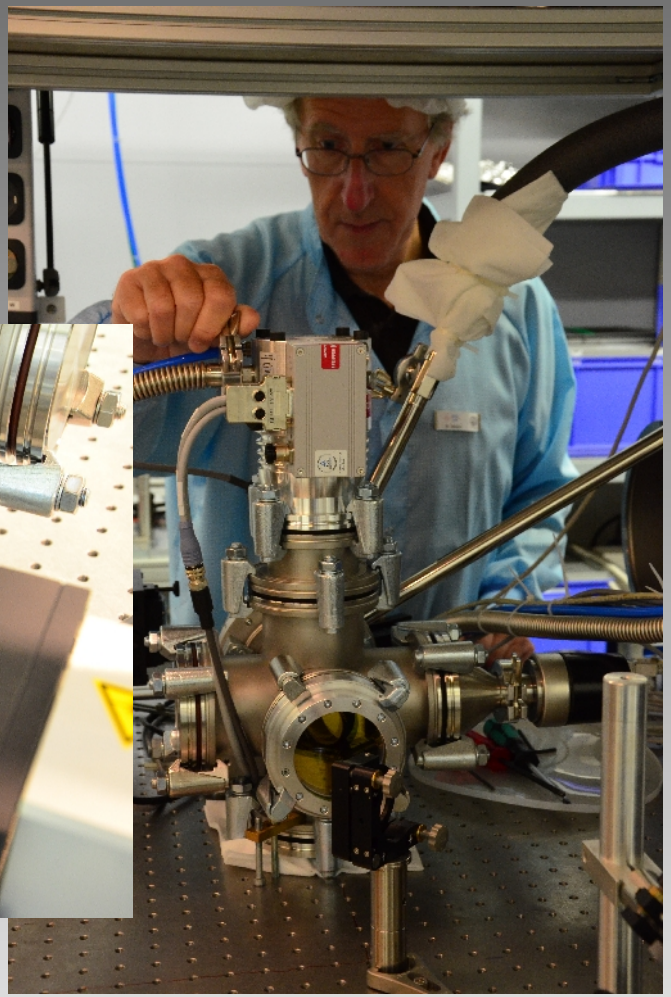


Imaging setup for amplifier S1



pump setup



LN2 cryostat (modified Janis ST500UC), 3W @80K

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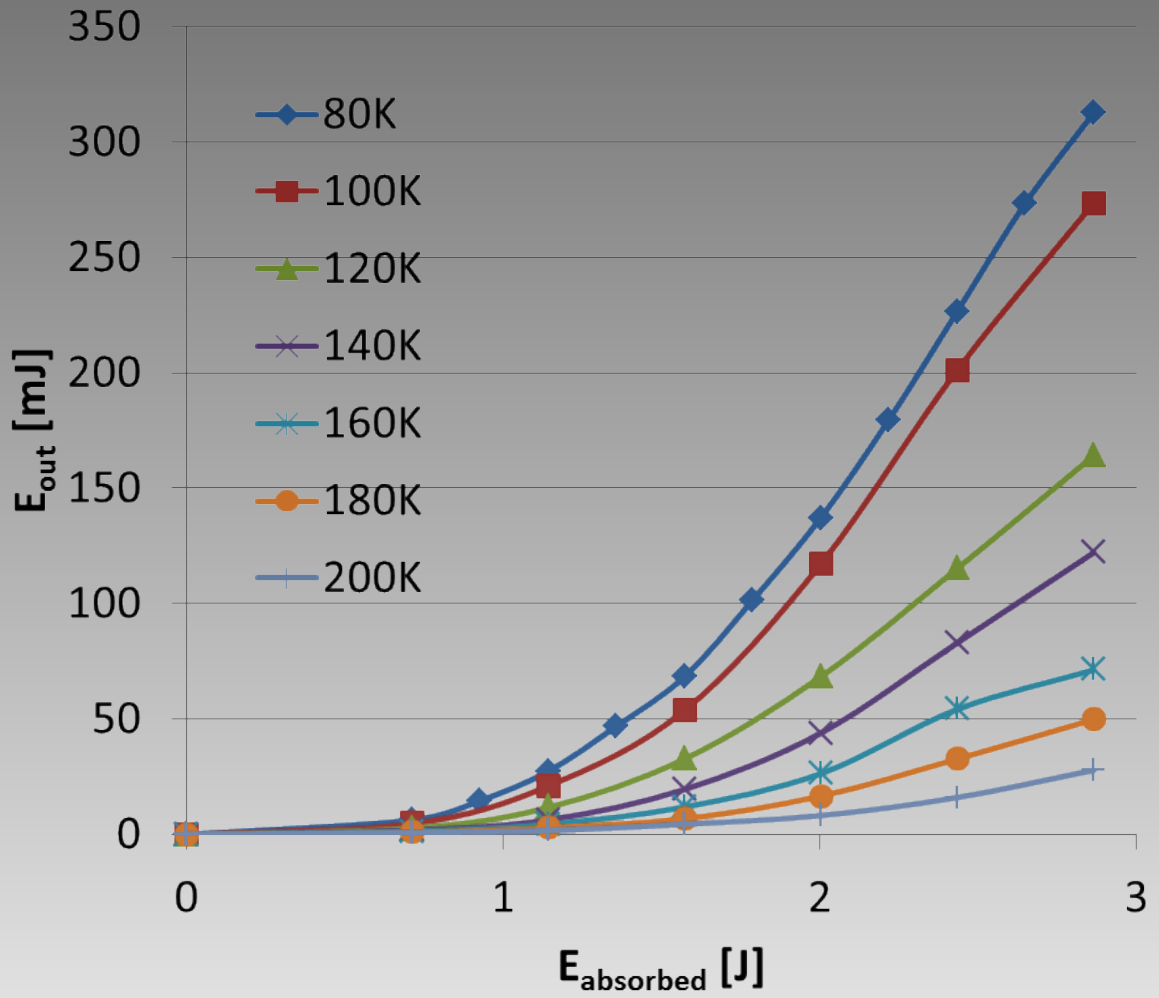
Amplifier S1 - results

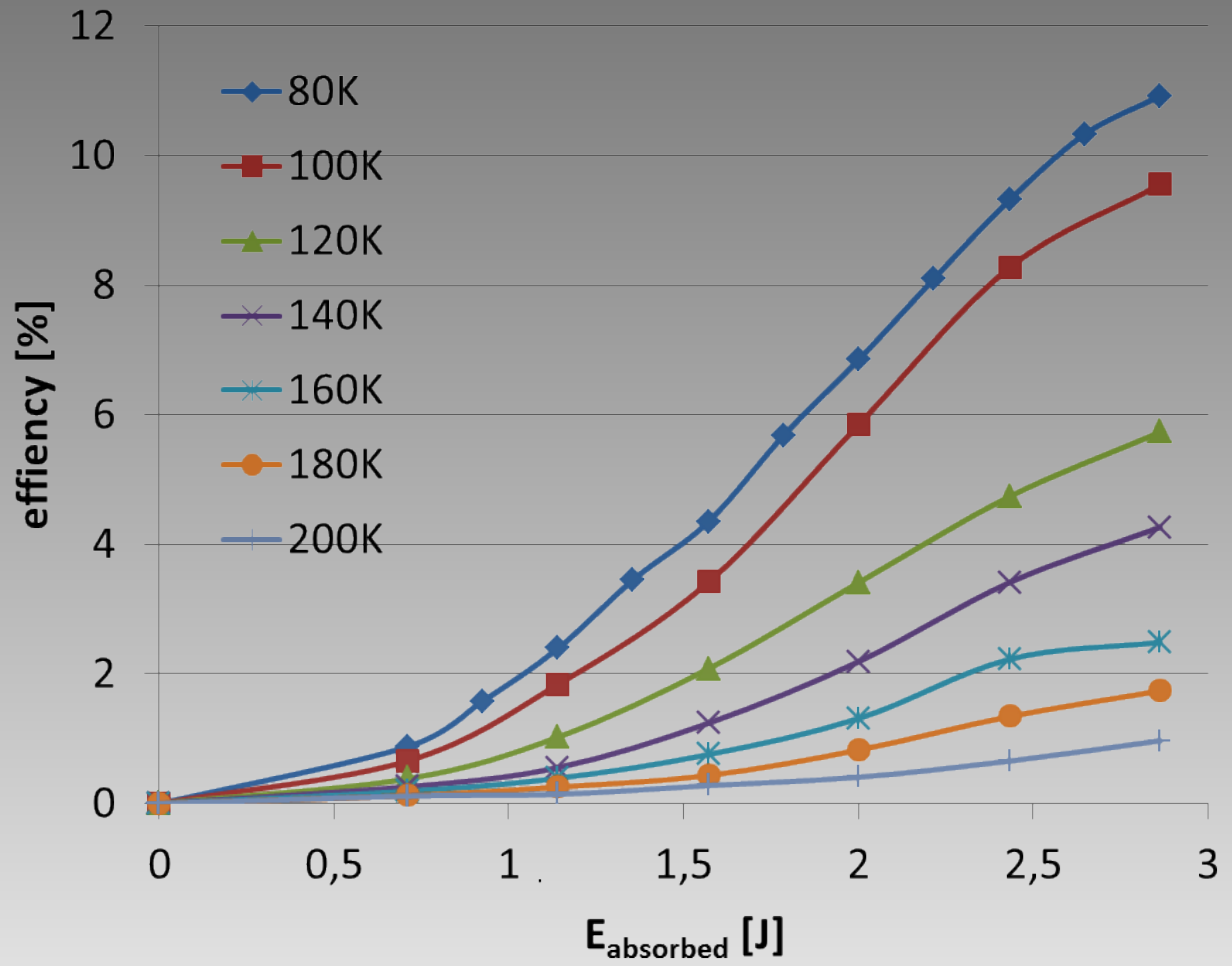


Input:
Burst of 500 pulses
150µJ total
1Mhz burst internal
Burst starts 1.5ms
after pump

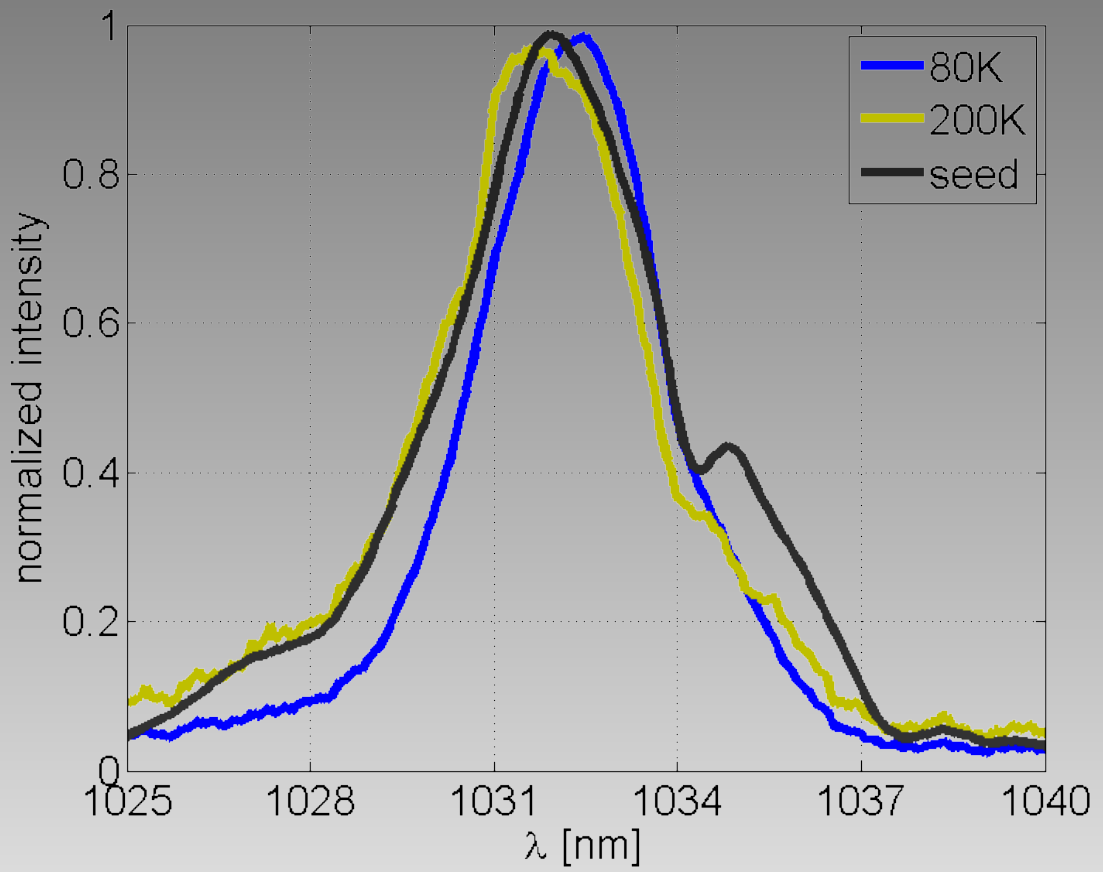
Amplifier:
24 passes
2.5 kW / 2 ms
Reprate 0.5 Hz
Gain up to 2000

Amplifier S1 - results

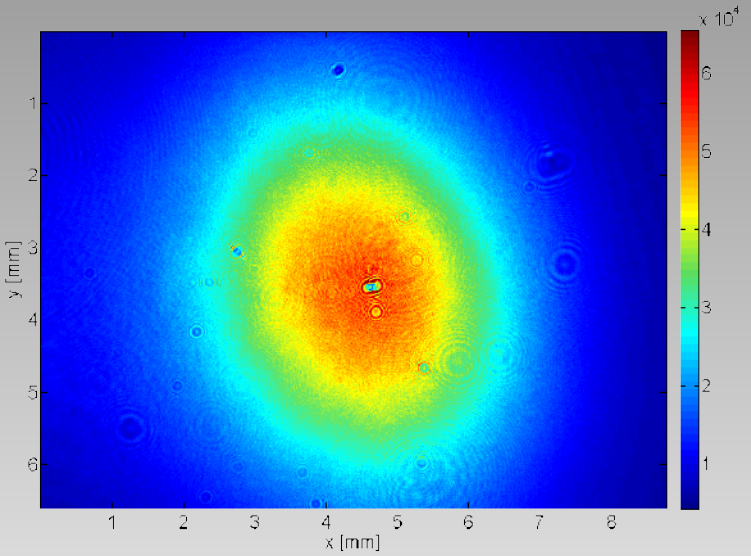
Extraction efficiency of more then 10 % @cryogenic temperature!

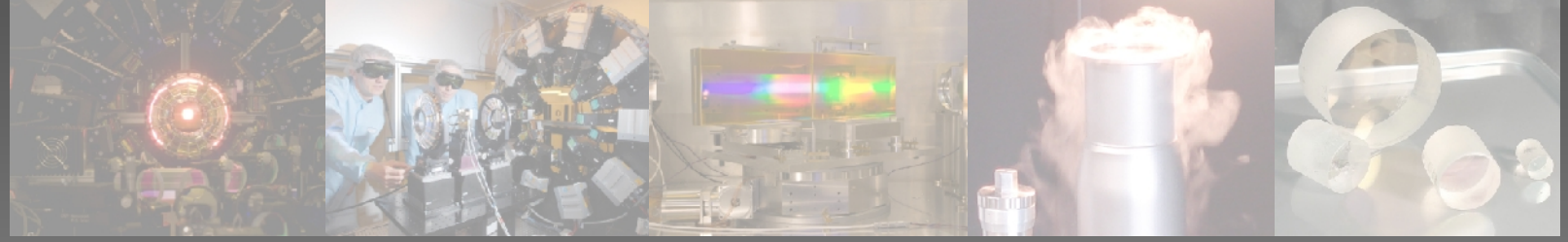


Amplifier S1 - results



- Gain narrowing low
- Good beam profile





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50W CW diode pumped

1MHz, 30W

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x mJ bursts

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16kW Diode pumped

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Installed + running
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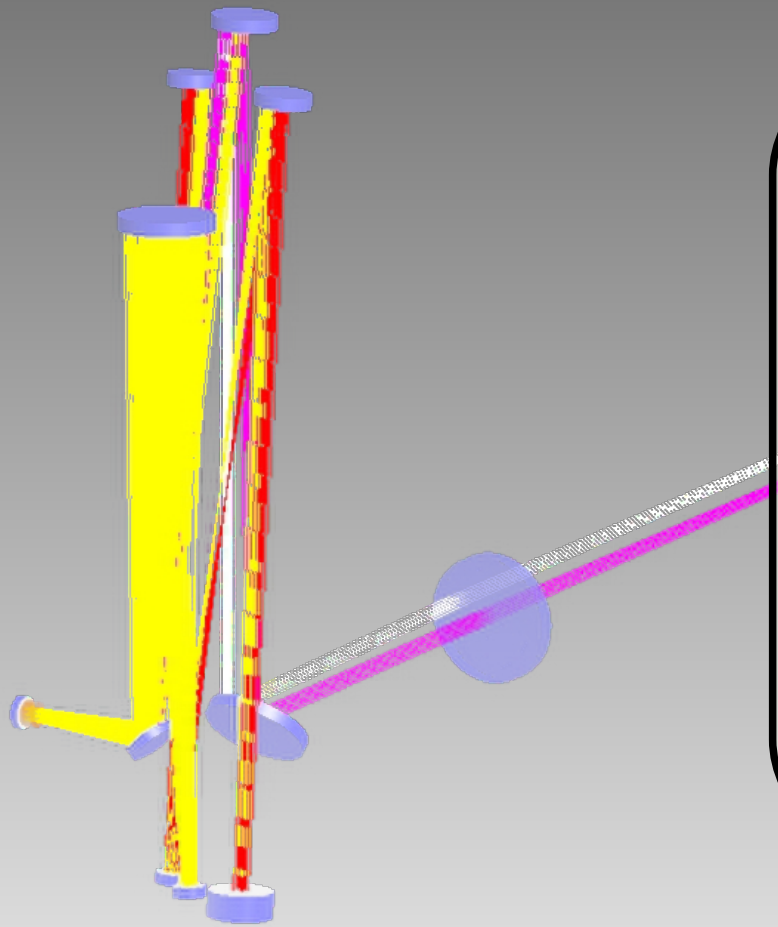
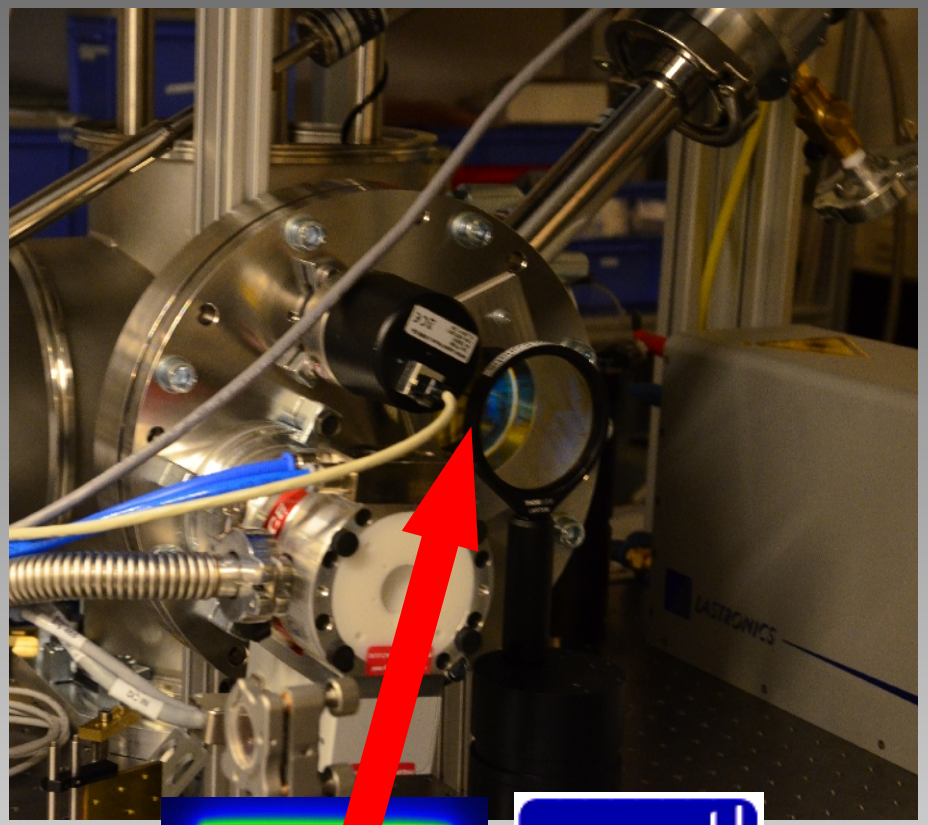
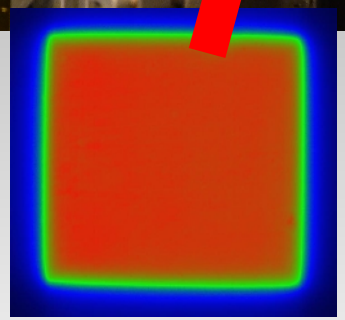
Amplifier S2 - setup



- Again two nested relay systems
- 16 passes through the material
- adaptive mirror can be applied
- very compact, whole amplifier fits in vacuum tube
- 1 cm beam diameter
- designed for up to 5J output

Amplifier S2 - setup





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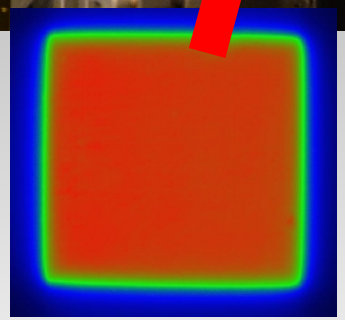
Amplifier S2 - setup

Commissioning soon!



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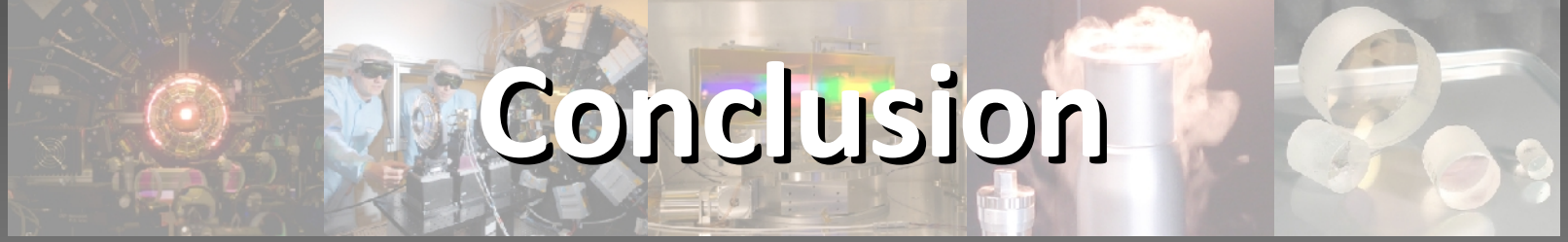

Conclusion

We are constructing an all diode pumped burst mode laser system:

- Based on Yb:CaF_2
- Burst mode allows higher extraction fluencies and effiency
- CPA system
- Designed for 5 J / burst + 10 Hz

Status:

Frontend:	ready, producing bursts of **500 pulses, 1MHz, 300fs**
S0:	CW – pumped preamp, on table, commisioning soon
S1:	cryogenic cooled, achieved **gain > 2000, > 300 mJ** with good beam profile, **FWHM bandwidth about 4.5 nm**, ready
S2:	cryogenic cooled, on table commisioning soon

Thank you for your attention!

Work supported by:

HZDR

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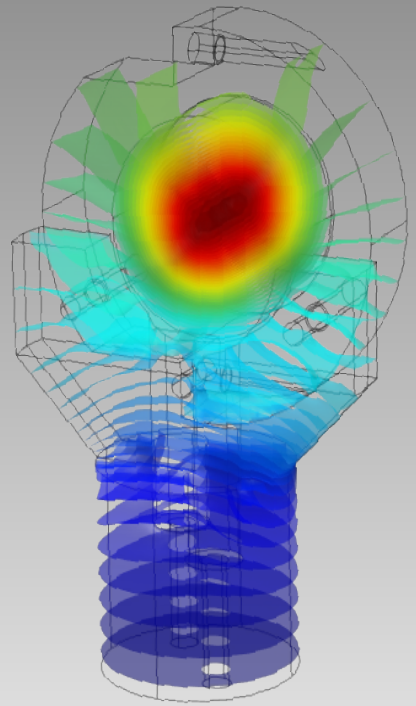
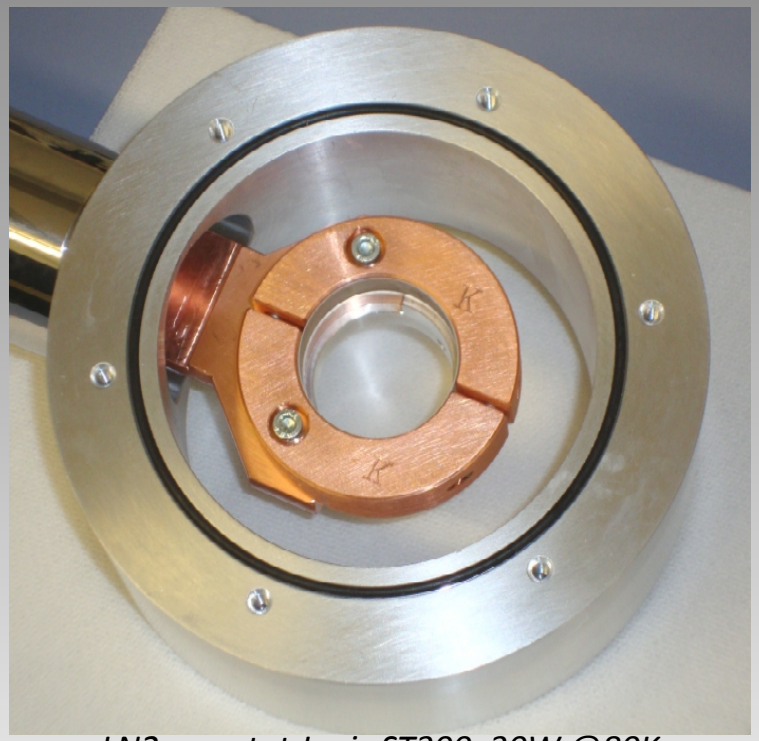
Amplifier S1 - setup

- thermal model predicts about 40 K temperature shift starting from cryo-head
- crystal under high vacuum enviroment (10-7 mbar achieved)



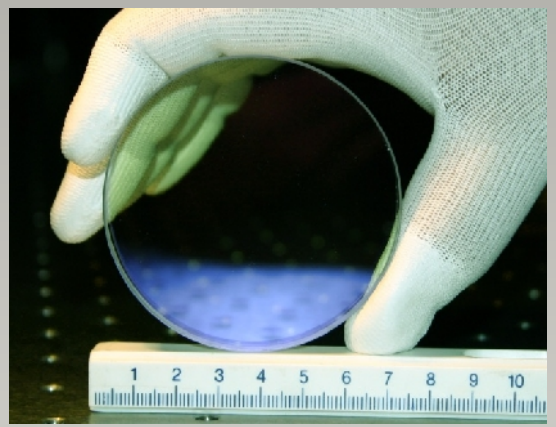
result from thermal modeling



LN2 cryostat Janis ST300, 30W @80K

System Layout

- Yb:CaF2 as laser medium for broadband amplification
  - down to 100 fs possible
  - very long lifetime (1.9 ms)
  - good thermal conductivity
  - especially @ cryogenic temperature



Yb:CaF2 amplifier medium with 7cm diameter

- amplification of bursts (up to several 100 pulses)
  - higher fluence extractable without damage
  - higher efficiency possible

- as vacuum enviroment is employed for cooling, we can also put the whole amplifier into vacuum:
  - less problems with air disturbances
  - focus planes dont need seperate vacuum tubes, window passes are spared