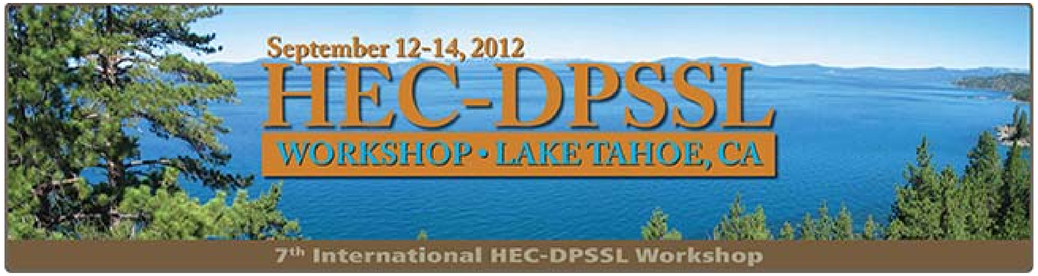
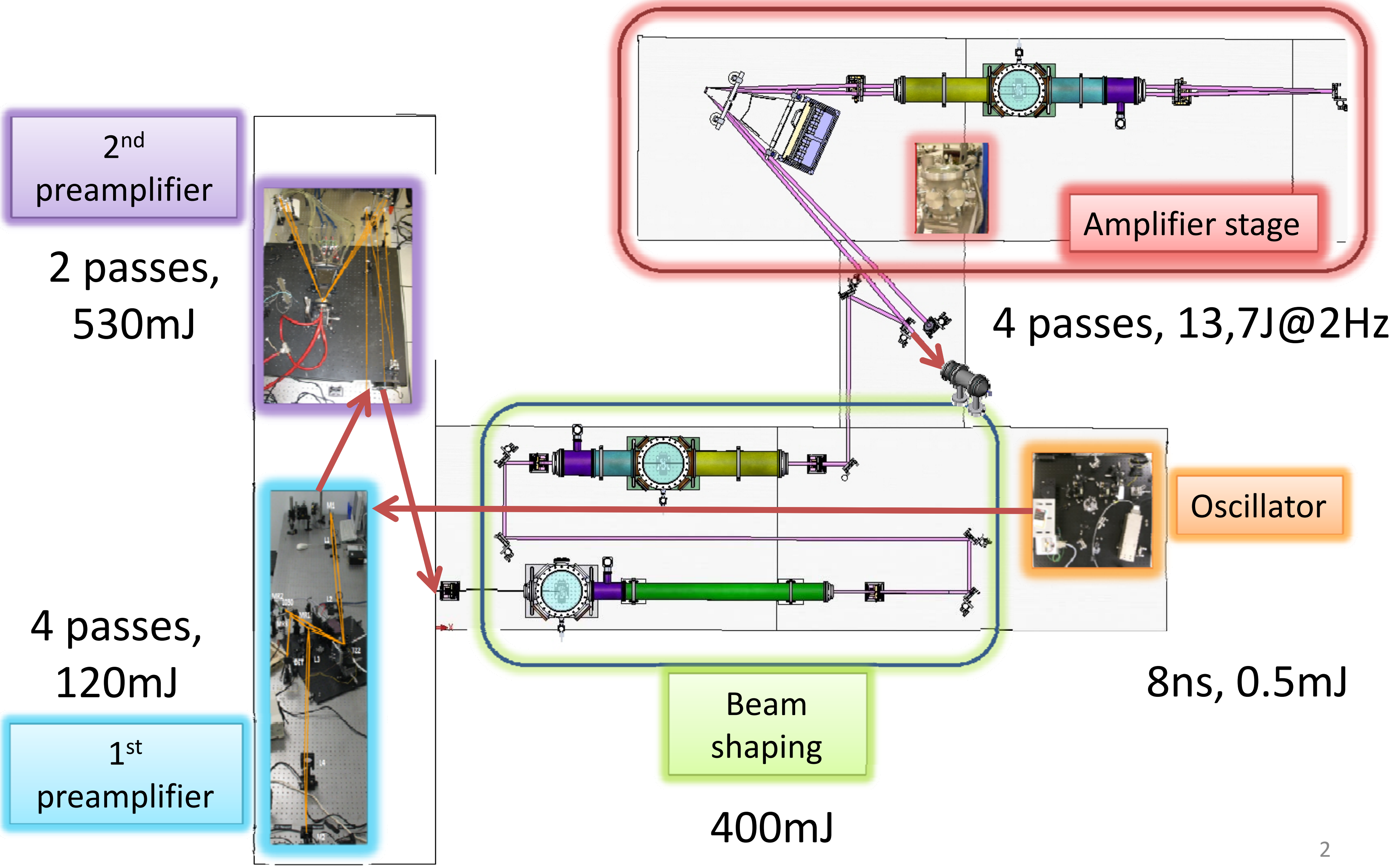


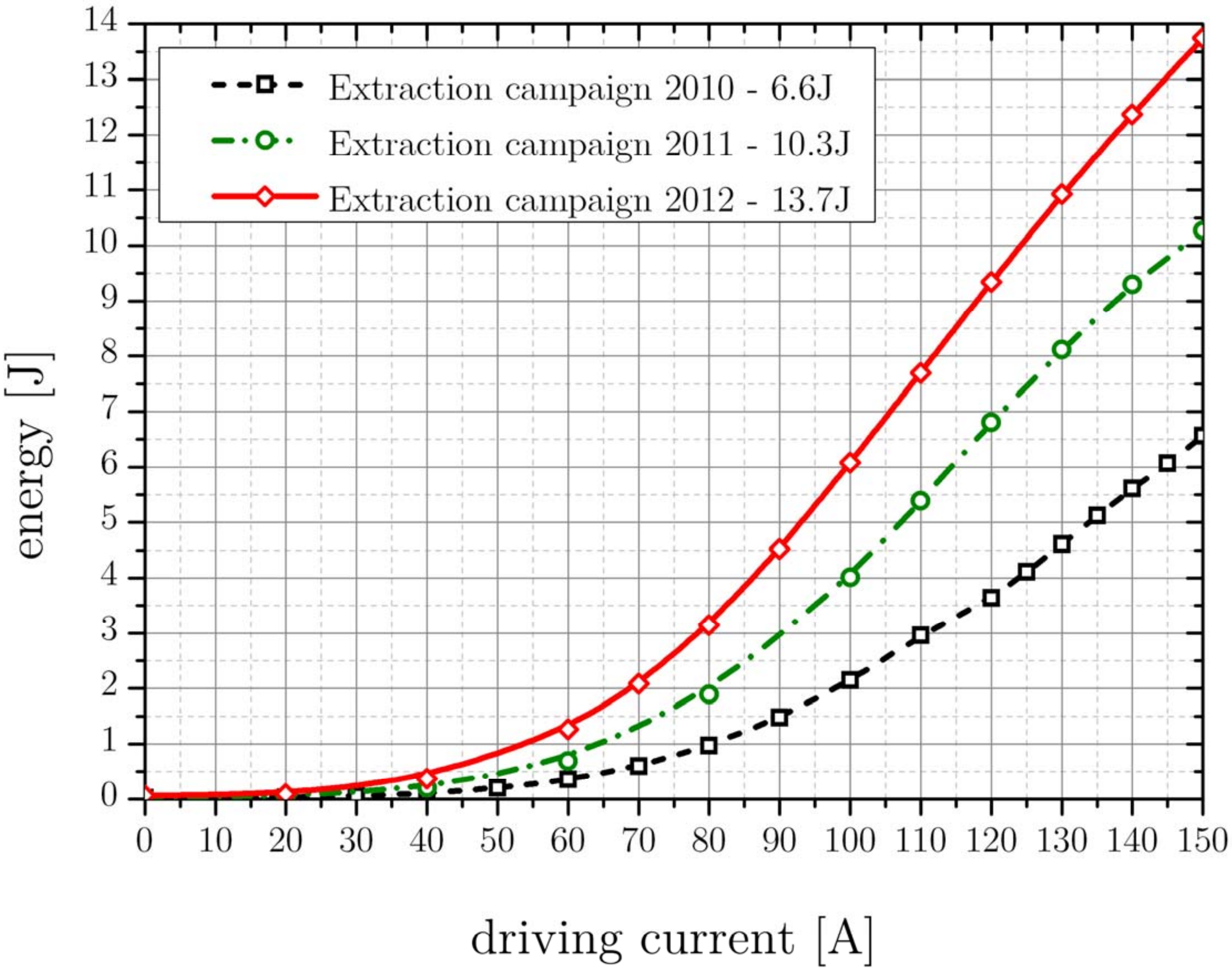
Lucia cryogenic amplifier head concept and qualification

T. Novo, D. Albach, B. Vincent and J.-C. Chanteloup
Laboratoire LULI, Ecole Polytechnique, Palaiseau, France

Diode pumped Yb:YAG Lucia laser system layout



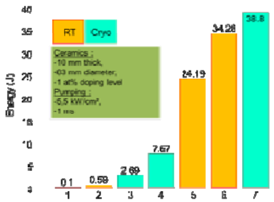
14 Joules achieved at 2Hz



Ramping up Lucia energy to the 30 J level with 2nd amplifier

Moving from 300 K toward 100-200 K operating temperatures for the 2nd amplifier implies :

-1- Increase of pump and emission cross section



➔ less pump intensity required (<6kW/cm²)

➔ reduced pump source budget (few 100 k€)

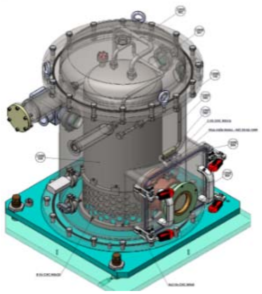
➔ reaching >30J in 3 passes

-2- Suppression of 1030 nm absorption

➔ No simple ASE management solution available anymore

➔ Co-sintered Cr^{4+}/Yb^{3+}:YAG ceramics needed

-3- Development of a new kind of thermal management approach

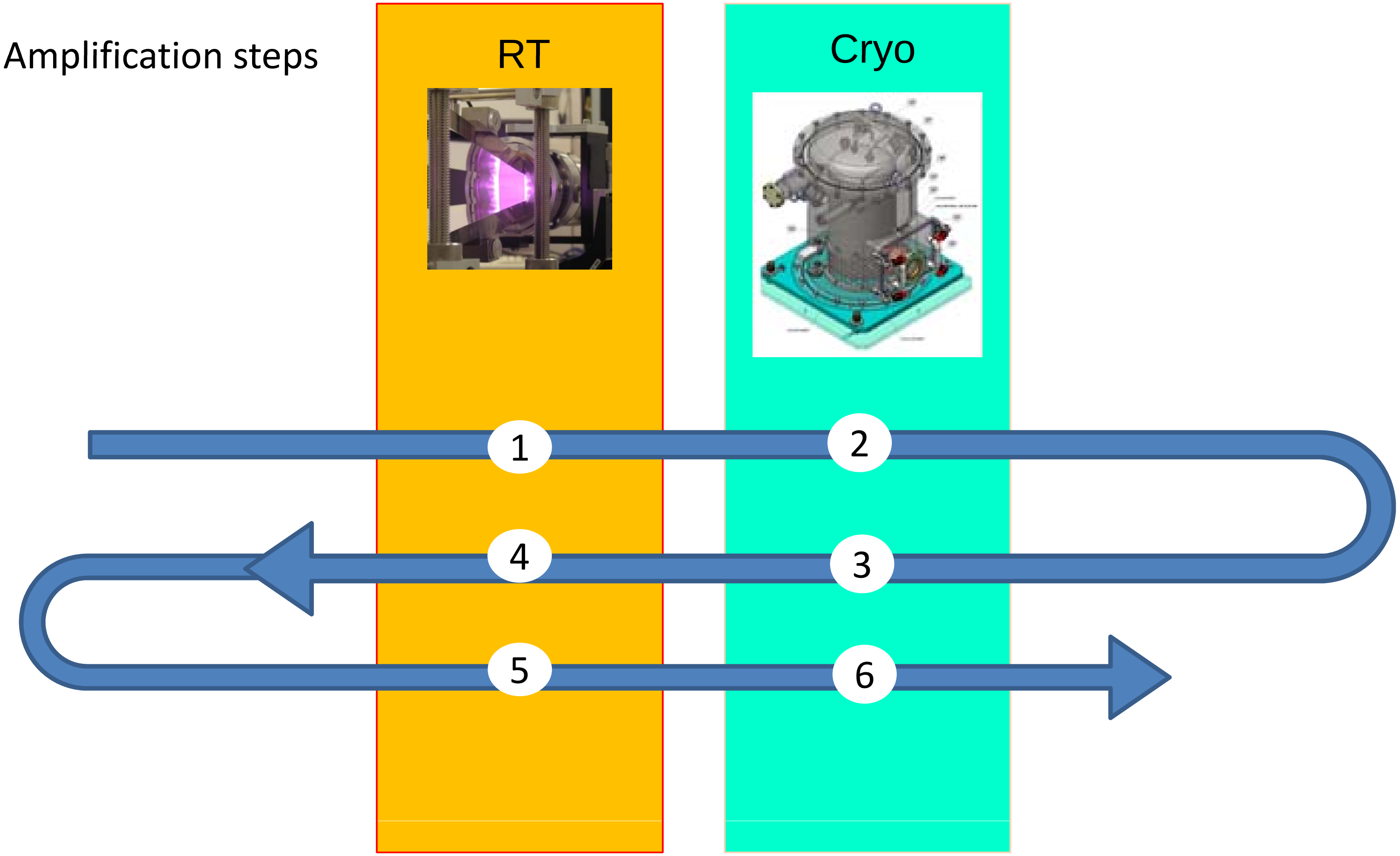


Achieving 30J milestone with 5.5kW/cm² pump brightness

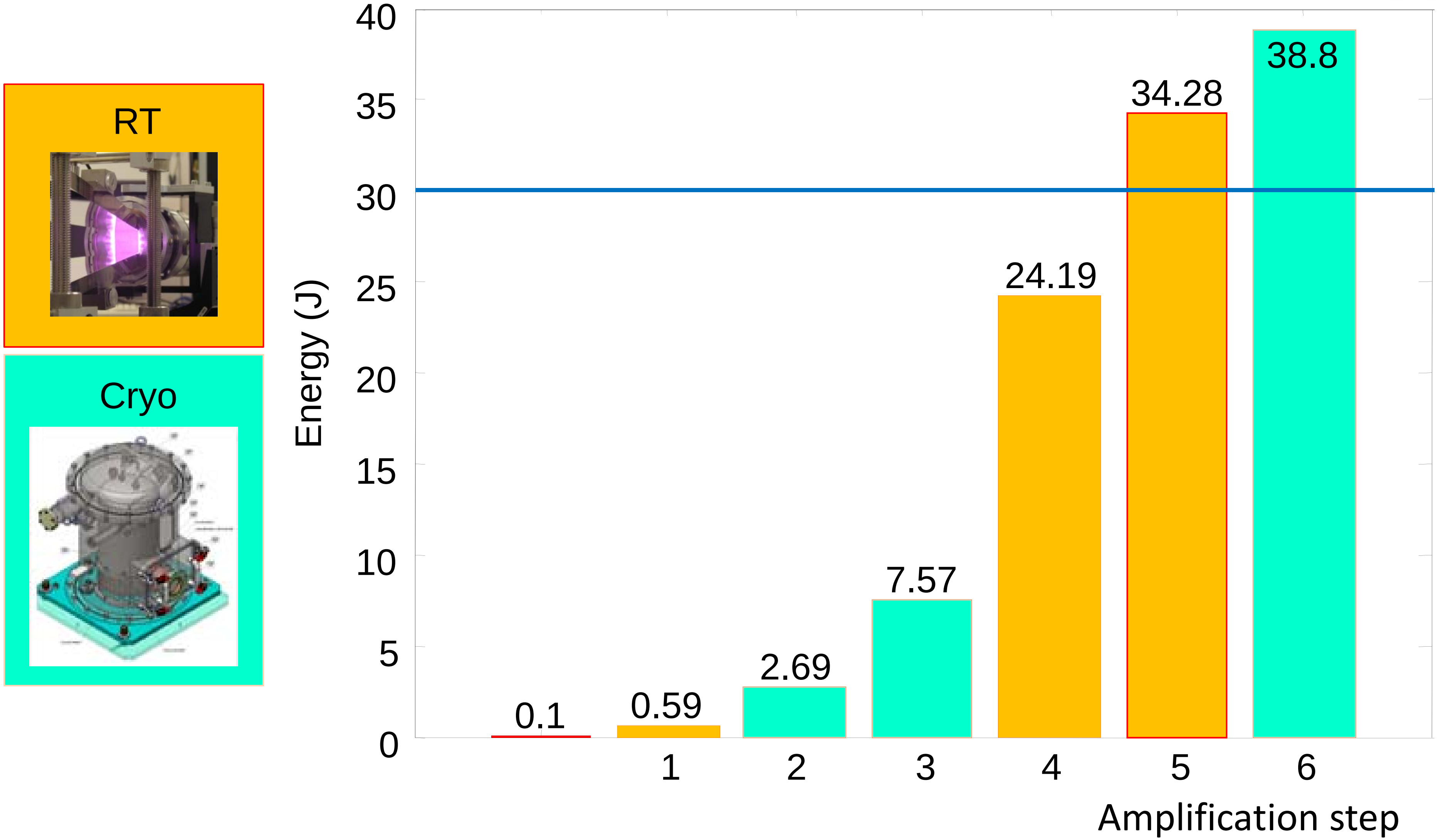
	Room Temp. Amplifier @300K	**Cryogenic Amplifier @160K**	**Factor**
Pump Absorption Cross Section [cm²]	$7.60\ 10^{-21}$	$1.30\ 10^{-20}$	2.3
Laser Emission Cross Section [cm²]	$2.40\ 10^{-20}$	$5.70\ 10^{-20}$	2.4
Pump Intensity [kW/cm²]	**16.00**	**5.50**	**0.34**
Pump Power [kW]	98.4	34.6	0.35
Stacks Number	41	18	0.44

3 passes through both amplifiers extraction scheme

6 Amplification steps



30 + Joules should be achievable



1030 nm absorption disappears at cryogenic Temperatures

Yb:YAG absorption cross-section at 300 and 175K

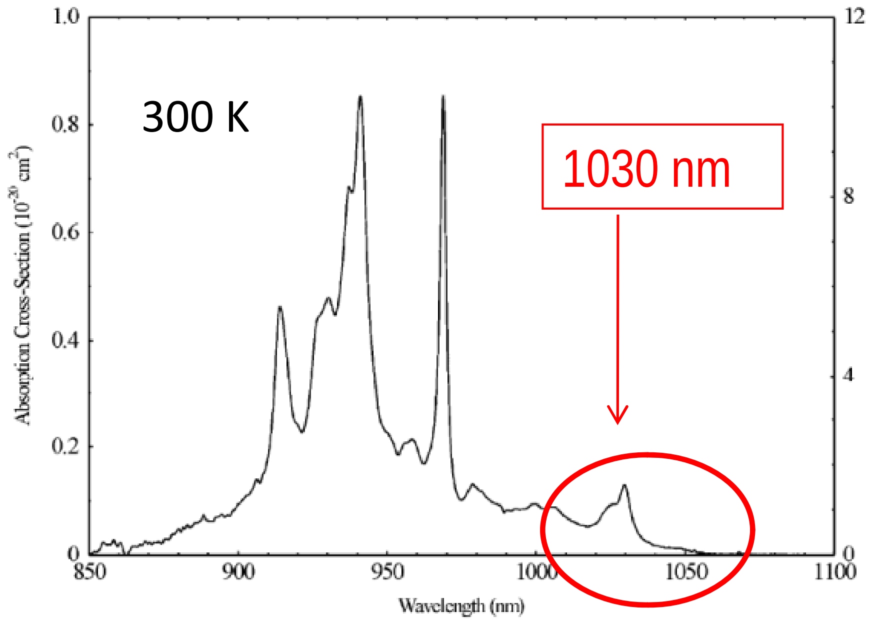


Fig. 1. Yb:YAG absorption cross section as a function of wavelength for a sample temperature of 300 K. Sample length was 0.24 mm and Yb concentration 9.8 at.%.

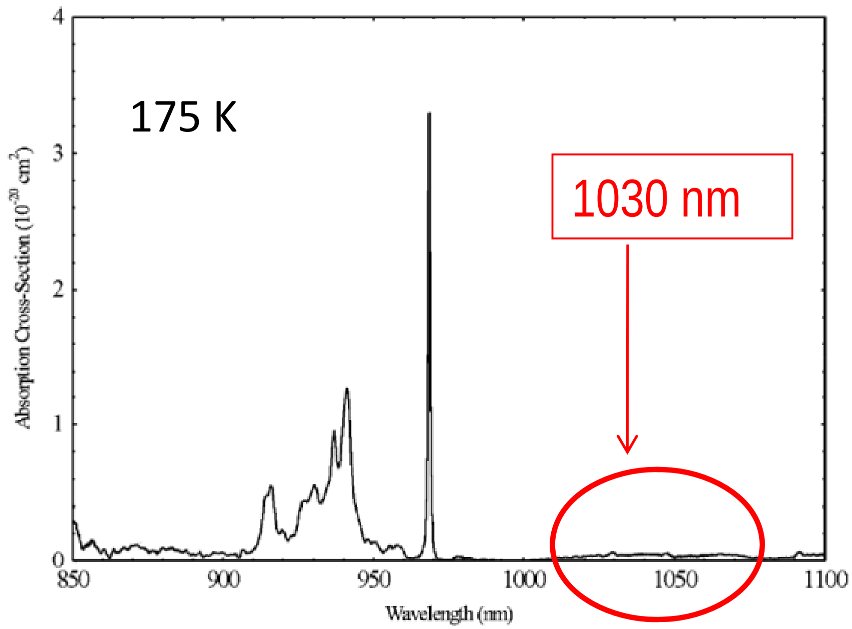
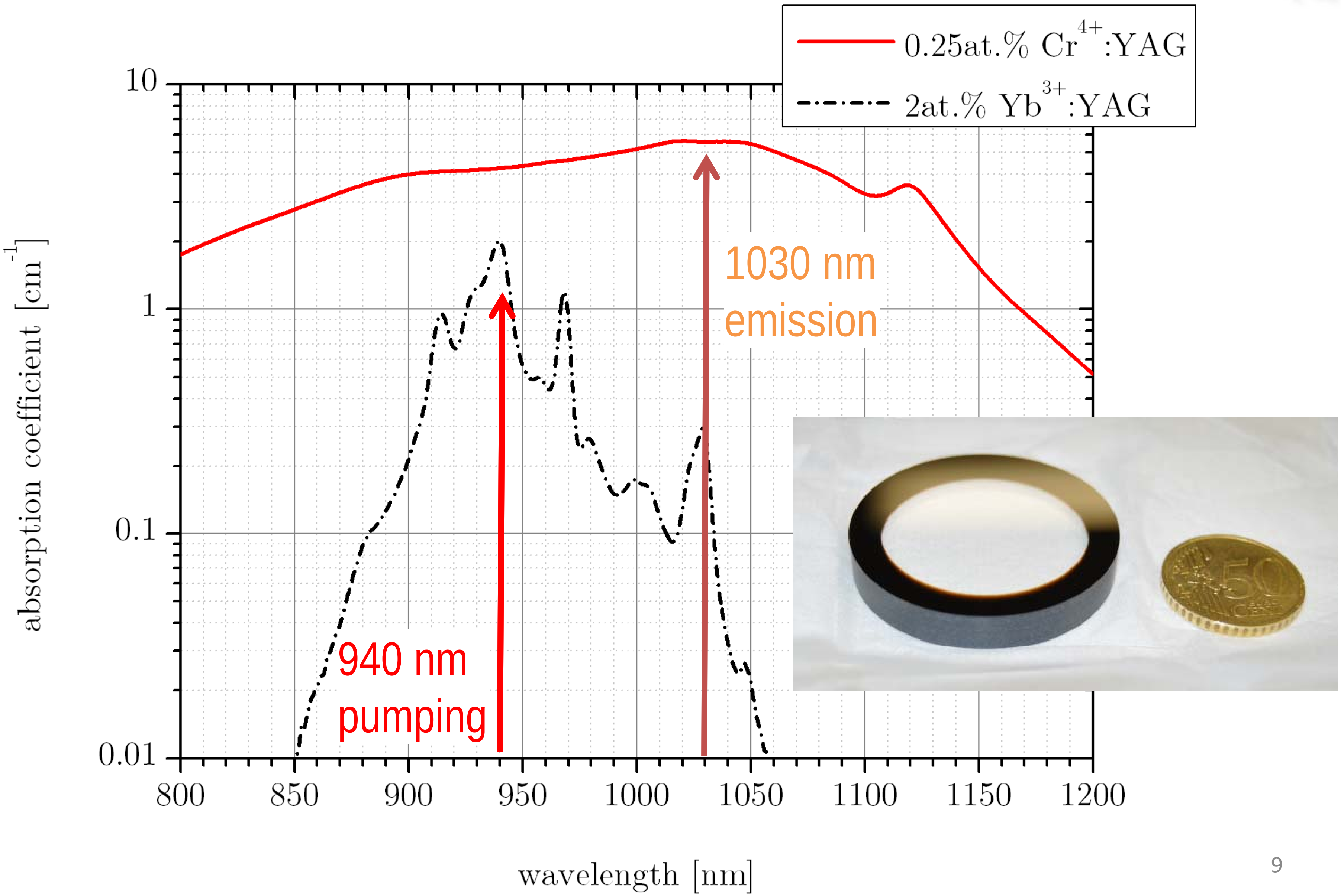


Fig. 2. Yb:YAG absorption cross section as a function of wavelength for a sample temperature of 175 K. Sample length was 0.24 mm and Yb concentration 9.8 at.%.

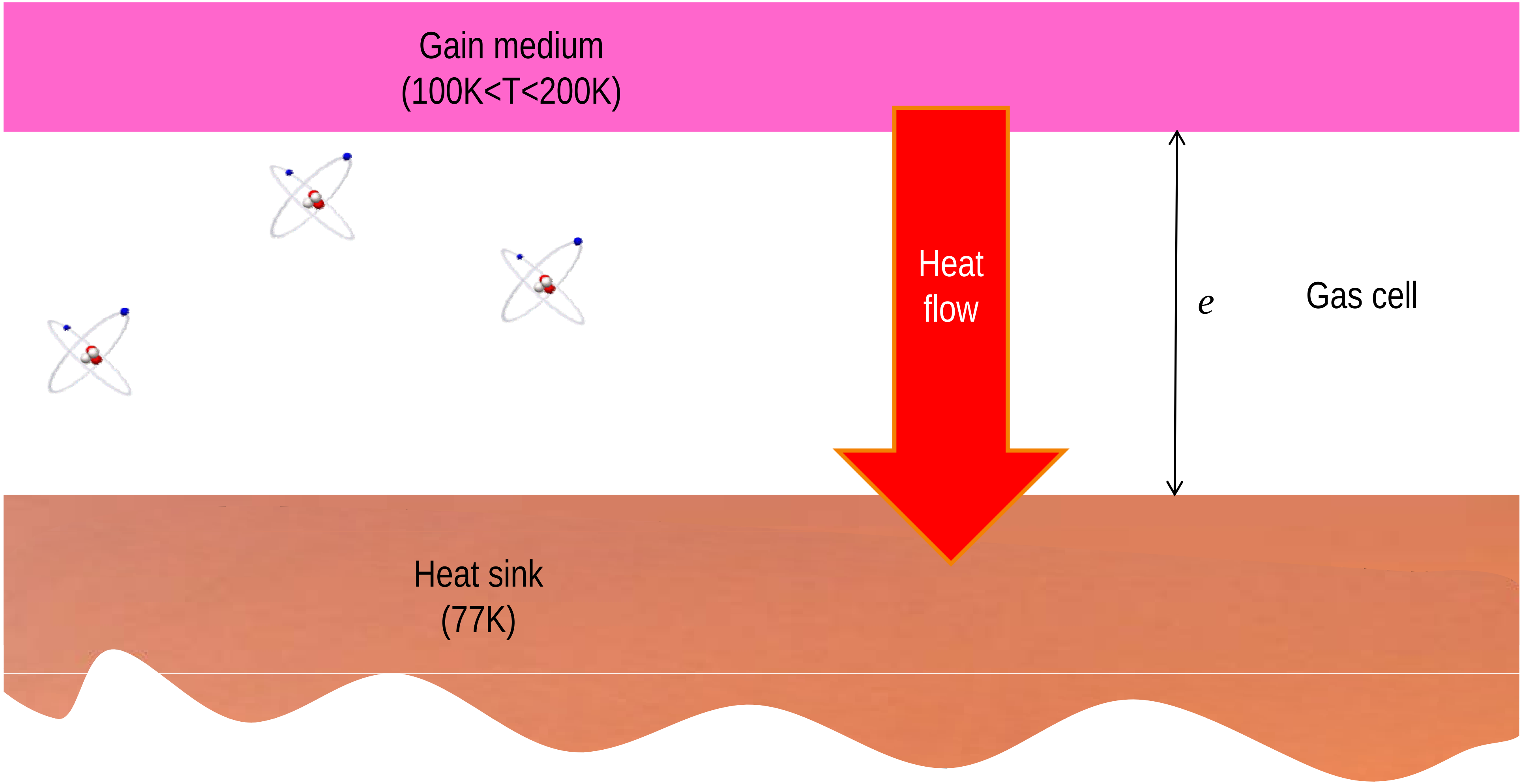
From David C. Brown et Al., "Yb:YAG Absorption at Ambient and Cryogenic Temperatures", IEEE J.of Sel. Top. Quant Elec, Vol.11, No.3, 2005

Co-sintered Cr^{4+}/Yb^{3+}:YAG ceramics already operat^{d} on Lucia



Gas cell thermal conductivity dependence

When the probability to hit another molecule becomes lower than hitting a wall, the thickness of the cell start impacting the thermal conductivity

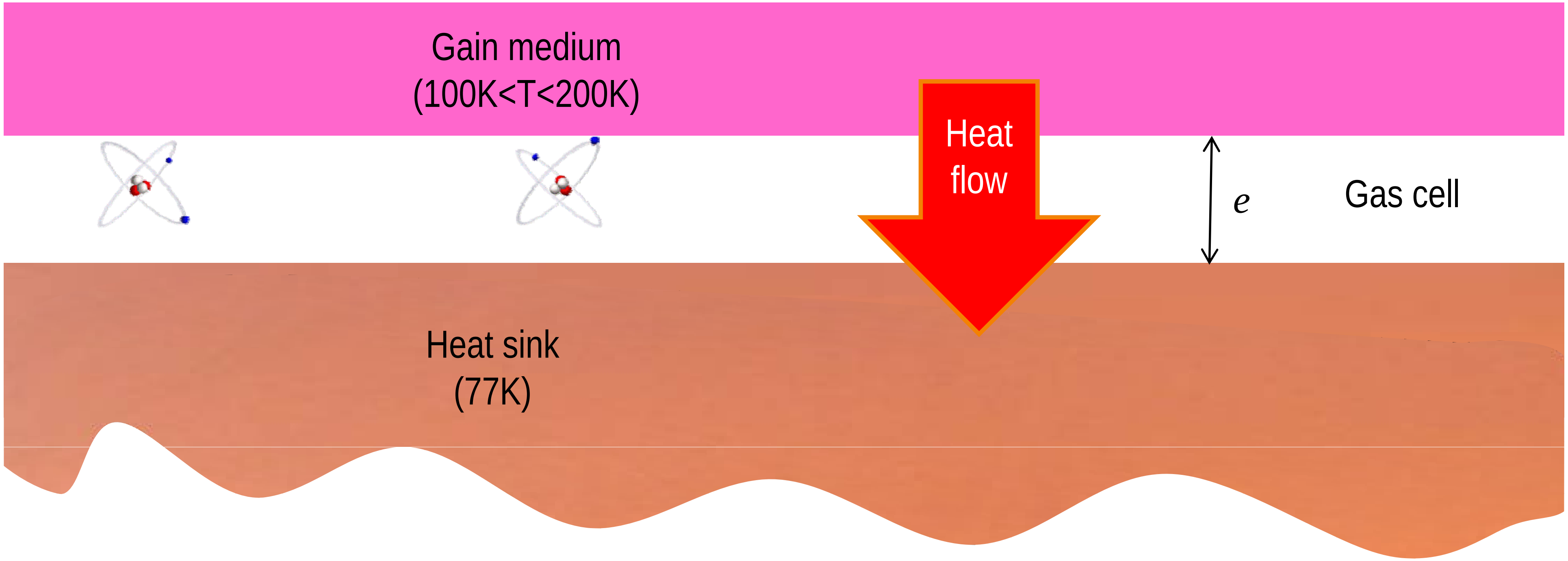


Gas cell thermal conductivity dependence

When the pressure p and/or the gap e become low enough the thermal conductivity can be described as follows :

$$k(T) = k_{bulk}(T) \cdot \left(1 + \frac{8}{3} \cdot \frac{k_{bulk}(T) \cdot T}{e \cdot p \cdot \sqrt{3 \cdot R \cdot T}} \cdot \left(\frac{1}{\alpha_1} + \frac{1}{\alpha_2} - 1\right)\right)^{-1}$$

α_1 and α_2 are the thermal accommodation factors and R is the specific gas constant for Helium

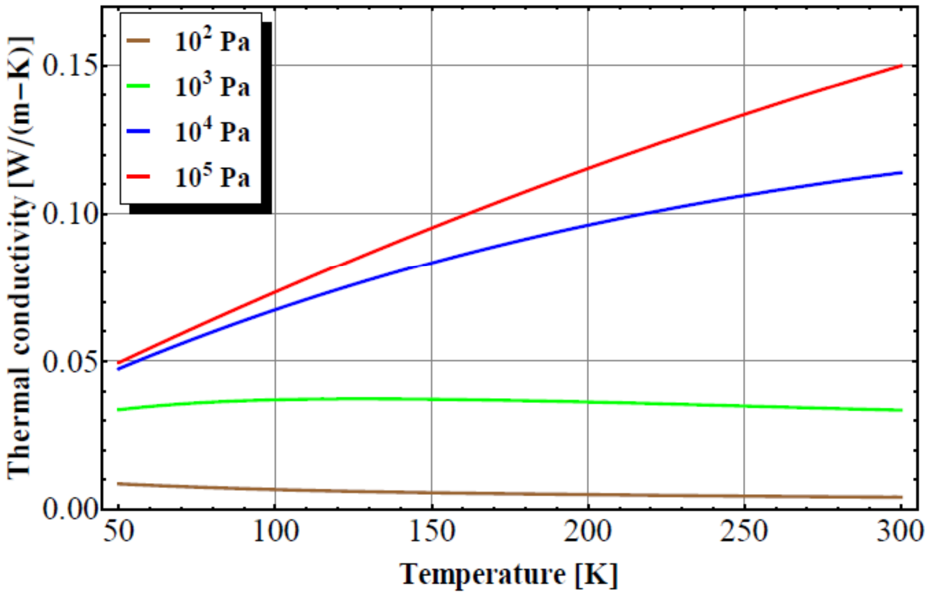


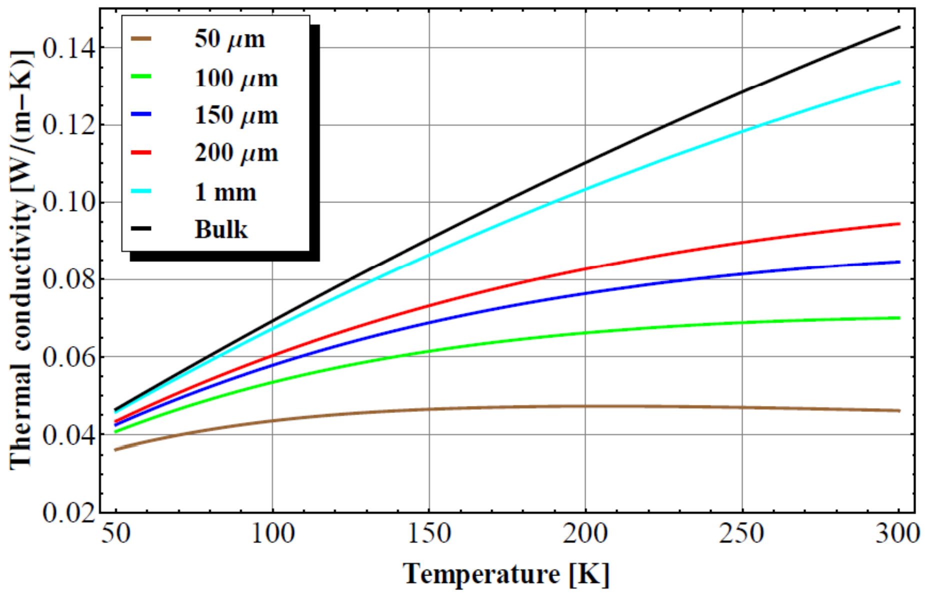
Helium thermal conductivity dependence

$$k(T) = k_{bulk}(T) \cdot \left(1 + \frac{8}{3} \cdot \frac{k_{bulk}(T) \cdot T}{e \cdot p \cdot \sqrt{3 \cdot R \cdot T}} \cdot \left(\frac{1}{\alpha_1} + \frac{1}{\alpha_2} - 1\right)\right)^{-1}$$

Fixed helium cell gap = 100µm

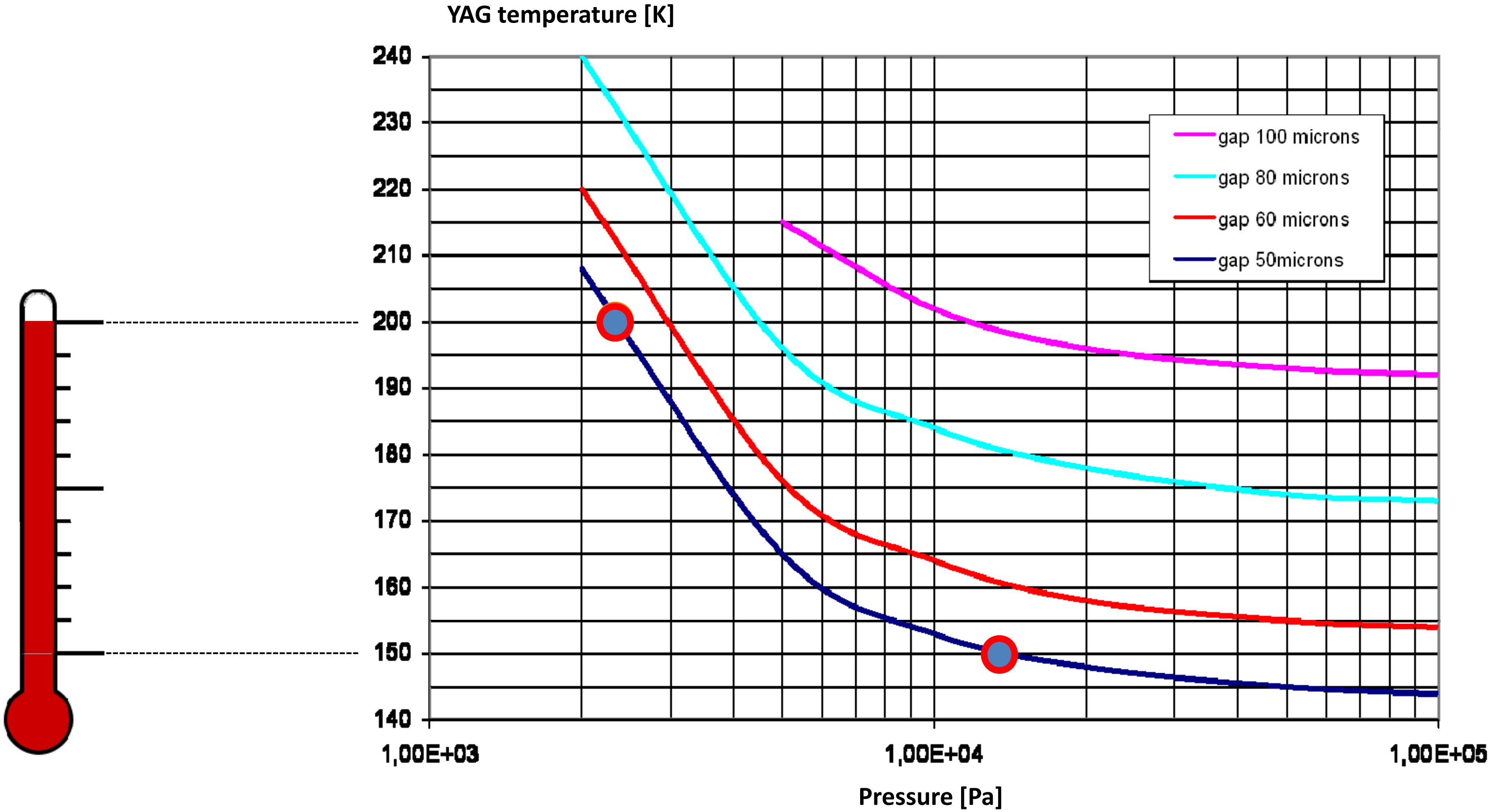
Fixed helium pressure = 10^5 = 1 Atm



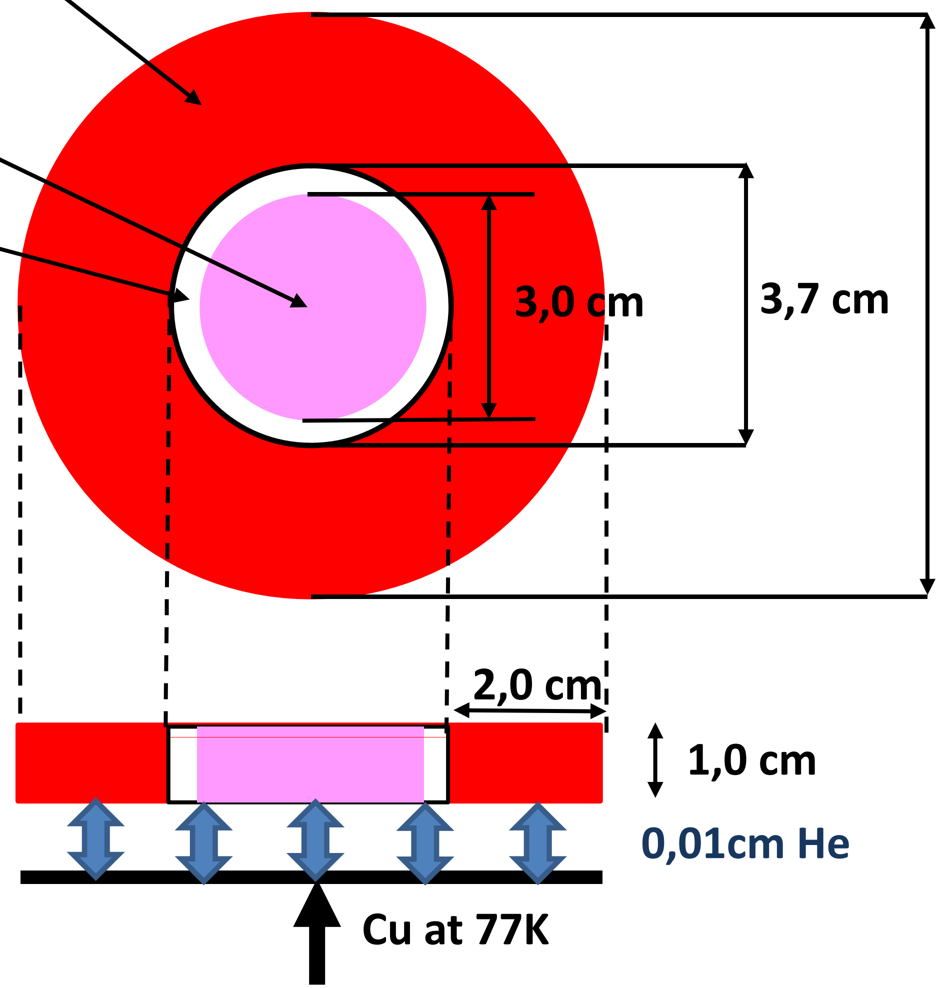


YAG Temperature fine tuning with Helium pressure

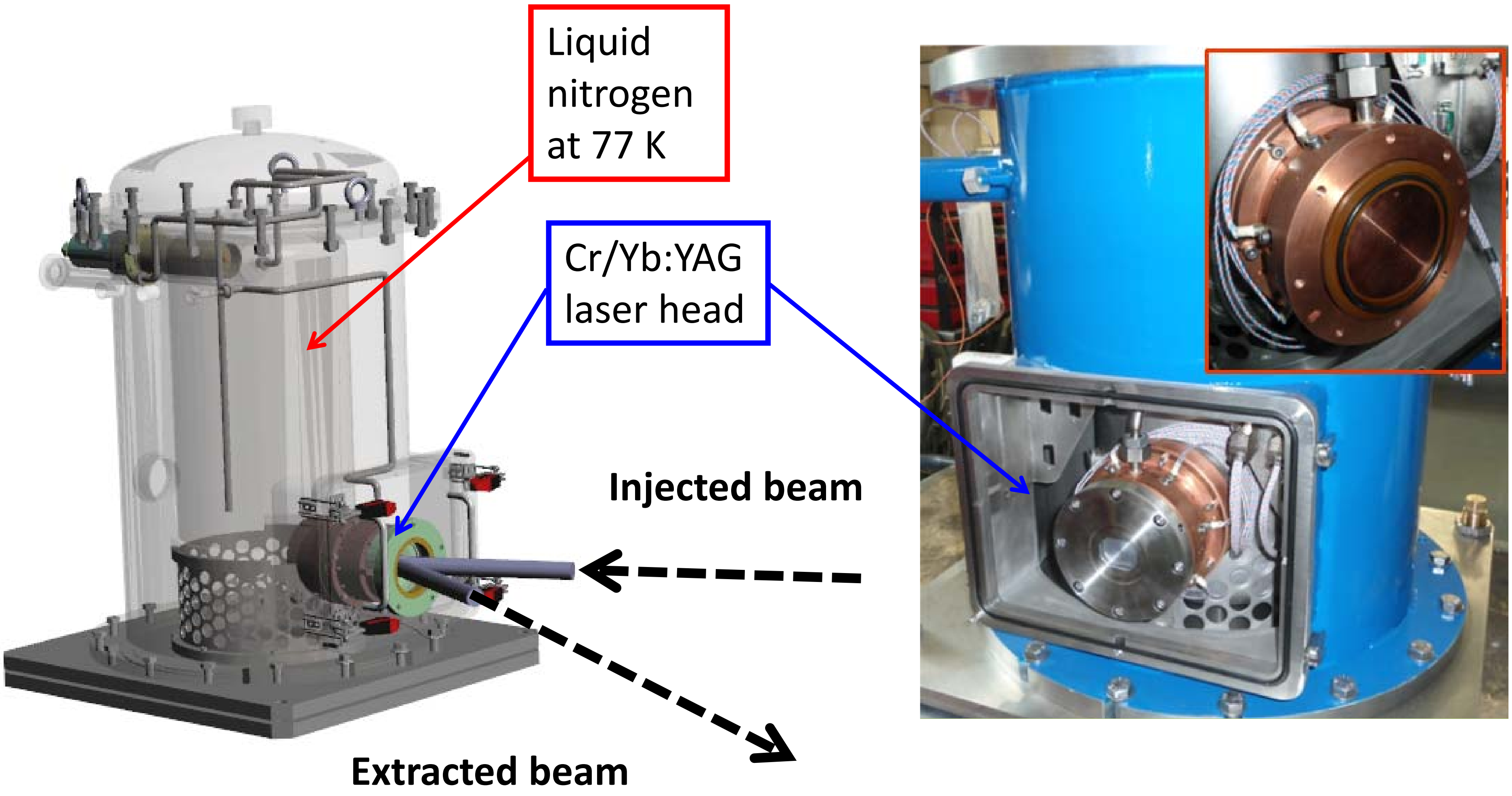
YAG temperature versus Helium pressure for 4 different gap thicknesses when the heat flux to be removed equals 10 W/cm².



Cr^{4+}/Yb^{3+}:YAG cryogenic amplifier disk structure

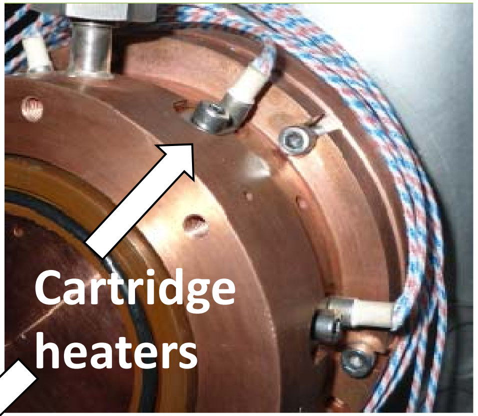


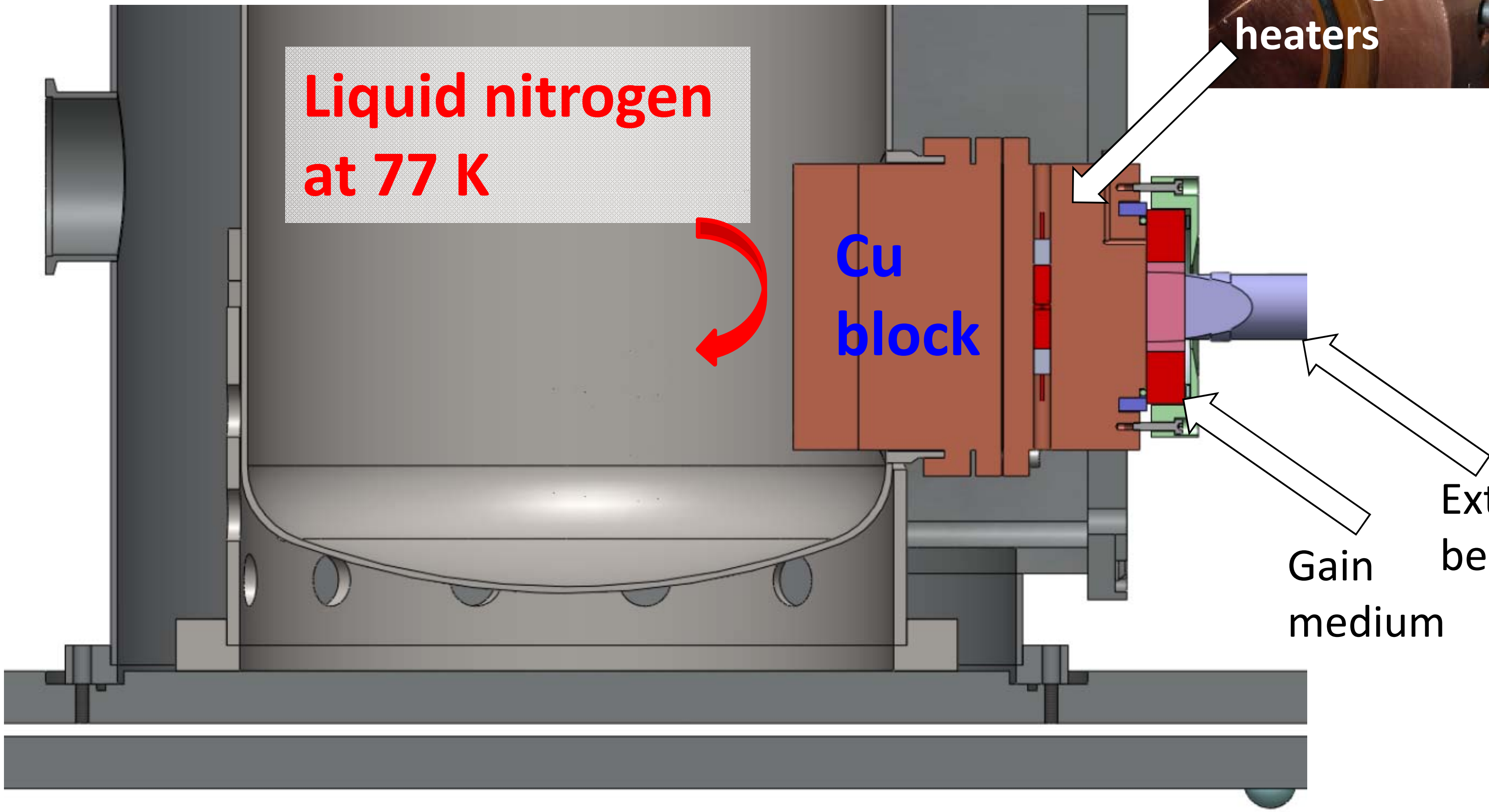
Cryostat


Liquid nitrogen at 77 K
Cr/Yb:YAG laser head
Injected beam
Extracted beam

Cooling head for cryogenic LUCIA disk

Copper block electrical heating :
- offers a new degree of freedom to adjust the YAG temperature
- allows to thermalize the YAG at the target temperature before starting pumping (gain would be to high at 77K ➔ ASE issues…)



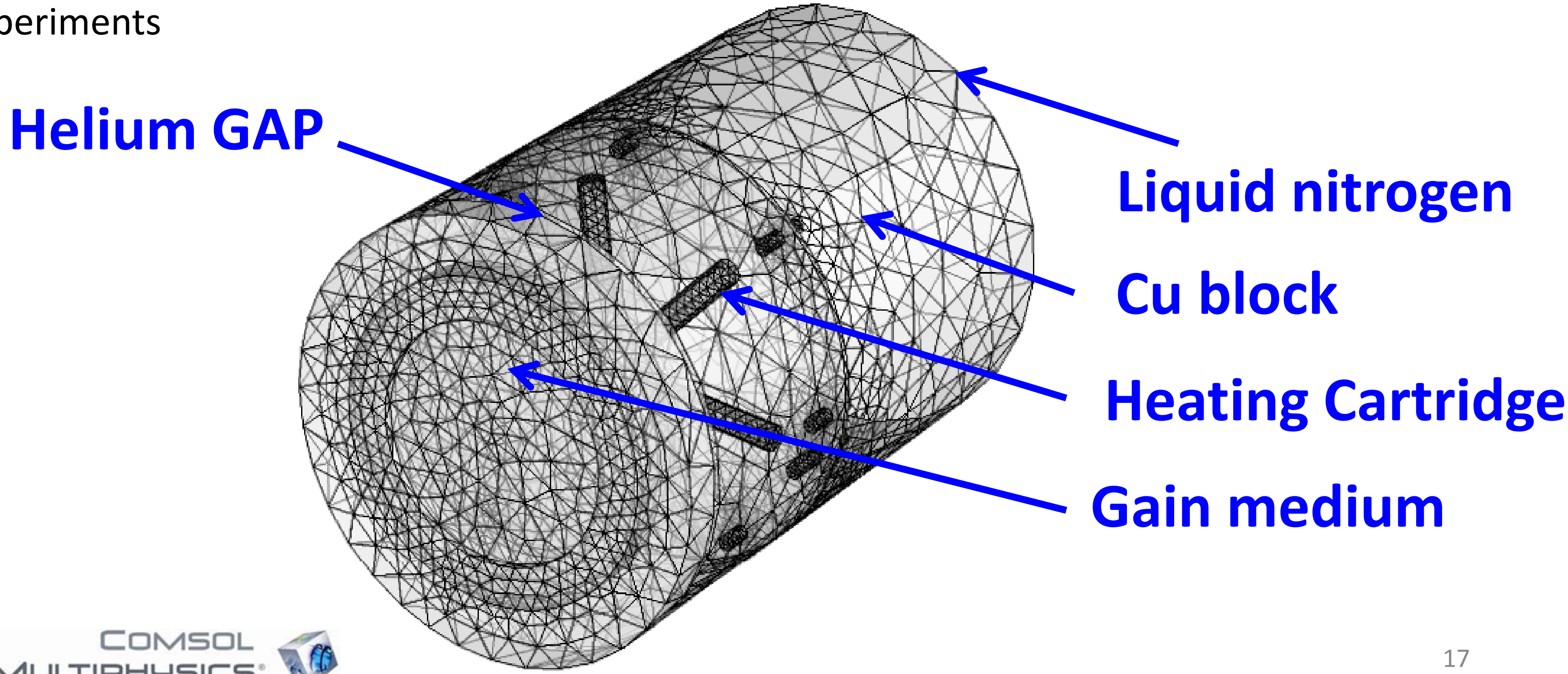


Cryogenic head FEM modeling

Laser head is modeled by Comsol Multiphysics Finite Element software which allow to:

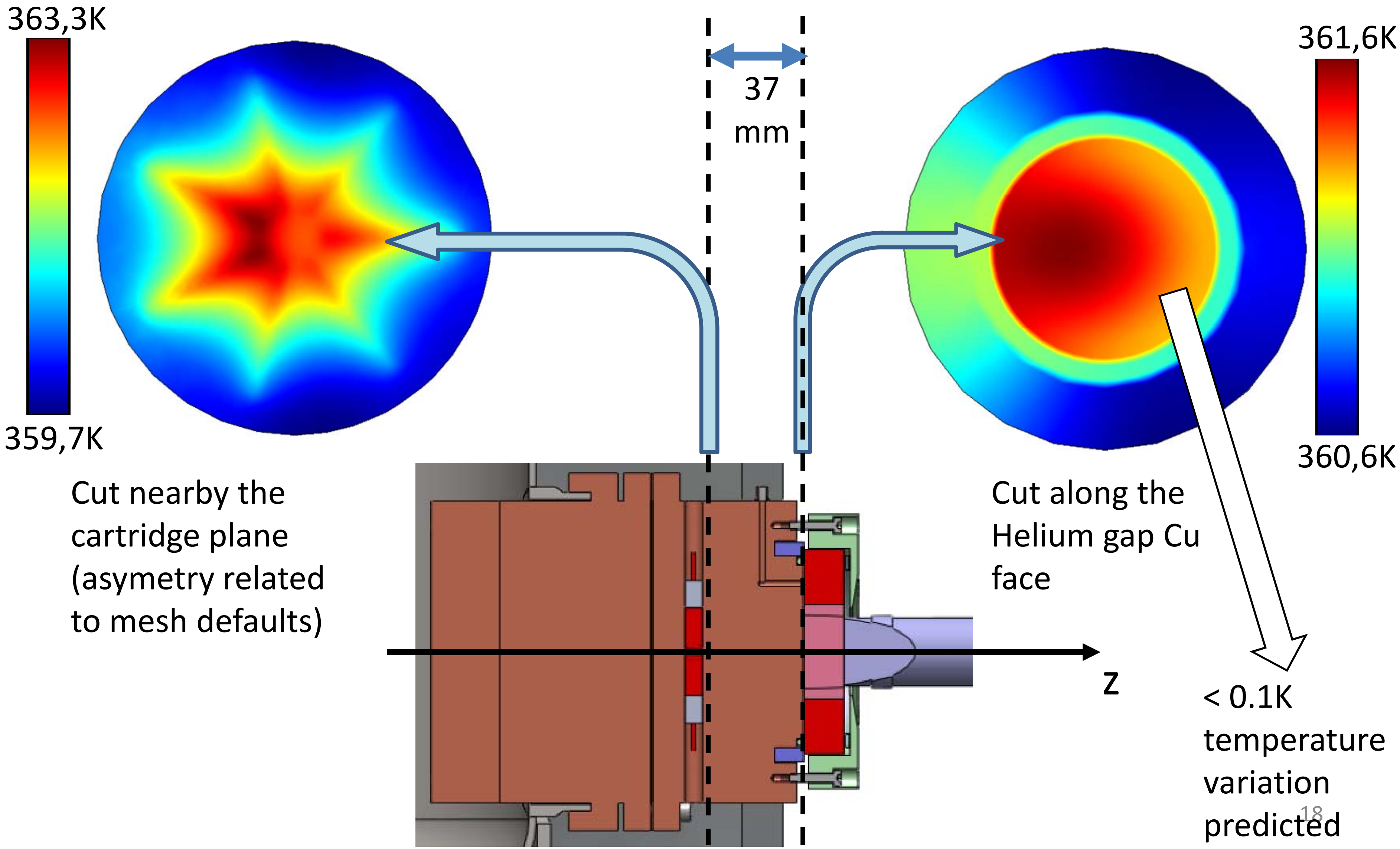
- define the geometry and the mesh
- specify the heat transfer $$div(k\overrightarrow{gradT}) + Q = \rho C_P \frac{\partial T}{\partial t}$$
- solve stationary and transient studies and visualize the results

The cooling capacity and the heat distribution in the gain medium will be benchmark with experiments



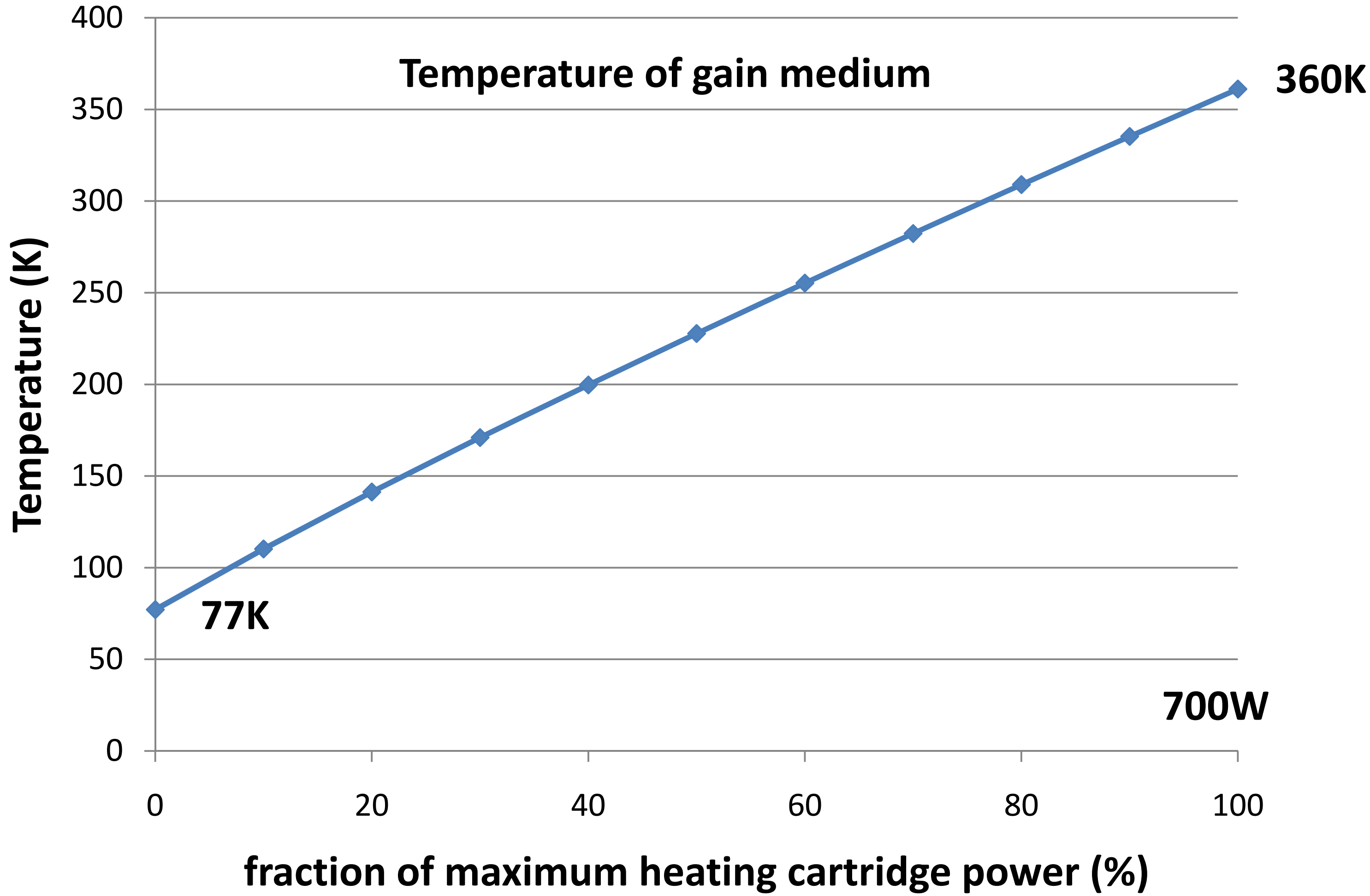
First study dedicated to temperature distribution analysis

Temperature distribution resulting from heating cartridges is uniform at Cu/He gap interface:



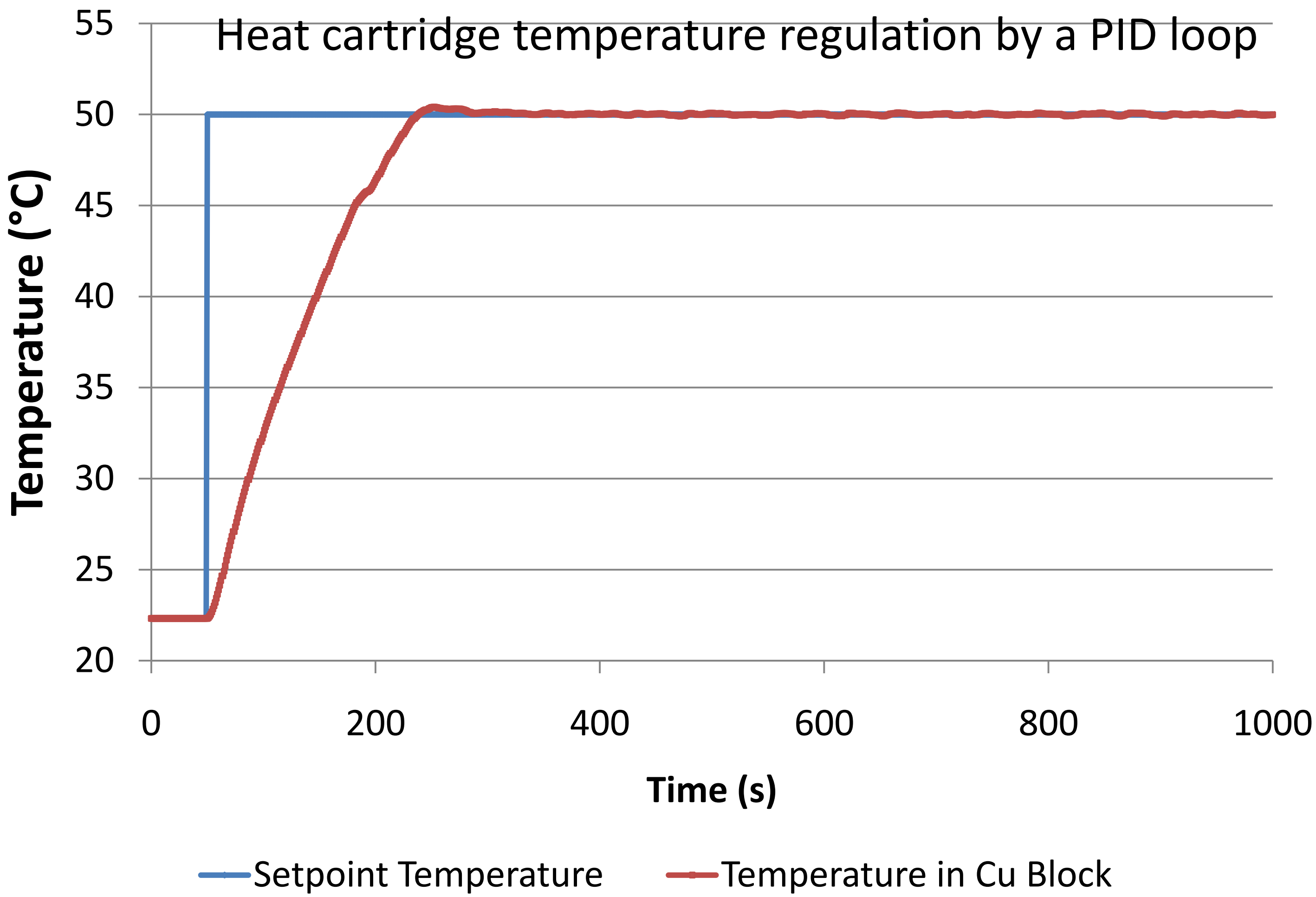
Gain medium temperature adjustment

Tuning the temperature in the gain medium can be achieved from 77K to 360K by adjusting the heating cartridge power



Temperature regulation

Temperature in the Cu Block can be finely adjust by a PID loop regulation



Helium gap thermal conductivity measurement

Heat cartridges generate a periodic heat variation :

- Damped variation thermal oscillation along the laser head optical axis (Oz)
- The damping and the delay of the oscillations depend of thermal properties of materials
- Different initial temperatures (T) and He pressure (P) give the T & P dependence of *He* gap thermal conductivity *k*

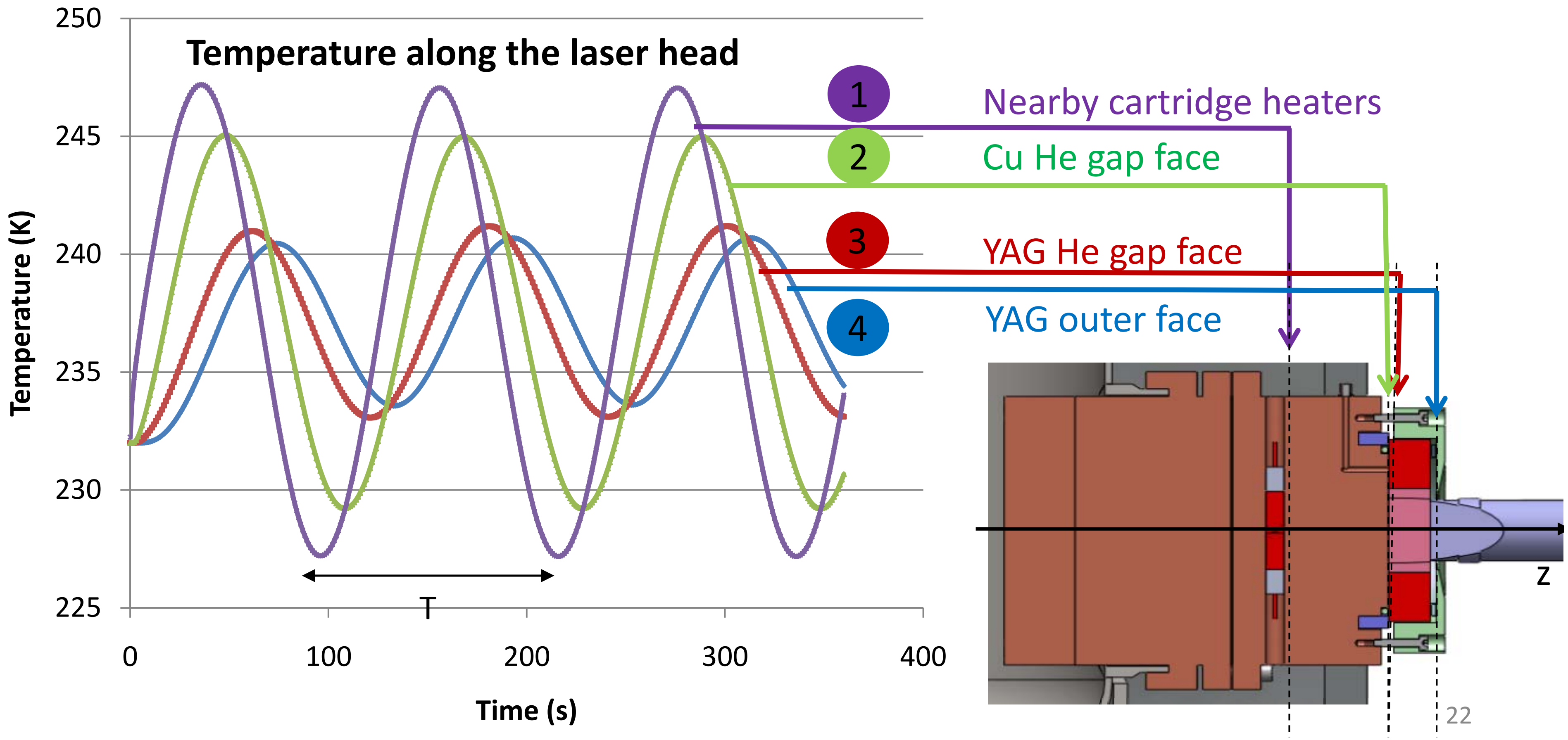
$$T(z,t) = T_0 + \Delta T e^{-z/\lambda} \cos(\omega t - z/\lambda)$$

$$with\ \lambda = \frac{\pi \rho C_P}{T k}$$

ρ: *density* $kg.m^{-3}$
C_P: heat capacity $J.kg^{-1}.K^{-1}$
k: thermal conductivity $W.m^{-1}.K^{-1}$
T: period of oscillation s

Helium gap thermal conductivity measurement

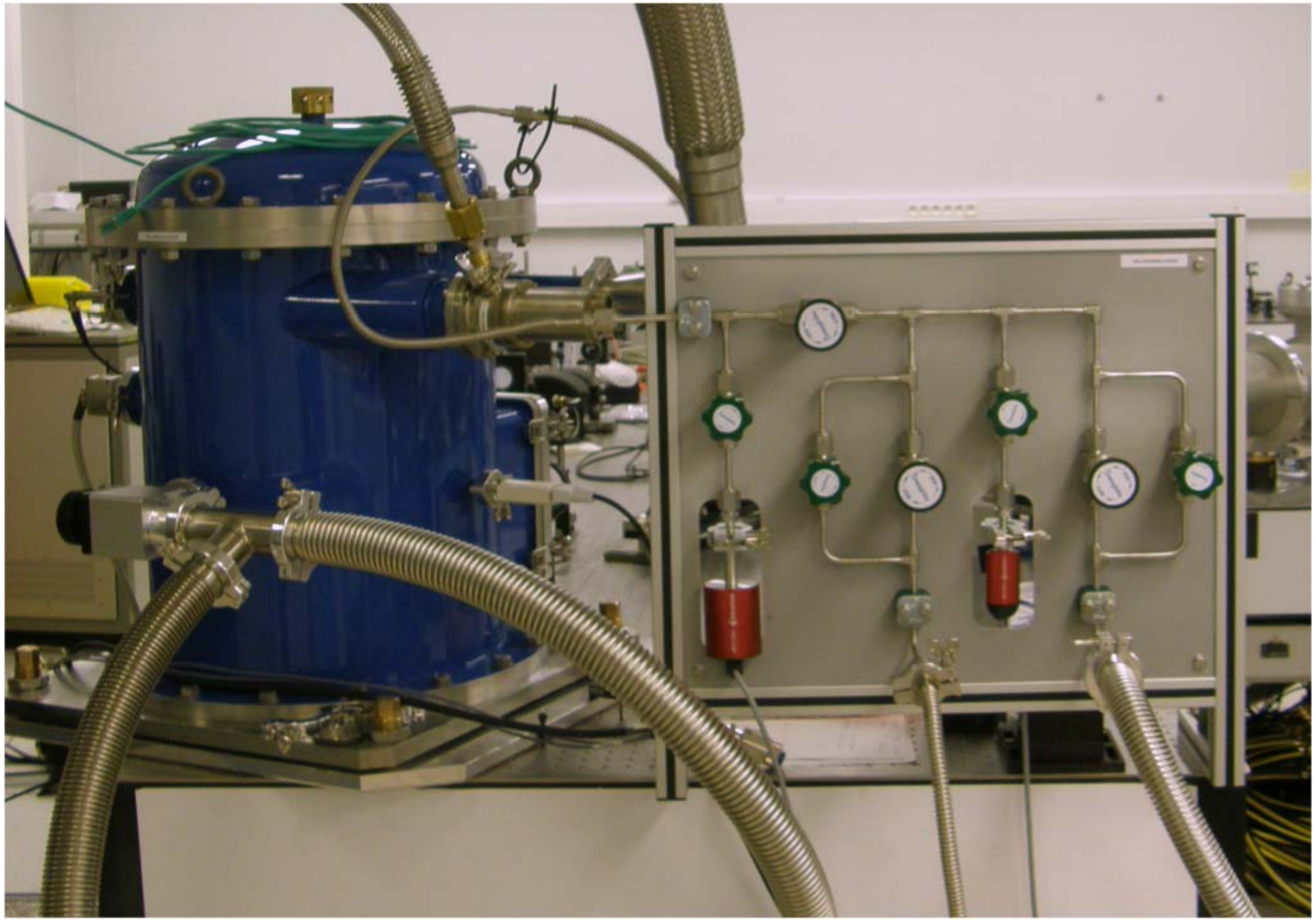
$$T(z,t) = T0 + \Delta T e^{-z/\lambda} \cos(\omega t - z/\lambda)$$



Helium circuit regulation

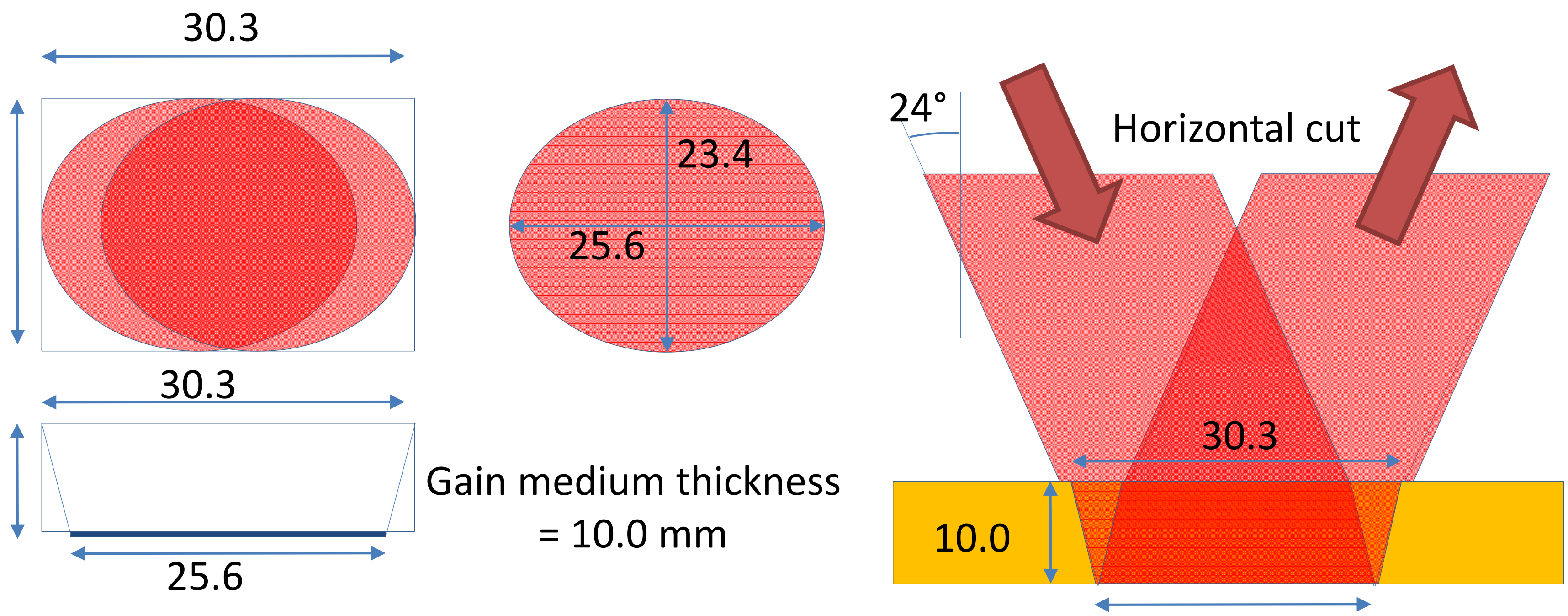
Helium pressure adjustment within a 10^3 Pa to 10^5 Pa range will be achieved with :

- a 10^2 Pa accuracy
- a specifically designed helium circuit.



Pumping source requirements

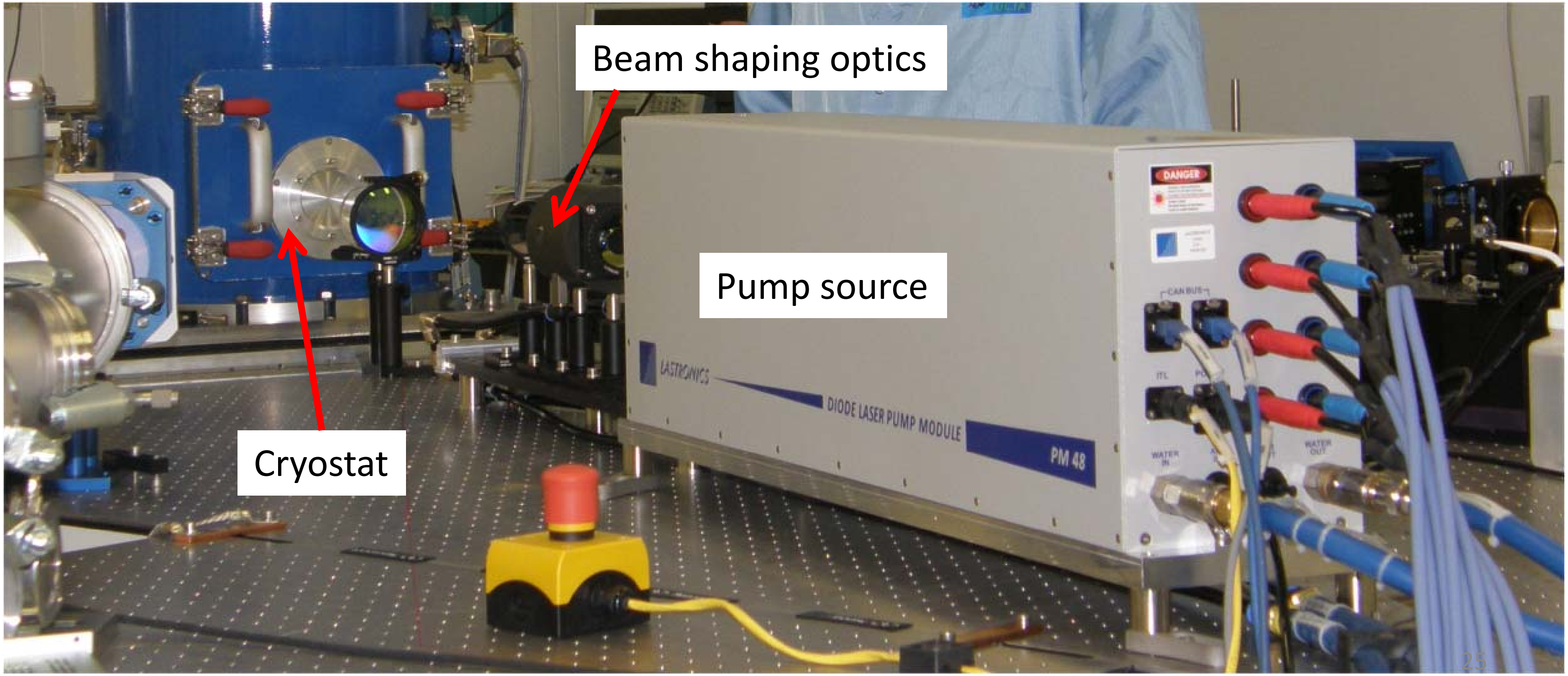
Considering Lucia active mirror architecture, the pumping energy distribution is elliptically shaped



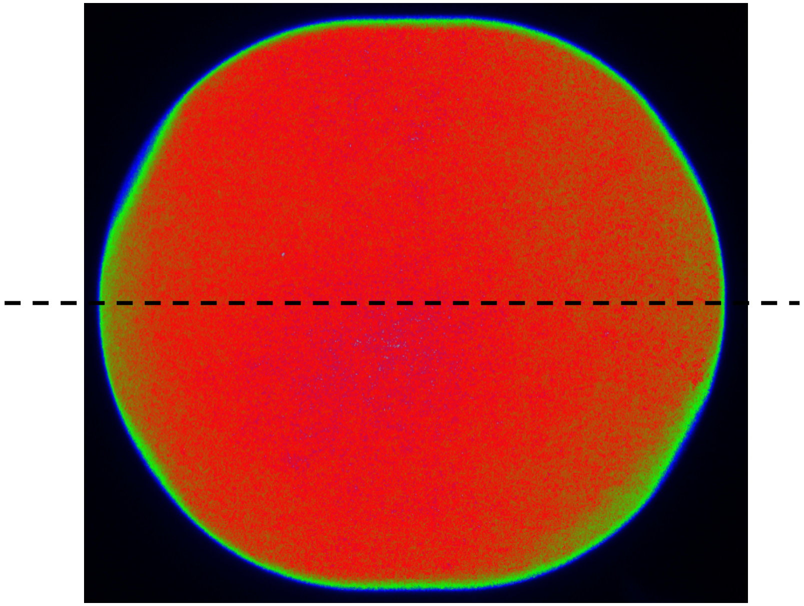
- Pump duration 1ms
- Pump wavelength 939nm
- Peak intensity 5,5 kW/cm^2, pump surface 6,1cm^2

Cryogenic head pump source

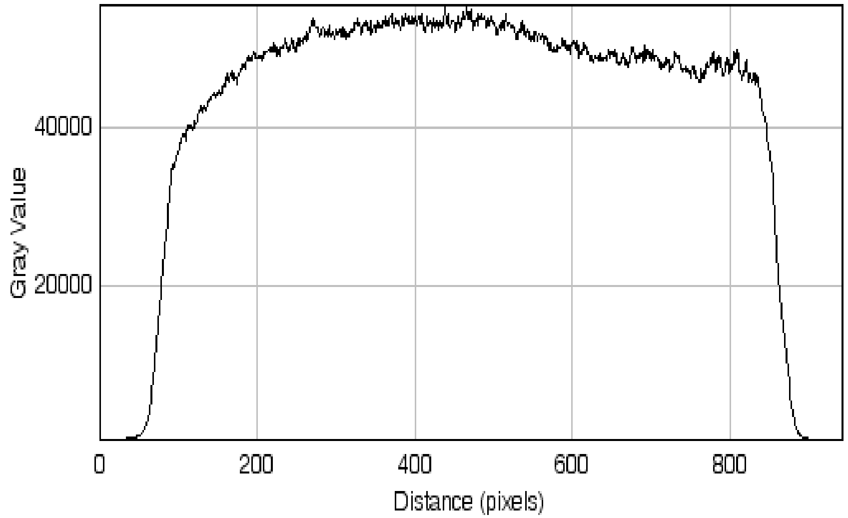
Our Lastronics pump source was delivered last week.
It relies on 18 eight bars stacks emitting 2.4 kW peak power each. 33 kW are delivered on target with a 77% efficiency.



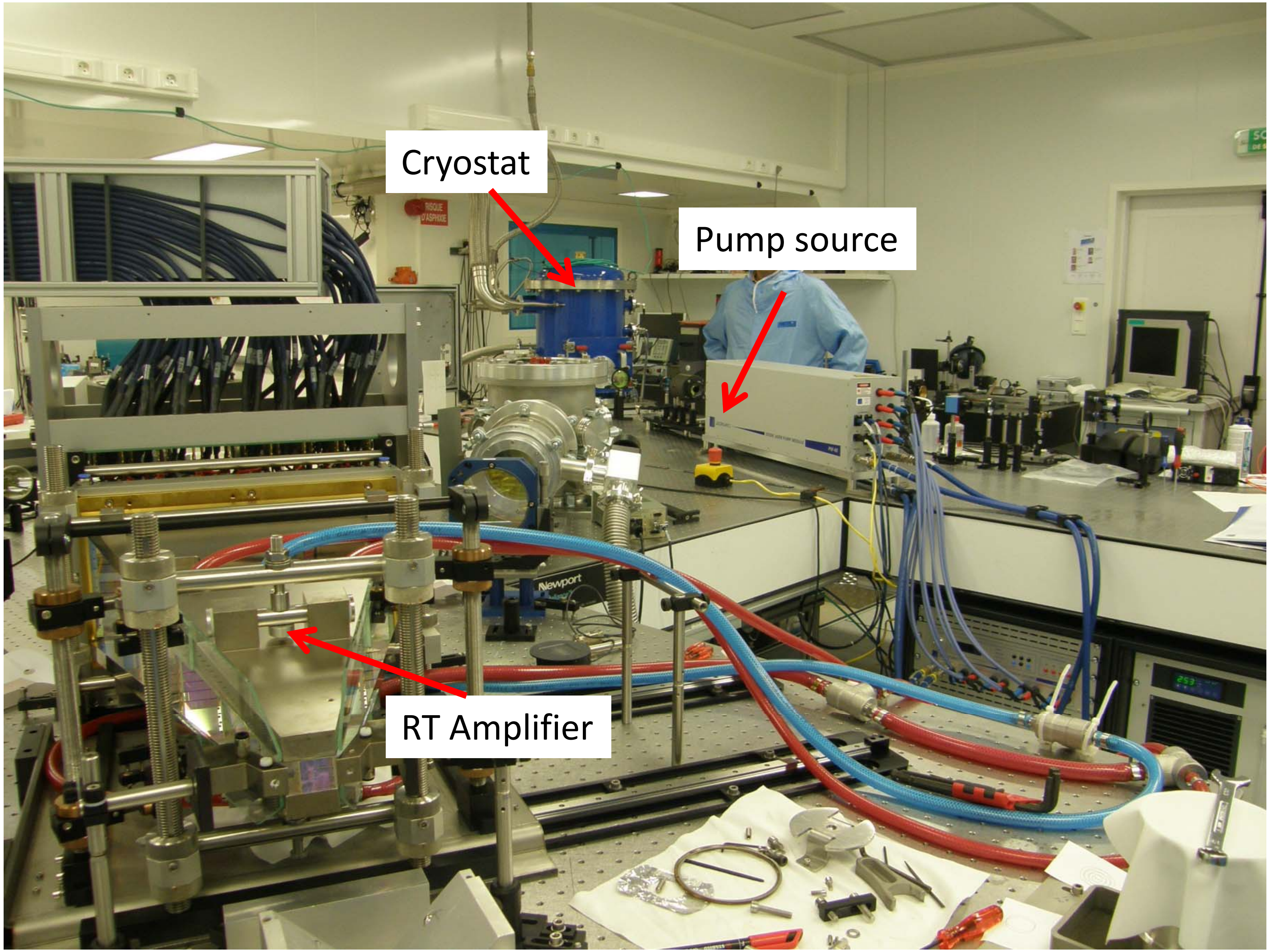
Beam profile



Horizontal profile



LUCIA overview with the cryogenic amplifier setup



Summary and outlook

- With the RT amplifier, 14J@2Hz was achieved
- To reach higher energy, we choose to implement a second amplifier operating at cryogenic temperature
- We need less pump brightness, co-sintered Cr^{4+}/Yb^{3+}:YAG ceramics
- We choose to rely on an innovative approach for thermal management

- The cryostat was delivered 2 months ago and only preliminary tests has been achieved
- Pump source was delivered last week
- The qualification will start now by studying the helium gas thermal conductivity
- Next we will carry on by measuring the temperature gain medium as a function of the He gap pressure with or without pump light
- Therefore, I hope I will show you good experimental results during the next workshop

Thank you for your attention