HiPER

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MO9

Laser Concepts for a Rep-Rated Multi-kJ ICF-Driver of the HiPER Facility

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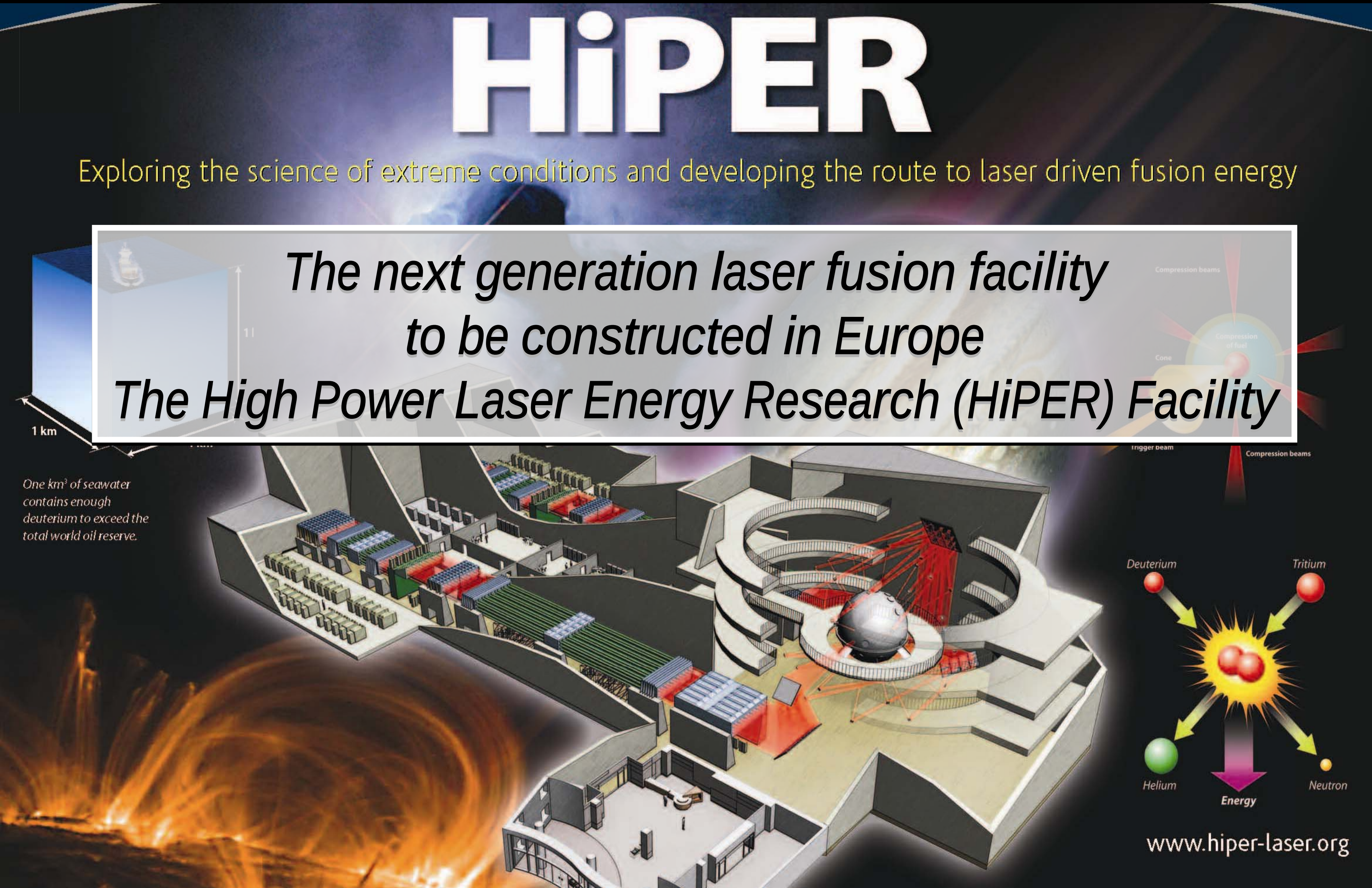
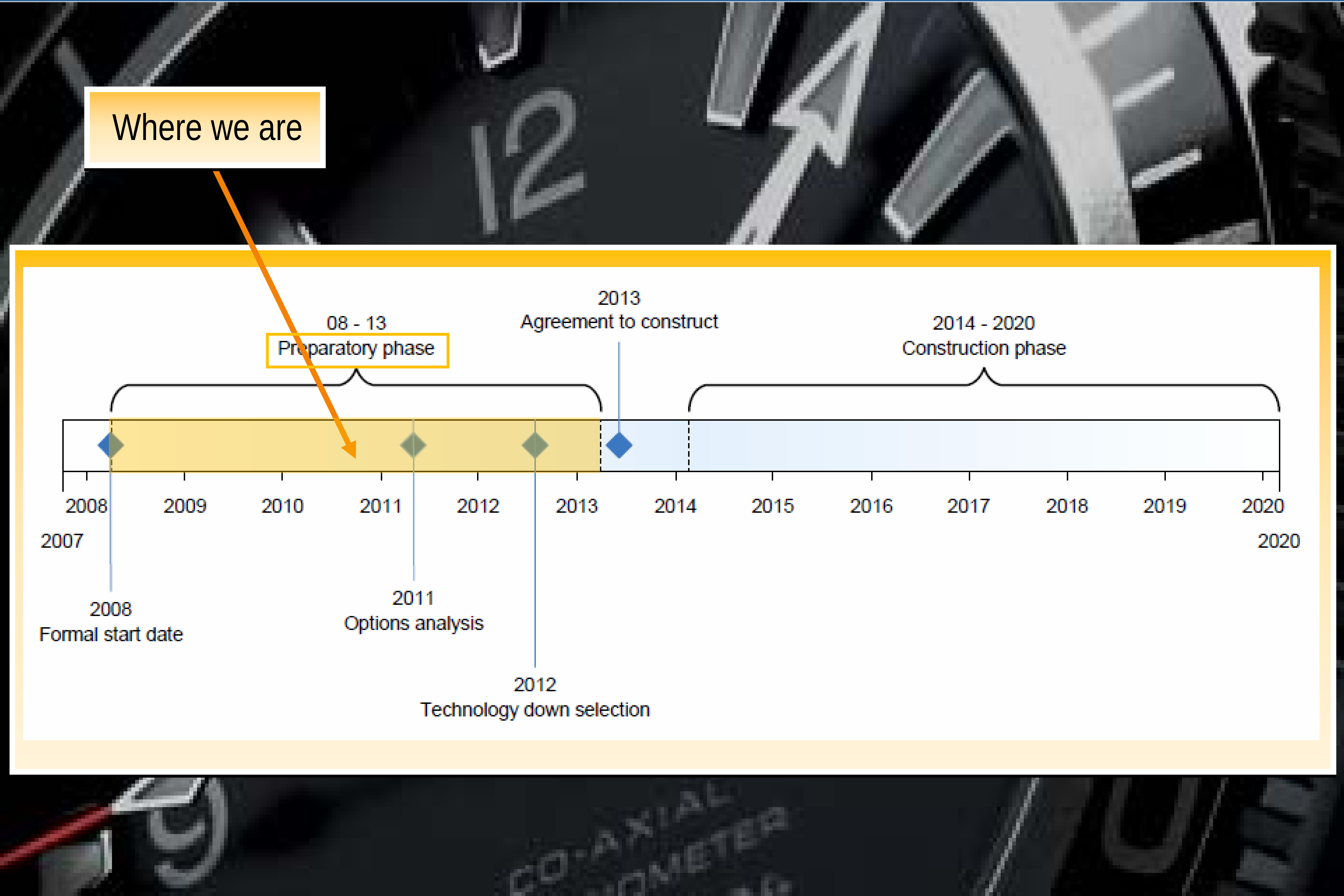
The next generation laser fusion facility to be constructed in Europe
The High Power Laser Energy Research (HiPER) Facility

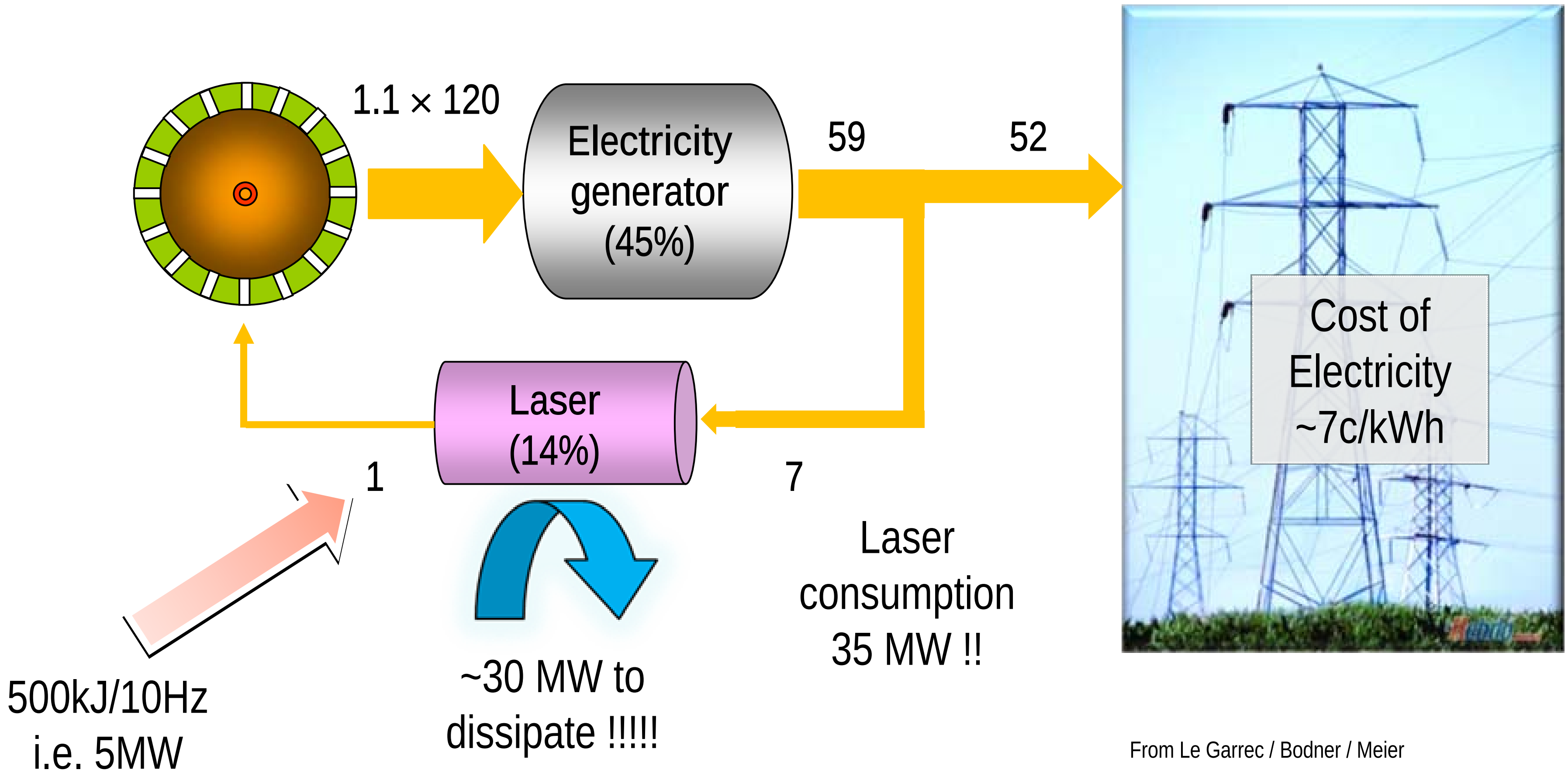


HiPER time line



Driver has to be efficient and rep-rated

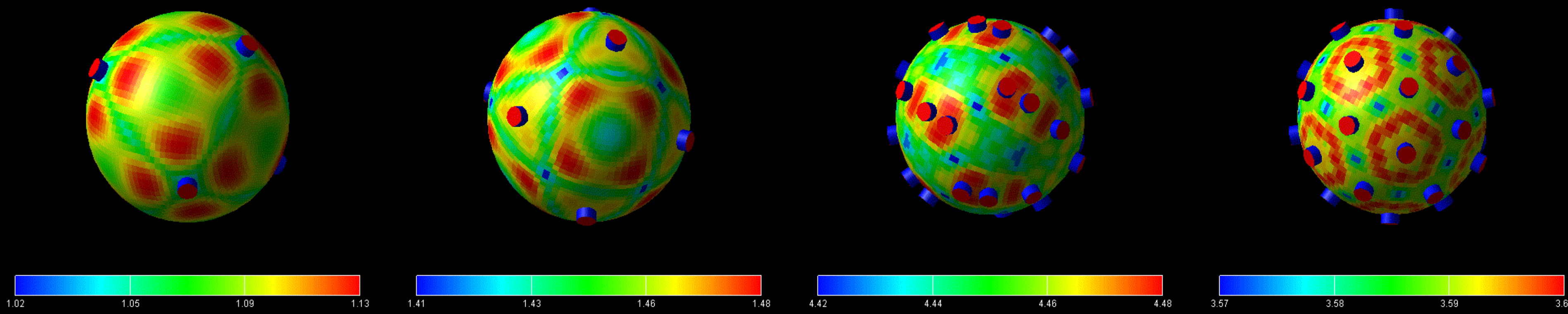
Laser driver for IFE needs to be efficient (ideally, at least 10% - 15%)
...and operate at a close to 10 Hz repetition rate



From Le Garrec / Bodner / Meier

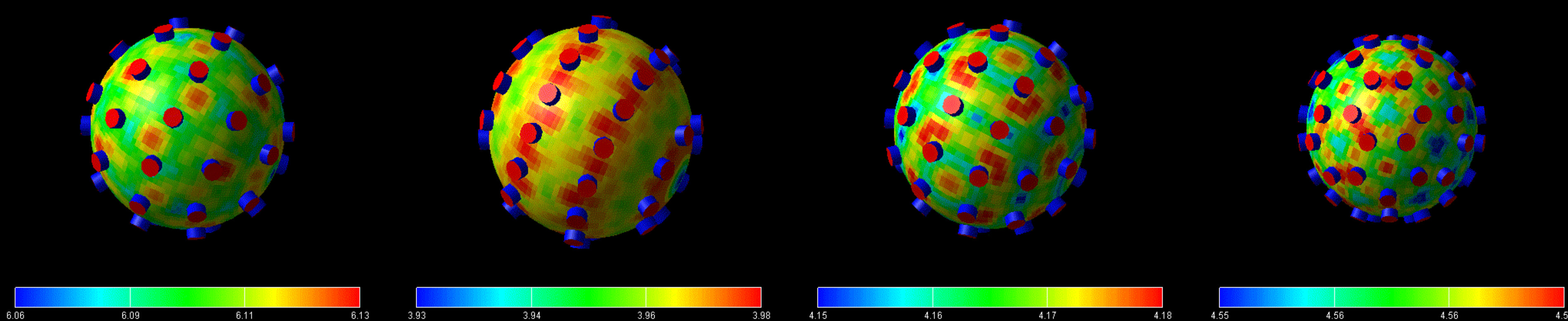
~10kJ of 1ω light needed per irradiation spot

In driving the compression phase of the capsule, symmetry is a key aspect.



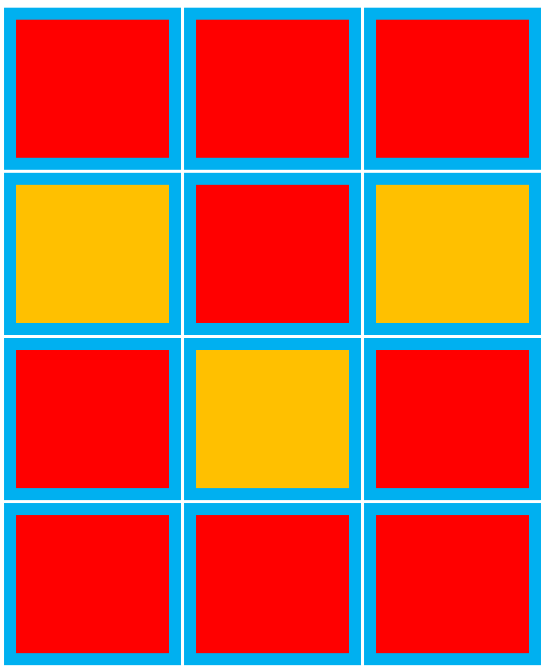
250 kJ in 48 beams (UV) appears to be optimum

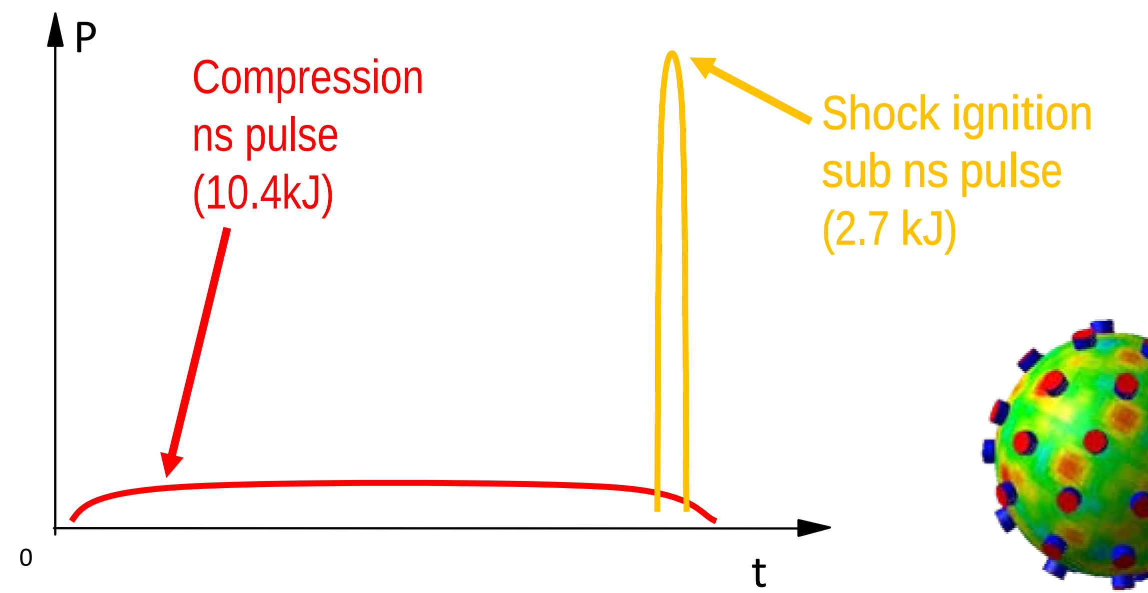
Each “spot” therefore needs ~10 kJ of fundamental light



Typical beam distribution

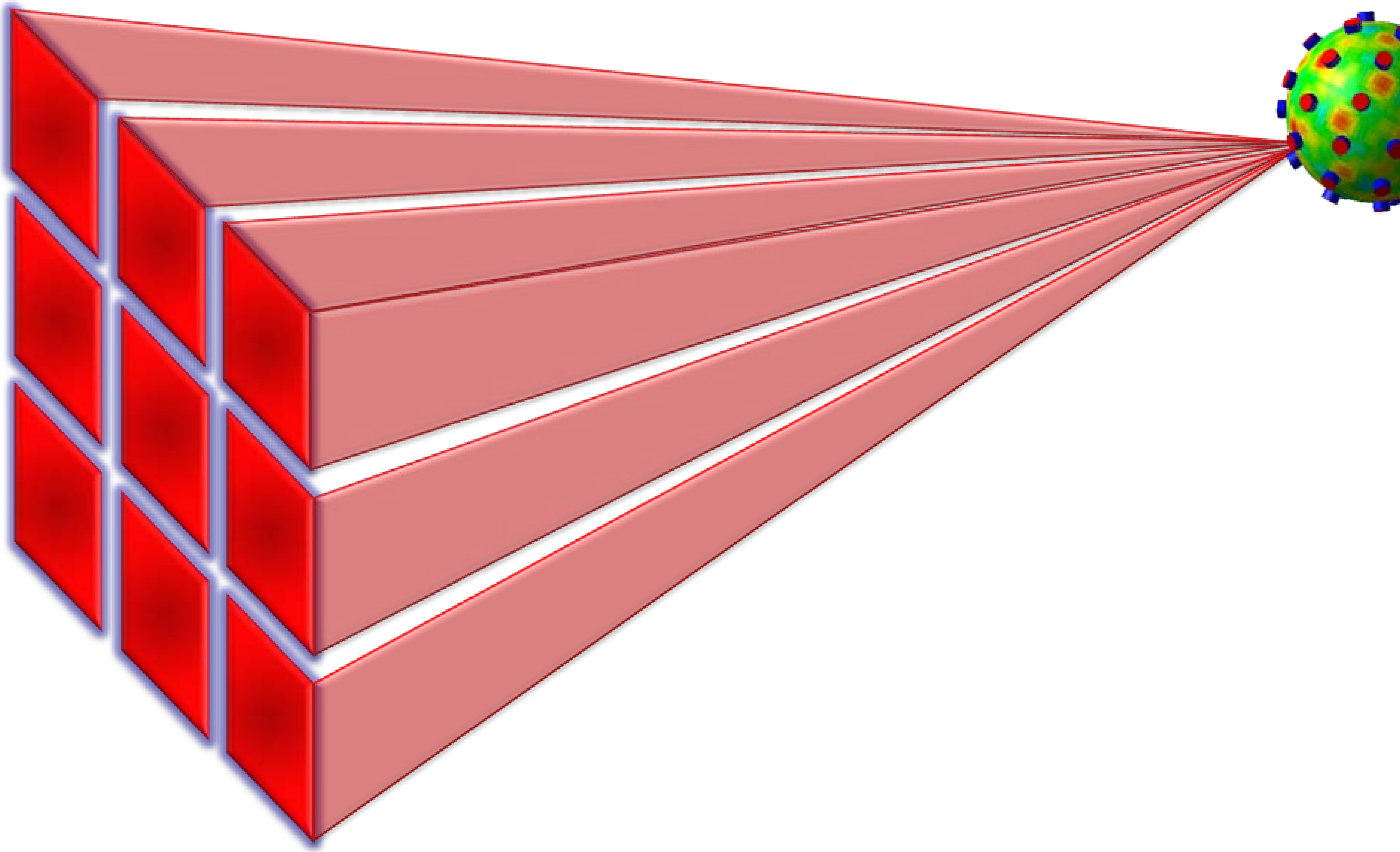
	Total energy (kJ)	Spots	energy per spot (kJ)	beam per bundle	energy per beam (kJ)
Compression	500	48	10,42	9	1,16
Shock Ignition	130	48	2,71	3	0,90
Total	630	48	13,125	12	-





48 bundles of 9 + 3 =twelve ~1 kJ beams

Versatility offered with a ~10 kJ bundle formed of several individual beamlets ….



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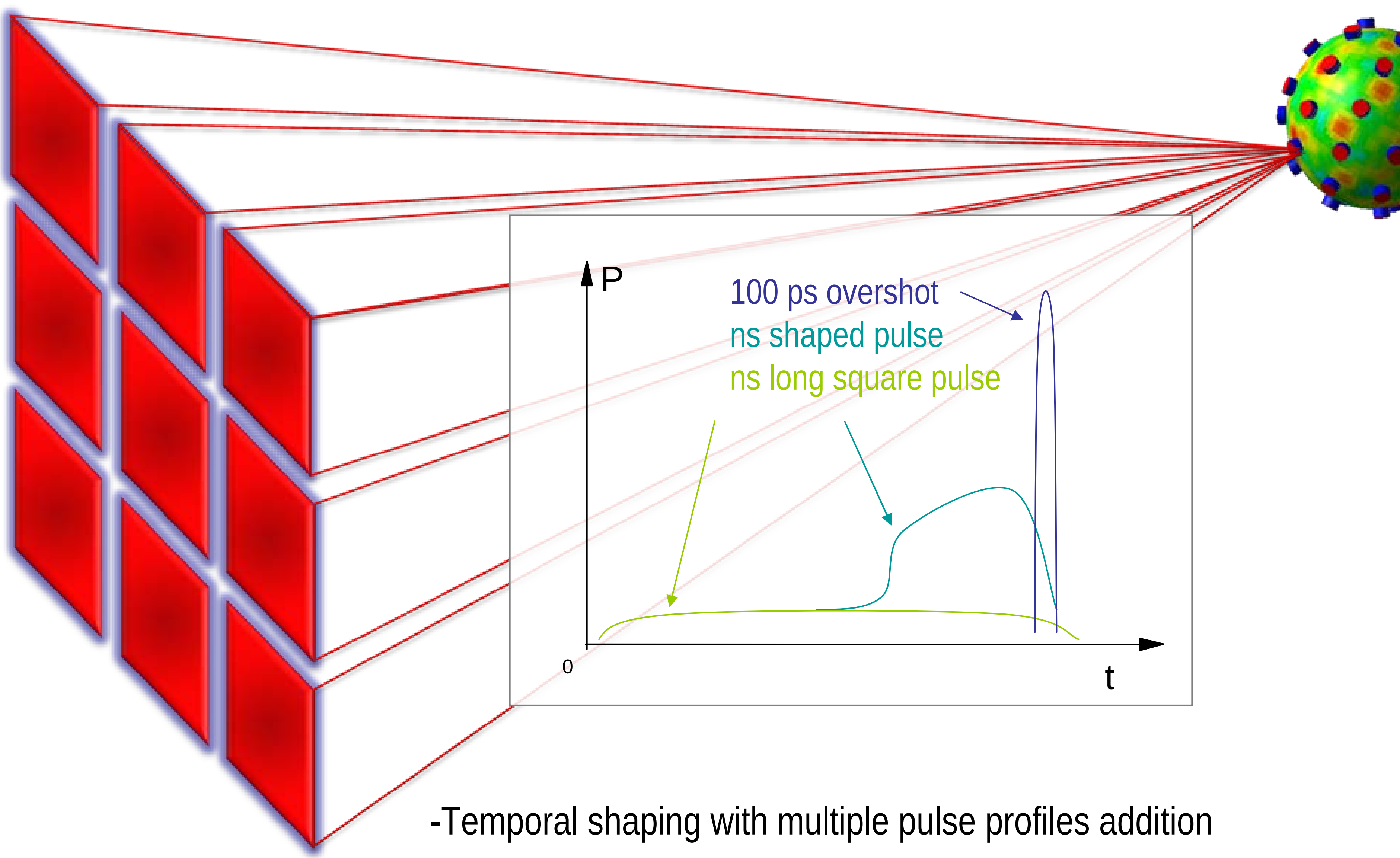
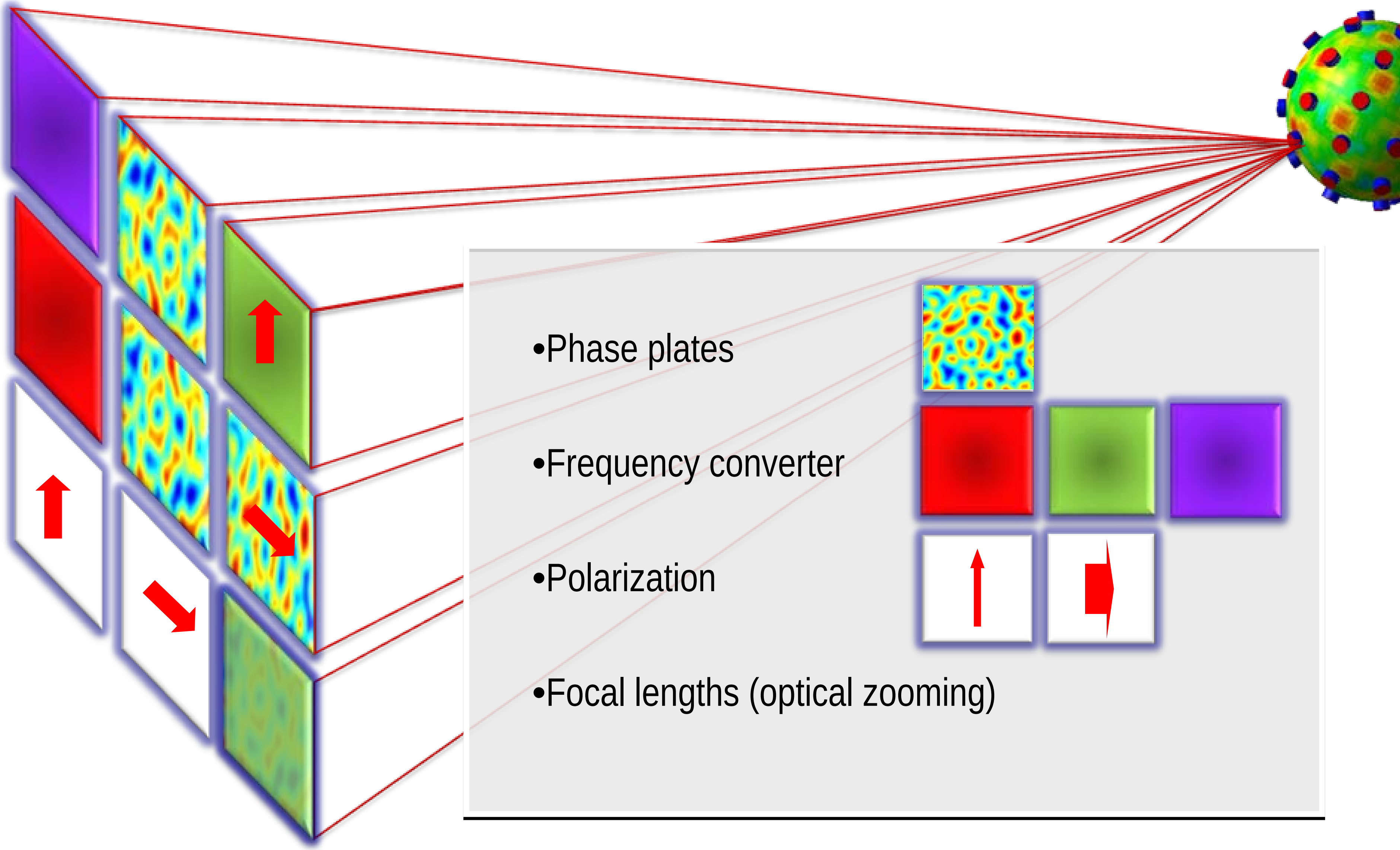


-Temporal shaping with multiple pulse profiles addition

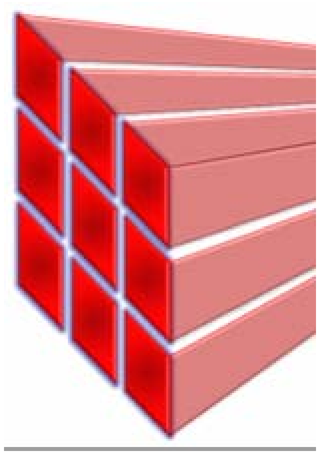
HiPER

Versatility offered with a ~10 kJ bundle formed of several individual beamlets ….

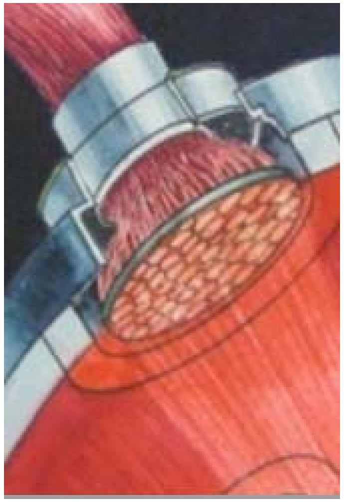
Focal spot energy distribution adjustment with different :



Even more flexibility might be possible



~10 ➔ ~millions beams



Laser energy requirements for HiPER

Beam name	Pulse duration	Total 1w energy (kJ)	Beam number	Energy per spot (kJ)	Demonstrator energy
Compression	4 to 10 ns	500	48	~10	1 to 10 kJ
shock ignition	0.4 ns	130	48	~3	1 to 3 kJ
fast ignition	10 ps	100	1	100	1 to 10 kJ

A continental integrated collaborative work

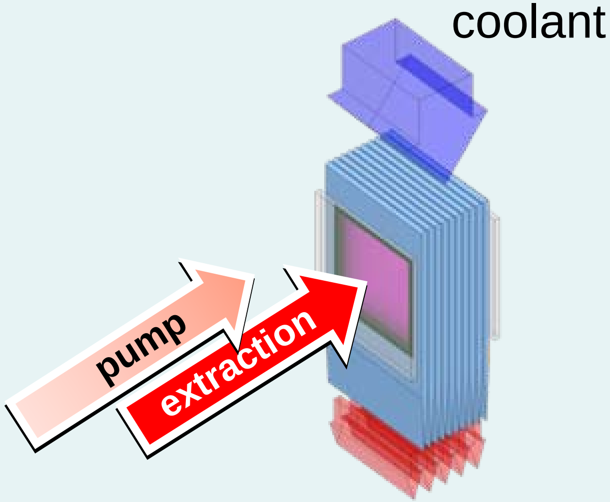
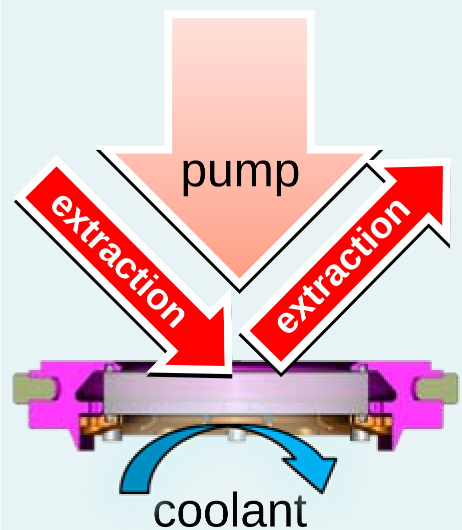
A key Preparatory Phase goal :
Proposing a technological solution
for a ~500 kJ ~10 Hz ~10 % efficient laser facility

Modular approach

Our current objective :
Designing a ~10kJ unit as a fully operational demonstrator

4 European teams are investigating options

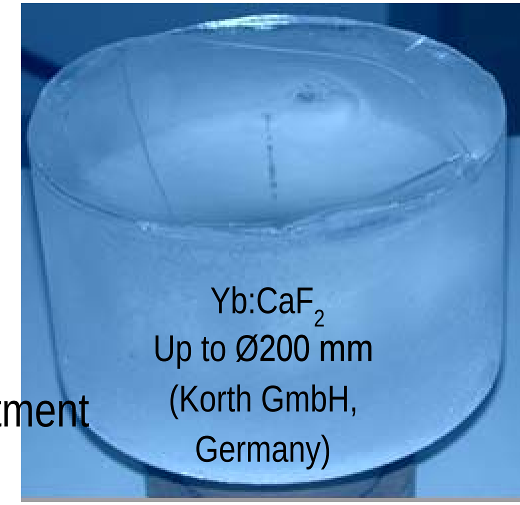
4 options investigated

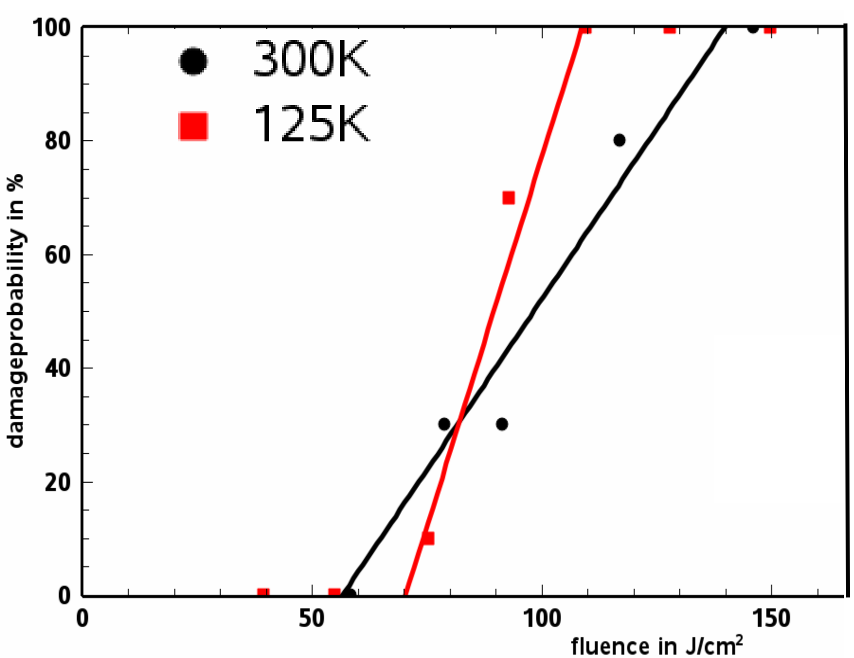
IOQ, Germany	STFC, UK	CNRS, France	CEA, France
CaF_2	YAG		Glass
Gas cooled plates		Active mirror	fiber
			

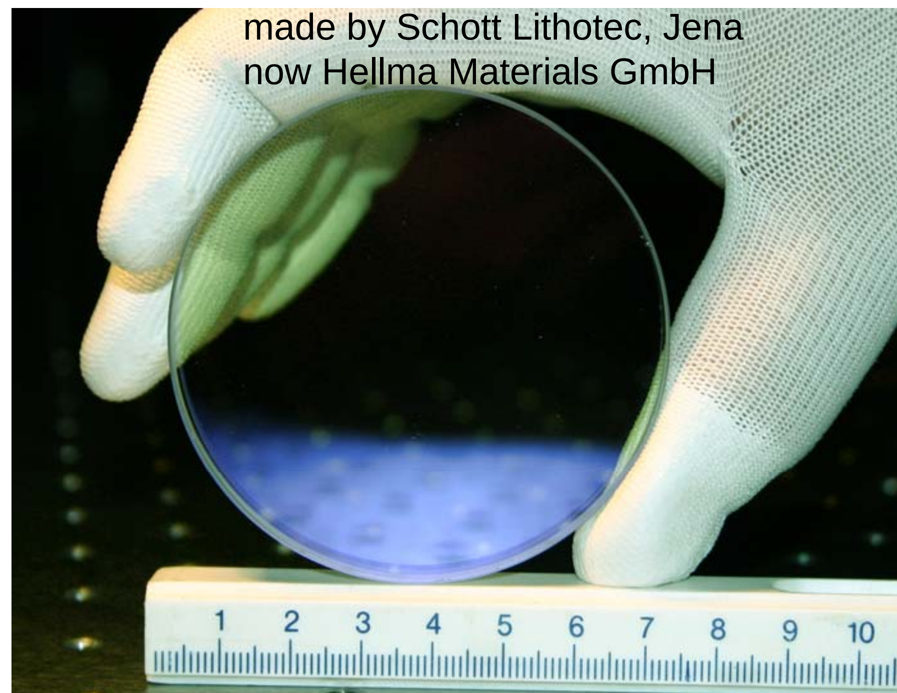
IOQ proposed option relies on $Yb:CaF_2$

Like Yb:YAG, $Yb:CaF_2$:
- carries a high thermal conductivity (increasing at low temperatures)
- is available in large size (cubic symmetry ➔ ceramic)

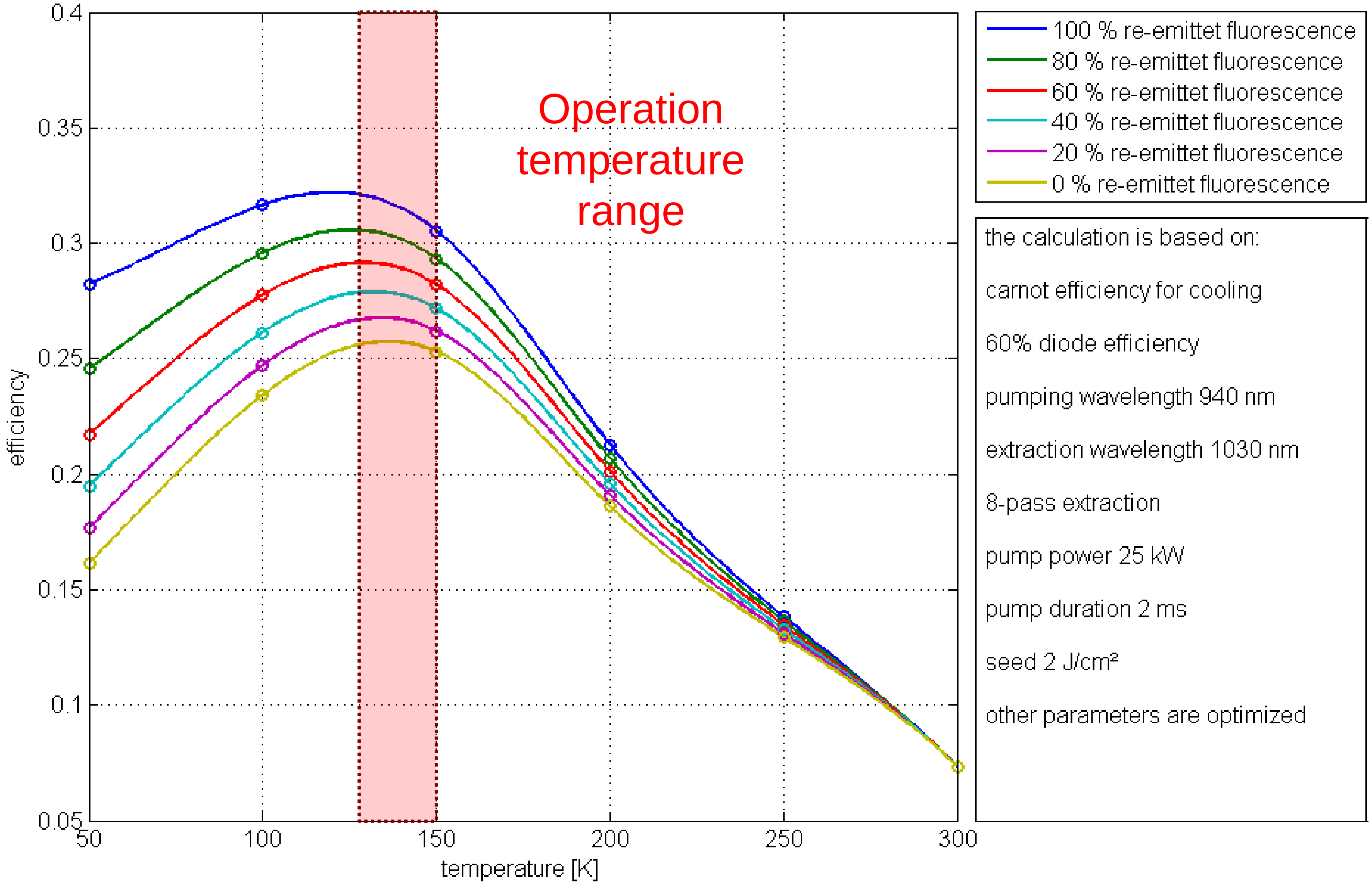
Moreover, $Yb:CaF_2$ offers:
- large absorption and emission band widths ➔ allow amplification of short pulses and wavelength multiplexing
- long fluorescence life time (2.4 ms) ➔ optimizing diode capital cost investment
- low nonlinear refractive index ➔ low B-integral at high fluence







Operating temperature range



the calculation is based on:

carnot efficiency for cooling

60% diode efficiency

pumping wavelength 940 nm

extraction wavelength 1030 nm

8-pass extraction

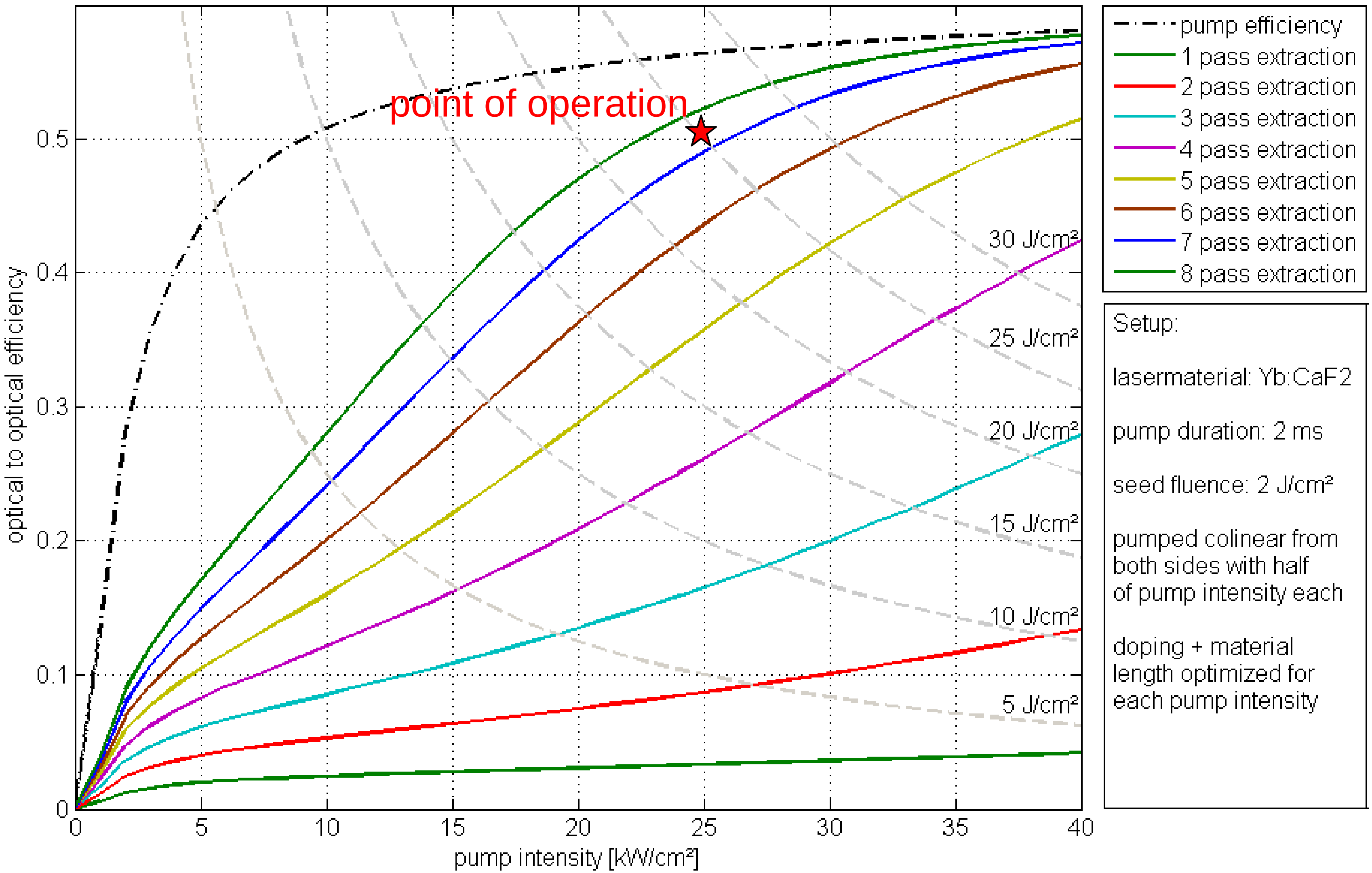
pump power 25 kW

pump duration 2 ms

seed 2 J/cm²

other parameters are optimized

FSU cryo CaF_2 concept point of operation

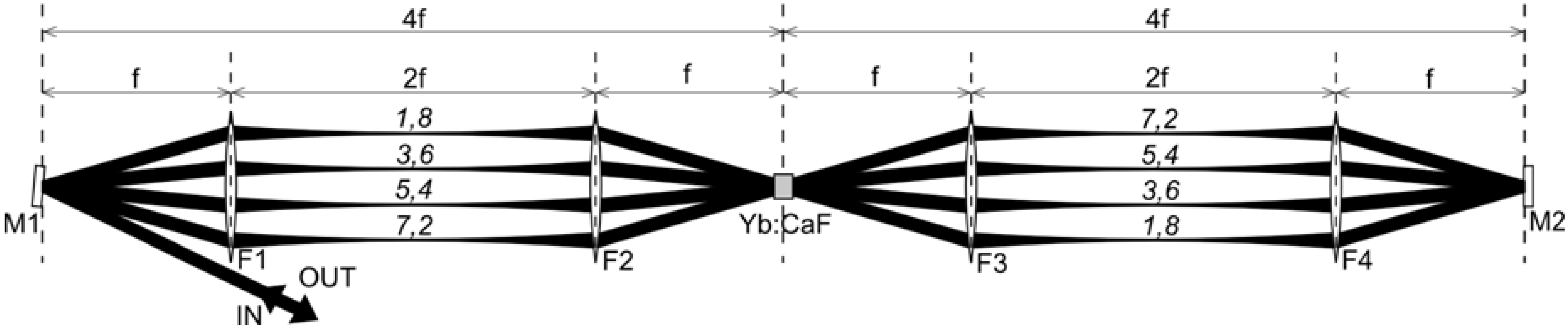


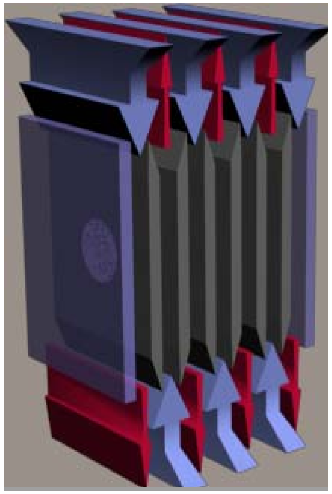
Summarized design parameters

- pump: **25 kW/cm², 2ms**
  - **8 pass** extraction
  - seed **2 J/cm²**
  - extraction approx. **25 J/cm²** (160 cm²/4 kJ)
  - theoretical diode light to laser efficiency about **50 %**
- operation temperature **130 – 150 K**
  - over all laser efficiency up to **30 %**

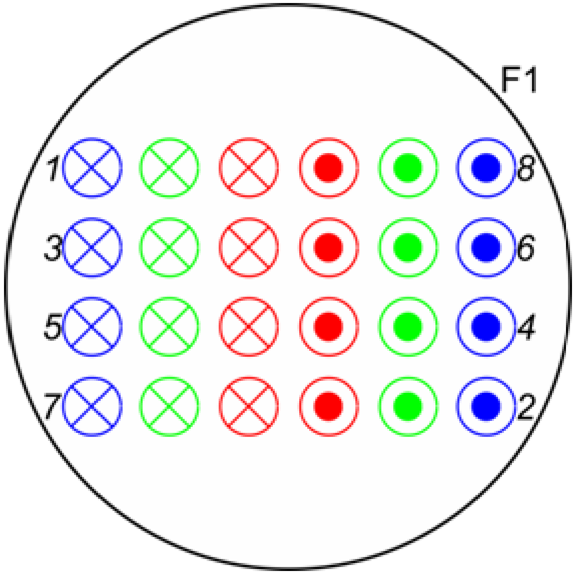
High extraction fluence and large number of passes need special effort in amplifier design.

Multi-pass angular & spectral multiplexing architecture





Use of cryogenic gas cooled amplifier heads



- 3 different beams are amplified in one amplifier
- each beam achieves 8 round trips
- time delays on a ns - scale avoid any overlap of the pulses in the amplifier

FSU CaF2 concept specifications

- 1kJ/4ns pulses single beam, 333J/0.4ns pulse
- 4 kJ total energy per amplifier
- rectangular 15.8x10.5 cm^2 shape:

→ quadratic arrangement of the 3 beams in the 8-pass amplifier (4 x 6) with a size of 63 cm x 63 cm

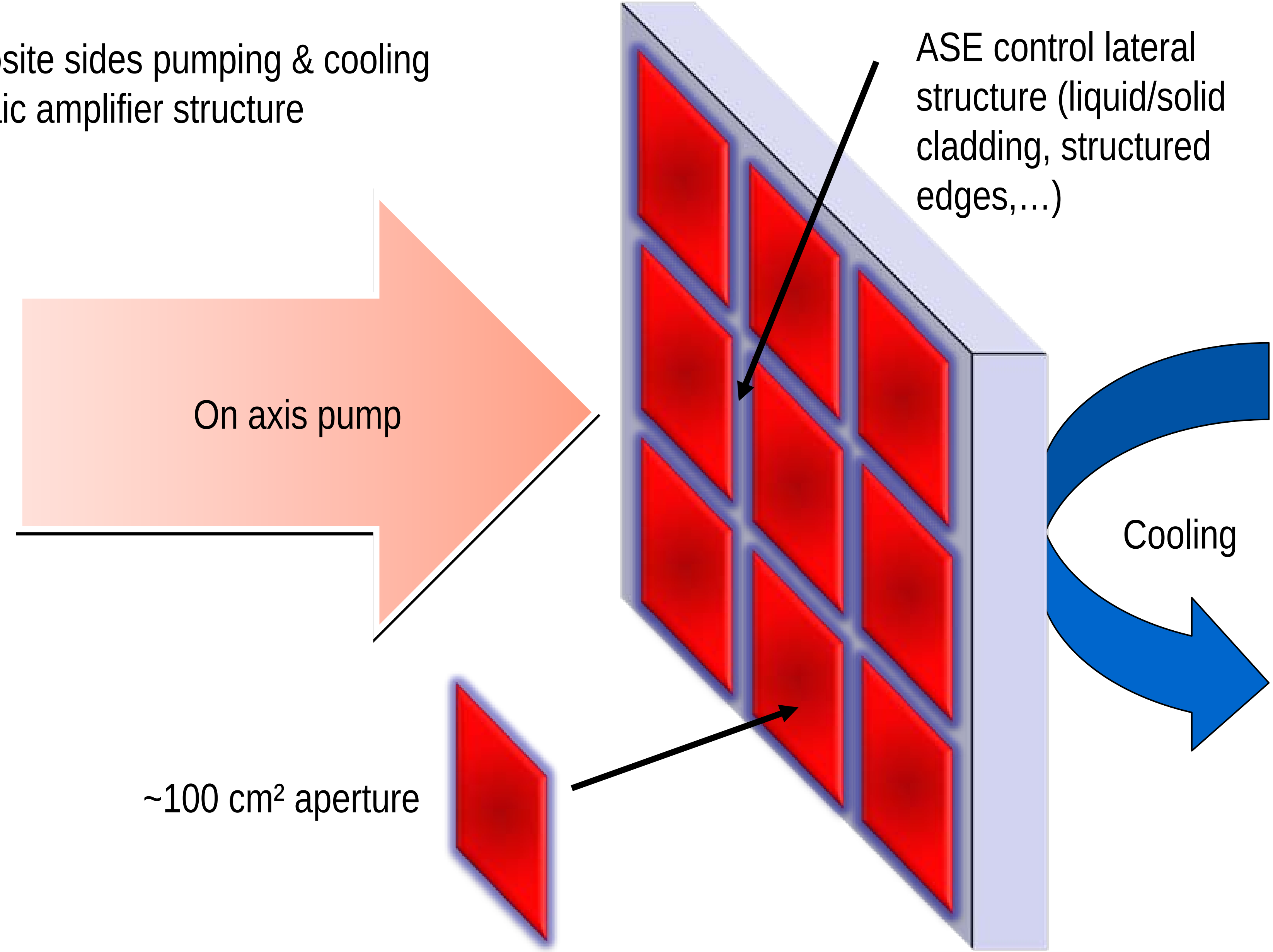
→ efficient cooling in a gas cooled laser head

→ doping concentration 1.5 %

- material thickness: 6.7 cm
- B-Integral < 0.8
- $g \cdot L = 1.88$ (diagonal)

CNRS option relies on active mirror mosaic amplifier structure

- Opposite sides pumping & cooling
- Mosaic amplifier structure



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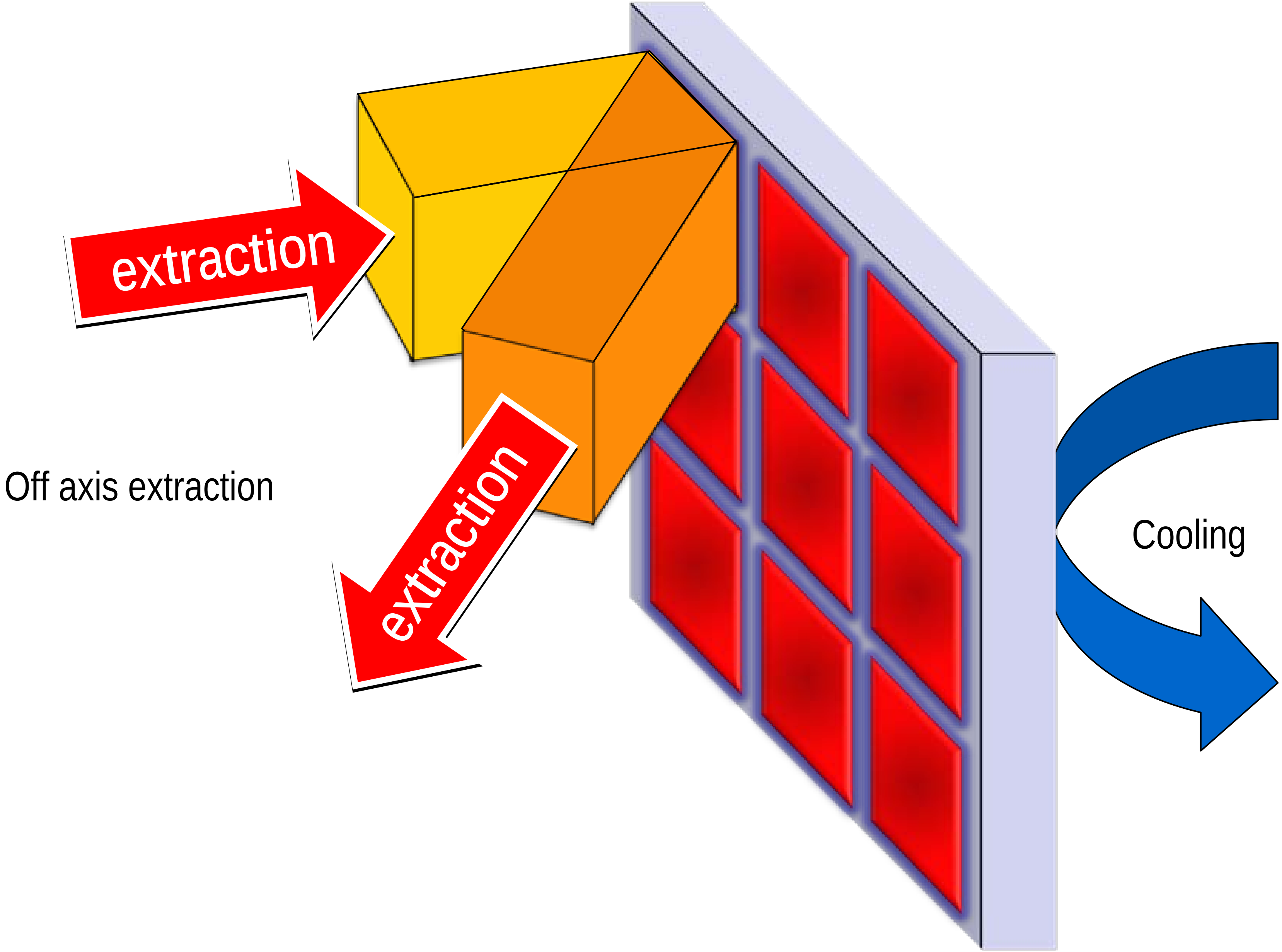

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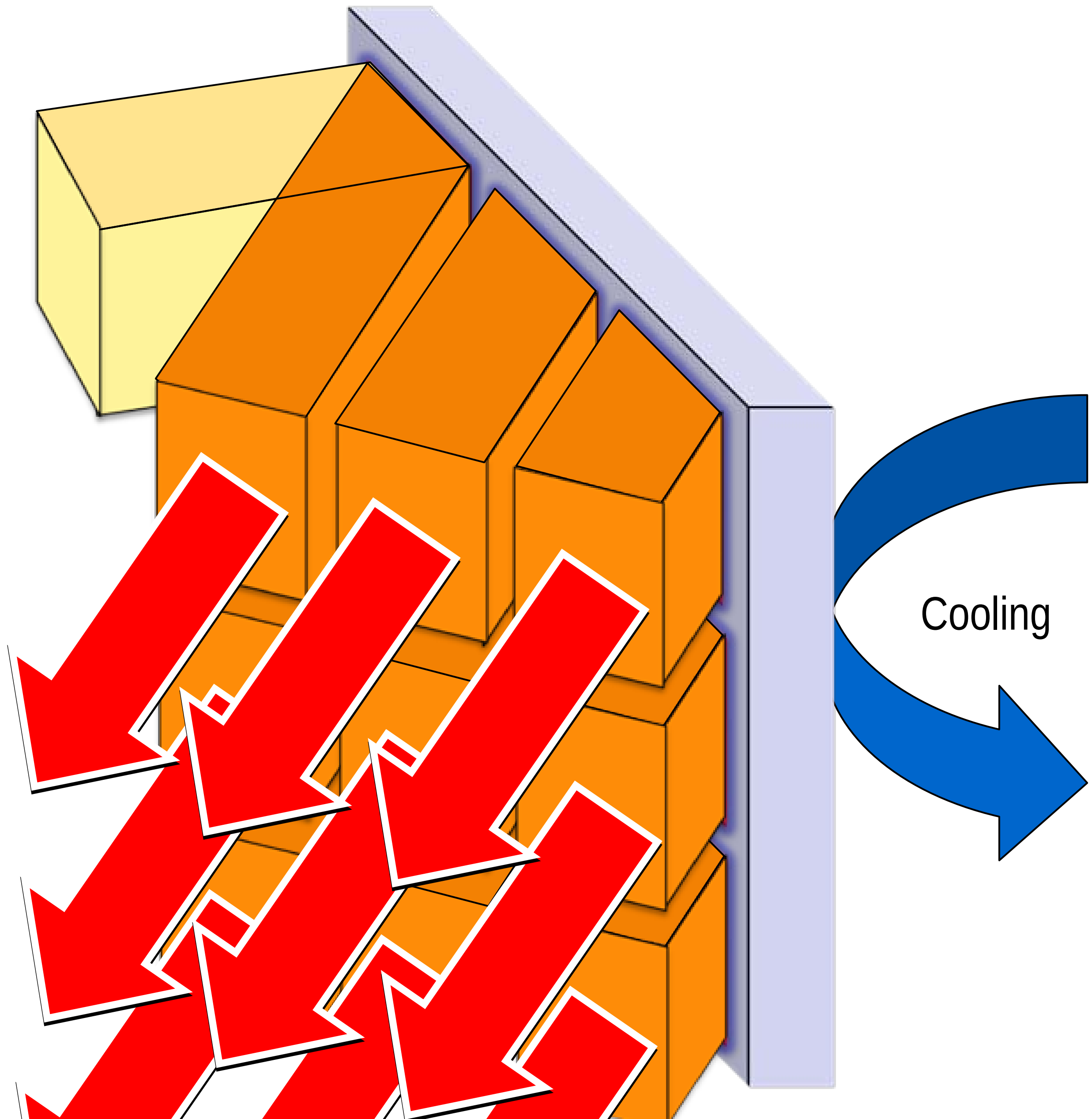
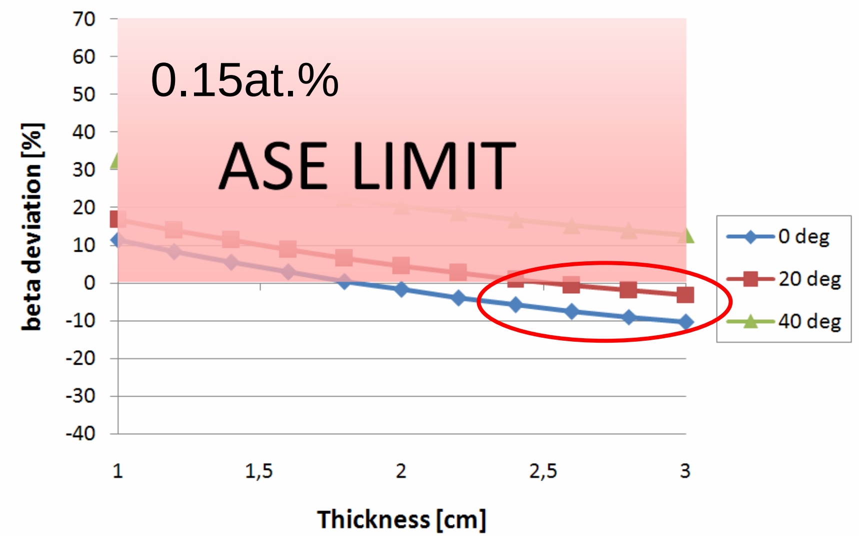
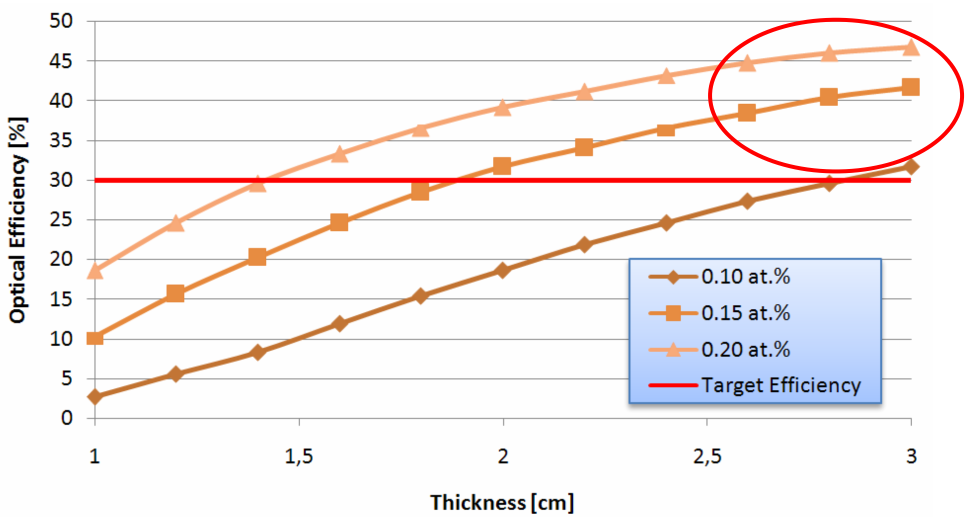


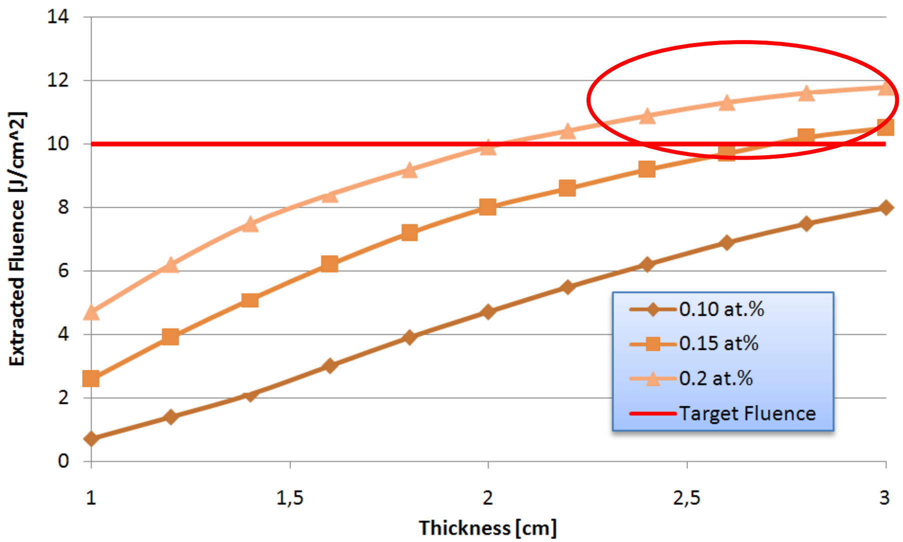
Selected point of operation

Doping level = 0.16 at%
Thickness > 2.6 cm
Extraction angle = 20°
Pump intensity = 6 kW/cm²
11x11 cm² aperture
➔

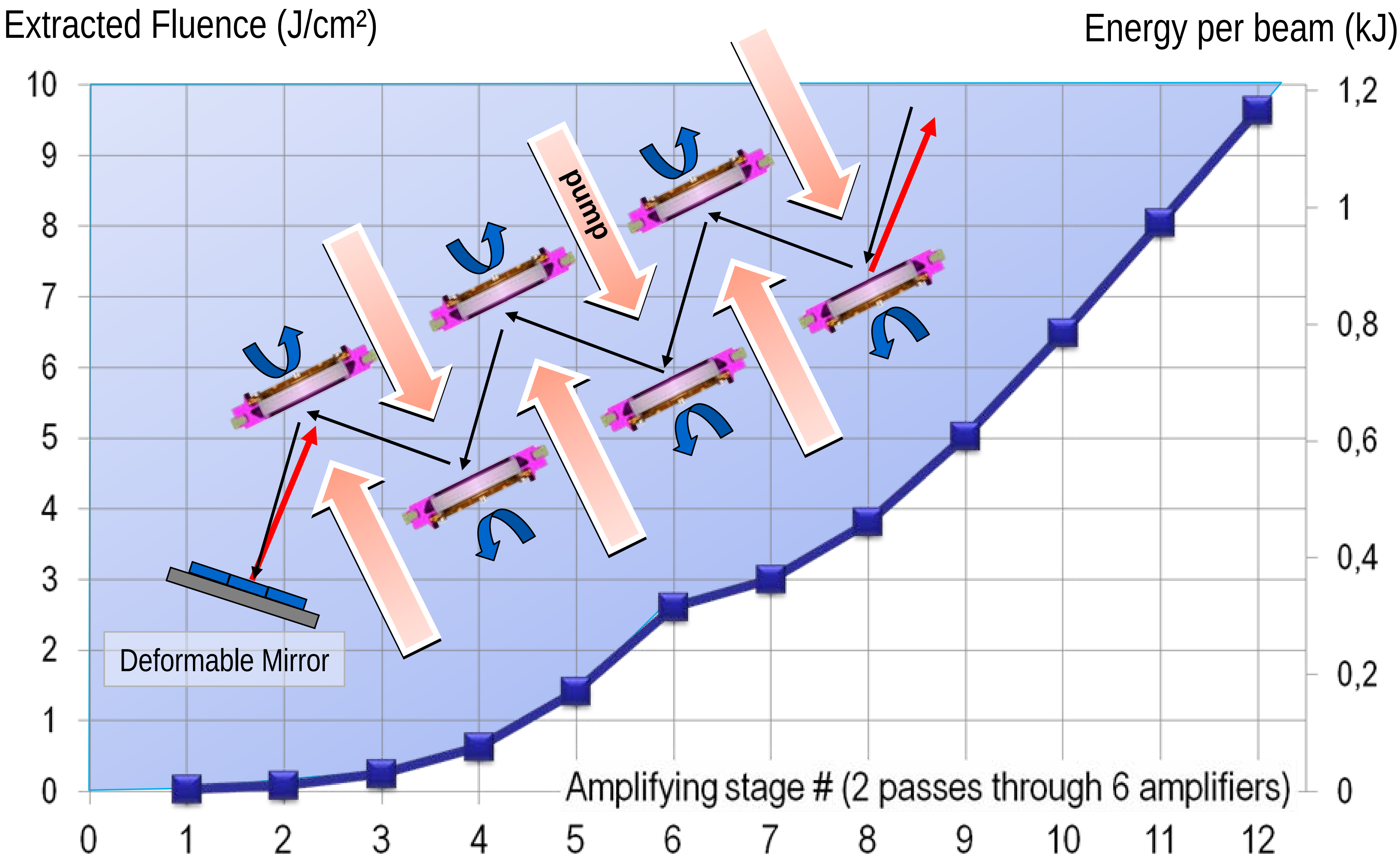
β_ASE < 0
Efficiency η > 30%
Extracted Fluence >~10 J/cm²



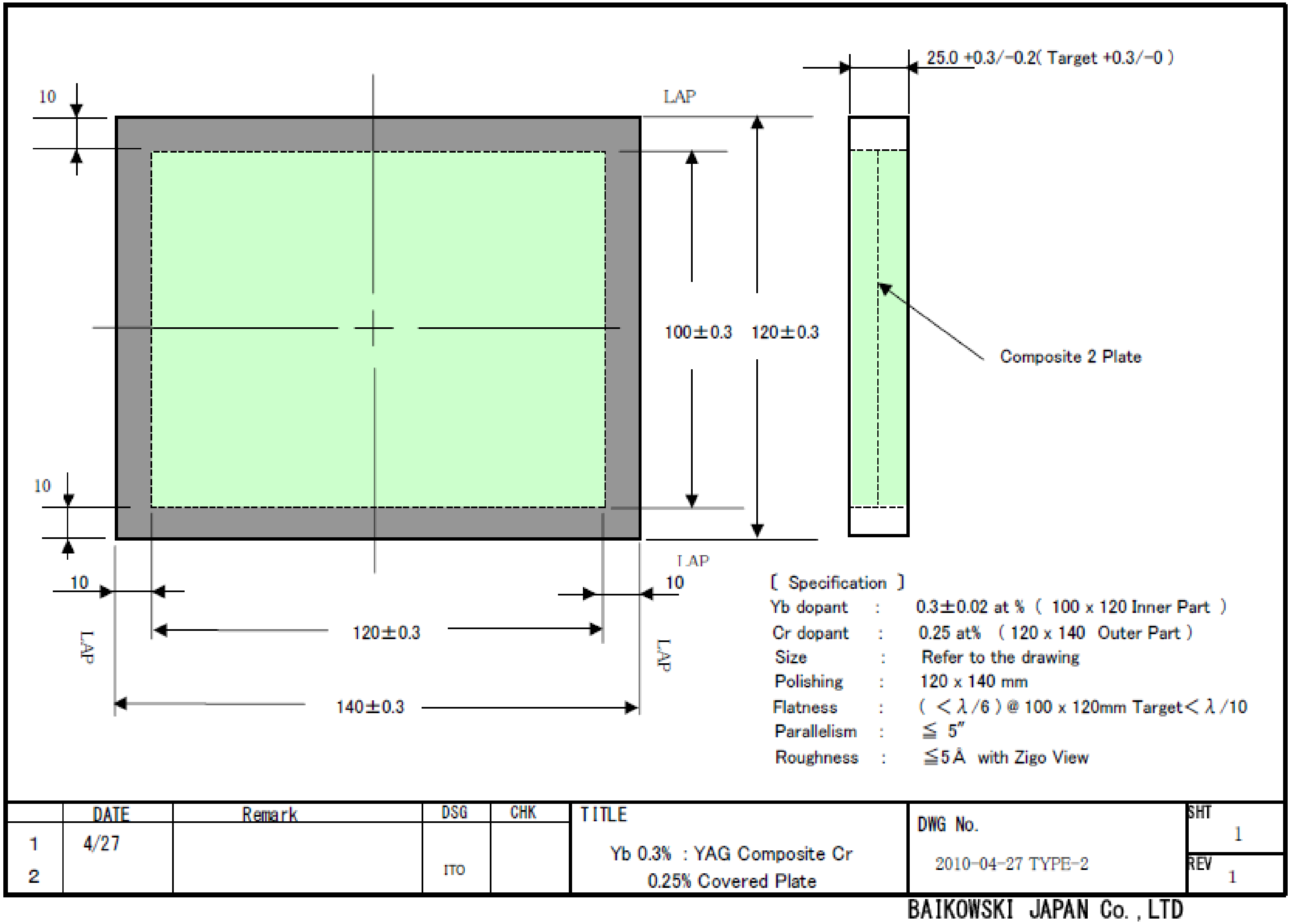




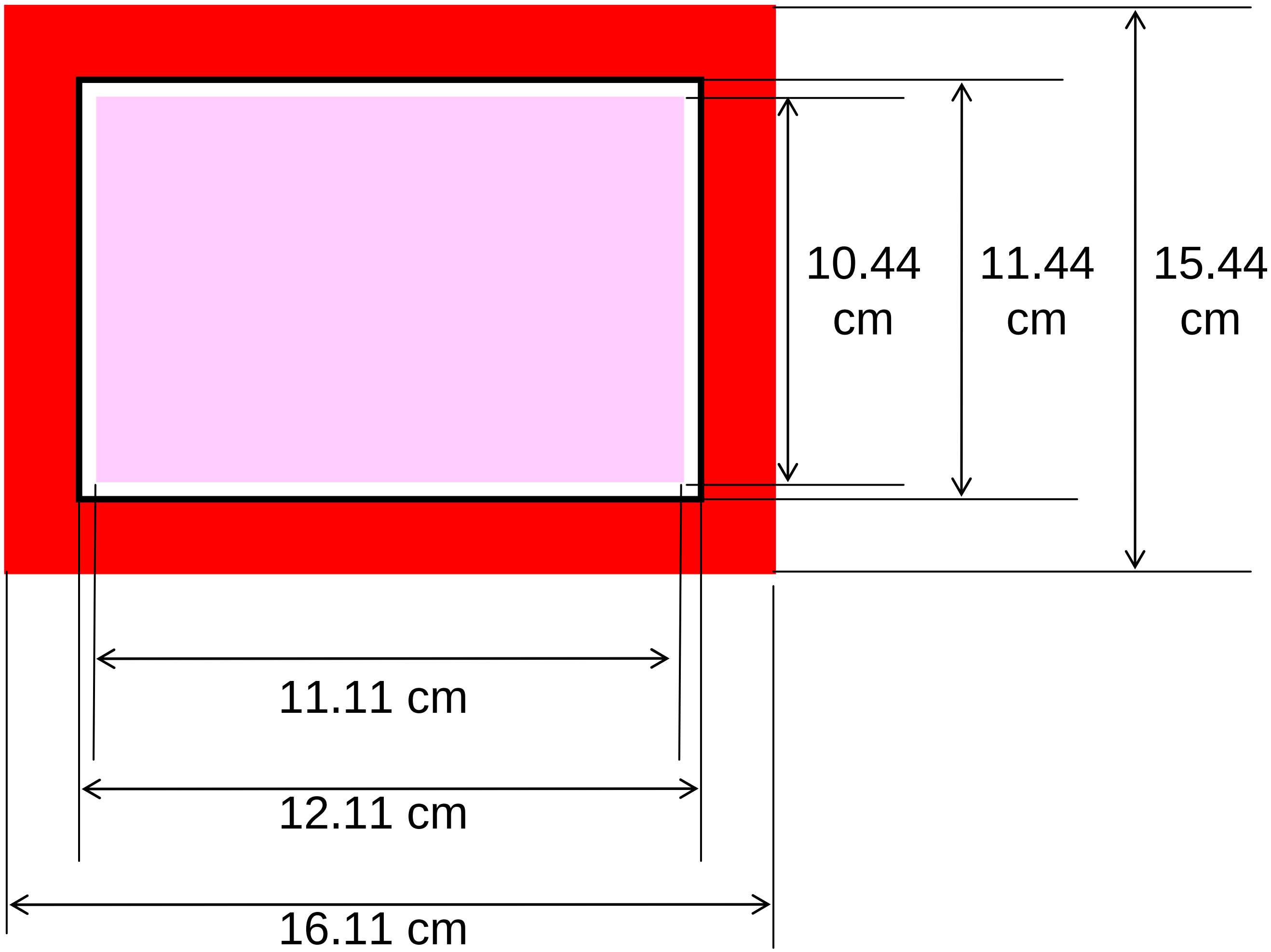
Energy build-up



Baikowski cosintered Yb/Cr:YAG ceramics satisfies HiPER requirements



Cryogenically cooled amplifiers



Pump:

0.7 ms, 10 Hz,

6 kW/cm^2

11.11 x 10.44 cm^2

Gain medium:

12.11 x 11.44 cm^2

Thickness = 2.6 cm

~0.15at.% Yb^{3+} doping

α = 0.269 cm^{-1}

Clad:

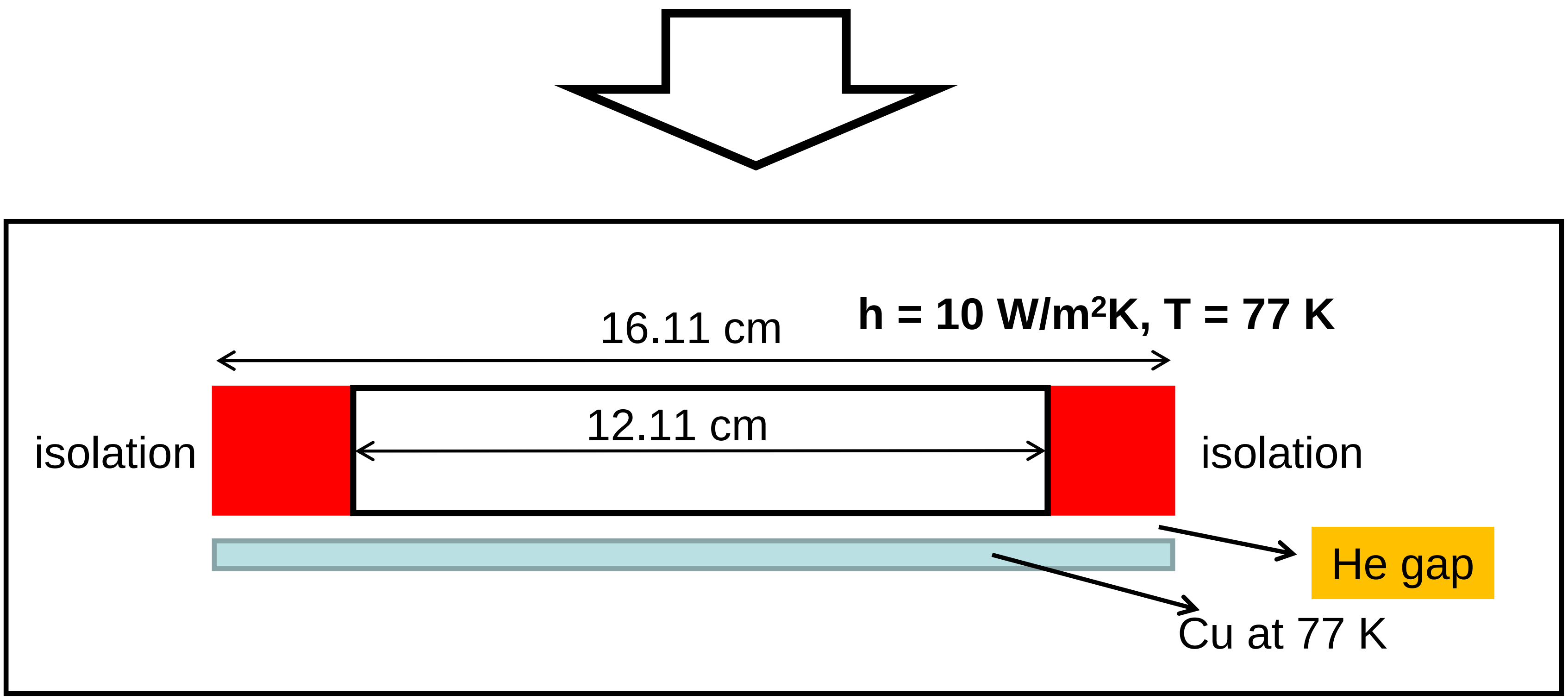
16.11 x 15.44 cm^2

Lateral dim. = 2.0 cm

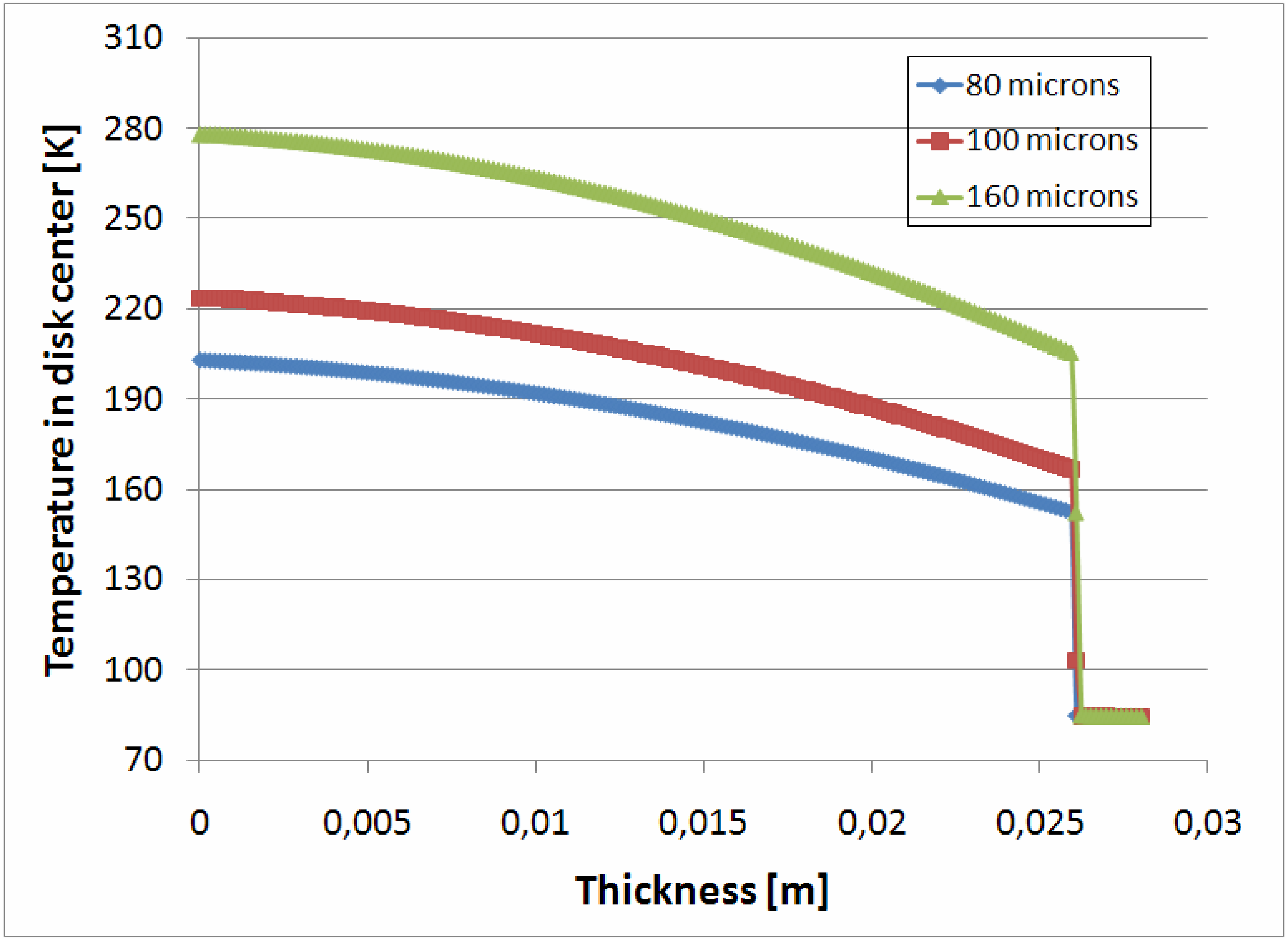
Thickness = 2.6 cm

α = 0.8 cm^{-1}

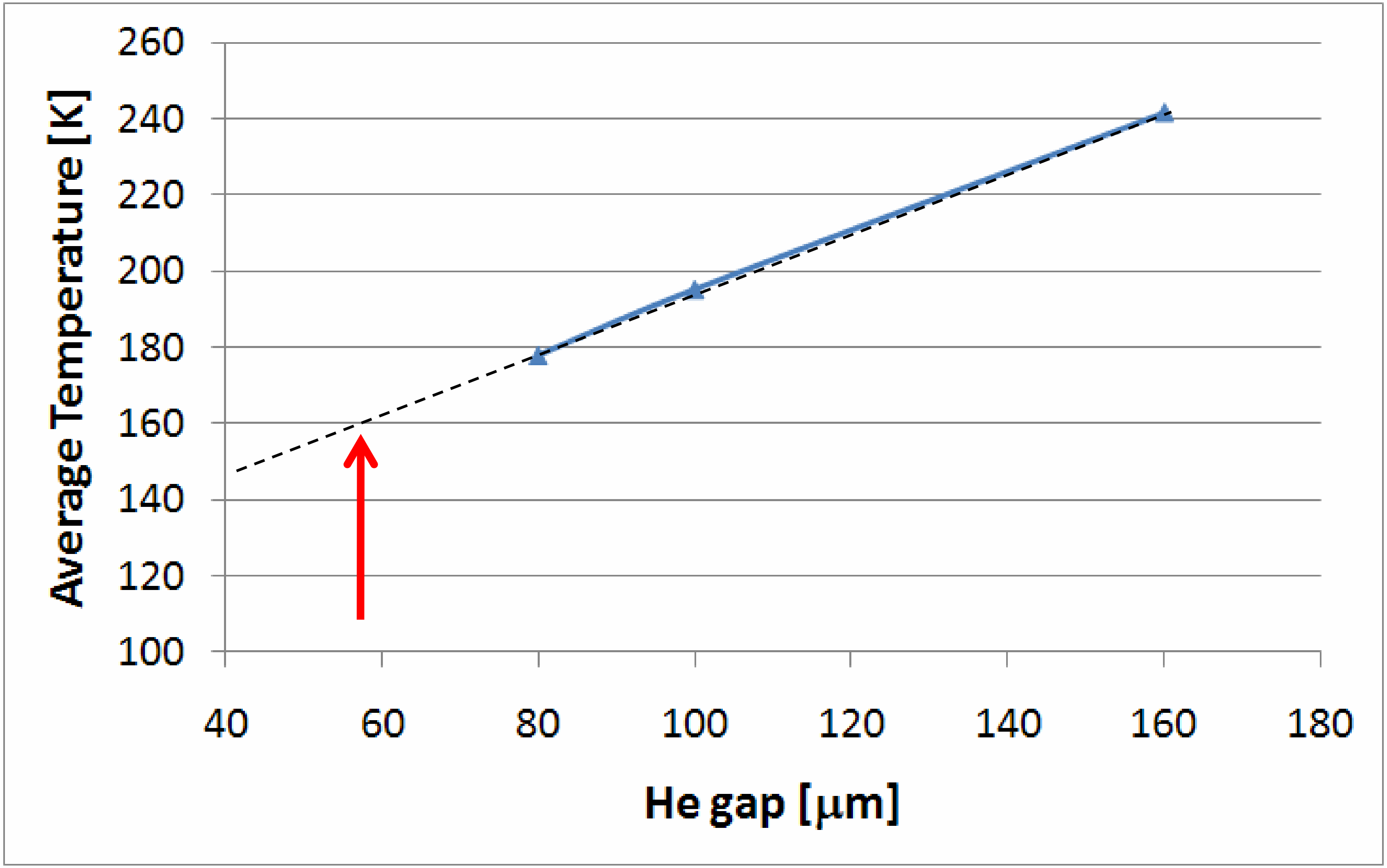
Variable average temperature in the laser disk by changing the thickness of cryogenic cooled He gap
(He pressure variation could be an option as well)



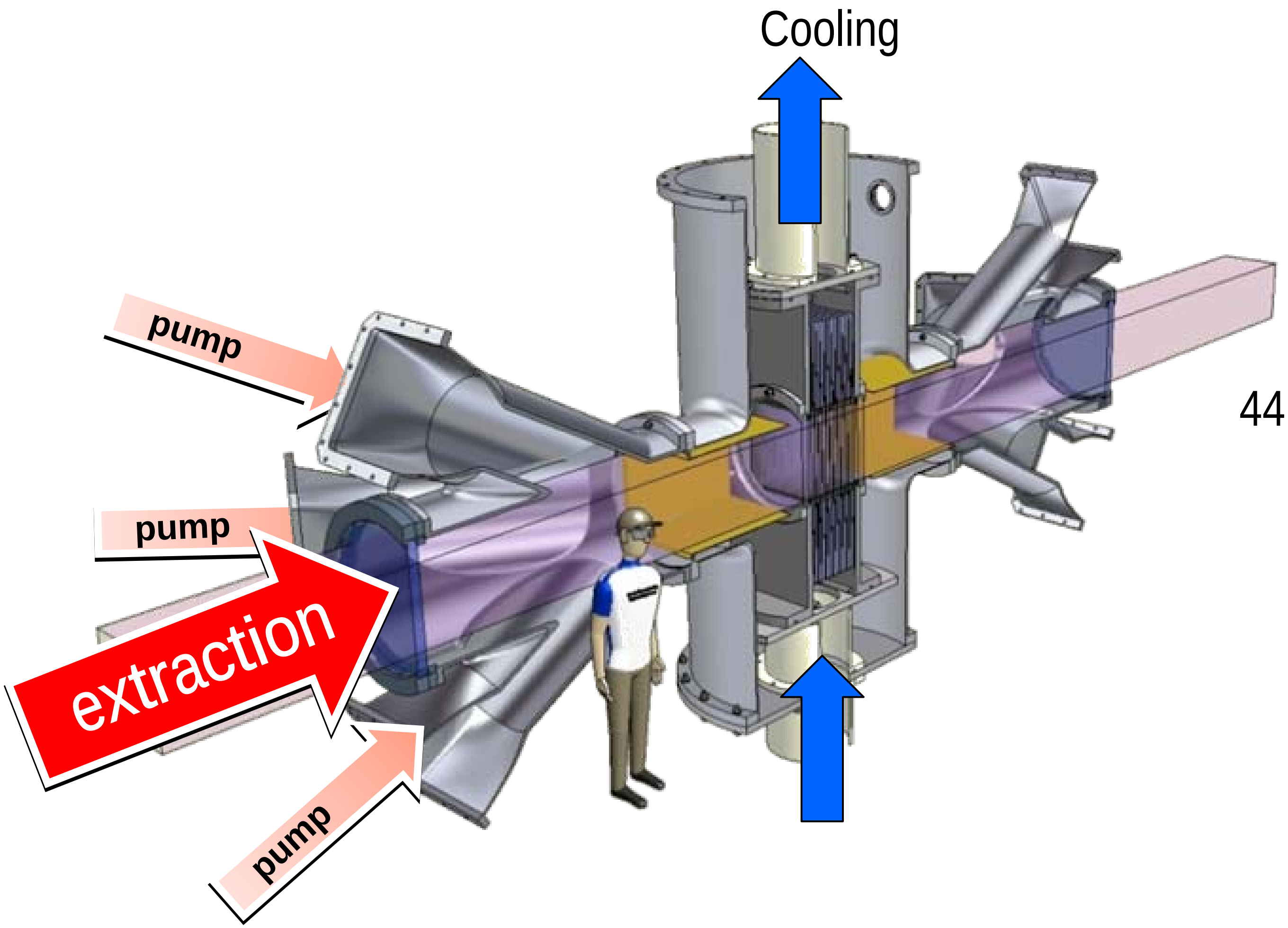
Temperature tunable through He thickness

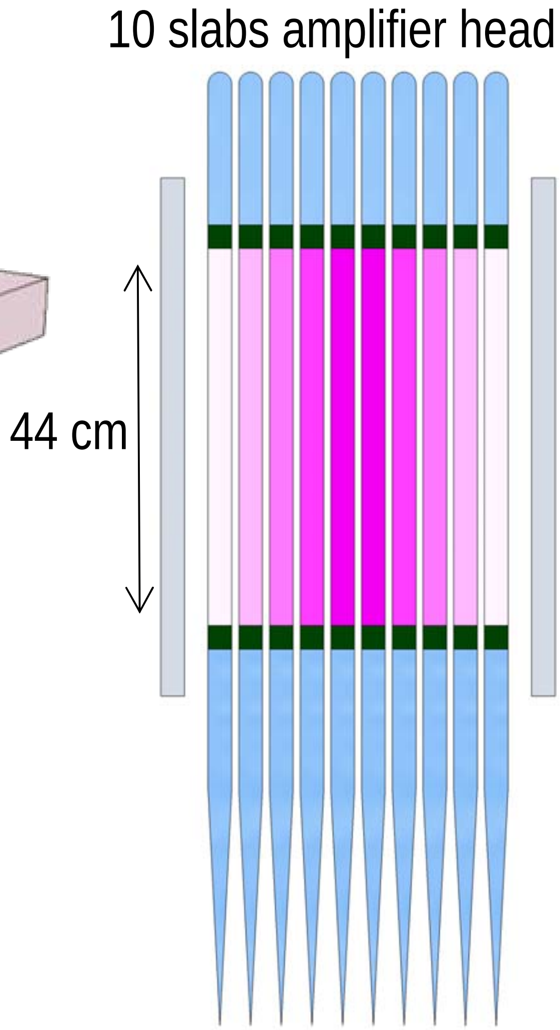


160K nominal point of operation for 60µm gap

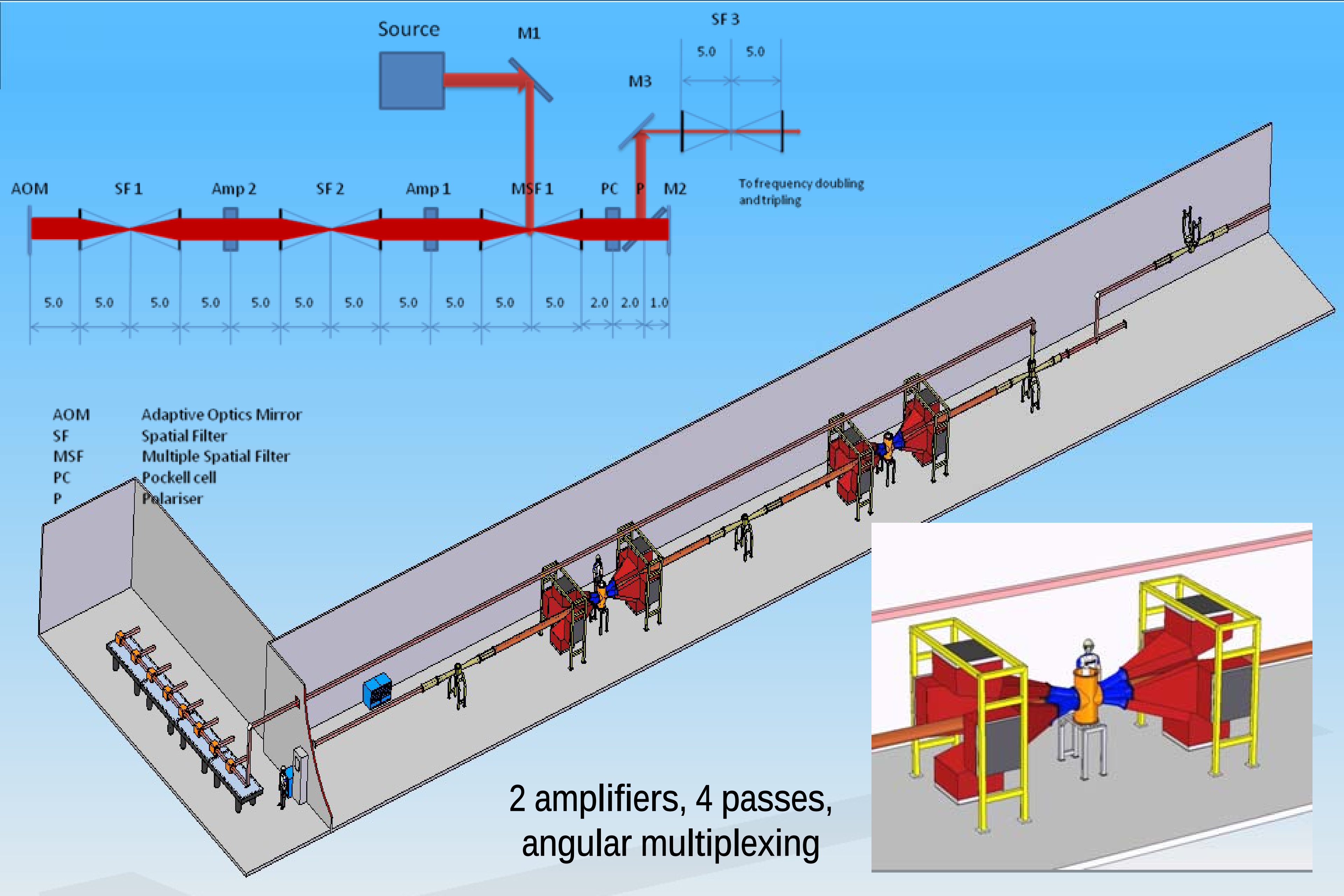


RAL option relies on Yb:YAG 175K gas cooled 10kJ amplifier



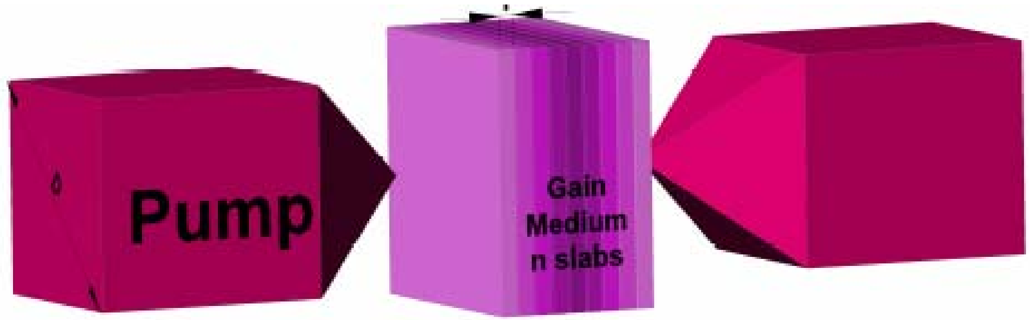


Optical layout



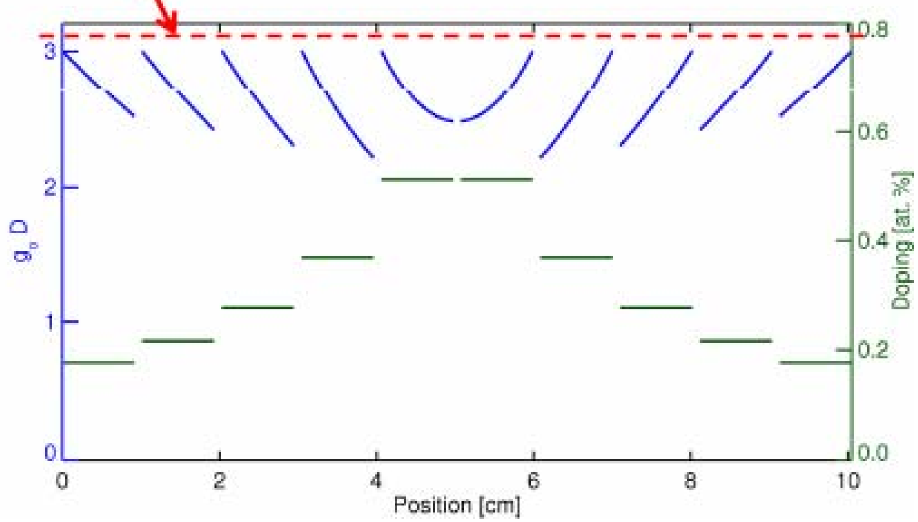
2 amplifiers, 4 passes, angular multiplexing

Amplifiers with variable doped slabs



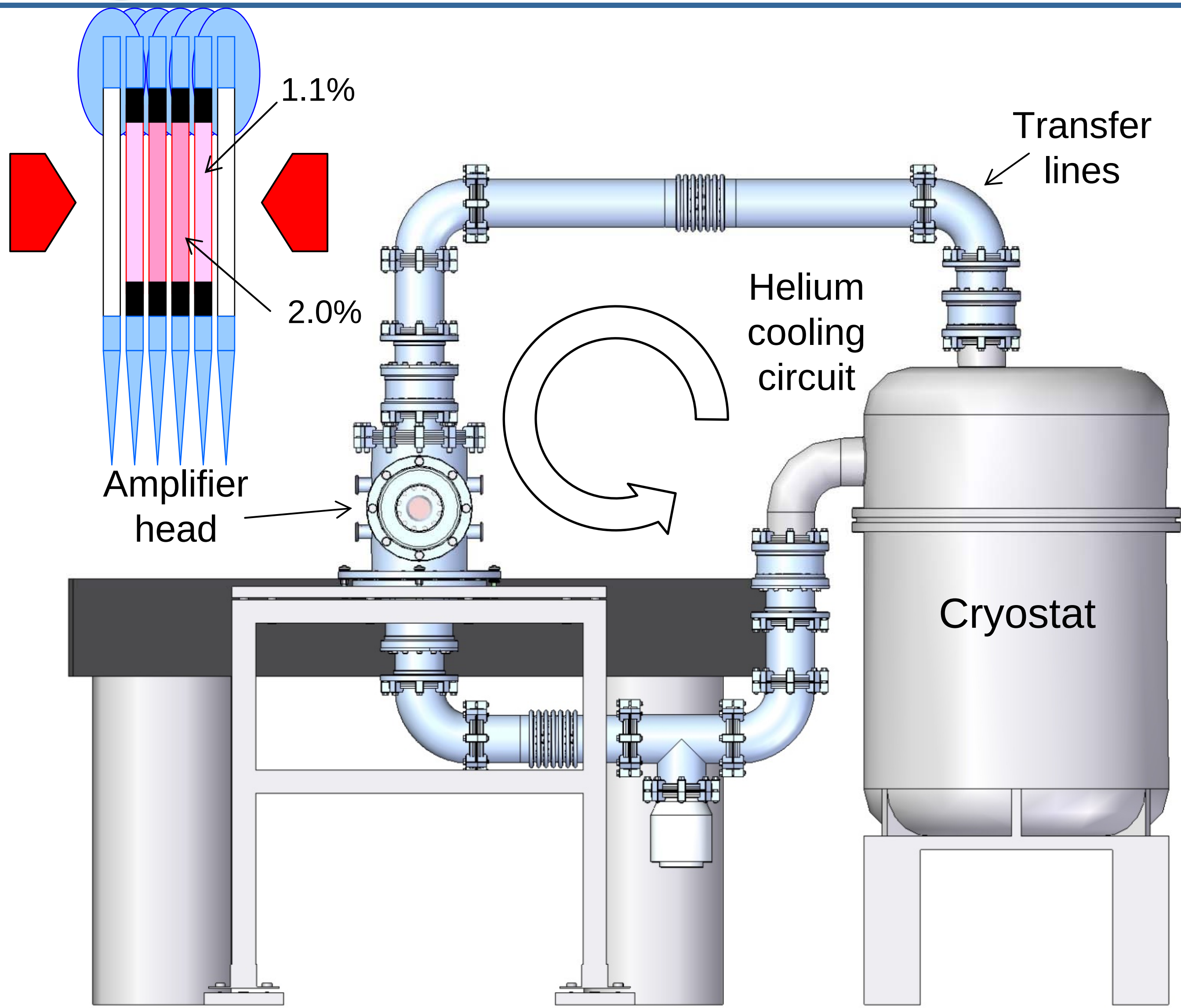
Doping concentration such to stay below (ASE management)

Parameter/Result	Value
No of slabs n	10
$g_{o,max}D$ in each slab	3
Slab thickness l	10 mm
Min doping	0.18 at %
Max doping	0.51 at %



➔ Reduced gain medium volume requirement and equalized heat load

RAL Dipole DPSSL program will be used as a testbed for HiPER



Fiber based concept

G.A. Mourou, C. Labaune, D. Hulin, A. Galvanauskas :
"New amplifying laser concept for Inertial Fusion Driver",
Journal of Physics: Conference Series ***112*** *(2008) 032052*

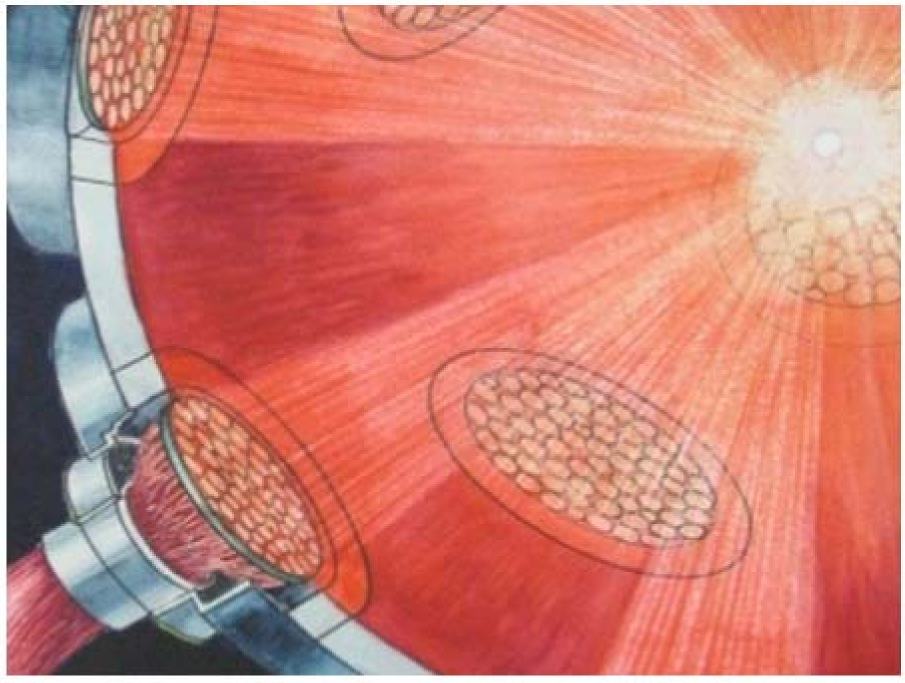
Fiber Concept

One single fibre being able to handle a limited power and wall-plug efficiency being limited as well, three main questions arise:

- How much power can we manage per fibre ?
- How many fibres shall we need ?
- How much thermal power has to be removed ?

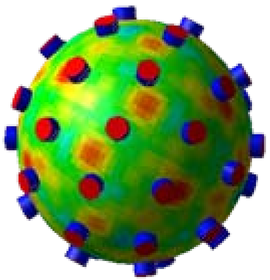
Limits to power scaling are :

- Thermal lensing
- Thermal rupture
- Optical damage
- Melting of the core
- Non linear effects, SBS and SRS
- X-ray, γ-ray and neutron induced damages

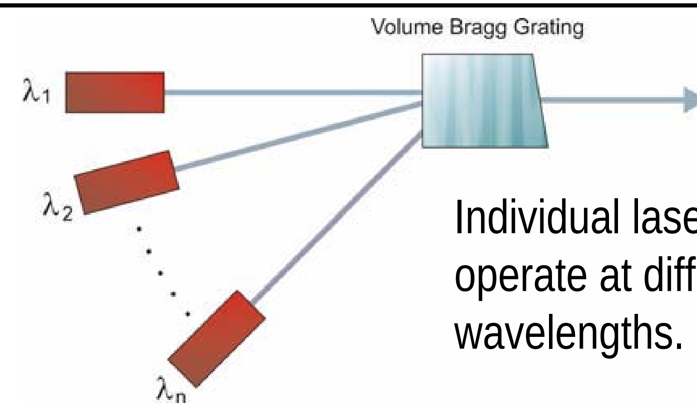


Beam combining

Two approaches

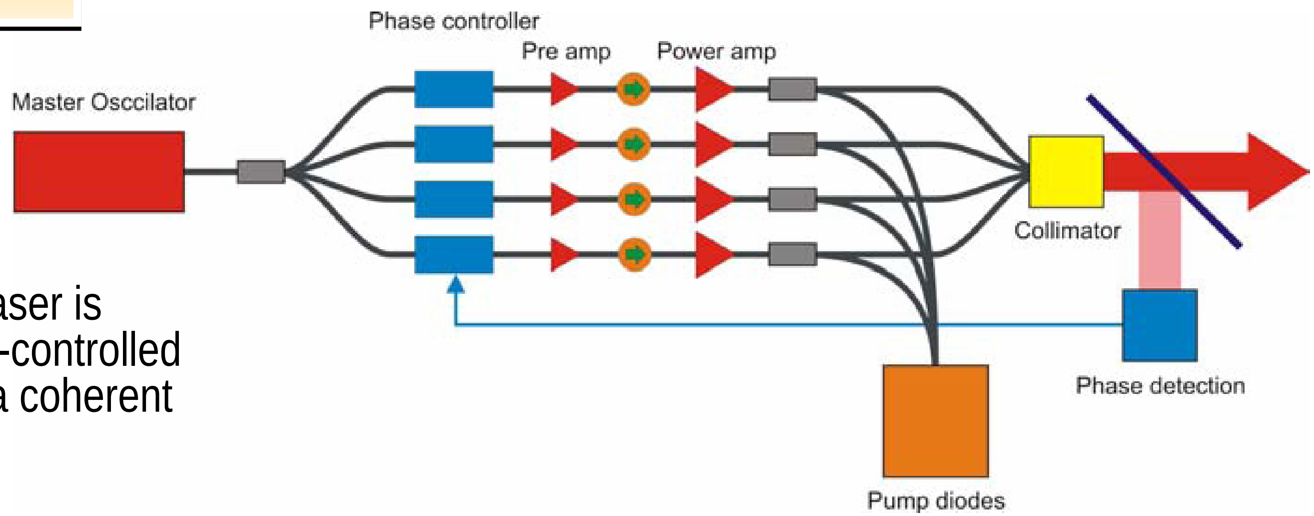


Spectral beam combining using a volume Bragg grating



Individual lasers operate at different wavelengths.

Coherent beam combining



A single-frequency seed laser is amplified through a phase-controlled amplifier array leading to a coherent output beam


Looking forward if we can find sustainable elements for bridging the gaps in technology
Watkins Glen State Park

Thanks to all HiPER contributors