The HORIZON project : towards face-cooled kiloWatt-class Yb:YAG laser systems

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2017-2023 : a wave of laser projects in Bordeaux

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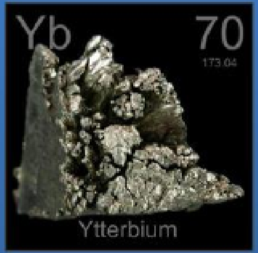
Centre Lasers Intenses et Applications

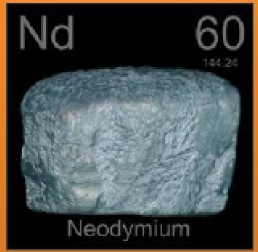
LEAP

AXE A
Matériaux Yb
Pompage diode
1 kHz - 1J
CELIA



HORIZON

AXE B
Matériaux Nd
Pompage diode
10 Hz - 2J
cea



AXE C
Matériaux Nd
Pompage flash
1 kJ - 1 tir/min
cea

FLASHDENCE

AXE D
Upgrade Eclipse
Radioprotection
1,5 J – 1Hz
CELIA

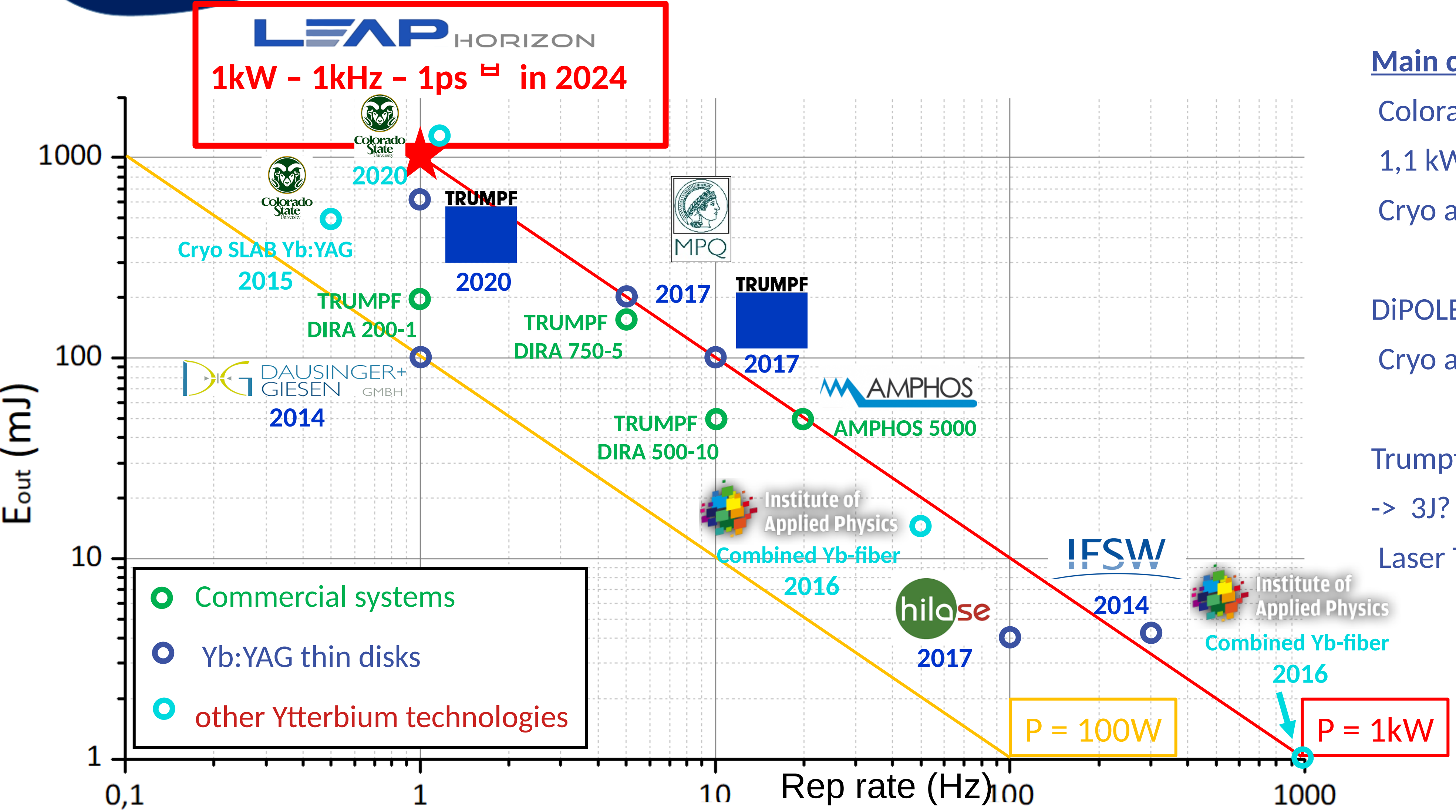
XPulse → Xray generation for oncology

Bergonié UNICANCER NOUVELLE-AQUITAINE
ALPhA NOV Centre Technologique Optique et Lasers
imagine optic

Convergence → Technology maturation

Amplitude

Horizon focus : high average power technologies



Main contenders :

Colorado State University

1,1 kW – 1kHz – 4,5ps

Cryo amplifier, active mirrors

DiPOLE / BiJOV

Cryo amplifier, He flow, multi-slabs

Trumpf scientific

-> 3J? - 1kHz - 1ps

Laser Thin disks / multiple heads

All developments based on Yb :YAG

LEAP HORIZON

Primary objective of LEAP/HORIZON : tech test bed

Main challenges :

High Yb:YAG saturation fluence (~ 9 J/cm^2)

Bandwidth optimization for « short » pulse operation

Thermal issues @ high average powers

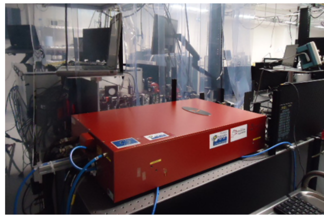
Wish to explore other technologies :

no active mirrors, no cryo ; tests of thin disks

Issues explored :

- Spectral control
- Coherent pulse stacking
- Thin-disk tech for regen
- Top-hat mode amplification
- Liquid face-cooling of power amp

HORIZON prototype scheme



Oscillator 1030nm

Amplitude

1 nJ / 40 MHz

Fiber stretcher

Spectral shaping

Fiber amps

Regen

5 nJ / 40 MHz

Amplitude

2 mJ - 1kHz

$\Delta\lambda$ = 3 nm

DG thin disk amplifier

High power head

> 1J / 1 kHz

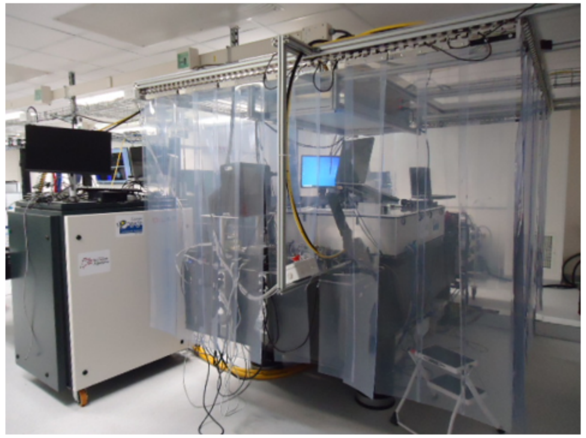
Compressor

1 J

1 kHz

1 ps

Fiber transport

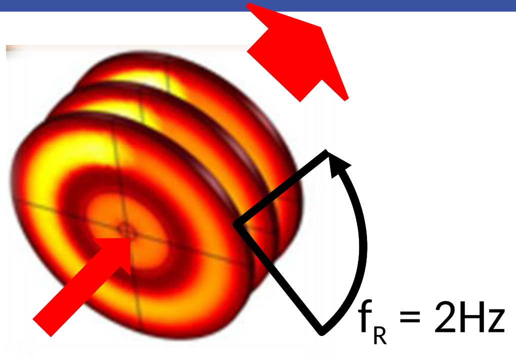


Pump power : 13 kW, 940 nm

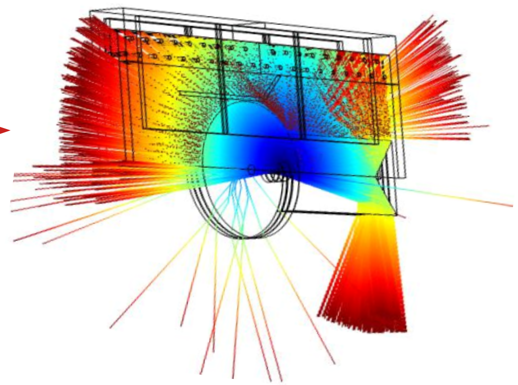
Output power : > 1 kW

4 technologies for HP amplification

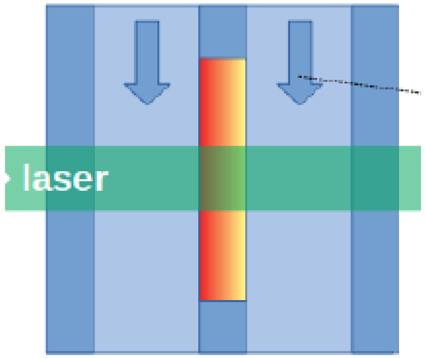
1) Rotating multi-disks



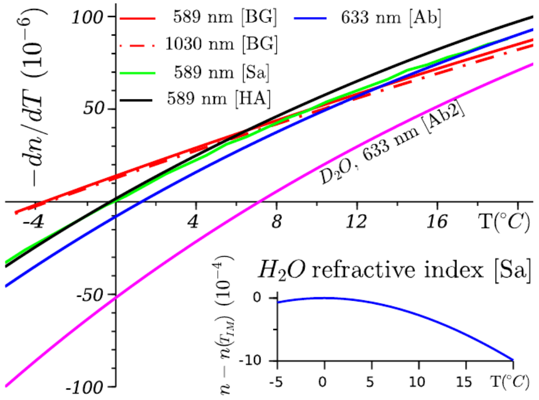
2) ASE transport & mitigation



3) Liquid face-cooling



4) Index leveling in face-cooling



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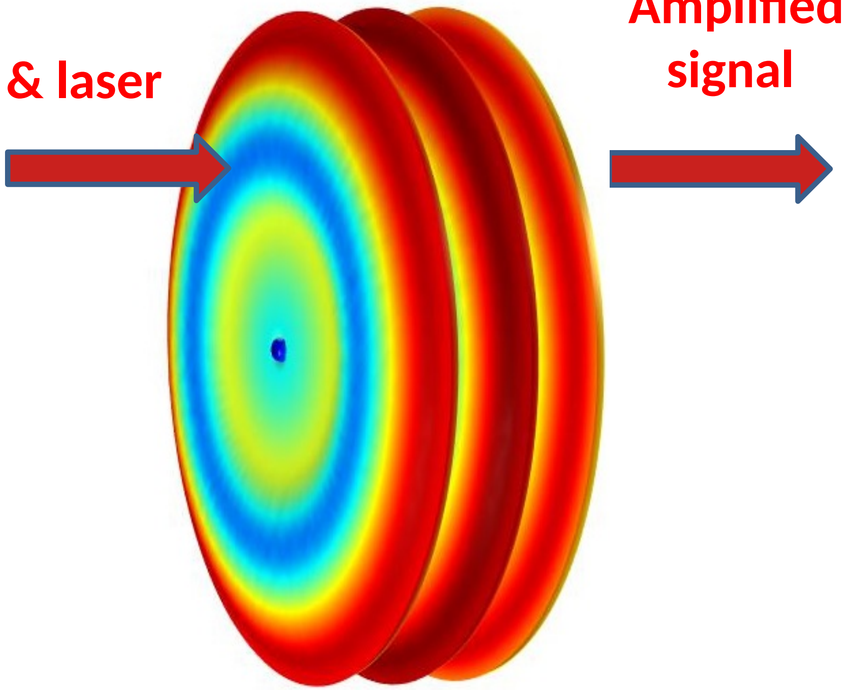
Rotating multi-slabs

Starting postulates :

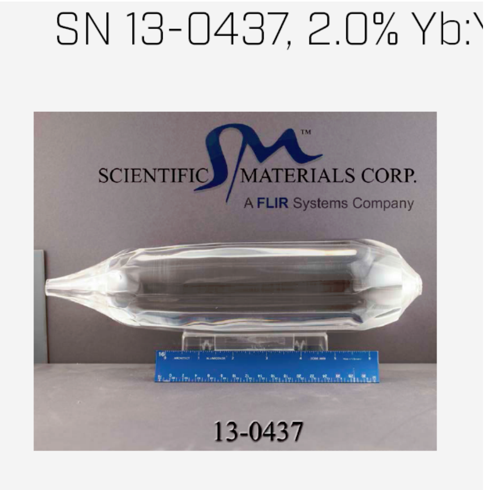
- 3 Yb:YAG slabs, d=70mm, e=2mm
- Heavy water face cooling
- Slab spacing : 500 µm
- Pump & laser through coolant

pump & laser

Amplified signal

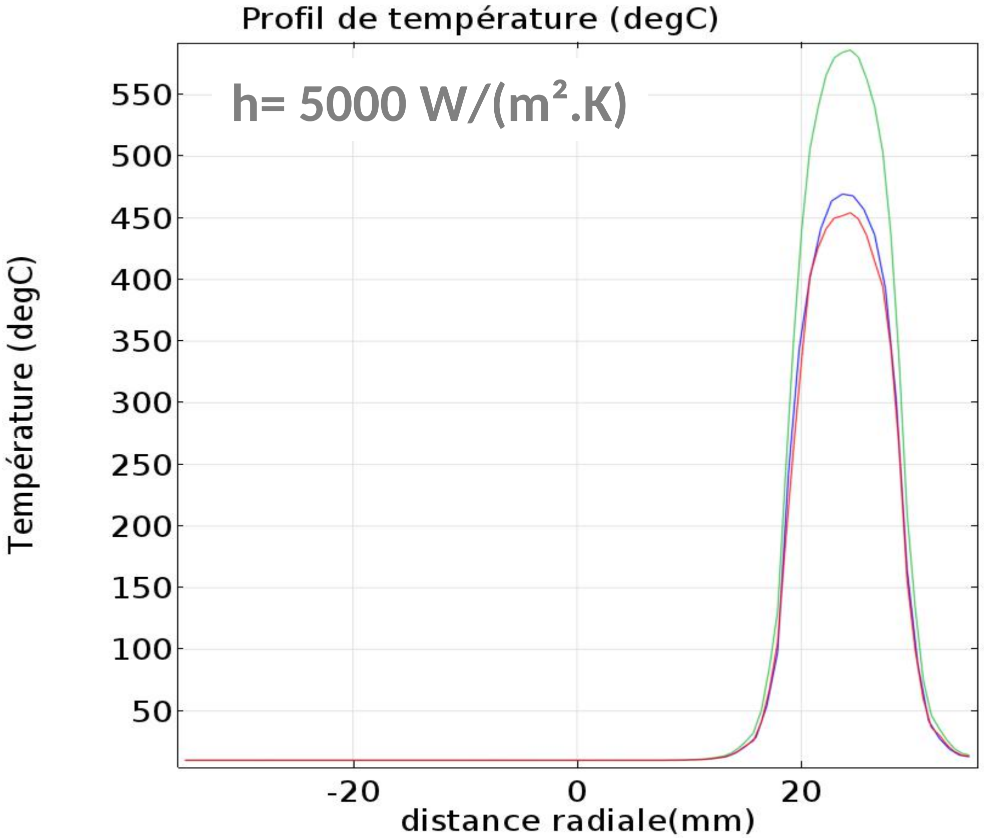


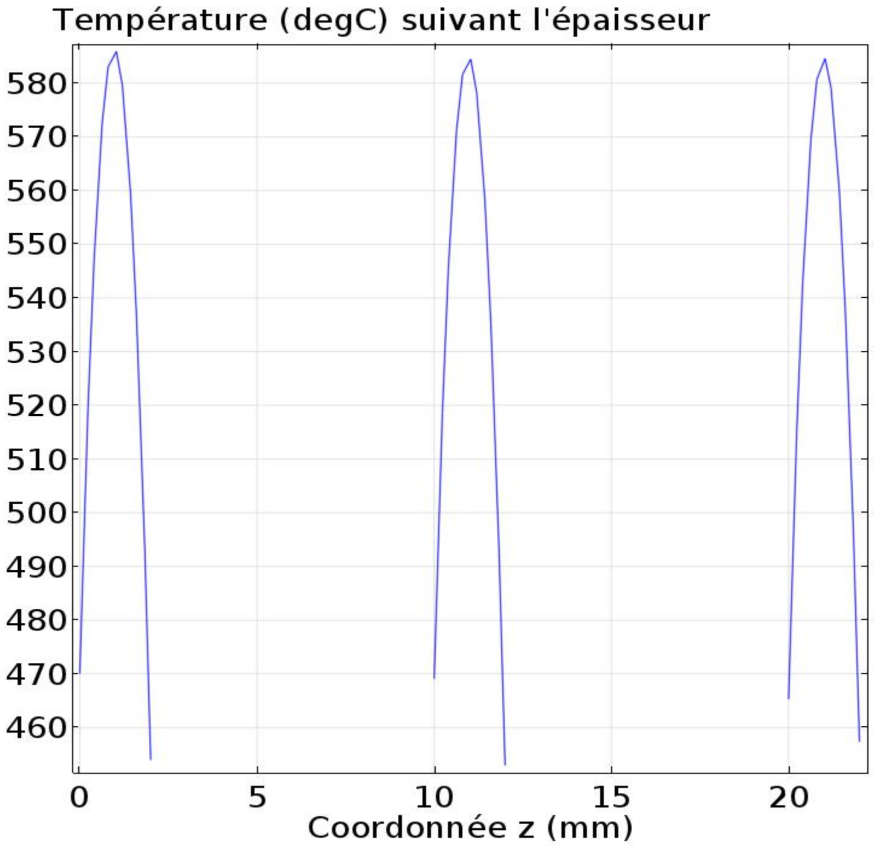
Slab procurement :
Scientific Materials



LEAP HORIZON

No rotation? *COMSOL modeling (thermal/hydro/optical)*

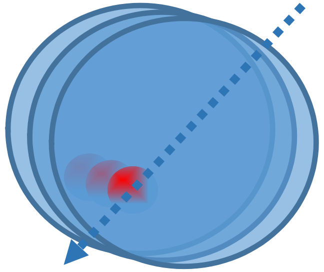




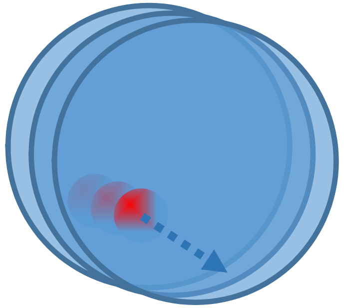
COMSOL MULTIPHYSICS®

Simulation parameters:

Pump P density: 16kW/cm²
Pump diameter: 10mm
Signal diameter : 8mm



Radial cut



Longitudinal cut

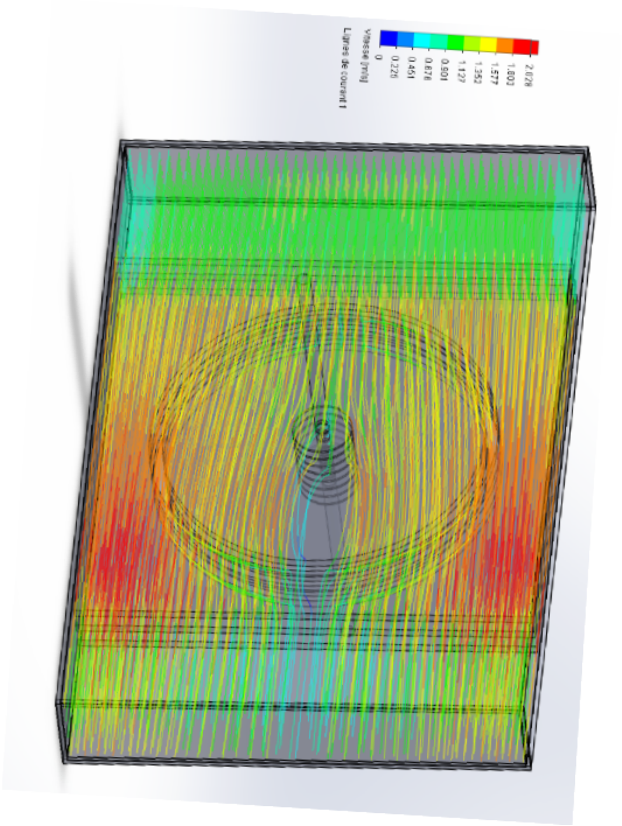
T max = 585 °C

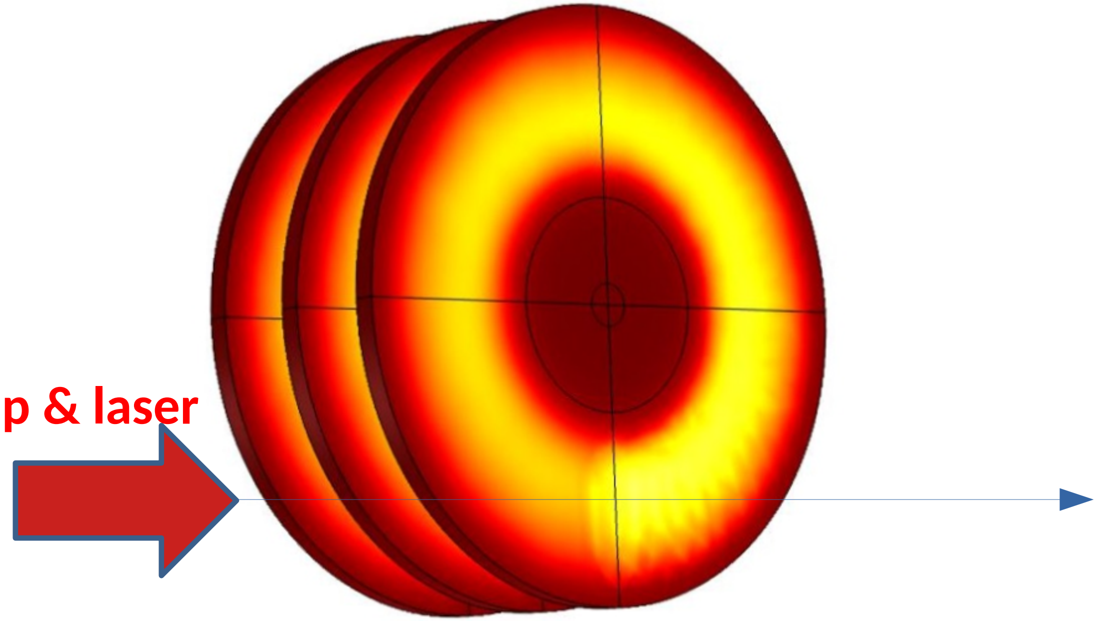
°C

LEAP HORIZON

How can you improve heat dissipation ?

Rotation of the multi-slab structure





-> Spread the thermal load on large ring

Extensive thermal and hydrodynamic modeling

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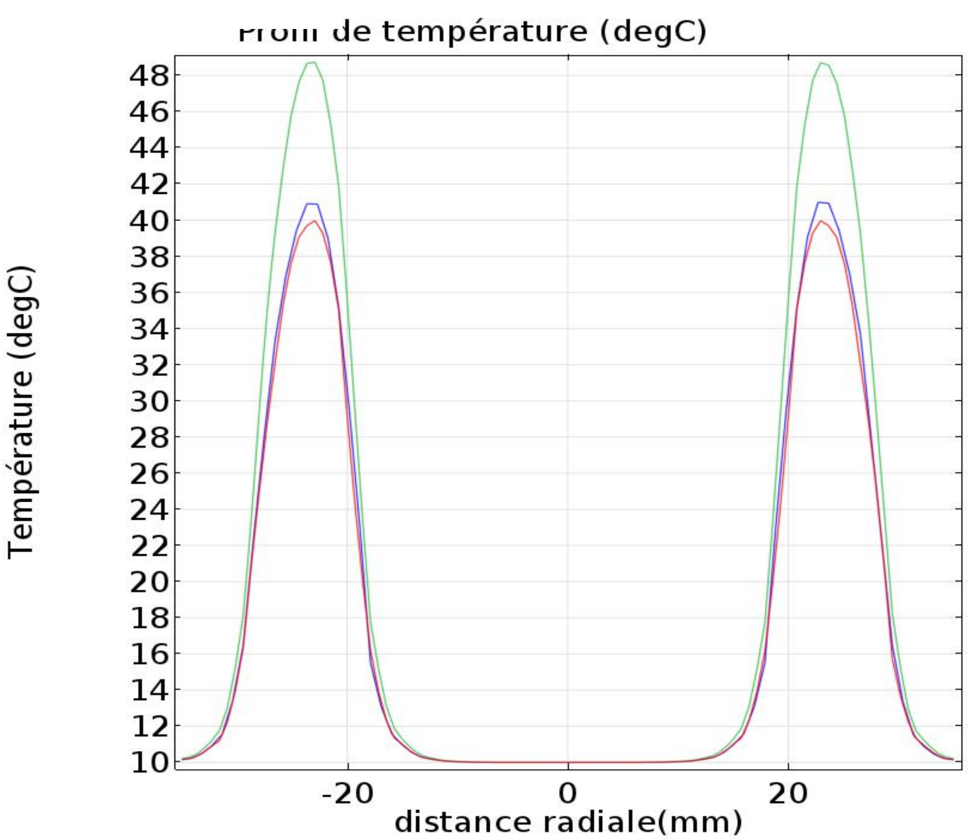
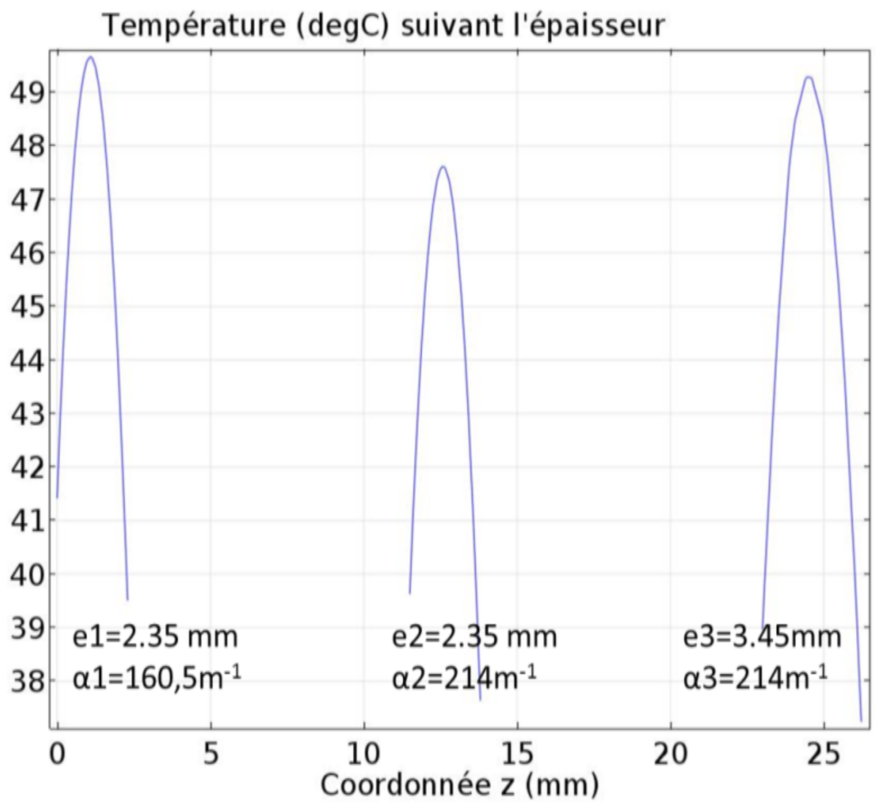
COMSOL simulation WITH **rotation**





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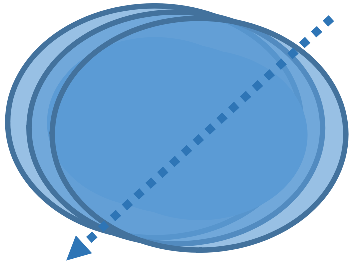
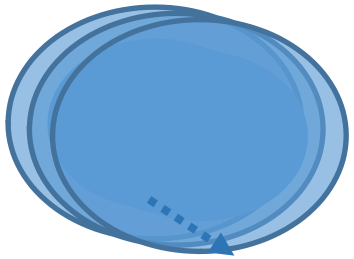
Rotation frequency : 2Hz

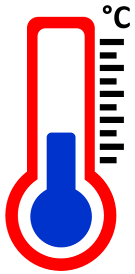


Radial cut



Longitudinal cut

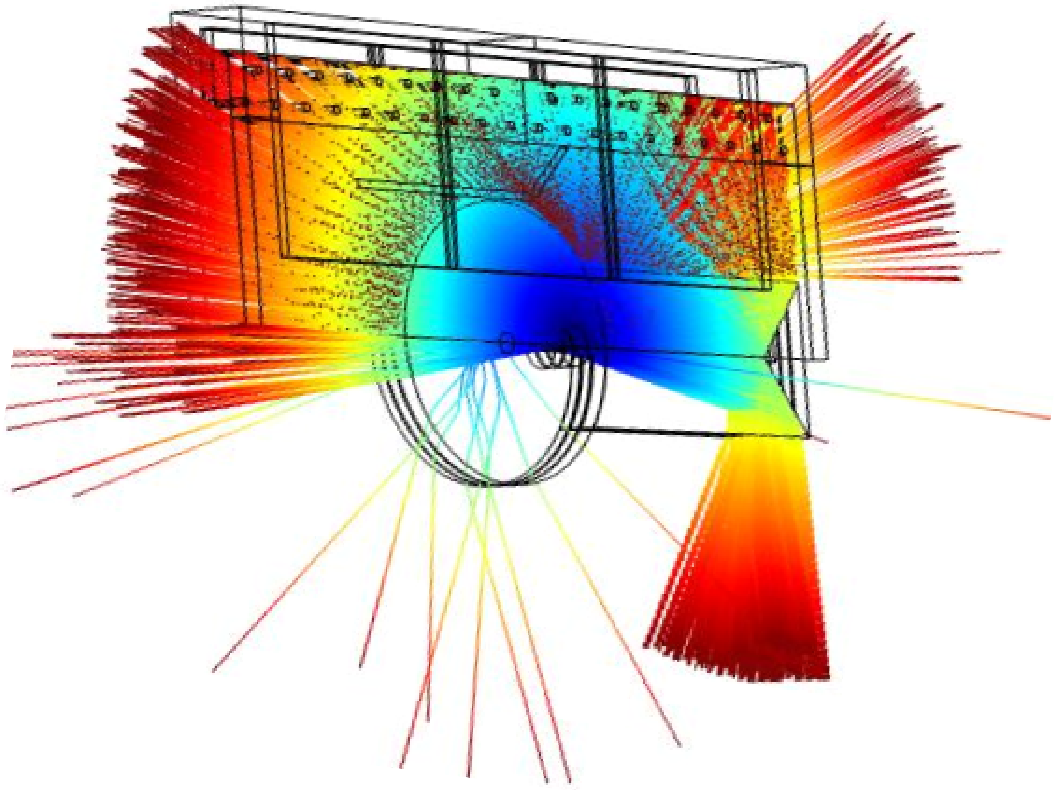
T max = 49 °C



LEAP HORIZON

ASE mitigation and transport :

Insertion of ASE waveguides next to lasing region



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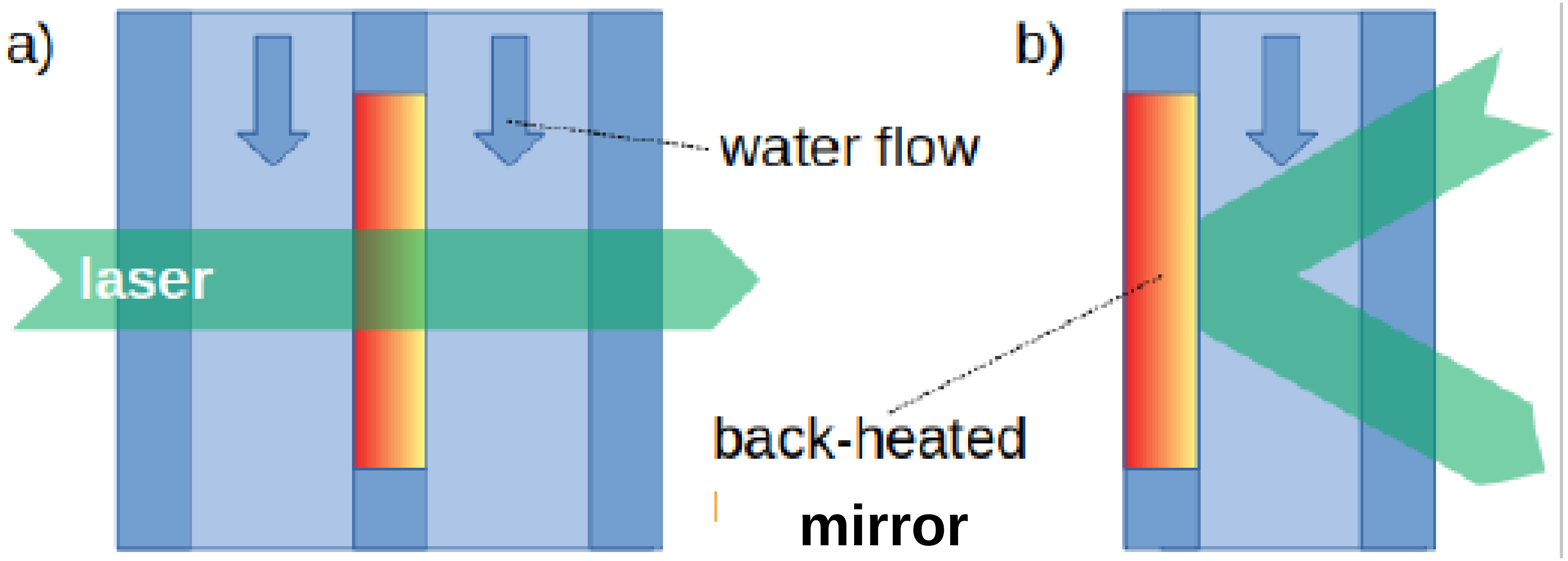
ray tracing

→ ASE energy transferred far from lasing region

Thermal & hydrodynamical study of liquid face-cooling

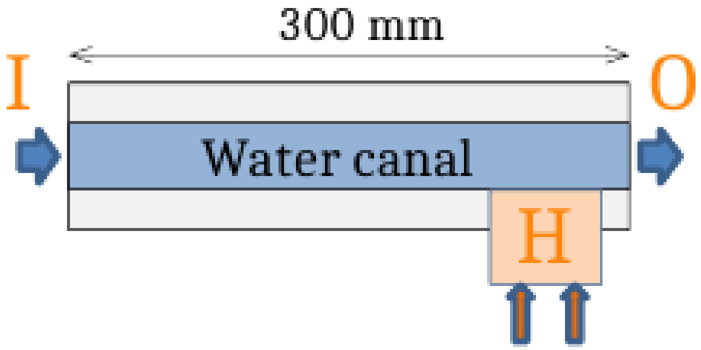
Face cooling : laser goes through the cooling fluid

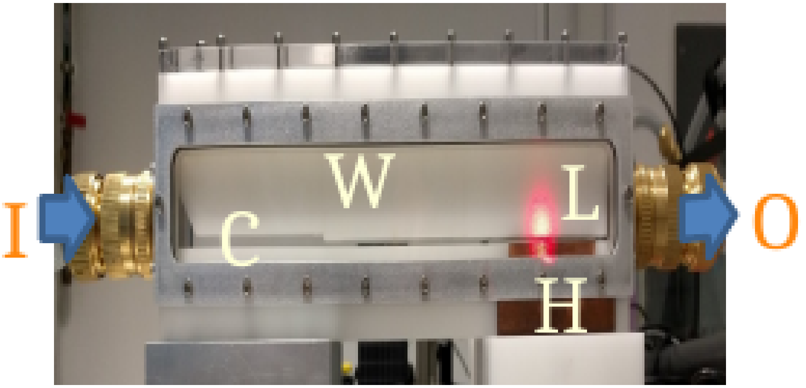
Is the flow regime laminar ?

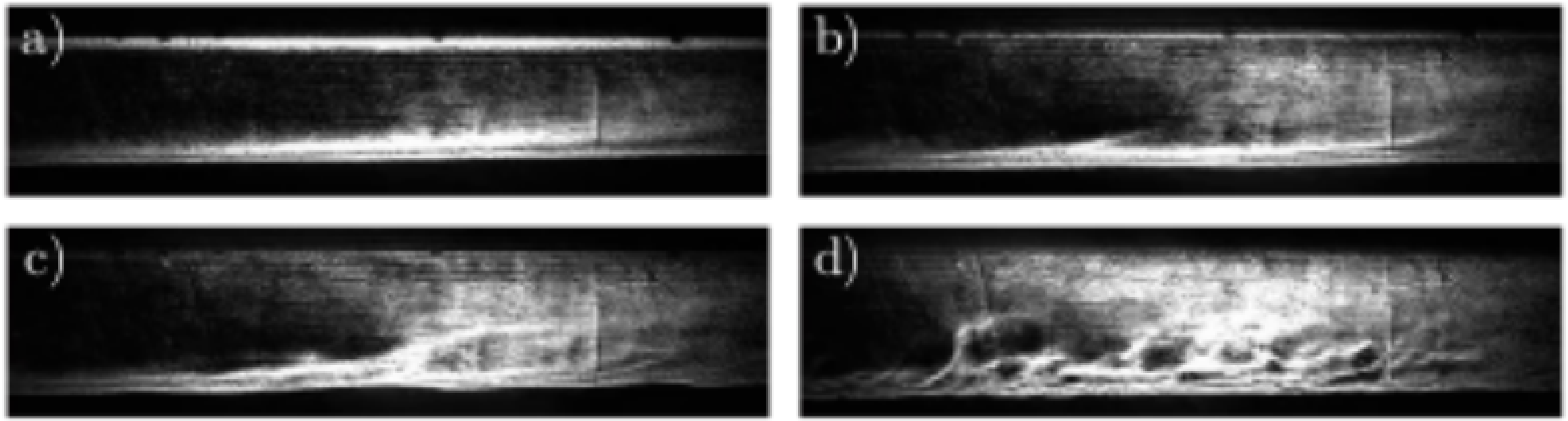


What happens in the coolant? “Waterbox” studies

Transverse imaging :





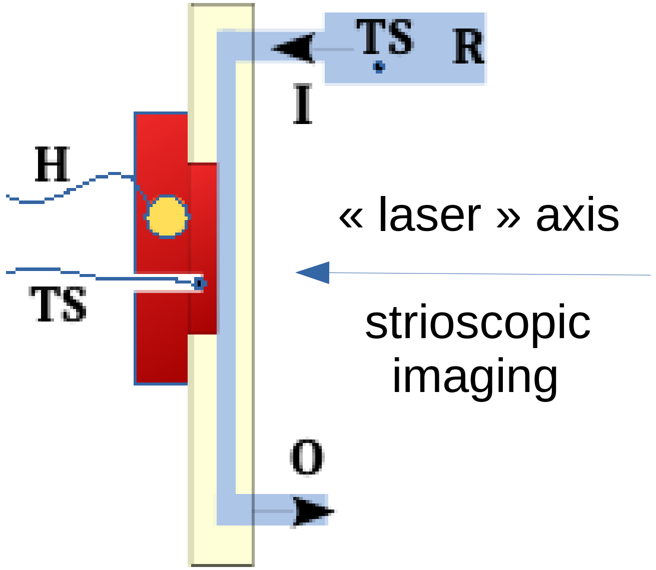


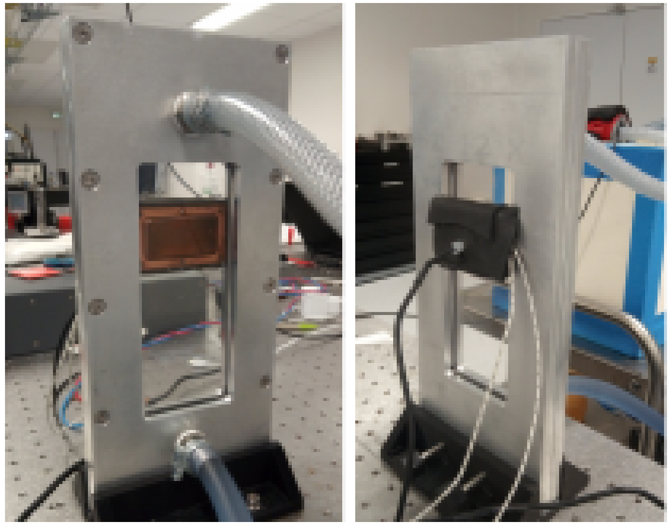
water flux

strioscopic imaging

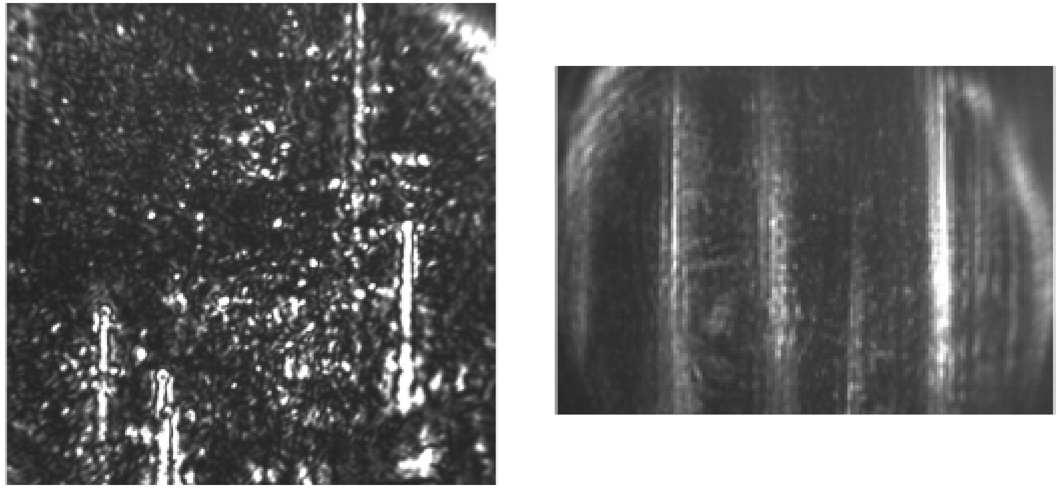
What happens in the coolant? "Waterbox" studies

imaging along laser axis :



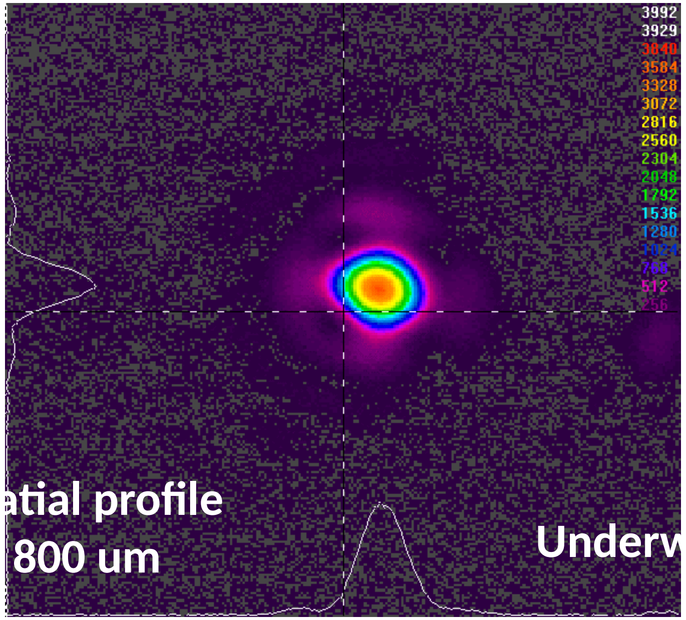


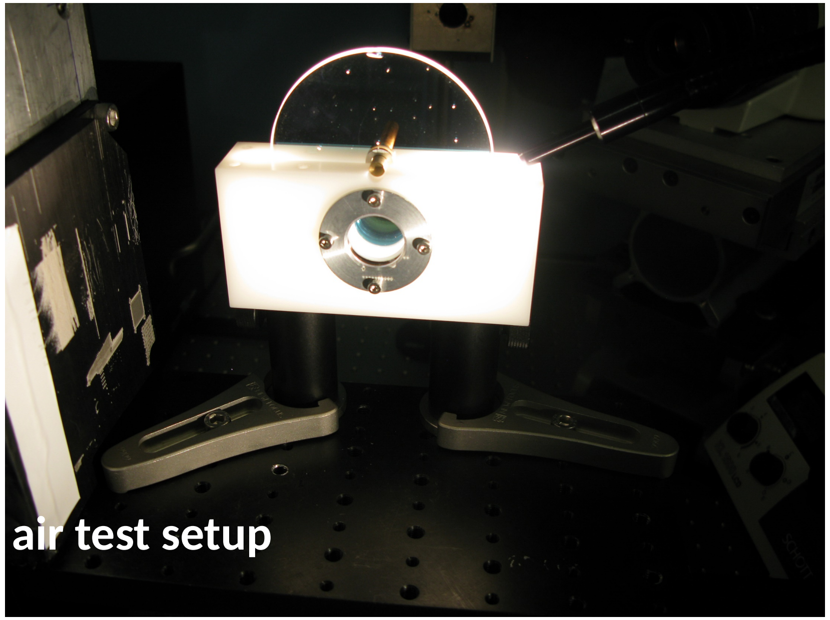
Appearance of a thermal streaking hydrodynamic instability :



Underwater LIDT campaign with CEA/CESTA

Collaboration with Laurent Lamaignère, CEA/CESTA/DLP/LMO





On average, LIDT is better underwater than in air !

→ opens the possibility to operate at higher fluences // better extraction

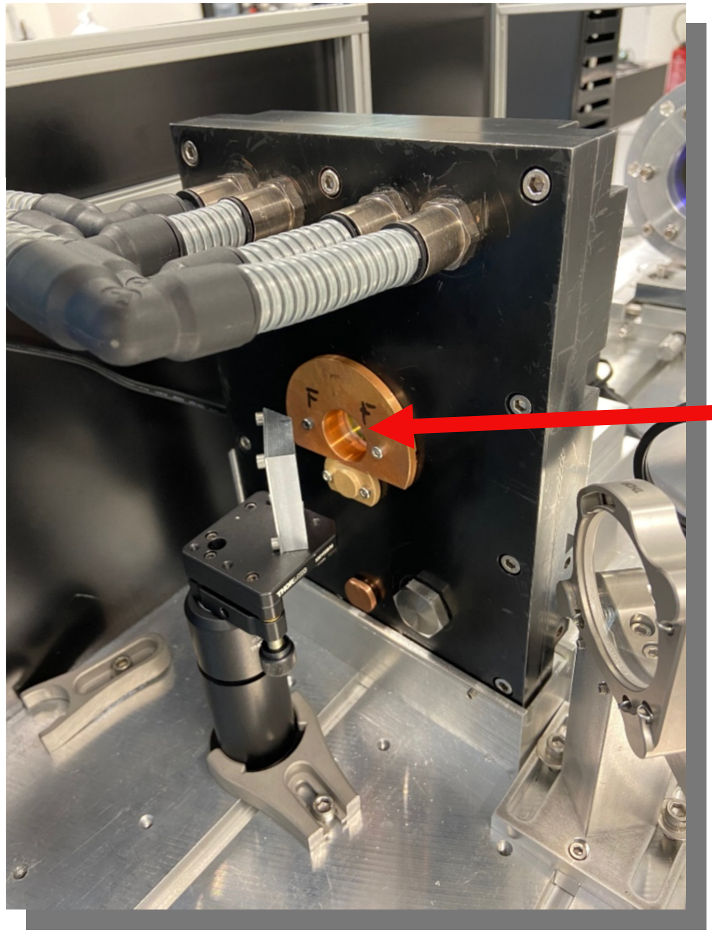
Lhermite, Lamaignere, et al. to be published

The rotating disk laser head

Water in

Water out

Water in



laser signal

Patent : INPI 1860215 // EP19790017.8A

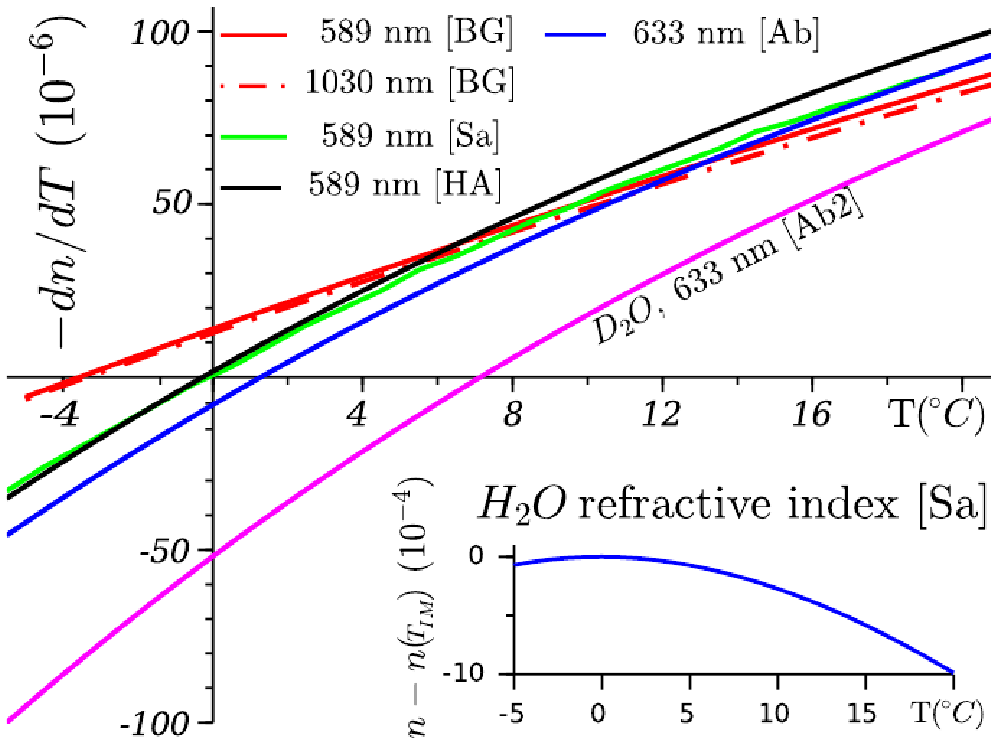
2018-11-06 (CNRS – Univ Bordeaux – CEA)

Inventors : C. Féral (CEA), J. Brandam (CNRS), J. Lhermite (CNRS), D. Marion (CEA)

Improvement? Face cooling by index leveling

Turbulence or hydro instabilities:

random mixing of « fluid particles » with different (T,P)



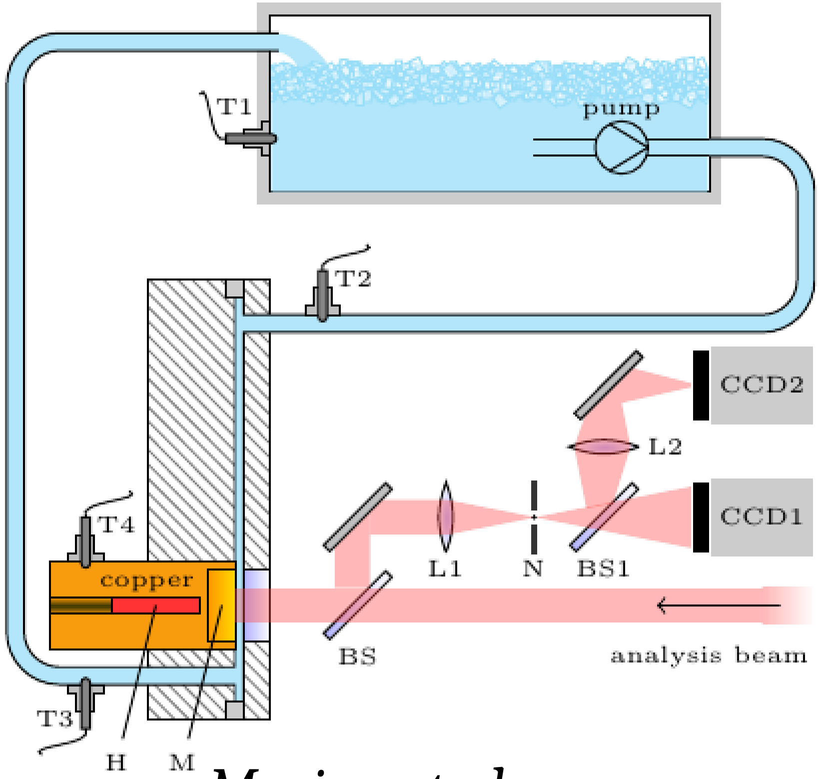
Hydro assumption : P ~ constant
→ dominant T effect
→ Main parameter : dn/dT

For water :
~ 0 °C, dn/dT ~ 0 !

→ **n independent of T :**
« index leveling »
→ **can it bleach index inhomogeneities ?**

Face cooling by index leveling

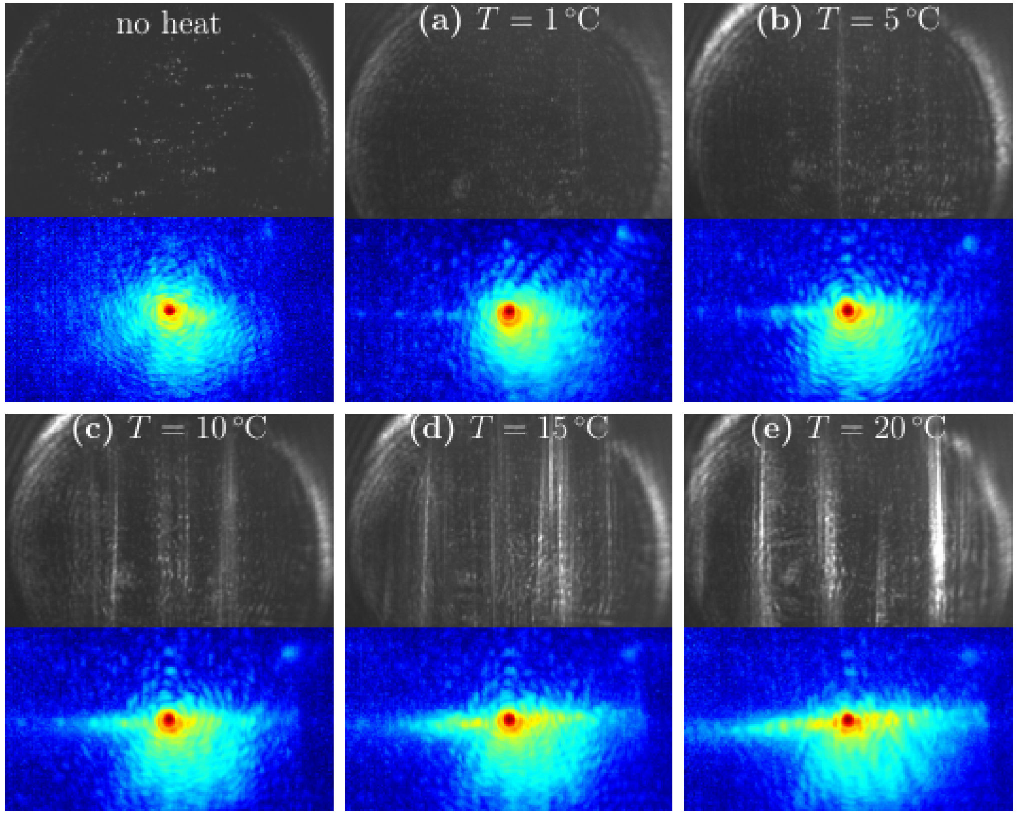
Optical test on an amplifier maquette



Marion et al.

Opt Lett. 47(11), 2850 (2022)

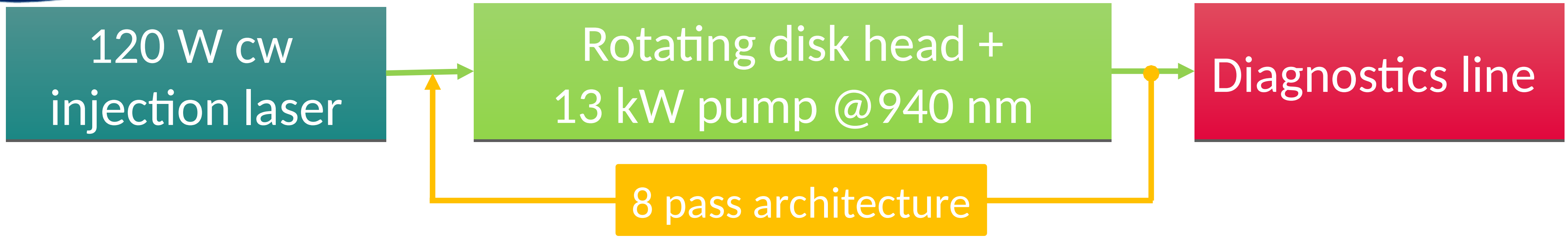
+ patent WO2023117482A1



- Same thermo-hydrodynamic conditions

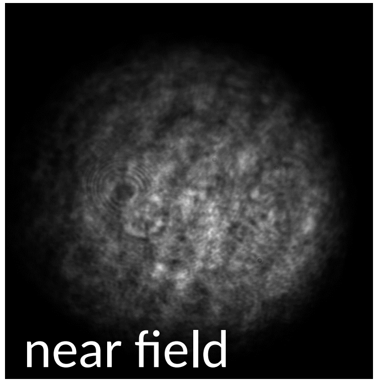
- Effective bleaching of streaks at index leveling

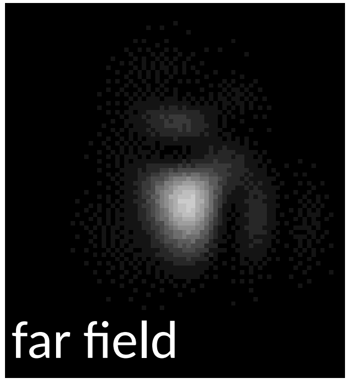
Amplification in cw regime



2,1 kW

- **Experimental data : 2.1 kW at 10 kW pump power**
- **Simulation results : 2.85 kW at 13 kW !**





100W

Few take-away messages from LEAP / HORIZON

- **New cooling techniques for multi-disks @ room T**
- **2.1 kW achieved in cw, >1 kW probable at kHz soon**
- **Start to understand the hydrodynamics of liquid cooling**
- **Index leveling should enhance output powers**
- **Scalable to other materials / working points (size, rep...)**
- **more to come ?**