EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA: THE WORLDWIDE FIRST 5GeV PLASMA-BASED ACCELERATOR WITH INDUSTRIAL BEAM QUALITY

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Forum ILP 15.06.2018

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

*on behalf of the laser work package of EuPRAXIA

Content

- The EuPRAXIA project
  - Accelerations strategies
  - EuPRAXIA laser systems
- Preliminary laser design
  - Main candidate components
  - Outstanding issues: possible solutions
- My Role: Transport and interaction point challenges
  - Compression → thermal issues
  - Focal spot stability and reproducibility → interface with users

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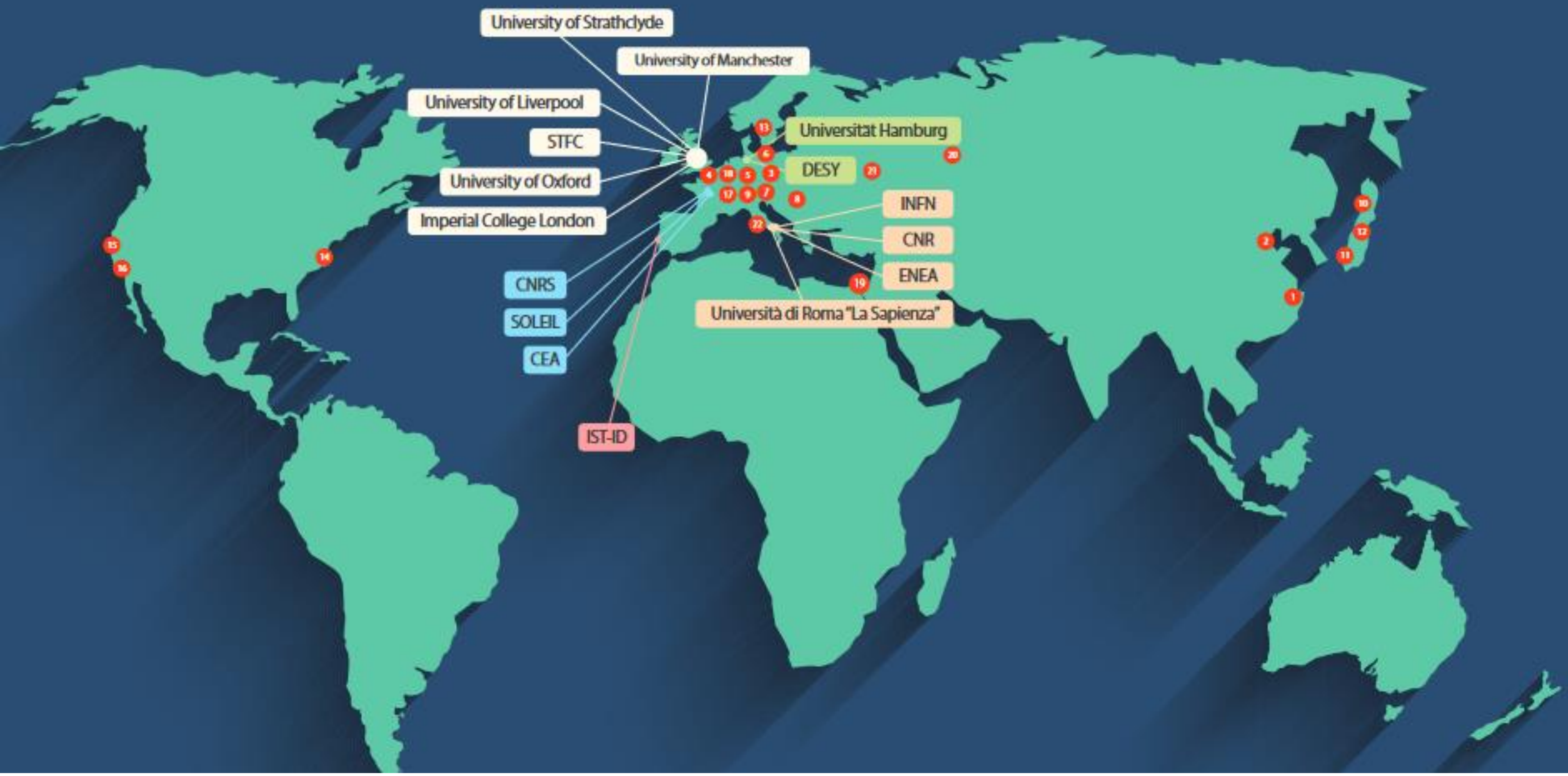
Collaborations

Horizon 2020

The EuPRAXIA Consortium is preparing a conceptual design for the world's first multi-GeV plasma-based accelerator with industrial beam quality and dedicated user areas.

EuPRAXIA brings together a consortium of 16 research institutions from 5 EU member states. The project, coordinated by DESY, is funded by the EU's Horizon 2020 programme. EuPRAXIA has been joined by 22 associated partners.



ASSOCIATED PARTNERS
(October 2016)

1. Shanghai Jiao Tong University, China
2. Tsinghua University Beijing, China
3. ELI – Extreme Light Infrastructure – Beamlines, International
4. PhLAM – Laboratoire de Physique des Lasers Atomes et Molécules, Université de Lille 1, France
5. Helmholtz-Institut Jena, Germany
6. Helmholtz-Zentrum Dresden-Rossendorf, Germany
7. Ludwig-Maximilians-Universität München, Germany
8. Wigner Fizikai Kutatóközpont, Hungary
9. CERN – European Organization for Nuclear Research, International
10. Kansai Photon Science Institute/Japan Atomic Energy Agency, Japan
11. Osaka University, Japan
12. RIKEN SPring-8 Center, Japan
13. Lunds Universitet, Sweden
14. CASE – Center for Accelerator Science and Education at Stony Brook University and Brookhaven National Laboratory, USA
15. LBLN – Lawrence Berkeley National Laboratory, USA
16. UCLA – University of California Los Angeles, USA
17. KIT – Karlsruher Institut für Technologie, Germany
18. Forschungszentrum Jülich, Germany
19. Hebrew University of Jerusalem, Israel
20. Institute of Applied Physics of the Russian Academy of Sciences, Russia
21. Joint Institute for High Temperatures of the Russian Academy of Sciences, Russia
22. Università degli Studi di Roma "Tor Vergata", Italy

Project timeline

09.2014	Proposal submission
07.2015	Approval
11.2015	**Start of EuPRAXIA project**
11.2016	First common study version of EuPRAXIA design
11.2017	**Mid-term**
08.2019	Application to **ESFRI roadmap** for 2020 update
10.2019	Final **conceptual design report** and end design study
2020+	*Construction decision*
> 2021 – 2025	*Construction*
> 2025 – 2035	*Operation*

Short time scale: **EuPRAXIA Laser design based on technology with high TRL**

Guideline: exploring extension of existing concepts and prototypes

EuPRAXIA WP4 - People

Horizon 2020

CNR – Italy

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Gian Carlo BUSSOLINO, INO-CNR, Pisa
Barbara PATRIZI, INO-CNR, Firenze
Guido TOCI, INO-CNR, Firenze
Matteo VANNINI, INO-CNR, Firenze

CNRS – France

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Zeudi MAZZOTTA, CNRS, Ecole Polytechnique (Eupraxia contract)
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Bruno LE GARREC, CNRS, Ecole Polytechnique
Audrey BELUZE, CNRS, Ecole Polytechnique
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Collaborators

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Amplitude Technologies: Franck FALCOZ

Thales Group: Christophe SIMON BOISSON, Sandrine RICAUD, Sebastien LAUX

Lawrence Livermore National Laboratory: Andy BAYRAMIAN, Constantin HAEFNER, Craig W. SIDERS, Tom SPINKA, K. CHESTNUT, E. ERLANDSON, T. GALVIN, K. SHAFFERS, E. SISTRUNK

Hamburg University: Oliver KARGER, Alexander KNETSCH

INFN LNF: Maria Pia ANANIA, Fabrizio BISESTO, Dario GIOVE, M. BELLAVEGLIA, S. GALLO

industries
laboratories
shaded major contributors/collaborators

EuPRAXIA Objectives

EuPRAXIA is a **conceptual design study** for a **5 GeV electron plasma accelerator** as a European research infrastructure. Goals:

1. Address **quality**. Show **plasma accelerator technology is usable**:
   - Incorporate established accelerator technology for optimal quality
   - Combine expertise from accelerator, laser labs, industry, international partners
   - Develop new technical solutions and a few use cases
2. Show **benefit in size and cost** versus established RF technology:
   - Proposed solutions must offer a significant benefit, e.g. fitting constrained spaces (small labs, hospitals) and/or must be less effective.
   - Cost benefits must include low operational costs (turn-key, industrial lasers at high repetition rate, cost-effective RF components, …): small team, remote OP, …

*Note: EuPRAXIA will initially be **low wall-plug power efficiency***

- *Efforts with **industry and laser institutes** to improve rep. rate & efficiency (incorporate all viable laser technologies with higher efficiency)*

Acceleration strategy three main laser systems

Starting point:

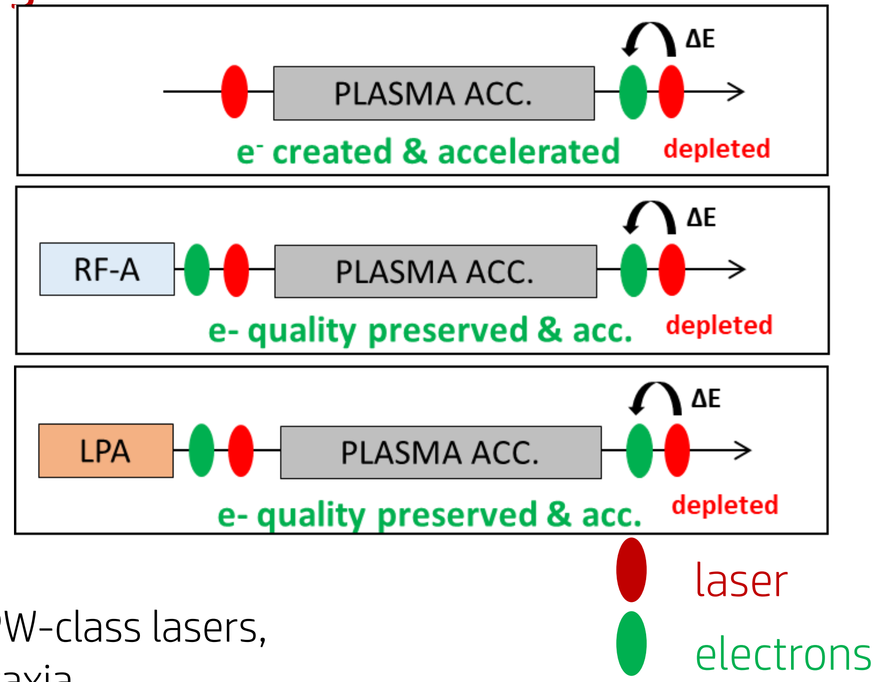
Laser system requirements emerged in WP 2 Physics and Simulation (A.Mosnier, L. Silva) and WP3 High Gradient Laser Plasma Accelerator Structure (B.Cros, Z.Najmudin)

Three main lasers envisaged:

Laser 1 : 150 MeV injector

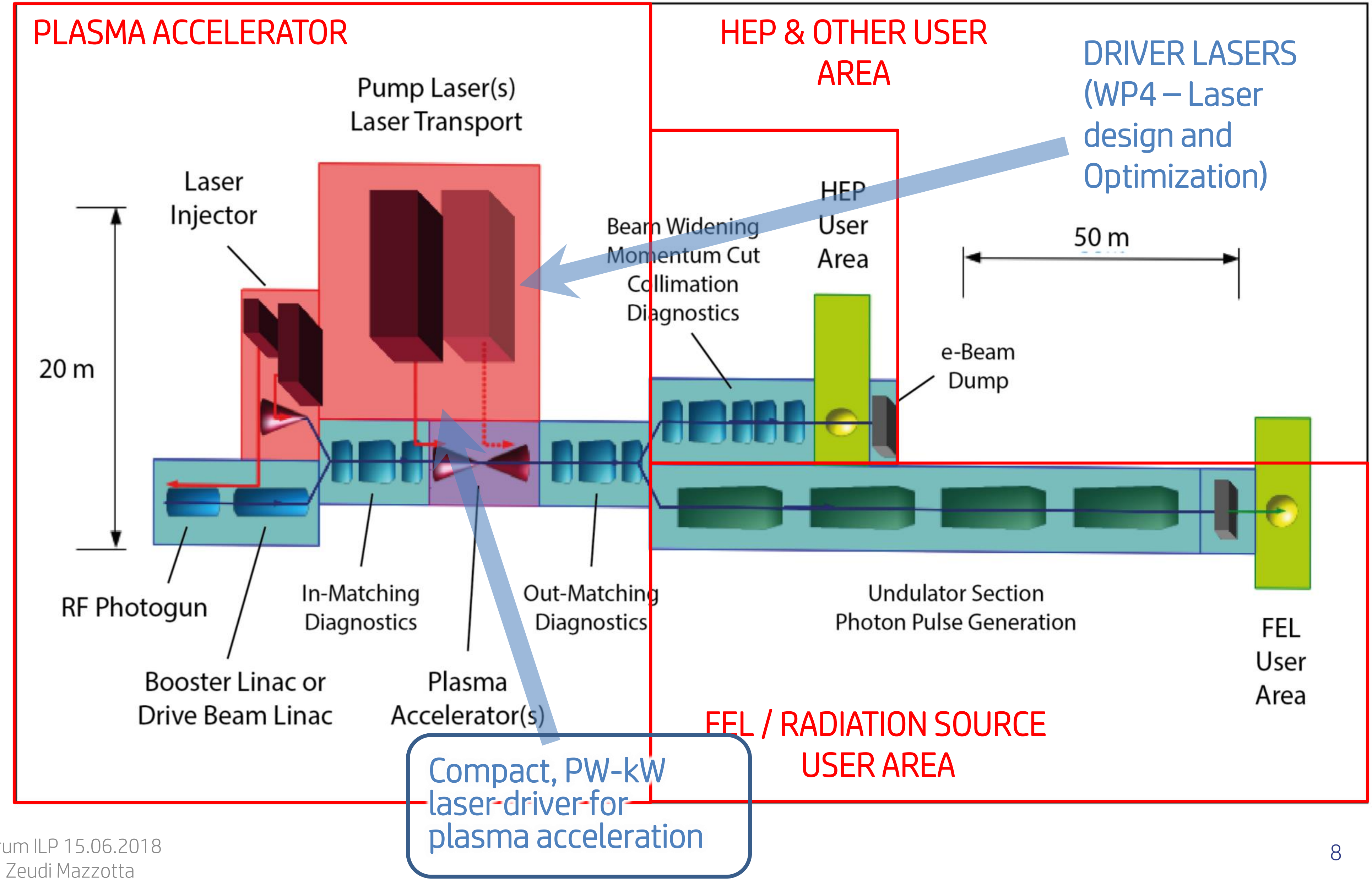
Laser 2 : 1 GeV injector

Laser 3 : 5 GeV accelerator



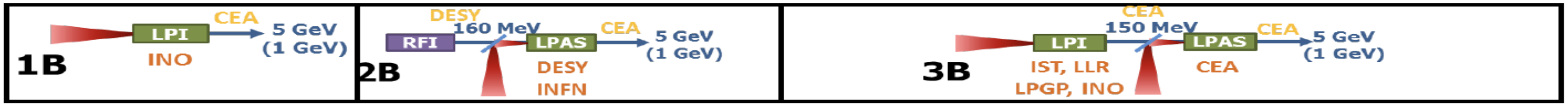
Strategy:

- Analysis of the available technologies for PW-class lasers,
- Comparison with the requirements of Eupraxia,
- Evaluation of the suitability for the given time frame for construction (<5 yrs)


PLASMA ACCELERATOR
HEP & OTHER USER AREA
DRIVER LASERS (WP4 – Laser design and Optimization)
Pump Laser(s) Laser Transport
Laser Injector
20 m
Beam Widening Momentum Cut Collimation Diagnostics
HEP User Area
50 m
e-Beam Dump
RF Photogun
In-Matching Diagnostics
Out-Matching Diagnostics
Undulator Section Photon Pulse Generation
FEL User Area
Booster Linac or Drive Beam Linac
Plasma Accelerator(s)
FEL / RADIATION SOURCE USER AREA
Compact, PW-kW laser driver for plasma acceleration

Laser-Plasma acceleration schemes under consideration (WP2)

EuPRAXIA — Horizon 2020



Final Energy	1B	2B	3B: 150 MeV	3B: 1Gev / 5 Gev
1 GeV	CNR-INO (P.Tomassini) DL: 0.9x8 J, 30 fs, 45 µm IL (2nd Harm.): 0.01 J, 38 fs, 3.5 µm delay 40 fs	DESY (E.Svystun & A.F. Pousa) 101 J 100 fs 54.4 µm INFN (Andrea Rossi) 6.4 J 110 fs 35 µm	IST-ID L. Silva & J. Vieira) 0.45 J 28 fs 8.4 µm CNRS-LLR (A. Beck) 10.5 J 28 fs 40 µm CNRS-LPGP (G. Maynard) 0.47 J 20 fs 16 µm CNR-INO (P.Tomassini)* DL: 0.7x4-0.3x8 J, 25 fs, 27 µm IL (3omega): 0.02 J, 30 fs, 4.2 µm delay 47 - 49 fs; *N2-Ar	CEA (X. Li & P. Nghiem) Quasi - linear: 15J, 1080 fs, 55 µm Bubble:
5 GeV	CNR-INO (P.Tomassini) DL: 2.2x8 J, 50 fs, 60 µm IL (3rd Harm.): 0.02 J, 60 fs, 3.5 µm delay 102 fs	DESY (E.Svystun & A.F. Pousa) 45.6 J 70 fs 50 µm INFN (Andrea rossi) 25.6 J 110 fs 70 µm		CEA (X. Li & P. Nghiem) Quasi - linear: 53J, 130 fs, 55 µm Bubble: 75 J, 108 fs, 48 µm

energy (J)
duration (fs) FWHM
waist (µm)

150 Mev
1GeV
5GeV

nothing proposed for the 4B

Large BW (≈30 fs) required for injector/1GeV stage. May be relaxed (≈50 fs ->100fs) for 5GeV stage.
That could be not compatible with many available direct CPA schemes (Nd, Yb).
MULTI-PULSE drivers attracting increasing attention.

Laser-Plasma acceleration schemes under consideration (WP2)

100 Hz

Final Energy

1 GeV

CNR-INO (P.Tomassini)		DESY (E.Svystun & A.F. Pousa)	IST-ID L. Silva & J. Vie
DL	IL (2nd Harm.)		
0.9x8 J	0.01 J	101 J	0.45 J
30 fs	38 fs	100 fs	
45 µm	3.5 µm	54.4 µm	
delay 40 fs			

INFN (Andrea Rossi)
6.4 J

CNRS-L

CNR-INO
DL
0.3x8 J
5 fs
7 µm
4.2 µm
delay 47 - 49 fs; *N2-Ar

energy (J)
duration (fs) FWHM
waist (µm)

LNF
500 M

150 MeV

1GeV

5 GeV

60 µm

50 µm

INFN (Andrea rossi)
25.6 J
110 fs
70 µm

CEA (X. Li & P. Nghiem)	
Quasi - linear	Bubble
53J	75 J
130 fs	108 fs
55 µm	48 µm

Large BW (≈30 fs) required for injector/1GeV stage. <u>May be relaxed (≈50 fs ->100fs) for 5GeV stage.</u>
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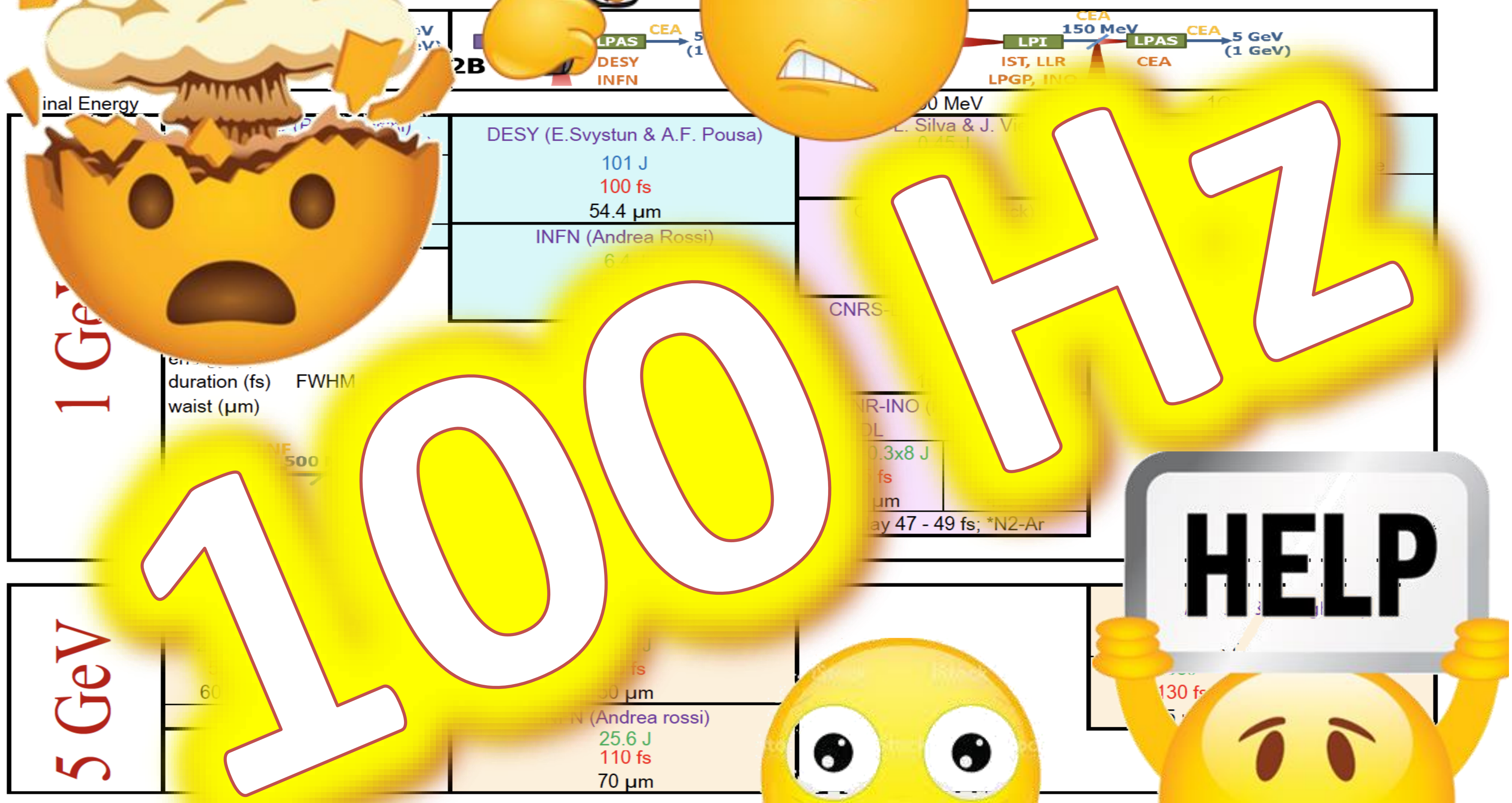
MULTI-PULSE drivers attracting increasing attention.

Laser-Plasma a ation schemes un n (WP2)

Horizon 2020



Large BW (s) required for injector/1GeV stage. M elaxed s ->100fs)
That could be not compatible with many avai schemes (Nd,
MULTI-PULSE drivers attractin reasing att n.

Three laser systems
Requirements

Produce a credible laser design to meet project specifications for a PW-class system, with demanding high average power (>1 **kW,** ideally 10 kW**)**

Laser 1 : 150 MeV injector→ 7J, 100 Hz, 25 fs

Laser 2 : 1 GeV injector→ 30J, 100 Hz, 30 fs

Laser 3 : 5 GeV accelerator→ 100J, 100 Hz, <100 fs

Major effort required to fill the gap between existing and required laser technology

Amplification strategy

TWO POSSIBLE SCENARIOS identified:

- Medium risk: **TiSa with DPSSL pump lasers**;
- High risk: **Direct CPA with new materials** (surely required for >100Hz);

Scenarios matching large programs at other institutions (e.g. LLNL, LBNL, STFC ...);

Is it possible to scale existing systems?

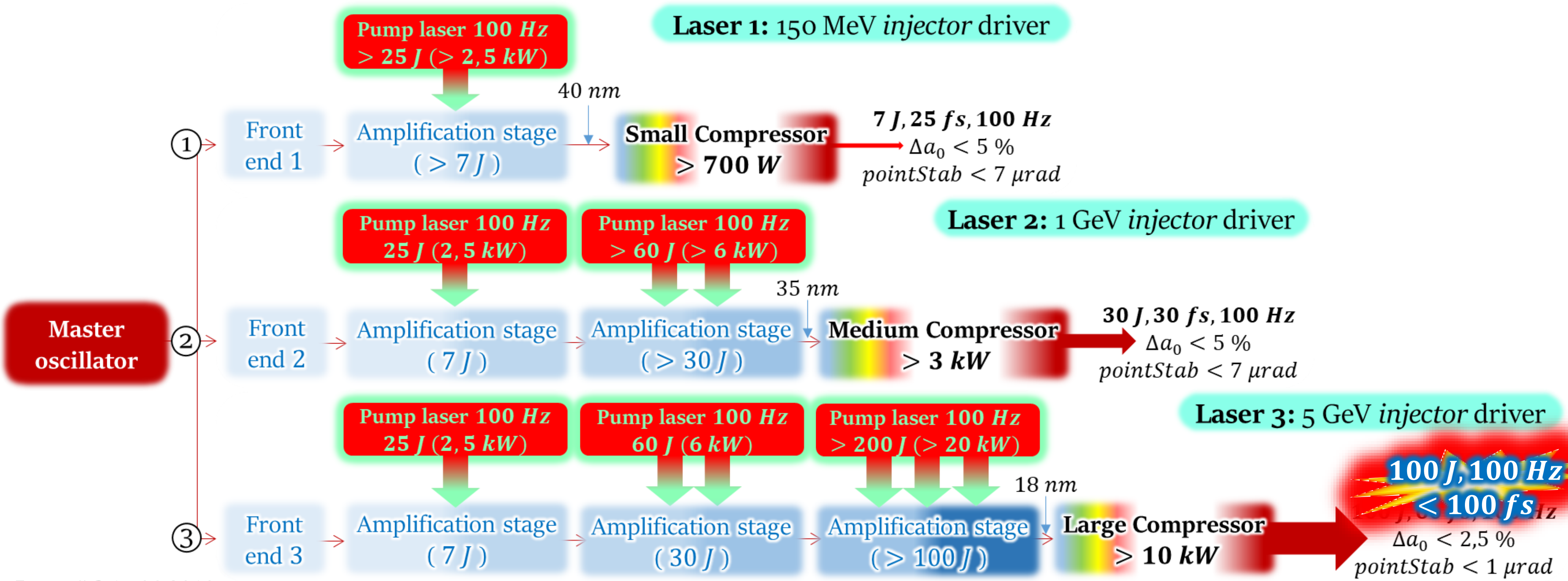
Horizon 2020

EuPRAXIA laser systems:

Laser 1 : drive a 150 MeV injector
Laser 2 : drive a 1 GeV injector
Laser 3 : drive a 5 GeV accelerator

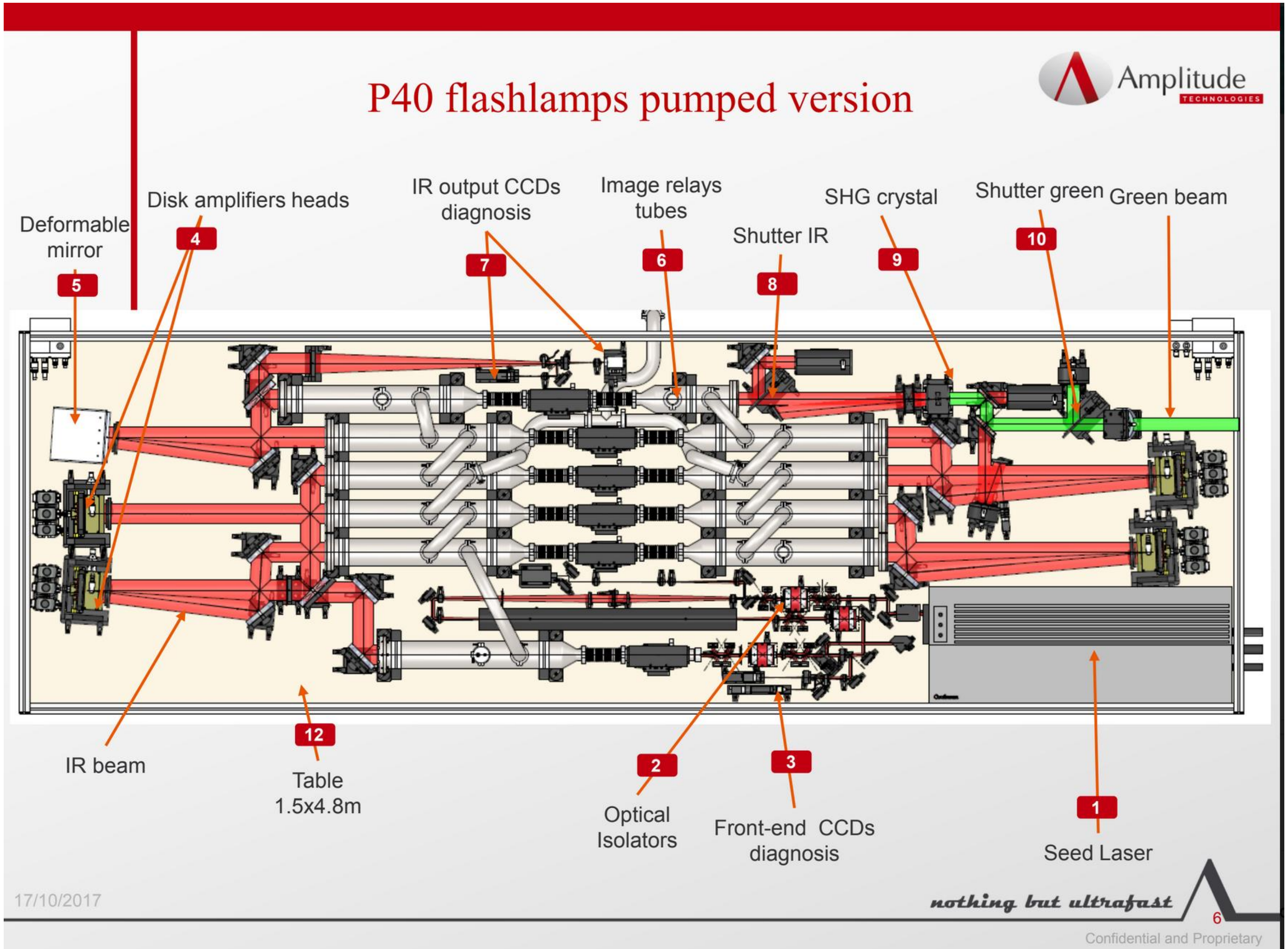
MAIN CHALLENGES

- Pumping technology (High rep. rate, high energy)
- Gain media (Bandwidth, Dimensions, Thermal load, Cooling)
- Grating technology (Dimensions, LIDT, Thermal load, Cooling)
- Pointing stability (Transport)



INDUSTRIAL SUBSYSTEMS pump lasers – P60 Amplitude

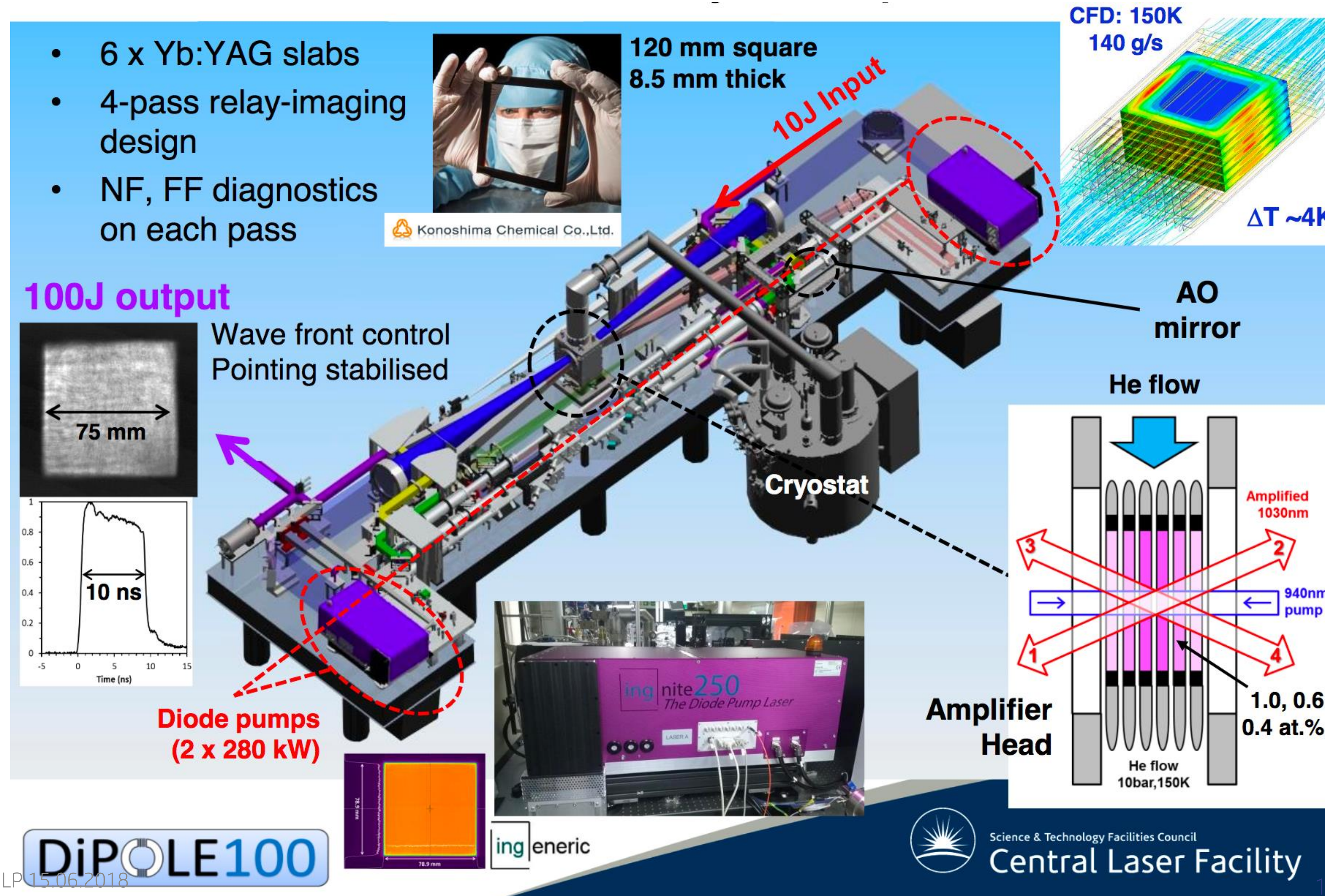
Industrial unit (P60): conversion to diode pumping fully designed



Flashlamp pumped Nd:YAG/
DPSSL possible
60 J @ 5 Hz, @532 nm
40 J @10 Hz @ 532 nm

- Cost of diode still an issue – currently 5x total (including operational) costs compared to flashlamps.
- Expected to decrease in 5-10 yrs.
- Maintenance free operation for 25-30 yrs.

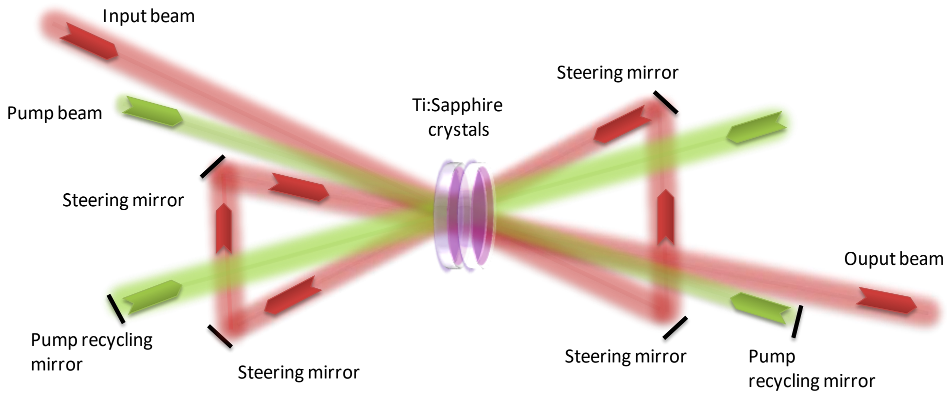
INDUSTRIAL SUBSYSTEMS pump lasers – DiPOLE 100



Amplification: Thermal management

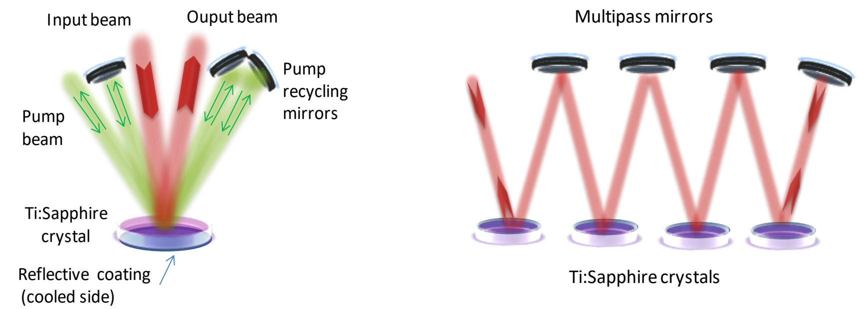
Transmission vs. "active mirror" configuration is currently being evaluated to account for thermal management

Transmission geometry

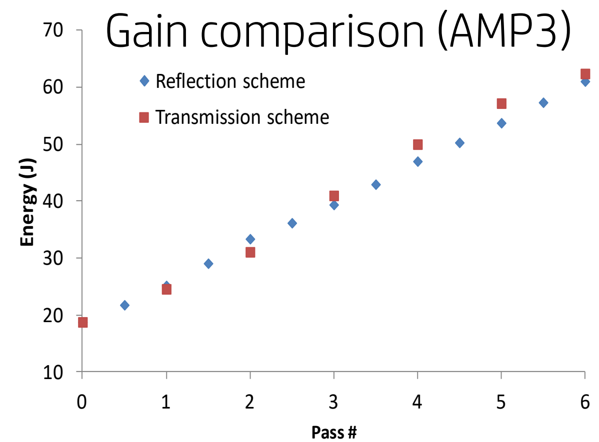


Pro: More efficient (double-side) cooling and reduced complexity;
Con: propagation through flowing cooling liquid

"Active mirror" geometry



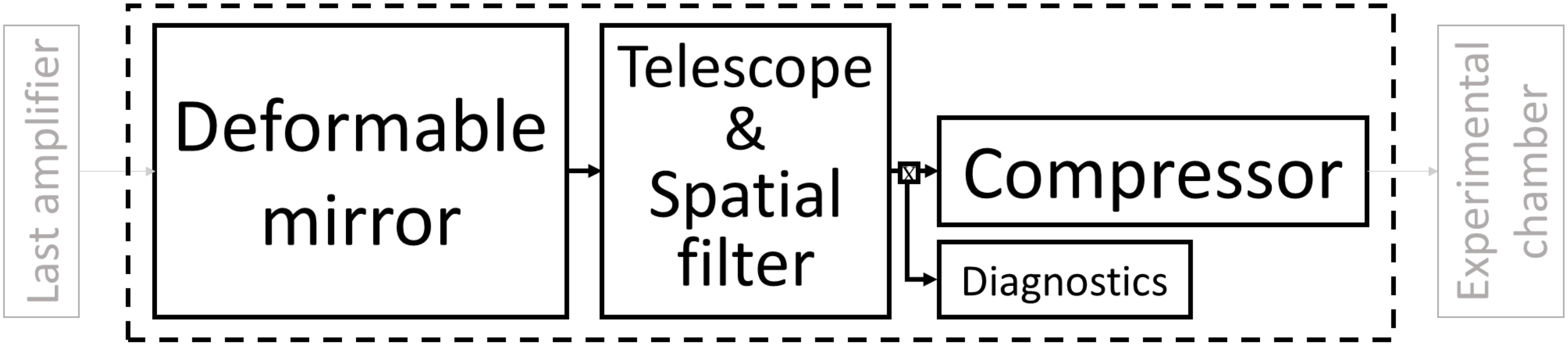
Pro: Well established concept with no propagation through cooling fluid
Con: limited cooling (single face), to be modelled

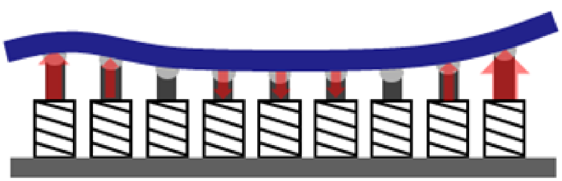


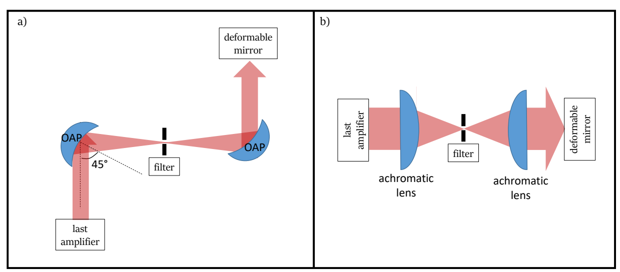
*) Water cooled Ti:Sa amplifier ("Active Mirror" configuration) under development at ELI-HU (After V. Cvhykov *et al.* , Opt. Lett, **41**, 3017, 2016)
) Fluid (D_2O) cooled Nd:YAG laser, 20 kW CW pump power, D_2O (After X. Fu *et al.* , Opt. Express, **22, 18421 (2014)
***) Fluid (Siloxane) cooled Nd:YLF laser, 5 kW CW pump power (After Z. Ye *et al.* , Opt. Express, **24**, 1758 (2016)

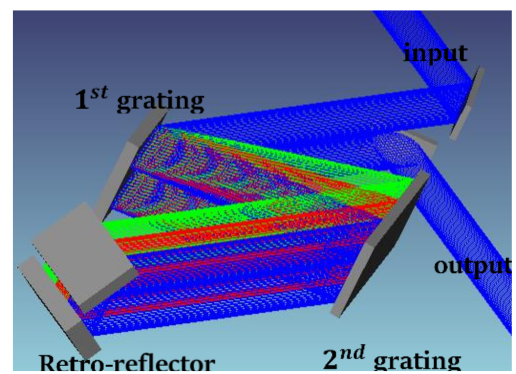
My role
Transport to the target

Main challenges: large optics, mechanical stability, cooling of gratings, beam quality control …









Compressor issues

At each compressor we will arrive with an average power of :

- Injector 150MeV
  - **1,2 kW** (12J @ 100Hz), needed 25 fs after compression (38nm bandwidth), spectral acceptance required: 120 nm
- Injector 1GeV
  - **5 kW** (50J @ 100Hz), needed 30-35 fs after compression (32nm bandwidth), spectral acceptance required: 100 nm
- Accelerator 5GeV
  - **16 kW** (160J @ 100Hz), needed 60 fs after compression (18nm bandwidth), spectral acceptance required: 60 nm

LIDT determines the laser fluence arriving on the compressor: $100mJ/cm^2$. This sets the value of the average intensity reaching the three compressors: $\mathbf{10\ W/cm^2}$

Focal spot characterization

Two purposes

characterization of

Spatial profile

Instabilities

$\Delta r, \Delta\theta$

To determine

Strehel Ratio

Dimension $\boldsymbol{w}$

To implement

To implement

Corrections

In order to reach a high quality beam profile and maximize the encircled energy

To determine

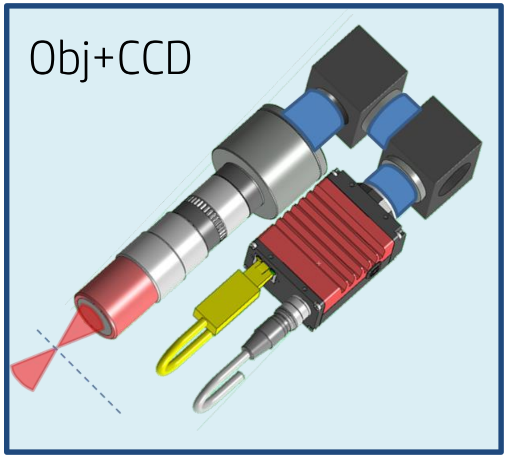
Intensity

Active and/or passive stabilisation

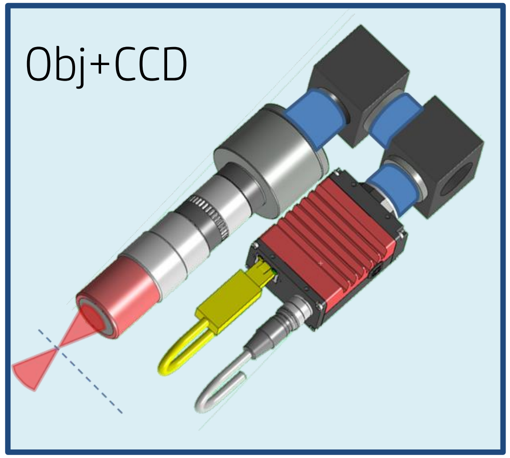
In order to stay below pointing stability requirements

How to measure

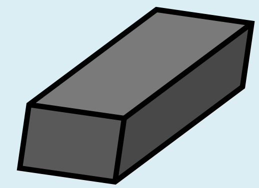
Spatial profile ↔ Instabilities $(\Delta r, \Delta\theta)$



To place at the focal plane



To place at the focal plane



Nouveau module pour measurer
<<1µrad, >>10Hz

To place wherever on the chain

Active and/or passive stabilisation

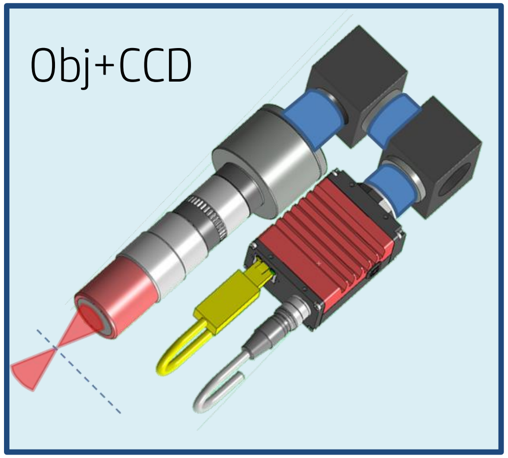
In order to stay below pointing stability requirements

Tip-tilt

Mechanical action on mountings: measure the stabilization **before** and **after** the intervention.

Ongoing measures (APOLLON)

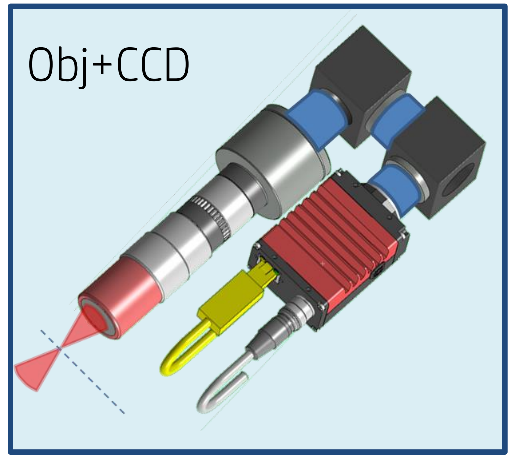
1) Compact module
< 20 cm x 10 cm

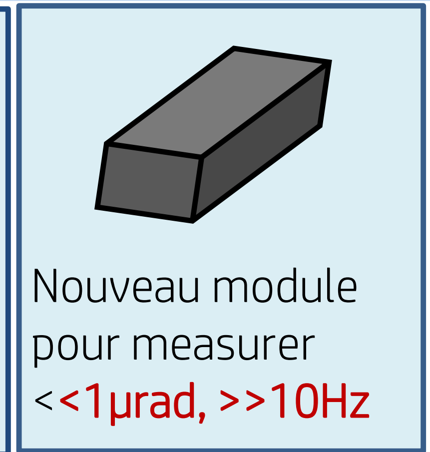


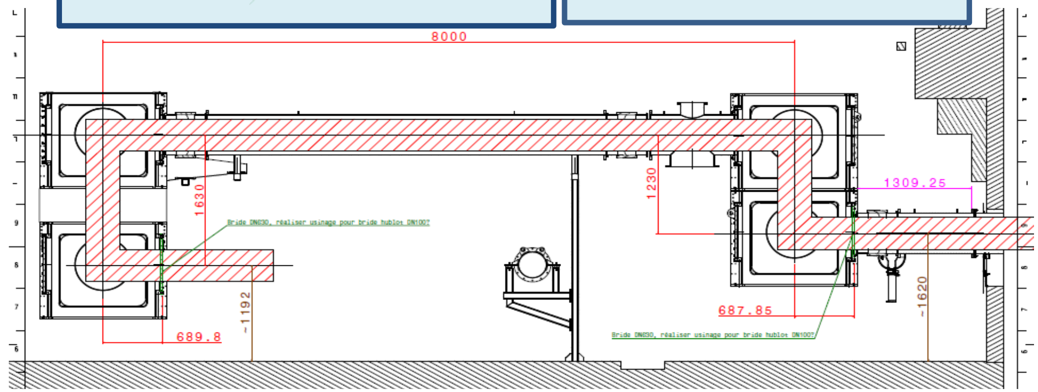
Test under vacuum of the complete module

Objective and other components already tested. To test: the camera (temperature and degassing) and the cabling (degassing and, also, resistance to irradiation) (kapton cables failed the tests due to the glues used by the company)

2)



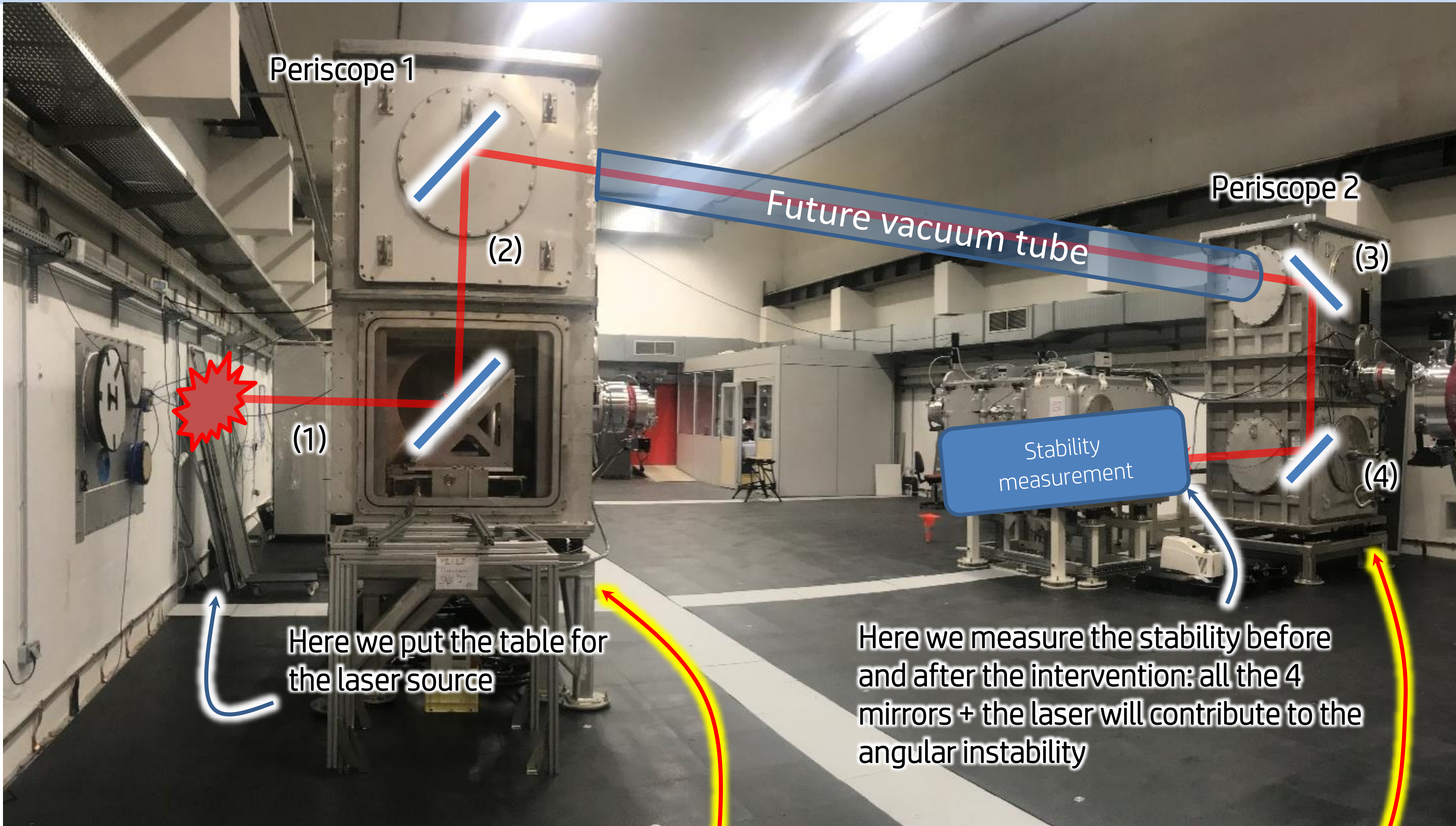


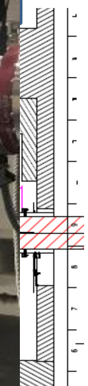


ISP intervention on the two big periscopes in APOLLON

Measure before and after the intervention with both modules, for a first real test of the new module and a doule check of respective performances. **ISP foresees a 10x improvement in the mechanical stability of the periscopes.**

Ongoing measures (APOLLON)





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ule

cables failed the tests due to the glues used by the company)

check of respective performances. ISP foresees a 10x improvement in the mechanical stability of the periscopes.

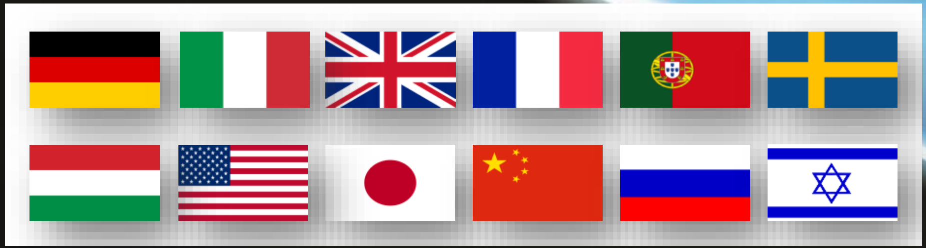
MAIN GOAL

Delivering industrial quality 5GeV electron beams to the users

Conclusion

Main challenges

- **100 Hz => Pumps? & Thermal issues**
  - For the active medium
  - For the compressor and the optics in general
- **Stability => measure and correction**



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Thanks to
- Staff Apollon
- STAFF LULI

EuPRAXIA

Thank you for your attention