EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

# WP12 – Laser Technology and Liaison to Industry

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# Preparatory Phase - WP12

Funded by the European Union

## Technical WP's Main Goals

**Update of CDR** concepts and parameters, towards technical design (full technical design requires more funding)

Specify in detail **Excellence Centers and their required funding**: TDR related R&D, prototyping, contributions to construction

Help in defining funding applications for various agencies

**Main Objective of WP12 / duration 48m :**
This is the Laser Technology R&D WP, dealing with all aspects required to target and address laser needs for EuPRAXIA

**As one of the TECHNICAL WPs of PP, WP12 should:**
- Make progress towards the technical design of the laser-driver for the 2nd laser-driven site;
- strengthen the role of industry to enable the delivery of a robust laser-driver to enable reliable and affordable operation;

**Effort**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Work package number | 12 | | | Lead beneficiary | | CNR | | |
| Work package title | Laser Technology and Liaison to Industry | | | | | | | |
| Participant number | 1 | 2 | 9 | 10 | 11 | 16 | 20 | 23 |
| Short name of part. | INFN | CNR | THAL | DESY | FBH | USZ | STFC | ELIBL |
| Person months per part.: | 0 (+12) | 18 (+30) | 0 (+4) | 6 (+6) | 6 (+2) | 0 (+6) | 0 (+12) | 18 (+6) |
| Participant number | 27 | 32 | 34 | | | | | |
| Short name of part. | CLPU | ILT | EMPA | | | | | |
| Person months per part.: | 0 (+2) | 0 (+1) | 0 (+56) | | | | | |
| Start month | 1 | | | End month | 48 | | | |

# Deliverables

| Del no. | Deliverable Name | WP no. | Beneficiary | Type | Diss. level | Due month |
|---|---|---|---|---|---|---|
| D12.1 | Report on structures to be funded from national/bilateral/european level for laser technology | WP12 | 2 - CNR | R — Document, report | PU - Public | 12 |
| D12.2 | Report on technical results achieved in the field of Lasers | WP12 | 2 - CNR | R — Document, report | PU - Public | 24 |
| D12.3 | TRL Report and maturity assessment on the development of Lasers | WP12 | 2 - CNR | R — Document, report | PU - Public | 42 |

Funded by the European Union

# Milestones

| Milestone No | Milestone Name | Work Package No | Lead Beneficiary | Means of Verificatio | Due Date (month) |
|---|---|---|---|---|---|
| 25 | Definition of criteria for down-selection of core industrial tech for the laser design | WP12 | 2-CNR | Report | 12 |
| 26 | Update of concepts for EuPRAXIA, systems status report (WP12) | WP12 | 2-CNR | Report | 24 |
| 27 | Design and project of transport beamlines focusing on the preservation of beam parameters | WP12 | 2-CNR | Report | 30 |

# Design study path for EuPRAXIA Laser-driver

Funded by the European Union

- **Baseline: proven technology based on Ti:Sa technology, pumped by diode-pumped lasers**
  - Strong R&D effort in place (e.g HAPLS@ELI **now entering into USER operation)**
  - ≈ 3-5 years to go to first industrial LWFA demonstrator [1]

- **Fully diode pumped with Direct Chirped Pulse Amplification** with lasing media pumped directly by diodes is ideal for higher efficiency and higher rep-rate;
  - several materials under consideration, Yb:CaF2, Tm:YLF, **Tm:Lu2O3 (Pisa)** …
  - PENELOPE (Jena) 150 J, 1 Hz, at 1030 nm
  - Available ps kW thin disk lasers using plasma modulation (Oxford [2])

- **OPCPA** optical parametric amplification within large-aperture (LBO) crystals;
  - ELI-Beamlines facility, L2 DUHA (100 TW, 2 to 5 J between 20, 50, 100 Hz)

Partially addressed by new/pending proposal

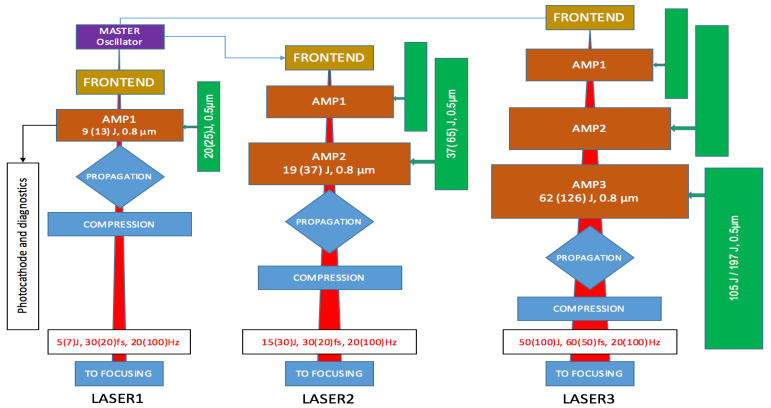
1. L.A Gizzi, F. Mathieu, P. Mason, P P Rajeev, *Laser drivers for Plasma Accelerators*, in Félicie Albert et al, *2020 roadmap on plasma accelerators*, 2021 New J. Phys. 23 031101, https://doi.org/10.1088/1367-2630/abcc62;
2. O. Jakobsson, S. M. Hooker and R. Walczak, PRL, 2021

# Conceptual Design of EuPRAXIA Laser driver

Funded by the European Union

A viable laser driver for a user plasma accelerator with high readiness

| LASER1 - Injector 150 MeV | | | |
|---|---|---|---|
| **Parameter** | **Unit** | **P0** | **P1** |
| **Wavelength** | nm | 800 | 800 |
| **Max Energy on Target** | J | 5 | 7 |
| **Max Total Output Energy** | J | 8.8 | 12.5 |
| **Shortest Pulse Duration** | fs | 30 | 20 |
| **Repetition Rate** | Hz | 20 | 100 |
| **Energy Stability RMS** | % | 1 | 0.6 |
| **LASER2 - Injector 1 GeV** | | | |
| **Parameter** | **Unit** | **P0** | **P1** |
| **Wavelength** | nm | 800 | 800 |
| **Max Energy on Target** | J | 15 | 30 |
| **Max Total Output Energy** | J | 18.8 | 37.5 |
| **Shortest Pulse Duration** | fs | 30 | 20 |
| **Repetition Rate** | Hz | 20 | 100 |
| **Energy Stability RMS** | % | 1 | 0.6 |
| **LASER3 - Accelerator 5 GeV** | | | |
| **Parameter** | **Unit** | **P0** | **P1** |
| **Wavelength** | nm | 800 | 800 |
| **Max Energy on Target** | J | 50 | 100 |
| **Max Total Output Energy** | J | 62.5 | 125 |
| **Shortest Pulse Duration** | fs | 60 | 50 |
| **Repetition Rate** | Hz | 20 | 100 |
| **Energy Stability RMS** | % | 1 | 0.6 |



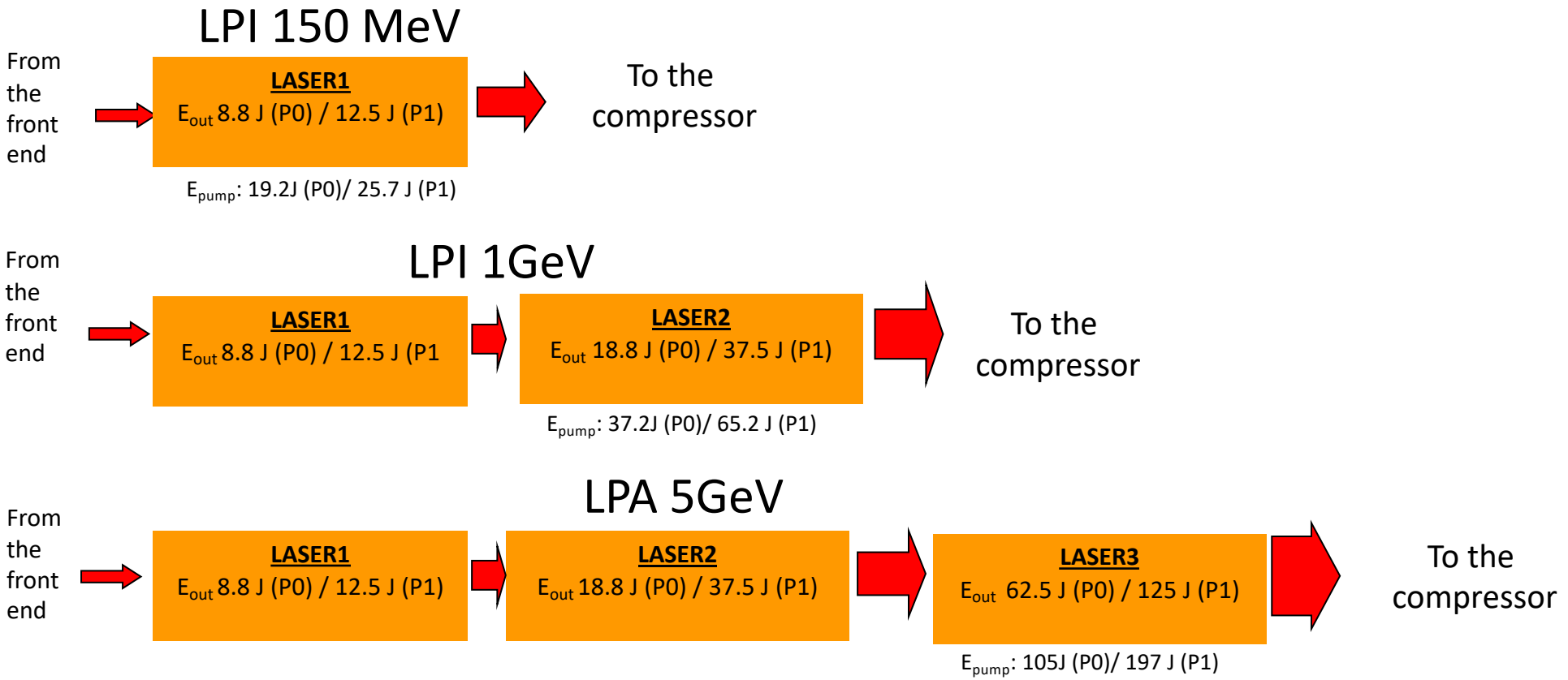


- L. A. Gizzi et al., NIMA 909, 58 (2018)
- G.Toci et al., Instruments 3, 40 (2019)

# EuPRAXIA Laser: Modular Architecture

Funded by the European Union

## Foreseen I/O energy and pump requirements




Three main modules: LASER1, LASER2, LASER3
LASER1: stand-alone for LPI 150 MeV
LASER2: output stage for LPI 1 GeV, second stage for LPA 5GeV
LASER3: high energy stage for LPA 5GeV
Two levels of performance : P0 and P1

# MAIN CDR ISSUES TOWARDS PP&TDR

Funded by the European Union

- Requirements set by the LPA working point
- Design based on Ti:Sapphire, dictated by requirements
- Thermal management issues
- Construction
- Integration Issues
- Main development needed

# Underpinning EuPRAXIA Laser TDR

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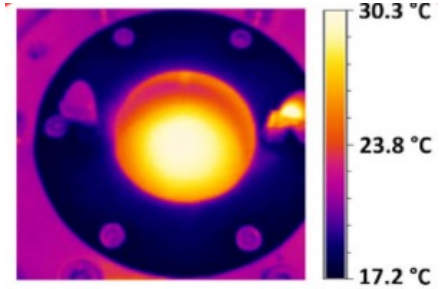
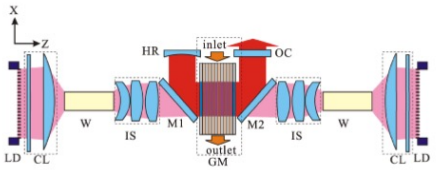
## THERMAL MANAGEMENT OF POWER AMPLIFIERS



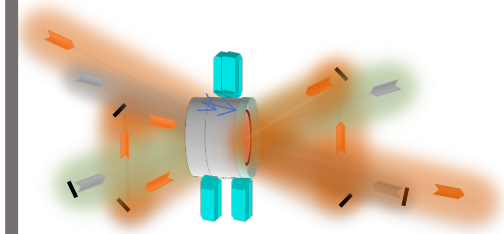

WATER/GAS COOLING



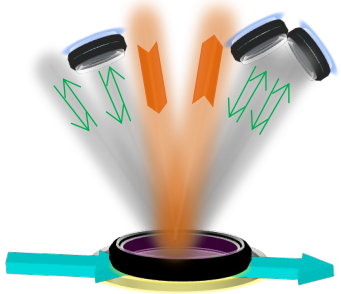

**Prototyping needed**

## AMPLIFIER GEOMETRY TRANSMISSION VS. REFLECTION

Multipass transmission

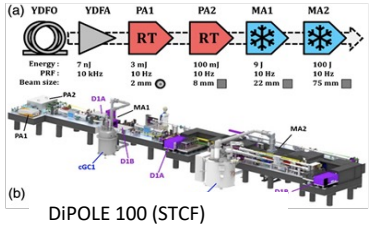


Multipass reflection

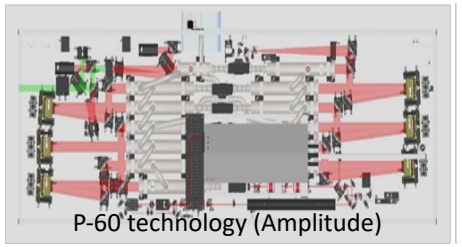


**Prototyping needed**

## DPSSL PUMP SOURCES TECHNOLOGY



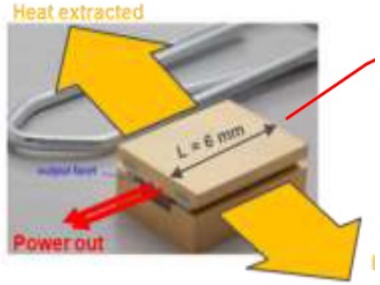

DiPOLE 100 (STCF)

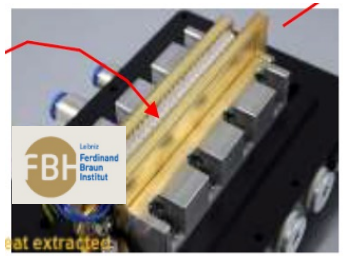


P-60 technology (Amplitude)

**Currently no solution for full system specs (P1): development**

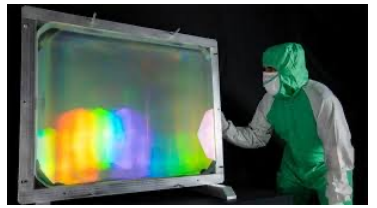
## DIODE LASERS EFFICIENCY, BRIGHTNESS AND LIFETIME



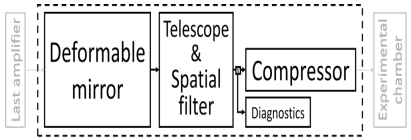

**Needs development**

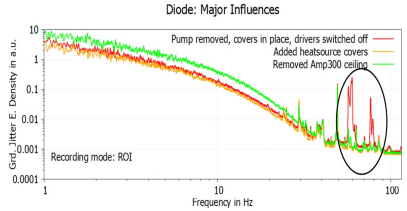
## COMPRESSOR AND TRANSPORT: THERMAL AND MECHANICAL STABILITY



Gold -> MD, MLD, MMLD

**reduction** of the thermal load
**cooling** of residual heat
**control** of thermal effects



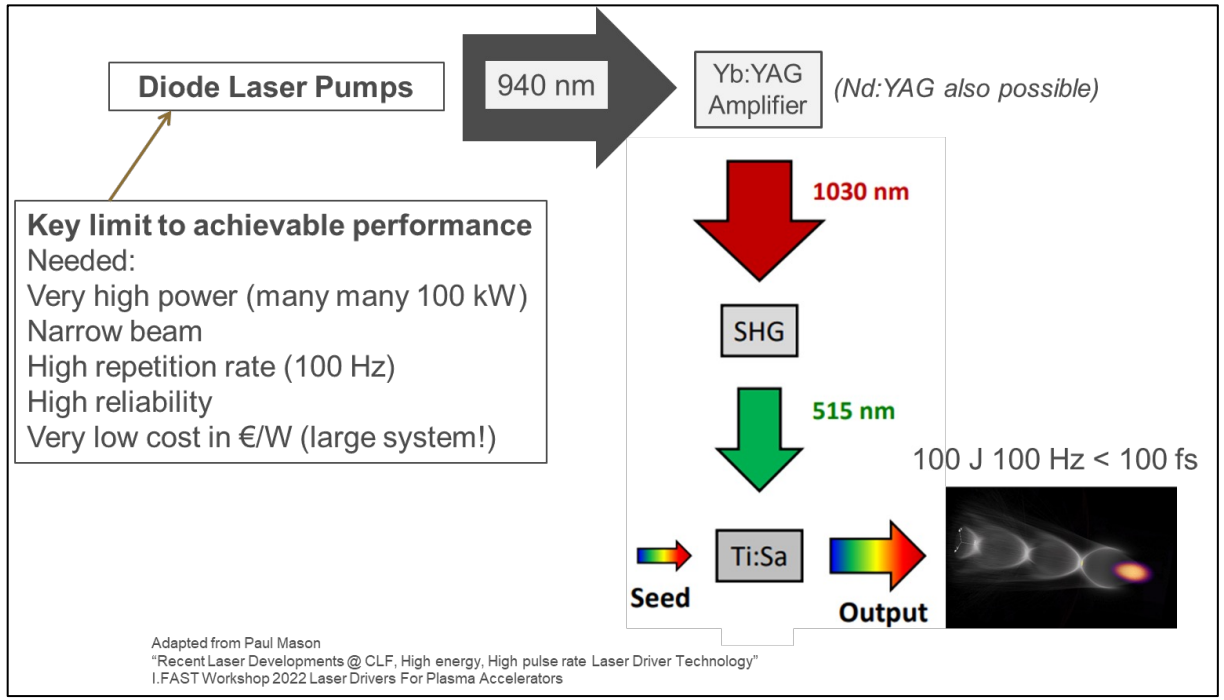




**Main challenges: large optics, mechanical stability, beam quality control, pointing stability**

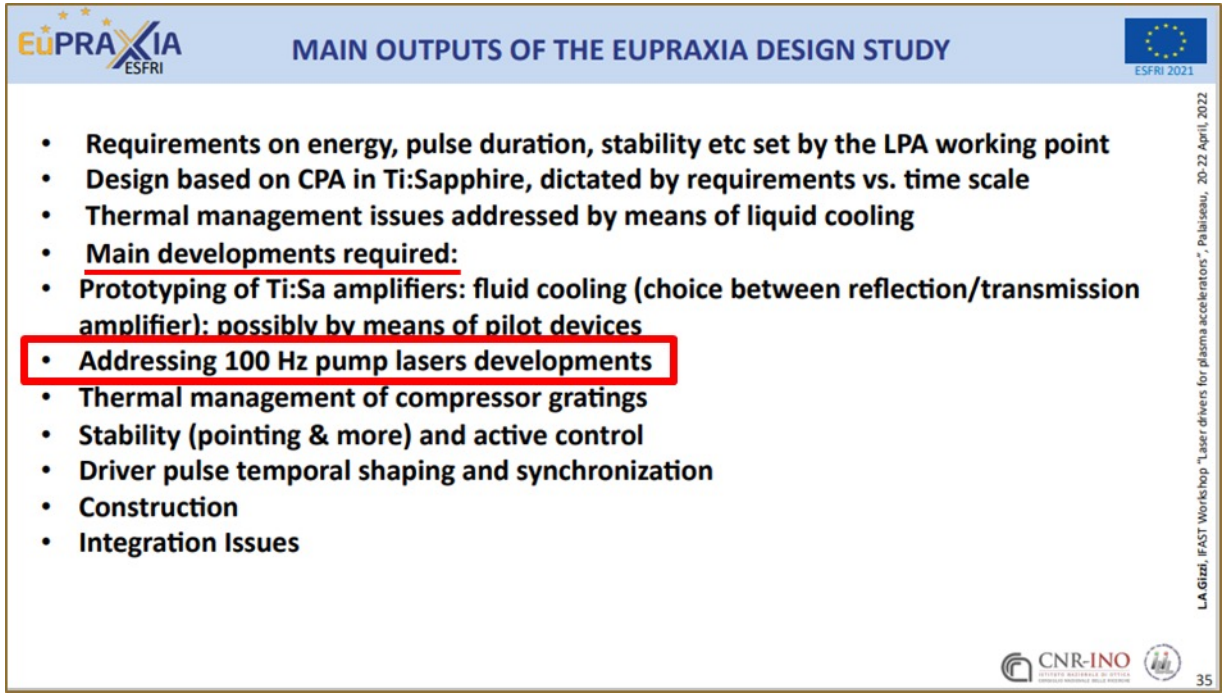
# Diode laser pump challenge: Economic 100 Hz

Funded by the European Union

## Diode lasers source of all optical power in EuPRAXIA




## Challenge: 100 Hz pump supply





**Preparatory review with Industry Berlin, held 5 October 2022** „Berlin Laser Tech Symposium"

Large industry: Coherent, Leonardo, Lumibird, Jenoptik, Hamamatsu, High-tech SMU: Lastronics

Research: CNR (Gizzi). Chair: FBH Berlin (Crump)

Consensus: **Economic high duty cycle diode laser pumps remain extremely challenging**

Improved packaging and diodes and their reliability assurance strongly demanded

Leibniz Ferdinand Braun Institut

# Diode specifications: known and open points

Funded by the European Union

**Diode pump laser technical specs broadly clear (performance)**

- 20…100 Hz
- ~ 80 $cm^2$ square flat-top beam, imaged into amplifier, with up to several meters offset
- < 6° divergence angle, high polarization purity
- Multiple 500 kW units needed for largest system
- Yb:YAG: $\lambda$ = 940 nm, ~ 500 µs pulses (5% duty cycle) – high duty cycle packaging needed
- Nd:YAG: $\lambda$ = 800 nm, ~ 200 µs pulses (2% duty cycle) – higher power diodes needed

**Key open topics:**

- Lifetime requirements (uptime, system size, replacement rates / failure rate)
- Costs (purchase, maintenance, operation)
- Efficiency (energy cost of operation)
- Specifications / requirements for alternative wavelengths

**Support also from parallel programs:**

- Innovative approaches via capability of FMD („research fab germany“ e.g. coop FBH-HHI)
- Lessons / technology from rapidly developing secondary-source industry (e.g. BMBF systems call, just closed)

# Diode development tasks: needs, activities

**Needed diode laser pump development goals and research efforts (2…3 years technology, 2…3 years qualification)**

- Improved diode laser performance: higher efficiency, higher power
- Improved packaging: high performance economical cooling
- Cost reduction: higher power (€/W), yield (€)
- Prototyping of new concepts (e.g 780 nm or 1600 nm for Thulium)

Progress on funding

- Reliability assurance (low failure rate)
- Security of supply: standardization, assurance of first, second, third-source suppliers; European supply

Gap!

**Ongoing / forthcoming matching funds and projects to meet EuPRAXIA needs (build towards „excellence center Berlin“)**

- <u>Diodes + package</u>: EU Grant application CREATE (on short list)
  - Higher duty-cycle economic packaging for Yb:YAG – (FBH, DILAS, STFC)
  - Higher power bars for Nd:YAG designs – (FBH, DILAS, Amplitude)
- <u>Package + diodes</u>: ERDF project on low-cost extremely high duty cycle diodes & modules (decision pending)
  - Innovative packaging, bars, process technology (FBH + Trumpf)
- <u>Diodes:</u> Higher power, highly efficient, high brightness diode lasers (funded)
  - Ongoing direct bilteral cooperation FBH-Trumpf
- <u>New concepts</u>: EFRE-supported FBH application centre for innovative diode pumps (decision pending)
  - Prototyping of new concepts e.g. innovative wavelengths, beam-forming, operation modes
- <u>New concepts</u>: ERDF project on continuous wave 780 nm pumps at FBH (funded, 2023)

# Towards EuPRAXIA 2nd Site

Funded by the European Union

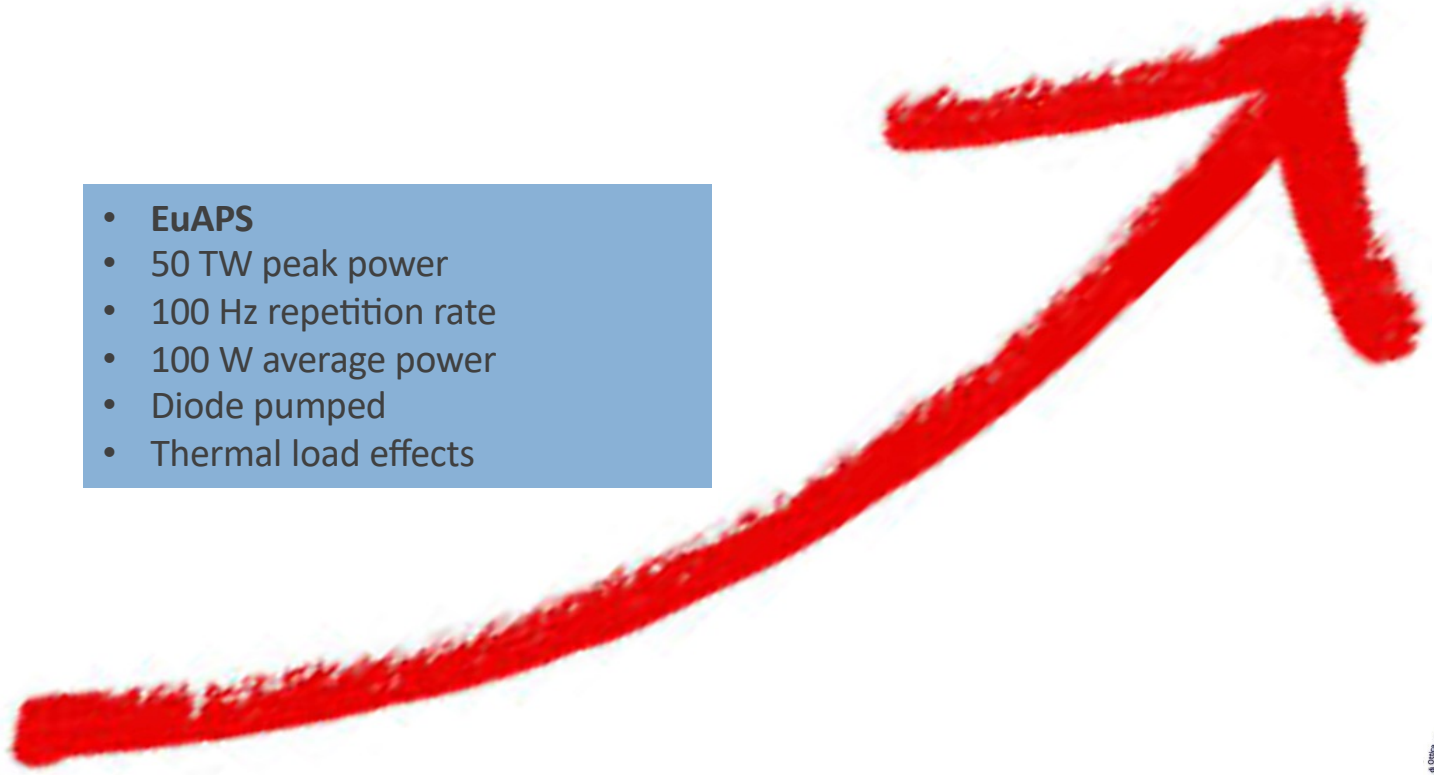
**Eupraxia laser development is aimed at delivering more efficient, kW class PW laser driver for plasma acceleration at >100 Hz rate**

- **EuPRAXIA**
- PW class,
- 100 Hz repetition rate,
- multi kW average power,
- diode pumped
- Full thermal load transport

EuPRAXIA

Advanced Photon Sources

- **EuAPS**
- 50 TW peak power
- 100 Hz repetition rate
- 100 W average power
- Diode pumped
- Thermal load effects

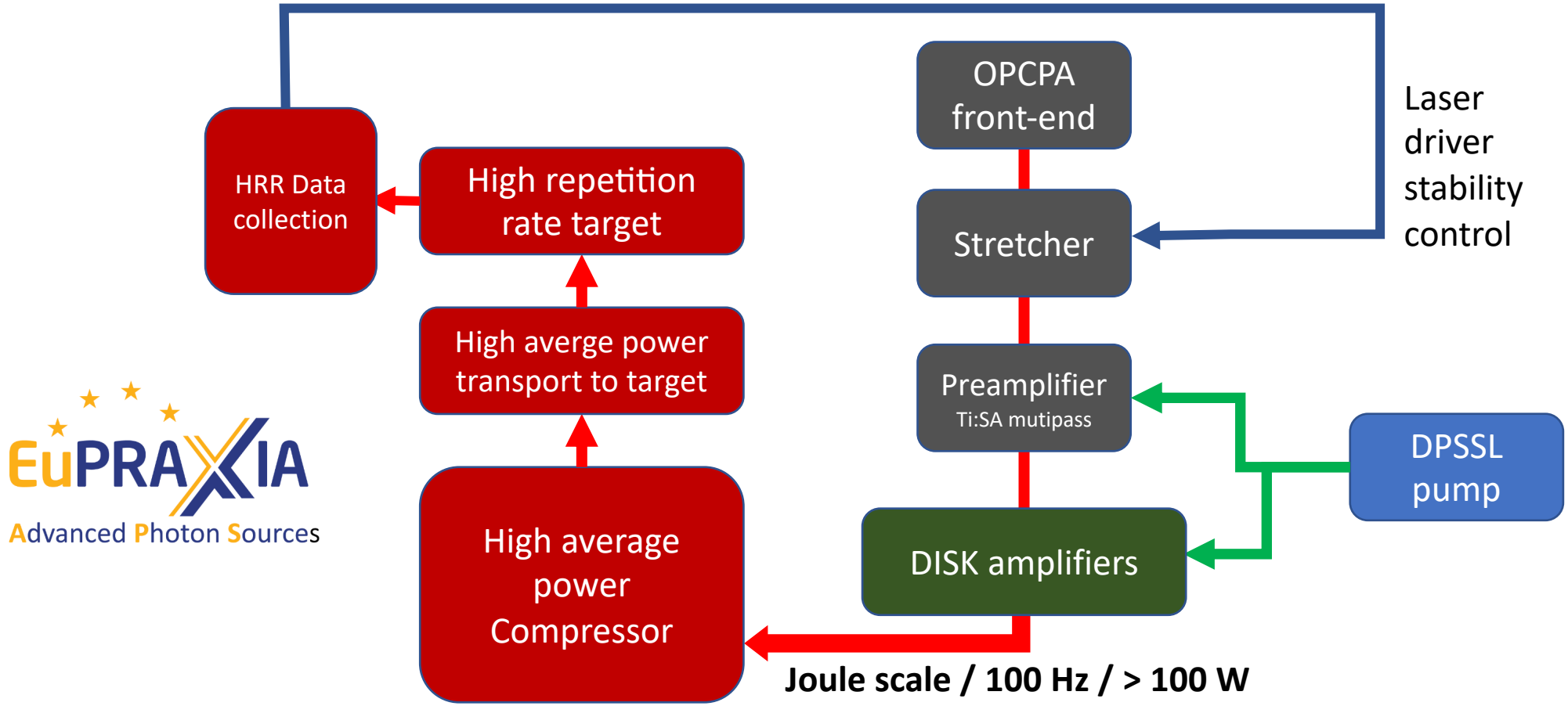


- **CURRENT**
- **PW class,**
- **Hz repetition rate,**
- **≈10 W average power**
- **flashlamp pumped**
- **No thermal load transport**

# EuPRAXIA Front-end development ongoing

Funded by the European Union

**100 Hz operation at Joule level pulse energy is outstanding and a unique opportunity to address HAP issues**



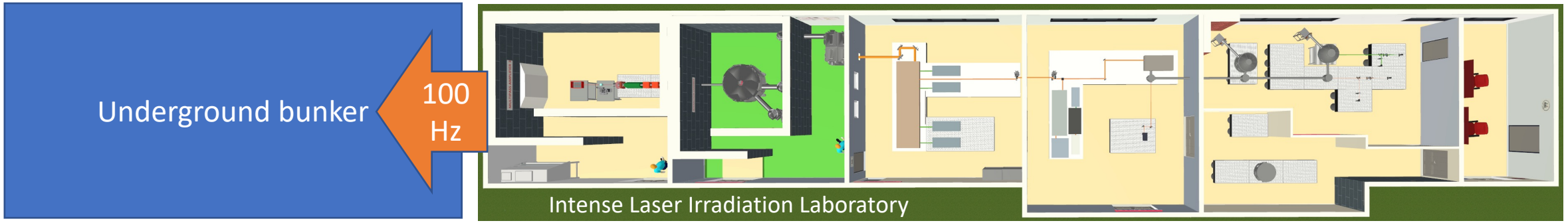

EuPRAXIA Advanced Photon Sources

**Part of the EUAPS (Eupraxia Advanced Photon Sources, 4.8 M€ dedicated funding @ CNR-Pisa)**

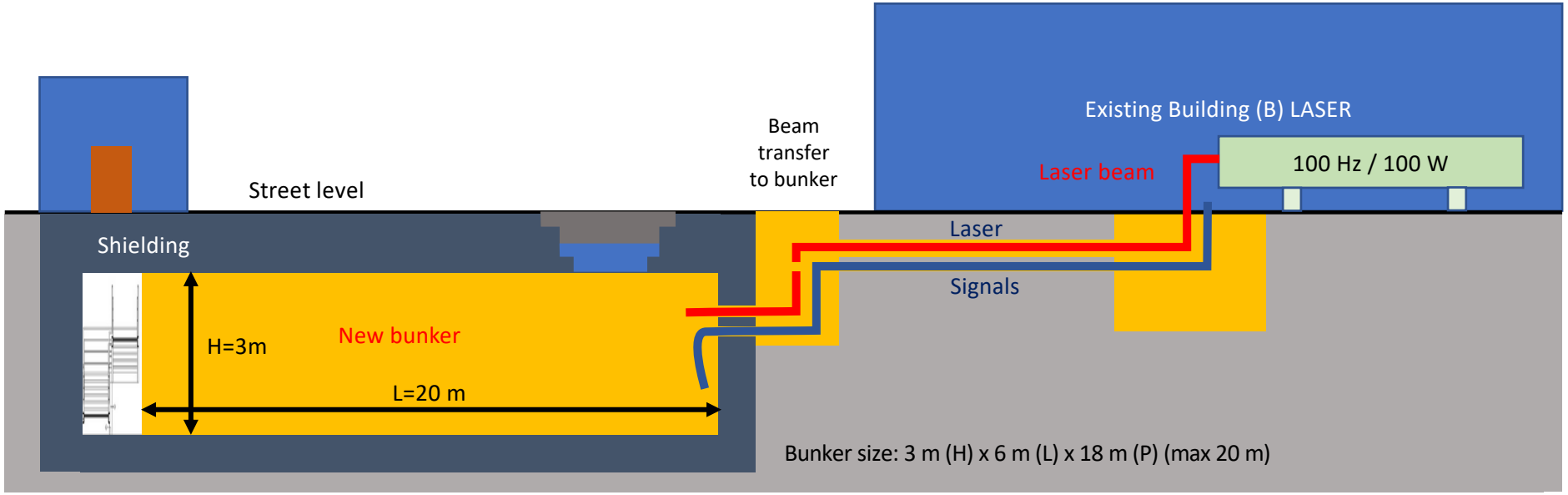
# User Facility Upgrade at CNR-Pisa (EULAb-Med)

Funded by the European Union

**Full 100 Hz system at Joule level will allow to tackle operational issues and mechanical stability**




New bunker
Designed for high dose irradiation (100 Hz)

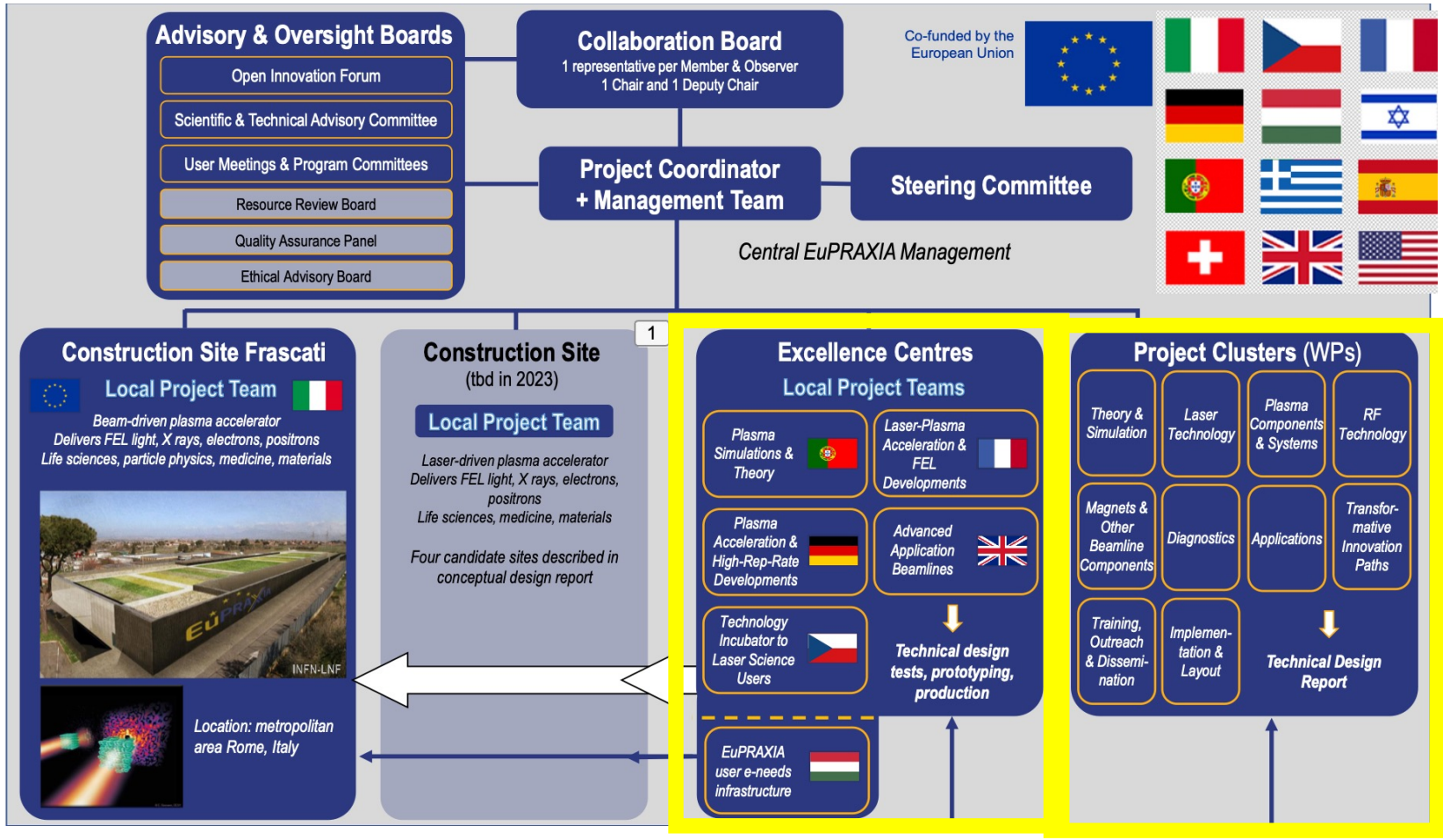



**Part of the IPHOQS (ELI/LENS/CUSBO Photonics Infrastructure), and Tuscan Health Ecosystem 4.5 M€ dedicated funding @ CNR-Pisa)**

# Role of Excellence Centers towards TDR

Funded by the European Union

## Reaching ultimate laser-driver performance for EuPRAXIA requires significant breakthroughs




Commitment of ***excellence centers*** is needed to address open technical issues to advance laser design towards TDR:

Cooperation with facilities and labs engaging **construction and operation** of medium-large scale installations will be crucial

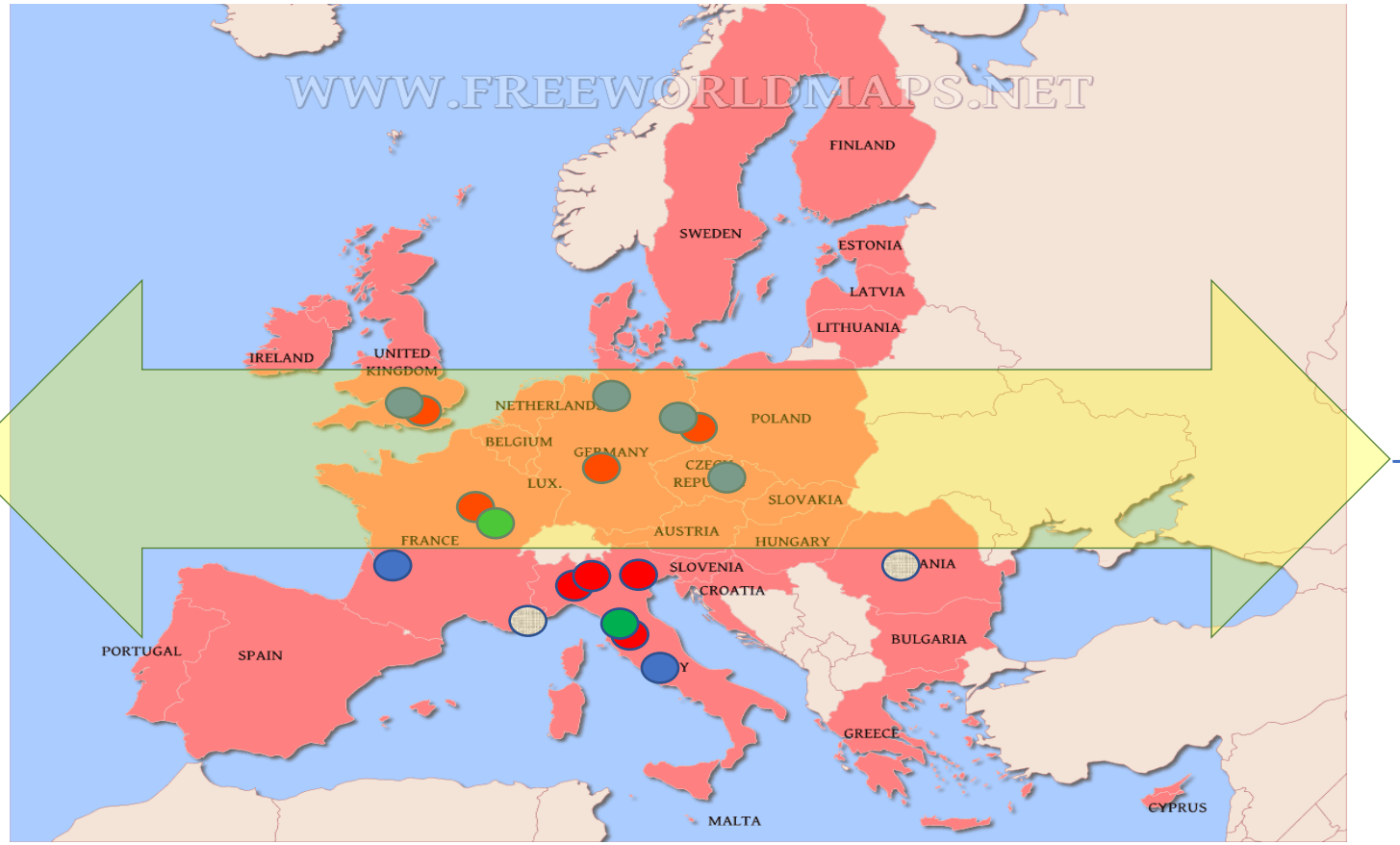
Funding towards shown pending **tasks and challenges** currently under development: needs effort

Continuing to engage collaborations with labs, also via matching networking programme (e.g. IFAST)

# Collaboration needed

Funded by the European Union

Increasing population of industrial players for laser and components development, in strong collaboration with Institututional players




Amplitude TECHNOLOGIES
THALES
SAFRAN
SourceLAB
VACUUM FAB
ISP SYSTEM
TRUMPF
VCS
imagine optic
DYNAMIC OPTICS
COHERENT | DILAS

Consiglio Nazionale delle Ricerche
cnrs centre national de la recherche scientifique
eli
FBH Leibniz Ferdinand Braun Institut
INFN Istituto Nazionale di Fisica Nucleare
Science & Technology Facilities Council
Lawrence Livermore Natl. Lab
Elettra Sincrotrone Trieste

*many more*

## The END