EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

Eupraxia Laser design optimization and industry

Leonida A. GIZZI
Istituto Nazionale di Ottica, CNR, Pisa, Italy
also at INFN, Pisa, Italy

3rd European Advanced Accelerator Concepts Workshop,
24-30 September 2017 La Biodola, Isola d'Elba

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

EuPRAXIA WP4 - People

Horizon 2020

CNR - Italy

Leonida A. GIZZI, Istituto Nazionale di Ottica-CNR, Pisa

Petra KOESTER INO-CNR, (EuPRAXIA contract), Pisa

Luca LABATE, INO-CNR, Pisa

Fernando BRANDI, INO-CNR, Pisa

Gian Carlo BUSSOLINO, INO-CNR, Pisa

Barbara PATRIZI, INO_CNR, Firenze

Guido TOCI, INO_CNR, Firenze

Matteo VANNINI, INO-CNR, Firenze

CNRS - France

François Mathieu, CNRS, Ecole Polytechnique

Dimitrios PAPADOPOULOS, CNRS, Ecole Polytechnique

Audrey BELUZE, CNRS, Ecole Polytechnique

Jean-Luc PAILLARD, CNRS, Ecole Polytechnique

Zeudi MAZZOTTA, CNRS, Ecole Polytechnique (Eupraxia contract)

Collaborators

Franck FALCOZ, Amplitude Technologies

Rajeev PATTATHIL, STFC Rutherford Appleton Laboratory

Christophe SIMON BOISSON, Thales Group

Maria Pia ANANIA, INFN-LNF

Fabrizio Bisesto, INFN-LNF

Marco GALIMBERTI, STFC Rutherford Appleton Laboratory

Dario GIOVE, INFN-MI

Klaus ERTEL, STFC Rutherford Appleton Laboratory

Craig W. SIDERS, LLNL

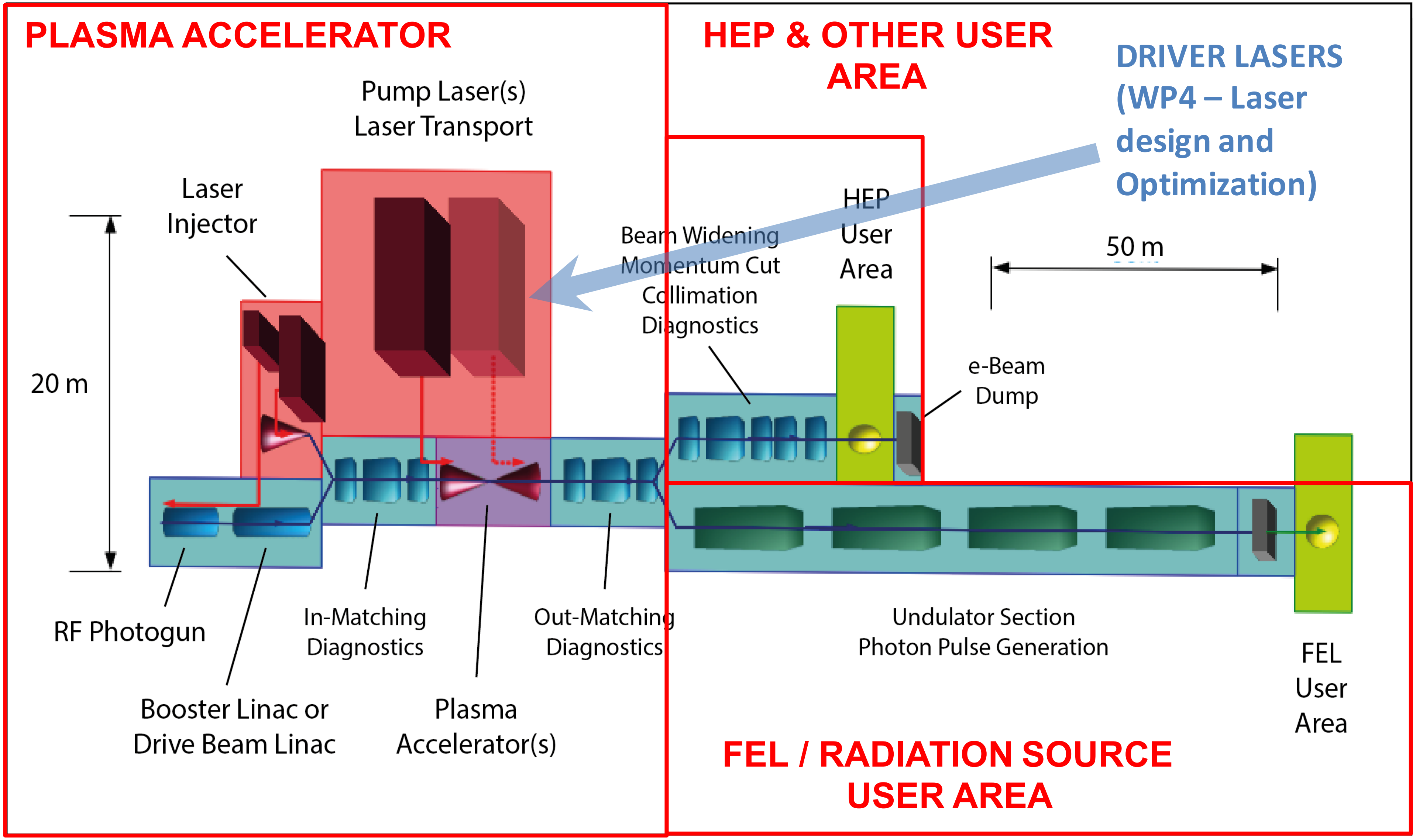
Sandrine RICAUD, Thales Group

Sebastien LAUX, Thales Group

Oliver KARGER Hamburg University (UHH)

Alexander KNETSCH Hamburg University (UHH)

EuPRAXIA Research Infrastructure



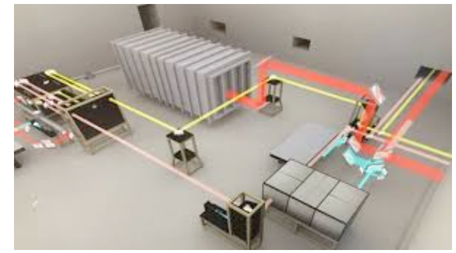
Content

- An industrial laser for EuPRAXIA?
- Strategy for a rep-rated PW laser
- Technology down-selection criteria
- Preliminary laser design
  - Main candidate components
  - Outstanding issues
- Transport and Interaction point challenges
  - Stability and reproducibility

Project deliverables

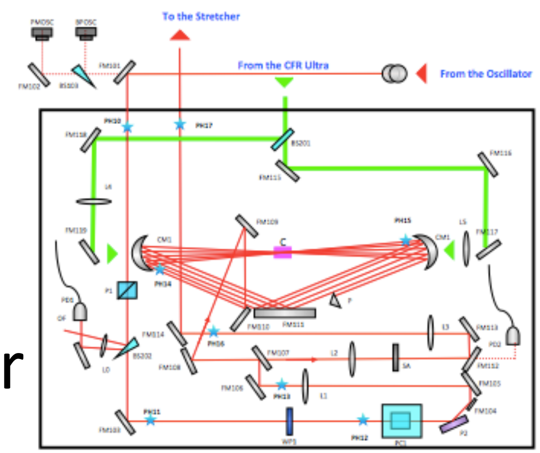
D4.1 (M12) Benchmarking of existing technologies and comparison with EuPraxia requirements

Explore and identify promising technologies



D4.2 (M24) Preliminary laser design

To be developed with an eye to perspective industrial development



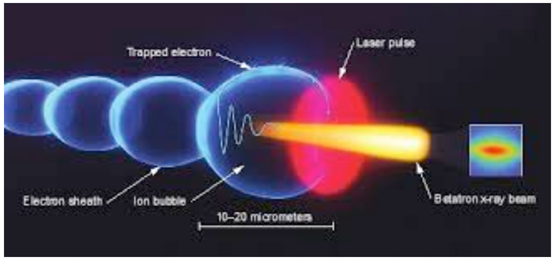
D4.3 (M24) Preliminary design of transverse functions

To account for final use of EuPRAXIA (user facility)

Project deliverables

D4.4 (M36) Final requirements of laser system

To comfortably accommodate LWFA design and other laser based activities



D4.5 (M36) Control command design system

To enable turn-key-like operation of the laser system

Engage key players

- World-wide scenario in Petawatt scale laser development is seeing major contributions from industry and research labs involved in challenging projects;
- After a first exploration meeting (Saclay, May 18°, 2016), potential contributors were identified and invited to contribute to the Eupraxia design.

Strategy: 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 : drive a 150 MeV injector
Laser 2 : drive a 1 GeV accelerator
Laser 3 : drive a 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)**

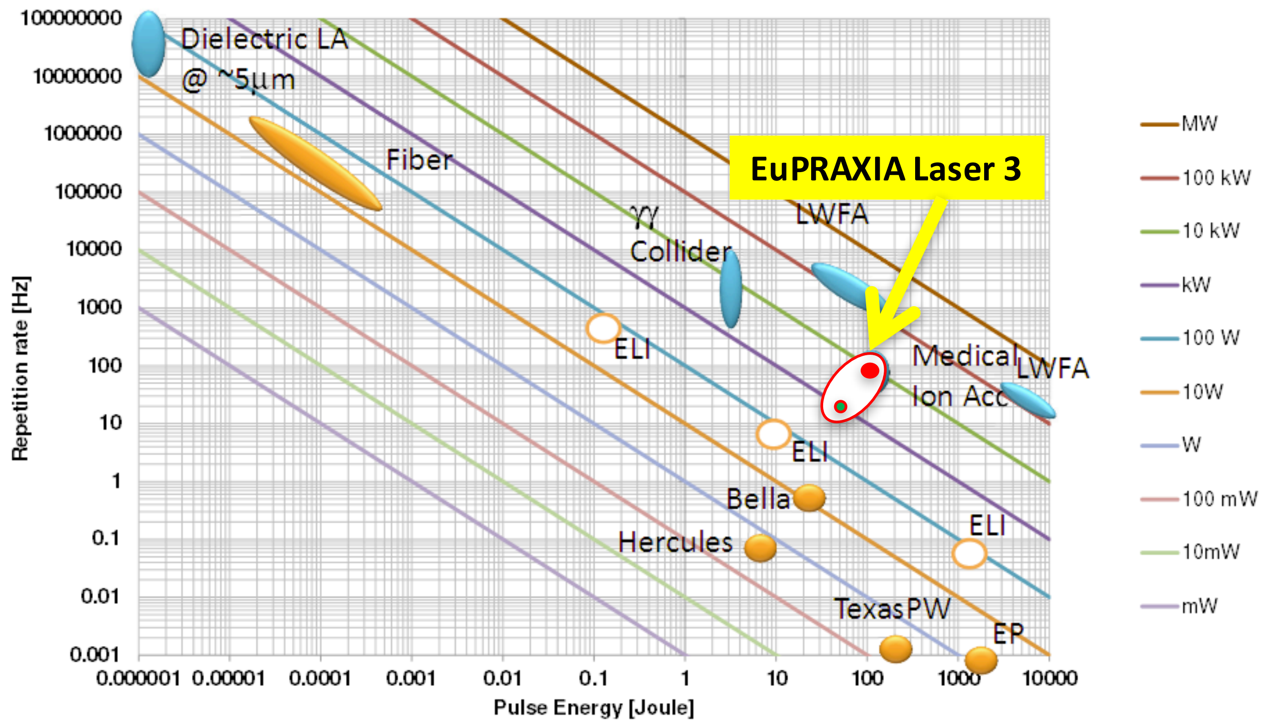
INPUT FROM LPA DESIGN AND EXPERIMENTS

Horizon 2020

- Discussion about detailed laser parameters and interaction with laser-plasma acceleration workpackages (WP2-3) to identify laser parameters for the most challenging performance (5GeV);
  - Minimum required pulse duration: 60 fs
  - Minimum required pulse energy: 50 J
- High repetition rate to enable active stabilization via feedback loops;
  - Ideally 1kHz, minimum 20 Hz, but exploring 100 Hz option
- Challenging problems in beam transport, focusing, diagnostics: a key part of the reliability of the laser system as a whole;
  - Extensive data acquisition from existing systems needed.

WP4 task

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



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

Laser 1 Specs: 150 MeV injector

Horizon 2020

Laser injector 150 MeV (Laser 1)			
Parameter	**Label**	**P0***	**P1****
Wavelength (nm)	$\lambda_{1\ (nm)}$	800	800
Maximum energy on target (J)	E_{target}	5	7
Energy tuning resolution (% of targeted value)	dE	7	5
Total output energy (incl. Diagnostic beams)	E_{tot}	7	10
Pulse length (FWHM) (fs)	τ_1	30	20
Repetition rate (Hz)	f_1	20	100
Contrast at 100 ps	C_1(100 ps)	1,00E+11	1,00E+12
Contrast at 50 ps	C_1(50 ps)	1,00E+10	1,00E+11
Contrast at 10 ps	C_1(10 ps)	1,00E+09	1,00E+10
Contrast at 1 ps	C_1(1 ps)	1,00E+06	1,00E+08
Contrast at 100 fs	C_1(100 fs)	1,00E+02	1,00E+03
Number of beams	N_1	1	2
Synchro. to global reference (P-V) (fs)	$\sigma_{\Delta t}$	10	5
Beam intensity distribution (x-y) in focal plane	-	Gaussian	Supergaussian (n=10)
Polarization in focal plane	P_1	linear	linear, circular
Max ellipticity of focal spot (Am/AM)		0.8	0,95
Polarization purity (%)		1	1
Requirement on energy stability (RMS) %	$\sigma_{\langle E \rangle}$	5	1
Requirement on focal size & Z_L stab. (RMS) %	$\sigma_{\langle ZL \rangle}$	10	5
Focal spot size stability (on target plane) (RMS) %	$\sigma_{\langle W0 \rangle}/W_0$	20	10
Pointing stability (RMS) (µrad)	$\sigma_{\langle x' \rangle}$, $\sigma_{\langle y' \rangle}$	1	1
Required lab room space (m2) including technical rooms but no beam transport	A_1	100	100

P0*	This value is mandatory
P1**	This value is a goal that we will try to reach

Laser 2 specs: 1GeV accelerator

Laser injector 1 GeV (Laser 2)			
Parameter	**Label**	**P0***	**P1****
Wavelength (nm)	$\lambda_{2\ (nm)}$	800	800
Maximum energy on target (J)	E_2	15	30
Energy tuning resolution (% of targeted value)	dE	7	5
Shortest pulse length (FWHM) (fs)	τ_2	30	20
Repetition rate (Hz)	f_2	20	100
Contrast at 100 ps	C_1(100 ps)	1,00E+11	1,00E+12
Contrast at 50 ps	C_1(50 ps)	1,00E+10	1,00E+11
Contrast at 10 ps	C_1(10 ps)	1,00E+10	1,00E+10
Contrast at 1 ps	C_1(1 ps)	1,00E+06	1,00E+08
Contrast at 100 fs	C_1(100 fs)	1,00E+02	1,00E+03
Number of beams	N_2	1	1
Synchro. to global reference (P-V) (fs)	$\sigma_{\Delta t}$	10	5
Beam intensity distribution (x-y) in focal plane	-	Gaussian	Supergaussian (n=10)
Polarization in focal plane	P_1	linear	linear, circular
Max ellipticity of focal spot (Am/AM)		0.8	0,95
Polarization purity (%)		1	1
Requirement on energy stability (RMS) %	$\sigma_{<E>}$	5	1
Requirement on focal size & Z_L stab. (RMS) %	$\sigma_{<ZL>}$	10	5
Focal spot size stability (on target plane) (RMS) %	$\sigma_{<w_0>}/w_0$	20	10
Pointing stability (RMS) (µrad)	$\sigma_{<x'>}, \sigma_{<y'>}$	5	1
Required lab room space (m2) including technical rooms but no beam transport	A_1	600	400

P0* This value is mandatory

P1** This value is a goal that we will try to reach

Laser 3 specs: 5 GeV accelerator

Laser Driver 5 GeV (Laser 3)			
Parameter	**Label**	**P0***	**P1****
Wavelength (nm)	$\lambda_{2\ (nm)}$	800	800
Maximum energy on target (J) *	E_2	50	100
Energy tuning resolution (% of targeted value)	dE	7	5
Shortest pulse length (FWHM) (fs)	τ_2	60	50
Repetition rate (Hz)	f_2	20	100
Contrast at 100 ps	C_1(100 ps)	1,00E+11	1,00E+12
Contrast at 50 ps	C_1(50 ps)	1,00E+10	1,00E+11
Contrast at 10 ps	C_1(10 ps)	1,00E+10	1,00E+10
Contrast at 1 ps	C_1(1 ps)	1,00E+06	1,00E+08
Contrast at 100 fs	C_1(100 fs)	1,00E+02	1,00E+03
Number of beams	N_2	1	1
Synchro. to global reference (P-V) (fs)	$\sigma_{\Delta t}$	10	5
Beam intensity distribution (x-y) in focal plane	-	Gaussian	Supergaussian (n=10)
Polarization in focal plane	P_1	linear	linear, circular
Max ellipticity of focal spot (Am/AM)		0.8	0,95
Polarization purity (%)		1	1
Requirement on energy stability (RMS) %	$\sigma_{<E>}$	5	1
Requirement on focal size & Z_L stab. (RMS) %	$\sigma_{<ZL>}$	10	5
Focal spot size stability (on target plane) (RMS) %	$\sigma_{<w_0>}/w_0$	20	10
Pointing stability (RMS) (µrad)	$\sigma_{<x'>}$, $\sigma_{<y'>}$	5	1
Required lab room space (m2) Including technical rooms but no beam transport	A_1	700	500

P0* This value is mandatory

P1** This value is a goal that we will try to reach

Scale existing systems?

Hold-ups for scalability of current systems include:

- Pumping technology: diode (direct or indirect) pumping;
- Gain media: material should be industrially available at laser quality, scalable in size and capable of supporting large bandwidth and efficient cooling;
- Grating technology to improve for higher damage threshold and smaller beam size
- Optics Damage threshold
- Thermal load, management, dissipation

Strategy

- TWO POSSIBLE SCENARIOS identified:
    - Medium risk: TiSa with DPSSL pump lasers;
    - High risk: Direct CPA with new materials (required for >100Hz);

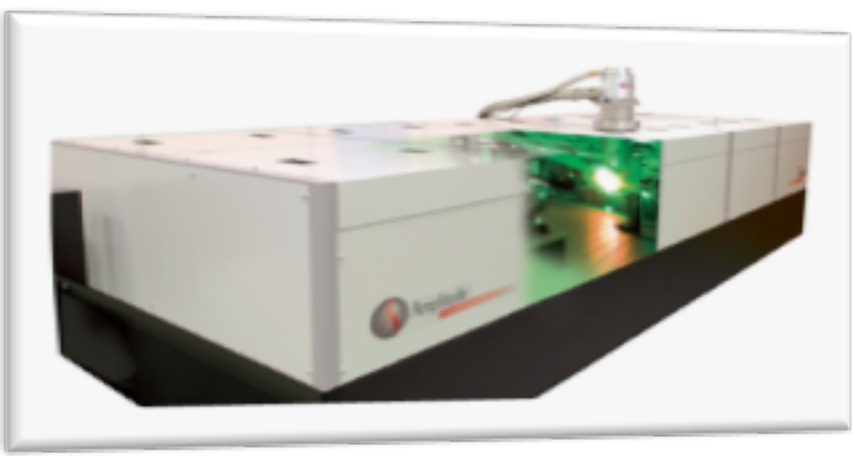
Scenarios matching large programmes at other institutions (e.g. LLNL, LBNL, STFC …);

Available subsystems (injector)

LWFA injector: required 7J @ 800 nm, 30 fs, 20 Hz (minimum)

May become available at industrial level from different suppliers e.g.:

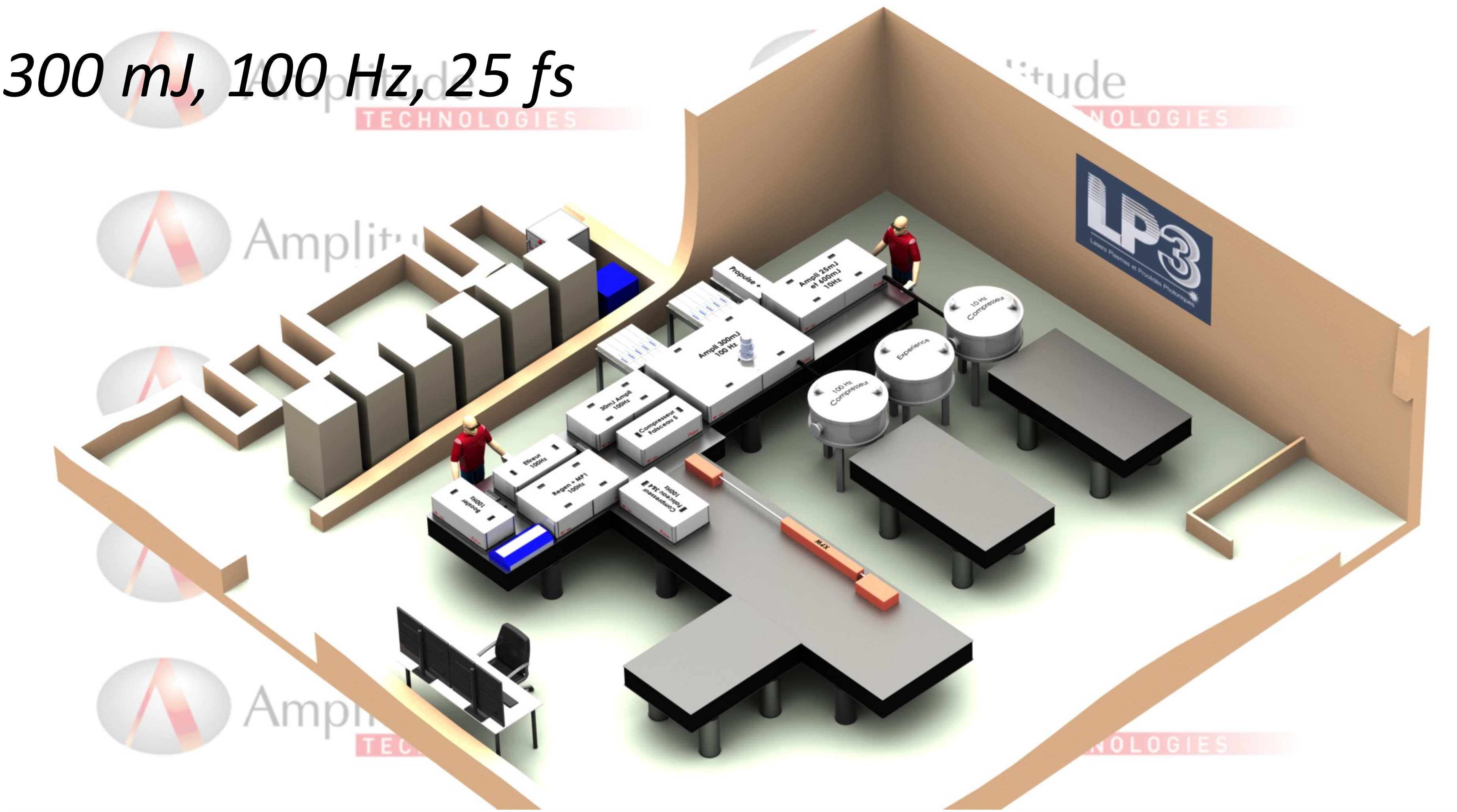
Amplitude Technologies
PULSAR: 5 J, <25 fs, 5-10 Hz
Ti:Sapphire



Thales
ALPHA5/XS: 20 J, 25 fs, 5 Hz
Ti:Sapphire

Available subsystems (front-end)

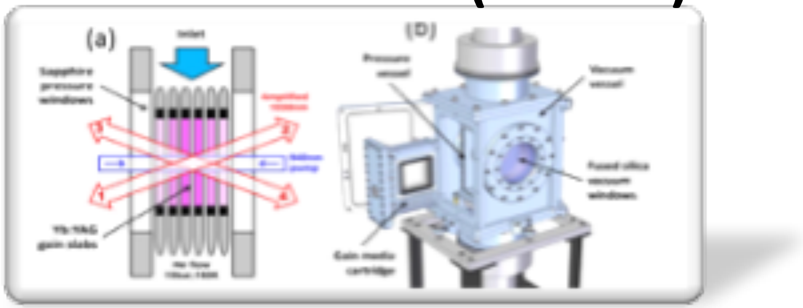
300 mJ, 100 Hz, 25 fs



Laser driver: DPSSL(upgradable) pump sources

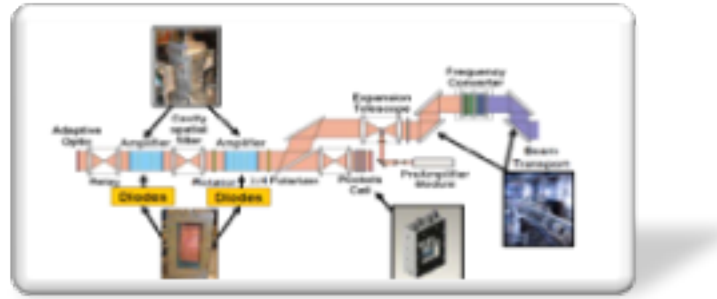
Horizon 2020

STFC DiPOLE 100 (HiLASE)



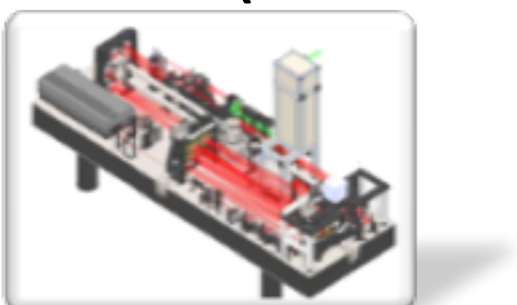
Diode pumped Yb:YAG slab, He-cooled
>100 J output energy demonstrated @ **10 Hz**, 1030 nm
> 60 J conversion @ 515 nm expected

LLNL HAPLS L3 (ELI-Beamlines)



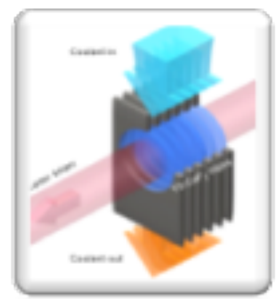
Diode pumped Nd:APG-1 glass, He-cooled
75 J output energy demonstrated @ **3.3 Hz**, 1053 nm
45 J SHG energy @ 526.5 nm demonstrated
Ramping up to 10 Hz, 200 J (design limit): in progress

Amplitude P-60 (ELI-ALPS HF)



Flashlamp pumped Nd:YAG/ **DPSSL possible**
45 J output energy demonstrated @ **10 Hz**, 1064 nm
60 J SHG energy @ 532 nm : design target
Ramping up to 10 Hz, full energy (design limit): in progress

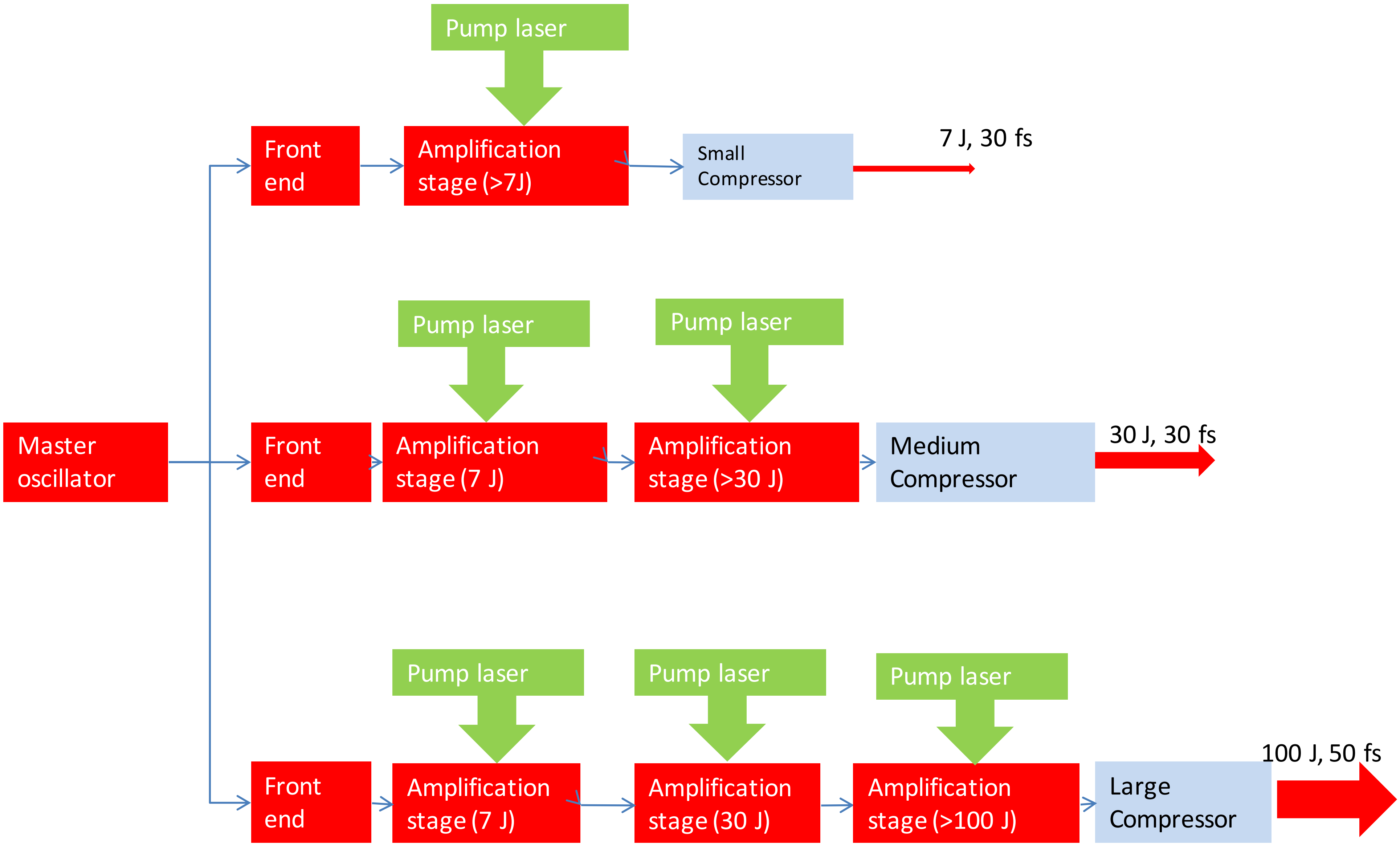
HZDR PEnELOPE



Direct DPSSL Amplif.

Developed by Dresden Helmoltz Institute
Diode-pumped Yb:CaF_2 slabs, He cooled
150 J, **150 fs**, **1 Hz,** 1030 nm,
Expected optical to optical conversion efficiency 5-10% before compression (unsaturated amplification)

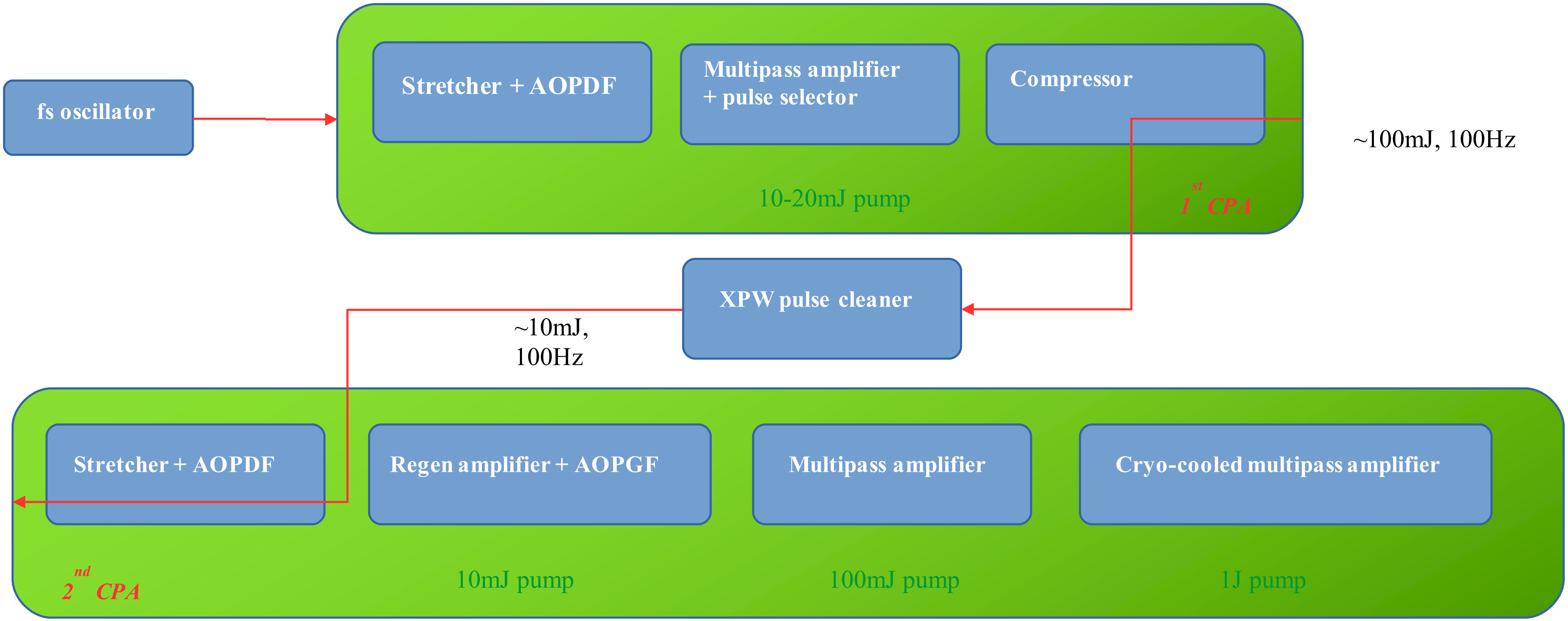
Block diagram of EuPRAXIA laser



Front-end

100Hz, high contrast ratio (>10^{12} at ps) front-end (very) preliminary layout

Preliminary scheme: double CPA scheme with XPW pulse cleaning



300mJ, 100Hz
>55nm FWHM, stretched to ~100ps

European companies potentially interested

ADDRESSING DRIVER NEEDS FOR LPA

Horizon 2020

A set of development activities have been identified to address main issues and proceed towards the construction of a driver for a plasma-based accelerator with the performance and quality as required by EuPRAXIA

- **Driver pulse temporal shaping and synchronization**
- **High repetition rate driver pulse: towards 100 Hz**
- **High repetition rate driver pulse: dpssl pumping**
- **Laser Driver design and test on LPA**
- **Laser Driver stability and active control**

Collaborating Institutes
IEP:Institute of Electrophysics (IEP), UD RAS, Russia
FBH:Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik
OX: Oxford University
IOQ: Institut für Optik und Quantenelektronik Jena
UHH: Hamburg University

Collaborating Industry
Amplitude Technologies
Thales: Thales Lasers

COMPRESSOR ISSUES

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

- **Injector 150MeV**
  - 1 kW (10J @ 100Hz), needed 25 fs after compression (38nm bandwidth), spectral acceptance required: 120 nm
- **Injector 1GeV**
  - 4 kW (40J @ 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 (16nm 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: **$10\ W/cm^2$**

INDUSTRIES and LABS

JOBIN YVON Technology

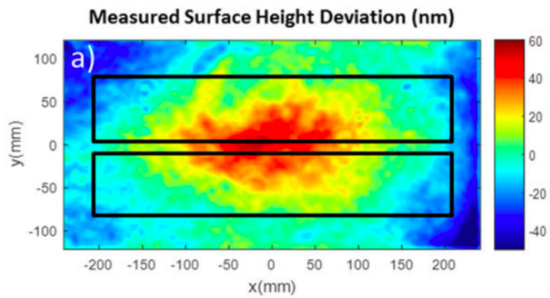
Gold Coated Grating without epoxy resin for lower thermal stress

Lawrence Livermore National Laboratory

Photoresist-Free High Average Power Compressor Gratings

Plymouth Grating Laboratory

World record for the largest **MultiLayer Dielectric (MLD) diffraction grating**



Work in progress at DESY (V. Leroux, WG7)

DESY

D.A. Alessi et al., Opt. Express **24**, 30015-30023 (2016)

Transport issues

High beam quality and pointing stability, optomechanics, mirrors, actuators

DYNAMIC OPTICS

ISP SYSTEM

imagine optic

Active stabilization

Passive stabilization

In contact with an industry whose action is to stabilize optic mountings in a "definitive" way.

Adaptive Optics

ILAO deformable mirror

+

HASO wavefront sensor

Close loop that allows for active (but also passive) correction of the beam spatial profile.

SAFRAN

INO-CNR, Pisa

VACUUM FAB MOTION CONTROL & OPTICS

... and many more

SUMMARY

- EuPRAXIA design study progressing rapidly;
- Mandatory laser specs set highly demanding kW system;
- Aiming at Ti:Sa with DPSSL pump lasers;
- Current DPSSL pump systems exceeding kW;
- Major effort required to meet focusing stability;
- Building on the experience of current PW facilities;
- Strong involvement of European industry and labs.

Consortium

Horizon 2020

16 Participants

DESY, INFN, Consiglio Nazionale delle Ricerche, CNRS, University of Strathclyde Glasgow, IST-ID Associação do Instituto Superior Técnico para a Investigação e Desenvolvimento, Science & Technology Facilities Council, SOLEIL Synchrotron, Manchester 1824 The University of Manchester, University of Liverpool, ENEA Italian National Agency for New Technologies, Energy and Sustainable Economic Development, CEA, Sapienza Università di Roma, Universität Hamburg, Imperial College London, University of Oxford

22 Associated Partners

(as of October 2016)

Shanghai Jiao Tong University, Université de Lille 1 Sciences et Technologies, eli beamlines, HI Jena Helmholtz Institute Jena, Tsinghua University, HZDR Helmholtz Zentrum Dresden Rossendorf, LMU Ludwig-Maximilians-Universität München, Wigner, KPSI Kansai Photon Science Institute JAEA, Osaka University, RIKEN, Stony Brook University CASE, CERN, Lund University, Berkeley Lab, UCLA, KIT Karlsruhe Institute of Technology, Università di Roma Tor Vergata, The Hebrew University of Jerusalem, ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ, ИЯФ РАН, Jülich Forschungszentrum

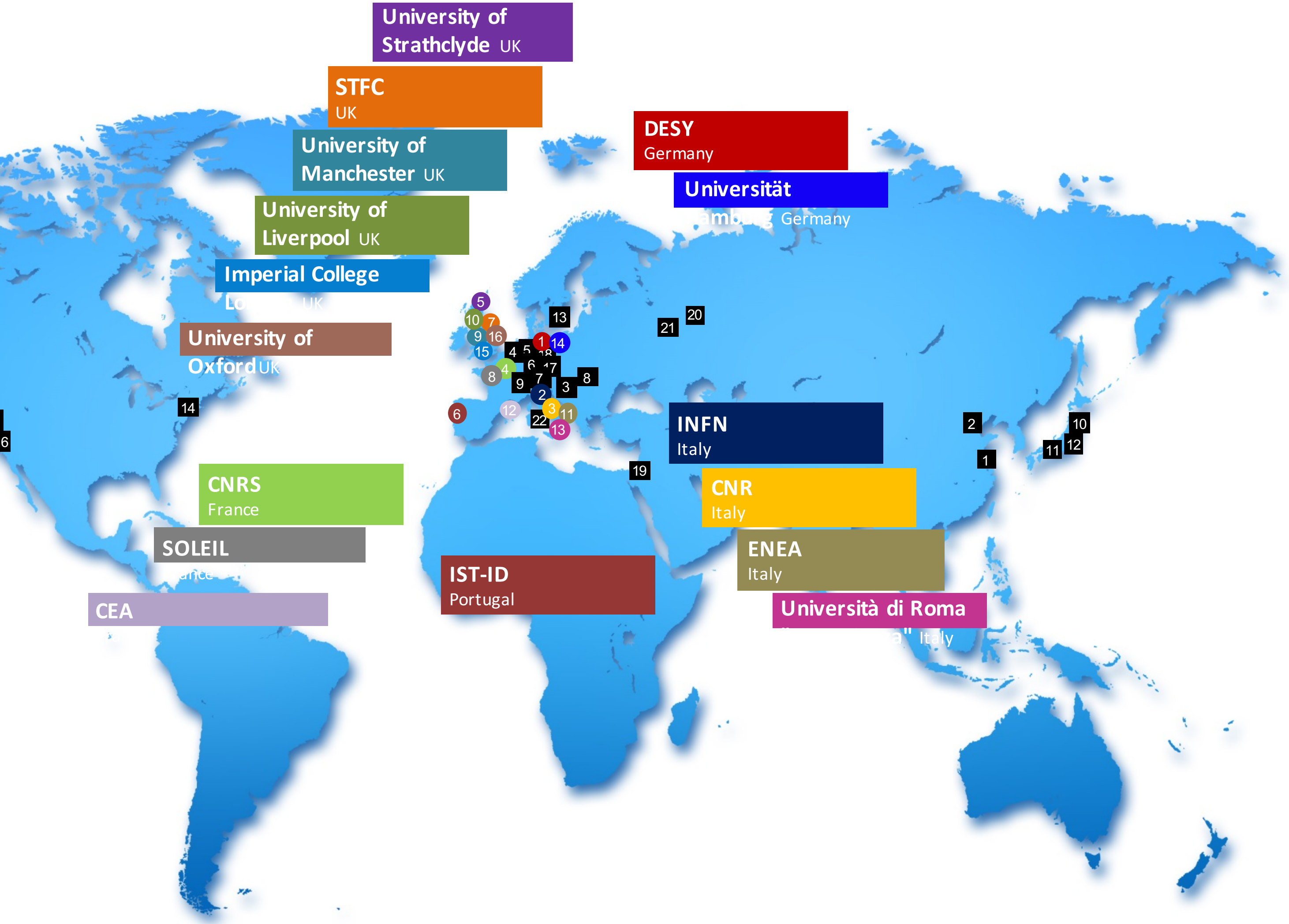
Participating Institutions

Horizon 2020

Associated Partners

(as of October 2016)

1. **Shanghai Jiao Tong-University**, China
2. **Tsinghua University Beijing**, China
3. **ELI Beamlines**, International
4. **PHLAM, Université de Lille**, France
5. **Helmholtz-Institut Jena**, Germany
6. **HZDR (Helmholtz)**, Germany
7. **LMU München**, Germany
8. **Wigner Fizikai Kutatóközpont**, Hungary
9. **CERN**, International
10. **Kansai Photon Science Institute**, Japan
11. **Osaka University**, Japan
12. **RIKEN SPring-8**, Japan
13. **Lunds Universitet**, Sweden
14. **Stony Brook University & Brookhaven NL**, USA
15. **LBNL**, USA
16. **UCLA**, USA
17. **Karlsruher Institut für Technologie**, Germany
18. **Forschungszentrum Jülich**, Germany
19. **Hebrew University of Jerusalem**, Israel
20. **Institute of Applied Physics**, Russia
21. **Joint Institute for High Temperatures**, Russia
22. **Università di Roma "Tor Vergata«**, Italy



Dissemination

Horizon 2020

www.eupraxia-project.eu

#EuPRAXIA
#plasma
#accelerator

Work Breakdown Structure