EuPRAXIA

# EUROPEAN PLASMA RESEARCH ACCELERATOR WITH EXCELLENCE IN APPLICATIONS

## WP4 – Summary of activity: 1st year


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cnrs dépasser les frontières

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# Flash Update of WP4

Horizon 2020

## Establishing contributors list following WP4 workshop & Pisa meeting

- Contributors include scientists from participating and non-participating institutions (es. LLNL). Define how to secure contribution from non-participating institutions (es. Consultant, Supplier, Member of working group …)

**Review preliminary laser parameters**: examine available table and add missing parameters

Deadline: 20th September 2016

Done, (CNRS, CNR)

## Next deadline: Deliverable 4.1

*Benchmarking of existing technology and comparison with the requirements*

- Identify existing commercial technology for short pulse lasers with the required pulse duration, energy per pulse and rep-rate to be used for the (i) laser-driven injector and (ii) laser driven acceleration stages.
- Identify existing, but not mature technology for short pulse lasers with the required pulse duration, energy per pulse and rep-rate to be used for the (i) laser-driven injector and (ii) laser driven acceleration stages.

Deadline: 1st November 2016

Final Draft submitted to coordinator (by CNR, CNRS, STFC)

**Plan the 2° WP4 meeting** to review existing technologies vs. Eupraxia laser parameters. Spring 2017?Decision will be taken at the yearly meeting.

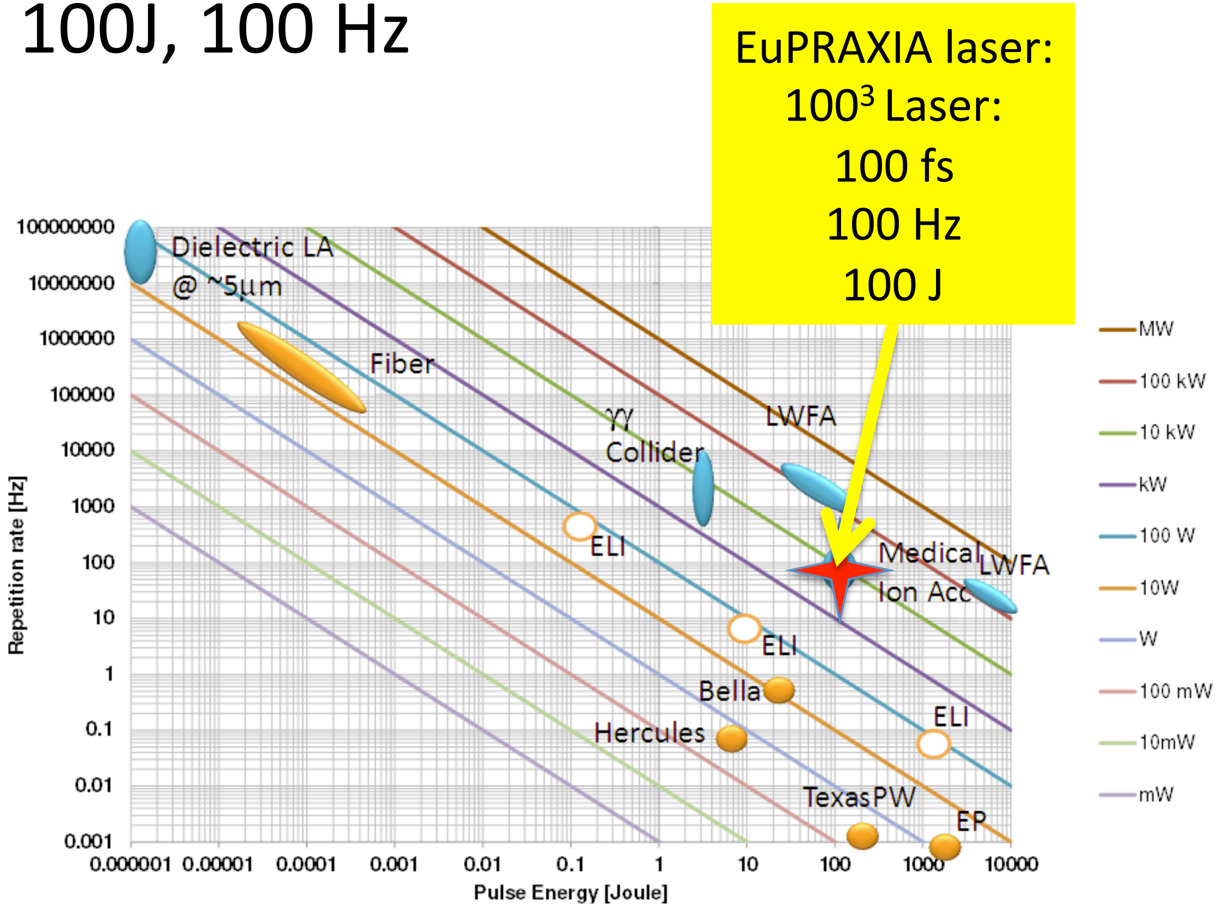
# WP4 - Personnel in place

**CNR**
Leonida A. GIZZI, Istituto Nazionale di Ottica-CNR, Pisa
Petra KOESTER Istituto Nazionale di Ottica-CNR, (EuPRAXIA contract), Pisa
Luca LABATE, Istituto Nazionale di Ottica-CNR-CNR, Pisa
Fernando BRANDI, Istituto Nazionale di Ottica-CNR-CNR, Pisa
Gian Carlo BUSSOLINO, Istituto Nazionale di Ottica-CNR-CNR, Pisa
Barbara PATRIZI, Istituto Nazionale di Ottica-CNR-CNR, Firenze
Guido TOCI, Istituto Nazionale di Ottica-CNR-CNR, Firenze
Matteo VANNINI, Istituto Nazionale di Ottica-CNR-CNR, Firenze

**CNRS**
François Mathieu, CNRS, Ecole Polytechnique
Dimitrios PAPADOPOULOS, CNRS, Ecole Polytechnique
Audrey BELUZE, CNRS, Ecole Polytechnique
Jean-Luc PAILLARD, CNRS, Ecole Polytechnique
*To be announced,* CNRS, Ecole Polytechnique (Eupraxia contract)

**Other personnel**
Rajeev PATTATHIL, STFC Rutherford Appleton Laboratory
Franck FALCOZ, Amplitude Technologies
Maria Pia ANANIA, INFN-LNF
Marco GALIMBERTI, STFC Rutherford Appleton Laboratory
Dario GIOVE, INFN-MI
Klaus ERTEL, STFC Rutherford Appleton Laboratory
Constantin HAEFNER, LLNL
Christophe SIMON BOISSON, Thales Group
Sandrine RICAUD, Thales Group
Sebastien LAUX, Thales Group
Oliver KARGER Hamburg University (UHH)
Alexander KNETSCH Hamburg University (UHH)

- Identification of baseline laser parameters:
  - 100fs, 100J, 100 Hz




High rep rate regarded as a qualifying parameter for a user oriented facility

# 1$^{st}$ WP4 Meeting

Horizon 2020

- May 18, 2016, the EuPRAXIA "Laser Design and Optimization" Work-package 4 held its first workshop in the premises of SOLEIL - France.


Preliminary exploration of “100$^3$” vs. existing technology

# Pisa Meeting

Horizon 2020

EuroNNAc and EuPRAXIA Workshop on a European Plasma Accelerator

29th June - 1st July 2016, CNR, Pisa, Italy

- “$100^3$” configuration is **under scrutiny** in view of requirements from other WPs;
- Industrial quality vs. outstanding performances: energy per pulse vs rep-rate is critical;
- Main (acceleration) beam, injector beam, photocathode beam, aux guiding beam …;
- Rep-rate of laser will drive technology down-selection
- Stabilization can be achieved independently (CW alignment laser);
- Injector and accelerator will require different laser specs (<100 fs vs. >100fs): Ti:Sa?;
- Indirect pumping – DPSSL Yb:YAG? Ceramics?
- Laser development strategy **awaiting decision of full parameters list**, including physics and user driven specifications.

# Updated parameters

Horizon 2020

## Laser 1

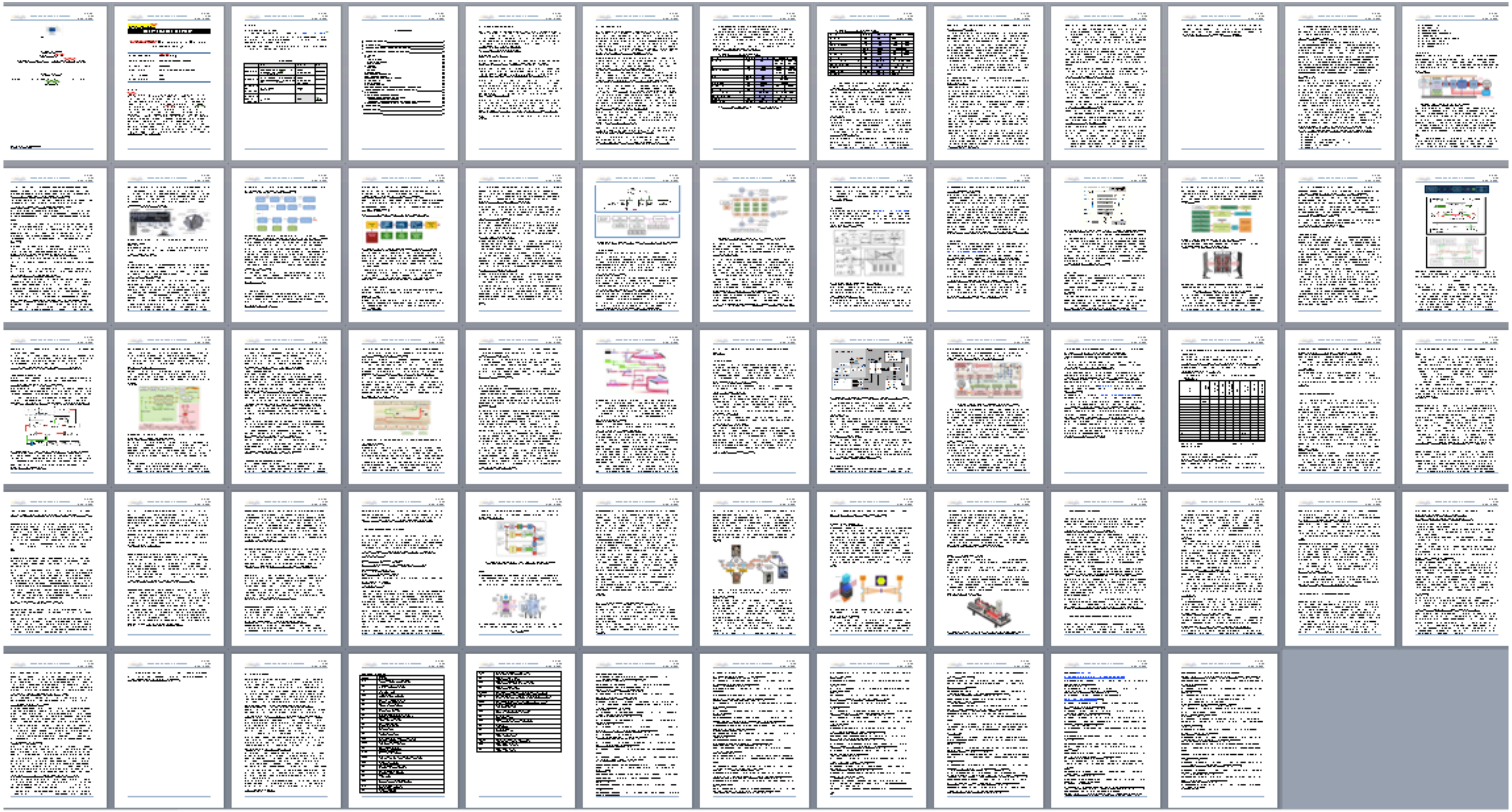
| LWFA injector laser (laser 1) | | | | |
|---|---|---|---|---|
| Wavelength | $\lambda_1$ | 800 nm | 800 nm | |
| Maximum energy | $E_1$ | 5 J | 5 J | 10 J |
| Shortest pulse length (FWHM) | $\tau_1$ | 30 fs | 20 fs | 40fs |
| Peak power | $P_{1,peak}$ | 167 TW | 150-250 TW | |
| Average power | $P_{1,ave}$ | 50 W | 5 W | 1 kW |
| Contrast at 100 ps | $C_1$(100 ps) | tbd | tbd | |
| Contrast at 10 ps | $C_1$(10 ps) | $1\ 10^{10}$ | $1\ 10^{10}$ | |
| Contrast at 1 ps | $C_1$(1 ps) | tbd | tbd | |
| Contrast at 100 fs | $C_1$(100 fs) | tbd | tbd | |
| Contrast at 50 ps | $C_1$(50 fs) | tbd | tbd | |
| Repetition rate | $f_1$ | 10 Hz | 1 Hz | 100 Hz |
| Number of beams | $N_1$ | 1 | 1 | |
| Synchro. to global reference (RMS) | $\sigma_{\Delta t}$ | 10 fs | 10 fs | |
| Pulse shape in focal plane | - | Gaussian | Gaussian | |
| Polarization in focal plane | $P_1$ | linear | linear, circular | |
| Requirement on energy stability | $\sigma_{<E>}$ | tbd | tbd | |
| Requirement on focal size & $Z_L$ stab. | $\sigma_{<ZL>}$ | tbd | tbd | |
| Focal spot position stability | $\sigma_{<W0>}$ | tbd | tbd | |
| Pointing stability | $\sigma_{<x'>}$, $\sigma_{<y'>}$ | 1 μrad | 1 μrad | |
| Required lab room space | $A_1$ | 100 $m^2$ | 100 $m^2$ | |
| including technical rooms but no beam transport | | - | - | |

# Updated parameters

## Laser 2

| Laser driver (laser 2) | | | | |
|---|---|---|---|---|
| Wavelength | $\lambda_2$ | 800 nm | 800 nm | |
| Maximum energy | $E_2$ | 100 J | 100 J | 500 J |
| Shortest pulse length (FWHM) | $\tau_2$ | 100 fs | 50 fs | 250 fs |
| Peak power | $P_{2,peak}$ | 1 PW | 1 - 2 PW | |
| Average power | $P_{2,ave}$ | 1 kW | 0.1 - 1 kW | |
| Contrast at 100 ps | $C_2(100\ ps)$ | tbd | tbd | |
| Contrast at 10 ps | $C_2(10\ ps)$ | $1\ 10^{10}$ | $1\ 10^{10}$ | |
| Contrast at 1 ps | $C_2(1\ ps)$ | tbd | tbd | |
| Contrast at 100 fs | $C_2(100\ fs)$ | tbd | tbd | |
| Contrast at 50 ps | $C_2(50\ fs)$ | tbd | tbd | |
| Repetition rate | $f_2$ | 10 Hz | 1 - 100 Hz | |
| Number of beams | $N_2$ | 2 | 2 | |
| Synchro. to global reference (RMS) | $\sigma_{\Delta t}$ | 10 fs | 10 fs | |
| Pulse shape in focal plane | - | Gaussian | Gaussian | |
| Polarization in focal plane | $P_2$ | linear | linear, circular | |
| Requirement on energy stability | $\sigma_{<E>}$ | tbd | tbd | |
| Requirement on focal size & $Z_L$ stab. | $\sigma_{<ZL>}$ | tbd | tbd | |
| Focal spot position stability | $\sigma_{<W0>}$ | tbd | tbd | |
| Pointing stability | $\sigma_{<x'>}, \sigma_{<y'>}$ | 1 µrad | 1 µrad | |
| Required lab room space | $A_2$ | 500 $m^2$ | 500 $m^2$ | |
| including technical rooms but no beam transport | | - | - | |

# Benchmarking report (draft)



# EuPRAXIA

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APPLICATIONS

# Deliverable 4.1: Report on *Benchmarking of existing technologies and comparison with the requirements*


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With contribution from:

Marco Galimberti (STFC), Luca Labate (CNR), Rajeev Dimitris Papadopoulos (CNRS), Pattathil(STFC), Constantin Heafner (LLNL), Franck Falcoz (Amplitude Tech.), Sebastien Laux (Thales) *and many more …*



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# Rationale

Horizon 2020

**Aim:** Analysis of the available technologies for PW-class lasers, comparison with the requirements of Eupraxia, evaluation of the suitability

**Starting point:** Laser system requirements emerged in WP 1 (Deliverable 1.2)

Two laser devices envisaged: Laser WakeField Accelerator (LWFA) Driver and LWFA injector

*LWFA driver requirements*

| Parameter | Baseline value | Lower limit | Upper limit |
|---|---|---|---|
| **Wavelength** | **800 nm** | 800 nm*<br>800 nm** | 1100 nm*<br>800 nm** |
| **Energy** | **100 J** | 100 J | 500 J |
| **Pulse length (FWHM)** | **100 fs** | 100 fs*<br>50 fs** | 1000 fs*<br>250 fs** |
| **Peak power** | 1 PW | 1 - 2 PW | |
| **Average power** | 1 kW | 0.1 - 1 kW | |
| **Contrast at 10 ps** | **$1\ 10^{10}$** | $1\ 10^{10}$ | |
| **Repetition rate** | **10 Hz** | 1 Hz | 100 Hz |

*LWFA injector requirements*

| Parameter | Baseline value | Lower limit | Upper limit |
|---|---|---|---|
| **Wavelength** | **800 nm** | 800 nm | |
| **Energy** | **5 J** | 5 J | 10 J |
| **Pulse length (FWHM)** | **30 fs** | 20 fs | 40fs |
| **Peak power** | 167 TW | 150-250 TW | |
| **Average power** | 50 W | 5 W | 1 kW |
| **Repetition rate** | **10 Hz** | 1 Hz | 100 Hz |

# Rationale

Survey of PW laser systems worldwide (**operational** or *under development*)

- analysis of the employed technologies
- (mis)matching with the EuPRAXIA requirements
- evaluation of scalability perspectives in the next 5 years

**Analyzed systems (16 total):**

Ti:Sapphire

**Apollon (France)**
**Bella (USA)**
**Laserix (France)**
**PULSER (South Korea)**
**Xtreme Light III (China)**
*HAPLS L3 (ELI-Beamlines)*
*HPLS (ELI-NP)*
*QUIANGGUANG 5PW (China)*
*RAL 10 Hz (UK)*

Nd:Glass

**Texas PW Laser (USA)**

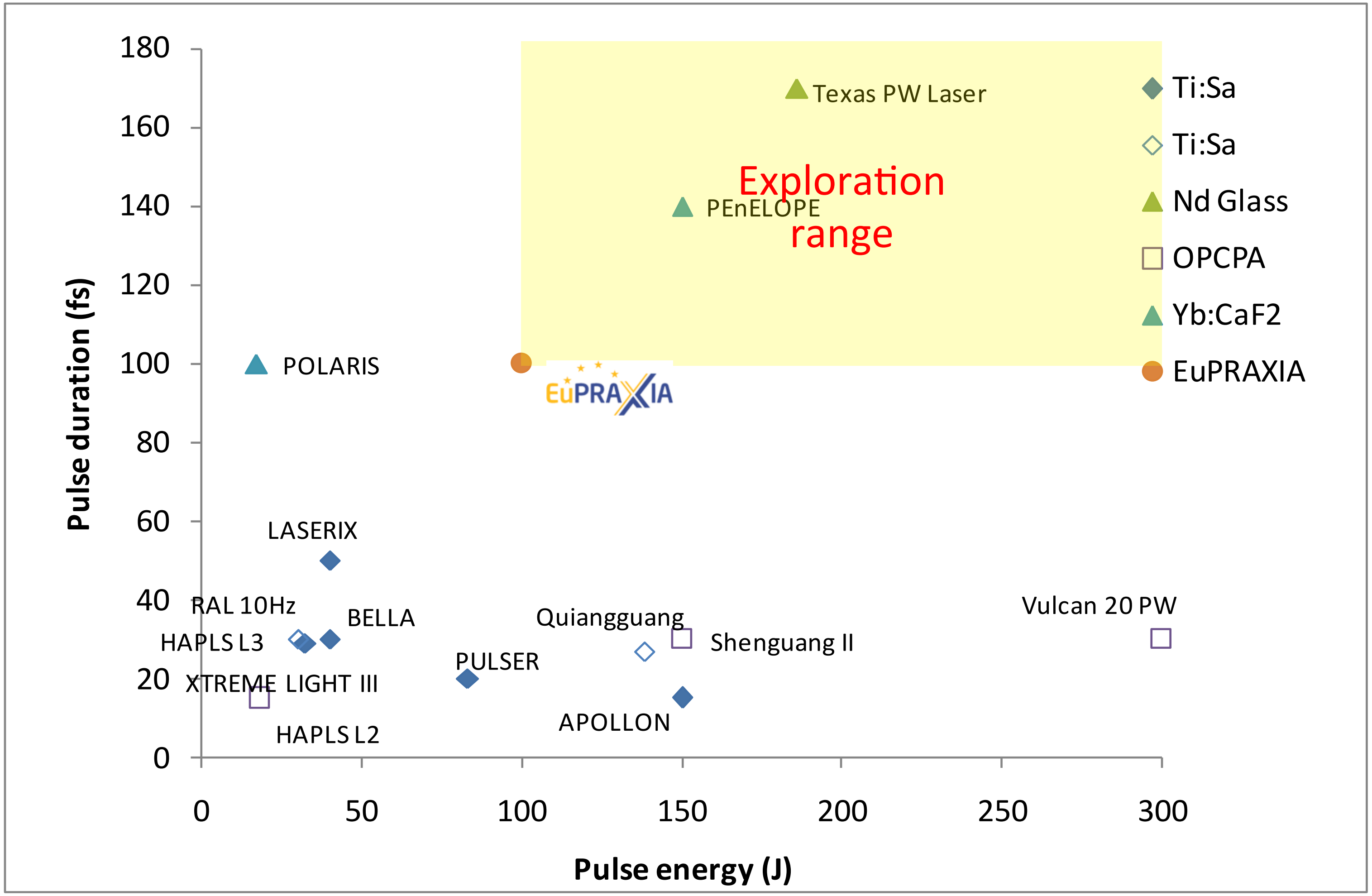
Yb diode-pumped

**PEnELOPE (Germany)**
**POLARIS (Germany)**

OPCPA

*HAPLS L2 (ELI-Beamlines)*
*SHENGUANG II (China)*
*Vulcan 20 PW (UK)*
*ALPS HF (ELI-NP)*

# Survey : Pulse duration vs. Energy

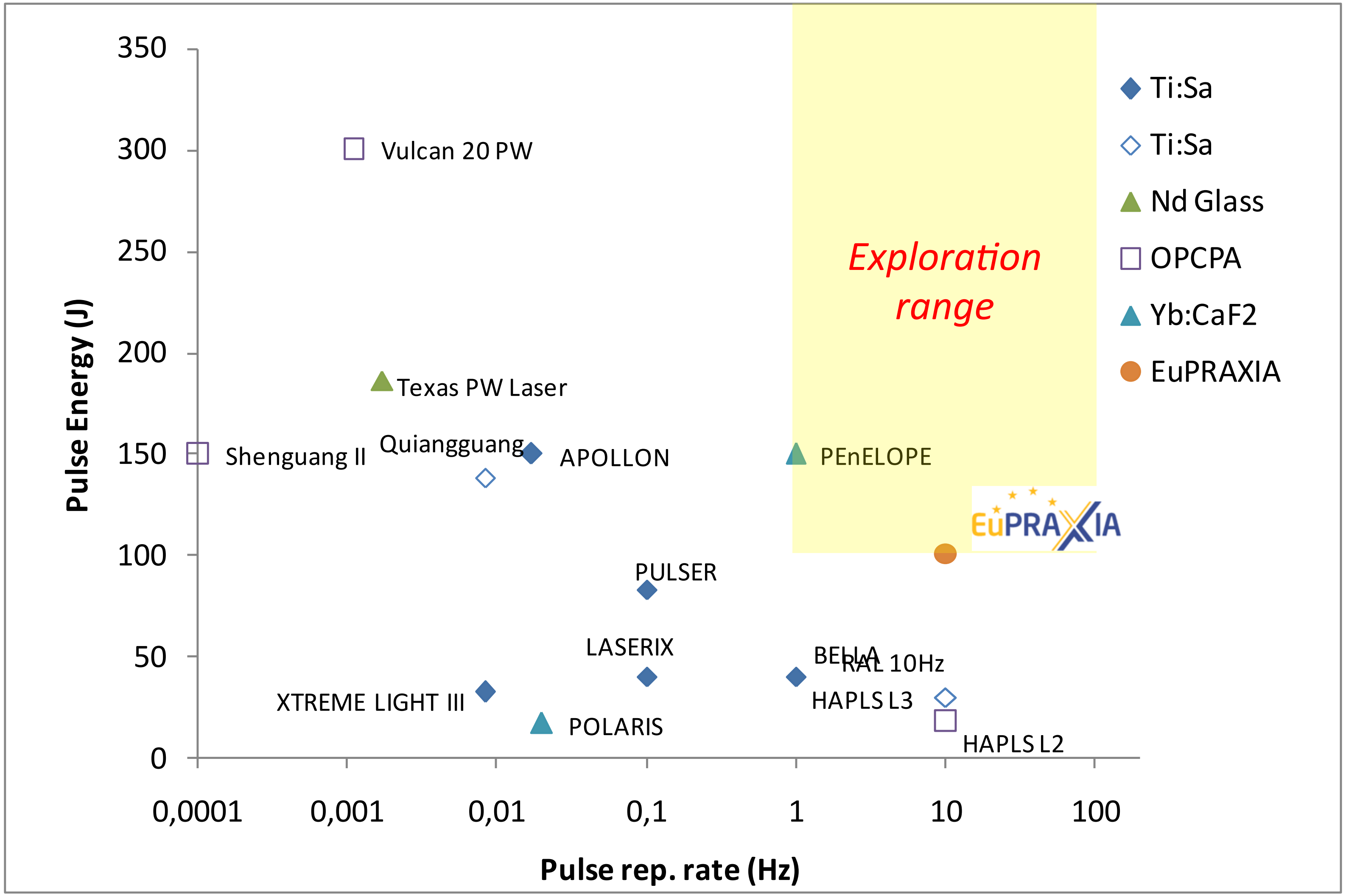



Solid symbols: operational

Open symbols : under development

# Survey: Energy vs. Rep. rate

Horizon 2020




Solid symbols: operational    Open symbols : under development

**Most critical point emerged**:

- Combination 10 Hz / 100 J beyond the limits of existing systems, at the boundary of next generation systems

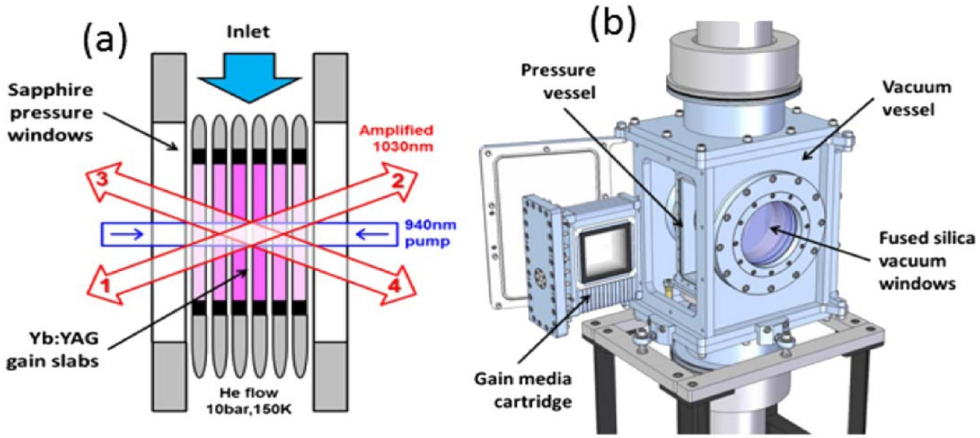
    - Ti:Sapphire /OPCPA systems would require ~ 250 J @ 10 Hz of pump laser pulse energy in the visible: very challenging for pump lasers

    - Yb based fs systems: direct diode pumping option (less difficult to scale up) but challenged in terms of pulse duration

**Already available:**

- Front end segment : several system with short pulse duration, high contrast, high rep. rate (e.g. Apollon)
- Technologies for LWFA injector: available at industrial level (Amplitude, Thales)

# DiPOLE 100




Under development at STFC-RAL (UK)

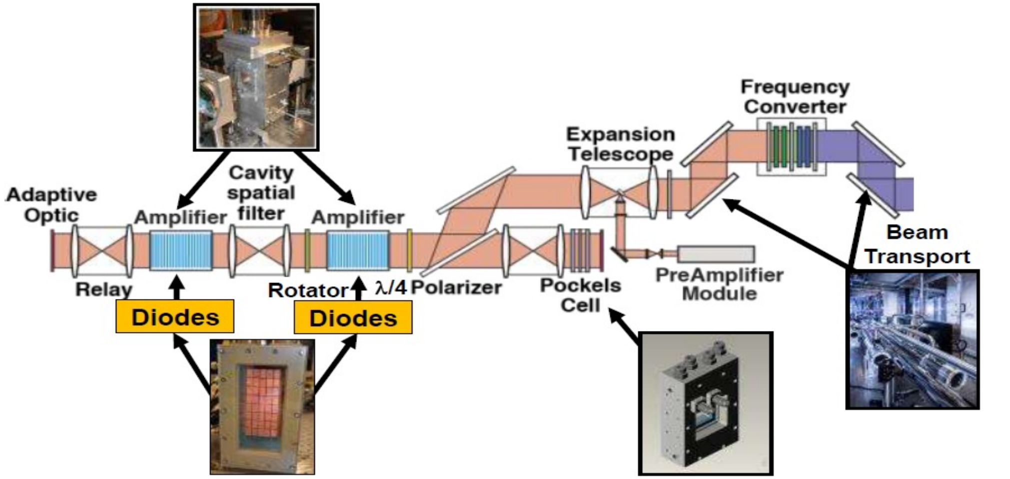
Diode pumped Yb:YAG slabs, He-cooled

**>100 J** output energy demonstrated @ **1 Hz**, 1030 nm

Ramping up to 10 Hz (design limit): in progress

> 60 J conversion @ 515 nm expected

## HAPLS L3 (ELI-Beamlines) pump source




Developed by Lawrence Livermore National Laboratory (USA)

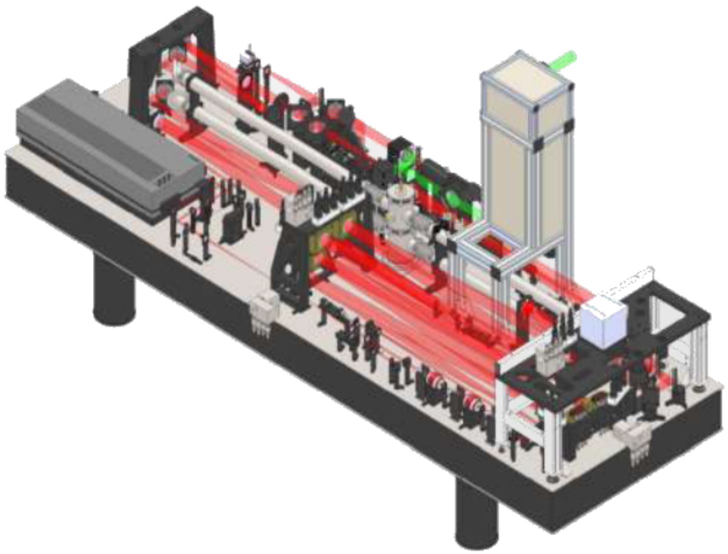
Diode pumped Nd:APG-1 glass, He-cooled

**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 pump laser (ELI-ALPS HF)



Developed by Amplitude Technologies

Flashlamp pumped Nd:YAG

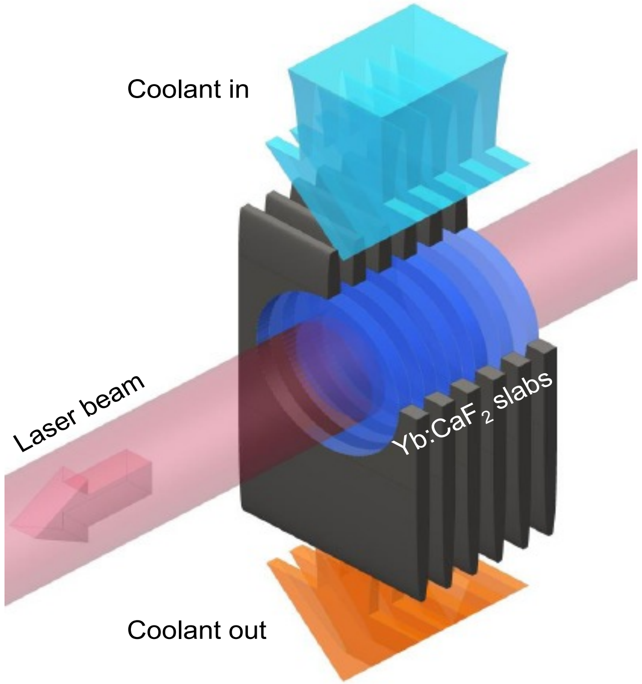
**45 J** output energy demonstrated @ **10 Hz**, 1064 nm

60 J SHG energy @ 532 nm : design target

Ramping up to 10 Hz, full energy (design limit): in progress

# Technologies for directly diode pumped amplification

## PEnELOPE




Developed by Dresden Helmoltz Institute

Diode-pumped Yb:$CaF_2$ slabs, He cooled

- **150 J** output energy,
- **145 fs** pulse duration
- **1 Hz**
- 1030 nm

Currently operational

# Conclusions

- Review of the existing PW-level laser technologies and benchmarking with EuPRAXIA requirements

- LWFA driver: very challenging, due to the high energy/high repetition rate/average power required;

- Very demanding for pump systems, in particular for Ti:Sapphire and OPCPA systems

- High pulse energy (100 J), 10 Hz pump sources in advanced development phase under several projects (diode pumped and flashlamp pumped systems), possible options in the next few years

- Operational examples of directly diode pumped femtosecond amplifiers, approaching EuPRAXIA requirements

# The End

*Thank you for your attention*

*Questions?*