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EXCELLENCE IN
APPLICATIONS

EuPRAXIA

Status of WP4

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Collaboration Week,

19th November 2018, Frascati, Italy

On behalf of WP4

http://eupraxia-project.eu

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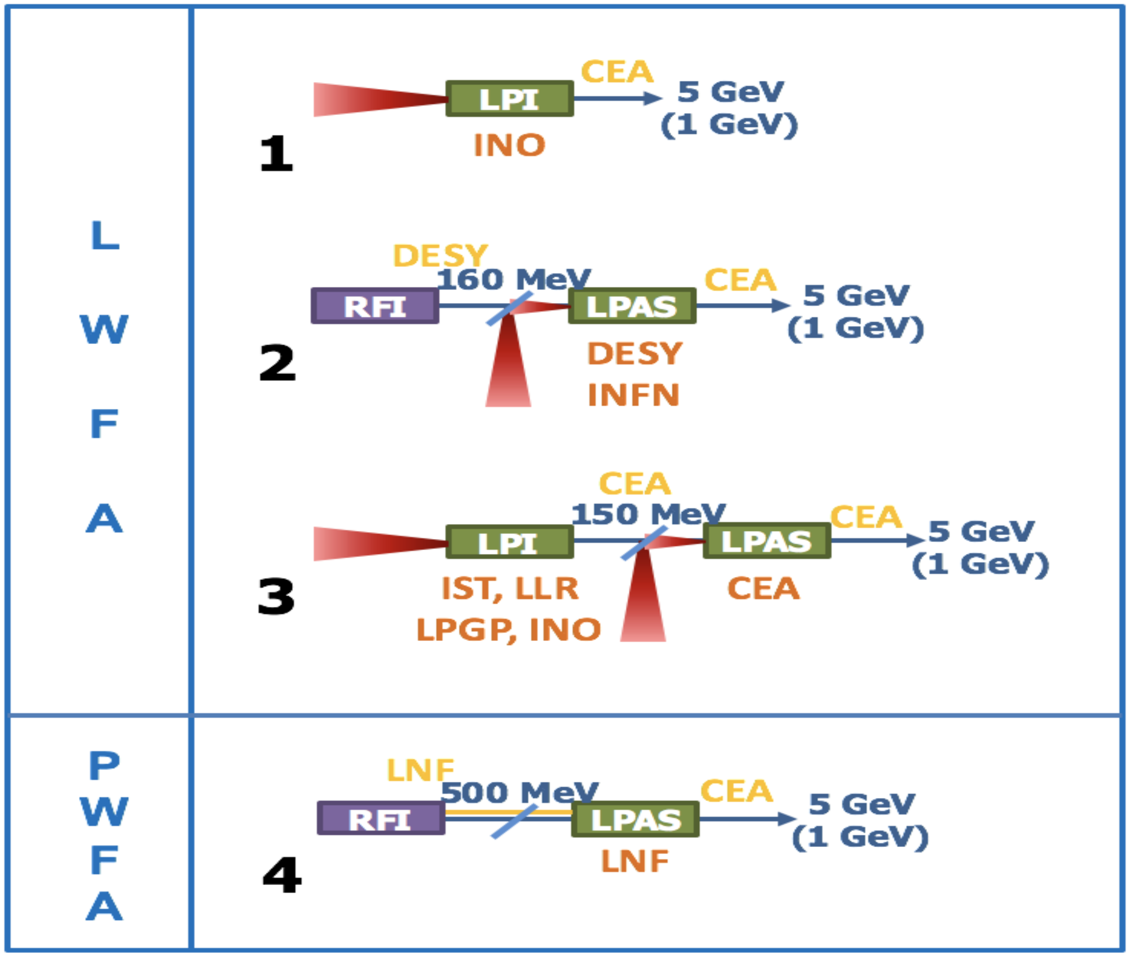
shaded — major contributors/collaborators

CONTENT

- Main EuPRAXIA laser requirements
- Current design and options
- SAC recommendations
- Conclusions

EuPRAXIA Laser Layout

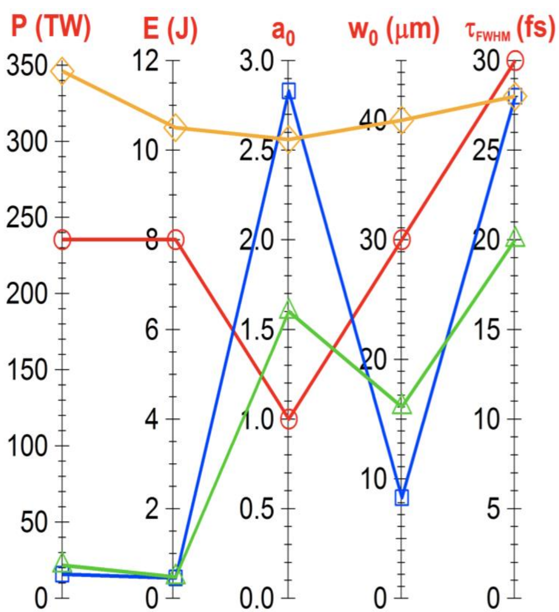
*Acceleration schemes (WP2), selected to provide a beam at **5 GeV** meeting FEL and HEPO requirements and a beam at **1 GeV** 'usable' for FEL and HEPO, as a 'commissioning' step.*

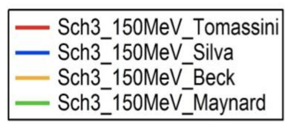


EuPRAXIA Laser Layout

Main laser requirements for acceleration schemes (from WP2)

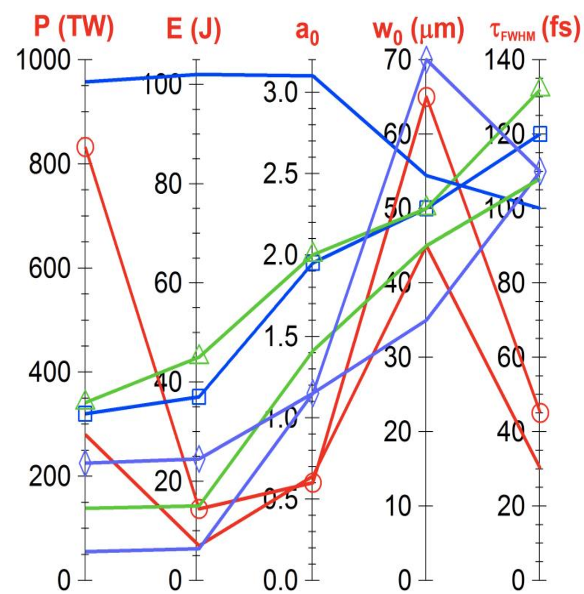
150 MeV Injector Laser (LASER1)

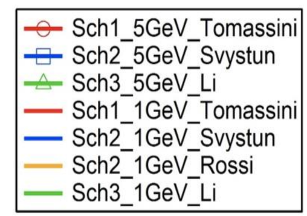




Bi-Gaussian pulse
λ = 800 nm

5 GeV accelerator Laser (LASER3)





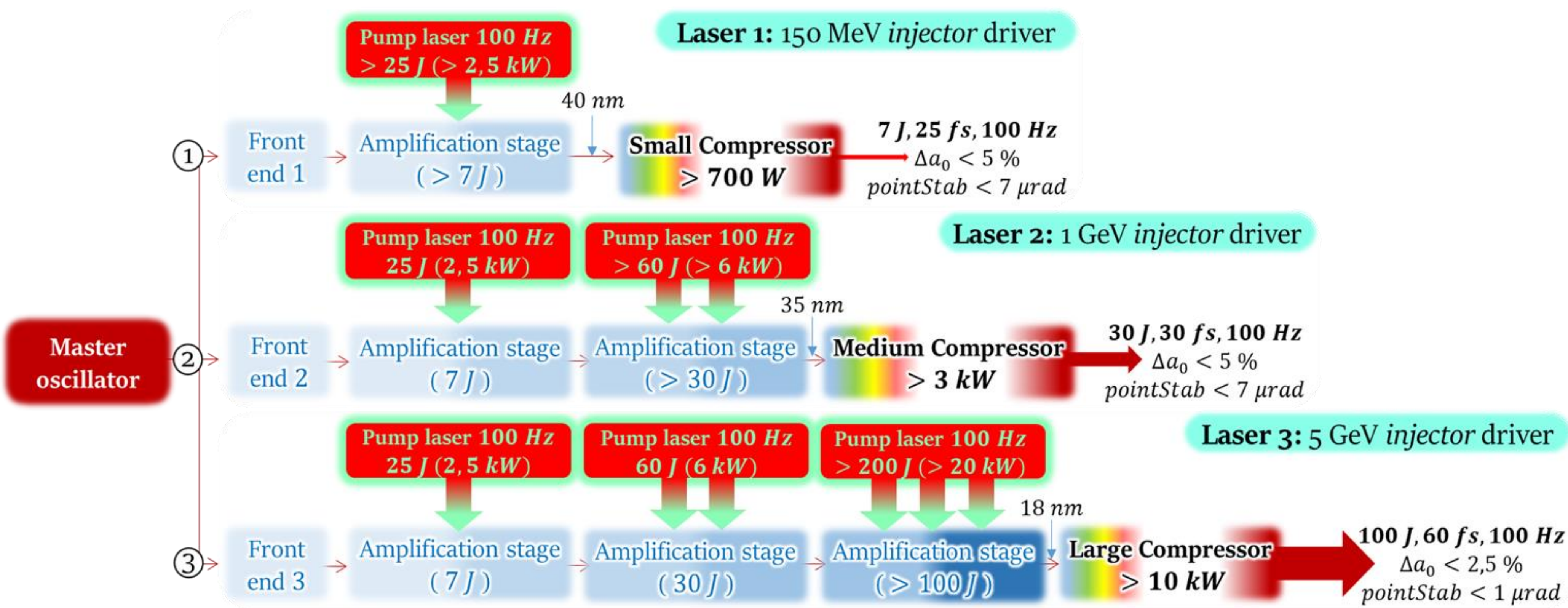
Bi-Gaussian pulse
λ = 800 nm

(cosine squared in longitudinal for Sch2_1 GeV_Rossi)

EuPRAXIA Laser Layout

The current EuPRAXIA laser design[1] relies on mature Titanium Sapphire industrial technology to deliver average and peak power as required by the project.

A set of three laser chains are considered, to drive the injectors at 150 MeV and 1 GeV, and the accelerator at 5 GeV.

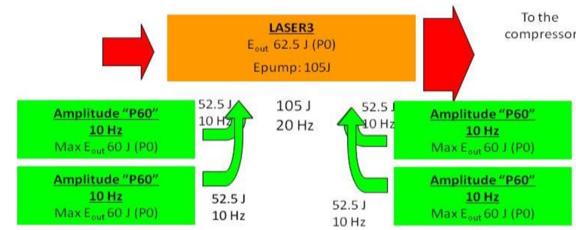


L.A.Gizzi et al., A viable laser driver for a user plasma accelerator., NIM-A, (2018).

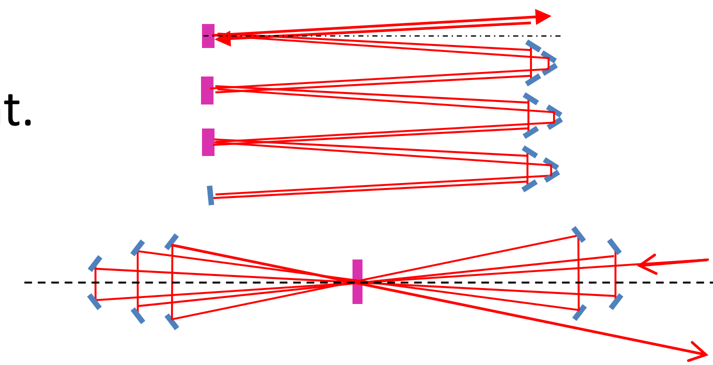
Laser design - Amplifiers

Horizon 2020

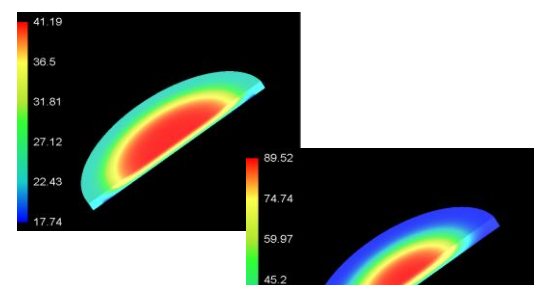
Main recent activities



Definition of **pump sources arrays** for the various amplification stages, based on available (SCLF DiPOLE / Amplitude P60) and perspective technologies



Design of **amplifier stages layout** (both for transmission and reflection amplifiers); evaluation of required footprint. Pump delivery /timing schemes for Extraction During Pumping



Optimization/simplification of **amplifier design** (reduction of number of stages/passes) and trade-off on thermal design

More at the WP4 meeting (Thu 3pm-5pm) by G. Toci

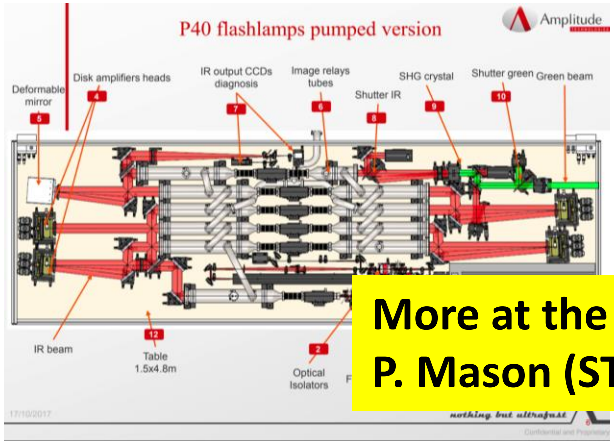
*) Water cooled Ti:Sa amplifier under development at ELI-HU (After V. Cvhykov *et al.* , Opt. Lett, **41**, 3017, 2016)

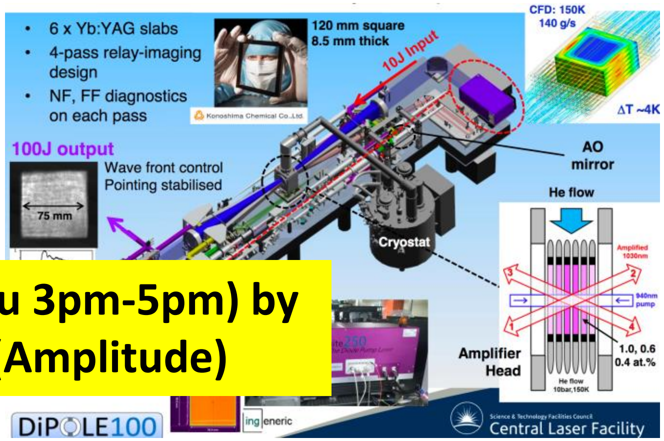
) Fluid (D_2O) cooled Nd:YAG laser, 20 kW CW pump power, D_2O (After X. Fu *et al.* , Opt. Express, **22, 18421 (2014)

***) Fluid (Siloxane) cooled Nd:YLF laser, 5 kW CW pump power (After Z. Ye *et al.* , Opt. Express, **24**, 1758 (2016)

Candidate pump energy sources

Promising developments based on diode pumping technology are in progress at EuPRAXIA industrial and research partners, progressively matching requirements





More at the WP4 meeting (Thu 3pm-5pm) by P. Mason (STFC) and F. Falcoz (Amplitude)

Amplitude P60
Flashlamp pumped Nd:YAG
Design: 60 J @ 10 Hz, 532 nm

<u>Conversion to DPSS fully designed</u>

- Expected rep. rate 50 Hz
- Cost of diode still an issue – currently 5x compared to flashlamps.
- Expected to decrease in 5-10 yrs.
- Maintenance free operation for 25-30 yrs.

DIPOLE[1] 100
DPSSL Yb:YAG, cryogenic He cooling
100 J @ 10 Hz, @515 nm
Planned developments: 10J @ 100 Hz

Route to 20 Hz pumping for EuPRAXIA
Scaling of cost of diodes

[1])P. Mason et al., Kilowatt average power 100J-level diode pumped solid state laser," Optica 4, 438-439 (2017)

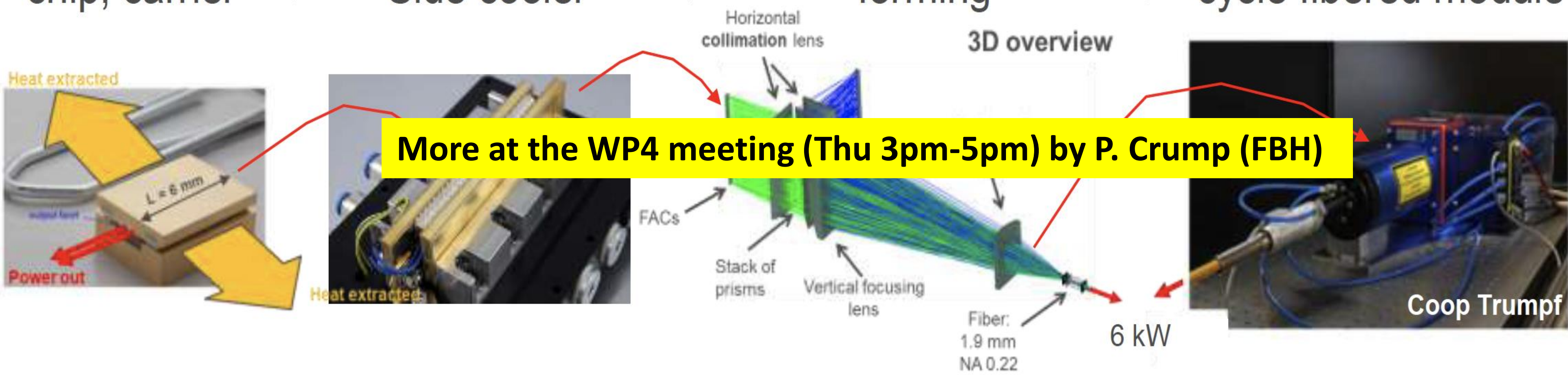
100 Hz pump laser

Horizon 2020

White paper 100 Hz pump trials to assist EuPRAXIA system design (STFC, LLNL, HZDR, FBH), supported by the Institute of Quantum Optics, Friedrich-Schiller-University, Jena in Germany

FBH brilliant high duty cycle pump: small-series prototype

Novel chip, carrier → Novel passive Side cooler → Custom beam forming → Brilliant, high duty cycle fibered module



More at the WP4 meeting (Thu 3pm-5pm) by P. Crump (FBH)

130W from 1.2mm
Peak: ~ 245 W
60% efficiency
2x brighter than bars

1…20% DC
1…100ms
Passive cooling

6 kW 60% efficiency
M^2 ~ 300 x 300

1.4 MW/cm^2-sr
50% efficiency
M^2 ~ 700

6 units delivered to Max Born Institut, Berlin; 2 in build

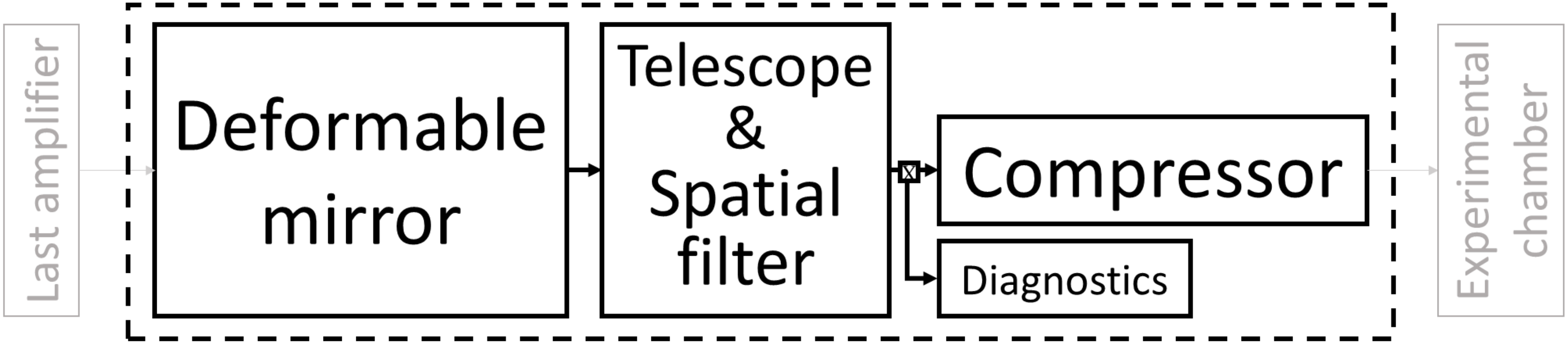
Leibniz Ferdinand Braun Institut

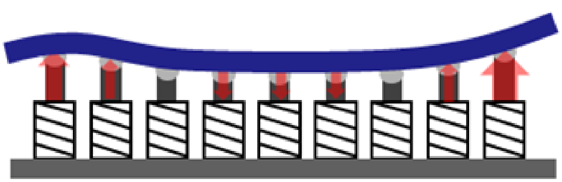
EuPRAXIA

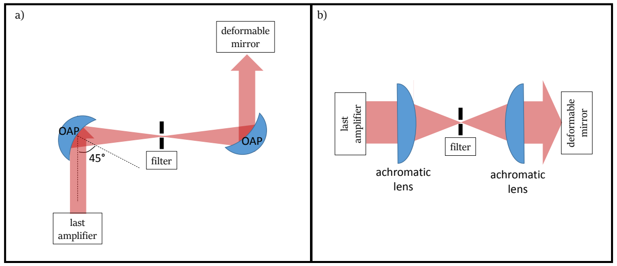
Transport to target

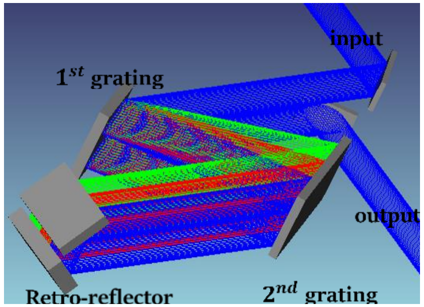
Horizon 2020

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









Different grating technologies under evaluation to address main issues with higher repetition rate. Strategy includes reduction of the thermal load at high average power, cooling of residual heat and control of thermal effects on compression quality.

Pulse train for resonant wakefield

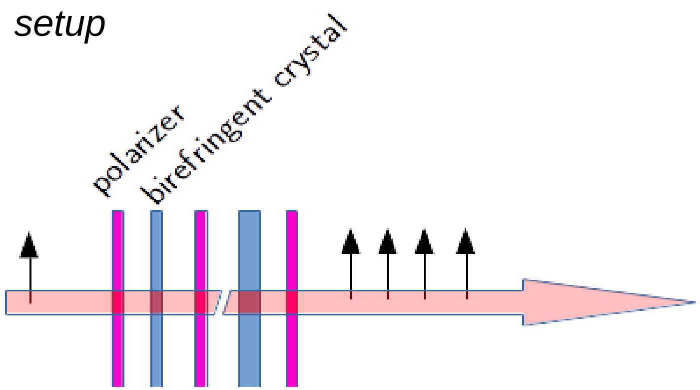
Horizon 2020

A (QUASI) LOSSLESS SCHEME

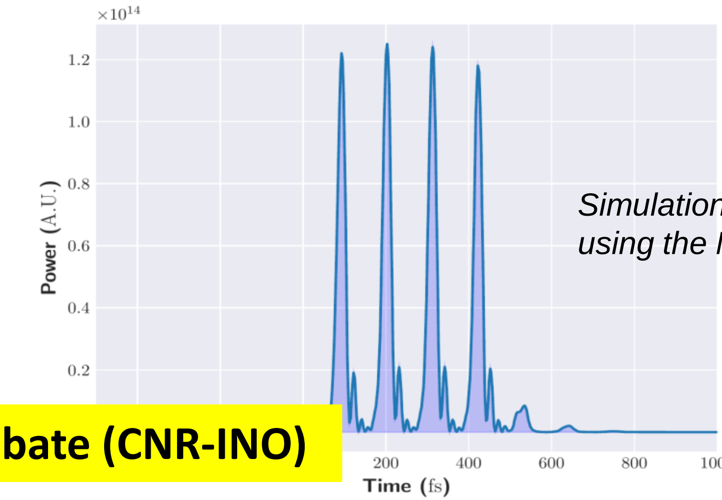
Motivation. Shortcomings of current proposed/employed schemes

- Complex setup, to be implemented on the compressed (large) beam
- Intensity homogeneity issues among the different pulses of the same train
- Possibly leading to very high energy losses (up to 50%) ← relevant for the EuPRAXIA laser design

Generation of multiple pulse by a stack of polarizers and birefringent crystals [1]
Shortcomings: remarkable energy loss, cumbersome setup



Quasi lossless Train gEneration by an early aMplitude dIvision (TEMPI) [2]
Splitting occurs very early in the laser chain. Effects due to pulse interference manageable



Simulation carried out using the MIRO code

More at the WP4 meeting (Thu 3pm-5pm) by L. Labate (CNR-INO)

Test experiment carried out at the ILIL laboratory

Energy losses negligible as compared to the overall pump energy
Compact and simple setup

CNR INO
CONSIGLIO NAZIONALE DELLE RICERCHE
ISTITUTO NAZIONALE DI OTTICA

[1] B. Dromey *et al., Appl. Opt.* **46**, 5142 (2007)
[2] L. Labate, G. Toci, P. Tomassini, L.A. Gizzi, *submitted*

Summary on developments

Horizon 2020

- Prototyping of Ti:Sa amplifiers
- Addressing 100 Hz pump lasers developments
- Thermal management of compressor gratings
- Stability (pointing & more) and active control
- Driver pulse temporal shaping (multi-pulse)
- Synchronization
- Construction
- Integration Issues
- …

Seed funding planned by internal collaboration.
De-rinking R&D phase expected prior to TDR.

SAC Recommendation

Horizon 2020

Rec12. Broaden the dialogue to other WPs (e.g. WP2, WP5, WP14) to inform on design space, specifically on critical parameters (e.g. a0 vs power/focal area). ***Effective interaction with WP2/3***

Rec13. Explore **feasibility** of **timing precision and jitter** requirements provided by WP2 and WP3, and how it can be verified at the target. ***Work in progress at Desy***

Rec14. Develop a better understanding of **pointing requirements** and metrics, specifically how they are coupled to the facility. ***Building DB of pointing performance at facilities***

Rec15. Develop a strategic **technology roadmap** that supports the overarching performance goals of EuPRAXIA. Get guidance on technology demonstrator vs science facility. Maintain perspective of technologies that can scale. ***Work in progress – requires additional funding***

Rec16. Given the timescales on how much technology development is required, how long does it take, and when construction of a system could start, identify **risk reduction experiments** that add credibility to the feasibility of certain technologies. ***Experiments identified***

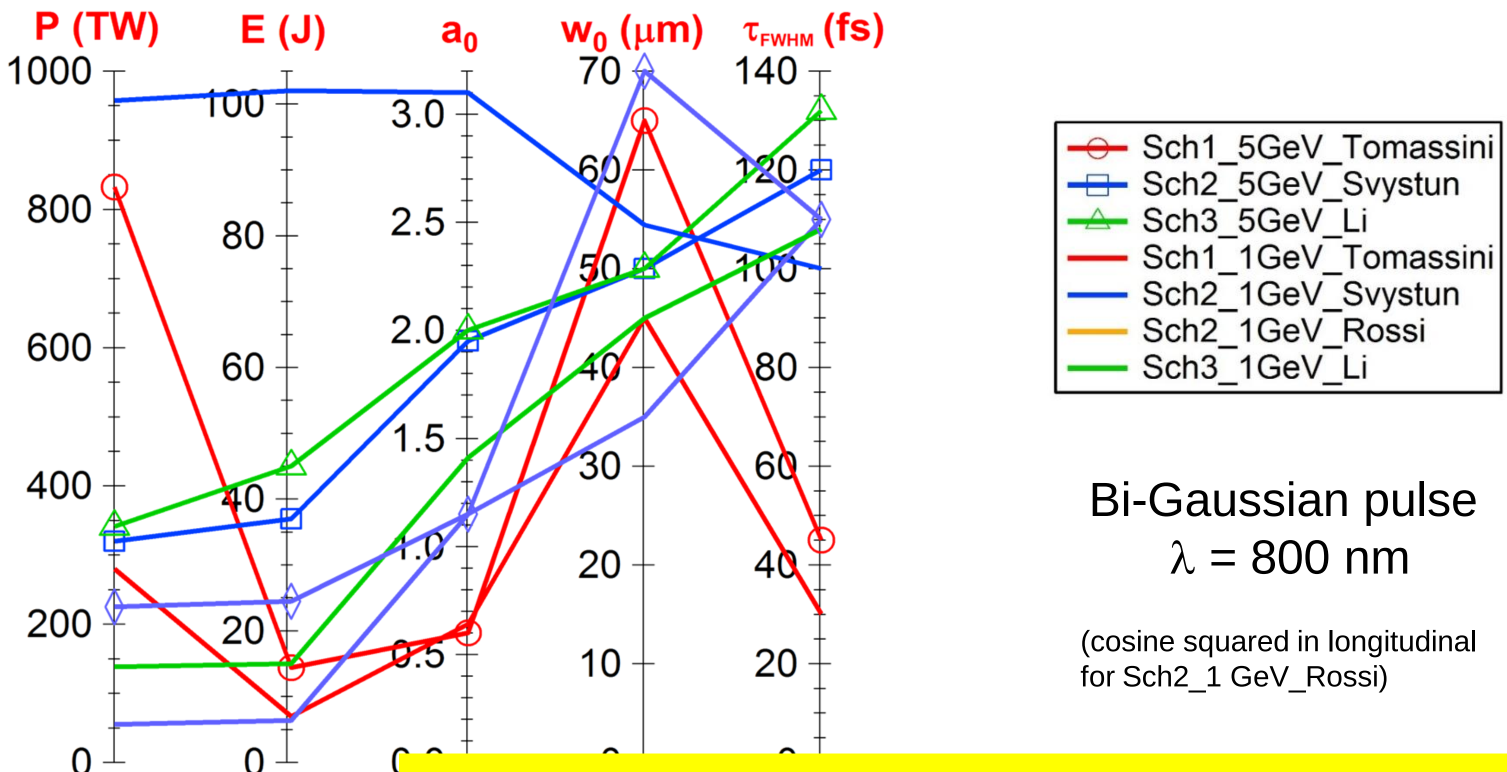
Rec17. Develop a crisp risk matrix for each technology approach, **identify bottlenecks** and areas where risk reduction experiments are needed. Identify synergetic efforts between technology paths. ***Set of bottlenecks identified and being explored***

Rec18. Use **technical readiness levels** for the integrated laser system concepts (not individual components) to assess and compare maturity of each solution. ***In progress in collaboration with industry***

SAC: Interaction with other WPS

Rec12. Broaden the dialogue to other WPs (e.g. WP2, WP5, WP14) to inform on design space, specifically on critical parameters (e.g. a0 vs power/focal area). ***Effective interaction with WP2/3***

Summary laser requirements from WP2



Bi-Gaussian pulse
λ = 800 nm

(cosine squared in longitudinal for Sch2_1 GeV_Rossi)

More at the WP4 meeting (Thu 3pm-5pm) by C. Siders (LLNL)

More interaction on wavelength scaling of LWFA to remain informed on impact of other scalable and more efficient, direct dpssl CPA technologies (e.g. Tm:YLF)

SAC: Risk reduction

Rec16. Given the timescales on how much technology development is required, how long does it take, and when construction of a system could start, identify **risk reduction experiments** that add credibility to the feasibility of certain technologies. ***Experiments identified***

Rec17. Develop a crisp risk matrix for each technology approach, **identify bottlenecks** and areas where **risk reduction experiments are needed**. Identify synergetic efforts between technology paths. ***Set of bottlenecks identified and being explored***

MAIN ITEMS

- **Pumping technology ($$$):**
  Scaled 100 Hz rep rep. rate, high energy pumping;
- **Gain media ($$):**
  Build a test amplifier to test Thermal load, Cooling
- **Grating technology ($$)**
  Run high average power illumination tests at existing facilities, to make assessments on LIDT, Thermal load, Cooling. Lifetime …
- **Pointing stability ($)**
- Build tools and run tests at existing facilities; define TDR for active stabilization
- ………

SAC: more for R&D phase

Rec13. Explore **feasibility** of **timing precision and jitter** requirements provided by WP2 and WP3, and how it can be verified at the target.

Knowledge and work in progress at Desy, LNF …

Rec15. Develop a strategic **technology roadmap** that supports the overarching performance goals of EuPRAXIA. Get guidance on technology demonstrator vs science facility. Maintain perspective of technologies that can scale.

R&D phase for demonstrators (seeking major funding)

Scalable technology being observed

Collaborative activities involving WP4 partners

Rec18. Use **technical readiness levels** for the integrated laser system concepts (not individual components) to assess and compare maturity of each solution.

Process ongoing in view of the Final Laser Design – in collaboration with Industry

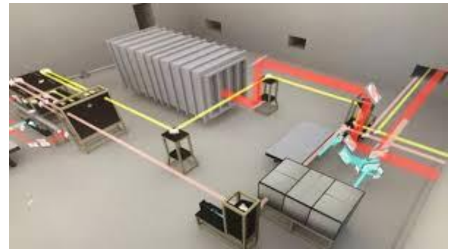
PROJECT DELIVERABLES

Horizon 2020

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

DELIVERED

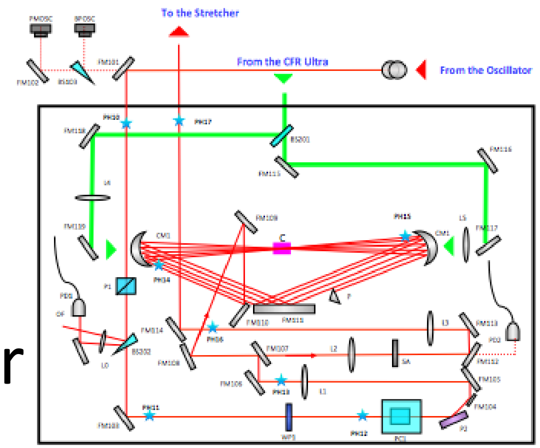
Explore and identify promising technologies



D4.2 (M24) Preliminary laser design

DELIVERED

To be developed with an eye to perspective industrial development



D4.3 (M24) Preliminary design of transverse functions

DELIVERED

To account for final use of EuPRAXIA (user facility)

EuPRAXIA

PROJECT DELIVERABLES

Horizon 2020

D4.4 (M36) Final requirements of laser system

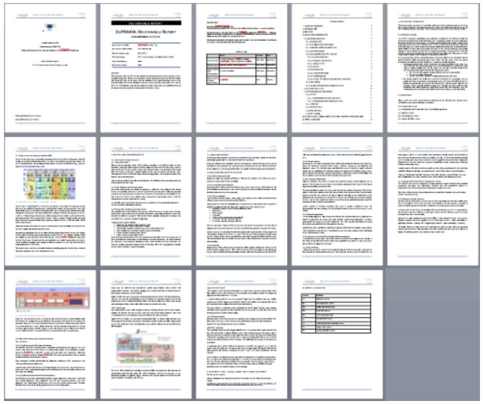
DELIVERED

To comfortably accommodate LWFA design and other laser based activities

D4.5 (M36) Control command design system

DELIVERED

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



PROJECT Milestones

M4.1 (M12) WP4 Personnel in place *(completed)*

M4.2 (M18) Preliminary Laser Requirements Table and Tech. Survey *(completed)*

M4.3 (M30) Preliminary Laser Design *(completed)*

M4.4 (M30) Final Laser and Controls Requirements Table *(completed)*

M4.5 (M42) Final Laser Design (in progress; 01.05.2019)

SUMMARY

- EuPRAXIA aiming at a PW-kW laser laser driver;
- Current requirements (WP2) compatible with Ti:Sa;
- Major recent progress of DPSSL technology matches 20 Hz operation requirements, with frequency doubled DPSSL based pumping units;
- Design phase ongoing: preliminary design going technical;
- Considering evolution towards 100 Hz repetition rate;
- Significant development activities and funding needed to solve standing technical issues for forthcoming TDR phase.

EuPRAXIA

LABs AND INDUSTRY

Horizon 2020

A wide collaboration is ready to be involved to tackle open issues

Amplitude Technologies

THALES

VCS

SAFRAN

VACUUM FAB

HORIBA JOBIN YVON

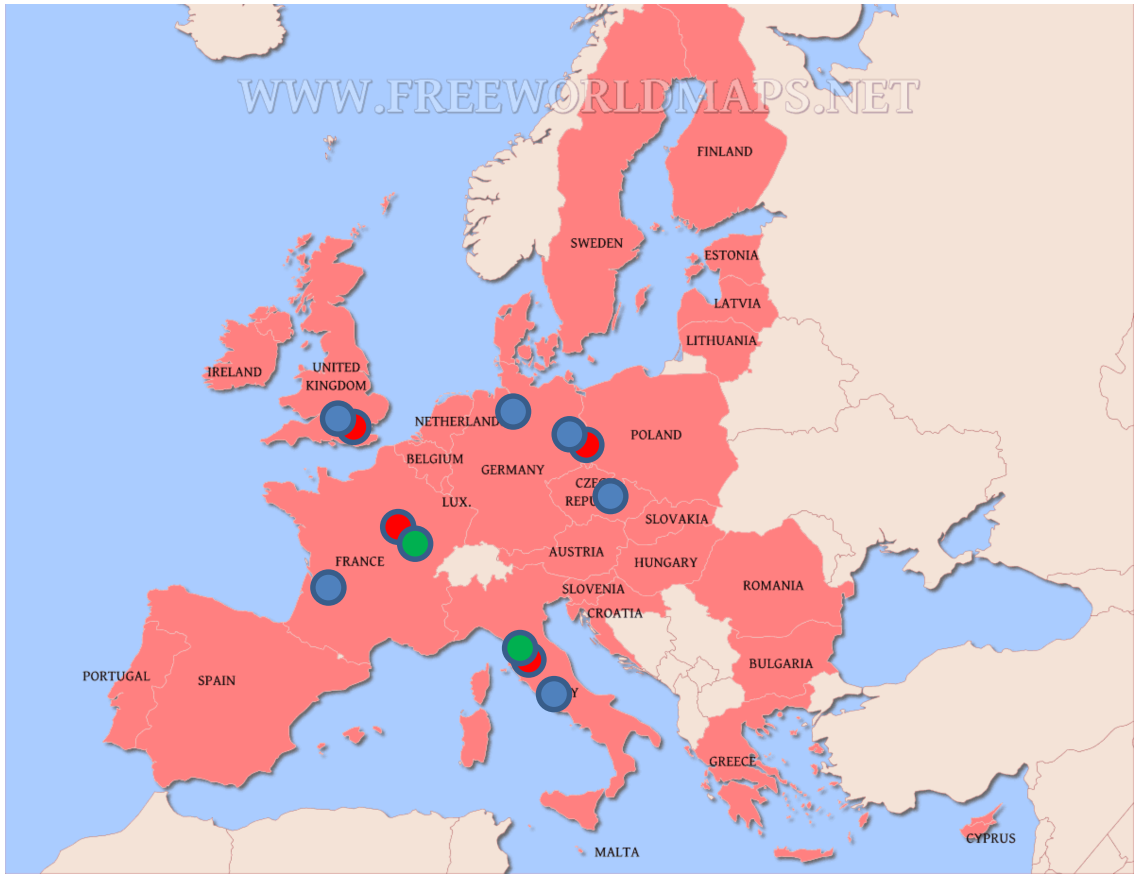
ISP SYSTEM

TRUMPF

imagine optic

DYNAMIC OPTICS

and many more



Consiglio Nazionale delle Ricerche

cnrs centre national de la recherche scientifique

Science & Technology Facilities Council

INFN Istituto Nazionale di Fisica Nucleare

Lawrence Livermore Natl. Lab

FBH Leibniz Ferdinand Braun Institut

EuPRAXIA

Consortium

Horizon 2020

16 Participants

22 Associated Partners

(as of October 2016)