

EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS



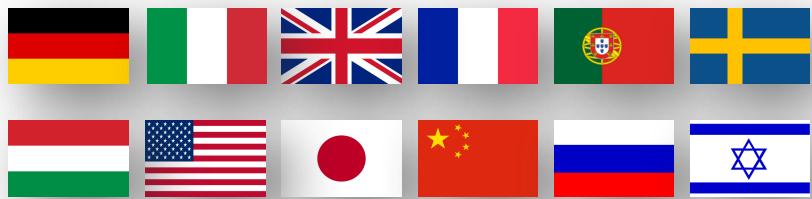
Layout considerations for EuPRAXIA

Paul Andreas Walker (DESY)

On behalf of the EuPRAXIA collaboration

3rd European Advanced Accelerator Conference

September 27th, 2017, Elba, Italy



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

- EuPRAXIA is a **conceptual design study** for a **5 GeV electron plasma accelerator** as an European research infrastructure
- 125 scientists work in 38 international partners
 - 16 EU laboratories are beneficiaries
 - 22 associated partners contribute in-kind
- This talk focuses on layout plan for facility
 - Other throughout the week discuss RF & plasma injector, acc. stages, transport, ...
 - **EuPRAXIA plenary session tomorrow at 11 am**
 - Ralph Assmann: EuPRAXIA overview
 - Leo Gizzi: Laser design and industry
 - Alban Mosnier: Simulations and performance



- Facility layout design is driven by many aspects:
 - Simulations
 - Experimental results
 - Timeline, funding & commitment
 - Applications targeted and their requirements
 - Concepts ready/work on
 - Infrastructure requirements: water/cooling/power etc.
 - Available space at existing laboratories
 - ...
- **Science & practical considerations** will determine final choice of configuration(s) and layout
- EuPRAXIA layout will be optimized for best synergy of lasers & RF technology

Nov. 2015	Start of EuPRAXIA project
2016/2017	Hiring of dedicated personnel 19 workshops on EuPRAXIA/EuroNNAC 15 scientific reports published, 7 to come later in the year → <i>Initial layout design (started 7/2016)</i> Study parameters table for facility Added 6 new institutes
2018/2019	Work with refined parameters Finalize laser and RF design Decide on options/combination → <i>Finalize layout design (summer 2019)</i> Finalize Conceptual Design Report (CDR) Application to ESFRI roadmap for 2020
Oct. 2019	Final conceptual design report
2020	<i>Construction decision</i>
2021 – 2025	<i>Construction</i>
2025 – 2035	<i>Operation</i>

More details tomorrow
in Ralph's talk at 11 am

There will be **at least 2 user areas**:

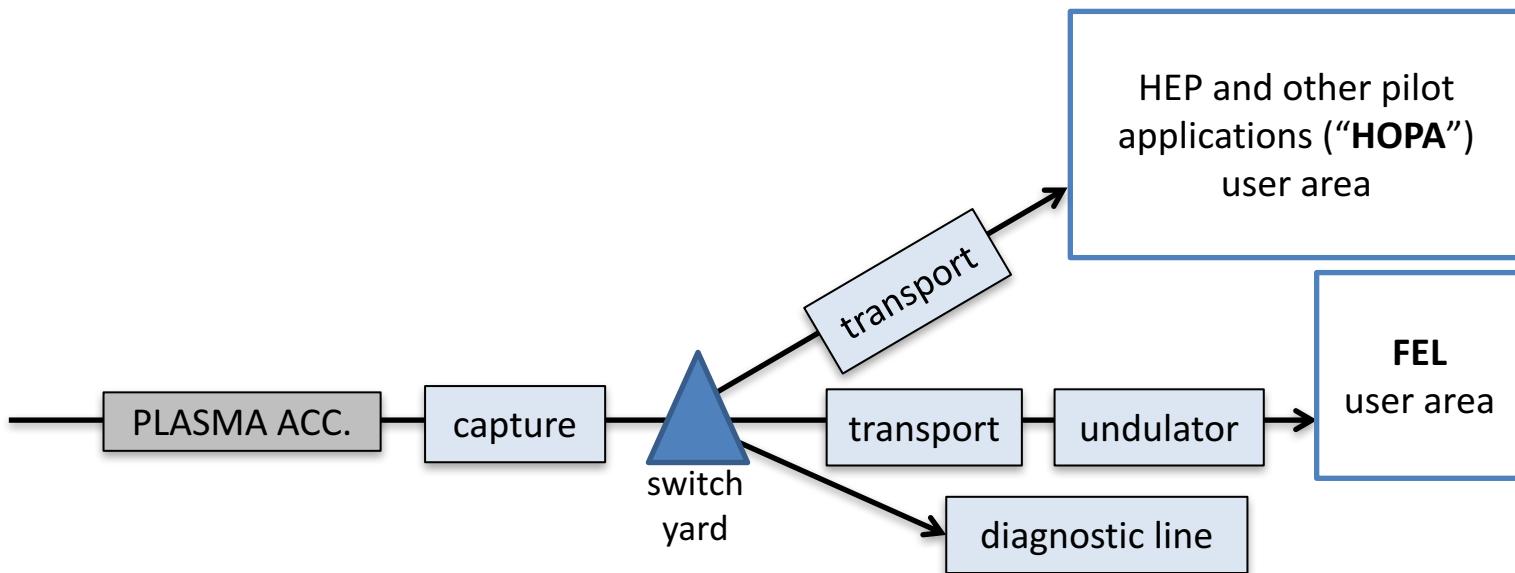
FEL user area:

- FEL's with new properties (complimentary to high power FEL's): *ultra-short pulses, pump-probe, excellent synchronization with low power (at least initially)*

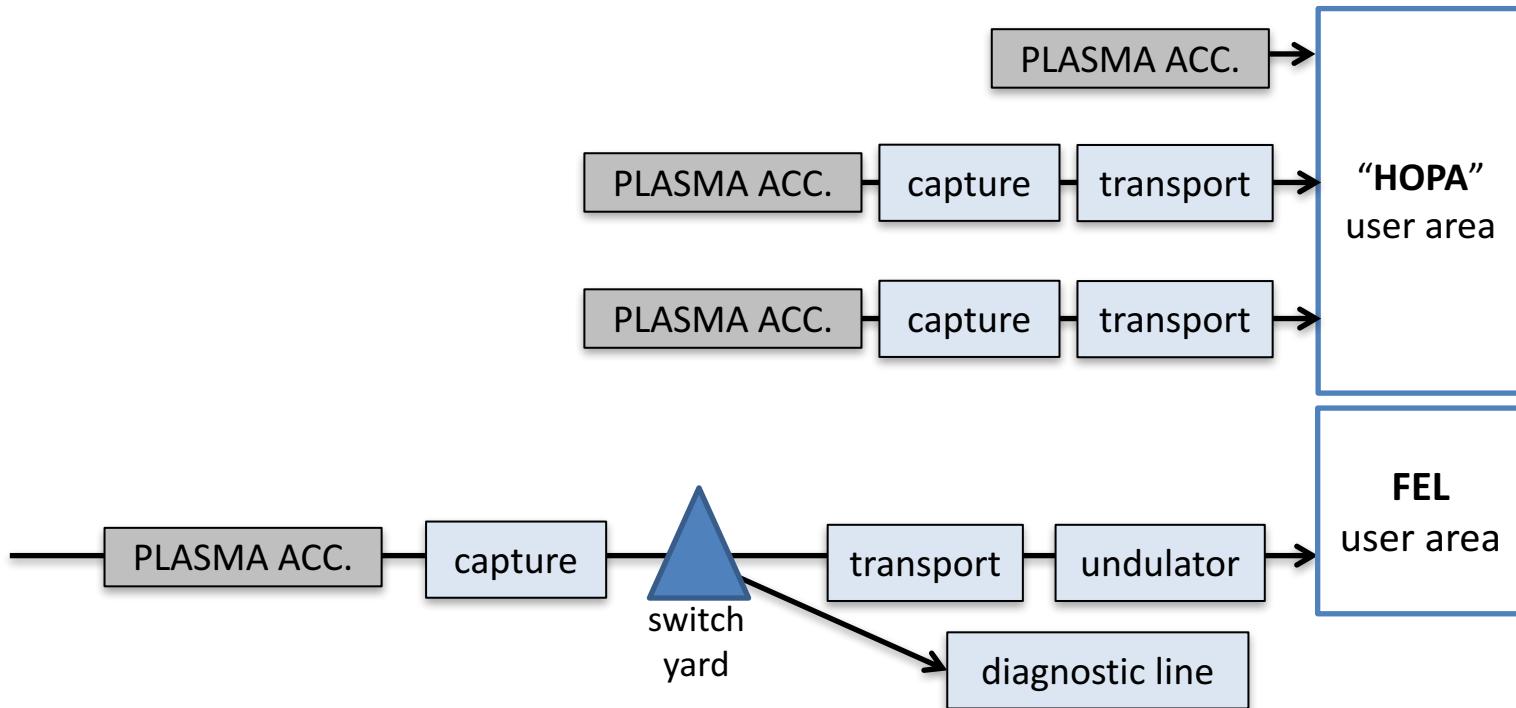
HEP test beams & other pilot application ("HOPA" user area):

- Table-top test beams for HEP detector development
- Compact X-rays sources for e.g. medical imaging
- Proximity experiments (no transport needed)

There will be **at least 2 user areas: FEL and HOPA**



There will be **at least 2 user areas: FEL and HOPA**



- 1) RF electron injector + laser plasma accelerator (LPA)
 (LWFA with external injection from an RF accelerator)



- 2) LPA with electron bunch created in plasma directly
 (LWFA with internal injection)



- 3) LPA electron injector + LPA
 (LWFA with external injection from a LPA)

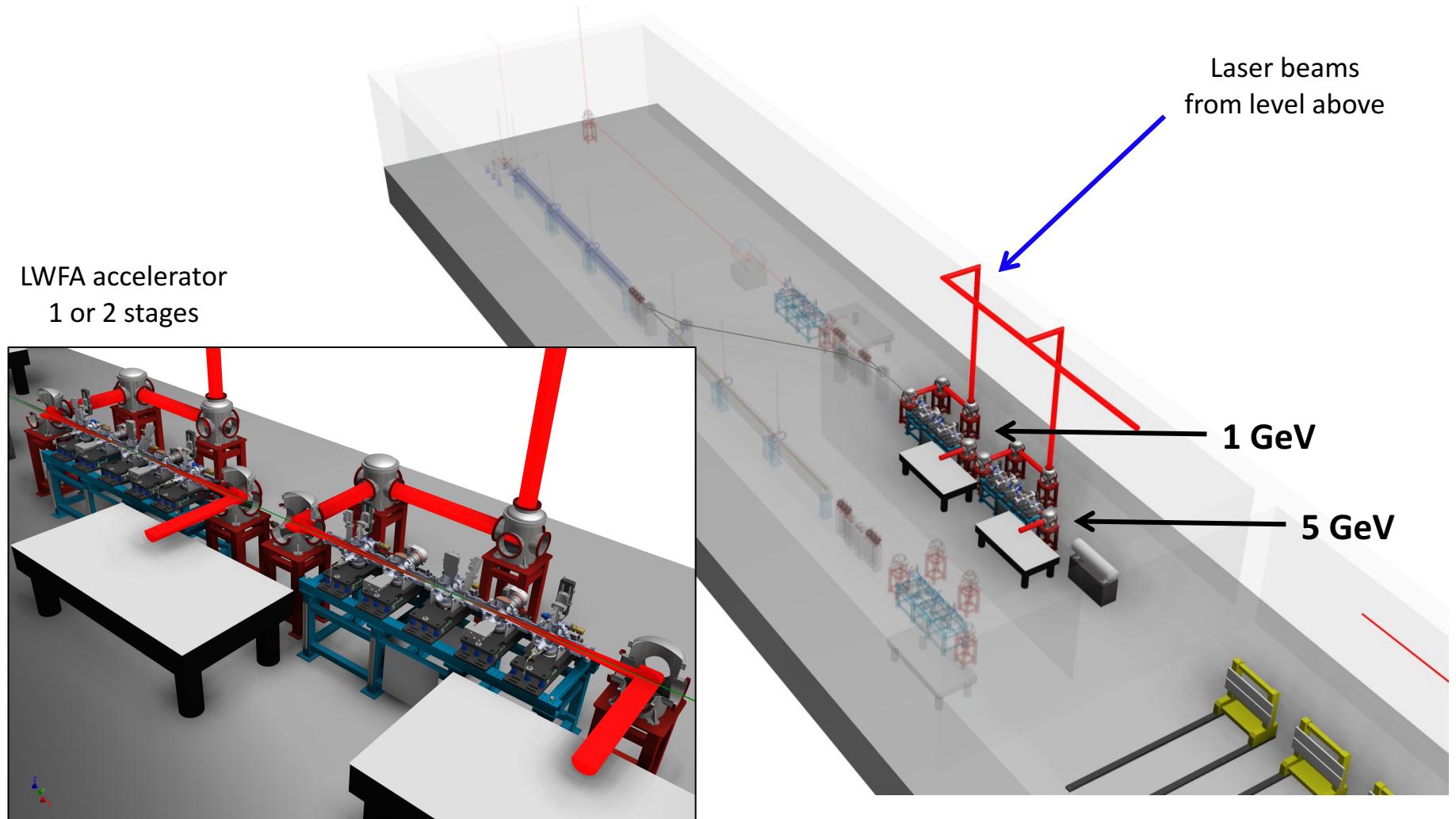


- 4) RF electron bunch as beam driver in LPA
 (PWFA with an RF electron beam)

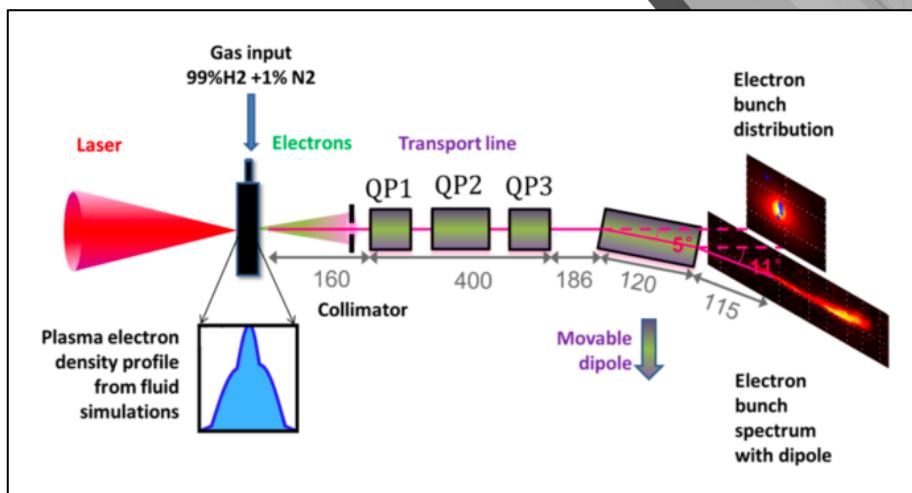


- 5) RF electron bunch as driver in a hybrid stage
 (PWFA with LWFA produced electron beam or Trojan Horse scheme)

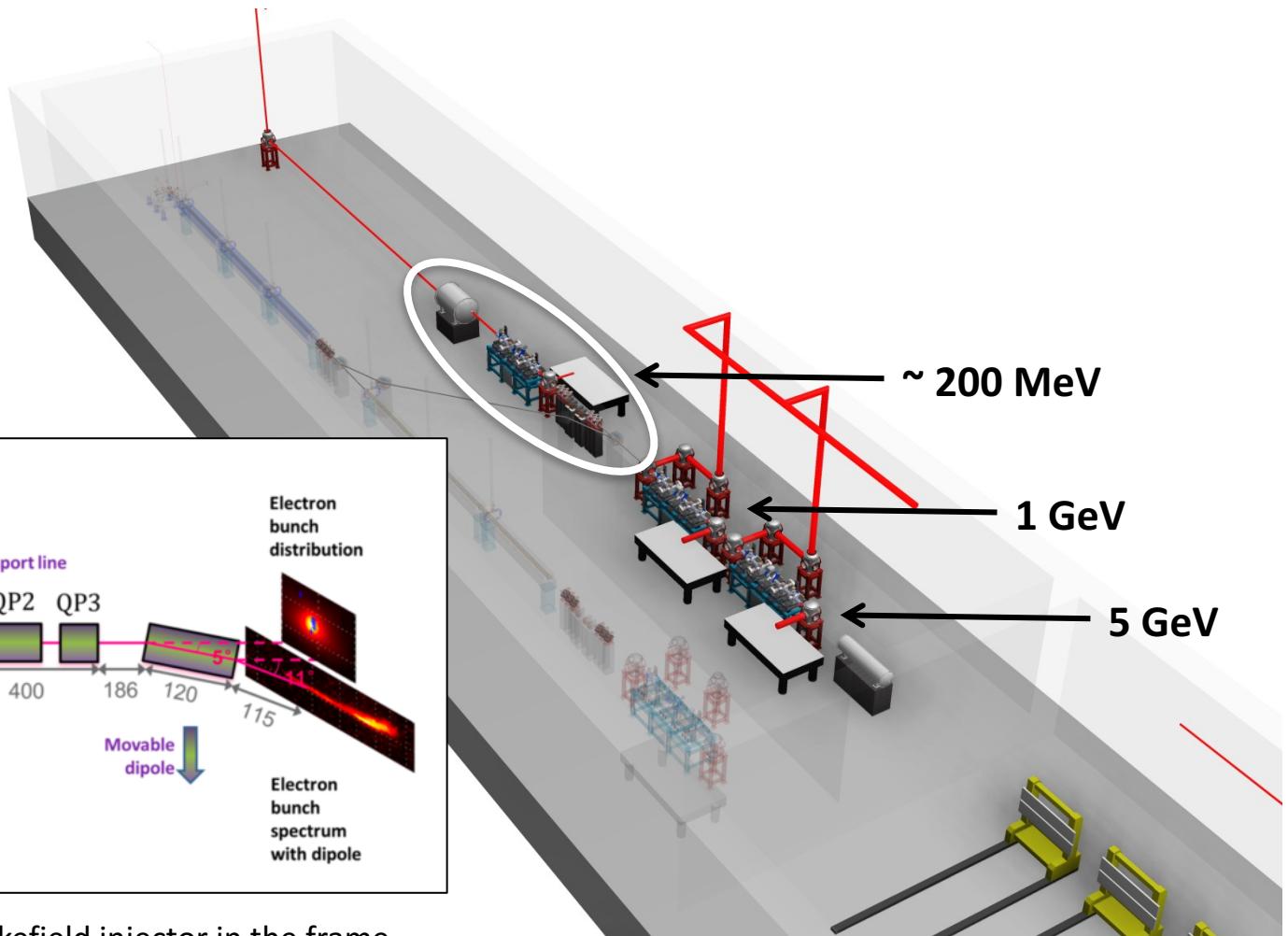




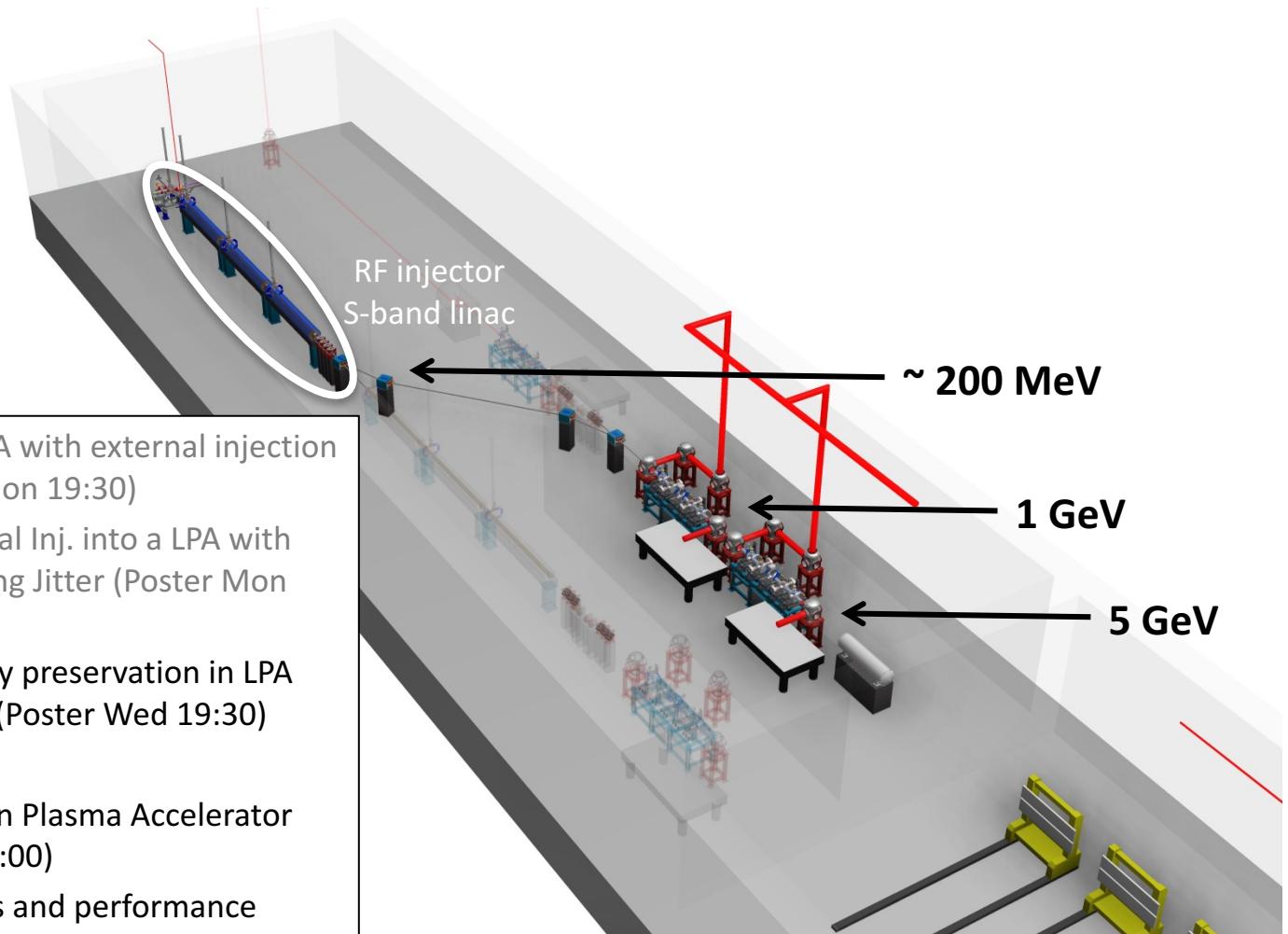
plasma injector



T. Audet et al., 'Laser wakefield injector in the frame of EuPRAXIA', EAAC17, WP4 Thursday 18:15

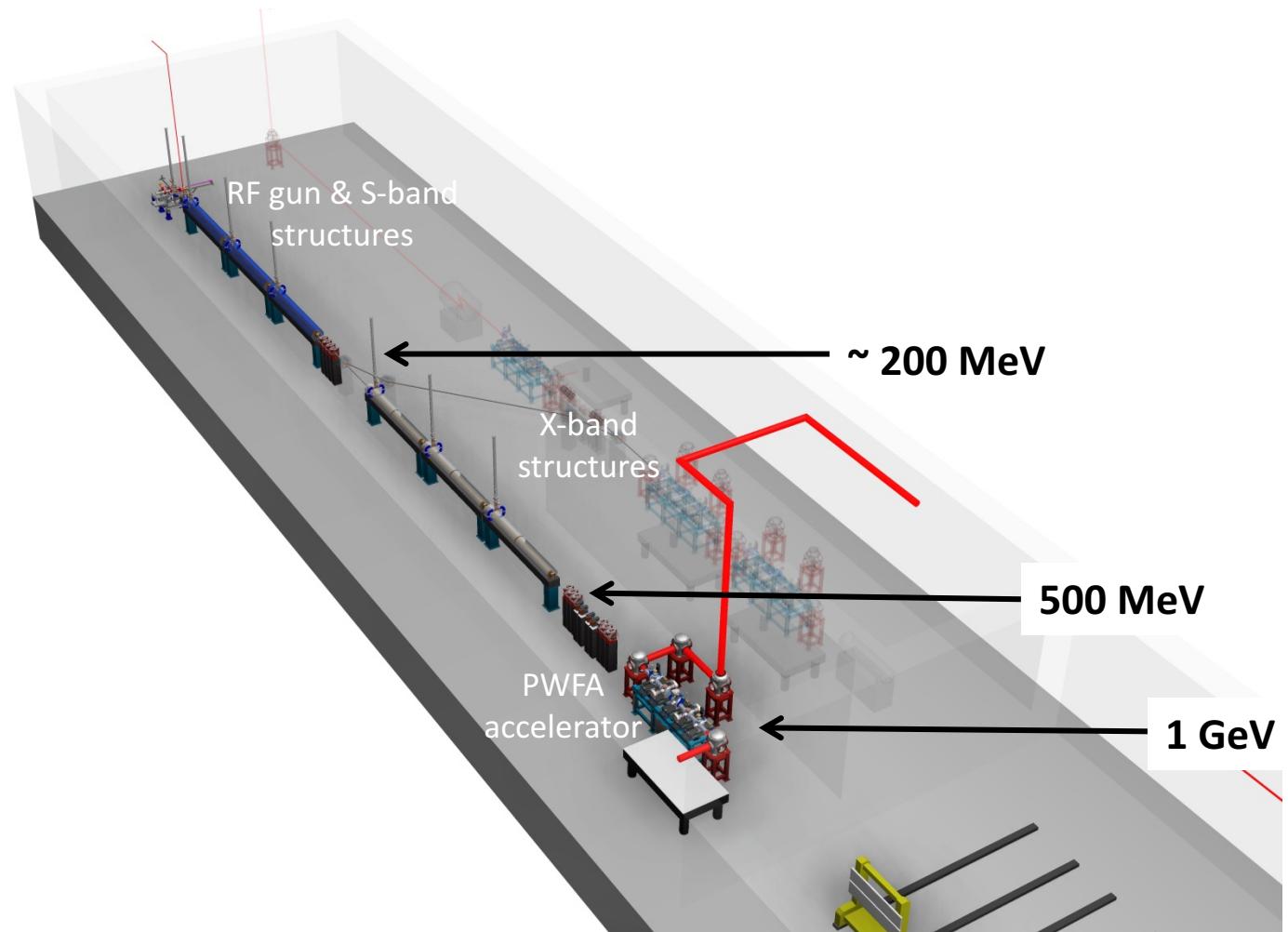


3D design by Dariusz Kocoń (ELI-Beams)



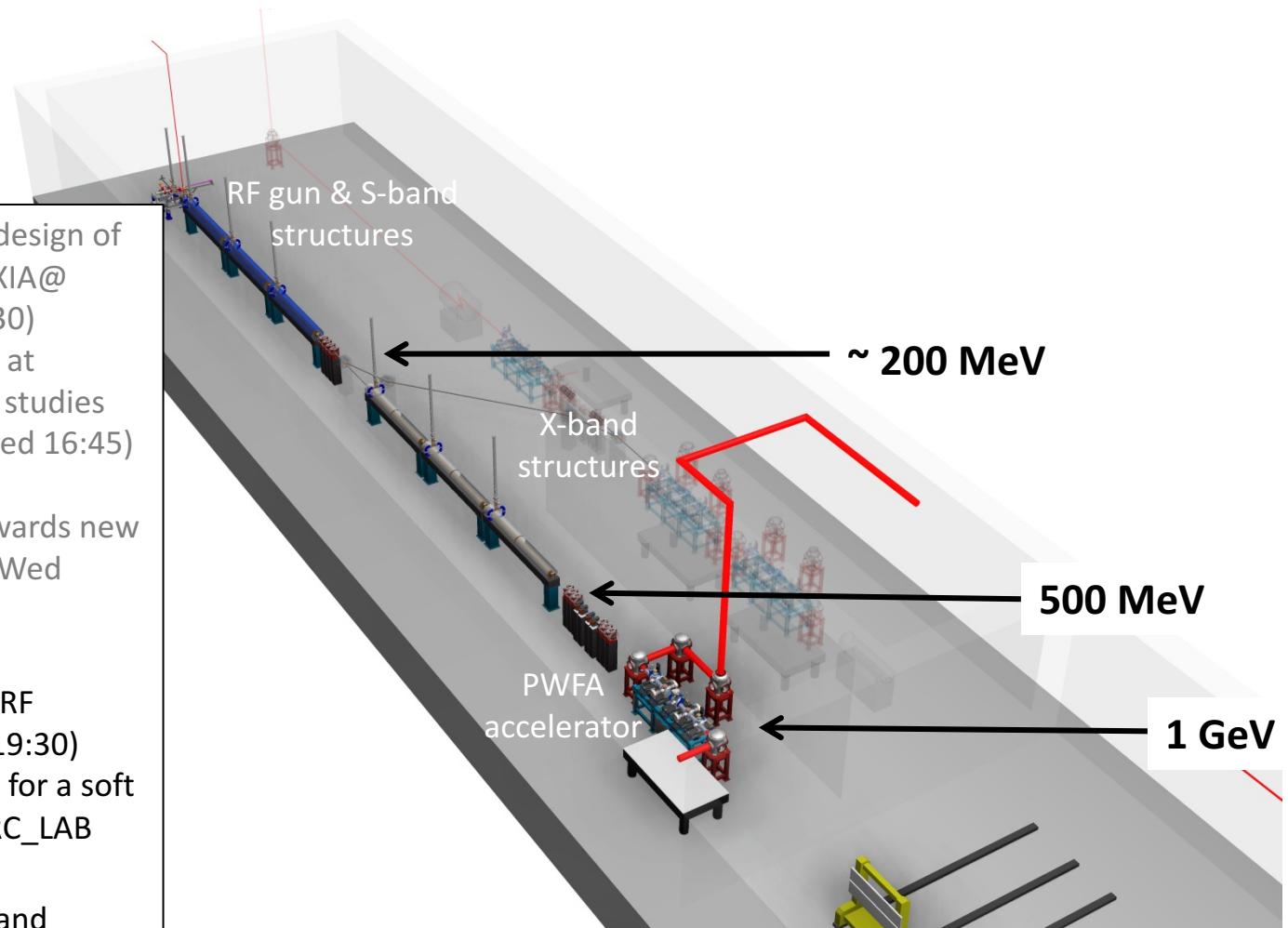
- Svystun: Single stage LPA with external injection for EuPRAXIA (Poster Mon 19:30)
- A. Ferran Pousa: External Inj. into a LPA with Sub-Femtosecond Timing Jitter (Poster Mon 19:30)
- E. Svystun: Beam quality preservation in LPA with external injection (Poster Wed 19:30)
- R. Assmann: A European Plasma Accelerator Project (Plenary Thu 11:00)
- A. Mosnier: Simulations and performance (Plenary Thu 11:50)

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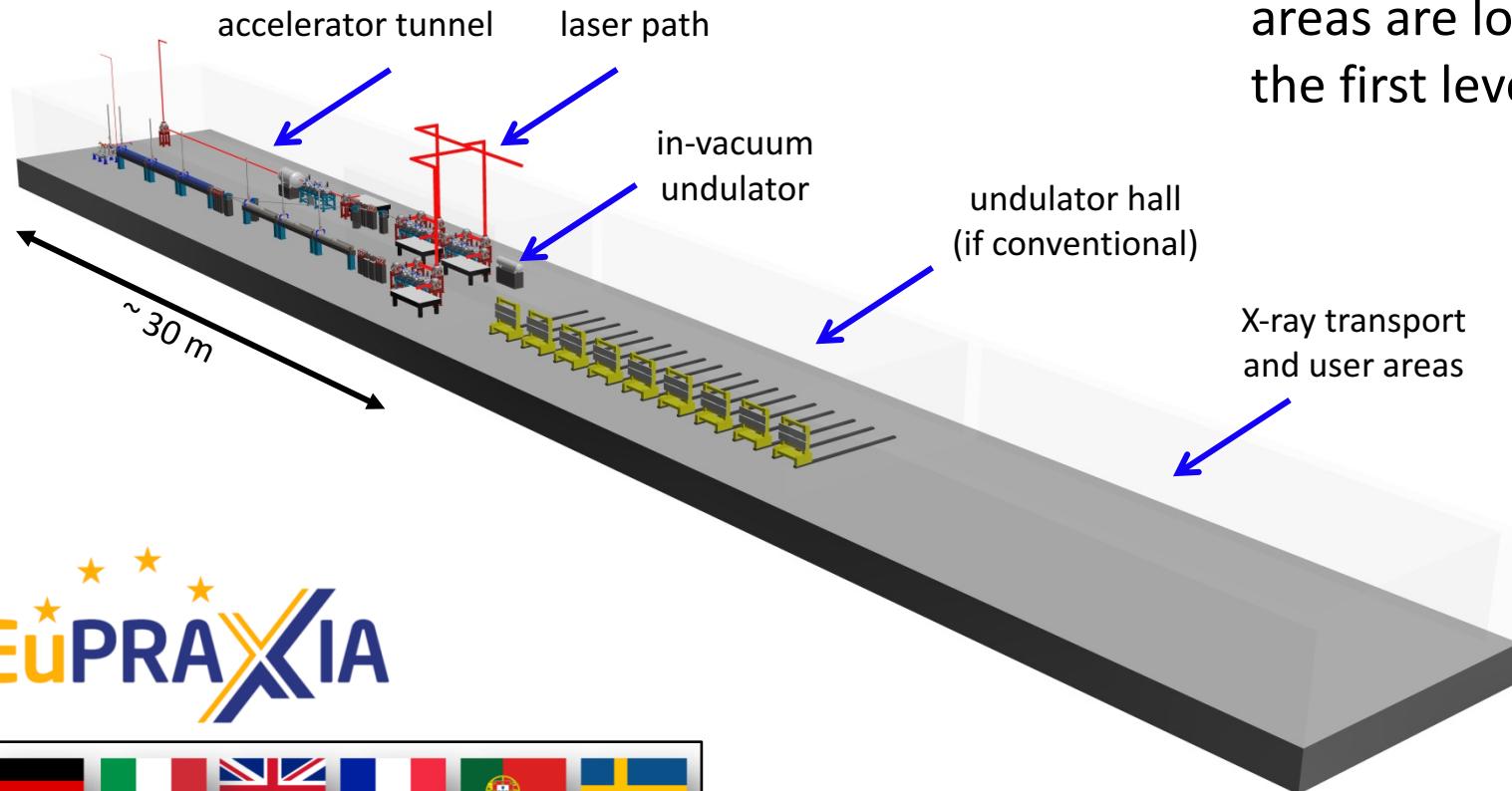


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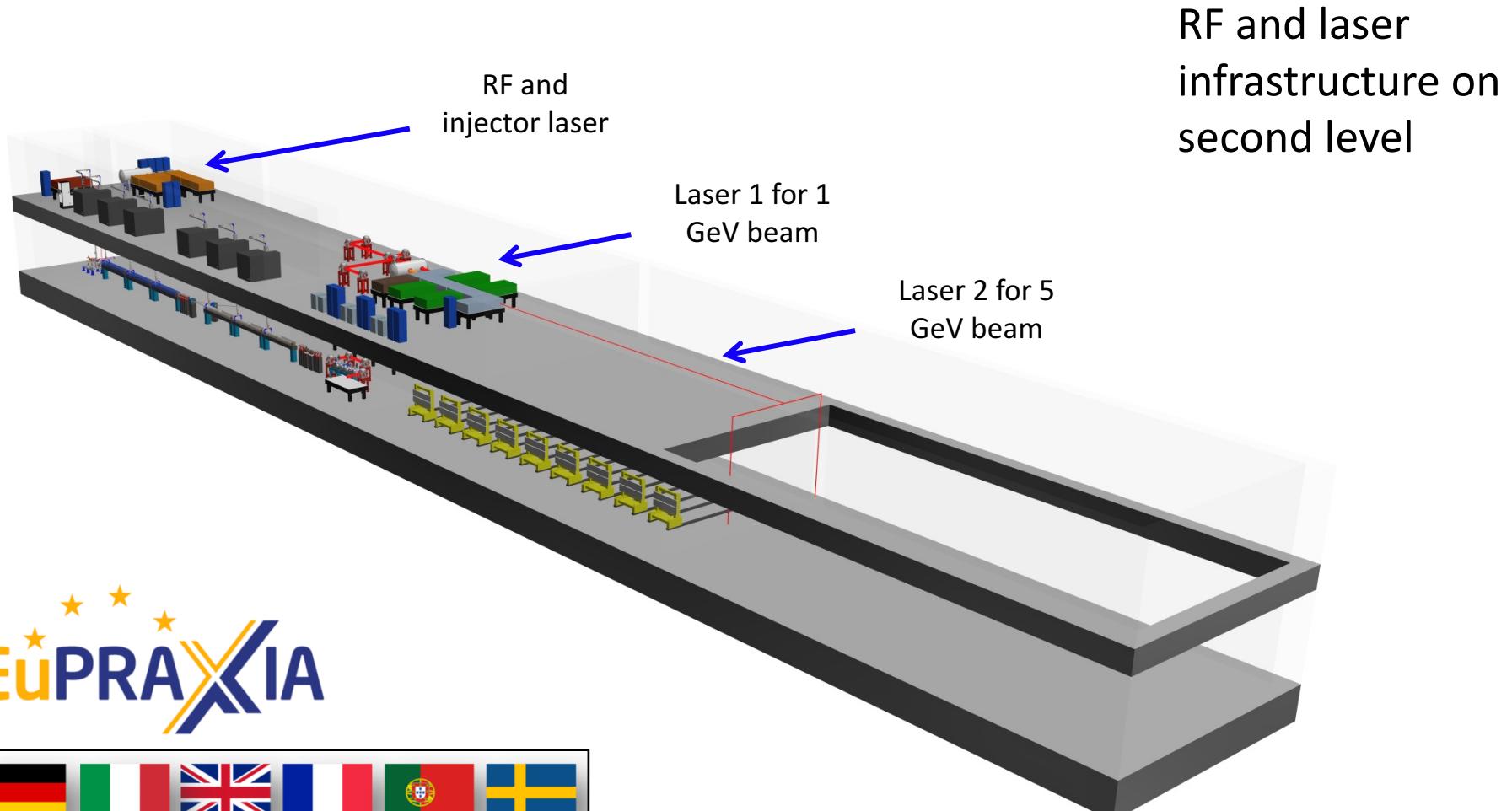
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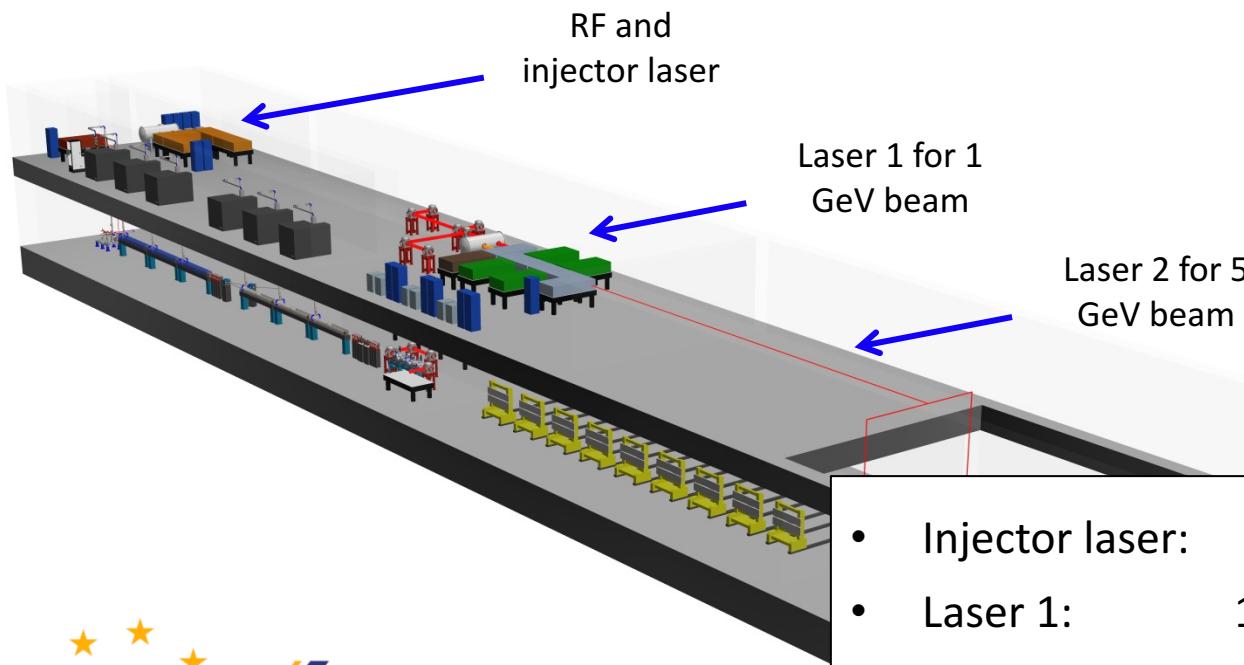
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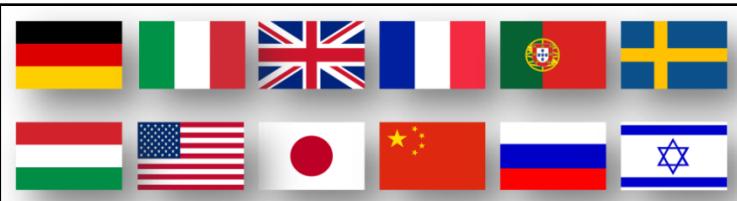
Accelerator research, undulators and user areas are located on the first level



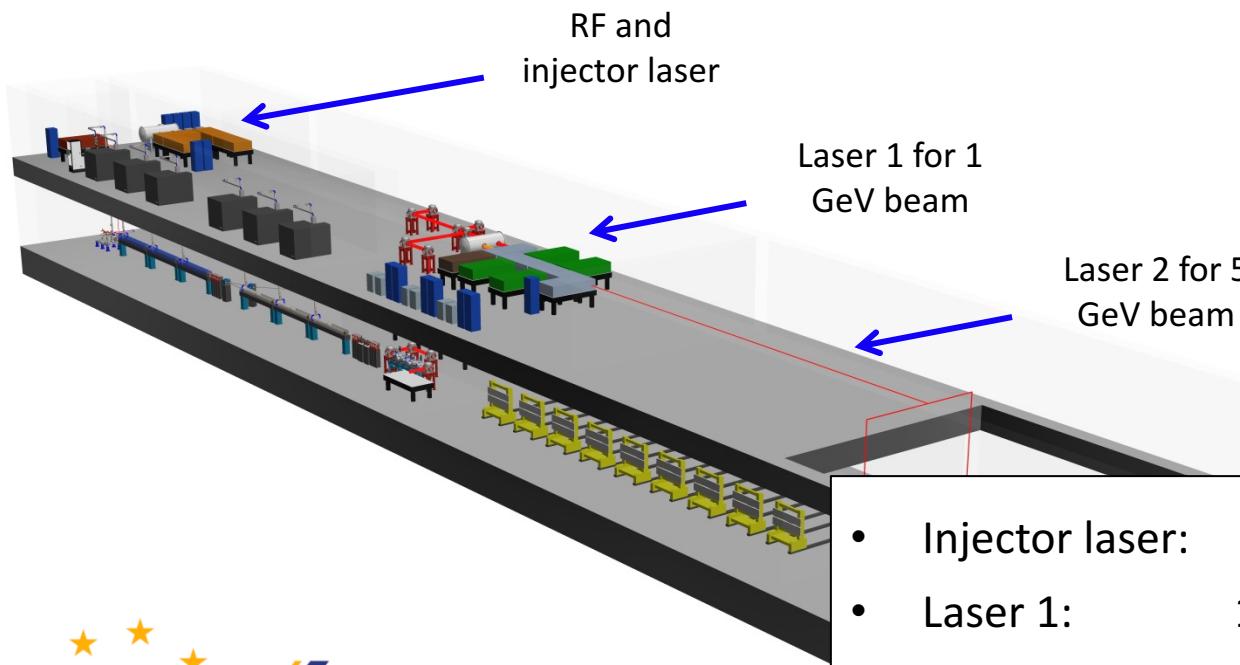
RF and laser infrastructure on second level



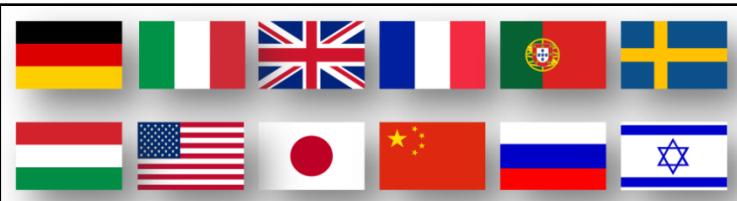
RF and laser infrastructure on second level



- Injector laser: 5 J, 30 fs, 20 Hz
- Laser 1: 15 J, 30 fs, 20 Hz
- Laser 2: 50 J, 60 fs, 20 Hz
 - Ti:Sa based architecture
 - Diode-pumped solid-state laser technology for high energy pump lasers
 - Option at higher repetition rate being worked out currently



RF and laser infrastructure on second level

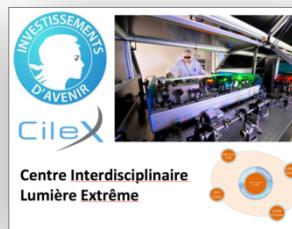
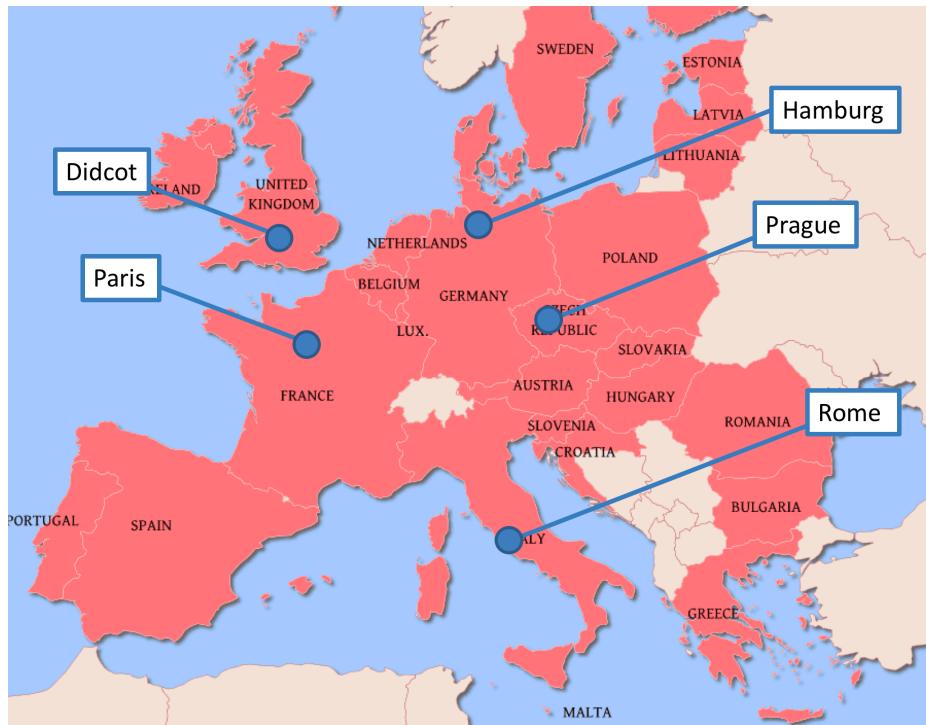


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 - Ti:Sa based architecture
 - Diode-pumped solid-state technology
 - Option at higher repetition rate being worked out currently

More details tomorrow in
Leo's talk (Thu 11:25)

EuPRAXIA site studies:

- Design study is site independent
- Five possible sites have been discussed so far
- We invite the suggestions of additional sites



- Include realistic space for:
 - diagnostics
 - beam transport
 - feedbacks systems
 - collimation
 - in/out-coupling of lasers/beams
- Estimate cost for individual configurations
- Decide for switch-yard or several plasma accelerators
- Work out individual site studies
- Refine parameter table: 2nd iteration will be published November 2017

*EuPRAXIA Yearly & Collaboration Meeting 2017
20th – 24th November in Lisbon, Portugal*



3D design by Dariusz Kocoń (ELI-Beams). Photo credit: google.



3D design by Dariusz Kocoń (ELI-Beams). Photo credit: google.

- Current layout consideration for **European 5 GeV electron beam accelerator facility** presented
- Design includes user areas for **FEL radiation, test beams for HEP detectors tests, and compact X-ray source** for medical imaging, and other applications
- Five facilities in European Union consider local design study for final CDR in October 2019
- This is a Horizon 2020 project and we acknowledge the support from the EU under grant agreement No. 653782.

This is EuPRAXIA:

The EuPRAXIA team

P. D. Alesini, A. S. Alexandrova, M. P. Anania, N. E. Andreev, R. W. Assmann, T. Audet, A. Bacci, I. F. Barna, A. Beaton, A. Beck, A. Beluze, A. Bernhard, S. Bielawski, F. G. Bisesto, J. Boedewadt, F. Brandi, O. Bringer, R. Brinkmann, E. Bründermann, M. Büscher, G. C. Bussolino, A. Chance, M. Chen, E. Chiadroni, A. Cianchi, J. Clarke, M. Croia, M. E. Couprie, B. Cros, J. Dale, G. Dattoli, N. Delerue, O. Delferriere, P. Delinikolas, J. Dias, U. Dorda, K. Ertel, Á. Ferran Pousa, M. Ferrario, F. Filippi, J. Fils, R. Fiorito, R. A. Fonseca, M. Galimberti, A. Gallo, D. Garzella, P. Gastinel, D. Giove, A. Giribono, L. A. Gizzi, F. J. Grüner, A. F. Habib, L. C. Haefner, T. Heinemann, B. Hidding, B. J. Holzer, S. M. Hooker, T. Hosokai, B. Imre, D. A. Jaroszynski, C. Joshi, M. Kaluza, O. S. Karger, S. Karsch, E. Khazanov, D. Khikhlikha, A. Knetsch, D. Kocon, P. Koester, O. Kononenko, G. Korn, I. Kostyukov, L. Labate, C. Lechner, W. P. Leemans, A. Lehrach, F. Y. Li, X. Li, A. Lifschitz, V. Litvinenko, W. Lu, A. R. Maier, V. Malka, G. G. Manahan, S. P. D. Mangles, B. Marchetti, A. Marocchino, A. Martinez de la Ossa, J. L. Martins, K. Masaki, F. Massimo, F. Mathieu, G. Maynard, T. J. Mehrling, A. Y. Molodozhentsev, A. Mosnier, A. Mostacci, A. S. Müller, Z. Najmudin, P. A. P. Nghiem, F. Nguyen, P. Niknejadi, J. Osterhoff, D. Papadopoulos, B. Patrizi, R. Pattathil, V. Petrillo, M. A. Pocsai, K. Poder, R. Pompili, L. Pribyl, D. Pugacheva, S. Romeo, A. R. Rossi, A. A. Sahai, Y. Sano, L. Schaper, P. Scherkl, U. Schramm, C. B. Schroeder, J. Schwindling, J. Scifo, L. Serafini, Z. M. Sheng, L. O. Silva, C. Simon, U. Sinha, A. Specka, M. J. V. Streeter, E. N. Svystun, D. Symes, C. Szwaj, G. Tauscher, A. G. R. Thomas, N. Thompson, G. Toci, P. Tomassini, C. Vaccarezza, M. Vannini, J. M. Vieira, F. Villa, C.-G. Wahlström, R. Walczak, P. A. Walker, M. K. Weikum, C. P. Welsch, J. Wolfenden, G. Xia, M. Yabashi, L. Yu, J. Zhu, A. Zigler



This is a Horizon 2020 project and we acknowledge the support from the EU under grant agreement No. 653782.

This is EuPRAXIA:



www.eupraxia-project.eu



UK	GERMANY	FRANCE	PORTUGAL	ITALY	ISRAEL
<ul style="list-style-type: none"> University of Strathclyde STFC University of Manchester University of Liverpool Imperial College London University of Oxford 	EuPRAXIA <ul style="list-style-type: none"> DESY Universität Hamburg 	<ul style="list-style-type: none"> CNRS CEA SOLEIL 	<ul style="list-style-type: none"> IST-AD 	<ul style="list-style-type: none"> INFN CNR ENEA Università di Roma "La Sapienza" 	<ul style="list-style-type: none"> Hebrew University of Jerusalem
ASSOCIATED PARTNERS	CHINA	FRANCE	GERMANY	HUNGARY	INTERNATIONAL
	<ul style="list-style-type: none"> Shanghai Jiao Tong University Tsinghua University Beijing 	<ul style="list-style-type: none"> PhLAM Université de Lille Kavli Photon Science Institute Osaka University RIKEN iPhyng 8 	<ul style="list-style-type: none"> Max-Planck-Institut für Physik (MPP) Heinrich Heine Universität Düsseldorf Heinrich Heine Universität Düsseldorf Leibniz-Institut Jena LMF München Karlsruhe Institut für Technologie Technische Universität München 	<ul style="list-style-type: none"> Wigner Fizikai Kutatásiközpont 	<ul style="list-style-type: none"> CERN ELI Beamlines
ITALY	INDIA	JAPAN	SWEDEN	USA	
<ul style="list-style-type: none"> Università di Roma "Tor Vergata" 	<ul style="list-style-type: none"> Indraprastha Institute of Information Technology Delhi 	<ul style="list-style-type: none"> Kavli Institute for the Physics and Mathematics of the Universe RIKEN iPhyng 8 Institute of Applied Physics Joint Institute for High Temperatures 	<ul style="list-style-type: none"> Lund University 	<ul style="list-style-type: none"> Sacred Heart University & Brookhaven NL LENL UCLA 	



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Posters today:

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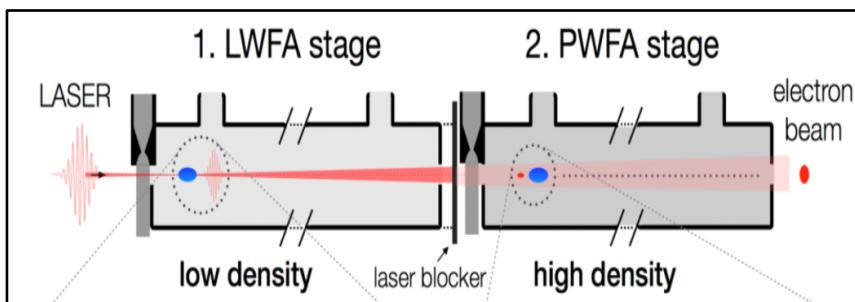
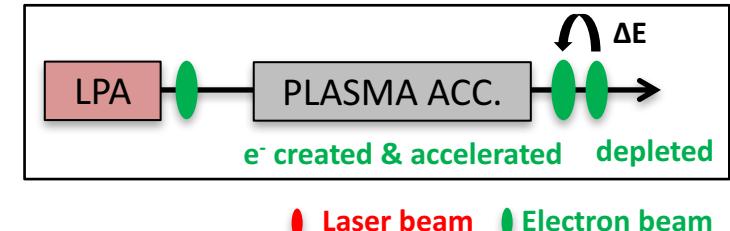
Talks tomorrow:

- R. Assmann: A European Plasma Accelerator Project (Plenary Thu 11:00)
- L. Gizzi: Laser design optimization and industry (Plenary Thu 11:25)
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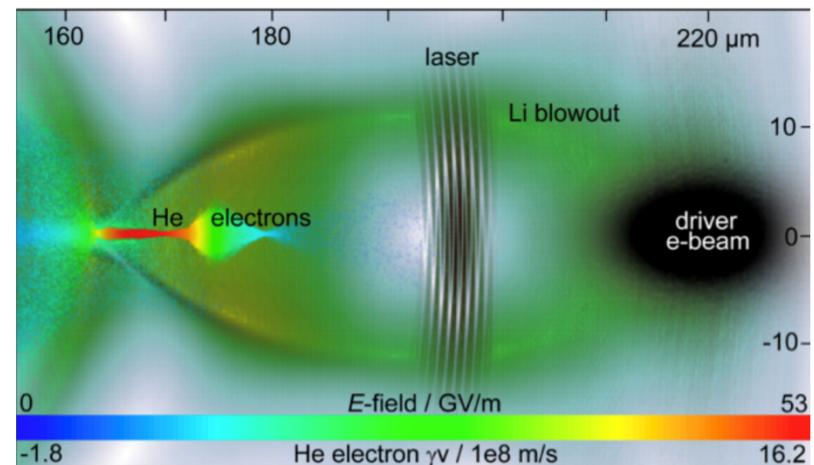
Backup Slides

RF electron bunch as the driver in a hybrid stage:

- 1st stage uses laser driver to accelerate electron beam
- 2nd stage uses electron beam as beam driver to accelerate high quality electron beam



L₂PWFA scheme (pictured above): A. Martinez de la Ossa *et al.*, Phys. Rev. Lett. **111**, 245003 (2013)



Trojan Horse scheme (pictured above): B. Hidding *et al.*, Phys. Rev. Lett. **108**, 035001 (2012)

- Detailed estimates of required space are ongoing:
 - Acc. tunnel + infrastructure **about 300 – 600 m² for 5 GeV** (depending on conf.)
 - Potential **factor of 5-10 footprint reduction** compared to RF based electron linac
 - Reduced footprint has potential to open many additional applications
- **Sufficient beam quality** required which is **central goal of EuPRAXIA**
 - Improve energy spread (“beam loading” [3] or “modulated plasma density” [4])
- EuPRAXIA will initially be **low power and low wall-plug power efficiency**
 - Efforts with industry and laser institutes to improve rep. rate & efficiency of currently used laser systems (also incorporate fiber-based lasers with 30 % eff.)
- EuPRAXIA report will be technical design report and project proposal:
 - Performance, required tolerances, footprint and cost will be assessed
 - We **hope for significant cost benefit** from this new technology

[3] S. Van der Meer, CLIC Note No. 3, CERN; PS, '85-65

[4] R. Brinkmann et al., arXiv:1603.08489, accepted for publication in PRL

PLASMA ACCELERATION

Conventional accelerators employ oscillating radio frequency (RF) fields to accelerate charged particles. The accelerating rate in these devices is restricted by electrical breakdown in the accelerating tube. This limits the amount of acceleration over any given space, requiring very long accelerators to reach high energies.

A new paradigm in particle acceleration

A new concept for particle accelerators was conceived in 1979 by Thomas Tajima and John M. Dawson [1]. The idea was to use an electromagnetic wave to accelerate particles. High electric fields required to accelerate particles. The advantage of this concept is that it demonstrates that their acceleration fields can be much stronger than those of conventional RF accelerators.

The electric fields are created by striking a laser pulse or a particle beam through a gas or a pre-formed plasma. The strong beam compression in the plasma, starting from the density changes imposed by the laser, merged the beam. The density imbalance between positive and negative charges in the wake of the beam creates a longitudinal electric field that drives the beam forward. The gradients per meter. Any electrons trapped in between the middle and the end of the beam will be accelerated to become the end of the beam in a week. Hence the term "wavefront" accelerator [2]. In the external injection scheme the electrons are strategically injected into the beam at the right time during maximum separation or deposition of the plasma electrons.

[1] When the plasma wave is formed by an electron or a proton beam the technique is called plasma-wheeled acceleration (PWIA). If a laser pulse is used instead it is called laser-wheeled acceleration (LWIA).

Experimental demonstration

The first experimental demonstration of wavefront acceleration (PWIA), was reported by a group from Argentine National Laboratory (CNEA) in 1996 [3]. An electron beam with energy of 1 MeV was accelerated at SLAC using PWIA in 200 m (cm) [2] whereas a conventional accelerator would have required 23 km to reach the same energy. The first experimental demonstration of wavefront acceleration (LWIA) using LWIA in accelerators, electrons to 1 GeV in about 3.3 m, was performed at the University of Regensburg, Germany. The team from Regensburg, led by Prof. Dr. Ralf Heinz, produced an electron beam up to 4.25 GeV [2].

[1] T. Tajima and J. M. Dawson, *Phys. Rev. Lett.*, **43**, 267 (1979)
[2] E. A. Woodworth et al., *Phys. Rev. Lett.*, **75**, 1496 (1995)
[3] W. F. Lambrecht et al., *Nature Physics* **11**, 866 (2015)
[2] M. P. Lissauer et al., *Phys. Rev. Lett.*, **113**, 240802 (2004)

Advantages of plasma accelerators

- Acceleration rates 2 - 3 orders of magnitude higher than in RF accelerators, reducing the required accelerator length by 100 to 1,000 times.
- Plasma acceleration is more efficient than RF acceleration in terms of the accelerating rates in relativistic RF structures.
- Ultra-short electron bunches, opening up opportunities for novel applications, i.e. the generation of ultra-fast processes in biomolecules.
- The cost of plasma accelerators is lower.

Current limitations

Plasma accelerators presently offer lower beam energy and lower beam quality than RF accelerators. However, the potential for intensity and optimization has only recently been appreciated. The potential of plasma accelerators is the fact that they can be working hours and days, and the switching-on and off process is very fast. The EuPRAXIA project EuPRAXIA addresses specifically these limitations by an extensive program of research covered in the different work packages.

1 electron volt (eV) is the energy acquired by an electron when it is accelerated by an electric potential of 1 volt.
1 eV = 1,602 x 10⁻¹⁹ J
1 GeV = 1,602 x 10¹⁹ eV
1 TeV = 1,602 x 10²⁰ eV
1 PeV = 1,602 x 10²³ eV
1 TeV is approximately the energy of a flying mosquito.

1 eV is approximately the energy of a flying mosquito.

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EUROPEAN PLASMA RESEARCH ACCELERATOR WITH EXCELLENCE IN APPLICATIONS

DESIGNING THE FUTURE

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

ADVANCED TECHNOLOGIES

EuPRAXIA aims novel acceleration technologies based on high-current lasers and large-scale wavefront shaping. The challenges and opportunities for the development of these technologies are discussed in a multidisciplinary field.

OPENING NEW HORIZONS

The project will bridge the gap between basic plasma science and its applications in medicine, diagnostics, energy and environmental science.

INTERNATIONAL COLLABORATION

EuPRAXIA brings together a consortium of 15 European member states, 3 EU member states, 10 international partners and 10 industrial partners. The project will contribute to the EU's Horizon 2020 programme and beyond. It will also contribute to the development of international projects to strengthen collaborations, to the European Strategy Forum on Research (ESFRI), high-energy physics, medicine and environmental science, and to the development of the project.

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EUROPEAN PLASMA RESEARCH ACCELERATOR WITH EXCELLENCE IN APPLICATIONS



THE EuPRAXIA FILES

ISSUE 1 – May 2016

Foreword

Our practitioners have been writing stories not only in academic beam energy but also in beam quality. This exciting story is still developing, as we can see from the publications that we collect in the first edition of "The EuPRAXIA File". As many of you are aware, EuPRAXIA is a European project, a consortium of 15 European member states and 10 international partners with leading expertise in plasma acceleration. Instead of just reviewing what we will regularly provide you with summaries of recent publications, letting the science speak for itself, we will also include some of our own work, such as the presentation given at a workshop in Paris at the end of June, organised together with the European Network for Accelerator Science and Applications (ENASA). We will also include some of our regular updates in "Accelerating news". We wish you some inspirational science reading in this edition of "The EuPRAXIA File", prepared by the EuPRAXIA outreach team in Liverpool with Ricardo Torres as lead compiler.

Research Highlights

Berkeley Lab Scientists Create the First-ever, 2-stage Laser-plasma Accelerator Powered by Independent Laser Pulses

Researchers from the Lawrence Berkeley National Laboratory in the US have made an important breakthrough in the development of ultra-compact high-energy plasma-based accelerators.

In their latest effort, the researchers have demonstrated for the first time the technique of staging, or sequencing multiple plasma acceleration stages in a single beamline. Staging is critical for high-energy plasma experiments of interest, such as the generation of high-energy photons and neutrinos. By staging, while maintaining accelerating gradients orders of magnitude above conventional techniques.

In their latest effort, the researchers have developed a two-stage plasma accelerator. The first stage was a standard plasma accelerator, while the second stage was a so-called "inertial confinement" plasma accelerator. What was particularly novel about this approach was that the two stages were powered by independent lasers. The first stage was driven by a pulsed laser, while the second stage was driven by a continuous-wave laser. This arrangement of two separate lasers allowed the system to remain extremely compact.

With this result, one can envision using the beam energies of interest for high-energy astrophysics in a compact footprint. However, these results are a first step toward that vision—experiments at higher beam energy and higher beam quality, which will be needed for future applications, will need to be performed to further develop plasma-based technology for next-generation colliders.

Read more at <http://newscenter.lbl.gov/2016/05/12/first-ever-2-stage-laser-plasma-accelerator/>

Members of the SLAC Center Shaping the Beamline

Members of the SLAC Center Shaping the Beamline (CSB) are shown here. From left to right, they are: Michael D. Gammie, Mark A. Kondratenko, Kelly Johnson, Anthony Giannini, and Michael C. Zisman. Not shown in the photo but part of the project are: Gennaro Grillo, Carl G. Johnson, and Michael A. Kondratenko. (Photo credit: Roy Kaltschmidt, Berkeley Lab)

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#EuPRAXIA
#plasma
#accelerator

