EUROPEAN PLASMA RESEARCH ACCELERATOR WITH EXCELLENCE IN APPLICATIONS

EuPRAXIA

CONTENTS

Novel and small plasma accelerator compared to the FLASH accelerator at DESY (Germany).

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INTRODUCTION

EuPRAXIA is a design study on a “European plasma research accelerator with excellence in applications”.

Over the last century, particle accelerators have become some of the most powerful and widely used tools for industry, medicine and science. Today there are more than 30,000 particle accelerators worldwide, all of them relying on highly developed technologies for increasing the energy of charged particles. However, the achievable energy of the particles is often limited by practical boundaries on size and cost, e.g. the available space in hospitals, the available funding in universities or the cost that society as a whole can afford for science projects at the energy frontier.

A revolution in particle accelerators

A new type of accelerator that uses plasmas instead of the conventional radiofrequency (RF) cavities provides acceleration rates that are 1000 times higher than those of conventional machines. This would allow much smaller accelerators that could be used for a wide range of applications.

EuPRAXIA will produce a conceptual design for the world’s first 5 GeV plasma-based accelerator with industrial beam quality and user areas. EuPRAXIA is the necessary intermediate step between proof-of-principle experiments and ground-breaking, compact accelerators for science, industry or medicine. The study will produce accelerator technology, lasers and feedback systems for improving the quality of plasma-accelerated electron beams.

User facility

Two user areas will be developed for free-electron laser (FEL) and high-energy physics detector science. An implementation model will be proposed, including a comparative study of possible sites in Europe, a cost estimate and a model for distributed construction and installation at one central site. EuPRAXIA will be a new research infrastructure with an estimated footprint of about 250 meters. If the design is approved, it will lay the foundation for a possible decision on construction in 2020.

International collaboration

EuPRAXIA brings together a consortium of 16 laboratories and universities from 5 EU member states. As of October 2016, 22 associated partners from 11 countries have joined with in-kind commitments (linking 3 additional EU member states). The scientists represent expertise from accelerator science and high-energy physics, design and construction of leading accelerators like the LHC, advanced acceleration test facilities like SPARC and frontier laser projects like CLF, CILEX-APOLLON and ELI. A project with 14 work packages has been defined, 8 of them funded by the EU.

Eupraxia will produce a conceptual design report for the worldwide first 5 GeV plasma-based accelerator with industrial beam quality and user areas.

Accelerator	Particle type	Size	Max. energy	Applications
Large Hadron Collider (Switzerland)	Protons / ions	27 km circular	13 TeV	Particle physics
SLAC (USA)	Electrons / positrons	3.2 km linear	50 GeV	Particle physics, ultrafast x-ray science, etc.
European XFEL (Germany)	Electrons	2.1 km linear	17.5 GeV	Ultrafast x-ray science, plasma physics, etc.
SOLEIL Synchrotron (France)	Electrons	354 m circular	2.75 GeV	Materials science, biomedical research, etc.
Radiotherapy machines (worldwide)	Electrons	~2 m linear	~25 MeV	Cancer therapy
Industrial linacs (worldwide)	Electrons	~2 m linear	~10 MeV	Non-destructive testing, cargo inspection, sterilization, etc.
EuPRAXIA (tbd)	Electrons	250 m linear	5 GeV	Ultrafast x-ray science, high-energy physics, etc.

PLASMA ACCELERATION

Conventional accelerators employ oscillating radio radiofrequency (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 accelerator was conceived in 1979 by Toshiki Tajima and John M. Dawson [1]. The idea was to use an ionized gas, or plasma, to maintain the high electric fields required to accelerate particles. The advantage of plasma accelerators is that their acceleration fields can be much stronger than those of conventional RF accelerators.

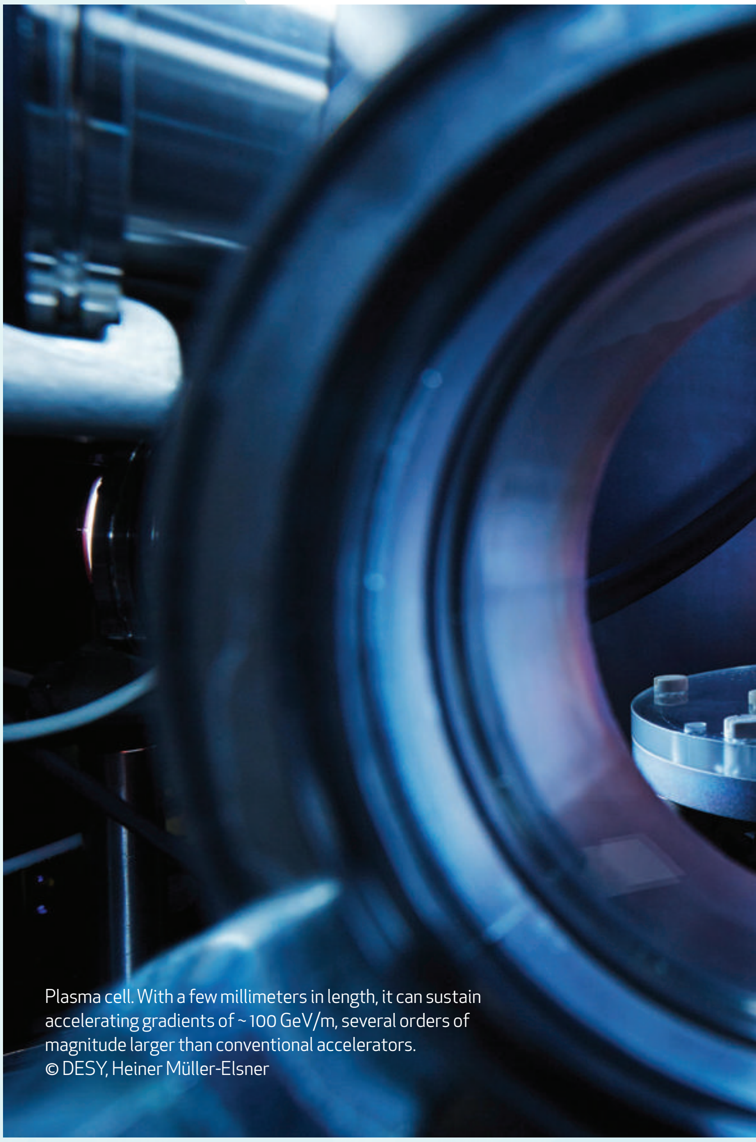
The electric fields are created by driving a laser pulse or a particle beam through a gas or a pre-ionized plasma. The driving beam creates ripples in the plasma density, displacing the negatively charged electrons from the positively charged ions. The local imbalance between positive and negative charges in the wake of the driving beam creates huge electric fields, of the order of 100 gigavolts per meter. Any electrons trapped in between the middle and the back of the wake will be accelerated forward like a surfer riding a wave, hence the name “wakefield” acceleration (*). In external injection schemes, electrons are strategically injected after the driver beam to arrive at the wake at the time of maximum expulsion of the plasma electrons..

(*) When the plasma wave is formed by an electron or proton bunch the technique is called plasma wakefield acceleration (PWFA); if a laser pulse is used instead it is called laser wakefield acceleration (LWFA).

Experimental demonstration

The first experimental demonstration of wakefield acceleration (PWFA), was reported by a group from Argonne National Laboratory (USA) in 1988 [2]. In 2007, a 42 GeV electron beam was obtained at SLAC using PWFA in just 85 cm [3] whereas a conventional accelerator would have required 2.6 km to reach the same energy. Scientists at Lawrence Berkeley National Laboratory (USA) used LWFA to accelerate electrons to 1 GeV in about 3.3 cm [4]. In 2014, the BELLA Laser Center at the Lawrence Berkeley National Laboratory produced electron beams up to 4.25 GeV [5].

[1] T. Tajima and J. M. Dawson, Phys. Rev. Lett. 43, 267 (1979).
[2] J. B. Rosenzweig *et al*., Phys. Rev. Lett. 61, 98 (1988).
[3] I. Blumenfeld *et al*., Nature 445, 741 (2007).
[4] W. P. Leemans *et al*., Nature Physics 418, 696 (2006).
[5] W. P. Leemans *et al*., Phys. Rev. Lett. 113, 245002 (2014).



Plasma cell. With a few millimeters in length, it can sustain accelerating gradients of ~ 100 GeV/m, several orders of magnitude larger than conventional accelerators.
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1 electron-volt (eV) is the energy acquired by an electron when it is accelerated by an electric potential of 1 volt.

1 keV = 1,000 eV
1 MeV = 1,000 keV = 1,000,000 eV
1 GeV = 1,000 MeV = 1,000,000,000 eV
1 TeV = 1,000 GeV = 1,000,000,000,000 eV

1 TeV is approximately the energy of a flying mosquito.

Electrons are accelerated in the plasma like surfers riding a wave.

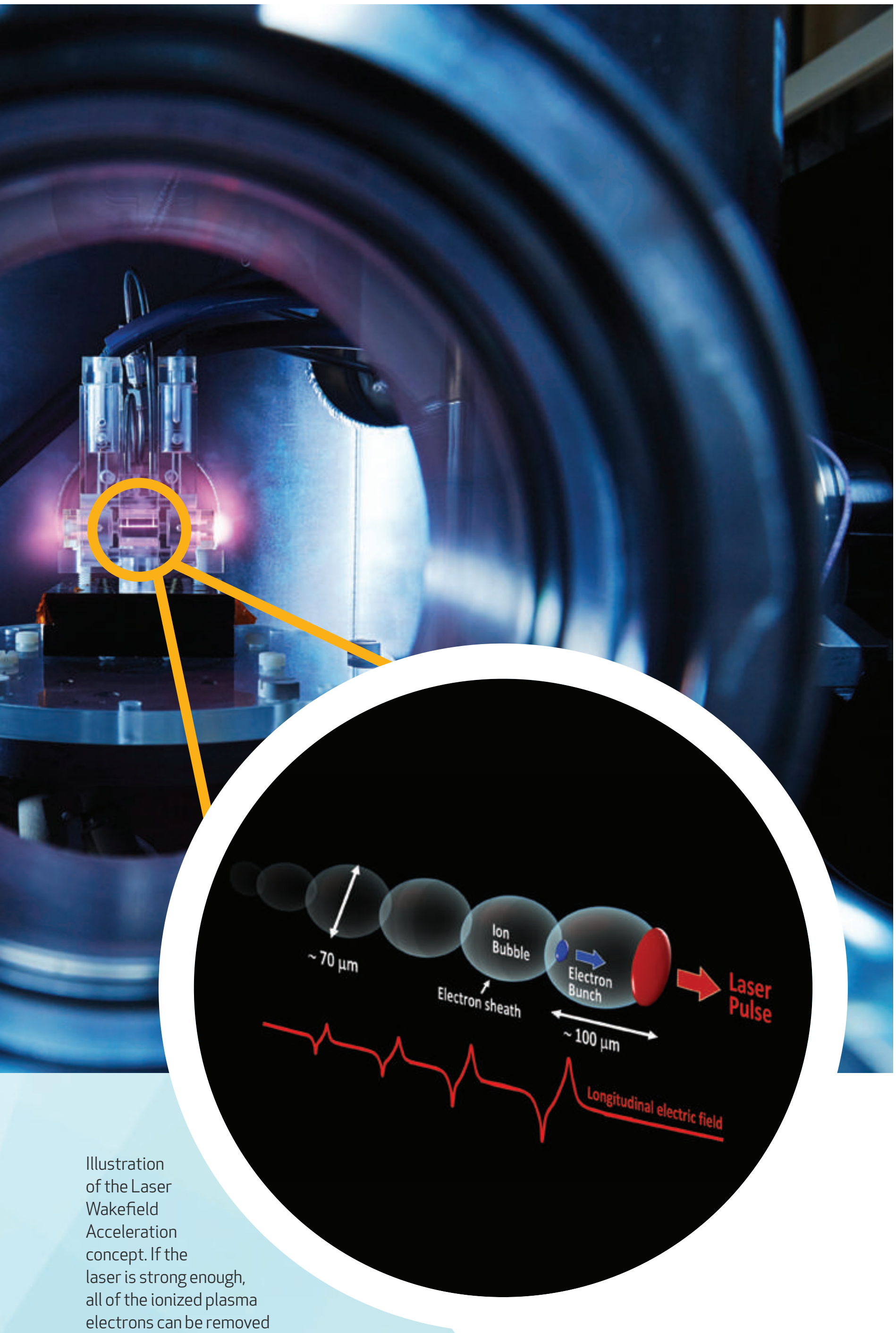


Illustration of the Laser Wakefield Acceleration concept. If the laser is strong enough, all of the ionized plasma electrons can be removed from the center of the wake: this is known as the “blowout regime”. It appears that a “bubble” of charge is moving through the plasma at close to the speed of light.

Advantages of plasma accelerators

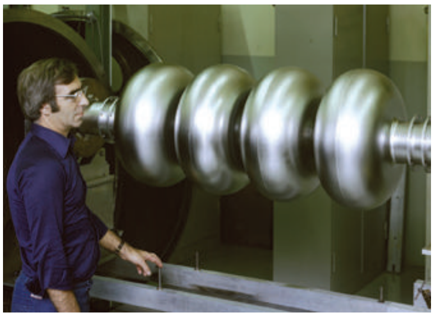
- Acceleration rates 2 – 3 orders of magnitude higher than conventional accelerators, reducing the required acceleration length by 100 to 1000 times.
- Plasma accelerators overcome the breakdown limit that restricts the accelerating gradients in metallic RF structures.
- Ultrashort electron bunches, opening up exciting new opportunities for research, i.e. the observation of ultrafast processes in biomolecules.
- The lasers required for driving plasma accelerators have become available from European companies, offering a supply chain that is not only comparable to RF industry but also developing in a more dynamic and innovative way.

A plasma is an ionized gas, that is, a state of matter in which electrons are detached from their atoms, which hence become ions. Familiar forms of plasma are lightning and neon lights. Although not so common on Earth, plasma is the most abundant form of ordinary matter in the Universe.

Current limitations

Plasma accelerators presently offer lower beam energy and lower beam quality than conventional accelerators. Shot-to-shot stability and optimization has only recently become a priority. The operation of plasma accelerators is so far limited to working hours and days, and the switching-on and off generates numerous stability problems.

EuPRAXIA addresses specifically these limitations by an extensive program of research covered in the different work packages.



RF cavity. Typically a few meters long, it sustains accelerating rates of ~ 0.1 GeV/m. © CERN.

THE EuPRAXIA FACILITY

Preliminary study concept

In principle there are several methods to create the high-quality multi-GeV electron beams by plasma acceleration proposed for EuPRAXIA. In the first place, the plasma wakefield can be driven by a high-power laser pulse (Laser Wakefield Acceleration – LWFA) or by a moderate energy electron beam (Plasma Wakefield Acceleration – PWFA). The first technique requires a laser system able to deliver pulses of around 100 fs duration in the petawatt regime; the second employs either a radiofrequency (RF) electron linac or a laser wakefield accelerator providing 0.5 – 1.0 GeV electrons in ultrashort bunches of a few femtoseconds.

Secondly, the accelerated particle beam may come from the plasma electrons trapped in the back of the wake (internal injection) or from an external electron beam, precisely timed to arrive at the plasma structure on the peak of the longitudinal electric field in the forward direction (external injection). The external electron beam, in turn, may come from a radiofrequency linac or a preceding laser wakefield accelerator.

Finally, the electrons may be accelerated up to the final energy in a single plasma structure or in a sequence of plasma structures where the electrons accelerated in the first stage are injected in a second stage for further acceleration.

The EuPRAXIA study is considering all possible combinations between these schemes at the moment, in order to reach its baseline parameters. In total there are nine different scenarios, of which the most promising ones will be selected in 2019:

Case 1 – LWFA with internal injection
A. Acceleration to 1 GeV and staging to 5 GeV
B. Acceleration to 5 GeV directly

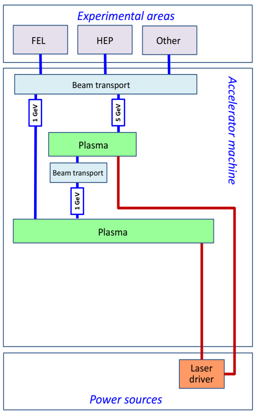
Case 2 – LWFA with external injection from RF accelerator
A. Acceleration to 1 GeV and staging to 5 GeV
B. Acceleration to 5 GeV directly

Case 3 – LWFA with external injection from laser plasma injector
A. Acceleration to 1 GeV and staging to 5 GeV
B. Acceleration to 5 GeV directly

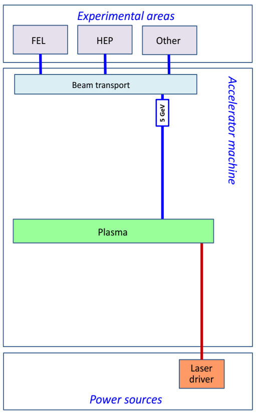
Case 4 – PWFA
A. Acceleration to 1 GeV
B. Acceleration to 5 GeV

Case 5 – Hybrid scheme
Laser Wakefield Acceleration and staging to a Plasma Wakefield Accelerator with acceleration to 3 GeV.

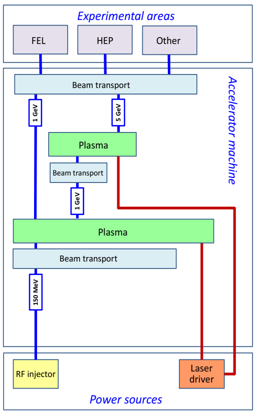
The figures below provide a schematic diagram of each of the nine scenarios considered in the study.



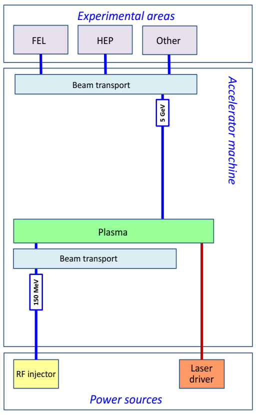
Case 1A – LWFA with internal injection, to 1 GeV and staging to 5 GeV



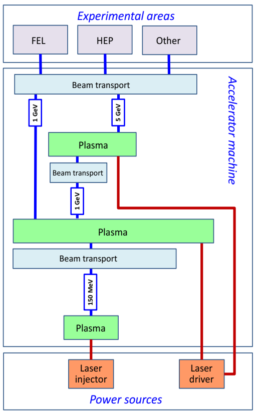
Case 1B – LWFA with internal injection, to 5 GeV directly



Case 2A – LWFA with ext. injection from RF, to 1 GeV and staging to 5 GeV



Case 2B – LWFA with ext. injection from RF, to 5 GeV directly



Case 3A – LWFA with ext. injection from LWFA, to 1 GeV and staging to 5 GeV

Facility structure

The EuPRAXIA facility can be divided into three main sections:

1) Power sources (RF electron linacs and high-power laser systems)

2) Accelerator machine, consisting of

- Plasma structures,
- Transport lines to carry the electron beams from the injectors to the plasma structures and to the experimental areas,
- Instrumentation to monitor and control the characteristics of the electron beams.

3) Experimental areas

- Free-electron lasers (FEL)
- High-energy physics (HEP) and other pilot applications

The total footprint of the facility, including power sources, plasma accelerator and the experimental areas for applications, is 250 m.

Power sources

The power sources will be designed around the established requirements for driving the accelerating plasma structures and the electron beam injection. The main parameters of the electron and laser beams required in each of the scenarios are summarized in Tables 1 – 4.

Output parameters

The baseline parameters for the electron beam output are defined by the main applications of EuPRAXIA: free-electron lasers (FEL), high-energy physics detector applications (HEP), and other pilot applications (Other).

Table 5 summarizes the main parameters which were proposed in October 2016. They will be discussed and updated over the next years.

Table 1 – Laser driver (Cases 1, 2, 3 & 5):

Wavelength	800 nm
Energy	100 J
Pulse length (FWHM)	100 fs
Repetition rate	10-100 Hz

Table 2 – Laser injector (Case 3):

Wavelength	800 nm
Energy	5 J
Pulse length (FWHM)	30 fs
Repetition rate	10-100 Hz

Table 3 – Electron beam injector (Cases 2 & 3):

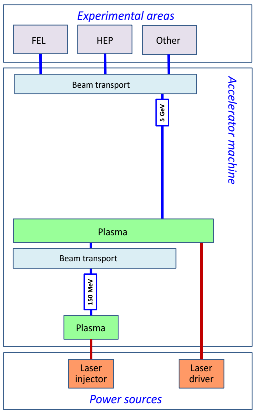
	From RF	From LWFA
Energy	160 MeV	150 MeV
Charge	50 pC	100 pC
Bunch length	38 fs	5 fs
Peak current per bunch	3 kA	20 kA

Table 4 – Electron beam driver (Case 5):

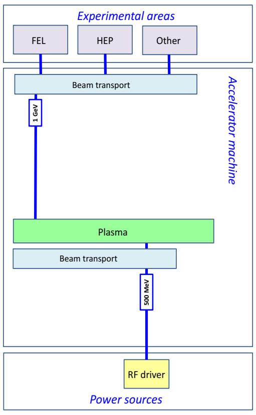
Energy	1 GeV
Charge	100 pC
Bunch length	10 fs
Peak current per bunch	10 kA

Table 5 – Electron beam output:

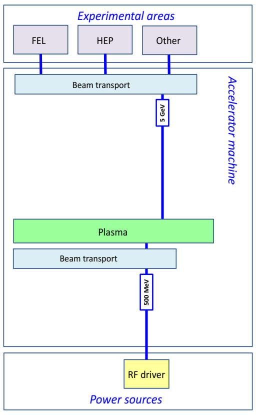
	Cases 1 – 4	Case 5
Energy	5 GeV	3 GeV
Charge	100 pC	30 pC
Bunch length	5 fs	3 fs
Peak current per bunch	20 kA	10 kA
Total energy spread (RMS)	5%	5%
Transverse normalized emittance	1 mm mrad	1 mm mrad
Transverse beam size (RMS)	0.32 μm	0.41 μm
Transverse divergence (RMS)	0.32 mrad	0.41 mrad
Jitter, beam to global reference (RMS)	10 fs	10 fs



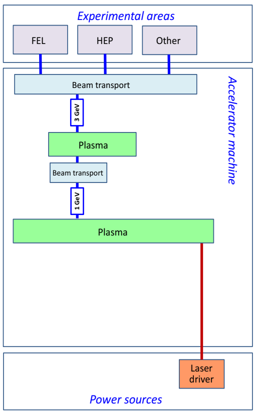
Case 3B – LWFA with ext. injection from LWFA, to 5 GeV directly



Case 4A – PWFA to 1 GeV



Case 4B – PWFA to 5 GeV



Case 5 – Hybrid scheme

SOCIETAL IMPACT

There are currently more than 30,000 accelerators in operation around the world. Large accelerators are used in particle physics as colliders, or as synchrotron light sources for the study of condensed matter physics and structural biology, among other applications. Smaller particle accelerators are used in a wide variety of applications, including cancer therapy, production of radioisotopes for medical diagnostics, ion implanters for the electronics industry, cargo inspection, food sterilization, etc.

Laser-driven plasma accelerators offer a revolutionary path to more cost-effective accelerators.

Novel applications

Plasma accelerators have immense promise for innovation of affordable and compact accelerators for various applications ranging from high energy physics to medical and industrial applications. Medical applications include betatron and free-electron light sources for diagnostics or radiation therapy and protons sources for hadron therapy.

Once fully developed, the technology could replace many of the traditional RF accelerators currently found in particle colliders, hospitals and research facilities.

Industrial innovation

The EuPRAXIA technology is closely linked to EU industry, and in particular to the high-power laser industry, where two European companies currently set the standards for petawatt-class lasers. The high demands of the EuPRAXIA project inspire and foster technological progress in this field, keeping the European laser industry at the leading edge of the sector.

Market opportunities

European companies are building the lasers for the most advanced plasma acceleration experiments as well as designing, building and selling accelerators for many applications. The European industry will therefore directly profit from the success of bringing plasma accelerators to the users, creating new market opportunities.

ILIL-PW laser system at Istituto Nazionale di Ottica (Italy). Credit: Paolo Tomassini, paolotomassini.com

Woman being prepared for radiation therapy. Credit: Michael Anderson (Photographer)

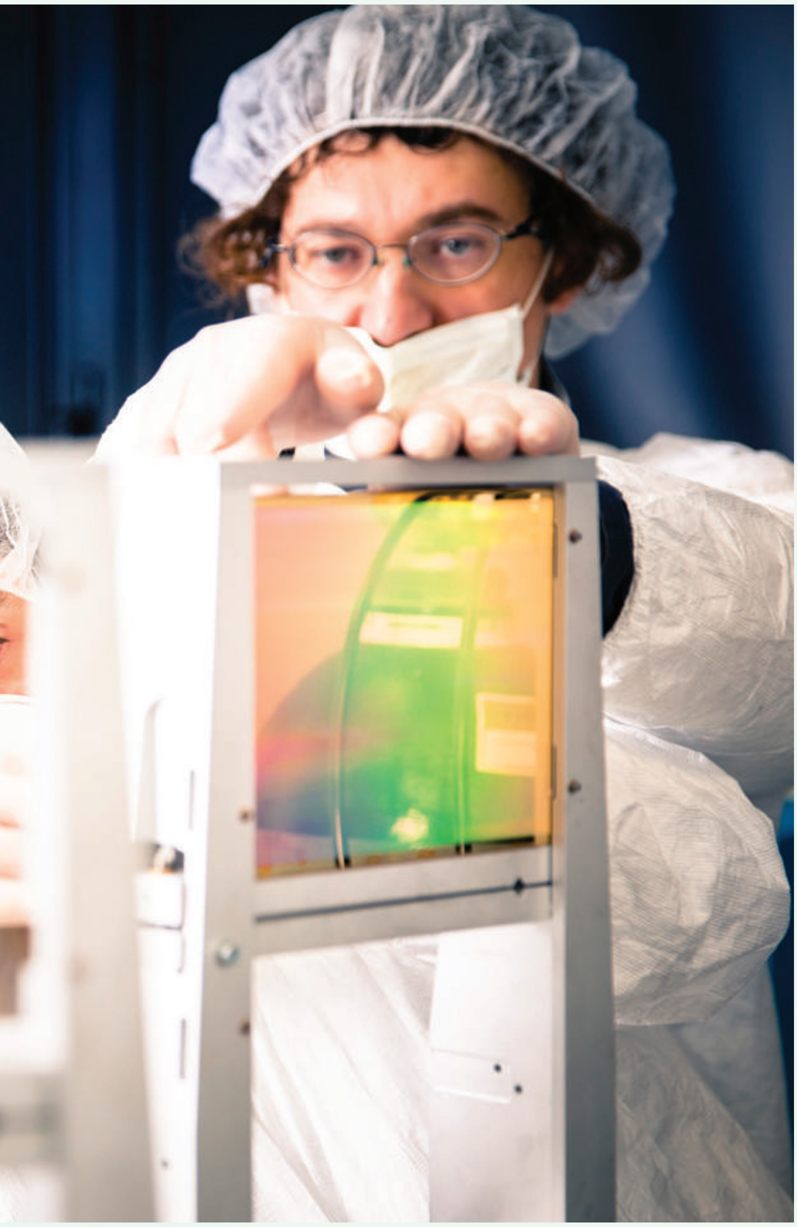
Knowledge transfer

The high-power lasers, compact magnets and undulators of EuPRAXIA will be built with parts produced by the European industry. General achievements, problems and solutions of EuPRAXIA are communicated to the industry and the rest of the scientific community in conferences and workshops. Moreover, the students and post-docs trained in EuPRAXIA will carry their knowledge to their future employers.

Key technologies:

Plasma accelerators are a highly demanding technology with requirements close to technical feasibility limits in several areas. EuPRAXIA contributes to strengthening the technological development capacity and effectiveness of the European Research Area at the frontiers of:

- Ultrafast synchronization, electronics and correction loops
- Compact accelerator magnets with high field quality
- Stabilized 1PW laser technology
- Plasma cell technology
- Compact FELs
- Fast photon science detection technologies
- HEP detector technology
- Medical accelerator technology



Control Room of SOLEIL (France). © Synchrotron Soleil

Children attending the Symposium on Lasers and Accelerators for Science and Society in Liverpool, June 2015

HIGH-POWER LASERS

1 femtosecond =
1/1,000,000,000,000,000 seconds.

If light travels 300,000 km in one second, in one femtosecond it travels just 0.3 micrometers, which is roughly the size of a virus.

1 petawatt =
1,000,000,000,000,000 watts.

1 petawatt is approximately equivalent to 80 times the average power consumption of the whole world.

Technology

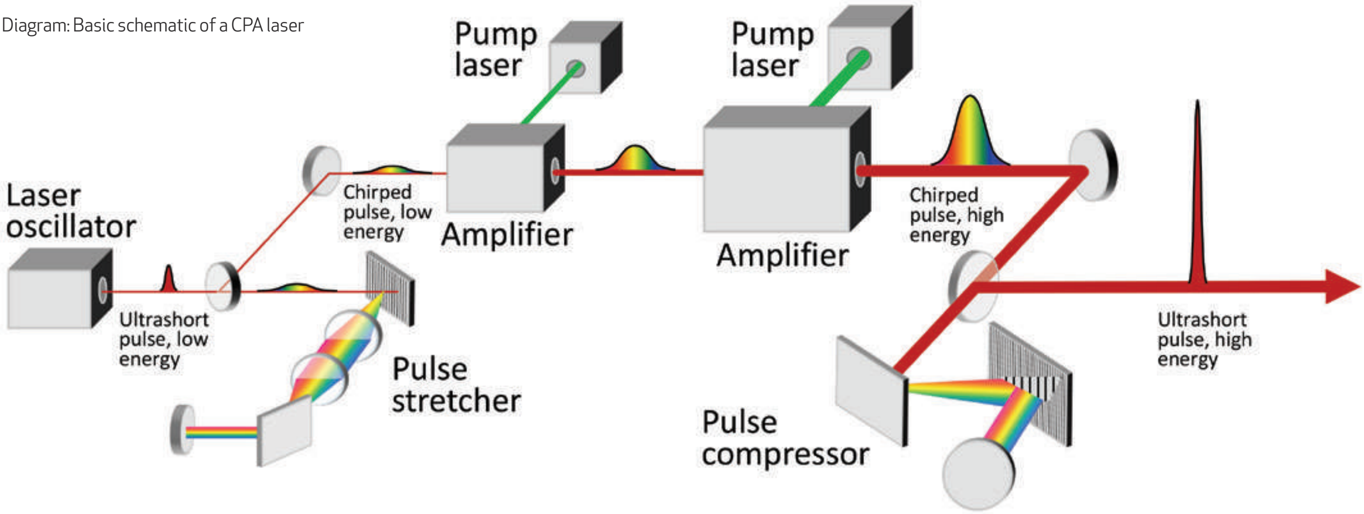
The implementation of a laser wakefield accelerator (LWFA) at the 5 GeV target energy of EuPRAXIA requires the most sophisticated and robust laser technologies available. The EuPRAXIA laser will produce ultrashort pulses of infrared light with a pulse duration as short as a few tens of femtoseconds and energies up to 100 joules, yielding a peak power of the order of several petawatts (1 PW = 10^{15} W). More importantly, the EuPRAXIA laser will deliver such pulses with a repetition rate as high as 100 Hz, a performance never achieved so far.

High-power lasers work by successively amplifying the ultrashort laser pulses that originate in a laser oscillator. In order to avoid damaging the laser components as the light power increases, the temporal duration of the laser pulse is lengthened in a pulse stretcher. In this way, the energy of the pulses can be safely amplified while maintaining their power below the damage threshold of the different optical components. After the last amplification stage the pulse is recompressed to the original duration in a pulse compressor, to come out as a high-power ultrashort laser pulse. This technique is called Chirped Pulse Amplification (CPA).

Although CPA lasers deliver a huge amount of power, they do so with a low repetition rate. State-of-the-art petawatt-level CPA lasers can deliver up to one pulse per second (1 Hz). Therefore, the average power (power emitted over an extended period of time) of a petawatt laser is not much higher than hundreds of watt.

The underlying requirement of CPA laser pulses is their large spectral bandwidth, up to tens of nanometers. As a consequence, CPA laser amplifiers use gain media which are capable of supporting amplification over such a large bandwidth. The most versatile gain media available today is titanium doped sapphire ($Ti^{3+}:Al_2O_3$, or simply Ti:Sa). It has excellent physical and optical properties and can amplify broadband laser light from 660 nm to 1100 nm. Ti:Sa can be pumped by radiation in the 400-600 nm spectral window, making frequency-doubled, flashlamp-pumped Nd:YAG lasers the ideal pumping source. This is also the main limitation to the scaling of Ti:Sa based lasers to the required EuPRAXIA specifications, namely the laser repetition rate.

Diagram: Basic schematic of a CPA laser



Challenges

Repetition rate and laser stability.
The repetition rate of the laser determines the repetition rate of the accelerated electron bunches. Although the peak current of the wakefield-accelerated electrons can be very high, the low repetition rate yields an average electron flux that is too low for some practical applications. It may also hamper the achievements of good statistics in measurements. Moreover, a low repetition rate is usually associated with poor laser stability in terms of energy and beam pointing. As an example, laser beam pointing stability of current systems is estimated to be approximately one order of magnitude worse than required for EuPRAXIA. Such an improvement will require automatic stabilization at high repetition rate.

There is currently a great international effort to increase the repetition rate of high-power lasers. The main impediments are the efficiency of the pump lasers, which must deliver a large amount of energy (of the order of tens of joules or more), and the thermal load on the laser crystals which must dissipate the excess energy. EuPRAXIA has identified this goal in the "100^3 challenge", that is, the design and construction of a laser capable of delivering pulses with a duration of 100 femtoseconds and an energy of 100 joules, at a repetition rate up to 100 hertz.

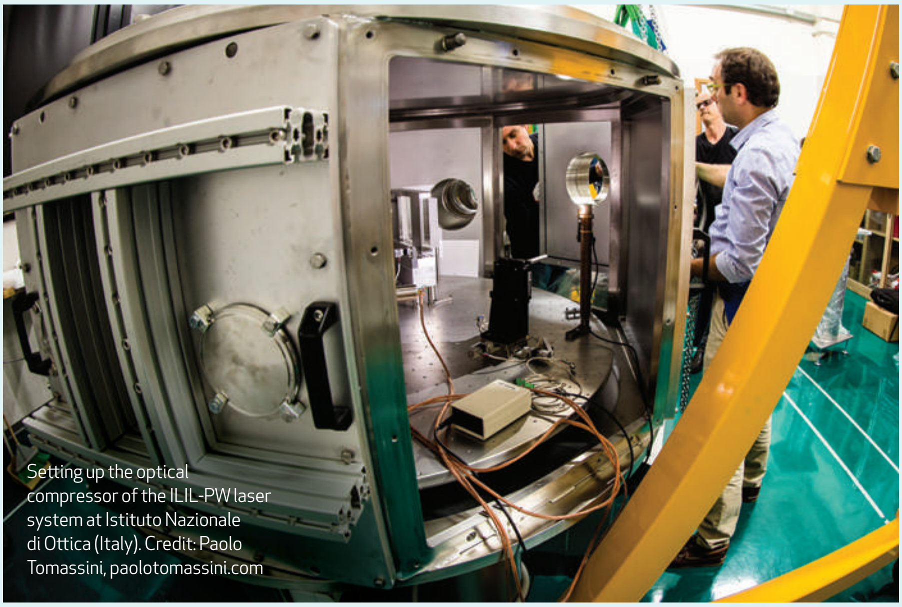
Femtosecond timing.
The timing and the accuracy required for a plasma accelerator are in the femtosecond domain. The mechanical miniaturization of the system (e.g. plasma structures) leads to a much reduced tolerance in the stability and goes hand in hand with ultrafast synchronization electronics and correction feedback loops that must react before the operational limits are violated.

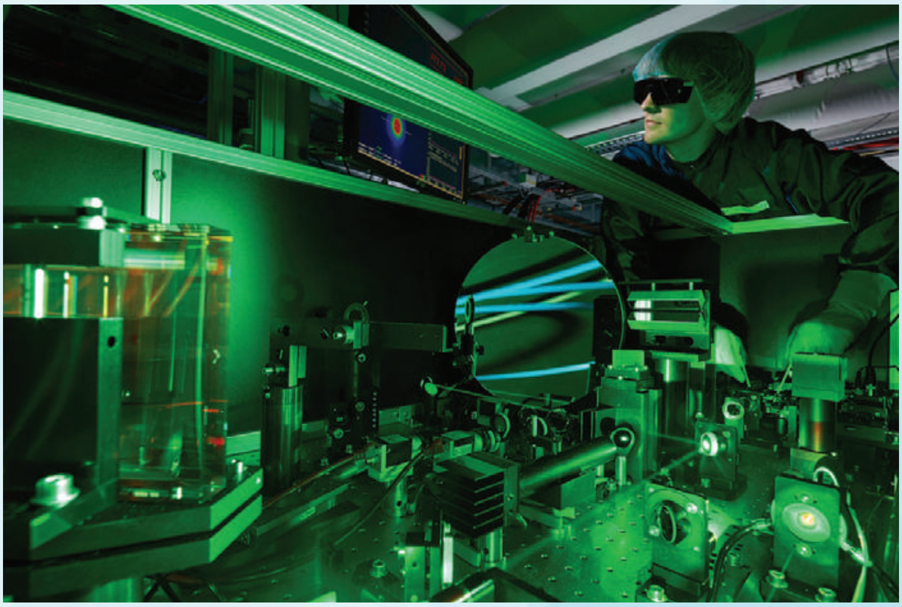
Innovation potential

High repetition rate petawatt lasers, pump laser technology.
The achievement of the "100^3 challenge" will bring significant advancements in the technology of high pulse energy lasers needed for pumping femtosecond amplification systems. Current systems based on flashlamp pumping, although very reliable, has inherent limitations in terms of overall efficiency and repetition rate. The Diode Pumped Solid State Laser (DPSSL) technology has the potential of overcoming this limitation, thanks to its superior overall efficiency. The definition and the evaluation of suitable and feasible DPSSL architectures based on this technology is one of the aims of EuPRAXIA.

Stabilized 1 PW laser technology.
EuPRAXIA aims at investigating laser stability limits and designing solutions that will improve laser stability. This can be achieved by optimizing the laser transport (e.g. mirror stabilization) and by optimizing the laser itself. Eventually, the EuPRAXIA laser will be an industrial system which will include all the technology developed in close collaboration with the manufacturer.

Ultrafast synchronization, electronics and correction loops.
EuPRAXIA will foster further progress on this technological frontier. Lasers that are timed precisely to an external reference and ultrafast electronics can be implemented in many technological devices, like laser heaters, laser vibration monitoring, laser wires, ultra-precise timing reference systems, femtosecond stabilization loops, etc. Ultrafast technology will contribute to the successful development of miniaturized technology.


Setting up the optical compressor of the ILIL-PW laser system at Istituto Nazionale di Ottica (Italy). Credit: Paolo Tomassini, paolotomassini.com


ANGUS 200 TW laser system at the University of Hamburg. © DESY, Heiner Müller-Elsner

ACCELERATOR TECHNOLOGY

Technology

The realization of a wakefield accelerator with the industrial beam quality of EuPRAXIA requires the external injection of high-brightness electron beams. Radiofrequency (RF) photoinjectors, can generate and accelerate those electron beams up to a few hundreds of MeV. The EuPRAXIA RF photoinjector employs state-of-the-art photocathode extraction, and RF acceleration and compression, both to shorten the bunch down to a few femtoseconds and to manipulate its longitudinal distribution. Multi-bunch trains are mandatory to increase the transformer ratio, i.e. the energy transfer efficiency.

In plasma wakefield acceleration, a train of driver electron bunches separated by a plasma wavelength, λ_p, resonantly excites a plasma wake, which accelerates a trailing witness bunch injected at the accelerating phase.

A train of high-brightness bunches, spaced by λ_p, is properly generated at the cathode and manipulated through the velocity bunching technique in order to be injected in the plasma target with the proper distance and length. Exploiting the fast response of metallic photocathodes, the bunch charge and spacing can be adjusted unbalancing the photocathode laser intensity and delaying its relative arrival time at the photocathode.

High-brightness electron beams must be transported from the source (the external RF injector or the plasma injector) to the plasma cell in which the electron beam is accelerated. Active plasma lenses are being studied to optimize the final focusing system.

High accuracy and precision diagnostic tools are also required for both transverse and longitudinal characterization of the electron beam along the whole accelerator in order to check the matching conditions and the acceleration process.

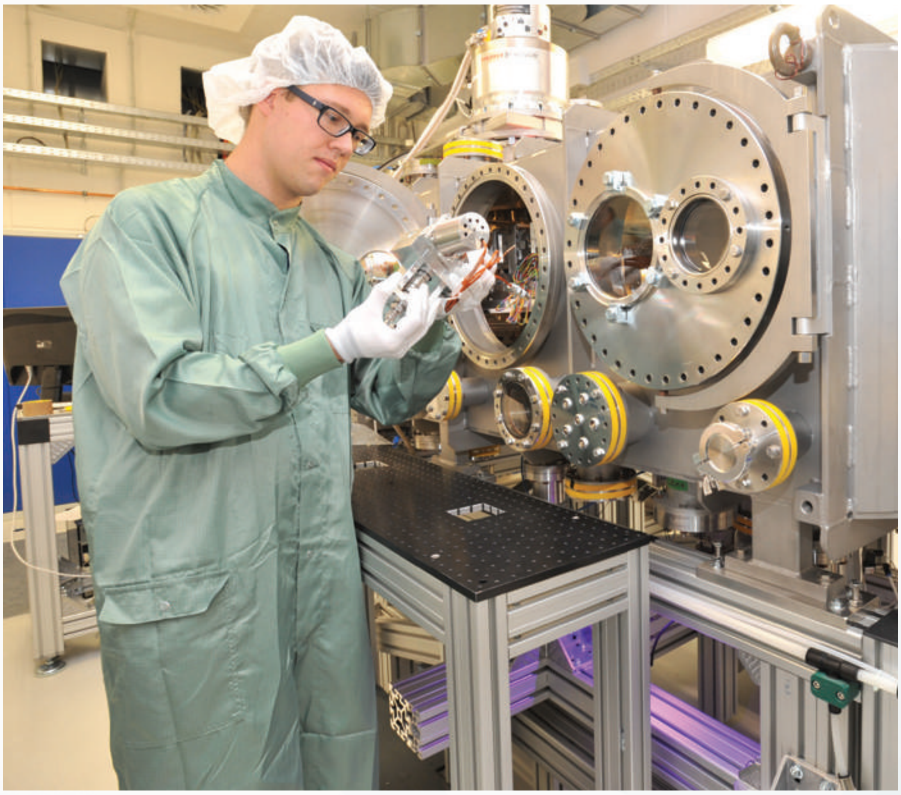
Challenges

Staging.
The energy gain in a single plasma cell is limited by several factors such as dephasing and laser diffraction. These problems may be mitigated by tailoring the plasma density, guiding the laser pulse in a preformed plasma waveguide, and properly shaping the electron bunch. In order to overcome the depletion of laser energy, it is necessary to sequence the accelerator into stages, each powered by a separate laser pulse. On the other hand, particle-driven acceleration is not affected by energy depletion.

Electron beam matching.
The current goal of the worldwide plasma, laser, and photoinjector communities is to demonstrate the stable and repeatable acceleration of high-brightness beams. The next step is the extraction and transport of the beam, preserving its quality, i.e. high 6D brightness, stability and reliability, to feed the user applications. The need for matching the electron beams in and out of plasma channels requires magnetic focusing to a small beam size of the order of one micrometer. While this has been done in conventional accelerators, conventional schemes have to be adapted for plasma accelerator needs or innovative devices must be developed, being plasma-based lenses the most promising candidates.

Beam transport.
The manipulation of the beam is particularly challenging because the beam must be only a few femtoseconds long and a few micrometers large at the entrance of the plasma accelerating structure. After the accelerating plasma structure, the electron beam must be optimized to fit the user needs.

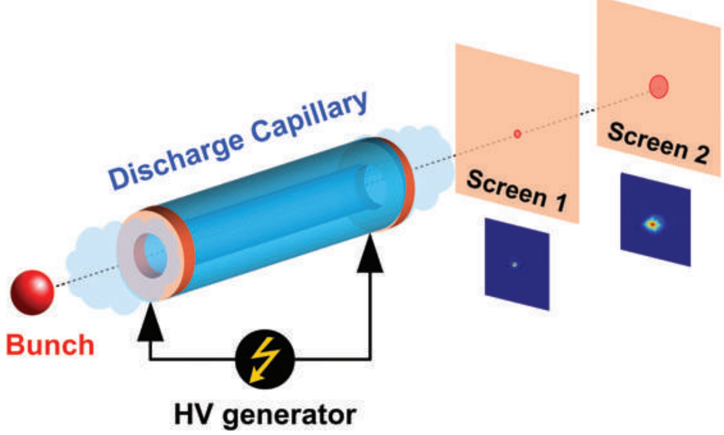
Beam diagnostics.
Preferably non-intercepting and single-shot diagnostics should provide the required resolution, i.e. few tens of femtoseconds bunch length and few micrometers transverse beam size. In addition, the quality of the accelerated beam critically depends on its proper injection at the right phase in the plasma wave.

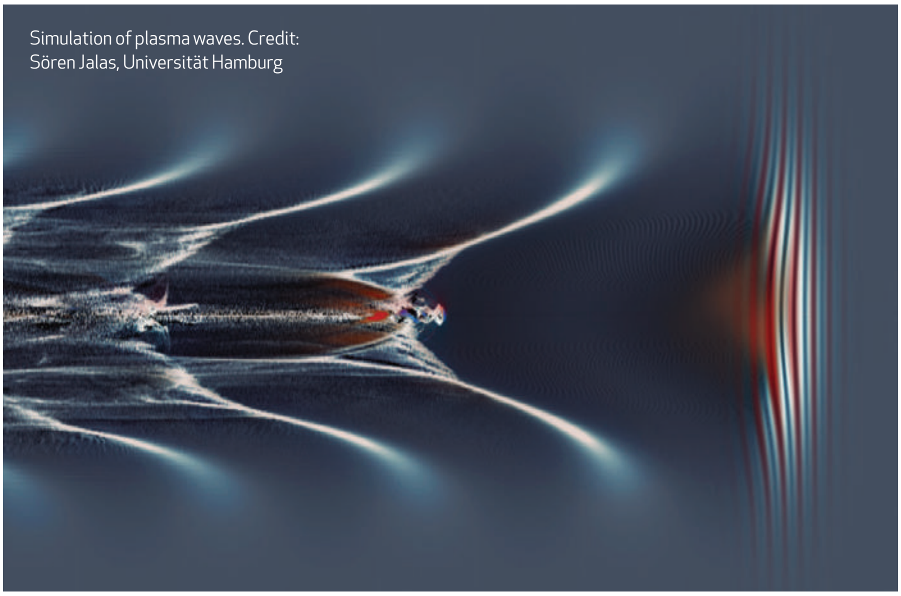


(Right) Laser wakefield acceleration chamber at HZDR (Germany).

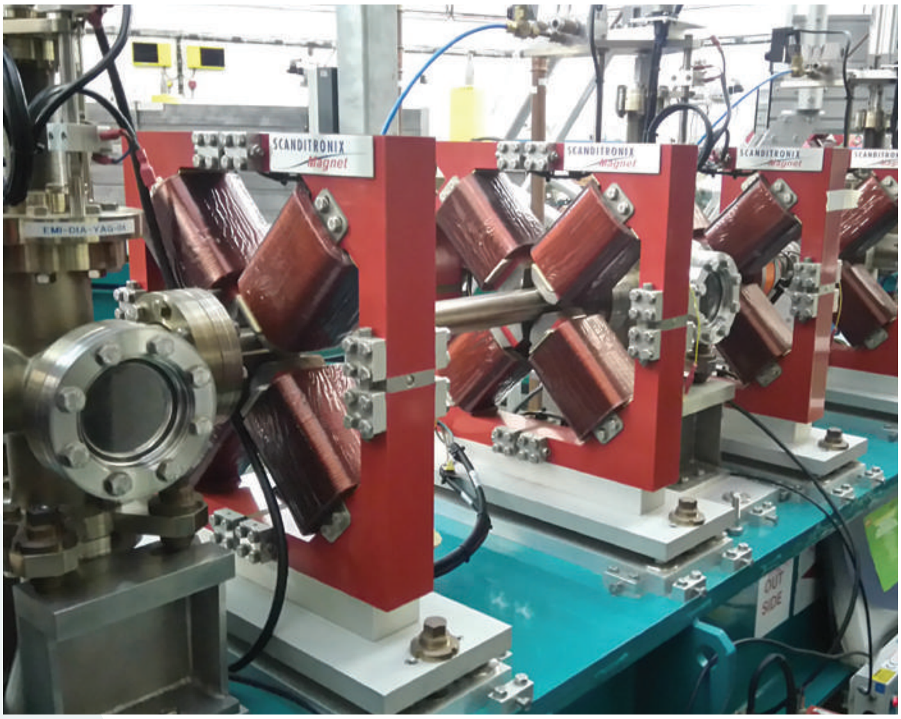
Credit: Frank Bierstedt, Helmholtz-Zentrum Dresden-Rossendorf

Diagram: Setting up a plasma lens for the final focus. Credit: INFN-LNF





Simulation of plasma waves. Credit: Sören Jalas, Universität Hamburg



(Left) The ALICE accelerator at STFC's Daresbury Laboratory (UK)

Innovation potential

Plasma cell technology. EuPRAXIA foresees the design of a plasma cell that can be cascaded, so that higher electron energies are reached, and the required tolerances for user applications can be fulfilled. The end goal is an "industrial" plasma cell design that provides a path to high beam energy by cascading. In addition to building whole accelerators with plasma structures, one or two of these structures could be used as add-ons to existing conventional facilities, boosting the energy reach and potential for science.

Compact accelerator magnets with high field quality. EuPRAXIA fosters developments towards compact accelerator magnets with high field quality, chromatic correction, and a certain tuning range. Permanent magnets as well as electromagnets are options that are considered together with industrial suppliers and accelerator labs. The magnets and lattice solutions from EuPRAXIA can have many other applications in the 30,000 accelerators installed around the world.

Ultrafast beam diagnostics. EuPRAXIA will define high-accuracy and precision diagnostic tools for both the transverse and longitudinal characterization of electron beams, developing novel techniques for sub-fs and sub-μm beam diagnostics.

Ultra-compact accelerators. Similarly to plasmas, laser-illuminated micromachined dielectric structures can sustain strong electric fields (hundreds of megavolts per meter) with the ability to accelerate particles to several MeV in distances of a few millimeters. This emerging technology is not as mature as wakefield acceleration but EuPRAXIA will also investigate dielectric structures with the aim of developing a future "accelerator-on-a-chip".

FREE-ELECTRON LASERS

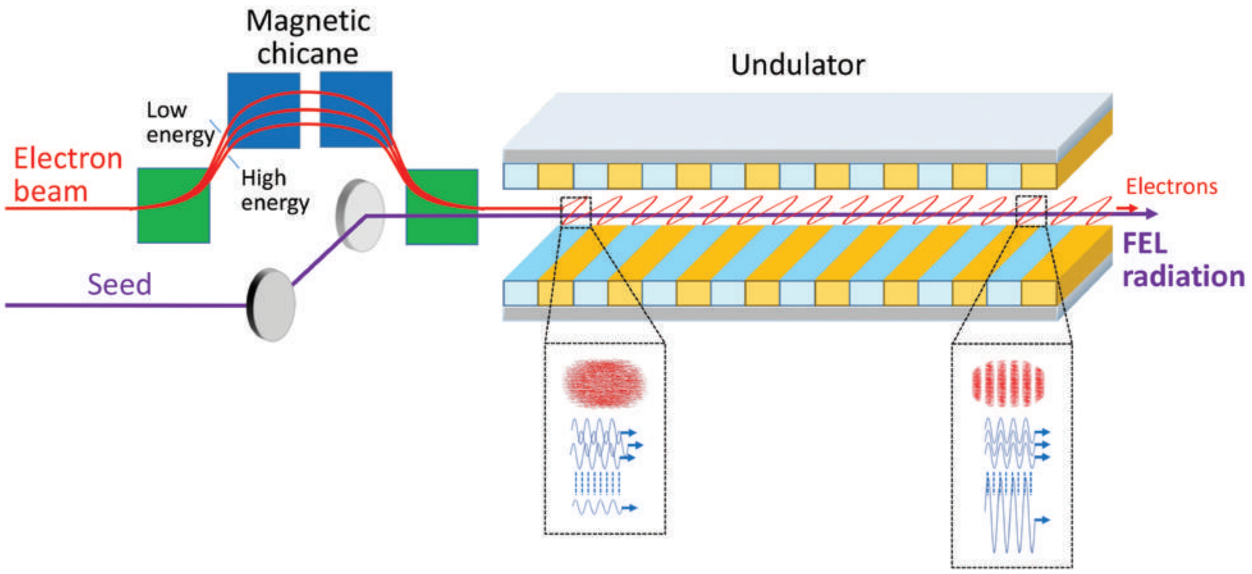
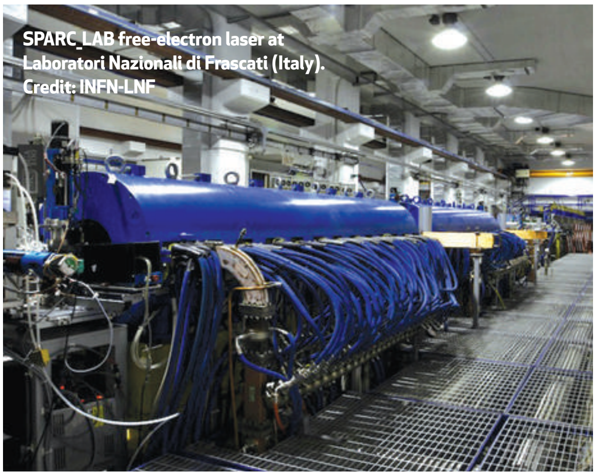


Diagram: Scheme of a free-electron laser

Technology

A free-electron laser (FEL) is a source of coherent (i.e. laser-like) radiation. It works by sending a beam of high-energy electrons down a tube surrounded by a series of magnets with alternate polarities. This magnet array, called undulator, causes the electrons to undergo a sinusoidal motion and emit synchrotron radiation due to their acceleration in the transverse plane. The emitted radiation interferes constructively in the successive oscillations, creating a beam of coherent tunable high-intensity x-rays. A low-energy x-ray beam may be used to 'seed' the FEL emission. Planar undulators lead to a linear polarization in the plane of the electrons.



SPARC_LAB free-electron laser at Laboratori Nazionali di Frascati (Italy). Credit: INFN-LNF

The periodic magnetic field of an undulator is created by either permanent magnets or electromagnets (superconducting or warm magnets) placed next to each other and separated by equal distance. The FEL performance depends on the beam properties and undulator quality.

FELs driven by conventional electron accelerators are currently used in material sciences, nanotechnology, electronic materials processing, microfabrication, and biochemistry, to name but a few of their applications.

One of the trends of FEL technology is the development of compact FEL designs, by replacing the constituting elements with alternative accelerator concepts, new undulator designs, or novel FEL schemes. In EuPRAXIA, the interest is to investigate the application of plasma accelerators as drivers for a FEL, paving the way towards FEL light sources of laboratory size for femtosecond time-resolved experiments. The combination of short-period undulators with high on-axis magnetic fields could enable plasma-driven FELs at water-window photon energies with relatively low-energy electron beams of 1 GeV.

Challenges

The development of an FEL for EuPRAXIA must overcome the intrinsic limitations of plasma-accelerated electrons, such as the large energy spread (typically a hundred times larger than conventional linacs) and 1 mrad divergence. To handle this issue, some electron beam manipulation has to be performed, either prior to the undulator with a demixing chicane or directly inside the undulator using a transverse gradient undulator.

Transverse gradient undulators are considered to be a promising solution for FELs utilizing electron beams with large energy spread. However dispersing the particles increases the beam size in the direction of dispersion (usually horizontal direction) and reduces the transverse coherence of the FEL radiation.

A particular interest concerns the push towards shorter undulator periods with high magnetic fields. Laser plasma acceleration naturally produces short electron bunches, therefore shorter undulator periods are needed to minimize the slippage and avoid the light from escaping the electron bunch along the undulator.

Shortening the undulator period means reducing the magnet size, which results in a lower magnetic field. Achieving a sufficient magnetic field sets requirements for the magnetic material and the undulator gap. In-vacuum undulators, which avoid the gap limitation imposed by the beam pipe, may be used to reach smaller gaps and hence higher magnetic fields.

Innovation potential

Compact FELs.
EuPRAXIA is developing strategies for short period undulators, such as in-vacuum cryogenic and superconducting undulators. Technologies for transverse gradient devices are also being investigated. Cryogenic permanent magnet undulators offer several technological advantages over on-air warm permanent magnet undulators, currently used in FEL facilities world-wide.

Ultrafast science.
The ultrashort x-ray pulses made available by the plasma accelerator-driven FEL open up a whole new range of possibilities to measure ultrafast processes in nature that can be analyzed at the electronic level without perturbation, e.g. time-resolved photoelectron spectroscopy, single-shot x-ray diffraction of biomolecules, proving warm dense matter, etc.

Fast photon detection technology.
The detector technology for ultrafast photon science has to be adapted to the plasma beam features; therefore EuPRAXIA will foster progress in ultrafast photon science detection technology.


Magnetic undulator for a free-electron laser.
© DESY, Heiner Müller-Elsner

FEL	**Wavelength** (nm)	**Electron bunch duration** (ps)	**Energy** (MeV)	**Undulator periods**	**Undulator wavelength** (cm)
SwissFEL (PSI, Switzerland)	70 – 800	0.5 – 3	100 – 220	265	1.5
SPARC (Frascati, Italy)	66 – 800	0.15 – 8	80 – 177	450	2.8
FERMI-2 (ELETTRA, Italy)	4 – 14.4	0.7 – 1.6	900 – 1500	396	3.5
FLASH2 (DESY, Germany)	4 – 80	0.05 – 0.5	500 – 1250	768	3.14
LCLS (SLAC, USA)	0.12	0.07	15400	3696	3
SACLA (SPring-8, Japan)	0.06 – 0.25	0.02 – 0.03	8300	6300	1.8

HIGH-ENERGY PHYSICS AND OTHER APPLICATIONS

Besides providing a driver beam for a free-electron laser, EuPRAXIA targets applications for high-quality electron beams that exploit the unique features of plasma accelerators.

The ultra-high instantaneous particle fluxes created by wakefield acceleration can be used for the characterization and calibration of novel particle detectors for high-energy physics, helping to assess sensor saturation effects, study detector resilience to high occupancy and pile-up, and develop enhanced particle reconstruction in a hostile, high-background environment.

Future generation light sources will make use of very short electron bunches, and therefore require beam diagnostics capable of measuring extreme bunch properties (e.g. electro-optical sampling). The short bunch duration of plasma-accelerated electrons is most suitable to measure precisely the intrinsic timing resolution of such beam diagnostics.

In contrast to existing irradiation facilities, the particular time structure of plasma-accelerated electron bunches coupled with their high energy can be of particular interest for studying radiation damage in components for space technology and nuclear applications, but also in material science and life sciences.

In addition to the high-quality electron beam, EuPRAXIA can provide a synchronized laser beam in the user area, which enables applications to high energy density physics, Inverse Compton Scattering, and neutral electron – positron beams.

EuPRAXIA will also examine the possibility to create a secondary beam positron source of modest intensity and inject it into a laser wakefield accelerator stage.

Innovation potential

Phase-contrast x-ray imaging using betatron radiation.
Phase-contrast x-ray imaging exploits the changes in the phase of x-ray beams traversing materials with different refractive index to discern the structures under analysis. The phase-contrast technique provides much higher contrast than normal absorption-contrast x-ray imaging, making it possible to see smaller details. It has become an important method for visualizing cellular and histological structures in a wide range of biological and medical studies.

The electrons trapped in a wakefield structure oscillate, producing bright short flashes of betatron radiation. EuPRAXIA could deliver the high-brilliance x-ray beams that are required for phase-contrast x-ray imaging. Their small source size, and therefore high spatial coherence, is ideal to reach the highest sensitivity.

Gamma ray sources by Inverse Compton Scattering.
Inverse Compton Scattering is a process in which a charged particle, usually an electron, transfers part of its energy to a photon. Some accelerator facilities scatter laser light off the electron beam to produce high-energy photons in the MeV to GeV range which are subsequently used for nuclear physics experiments.

EuPRAXIA could provide an all optical gamma ray source by scattering a laser off the laser wakefield-accelerated electron beam. The extremely bright gamma ray beams emitted may be used to trigger nuclear processes like Nuclear Resonance Fluorescence and photofission.

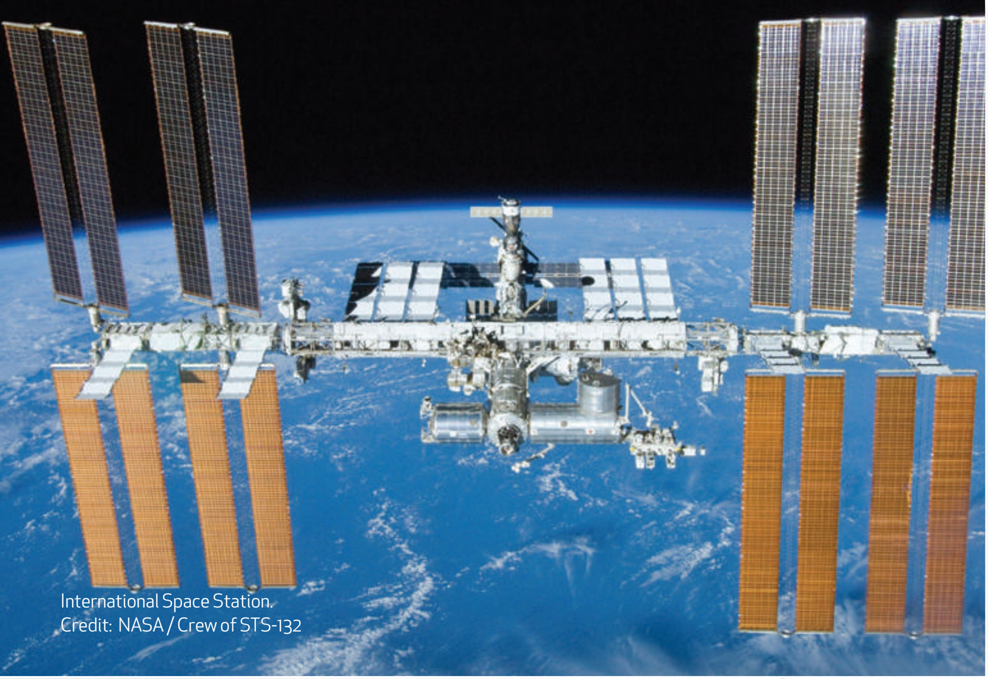
High-energy-density physics.
High-energy-density physics is the study of matter under extreme states of pressure (from 1 megabar to 1000 gigabar). These conditions occur, for example, at the Earth's core, the Sun's core, and the plasmas in an Inertial Confinement Fusion reactor. This type of research is important for understanding the formation of stars, the synthesis of elements, and harnessing fusion energy on Earth.

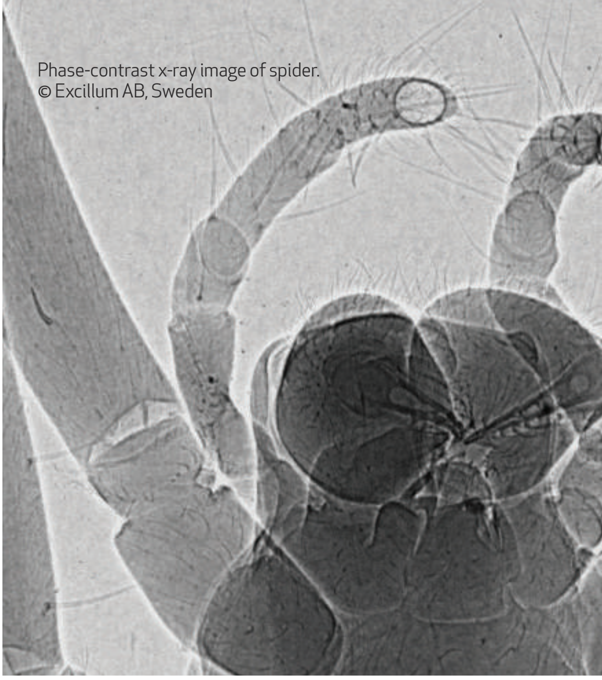
The bright hard x-rays generated by betatron radiation in the wakefield accelerator of EuPRAXIA could be an ideal tool for probing high-energy-density plasmas. Their broadband and short pulse duration would enable new approaches to x-ray absorption spectroscopy and white light Laue diffraction.

Medical accelerator technology.
Medical applications are not explicitly included in EuPRAXIA. However, the knowledge and achievements in EuPRAXIA towards stable plasma accelerators will directly demonstrate the path to medical applications like Microbeam Radiation Therapy (MRT).

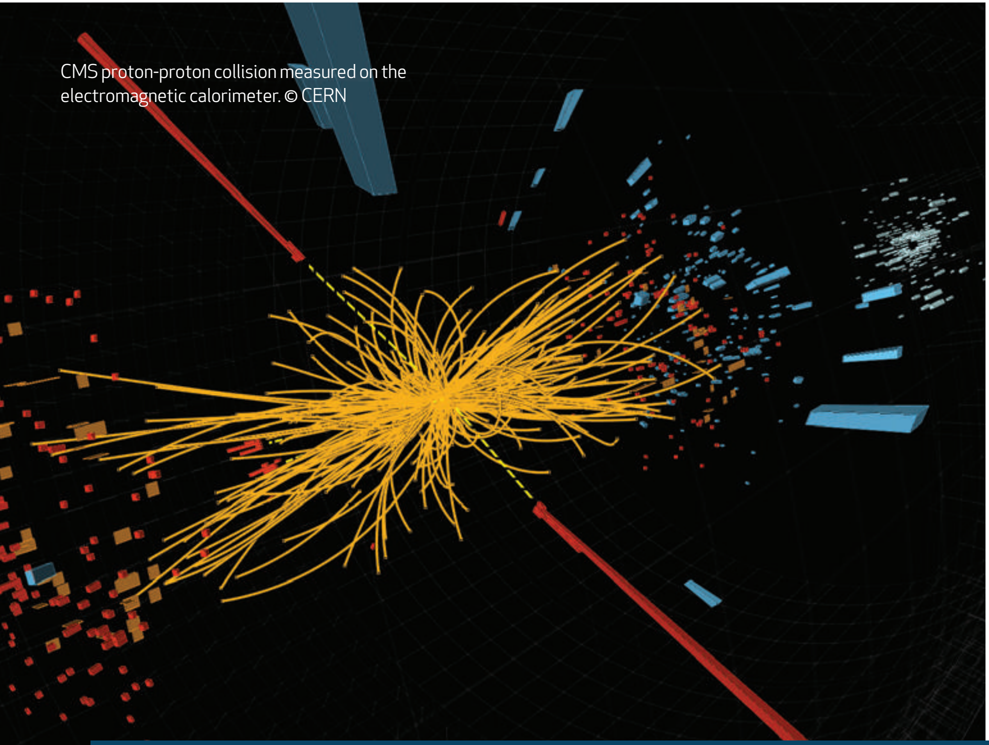
MRT is a novel form of radiotherapy which uses highly collimated, quasi-parallel arrays of x-ray microbeams of 50 – 600 keV. The extremely high dose rate and very small beam divergence of the x-ray source allows the delivery of therapeutic doses in microscopic volumes, thus reducing the impact on healthy tissue.

The technology developed in EuPRAXIA can be expected to be quickly adopted for medical applications, once its potential, stability and safety has been proven in our project.


International Space Station.
Credit: NASA / Crew of STS-132


Phase-contrast x-ray image of spider.
© Excillum AB, Sweden


LHCb VErtex LOcator (VELO) system. © CERN


CMS proton-proton collision measured on the electromagnetic calorimeter. © CERN

Terrestrial reproduction of space radiation.
High fluxes of high-energy cosmic particles pose a serious threat to spacecraft electronics and crews. Therefore, the reproduction of space radiation on Earth is crucial for testing the electronics and assessing the dose on human crews before missions. Since the generation of the broadband radiation by wakefield acceleration is much easier than the monoenergetic beams, early applications of the EuPRAXIA facility for space radiation reproduction are possible.

High-energy physics detector technology.
EuPRAXIA will provide a dedicated user area for developing and commissioning the latest detector technology for high-energy physics, like high-granularity calorimeters. Detector components can profit from superior timing of beam electrons (down to picosecond level), variable number of electrons in beam bunches (from 1 to 1000), a large range of beam diameters (1 cm to 1 m) and angular divergences (1 to 100 mrad). EuPRAXIA will contribute to the development of state-of-the-art detectors providing a testing environment not available at conventional facilities.

Positron sources.
EuPRAXIA offers significant potential for the development of low-emittance high-charge positron beams for applications ranging from colliders for particle physics to positron annihilation spectroscopy for material science as well as creation of positron-electron neutral charge plasma for fundamental studies of processes relevant in astrophysics.

NETWORK ACTIVITIES

The EuPRAXIA study involves scientists working on accelerators, high-power lasers, free-electron lasers and high-energy physics. Moreover, research and development on electron plasma acceleration is carried out in multiple institutions scattered around Europe, Asia and the United States.


Participants in the EuroNNAc and EuPRAXIA Workshop on a European Plasma Accelerator. Pisa, June 2016. Credit: Federico Parenti

In order to bring together such a diverse community, to strengthen the links with the relevant industries, and to connect interested users from a variety of fields, the EuPRAXIA consortium carries out an extensive program of networking activities.

As well as regular meetings and workshops within each work package, EuPRAXIA organizes network-wide yearly meetings to assess the development of the project.

Communication and dissemination

Progress made in EuPRAXIA can be followed through the project website www.eupraxia-project.eu and articles published regularly in scientific journals and magazines.

“The EuPRAXIA Files”, a newsletter highlighting published papers that are relevant for the EuPRAXIA study, is produced every four months and distributed to all the participants and associated partners of EuPRAXIA.

The EuPRAXIA consortium is present in most major conferences on accelerators and laser science, where the strategy, results and design choices of EuPRAXIA are disseminated.

Public engagement

The EuPRAXIA consortium is strongly committed with public engagement and endeavors to communicate its objectives and results to the general public through the publication of feature articles in the general media, participation in outreach events, and the organization of an open symposium, with the participation of all members of the consortium and representatives from the industry.

The symposium will be organized in Liverpool in 2018 as a finale to the outreach activities undertaken during the course of the project. This will present the main project findings in an accessible way for the public, emphasizing the possible applications of the technologies concerned.

EuPRAXIA MANAGEMENT STRUCTURE

The management bodies organize, lead and control the project’s activities and make sure that objectives are met.

Collaboration board

The collaboration board reviews work progress, including deliverables, and decides on modifications to the work program, the allocation of the EC funding, and the accession and withdrawal of partners.

Work package coordinators

Each work package has two coordinators. The work package coordinators ensure the effective cooperation between the participants in their work package, monitor progress of the work and review milestones and deliverables.

Management support team

The management support team assists the management in financial matters, as well as in the organization of events, communication and liaison with the media.

Scientific advisory committee

The scientific advisory committee (SAC) is an advisory body to the collaboration board. The SAC members are recognized experts that do not participate in the EuPRAXIA Study.

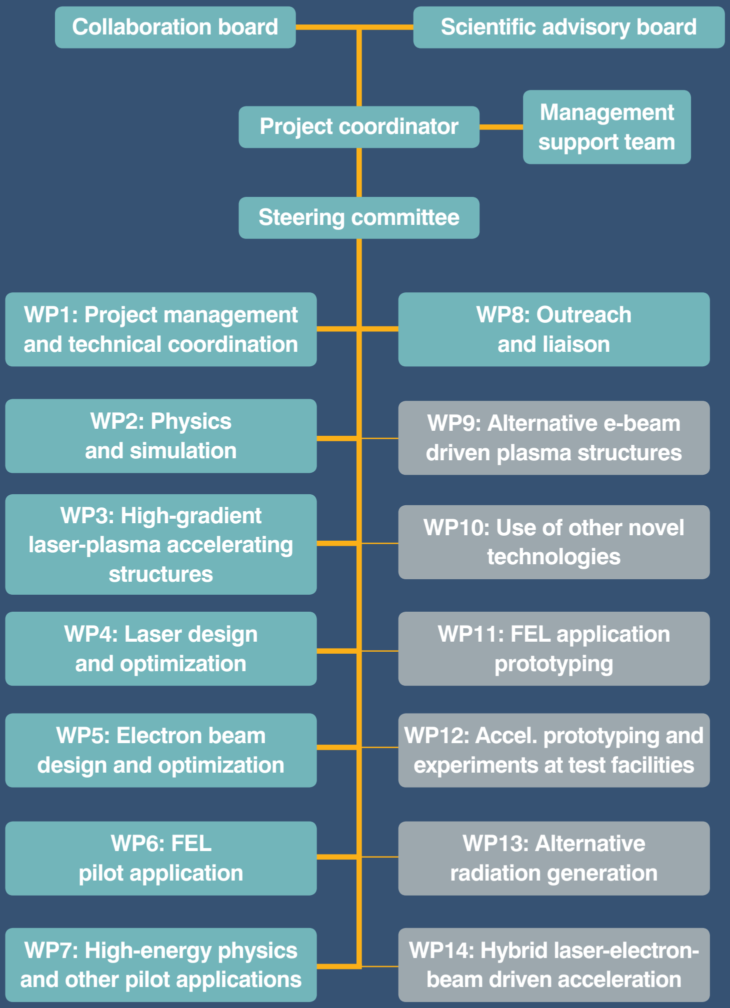
Steering committee

The steering committee is the executive body of the EuPRAXIA project and as such it is responsible for the coordination and management of the work packages.

Project coordinator

The project coordinator is the coordinating person of the EuPRAXIA proposal with a mandate for two years, renewable. He is responsible for the day-to-day management and coordination of the EuPRAXIA design study and, in this capacity, he follows up on milestones and deliverables, and monitors the use of resources. The project coordinator chairs and organizes the steering committee meetings.

Below: Structure of the EuPRAXIA Design Study. The blue background denotes the work packages funded by the EU.



PARTICIPANTS

EuPRAXIA brings together a consortium of 16 laboratories and universities from 5 EU member states sharing a budget of 3 M€ funded by the European Union's Horizon 2020 program. As of October 2016, 22 associated partners from 11 countries have joined with in-kind commitments (linking 3 additional EU member states).

BENEFICIARY PARTNERS ▶▶▶▶▶▶▶▶

DESY – Deutsches Elektronen Synchrotron, Germany

DESY is a leading German research center for accelerators, photon science and high-energy physics. DESY has a long history and experience in the design and operation of large research infrastructures such as the HERA, PETRA, DORIS and FLASH accelerators. FLASH is the most advanced SASE FEL infrastructure and serves also as a unique test bed for superconducting RF technology. DESY is presently strongly involved in the construction of the European XFEL. The development, construction and operation of particle accelerators involves special challenges for both humans and machines. Over 50 years DESY has accumulated vast experience in accelerator development, construction and operation, and is one of the world's leading laboratories in this field.

Contact: Ralph Assmann

INFN – Istituto Nazionale di Fisica Nucleare, Italy

INFN is a research institute aimed at the study of the fundamental constituents of matter. It conducts theoretical and experimental research in the fields of sub-nuclear, nuclear, astroparticle and particle accelerator physics. This requires the use of cutting-edge technologies and instrumentation, which the INFN develops both in its own laboratories and in collaboration with industries and institutions from all over the world.

The Laboratori Nazionali di Frascati (LNF) is one of the four main laboratories of INFN. LNF has also addressed dedicated R&D on advanced accelerator concepts at the SPARC_LAB multidisciplinary test facility. Born from the integration of a high-brightness photoinjector (SPARC) and of a high-power laser (FLAME), SPARC_LAB is now mainly devoted to perform further developments, characterization and application of compact radiation sources (FEL, THz, Compton) driven by plasma based accelerator modules with both LWFA and PWFA techniques.

Contact: Massimo Ferrario

CNR – Consiglio Nazionale delle Ricerche, Italy

The Intense Laser Irradiation Laboratory (ILIL) at INO-CNR operates in the field of high-intensity laser interactions with matter and applications to life, material and fundamental sciences. Since 2004 the laboratory hosts an ultrashort pulse, high-power laser installation now featuring 10 TW on target and currently undergoing a major upgrade (ILIL-PW).

Experimental rooms with multiple interaction chambers dedicated to laser-gas and laser-solid interactions are combined with a full range of detection techniques, including spectroscopy and imaging from the IR to the gamma ray.

Its main topics of research are: rep-rated laser-plasma electron source for medical applications; ultraintense laser-plasma interactions, including advanced ICF ignition; laser-driven x-ray and gamma ray fluorescence and scattering sources; and the development of a laser-driven proton beamline.

The laboratory has well-established links with many leading international high-power laser laboratories and facilities, as well as academic groups and has a close collaboration with the INFN Laboratori Nazionali di Frascati where the Flame laser system operates since 2009.

Contact: Leo A. Gizzi

CNRS – Centre National de la Recherche Scientifique, France

Centre National de la Recherche Scientifique (CNRS) is a government-funded research organization, under the administrative authority of France's Ministry of Research. The CNRS operates over one thousand research units, hosts more than 32,000 employees and wields a global budget of 3.4 billion euros. As the largest fundamental research organization in Europe, CNRS conducts research in many fields of knowledge through its ten research departments and participates in 460 international research programs. CNRS participates in EuPRAXIA through four laboratories:

- LPGP is associated to CNRS and Université Paris-Sud (Orsay). The research activity is related to plasma physics, ranging from ultraintense laser interaction with plasmas to electrical discharge plasmas and their applications.
- LOA is associated to CNRS and ENSTA. Research at LOA covers the development of ultrashort pulse lasers, laser-plasma interactions, and derived particle and radiation sources.
- LULI is associated to CNRS and École Polytechnique. Research topics are plasma physics of hot dense matter, laser-matter interaction, acceleration of particles with plasma waves, and development of lasers.
- LLR is associated to CNRS and École Polytechnique. LLR is a high-energy physics laboratory with research groups working in particle physics experiments at CERN (LHC), and Japan, on astroparticle physics (FERMI, HESS, CTA) and laser-plasma acceleration (CILEX).

Contact: Arnd Specka

University of Strathclyde, UK

The University of Strathclyde team has been working on advanced particle accelerators funded by the EPSRC through the ALPHA-X project over the last 15 years, which aims to create a compact laser-plasma coherent x-ray source.

The ALPHA-X facilities include a laser plasma wakefield accelerator with an electron and radiation beamline, undulators, a 40 TW laser and advanced diagnostics. The project made the first demonstration of controlled wakefield acceleration published as one of the "Dream Beam" papers in Nature in 2004 and a laser-plasma driven synchrotron source, initially in the visible and now in the VUV. It has recently led to the formation of the Scottish Centre for the Application of Plasma-based Accelerators, SCAPA, supported by the University of Strathclyde and other participating universities through SUPA and the SFC (Scottish Funding Council).

The new laser facilities of SCAPA will be capable of delivering 350 TW with multiple beamlines to enable a variety of particle and photon sources to be utilized in a number of applications ranging from pure academic research to medical applications.

Contacts: Bernhard Hidding and Dino Jaroszinsky

IST-ID – Associação do Instituto Superior Técnico para a Investigação e Desenvolvimento, Portugal

The Association of Instituto Superior Técnico for Research and Development (IST-ID) is a private not-for-profit institution, which primarily aims at carrying out science and technology activities, fostering knowledge transfer and promoting the involvement of national and foreign researchers, internally and externally, in RD&I projects in their areas of expertise.

IST-ID's Laser and Plasma Group (GoLP) is integrated in the Institute for Plasmas and Nuclear Fusion (IPFN), an associated laboratory for plasma physics, nuclear fusion and intense lasers – a status given by the Portuguese Ministry of Science to the top research units of high strategic relevance to the country. GoLP excellence is in the field of theory, advanced computing and experiments in laser-plasma interaction, including electron acceleration, high-harmonic generation and tunable sources.

Contact: Luís Oliveira e Silva

STFC – Science and Technology Facilities Council, UK

STFC is one of the UK's seven publicly funded Research Councils, supporting particle physics and astronomy, enabling access to international facilities such as CERN, and operating large-scale science facilities such as the ISIS spallation source and Central Laser Facility (CLF). STFC has an annual budget of over £400M, and employs over 1,600 people, principally within its Daresbury and Rutherford Appleton National Laboratories. STFC produced the design for NLS, a 4th generation superconducting FEL facility for the UK, is actively engaged in FEL projects such as the SwissFEL, and is leading the design of the CLARA FEL Test Facility at Daresbury Laboratory. STFC's Central Laser Facility houses some of the most intense lasers in the world. Since its inception, CLF has been at the forefront of plasma based accelerator research, having led some of the seminal works in the field in its facilities. CLF's latest high-power laser, Gemini, is the first high-repetition rate dual-beam petawatt laser, ideally suited for applications of intense lasers, including plasma accelerators. CLF pioneers intense laser technology, including the diode pumping technology for high-repetition rate lasers. Its commercial wing, CALTA has already won several contracts to sell diode pumping technology to European infrastructures like ELI and Hamburg XFEL.

Contacts: ASTeC - Jim Clarke, CLF - Rajeev Pattathil

Synchrotron SOLEIL, France

Synchrotron SOLEIL is the French national synchrotron facility created by CNRS and CEA. SOLEIL offers a unique panorama of experiments with 29 beamlines in operation, covering the far IR to the hard x-ray range, and open to a large scientific and industrial users community in a very broad range of fields from life-sciences to material science including surface, solid state and gas phase physics and chemistry, as well as geosciences and cultural heritage sciences. SOLEIL storage ring makes massive use of straight sections equipped with undulators and wigglers, which are tailor-made to best meet the needs of users.

Since 2008, SOLEIL has welcomed more than 5,700 users coming from 1,420 laboratories (French, European and overseas) to carry out research at its facilities. SOLEIL source division includes typically 60 accelerator experts both for dynamics and different technologies. SOLEIL has a strong expertise in free-electron lasers and it is also involved in the laser wakefield acceleration application of the APOLLON laser (CILEX).

Contact: Marie-Emmanuelle Couprie

University of Manchester, UK

The University of Manchester is a major center for research as a member of the Russell Group of leading British research universities. In the first national assessment of higher education research since the university's founding, the 2008 Research Assessment Exercise, it was ranked third in terms of research power and sixth for grade point average quality among multi-faculty institutions. The School of Physics and Astronomy of the university is one of the largest and most active schools in the UK, with more than 150 academic and research staff, including two Nobel Laureates.

The Manchester Accelerator Group is involved in many aspects of accelerator physics research and participates in numerous international collaborations. It specialized in beam dynamics, plasma accelerators, antimatter research, cavity design, collimator design, and wakefield studies. The group is involved in many experiments at LHC, CLIC, ILC, AWAKE, ALPHA, EMMA, CONFORM, FLASH, etc. The group is part of the Cockcroft Institute and has a close relationship with the Manchester particle physics and nuclear physics groups, the Photon Science Institute (PSI), and the Dalton Nuclear Institute. In addition, it also collaborates with ASTeC on novel acceleration research using the VELA and CLARA accelerators in Daresbury Laboratory.

Contact: Guoxing Xia

University of Liverpool, UK

A member of the Russell Group of major research-intensive universities in the UK, the University of Liverpool has an outstanding international reputation for innovative research. Currently around 20,000 students are enrolled into more than 400 programs spanning 54 subject areas at its 3 faculties, including Health and Life Sciences; Humanities and Social Sciences; and Science and Engineering.

A rich variety of research is performed at Liverpool, including Particle Physics, Nuclear Physics and Condensed Matter Physics. Moreover, the University is a key partner in the Cockcroft Institute, an international center of excellence for accelerator science and technology. Embracing academia, government and industry, it is unique in providing the intellectual focus, educational infrastructure and the essential facilities in innovating tools for scientific discoveries and wealth generation.

The University of Liverpool's Project TEAM based at the Cockcroft Institute has a strong expertise in scientific communication and outreach. It has the leading role in the communication and dissemination of several large European projects in the field of accelerator science.

Contact: Carsten P. Welsch

ENEA – Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Italy

ENEA is the Italian agency for energy and environmental resources. At the ENEA Frascati center various research projects are conducted within the framework of fusion programs, laser physics, accelerator physics and free-electron lasers. Regarding the latter, ENEA Frascati has been involved in the field of FEL physics since its very beginning and important results have been obtained. Several members of the ENEA team have been awarded in the past with the yearly FEL Prize. Different accelerator and free-electron laser devices are present in the center. In particular, a THz source and the FEL test facility SPARC operate with the National Institute of Nuclear Physics (INFN).

Contact: Giuseppe Dattoli

CEA – Commissariat à l'Énergie Atomique et aux Énergies Alternatives, France

CEA is the leading French organization for research, development, and innovation in the fields of energy, defense, information technologies, communication and health. The Physical Sciences Division (DSM) is the 'Directorat' (about 1,700 permanent staff) of CEA, involved in physics research and associated technologies. Within CEA-DSM, IRFU (Institute for Research into the Fundamental laws of the Universe) is the CEA contributor to EuPRAXIA. With more than 600 permanent staff, it performs research on particle physics, nuclear physics and astrophysics.

The position of IRFU in developing and realizing particle accelerators, cryogenic systems and superconducting magnets is unique in France. It is based on a backbone of scientific skills and a large technological platform of 25,000 m^2 run by the Service of Accelerators, Cryogenics and Magnetism (SACM) supported by the large System Engineering Division (SIS). As a result IRFU is a key partner for the construction of international accelerators for fundamental science such as LHC at CERN, E-XFEL in DESY (Germany), the FAIR complex at GSI (Germany), the SPIRAL2 accelerator at GANIL (France), ESS (Sweden), and of fusion-related facilities (ITER in France, JT60SA and IFMIF in Japan).

Contact: Alban Mosnier

Università di Roma “La Sapienza”, Italy

The University of Rome “La Sapienza” is the largest university in Europe. It consists of 23 faculties, and about 5,000 employees. The Department of Basic and Applied Sciences for Engineering and Physics (SBAI) joins researchers in the field of general, atomic and nuclear physics. In recent years it has been focusing on FEL photoinjectors for the new generation of coherent radiation sources and laser-based secondary sources.

The accelerator team of the SBAI department is heavily involved in theoretical studies, modelling and numerical simulations, and studying the electron beam dynamics inside the plasma as well as in the development and operation of plasma diagnostics.

The expertise of the unit of beam physics at “La Sapienza” is supported by international long-standing collaborations with groups having strong experience in accelerator physics within EU as well as in the US.

University of Rome “La Sapienza” is contributing to all SPARC_LAB experiments ranging from conventional applications of high brightness beams (FEL or Compton sources) to plasma-based acceleration of high-quality beams.

Contact: Andrea Mostacci

Universität Hamburg, Germany

The Physics Department at the University of Hamburg is very active in the fields of laser and accelerator physics. Especially the group for accelerator physics, located in close proximity to DESY, has a strong link to forefront research in this field, and has been the driving force for many innovations.

The university’s group for accelerator physics is part of CFEL, the Centre for Free-Electron Laser Science, as well as LAOLA, the joint University of Hamburg / DESY laboratory for plasma-driven particle acceleration. Within LAOLA the group for plasma-driven light sources operates a 200 TW laser and two dedicated beamlines for laser-plasma acceleration. This includes experiments on undulator radiation, driven by plasma-accelerated electron beams, and the external injection of a well-defined electron beam from a conventional electron gun into a laser-driven wakefield.

Members of the Hamburg University group of accelerator physics have pioneered many aspects of laser-plasma acceleration for applications, including first experiments for plasma-driven undulator radiation in the soft x-ray range, beam transport and beam characterization.

Contact: Andreas Maier

Imperial College London, UK

The Imperial College’s plasma acceleration group, which is part of the John Adams Institute for Accelerator Science has been one of the leading teams working on laser-driven plasma acceleration for more than 20 years. The team has been responsible for the development of self-injecting accelerators, and for the demonstration that wakefield accelerators can support narrow energy spread beams. The group has also made significant contributions in the scaling of plasma accelerators to the high-energy frontier and for advanced diagnosis of laser wakefield interactions and also in advancing plasma targetry. A particular recent emphasis has been on the use of laser-plasma accelerators as a source of high-quality radiation for advanced applications such as medical imaging.

As part of EuPRAXIA, the Imperial College team extends their work on scaling laser wakefield accelerators to the high-energy frontier through theoretical / simulation work that will be tied to the extensive experimental program that runs concurrently at Imperial College. This work informs the EuPRAXIA project on the requirements in terms of laser and plasma targetry for future European laser wakefield facilities.

Contact: Zulfikar Najmudin

University of Oxford, UK

The laser plasma acceleration group at Oxford University, is a part of the John Adams Institute for Accelerator Science. Its researchers have pioneered the development of plasma channels for high-intensity laser pulses, and their applications to LWFA, which enabled the generation of GeV beams from a laser-plasma accelerator for the first time. They have also contributed to the development of soft x-radiation sources, novel approaches for controlling electron injection, and the development of new diagnostics. The group is currently working on the prospect of driving the wakefield by a train of low-energy laser pulses, rather than a single high-energy pulse; this opens plasma accelerators to new types of laser technology, such as ultrafast fiber lasers or disk lasers, and offers a route to achieving efficient operation at multi-kilohertz pulse repetition rates.

As part of EuPRAXIA, the Oxford University team works on developing the plasma accelerating structure, methods for controlling electron injection, and the design of the 'high-energy physics and other applications' beamlines and user areas.

Contact: Roman Walczak

QUANTUM LEAP TO A NEW GENERATION OF PARTICLE ACCELERATORS

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(October 2016)

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2. **Tsinghua University Beijing,** China
3. **ELI – Extreme Light Infrastructure – Beamlines,** International
4. **PhLAM – Laboratoire de Physique des Lasers Atomes et Molécules, Université de Lille 1,** France
5. **Helmholtz-Institut Jena,** Germany
6. **Helmholtz-Zentrum Dresden-Rossendorf,** Germany
7. **Ludwig-Maximilians-Universität München,** Germany
8. **Wigner Fizikai Kutatóközpont,** Hungary
9. **CERN – European Organization for Nuclear Research,** International
10. **Kansai Photon Science Institute/Japan Atomic Energy Agency,** Japan
11. **Osaka University,** Japan
12. **RIKEN SPring-8 Center,** Japan
13. **Lunds Universitet,** Sweden
14. **CASE – Center for Accelerator Science and Education at Stony Brook University and Brookhaven National Laboratory,** USA
15. **LBLN – Lawrence Berkeley National Laboratory,** USA
16. **UCLA – University of California Los Angeles,** USA
17. **KIT – Karlsruher Institut für Technologie,** Germany
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ACCELERATOR INNOVATION FOR NEW HORIZONS IN SCIENCE
SMALLER SIZE AND IMPROVED COST-EFFICIENCY

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