18. December 2018

The EuPRAXIA Research Infrastructure: A Required Intermediate Step Towards Plasma Accelerators for the Energy Frontier

Abstract

The EU Horizon2020 program funded the EuPRAXIA design study in 2015. The project is coordinated by DESY and by now has 41 participating institutes from Europe, Asia and the US. It will deliver a conceptual design report in October 2019. EuPRAXIA aims at the construction of an innovative linear electron accelerator based on plasma acceleration technology. This machine will have an accelerating field of 50 GV/m, a final electron beam energy of 1 to 5 GeV, significantly improved beam quality, various user applications and demonstrated benefits in size and cost when compared to RF technology. The improved beam quality and the ultra-high accelerating fields will be achieved by combining cutting-edge plasma accelerator technology, high power lasers from European industry, modern RF technology (including X-band from CERN) and latest diagnostics and instrumentation. EuPRAXIA is designed to fully develop a 5 GeV plasma accelerator module to user readiness. It is the required intermediate step to a plasma based linear collider that would then combine many such modules. We propose that the next European Strategy for Particle Physics should explicitly list ultra-high gradient plasma acceleration and, if possible, the EuPRAXIA project as essential R&D towards a compact alternative for future colliders.

Contact: Ralph Assmann (ralph.assmann@desy.de)

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Statement from the Horizon2020 Design Study for a
"European Plasma Research Accelerator with eXcellence In Applications"
(EuPRAXIA)
to the European Strategy Preparatory Group (ESPG)

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The EuPRAXIA Consortium

The EuPRAXIA Consortium is a EU funded Horizon2020 Conceptual Design Study that develops the concept of a "**Eu**ropean **P**lasma **R**esearch **A**ccelerator with e**X**cellence **I**n **A**pplications" [1]. **It serves as an open innovation platform that brings together 16 participants and 25 associated partners from Europe, Asia and the US**. Among the 41 members of the consortium are international organizations, major national laboratories and universities, therefore combining interdisciplinary excellence from particle accelerators, laser science, plasma physics, theory, simulations and accelerator-based user facilities.

EuPRAXIA is the **first European project that develops a dedicated accelerator research infrastructure based on novel plasma concepts and laser technology**. It keeps a strict focus on the development of particle accelerators, their user communities and on the exploitation of existing accelerator infrastructures in Germany, Italy, France and UK. The laser community, in particular the Extreme Light Infrastructure (ELI) and its new laser infrastructures, are connected as associated partners, ensuring complementarity and full knowledge exchange.

The EuPRAXIA work is organized in **15 work packages**, each led by two senior scientists from European institutes. The EuPRAXIA Consortium connects to **representatives from leading European laser companies** through its scientific advisory board and its laser work package. Industry experts from Thales, Amplitude Technologies and Trumpf Scientific are in this way directly contributing to the project.

Technical and Scientific Goals

The EuPRAXIA project aims at the **construction of an innovative plasma-based electron accelerator with a beam energy of 1 to 5 GeV, a significantly improved beam quality and demonstrated benefits in size and cost when compared to RF technology**.

The EuPRAXIA facility with its improved electron beam quality will establish user-readiness and will **deliver electron beams and photons to users as a first demonstrator of this new technology.** The EuPRAXIA energy range and its performance goals will enable versatile applications in various domains, e.g. a compact FEL, compact medical imaging, a compact positron source, table-top test beams for particle detectors and highly mobile but deeply penetrating X-ray sources for material testing. **EuPRAXIA will demonstrate a high-quality plasma accelerator module and is therefore the required stepping stone to possible plasma-based linear colliders** at the high-energy physics (HEP) energy frontier, which would combine many modules.

In more detail, the EuPRAXIA scientific and technical goals include:

- Achievement of **single- and multi-stage acceleration of electron beams** to final energies between 1 and 5 GeV, with pulse duration of a few femto-seconds, with transverse emittance of about 1 mm-mrad and with relative energy spread reaching from a few % down to a few 10^{-3} total and few 10^{-4} in a 1 micrometer slice of the beam. The EuPRAXIA specifications approach the regime of modern free-electron lasers (FELs), open various application paths and do also fulfill basic requirements for a 5 GeV plasma accelerator stage of a linear collider.
- Implementation of a **highly compact machine layout**, initially realizing at least a factor 3 gain in required floor space for the accelerator. This includes all required components and infrastructure. EuPRAXIA implements a realistic, step-wise strategy of miniaturization towards a factor 10 gain and beyond.
- Development and construction **of new generations of petawatt-scale pulsed lasers** as drivers for plasma wakefields, together with industry and laser institutes. These lasers will operate with high stability at 20 Hz and later at 100 Hz, therefore enabling laser-based and beam-based fast feedbacks. The improved feedback efficiency with increased repetition rates will allow much better pulse-to-pulse stability.
- Development and construction of **a compact beam driver based on X-band RF technology from CERN**. The EuPRAXIA X-band linac will be the RF linear accelerator with the highest acceleration per meter worldwide.
- **Development and construction of distributed and versatile user areas** that exploit the inherent advantageous features of the plasma accelerator, namely:
    - the possibility of **massively parallel user lines** for laser-driven accelerators
    - the generation of **ultra-fast electron and photon pulses** with naturally short pulse lengths
    - the **quasi-point-like emission of X-rays** inside plasmas with the potential for ultra-sharp imaging
    - unique pump probe configurations with the **synchronized EuPRAXIA particle and laser beams**.

The EuPRAXIA Consortium has developed and published since 2015 a number of concepts that describe novel solutions for improved beam quality and will allow reaching these goals.

Societal Goals

The EuPRAXIA project will serve society in a number of ways:

- The broad and interdisciplinary EuPRAXIA Collaboration in Europe and with international partners will create a critical mass of expertise and capabilities in Europe. It will **defend and further position Europe as a clear worldwide leader in accelerator innovation**.

- The expertise in ultra-high gradient particle accelerators that would be fostered by a EuPRAXIA infrastructure has the potential to pave the way towards new discovery machines that are **more compact and more affordable**. These machines could on the long term **create discovery reach into beam energies and physics territory which are not accessible today**.
- The EuPRAXIA project will challenge and support the European and worldwide laser industry to further develop and improve their products on high power pulsed lasers. This will **strengthen laser industry overall but in particular also enable the European laser companies to stay world-leading** in a fair and competitive effort.
- New generations of scientists and technicians in the EU will be exposed to innovative and highly challenging technical and intellectual problems in centrally located and well-integrated R&D facilities. The proximity to major metropolitan areas in the EU will amplify the capability of EuPRAXIA to **fascinate young generations for science and technology, to foster innovative "out-of-the-box" thinking, to serve as a high-tech training base and to strengthen the job base for technical work**.
- A compact particle accelerator product as a result of the EuPRAXIA project could **make accelerators available as versatile tools to new users and in new locations**, e.g. laboratory spaces at university, hospitals, mobile platforms, and beyond. This would multiply access to accelerators and could create major advances in knowledge and capabilities, some of them yet unimaginable. We can, for example, foresee that ultra-fast X-ray pulses from compact accelerators could serve tens of thousands of PhD students and post-docs to scan features of the many million types of viruses and bacteria, materials and medical compounds. The most promising cases would then be studied further and with more accuracy in big science facilities.

Tentative EuPRAXIA Schedule

The following project steps are foreseen for EuPRAXIA, provided that sufficient funding for this new European research infrastructure can be obtained:

October 2019	Publication of Conceptual Design Report for EuPRAXIA (funded by EU Horizon2020 grant).
2020 – 2025	Technical design and prototyping phase, in industry and research institutes following the open innovation approach.
2021	Project aim: EuPRAXIA on the ESFRI roadmap.
2026 – 2029	Implementation and construction.
2030 – 2065	Operation.

The project schedule could be accelerated in case that a sufficient level of funding for an accelerated program can be quickly identified.

References

[1] Horizon2020 EU Design Study for a European Research Plasma Accelerator with eXcellence In Applications (EuPRAXIA), coordinated by DESY (R. Assmann et al), a consortium of 41 institutes, http://www.eupraxia-project.eu

Official Acknowledgement

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List of EuPRAXIA Institutes and Steering Committee

EuPRAXIA is a collaboration of ***16 partners****, Deutsches Elektronen Synchrotron (DESY), Istituto Nazionale di Fisica Nucleare (INFN), Consiglio Nazionale delle Ricerche (CNR), Centre National de la Recherche Scientifique (CNRS), University of Strathclyde (USTRATH), Instituto Superior Técnico (IST-ID), Science & Technology Facilities Council (STFC), Synchrotron Soleil (SOLEIL), University of Manchester (UMAN), University of Liverpool (ULIV), Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenible (ENEA), Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA), Università di Roma "La Sapienza" (UROM), Universität Hamburg (UHH), Imperial College London (ICL), University of Oxford (UOXF) and* ***25 asscociated partners****, Shanghai Jiao Tong-University , Tsinghua University Beijing, Extreme Light Infrastructure – Beamlines, Laboratoire de Physique des Lasers Atomes et Molécules Université de Lille 1, Helmholtz Institut Jena, Helmholtz-Zentrum Dresden-Rossendorf, Ludwig-Maximilians-Universität München, Wigner Research Centre of the Hungarian Academy of Science, European Organization for Nuclear Research, Kansai Photon Science Institute, Japan Atomic Energy Agency, Osaka University, RIKEN SPring-8 Center, Lunds Universitet, Center for Accelerator Science and Education at Stony Brook University and Brookhaven National Laboratory, Lawrence Berkeley National Laboratory, University of California Los Angeles, Karlsruher Institut für Technologie, Forschungszentrum Jülich, Hebrew University of Jerusalem, Institute of Applied Physics of the Russian Academy of Science, Joint Institute for High Temperatures of the Russian Academy of Sciences, Università degli Studi di Roma "Tor Vergata", Queen's University Belfast, Ferdinand-Braun-Institut, York University.*

The ***Steering Committee*** *is composed of Ralph Assmann (DESY), Antoine Chance (CEA), Enrica Chiadroni (INFN), Alessandro Cianchi (UTV), Marie-Emmanuelle Couprie (SOLEIL), Brigitte Cros (CNRS), Giuseppe Dattoli and Federico Nguyen (ENEA), Alberto de la Ossa (DESY), Nicolas Delerue (CNRS), Ulrich Dorda (DESY), Massimo Ferrario (INFN), Leonida Antonio Gizzi (CNR), Bernhard Hidding (USTRATH), Dino Jaroszynski (USTRATH), Andreas Maier (UHH), Victor Malka (CNRS), François Mathieu (CNRS), Andrea Mostacci (UROM), Zulfikar Najmudin (ICL), Phi Nghiem (CEA), Jens Osterhoff (DESY), Rajeev Pattathil (STFC), Zhengming Sheng (USTRATH), Luís Oliveira Silva (IST-ID), Arnd Specka (CNRS), Roman Walczak (UOXF), Carsten Welsch (ULIV), and Guoxing Xia (UMAN).*

More details can be found at: http://www.eupraxia-project.eu