Letter of Intend for Snowmass ‘21

EuPRAXIA – A Concept for a Research Infrastructure based on Plasma Accelerators and First user Applications

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Summary

The concept of the EuPRAXIA Research Infrastructure has been defined in its Conceptual Design Report (CDR), which is available at

http://www.eupraxia-project.eu/eupraxia-conceptual-design-report.html

and provides a technical description, start-to-end simulation results, performance estimates and other details. The EuPRAXIA project aims at the construction of an innovative electron accelerator using laser- and electron-beam-driven plasma wakefield acceleration that offers a significant reduction in size and possible savings in cost over current state-of-the-art radiofrequency (RF)-based accelerators. EuPRAXIA envisions a beam energy of 1 to 5 GeV and a beam quality (single pulse) equivalent to present RF-based linacs. EuPRAXIA will demonstrate high-quality beam generation from a plasma-accelerator module and several applications of high societal importance at its energy regime. It is therefore one of the required stepping stones to possible future plasma-based facilities, such as linear colliders at the high-energy physics (HEP) energy frontier, that would combine many plasma acceleration stages. Implementation measures have been advanced with a site at the Frascati National Accelerator Laboratory in Italy confirmed, partial funding secured and an application to the ESFRI roadmap in Europe well advanced. EuPRAXIA is supported by a Consortium of 40 member institutes and 11 observers, including national accelerator labs and leading institutes and industry.

EuPRAXIA Concept and Goals

The worldwide interest in plasma-based electron accelerators is driven by the need of a new technology to overcome the multi-TeV barrier for particle accelerators and the desire to make electron-beam and associated radiation facilities (FELs, synchrotrons, etc.) available to a larger user base. Advancing into the next generation of light sources, such a facility must realise excellent beam quality and high repetition rate, but also demonstrate a clear size and cost reduction to fully harvest the scientific and commercial prospects. EuPRAXIA aims in a realistic and stepwise approach at realising the first laser plasma user facility worldwide, demonstrating feasibility and gaining operational and user experience.

The EuPRAXIA energy range and its performance goals will enable versatile applications in various domains, e.g. as a compact free-electron laser (FEL), compact sources for medical imaging and positron generation, tabletop test beams for particle detectors, as well as deeply penetrating X-ray and gamma-ray sources for material testing. Consistent with a high-confidence approach, the EuPRAXIA project includes measures to retire risk by establishing scaled technology demonstrators. The EuPRAXIA facility will integrate lessons learned and establish user readiness by 2030.

Initial system designs have been developed using start-to-end simulations to achieve the single- and multi-stage acceleration of electron beams, predicting a quality much superior to present state-of-the-art plasma acceleration experiments. In some parameters, a factor 10 improvement is predicted. At the same time, the design initially realises at least a factor 6 gain in required floor space for the accelerator if compared to existing accelerator facilities. This includes the accelerator system itself and its support infrastructure. A final gain of a factor 10 and more for the accelerator-only footprint – with sufficient electron beam quality and control – seems achievable in a phased approach.

The development and construction of new generations of pulsed lasers with petawatt peak power as drivers for plasma wakefield accelerators will be performed jointly with industry and national laboratories specialised in energetic laser development. These lasers will operate with high stability at 20 to 100 Hz, a modest advancement of a factor 2 to 10 over the current state of the art. In parallel, focused R&D activities will be pursued on the rapid development of laser systems that can operate at kHz repetition rates and deliver peak-power levels at 100 TW or more. The parallel development is envisioned to facilitate innovation in high-repetition-rate plasma-accelerator technology, enabling additional applications and science reach while maintaining the 100 Hz laser systems as a project baseline for a risk-balanced approach.

Finally, EuPRAXIA also includes the development and construction of a compact X-band RF accelerator based on technology from CERN to realise a beam-driven plasma accelerator. Such an X-band linear accelerator will exploit the capabilities with the most compact RF technology available today and provide an excellent science test facility with a complementary technological approach that decouples the plasma accelerator from laser science.

Distributed and versatile user areas will be set up to exploit the inherent advantageous features of the plasma accelerator, for example multiple 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, and unique pump-probe configurations with the synchronised EuPRAXIA particle and laser beams. Performance goals are discussed in the next section.

The EuPRAXIA infrastructure is implemented through several components: clusters, excellence centres, and construction site(s). Clusters of European institutes collaborate jointly to address well-defined challenges and guide the overall R&D and design of the project. This is complemented by EuPRAXIA centres of excellence at existing large infrastructures, such as in Hamburg (DESY - Germany), in the Orsay-Saclay area (France), in Lisbon (IST - Portugal), in the UK (CLF and SCAPA), and at ELI Beamlines (Czech Republic). The centres of excellence perform mission-critical R&D, prototyping, testing, and construction tasks bringing in and upgrading their existing infrastructures and delivering fully tested components to the EuPRAXIA construction site(s). As a central component to the infrastructure concept, one or two construction sites will host new large research facilities, exploiting beam-driven (BPA) and laser-driven plasma-accelerator (LPA) technology. At these construction site(s), the consortium will set up several plasma-accelerator beamlines realising complementary technologies and applications and providing pilot access to academic and industrial users once target parameters have been reached. INFN - Frascati (Italy) has been agreed as the construction site for a beam-driven plasma accelerator facility and will include user areas for four applications: a free-electron laser, a gamma-ray source based on inverse Compton scattering, a GeV-class positron source and a high-energy physics detector test area. It is ready to proceed and will be realised in the first phase of the project. For the laser-driven construction site, four different applications with user areas have been foreseen: a free-electron laser, an ultra compact low-energy positron source, a table-top test beam area and a betatron X-ray source. A strong concept has been developed at this stage for the site, and multiple candidate sites have been identified based on the varied research landscape for laser-driven plasma acceleration already existing across Europe. A site decision for the construction of the laser-driven plasma accelerator will be taken during the Preparatory Phase of EuPRAXIA.

The full-scale EuPRAXIA implementation is a European project with strong international ties that realises a major competitive advantage, strong scientific impact, and important societal benefits. Proceeding at full speed, we estimate that the EuPRAXIA research infrastructure would start full operation in 8 - 10 years. Parts of EuPRAXIA, in particular the beam-driven construction site in Italy, could go into operation at significantly earlier times.

Bibliography

R. Assmann, M. Weikum (eds), et al, “EuPRAXIA Conceptual Design Report”. Accepted for publication at Eur. Phys. Journal Special Topics.

See detailed and full list of references on EuPRAXIA work and relevant literature in the CDR. The CDR is also available for download at http://www.eupraxia-project.eu/eupraxia-conceptual-design-report.html