ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPGW025

FACILITY CONSIDERATIONS FOR A EUROPEAN PLASMA ACCELERATOR INFRASTUCTURE (EuPRAXIA)*

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Abstract

EuPRAXIA (European Plasma Research Accelerator with eXcellence In Applications) is a conceptual design study for a compact European infrastructure with 5 GeV electron beams based on plasma accelerators [1-3]. The concept foresees two main construction sites, one at INFN in Frascati, Italy and one at DESY in Hamburg, Germany. Four centres of excellence in Portugal, France, the United Kingdom, and the Czech Republic, will support both construction sites. In Frascati, an RF injector based on S-band and X-band technology will be used while at DESY, an RF injector based on S-band technology or alternatively a laser plasma injector (LPA) will be used before the beam is transported into the plasma accelerator. A single-stage laser plasma accelerator (LPA) will also be used to reach the 5 GeV target energy. User areas will provide access to FEL pilot experiments, positron generation, compact radiation sources, and test beams for HEP detector development.

INTRODUCTION

The pan-European approach of EuPRAXIA [4] foresees six different centres of excellence across the continent. Two main construction and experimental sites - one at INFN in Frascati, Italy, and one at DESY in Hamburg, Germany – will be complemented by four centers of excellence in France, Portugal, the United Kingdom, and the Czech Republic (Figure 1). The excellence center in France will focus on lasers and FEL radiation, Portugal will focus on simulations studies, the UK will specialize in application beamlines, and the Czech Republic is planned as an incubator for laser technology. User areas will provide access to free-electron laser (FEL) pilot experiments, positron generation, test beams for high energy physics (HEP) detector development, and compact radiation sources, such as Thompson radiation and betatron sources.

RF AND PLASMA TECHNOLOGY

Figure 2 provides an overview of the different technical setups considered for EuPRAXIA. Both particle-driven and laser-driven plasma acceleration will be explored to

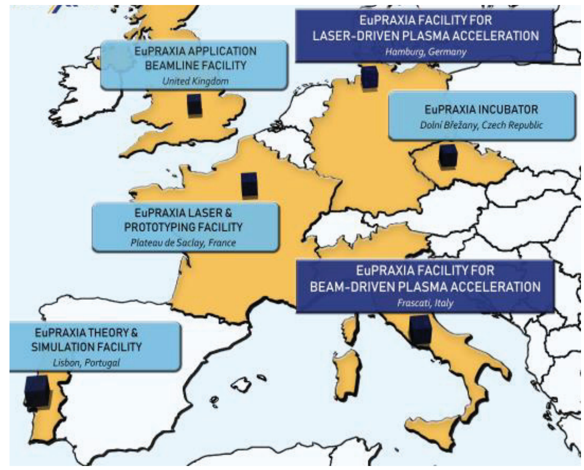

Figure 1: Map of the six European countries in which main construction and experimental sites (Italy, Germany) and centers of excellence (France, Portugal, the UK, and Czech Republic) will be housed.

reach a final electron energy of 5 GeV. In Frascati, a radio frequency (RF) injector based on S-band and X-band technology (with electron energy up to 1 GeV [5-8]) will be constructed and used as a drive beam for particle-driven plasma wakefield acceleration (Figure 2e). DESY will implement both external and internal injection LWFA mechanisms. In the former, an RF injector based on S-band technology (with electron energy up to 250 MeV [9,10]) will be employed before the beam is injected into the final laser plasma accelerator (LPA) stage (Figure 2c and d). As an alternative to the RF injector, a plasma injector (with electron energy up to 150 MeV [11]) can be used (Figure 2b). A single-stage LPA will also be built alongside the staged approach to reach the 5 GeV energy target (Figure 2a). The hybrid option (Figure 2f), in which an LPA produces an electron beam, which in turn is used to drive a PWFA stage, can be implemented in both sites [12]. Each country involved in EuPRAXIA will have a particular specialization within the project. A centre for FEL research will be based in France, which will also coordinate the development of laser technology for the EuPRAXIA laser together with the European laser industry [13].

* This work was supported by the European Union's Horizon 2020 Research and Innovation programme under grant agreement No. 653782.
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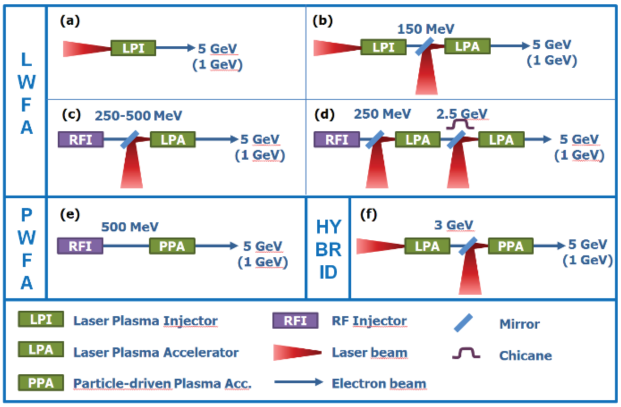

Figure 2: Overview of the injection and acceleration methods considered in EuPRAXIA. (a) LWFA with internal injection. (b/c) LWFA with external injection from a laser plasma/ or RF injector. (d) LWFA with external injection from an RF injector with two LPAs. (e) Particle-driven plasma accelerator. (f) Hybrid approach using an laser- and beam-driven plasma accelerator stage [14].

The laser design has been finalized and encompasses a titanium sapphire technology system with diode-pumped solid-state lasers. Laser pulse energies of 5 J, 15 J and 50 J will be available for different acceleration stages [13].

The theory and plasma simulation centre will be located in Portugal, building on a long tradition of excellent simulation work at the Instituto Superior Técnico (IST) in Lisbon. So far, many of the simulations for the EuPRAXIA design study have used codes developed by IST, and Lisbon will lead on EuPRAXIA's future simulation efforts.

Figure 3: Overview of the preliminary structure of technical clusters in EuPRAXIA.

The application beamlines will be coordinated by a centre in the UK. In the beginning, each experimental site in Germany and Italy will focus on three main applications: Both sites at DESY and INFN plan to offer pilot experiments using FEL radiation as well as positron generation. While DESY focuses on creating ultra-compact positron beam sources and table-top test beams, INFN will specialise in generating GeV-class positron beams and provide them for HEP detector test stands. The third specialisation is different: INFN will build a compact Compton source, while DESY focuses on medical imaging using X-rays generated as betatron radiation. All these initial application foci are rooted in experience on-site and therefore complement the laboratory environments at both INFN and DESY.

To coordinate the technical work necessary for these different sites in a more centralised way, especially during the final design stage, a set of technical clusters will be set up, as shown in Fig. 3. Bringing together groups of consortium partner institutes working on specific topics or components, this structure will ensure minimum duplication of work. Diagnostics work both for the electron beam, the laser, the plasma structures, and the radiation produced will also be coordinated via a cluster [15].

Table 1: Parameters of the Laser Plasma Injector, the RF Injectors and the Final Beam

Parameter	LP injector	RF injector	Accel-erator
Energy (GeV)	0.150	0.28-0.5	5 (1)
Charge (pC)	30	30	30
Bunch length$_{FWHM}$ (fs)	10	10	10
RMS en.spread (%)	5	0.2	1
RMS emittance (μm)	1	1	1

FACILITY LAYOUT

Figure 4 shows how these different technical options flow into the current version of the facility layout for the two main construction sites at DESY and INFN. At the Italian facility two beamlines are foreseen, both fed by the same RF accelerator. With the FEL operation and the inverse Compton scattering interaction having similar use the beam from a plasma accelerator stage focused on preserving the initial high electron bunch quality of the RF injector. For positron generation, on the other hand, high charge is a more dominant criterion thus warranting a separate beamline that can be optimized in this regard. As the HEP detector test beam application will require only a small number of electrons, these can be taken from the remaining electron beam leaving the converter in the positron stage, thus providing a complementary application to the latter.

For the German construction site focused on laser-driven plasma acceleration, a similar layout is proposed. To push the compact size as a strong advantage of the low-energy positron source at EuPRAXIA and considering its comparably lower electron beam quality requirements, an all-optical accelerator setup is foreseen for this beamline. For the FEL-line, the baseline plans an external injection setup with an RF injector to ensure best beam quality. Other schemes, such as a single, high-energy plasma injector stage or a hybrid setup, as described above, are considered as options to implement in the layout over time; thanks to the compact size of individual plasma stages, this can be achieved with little or no extra cost in the shown baseline setup. Finally, the DESY site includes a third, all-plasma-based beamline optimized for

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betatron radiation generation for imaging experiments and other possible applications.

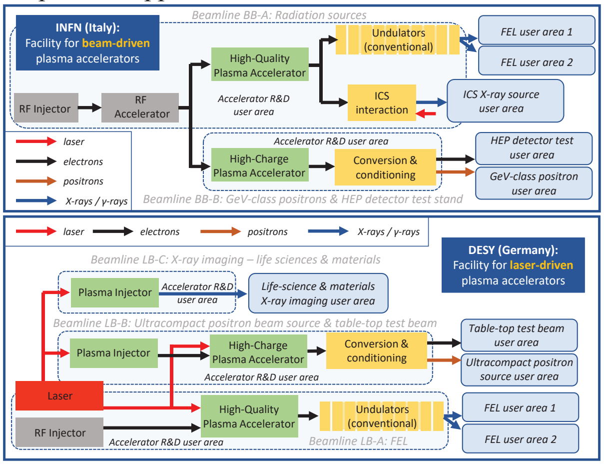

Figure 4: Simplified layout of the two EuPRAXIA construction sites in Italy (top) and Germany (bottom). Both electron beam requirements, including low energy spread and emittance, they are based on the same beamline and beam-driven and laser-beam driven cases are possible at both sites.

A relevant feature in both layouts is the presence of accelerator R&D user sections along the beamlines additionally to the more classical user areas. With the EuPRAXIA infrastructure designed as a demonstrator facility for plasma acceleration and its applications, an essential user group is expected to include those interested in improving plasma accelerator concepts and investigating new ones. These dedicated accelerator R&D areas will allow such users to test their research and its applicability directly (with constraints) within a user machine.

CONCLUSION

Based on this layout, EuPRAXIA aims to achieve a size reduction in comparison to conventionally accelerated beams by a factor between two and four depending on the beam energy. A significant factor in this context is the decreased accelerator length, whereas the undulator, photon beamline and user areas are not planned to be minimised at this stage. Finally, throughout the lifetime of EuPRAXIA, it is planned to reduce the facility size further, up to a factor of 10 and beyond, through additional improvements as well as the step-wise implementation of more compact, novel beam transport, diagnostics and other key components.

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