THE EuPRAXIA FILES

ISSUE 18 – June 2026

Supported by PACRI

FOREWORD

A new issue of The EuPRAXIA Files is presented here, bringing together a selection of recent publications relevant to plasma accelerators, lasers, accelerator science, and the enabling technologies that support EuPRAXIA and PACRI.

The EuPRAXIA Consortium is continuing its work towards the implementation of the two main sites at Frascati, hosted by INFN, and Prague, hosted by ELI-ERIC, alongside the wider development of the EuPRAXIA network for future user access.

Since its inclusion in the ESFRI Roadmap in 2021, EuPRAXIA has entered a crucial phase of development. Over the coming years, the collaboration will work towards the establishment of a sustainable governance model, the creation of a legal entity, the preparation of a long-term scientific programme, and the launch of user operations.

This issue highlights recent work that supports those goals, from plasma-accelerator physics and beam transport to compact FELs, plasma sources, diagnostics, optimisation, and emerging applications.

I would like to thank Joe and Debdeep for preparing this issue, and I wish you an interesting read.

Pierluigi Campana

CONTENTS

FOREWORD 1
SPECIAL FEATURE 2
FUNDAMENTALS 3
CONTROL & OPTIMIZATION 4
TECHNOLOGY 7
BEAMLINES & APPLICATIONS 10
THEORY & SIMULATION 12

SPECIAL FEATURE

EuPRAXIA@SPARC_LAB Technical Design Report

D. Alesini, M. P. Anania, F. Anelli, A. Bacci, S. Bini, M. Bellaveglia, et al.
INFN Open Access Repository, INFN-2026-01-LNF (FEB 5 2026)
https://doi.org/10.15161/oar.it/k57qz-5qk09

The purpose of the EuPRAXIA@SPARC_LAB User Facility is to establish a research infrastructure that pioneers the use of Plasma Wake-Field Acceleration (PWFA) for driving a high-brightness Free-Electron Laser (FEL) user facility in the soft X-ray regime. As one of the two core pillars of the pan-European Plasma Research Accelerator with eXcellence In Applications (EuPRAXIA) Research Infrastructure, EuPRAXIA@SPARC_LAB will be hosted at the INFN Frascati National Laboratory (LNF) serving both as a cutting-edge scientific facility for users and as a technological demonstrator. It will validate the integration of high-gradient plasma acceleration and X-band RF technology within a compact FEL light source, laying the groundwork for future compact user facilities. This will improve their sustainability by significantly reducing the size, energy consumption, and operational costs typically associated with conventional accelerator-based FEL light sources, making advanced photon science more accessible and environmentally responsible in the long term. The user facility is expected to begin operations in 2031. Its first user beamline, AQUA, will deliver ultrashort femtosecond soft X-ray pulses within the biologically relevant "water window" spectrum, enabling real-time imaging, advanced materials development, and investigation of chemical processes with unprecedented spatial and temporal resolution. By transitioning plasma-based accelerators from proof-of-concept to operational systems and validating them under real user facility conditions, EuPRAXIA@SPARC_LAB closes a critical gap in the Technology Readiness Level (TRL) chain (from the current TRL ≈ 5 to the final TRL > 7). This will position Europe at the forefront of global innovation in compact accelerators and strengthen its capacity to lead future high-energy physics, photon science, and interdisciplinary research programs. The inclusion in the European Strategy Forum on Research Infrastructures (ESFRI) roadmap since 2021 marks the strategic importance of the project at the European level. The realization of the facility entails the construction of new buildings to host the accelerator systems, experimental halls, and support laboratories. This new infrastructure, to be built within the INFN LNF site, represents the project's first significant step and challenge. From the outset, the design and construction will prioritize incorporating energy-efficient solutions, environmentally responsible materials, and infrastructure choices aligned with long-term ecological and operational resilience.

The Technical Design Report (TDR) for the EuPRAXIA@SPARC_LAB facility presents a comprehensive technical reference for the construction and scientific exploitation of the user facility. The TDR is structured to:

- Define the scientific and technological objectives of the facility (this Executive Summary);
- Outline the scientific cases and user applications (Chapter 2);
- Demonstrate feasibility through simulations and design studies (Chapter 3);
- Deliver a technical description of the facility and its components including technical readiness and potential risks evaluation (Chapters 4-21);
- Support funding efforts and stakeholder engagement (Chapter 22).

This Executive Summary aims to define the scientific and technological objectives of the facility and to provide a concise overview of the full TDR, tailored for funding agencies, institutional stakeholders, and expert reviewers. It distills the key content into an accessible format that emphasizes the facility's maturity, technical feasibility, and scientific relevance. The summary is also intended to support informed decision-making and alignment with European research priorities and funding instruments, particularly those related to ESFRI and Horizon Europe.

FUNDAMENTALS

Bright electron bunches from a plasma-wakefield accelerator with a steep density down-ramp

J. C. Wood, L. Boulton, J. Beinortaite, J. Bjorklund Svensson, S. Bohlen, G. Boyle, J. M. Garland, P. Gonzalez Caminal, C. A. Lindstrom, G. Loisch, S. M. Mewes, T. Parikh, F. Pena Asmus, K. Poder, S. Schroder, M. Thevenet, S. Wesch, J. Osterhoff, and R. D'Arcy
NATURE COMMUNICATIONS 17, 1588 (FEB 11 2026)
https://doi.org/10.1038/s41467-026-69283-6

High-brightness electron bunches drive fundamental research in particle physics and photon science. Key to achieving a high brightness is to have a low transverse emittance, which ensures that the bunch can be tightly focussed. In radiofrequency accelerators a low initial emittance can be rapidly degraded due to space charge forces, which are greatly diminished once the electron bunch attains a relativistic velocity. A plasma accelerator can maintain orders-of-magnitude higher accelerating fields than radiofrequency accelerators, while multiple techniques exist to create a low emittance electron bunch directly inside the plasma accelerator structure. Plasma accelerators therefore offer a possibility to create high-brightness bunches in wakefields driven even by low-quality drive bunches. Here we demonstrate the injection and gigavolt-per-metre acceleration of electron bunches with mm-mrad normalised emittance, O(10 pC/MeV) spectral density and per-cent-level energy spread, all with excellent reproducibility.

First electron acceleration in a tunable-velocity laser wakefield

A. Liberman, A. Golovanov, S. Smartsev, A.-M. Talposi, S. Tata, and V. Malka
PHYSICAL REVIEW RESEARCH 8, L022001 (APR 1 2026)
https://doi.org/10.1103/x5pr-mdvj

We present the first experimental confirmation that a laser-wakefield accelerator produced by a flying focus pulse is able to maintain the coherent structures necessary to accelerate electrons to relativistic energies. Through a combination of spatio-temporal near-field shaping of the beam and focusing with an axiparabola - a long-focal-depth mirror that produces a quasi-Bessel beam - the propagation velocity of the wakefield is tuned to control the maximum electron energy achievable. The experimental data are supported by advanced optical and particle-in-cell simulations and are aligned with a simplified analytical model. Together, the results significantly strengthen the case for the flying-focus wakefield as a strategy for mitigating dephasing in laser-wakefield acceleration.

Tailored laser wakefield acceleration for decaying particles

C. Badiali, R. Almeida, B. Malaca, R. A. Fonseca, T. Silva, and J. Vieira
PHYSICAL REVIEW RESEARCH 8, 023077 (APR 27 2026)
https://doi.org/10.1103/1pp8-qx35

We introduce a plasma wakefield acceleration scheme capable of boosting initially subrelativistic particles to relativistic velocities within millimeter-scale distances. A subluminal light pulse drives a wake whose velocity is continuously matched to the beam speed through a tailored plasma density, thereby extending the dephasing length. We develop a theoretical model that is generalizable across particle mass, initial velocity, and the particular accelerating bucket being used, and we verify its accuracy with particle-in-cell simulations using laser drivers with energies in the joule range.

Asymmetric self-injection of electrons in a laser wakefield accelerator via localized laser redshifting

Z. Lecz, A. Hughes, A. A. J. Ajam, J. Hills, L. Forrester, S. Majorosi, D. Papp, T. Lucza, K. Nacsa, K. Nelissen, M. Kiss, M. Kalashnikov, L. Lejotai, V. Pajer, N. Csernus-Lukács, J. Bohus, R. S. Nagymihály, Z. Najmudin, C. Kamperidis, and N. A. M. Hafz

PHYSICAL REVIEW RESEARCH 8, 023080 (APR 27 2026)

https://doi.org/10.1103/q9m2-czfl

Propagation of intense laser pulses in underdense plasma always involves nonlinear evolution of the laser envelope, which leads to large deviations from the initial Gaussian intensity profile. The modulations in the intensity envelope have strong influence not only on the formation of the wakefield, but also in the process of electron injection; thus, it defines the final spectral and angular distribution of the accelerated electrons. Better understanding of the laser pulse evolution is crucial for the correct interpretation of the experimental results, especially in the highly relativistic regime. We developed a simple numerical tool, which adequately models the evolution of the laser envelope up to the point when the spectral broadening becomes significant. Our numerical modeling sheds light on the asymmetric wakefield generation and consequent off-axis injection of electrons, observed in experiments and particle-in-cell simulations.

CONTROL & OPTIMIZATION

ENERGY SPREAD & EMITTANCE

Self-adaptive stabilization and quality boost for electron beams from all-optical plasma wakefield accelerators

D. Campbell, T. Heinemann, A. Dickson, T. Wilson, L. Berman, M. Cerchez, S. Corde, A. Dopp, A. F. Habib, A. Irman, S. Karsch, A. Martinez de la Ossa, A. Pukhov, L. Reichwein, U. Schramm, A. Sutherland, and B. Hidding

PHYSICAL REVIEW RESEARCH 8, 013273 (MAR 10 2026)

https://doi.org/10.1103/p6ss-vgq5

Shot-to-shot fluctuations in electron beams from laser wakefield accelerators present a significant challenge for applications. Here, we show that instead of using such fluctuating beams directly, employing them to drive a plasma photocathode-based wakefield refinement stage can produce secondary electron beams with greater stability, higher quality, and improved reliability. Our simulation-based analysis reveals that drive beam jitters are compensated by both the insensitivity of beam-driven plasma wakefield acceleration, and the decoupled physics of plasma photocathode injection. While beam-driven, dephasing-free plasma wakefield acceleration mitigates energy and energy spread fluctuations, intrinsically synchronized plasma photocathode injection compensates charge and current jitters of incoming electron beams, and provides a simultaneous quality boost. Our findings suggest plasma photocathodes are ideal injectors for hybrid laser-plasma wakefield accelerators, and nurture prospects for demanding applications such as free-electron lasers.

Electron bunch optimization in laser wakefield acceleration through temporally asymmetric pulse shaping in ionization injection regime

Ravina, S. Kim, D. N. Gupta, and H. Suk
SCIENTIFIC REPORTS 16, 15019 (MAR 25 2026)
https://doi.org/10.1038/s41598-026-41795-7

In the ionization injection regime of laser wakefield acceleration (LWFA), the control and optimization of electron bunches is a major concern. We address this by demonstrating the generation of tunable electron bunches in LWFA using temporally asymmetric laser pulses in the ionization injection regime. The introduction of pulse asymmetry modifies the wakefield structure, which affects the accelerating field and electron trapping in the ionization injection regime. Our 2D PIC simulations show that fast trailing edge asymmetry of the laser pulse produces narrow electron bunches with improved energies, whereas slow trailing edge asymmetry favors prolonged injection and yields broader bunches with higher charge. These results reveal that the temporal shape of the driving laser pulse serves as a control parameter for tailoring the charge, duration, and quality of the injected electron beam. This approach offers a versatile pathway for tunable electron bunch generation in LWFA without requiring changes in plasma density or gas composition. This paves the way for the development of compact, high-brightness electron sources for advanced accelerator and radiation applications.

Ultralow-emittance electron beams from laser wakefield accelerators based on sharp density transition injection

Y. Ge, K. Feng, R. Hu, K. Jiang, H. Jiang, X. Chen, S. Luan, W. Wang, and R. Li
PLASMA PHYSICS AND CONTROLLED FUSION 68, 045036 (APR 21 2026)
https://doi.org/10.1088/1361-6587/ae5e07

We numerically investigate a scheme for generating ultralow-emittance electron beams using hydrodynamic optical-field-ionization (HOFI)-induced shock injection in laser wakefield acceleration (LWFA). A steep density down-ramp formed by the HOFI process enables electron injection at low laser amplitude a_0, reducing transverse forces and favoring longitudinal injection to minimize the beam emittance. Particle-in-cell simulations demonstrate the production of high-quality electron beams with a charge of 28 pC, an energy of approximately 350 MeV, an rms energy spread of about 3%, and a normalized projected emittance of about 80 nmrad. Unlike mechanically driven shocks commonly used in LWFA, the HOFI-induced shock exhibits superior stability, enabling precise control over the electron injection process. Moreover, because injection occurs where a_0 is relatively low and slowly varying, the scheme shows enhanced tolerance to laser energy jitter. This approach provides a promising pathway for generating high-quality electron beams suited for downstream applications such as GeV-class plasma accelerators and free-electron lasers.

STABILITY, AUTOMATION & FEL OPTIMISATION

Optimized Laser Wakefield Acceleration: Generating Stable, High-Energy, Monoenergetic Electron Beams and Demonstrating Extreme-Ultraviolet Free Electron Lasers

Z. Jin, M. Kando, Y.-J. Gu, K. Huang, N. Nakanii, I. Daito, Z. Lei, S. Sato, H. Sano, T. Muto, S. Yamamoto, and T. Hosokai

PHYSICAL REVIEW RESEARCH 8, 013207 (FEB 24 2026)
https://doi.org/10.1103/qvg7-ng8n

Free electron lasers (FELs) are powerful, tunable light sources capable of delivering ultrashort, coherent radiation over a wide spectral range, but their broad scientific and technological impact is limited by the size and cost of large-scale accelerators. Laser wakefield acceleration (LWFA) offers a compact alternative via the ultrahigh accelerating gradients, though achieving FEL gain with such beams remains a major challenge due to the stringent beam-quality requirements. Here, we present a successful demonstration of a laser-plasma accelerator-driven FEL operating at a central wavelength of 40nm with a highly nonlinear gain. A compact 0.8J laser system, combined with precise control over the plasma-density profile, injection conditions, and the stability of both laser wave front and gas jet, enabled the generation of high-quality monoenergetic electron beams with excellent shot-to-shot reproducibility. A comprehensive start-to-end simulation framework was established, incorporating beam acceleration, transport, and FEL generation. Each stage of the simulation shows good agreement with the experimental diagnostics. The resulting FEL radiation exhibits clear exponential gain of approximately 20 times. This work highlights a reliable route toward compact, tunable, x-ray FELs driven by LWFA, and represents a significant step toward practical applications of laser-plasma-based light sources.

Robustness Optimization for Compact Free-electron Laser Driven by Laser Wakefield Accelerators

H. Jiang, K. Feng, R. Hu, Q. Zhan, W. Wang, and R. Li

PHYSICAL REVIEW RESEARCH 8, 013204 (FEB 23 2026)
https://doi.org/10.1103/2mn1-6tb4

Despite the successful demonstration of compact free-electron lasers (FELs) driven by laser wakefield accelerators (LWFAs), the inherent shot-to-shot fluctuations in LWFAs, including both laser and plasma instabilities, remain a primary obstacle to realizing LWFA-driven FELs with robust operation. Here, we present a conceptual design for LWFA-driven FELs with sufficient tolerance against shot-to-shot fluctuations using the covariance matrix adaptation evolution strategy. Start-to-end simulations demonstrated that this systematic optimization resulted in a significant improvement in the robustness of FELs. With the optimized configurations, the radiation energy can be maintained above 1μJ at a wavelength of approximately 25 nm, even when accounting for twice the root-mean-square ranges of these instabilities. This proposed scheme represents a substantial advancement in the development of compact LWFA-driven FEL systems, enabling robust operation and paving the way for the realization of reliable and widely accessible sources.

Batch Bayesian optimization of attosecond betatron pulses from laser wakefield acceleration

D. Maslarova, A. Hansson, M. Luo, V. Horny, J. Ferri, I. Pusztai, and T. Fulop

COMMUNICATIONS PHYSICS 9, 92 (FEB 18 2026)
https://doi.org/10.1038/s42005-026-02542-6

Laser wakefield acceleration can generate a femtosecond-scale broadband X-ray betatron radiation pulse from electrons accelerated by an intense laser pulse in a plasma. The micrometer-scale of the source makes wakefield betatron radiation well-suited for advanced imaging techniques, including diffraction and phase-contrast imaging. Recent progress in laser technology can expand these capabilities into the attosecond regime, where the practical applications would significantly benefit from the increased energy contained within the pulse. Here we use numerical simulations combined with batch Bayesian optimization to enhance the radiation produced by an attosecond betatron source. The method enables an efficient exploration of a multi-parameter space and identifies a regime in which a plasma density spike triggers the generation of a high-charge electron beam. This results in an improvement of more than one order of magnitude in the on-axis time-averaged power within the central time containing half of the radiated energy, compared to the reference case without the density spike.

Laser field reconstruction for the modeling of laser-plasma interaction in cylindrical geometry

F. Massimo, I. Moulanier, A. Guerente, O. Khomyshyn, M. Masckala, T. L. Steyn, U. Schramm, A. Irman, and B. Cros

PHYSICAL REVIEW E 113, 055211 (MAY 14 2026)
https://doi.org/10.1103/m1lt-wz5h

High-accuracy modeling of laser-plasma interactions at high intensity requires precise knowledge of the laser field, including its asymmetries. However, the experimental characterization of such lasers is often limited to fluence measurements in transverse planes, which creates the need for a reliable field reconstruction method. In this work, we present an implementation of the Gerchberg-Saxton algorithm with mode decomposition (GSA-MD) using the Laguerre-Gauss mode basis in cylindrical geometry. We show that, for lasers with a high degree of cylindrical symmetry, this approach can be more efficient than its Cartesian counterpart. Additionally, we show how the reconstructed laser field can be more directly used as input in particle-in-cell simulations using the azimuthal Fourier decomposition through simple analytical expressions. Both versions of the GSA-MD and examples of inputs integrating the reconstructed laser in particle-in-cell simulations are made available.

TECHNOLOGY

MAGNETS

Modular quadrupole array capture line for plasma-accelerated electrons

B. D. Muratori, D. Angal-Kalinin, A. R. Bainbridge, J. Crone, C. Hill, J. Jones, H. Owen, T. Pacey, Y. Saveliev, N. Thompson, D. Symes, N. Bourgeois, O. Finlay, and N. R. Thompson

PHYSICAL REVIEW ACCELERATORS AND BEAMS 29, 054601 (MAY 7 2026)
https://doi.org/10.1103/8hns-3zqp

The UK Extreme Photonics Applications Centre (EPAC) intends to flexibly provide laser-accelerated GeV-scale electrons to a wide array of experiments and like other such facilities must efficiently capture them from a laser-wakefield acceleration (LWFA) source. Here we describe a unique, modular beam capture optics system based on a FODO array of Halbach permanent-magnet quadrupoles and show how that modular arrangement can be used in different configurations to provide energy-selected and focused bunches for different purposes. We present an engineering concept for the beamline that incorporates diagnostics and drive laser extraction and describe the effect of field errors and misalignments and their mitigation.

PLASMA SOURCES

Meter-Scale Discharge Capillaries for Plasma-Based Accelerators

L. Crincoli, R. Demitra, V. Lollo, D. Pellegrini, M. Ferrario, and A. Biagioni

APPLIED SCIENCES 16, 3291 (MAR 28 2026)
https://doi.org/10.3390/app16073291

Gas-filled discharge capillaries are widely used in the field of plasma-based particle accelerators, due to their compactness, cost-effectiveness and versatility for different applications. Technological improvement of such plasma sources is necessary to enable high energy gain acceleration at the meter scale, as required for next-generation particle colliders and light sources. Beam quality preservation within such an acceleration length involves accurate tuning of the plasma properties. In particular, precise tailoring of the plasma density distribution is required to control the emittance growth of particle bunches during the acceleration process. In this context, this paper presents a scalable and versatile approach for the design of meter-scale discharge capillaries, aimed at achieving fine tuning of the plasma density distribution, with the possibility of locally controlling the density profile by acting on the source geometry. Forty-centimeter-long capillaries are designed using numerical fluid dynamics simulations and tested in a dedicated plasma module. Different arrangements of the gas inlets are tested, with their number and diameter varied, to assess the effect of the capillary geometry on the plasma properties. Plasma density measurements show that a higher number of inlets with variable diameter along the plasma formation channel provides an enhancement in the homogeneity of the electron plasma density distribution. Longitudinal density plateaus are observed along most of the plasma channel length, with a center-to-end density uniformity of up to 80%. The experimental results highlight the proposed approach's capability to modulate the longitudinal plasma density distribution by acting on the capillary geometry, thus providing uniform density profiles over the meter scale, as required for plasma-based acceleration experiments.

Simulation-based modeling and machine learning optimization of plasma discharge capillary in LWFA systems

S. Arjmand, G. S. Mauro, A. Sciuto, A. Pidatella, A. Amato, R. Catalano, C. Manna, D. Oliva, A. D. Pappalardo, F. Vinciguerra, D. Mascali, and G. A. P. Cirrone

LASER AND PARTICLE BEAMS 44(2), 20001 (MAR 30 2026)
https://doi.org/10.3788/LPB.2026.20001

Laser-plasma accelerators (LPAs) provide a compact, high-gradient alternative to conventional accelerators, enabling applications in advanced light sources, particle physics, and medical therapies. However, the laser–plasma interaction is highly sensitive to parameters like plasma density and length, making stable operation challenging. This work examines key optimization strategies for LPAs, including plasma density tailoring to control dephasing and beam loading, capillary-based laser guiding to extend acceleration lengths, and machine learning (ML)-assisted parameter optimization. Using COMSOL Multiphysics, the discharge plasma in a gas-filled capillary was modeled and integrated with an ML-based surrogate model, enabling rapid prediction and inverse design of plasma density profiles across a two-parameter space. These strategies are

being implemented at I-LUCE, the INFN-LNS laser wakefield test-bed in Catania, Italy, to accelerate the development of robust and reproducible LPA systems.

Plasma Discharge Undulator: Concept, theory, and numerical study

A. Frazzitta
PHYSICAL REVIEW E 113, 055201 (MAY 8 2026)
https://doi.org/10.1103/g2z4-wgbn

Plasma discharge devices have recently emerged as compact and versatile tools for particle beam manipulation. Building upon the active plasma lens (APL) and its curved extension, the active plasma bending, this work introduces the concept of the plasma discharge undulator (PDU). In a PDU, a high-current discharge within a capillary generates an azimuthal magnetic field providing strong linear focusing [O(kT/m)], while a controlled and periodical spatial modulation of the discharge axis acts as a geometric driving term. The resulting beam dynamics can be modeled as a forced harmonic oscillator, yielding a well-defined oscillation at wavelength λ_{PDU}, distinct from the natural betatron wavelength λ_β related to APL focusing. Proper injection conditions result in the suppression of collective betatron oscillations, significantly reducing the intrinsic undulator strength spread typical of conventional plasma undulators while allowing for matched beam transport thanks to strong APL focusing. Analytical models for particle trajectories and radiation emission are developed, and the one-dimensional requirements for free-electron laser (FEL) emission are evaluated, providing scaling relations and feasibility criteria for FEL operation in the proposed scheme. Theoretical estimates are validated through multiparticle simulations of beam dynamics and radiation emission, confirming that the PDU can operate in the short-period regime (λ_{PDU} of millimeters to centimeters) with tunable undulator strength K_{PDU}, supporting narrow-band radiation emission. Numerical studies further demonstrate that the PDU is capable of sustaining seeded longitudinal microbunching analogous to that occurring in conventional magnetic undulators. The PDU thus provides a pathway toward miniaturized, tunable, fully plasma based light sources with enhanced control over focusing and spectral properties.

Validation of a Compact and Tunable Continuous Gas-Flow Laser-Plasma Target for Electron Beam Production Above 150 MeV

P. Drobniak, J. Serhal, M. P. Anania, E. Baynard, A. Beck, C. Bruni, A. Cauchois, G. Costa, L. Crincoli, D. Douillet, J. Gautier, J. P. Goddet, C. Guyot, G. Iaquaniello, G. Kane, S. Kazamias, O. Kononenko, V. Kubytskyi, B. Lucas, A. Mahjoub, A. Maitrallain, O. Neveu, Y. Peinaud, M. Pittman, P. Rousseau, J. S. Ramírez Amado, A. Specka, C. Thaury, and K. Cassou
APPLIED SCIENCES 16(5), 2312 (MAR 1 2026)
https://doi.org/10.3390/app16052312

The present article reports on the generation of stable 50 pC low-divergence electron beams above 150 MeV from laser-driven wakefield acceleration using a continuous-flow gas target prototype tested at the 60 TW Salle Jaune facility at LOA. The gas target design is meant to be easily transported and integrated as an element of the beamline with a differential pumping system offering some 10^{-4} mbar pressure in the rest of the line. A dedicated gas injection system allows for the control of the gas mixture concentration and gas pressure in two different regions of the target within the frame of controlled ionisation injection schemes. The measured electron beam parameters show the importance of gas density profiles and longitudinal gas mixture confinement.

BEAMLINES & APPLICATIONS

RADIATION SOURCES & FELs

Over 8 hours of continuous operation of a free-electron laser driven by a laser-plasma accelerator

F. Kohrell, S. K. Barber, C. E. Doss, K. Jensen, S. Schröder, C. Berger, Z. Eisentraut, K. Nakamura, A. J. Gonsalves, F. Isono, G. R. Plateau, R. A. van Mourik, M. Gracia-Linares, L. Labun, B. M. Hegelich, S. V. Milton, C. G. R. Geddes, J. Osterhoff, E. H. Esarey, C. B. Schroeder, F. Grüner, and J. van Tilborg
PHYSICAL REVIEW ACCELERATORS AND BEAMS 29, 041301 (APR 7 2026)
https://doi.org/10.1103/z2d3-bhyt

Since the emergence of laser-plasma accelerators (LPAs), substantial work has been dedicated to using LPAs to drive free-electron lasers (FELs) for a broad range of applications. Despite recent breakthroughs, which have proven the fundamental feasibility of operating FELs with an LPA source, stable FEL operation over multiple hours without operator input had yet to be achieved. In this work, we report significant improvements to the stability of a hundred terawatt laser system, resulting in successful demonstration of reliable, long-term operation of an LPA-driven FEL in the self-amplified spontaneous emission (SASE) regime at 420 nm. The LPA source delivered 100 MeV electron beams at 1 Hz with high stability over more than 10 h, enabling over 8 h of continuous FEL operation without operator input. The acquired data were subsequently used to investigate correlations between the measured undulator radiation and parameters of the drive laser, plasma source, and electron beam. The revealed connections between LPA and FEL performance gave important additional insights into ways to further improve and stabilize the system, thus demonstrating the capability of our setup to serve as a powerful platform for future studies of LPA-driven FEL operation. The one-of-a-kind integration of multiple stabilization concepts onto the LPA facility discussed in this manuscript yielded significant accelerator and light source improvements (with residual correlations suggesting even more is possible), which will positively impact LPA applications at large.

Nanometer-scale prebunched electron beams generated from all-optical plasma-based acceleration

Z. Wang, Z. Xu, Q. Ma, Y. Xia, L. Liu, C. Wang, T. Dalichaouch, X. Yan, X. Xu, and W. B. Mori
PHYSICAL REVIEW ACCELERATORS AND BEAMS 29, 044601 (APR 9 2026)
https://doi.org/10.1103/5yxp-sjmh

High-quality and prebunched electron beams can produce coherent x-rays with high intensity and narrow bandwidth, which are essential for modern light sources. An all-optical scheme based on plasma-based acceleration for producing bright electron beams that are prebunched on the nanometer scale is proposed. By using a density modulation created by two low intensity counterpropagating lasers, the phase velocity of the plasma wake excited by an intense driver laser in a uniform plasma can be modulated at a frequency twice that of the colliding lasers, thus turning the injection on and off. The injected electrons are microbunched at the Doppler-shifted modulated wavelength, corresponding to the phase velocity of the gradually expanding wakefield. It is demonstrated that by controlling the properties of the drive and colliding lasers, beams with exotic prebunched structures can be produced, which may have critical applications in ultrafast high power x-rays. This extremely compact, all-optical scheme for producing ultrabright prebunched electron beams may therefore enable novel applications for ultrafast x-ray users and arouse general interest in various fields.

SPARC_LAB facility for advanced acceleration and radiation experiments

R. Pompili, M. P. Anania, I. Balossino, M. Bellaveglia, A. Biagioni, F. Cardelli, M. Carillo, E. Chiadroni, A. Cianchi, G. Costa, L. Crincoli, A. Del Dotto, M. Del Franco, M. Del Giorno, R. Demitra, F. Demurtas, V. Dompè, A. Frazzitta, M. Galletti, A. Gallo, L. Giannessi, C. Di Giulio, A. Giribono, G. Latini, A. Liedl, A. Michelotti, M. Opromolla, G. Parise, E. Di Pasquale, A. Petralia, L. Piersanti, S. Pioli, G. Di Pirro, S. Romeo, A. R. Rossi, L. Sabbatini, B. Serenellini, V. Shpakov, G. J. Silvi, L. Spallino, A. Stella, F. Stocchi, C. Vaccarezza, A. Vannozzi, L. Verra, F. Villa, and M. Ferrario

PHYSICAL REVIEW ACCELERATORS AND BEAMS 29, 051602 (MAY 19 2026)
https://doi.org/10.1103/rnz7-3qyj

The SPARC_LAB facility, operating at the LNF-INFN laboratories in Frascati, has been devoted over the past years to R&D related to accelerators, advanced diagnostics, and generation of radiation ranging from THz to extreme UV light. The facility has recently been significantly upgraded and moved toward user-oriented applications, especially after the approval of two additional projects with the goal to develop radiation sources up to the soft x-ray range and in view of the EuPRAXIA project, whose preparatory phase is ongoing with the support of the European Commission. This paper summarizes the electron beam and radiation parameters and describes the layout and main features of the upgraded facility in view of future user-oriented experimental activities and applications.

HEP

Experimental evidence of production of directional muons from a laser-wakefield accelerator

L. Calvin, E. Gerstmayr, C. Arran, L. Tudor, T. Foster, K. Fleck, B. Bergmann, D. Doria, B. Kettle, H. Maguire, V. Malka, P. Manek, S. P. D. Mangles, P. McKenna, R. E. Mihai, S. Popa, C. Ridgers, J. Sarma, P. Smolyanskiy, R. Wilson, R. M. Deas, and G. Sarri

PLASMA PHYSICS AND CONTROLLED FUSION 68, 035015 (MAR 13 2026)
https://doi.org/10.1088/1361-6587/ae4d05

We report on experimental evidence of the generation of directional muons from a laser-wakefield accelerator driven by a PW-class laser. The muons were generated following the interaction of a GeV-scale high-charge electron beam with a 2 cm-thick Pb target and were detected using a Timepix3 detector placed behind a suitable shielding configuration. Data analysis indicates a (99.1 ± 0.5) % confidence of muon detection over noise, in excellent agreement with numerical modelling. Extrapolation of the experimental setup to higher electron energies and charges suggests the potential to guide and separate from noise approximately 10^4 muons s^{-1} onto cm2-scale areas for applications using a 10 Hz PW laser. These results demonstrate the possibility of generating and transporting directional muon beams using high-power lasers and establish a foundation for the systematic application of laser-driven high-energy muon beams.

VHEE

A structured plasma profile for an optimized laser-driven accelerator of quality enhanced very high energy electrons (VHEE)

F. Avella, P. Tomassini, L. Labate, and L. A. Gizzi

PHYSICS OF PLASMAS 33(4), 043101 (APR 1 2026) https://doi.org/10.1063/5.0315070

We present a numerical study on a structured plasma target to simultaneously improve the energy spread and divergence of a laser-driven very high energy electron (VHEE) beam designed for VHEE-radiotherapy (RT) application. The main concept to obtain such an enhanced quality beam is to localize the injection, acceleration, and extraction of the electrons by tailoring the plasma target density profile. The injection space is truncated by spatially confining the ionization-injection dopant, while the rest of the target is filled with He atoms. In order to reduce the emittance growth during the bunch extraction, an optimized density downramp profile is adopted. By using a 100 TW class Ti:Sa laser system and an ionization-injection scheme in the blow-out regime, a relatively high charge (≥120 pC) beam with mean energy ≥200 MeV, rms energy spread ≤6%, and normalized emittance $\varepsilon_{nx} < 4$ mm mrad can be obtained. This combination of bunch specification enables an efficient transport and focusing of the particles, thus making the beam of particular interest for VHEE-RT.

Start-to-end modelling of laser-plasma acceleration, beam transport and dose deposition of very high-energy electrons for radiotherapy

R. Kalvala, A. Golovanov, A. Courvoisier, T. Friling, E. Kroupp, L. Grishko, and V. Malka
SCIENTIFIC REPORTS (APR 24 2026)
https://doi.org/10.1038/s41598-026-49116-8

The proposed radiotherapy using very high-energy electron (VHEE) beams generated by a laser-plasma accelerator has garnered significant interest due to its dose distribution capabilities and potential to address limitations of traditional photon-based radiotherapy. To explore the feasibility of such an approach, we develop a start-to-end simulation workflow to model VHEE radiotherapy from the electron source through the beamline to dose delivery in the target. The presented study uses the parameters of OONA, the commercial <1.3 J, <25 fs pulse duration laser recently installed at the Weizmann Institute of Science. Through particle-in-cell simulations of laser-plasma interaction, realistic electron beams are obtained. A beamline consisting of quadrupoles, a collimator, and dipoles is then used to collimate and filter the beams and arrange them into a beam array. Using GEANT4 simulations, we calculate the dose deposition in water phantoms and heterogeneous phantoms with bone inserts. Multifield irradiation setup and the dose distribution at the isocenter through different incidence angles are studied, simulating multi-angle conformal delivery. Our findings demonstrate that polychromatic VHEE beams generated from laser-plasma accelerators, when delivered through such a beamline, can achieve favorable dose distribution for reaching areas deep inside the phantom. This study highlights the potential of the developed start-to-end workflow for exploring and optimizing LPA-generated VHEE radiotherapy, paving the way for further research and potential clinical implementation.

THEORY & SIMULATION

Beam transverse dynamics in laser-plasma accelerators

L. Batista, S. Marini, N. Chauvin, A. Chance, D. Uriot, and P. A. P. Nghiem
PHYSICAL REVIEW E 113, 045207 (APR 2 2026)
https://doi.org/10.1103/6g4s-8d81

Beyond beam energy and energy spread, transverse beam parameters are crucial in laser-plasma accelerator projects that aim to deliver a high-quality beam to a user's community. In this article, transverse beam physics is thoroughly studied throughout an entire plasma stage, including a plasma density plateau surrounded by density up-ramp and down-ramp. Physical mechanisms, analytical calculations, and numerical simulations are employed to study the evolution of the beam Twiss parameters and emittance. The key parameters and key roles of the different plasma sections are identified. Guidelines are provided for efficiently minimizing emittance growth all along the plasma acceleration stage and the coupling with upstream and downstream transport lines.

Optimized matching conditions for self-guided laser wakefield accelerators

P. Valenta, K. G. Miller, B. K. Russell, M. Lamač, M. Jech, G. M. Grittani, and S. V. Bulanov

MACHINE LEARNING: SCIENCE AND TECHNOLOGY 7, 025030 (MAR 24 2026)

https://doi.org/10.1088/2632-2153/ae51e0

We revisit the matching conditions for self-guided laser pulse propagation in plasma and refine their formulation to maximize the energy of electrons produced via laser wakefield acceleration. Bayesian optimization, combined with particle-in-cell simulations carried out in a quasi-three-dimensional geometry and a Lorentz-boosted frame, is employed. The optimization identifies the maximum electron energy that a self-guided laser wakefield accelerator, driven by a laser of a given energy, can produce, together with the corresponding acceleration distance. Our results further demonstrate that electrons with energies close to the maximum value can be obtained across a relatively wide range of input parameters and without the need for their precise tuning. This provides substantial flexibility for experimental implementation and significantly relaxes the operational constraints associated with self-guided laser wakefield accelerators.

Laser Wakefield Electron Acceleration in a Periodically Modulated Plasma Density Profile

R. Iovănescu, R. P. Daia, A. C. Gîrlea, E.-I. Slușanschi, and C. M. Ticoș

PLASMA 9, 12 (APR 29 2026)

https://doi.org/10.3390/plasma9020012

We investigate laser wakefield electron acceleration in a periodic plasma density profile using 2D PIC simulations with the EPOCH code. The profile of the electron density has the form $n(x)=n_0[1+\delta\sin(2\pi x/x_0)]$, where n_0 is the steady electron density, x_0=100 µm is the spatial periodicity in the laser propagation direction and δ, taking the values 0, 0.1, 0.3, 0.5 and 0.7, is the modulation parameter. The bubble size varies with the modulated plasma density, thereby influencing the electron acceleration, which occurs within a continuously changing bubble structure. We propose an analytical model to estimate the energies of the accelerated electrons, and evaluate the maximum electron energies at 500 fs intervals for the five modulated density profiles. We then calculate the dephasing and depletion lengths for these modulated plasma profiles and examine their dependence on δ. The results show a growth in both lengths with δ, with depletion being the main limitation in these cases. Additionally, we compute and compare the transverse emittance of the self-injected electron bunches corresponding to the various density profiles at the same simulation time, and other characteristics, like the center energy and energy spread. Emittance is observed to experience a decrease with the increase in the modulation parameter.

THE EuPRAXIA FILES is a collection of publicly available abstracts from published papers that are relevant to the EuPRAXIA and PACRI projects. If you want your published paper to be included in the next issue of the newsletter, please contact Joseph Wolfenden at Joseph.Wolfenden@liverpool.ac.uk

www.eupraxia-pp.org

Funded by the European Union