FOREWORD

A new issue of the EuPRAXIA Files is presented here, recollecting the most relevant books and papers recently appeared in literature about accelerators, lasers and plasma science and strictly correlated with technologies that will be used at EuPRAXIA.

EuPRAXIA Consortium is actively preparing the implementation of the two sites at Frascati (INFN) and Prague (ELI-ERIC), together with all necessary steps in terms of governance and funding needed to complete the installations and to guarantee the inclusion in the ESFRI Landmarks.

Considering these important tasks, the EuPRAXIA files can bring further support to prepare our distributed network of research infrastructures. Special thanks go to Ricardo Torres, who is leaving EuPRAXIA, for his very passionate work of the last years. Thanks Ricardo !

I wish you an interesting reading.

Pierluigi Campana

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FUNDAMENTALS

Electron Acceleration in Ionizing Gas by Self-Divergent Amplitude-Modulated Laser Pulses

Ravina, Devki Nandan; Gupta, Devki Nandan; Suk, Hyyong; Sharma, Jyotsna
IEEE TRANSACTIONS ON PLASMA SCIENCE 53(7) 1465-1472 (JUL 2025)
https://doi.org/10.1109/TPS.2025.3571548

We investigate electron acceleration driven by a self-diverging laser filament propagating through a tunnel-ionizing gas. When a high-intensity, amplitude-modulated laser interacts with the gas, it ionizes the medium and generates plasma. Due to local plasma density gradients, the laser filament diverges as it propagates, altering the dynamics of electron acceleration. Electrons can gain energy from the rising edge of the laser pulse, while the subsequent divergence of the laser helps mitigate deceleration by reducing the overlap

between the trailing fields and the electron trajectory. Consequently, a significant portion of the acquired energy can be retained. To optimize the acceleration process, the spatial alignment between the laser pulse peak and the electron position is crucial. We develop a theoretical model to describe the divergence behavior of the laser filament and its impact on electron dynamics. Using this model, we estimate the achievable electron energy gain and derive scaling laws to guide the optimization and control of the acceleration process. This work suggests a novel mechanism for enhancing electron energy gain through the interaction of amplitude-modulated laser filaments with gas jets.

High charge laser acceleration of electrons to 10 GeV

Rockafellow, Ela; Shrock, Jaron E.; Miao, Bo; Sloss, Ari J.; Le, Manh S.; Hancock, Scott W.; Zahedpour, Sina; Hollinger, Reed C.; Wang, Shoujun; King, James; Zhang, Ping; Sisma, Jiri; Grittani, Gabriele M.; Versaci, Roberto; Gordon, Daniel F.; Williams, Gerald J.; Reagan, Brendan A.; Rocca, Jorge J.; Milchberg, Howard M.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS; SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1077, 170586 (AUG 2025)
https://doi.org/10.1016/j.nima.2025.170586

Recent demonstrations of all-optical multi-GeV laser wakefield acceleration (LWFA) have been enabled by University of Maryland's development of low-density, meter scale plasma waveguides generated in greatly extended supersonic gas jets. We present a review of our recent LWFA efforts, including experiments and simulations to benchmark plasma waveguide generation, a new 3-stage model for relativistic pulse propagation in meter-scale waveguides, and recent LWFA experiments using waveguides up to 30 cm long. These experiments demonstrate sub-milliradian divergence electron bunches with integrated charge >1 nC above 1 GeV, and energy spectra including less than or ~ 10 pC features above 9 GeV with tails extending to slightly beyond 10 GeV, representing a laser to electron conversion efficiency of at least ~ 30%.

Electron Filament Structures of Injected Electrons in LWFA

Iovanescu, R.; Daia, R. P.; Slusanschi, E. I.; Ticos, C. M.
IEEE TRANSACTIONS ON PLASMA SCIENCE 53(4), 780-787 (APR 2025)
https://doi.org/10.1109/TPS.2025.3545973

We observe the formation of thread-like elongated electron structures, referred to as electron filaments, during the self-injection in the bubble regime of laser wakefield acceleration (LWFA) using 2-D particle in cell (PIC) simulations, for no plasma density upramp preceding the laser pulse. At relatively low plasma densities, around 10^{18} cm^{-3}, the self-injected electrons continue to move on separate trajectories inside the bubble creating well-defined electron filaments when a large bubble closes its rear edges from behind, making an angle larger than 180 degrees measured from the interior of the bubble. At higher plasma densities, above 2.5 x 10^{18} cm^{-3}, the bubble closes at its rear with the edges making a smaller angle than 180 degrees, resulting in a different injection dynamics. We examine these trajectories using Hamiltonian mechanics and how they impact the betatron oscillations in these cases. The results indicate that higher plasma densities result in smaller betatron oscillation amplitudes and larger wiggler strength parameter due to the stronger accelerating fields in the bubble, which accelerate the electrons to higher energies, giving higher Lorentz factors. We also show that by introducing a linear density upramp at the beam entrance, the bubble's geometry is modified, thereby influencing the betatron oscillations and potentially tuning the acceleration process.

Observation of quasi-monoenergetic electrons in the plasma produced by sub-nanosecond laser pulse

Singh, S.; Krupka, M.; Krasa, J.; Agarwal, S.; Devi, P.; Dudzak, R.; Cikhardt, J.; Burian, T.; Dostal, J.; Chodukowski, T.; Rusiniak, Z.; Pisarczyk, T.; Krus, M.; Morace, A.; Juha, L.
PHYSICS OF PLASMAS 32(5), 052702 (MAY 2025)
https://doi.org/10.1063/5.0253017

We experimentally demonstrate the generation of quasi-monoenergetic electron bunch at the end of the electron energy distribution. The experiment was conducted at the Prague Asterix Laser System where iodine laser supplies laser energy up to 600 J at the fundamental wavelength of 1.315 μm with a pulse duration of 350 ps. The thickness of different target materials (Cu, Sn, Ta, Pb) was varied between 10 and 25 μm. The energy spectrum of electrons was measured using an array of electron spectrometers at different angular directions with respect to the laser axis. Three frame femtosecond interferometry driven by a Ti:Sa laser was implemented to scan the changes in electron density during plasma ignition by the iodine laser. The experimental results indicate the generation of well-defined quasi-monoenergetic peaks in the electron energy distribution. The energy range of the measured quasi-monoenergetic peaks lies between 0.6 and 1.5 MeV; however, the energy spread of the distribution varies between 4% and 12%. These features were observed consistently in the electron spectrum and illustrate the quasi-monoenergetic electron beam generation by interaction of a sub-nanosecond laser beam with plasma. In addition, a comparison of electron spectra from spectrometers located in opposite directions relative to the position of the laser focus indicates the splitting of the electron cloud into plasma blocks during the acceleration of hot electrons by Coulomb repulsion. These findings can be applicable in fast electron beam-driven radiation sources, electromagnetic pulse generation, charge particle acceleration, and inertial fusion studies. (c) s025 Author(s).

Development of a high charge 10 GeV laser electron accelerator

Rockafellow, E.; Miao, B.; Shrock, J. E.; Sloss, A.; Le, M. S.; Hancock, S. W.; Zahedpour, S.; Hollinger, R. C.; Wang, S.; King, J.; Zhang, P.; Sisma, J.; Grittani, G. M.; Versaci, R.; Gordon, D. F.; Williams, G. J.; Reagan, B. A.; Rocca, J. J.; Milchberg, H. M.

PHYSICS OF PLASMAS 32(5), 053102 (MAY 2025)
https://doi.org/10.1063/5.0265640

Low-density meter-scale plasma waveguides produced in meter-scale supersonic gas jets have paved the way for recent demonstrations of all-optical multi-gigaelectronvolt laser wakefield acceleration (LWFA). This paper reviews recent advances by the University of Maryland, which have enabled these results, focusing on the development of elongated supersonic gas jets up to ~ 1 m in length, experimental and simulation studies of plasma waveguide formation, and a new three-stage model for relativistic pulse propagation dynamics in these waveguides. We also present results from recent LWFA experiments conducted at the Laboratory for Advanced Lasers and Extreme Photonics at Colorado State University demonstrating high charge, low divergence electron bunches to ~ 10 GeV , with laser-to-electron beam efficiency of at least ~ 30%.

Generation and Acceleration of Isolated- Attosecond Electron Bunch via Phase-Compressed Injection

Zhang, Liang-Qi; Si, Mei-Yu; Yu, Tong-Pu; Bi, Yuan-Jie; Huang, Yong-Sheng

ULTRAFAST SCIENCE 5, 0101 (JUN 2025)
https://doi.org/10.34133/ultrafastscience.0101

We propose a novel scheme for generating and accelerating simultaneously a dozen-GeV isolated attosecond electron bunch via phase-compressed injection in a radiative-wakefield-breaking process from an electron beam-driven hollow-channel plasma target. During the beam-target interaction, transverse oscillations of plasma electrons are induced, and subsequently, a radiative wakefield is generated. Meanwhile, a large number of plasma electrons of close to the speed of light are injected transversely toward the center of the hollow channel from the position of the transverse electric field of radiative wakefield, forming an isolated attosecond electron bunch due to the phase compression in the radiative-wakefield-breaking process. The injected attosecond electron bunch is then located just in the acceleration phase of the longitudinal electric field of the radiative wakefield and is importantly accelerated to high energies by the radiative wakefield. It is demonstrated theoretically and numerically that this scheme can efficiently generate an isolated attosecond electron bunch with a charge of more than 2 nC, a peak energy up to 13 GeV of more than 2 times that of the driving electron beam, a peak divergence angle of less than 5 mrad, a duration of 276 as, and an energy conversion efficiency of 36.7% as well as a high stability as compared with the laser-beam drive case. Such an isolated attosecond electron bunch in the range of GeV would provide critical applications in ultrafast physics and high-energy physics.

Study of nonlinear theory refinements for small plasma bubbles

Yan, Jiayang; Jain, Arohi; Zhang, Xuan; Vafaei-Najafabadi, Navid
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS; SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1079, 170602 (OCT 2025)
https://doi.org/10.1016/j.nima.2025.170602

Beam-driven plasma wakefield accelerators (PWFAs) have demonstrated exceptionally high acceleration gradients, reaching GV/m in the nonlinear blowout regime. While the well-established nonlinear theory provides accurate approximations for bubble structure, wake potential, and the longitudinal electric field near the bubble center, it is primarily suited for large plasma bubbles. However, this approximation becomes less accurate for small-radius bubbles ($k_p R_b < 4$, where k_p is the plasma wavenumber and Rb is the maximum plasma bubble radius). This proceeding presents a modified model tailored for small-radius plasma bubbles, informed by simulation studies. The proposed corrections are compared with Particle-In-Cell (PIC) simulations, focusing on bubbles with $k_p R_b < 4$. The refined model is further applied to calculate witness beam profiles that enabling complete beam loading in small bubbles.

CONTROL & OPTIMIZATION

Achieving high-energy electrons in laser wakefield acceleration through precise parameter control

Sharma, Vivek; Thakur, Vishal
JOURNAL OF OPTICS-INDIA (MAY 2025)
https://doi.org/10.1007/s12596-025-02767-8

Laser wakefield acceleration (LWFA) is a very promising technique used to generate electron beams with high energy inside a confined physical area. It is feasible to overcome the traditional limitations on electron energy like low energy efficiency, beam divergence effect, radiation losses, low acceleration gradient, big size etc., by taking use of the nonlinear characteristics of laser plasma interaction. This study presents a comprehensive summary of the most recent advancements in using nonlinear effects to increase electron energy in laser wakefield acceleration. This work presents the formulation of a differential equation that represents the wake potential produced by LWFA in the weakly-relativistic domain inside a homogeneous plasma under dense conditions. An analytical calculation has been performed to determine the wakefield and energy gain by using the wake potential generated by a Gaussian-like sinusoidal laser pulse. This study examines the impact of laser electric field amplitude on the magnitude of the produced wakefield. An analysis of laser pulse length reveals that the highest electron energy gain may be achieved when the laser pulse length is 0.65 times the plasma wavelength. The present study aims to enhance electron energy by precise adjustment of parameters related to wakefield phenomena.

LASERS, PLASMA TECHNOLOGY & DIAGNOSTICS

Meter-scale supersonic gas jets for multi-GeV laser-plasma accelerators

Miao, B.; Shrock, J. E.; Rockafellow, E.; Sloss, A. J.; Milchberg, H. M.
REVIEW OF SCIENTIFIC INSTRUMENTS 96(4), 043003 (APR 2025)
https://doi.org/10.1063/5.0248959

Pushing the high energy frontier of laser wakefield electron acceleration to 10 GeV and beyond requires extending the propagation of relativistic intensity pulses to ~ 1 m in a low density ($Ne \sim 10^{17}$ cm^{-3}) plasma waveguide. We present the development and characterization of two types of supersonic gas jets for meter-scale multi-GeV laser wakefield accelerators. The first type is a 30-cm long single-module gas jet, which demonstrates good axial uniformity using hydrogen. The second type is a modular jet composed of multiple 11-cm-long modules. Longitudinal density profile control is demonstrated with a 2-module (22 cm long) hydrogen jet using gas valve trigger timing. A 1.0-m-long jet is then assembled from nine modules, and generation of 1.0-m long hydrogen plasma is demonstrated using a femtosecond Bessel beam. To our knowledge, this is the longest gas jet laser plasma yet generated.

Highly sensitive double-grating interferometer for direct measurement of a neutral helium gas density in a capillary cell

Roh, Kyungmin; Lee, Youngmin; Kim, Hyunil Benjamin; Jeon, Seongjin; Lee, Hyojeong; Suk, Hyyong
OPTICS EXPRESS 33(8), 18591-18600 (APR 2025)
https://doi.org/10.1364/OE.562060

We developed a highly sensitive double-grating interferometer using four probe beams, which can measure one order of magnitude smaller phase shifts compared with other conventional interferometers. To achieve the unprecedented sensitivity, a highly dynamic 16-bit CCD camera was used and the balanced detection technique with four probe beams was employed in the 2-dimensional (2-D) interferometry for the first time. By using this interferometer, we could directly measure a low helium (He) gas density of n similar or equal to 1 x 10^{17} cm^{-3} in a capillary gas cell for the laser-plasma acceleration research, which is almost impossible with other conventional laser interferometers. This interferometer may provide a new tool for applications with extremely small phase shifts in science. (c) 2025 Optica Publishing Group under the terms of the Optica Open Access Publishing Agreement

Pointing stabilization of a 1 Hz high-power laser via machine learning

Amodio, Alessio; Wang, Dan; Berger, Curtis; Tsai, Hai-En; Barber, Samuel K.; van Tilborg, Jeroen; Picksley, Alexander; Eisentraut, Zachary; Vora, Neel Rajeshbhai; Logantha, Mahek; Ji, Qing; Wilcox, Russell; Du, Qiang; Gonsalves, Anthony
HIGH POWER LASER SCIENCE AND ENGINEERING 13, e35 (APR 2025)
https://doi.org/10.1017/hpl.2025.41

High-power lasers are vital for particle acceleration, imaging, fusion and materials processing, requiring precise control and high-energy delivery. Laser plasma accelerators (LPAs) demand laser positional stability at focus to ensure consistent electron beams in applications such as X-ray free-electron lasers and high-energy colliders. Achieving this stability is especially challenging for the low-repetition-rate lasers in current LPAs. We present a machine learning method that predicts and corrects laser pointing instabilities in real-time using a high-frequency pilot beam. By preemptively adjusting a correction mirror, this approach overcomes traditional feedback limits. Demonstrated on the BELLA petawatt laser operating at the terawatt level (30 mJ amplification), our method achieved root mean square pointing stabilization of 0.34 and 0.59 μrad in the x and y directions, reducing jitter by 65% and 47%, respectively. This is the first successful application of predictive control for shot-to-shot stabilization in low-repetition-rate laser systems, paving the way for full-energy petawatt lasers and transformative advances across science, industry and security.

Acceleration and focusing electron/positron bunches in plasma-dielectric wakefield accelerator

Sotnikov, Gennadiy V.; Galaydych, Kostyantyn V.; Markov, Peter I.; Onishchenko, Ivan M.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS; SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1077, 170522 (AUG 2025)
https://doi.org/10.1016/j.nima.2025.170522

To mitigate the beam breakup (BBU) instability and improve the characteristics of accelerated bunches in the Dielectric Wakefield Accelerator (DWA), use could be made of the isotropic plasma filling of the transport channel. Here we present the results of analytical and numerical studies into the dynamics of accelerated electron/positron and drive-electron bunches under wake acceleration in a plasma DWA (PDWA) having a vacuum channel. In the case under consideration the wakefield is excited by an electron bunch in a quartz dielectric tube inserted into a cylindrical metal waveguide. The inner region of the dielectric tube is filled with plasma that has a vacuum channel along the waveguide axis. The energy and spatial characteristics, efficiency, emittance, and energy spread of the accelerated positron and electron bunches have been numerically simulated for various values of the vacuum channel radius. The transverse instability of the drive bunch in the PDWA has been studied analytically and numerically. The analytical studies have revealed the presence of one surface and one bulk eigenwaves present in the PDWA which were absent in the corresponding dielectric-loaded waveguide with no plasma filling. The transverse wakefield amplitude, responsible for stabilization of the transverse motion of bunches, is mainly contributed by the bulk plasma eigenwave. The comparative analysis of the analytical data and the data obtained by numerical simulation has demonstrated qualitative agreement between the results.

Longitudinal shaping of plasma waveguides using diffractive axicons for laser wakefield acceleration

Tripathi, N.; Miao, B.; Sloss, A.; Rockafellow, E.; Shrock, J. E.; Hancock, S. W.; Milchberg, H. M.
OPTICS LETTERS
50(10), 3441-3444 (MAY 2025)
https://doi.org/10.1364/OL.561318

New techniques for the optical generation of plasma waveguides-optical fibers for ultra-intense light pulses-have become vital to the advancement of multi-GeV laser wake-field acceleration. Here, we demonstrate the fabrication and characterization of a transmissive 8-level logarithmic diffractive axicon (LDA) for the generation of meter-scale plasma waveguides. These LDAs enable the formation of a Bessel-like beam with controllable start and end locations of the focal line and near-constant intensity on axis. We present measurements of the Bessel-like focal profile produced by the LDA and of the leading end of the plasma column generated by it. One important feature is the formation of a funnel-mouthed plasma channel entrance that can act as waveguide coupler. We also compare the diffraction efficiency of our 8level LDA to 4-level and binary versions, with measurements comparing well to theory. (c) 2025 Optica Publishing Group. All rights, including for text and data mining (TDM), Artificial Intelligence (AI) training, and similar technologies, are reserved.

Diagnostics for plasma acceleration and secondary radiation sources for EuAPS project at FLAME laser facility

Stocchi, F.; Anania, M. P.; Cianchi, A.; Costa, G.; Curcio, A.; Del Giorno, M.; Dompe, V.; Francescone, D.; Galletti, M.; Ghigo, A.; Ferrario, M.
JOURNAL OF INSTRUMENTATION 20(6), C06079 (JUN2025)
https://doi.org/10.1088/1748-0221/20/06/C06079

The Laser WakeField Acceleration (LWFA) process in a gas target requires laser and plasma diagnostics to monitor the interaction, such as a Mach-Zehnder interferometer for plasma density analysis. In addition, other diagnostics are used to characterize the accelerated particle beams and the secondary X-ray radiation produced, such as an energy spectrometer and a CCD-X camera. This X-ray radiation has distinctive features that open up the possibility of significant applications in fields such as materials science, biological research, medicine and industry. In the next few years, these radiation sources will become a good alternative to conventional ones due to the reduction in cost and the smaller dimension of such facilities. In this contribution, we present the diagnostics and the experimental results of several experimental campaigns carried out to characterize the LWFA process at the Frascati Laser for Acceleration and Multidisciplinary Experiments (FLAME) facility at the Laboratori Nazionali di Frascati-INFN in the framework of the EuPRAXIA Advanced Photon Sources (EuAPS) project.

Guidance of vortex beams in curved plasma channels

Liu, Yuanyuan; Zhang, Xiaomei; Shen, Baifei; Xing, Jinlong; Kong, Fanqiu; Li, Xiaofei; Shi, Mengxiao
PHYSICS OF PLASMAS 32(6), 063107 (JUN2025)
https://doi.org/10.1063/5.0267081

This study focuses on exploring the guidance of vortex beams with orbital angular momentum in a curved plasma channel, which holds promise for achieving efficient cascaded laser wakefield acceleration and other applications. Three-dimensional particle-in-cell simulations show that weakly relativistic Laguerre-Gaussian (LG) beams with different topological charges can be effectively guided by a curved plasma channel into a straight channel, maintaining a good vortex structure in the straight channel for distances of millimeters or even centimeters. However, when guiding relativistic LG beams through the curved plasma channel, the symmetry of the three-dimensional beam structure is slightly disrupted. Moreover, the larger the topological charge l, the less effectively the beam's topological structure is preserved. Considering the advantages of light spring (LS) beams for particle acceleration, the guidance of these beams in a curved channel was also investigated. Simulations indicate that weak LS beams can also be guided by the curved plasma channel while maintaining the spring structure. This study provides valuable insight into achieving efficient cascaded laser wakefield accelerators driven by vortex beams, generating wakefields with specialized structures for accelerating positively charged particles, manipulating electron beams with orbital angular momentum, and exploring more complex physical phenomena in plasmas. (c) 2025 Author(s).

Arbitrary-velocity laser pulses in plasma waveguides

Palastro, J. P.; Miller, K. G.; Edwards, M. R.; Elliott, A. L.; Mack, L. S.; Singh, D.; Thomas, A. G. R.
PHYSICAL REVIEW RESEARCH 7(2), 023249 (JUN 2025)
https://doi.org/10.1103/vysz-9pkl

Space-time structured laser pulses feature an intensity peak that can travel at an arbitrary velocity while maintaining a near-constant profile. These pulses can propagate in uniform media, where their frequencies are correlated with continuous transverse wave vectors, or in structured media, such as a waveguide, where their frequencies are correlated with discrete mode numbers. Here, we demonstrate the formation and propagation of arbitrary-velocity laser pulses in a plasma waveguide where the intensity can be orders of magnitude higher than in a solid-state waveguide. The flexibility to control the velocity of the peak intensity in a plasma waveguide enables new configurations for plasma-based sources of radiation and energetic particles, including THz generation, laser wakefield acceleration, and direct laser acceleration.

Progress in the development of a versatile table-top kHz-rate laser-plasma accelerator for mixed radiation sources

Patnaik, Anil K.; Dexter, Michael L.; Frische, Kyle D.; Knight, Benjamin M.; Tamminga, Nathaniel; Desai, Ronak; Snyder, Joseph; Orban, Chris M.; Chowdhury, Enam A.
APPLIED OPTICS 64(18), E152-E163 (JUN 2025)
https://doi.org/10.1364/AO.558553

Ultra-intense laser and plasma interactions with their ability to accelerate particles reaching relativistic speed are exciting from a fundamental high-field physics perspective. Such relativistic laser-plasma interaction (RLPI) offers a plethora of critical applications for energy, space, and defense enterprise. At AFIT's Extreme Light Laboratory (ELL), we have demonstrated such RLPI employing a table-top ~10 mJ, 40 fs laser pulses at a kHz repetition rate that produce different types of secondary radiations via target normal sheath acceleration (TNSA). With our recent demonstration of laser-driven fusion, the secondary radiations generated are neutrons, x-ray emission, and MeV energy electrons and protons-all at a kHz rate. To achieve the high repetition rate, we developed the enabling kHz-repetition-rate-compatible liquid targets in the form of microjets, droplets, and submicron-thick sheets. These targets, combined with high repetition rate diagnostics, enable a unique, real-time feedback loop between the experimental inputs (laser and target parameters) and generated sources (x-rays, electrons, ions, etc.) to develop machine learning (ML)-based

control of mixed radiation. The goal of this paper is to provide an overview of the capabilities of ELL, describe the diagnostics and characteristics of the secondary radiation, data analysis, and quasireal-time ML functionality of this platform that have been developed over the last decade and a half.

Optical and structural requirements for x-ray distributed feedback lasing across a resonant thin film

Rameshbabu, Sharath; Zenklusen, Raffaele; Muller, Arnold; Vockenhuber, Christof; Bleiner, Davide
JOURNAL OF APPLIED PHYSICS 138(9), 093107 (SEP 2025)
https://doi.org/10.1063/5.0278763

The requirements for developing chip-scale distributed-feedback x-ray lasers were investigated to address the critical challenge of miniaturizing coherent short-wavelength laser sources. A central concept introduced in this work is the use of "Röntgen materials" that can simultaneously serve as a gain medium and support the optical feedback structure required for lasing. As a model system, $La_{0.5}Sr_{0.5}CoO_3$ (LSCO) was selected due to its high atomic number constituents, tunable stoichiometry, and favorable optical properties. High-quality LSCO thin films were synthesized using pulsed laser deposition to ensure epitaxial growth and precise compositional control. Structural and compositional integrity was confirmed via x-ray diffraction, reciprocal space mapping, and Rutherford backscattering spectrometry. The gain performance was evaluated based on fluorescence efficiency, crystal orientation, and lattice plane alignment. A key finding was that high-Z materials with optimal refractive index contrast and reduced non-radiative Auger losses support conditions for coherent x-ray amplification. By leveraging higher-order diffraction planes and targeted gain optimization strategies, this work advances the feasibility of compact x-ray laser systems with potential applications in biomedical imaging, materials analysis, and high-resolution spectroscopy.

On the Universality of the Dependence of Magnetic Parameters on Residual Stresses in Steels

Vourna, Polyxeni P.; Ktena, Aphrodite; Svec, Peter; Hristoforou
IEEE TRANSACTIONS ON MAGNETICS 52(5), 1-6 (MAY 2016)
https://doi/org/10.1109/TMAG.2015.2509642

A method for the monitoring of residual stress distribution in steels has been developed based on non-destructive magnetic permeability measurements. The dependence of differential permeability on residual stresses induced through a controlled process of applied tensile and compressive stress in the elastic region, of all three zones of the welded metal, yields the magnetic stress calibration curve (MASC). MASC is obtained on flawless welded steel plates and can be measured for any grade of ferromagnetic steels. A surface MASC correlates the magnetic permeability with the spatial stress distribution, as determined by the X-Ray Diffraction Bragg-Brentano diffraction. A bulk MASC correlates the bulk magnetic permeability with residual stresses, as determined by the neutron diffraction. The resulting calibration curves, obtained for several grades of ferromagnetic steels, have a sigmoid shape but are unique for each grade of steels. Normalizing the magnetic permeability and the stress values against the differential permeability measured at the yield point and yield stress, respectively, the dependence of the local magnetic permeability on residual stresses for all different tested grades of steels results in a universal curve relating magnetic and elastic properties of steels at the macroscopic level.

High-precision alpha spectroscopy using sCVD diamond detectors

Divya; Melbinger, Julian; Griesmayer, Erich; Weiss, Christina; Hainz, Dieter
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1080, 170664 (NOV 2025)
https://doi.org/10.1016/j.nima.2025.170664

Single-crystal chemical vapor deposition (sCVD) diamond detectors are known for their high radiation tolerance and excellent performance at elevated temperatures. sCVD diamond sensors are promising candidates for particle spectroscopy in harsh radiation environments. In this study, we present the energy resolution of sCVD diamond detector. Alpha spectroscopy, a reliable technique for detector calibration is performed. The measurements were conducted in a vacuum environment using an ^{241}Am alpha-particle source and CIVIDEC's high-resolution data acquisition system, ROSY (R) AX106. Geant4 simulations were performed to study the factors contributing to the energy resolution of sCVD diamond detectors.

Permeability Sensors for Magnetic Steel Structural Health Monitoring

Histoforou, Evangelos V.
SENSORS 25(3), 606 (JAN 2025)
https://doi.org/10.3390/s25030606

In this paper, magnetic permeability sensors able to perform structural health monitoring of magnetic steels, by means of determining residual strain and stress amplitude and gradient distribution, responsible for crack initiation, are presented. The good agreement between magnetic properties and residual strains and stresses is illustrated first, resulting in the determination of the magnetic stress calibration (MASC) curves and the Universal MASC curve. Having determined differential magnetic permeability as a key magnetic property, able to measure and monitor residual strain and stress distribution in magnetic steels, the paper is devoted to the presentation of the permeability instruments and sensors developed in our lab. The classic single sheet testers and the electromagnetic yokes, are compared with new, low-power-consumption permeability sensors using the Hall effect and the anisotropic magnetoresistive (AMR) effect, discussing their advantages and disadvantages in magnetic steel structural health monitoring.

Spatio-temporal single-shot diagnostics for characterizing pulse front tilt and dispersion in Joule-level chirped-pulse amplification systems

Hemani, Yousuf; Galimberti, Marco; Bleiner, Davide
OPTICS AND LASER TECHNOLOGY 192, 113514 (DEC 2025)
https://doi.org/10.1016/j.optlastec.2025.113514

Continuous, single-shot diagnostics of high-energy laser pulses are technically demanding but essential for maintaining pulse integrity in chirped pulse laser applications. Angular dispersion and pulse duration are among the most critical parameters, as chromatic aberrations can introduce significant spatio-temporal distortions that degrade performance. In this study, a comprehensive diagnostic scheme was implemented and validated for Joule-level chirped-pulse amplification systems. A novel angular dispersion diagnostic enabled precise quantification of wavefront tilt, while a second-order autocorrelator provided accurate, single-shot measurements of pulse duration. The combined diagnostics revealed measurable pulse distortions attributable to chromatic effects, confirming the necessity of shot-by-shot monitoring. Additional parameters-including spectral content, beam profile, and pulse energy-were simultaneously tracked. The system's reliability and safety were confirmed through B-integral estimation. These results demonstrate that the proposed compact diagnostic framework enables effective real-time optimization of pulse quality, supporting stable and reproducible high-intensity laser--matter interactions.

BEAMLINES & APPLICATIONS

Review of VHEE Beam Energy Evolution for FLASH Radiation Therapy Under Ultra-High Dose Rate (UHDR) Dosimetry

Gazis, Nikolaos; Gazis, Evangelos
QUANTUM BEAM SCIENCE 9(4), 29 (OCT 2025)
https://doi.org/10.3390/qubs9040029

Very-high-energy electron (VHEE) beams, ranging from 50 to 300 or 400 MeV, are the subject of intense research investigation, with considerable interest concerning applications in radiation therapy due to their accurate energy deposition into large and deep-seated tissues, sharp beam edges, high sparing properties, and minimal radiation effects on normal tissues. The very-high-energy electron beam, which ranges from 50 to 400 MeV, and Ultra-High-Energy Electron beams up to 1–2 GeV, are considered extremely effective for human tumor therapy while avoiding the spatial requirements and cost of proton and heavy ion facilities. Many research laboratories have developed advanced testing infrastructures with VHEE beams in Europe, the USA, Japan, and other countries. These facilities aim to accelerate the transition to clinical application, following extensive simulations for beam transport that support preclinical trials and imminent clinical deployment. However, the clinical implementation of VHEE for FLASH radiation therapy requires advances in several areas, including the development of compact, stable, and efficient accelerators; the definition of sophisticated treatment plans; and the establishment of clinically validated protocols. In addition, the perspective of VHEE for accessing ultra-high dose rate (UHDR) dosimetry presents a promising procedure for the practical integration of FLASH radiotherapy for deep tumors, enhancing normal tissue sparing while maintaining the inherent dosimetry advantages. However, it has been proven that a strong effort is necessary to improve the main operational accelerator conditions, ensuring a stable beam over time and across space, as well as compact infrastructure to support the clinical implementation of VHEE for FLASH cancer treatment. VHEE-accessing ultra-high dose rate (UHDR) perspective dosimetry is integrated with FLASH radiotherapy and well-prepared cancer treatment tools that provide an advantage in modern oncology regimes. This study explores technological progress and the evolution of electron accelerator beam energy technology, as simulated by the ASTRA code, for developing VHEE and UHEE beams aimed at medical applications. FLUKA code simulations of electron beam provide dose distribution plots and the range for various energies inside the phantom of PMMA.

Controlled Betatron radiation from high-charge electron beams in multiple plasma channels

Chu, Mengyuan; Luan, Shixia; Yang, Hetian; Feng, Ke; Tian, Yongzhi; Yang, Xiaohu; Wang, Wentao
OPTICS EXPRESS 33(10), 21070-21078 (MAY 2025)
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We propose what we believe is a novel approach for generating intense Betatron radiation in multiple plasma channels induced by the interference of two relativistic, res laser pulses in near-critical density plasma (NCDP). Our method uses particle-in-cell (PIC) simulations to explore the effects of cross-propagating laser pulses at specific angles as they overlap in the NCDP. This overlap leads to the formation of a strong transverse standing wave, resulting in spatially periodic plasma channels. Compared to the conventional single-channel structure formed by a single laser beam, multiple plasma channels enable more efficient Betatron radiation generation. Three-dimensional (3D) PIC simulations show that over 0.8 μC of electrons can be accelerated to a maximum energy of 300 MeV when two femtosecond, 56 J laser pulses interact with NCDP at an angle of 5°. This setup generates an X-ray spectrum with a photon number of 1.8×10^{13} (>1keV) and a peak flux of 5.8×10^{8} photons/0.1%BW. To further investigate the formation of the Betatron electron oscillations, additional PIC simulations are conducted to examine the dependence on various laser parameters. Overall, our proposed method provides a promising and controlled mechanism for creating novel X-ray sources with desirable properties such as compact size, high efficiency, and tunable spectral characteristics.

The positron arm of a plasma-based linear collider

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NATURE PHYSICS 21(6), 885-894 (JUN2025)
https://doi.org/10.1038/s41567-025-02910-z

Plasma-based acceleration of electrons has produced high-energy beams at high accelerating gradients with a narrow energy spread and high efficiency both in experiments and simulations. It is now being considered as a complementary approach to the use of radiofrequency cavities in next-generation lepton accelerators. However, compared with electrons, plasma-based positron acceleration is at the present time much less advanced. Although high-gradient positron acceleration in a plasma has been achieved, we are one to three orders of magnitude away from delivering the high-quality positron beams needed for a future high-energy linear collider. Here we review the status of plasma-based acceleration of electrons and positrons and discuss the prospects for substantial progress towards developing the positron arm of a plasma-based electron-positron linear collider in the next decade.

Improved Bethe-Heitler positron creation and retention by combining direct laser acceleration and solid target interaction within a gas jet

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PLASMA PHYSICS AND CONTROLLED FUSION 67(5), 055025 (MAY 2025)
https://doi.org/10.1088/1361-6587/adc9df

The next generation of Petawatt-class lasers presents the opportunity to study positron production and acceleration experimentally, in an all-optical setting. Several configurations were proposed to produce and accelerate positrons in a single laser stage. However, these configurations have yielded limited positron beam quality and low particle count. This paper presents methods for improving the injection and retention of positrons obtained via Bethe-Heitler pair production and accelerated using direct laser acceleration in a plasma channel. The work first introduces a semi-analytical model which predicts laser energy depletion in this highly nonlinear regime. We demonstrate through PIC simulations that accelerated electrons can induce charge inversion within the channel, leading to positron trapping and acceleration. We investigate how laser focusing position, channel wall density, target foil position and target thickness influence positron creation and retention. Our configuration can achieve an 8-fold increase in positron retention compared to previous studies and a higher number of positrons produced overall. This work establishes a robust, single-stage approach for obtaining positron beams, opening new avenues for experiments with Petawatt-class lasers and potential applications in electron-positron collisions and QED cascades.

Biological applications at the AQUA beamline of the EuPRAXIA@SPARC_LAB free electron laser

Santis, Emiliano De; Andre, Tomas; Alleva, Stefania; Bean, Richard; Ferrario, Massimo; Marcelli, Augusto; Minicozzi, Velia; Principi, Emiliano; Timneanu, Nicusor; Caleman, Carl; Stellato, Francesco
EUROPEAN BIOPHYSICS JOURNAL (JUL 2025)
https://doi.org/10.1007/s00249-025-01778-4

The EuPRAXIA project is a European initiative aimed at developing groundbreaking, ultra-compact accelerator research infrastructures based on novel plasma acceleration concepts. The EuPRAXIA@SPARC_LAB facility, located in the Italian National Institute for Nuclear Physics-Frascati National Laboratory, will be the first operating Free Electron Laser facility of EuPRAXIA, based on an accelerator module driven by an electron bunch driver. The Free Electron Laser will produce ultra-short photon pulses in the soft X-ray region. The photons will be delivered to an endstation, called AQUA, to perform a wide range of experiments in atomic and molecular physics, chemistry, and life sciences for both academic and industrial users. Thanks to its wavelength, which falls within the so-called 'water window', AQUA will be particularly well-suited for coherent imaging and ion spectroscopy measurements on biological samples at room temperature in a fully hydrated environment. This unique capability opens up innovative experimental schemes for studying biological systems in states that closely resemble their physiological conditions. This paper presents numerical simulations of coherent diffraction imaging and Coulomb explosion imaging experiments, anticipating future studies at AQUA on biological samples.

Novel Radiation Facilities Based on Plasma Acceleration: The Future of Free Electron Lasers

Coreno, Marcello; Ferrario, Massimo; Marcelli, Augusto; Stellato, Francesco

CONDENSED MATTER 10(2), 25 (APR 2025)
https://doi.org/10.3390/condmat10020025

Radiative recombination as a transient spectroscopic fingerprint for sample oxidation using laser-induced XUV spectroscopy (LIXS)

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SPECTROCHIMICA ACTA PART B-ATOMIC SPECTROSCOPY 229, 107203 (JUL 2025)
https://doi.org/10.1016/j.sab.2025.107203

The deconvolution of Laser-Induced XUV Spectroscopy (LIXS) recombination signals for d-block transition and heavy metals, in hot and dense plasmas, was studied. Using a self-developed XUV spectrograph, ion stages of nickel (Ni) and gold (Au) under varying electron densities and plasma temperatures were investigated. The results revealed stabilization of specific ion species, with Ni favoring Ne-like configurations and Au exhibiting complex d-f orbital interactions. Supported by non-local thermodynamic equilibrium (NLTE) simulations, this study provides insights into plasma ionization dynamics and the robustness of closed-shell configurations as oxidation state proxies, enhancing LIXS applications in material analysis.

Fully plasma-based electron injector for a linear collider or XFEL

Dalichaouch, T. N.; Xu, X. L.; Li, F.; Tsung, F. S.; Mori, W. B.

PHYSICAL REVIEW RESEARCH 7(2), 023118
https://doi.org/10.1103/PhysRevResearch.7.023118

We demonstrate through high-fidelity particle-in-cell (PIC) simulations a simple approach for efficiently generating 20+ GeV electron beams with the necessary charge, energy spread, and emittance for use as an injector in a future linear collider or a next generation XFEL. A high quality injected bunch is generated by self-focusing an unmatched electron driver in a nonlinear plasma wakefield. Over pump depletion distances, the drive beam dynamics and self-loading effects lead to high energy, low-energy spread output beams. For plasma densities of 10^{18} cm^{-3}, PIC simulation results indicate that self-injected beams with 0.52 nC charge can be accelerated to 20 GeV with projected core energy spreads of < 1%, normalized slice emittances of 110 nm, peak normalized brightness of $>10^{19}$ $A/m^2/rad^2$, and transfer efficiencies of >44%.

Improvement of photon energy at X-ray free-electron lasers using plasma-based afterburner

Liu, Letian; Ma, Qianyi; Xia, Yuhui; Wang, Zhenan; Chen, Yuekai; Yang, Zhiyan; Cai, Dongchi; Xu, Zewei; Tang, Ziyao; Hu, Jianghao; An, Weiming; Feng, Chao; Yan, Xueqing; Xu, Xinlu

MATTER AND RADIATION AT EXTREMES 10(4), 047202 (JUL 2025)
https://doi.org/10.1063/5.0272184

X-ray free-electron lasers (XFELs) can generate bright X-ray pulses with short durations and narrow bandwidths, leading to extensive applications in many disciplines such as biology, materials science, and ultrafast science. Recently, there has been a growing demand for X-ray pulses with high photon energy, especially from developments in "diffraction-before-destruction" applications and in dynamic mesoscale materials science. Here, we propose utilizing the electron beams at XFELs to drive a meter-scale two-bunch plasma wakefield accelerator and double the energy of the accelerated beam in a compact and inexpensive way. Particle-in-cell simulations are performed to study the beam quality degradation under different beam loading scenarios and nonideal issues, and the results show that more than half of the accelerated beam can meet the requirements of XFELs. After its transport to the undulator, the accelerated beam can improve the photon energy to 22 keV by a factor of around four while maintaining the peak power, thus offering a promising pathway toward high-photon-energy XFELs.

Three-dimensional beam size compression for external injection of plasma wakefield acceleration

Shi, Xueyan; Ma, Ande; Li, Dazhang; Wang, Yiwei; Xu, Haisheng
RADIATION DETECTION TECHNOLOGY AND METHODS (JUL 2025)
https://doi.org/10.1007/s41605-025-00584-y

Plasma acceleration is a novel acceleration principle characterized by a high acceleration gradient. This area has garnered extensive research interest from major accelerator laboratories worldwide because of its potential to increase accelerator energy and reduce accelerator size. Currently, using existing conventional accelerators as external injectors for plasma-based accelerators is a promising direction that has attracted notable interest from the research community. However, a critical challenge is matching the three-dimensional beam sizes produced by conventional radio-frequency (RF) accelerators to the plasma accelerating structures. This alignment is crucial for utilizing existing non-state-of-the-art accelerators in plasma-based acceleration research. For instance, the BEPCII linac generates beams with transverse sizes approximately one millimeter and longitudinal sizes around ten picoseconds, while plasma accelerating structures are typically on the order of hundreds of micrometers. Addressing this mismatch is essential for advancing plasma acceleration research. In our recent work at BEPCII, we tackled the challenge of transporting both electron and positron beams from an RF linac into the plasma.

We adopted an innovative design concept that decouples longitudinal and transverse beam size compression, implementing them in separate stages. For transverse beam size compression, we utilized a global optimization method that balances the nominal beta functions with chromatic aberrations at the interaction point and provides self-compensation for chromatic aberrations along the beamline.

By using this approach, we developed a beam transport line for BEPCII that achieves a tenfold compression of the three-dimensional beam sizes produced by the conventional accelerator.

This paper presents our design concept and the resulting transport line design, demonstrating its effectiveness in addressing the beam size matching challenge for plasma acceleration.

THEORY & SIMULATION

Ten-moment fluid modeling of the Weibel instability

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JOURNAL OF PLASMA PHYSICS 91(2), E66 (APR 2025)
https://doi.org/10.1017/S0022377825000303

We investigate the one-dimensional non-relativistic Weibel instability through the capture of anisotropic pressure tensor dynamics using an implicit 10-moment fluid model that employs the electromagnetic Darwin approximation. The results obtained from the 10-moment model are compared with an implicit particle-in-cell simulation. The linear growth rates obtained from the numerical simulations are in good agreement with the theoretical fluid and kinetic dispersion relations. The fluid dispersion relations are derived using Maxwell's equations and the Darwin approximation. We also show that the magnetohydrodynamic approximation can be used to model the Weibel instability if one accounts for an anisotropic pressure tensor and unsteady terms in the generalised Ohm's law. In addition, we develop a preliminary theory for the saturation magnetic field strength of the Weibel instability, showing good agreement with the numerical results.

A particle-based field ionization algorithm in quasi-static PIC codes

Tang, Rong; An, Weiming; Wang, Jianzhao; Meng, Weiyu; Wang, Hainan; Zhong, Jiayong; Zhao, Yujian; Li, Fei; Su, Qianqian; Hildebrand, Lance; Dalichaouch, Thamine N.; Decyk, Viktor K.; Mori, Warren B.
PLASMA PHYSICS AND CONTROLLED FUSION 67(7), 075001 (JUL 2025)

https://doi.org/10.1088/1361-6587/ade3ff

Particle-in-cell (PIC) simulation code, especially the quasi-static PIC code, has been an indispensable tool to the development of the plasma wake field accelerator (PWFA). Such an advanced accelerator scheme uses a drive particle beam or a laser pulse to generate wake fields inside a plasma for accelerating another particle beam. The acceleration gradient can be 10 GeV m^{-1} or higher in the PWFA, which makes it a promising candidate as the main acceleration method in the future high energy electron-positron colliders or x-ray free electron laser facilities. In the plasma wake field acceleration, the plasma can be generated by ionizing the neutral gas with the Coulomb field around the particle beam or the electric field of the laser pulse. Therefore, the field ionization process plays a key role in the plasma wake field acceleration experiments. The 3D PIC code QuickPIC, which is based on the quasi-static approximation, has been widely used for efficiently modeling the PWFA problems including the field ionization process. However, the current field ionization algorithm in QuickPIC cannot simulate mobile ions. In this work, we developed a particle-based ionization method in order to track the motion of ions that generated during the ionization process. We also implement the new algorithm in another quasi-static PIC code QPAD, which additionally applied the azimuthal Fourier decomposition method compared with QuickPIC. The comparison of simulation results between the old and new algorithm and between QuickPIC and QPAD are presented. The comparison shows that for the plasma wake field acceleration simulation without the plasma ion motion, the particle-based method works as well as the old algorithm in both codes of QuickPIC and QPAD. When including the mobile ions in the field ionized plasma, QuickPIC and QPAD with the particle-based method show a well agreement with each other.

Visualization of High-Intensity Laser-Matter Interactions in Virtual Reality and Web Browser

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PHOTONICS 12(5), 436 (APR 2025)
https://doi.org/10.3390/photonics12050436

We present the Virtual Beamline (VBL) application, an interactive web-based platform for visualizing high-intensity laser-matter interactions using particle-in-cell (PIC) simulations, with future potential for experimental data visualization. These interactions include ion acceleration, electron acceleration, gamma-flash generation, electron-positron pair production, and attosecond and spiral pulse generation. Developed at the ELI Beamlines facility, VBL integrates a custom-built WebGL engine with WebXR-based Virtual Reality (VR) support, allowing users to explore complex plasma dynamics in non-VR mode on a computer screen or in fully immersive VR mode using a head-mounted display. The application runs directly in a standard web browser, ensuring broad accessibility. VBL enhances the visualization of PIC simulations by efficiently processing and rendering four main data types: point particles, 1D lines, 2D textures, and 3D volumes. By utilizing interactive 3D visualization, it overcomes the limitations of traditional 2D representations, offering enhanced spatial understanding and real-time manipulation of visualization parameters such as time steps, data layers, and colormaps. Users can interactively explore the visualized data by moving their body or using a controller for navigation, zooming, and rotation. These interactive capabilities improve data exploration and interpretation, making VBL a valuable tool for both scientific analysis and educational outreach. The visualizations are hosted online and freely accessible on our server, providing researchers, the general public, and broader audiences with an interactive tool to explore complex plasma physics simulations. By offering an intuitive and dynamic approach to large-scale datasets, VBL enhances both scientific research and knowledge dissemination in high-intensity laser-matter physics.

Neural-network-based longitudinal electric field prediction in nonlinear plasma wakefield accelerators

Wang, Xiaoning; Zeng, Ming; Li, Dazhang; An, Weiming; Lu, Wei
PLASMA PHYSICS AND CONTROLLED FUSION 67(5), 055038 (MAY 2025)

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Plasma wakefield acceleration holds remarkable promise for future advanced accelerators. The design and optimization of plasma-based accelerators typically require particle-in-cell simulations, which can be computationally intensive and time consuming. In this study, we train a neural network model to obtain the on-axis longitudinal electric field distribution directly without conducting particle-in-cell simulations for designing a two-bunch plasma wakefield acceleration stage. By combining the neural network model with an advanced algorithm for achieving the minimal energy spread, the optimal normalized charge per unit length of a trailing beam leading to the optimal beam-loading can be quickly identified. This approach can reduce computation time from around 7.6 min in the case of using particle-in-cell simulations to under 0.1 s. Moreover, the longitudinal electric field distribution under the optimal beam-loading can be visually observed. Utilizing this model with the beam current profile also enables the direct extraction of design parameters under the optimal beam-loading, including the maximum decelerating electric field within the drive beam, the average accelerating electric field within the trailing beam and the transformer ratio. This model has the potential to significantly improve the efficiency of designing and optimizing the beam-driven plasma wakefield accelerators.

Toward intelligent control of MeV electrons and protons from kHz repetition rate ultra-intense laser interactions

Tamminga, Nathaniel; Feister, Scott; Frische, Kyle D.; Desai, Ronak; Snyder, Joseph; Felice, John J.; Smith, Joseph R.; Orban, Chris; Chowdhury, Enam A.; Dexter, Michael L.; Patnaik, Anil K.

APL MACHINE LEARNING 3(2), 026115 (JUN 2025)
https://doi.org/10.1063/5.0253529

Ultra-intense laser-matter interactions are often difficult to predict from first principles because of the complexity of plasma processes and the many degrees of freedom relating to the laser and target parameters. An important approach to controlling and optimizing ultra-intense laser interactions involves gathering large datasets and using these data to train statistical and machine learning models. In this paper, we describe experimental efforts to accelerate electrons and protons to ~ MeV energies with this goal in mind. These experiments involve a 1 kHz repetition rate ultra-intense laser system with ~ 10 mJ per shot, a peak intensity near 5 x 10^{18} W/cm^2, and a "liquid leaf" target. Improvements to the data acquisition capabilities of this laser system greatly aided this investigation. Generally, we find that the trained models were very effective in controlling the numbers of MeV electrons ejected. The models were less successful at shifting the energy range of ejected electrons. Simultaneous control of the numbers of ~ MeV electrons and the energy range will be the subject of future experimentation using this platform.

Modeling laser-wakefield accelerators using the time-averaged ponderomotive approximation in a Lorentz boosted frame

Massimo, F.; Benedetti, C.; Terzani, D.; Beck, A.; Cros, B.

PLASMA PHYSICS AND CONTROLLED FUSION 67(6), 065032 (JUN 2025)
https://doi.org/10.1088/1361-6587/addc97

Future, high-fidelity simulations of multi-GeV-class laser Wakefield accelerators (LWFAs) will need to model the propagation of high-intensity laser drivers over meter-scale plasmas with high spatial and temporal resolutions, thus requiring high amounts of computational resources. Various techniques have been devised over the years to reduce the computational cost of such simulations, including the time-averaged ponderomotive approximation, and the use of the Lorentz boosted frame technique. In this paper we discuss the combination of these two computational techniques, highlighting the resulting significant reduction in the computational cost of LWFA simulations and the limitations of this approach. The combination of the two techniques can potentially become essential for the modeling of a multi-TeV, LWFA-based collider.

Artificial intelligence time series forecasting for feed-forward laser stabilization

Berger, Curtis; Gonsalves, Anthony; Jensen, Kyle; van Tilborg, Jeroen; Wang, Dan; Amodio, Alessio; Barber, Sam

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS; SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1078, 170561 (SEP 2025)
https://doi.org/10.1016/j.nima.2025.170561

Laser plasma accelerators, typically operating at 1-10 Hz repetition rates, have the ability to produce high-quality electron beams in compact, all-optical-driven configurations, with the electron beams uniquely suited for a wide variety of accelerator-based applications. However, fluctuations and drifts in the laser delivery to the meter-scaled and below plasma target (the electron beam source) will translate into electron beam source variations that can limit their utility for demanding applications like light sources or linear colliders. Commercially available active feedback laser stabilization systems are intrinsically bandwidth limited due to their integration with multi-inch corrective mirror mounts which minimizes their effectiveness. In this manuscript, we present a Neural Network time series forecaster that can predict laser position fluctuations of the laser delivery to the final target well ahead of a future laser shot. The Root-Mean-Square-Error (RMSE) of the prediction accuracy was <2 μm for a $1/e^2$ beam radius of 34 μm. Our feed-forward approach serves as a first-step in circumventing the bandwidth limitations imposed by the currently available stabilization systems since it allows for mirrors to be moved into position ahead of time to offset the predicted future position drift. This will help advance laser plasma accelerator research by providing greater robustness and stability needed for its applications.

Hydrodynamic modeling of plasma channel systems for laser plasma accelerators

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1079, 170610 (OCT 2025)
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Structured plasma channels are an essential technology for driving high-gradient, plasma-based acceleration and control of electron and positron beams for advanced concepts accelerators. Laser and gas technologies can permit the generation of long plasma columns known as hydrodynamic, optically-field-ionized (HOFI) channels, which feature low on-axis densities and steep walls. By carefully selecting the background gas and laser properties, one can generate narrow, tunable plasma channels for guiding high intensity laser pulses. We present on the development of simulations of HOFI channels using the FLASH code, a publicly available radiation hydrodynamics code. We explore sensitivities of the channel evolution to laser profile, intensity, and background gas conditions, and identify relevant scalings with laser intensity through a range of practical channel delays.

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