THE EuPRAXIA FILES

ISSUE 15 – May 2025

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.

Since the last issue, an important decision has been taken by the Collaboration Board. The expert panel has proposed to the EuPRAXIA governing body to endorse the choice of ELI-ERIC Beamlines as second site for the ESFRI Research Infrastructure, and the proposal has been unanimously accepted. The other two candidates, EPAC-STFC and INO-CNR will act as national nodes/facilities centres, with the Harwell Laboratory devoted to the R&D toward 5 GeV FEL-quality electron beams, and the Pisa Laboratory working in strict connection with the Prague site, especially in developing industrial laser options.

Considering this important milestone, The EuPRAXIA files can bring further insights in supporting the implementation of our research sites. I wish you an interesting reading.

Pierluigi Campana

CONTENTS

FUNDAMENTALS

Optical Imaging of Laser-Driven Fast Electron Weibel-like Filamentation in Overcritical Density Plasma

Dover, N. P.; Tresca, O.; Cook, N.; Ettlinger, O. C.; Kingham, R. J.; Maharjan, C.; Polyanskiy, M. N.; Shkolnikov, P.; Pogorelsky, I.; Najmudin, Z.

PHYSICAL REVIEW LETTERS 134(2), 025102 (JAN 2025)
https://doi.org/10.1103/PhysRevLett.134.025102

We report on the measurement of filamented transport of laser-generated fast electron beams in near-critical density plasma. A relativistic intensity long-wave-infrared laser irradiated a hydrodynamically shaped helium gas flow at an electron density $n_e \simeq 10^{25}$ m^{-3}, generating a large flux of fast electrons that propagated beyond the critical surface. The beam-to-background electron density ratio was sufficiently high to drive growth of Weibel-like filamentation, which was measured by optical probing to extend up to 800 µm with radii 10 µm. Particle-in-cell simulations reproduce the main features of the filamentation generation, suggesting that collisionless processes are dominant in these interactions. Expansion of the filaments after formation infers a fast electron heated plasma temperature 400 eV in the overcritical density plasma.

Experimental Observation of the Motion of Ions in a Resonantly Driven Plasma Wakefield Accelerator

Turner, M.; Walter, E.; Amoedo, C.; Torrado, N.; Lopes, N.; Sublet, A.; Bergamaschi, M.; Pucek, J.; Mezger, J. et al. (AWAKE Collaboration)

PHYSICAL REVIEW LETTERS 134, 155001 (APR 2025)
https://doi.org/10.1103/PhysRevLett.134.155001

We show experimentally that an effect of motion of ions, observed in a plasma-based accelerator, depends inversely on the plasma ion mass. The effect appears within a single wakefield event and manifests itself as a bunch tail, occurring only when sufficient motion of ions suppresses wakefields. Wakefields are driven resonantly by multiple bunches, and simulation results indicate that the ponderomotive force causes the motion of ions. In this case, the effect is also expected to depend on the amplitude of the wakefields, experimentally confirmed through variations in the drive bunch charge.

Coupling and acceleration of externally injected electron beams in laser-driven plasma wakefields

Maity, Srimanta; Sasorov, Pavel; Molodozhentsev, Alexander

JOURNAL OF PHYSICS D-APPLIED PHYSICS 58(14), 145204 (APR 2025)
https://doi.org/10.1088/1361-6463/adb6b9

The multi-stage method of laser wakefield acceleration (LWFA) presents a promising approach for developing stable, full-optical, high-energy electron accelerators. By segmenting the acceleration process into several booster stages, each powered by independent laser drivers, this technique effectively mitigates challenges such as electron dephasing, pump depletion, and laser diffraction. A critical aspect of multi-stage LWFA is the nonlinear interaction between the injected electron beam and the laser-driven wakefields in the booster stage. This study investigates the injection and acceleration of external electron beams within wakefields in the booster stage using multi-dimensional particle-in-cell simulations. We provide both qualitative and quantitative descriptions of the observed physical processes. Key parameters influencing charge coupling process and the resultant beam quality have been identified. Furthermore, we have examined how off-axis injection relative to the driver laser influences the acceleration process and beam quality. Our findings provide valuable insights for advancing and optimizing multi-stage plasma-based accelerators.

Development of self-modulation as a function of plasma length

Clairembaud, Arthur; Turner, Marlene; Muggli, Patric
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1073, 170265 (APR 2025)
https://doi.org/10.1016/j.nima.2025.170265

We use numerical simulations to determine whether the saturation length of the self-modulation (SM) instability of along proton bunch in plasma could be determined by measuring the radius of the bunch halo SM produces. Results show that defocused protons acquire their maximum transverse momentum and exit the wakefields at a distance approximately equal to the saturation length of the wakefields. This suggests that measuring the radius of the halo as a function of plasma length in the AWAKE experiment would yield a very good estimate for the saturation length of SM.

Performance envelope of laser wakefield accelerators

Labun, Lance; Gracia-Linares, Miguel; Labun, Ou Z.; Milton, Stephen, V
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1076, 170468 (JUL 2025)
https://doi.org/10.1016/j.nima.2025.170468

Laser wakefield accelerator experiments have made enormous progress over the past $\sim$ 20 years, but their promise to revolutionize high-energy particle sources is only beginning to be realized. To make the next step toward engineering LWFAs for different accelerator outcomes, we need more reliable and quantitative models to predict performance. Using the data from > 50 published experiments, we estimate scalings and the performance envelope. We compare the observed scalings with several models in the literature. We find that the total beam energy (centroid energy times beam charge) scales almost linearly with laser energy, supporting the value of investment in progressively higher energy driver lasers. The dataset includes pulse durations from 8 to 160 fs, but only laser wavelengths of 800 nm and 1 μm, meaning we could not check proposed wavelength scalings for alternative laser technologies. As a benchmark next-generation case, the observed scalings suggest that achieving a 100-GeV LWFA stage will require a $\gtrsim$ 30 PW laser operating at electron density < $10^{17}/cm^3$.

Direct visualization of shock front induced nonlinear laser wakefield dynamics

Levine, Eitan Y.; Wan, Yang; Tata, Sheroy; Raspopova, Daria; Kroupp, Eyal; Malka, Victor
PHYSICAL REVIEW RESEARCH 7(1), L012041 (FEB 2025)
https://doi.org/10.1103/PhysRevResearch.7.L012041

Laser-plasma acceleration is considered to be a promising candidate for compactly delivering high-energy high-quality electron beams. One of the most common methods for injecting plasma electrons into the wakefield structure is the shock front injection. Here we present the first direct visualization of the nonlinear laser wakefield dynamics resulting from a tilted shock front using the femtosecond relativistic electron microscopy technique. Our observations reveal the occurrence of a split in the wakefield, with the formation of an on-axis laser-driven wakefield and an off-axis beam-driven wakefield just after the passage through the hydrodynamic shock. Using experimental and three-dimensional numerical evidence, we identify the mechanism of this newly observed phenomenon as an off-axis electron injection from the tilted shock, which amplified the betatron oscillations of the bunch until its breakup. These results propel our comprehension of the intricate and nonlinear laser-plasma dynamics within the widely employed shock-front injection scheme, providing crucial information for high-quality beam generation in real-time operations.

Electron acceleration in ambient air using tightly focused ultrashort infrared laser beams

Lytova, Marianna; Fillion-Gourdeau, Francois; Vallieres, Simon; Fourmaux, Sylvain; Payeur, Stephane; Powell, Jeffrey; Legare, Francois; MacLean, Steve
PHYSICAL REVIEW E 111(3), 035210 (MAR 2025)
https://doi.org/10.1103/PhysRevE.111.035210

Recent experimental and theoretical results have demonstrated the possibility of accelerating electrons in the MeV range by focusing tightly a few-cycle laser beam in ambient air [S. Vallières et al., High dose-rate MeV electron beam from a tightly-focused femtosecond IR laser in ambient air, Laser Photonics Rev. 18, 2300078 (2024)]. Using Particle-In-Cell (PIC) simulations, this configuration is revisited within a more accurate modeling approach to analyze and optimize the mechanism responsible for electron acceleration. In particular, an analytical model for a linearly polarized tightly focused ultrashort laser field is derived and coupled to a PIC code, allowing us to model the interaction of laser beams reflected by high-numerical aperture mirrors with laser-induced plasmas. A set of 3D PIC simulations is performed where the laser wavelength is varied from 800 nm to 7.0 μm while the normalized amplitude of the electric field is varied from $a_0 = 3.6$ to $a_0 = 7.0$. The preferential forward acceleration of electrons, as well as the analysis of the laser intensity evolution in the plasma and data on electron number density, confirm that the relativistic ponderomotive force is responsible for the acceleration. We also demonstrate that the electron kinetic energy reaches a maximum of approximate to 1.6 MeV when the central wavelength is of 2.5 μm.

Effect of frequency-chirped ionization laser on accelerated electron beam characteristics in plasma wakefield acceleration

Singh, Jagnishan; Kumar, Sandeep; Kant, Niti; Rajput, Jyoti
EUROPEAN PHYSICAL JOURNAL PLUS 140(2), 135 (FEB 2025)
https://doi.org/10.1140/epjp/s13360-025-06061-1

Trojan Horse underdense photocathode plasma wakefield acceleration is an effective technique for generating ultralow-emittance electron bunches. In this study, we investigate the impact of frequency chirp in the ionization laser on the properties of the accelerated electron bunches using two-dimensional (2D) particle-in-cell (PIC) simulations. It is found that the total charge of the high-energy electrons produced in the acceleration process depends strongly on the magnitude and the sign of frequency chirp in ionization laser. For an un-chirped ionization laser, an electron bunch gets a maximum acceleration of up to 400 MeV with bunch current $I_p \sim 0.27$kA. However, the use of a negative-chirped ionization laser shows lower energy gain, i.e., 200 MeV with an enhanced bunch current $I_p \sim 5$kA, with normalized emittance $\varepsilon_n \sim 0.78$ μm in 7.5-mm-long plasma channel. Such high current electron bunches will be useful for compact hard X-ray free-electron laser (FEL) sources.

Wakefield generation and electron acceleration via propagation of radially polarized laser pulses in homogeneous plasma

Aggarwal, Shivani; Singh, Saumya; Mishra, Dinkar; Kumar, Bhupesh; Jha, Pallavi
LASER PHYSICS 35(4), 045401 (APR 2025)
https://doi.org/10.1088/1555-6611/adbad5

This paper presents a study of wakefield generation and electron injection via the propagation of radially polarized laser pulses in homogeneous pre-ionized plasma. The analytical study is based on Lorentz force and continuity equations. A perturbation technique and quasi-static approximations are used to evaluate the generated longitudinal wakefields. Trapping and acceleration of electrons are examined by injecting test electrons into the generated wakefields. The results are compared with those obtained via linearly polarized laser pulses. Validation of the analytical results is performed using the Fourier-Bessel particle-in-cell simulation code. It is shown that there is a significant enhancement in the amplitude of the longitudinal wakefield generated and electron energy gain via radially polarized laser pulses as compared to the linearly polarized laser pulse case.

Enhanced plasma wave excitation in a tapered plasma channel through chirped laser beatwaves

Arefnia, M.; Kim, S.; Lee, C.; Ghorbanalilu, M.; Suk, H.
AIP ADVANCES 15(2), 025301 (FEB 2025)
https://doi.org/10.1063/5.0245587

The excitation of plasma waves by the beatwave of two-color laser beams within a tapered plasma channel has been investigated both analytically and through particle-in-cell (PIC) simulations. This study presents a promising approach for beatwave accelerators. The design aims to achieve a more stable and enhanced plasma wave amplitude, even under non-resonant conditions, compared to untapered channels. For the analytical description, we solved the plasma wave equation generated by two beating laser beams propagating through a tapered channel with a linear radial density profile. The study further validates its results by comparing the analytical predictions with PIC simulations of the beatwave phenomenon in the tapered channel. The findings confirm that this design significantly enhances plasma wave amplitude compared to untapered channels. In addition, we demonstrated that employing a chirped laser pulse with a fast rise time can significantly increase the strength of the plasma wave.

CONTROL & OPTIMIZATION

ENERGY SPREAD & EMITTANCE

Active energy compression of a laser-plasma electron beam

Winkler, P.; Trunk, M.; Huebner, L.; de la Ossa, A. Martinez; Jalas, S.; Kirchen, M.; Agapov, I.; Antipov, S. A.; Brinkmann, R.; Eichner, T.; Pousa, A. Ferran; Huelsenbusch, T.; Palmer, G.; Schnepp, M.; Schubert, K.; Thevenet, M.; Walker, P. A.; Werle, C.; Leemans, W. P.; Maier, A. R.
NATURE (APR 2025)
https://doi.org/10.1038/s41586-025-08772-y

Radio-frequency (RF) accelerators providing high-quality relativistic electron beams are an important resource enabling many areas of science, as well as industrial and medical applications. Two decades ago, laser-plasma accelerators that support orders of magnitude higher electric fields than those provided by modern RF cavities produced quasi-monoenergetic electron beams for the first time. Since then, high-brightness electron beams at gigaelectronvolt (GeV) beam energy and competitive beam properties have been demonstrated from only centimetre-long plasmas, a substantial advantage over the hundreds of metres required by RF-cavity-based accelerators. However, despite the considerable progress, the comparably large energy spread and the fluctuation (jitter) in beam energy still effectively prevent laser-plasma accelerators from driving real-world applications. Here we report the generation of a laser-plasma electron beam using active energy compression, resulting in a performance so far only associated with modern RF-based accelerators. Using a magnetic chicane, the electron bunch is first stretched longitudinally to imprint an energy correlation, which is then removed with an active RF cavity. The resulting energy spread and energy jitter are reduced by more than an order of magnitude to below the permille level, meeting the acceptance criteria of a modern synchrotron, thereby opening the path to a compact storage ring injector and other applications.

Sub-per-mille bunch energy spread in a quasi-linear laser-wakefield accelerator via periodical de-chirpings

Yu, Changhai; Qin, Zhiyong; Xiang, Zhongtao; Huang, Ya; Liu, Jiansheng
COMMUNICATIONS PHYSICS 8(1), 137 (APR 2025)
https://doi.org/10.1038/s42005-025-02057-6

Plasma-wakefield-based acceleration technology has enabled the generation of very bright particle bunches of ultrashort duration, micrometer size and low emittance. However, it is still extremely challenging to break through the barrier of per-mille energy spread. Here, we utilize a quasi-linear laser-driven wakefield accelerator with a uniquely designed density-modulated plasmas to achieve periodical de-chirpings of the seeded bunch and have almost eliminated the accumulated energy chirp in each period during the periodical quasi-phase-stable acceleration. Quasi-three-dimensional particle-in-cell simulations verify that a quasi-linear plasma wave with a stable propagation of more than 30-fold Rayleigh lengths can be generated to stably accelerate both the electron and positron bunches up to GeV scale. The energy spread of the bunch can be ultimately reduced to be less than 0.05% while maintaining a small beam emittance. This scheme is highly feasible and desirable for achieving an ultralow-energy-spread plasma-based accelerator and facilitating broader applications.

Achieving high quality electron beam with ultralow energy spread from mismatched plasma channels

Guan, Jiabao; Lei, Qiannan; Zhong, Jianhua; Liu, Lanxin; Nie, Yuancun; Xia, Guoxing; Wang, Jike
SCIENTIFIC REPORTS 15(1), 11774 (APR 2025)
https://doi.org/10.1038/s41598-025-90741-6

Intense electric fields generated by laser plasma wakefield accelerators can rapidly accelerate electrons to high energies over short distances, potentially reducing both the length and cost of accelerator facilities significantly. However, the electron beams produced often exhibit substantial energy spreads, which imposes significant constraints on their broader applicability. We propose a novel method for reducing energy spread by utilizing periodic changes in the acceleration field slope induced by mismatched plasma channels, allowing for periodic compensation of the energy spread. Simulations of a 1GeV, 10pC electron accelerator demonstrate that this method can reduce the energy spread of the electron beam to 0.17%, while effectively preserving other beam quality parameters. This approach is approaching the state-of-the-art in laser plasma wakefield accelerators and holds promise for applications in free electron lasers and synchrotron radiation source injectors.

Simulation of laser plasma wakefield acceleration with external injection based on Bayesian optimization

Zhong, Jianhua; Guan, Jiabao; Liu, Lanxin; Xia, Guoxing; Wang, Jike; Nie, Yuancun
PLASMA SCIENCE & TECHNOLOGY 27(4), 044003 (APR 2025)
https://doi.org/10.1088/2058-6272/ad91e8

In laser wakefield acceleration, injecting an external electron beam at a certain energy is a promising approach for achieving a high-quality electron beam with low energy spread and low emittance. In this paper, the process of laser wakefield acceleration with an external injection at 10 pC has been studied in simulations. A Bayesian optimization method is used to optimize the key laser and plasma parameters so that the electron beam is accelerated to the expected energy with a small emittance and energy spread growth. The effect of the rising edge of the plasma on the transverse properties of the electron beam is simulated and optimized in order to ensure that the external electron beam is injected into the plasma without significant emittance growth. Finally, a high-quality electron beam with an energy of 1.5 GeV, a normalized transverse emittance of 0.5 mm · mrad and a relative energy spread of 0.5% at 10 pC is obtained.

All-Optical Blast-Wave Control of Laser Wakefield Acceleration in a Near-Critical Plasma

Tsymbalov, I.; Gorlova, D.; Ivanov, K.; Starodubtseva, E.; Volkov, R.; Tsygvintsev, I.; Kochetkov, Yu.; Korneev, Ph.; Polonski, A.; Savel'ev, A.
PHYSICAL REVIEW LETTERS 134(2), 025101 (JAN 2025)
https://doi.org/10.1103/PhysRevLett.134.025101

We propose a novel method for changing the length of laser wakefield electron acceleration in a gas jet using a cylindrical blast-wave created by a perpendicularly focused nanosecond laser pulse. The shock front modifies the wake significantly and stops interaction between the laser pulse and accelerated electron bunch, allowing one to directly control the interaction length and avoid dephasing. It also improves the electron beam quality through the plasma lensing effect between the two shock fronts. We demonstrated both experimentally and numerically how this approach can be used to form a quasi-monoenergetic electron bunch with controlled energy and improved divergence as well as tracking changes in the bunch parameters during acceleration.

ENERGY GAIN

Optimizing laser wakefield acceleration through plasma density profile analysis

Singh, Jagnishan; Rajput, Jyoti; Kumar, Sandeep
JOURNAL OF OPTICS-INDIA (APR 2025)
https://doi.org/10.1007/s12596-025-02677-9

Laser wakefield acceleration (LWFA) is a promising method for compact particle acceleration with prospective applications in high-energy physics and medical sciences. This study compares how different plasma density profiles influence the effectiveness of LWFA. In this study, we investigate the electron acceleration dynamics in plasma structures with varying density profiles using detailed numerical simulations and theoretical studies. Generated wake potential, wakefield and energy gain are observed for the different plasma density profiles. The findings show that the wakefield, wake potential and final energy gain are strongly influenced by plasma density. Through the strategic optimization of plasma and laser parameters, including the plasma density profile and laser field parameter, it is possible to exert control over the generated wakefield and wake potential, thus maximizing the energy gain to a maximum of 393 MeV. The fundamental purpose of this research is to develop accurate correlations to improve LWFA settings, gain a better knowledge of plasma-assisted particle acceleration, and realize the untapped potential of this exciting technology.

Acceleration rate enhancement by negative plasma density gradient in multi-bunch driven plasma wakefield accelerator

Okhotnikov, N. V.; Lotov, K. V.
PHYSICS OF PLASMAS 32(3), 033102 (MAR 2025)
https://doi.org/10.1063/5.0249127

In a plasma wakefield accelerator driven by a train of short particle bunches, it is possible to locally increase the acceleration rate by slightly decreasing the plasma density and introducing its small negative gradient. There is a regime in which changing the density affects only the relative phasing of the driver bunches and the wave, keeping the wave phase behind the driver stable. With this technique, it is possible to increase the energy gain of the accelerated witness bunch in a plasma section of limited length.

Energy boosting and scaling of self-guided hybrid laser-plasma wakefield acceleration in a single uniform plasma

Chang, Xinyuan; Zeng, Ming; Wang, Jia; Li, Dazhang
NEW JOURNAL OF PHYSICS 27(2), 023021 (FEB 2025)
https://doi.org/10.1088/1367-2630/adb2b9

In laser-driven plasma wakefield acceleration (LWFA), laser pump depletion and electron dephasing are the major constraints of the electron energy gain. Hybrid laser-PWFA, which uses the laser-accelerated electron beam to drive a beam-driven plasma wakefield in separated stages, has been proposed to increase the beam brightness. However, the overall electron energy gain in hybrid acceleration is even lower than single-stage laser acceleration. In this paper, we report the observation of the energy boosting effect of the hybrid acceleration in single uniform plasmas through a series of particle-in-cell simulations. The self-injected electron beam from the laser-driven wakefield automatically moves forward to drive the beam-driven wakefield after laser depletion. The electrons at the beam tail are then accelerated by the beam-driven plasma wakefield, and the energy gain is at least doubled compared to previous single-stage experiments with the same laser energy. We also propose the scaling of the electron energy gain and the acceleration distance with the laser energy. For example, with a 9.1 J energy laser pulse and a 3.5 cm long plasma of $1.6\mathrm{x}10^{18}$ cm^{-3} density, one can produce a quasi-monoenergetic electron beam at 3.5 GeV energy with 23 pC charge.

BEAM CHARGE & LUMINOSITY

Wakefield regeneration in a plasma accelerator

Farmer, J. P.; Della Porta, G. Zevi
PHYSICAL REVIEW RESEARCH 7(1), L012055 (MAR 2025)
https://doi.org/10.1103/PhysRevResearch.7.L012055

Plasma wakefields offer high acceleration gradients, orders of magnitude larger than conventional RF accelerators. However, the achievable luminosity remains relatively low, typically limited by the repetition rate and the charge accelerated per shot. In this work, we show that a train of drive bunches can be harnessed to accelerate multiple witness bunches in a single shot. We demonstrate that periodically loading the wakefields removes the limit on the energy transfer from the drive beam to the plasma, which allows the luminosity to be increased. Proof-of-concept simulations for the AWAKE scheme are carried out to demonstrate the technique, achieving a doubling of the accelerated charge while exploiting only a fraction of the drive train.

Physics of high-charge laser-plasma accelerators for few-MeV applications

Martelli, L.; Kononenko, O.; Andriyash, I. A.; Wheeler, J.; Gautier, J.; Goddet, J. -p.; Tafzi, A.; Lahaye, R.; Giaccaglia, C.; Flacco, A.; Tomkus, V.; Mackeviciute, M.; Dudutis, J.; Stankevic, V.; Gecys, P.; Raciukaitis, G.; Kraft, H.; Dinh, X. Q.; Thaury, C.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 28(3), 034033 (MAR 2025)
https://doi.org/10.1103/PhysRevApplied.23.034033

Laser-plasma accelerators represent a promising technology for future compact accelerating systems, enabling the acceleration of tens of pC to above 1 GeV over just a few centimeters. Nonetheless, these devices currently lack the stability, beam quality, and average current of conventional systems. While many efforts have focused on improving acceleration stability and quality, little progress has been made in increasing the beam's average current, which is essential for future laser-plasma-based applications, such as three-dimensional X-ray tomography for cargo inspection. In this paper, we investigate a laser-plasma

acceleration regime aimed at increasing the beam average current with energies up to few MeVs, efficiently enhancing the beam charge. We present experimental results on configurations that allow reaching charges of 5-30 nC and a maximum conversion efficiency of around 14%. Through comprehensive particle-in- cell simulations, we interpret the experimental results and present a detailed study on electron dynamics. From our analysis, we show that most electrons are not trapped in a plasma wave; rather, they experience ponderomotive acceleration. Thus, we prove the laser pulse as the main driver of the particles' energy gain process.

TECHNOLOGY

DIAGNOSTICS

Reconstruction of beam parameters and betatron radiation spectra measured with a Compton spectrometer

Yadav, M.; Oruganti, M. H.; Naranjo, B.; Zhang, S.; Andonian, G.; Zhuang, Y.; Apsimon, O.; Welsch, C. P.; Rosenzweig, J. B.

PHYSICAL REVIEW ACCELERATORS AND BEAMS 28(4), 042802 (APR 2025)

https://doi.org/10.1103/PhysRevAccelBeams.28.042802

The photon flux resulting from high-energy electron beam interactions with high-field systems, such as those found in the upcoming FACET-II experiments at the SLAC National Accelerator Laboratory, yields deep insight into the electron beam's underlying dynamics during the interaction. However, extracting this information is an intricate process. To demonstrate how to approach this challenge using modern methods, this paper utilizes simulated data that models plasma wakefield acceleration-derived betatron radiation in experiments to determine reliable methods of reconstructing key beam and beam-plasma interaction properties. For betatron radiation measurements, translating the observed 200 keV to 30 MeV photon double-differential energy-angle spectra obtained from an advanced Compton spectrometer requires testing multiple methods to optimize the pipeline from its response to incident electron beam information. The paper compares maximum likelihood estimation and machine learning to refine the translation of photon spectra into precise electron beam metrics, such as spot size, energy, and emittance, enhancing the understanding of beam behavior within these dense, high-field environments. We also introduce machine learning and the expected maximization algorithm to reconstruct the primary photon spectrum, employing a multilayer neural network for regression analysis of the energy and angle spectra. With appropriate modifications, the advanced methods reproduce relevant incident beam parameters with high accuracy, even for beam sizes in the <10 µm range. This capacity is critical to understanding intense beam propagation and its optimization in plasma.

Design and experimental verification of a bunch length monitor based on coherent Cherenkov diffraction radiation

Davut, C.; Xia, G.; Apsimon, O.; Mcgunigal, J.; Karataev, P.; Lefevre, T.; Mazzoni, S.; Senes, E.

PHYSICAL REVIEW ACCELERATORS AND BEAMS 28(2), 013193 (FEB 2025)

https://doi.org/10.1103/PhysRevResearch.7.013193

This paper presents the design and experimental commissioning of a noninvasive electron bunch length monitor based on the detection of coherent Cherenkov diffraction radiation (ChDR). The measurement technique effectively eliminates the influence of bunch-by-bunch charge fluctuations, as each detector measures the signal from the same bunch while mitigating the impact of bunch position jitter on the measurements, providing a potential real-time diagnostic tool with significant operational advantages. The sensitivity of the measurements to both bunch length and longitudinal bunch profile was experimentally demonstrated, with results validated against invasive radio frequency deflector measurements at the CLEAR electron test facility at CERN. The ChDR bunch length monitor can be applied to accelerators operating with ultrashort bunches.

Implementation of light diagnostics for wakefields at AWAKE

Mezger, J.; Bergamaschi, M.; Ranc, L.; Sublet, A.; Pucek, J.; Turner, M.; Clairembaud, A.; Muggli, P.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1075, 170426 (JUN 2025)
https://doi.org/10.1016/j.nima.2025.170426

We describe the implementation of light diagnostics for studying the self-modulation instability of a long relativistic proton bunch in a 10 m-long plasma. The wakefields driven by the proton bunch dissipate their energy in the surrounding plasma. The amount of light emitted as atomic line radiation is related to the amount of energy dissipated in the plasma. We describe the setup and calibration of the light diagnostics, configured for a discharge plasma source and a vapor plasma source. For both sources, we analyze measurements of the light from the plasma only (no proton bunch). We show that with the vapor plasma source, the light signal is proportional to the energy deposited in the vapor/plasma by the ionizing laser pulse. We use this dependency to obtain the parameters of an imposed plasma density step. This dependency also forms the basis for ongoing studies, focused on investigating the wakefield evolution along the plasma.

Transient chirp reconstruction of an ultrafast electron beam via a tightly focused chirped laser pulse

Zhang, Zhijun; Zhou, Shiyi; Liu, Jiansheng
OPTICS LETTERS 50(6), 2025-2028 (MAR 2025)
https://doi.org/10.1364/OL.552063

Controlling particle beam phase space is essential for producing high-quality, ultrashort electron beams (e-beams) in plasma-based accelerators. Diagnosing the rapidly evolving transient energy chirp during early acceleration remains challenging. We propose what we believe to be a novel method using tightly focused and chirped laser pulses to reconstruct the chirp profile. By analyzing conditions for enhancing divergence modulation and leveraging intrinsic phase correlations in phase space, precise chirp reconstruction is achieved. Additionally, temporal delay between the laser and e-beam is determined via Fourier analysis of the divergence modulation. This method enables attosecond-level precision laser streaking for relativistic ultrashort e-beams, offering a powerful tool for ultrafast electron dynamics diagnosis. (c) 2025 Optica Publishing Group.

Compact in-vacuum gamma-ray spectrometer for high-repetition rate PW-class laser-matter interaction

Fauvel, G.; Tangtartharakul, K.; Arefiev, A.; De Chant, J.; Hakimi, S.; Klimo, O.; Manuel, M.; Mcilvenny, A.; Nakamura, K.; Obst-Huebl, L.; Rubovic, P.; Weber, S.; Condamine, F. P.
REVIEW OF SCIENTIFIC INSTRUMENTS 96(2), 023102 (FEB 2025)
https://doi.org/10.1063/5.0206348

With the advent of high repetition rate laser facilities, novel diagnostic tools compatible with these advanced specifications are required. This paper presents the design of an active gamma-ray spectrometer intended for these high repetition rate experiments, with particular emphasis on functionality within a PW level laser-plasma interaction chamber's extreme conditions. The spectrometer uses stacked scintillators to

accommodate a broad range of gamma-ray energies, demonstrating its adaptability for various experimental setups. In addition, it has been engineered to maintain compactness, electromagnetic pulse resistance, and ISO-5 cleanliness requirements while ensuring high sensitivity. The spectrometer has been tested in real conditions inside the PW-class level interaction chamber at the BELLA center, LBNL. The paper further details the calibration process, which utilizes a Co-60 radioactive source, and describes the unfolding technique implemented through a stochastic minimization method. (c) 2025 Author(s).

PLASMA TARGETS

Femtosecond laser-induced plasma filaments for beam-driven plasma wakefield acceleration

Galletti, M.; Crincoli, L.; Pompili, R.; Verra, L.; Villa, F.; Demitra, R.; Biagioni, A.; Zigler, A.; Ferrario, M.
PHYSICAL REVIEW E 111(2), 025202 (FEB 2025)
https://doi.org/10.1103/PhysRevE.111.025202

We describe the generation of plasma filaments for application in plasma-based particle accelerators. The complete characterization of a plasma filament generated by a low-energy self-guided femtosecond laser pulse is studied experimentally and theoretically in a low-pressure nitrogen gas environment. For this purpose, we adopted a spectroscopic methodology to measure the plasma density and electron temperature. In addition to this, we also employed a side-imaging technique to retrieve the plasma column sizes (length and diameter). The measurements show the stable generation of a 4-cm-long plasma filament with 300 μm diameter. The peak plasma density and temperature are ne 10^{16} cm^{-3} and T_e 1.3 eV, respectively, with a decay time of approximately 8 ns. We show that the experimental results are in agreement with numerical simulations in terms of filament size and density decay time.

Advanced ceramic plasma discharge capillaries for high repetition rate operation

Crincoli, Lucio; Demitra, Romain; Lollo, Valerio; Pellegrini, Donato; Pitti, Marco; Pronti, Lucilla; Romani, Martina; Ferrario, Massimo; Biagioni, Angelo
SCIENTIFIC REPORTS 15(1), 12456 (APR 2025)
https://doi.org/10.1038/s41598-025-96882-y

In view of future applications of plasma-based particle accelerators, within the fields of high-energy physics and new light sources, the capability of plasma sources to operate at high repetition rates is crucial. In particular for gas-filled plasma discharge capillaries, which allow direct control over plasma properties, a key aspect is the longevity of the material, subject to erosion due to the heat flux delivered by high voltage plasma discharges. In this regard, we present an innovative design of discharge capillaries based on the use of different ceramic materials, which can sustain high voltage plasma discharges at high repetition rate and, moreover, be easily machined for the complex geometries required for plasma-based accelerators. Experimental campaigns are carried out at 10-150 Hz, assessing the longevity of ceramic capillaries by means of different diagnostic techniques. In addition, numerical simulations are performed to analyze the heat transfer within the whole plasma source. Results from experimental and numerical analysis highlight the capability of ceramic capillaries to preserve plasma properties and the integrity of the source during long-term plasma discharge operation at high repetition rate. In particular, we demonstrated the suitability of the proposed solution for the operative range of 100-400 Hz, foreseen for EuPRAXIA@SPARC_LAB project.

Effect of dielectric wakefields in a capillary discharge for plasma wakefield acceleration

Verra, L.; Galletti, M.; Pompili, R.; Biagioni, A.; Carillo, M.; Cianchi, A.; Crincoli, L.; Curcio, A.; Demurtas, F.; Di Pirro, G.; Lollo, V.; Parise, G.; Pellegrini, D.; Romeo, S.; Silvi, G. J.; Villa, F.; Ferrario, M.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1072, 170157 (MAR 2025)
https://doi.org/10.1016/j.nima.2024.170157

Dielectric capillaries are widely used to generate plasmas for plasma wakefield acceleration. When a relativistic drive bunch travels through a capillary with misaligned trajectory with respect to the capillary axis, it is deflected by the effect of the dielectric transverse wakefields it drives. We experimentally show that the deflection effect increases along the bunch and with larger misalignment, and we investigate the decay of dielectric wakefields by measuring the effect on the front of a trailing bunch. We discuss the implications for the design of a plasma wakefield accelerator based on dielectric capillaries.

Experimental characterization of discharge plasma dynamics in a square capillary for prospective applications in laser wakefield acceleration

Kruchinin, K. O.; Mondal, A.; Sasorov, P. V.; Zimmermann, P.; Niekrasz, S.; Molodozhentsev, A. Yu.
PHYSICS OF PLASMAS 32(4), 043511 (APR 2025)
https://doi.org/10.1063/5.0260100

Research on plasma generated by electrical discharge in gas-filled capillaries plays an important role in advancing laser wakefield accelerators. We present a comprehensive study of the temporal and spatial distribution of plasma density within a short, 1 cm long, square-shaped capillary filled with hydrogen gas. Two transverse capillary sizes, 500 µm and 300 µm, were investigated achieving peak plasma densities of 0.9 x 10^{18} cm^{-3} and 2.5 x 10^{18} cm^{-3}, respectively, at the capillary center. In addition, we explore how these distributions depend on discharge parameters, specifically discharge current and gas flow through the capillary. Plasma density was determined by analyzing the Stark broadening of the hydrogen Balmer-alpha line. The results obtained were compared with the theoretical models and simulations. The comparison between the model predictions and the experimental data at the transient ionization stage of the discharge reveals a discrepancy of a factor of ∼ 1.3-2.1, depending on the capillary size, which is thoroughly discussed.

Longitudinal tapering in gas jets for increased efficiency of 10-GeV class laser plasma accelerators

Li, R.; Picksley, A.; Benedetti, C.; Filippi, F.; Stackhouse, J.; Fan-Chiang, L.; Tsai, H. E.; Nakamura, K.; Schroeder, C. B.; van Tilborg, J.; Esarey, E.; Geddes, C. G. R.; Gonsalves, A. J.
REVIEW OF SCIENTIFIC INSTRUMENTS 96(4), 043306 (APR 2025)
https://doi.org/10.1063/5.0250698

Modern laser plasma accelerators often require plasma waveguides tens of centimeters long to propagate a high-intensity drive laser pulse. Tapering the longitudinal gas density profile in 10 cm scale gas jets could allow for single stage laser plasma acceleration well beyond 10 GeV with current petawatt-class laser systems. Via simulation and interferometry measurements, we show density control by longitudinally adjusting the throat width and jet angle. Density profiles appropriate for tapering were calculated analytically and via particle-in-cell simulations and were matched experimentally. These simulations show that tapering can increase electron beam energy using 19 J laser energy from ∼ 9 GeV to >12 GeV in a 30 cm plasma and the accelerated charge by an order of magnitude.

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 ($N_e \sim 10^{17}$ 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.

Differential pumping for kHz operation of a laser wakefield accelerator based on a continuously flowing hydrogen gas jet

Monzac, J.; Smartsev, S.; Huijts, J.; Rovige, L.; Andriyash, I. A.; Vernier, A.; Tomkus, V.; Girdauskas, V.; Raciukaitis, G.; Mackeviciute, M.; Stankevic, V.; Cavagna, A.; Kaur, J.; Kalouguine, A.; Lopez-Martens, R.; Faure, J.
REVIEW OF SCIENTIFIC INSTRUMENTS 96(4), 043302 (APR 2025)
https://doi.org/10.1063/5.0246912

Laser-Wakefield Accelerators (LWFAs) running at kHz repetition rates hold great potential for applications. They typically operate with low-energy, highly compressed laser pulses focused on high-pressure gas targets. Experiments have shown that the best-quality electron beams are achieved using hydrogen gas targets. However, continuous operation with hydrogen requires a dedicated pumping system. In this work, we present a method for designing a differential pumping system, which we successfully implemented in our experiments. This enabled the first demonstration of continuous operation of a kHz LWFA using a high-pressure hydrogen gas jet. The system effectively maintained a pressure below 3×10^{-4} mbar, even with a free-flowing gas jet operating at 140 bar backing pressure. Numerical fluid dynamics and optical simulations were used to guide and validate the system's design.

Parametric study of voltage in plasma-discharge capillary systems: a benchmarking of experimental and simulation data

Arjmand, S.; Amato, A.; Catalano, R.; Manna, C.; Mascali, D.; Mauro, G. S.; Oliva, D.; Pappalardo, A. D.; Pidatella, A.; Suarez, J.; Vinciguerra, F.; Cirrone, G. A. P.
JOURNAL OF INSTRUMENTATION 20(3), C03035 (MAR 2025)
https://doi.org/10.1088/1748-0221/20/03/C03035

We explore the use of gas-filled plasma-discharge capillaries for laser wakefield acceleration (LWFA) by employing a hybrid system that integrates an external high-voltage source to driven an electrical discharge, generate plasma within the capillary channel before to the main laser pulse. The process enhances plasma formation, boosts operational efficiency, and maintains laser intensity over multiple Rayleigh lengths, enabling high-energy electron acceleration. The electrical discharge creates a stable, uniform plasma environment, improving beam charge, energy stability, and reducing energy spread. This uniform plasma ensures better laser coupling and mitigates instabilities, leading to improved beam quality. This method supports efficient acceleration and the production of very-highenergy electron (VHEE) pencil beams (250 MeV) in a compact, cost-effective system designed for radiobiological studies at the future I-LUCE (INFN-

Laser indUCEd Radiation Production) facility at the Istituto Nazionale di Fisica Nucleare-Laboratori Nazionali del Sud (INFN-LNS) in Catania, Italy. The system aims to generate high-energy electron beams tailored for VHEE and FLASH radiotherapy (FLASH-RT) applications. In this paper, we present simulations of capillaries performed using COMSOL Multiphysics software, where plasma density is obtained as a function of the applied voltage. We analyze plasma behavior under varying voltage and compare the results with experimental data, demonstrating the model's accuracy in predicting plasma characteristics and its potential to optimize discharge conditions.

Two-chamber gas target for laser-plasma electron source

Drobniak, P.; Baynard, E.; Beck, A.; Demailly, J.; Douillet, D.; Gonnin, A.; Iaquaniello, G.; Kane, G.; Kazamias, S.; Kubytskyi, V.; Lenivenko, M.; Lericheux, N.; Lucas, B.; Mercier, B.; Peinaud, Y.; Pittman, M.; Serhal, J.; Cassou, K.
REVIEW OF SCIENTIFIC INSTRUMENTS 96(3), 033304 (MAR 2025)
https://doi.org/10.1063/5.0226055

Exploring novel target schemes for laser wakefield accelerators is essential to address the challenge of increasing repetition rates while ensuring the stability and quality of the produced electron beams. This paper introduces and discusses the prototyping of a two-chamber gas target, integrated into the beamline and operating under continuous gas flow, in the framework of ionization injection. We present the numerical fluid modeling employed to assist the density profile shaping, with a focus on gas mixing and dopant confinement. The importance of localized high-Z gas for ionization injection is demonstrated through particle-in-cell simulations using the simulated gas profiles. We describe the test bench used for prototype evaluation, specifically addressing the plasma electron density and the longitudinal distribution of species relevant to ionization injection. The lifetime of the target at 10 Hz and 60 mJ is measured for different materials, and its effect on the resulting electron beam is assessed using particle-in-cell simulations. Finally, we outline perspectives on high-power operation.

Advanced plasma target from pre-ionized low-density foam for effective and robust direct laser acceleration of electrons

Rosmej, Olga N.; Gyrdymov, Mikhail; Andreev, Nikolay E.; Tavana, Parysatis; Popov, Vyacheslav; Borisenko, Nataliya G.; Gromov, Alexandr I.; Gus'kov, Sergey Yu.; Yakhin, Rafael; Vegunova, Galina A.; Bukharskii, Nikolai; Korneev, Philipp; Cikhardt, Jakub; Zaehter, Sero; Busch, Sebastian; Jacoby, Joachim; Pimenov, Vladimir G.; Spielmann, Christian; Pukhov, Alexander
HIGH POWER LASER SCIENCE AND ENGINEERING 13, e3 (FEB 2025)
https://doi.org/10.1017/hpl.2024.85

Low-density polymer foams pre-ionized by a well-controlled nanosecond pulse are excellent plasma targets to trigger direct laser acceleration (DLA) of electrons by sub-picosecond relativistic laser pulses. In this work, the influence of the nanosecond pulse on the DLA process is investigated. The density profile of plasma generated after irradiating foam with a nanosecond pulse was simulated with a two-dimensional hydrodynamic code, which takes into account the high aspect ratio of interaction and the microstructure of polymer foams. The obtained plasma density profile was used as input to the three-dimensional particle-in-cell code to simulate energy, angular distributions and charge carried by the directional fraction of DLA electrons. The modelling shows good agreement with the experiment and in general a weak dependence of the electron spectra on the plasma profiles, which contain a density up-ramp and a region of near-critical electron density. This explains the high DLA stability in pre-ionized foams, which is important for applications.

BEAM TRANSPORT

Development of a nonlinear plasma lens for achromatic beam transport

Drobniak, P.; Adli, E.; Anderson, H. Bergravf; Dyson, A.; Mewes, S. M.; Sjobak, K. N.; Thevenet, M.; Lindstrom, C. A.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1072, 170223 (MAR 2025)
https://doi.org/10.1016/j.nima.2025.170223

We introduce the new idea of a nonlinear active plasma lens, as part of a larger transport lattice for achromatic electron beam transport. The proposed implementation uses an external dipole magnet acting on a plasma and is motivated by 1D-hydrodynamic simulations. The manufactured design is presented, including its undergoing experimental characterisation on the CLEAR beam-line at CERN.

ELECTRON BEAM INJECTORS

Verification of electron beam alignment and optics for external off-axis injection in AWAKE Run 2b

van Gils, Nikita Z.; Turner, Marlene; Bencini, Vittorio; Bergamaschi, Michele; Ranc, Lucas; Pakuza, Collette; Pannell, Fern; Della Porta, Giovanni Zevi; Velotti, Francesco; Gerbershagen, Alexander; Gschwendtner, Edda
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1072, 170204 (MAR 2025)
https://doi.org/10.1016/j.nima.2025.170204

The Advanced Wakefield Experiment (AWAKE) has the long term goal to accelerate electrons to particle physics relevant energies using self-modulated proton bunches as drivers in plasma. AWAKE is currently in its Run 2b (2023-2025), where the goal is to stabilise the wakefield amplitude after the saturation of the self-modulation process by introducing a plasma density step. To optimise witness electron injection, retractable YAG screens have been installed inside the vapour source. These screens enable, for the first time, direct measurements of electron bunch sizes at the injection location and estimates of the spatial overlap with the wakefields. This manuscript presents an overview of the upgraded experimental setup and measurements of the transverse distribution of the electron bunches, crucial for improved control over the injection process. Additionally, results show agreement between simulated and measured transverse bunch sizes and positions, and the influence of various factors (e.g., plasma density, electron bunch charge, and witness bunch timing) on the electron charge overlapping with the wakefields. Furthermore, alignment challenges as well as potential solutions are discussed.

Simulation study of high-quality electron beam injector for external injection of laser plasma wakefield acceleration

Liu, Lanxin; Zhong, Jianhua; Guan, Jiabao; Dai, Zeyi; Xia, Guoxing; Wang, Jike; Nie, Yuancun
NUCLEAR ENGINEERING AND TECHNOLOGY 57(7), 103531 (JUL 2025)
https://doi.org/10.1016/j.net.2025.103531

The laser wakefield acceleration (LWFA) with external injection requires high-quality, ultra-short electron bunches, which can be produced by using a photocathode injector based on the room-temperature RF electron gun. In this paper, the physics design of such a photocathode injector system is discussed for two operating modes: low charge (10 pC) and high charge (50 pC). The front end of the injector was optimized by combining the beam dynamics simulation software ASTRA with the multi-objective genetic algorithm NSGA-II. The downstream section was simulated using CSRtrack and ASTRA to optimize the magnetic chicane and match the Twiss parameters. A slit collimator was inserted in the middle of the chicane to filter part of the

electrons, and hence shorten the bunch length and reduce the relative energy spread. The obtained beam parameters meet the requirements for an external injection of the LWFA, where the electrons can be further accelerated from 100 MeV to 1.5 GeV. Such a photocathode injector combined with the LWFA has the potential to be applied in the accumulation injection of a 1.5 GeV storage ring at Wuhan Advanced Light Source.

LASERS & OPTICS

Orbital-angular-momentum-controlled laser pulses with near-relativistic intensity

Li, Jiajun; Wang, Xianzhi; Wang, Zhaohua; Wei, Zhiyi
PHYSICAL REVIEW A 111(2), 023506 (FEB 2025)
https://doi.org/10.1103/PhysRevA.111.023506

The spiral phase plate is an essential optical component for the generation of Laguerre-Gaussian laser pulses with doughnut intensity profiles and helical wavefronts. This is due to its extraordinary ability to create and manipulate polarization distributions and orbital angular momentum of laser pulses. Here, we show that Gaussian laser pulses with near-relativistic intensity can acquire orbital angular momentum directly through a fixed-thickness plasma transmission spiral phase plate, whose density increases proportionally to the azimuthal angle around the plasma center. We propose the design for a plasma spiral phase plate and outline how the thickness and density distribution of the plasma determine the orbital angular momentum. We also use three-dimensional particle-in-cell simulations to examine the properties of plasma transmission spiral phase plates, such as orbital angular momentum generation and high-intensity laser pulses manipulation. The simulations suggest that Gaussian laser pulses could be turned into Laguerre-Gaussian laser pulses carrying orbital angular momentum through a 10-μm plasma plate, with the conversion efficiency above 90% at high light intensity exceeding 10^{17} W/cm^2. Our scheme offers a method for producing near-relativistic intensity vortex laser pulses with controlled orbital angular momentum, which could significantly advance the development of intense twisted laser pulses in high-field physics. Potential applications include the rotational dynamics of particle clumps, the generation of high-energy particles in plasma accelerators, and the radiation of attosecond pulses radiation with orbital angular momentum.

Dynamics and manipulation of ultrashort laser pulses via plasma shutter

Wei, Wen-Qing; Wang, Yu; Ge, Xu-Lei; Deng, Yan-Qing; Zhang, Shi-Zheng; Wan, Feng; Li, Jian-Xing; Zhao, Yong-Tao; Yuan, Xiao-Hui
PHYSICS OF PLASMAS 32(1), 013109 (JAN 2025)
https://doi.org/10.1063/5.0249515

The characterization and manipulation of ultrashort high-intensity laser pulses were investigated both numerically and experimentally using an ultrathin foil as plasma shutter. Our work revealed a laser intensity enhancement with a clean and steepened leading edge when the pulse passed through an expanded moderate-density plasma. The fast dynamics of laser-plasma interaction in underdense, transparent, and overdense regimes were elucidated by measuring the temporal-spatial intensity and phase profiles of the transmitted pulses. Key nonlinear effects such as relativistic self-focusing, self-phase modulation, self-induced transparency, and hole-boring were identified as factors influencing laser pulse shaping, with their impact determined by the plasma density. Our approach allows for the robust utilization of the plasma shutter in existing laser facilities without additional requirements. By controlling the spatiotemporal properties of high-power laser pulses, it opens up the possibility for developing compact laser-driven particle accelerators, ultrabright radiation sources, and plasma photonics.

High-intensity lasers and research activities in China

Li, Yutong; Chen, Liming; Chen, Min; Liu, Feng; Gu, Yuqiu; Guo, Bing; Hua, Jianfei; Huang, Taiwu; Leng, Yuxin; Li, Fei; Li, Lu; Li, Ruxin; Lin, Chen; Lu, Wei; Lyu, Zhihui; Ma, Wenjun; Ning, Xiaonan; Peng, Yujie; Wan, Yang; Wang, Jinguang; Wang, Zhaohua; Wei, Zhiyi; Yan, Xueqing; Zhang, Jie; Zhao, Baozhen; Zhao, Zengxiu; Zhou, Cangtao; Zhou, Kainan; Zhou, Weimin; Zhu, Jianqiang; Zhu, Ping

HIGH POWER LASER SCIENCE AND ENGINEERING 13, e12 (MAR 2025)
https://doi.org/10.1017/hpl.2024.69

This paper provides an overview of the current status of ultrafast and ultra-intense lasers with peak powers exceeding 100 TW and examines the research activities in high-energy-density physics within China. Currently, 10 high-intensity lasers with powers over 100 TW are operational, and about 10 additional lasers are being constructed at various institutes and universities. These facilities operate either independently or are combined with one another, thereby offering substantial support for both Chinese and international research and development efforts in high-energy-density physics.

Generation and regulation of electromagnetic pulses induced by multi-petawatt laser coupling with gas jets

He, Qiang-You; Wang, Zi-Tao; Deng, Zhi-Gang; Feng, Jie; Xia, Ya-Dong; Hu, Xi-Chen; Zhu, Ming-Yang; Xie, Jia-Jie; Yuan, Zong-Qiang; Zhang, Zhi-Meng; Lu, Feng; Yang, Lei; Cheng, Hao; Li, Yu-Ze; Yan, Yang; Fang, Yan-Lv; Li, Chen-Tong; Zhou, Wei-Min; Li, Ting-Shuai; Chen, Li-Ming; Lin, Chen; Yan, Xue-Qing

NUCLEAR SCIENCE AND TECHNIQUES 36(6), 100 (JUN 2025)
https://doi.org/10.1007/s41365-025-01692-6

High-power laser pulses interacting with targets can generate intense electromagnetic pulses (EMPs), which can disrupt physical experimental diagnostics and even damage diagnostic equipment, posing a threat to the reliable operation of experiments. In this study, EMPs resulting from multi-petawatt laser irradiating nitrogen gas jets were systematically analyzed and investigated. The experimental results revealed that the EMP amplitude is positively correlated with the quantity and energy of the electrons captured and accelerated by the plasma channel. These factors are reflected by parameters such as laser energy and nitrogen gas jet pressure. Additionally, we propose several potential sources of EMPs produced by laser-irradiated gas jets and separately analyzed their spatiotemporal distributions. The findings provide insight into the mechanisms of EMP generation and introduce a new approach to achieve controllable EMPs by regulating the laser energy and gas jet pressure.

BEAMLINES & APPLICATIONS

Very High-Energy Electron Therapy Toward Clinical Implementation

Panaino, Costanza Maria Vittoria; Piccinini, Simona; Andreassi, Maria Grazia; Bandini, Gabriele; Borghini, Andrea; Borgia, Marzia; Di Naro, Angelo; Labate, Luca Umberto; Maggiulli, Eleonora; Portaluri, Maurizio Giovanni Agostino; Gizzi, Leonida Antonio

CANCERS 17(2), 181 (JAN 2025)
https://doi.org/10.3390/cancers17020181

The use of very high energy electron (VHEE) beams, with energies between 50 and 400 MeV, has drawn considerable interest in radiotherapy due to their deep tissue penetration, sharp beam edges, and low sensitivity to tissue density. VHEE beams can be precisely steered with magnetic components, positioning VHEE therapy as a cost-effective option between photon and proton therapies. However, the clinical implementation of VHEE therapy (VHEET) requires advances in several areas: developing compact, stable, and efficient accelerators; creating sophisticated treatment planning software; and establishing clinically validated protocols. In addition, the perspective of VHEE to access ultra-high dose-rate regime presents a promising avenue for the practical integration of FLASH radiotherapy of deep tumors and metastases with VHEET (FLASH-VHEET), enhancing normal tissue sparing while maintaining the inherent dosimetric advantages of VHEET. However, FLASH-VHEET systems require validation of time-dependent dose parameters, thus introducing additional technological challenges. Here, we discuss recent progress in VHEET research, focusing on both conventional and FLASH modalities, and covering key aspects including dosimetric properties, radioprotection, accelerator technology, beam focusing, radiobiological effects, and clinical outcomes. Furthermore, we comprehensively analyze initial VHEET in silico studies on coverage across various tumor sites.

Enhanced Isomer Population via Direct Irradiation of Solid-Density Targets Using a Compact Laser-Plasma Accelerator

Jacob, Robert E.; Tannous, Speero M.; Bernstein, Lee A.; Brown, Joshua; Ostermayr, Tobias; Chen, Qiang; Schneider, Dieter H. G.; Schroeder, Carl B.; van Tilborg, Jeroen; Esarey, Eric H.; Geddes, Cameron G. R.
PHYSICAL REVIEW LETTERS 134(5), 052504 (FEB 2025)
https://doi.org/10.1103/PhysRevLett.134.052504

Excitation of long-lived states in bromine nuclei using a tabletop laser-plasma accelerator providing pulsed (<100 fs) electron beams provided a sensitive probe of gamma strength and level densities in the nuclear quasicontinuum and may indicate angular momentum coupling through electron-nuclear interactions. Solid-density active $LaBr_3$ targets absorb real and virtual photons up to 35 +/- 2.5 MeV and deexcite through gamma cascade into different states. A factor of 4.354 +/- 0.932 enhancement of the $^{80}Br^{m}/^{80}Br^{g}$ isomeric ratio was observed following electron irradiation, as compared to bremsstrahlung. Additional angular momentum transfer could possibly occur through nuclear-plasma or electron-nuclear interactions enabled by the ultrashort electron beam. Further investigation of these mechanisms could have far-reaching impact including decreased storage of long-term nuclear waste and an improved understanding of heavy element formation in astrophysical settings.

Laser-plasma-based radiation sources with intense laser pulses

Yun, H.; Bae, L. J.; Mirzaie, M.; Kim, H. T.
REVIEWS OF MODERN PLASMA PHYSICS 9(1), 13 (MAR 2025)
https://doi.org/10.1007/s41614-025-00181-y

Laser-plasma interactions with ultra-intense lasers yield a variety of particle and radiation sources. Compared to synchrotron facilities, which provide short-wavelength, high-brilliance sources, laser-plasma sources offer a compact and cost-effective alternative. These sources can produce electromagnetic radiation spanning from radio frequencies to gamma-rays. In this review, we explore diverse schemes of laser-plasma-based radiations, including Bremsstrahlung, characteristic X-rays, X-ray lasers, high-order harmonic generation, betatron radiation, inverse Compton scattering, laser-plasma THz sources, and other recently developed radiation sources based on laser-plasma interactions. The versatility of radiation sources from laser-plasma interactions makes them valuable for applications in fields such as biomedical science, material science, nuclear physics, non-destructive inspection technologies, and semiconductor technologies.

Measurement of femtosecond incoherent XUV pulses using shot-noise-driven fluctuations in plasma betatron sources

Curcio, A.; Berlanga, M. L.; Boudjema, N.; Chiadroni, E.; Cianchi, A.; Del Dotto, A.; Francescone, D.; Galletti, M.; Horny, V.; Huerta, A.; Mostacci, A.; Perez-Hernandez, J. A.; Petrarca, M.; Rodriguez, I.; Salgado-Lopez, C.; Stocchi, F.; Tomassini, P.; Vladisavlevici, I.; Frias, M. D.; Ferrario, M.; Gatti, G.
PHYSICAL REVIEW E 111(1), L013201 (JAN 2025)
https://doi.org/10.1103/PhysRevE.111.L013201

The duration of incoherent XUV pulses down to the femtoseconds (fs) can be retrieved through a statistical analysis of the modulations on the observed radiation spectrum. Uncorrelated shot-noise fluctuations in the pulse temporal profile result in incoherent radiation showing a multispike spectrum where the spike width is inversely proportional to the pulse length. In this Letter, single-shot temporal characterization of the betatron radiation pulses emitted by fs-long, 100's MeV electron bunches undergoing acceleration, and propagating through a plasma wiggler was performed in the XUV domain. The retrieved pulse lengths agree with independent measurements performed in the THz spectral range and with theoretical predictions.

Coherent frequency combs from electrons colliding with a laser pulse

Quin, Michael J.; Di Piazza, Antonino; Tamburini, Matteo
PLASMA PHYSICS AND CONTROLLED FUSION 67(5), 055008 (MAY 2025)
https://doi.org/10.1088/1361-6587/adc59c

Highly coherent and powerful light sources capable of generating soft x-ray frequency combs are essential for high precision measurements and rigorous tests of fundamental physics. In this work, we derive the analytical conditions required for the emission of coherent radiation from an electron beam colliding with a laser pulse, modeled as a plane wave. These conditions are applied in a series of numerical simulations, where we show that a soft x-ray frequency comb can be produced if the electrons are regularly-spaced and sufficiently monoenergetic. High quality beams of this kind may be produced in the near future from laser-plasma interactions or linear accelerators. Furthermore, we highlight the advantageous role of employing few-cycle laser pulses in relaxing the stringent monoenergeticity requirements for coherent emission. The conditions derived here can also be used to optimize coherent emission in other frequency ranges, such as the terahertz domain.

Enhanced terahertz emission from the wakefield of CO_2-laser-created plasma

Maity, Srimanta; Arora, Garima
PHYSICAL REVIEW E 111(4), 045205 (APR 2025)
https://doi.org/10.1103/PhysRevE.111.045205

High-field terahertz (THz) pulse generation is investigated through the interaction of an intense single-color CO_2 laser pulse with helium (He) gas targets. Employing particle-in-cell (PIC) simulations, this study reveals a substantial enhancement in THz generation efficiency, even with a single-color laser pulse interacting with gas targets in the self-modulated-laser-wakefield (SMLWF) regime. Our study demonstrates that in the presence of photoionization, a synergistic interplay of laser self-modulation, self-focusing, and local pump depletion leads to the generation of robust THz pulses polarized parallel to the laser electric field. The dependence of THz generation efficiency on target density, laser intensity, and laser pulse duration has been investigated. Our study identifies a favorable parametric regime for producing THz fields with amplitudes reaching hundreds of GV/m, surpassing those reported in previous studies.

Generation of narrow-band low frequency radiation via laser-generated electron bunches and resonant cavities

Robinson, A. P. L.
PLASMA PHYSICS AND CONTROLLED FUSION 67(4), 045026 (APR 2025)
https://doi.org/10.1088/1361-6587/adbd74

It is shown that the single transit of a laser-generated electron bunch can generate strong, narrow-band radiation in a resonant cavity. This is shown numerically for an electron bunch relevant to those produced by laser wakefield acceleration. The bunch can also transit through two adjacent cavities and generate radiation in both. The phase relation between the radiation in the two cavities is well defined implying that coherent combination of radiation from multiple cavities is theoretically achievable.

Generation of multi-cycle relativistic terahertz radiation from photon deceleration in a long self-induced plasma wake

Lu, Huangang; Liu, Jiaxin; Cai, Jie; Wu, Xuezhi; Zhang, Jianyao; Ma, Qianyi; Wang, Zhenan; Xia, Yuhui; Ma, Wenjun; Lin, Chen; Nie, Zan; Yu, Jinqing; Xu, Xinlu; Yan, Xueqing
PHYSICS OF PLASMAS 32(2), 023104 (FEB 2025)
https://doi.org/10.1063/5.0241144

Intense terahertz (THz) radiation with multiple cycles is of great interest in many active research fields ranging from particle acceleration to space communication. However, its generation remains a challenge since multi-cycle pulses produced from crystal-based or plasma-based methods are usually characterized by non-relativistic intensity, while plasma-based techniques can deliver much more intense pulses but with few cycles. In this study, we propose a scheme to generate THz radiation with relativistic intensity and multi-cycle duration by shooting a ∼ 100 TW laser pulse into an underdense plasma with a structured density profile. In this process, laser photons are decelerated by the co-moving refractive index gradient formed by the laser-plasma interaction and slide back to be stored in the self-induced long plasma wake. Particle-in-cell simulations demonstrate the generation of THz radiation with a frequency of 21.4 THz, a pulse length of ∼100 µm (∼7 cycles), a pulse energy up to 18.5 mJ, and an energy conversion efficiency of ∼2%. These pulses may enable access to unexplored regimes of strong THz-material interaction, or open up possibilities for relativistic THz optics.

Enhanced gamma-ray emission from all-optical nonlinear inverse Compton scattering with down-ramp density plasma

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EUROPEAN PHYSICAL JOURNAL-SPECIAL TOPICS (MAR 2025)
https://doi.org/10.1140/epjs/s11734-025-01541-y

The impressive progress in high-powered lasers has resulted in all-optical nonlinear inverse Compton scattering emerging as a potential method for generating ultra-short, brilliant γ ray in a remarkably compact setup. Nonetheless, the conversion efficiency and energy of currently implemented Compton γ-ray sources are still low. We present three-dimensional particle-in-cell simulations investigating the γ-ray emission resulting from the interaction of a femtosecond laser pulse ($I = 5\times10^{21}$ W/cm^2) with a down-ramp density plasma. Our study reveals that a down-ramp density plasma affects the self-injection of electrons, resulting in a lower self-injection threshold. Consequently, more electrons can be trapped in the wakefield for acceleration. The simulation results demonstrate the production of high-energy γ ray with a maximum energy of $E_{\gamma,max}$ = 148.18 MeV and a low emittance of θ_γ = 4.2 mm · mrad. Compared to the scheme without down-ramp density plasma, the conversion efficiency of laser energy to photons is improved from approximately 0.13 to 0.29%. With this scheme, we can avoid using high-power laser pulses and generate high-energy γ ray by using shaped-intensity laser pulses. This broadens the application range of all-optical Compton scattering.

Collimated γ-ray emission enabled by efficient direct laser acceleration

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NEW JOURNAL OF PHYSICS 27(2), 023024 (FEB 2025)
https://doi.org/10.1088/1367-2630/adb3c1

We investigate the mechanisms responsible for single-lobed versus double-lobed angular distributions of emitted gamma-rays in laser-irradiated plasmas, focusing on how direct laser acceleration (DLA) shapes the emission profile. Using test-particle calculations, we show that the efficiency of DLA plays a central role. In the inefficient DLA regime, electrons rapidly gain and lose energy within a single laser cycle, resulting in a double-lobed emission profile heavily influenced by laser fields. In contrast, in the efficient DLA regime, electrons steadily accumulate energy over multiple laser cycles, achieving much higher energies and emitting orders of magnitude more energy. This emission is intensely collimated and results in single-lobed profiles dominated by quasi-static azimuthal magnetic fields in the plasma. Particle-in-cell simulations demonstrate that lower-density targets create favorable conditions for some electrons to enter the efficient DLA regime. These electrons can dominate the emission, transforming the overall profile from double-lobed to single-lobed, even though inefficient DLA electrons remain present. These findings provide valuable insights for optimizing laser-driven gamma-ray sources for applications requiring high-intensity, well-collimated beams.

Vacuum-plasma transition effect on positron acceleration in the bubble regime plasma wakefield accelerators

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PHYSICAL REVIEW ACCELERATORS AND BEAMS 28(3), 031301 (MAR 2025)
https://doi.org/10.1103/PhysRevAccelBeams.28.031301

In recent years, the field of positron acceleration in plasma wakefield accelerators has witnessed rapid theoretical advancements, and several effective schemes have been proposed. In these studies, longitudinally uniform plasma is taken into account, with the positron beam located at the start of the second wakefield bubble. The electron filament near the positron beam provides Coulomb attraction force for the guiding of the positron beam. However, the influence of vacuum-plasma transition on positron beams has not been considered yet, where wakefield bubble is larger than that in the density plateau region, and the positron beam is in the defocusing region. In this paper, we study the evolution of positron beam size in the vacuum-plasma transition region and find out that the transition is detrimental to low-energy positron beams. Wide drive beams with relatively large transverse sizes are proposed as a possible solution to this difficulty.

FELs

Coherence and superradiance from a plasma-based quasiparticle accelerator

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NATURE PHOTONICS 18(1) (JAN 2024)
https://doi.org/10.1038/s41566-023-01311-z

Coherent light sources, such as free-electron lasers, provide bright beams for studies in biology, chemistry and physics. However, increasing the brightness of these sources requires progressively larger instruments, with the largest examples, such as the Linac Coherent Light Source at Stanford, being several kilometres long. It would be transformative if this scaling trend could be overcome so that compact, bright sources could be employed at universities, hospitals and industrial laboratories. Here we address this issue by rethinking the basic principles of radiation physics. At the core of our work is the introduction of quasiparticle-based light

sources that rely on the collective and macroscopic motion of an ensemble of light-emitting charges to evolve and radiate in ways that would be unphysical for single charges. The underlying concept allows for temporal coherence and superradiance in new configurations, such as in plasma accelerators, providing radiation with intriguing properties and clear experimental signatures spanning nearly ten octaves in wavelength, from the terahertz to the extreme ultraviolet. The simplicity of the quasiparticle approach makes it suitable for experimental demonstrations at existing laser and accelerator facilities and also extends well beyond this case to other scenarios such as nonlinear optical configurations.

Tunability of a red-shifted free electron laser

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PHYSICAL REVIEW ACCELERATORS AND BEAMS 28(2), 020702 (FEB 2025)
https://doi.org/10.1103/PhysRevAccelBeams.28.020702

The development of red-shifted free electron lasers (FELs), based on strongly chirped electron beams, emerged a few years ago. Here we present a thorough study of the tunability of a seeded red-shifted FEL. An analytical model is introduced to describe the complex FEL resonance condition and its consequence for the FEL emission wavelength. This model is then benchmarked with experimental data from the COXINEL (COherence Xray source INferred from Electrons accelerated by Laser) FEL beamline driven by a laser plasma accelerator at Helmholtz-Zentrum Dresden-Rossendorf. We show that the FEL emission wavelength can be tuned not only with the undulator gap and taper geometry but also with the time delay between the seed laser pulse and the electron beam. Particularly a combination of individually chirped electron and seed beams promotes a wider tuning range compared with the usual undulator gap. This could serve as an additional yet simple tuning knob to tailor the FEL emission wavelength.

Spatiospectral properties of redshifted free electron laser radiation

Labat, Marie; Prazeres, Rui; Roussel, Eleonore; Chang, Yen-Yu; Ghaith, Amin; LaBerge, Maxwell; Schoebel, Susanne; Schramm, Ulrich; Ufer, Patrick; Couprie, Marie-Emmanuelle; Irman, Arie
PHYSICAL REVIEW RESEARCH 7(2), 023061 (APR 2025)
https://doi.org/10.1103/PhysRevResearch.7.023061

Free electron lasers (FELs) are advanced light sources delivering pulses with unprecedented intensity down to the hard x-ray range. Redshifted FEL represents a new scheme exploiting strongly chirped electron beams to emit tunable coherent radiation at wavelengths longer than the FEL's resonant condition. While theoretical studies and proposals for this scheme are rapidly advancing, experimental evidences are so far very limited. Here, we report on the nature of spatiospectral properties of a redshifted FEL, presenting analytical and numerical models benchmarked with experimental data from the COXINEL (coherence x-ray source inferred from electrons accelerated by laser) FEL beamline driven by a laser plasma accelerator at Helmholtz-Zentrum Dresden-Rossendorf (Germany). We reveal how those properties are governed by a peculiar, V-shape like, transverse spatial phase inherited from single-electron synchrotron radiation. Moving the observation point inside the undulator, i.e., backpropagating the radiation, it is shown how this synchrotron radiation inheritage imprints localized fringes on the spatiospectral intensity distribution, uniquely allowing to retrieve the FEL source point location. Building on these results, we anticipate a twofold impact towards development of the future high-average power cavity-based x-ray regenerative amplifier FEL and further advancement of a compact laser-plasma-based x-ray FEL.

FEL performance and tolerance studies of the EuPRAXIA@SPARC_LAB beamline AQUA

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1074, 170291 (MAY 2025)
https://doi.org/10.1016/j.nima.2025.170291

The AQUA beamline of the EuPRAXIA@SPARC_LAB facility is a SASE free-electron laser designed to operate in the water window, in the 3-4 nm wavelength range. The electron beam driving this source is accelerated up to about 1-1.2 GeV by an X-band normal conducting linear accelerator, followed by a plasma wakefield acceleration stage. The main radiator consists of an array often APPLE-X permanent magnet undulator modules, each 2 m long and with a period length of 18 mm. Tolerance analyses against resistive wall wakefields and injection misalignments at undulator entrance are performed, and the related effects on the laser yield performance are evaluated and discussed.

Investigation of correlations between spectral phase fluctuations of the laser pulse and the performance of an LPA

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1073, 170267 (APR 2025)
https://doi.org/10.1016/j.nima.2025.170267

Successfully using electron bunches generated from Laser-Plasma Accelerators (LPAs) to drive reliable Free-Electron Lasers (FELs) requires exceptional stability of the parameters involved in the LPA interaction. On the BELLA Center's Hundred Terawatt Undulator (HTU) System at Lawrence Berkeley National Laboratory (LBNL) we use a 100 Terawatt Ti:Sapph laser, capable of supplying 2.5 Joule, sub 40 fs pulses at 1 Hz on target, to produce 100 MeV, quasi-monoenergetic electron beams. As part of the effort to characterize and stabilize the laser pulses, a non-invasive on-shot spectral phase diagnostic was designed and commissioned on the HTU beamline. The results allow studying the direct correlations of spectral phase fluctuations to LPA and FEL parameters and chart a path towards further stabilization of the LPA process.

THEORY & SIMULATION

Computational methods for focused arbitrary laser fields in plasma simulations

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PHYSICS OF PLASMAS 32(4), 043901 (APR 2025)
https://doi.org/10.1063/5.0250718

An open-source code, arbitrary laser fields for particle-in-cell (ALFP), is provided to enable the use of accurately focused arbitrary beam structures in particle-in-cell (PIC) simulations, and is used to demonstrate the utility of space-time coupled beams for ion acceleration. ALFP provides significant flexibility for simulating focused beams with complex space, time, and polarization couplings in PIC simulations. This facilitates exploration of laser-matter interactions beyond the standard Gaussian laser pulse interaction. Additionally, polychromatic focusing effects that are often left out of analytic formulations are included. ALFP is first verified against theory, both directly with its computed output field and with 3D PIC simulations. Then ALFP is used to simulate space-time coupled beams in laser-matter interaction 2D PIC simulations, revealing improvements in ion collimation. (c) 2025 Author(s).

Control of instability in a Vlasov-Poisson system through an external electric field

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JOURNAL OF COMPUTATIONAL PHYSICS 530, 113904 (JUN 2025)
https://doi.org/10.1016/j.jcp.2025.113904

Plasma instabilities are a major concern in plasma science, for applications ranging from particle accelerators to nuclear fusion reactors. In this work, we consider the possibility of controlling such instabilities by adding an external electric field to the Vlasov-Poisson equations. Our approach to determining the external electric field is derived from a linear analysis that examines the revised dispersion relation. Allowing the external electric field to depend on time and space, we show that it is possible to completely suppress the plasma instabilities when the equilibrium distribution and the perturbation are known, with one particular choice of external field turning the system back to free-streaming. Numerical simulations of the nonlinear two-stream and bump-on-tail instabilities verify our theory and demonstrate the effectiveness of the few choices of external electric field that we derive.

Parallel Bayesian optimization of free-electron lasers based on laser wakefield accelerators

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PLASMA PHYSICS AND CONTROLLED FUSION 67(2), 025031 (FEB 2025)
https://doi.org/10.1088/1361-6587/adab1d

In this paper, the parallel Bayesian optimization algorithm is investigated for the simulation optimization of compact free electron lasers (FELs) driven by laser wakefield accelerators (LWFAs). The radiation energy serves as the objective function, which can be optimized to 25 μJ after several tens of iterations, initiating from random input samplings in soft x-ray regimes. The analysis of the FEL gain process has revealed that the localized properties of the electron beam (e beam) can be concurrently optimized, ensuring a high efficiency of energy extraction from the e beam. Our proposed scheme not only presents a viable design for compact FELs driven by LWFAs in the soft x-ray regime utilizing the start-to-end model, but also highlights the great potential of parallel Bayesian optimization algorithms for tackling the challenges associated with costly and complex black-box optimization problems.

Particle-in-cell simulation of laser wakefield accelerators with oblique lasers in quasi-cylindrical geometry

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PHYSICAL REVIEW A 111(2), 021301 (FEB 2025)
https://doi.org/10.1103/PhysRevAccelBeams.28.021301

In the studies of optical injections in laser or beam-driven wakefield accelerators, there is a frequent demand for using obliquely propagating assistant lasers in particle-in-cell simulations. In conventional methods, this is only possible in either two- or three-dimensional Cartesian geometries, which have the drawbacks of either lack of fidelity for the actual situation or requiring a huge amount of computational resources. In this work, we develop a new method that uses an expression-defined oblique laser field to simulate such situations in quasi-cylindrical geometry particle-in-cell simulations, having the advantages of both maintaining good fidelity and saving computational resources. As an example, we use this method in the scissor-cross ionization injection scheme for the optimization of the injected beam quality. This method is widely applicable to particle injections with assistant lasers in wakefield accelerators, as long as the assistant lasers only influence the injected particles during the injection process.

Declustering of macroparticles in long-term simulations of plasma wakefield acceleration

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PHYSICS OF PLASMAS 32(2), 023905 (FEB 2025)
https://doi.org/10.1063/5.0251688

A recently developed three-dimensional version of the quasistatic code LCODE has a novel feature that enables high-accuracy simulations of the long-term evolution of waves in plasma wakefield accelerators. Equations of plasma particle motion are modified to suppress clustering and numerical heating of macroparticles, which otherwise occur because the Debye length is not resolved by the numerical grid. The previously observed effects of premature wake chaotization and wavebreaking disappear with the modified equations. (C) 2025 Author(s).

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Funded by the European Union