CONTENTS

FUNDAMENTALS

Matched Guiding and Controlled Injection in Dark-Current-Free, 10-GeV-Class, Channel-Guided Laser-Plasma Accelerators

Picksley, A.; Stackhouse, J.; Benedetti, C.; Nakamura, K.; Tsai, H. E.; Li, R.; Miao, B.; Shrock, J. E.; Rockafellow, E.; Milchberg, H. M.; Schroeder, C. B.; van Tilborg, J.; Esarey, E.; Geddes, C. G. R.; Gonsalves, A. J.
PHYSICAL REVIEW LETTERS 133(25), 255001 (DEC 2024)
https://doi.org/10.1103/PhysRevLett.133.255001

We measure the high-intensity laser propagation throughout meter-scale, channel-guided laser-plasma accelerators by adjusting the length of the plasma channel on a shot-by-shot basis, showing high-quality guiding of 500 TW laser pulses over 30 cm in a hydrogen plasma of density $n_0 \approx 1 \times 10^{17}$ cm^{-3}. We observed transverse energy transport of higher-order modes in the first ≈ 12 cm of the plasma channel, followed by quasimatched propagation, and the gradual, dark-current-free depletion of laser energy to the wake. We quantify the laser-to-wake transfer efficiency limitations of currently available petawatt-class lasers and demonstrate via simulation how control over the laser mode can significantly improve beam parameters. Using 21.3 J of laser energy, and triggering localized electron injection, we observed electron bunches with single, quasimonoenergetic peaks up to 9.2 GeV with charge extending beyond 10 GeV.

Laser Wakefield Acceleration of Ions with a Transverse Flying Focus

Gong, Zheng; Cao, Sida; Palastro, John P.; Edwards, Matthew R.
PHYSICAL REVIEW LETTERS 133(26), 265002 (DEC 2024)
https://doi.org/10.1103/PhysRevLett.133.265002

The extreme electric fields created in high-intensity laser-plasma interactions could generate energetic ions far more compactly than traditional accelerators. Despite this promise, laser-plasma accelerator experiments have been limited to maximum ion energies of 100 MeV/nucleon. The central challenge is the low charge-to-mass ratio of ions, which has precluded one of the most successful approaches used for electrons: laser wakefield acceleration. Here, we show that a laser pulse with a focal spot that moves transverse to the laser propagation direction enables wakefield acceleration of ions to GeV energies in underdense plasma. Three-

dimensional particle-in-cell simulations demonstrate that this relativistic-intensity "transverse flying focus" can trap ions in a comoving electrostatic pocket, producing a monoenergetic collimated ion beam. With a peak intensity of 10^{20} W/cm^2 and an acceleration distance of 0.44 cm, we observe a proton beam with 23.1 pC charge, 1.6 GeV peak energy, and 3.7% relative energy spread. This approach allows for compact high-repetition-rate production of high-energy ions, highlighting the capability of more generalized spatiotemporal pulse shaping to address open problems in plasma physics.

Energy depletion and re-acceleration of driver electrons in a plasma-wakefield accelerator

Pena, F.; Lindstrom, C. A.; Beinortaite, J.; Svensson, J. Bjoerklund; Boulton, L.; Diederichs, S.; Foster, B.; Garland, J. M.; Caminal, P. Gonzalez; Loisch, G.; Schroeder, S.; Thevenet, M.; Wesch, S.; Wood, J. C.; Osterhoff, J.; D'Arcy, R.

PHYSICAL REVIEW RESEARCH 6(4), 043090 (NOV 2024)

https://doi.org/10.1103/PhysRevResearch.6.043090

For plasma-wakefield accelerators to fulfill their potential for cost effectiveness, it is essential that their energy-transfer efficiency be maximized. A key aspect of this efficiency is the near-complete transfer of energy, or depletion, from the driver electrons to the plasma wake. Achieving full depletion is limited by the process of re-acceleration, which occurs when the driver electrons decelerate to nonrelativistic energies, slipping backward into the accelerating phase of the wakefield and being subsequently re-accelerated. Such re-acceleration is unambiguously observed here for the first time. At this re-acceleration limit, we measure abeam driver depositing (57 +/- 3)% of its energy into a 195-mm-long plasma. This suggests that the energy-transfer efficiency of plasma accelerators could approach that of conventional accelerators.

Electrothermal filamentation of igniting plasmas

Martin, H.; Paddock, R. W.; Leyen, M. W. von der; Eliseev, V.; Ruskov, R. T.; Timmis, R.; Lee, J. J.; James, A.; Norreys, P. A.

PHYSICAL REVIEW E 110(3), 035205 (SEP 2024)

https://doi.org/10.1103/PhysRevE.110.035205

Dense, hot plasmas are susceptible to the electrothermal instability: a collisional process which permits temperature perturbations in electron currents to grow. It is shown here that linearizing a system comprised of two opposing currents and a mobile ion background as three distinct fluids yields unstable modes with rapid growth rates ($\sim 10^{13}$ s^{-1}) for wavenumbers below a threshold k_{th}. An analytical threshold condition is derived, this being surpassed for typical hot-spot and shell parameters. Particle-in-cell simulations successfully benchmark the predicted growth rates and threshold behavior. Electrothermal filamentation within the shell will impact the burn wave propagation into the cold fuel and resulting burn dynamics.

Wakefield-driven filamentation of warm beams in plasma

Walter, Erwin; Farmer, John P.; Weidl, Martin S.; Pukhov, Alexander; Jenko, Frank

PHYSICAL REVIEW E 110(3), 035208 (SEP 2024)

https://doi.org/10.1103/PhysRevE.110.035208

Charged and quasineutral beams propagating through an unmagnetized plasma are subject to numerous collisionless instabilities on the small scale of the plasma skin depth. The electrostatic two-stream instability, driven by longitudinal and transverse wakefields, dominates for dilute beams. This leads to modulation of the beam along the propagation direction and, for wide beams, transverse filamentation. A three-dimensional spatiotemporal two-stream theory for warm beams with a finite extent is developed. Unlike the cold beam limit, diffusion due to a finite emittance gives rise to a dominant wave number and a cutoff wave number above which filamentation is suppressed. Particle-in-cell simulations with quasineutral electron-positron beams in the relativistic regime give excellent agreement with the theoretical model. This paper provides deeper insights into the effect of diffusion on filamentation of finite beams, crucial for comprehending plasma-based accelerators in laboratory and cosmic settings.

Self-consistent effects in the ponderomotive acceleration of electron beams

Almansa, I.; Russman, F.; Peter, E.; Marini, S.; Rizzato, F. B.
JOURNAL OF PLASMA PHYSICS 90(4), 905900413 (SEP 2024)
https://doi.org/10.1017/S0022377824000758

In the present work, we extend the results of a previous investigation on the dynamics of electrons under the action of an inverse free-electron-laser scheme (Almansa *et al.*, Phys. Plasmas, vol. 26, 2019, 033105). While the former work examined electrons as single test particles subject to the combined action of a modulated wiggler plus a laser field, we now look at electrons as composing a particle beam, where collective space-charge effects are relevant and included in the analysis. Our previous work showed that effective acceleration is achieved when the initial velocities of the particles are close enough to the phase velocity of the beat-wave mode formed by the laser and the wiggler fields. Electrons are then initially accelerated by a ponderomotive uphill effect generated by the beat mode and, once reaching the phase velocity of the beat, undergo a final strong resonant acceleration step resembling a catapult effect. The present work shows that, under proper conditions, space-charge effects play a similar role as the initial (or injected) velocity of the beam. Even if acceleration is absent when space charge is neglected, it may be present and effective when charge effects are taken into account. We also discuss how far the space charge can grow without affecting the sustainability of the acceleration process.

Statistical theory of the broadband two-plasmon decay instability

Ruskov, R. T.; Bingham, R.; Silva, L. O.; Harper, M.; Aboushelbaya, R.; Myatt, J. F.; Norreys, P. A.
JOURNAL OF PLASMA PHYSICS 90(6), 905900621 (DEC 2024)
https://doi.org/10.1017/S0022377824000953

There is renewed interest in direct-drive inertial confinement fusion, following the milestone December 2022 3.15 MJ ignition result on the National Ignition Facility. A key obstacle is the control of the two-plasmon decay instability. Here, recent advances in inhomogeneous turbulence theory are applied to the broadband parametric instability problem for the first time. A novel dispersion relation is derived for the two-plasmon decay in a uniform plasma valid under broad-bandwidth laser fields with arbitrary power spectra. The effects of temporal incoherence on the instability are then studied. In the limit of large bandwidth, the well-known scaling relations for the growth rate are recovered, but it is shown that the result is more sensitive to the spectral shape of the laser pulse rather than to its coherence time. The range of wavenumbers of the excited plasma waves is shown to be substantially broadened, suggesting that the absolute instability is favoured in regions further away from the quarter critical density. The intermediate-bandwidth regime is explored numerically - the growth rate is reduced to half its monochromatic value for laser intensities of 10^{15} W cm^{-2} and relatively modest bandwidths of 5 THz. The instability-quenching properties of a spectrum of discrete lines spread over some bandwidth have also been studied. The reduction in the growth rate is found to be somewhat lower compared with the continuous case but is still significant, despite the fact that, formally, the coherence time of such a laser pulse is infinite.

Coherent Control of Relativistic Electron Dynamics in Plasma Nanophotonics

Dulat, Ankit; Rakeeb, S. K.; Dam, Sagar; Lad, Amit D.; Ved, Yash M.; Kruk, Sergey; Kumar, G. Ravindra
LASER & PHOTONICS REVIEWS 2401570 (NOV 2024)
https://doi.org/10.1002/lpor.202401570

Intense femtosecond laser pulses interacting with solids can drive electrons to relativistic energies, enabling miniaturized particle accelerators and bright extreme-UV light sources. In-situ space-time control of these electrons is crucial for developing next-generation laser-based accelerators but remains extremely challenging. A novel approach is presented to achieve such control by manipulating the local fields driving these electrons using a nanoengineered dielectric nanopillar target. Via experiments and simulations, it is demonstrated that this sub-femtosecond and nanometer-scale control enables enhanced electron acceleration and control of the directionality of relativistic electrons over a wide angular range and predicts the coherent formation of sub-femtosecond electron bunches from the nanopillars. This research bridges nanophotonics and strong-field plasma physics, offering new opportunities for in-situ control of high-energy particles and advancements in plasma technology.

Summary of Working Group 1: Laser-driven plasma wakefield acceleration

Lehe, R.; Miao, B.; Shrock, J. E.; Hidding, B.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1072, 170133 (MAR 2025)
https://doi.org/10.1016/j.nima.2024.170133

Working Group 1 discussed progress and advanced concepts in laser-driven wakefield acceleration (LWFA). LWFA technology has potential applications for e.g., future TeV-scale colliders, as well as compact high-energy light sources (e.g. plasma-based FEL). This working group included presentations of experimental, simulation, and theoretical results towards improving the performance of LWFA for these and other applications.

Summary of Working Group 2: Laser-driven plasma acceleration of ions

Kemp, Andreas; Palmer, Charlotte
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1072, 170156 (MAR 2025)
https://doi.org/10.1016/j.nima.2024.170156

This article summarizes contributions in WG2 (Laser-driven plasma acceleration of ions) made at AAC24. Topics include advancing the maximum proton energy beyond 100 MeV; repetition rate, innovative targets; and characterisation and improvement of shot-to-shot stability, beam quality, and conversion efficiency. Applications of interest for ion beams presented at AAC24 include radiobiology, materials science, fundamental physics, and fast-ignition inertial confinement fusion (ICF).

Summary of Working Group 3: Beam-driven plasma acceleration

O'Shea, Brendan; Muggli, Patric
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1072, 170130 (MAR 2025)
https://doi.org/10.1016/j.nima.2024.170130

We briefly summarize presentations that were made in the four sessions of the working group on beam-driven plasma acceleration (WG 3) that spanned over six hours.

PLASMA TECHNOLOGY, TARGETS & DIAGNOSTICS

Experimental Demonstration of an Emittance-Preserving Beam Energy Dechirper Using a Hollow Channel Plasma

Liu, Shuang; Li, Fei; Du, Yingchao; Peng, Bo; Fang, Yu; Ning, Xiaonan; Zhang, Tianliang; Chen, Jiucheng; Song, Zhi; Xiao, Hengyuan; Zhou, Linyi; Zhou, Bing; Hua, Jianfei; Lu, Wei
PHYSICAL REVIEW LETTERS 133(17), 175001 (OCT 2024)
https://doi.org/10.1103/PhysRevLett.133.175001

Plasma-based acceleration has emerged as a highly promising candidate for future colliders and compact x-ray free electron lasers owing to its capability to efficiently accelerate electron and positron beams with high brightness over short distances. However, a major obstacle to its application in free electron lasers and colliders is the imposition of a substantial energy chirp on the output beams, resulting from the longitudinally dependent acceleration field. This Letter presents the first experimental demonstration of a beam energy dechirper using a hollow plasma channel. This novel approach simultaneously enables the mitigation of energy chirp and preservation of beam emittance. Experimental results demonstrate a substantial reduction in energy spread by nearly 1 order of magnitude (from 0.93% to 0.11% FWHM), while maintaining a negligible increase in emittance. Simulation suggests that the corrected energy spread may have been reduced to 10 keV (0.025%), thereby meeting the stringent requirement of colliders or x-ray free electron lasers.

Target sensitivity study of density transition-injected electrons in laser wakefield accelerators

Cobo, C. C.; Arran, C.; Bourgeois, N.; Calvin, L.; Carderelli, J.; Cavanagh, N.; Colgan, C.; Dann, S. J. D.; Fitzgarrald, R.; Gerstmayr, E.; Kettle, B.; Los, E. E.; Mangles, S. P. D.; Mckenna, P.; Najmudin, Z.; Rajeev, P. P.; Ridgers, C. P.; Sarri, G.; Streeter, M. J. V.; Symes, D. R.; Thomas, A. G. R.; Watt, R.; Murphy, C. D.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 27(11), 111301 (NOV 2024)
https://doi.org/10.1103/PhysRevAccelBeams.27.111301

While plasma-based accelerators have the potential to positively impact a broad range of research topics, a route to application will only be possible through improved understanding of their stability. We present experimental results of a laser wakefield accelerator in the nonlinear regime in a helium gas jet target with a density transition produced by a razor blade in the flow. Modifications to the target setup are correlated with variations in the plasma density profile diagnosed via interferometry and the shot-to-shot variations of the density profile for nominally equal conditions are characterized. Through an in-depth sensitivity study using particle-in-cell simulations, the effects of changes in the plasma density profile on the accelerated

electron beams are investigated. The results suggest that blade motion is more detrimental to stability than gas pressure fluctuations, and that early focusing of the laser may reduce the deleterious effects of such density fluctuations.

Combined plasma lens and rephasing stage for a laser wakefield accelerator

Gustafsson, Cornelia; Lofquist, Erik; Svendsen, Kristoffer; Angella, Andrea; Persson, Anders; Lundh, Olle
SCIENTIFIC REPORTS 14(1), 26286 (NOV 2024)
https://doi.org/10.1038/s41598-024-78143-6

Electrons from a laser wakefield accelerator have a limited energy gain due to dephasing and are prone to emittance growth, causing a large divergence. In this paper, we experimentally show that adjusting the plasma density profile can address both issues. Shock-assisted ionisation injection is used to produce 100 MeV quasi-monoenergetic electron bunches in the primary part of the accelerator. Downstream from the accelerator, a second, independently tuneable density region is added, which can be used to either boost the energy of the electron bunches or as a plasma lens for significant divergence reduction. An additional energy gain of 25% and a 40% divergence reduction are obtained. Theoretical models validate the effects.

Oscillation damper for misaligned witness in plasma wakefield accelerator

Lotov, Konstantin V.; Kargapolov, Ivan Yu.; Tuev, Petr V.
PHYSICS OF PLASMAS 31(12), 123103 (DEC 2024)
https://doi.org/10.1063/5.0239380

If a laser- or particle beam-driven plasma wakefield accelerator operates in the linear or moderately nonlinear regime, injecting an externally produced particle bunch (witness) to be accelerated may encounter an alignment problem. Witness alignment tolerances can be relaxed by using a damper, an additional particle bunch produced by the same injector and propagating at a submillimeter distance ahead of the witness. If misaligned, the damper perturbs the wakefield in such a way that the witness shifts on-axis with no quality loss.

BEAMLINES & APPLICATIONS

Elevating electron energy gain and betatron x-ray emission in proton-driven wakefield acceleration

Saberi, Hossein; Xia, Guoxing; Liang, Linbo; Farmer, John Patrick; Pukhov, Alexander
PHYSICS OF PLASMAS 31(9), 093104 (SEP 2024)
https://doi.org/10.1063/5.0216713

The long proton beams present at CERN have the potential to evolve into a train of microbunches through the self-modulation instability process. The resonant wakefield generated by a periodic train of proton microbunches can establish a high acceleration field within the plasma, facilitating electron acceleration. This paper investigates the impact of plasma density on resonant wakefield excitation, thus influencing the acceleration of a witness electron bunch and its corresponding betatron radiation within the wakefield. Various scenarios involving different plasma densities are explored through particle-in-cell simulations. The peak wakefield in each scenario is calculated by considering a long pre-modulated proton driver with a fixed peak current. Subsequently, the study delves into the witness beam acceleration in the peak wakefield and its radiation emission. Elevated plasma density increases both the number of microbunches and the accelerating gradient of each microbunch, consequently resulting in heightened resonant wakefield. Nevertheless, the scaling is disrupted by the saturation of the resonant wakefield due to the nonlinearities. The simulation results reveal that at high plasma densities, an intense and broadband radiation spectrum extending into the domain of the hard x-rays and gamma rays is generated. Furthermore, in such instances, the energy gain of the witness beam is significantly enhanced. The impact of wakefield on the witness energy gain and the corresponding radiation spectrum is clearly evident at elevated densities.

Preliminary investigation of a Higgs factory based on proton-driven plasma wakefield acceleration

Farmer, J.; Caldwell, A.; Pukhov, A.
NEW JOURNAL OF PHYSICS 26(11), 113011 (NOV 2024)
https://doi.org/10.1088/1367-2630/ad8fc5

A Higgs Factory is considered the highest priority next collider project by the high-energy physics community. Very advanced designs based on radio-frequency cavities exist, and variations on this approach are still being developed. Recently, an option based on electron-bunch driven plasma wakefield acceleration has also been proposed. In this article, we discuss a further option based on proton-driven plasma wakefield acceleration. This option has significant potential advantages due to the high energy of the plasma wakefield driver, simplifying the plasma acceleration stage. Its success will depend on further developments in producing compact high-energy proton bunches at a high rate, which would also make possible a broad range of synergistic particle-physics research.

Research progress on advanced positron acceleration

Si, Meiyu; Huang, Yongsheng
EUROPEAN PHYSICAL JOURNAL A 60(10), 210 (OCT 2024)
https://doi.org/10.1140/epja/s10050-024-01433-0

Plasma Wakefield Acceleration (PWFA) is a highly promising method that can reduce the scale and cost of future electron-positron collider experiments. While significant breakthroughs have been achieved in electron acceleration both theoretically and experimentally, generating high-quality positron beams in plasma presents greater challenges. This paper reviews advanced positron acceleration schemes, including particle beam-driven wakefield acceleration, laser-driven wakefield acceleration, radiation acceleration, and hollow plasma channel acceleration. The hollow plasma channel scheme is a promising method that can provide stable and efficient acceleration of positrons, making it more advantageous for experimental implementation.

Compact ultrafast neutron sources via bulk acceleration of deuteron ions in an optical trap

Lei, Zhiyu; Ma, Hanghang; Zhang, Xiaobo; Yu, Lin; Zhang, Yihang; Li, Yutong; Weng, Suming; Chen, Min; Zhang, Jie; Sheng, Zhengming
MATTER AND RADIATION AT EXTREMES 9(5), 057202 (SEP 2024)
https://doi.org/10.1063/5.0208901

A scheme for a quasi-monoenergetic high-flux neutron source with femtosecond duration and highly anisotropic angular distribution is proposed. This scheme is based on bulk acceleration of deuteron ions in an optical trap or density grating formed by two counter-propagating laser pulses at an intensity of $\sim 10^{16}$

W/cm^2 in a near-critical-density plasma. The deuterons are first pre-accelerated to an energy of tens of keV in the ambipolar fields formed in the optical trap. Their energy is boosted to the MeV level by another one or two laser pulses at an intensity of $\sim 10^{20}$ W/cm^2, enabling fusion reactions to be triggered with high efficiency. In contrast to previously proposed pitcher-catcher configurations, our scheme can provide spatially periodic acceleration structures and effective collisions between deuterons inside the whole target volume. Subsequently, neutrons are generated directly inside the optical trap. Our simulations show that neutron pulses with energy 2-8 MeV, yield 10^{18} - 10^{19} n/s, and total number 10^6 - 10^7 in a duration $\sim$ 400 fs can be obtained with a 25 μm target. Moreover, the neutron pulses exhibit unique angularly dependent energy spectra and flux distributions, predominantly along the axis of the energy-boosting lasers. Such microsize femtosecond neutron pulses may find many applications, such as high-resolution fast neutron imaging and nuclear physics research.

FACILITIES

First Thomson scattering results from AWAKE's helicon plasma source

Stollberg, C.; Guittienne, Ph; Karimov, R.; Sublet, A.; Furno, I; Vincent, B.; Andrebe, Y.; Buttenschoen, B.
PLASMA PHYSICS AND CONTROLLED FUSION 66(11), 115011 (NOV 2024)
https://doi.org/10.1088/1361-6587/ad7d36

We present the first results of electron density and temperature measurements obtained from Thomson scattering at the helicon plasma source (HPS) for the AWAKE project. These measurements are compared to simulation results from a 1D power and particle balance model (PPM), confirming that the plasma can be fully sustained by collisional power dissipation. The variations in plasma parameters under different experimental conditions are evaluated in the PPM framework. We discuss current limitations of the model and propose possible improvements. Additionally, we suggest modifications to the existing HPS setup to enhance axial plasma homogeneity.

Optimizing beam dynamics in the EuPRAXIA@SPARC_LAB RF injector

Silvi, G. J.; Bacci, A. L.; Carillo, M.; Chiadroni, E.; Faillace, L.; Giribono, A.; Mostacci, A.; Ferario, M.; Vaccarezza, C.
NUOVO CIMENTO C-COLLOQUIA AND COMMUNICATIONS IN PHYSICS 47(5), 323 (SEP-OCT 2024)
https://doi.org/10.1393/ncc/i2024-24323-5

The EuPRAXIA@SPARC_LAB RF injector provides high-brightness electron beams accelerated and longitudinally manipulated in the velocity bunching regime (VB). The RF injector works in the so-called comb configuration. It foresees a 30 pC witness and a 200 pC driver longitudinally compressed in the first two accelerating structures both operated in the VB regime. The beam stability can be improved by adding a High Harmonic Cavity (HHC), interposed between the Gun and the first accelerating structure, to shorten and flatter the charge distribution and manipulate the beams to reach proper transverse and longitudinal parameters. The paper reports on beam dynamics studies performed with the insertion of the X-band RF cavity that is proposed to shape the beam current distribution, linearize the longitudinal phase space, and stabilize it with respect to RF jitters.

Overview and Recent Developments of the Frascati Laser for Acceleration and Multidisciplinary Experiments Laser Facility at SPARC_LAB

Galletti, Mario; Stocchi, Federica; Costa, Gemma; Curcio, Alessandro; Del Giorno, Martina; Pompili, Riccardo; Cacciotti, Luciano; Di Pirro, Giampiero; Dompe, Valentina; Verra, Livio; Villa, Fabio; Cianchi, Alessandro; Anania, Maria Pia; Ghigo, Andrea; Zigler, Arie; Ferrario, Massimo
APPLIED SCIENCES-BASEL 14(19), 8619 (OCT 2024)
https://doi.org/10.3390/app14198619

An overview of the 200 TW Frascati Laser for Acceleration and Multidisciplinary Experiments (FLAME) at the SPARC_LAB Test Facility at the National Laboratories of Frascati (LNF-INFN) is presented. The FLAME laser is employed to investigate different laser-matter interaction schemes, i.e., electron acceleration and secondary radiation sources through Laser Wakefield Acceleration (LWFA) or ion and proton generation through Target Normal Sheath Acceleration (TNSA), for a wide range of scientific areas including the biomedical applications. Finally, recently performed experimental campaigns within the EuAPS and EuPRAXIA frameworks are reported.

Technical Design Report for the LUXE experiment

Abramowicz, H. et al. (LUXE Collaboration)
EUROPEAN PHYSICAL JOURNAL-SPECIAL TOPICS 233(10), 1709-1974 (OCT 2024)
https://doi.org/10.1140/epjs/s11734-024-01164-9

This Technical Design Report presents a detailed description of all aspects of the LUXE (Laser Und XFEL Experiment), an experiment that will combine the high-quality and high-energy electron beam of the European XFEL with a high-intensity laser, to explore the uncharted terrain of strong-field quantum electrodynamics characterised by both high energy and high intensity, reaching the Schwinger field and beyond. The further implications for the search of physics beyond the Standard Model are also discussed.

THEORY & SIMULATION

The collisional particle-in-cell method for the Vlasov-Maxwell-Landau equations

Bailo, Rafael; Carrillo, Jose A.; Hu, Jingwei
JOURNAL OF PLASMA PHYSICS 90(4), 905900415 (OCT 2024)
https://doi.org/10.1017/S0022377824001077

We introduce an extension of the particle-in-cell method that captures the Landau collisional effects in the Vlasov-Maxwell-Landau equations. The method arises from a regularisation of the variational formulation of the Landau equation, leading to a discretisation of the collision operator that conserves mass, charge, momentum and energy, while increasing the (regularised) entropy. The collisional effects appear as a fully deterministic effective force, thus the method does not require any transport-collision splitting. The scheme can be used in arbitrary dimension, and for a general interaction, including the Coulomb case. We validate the scheme on scenarios such as the Landau damping, the two-stream instability and the Weibel instability, demonstrating its effectiveness in the numerical simulation of plasma.

Acceleration of the particle-in-cell code OSIRIS with graphics processing units

Lee, Roman P.; Pierce, Jacob R.; Miller, Kyle G.; Almanza, Maria; Tableman, Adam; Decyk, Viktor K.; Fonseca, Ricardo A.; Alves, E. Paulo; Mori, Warren B.
JOURNAL OF PLASMA PHYSICS 91(1), E8 (JAN 2025)
https://doi.org/10.1017/S0022377824001569

Fully relativistic particle-in-cell (PIC) simulations are crucial for advancing our knowledge of plasma physics. Modern supercomputers based on graphics processing units (GPUs) offer the potential to perform PIC simulations of unprecedented scale, but require robust and feature-rich codes that can fully leverage their computational resources. In this work, this demand is addressed by adding GPU acceleration to the PIC code OSIRIS. An overview of the algorithm, which features a CUDA extension to the underlying Fortran architecture, is given. Detailed performance benchmarks for thermal plasmas are presented, which demonstrate excellent weak scaling on NERSC's Perlmutter supercomputer and high levels of absolute performance. The robustness of the code to model a variety of physical systems is demonstrated via simulations of Weibel filamentation and laser-wakefield acceleration run with dynamic load balancing. Finally, measurements and analysis of energy consumption are provided that indicate that the GPU algorithm is up to $\sim$ 14 times faster and $\sim$ 7 times more energy efficient than the optimized CPU algorithm on a node-to-node basis. The described development addresses the PIC simulation community's computational demands both by contributing a robust and performant GPU-accelerated PIC code and by providing insight into efficient use of GPU hardware.

Pseudospectral particle-in-cell formulation with arbitrary charge and current-density time dependencies for the modeling of relativistic plasmas

Shapoval, Olga; Zoni, Edoardo; Lehe, Remi; Thevenet, Maxence; Vay, Jean-Luc
PHYSICAL REVIEW E 110(2), 025206 (AUG 2024)
https://doi.org/10.1103/PhysRevE.110.025206

This paper introduces a formulation of the particle-in-cell (PIC) method for the modeling of relativistic plasmas, that leverages the ability of the pseudospectral analytical time-domain solver (PSATD) to handle arbitrary time dependencies of the charge and current densities during one PIC cycle (applied to second-order polynomial dependencies here). The formulation is applied to a modified set of Maxwell's equations that was proposed earlier in the context of divergence cleaning, and to recently proposed extensions of the PSATD-PIC algorithm. Detailed analysis and testings revealed that, under some condition, the formulation can expand the range of numerical parameters under which PIC simulations are stable and accurate when modeling relativistic plasmas such as, e.g., plasma-based particle accelerators.

Thermal fluid closures and pressure anisotropies in numerical simulations of plasma wakefield acceleration

Simeoni, Daniele; Rossi, Andrea Renato; Parise, Gianmarco; Guglietta, Fabio; Sbragaglia, Mauro
PHYSICS OF PLASMAS 31(9), 093103 (SEP 2024)
https://doi.org/10.1063/5.0216707

We investigate the dynamics of plasma-based acceleration processes with collisionless particle dynamics and non-negligible thermal effects. We aim at assessing the applicability of fluid-like models, obtained by suitable

closure assumptions applied to the relativistic kinetic equations, thus not suffering from statistical noise, even in the presence of a finite temperature. The work here presented focuses on the characterization of pressure anisotropies, which crucially depend on the adopted closure scheme, and hence are useful to discern the appropriate thermal fluid model. To this aim, simulation results of spatially resolved fluid models with different thermal closure assumptions are compared with the results of particle-in-cell simulations at changing temperature and amplitude of plasma oscillations.

***WAKE up* is a collection of publicly available abstracts from published papers that are relevant to the AWAKE project. If you want your published paper to be included in the next issue of the newsletter, please contact Ricardo Torres at ricardo.torres@cockcroft.ac.uk**

www.awake-uk.org