FOREWORD

EuPRAXIA has recently been on the spotlight, featuring prominently at the IPAC conference. Hosted by Elettra and INFN in the beautiful city of Venice, IPAC'23 was one of the most successful accelerator conferences ever held in terms of attendance.

The conference was opened by EuPRAXIA coordinator Ralph Assmann, who was also the chair of the IPAC'23 organising committee. Massimo Ferrario introduced EuPRAXIA and its particle-driven site in Frascati, on behalf of the whole EuPRAXIA collaboration. He talked about the status of the technical design of the accelerator, general infrastructure plans and future pilot applications in the user community. The EuPRAXIA Doctoral Network was also presented by Carsten Welsch in the poster session, along with several other posters covering different aspects of research in EuPRAXIA. Even the outreach talk, given by Carsten Welsch on the Physics of Star Wars, featured the science of EuPRAXIA among some of facts defying fiction.

Supporting the talks and posters, INFN distributed promotional material of EuPRAXIA from a stand in the industry exhibition, making sure all participants in the conference had a chance to learn about this fascinating project and its possibilities.

We hope that this new issue of The EuPRAXIA Files will continue to strengthen the EuPRAXIA community.

Massimo Ferrario presenting EuPRAXIA at IPAC.

CONTENTS

FUNDAMENTALS

Experimental Demonstration of Laser Guiding and Wakefield Acceleration in a Curved Plasma Channel

Zhu, Xinzhe; Li, Boyuan; Liu, Feng ; Li, Jianlong; Bi, Zewu; Ge, Xulei; Deng, Hongyang; Zhang, Ziyang; Cui, Peilin; Lu, Lin; Yan, Wenchao; Yuan, Xiaohui; Chen, Liming; Cao, Qiang; Liu, Zhenyu; Sheng, Zhengming; Chen, Min; Zhang, Jie
PHYSICAL REVIEW LETTERS 130(21), 215001 (2023)
https://doi.org/10.1103/PhysRevLett.130.215001

Curved plasma channels have been proposed to guide intense lasers for various applications, such as x-ray laser emission, compact synchrotron radiation, and multistage laser wakefield acceleration [e.g. J. Luo et al., Phys. Rev. Lett. 120, 154801 (2018)]. Here, a carefully designed experiment shows evidences of intense laser guidance and wakefield acceleration in a centimeter-scale curved plasma channel. Both experiments and simulations indicate that when the channel curvature radius is gradually increased and the laser incidence offset is optimized, the transverse oscillation of the laser beam can be mitigated, and the stably guided laser pulse excites wakefields and accelerates electrons along the curved plasma channel to a maximum energy of 0.7 GeV. Our results also show that such a channel exhibits good potential for seamless multistage laser wakefield acceleration.

Photon Acceleration from Optical to XUV

Sandberg, R. T.; Thomas, A. G. R.
PHYSICAL REVIEW LETTERS 130(8), 085001 (2023)
https://doi.org/10.1103/PhysRevLett.130.085001

The propagating density gradients of a plasma wakefield may frequency upshift a trailing witness laser pulse, a process known as "photon acceleration." In uniform plasma, the witness laser will eventually dephase because of group delay. We find phase-matching conditions for the pulse using a tailored density profile. An analytic solution for a 1D nonlinear plasma wake with an electron beam driver indicates that, even though the plasma density decreases, the frequency shift reaches no asymptotic limit, i.e., is unlimited provided the wake can be sustained. In fully self-consistent 1D particle-in-cell (PIC) simulations, more than 40 times frequency shifts were demonstrated. In quasi-3D PIC simulations, frequency shifts up to 10 times were observed, limited only by simulation resolution and nonoptimized driver evolution. The pulse energy increases in this process, by a factor of 5, and the pulse is guided and temporally compressed by group velocity dispersion, resulting in the resulting extreme ultraviolet laser pulse having near-relativistic ($a_0 \sim 0.4$) intensity.

Controllable electron self-injection in laser wakefield acceleration with asymmetric gas-jet nozzle

Lei, Zhenzhe; Jin, Zhan; Zhidkov, Alexei; Pathak, Naveen; Mizuta, Yoshio; Huang, Kai; Nakanii, Nobuhiki; Daito, Izuru; Kando, Masaki; Hosokai, Tomonao

PROGRESS OF THEORETICAL AND EXPERIMENTAL PHYSICS 2023(3), 033J01 (2023)
https://doi.org/10.1093/ptep/ptad030

Beam charge control in the staging of laser wakefield acceleration (LWFA) is a crucial technique for developing full-optical jitter-free high-energy electron accelerators. Precise control of total charge in pre-accelerated electron bunches is necessary to achieve practical electron beam characteristics in the final acceleration stage(s). In contrast to the well-known cathode techniques in conventional accelerators, in LWFA the electron injection results from non-linear processes originating from plasma wave breaking. Therefore, the development of charge control requires a deep understanding of the electron self-injection processes and applications of non-trivial tools. The use of asymmetric gas-jet nozzles seems to be a promising way in developing charge control via tuning the target parameters such as plasma density, density slope, and acceleration length. Here, we demonstrate and characterize controllable electron self-injection, owing to a parametric resonance in slantwise density gas jets irradiated by 50 TW femtosecond laser pulses. The measured characteristics of the electron bunches, in which charge and energy distribution depend on the gas density and gas density gradient, agree well with those obtained by multidimensional particle-in-cell simulation and confirm the possibility of charge control.

Numerical study of electron acceleration driven by two-color laser pulses

Tabrizi, J. Sharifzadeh; Khorashadizadeh, S. M.; Fallah, R.; Niknam, A. R.

AIP ADVANCES 13(4), 045221 (2023)
https://doi.org/10.1063/5.0140834

The use of two-color relativistic femtosecond laser pulses for large-amplitude wakefield excitation and electron acceleration to relativistic energies in very short distances is a promising candidate that has recently been investigated experimentally and numerically by using the particle-in-cell method. Here, we have numerically studied the evolution of a large-amplitude wakefield excited by two-color relativistic femtosecond laser pulses in an underdense plasma. Moreover, the effects of some physical parameters such as two-color pulse polarization and time delay on the wakefield, and the electron acceleration are investigated. The results show that the wakefield amplitude and the energy of the accelerated electrons can be controlled by these parameters. We compare some results with those obtained by applying single-color pulses with similar energy. According to the comparison results, by applying two-color laser pulses, a stronger wakefield and higher electron energies can be obtained. We also show that our results are in good agreement with the experimental data obtained earlier.

Overcritical electron acceleration and betatron radiation in the bubble-like structure formed by re-injected electrons in a tailored transverse plasma

Zhao, Yuan; Lu, Haiyang; Zhou, Cangtao; Zhu, Jungao

MATTER AND RADIATION AT EXTREMES 8(1), 014403 (2023)
https://doi.org/10.1063/5.0121558

We present a novel scheme for dense electron acceleration driven by the laser irradiation of a near-critical-density plasma. The electron reflux effect in a transversely tailored plasma is particularly enhanced in the area of peak density. We observe a bubble-like distribution of re-injected electrons, which forms a strong quasistatic electromagnetic field that can accelerate electrons longitudinally while also preserving the electron transverse emittance. Simulation results demonstrate that over-dense electrons could be trapped in

such an artificial bubble and accelerated to an energy of ~500 MeV. The obtained relativistic electron beam can reach a total charge of up to 0.26 nC and is well collimated with a small divergence of 17 mrad. Moreover, the wavelength of electron oscillation is noticeably reduced due to the shaking of the bubble structure in the laser field. As a result, the energy of the produced photons is substantially increased to the gamma range. This new regime provides a path to generating high-charge electron beams and high-energy gamma-ray sources. (C) 2022 Author(s).

Control of electron beam current, charge, and energy spread using density downramp injection in laser wakefield accelerators

Hue, Celine S.; Wan, Yang; Levine, Eitan Y.; Malka, Victor
MATTER AND RADIATION AT EXTREMES 8(2), 024401 (2023)
https://doi.org/10.1063/5.0126293

Density downramp injection has been demonstrated to be an elegant and efficient approach for generating high-quality electron beams in laser wakefield accelerators. Recent studies have demonstrated the possibilities of generating electron beams with charges ranging from tens to hundreds of picocoulombs while maintaining good beam quality. However, the plasma and laser parameters in these studies have been limited to specific ranges or attention has been focused on separate physical processes such as beam loading, which affects the uniformity of the accelerating field and thus the energy spread of the trapped electrons, the repulsive force from the rear spike of the bubble, which reduces the transverse momentum pl of the trapped electrons and results in small beam emittance, and the laser evolution when traveling in the plasma. In this work, we present a comprehensive numerical study of downramp injection in the laser wakefield, and we demonstrate that the current profile of the injected electron beam is directly correlated with the density transition parameters, which further affects the beam charge and energy evolution. By fine-tuning the plasma density parameters, electron beams with high charge (up to several hundreds of picocoulombs) and low energy spread (around 1% FWHM) can be obtained. All these results are supported by large-scale quasi-three-dimensional particle-in-cell simulations. We anticipate that the electron beams with tunable beam properties generated using this approach will be suitable for a wide range of applications.

Efficient plasma electron accelerator driven by linearly chirped multi-10-TW laser pulses

Grigoriadis, A.; Andrianaki, G.; Tazes, I.; Dimitriou, V.; Tatarakis, M.; Benis, E. P.; Papadogiannis, N. A.
SCIENTIFIC REPORTS 13(1) (2023)
https://doi.org/10.1038/s41598-023-28755-1

The temporal rearrangement of the spectral components of an ultrafast and intense laser pulse, i.e., the chirp of the pulse, offers significant possibilities for controlling its interaction with matter and plasma. In the propagation of ultra-strong laser pulses within the self-induced plasma, laser pulse chirp can play a major role in the dynamics of wakefield and plasma bubble formation, as well as in the electron injection and related electron acceleration. Here, we experimentally demonstrate the control of the generation efficiency of a relativistic electron beam, with respect to maximum electron energy and current, by accurately varying the chirp value of a multi-10-TW laser pulse. We explicitly show that positively chirped laser pulses, i.e., pulses with instantaneous frequency increasing with time, accelerate electrons in the order of 100 MeV much more efficiently in comparison to unchirped or negatively chirped pulses. Corresponding Particle-In-Cell simulations strongly support the experimental results, depicting a smoother plasma bubble density distribution and electron injection conditions that favor the maximum acceleration of the electron beam, when positively chirped laser pulses are used. Our results, aside from extending the validity of similar studies reported for PW laser pulses, provide the ground for understanding the subtle dynamics of an efficient plasma electron accelerator driven by chirped laser pulses.

Electron acceleration by laser plasma wedge interaction

Marini, S.; Grech, M.; Kleij, P. S.; Raynaud, M.; Riconda, C.
PHYSICAL REVIEW RESEARCH 5(1), 013115 (2023)
https://doi.org/10.1103/PhysRevResearch.5.013115

An electron acceleration mechanism is identified that develops when a relativistically intense laser irradiates the wedge of an overdense plasma. This induces a diffracted electromagnetic wave that carries a significant longitudinal electric field and that accelerates electrons from the plasma over long distances to relativistic energies. Well collimated, highly charged (nC) electron bunches with energies up to hundreds of MeV are obtained using a laser beam with $I \lambda_0^2 = 3.5 \times 10^{19}$ W $\mu m^2/cm^2$. Multidimensional particle-in-cell simulations, supported by a simple analytical model, confirm the efficiency and robustness of the proposed acceleration scheme.

Demonstration of efficient relativistic electron acceleration by surface plasmonics with sequential target processing using high repetition lasers

Arikawa, Yasunobu; Morace, Alessio; Abe, Yuki; Iwata, Natsumi; Sentoku, Yasuhiko; Yogo, Akifumi; Matsuo, Kazuki; Nakai, Mitsuo; Nagatomo, Hideo; Mima, Kunioki; Nishimura, Hiroaki; Fujioka, Shinsuke; Kodama, Ryosuke; Inoue, Shunsuke; Hashida, Masaki; Sakabe, Shuji; De Luis, Diego; Gatti, Giancarlo; Huault, Marine; Perez-Hernandez, Jose Antonio; Roso, Luis; Volpe, Luca
PHYSICAL REVIEW RESEARCH 5(1), 013062 (2023)
https://doi.org/10.1103/PhysRevResearch.5.013062

For high repetition ultrahigh-intensity laser system, automatic alignment of structured target is key to achieving consistent particle acceleration and plasma heating. In this work, we demonstrate efficient electron acceleration with two sequential steps of laser processing using a high repetition rate, 30-fs ultrahigh-intensity laser. The first pulse does laser machining and creates a steep cylindrical crater on the surface of a flat stainless -steel target. The crater is formed by the hydrodynamic expansion of the heated surface and by spallation of the inner, deeper material by nonthermal relativistic electrons. The crater shape is well controlled and reproducible with 200 μm width and 350 μm depth. The second pulse irradiates deeply inside the crater and interacts with the crater wall, efficiently accelerating electrons via surface plasmonic, without need for target realignment. The laser absorption efficiency increases from 32.5 to 97.5% by the process.

Arbitrarily structured laser pulses

Pierce, Jacob R.; Palastro, John P.; Li, Fei; Malaca, Bernardo; Ramsey, Dillon; Vieira, Jorge; Weichman, Kathleen; Mori, Warren B.
PHYSICAL REVIEW RESEARCH 5(1), 013085 (2023)
https://doi.org/10.1103/PhysRevResearch.5.013085

Spatiotemporal control refers to a class of optical techniques for structuring a laser pulse with coupled spacetime-dependent properties, including moving focal points, dynamic spot sizes, and evolving orbital angular momenta. Here we introduce the concept of arbitrarily structured laser (ASTRL) pulses, which generalizes these techniques. The ASTRL formalism employs a superposition of prescribed pulses to create a desired electromag-netic field structure. Several examples illustrate the versatility of ASTRL pulses to address a broad range of laser-based applications, including laser wakefield acceleration, inertial confinement fusion, nanophotonics, and attosecond physics.

Polarization and phase control of electron injection and acceleration in the plasma by a self-steepening laser pulse

Kim, Jihoon; Wang, Tianhong; Khudik, Vladimir; Shvets, Gennady

NEW JOURNAL OF PHYSICS 25(3), 033009 (2023)
https://doi.org/10.1088/1367-2630/acbed5

We describe an interplay between two injection mechanism of background electrons into an evolving plasma bubble behind an intense laser pulse: one due to the overall bubble expansion, and another due to its periodic undulation. The two mechanisms occur simultaneously when an intense laser pulse propagating inside a plasma forms a shock-like steepened front. Periodic undulations of the plasma bubble along the laser propagation path can either inhibit or conspire with electron injection due to bubble expansion. We show that carrier-envelope-phase (CEP) controlled plasma bubble undulation induced by the self-steepening laser pulse produces a unique electron injector-expanding phase-controlled undulating bubble (EPUB). The longitudinal structure of the electron bunch injected by the EPUB can be controlled by laser polarization and power, resulting in high-charge (multiple nano-Coulombs) high-current (tens of kilo-amperes) electron beams with ultra-short (femtosecond-scale) temporal structure. Generation of high-energy betatron radiation with polarization- and CEP-controlled energy spectrum and angular distribution is analyzed as a promising application of EPUB-produced beams.

Time-resolved measurements of sub-optical-cycle relativistic electron beams

Li, Cheng; Zhang, Haoran; Guo, Zixin; Xu, Xiazhen; He, Zhigang; Zhang, Shancai; Jia, Qika; Wang, Lin

NEW JOURNAL OF PHYSICS 25(1), 013024 (2023)
https://doi.org/10.1088/1367-2630/acb37b

We propose an all-optical technique to record the time information of relativistic electron beams with sub-optical-cycle duration. The technique is based on the interaction of the electron beam with the ponderomotive potential of an optical traveling wave generated by two counter-propagating circularly polarized optical fields at different frequencies in vacuum. One of the optical pulses is a vortex laser pulse, and the other is a normal Gaussian laser pulse. The time information of the electron beam is mapped into the angular information, which can be converted into a spatial distribution after a drift section. Thus, the temporal profile and arrival time of the electron beam can be retrieved from the spatial distribution of the electron beam. The measurement has a dynamic range comparable to the period of the optical intensity grating formed by two counter-propagating laser pulses. This technique may have wide applications in many research fields that require sub-optical-cycle electron beams.

Resonance excitation of nonlinear wake field by non-uniform train of laser pulses

Yousefi, Fatemeh; Mirzanejhad, Saeed; Sohbatzadeh, Farshad

PHYSICA SCRIPTA 98(3), 035604 (2023)
https://doi.org/10.1088/1402-4896/acb7a9

Wake field excitation by a train of the laser pulses is an attractive branch of the laser wake field acceleration (LWFA). In this paper, we first discuss analytical formalism for constructing uniform and non-uniform train of laser pulses from a chirped laser pulse in the Michelson interferometer. Afterward, special criteria for resonance generation of wake field with the laser multi-pulses (MP-LWFA) are discussed numerically. We show that in the nonlinear regime of the laser wake field, a non-uniform train of laser pulse can be attractive in maintaining the resonance condition. For large laser amplitudes, $3 < a_0 < 10$ $a_0 = eE/mc\omega$), the optimized non-uniform train of laser pulses shows >30% increase in the acceleration gradient compared to the uniform train of laser pulses.

Laser wakefield acceleration of electrons using Bessel-Gauss doughnut beams for accelerating beam guiding

Tomkus, V.; Girdauskas, V.; Abedi-Varaki, M.; Raciukaitis, G.
JOURNAL OF PLASMA PHYSICS 89(2), 905890209 (2023)
https://doi.org/10.1017/S0022377823000247

A high-intensity laser pulse propagating through a gas target disturbs the uniform plasma distribution. Plasma density structures, created by high-order Bessel-Gauss beams for guiding the accelerating Gaussian beam and laser wakefield acceleration of electrons, are analysed using Wake-T and Fourier-Bessel particle-in-cell (FBPIC) simulation tools. The use of Bessel-Gauss doughnut beams increases the acceleration distance and energy of accelerated electrons up to 2.3 times at a 2 mm distance relative to the Gaussian beam of the same intensity.

Electron and ion acceleration from femtosecond laser-plasma peeler scheme

Shen, X. F.; Pukhov, A.; Qiao, B.
PLASMA PHYSICS AND CONTROLLED FUSION 65(3), 034005 (2023)
https://doi.org/10.1088/1361-6587/acb4e6

Using three-dimensional particle-in-cell simulations, we further investigate the electron and ion acceleration from femtosecond laser-plasma peeler scheme which was proposed in our recent paper (Shen et al 2021 Phys. Rev. X 11 041002). In addition to the standard setup where a laser pulse impinges on an edge of a single tape target, two new variants of the target, i.e. a parallel tape and a cross tape target, were proposed, where strong surface plasma waves can also be efficiently excited at the front edges of the target. By using a tabletop 200 TW-class laser pulse, we observe generation of high-flux, well-collimated, superponderomotive electrons. More importantly, quasimonoenergetic proton beams can always be obtained in all the three setups, while with the single tape case, the obtained proton beam has the highest peak energy and narrowest spectrum.

The role of laser chirp in relativistic electron acceleration using multi-electron gas targets

Grigoriadis, A.; Andrianaki, G.; Tatarakis, M.; Benis, E. P.; Papadogiannis, N. A.
PLASMA PHYSICS AND CONTROLLED FUSION 65(4), 044001 (2023)
https://doi.org/10.1088/1361-6587/acbb25

The role of multi-10 TW chirped laser pulses interacting with N_2 gas jet targets, as a test case for multi-electron targets, is experimentally examined. Complementary measurements using He gas jet targets, which are fully ionized well before the laser pulse peak, are also presented for comparison with the measurements for the multi-electron N_2 targets. It is found that for both gases positively chirped laser pulses accelerate electrons more efficiently compared to the Fourier transform-limited and negatively chirped pulses. Furthermore, multi-electron targets offer additional electron injection mechanisms for efficient electron acceleration as a function of the chirp, due to the dynamic ionization of inner-shell electrons near the peak of the laser pulse. Finally, we show that the background plasma density value plays a critical role in the efficient acceleration of positively chirped pulses as well as in the tuning of the positive chirp value for maximizing the electron energy. We clearly observe that larger plasma density values require higher positive chirp values for efficient electron acceleration.

Modeling of the driver transverse profile for laser wakefield electron acceleration at APOLLON research facility

Moulanier, I.; Dickson, L. T. ; Ballage, C.; Vasilovici, O.; Gremaud, A.; Dobosz Dufrenoy, S.; Delerue, N.; Bernardi, L.; Mahjoub, A.; Cauchois, A.; Specka, A.; Massimo, F.; Maynard, G.; Cros, B.
PHYSICS OF PLASMAS 30(5), 053109 (2023)
https://doi.org/10.1063/5.0142894

The quality of electron bunches accelerated by laser wakefields is highly dependant on the temporal and spatial features of the laser driver. Analysis of experiments performed at APOLLON PW-class laser facility shows that spatial instabilities of the focal spot, such as shot-to-shot pointing fluctuations or asymmetry of the transverse fluence, lead to charge and energy degradation of the accelerated electron bunch. It is shown that PIC simulations can reproduce experimental results with a significantly higher accuracy when the measured laser asymmetries are included in the simulated laser's transverse profile, compared to simulations with ideal, symmetric laser profile. A method based on a modified Gerchberg–Saxton iterative algorithm is used to retrieve the laser electric field from fluence measurements in vacuum in the focal volume, and accurately reproduce experimental results using PIC simulations, leading to simulated electron spectra in close agreement with experimental results, for the accelerated charge, energy distribution, and pointing of the electron beam at the exit of the plasma.

Radiation reaction and its impact on plasma-based energy-frontier colliders

Saberi, Hossein; Xia, Guoxing; Islam, Mohammad R. R.; Liang, Linbo; Davut, Can
PHYSICS OF PLASMAS 30(4), 043104 (2023)
https://doi.org/10.1063/5.0140525
Energy-frontier TeV colliders based on plasma accelerators are attracting much attention due to the recent achievements in multi-stage laser acceleration as well as the remarkable advances in electron- and proton-driven plasma accelerators. Such colliders may suffer a fundamental energy loss due to the radiation reaction (RR) effect, as the electrons lose energy through betatron radiation emission. Although the RR may not be critical for low-energy accelerators, it will exert limitations on TeV-class plasma-based colliders that need to be considered. In this paper, we have provided an extensive study of the RR effect in all pathways toward such colliders, including multi-stage plasma acceleration driven by the state-of-the-art lasers and the relativistic electron beam as well as the single-stage plasma acceleration with the energetic proton beams available at the CERN accelerator complex. A single-particle Landau-Lifschitz approach is used to consider the RR effect on an electron accelerating in the plasma blow-out regime. The model determines the boundaries where RR plays an energy limiting role on such colliders. The energy gain, the radiation loss, and the validity of the model are numerically explored.

Enhanced electron acceleration by high-intensity lasers in extended (confined) preplasma in cone targets

Rusby, D. R.; Cochran, G. E.; Aghedo, A.; Albert, F.; Armstrong, C. D.; Haid, A.; Kemp, A. J.; Kerr, S. M.; King, P. M.; Lemos, N.; Manuel, M. J. -E.; Ma, T.; MacPhee, A. G.; Pagano, I.; Pak, A.; Scott, G. G.; Siders, C. W.; Simpson, R. A.; Sinclair, M.; Wilks, S. C.; Williams, G. J.; Mackinnon, A. J.
PHYSICS OF PLASMAS 30(2), 023103 (2023)
https://doi.org/10.1063/5.0127580

We report on experimental results from a high-intensity laser interaction with cone targets that increase the number (x3) and temperature (x3) of the measured hot electrons over a traditional planar target. This increase is caused by a substantial increase in the plasma density within the cone target geometry, which was induced by 17 +/- 9 mJ prepulse that arrived 1.5 ns prior to the main high intensity (> 10^{19} W/cm^2).

Three-dimensional hydrodynamic simulations are conducted using HYDRA which show that the cone targets create substantially longer and denser plasma than planar targets due to the geometric confinement of the expanding plasma. The density within the cone is a several hundred-micron plasma "shelf" with a density of approximately 10^{20} n_e/cc. The HYDRA simulated plasma densities are used as the initial conditions for two-dimensional particle-in-cell simulations using EPOCH. These simulations show that the main acceleration mechanism is direct-laser-acceleration, with close agreement between experimentally measured and simulated electron temperatures. Further analysis is conducted to investigate the acceleration of the electrons within the long plasma generated within a compound parabolic concentrator by the prepulse.

Effect of a Femtosecond-Scale Temporal Structure of a Laser Driver on Generation of Betatron Radiation by Wakefield Accelerated Electrons

Sladkov, Andrey D. D.; Korzhimanov, Artem V. V.
PHOTONICS 10(2), 108 (2023)
https://doi.org/10.3390/photonics10020108

The brightness of betatron radiation generated by laser wakefield accelerated electrons can be increased by utilizing the laser driver with shorter duration at the same energy. Such shortening is possible by pulse compression after its nonlinear self-phase modulation in a thin plate. However, this method can lead to a rather complex femtosecond-scale time structure of the pulse. In this work, the results of numerical simulations show that the presence of prepulses containing a few percent of the main pulse energy can significantly alter the acceleration process and lead to either lower or higher energies of accelerated electrons and generated photons, depending on the prepulse parameters. Simultaneously, the presence of a pedestal inhibits the acceleration process lowering the brightness of the betatron source. Furthermore, postpulses following the main pulse are not found to have a significant effect on betatron radiation.

Progress in Hybrid Plasma Wakefield Acceleration

Hidding, Bernhard; Assmann, Ralph; Bussmann, Michael; Campbell, David; Chang, Yen-Yu; Corde, Sebastien; Cabadag, Jurjen Couperus; Debus, Alexander; Doepp, Andreas; Gilljohann, Max; Goetzfried, J.; Foerster, F. Moritz; Haberstroh, Florian; Habib, Fahim; Heinemann, Thomas; Hollatz, Dominik; Irman, Arie; Kaluza, Malte; Karsch, Stefan; Kononenko, Olena; Knetsch, Alexander; Kurz, Thomas; Kuschel, Stephan; Koehler, Alexander; de la Ossa, Alberto Martinez; Nutter, Alastair; Pausch, Richard; Raj, Gaurav; Schramm, Ulrich; Schoebel, Susanne; Seidel, Andreas; Steiniger, Klaus; Ufer, Patrick; Yeung, Mark; Zarini, Omid; Zepf, Matt
PHOTONICS 10(2), 99 (2023)
https://doi.org/10.3390/photonics10020099

Plasma wakefield accelerators can be driven either by intense laser pulses (LWFA) or by intense particle beams (PWFA). A third approach that combines the complementary advantages of both types of plasma wakefield accelerator has been established with increasing success over the last decade and is called hybrid LWFA -> PWFA. Essentially, a compact LWFA is exploited to produce an energetic, high-current electron beam as a driver for a subsequent PWFA stage, which, in turn, is exploited for phase-constant, inherently laser-synchronized, quasi-static acceleration over extended acceleration lengths. The sum is greater than its parts: the approach not only provides a compact, cost-effective alternative to linac-driven PWFA for exploitation of PWFA and its advantages for acceleration and high-brightness beam generation, but extends the parameter range accessible for PWFA and, through the added benefit of co-location of inherently synchronized laser pulses, enables high-precision pump/probing, injection, seeding and unique experimental constellations, e.g., for beam coordination and collision experiments. We report on the accelerating progress of the approach achieved in a series of collaborative experiments and discuss future prospects and potential impact.

Characteristics of electron beams accelerated by parallel and antiparallel circularly polarized Laguerre-Gaussian laser pulses

Song, Hoon; Pae, Ki Hong; Won, Junho; Song, Jaehyun; Lee, Seongmin; Kim, Chul Min; Ryu, Chang-Mo; Bang, Woosuk; Nam, Chang Hee
APPLIED PHYSICS B-LASERS AND OPTICS 129(4), 56 (2023)
https://doi.org/10.1007/s00340-023-07996-y

A direct comparison of the properties of electron beam generated by antiparallel circularly polarized Laguerre-Gaussian (CPLG) laser pulse and parallel CPLG laser pulse has been performed with three-dimensional particle-in-cell simulations. It is known that the longitudinal field of an antiparallel CPLG laser pulse with opposite signs of spin and orbital quantum number preferentially accelerates electrons to high energy. However, a direct comparison of electron beam between the other combination of spin and orbital angular momentum, the parallel CPLG laser pulse with the same sign of spin and orbital angular quantum number, has not been conducted. While the two pulses have an identical transverse field envelope, the generated electron beam properties are different. Although the magnitude of the longitudinal field is about one order of magnitude less than that of the transverse field, it has a significant effect on beam divergence. For antiparallel CPLG laser pulse, collimated electron bunches are formed with small divergence (< 50 mrad); while for parallel CPLG laser pulse, a diverging (> 100 mrad) electron beam is formed. This difference in beam quality can indicate a field-induced acceleration in actual experiments. A few-cycle laser pulse and low-density plasma are used to rule out the effect of laser-plasma interaction. It is also shown that for antiparallel CPLG laser pulse, the maximum kinetic energy increases with the square root of incident laser power, consistent with the scaling law for field-induced acceleration.

Active nonperturbative stabilization of the laser-plasma-accelerated electron beam source

Berger, Curtis; Barber, Sam; Isono, Fumika; Jensen, Kyle; Natal, Joseph; Gonsalves, Anthony; van Tilborg, Jeroen
PHYSICAL REVIEW ACCELERATORS AND BEAMS 26(3), 032801 (2023)
https://doi.org/10.1103/PhysRevAccelBeams.26.032801

Laser plasma accelerators have the ability to produce high-quality electron beams in compact, all optical-driven configurations, with the electron beams uniquely suited for a wide variety of acceleratorbased applications. However, fluctuations and drifts in the laser delivery to the mm-scale plasma target (the electron beam source) will translate into electron beam source variations that can limit their utility for demanding applications like light sources. Based on previous work in developing a nonperturbative diagnostic for the high-power laser delivery at focus, we present a full four-dimensional active stabilization system for the laser (transverse laser focus position and laser pointing angle in both transverse planes) and experimentally demonstrate how, as a result of the laser stabilization, critical parameters in the electron beam source were stabilized. Through the use of an energy resolved imaging system for the electron beam, we directly monitor the jitter in the transverse electron beam source location. Furthermore, the dispersion in the orthogonal plane to the magnetic spectrometer was recorded for each shot which is tied to the source pointing angle of the electron beam and, in part, driven by the angle of the laser at the interaction point. Our laser stabilization system reduced variation in the electron beam source location from ~12 to 3 mu m and reduced the dispersion jitter of the electron beam by 20%.

Modulational instability in large-amplitude linear laser wakefields

von Boetticher, A.; Walczak, R.; Hooker, S. M.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 26(2), L023201 (2023)
https://doi.org/10.1103/PhysRevE.107.L023201

We investigate the growth of ion density perturbations in large-amplitude linear laser wakefields via two-dimensional particle-in-cell simulations. Growth rates and wave numbers are found to be consistent with a longitudinal strong-field modulational instability. We examine the transverse dependence of the instability for a Gaussian wakefield envelope and show that growth rates and wave numbers can be maximized off axis. On-axis growth rates are found to decrease with increasing ion mass or electron temperature. These results are in close agreement with the dispersion relation of a Langmuir wave with an energy density that is large compared to the plasma thermal energy density. The implications for wakefield accelerators, in particular multipulse schemes, are discussed.

Spatio-temporal variation of Laguerre-Gaussian laser pulse and its effect on electron acceleration

Kad, Proxy; Singh, Arvinder
CHINESE JOURNAL OF PHYSICS 82, 171-181 (2023)
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In this paper, the longitudinal and transverse variation of Laguerre-Gaussian laser pulse has been investigated, when it is propagating inside the nonlinear plasma medium under the united impact of both relativistic and ponderomotive nonlinearity. Two second-order differential equations for transverse and longitudinal pulse width parameters have been derived using the approach of method of moments. The solution of both equations are obtained numerically and variation in spatio-temporal pulse width parameters is obtained. The excited plasma wave generated by the laser-plasma interaction, accelerate the plasma electrons to high gradients. The effect of the spatio-temporal variation on electron acceleration has also been studied and it has been observed that the laser pulse with smaller pulse duration results in better energy gain by the electrons.

Plasma density transition-based electron injection in laser wake field acceleration driven by a flying focus laser

Geng, Pan-Fei; Chen, Min; An, Xiang-Yan; Liu, Wei-Yuan; Zhu, Xin-Zhe; Li, Jian-Long; Li, Bo-Yuan; Sheng, Zheng-Ming
CHINESE PHYSICS B 32(4), 044101 (2023)
https://doi.org/10.1088/1674-1056/acae79

By using a high-intensity flying focus laser, the dephasingless [Phys. Rev. Lett. 124 134802 (2020)] or phase-locked [Nat. Photon. 14 475 (2020)] laser wakefield acceleration (LWFA) can be realized, which may overcome issues of laser diffraction, pump depletion, and electron dephasing which are always suffered in usual LWFA. The scheme thus has the potentiality to accelerate electrons to TeV energy in a single acceleration stage. However, the controlled electron injection has not been self-consistently included in such schemes. Only external injection was suggested in previous theoretical studies, which requires other accelerators and is relatively difficulty to operate. Here, we numerically study the actively controlled density transition injection in phase-locked LWFA to get appropriate density profiles for amount of electron injection. The study shows that compared with LWFA driven by lasers with fixed focus, a larger plasma density gradient is necessary. Electrons experience both transverse and longitudinal loss during acceleration due to the superluminal group velocity of the driver and the variation of the wakefield structure.

Furthermore, the periodic deformation and fracture of the flying focus laser in the high-density plasma plateau make the final injected charge also depend on the beginning position of the density downramp. Our studies show a possible way for amount of electron injection in LWFA driven by flying focus lasers.

Transverse X-ray radiation from petawatt-laser-driven electron acceleration in a gas cell

Pak, Tae Gyu; Rhee, Yong Joo; Mirzaie, Mohammad; Hojbota, Calin Ioan; Jeon, Jong Ho; Jo, Sung Ha; Nam, Chang Hee; Rezaei-Pandari, Mohammad; Sung, Jae Hee; Lee, Seong Ku; Kim, Ki Yong
JOURNAL OF THE KOREAN PHYSICAL SOCIETY 82(5), 455-461 (2023)
https://doi.org/10.1007/s40042-023-00730-z

We measure X-rays emitted perpendicular to the laser propagation direction in petawatt-laser-driven wakefield acceleration of electrons in a gas cell. Multi-mega-electronvolt electrons are ejected in the transverse direction by laser-driven plasma wakefields, generating bremsstrahlung X-rays when they encounter a dense medium such as a gas-cell window. The X-rays, detected and characterized by two separate filter-stack spectrometers containing a series of imaging plates, exhibit peak energy fluences at ~150-200 keV. The mechanism of electron acceleration in the transverse direction and subsequent bremsstrahlung X-ray generation is also examined and confirmed using particle-in-cell and Monte Carlo FLUKA simulations.

Wakefield Generation and Enhancement of Electron Energy to the Multi-GeV in a Magnetized Plasma

Nikrah, B.; Jafari, S.
IRANIAN JOURNAL OF SCIENCE (2023)
https://doi.org/10.1007/s40995-023-01442-6

The nonlinear interaction of an intense chirped laser pulse with transversely magnetized plasma is studied theoretically. The work described in this investigation is dealing with the characteristics of the wakefield generation by different chirping functions. Numerical results reveal that the amplitude and wavelength of the generated wakefield are highly influenced by the chirping constant and types of chirping function. Moreover, for the linear chirping function the positive chirping constant and for the nonlinear chirping functions the negative chirping constants excite larger wake amplitudes. In addition, it was found that by choosing a proper chirping constant for each chirping functions, one could obtain highly GeV electron energy gain. The maximum energy is obtained for the electron injected in the wakefield induced by the Exp and Linear chirped pulse. The maximum electron energy is about 2.5 GeV for the wake excited by the negative Exp chirp function. Further results revealed that the energy of the electron is significantly enhanced using an external transverse magnetic field.

PLASMA TECHNOLOGY

TeV/m catapult acceleration of electrons in graphene layers

Bontoiu, Cristian; Apsimon, Oznur; Kukstas, Egidijus; Rodin, Volodymyr; Yadav, Monika; Welsch, Carsten; Resta-Lopez, Javier; Bonatto, Alexandre; Xia, Guoxing
SCIENTIFIC REPORTS 13(1), 1330 (2023)
https://doi.org/10.1038/s41598-023-28617-w

Recent nanotechnology advances enable fabrication of layered structures with controllable inter-layer gap, giving the ultra-violet (UV) lasers access to solid-state plasmas which can be used as medium for electron acceleration. By using a linearly polarized 3 fs-long laser pulse of 100 nm wavelength and 10^{21} W/cm^2 peak intensity, we show numerically that electron bunches can be accelerated along a stack of ionized graphene layers. Particle-In-Cell (PIC) simulations reveal a new self-injection mechanism based on edge plasma oscillations, whose amplitude depends on the distance between the graphene layers. Nanometre-size electron ribbons are electrostatically catapulted into buckets of longitudinal electric fields in less than 1 fs, as opposed to the slow electrostatic pull, common to laser wakefield acceleration (LWFA) schemes in gas-plasma. Acceleration then proceeds in the blowout regime at a gradient of 4.79 TeV/m yielding a 0.4 fs-long bunch with a total charge in excess of 2.5 pC and an average energy of 6.94 MeV, after travelling through a graphene target as short as 1.5 μm. These parameters are unprecedented within the LWFA research area and, if confirmed experimentally, may have an impact on fundamental femtosecond research.

One-Body Capillary Plasma Source for Plasma Accelerator Research at e-LABs

Lee, Sihyeon; Kwon, Seong-hoon; Nam, Inhyuk; Cho, Myung-Hoon; Jang, Dogeun; Suk, Hyyong; Kim, Minseok
APPLIED SCIENCES-BASEL 13(4), 2564 (2023)
https://doi.org/10.3390/app13042564

We report on the development of a compact, gas-filled capillary plasma source for plasma accelerator applications. The one-body sapphire capillary was created through a diamond machining technique, which enabled a straightforward and efficient manufacturing process. The effectiveness of the capillary as a plasma acceleration source was investigated through laser wakefield acceleration experiments with a helium-filled gas cell, resulting in the production of stable electron beams of 200 MeV. Discharge capillary plasma was generated using a pulsed, high-voltage system for potential use as an active plasma lens. A peak current of 140 A, corresponding to a focusing gradient of 97 T/m, was observed at a voltage of 10 kV. These results demonstrate the potential utility of the developed capillary plasma source in plasma accelerator research using electron beams from a photocathode gun.

Exploring ultra-high-intensity wakefields in carbon nanotube arrays: An effective plasma-density approach

Bonatto, A.; Xia, G.; Apsimon, O.; Bontoiu, C.; Kukstas, E.; Rodin, V.; Yadav, M.; Welsch, C. P.; Resta-Lopez, J.
PHYSICS OF PLASMAS 30(3), 033105 (2023)
https://doi.org/10.1063/5.0134960

Charged particle acceleration using solid-state nanostructures has attracted attention in recent years as a method of achieving ultra-high-gradient acceleration in the TV/m domain. More concretely, metallic hollow nanostructures could be suitable for particle acceleration through the excitation of wakefields by a laser or a high-intensity charged particle beam in a high-density solid-state plasma. For instance, due to their special channeling properties as well as optoelectronic and thermo-mechanical properties, carbon nanotubes could be an excellent medium for this purpose. This article investigates the feasibility of generating ultra-high-gradient acceleration using carbon nanotube arrays, modeled as solid-state plasmas in conventional particle-in-cell simulations performed in a two-dimensional axisymmetric (quasi-3D) geometry. The generation of beam-driven plasma wakefields depending on different parameters of the solid structure is discussed in detail. Furthermore, by adopting an effective plasma-density approach, existing analytical expressions, originally derived for homogeneous plasmas, can be used to describe wakefields driven in periodic non-uniform plasmas.

Electromagnetic design of the transition section between modules of a wakefield accelerator

Siy, A.; Behdad, N.; Booske, J.; Waldschmidt, G.; Zholents, A.

PHYSICAL REVIEW ACCELERATORS AND BEAMS 26(1), 012802 (2023)
https://doi.org/10.1103/PhysRevAccelBeams.26.012802

The electromagnetic design of a transition section consisting of couplers for extracting the 180-GHz TM_{01} accelerating mode and 190-GHz HE_{11} dipole mode of a cylindrical corrugated waveguide used as a collinear wakefield accelerator is presented. Extraction of the high power accelerating mode reduces the power dissipation in the corrugated accelerating structure and allows the much weaker HE_{11} mode to be isolated and used to monitor the stability of the 10-nC electron drive bunch. The final design demonstrates wide bandwidth and high coupling efficiency of two couplers. The design was also optimized to have the surface electric and magnetic fields that do not exceed those in the corrugated waveguide. Finally, coupling between the drive electron bunch and the HE_{11} dipole mode in the corrugated waveguide is considered and the utility of the TE_{11} coupler for detecting the electron beam oscillations in the wakefield accelerator is demonstrated using a few representative examples of oscillations below and above a threshold of the beam breakup instability.

Underdense plasma lens with a transverse density gradient

Doss, C. E.; Ariniello, R.; Cary, J. R.; Corde, S.; Ekerfelt, H.; Gerstmayr, E.; Gessner, S. J.; Gilljohann, M.; Hansel, C.; Hidding, B.; Hogan, M. J.; Knetsch, A.; Lee, V.; Marsh, K.; O'Shea, B.; Claveria, P. San Miguel; Storey, D.; Sutherland, A.; Zhang, C.; Litos, M. D.

PHYSICAL REVIEW ACCELERATORS AND BEAMS 26(3), 031302 (2023)
https://doi.org/10.1103/PhysRevAccelBeams.26.031302

We explore the implications of a transverse density gradient on the performance of an underdense plasma lens and nonlinear plasma-based accelerator. Transverse density gradients are unavoidable in plasma sources formed in the outflow of standard gas jets, which are used heavily in plasma accelerator communities. These density gradients lead to longitudinal variations in the transverse wakefields, which can transversely deflect an electron beam within the blowout wake. We present a theoretical model of the fields within the plasma blowout cavity based on empirical analysis of 3D particle-in-cell (PIC) simulations. Using this model, the transverse beam dynamics may be studied analytically, allowing for an estimation of the net kick of a witness electron bunch from an underdense plasma lens and for density uniformity tolerance studies in plasma accelerators and plasma lenses. This model is compared to PIC simulations with a single electron bunch and constant density profile, and to PIC simulations with two bunches and a thin, underdense plasma lens density profile with density ramps.

Femtosecond Laser Fabrication of Curved Plasma Channels with Low Surface Roughness and High Circularity for Multistage Laser-Wakefield Accelerators

Deng, Hongyang; Zhang, Ziyang; Chen, Min; Li, Jianlong; Cao, Qiang; Hu, Xuejiao

MATERIALS 16(8), 3278 (2023)
https://doi.org/10.3390/ma16083278

A multistage laser-wakefield accelerator with curved plasma channels was proposed to accelerate electrons to TeV energy levels. In this condition, the capillary is discharged to produce plasma channels. The channels will be used as waveguides to guide intense lasers to drive wakefields inside the channel. In this work, a curved plasma channel with low surface roughness and high circularity was fabricated by a femtosecond laser ablation method based on response surface methodology. The details of the fabrication and performance of the channel are introduced here. Experiments show that such a channel can be successfully used to guide lasers, and electrons with an energy of 0.7 GeV were achieved.

BEAMLINES & APPLICATIONS

Compact Polarized X-Ray Source Based on All-Optical Inverse Compton Scattering

Ma, Yue; Hua, Jianfei; Liu, Dexiang; He, Yunxiao; Zhang, Tianliang; Chen, Jiucheng; Yang, Fan; Ning, Xiaonan; Zhang, Hongze; Du, Yingchao; Lu, Wei

PHYSICAL REVIEW APPLIED 19(1), 014073 (2023)
https://doi.org/10.1103/PhysRevApplied.19.014073

Polarized x-ray source is a useful probe for many fields, such as fluorescence imaging, magnetic microscopy, and nuclear physics research. All-optical inverse Compton scattering source (AOCS) based on a laser wakefield accelerator (LWFA) has drawn great attention in recent years due to its compact scale and high performance, especially its potential to generate polarized x rays. Here, polarization-tunable AOCS x rays are generated by a plasma-mirror-based scheme. The linearly and circularly polarized AOCS x rays are measured to have the mean photon energy of 60(+/- 5)/64(+/- 3) keV and the single-shot photon yield of approximately 1.1/1.3 x 10^7. A Compton polarimeter is designed to diagnose the x-ray polarization states, demonstrating the polarization tunability of AOCS, and indicating that the average polarization degree of the linearly polarized AOCS is 75(+/- 3)% within 18.2 mrad x-ray divergence.

High-flux positron generation via the ultra-intense laser irradiating density-modulated plasmas

Liu, Jian-Xun; Gao, Ting; Wang, Xu; Jin, Hong-Bin; Deng, Wei-Qiang; Liu, Tai-Yang; Yu, Tong-Pu

FRONTIERS IN PHYSICS 10, 1052654 (2023)
https://doi.org/10.3389/fphy.2022.1052654

To investigate plasma density during the Breit-Wheeler positron generation, a comparative study of four plasma targets is performed via the PIC (particle-in-cell) code EPOCH. When an ultra-intense laser (2.8 x 10^{23} Wcm^{-2}) is incident, more positrons with high energy are generated in the increasing density plasmas. The positron yield is already 1.5 x 10^8 with a cutoff energy of 2 GeV at t = 37 T_0. It is demonstrated that increasing density plasmas will enhance gamma photon radiation and positron generation. In increasing density plasmas, under-dense plasmas favor electron acceleration, and over-dense plasmas will induce laser reflection. Cross sections of the Compton back-scattering and the BW positron generation are both increased via high-energy electrons colliding with the reflected laser. In addition, increasing the laser intensity will directly enhance positron generation. This investigation will further facilitate high -flux positron generation and application.

Precise pointing control of high-energy electron beam from laser wakefield acceleration using an aperture

Nakanii, Nobuhiko; Huang, Kai; Kondo, Kotaro; Kiriyama, Hiromitsu; Kando, Masaki

APPLIED PHYSICS EXPRESS 16(2), 026001 (2023)
https://doi.org/10.35848/1882-0786/acb892

We demonstrated the precise directional control of high-energy electron beams of several hundred MeV by moving a circular serrated aperture smaller than the laser diameter perpendicular to the laser propagation direction before the final focusing optics in a laser system. This technique is simple and effective because the direction of the electron beam can be precisely controlled without any additional manipulation of the optics in the laser system and the gas target. This will be a useful guideline and of great significance for the future development towards practical uses and applications of laser-plasma accelerators.

Multistage Positron Acceleration by an Electron Beam-Driven Strong Terahertz Radiation

Zhao, Jie; Hu, Yan-Ting; Zhang, Hao; Lu, Yu; Hu, Li-Xiang; Shao, Fu-Qiu; Yu, Tong-Pu
PHOTONICS 10(4), 364 (2023)
https://doi.org/10.3390/photonics10040364

Laser-plasma accelerators (LPAs) have been demonstrated as one of the candidates for traditional accelerators and have attracted increasing attention due to their compact size, high acceleration gradients, low cost, etc. However, LPAs for positrons still face many challenges, such as the beam divergence controlling, large energy spread, and complicated plasma backgrounds. Here, we propose a possible multistage positron acceleration scheme for high energy positron beam acceleration and propagation. It is driven by the strong coherent THz radiation generated when an injected electron ring beam passes through one or more solid targets. Multidimensional particle-in-cell simulations demonstrated that each acceleration stage is able to provide nearly 200 MeV energy gain for the positrons. Meanwhile, the positron beam energy spread can be controlled within 2%, and the beam emittance can be maintained during the beam acceleration and propagation. This may attract one's interests in potential experiments on both large laser facilities and a traditional accelerator together with a laser system.

Creation and direct laser acceleration of positrons in a single stage

Martinez, Bertrand; Barbosa, Bernardo; Vranic, Marija
PHYSICAL REVIEW ACCELERATORS AND BEAMS 26(1), 011301 (2023)
https://doi.org/10.1103/PhysRevAccelBeams.26.011301

Relativistic positron beams are required for fundamental research in nonlinear strong field QED, plasma physics, and laboratory astrophysics. Positrons are difficult to create and manipulate due to their short lifetime, and their energy gain is limited by the accelerator size in conventional facilities. Alternative compact accelerator concepts in plasmas are becoming more and more mature for electrons, but positron generation and acceleration remain an outstanding challenge. Here, we propose a new setup where we can generate, inject, and accelerate them in a single stage during the propagation of an intense laser in a plasma channel. The positrons are created from a laser-electron collision at 90 degrees, where the injection and guiding are made possible by an 800-nC electron beam loading which reverses the sign of the background electrostatic field. We obtain a 17-fC positron beam, with GeV-level central energy within 0.5 mm of plasma.

Monte Carlo modeling of focused Very High Energy Electron beams as an innovative modality for radiotherapy application

Krim, Deae-eddine; Rrhioua, Abdeslem; Zerfaoui, Mustapha; Bakari, Dikra
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS; SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1047, 167785 (2023)
https://doi.org/10.1016/j.nima.2022.167785
After the invention of the Linear Electron Accelerator for Research (CLEAR) based on the Advanced Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE) at CERN, the development of an accurate and accessible high energy electron radiotherapy treatment is a major challenge in medical physics. The technological advances of the linear collider and the relativistic effects of Very High Energy Electron (VHEE) particles; have led researchers to propose a simple management of collimated beams in the energy range of 50-250 MeV to reduce scattering and enable irradiation of deep-seated tumor position. However, the measured entry and exit doses and lateral scattering for collimated VHEE beams treatment are very high compared with other treatment modalities. This task provides a new approach based on focused VHEE

obtained by combining an accurate Monte Carlo (MC) simulation with a complex modeling electron transport with very high energy inside a water phantom. This focused VHEE is compared to stereotactic cyberknife, protontherapy and VHEE treatment using a collimator. The results demonstrated that radiotherapy with a focused VHEE beam of energy greater than 100 MeV can surround deep-seated and highly inhomogeneous tumors with great accuracy. It could represent a valid alternative for a better preservation of healthy tissues, since the dispersion of the dose over a large volume reduces the entry and exit dose. Moreover, this approach can be shaped or scanned to treat deep-seated tumors, as the dose will be concentrated into a small well-defined volumetric element.

Multi-millijoule terahertz emission from laser-wakefield-accelerated electrons

Pak, Taegyu; Rezaei-Pandari, Mohammad; Kim, Sang Beom; Lee, Geonwoo; Wi, Dae Hee; Hojbota, Calin Ioan; Mirzaie, Mohammad; Kim, Hyeongmun; Sung, Jae Hee; Lee, Seong Ku; Kang, Chul; Kim, Ki-Yong
LIGHT-SCIENCE & APPLICATIONS 12(1), 37 (2023)
https://doi.org/10.1038/s41377-022-01068-0

High-power terahertz radiation was observed to be emitted from a gas jet irradiated by 100-terawatt-class laser pulses in the laser-wakefield acceleration of electrons. The emitted terahertz radiation was characterized in terms of its spectrum, polarization, and energy dependence on the accompanying electron bunch energy and charge under various gas target conditions. With a nitrogen target, more than 4 mJ of energy was produced at < 10 THz with a laser-to-terahertz conversion efficiency of ~ 0.15%. Such strong terahertz radiation is hypothesized to be produced from plasma electrons accelerated by the ponderomotive force of the laser and the plasma wakefields on the time scale of the laser pulse duration and plasma period. This model is examined with analytic calculations and particle-in-cell simulations to better understand the generation mechanism of high-energy terahertz radiation in laser-wakefield acceleration.

THEORY & SIMULATION

Energy-Conserving Theory of the Blowout Regime of Plasma Wakefield

Golovanov, A.; Kostyukov, Yu.; Pukhov, A.; Malka, V.
PHYSICAL REVIEW LETTERS 130(10), 105001 (2023)
https://doi.org/10.1103/PhysRevLett.130.105001

We present a self-consistent theory of strongly nonlinear plasma wakefield (bubble or blowout regime of the wakefield) based on the energy conservation approach. Such wakefields are excited in plasmas by intense laser or particle beam drivers and are characterized by the expulsion of plasma electrons from the propagation axis of the driver. As a result, a spherical cavity devoid of electrons (called a "bubble") and surrounded by a thin sheath made of expelled electrons is formed behind the driver. In contrast to the the energy conservation law, does not require any external fitting parameters, and describes the bubble structure and the electromagnetic field it contains with much higher accuracy in a wide range of parameters. The obtained results are verified by 3D particle-in-cell simulations.

Multi-objective and multi-fidelity Bayesian optimization of laser-plasma acceleration

Irshad, F.; Karsch, S.; Doepp, A.
PHYSICAL REVIEW APPLIED 19(1), 013063 (2023)
https://doi.org/10.1103/PhysRevResearch.5.013063

Beam parameter optimization in accelerators involves multiple, sometimes competing, objectives. Condensing these individual objectives into a single figure of merit unavoidably results in a bias towards particular outcomes, often in an undesired way in the absence of prior knowledge. Finding an optimal objective definition then requires operators to iterate over many possible objective weights and definitions, a process that can take many times longer than the optimization itself. A more versatile approach is multi-objective optimization, which establishes the trade-off curve or Pareto front between objectives. Here we present the first results on multi-objective Bayesian optimization of a simulated laser-plasma accelerator. We find that multi-objective optimization reaches comparable performance to its single-objective counterparts while allowing for instant evaluation of entirely new objectives. This dramatically reduces the time required to find appropriate objective definitions for new problems. Additionally, our multi-objective, multi-fidelity method reduces the time required for an optimization run by an order of magnitude. It does so by dynamically choosing simulation resolution and box size, requiring fewer slow and expensive simulations as it learns about the Pareto-optimal solutions from fast low-resolution runs. The techniques demonstrated in this paper can easily be translated into many different computational and experimental use cases beyond accelerator optimization.

A fermi acceleration model to study the electron acceleration in laser-produced plasma with localized structures formation and turbulence generation

Singh, Indraj; Uma, R.; Sharma, R. P.
PHYSICS OF PLASMAS 30(2), 022108 (2023)
https://doi.org/10.1063/5.0131281

This investigation presents a model based on the nonlinear coupling of waves for studying electron acceleration in laser-produced plasma. The impact of the localized structures formation and turbulence generation on electron acceleration is investigated via a second-order Fermi acceleration mechanism. For this purpose, the dynamical coupled equations of the extraordinary mode laser and the upper hybrid wave are formulated by taking into account relativistic and ponderomotive nonlinearity. These coupled equations are solved by laboratory simulations using pseudo-spectral and finite difference methods. The simulation results show the turbulent wavenumber spectrum associated with the localization of the laser beam. The power-law scaling of turbulence generation has been utilized to study the formation of the thermal tail of energetic electrons, which may be responsible for the acceleration of the electrons. A fractional diffusion method has been exploited to determine electron acceleration. This study also provides a simplified model for a better understanding of the nonlinear progression of the laser beam during propagation inside the magnetized plasma.

Improved modellisation of laser-particle interaction in particle-in-cell simulations

Bourgeois, Pierre-Louis; Davoine, Xavier
JOURNAL OF PLASMA PHYSICS 89(2), 905890206 (2023)
https://doi.org/10.1017/S0022377823000223

A new method named B-TIS (Bourgeois & Davoine, J. Comput. Phys., vol. 413, 2020, 109426) has recently been proposed for suppressing the influence of numerical Cherenkov radiation that appears in particle-in-cell (PIC) simulation of laser wakefield acceleration (LWFA). However, while this method provides good results when applied to the already accelerated electrons, we show here that it cannot model correctly most of the plasma electron bulk interacting with the laser field. We thus investigate in this paper the origins of this limitation and propose an improved method for which this limitation is removed. This new method, named B-TIS3, can now be applied to a much broader variety of problems and improve the performance in comparison with the standard PIC algorithm. We show that, for an electron interacting directly with a laser pulse, this new technique offers greater accuracy in terms of momentum and motion than the conventional scheme used in many PIC codes. These improvements translate into more faithful energy spectrum and electric charge for the accelerated beam in simulations of vacuum laser acceleration (VLA) or LWFA involving direct laser acceleration (DLA) at low plasma density. This new method, easy to implement and not computationally demanding, should then prove useful to study in depth and help develop novel VLA, DLA and LWFA techniques.

Modeling of three-dimensional betatron oscillation and radiation reaction in plasma accelerators

Liu, Yulong; Zeng, Ming
PHYSICAL REVIEW ACCELERATORS AND BEAMS 26(3), 031301 (2023)
https://doi.org/10.1103/PhysRevAccelBeams.26.031301

Betatron oscillation is a commonly known phenomenon in laser or beam-driven plasma wakefield accelerators. In the conventional model, the plasma wake provides a linear focusing force to a relativistic electron, and the electron oscillates in one transverse direction with the betatron frequency proportional to $1/\sqrt{\gamma}$, where γ is the Lorentz factor of the electron. In this work, we extend this model to three-dimensional by considering the oscillation in two transverse and one longitudinal directions. The long-term equations, with motion in the betatron time scale averaged out, are obtained and compared with the original equations by numerical methods. In addition to the longitudinal and transverse damping due to radiation reaction which has been found before, we show phenomena including the longitudinal phase drift oscillation, betatron phase shift, and betatron polarization change based on our long-term equations. This work can be highly valuable for future plasma-based high-energy accelerators and colliders.

Numerical Studies on Bow Waves in Intense Laser-Plasma Interaction

Ning, Li; Jie, Mu; Fancun, Kong
LASER AND PARTICLE BEAMS 2023), 9414451 (2023)
https://doi.org/10.1155/2023/9414451

Laser-driven wakefield acceleration (LWFA) has attracted lots of attention in recent years. However, few writers have been able to make systematic research into the bow waves generated along with the wake waves. Research about the bow waves will help to improve the understanding about the motion of the electrons near the wake waves. In addition, the relativistic energetic electron density peaks have great potential in electron acceleration and reflecting flying mirrors. In this paper, the bow waves generated in laser-plasma interactions as well as the effects of different laser and plasma parameters are investigated. Multidimensional particle-in-cell simulations are made to present the wake waves and bow waves by showing the electron density and momentum distribution as well as the electric field along x and y directions. The evolution of the bow wave structure is investigated by measuring the open angle between the bow wave and the wake wave cavity. The angle as well as the peak electron density and transverse momentum is demonstrated with respect to different laser intensities, spot sizes, plasma densities, and preplasma lengths. The density peak emits high-order harmonics up to 150 orders and can be a new kind of "flying mirror" to generate higher order harmonics. The study on the bow waves is important for further investigation on the electron motion around the wake waves, generation of dense electron beams, generation of high-order harmonics, and other research and applications based on the bow waves.

Laser wakefield accelerator modelling with variational neural networks

Streeter, M. J. V.; Colgan, C.; Cobo, C. C.; Arran, C.; Los, E. E.; Watt, R.; Bourgeois, N.; Calvin, L.; Carderelli, J.; Cavanagh, N.; Dann, S. J. D.; Fitzgarrald, R.; Gerstmayr, E.; Joglekar, A. S.; Kettle, B.; Mckenna, P.; Murphy, C. D.; Najmudin, Z.; Parsons, P.; Qian, Q.; Rajeev, P. P.; Ridgers, C. P.; Symes, D. R.; Thomas, A. G. R.; Sarri, G.; Mangles, S. P. D.
HIGH POWER LASER SCIENCE AND ENGINEERING 11, e9 (2023)
https://doi.org/10.1017/hpl.2022.47

A machine learning model was created to predict the electron spectrum generated by a GeV-class laser wakefield accelerator. The model was constructed from variational convolutional neural networks, which mapped the results of secondary laser and plasma diagnostics to the generated electron spectrum. An ensemble of trained networks was used to predict the electron spectrum and to provide an estimation of the uncertainty of that prediction. It is anticipated that this approach will be useful for inferring the electron spectrum prior to undergoing any process that can alter or destroy the beam. In addition, the model provides insight into the scaling of electron beam properties due to stochastic fluctuations in the laser energy and plasma electron density.

FACILITIES

The INFN-LNF present and future accelerator-based light facilities

Balerna, Antonella; Ferrario, Massimo; Stellato, Francesco
EUROPEAN PHYSICAL JOURNAL PLUS 138(1), 37 (2023)
https://doi.org/10.1140/epjp/s13360-022-03611-9

The INFN-Frascati National Laboratory (LNF) is nowadays running a 0.51 GeV electron-positron collider, DAΦNE, that also represents the synchrotron radiation source of the beamlines of the DAΦNE-Light facility. Not being DAΦNE dedicated to synchrotron radiations activities, the DAΦNE-Light facility can use it mainly in parasitic mode. Particle accelerators and high energy physics (HEP) have been and are the main core of the LNF research activity, but like other HEP international laboratories also LNF is now moving in the direction of developing a dedicated free electron laser (FEL) user facility, EuPRAXIA@SPARC_Lab, based on plasma acceleration. This new facility in the framework of the EuPRAXIA (European Plasma Research Accelerator with eXcellence in Applications) EU project should produce FEL radiation beams for a wide range of applications using a smaller accelerator compared to actual radio frequency-based accelerator sources dimensions.

EDUCATION

Surfatron: Catch the wave of accelerators.

Torres, R.
SCIENCE IN SCHOOL 62 (2023)
https://www.scienceinschool.org/article/2023/surfatron-catch-the-wave-of-accelerators/

Try your hand at Surfatron, a game that lets students experience the challenges faced by particle accelerator scientists while learning about the physics of waves.

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EuPRAXIA

www.eupraxia-facility.org

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