THE EuPRAXIA FILES

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Foreword

Dr Ralph Aßmann
EuPRAXIA Coordinator

The Horizon 2020 design study EuPRAXIA is now in its final year. We have already made a significant impact, including a mention of EuPRAXIA in the recently published ESFRI roadmap and there is continuing strong interest in what we will propose in October 2019. The political environment in Europe for plasma accelerators and their short/medium-term applications aimed for with EuPRAXIA remains remarkably positive.

The success of EuPRAXIA will depend critically on delivering a clear message supported by our research. With this in mind, the present issue of *The EuPRAXIA Files* contains fifteen published papers co-authored by members of the EuPRAXIA Consortium, including a *Nature Communications* and two *Physical Review Letters*. These outstanding results bode well for the successful delivery of a convincing Conceptual Design Report.

Research Papers

Control of laser plasma accelerated electrons for light sources

Andre, T.; Andriyash, I. A.; Loulergue, A.; Labat, M.; Roussel, E.; Ghaith, A.; Khojoyan, M.; Thaury, C.; Valleau, M.; Briquez, F.; Marteau, F.; Tavakoli, K.; N'Gotta, P.; Dietrich, Y.; Lambert, G.; Malka, V.; Benabderrahmane, C.; Veteran, J.; Chapuis, L.; El Ajjouri, T.; Sebdaoui, M.; Hubert, N.; Marcouille, O.; Berteaud, P.; Leclercq, N.; El Ajjouri, M.; Rommeluere, P.; Bouvet, F.; Duval, J. -P.; Kitegi, C.; Blache, F.; Mahieu, B.; Corde, S.; Gautier, J.; Ta Phuoc, K.; Goddet, J. P.; Lestrade, A.; Herbeaux, C.; Evain, C.; Szwaj, C.; Bielawski, S.; Tafzi, A.; Rousseau, P.; Smartsev, S.; Polack, F.; Dennetiere, D.; Bourassin-Bouchet, C.; De Oliveira, C.; Couprie, M. -E.
NATURE COMMUNICATIONS 9, 1334 (APR 6 2018)
https://doi.org/10.1038/s41467-018-03776-x

With gigaelectron-volts per centimetre energy gains and femtosecond electron beams, laser wakefield acceleration (LWFA) is a promising candidate for applications, such as ultrafast electron diffraction, multistaged colliders and radiation sources (betatron, compton, undulator, free electron laser). However, for some of these applications, the beam performance, for example, energy spread, divergence and shot-to-shot fluctuations, need a drastic improvement. Here, we show that, using a dedicated transport line, we can mitigate these initial weaknesses. We demonstrate that we can manipulate the beam longitudinal and transverse phase-space of the presently available LWFA beams. Indeed, we separately correct orbit mis-steerings and minimise dispersion thanks to specially designed variable strength quadrupoles, and select the useful energy range passing through a slit in a magnetic chicane. Therefore, this matched electron beam leads to the successful observation of undulator synchrotron radiation after an 8m transport path. These results pave the way to applications demanding in terms of beam quality.

Laser-accelerated particle beams for stress testing of materials

Barberio, M.; Sciscio, M.; Vallieres, S.; Cardelli, F.; Chen, S. N.; Famulari, G.; Gangolf, T.; Revet, G.; Schiavi, A.; Senzacqua, M.; Antici, P.
NATURE COMMUNICATIONS 9, 372 (JAN 25 2018)
https://doi.org/10.1038/s41467-017-02675-x

Laser-driven particle acceleration, obtained by irradiation of a solid target using an ultra-intense ($I > 10^{18}$ W/cm^2) short-pulse (duration <1 ps) laser, is a growing field of interest, in particular for its manifold potential applications in different domains. Here, we provide experimental evidence that laser-generated particles, in particular protons, can be used for stress testing materials and are particularly suited for identifying materials to be used in harsh conditions. We show that these laser-generated protons can produce, in a very short time scale, a strong mechanical and thermal damage, that, given the short irradiation time, does not allow for recovery of the material. We confirm this by analyzing changes in the mechanical, optical, electrical, and morphological properties of five materials of interest to be used in harsh conditions.

Electron acceleration by wave turbulence in a magnetized plasma

Rigby, A.; Cruz, F.; Albertazzi, B.; Bamford, R.; Bell, A. R.; Cross, J. E.; Fraschetti, F.; Graham, P.; Hara, Y.; Kozlowski, P. M.; Kuramitsu, Y.; Lamb, D. Q.; Lebedev, S.; Marques, J. R.; Miniati, F.; Morita, T.; Oliver, M.; Reville, B.; Sakawa, Y.; Sarkar, S.; Spindloe, C.; Trines, R.; Tzeferacos, P.; Silva, L. O.; Bingham, R.; Koenig, M.; Gregori, G.
NATURE PHYSICS 14(5), 475 (MAY 2018)
https://doi.org/10.1038/s41567-018-0059-2

Astrophysical shocks are commonly revealed by the non-thermal emission of energetic electrons accelerated in situ. Strong shocks are expected to accelerate particles to very high energies; however, they require a source of particles with velocities fast enough to permit multiple shock crossings. While the resulting diffusive shock acceleration process can account for observations, the kinetic physics regulating the continuous injection of non-thermal particles is not well understood. Indeed, this injection problem is particularly acute for electrons, which rely on high-frequency plasma fluctuations to raise them above the thermal pool. Here we show, using laboratory laser-produced shock experiments, that, in the presence of a strong magnetic field, significant electron pre-heating is achieved. We demonstrate that the key mechanism in producing these energetic electrons is through the generation of lower-hybrid turbulence via shock-reflected ions. Our experimental results are analogous to many astrophysical systems, including the interaction of a comet with the solar wind, a setting where electron acceleration via lower-hybrid waves is possible.

Diagnostics for plasma-based electron accelerators

Downer, M. C.; Zgadzaj, R.; Debus, A.; Schramm, U.; Kaluza, M. C.
REVIEWS OF MODERN PHYSICS 90(3), 035002 (AUG 8 2018)
https://doi.org/10.1103/RevModPhys.90.035002

Plasma-based accelerators that impart energy gain as high as several GeV to electrons or positrons within a few centimeters have engendered a new class of diagnostic techniques very different from those used in connection with conventional radio-frequency (rf) accelerators. The need for new diagnostics stems from the micrometer scale and transient, dynamic structure of plasma accelerators, which contrasts with the meter scale and static structure of conventional accelerators. Because of this micrometer source size, plasma-accelerated electron hunches can emerge with smaller normalized transverse emittance ($\epsilon_n < 0.1$ mm mrad) and shorter duration ($\tau_b \sim 1$ fs) than bunches from rf linacs. Single-shot diagnostics are reviewed that determine such small ϵ_n and τ_b noninvasively and with high resolution from wide-bandwidth spectral measurement of electromagnetic radiation the electrons emit: ϵ_n from x rays emitted as electrons interact with transverse internal fields of the plasma accelerator or with external optical fields or undulators; τ_b from THz to optical coherent transition radiation emitted upon traversing interfaces. The duration of $\sim$ 1 fs bunches can also be measured by sampling individual cycles of a copropagating optical pulse or by measuring the associated magnetic field using a transverse probe pulse. Because of their luminal velocity and micrometer size, the evolving structure of plasma accelerators, the key determinant of accelerator performance, is exceptionally challenging to visualize in the laboratory. Here a new generation of laboratory diagnostics is reviewed that yield snapshots, or even movies, of laser- and particle-beam-generated plasma accelerator structures based on their phase modulation or deflection of femtosecond electromagnetic or electron probe pulses. Spatiotemporal resolution limits of these imaging techniques are discussed, along with insight into plasma-based acceleration physics that has emerged from analyzing the images and comparing them to simulated plasma structures.

Energy-Chirp Compensation in a Laser Wakefield Accelerator

Doepp, A.; Thaury, C.; Guillaume, E.; Massimo, F.; Lifschitz, A.; Andriyash, I.; Goddet, J. -P.; Tazfi, A.; Phuoc, K. Ta; Malka, V.

PHYSICAL REVIEW LETTERS 121(7), 074802 (AUG 17 2018)
https://doi.org/10.1103/PhysRevLett.121.074802

The energy spread in laser wakefield accelerators is primarily limited by the energy chirp introduced during the injection and acceleration processes. Here, we propose the use of longitudinal density tailoring to reduce the beam chirp at the end of the accelerator. Experimental data sustained by quasi-3D particle-in-cell simulations show that broadband electron beams can be converted to quasimonoenergetic beams of <= 10% energy spread while maintaining a high charge of more than 120 pC. In the linear and quasilinear regimes of wakefield acceleration, the method could provide even lower, subpercent level, energy spread.

Intrinsic Stabilization of the Drive Beam in Plasma-Wakefield Accelerators

Martinez de la Ossa, A.; Mehrling, T. J.; Osterhoff, J.

PHYSICAL REVIEW LETTERS 121(6), 064803 (AUG 8 2018)
https://doi.org/10.1103/PhysRevLett.121.064803

The hose instability of the drive beam constitutes a major challenge for the stable operation of plasma-wakefield accelerators. In this Letter, we show that drive beams with a transverse size comparable to the plasma blowout radius generate a wake with a varying focusing along the beam, which leads to a rapid detuning of the slice-betatron oscillations and suppresses the instability. This intrinsic stabilization principle provides an applicable and effective method for the suppression of the hosing of the drive beam and allows for a stable acceleration process.

Optical Control of the Topology of Laser-Plasma Accelerators

Vieira, J.; Mendonca, J. T.; Quere, F.

PHYSICAL REVIEW LETTERS 121(5), 054801 (JUL 30 2018)
https://doi.org/10.1103/PhysRevLett.121.054801

We propose a twisted plasma accelerator capable of generating relativistic electron vortex beams with helical current profiles. The angular momentum of these vortex bunches is quantized, dominates their transverse motion, and results in spiraling particle trajectories around the twisted wakefield. We focus on a laser wakefield acceleration scenario, driven by a laser beam with a helical spatiotemporal intensity profile, also known as a light spring. We find that these light springs can rotate as they excite the twisted plasma wakefield, providing a new mechanism to control the twisted wakefield phase velocity and enhance energy gain and trapping efficiency beyond planar wakefields.

Observation of High Transformer Ratio Plasma Wakefield Acceleration

Loisch, G.; Asova, G.; Boonpornprasert, P.; Brinkmann, R.; Chen, Y.; Engel, J.; Good, J.; Gross, M.; Gruener, F.; Huck, H.; Kalantaryan, D.; Krasilnikov, M.; Lishilin, O.; Martinez de la Ossa, A.; Mehrling, T.J.; Melkumyan, D.; Oppelt, A.; Osterhoff, J.; Qian, H.; Renier, Y.; Stephan, F.; Tenholt, C.; Wohlfarth, V.; Zhao, Q.
PHYSICAL REVIEW LETTERS 121(6), 064801 (AUG 7 2018)
https://doi.org/10.1103/PhysRevLett.121.064801

Particle-beam-driven plasma wakefield acceleration (PWFA) enables various novel high-gradient techniques for powering future compact light-source and high-energy physics applications. Here, a driving particle bunch excites a wakefield response in a plasma medium, which may rapidly accelerate a trailing witness beam. In this Letter, we present the measurement of ratios of acceleration of the witness bunch to deceleration of the driver bunch, the so-called transformer ratio, significantly exceeding the fundamental theoretical and thus far experimental limit of 2 in a PWFA. An electron bunch with ramped current profile was utilized to accelerate a witness bunch with a transformer ratio of 4.6(-0.7)(+2.2) in a plasma with length ∼ 10 cm, also demonstrating stable transport of driver bunches with lengths on the order of the plasma wavelength.

High-Brilliance Betatron gamma-Ray Source Powered by Laser-Accelerated Electrons

Ferri, J.; Corde, S.; Doepp, A.; Lifschitz, A.; Doche, A.; Thaury, C.; Phuoc, K. Ta; Mahieu, B.; Andriyash, I. A.; Malka, V; Davoine, X.
PHYSICAL REVIEW LETTERS 120(25), 254802 (JUN 21 2018)
https://doi.org/10.1103/PhysRevLett.120.254802

Recent progress in laser-driven plasma acceleration now enables the acceleration of electrons to several gigaelectronvolts. Taking advantage of these novel accelerators, ultrashort, compact, and spatially coherent x-ray sources called betatron radiation have been developed and applied to high-resolution imaging. However, the scope of the betatron sources is limited by a low energy efficiency and a photon energy in the 10 s of kiloelectronvolt range, which for example prohibits the use of these sources for probing dense matter. Here, based on three-dimensional particle-in-cell simulations, we propose an original hybrid scheme that combines a low-density laser-driven plasma accelerator with a high-density beam-driven plasma radiator, thereby considerably increasing the photon energy and the radiated energy of the betatron source. The energy efficiency is also greatly improved, with about 1% of the laser energy transferred to the radiation, and the gamma-ray photon energy exceeds the megaelectronvolt range when using a 15 J laser pulse. This high-brilliance hybrid betatron source opens the way to a wide range of applications requiring MeV photons, such as the production of medical isotopes with photonuclear reactions, radiography of dense objects in the defense or industrial domains, and imaging in nuclear physics.

Observation of Laser Power Amplification in a Self-Injecting Laser Wakefield Accelerator

Streeter, M. J. V; Kneip, S.; Bloom, M. S.; Bendoyro, R. A.; Chekhlov, O.; Dangor, A. E.; Doepp, A.; Hooker, C. J.; Holloway, J.; Jiang, J.; Lopes, N. C.; Nakamura, H.; Norreys, P. A.; Palmer, C. A. J.; Rajeev, P. P.; Schreiber, J.; Symes, D. R.; Wing, M.; Mangles, S. P. D.; Najmudin, Z.
PHYSICAL REVIEW LETTERS 120(25), 254801 (JUN 19 2018)
https://doi.org/10.1103/PhysRevLett.120.254801

We report on the depletion and power amplification of the driving laser pulse in a strongly driven laser wakefield accelerator. Simultaneous measurement of the transmitted pulse energy and temporal shape indicate an increase in peak power from 187 +/- 11 TW to a maximum of 318 +/- 12 TW after 13 mm of propagation in a plasma density of 0.9 x 10^{18} cm^{-3} . The power amplification is correlated with the injection and acceleration of electrons in the nonlinear wakefield. This process is modeled by including a localized redshift and subsequent group delay dispersion at the laser pulse front.

Multistage Coupling of Laser-Wakefield Accelerators with Curved Plasma Channels

Luo, J.; Chen, M.; Wu, W. Y.; Weng, S. M.; Sheng, Z. M.; Schroeder, C. B.; Jaroszynski, D. A.; Esarey, E.; Leemans, W. P.; Mori, W. B.; Zhang, J.

PHYSICAL REVIEW LETTERS 120(15), 154801 (APR 10 2018)
https://doi.org/10.1103/PhysRevLett.120.154801

Multistage coupling of laser-wakefield accelerators is essential to overcome laser energy depletion for high-energy applications such as TeV-level electron-positron colliders. Current staging schemes feed subsequent laser pulses into stages using plasma mirrors while controlling electron beam focusing with plasma lenses. Here a more compact and efficient scheme is proposed to realize the simultaneous coupling of the electron beam and the laser pulse into a second stage. A partly curved channel, integrating a straight acceleration stage with a curved transition segment, is used to guide a fresh laser pulse into a subsequent straight channel, while the electrons continue straight. This scheme benefits from a shorter coupling distance and continuous guiding of the electrons in plasma while suppressing transverse beam dispersion. Particle-in-cell simulations demonstrate that the electron beam from a previous stage can be efficiently injected into a subsequent stage for further acceleration while maintaining high capture efficiency, stability, and beam quality.

Few-femtosecond electron beam with terahertz-frequency wakefield-driven compression

Zhao, L.; Jiang, T.; Lu, C.; Wang, R.; Wang, Z.; Zhu, P.; Shi, Y.; Song, W.; Zhu, X.; Jing, C.; Antipov, S.; Xiang, D.; Zhang, J.

PHYSICAL REVIEW ACCELERATORS AND BEAMS 21(8), 082801 (AUG 29 2018)
https://doi.org/10.1103/PhysRevAccelBeams.21.082801

We propose and demonstrate a novel method to produce few-femtosecond electron beam with relatively low timing jitter. In this method a relativistic electron beam is compressed from about 150 fs (rms) to about 7 fs (rms, upper limit) with the wakefield at THz frequency produced by a leading drive beam in a dielectric tube. By imprinting the energy chirp in a passive way, we demonstrate through laser-driven THz streaking technique that no additional timing jitter with respect to an external laser is introduced in this bunch compression process, a prominent advantage over the conventional method using radio-frequency bunchers. We expect that this passive bunching technique may enable new opportunities in many ultrashort-beam based advanced applications such as ultrafast electron diffraction and plasma wakefield acceleration with externally injected beam.

Quasimonoenergetic laser plasma positron accelerator using; particle-shower plasma-wave interactions

Sahai, A. A.

PHYSICAL REVIEW ACCELERATORS AND BEAMS 21(8), 081301 (AUG 8 2018)
https://doi.org/10.1103/PhysRevAccelBeams.21.081301

An all-optical centimeter-scale laser-plasma positron accelerator is modeled to produce quasimonoenergetic beams with tunable ultrarelativistic energies. A new principle elucidated here describes the trapping of divergent positrons that are part of a laser-driven electromagnetic particle-shower with a large energy spread and their acceleration into a quasimonoenergetic positron beam in a laser-driven plasma wave. Proof of this principle using analysis and particle-in-cell simulations demonstrates that, under limits defined here, existing lasers can accelerate hundreds of MeV pC quasi-monoenergetic positron bunches. By providing an affordable alternative to kilometer-scale radio-frequency accelerators, this compact positron accelerator opens up new avenues of research.

Novel fast simulation technique for axisymmetric plasma wakefield acceleration configurations in the blowout regime

Baxevanis, P.; Stupakov, G.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 21(7), 071301 (JUL 24 2018)
https://doi.org/10.1103/PhysRevAccelBeams.21.071301

In the blowout regime of plasma wakefield acceleration (PWFA), which is the most relevant configuration for current and future applications and experiments, the plasma flow that is excited by the ultrarelativistic drive beam is highly nonlinear. Thus, fast and accurate simulation codes are indispensable tools in the study of this extremely important problem. We have developed a novel algorithm that deals with the propagation of axisymmetric bunches of otherwise arbitrary profile through a cold plasma of uniform density. In contrast to the existing PWFA simulation tools, our code PLEBS (plasmaelectron beam simulations) uses a new computational scheme which ensures that the transverse and longitudinal directions are completely decoupled-a feature which significantly enhances the speed and robustness of the new method. Our numerical results are benchmarked against the QUICKPIC code and excellent agreement is established between the two approaches. Moreover, our new technique provides a very convenient framework for studying issues such as beam loading and short-range wakefields within the plasma cavity.

Optimization of laser-plasma injector via beam loading effects using ionization-induced injection

Lee, P.; Maynard, G.; Audet, T. L.; Cros, B.; Lehe, R.; Vay, J. -L.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 21(5), 052802 (MAY 9 2018)
https://doi.org/10.1103/PhysRevAccelBeams.21.052802

Simulations of ionization-induced injection in a laser driven plasma wakefield show that high-quality electron injectors in the 50-200 MeV range can be achieved in a gas cell with a tailored density profile. Using the PIC code Warp with parameters close to existing experimental conditions, we show that the concentration of N_2 in a hydrogen plasma with a tailored density profile is an efficient parameter to tune electron beam properties through the control of the interplay between beam loading effects and varying accelerating field in the density profile. For a given laser plasma configuration, with moderate normalized laser amplitude, a_0 = 1.6 and maximum electron plasma density, $n_{e0} = 4 \times 10^{18}$ cm^{-3} , the optimum concentration results in a robust configuration to generate electrons at 150 MeV with a rms energy spread of 4% and a spectral charge density of 1.8 pC/MeV.

High flux femtosecond x-ray emission from the electron-hose instability in laser wakefield accelerators

Dong, C. F.; Zhao, T. Z.; Behm, K.; Cummings, P. G.; Nees, J.; Maksimchuk, A.; Yanovsky, V.; Krushelnick, K.; Thomas, A. G. R.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 21(4), 041303 (APR 24 2018)
https://doi.org/10.1103/PhysRevAccelBeams.21.041303

Bright and ultrashort duration x-ray pulses can be produced by through betatron oscillations of electrons during laser wakefield acceleration (LWFA). Our experimental measurements using the HERCULES laser system demonstrate a dramatic increase in x-ray flux for interaction distances beyond the depletion/dephasing lengths, where the initial electron bunch injected into the first wake bucket catches up with the laser pulse front and the laser pulse depletes. A transition from an LWFA regime to a beam-driven plasma wakefield acceleration regime consequently occurs. The drive electron bunch is susceptible to the electron-hose instability and rapidly develops large amplitude oscillations in its tail, which leads to greatly enhanced x-ray radiation emission. We measure the x-ray flux as a function of acceleration length using a variable length gas cell. 3D particle-in-cell simulations using a Monte Carlo synchrotron x-ray emission algorithm elucidate the time-dependent variations in the radiation emission processes.

Short-range wakefields generated in the blowout regime of plasma-wakefield acceleration

Stupakov, G.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 21(4), 041301 (APR 2 2018)
https://doi.org/10.1103/PhysRevAccelBeams.21.041301

In the past, calculation of wakefields generated by an electron bunch propagating in a plasma has been carried out in linear approximation, where the plasma perturbation can be assumed small and plasma equations of motion linearized. This approximation breaks down in the blowout regime where a high-density electron driver expels plasma electrons from its path and creates a cavity void of electrons in its wake. In this paper, we develop a technique that allows us to calculate short-range longitudinal and transverse wakes generated by a witness bunch being accelerated inside the cavity. Our results can be used for studies of the beam loading and the hosing instability of the witness bunch in plasma-wakefield and laser-wakefield acceleration.

Emittance preservation of an electron beam in a loaded quasilinear plasma wakefield

Berglyd Olsen, V. K.; Adli, E.; Muggli, P.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 21(1), 011301 (JAN 16 2018)
https://doi.org/10.1103/PhysRevAccelBeams.21.011301

We investigate beam loading and emittance preservation for a high-charge electron beam being accelerated in quasilinear plasma wakefields driven by a short proton beam. The structure of the studied wakefields are similar to those of a long, modulated proton beam, such as the AWAKE proton driver. We show that by properly choosing the electron beam parameters and exploiting two well known effects, beam loading of the wakefield and full blow out of plasma electrons by the accelerated beam, the electron beam can gain large amounts of energy with a narrow final energy spread (%-level) and without significant emittance growth.

Efficiency versus instability in plasma accelerators

Lebedev, V.; Burov, A.; Nagaitsev, S.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 20(12), 121301 (DEC 20 2017
https://doi.org/10.1103/PhysRevAccelBeams.20.121301

Plasma wakefield acceleration is one of the main technologies being developed for future high-energy colliders. Potentially, it can create a cost-effective path to the highest possible energies for e^+e^- or γ-γ colliders and produce a profound effect on the developments for high-energy physics. Acceleration in a blowout regime, where all plasma electrons are swept away from the axis, is presently considered to be the primary choice for beam acceleration. In this paper, we derive a universal efficiency-instability relation, between the power efficiency and the key instability parameter of the trailing bunch for beam acceleration in the blowout regime. We also show that the suppression of instability in the trailing bunch can be achieved through Balakin-Novokhatsky-Smirnov damping by the introduction of a beam energy variation along the bunch. Unfortunately, in the high-efficiency regime, the required energy variation is quite high and is not presently compatible with collider-quality beams. We would like to stress that the development of the instability imposes a fundamental limitation on the acceleration efficiency, and it is unclear how it could be overcome for high-luminosity linear colliders. With minor modifications, the considered limitation on the power efficiency is applicable to other types of acceleration.

Experimental Evidence of Radiation Reaction in the Collision of a High-Intensity Laser Pulse with a Laser-Wakefield Accelerated Electron Beam

Cole, J. M.; Behm, K. T.; Gerstmayr, E.; Blackburn, T. G.; Wood, J. C.; Baird, C. D.; Duff, M. J.; Harvey, C.; Ilderton, A.; Joglekar, A. S.; Krushelnick, K.; Kuschel, S.; Marklund, M.; McKenna, P.; Murphy, C. D.; Poder, K.; Ridgers, C. P.; Samarin, G. M.; Sarri, G.; Symes, D. R.; Thomas, A. G. R.; Warwick, J.; Zepf, M.; Najmudin, Z.; Mangles, S. P. D.

PHYSICAL REVIEW X 8(1), 011020 (FEB 7 2018)
https://doi.org/10.1103/PhysRevX.8.011020

The dynamics of energetic particles in strong electromagnetic fields can be heavily influenced by the energy loss arising from the emission of radiation during acceleration, known as radiation reaction. When interacting with a high-energy electron beam, today's lasers are sufficiently intense to explore the transition between the classical and quantum radiation reaction regimes. We present evidence of radiation reaction in the collision of an ultrarelativistic electron beam generated by laser-wakefield acceleration ($\epsilon > 500$ MeV) with an intense laser pulse ($a_0 > 10$). We measure an energy loss in the postcollision electron spectrum that is correlated with the detected signal of hard photons (gamma rays), consistent with a quantum description of radiation reaction. The generated gamma rays have the highest energies yet reported from an all-optical inverse Compton scattering scheme, with critical energy $\epsilon_{crit} > 30$ MeV.

Electron shock-surfing acceleration in the presence of magnetic field

Li, R.; Zhou, C. T.; Huang, T. W.; Zhang, H.; Qiao, B.; Yu, M. Y.; Ruan, S. C.; He, X. T.

PHYSICS OF PLASMAS 25(8), 082103 (AUG 2018)
https://doi.org/10.1063/1.5030184

The effect of perpendicular (to the direction of shock propagation) magnetic fields on electron shock-surfing acceleration (ESSA) is investigated. Two-dimensional particle-in-cell simulations show that the strength of background magnetic fields can significantly affect the shock formation process and the electrostatic field structure near the leading edge of the shock. It is found that ESSA is most efficient when the ratio of electron cyclotron frequency to plasma frequency is about 0.1. In this case, there are two types of electrostatic field structures near the shock edge, namely, small-scale filamentary and large-scale dipole electric fields, induced by the Buneman instability and fluid compression, respectively. In such a mixed field structure, the affected electrons can undergo multiple accelerations and gain much higher energies than that under weaker or stronger background magnetic fields. Published by AIP Publishing.

Hybrid capillary discharge waveguide for laser wakefield acceleration

Qin, Z.; Li, W.; Liu, J.; Liu, J.; Yu, C.; Wang, W.; Qi, R.; Zhang, Z.; Fang, M.; Feng, K.; Wu, Y.; Ke, L.; Chen, Y.; Wang, C.; Li, R.; Xu, Z.

PHYSICS OF PLASMAS 25(7), 073102 (JUL 2018)
https://doi.org/10.1063/1.5025847

A hybrid capillary discharge waveguide formed by injecting low-pressure hydrogen (< 3.8Torr) into a pure ablative capillary is presented to supply the stable guiding for multi-GeV laser wakefield acceleration. The injected low-pressure gas only provides the seed plasma for ablative discharge breakdown, like the adsorbed gas in the inner wall of the ablative capillary. With this hybrid capillary, a stable discharge with low jitter (~ 5 ns) can be achieved in a simple way, and the plasma density inside the plasma channel can also be controlled in the range of $\sim 0.7 \times 10^{18}cm^{-3}$-$1.2 \times 10^{18}cm^{-3}$ within a 150-ns temporal window. Furthermore, the hybrid capillary can also be easily extended to a longer length by adding multiple segments, and femtosecond laser pulses can be well guided in both the single and multiple segment modes. With these advantages, the hybrid capillary may provide an attractive plasma channel for multi-GeV-scale laser wakefield acceleration. Published by AIP Publishing.

Plasma waves excitation by a short pulse of focused laser radiation

Grishkov, V. E.; Uryupin, S. A.
PHYSICS OF PLASMAS 25(8), 082104 (AUG 2018)
https://doi.org/10.1063/1.5032188

The excitation of plasma waves by a short pulse of focused laser radiation is studied. Since the excitation of waves depends strongly on the pulse form, we described in detail its form and the conditions when the expression for the pulse field is applicable. Limitations on the pulse duration and the degree of laser radiation focusing are given. The basis for studying the excitation of plasma waves is the equation for potential electric fields. This equation describes the dispersion, weak damping due to collisions of electrons with ions, and wave excitation due to the ponderomotive effect of a short pulse of laser radiation. The dispersion of waves is described by a small integral term that takes into account the thermal motion of electrons. The effect of electron collisions on the damping of waves is described by the Fokker-Planck collision integral. The expression for the ponderomotive force is written taking into account the fact that the laser pulse propagates with a group velocity close to the speed of light. From the equation for waves, we find the Fourier transform of the electric field, which makes it possible to analyze the spectral composition of the excited waves and their radiation patterns. When radiation is weakly focused, waves are excited along the direction of laser pulse propagation. In the case of strong focusing, plasma waves are excited at an angle to this direction, and the greater the angle magnitude, the greater the difference of wave frequency from the electron plasma frequency. Published by AIP Publishing.

Effects of plasma density on laser-generated energetic electron generation and transport in a plasma channel

Ji, Y.; Li, B.; Duan, T.; Zhou, W.; Wu, F.; Zhang, Z.; Ye, B.; Tang, Y.
PHYSICS OF PLASMAS 25(6), 063114 (JUN 2018)
https://doi.org/10.1063/1.5021108

We use two-dimensional particle-in-cell simulations to investigate how the plasma density n_0 of the channel target affects energetic-electron generation and transportation. The simulations show that the optimum plasma-density regime is $10 <= n_0 <= 25$ for the present simulation parameters, which results in a peak energy flux and coupling efficiency from laser to electrons. In this case, the laser beam propagates stably in the channel, which has the advantage of increasing the acceleration length and more effectively generating high-energy electrons. Furthermore, the high-current electron beam and the density modulation induce strong azimuthal magnetic fields and double-layer radial electric fields around the inner surface of the channel, which consistently guide and collimate the hot-electron bunch so that it propagates over rather long times and distances. Upon further increasing the plasma density n_0, the hot electrons are scattered out of the channel by the damped laser pulse and the reduced quasistatic interface electromagnetic fields, reducing the long-time transport. The use of a proper plasma-density channel stably guides the relativistically intense laser pulse and greatly improves the properties of the electron beam. Published by AIP Publishing.

Frontiers of beam diagnostics in plasma accelerators: Measuring the ultra-fast and ultra-cold

Cianchi, A.; Anania, M. P.; Bisesto, F.; Chiadroni, E.; Curcio, A.; Ferrario, M.; Giribono, A.; Marocchino, A.; Pompili, R.; Scifo, J.; Shpakov, V.; Vaccarezza, C.; Villa, F.; Mostacci, A.; Bacci, A.; Rossi, A. R.; Serafini, L.; Zigler, A.
PHYSICS OF PLASMAS 25(5), 056704 (MAY 2018)
https://doi.org/10.1063/1.5017847

Advanced diagnostics are essential tools in the development of plasma-based accelerators. The accurate measurement of the quality of beams at the exit of the plasma channel is crucial to optimize the parameters of the plasma accelerator. 6D electron beam diagnostics will be reviewed with emphasis on emittance measurement, which is particularly complex due to large energy spread and divergence of the emerging beams, and on femtosecond bunch length measurements. Published by AIP Publishing.

Betatron x-ray radiation from laser-plasma accelerators driven by femtosecond and picosecond laser systems

Albert, F.; Lemos, N.; Shaw, J. L.; King, P. M.; Pollock, B. B.; Goyon, C.; Schumaker, W.; Saunders, A. M.; Marsh, K. A.; Pak, A.; Ralph, J. E.; Martins, J. L.; Amorim, L. D.; Falcone, R. W.; Glenzer, S. H.; Moody, J. D.; Joshi, C.
PHYSICS OF PLASMAS 25(5), 056706 (MAY 2018)
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A comparative experimental study of betatron x-ray radiation from laser wakefield acceleration in the blowout and self-modulated regimes is presented. Our experiments use picosecond duration laser pulses up to 150 J (self-modulated regime) and 60 fs duration laser pulses up to 10 J (blowout regime), for plasmas with electronic densities on the order of 10^{19} cm^{-3}. In the self-modulated regime, where betatron radiation has been very little studied compared to the blowout regime, electrons accelerated in the wake of the laser pulse are subject to both the longitudinal plasma and transverse laser electrical fields. As a result, their motion within the wake is relatively complex; consequently, the experimental and theoretical properties of the x-ray source based on self-modulation differ from the blowout regime of laser wakefield acceleration. In our experimental configuration, electrons accelerated up to about 250 MeV and betatron x-ray spectra with critical energies of about 10-20 keV and photon fluxes between 10^8 and 10^{10} photons/eV Sr are reported. Our experiments open the prospect of using betatron x-ray radiation for applications, and the source is competitive with current x-ray backlighting methods on multi-kJ laser systems. Published by AIP Publishing.

Enhancement and control of laser wakefields via a backward Raman amplifier

Ludwig, J. D.; Masson-Laborde, P. -E.; Huller, S.; Rozmus, W.; Wilks, S. C.
PHYSICS OF PLASMAS 25(5), 053108 (MAY 2018)
https://doi.org/10.1063/1.5023387

The Backward Raman Amplifier (BRA) is proposed as a possible scheme for improving laser driven plasma wakefields. One- and two-dimensional particle-in-cell code simulations and a 3-Wave coupling model are presented and compared to demonstrate how the BRA can be applied to the laser wakefield accelerator (LWFA) in the non-relativistic regime to counteract limitations such as pump depletion and diffraction. This article provides a discussion on optimal parameters for the combination of BRA and LWFA and a prescription for a BRA pump frequency chirp to ensure coupling beyond the particle dephasing limit. Simulation results demonstrate a reduction or alleviation of the effects of diffraction and an increase in wake amplitude and sustainability and provide direct insights into new methods of controlling plasma wakes in LWFA and other applications. Published by AIP Publishing.

On the properties of synchrotron-like X-ray emission from laser wakefield accelerated electron beams

McGuffey, C.; Schumaker, W.; Matsuoka, T.; Chvykov, V.; Dollar, F.; Kalintchenko, G.; Kneip, S.; Najmudin, Z.; Mangles, S. P. D.; Vargas, M.; Yanovsky, V.; Maksimchuk, A.; Thomas, A. G. R.; Krushelnick, K.
PHYSICS OF PLASMAS 25(4), 043104 (APR 2018)
https://doi.org/10.1063/1.5024547

The electric and magnetic fields responsible for electron acceleration in a Laser Wakefield Accelerator (LWFA) also cause electrons to radiate x-ray photons. Such x-ray pulses have several desirable properties including short duration and being well collimated with tunable high energy. We measure the scaling of this x-ray source experimentally up to laser powers greater than 100 TW. An increase in laser power allows electron trapping at a lower density as well as with an increased trapped charge. These effects resulted in an x-ray fluence that was measured to increase non-linearly with laser power. The fluence of x-rays was also compared with that produced from K-alpha emission resulting from a solid target interaction for the same energy laser pulse. The flux was shown to be comparable, but the LWFA x-rays had a significantly smaller source size. This indicates that such a source may be useful as a backlighter for probing high energy density plasmas with ultrafast temporal resolution. Published by AIP Publishing.

Effect of injection-gas concentration on the electron beam quality from a laser-plasma accelerator

Mirzaie, M.; Zhang, G.; Li, S.; Gao, K.; Li, G.; Ain, Q.; Hafz, N. A. M.
PHYSICS OF PLASMAS 25(4), 043106 (APR 2018)
https://doi.org/10.1063/1.5008561

By using 25-45 TW ultra-short (30 fs) laser pulses, we report on the effect of the injection gas concentration on the quality of electron beams generated by a laser-driven plasma wakefield acceleration employing the ionization-injection. For a plasma formed from helium-nitrogen gas mixture and depending on the concentration of the nitrogen gas, we could distinguish a clear trend for the quality of the generated electron beams in terms of their peak energy, energy-spread, divergence angle, and beam charge. The results clearly showed that the lower the nitrogen concentration, the better the quality (higher peak energy, smaller energy spread, and smaller emittance) of the generated electron beams. The results are in reasonable agreement with two-dimensional particle-in-cell simulations. Published by AIP Publishing.

Optimization of gas-filled quartz capillary discharge waveguide for high-energy laser wakefield acceleration

Qin, Z.; Li, W.; Liu, J.; Liu, J.; Yu, C.; Wang, W.; Qi, R.; Zhang, Z.; Fang, M.; Feng, K.; Wu, Y.; Ke, L.; Chen, Y.; Wang, C.; Li, R.; Xu, Z.
PHYSICS OF PLASMAS 25(4), 043117 (APR 2018)
https://doi.org/10.1063/1.5024251

A hydrogen-filled capillary discharge waveguide made of quartz is presented for high-energy laser wakefield acceleration (LWFA). The experimental parameters (discharge current and gas pressure) were optimized to mitigate ablation by a quantitative analysis of the ablation plasma density inside the hydrogen-filled quartz capillary. The ablation plasma density was obtained by combining a spectroscopic measurement method with a calibrated gas transducer. In order to obtain a controllable plasma density and mitigate the ablation as much as possible, the range of suitable parameters was investigated. The experimental results demonstrated that the ablation in the quartz capillary could be mitigated by increasing the gas pressure to ~ 7.5-14.7 Torr and decreasing the discharge current to ~ 70-100 A. These optimized parameters are promising for future high-energy LWFA experiments based on the quartz capillary discharge waveguide. Published by AIP Publishing.

Control of quasi-monoenergetic electron beams from laser-plasma accelerators with adjustable shock density profile

Tsai, H.-E.; Swanson, K. K.; Barber, S. K.; Lehe, R.; Mao, H.-S.; Mittelberger, D. E.; Steinke, S.; Nakamura, K.; van Tilborg, J.; Schroeder, C.; Esarey, E.; Geddes, C. G. R.; Leemans, W.
PHYSICS OF PLASMAS 25(4), 043107 (APR 2018)
https://doi.org/10.1063/1.5023694

The injection physics in a shock-induced density down-ramp injector was characterized, demonstrating precise control of a laser-plasma accelerator (LPA). Using a jet-blade assembly, experiments systematically varied the shock injector profile, including shock angle, shock position, up-ramp width, and acceleration length. Our work demonstrates that beam energy, energy spread, and pointing can be controlled by adjusting these parameters. As a result, an electron beam that was highly tunable from 25 to 300MeV with 8% energy spread (DEFWHM/E), 1.5 mrad divergence, and 0.35 mrad pointing fluctuation was produced. Particle-in-cell simulation characterized how variation in the shock angle and up-ramp width impacted the injection process. This highly controllable LPA represents a suitable, compact electron beam source for LPA applications such as Thomson sources and free-electron lasers. Published by AIP Publishing.

Wakefield in solid state plasma with the ionic lattice force

Hakimi, S.; Nguyen, T.; Farinella, D.; Lau, C. K.; Wang, H.-Y.; Taborek, P.; Dollar, F.; Tajima, T.
PHYSICS OF PLASMAS 25(2), 023112 (FEB 2018)
https://doi.org/10.1063/1.5016445

The advent of the path to a single cycle X-ray laser pulse via thin film compression and the relativistic compression enables laser wakefield acceleration in solid materials. We study the collective interaction of the X-ray laser pulse with the solid-state plasma, including ultrafast polariton effects, giving rise to TeV/cm wakefields with highly increased critical density. Our particle-in-cell computational analysis delineates wakefield effects and polariton dynamics. We show that a good quality wakefield can be excited even in the presence of the lattice force and the electron acceleration process is not influenced by polaritons. The applications and implications of the ultrafast wakefield and ultrafast plasmonics are discussed. Published by AIP Publishing.

Simulation study of the sub-terawatt laser wakefield acceleration operated in self-modulated regime

Hsieh, C. -Y.; Lin, M. -W.; Chen, S. -H.
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Laser wakefield acceleration (LWFA) can be accomplished by introducing a sub-terawatt (TW) laser pulse into a thin, high-density gas target. In this way, the self-focusing effect and the self-modulation that happened on the laser pulse produce a greatly enhanced laser peak intensity that can drive a nonlinear plasma wave to accelerate electrons. A particle-in-cell model is developed to study sub-TW LWFA when a 0.6-TW laser pulse interacts with a dense hydrogen plasma. Gas targets having a Gaussian density profile or a flat-top distribution are defined for investigating the properties of sub-TW LWFA when conducting with a gas jet or a gas cell. In addition to using 800nm laser pulses, simulations are performed with 1030-nm laser pulses, as they represent a viable approach to realize the sub-TW LWFA driven by high-frequency, diode-pumped laser systems. The peak density which allows the laser peak power $P_L \sim 2P_{cr}$ of self-focusing critical power is favourable for conducting sub-TW LWFA. Otherwise, an excessively high peak density can induce an undesired filament effect which rapidly disintegrates the laser field envelope and violates the process of plasma wave excitation. The plateau region of a flat-top density distribution allows the self-focusing and the self-modulation of the laser pulse to develop, from which well-established plasma bubbles can be produced to accelerate electrons. The process of electron injection is complicated in such high-density plasma conditions; however, increasing the length of the plateau region represents a straightforward method to realize the injection and acceleration of electrons within the first bubble, such that an improved LWFA performance can be accomplished. Published by AIP Publishing.

Radiation pressure injection in laser-wakefield acceleration

Liu, Y. L.; Kuramitsu, Y.; Isayama, S.; Chen, S. H.
PHYSICS OF PLASMAS 25(1), 013110 (JAN 2018)
https://doi.org/10.1063/1.5006325

We investigated the injection of electrons in laser-wakefield acceleration induced by a self-modulated laser pulse by a two dimensional particle-in-cell simulation. The localized electric fields and magnetic fields are excited by the counter-streaming flows on the surface of the ion bubble, owing to the Weibel or two stream like instability. The electrons are injected into the ion bubble from the sides of it and then accelerated by the wakefield. Contrary to the conventional wave breaking model, the injection of monoenergetic electrons are mainly caused by the electromagnetic process. A simple model was proposed to address the instability, and the growth rate was verified numerically and theoretically. Published by AIP Publishing.

Prospects and limitations of wakefield acceleration in solids

Wettervik, B. Svedung; Gonoskov, A.; Marklund, M.
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Advances in the generation of relativistic intensity pulses with wavelengths in the X-ray regime, through high harmonic generation from near-critical plasmas, open up the possibility of X-ray driven wakefield acceleration. The similarity scaling laws for laser plasma interaction suggest that X-rays can drive wakefields in solid materials providing TeV/cm gradients, resulting in electron and photon beams of extremely short duration. However, the wavelength reduction enhances the quantum parameter χ, hence opening the question of the role of non-scalable physics, e.g., the effects of radiation reaction. Using 3D PIC simulations incorporating QED effects, we show that for the wavelength λ = 5 nm and relativistic amplitudes a_0 = 10-100, similarity scaling holds to a high degree, combined with $\chi \sim 1$ operation already at moderate $a_0 \sim 50$, leading to photon emissions with energies comparable to the electron energies. Contrasting to the generation of photons with high energies, the reduced frequency of photon emission at X-ray wavelengths (compared with that at optical wavelengths) leads to a reduction in the amount of energy that is removed from the electron population through radiation reaction. Furthermore, as the emission frequency approaches the laser frequency, the importance of radiation reaction trapping as a depletion mechanism is reduced, compared with that at optical wavelengths for a_0 leading to similar χ. (C) 2018 Author(s).

Gamma-ray generation from laser-driven electron resonant acceleration: In the non-QED and the QED regimes

Qiao, B.; Chang, H. X.; Xie, Y.; Xu, Z.; He, X. T.
PHYSICS OF PLASMAS 24(12), 123101 (DEC 2017)
https://doi.org/10.1063/1.5013019

Electron acceleration and γ-ray emission by circularly polarized laser pulses interacting with near-critical-density plasmas are systematically investigated for both the non-quantum-electrodynamic (non-QED) and QED regimes. In the non-QED regime, since electron density in the plasma channel is small and the self-generated electromagnetic fields are weak, only a few electrons can achieve the resonant acceleration, leading to weak γ-ray emission. However, when it comes to the QED regime, the radiation recoil force significantly affects the electron dynamics, which helps in not only the trapping of electrons, but also the relaxing of the condition for electrons to hit the resonance with laser fields, resulting in the formation of an ultradense helical electron bunch under resonant acceleration in the plasma channel. Therefore, an intense γ -ray pulse with unprecedented flux can be generated. Theoretical analysis and 3D PIC simulations are carried out to compare the dynamics in two different regimes. Published by AIP Publishing.

Laser wakefield acceleration in Kr-He plasmas and its application to positron beam generation

Ain, Q.; Hafz, N. A. M.; Li, S.; Mirzaie, M.; Gao, K.; Li, G.; Zhang, J.
PLASMA PHYSICS AND CONTROLLED FUSION 60(8), 085012 (AUG 2018)
https://doi.org/10.1088/1361-6587/aacb66

We present the generation of quasi-monoenergetic electron beams via ionization injection in a laser wakefield acceleration by using a krypton-helium plasma. We obtained higher-energy electron beams of low divergence as compared with beams from the nitrogen-helium plasma at low plasma densities. This is attributed to an immediate ionization, trapping and acceleration of many electrons from several inner shells of the krypton atoms. On the other hand, there are very high ionization potentials of the K-shell nitrogen electrons which require the pulse (in our laser-plasma parameters) to experience a self-focusing (after 1.6 mm of propagation) at first before any ionization injection and acceleration of those two electrons per atom can occur. Based on those high-quality electron beams from the Kr-He plasmas, we generated ultra-relativistic positron beams with energies up to 100 MeV by placing a lead slab converter with a thickness of the order of its radiation length in the electron beam path after the gas jet. Experimental and Mont-Carlo simulated energy spectra of the positron beams are compared for the energy range of 30 MeV <= Ee+ <= 100 MeV along with the positron yields. In addition, various parameters of the positrons are investigated against the primary electron beam parameters. Such electron-positron cascading experiment could be helpful in future development for the composition of an all-optical electron-positron collider.

Betatron resonance electron acceleration and generation of relativistic electron beams using 200fs Ti: sapphire laser pulses

Hazra, D.; Moorti, A.; Rao, B. S.; Upadhyay, A.; Chakera, J. A.; Naik, P. A.
PLASMA PHYSICS AND CONTROLLED FUSION 60(8), 085015 (AUG 2018)
https://doi.org/10.1088/1361-6587/aac97c

The generation of relativistic electron beams with quasi-thermal energy distribution (maximum energy: 30 MeV) by the interaction of a Ti:sapphire laser pulse of 200 fs duration, focussed to an intensity of ~ 2.1 x 10^{18}W cm^{-2}, with an underdense (electron density ~ 3.6 x 10^{19} to ~ 1.1 x 10^{20} cm^{-3}) He gas-jet plasma was observed. We observed two stages of self-focusing of the laser pulse in the plasma. Two groups of accelerated electrons associated with these two stages of laser channeling were also observed, and are attributed to the betatron resonance acceleration mechanism. This is supported by 2D PIC simulations performed using the EPOCH code and a detailed theoretical analysis. Further, the generation of quasi-monoenergetic ($\Delta E/E$ ~ 10%-20%) electron beams with a peak energy of ~ 17-22 MeV was also observed, even with such long laser pulses, although with a low probability of occurrence.

Correlation between macroscopic plasma dynamics and electron beam parameters in a laser-plasma accelerator

Li, S.; Zhao, Q.; Hafz, N. A. M.; Weng, S.; Gao, K.; Mirzaie, M.; Li, G.; Ain, Q.; Zhang, J.
PLASMA PHYSICS AND CONTROLLED FUSION 60(8), 085020 (AUG 2018)
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Ultrafast laser-based shadowgraphic-interferometric imaging of a high-density plasma generated by intense laser-matter interactions is a key diagnostic technique providing information on the evolution and ultrafast dynamics of such a plasma state. However, shadowgraphic techniques have received modest attention in diagnosing low-density gaseous plasmas similar to those used in laser-plasma wakefield accelerators. Here, by using an ultrafast 30 fs probe laser beam, we derived a correlation between the plasma dynamics and electron beam characteristics in a laser-plasma acceleration experiencing ionization injection in the plasma of a $He-N_2$ gas mixture. The ultrafast transverse expansion dynamics of the laser-plasma channel front tends to be faster at higher nitrogen concentrations, which leads to an increase in the divergence angle and yield (charge) of the 100-200 MeV electron beams generated in the current experiment. Computer simulation shows a distinct difference between the dynamics of the self-injection and that of the ionization-injection processes and supports the experimental observations.

Optimization of electron acceleration by short laser pulses from low-density targets

Lobok, M. G.; Brantov, A. V.; Gozhev, D. A.; Bychenkov, V. Yu
PLASMA PHYSICS AND CONTROLLED FUSION 60(8), 084010 (AUG 2018)
https://doi.org/10.1088/1361-6587/aaca79

Based on multidimensional particle-in-cell simulations of a short laser pulse interaction with a homogeneous planar target, we perform an optimization study to find the best design parameters for maximizing the number of high-energy electrons generated by a sub-petawatt class laser system for deep gamma radiography purposes. We find that a low-density target with an electron density of 10% of the critical density and a thickness of 240 µm irradiated by a 30 fs 4 J laser pulse can generate 7-nC electron bunches with a mean characteristic energy of 100 MeV.

Sharp plasma pinnacle structure based on shockwave for an improved laser wakefield accelerator

Fang, M.; Zhang, Z.; Wang, W.; Liu, J.; Li, R.
PLASMA PHYSICS AND CONTROLLED FUSION 60(7), 075008 (JUL 2018)
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We created a sharp plasma pinnacle structure for localized electron injection and controlled acceleration in a laser wakefield accelerator. The formation of this shockwave-based pinnacle structure was investigated using aerodynamic theory. Details and scaling laws for the shockwave angle, shock position, shock width, and density ratio were experimentally and theoretically presented. Such work is crucial to yielding an expected plasma density distribution in a laser-plasma experiment but has had little discussion in the literature. Compared with the commonly used shock downramp structure, the particle-in-cell simulations demonstrated that the e beam injected in the created pinnacle structure could be accelerated to higher energy with much smaller root-mean-square relative energy spread. Moreover, this study indicated that the beam charge and transverse emittance can be tuned by the shock angle.

Trains of electron micro-bunches in plasma wake-field acceleration

Lecz, Z.; Andreev, A.; Konoplev, I.; Seryi, A.; Smith, J.
PLASMA PHYSICS AND CONTROLLED FUSION 60(7), 075012 (JUL 2018)
https://doi.org/10.1088/1361-6587/aac064

Plasma-based charged particle accelerators have been intensively investigated in the past three decades due to their capability to open up new horizons in accelerator science and particle physics yielding electric field accelerating gradient more than three orders of magnitudes higher than in conventional devices. At the current stage the most advanced and reliable mechanism for accelerating electrons is based on the propagation of an intense laser pulse or a relativistic electron beam in a low density gaseous target. In this paper we concentrate on the electron beam-driven plasma wake-held acceleration and demonstrate using 3D PiC simulations that a train of electron micro-bunches with $\sim$ 10 fs period can be generated behind the driving beam propagating in a density down-ramp. We will discuss the conditions and properties of the microbunches generated aiming at understanding and study of multi-bunch mechanism of injection. It is show that the periodicity and duration of micro-bunches can be controlled by adjusting the plasma density gradient and driving beam charge.

Optical injection dynamics in two laser wakefield acceleration configurations

Horny, V.; Maslarova, D.; Petrzilka, V.; Klimo, O.; Kozlova, M.; Krus, M.
PLASMA PHYSICS AND CONTROLLED FUSION 60(6), 064009 (JUN 2018)
https://doi.org/10.1088/1361-6587/aabd07

The injection and acceleration dynamics of electron bunches generated by two different optical injection mechanisms, the injection by an orthogonally crossing pulse with perpendicular polarization and injection by a copropagating preceding pulse, are studied by means of 2D numerical particle-in-cell (PIC) simulations. The effect of the ion cavity (bubble) shape variations induced by injection pulses on the electron bunch formation and observable parameters is explored for early injection and acceleration phases. Even if both schemes have three different injection regions, from which three independent electron sub-bunches emerge, the final merged electron bunch does not exhibit a significant substructure in studied parameters as transverse and longitudinal emittance. The 2D PIC simulations also reveal that the final electron bunch parameters are mainly affected by the spatial charge distribution of individual subbunches. Further, the model of the electric and magnetic fields within the slowly evolving ellipsoidal bubble is derived. The electron trajectories in acceleration later stages are analyzed by employing this model for the dynamic changes in the bubble size observed in PIC simulations.

Laser dynamics in transversely inhomogeneous plasma and its relevance to wakefield acceleration

Pathak, V. B.; Vieira, J.; Silva, L. O.; Nam, C. H.
PLASMA PHYSICS AND CONTROLLED FUSION 60(5), 054001 (MAY 2018)
https://doi.org/10.1088/1361-6587/aab220

We present full set of coupled equations describing the weakly relativistic dynamics of a laser in a plasma with transverse inhomogeneity. We apply variational principle approach to obtain these coupled equations governing laser spot-size, transverse wavenumber, curvature, transverse centroid, etc. We observe that such plasma inhomogeneity can lead to stronger self-focusing. We further discuss the guiding conditions of laser in parabolic plasma channels. With the help of multi-dimensional particle in cell simulations the study is extended to the blowout regime of laser wakefield acceleration to show laser as well as self-injected electron bunch steering in plasma to generate unconventional particle trajectories. Our simulation results demonstrate that such transverse inhomogeneities due to asymmetric self focusing lead to asymmetric bubble excitation, thus inducing off-axis self-injection.

Improved performance of laser wakefield acceleration by tailored self-truncated ionization injection

Irman, A.; Couperus, J. P.; Debus, A.; Koehler, A.; Kraemer, J. M.; Pausch, R.; Zarini, O.; Schramm, U.
PLASMA PHYSICS AND CONTROLLED FUSION 60(4), 044015 (APR 2018)
https://doi.org/10.1088/1361-6587/aaaef1

We report on tailoring ionization-induced injection in laser wakefield acceleration so that the electron injection process is self-truncating following the evolution of the plasma bubble. Robust generation of high-quality electron beams with shot-to-shot fluctuations of the beam parameters better than 10% is presented in detail. As a novelty, the scheme was found to enable well-controlled yet simple tuning of the injected charge while preserving acceleration conditions and beam quality. Quasi-monoenergetic electron beams at several 100 MeV energy and 15% relative energy spread were routinely demonstrated with a total charge of the monoenergetic feature reaching 0.5 nC. Finally these unique beam parameters, suggesting unprecedented peak currents of several 10 kA, are systematically related to published data on alternative injection schemes.

Transverse phase space diagnostics for ionization injection in laser plasma acceleration using permanent magnetic quadrupoles

Li, F.; Nie, Z.; Wu, Y. P.; Guo, B.; Zhang, X. H.; Huang, S.; Zhang, J.; Cheng, Z.; Ma, Y.; Fang, Y.; Zhang, C. J.; Wan, Y.; Xu, X. L.; Hua, J. F.; Pai, C. H.; Lu, W.; Mori, W. B.
PLASMA PHYSICS AND CONTROLLED FUSION 60(4), 044007 (APR 2018)
https://doi.org/10.1088/1361-6587/aaacc2

We report the transverse phase space diagnostics for electron beams generated through ionization injection in a laser-plasma accelerator. Single-shot measurements of both ultimate emittance and Twiss parameters are achieved by means of permanent magnetic quadrupole. Beams with emittance of μm rad level are obtained in a typical ionization injection scheme, and the dependence on nitrogen concentration and charge density is studied experimentally and confirmed by simulations. A key feature of the transverse phase space, matched beams with Twiss parameter $\alpha_T \simeq 0$, is identified according to the measurement. Numerical simulations that are in qualitative agreement with the experimental results reveal that a sufficient phase mixing induced by an overlong injection length leads to the matched phase space distribution.

Plasma wakefield acceleration experiments at FACET II

Joshi, C.; Adli, E.; An, W.; Clayton, C. E.; Corde, S.; Gessner, S.; Hogan, M. J.; Litos, M.; Lu, W.; Marsh, K. A.; Mori, W. B.; Vafaei-Najafabadi, N.; O'shea, B.; Xu, Xinlu; White, G.; Yakimenko, V.
PLASMA PHYSICS AND CONTROLLED FUSION 60(3), 034001 (MAR 2018)
https://doi.org/10.1088/1361-6587/aaa2e3

During the past two decades of research, the ultra-relativistic beam-driven plasma wakefield accelerator (PWFA) concept has achieved many significant milestones. These include the demonstration of ultra-high gradient acceleration of electrons over meter-scale plasma accelerator structures, efficient acceleration of a narrow energy spread electron bunch at high-gradients, positron acceleration using wakes in uniform plasmas and in hollow plasma channels, and demonstrating that highly nonlinear wakes in the 'blow-out regime' have the electric field structure necessary for preserving the emittance of the accelerating bunch. A new 10 GeV electron beam facility, Facilities for Accelerator Science and Experimental Test (FACET) II, is currently under construction at SLAC National Accelerator Laboratory for the next generation of PWFA research and development. The FACET II beams will enable the simultaneous demonstration of substantial energy gain of a small emittance electron bunch while demonstrating an efficient transfer of energy from the drive to the trailing bunch. In this paper we first describe the capabilities of the FACET II facility. We then describe a series of PWFA experiments supported by numerical and particle-in-cell simulations designed to demonstrate plasma wake generation where the drive beam is nearly depleted of its energy, high efficiency acceleration of the trailing bunch while doubling its energy and ultimately, quantifying the emittance growth in a single stage of a PWFA that has optimally designed matching sections. We then briefly discuss other FACET II plasma-based experiments including in situ positron generation and acceleration, and several schemes that are promising for generating sub-micron emittance bunches that will ultimately be needed for both an early application of a PWFA and for a plasma-based future linear collider.

Characteristics of electron beam in laser wakefield accelerator using pure nitrogen gas

Kim, J.; Hwangbo, Y. H.; Kim, K. N.
PLASMA PHYSICS AND CONTROLLED FUSION 60(3), 034008 (MAR 2018)
https://doi.org/10.1088/1361-6587/aaa694

Pure nitrogen gas target and a 10 TW laser were used to accelerate electrons by a laser wakefield acceleration. A well collimated with stable pointing electron beam was generated. When the density was 9.4×10^{18} cm^{-3}, electron beams with divergences 5.2 ± 1.2 mrad in horizontal and 4.2 ± 0.8 mrad in the vertical directions were generated. The electron peak energy was 117 ± 12 MeV which is close to the expected value by the scaling formula. The tendency of the maximum energy and energy distribution changes with different density shows that electrons were accelerated to dephasing length with high density and acceleration distance was less than the dephasing length with low density. From this, it seems that the length of the plasma for deformation of the laser is required for the ionization injection, and the plasma length should be longer than the dephasing length.

Extremely intense laser-based electron acceleration in a plasma channel

Vranic, M.; Fonseca, R. A.; Silva, L. O.
PLASMA PHYSICS AND CONTROLLED FUSION 60(3), 034002 (MAR 2018)
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Laser pulses of extreme intensities ($I > 10^{22}$ W cm^{-2}) are about to become available in the laboratory. The prepulse of such a laser can induce a plasma expansion that generates a low-density channel in near-critical gas jets. We present a study of channel formation and subsequent direct laser acceleration of electrons within the pre-formed channel. Radiation reaction affects the acceleration in several ways. It first interferes with the motion of the return current on the channel walls. In addition, it reduces the radial expelling efficiency of the transverse ponderomotive force, leading to the radiative trapping of particles near the channel axis. These particles then interact with the peak laser intensity and can attain multi-GeV energies.

Numerical study of laser energy effects on density transition injection in laser wakefield acceleration

Massimo, F.; Lifschitz, A. F.; Thaury, C.; Malka, V.
PLASMA PHYSICS AND CONTROLLED FUSION 60(3), 034005 (MAR 2018)
https://doi.org/10.1088/1361-6587/aaa336

Density transition (or shock-front) injection is a technique to obtain high quality electron beams in laser wakefield acceleration. This technique, which requires no additional laser pulse, is easy to implement and is receiving increasing interest. In addition to its performances, its setup realized with a blade inserted in a gas jet allows a certain flexibility in controlling the density transition shape, whose effects on the beam quality have been studied theoretically and experimentally. We report the results of particle-in-cell simulations where the laser energy is systematically varied for different shapes of the density transition. Our study shows how the laser energy affects the injection process, increasing the injected charge and influencing the other beam characteristics (e.g. energy and duration).

Evolution of plasma wakes in density up- and down-ramps

Zhang, C. J.; Joshi, C.; Xu, X. L.; Mori, W. B.; Li, F.; Wan, Y.; Hua, J. F.; Pai, C. H.; Wang, J.; Lu, W.
PLASMA PHYSICS AND CONTROLLED FUSION 60(2), 024003 (FEB 2018)
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The time evolution of plasma wakes in density up-and down-ramps is examined through theory and particle-in-cell simulations. Motivated by observation of the reversal of a linear plasma wake in a plasma density upramp in a recent experiment (Zhang et al 2017 Phys. Rev. Lett. 119 064801) we have examined the behaviour of wakes in plasma ramps that always accompany any plasma source used for plasma-based acceleration. In the up-ramp case it is found that, after the passage of the drive pulse, the wavenumber/wavelength of the wake starts to decrease/increase with time until it eventually tends to zero/infinity, then the wake reverses its propagation direction and the wavenumber/wavelength of the wake begins to increase/shrink. The evolutions of the wavenumber and the phase velocity of the wake as functions of time are shown to be significantly different in the up-ramp and the down-ramp cases. In the latter case the wavenumber of the wake at a particular position in the ramp increases until the wake is eventually damped. It is also shown that the waveform of the wake at a particular time after being excited can be precisely controlled by tuning the initial plasma density profile, which may enable a new type of plasma-based ultrafast optics.

Experimental signatures of direct-laser-acceleration-assisted laser wakefield acceleration

Shaw, J. L.; Lemos, N.; Marsh, K. A.; Froula, D. H.; Joshi, C.
PLASMA PHYSICS AND CONTROLLED FUSION 60(4), 044012 (APR 2017)
https://doi.org/10.1088/1361-6587/aaade1

The direct laser acceleration (DLA) of electrons in a laser wakefield accelerator (LWFA) operating in the forced or quasi-blowout regimes has been investigated through experiment and simulation. When there is a significant overlap between the trapped electrons and the drive laser in a LWFA cavity, the resulting electrons can gain energy from both the LWFA and the DLA mechanisms. Experimental work investigates the properties of the electron beams produced in a LWFA with ionization injection by dispersing those beams in the direction perpendicular to the laser polarization. These electron beams show certain spectral features that are characteristic of DLA. These characteristic features are reproduced using particle-in-cell simulations, where particle tracking was used to elucidate the roles of LWFA and DLA to the energy gain of the electrons in this experimental regime and to demonstrate that such spectral features are definitive signatures of the presence of DLA in LWFA.

Stable bunch trains for plasma wakefield acceleration

Lotov, K. V.
PLASMA PHYSICS AND CONTROLLED FUSION 60(2), 024002 (FEB 2018)
https://doi.org/10.1088/1361-6587/aa9f97

A train of short charged particle bunches can efficiently drive a strong plasma wakefield over a long propagation distance only if all bunches reside in focusing and decelerating phases of the wakefield. This is shown possible with equidistant bunch trains, but requires the bunch charge to increase along the train and the plasma frequency to be higher than the bunch repetition frequency.

Stimulated Raman backscattering from a laser wakefield accelerator

Hussein, A. E.; Ludwig, J.; Behm, K.; Horovitz, Y.; Masson-Laborde, P-E; Chvykov, V; Maksimchuk, A.; Matsuoka, T.; McGuffey, C.; Yanovsky, V; Rozmus, W.; Krushelnick, K.
NEW JOURNAL OF PHYSICS 20, 073039 (JUL 19 2018)
https://doi.org/10.1088/1367-2630/aaceeb

Experiments were performed using the HERCULES laser system at the University of Michigan to study backward stimulated Raman scattering (BSRS) from a laser wakefield accelerator driven with a 30 fs pulse. 'The spectrum of backscattered light was found to be significantly broadened and red-shifted in cases where electrons were accelerated. BSRS broadening (red-shifting) was found to increase with respect to both plasma density and accelerated electron charge for laser powers exceeding 100 TW. Two-dimensional Particle-in-Cell simulations reveal temporal dynamics for the BSRS emission, which ceases as the wakefield bubble is evacuated of plasma electrons because of relativistic self-focusing. The intensity and duration of the BSRS signal was found to vary with plasma density and laser intensity. Both experimental and simulation results indicate that backward SRS is associated with plasma electron density within the wakefield bubble. This measurement can serve as a diagnostic of bubble dynamics, and is correlated with trapped electron charge in this regime.

Ionization injection in a laser wakefield accelerator subject to a transverse magnetic field

Zhao, Q.; Weng, S.M.; Sheng, Z.M.; Chen, M.; Zhang, G.B.; Mori, W.B.; Hidding, B.; Jaroszynski, D.A.; Zhang, J.
NEW JOURNAL OF PHYSICS 20, 063031 (JUN 20 2018)
https://doi.org/10.1088/1367-2630/aac926

The effect of an external transverse magnetic field on ionization injection of electrons in a laser wakefield accelerator (LWFA) is investigated by theoretical analysis and particle-in-cell simulations. On application of a few tens of Tesla magnetic field, both the electron trapping condition and the wakefield structure changes significantly such that injection occurs over a shorter distance and at an enhanced rate. Furthermore, beam loading is compensated for, as a result of the intrinsic trapezoidal-shaped longitudinal charge density profile of injected electrons. The nonlinear ionization injection and consequent compensation of beam loading lead to a reduction in the energy spread and an enhancement of both the charge and final peak energy of the electron beam from a LWFA immersed in the magnetic field.

Manipulating the topological structure of ultrarelativistic electron beams using Laguerre-Gaussian laser pulse

Ju, L. B.; Zhou, C. T.; Jiang, K.; Huang, T. W.; Zhang, H.; Cai, T. X.; Cao, J. M.; Qiao, B.; Ruan, S. C.
NEW JOURNAL OF PHYSICS 20, 063004 (JUN 5 2018)
https://doi.org/10.1367-2630/aac68a

A method of using intense Laguerre-Gaussian (LG) laser pulse is proposed to generate ultrarelativistic (multi-GeV) electron beams with controllable helical structures based on a hybrid electron acceleration regime in underdense plasmas, where both the longitudinal charge-separation electric field and transverse laser electric field play the role of accelerating the electrons. By directly interacting with the LG laser pulse, the topological structure of the accelerated electron beam is manipulated and it is spatially separated into multi-slice helical bunches. These results are clearly demonstrated by our three-dimensional particle-in-cell simulations and explained by a theoretical model based on electron phase-space dynamics. This novel regime offers a new degree of freedom for manipulating ultrashort and ultrarelativistic electrons, and it provides an efficient way for generating high-energy high-angular-momentum helical electron beams, which may find applications in wide-ranging areas.

Effects of the dopant concentration in laser wakefield and direct laser acceleration of electrons

Gonzalez, I. Gallardo; Ekerfelt, H.; Hansson, M.; Audet, T. L.; Aurand, B.; Desforges, F. G.; Dufrenoy, S. Dobosz; Persson, A.; Davoine, X.; Wahlstrom, C-G; Cros, B.; Lundh, O.
NEW JOURNAL OF PHYSICS 20, 053011 (MAY 4 2018)
https://doi.org/10.1088/1367-2630/aabe14

In this work, we experimentally study the effects of the nitrogen concentration in laser wakefield acceleration of electrons in a gas mixture of hydrogen and nitrogen. A 15 TW peak power laser pulse is focused to ionize the gas, excite a plasma wave and accelerate electrons up to 230 MeV. We find that at dopant concentrations above 2% the total divergence of the electrons is increased and the high energy electrons are emitted preferentially with an angle of ± 6 mrad, leading to a forked spatio-spectral distribution associated to direct laser acceleration (DLA). However, electrons can gain more energy and have a divergence lower than 4 mrad for concentrations below 0.5% and the same laser and plasma conditions. Particle-in-cell simulations show that for dopant concentrations above 2%, the amount of trapped charge is large enough to significantly perturb the plasma wave, reducing the amplitude of the longitudinal wakefield and suppressing other trapping mechanisms. At high concentrations the number of trapped electrons overlapping with the laser fields is increased, which rises the amount of charge affected by DLA. We conclude that the dopant concentration affects the quantity of electrons that experience significant DLA and the beam loading of the plasma wave driven by the laser pulse. These two mechanisms influence the electrons final energy, and thus the dopant concentration should be considered as a factor for the optimization of the electron beam parameters.

High-energy coherent terahertz radiation emitted by wide-angle electron beams from a laser-wakefield accelerator

Yang, X.; Brunetti, E.; Jaroszynski, D. A.
NEW JOURNAL OF PHYSICS 20, 043046 (APR 20 2018)
https://doi.org/10.1088/1367-2630/aab74d

High-charge electron beams produced by laser-wakefield accelerators are potentially novel, scalable sources of high-power terahertz radiation suitable for applications requiring high-intensity fields. When an intense laser pulse propagates in underdense plasma, it can generate femtosecond duration, self-injected picocoulomb electron bunches that accelerate on-axis to energies from 10s of MeV to several GeV, depending on laser intensity and plasma density. The process leading to the formation of the accelerating structure also generates non-injected, sub-picosecond duration, 1-2 MeV nanocoulomb electron beams emitted obliquely into a hollow cone around the laser propagation axis. These wide-angle beams are stable and depend weakly on laser and plasma parameters. Here we perform simulations to characterise the coherent transition radiation emitted by these beams if passed through a thin metal foil, or directly at the plasma-vacuum interface, showing that coherent terahertz radiation with 10s. μJ to mJ-level energy can be produced with an optical to terahertz conversion efficiency up to 10^{-4} - 10^{-3}.

Observation of non-symmetric side-scattering during high-intensity laser-plasma interactions
Arunachalam, A. K.; Schwab, M. B.; Saevert, A.; Kaluza, M. C.
NEW JOURNAL OF PHYSICS 20, 033027 (MAR 29 2018)
https://doi.org/10.1088/1367-2630/aab039

Non-symmetric side-scattering has been observed during the interaction between a high-intensity laser pulse and under-dense argon plasma. The angle between the laser's forward direction and the scattered radiation is found to decrease for increasing electron densities ranging from 0.01 to $0.25n_c$, where n_c is the critical density for the laser wavelength. We show that the observed features of the scattering cannot be described by Raman side-scattering but can be explained to be a consequence of the non-uniform density distribution of the plasma with the scattering angle being oriented along the direction of the resulting electron density gradient.

Optically controlled laser-plasma electron accelerator for compact gamma-ray sources
Kalmykov, S. Y.; Davoine, X.; Ghebregziabher, I.; Shadwick, B. A.
NEW JOURNAL OF PHYSICS 20, 023047 (FEB 22 2018)
https://doi.org/10.1088/1367-2630/aaad57

Generating quasi-monochromatic, femtosecond gamma-ray pulses via Thomson scattering (TS) demands exceptional electron beam (e-beam) quality, such as percent-scale energy spread and five-dimensional brightness over 10^{16} A m^{-2}. We show that near-GeV e-beams with these metrics can be accelerated in a cavity of electron density, driven with an incoherent stack of Joule-scale laser pulses through a mm-size, dense plasma ($n_0 \sim 10^{19}$ cm^{-3}). Changing the time delay, frequency difference, and energy ratio of the stack components controls the e-beam phase space on the femtosecond scale, while the modest energy of the optical driver helps afford kHz-scale repetition rate at manageable average power. Blue-shifting one stack component by a considerable fraction of the carrier frequency makes the stack immune to self-compression. This, in turn, minimizes uncontrolled variation in the cavity shape, suppressing continuous injection of ambient plasma electrons, preserving a single, ultra-bright electron bunch. In addition, weak focusing of the trailing component of the stack induces periodic injection, generating, in a single shot, a train of bunches with controllable energy spacing and femtosecond synchronization. These designer e-beams, inaccessible to conventional acceleration methods, generate, via TS, gigawatt gamma-ray pulses (or multi-color pulse trains) with the mean energy in the range of interest for nuclear photonics (4-16 MeV), containing over 10^6 photons within a microsteradian-scale observation cone.

Stable electron beams from laser wakefield acceleration with few-terawatt driver using a supersonic air jet
Bohacek, K.; Kozlova, M.; Nejdl, J.; Chaulagain, U.; Horny, V.; Krus, M.; Phuoc, K. Ta
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS; SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 883, 24-28 (MAR 1 2018)
https://doi.org/10.1016/j.nima.2017.11.022

The generation of stable electron beams produced by the laser wakefield acceleration mechanism with a few-terawatt laser system (600 mJ, 50 fs) in a supersonic synthetic air jet is reported and the requirements necessary to build such a stable electron source are experimentally investigated in conditions near the bubble regime threshold. The resulting electron beams have stable energies of (17.4 +/- 1.1) MeV and an energy spread of (13.5 +/- 1.5) MeV (FWHM), which has been achieved by optimizing the properties of the supersonic gas jet target for the given laser system. Due to the availability of few-terawatt laser systems in many laboratories around the world these stable electron beams open possibilities for applications of this type of particle source.

Effect of temporal asymmetry of the laser pulse on electron acceleration in vacuum

Rezaei-Pandari, M.; Akhyani, M.; Jahangiri, F.; Niknam, A. R.; Massudi, R.
OPTICS COMMUNICATIONS 429, 46-52 (DEC 15 2018)
https://doi.org/10.1016/j.optcom.2018.07.081

We explore the electron dynamics in a Gaussian laser pulse to assess the contribution of the temporal parameters to the mechanism of vacuum laser acceleration. Our numerical study reveals that a considerable nonzero energy gain can be achieved through a spatio-temporally controlled electron injection. Moreover, three-dimensional optimization of the electron's injection angle suggests that the highest energy gain is obtained by using a sideways injection scheme. We also present the dependence of the electron energy gain on the laser polarization by comprehensively comparing all possible polarization states. It is found that the temporal sensitivity of the electron injection is determined by the polarization of the laser pulse. In addition, it is shown that although the energy gain is maximized in linearly polarized short laser pulses, circularly polarized laser pulses with longer duration would also lead to comparable energy gains but with much less temporal sensitivity for electron injection. To address the technical feasibility of the acceleration procedure under the mentioned optimized conditions, an experimental setup is proposed.

Energy enhancement of the target surface electron by using a 200 TW sub-picosecond laser

Mao, J. Y.; Rosmej, O.; Ma, Y.; Aurand, B.; Gaertner, F.; Wang, W. M.; Urbancic, J.; Schoenlein, A.; Zielbauer, B.; Eisenbarth, U.; Bagnoud, V; Wagner, F.; Horst, F.; Syha, M.; Mathias, S.; Li, Y. T.; Aeschlimann, M.; Chen, L. M.; Kuehl, T.
OPTICS LETTERS 43(16), 3909-3912 (AUG 15 2018)
https://doi.org/10.1364/OL.43.003909

One order of magnitude energy enhancement of the target surface electron beams with central energy at 11.5 MeV is achieved by using a 200 TW, 500 fs laser at an incident angle of 72 degrees with a prepulse intensity ratio of 5×10^{-6}. The experimental results demonstrate the scalability of the acceleration process to high electron energy with a longer (sub-picosecond) laser pulse duration and a higher laser energy (120 J). The total charge of the beam is 400 +/- 20 pC(E > 2.7 MeV). Such a high orientation and mono-energetic electron jet would be a good method to solve the problem of the large beam divergence in fast ignition schemes and to increase the laser energy deposition on the target core. (C) 2018 Optical Society of America

Laser wakefield acceleration with mid-IR laser pulses

Woodbury, D.; Feder, L.; Shumakova, V.; Gollner, C.; Schwartz, R.; Miao, B.; Salehi, F.; Korolov, A.; Pugzlys, A.; Baltuska, A.; Milchberg, H. M.
OPTICS LETTERS 43(5), 1131-1134 (MAR 1 2018)
https://doi.org/10.1364/OL.43.001131

We report on, to the best of our knowledge, the first results of laser plasma wakefield acceleration driven by ultrashort mid-infrared (IR) laser pulses (λ = 3.9 μm, 100 fs, 0.25 TW), which enable near-and above-critical density interactions with moderate-density gas jets. Relativistic electron acceleration up to ~ 12 MeV occurs when the jet width exceeds the threshold scale length for relativistic self-focusing. We present scaling trends in the accelerated beam profiles, charge, and spectra, which are supported by particle-in-cell simulations and time-resolved images of the interaction. For similarly scaled conditions, we observe significant increases in the accelerated charge, compared to previous experiments with near-infrared (λ = 800 nm) pulses. (c) 2018 Optical Society of America

Laser-driven electron acceleration in hydrogen pair-ion plasma containing electron impurities

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LASER AND PARTICLE BEAMS 36(2), 203-209 (JUN 2018)
https://doi.org/10.1017/S0263034618000174

In this paper, the intense laser heating of hydrogen pair-ion plasma with and without electron impurities through investigation of related nonlinear phenomena has been studied in detail, using a developed relativistic particle-in-cell simulation code. It is shown that the presence of electron impurities has an essential role in the behavior of nonlinear phenomena contributing to the laser absorption including phase mixing, wave breaking, and stimulated scatterings. The inclusion of electron into an initial pure hydrogen plasma not only causes the occurrence of stimulated scattering considerably but also leads to the faster phase-mixing and wave breaking of the excited electrostatic modes in the system. These nonlinear phenomena increase the laser absorption rate in several orders of magnitude via inclusion of the electrons into a pure hydrogen pair-ion plasma. Moreover, results show that the electrons involved in enough low-density hydrogen pair-ion plasma can be accelerated to the MeV energy range.

Electron energy optimization by plasma density ramp in laser wakefield acceleration in bubble regime

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LASER AND PARTICLE BEAMS 36(2), 195-202 (JUN 2018)
https://doi.org/10.1017/S0263034618000162

Energy gain of electron beams in bubble regime of the laser wakefield accelerator can be optimized by improving the acceleration length, radial accelerating and focusing force, number of monoenergetic electrons trapped inside the bubble, and increasing dephasing length. In order to enlarge the dephasing length, the phase velocity of the plasma wave can be increased by optimizing the plasma density profile. We report the estimation of dephasing length using plasma density distribution with the flat and linear-upward profile using two-dimensional particle-in-cell simulations. The size of wakefield bubble depends on the plasma density. With a positive plasma density gradient, the size of bubble decreases. The front and trail part of wake bubble will have different phase velocity in plasma density gradient region. After density transition in constant density region, the bubble elongates and the velocity of the back part of the bubble increases so that the accelerated electron phase synchronizes with the phase of the plasma wave. In a result, the electron acceleration length enhances to improve the beam quality.

Transverse electromagnetic Hermite-Gaussian mode-driven direct laser acceleration of electron under the influence of axial magnetic field

Ghotra, H. S.; Jaroszynski, D.; Ersfeld, B.; Saini, N. S.; Yoffe, S.; Kant, N.

LASER AND PARTICLE BEAMS 36(1), 154-161 (MAR 2018)
https://doi.org/10.1017/S0263034618000083

Hermite-Gaussian (HG) laser beam with transverse electromagnetic (TEM) mode indices (m, n) of distinct values (0, 1), (0, 2), (0, 3), and (0, 4) has been analyzed theoretically for direct laser acceleration (DLA) of electron under the influence of an externally applied axial magnetic field. The propagation characteristics of a TEM HG beam in vacuum control the dynamics of electron during laser-electron interaction. The applied magnetic field strengthens the **v** x **B** force component of the fields acting on electron for the occurrence of strong betatron resonance. An axially confined enhanced acceleration is observed due to axial magnetic field. The electron energy gain is sensitive not only to mode indices of TEM HG laser beam but also to applied magnetic field. Higher energy gain in GeV range is seen with higher mode indices in the presence of applied magnetic field. The obtained results with distinct TEM modes would be helpful in the development of better table top accelerators of diverse needs.

Electron acceleration by an intense laser pulse inside a density profile induced by non-linear pulse evolution

Pishdast, M.; Yazdanpanah, J.; Ghasemi, S. A.
LASER AND PARTICLE BEAMS 36(1), 41-48 (MAR 2018)
https://doi.org/10.1017/S0263034617000970

By sophisticated application of particle-in-cell simulations, we demonstrate the ultimate role of non-linear pulse evolutions in accelerating electrons during the entrance of an intense laser pulse into a preformed density profile. As a key point in our discussions, the non-linear pulse evolutions are found to be very fast even at very low plasma densities, provided that the pulse length exceeds the local plasma wavelength. Therefore, these evolutions are sufficiently developed during the propagation of typical short density scale lengths occurred at high contrast ratios of the pulse, and lead to plasma heating via stochastic acceleration in multi-waves. Further analysis of simulation data at different physical parameters indicates that the rate of evolutions increases with the plasma density leading to higher plasma heating and overgrown energetic electrons. In the same way, shortening the density scale length results into increase in the evolution rate and, simultaneously, decrease in the interaction time. This behavior can describe the observed optimum value of pre-plasma scale length for the maximum electron heating.

Trapping and acceleration of short electron bunches in the laser wakefields

Andreev, N. E.; Baranov, V. E.; Matevosyan, H. H.
LASER AND PARTICLE BEAMS 35(4), 569-573 (DEC 2017)
https://doi.org/10.1017/S0263034617000556

The processes of trapping, compression, and acceleration of short electron bunches externally injected into the wakefields generated by intense femtosecond laser pulse in a plasma channel are analyzed and optimized. The influence of the laser non-linear dynamics to the longitudinal bunch compression and impact of the beam loading effect (self-action of the bunch charge) to the finite energy and the energy spread of the accelerated electrons are investigated. The limitations to the charge of accelerated electron bunch determined by the requirement of a small width of the electron energy distribution of the bunch are found.

Generation of electron plasma wave and particle acceleration by beating of two intense cross focused elliptical laser beams in collisionless plasma

Purohit, G.; Rawat, P.
LASER PHYSICS 28(9), 096001 (SEP 2018)
https://doi.org/10.1088/1555-6611/aac905

This paper presents the propagation of two intense cross-focused elliptical laser beams (ELBs) in a collisionless plasma and their effect on the excitation of electron plasma waves (EPWs) and particle acceleration, when relativistic and ponderomotive nonlinearities are operative. Due to the mutual interaction of the two ELBs, cross-focusing takes place in the plasma. An EPW is generated on account of the beating of the two cross-focused ELBs of frequencies ω_1 and ω_2. Nonlinear differential equations have been set up for the beamwidth parameters of the ELBs, the power of the EPW and the energy gained by the electrons using WKB and paraxial ray approximations. Numerical simulations have been carried out to investigate the effect of various laser and plasma parameters such as incident laser intensity and plasma density on the focusing of ELBs in plasmas and its effect on the power of excited EPWs and particle acceleration. Numerical results show that the focusing and intensity of both beams in plasma increase with increasing values of incident laser intensity and plasma density. It is observed that the cross-focusing of two ELBs enhances the power of generated EPWs and the yield of energy gain. This study is useful for determining the propagation dynamics of ELBs in plasma and the results are helpful for various applications requiring multiple laser beams.

Conceptual and Technical Design Aspects of Accelerators for External Injection in LWFA
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APPLIED SCIENCES 8(5), 757 (MAY 2018)
https://doi.org/10.3390/app8050757

Laser driven Wake-Field Acceleration (LWFA) has proven its capability of accelerating electron bunches (e-bunches) to up to 4 GeV energy in a single stage while reaching gradients up to hundreds of GV/m. Because of the short period of the accelerating field (typically ranging from 100 fs to 1 ps duration) and the requirement of extremely small beam size (typically < 1 µm) to match the channel, e-bunches can reach extremely high densities. They can be either extracted directly from the plasma or externally injected. The study of the external injection is interesting for two main reasons. On the one hand this method allows better control of the quality of the input beam and on the other hand it is in general necessary when a staged approach of the accelerator is considered. The interest in producing, characterizing and transporting high brightness ultra-short e-bunches has grown together with the interest in LWFA and other novel high-gradient acceleration techniques. In this paper we will review the principal techniques for producing and shaping ultra-short electron bunches with the example of the SINBAD-ARES (Accelerator Research Experiment at SINBAD) linac at the Deutsches Elektronen-Synchrotron (DESY). Our goal is to show how the design of the SINBAD-ARES linac satisfies the requirements for generating high brightness LWFA probes. In the last part of the paper we shall also comment on the technical challenges for electron control and characterization.

3D-printed capillary for hydrogen filled discharge for plasma based experiments in RF-based electron linac accelerator
Filippi, F.; Anania, M. P.; Biagioni, A.; Chiadroni, E.; Cianchi, A.; Ferber, Y.; Ferrario, M.; Zigler, A.
REVIEW OF SCIENTIFIC INSTRUMENTS 89(8), 083502 (AUG 2018)
https://doi.org/10.1063/1.5010264

Plasma-based acceleration experiments require capillaries with a radius of a few hundred microns to confine plasma up to a cm- scale capillary length. A long and controlled plasma channel allows to sustain high fields which may be used for manipulation of the electron beams or to accelerate electrons. The production of these capillaries is relatively complicated and expensive since they are usually made with hard materials whose manufacturing requires highly specialized industries. Fine variations of the capillary shape may significantly increase the cost and time needed to produce them. In this article, we demonstrate the possibility of using 3D printed polymeric capillaries to drive a hydrogen-filled plasma discharge up to 1 Hz of repetition rate in an RF based electron linac. The plasma density distribution has been measured after several shot intervals, showing the effect of the surface ablation on the plasma density distribution. This effect is almost invisible in the earlier stages of the discharge. After more than 55000 shots (corresponding to more than 16 h of working time), the effects of the ablation on the plasma density distribution are not evident and the capillary can still be used. The use of these capillaries will significantly reduce the cost and time for prototyping, allowing us to easily manipulate their geometry, laying another building block for future cheap and compact particle accelerators. Published by AIP Publishing.

Compact and tunable focusing device for plasma wakefield acceleration
Pompili, R.; Anania, M. P.; Chiadroni, E.; Cianchi, A.; Ferrario, M.; Lollo, V.; Notargiacomo, A.; Picardi, L.; Ronsivalle, C.; Rosenzweig, J. B.; Shpakov, V.; Vannozzi, A.
REVIEW OF SCIENTIFIC INSTRUMENTS 89(3), 033302 (MAR 2018)
https://doi.org/10.1063/1.5006134

Plasma wakefield acceleration, either driven by ultra-short laser pulses or electron bunches, represents one of the most promising techniques able to overcome the limits of conventional RF technology and allows the development of compact accelerators. In the particle beam-driven scenario, ultra-short bunches with tiny spot sizes are required to enhance the accelerating gradient and preserve the emittance and energy spread of the accelerated bunch. To achieve such tight transverse beam sizes, a focusing system with short focal length is mandatory. Here we discuss the development of a compact and tunable system consisting of three small-bore permanent-magnet quadrupoles with 520 T/m field gradient. The device has been designed in view of the plasma acceleration experiments planned at the SPARC_LAB facility. Being the field gradient fixed, the focusing is adjusted by tuning the relative position of the three magnets with nm resolution. Details about its magnetic design, beam-dynamics simulations, and preliminary results are examined in the paper. Published by AIP Publishing.

All optical dual stage laser wakefield acceleration driven by two-color laser pulses

Pathak, V. B.; Kim, H. T.; Vieira, J.; Silva, L. O.; Nam, C. H.
SCIENTIFIC REPORTS 8, 11772 (AUG 6 2018)
https://doi.org/10.1038/s41598-018-30095-4

We propose an all-optical dual-stage laser wakefield acceleration (LWFA), staged with co-propagating two-color laser pulses in a plasma medium, to enhance the electron bunch energy. After the depletion of the leading fundamental laser pulse that initiates self-injection and sets up the first stage particle acceleration, the subsequent second-harmonic laser pulse takes over the acceleration process and accelerates the electron bunch in the second stage over a significantly longer distance than in the first stage. In this all optical dual-stage LWFA, the electrons can gain 3 times higher energy as compared to the energy gain from the single stage LWFA driven by a single-color laser pulse with equivalent energy. Our multi-dimensional particle-in-cell simulations demonstrate that a 10-GeV electron bunch with 20-pC charge can be obtained by the two-color dual-stage LWFA using total input laser power of 0.6 PW.

Multi-GeV electron-positron beam generation from laser-electron scattering

Vranic, M.; Klimo, O.; Korn, G.; Weber, S.
SCIENTIFIC REPORTS 8, 4702 (MAR 16 2018)
https://doi.org/10.1038/s41598-018-23126-7

The new generation of laser facilities is expected to deliver short (10 fs-100 fs) laser pulses with 10-100 PW of peak power. This opens an opportunity to study matter at extreme intensities in the laboratory and provides access to new physics. Here we propose to scatter GeV-class electron beams from laser-plasma accelerators with a multi-PW laser at normal incidence. In this configuration, one can both create and accelerate electron-positron pairs. The new particles are generated in the laser focus and gain relativistic momentum in the direction of laser propagation. Short focal length is an advantage, as it allows the particles to be ejected from the focal region with a net energy gain in vacuum. Electron-positron beams obtained in this setup have a low divergence, are quasi-neutral and spatially separated from the initial electron beam. The pairs attain multi-GeV energies which are not limited by the maximum energy of the initial electron beam. We present an analytical model for the expected energy cutoff, supported by 2D and 3D particle-in-cell simulations. The experimental implications, such as the sensitivity to temporal synchronisation and laser duration is assessed to provide guidance for the future experiments.

High Energy electron and proton acceleration by circularly polarized laser pulse from near critical density hydrogen gas target

Sharma, A.
SCIENTIFIC REPORTS 8, 2191 (FEB 1 2018)
https://doi.org/10.1038/s41598-018-20506-x

Relativistic electron rings hold the possibility of very high accelerating rates, and hopefully a relatively cheap and compact accelerator/collimator for ultrahigh energy proton source. In this work, we investigate the generation of helical shaped quasi-monoenergetic relativistic electron beam and high-energy proton beam from near critical density plasmas driven by petawatt-circularly polarized-short laser pulses. We numerically observe the efficient proton acceleration from magnetic vortex acceleration mechanism by using the three dimensional particle-in-cell simulations; proton beam with peak energy 350 MeV, charge ∼ 10nC and conversion efficiency more than 6% (which implies 2.4 J proton beam out of the 40 J incident laser energy) is reported. We detailed the microphysics involved in the ion acceleration mechanism, which requires investigating the role of self-generated plasma electric and magnetic fields. The concept of efficient generation of quasi-monoenergetic electron and proton beam from near critical density gas targets may be verified experimentally at advanced high power high repetition rate laser facilities e.g. ELI-ALPS. Such study should be an important step towards the development of high quality electron and proton beam.

Ultrahigh-order Maxwell solver with extreme scalability for electromagnetic PIC simulations of plasmas

Vincenti, H.; Vay, J.-L.

COMPUTER PHYSICS COMMUNICATIONS 228, 22-29 (JUL 2018)
https://doi.org/10.1016/j.cpc.2018.03.018

The advent of massively parallel supercomputers, with their distributed-memory technology using many processing units, has favored the development of highly-scalable local low-order solvers at the expense of harder-to-scale global very high-order spectral methods. Indeed, FFT-based methods, which were very popular on shared memory computers, have been largely replaced by finite-difference (FD) methods for the solution of many problems, including plasmas simulations with electromagnetic Particle-In-Cell methods. For some problems, such as the modeling of so-called "plasma mirrors" for the generation of high-energy particles and ultra-short radiations, we have shown that the inaccuracies of standard FD-based PIC methods prevent the modeling on present supercomputers at sufficient accuracy. We demonstrate here that a new method, based on the use of local FFTs, enables ultrahigh-order accuracy with unprecedented scalability, and thus for the first time the accurate modeling of plasma mirrors in 3D.

Photon and positron generation by ultrahigh intensity laser interaction with electron beams

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FRONTIERS OF PHYSICS 13(4), 135202 (AUG 2018)
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This study investigates the generation of high energy photons and positrons using focused ultrahigh intensity femtosecond laser pulses on a relativistic electron beam with a set of two-dimensional particle-in-cell simulations. We consider circularly and linearly polarized, single and spatially separated double laser pulses. We model both 500 MeV and 1 GeV electron beams. Higher positron production is obtained using circularly polarized laser pulses. Using double pulses, the focusing effect of the ponderomotive force confines the electrons to a small volume, generating additional energetic photons and positrons. The positron spectral distributions are effectively modified by these variations. When the electron beam energy is doubled, the number of positrons increased, while the cutoff energy remained nearly constant.

Electron acceleration from rest to GeV energy by chirped axicon Gaussian laser pulse in vacuum in the presence of wiggler magnetic field

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HIGH ENERGY DENSITY PHYSICS 26, 16-22 (MAR 2018)
https://doi.org/10.1016/j.hedp.2017.11.003

This paper presents a scheme of electron energy enhancement by employing frequency - chirped lowest order axicon focussed radially polarised (RP) laser pulse in vacuum under the influence of wiggler magnetic field. Terawatt RP laser can be focussed down to ~ 5 μm by an axicon optical element, which produces an intense longitudinal electric field. This unique property of axicon focused Gaussian RP laser pulse is employed for direct electron acceleration in vacuum. A linear frequency chirp increases the time duration of laser-electron interaction, whereas, the applied magnetic wiggler helps in improving the strength of ponderomotive force **v** x **B** and periodically deflects electron in order to keep it traversing in the accelerating phase up to longer distance. Numerical simulations have been carried out to investigate the influence of laser, frequency chirp and magnetic field parameters on electron energy enhancement. It is noticed that an electron from rest can be accelerated up to GeV energy under optimized laser and magnetic field parameters. Significant enhancement in the electron energy gain of the order of 11.2 GeV is observed with intense chirped laser pulse in the presence of wiggler magnetic field of strength 96.2 kG.

Intra-cycle depolarization of ultraintense laser pulses focused by off-axis parabolic mirrors

Labate, L.; Vantaggiato, G.; Gizzi, L. A.
HIGH POWER LASER SCIENCE AND ENGINEERING 6, e32 (JUN 6 2018)
https://doi.org/10.1017/hpl.2018.27

A study of the structure of the electric and magnetic fields of ultraintense laser pulses focused by an off-axis parabolic mirror is reported. At first, a theoretical model is laid out, whose final equations integration allows the space and time structure of the fields to be retrieved. The model is then employed to investigate the field patterns at different times within the optical cycle, for off-axis parabola parameters normally employed in the context of ultraintense laser-plasma interaction experiments. The results show that nontrivial, complex electromagnetic field patterns are observed at the time at which the electric and magnetic fields are supposed to vanish. The importance of this effect is then studied for different laser polarizations, f numbers and off-axis angles.

Micro-spot gamma-ray generation based on laser wakefield acceleration

Dong, K.; Zhang, T.; Yu, M.; Wu, Y.; Zhu, B.; Tan, F.; Wang, S.; Yan, Y.; Yang, J.; Yang, Y.; Lu, F.; Li, G.; Fan, W.; Hong, W.; Zhao, Z.; Zhou, W.; Cao, L.; Gu, Y.
JOURNAL OF APPLIED PHYSICS 123(24), 243301 (JUN 28 2018)
https://doi.org/10.1063/1.4997142

The radiography of gamma-ray is one of the most important non-destructive testing in many fields. However, the spot size is always in millimeter scale for the generation of gamma-ray by conventional way. As the development of laser wakefield acceleration, the electron beam with small divergence and spot size can be generated easily in the experiment by tens of terawatt ultra-short laser pulse. Based on this electron beam, gamma-ray with micro spot size is generated and the properties are measured and tested in detail experimentally. The experiment demonstrates that the spot size of this gamma-ray is always smaller than 200 μm, no matter the conversion target thickness, and can be as small as about 40 pm when the conversion target thickness of 0.2 mm is used. The spatial resolution of this gamma-ray is much better than 2.5 LP/mm, the fitting temperature (which is relative to the average energy of gamma-ray) is between 5 MeV and 8 MeV, and the maximum yield per shot of the gamma-ray can be up to 9.1×10^9 photons (energy higher than 1 MeV). High-resolution radiography shows that the areal density of the gamma-ray radiography can be up to 51.3 g/cm^2 (stainless steel thickness equivalent is about 6.5 cm). Such micro-spot gamma-ray can play an important role in the high-resolution radiography of high areal density objects. Published by AIP Publishing.

Travelling waves and a fruitful 'time' reparametrization in relativistic electrodynamics

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JOURNAL OF PHYSICS A-MATHEMATICAL AND THEORETICAL 51(8), 085203 (FEB 23 2018)
https://doi.org/10.1088/1751-8121/aaa304

We simplify the nonlinear equations of motion of charged particles in an external electromagnetic field that is the sum of a plane travelling wave $F_t^{\mu\nu}(ct - z)$ and a static part $F_s^{\mu\nu}$ (x, y, z): by adopting the light-like coordinate $\xi = ct - z$ instead of time t as an independent variable in the Action, Lagrangian and Hamiltonian, and deriving the new Euler-Lagrange and Hamilton equations accordingly, we make the unknown z(t) disappear from the argument of $F_t^{\mu\nu}$. We first study and solve the single particle equations in a few significant cases of extreme accelerations. In particular, we obtain a rigorous formulation of a Lawson-Woodward-type (no-final-acceleration) theorem and a compact derivation of cyclotron autoresonance, beside new solutions in the presence of uniform $F_s^{\mu\nu}$. We then extend our method to plasmas in hydrodynamic conditions, and apply it to plane problems: the system of (Lorentz-Maxwell + continuity) partial differential equations may be partially solved or sometimes even completely reduced to a family of decoupled systems of ordinary ones; this occurs e.g. with the impact of the travelling wave on a vacuum-plasma interface (what may produce the slingshot effect). Our method can be seen as an application of the light-front approach. Since Fourier analysis plays no role in our general framework, the method can be applied to all kinds of travelling waves, ranging from almost monochromatic to so-called 'impulses', which contain few, one or even no complete cycles.

Guiding of charged particle beams in curved capillary-discharge waveguides

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AIP ADVANCES 8(1), 015326 (JAN 2018)
https://doi.org/10.1063/1.5011964

A new method able to transport charged particle beams along a curved path is presented. It is based on curved capillary-discharge waveguides where the induced azimuthal magnetic field is used to focus the beam and, at the same time, keep it close to the capillary axis. We show that such a solution is highly tunable, it allows to develop compact structures providing large deflecting angles and, unlike conventional solutions based on bending magnets, preserves the beam longitudinal phase space. Such a feature, in particular, is very promising when dealing with ultra-short bunches for which non-trivial manipulations on the longitudinal phase spaces are usually required when employing conventional deflecting devices. (c) 2018 Author(s).

A reformulation of mechanics and electrodynamics

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Classical mechanics, as commonly taught in engineering and science, are confined to the conventional Newtonian theory. But classical mechanics has not really changed in substance since Newton formulation, describing simultaneous rotation and translation of objects with somewhat complicate drawbacks, risking interpretation of forces in non-inertial frames. In this work we introduce a new variational principle for out-of-equilibrium, rotating systems, obtaining a set of two first order differential equations that introduces a thermodynamic-mechanistic time into Newton's dynamical equation, and revealing the same formal symplectic structure shared by classical mechanics, fluid mechanics and thermodynamics. The results is a more consistent formulation of dynamics and electrodynamics, explaining natural phenomena as the outcome from a balance between energy and entropy, embedding translational with rotational motion into a single equation, showing centrifugal and Coriolis force as derivatives from the transport of angular momentum, and offering a natural method to handle variational problems, as shown with the brachistochrone problem. In consequence, a new force term appears, the topological torsion current, important for spacecraft dynamics. We describe a set of solved problems showing the potential of a competing technique, with significant interest to electrodynamics as well. We expect this new approach to have impact in a large class of scientific and technological problems.

Electron and photon diagnostics for plasma acceleration-based FELs

Labat, M.; El Ajjouri, M.; Hubert, N.; Andre, T.; Loulergue, A.; Couprie, M.-E.
JOURNAL OF SYNCHROTRON RADIATION 25, 59-67 (JAN 2018)
https://doi.org/10.1107/S1600577517011742

It is now well established that laser plasma acceleration (LPA) is an innovative and good candidate in the beam acceleration field. Relativistic beams are indeed produced up to several GeV but their quality remains to be demonstrated in the highly demanding case of free-electron lasers (FELs). Several experiments have already shown the feasibility of synchrotron radiation delivery based on LPA but free-electron lasing has still to be achieved. Since the quality of the LPA beam inside the undulator is the critical issue, any LPA-based FEL experiment requires a refined characterization of the beam properties along the transport line and of the photon beam at the undulator exit. This characterization relies on diagnostics which must be adapted to the LPA specificities. Here, the electron and photon diagnostics already used on LPAs and required for LPA-based FELs are reviewed, and the critical points are illustrated using recent experiments performed around the world.

Optical rectification for a new shot to shot feedback system for laser-driven plasma wakefield accelerators

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NONLINEAR OPTICS AND ITS APPLICATIONS 10684, UNSP 1068412 (2018)
https://doi.org/10.1117/12.2306429

Plasma-based particle accelerators driven by either lasers or particle beams are an important new technology in order to reduce the large size of conventional accelerators and to minimize the construction costs. Using laser driven plasma wake field accelerators, the synchronization between electron bunch and the ultrashort laser is crucial to obtain a stable acceleration. In order to minimize the electron bunch arrival-time jitter, the development of a new shot to shot feedback system with a time resolution of less than 1 fs is planned. As a first step, stable Terahertz pulses (THz pulses) should be performed by optical rectification of high energy femtosecond laser pulses in a nonlinear crystal. It is planed that the generated THz pulses will energy modulate the electron bunches shot to shot before the plasma to achieve the time resolution of 1fs. The selection of the nonlinear material for optical rectification is a critical aspect for the development of laser driven THz sources. In this contribution we systematically investigate the influence of the optical properties, and in particular adsorption coefficient of lithium niobate crystal as well as the theoretical description of the THz generation on the conversion efficiency of the generation of short THz pulses.

Wakefield generation by chirped super-Gaussian laser pulse in inhomogeneous plasma

Yao, Z.; Cheng, L.; Tang, R.; Xue, J.
PLASMA SCIENCE & TECHNOLOGY 20(11), UNSP 115002 (NOV 2018)
https://doi.org/10.1088/2058-6272/aacbbf

We study the effect of nonlinearly chirped super-Gaussian (SG) laser pulse on wakefield generation in an inhomogeneous plasma. The different types of nonlinearly chirped pulse are employed, and different kinds of inhomogeneous plasma density are used. The maximum wakefield amplitude as the function of nonlinearly chirped laser pulse and inhomogeneous plasma density in parameter space are obtained. Moreover, the dependence of the maximum wakefield amplitude on the SG laser pulse index is discussed. This shows that a larger wakefield can be obtained when the chirped pulse and inhomogeneous density are in the critical regions. Wakefield generation can be controlled by adjusting the chirped SG pulse and inhomogeneous plasma density parameters. That is, we provide an efficient way for the controlled generation of the wakefield.

Electron Acceleration by a Relativistic Electron Plasma Wave in Inverse-Free-Electron Laser Mechanism

Yadav, M.; Sharma, S. C.; Gupta, D. N.
IEEE TRANSACTIONS ON PLASMA SCIENCE 46(7), 2521-2527 (JUL 2018)
https://doi.org/10.1109/TPS.2018.2843362

It has been revealed that a relativistic plasma wave, having an extremely large electric field, may be utilized for the acceleration of plasma particles. The large accelerating field gradient driven by a plasma wave is the basic motivation behind the acceleration mechanism. Such a plasma wave can be excited by a single laser in the form of wake-field in laser-plasma interactions. In this paper, we study the enhancement of electron acceleration by plasma wave in the presence of a wiggler magnetic field. Electrons trapped in the plasma wave are accelerated due to the additional resonance provided effectively by the wiggler field, which contributes in large energy gain of electrons during acceleration. The resonant enhancement of electron acceleration by the wiggler magnetic field has been validated by single particle simulations. The dependence of energy gain on plasma wave amplitude, initial electron energy, wiggler magnetic field strength has been investigated. Using the model, the involvement and importance of inverse free-electron laser mechanism in electron acceleration by the plasma wave was analyzed. A scaling law for electron energy optimization was proposed for future electron accelerator development.

Laser-plasma generated very high energy electrons (VHEEs) in radiotherapy

Kokurewicz, K.; Welsh, G. H.; Brunetti, E.; Wiggins, S. M.; Boyd, M.; Sorensen, A.; Chalmers, A.; Schettino, G.; Subiel, A.; Desrosiers, C.; Jaroszynski, D. A.

MEDICAL APPLICATIONS OF LASER-GENERATED BEAMS OF PARTICLES IV: REVIEW OF PROGRESS AND STRATEGIES FOR THE FUTURE 10239, UNSP 102390C (2017)

https://doi.org/10.1117/12.2271183

As an alternative modality to conventional radiotherapy, electrons with energies above 50 MeV penetrate deeply into tissue, where the dose can be absorbed within a tumour volume with a relatively small penumbra. We investigate the physical properties of VHEEs and review the state-of-the-art in treatment planning and dosimetry. We discuss the advantages of using a laser wakefield accelerator (LWFA) and present the characteristic features of the electron bunch produced by the LWFA and compare them with that from a conventional linear accelerator.

High-resolution µCT of a mouse embryo using a compact laser-driven X-ray betatron source

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PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA 115(25), 6335-6340 (JUN 19 2018)

https://doi.org/10.1073/pnas.1802314115

In the field of X-ray microcomputed tomography (µCT) there is a growing need to reduce acquisition times at high spatial resolution (approximate micrometers) to facilitate in vivo and high-throughput operations. The state of the art represented by synchrotron light sources is not practical for certain applications, and therefore the development of high-brightness laboratory scale sources is crucial. We present here imaging of a fixed embryonic mouse sample using a compact laser-plasma-based X-ray light source and compare the results to images obtained using a commercial X-ray µCT scanner. The radiation is generated by the betatron motion of electrons inside a dilute and transient plasma, which circumvents the flux limitations imposed by the solid or liquid anodes used in conventional electron-impact X-ray tubes. This X-ray source is pulsed (duration < 30 fs), bright ($>10^{10}$ photons per pulse), small (diameter < 1 µm), and has a critical energy > 15 keV. Stable X-ray performance enabled tomographic imaging of equivalent quality to that of the µCT scanner, an important confirmation of the suitability of the laser-driven source for applications. The X-ray flux achievable with this approach scales with the laser repetition rate without compromising the source size, which will allow the recording of high-resolution µCT scans in minutes.

Seamless multistage laser-plasma acceleration toward future high-energy colliders

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LIGHT-SCIENCE & APPLICATIONS 7, 21 (JUN 20 2018)

https://doi.org/10.1038/s41377-018-0037-6

Multistage laser wakefield accelerators that are coupled with variable-curvature plasma channels make it possible to efficiently accelerate electrons to high energies that exceed dephasing and pump depletion limits. Seamless coupling between laser and particle beams may envisage future energy-frontier colliders of revolutionarily small size and cost.

Influence of Gaussian, Super-Gaussian, and Cosine-Gaussian Pulse Properties on the Electron Acceleration in a Homogeneous Plasma

Fallah, R.; Khorashadizadeh, S. M.
IEEE TRANSACTIONS ON PLASMA SCIENCE 46(6), 2085-2090 (JUN 2018)
https://doi.org/10.1109/TPS.2018.2834512

In this paper, the process of electron acceleration in a homogeneous plasma is determined for the Gaussian pulse (GP), super-GP, and cosine-GP (CGP). In addition to the wake-field (E-w) behind the laser pulses, the expressions for the electron energy gain and density perturbation are obtained and compared with each other for all these types of laser pulses by making the pulse duration the same as the electron plasma period. The analytical results show that the amplitude of wakefield depends on the laser intensity, pulse wavelength, pulse length, and plasma electron density. By comparing the results, the CGP is found to be most significant as in this case the electron can be accelerated up to 800 MeV when I = 3 x 10^{22}(W/m^2), λ = 820 nm, and n = 3.4 x 10^{24} m^{-3}.

***The EuPRAXIA Files* is a collection of abstracts from publicly available published papers that are relevant to the EuPRAXIA study. 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**

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