THE EuPRAXIA FILES

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Foreword

Dr Ralph Aßmann
EuPRAXIA Coordinator

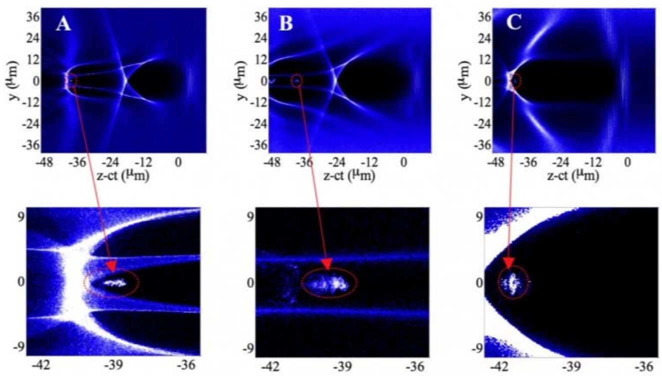
The field of novel accelerators is highly productive, as one can see in the number and variety of publications that we point to in this second edition of *The EuPRAXIA Files*. It is particularly important that a number of studies start addressing the impact of imperfections on the beam quality. This is the theme of EuPRAXIA: generating high quality electron beams in a compact and highly cost-effective facility. It has been a very fruitful and busy year for EuPRAXIA with the Pisa workshop in June 2016 being one of several highlights. More than 120 scientists gathered at Pisa, the place where Galilei for the first time correctly described acceleration. He achieved this by building one of the first research infrastructures: an inclined plane for rolling balls of different weights. Writing this short text I am at the International Conference for Research Infrastructures (ICRI2016) in South Africa. The outreach to emerging and developing nations is a big topic here, to be achieved by open access to large facilities, their data and results. We should realize that the construction of compact and lower cost accelerators is a way to give more countries the opportunity to perform world-class research. EuPRAXIA can be an additional way to democratize science for the less wealthy parts of our world. Let's work towards this ambitious but very worthy goal. Please enjoy this second edition of *The EuPRAXIA Files* and let us know your view or opinion on novel accelerators.

Research Highlights

Energy spread minimization in a cascaded laser wakefield accelerator via velocity bunching

Laser wakefields have the potential to accelerate electrons to near the speed of light in a much smaller distance than is required by conventional accelerators. However, the usually large energy spread of the beams generated in wakefield accelerators prevents the use of this technology for practical applications.

In a paper published in Physics of Plasmas, a team of researchers from China, South Korea and the U.S. has proposed a new method to minimize the energy spread of an electron beam in a cascaded laser wakefield accelerator.



Two-dimensional electron density distribution for the injector stage (A), compressor stage (B) and accelerator stage (C), where the target e-beam is circled by a dashed circle (in red). Jiansheng Liu/Chinese Academy of Sciences.

The technique consists on inserting a plasma compressor between the injection and acceleration stages to reduce the longitudinal spatial distribution of the beam. The compressor also reverses the energy chirp of the beam so that the electrons can be accelerated to a much higher energy before its chirp is compensated.

Previous schemes to reduce the energy spread of the electrons, either by optimizing the injection process or shaping the accelerating field, have produced beams with an energy spread of a few per cent.

In this work, the authors employ a one-dimensional theory and 2D particle-in-cell simulations to demonstrate the scheme and show that electron beams with 0.2% rms energy spread and low transverse emittance could be generated without loss of charge.

Journal Reference:
Zhang, Zhijun; Li, Wentao; Liu, Jiansheng; Wang, Wentao; Yu, Changhai; Tian, Ye; Nakajima, Kazuhisa; Deng, Aihua; Qi, Rong; Wang, Cheng; Qin, Zhiyong; Fang, Ming; Liu, Jiaqi; Xia, Changquan; Li, Ruxin; Xu, Zhizhan
PHYSICS OF PLASMAS 23 (5), 053106 (MAY 2016)
10.1063/1.4947536

Research Papers

Plasma optical modulators for intense lasers

Yu, Lu-Le; Zhao, Yao; Qian, Lie-Jia; Chen, Min; Weng, Su-Ming; Sheng, Zheng-Ming; Jaroszynski, D. A.; Mori, W. B.; Zhang, Jie
NATURE COMMUNICATIONS 7, 11893 (JUN 2016)
10.1038/ncomms11893

Optical modulators can have high modulation speed and broad bandwidth, while being compact. However, these optical modulators usually work for low-intensity light beams. Here we present an ultrafast, plasma-based optical modulator, which can directly modulate highpower lasers with intensity up to 10^{16} Wcm^{-2} to produce an extremely broad spectrum with a fractional bandwidth over 100%, extending to the mid-infrared regime in the low-frequency side. This concept relies on two co-propagating laser pulses in a sub-millimetre-scale underdense plasma, where a drive laser pulse first excites an electron plasma wave in its wake while a following carrier laser pulse is modulated by the plasma wave. The laser and plasma parameters suitable for the modulator to work are based on numerical simulations.

Nanoscale Electron Bunching in Laser-Triggered Ionization Injection in Plasma Accelerators

Xu, X. L.; Pai, C.-H.; Zhang, C. J.; Li, F.; Wan, Y.; Wu, Y. P.; Hua, J. F.; Lu, W.; An, W.; Yu, P.; Joshi, C.; Mori, W. B.
PHYSICAL REVIEW LETTERS 117 (3), 034801 (JUL 2016)
10.1103/PhysRevLett.117.034801

Ionization injection is attractive as a controllable injection scheme for generating high quality electron beams using plasma-based wakefield acceleration. Because of the phase-dependent tunneling ionization rate and the trapping dynamics within a nonlinear wake, the discrete injection of electrons within the wake is nonlinearly mapped to a discrete final phase space structure of the beam at the location where the electrons are trapped. This phenomenon is theoretically analyzed and examined by three-dimensional particle-in-cell simulations which show that three-dimensional effects limit the wave number of the modulation to between $> 2k_0$ and about $5k_0$, where k_0 is the wave number of the injection laser. Such a nanoscale bunched beam can be diagnosed by and used to generate coherent transition radiation and may find use in generating high-power ultraviolet radiation upon passage through a resonant undulator.

Enhanced Multi-MeV Photon Emission by a Laser-Driven Electron Beam in a Self-Generated Magnetic Field

Stark, D. J.; Toncian, T.; Arefiev, A. V.
PHYSICAL REVIEW LETTERS 116 (18), 185003 (MAY 2016)
10.1103/PhysRevLett.116.185003

We use numerical simulations to demonstrate that a source of collimated multi-MeV photons with high conversion efficiency can be achieved using an all-optical single beam setup at an intensity of $5x10^{22}$ W/cm^2 that is already within reach of existing laser facilities. In the studied setup, an unprecedented quasistatic magnetic field (0.4 MT) is driven in a significantly overdense plasma, coupling three key aspects of laser-plasma interactions at high intensities: relativistic transparency, direct laser acceleration, and synchrotron photon emission. The quasistatic magnetic field enhances the photon emission process, which has a profound impact on electron dynamics via radiation reaction and yields tens of TW of directed MeV photons for a PW-class laser.

Generation of Superponderomotive Electrons in Multipicosecond Interactions of Kilojoule Laser Beams with Solid-Density Plasmas

Sorokovikova, A.; Arefiev, A. V.; McGuffey, C.; Qiao, B.; Robinson, A. P. L.; Wei, M. S.; McLean, H. S.; Beg, F. N.
PHYSICAL REVIEW LETTERS 116 (15), 155001 (APR 2016)
10.1103/PhysRevLett.116.155001

The interaction of a multipicosecond, kilojoule laser pulse with a surface of a solid target has been shown to produce electrons with energies far beyond the free-electron ponderomotive limit $m_e c^2 a_0^2/2$. Particle-in-cell simulations indicate that an increase in the pulse duration from 1 to 10 ps leads to the formation of a low-density shelf (about 10% of the critical density). The shelf extends over 100 μm toward the vacuum side, with a nonstationary potential barrier forming in that area. Electrons reflected from the barrier gain superponderomotive energy from the potential. Some electrons experience an even greater energy gain due to ponderomotive acceleration when their "dephasing rate" $R=\gamma-p_x/m_e c$ drops well below unity, thus increasing acceleration by a factor of 1/R. Both 1D and 2D simulations indicate that these mechanisms are responsible for the generation of extensive thermal distributions with T_e>10 MeV and a high-energy cutoff of hundreds of MeV.

Generation of femtosecond gamma-ray bursts stimulated by laser-driven hosing evolution

Ma, Yong; Chen, Liming; Li, Dazhang; Yan, Wenchao; Huang, Kai; Chen, Min; Sheng, Zhengming; Nakajima, Kazuhisa; Tajima, Toshiki; Zhang, Jie
SCIENTIFIC REPORTS 6, 30491 (JUL 2016)
10.1038/srep30491

The promising ability of a plasma wiggler based on laser wakefield acceleration to produce betatron X-rays with photon energies of a few keV to hundreds of keV and a peak brilliance of 10^{22}-10^{23} photons/s/mm^2/$mrad^2$/0.1% BW has been demonstrated, providing an alternative to large-scale synchrotron light sources. Most methods for generating betatron radiation are based on two typical approaches, one relying on an inherent transverse focusing electrostatic field, which induces transverse oscillation, and the other relying on the electron beam catching up with the rear part of the laser pulse, which results in strong electron resonance. Here, we present a new regime of betatron.-ray radiation generated by stimulating a large-amplitude transverse oscillation of a continuously injected electron bunch through the hosing of the bubble induced by the carrier envelope phase (CEP) effect of the self-steepened laser pulse. Our method increases the critical photon energy to the MeV level, according to the results of particle-in-cell (PIC) simulations. The highly collimated, energetic and femtosecond gamma-ray bursts that are produced in this way may provide an interesting potential means of exploring nuclear physics in table top photo nuclear reactions.

Ultrahigh brilliance quasi-monochromatic MeV gamma-rays based on self-synchronized all-optical Compton scattering

Yu, Changhai; Qi, Rong; Wang, Wentao; Liu, Jiansheng; Li, Wentao; Wang, Cheng; Zhang, Zhijun; Liu, Jiaqi; Qin, Zhiyong; Fang, Ming; Feng, Ke; Wu, Ying; Tian, Ye; Xu, Yi; Wu, Fenxiang; Leng, Yuxin; Weng, Xiufeng; Wang, Jihu; Wei, Fuli; Yi, Yicheng; Song, Zhaohui; Li, Ruxin; Xu, Zhizhan
SCIENTIFIC REPORTS 6, 29518 (JUL 2016)
10.1038/srep29518

Inverse Compton scattering between ultra-relativistic electrons and an intense laser field has been proposed as a major route to generate compact high-brightness and high-energy gamma-rays. Attributed to the inherent synchronization mechanism, an all-optical Compton scattering gamma-ray source, using one laser to both accelerate electrons and scatter via the reflection of a plasma mirror, has been demonstrated in proof-of-principle experiments to produce a x-ray source near 100 keV. Here, by designing a cascaded laser wakefield accelerator to generate high-quality monoenergetic e-beams, which are bound to head-on collide with the intense driving laser pulse via the reflection of a 20-μm thick Ti foil, we produce tunable quasi-monochromatic MeV gamma-rays (33% full-width at half-maximum) with a peak brilliance of similar to $3x10^{22}$ photons s^{-1} mm^{-2} $mrad^{-2}$ 0.1% BW at 1 MeV. To the best of our knowledge, it is one order of magnitude higher than ever reported value of its kinds in MeV regime. This compact ultrahigh brilliance gamma-ray source may provide applications in nuclear resonance fluorescence, x-ray radiology and ultrafast pump-probe nondestructive inspection.

Effect of experimental laser imperfections on laser wakefield acceleration and betatron source

Ferri, J.; Davoine, X.; Fourmaux, S.; Kieffer, J. C.; Corde, S.; Phuoc, K. Ta; Lifschitz, A.
SCIENTIFIC REPORTS 6, 27846 (JUN 2016)
10.1038/srep27846

Laser pulses in current ultra-short TW systems are far from being ideal Gaussian beams. The influence of the presence of non-Gaussian features of the laser pulse is investigated here from experiments and 3D Particle-in-Cell simulations. Both the experimental intensity distribution and wavefront are used as input in the simulations. It is shown that a quantitative agreement between experimental data and simulations requires to use realistic pulse features. Moreover, some trends found in the experiments, such as the growing of the X-ray signal with the plasma length, can only be retrieved in simulations with realistic pulses. The performances on the electron acceleration and the synchrotron X-ray emission are strongly degraded by these non-Gaussian features, even keeping constant the total laser energy. A drop on the X-ray photon number by one order of magnitude was found. This clearly put forward the limitation of using a Gaussian beam in the simulations.

Direct acceleration of electrons by a CO_2 laser in a curved plasma waveguide

Yi, Longqing; Pukhov, Alexander; Shen, Baifei
SCIENTIFIC REPORTS 6, 28147 (JUN 2016)
10.1038/srep28147

Laser plasma interaction with micro-engineered targets at relativistic intensities has been greatly promoted by recent progress in the high contrast lasers and the manufacture of advanced micro- and nano-structures. This opens new possibilities for the physics of laser-matter interaction. Here we propose a novel approach that leverages the advantages of high-pressure CO_2 laser, laser-waveguide interaction, as well as micro-engineered plasma structure to accelerate electrons to peak energy greater than 1 GeV with narrow slice energy spread (similar to 1%) and high overall efficiency. The acceleration gradient is 26 GV/m for a 1.3 TW CO_2 laser system. The micro- bunching of a long electron beam leads to the generation of a chain of ultrashort electron bunches with the duration roughly equal to half-laser-cycle. These results open a way for developing a compact and economic electron source for diverse applications.

Resonantly Enhanced Betatron Hard X-rays from Ionization Injected Electrons in a Laser Plasma Accelerator

Huang, K.; Li, Y. F.; Li, D. Z.; Chen, L. M.; Tao, M. Z.; Ma, Y.; Zhao, J. R.; Li, M. H.; Chen, M.; Mirzaie, M.; Hafz, N.; Sokollik, T.; Sheng, Z. M.; Zhang, J.
SCIENTIFIC REPORTS 6, 27633 (JUN 2016)
10.1038/srep27633

Ultrafast betatron x-ray emission from electron oscillations in laser wakefield acceleration (LWFA) has been widely investigated as a promising source. Betatron x-rays are usually produced via self-injected electron beams, which are not controllable and are not optimized for x-ray yields. Here, we present a new method for bright hard x-ray emission via ionization injection from the K-shell electrons of nitrogen into the accelerating bucket. A total photon yield of $8x10^8$/shot and 10^8 photons with energy greater than 110 keV is obtained. The yield is 10 times higher than that achieved with self-injection mode in helium under similar laser parameters. The simulation suggests that ionization-injected electrons are quickly accelerated to the driving laser region and are subsequently driven into betatron resonance. The present scheme enables the single-stage betatron radiation from LWFA to be extended to bright.-ray radiation, which is beyond the capability of 3rd generation synchrotrons.

Enabling Lorentz boosted frame particle-in-cell simulations of laser wakefield acceleration in quasi-3D geometry

Yu, Peicheng; Xu, Xinlu; Davidson, Asher; Tableman, Adam; Dalichaouch, Thamine; Li, Fei; Meyers, Michael D.; An, Weiming; Tsung, Frank S.; Decyk, Viktor K.; Fiuza, Frederico; Vieira, Jorge; Fonseca, Ricardo A.; Lu, Wei; Silva, Luis O.; Mori, Warren B.
JOURNAL OF COMPUTATIONAL PHYSICS 316, 747-759 (JUL 2016)
10.1016/j.jcp.2016.04.014

When modeling laser wakefield acceleration (LWFA) using the particle-in-cell (PIC) algorithm in a Lorentz boosted frame, the plasma is drifting relativistically at $\beta_b c$ towards the laser, which can lead to a computational speedup of $\sim \gamma_b^2 = (1 - \beta_b^2)^{-1}$. Meanwhile, when LWFA is modeled in the quasi-3D geometry in which the electromagnetic fields and current are decomposed into a limited number of azimuthal harmonics, speedups are achieved by modeling three dimensional (3D) problems with the computational loads on the order of two dimensional r-z simulations. Here, we describe a method to combine the speedups from the Lorentz boosted frame and quasi-3D algorithms. The key to the combination is the use of a hybrid Yee-FFT solver in the quasi-3D geometry that significantly mitigates the Numerical Cerenkov Instability (NCI) which inevitably arises in a Lorentz boosted frame due to the unphysical coupling of Langmuir modes and EM modes of the relativistically drifting plasma in these simulations. In addition, based on the space-time distribution of the LWFA data in the lab and boosted frame, we propose to use a moving window to follow the drifting plasma, instead of following the laser driver as is done in the LWFA lab frame simulations, in order to further reduce the computational loads. We describe the details of how the NCI is mitigated for the quasi-3D geometry, the setups for simulations which combine the Lorentz boosted frame, quasi-3D geometry, and the use of a moving window, and compare the results from these simulations against their corresponding lab frame cases. Good agreement is obtained among these sample simulations, particularly when there is no self-trapping, which demonstrates it is possible to combine the Lorentz boosted frame and the quasi-3D algorithms when modeling LWFA. We also discuss the preliminary speedups achieved in these sample simulations.

Modeling ultrafast shadowgraphy in laser-plasma interaction experiments

Siminos, E.; Skupin, S.; Saevert, A.; Cole, J. M.; Mangles, S. P. D.; Kaluza, M. C.
PLASMA PHYSICS AND CONTROLLED FUSION 58 (6), 065004 (JUN 2016)
10.1088/0741-3335/58/6/065004

Ultrafast shadowgraphy is a new experimental technique that uses few-cycle laser pulses to image density gradients in a rapidly evolving plasma. It enables structures that move at speeds close to the speed of light, such as laser driven wakes, to be visualized. Here we study the process of shadowgraphic image formation during the propagation of a few cycle probe pulse transversely through a laser-driven wake using three-dimensional particle-in-cell simulations. In order to construct synthetic shadowgrams a near-field snapshot of the ultrashort probe pulse is analyzed by means of Fourier optics, taking into account the effect of a typical imaging setup. By comparing synthetic and experimental shadowgrams we show that the generation of synthetic data is crucial for the correct interpretation of experiments. Moreover, we study the dependence of synthetic shadowgrams on various parameters such as the imaging system aperture, the position of the object plane and the probe pulse delay, duration and wavelength. Finally, we show that time-dependent information from the interaction can be recovered from a single shot by using a broadband, chirped probe pulse and subsequent spectral filtering.

Multi-GeV electron acceleration by a periodic frequency chirped radially polarized laser pulse in vacuum

Ghotra, Harjit Singh; Kant, Niti
LASER PHYSICS LETTERS 13 (6), 065402 (JUN 2016)
10.1088/1612-2011/13/6/065402

Linear and periodic effects of frequency chirp on electron acceleration by radially polarized (RP) laser pulse in vacuum have been investigated. A frequency chirp influences the electron dynamics, betatron resonance, and energy gain by electron during interaction with the RP laser pulse and ensures effective electron acceleration with high energy gain (similar to GeV). The electron energy gain with a periodic frequency chirped laser pulse is about twice as high as with a linear chirp. Our observations reveal electron energy gain of about 10.5 GeV with a periodic chirped RP petawatt laser pulse in vacuum.

Energetic electron-bunch generation in a phase-locked longitudinal laser electric field

Xiao, K. D.; Huang, T. W.; Ju, L. B.; Li, R.; Yang, S. L.; Yang, Y. C.; Wu, S. Z.; Zhang, H.; Qiao, B.; Ruan, S. C.; Zhou, C. T.; He, X. T.
PHYSICAL REVIEW E 93 (4), 043207 (APR 2016)
10.1103/PhysRevE.93.043207

Energetic electron acceleration processes in a plasma hollow tube irradiated by an ultraintense laser pulse are investigated. It is found that the longitudinal component of the laser field is much enhanced when a linear polarized Gaussian laser pulse propagates through the plasma tube. This longitudinal field is of $\pi/2$ phase shift relative to the transverse electric field and has a pi phase interval between its upper and lower parts. The electrons in the plasma tube are first pulled out by the transverse electric field and then trapped by the longitudinal electric field. The trapped electrons can further be accelerated to higher energy in the presence of the longitudinal electric field. This acceleration mechanism is clearly illustrated by both particle-in-cell simulations and single particle modelings.

High quality electron beam acceleration by ionization injection in laser wakefields with mid-infrared dual-color lasers

Zeng, Ming; Luo, Ji; Chen, Min; Mori, Warren B.; Sheng, Zheng-Ming; Hidding, Bernhard
PHYSICS OF PLASMAS 23 (6), 063113 (JUN 2016)
10.1063/1.4953895

For the laser wakefield acceleration, suppression of beam energy spread while keeping sufficient charge is one of the key challenges. In order to achieve this, we propose bichromatic laser ionization injection with combined laser wavelengths of 234 μm and 0.8 μm for wakefield excitation and triggering electron injection via field ionization, respectively. A laser pulse at 2.4 μm wavelength enables one to drive an intense acceleration structure with a relatively low laser power. To further reduce the requirement of laser power, we also propose to use carbon dioxide as the working gas medium, where carbon acts as the injection element. Our three dimensional particle-in-cell simulations show that electron beams at the GeV energy level with both low energy spreads (around 1%) and high charges (several tens of picocoulomb) can be obtained by the use of this scheme with laser peak power totaling sub-100 TW. Published by AIP Publishing.

Beyond the ponderomotive limit: Direct laser acceleration of relativistic electrons in sub-critical plasmas

Arefiev, A. V.; Khudik, V. N.; Robinson, A. P. L.; Shvets, G.; Willingale, L.; Schollmeier, M.
PHYSICS OF PLASMAS 23 (5), 056704 (MAY 2016)
10.1063/1.4946024

We examine a regime in which a linearly polarized laser pulse with relativistic intensity irradiates a sub-critical plasma for much longer than the characteristic electron response time. A steady-state channel is formed in the plasma in this case with quasi-static transverse and longitudinal electric fields. These relatively weak fields significantly alter the electron dynamics. The longitudinal electric field reduces the longitudinal dephasing between the electron and the wave, leading to an enhancement of the electron energy gain from the pulse. The energy gain in this regime is ultimately limited by the superluminosity of the wave fronts induced by the plasma in the channel. The transverse electric field alters the oscillations of the transverse electron velocity, allowing it to remain anti-parallel to laser electric field and leading to a significant energy gain. The energy enhancement is accompanied by the development of significant oscillations perpendicular to the plane of the driven motion, making trajectories of energetic electrons three-dimensional. Proper electron injection into the laser beam can further boost the electron energy gain. Published by AIP Publishing.

Laser-driven electron acceleration in a plasma channel with an additional electric field

Cheng, Li-Hong; Xue, Ju-Kui; Liu, Jie
PHYSICS OF PLASMAS 23 (5), 053102 (MAY 2016)
10.1063/1.4948416

We examine the electron acceleration in a two-dimensional plasma channel under the action of a laser field and an additional static electric field. We propose to design an appropriate additional electric field (its direction and location), in order to launch the electron onto an energetic trajectory. We find that the electron acceleration strongly depends on the coupled effects of the laser polarization, the direction, and location of the additional electric field. The additional electric field affects the electron dynamics by changing the dephasing rate. Particularly, a suitably designed additional electric field leads to a considerable energy gain from the laser pulse after the interaction with the additional electric field. The electron energy gain from the laser with the additional electric field can be much higher than that without the additional electric field. This engineering provides a possible means for producing high energetic electrons. Published by AIP Publishing.

Energy boost in laser wakefield accelerators using sharp density transitions

Dopp, A.; Guillaume, E.; Thaury, C.; Lifschitz, A.; Phuoc, K. Ta; Malka, V.
PHYSICS OF PLASMAS 23 (5), 056702 (MAY 2016)
10.1063/1.4946018

The energy gain in laser wakefield accelerators is limited by dephasing between the driving laser pulse and the highly relativistic electrons in its wake. Since this phase depends on both the driver and the cavity length, the effects of dephasing can be mitigated with appropriate tailoring of the plasma density along propagation. Preceding studies have discussed the prospects of continuous phase-locking in the linear wakefield regime. However, most experiments are performed in the highly non-linear regime and rely on self-guiding of the laser pulse. Due to the complexity of the driver evolution in this regime, it is much more difficult to achieve phase locking. As an alternative, we study the scenario of rapid rephasing in sharp density transitions, as was recently demonstrated experimentally. Starting from a phenomenological model, we deduce expressions for the electron energy gain in such density profiles. The results are in accordance with particle-in-cell simulations, and we present gain estimations for single and multiple stages of rephasing. Published by AIP Publishing.

Electron injection for direct acceleration to multi-GeV energy by a Gaussian laser field under the influence of axial magnetic field

Ghotra, Harjit Singh; Kant, Niti
PHYSICS OF PLASMAS 23 (5), 053115 (MAY 2016)
10.1063/1.4951715

Electron injected in the path of a circularly polarized Gaussian laser beam under the influence of an external axial magnetic field is shown to be accelerated with a several GeV of energy in vacuum. A small angle of injection δ with $0^o < \delta < 20^o$ for a sideway injection of electron about the axis of propagation of laser pulse is suggested for better trapping of electron in laser field and stronger betatron resonance under the influence of axial magnetic field. Such an optimized electron injection with axial magnetic field maximizes the acceleration gradient and electron energy gain with low electron scattering. Published by AIP Publishing.

Calculating the radiation characteristics of accelerated electrons in laser-plasma interactions

Li, X. F.; Yu, Q.; Gu, Y. J.; Qu, J. F.; Ma, Y. Y.; Kong, Q.; Kawata, S.
PHYSICS OF PLASMAS 23 (3), 033113 (MAR 2016)
10.1063/1.4943408

In this paper, we studied the characteristics of radiation emitted by electrons accelerated in a laser-plasma interaction by using the Lienard-Wiechert field. In the interaction of a laser pulse with a underdense plasma, electrons are accelerated by two mechanisms: direct laser acceleration (DLA) and laser wakefield acceleration (LWFA). At the beginning of the process, the DLA electrons emit most of the radiation, and the DLA electrons emit a much higher peak photon energy than the LWFA electrons. As the laser-plasma interaction progresses, the LWFA electrons become the major radiation emitter; however, even at this stage, the contribution from DLA electrons is significant, especially to the peak photon energy. (C) 2016 AIP Publishing LLC.

Acceleration and evolution of a hollow electron beam in wakefields driven by a Laguerre-Gaussian laser pulse

Zhang, Guo-Bo; Chen, Min; Schroeder, C. B.; Luo, Ji; Zeng, Ming; Li, Fei-Yu; Yu, Lu-Le; Weng, Su-Ming; Ma, Yan-Yun; Yu, Tong-Pu; Sheng, Zheng-Ming; Esarey, E.
PHYSICS OF PLASMAS 23 (3), 033114 (MAR 2016)
10.1063/1.4943892

We show that a ring-shaped hollow electron beam can be injected and accelerated by using a Laguerre-Gaussian laser pulse and ionization-induced injection in a laser wakefield accelerator. The acceleration and evolution of such a hollow, relativistic electron beam are investigated through three-dimensional particle-in-cell simulations. We find that both the ring size and the beam thickness oscillate during the acceleration. The beam azimuthal shape is angularly dependent and evolves during the acceleration. The beam ellipticity changes resulting from the electron angular momenta obtained from the drive laser pulse and the focusing forces from the wakefield. The dependence of beam ring radius on the laser-plasma parameters (e.g.; laser intensity, focal size, and plasma density) is studied. Such a hollow electron beam may have potential applications for accelerating and collimating positively charged particles. (C) 2016 AIP Publishing LLC.

Bubble structure in laser wake-field acceleration

Toosi, Ershad Sadeghi; Mirzanejhad, Saeed; Dorranian, Davoud
LASER AND PARTICLE BEAMS 34 (2), 193-201 (JUN 2016)
10.1017/S026303461600001X

Highly nonlinear ellipsoid bubble regime of the laser wake-field acceleration with high-intensity laser pulse is considered with analytical and numerical calculations. The important property of this regime is the production of the mono-energetic high-quality electron beam. We introduce a new twofold ellipsoid structure of the bubble (egg shape) by referring to some published two-dimensional (2D) and 3D simulations. In this paper, a new analytical formalism is introduced, in which dimensions of the front part of the ellipsoid bubble are related to the laser pulse and plasma parameters. These relationships are in agreement with 2D particle-in-cell code results in recent work (Benedetti et al.; 2013).

Electron acceleration at grazing incidence of a subpicosecond intense laser pulse onto a plane solid target

Andreev, N. E.; Pugachev, L. P.; Povarnitsyn, M. E.; Levashov, P. R.
LASER AND PARTICLE BEAMS 34 (1), 115-122 (MAR 2016)
10.1017/S0263034615001032

Generation of hot electrons at grazing incidence of a subpicosecond relativistic-intense laser pulse onto a plane solid target is analyzed for the parameters of petawatt class laser systems. We study preplasma formation on the surface of solid aluminum targets produced by laser prepulses with a different time structure. For modeling of the preplasma dynamics, we use a wide-range two-temperature hydrodynamic model. As a result of simulations, the preplasma expansion under the action of the laser prepulse and the plasma density profiles for different contrast ratios of the nanosecond pedestal are found. These density profiles are used as the initial density distributions in three-dimensional particle-in-cell simulations of electron acceleration by the main P-polarized laser pulse. Results of modeling demonstrate a substantial increase of the characteristic energy and number of accelerated electrons for the grazing incidence of a subpicosecond intense laser pulse in comparison with the ponderomotive scaling of laser-target interaction.

Optimization of positrons generation based on laser wakefield electron acceleration

Wu, Yuchi; Han, Dan; Zhang, Tiankui; Dong, Kegong; Zhu, Bin; Yan, Yonghong; Gu, Yuqiu
PHYSICAL REVIEW ACCELERATORS AND BEAMS 19 (8), 081303 (AUG 2016)
10.1103/PhysRevAccelBeams.19.081303

Laser based positron represents a new particle source with short pulse duration and high charge density. Positron production based on laser wakefield electron acceleration (LWFA) has been investigated theoretically in this paper. Analytical expressions for positron spectra and yield have been obtained through a combination of LWFA and cascade shower theories. The maximum positron yield and corresponding converter thickness have been optimized as a function of driven laser power. Under the optimal condition, high energy (>100 MeV) positron yield up to $5x10^{11}$ can be produced by high power femtosecond lasers at ELI-NP. The percentage of positrons shows that a quasineutral electron-positron jet can be generated by setting the converter thickness greater than 5 radiation lengths.

Simple model of the slingshot effect

Fiore, Gaetano; De Nicola, Sergio
PHYSICAL REVIEW ACCELERATORS AND BEAMS 19 (7), 071302 (JUL 2016)
10.1103/PhysRevAccelBeams.19.071302

We present a detailed quantitative description of the recently proposed "slingshot effect." Namely, we determine a broad range of conditions under which the impact of a very short and intense laser pulse normally onto a low-density plasma (or matter locally completely ionized into a plasma by the pulse) causes the expulsion of a bunch of surface electrons in the direction opposite to the one of propagation of the pulse, and the detailed, ready-for-experiments features of the expelled electrons (energy spectrum, collimation, etc). The effect is due to the combined actions of the ponderomotive force and the huge longitudinal field arising from charge separation. Our predictions are based on estimating 3D corrections to a simple, yet powerful plane 2-fluid magnetohydrodynamic (MHD) model where the equations to be solved are reduced to a system of Hamilton equations in one dimension (or a collection of) which become autonomous after the pulse has overcome the electrons. Experimental tests seem to be at hand. If confirmed by the latter, the effect would provide a new extraction and acceleration mechanism for electrons, alternative to traditional radio-frequency-based or Laser-Wake-Field ones.

Demonstration of passive plasma lensing of a laser wakefield accelerated electron bunch

Kuschel, S.; Hollatz, D.; Heinemann, T.; Karger, O.; Schwab, M. B.; Ullmann, D.; Knetsch, A.; Seidel, A.; Roedel, C.; Yeung, M.; Leier, M.; Blinne, A.; Ding, H.; Kurz, T.; Corvan, D. J.; Saevert, A.; Karsch, S.; Kaluza, M. C.; Hidding, B.; Zepf, M.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 19 (7), 071301 (JUL 2016)
10.1103/PhysRevAccelBeams.19.071301

We report on the first demonstration of passive all-optical plasma lensing using a two-stage setup. An intense femtosecond laser accelerates electrons in a laser wakefield accelerator (LWFA) to 100 MeV over millimeter length scales. By adding a second gas target behind the initial LWFA stage we introduce a robust and independently tunable plasma lens. We observe a density dependent reduction of the LWFA electron beam divergence from an initial value of 2.3 mrad, down to 1.4 mrad (rms), when the plasma lens is in operation. Such a plasma lens provides a simple and compact approach for divergence reduction well matched to the mm-scale length of the LWFA accelerator. The focusing forces are provided solely by the plasma and driven by the bunch itself only, making this a highly useful and conceptually new approach to electron beam focusing. Possible applications of this lens are not limited to laser plasma accelerators. Since no active driver is needed the passive plasma lens is also suited for high repetition rate focusing of electron bunches. Its understanding is also required for modeling the evolution of the driving particle bunch in particle driven wake field acceleration.

Sub-fs electron bunch generation with sub-10-fs bunch arrival-time jitter via bunch slicing in a magnetic chicane

Zhu, J.; Assmann, R. W.; Dohlus, M.; Dorda, U.; Marchetti, B.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 19 (5), 054401 (MAY 2016)
10.1103/PhysRevAccelBeams.19.054401

The generation of ultrashort electron bunches with ultrasmall bunch arrival-time jitter is of vital importance for laser-plasma wakefield acceleration with external injection. We study the production of 100-MeV electron bunches with bunch durations of subfemtosecond (fs) and bunch arrival-time jitters of less than 10 fs, in an S-band photoinjector by using a weak magnetic chicane with a slit collimator. The beam dynamics inside the chicane is simulated by using two codes with different self-force models. The first code separates the self-force into a three-dimensional (3D) quasistatic space-charge model and a one-dimensional coherent synchrotron radiation (CSR) model, while the other one starts from the first principle with a so-called 3D sub-bunch method. The simulations indicate that the CSR effect dominates the horizontal emittance growth and the 1D CSR model underestimates the final bunch duration and emittance because of the very large transverse-to-longitudinal aspect ratio of the sub-fs bunch. Particularly, the CSR effect is also strongly affected by the vertical bunch size. Due to the coupling between the horizontal and longitudinal phase spaces, the bunch duration at the entrance of the last dipole magnet of the chicane is still significantly longer than that at the exit of the chicane, which considerably mitigates the impact of space charge and CSR effects on the beam quality. Exploiting this effect, a bunch charge of up to 4.8 pC in a sub-fs bunch could be simulated. In addition, we analytically and numerically investigate the impact of different jitter sources on the bunch arrival-time jitter downstream of the chicane, and define the tolerance budgets assuming realistic values of the stability of the linac for different bunch charges and compression schemes.

Polarization effect of a Gaussian laser pulse on magnetic field influenced electron acceleration in vacuum

Ghotra, Harjit Singh; Kant, Niti
OPTICS COMMUNICATIONS 365, 231-236 (APR 2016)
10.1016/j.optcom.2015.12.014

Electron acceleration by a laser pulse in the presence of azimuthal magnetic field in vacuum has been analyzed. The azimuthal magnetic field influences the trajectory of an accelerated electron during the laser electron interaction in vacuum. The electron trajectory in the absence and presence of azimuthal magnetic field with a linearly polarized (LP) and circularly polarized (CP) laser pulses is analyzed. Due to the presence of azimuthal magnetic field, a confined trajectory of accelerated electron is observed in the direction of propagation of laser pulse. Resonance between the electron and the laser field occurs at optimum values of magnetic field, electron gains high energy from the laser and gets accelerated in the direction of propagation of laser pulse. The azimuthal magnetic field keeps the electron motion close to the axis parallel to the direction of propagation due to which the electron gains and retains high energy for longer distances. The electron energy gain is relatively higher with a CP laser pulse than that with LP laser pulse. The high energy gain of about 2GeV is observed with a CP laser pulse of peak intensity 2.74 x 10^{20} W/cm^2 in the presence of azimuthal magnetic field of 534kG.

Density profile of a line plasma generated by laser ablation for laser wakefield acceleration

Kim, J.; Hwangbo, Y.; Ryu, W. -J.; Kim, K. N.; Park, S. H.
JOURNAL OF INSTRUMENTATION 11, C03012 (MAR 2016)
10.1088/1748-0221/11/03/C03012

An elongated line plasma generated by a laser ablation of an aluminum target was investigated, which can be used in the laser wakefield acceleration (LWFA) by employing ultraintense laser pulse through the longitudinal direction of the plasma. To generate a uniform and long plasma channel along the propagation

of ultra-intense laser pulse (main pulse), a cylindrical lens combined with a biprism was used to shape the intensity of a ns Nd:YAG laser (pre-pulse) on the Al target. A uniformity of laser intensity can be manipulated by changing the distance between the biprism and the target. The density profile of the plasma generated by laser ablation was measured using two interferometers, indicating that a 3-mm long uniform line plasma with a density of $6x10^{17}$ cm^{-3} could be generated. The density with main pulse was also measured and the results indicated that the density would increase further due to additional ionization of the plasma by the main ultra-intense laser pulse. The resulting plasma density, which is a crucial parameter for the LWFA, can be controlled by the intensity of the pre-pulse, the time delay between the pre- and main pulse, and the distance of the main pulse from the target surface.

Beam manipulation with velocity bunching for PWFA applications

Pompili, R.; Anania, M. P.; Bellaveglia, M.; Biagioni, A.; Bisesto, F.; Chiadroni, E.; Cianchi, A.; Croia, M.; Curcio, A.; Di Giovenale, D.; Ferrario, M.; Filippi, F.; Galletti, M.; Gallo, A.; Giribono, A.; Li, W.; Marocchino, A.; Mostacci, A.; Petrarca, M.; Petrillo, V.; Di Pirro, G.; Romeo, S.; Rossi, A. R.; Scifo, J.; Shpakov, V.; Vaccarezza, C.; Villa, F.; Zhu, J.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 17-23 (SEP 2016)
10.1016/j.nima.2016.01.061

The activity of the SPARC_LAB test-facility (LNF-INFN, Frascati) is currently focused on the development of new plasma-based accelerators. Particle accelerators are used in many fields of science, with applications ranging from particle physics research to advanced radiation sources (e.g. FEL). The demand to accelerate particles to higher and higher energies is currently limited by the effective efficiency in the acceleration process that requires the development of km-size facilities. By increasing the accelerating gradient, the compactness can be improved and costs reduced. Recently, the new technique which attracts main efforts relies on plasma acceleration. In the following, the current status of plasma-based activities at SPARC_LAB is presented. Both laser- and beam-driven schemes will be adopted with the aim to provide an adequate accelerating gradient (1-10 GV/m) while preserving the brightness of the accelerated beams to the level of conventional photo-injectors. This aspect, in particular, requires the use of ultra-short (< 100 fs) electron beams, consisting in one or more bunches. We show, with the support of simulations and experimental results, that such beams can be produced using RF compression by velocity-bunching. (C) 2016 Elsevier B.V. All rights reserved.

Generation of attosecond electron bunches in a laser-plasma accelerator using a plasma density upramp

Weikum, M. K.; Li, F. Y.; Assmann, R. W.; Sheng, Z. M.; Jaroszynski, D.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 33-36 (SEP 2016)
10.1016/j.nima.2016.01.003

Attosecond electron bunches and attosecond radiation pulses enable the study of ultrafast dynamics of matter in an unprecedented regime. In this paper, the suitability for the experimental realization of a novel scheme producing sub-femtosecond duration electron bunches from laser-wakefield acceleration in plasma with self-injection in a plasma upramp profile has been investigated. While it has previously been predicted that this requires laser power above a few hundred terawatts typically, here we show that the scheme can be extended with reduced driving laser powers down to tens of terawatts, generating accelerated electron pulses with minimum length of around 166 attoseconds and picocoulombs charge. Using particle-in-cell simulations and theoretical models, the evolution of the accelerated electron bunch within the plasma as well as simple scalings of the bunch properties with initial laser and plasma parameters are presented. (C) 2016 Elsevier B.V. All rights reserved.

First results of the plasma wakefield acceleration experiment at PITZ

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 37-42 (SEP 2016)
10.1016/j.nima.2016.01.005

The self-modulation instability of long particle beams was proposed as a new mechanism to produce driver beams for proton driven plasma wakefield acceleration (PWFA). The PWFA experiment at the Photo Injector Test facility at DESY, Zeuthen site (PITZ) was launched to experimentally demonstrate and study the self modulation of long electron beams in plasma. Key aspects for the experiment are the very flexible photocathode laser system, a plasma cell and well-developed beam diagnostics. In this contribution we report about the plasma cell design, preparatory experiments and the results of the first PWFA experiment at PITZ. (C) 2016 Elsevier B.V. All rights reserved.

Customizable electron beams from optically controlled laser plasma acceleration for gamma-ray sources based on inverse Thomson scattering

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 52-57 (SEP 2016)
10.1016/j.nima.2015.12.066

Laser wakefield acceleration of electrons in the blowout regime can be controlled by tailoring the laser pulse phase and the plasma target. The 100 nm-scale bandwidth and negative frequency chirp of the optical driver compensate for the nonlinear frequency red-shift imparted by wakefield excitation. This mitigates pulse self-steepening and suppresses continuous injection. The plasma channel suppresses diffraction of the pulse leading edge, further reducing self-steepening, making injection even quieter. Besides, the channel destabilizes the pulse tail confined within the accelerator cavity (the electron density "bubble"), causing oscillations in the bubble size. The resulting periodic injection generates background-free comb-like beams – sequences of synchronized, low phase-space volume bunches. Controlling the number of bunches, their energy, and energy spacing by varying the channel radius and the pulse length (as permitted by the large bandwidth) enables the design of a tunable, all-optical source of polychromatic, pulsed gamma-rays using the mechanism of inverse Thomson scattering. Such source may radiate $\sim 10^7$ quasi-monochromatic 10 MeV-scale photons per shot into a microsteradian-scale observation angle. The photon energy is distributed among several distinct bands, each having sub-25% energy spread dictated by the mrad-scale divergence of electron beam. (C) 2016 Elsevier B.V. All rights reserved.

Status of the proton and electron transfer lines for the AWAKE Experiment at CERN

Schmidt, J. S.; Bauche, J.; Biskup, B.; Bracco, C.; Doebert, S.; Goddard, B.; Gschwendtner, E.; Jensen, L. K.; Jones, O. R.; Mazzoni, S.; Meddahi, M.; Pepitone, K.; Petrenko, A.; Velotti, F. M.; Vorozhtsov, A.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 58-62 (SEP 2016)
10.1016/j.nirna.2016.01.026

The AWAKE project at CERN is planned to study proton driven plasma wakefield acceleration with an externally injected electron beam. Therefore two transfer lines are being designed in order to provide the proton beam from the SPS and the electron beam from an RF gun to the plasma cell. The commissioning of the proton line will take place in 2016 for the first phase of the experiment, which is focused on the self-modulation of a 12 cm long proton bunch in the plasma. The electron line will be added for the second phase of AWAKE in 2017, when the wakefield will be probed with an electron beam of 1020 MeV/c. The challenge for these transfer lines lies in the parallel operation of the proton, electron and laser beam used to ionize the plasma and seed the self-modulation. These beams, of different characteristics, need to be synchronized and positioned for optimized injection conditions into the wakefield. This task requires great flexibility in the transfer line optics. The status of these designs will be presented in this paper. (C) 2016 The Authors. Published by Elsevier B.V.

Stability study for matching in laser driven plasma acceleration

Rossi, A. R.; Anania, M. P.; Bacci, A.; Belleveglia, M.; Bisesto, F. G.; Chiadroni, E.; Cianchi, A.; Curcio, A.; Gallo, A.; Di Giovenale, D.; Di Pirro, G.; Ferrario, M.; Marocchino, A.; Massimo, F.; Mostacci, A.; Petrarca, M.; Pompili, R.; Serafini, L.; Tomassini, P.; Vaccarezza, C.; Villa, F.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 67-72 (SEP 2016)
10.1016/j.nima.2016.02.015

In a recent paper [14], a scheme for inserting and extracting high brightness electron beams to/from a plasma based acceleration stage was presented and proved to be effective with an ideal bi-Gaussian beam, as could be delivered by a conventional photo-injector. In this paper, we extend that study, assessing the method stability against some jitters in the properties of the injected beam. We find that the effects of jitters in Twiss parameters are not symmetric in results; we find a promising configuration that yields better performances than the setting proposed in 041 Moreover we show and interpret what happens when the beam charge profiles are modified.

The electron accelerator for the AWAKE experiment at CERN

Pepitone, K.; Doebert, S.; Burt, G.; Chevallay, E.; Chritin, N.; Delory, C.; Fedosseev, V.; Hessler, Ch.; McMonagle, G.; Mete, O.; Verzilov, V.; Apsimon, R.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 73-75 (SEP 2016)
10.1016/j.nima.2016.02.025

The AWAKE collaboration prepares a proton driven plasma wakefield acceleration experiment using the SPS beam at CERN. A long proton bunch extracted from the SPS interacts with a high power laser and a 10 m long rubidium vapour plasma cell to create strong wakefields allowing sustained electron acceleration. The electron bunch to probe these wakefields is supplied by a 20 MeV electron accelerator. The electron accelerator consists of an RF-gun and a short booster structure. This electron source should provide beams with intensities between 0.1 and 1 nC, bunch lengths between 0.3 and 3 ps and an emittance of the order of 2 mm mrad. The wide range of parameters should cope with the uncertainties and future prospects of the planned experiments. The layout of the electron accelerator, its instrumentation and beam dynamics simulations are presented.

Electron beam manipulation, injection and acceleration in plasma wakefield accelerators by optically generated plasma density spikes

Wittig, Georg; Karger, Oliver S.; Knetsch, Alexander; Xi, Yunfeng; Deng, Aihua; Rosenzweig, James B.; Bruhwiler, David L.; Smith, Jonathan; Sheng, Zheng-Ming; Jaroszynski, Dino A.; Manahan, Grace G.; Hidding, Bernhard
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 83-87 (SEP 2016)
10.1016/j.nima.2016.02.027

We discuss considerations regarding a novel and robust scheme for optically triggered electron bunch generation in plasma wakefield accelerators [1]. In this technique, a transversely propagating focused laser pulse ignites a quasi-stationary plasma column before the arrival of the plasma wake. This localized plasma density enhancement or optical "plasma torch" distorts the blowout during the arrival of the electron drive bunch and modifies the electron trajectories, resulting in controlled injection. By changing the gas density, and the laser pulse parameters such as beam waist and intensity, and by moving the focal point of the laser pulse, the shape of the plasma torch, and therefore the generated trailing beam, can be tuned easily. The proposed method is much more flexible and faster in generating gas density transitions when compared to hydrodynamics-based methods, and it accommodates experimentalists needs as it is a purely optical process and straightforward to implement.

Acceleration of electrons under the action of petawatt-class laser pulses onto foam targets

Pugachev, L. P.; Andreev, N. E.; Levashov, P. R.; Rosmej, O. N.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 88-93 (SEP 2016)
10.1016/j.nima.2016.02.053

Optimization study for future experiments on interaction of petawatt laser pulses with foam targets was done by 3D PIC simulations. Densities in the range $0.5n_c$ - n_c and thicknesses in the range 100-500 μm of the targets were considered corresponding to those which are currently available. It is shown that heating of electrons mainly occurs under the action of the ponderomotive force of a laser pulse in which amplitude increases up to three times because of self-focusing effect in underdense plasma. Accelerated electrons gain additional energy directly from the high-frequency laser field at the betatron resonance in the emerging plasma density channels. For thicker targets a higher number of electrons with higher energies are obtained. The narrowing of the angular distribution of electrons for thicker targets is explained by acceleration in multiple narrow filaments. Obtained energies of accelerated electrons can be approximated by Maxwell distribution with the temperature 8.5 MeV. The charge carried by electrons with energies higher than 30 MeV is about 30 nC, that is 3-4 order of magnitude higher than the charge predicted by the ponderomotive scaling for the incident laser amplitude.

Injection of electrons by colliding laser pulses in a laser wakefield accelerator

Hansson, M.; Aurand, B.; Ekerfelt, H.; Persson, A.; Lundh, O.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 99-103 (SEP 2016)
10.1016/j.nima.2016.02.070

To improve the stability and reproducibility of laser wakefield accelerators and to allow for future applications, controlling the injection of electrons is of great importance. This allows us to control the amount of charge in the beams of accelerated electrons and final energy of the electrons. Results are presented from a recent experiment on controlled injection using the scheme of colliding pulses and performed using the Lund multi-terawatt laser. Each laser pulse is split into two parts close to the interaction point. The main pulse is focused on a 2 mm diameter gas jet to drive a nonlinear plasma wave below threshold for self-trapping. The second pulse, containing only a fraction of the total laser energy, is focused to collide with the main pulse in the gas jet under an angle of 150^{0}. Beams of accelerated electrons with low divergence and small energy spread are produced using this set-up. Control over the amount of accelerated charge is achieved by rotating the plane of polarization of the second pulse in relation to the main pulse. Furthermore, the peak energy of the electrons in the beams is controlled by moving the collision point along the optical axis of the main pulse, and thereby changing the acceleration length in the plasma.

A "slingshot" laser-driven acceleration mechanism of plasma electrons

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 104-108 (SEP 2016)
10.1016/j.nima.2016.02.085

We briefly report on the recently proposed Fiore et al. [1] and Fiore and De Nicola [2] electron acceleration mechanism named "slingshot effect": under suitable conditions the impact of an ultra-short and ultra-intense laser pulse against the surface of a low-density plasma is expected to cause the expulsion of a bunch of superficial electrons with high energy in the direction opposite to that of the pulse propagation; this is due to the interplay of the huge ponderomotive force, huge longitudinal field arising from charge separation, and the finite size of the laser spot.

Matching sub-fs electron bunches for laser-driven plasma acceleration at SINBAD

Zhu, J.; Assmann, R. W.; Dorda, U.; Marchetti, B.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 229-232 (SEP 2016)
10.1016/j.nima.2016.01.066

We present theoretical and numerical studies of matching sub-femtosecond space-charge-dominated electron bunch into the Laser-plasma Wake Field Accelerator (LWFA) foreseen at the SINBAD facility. The longitudinal space-charge (SC) effect induced growths of the energy spread and longitudinal phase-space chirp are major issues in the matching section, which will result in bunch elongation, emittance growth and spot size dilution. In addition, the transverse SC effect would lead to a mismatch of the beam optics if it were not compensated for. Start-to-end simulations and preliminary optimizations were carried out in order to understand the achievable beam parameters at the entrance of the plasma accelerator.

Transport studies of LPA electron beam towards the FEL amplification at COXINEL

Khojoyan, M.; Briquez, E.; Labat, M.; Loulergue, A.; Marcouille, O.; Marteau, F.; Sharma, G.; Couprie, M. E.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 260-264 (SEP 2016)
10.1016/j.nima.2016.02.030

Laser Plasma Acceleration (LPA) [1] is an emerging concept enabling to generate electron beams with high energy, high peak current and small transverse emittance within a very short distance. The use of LPA can be applied to the Free Electron Laser (FEL) [2] case in order to investigate whether it is suitable for the light amplification in the undulator. However, capturing and guiding of such beams to the undulator is very challenging, because of the large divergence and high energy spread of the electron beams at the plasma exit, leading to large chromatic emittances.; A specific beam manipulation scheme was recently proposed for the COXINEL (Coherent X-ray source inferred from electrons accelerated by laser) setup, which makes an advantage from the intrinsically large chromatic emittance of such beams [3]. The electron beam transport is studied using two simulation codes: a SOLEIL in-house one and ASTRA [4]. The influence of the collective effects on the electron beam performance is also examined.

Electron-beam manipulation techniques in the SINBAD Linac for external, injection in plasma wake-field acceleration

Marchetti, B.; Assmann, R.; Behrens, C.; Brinkmann, R.; Dorda, U.; Floettmann, K.; Hartl, I.; Huening, M.; Nie, Y.; Schlarb, H.; Zhu, J.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 278-283 (SEP 2016)
10.1016/j.nima.2016.03.041

The SINBAD facility (Short and INnovative Bunches and Accelerators at Desy) is foreseen to host various experiments in the field of production of ultra-short electron bunches and novel high gradient acceleration techniques. Besides studying novel acceleration techniques aiming to produce high brightness short electron bunches, the ARD group at DESY is working on the design of a conventional RF accelerator that will allow the production of low charge (0.5 pC - few pC) ultra-short electron bunches (having full width half maximum, FWHM, length <= 1 fs - few fs). The setup will allow the direct experimental comparison of the performance achievable by using different compression techniques (velocity bunching, magnetic compression, hybrid compression schemes). At a later stage the SINBAD linac will be used to inject such electron bunches into a laser driven Plasma Wakefield Accelerator, which imposes strong requirements on parameters such as the arrival time jitter and the pointing stability of the beam. In this paper we review the compression techniques that are foreseen at SINBAD and we underline the differences in terms of peak current, beam quality and arrival time stability.

Electron injector for compact staged high energy accelerator

Audet, T. L.; Desforges, F. G.; Maitrallain, A.; Dufrenoy, S. Dobosz, Bougeard, M.; Maynard, G.; Lee, P.; Hansson, M.; Aurand, B.; Persson, A.; Gallardo Gonzalez, I.; Monot, P.; Wahlstrom, C. -G.; Lundh, O.; Cros, B.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 304-308 (SEP 2016)
10.1016/j.nima.2016.01.035

An electron injector for multi-stage laser wakefield experiments is presented. It consists of a variable length gas cell of small longitudinal dimension (<= 10 mm). The gas filling process in this cell was characterized both experimentally and with fluid simulation. Electron acceleration experiments were performed at two different laser facilities. Results show low divergence and low pointing fluctuation electron bunches suitable for transport to a second stage, and a peaked energy distribution suitable for injection into the second stage wakefield accelerator. (C) 2016 Elsevier B.V. All rights reserved.

Laser-capillary interaction for the EXIN project

Bisesto, F. G.; Anania, M. P.; Bacci, A. L.; Bellaveglia, M.; Chiadroni, E.; Cianchi, A.; Curcio, A.; Di Giovenale, D.; Di Pirro, G.; Ferrario, M.; Galletti, M.; Gallo, A.; Ghigo, A.; Marocchino, A.; Mostacci, A.; Petrarca, M.; Pompili, R.; Rossi, A. R.; Serafini, L.; Vaccarezz, C.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 309-313 (SEP 2016)
10.1016/j.nima.2016.01.037

The EXIN project is under development within the SPARC_LAB facility of the National Laboratory of Frascati (LNF-INFN). This project aims to accelerate pre-existing electron bunches with high brightness by exploiting the wakefield plasma acceleration technique, while preserving the initial brightness. The wakefield is excited inside a dielectric capillary by high intensity laser pulses produced by the FLAME laser interacting with a gas. In this work, we present numerical simulations in order to optimize energy coupling between our laser with super-Gaussian transverse profile and a dielectric capillary. Moreover, an overview of the experimental layout will be given. (C) 2016 Elsevier B.V. All rights reserved.

Measurement of ultra low transverse emittance at REGAE

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 318-320 (SEP 2016)
10.1016/j.nima.2016.01.065

The linear accelerator REGAE at DESY produces short and low charged electron bunches, on the one hand to resolve the excitation transitions of atoms temporally by pump-probe electron diffraction experiments and on the other hand to investigate principal mechanisms of laser plasma acceleration. For both cases a high quality electron beam is required which can be identified with a small beam emittance. A standard magnet scan is used for the emittance measurement which is in case of a low charged bunch most sensitive to the beam size determination (RMS or 2^{nd} central moment of a distribution). Therefore the diagnostic and a routine to calculate proper central moments of an arbitrary distribution will be introduced and discussed. (C) 2016 Elsevier B.V. All rights reserved.

Plasma density characterization at SPARC_LAB through Stark broadening of Hydrogen spectral lines

Filippi, F.; Anania, M. P.; Bellaveglia, M.; Biagioni, A.; Chiadroni, E.; Cianchi, A.; DiGiovenale, D.; Di Pirro, G.; Ferrario, M.; Mostacci, A.; Palumbo, L.; Pompili, R.; Shpakov, V.; Vaccarezza, C.; Villa, F.; Zigler, A.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 326-329 (SEP 2016)
10.1016/j.nima.2016.02.071

Plasma-based acceleration techniques are of great interest for future, compact accelerators due to their high accelerating gradient. Both particle-driven and laser-driven Plasma Wakefield Acceleration experiments are foreseen at the SPARC_LAB Test Facility (INFN National Laboratories of Frascati, Italy), with the aim to accelerate high-brightness electron beams. In order to optimize the efficiency of the acceleration in the

plasma and preserve the quality of the accelerated beam, the knowledge of the plasma electron density is mandatory. The Stark broadening of the Hydrogen spectral lines is one of the candidates used to characterize plasma density. The implementation of this diagnostic for plasma-based experiments at SPARC_LAB is presented.

Recent advances in high-performance modeling of plasma-based, acceleration using the full PIC method

Vay, J. -L.; Lehe, R.; Vincenti, H.; Godfrey, B. B.; Haber, I.; Lee, P.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 353-357 (SEP 2016)
10.1016/j.nima.2015.12.033

Numerical simulations have been critical in the recent rapid developments of plasma-based acceleration concepts. Among the various available numerical techniques, the particle-in-cell (PIC) approach is the method of choice for self-consistent simulations from first principles. The fundamentals of the PIC method were established decades ago, but improvements or variations are continuously being proposed. We report on several recent advances in PIC-related algorithms that are of interest for application to plasma-based accelerators, including (a) detailed analysis of the numerical Cherenkov instability and its remediation for the modeling of plasma accelerators in laboratory and Lorentz boosted frames, (b) analytic pseudo-spectral electromagnetic solvers in Cartesian and cylindrical (with azimuthal modes decomposition) geometries, and (c) novel analysis of Maxwell's solvers' stencil variation and truncation, in application to domain decomposition strategies and implementation of perfectly matched layers in high-order and pseudo-spectral solvers.

Modeling laser-driven electron acceleration using WARP with Fourier decomposition

Lee, P.; Audet, T. L.; Lehe, R.; Vay, J. -L.; Maynard, G.; Cros, B.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 358-362 (SEP 2016)
10.1016/j.nima.2015.12.036

WARP is used with the recent implementation of the Fourier decomposition algorithm to model laser driven electron acceleration in plasmas. Simulations were carried out to analyze the experimental results obtained on ionization-induced injection in a gas cell. The simulated results are in good agreement with the experimental ones, confirming the ability of the code to take into account the physics of electron injection and reduce calculation time. We present a detailed analysis of the laser propagation, the plasma wave generation and the electron beam dynamics.

Generation of laser pulse trains for tests of multi-pulse laser wakefield acceleration

Shalloo, R. J.; Corner, L.; Arran, C.; Cowley, J.; Cheung, G.; Thornton, C.; Walczak, R.; Hooker, S. M.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 383-385 (SEP 2016)
10.1016/j.nima.2016.02.044

In multi-pulse laser wakefield acceleration (MP-LWFA) a plasma wave is driven by a train of low-energy laser pulses separated by the plasma period, an approach which offers a route to driving plasma accelerators with high efficiency and at high pulse repetition rates using emerging technologies such as fibre and thin-disk lasers. Whilst these laser technologies are in development, proof-of-principle tests of MP-LWFA require a pulse train to be generated from a single, high-energy ultrafast pulse. Here we demonstrate the generation of trains of up to 7 pulses with pulse separations in the range 150-170 fs from single 40 fs pulses produced by a Ti:sapphire laser.

Piecewise-homogeneous model for electron side injection into linear plasma waves

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 392-396 (SEP 2016)
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An analytical piecewise-homogeneous model for electron side injection into linear plasma waves is developed. The dynamics of transverse betatron oscillations are studied. Based on the characteristics of the transversal motion the longitudinal motion of electrons is described. The electron parameters for which the electron trapping and subsequent acceleration are possible are estimated. The analytical results are verified by numerical simulations in the scope of the piecewise-homogeneous model. The results predicted by this model are also compared to the results given by a more realistic inhomogeneous model.

Emission of strong Terahertz pulses from laser wakefields in weakly coupled plasma

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10.1016/j.nima.2016.03.108

The present paper discusses the laser plasma interaction for the wakefield excitation and the role of external magnetic field for the emission of Terahertz radiation in a collisional plasma. Flat top lasers are shown to be more appropriate than the conventional Gaussian lasers for the effective excitation of wakefields and hence, the generation of strong Terahertz radiation through the transverse component of wakefield.

Comparison of self-injection thresholds in He and N_2 and role of self-focusing in LWFA

Palla, D.; Baffigi, F.; Brandi, F.; Fulgentini, L.; Koester, P.; Labate, L.; Londrillo, P.; Gizzi, L. A.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 408-412 (SEP 2016)
10.1016/j.nima.2016.03.109

We present an experimental study of laser-plasma acceleration in which the injected charge was measured at self-injection threshold for He and N_2. We use numerical particle-in-cell simulation to unfold the role of ionization in the self-injection process and to reconstruct the local electrons density from the atomic density and the ionization degree. Comparison of measured and calculated self-injection thresholds yields the dependence of injected charge upon the electron density and sheds light on the possible role of the picosecond pedestal of femtosecond laser pulses in setting the initial charge state of the plasma.

Semi-analytical fluid study of the laser wake field excitation in the strong intensity regime

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 413-417 (SEP 2016)
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We present an analytical and numerical study of the interaction of a multi-petawatt, pancake-shaped laser pulse with an unmagnetized plasma. The study has been performed in the ultrarelativistic regime of electron jitter velocities, in which the plasma electrons are almost completely expelled from the pulse region. The calculations are applied to a laser wake field acceleration scheme with specifications that may be available in the next generation of Ti:Sa lasers and with the use of recently developed pulse compression techniques. A

set of novel nonlinear equations is derived using a three-timescale description, with an intermediate timescale associated with the nonlinear phase of the electromagnetic wave and with the spatial bending of its wave front. They describe, on an equal footing, both the strong and the moderate laser intensity regimes, pertinent to the core and to the edges of the pulse.

Load management strategy for Particle-In-Cell simulations in high energy particle acceleration

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 829, 418-421 (SEP 2016)
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In the wake of the intense effort made for the experimental CILEX project, numerical simulation campaigns have been carried out in order to finalize the design of the facility and to identify optimal laser and plasma parameters. These simulations bring, of course, important insight into the fundamental physics at play. As a by-product, they also characterize the quality of our theoretical and numerical models. In this paper, we compare the results given by different codes and point out algorithmic limitations both in terms of physical accuracy and computational performances. These limitations are illustrated in the context of electron laser wakefield acceleration (LWFA). The main limitation we identify in state-of-the-art Particle-In-Cell (PIC) codes is computational load imbalance. We propose an innovative algorithm to deal with this specific issue as well as milestones towards a modern, accurate high-performance PIC code for high energy particle acceleration.

Dynamics of electron bunches at the laser-plasma interaction in the bubble regime

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The multi-bunches self-injection, observed in laser plasma accelerators in the bubble regime, affects the energy gain of electrons accelerated by laser wakefield. However, understanding of dynamics of the electron bunches formed at laser-plasma interaction may be challenging. We present here the results of fully relativistic electromagnetic particle-in-cell (PIC) simulation of laser wakefield acceleration driven by a short laser pulse in an underdense plasma. The trapping and acceleration of three witness electron bunches by the bubble-like structures were observed. It has been shown that with time the first two witness bunches turn into drivers and contribute to acceleration of the last witness bunch.

BESTIA - The next generation ultra-fast CO_2 laser for advanced accelerator research

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10.1016/j.nima.2015.11.126

Over the last two decades, BNL's ATF has pioneered the use of high-peak power CO_2 lasers for research in advanced accelerators and radiation sources. Our recent developments in ion acceleration, Compton scattering, and IFELs have further underscored the benefits from expanding the landscape of strong-field laser interactions deeper into the mid-infrared (MIR) range of wavelengths. This extension validates our ongoing efforts in advancing CO_2 laser technology, which we report here. Our next-generation, multiterawatt, femtosecond CO_2 laser will open new opportunities for studying ultra-relativistic laser interactions with plasma in the MIR spectral domain, including new regimes in the particle acceleration of ions and electrons.

Generation of high-quality electron beams by ionization injection in a single acceleration stage

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HIGH POWER LASER SCIENCE AND ENGINEERING 4, e24 (AUG 2016)
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Ionization-induced electron injection in laser wakefield accelerators, which was recently proposed to lower the laser intensity threshold for electron trapping into the wake wave, has the drawback of generating electron beams with large and continuous energy spreads, severely limiting their future applications. Complex target designs based on separating the electron trapping and acceleration stages were proposed as the only way for getting small energy-spread electron beams. Here, based on the self-truncated ionization-injection concept which requires the use of unmatched laser-plasma parameters and by using tens of TW laser pulses focused onto a gas jet of helium mixed with low concentrations of nitrogen, we demonstrate single-stage laser wakefield acceleration of multi-hundred MeV electron bunches with energy spreads of a few percent. The experimental results are verified by PIC simulations.

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