THE EuPRAXIA FILES

ISSUE 3 – March 2017

Foreword

Dr Ralph Aßmann
EuPRAXIA Coordinator

EuPRAXIA is just starting its second year of life and the project is running full steam ahead. The first yearly meeting, held in Paris at the end of October, evidenced the excellent progress made in all the work packages of the project. Plasma accelerators continue to drive enthusiasm in the community, and six more institutions joined the EuPRAXIA family, making a total of 38 members so far. One of the highlights of the meeting was the presentation and approval of the Preliminary Study Concept of EuPRAXIA, which incorporates the inputs from all the workshops held by the working groups over the last year. But the main feature of the meeting was the presentation of the first results of research done specifically for EuPRAXIA. As the publication of articles from the project is gathering momentum, we will highlight with an 'X' the articles reporting research funded by EuPRAXIA in the present and subsequent editions of *The EuPRAXIA Files*. As you can see from the number of publications collected, the field continues to be highly productive.

Research Highlights

Eliminating the numerical Cherenkov instability in PIC simulations

The numerical Cherenkov instability (NCI) is a well-known source of errors in particle-in-cell (PIC) simulations produced by an unphysical resonance between fast particles and electromagnetic waves of matching phase velocity. The NCI renders impossible the simulation of relativistic flowing plasmas, like those present in laser-wakefield acceleration when viewed in a Lorentz-boosted frame.

In an article published in Physical Review E, Remi Lehe and co-workers show that the NCI for a plasma drifting at a uniform relativistic velocity can be simply eliminated. The method consists in integrating the PIC equations in Galilean coordinates that follow the plasma (also known as comoving coordinates) and it is applicable both to Cartesian and quasicylindrical geometry.

In the paper, the elimination of the NCI is verified empirically and confirmed by a theoretical analysis of the instability.

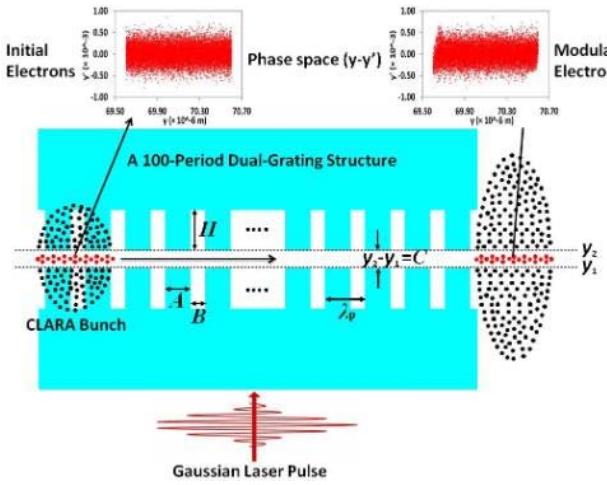
This new numerical scheme opens promising possibilities, especially for Lorentz-boosted simulations of laser-wakefield acceleration.

Journal reference:

R. Lehe, M. Kirchen, B. B. Godfrey, A. R. Maier, and J.-L. Vay, "Elimination of numerical Cherenkov instability in flowing-plasma particle-in-cell simulations by using Galilean coordinates", Phys. Rev. E 94(5), 053305 (2016). http://doi.org/10.1103/PhysRevE.94.053305

Dielectric laser-driven accelerators – Size matters

In 2013, scientists at SLAC demonstrated for the first time the acceleration of electron beams with a gradient of 300 MV/m in a dielectric grating structure powered by a commercial laser beam. These dielectric laser-driven accelerators (DLAs) are considered to be one of the most promising technologies to reduce the size and cost of future particle accelerators. However, few studies have been done of the all-important quality of the particle beams that can be obtained from such 'micro- accelerators'.



Schematic of an electron bunch travelling through the optimum structure to interact with a laser pulse.

In an open access paper just published in Physics of Plasmas, Yelong Wei and co-authors use simulations to investigate the beam quality of a grating-based DLA. In the simulations the beam is given the same properties as expected in CLARA which is a planned x-ray free electron laser test facility to be located at the Daresbury Laboratory, UK. An electron bunch is fed into a specially-shaped grating-like structure with 100 miniature cut-outs called 'periods'. Inside the device it interacts with a laser pulse, as shown in the figure. The various important properties of the electrons which have been 'modulated' or modified are then examined in detail.

This paper shows for the first time how to generate a beam with the required quality in a micro-accelerator, paving the way for actually constructing such device in the future.

Journal reference:

Y. Wei *et al.*, "Beam quality study for a grating-based dielectric laser-driven accelerator", Phys. Plasmas 24, 023102 (2017). http://dx.doi.org/10.1063/1.4975080

Research Papers

High Orbital Angular Momentum Harmonic Generation

J. Vieira, R. M. G. M. Trines, E. P. Alves, R. A. Fonseca, J. T. Mendonça, R. Bingham, P. Norreys, and L. O. Silva
PHYSICAL REVIEW LETTERS 117 (26), 265001 (DEC 2016)
http://doi.org/10.1103/PhysRevLett.117.265001

We identify and explore a high orbital angular momentum (OAM) harmonics generation and amplification mechanism that manipulates the OAM independently of any other laser property, by preserving the initial laser wavelength, through stimulated Raman backscattering in a plasma. The high OAM harmonics spectra can extend at least up to the limiting value imposed by the paraxial approximation. We show with theory and particle-in-cell simulations that the orders of the OAM harmonics can be tuned according to a selection rule that depends on the initial OAM of the interacting waves. We illustrate the high OAM harmonics generation in a plasma using several examples including the generation of prime OAM harmonics. The process can also be realized in any nonlinear optical Kerr media supporting three-wave interactions.

Collective Deceleration of Laser-Driven Electron Bunches

Chou, S.; Xu, J.; Khrennikov, K.; Cardenas, D. E.; Wenz, J.; Heigoldt, M.; Hofmann, L.; Veisz, L.; Karsch, S.
PHYSICAL REVIEW LETTERS 117, 144801 (SEP 2016)
http://doi.org/10.1103/PhysRevLett.117.144801

Few-fs electron bunches from laser wakefield acceleration (LWFA) can efficiently drive plasma wakefields (PWFs), as shown by their propagation through underdense plasma in two experiments. A strong and density -insensitive deceleration of the bunches has been observed in 2 mm of 10^{18} cm^{-3} density plasma with 5.1 GV/m average gradient, which is attributed to a self-driven PWF. This observation implies that the physics of PWFs, usually relying on large-scale rf accelerators as drivers, can be studied by tabletop LWFA electron sources.

High-Brightness High-Energy Electron Beams from a Laser Wakefield Accelerator via Energy Chirp Control

W. T. Wang, W. T. Li, J. S. Liu, Z. J. Zhang, R. Qi, C. H. Yu, J. Q. Liu, M. Fang, Z. Y. Qin, C. Wang, Y. Xu, F. X. Wu, Y. X. Leng, R. X. Li, and Z. Z. Xu
PHYSICAL REVIEW LETTERS 117, 124801 (SEP 2016)
http://doi.org/10.1103/PhysRevLett.117.124801

By designing a structured gas density profile between the dual-stage gas jets to manipulate electron seeding and energy chirp reversal for compressing the energy spread, we have experimentally produced high-brightness high-energy electron beams from a cascaded laser wakefield accelerator with peak energies in the range of 200–600 MeV, 0.4%–1.2% rms energy spread, 10–80 pC charge, and ~0.2 mrad rms divergence. The maximum six-dimensional brightness $B_{6D,n}$ is estimated as $\sim 6.5\times10^{15}$ $A/m^2/0.1\%$, which is very close to the typical brightness of *e* beams from state-of-the-art linac drivers. These high-brightness high-energy *e* beams may lead to the realization of compact monoenergetic gamma-ray and intense coherent x-ray radiation sources.

A compact tunable polarized X-ray source based on laser-plasma helical undulators

J. Luo, M. Chen, M. Zeng, J. Vieira, L. L. Yu, S. M. Weng, L. O. Silva, D. A. Jaroszynski, Z. M. Sheng, and J. Zhang
SCIENTIFIC REPORTS 6, 29101 (JUL 2016)
http://doi.org/10.1038/srep29101

Laser wakefield accelerators have great potential as the basis for next generation compact radiation sources because of their extremely high accelerating gradients. However, X-ray radiation from such devices still lacks tunability, especially of the intensity and polarization distributions. Here we propose a tunable polarized radiation source based on a helical plasma undulator in a plasma channel guided wakefield accelerator. When a laser pulse is initially incident with a skew angle relative to the channel axis, the laser and accelerated electrons experience collective spiral motions, which leads to elliptically polarized synchrotron-like radiation with flexible tunability on radiation intensity, spectra and polarization. We demonstrate that a radiation source with millimeter size and peak brilliance of 2×10^{19} photons/s/mm^2/$mrad^2$/0.1% bandwidth can be made with moderate laser and electron beam parameters. This brilliance is comparable with third generation synchrotron radiation facilities running at similar photon energies, suggesting that laser plasma based radiation sources are promising for advanced applications.

Comparisons of time explicit hybrid kinetic-fluid code Architect for Plasma Wakefield Acceleration with a full PIC code

F. Massimo, S. Atzeni, A. Marocchino
JOURNAL OF COMPUTATIONAL PHYSICS 327, 841–850 (OCT 2016)
http://doi.org/10.1016/j.jcp.2016.09.067

Architect, a time explicit hybrid code designed to perform quick simulations for electron driven plasma wakefield acceleration, is described. In order to obtain beam quality acceptable for applications, control of the beam-plasma-dynamics is necessary. Particle in Cell (PIC) codes represent the state-of-the-art technique to investigate the underlying physics and possible experimental scenarios; however PIC codes demand the necessity of heavy computational resources. Architect code substantially reduces the need for computational resources by using a hybrid approach: relativistic electron bunches are treated kinetically as in a PIC code and the background plasma as a fluid. Cylindrical symmetry is assumed for the solution of the electromagnetic fields and fluid equations. In this paper both the underlying algorithms as well as a comparison with a fully three dimensional particle in cell code are reported. The comparison highlights the good agreement between the two models up to the weakly non-linear regimes. In highly non-linear regimes the two models only disagree in a localized region, where the plasma electrons expelled by the bunch close up at the end of the first plasma oscillation.

Spectral and spatial characterisation of laser-driven positron beams

Sarri, G.; Warwick, J.; Schumaker, W.; Poder, K.; Cole, J.; Doria, D.; Dzelzainis, T.; Krushelnick, K.; Kuschel, S.; Mangles, S.P.D.; Najmudin, Z.; Romagnani, L.; Samarin, G.M.; Symes, D.; Thomas, A.G.R.; Yeung, M.; Zepf, M.
PLASMA PHYSICS AND CONTROLLED FUSION 59(1), 014015 (JAN 2017)
http://doi.org/10.1088/0741-3335/59/1/014015

The generation of high-quality relativistic positron beams is a central area of research in experimental physics, due to their potential relevance in a wide range of scientific and engineering areas, ranging from fundamental science to practical applications. There is now growing interest in developing hybrid machines that will combine plasma-based acceleration techniques with more conventional radio-frequency accelerators, in order to minimise the size and cost of these machines. Here we report on recent experiments on laser-driven generation of high-quality positron beams using a relatively low energy and potentially table-top laser system. The results obtained indicate that current technology allows to create, in a compact setup, positron beams suitable for injection in radio-frequency accelerators.

Electron energy enhancement by frequency chirp of a radially polarized laser pulse during ionization of low-density gases

Singh, Kunwar Pal; Arya, Rashmi; Malik, Anil K.; Fisch, N. J.
PLASMA PHYSICS AND CONTROLLED FUSION 58(11), 115011 (NOV 2016)
http://doi.org/10.1088/0741-3335/58/11/115011

A scheme is proposed to enhance the energy of the electrons generated during the ionization of low-density krypton ions Kr^{32+} and argon ions Ar^{16+} by a radially polarized laser pulse using a negative frequency chirp. If a suitable frequency chirp is introduced then the energy of the electrons increases significantly and scattering decreases. The optimum value of the frequency chirp decreases with laser intensity and as well as spot size. The laser spot size also has an optimum value. The electron energy shows strong initial phase dependence. The scheme can be used to obtain quasi-monoenergetic collimated MeV/GeV electrons using the right choice of parameters. The chirped radially polarized laser pulse is more efficient than a chirped circularly polarized laser pulse to enhance energy and obtain quasi-monoenergetic electron beams.

Enhanced x-rays from resonant betatron oscillations in laser wakefield with external wigglers

Zhang, Z. M.; Zhang, B.; Hong, W.; Yu, M. Y.; Deng, Z. G.; Teng, J.; He, S. K.; Gu, Y. Q.
PLASMA PHYSICS AND CONTROLLED FUSION 58(10), 105009 (OCT 2016)
http://doi.org/10.1088/0741-3335/58/10/105009

Generation of ultra-short betatron x-rays by laser-accelerated electron beams is of great research interest as it has many applications. In this paper, we propose a scheme for obtaining bright betatron x-rays by applying external wiggler magnetic field in the laser wakefield to resonantly drive the betatron oscillations of the accelerated electrons therein. This results in a significant enhancement of the betatron oscillation amplitude and generation of bright x-rays with high photon energy. The scheme is demonstrated using two-dimensional particle-in-cell simulation and discussed using a simple analytical model.

Characterization of electrons and x-rays produced using chirped laser pulses in a laser wakefield accelerator

Zhao, T. Z.; Behm, K.; He, Z-H; Maksimchuk, A.; Nees, J. A.; Yanovsky, V.; Thomas, A. G. R.; Krushelnick, K.
PLASMA PHYSICS AND CONTROLLED FUSION 58(10), 105003 (OCT 2016)
http://doi.org/10.1088/0741-3335/58/10/105003

The electron injection process into a plasma-based laser wakefield accelerator can be influenced by modifying the parameters of the driver pulse. We present an experimental study on the combined effect of the laser pulse duration, pulse shape, and frequency chirp on the electron injection and acceleration process and the associated radiation emission for two different gas types – a 97.5% He and 2.5% N_2 mixture and pure He. In general, the shortest pulse duration with minimal frequency chirp produced the highest energy electrons and the most charge. Pulses on the positive chirp side sustained electron injection and produced higher charge, but lower peak energy electrons, compared with negatively chirped pulses. A similar trend was observed for the radiant energy. The relationship between the radiant energy and the electron charge remained linear over a threefold change in the electron density and was independent of the drive pulse characteristics. X-ray spectra showed that ionization injection of electrons into the wakefield generally produced more photons than self-injection for all pulse durations/frequency chirp and had less of a spread in the number of photons around the peak x-ray energy.

Elimination of numerical Cherenkov instability in flowing-plasma particle-in-cell simulations by using Galilean coordinates

Lehe, Remi; Kirchen, Manuel; Godfrey, Brendan B.; Maier, Andreas R.; Vay, Jean-Luc
PHYSICAL REVIEW E 94(5), 053305 (NOV 2016)
http://doi.org/10.1103/PhysRevE.94.053305

Particle-in-cell (PIC) simulations of relativistic flowing plasmas are of key interest to several fields of physics (including, e.g., laser-wakefield acceleration, when viewed in a Lorentz-boosted frame) but remain sometimes infeasible due to the well-known numerical Cherenkov instability (NCI). In this article, we show that, for a plasma drifting at a uniform relativistic velocity, the NCI can be eliminated by simply integrating the PIC equations in Galilean coordinates that follow the plasma (also sometimes known as comoving coordinates) within a spectral analytical framework. The elimination of the NCI is verified empirically and confirmed by a theoretical analysis of the instability. Moreover, it is shown that this method is applicable both to Cartesian geometry and to cylindrical geometry with azimuthal Fourier decomposition.

Beam quality study for a grating-based dielectric laser-driven accelerator

Y. Wei, S. Jamison, G. Xia, K. Hanahoe, Y. Li, J. D. A. Smith, and C. P. Welsch
PHYSICS OF PLASMAS 24, 023102 (FEB 2017)
http://dx.doi.org/10.1063/1.4975080

Dielectric laser-driven accelerators (DLAs) based on grating structures are considered to be one of the most promising technologies to reduce the size and cost of future particle accelerators. They offer high accelerating gradients of up to several GV/m in combination with mature lithographic techniques for structure fabrication. This paper numerically investigates the beam quality for acceleration of electrons in a realistic dual-grating DLA. In our simulations, we use beam parameters of the future Compact Linear Accelerator for Research and Applications facility to load an electron bunch into an optimized 100-period dual-grating structure where it interacts with a realistic laser pulse. The emittance, energy spread, and loaded accelerating gradient for modulated electrons are then analyzed in detail. Results from simulations show that an accelerating gradient of up to 1.13 +/- 0.15 GV/m with an extremely small emittance growth, 3.6%, can be expected. *Published by AIP Publishing.*

Effect of halo on high power laser pulse wake in underdense plasma

Pathak, Naveen; Zhidkov, Alexei; Masuda, Shinichi; Hosokai, Tomonao; Kodama, Ryosuke
PHYSICS OF PLASMAS 23(11), 113106 (NOV 2016)
http://doi.org/10.1063/1.4968240

Strong disturbance in the wake of the laser pulses propagating in underdense plasma and consequent unstable electron acceleration by the wakefield can be provoked by pulse's halo, which always exists as a result of an imperfect optical focusing. When the power in the halo part exceeds a critical level for the self-focusing, it evolves in the plasma as an independent mode, which later gets coupled with the propagation of the central Gaussian spot of the pulse resulting in a novel instability. Here, this instability is investigated numerically via fully relativistic 3D particle-in-cell simulations and is shown to be partially suppressed by using plasma channels for pulse guiding. *Published by AIP Publishing.*

Universal scalings for laser acceleration of electrons in ion channels

Khudik, Vladimir; Arefiev, Alexey; Zhang, Xi; Shvets, Gennady
PHYSICS OF PLASMAS 23(10), 103108 (OCT 2016)
http://doi.org/10.1063/1.4964901

We analytically investigate the acceleration of electrons undergoing betatron oscillations in an ion channel, driven by a laser beam propagating with superluminal (or luminal) phase velocity. The universal scalings for the maximum attainable electron energy are found for arbitrary laser and plasma parameters by deriving a set of dimensionless equations for paraxial ultra-relativistic electron motion. One of our analytic predictions is the emergence of forbidden zones in the electrons' phase space. For an individual electron, these give rise to a threshold-type dependence of the final energy gain on the laser intensity. The universal scalings are also generalized to the resonant laser interaction with the third harmonic of betatron motion and to the case when the laser beam is circularly polarized. *Published by AIP Publishing.*

Beam loading in the bubble regime in plasmas with hollow channels

Golovanov, A. A.; Kostyukov, I. Yu.; Thomas, J.; Pukhov, A.
PHYSICS OF PLASMAS 23(9), 093114 (SEP 2016)
http://doi.org/10.1063/1.4962565

Based on the already existing analytical theory of the strong nonlinear wakefield (which is called "bubble") in transversely inhomogeneous plasmas, we study the particular behavior of non-loaded (empty) bubbles and bubbles with accelerated bunches. We obtain an analytical expression for the shape of a non-loaded bubble in a general case and verify it with particle-in-cell (PIC) simulations. We derive a method of calculating the acceleration efficiency for arbitrary accelerated bunches. The influence of flat-top electron bunches on the shape of a bubble is studied. It is also shown that it is possible to achieve the acceleration in a homogeneous longitudinal electric field by the adjustment of the longitudinal density profile of the accelerated electron bunch. The predictions of the model are verified by 3D PIC simulations and are in a good agreement with them. *Published by AIP Publishing.*

Direct laser acceleration in an inhomogeneous cylindrical plasma channel

Zhang, Rong; Cheng, Li-Hong; Tang, Rong-An; Xue, Ju-Kui
PHYSICS OF PLASMAS 23(9), 093105 (SEP 2016)
http://doi.org/10.1063/1.4962503

We discuss the development of the instability for electron acceleration and energy gain of electrons from laser waves in both homogeneous and inhomogeneous non-planar cylindrical plasma channels. We find that the instability (i.e., electron acceleration) in the cylindrical plasma channel can be developed more quickly and strongly than that in the planar two-dimensional plasma channel. Then, enhancement of energy gain and shortening of acceleration length in the cylindrical plasma channel are observed. For the cylindrical plasma channel, the electron in the inhomogeneous plasma channel can gain more energy from the laser and the acceleration length can be shortened by adjusting the width of the laser and the inhomogeneous charge density distributions. *Published by AIP Publishing.*

Photo-transmutation of long-lived radionuclide ^{135}Cs by laser-plasma driven electron source

Wang, X. -L.; Tan, Z. -Y.; Luo, W.; Zhu, Z. -C.; Wang, X. -D.; Song, Y. -M.
LASER AND PARTICLE BEAMS 34(3), 433-439 (SEP 2016)
http://doi.org/10.1017/S0263034616000318

Laser-driven relativistic electrons can be focused onto a high-Z convertor for generating high-brightness gamma-rays, which in turn can be used to induce photonuclear reactions. In this work, photo-transmutation of long-lived radionuclide ^{135}Cs induced by laser-plasma-interaction-driven electron source is demonstrated using Geant4 simulation (Agostinelli *et al.*, 2003 Nucl. Instrum. Meth. A 506, 250). High-energy electron generation, bremsstrahlung, as well as photonuclear reaction are observed at four different laser intensities: 10^{20}, 5 x 10^{20}, 10^{21}, and 5 x 10^{21} W/cm^2. The transmutation efficiency depends on the laser intensity and target size. An optimum laser intensity, namely 10^{21} W/cm^2, was found, with the corresponding photonuclear reaction yield reaching 10^8 J^{-1} of the laser energy. Laser-generated electrons can therefore be a promising tool for transmutation reactions. Potential application in nuclear waste management is suggested.

Particle-in-cell simulation of x-ray wakefield acceleration and betatron radiation in nanotubes

Zhang, Xiaomei; Tajima, Toshiki; Farinella, Deano; Shin, Youngmin; Mourou, Gerard; Wheeler, Jonathan; Taborek, Peter; Chen, Pisin; Dollar, Franklin; Shen, Baifei

PHYSICAL REVIEW ACCELERATORS AND BEAMS 19(10), 101004 (OCT 2016)
http://doi.org/10.1103/PhysRevAccelBeams.19.101004

Though wakefield acceleration in crystal channels has been previously proposed, x-ray wakefield acceleration has only recently become a realistic possibility since the invention of the single-cycled optical laser compression technique. We investigate the acceleration due to a wakefield induced by a coherent, ultrashort x-ray pulse guided by a nanoscale channel inside a solid material. By two-dimensional particle-in-cell computer simulations, we show that an acceleration gradient of TeV/cm is attainable. This is about 3 orders of magnitude stronger than that of the conventional plasma-based wakefield accelerations, which implies the possibility of an extremely compact scheme to attain ultrahigh energies. In addition to particle acceleration, this scheme can also induce the emission of high energy photons at $\sim O$(10-100) MeV. Our simulations confirm such high energy photon emissions, which is in contrast with that induced by the optical laser driven wakefield scheme. In addition to this, the significantly improved emittance of the energetic electrons has been discussed.

Electron acceleration and generation of high-brilliance x-ray radiation in kilojoule, subpicosecond laser-plasma interactions

Ferri, J.; Davoine, X.; Kalmykov, S. Y.; Lifschitz, A.

PHYSICAL REVIEW ACCELERATORS AND BEAMS 19(10), 101301 (OCT 2016)
http://doi.org/10.1103/PhysRevAccelBeams.19.101301

Petawatt, picosecond laser pulses offer rich opportunities in generating synchrotron x-rays. This paper concentrates on the regimes accessible with the PETAL laser, which is a part of the Laser Megajoule (LMJ) facility. We explore two physically distinct scenarios through Particle-in-Cell simulations. The first one realizes in a dense plasma, such that the period of electron Langmuir oscillations is much shorter than the pulse duration. Hallmarks of this regime are longitudinal breakup ("self-modulation") of the picosecond-scale laser pulse and excitation of a rapidly evolving broken plasma wake. It is found that electron beams with a charge of several tens of nC can be obtained, with a quasi-Maxwellian energy distribution extending to a few-GeV level. In the second scenario, at lower plasma densities, the pulse is shorter than the electron plasma period. The pulse blows out plasma electrons, creating a single accelerating cavity, while injection on the density downramp creates a nC quasi-monoenergetic electron bunch within the cavity. This bunch accelerates without degradation beyond 1 GeV. The x-ray sources in the self-modulated regime offer a high number of photons ($\sim 10^{12}$) with the slowly decaying energy spectra extending beyond 60 keV. In turn, quasimonoenergetic character of the electron beam in the blowout regime results in the synchrotron-like spectra with the critical energy around 10 MeV and a number of photons > 10(9). Yet, much smaller source duration and transverse size increase the x-ray brilliance by more than an order of magnitude against the self-modulated case, also favoring high spatial and temporal resolution in x-ray imaging. In all explored cases, accelerated electrons emit synchrotron x-rays of high brilliance, B > 10^{20} photons/s/mm^2/mrad^2/0.1% BW. Synchrotron sources driven by picosecond kilojoule lasers may thus find an application in x-ray diagnostics on such facilities such as the LMJ or National Ignition Facility (NIF).

Mid-infrared lasers for energy frontier plasma accelerators

Pogorelsky, I. V.; Polyanskiy, M. N.; Kimura, W. D.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 19(9), 091001 (SEP 2016)
http://doi.org/10.1103/PhysRevAccelBeams.19.091001

Plasma wake field accelerators driven with solid-state near-IR lasers have been considered as an alternative to conventional rf accelerators for next-generation TeV-class lepton colliders. Here, we extend this study to the mid-IR spectral domain covered by CO_2 lasers. We conclude that the increase in the laser driver wavelength favors the regime of laser wake field acceleration with a low plasma density and high electric charge. This regime is the most beneficial for gamma colliders to be converted from lepton colliders via inverse Compton scattering. Selecting a laser wavelength to drive a Compton gamma source is essential for the design of such a machine. The revealed benefits from spectral diversification of laser drivers for future colliders and off-spring applications validate ongoing efforts in advancing the ultrafast CO_2 laser technology.

GeV electron acceleration by a Gaussian field laser with effect of beam width parameter in magnetized plasma

Ghotra, Harjit Singh; Kant, Niti
OPTICS COMMUNICATIONS 383, 169-176 (JAN 2017)
http://doi.org/10.1016/j.optcom.2016.08.061

Electron acceleration due to a circularly polarized (CP) Gaussian laser field has been investigated theoretically in magnetized plasma. A Gaussian laser beam possesses trapping forces on electrons during its propagation through plasma. A single particle simulation indicates a resonant enhancement of electron acceleration with a Gaussian laser beam. The plasma is magnetized with an axial magnetic field in same direction as that of laser beam propagation. The dependence of laser beam width parameter on electron energy gain with propagation distance has been presented graphically for different values of laser intensity. Electron energy gain is relatively high where the laser beam parameter is at its minimum value. Enhanced energy gain of the order of GeV is reported with magnetic field under 20 MG in plasma. It is also seen that the axial magnetic field maintains the electron acceleration for large propagation distance even with an increasing beam width parameter.

Effects of small misalignments on the intensity and Strehl ratio for a laser beam focused by an off-axis parabola

Luca Labate, Paolo Ferrara, Lorenzo Fulgentini, and Leonida A. Gizzi
APPLIED OPTICS 55 (23), 6506 – 6515 (JUL 2016)
http://doi.org/10.1364/AO.55.006506

A general procedure is described to calculate the intensity and Strehl ratio, at a generic plane in the focal region, of a beam focused by an off-axis parabolic mirror in the presence of small misalignments. The general theoretical framework is first developed, which allows a full vector diffraction treatment in the case of general misalignments. Then, a parametric numerical study is reported, aimed at highlighting the tolerances of both the intensity and Strehl ratio for small misalignments, for different focusing and off-axis parabola parameters. A set of experimental measurements aimed at validating the theoretical model is also discussed.

Note: Real-time monitoring via second-harmonic interferometry of a flow gas cell for laser wakefield acceleration

F. Brandi, F. Giammanco, F. Conti, F. Sylla, G. Lambert, and L. A. Gizzi
REVIEW OF SCIENTIFIC INSTRUMENTS 87 (8), 086103 (AUG 2016)
http://doi.org/10.1063/1.4960399

The use of a gas cell as a target for laser wakefield acceleration (LWFA) offers the possibility to obtain stable and manageable laser-plasma interaction process, a mandatory condition for practical applications of this emerging technique, especially in multi-stage accelerators. In order to obtain full control of the gas particle number density in the interaction region, thus allowing for a long term stable and manageable LWFA, real-time monitoring is necessary. In fact, the ideal gas law cannot be used to estimate the particle density inside the flow cell based on the preset backing pressure and the room temperature because the gas flow depends on several factors like tubing, regulators, and valves in the gas supply system, as well as vacuum chamber volume and vacuum pump speed/throughput. Here, second-harmonic interferometry is applied to measure the particle number density inside a flow gas cell designed for LWFA. The results demonstrate that real-time monitoring is achieved and that using low backing pressure gas (<1 bar) and different cell orifice diameters (<2 mm) it is possible to finely tune the number density up to the 1019 cm−3 range well suited for LWFA.

Spectroscopic measurements of plasma emission light for plasma-based acceleration experiments

Filippi, F.; Anania, M.P.; Biagioni, A.; Chiadroni, E.; Cianchi, A.; Ferrario, M.; Mostacci, A.; Palumbo, L.; Zigler, A.
JOURNAL OF INSTRUMENTATION 11, C09015 (SEP 2016)
http://doi.org/10.1088/1748-0221/11/09/C09015

Advanced particle accelerators are based on the excitation of large amplitude plasma waves driven by either electron or laser beams. Future experiments scheduled at the SPARC_LAB test facility aim to demonstrate the acceleration of high brightness electron beams through the so-called resonant Plasma Wakefield Acceleration scheme in which a train of electron bunches (drivers) resonantly excites wakefields into a preformed hydrogen plasma; the last bunch (witness) injected at the proper accelerating phase gains energy from the wake. The quality of the accelerated beam depends strongly on plasma density and its distribution along the acceleration length. The measurements of plasma density of the order of 10^{16}-10^{17} cm^{-3} can be performed with spectroscopic measurements of the plasma-emitted light. The measured density distribution for hydrogen filled capillary discharge with both Balmer alpha and Balmer beta lines and shot-to-shot variation are here reported.

Control and optimization of a staged laser-wakefield accelerator

Golovin, G.; Banerjee, S.; Chen, S.; Powers, N.; Liu, C.; Yan, W.; Zhang, J.; Zhang, P.; Zhao, B.; Umstadter, D.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 830, 375-380 (SEP 2016)
http://doi.org/10.1016/j.nima.2016.06.022

We report results of an experimental study of laser-wakefield acceleration of electrons, using a staged device based on a double jet gas target that enables independent injection and acceleration stages. This novel scheme is shown to produce stable, quasi-monoenergetic, and tunable electron beams. We show that optimal accelerator performance is achieved by systematic variation of five critical parameters. For the injection stage, we show that the amount of trapped charge is controlled by the gas density, composition, and laser power. For the acceleration stage, the gas density and the length of the jet are found to determine the final electron energy. This independent control over both the injection and acceleration processes

enabled independent control over the charge and energy of the accelerated electron beam while preserving the quasi-monoenergetic character of the beam. We show that the charge and energy can be varied in the ranges of 2-45 pC, and 50-450 MeV, respectively. This robust and versatile electron accelerator will find application in the generation of high-brightness and controllable x-rays, and as the injector stage for more conventional devices. *(C) 2016 The Authors. Published by Elsevier B.V.*

Tomographic characterisation of gas-jet targets for laser wakefield acceleration

Couperus, J. P.; Koehler, A.; Wolterink, T. A. W.; Jochmann, A.; Zarini, O.; Bastiaens, H. M. J.; Boller, K. J.; Irman, A.; Schramm, U.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 830, 504-509 (SEP 2016)
http://doi.org/10.1016/j.nima.2016.02.099

Laser wakefield acceleration (LWFA) has emerged as a promising concept for the next generation of high energy electron accelerators. The acceleration medium is provided by a target that creates a local well-defined gas-density profile inside a vacuum vessel. Target development and analysis of the resulting gas density profiles is an important aspect in the further development of LWFA. Gas jet targets are widely used in regimes where relatively high electron densities over short interaction lengths are required (up to several millimetres interaction length, plasma densities down to ~ 10^{18} cm^{-3}). In this paper we report a precise characterisation of such gas jet targets by a laser interferometry technique. We show that phase shifts down to 4 mrad can be resolved. Tomographic phase reconstruction enables detection of non-axisymmetrical gas-density profiles which indicates defects in cylindrical nozzles, analysis of slit-nozzles and nozzles with an induced shock-wave density step. In a direct comparison between argon and helium jets we show that it cannot automatically be assumed, as is often done, that a nozzle measured with argon will provide the same gas density with helium. *(C) 2016 Elsevier B.V. All rights reserved.*

A bremsstrahlung gamma-ray source based on stable ionization injection of electrons into a laser wakefield accelerator

Doepp, A.; Guillaume, E.; Thaury, C.; Lifschitz, A.; Sylla, F.; Goddet, J-P.; Tafzi, A.; Iaquanello, G.; Lefrou, T.; Rousseau, P.; Conejero, E.; Ruiz, C.; Phuoc, K. Ta; Malka, V.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 830, 515-519 (SEP 2016)
http://doi.org/10.1016/j.nima.2016.01.086

Laser wakefield acceleration permits the generation of ultra-short, high-brightness relativistic electron beams on a millimeter scale. While those features are of interest for many applications, the source remains constraint by the poor stability of the electron injection process. Here we present results on injection and acceleration of electrons in pure nitrogen and argon. We observe stable, continuous ionization-induced injection of electrons into the wakefield for laser powers exceeding a threshold of 7 TW. The beam charge scales approximately with the laser energy and is limited by beam loading. For 40 TW laser pulses we measure a maximum charge of almost 1 nC per shot, originating mostly from electrons of less than 10 MeV energy. The relatively low energy, the high charge and its stability make this source well-suited for applications such as non-destructive testing. Hence, we demonstrate the production of energetic radiation via bremsstrahlung conversion at 1 Hz repetition rate. In accordance with GEANT4 Monte-Carlo simulations, we measure a gamma-ray source size of less than 100 μm for a 0.5 mm tantalum converter placed at 2 mm from the accelerator exit. Furthermore we present radiographs of image quality indicators. *(C) 2016 Elsevier B.V. All rights reserved.*

Space-Charge Field Assisted Electron Acceleration by Plasma Wave in Magnetic Plasma Channel

Gupta, Devki Nandan; Kaur, Maninder; Gopal, Krishna; Suk, Hyyong
IEEE TRANSACTIONS ON PLASMA SCIENCE 44(11), 2867-2873 (NOV 2016)
http://doi.org/10.1109/TPS.2016.2615649

When the duration of a laser pulse is comparable to the plasma wave period, a large-amplitude plasma wave can be driven by the laser. In the presence of a guiding magnetic field, the large-amplitude plasma wave of finite transverse extent and large phase velocity resonantly accelerates the electrons to a higher energy level. For a small laser spot size, the laser exerts an axial as well as the radial ponderomotive force on the electrons that creates a density depression on the laser axis. This electron-depleted channel also creates a radial electric field (ion space-charge field). The acceleration of electrons in this channel is investigated, where the effect of ion space-charge field is considered, by solving the single particle dynamical equations. This paper shows that the space charge field plays an important role in electron energy gain during acceleration by a plasma wave in a magnetic plasma channel. This paper may be crucial in understanding the dynamics of particle motion and improving the quality of accelerated electron beam in the laser wakefield accelerators.

Stability of a large amplitude plasma wave to oscillating two-stream instability

Ahmad, Nafis; Mahmoud, Saleh T.; Ahmad, Moiz
INDIAN JOURNAL OF PURE & APPLIED PHYSICS 54(11), 720-726 (NOV 2016)

The stability of a long wavelength large amplitude plasma wave, generated in a laser wakefield accelerator at moderately relativistic laser intensity, to oscillating two-stream instability has been examined. In the limit when the oscillatory velocity of electrons due to the plasma wave, $\vec{v}_0$, exceeds the electron thermal speed, the short wavelength plasma wave turns out to be $\omega^2 = \omega_p^2 + \left|\vec{k}\cdot\vec{v}_0\right|^2/2$. In the four wave parametric process, involving the pump plasma wave, a short wavelength low frequency quasimode and two short wavelength plasma wave sidebands, the pump and the sidebands exert a ponderomotive force on the electrons driving a low frequency quasimode. The electron density perturbation associated with this mode couples with the pump driven electron oscillatory velocity to produce nonlinear currents driving the sidebands. We find that this process has no growth when the ion motion is ignored. However, with the inclusion of ion motion the parametric instability is important on the time scale of an ion plasma period.

Laser Wakefield Acceleration Using Mid-Infrared Laser Pulses

Zhang, Guo-Bo; Hafz, N. A. M.; Ma, Yan-Yun; Qian, Lie-Jia; Shao, Fu-Qiu; Sheng, Zheng-Ming
CHINESE PHYSICS LETTERS 33(9), 095202 (SEP 2016)
http://doi.org/10.1088/0256-307X/33/9/095202

We study a laser wakefield acceleration driven by mid-infrared (mid-IR) laser pulses through two-dimensional particle-in-cell simulations. Since a mid-IR laser pulse can deliver a larger ponderomotive force as compared with the usual 0.8 μm wavelength laser pulse, it is found that electron self-injection into the wake wave occurs at an earlier time, the plasma density threshold for injection becomes lower, and the electron beam charge is substantially enhanced. Meanwhile, our study also shows that quasimonoenergetic electron beams with a narrow energy-spread can be generated by using mid-IR laser pulses. Such a mid-IR laser pulse can provide a feasible method for obtaining a high quality and high charge electron beam. Therefore, the current efforts on constructing mid-IR terawatt laser systems can greatly benefit the laser wakefield acceleration research.

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**

www.eupraxia-project.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.