THE EuPRAXIA FILES

ISSUE 5 – December 2017

Foreword

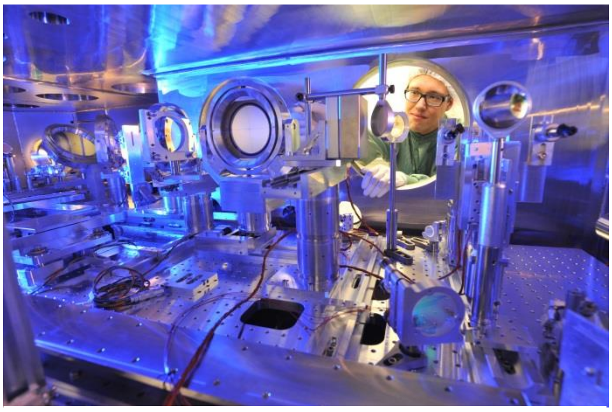
Dr Ralph Aßmann
EuPRAXIA Coordinator

The present issue of The EuPRAXIA Files contains amongst general research papers a record of thirteen published works funded, at least partially, by the EuPRAXIA project. These include proceedings from the SPIE Conference and IPAC 2017, where EuPRAXIA was presented to the world (see the article by P. A. Walker *et al*.) Having passed the halfway mark of the project, there couldn't be a better measure of the progress made in all fronts of research. The results give us the confindence to look forward to the delivery of an excellent Conceptual Design Report for a highly compact and cost-effective plasma accelerator facility. We use this opportunity to welcome the Queen's University Belfast and the Ferdinand Braun Institute of the Leibniz Association as new Associated Partners to EuPRAXIA. The new Associated Partners were approved at the recent Yearly Meeting that was kindly hosted by the IST in Lisbon, Portugal.

Research Highlights

Right Time + Right Place = Perfect Acceleration

With their small footprint and high peak currents, laser plasma accelerators could be the basis for the next generation of compact light sources. So far, the challenge with laser accelerators has been to create a reliable and stable electron beam, which is the prerequisite for possible applications. Physicists at the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) have now developed a method to increase both beam stability and quality.



Laser wakefield acceleration chamber at HZDR
Photo: Frank Bierstedt / HZDR.

The strength of the secondary radiation greatly depends on the particles' electrical current. Laser-powered acceleration therefore holds great potential, because it reaches significantly higher peak currents in comparison with the conventional method. However, as Jurjen Couperus points out, the so-called beam loading effect kicks in: "These higher currents create an electric self-field strong enough to superimpose and disturb the laser-driven wave, distorting thereby the beam. The bundle is stretched out and not accelerated properly. The electrons therefore have different energies and quality levels." But in order to use them as a tool for other experiments, each beam must have the same parameters. "The electrons have to be in the right place at the right time."

The HZDR scientists were the first to demonstrate how the beam loading effect can be exploited for improved beam quality. They add a bit of nitrogen to the helium at which the laser beam is usually directed. "We can control the number of electrons we feed into the process by changing the concentration of the nitrogen," Dr. Arie Irman explains. "In our experiments, we found out that conditions are ideal at a charge of about 300 picocoulomb. Any deviation from it – if we add more or fewer electrons to the wave – results in a broader spread of energy, which impairs beam quality."

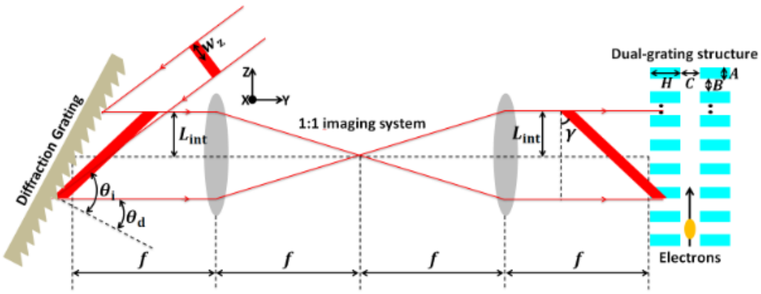
As the physicists' calculations have shown, experiments under ideal conditions yield peak currents of about 50 kiloamperes. Couperus is confident that they can beat their own record: "Using our findings and a laser pulse in the petawatt range, which our high-intensity laser DRACO can achieve, we should be able to generate a high-quality electron beam with peak currents of 150 kiloamperes. That would exceed modern large-scale research accelerators by about two orders of magnitude." An achievement which the researchers from Dresden believe would pave the way for the next generation of compact radiation sources.

Journal reference:

J. P. Couperus *et al.*, "Demonstration of a beam loaded nanocoulomb-class laser wakefield accelerator", Nature Communications 8, 487 (2017) https://doi:10.1038/s41467-017-00592-7

Towards particle accelerators "on a chip"

Dielectric laser-driven accelerators (DLAs) have been demonstrated to accelerate electrons with an accelerating gradient of 690 ± 100 MeV/m, opening the concept of particle accelerators "on a chip". Previous DLA studies were performed with a normally-incident laser beam. However, in that case the increase in electron energy is limited by the short interaction length between the laser pulses and the electron bunch.



Optical system generating a pulse-front-tilted (PFT) laser.

In an open access paper published in Applied Optics, University of Liverpool's Yelong Wei and co-authors investigate numerically dual-grating dielectric accelerators driven by a pulse-front-tilted (PFT) laser, which extends the interaction length and boosts the electrons' energy gain. The optical system necessary to generate PFT laser beams with an ultrashort pulse duration of 100 fs is also studied in detail. Through two-dimensional (2D) particle-in-cell simulations, they show that such a PFT laser effectively increases the energy gain by (91 ± 25) % compared to that of a normally-incident laser with a waist radius of 50 µm for a 100-period dual-grating structure. Moreover, they found that the energy gain is strongly dependent on the tilt angle, incident laser waist radius and the number of structure periods.

Yelong Wei and his colleagues also investigated dual-grating structures driven by THz pulses to accelerate electrons. The wakefield effect which may result in bunch energy modulation in the dual-grating structures is studied in detail in another open access paper published in Nuclear Instruments and Methods A. When the bunch travels out of the structure, the average energy is reduced due to its interaction with the longitudinal decelerating wakefield. Then, an intense THz pulse is added into the simulation to interact with the electron bunch in the optimized structure. The simulations show that an accelerating gradient of 348 ± 12 MV/m with an emittance growth of 3.0% can be obtained.

Journal references:

Y. Wei, *et al.*, "Dual-grating dielectric accelerators driven by a pulse-front-tilted laser", Applied Optics 56, 8201-8206 (2017) https://doi.org/10.1364/AO.56.008201

Y. Wei, *et al.*, "Investigations into dual-grating THz-driven accelerators", Nuclear Instruments and Methods A 877, 173-177 (2018) https://doi.org/10.1016/j.nima.2017.09.050

Research Papers

Demonstration of sub-luminal propagation of single-cycle terahertz pulses for particle acceleration

Walsh, D. A.; Lake, D. S.; Snedden, E. W.; Cliffe, M. J.; Graham, D. M.; Jamison, S. P.
NATURE COMMUNICATIONS 8, 421 (SEP 2017)
https://doi.org/10.1038/s41467-017-00490-y

The sub-luminal phase velocity of electromagnetic waves in free space is generally unobtainable, being closely linked to forbidden faster than light group velocities. The requirement of sub-luminal phase-velocity in laser-driven particle acceleration schemes imposes a limit on the total acceleration achievable in free space, and necessitates the use of dispersive structures or waveguides for extending the field-particle interaction. We demonstrate a travelling source approach that overcomes the sub-luminal propagation limits. The approach exploits ultrafast optical sources with slow group velocity propagation, and a group-to-phase front conversion through nonlinear optical interaction. The concept is demonstrated with two terahertz generation processes, nonlinear optical rectification and current-surge rectification. We report measurements of longitudinally polarised single-cycle electric fields with phase and group velocity between 0.77c and 1.75c. The ability to scale to multi-megawatt-per-metre field strengths is demonstrated. Our approach paves the way towards the realisation of cheap and compact particle accelerators with femtosecond scale control of particles.

Demonstration of a beam loaded nanocoulomb-class laser wakefield accelerator

Couperus, J. P.; Pausch, R.; Köhler, A.; Zarini, O.; Krämer, J.M.; Garten, M.; Huebl, A.; Gebhardt, R.; Helbig, U.; Bock, S.; Zeil, K.; Debus, A.; Bussmann, M.; Schramm, U.; Irman, A.
NATURE COMMUNICATIONS 8, 487 (SEP 2017)
https://doi:10.1038/s41467-017-00592-7

Laser-plasma wakefield accelerators have seen tremendous progress, now capable of producing quasi-monoenergetic electron beams in the GeV energy range with few-femtoseconds bunch duration. Scaling these accelerators to the nanocoulomb range would yield hundreds of kiloamperes peak current and stimulate the next generation of radiation sources covering high-field THz, high-brightness X-ray and γ-ray sources, compact free-electron lasers and laboratory-size beam-driven plasma accelerators. However, accelerators generating such currents operate in the beam loading regime where the accelerating field is strongly modified by the self-fields of the injected bunch, potentially deteriorating key beam parameters. Here we demonstrate that, if appropriately controlled, the beam loading effect can be employed to improve the accelerator’s performance. Self-truncated ionization injection enables loading of unprecedented charges of ~0.5 nC within a mono-energetic peak. As the energy balance is reached, we show that the accelerator operates at the theoretically predicted optimal loading condition and the final energy spread is minimized.

Towards Attosecond High-Energy Electron Bunches: Controlling Self-Injection in Laser-Wakefield Accelerators Through Plasma-Density Modulation

Tooley, M. P.; Ersfeld, B.; Yoffe, S. R.; Noble, A.; Brunetti, E.; Sheng, Z. M.; Islam, M. R.; Jaroszynski, D. A.
PHYSICAL REVIEW LETTERS 119(4), 044801 (JUL 2017)
https://doi.org/10.1103/PhysRevLett.119.044801

Self-injection in a laser-plasma wakefield accelerator is usually achieved by increasing the laser intensity until the threshold for injection is exceeded. Alternatively, the velocity of the bubble accelerating structure can be controlled using plasma density ramps, reducing the electron velocity required for injection. We present a model describing self-injection in the short-bunch regime for arbitrary changes in the plasma density. We derive the threshold condition for injection due to a plasma density gradient, which is confirmed using particle-in-cell simulations that demonstrate injection of subfemtosecond bunches. It is shown that the bunch charge, bunch length, and separation of bunches in a bunch train can be controlled by tailoring the plasma density profile.

Stable multi-GeV electron accelerator driven by waveform-controlled PW laser pulses

Kim, Hyung Taek; Pathak, V. B.; Pae, Ki Hong; Lifschitz, A.; Sylla, F.; Shin, Jung Hun; Hojbota, C.; Lee, Seong Ku; Sung, Jae Hee; Lee, Hwang Woon; Guillaume, E.; Thaury, C.; Nakajima, Kazuhisa; Vieira, J.; Silva, L. O.; Malka, V.; Nam, Chang Hee
SCIENTIFIC REPORTS 7, 10203 (AUG 2017)
https://doi.org/10.1038/s41598-017-09267-1

The achievable energy and the stability of accelerated electron beams have been the most critical issues in laser wakefield acceleration. As laser propagation, plasma wave formation and electron acceleration are highly nonlinear processes, the laser wakefield acceleration (LWFA) is extremely sensitive to initial experimental conditions. We propose a simple and elegant waveform control method for the LWFA process to enhance the performance of a laser electron accelerator by applying a fully optical and programmable technique to control the chirp of PW laser pulses. We found sensitive dependence of energy and stability of electron beams on the spectral phase of laser pulses and obtained stable 2-GeV electron beams from a 1-cm gas cell of helium. The waveform control technique for LWFA would prompt practical applications of centimeter-scale GeV-electron accelerators to a compact radiation sources in the x-ray and gamma-ray regions.

Short-wavelength free-electron laser sources and science: a review

Seddon, E. A.; Clarke, J. A.; Dunning, D. J.; Masciovecchio, C.; Milne, C. J.; Parmigiani, F.; Rugg, D.; Spence, J. C. H.; Thompson, N. R.; Ueda, K.; Vinko, S. M.; Wark, J. S.; Wurth, W.
REPORTS ON PROGRESS IN PHYSICS 80(11), 115901 (NOV 2017)
https://doi.org/10.1088/1361-6633/aa7cca

This review is focused on free-electron lasers (FELs) in the hard to soft x-ray regime. The aim is to provide newcomers to the area with insights into: the basic physics of FELs, the qualities of the radiation they produce, the challenges of transmitting that radiation to end users and the diversity of current scientific applications. Initial consideration is given to FEL theory in order to provide the foundation for discussion of FEL output properties and the technical challenges of short-wavelength FELs. This is followed by an overview of existing x-ray FEL facilities, future facilities and FEL frontiers. To provide a context for information in the above sections, a detailed comparison of the photon pulse characteristics of FEL sources with those of other sources of high brightness x-rays is made. A brief summary of FEL beamline design and photon diagnostics then precedes an overview of FEL scientific applications. Recent highlights are covered in sections on structural biology, atomic and molecular physics, photochemistry, non-linear spectroscopy, shock physics, solid density plasmas. A short industrial perspective is also included to emphasise potential in this area.

Experimental characterization of the effects induced by passive plasma lens on high brightness electron bunches

Marocchino, A.; Anania, M. P.; Bellaveglia, M.; Biagioni, A.; Bini, S.; Bisesto, F.; Brentegani, E.; Chiadroni, E.; Cianchi, A.; Croia, M.; Di Giovenale, D.; Ferrario, M.; Filippi, F.; Giribono, A.; Lollo, V.; Marongiu, M.; Mostacci, A.; Di Pirro, G.; Pompili, R.; Romeo, S.; Rossi, A. R.; Scifo, J.; Shpakov, V.; Vaccarezza, C.; Villa, F.; Zigler, A.
APPLIED PHYSICS LETTERS 111(18), 184101 (OCT 2017)
https://doi.org/10.1063/1.4999010

We report on the experimental characterization of the effect that a passive plasma lens in the overdense regime has on high-brightness bunch quality by means of 6D phase-space analysis. The passive lens is generated by confining hydrogen gas with a capillary tube pre-ionized with a high-voltage discharge. We observed that the optimum condition is retrieved at the end of the overdense regime with almost no effect on bunch brightness. The presence of gas jets, leaking from the hollow capillary end-points, extends the lens effects also outside of the capillary, resulting in longer focusing channels. Experimental results are supported with numerical simulations of the complete accelerator line together with the plasma channel section. *Published by AIP Publishing.*

Terahertz emission driven by two-color laser pulses at various frequency ratios

Wang, W. -M.; Sheng, Z. -M.; Li, Y. -T.; Zhang, Y.; Zhang, J.

PHYSICAL REVIEW A 96(2), 023844 (AUG 2017)
https://doi.org/10.1103/PhysRevA.96.023844

We present a simulation study of terahertz radiation from a gas driven by two-color laser pulses in a broad range of frequency ratios ω_1/ω_0. Our particle-in-cell simulation results show that there are three series with $\omega_1/\omega_0 = 2n$, $n + 1/2$, n +/- 1/3 (n is a positive integer) for high-efficiency and stable radiation generation. The radiation strength basically decreases with the increasing ω_1 and scales linearly with the laser wavelength. These rules are broken when $\omega_1/\omega_0 < 1$ and much stronger radiation may be generated at any ω_1/ω_0. These results can be explained with a model based on gas ionization by two linear-superposition laser fields, rather than a multiwave mixing model.

The resonant multi-pulse ionization injection

Tomassini, Paolo; De Nicola, Sergio; Labate, Luca; Londrillo, Pasquale; Fedele, Renato; Terzani, Davide; Gizzi, Leonida A.

PHYSICS OF PLASMAS 24(10), 103120 (OCT 2017)
https://doi.org/10.1063/1.5000696

The production of high-quality electron bunches in Laser Wake Field Acceleration relies on the possibility to inject ultra-low emittance bunches in the plasma wave. In this paper, we present a new bunch injection scheme in which electrons extracted by ionization are trapped by a large-amplitude plasma wave driven by a train of resonant ultrashort pulses. In the Resonant Multi-Pulse Ionization injection scheme, the main portion of a single ultrashort (e.g., Ti: Sa) laser system pulse is temporally shaped as a sequence of resonant sub-pulses, while a minor portion acts as an ionizing pulse. Simulations show that high-quality electron bunches with normalized emittance as low as 0.08 mm x mrad and 0.65% energy spread can be obtained with a single present-day 100TW-class Ti: Sa laser system. *Published by AIP Publishing.*

Accurate modeling of plasma acceleration with arbitrary order pseudo-spectral particle-in-cell methods

Jalas, S.; Dornmair, I.; Lehe, R.; Vincenti, H.; Vay, J. -L.; Kirchen, M.; Maier, A. R.

PHYSICS OF PLASMAS 24(3), 033115 (MAR 2017)
https://doi.org/10.1063/1.4978569

Particle in Cell (PIC) simulations are a widely used tool for the investigation of both laser- and beam-driven plasma acceleration. It is a known issue that the beam quality can be artificially degraded by numerical Cherenkov radiation (NCR) resulting primarily from an incorrectly modeled dispersion relation. Pseudo-spectral solvers featuring infinite order stencils can strongly reduce NCR-or even suppress it-and are therefore well suited to correctly model the beam properties. For efficient parallelization of the PIC algorithm, however, localized solvers are inevitable. Arbitrary order pseudo-spectral methods provide this needed locality. Yet, these methods can again be prone to NCR. Here, we show that acceptably low solver orders are sufficient to correctly model the physics of interest, while allowing for parallel computation by domain decomposition. *Published by AIP Publishing.*

Ultra-bright keV X-ray source generated by relativistic femtosecond laser pulse interaction with thin foils and its possible application for HEDS investigations

Faenov, A. Y.; Pikuz, T. A.; Vergunova, G. A.; Pikuz, S. A.; Skobelev, I. Y.; Andreev, A.; Zhidkov, A.; Kodama, R.
LASER AND PARTICLE BEAMS 35(3), 450 – 457 (SEP 2017)
https://doi.org/10.1017/S0263034617000428

It was shown that the energy of femtosecond laser pulses with relativistic intensity approaching to ~10^{21} W/cm^2 is efficiently converted to X-ray radiation and produces exotic states in solid density plasma periphery. We propose and show by one-dimensional two-temperature hydrodynamic modeling, that applying two such unique ultra-bright X-ray sources with intensities above 10^{17} W/cm^2 - allow to generate shock waves with strength of up to some hundreds Mbar, which could give new opportunities for studies of matter in extreme conditions.

Development for a supercompact X-band pulse compression system and its application at SLAC

Wang, Juwen W.; Tantawi, Sami G.; Xu, Chen; Franzi, Matt; Krejcik, Patrick; Bowden, Gordon; Condamoor, Shantha; Ding, Yuantao; Dolgashev, Valery; Eichner, John; Haase, Andrew; Lewandowski, James R.; Xiao, Liling
PHYSICAL REVIEW ACCELERATORS AND BEAMS 20(11), 110401 (NOV 2017)
https://doi.org/10.1103/PhysRevAccelBeams.20.110401

We have successfully designed, fabricated, installed, and tested a super compact X-band SLAC Energy Doubler system at SLAC. It is composed of an elegant 3 dB coupler-mode converter-polarizer coupled to a single spherical energy storage cavity with high Q_0 of 94000 and a diameter less than 12 cm. The available rf peak power of 50 MW can be compressed to a peak average power of more than 200 MW in order to double the kick for the electron bunches in a rf transverse deflector system and greatly improve the measurement resolution of both the electron bunches and the x-ray free-electron laser pulses. The design physics and fabrication as well as the measurement results will be presented in detail. High-power operation has demonstrated the excellent performance of this rf compression system without rf breakdown, sign of pulse heating, and rf radiation.

Using a Bessel light beam as an ultrashort period helical undulator

Jiang, B. C.; Zhang, Q. L.; Chen, J. H.; Zhao, Z. T.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 20(7), 070701 (JUL 2017)
https://doi.org/10.1103/PhysRevAccelBeams.20.070701

An undulator is a critical component to produce synchrotron radiation and a free electron laser. When a Bessel light beam carrying the orbit angular momentum copropagates with an electron beam bunch, a net transverse deflection force will be subjected to the latter one. As a result of dephasing effect, the deflection force will oscillate and act as an undulator. For such a laser based undulator, the period length can reach submillimeter level, which will greatly reduce the electron energy for the required x-ray production.

An optical cavity design for a compact wave-undulator based-FEL

Curcio, A.; Dattoli, G.; Ferrario, M.; Giulietti, D.; Nguyen, F.
OPTICS COMMUNICATIONS 405, 197 – 200 (DEC 2017)
https://doi.org/10.1016/j.optcom.2017.08.029

We have considered a novel scheme of wave undulator FEL. The system employs a recirculated radiation pulse serving as undulator provided by a high power laser. Non conventional electron acceleration schemes promise nowadays high gradient acceleration yielding the GeV on the scale of few centimeters, however these solutions might solve the problem of the accelerator length, but not that associated with the saturation length and thus of the length of the undulator, which remains on the order of tens of meters. The option of wave-undulator based FEL might provide a valid solution in the future.

Dual-grating dielectric accelerators driven by a pulse-front-tilted laser

Wei, Y.; Ibison, M.; Xia, G.; Smith, J. D. A.; Welsch, C. P.
APPLIED OPTICS 56(29), 8201 (OCT 2017)
https://doi.org/10.1364/AO.56.008201

This paper investigates numerically dual-grating dielectric laser-driven accelerators driven by a pulse-front-tilted (PFT) laser, which extends the interaction length and boosts the electrons' energy gain. The optical system necessary to generate PFT laser beams with an ultrashort pulse duration of 100 fs is also studied in detail. Through two-dimensional particle-in-cell simulations, we show that such a PFT laser effectively increases the energy gain by (91 ± 25) % compared to that of a normally incident laser with a waist radius of 50 μm for a 100-period dual-grating structure.

Beam manipulation for resonant plasma wakefield acceleration

Chiadroni, E.; Alesini, D.; Anania, M. P.; Bacci, A.; Bellaveglia, M.; Biagioni, A.; Bisesto, F. G.; Cardelli, F.; Castorina, G.; Cianchi, A.; Croia, M.; Gallo, A.; Di Giovenale, D.; Di Pirro, G.; Ferrario, M.; Filippi, F.; Giribono, A.; Marocchino, A.; Mostacci, A.; Petrarca, M.; Piersanti, L.; Pioli, S.; Pompili, R.; Romeo, S.; Rossi, A. R.; Scifo, J.; Shpakov, V.; Spataro, B.; Stella, A.; Vaccarezza, C.; Villa, F.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 865, 139 – 143 (SEP 2017)
https://doi.org/10.1016/j.nima.2017.01.017

Plasma-based acceleration has already proved the ability to reach ultra-high accelerating gradients. However the step towards the realization of a plasma-based accelerator still requires some effort to guarantee high brightness beams, stability and reliability. A significant improvement in the efficiency of PWFA has been demonstrated so far accelerating a witness bunch in the wake of a higher charge driver bunch. The transformer ratio, therefore the energy transfer from the driver to the witness beam, can be increased by resonantly exciting the plasma with a properly pre-shaped drive electron beam. Theoretical and experimental studies of beam manipulation for resonant PWFA will be presented here.

Results of test of prototype of variable period undulator

Davidyuk, I. V.; Shevchenko, O. A.; Tcheskidov, V. G.; Vinokurov, N. A.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 871, 77 – 82 (NOV 2017)
https://doi.org/10.1016/j.nima.2017.07.060

The development of the permanent-magnet variable-period undulator (VPU) is aimed at improving the parameters of the Novosibirsk free electron laser (FEL). The key features of this design are the possibility of increasing the number of poles for shorter periods with constant undulator length and wider radiation wavelength tuning range as compared with conventional undulators. As the idea of the permanent-magnet VPU has not been properly tested yet, there are several issues to be solved before THE manufacture of the

device. Two short prototypes of the VPU were made for the purpose of testing solutions to existing problems. We present here the results of mechanical and magnetic measurements of the undulator prototypes and compare the characteristics of the prototypes with those predicted by simulations.

Investigations into dual-grating THz-driven accelerators

Wei, Y.; Ischebeck, R.; Dehler, M.; Ferrari, E.; Hiller, N.; Jamison, S.; Xia, G.; Hanahoe, K.; Li, Y.; Smith, J. D. A.; Welsch, C. P.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 877, 173-177 (JAN 2018)
https://doi.org/10.1016/j.nima.2017.09.050

Advanced acceleration technologies are receiving considerable interest in order to miniaturize future particle accelerators. One such technology is the dual-grating dielectric structures, which can support accelerating fields one to two orders of magnitude higher than the metal RF cavities in conventional accelerators. This opens up the possibility of enabling high accelerating gradients of up to several GV/m. This paper investigates numerically a quartz dual-grating structure which is driven by THz pulses to accelerate electrons. Geometry optimizations are carried out to achieve the trade-offs between accelerating gradient and vacuum channel gap. A realistic electron bunch available from the future Compact Linear Accelerator for Research and Applications (CLARA) is loaded into an optimized 100-period dual-grating structure for a detailed wakefield study. A THz pulse is then employed to interact with this CLARA bunch in the optimized structure. The computed beam quality is analyzed in terms of emittance, energy spread and loaded accelerating gradient. The simulations show that an accelerating gradient of 348 ± 12 MV/m with an emittance growth of 3.0% can be obtained.

Study of the beam tolerance for plasma based ion channel lasers

Shpakov, V.; Chiadroni, E.; Curcio, A.; Fares, H.; Ferrario, M.; Marocchino, A.; Petrillo, V.; Rossi, A. R.; Romeo, S.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION B 402, 384 – 387 (JUL 2017)
https://doi.org/10.1016/j.nimb.2017.03.107

In this work we use the one-dimensional free electron laser (FEL) model to define necessary parameters of an electron beam to produce self-amplified spontaneous emission (SASE) in an ion channel laser (ICL) undulator. Limits and constraints on beam parameters are given, based on theoretical argument and numerical simulations results using the Architect hybrid code.

First measurements of betatron radiation at FLAME laser facility

Curcio, A.; Anania, M.; Bisesto, F.; Chiadroni, E.; Cianchi, A.; Ferrario, M.; Filippi, F.; Giulietti, D.; Marocchino, A.; Mira, F.; Petrarca, M.; Shpakov, V.; Zigler, A.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION B 402, 388 – 392 (JUL 2017)
https://doi.org/10.1016/j.nimb.2017.03.106

The first results on betatron radiation obtained in laser-plasma acceleration experiments at the FLAME laser facility are presented. The diagnostic apparatus for the X-ray detection available at the facility is described together with the experimental setup for the generation of betatron radiation.

Free Electron Laser as a tool for fundamental quantum physics

Dattoli, Giuseppe; Nguyen, Federico
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION B 402, 336 – 338 (JUL 2017)
https://doi.org/10.1016/j.nimb.2017.03.044

FEL radiation properties are considered through a quantum interaction picture.

A source to deliver mesoscopic particles for laser plasma studies

Gopal, R.; Kumar, R.; Anand, M.; Kulkarni, A.; Singh, D. P.; Krishnan, S. R.; Sharma, V.; Krishnamurthy, M.
REVIEW OF SCIENTIFIC INSTRUMENTS 88(2), 023301 (FEB 2017)
https://doi.org/10.1063/1.4974973

Intense ultrashort laser produced plasmas are a source for high brightness, short burst of X-rays, electrons, and high energy ions. Laser energy absorption and its disbursement strongly depend on the laser parameters and also on the initial size and shape of the target. The ability to change the shape, size, and material composition of the matter that absorbs light is of paramount importance not only from a fundamental physics point of view but also for potentially developing laser plasma sources tailored for specific applications. The idea of preparing mesoscopic particles of desired size/shape and suspending them in vacuum for laser plasma acceleration is a sparsely explored domain. In the following report we outline the development of a delivery mechanism of microparticles into an effusive jet in vacuum for laser plasma studies. We characterise the device in terms of particle density, particle size distribution, and duration of operation under conditions suitable for laser plasma studies. We also present the first results of x-ray emission from micro crystals of boric acid that extends to 100 keV even under relatively mild intensities of 10^{16} W/cm^2. *Published by AIP Publishing.*

Specific features of betatron oscillations and betatron emission in a hollow-channel plasma

Golovanov, A. A.; Kostyukov, I. Yu.
QUANTUM ELECTRONICS 47(3), 188 – 193 (2017)
https://doi.org/10.1070/QEL16305

Transverse betatron oscillations and the corresponding betatron emission are investigated for electrons in a strongly nonlinear wake wave excited by a high-power laser pulse in a hollowchannel plasma. The expressions for the oscillation period and critical frequency in the synchrotron regime of betatron emission are derived. A two-stage scheme is considered, in which an electron bunch formed in a plasma possessing a certain set of parameters generates betatron emission in a plasma possessing another set of parameters. The emission spectrum at the second stage is calculated in the absence of bunch acceleration.

Wakefields studies for the SXFEL user facility

Song, Ming-Hao; Feng, Chao; Huang, Da-Zhang; Deng, Hai-Xiao; Liu, Bo; Wang, Dong
NUCLEAR SCIENCE AND TECHNIQUES 28(7), 90 (JUL 2017)
https://doi.org/10.1007/s41365-017-0242-7

Besides the original seeded undulator line, in the soft X-ray free-electron laser (SXFEL) user facility in Shanghai, a second undulator line based on self-amplified spontaneous emission is proposed to achieve 2-nm laser pulse with extremely high brightness. In this paper, the beam energy deviation induced by the undulator wakefields is numerically calculated, and 3D and 2D results agree well with each other. The beam energy loss along the undulator degrades the expected FEL output performances, i.e., the pulse energy, radiation power and spectrum, which can be compensated with a proper taper in the undulator. Using the planned time-resolved diagnostic, a novel experiment is proposed to measure the SXFEL longitudinal wakefields.

Interaction of a relativistic electron beam with a laser pulse in the presence of a magnetized plasma medium

Hedayati, Roohollah; Jafari, Saed; Batebi, Saeed
HIGH ENERGY DENSITY PHYSICS 23, 138 – 152 (JUN 2017)
https://doi.org/10.1016/j.hedp.2017.04.002

Significant progress has been made using plasma channels to guide relativistic e-beams in magnetostatic wiggler free-electron lasers (FELs). In this regard, we study the interaction of an intense laser pulse (as a laser wiggler) with a relativistic electron beam embedded in a background of magnetized plasma. The short wavelength of the laser wiggler (~ μm) allows a higher radiation frequency to be obtained than from conventional magnetostatic wigglers. Laser-plasma interaction in a magnetized plasma channel has been studied. Numerical results reveal that the laser self-focusing and self-compression can be enhanced with increasing the external axial magnetic field strength, which leads to a decrease in the spot size of the laser beam. Hence, we employ the laser beam as a suitable laser wiggler in a FEL-device. Injection of plasma in the interaction region of a laser-wiggler-FEL suggests the possibility of producing short wavelengths (~ x-ray) using lower energy beams (~ O(10) MeV). Furthermore, this configuration has a higher tunability by controlling the plasma density in addition to the e-beam energy tunability of the conventional FELs. Effects of the external axial guide magnetic field and plasma medium on the gain of the FEL have been studied. It is found that by increasing the plasma frequency the FEL-gain increases. The effects of e-beam self-electric and self-magnetic fields on the laser gain have also been investigated in the presence of various plasma frequencies. The results indicate that in the presence of beam self-fields, the sensitivity of the gain increases in the vicinity of resonance regions. Besides, the normalized wiggler-induced self-magnetic field has been obtained which reveals that it is a positive parameter, i.e., it can act as a paramagnetic correction to the wiggler magnetic field, therefore, the gain enhancement can be due to the paramagnetic effect of the self-magnetic field. This concept opens a path toward a new source of soft x-ray pulse based on table-top plasma loaded laser wigglers.

Horizon 2020 EuPRAXIA design study

Walker, P. A. *et al*.
8TH INTERNATIONAL PARTICLE ACCELERATOR CONFERENCE (IPAC 2017)
Journal of Physics Conference Series 874, 012029 (2017)
https://doi.org/10.1088/1742-6596/874/1/012029

The Horizon 2020 Project EuPRAXIA ("European Plasma Research Accelerator with eXcellence In Applications") is preparing a conceptual design report of a highly compact and cost-effective European facility with multi-GeV electron beams using plasma as the acceleration medium. The accelerator facility will be based on a laser and/or a beam driven plasma acceleration approach and will be used for photon science, high-energy physics (HEP) detector tests, and other applications such as compact X-ray sources for medical imaging or material processing. EuPRAXIA started in November 2015 and will deliver the design report in October 2019. EuPRAXIA aims to be included on the ESFRI roadmap in 2020.

Gas-filled capillaries for plasma-based accelerators

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Journal of Physics Conference Series 874, 012036 (2017)
https://doi.org/10.1088/1742-6596/874/1/012036

Plasma Wakefield Accelerators are based on the excitation of large amplitude plasma waves excited by either a laser or a particle driver beam. The amplitude of the waves, as well as their spatial dimensions and the consequent accelerating gradient depend strongly on the background electron density along the path of the accelerated particles. The process needs stable and reliable plasma sources, whose density profile must be controlled and properly engineered to ensure the appropriate accelerating mechanism. Plasma confinement

inside gas filled capillaries have been studied in the past since this technique allows to control the evolution of the plasma, ensuring a stable and repeatable plasma density distribution during the interaction with the drivers. Moreover, in a gas filled capillary plasma can be pre-ionized by a current discharge to avoid ionization losses. Different capillary geometries have been studied to allow the proper temporal and spatial evolution of the plasma along the acceleration length. Results of this analysis obtained by varying the length and the number of gas inlets will be presented.

External injection into a laser-driven plasma accelerator with sub-femtosecond timing jitter

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8TH INTERNATIONAL PARTICLE ACCELERATOR CONFERENCE (IPAC 2017)
Journal of Physics Conference Series 874, 012032 (2017)
https://doi.org/10.1088/1742-6596/874/1/012032

The use of external injection in plasma acceleration is attractive due to the high control over the electron beam parameters, which can be tailored to meet the plasma requirements and therefore preserve its quality during acceleration. However, using this technique requires an extremely fine synchronization between the driver and witness beams. In this paper, we present a new scheme for external injection in a laser-driven plasma accelerator that would allow, for the first time, sub-femtosecond timing jitter between laser pulse and electron beam.

Wide-angle electron beams from laser-wakefield accelerators

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LASER ACCELERATION OF ELECTRONS, PROTONS, AND IONS IV
Proceedings of SPIE 10240, 102400P (APR 2017)
https://doi.org/10.1117/12.2269314

Advances in laser technology have driven the development of laser-wakefield accelerators, compact devices that are capable of accelerating electrons to GeV energies over centimetre distances by exploiting the strong electric field gradients arising from the interaction of intense laser pulses with an underdense plasma. A side-effect of this acceleration mechanism is the production of high-charge, low-energy electron beams at wide angles. Here we present an experimental and numerical study of the properties of these wide-angle electron beams, and show that they carry off a significant fraction of the energy transferred from the laser to the plasma. These high-charge, wide-angle beams can also cause damage to laser-wakefield accelerators based on capillaries, as well as become source of unwanted bremsstrahlung radiation.

High-Quality electron bunch production for high-brilliance Thomson Scattering sources

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LASER ACCELERATION OF ELECTRONS, PROTONS, AND IONS IV
Proceedings of SPIE 10240, 102400T (APR 2017)
https://doi.org/10.1117/12.2266938

Laser Wake Field accelerated electrons need to exhibit a good beam-quality to comply with requirements of FEL or high brilliance Thomson Scattering sources, or to be post-accelerated in a further LWFA stage towards TeV energy scale. Controlling electron injection, plasma density profile and laser pulse evolution are therefore crucial tasks for high-quality e-bunch production. A new bunch injection scheme, the Resonant Multi-Pulse Ionization Injection (RMPII), is based on a single, ultrashort Ti:Sa laser system. In the RMPII the main portion of the pulse is temporally shaped as a sequence of resonant sub-pulses, while a minor portion acts as an ionizing pulse. Simulations show that high-quality electron bunches with energies in the range 265MeV - 1.15GeV, normalized emittance as low as 0.08 mm.mrad and 0.65% energy spread can be obtained with a single 250 TW Ti:Sa laser system. Applications of the e-beam in high-brilliance Thomson Scattering source, including 1.5 - 26.4 MeV gamma sources with peak brilliance up to 10^{28}ph/(s mm^2 $mrad^2$ 0.1%bw), are reported.

Laser-assisted capillary discharge for enhanced guiding of tightly-focused laser pulses at low densities

Daniels, J.; Gonsalves, A. J.; Pieronek, C. V.; Benedetti, C.; Nakamura, K.; Mao, H. -S; Bulanov, S. S.; Schroeder, C. B.; Steinke, S.; Toth, C.; Leemans, W. P.
LASER ACCELERATION OF ELECTRONS, PROTONS, AND IONS IV
Proceedings of SPIE 10240, 102400N (2017)
https://doi.org/10.1117/12.2267432

Laser-plasma accelerators (LPAs) rely on intense laser fields that create wakes in plasmas. Advancement in the field of LPAs depends on extending the laser-plasma interaction length. State-of-the-art accelerators make use of laser guiding by capillary discharge channels. The transverse density profile (channel depth) of such channels confines the laser, and the on-axis density determines the energy transfer to the wake. The transverse profile can be controlled by choosing the radius of the capillary, but laser-induced capillary damage occurs when the radius is reduced to achieve the required channel depth. Both the on-axis density and the transverse profile depend on the pressure inside the capillary before discharge. As the pressure is reduced to increase the interaction length, confinement of the laser beam is reduced. A scheme to improve laser guiding at low densities by locally heating the plasma with a secondary, nanosecond-scale heater laser has been implemented, and preliminary results are presented here. Heating of the plasma and modified confinement of the main laser pulse have been demonstrated.

Optimization of the electron beam properties from intense laser pulses interacting with structured gas jets

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LASER ACCELERATION OF ELECTRONS, PROTONS, AND IONS IV
Proceedings of SPIE 10240, 1024001 (2017)
https://doi.org/10.1117/12.2266276

Laser plasma acceleration has been intensely investigated for its ability to produce energetic, ultrashort electron bunches in a compact distance. A high intensity laser pulse propagating through a plasma expels the electrons from the optical axis via the ponderomotive force, leaving behind a column of ions and driving a density wake. The accelerating electric fields present in the wake can reach several orders of magnitude greater than those found in radio-frequency cavities, allowing for compact systems much smaller than those using conventional accelerators. This compact source can provide electrons for various applications including stages for a high energy collider or for production of x-ray pulses from coherent undulator radiation. However, these applications require tunable, stable and high-quality electron beams.; We report on a study of controlled injection along a shock-induced density downramp of laser-plasma accelerated electrons through precision tailoring of the density profile produced from a mm-scale gas jet. Using BELLA Center's TREX Ti:Sapphire laser, the effects of the plasma density profile and the tilt of the shock front on the beam spatial profile, steering, and energy were investigated experimentally. To explain these relationships, we propose simple models which agree well with experimental results. Using this technique, electron beam quality was tailored, allowing for the production of high-quality electron beams with percent-level energy spreads over a range of energies.

On the energy-momentum tensor of light in strong fields: an all optical view of the Abraham-Minkowski controversy

Macleod, Alexander J.; Noble, Adam; Jaroszynski, Dino A.
RELATIVISTIC PLASMA WAVES & PARTICLE BEAMS AS COHERENT AND INCOHERENT RADIATION SOURCES II
Proceedings of SPIE 10234, 102340F (APR 2017)
https://doi.org/10.1117/12.2269630

The Abraham-Minkowski controversy is the debate surrounding the "correct" form of the energy-momentum tensor of light in a medium. Over a century of theoretical and experimental studies have consistently produced conflicting results, with no consensus being found on how best to describe the influence of a material on the propagation of light. It has been argued that the total energy-momentum tensor for each of the theories, which includes both wave and material components, are equal. The difficulty in separating the full energy-momentum tensor is generally attributed to the fact that one cannot obtain the energy-momentum tensor of the medium for real materials. Non-linear electrodynamics provides an opportunity to approach the debate from an all optical set up, where the role of the medium is replaced by the vacuum under the influence of a strong background field. We derive, from first principles, the general form of the energy-momentum tensor in such theories, and use our results to shed some light on this long standing issue.

Electron beam cooling in intense focussed laser pulses

Yoffe, Samuel R.; Noble, Adam; Macleod, Alexander J.; Jaroszynski, Dino A.
RELATIVISTIC PLASMA WAVES & PARTICLE BEAMS AS COHERENT AND INCOHERENT RADIATION SOURCES II
Proceedings of SPIE 10234, 102340E (2017)
https://doi.org/10.1117/12.2265812

In the coming years, a new generation of high-power laser facilities (such as the Extreme Light Infrastructure) will become operational, for which it is important to understand how the interaction with intense laser pulses affects the bulk properties of relativistic electron bunches. At such high field intensities, we expect both radiation reaction and quantum effects to have a dominant role to play in determining the dynamics. The reduction in relative energy spread (beam cooling) at the expense of mean beam energy predicted by classical theories of radiation reaction has been shown to occur equally in the longitudinal and transverse directions, whereas this symmetry is broken when the theory is extended to approximate certain quantum effects. The reduction in longitudinal cooling suggests that the effects of radiation reaction could be better observed in measurements of the transverse distribution, which for real-world laser pulses motivates the investigation of the angular dependence of the interaction. Using a stochastic single-photon emission model with a (Gaussian beam) focussed pulse, we find strong angular dependence of the stochastic heating.

Summary Report of Working Group1: Laser-Plasma Wakefield Acceleration

Gonsalves, Anthony; Pollock, Bradley; Lu, Wei
ADVANCED ACCELERATOR CONCEPTS
AIP Conference Proceedings 1812, 030001 (2017)
https://doi.org/10.1063/1.4975840

The work presented in the laser-plasma acceleration working group at the 2016 Advanced Accelerator Concepts (AAC) Workshop is summarized. Some of the highlights include: direct visualization of the electric and magnetic fields using a LPA (laser plasma accelerator) electron probe, offering transverse snapshots of the wakefield even for very low density; first demonstration of multi-pulse LPA and wakefield cancellation with a trailing pulse (first step to energy recovery); and control over the shock front angle to optimize density transition injection, which provides stable and low-energy-spread beams that are critical for increasing the efficiency of the recently presented staged LPA. Interesting ongoing and future work discussed included LPAs driven by CO2 lasers and scaling to 10 GeV with and without optical guiding. Further details on each of these topics can be found in the respective papers in these Proceedings.

Diagnostics and Controls for Spatiotemporal Couplings for Laser-Plasma Accelerator Drivers

Nakamura, K.; Vincenti, H.; Mittelberger, D. E.; Mao, H-S.; Gonsalves, A. J.; Toth, C.; Leemans, W. P.
ADVANCED ACCELERATOR CONCEPTS
AIP Conference Proceedings 1812, 110008 (2017)
https://doi.org/10.1063/1.4975921

Diagnostic and control of spatiotemporal couplings for laser-plasma acceleration drive lasers are discussed. Near-field angular dispersion and spatial chirp were measured by GRENOUILLE. The calculation of the pulse front tilt evolution is presented, and it is shown that the pulse front angle near focus can be controlled within 5 mrad, and finely tuned through temporal chirp.

Concept of a Staged FEL Enabled by Fast Synchrotron Radiation Cooling of Laser-Plasma Accelerated Beam by Solenoidal Magnetic Fields in Plasma Bubble

Seryi, Andrei; Lesz, Zsolt; Andreev, Alexander; Konoplev, Ivan
ADVANCED ACCELERATOR CONCEPTS
AIP Conference Proceedings 1812, 040003-1 (2017)
https://doi.org/10.1063/1.4975850

A novel method for generating GigaGauss solenoidal fields in a laser-plasma bubble, using screw-shaped laser pulses, has been recently presented. Such magnetic fields enable fast synchrotron radiation cooling of the beam emittance of laser-plasma accelerated leptons. This recent finding opens a novel approach for design of laser-plasma FELs or colliders, where the acceleration stages are interleaved with laser-plasma emittance cooling stages. In this concept paper, we present an outline of what a staged plasma-acceleration FEL could look like, and discuss further studies needed to investigate the feasibility of the concept in detail.

Staging and Laser Acceleration of Ions in Underdense Plasma

Ting, A.; Hafizi, B.; Helle, M.; Chen, Y.-H.; Gordon, D.; Kaganovich, D.; Polyanskiy, M.; Pogorelsky, I.; Babzien, M.; Miao, C.; Dover, N.; Najmudin, Z.; Ettlinger, O.
ADVANCED ACCELERATOR CONCEPTS
AIP Conference Proceedings 1812, 020001 (2017)
https://doi.org/10.1063/1.4975837

Accelerating ions from rest in a plasma requires extra considerations because of their heavy mass. Low phase velocity fields or quasi-electrostatic fields are often necessary, either by operating above or near the critical density or by applying other slow wave generating mechanisms. Solid targets have been a favorite and have generated many good results. High density gas targets have also been reported to produce energetic ions. It is interesting to consider acceleration of ions in laser-driven plasma configurations that will potentially allow continuous acceleration in multiple consecutive stages. The plasma will be derived from gaseous targets, producing plasma densities slightly below the critical plasma density (underdense) for the driving laser. Such a plasma is experimentally robust, being repeatable and relatively transparent to externally injected ions from a previous stage. When optimized, multiple stages of this underdense laser plasma acceleration mechanism can progressively accelerate the ions to a high final energy. For a light mass ion such as the proton, relativistic velocities could be reached, making it suitable for further acceleration by high phase velocity plasma accelerators to energies appropriate for High Energy Physics applications. Negatively charged ions such as antiprotons could be similarly accelerated in this multi-staged ion acceleration scheme.

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.