FOREWORD

This is the second issue of the quarterly newsletter for members and friends of the AWAKE-UK collaboration, with abstracts of published articles that are relevant to the AWAKE project. The list is by no means exhaustive and its purpose is to facilitate your research and continue to strengthen the AWAKE-UK community. If you have any suggestion or an article that should be included in the next issue, please send an email to the address at the end of this newsletter.

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FUNDAMENTALS

Photon Acceleration from Optical to XUV

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

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

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

Saberi, Hossein; Xia, Guoxing; Islam, Mohammad R. R.; Liang, Linbo; Davut, Can
PHYSICS OF PLASMAS 30(4), 043104 (2023)
https://doi.org/10.1063/5.0140525

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

Progress in Hybrid Plasma Wakefield Acceleration

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

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

PLASMA TECHNOLOGY

TeV/m catapult acceleration of electrons in graphene layers

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

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

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

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

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

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

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

Charged particle acceleration using solid-state nanostructures has attracted attention in recent years as a method of achieving ultra-high-gradient acceleration in the TV/m domain. More concretely, metallic hollow nanostructures could be suitable for particle acceleration through the excitation of wakefields by a laser or a high-intensity charged particle beam in a high-density solid-state plasma. For instance, due to their special channeling properties as well as optoelectronic and thermo-mechanical properties, carbon nanotubes could

be an excellent medium for this purpose. This article investigates the feasibility of generating ultra-high-gradient acceleration using carbon nanotube arrays, modeled as solid-state plasmas in conventional particle-in-cell simulations performed in a two-dimensional axisymmetric (quasi-3D) geometry. The generation of beam-driven plasma wakefields depending on different parameters of the solid structure is discussed in detail. Furthermore, by adopting an effective plasma-density approach, existing analytical expressions, originally derived for homogeneous plasmas, can be used to describe wakefields driven in periodic non-uniform plasmas.

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

Siy, A.; Behdad, N.; Booske, J.; Waldschmidt, G.; Zholents, A.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 26(1), 012802 (2023)
https://doi.org/10.1103/PhysRevAccelBeams.26.012802

The electromagnetic design of a transition section consisting of couplers for extracting the 180-GHz TM01 accelerating mode and 190-GHz HE11 dipole mode of a cylindrical corrugated waveguide used as a collinear wakefield accelerator is presented. Extraction of the high power accelerating mode reduces the power dissipation in the corrugated accelerating structure and allows the much weaker HE11 mode to be isolated and used to monitor the stability of the 10-nC electron drive bunch. The final design demonstrates wide bandwidth and high coupling efficiency of two couplers. The design was also optimized to have the surface electric and magnetic fields that do not exceed those in the corrugated waveguide. Finally, coupling between the drive electron bunch and the HE11 dipole mode in the corrugated waveguide is considered and the utility of the TE11 coupler for detecting the electron beam oscillations in the wakefield accelerator is demonstrated using a few representative examples of oscillations below and above a threshold of the beam breakup instability.

Underdense plasma lens with a transverse density gradient

Doss, C. E.; Ariniello, R.; Cary, J. R.; Corde, S.; Ekerfelt, H.; Gerstmayr, E.; Gessner, S. J.; Gilljohann, M.; Hansel, C.; Hidding, B.; Hogan, M. J.; Knetsch, A.; Lee, V.; Marsh, K.; O'Shea, B.; Claveria, P. San Miguel; Storey, D.; Sutherland, A.; Zhang, C.; Litos, M. D.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 26(3), 031302 (2023)
https://doi.org/10.1103/PhysRevAccelBeams.26.031302

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

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

Deng, Hongyang; Zhang, Ziyang; Chen, Min; Li, Jianlong; Cao, Qiang; Hu, Xuejiao
MATERIALS 16(8), 3278 (2023)
https://doi.org/10.3390/ma16083278

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

DIAGNOSTICS

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

Li, Cheng; Zhang, Haoran; Guo, Zixin; Xu, Xiazhen; He, Zhigang; Zhang, Shancai; Jia, Qika; Wang, Lin
NEW JOURNAL OF PHYSICS 25(1), 013024 (2023)
https://doi.org/10.1088/1367-2630/acb37b

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

Diagnosis of ultrafast surface dynamics of thin foil targets irradiated by intense laser pulses

Bae, L. J.; Kang, G. B.; Kim, M.; Lee, G. S.; Sohn, J. H.; Nam, C. H.; Cho, B. I.
OPTICS EXPRESS 31(4), 5767-5776 (2023)
https://doi.org/10.1364/OE.474759Journal

The temporal modulation of an electron bunch train accelerated from a foil target irradiated by an intense laser pulse is studied by measuring the coherent transition radiation (CTR) from the rear surface of a target. We experimentally obtained CTR spectra from a 1 μm thick foil target irradiated at a maximum intensity of 6.5 x 10^{19} W/cm^2. Spectral redshifts of the emitted radiation corresponding to increases in laser intensity were observed. These measurements were compared with the theoretical calculation of CTR spectra considering ultrafast surface dynamics, such as plasma surface oscillation and relativistically induced transparency. Plasma surface oscillations induce a spectral redshift, while relativistic transparency causes a spectral blueshift. Both effects are required to find reasonable agreement with the experiment over the entire range of laser intensities.

Direction-dependent polarization modulation of Cherenkov diffraction radiation based on metasurfaces

Xu, Wenxia; Li, Wenjia; Jiang, Zhaoqi; Sun, Botian; Qin, Chunhua; Lv, Bo; Guan, Chunying; Liu, Jianlong; Shi, Jinhui
JOURNAL OF APPLIED PHYSICS 132(11), 113101 (2022)
https://doi.org/10.1063/5.0109322

The polarization modulation of Cherenkov diffraction radiation facilitates intriguing potentials to explore material properties and advanced technologies such as free-electron lasers; however, it is still challenging to achieve polarization modulation. Here, we propose versatile on-chip silicon-patterned silicon-nitride photonic integrated waveguides to produce a direction-dependent polarization modulator for Cherenkov diffraction radiation. The radiation angle can be manipulated arbitrarily by arranging the period of the grating and the propagation direction of the electron beam. Furthermore, the polarization and the number of output directions of the radiation can be controlled by the gradient metasurfaces. In particular, the linear, left-, and right-handed circular polarized Cherenkov diffraction radiation could be generated in separate radiation directions. Our results pave the way to modulate the polarization of free-electron radiation and further promote the development of on-chip light sources.

Sub-micron normalized emittance measurement for a MeV continuous-wave electron gun

Tan, Tao; Jia, Haoyan; Zhao, Sheng; Li, Tianyi; Wang, Tianyi; Liu, Zhongqi; Zhang, Xiang; Huang, Senlin; Lin, Lin; Feng, Liwen; Xie, Huamu; Quan, Shengwen; Liu, Kexin
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS; SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1145, 167552 (2023)
https://doi.org/10.1016/j.nima.2022.167552

Continuous-wave (CW) electron sources with sub-micron normalized emittance are of critical importance for advanced linear accelerator based light sources. The DC-SRF-II gun, designed as such a source, has been newly constructed and brought into operation. To characterize the performance of the gun, we have developed an emittance measurement system based upon single slit scanning method under a dedicated beam diagnostics mode. With this system, the measurement of sub-micron normalized emittance, together with a reconstruction of the phase space distribution, has been achieved with high reproducibility. This paper presents a detailed description of the system.

Detector challenges of the strong-field QED experiment LUXE at the European XFEL

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS; SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1043, 167494 (2022)
https://doi.org/10.1016/j.nima.2022.167494

The LUXE experiment aims at studying high-field QED in electron-laser and photon-laser interactions, with the 16.5 GeV electron beam of the European XFEL and a laser beam with power of up to 350 TW. The experiment will measure the spectra of electrons, positrons and photons in the expected range of 10^{-3} to 10^{9} per 1 Hz bunch crossing, depending on the laser power and focus. These measurements have to be performed in the presence of low-energy high radiation-background. To meet these challenges, for high-rate electron and photon fluxes, the experiment will use Cherenkov radiation detectors, scintillator screens, sapphire sensors as well as lead-glass monitors for backscattering off the beam-dump. A four-layer silicon-

pixel tracker and a compact electromagnetic tungsten calorimeter with GaAs sensors will be used to measure the positron spectra. The layout of the experiment and the expected performance under the harsh radiation conditions, together with the test of the Cherenkov detector and the electromagnetic (EM) calorimeter performed recently at DESY, are presented. The experiment received a stage 0 critical approval (CD0) from the DESY management and is in the process of preparing its technical design report (TDR). It is expected to start running in 2025/2026.

Measurement of the longitudinal bunch-shape distribution for a high-intensity negative hydrogen ion beam in the low-energy region

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PHYSICAL REVIEW ACCELERATORS AND BEAMS 26(3), 032802 (2023)
https://doi.org/10.1103/PhysRevAccelBeams.26.032802

A bunch-shape monitor (BSM) is a useful device for performing longitudinal beam tuning using the pointwise longitudinal phase distribution measured at selected points in the beam transportation. To measure the longitudinal phase distribution of a low-energy negative hydrogen (H-) ion beam, highly oriented pyrolytic graphite (HOPG) was adopted for the secondary-electron-emission target to mitigate the thermal damage due to the high-intensity beam loading. The HOPG target enabled the measurement of the longitudinal phase distribution at the center of a 3-MeV H- ion beam with a high peak current of about 50 mA. The longitudinal bunch width was measured using HOPG-BSM at the test stand, which was consistent with the beam simulation. The correlation measurement between the beam transverse and longitudinal planes was demonstrated using HOPG-BSM. The longitudinal Twiss and emittance measurement with the longitudinal Q-scan method was conducted using HOPG-BSM. The measured longitudinal emittance is consistent with the beam simulation using the radio-frequency quadrupole design input.

FOCUS: fast Monte Carlo approach to coherence of undulator sources

Siano, M.; Geloni, G.; Paroli, B.; Butti, D.; Lefevre, T.; Mazzoni, S.; Trad, G.; Iriso, U.; Nosych, A. A.; Torino, L.; Potenza, M. A. C.
JOURNAL OF SYNCHROTRON RADIATION 30, 217-226 (2023)
https://doi.org/10.1107/S1600577522010748

FOCUS (Fast Monte CarlO approach to Coherence of Undulator Sources) is a new GPU-based simulation code to compute the transverse coherence of undulator radiation from ultra-relativistic electrons. The core structure of the code, which is written in the language C++ accelerated with CUDA, combines an analytical description of the emitted electric fields and massively parallel computations on GPUs. The combination is rigorously justified by a statistical description of synchrotron radiation based on a Fourier optics approach. FOCUS is validated by direct comparison with multi-electron Synchrotron Radiation Workshop (SRW) simulations, evidencing a reduction in computation times by up to five orders of magnitude on a consumer laptop. FOCUS is then applied to systematically study the transverse coherence in typical third- and fourth-generation facilities, highlighting peculiar features of undulator sources close to the diffraction limit. FOCUS is aimed at fast evaluation of the transverse coherence of undulator radiation as a function of the electron beam parameters, to support and help prepare more advanced and detailed numerical simulations with traditional codes like SRW.

Average and statistical properties of coherent radiation from steady-state microbunching

Deng, X. J.; Zhang, Y.; Pan, Z. L.; Li, Z. Z.; Bian, J. H.; Tsai, C-Y; Li, R. K.; Chao, A. W.; Huang, W. H.; Tang, C. X.
JOURNAL OF SYNCHROTRON RADIATION 30, 35-50 (2023)
https://doi.org/10.1107/S1600577522009973

A promising accelerator light source mechanism called steady-state microbunching (SSMB) is being actively studied. With the combination of strong coherent radiation from microbunching and high repetition rate of a storage ring, high-average-power narrow-band radiation can be anticipated from an SSMB storage ring, with wavelengths ranging from THz to soft X-ray. Such a novel light source could provide new opportunities for accelerator photon science like high-resolution angle-resolved photoemission spectroscopy and industrial applications like extreme ultraviolet (EUV) lithography. In this paper, a theoretical and numerical study of the average and statistical properties of coherent radiation from SSMB are presented. The results show that 1 kW average-power quasi-continuous-wave EUV radiation can be obtained from an SSMB ring provided that an average current of 1 A and a microbunch train with bunch length of 3 nm can be formed at the radiator which is assumed to be an undulator. Together with the narrow-band feature, the EUV photon flux can reach 6×10^{15} photons s^{-1} within a 0.1 meV energy bandwidth, which is three orders of magnitude higher than that in a conventional synchrotron source and is appealing for fundamental condensed matter physics and other research. In this theoretical investigation, we have generalized the definition and derivation of the transverse form factor of an electron beam which can quantify the impact of its transverse size on coherent radiation. In particular, it has been shown that the narrow-band feature of SSMB radiation is strongly correlated with the finite transverse electron beam size. Considering the pointlike nature of electrons and quantum nature of radiation, the coherent radiation fluctuates from microbunch to microbunch, or for a single microbunch from turn to turn. Some important results concerning the statistical properties of SSMB radiation are presented, with a brief discussion on its potential applications, for example the beam diagnostics. The presented work is of value for the development of SSMB to better serve potential synchrotron radiation users. In addition, this also sheds light on understanding the radiation characteristics of free-electron lasers, coherent harmonic generation, etc.

Monochromatic Optical Cherenkov Radiation of Moderately Relativistic Ions in Radiators with Frequency Dispersion

Potylitsyn, A. P.; Alekseev, B. A.; Vukolov, A. V.; Shevelev, M., V; Baldin, A. A.; Bleko, V. V.; Karataev, P., V; Kubankin, A. S.
JETP LETTERS 115(8), 439-443 (2022)
https://doi.org/10.1134/S0021364022100393

Optical Cherenkov radiation of moderately relativistic ions in a CVD-diamond plate with frequency dispersion is considered. It has been shown that Cherenkov radiation extracted from the inclined diamond plate to vacuum at a fixed observation angle becomes monochromatic. The wavelength of the spectral line depends on the energy of an ion and on the geometry of an experiment (observation angle and plate inclination angle). An experiment has been proposed to study the monochromatization of Cherenkov radiation on the beam of the JINR Nuclotron for the purpose of its subsequent use in the diagnostics of ion beams. The method can be applied to monitor the NICA ion beams energy.

Observation of quasi-monochromatic resonant Cherenkov diffraction radiation

Karataev, P.; Naumenko, G.; Potylitsyn, A.; Shevelev, M.; Artyomov, K.
RESULTS IN PHYSICS 33), 105079 (2022)
https://doi.org/10.1016/j.rinp.2021.105079

The first observation and investigation of a new mechanism of resonant Cherenkov diffraction radiation appearing when relativistic 6 MeV electrons move alongside a periodically shaped Teflon target have been presented and analysed. Numerical simulations performed using computer code KARAT are in good agreement with the experimental results. This new mechanism is a promising technique for generation and monochromatisation of THz and sub-THz radiation beams that could be integrated into any short bunch linear accelerator facility including 4th generation light sources providing new opportunities for user community.

BEAMLINES & APPLICATIONS

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

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

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

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

Krim, Deae-eddine; Rrhioua, Abdeslem; Zerfaoui, Mustapha; Bakari, Dikra
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS; SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1047, 167785 (2023)
https://doi.org/10.1016/j.nima.2022.167785

After the invention of the Linear Electron Accelerator for Research (CLEAR) based on the Advanced Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE) at CERN, the development of an accurate and accessible high energy electron radiotherapy treatment is a major challenge in medical physics. The technological advances of the linear collider and the relativistic effects of Very High Energy Electron (VHEE) particles; have led researchers to propose a simple management of collimated beams in the energy range of 50-250 MeV to reduce scattering and enable irradiation of deep-seated tumor position. However, the measured entry and exit doses and lateral scattering for collimated VHEE beams treatment are very high compared with other treatment modalities. This task provides a new approach based on focused VHEE obtained by combining an accurate Monte Carlo (MC) simulation with a complex modeling electron transport with very high energy inside a water phantom. This focused VHEE is compared to stereotactic cyberknife, protontherapy and VHEE treatment using a collimator. The results demonstrated that radiotherapy with a focused VHEE beam of energy greater than 100 MeV can surround deep-seated and highly inhomogeneous tumors with great accuracy. It could represent a valid alternative for a better preservation of healthy tissues, since the dispersion of the dose over a large volume reduces the entry and exit dose. Moreover, this approach can be shaped or scanned to treat deep-seated tumors, as the dose will be concentrated into a small well-defined volumetric element.

Quasi-Alvarez drift-tube linac structures for heavy ion therapy accelerator facilities

Khalvati, Mohammad Reza; Bencini, Vittorio; Ramberger, Suitbert
PHYSICAL REVIEW ACCELERATORS AND BEAMS 26(2), 022001 (2023)
https://doi.org/10.1103/PhysRevAccelBeams.26.022001

Next generation heavy ion therapy and research facilities require efficient accelerating structures. Particularly, at low beam energies, right after the standard scheme of the ion source, low-energy beam transfer, and radio-frequency quadrupole (RFQ), several options for accelerating structures are available including the classic drift-tube linac (DTL), the interdigital H-mode DTL (IH-DTL), and superconducting quarter-wave resonators. These structures need to integrate the beam acceleration with the focusing channel, nowadays typically provided by permanent-magnet quadrupoles (PMQs). The frequency of operation needs to be in line with that of the RFQ structure, and it has been chosen at 750 MHz for practical considerations for the Next Ion Medical Machine Study (NIMMS) that is the application focus of this manuscript. While classic DTL structures at low ion beam energies do not provide enough space for PMQs at that frequency within a single beta lambda period, IH-DTL structures do not provide the regular focusing channel with consequences on the beam quality. For these reasons, quasi-Alvarez drift-tube linac (QA-DTL) structures are reevaluated in this manuscript as they might fill this gap. They have not received much attention in the literature far and therefore their design is described in detail. The design procedure presented here may serve as a blueprint for DTL design in general. In addition to the overall rf design, axial field stabilization with a new technique and multiphysics studies of the rf structure are described. A cost estimation completes the NIMMS QA-DTL study.

THEORY & SIMULATION

Energy-Conserving Theory of the Blowout Regime of Plasma Wakefield

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

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

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

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

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

Laser wakefield accelerator modelling with variational neural networks

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

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

FACILITIES

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

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

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

Longitudinal mode-coupling instabilities of proton bunches in the CERN Super Proton Synchrotron

Karpov, Ivan
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In this paper, we study single-bunch instabilities observed in the CERN Super Proton Synchrotron (SPS). According to the linearized Vlasov theory, radial or azimuthal mode-coupling instabilities result from a coupling of bunch-oscillation modes, which belong to either the same or adjacent azimuthal modes, respectively. We show that both instability mechanisms exist in the SPS by applying the Oide-Yokoya approach to compute van Kampen modes for the realistic longitudinal impedance model of the SPS. The results agree with macroparticle simulations and are consistent with beam measurements. In particular, we see that the uncontrolled longitudinal emittance blowup of single bunches observed before the recent impedance reduction campaign (2018-2021) is due to the radial mode-coupling instability. Unexpectedly, this instability is as strong as the azimuthal mode-coupling instability, which is possible in the SPS for other combinations of bunch length and intensity. We also demonstrate the significant role of rf nonlinearity and potential-well distortion in determining these instability thresholds. Finally, we discuss the effect of the recent impedance reduction campaign on beam stability in single-and double-rf configurations.

EDUCATION

Surfatron: Catch the wave of accelerators.

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

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

***WAKE up* is a collection of publicly available abstracts from published papers that are relevant to the AWAKE project. 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.awake-uk.org