FOREWORD

This is the third 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.

CONTENTS

FUNDAMENTALS

Progress in hybrid plasma wakefield acceleration

Hidding, B.; Assmann, R.; Bussmann, M.; Campbell, D.; Chang, Y.-Y.; Corde, S.; Couperus Cabadağ, J.; Debus, A.; Döpp, A.; Gilljohann, M.; Götzfried, J.; Foerster, F.M.; Haberstroh, F.; Habib, F.; Heinemann, T.; Hollatz, D.; Irman, A.; Kaluza, M.; Karsch, S.; Kononenko, O.; Knetsch, A.; Kurz, T.; Kuschel, S.; Köhler, A.; Martinez de la Ossa, A.; Nutter, A.; Pausch, R.; Raj, G.; Schramm, U.; Schöbel, S.; Seidel, A.; Steiniger, K.; Ufer, P.; Yeung, M.; Zarini, O.; Zepf, M.
PHOTONICS 10, 99 (JAN 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.

BEAMLINES & APPLICATIONS

Characteristics of betatron radiation in AWAKE Run 2 experiment

Liang, Linbo; Saberi, Hossein; Xia, Guoxing; Farmer, John Patrick; Pukhov, Alexander
JOURNAL OF PLASMA PHYSICS 89(3), 965890301 (JUN 2023)
https://doi.org/10.1017/S0022377823000491

The oscillating relativistic electrons in the accelerating/focusing wakefields of plasma accelerators emit electromagnetic radiation known as betatron radiation (BR). The proton-driven plasma wakefield acceleration has been demonstrated in the Advanced Wakefield Experiment (AWAKE) at CERN; however, its accompanying radiation emission is less explored compared with those in the laser- and electron beam-driven plasma accelerators. In this paper, a detailed simulation study of BR in the AWAKE is presented. Considering the new set-up of the AWAKE Run 2 (2021-), the radiation emission from both the witness electron beam and the seeding electron beam is investigated using particle-in-cell simulations. The influence of radial size mismatch and misaligned off-axis injection on the witness beam dynamics, as well as the spectral features of the relevant BR are studied. These non-ideal electron injections are likely to occur in experiment. The proton self-modulation stage is also investigated with a close look at the seeding electron beam dynamics and its BR. As a footprint of the emitting particles, BR can provide valuable information about the beam dynamics. Some practical challenges to implement the betatron diagnostic in the AWAKE Run 2 experiment are also addressed.

Positron acceleration by terahertz wave and electron beam in plasma channel

Xu, Zhangli; Shen, Baifei; Si, Meiyu; Huang, Yongsheng
NEW JOURNAL OF PHYSICS 25(6), 063013 (JUN 2023)
https://doi.org/10.1088/1367-2630/acdc47

We present a scheme of positron acceleration by intense terahertz (THz) wave together with the driving large-charge electron beam in a plasma channel. The THz wave rapidly evolves into a transversely uniform acceleration field and a weakly focusing/defocusing lateral field in the channel. The THz wave is partially formed with the scheme of coherent transition radiation when the electron beam goes through a metal foil and partially because of the wakefield in the plasma channel. The electron beam continuously supplies energy to the THz wave. Such a field structure offers the feasibility of long-distance positron acceleration while preserving beam quality. By two-dimensional simulations, we demonstrate the acceleration of positrons from initial 1 GeV to 126.8 GeV with a charge of ~ 10 pC over a distance of 1 m. The energy spread of accelerated positrons is 2.2%. This scheme can utilize the electron beam either from laser-driven or conventional accelerators, showing prospects towards high-quality and flexible THz-driven relativistic positron sources of ~ 100 GeV.

Generation of Large-Bandwidth High-Power X-Ray Free-Electron-Laser Pulses Using a Hollow-Channel Plasma

Peng, Bo; Feng, Chao; Wang, Zhen; Hua, Jianfei; Wu, Yipeng; Deng, Haixiao; Li, Fei; Lu, Wei; Zhao, Zhentang
PHYSICAL REVIEW APPLIED 19(5), 054066 (MAY 2023)
https://doi.org/10.1103/PhysRevApplied.19.054066

Large-bandwidth x-ray free-electron-laser (XFEL) facilities are desirable scientific tools in various fields, such as molecular structural dynamics and spectroscopy diagnosis. Various methods are proposed to broaden the FEL spectra. Here, a method is proposed to generate high-power XFEL radiation of tunable spectral

bandwidth using plasma wakefield acceleration. An ultrabroad bandwidth is achieved by chirping the electron beam in a hollow-channel plasma without noticeable slice-beam-quality degradation. A dedicated beamline can match the beams with a large energy chirp in the undulators almost without beam loss. Numerical simulations demonstrate that a relative spectral bandwidth (full width) of up to 24% can be obtained with optimized beam and plasma parameters.

Temperature effects in plasma-based positron acceleration schemes using electron filaments

Diederichs, S.; Benedetti, C.; Esarey, E.; Thevenet, M.; Sinn, A.; Osterhoff, J.; Schroeder, C. B.
PHYSICS OF PLASMAS 30(7), 073104 (JUL 2023)
https://doi.org/10.1063/5.0155489

Preserving the quality of a positron beam in a plasma-based accelerator, where a wakefield suitable for positron transport and acceleration is generated by means of an electron filament, is challenging. This is due to the nature of the wakefields, characterized by focusing fields that vary nonlinearly in the transverse direction, and by accelerating fields that are non-uniform. These fields also change slice-by-slice along the beam. Maintaining a high beam quality is pivotal for application of positron beams in a plasma-based collider. In this paper, we show that an initial background plasma temperature can help mitigate the positron beam quality degradation in plasma-based accelerators that rely on electron filaments. We show that temperature effects broaden the electron filament and smooth radially both the non-linear transverse and the non-uniform longitudinal wakefields. Using warm plasmas opens up new possibilities to improve beam quality in several plasma-based positron acceleration concepts.

PLASMA TECHNOLOGY & DIAGNOSTICS

Beam characterization and optimisation for AWAKE 18 MeV electron line

Bencini, V.; Doebert, S.; Gschwendtner, E.; Granados, E.; Velotti, F.M.; Verra, L.; Zevi Della Porta, G.
Proceedings IPAC’23
https://indico.jacow.org/event/41/contributions/1204/

After the successful conclusion of Run1 in 2018, the AWAKE experiment is presently undergoing its second phase (Run2), which aims to demonstrate the possibility of producing high quality electron beams for high energy physics applications.

Over the last year, a significant time-investment was made to study proton beam centroid modulation effects in plasma induced by a seeding electron bunch (i.e. hosing). The high beam pointing accuracy needed for the study translated in tighter constraints for the 18 MeV electrons injection line. To address the new requirements, a measurements campaign was dedicated to the characterization and optimization of the beam line. In the first part of this paper, we present the results of the measurements and simulations carried out for the line characterization. The second part focuses on the description of the operational tools developed to address the new beam requirements and performance.

Electron beam studies on a beam position monitor based on Cherenkov diffraction radiation

Pakuza, C. ; Burrows, P.N.; Spear, B.; Aksoy, A.; Chritin, N.; Corsini, R.; Farabolini, W.; Korysko, P.; Krupa, M.; Lasocha, K.; Lefevre, T.; Malyzhenkov, A.; Mazzoni, S.; Schlögelhofer, A.; Senes, E.; Wendt. M.

Proceedings IPAC'23

https://indico.jacow.org/event/41/contributions/2700/

A beam position monitor based on Cherenkov diffraction radiation (ChDR BPM) is currently under investigation to disentangle the electromagnetic field of an electron bunch from that of a proton bunch travelling together in time and space in the beam-line of the AWAKE plasma acceleration experiment at CERN. The signals from a horizontal pair of ChDR BPM radiators have been studied under a variety of beam conditions at the CLEAR electron beam test facility. This paper summarizes the results using microwave signal processing at different frequency ranges.

Cherenkov diffraction radiation dielectric button characterization via a slab-line

Pakuza, C.; Wendt, M.

Proceedings IPAC'23

https://indico.jacow.org/event/41/contributions/2706/

The generation of Cherenkov diffraction radiation when a charged particle beam passes in close proximity to a dielectric target is being studied and developed for various non-invasive beam instrumentation applications. One such instrument is a beam position monitor (BPM) composed of four cylindrical dielectric inserts. A challenge of using the conventional stretched wire technique to characterize the BPM is the coupling of higher order modes (HOMs) into the inserts that are dielectric-loaded circular waveguides. To minimize the generation of HOMs and excite mainly the transverse electromagnetic (TEM) mode as a model of the beam field, a set-up comprising a dielectric insert mounted on a slab line with 50 Ohms characteristic impedance was tested. The results and comparison with numerical simulations in CST are presented.

Stability of the modulator in a plasma-modulated plasma accelerator

van de Wetering, J. J.; Hooker, S. M.; Walczak, R.

PHYSICAL REVIEW E 108(1), 015204 (JUL 2023)

https://doi.org/10.1103/PhysRevE.108.015204

We explore the regime of operation of the modulator stage of a recently proposed laser-plasma accelerator scheme [Phys. Rev. Lett. 127, 184801 (2021)], dubbed the plasma-modulated plasma accelerator (P-MoPA). The P-MoPA scheme offers a potential route to high-repetition-rate, GeV-scale plasma accelerators driven by picosecond-duration laser pulses from, for example, kilohertz thin-disk lasers. The first stage of the P-MoPA scheme is a plasma modulator in which a long, high-energy "drive" pulse is spectrally modulated by copropagating in a plasma channel with the low-amplitude plasma wave driven by a short, low-energy "seed" pulse. The spectrally modulated drive pulse is converted to a train of short pulses, by introducing dispersion, which can resonantly drive a large wakefield in a subsequent accelerator stage with the same on-axis plasma density as the modulator. In this paper we derive the 3D analytic theory for the evolution of the drive pulse in the plasma modulator and show that the spectral modulation is independent of transverse coordinate, which is ideal for compression into a pulse train. We then identify a transverse mode instability (TMI), similar to the TMI observed in optical fiber lasers, which sets limits on the energy of the drive pulse for a given set of laser-plasma parameters. We compare this analytic theory with particle-in-cell (PIC) simulations and find that even higher energy drive pulses can be modulated than those demonstrated in the original proposal.

Shot-by-shot stability of the discharge produced plasmas in suitably shaped capillaries

Arjmand, S.; Anania, M. P.; Biagioni, A.; Ferrario, M.; Del Franco, M.; Galletti, M.; Lollo, V.; Pellegrini, D.; Pompili, R.; Zigler, A.

JOURNAL OF INSTRUMENTATION 18(4), C04016 (APR 2023)
https://doi.org/10.1088/1748-0221/18/04/C04016

Compact accelerator machines are capable of producing accelerating gradients in the GV/m scale, which is significantly higher than the MV/m scale of conventional machines. As accelerators are widely used in many fields, such as industrial, research institutes, and medical applications, the development of these machines will undoubtedly have a profound impact on people's daily lives. SPARC_LAB, a test facility at INFN-LNF (Laboratori Nazionali di Frascati), is focused on enhancing particle accelerator research infrastructure using innovative plasma acceleration concepts. Within SPARC_LAB, we utilize plasma-filled capillaries with lengths of up to tens of centimeters. However, the plasma formation process is critical to ensure proper oversight of the plasma properties, which subsequently affects the dynamics of the electron bunch to be accelerated. One of the most critical points that significantly affects the properties of the electron beam passing through the plasma source is the shot-by-shot stability of the plasma density along the longitudinal dimension of the plasma-discharge capillary. Therefore, this paper aims to investigate the shot-by-shot stability of the plasma density during discharge, contributing to further advancements in the field of plasma acceleration.

Fabrication of THz corrugated wakefield structure and its high power test

Kong, H.; Chung, M.; Doran, D. S.; Ha, G.; Kim, S. -H.; Kim, J. -H.; Liu, W.; Lu, X.; Power, J.; Seok, J. -M.; Shin, S.; Shao, J.; Whiteford, C.; Wisniewski, E.

SCIENTIFIC REPORTS 13, 3207 (FEB 2023)
https://doi.org/10.1038/s41598-023-29997-9

We present overall process for developing terahertz (THz) corrugated structure and its beam-based measurement results. 0.2-THz corrugated structures were fabricated by die stamping method as the first step demonstration towards GW THz radiation source and GV/m THz wakefield accelerator. 150-µm thick disks were produced from an OFHC (C10100) foil by stamping. Two types of disks were stacked alternately to form 46 mm structure with ~ 170 corrugations. Custom assembly was designed to provide diffusion bonding with a high precision alignment of disks. The compliance of the fabricated structure have been verified through beam-based wakefield measurement at Argonne Wakefield Accelerator Facility. Both measured longitudinal and transverse wakefield showed good agreement with simulated wakefields. Measured peak gradients, 9.4 MV/m/nC for a long single bunch and 35.4 MV/m/nC for a four bunch trains, showed good agreement with the simulation.

Investigating of plasma diagnostics by utilizing spectroscopic measurements of Balmer emission

Arjmand, S.; Anania, M. P.; Biagioni, A.; Ferrario, M.; Del Franco, M.; Galletti, M.; Lollo, V.; Pellegrini, D.; Pompili, R.; Zigler, A.

JOURNAL OF INSTRUMENTATION 18(5), C05007 (MAY 2023)
https://doi.org/10.1088/1748-0221/18/05/C05007

Plasma technology offers revolutionary potential for particle accelerators by enabling the acceleration of electron beams to ultra-relativistic velocities in a small-scale dimension. The compact nature of plasma-based accelerators permits the creation of accelerating gradients on the GV scale. Plasma acceleration structures are created by utilizing either ultra-short laser pulses (Laser Wakefield Acceleration, LWFA) or

energetic particle beams (Particle Wakefield Acceleration, PWFA), which need to be tailored to the plasma parameters. However, both methods face the challenge of limited acceleration length, which is currently only a few centimeters. To overcome this challenge, one approach is to generate plasma within a capillary tube, which can extend the acceleration length up to approximately forty centimeters or more. Consequently, it is crucial to characterize the produced plasma in terms of density and geometric structure. Optical emission spectroscopy (EOS) methods can be employed to measure and characterize the plasma electron density by analyzing the emitted plasma light. This paper presents measurements of the plasma electron density distribution for a hydrogen-filled capillary tube using both Balmer alpha (H_α) and Balmer beta (H_β) lines. Comparing the intensities of H_α and H_β emissions enables more precise measurements of the plasma electron density and provides additional information about other plasma properties.

FACILITIES

Design of the new 18 MeV electron injection line for AWAKE Run2c

Bencini, V.; Velotti, F.M.

Proceedings IPAC'23

https://indico.jacow.org/event/41/contributions/1170/

The Advanced Wakefield Experiment (AWAKE) has demonstrated during its first run (Run1, concluded in 2018) the capability of accelerating electrons up to the energy of 2 GeV using proton driven plasma wakefield acceleration. AWAKE Run 2 has started and during the third phase of the program, Run 2c, which aims to demonstrate stable accelerating gradients of 0.5-1 GV/m and emittance preservation of the electron bunches during acceleration, the layout of the experiment will be modified to accommodate a second plasma cell. Among the many changes, the position of the primary 18 MeV electron beam line will be shifted. The beam line layout and optics will need, therefore, to be redesigned to fit the new footprint constraints and match the new beam requirements. This paper presents the proposed layout of the new 18 MeV line, detailing the constraints and specifications, describing the design procedure and showing the main results.

Linear colliders based on laser-plasma accelerators

Schroeder, C. B.; Albert, F.; Benedetti, C.; Bromage, J.; Bruhwiler, D.; Bulanov, S. S.; Campbell, E. M.; Cook, N. M.; Cros, B.; Downer, M. C.; Esarey, E.; Froula, D. H.; Fuchs, M.; Geddes, C. G. R.; Gessner, S. J.; Gonsalves, A. J.; Hogan, M. J.; Hooker, S. M.; Huebl, A.; Jing, C.; Joshi, C.; Krushelnick, K.; Leemans, W. P.; Lehe, R.; Maier, A. R.; Milchberg, H. M.; Mori, W. B.; Nakamura, K.; Osterhoff, J.; Palastro, J. P.; Palmer, M.; Poder, K.; Power, J. G.; Shadwick, B. A.; Terzani, D.; Thevenet, M.; Thomas, A. G. R.; van Tilborg, j.; Turner, M.; Vafaei-Najafabadi, N.; Vay, J. -l.; Zhou, T.; Zuegel, J.

JOURNAL OF INSTRUMENTATION 18(6), T06001 (JUN 2023)

https://doi.org/10.1088/1748-0221/18/06/T06001

Laser-plasma accelerators are capable of sustaining accelerating fields of 10-100 GeV/m, 100-1000 times that of conventional technology and the highest fields produced by any of the widely researched advanced accelerator concepts. Laser-plasma accelerators also intrinsically accelerate short particle bunches, several orders of magnitude shorter than that of conventional technology, which leads to reductions in beamstrahlung and, hence, savings in the overall power consumption to reach a desired luminosity. These properties make laser-plasma accelerators a promising accelerator technology for a more compact, less expensive high-energy linear collider providing multi-TeV polarized leptons. In this submission to the Snowmass 2021 Accelerator Frontier, we discuss the motivation for a laser-plasma-accelerator-based linear collider, the status of the field, and potential linear collider concepts up to 15 TeV. We outline the research and development path toward a collider based on laser-plasma accelerator technology, and highlight near-term and mid-term applications of this technology on the collider development path. The required experimental facilities to carry out this research are described. We conclude with community recommendations developed during Snowmass.

Design of the proton and electron transfer lines for AWAKE Run 2c

Ramjiawan, R.; Bencini, V.; Burrows, P. N.; Velotti, F. M.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS; SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT 1049, 168094 (APR 2023)
https://doi.org/10.1016/j.nima.2023.168094

The Advanced Wakefield (AWAKE) Run 1 experiment, which concluded in 2018, achieved electron acceleration to 2 GeV via plasma wakefield acceleration driven by 400 GeV, self-modulated proton bunches extracted from the CERN SPS. The Run 2c phase of the experiment aims to advance these results by demonstrating acceleration up to about 10 GeV while preserving the quality of the accelerated electron beam. For Run 2c, the Run 1 proton transfer line will be reconfigured to shift the first plasma cell 40 m longitudinally and a second plasma cell will be added 1 m downstream of the first. In addition, a new 150 MeV beamline will be required to inject a witness electron beam, with a beam size of several microns, into the second plasma cell to probe the accelerating fields. Proposed adjustments to the proton transfer line and the design of the 150 MeV electron transfer line are detailed in this paper.

THEORY & SIMULATION

Six-Dimensional Beam-Envelope Equations: An Ultrafast Computational Approach for Interactive Modeling of Accelerator Structures

Kelisani, M. D.; Barzegar, S.; Craievich, P.; Doebert, S.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 26(5), 054011 (MAY 2023)
https://doi.org/10.1103/PhysRevApplied.19.054011

The design and implementation of accelerators capable of providing high-quality bunches require precise and efficient online modeling tools. Current comprehensive beam dynamics studies are prohibitively costly and challenging to use for interactive system design. A precise high-speed method for beam dynamics analysis in accelerator components is presented and compared to the results of the conventional particle-in-cell codes. Using powerful mathematical techniques, the suggested method evaluates the temporal evolution of a bunch shape in six-dimensional (6D) phase space along the accelerators. The moment equations that govern the evolution of the bunch envelope in 6D phase space are introduced. The three-dimensional space-charge, external, and emittance forces are calculated to be fully analytically insensitive to different beam envelopes. Substituting the obtained forces into the beam-envelope equations establishes a set of six modified equations describing the beam dynamics using simple algebraic expressions. The whole solution considers the energy spread inherent to an electron beam. The model accuracy is demonstrated by studying beam transport through various components of an accelerator. Applying this analytical approach not only forms a style of physical thinking by indicating the factors that affect the behavior of the charged particle bunches but also has an ultrafast computational speed that is at least 3 orders of magnitude faster than that of particle tracking codes for designing today's linear accelerators. Finally, the model's feasibility is benchmarked for successfully designing a photoinjector for the advanced proton driven plasma wakefield acceleration experiment.

Optimization of transformer ratio and beam loading in a plasma wakefield accelerator with a structure-exploiting algorithm

Su, Q.; Larson, J.; Dalichaouch, T. N.; Li, F.; An, W.; Hildebrand, L.; Zhao, Y.; Decyk, V.; Alves, P.; Wild, S. M.; Mori, W. B.
PHYSICS OF PLASMAS 30(5), 053108 (MAY 2023)
https://doi.org/10.1063/5.0142940

Plasma-based acceleration has emerged as a promising candidate as an accelerator technology for a future linear collider or a next-generation light source. We consider the plasma wakefield accelerator (PWFA) concept where a plasma wave wake is excited by a particle beam and a trailing beam surfs on the wake. For a linear collider, the energy transfer efficiency from the drive beam to the wake and from the wake to the trailing beam must be large, while the emittance and energy spread of the trailing bunch must be preserved. One way to simultaneously achieve this when accelerating electrons is to use longitudinally shaped bunches and nonlinear wakes. In the linear regime, there is an analytical formalism to obtain the optimal shapes. In the nonlinear regime, however, the optimal shape of the driver to maximize the energy transfer efficiency cannot be precisely obtained because currently no theory describes the wake structure and excitation process for all degrees of nonlinearity. In addition, the ion channel radius is not well defined at the front of the wake where the plasma electrons are not fully blown out by the drive beam. We present results using a novel optimization method to effectively determine a current profile for the drive and trailing beam in PWFA that provides low energy spread, low emittance, and high acceleration efficiency. We parameterize the longitudinal beam current profile as a piecewise-linear function and define optimization objectives. For the trailing beam, the algorithm converges quickly to a nearly inverse trapezoidal trailing beam current profile similar to that predicted by the ultrarelativistic limit of the nonlinear wakefield theory. For the drive beam, the beam profile found by the optimization in the nonlinear regime that maximizes the transformer ratio also resembles that predicted by linear theory. The current profiles found from the optimization method provide higher transformer ratios compared with the linear ramp predicted by the relativistic limit of the nonlinear theory.

Mitigation of the Onset of Hosing in the Linear Regime through Plasma Frequency Detuning

Moreira, Mariana; Muggli, Patric; Vieira, Jorge
PHYSICAL REVIEW LETTERS 130(11), 115001 (MAR 2023)
https://doi.org/10.1103/PhysRevLett.130.115001

The hosing instability poses a feasibility risk for plasma-based accelerator concepts. We show that the growth rate for beam hosing in the linear regime (which is relevant for concepts that use a long driver) is a function of the centroid perturbation wavelength. We demonstrate how this property can be used to damp centroid oscillations by detuning the plasma response sufficiently early in the development of the instability. We also develop a new theoretical model for the early evolution of hosing. These findings have implications for the general control of an instability's growth rate.

***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