THE EuPRAXIA FILES

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Foreword

Dr Ralph Aßmann
EuPRAXIA Coordinator

The present issue of *The EuPRAXIA Files* is dominated by the proceedings of the 3rd European Advanced Accelerator Concepts workshop (EAAC) which were published in *Nuclear Instruments and Methods in Physics Research Section A*. The workshop had no less than 34 contributions from members of EuPRAXIA, demonstrating the strong impact that the project has on the particle accelerator community. You can find the abstracts as well as the links to the full articles below.

Furthering on its engagement with the broader community, EuPRAXIA will be present once more in the International Particle Accelerator Conference (IPAC) in Melbourne, Australia, both in the scientific programme and in the industry exhibition. Visit us at the booth of the University of Liverpool (#D13).

Research Highlights

Mastering the laser plasma acceleration electron beam transport

The development of high accelerating gradient LPA has offered the possibility of producing ultra-compact Free Electron Lasers. However, the hopes put in LPA to drive undulator radiation and FEL light sources are challenged by LPA parameters that do not meet conventional accelerator state-of-the-art performance, in particular for the energy spread and for the divergence. Demonstration of a proper electron beam control is the first challenge to overcome in the path towards LPA based FELs and requires specific beam handling.

In the frame of an European Research Council (ERC) Advanced Grant COXINEL whose Principal Investigator is Marie-Emmanuelle Couprie, a specific manipulation line has been designed and built at Synchrotron SOLEIL considering 200-400 MeV beams with 1% energy spread, 1 mrad divergence, 1 µm size and 4 kA peak current. It is now installed at Laboratoire d'Optique Appliquée (LOA), where the LPA electrons are produced and accelerated. The divergence is rapidly mitigated via strong focusing with a triplet of so-called QUAPEVA permanent magnet quadrupoles of variable strength and of adjustable magnetic center position. A magnetic chicane then longitudinally stretches the beam, sorts electrons in energy and selects the energy range of interest via a removable and adjustable slit mounted in the middle of the chicane. A second set of quadrupoles matches the beam inside an in-

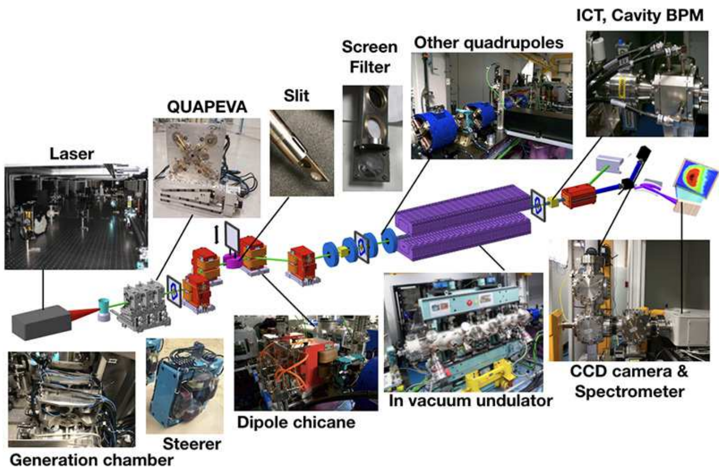

Fig. 1: COXINEL line with its associated equipment

vacuum undulator. The electron beam can be monitored with current transformers and cavity beam position monitors or by inserting scintillator screens along the line.

The LPA development in LOA, in the frame of an ERC Advanced Grant X-FIVE, uses a Ti:Sapphire laser system delivering 1.5 J, 30 fs pulses. For the COXINEL experiment, the laser is focused into a supersonic jet of He-N_2 gas mixture for the LPA to operate in the robust ionisation injection, providing beams of up to 100 pC in a broad energy range up to 200 MeV with 1-5 mrad divergence. Transfer line components and LPA laser are aligned within ±100 µm on the same reference axis.

After a first rough beam transport along the line where chromatic effects play an important role, a Beam Position Alignment Compensation strategy based on the matrix response approach is developed for separate correction of beam dispersion and position thanks to a proper setting of the QUAPEVA magnetic axis, enabling mitigation of pointing fluctuations. The QUAPEVA strength is then slightly adjusted to optimize the focusing. The matched transported beam measurements agree with simulations for measured beam characteristics (dipole spectrometer and observation on a screen), as displayed in Fig. 2.

A slit in the chicane selects the desired energy range. Undulator radiation is characterized with a CCD camera with bandpass filters for spectral selection, and with a spectrometer equipped with a CCD camera to provide some insight on the beam quality. The possibility to observe FEL amplification depends strongly on the LPA beam parameters that can be experimentally achieved. The qualification of the LPA with a FEL application still remains a major challenge.

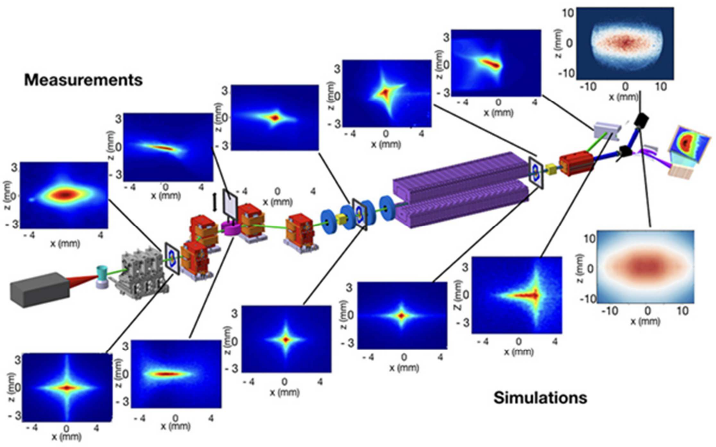

Fig. 2: Electron beam / photon measurements and simulations

In conclusion, scientists have shown that the LPA electron beam properties can be manipulated through an adequate transport line, mitigating their poor performance compared with state-of-the-art conventional accelerators. These results pave the way for further merging of novel and conventional accelerator techniques towards future applications, such as the new generation of colliders, requiring stages of LPA accelerating modules or free electron laser applications, relying on more optimised LPA performance that are progressing very fast.

Related publications:

M.E. Couprie *et al.* "An application of laser-plasma acceleration: towards a free-electron laser amplification", Plasma Physics & Controlled Fusion 58(3), 034020 (2016) https://doi.org/10.1088/0741-3335/58/3/034020

F. Marteau *et al.*, "Variable high gradient permanent magnet quadrupole (QUAPEVA)", Applied Physics Letters 111(25), 253503 (2017) https://doi.org/10.1063/1.4986856

T. André *et al.*, "Control of laser plasma accelerated electrons for light sources", Nature Communications 9, 1334 (2018) https://doi.org/10.1038/s41467-018-03776-x

Research Papers

Longitudinal Phase-Space Manipulation with Beam-Driven Plasma Wakefields

Shpakov, V. *et al.*
PHYSICAL REVIEW LETTERS 122(11), 114801 (MAR 2019)
https://doi.org/10.1103/PhysRevLett.122.114801

The development of compact accelerator facilities providing high-brightness beams is one of the most challenging tasks in the field of next-generation compact and cost affordable particle accelerators, to be used in many fields for industrial, medical, and research applications. The ability to shape the beam longitudinal phase space, in particular, plays a key role in achieving high-peak brightness. Here we present a new approach that allows us to tune the longitudinal phase space of a high-brightness beam by means of plasma wakefields. The electron beam passing through the plasma drives large wakefields that are used to manipulate the time-energy correlation of particles along the beam itself. We experimentally demonstrate that such a solution is highly tunable by simply adjusting the density of the plasma and can be used to imprint or remove any correlation onto the beam. This is a fundamental requirement when dealing with largely time-energy correlated beams coming from future plasma accelerators.

Tunable Plasma-Based Energy Dechirper

D'Arcy, R. *et al.*
PHYSICAL REVIEW LETTERS 122(3), 034801 (JAN 2019)
https://doi.org/10.1103/PhysRevLett.122.034801

A tunable plasma-based energy dechirper has been developed at FLASHForward to remove the correlated energy spread of a 681 MeV electron bunch. Through the interaction of the bunch with wakefields excited in plasma the projected energy spread was reduced from a FWHM of 1.31% to 0.33% without reducing the stability of the incoming beam. The experimental results for variable plasma density are in good agreement with analytic predictions and three-dimensional simulations. The proof-of-principle dechirping strength of 1.8 GeV/mm/m significantly exceeds those demonstrated for competing state-of-the-art techniques and may be key to future plasma wakefield-based free-electron lasers and high energy physics facilities, where large intrinsic chirps need to be removed.

Controlling the Self-Injection Threshold in Laser Wakefield Accelerators

Kuschel, S.; Schwab, M. B.; Yeung, M.; Hollatz, D.; Seidel, A.; Ziegler, W.; Saevert, A.; Kaluza, M. C.; Zepf, M.
PHYSICAL REVIEW LETTERS 121(15), 154801 (OCT 2018)
https://doi.org/10.1103/PhysRevLett.121.154801

Controlling the parameters of a laser plasma accelerated electron beam is a topic of intense research with a particular focus placed on controlling the injection phase of electrons into the accelerating structure from the background plasma. An essential prerequisite for high-quality beams is dark-current free acceleration (i.e., no electrons accelerated beyond those deliberately injected). We show that small-scale density ripples in the background plasma are sufficient to cause the uncontrolled (self-)injection of electrons. Such ripples can be as short as ∼ 50 µm and can therefore not be resolved by standard interferometry. Background free injection with substantially improved beam characteristics (divergence and pointing) is demonstrated in a gas cell designed for a controlled gas flow. The results are supported by an analytical theory as well as 3D particle in cell simulations.

Focusing of High-Brightness Electron Beams with Active-Plasma Lenses

Pompili, R. *et al.*
PHYSICAL REVIEW LETTERS 121(17), 174801 (OCT 2018)
https://doi.org/10.1103/PhysRevLett.121.174801

Plasma-based technology promises a tremendous reduction in size of accelerators used for research, medical, and industrial applications, making it possible to develop tabletop machines accessible for a broader scientific community. By overcoming current limits of conventional accelerators and pushing particles to larger and larger energies, the availability of strong and tunable focusing optics is mandatory also because plasma-accelerated beams usually have large angular divergences. In this regard, active plasma lenses represent a compact and affordable tool to generate radially symmetric magnetic fields several orders of magnitude larger than conventional quadrupoles and solenoids. However, it has been recently proved that the focusing can be highly nonlinear and induce a dramatic emittance growth. Here, we present experimental results showing how these nonlinearities can be minimized and lensing improved. These achievements represent a major breakthrough toward the miniaturization of next-generation focusing devices.

Adaptive control of laser-wakefield accelerators driven by mid-IR laser pulses

Lin, J.; Ma, Y.; Schwartz, R.; Woodbury, D.; Nees, J. A.; Mathis, M.; Thomas, A. G. R.; Krushelnick, K.; Milchberg, H.
OPTICS EXPRESS 27(8), 10912-10923 (APR 2019)
https://doi.org/10.1364/OE.27.010912

There has been growing interest both in studying high-intensity ultrafast laser plasma interactions with adaptive control systems as well as using long wavelength driver beams. We demonstrate the coherent control of the dynamics of laser-wakefield acceleration driven by ultrashort (~ 100 fs) mid-infrared (~ 3.9 μm) laser pulses. The critical density at this wavelength is 7.3 x 10^{19} cm^{-3}, which is achievable with an ordinary gas target system. Interactions between mid-infrared laser pulses and such near-critical-density plasma may be beneficial due to much higher absorption of laser energy. In addition, the normalized vector potential of the laser field a_0 increases with longer laser wavelength, lowering the required peak laser intensity to drive non-linear laser-wakefield acceleration. Here, MeV level, collimated electron beams with non-thermal, peaked energy spectra are generated. Optimization of electron beam qualities are realized through adaptive control of the laser wavefront. A genetic algorithm controlling a deformable mirror improves the electron total charge, energy spectra, beam pointing and stability at various plasma density profiles. Particle-in-cell simulations reveal that the optimal wavefront causes an earlier injection on the density up-ramp and thus higher energy gain as well as less filamentation during the interaction, which leads to the improvement in electron beam collimation and energy spectra.

Electron acceleration by a radially-polarized laser pulse in a plasma micro-channel

Wen, Meng; Salamin, Yousef, I; Keitel, Christoph H.
OPTICS EXPRESS 27(2), 557-566 (JAN 2019)
https://doi.org/10.1364/OE.27.000557

Encouraged by recent advances in radially-polarized laser technology, simulations have been performed of electron acceleration by a tightly-focused, ultra-short pulse in a parabolic plasma micro-channel. Milli-joule laser pulses, generated at kHz repetition rates, are shown to produce electron bunches of MeV energy, pC charge, low emittance and low divergence. The pivotal role played by the channel length in controlling the process is demonstrated, and the roles of direct and wakefield acceleration are distinguished.

Optimization of soft X-ray phase-contrast tomography using a laser wakefield accelerator

Svendsen, K.; Gonzalez, I. Gallardo; Hansson, M.; Svensson, J. Bjorklund; Ekerfelt, H.; Persson, A.; Lundh, O.
OPTICS EXPRESS 26(26), 33930-33941 (DEC 2018)
https://doi.org/10.1364/OE.26.033930

X-ray phase-contrast imaging allows for non-invasive analysis in low-absorbing materials, such as soft tissue. Its application in medical or materials science has yet to be realized on a wider scale due to the requirements on the X-ray source, demanding high flux and small source size. Laser wakefield accelerators generate betatron X-rays fulfilling these criteria and can be suitable sources for phase-contrast imaging. In this work, we present the first phase-contrast images obtained by using ionization injection-based laser wakefield acceleration, which results in a higher photon yield and smoother X-ray beam profile compared to self-injection. A peak photon yield of 1.9×10^{11} ph/sr and a source size of 3 µm were estimated. Furthermore, the current laser parameters produce an X-ray spectrum mainly in the soft X-ray range, in which laser-plasma based phase-contrast imaging had yet to be studied. The phase-contrast images of a Chrysopa lacewing resolve features on the order of 4 µm. These images are further used for a tomographic reconstruction and a volume rendering, showing details on the order of tens of µm. (C) 2018 Optical Society of America under the terms of the OSA Open Access Publishing Agreement

High-quality GeV-scale electron bunches with the Resonant Multi-Pulse Ionization Injection

Tomassini, P.; De Nicola, S.; Labate, L.; Londrillo, P.; Fedele, R.; Terzani, D.; Nguyen, F.; Vantaggiato, G.; Gizzi, L. A.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 1-4 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.03.002

Recently a new injection scheme for Laser Wake Field Acceleration, employing a single 100-TW-class laser system, has been proposed. In the Resonant Multi-Pulse Ionization injection (ReMPI) a resonant train of pulses drives a large amplitude plasma wave that traps electrons extracted from the plasma by further ionization of a high-Z dopant (Argon in the present paper). While the pulses of the driver train have intensity below the threshold for the dopant's ionization, the properly delayed and frequency doubled (or more) ionization pulse possesses an electric field large enough to extract electrons, though its normalized amplitude is well below unity. In this paper we will report on numerical simulations results aimed at the generation of GeV-scale bunches with normalized emittance and rms energy below 80 nm x rad and 0.5%, respectively. Analytical consideration of the FEL performance for a 1.3 GeV bunch will be also reported.

Design of a 5 GeV laser-plasma accelerating module in the quasi-linear regime

Li, Xiangkun; Mosnier, Alban; Phu Anh Phi Nghiem
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 49-53 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.02.104

Multi-GeV-class laser-plasma accelerating modules are key components of laser-plasma accelerators, because they can be used as a booster of an upstream plasma or conventional injector or as modular acceleration sections of a multi-staged high energy plasma linac. Such a plasma module, operating in the quasi-linear regime, has been designed for the 5 GeV laser-plasma accelerator stage (LPAS) of the EuPRAXIA project. The laser pulse (∼ 150 TW, ∼ 15 J) is quasi-matched into a plasma channel ($n(p) = 1.5 \times 10^{17}$ cm^3, L ∼ 30 cm) and the bi-Gaussian electron beam is externally injected into the wakefield. The beam emittance is preserved through the acceleration by matching the beam size to the transverse focusing fields. And a final energy spread of <1% has been achieved by optimizing the beam loading effect. Several methods have been proposed to reduce the slice energy spread and are found to be effective. The simulations were conducted with the 3D PIC code Warp in the Lorentz boosted frame.

Towards compact Free Electron-Laser based on laser plasma accelerators

Couprie, Marie Emmanuelle

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 5-15 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.02.090

The laser invention more than fifty years ago was a major scientific revolution. Among the different possible gain media, the Free Electron-Lasers (FEL) uses free electrons in the period permanent magnetic field of an undulator, covering wavelengths from far infrared to X-ray, with easy tuneability and high peak power. Nowadays, the advent of tuneable intense (mJ level) short pulse FELs with record peak power (GW level) in the X-ray domain sets a major step in laser development, and enables to explore new scientific areas, such as deciphering molecular reactions in real time, understanding functions of proteins. Besides, lasers have also been considered for driving plasma electron acceleration. A high-power femtosecond laser is focused into a gas target and resonantly drives a nonlinear plasma wave in which plasma electrons are trapped and accelerated with high energy gain of GeV/m. Nowadays, laser wakefield acceleration became reality and electron beams with multi-GeV energies, hundreds of pC charge, sub-percent energy spread and sub-milliradian divergence can be produced. It is relevant to consider a FEL application to quality these laser plasma produced electrons. After having described the FEL panorama, the strategies towards laser plasma based acceleration based FELs will be discussed, including the mitigation of the large energy spread and divergence of these beams should be mitigated.

Characterisation of beam driven ionisation injection in the blowout regime of plasma acceleration

Mira, F.; Ferrario, M.; Londrillo, P.; Marocchino, A.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 441-445 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.01.019

Beam driven ionisation injection is characterised for a variety of high-Z dopant. We discuss the region of extraction and why the position where electrons are captured influences the final quality of the internally-injected bunch. The beam driven ionisation injection relies on the capability to produce a high gradient fields at the bubble closure, with magnitudes high enough to ionise by tunnelling effect the still bounded electrons (of a high-Z dopant). The ionised electrons are captured by the nonlinear plasma wave at the accelerating and focusing wake phase leading to high-brightness trailing bunches. The high transformer ratio guarantees that the ionisation only occurs at the bubble closure. The quality of the ionisation-injected trailing bunches strongly and non-linearly depends on the properties of the dopant gas (density and initial ionisation state). We use the full 3D PIC code ALaDyn to consider the highly three-dimensional nature of the effect. By means of a systematic approach we have investigated the emittance and energy spread formation and the evolution for different dopant gases and configurations.

A viable laser driver for a user plasma accelerator

Gizzi, L. A.; Koester, P.; Labate, L.; Mathieu, F.; Mazzotta, Z.; Toci, G.; Vannini, M.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 58-66 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.02.089

The construction of a novel user facility employing laser-driven plasma acceleration with superior beam quality will require an industrial grade, high repetition rate petawatt laser driver which is beyond existing technology. However, with the ongoing fast development of chirped pulse amplification and high average power laser technology, options can be identified depending on the envisioned laser-plasma acceleration scheme and on the time scale for construction. Here we discuss laser requirements for the EuPRAXIA infrastructure design and identify a suitable laser concepts that is likely to fulfill such requirements with a moderate development of existing technologies.

Modelling of pulse train generation for resonant laser wakefield acceleration using a delay mask

Vantaggiato, G.; Labate, L.; Tomassini, P.; Gizzi, L. A.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 114-117 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.02.024

A new method for the generation of a train of pulses from a single high-energy, ultra short pulse is presented, suited for Resonant Multi-Pulse Ionization injection. The method is based on different transverse portion of the pulse being delayed by a "mask'' sectioned in concentric zones with different thicknesses, in order to deliver multiple laser pulses. The mask is placed right before the last focusing parabola. A hole in the middle of the mask lets part of the original pulse to pass through to drive electron injection. In this paper a full numerical modelling of this scheme is presented. In particular we discuss the spatial and temporal profile of the pulses emerging from the mask and how they are related to the radius and thickness of each section.

Plasma boosted electron beams for driving Free Electron Lasers

Rossi, A. R.; Petrillo, V.; Bacci, A.; Chiadroni, E.; Cianchi, A.; Ferrario, M.; Giribono, A.; Marocchino, A.; Conti, M. Rossetti; Serafini, L.; Vaccarezza, C.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 54-57 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.02.092

In this paper, we report results of simulations, in the framework of both EuPRAXIA and EuPRAXIA@SPARC_LAB projects, aimed at delivering a high brightness electron bunch for driving a Free Electron Laser (FEL) by employing a plasma post acceleration scheme. The boosting plasma wave is driven by a tens of TW class laser and doubles the energy of an externally injected beam up to 1 GeV. The injected bunch is simulated starting from a photoinjector, matched to plasma, boosted and finally matched to an undulator, where its ability to produce FEL radiation is verified to yield $O(10^{11})$ photons per shot at 2.7 nm.

Gas cell density characterization for laser wakefield acceleration

Audet, T. L.; Lee, P.; Maynard, G.; Dufrenoy, S. Dobosz; Maitrallain, A.; Bougeard, M.; Monot, P.; Cros, B.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 383-386 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.01.053

In the design of laser plasma electron injectors for multi-stage laser driven wakefield accelerators, the control of plasma density is a key element to stabilize the acceleration process. A cell with variable parameters is used to confine the gas and tailor the density profile. The gas filling process was characterized both experimentally and by fluid simulations. Results show a good agreement between experiments and simulations. Simulations were also used to study the effect of each of the gas cell parameters on the density distribution and show the possibility to finely control the density profile.

Overview of plasma lens experiments and recent results at SPARC_LAB

Chiadroni, E. *et al.*
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 16-20 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.02.014

Beam injection and extraction from a plasma module is still one of the crucial aspects to solve in order to produce high quality electron beams with a plasma accelerator. Proper matching conditions require to focus the incoming high brightness beam down to few microns size and to capture a high divergent beam at the exit without loss of beam quality. Plasma-based lenses have proven to provide focusing gradients of the order of kT/m with radially symmetric focusing thus promising compact and affordable alternative to permanent magnets in the design of transport lines. In this paper an overview of recent experiments and future perspectives of plasma lenses is reported.

A complementary compact laser based neutron source

Cianchi, A.; Andreani, C.; Bedogni, R.; Festa, G.; Sans-Planell, O.; Senesi, R.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 323-326 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.01.052

Several experiments of neutron generation using high intensity laser sources, with a power exceeding 10^{19}W/cm^2 via TNSA (Target Normal Sheath Acceleration) or other similar methods, have been performed in the past years in different laboratories. However, so far there is no one running neutron source based on such a technology. In the framework of the Conceptual Report Design of a new accelerator in the Eupraxia project we are studying the possibility to have a laser-based neutron source, not only by TNSA but also from self-injection schemes. We focus our attention on the applications in cultural heritage studies as well also on the complementary role that such a source can have in the framework of large facilities devoted to radiation production. (C) 2018 Elsevier B.V. All rights reserved.

Simulation design for forthcoming high quality plasma wakefield acceleration experiment in linear regime at SPARC_LAB

Romeo, S.; Chiadroni, E.; Croia, M.; Ferrario, M.; Giribono, A.; Marocchino, A.; Mira, F.; Pompili, R.; Rossi, A. R.; Vaccarezza, C.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 71-75 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.02.081

In the context of plasma wakefield acceleration beam driven, we exploit a high density charge trailing bunch whose self-fields act by mitigating the energy spread increase via beam loading compensation, together with bunch self-contain operated by the self-consistent transverse field. The work, that will be experimentally tested in the SPARC_LAB test facility, consists of a parametric scan that allows to find optimized parameters in order to preserve the high quality of the trailing bunch over the entire centimeters acceleration length, with a final energy spread increase of 0.1% and an emittance increase of 5 nm. The stability of trailing bunch parameters after acceleration is tested employing a systematic scan of the parameters of the bunches at the injection. The results show that the energy spread increase keeps lower than 1% and the emittance increase is lower than 0.02 mm mrad in all the simulations performed. The energy jitter is of the order of 5%.

Beam quality preservation studies in a laser-plasma accelerator with external injection for EuPRAXIA

Svystun, E.; Assmann, R. W.; Dorda, U.; Pousa, A. Ferran; Heinemann, T.; Marchetti, B.; de la Ossa, A. Martinez; Walker, P. A.; Weikum, M. K.; Zhu, J.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 90-94 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.02.060

Over the past decade the production of multi-GeV electron beams from laser-driven plasma accelerators has been successfully demonstrated. However, demanding applications such as compact electron-driven X-ray sources require further improvements on beam energy spread and transverse emittance. One promising candidate to satisfy these requirements is to externally inject an electron beam generated by an RF linac into a laser-driven plasma accelerator. We present studies on the optimization of the final quality of the externally injected electron beam accelerated to GeV energy, using simulations with the particle-in-cell code OSIRIS. We quantified the effect of the injection phase on the quality of the accelerated beam. Tailoring the longitudinal plasma density profile by a smooth vacuum-plasma transition has been used to minimize the induced emittance growth.

Layout considerations for a future electron plasma research accelerator facility EuPRAXIA

Walker, P. A.; Assmann, R. W.; Brinkmann, R.; Chiadroni, E.; Dorda, U.; Ferrario, M.; Kocon, D.; Marchetti, B.; Pribyl, L.; Specka, A.; Walczak, R.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 111-113 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.02.028

The Horizon 2020 Project EuPRAXIA ("European Plasma Research Accelerator with eXcellence In Applications'') is preparing a conceptual design for a highly compact and cost-effective European facility with multi-GeV electron beams using plasma as the acceleration medium. The design includes two user areas: one for FEL science and one for High Energy Physics (HEP) detector development and other pilot applications. The accelerator facility will be based on a laser and/or a beam driven plasma acceleration approach. This contribution introduces layout considerations of the future plasma accelerator facilities in the context of EuPRAXIA. It compares conventional and novel plasma accelerator facility requirements and presents potential layouts for the future site. Together with performance analysis, cost effectiveness, and targeted user cases of the individual configurations, such layout studies will later enable a ranking of potential configurations. Based on this information the optimal combination of technologies will be defined for the 2019 conceptual design report of the EuPRAXIA facility.

EuPRAXIA@SPARC_LAB Design study towards a compact FEL facility at LNF

Ferrario, M. *et al.*

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 134-138 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.01.094

On the wake of the results obtained so far at the SPARC_LAB test-facility at the Laboratori Nazionali di Frascati (Italy), we are currently investigating the possibility to design and build a new multi-disciplinary user-facility, equipped with a soft X-ray Free Electron Laser (FEL) driven by a ∼ 1 GeV high brightness linac based on plasma accelerator modules. This design study is performed in synergy with the EuPRAXIA design study. In this paper we report about the recent progresses in the on going design study of the new facility.

RF injector design studies for the trailing witness bunch for a plasma-based user facility

Giribono, A.; Bacci, A.; Chiadroni, E.; Cianchi, A.; Croia, M.; Ferrario, M.; Marocchino, A.; Petrillo, V.; Pompili, R.; Romeo, S.; Conti, M. Rossetti; Rossi, A. R.; Vaccarezza, C.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 229-232 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.01.042

The interest in plasma-based accelerators as drivers of user facilities is growing worldwide thanks to its compactness and reduced costs. In this context the EuPRAXIA collaboration is preparing a conceptual design report for a multi-GeV plasma-based accelerator with outstanding electron beam quality to pilot, among several applications, the operation of an X-ray FEL, the most demanding in terms of beam brightness. Intense beam dynamics studies have been performed to provide a reliable working point for the RF injector to generate a high-brightness trailing witness bunch suitable in external injection schemes, both in particle beam and laser driven plasma wakefield acceleration. A case of interest is the generation of a witness beam with 1 GeV energy, less than 1 mm mrad slice emittance and 30 pC in 10 fs FWHM bunch length, which turns into 3 kA peak current at the undulator entrance. The witness beam has been successfully compressed down to 10 fs in a conventional SPARC-like photo-injector and boosted up to 500 MeV in an advanced high-gradient X-band linac reaching the plasma entrance with 3 kA peak current and the following RMS values: 0.06% energy spread, 0.5 mm mrad transverse normalised emittance and a focal spot down to 1 μm. RF injector studies are here presented with the aim to satisfy the EuPRAXIA requests for the Design Study of a plasma-based user facility.

Recent results at SPARC_LAB

Pompili, R. *et al.*

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 139-144 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.01.071

The current activity of the SPARC_LAB test-facility is focused on the realization of plasma-based acceleration experiments with the aim to provide accelerating field of the order of several GV/m while maintaining the overall quality (in terms of energy spread and emittance) of the accelerated electron bunch. In the following, the current status of such an activity is presented. We also show results related to the usability of plasmas as focusing lenses in view of a complete plasma-based focusing and accelerating system.

Characterization of self-injected electron beams from LWFA experiments at SPARC_LAB

Costa, G.; Anania, M. P.; Bisesto, F.; Chiadroni, E.; Cianchi, A.; Curcio, A.; Ferrario, M.; Filippi, F.; Marocchino, A.; Mira, F.; Pompili, R.; Zigler, A.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 118-122 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.02.008

The plasma-based acceleration is an encouraging technique to overcome the limits of the accelerating gradient in the conventional RF acceleration. A plasma accelerator is able to provide accelerating fields up to hundreds of GeV/m, paving the way to accelerate particles to several MeV over a short distance (below the millimetre range).; Here the characteristics of preliminary electron beams obtained with the self-injection mechanism produced with the FLAME high-power laser at the SPARC_ LAB test facility are shown.; In detail, with an energy laser on focus of 1.5 J and a pulse temporal length (FWHM) of 40 fs, we obtained an electron plasma density due to laser ionization of about 6 x 10(18) cm^3, electron energy up to 350 MeV and beam charge in the range (50-100) pC.

EuPRAXIA@SPARC_LAB: The high-brightness RF photo-injector layout proposal

Giribono, A.; Bacci, A.; Chiadroni, E.; Cianchi, A.; Croia, M.; Ferrario, M.; Marocchino, A.; Petrillo, V.; Pompili, R.; Romeo, S.; Conti, M. Rossetti; Rossi, A. R.; Vaccarezza, C.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 282-285 (NOV 2018)
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At EuPRAXIA@SPARC_LAB, the unique combination of an advanced high-brightness RF injector and a plasmabased accelerator will drive a new multi-disciplinary user-facility. The facility, that is currently under study at INFN-LNF Laboratories (Frascati, Italy) in synergy with the EuPRAXIA collaboration, will operate the plasma-based accelerator in the external injection configuration. Since in this configuration the stability and reproducibility of the acceleration process in the plasma stage is strongly influenced by the RF-generated electron beam, the main challenge for the RF injector design is related to generating and handling high quality electron beams. In the last decades of R& D activity, the crucial role of high-brightness RF photo-injectors in the fields of radiation generation and advanced acceleration schemes has been largely established, making them effective candidates to drive plasma-based accelerators as pilots for user facilities. An RF injector consisting in a high-brightness S-band photo-injector followed by an advanced X-band linac has been proposed for the EuPRAXIA@SPARC_LAB project. The electron beam dynamics in the photo-injector has been explored by means of simulations, resulting in high-brightness, ultra-short bunches with up to 3 kA peak current at the entrance of the advanced X-band linac booster. The EuPRAXIA@SPARC_LAB high-brightness photo-injector is described here together with performance optimisation and sensitivity studies aiming to actual check the robustness and reliability of the desired working point.

Nano-machining, surface analysis and emittance measurements of a copper photocathode at SPARC_LAB

Scifo, J. *et al.*

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R&D activity on Cu photocathodes is under development at the SPARC_LAB test facility to fully characterize each stage of the photocathode "life'' and to have a complete overview of the photoemission properties in high brightness photo-injectors. The nano(n)-machining process presented here consists in diamond milling, and blowing with dry nitrogen. This procedure reduces the roughness of the cathode surface and prevents surface contamination introduced by other techniques, such as polishing with diamond paste or the machining with oil. Both high roughness and surface contamination cause an increase of intrinsic emittance and consequently a reduction of the overall electron beam brightness. To quantify these effects, we have characterized the photocathode surface in terms of roughness measurement, and morphology and chemical composition analysis by means of Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy (EDS), and Atomic Force Microscopy (AFM) techniques. The effects of n-machining on the electron beam quality have been also investigated through emittance measurements before and after the surface processing technique. Finally, we present preliminary emittance studies of yttrium thin film on Cu photocathodes.

Preliminary RF design of an X-band linac for the EuPRAXIA@SPARC_LAB project

Diomede, M.; Alesini, D.; Bellaveglia, M.; Buonomo, B.; Cardelli, F.; Lasheras, N. Catalan; Chiadroni, E.; Di Pirro, G.; Ferrario, M.; Gallo, A.; Ghigo, A.; Giribono, A.; Grudiev, A.; Piersanti, L.; Spataro, B.; Vaccarezza, C.; Wuensch, W.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 243-246 (NOV 2018)
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In the framework of the upgrade of the SPARC_LAB facility at INFN-LNF (Frascati, Italy), named Eu-PRAXIA@SPARC_LAB, a high gradient linac is foreseen. One of the most suitable options is to realize it in X-band. A preliminary design study of both accelerating structures and power distribution system has been performed. It is based on 0.5 m long traveling wave (TW) accelerating structures operating in the 2 pi/3 mode and fed by klystrons and pulse compressor systems. The main parameters of the structures and linac are presented with the basic RF linac layout.

Wake fields effects in dielectric capillary

Biagioni, A.; Anania, M. P.; Bellaveglia, M.; Brentegani, E.; Castorina, G.; Chiadroni, E.; Cianchi, A.; Di Giovenale, D.; Di Pirro, G.; Fares, H.; Ficcadenti, L.; Filippi, F.; Ferrario, M.; Mostacci, A.; Pompili, R.; Scifo, J.; Spataro, B.; Vaccarezza, C.; Villa, F.; Zigler, A.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 247-251 (NOV 2018)
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Plasma wake-field acceleration experiments are performed at the SPARC_LAB test facility by using a gas-filled capillary plasma source composed of a dielectric capillary. The electron can reach GeV energy in a few centimeters, with an accelerating gradient orders of magnitude larger than provided by conventional techniques. In this acceleration scheme, wake fields produced by passing electron beams through dielectric structures can determine a strong beam instability that represents an important hurdle towards the capability to focus high-current electron beams in the transverse plane. For these reasons, the estimation of the transverse wake-field amplitudes assumes a fundamental role in the implementation of the plasma wake-field acceleration. In this work, it presented a study to investigate which parameters affect the wake-field formation inside a cylindrical dielectric structure, both the capillary dimensions and the beam parameters, and it is introduced a quantitative evaluation of the longitudinal and transverse electric fields.

Design study of a photon beamline for a soft X-ray FEL driven by high gradient acceleration at EuPRAXIA@SPARC_LAB

Villa, Fabio; Cianchi, Alessandro; Coreno, Marcello; Dabagov, Sultan; Marcelli, Augusto; Minicozzi, Velia; Morante, Silvia; Stellato, Francesco

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 294-297 (NOV 2018)
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We are proposing a facility based on high gradient acceleration via X-band RF structures and plasma acceleration. We plan to reach an electron energy of the order of 1 GeV, suitable to drive a Free Electron Laser for applications in the so called water window (2-4 nm). A conceptual design of the beamline, from the photon beam from the undulators to the user experimental chamber, mainly focusing on diagnostic, manipulation and transport of the radiation is presented and discussed. We also briefly outline a user end station for coherent imaging, laser ablation and pump-probe experiments.

EUPRAXIA@SPARC_LAB: Beam dynamics studies for the X-band Linac

Vaccarezza, C.; Alesini, D.; Bacci, A.; Cianchi, A.; Chiadroni, E.; Croia, M.; Diomede, M.; Ferrario, M.; Gallo, A.; Giribono, A.; Latina, A.; Marocchino, A.; Petrillo, V.; Pompili, R.; Romeo, S.; Conti, M. Rossetti; Rossi, A. R.; Serafini, L.; Spataro, B.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 314-317 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.01.100

In the framework of the Eupraxia Design Study an advanced accelerator facility EUPRAXIA@SPARC_LAB has been proposed to be realized at Frascati (Italy) Laboratories of INFN. Two advanced acceleration schemes will be applied, namely an ultimate high gradient 1 GeV X-band linac together with a plasma acceleration stage to provide accelerating gradients of the GeV/m order. A FEL scheme is foreseen to produce X-ray beams within 3-10 nm range. A 500-TW Laser system is also foreseen for electron and ion production experiments and a Compton backscattering Interaction is planned together with extraction beamlines at intermediate electron beam energy for neutron beams and THz radiation production. The electron beam dynamics studies in the linac are here presented together with the preliminary machine layout.

Lux – A laser-plasma driven undulator beamline

Delbos, N.; Werle, C.; Dornmair, I.; Eichner, T.; Huebner, L.; Jalas, S.; Jolly, S. W.; Kirchen, M.; Leroux, V.; Messner, P.; Schnepp, M.; Trunk, M.; Walker, P. A.; Winkler, P.; Maier, A. R.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 318-322 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.01.082

The Lux beamline is a novel type of laser-plasma accelerator. Building on the joint expertise of the University of Hamburg and Desy the beamline was carefully designed to combine state-of-the-art expertise in laserplasma acceleration with the latest advances in accelerator technology and beam diagnostics. Lux introduces a paradigm change moving from single-shot demonstration experiments towards available, stable and controllable accelerator operation. Here, we discuss the general design concepts of Lux and present first critical milestones that have recently been achieved, including the generation of electron beams at the repetition rate of up to 5 Hz with energies above 600MeV and the generation of spontaneous undulator radiation at a wavelength well below 9 nm.

Tapering of plasma density ramp profiles for adiabatic lens experiments

Filippi, F.; Anania, M. P.; Biagioni, A.; Brentegani, E.; Chiadroni, E.; Cianchi, A.; Deng, A.; Ferrario, M.; Pompili, R.; Rosenzweig, J.; Zigler, A.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 339-342(NOV 2018)

https://doi.org/10.1016/j.nima.2018.04.037

One of the key elements of the plasma wakefield blowout regime is the strong, linear focusing provided by the ion density. One advantage of this focusing is its extraordinary strength whose gradient is proportional to the local background plasma density, that is particularly important for adiabatic focusing schemes in future compact linear colliders. Local plasma density variations can be obtained in gas-filled capillaries by varying monotonically the diameter of the capillary. Here we present the ongoing study of the plasma density profile obtained for different tapering angles of the capillary shape and we discuss their use for the adiabatic plasma lens experiment proposed at SPARC_LAB.

Plasma ramps caused by outflow in gas-filled capillaries

Filippi, F.; Anania, M. P.; Biagioni, A.; Brentegani, E.; Chiadroni, E.; Cianchi, A.; Ferrario, M.; Marocchino, A.; Zigler, A.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A909, 346-349 (NOV 2018)

https://doi.org/10.1016/j.nima.2018.02.102

Plasma confinement inside capillaries has been developed in the past years for plasma-based acceleration to ensure a stable and repeatable plasma density distribution during the interaction with either particles or laser beams. In particular, gas-filled capillaries allow a stable and almost predictable plasma distribution along the interaction with the particles. However, the plasma ejected through the ends of the capillary interacts with the beam before the inner plasma, affecting the quality of the beam. In this article we report the measurements on the evolution of the plasma flow at the two ends of a 1 cm long, 1 mm diameter capillary filled with hydrogen. In particular, we measured the longitudinal density distribution and the expansion velocity of the plasma outside the capillary. This study will allow a better understanding of the beam-plasma interaction for future plasma-based experiments.

Conceptual design of electron beam diagnostics for high brightness plasma accelerator

Cianchi, A.; Alesini, D.; Anania, M. P.; Biagioni, F.; Bisesto, F.; Chiadroni, E.; Curcio, A.; Ferrario, M.; Filippi, F.; Ghigo, A.; Giribono, A.; Lollo, V.; Mostacci, A.; Pompili, R.; Sabbatini, L.; Shpakov, V.; Stella, A.; Vaccarezza, C.; Vannozzi, A.; Villa, F.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 350-354 (NOV 2018)

https://doi.org/10.1016/j.nima.2018.02.095

A design study of the diagnostics of a high brightness linac, based on X-band structures, and a plasma accelerator stage, has been delivered in the framework of the EuPRAXIA@SPARC_LAB project. In this paper, we present a conceptual design of the proposed diagnostics, using state of the art systems and new and under development devices. Single shot measurements are preferable for plasma accelerated beams, including emittance, while µm level and fs scale beam size and bunch length respectively are requested. The needed to separate the driver pulse (both laser or beam) from the witness accelerated bunch imposes additional constrains for the diagnostics. We plan to use betatron radiation for the emittance measurement just at the end of the plasma booster, while other single-shot methods must be proven before to be implemented. Longitudinal measurements, being in any case not trivial for the fs level bunch length, seem to have already a wider range of possibilities.

Energy measurements by means of transition radiation in novel Linacs

Marongiu, M.; Castellano, M.; Chiadroni, E.; Cianchi, A.; Franzini, G.; Giribono, A.; Mostacci, A.; Palumbo, L.; Shpakov, V.; Stella, A.; Variola, A.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 355-358 (NOV 2018)

https://doi.org/10.1016/j.nima.2018.02.093

Advanced linear accelerator design may use Optical Transition Radiation (OTR) screens to measure beam spot size; for instance, such screens are foreseen in plasma based accelerators (EuPRAXIA@SPARC_LAB) or Compton machines (Gamma Beam Source@ELI-NP). Optical Transition Radiation angular distribution strongly depends on beam energy. Since OTR screens are typically placed in several positions along the Linac to monitor the beam envelope, one may perform a distributed energy measurement along the machine. Furthermore, a single shot energy measurement can be useful in plasma accelerators to measure shot to shot energy variations after the plasma interaction. Preliminary measurements of OTR angular distribution of about 100 MeV electrons have been performed at the SPARC_LAB facility. In this paper, we discuss the sensitivity of this measurement to beam divergence and others parameters, as well as the resolution required and the needed upgrades of conventional OTR diagnostics, using as an example the data collected at SPARC_LAB.

Design of high brightness Plasma Wakefield Acceleration experiment at SPARC_LAB test facility with particle-in-cell simulations

Marocchino, A.; Chiadroni, E.; Ferrario, M.; Mira, F.; Rossi, A. R.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 408-413 (NOV 2018)

https://doi.org/10.1016/j.nima.2018.02.068

The present numerical investigation of a Plasma Wakefield Acceleration scenario in the weakly non linear regime with external injection is motivated by the upcoming campaigns at the SPARC_LAB test facility where the final goal is to demonstrate modest gradient acceleration ($\sim$ 1 GV/m) with no quality loss. The accelerated bunch can be envisioned to seed a free electron laser. The numerical study has been conducted with the particle-in-cell code ALaDyn, an exhaustive description of the plasma-acceleration version is provided. The configuration consider a two bunches setup with parameters in the facility range, the bunches are generated and pre-accelerated up to 100 MeV by a high brightness photo-injector prior plasma injection. To verify the working point robustness we have considered case scenario where the driver bunch reaches the plasma or with a larger dimension or with large emittance. We also present an analytical approach based on the envelope equation that allows to reduce the matching condition in the presence of a ramp. Here, we limit our interest to a simplified theoretical case with a linear plasma ramp. As a final aspect we propose to combine classical integrated bunch diagnostics with the test by Shapiro-Wilk, a mathematical test to diagnose bunch deviation from a Gaussian distribution.

Evolution of the electric fields induced in high intensity laser-matter interactions

Bisesto, F. G.; Anania, M. P.; Botton, M.; Chiadroni, E.; Cianchi, A.; Curcio, A.; Ferrario, M.; Galletti, M.; Henis, Z.; Pompili, R.; Schleifer, E.; Zigler, A.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 398-401 (NOV 2018)

https://doi.org/10.1016/j.nima.2018.03.040

Multi MeV protons (Snavely et al., 2000) and heavier ions are emitted by thin foils irradiated by high-intensity lasers, due to the huge accelerating fields, up to several teraelectronvolt per meter, at sub-picosecond timescale (Dubois et al., 2014). The evolution of these huge fields is not well understood till today. Here we report, for the first time, direct and temporally resolved measurements of the electric fields produced by the interaction of a short-pulse high-intensity laser with solid targets. The results, obtained with a sub-100 fs temporal diagnostics, show that such fields build-up in few hundreds of femtoseconds and lasts after several picoseconds.

Numerical studies on capillary discharges as focusing elements for electron beams

Brentegani, E.; Anania, M. P.; Atzeni, S.; Biagioni, A.; Chiadroni, E.; Croia, M.; Ferrario, M.; Filippi, F.; Marocchino, A.; Mostacci, A.; Pompili, R.; Romeo, S.; Schiavi, A.; Zigler, A.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 404-407 (NOV 2018)
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Active plasma lenses are promising technologies for the focusing of high brightness electron beams due to their radially symmetric focusing and their high field gradients (up to several kT/m). However, in a number of experimental situations, the transverse non-uniformity of the current density flowing in the lens causes beam emittance growth and increases the minimum achievable spot size. To study the physics of the capillary discharge processes employed as active plasma lenses, we developed a 2-D hydrodynamic computational model. Here, we present preliminary simulation results and we compare the computed magnetic field profile with one from literature, which has been experimentally inferred. The result of the comparison is discussed.

Investigation of the dynamics of ionization induced injected electrons under the influence of beam loading effects

Lee, P.; Audet, T. L.; Lehe, R.; Vay, J. -L.; Maynard, G.; Cros, B.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 428-432 (NOV 2018)
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In laser-driven wakefield, ionization induced injection is an efficient way to inject electrons in the plasma wave. A detailed study on the beam dynamics under the influence of beam loading effects, which can be controlled by the concentration of nitrogen impurity introduced in the hydrogen gas was conducted. For a specific value of this percentage, the final energy of the high-energy electron bunch becomes nearly independent of the trapped positions, thus leading to a small energy dispersion. We also show that the final beam emittance is mainly determined by the injection process.

The FLAME laser at SPARC_LAB

Bisesto, F. G.; Anania, M. P.; Bellaveglia, M.; Chiadroni, E.; Cianchi, A.; Costa, G.; Curcio, A.; Di Giovenale, D.; Di Pirro, G.; Ferrario, M.; Filippi, F.; Gallo, A.; Marocchino, A.; Pompili, R.; Zigler, A.; Vaccarezza, C.

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https://doi.org/10.1016/j.nima.2018.02.027

FLAME is a high power laser system installed at the SPARC_LAB Test Facility in Frascati (Italy). The ultra-intense laser pulses are employed to study the interaction with matter for many purposes: electron acceleration through LWFA, ion and proton generation exploiting the TNSA mechanism, study of new radiation sources and development of new electron diagnostics. In this work, an overview of the FLAME laser system will be given, together with recent experimental results.

Plasma acceleration limitations due to betatron radiation

Shpakov, V.; Chiadroni, E.; Curcio, A.; Fares, H.; Ferrario, M.; Marocchino, A.; Mira, F.; Petrillo, V.; Rossi, A. R.; Romeo, S.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 463-466 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.02.058

High energy spread caused by the longitudinal size of the beam is well known in wake-field acceleration. Usually this issue can be solved with beam loading effect that allows to keep accelerating field nearly constant, along the whole duration of the beam. In this work, however, we would like to address another source of energy spread that arises at high energy, due to betatron radiation.

Photocathode laser based bunch shaping for high transformer ratio plasma wakefield acceleration

Loisch, G.; Good, J.; Gross, M.; Huck, H.; Isaev, I.; Krasilnikov, M.; Lishilin, O.; Oppelt, A.; Renier, Y.; Stephan, F.; Brinkmann, R.; Gruener, F.; Will, I.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 107-110 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.02.043

Beam driven plasma acceleration is one of the most promising candidates for future compact particle accelerator technologies. In this scheme a particle bunch drives a wake in a plasma medium. The fields inside of the wake can be used to accelerate a trailing witness bunch. To maximise the ratio between acceleration of the witness to deceleration of the drive bunch, the so called transformer ratio, several methods have been proposed. The ones yielding the most favorable results are based on shaped drive bunches that are long in terms of the plasma wavelength. We present here methods to create such drive bunches employing temporally shaped UV-laser pulses for the extraction of electron bunches from a photo-electron gun. Theoretical considerations, experimental results and possibilities for further improvements are discussed.

General features of experiments on the dynamics of laser-driven electron-positron beams

Warwick, J. R.; Alejo, A.; Dzelzainis, T.; Schumaker, W.; Doria, D.; Romagnani, L.; Poder, K.; Cole, J. M.; Yeung, M.; Krushelnick, K.; Mangles, S. P. D.; Najmudin, Z.; Samarin, G. M.; Symes, D.; Thomas, A. G. R.; Borghesi, M.; Sarri, G.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 95-101 (NOV 2018)
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The experimental study of the dynamics of neutral electron-positron beams is an emerging area of research, enabled by the recent results on the generation of this exotic state of matter in the laboratory. Electron-positron beams and plasmas are believed to play a major role in the dynamics of extreme astrophysical objects such as supermassive black holes and pulsars. For instance, they are believed to be the main constituents of a large number of astrophysical jets, and they have been proposed to significantly contribute to the emission of gamma-ray bursts and their afterglow. However, despite extensive numerical modelling and indirect astrophysical observations, a detailed experimental characterisation of the dynamics of these objects is still at its infancy. Here, we will report on some of the general features of experiments studying the dynamics of electron-positron beams in a fully laser-driven setup.

Laser wakefield acceleration with high-power, few-cycle mid-IR lasers

Papp, Daniel; Wood, Jonathan C.; Gruson, Vincent; Bionta, Mina; Gruse, Jan-Niclas; Cormier, Eric; Najmudin, Zulfikar; Legare, Francois; Kamperidis, Christos
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 145-148 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.01.050

The study of laser wakefield electron acceleration (LWFA) using mid-IR laser drivers is a promising path for future laser driven electron accelerators, when compared to traditional near-IR laser drivers operating at 0.8-1 µm central wavelength (λ_{laser}), as the necessary vector potential (a_0) for electron injection can be achieved with smaller laser powers due to the linear dependence on λ_{laser}. In this work, we perform 2D PIC simulations on LWFA using few-cycle, high power (5-15 TW) laser systems with λ_{laser} ranging from 0.88 to 10 µm. Such fewcycle systems are currently under development, aiming at Gas High Harmonics Generation applications, where the favorable λ^2_{laser} scaling extends the range of the XUV photon energies. We keep a_0 and n_e/n_{cr} (n_e being the plasma density and n_{cr} the critical density for each λ_{laser}) as common denominators in our simulations, allowing for comparisons between drivers with different λ_{laser}, with respect to the accelerated electron beam energy, charge and conversion efficiency. While the electron energies are mainly dominated by the plasma dynamics, the laser to electron beam energy conversion efficiency shows significant enhancement with longer wavelength laser drivers.

Recent studies on single-shot diagnostics for plasma accelerators at SPARC_LAB

Bisesto, F. G.; Anania, M. P.; Botton, M.; Castellano, M.; Chiadroni, E.; Cianchi, A.; Curcio, A.; Ferrario, M.; Galletti, M.; Henis, Z.; Pompili, R.; Schleifer, E.; Shpakov, V.; Zigler, A.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 909, 364-368 (NOV 2018)
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Plasma wakefield acceleration is the most promising acceleration technique for compact and cheap accelerators, thanks to the high accelerating gradients achievable. Nevertheless, this approach still suffers of shot-to-shot instabilities, mostly related to experimental parameters fluctuations. Therefore, the use of single shot diagnostics is needed to properly understand the acceleration mechanism. In this work, we present two diagnostics to probe electron beams from laser-plasma interactions, one relying on Electro Optical Sampling (EOS) for laser-solid matter interactions, the other one based on Optical Transition Radiation (OTR) for single shot measurements of the transverse emittance of plasma accelerated electron beams, both developed at the SPARC_LAB Test Facility.

Transport and analysis of electron beams from a laser wakefield accelerator in the 100 MeV energy range with a dedicated magnetic line

Maitrallain, A.; Audet, T. L.; Dufrenoy, S. Dobosz; Chance, A.; Maynard, G.; Lee, P.; Mosnier, A.; Schwindling, J.; Delferriere, O.; Delerue, N.; Specka, A.; Monot, P.; Cros, B.

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A 908, 159-166 (NOV 2018)
https://doi.org/10.1016/j.nima.2018.08.004

Electron bunches generated by laser driven wakefield acceleration are transported and analyzed using a magnetic line composed of a triplet of quadrupoles and a dipole. Short pulse bunches with a total charge of approximate to 130 pC, and broad band energy spectra in the range 45 to 150 MeV are generated by ionization assisted injection in a gas cell. The electron source is imaged about one meter away from the exit of the gas cell by the magnetic line, delivering electron bunches at a stable position in the image plane where a charge density of approximate to 2.9 pC/mm^2 at an energy of 69.4 +/- 0.6 MeV is achieved. This magnetic line improves dramatically the accuracy of energy determination of this electron source, leading to an energy error as low as 8.6%parts per thousand in the 70 MeV range for 5 mrad divergence electron bunch and considering the resolution of the entire detection system. The transport of bunches with improved stability and energy selection paves the way to various applications including multi-stage laser plasma acceleration.

X-ray analysis methods for sources from self-modulated laser wakefield acceleration driven by picosecond lasers

King, P. M.; Lemos, N.; Shaw, J. L.; Milder, A. L.; Marsh, K. A.; Pak, A.; Hegelich, B. M.; Michel, P.; Moody, J.; Joshi, C.; Albert, F.

REVIEW OF SCIENTIFIC INSTRUMENTS 90(3), 033503 (MAR 2019)
https://doi.org/10.1063/1.5082965

A versatile set of methods for analyzing x-ray energy spectra and photon flux has been developed for laser plasma accelerator experiments driven by picosecond lasers. Forward fit provides extrapolated broad energy spectrum measurements, while Ross pair and differential average transmission analysis provide directly measured data points using a particular diagnostic. Combining these methods allows the measurement of x-ray energy spectra with improved confidence. We apply the methods to three diagnostics (filter wheel, stacked image plate spectrometer, and step wedge), each sensitive to a different region of x-ray energies (<40 keV, 35-100 keV, and 60-1000 keV, respectively), to characterize the analysis methods using laser-driven bremsstrahlung x-rays. We then apply the methods to measure three x-ray mechanisms, betatron, inverse Compton scattering, and bremsstrahlung, driven by a laser plasma accelerator. The analysis results in the measurement of x-ray energy spectra ranging from 10 keV to 1 MeV with peak flux > 10^{10} photons/keV/Sr. The combined analysis methods provide a robust tool to accurately measure broadband x-ray sources (keV to MeV) driven by laser plasma acceleration with picosecond, kilojoule-class lasers. Published under license by AIP Publishing.

Few-cycle laser wakefield acceleration on solid targets with controlled plasma scale length

Zaim, N.; Bohle, F.; Bocoum, M.; Vernier, A.; Haessler, S.; Davoine, X.; Videau, L.; Faure, J.; Lopez-Martens, R.
PHYSICS OF PLASMAS 26(3), 033112 (MAR 2019)
https://doi.org/10.1063/1.5084783

We measure the emission of energetic electrons from the interaction between relativistic-intensity ultrashort laser pulses and a solid density plasma with a tunable density gradient scale length. We detect an electron beam that only appears with few-cycle pulses (<10 fs) and large plasma scale lengths ($L > \lambda_0$). Numerical simulations, in agreement with the experiments, reveal that these electrons are accelerated by a laser wakefield. Plasma waves are indeed resonantly excited by the few-cycle laser pulses in the near-critical density region of the plasma. Electrons are then injected by ionization into the plasma waves and accelerated to relativistic energies. In this laser wakefield acceleration regime, the plasma waves are rotated by the plasma density gradient, which results in the electrons not being emitted in the same direction as the driving laser pulse.

Angular streaking of betatron X-rays in a transverse density gradient laser-wakefield accelerator

Ma, Y.; Seipt, D.; Dann, S. J. D.; Streeter, M. J. V.; Palmer, C. A. J.; Willingale, L.; Thomas, A. G. R.
PHYSICS OF PLASMAS 25(11), 113105 (NOV 2018)
https://doi.org/10.1063/1.5054807

In a plasma with a transverse density gradient, laser wavefront tilt develops gradually due to phase velocity differences in different plasma densities. The wavefront tilt leads to a parabolic trajectory of the plasma wakefield and hence the accelerated electron beam, which leads to an angular streaking of the emitted betatron radiation. In this way, the temporal evolution of the betatron X-ray spectra will be converted into angular "streak," i.e., having a critical energy-angle correlation. An analytical model for the curved trajectory of a laser pulse in a transverse density gradient is presented. This gives the deflection angle of the electron beam and the betatron X-rays as a function of the plasma and laser parameters, and it was verified by particle-in-cell simulations. This angular streaking could be used as a single-shot diagnostic technique to reveal the temporal evolution of betatron X-ray spectra and hence the electron acceleration itself. Published by AIP Publishing.

Energetic electron bunch generation by laser interaction with xenon clusters

Venkat, Prachi; Holkundkar, Amol R.
PHYSICS OF PLASMAS 25(10), 103112 (OCT 2018)
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We study the interaction of intense, sub-cycle, and few-cycle laser pulses with xenon clusters for the generation of mono-energetic electron bunches. For this purpose, we used three dimensional, relativistic, molecular dynamics simulations. In this work, we used two mutually perpendicularly polarized (MPP) pulses separated by a finite temporal phase delay. The first pulse is responsible for the generation of electrons by field ionization of atomic clusters. However, the second pulse tends to accelerate the electrons (created by the first pulse) as a bunch. The effect of phase delay, pulse duration, and peak laser intensity on the generation of energetic electron bunches is studied. Under optimum conditions, the electrons are found to be accelerated to energies as high as 2.5 MeV. The feasibility of further acceleration of these electron bunches utilizing laser wakefield acceleration is also explored in this work by treating the accelerated electron bunch by MPP pulses as an initial condition to the nonlinear one-dimensional laser wakefield equations. The rough estimate of the final accelerated electron energies after laser wakefield acceleration has also been made. Published by AIP Publishing.

Multi-electron beam generation using co-propagating, parallel laser beams

Elle, J.; Zhao, T. Z.; Ma, Y.; Behm, K.; Lucero, A.; Maksimchuk, A.; Nees, J. A.; Thomas, A. G. R.; Schmitt-Sody, A.; Krushelnick, K.
NEW JOURNAL OF PHYSICS 20, 093021 (SEP 2018)
https://doi.org/10.1088/1367-2630/aaded4

High intensity short pulse laser plasma interaction experiments were performed to investigate laser wakefield acceleration (LWFA) in the 'bubble' regime. Using a specially designed phase plate, two high intensity laser focal spots were generated adjacent to each other with a transverse spacing of 70 µm and were focused onto a low density plasma target. We found that this configuration generated two simultaneous relativistic electron beams from LWFA (with low divergence) and that these beams often interact strongly with each other for longer propagation distances in the plasma thus reducing beam quality. In addition, it was observed that the existence of an adjacent laser driven wakefield significantly reduced the self-trapping threshold for injection of electrons. Numerical modeling of these interactions demonstrated similar phenomena and also showed that electron beam properties can be affected through precise control of the phase and polarization of the incident laser beam.

Laser-wakefield accelerators for high-resolution X-ray imaging of complex microstructures

Hussein, A. E. *et al.*
SCIENTIFIC REPORTS 9, 3249 (MAR 2019)
https://doi.org/10.1038/s41598-019-39845-4

Laser-wakefield accelerators (LWFAs) are high acceleration-gradient plasma-based particle accelerators capable of producing ultra-relativistic electron beams. Within the strong focusing fields of the wakefield, accelerated electrons undergo betatron oscillations, emitting a bright pulse of X-rays with a micrometer-scale source size that may be used for imaging applications. Non-destructive X-ray phase contrast imaging and tomography of heterogeneous materials can provide insight into their processing, structure, and performance. To demonstrate the imaging capability of X-rays from an LWFA we have examined an irregular eutectic in the aluminum-silicon (Al-Si) system. The lamellar spacing of the Al-Si eutectic microstructure is on the order of a few micrometers, thus requiring high spatial resolution. We present comparisons between the sharpness and spatial resolution in phase contrast images of this eutectic alloy obtained via X-ray phase contrast imaging at the Swiss Light Source (SLS) synchrotron and X-ray projection microscopy via an LWFA source. An upper bound on the resolving power of 2.7 +/- 0.3 µm of the LWFA source in this experiment was measured. These results indicate that betatron X-rays from laser wakefield acceleration can provide an alternative to conventional synchrotron sources for high resolution imaging of eutectics and, more broadly, complex microstructures.

Laser-driven high-quality positron sources as possible injectors for plasma-based accelerators

Alejo, Aaron; Walczak, Roman; Sarri, Gianluca
SCIENTIFIC REPORTS 9, 5279 (MAR 2019)
https://doi.org/10.1038/s41598-019-41650-y

The intrinsic constraints in the amplitude of the accelerating fields sustainable by radio-frequency accelerators demand for the pursuit of alternative and more compact acceleration schemes. Among these, plasma-based accelerators are arguably the most promising, thanks to the high-accelerating fields they can sustain, greatly exceeding the GeV/m. While plasma-based acceleration of electrons is now sufficiently mature for systematic studies in this direction, positron acceleration is still at its infancy, with limited projects currently undergoing to provide a viable test facility for further experiments. In this article, we study the feasibility of using a recently demonstrated laser-driven configuration as a relatively compact and inexpensive source of high-quality ultra-relativistic positrons for laser-driven and particle-driven plasma wakefield acceleration studies. Monte-Carlo simulations show that near-term high-intensity laser facilities can produce positron beams with high-current, femtosecond-scale duration, and sufficiently low normalised emittance at energies in the GeV range to be injected in further acceleration stages.

Controlled electron injection facilitated by nanoparticles for laser wakefield acceleration

Cho, Myung Hoon; Pathak, Vishwa Bandhu; Kim, Hyung Taek; Nam, Chang Hee
SCIENTIFIC REPORTS 8, 16924 (NOV 2018)
https://doi.org/10.1038/s41598-018-34998-0

We propose a novel injection scheme for laser-driven wakefield acceleration in which controllable localized electron injection is obtained by inserting nanoparticles into a plasma medium. The nanoparticles provide a very confined electric field that triggers localized electron injection where nonlinear plasma waves are excited but not sufficient for background electrons self-injection. We present a theoretical model to describe the conditions and properties of the electron injection in the presence of nanoparticles. Multi-dimensional particle-in-cell (PIC) simulations demonstrate that the total charge of the injected electron beam can be controlled by the position, number, size, and density of the nanoparticles. The PIC simulation also indicates that a 5-GeV electron beam with an energy spread below 1% can be obtained with a 0.5-PW laser pulse by using the nanoparticle-assisted laser wakefield acceleration.

Generation of GeV Electron Beam From a Laser-Plasma Accelerator and Its Prospect as a Desktop Source of Energetic Positrons and Gamma Rays For Applications

Ain, Quratul; Li, Song; Mirzaie, Mohammad; Hafz, Nasr A. M.
IEEE TRANSACTIONS ON NUCLEAR SCIENCE 65(10), 2671-2678 (OCT 2018)
https://doi.org/10.1109/TNS.2018.2869558

Laser wakefield acceleration (LWFA) is a plasma-based electron beam accelerator technology that can deliver electron beams with energies up to several GeVs, depending mainly on the power of the used laser system and the electron injection scheme. Here, we present the results from a GeV electron accelerator with a high reproducibility and a charge up to 30 pC using 110-120-TW laser pulses and by employing the well-established self-truncated ionization injection (STII) mechanism. These electron beams can be further used via bremsstrahlung in high-Z solid materials for the generation of gamma-rays and positron beams, therefore, composing a compact radiation source for various applications. Here, we use the Monte Carlo simulation code "Geant4" for studying the properties of those radiations. As expected, the characteristics of the generated gamma-rays and positron beams showed a strong dependence on the incident electron beam, target material, and thickness. The trend of positrons and gamma-rays energies and yield is shown for different high-Z to low-Z targets with the same areal mass density. Thicknesses of the target material in terms of its radiation length have been varied periodically in order to find the optimal thickness for obtaining the maximum energy and yield of the radiations. A trend can be seen in terms of energy spectra of the gamma-rays and positrons while increasing the thickness of the targets. The amount of radiation yields is also crucial to the choice of appropriate thickness of the target. In addition, this paper provides a brief description of the electrodynamics processes such as bremsstrahlung and electron-positron pair production initiated by LWFA electron beams.

Terahertz-driven wakefield electron acceleration

Sharma, A.; Tibai, Z.; Hebling, J.; Fulop, J. A.
JOURNAL OF PHYSICS B-ATOMIC MOLECULAR AND OPTICAL PHYSICS 51(20), 204001 (OCT 2018)
https://doi.org/10.1088/1361-6455/aadf50

A relativistic electron source is proposed, driven by the wakefield of an intense terahertz (THz) pulse in low-density gas plasma. In contrast to the optical and near-infrared regimes, the low (3.5 THz) frequency and the long (λ_T = 85.6 μm) wavelength of the THz pulse offers distinct advantages, such as the λ^2_T -scaling of the electron ponderomotive energy. Two-dimension-in-space and three-dimension-in-velocity particle-in-cell simulation results show that relativistic electrons of ~ 1 MeV energy and high charge can be generated by an intense THz pulse at kilohertz repetition rate from a gas plasma target. These results may lead to a new regime of applications, such as ultrafast electron diffraction or high-repetition-rate gamma ray sources for materials characterization or medical radiography, which would benefit from lower energy (1-10 MeV) but higher repetition rate (~ 1 kHz) sources of relativistic electrons.

Laser pulse compression towards collapse and beyond in plasma

Wilson, T. C.; Li, F. Y.; Weng, S. M.; Chen, M.; McKenna, P.; Sheng, Z. M.
JOURNAL OF PHYSICS B-ATOMIC MOLECULAR AND OPTICAL PHYSICS 52(5), 055403 (MAR 2019)
https://doi.org/10.1088/1361-6455/ab0132

The dynamics of three-dimensional (3D) compression of ultrashort intense laser pulses in plasma is investigated theoretically and numerically. Starting from the slowly-varying envelope model, we derive equations describing the spatiotemporal evolution of a short laser pulse towards the singularity, or collapse, based on the variational method. In particular, the laser and plasma conditions leading to spherical compression are obtained. 3D particle-in-cell simulations are carried out to verify these conditions, which also enable one to examine the physical processes both towards and beyond the pulse collapse. Simulations suggest that the laser pulse can be spherically compressed down to a minimum size of the order of the laser wavelength, the so called lambda-cubic regime. The compression process develops over twice as fast in simulation than is predicted by the envelope model, due to the simplified nature of the latter. The final result of this process is pulse collapse, which is accompanied with strong plasma density modulation and spectrum broadening. The collapse can occur multiple times during the laser pulse propagation, until a significant part of the pulse energy is dissipated to electron acceleration by the laser ponderomitve force. It is also shown that a strong external DC magnetic field applied along the laser propagation direction can enhance the rate of compression for circularly-polarised laser pulses, when compared to an unmagnetised plasma, allowing access to strong compression and focusing in the low-density and low-amplitude regime.

Betatron x-ray radiation in the self-modulated laser wakefield acceleration regime: prospects for a novel probe at large scale laser facilities

Albert, F.; Lemos, N.; Shaw, J. L.; King, P. M.; Pollock, B. B.; Goyon, C.; Schumaker, W.; Saunders, A. M.; Marsh, K. A.; Pak, A.; Ralph, J. E.; Martins, J. L.; Amorim, L. D.; Falcone, R. W.; Glenzer, S. H.; Moody, J. D.; Joshi, C.
NUCLEAR FUSION 59(3), 032003 (MAR 2019)
https://doi.org/10.1088/1741-4326/aad058

This paper presents an experimental and theoretical study of betatron x-ray radiation from laser wakefield acceleration in the self-modulated regime. Our experiments use picosecond duration laser pulses up to 150 J, for plasmas with electronic densities on the order of 10^{19} cm^3. In the self-modulated regime, electrons accelerated in the wake of the laser pulse are subject to both the longitudinal plasma and transverse laser electrical fields. As a result, they undergo oscillations and radiate a synchrotron-like spectrum. In our experimental configuration, electrons accelerated up to about 300 MeV, as well as betatron x-ray spectra with energies of 10s of keV and photon fluxes between 10^8-10^{10} photons/eV/Sr are reported. Our experiments open the prospect of using betatron x-ray radiation for applications, and the source could be competitive with current x-ray backlighting methods on multi-kilojoule laser systems used for high energy density or fusion sciences.

Inverse Compton scattering x-ray source from laser electron accelerator in pure nitrogen with 15 TW laser pulses

Zhu, Changqing; Wang, Jinguang; Feng, Jie; Li, Yifei; Li, Dazhang; Li, Minghua; He, Yuhang; Ma, Jinglong; Tan, Junhao; Zhang, Baolong; Yan, Wenchao; Chen, Liming
PLASMA PHYSICS AND CONTROLLED FUSION 61(2), 024001 (FEB 2019)
https://doi.org/10.1088/1361-6587/aaebe3

Using 15 TW laser pulses, we present a systematic investigation on tabletop inverse Compton scattering (ICS) hard x-ray source based on the self-synchronized combination of laser-driven pure nitrogen plasma accelerator and plasma mirror (PM). In the scheme of pure nitrogen medium and ionization induced injection, the laser wake-field acceleration (LWFA) is performed at a lower laser intensity of $a_0 \sim 2$ and a lower plasma density of $n_e \sim$-8 x 10(18) cm^3, which lead to the weak evolution of beam profile and high

energy transmission rate of 95%. We found the quality of electron beam is insensitive to the focus position of the laser pulse near the tail of gas jet, so it becomes possible to place the focus close to the PM. Tunning the collision point of accelerated electron bunch and reflected laser beam to the optical focal spot, ICS is dramatically increased. Ultimately, the produced ICS x-rays have the yield of 4.5×10^7. And the photon number exceeding 200 keV is about 1.2×10^7. Demonstrated by our results, stable and high yield of x-ray source in hundreds of keV range could be achieved via all-optical ICS driven by only ten terawatt lasers. This reduces the threshold of obtaining high-energy femtosecond x-rays.

Direct Observation of Plasma Waves and Dynamics Induced by Laser-Accelerated Electron Beams

Gilljohann, M. F.; Ding, H.; Doepp, A.; Goetzfried, J.; Schindler, S.; Schilling, G.; Corde, S.; Debus, A.; Heinemann, T.; Hidding, B.; Hooker, S. M.; Irman, A.; Kononenko, O.; Kurz, T.; de la Ossa, A. Martinez; Schramm, U.; Karsch, S.
PHYSICAL REVIEW X 9(1), 011046 (MAR 2019)
https://doi.org/10.1103/PhysRevX.9.011046

Plasma wakefield acceleration (PWFA) is a novel acceleration technique with promising prospects for both particle colliders and light sources. However, PWFA research has so far been limited to a few largescale accelerator facilities worldwide. Here, we present first results on plasma wakefield generation using electron beams accelerated with a 100-TW-class Ti:sapphire laser. Because of their ultrashort duration and high charge density, the laser-accelerated electron bunches are suitable to drive plasma waves at electron densities in the order of 10^{19} cm^3. We capture the beam-induced plasma dynamics with femtosecond resolution using few-cycle optical probing and, in addition to the plasma wave itself, we observe a distinctive transverse ion motion in its trail. This previously unobserved phenomenon can be explained by the ponderomotive force of the plasma wave acting on the ions, resulting in a modulation of the plasma density over many picoseconds. Because of the scaling laws of plasma wakefield generation, results obtained at high plasma density using high-current laser-accelerated electron beams can be readily scaled to low-density systems. Laser-driven PWFA experiments can thus act as miniature models for their larger, conventional counterparts. Furthermore, our results pave the way towards a novel generation of laser-driven PWFA, which can potentially provide ultralow emittance beams within a compact setup.

Robustness of a plasma acceleration based free electron laser

Labat, M.; Loulergue, A.; Andre, T.; Andriyash, I. A.; Ghaith, A.; Khojoyan, M.; Marteau, F.; Valleau, M.; Briquez, F.; Benabderrahmane, C.; Marcouille, O.; Evain, C.; Couprie, M. E.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 21(11), 114802 (NOV 2018)
https://doi.org/10.1103/PhysRevAccelBeams.21.114802

Laser plasma accelerators (LPA) can sustain GeV/m accelerating fields offering outstanding new possibilities for compact applications. The LPA beam brightness can now be comparable to radio-frequency accelerators' (RFA), thanks essentially to the beams short duration (< 3 fs) and low emittance (as small as 0.1 micron). Still, the mrad level divergence and few percent level energy spread, remain limiting parameters in the cases of demanding applications such as free electron lasers (FELs). Several concepts of transfer line were proposed to mitigate those intrinsic properties targeting undulator radiation applications. We study here the robustness of the chromatic matching strategy for FEL amplification at 200 nm in a dedicated transport line, and analyze its sensitivity to several parameters. We consider not only the possible LPA source jitters, but also various realistic defaults of the equipment such as magnetic elements misalignments or focussing strength errors, imperfect undulator fields, etc.

Enhancement of betatron x rays through asymmetric laser wakefield generated in transverse density gradients

Ferri, J.; Davoine, X.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 21(9), 091302 (SEP 2018)
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Laser wakefield acceleration of electrons usually offers an axisymmetry around the laser propagation axis. Thus, the accelerating electrons that are focused on axis often execute small transverse oscillations. In this article, we propose a simple scheme to break this symmetry, which enhances the transverse wiggling of electrons and boosts the betatron radiation emission. Through 3D particle-in-cell simulations, we show that sending the laser with a small angle of incidence on a transverse plasma density gradient generates an asymmetric wakefield. It first provokes injection and then increases the wiggling of the electrons through the transverse shifting of the wakefield axis which occurs when the laser pulse leaves the gradient. Consequently, we show that the radiated energy per unit of charge can increase by a factor >20 when using this scheme, and that the critical energy of the radiation quintuples compared with a reference case without the transverse density gradient.

Low-density hydrodynamic optical-field-ionized plasma channels generated with an axicon lens

Shalloo, R. J.; Arran, C.; Picksley, A.; von Boetticher, A.; Corner, L.; Holloway, J.; Hine, G.; Jonnerby, J.; Milchberg, H. M.; Thornton, C.; Walczak, R.; Hooker, S. M.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 22(4), 041302 (APR 2019)
https://doi.org/10.1103/PhysRevAccelBeams.22.041302

We demonstrate optical guiding of high-intensity laser pulses in long, low-density hydrodynamic optical-field-ionized (HOFI) plasma channels. An axicon lens is used to generate HOFI plasma channels with on-axis electron densities as low as $n_e(0) = 1.5 \times 10^{17}$ cm^3 and matched spot sizes in the range 20 μm $\lesssim W_M \lesssim$ 40 μm. Control of these channel parameters via adjustment of the initial cell pressure and the delay after the arrival of the channel-forming pulse is demonstrated. For laser pulses with a peak axial intensity of 4×10^{17} W cm^{-2} , highly reproducible, high-quality guiding over more than 14 Rayleigh ranges is achieved at a pulse repetition rate of 5 Hz, limited by the available channel-forming laser and vacuum pumping system. Plasma channels of this type would seem to be well suited to multi-GeV laser wakefield accelerators operating in the quasilinear regime.

Mechanisms for the mitigation of the hose instability in plasma-wakefield accelerators

Mehrling, T. J.; Fonseca, R. A.; de la Ossa, A. Martinez; Vieira, J.
PHYSICAL REVIEW ACCELERATORS AND BEAMS 22(3), 031302 (MAR 2019)
https://doi.org/10.1103/PhysRevAccelBeams.22.031302

In this work we provide an in-depth analysis of mechanisms which mitigate the hose instability in the blowout regime in plasma-wakefield accelerators. We show by means of theory and three-dimensional particle-in-cell simulations that the mitigation mechanisms related to a beam energy spread are effective for parameters as used in major plasma-wakefield accelerator experiments and for various beam energies, beam current profiles, and types of hosing seed. In addition, we establish the theoretical principles for the reduction of the initial hosing seed in tapered vacuum-to-plasma transitions and derive respective analytic predictions which are successfully benchmarked against particle-in-cell simulations. We also investigate the possibility to facilitate efficient and stable acceleration of witness beams in the blowout regime. This work therefore provides a deepened understanding for the methods that allow for the mitigation of hosing, a crucial prerequisite to facilitate stable acceleration of high quality beams in plasma-wakefield accelerators.

Preserving emittance by matching out and matching in plasma wakefield acceleration stage

Li, Xiangkun; Chance, Antoine; Phu Anh Phi Nghiem
PHYSICAL REVIEW ACCELERATORS AND BEAMS 22(2), 021304 (FEB 2019)
https://doi.org/10.1103/PhysRevAccelBeams.22.021304

In more than four decades, particle acceleration by plasma wakefield has demonstrated its feasibility and efficiency. This acceleration technique is now starting to be planned for providing high-quality beams to well-defined user communities. High beam energy is also considered by piling successive plasma acceleration stages. In this context, avoiding beam degradation, on top of all emittance degradation, is the main concern when transferring the accelerated beam to the users or to the following acceleration stage. After examining the behavior of the trace and the phase emittances when crossing through a conventional transfer line, we are able to determine the criteria to be achieved in the plasma ramps so as to minimize emittance growth. Then the optimal density profile is studied for these ramps at the entrance and exit of a plasma stage accelerating electrons from the energy of 150 MeV to 5 GeV. Finally, the design of an optimal transfer line allows showing that the emittance growth can be contained to less than 10% in realistic conditions when transferring a beam to a free-electron laser.

Toward low energy spread in plasma accelerators in quasilinear regime

Li, Xiangkun; Phu Anh Phi Nghiem; Mosnier, Alban
PHYSICAL REVIEW ACCELERATORS AND BEAMS 21(11), 111301 (NOV 2018)
https://doi.org/10.1103/PhysRevAccelBeams.21.111301

In this paper, we address the energy spread and slice energy spread of an externally injected electron beam in plasma wakefield accelerators operating in the linear or quasilinear regime. The energy spread is first derived taking into account the phase dependence of the wakefield along the finite-length bunch together with the dephasing during acceleration and found to be strongly dependent on the bunch length. This could be compensated by the beam loading effect, the energy spread from which is then derived and found to be nearly independent of the bunch length. However, the transverse dependence of the beam loading effect also makes the particles at the same longitudinal position experience different accelerating fields, introducing a significant slice energy spread. To estimate the slice energy spread, a theoretical analysis was conducted by taking the transverse betatron motion into account. As a study case, 3D simulations for the 5 GeV laser-plasma acceleration stage of the European Plasma Research Accelerator with eXcellence in Applications project have been performed. Careful optimization of the parameters allows one to obtain an energy spread of <= 1% and a slice energy spread of <= 0.1%, with good agreement between theories and simulations.

Temperature analysis in the shock waves regime for gas-filled plasma capillaries in plasma-based accelerators

Biagioni, A. *et al.*
JOURNAL OF INSTRUMENTATION 14, C03002 (MAR 2019)
https://doi.org/10.1088/1748-0221/14/03/C03002

Plasma confinement represents a crucial point for plasma-based accelerators and plasma lenses because it can strongly affect the beam properties. For this reason, an accurate measurement of the plasma parameters, as plasma temperature, pressure and electron density, must be performed. In this paper, we introduce a novel method to detect the plasma temperature and the pressure for gasfilled capillaries in use at the SPARC_LAB test facility. The proposed method is based on the shock waves produced at the ends of the capillary during the gas discharge and the subsequent plasma formation inside it. By measuring the supersonic speed of the plasma outflow, the thermodynamic parameters have been obtained both outside and inside the capillary. A plasma temperature around 1.4 eV has been measured, that depends on the geometric properties and the operating conditions of the capillary.

Observation of anomalous side-scattering in laser waketield accelerators

Krushelnick, K.; Dangor, A. E.; Kaluza, M.; Mangles, S. P. D.; Murphy, C. D.; Najmudin, Z.; Thomas, A. G. R.
LASER AND PARTICLE BEAMS 36(3), 391-395 (SEP 2018)
https://doi.org/10.1017/S0263034618000411

High-intensity femtosecond laser-plasma interaction experiments were performed to investigate laser-plasma wakefield acceleration in the "bubble" regime. Using a 15 TW laser pulse, the emission of side-scattered radiation was spectrally and spatially resolved and was consequently used to diagnose the evolution of the laser pulse during the acceleration process. Side-scattered emission was observed immediately before wavebreaking at a frequency of $\omega_L + 1.7\ \omega_p$ (where ω_L is the laser frequency and ω_p is the background plasma frequency). This emission may result from scattering of laser light by large amplitude plasma oscillations generated in the shell of the wakefield "bubble" and which occurs immediately prior to the wavebreaking/injection process. The observed variation of the frequency of scattered light with electron density agrees with theoretical estimates.

Development of mini-undulators for a table-top free-electron laser

Petrov, G.; Davis, J.; Schumaker, W.; Vargas, M.; Chvykov, V; Hou, B.; Maksimchuk, A.; Yanovsky, V; Thomas, A. G. R.; Krushelnick, K.; Garraud, A.; Arnold, D. P.; Peterson, B. A.; Allen, M. G.
LASER AND PARTICLE BEAMS 36(3), 396-404 (SEP 2018)
https://doi.org/10.1017/S0263034618000423

The development of laser wakefield accelerators (LWFA) over the past several years has led to an interest in very compact sources of X-ray radiation - such as "table-top" free electron lasers. However, the use of conventional undulators using permanent magnets also implies system sizes which are large. In this work, we assess the possibilities for the use of novel mini-undulators in conjunction with a LWFA so that the dimensions of the undulator become comparable with the acceleration distances for LWFA experiments (i.e., centimeters). The use of a prototype undulator using laser machining of permanent magnets for this application is described and the emission characteristics and limitations of such a system are determined. Preliminary electron propagation and X-ray emission measurements are taken with a LWFA electron beam at the University of Michigan.

The Potential of EuPRAXIA@SPARC_LAB for Radiation Based Techniques

Balerna, A. *et al.*
CONDENSED MATTER 4(1), 30 (MAR 2019)
https://doi.org/10.3390/condmat4010030

A proposal for building a Free Electron Laser, EuPRAXIA@SPARC_LAB, at the Laboratori Nazionali di Frascati, is at present under consideration. This FEL facility will provide a unique combination of a high brightness GeV-range electron beam generated in a X-band RF linac, a 0.5 PW-class laser system and the first FEL source driven by a plasma accelerator. The FEL will produce ultra-bright pulses, with up to 10^{12} photons/pulse, femtosecond timescale and wavelength down to 3 nm, which lies in the so called "water window". The experimental activity will be focused on the realization of a plasma driven short wavelength FEL able to provide high-quality photons for a user beamline. In this paper, we describe the main classes of experiments that will be performed at the facility, including coherent diffraction imaging, soft X-ray absorption spectroscopy, Raman spectroscopy, Resonant Inelastic X-ray Scattering and photofragmentation measurements. These techniques will allow studying a variety of samples, both biological and inorganic, providing information about their structure and dynamical behavior. In this context, the possibility of inducing changes in samples via pump pulses leading to the stimulation of chemical reactions or the generation of coherent excitations would tremendously benefit from pulses in the soft X-ray region. High power synchronized optical lasers and a TeraHertz radiation source will indeed be made available for THz and pump-probe experiments and a split-and-delay station will allow performing XUV-XUV pump-probe experiments.

Permanent Magnet-Based Quadrupoles for Plasma Acceleration Sources

Amin Ghaith, Driss Oumbarek, Charles Kitégi, Mathieu Valléau, Fabrice Marteau, Marie-Emmanuelle Couprie

INSTRUMENTS 3, 27 (APR 2019)
https://doi.org/10.3390/instruments3020027

The laser plasma accelerator has shown a great promise where it uses plasma wakefields achieving gradients as high as GeV/cm. With such properties, one would be able to build much more compact accelerators, compared to the conventional RF ones, that could be used for a wide range of fundamental research and applied applications. However, the electron beam properties are quite different, in particular, the high divergence, leading to a significant growth of the emittance along the transport line. It is, thus, essential to mitigate it via a strong focusing of the electron beam to enable beam transport. High-gradient quadrupoles achieving a gradient greater than 100 T/m are key components for handling laser plasma accelerator beams. Permanent magnet technology can be used to build very compact quadrupoles capable of providing a very large gradient up to 500 T/m. We present different designs, modeled with a 3D magnetostatic code, of fixed and variable systems. We also review different quadrupoles that have already been built and one design is compared to measurements.

Vacancies

Call for applications to PhD programmes at the University of Pisa

The University of Pisa is now accepting applications for the admission to its PhD Programmes for the academic year 2019/2020 (35° cycle). The list of available programmes and grants is given can be found here.

The educational activity of the Doctoral Programmes starts on the 1st of November of its first year and ends on the 31st of October 31st of its third year. In order to participate in the application process and avoid being disqualified, the candidate must register online **by May 29th, 2019, 1.00 pm (Italian Time).**

More information about the application process and admission requirements can be found here or on the website: http://dottorato.unipi.it/index.php/en/application-process-for-the-academic-year-2019-2020.html

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