EuPRAXIA_PP Annual Meeting 2024

Sunday, 22 September 2024 - Saturday, 28 September 2024

Hotel Hermitage, La Biodola Bay, Isola d'Elba, Italy

Book of Abstracts

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Opening talk: Recoil dominated electron-photon beam collisions, a way towards novel radiation sources, advanced secondary beams and new phenomena in astrophysics

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Recoil dominated electron-photon beam collisions, a way towards novel radiation sources, advanced secondary beams and new phenomena in astrophysics.
L. Serafini & V. Petrillo (INFN-Milano and University of Milano)

Abstract: Revisiting 100 years of Compton scattering, with emphasis on deep recoil regime of electron-photon collisions, spanning the full kinematics range from direct Compton effect of photons on targets to inverse Compton scattering of relativistic electrons with photon beams, let us discover some new effects of entropy exchange between the colliding beams. These phenomena have great potentialities for applications in several fields: from spectral purification effects that can be exploited for compact & sustainable mono-chromatic gamma ray sources, to plasma heating by trapped electrons in magnetic bottles, from advanced secondary beam production (positrons, muons) with very small emittance, to exotic effects of stopping ultra-high energy electrons with 255.5 keV X-rays, that may have impacts in the astro-physical field. Advanced plasma based GeV-class electron accelerators may represent the natural cradle for test experiments of deep recoil electron-photon interactions due to their compactness, versatility and flexibility to arrange beam-lines within a multi-faceted lay-out of electron beams and radiation of diverse nature (lasers, FELs, betatron beams, ICS X-rays, channeling radiation beams). Last but not least, exploring the deep recoil regime fundamental investigations of QED interactions may become feasible in dynamical ranges never explored before.

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Overview of Plasma based Linear Collider efforts

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Dielectric wakefield acceleration: application to linear colliders

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We discuss the rich physics of dielectric wakefield acceleration (DWA), with an eye to applications. Newly uncovered physical limitations on achievable gradient are examined, as well as fundamental issues concerning beam stability. In the latter context we introduce the concept of strong, alternating gradient wake focusing. We discuss the wide varieties of wakefield structures now under consideration. With this background, we present two scenarios of wakefield-based colliders where the positrons are accelerated in DWA to avoid complications present in plasma –a dual DWA accelerator, and a PWFA/DWA hybrid design.

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WP14 - Transformative Innovation Paths

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Beam Driven Acceleration Scheme to 5 GeV Energy for EuPRAXIA@SPARC_LAB

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The EUPRAXIA@SPARC_LAB facility will host the first ever FEL user facility in the nm range guided by a 1 GeV high-brighness electron beam. Beside this application, plans are underway to provide beams with energies up to 5 GeV through beam driven acceleration schemes relying on the existing RF accelerator whose maximum energy is 1 GeV to date. Different PWFA schemes have been proposed and described in literature to enable several GV/m accelerating gradient in the plasma thanks to the maximisation of the so called transformer ratio'. The paper reports on the techniques useful to produce electron beams through the designed EuPRAXIA@SPARC_LAB RF injector and drive the plasma stage so to provide final beam energy five times higher than the initial one.

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EuPRAXIA@SPARC_LAB energy boosting to 5 GeV by LWFA and external injection

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We propose a possible setup able to produce 5 GeV electron beams in the framework of the existing layout of the EuPRAXIA@SPARC_LAB facility. Although placing the plasma module for reaching the target energy downstream the existing beam line may seem the most natural solution, it faces dramatic problems in therm of overall footprint and interference with foreseen equipment. Since a high power laser will be part of the base instrumentation present in the facility, we plan to meet the target energy employing the external injection scheme in a laser driven plasma module, allowing for a much more compact solution. Moreover, taking advantage of past experience and technical solutions, we propose to install the module in a new beamline, parallel to the main one, in order to ease the beam manipulation, implementation of beam diagnostics and, possibly, its exploitation in user oriented applications.

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Plasma-Based Solutions for Beam Handling and Driver Extraction

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Plasma wakefield acceleration (PWFA) has achieved significant energy gains of gigaelectronvolts over centimeter-scale distances while maintaining high beam quality essential for high-brilliance applications. However, key challenges persist, particularly in managing the transverse handling of beams and removing the depleted high-charge driver without compromising the accelerated witness bunch.
We propose plasma-based solutions to address these challenges. Active-plasma lenses can be utilized for focusing, matching, and extracting the witness bunch, thereby reducing divergence and maintaining beam quality. Also, an innovative system of beam collimators and discharge capillaries enables the removal of the high-charge driver while preserving the emittance and peak current of the witness bunch.
These solutions are validated through numerical simulations, detailed particle-collimator interaction studies, and supported by experimental results.
This approach aims to enhance the practical implementation of PWFA, paving the way for compact, high-performance accelerators suitable for next-generation scientific and technological applications.

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Stable Beam driven wakefield in structured plasmas

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Wakefield excitation by structured electron bunches in hollow gaps between plasma wedges, Fig.1, is studied using three-dimensional particle-in-cell simulations. The main part of the electron bunch has a triangular current distribution in the longitudinal direction with a smooth head and short tail. These bunches propagate stably in the hollow gap while being attached to cusps of the plasma wedges. The excited wakefield profile may have a very high transformer ratio and allows to accelerate witness bunches to energies much higher than that of the driver bunch. Unlike round hollow channels, where asymmetric wakefields are difficult to avoid, no deleterious transverse beam break-up (BBU) is observed in the gap between cusp-shaped plasma layers.

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EuPRAXIA possible contributions to the Linear Collider development

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The African School of Physics

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Towards 400 Hz RF system for EuPRAXIA@SPARC_LAB

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The EuPRAXIA@SPARC_LAB project aims to develop a free-electron laser (FEL) facility using beam-driven plasma wakefield acceleration with a plasma module powered by a high-brightness linear accelerator. The linac is designed to produce a beam up to 1 GeV at a repetition rate of 100 Hz, employing an S-band photoinjector and an X-band booster. An exciting prospect is upgrading the linac to a 400 Hz RF system, which could substantially enhance the facility's performance. This presentation will address the technical challenges and potential solutions related to modifying the X-band booster and injector for higher frequency operation, focusing on RF power generation, RF structures, and overall thermal management.

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High repetition rate C-band Photoinjector

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C-band technology holds the potential to generate a high-energy, high-brightness electron beam by elevating the peak field of both the cathode and cavity within the machine. This proposed injector offers a promising avenue for achieving a high repetition rate, facilitating kHz operation. The conceptualization of this injector draws inspiration from the EuPRAXIA@SPARC LAB S-band injector, wherein the original gun is replaced with a 2.6-cell C-band RF gun. The entire beamline is proportionally scaled, reducing longitudinal lengths by a factor of 2 while doubling electric and magnetic fields. Operating with brief RF pulses, the 2.6-cell C-band RF gun effectively mitigates breakdown rates and power dissipation. By capitalizing on higher peak fields and applying established scaling laws to reduce laser spot size and duration, it becomes feasible to minimize both cathode and space charge emittance. The incorporation of a complete Cband injector is anticipated within the framework of the X-band Linacs for the EuPRAXIA@SPARC LAB design study, aiming to produce ultra-high-quality beams primed for applications such as light production or plasma acceleration.

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High Repetition rate Plasma sources

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In view of the realization of the EuPRAXIA@SPARC LAB facility, designed to operate a plasma-driven FEL source at 100-400 Hz, the capability of plasma sources to operate at high repetition rates plays a key role. Concerning gas-filled

plasma discharge capillaries, which allow direct control over plasma properties, a crucial aspect is related to the longevity of the material, exposed to the heat flux delivered by high voltage plasma discharges. In this regard, the innovative design of gas-filled discharge capillaries, based on the use of ceramic materials, represents a reliable solution in terms of high temperature resistance and cost-effectiveness. In addition, a suitable option for high repetition rate plasma sources is given by laser-induced plasma filaments, which can sustain high repetition rate operation without material overheating, due to the low thermal load delivered onto the capillary walls by few-mJ femtosecond laser pulses. Furthermore, plasma filaments are characterized by high stability and tunable parameters, such as filament length and density, thus meeting the requirements outlined in the EuPRAXIA scientific case.

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Fully synchronized high repetition rate Petawatt laser driver for betatron beamline on EuPRAXIA@SparcLab machine

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Precise synchronization plays a major role in the stability of an accelerator-based light source, or for ultrafast dynamics studies. We will present our strategy and recent achievements applied to synchronize a kHz Ti:Sa ultrafast laser to a Terawatt Yb ultrafast laser. We report on the synchronization at few fs rms level, both on short-term and long-term.
We first synchronize the slave oscillator (Yb) to the master oscillator (TiSa) using an optical cross-correlator. The fast actuator in the slave oscillator compensates for the fast and slow timing fluctuations, leading to 5fs rms relative timing jitter.
Additionally, we implement a second optical cross-correlator placed at the outputs of both amplifiers, measuring the relative jitter and drift between the 2 amplification. A motorized fibered optical delay line is used to compensate for the slow drift between both amplifiers, with a long-term stability of 16fs rms over 8 hours.
We will discuss on the limitations and improvement perspectives of such solution, and identify how this technique can be applied to a high repetition rate Petawatt laser driver of the betatron beamline installed on Eupraxia@SparcLab machine.

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WP14 physics progress

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VUV Applications at EuPRAXIA@SPARC_LAB

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The scientific applications of ARIA, a VUV-seeded FEL beamline that will be part of the EuPRAXIA@SPARC_LAB user facility, are presented here. ARIA will deliver ultra-bright, ultra-short photon pulses in the 50 to 180 nm energy range, with tunable linear and circular polarization. This makes it an ideal source for time-resolved studies in atomic, molecular, and cluster physics, as well as for the investigation of gas phase systems and liquids. Key experimental techniques will include resonant VUV measurements, photoelectron and ion spectroscopy, two-photon photo-emission and small- and wide-angle scattering. A schematic overview of the experimental endstation required to perform these classes of experiments will also be given.

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Theory and simulations for high K/γ regimes in undulator and ion channel devices

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A fundamental comparison between undulator and ion channel radiation is presented. Conventional theory for both devices fails at describing high K and K/γ regimes, providing an underestimation of particle trajectory amplitude and period. This may lead to a wrong estimation of radiation emission in many setups of practical interest, as the ion column. A redefinition of plasma density and undulator strength expressions leads to a more reliable prediction of particle behavior, reproducing the closest possible conditions in the two devices. Then, differences in spectral features may be addressed via analytical and numerical simulations of single particle and full beam dynamics. In this contribution we outline a theoretical framework and show the unique spectral features and drawbacks related to such an extreme undulation regime.

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Plasma components for electron sources

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