3rd Topical Workshop on Novel Acceleration Techniques

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HZDR

Book of Abstracts

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Overview of Laser Plasma Accelerators

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Since the first idea to use intense laser pulse to generate collective electron motion suitable for electrons acceleration, many new ideas have been proposed and have been successfully demonstrated. The tremendous progresses that have been done over the world these recent years show the vitality of a new and growing community at the interface of accelerator, plasma and laser sciences. These accelerators based on laser plasma cavities have the particularity to support very intense electric field, with values of the order of hundreds of GV/m that can be used to deliver high quality electron beam with unique parameters. This alternative approach, rich in very exciting physical phenomena, opens the route for many applications.

I'll present the fascinating history of laser plasma accelerators.

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Advanced Proton Driven Plasma Wake-field Acceleration Experiment at CERN: AWAKE Collaboration

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Advanced Proton Driven Plasma Wake-field Acceleration Experiment at CERN: AWAKE Collaboration

by Mikhail Martyanov (CERN) on behalf of AWAKE Collaboration

The AWAKE Collaboration has been formed in order to demonstrate proton-driven plasma wakefield acceleration of electrons for the first time ever. This technology could lead to future colliders of high energy of electrons but of a much reduced length compared to proposed future linear accelerators. The 400 GeV/c SPS proton beam will be extracted towards the AWAKE facility and injected into a 10 meters Rubidium plasma cell where the long proton bunches will be modulated into significantly shorter micro-bunches. The seeding of a micro-bunching instability of relatively long SPS proton bunch will be done by co-propagating ionization front induced by a powerful fs-laser pulse in Rubidium vapour. Proton micro-bunches will then initiate a strong wake-field in the plasma with peak fields above 1 GV/m that will be capable to accelerate a bunch of electrons from about 20 MeV up to the GeV scale within a few meters. The experimental program is based on detailed numerical simulations of proton / electron beams and plasma interactions. First protons to the experiment are expected at the end of 2016 and this will be followed by an initial 3–4 year experimental program. The AWAKE project at CERN has been already started at 2013 and it is an accelerator R&D experiment which is a prerequisite for the future larger-scale facilities of proton-driven plasma wake-field acceleration and applications to high energy colliders.

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From 1-D fluid models to 3D PIC simulations for resonant PWFA experiments at SPARC_LAB

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Considerable interest has been shown in the last few years in compact plasma accelerators characterized by extremely high accelerating gradients generated, e.g., by high brightness particle beams (Plasma WakeField Acceleration mechanism - PWFA). PWFA is currently under investigation at SPARC_Lab test facility [1] – INFN-LNF (Frascati, Italy). SPARC_Lab is an ideal place to test PWFA schemes due to the versatility offered by the high brightness photo-injector. At present train of ultra-short (100 fs) low emittance electron bunches can be generated and manipulated to achieve high accuracy temporal separation.

Our work spans from simple and fast one-dimensional fluid [2] simulations to fully 3D PIC simulations (ALaDyn Code [3]). One-dimensional fluid models are somehow too simple to catch the entire underlying physics, nevertheless they offer a simple and fast tool to asses working points. We discuss how these models can be analytically modified to extend its validity in the quasi-non-linear regime to phenomenologically account for damping effects and how it compares with 1D-PIC code as well as on the on-axis results of fully 3D-PIC code.

We will also show fully 3D simulations for a plausible two bunches (driver plus witness) SPARC_Lab configuration. We discuss pros and cons of a strongly elongated driver, maximum achievable transformer ratios and energies.

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Plasma-based acceleration experiments at SPARC LAB

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The current goal of the world wide R&D programs is to demonstrate the stable and repeatable production of high brightness beams (HBEBs), as those required for example by Free Electron Lasers which is one of the most demanding application of electron particle accelerators.
The scheme proposed at the SPARC_LAB test facility is based on the external injection of the electrons inside the plasma in order to achieve low beam emittance and low energy spread. Two different mechanisms are proposed for generating the conditions suitable to achieve acceleration of the electron beam inside the plasma: an external injection laser wakefield acceleration (LWFA), by combining the multi-hundreds power laser (Flame) and the HBEB from the SPARC photo-injector, and a resonant plasma wakefield acceleration (PWFA), by using a train of high brightness electron

bunches, the so-called comb beam.
The experience gained at SPARC_LAB on the generation, manipulation, acceleration and application of high brightness electron beams enable us to face with this challenging task.

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Research on superintense laser-driven ion acceleration at Politecnico di Milano

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In this talk, the research activities on superintense laser-driven ion acceleration under development at Politecnico di Milano (Polimi) are presented.
The discovery in 2000 of brilliant, multi-MeV, collimated ion sources emerging from targets irradiated by intense laser pulses stimulated great interest worldwide, boosted by the ultra-compact spatial scale of the accelerator and the properties of the laser-driven ion beams. The laser-target system provides unique appealing features to fundamental physics, since the acceleration of macroscopic quantities of matter towards GeV/nucleon energies on a microscale and relativistic, collective many-body effects are intrinsically merged, continuously raising new challenging issues which can be studied in a small laboratory scale. Laser driven ion-beams can also have the potential to be used, in the future, in many scientific, technological and medical areas [1].
At Polimi, laser-ion acceleration is investigated both at the theoretical and at the experimental level. The main ion acceleration mechanisms are theoretically investigated, using both simplified analytical models and advanced multi-dimensional particle-in-cell simulations, to achieve deeper, more satisfactory understanding and to propose improvements and optimizations of the basic schemes. A major part of the research is focused on the design, production and testing of micro- and nano-engineered targets whose characteristics are tailored to optimize the production of energetic ions.
As a specific example, the use of multi-layered targets, obtained by deposition of a low density (foam) material on a thin metal foil, will be discussed. The foam material (originally designed, produced and fully characterized at NanoLab, Polimi [2]) can have an average density more than two orders of magnitude lower than the solid material, which fills the gap between the density of solid and gaseous targets. The low-density layer can allow to enhance ion acceleration, as already investigated by numerical simulations [3]. Preliminary, promising laser-ion acceleration experiments using these targets have been conducted [4].
More generally, a brief review of the experimental, theoretical and numerical results activities will be presented, together with an outline of the future programs, with special emphasis on the challenges to be faced to properly understand the behavior of advanced target configurations.
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THz-pulse-driven particle accelerators

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Because of their suitable wavelength and temporal period, THz pulses with extremely high field strength are ideal for driving miniature particle accelerators. However, this fact is not yet well recognized. Here we give an overview of the possibilities and challenges of THz-pulse-driven electron and proton/ion accelerators.

Summary:

According to numerical studies, with dielectric laser accelerators (DLAs) based on a double-grating dielectric structure it is possible to achieve loaded gradients exceeding 1 GeV/m [1]. Very recently, the working of such a miniature accelerator was demonstrated in proof-of-principle experiments [2]. However, these results also show the drawback of this approach: for a laser with about 1 μm wavelength the gap between the dielectric structures can be only a few hundred nm, thereby limiting the charge of the accelerated electron/ion bunch. In a recent publication we drew the attention to the fact that THz pulses with extremely high field strength available at present or becoming available in the near future, owing to their two orders of magnitude longer wavelength, are better suited for charged particle manipulation, including acceleration, bending, spatial or temporal focusing [3]. In this contribution we give an overview of the possibilities and challenges of THz-pulse-driven electron and proton/ion accelerators. Nowadays the main challenges are to achieve tens-of-mJ THz pulse energy and to optimize the geometry and the materials of the accelerating dielectric structure.

In the last ten years THz pulse generation with tilted-pulse-front-excitation [4] of $LiNbO_3$ (LN) resulted in the increase of THz energy by seven orders of magnitude, reaching the 100-μJ level [5]. In the next few years using optimal conditions (contact grating, long-pulse excitation, and cryogenic temperatures) will result in THz pulses with 10 MV/cm focused electric field strength and energies on the tens-of-mJ level [6].
According to numerical simulations using 20-mJ, 0.6-THz driving pulses for electron acceleration in dielectric-loaded metallic waveguides it is possible to accelerate a 1.6-pC electron bunch from 1 MeV to 10 MeV by simultaneously compressing it from 100 fs to 2 fs [7]. For such a device, and similarly for dielectric grating accelerators [1,2,8], using THz driving pulses rather than visible/near-infrared ones enables to exploit advantages of the two-to-three orders of magnitude longer wavelength and oscillation period of THz pulses. The allowed transversal size of the device is proportional to the wavelength. Larger transversal size allows larger bunch charge and results in larger throughput. Longer temporal period also allows a larger temporal jitter tolerance between the electron bunch and the driving pulse.

The dielectric grating accelerator can be used for acceleration of slow electrons and protons/ions, too, if the period of the structure is shorter than the wavelength of the driving pulse [9]. In this case evanescent fields are generated in the dielectric gap and this field accelerates the ions. We proposed another THz-driven device for postacceleration and monochromatization of proton beams [10]. Here two identical and synchronized THz pulses create the accelerating evanescent field between the two symmetrically arranged dielectric prisms. According to simulations, a proton bunch with 40 MeV initial energy can be boosted by 28% in this way.

In a joint project University of Pécs and HZDR work together to explore possibilities of THz-pulse-driven electron and proton acceleration. As a first step we plan to experimentally demonstrate the acceleration of slow electrons with intense THz pulses. Various dielectric structure geometries will be investigated to maximize the output energy. In the second phase intense THz pulses will be used to post-accelerate protons. First results of preliminary calculations on electron acceleration will be shown.

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Compact electron acceleration and bunch compression in THz waveguides

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We numerically investigate the acceleration and bunch compression capabilities of 20 mJ, 0.6 THz-centered coherent terahertz pulses in optimized metallic dielectric-loaded cylindrical waveguides. In particular, we theoretically demonstrate the acceleration of 1.6 pC and 16 pC electron bunches from 1 MeV to 10 MeV over an interaction distance of 20mm, the compression of a 1.6 pC 1 MeV bunch from 100 fs to 2 fs (50 times compression) over an interaction distance of about 18mm, and the compression of a 1.6 pC 10 MeV bunch from 100 fs to 1.61 fs (62 times) over an interaction distance of 42 cm. The obtained results show the promise of coherent THz pulses in realizing compact electron acceleration and bunch compression schemes. These schemes are the key concepts toward achieving a coherent compact X-ray source in the framework of AXSIS project.

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Optimization study of a transport line for laser-plasma generated electron beams

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The need of conceiving a transport line for laser-generated beams of electrons comes from the fact that these beams quickly loose their remarkable characteristics, such as the transverse normalized emittance and beam dimensions, as soon as they exit the plasma medium.
Thus, in order to exploit these novel electron sources, proper devices must be designed, able to deliver beams to users preserving their quality. This would make them a competitive alternative to conventional accelerators based on RF technology.

The main reason of degradation lies in the high divergence and energy spread these beams present at the source, causing a difficult control which requires uncommon magnetic strenghts.

We report on an optimization study related to the coupling of laser-accelerated electrons with conventional magnetic transport lines. We analyze different configurations and different beam energies. We point out and discuss the main problems arising by matching state-of-the-art laser-plasma electron beams with traditional accelerator facilities.

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Final Focus System for Thomson Scattering at ELBE

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The design of a Final Focus System optimized for Thomson scattering at ELBE is presented. This telescope system consisting of four permanent magnet based quadrupoles will retain focusing properties like the position of the focal plane and spot size for electron energies between 20 and 30 MeV by adjusting the quadrupole positions individually on a motorized stage. Since the electron beam is chirped for bunch compression and therefore obtained a large rms energy spread of 400 keV, the 6D phase space dynamics were studied in second order to include chromatic effects.
We also present the design of the permanent magnet quadrupoles for the Final Focus System. Iron poles ensure a high field quality and adjustable shunts allow for fine adjustment of the field strength and compensation of deviations in the permanent magnet material.

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Compton backscattering experiments at LOA

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Synchrotron-radiation from Compton backscattering of high intensity laser pulses by laser-accelerated electrons holds out he prospect of generating quasi-monochromatic X and Gamma-Ray using medium scale laser facilities.
In this talk we are going to discuss simulations on Compton backscattering for various possible experimental configurations for experiments using the Salle Jaune Laser Facility at Laboratoire d'Optique Appliquée in Palaiseau, France. Furthermore preliminary results from recent experiments on Compton backscattering using a plasma-mirror are presented.

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Laser-driven ion acceleration with ultra-thin targets

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Laser-driven plasma accelerators can potentially produce proton and ion beams of very high quality, which could be utilised in a wide range of applications including proton radiography and hadron therapy.
Important aspects of the interaction of petawatt lasers with ultrathin foils that affect the ion acceleration process will be reviewed and some preliminary results from experimental campaigns in the ASTRA-Gemini and VULCAN laser systems of the Central Laser Facility (Didcot, UK) will be presented.
Furthermore estimations for the capabilities of the future VEGA laser system of the CLPU (Salamanca, Spain) will be given.

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Experimental Results and Future Directions of Various Dielectric Laser Accelerators

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Recent experimental results showing proof-of principle acceleration in three distinct Dielectric Laser Accelerator designs are presented and discussed. These designs include the "Double-Grating" structure developed at SLAC, the resonant cavity "Micro-Accelerator Platform developed at UCLA and the "Single-Grating" structure developed at MPQ and the University of Erlangen-Nuremberg. Additionally, the next steps being taken to further develop the Single-Grating structure are highlighted.