LA³NET - AN INTERNATIONAL NETWORK ON LASER APPLICATIONS AT ACCELERATORS

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Abstract

Lasers have become increasingly important for the successful operation and continuous optimization of particle accelerators: Laser-based particle sources are well suited for delivering the highest quality ion and electron beams, laser acceleration has demonstrated unprecedented accelerating gradients and might be an alternative for conventional particle accelerators in the future, and without laser-based beam diagnostics it would not be possible to unravel the characteristics of many complex particle beams. The LA³NET project brings together research centres, universities, and industry partners to jointly train 17 early stage researchers. In addition, the consortium will also organize a number of international training events, such as schools, topical workshops and conferences. This contribution gives examples from the network's broad research program and summarizes planned training events.

INTRODUCTION

The advancement of science and engineering in the past decades is inherently linked to the development of lasers. Ever higher laser beam powers, brightness and shorter pulse lengths have helped establish them as an invaluable tool for both a wide range of industry and medical applications, such as for example material treatment, precision measurements, laser cutting, display technologies, laser surgery, and for fundamental research. In fact, many of the most advanced experiments in astrophysics, atomic, molecular and optical physics, as well as in plasma research would be impossible without the latest laser technology.

Moreover, lasers have become increasingly important for the successful operation and continuous optimization of particle accelerators: laser-based particle sources are well suited for delivering the highest quality ion and electron beams, laser acceleration has demonstrated unprecedented accelerating gradients that might provide the alternative technology needed for the next generation of particle accelerators in the future, and without laser-based beam diagnostics it would not be possible to unravel the characteristics of many complex particle beams.

The LA^{3}NET consortium proposes to develop **la**ser **a**pplications for particle **a**ccelerators within an initial training **net**work. The network brings together research centres, such as CERN, CLPU and HZDR, universities from across Europe, and industry partners to jointly provide training through research to the next generation of postgraduate researchers. The network will also forge and develop long term collaboration and links between the teams involved across sectors and disciplinary boundaries and define improved research and training standards in this multi-faceted field.

The project started on 1.10.2011 and has a duration of 48 months. With a maximum project budget of up to 4.6 M€, it is one of the very large projects funded within the FP7 Marie Curie Actions ITN scheme and one of the largest research and training initiatives in beam instrumentation to date.

RESEARCH PROGRAM

The aim of LA³NET is to train early stage researchers (ESRs) in a large spectrum of laser-based applications at accelerator facilities. The projects are closely linked to an overall optimization of existing and future research infrastructures and through these developments the trainees will automatically contribute to and expand the experimental programs at these facilities. The following paragraphs outline some of the research projects within three of the main work packages of the network.

Particle Sources

Lasers have been successfully used to provide highest brightness electron and exotic ion beams that cannot be realized by any other technique. They have unmatched selectivity in multi-step resonant ionization by wavelength-tuneable lasers at ISOL facilities and are able to provide very high currents for energy applications in heavy ion fusion. Within LA^{3}NET, laser-based particle sources will be developed at CERN, HZDR, and GANIL. All three projects will challenge existing techniques and technologies. One ESR project at CERN covers the development of a solid state laser system for Resonance Ionization Laser Ion Source (RILIS) of the ISOLDE on-line isotope separator [1]. The aim is to improve the efficiency and reliability and to develop new ionization schemes and modernize the optical layout of the RILIS setup. The laser ion source of the ISOLDE on-line isotope separator is based on highly selective, multi-step resonant ionization by wavelength-tuneable lasers. The availability of a UV pump beam opens up possibilities for much broader choices of atomic transitions in the resonance ionization process. The present technologies for wavelength tuning, such as dye lasers, Ti:Sapphire lasers and optical parametric generators, will be exploited in the course of this project and will require close links to the industry sector.

The second ESR at CERN will work on the development of a laser source for polarized electrons. A

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test bench for the production of polarized electrons will be set up and the critical parameters of the source will be analyzed in detail. A substantial upgrade of the existing CTF3 photo injector [2] will be the production of polarized electrons by lasers at wavelengths in the vicinity of 700 nm using GaAs photo cathodes. The envisaged characteristics of the source are very challenging regarding the time structure of the laser: 0.96 nC bunches of polarized electrons are to be spaced by 500 ps to form 156 ns long macro-bunches repeated at the machine operation rate of 50 Hz. The goal will be to develop a 2 GHz optical pulse train, chopped and amplified to the target pulse length and bunch energy.

The ESR project at HZDR concerns the development of a high brightness superconducting RF photo injector for electron-laser interaction experiments at the ELBE accelerator facility [3]. At HZDR the world's first successful proof-of-principle setup was installed and later a second SRF gun for operation at the ELBE accelerator was developed, installed, and put into operation. Although in operation, critical components of the SRF gun need further optimization and refinement, such as the superconducting cavity, photo cathodes, as well as the drive laser system. Besides an increased acceleration gradient, approaches that will be tested as part of this project are RF focusing, the installation of a solenoid, shaped photo cathode surfaces, or an additional TE-mode wave, coupled into the cavity. Particularly promising is the pulse shaping of the UV drive laser for the production of very short and high-charge electron bunches..

Laser Acceleration

It is a significant engineering and physics challenges to realize and control increased field gradients for the acceleration of particle beams. This is highly desirable for many applications, both in fundamental sciences and in industry to substantially reduce the size of accelerator facilities andopen avenues for providing beam currents above present limits This includes applications in medical infrastructures for treatment and diagnostic purposes that can be realized with a substantially reduced effort, and even 'pocket accelerators', based on a laser/optical fibre combinations.

CLPU is a national facility created by a consortium formed by the Spanish Ministry of Science and Innovation, the regional government and the University of Salamanca and focuses on strong field physics. The centre has extensive experience in simulation studies and experiments on atoms, molecules, nuclei, and plasmas in strong laser fields. There, the ESR will work on investigations into particle acceleration for hadron therapy. Petawatt range lasers, interacting with matter, can generate beams of accelerated protons and other ions which in turn can be used for hadron cancer therapy. Such laser-generated beams are a potentially cheaper and more compact alternative to conventional proton accelerators, but so far the beam energies attained with laser accelerators are not high enough to make them useful for this purpose. The aim of this project is to identify adequate parameter sets, target geometries, and beam shaping and control schemes to obtain proton and ion beams which can ultimately be used for therapy. The ESR will first simulate the generation of particle beams by means of plasma codes before conducting experimental studies with CLPU's laser system, as well as completing experiments on proton acceleration at lower energies.

The ESR project at the Danish industrial partner Danfysik will look into developing the current experimental research into laser acceleration to a pre-commercial level in terms of identifying the needs and required specifications for different applications. One of the main challenges for laser acceleration remains to control the 6-dimensional phase space of particles and transport a well defined beam in a stable and industrially robust manner to the target or the application process. The focus in this project is hence on the development, design and manufacturing of prototypes of beam separating and beam transport sections, including diagnostics, vacuum, cryogenics, and system integration. Prototype R&D and experimental tests will be performed in collaboration with HZDR, University of Liverpool and CLPU.

Beam Diagnostics

Diagnostics systems are essential constituents of any accelerator; they reveal the properties of a beam and how it behaves in a machine. Without an appropriate set of diagnostic elements, it would simply be impossible to operate any accelerator let alone optimize its performance. The DITANET project [4] has pioneered a new approach to researcher training in this field and the concepts developed by this consortium have formed the basis also for the new initiative presented here.

A laser velocimeter for the characterization of particle beams or gas jets will be developed at the Cockcroft Institute / University of Liverpool, UK. Such gas targets are important for a number of accelerator-based experiments, either as cold targets for collision experiments, but also for beam diagnostic purposes [5]. In the latter case, a curtain shaped, supersonic gas jet is crossed with the charged particle beam to be characterized. By crossing the main beam at an angle of 45° and varying the jet density, least intrusive online measurements of the 2D transverse beam profile of any particle beam can be achieved, ranging from low energy ion beams, to high intensity proton beams in spallation sources and high energy colliders. To date, very few studies have addressed the optimization of the application of these jets. The development of a laser velocimeter for an in-detail characterization of the gas jet and investigations into the jet dynamics, probing simultaneously its density, velocity, and temperature will be all realized within this project. For this purpose, laser self-mixing will be used for jet analysis, providing unambiguous measurements from a single interferometric channel, realizable in a compact experimental setup.

The optimum exploitation of the Large Hadron Collider (LHC) ultimately depends on the quality and availability of the beams prepared in the injector complex. For this reason, a consolidation program of this complex is currently underway at CERN, aimed at improving both the beam quality and the reliability of the injectors. The first step of this program consists in the replacement of the low energy proton linear accelerator with a 160 MeV H^- ion injector, named LINAC4 [6]. To set up this new machine and achieve the best performance, it is important to measure the transverse emittance of the beam as it exits LINAC4. A new technique has been proposed, based on the "slit & grid" technique, but using a laser beam rather than a physical slit. An ESR at CERN will focus on the development of a laser emittance meter. The parameters of the laser and the required optical components will be determined, the signals induced in a detector will be simulated and the most suitable detector type will be identified A prototype setup will be designed, built and tested directly on LINAC4 or on another machine with similar characteristics.

TRAINING EVENTS

Training of all fellows will mostly be through specific project-based research realized by the respective host institutions with specific secondments to other partners for specialized techniques and cross-sector experience. In addition, the consortium will organize a number of network-wide events that will be open to the wider community.

International Schools

Two one week schools on "Laser Technology and Applications at Accelerators" will be organized during the first and the third year of LA^{3}NET: the first school will be held between 15th-19th October 2012 at GANIL in France. The school will focus on the basic principles of laser technology, electro optic effects, beam shaping and handling, and the integration and utilization of lasers at particle accelerators. In addition, the challenges for laser systems in future projects such as the Extreme Light Infrastructure (ELI) will be presented in detail and the international relevance of the network activities on a global scale will be explained. The network's industry partners will also contribute a session on 'technology transfer' and on how to bring ideas to the market. The second school will be held in 2014 at CLPU and will cover advanced laser technologies, in particular the combination of different fundamental techniques.

Topical Workshops

The network will initiate a series of Topical Workshops that cover topics, such as 'Particle Sources', 'Acceleration Techniques', 'Laser Technology and Optics Design' and 'Beam Diagnostics'. All workshops will be announced via the project's web page [7] and its quarterly newsletter (subscription is via the web page).

Conference on Laser Applications

In the last year of LA^{3}NET, a 3-day international conference on R&D in laser applications at accelerators will be organized, with a focus on the methods developed within the network. This may be organized as a satellite conference to one of the very large events such as the World of Photonics or the International Particle Accelerator Conference. This event will also serve as a career platform for the network's trainees who will get the opportunity to present the outcomes of their research projects.

LA^{3}NET Prize

The consortium will award an annual cash prize of 1,000 € for an outstanding contribution to the field of laser applications at accelerators to a researcher in the first five years of their professional career. Applications for the 2012 prize can be submitted until 30.9.2012. Full application details can be found on the LA^{3}NET web site. In addition, the consortium is sponsoring the Young Scientist Award at the International Conference on Laser Probing (LAP2012) [8]. This prize will be awarded based on a poster or oral contribution to the conference by an early stage researcher.

CONCLUSION

With a project budget of up to €4.6 million LA^{3}NET is one of the largest ever EU funded research and training project for early stage researchers in the field of laser applications for particle accelerators. The consortium delivering this action presently comprises 25 partner institutions from academia and industry. Besides a cutting edge research program, the network will also offer a large number of training events to the world-wide laser and accelerator communities. Close collaboration between all participants with a very prominent role of industry will provide an interdisciplinary basis for LA^{3}NET across sector boundaries to ensure that the clearly identified long term research and training objectives are achieved.

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