Cockcroft-12-12

BEAM DIAGNOSTICS DEVELOPMENTS WITHIN LA³NET

C.P. Welsch
Cockcroft Institute and The University of Liverpool, UK on behalf of the LA³NET Consortium

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Abstract

Lasers have become increasingly important for the successful operation and continuous optimization of particle accelerators. For beam diagnostics lasers provide the highest time and spatial resolutions for transverse and longitudinal beam profile measurements. They also allow the detection of density differences in particle beams with high dynamics ranges and permit measurements of very important machine parameters such as the momentum compaction factor and beam emittance. The development of these laser applications for accelerators is the focus of the LA3NET project funded by the EC with a €4.6 million grant. This FP7 Marie Curie Initial Training Network (ITN) will bring together more than 20 academic and industrial institutions from around the world. 17 early stage researchers (ESRs) will be recruited to the project to each work on dedicated research projects at specific partner sites. In addition, the network will organize a number of international training events. In this contribution, an overview of the broad research and training program is given with examples of 3 out of the 17 research projects.

INTRODUCTION

Lasers can be used for the generation of high brightness electron and exotic ion beams, the acceleration of particles with the highest accelerating gradients, as well as for the characterization of many complex particle beams by means of laser-based beam diagnostics methods. In addition, (free electron) lasers can be used for achieving the highest time resolution and strongest fields for experiments in atomic physics, chemistry and biology, i.e. for studies into the dynamics of some of the most fundamental processes in nature.

Without constant progress in laser technology and close collaboration between laser experts and accelerator scientists, many of today's most advanced experiments would simply be impossible. The LA³NET consortium will combine developments in laser technology and sensors with their application at advanced accelerator facilities, providing complex beams ranging from the highest brightness electron beams in fourth generation light sources to high intensity proton beams in spallation sources. This way a very broad, yet closely interconnected, experimental program will be covered that combines many different scientific disciplines, such as for example mechanical and rf engineering, physics, electronics, IT, material sciences, and medical applications. This will provide an interdisciplinary foundation for the network and an excellent basis for the training of early stage researchers. The strong participation of the industry sector within the consortium and their active input during the definition phase of all research projects and along the ongoing training within LA³NET ensures that the transfer of industry-relevant skills is an integral part of all individual research and training projects.

The network comprises a substantial part of the European expertise in this field, either in the form of the beneficiary partners or as associate and adjunct partners [1]. All members of the consortium have well-proven expertise in finding solutions to the technological and scientific challenges related to the development of cutting edge laser systems and their applications at accelerator-based research infrastructures. A continuous exchange of knowledge and researchers within the network will stimulate on the one hand the search for the most advanced methods and technologies whilst ensuring at the same time a comprehensive training of all early stage researchers. This approach will guarantee that all LA³NET fellows will get the unique possibility to become experts not only in their main research field, but also in related techniques and thus provide them with an ideal skills set for a future career in both the academic and industry sectors.

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.

BEAM DIAGNOSTICS R&D

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 [2] 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 here-presented new initiative.

A focused R&D program in laser based beam diagnostics is a central element in the LA³NET project. In this section, some examples of the broad beam instrumentation research program are given on the following pages.

*Work supported by the EU under contract PITN-GA-2011-289191.
#c.p.welsch@liverpool.ac.uk

Development of a Laser Velocimeter

Pencil or curtain-shaped neutral gas jet targets are important for a number of accelerator-based experiments, either as cold targets for collision experiments [2] or for example for beam diagnostic purposes [3,4]. In the latter case, a curtain shaped, supersonic gas jet is crossed with the charged particle beam that shall 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.

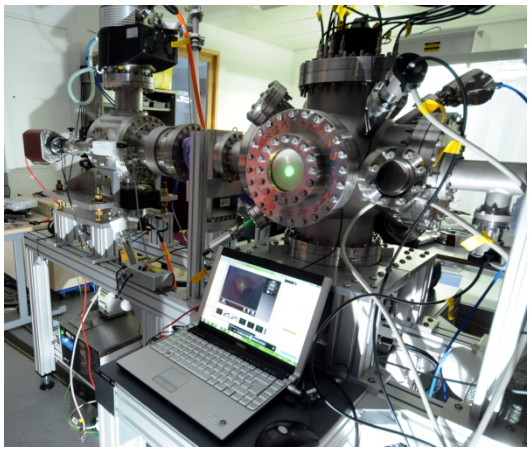

Figure 1: Photograph of the curtain gas jet setup at the Cockcroft Institute, UK.

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 the aim of an ESR project at the Cockcroft Institute/University of Liverpool. 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 that can be installed even in radiation-exposed environments. A low cost laser/sensor combination shall be developed that can easily be aligned even in complex geometries.

Laser Emittance Meter for LINAC4

The optimum exploitation of the 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. The project is closely linked to activities at Royal Holloway University of London, where the trainee will become familiarized with the concept of a laser wire scanner, laser beam handling and manipulation techniques, as well as critical detector components at the beginning of the project. The timing link between the laser and the beam, together with an envisaged real time monitoring put strong requirements on the photon detectors, the IT and control systems.

High Resolution Longitudinal Beam Profile Measurements

Single-shot electro-optic (EO) techniques can be used to measure THz radiation. The technique can be used to detect the electric field of coherent transition radiation, coherent synchrotron radiation and coherent diffraction radiation as well as coherent FEL radiation from an undulator. These techniques measure the phase information directly eliminating the ambiguities associated with spectral measurements. Experimental work has been carried out at the FELIX facility and at the FLASH soft x-ray FEL at DESY, where the shortest electron bunches measured to date correspond to 60 ± 7 femtoseconds rms [7]. An ESR project at the University of Dundee aims at pushing the limits of these EO techniques to measure electron bunches with a time resolution better than 20 femtoseconds. Such an ambitious extension requires advances in both, the theoretical and experimental aspects of the problem, and will require work on new optical materials and advanced laser techniques. The ability to measure electron bunches with this time resolution would have a significant impact on state-of-the-art light sources, such as LCLS or the XFEL, since the generation of coherent x-ray beams from these machines depends critically on maintaining an ultrashort bunch length, and direct measurement is not currently feasible. Measurements will be carried out with a number of optical materials such as GaSe, DAST, MBANF, and a range of poled organic polymers. These are anticipated to have a much higher optical bandwidth than the ZnTe and GaP crystals currently in use.

TRAINING EVENTS

Training of all fellows will mostly be through research on dedicated individual projects realized by the respective host institutions with specific secondments to other partners for specialized techniques and cross-sector experience. In addition, the LA³NET consortium will also

organize a number of network-wide events that will be open to the wider scientific 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 LA³-NET.

The first school will be held in 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 school will be complemented by study and Q&A sessions that will provide feedback to the participating universities and serve as a quality control factor of the LA³-NET training program.

The second school will be held in 2014 at CLPU in Spain and will cover advanced laser technologies, in particular the combination of different fundamental techniques. At this point in time, first results from the network participants will be emerging and a focus of this school will be to put the individual projects into a global context and indicate mid- and long-term perspectives for further advances. A poster session will allow all participants to present their research results.

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'. A typical workshop will bring together 25-30 experts and will last 2 days. Organizers have already been identified.

A two day workshop on 'Knowledge Transfer and Spin-off Development', organized by industrial partner ,RI will focus on the important differences that exist in research projects in the academic and industry sectors. This workshop will familiarize all trainees with intellectual property rights (IPR) and patent regulations, University-specific laws in different countries and provide an overview of start-up funding opportunities.

Finally, the trainees will be given the resources to organize a 2-day workshop themselves during the 2nd year of the project. This will familiarize them with the challenges linked to event organization, compilation of a list of international experts and event advertisement.

Conference on Laser Applications

In the last year of LA³-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 organised as a satellite conference to one of the very large events such as the World of Photonics or the International Particle Accelerator Conference is under consideration. 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.

LA³NET 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 LA³NET web site [1]. In addition, the consortium sponsored 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

LA³NET is a €4.6 million ($6 million) 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 LA³NET across sector boundaries to ensure that the clearly identified long term research and training objectives are achieved.

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