IMPROVING ION AND ELECTRON BEAM CHARACTERISTICS WITHIN LA³NET*

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

Abstract

Lasers are widely used at accelerator and light source facilities for beam generation, acceleration and optimization. Research within LA³NET focuses on laser-based particle sources (photo injectors and laser ion sources), laser acceleration, and laser-based beam diagnostics. This project was recently selected as a 'success story' by the European Commission for its research achievements. This paper presents selected numerical and experimental results. From HZDR results of electron transport simulations in their new SRF gun II cavity, super-conductive solenoid and downstream accelerators are shown. The results from optimization studies into asymmetric grating structures obtained at the University of Liverpool are also presented, along with initial results from studies into novel diagnostics for high intensity proton beams at CERN and low energy electron beams at KIT. Finally, the events organized by the consortium to date and future plans are summarized.

INTRODUCTION

The advancement of science and engineering in the past decades has been 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. LA³NET is built around 17 early stage researchers working on dedicated projects to research and develop a complete spectrum of laser-based applications for accelerators [1]. The project is supported by the EU with a budget of 4.6 M€ between 2011-2015 and presently consists of an international consortium of more than 30 partner organizations including universities, research centers and private companies.

RESEARCH

R&D within LA³NET is split into 5 work packages: Laser-based particle sources, laser driven particle beam acceleration, laser-based beam diagnostics, system integration and laser and photon detector technology. Here, examples of recent research highlights are given.

* This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 289191.
# carsten.welsch@cockcroft.ac.uk

Simulation of the ELBE SRF Gun II

The ELBE SRF gun II is a recently developed photo injector that was installed at HZDR in Germany in May 2014 [2]. The main improvements include a new 3½ cell fine grain Nb cavity and a super-conducting solenoid at 100 mm after the cavity. As a result, higher energy (up to 9 MeV) and improved bunch characteristics can be expected. Further transport of the beam is expected to go through a dogleg and then the Linac beam line of the ELBE accelerator to conduct Thomson backscattering experiments. In order to optimize beam transport complete start-to-end simulations have been realized by Fellow P. Lu at HZDR in Germany, Fig. 1.

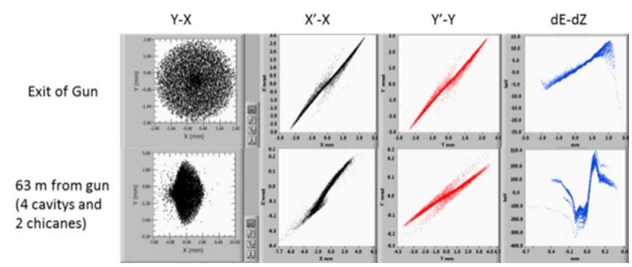

Figure 1: Bunch distribution and phase space of the optimized beam at the exit of the gun and after 63 m of beam transport.

First, the ASTRA simulation code was used to simulate the SRF gun output with 1D field data obtained from Superfish. After that beam transport was described using ELEGANT. A user-friendly interface was developed in Labview, linking all codes. The 6D phase space of the electron bunch at the cathode surface was based on a thermal-emission model and realistic laser pulse parameters; no other assumptions were made. To describe beam transport 3rd order matrices were used, including effects from space charge and coherent synchrotron radiation. So far studies focused on transport of a 77 pC beam with a final energy of 47 MeV, energy spread of 150 keV and bunch length of 0.42 ps. The non-linear behavior in longitudinal phase space shown in Fig. 1 results from space charge effects. For further details, see [3].

Dielectric Laser Acceleration

Optical scale dielectric structures are promising candidates for realizing future compact, low cost particle accelerators, since they can sustain high acceleration gradients in the range of GeV/m [4]. Numerical simulations into a dielectric asymmetric dual-grating accelerator were carried out by A. Aimidula, based at the

ISBN 978-3-95450-132-8

Cockcroft Institute/University of Liverpool, UK. Asymmetric dual-grating structures were analyzed with regard to their ability to efficiently modify the laser field to synchronize it with relativistic electrons [5].

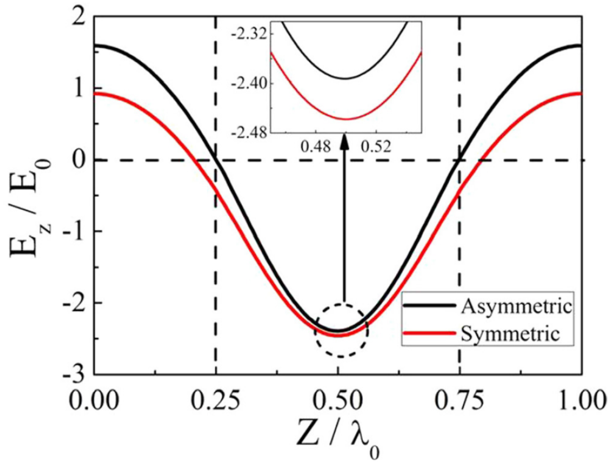

Figure 2: Z-component of the peak electric field on the central axis along the vacuum channel; red line A=B=λ/2, black line A+B=λ_0, A=λ/2–Δh. Here, Δh=0 for the symmetric structure (red line); Δh=0.044λ_0 for the asymmetric structure (black line); the vacuum channel width C and pillar height L have been set to 0.24 λ_0 and 0.94 λ_0, respectively.

It was shown that by using asymmetric structures one can increase the average acceleration gradient by up to 10% as compared to symmetric structures, see Fig. 2. The optimum pillar height that was determined by simulation agrees well with that estimated analytically. The optimization work also allowed the required laser parameters to be determined to power the structure and to enable proposal of a suitable laser as energy source for future experiments.

Laser-based Emittance Meter for H^- Beams

The LINAC4 accelerator at CERN can accelerate H^- ions from 45 keV to 160 MeV [6]. The transverse emittance is one of the key parameter for reaching higher luminosity in the LHC and needs to be measured with high accuracy. Whilst the commonly used slit-grid method provides good results at energies up to 50 MeV, the ions can no longer be efficiently stopped at higher energies and a different diagnostics approach is needed.

LA³NET Fellow T. Hoffmann who is based at CERN in Switzerland has studied a laser system for transverse profile measurements based on photon detachment of electrons from the H^- ions. In his setup a pulsed laser crosses the particle beam. Since the binding energy of one electron is only 0.75 eV the detachment cross-section exceeds $3.5 \cdot 10^{-17}$ cm^2 in the target wavelength range. This leads to the creation of an H_0 beamlet and free electrons. By using a bending magnet and a Faraday cup one can obtain a signal proportional to the number of H^- ions at the position of the laser from which one can also derive the divergence of the H^- beam. By doing an x/y-scan with the laser the transverse emittance of the H^- beam can be measured. The interaction of the laser with the H^- ions was modelled by simulating first the photon flux of the laser. A Gaussian beam with quality factor M^2 was assumed for the laser, whilst a model of the particle beam was available from previous beam dynamics simulations. After a drift space the weighted particles were then integrated and an example of the simulated signal at the detector is shown in Fig. 3 [7].

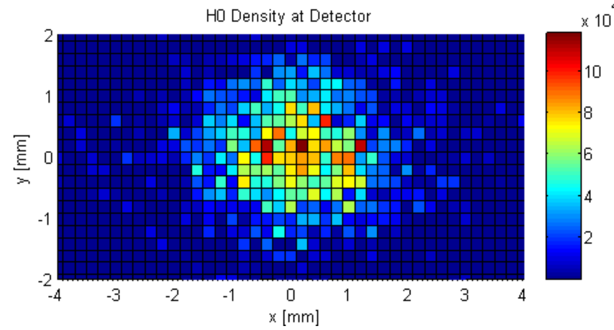

Figure 3: H^0 distribution at the detector 3.5 m downstream the laser.

Beam Energy Measurements by Detection of Compton Backscattered Photons

The exact knowledge of beam energy is very important in electron accelerators. At the ANKA storage ring in Karlsruhe, Germany, the method of resonant depolarization has been used to accurately determine the energy of its 2.5GeV electron beam. A good alternative for lower beam energies is the detection of Compton backscattered photons, generated by laser light scattered off the relativistic electron beam. In order to achieve compactness and guarantee smooth integration into the storage ring, transverse scattering has been proposed instead of more conventional head-on collision. The transverse setup is expected to reduce the cut-off energy on the spectrum of backscattered photons by a factor of two and therefore enlarge capability of energy measurement using the same detector.

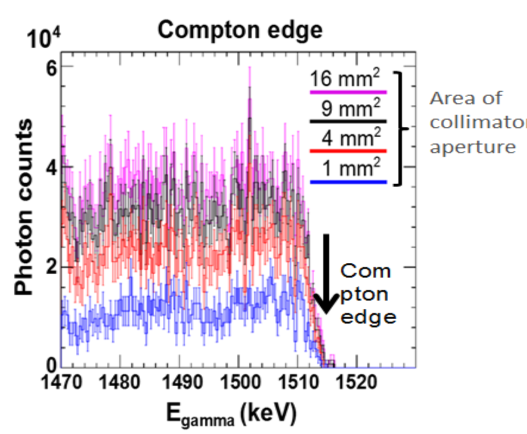

Figure 4: Number of photons as a function of their energy.

Feasibility studies into such monitor have been carried out by C. Chang and colleagues at KIT/ANKA in Germany through comparison of the resulting Compton backscattered photons as simulated with AT and CAIN 2.35 and actual measurement of background radiation with a High Purity Germanium spectrometer [8]. Fig. 4 illustrates the number of backscattered photons reaching the detector when a 10W CW CO_2 laser interacted with a 40 mA electron beam at low-α_c mode for 20 minutes.

TRAINING EVENTS

The core training within LA³NET consists of a cutting edge R&D project each Fellow realizes at the respective host institutions with specific secondments to other partners for cross-sector experience. In addition, the consortium organizes a number of network-wide events that are open to the wider community, including schools, topical workshops, as well as an international conference and symposium in the project's final year.

International Schools

A first international school on laser applications was held at GANIL, France in 2012 and was reported on in the Proceedings of IPAC13 [9]. An advanced school will be hosted by the Centre for Ultrashort Ultraintense Pulsed Lasers (CLPU) and held at the University of Salamanca between 29 September and 3 October 2014. The school will cover a broad range of topics, including an introduction to lasers, accelerators and FELs, laser ion, electron and x-ray sources, laser acceleration, laser-based beam diagnostics and industrial applications. In addition to the lectures there will be study groups, a poster session with industry displays, an interactive panel session and evening seminars including outreach. There will also be opportunities for discussion and networking during a tour of the CLPU facilities and at evening events. Registration has opened recently and can be accessed via the school's indico page [10].

Topical Workshops

To date LA³NET has organized three workshops on specific R&D topics that stretch across the network's main work packages (particle sources, acceleration techniques and beam diagnostics). Information about the first workshop on particle sources that was held at CERN in February 2013 can be found on the project web page [1] and in the Proceedings of IPAC13 [9]. A 2nd Workshop on 'Laser technology and optics design' was held at the Fraunhofer Institute for Laser Technology (ILT) in Aachen, Germany between 4-6 November 2013 [11]. The workshop addressed the key aspects of optics design relevant for particle accelerators and attracted over 50 participants from across Europe including all of the LA³NET Fellows. This included an overview of the diverse current applications and future potential for laser technology, general optics design, laser sources and a comparison between photon and charged particle beams on the first day. The second day addressed more advanced topics with details of beam characterization and optical component characterization, high power enhancement cavities, tunable lasers and frequency conversion. The final day included ultrafast TW-lasers for particle acceleration, design of beam transfer lines and imaging optics, as well as a discussion on the state-of-the art in lasers and optics design and future requirements for funding.

There was a huge response to the third LA³NET workshop on Novel Acceleration Techniques demonstrating the interest this field is generating among accelerator and laser scientists. The event took place between 28-30 April 2014 and was hosted by the Helmholtz Zentrum Dresden-Rossendorf (HZDR) in Dresden. Over 60 participants took part in the 3 day workshop including eight invited speakers and 23 contributed talks with presentations on the work achieved by five of the Fellows from LA³NET. Presentations are uploaded to be viewed on the workshop indico site [12].

The consortium will next organize a workshop on laser based beam diagnostics, including ultra-fast timing systems in March 2015. This event will be organized together with an international conference on laser applications at accelerators and held in Mallorca, Spain. The conference will highlight the R&D results of the network and also include presentations from research leaders around the world. It will be open to researchers from within the LA³NET consortium, as well as the wider accelerator and laser communities [1].

Finally, the project will host an outreach symposium open to the general public in Liverpool. This will be organized in June 2015 together with an advanced school on researcher skills for all Fellows. Via the symposium the network will present its research results to a much wider audience and thus promote researcher careers to pupils, college and university students, policy makers and the general public.

SUMMARY

This paper gave 4 examples of recent research results by LA³NET Fellows. Stretching across laser-based particle beam generation, acceleration and diagnostics, the network provides a unique international framework where research centers, universities and industry jointly develop cutting edge technologies and beyond state-of-the-art techniques. The network was formally reviewed in 2013 and commended as a European 'success story' in a number of areas, including Fellow R&D, international dissemination, project management and coordination. This highly successful training program shall serve as a basis for future initiatives and help attract more researchers into accelerator science and technology.

REFERENCES

[1] http://www.la3net.eu

[2] P. Murcek et al., "The SRF Photoinjector at ELBE – Design and Status 2013", Proc. 16th Int. Conf. on RF Superconductivity, Paris, France (2013).

[3] P. Lu, et al, “Simulation of the ELBA SRF GUN II”, Proc. IPAC14, MOPRIO23, Dresden, Germany (2014).
[4] E.A. Peralta, et al., Nature 503, 91-94 (2013).
[5] A. Aimidula, et al., Physics of Plasmas 21, 023110 (2014).
[6] L. Arnaudon, et al., “Linac4 Technical Design Report”, CERN-AB-2006-084 ABP/RF (2006).
[7] S.M. Gibson, et al., „A Fibre Coupled, Low Power Laserwire Emittance Scanner at CERN LINAC4”, Proc. IPAC14, THPME190, Dresden, Germany (2014).
[8] C. Chang, et al., “Design of a Compact Setup to Determine Beam Energy by Detection of Compton Backscattered Photons at ANKA”, Proc. IPAC14, Dresden, Germany (2014).
[9] C.P. Welsch, “R&D into Laser Applications for Accelerators”, Proc. IPAC13, THPWA044, Shanghai, China (2013).
[10] indico.cern.ch/conferenceDisplay.py?confId=285698
[11] indico.cern.ch/conferenceDisplay.py?confId=266133
[12] indico.cern.ch/conferenceDisplay.py?confId=285723

ISBN 978-3-95450-132-8