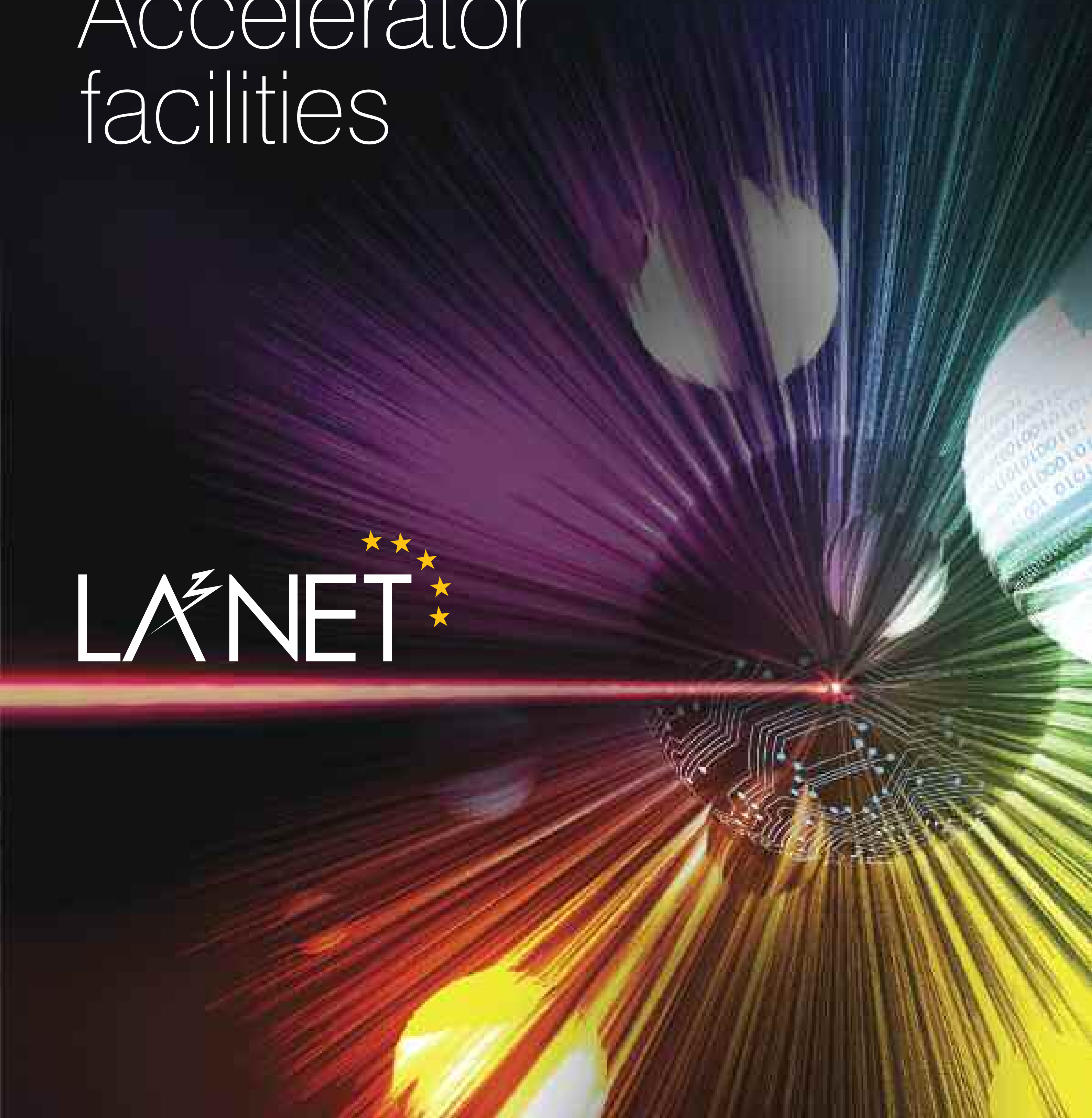
LAsers for Applications at Accelerator facilities



LA³NET

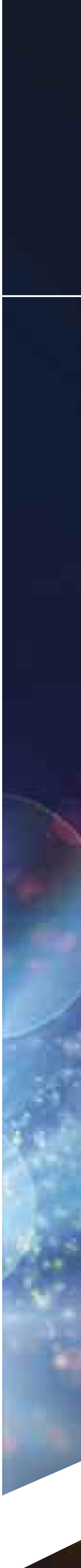
CONTENTS

LASERS
A KEY TOOL FOR PARTICLE BEAM GENERATION ACCELERATION AND DIAGNOSTICS

Particle accelerators are propellers for future science enabling fundamental research and new technological developments

Accelerators have numerous practical applications across many fields including medicine, electronics, environment and energy. New methods of ion generation will expand the boundaries of research and open up new practical applications for the everyday world. As the limits of performance are reached new methods for particle acceleration and beam optimization are needed. Lasers will play a key role in the development of accelerators by improving the generation of high brightness electron and exotic ion beams and through increasing the acceleration gradient. Lasers will also make an increasingly important contribution to the characterization of many complex particle beams by means of laser-based beam diagnostics methods.

The LA³NET network has been built around 19 early stage researchers working on dedicated projects to research and develop a complete spectrum of laser-based applications for accelerators. The network consisted of an international consortium of almost 40 partner organizations including universities, research centres and private companies working in this field. This has provided a cross-sector interdisciplinary environment for beyond state-of-the-art research and researcher training while developing links and new collaborations.



LASERS R & D

Lasers and Accelerators – A unique combination for cutting edge research

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.

Laser-based particle sources

Lasers have been successfully used to provide high brightness electron beams and exotic ion beams that cannot be realized with any other technique. Wavelength tunable lasers are used for ion sources at Isotope Separator On-line (ISOL) facilities to achieve unmatched selectivity by performing multi-step resonance. Within LA^{3}NET, laser-based sources have been developed in six projects that have expanded upon existing techniques and technologies.

Laser-driven particle beam acceleration

Very high field gradients for the acceleration of particle beams are highly desirable for many applications, both in fundamental sciences and in industry. There are significant engineering and physics challenges to realize and control such gradients. Laser-driven particle beam acceleration could help to substantially reduce the size of accelerator facilities, open avenues for providing beam currents above present limits and for advanced medical infrastructures for treatment and diagnostic purposes. Laser/optical fibre combinations may also enable the development of 'pocket accelerators'. There have been five LA^{3}NET projects in this area.

Lasers for 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. Lasers provide the highest time and spatial resolutions for transverse and longitudinal beam profile measurements, they allow the detection of density differences in particle beams with high dynamic ranges and permit measurements of very important machine parameters, such as the momentum compaction factor and beam emittance. Five projects have been carried out on beam diagnostics.

System integration

In a complex research environment, such as an accelerator facility, it is very important that all components interface smoothly with each other. The integration of laser systems regularly poses high challenges on the machine-wide control and timing system, interface cards and electronics. Often commercially available systems do not readily integrate into purpose-built systems at research centres, requiring considerable R&D effort. Interaction with private companies at all stages of the integration process has been vital and a central element within LA^{3}NET. Whilst all projects within this consortium have contributed to this important topic, two have focused specifically on research into system integration.

Laser and photon detector technology

All partners have been involved in this technology with all projects contributing by pushing the technological limits further. The technology has profited greatly from the expertise of the industry partners which helped to fully exploit the potential of the developments within the network for applications, even beyond the field of accelerators. There has been one project dedicated to this topic of detector R&D within the unique laser environment of the ELI facility.

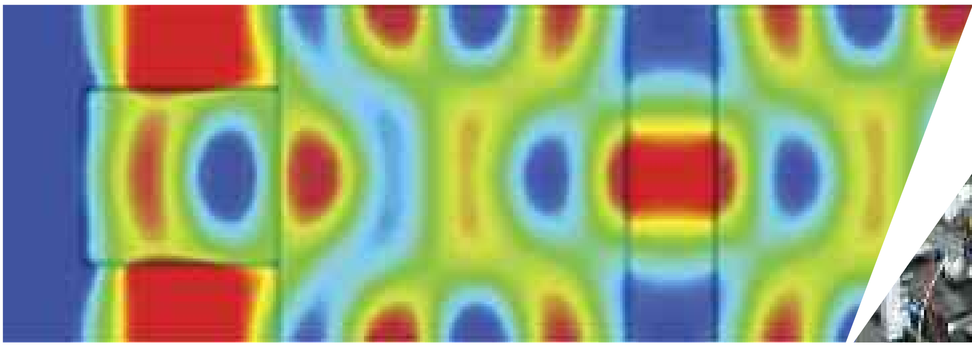
UNIVERSITY OF LIVERPOOL

UNIVERSITY OF LIVERPOOL

A member of the Russell Group of major research-intensive universities in the UK, the University of Liverpool has an enviable international reputation for innovative research. Currently around 20,000 students are enrolled into more than 400 programmes spanning 54 subject areas at its 3 faculties, including Health and Life Sciences; Humanities and Social Sciences; and Science and Engineering.

The Department of Physics at Liverpool is currently one of the very few academic departments in the UK to obtain top ratings for both teaching and research. A rich variety of research is performed at Liverpool, including Particle Physics, Nuclear Physics, Condensed Matter Physics, Surface Science and Astrophysics.

Moreover, the University has the lead role in the Cockcroft Institute, an international centre of excellence for accelerator science and technology. Embracing academia, government and industry, it is unique in providing the intellectual focus, educational infrastructure and the essential facilities in innovating tools for scientific discoveries and wealth generation and the perfect environment for the coordination of a complex network such as LA³NET.


Simulation of electric field distribution in a micro accelerator


Gas jet beam profile monitor

Project:
Investigation into dielectric laser-driven acceleration of electrons in a grating-based microstructure.

Dielectric laser-driven accelerators (DLAs) based on gratings structures have received a lot of interest due to their high acceleration gradient up to GV/m and mature lithographic techniques for fabrication. They might open up new avenues for future high energy physics accelerators and free-electron lasers. Within this project numerical investigations into the acceleration of relativistic and non-relativistic electrons in double gratings silica structures have been carried out so far. The optimization of these structures with regards to maximum acceleration efficiency for different spatial harmonics has been discussed. Simulations were performed with the commercial CST and VSim simulation codes and results from both codes have been compared. In a next step a multistage DLA from the non-relativistic to highly relativistic regime will be investigated. It is also planned to carry out experimental studies into these structures in the near future, using the available electron beam at Daresbury Laboratory.

Researcher:
Yelong Wei

Yelong Wei received his Master's degree in July 2012 from the University of Chinese Academy of Sciences (UCAS) with a major in Electromagnetic Fields and Microwave Technology. His Bachelor's degree was awarded in June 2009 from Nanjing University of Aeronautics and Astronautics. During his Master's degree he devoted himself to research on the design of the superconducting RF accelerating cavity and relevant microwave systems in Shanghai Synchrotron Radiation Facility. In July 2012, after graduation from UCAS, he joined Tektronix Inc. and worked as an RF Design Engineer. His work mainly focused on RF modules including passive/active circuits design in the RF signal generator. Yelong joined LA³NET network at the University of Liverpool in March 2014.

Project:
Development of a laser velocimeter

The aim of the project has been the development of a laser velocimeter for in-detail characterization of gas jets allowing for investigations into the jet dynamics itself, its density and velocity. For those purposes a laser-feedback interferometer based on the self-mixing effect has been developed as a low-cost, compact and non-invasive sensor for velocity, displacement and density measurements of different targets.

A theoretical and experimental analysis of factors influencing the performance of the self-mixing laser diode sensor has been done. Target parameters such as its velocity, its reflectivity and the concentration of seeders have been studied. Experiments have demonstrated the possibility to use the self-mixing technique for measuring the velocity of solid targets up to 100 m/s and fluids up to 2 m/s.

Researcher:
Alexandra Alexandrova

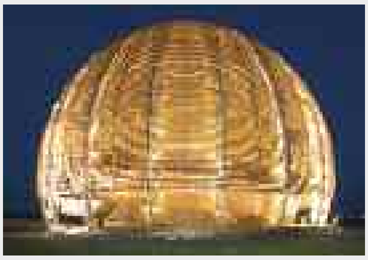
Alexandra Alexandrova studied physics and engineering at the National Research Nuclear University MEPhI in Moscow, Russia, from 2006 to 2012. Her speciality is condensed matter physics with laser physics as major subject. She has experience with laser interferometers and different laser systems for ITER (International Thermonuclear Experimental Reactor). She participated in developing the Photonic Doppler Velocimeter for measurement of the fast processes in matter.

Alexandra has worked on her individual project within the LA³NET network since September 2012. While working on the development of a laser velocimeter she has extended her knowledge in accelerator physics, laser interferometers, scattering, physical optics, signal processing, and beam instrumentation.

CERN

CERN: The European Organization for Nuclear Research is a world leading center for fundamental nuclear, atomic and particle physics. It acts as a focal point for European physics and technology collaborations, each year hosting a community of over 10,000 visiting scientists from more than 600 institutes around the world.

CERN also functions as a hub for scientific training within Europe, with around 11,000 days of training facilitated annually. Consequently, this environment is ideal for early stage researchers (ESRs), who can benefit from the experience and infrastructure developed during the facility's illustrious history.

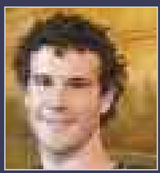


The Globe of Science and Innovation. Image courtesy CERN

Project: Ionization scheme and ion source development for the ISOLDE Resonance Ionization Laser Ion Source (RILIS)

The Resonance Ionization Laser Ion Source (RILIS) is the principle ion source of the ISOLDE radioactive ion beam facility located at CERN. This project has focused on expanding the scope of the ISOLDE RILIS and applying the new capabilities for both standard RILIS operation and nuclear physics experiments at ISOLDE. There have been two principle avenues for RILIS development, laser ionization scheme development and development of the laser atom overlap region.

RILIS ionization schemes have been developed, bringing the total number of available elements from the ISOLDE RILIS to 35. What is believed to be the first resonance ion-ionization in a hot cavity was demonstrated, creating Ba2+ to meet a specific need to eliminate the problem of a surface ionized isobaric background. The RILIS was integrated with the VADIS, ISOLDE's FEBIAD type arc discharge ion source, providing new capabilities and beginning a process of development of both types of ion source. In-source laser spectroscopy, using the new Hg scheme within the VADIS, has successfully measured the isotope shifts of short-lived Hg isotopes, revealing the extent of the propagation of the famously pronounced odd-even staggering.



Researcher: Tom Day Goodacre

Tom studied a BSc in Mathematics at the University of Leeds, graduating in 2010. He completed an MSc in Photon Science at the University of Manchester. Tom's dissertation focused on the effects of implanting Aperiodic Distributed Feedback (ADFB) gratings into THz Quantum Cascade Lasers (QCLs).

Following the completion of his MSc, in September 2012, Tom joined the LA³NET project working at CERN on the ISOLDE RILIS. Tom has worked on expanding the capabilities of the RILIS, while taking part in in-source laser spectroscopy experiments. He is currently working towards a PhD in Nuclear Physics with The University of Manchester using results obtained during the LA³NET Fellowship.

Project: Research and development of photocathodes sensitive to visible laser beams for photoinjector applications

Within the CLIC (Compact Linear Collider) project, feasibility studies of a photoinjector option for the drive beam as an alternative to its baseline design using a thermionic electron gun are on-going. This R&D programme covers both the laser and the photocathode side. The main challenge for a drive-beam photoinjector is to achieve high bunch charges, long trains and high bunch repetition rates together with sufficiently long cathode lifetimes. At present, CsTe photocathodes in combination with UV lasers are usually used for such purposes. However the CLIC drive beam design parameters are more challenging: the available laser pulse energy in UV for 140 µs long pulse trains is currently limited due to a degradation of the beam quality during the 4th harmonics conversion process. Using green laser beam in combination with Cs3Sb cathodes is a potential solution. Both Cs3Sb and Cs2Te photocathodes were produced at CERN by co-deposition process and tested in the high-charge PHIN RF photoinjector. A systematic study of the different photoemissive materials was also performed using XPS (X-ray Photoemission Spectroscopy) analysis in order to characterized newly produced and used photocathodes and correlate the surface properties with their performance.

Researcher: Irene Martini

Irene Martini obtained a BSc in Physics Engineering at Politecnico di Milano and a MSc degree in Nuclear Engineering at the same university. Her main subjects were solid-state physics, radiation-matter interaction and its applications. She worked on her MSc thesis during an internship at CERN within the framework of material studies for the CLIC RF cavities.

In July 2012 Irene joined the LA³NET project at CERN. She has been involved in the photocathodes production and characterization as well as the operation of the DC gun beam line and the PHIN RF photoinjector. Irene managed autonomously the XPS studies done in collaboration with the CERN vacuum group. The obtained research results will be discussed during her PhD defense at Politecnico di Milano.

Project:
The development of narrow linewidth lasers for high resolution RILIS applications

The Resonance Ionization Laser Ion Source (RILIS) is based on highly selective interaction of laser radiation with atoms, which makes it extremely valuable for extraction of pure ion beams of radioactive isotopes produced at ISOL facilities such as ISOLDE at CERN. In addition to element selectivity, the RILIS is capable of producing ion beams with isomer selectivity, which is unique among the ion source types. With the recent implementation of solid state Ti:Sapphire lasers at ISOLDE RILIS, new opportunities for an advancement of high resolution RILIS technology are being investigated. Matthieu Veinhard has contributed to the development and optimization of narrow linewidth lasers for high resolution RILIS applications. A synthetic combination of solid state and dye laser technology has been in the focus of the project.

Researcher:
Matthieu Veinhard

Matthieu studied applied physics at the University Paris VI – Pierre et Marie CURIE in France where he graduated with a Bachelor's degree in 2012. After a year of ERASMUS exchange at the University of Manchester he continued his Master's studies in Fusion Sciences at the University Paris VI. In 2014 he defended his Master's thesis on the investigation of laser photo-detachment as a tool to measure the negative ion density in a highly electronegative plasma, aimed to be used for space propulsion.

In October 2014 Matthieu joined the LA³NET project in partnership with the CERN Resonance Ionization Laser Ion Source (RILIS) team at ISOLDE, the radioactive ion beam facility of CERN. He has been involved in the development of narrow line-width lasers for high resolution RILIS applications.

Project:
Development of a laser emittance meter

The transverse emittance is one of the most important beam parameters at any particle accelerator. To develop an instrument which is able to determine this in a non-destructive manner has been the aim of this project.

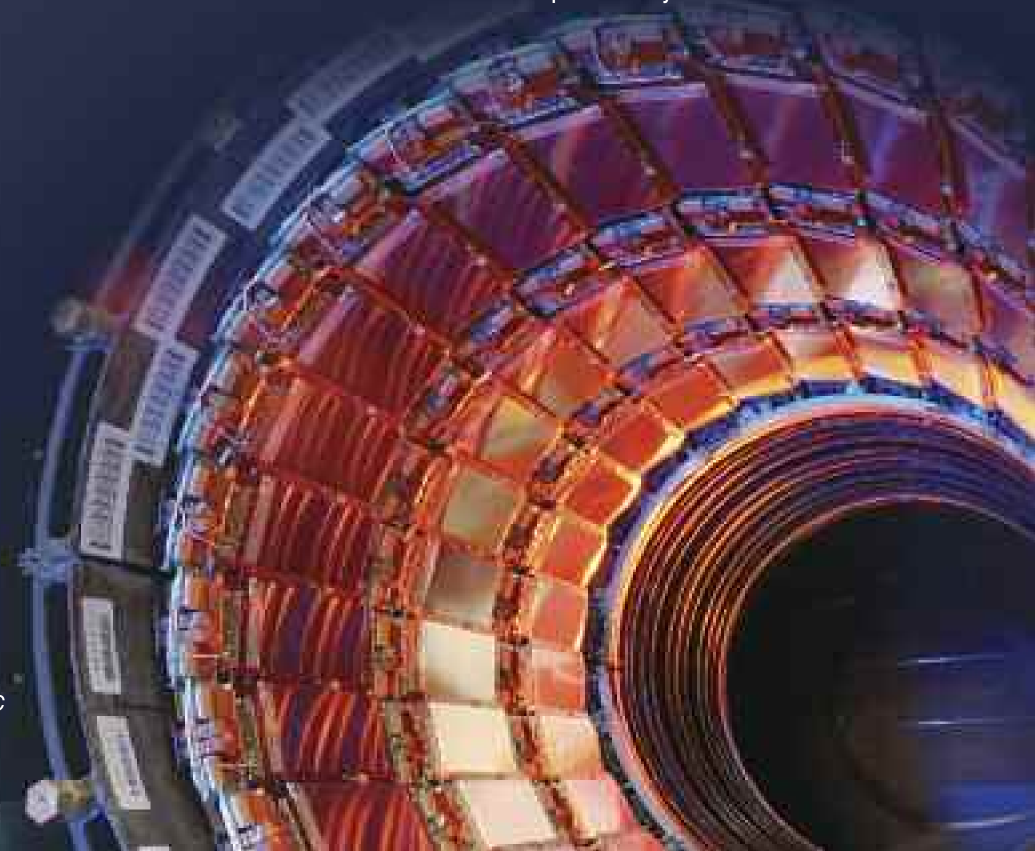
Thomas Hofmann worked on this project while CERN's new LINAC4 was being commissioned. He started with simulations of the photon-ion interaction and then determined accordingly the requirements for the laser and detector systems. He set up a prototype system based on a fiber-laser and a diamond detector and tested it successfully while the LINAC4 was being commissioned at two different beam energies. In particular, the delivery of the high-power laser via optical fiber and the use of a high-sensitive diamond detector pushed the state of the art in this field. The findings were presented on several international conferences. Due to the convincing results, CERN decided to use this instrument permanently at LINAC4 to measure the beam emittance non-destructively.

Researcher:
Thomas Hofmann

In 2007 Thomas Hofmann finished his electrical engineering studies at the University of Nuremberg. Thereafter he continued with a Master's course on photonic engineering. From 2009 to 2012 Thomas worked for Thermosensorik GmbH, a company building infrared high precision camera systems.

His projects were always application targeted and involved a combination of optical and electrical engineering. In his diploma thesis at Infratec GmbH in Dresden Thomas built a test station for a pyroelectric infrared detector with fabry-perot-interferometer. His Master's thesis which he did at the POF-Application Center concerned a CMOS-camera module for Polymer Optic Fibres and at Thermosensorik he worked at the calibration process for infrared cameras.

Thomas started his Fellowship at CERN in September 2012. He has worked on the development of a laser emittance meter for the linear particle accelerator LINAC4. For the last three years Thomas has simulated the laser-particle interaction and used the results to build an instrument based on a fiberlaser and a diamond detector. The instrument was successfully tested and will be used permanently at LINAC4.



First half of CMS inner tracker barrel at the LHC

CENTRO DE LÁSERES PULSADOS (CLPU)

The Spanish Pulsed Laser Centre (CLPU) is a new research facility that has been created as a Consortium of the Spanish Ministry of Education and Science, the Regional Government of Castilla y León and the University of Salamanca, as part of the implementation of the Spanish Scientific Infrastructures Roadmap.

The objectives of CLPU are to build and operate a petawatt laser system, to develop ultra-short-pulse technology, and to promote the use of such technology in several fields such as physics, engineering, chemistry, or biomedicine.

The main system of CLPU is the VEGA laser. Based on titanium:sapphire, it delivers pulses of 30 femtoseconds at 800 nm in three different outputs at 20 terawatt, 200 terawatt and 1 petawatt. The three outputs are fully synchronized with the first two operating at 10 Hz and the third one having a maximum repetition rate of 1 Hz. CLPU aims at becoming a reference center for research in laser-plasma interactions and related applications such as laser particle acceleration. CLPU also hosts several state-of-the-art systems dedicated to attosecond, strong-field atomic physics, and microprocessing of materials.

Project:
Laser-driven Ion Acceleration from ultra-thin targets

In his LA^{3}NET project, Luca C. Stockhausen has been investigating laser-driven acceleration of protons and heavy ions from ultra-thin solid targets. Besides the Target Normal Sheath Acceleration, in which protons are accelerated through a large charge-separation field at the rear side of an opaque plasma, other promising mechanisms have emerged. Radiation Pressure Acceleration (RPA), based on the momentum transfer from photons to electrons, offers a much better scaling and produces tens of MeV ions. Other schemes for near-transparent plasmas like the Breakout Afterburner (BOA), where the interaction changes from surface-dominated to volumetric, have also developed. Both RPA and BOA dominate for ultra-thin overdense targets in the range of nanometres (10^{-9} m).

Luca approached his project both experimentally and theoretically. He conducted several experimental campaigns in collaboration with the University of Strathclyde at the VULCAN and ASTRA-Gemini laser systems of the Rutherford Appleton Laboratory (Oxfordshire, UK). These experiments investigated the complex particle-dynamics occurring when a petawatt (10^{15} W) class laser beam interacts with nanoscale targets, measuring signatures of the RPA and BOA regime.

Luca also simulated the generation of ion beams with the fully relativistic particle-in-cell code OSIRIS, developed by the Instituto Superior Tecnico (Lisbon, Portugal) and UCLA (California, US). Thereby adequate laser and target parameter sets for an efficient acceleration and control of ion beams were identified, also under the unique conditions provided by the VEGA laser system at CLPU.

Laser-generated ion beams with their unique characteristics, have the potential to find wide application in sectors ranging from high-energy physics to industry and medicine. Laser-generated beams are a potentially cheaper and more compact alternative to conventional proton accelerators, and therefore have great potential for medical applications. Laser-produced proton beams may be employed to generate short-lived isotopes to be used as radiotracers in Positron Emission Tomography (PET), or directly to treat tumours by hadron therapy, which is currently applied in costly cyclotron facilities.

Researcher:
Luca Christopher Stockhausen

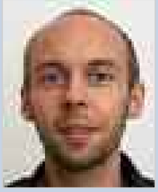
Luca C. Stockhausen was born in 1990 in Cologne, Germany. After successfully completing his Abitur in 2008, he studied Physics at the University of Liverpool and attained his Master's degree in July 2012. In his Master's thesis he conducted a feasibility study of an imaging system during non-invasive radiotherapy.

Shortly after Luca joined the LA^{3}NET network and has been working on laser-driven ion acceleration as a Fellow at CLPU in Spain under the supervision of Ricardo Torres and Enrique Conejero. In parallel he has been enrolled into the PhD programme of the University of Salamanca. Within his project Luca has been working internationally in collaboration with the University of Strathclyde, experimentally several months at large-scale research facilities in the UK and carried out computer simulations at the Instituto Superior Tecnico in Lisbon. He presented his LA^{3}NET-related results at various international conferences and workshops.

Luca is a passionate footballer and also enjoys travelling, skiing, good food and cooking.

Project:
Research and developments towards staged laser-plasma light sources

Laser-plasma acceleration (LPA) has an immense potential for next generation compact light sources. In this project, various injection techniques (shock front injection and ionization injection) have been studied and an experimental method for re-phasing between the laser driver and the electron beam has been established. Furthermore, it has been shown that the electron beam divergence is reduced significantly using a laser-plasma lens, which is important step towards compact LPA-based free-electron lasers. Moreover, the generation of X- and gamma ray from bremsstrahlung conversion, betatron radiation and Compton backscattering have been studied extensively.



Researcher:
Andreas Döpp

Andreas studied physics at RWTH Aachen University, the Swiss Institute of Technology in Lausanne (EPFL), University of Paris 11 and Imperial College London.

He started to work on laser-plasma interactions during his Bachelor's project on finite difference schemes for laser-pulse propagation in plasmas at RWTH Aachen. Thereafter he went to Lausanne where he specialized in high-energy particle physics, while continuing to work on numerical schemes for plasma simulations at the Plasma Physics Research Center (CRPP). For his Master's project he first joined the Plasma Physics Laboratory (LPGP) at Paris 11 and later the Plasma Physics Group at Imperial College London.

His training included participation in experiments at the Lund Laser Centre in Sweden and the Central Laser Facility at Rutherford Appleton Laboratory. In early 2012 he graduated at RWTH Aachen with a MSc degree on betatron radiation in laser-driven electron accelerators.

As a member of the FLEX group at Laboratoire d'Optique Appliquée and the scientific division of Centro de Laseres Pulsados, Andreas has performed experiments on laser-driven electron acceleration and radiation sources at the Salle Jaune Laser Facility and the ASTRA Gemini Laser at Rutherford Appleton Laboratory.

DANFYSIK

Danfysik has been driven by the fascination of accelerator technology in its most advanced form for more than 45 years.

What started in a humble farm house 'factory' with small scale development and production of components like magnet power supplies and accelerator magnets, has expanded towards building complete accelerator systems with great attention to customers' needs and demands.

Danfysik is today one of the world's leading companies within the development and manufacturing of high quality equipment for particle accelerator laboratories, healthcare and industry, and employs some of the most skilled, experienced and dedicated engineers and technicians. Danfysik has customers and partners all over the world.

Project: Developing the current experimental research into laser acceleration to a pre-commercial level

One of the main challenges for laser-based acceleration systems is to control the six-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. Similar challenges apply for reverse experiments like the interaction between electron beams and high power lasers.

The focus in this project has been hence to specify, design, build and test a final focus magnetic lens system employed for Thomson scattering experiments at the ELBE facility at HZDR. Start-to-end simulation of the electron accelerator and characterization of the focused beam on target have been undertaken optimizing the spatio-temporal overlap with the DRACO laser system. Diagnostics for laser, electron beam, timing and Thomson X-rays have been installed in the target area establishing the interaction of both beams. Finally, the resulting linear and nonlinear spectrum of Thomson X-rays has been measured with a high angular resolution.

The experience gained in designing the magnet system for this work has also been applied to investigate the use of permanent-magnet based lenses for collection and collimation of laser accelerated particle beams for potential applications.

Researcher: Jakob Krämer

Jakob Krämer studied physics at the University of Duisburg-Essen, Germany, obtaining his Master's degree in September 2012. During his master studies he finished the commissioning of an irradiation facility for highly charged ions and investigated the defect creation in graphene on calcium fluoride. For his studies Jakob was awarded a scholarship by the Cusanuswerk, the scholarship body of the Catholic Church in Germany.

In October 2012 Jakob took up his position at Danfysik and enrolled as a PhD student at the Technical University of Dresden via the HZDR. He has received training and gained experience in accelerator and laser physics, emphasizing charged particle beam optics and beamline design as well as magnet design and magnet test. His research has focused on nonlinear Laser Thomson Backscattering and the development of a high flux Thomson X-ray source. For this purpose, he developed an electron beam focusing system for the radiation facility ELBE in Dresden-Rossendorf which will increase the yield of X-rays generated by Thomson scattering with the 150 TW laser DRACO.

Inspection of a sextupole magnet in the workshop

FOTON

FOTON is a Czech company specializing in designing and manufacturing of advanced scientific instrumentation. Its activities include high voltage supplies, special electronics systems, optoelectronics, micro positioning automation, plasma diagnostics, vacuum control technology and instrumental engineering.

FOTON specializes in highly customized scientific instrumentation. Its products have been used in many prestigious scientific and technical projects, e.g. vacuum control technology for high-power laser labs and particle accelerators, high voltage supplies for nuclear technology, as well as the high temperature plasma diagnostic instrumentation.

During its 12 year's existence FOTON has designed and manufactured more than 100 innovative product prototypes for its customers, mainly special power supplies and vacuum controllers. High reliability, state-of-the-art design, long-time experience in scientific applications and a professional approach guarantee high quality of all products and an exceptionally high degree of customer satisfaction.

Project:
Computer-based modelling and experimental optimization studies into novel high voltage supplies and generators

High voltage (HV) supplies and generators are a requirement of many projects within LA³NET. At FOTON Kamil worked on the design of novel HV power supplies and generators, carrying out tests and experimental work.

Hands-on work at FOTON on understanding different elemental blocks used in a HV power supplies allowed him to accumulate comprehensive knowledge about overall efficiency, accuracy, electromagnetic compatibility (EMC) properties and thermal management of power supplies and create better solutions. Within this project he designed the 30 kV HV capacitor charger, which is now available in the company's product portfolio.

Kamil has appreciated the number of practical tasks he had, as well as the fact that he was involved in the whole process of power supply design and had influence on decisions taken.

Researcher:
Kamil Nowacki

Kamil studied Electronics and Telecommunications at the Military University of Technology in Warsaw, Poland. As a graduate with specialization in optoelectronic, he received a thorough education in the field of photonics and had the opportunity to participate in many theoretical and practical classes. During his studies he developed a keen interest in the subject of advanced power supply units and control systems.

In his Master's thesis, Kamil focused on developing a high power laser diode power supply with current and temperature stabilization for a project carried out by the Institute of Optoelectronics at the Military University of Technology in Warsaw. From 2008 he developed his professional competencies in the R&D department of a private company operating in a CCTV market.

In June 2012, Kamil joined the LA³NET project as a trainee at FOTON where he worked on design of novel high voltage power supplies.

Cockcroft-Walton voltage multiplier in Multisim environment

GRAND ACCELERATEUR NATIONAL D'ION LOURDS

**GANIL is one of the four largest laboratories in the world dedicated to research using ion beams.
Its experimental programme ranges from radiotherapy to the physics of the atom and its nucleus, from condensed matter to astrophysics.**

In nuclear physics, work at GANIL has led to numerous discoveries related to the atomic nucleus, to its thermal and mechanical properties, and to so-called exotic nuclei, as these do not exist naturally on Earth. For 10 years, GANIL has been one of the major facilities in the world for delivering accelerated radioactive ion beams with SPIRAL1. As the host facility for the next generation RIB factory SPIRAL2, GANIL is naturally involved in the R&D programmes for the production of new radioactive beams.

Project:
Integration of a resonant ionization laser ion source system into the existing off line test bench of the SPIRAL2 TISS

Jose Luis Henares has focused on the development of the Resonant Ionization Laser Ion Source system (RILIS) at GANIL off-line test bench. The production of Radioactive Ion Beams (RIB) far from stability using RILIS technique is of major interest in on-line nuclear facilities due to its inherent Z-selectivity and efficiency. These results will be used in a future ion source prototype conception and development for the integration of a resonant ionization laser ion source system in an on-line facility. The aim of this project has been to find the best technical solution that combines high selectivity and ionization efficiency with small ion beam emittance and stable long term operation.

The ion source has been optimized to maximize the photo-ionization efficiency of the element of interest while minimizing the surface ionization of unwanted elements. Therefore different ionizer diameters and lengths, as well as field geometries has been studied. The extraction system has been optimized using SIMION simulations. Furthermore, a low work function material has been tested to diminish the contaminants and molecular sidebands generated inside the ion source. Moreover, an apparatus to measure the time profile of the ion bunch has been installed and developed. Using an upgrade of this system the energy distribution of the ion beam as a function of the time of flight was measured.

Researcher:
Jose Luis Henares

Jose Luis Henares was born in Palencia, Spain. He studied Materials Science Engineering at the University of Salamanca and attained his Master's degree in June 2011. His Master's thesis concerned the study of the tribological properties of metallic surfaces structured with femtosecond laser. The objective was to improve the life of mechanical parts subjected to wear strains.

He worked 18 months for the University of Salamanca in a project of aluminium sinterization from workshop debris and he spent 10 months at the CLPU facility in Salamanca employed to study radiation generation by femtosecond laser sources. He also received training on Industrial Design and Art History.

In 2012 Jose Luis joined the LA³NET project at the ion accelerator GANIL in Caen, France and enrolled in the PhD program of the University of Caen. His work has focused on the development of the Resonant Ionization Laser Ion Source system (RILIS) at GANIL to produce and study selective ion beams. During his research he has gained significant experience in laser technology, high voltage procedures, vacuum systems, detection techniques, ion beam transport and simulations.

Project:
Study of resonant laser ionization in the REGLIS low energy branch of the S3 spectrometer at SPIRAL2-GANIL

The aim of Lara's project is to develop the Ti:Sa cavities found at the GISELE setup in order to adapt them for REGLIS, which will be the new device for the production of radioactive ion beams at low energy. It consists of a gas cell in which the heavy-ion beam coming from S3 is stopped, thermalized and neutralized in a gas cell, the laser beam is sent either in the gas cell or in the gas jets streaming out of the cell that assures a selective re-ionization of the atoms of interest when the ionization process is based on RILIS. A radiofrequency quadrupole is added to capture the photo-ions and to guide them to the low-pressure zone thereby achieving good emittance of the produced low-energy beam that will be sent to a MR-TOF-MS (Multi Reflection Time Of Flight Mass spectrometer). To select the species of interest from the contaminating ions, the MR-TOF-MS is followed by a Bradbury-Nielsen gate (BNG); finally the ions of interest will go into a detection system.

Lara has also worked on testing the gas cell of REGLIS and finding the spectrum of Zirconium.

Researcher:
Lara Hijazi

Lara Hijazi completed her Bachelor's and first Master's degree in high energy physics at the Lebanese University. She obtained her second Master's degree at Paris-Sud University within NPAC (nuclear, particle, astroparticle and cosmology) in 2014 where she followed the nuclear physics domain working at the Institute of Nuclear Physics of Orsay (IPNO) in collaboration with GSI Germany. It was related to hadronic physics and studies for experiments with the HADES detector and secondary pion beam. Lara also did internships at CEA Saclay and LAL Orsay.

In September 2014, Lara joined the LA³NET network to work on improving and developing the laser system to be used in the REGLIS device at Spiral 2 facility.

HELMHOLTZ ZENTRUM DRESDEN-ROSSENDORF (HZDR)

Helmholtz Zentrum Dresden-Rossendorf (HZDR) is a public-funded research institute conducting research in those fields that are of great relevance to society such as health, energy, and matter.

The HZDR has been a member of the Helmholtz Association, Germany's largest research organization, since January 1, 2011. It is located at four sites in Dresden, Freiberg, Leipzig and Grenoble employing more than 900 people – 430 of whom are scientists including 160 doctoral candidates. PhD students are educated in collaboration with Dresden University of Technology and with other universities and research organizations in the Dresden area.

The HZDR organizes special lecture series and workshops for PhD students and young researchers. HZDR maintains three user facilities: the Radiation Source ELBE, the Ion Beam Center and the Dresden High Magnetic Field Laboratory.

The Radiation Source ELBE is a user facility based on a superconducting linear accelerator with high brilliance and low emittance. The electron beams are used to produce different kinds of radiations: gamma-ray, x-ray, infrared light from two free-electron lasers, neutrons and positrons. Together with the DRACO laser system (5 J in 30 fs to be upgraded to 500 TW in 2013), this facility is used in the education of young researchers and PhD students and a resource for research projects in accelerator physics, laser physics, laser-plasma acceleration, radiation physics, laser-beam interaction, application of radiation in semiconductor physics, material research and biology.

Project:
Development of a high brightness SRF photo injector for electron-laser interaction experiments

The HZDR developed a superconducting RF photo injector which is in operation at ELBE. One of the advanced applications will be the Thompson backscattering experiment. The electron beam produced by the SRF gun and accelerated in ELBE will interact with the high-power laser beam of DRACO to produce mono-energetic, short-pulse X-rays.

For such a purpose the optimization of the injector and the electron beam transport are both significant. A user-friendly simulation tool based on the codes of "ASTRA" and "elegant" has been developed. Optimizations of the SRF gun and the ELBE accelerator are automatic. With this simulation tool a lot of predictions have already been made, including how to further improve the accelerator performance by both adding new elements and different operation strategy.

Experimentally the beam diagnostics are being step by step developed, including the control of a slit scan emittance meter and calculation of quad-scan method as well as the longitudinal measurements. The beam quality from the SRF Gun at 5 MeV with a copper cathode is being measured and crosschecked with simulation. Cs_2Te cathodes are under preparation and will be installed soon. So far the measurements agree well with simulations.

Researcher:
Pengnan Lu

Pengnan Lu obtained his Bachelor's degree in physics in 2009 and a Master's degree in accelerator physics in 2012, both at Peking University, China. During his master studies he worked on space charge compensation of ECR proton ion sources and the emittance measurement of high intensity ion beams.

In July 2012 Pengnan joined the LA³NET network at HZDR, Germany. He has worked there on developing an SRF photo injector. Pengnan Lu is in charge of the optimization of the injector as well as the beam transport to the Compton backscattering experiment. The optimization includes development of beam diagnostics and simulations of the system. Pengnan Lu is also registered at the TU Dresden as a PhD student of physics.

Superconducting Radio Frequency (SRF) gun

HELMHOLTZ ZENTRUM DRESDEN-ROSSENDORF (HZDR)

Project:
Laser particle acceleration and laser driven Thomson X-ray backscattering on electron sources

The DRACO laser system is a high power (25 + 4 J, 30 fs) laser system. Recent experiments with the DRACO system on laser wakefield acceleration (LWFA) have proven its capability to accelerate electron beams to high energies above 100 MeV in a much shorter acceleration length than required with conventional electron accelerators. With further development, LWFA is believed to be able to act as an electron source able to provide short (fs-range) and low emittance electron bunches. These LWFA electrons can be used as a driving beam for a laser-electron Thomson scattering X-ray source which produces ultrashort, bright X-ray pulses.

In combination with ion sources, this opens new experimental opportunities for the generation and ultrafast probing of matter under extreme conditions (pump-probe experiments), for example by heating matter isochorically with laser-accelerated protons and probing on the sub-ps time scale the dynamics of the ion-induced melting and subsequent relaxation processes in the material. Such techniques are expected to be important for future research programmes at XFEL and LCLS.

Realizing such complex, multiple-species pump-probe experiments requires significant improvements in many aspects of LWFA, including spectral distribution, charge optimization and shot-to-shot stability and sources synchronization.

During the LA³NET project, a new experimental area that offers access to the DRACO laser system as well as to the conventional ELBE electron source has been established. This area enables further development of both LWFA and Thomson-scattering experiments under well-controlled circumstances combined with a wide range of diagnostic tools. For LWFA, both gas-jet and capillary discharge targets for different acceleration regimes have been developed, characterized and consequently implemented into the new experimental area.

First results from these targets show promising prospects. Simultaneously, further development of the PHOENIX X-ray source has been ongoing. This source relies on Thomson scattering of conventional accelerated electrons from the ELBE source with the DRACO laser system. Its development is seen as a crucial stepping stone towards Thomson scattering on LWFA electrons as an all-optical X-ray source.

Within the LA³NET project both LWFA and PHOENIX experiments have been re-commissioned following an experiment relocation and laser upgrade. These sources are being further developed, which will lead to X-ray and electron sources being combined for pump-probe experiments.

Researcher:
Jurjen Couperus

Jurjen studied Applied Physics at the University of Twente, the Netherlands. After finishing his Bachelor's degree in 2008, he continued his studies within the Optics and Biophysics master track of Applied Physics. During his education he developed a keen interest in lasers and their nonlinear applications. He became a student member in the Laser Physics and Nonlinear Optics research group.

In the final phases of his studies Jurjen familiarised himself with working with high-intensity short pulse laser systems. During his internship he developed and implemented on-site diagnostics for the 150 TW high power DRACO laser system.

In his Master's thesis, performed within a cooperation program between the University of Twente and the HZDR, Jurjen focused on Laser Wakefield Acceleration (LWFA) of electrons. He realized an interferometric setup where helium gas-jet targets for LWFA can be analysed, and subsequently used these characterizations, together with theory scaling laws, to determine a set of initial parameters for experiments with the DRACO laser system. The experiments lead to the first laser accelerated electrons at the HZDR.

In March 2012, Jurjen joined the LA³NET network. As a Fellow based at the HZDR he has continued his research in laser particle acceleration. Following an upgrade of the DRACO research facility he has coordinated the establishment and subsequent commissioning of the new target area for LWFA and Thomson backscattering. Currently he is entering the final stage of his project on LWFA of electrons on which he plans to submit his PhD thesis at the TU Dresden in 2016.

INSTITUTUL NATIONAL PENTRU FIZICA SI INGINERIE HORIA HULUBEI (IFIN-HH)

IFIN-HH is the central institute for nuclear and atomic physics research in Romania. Its more than 400 scientists are collaborating with numerous institutes in almost all fields of fundamental and applied nuclear physics.

IFIN-HH has a very strong record as a national training centre and extensive experience in hosting Diploma and PhD students. The Department of Nuclear Physics IFIN-HH is a multidisciplinary research unit in the field of nuclear and atomic physics.

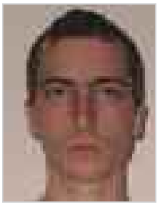
The department's mission lies in the areas of basic and applied research, particularly in the fields which are relevant for sustainable development and the national endeavour for integration in the European Union. Moreover, the Nuclear Physics (NP) pillar of the Extreme Light Infrastructure (ELI) has been approved by the European Commission for construction by IFIN-HH on its premises in partnership with other research institutes in the Magurele Campus and in a growing international collaboration. Once completed, the ELI-NP will be the most powerful, exawatt-class laser in the world. ELI-NP is a very complex facility and will create a new European laboratory to consistently investigate a very broad range of science domains, from new fields of fundamental physics, new nuclear physics and astrophysics topics, to applications in material science, life sciences and nuclear materials management.

Project:
Study of neutron production from two-stage nuclear reactions driven by terawatt laser-target interactions

The high power laser pulses are able to accelerate electrons and heavy ions at high energies, inducing a huge number of nuclear reactions events and intense fluxes of radiations including X-rays, gamma rays and neutrons. Whether for the optimization of laser driven neutron generators or for the characterization of heavy ion acceleration mechanisms, a complex neutron detection system will be a valuable tool to measure the energy and angular distribution of generated neutron flux taking advantage of neutron time of flight to cope with huge prompt gamma ray flash.

Experimental data from a laser-driven neutron production experiment has been analysed within the project. The time of flight of the produced neutrons has been studied. The analysis of the angular and energy distribution of the neutrons required performing of simulations of the experimental setup. For this purpose the Geant4 toolkit for simulation of the passage of particles through matter was used and the experimental conditions were simulated. A comparison between the real data and the simulations has been performed and the effect of the different components of the setup on the time of flight has been studied. The work has been done within international collaboration with European partners that have high power lasers systems in operation.

The IFIN-HH Tandem accelerator



Researcher:
Stanimir Kisyov

Stanimir studied Astrophysics, Meteorology and Geophysics at the University of Sofia, Bulgaria and obtained his Bachelor's degree in 2010. Thereafter he started a Master's degree in Nuclear Physics and Physics of Elementary Particles and graduated in 2012. The main topics of his study were: nuclear structure, gamma-spectroscopy, experimental techniques in nuclear physics, fast-timing scintillation detectors and measurements of half-lives of excited nuclear states. Stanimir started a PhD in Nuclear Physics in 2013 on the subject of the structure of transitional nuclei around A~100 and the experimental techniques for measuring their properties.

In August 2014 Stanimir joined the LA^{3}NET network to work on computer simulations of a neutron detection setup consisting of plastic scintillators. He has analysed data from a laser-driven experiment for neutron production and he has performed simulations of the experimental conditions using the Geant4 toolkit. His work has been mainly focused on the study of the time of flight technique of the neutrons produced in the experiment.

KARLSRUHE INSTITUTE OF TECHNOLOGY (KIT)

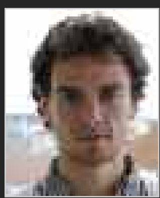
KIT was founded on the first of October 2009 by a merger of Forschungszentrum Karlsruhe and Universität Karlsruhe. KIT bundles the missions of both precursory institutions:

A university of the state of Baden-Wuerttemberg with teaching and research tasks and a large-scale research institution of the Helmholtz Association conducting programme-oriented research on behalf of the Federal Republic of Germany. With 8,000 employees, more than 18,000 students and an annual budget of €700 million, one of the largest research and teaching institutions worldwide was established.

The ANKA Synchrotron Radiation Facility at the KIT is responsible for the operation and expansions of the storage-ring based light source ANKA. Research and development in accelerator physics currently under way at ANKA includes the optimization of coherent Terahertz (THz) radiation production in the storage ring with the use of low momentum compaction factor (low-alpha) optics. A broad research programme on the characterization of coherent THz radiation as well as on the properties of the low-alpha mode has been established including both single particle dynamics issues as well as collective effects. These activities are also part of a longer term effort towards the realization of a state-of-the-art LINAC based coherent THz source currently under design: the TBONE (THz Beam Optics for New Experiments) facility. A test facility for a versatile, compact linac-based source of coherent THz radiation, FLUTE, is currently under construction at KIT.

Project:
Measurement of the longitudinal bunch shape with electro-optical techniques in an electron accelerator

The linear accelerator FLUTE is currently under construction at KIT and it is expected to have a longitudinal bunch length detection system incorporated. During the development of a bunch profile monitor a set of simulation studies has been performed to make the best possible design for the specific beam parameters of the machine. Within the project, the laser for electro-optical detection system has been assembled at DESY in collaboration with the colleagues from FLUTE. The whole system will be installed at FLUTE to further the understanding of beam dynamics effects.



Researcher:
Andrii Borysenko

Andrii studied physics at the Taras Shevchenko National University of Kyiv, Department of Nuclear Physics and Engineering. He graduated in 2012 with a Master's degree in Nuclear and High Energy Physics. During his studies he participated in internships at the Research Center Jülich and at the Max Planck Institute for Nuclear Physics in Heidelberg, gaining experience for his scientific career.

In September 2012 Andrii started a Fellowship at Karlsruhe Institute of Technology (KIT), where he joined the ANKA THz group. Within this group he has been involved in experimental studies of coherent synchrotron radiation and particular properties of machine operation. Longitudinal bunch profile measurements have been his main field of research. He also had a secondment at Cobolt AB, the laser manufacturing company. At Cobolt he studied the manufacturing process of solid-state lasers.

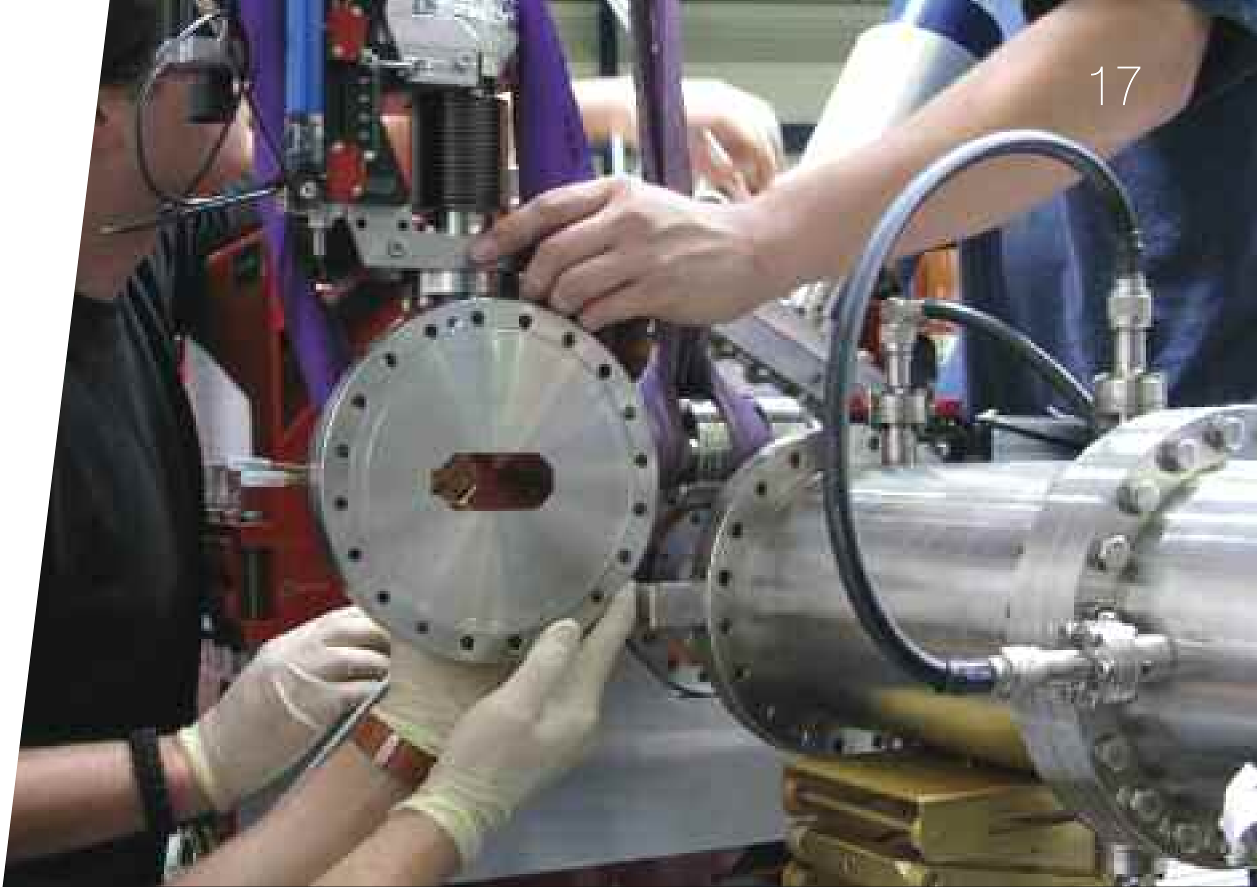
Project:
Precision determination of electron beam energy with Compton backscattered laser photons at ANKA

The aim of this project has been to design and develop a compact CBS setup for electron energy measurement. In contrast to conventional head-on collisions, the setup at ANKA has, for the first time, realized a transverse configuration where the laser beam hits the electron beam at an angle of ~90°. Consequently, a compact, relatively low-cost setup has been achieved and can be used at storage rings or other circular accelerators with restricted space. Furthermore, the transverse configuration enlarges the measurement capability of such method and makes measurements and detector calibration considerably easier. It also provides a successful supplementary beam diagnostic instrument at ANKA. For instance, it can be used to obtain precisely the energy and therefore the precise momentum compaction factor.

Researcher:
Cheng Chang

Cheng is now a Ph.D. candidate in physics at Karlsruhe Institute of Technology (KIT), Germany. He attained a Bachelor of Science in physics and a Master of Engineering in nuclear technology and applications, both from the Physics Department of Peking University in China.

During his Master's degree in the field of accelerator physics Cheng gained experience in designing a Compton Back Scattering (CBS) X-ray source. In this way X-rays are generated by laser light scattered off the relativistic electron beam. The laser pulses are amplified in a storage cavity and electron beam provided by an energy recovery linac. Cheng has also had a broad experience related to superconducting accelerator physics and engineering issues such as Cs_2Te photocathode fabrication, superconducting cavity tuning and Radio Frequency (RF) studies.



Installation works in the ANKA storage ring

Electro-optical crystal (GaP) mounted on support

SCIENCE AND TECHNOLOGY FACILITIES COUNCIL (STFC)

STFC is the UK organization responsible for providing large scale accelerator facilities within the UK, and UK involvement in international accelerator programmes.

The Accelerator Science and Technology Centre (ASTeC) is a distinct department with STFC which has the remit to undertake advanced research and development activities that will allow STFC to provide or contribute to current and future accelerator projects, both with the UK and internationally. ASTeC is responsible for the operation, and the setting of R&D priorities, for the ALICE (Accelerators and Lasers in Combine Experiments) superconducting energy recovery test accelerator at Daresbury Laboratory. It has a lead role in delivering the EMMA (Electron Machine with Many Applications) project, the world's first non-scaling Fixed Field Alternating Gradient (FFAG) accelerator, in which it has significant responsibility for the accelerator design and construction.

Project:
Accelerator Timing Monitor with Femtosecond Precision

The next generation of accelerators requires unprecedented stability and precision in the synchronization. The project aim has been to develop single-shot techniques for measuring the arrival time of electron bunches.

The use of nonlinear optical materials with ultrafast response times have been targeted to achieve femtosecond level precision in determining arrival times, and the bunch arrival-time monitor (BAM) has formed a critical part of the optical timing system. Within the project, ultrafast laser pulses (1.5 μm) propagating in a fibre have been studied and simulated. Two novel schemes of BAM, based on electro-optic spectral decoding and sampling have been designed. The simulation shows both EO BAMs have a potential to achieve sub-femtosecond resolution. Meanwhile, a front end of an RF pickup-based BAM, which combines signals from an RF pickup and modulates the laser intensity, has been designed and is being implemented.

Researcher:
Rui Pan

Rui graduated from Capital Normal University (CNU), Beijing, China in 2010 with a Master's degree. His Master's thesis focused on THz time domain spectroscopy system and THz imaging.

In 2011, Rui joined the DITANET network and worked on the development of an electro-optical test set-up to measure longitudinal bunch profile on CALIFES which is a probe beam of CLIC test facility 3 at CERN. At the same time, Rui also worked towards a PhD at the University of Dundee in the topic of 'Electro-optic diagnostic techniques for the linear collider'.

Rui joined the LA³NET project in December 2013 working in the Lasers and Diagnostics Group of The Accelerator Science and Technology Centre (ASTeC). He has mainly worked on developing single-shot techniques for measuring the arrival time of electron bunches, based on electro-optic techniques.

Optical clock distribution system

UNIVERSITY OF DUNDEE

The University of Dundee is one of the UK's leading universities, internationally recognized for its expertise across a range of disciplines including science, medicine, engineering and art.

The Carnegie Laboratory of Physics at Dundee has a history of world leading research into photonics, materials, biophysics and communications. Many advances and world firsts have been achieved including thin film electronics and flat panel displays. It now focuses strongly on photonics, nano-materials, biophysics, sustainable energy and imaging. Its laboratories are equipped with state-of-the-art facilities for miniature laser development, bio-photonics, biomedical physics and optical manipulation, materials deposition and laser processing, nano-scale materials research, and organic materials.

Laser processing lab

Project:
An advanced electro-optic bunch time profile monitor for the CERN CLIC Project – development of novel materials and techniques

This project aims at pushing the limits of electro-optic (EO) techniques to measure relativistic electron bunches with a time resolution better than 20 femtoseconds. The ability to measure electron bunches with this time resolution have a significant impact on coherent light sources like LCLS or X-FEL, 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.

Such a project requires advances in both the theoretical and experimental aspects of the problem, and involves work on new optical materials and advanced laser techniques.

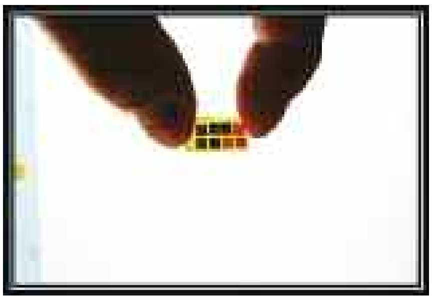
Measurements have been carried out in the University of Dundee, with a range of novel nanostructured metamaterials based on metal-glass nanocomposites (MGN). These silver-doped glass nanocomposites have been processed using a picosecond laser system in order to change the structure and shape of embedded nanoparticles. This process resulted in a higher efficiency of the nonlinear optical properties of the samples. Tests have also been carried out with mechanically stretched MGNs where the shape of previously spherical nanoparticles of silver changed into highly elongated ellipsoids. Measurements at STFC Daresbury Laboratory have been performed for further nonlinear optical characterization as well as for EO based characterization of samples, with the conclusion that they could in principle solve many of the problems associated with 'classical' materials like ZnTe and GaP.

Researcher:
Mateusz A. Tyrk

Mateusz Amadeusz Tyrk is an LA³NET Fellow based at the University of Dundee. Before joining the network he studied Applied Physics (MSc Eng) in the Gdańsk University of Technology (Politechnika Gdańska), where he gained experience from the interfaces of applied physics, mathematics and numerical analysis.

After moving to Scotland in 2012 he started working as a laser systems engineer at Coherent Glasgow – the Scottish branch of one of the biggest laser manufacturers in the world. In September 2012 he joined the LA³NET consortium.

Within his project he has been developing novel electro-optic (EO) materials in the form of thin-film 2D birefringent 'metamaterials' artificially produced to yield a high EO coefficient. These materials have been structured via laser processing of a suitable nanocomposite substrate doped with a noble metal. Various parameters for laser processing have been tested in order to achieve best results. Nonlinear optical methods have been utilised for accurate metamaterial characterization. Project activities included development and testing of the metamaterials at the University of Dundee and STFC Daresbury Laboratory, and incorporating them into EO beam profile monitors at Daresbury.



Silver nanoparticles embedded in glass and irradiated with laser beam to change their shape. Dichroism from polarised light penetrating the sample

TRAINING

Training the next generation of particle accelerator experts

Future generation scientists & engineers

The multi-disciplinary nature of the accelerator field is an ideal training ground for future scientists and engineers. The LA³NET consortium has combined developments into 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. The partners have covered a very broad, yet closely interconnected, experimental programme that combines many different scientific disciplines, such as for example mechanical and radio frequency engineering, physics, electronics, IT, material sciences and medical applications.

This has created a truly collaborative network within a strong interdisciplinary environment that has provided an excellent basis for the training of researchers. The contribution of industry partners to the definition phase of all research projects and their continued active role has ensured that the transfer of industry-relevant skills has been an integral part of all individual research and training projects.

Consequently, the skill-sets gained by the researchers through LA³NET will be valuable for application across a wide range of disciplines both in academia and industry. This is a perfect launch pad for the careers of the researchers while contributing to the European Research Area (ERA) and the future economic competitiveness of Europe.

Now is the Time!

Now is the perfect time for training motivated early stage researchers at the interface between accelerator R&D and laser technology as this field will play a crucial role in the future development of 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 could potentially be a better alternative for conventional particle accelerators in the future
- Laser-based beam diagnostics provide the only way to characterise many complex particle beams

Secondments

Cross-sector work experience is very important to help researchers making their career choices. An extensive secondment scheme has been set up to enable all LA³NET Fellows to spend time working at other institutions within the network. It has provided them with hands-on training in specific relevant techniques and given them broader experience including different sectors. The established consortium has expanded with new adjunct partners joining to provide additional training opportunities as the project has progressed.

LA³NET Training Programme

The fundamental core of the training has been a dedicated cutting-edge research project for each researcher. Most trainees have been in post for 36 months and have also been registered into a PhD programme. Their training has been to a large extent through research, and has been complemented by secondment opportunities plus a series of network-wide events that have also been open to the wider scientific community.

International Schools and Workshops

The first International School on Laser Applications in October 2012 kick-started a packed series of events delivered by LA³NET. This has ranged from **complementary skills training** for all LA³NET Fellows to **Schools** and **Topical Workshops.** These events have brought together experts from across the world in focused research areas to discuss the present state-of-the-art and to review challenges with the LA³NET scientists and researchers.

Schools:

The First School on Laser Applications was held at GANIL, France in 2012. Renowned lecturers covered topics such as introduction to lasers, beam shaping, laser ion sources, laser acceleration, laser-based beam diagnostics, industrial applications and knowledge transfer.

The School brought together researchers from the laser and accelerator communities in the perfect environment for learning and discussion. In addition to the lectures there were study groups, poster sessions and two seminars on major international initiatives in the laser and light sources field.

The follow-up event on Laser Applications at Accelerators was hosted by CLPU in Salamanca, Spain in 2014. It attracted over 70 participants from all over the world. The school included lectures, study sessions, a visit to facilities at CLPU, a poster display, an industry exhibition and an outreach talk that attracted more than 100 students from the university and local high schools in addition to the school participants.

Complementary Skills Training:

A good set of complementary skills will help the researchers achieve the greatest impact from any technical or scientific knowledge they gain. Complementary skills will also make the researchers more attractive to employers and give them a valuable advantage in the competitive jobs arena. These skills are transferable and so make them more robust and flexible; ready to take advantage of cross-sector opportunities between industry and academia or to work better at an interdisciplinary level.

The LA³NET researchers have received training in complementary skills through an established quality school programme. This has provided them with the non-technical skills that will be invaluable for their future careers whether that be in academia or industry. The second LA³NET School on Complementary Skills was held in Liverpool and included training on presentation skills, scientific writing, career planning, project management and team working.

Building on this school, a two day workshop on Knowledge Transfer & Spin-offs and an Advanced Researcher Skills School was organized by The University of Liverpool – Cockcroft Institute in June 2015. It familiarized the trainees with intellectual property rights, knowledge protection, patent regulations, grant writing and opportunities for start-up funding. The Fellows also received training in skills useful in the labour market, such as CV writing and job interviews and were made aware of different career pathways.

Topical Workshops:

A series of Topical Workshops has been delivered covering all important research areas of the LA³NET project. Each Topical Workshop brought together 25-50 experts and lasted 2 or 3 days. Participation was always open to researchers from outside the consortium.

The topics included laser based particle sources, laser technology and optics design (2012) and novel acceleration techniques (2013). In addition, a “Scientists Go Industry” workshop was organized in 2014 to explore a slightly different area of industry and the commercial world and provide an insight into opportunities available outside of academia.

The penultimate LA³NET Topical Workshop took place in Mallorca in March 2015. It covered the area of beam diagnostics and was followed by the final LA³NET Conference.

Final LA³NET Conference:

The LA³NET Conference on Laser Applications at Accelerators took place in Mallorca in March 2015. This event brought together around 70 experts to discuss the state of the art in the network’s R&D area. All LA³NET Fellows presented the outcomes of their research in form of talks and the conference also featured presentations by research leaders from around the world. Sessions were organized along the network’s research work packages and triggered many interesting and stimulating discussions.

Symposium on Lasers and Accelerators for Science & Society:

Finally, the project hosted an outreach symposium in Liverpool on 26 June 2015. There, the network presented its research results to a very wide audience to help promote researcher careers in the field of accelerator science and technology.

DISSEMINATION & OUTREACH

Prize-giving at the First Laser Applications School at GANIL including presentation of the LA³NET Prize 2012

The project has disseminated its research results via leading peer reviewed journals and at symposia, conferences and workshops. Preprints of publications are also available via the project web site www.la3net.eu.

The site has been regularly updated with consortium news. This has been complemented by the LA³NET Facebook page and a quarterly newsletter that has addressed the wider scientific community and public at large.

Dialogue with laser and accelerator workers from outside LA³NET has been promoted through the series of LA³NET events open to external participants. The consortium has also awarded annual prizes of 1,000 € to young researchers who made a substantial contribution in the field of laser application at accelerator facilities.

The LA³NET researchers have been the driving force behind the network's outreach activities including engagement with schools. They have done many school visits and met with children of different ages to introduce them to science and the life of a scientist. They have participated in open days and other outreach events that aimed at attracting young people to science. The LA³NET researchers have also contributed directly to outreach activities by producing video web casts about their individual research projects. The videos are available via the project web page and YouTube.

The most important outreach event took place on 26 June 2015 in Liverpool, UK. The Symposium on Lasers and Accelerators for Science & Society hosted by The University of Liverpool – Cockcroft Institute gathered around 250 participants. World-renowned scientists presented highlights in accelerator and laser research and the enormous impact these tools have on science and society. They were joined by Fellows from the LA³NET and oPAC networks who presented the results of their research and shared their fascination for science.

MANAGEMENT STRUCTURE

The Steering Committee

The Steering Committee has been responsible for the overall network strategy and all decisions concerning the network.
In the final year of the project it consists of the following elected members:

Dr. Michael Budde, Head of the Physics Design group of Danfysik, Denmark, is representing industry in the Steering Committee. He has worked at universities in US and Denmark before moving to the industry sector.

Dr. Enrique Conejero Jarque is working at the University of Salamanca and Centro de Láseres Pulsados Ultracortos Ultraintensos (CLPU), Spain on laser-plasma interactions in the ultra-short ultra-intense regime.

Prof. Allan Gillespie has held the Chair of Photonics at the University of Dundee, UK since December 2004. His research currently focuses on FELs and lights sources, mobile computing and nanomaterials.

Dr. Nathalie Lecesne is leader of the Resonant Ionization Laser Ion Source (RILIS) project at GANIL, France. She studied in Orsay and Caen and has also worked at TRIUMF, Canada.

Luca C. Stockhausen, based at CLPU is the researcher elected to represent the Fellows in the final year of the project. In previous years the Fellows were represented by Andrii Borysenko and Jurjen Couperus.

Prof. Carsten P. Welsch initiated the LA^{3}NET project and is the scientific coordinator on behalf of the University of Liverpool based at the Cockcroft Institute, UK. His research is in accelerator R&D with a focus on low energy accelerators and beam instrumentation.

EU Project T.E.A.M.

EU PROJECT T.E.A.M.
Training, Enterprise, Administration, Management

A dedicated EU Project T.E.A.M. has been established at the University of Liverpool and based at the Cockcroft Institute, UK to assist the project coordinator in the day-to-day running of LA^{3}NET. Dr. Rob Ashworth and Magdalena Klimontowska have been managing the project, Samina Faisal has been responsible for the financial project administration, Blaise Guénard has provided administrative support and Alexandra Welsch has been responsible for developing and managing the web presence and newsletters.

The Supervisory Board

Each partner has been represented on the Supervisory Board which has met annually to monitor progress and ensure that training has been of highest standard and has remained relevant, particularly in relation to industry.

Partners

LA^{3}NET is comprised of eleven beneficiary partners, twelve associated partners and fifteen adjunct partners. The beneficiary partners all have hosted between one and four early stage researchers (ESRs), each dedicated to a specific research project. Associated and adjunct partners have played a role in the network-wide training and some have provided secondment places for ESRs in relevant scientific or technological areas. More than ten partners have represented industry.

ASSOCIATED & ADJUNCT PARTNERS

Aquenos GmbH

Aquenos GmbH develops software solutions, provides system and network administration, as well as IT consulting for customers from different sectors and with diverse backgrounds and needs. Its product portfolio includes integrated solutions as well as purpose-developed key components for specific client needs.

The company has extensive experience in the maintenance of Linux- and windows-based systems, in particular within heterogeneous IT environments.

CFEL – Center for Free-Electron Laser Science

CFEL is a cooperation of DESY, the Max-Planck Society and the University of Hamburg, located on DESY campus, with close connections to the European XFEL. The main topic of CFEL is to advance science with next generation light sources, especially studying matter on atomic length and time scales. LUX, the CFEL Junior Research Group for Laser-Plasma Driven Light Sources, was established in 2013 to build, operate and study new sources of femtosecond X-ray pulses.

A new 200 TW laser system was recently installed within a cooperation of DESY and the University of Hamburg, and will be used by the CFEL group to set up a series of experiments dedicated to laser-plasma acceleration of electrons and the subsequent generation of X-ray beams from these novel sources.

Cobolt AB

Cobolt AB develops manufactures and supplies diode-pumped solid-state lasers (DPSSLs) in the visible and near infrared spectral ranges. The company provides a broad range of market-adapted laser products built on a wavelength flexible, power-scalable and robust technology platform. The lasers are particularly suitable for OEM integration, but do also comply with applicable standards and directives for use as stand-alone devices in a laboratory environment.

Cobolt is committed to supplying innovative laser products that meet or exceed the market's expectations concerning quality, reliability and performance.

Cosylab

Cosylab is developing next generation technologies for global niche markets and is a fast growing technological company, committed to creating innovative products and services intended for demanding markets and customers. The company started in a laboratory at the Jožef Stefan Institute, the largest Slovenian research institute. Due to first-hand experience of working in major accelerator facilities it soon became the largest company specialized in developing control systems for particle accelerators.

Cosylab specializes in the field of control systems for particle accelerators and other large experimental physics facilities. They cover hardware and software products and accompanying services such as customization and integration of already existing solutions, custom development, consulting and tutoring.

EdgeWave GmbH

Laser technology has become an indispensable part of many aspects of modern life. It has brought about lasting changes in the fields of industrial manufacturing, medical and environmental engineering, micro- and nano-technology and ICT. Founded in 2001, EdgeWave has successfully commercialized the INNOSLAB technology. This robust and efficient laser design enabled the development of high power pulsed laser systems. EdgeWave holds a number of world records in this area and is still pushing the limits with a brand new 400 W ps laser.

Franhofer, Institute for Laser Technology (ILT)

ILT has more than 250 employees and 10,000m² of usable floor space and is one of the most important development and contract research institutes of its specific field in the world. ILT activities cover a wide range of areas such as the development of new laser beam sources and components, the use of modern laser measurement and testing technology and laser-supported manufacturing. This includes for example laser cutting, caving, drilling, welding and soldering as well as surface treatment, micro-processing and rapid prototyping.

High Q Laser

High Q Laser develops, manufactures and distributes a complete range of solid-state

pico- and femtosecond oscillators and amplifiers. In this field, High Q Laser is a world leading supplier for scientific, medical and industrial markets offering standard as well as individually customized ultrafast laser systems.
By employing a modular product concept, High Q Laser can quickly tailor ultrafast products for use in OEM, imaging, medical, nano-processing, semiconductor and research applications.

INFN – Laboratori Nazionali del Sud (LNS)

Laboratori Nazionali del Sud (LNS) is one of the four national laboratories of INFN, Italy. Founded in 1976 it currently employs about 150 people and is an advanced development center for technology and instrumentation. The research activity is mainly devoted to the study of the structure and properties of atomic nuclei in collaboration with researchers coming from several countries.

At LNS two particle accelerators are available: a 15 MV Tandem Van De Graaff that started to be used for the first experiments in the early '80s and a K800 Superconducting Cyclotron in full operation since 1996. The EXCYT facility for the production of exotic beams based on the coupled operation of these two accelerators is already in operation.

Laser Quantum GmbH

Laser Quantum GmbH is a world class manufacturer of femtosecond lasers and oscillators. The company has a long history in the research, design and manufacture of ultracompact Ti:Sapphire oscillators with repetition rates from 333 MHz to 1 GHz and is a provider of advanced ultrafast time-domain and THz spectroscopy systems and components.

In 2005, the company greatly advanced the field of ultrafast time-domain spectroscopy by introducing high-speed asynchronous optical sampling as a time-delaying technique without mechanical scanners.

Litron Lasers Ltd

Litron Lasers is a UK company specializing in the design and manufacture of pulsed Nd:YAG laser systems for scientific and industrial applications. They are the market leader in high power, high repetition rate lasers offering both standard and custom options. Litron currently has an installed base of several thousand units, many of which are used in industrial 24/7 applications.

A large proportion of Litron's products are being used in scientific applications and so this market has been targeted for future growth and expansion. Litron is involved in many different areas of research that use lasers in accelerator based applications at CERN, SLAC and numerous other research institutes across the globe in applications ranging from Ti:Sa to OPO pumping.

Ludwig Maximilian University of Munich

The newly established Chair of Experimental Physics – Medical Physics in the Faculty for Physics of the Ludwig-Maximilians-Universität München (LMU) aims to promote research and teaching in the field of medical physics, with special focus on advances in pre-clinical and clinical radiotherapy. The R&D activities include new detector developments for dosimetry and in-vivo imaging as well as analytical and stochastic (Monte Carlo) computational methods for application to a wide range of beam modalities, from established conventional sources of photons and hadrons up to laser-based systems.

LOA - Laboratoire d'Optique Appliquée

LOA is a French laboratory located in Palaiseau, near Paris. It is a CNRS laboratory combined with ENSTA and Ecole Polytechnique. The aim of the laboratory is to develop intense femtosecond lasers and their applications. In particular, LOA has a long experience in very high intensity laser and laser-plasma interaction. LOA is a European laser facility with several lasers delivering light pulses with peak power from a few TW to hundreds of TW. The latest laser system can deliver two laser pulses of 60 TW (30 fs) each at 1 Hz into three experimental sites essentially dedicated to laser plasma-acceleration, femtosecond X-ray sources and X-ray lasers.

Max Planck Institute for Nuclear Physics (MPI-K)

MPI-K is one out of 80 institutes and research establishments of the Max Planck Society for the Advancement of Science, which was founded in 1948 succeeding the Kaiser-Wilhelm-Gesellschaft and is committed to basic research.

The institute's research programme presently concentrates on two interdisciplinary research fields, namely Astroparticle Physics and Quantum Dynamics. The institute has a long standing research background in accelerator R&D. Many of the institute's research activities strongly rely on the use of lasers.

Polytechnic University of Milan

The Polytechnic University of Milan is a major Italian technical university with over 1,300 teachers and 38,000 students of engineering, architecture and design. The Department of Energy offers major contributions to the courses in Energy Engineering and in Nuclear Engineering and contributes to Electrical, Chemical and Materials and Nanotechnology Engineering. Beside the long standing experience of the Physics Department in the laser field, the Department of Energy hosts other physics expertise aimed at either the understanding of fundamental physical phenomena or the development of technological applications. The main focus is on synthesis and investigation of novel materials, namely nanostructured films and surfaces, produced by physical vapour deposition techniques like Pulsed Laser Deposition.

Paul Scherrer Institute (PSI)

The Paul Scherrer Institute is the largest research centre for natural and engineering sciences in Switzerland with its research activities concentrated on three main subject areas: Matter and Material; Energy and the Environment and Health. The PSI develops, constructs and operates complex large-scale research facilities, such as the SINQ neutron source, the Swiss Light Source (SLS) and the S S muon source. A hard X-ray free electron laser, named SwissFEL, is currently under construction and will go on-line in 2017.

Research Instruments GmbH

Research Instruments develops and provides special products for physics and energy research as well as for medical applications focusing on radio frequency cavities and systems, linear accelerators, particle sources, beam lines and diagnostics.

Through their company history of Interatom, Siemens, ACCEL and now as part of Bruker Corporation they are continuously developing turn-key accelerator systems and key components for large scale accelerator facilities. Many of these projects were carried out in partnership with Universities and research centres from around the world.

Royal Holloway University of London

Royal Holloway was a founding member of the John Adams Institute (JAI) together with Oxford University and the UK Science and Technology Facilities Council (STFC). Central to the mission of the JAI is the training of accelerator physicists at PhD level. This includes world-leading efforts in the developments of laser wire scanners for high energy particle accelerators as well as investigations into the measurement of longitudinal beam profiles.

The group has been involved in many research and training programmes at the national and international level and has successfully collaborated with a number of the LA³NET partners in the past.

SLAC National Accelerator Laboratory

Home to the world's longest particle accelerator and top-notch research facilities, SLAC National Accelerator Laboratory attracts thousands of users, visiting scientists and students from all over the world each year. The same 2-mile-long linear accelerator that has enabled Nobel prize-winning discoveries in particle physics now powers a revolutionary X-ray free electron laser, the Linac Coherent Light Source (LCLS). Launched in 2009, the LCLS pushes photon science to new frontiers with ultrabright, ultrashort X-ray pulses that allow atomic-scale snapshots of material dynamics in the femtosecond regime.

SourceLAB

SourceLAB is a spin-off from the Laboratoire d'Optique Appliquée (LOA) with a mission to develop and commercialize innovative solutions for compact sources of particles and radiation (electrons, ions, X-rays and neutrons) using ultra-intense lasers to meet the growing market needs for scientific research equipment, industrial non-destructive testing and medical imaging. These new generation sources are based on the revolutionary technology of laser-plasma acceleration to provide the most intense acceleration that exists. This will promote interest in exploring some unanswered questions of efficacy, safety, compactness and cost of accelerators.

Thorlabs

Thorlabs strives to provide worldwide researchers with adapted tools and share its know-how and expertise to facilitate efficient research. Founded 21 years ago, Thorlabs is one of the leading suppliers of scientific equipment for research and development in the field of photonics offering more than 12,000 products ranging from simple lenses and mirrors to advanced laser stabilization feedback systems or 2 photon confocal microscopes. Thorlabs has a worldwide presence producing more than 90% of its products directly and offering a large number of customized solutions.

University of Bari

The University of Bari hosts more than 56,000 students and 2,000 teachers offering a broad range of courses to its students. It has a central site in Bari with 11 campuses and 2 off-site branches in

Taranto and Foggia with a total of 15 Faculties and 63 Departments.

The Department of Physics promotes and coordinates teaching and research activities in the following areas: condensed matter physics; optoelectronic and quantum devices; laser physics; applied physics; theoretical and computational physics; particle physics; nuclear physics; planetary and space physics; teaching and history of physics. It scored top of the list in the last Italian university ranking.

University of Mainz

With more than 35,000 students Johannes Gutenberg-Universität at Mainz is one of the ten largest universities in Germany. In the fields of natural science the Cluster of Excellence on "Precision Physics, Fundamental Interactions and Structure of Matter" (PRISMA), and the Graduate School of Excellence "MAterials Science IN MainZ" (MAINZ) are considered among the elite research groups worldwide while unique large-scale research equipment includes the TRIGA light water research reactor and the MAMI electron accelerator devoted to hadron physics.

University of Nova Gorica

The University of Nova Gorica, Slovenia is an independent, research oriented and student friendly university that serves around 800 students. The University has five major research centres and six research laboratories which includes the research unit on Quantum Optics linked to LA^3NET. In recent years the activities of Nova Gorica University in the field of laser science and technology developed along three main lines: 1) Design and implementation of a seeded free-electron laser on the Elettra storage ring at Sincrotrone Trieste; 2) Design and commissioning of the single-pass seeded free-electron laser FERMI@Elettra at Sincrotrone Trieste and 3) Development of a state-of-the-art light source based on the principle of laser high-order harmonic generation in gas.

University of Seville / Centro Nacional de Aceleradores (CNA)

The University of Seville's CNA is the national Centre of Excellence for particle accelerator based interdisciplinary research and carries out fundamental and applied research. The laboratory is composed of a 3 MV tandem van de Graaff, a 18 MeV proton cyclotron and 1 MV tandem Cockcroft-Walton for accelerator mass spectrometry. Beside these instruments, the centre has sample preparation laboratories as well as an installation for radiopharmaceutical production. A small positron emission tomograph for animal studies completes the cyclotron laboratory.

At CNA there are seven independent beam lines. In 2008 a new ion source of the Duoplasmatron type was installed.

University of Strathclyde

The University of Strathclyde Glasgow in the UK is committed to 'useful learning' through the provision of relevant, high quality, educational opportunities, the global application of research and focus on knowledge exchange to benefit the wider economy and society. The University of Strathclyde has the third largest number of students of the Scottish universities and was awarded UK University of the Year 2012/13 by the Times Higher Education. Strathclyde is to be the base for the Centre for Applied Photonics in collaboration with the Fraunhofer Gesellschaft, Europe's largest organisation for contract research. The Intense Laser Interaction Studies (SILIS) group within the University conducts both experimental and theoretical research into high-power laser-plasma interactions.

University of Sussex

Sussex is a leading research university with over 90 per cent of Sussex research activity rated as world leading, internationally excellent or internationally recognised. This places the University among the leading 30 research universities in the UK.

The Experimental Particle Physics (EPP) Research Group aims to answer some of the fundamental questions posed by modern physics. In attempting to answer these questions the EPP group has leading roles in a number of experiments: ATLAS at CERN's Large Hadron Collider; NOvA and MINOS+ that use the NuMI neutrino beam at Fermilab, USA; CryoEDM that is searching for the Electric Dipole Moment (EDM) of the neutron at ILL, Grenoble; SNO+ and DEAP that are located at SNOLAB, Canada.

Uppsala University Accelerator Physics Group, Department of Physics and Astronomy

Uppsala University is the oldest university in the Nordic countries, with a living cultural environment and 40,000 students. World-class research and high quality education pursued here benefit society and business on a global level. The University is characterized by diversity and breadth, with international frontline research at nine faculties and limitless educational offerings at undergraduate and master levels.

The members of the Accelerator Physics Group participate in the realization of several large international projects ranging from the X-ray free electron laser X-FEL at DESY in Hamburg, seeding experiments at FLASH, various activities at CERN in Geneva such as the design and construction of the Two-beam Test-stand at CLIC test facility CTF3 to work at the European Spallation Source ESS in Lund, Sweden.

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