ASTeC SCIENCE HIGHLIGHTS 2012 - 2013

Science & Technology Facilities Council

Science Highlights
2012 - 2013

This report covers the work accomplished by
the Accelerator Science & Technology Centre
(ASTeC) for the financial year 2012 - 2013

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1 FOREWORD

This document presents the highlights from the R&D programme carried out by the Accelerator Science and Technology Centre (ASTeC). Despite the difficult funding climate, the staff within ASTeC and our partners have been able to deliver a first class programme of research and development across an impressively broad range of technical and scientific areas relevant to particle accelerator facility delivery.

At the core of our R&D are state-of-the-art test facilities such as ALICE and EMMA and this year's report outlines the exciting research being carried out on both facilities. The EMMA programme has probed further the workings of this new class of accelerators and the ALICE programme has diversified with accelerator research being carried out in parallel to Liverpool University led investigations of a potential new technique for cancer diagnoses.

Our latest facility, which is undergoing commissioning this year, is somewhat different from those mentioned. The Versatile Electron Linac for Applications (VELA) is the first of its kind and it has been designed and set up to offer industry prototyping and test beam facilities in a flexible access mode together with enabling accelerator research to underpin future science facilities. Just two years on from the funding announcement from BIS we have produced the first high brightness beams of electrons. This rapid progress through design to implementation is impressive and a credit to the professionalism of all the scientist and engineers involved. Our next steps will be to engage with industry to demonstrate how VELA can accelerate the time from design to market, speeding up the process of prototype development.

Free electron lasers (FELs) are now demonstrating an exceptional leap in capability for photon science. This is a capability that is being exploited by a growing number of scientists across the globe and ASTeC is researching concepts to push the boundaries to produce ever shorter pulses of light. This year, through the publication of the conceptual design report for the Compact Linear Accelerator for Research and Applications (CLARA), we took a significant step towards ensuring the UK can provide world-leading facilities for future FEL users. The plan is that CLARA will extend the VELA injector facility, building a flexible testing and development bed for novel FEL schemes. This facility would lower the cost and risk of implementing such schemes on existing or new facilities, making it more likely that the UK can afford, and be capable of delivering, a truly world leading national FEL facility in the future.

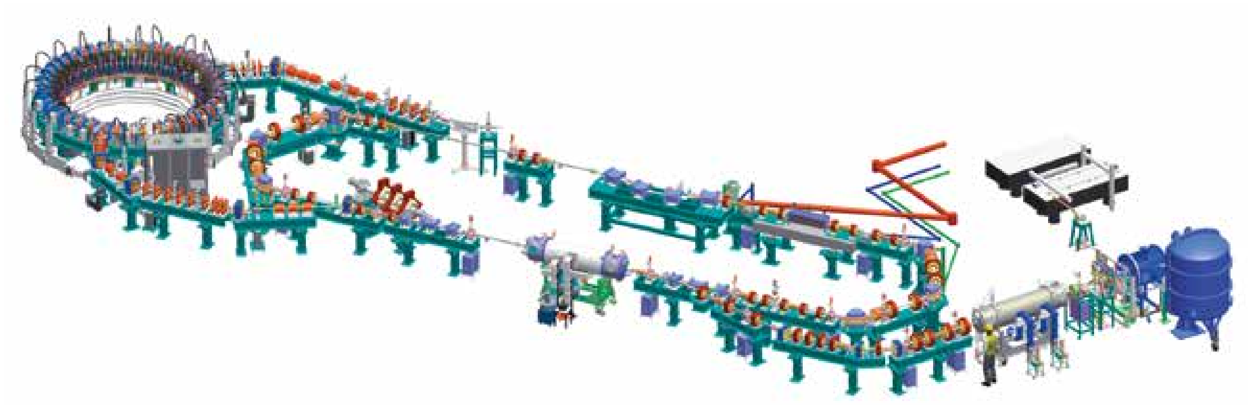
This year's report shows that ASTeC is pursuing a large variety of research which takes place across the broad range of technologies and expertise supporting the multidisciplinary nature of accelerator facility design. An important aspect of sustaining an expansive research portfolio is the fostering of strong collaborations and partnerships. Conferences, workshops and visits are the breeding ground for new opportunities and for collaborations and this year we have hosted and attended a significant number of events covering the largest accelerators for particle physics to the most compact designs for accelerators in health and industry.

Inspiring youngsters to continue to pursue an education or career in science and technology has never been more important to the UK. It is widely recognised that our prosperity will depend on the UK having the skills to grow our future businesses particularly in high technology areas. To engage with youngsters effectively takes not just resource but a real enthusiasm and engagement from those involved and I would like to thank the ASTeC staff who have put tremendous energy into ensuring we made a great success of training students in our research areas and running an extensive programme of outreach activities with schools including the Daresbury Particle Physics Masterclass held in partnership with the Cockcroft Institute Universities.

Professor Susan Smith
ASTeC Director & Head of Daresbury Laboratory

ALICE

Accelerators and Lasers In Combined Experiments



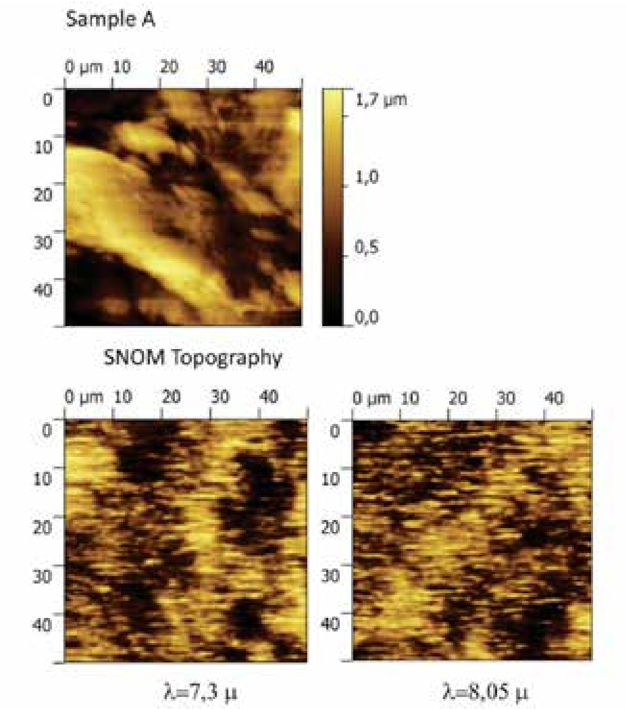
ALICE (Accelerators and Lasers In Combined Experiments) is one of ASTeC's major facilities for the pursuit of cutting edge research, both in pure accelerator science and its applications. It is a multifunctional facility hosting a wide range of projects from accelerator physics to life sciences.

ALICE in recent years had been a demonstrator of several breakthrough concepts in accelerator science. These include demonstration of energy recovery, compton backscattering x-ray production, and operation of a free electron laser. The ALICE facility utlises advanced, state-of-the-art accelerator technology, including a fully operating DC photoinjector and a superconducting RF linac. Many of ALICE's applications and fundamental technology are at the forefront of worldwide accelerator science, and were new to the UK before ALICE was developed. In the case of energy recovery, this was the first (and still only) demonstration in Europe.

In 2012 ALICE development and utilisation was continued. The electron source, the high voltage gun, was modified by the implementation of a new ceramic insulator, which enabled a much higher initial beam accelerator. Previously, the maximum gun voltage was 230 kV, with the new insulator the gun is operated routinely at 325 kV. This improvement is an enhancement of beam quality which is beneficial for all ALICE projects. The advanced type of ALICE electron source is one of only a handful around the world.

Throughout 2012 ALICE operated a programme of scientific exploitation with various projects, including use of ALICE as the injector to the EMMA FFAG (non-scaling Fixed Field Alternating Gradient accelerator), studies of the IR-FEL, THz and fundamental accelerator physics, development of a coherent transition radiation bunch length monitor; and applications including the use of THz to probe microfluidics and the use of the IR-FEL in scanning near field optical microscopy (SNOM). The staff of ASTeC, alongside university collaborators, provide the skills required to optimise and maintain the machine for these science projects, usually operating 16 hours a day, seven days a week.

Antonio Cricenti and Marco Luce (from Rome), who developed the SNOM technique, with their instrument on the IR-FEL facility



Scanning near field optical images of oesophageal cancer using the ALICE InfraRed Free Electron Laser (IR-FEL)

The SNOM was one of the major applications of ALICE in 2012, and the goal of this technique is to develop diagnostic methods for cancer in human oesophageal cells. This work is a collaboration between ASTeC, the University of Liverpool Physics Department, the Royal Liverpool and Broadgreen University Hospitals NHS Trust, the National Research Council ISM of Rome Tor Vergata and the Institute of Translational Medicine. This year a programme of studies was pursued to gather optical images of oesophageal cancer using the SNOM technique. In January results from these studies were published in Applied Physics Letters 102, 053701 (2013) 'Near-field optical microscopy with an infra-red free electron laser applied to cancer diagnosis'. Further details are available on page 46.

Other accelerator physics developments include the implementation of more advanced diagnostics such as: fast beam position monitors capable of detecting individual bunches; optical beam arrival time monitors; fast photo detectors to measure the pulse-by-pulse FEL energy. These advancements were reported in international accelerator conferences during FY 12-13. A programme of advanced beam tomography measurements using the ALICE-to-EMMA transfer line was pursued by university collaborators and results were published in the Journal of Instrumentation (M Ibison et al 'ALICE tomography section: measurements and analysis' April 2012).

ALICE has been ASTeC's main test facility and the focus of operational efforts for several years. With the advent of the VELA (Versatile Electron Linear Accelerator) electron source to complement ASTeC's facilities, the scope of experimental, scientific, and technical accelerator experience within ASTeC is very broad.

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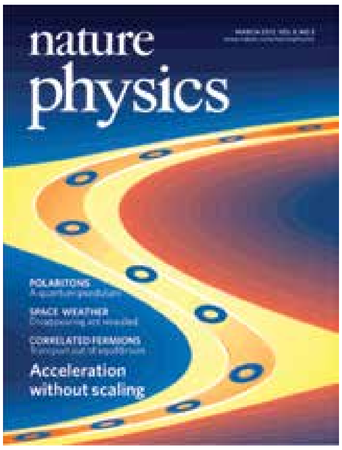
EMMA

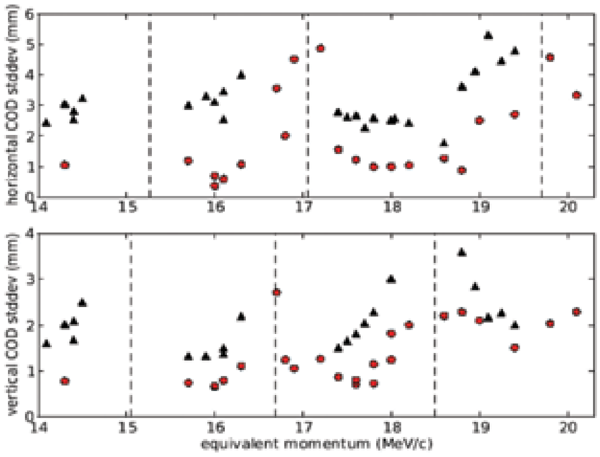


Cover of the edition of Nature Physics showing serpentine acceleration

EMMA is the world's first non-scaling Fixed Field Alternating Gradient (ns-FFAG) accelerator and represents a proof of principle of a novel transport concept as well as a new accelerating technique. The uses for ns-FFAGs range from medical applications such as hadron therapy to Accelerator Driven Subcritical Reactors (ADSRs), muon colliders and a neutrino factory. The main property of this type of machine is that it would be the first to allow for the transport of a heavily disordered beam, together with acceleration, at low cost. This means EMMA has a large acceptance, both longitudinally and transversely.

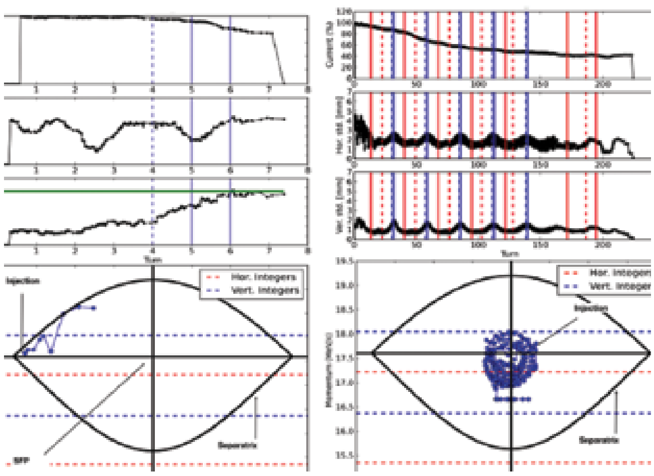
As well as the demonstration of acceleration in the serpentine channel, published in Nature Physics in March 2012, the front cover of Nature Physics for the relevant issue is shown above, the acceptance of the EMMA ring, both transverse and longitudinal, was explored. This resulted in an approximate mapping which agrees broadly with theory. However, despite this progress, the ring acceptance needs to be measured over the full acceleration range and with a more precise scanning, in order to fully understand the dynamics of ns-FFAGs.

A substantial (~ 10 mm) closed orbit distortion exists in EMMA, when uncorrected, in both the horizontal and vertical planes. The response matrix was measured at various momenta to implement a correction scheme and this resulted in a substantial reduction of the closed orbit distortion. It is now necessary to implement this at a range of energies. This should result in a larger acceptance and a more stable beam with which to explore the dynamics of the EMMA ring. The results achieved so far are shown below.



COD before (black triangles) and after (red circles) correction in the horizontal (top) and vertical panels over the momentum range

The crossing of resonances was also explored on EMMA. It is crucial for this to be understood for proton therapy applications, where the acceleration cannot be fast and resonances may become an issue. Initial mapping of resonance crossing was performed at several energies, but not for the full energy range available on EMMA. The experience so far shows that this phenomenon broadly agrees with theoretical predictions. The figure below shows the amplitude growth and longitudinal phase space, together with

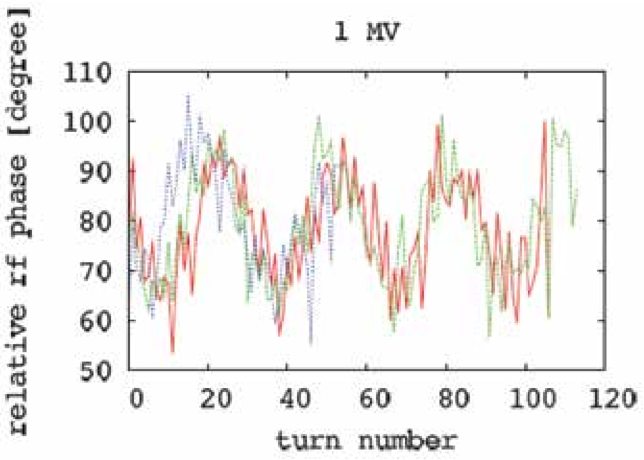


Amplitude growth and longitudinal phase space for a bunch accelerated at 0.2 MV/turn, at the edge (left) and centre of the RF bucket. The red and blue lines represent the locations of the horizontal and vertical integer tunes respectively.

the charge and transverse displacement, for a bunch accelerated at 0.2 MV/turn and similar crossing speeds when injection takes place at the edge of the bucket (left) or in the middle of it. The red/blue indicate horizontal/vertical integers. Similar behaviour is seen at other accelerating voltages.

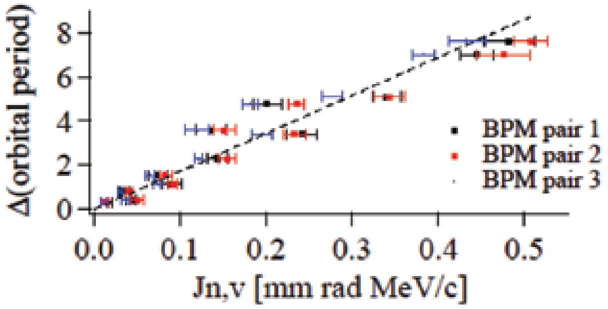
The Large Hadron Collider (LHC) at CERN enables us to look at physics beyond the current Standard Model (SM), however, new results from current neutrino oscillation experiments looking at the physics of flavour changing in the neutral leptonic sector, have shown that quantities, like θ_{13}, are non-zero. This opens the possibility to measure CP violation and suggests that non-trivial physics may be coupled with the leptonic sector of the particle spectrum. Charged lepton flavour violation processes are a very important area to search for physics beyond the SM, with important implications for our understanding of particle physics. Therefore, muon to electron conversion searches are rapidly gaining interest with two proposed experiments COMET and Mu2e. In particular, the COMET experiment will be built in two stages and the beam line for COMET stage 1 has been approved by JPARC. Both experiments are expected to reach a single event sensitivity of < 10–16. PRISM (Phase Rotated Intense Source of Muons) constitutes an upgrade of the COMET experiment and should give access to the higher sensitivity of < 10-18. The PRISM experiment requires intense quasi-monochromatic muon beams, obtained by performing RF phase rotation in an FFAG ring. Experiments have been performed using EMMA in which a bunch is allowed to undergo 1/4 of a synchrotron oscillation (over 3 turns), as would be the case in PRISM (over 6 turns), this is accomplished by injecting a bunch of known energy into the centre of an RF bucket, and then extracting it one or more turns later to measure the properties of the longitudinal phase space.

The synchrotron oscillations are shown below.



Synchrotron oscillations in EMMA

Related to PRISM, the dependence of orbital period upon betatron oscillation amplitude has been measured and compared with theory. The experimental values were found to be in good agreement with theory, shown below. This is a significant demonstration relevant to large emittance bunches in high chromaticity accelerators, such as future muon collider rings, for example.



Change in orbital period vs. vertical transverse action with the dashed line representing the theoretical prediction

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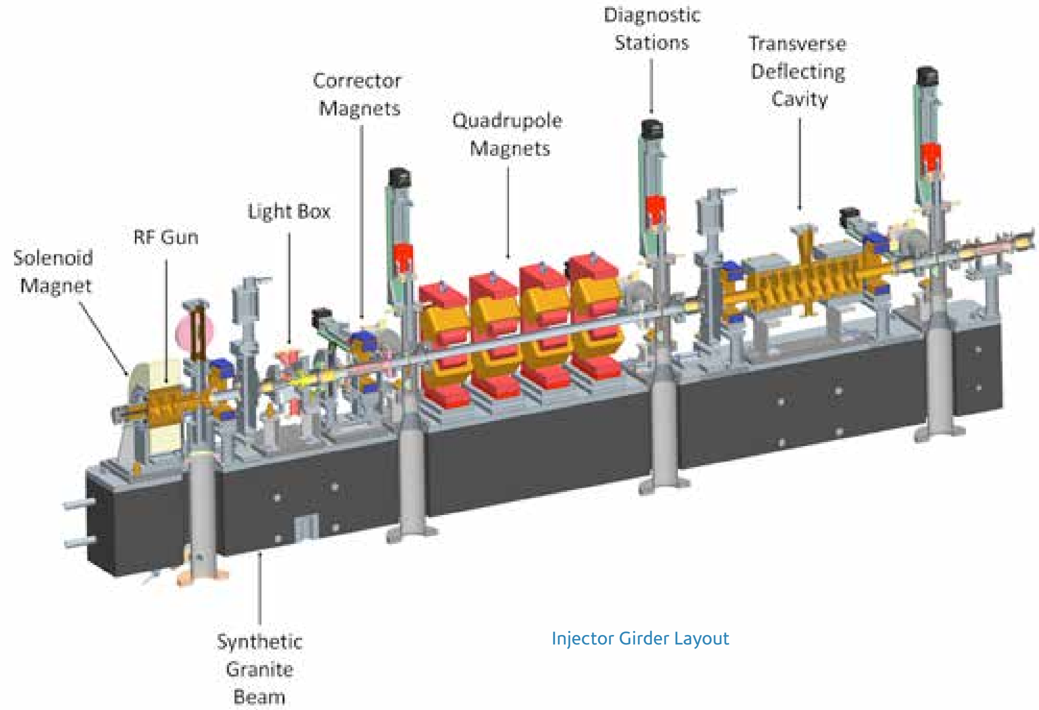
VELA

New UK Particle Accelerator Heralds Exciting Opportunities for Industry



Injector Girder Layout

The new UK particle accelerator VELA (Versatile Electron Linear Accelerator) has achieved a significant electron acceleration milestone, which heralds exciting new opportunities for industry to apply the latest particle accelerator technology to its most critical commercial challenges.

In August 2011, Prime Minister David Cameron announced a £2.5M investment into the Science and Technology Facilities Council's Daresbury Laboratory for accelerator technology developments, as part of a series of investments across the wider Sci-Tech Daresbury Campus. VELA's unique electron beam characteristics, coupled with its exceptional repeatability and flexibility, make it ideal for applications development across a broad range of key market sectors; everything from seeing through aircraft luggage and developing more effective hospital radiotherapy machines, to shrink-wrapping cable bundles and curing ink.

On 5 April 2013 VELA's first beam of electrons was successfully accelerated and captured, making it the latest innovative particle accelerator from the Science and Technology Facilities Council's Daresbury Laboratory in Cheshire. VELA has been purpose-designed to assist industry in bridging the gap between prototypes and market ready products through the use of charged particle beams. This first successful demonstration of VELA means that it is now expected to be ready for commercial and research use in Summer 2013 with the first commercial users already booked.

'VELA has huge potential for the development of novel technologies across many sectors, such as security, healthcare and manufacturing. As the facility becomes operational, we look forward to realising the impact of these technological advances for the benefit of UK industry,' said Professor Susan Smith, Director of the Accelerator Science and Technology Centre (ASTeC), following the achievement of this significant milestone. 'A lot of hard work has gone into the development of VELA, and it's great to see it starting to pay off.'

Accelerators pervade many aspects of modern life: every year, £340 billion of end products are produced, sterilized or examined using industrial accelerators worldwide. Therefore it is important for UK industry to have access to such facilities. To this end the VELA development has been backed by three major commercial partners – Siemens , Rapiscan and e2v and over 80 companies ranging from blue chips to SMEs have supported its construction. Strathclyde University has also collaborated with STFC to develop the VELA facility in order to demonstrate the operating performance of an advanced electron beam injector for laser wakefield accelerator applications.

Accelerators are also used extensively in hospitals for cancer therapy. Technological advances which make accelerators more compact and cheaper to operate will only increase their industrial applicability – resulting in new opportunities for high value manufacturing and a significant economic impact across a breadth of sectors.

The accelerator facilities and expertise within STFC are positioning the UK to unlock the potential of these technological advances for the benefit of UK industry and the national economy.

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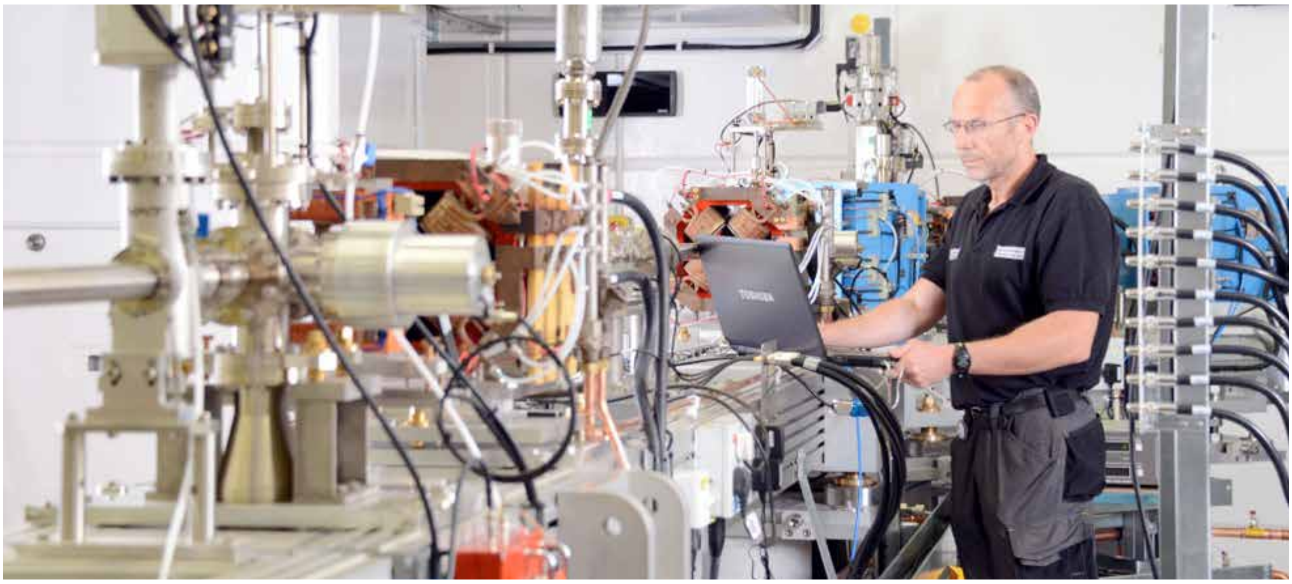
VELA

Photo-Injector RF Cavity Conditioning

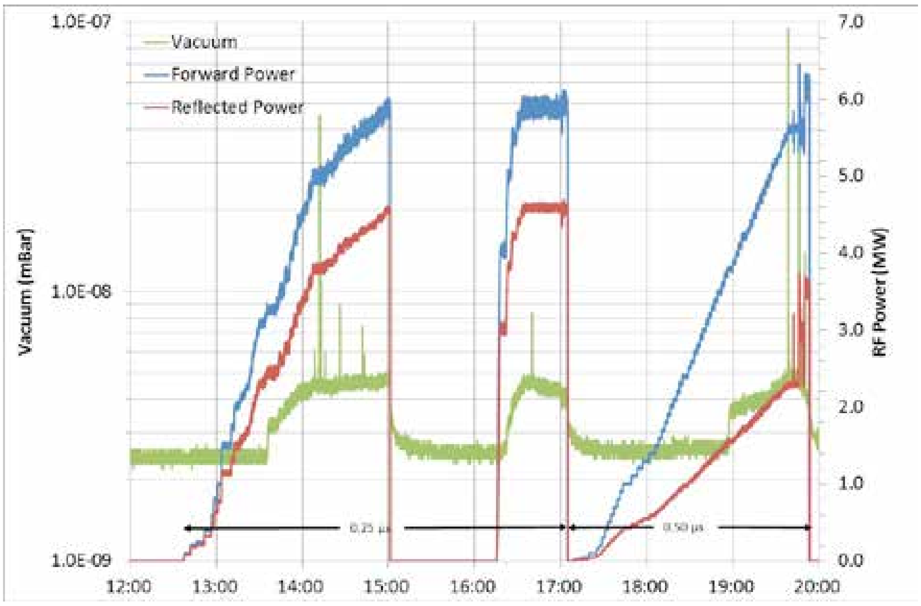


Commissioning work being undertaken on the VELA facility

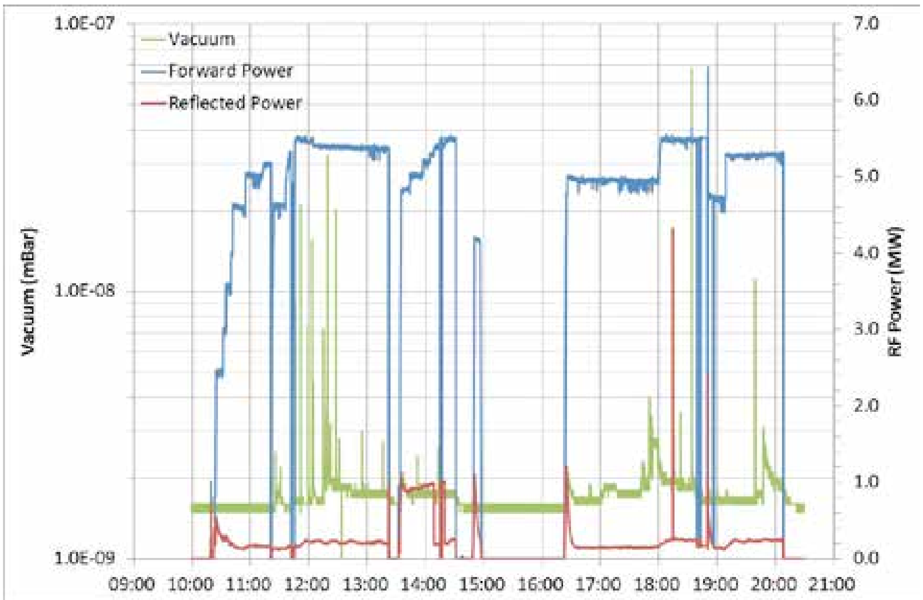
The Versatile Electron Linear Accelerator (VELA) is designed to provide a 4–6 MeV beam of electron bunches at charges between 10-250 pC with low transverse emittance and short bunch length to two separate user areas and will have an advanced diagnostics section to enable the beam parameters to be characterised in different charge regimes. VELA is presently under construction at Daresbury Laboratory. The first stage, consisting of an S-band RF photoinjector gun, a high power pulsed klystron modulator, a frequency tripled titanium sapphire laser system with a pulse energy of 2 mJ at 266 nm, and a beam diagnostic section comprising of a wall current monitor, Two Yttrium_ Aluminum Garnet (YAG) screens, and a Faraday Cup has been completed.

The photoinjector cavity incorporating a copper cathode has been provided by Strathclyde University and was built by Laboratoire de l'Accélérateur Linéaire (LAL) in France, based on the design developed by Eindhoven University of Technology in the Netherlands. It is a 2½ cell, standing wave cavity which operates in the π mode and is designed to provide 6.5 MeV (equivalent to an accelerating gradient of 100 MV/m) at a frequency of 2998.5 MHz. The frequency of the cavity is maintained by a temperature stabilised water circuit designed to control the temperature to ± 0.1°C, and prior to its installation it was confirmed that the tuning rate was 48.8 kHz/°C. Prior to commencement of RF commissioning, the photoinjector cavity was baked to 120°C to remove any water content and to improve the vacuum of the cavity.

The RF power to the photoinjector cavity is provided by a Thales TH2157 klystron, which is incorporated in a ScandiNova K2 klystron modulator. The klystron operates at 167 kV, 119 A providing a peak RF power of up to 10 MW with a pulse width of 0.25–3 μs, at a repetition rate between 1–10 Hz. The modulator is capable of 400 Hz, but is limited to 10 Hz due to the average power dissipation capability of the cavity.



Conditioning of the photo-injector cavity with a RF pulse width of 0.25 μs and 0.5 μs, at a repetition rate of 10 Hz



Conditioning of the photoinjector cavity with a RF pulse width of 2.5 μs, at a repetition rate of 10 Hz

The cavity was successfully conditioned to a peak RF power of 5.7 MW with a pulse width of 2.5 μs and a baseline vacuum pressure of 1.6×10^{-9} mbar.

Having achieved the initial required gradient and pulse width the photoinjector laser was aligned onto the copper cathode and with a peak RF power was set to 5 MW, a laser pulse energy set to 1.2 mJ, evidence of the first electron beam was seen on the first YAG screen. The beam was subsequently transported onto the Faraday cup where the charge was measured at greater than 170 pC.

Installation of the remaining sections of the VELA facility is now planned, with the aim to provide beam into the two user areas for scientific and industrial applications.

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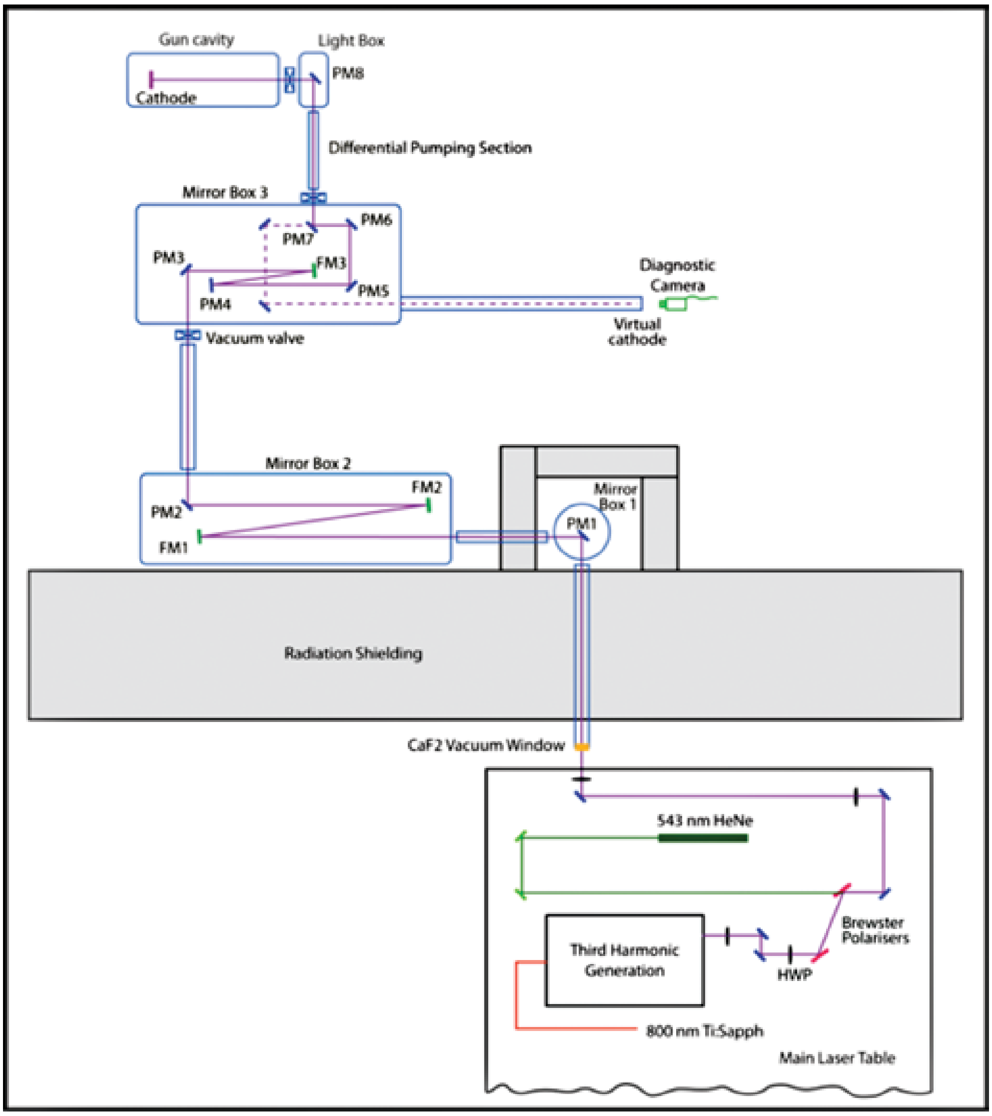
Designing the UV Laser Transport for VELA

Reuben Santer is seen placing one of the laser mirrors onto the measuring stage of the LTP in the Optics Metrology Laboratory

The task of the transport system for the UV photoinjector laser can be stated quite simply. The light pulses at 266 nm wavelength should be transported from the laser room to the photoinjector cathode and demagnified to a spot size of about 1 mm FWHM without changing the pulse length. However, simplicity of this statement belies what is quite a complicated task due to a number of constraints.

Firstly, the layout of the transport system is constrained by the physical positioning of the laser and the cathode, which were already defined. This layout demanded a number of bends in the light path that had to be incorporated into the overall optical scheme.

Secondly, the UV pulse is very intense, especially as the beam size is decreased. With a pulse duration as short as 180 fs and an energy as high as 2 mJ, the peak intensity at the focus could be as high as 460 GW/cm2. This huge intensity is sufficient to cause 'non-linear' interactions in any matter through which the beam propagates. Such interactions must be avoided as they cause serious disruption to the beam. Therefore, as much as the transport as possible is



Schema of the UV laser transport system

performed in-vacuum and all focussing of the beam is done with mirrors (not lenses). In general, transmissive optics can only be allowed where the beam is at its largest, i.e. where it is generated in the laser room.

Thirdly, a degree of flexibility is required in the optical design to allow the beam spot size to be changed and to accommodate improvements in the spatial properties of the UV source. The optical design, for reasons of cost, speed of procurement, and ease of change, had to be based around standard spherical and plane mirrors. However spherical mirrors do not give ideal focussing as they introduce astigmatism into the beam unless they are operated at normal incidence (which is not practical). They should operate at as near to normal incidence as possible, and this complicates the layout.

These considerations have resulted in a transport system with the following key features (see above):

A beam attenuator on the laser table made from a half-wave plate and a pair of brewster polarisers. This can attenuate the beam by a factor of at least 15 and is required to prevent damage to the optics.

A 543 nm HeNe laser, also on the laser table, is merged to a common path with the UV laser to ease alignment (since the UV beam cannot be seen with the naked eye).

An air-to-vacuum window made from optically flat calcium fluoride is at the start of the vacuum system as the beam exits the laser room. Calcium fluoride is used rather than UV-grade fused silica as it has a smaller non-linear index and also does not allow two-photon absorption at 266 nm. The UV beam is transported in vacuum after this window.

The beam passes through 2 m of concrete radiation shielding into the accelerator area and into Mirror Box 1 (MBOX1), which contains a plane mirror (PM1) that deflects the beam through 90° so that it is parallel to the accelerator. MBOX1 sits within additional radiation shielding and the primary function is to prevent any radiation generated in the accelerator area from passing down the beam tube into the laser room.

Mirror Box 2 (MBOX2) is immediately after MBOX1 and contains a pair of spherical mirrors, FM1 and FM2, at 4° angle of incidence. These compress the beam and the degree of compression can be changed by adjusting the separation of the two mirrors with a motorised translator. A plane mirror (PM2) deflects the beam towards Mirror Box 3 (MBOX3).

Mirror Box 3 contains the third spherical mirror (FM3) that does the final focussing to the cathode. As this mirror is also at 4° angle of incidence, there is some complexity in the optical arrangement with additional plane mirrors (PM3, PM4, PM7) used to bring the beam to the correct axis to enter the part of the accelerator known as the light box and allow small positional changes on the cathode (PM5 and PM6). Further plane mirrors take the small amount of the beam passing through PM7 to the 'Virtual Cathode' (VC). This is a fluorescent screen that is positioned at an optically equivalent position to the real cathode. It allows the beam shape and position at the actual cathode to be monitored.

The high beam intensity means it is not possible to isolate the laser transport vacuum from the machine vacuum with a window. Therefore, a differential pumping section is used to ensure ultra-high vacuum can be maintained in the accelerator.

The last mirror (PM8) before the beam reaches the cathode is in the light box, which is part of the accelerator. This is a special mirror as it is made from copper with a protected aluminium coating to reflect the UV light. The environment of the light box is quite hostile to conventional mirror substrates due to the close proximity of the mirror to the electron beam. The copper substrate allows for dissipation of any stray charges without damage.

Metrology of VELA Optics

Bath University sandwich student Reuben Santer took time away from running software simulations of FELs to help the VELA project by checking a batch of twenty 2 inch diameter plane laser mirrors. He used the Long Trace Profiler (LTP) in the Daresbury Optics Metrology Laboratory (OML) to check the mirrors met the required specification for flatness. This instrument is able to measure unevenness in the mirrors surface with nanometre precision. Although all the mirrors were within specification, some were inevitably better than others. The flatness data of all the mirrors was therefore invaluable when the transport system was being assembled as the best mirrors were used at points where the beam is largest to minimise the impact on the transported wavefront. The mirrors were also checked for roughness of the dielectric coating using the interferometric microscope in the OML.

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DICC

The Daresbury International Cryomodule Collaboration

ASTeC, through its leadership of an international collaboration (ASTeC, Stanford and Cornell Universities, Lawrence Berkeley National Laboratory in the USA, FZD Rossendorf and DESY in Germany and TRIUMF in Canada) has taken the responsibility for pushing the development of Superconducting RF (SRF) technology by designing and constructing a new cryomodule for optimised operation on energy recovery facilities and other high duty cycle accelerators.

The preferred technology solutions for this cryomodule include: 7-cell 1.3 GHz cavities, ferrite beam pipe HOM absorbers, high power adjustable input couplers and triple independent layers of magnetic shielding. All are intended to achieve an overall performance of >20 MV/m at a Q_o of $>10^{10}$. A series of qualification tests at cryogenic temperatures were conducted successfully to evaluate its performance and response to tuner operation. The module has been installed on ALICE and was successfully cooled down to 2K in the first attempt.

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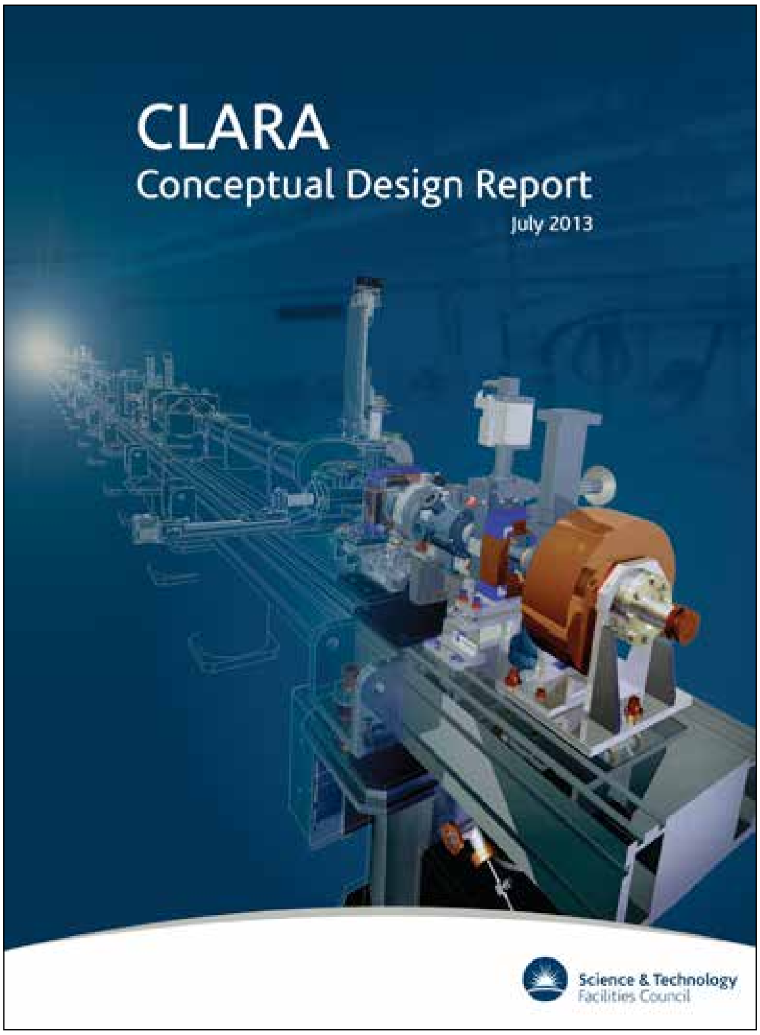
DICC

CLARA Conceptual Design Completed



CLARA (Compact Linear Accelerator for Research and Applications), the proposed major upgrade to VELA has made significant progress during the year, culminating in the publication of the Conceptual Design Report. The facility would serve two goals – as a free electron laser (FEL) test accelerator, able to test new ideas and concepts which would target the generation of ultrashort photon pulse generation and output stability, and also as a facility for the development of novel particle accelerator technologies and applications for both academia and industry, extending the capabilities of VELA dramatically.

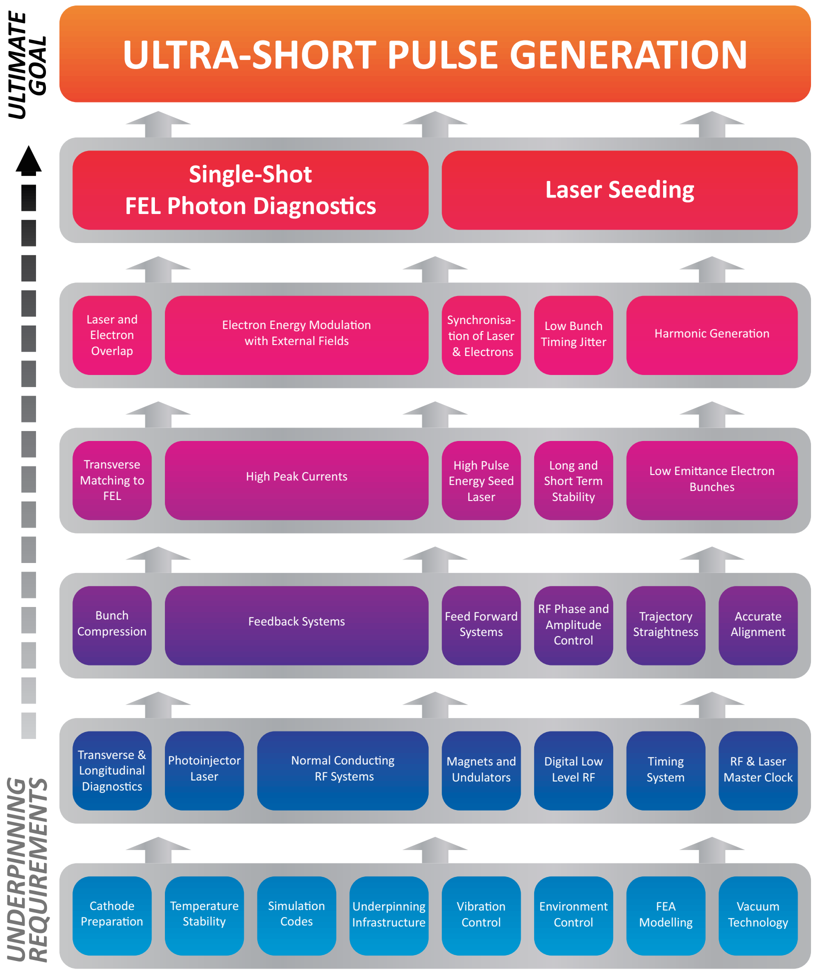
FELs have made huge advances in the past few years with the first successful demonstration of an x-ray FEL at LCLS (Linac Coherent Light Source) in the USA in 2009, followed by similar success at SACLA (SPring-8 Angstrom Compact free electron LAser) in Japan in 2011. New x-ray facilities are currently under construction in Germany, Switzerland, and elsewhere and soft x-ray FELs, such as FLASH in Germany and FERMI@Elettra in Italy, are also operating for users routinely. Whilst the new x-ray FELs are remarkable in their performance, the potential for improvements is enormous. Many suggestions have been made by FEL experts for improving the FEL photon output in terms of temporal coherence, wavelength stability, increased power, intensity stability and ultrashort pulse generation. Unfortunately, given the low number of operating FELs and the pressure to dedicate significant time for user exploitation it is not surprising that very few of these ideas have been tested experimentally. The Conceptual Design Report describes the design of CLARA, a dedicated flexible FEL test facility, which will be able to test several of the most promising of the new schemes.

CLARA will not operate in isolation and existing FELs are already dedicating their limited machine development time for the testing of new ideas, such as self seeding or harmonic generation, and this is sure to continue given the strong call from users for ever higher quality light output. The short term focus of existing FELs has been carefully assessed and it has been strategically decided that CLARA should have a longer term vision and be targeted at proving concepts which will not just have an incremental impact on FEL performance but take FELs into a whole new regime. It is believed that this will ensure that the international impact of CLARA will be maximized and place the UK in a vanguard position should it choose to develop its own future national FEL facility.

The vision for CLARA is that it should be dedicated to the production of ultrashort photon pulses of high brightness coherent light. Existing x-ray FELs are already capable of generating pulses of light that are only tens of femtoseconds in duration (tens of thousands of optical cycles) but FEL experts have proposed several schemes which have the potential to generate pulses that are two or three orders of magnitude shorter than this (hundreds or tens of attoseconds). The science which is enabled by ultrashort photon pulses was described in detail in the NLS Science Case. In order to achieve this vision for ultrashort pulse generation, CLARA must be able to implement advanced techniques, such as laser seeding, laser electron bunch manipulation, and femtosecond synchronisation. These can only be achieved by developing a state-of-the-art accelerator with the capability to drive current FEL designs. CLARA is therefore of direct relevance to the wider international accelerator community and will also ensure that the UK has all the skills required should it choose to develop its own future national FEL facility.

In detail the goals, opportunities and benefits of CLARA will be:

- Proof-of-principle demonstrations of ultrashort 'attosecond' photon pulse generation (of the order of the coherence length or less, typically less than 100 optical cycles) using schemes which are applicable to x-ray FELs (such as laser slicing, mode locking or single spike Self-Amplified Spontaneous



To achieve the primary goal of CLARA will require the mastery and understanding of many other techniques and technologies

Emission (SASE) and with extreme levels of synchronisation.

- The ability to test novel schemes for increasing the intrinsic FEL output intensity stability, wavelength stability, or longitudinal coherence using external seeding, self seeding or through the introduction of additional delays within the radiator section.
- The ability to generate higher harmonics of a seed source using Echo Enabled Harmonic Generation (EEHG), High Gain Harmonic Generation (HGHG), or other novel schemes.
- The generation and characterisation of very bright (in 6D) electron bunches and the subsequent manipulation of their properties with externally injected radiation fields, and the testing of mitigation techniques against unwanted short electron bunch effects.
- The development and demonstration of advanced accelerator technologies, with many wide ranging applications well beyond FELs, such as a high repetition rate normal conducting Radio Frequency (RF) photoinjector, novel undulators, RF accelerating structures and sources, single bunch low charge diagnostics, and novel photocathode materials and preparation techniques. The potential to test the new generation of plasma-based accelerators as drivers of FELs is also a significant consideration. The experimental testing of such advanced ideas, that scale well to larger projects, can result in leaps forward in capability.
- The enhancement of VELA, in terms of energy, beam power, and repetition rate, enabling additional industrial applications of electron beams that are currently excluded.
- A flexible, high quality, electron test accelerator available to the entire UK accelerator community on a proposal driven basis, enabling wide ranging, high impact accelerator R&D.
- The development and retention of vital skills within the UK accelerator community, including providing excellent opportunities for attracting the best PhD students and early stage researchers to work on a world class accelerator test facility.
- The possibility to use the high quality bright electron beam for other scientific research applications such as ultra fast electron diffraction experiments, plasma wakefield accelerators (as a witness bunch or a drive bunch), as the drive beam for a Compton scattering source of x-rays or gamma photons, and for other novel acceleration schemes such as dielectric wakefield accelerators and exotic storage rings.

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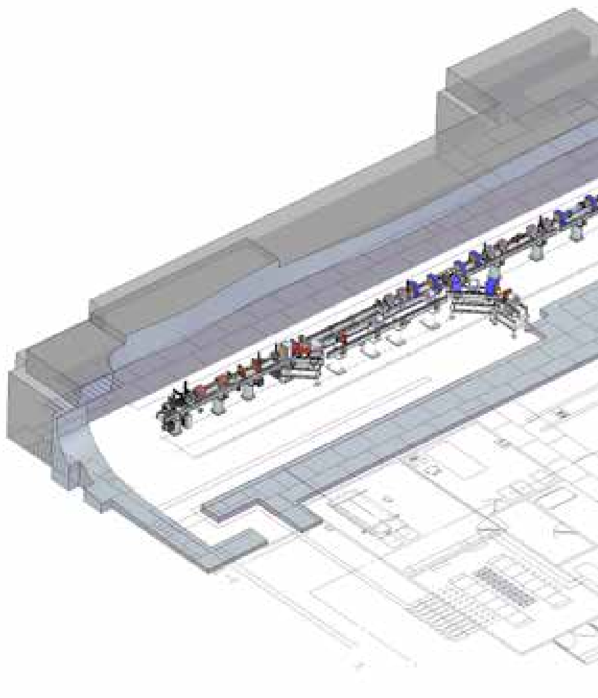
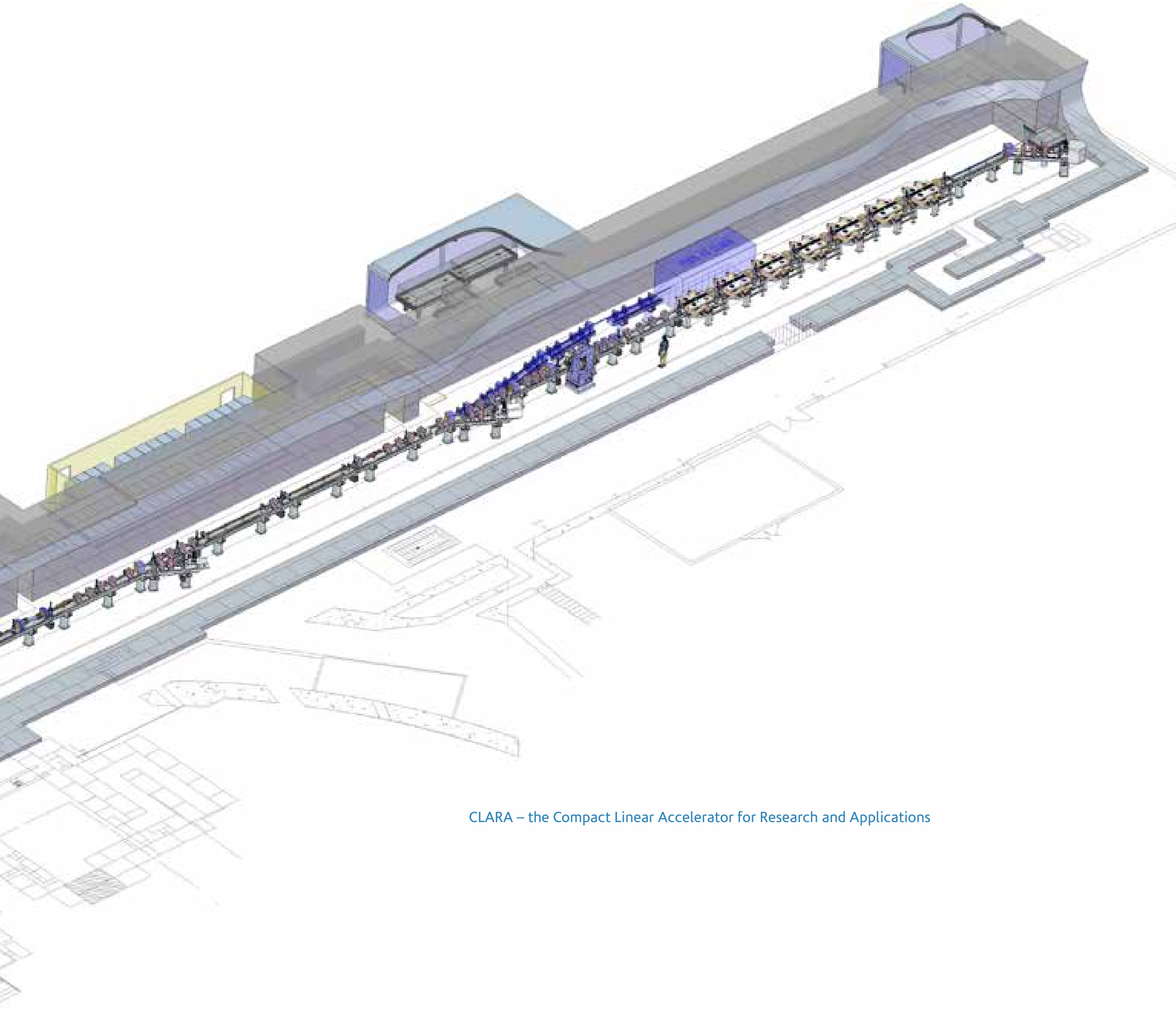
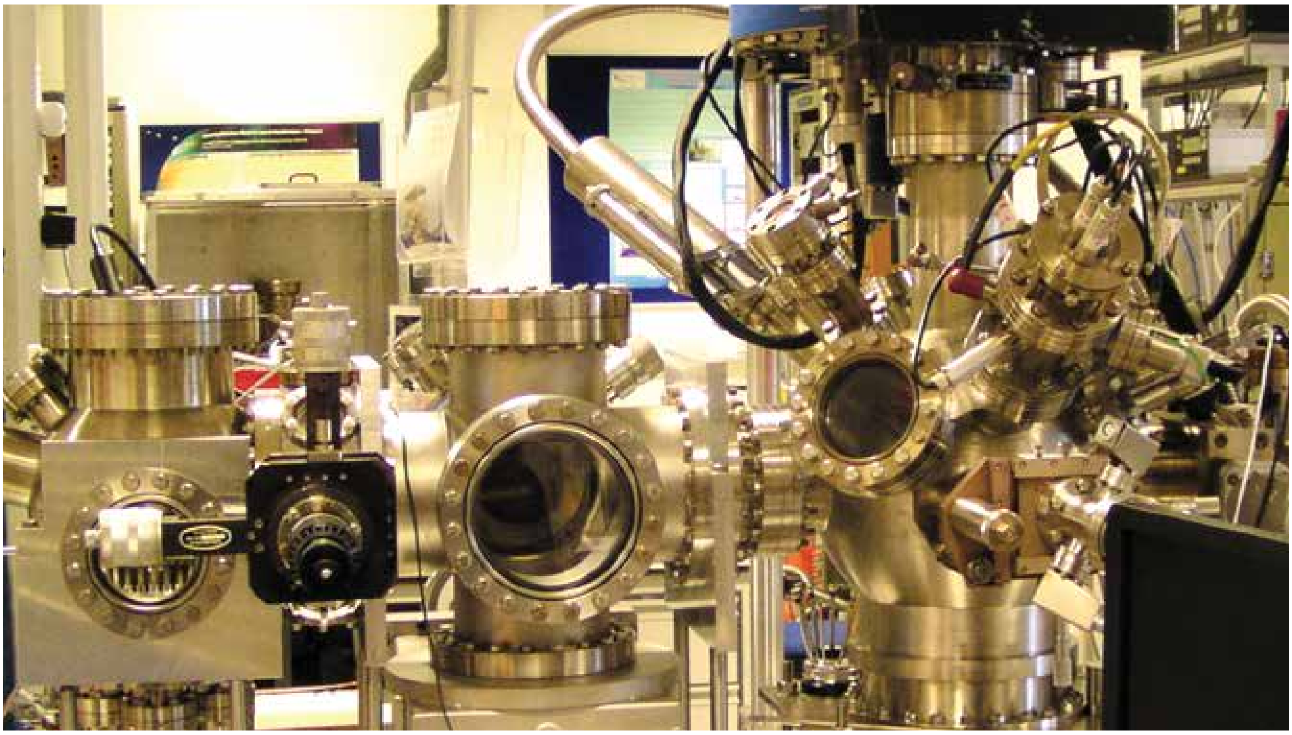




CLARA – the Compact Linear Accelerator for Research and Applications

Photocathode R&D



The UHV multi-probe surface analysis system

In modern electron accelerators the properties of the beam are typically limited by the quality of the bunches generated by the photocathode electron source. It is for this reason that ASTeC devotes considerable effort to photocathode research, which remains one of the key underpinning technologies for accelerator development. This year ASTeC has continued to develop state-of-the-art equipment for the characterisation of photocathode materials, including the transverse energy spread spectrometer (TESS) and a UHV multi-probe surface analysis system dedicated to the investigation of the properties of various photocathode materials and the different surface preparation procedures that can be employed to maximise their performance. Research in this area has continued to include gallium arsenide semiconductors, but has increasingly focussed on metal photocathodes, because of their ability to produce the ultra short pulses needed by many modern electron accelerators, in particular future light sources. Meanwhile the ESCALAB-II instrument continues to provide vital support for the VELA programme and has contributed to the identification of a suitable preparation procedure for the copper photocathodes, enabling sufficient quantum efficiency (QE) to be achieved.

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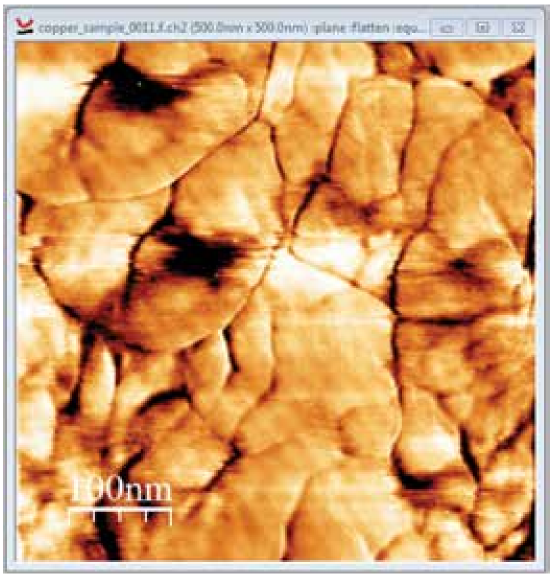
UHV Multiprobe Surface Analysis System

A new multiprobe surface analysis system has been constructed for photocathode research. A UHV vacuum system has been assembled which will allow samples to be prepared in an environment close to that expected in a 'real' photoinjector. The vacuum system will also allow the controlled admission of various gases into the system to mimic the long term degradation of photocathodes by exposure to known contaminant species. The photocathode samples are mounted on small back plates which can be rapidly introduced to the vacuum system and moved between the various preparation and analysis facilities. The system has been designed to be flexible so that additional preparation and analysis facilities can be added at a later date if required.

The multiprobe system houses a Thermo Scientific ALPHA 110 high resolution hemispherical electron energy analyser which can be used with the VG Al K_α x-ray source to obtain x-ray photoelectron spectroscopy data. XPS is an excellent technique for determining the composition of the photocathode surface and in addition, through the small shifts in the measured peak positions, the chemical state of each element. This information helps in understanding the role of surface chemistry in determining the photocathode performance in terms of key parameters such as QE. This technique may be particularly important for determining the effectiveness of surface cleaning procedures and the relative importance of various contaminant species in photocathode performance.

The instrument also has an Omicron scanning tunnelling microscope (STM)/atomic force microscope (AFM) instrument. These techniques are able to provide extremely high resolution images of the surface and can achieve atomic resolution under ideal conditions. For these studies, perhaps the most important information that will be provided is the surface roughness for various samples and preparation procedures. Surface topography is thought to be a key element in defining the transverse energy spread of the emitted beams, with macroscopically rough samples giving much higher energy spread. Topographic information is typically gathered in AFM mode, but STM may also be useful because of the ability to obtain position sensitive information on electronic properties via Scanning Tunnelling Spectroscopy (STS).



500nm x 500 nm AFM image of a copper surface

It is also intended to mount the Kelvin Probe apparatus (currently on the ESCALAB-II) on this system. This instrumentation uses contact potential difference measurements to measure the work function of a photocathode surface. This parameter (along with the wavelength of the incident laser light) defines not only the QE of the photocathode but also the energy spread of the emitted electrons. Monitoring the work function in concert with surface chemical changes will allow a better understanding of the various surface preparation procedures and contamination mechanisms to be gained.

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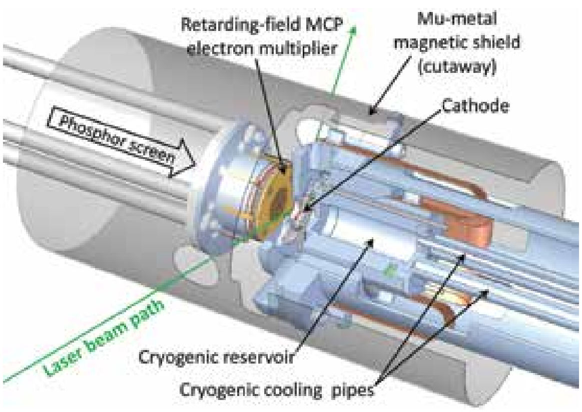
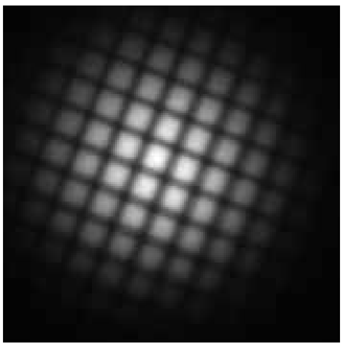
TESS – The Transverse Energy Spread Spectrometer



The TESS experiment, cutaway to show the retarding field electron detector, and details of the cryogenic system

The construction of TESS has recently been completed by ASTeC with the assistance of the Technology Department at Daresbury Laboratory. The transverse energy spread (or mean transverse energy) of electrons emitted from a photocathode source is an important physical quantity which fundamentally limits the maximum achievable brightness of the generated beam.

The TESS electron detector combines a retarding-field analyser (RFA) with a micro-channel plate electron multiplier and phosphor readout screen. To measure the transverse energy component of electrons emitted from a photocathode, an accelerating field is created between the photocathode source and the front grid of the RFA. Whilst 'in flight' between the source and the front grid, the electron's transverse motion is dominated by their transverse energy component, so the beam footprint increases in size according to the flight time and the magnitude of the transverse energy. The electron multiplier provides significant levels of gain of up to 106, and these electrons are then accelerated further until they collide with the phosphor display screen, causing florescence and thereby creating an image of the electron emission. After capturing these images with a highly sensitive CCD camera, image analysis allows us to determine an upper limit on the mean transverse energy of the source photoelectrons to be determined.



Electron emission footprint from a GaAs photocathode, showing structure from the grids that comprise the retarding field analyser.

Several factors affect the mean transverse energy, such as the temperature and quantum efficiency of the photocathode, the level of surface roughness and the wavelength of the light source used to stimulate electron emission. TESS incorporates a piezo-electric leak valve which will allow precision controlled degradation of photocathode sources while simultaneously acquiring data so that the evolution of the mean transverse energy can be studied. A facility to cool the photocathode to liquid nitrogen temperature (77 K) is also included. TESS also boasts a number of different laser light sources, so comparison under different illumination conditions can be made. In time, the effects of each of these parameters will be investigated with the goal of improving photocathode performance.

With assistance from colleagues based at the Institute of Semiconductor Physics in Novosibirsk (Russia), the TESS system has recently been commissioned. Data has been obtained that showed that the mean transverse energy for photoelectrons from a GaAs photocathode agrees well with values already published at red and green wavelengths. Following some minor modifications to improve the system, it will be used in an extensive programme to characterise GaAs photocathodes under a range of operating conditions, before moving on to investigate the performance of metal photocathodes.

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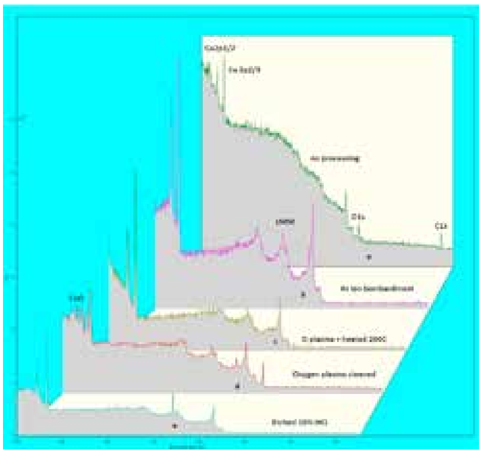
Metal Photocathode Research for VELA

Research into suitable ex-situ preparation procedures for the copper photocathodes used in the VELA facility has been carried out to try to establish a reliable and reproducible method. The VELA photocathodes are polycrystalline, oxygen-free copper machined to a 1 µm roughness finish. Preparation has to be carried out before the cathodes are installed into the machine, since there is no possibility of processing them in-situ. Experimental measurements were made using the ESCALAB-II instrument to provide XPS data and quantum efficiency measurements using a 265 nm UV LED. Assessment of the surface roughness was carried out ex-situ using optical interferometry.

Prior to treatment all the samples were degreased. A set of samples were etched using an HCl/IPA solution (1:10 by volume) for between 2 and 20 minutes and another sample was oxygen plasma treated (100 mbar, 20 min). Comparison was also made with an in-vacuum argon ion sputtered sample (5 keV, 50 µA for 10 min). XPS data indicated that both ex-situ treatments removed carbon contamination from the surface and the etching also removed the oxygen. Heating the plasma treated sample to 200°C in vacuum caused the surface oxygen to disappear, presumably through dissolution into the bulk material. Argon ion bombardment gave rise to an essentially contamination free surface.

Interferometry measurements indicated that etching gave rise to a slight reduction in surface roughness with treatment time, whereas for the oxygen plasma treated sample the roughness was unchanged. Argon ion bombardment caused gross roughening of the surface. Photocurrent could only be measured for the ion bombarded sample (QE = 4.5×10^{-5}) and the sample that had been oxygen plasma treated and subsequently annealed (QE = 2.0×10^{-5}). Since Ar ion bombardment is not possible in the gun cavity, the plasma treatment is currently the preferred method of preparation for photocathodes used in the VELA accelerator.



XPS spectra of copper photocathode samples with various surface treatments

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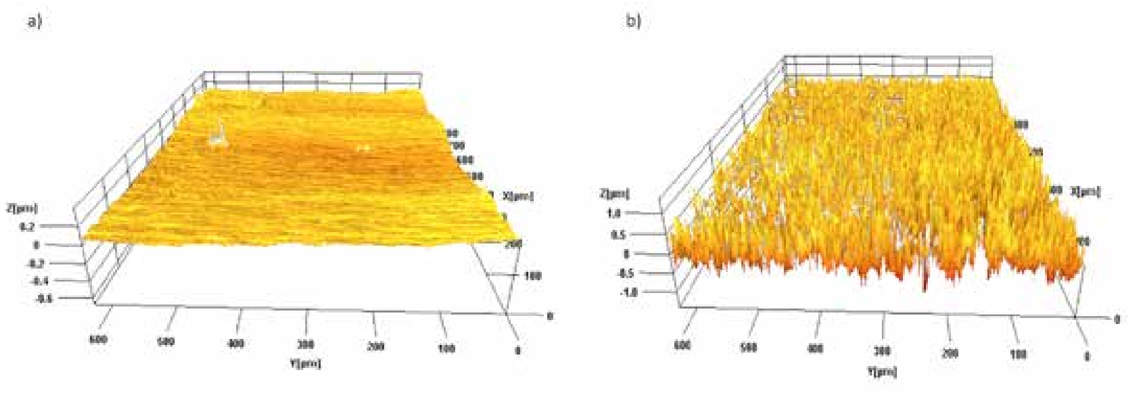
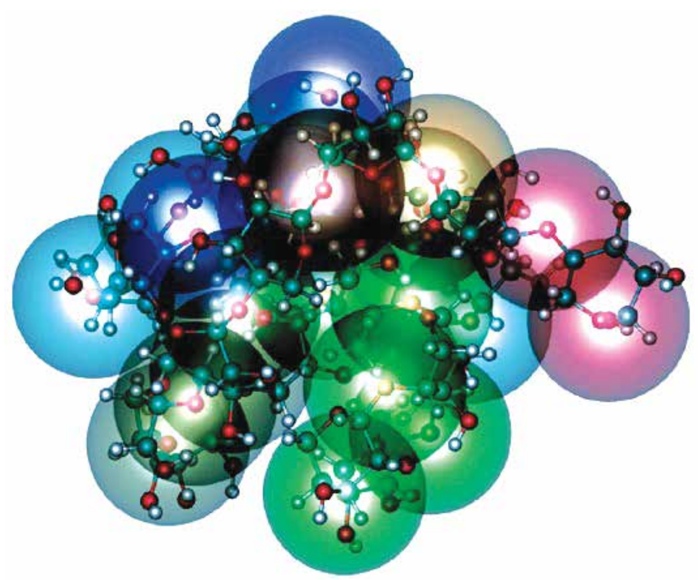


800 x 600 µm2 optical interferometry maps in extended mode of a) an as-loaded copper surface, and b) after argon ion sputtering

The Evolving Structure of Materials

Illustration by Zhou Tao, ShanghaiDaily.com

In the 20th century structure determination by x-ray diffraction has had a profound effect on our lives. Understanding the structure of DNA has led to the development of personalised medicine.



Off-lattice representation of oligosaccharide (larger semi-transparent spheres) superimposed on corresponding atomic configuration (Credit: Dmytro Antypov)

The properties of materials are inherently linked to the structure, that is the location and bonding of the constituent atoms in the material, and so understanding structure is fundamental in engineering design, biotechnology, drug development, greener energy production, energy storage, high performance computing and consumer electronics. It is no exaggeration to state that a nation's health and economy rely on knowledge of material structure.

Of course, materials are not static but undergo changes when exposed to external influences such as heat or intense light or radiation or by interaction with other materials. Understanding these structural changes are important in mitigating against component failure such as in aircraft, and in designing drugs to access particular targets in the body.

Two key advances in structural science are now needed:

(1) the ability to obtain the structure of protein nanocrystals before they are damaged by the probing beam, and

(2) the ability to follow structural changes during the course of molecular reactions.

Advanced accelerator technologies offer two approaches to these problems: ultrafast x-ray diffraction with free electron lasers, and ultrafast electron diffraction with high quality MeV electron beams from smaller scale accelerators.

Electron diffraction has a number of advantages over x-rays. Scattering cross sections for electrons are up to a million fold higher than x-rays, so much less material is needed, and many orders of magnitude less energy is dumped into the sample to cause damage. The outright game changer, however, is that very much smaller scale accelerators are required for ultrafast electron diffraction.

Electron Diffraction on VELA - Why use MeV Beams for Electron Diffraction?

VELA at Daresbury is an advanced accelerator based on a femtosecond response photocathode coupled to RF acceleration; these are the key components for an Ultrafast Electron Diffraction facility. By deploying relativistic electron beams of a few MeV from an accelerator as opposed to lower energy beams available in university laboratories, we can maintain very short (sub-100 fs) high charge bunches of electrons required for probing the evolving structure.

In order to observe the evolution of structural changes, a series of images from which the structure can be determined will be recorded as a function of time. This process is sometimes referred to as the making of a "molecular movie". The structural change in the material is initiated by the absorption of an intense pulse of light. This so called 'pump' pulse simulates, for example, a rapid temperature rise in the sample. A timed sequence of images is then recorded to monitor the evolution in the spatial structure of the sample. This step is the 'probe' part of the measurement. Each frame in the "molecular movie" gives the position of the atoms within the sample at the instant that the frame is recorded. Thus, this procedure allows changes in the material to be monitored as it undergoes phase changes or molecular rearrangements. Each frame is actually obtained from an ultrafast diffraction measurement taken with a flash of radiation.

This programme is a collaboration between ASTeC and Dr Jonathan Underwood (UCL physics and astronomy), Dr Will Bryan (Swansea University) and Dr Derek Wann (University of York chemistry).

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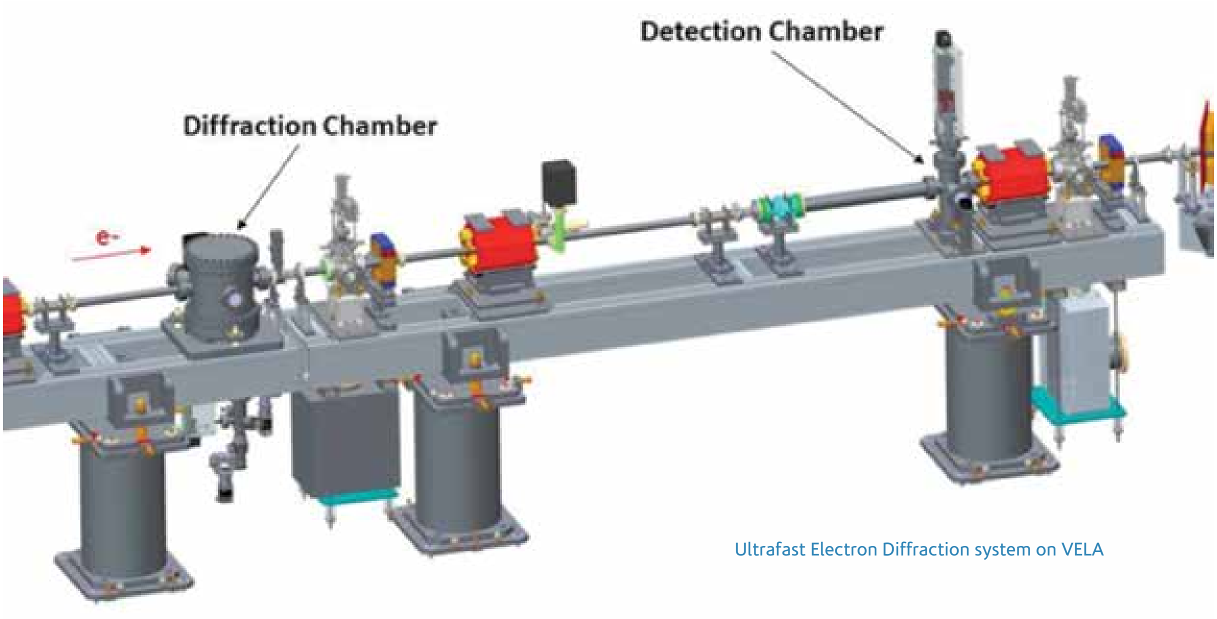
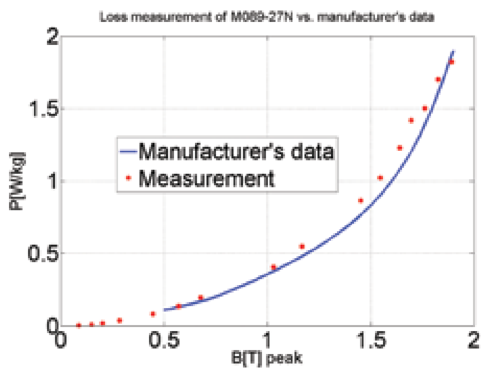


Ultrafast Electron Diffraction system on VELA

Magnetic Material Characterization



The design of a number of magnetic applications such as transformers and inductors requires prior knowledge of the magnetic properties of the material under consideration. It is indeed the case that magnetic material manufacturers supply some information about their products in the form of BH curves and core loss tables. These datasets, however, are quite often only relevant to the standard conditions of sinusoidal excitations at 50 Hz or 60 Hz. Data pertaining to the case of non-sinusoidal material excitation is almost never available and this is precisely the case important for pulsed magnet design and operation. In addition the requirements imposed on the magnetic material performance by a pulsed magnet are quite different from those imposed by a transformer. In the latter case the main limiting factor is the core loss. In contrast, due to the presence of the gap, core losses play a less significant role in pulsed magnet operation. As a result of that it is quite often possible to build a high frequency pulsed magnet from a material intended for low frequency tranformer construction. However, magnetic material manufacturers see pulsed magnets as a niche application and, naturally, aim for the much bigger market supplying data only relevant to tranformer applications.

Another interesting case is the use of structural steel in large scale shielding applications, such as the MICE shielding project. Unlike electrical steel magnetic properties are not necessarily guaranteed for structural steel and the acquisition of a large amount of the latter from different manufacturers may result in BH-curve variation from one batch to another and this is likely to cause problems.

All of the above clearly shows the need for independent magnetic material characterization capability. In this way materials can be assessed under the operating conditions of their intended accelerator technology applications. ASTeC's MARS group has recently started the development of such a capability and the results obtained are quite encouraging. Two different magnetic cores – made from a standard transformer steel (left hand side photo below) and a specialized high frequency, high magnetic field strength core (seen in right hand side photo below) have been tested. As an illustration the graph on the right hand side shows a comparison between the in-house measured core loss factor for the transformer steel core and the manufacturer's data. As can be seen the two datasets are in very good agreement and this validates the experimental technique developed. In addition data is available in a range broader than the one supplied by the manufacturer and this is important for some applications, e.g. shielding . This capability is currently being expanded to include variable waveform and variable frequency non-sinusoidal excitations.

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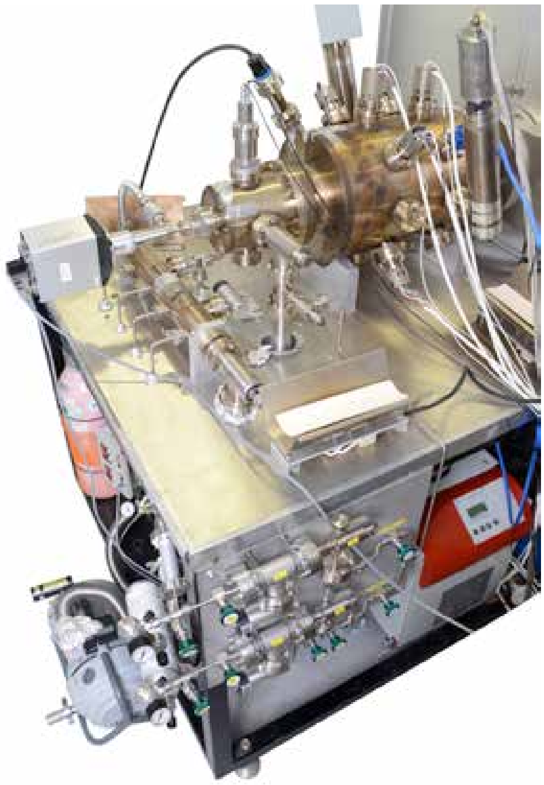
Residual Gas Analyser Calibration

Ultra High Vacuum (UHV) or even eXtreme High Vacuum (XHV) is a key specification for operating particle accelerators because beam gas interactions reduce the beam lifetime, can cause emmitance growth, Bremsstrahlung radiation and other unwanted effects. Not only is total pressure important, but partial pressures need to be considered, especially higher mass species due to the larger interaction cross section as beam lifetime varies with Z2 where Z is the atomic number of the scattering species. Some parts of the accelerator are sensitive to particular gas species only, for example, GaAs photocathode lifetimes can be reduced significantly with the presence of oxygen containing gases, some mirrors are sensitive to the presence of hydrocarbons, etc. Therefore it is important to know the residual gas composition. The residual gas analysers (RGA) are used for this in many applications: in scientific research, in surface and material science as well as in many industrial applications from the semiconductor industry, photovoltaic, etc.

The RGA's that are available on the market can only provide qualitative measurements. To perform accurate qualitative measurements the ASTeC Vacuum Science Group (VSG) has developed its own in-situ RGA calibration procedure. It was found that RGA's are difficult to calibrate and, as it was found, at present there is no traceability to any national primary standard, hence the SI.

The European Metrology Research Programme and the EU decided to fund, from September 2011, the project IND12 'Vacuum metrology for production environments', in which the metrological characteristics of quadrupole mass spectrometers shall be investigated and the key parameters identified for a possible calibration. ASTeC VSG is participating in the technical work package - WP3 - partial pressure and outgassing rate measurement.



ASTeC VSG members attended the EMRP-IND12 Workshop on measurement characteristics and use of quadrupole mass spectrometers for vacuum applications. The workshop aim was the exchange of information between experts that know of the industrial applications of quadrupole mass spectrometers, experts who design them and experts who have investigated the metrological characteristics of them. Dr Oleg Malyshev gave a talk on practical approach and problems in in-situ RGA 'calibration', reporting the RGA calibration procedure, results, difficulties and problems related with this.

As a result of the collaboration and the workshop the existing ASTeC total gauge calibration facility was upgraded to be used for RGA calibration studies, allowing comparison of various RGA's to an extractor gauge calibrated to a primary standard at PTB (Germany).

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Interactions with the Hartree Centre

Advanced Computing for Accelerators - practical session

ASTeC is developing its interactions with STFC's new Hartree Centre for high performance computing, aimed at harnessing the power of new parallel computing facilities for particle accelerators. Developments included a three day workshop at Daresbury Laboratory, as well as the initiation of projects to gain early access to the Hartree facilities.

One of ASTeC's significant involvements with the Hartree Centre in 2012-13 was the 'Advanced Computing for Accelerators' workshop at Daresbury Laboratory. The event was organised in collaboration between staff from STFC's Hartree Centre and ASTeC, and members of the University of Huddersfield and the Cockcroft Institute. The aim was to increase the use of high performance computing to address research challenges in particle accelerators.

The workshop ran from 15-17 January 2013 and attracted a high level of interest, with over 70 delegates in attendance. ASTeC staff were among both the delegates and the tutors in practical sessions running different particle accelerator simulation codes on the Hartree Centre's 'Blue Wonder' IBM iDataPlex parallel computer. ASTeC staff were also prominent giving presentations and in discussion sessions, in which a number of ideas to use high performance computing for accelerator research were identified.

ASTeC's other significant interactions with the Hartree Centre were in the form of 'Early Access' projects to be among the first users of the new Hartree Centre facilities. One such project, initiated in collaboration with the University of Strathclyde, is to develop Strathclyde's new free electron laser code PUFFIN, and to use it in modelling advanced free electron laser concepts.

Another project on accelerator physics modelling was also initiated. This was aimed at aiding the study and design of existing and future accelerator facilities through high performance computing. One of the methods under development was the incorporation and testing of genetic optimisation of machine parameters within the General Particle Tracer code, this work was done in collaboration with Pulsar Physics of the Netherlands.

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TRANSHELIOS

Prototype MRI magnet's new life as a physics experiment

TRANSHELIOS magnet being cooled with liquid helium

The original prototype MRI magnet that was first used in diagnostic medical imaging in 1991 by Peter Mansfield who was awarded a Noble Prize in 2003, is being transformed into a Helical Orbit Spectrometer (TransHelios) at Daresbury Laboratory. ASTeC is leading this transformation at Daresbury Laboratory as a part of the UK Nuclear Physics Collaboration. The 22 year old magnet was successfully recommissioned and tested. A vacuum chamber is being built to install nuclear detectors inside the magnet bore of 1. The transformed magnet, once ready, will be installed on the ISOLDE experiment at CERN. The fascinating project has been covered in the April 6th issue of the New Scientist.

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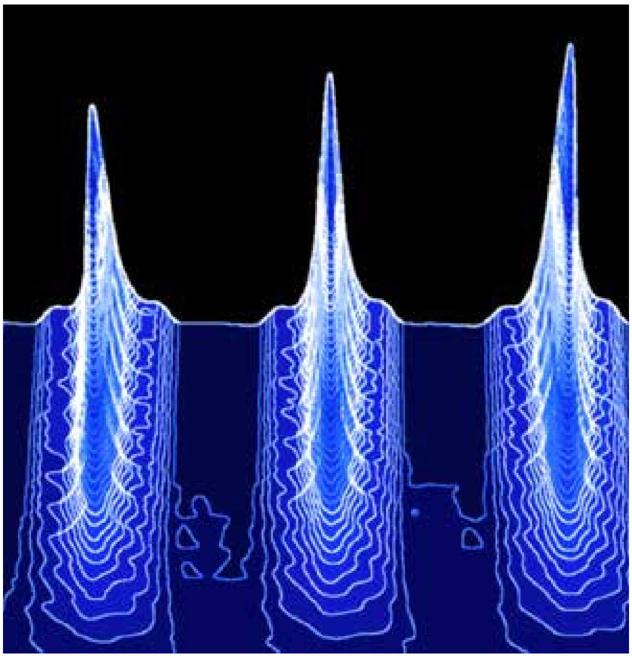
Advancing Free Electron Laser Concepts



Series of pulses from computer simulations of the new technique

ASTeC scientists have developed two innovative new concepts for free electron lasers (FELs) that could deliver the shortest and the brightest x-ray pulses ever made. Both concepts have been published in Physical Review Letters, and could be tested in future on machines such as CLARA, (Compact Linear Accelerator for Research and Applications) before implementing at x-ray facilities. The work was carried out in close collaboration with the University of Strathclyde.

Towards zeptosecond-scale pulses from x-ray FELs

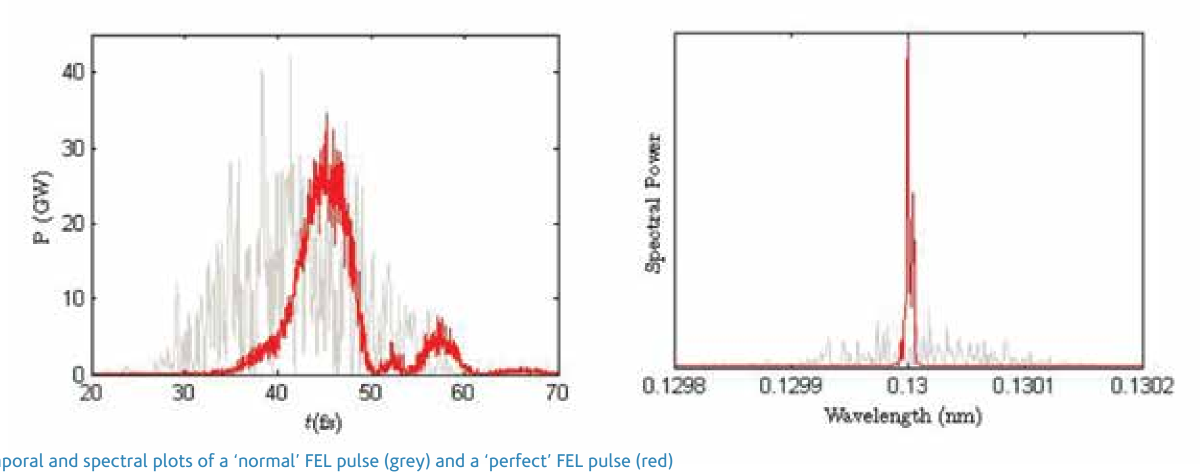
Free electron lasers can operate at x-ray wavelengths with much shorter wavelength than conventional lasers and have much higher power than other x-ray sources such as synchrotrons. This combination of properties means they have the potential to generate intense and ultra short pulses of light. ASTeC and Strathclyde researchers are looking to push this to the limit by considering ways in which pulses of only a few wavelengths, or 'cycles', could be generated.

The purpose of generating ultra-short pulses of light is to study dynamics that occur on ultra fast timescales such as electron motion within atoms or molecules. Presently the shortest pulse of laser light ever generated is approximately 67 attoseconds (1 attosecond = 1×10^{-18} seconds).The new technique would allow a few-cycle pulses at x-ray wavelengths (approximately 0.1 nm), corresponding to pulse durations of a single attosecond, or even shorter – into the zeptosecond (1×10^{-21} second) scale.

The concept works by modulating the relatively long electron beams used in FELs, to give a series of much shorter high quality regions, each of which can be made to emit a short burst of radiation. A relatively compact extension which the team calls a 'mode-locked afterburner' could be retrofitted to existing FEL facilities to deliver this.

The concept has been extensively computer modelled and the next step is for the idea to be proven in practice. This could be carried out at a dedicated FEL test facility, such as the proposed CLARA project, an upgrade to the existing VELA (Versatile Electron Linear Accelerator) facility at Daresbury Laboratory. It would only require a modest addition to an existing x-ray Free Electron Laser (FEL), such as the LCLS (Linac Coherent Light Source) in the USA or SACLA (SPring-8 Angstrom Compact free electron LAser) in Japan, for the idea to then be implemented at x-ray wavelengths.

By using the new technique to move to the scale of an attosecond or less, it may be possible to probe deeper than with previous sources and observe much faster dynamic processes, such as electrons interacting with the nucleus, or even the dynamics of the nucleus itself. In future the capability could potentially be used to



Temporal and spectral plots of a 'normal' FEL pulse (grey) and a 'perfect' FEL pulse (red)

generate a deeper understanding of processes relating to how medicines interact within the body or catalytic processes in new materials for energy storage.

The image on the previous page shows a series of pulses from computer simulations of the new technique.

A new concept for 'perfect pulses' from x-ray FELs

ASTeC researchers have been developing a new technique which they first proposed in 2010 to dramatically improve the output quality of x-ray Free Electron Lasers (FELs). The technique should make the x-ray pulses more reproducible and provide users with many more photons in the very narrow wavelength bands relevant to their experiments. In effect the useful 'brightness' of the FEL can be greatly enhanced. The work has been done in collaboration with the University of Strathclyde and was recently published in Physical Review Letters.

X-ray Free Electron Lasers FELs (such as the LCLS at SLAC in California, SACLA at SPring-8 in Japan) use high energy electron bunches, produced by particle accelerators, to generate intense pulses of x-rays. While these FELs are currently opening up many new frontiers across science their full potential is still limited by the chaotically noisy time structure and wavelength composition of the pulses of x-rays they produce. What is really needed for a number of applications are reproducible pulses where each x-ray photon is at almost exactly the same wavelength. Such 'perfect pulses' could open up new scientific frontiers, such as in time resolved x-ray spectroscopy or studies of molecular and cluster fragmentation.

Although other methods do exist for generating high quality pulses from FELs these can require complex optical components or synchronisation with other lasers which limits the wavelength tuning or repetition rate of the output. The new method proposed by the ASTeC researchers and collaborators does not rely on optics or lasers and can therefore be used at any wavelength or repetition rate. The idea is to use extra magnets along the FEL to slow down the electron bunches so they slip back through the x-ray pulse and 'smear out' the noise. By doing this, the narrow wavelength band of the x-ray photons is reduced by a factor of over one hundred and all the pulses become smooth and reproducible. Computer simulations of the technique predict it may be possible to produce 'near-perfect' pulses of x-ray.

This is just one of the novel FEL concepts that could be proven in principle then further developed on a dedicated FEL test facility, such as the proposed CLARA project.

The two images above show in grey the normal output pulse from a hard x-ray FEL. The first image shows the pulse time structure, and the second image the breakdown of power over different wavelengths. With the new technique applied the output would be as shown in red. The pulse profile has been dramatically smoothed and the range of wavelengths of the x-ray photons has been compressed into a far narrower band.

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CLIC Permanent Magnet Quadrupoles

Building the magnet

ASTeC and Technology Department, in collaboration with CERN in Switzerland, have built a prototype of an adjustable permanent magnet quadrupole (PMQ) for the Compact Linear Collider (CLIC) project.

CLIC employs a unique 'two-beam' acceleration mechanism, where energy is transferred from a drive beam to a main beam using Power Extraction Transfer Structures (PETS). For the drive beam decelerator, ASTeC is investigating the feasibility of quadrupoles based on permanent magnet (PM) technology. ASTeC's MaRS group has developed an innovative adjustable strength PMQ. The quadrupole gradient can be varied by moving two pairs of large permanent magnets, with the central poles being fixed in position. The use of PMs in this type of magnet is a highly innovative development, and represents a huge potential saving in infrastructure and running costs for this type of facility, as the standard is to use high current electromagnets cooled by forced water flow.

The motion of the magnets is controlled using a single stepper motor and gearbox, and can be set to an accuracy of 10 μm. The PMs have a movement range of 64 mm, allowing the gradient to be set between 15-60 T/m.

The CLIC drive beam decelerator requires a total of around 41,000 quadrupoles to keep the beam focussed along its length. Two types of PMQ are sufficient to cover the range of gradients needed – a low strength version and a high strength version. A prototype of the high strength version was built and tested at Daresbury in 2012, with additional tests being carried out by collaborators in CERN's magnet group.

Initial tests of the magnet showed that the magnet performed very well, with the gradient varying exactly as predicted from the model. The accuracy of positioning the PMs was also excellent despite the huge forces involved – the maximum pull experienced by the magnets is about 14 kN, equivalent to the weight of a rhinoceros. However, there were some issues to resolve. The field quality was significantly worse than expected – around 2%, compared to the specified value of 0.2%. This was shown to be due to inaccurate positioning of the poles. The magnet was disassembled and put back together, paying special attention to the precise positioning of the four poles. The field quality was improved to around 0.4% over the central 23 mm. This is comparable to the results obtained from the electromagnetic quadrupole built for the same project. Further improvements could be made by refining our assembly techniques; this will be applied to the second (low-strength) prototype.

Another issue relates to the position of the magnetic centre. An ideal quadrupole has zero field at the exact centre of the magnet, and the centre position is independent of the quadrupole strength. However, tests on this PMQ prototype revealed that the centre position was moving up and down slightly as the strength was adjusted. This is thought to be due to the components of the motion system; some parts of this are made from weakly ferromagnetic steel, which is thought to interfere with the field in the magnet's centre when the gradient is adjusted. The effect is small (around 80 μm) but significant. Some additional tests will be carried out in 2013 to verify this effect, and work is ongoing to find a solution for it.

A second prototype will be built in summer 2013. This one is designed for the lower energy end of the decelerator line, and has a lower overall strength. The adjustment range is much greater (a factor of 12 between maximum and minimum gradient) and so this magnet will be as challenging as the previous one.

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Digital LLRF Development at Daresbury Laboratory

LLRF4 board

To maintain the RF field amplitude/phase stability of the RF cavities installed on particle accelerators a low level RF control system is required. Since 2009, the RF group in ASTeC, has been developing the digital low level RF control systems to meet the requirements for ALICE (Accelerators and Lasers in Combined Experiments) and VELA (Versatile Electron Linear Accelerator).

The reasons for choosing a digital system rather than an analogue system are that digital systems are more easily reconfigured, capable of more complicated signal processing and it is possible to change parameters in real time. Also in recent years digital devices are becoming faster and cheaper, making it even more competitive compared with analogue systems.

A 1.3 GHz digital LLRF system has been designed for the ALICE superconducting RF cavities. This system contains a LLRF4 Field Programmable Gate Array board designed by L. Doolittle of Lawrence Berkeley National Laboratory, USA. Within FPGA, complicated signal processing is performed to achieve functions of RF signal modulation/demodulation, filtering, fast feedback control of RF field amplitude/phase, adaptive feed forward control for beam loading compensation, controlled RF cavity start-up, etc. The first prototype digital LLRF system was installed and tested on the ALICE buncher cavity, a single cell, normal conducting copper cavity. An rms phase error of 0.024° has been achieved on the buncher cavity. Later this year the system is going to be installed and tested on the DICC (Daresbury International Cryomodule Collaboration) module, which contains two 7-cell niobium superconducting cavities.

As a benefit of the digital system, this system can be easily configured to work at 'operational mode' to maintain cavity field stability during operation of the accelerator or in a 'testing mode' during the conditioning and evaluation of a superconducting cavity, especially in high Q mode. In 'operational mode' the RF frequency is maintained constant. While in a 'testing mode', the RF system is configured into a digital self-excited loop; the advantage of this set up is that the LLRF system can track the cavity frequency change due to microphonics and Lorentz force detuning which affects the RF cavity frequency/phase stability significantly especially when the RF cavity is run at high Q. A first performance test of the DICC was carried out with this digital LLRF system in May 2013. Fundamental features of the cavity such as cavity Qs and microphonics have been measured.

As the DICC module is expected to be run at high Q, high gradient level a Piezo actuator has been installed on each of the cavities for fast cavity frequency tuning. A Matlab programme is developed to mechanically compensate for Lorentz force induced detuning and reduce RF power overheads. This work is performed in collaboration with FERMI Laboratory, USA. The Piezo based mechanical control system will be tested on the DICC module in conjunction with the digital LLRF system.

A 3 GHz digital LLRF system has been developed in parallel for the VELA RF cavity. As VELA is run at short pulse (a few microseconds compared to ALICE where it is a few milliseconds), and the RF gun cavity has no probe, fast feedback control is not possible. Therefore a phase calibration system is required to suppress the phase errors, which is performed during the RF pulse off period by sending a calibration pulse and measuring the returned phase errors on different RF channels. This system has been built and is to be tested on the VELA gun cavity shortly.

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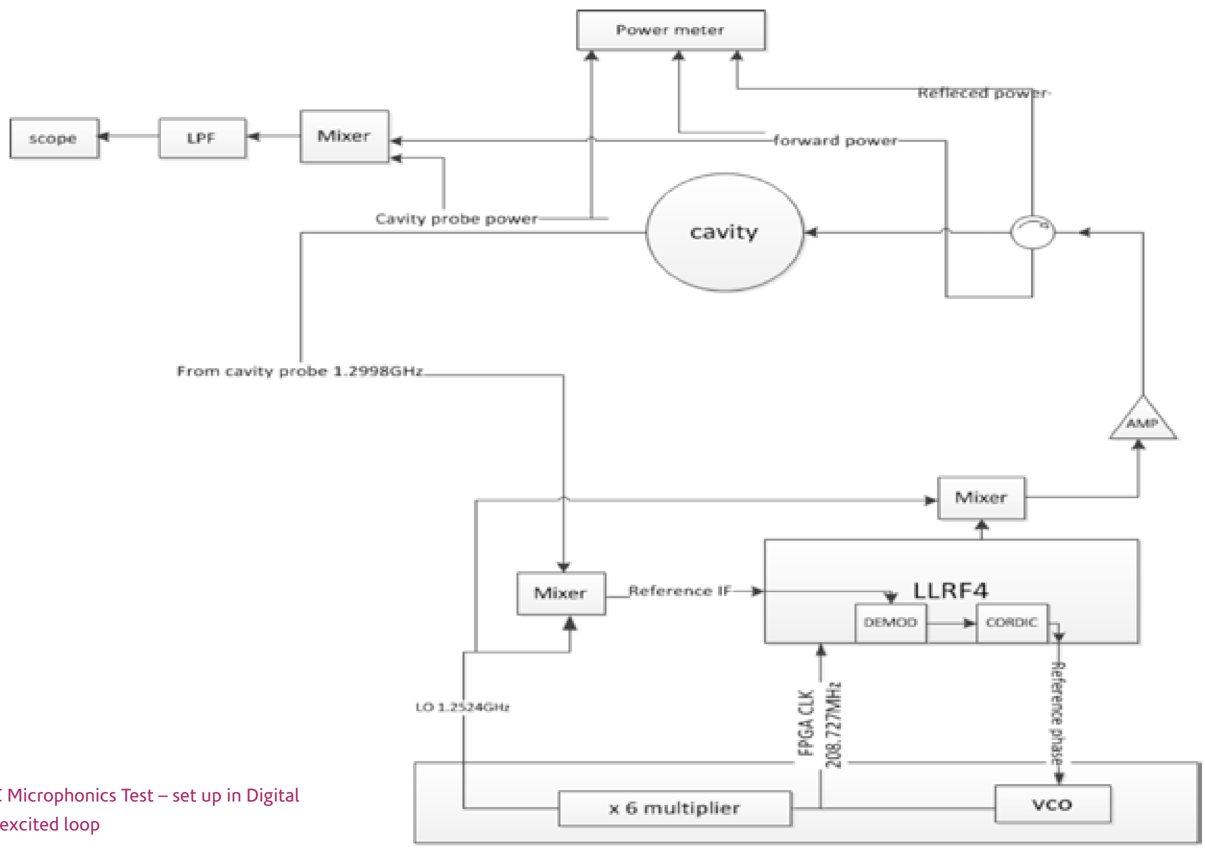
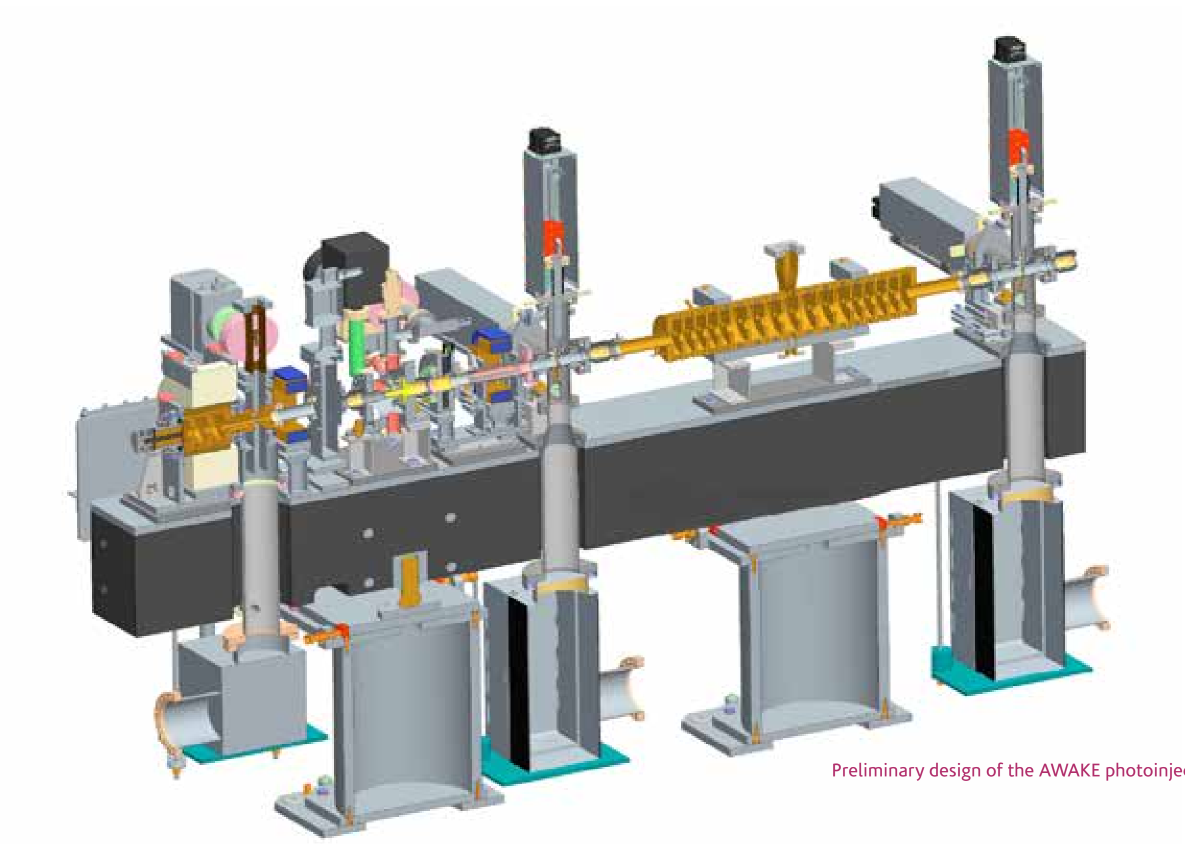


DICC Microphonics Test – set up in Digital Self-excited loop

AWAKE



Preliminary design of the AWAKE photoinjector

Recently there has been increased interest within the accelerator community in the use of plasma wakefields as an alternative technology to accelerate electrons to high energies. This interest arises because plasmas have the potential to achieve much higher field gradients than those of a typical radio frequency cavity used in a conventional accelerator. Potential technologies include laser wakefield acceleration (e.g. the ALPHA-X project at Strathclyde University) and particle driven wakefield acceleration (e.g. the FACET experiment at SLAC (USA), which uses electrons as the driver). However, there has also been interest in the possibility of using protons as the primary driver because of their potential to carry much more energy than either photons or electrons. For this reason a test experiment named AWAKE (formerly known as PDPWFA) is being planned at CERN using beam from the SPS ring to provide 450 GeV protons as the primary wakefield driver. CERN is the only place where such high energy protons are available for experiments.

The AWAKE experiment is planned to be situated in the experimental area recently vacated by the CNGS neutrino generation facility. The 450 GeV protons will be fed into a laser ionized Li vapour cell, where the relatively long bunches will self-modulate to form a regular train of microbunches, which will then develop the very high gradient wakefields required by the experiment. At some distance down the plasma, a second beam of well defined but relatively low energy electrons will be injected into the wakefield to provide a witness beam, which will demonstrate electron acceleration, as measured by a suitable spectrometer at the exit of the plasma cell. In addition, several novel diagnostic techniques will be used to characterise both the electron beam and the plasma itself.

ASTeC's interest in this project dates back to February 2012 when it was asked to play an active role in the development of the electron source for providing the witness beam (staff are currently electron source work package leaders). This part of the project has clear synergies with other interests of the department, since the proposed source is essentially very similar to the VELA RF gun and the first stage of the proposed CLARA accelerator. ASTeC have suggested the use of a two and a half cell S-band radio frequency photoinjector with a copper photocathode and high power UV laser. The use of a copper photocathode not only ensures reliable operation of the source without sophisticated re-preparation procedures, but can also, by virtue of its fast response time, deliver the very short pulses of less than 1 ps, that might be required by the experiment (if a suitable short pulse photoinjector laser is used). Since the optimum electron beam energy for capture by the wakefields is in the region of 10 – 20 MeV, a short linac booster section will also be needed.

A preliminary design of the AWAKE photoinjector has been produced by ASTeC with assistance from the Technology Department at Daresbury Laboratory and has been incorporated into the conceptual design report submitted to the CERN management in March 2013. Accelerator physics simulations using the ASTRA code have demonstrated the ability of this design to produce suitable low emittance beams of up to 250 pC per bunch for a 5 ps bunch length. For shorter pulses, much reduced bunch charge can be obtained, but work continues to assess the potential increase that can be achieved when a suitable bunch compression scheme is employed.

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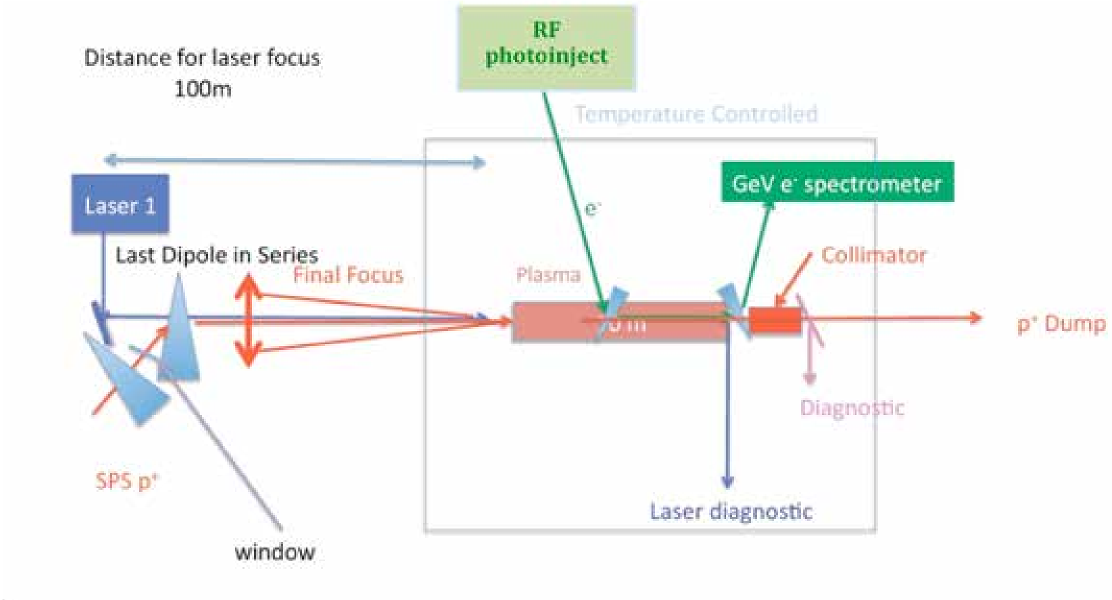

Schematic of the AWAKE experiment

MICE

As part of the Muon Ionization Cooling Experiment (MICE), the RF group at ASTeC have been developing the design for the RF system as part of the international collaboration. Work has been focussed on the provision of RF power for the experiment, the distribution system and the control system to ensure successful operation of the RF system during the experiment.

To reduce cost to the project the power amplifiers have been donated to the experiment from Lawrence Berkeley National Laboratory (LBNL, USA) and CERN (Switzerland). These amplifier systems use tetrode and triode electron valves to produce 1 MW of peak RF power for each cavity, with eight cavities producing an accelerating gradient of 21 MV.

The amplifiers were originally built in the 1950's and several of them needed complete refurbishment to bring them back into operation, in some cases modifications had been carried out for different applications providing a greater challenge to understand and reverse engineer the systems back into a standard configuration, this work was carried out under the guidance of the ASTeC RF group.

The RF system consists of a 4 kW solid state amplifier, a 250 kW tetrode and a 2 MW triode amplifier operating at 201 MHz in pulsed mode; 1 ms at a repetition rate of 1 Hz. The high voltage power supplies needed to operate the power amplifiers have been designed and built by Technology Department at Daresbury Laboratory.

A number of technical issues with safety protection circuits have been overcome recently. This has allowed the triode amplifier to be operated at a nominal 35 kV with 130 A per pulse, and for the amplifier system to be tuned to provide a peak RF power of 2 MW at an RF conversion efficiency of 50%. This meets the requirements for MICE and the complete RF system is now to be dismantled and installed in the MICE hall at RAL.

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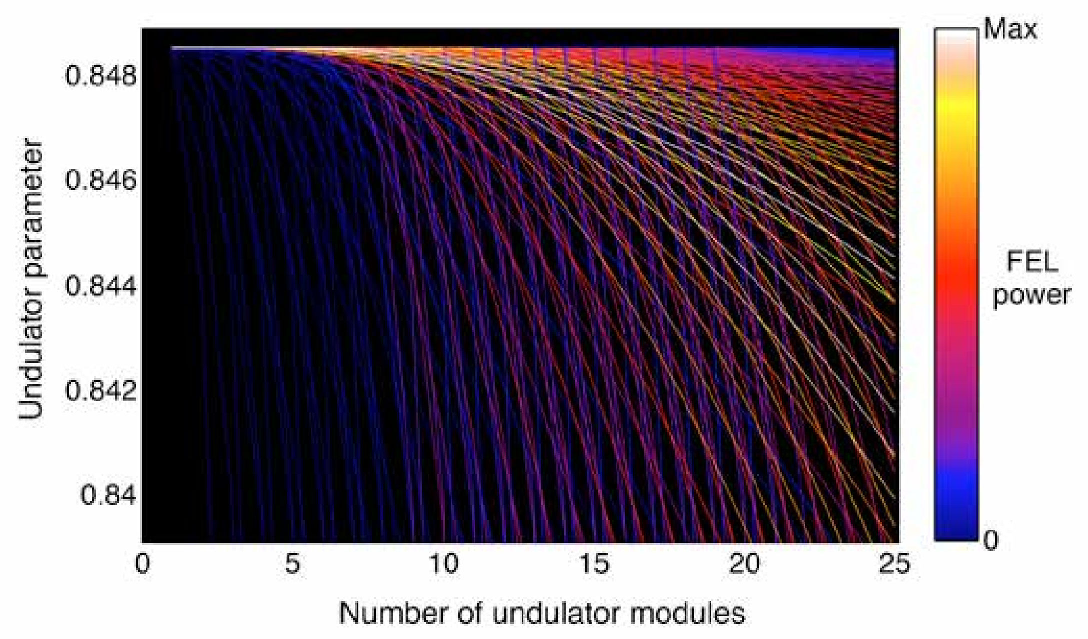
SwissFEL Modelling



Steadystate Scan (Credit: PSI)

ASTeC continued a programme of work on studies aimed at going beyond the baseline design of the SwissFEL facility. Previous work evaluated a self-seeding scheme, as proposed by Geloni et al from Deutsches Elektronen Synchrotron (DESY) in Germany and recently successfully demonstrated at the hard x-ray Linac Coherent Light Source (LCLS) in the USA, and this work was presented in a joint paper with SwissFEL at the FEL '12 conference in Nara, Japan. This work involves a concept in which a crystal is used to spectrally filter the FEL radiation developing in the first section of the undulator before amplifying it to saturation in the remainder of the undulator. The resulting improved spectral temporal coherence makes this method highly compatible with another FEL concept to increase the peak power from the FEL.

FELs operate by converting the energy in an electron beam into light – x-rays in the case of SwissFEL. However when this energy loss becomes too great the emission process stops because the electrons fall out of resonance with the previously emitted light. However, this can be mitigated by reducing the strength of the FEL's undulator magnet to compensate the electron's energy loss such that they remain in resonance. This so called undulator tapering potentially allows much higher powers to be reached. ASTeC staff studied the potential for implementing this scheme in combination with the previous self-seeding scheme, and produced a report indicating the predicted performance for the SwissFEL facility.

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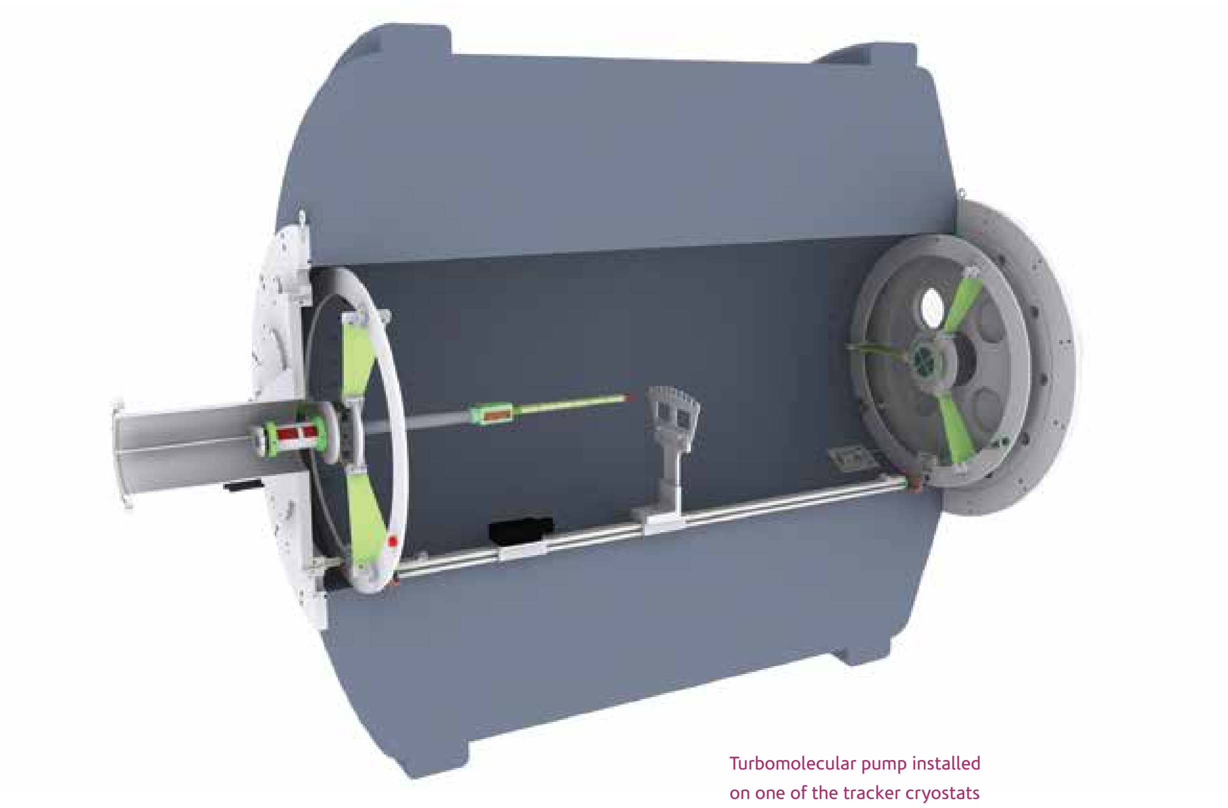
Magnetic Shielding

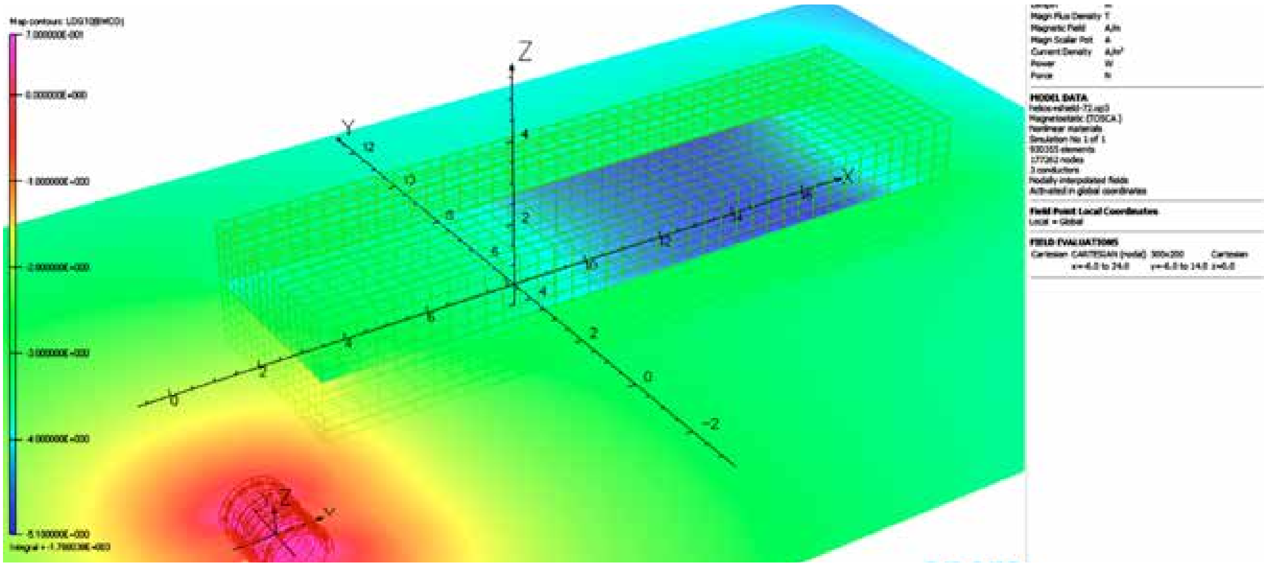


Turbomolecular pump installed on one of the tracker cryostats

Superconducting solenoid magnets are in use in many accelerators, and form the basis of all Magnetic Resonance Imaging (MRI) scanners. These magnets are designed to produce very high fields (3 T or more) within the bore of the magnet, and they can also produce high stray fields if not properly shielded. Modern hospital based MRI magnets employ a technique called active shielding that consists of coils wired in the opposite direction to the main coil, effectively cancelling out the field outside the magnet and reducing the stray fields to almost zero. In a hospital environment, where space is limited and life saving equipment can be adversely affected by magnetic fields, this shielding is essential. However, it is not usually used on accelerator beamlines, and alternative shielding usually has to be used to protect sensitive electronics in the accelerator hall.

TransHELIOS

TransHELIOS is a project to use an old research MRI magnet on the HIE-ISOLDE experiment at CERN. The magnet is one of the oldest MRI devices in existence, and was used at the University of Nottingham for over 20 years. It was built before active shielding was routinely used, and consequently the stray fields it generates are very high. This was identified as a major concern for installing the magnet at CERN, as the field could have an adverse effect on nearby beamlines. Superconducting linac modules have been identified as a particular concern, as they can be sensitive to a field as low as 2 G. The current beamline layout means that the MRI magnet's stray field can be as high as 25 G in the vicinity of the linac modules, so this is a challenging task.



ASTeC's MaRS group has been investigating the feasibility of shielding the beamline against stray fields from the 3 T superconducting solenoid magnet. Placing a steel box around the magnet appears to be the simplest solution, but the thickness of steel required is in the order of 10 cm, meaning that the box would be extremely heavy and prohibitively expensive. A more cost effective option would be to shield the beamline, encasing sensitive components in thin walled steel boxes to divert the stray fields around them. The thickness of steel required in this case is typically around 3 mm, so this represents a substantial saving.

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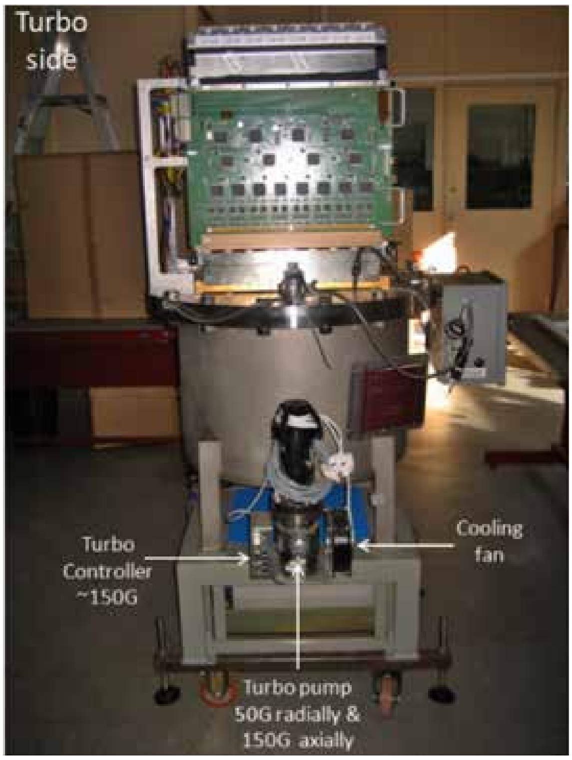
MICE

The International Muon Ionization Cooling Experiment (MICE) is an experiment aiming for the demonstration of ionization cooling of muons. A successful outcome from this experiment would have a significant impact upon the design and construction of future Neutrino Factories and Muon Colliders. Reduction of the muon beam emittance (referred to as 'cooling') is achieved through ionization – by the incoming muon beam – of hydrogen contained in the absorber vessels as this process involves energy dissipation, as required by Liouville's theorem. The cooling channel is placed between two tracking detectors, or 'trackers'. These are scintillating fibre optic matrices that measure the beam emittance before and after the cooling process and in this way a direct comparison between both values can be made. The scintillations result in optical signal guided by a set of fibre-optic cables to the tracker cryostats – detectors where the optical signals from the trackers are converted into electronic ones at liquid helium temperatures and then processed further. Both the cooling and the detection processes take place in an external magnetic field of the order of several Tesla generated by superconducting coils. Since the coils are yoke free their field extends in the surrounding area affecting and possibly even preventing from operation some of the instrumentation used in the experiment. A possible solution to this stray field problem is the installation of a 30 tonne, 10-12 cm thick partial return steel yoke around the trackers and the cooling channel. This is a rather elegant solution capable of eliminating the stray magnetic field completely. However, its implementation is not risk free and requires a significant investment of both funds and engineering/ construction effort.



ASTeC's MARS group has been asked to find a possible alternative in the form of a local shielding solution for the tracker cryostats. This is the most crucial component affected by the external field since without it functioning properly no cooling data will be available for analysis. Since the cryostat modules are placed in close proximity to the coils they are subjected to magnetic field strengths significantly exceeding those that they could safely tolerate.

Given the extent to which an external magnetic field needs to be attenuated by a shield (the suppression ratio) and the magnetic properties of the shielding material it can be easily shown that the necessary shield wall thickness increases in proportion to the shielded volume. Therefore minimizing the shielded volume by using individual shields for each sensitive component is advantageous compared to the installation of a single, large shield. Designing effective magnetic shields relies upon understanding the physics of the process. For example a shield in the form of a sufficiently long cylinder is most effective when the external field is perpendicular to the cylinder axis. Hence, if an axial field of certain strength can be attenuated sufficiently by such a shield then fields of similar strength would be reliably shielded against regardless of their direction.

The photograph on the left hand side of the page shows the turbomolecular pump installed on one of the tracker cryostats. The plot on the right hand side is the resulting magnetic field distribution obtained when the proposed shielding solution for the pump (a capped cylinder) is placed in an external field of 40 mT strength, which is comparable to the stray field strength at the location of the pump. The external field makes an angle of 45° with the cylinder axis. As can be seen in the figure below, the field strength in the shielded volume is of the order of 0.5 mT. The weight of the shield is approximately 8 kg.

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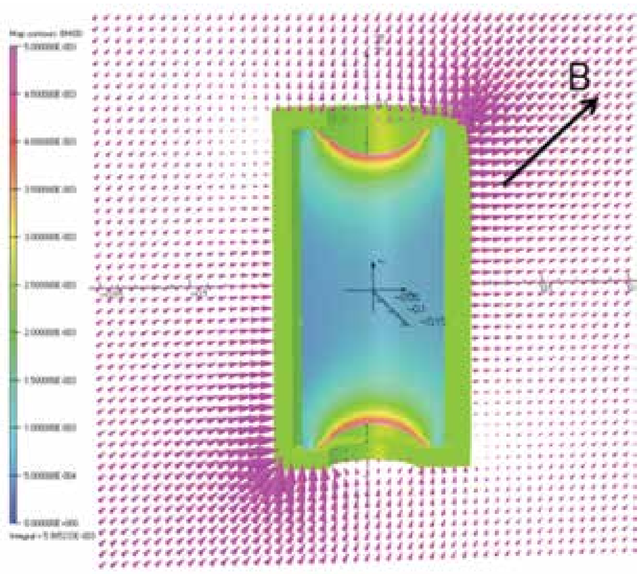

ASTeC involvement in HL-LHC

ASTeC has been involved in the High Luminosity upgrade for the LHC (HL-LHC) at CERN. The work done consisted of looking at various luminosity levelling scenarios, together with the beam-beam instability. Luminosity levelling is a technique which aims at spoiling the initial luminosity at the start of a run and subsequently compensating for its natural decay as the run progresses. The goal being to keep the effective luminosity the experiments see in the detectors constant for as long as possible. There are several ways to do luminosity levelling, each has advantages and disadvantages, and each needs to be modelled so that all the effects are understood when the beams are brought into collision. Luminosity levelling with both offset and a squeezing of the beam was also considered experimentally at the LHC and the results are shown below. This shows an increase of luminosity during a time interval of approximately six hours. This is because the important things to measure are the settings the two colliding beams have as the beam is squeezed and offset, once these are registered, they can subsequently be put in the right order so as to achieve a constant luminosity for as long as possible.

ASTeC has also been involved in beam-beam studies from a theoretical point of view as well as intra beam scattering (IBS) studies for the HL-LHC. Intra beam scattering in the LHC proton beams will be stronger in the HL-LHC than present because of the high bunch intensities, small emittances and new proposed optics. In order to evaluate the effect of intra beam scattering on decay of luminosity, the growth rates of intra beam scattering are estimated using different formalisms and computer codes. ASTeC carried out benchmarking of intra beam scattering in the present LHC using different formalisms and codes and have used these to evaluate HL-LHC beam parameters and optics.

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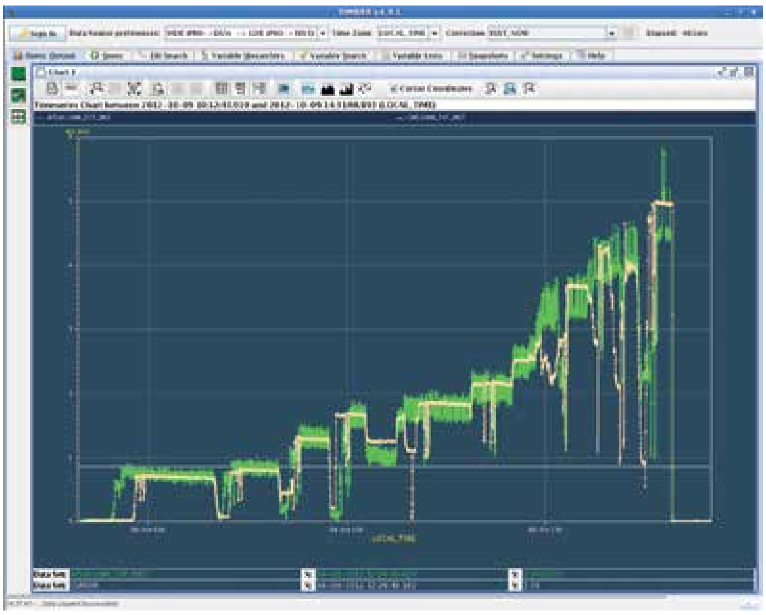

Luminosity levelling experiment at the LHC (October 2012)

HiLumi Crab-Cavity Cryomodule

To extend the discovery potential of the LHC, CERN has launched a major upgrade program 'Hi-Lumi-LHC' (High Luminosity LHC) to improve the luminosity performance of LHC, aiming for $L = 5 \times 10^{34}$ $cm^{-2}s^{-1}$ from 2022. Luminosity, or the number of collisions, can be increased by using a crabbing technique. Such a technique can be realised using SRF crab cavities but, has never been utilised for hadron beams.

To mitigate any risks which may arise due to the complexity of the LHC it is necessary to understand the interaction between the powerful LHC beam and the RF crabbing field prior to its final implementation. Therefore a prototype SRF cryomodule, comprising of two compact crab cavities is foreseen to be installed and tested on the SPS drive accelerator at CERN during 2016-17 prior to the long shut down period LS2 in 2018 to evaluate performance with high intensity proton beams. A series of boundary conditions influence the design of the cryomodule prototype, arising from the complexity of the cavity design, the requirement for multiple RF couplers, the close proximity to the second LHC beam pipe and the tight space constraints in the SPS and LHC tunnels. ASTeC in collaboration with the University of Lancaster, Cockcroft Institute, CERN and LARP (US LHC Accelerator Research Program) has proposed a design of a cryomodule for the 4-rod crab cavities for the SPS tests. Detailed engineering design is being developed.

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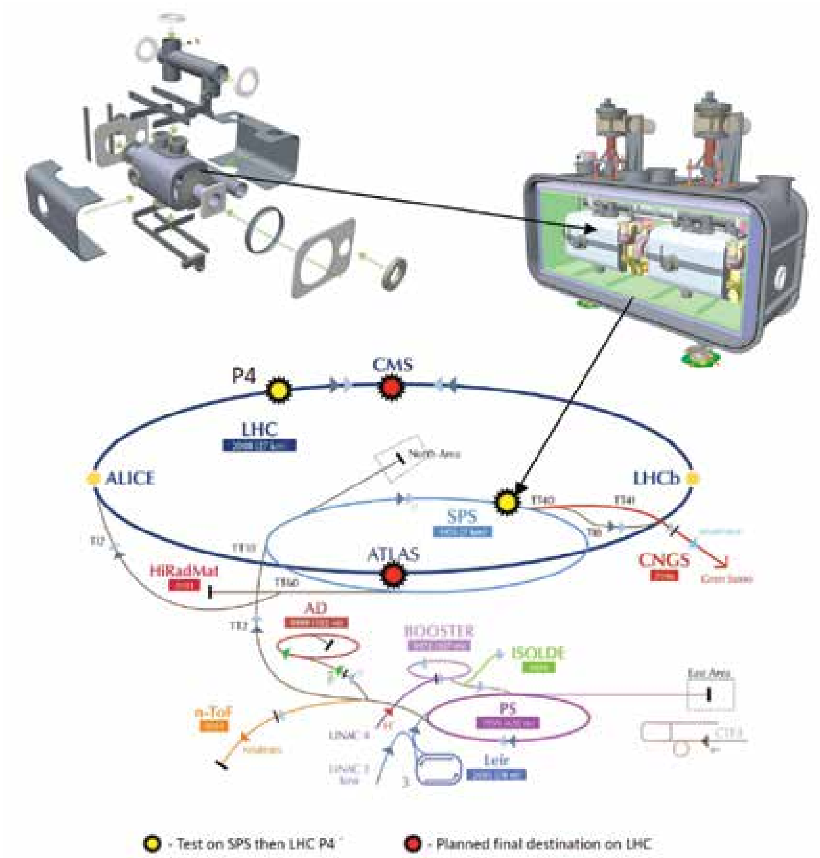

Top left
SRF compact crab cavity inside the helium vessel (developed by the University of Lancaster, ASTeC, and STFC Technology department)

Top Right
A concept cryomodule for tests with SPS (developed by ASTeC, the University of Lancaster and STFC Technology Department)

Lower
LHC and SPS drive accelerators

First Engineering Meeting on the Development of Crab Cavities for HiLumi LHC

STFC, in collaboration with the University of Lancaster, is currently leading an international design effort to develop Compact Crab Cavities as a part of the major upgrade project 'Hi-Lumi-LHC ' (High Luminosity LHC) for improving the luminosity performance of LHC, aiming to $L = 5 \times 10^{34}\ cm^{-2}s^{-1}$ in a period of 10 to 12 years after the upgrade in 2022.

In order to evaluate the performance of these cavities a prototype cryomodule will be developed, installed and tested on SPS at CERN in 2015-16. The first global engineering meeting was held at the Fermilab on 13 and 14 December 2012 to discuss and establish the requirement of these tests.

Shrikant Pattalwar (ASTeC), Tom Jones (Technology) and Graeme Burt (Cockcroft Institute and University of Lancaster) participated in the meeting and presented their ideas and concepts on the Crab Cavity cryomodule.

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The ALICE Light Source: a tool for medical research

Clinicians from three hospitals collaborate on experiments on ALICE to develop better understanding of the progress of cancers

Towards disease diagnosis through spectrochemical imaging of tissue architecture

This EPSRC funded programme brings together a critical mass of scientists and clinicians from four universities (Liverpool, Manchester, Lancaster and Cardiff) and three hospitals (Royal Liverpool, Christie and Lancaster Infirmary) with the complementary experience and expertise to advance the understanding, diagnosis and treatment of cervical, oesophageal and prostate cancer, develop new diagnostic techniques and explore a new approach to monitoring interactions between pathogens, pharmaceuticals and healthy and diseased cells or tissue.

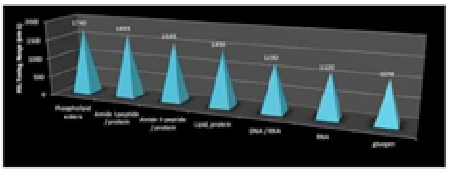
The research grant will fund operations of the ALICE accelerator for three months every year for three years and ALICE underpins all aspects of the research programme as can be seen opposite.

ALICE - Upgrades to a Light Source

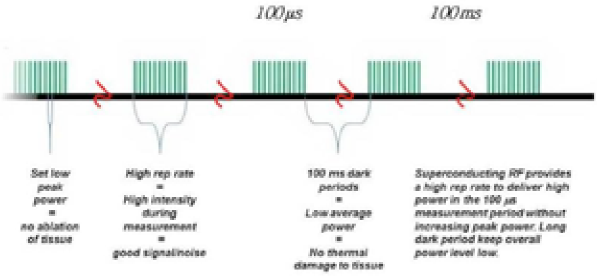
In the last year the tuning range of ALICE has been extended down to 11 microns (900 cm^{-1}) and now covers the main fingerprint absorptions in biomolecules. The upgrade of the superconducting linac, described elsewhere in this report, is expected to allow ALICE to accelerate to higher electron energy and thereby enable the FEL tuning range to increase to shorter wavelength. ASTeC will invest in improving the stability of ALICE by developing an active laser and RF feedback system to correct phase drift, whilst Manchester University will develop wavelength feedback to the ALICE control system to lock the FEL wavelength, enabling high quality data to be obtained without operator intervention. See also p. 4.

Why ALICE?

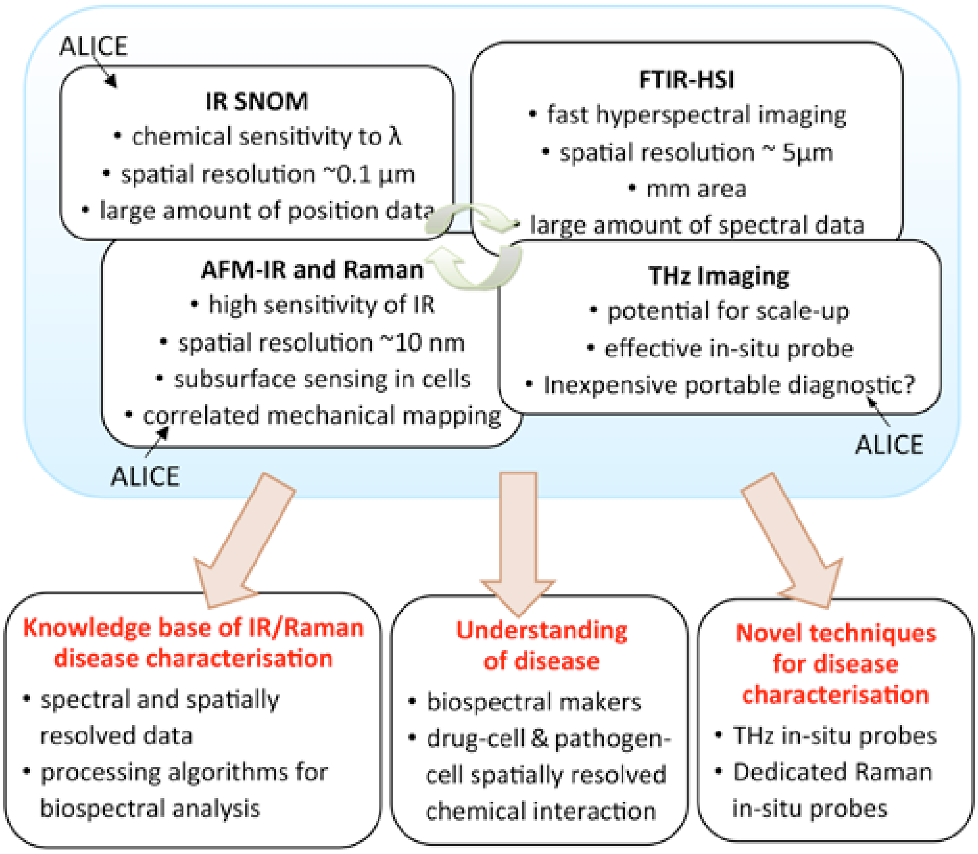
1. Alice FEL Tuning Range covers characteristic absorptions in biomolecules.



2. ALICE provides ideal pulse structure for SNOM



3. Alice Tissue Lab provides controlled environment for medical research



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From Cancer Therapy to Security

Using the UK's Accelerator Technology Expertise to Accelerate Business

Dr Paul Beasley, from Siemens Corporate Technology and Concepts, spoke at the event about how working with STFC has significantly benefited the company

More than thirty representatives of innovative high-tech companies from across the UK met at the Daresbury Science and Innovation Campus (DSIC) on 17 April 2012, to find out how the country's leading designers, developers and builders of particle accelerators could be beneficial to their own businesses.

It is estimated that more than 30,000 accelerators are used across the world and the innovative technologies developed to create these are applicable to many industrial and scientific sectors including healthcare, particularly in cancer detection and therapy; energy and environment, in supporting future energy programmes and safer disposal of radioactive nuclear waste; in the automotive and aerospace engineering sector to make more efficient use of fuel; as well as in the security sector, particularly for airport passenger and cargo screening.

'Accelerating Science, Accelerating Business', organised by STFC and the Cockcroft and John Adams Institutes, which STFC funds, enabled industry to gain a deeper insight into the technology requirements that drive accelerator-based scientific research and to identify opportunities for them to collaborate with the UK's research organisations to solve their R&D challenges and develop new products, processes or services for commercial exploitation.

Industry representatives attending the one day event heard from Dr Paul Beasley, Head of Strategic Development from Siemens Corporate Technology and Concepts, about how working with STFC to solve research challenges using accelerator technology has significantly benefited the company. Dr Beasley highlighted how STFC's knowledgeable staff, extensive resources, large scale infrastructure and supportive collaboration had proved the ideal partner to enable timely and highly efficient development and testing of Siemens' innovative accelerator systems.

The event also provided an opportunity for many of the companies present to air their future technology development challenges to the expert audience and prompted much lively discussion during the extensive networking sessions. The delegates were also treated to a rare opportunity to view first hand the world class test-bed accelerators and extensive supporting infrastructure located on the Campus; facilities which included the ALICE and EMMA operational accelerators and the new Versatile Electron Linear Accelerator (VELA) which is currently under construction, plus the Engineering Technology Centre (ETC).

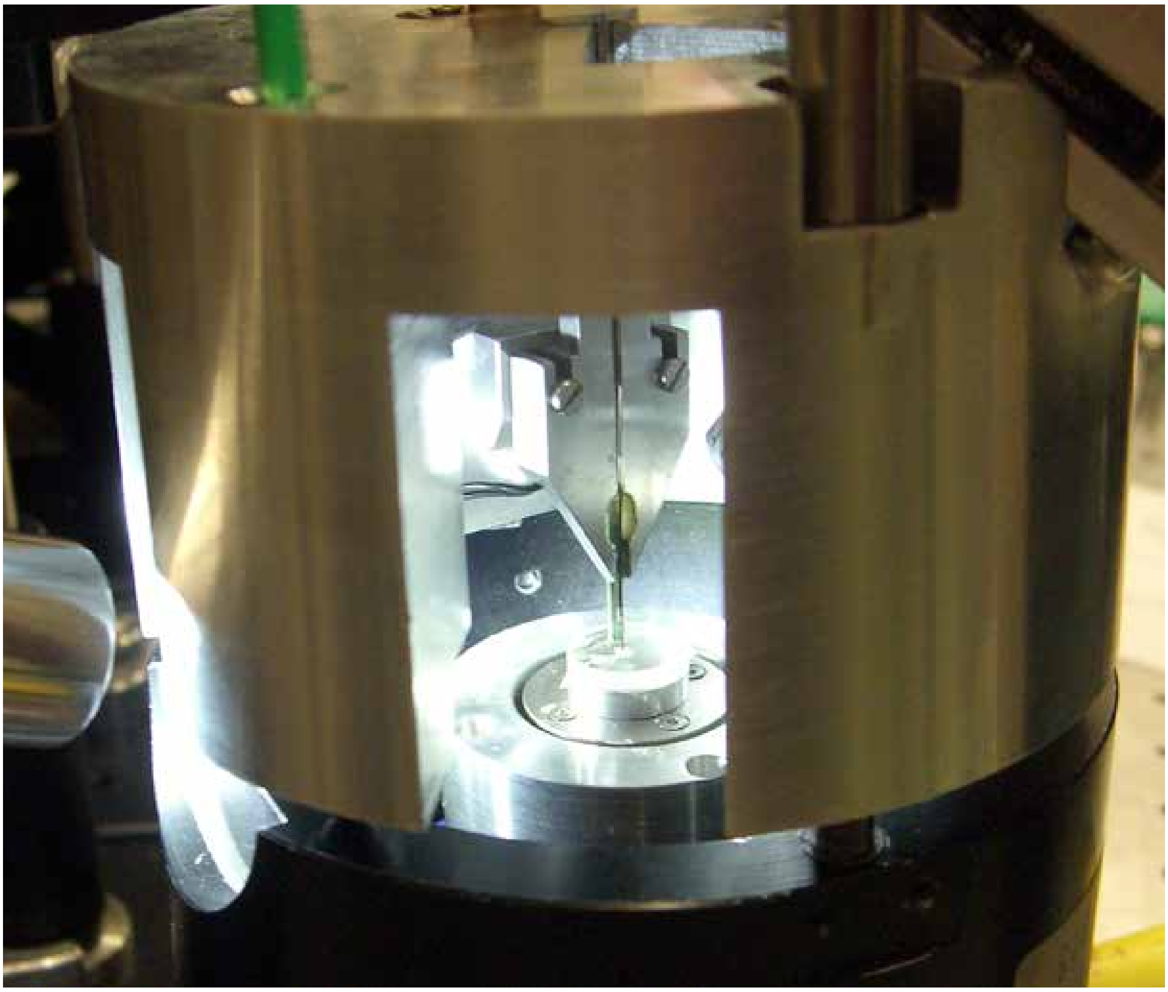
Through this successful event and future industry focussed activities, STFC will continue to strengthen its role supporting economic and employment growth in the high-tech sector; both through commercial partnerships to expedite technology and product development, and through the effective transfer of its world class expertise to the UK's expanding high-tech commercial base.

Credit: Dreamstime.com

Physics to Healthcare Workshop

Credit: Dreamstime.com

On Thursday 6 July 2012, STFC hosted a 'Physics to Healthcare Workshop' KTN event at Hamilton House, London which attracted a wide spectrum of representatives encompassing the clinical, scientific and industrial applications for the diagnosis, treatment and long term care for patients identified with a variety of cancer related diseases. Along with over 100 delegates for the event, Peter McIntosh, Professor Jim Clarke and Dr Anthony Gleeson attended; presenting a poster on accelerator applications in the healthcare sector and Dr Suzie Sheehy gave an invited presentation on, 'Accelerating Proton Therapy – Can a New Breed of Accelerator Help Oncologists?'
Peter Weightman (Liverpool University) also presented the breakthrough work completed on the ALICE accelerator for the diagnosis of oesophageal cancer entitled, 'The Potential of Infrared Free Electron Lasers for the Study of Cancer'. The networking context of the meeting was intended to bring together technology developers in the medical field and clinical users. Funding streams within STFC and the wider UK frameworks were identified, with case study representations from STFC, The Institute of Cancer Research, University of Liverpool and Cambridge University Hospitals NHS Foundation Trust, all explicitly detailing examples of how successful collaborations have been substantiated to deliver improved capabilities and impact in the medical and health arenas.



Working with the Institute of Physics

IOP Institute of Physics

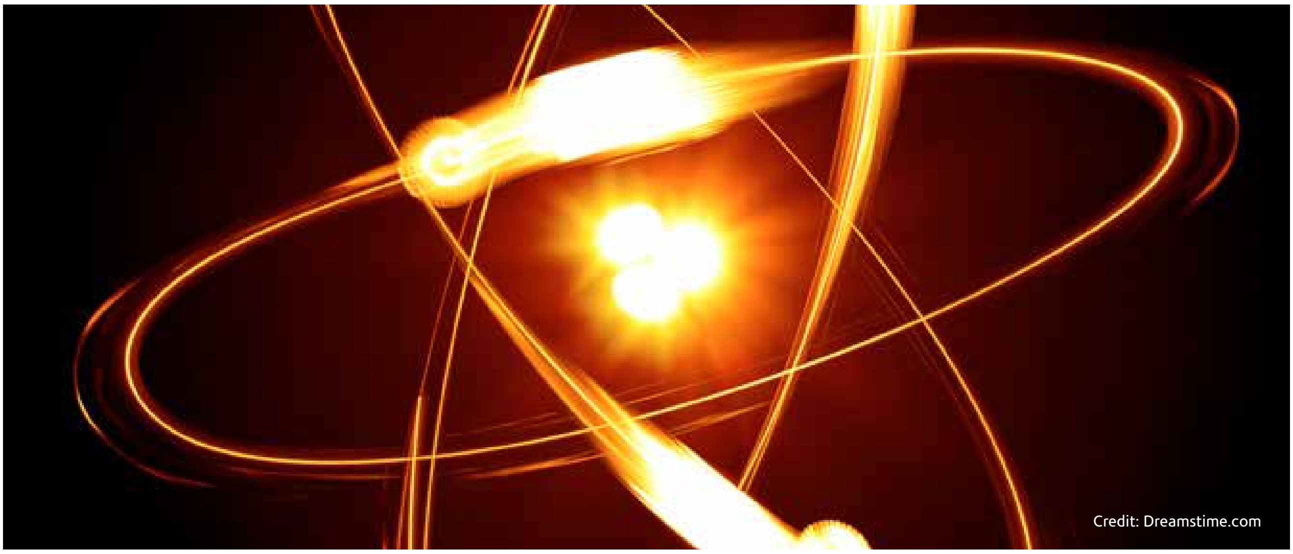
The Institute of Physics (IoP) is a leading scientific society, providing a platform where researchers from academy, national laboratories and industry can work together to advance physics education, research and application. Many ASTeC scientists are members of the Institute of Physics, a few are Chartered Physicists (CPhys) and Fellows (FintP) of the Institute of Physics. ASTeC IoP members took the lead in establishing the Particle Accelerator and Beams Group and continue to play an active role in the running of the group. Additionally ASTeC staff have played a significant role in the running of the Vacuum Group over a number of decades.

The Particle Accelerator and Beams (PAB) group of the IOP was founded in 2009 with the aim of promoting the professional standing of members in the field of particle accelerators, through exposure, events, outreach and increased academic profile. Professor Mike Poole (former ASTeC director) was the founding Chair and continues to play an active role on the committee since his retirement from STFC. The current group committee chair is Professor Phil Burrows (JAI/ Oxford) although Mike remains an active committee member. Dr Peter Williams (ASTeC Accelerator Physics Group) is currently the group secretary, and Professor Susan Smith (ASTeC Director) is a committee member. ASTEC staff are active within this group.

PAB Group covers the physics of the generation, acceleration and manipulation of charged particles. It includes their utilisation in fixed target and colliding beam systems, in the generation of synchrotron radiation and neutron beams, and delivery of other secondary beams. The Group has interest in all applications of particle accelerators, not only in academia but also in, for example, medical, security and industrial contexts. The Groups remit also includes associated technologies such as magnet systems, diagnostic devices, radiofrequency structures and extreme vacuum science environments. All of these form parts of practical particle accelerator solutions ranging from bench examples to national and international facilities (e.g. ISIS, Diamond, CERN).

PAB group has organised a number of events such as:

- Compact Accelerators half-day meeting, CI, 18 April (see p.63)
- Ion Source Technology full day meeting: RAL, 27 November
- Advanced Computing for Accelerators 3 day meeting: DL, 29 January (see p.28)
- Training the next generation of accelerator scientists and engineers half-day meeting: JAI, Oxford, 19 March



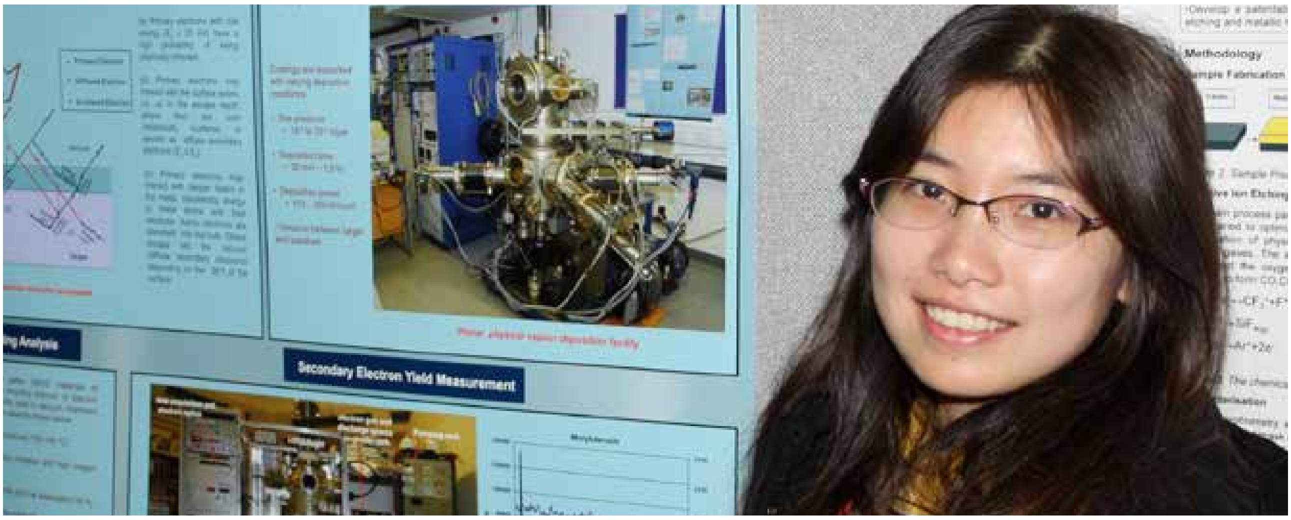
Professor Neil Marks received the inaugural PAB group outstanding professional contributions prize at the 2012 annual meeting (June 2012).

The ASTeC Vacuum Science Group has a long history of supporting the **IoP Vacuum Group.** Dr Ron Reid (now retired from STFC) first represented the group in the late 1970s and served for many years, including the roles of Chair and Secretary. Joe Herbert has served on the committee since 2005 and as treasurer since 2010. Dr Oleg Malyshev joined the committee in 2012, having been invited in part due to his role as associate editor of the journal Vacuum. The group organises technical meetings covering topics of interest to the wider vacuum community as well as more focussed topics that relate to large vacuum systems and particle accelerators. Providing training and education, particularly for users of vacuum, has been a major activity in recent years and has proved to be very popular in industry.

A particular highlight is the support Joe Herbert was able to gain from this group to enable the establishment of a successful annual vacuum meeting – Vacuum Symposium UK. The 3rd Vacuum Symposium UK was held on 17-18 October 2012 in Coventry. (see p.61).

5 OUTREACH

Training for the Future



PhD student Sihui Wang with her poster at the 3rd Vacuum Symposium

Every year a number of postgraduate and undergraduate students participate in the ASTeC research programme working under the supervision of ASTeC staff. The students take part in the ASTeC projects and gain knowledge in a subject they study, experimental and analytical experience, they also gain practical skills in using experimental equipment and tools, various software and in presenting their results. They practice working in a team, working timely and taking responsibility.

PhD Student Training at ASTeC

ASTeC, together with the Cockcroft Institute (CI) partners as well as other UK universities, provides a good opportunity and ideal conditions for a PhD education and training in various accelerator related disciplines for bringing up the next generation of scientists who participate in both fundamental research and new technological development. PhD students, supervised by ASTeC staff, were working on the following projects:

- Sihui Wang (Loughborough University) supervised by Dr Mike Cropper (Loughborough University) and Dr Oleg Malyshev/Dr Reza Valizadeh (ASTeC) investigates the Low Secondary Electron Yield (SEY) coatings for an electron cloud mitigation in an accelerator beam chamber. Her research requires the film deposition at various conditions, the systematic surface analysis and the SEY measurements.
- Jimmy Garland supervised by Dr Hywel Owen (Manchester University) and Dr Bruno Muratori (ASTeC). His work was on slow resonance crossing in the EMMA non-scaling FFAG. As was shown in the Nature Physics paper, resonances can be crossed easily, provided this is done quickly with a fast acceleration. The question of just how slow resonances can be crossed is natural and is also one that has important applications in all sorts of machines related to FFAGs and also for exploring the potential of induction acceleration to be used in conjunction with ns-FFAGs.

Two students have successfully completed their PhD in the reported year:

- Neil Thompson: 'Improved Temporal Coherence and Short Pulse Generation in Free-Electron Lasers' (University of Strathclyde)
- Richard d'Arcy (also supervised by Mark Lancaster from UCL): Richard completed his PhD in December 2012. He studied the COMET and PRISM projects.

He looked at the modelling of EMMA in GPT (General Particle Tracer), this means, modelling EMMA with space charge. In order to do this, important changes had to be implemented in the code GPT. This was done in conjunction with the authors of the program and Bruno Muratori. As a result, non-scaling FFAGs can now be modelled in GPT and an article on this is due in the near future.

During their PhD studentship all students attend the Cockcroft Institute Lecture Course given by leading scientists from CI (including ASTeC) and by invited field leaders from other research centres. In the reporting year ASTeC scientists gave lectures on the following subjects:

- Physics and Operation of FFAG Accelerators – Dr Shinji Machida
- Introduction to Magnets and Conventional Magnets for Accelerators – Professor Neil Marks
- Elements of Electromagnetism for Accelerators – Dr Chris Prior
- Insertion Devices – Professor Jim Clarke
- Laser Based Beam Diagnostics – Dr Steve Jamison

Undergraduate Student Training at ASTeC

Within the sandwich student placement programme advertised through STFC, every year ASTeC offers a few one-year placements for undergraduate students. This is a good opportunity for the students to gain experience working in the National Laboratory participating in scientific projects, studying new disciplines, working in a research multi-skilled team and taking responsibility on their part of the project.

Ben Hogan, a sandwich student from the Bath University describes his 13-month work at ASTeC as follows:

"My placement with ASTeC was a great experience, giving me a fantastic opportunity to work on real scientific research. This built on the skills and knowledge I have learnt during my degree while also extending into new and exciting areas I otherwise would not have experienced. I hope that in the future I will have the opportunity to return to ASTeC as part of my career."

A gap year student Erin Nolan adds the following:

"It's difficult to summarise all of the amazingness of last year into a few sentences! Working in ASTeC for a year was a brilliant experience and not only did I enjoy every minute of it (yes, even the time spent getting frustrating experiment results) but I also developed my knowledge and skills across the fields of science and engineering, something I feel will benefit me wherever I go in the future."

In addition, there are a number of summer students and work experience students who spend between two weeks and three months working with ASTeC staff.

Daresbury Laboratory Particle Physics Masterclass 2013

The annual Particle Physics Masterclass (PPMC) was held in March, and saw students from schools across the North West travelling to join scientists from the Cockcroft Institute (CI) for the event at Daresbury Laboratory. The event continues to develop, and this year it has benefited from use of the newly equipped Brunner-Mond computational science suite. The suite contains around 50 independent PC workstations which allowed each student attending the masterclass to work independently on the accelerator physics and particle physics simulations which form part of the class programme. This gave each student more time to focus on the task at hand, and increased the learning impact.

A highlight of the class for students is the opportunity to carry out a simple measurement on the ALICE accelerator which ultimately yields an estimate for the injection beam energy. This is a hands-on activity inside the accelerator vault, so is always exciting for visiting students to carry out under supervision.

The class also made use of what have become 'conventional' outreach apparatus such as an electrostatic accelerator and a demonstration of the Meissner effect (the expulsion of a magnetic field from a superconductor), neither of which are easily achievable in a school science laboratory. Linking these demonstrations to a light hearted look at vacuum and its effects on everyday things,

plus the ALICE promotional video created a final less demanding activity for the masterclass. This successful combination of lectures, hands-on tasks and demonstrations was highlighted in feedback received:

"Thank you for a fantastic day at Daresbury last Thursday. I felt there was an excellent mix of information and activities that I and the students were enthused and impressed by. Most were also worn out and were very quiet on the return journey after an intense day" – Andrew Turner, Eaton Bank Academy

A lunch was provided, and while students browsed the exhibits in the science centre or checked their facebook account, the teachers used the opportunity to discuss science and outreach opportunities with the ASTeC and CI staff present. The students were also given the opportunity during the lunch break to view the LHC roadshow which was set up at Daresbury Laboratory at the time of the masterclass.

Lee Jones, lead organiser of the event said "our master class programme keeps improving, and I am delighted to see that we are connecting even more strongly with the children who attend, and notably with their teachers too. A big thank you has to go to the team of helpers who have made the activities possible – there would be no masterclass if these people did not give up some of their time to talk about what they do to what might be the next generation of particle accelerator scientists."

For more information contact: lee.jones@stfc.ac.uk

The Big Bang regional event

On 10 July, less than a week after CERN announced the discovery of a Higgs-like particle, the Big Bang came to Liverpool. The Big Bang event is the UK's largest science and technology fair. The North West regional event is a chance for school children to meet real scientists and engineers, to talk with them about their work, and gain an insight into what it is they do. It is also the culmination of much work for the student participants from schools all over the region who have submitted projects from which a winner is selected to represent the North West at the next national Big Bang event in London 2013.

Staff and students from the Cockcroft Institute attended the event which was held over 2 sites this year: The World Museum and St. George's Hall. The CI stand was in St. George's Hall, and it attracted lots of interest from the visitors. The noise of the hall was frequently punctuated by whoops of delight and amazement on seeing a friend's hair stood on end by the high voltage from a Van de Graaff generator. The explanation of this phenomena is that 'like charges repel', so after demonstrating how hairs can be made to repel each other and stand on end, visitors were interested to see how an identical high voltage source could be used to drive a model demonstration of a cyclotron (a type of particle accelerator) which relies on the same principle.

The Vacuum Science group gave demonstrations of such things as the triple-point of water and Magdeburg hemispheres, and many other interesting and unexpected aspects of vacuum science. There were more than 1,700 staff and student visitors from 80 schools booked into the event, having travelled from all over the region, plus many more casual visitors

on the day. While it was a busy day for everyone on the stand, it was very pleasing to see so many visitors to the event, all asking questions and expressing great interest in the science and engineering they saw, and especially in particle accelerators and the work of the Cockcroft Institute.

Erin Nolan (Wirral Grammar School for Girls) won the prize for the North West Young Engineer of the Year, and will represent the region at the national event in London next year. She also began a Year in Industry placement at Daresbury Laboratory within the Cockcroft Institute in September 2012, so double-congratulations to Erin.

For further information contact: lee.jones@stfc.ac.uk

IPAC12 - New Orleans

The 3rd of the new International Particle Accelerator Conference (IPAC) series and the first one in North America, took place at New Orleans, Louisiana, USA on 20-25 May 2012 and was chaired by the ex-founding Director of ASTeC, Professor Vic Suller (CAMD).

A total of 16 delegates from ASTeC participated in this conference, presenting one contributed oral and 40 poster papers, covering a wide variety of accelerator and technology areas, which included:

National Projects

- ALICE status & beam dynamics
- Versatile Electron Linear Accelerator (VELA) overview, optics design, photocathode R&D and ultra short bunches diagnostics with transverse deflecting cavity
- CLARA overview, compression schemes and FEL delay line
- EMMA modelling, slow integer crossing, EBPM calibration, new injector, racetrack and orbit correction, phase rotation experiment on EMMA for testing non scaling FFAG for PRISM
- LEBT experimental studies and wire scanner
- ISIS linac modelling
- FETS status

International Projects

- Cryomodule assembly
- CLIC collimation and permanent magnet quadrupoles
- European ELI-NP proposal
- ESS simulations
- LHC crab cavity
- In-vacuum undulator development
- Neutrino Factory NS-FFAG, proton driver, vertical orbit, high power scaling, decay ring, front end beam losses and cooling lattice
- PRISM FFAG design
- SwissFEL collimation

As a member of the JACOW publishing team, Sue Waller supported the publication of >1200 paper submissions, throughout the duration of the conference. The ASTeC Director, Professor Susan Smith, chaired the contributed oral session on Sources/ Alternative Acceleration Techniques and Dr Bruno Muratori also presented 'New Results from the EMMA Experiment' in the contributed oral session on Particle Sources/Alternative Acceleration Techniques.

3rd Vacuum Symposium UK,

Ricoh Arena, Coventry, 17-18 October 2012

This series of meetings grew out of a 'call' from the UK vacuum community for an annual national meeting incorporating both technical and commercial elements. The ASTeC vacuum science group spearheaded the inauguration by organising the first meeting at Daresbury Laboratory in 2010 through the already successful RGA Users Group. The success of the meeting attracted significant additional interest from the British Vacuum Council and the Institute of Physics Vacuum Group such that the meeting is now a regular annual event. The meeting has since been strengthened by introducing vacuum training courses and a large vacuum equipment exhibition (VACUUM EXPO). Two members of the vacuum science group, Joe Herbert and Mark Pendleton are members of the organising committee for Vacuum Symposium UK and take the lead role in organising and developing the training modules. Additionally Sue Waller supported the organisation of the conference.

There were three technical sessions at this year's conference:

- 'Vacuum and Plasmas for Industry, essential ingredients for manufacturing success.' This programme highlighted areas where vacuum and the use of plasmas are important (and often essential) ingredients in industrial processes and the requirements of vacuum for manufacturing success. Topics included 'freeze drying', 'coatings for glass', process control of plasmas in semiconductors' and 'wear reduction in bearings'.
- 'Nanostructured Metal Oxide Thin Films.' This programme covered deposition techniques and growth processes, characterisation and properties of single/multi-layer oxide coating and modelling.
- Big Science/Large Vacuum Systems – goals, challenges, choices and solutions'. This meeting focussed on the challenges faced in designing large vacuum systems and the long term testing required to ensure reliability and longevity. Certain design solutions were presented and discussions about the impact of large scale facilities were included.

The AVS 59th International Symposium and Exhibition

The International Symposium and Exhibition organised annually by the American Vacuum Society is the largest American, and one of the largest international, events in the field of vacuum science, technology and applications. It brings together academic, Industrial, government and consulting professionals involved in a variety of disciplines related to the basic science, technology development, and commercialisation of materials, interfaces, and processing.

The AVS 59th International Symposium and Exhibition was held in Tampa (Florida, USA) from 28 October to 2 November 2012. ASTeC Vacuum Science Group has established a strong relationship with the AVS Vacuum Technology Division for a number of years. This group provides an effective bridge between the American and European vacuum communities. This year the AVS Vacuum Technology Division emphasised the core topic of pumping, gas dynamics and modelling, inviting Dr Oleg Malyshev to give a talk on gas dynamics and its applications to particle accelerator modelling, design and operation.

ECCOMAS 2012 Congress

The 6th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2012) was held at the Vienna University of Technology on 10-14 September 2012. About 2100 participants from 61 countries around the world attended the Congress presenting results from various areas of computational methods and computer simulations in applied sciences and engineering. The scientific programme of ECCOMAS 2012 consists of plenary and semi-plenary lectures, mini-symposia, special technology sessions, an industrial symposium and 36 technical sessions. The main objective of the Congress is to provide a forum for presentation and discussion of state-of-the-art advances in computational methods in applied sciences and engineering, including basic methodologies, scientific developments and industrial applications, and to serve as a platform for establishing links between research groups of academia and industry with common as well as complementary activities.

Thus, a special interest mini-symposia of ECCOMAS was organised on modelling of vacuum gas dynamics problems focussing on analytical and numerical problem solving. Scientists from academic and industrial research groups (CERN, ASTeC, ITER, SAES Getters, etc) presented and discussed their results. Dr Oleg Malyshev presented a talk on Vacuum Gas Dynamics for Particle Accelerators focussing on modelling design workflow from experimental input data, data interpretation and selecting the model to the results of the model and their implication for a particle accelerator design.

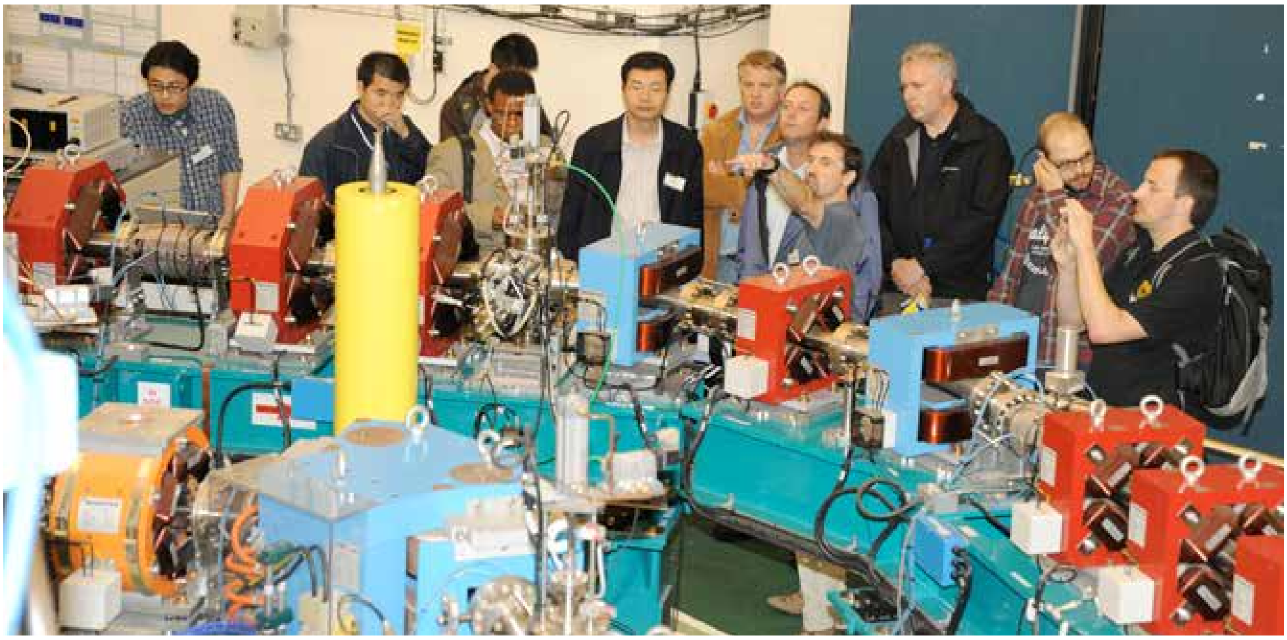
Compact Particle Accelerators Meeting

In April 2012 the Cockcroft Institute and ASTeC hosted a half day meeting on compact particle accelerators. The meeting, sponsored by the Institute of Physics Particle Accelerators and Beams Group, focussed on compact medium energy particle accelerators and covered electrostatic, RF and laser based accelerator concepts. The meeting had a good mix of many accelerator physicists and engineers from all over the UK and around 40 people attended the meeting. Speakers from ASTeC, the Cockcroft Institute universities, Belfast, Rutherford Appleton Laboratory, Huddersfield, Strathclyde, CERN and Siemens gave several interesting talks on the state-of-the-art in compact accelerators. The meeting was split into two sections, one focussing on 'conventional' electrostatic and RF based accelerators and the other on 'exotic' millimeter wave and laser based accelerators.

The 'conventional' session was anything but, with talks on compact linacs, cyclotrons and FFAG's as well as some very novel compact accelerator concepts from Siemens. The meeting concluded with a lively discussion led by Professor Mike Poole on limitations and other opportunities for compact accelerators.

The exotic session lived up to its name with talks on metamaterials, photonics, pseudospark sources, laser wakefield acceleration and proton acceleration through shining a laser on a target.

HOMSC12 Workshop



During the last week of June the Cockcroft Institute and ASTeC hosted the International Workshop on Higher Order Mode Diagnostics and Suppression in Superconducting Cavities (HOMSC12). Beam excited higher order modes (HOMs), if left unchecked, can appreciably dilute the beam quality, and in the worst case scenario can give rise to a beam break up instability.

This workshop brought together researchers from Europe, Asia and the USA –all with the common purpose to study HOM suppression in superconducting cavities in fields ranging from energy recovery linacs, light sources and linear collider applications. The Local Organising Committee was chaired by Steve Buckley (ASTeC) and the Scientific Programme Committee by Professor Roger M Jones (Cockcroft Institute/University of Manchester).

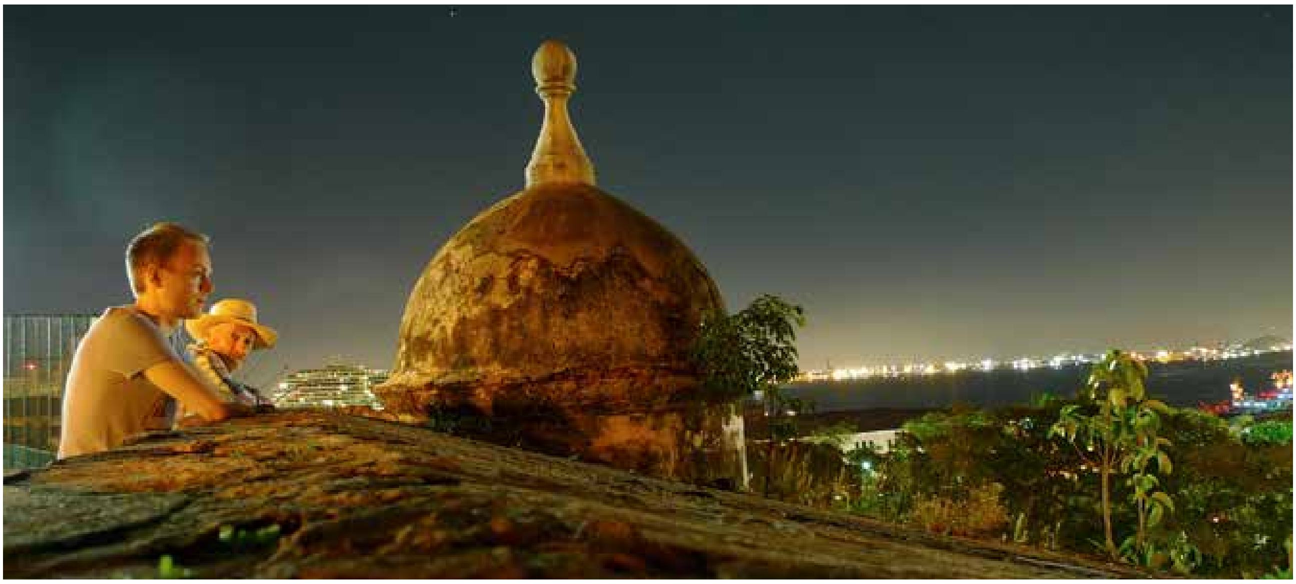
Both invited plenary and contributed sessions were included in the 2.5 day meeting. This workshop encompassed issues in both electron and proton linacs, TESLA style cavities, third harmonic cavities, and TEM crabbing and other cavity designs.

Highlights included a plenary talk by Peter McIntosh on SRF Cryomodule Development for ERL Applications, Professor V P Yakovlev on Higher Order Modes in the Project-X, and Professor Jean Delayen with HOM Modes in Parallel-bar Deflecting /Crabbing Cavities.

In addition, tutorials were presented each day by Dr Inna Nesmiyan, Dr Jonathan Smith and Dr Ian Shinton. A prize was presented to the best student poster and to the runner up. Selected papers from this workshop will be published in a special issue of Nuclear Instruments and Methods in Physics Research Section A.

HBEB 2013

Physics and Applications of High Brightness Beams: Towards a Fifth Generation Light Source



ASTeC staff members David Dunning and Neil Thompson, together with Brian McNeil from the University of Strathclyde, attended the 'Physics and Applications of High Brightness Beams' workshop in San Juan, Puerto Rico from 25–28 March 2013. The goal of the workshop was to gather experts in advanced light sources, beam physics, and novel acceleration techniques, to consider how best to combine these fields towards delivering a '5th generation light source'. The general view was that this means either significantly improving the properties of present light sources, or significantly reducing their size and cost – or a combination of both. Many new concepts were presented and discussed. David Dunning gave a presentation titled 'Towards Zeptosecond-Scale Pulses from X-Ray FELs', Neil Thompson presented a talk on 'High Brightness SASE Operation of X-Ray FELs', and Brian McNeil talked about 'Advancements on Theory and Simulations of FELs'.

Further details on these topics are given in the article 'Advancing free electron laser concepts' (p.30).

LHeC Meeting at Daresbury Laboratory

The Large Hadron Electron Collider (LHeC) is under development as the electron-proton/ion (ep/A) complement of the LHC at CERN, with which parton dynamics and new phenomena are explored with unprecedented luminosity and energy in deep inelastic scattering. The LHeC conceptual Design Report was published in June 2012, and CERN, ECFA and NuPECC have encouraged the further development of the project.

With a mandate from the CERN Directorate, the decision was taken at the LHeC Workshop in June 2012, to further develop the technical design of the electron accelerator as a multi-pass, energy recovery linac (ERL). This work is now being pursued, and collaborations between CERN and international partners have emerged. A particularly strong collaboration is being established with ASTeC, Cockcroft Institute, Jefferson National Accelerator Laboratory and the Brookhaven National Accelerator Laboratory, building on their unique expertise with the energy recovery test facilities. Experts from these laboratories along with key accelerator experts from CERN met at Daresbury Laboratory on 22 and 23 January 2013 to discuss the design of the LHeC ERL test facility at CERN. The two main goals of this meeting were to discuss the choice of the LHeC linac frequency (1.3 GHz or lower), considering beam dynamics, performance and other issues, and to gather the experience obtained with the US and UK ERL designs and facilities in view of the LHeC test facility.

The considerations for the frequency choice will be verified and the frequency be determined, as is required for further progress. The test facility requirements will also be consolidated and discussed in detail at the next LHeC workshop, in September 2013. The meeting at Daresbury opened the prospects for a productive collaboration on the design, development and production of the LHeC test facility elements, such as sources and cavity cryo modules, possibly involving also further partners, a collaboration which would enable a new CERN facility to be built in the not too distant future.

TESLA Technology Collaboration Meeting 2012 (TTC12)

Peter McIntosh, Alan Wheelhouse and Shrikant Pattalwar attended the TESLA Technology Collaboration meeting that took place at Jefferson Laboratory 5–9 November 2012, with Peter convening a 'Specialised Cavity System Developments' working group session and Shrikant presenting latest results of the 'Integration and Cold Testing of the CW ERL Cryomodule at Daresbury'. The mission of the TESLA Technology Collaboration is to advance SRF technology R&D and related accelerator studies across the broad diversity of scientific applications, and to keep open and provide a bridge for communication and sharing of ideas, developments, and testing across associated projects. The TTC then supports and encourages free and open exchange of scientific and technical knowledge, expertise, engineering designs, and equipment. The TTC organises regular collaboration meetings where new developments are reported, recent findings are discussed and technical issues are concluded.

Renewable Energy Technology Showcase Event

The Renewable Energy Technology Showcase Event was organised by STFC in collaboration with the Electronics, Sensors, Photonics KTN in London on the 27 February 2013. The development and applying of renewable energy technologies are essential for reducing carbon emission. The aim of this event was to enhance knowledge, skills and technology transfer from the STFC funded researchers to the UK economy.

From one side the STFC Futures and KNT representatives gave talks on various available ways of supporting the collaborative projects through its family of funding schemes, which include the Innovations Partnership Scheme (IPS and Mini-IPS) and an annual challenge led CLASP call.

From another side the STFC researchers gave talks on technologies developed through STFC funding and demonstrated successful application of technology, originally developed for use in fundamental physics experiments, to the renewable energy sector. Dr Oleg Malyshev from ASTeC gave a talk entitled 'Modern Getters, Non-evaporable Getter Coatings and their Applications' in which he demonstrated the benefit of using NEG coatings for ultra high vacuum solar collectors. The talk was well received followed by a number of questions.

The whole event was found by the industrial participants to be a very useful meeting.

£30 Million to Lead Global Computing Technology

Chancellor of the Exchequer, Rt. Hon George Osborne MP touring VELA

A major new £30 million government investment was announced, 1 February 2013, by the Chancellor of the Exchequer, Rt. Hon George Osborne, as he visited the Science and Technology Facilities Council's Daresbury Laboratory. The investment, part of the £600M announced in the 2012 Autumn Statement, is designed to firmly establish the UK as the world leader in energy efficient supercomputer software development to meet big data challenges. Economy boosting partnerships between research and industry are just some of the benefits poised to come from investment that will confirm the UK as a leader in the development of energy efficient super-technologies and software.

£19M of this investment has been allocated to Daresbury Laboratory's Hartree Centre, the world's largest centre dedicated to software development and home to the most powerful supercomputer in the UK. The investment will support the progress of power efficient computing technologies designed for a range of industrial and scientific applications, and particularly in the development of software that can handle the huge amounts of data created by large experimental research initiatives, such as the Square Kilometre Array (SKA) and CERN, the largest generators of scientific data in existence.

The Chancellor, Mr Osborne said: 'Britain is in a global race and we are in a position to lead the way in science and technology. Projects like the Daresbury development are crucial to boosting the economy and putting the UK at the forefront of the big data revolution.'

The other £11M have been earmarked for the SKA, the world's largest radio telescope, to develop the software capable of handling the unprecedented amount of data it would produce. To put this into perspective, the data collected by the SKA in a single day would take nearly two million years to playback on an iPod.

Minister for Universities and Science David Willetts, who accompanied Mr Osborne, said: 'The next generation of scientific discovery will be data-driven. This £30 million investment will support one of the world's leading high performance computing software centres. It will help ensure UK science and industry remains at the very forefront of research and development.'

Professor John Womersley, Chief Executive at STFC, said: 'This investment will enable the development of new, more capable and more energy efficient computing for an immense range of applications. For industry this could mean extreme modelling for smart materials for industrial adhesives or coatings, or in the engineering and manufacturing for the car and aerospace industries. For the consumer, it could result in longer life mobile communications for phones and tablet computers. With the government's strong support and continued investment, we can convert world leading R&D into commercial opportunities, and provide UK businesses with the technology they need to be able to grow and compete on a global scale. We have already started to work with a number of major industrial partners and this announcement confirms how important science and technology are to the UK economy.'

During his visit Mr Osborne saw how the Hartree Centre is already seeing the benefits of recent government investment, through which partnerships with companies such as IBM and Intel are already in place. He also heard how a new strategic collaboration with Unilever will use high performance computing to develop new software tools that will speed up its product development processes and time to market for new products.

Mr Osborne went on to see how companies, such as Bentley, are able to use the Hartree's cutting edge 3D Visualisation Suite to dramatically reduce the number of prototypes required in the development cycle of a new model. He also saw the most powerful supercomputer in the UK in action, the IBM BlueGene/Q. Known as the Blue Joule it is also one of the most energy efficient supercomputers in the world and was the result of Government investment as part of its e-infrastructure initiative in 2011/12, which resulted in a 'collaboratory' partnership with IBM. Mr Osborne also heard about a further, new strategic partnership between the Hartree Centre, IBM and the Lawrence Livermore National laboratory in the US, which will focus on the twin goals of assisting industry to exploit today's high performance computing systems whilst enabling the development of the critical software that will run on the supercomputers of the future.

Professor Womersley added: 'It is really encouraging that the government recognises the critical role that the relationship between science, innovation and industry plays in supporting economic growth in the UK. Here at Daresbury, which sits within the thriving and successful Sci-Tech Daresbury Enterprise Zone, we have world leading research, facilities and skills working with the smallest of SMEs to the largest, most impressive industrial names, that together will drive innovation and help rebalance the UK economy.'

The Chancellor of the Exchequer, Rt. Hon George Osborne MP

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CN Booth, P Hodgson, L Howlett et al
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A Bowfield, GM Holder, D Moss et al
Fundamental Differences in Model Cell-surface Polysaccharides Revealed by Complementary Optical and Spectroscopic Techniques
Soft Matter 8 (24) 2521-2527 (2012)

SJ Brooks
Vertical Orbit Excursion Fixed Field Alternating Gradient Accelerators
Phys Rev Special Topics 16, no. 8 (2013): 084001

Author's names may appear here in a different order than in the journal or conference proceedings.

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J Chem Phys 136, no. 6 (2012): 064520

G Burt, A C Dexter, P Goudket et al.
Phase Space Analysis of Multipactor Saturation in Rectangular Waveguide
Physics of Plasmas 19 (3) 032106 (2012)

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8 FINANCE

ASTeC ACTIVITIES 12/13

INCOME SOURCES 12/13	£K
SCIENCE PROGRAMME	853
CORE ASTeC PROGRAMME	7801
EU	363
OTHER	566
	9716

EXPENDITURE 12/13	£K
SCIENTIFIC & ENGINEERING STAFF COSTS	5117
CONSUMABLES	2944
CAPITAL EXPENDITURE	1655
	9716

EXPENDITURE BY PROGRAMME 12/13	£K
UK-NF PROGRAMME	143
HIGH POWER PROTON ACCELERATORS	1036
STGA00091,STGA00004.2 &3	
HIGH BRIGHTNESS ELECTRON ACCELERATORS	2496
VELA PROJECT	1823
CLARA PROJECT	980
UNDERPINNING RESEARCH	562
COCKCROFT INSTITUTE AND NEW INITIATIVES	549
OTHER PROFESSIONAL ACTIVITIES	874
EU	455
EuroNU,IRUVX,HLLHC,TIARA	
PHOTON STUDIES	187
OTHER REPAYMENT WORK	611
	9716

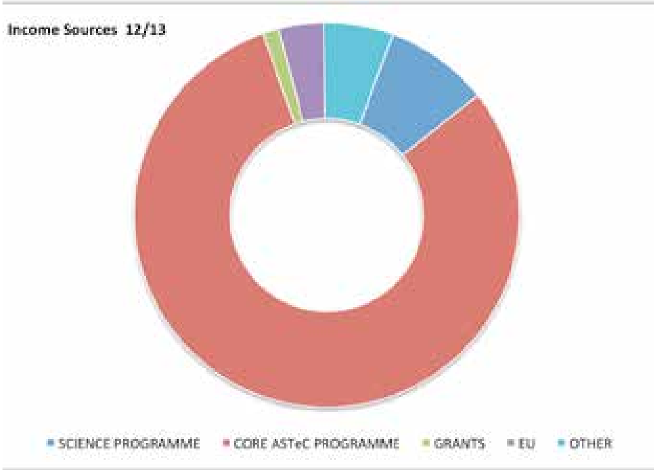
Notes

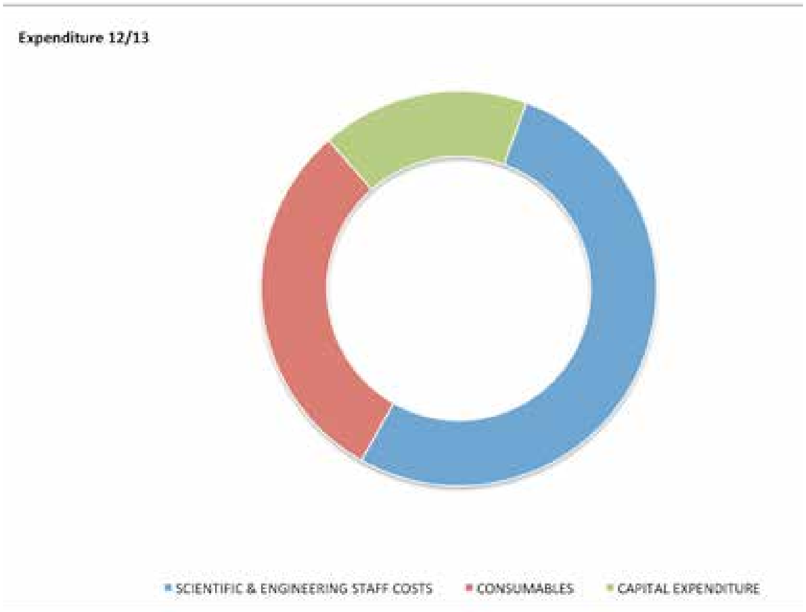
Income earning work has been costed including overheads in the Expenditure by Programme

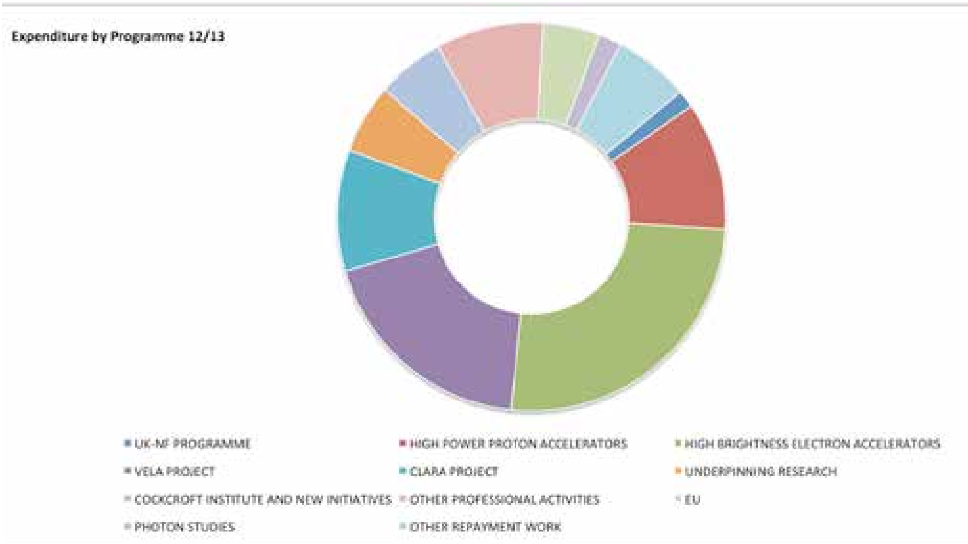
The overhead recovery has been deducted from the Other professional activities which is the ASTeC overheads/ general support cost centre

Lab costs have been taken out of overheads and added to underpinning or Photon Studies

The remaining overheads have not been reallocated. In previous years overheads were added to the Science programme projects e.g. UKNF,FETS


Income Sources 12/13
SCIENCE PROGRAMME
CORE ASTeC PROGRAMME
GRANTS
EU
OTHER


Expenditure 12/13
SCIENTIFIC & ENGINEERING STAFF COSTS
CONSUMABLES
CAPITAL EXPENDITURE

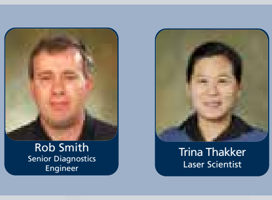

Expenditure by Programme 12/13
UK-NF PROGRAMME
HIGH POWER PROTON ACCELERATORS
HIGH BRIGHTNESS ELECTRON ACCELERATORS
VELA PROJECT
CLARA PROJECT
UNDERPINNING RESEARCH
COCKCROFT INSTITUTE AND NEW INITIATIVES
OTHER PROFESSIONAL ACTIVITIES
EU
PHOTON STUDIES
OTHER REPAYMENT WORK

Science & Technology Facilities Council

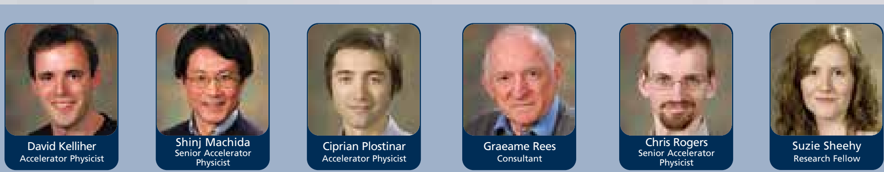
ASTeC

Accelerator Science and Technology Centre

Lee Jones, Senior Accelerator Physicist · Tim Noakes, Senior Scientist · Julian McKenzie, Accelerator Physicist · Boris Militsyn, Senior Accelerator Physicist · Bruno Muratori, Senior Accelerator Physicist · Yuri Saveliev, Senior Accelerator Physicist · Peter Williams, Senior Accelerator Physicist



Rob Smith, Senior Diagnostics Engineer · Trina Thakker, Laser Scientist



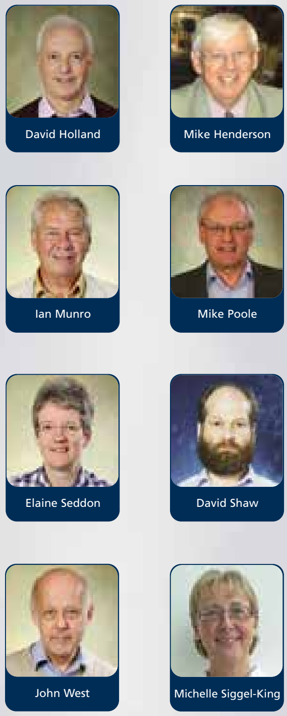
David Kelliher, Accelerator Physicist · Shinji Machida, Senior Accelerator Physicist · Ciprian Plostinar, Accelerator Physicist · Graeame Rees, Consultant · Chris Rogers, Senior Accelerator Physicist · Suzie Sheehy, Research Fellow

Mark Roper, Senior Optics Scientist · Duncan Scott, Physicist · Ben Shepherd, Physicist · Mark Surman, Senior Scientist · Neil Thompson, Senior Physicist · Neil Marks, Consultant

Louise Cowie, RF Scientist · Philippe Goudket, RF Scientist · Lili Ma, Diagnostics Engineer · Andy Moss, Senior RF Engineer · Shrikant Pattalwar, Senior Cryogenics Engineer

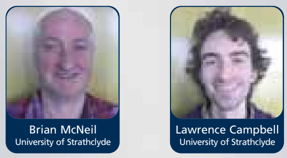
Keith Middleman, Senior Vacuum Scientist · Mark Pendleton, Vacuum Engineer · Reza Valizadeh, Senior Materials & Surface Scientist

Honorary Scientists



David Holland · Mike Henderson · Ian Munro · Mike Poole · Elaine Seddon · David Shaw · John West · Michelle Siggel-King

Associate Appointments



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