ASTeC SCIENCE HIGHLIGHTS 2013 - 2014

Science & Technology Facilities Council

Science Highlights
2013 - 2014

This report covers the work accomplished by
the Accelerator Science & Technology Centre
(ASTeC) for the financial year 2013 - 2014

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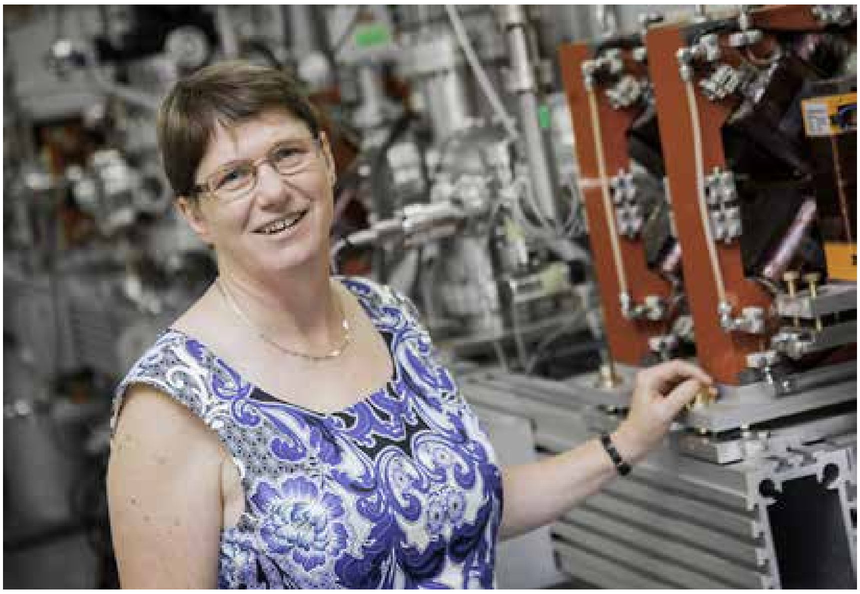


Science Highlights is ASTeC department's opportunity to present our activities across this year as a centre of excellence in accelerator R&D. During a period where funding has been constrained, ASTeC has never-the-less been able to continue to pursue a vibrant programme of R&D, in readiness for anticipated facility investment in the future.

The vison for the CLARA free electron laser (FEL) is to deliver a state-of-the-art facility, pushing the UK to the forefront of FEL research. The conceptual design has been published and subjected to rigorous community review. This review has confirmed that the facility will provide an invaluable and unique scientific capability. The design is demanding, requiring the ASTeC teams and their collaborators provide innovative, technical solutions as the design detail is delivered. The team at Daresbury can be credited for their effort and planning which has allowed us to take on the development of CLARA and undertake our other research programmes whilst operating VELA for our first industrial users. We are now putting the case forward for the capital resources to deliver a fully operational facility in a timely fashion.

As well as delivering on the electron test facilities at Daresbury, the research programme presented illustrates that we are applying our skills and technologies to support a number of national and international facilities. These facility focussed programmes include contributions to Diamond, MICE, LHC, CLIC and SwissFEL. Through this research we are delivering innovative and demanding solutions to tackle challenges in the areas of magnet design, radio frequency, diagnostics, accelerator physics and vacuum. For example, our RF expertise is delivering high power systems to the MICE project, magnets are being developed for Diamond, CLIC and SwissFEL, our vacuum scientists are designing systems for the ELI-NP project and our accelerator physicists are studying a number of beam physics challenges related to the high luminosity upgrade of the large hadron collider at CERN. Much of this research, although undertaken for specific facilities, also develops capabilities with more generic applicability. For instance the laser diagnostic techniques being developed on CLIC will be important to realising the FEL capabilities required for CLARA.

Our research and development programme is very much pursued in partnership with universities and national accelerator laboratories globally, to ensure that STFC and our collaborators can benefit from the sharing of expertise and exploitation of research facilities. A promising collaboration on a bench top plasma trap has been established with a group at Hiroshima University, Japan. This is providing access to a unique simulation tool for intense, space change dominated beams. This collaboration allows ASTeC's Intense Beams group based at Rutherford Appleton Laboratory (RAL), to study important dynamic effects in fixed field alternating gradient (FFAG) accelerators. This type of accelerator could have applications in many areas. For instance FFAGs are being considered in highly ambitious designs to boost the power of the ISIS neutron facility at RAL sometime in the future.

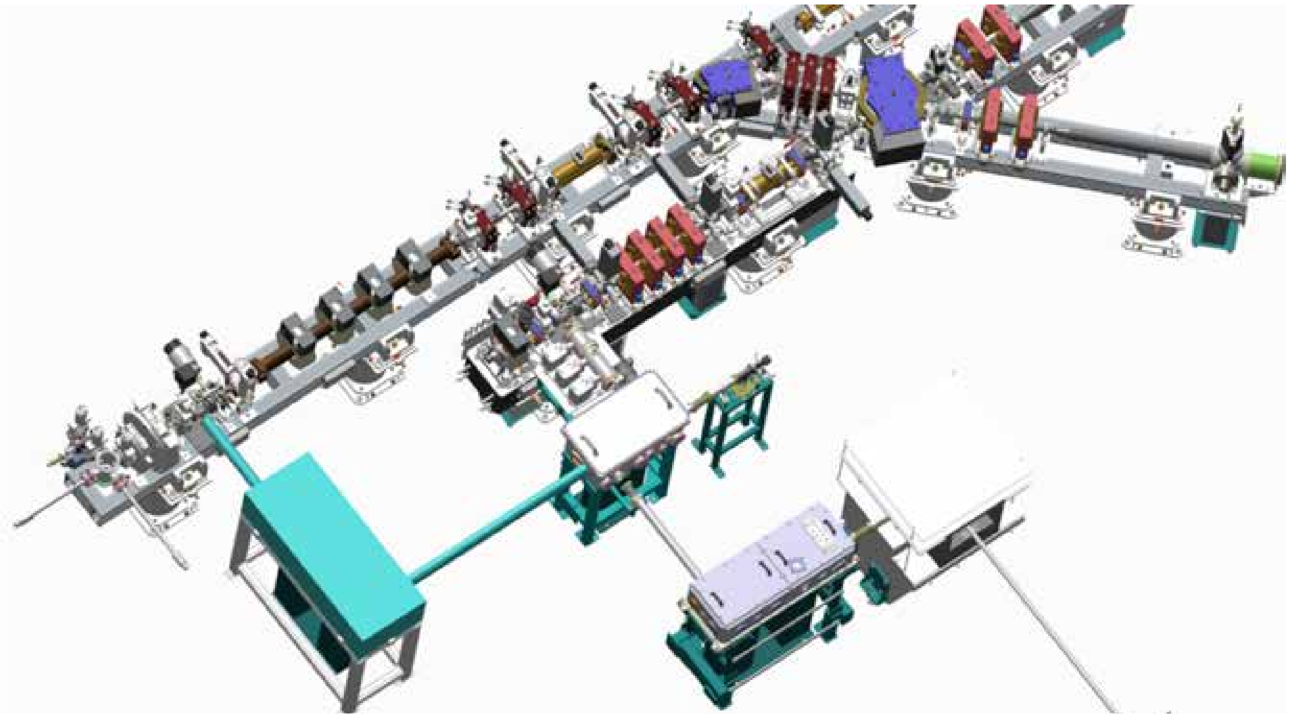
Pushing forward accelerator performance for future applications requires the development and measurement of innovative materials and the investigation of surface properties. Using our extensive analysis equipment, this report outlines progress in a number of project areas which include: the investigation of super conducting coatings for RF-Cavities, non-evaporable getter coatings for long accelerator transport lines, the suppression of secondary electron emission and a general programme on photocathode materials. This research programme will realise results that could have a fundamental impact on the performance and cost of future science facilities.

In this year's report we also highlight the role that ASTeC is taking in training PhD, post-doc and Year In Industry students. With our cutting edge programmes using ASTeC expertise and facilities, we provide a highly stimulating and educational environment to learn in. Through collaborations with the Cockcroft Institute and other UK universities we have nurtured a significant cohort of young researchers. These youngsters get the opportunity to work side-by-side with internationally leading accelerator experts, picking up technical skills and knowledge, which will be widely applicable to both industry and academia in the future.

We continue to lead and collaborate in the delivery of a range of outreach programmes. Our staff have introduced a number of exciting demonstrations to inspire young people to pursue a career in science and engineering. The UK struggles to attract students in general and young women in particular to these subjects, making the success of this activity more important than ever. The participation of students in these outreach events is increasing and student feedback shows that through the enthusiasm and professionalism of our staff we are indeed making an impact. As these students are enthused and encouraged to continue to study so called "hard" subjects, we are helping to meet the demands of an economy increasingly reliant on high-tech skills.

Professor Susan Smith
ASTeC Director & Head of Daresbury Laboratory

CLARA Looking Bright



The Conceptual Design Report for CLARA (Compact Linear Accelerator for Research and Applications) was published by STFC in July 2013 and later in the Journal of Instrumentation (JINST 9 T05001, 2014). The CLARA facility will serve two goals – as a free electron laser (FEL) test facility, able to test new ideas and concepts which would target the generation of ultrashort photon pulse generation and output stability and quality, 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.

The team has continued to develop the design of CLARA in detail and this year has primarily focussed on the Front End, which is the first acceleration stage after the photoinjector. A number of key decisions had to be taken before tendering for the major RF and magnet components. The layout of the Front End is now set in stone and contracts have been placed for the normal conducting linac (Research Instruments), which will increase the beam energy to over 50 MeV, and the associated klystron (Thales) and modulator (Diversified Technologies). The other major order was for the quadrupoles, dipoles, and corrector magnets that are required for this section. These magnets are now being fabricated by Danfysik in Denmark.

The integration of CLARA alongside VELA has called for some innovative engineering and physics solutions to enable VELA users to benefit from the increased energy beams from CLARA but also whilst minimising the enforced downtime during which CLARA will be installed in the same enclosure. The solution adopted has been to place CLARA parallel to VELA, offset by 1.25 m, and to incorporate a short section which connects

CLARA to VELA, enabling the brighter and more energetic electron beam from CLARA to be sent to User Areas 1 and 2 of VELA for industrial and academic users. The short beamline connection between CLARA and VELA works in a similar way to the points on a railway track, using strong dipole magnets to steer the electrons from one line to another when required.

A major consequence of the integration of the CLARA Front End with VELA is on the concrete shielding required for radiation protection since the photoinjector for CLARA is approximately 3 m further back than the existing VELA photoinjector. This has meant that the back shield wall and nearby access labyrinth has had to be completely redesigned, in conjunction with experts in calculating the levels of radiation generated by relativistic particles, and this work is now complete. The wall and labyrinth will be rebuilt during a dedicated shutdown at the start of 2015.

The science case for CLARA has continued to grow with a detailed proposal developed for plasma acceleration using the electron beam of CLARA as the drive beam by academics from Strathclyde and Manchester Universities. This novel method of acceleration is now receiving considerable attention as it promises very high accelerating gradients and very low emittance beams. Two other experimental test facilities are under development in Europe, SPARC at INFN Frascati and FLASHForward at DESY, and we are working closely with colleagues from these other facilities to generate a complementary experimental programme to maximise the role of Europe in this exciting new area of accelerator science.

The alternative to electron driven plasma acceleration is laser driven plasma acceleration and many groups within the UK have expertise in this area. One of the key problems for the experimental groups is access to high enough power lasers. Fortunately, ASTeC has a 20 TW laser which was previously used on ALICE for a Compton back-scattering programme, and this laser is ideal for laser driven wakefield studies. A new laser room has now been built adjacent to the VELA/CLARA enclosure so that the 20 TW laser can be exploited in conjunction with the bright electron beams available. This laser has now been relocated within this new room and recommissioned. Initial plans are now in place for exploiting this laser in 2015, in conjunction with plasma experts from UK academia.

Another technology which is receiving much attention at the moment is the use of X-band linac structures (12 GHz) instead of the more common S-band systems (3 GHz). The X-band systems have been developed by both CERN and SLAC for next generation lepton colliders but they could also be appropriate for future FELs. Their key advantages are enhanced accelerating gradients, which means that the same final energy can be achieved in a much smaller building, and also the lower electrical power consumption – a major issue for all new accelerator facilities. Overall the cost benefit to a future accelerator could be very attractive. ASTeC staff visited CERN to discuss a possible long term collaboration in this area and the CERN team were very excited by the prospect of carrying out genuine FEL beam tests on CLARA as access to such a test facility is not currently available to them. The CLARA team is now examining the implications of using a CERN built X-band linac structure instead of the last S-band linac structure which is currently in the baseline design. Since all of the remaining required S-band linacs are being given to CLARA by PSI in Switzerland, in return for experimental access to CLARA, it is possible for CLARA to start with all S-band systems in the short term and to swap the last one to X-band in the future when CERN have fabricated an appropriate structure optimised for FEL use.

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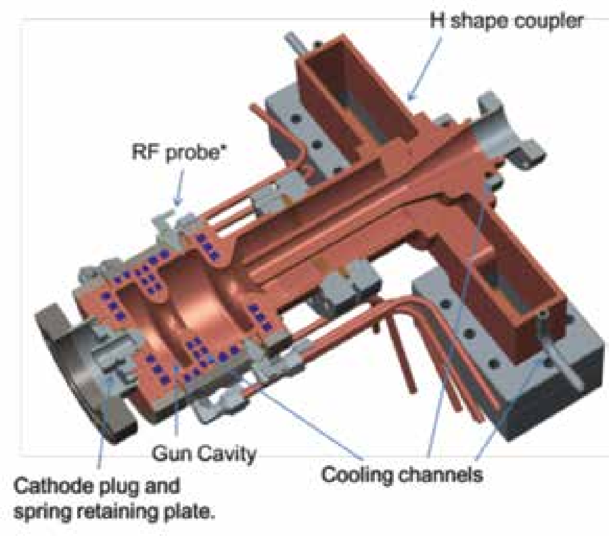
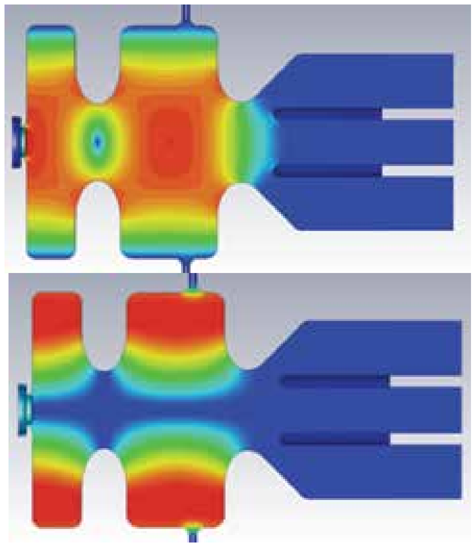
High Repetition Rate Photocathode Gun for CLARA



Mechanical model of the gun showing the coaxial coupler and cooling channels



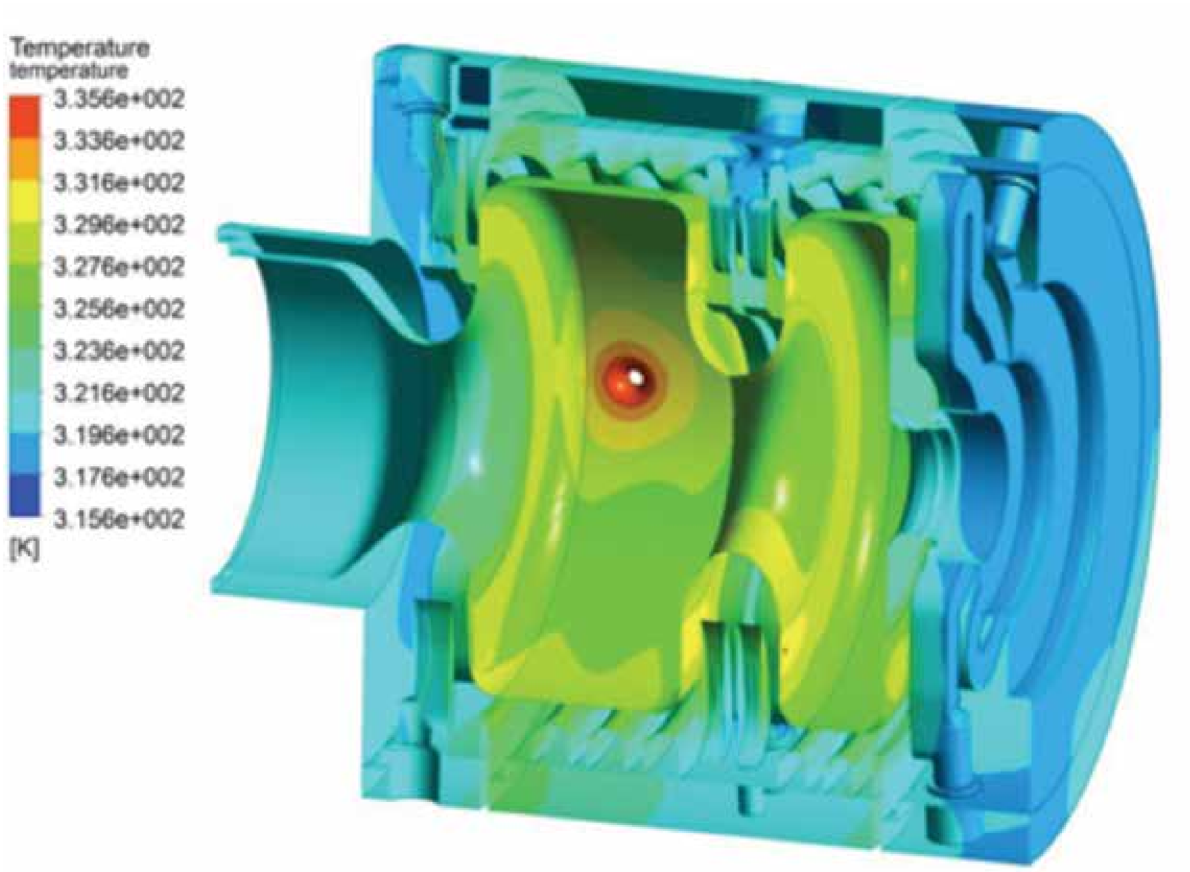
Electric (top) and magnetic (bottom) field distributions in the cavity

As part of the CLARA (Compact Linear Accelerator for Research and Applications) project and in order to fulfil requirements for operation of VELA at high frequency, a highly stable High Repetition Rate photocathode Gun (HRRG) is under development at ASTeC. This gun can also be considered as an electron source for a future UK Free Electron Laser. Operating as the VELA/ CLARA electron source requires the gun to deliver ultra bright, with emittance less than 1 mm·mrad, 250 pC electron bunches at a repetition rate of up to 400 Hz. Experiments on CLARA with laser-beam interaction demand phase and amplitude stability of the gun of 0.1° and 0.01% respectively. These requirements for the gun performance challenge the ASTeC and TD design team to reach world class expertise in the design of high power RF structures.

In order to optimise the longitudinal and transverse beam parameters, a 1.5 cell S-band scheme operating with the maximum operational field of up to 120 MV/m has been chosen. The gun will be fed with a coaxial coupler integrated with a novel H-shape dual feed. Due to the tight synchronisation requirements for operation with CLARA, an RF probe is introduced for active monitoring of the field in the gun and to provide information for feed-forward and feed-back systems. This also imposes very high requirements to the gun thermal stabilisation system which should maintain the gun temperature at a level of 0.01°C. A state of the art chiller is under development along with the gun.

The RF design of the gun has been optimised using RF simulation codes including Superfish and CST Studio Suite. The cells are cylindrical with rounded edges to allow for a better distribution of the peak magnetic field and, as a result, heat load. The irises between the cells have an elliptical shape and were optimised to minimise peak electric fields to prevent field emission.

Operating in the VELA mode at a field of 100 MV/m and a repetition rate of 400 Hz the heat load will be as high as 6.8 kW so an effective cooling is required. This will be provided by water channels cut into the bulk of the cavity.



Calculated distribution of the temperature on the cavity surface

The design of the channels is informed by fluid dynamics simulations of the cavity and coupler taking into account the distribution and magnitude of the RF field.

The gun will be equipped with a photocathode exchange system to accept photocathode plugs of the INFN/DESY type. Such a system allows for cathode changeover without breaking the cavity vacuum, and enables different metal and alkali photocathodes to be tested. The cathode is inserted through a plug in the back plate of the first cell.

The gun cavity will be surrounded by a solenoid for emittance compensation and transverse focussing, as well as a bucking coil behind the cavity to cancel the magnetic field on the cathode plane. It will initially be tested on the VELA bench which is equipped with a suite of diagnostics to fully characterise the 6D phase space of the emitted electron beam.

As a first stage, the recently upgraded 400 Hz high power RF system will be commissioned. For that purpose the cavity designed at Diamond Light Source Ltd will be used as a temporary load. It will allow for commissioning both the DLS cavity and ASTeC thermal stabilisation system.

The design has been done by the ASTeC, Technical Department and Lancaster University team in collaboration with the Institute of Nuclear Research of Russian Academy of Science well known for its contribution to the design of PITZ/FLASH/X-FEL injector.

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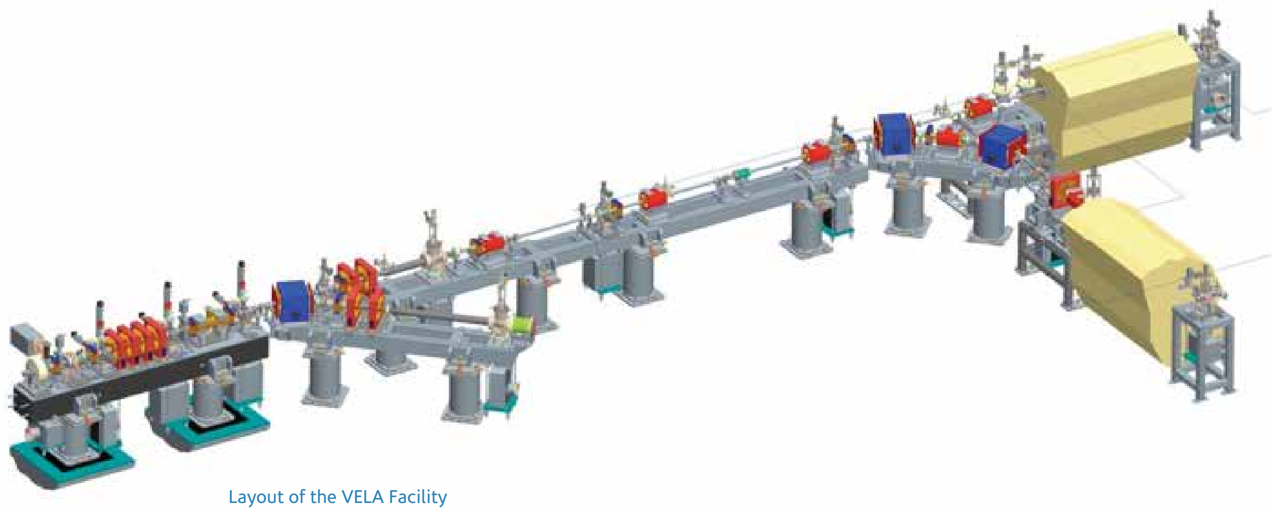
VELA

Beam Commissioning and Delivery of Beam to First Users



Layout of the VELA Facility

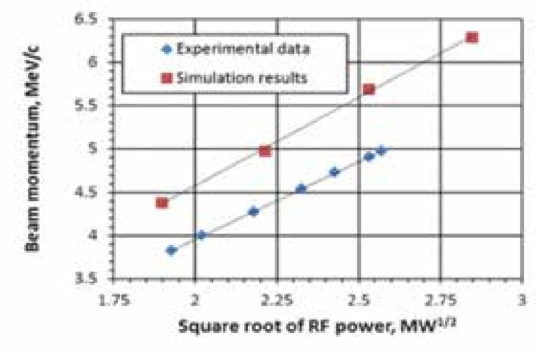
The Versatile Electron Linear Accelerator (VELA) facility at Daresbury Laboratory has been purpose-designed to provide infrastructures targeted at the development and testing of novel and compact accelerator technologies. The facility has now been commissioned at Daresbury Laboratory and is being utilised by academic and industrial groups who are able to take advantage of the variable electron beam parameters available on VELA to either demonstrate new techniques and/or processes or otherwise develop new technologies for future commercial realisation.

After achieving the first beam from the VELA photo-injector on 5 April 2013, beam was successfully provided to first commercial users in the purpose built user area in September 2013. Machine study runs have concentrated on characterisation of main beam parameters like bunch charge, its momentum, beam emittance and dependence of these parameters on the launching RF phase, dark current from the gun and long term stability of the photoinjector.

The VELA beam line comprises a dedicated diagnostics suite including a spectrometer beam line to characterise beam from the photoinjector. A beam momentum of 4.9 MeV/c has been measured with power of ~6.5 MW measured at the entry of the gun. Several devices are used to measure the bunch charge, a Wall Current Monitor (WCM) placed immediately after the gun, Integrated Current Transformer (ICT) located at around 6.5 m downstream from the gun, and Faraday Cup (FCUP) at the end of the beam spectrometer line. A temporary FCUP was installed in user area1 and a sum signal of Beam Position Monitor (BPM) located adjacent to this FCUP. It was calibrated before connecting the user kit to give an indication of beam charge being delivered to the user.

A Transverse Deflecting Cavity (TDC) will be installed before the spectrometer dipole next year for detailed 6D beam characterisation. Bunch length can be measured by using a TDC to streak the longitudinal position of the particles onto the transverse plane,

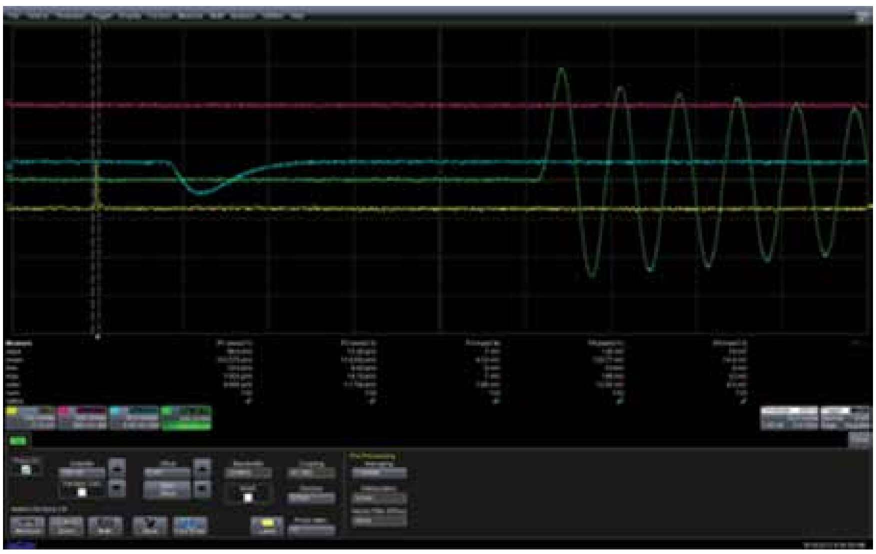
Beam on YAG screen



Measured and Simulated Beam Momentum vs sqrt of power in the gun

thus making it viewable on the YAG screen. Furthermore, if the streak is performed in the vertical plane, then passing the beam around the horizontal spectrometer dipole will make the longitudinal phase-space directly viewable on the screen. Combining the TDC with the transverse beam diagnostics will allow time-sliced emittance measurements to be made.

Rapiscan Systems produce a wide range of security scanning and screening equipment to the civil aviation and cargo handling industries amongst others. In ever more vigilant times, manufacturers of such equipment are continually looking to improve threat detection through enhanced image resolution, full 3D imaging and accurate material identification, whilst the need for increased throughput requires detection systems to be more convenient in terms of installation, simple to use and cost effective in order to promote widespread adoption. Rapiscan's solution, in collaboration with the University College London (UCL), combines Compton Scatter Imaging with time-of-flight information of the photon to recover the point of interaction and provide 3D information about the object. This requires a high flux, high energy beam with extremely narrow pulse widths and advanced diagnostics to successfully image the object. VELA therefore provides the ideal tool to demonstrate the feasibility of such a technique and close collaboration between STFC and Rapiscan enabled a suitable experimental arrangement and data collection protocol to be devised.



Oscilloscope traces showing measurement of charge in WCM (yellow trace) located immediately after the gun, ICT (light blue trace) located at a distance of ~7m from the gun and temporary FCUP in User area 1 (green trace) before connecting the user station

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VELA

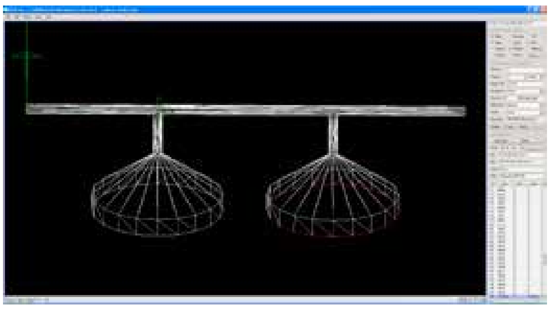
Challenges of VELA Laser Transport Vacuum System

The VELA accelerator generates electrons by utilising a UV laser pulse at 266 nm on to a polycrystalline Cu cathode inside the RF gun. The laser is transported under a vacuum of 10^{-6} mbar whilst the RF gun operates in an ultra high vacuum of 10^{-10} mbar.

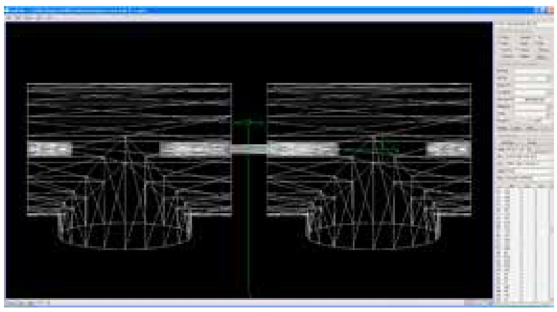
Initially a decision was made to separate the two vacuum systems by a vacuum window, however, after looking at the design more closely it was decided a window was not possible due to adverse effects on the quality of the laser pulse.

As a result, a differential pump system would be required to minimise the impact of the laser transport vacuum system at 10^{-6} mbar on the 10^{-10} mbar vacuum of the RF gun all within a 50 cm space. Four different systems were modelled and the results are presented below.

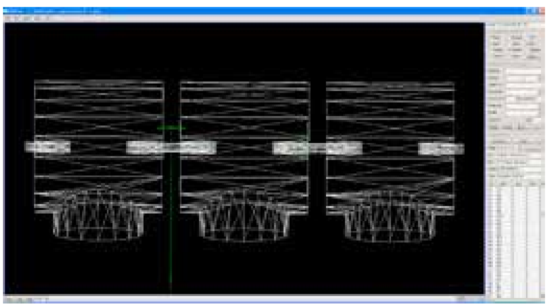
Boundary conditions were set for each model, 1 x 10^{-5} mbar at one end (laser transport) and 1 x 10^{-9} mbar at the other end (VELA lightbox). The idea behind the structures is that there is a tube which requires a minimum of 10 mm diameter for laser transport and the pumping ports are there to enable the capture of gas molecules. The 1st design was the simplest solution but the modelling results shown below indicate that it is a poor design. Designs 2 and 3 show a break in the central tube, this is to allow the gas molecules to escape and be pumped and these solutions are ideal as shown by the results. Design 4 was the same as design 2 except that the central tube was reduced from 10 to 8 mm, this was to analyse the impact on the vacuum performance.



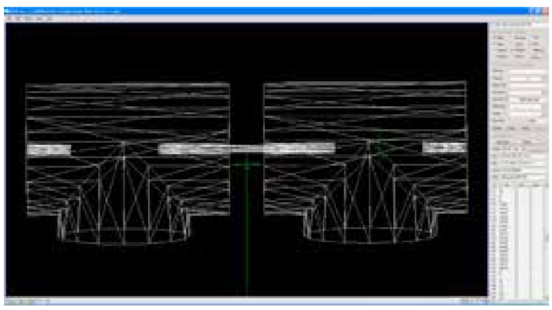
1st design – 10 mm tube



2nd design – 10 mm tube

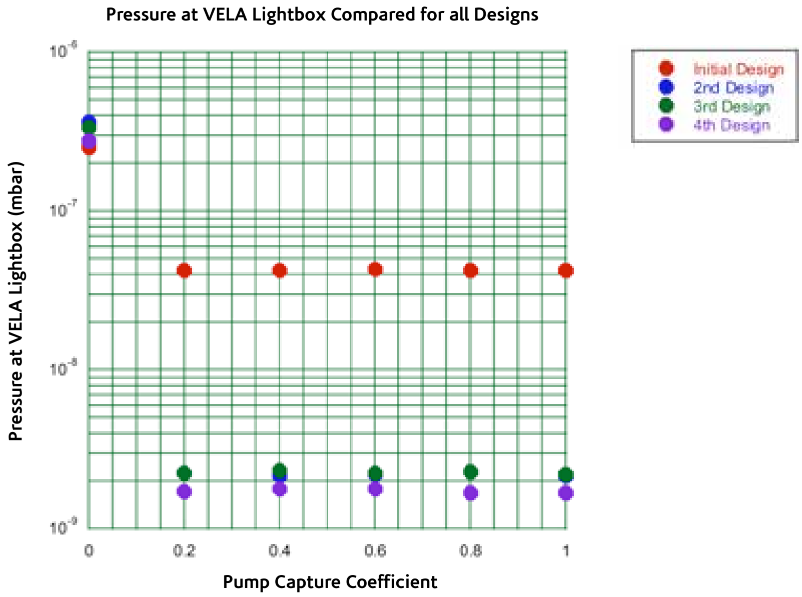


3rd design – 10 mm tube

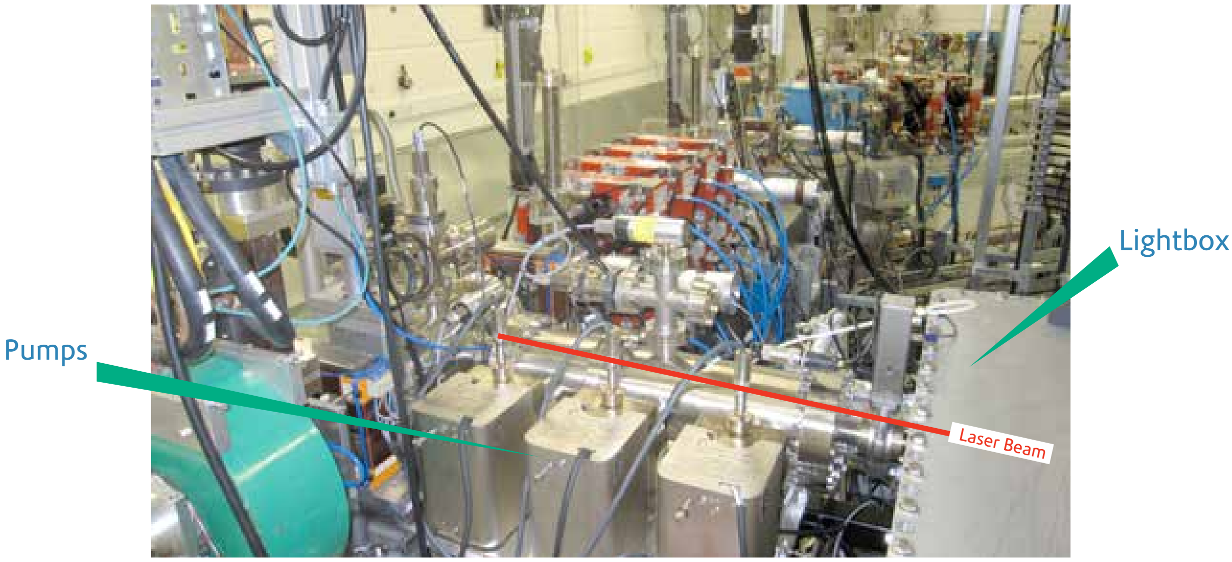


4th design – 8 mm tube

Four different pumping system designs studied with MOLFLOW code



Results of modelling for differential pumping system of VELA laser transport system



Picture of the differential pumping system, based on the 3rd design installed on VELA

As seen above, as the sticking coefficient increases the pressure at the VELA lightbox remains the same, this indicates that for all 4 design solutions increasing the pumping speed has no effect at all on the pressure at the VELA lightbox. This is because there is a strong beaming effect between the laser transport system and the VELA lightbox, essentially 1 in every 10000 molecules is travelling directly from the laser transport vacuum straight in to the VELA lightbox, irrespective of pumping speed. As a result of this work design 3 was chosen and implemented and has been successful. A picture of design 3 on VELA is shown above.

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Photocathode Research and Development

The transverse energy spread spectrometer (TESS)

The development of photocathodes for high brightness electron sources continues to be an important part of ASTeC's underpinning research portfolio. High brightness sources are essential for the next generation of electron accelerators, both for light source applications such as FELs and ERLs and for e^+/e^- colliders for high energy particle physics. In these machines brightness can often be limited by the intrinsic emittance of the electron beam produced at the photocathode. It is for this reason that a key part of ASTeC's photocathode research includes the continued development and exploitation of the transverse energy spread spectrometer (TESS) that will allow detailed measurement of this important parameter. This instrument allows both transverse and longitudinal emittance to be characterised with excellent resolution and is initially being used with GaAs (Cs,O) photocathodes such as those used in the ALICE accelerator at Daresbury. A considerable amount of effort has also gone into the investigation of metal photocathodes, which are being developed for the VELA accelerator and future CLARA project. Surface analysis and techniques are being used to evaluate alternative metals and preparation procedures with a view to producing photocathodes that will give improved performance, both in terms of quantum efficiency and bunch properties. This year an additional capability for metal photocathode research has been developed, in the form of a compact UV laser system, which is currently housed on the surface characterisation instrument, but could also be used on TESS and our multi-probe surface analysis system in the future.

Transverse Electron Energy Spread Spectrometer (TESS)

The TESS instrument, which is housed in the vacuum science laboratory in the Cockcroft Institute building, has been developed to allow the characterisation of the energy spread of electrons generated from a photocathode in the absence of the large fields and possible effects of space charge typically seen in a real accelerator environment. Sample photocathodes can be mounted on an electrically isolated stage that allows the potential to be precisely controlled; it also has the capability to be cooled with liquid nitrogen.

The photocathodes can be illuminated by a series of LED light sources with different wavelengths that provide the energy to stimulate electron emission. The laser light is focussed into a very small beam, less than 100 microns in diameter. From the photocathode, the electrons traverse a drift space where the transverse energy acts to spread out the electrons, forming a large image on the detector that is collected using a high resolution camera. The data can then be analysed using software developed as part of the on-going collaboration between ASTeC and the Institute of Semiconductor Physics in Novosibirsk (part of the Siberian Branch of the Russian Academy of Science) who also played a key role in the development of the instrument. This analysis allows the mean transverse energy to be extracted from the raw images.

A series of experiments have been carried out to monitor the change in quantum efficiency (the fraction of incident photons that lead to an emitted electron) and transverse energy spread as a cathode is purposefully degraded using oxygen (a common contaminant in accelerator vacuum systems).

These experiments were carried out using low quantum efficiency (positive electron affinity) GaAs (Cs,O) photocathodes illuminated with a red (635 nm) laser light source. As expected for positive electron affinity cathodes, although the quantum efficiency dropped as the exposure time increased, the transverse energy spread remained essentially unchanged. Results from higher quantum efficiency, negative electron affinity, GaAs (Cs,O) photocathodes are expected in the very near future.

Further development of the TESS instrument this year has included the commissioning of longitudinal energy spread measurements as part of a Cockcroft Institute collaboration with the QUASAR group in the University of Liverpool. The TESS detector features three fine mesh grids directly preceding the multi-channel plate and scintillator screen detector. If the first and last grids are held at earth potential then a bias applied to the central grid can be used as an energy filter for the emitted electrons. By measuring the total intensity seen by the detector (channel plates, screen and camera) as the central grid potential is raised, a plot can be obtained which when differentiated numerically will provide the longitudinal energy distribution. It is hoped to compare the longitudinal energy resolution with predictions made by electrostatic modelling of the TESS detector carried out by the Liverpool group.

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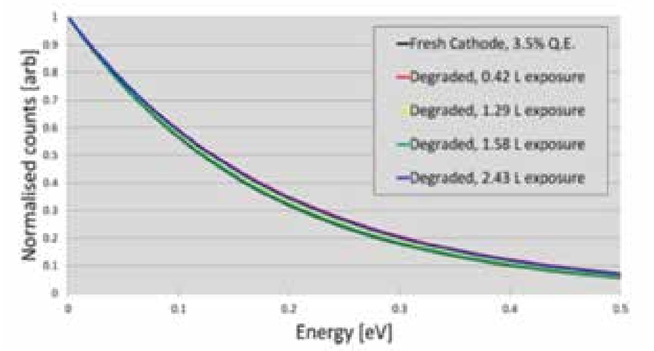
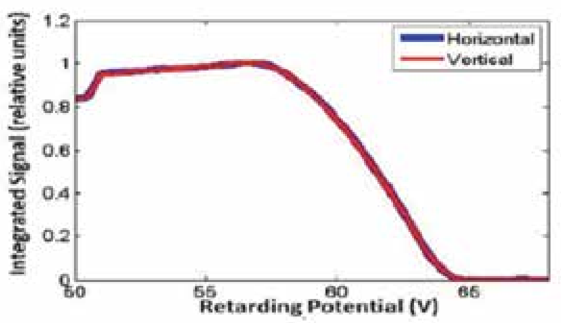
An exploded view of the TESS detector



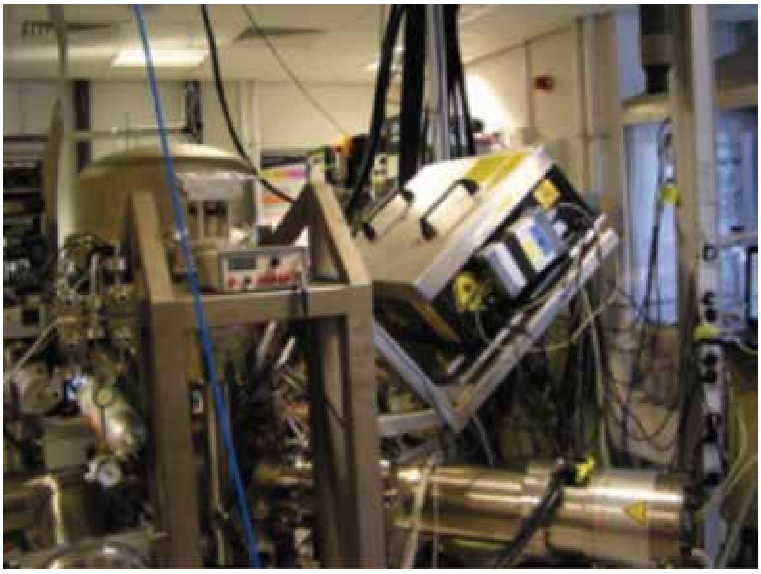
TESS data from a degradation experiment using a PEA GaAs (Cs,O) photocathode



The longitudinal energy spread data taken by varying the potential on the middle grid

Metal Photocathode Research

Research into the use of metal photocathodes for normally conducting RF guns has continued, motivated by the use of these materials in the VELA (and future CLARA) accelerator.
An oxygen plasma treated copper photocathode has been used successfully in the VELA RF gun for the past year and estimates of quantum efficiency of 2×10^{-5} are in line with predicted values from previous laboratory based studies.
This year, effort has been focussed on the screening of a number of different metals to try to identify an improved alternative to copper for this application.



The new compact UV laser system on the ESCALAB Mk. II instrument

The alternative metal samples were cleaned by argon ion sputtering before analysis. X-ray photoelectron spectroscopy (XPS) was used to determine surface cleanliness, a Kelvin probe apparatus was employed to measure the work function and quantum efficiency was evaluated using a UV LED source, coupled with sample drain current measurement.
For some samples, analysis was also carried out after a gentle annealing to 200 °C, the temperature typically achieved during vacuum baking of the VELA RF gun. In trying to compare the quantum efficiency measurements with the work function measurements, it was difficult to see any clear correlation. This suggests that the improvement in quantum efficiency typically seen after ion cleaning does not simply arise as a result of a reduction in work function, but has more complex origins. The best quantum efficiency achieved was with the magnesium sample, which was not unexpected as many other groups have identified this material as a good candidate for this application. Interestingly, the magnesium sample exhibited high quantum efficiency despite the significant levels of oxygen (seen by XPS) remaining at the surface even after ion bombardment cleaning. Lead and niobium samples were also seen to give high quantum efficiency; these metals could be used in superconducting RF guns. Further work in this area will be directed towards alternative sample cleaning procedures, such as oxygen plasma cleaning, that will give rise to less surface roughening than the ion bombardment procedure used here.

Quantum efficiency measurements made during these experiments were carried out using an LED UV light source (265 nm wavelength). There were two drawbacks of using this source, the low intensity (making accurate measurement of the drain current difficult for low quantum efficiency materials) and high bandwidth (12 nm FWHM). For these reasons a new compact UV laser source has been developed to replace the LED in these experiments. The UV laser at the heart of this new capability is an off-the-shelf model, but considerable effort has been required to prepare it for use in a standard vacuum science laboratory not normally used for laser experiments Initial tests suggest improved light intensity from this system, evidenced by significant increases in the photocurrent generated, which also has at least two orders of magnitude less bandwidth. In the first instance, commissioning has been carried out using the surface characterisation instrument, but in future the laser could be used on both the new multi-probe surface analysis system and TESS, where the better beam profile characteristics it offers will also be required.

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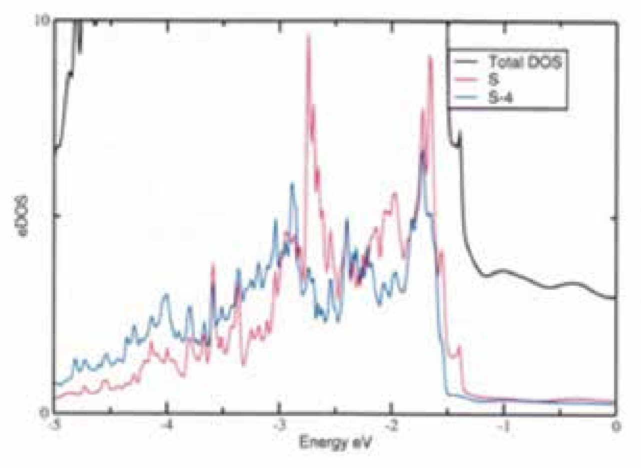
Theoretical Modelling of Photocathode Materials

Recently, a new collaboration has been initiated between ASTeC, the Scientific Computing Department at Daresbury and researchers at Imperial College on the theoretical modelling of photocathode materials. This project involves expertise in the use of density functional theory (DFT) to calculate the electronic band structure of materials. From the band structure the electronic density of states in both the bulk material and surface region can be derived, and from this information it should be possible to predict the photoemission properties of the materials that are critical to their performance as photocathodes. In the first instance, this work will concentrate on metal photocathodes, again because of their importance to on-going projects in ASTeC (VELA and CLARA).

A student has been recruited by Imperial College to work on this collaboration and has already had success in using DFT to generate the electronic band structure of clean single crystal copper. A comparison of the density of states of the bulk and surface region of copper shows significant differences as a result of 'surface' states. These states are likely to be highly susceptible to the presence of adsorbed species at the surface and indicate once more the likely sensitivity of photocathode performance to small levels of surface contamination. The next stage in the process is to derive the important photoemission properties such as quantum



Electronic density-of-states calculated for the surface (red) and sub-surface (blue) regions of clean single crystal copper

efficiency, transverse energy spread and time response from this information. Alternative methods of achieving this are being investigated, including using the well known Spicer three step model of photoemission.

It is hoped that this work will lead to a greater understanding of the behaviour of current photocathode materials and how they change with use in the accelerator environment. In addition, modelling could allow rapid screening of new materials that might provide enhanced performance in this demanding application.

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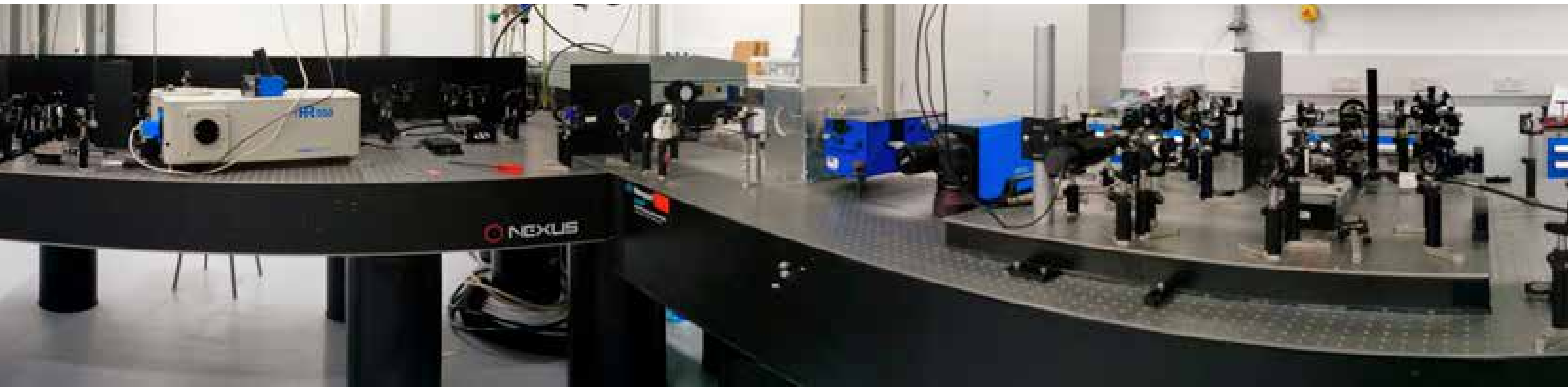
The kick-off meeting for the ASTeC/Scientific Computing/Imperial College collaboration on theoretical modelling of photocathode materials

Laser Diagnostics

Pushing the Boundaries of Ultrafast Electro-Optic Detection

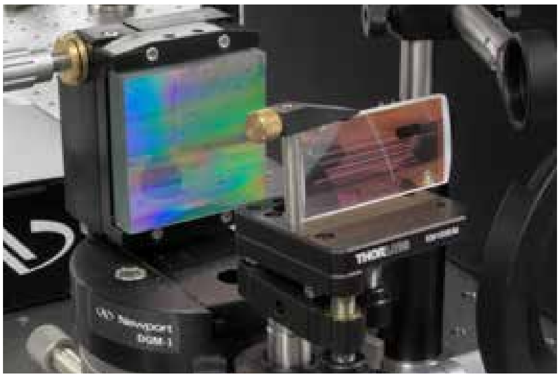


View from inside the new Laser, Terahertz and Terawatt Experiments ('Latte') laboratory at Daresbury, housed in the VELA/CLARA outer hall

In the operation and utilisation of modern linear electron accelerators, including Free Electron Laser facilities such as CLARA, accurate knowledge of the longitudinal electron bunch profile is vital. Direct particle methods, such as transverse deflecting cavities, can provide this information but destroy the beam in the measurement process; such technology furthermore does not scale well to high beam energies. Over the last decade, electro-optic (EO) detection has provided the means to noninvasively characterise the bunch duration by measurement of the bunch Coulomb field, which is similar in nature to a pulse of terahertz (THz) radiation. The basis of EO detection is to transfer the information associated with a THz pulse into an optical pulse which is much easier to handle and detect; this is currently most commonly achieved through a non-linear interaction in specific types of crystal.

In recent years the shortest pulse duration that could be reliably detected with EO detection was 100 fs, which falls short of modern demands. As part of their involvement in the CLIC-UK project, researchers with the Lasers and Diagnostics Group at ASTeC have been looking to push the boundaries of EO detection towards the 20 fs target of CLIC, whilst at the same time designing such methods to be as sufficiently robust and practical as possible.

Research performed at Daresbury and published in Optics Express during 2014 has shed light into the geometric factors which influence the temporal limitations of EO detection. Other research has focussed on an experimental simplification of the EO experiment called 'Spectral Upconversion', which utilises optical probe pulses generated using turn-key nanosecond lasers, as opposed to those from more complex femtosecond lasers. This represents a significant technological simplification which also reduces the sensitivity of the diagnostic to timing jitter between the laser and electron bunch.



In April 2014 group members played a vital role in the development and successful commissioning of an EO Spectral Decoding bunch profile monitor on CALIFES, the probe beam line of the CLIC Test Facility 3 at CERN. The experiments were considered a clear demonstration of the reliability of EO detection for diagnostic purposes in the complex environment of a working accelerator. Following on from laboratory experiments performed at Daresbury, a practical demonstration of Spectral Upconversion at a short-bunch facility is planned for the second half of 2014.

In the future the group hope to realise the long-term goal of realising a sub-10 fs electron bunch measurement. This currently requires significant research and development into new non-linear materials for the EO effect. Researchers are currently collaborating with members of the Materials and Photonic Systems Group at Dundee University in the utilisation of novel nanoplasmonic materials.
The output of this research and other future projects has been enhanced following the completion in March 2014 of a new laser laboratory at ASTeC situated immediately adjacent to the VELA and CLARA accelerator beam lines. The Laser, Terahertz and Terawatt (‘LaTTE’) laboratory will not only allow the group to continue their world-class research into non-linear and THz optics, but also presents the opportunity to utilise these accelerators as test platforms for advanced laser diagnostic concepts.

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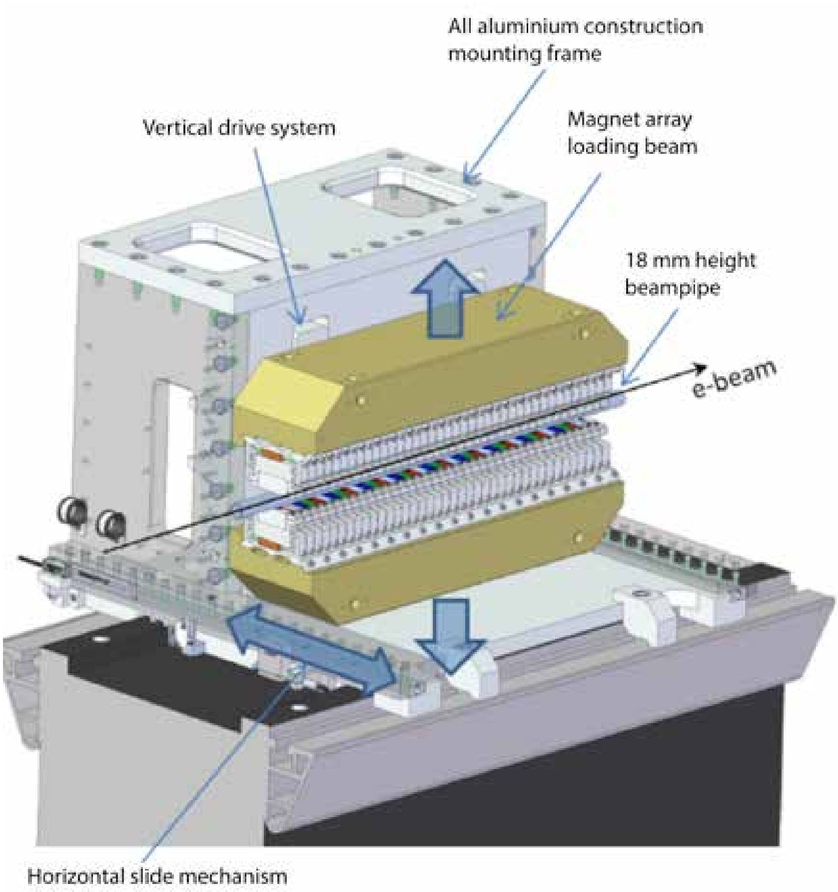
The SwissFEL Laser Heater Undulator, or 'Bazin, the Faithful Servant'



Schematic of Bazin, the undulator for the SwissFEL Laser Heater System

SwissFEL is an x-ray Free Electron Laser (FEL) facility currently under construction at the Paul Scherrer Institute (PSI) near Zurich, Switzerland. It features two separate FELs, named Aramis and Athos, to cover the wavelength range 0.1-7.0 nm. Under a formal Memorandum of Understanding (MoU) between STFC and PSI, ASTeC is contributing in a number of different areas in which our scientists have specific expertise.

One area is a system called the Laser Heater which is required to ensure optimum performance from the FEL. This is because FELs require a high quality electron bunch to lase. One quality factor is the energy spread within the bunch which must be very small. An issue identified in similar FEL designs to SwissFEL is that small intrinsic density modulations in the electron bunch can cause the strong emission of coherent synchrotron radiation (CSR), whenever the electron bunch is steered in a dipole magnet. The energy in this radiation comes from the kinetic energy of the electrons, so the small energy spread in the bunch can be amplified enough to degrade the performance of the FEL. As a solution, somewhat counter-intuitively, the electron bunch can be `heated' by smearing out and enhancing its energy spread artificially while the electrons are at low energy.

This is done using a laser which co-propagates with the bunch through a short array of alternating polarity dipole magnets called an undulator. This creates an energy modulation along the bunch. The electron bunch then passes through a magnetic dogleg in which this energy modulation is 'smeared out' which also then smooths the density modulations which generate the CSR. The result is that when the electron bunch enters the FEL its energy spread is smaller than it would have been without the use of the laser heater, and crucially, small enough for the FEL to lase effectively. In this way the small undulator which forms the heart of the laser heater system has helped the FEL undulators to deliver their best performance. To recognise this, and following the Three Musketeers naming convention in which the FELs are named after musketeers, the laser heater undulator has been called Bazin because he was their faithful servant.

ASTeC's responsibilty is the design, procurement, manufacture, testing and delivery of Bazin. ASTeC physicists have made the necessary calculations and simulations to determine the precise specification of the magnets and the Daresbury Technology Department have designed the support structures to allow the magnetic arrays to be precisely positioned and controlled. The formal specification proposed by STFC was agreed by PSI in December 2013 and construction at Daresbury has now begun. In the following weeks Bazin will be subjected to a programme of mechanical, electrical and magnetic testing before being delivered to PSI ready to perform as the faithful servant of Aramis and Athos.

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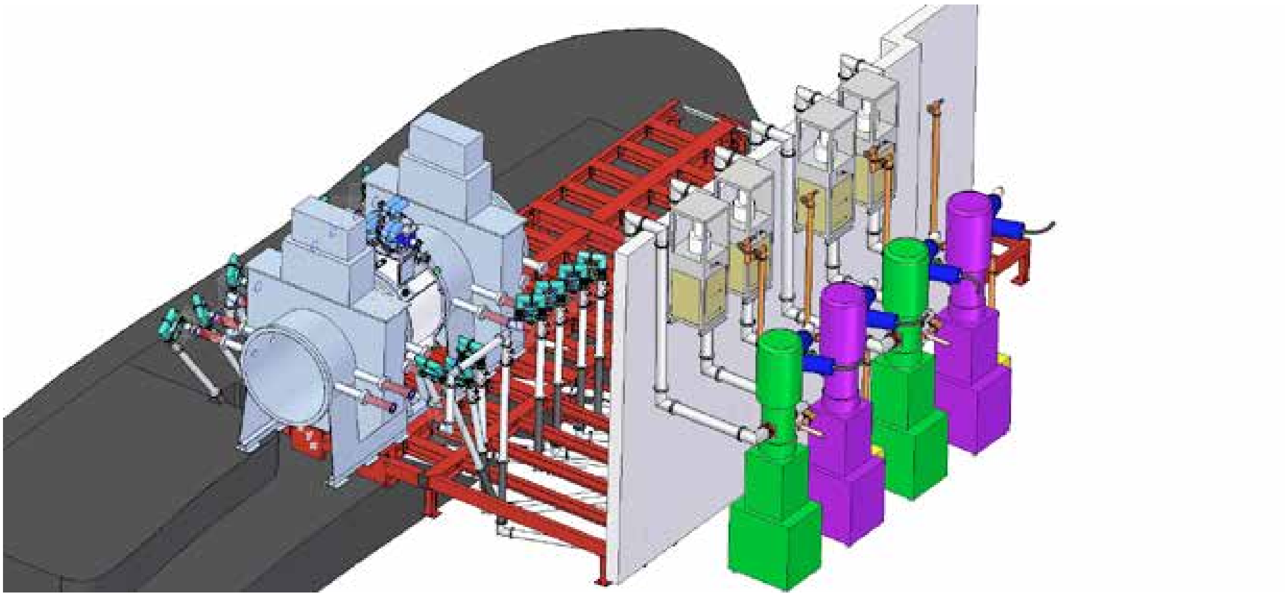
Meeting the MICE RF Requirements



The muon ionisation cooling experiment (MICE) is a demonstration of practical cooling for future muon acceleration schemes. Liquid hydrogen absorbers followed by RF cavities to reaccelerate the muon beam will provide a reduction of emittance in the momentum range of 140-240 MeV/c. For the MICE experiment muons are produced from decaying pions formed by plunging a target into the proton beam of the ISIS synchrotron. The muons produced are relatively random in time so only partial capture and reacceleration within the cooling channel is possible. The RF system consists of a system of amplifiers operating in pulse mode at 1 mSec 1 Hz timed to coincide with the target application. Recent trials with the amplifier have succeeded in operating at the design requirements of 2 MW RF output power at the desired frequency of 201 MHz at the RF test area at Daresbury Laboratory.

The RF power generated by the amplifier system is transmitted to the cooling channel cavities by rigid coax lines pressurised with nitrogen gas; this is done to raise voltage standoff capabilities. As the cavities are fed via two opposing couplers and each amplifier system supplies two cavities the coax system has to include hybrid power splitters. The beam energy then governs the cavity phase angles required and equates to a phase lead of 16 degrees between each second cavity in the distribution chain. This requires the length of each coax run to be designed and installed with millimetre accuracy.

The design of the coax distribution system was done by ASTEC RF staff in conjunction with Technology department and Strathclyde and Imperial University.

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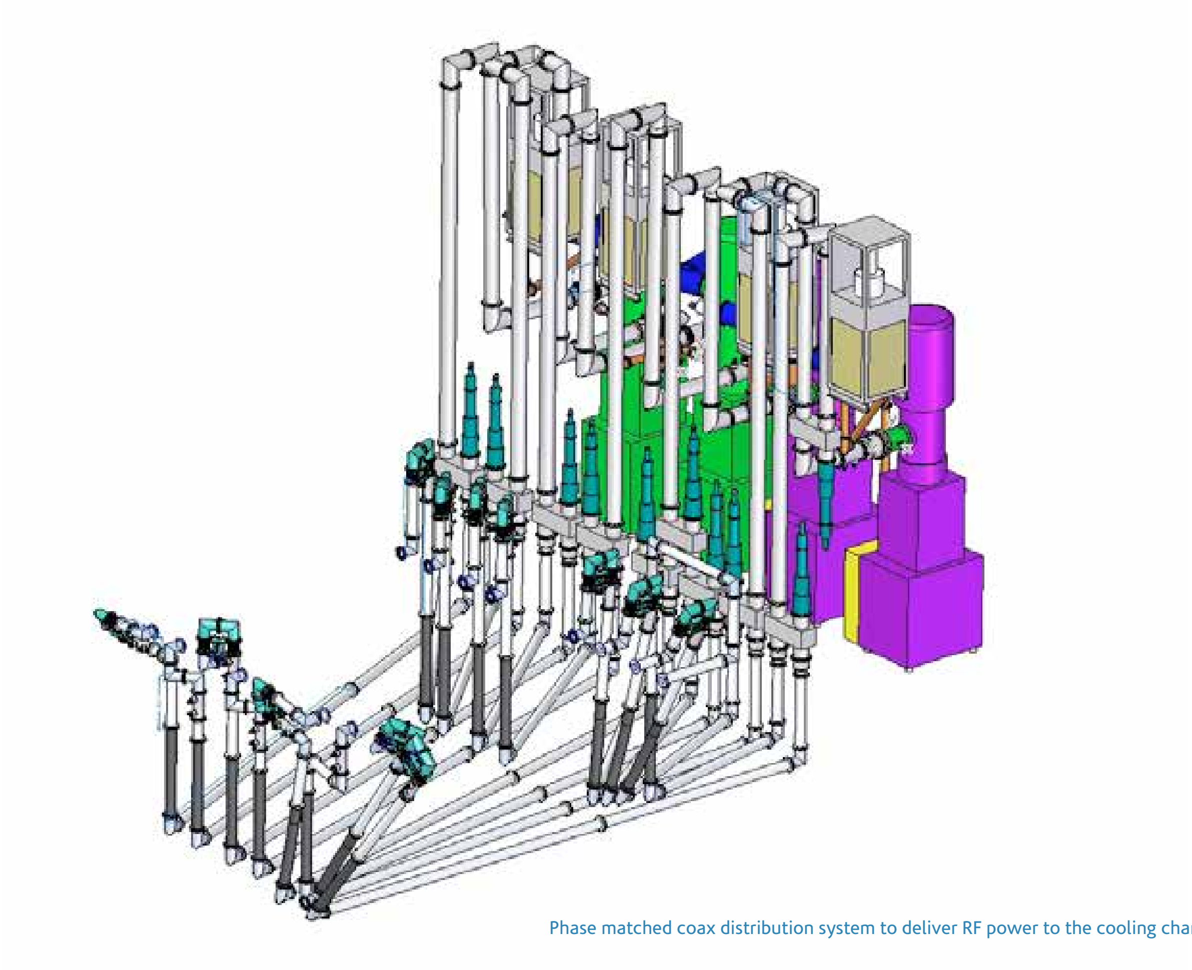
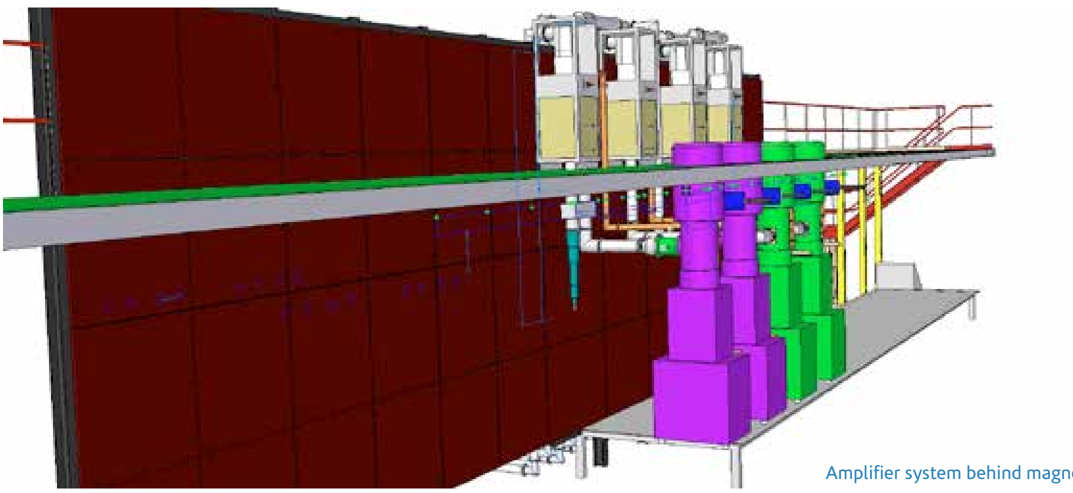
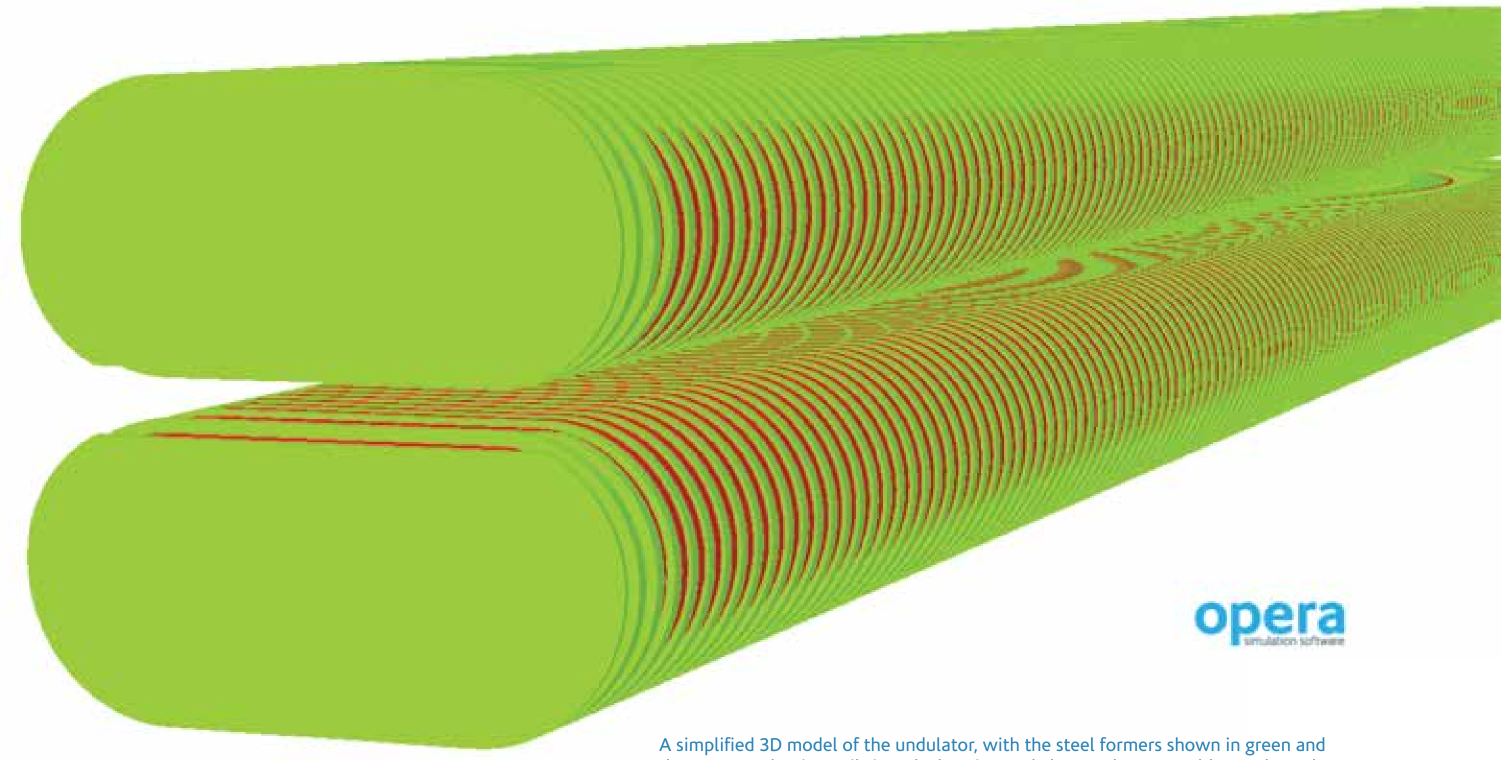


Phase matched coax distribution system to deliver RF power to the cooling channel



Amplifier system behind magnetic shield wall

Superconducting Undulator Modelling

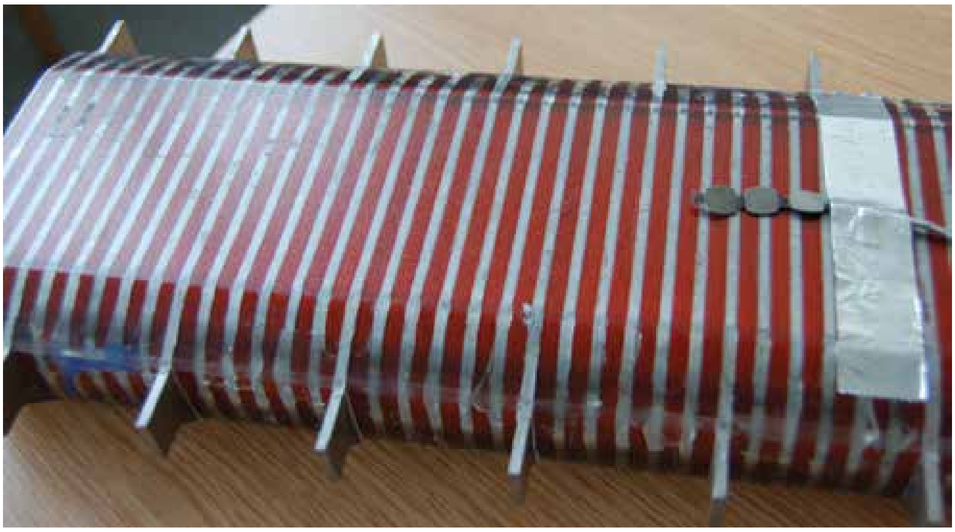


A simplified 3D model of the undulator, with the steel formers shown in green and the superconducting coils in red. The Diamond electron beam would pass through a tube midway between the formers

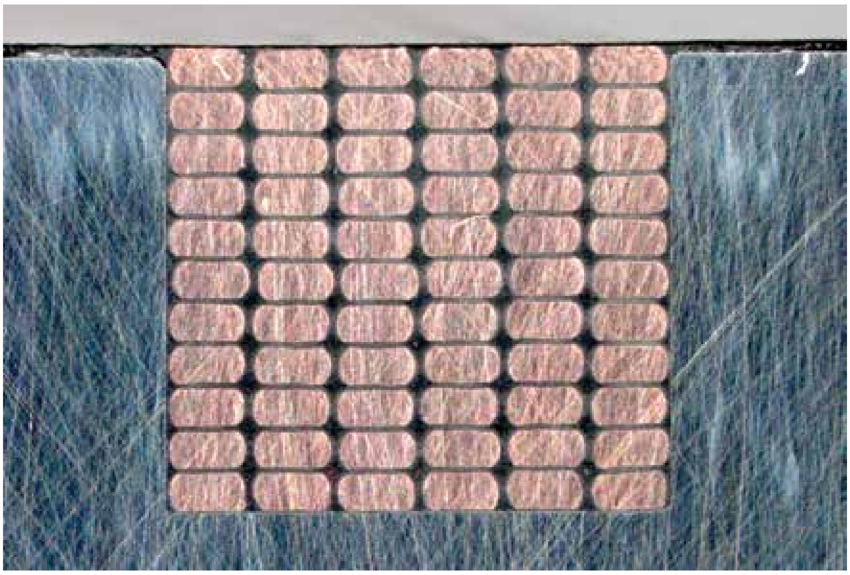
STFC and Diamond Light Source are collaborating to design and build a superconducting undulator for the UK. The undulator will be installed on Diamond, the UK's 3 GeV synchrotron light source. Superconducting undulators have the potential to give higher on-axis peak fields than any other technology, but potentially have very challenging requirements for field quality. Field quality for undulators is expressed in terms of the phase error – the difference in phase between the electron beam and the photon beam. A lower phase error results in higher brightness light output.

The phase error specification for this undulator is less than 3°; to meet this, the manufacturing tolerances must be extremely tight. Different types of mechanical errors result in different field errors, and therefore extensive modelling must be performed to assess the effect of errors. However, 3D modelling of a complete undulator takes a significant amount of computing time.

The MaRS group have been working on a numerical simulation code to translate manufacturing errors into field quality errors, in an accurate and time efficient way. Using a 3D modelling code, a field error signature is created. This can be replicated numerically over the whole length of the undulator. Many random errors can be then added together to simulate the effect of a real undulator with realistic manufacturing errors.



A 300 mm long prototype of the undulator former, with the superconducting wires wound around it



A section through the undulator former, showing the stack of superconducting wires. The prototype was cut into sections to assess how it compared to the required tolerances for the final device, and in order to make improvements to the design and manufacture

This work has been carried out for several different types of error, in order to ascertain the manufacturing tolerances that need to be met in order to meet Diamond's demanding specification for the undulator. With this added information from numerical simulations, we have confidence that the field quality produced by the undulator will be exceptional.

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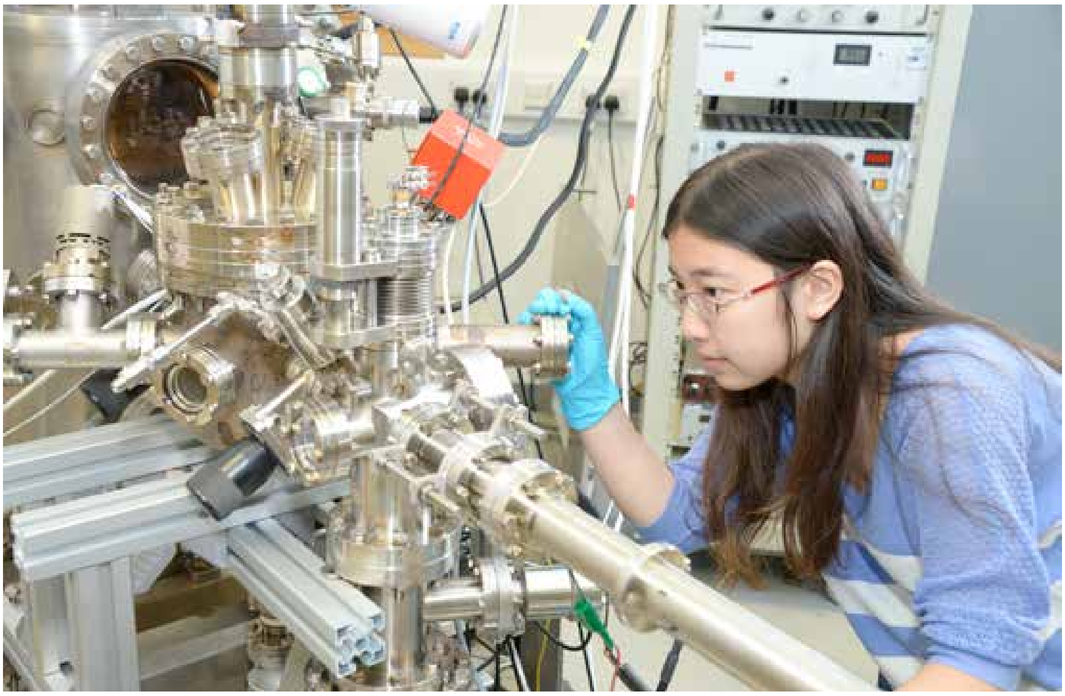
Secondary Electron Yield Mitigation Study



A facility for secondary electron yield measurements

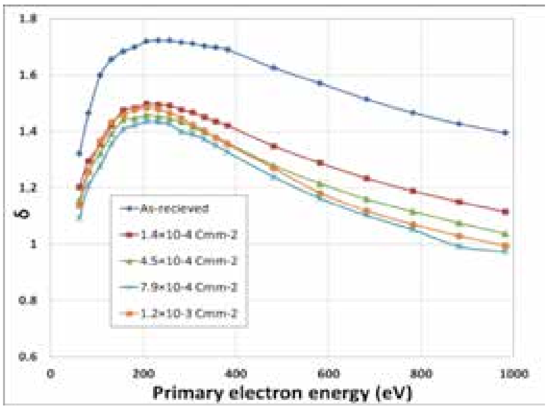
Electron cloud is one of the limitations for operating particle accelerators with positively charged beams of high intensity and short bunch spacing. Electrons originate from ionised residual gas molecules, by photoemission and by secondary electron emission from the vacuum chamber walls. They may move resonantly with beam bunches and can collide with both the charged particle beam and the walls in the vacuum chamber. If the secondary electron yield (SEY) of the vacuum chamber is larger than unity, then electron multipacting may occur. The SEY is one of the key parameters controlling electron cloud build-up in the particle accelerators.

This year ASTeC developed the equipment for SEY measurement. This setup includes load lock chamber, SEY measurement chamber and surface analysis chamber equipped with x-ray photoelectron spectroscopy (XPS) for surface chemical analysis, an Argon gun for removing a few top layers from the sample and a flooding electron gun for surface conditioning with large electron dose. The total SEY, or δ, is defined as

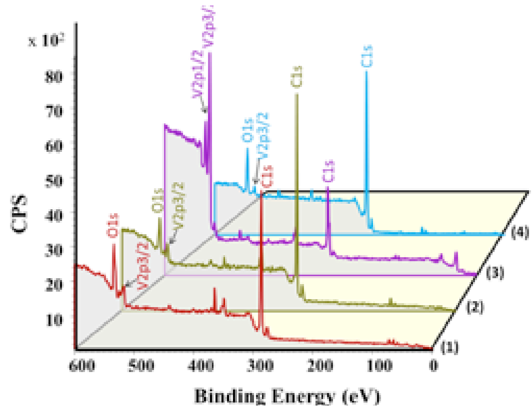
$$\delta = \frac{I_F}{I_P} = \frac{I_F}{I_F + I_S}, \quad (1)$$

where I_S is the secondary electron current (including both elastic and inelastic processes) measured at the sample, I_F is the current on the Faraday Cup and I_P is the primary beam current.

The SEY as a function of primary electron energy was measured over the range 80 to 1000 eV and at normal incidence. Measurements were performed using a



SEY of the V sample as a function of primary electron energy reducing with accumulated electron dose



The XPS spectra of the V sample (1) as-received, (2) after an electron dose of 1.2×10^{-3} C•mm^{-2}, (3) after thermal treatment to 250 °C and (4) after prolonged electron conditioning (dose 7.0×10^{-3} C•mm^{-2})

Kimball electron gun. The pressure in the test chamber was 2×10^{-10} mbar without electron bombardment and 2-5×10^{-9} mbar during electron bombardment. The net current at the sample biased at –18 V and the Faraday Cup at ground potential were measured with two current amplifiers. The accuracy of the SEY measurements was estimated to be within 1% for primary electron energies between 80 and 800 eV and about 6% for primary electron energies above 800 eV.

Since surface condition is an important factor influencing SEY, it is necessary to measure the difference of surface composition and chemical bonding between atomically cleaned sample and as received sample.

Non-evaporable getter (NEG) thin films, which are currently being used in the ultra high vacuum system of the Large Hadron Collider (LHC), were deposited by physical vapour deposition (PVD). NEG coatings (after *in-situ* baking) not only provide valuable pumping and reduction of outgassing but they also have a low SEY. NEG films are usually composed of a mixture of Ti, Zr, V and Hf. The first study of this project is from these transition metals.

An example of the results obtained for vanadium is shown in the figures above. As-received samples after being exposed to air post deposition depicts the highest SEY due to the formation of native oxide layer. Electron conditioning leads to a build up of a carbon layer and reduction of oxygen which reduced the SEY. The SEY of air-exposed metals can be decreased by different surface treatments such as electron conditioning, *in-situ* vacuum bakeouts and ion bombardment. The XPS results reveal the change of surface chemistry due to different surface treatment.

The results of this study are important to choose the best technology and surface treatment practise to supress electron multipacting and electron cloud build up in the next generation of high intensity accelerators.

The results of this work were presented by Sihui Wang, ASTeC PhD Student, at the PhD student conference at Loughborough University in May 2014 and won the Sir David Wallace Physics prize.

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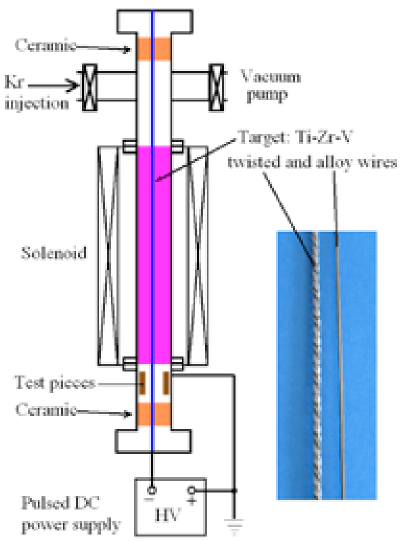
Optimisation of NEG Coatings for the Accelerator Beam Chamber

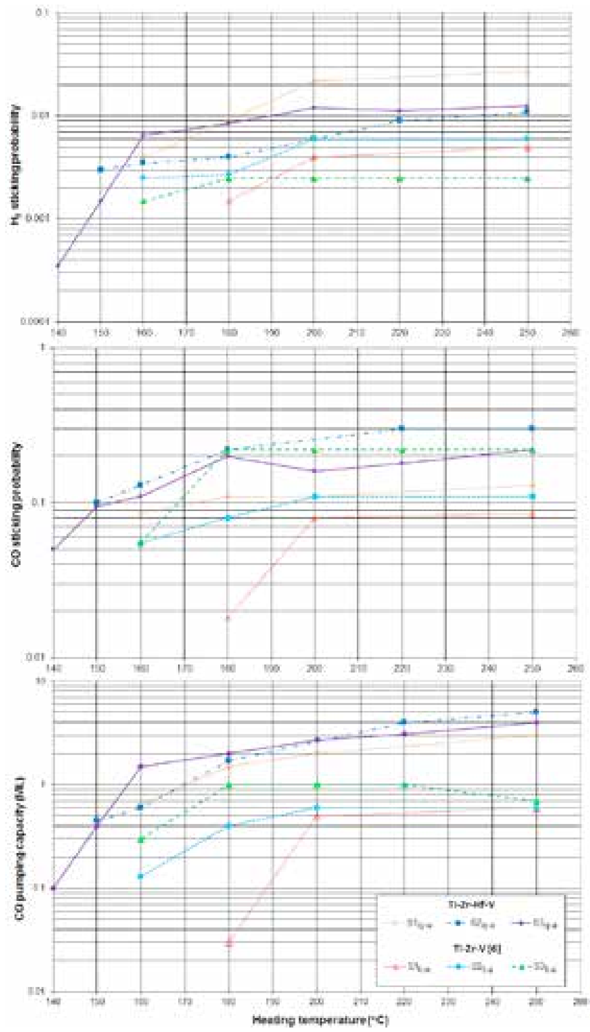
Improving Pumping Properties



A schematic layout of the NEG deposition facility and a photo of twisted and alloy wires

The non-evaporable getter (NEG) coating invented at CERN in the 1990's is used nowadays in many particle accelerators such as LHC, ESRF, Soleil, Elettra, MAX-IV and many others. The main advantages of using NEG coatings are low thermal outgassing, low photon and electron stimulated gas desorption, as well as evenly distributed pumping speed allowing to reach the required UHV conditions with a fewer number of pumps with lower pumping speed or where the required UHV conditions cannot be reached by other means such as a narrow vacuum chamber. ASTeC's vacuum science group has focussed on further optimisation of NEG coatings in the following directions: reducing the NEG activation temperature, increasing pumping properties and reducing photon and electron stimulated gas desorption.

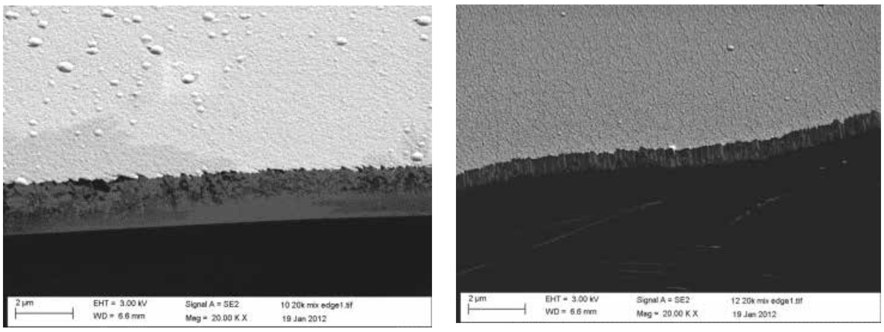
The internal surface of identical 38 mm diameter and 0.5 m long 316 L stainless tubular was coated using either twisted 1 mm diameter wires of single metal: Ti, Zr and V (Sample S1t-w) or Ti, Zr, Hf and V (S1q-w), or a 3 mm diametre alloy rod as target: Ti-Zr- V (S1t-a) or Ti-Zr- Hf-V (S1q-a), see figure above.



H_2 and CO sticking probability and CO sorption capacity as a function of activation temperature

The pumping properties of these samples were measured after consequent activations to temperatures from 140 to 300 °C shown in the same figure.

The main results are the following. The quaternary Ti-Zr-Hf-V NEG coating demonstrates the lowest activation temperature of 140 –150 °C. The H_2 and CO



Cross section SEM micrographs of dense (left) and columnar (right) films

sticking probabilities and the CO pumping capacity of Ti-Zr-Hf-V are higher than for Ti-Zr-V coating. Reducing the lowest activation temperature can be achieved by replacing a twisted target with an alloy target and by using a quaternary Ti-Zr-Hf-V alloy instead of ternary Ti-Zr-V. The best results were achieved in combination of both when the NEG coating was deposited with use of a Ti-Zr-Hf-V alloy target.

Electron Stimulated Desorption

The gas density along the accelerator vacuum chamber is proportional to the desorption yield and is decreasing with sticking probability. These two properties of the NEG coating allow the reduction of the gas density along the accelerator vacuum chamber (or its sections) by orders of magnitude or achieving the specified gas density at much lower cost. It was known from previous studies that the columnar structure of the NEG film provides greater sticking probability and capacity than the dense one. However, there was no data to compare vacuum performance of dense and columnar coatings under bombardment by energetic particles, such as photons, electrons and ions.

It was demonstrated that the samples coated with a Ti-Zr-Hf-V alloy depicted lower ESD yields compared to Ti-Zr-V alloy. However, after activation at higher temperatures the ESD yield for H_2 at large doses for the columnar NEG coating could be comparable to one of the bare stainless steel while the dense NEG demonstrates lower ESD yields. In particle accelerators the lowest pressure and long term performance will be achieved with a vacuum fired vacuum chamber coated with dense Ti-Zr-Hf-V coating activated at 180 °C. It was also demonstrated that vacuum firing is an efficient technology to reduce ESD yield by an order of magnitude for both columnar and dense NEG.

CH_4 Pumping Induced by Electron Bombardment

The selective pumping of NEG coating is a performance limiting factor. NEG pumps H_2, H_2O, CO, CO_2 and some other gas species but does not pump noble gases and hydrocarbons. If the vacuum system has no leaks to air and no gas injection then the amount of the noble gases should be negligible. Contrary to that, there are very little hydrocarbons in air and in a conventional vacuum chamber, but they (mainly CH_4) are generated on the NEG surface during the absorption process of H_2, H_2O, CO and CO_2. However, it was found that under electron bombardment the Ti-Zr-Hf-V NEG coating provides pumping of CH_4 by cracking it to H_2 and CO, the electron stimulated pumping coefficient was estimated to be ~2×10^{-5} CH_4/e^-. Some electron stimulated pumping of Ar was also observed. Even without electron bombardment Ti-Zr-Hf-V NEG coating provides some pumping speed for CH_4.

Since SR cause significant electron emission in an accelerator vacuum chamber, it is very likely that similar effects of SR induced pumping of CH_4 and Ar can be observed.

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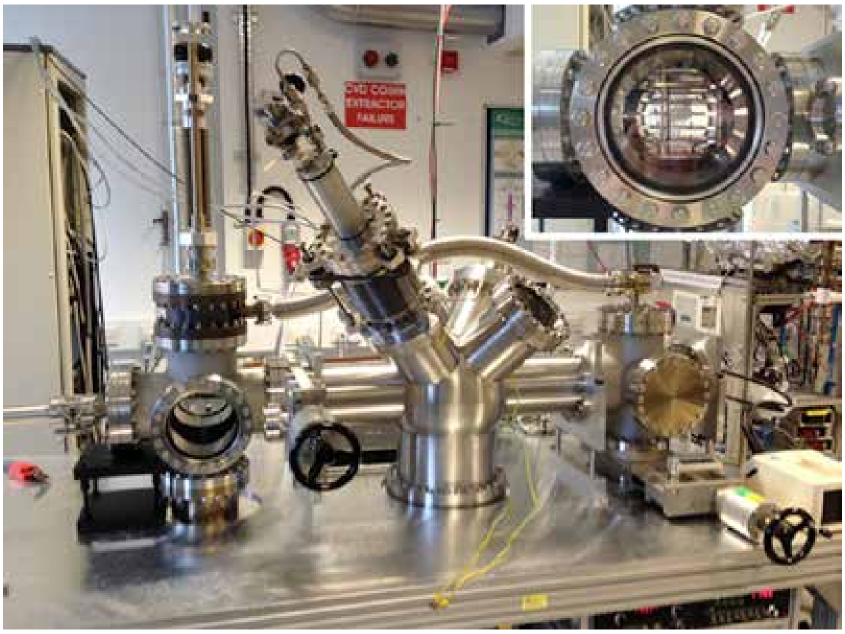
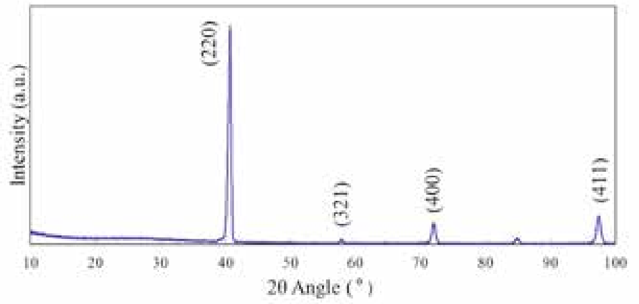
Physical Vapour Deposition for SRF Cavity Coatings



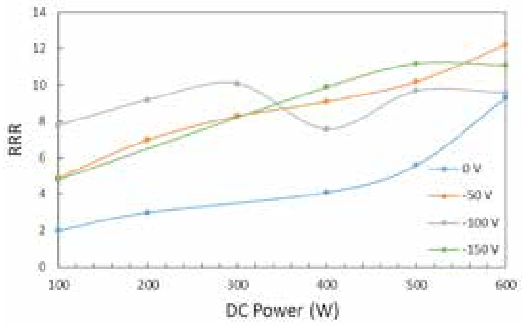
The deposition system and seven sample insertion system (in the inset)

Superconducting radiofrequency (SRF) cavity technology in particle accelerators is now reaching the limit of performance achievable with bulk niobium cavities. Superconducting coatings for SRF cavities is an intensively developing field that should ultimately lead to acceleration gradients better than those obtained by bulk niobium RF cavities. ASTeC has built and developed experimental systems for superconducting thin film deposition, surface analysis and measurement of Residual Resistivity Ratio (RRR). Collaborators in ISIS at Rutherford Appleton Laboratory and Loughborough University have given access to DC SQUID Magnetometer systems to analyse magnetic properties of thin films.

Niobium thin films were deposited by magnetron sputtering within a purpose built ultra high vacuum chamber which has a base pressure of 10^{-9} mbar. Krypton gas is injected into the deposition chamber at a pressure 10^{-2} – 10^{-3} mbar where the gas is ionised in the magnetic field of the magnetron. Krypton ions are accelerated towards a niobium sputter target where the kinetic energy of the impacting ions cause niobium atoms and ions to be expelled. The niobium will then travel along a parabolic trajectory and coat any surface that is in the line of sight of the target.
The deposition facility makes use of various power supplies to the magnetron with a selection of DC, pulsed DC, RF and HiPIMS. Deposition substrates can be self biased with negative DC voltages or RF power to accelerate sputtered niobium ions as they arrive.
A heating system can uniformly heat substrates from room temperature to 800 °C and a motor positioned below the substrate holder allows for continuous rotation during deposition. Samples are inserted into the system seven at a time without the need to vent or cool the system between sample transfer. A differential pumping system allows samples of the sputter gas to be sent back to the load lock chamber where it can be analysed by the residual gas analyser.



XRD spectrum for thin niobium film



RRR as a function of bias for various bias voltages

Fifty five samples have been deposited so far in the study and a selection have been analysed to highlight their morphological properties. X-ray diffraction is used to determine the lattice orientation and the average grain sizes within niobium films. Early results have shown films with peak intensity at 2θ = 41° corresponding to the (110) grain orientation. Smaller peaks have also been present at 72° (400) and 97° (411). Average grain sizes were 9±2 to 18±3 nm.

Electron back scattering diffraction (EBSD) is used to determine the size and orientation of grains at the surface of the film.

EBSD image showing grain sizes up to 250nm across at the surface of a film

Scanning electron microscopes (SEM) are used to produce magnified high resolution images of films. Film thicknesses and a visible indication of grain structure i.e. columnar or densely packed grains, are obtained from the SEM images. Film thicknesses have been measured between 173.9 and 2768 nm with growth rates of 1.16 and 18.5 nm/min respectively.

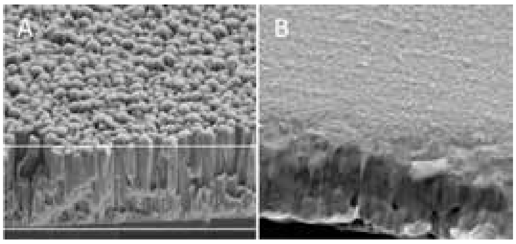
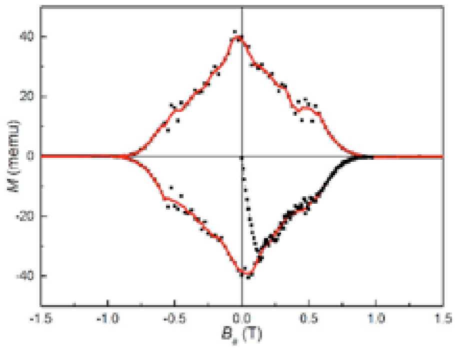


Image A shows columnar grains containing many voids whilst image B shows a dense film of higher quality

Superconducting properties of deposited films have been conducted by both RRR and DC SQUID magnetic susceptibility measurements. RRR can give an indication of the quality of a film; a higher RRR will show fewer discontinuities or impurities as required for higher superconducting critical fields. RRR has peaked at 22 and has been shown to increase with a biased substrate relative to unbiased.



DC SQUID measurement of a niobium thin film sample

DC SQUID magnetic measurements indicate the first and second critical magnetic fields within the superconducting thin film. The first critical field is the point where magnetic flux first penetrates the sample and the second critical field is the point where superconductivity is suppressed. We aim to produce films with the highest critical parameters and can therefore produce higher acceleration gradients within an accelerating cavity.

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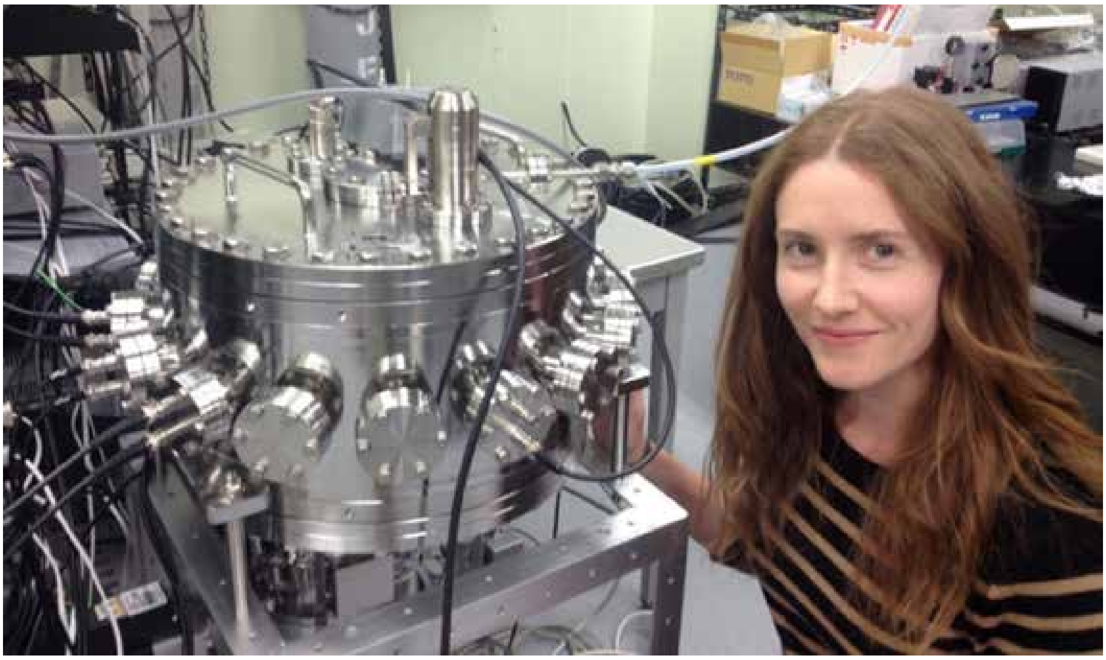
Re-creating Complex Beam Dynamics using a Bench-top Plasma Trap

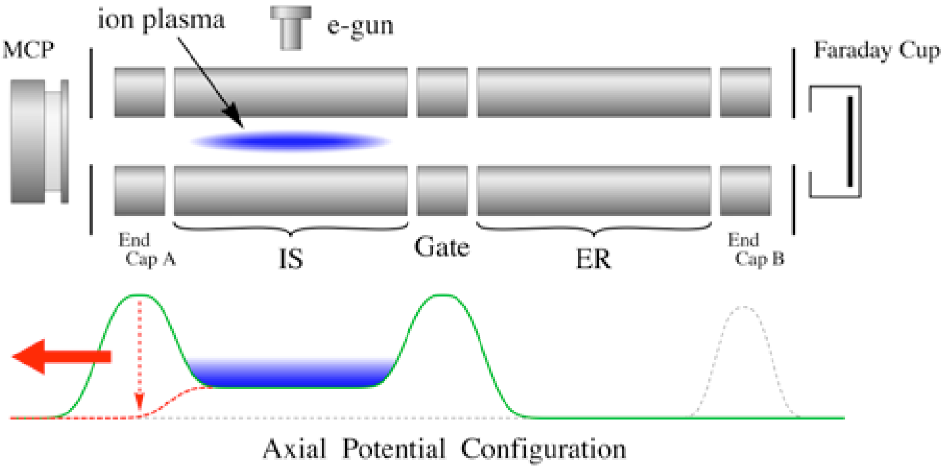


Dr Suzie Sheehy (IB Group) working with the S-POD system at Hiroshima University, Japan

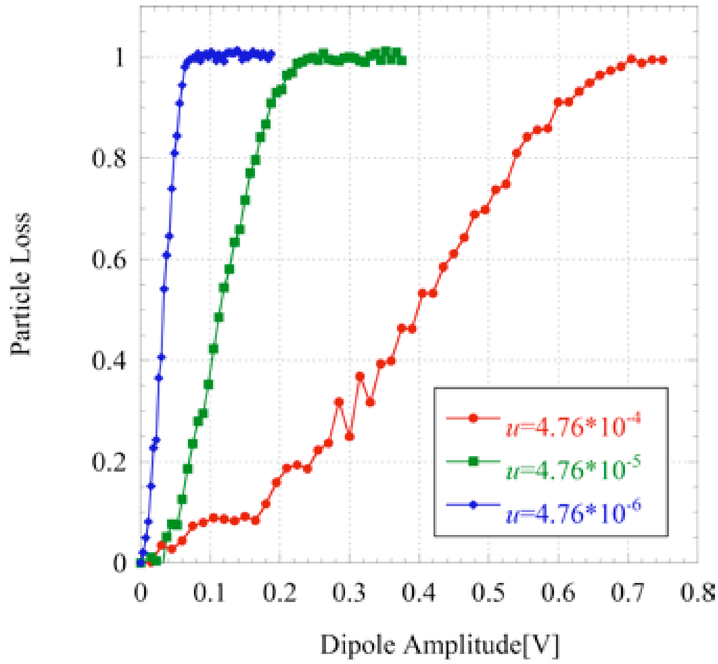
Staff in the Intense Beams Group at RAL have recently established new collaborative research with Professor Hiromi Okamoto's Beam Physics Group at Hiroshima University, Japan. The idea of the collaboration is to study accelerator beam dynamics experimentally using a bench-top sized device known as 'S-POD'.

The Simulator of Particle Orbit Dynamics (S-POD) is a linear Paul trap, which uses electric RF fields to confine and focus a non-neutral plasma (typically Argon ions). At a fundamental level the beam dynamics of such a trap is analogous to that of a bunch of particles in a linear focusing channel of an accelerator. The system allows the teams to quickly study a huge range of parameters and situations which would either not be possible or time effective with a real accelerator. This technique is complementary to accelerator based experiments and large scale simulations and in many cases, it is faster to carry out the S-POD experiment than to run the equivalent simulation.

During 2013 and 2014 the two groups have worked together to study the phenomenon of integer resonance crossing in fixed field alternating gradient (FFAG) accelerators, an important topic which will enhance understanding of beam dynamics in this area. For present studies S-POD has been configured to simulate the non-scaling FFAG EMMA. By studying the conditions under which ions in the trap are lost, the groups are able to build up a picture of the physics behind resonance-crossing in general.



The basic experimental setup of the S-POD trap system



An example of ion loss for varying resonance crossing speeds (u) and varying levels of dipole error source

This technique has wide-ranging applications and will allow the groups to establish understanding in beam dynamics topics which are vital for the design of future high power proton or ion accelerators. One example is to study the possibility of an FFAG ring for a future spallation neutron source, which could be both smaller and have a higher power beam than existing machines.

Going forward the two groups have recently signed a Memorandum of Understanding to continue their collaborative research. They are planning to study the effects of nonlinearities and amplitude detuning in more detail and to extend present studies to include high intensity effects. In parallel, ideas for novel beam dynamics experiments using this device are being developed with other research groups including ones at ISIS and CERN.

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CLIC Low Strength Permanent Magnet Quadrupole

ASTeC and Technology Department in collaboration with CERN has developed a novel type of tunable permanent magnet quadrupole (PMQ) for the Compact Linear Collider (CLIC).

The CLIC drive beam decelerates two sections of drive beams from 2.37 GeV to 237 MeV transferring its energy to the main beam using Power Extraction Transfer Structures (PETS). The two beamlines are placed in a 4.5 m diameter tunnel where the maximum heat load has been set to 150 W/m. This is very challenging from the point of view of magnets (not to mention many other heat generating components), as high currents used in typical electromagnets generate large amounts of heat and usually require active water cooling.

The ZEPTO (Zero-Power Tunable Optics) project has developed PM-based, highly adjustable magnets. Having no coils and no water cooling, these magnets produce the gradient required to keep the CLIC beam focussed using zero electrical power.

The lower strength version of the PMQ was assembled at Daresbury in 2013. This prototype consists of two movable NdFeB permanent magnet blocks placed vertically above and below the beam axis. These blocks are moved with high accuracy by a single stepper motor along the vertical direction and this changes the field gradient within the aperture. There is a ferromagnetic shell that is placed around the outside of the magnet which provides an alternate flux path as the PMs are retracted and helps to reduce the minimum gradient.

Initial magnetic measurements were made using the Hall probe technique. The variation of the central gradient and integrated gradient agreed very well with the model. The field quality was found to be somewhat more than the specification of ± 0.1% in the central aperture of 23 mm. This is likely because of non-optimal positioning of the poles and future improvements in manufacture techniques are envisaged to mitigate this.

The magnet will be sent to CERN for further integral measurements using stretched wire and rotating coil techniques.

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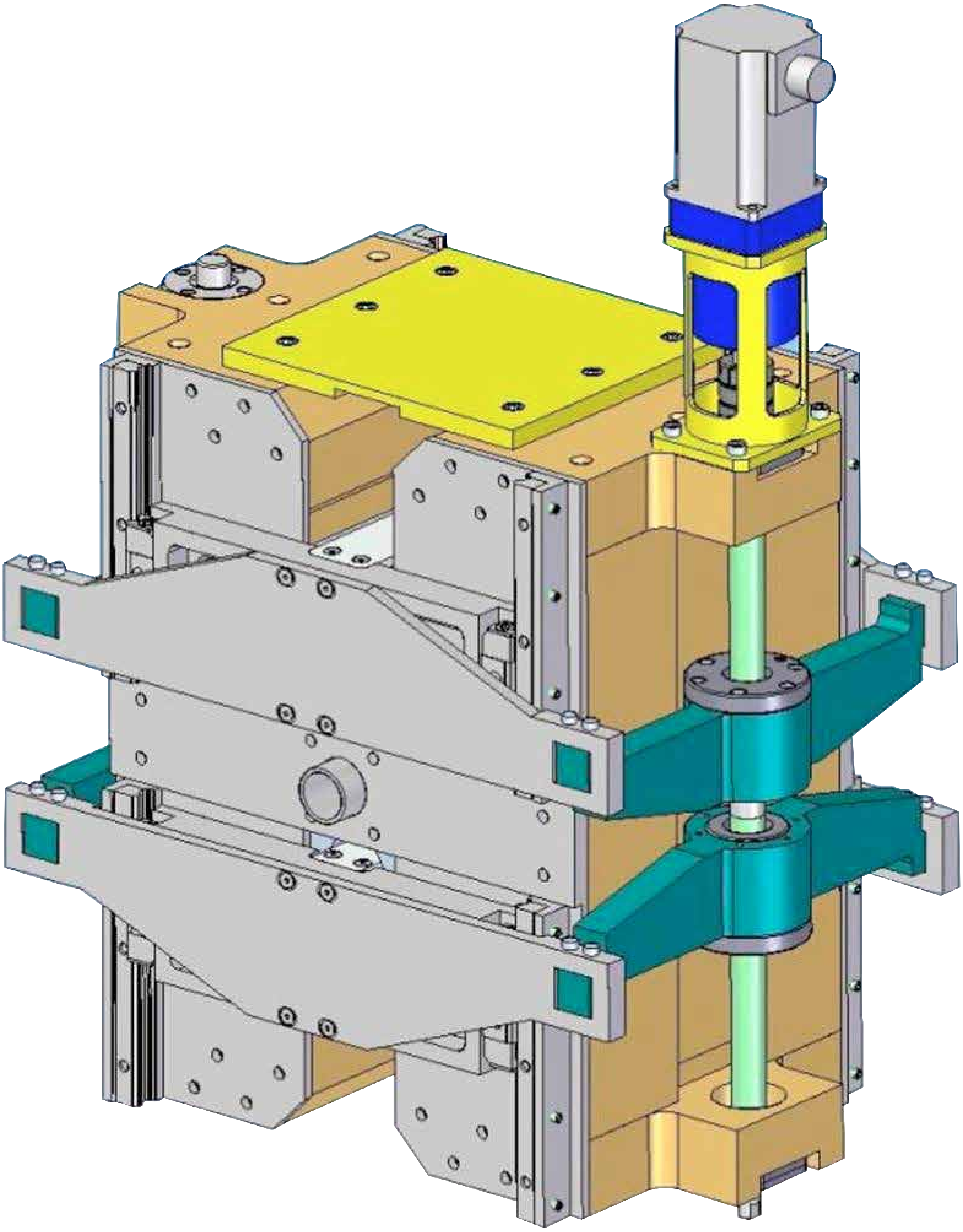

ASTeC Contribution to HL-LHC

ASTeC has been involved in the High Luminosity upgrade for the LHC (HL-LHC) at CERN since November 2010. The work done consisted of looking at the beam-beam instability together with various luminosity levelling scenarios. Luminosity levelling aims at spoiling the initial luminosity at the start of a run and then compensating for its natural decay as the run progresses. The ultimate goal is to keep the effective luminosity the experiments see in all the detectors constant for as long as possible. This ensures that the number of events recorded by the detectors is as even as possible. Given that there are so many events to be recorded after every interaction, this is very beneficial to data collection. There are several options for implementing this levelling, designed for the high luminosity upgrade but to be tested in the LHC today. The upgrade of the LHC from the current set-up to high luminosity performances will provide new challenges from the point of view of beam-beam as well as other collective effects and levelling. The simplest option is levelling with an offset between the two beams. In particular, the idea of using flat beams in the interaction points (IPs) for all the available options and investigate their benefits and drawbacks, using the code COMBI (COherent Multi Bunch Interaction), is under investigation. Flat beams would allow an additional degree of freedom, with the levelling only required in one of the planes at any given IP. To this end, various scenarios were looked at, both with and without crab cavities.

A detailed development of fringe fields was done by ASTeC for multipoles, including the full solution to the magneto-static Maxwell equations. This is the first time that fully analytic, closed form, expressions are given for quadrupole and higher order magnets fringe fields. From these it is possible to construct a model, in such programs as MAD (Methodical Accelerator Design) or GPT (General Particle Tracer), which incorporates fringe fields not just for dipoles at the start of a project, rather than waiting for a full magnet field map to be available. The expressions found also include potentials for the fringe fields, both scalar and vector.

Using the first, it is possible to look at the pole-face of a multipole easily which aids the magnetic modelling. An example of this is shown in the figure below for the HL-LHC inner triplet quadrupole poleface. With the second, the vector potential, it is possible to create a symplectic kick which is vital in order to avoid unphysical beam emittance growth in multi-turn tracking of any accelerator. It shall be possible to implement these symplectic multipole kicks in tracking codes for the first time. Therefore, it should now be possible to implement fringe fields to all orders in multi-turn tracking programs like SIXTRACK which is one of the main programs used for the design of the HL-LHC at CERN. It should also be possible to create a complete model of ns-FFAG's, including space charge, in codes such as GPT. As the beam goes considerably off-axis in the quadrupoles, GPT holds the promise of being the first code to model a ns-FFAG completely correctly at the start of a project when no magnetic field map is as yet available.

In conjunction with the numerical approaches described above for studying the beam-beam instability, ASTeC is developing a theoretical approach to the complete six dimensional kick. This approach is based on looking into the possibility of applying the analytical expressions and the techniques, developed recently by ASTeC for fringe fields in multipoles to the beam-beam interaction where the longitudinal part has not been fully included in the presence of the hourglass effect at the interaction point. Though the equations are clearly different, the mathematical framework promises to be similar.

ASTeC has also been involved in 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 the 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 these have been used to evaluate HL-LHC beam parameters and optics.

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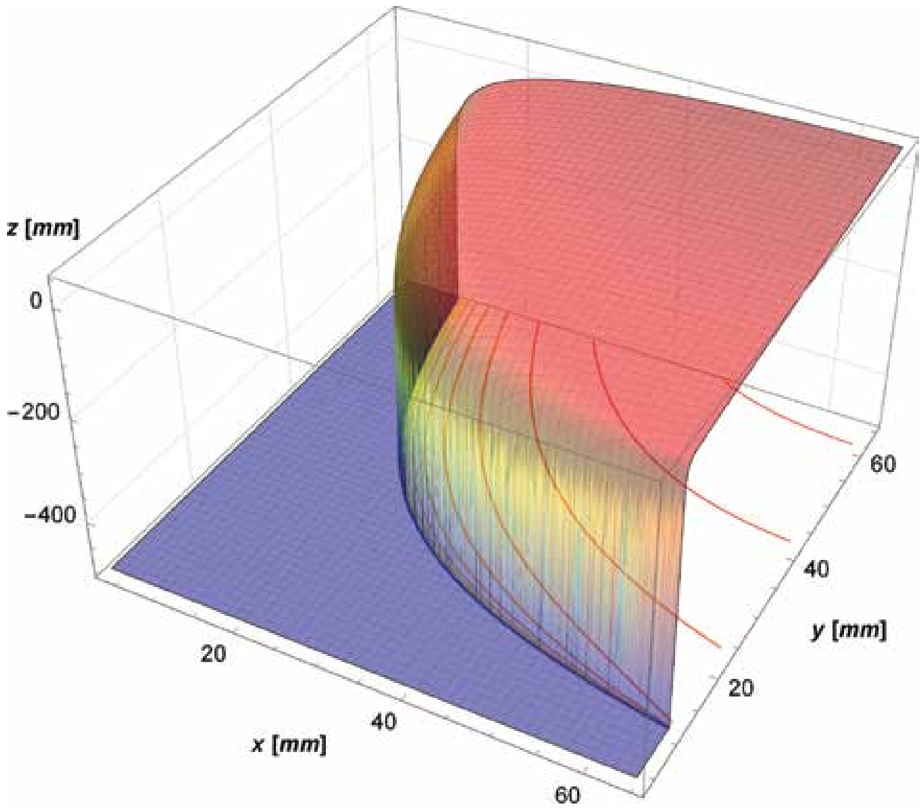
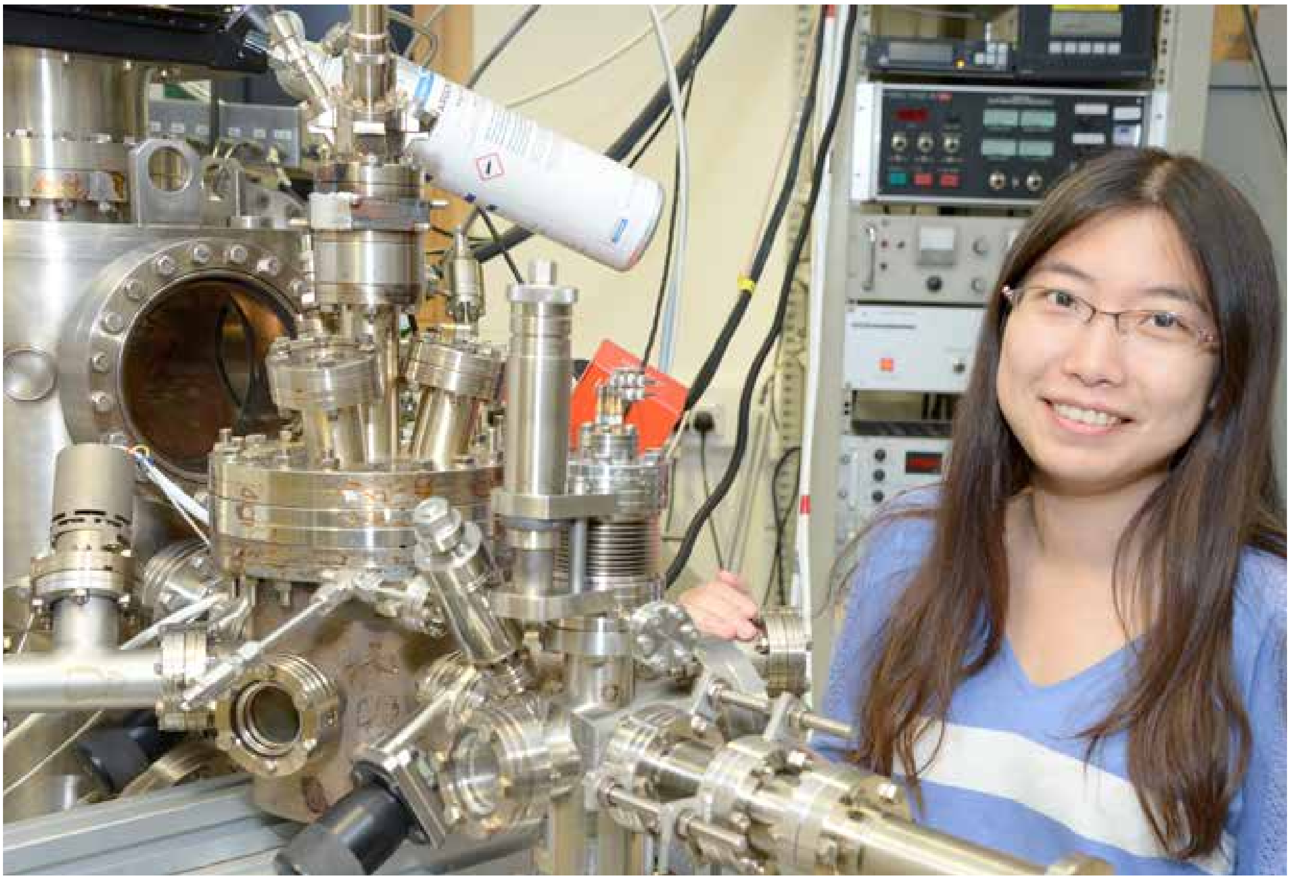


Poleface (from the scalar potential) in a representation of the HL-LHC inner triplet quadrupole, with gradient falling as an Enge function in the fringe field

Ideal Placements for PhD Studentships



Sihui Wang

A number of postgraduate and undergraduate students join ASTeC every year to learn particle accelerator related disciplines. Under the supervision of enthusiastic ASTeC scientists and engineers they participate in the ASTeC research programme. A combination of a number of conditions such as highly motivated staff, well equipped laboratories and personal responsibility in big projects creates an ideal atmosphere and conditions for bringing up the next generation of scientists. By taking part in the ASTeC projects the students gain knowledge, experimental and analytical experience in a subject they study, also learning how to work in a team and how to deliver on time.

ASTeC, together with the Cockcroft Institute (CI) partners, provides a three-term course of lectures in accelerator science related disciplines. In the reporting year ASTeC scientists gave lectures on the following subjects:

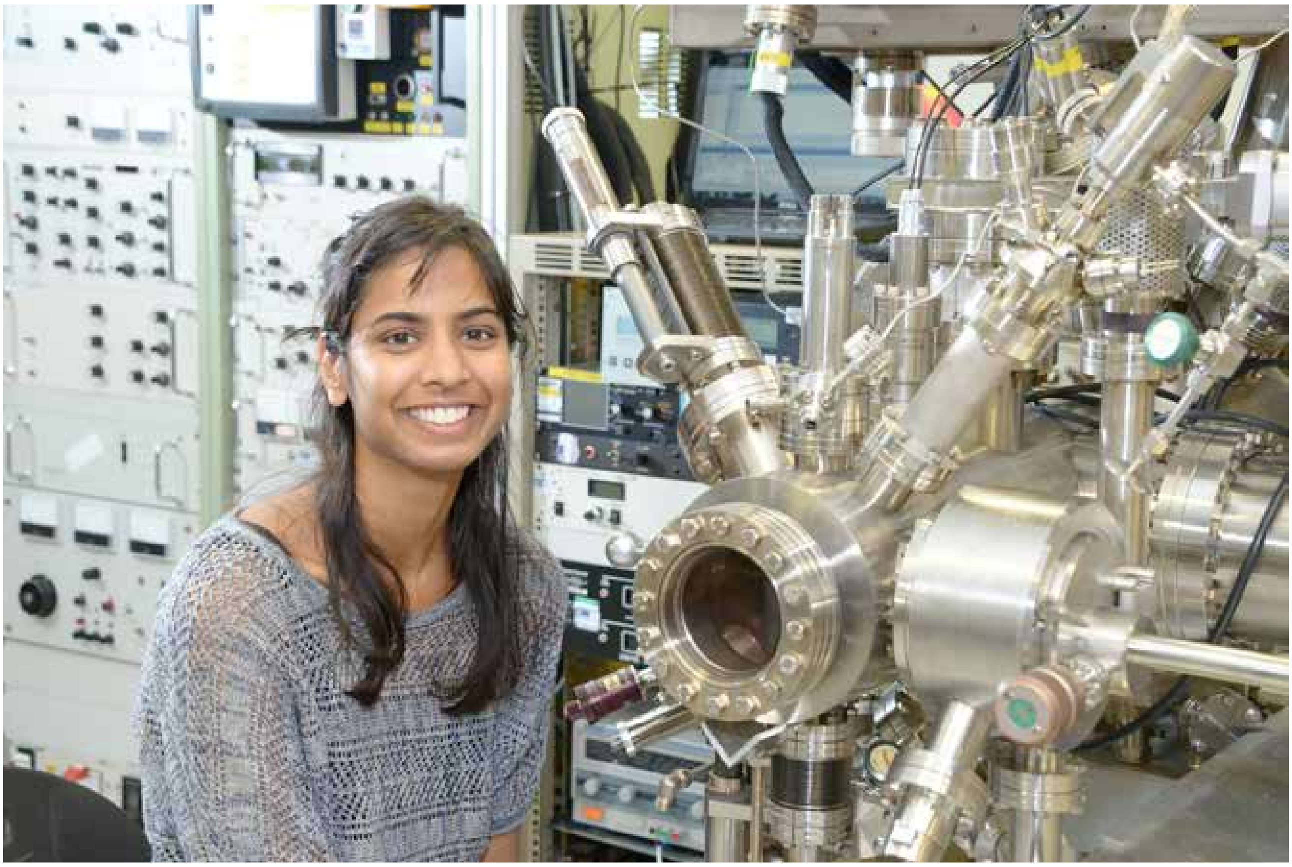
- Project Management for Accelerator Projects – Andy Goulden
- Electron Sources – Dr Boris Militsyn
- Intermediate Beam Dynamics – Dr Bruno Muratori
- Vacuum Science and Technology in Accelerators – Dr Oleg Malyshev, Dr Keith Middleman, Dr Reza Valizadeh and Joe Herbert.

In addition, for the first time the Cockcroft Institute Particle Accelerator School (CIPAS) was jointly organised in the form of a two week introductory course for all PhD students in 2013. A number of ASTeC scientists participated in organising the school and giving lectures and tutorials: Professor Jim Clarke, Dr Lee Jones, Dr Oleg Malyshev, Professor Neil Marks, Dr Bruno Muratori, Professor Mike Poole, Dr Chris Prior, Dr Yuri Saveliev. The outcome of this course was found to be very satisfactory by both organisers and students; therefore it was decided to repeat CIPAS every two years.

This ideal condition for incubation of new scientists registered at a university and working under the supervision of ASTeC staff, led to an increased number of PhD students working in ASTeC. The PhD students were working on the following projects:

- Sophie Middleton (Imperial College) supervised by Professor David Colling (Imperial College, London) and Dr Chris Rogers (ASTeC) is studying the beam polarisation in the Muon Ionisation Cooling Experiment (MICE) as part of an attempt to measure beam depolarisation effects on muons as they pass through materials and characterisation of decay electron backgrounds in the MICE detector systems. She will go on to characterise the alignment of the main scintillating fibre tracking detectors and magnet systems, together with a measurement of multiple Coulomb scattering in the emittance absorbers.
- Sihui Wang (Loughborough University) supervised by Dr M 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.
- Bruno Camino supervised by Professor Nicholas Harrison (Imperial College) and Dr Tim Noakes / Dr Mark Surman (ASTeC) working on designing new materials for photocathodes. He is using state of the art computational chemistry to model and optimise photocathode properties for advanced accelerators.
- Stuart Wilde (Loughborough University) supervised by Dr B Chesca (Loughborough University) and Dr Reza Valizadeh/Dr Oleg Malyshev (ASTeC) working on thin film superconducting coating for RF cavities. His research requires the PVD deposition of Nb films at various conditions, the surface analysis, the RRR and DC susceptibility measurements.
- Sonal Mistry (Loughborough University) supervised by Dr M Cropper (Loughborough University) and Dr Boris Militsyn/Dr Reza Valizadeh (ASTeC) aims to investigate and develop different metallic photocathodes and assess their QE, thermal emittance and stability. Her research requires the surface conditioning, the surface analysis, an impurity analysis and the Quantum Efficiency (QE) measurements.
- Alvaro Sanchez-Gonzalez (Imperial College) supervised by Professor Jon Marangos (Imperial College, London) and Professor Jim Clarke (ASTeC). His project entitled 'Time Resolved Molecular Dynamics at FELs', is aiming at developing techniques of measuring ultra fast processes using free electron lasers. He will feed back to ASTeC the acquired insights on this application of FELs, so as to further inform future light source designs.
- Thomas Halstead (University of Liverpool) supervised by Professor Samar Hasnain / Dr Svetlana Antonyuk (University of Liverpool), Mark Roper (ASTeC) and Dr Masaki Yamamoto (RIKEN, Japan). His project title is 'Structural Biology of Membrane Proteins and Protein Complexes using x-rays from Synchrotrons and Free Electron Laser'. Ultra-bright x-ray sources allow tightly focussed beams that are necessary for the crystallography of micro- and nano- protein crystals but the high intensity of the focussed x-ray beam damages the crystals. This project will develop techniques that allow the scattering data to be collected without degradation from the inevitable damage to the protein structure. For example, with ultra fast pulses from the SACLA FEL, the x-rays are scattered before the damage propagates through the crystal structure.

3 PROFESSIONAL DEVELOPMENT



Sonal Mistry

- **Chris Topping** (University of Liverpool) supervised by Professor Andy Wolski (University of Liverpool) and Dr Boris Militsyn (ASTeC) aims to investigate and develop the emittance measurement procedure of the low energy space charge dominated beams. His research comprises development and computer simulations of the measurement procedures and their implementation on VELA/CLARA accelerator.

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 a 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.

- **Palak Wadhwa** supervised by Ben Shepherd has been working on magnets in the MaRS group. She worked on several different projects, including modelling dipoles for the CLARA front end, making measurements of the CLIC low-strength quadrupole prototype, and commissioning the magnet laboratory's new rotating coil bench.

Stuart Wilde

- **Billy Liggins** supervised by Dr Peter Williams participated in CLARA design and simulations, he worked to develop the physics lattice of CLARA and performed a tolerance and jitter analysis to establish the timing stability for the seeded FEL.
- **Erin Nolan** supervised by Dr Keith Middleman / Shrikant Pattalwar participated in modifying the ESD facility and building up a new facility for RRR measurements.
- **Ben Hogan** supervised by Dr Oleg Malyshev performed experimental study in ESD from stainless steel samples treated by various techniques such as surface polishing, vacuum firing and NEG coatings.

All the sandwich students have also done a great deal of work supporting ASTeC's outreach activities.

Additionally, there are a number of summer students and work experience students who spend from two weeks to three months working with ASTeC staff.

ASTeC's involvement in the Institute of Physics

ASTeC is continuously supporting the activities within the Institute of Physics. ASTeC plays a key role in two IoP groups: Particle Accelerators and Beams (PAB) group and Vacuum Group (VG).

Particle Accelerators and Beams Group

ASTeC involvement in the IOP Particle Accelerators and Beams group continues to be strong with Peter Williams serving as Honorary Secretary; and Susan Smith and Mike Poole serving as committee members.

The 2013 annual meeting of the IOP Particle Accelerators and Beams group was held in the Cockcroft Institute on 10 April 2013. The meeting was the most successful yet with over 120 participants. Neil Marks gave the PAB prize lecture as winner of the 2012 outstanding professional contributions award. Neil gave an entertaining tour through his many innovative contributions to magnet design:
"Weird Magnets I have Known".

Other events organised by the group in 13/14 were:

- Plasma acceleration workshop – Daresbury, 18 June 2013
- Accelerators for Security Applications – AWE, 9 September 2013
- Particle Accelerators National Postgraduate Open Day – Cockcroft Inst, 4 December 2013
- Accelerators for future Spallation Sources – Cockcroft Inst, 12 December 2013
- CLARA FEL workshop – Cockcroft Institute, 13 January 2014
- Plasma Acceleration National Forum, IOP London, 31 January 2014

The IOP PAB Group 2014 Prize for Outstanding Professional Contributions has been awarded to Professor Christopher Prior, Leader of the ASTeC Intense Beams Group. The citation reads: To Christopher Prior for his seminal contributions to the mathematical modelling of intense particle beams in particular for his development of novel simulation methods and codes; for his generation of innovative accelerator concepts; for his educational and intellectual leadership; and for his many related contributions to the success of state of the art accelerator facilities in the UK and around the world.

Chris will deliver his Prize lecture at the 2015 Group annual conference.

Vacuum Group

ASTeC continues to support the IOP Vacuum Group through various ways with Joe Herbert and Oleg Malyshev serving on the committee and Mark Pendleton, Adrian Hannah, Sue Waller and Marie White supporting the organisation of the annual national vacuum symposium meeting. The Cockcroft Institute has also been the venue of choice for committee meetings while the IOP headquarters in London are relocated.

The main events held during the year include:-

- Thin Film Oxide Coatings – Manchester University, 16 April 2014
- RGA Calibration in Industry and Research – Ricoh Arena, part of 4th Vacuum Symposium (VS4), 16 October 2013.
- Vacuum –based Coatings Technology and Applications – VS4, 16 October, 2013.
- Functional Thin Films – VS4, 17 October , 2013.
- All Aspects of Leak Detection – VS4, 17 October, 2013.
- Student and Technician Training in Vacuum Technology, 5 training sessions, 38 students – VS4, 16 and 17 October, 2013.

The Vacuum Group 2013 Poster Prize was awarded to Haley Brown (Surrey University) for her poster 'Nanostructured Gas Barrier Films for Plastic Electronics Deposited by Remote Plasma Sputtering.

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IOP Institute of Physics

ASTeC Vacuum Science Group Assist UK PLC to gain Product Certification

SS Scientific is an SME (small to medium enterprise) based in Eastbourne that specialises in vacuum components and systems, providing technical solutions for research and industrial organisations. As a respected player in this field, the company recently had the opportunity to supply their specialised vacuum switches to a government research facility in the USA. In order to win the contract, SS Scientific needed to acquire Safety Integrity Level 3 (SIL3) certification to prove that their product met stringent requirements.

Therefore, through existing national networks, SS Scientific were able to identify and approach the ASTeC Vacuum Science Group who have the knowledge and technical capabilities to devise and implement an experimental programme. Utilising ASTeC's test facilities and extensive vacuum expertise, members of the group were able to carry out the required trial on a sample of vacuum switches to demonstrate their compliance with the SIL3 standard criteria.

The SIL3 trial concluded that SS Scientific's vacuum switches met the desired criteria, allowing the product to gain the SIL3 rating approval, thus enabling SS Scientific to win a substantial contract with a national laboratory in the USA. Having now achieved certification for their product, the company will be able to use the results of their collaboration to promote the product to various other international laboratories, such as CERN and the European Synchrotron Radiation Facility (ESRF). Access to the facilities available at ASTeC was vital in order for this UK company to gain access to a challenging and restricted area of the vacuum technology market, and will lead to increased revenue for the company. This new foothold in an international market may also provide the potential for wider global exposure of the company's products.

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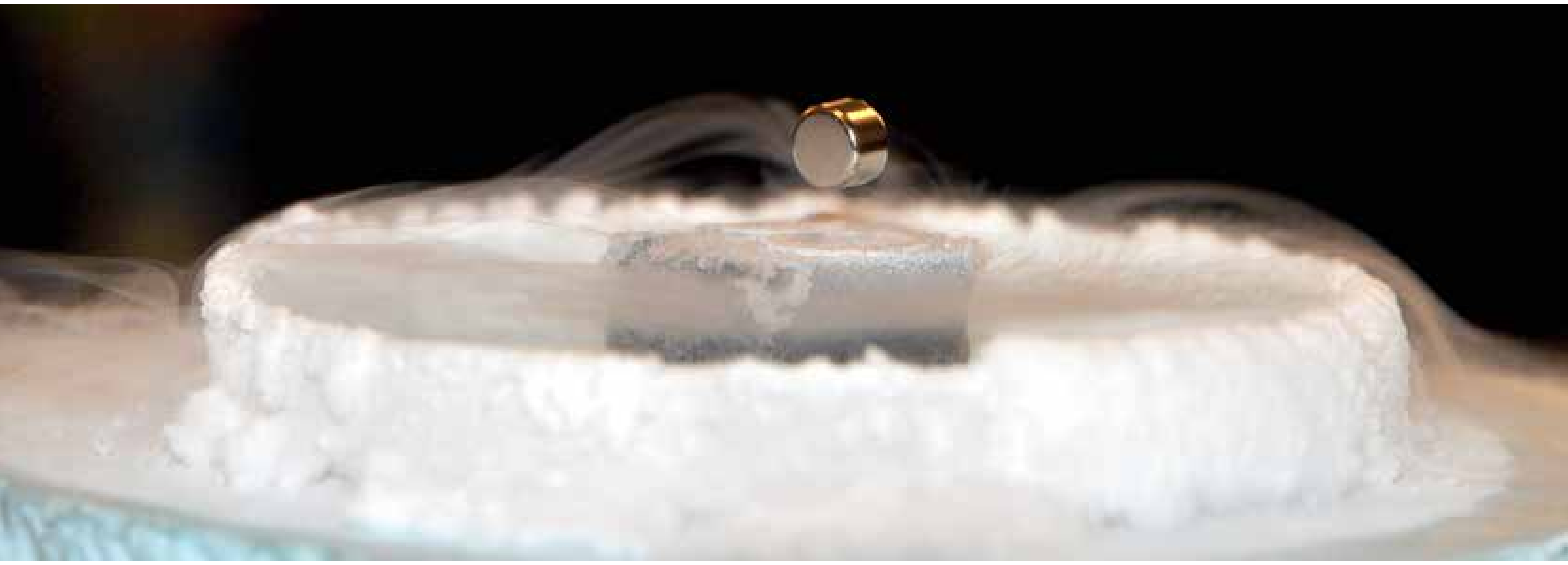
The Big Bang Fair and the Particle and Accelerator Physics Masterclass



The Big Bang

ASTeC and the Cockcroft Institute featured in the national Big Bang event (the largest science and technology fair in the UK) which ran over four days at the NEC in Birmingham, attracting nearly 55,000 visitors. The exhibition stand included two Van de Graff generators, one of which provided the high voltage needed to drive a model cyclotron accelerator, and the other generally had a queue of children (and some parents) waiting to have their hair raised by placing a hand on the dome and allowing themselves to be charged to high voltage. Other extremely popular demonstrations included the permanent magnetic accelerator and the Meisner effect. The magnetic accelerator is a simple device whose operation both surprises and delights everyone who sees it (including teachers), and it elegantly demonstrates several basic and very important aspects of physics. The Meisner effect demonstration combines the phenomena of superconductivity and magnetism such that a magnet is seen to 'float' above a superconductor, and vice-versa. The Vacuum Science Group were also on-hand to deliver their ever popular demonstrations. The multitude of demonstrations, fact cards and giveaways packed into the small 3 m × 3 m stand ensured that we were constantly busy during the event, and the sheer number of visitors to the stand made this the most significant and successful outreach opportunity of the year.

'Coordinating and delivering an exhibit like this at a national event can be extremely challenging and quite costly, but the level of attendance (particularly at the weekend) and the enthusiasm and delight evident in the visitors at the Cockcroft Institute stand demonstrated clearly to the whole team the importance of this work, and the impact we had achieved on behalf of the accelerator science community.'

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Accelerator Physics Masterclass

The Daresbury Laboratory particle and accelerator physics Masterclass again reached new heights in what was the largest event for many years. More than 330 students and 20 teachers attended over 3 days, some travelling from Oldham and the Lake District, to listen to a series of inspiring lectures and participate in various practical activities led by world-renowned experts in their fields.

The Masterclass programme has matured over recent years into a busy combination of lectures and activities which span the field of particle and accelerator physics, with talks on particle physics and astro-particle physics coming from the Universities of Manchester and Liverpool respectively, a talk on the GridPP worldwide data processing network used for LHC data analysis given by the University of Manchester. Lack of access to the ALICE accelerator prevented what is seen by many as the highlight of the day: a hands-on experiment to measure the energy of the electron beam in the ALICE injector line. However with foreknowledge of this, the organisers planned to stage the activity as a classroom exercise which worked extremely well, and removed the upper limit on student group size dictated by access to the ALICE accelerator, thereby allowing us to bring many more students onsite for the Masterclass. Under expert guidance from ASTeC staff and PhD students, the visiting students were able to complete the calculation and estimate the energy of this relativistic electron beam.

The visiting students were also fortunate enough to be able to see the travelling LHC Roadshow which happened to be onsite at Daresbury during the week of the Masterclass. This added an extra, unplanned dimension to the day.

The students also got to try their hand at interpreting some real LHC collision data using the Lancaster Particle Physics Package, and also to model accelerator optics at a collision point in an accelerator using the MAD (Methodology for Accelerator Design) package. Aspects of underpinning accelerator technology such as vacuum, superconductivity and the application of high voltages, electric and magnetic fields were also presented to the students.

Lee Jones, lead organiser for ASTeC and the Cockcroft Institute said:

'This is undoubtedly the best Daresbury Masterclass I have been involved with, and the impact was clear to see on the faces of the students and teachers as they left the Laboratory. It's been great to see so many of our Ph.D. students actively involved, and benefitting themselves from the outreach experience. My sincere thanks go to those ASTeC staff and students who supported the Masterclass, without whom it would not be possible to run the event.'

It was clear from feedback immediately after the event that the mixture of practical activities, demonstrations and talks had really stimulated the imaginations of the visiting students and kept them engaged throughout the day, and the timing of the event fitted well with study of the particle physics units at many of the participating schools.

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'Gastronaut Extreme' show puts Particle Accelerators Center Stage at the Big Bang Fair


Stefan, Suzie and the team during the exploding hydrogen balloon finale

In March 2014 Suzie Sheehy, from the Intense Beams Group, co-presented the 'Gastronaut Extreme' headline show at the Big Bang Fair alongside well known food writer and TV presenter Stefan Gates. Using Stefan's expertise in food and Suzie's expertise in physics together they developed and presented an engaging demonstration-packed show to 12,000 audience members over four days.

Despite food and accelerator physics being two disparate areas, they found a surprising number of exciting ideas to bring the two together: from talking about energy transformations to ideas of temperature and pressure, right through to creating a plasma from a grape live on stage using a microwave, while explaining why a microwave is like (but isn't quite) a particle accelerator.

Many of the most popular demonstrations and moments in the show were the parts about accelerators. In one demonstration Suzie turned the audience into a particle accelerator by asking them to accelerate giant beach balls on an audience wave, using this highly memorable moment to explain the science behind how a microwave cavity works and how waves in an RF cavity can give particles energy.

Of course, it all had to end with a big finale. For this, the team used a large scale hydrogen balloon explosion to create a spectacular display which quite literally

A full-house audience accelerating 'particles' during the show

shook the theatre. This brought the discussion of the 'emissions' from cows and food sustainability together with the physics of hydrogen, being the most abundant element in the universe and the source of protons in a particle accelerator. The shows ended with a bang, quite literally.

A fantastic learning experience for both presenters, Suzie and Stefan are now discussing new ideas for bringing these two topics and other STFC science together in the future.

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A Career Academy Student Develops a Levitating Train for the Outreach Event

Staff at the Daresbury Laboratory were joined in January by Ethan Nelson, a sixth form student at St Chad's High School in Runcorn. Ethan was selected by his school to spend four weeks at the laboratory as part of the Career Academies UK scheme, in order to gain experience outside of the normal curriculum. He was supervised by Andrew May, a sandwich student on a one year placement in the Radio Frequency and Cryogenics Group of ASTeC and he was tasked with producing an experimental demonstration of 'magnetic levitation' using a superconductor.

The application of superconductivity is critical to the design and operation of many high energy machines. During his placement Ethan learnt a huge amount about some of the physics behind the operation of particle accelerators, as well as gaining hands-on experience in the laboratory.

After cryogenics handling training and under close supervision, Ethan was able to successfully demonstrate the levitation of a small magnet above a superconducting block submerged in liquid nitrogen. This impressive quantum mechanical phenomenon occurs because the magnetic field becomes 'trapped' inside the superconductor. The magnet and superconductor then become fixed in space relative to each other, giving rise to the levitation effect. Reversing the position of magnet and superconductor, Ethan was subsequently able to construct a track of magnets allowing the free motion of the superconductor along the length of the track.

Ethan gave two presentations of his completed project: the first to ASTeC staff and the second to a group of visiting secondary school students who were touring the site. Andy and Ethan put together a kit to demonstrate a levitating model train which has now become a new addition to the outreach events such as the Big Bang.

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Liquid
nitrogen

IPAC13

From 12 to 17 May a group of 16 staff and students represented ASTeC at the International Particle Accelerator Conference (IPAC '13) in Shanghai, China. This is the largest annual international conference in accelerator science, with over 1000 delegates.

ASTeC facilities and science were well represented in the main sessions of the conference. Detailed measurements using the ALICE (Accelerators and Lasers in Combined Experiments) and EMMA (Electron Machine with Many Applications) accelerators were the main topic of a talk by Kai Hock from the University of Liverpool. ALICE, one of a few operating ERLs worldwide, also featured in another talk by R Hajima from the Japanese Atomic Energy Authority on 'Beam Commissioning of Energy Recovery Linacs'.

Recent publications from Neil Thompson and David Dunning from the MARS (Magnets and Radiation Sources) group on novel free electron laser design schemes featured in talks by S Reiche and J Wu from Paul Scherrer Institute and the Stanford Linear Accelerator Centre.

Apart from the main oral sessions, a key part of IPAC conferences are the poster sessions, at which ASTeC presented around 35 papers as either lead or contributing author.

The contributions reflected the diverse range of research and technology development carried out in the centre. A number of papers highlighted the recent achievement of first beam on VELA (Versatile Electron Linear Accelerator) at Daresbury Laboratory in April 2013. Progress on the design of a proposed advanced test facility for future light sources 'CLARA' (Compact Linear Accelerator for Research and Applications) was also covered in detail.

ASTeC's strong knowledge base in FFAG (Fixed Field Alternating Gradient) accelerators was strongly represented with papers on lattice and beam dynamics both in EMMA and for future accelerators. Hadron and muon accelerator expertise was represented in papers on the Front End Test Stand developments at RAL, ASTeC's contributions to ISIS upgrades and designs for the Neutrino Factory. The status and recent achievements of the Muon Ionisation and Cooling Experiment (MICE) at RAL was also presented. Technological developments are an integral part of ASTeC's research and were described in papers on permanent magnet quadrupoles for the Compact Linear Collider project, the UK superconducting planar undulator project, Crab Cavities for the Large Hadron Collider High Luminosity Upgrade and the Daresbury International Cryomodule Project.

The conference would not run so smoothly without the contributions of staff to assist in it's running. As a member of the JACOW publishing team, Sue Waller supported the publication of the paper submissions throughout the duration of the conference. Deepa Angal-Kalinin, leader of the Accelerator Physics Group, chaired the contributed oral session on beam instrumentation and feedback.

FEL 2013

In August 2013 four members of ASTeC attended the 35th International Free Electron Laser Conference, which was held in New York City in the vibrant surroundings of Times Square! The ASTeC delegates were Jim Clarke, Dave Dunning, Frank Jackson, and Lee Jones. Between them they presented work on a range of ASTeC projects, including experimental results from the ALICE Infra-Red FEL, details of the conceptual design for the proposed FEL test facility CLARA, as well as details of TESS – an experimental facility for measuring the electron energy distribution from photocathodes.

Opening the session devoted to novel techniques for FELs, Dave Dunning gave an invited presentation in which he highlighted the potential of FELs to generate the shortest ever pulses of light (towards attoseconds or even zeptosecond-scale), and outlined ASTeC / Strathclyde proposals to achieve this.

A conference programme featuring talks, poster sessions and a conference dinner boat cruise around Manhattan were utilised by ASTeC staff to interact with other delegates on technical issues and to develop new opportunities. Staff also took the chance to visit Brookhaven National Laboratory, where they visited facilities including the NSLS-II and the STAR detector at RHIC.

19th International Vacuum Congress (IVC-19)

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This conference is the flagship meeting organised by the International Union for Vacuum Science, Technique and Applications, organised every three years. In 2013 the French Vacuum Society (SFV) took the lead role in organising the conference at the Palais des Congres de Paris (Paris Convention Centre) 9-13 September. The main conference reception was held at La Conciergerie – a former prison for rebels of the French Revolution. The conference attracted over 1800 abstracts from over 70 countries producing a scientific programme arranged in 15 parallel oral sessions each day along with 3 large poster sessions. Joe Herbert represented the UK on the Vacuum Science and Technology International Scientific Committee and Oleg Malyshev co-organised a short course on Vacuum Gas Dynamics : Theory, Experiments and Applications. Gavin Tracey presented the latest information on ASTeC activities through a stand in the main manufacturers exhibition held throughout the week.

A total of 5 talks were delivered from the Vacuum Science Group:

- Session – Vacuum Measurement, Primary Standards and Calibration: Comparative RGA Measurements in the range from 10^{-10} to 10^{-05} mbar by Mark Pendleton
- Session – Large Vacuum Systems: The Vacuum System Design of a New Electron Beam Test Facility (EBTF) at Daresbury Laboratory (now renamed VELA) by Joe Herbert
- Session – XHV Production / Measurement and Outgassing: Electron Stimulated Desorption from Stainless Steel by Oleg Malyshev; Optimisation of Non-Evaporable Getter Coatings for Particle Accelerator Vacuum Systems by Reza Valizadeh; Vacuum Lifetime Studies of GaAs Photocathodes by Keith Middleman

SRF 2013

The 16th International Conference on RF Superconductivity, SRF 2013 was hosted at the Cité Internationale Universitaire, in downtown Paris, France 22-27 September 2013. Work was presented by the RF & Cryogenic group on the ERL International cryomodule development, Innovations Partnership Scheme (IPS) grant to develop the UK capability to fabricate, process, and test a niobium, 9-cell, 1.3 GHz superconducting RF cavity and a conceptual design of a cryomodule for compact crab cavities for the Hi-Lumi Large Hadron Collider, CERN. The conference covered a vast range of areas from SRF challenges, material studies, thin film work, processing improvements to production challenges.

Participants enjoyed a river cruise on the Seine on the Wednesday afternoon and had the opportunity to visit a number of the accelerator facilities located in Paris (Synchrotron SOLEIL, CEA Saclay, IPNO: Institut de Physique Nucléaire d'Orsay, and LAL: Laboratoire de l'Accélérateur Linéaire).

4th Vacuum Symposium UK

Vacuum Symposium UK was formed to embrace all of the UK vacuum community. Its aim is to bring together academics, industrialists, engineers, manufacturers and anyone using vacuum to promote UK pre-eminence in the subject. The event took place on 16-17 October in Ricoh Arena in Coventry. The ASTeC Vacuum Science Group and events team have made significant contributions to the establishment and the smooth running of this very successful event.

Vacuum is a key enabling technology for a wide variety of applications that are of growing importance in the 21st century. Whilst there is an abundance of information on the internet we believe that the annual event organised by Vacuum Symposium UK provides a unique opportunity for networking and education, in addition to topical meetings of interest to vacuum users.

This year there were four, free to attend, technical meetings arranged with support from a number of commercial sponsors as well as the Institute of Physics and the British Vacuum Council.

The Vacuum-based Coating Technology and Applications meeting provided an update on methods where vacuum, plasmas and energy-assistance methods are used in industrial coating processes. John Colligon, a collaborator with the ASTeC Vacuum Science Group, chaired this programme.

The RGA Calibration in Industry and Research meeting was the 11th meeting organised by the RGA User Group. The programme focussed on the requirements that users have for calibrating quadrupole mass spectrometers and developments in providing suitable calibration techniques including insitu methods. The meeting was pleased to welcome Karl Jousten (PTB, Berlin) and Janez Setina (IMT, Slovenia), as leading scientists in this field. They covered the topics of 'Recent steps towards traceability for partial pressure and outgassing measurements' and 'First results of investigations of metrological characteristics of QMS within EMRP IND12' (a European project). Other talks included an overview of the use of RGA at Diamond Light Source and latest results from comparative tests carried out in ASTeC at Daresbury Laboratory.

The Functional Thin Films meeting provided a comprehensive mix of presentations on the production, characterisation and commercial applications of functional coatings. Speakers from a range of prestigious industrial and academic institutions gave high quality presentations in sessions on "Characterisation of functional thin films", "Industrial processing", and "Materials and applications".

ASTeC's Mark Pendleton organised the All Aspects of Leak Detection meeting and it proved to be very popular with delegates wishing to learn more about leak detection methods and see the latest instruments presented by vacuum equipment suppliers. At the end of the technical meeting a one hour hands on session was held in the vacuum exhibition hall and this allowed delegates to see the latest leak detectors available on the market and to try them out.

Once again Joe Herbert organised a series of training courses to run during the symposium with Austin Chambers and Ron Reid delivering the courses. Demand for basic and advanced training in vacuum science and technology within the UK continues to be high. This was underlined by the fact that each of the courses offered this year were oversubscribed before the symposium began. A total of 38 individuals received training through 3 different training courses over 2 days with a total attendance figure across all courses of 83.

Workshop on the Operation of Large Vacuum Systems

The Fourth Workshop on the Operation of Large Vacuum Systems (OLAV-IV) was held at the National Synchrotron Radiation Research Center (NSRRC) in Taiwan from 1 to 4 April 2014. Joe Herbert, who has been part of the Organising Committee for all previous OLAV meetings, helped bring together 42 specialists and scholars in the field of vacuum research from 24 institutes in 12 nations to participate in the four-day workshop.

The workshop contained 46 invited talks, 5 of which were given by ASTeC staff. Keith Middleman, Joe Herbert and Mark Pendleton each gave talks on key ASTeC projects and there was great interest in the work ASTeC is doing.

A number of topics were covered including the latest developments at related institutes: accelerator systems, control and interlocking systems; operational issues and long-term experiences; vacuum failures & recovery procedures; advances in vacuum technology, XFEL, NEG and coatings, and critical components; outgassing of materials; pressure measurements and RGA. The attendees were inspired by the presentations and had enthusiastic discussions and exchanges throughout all of the sessions.

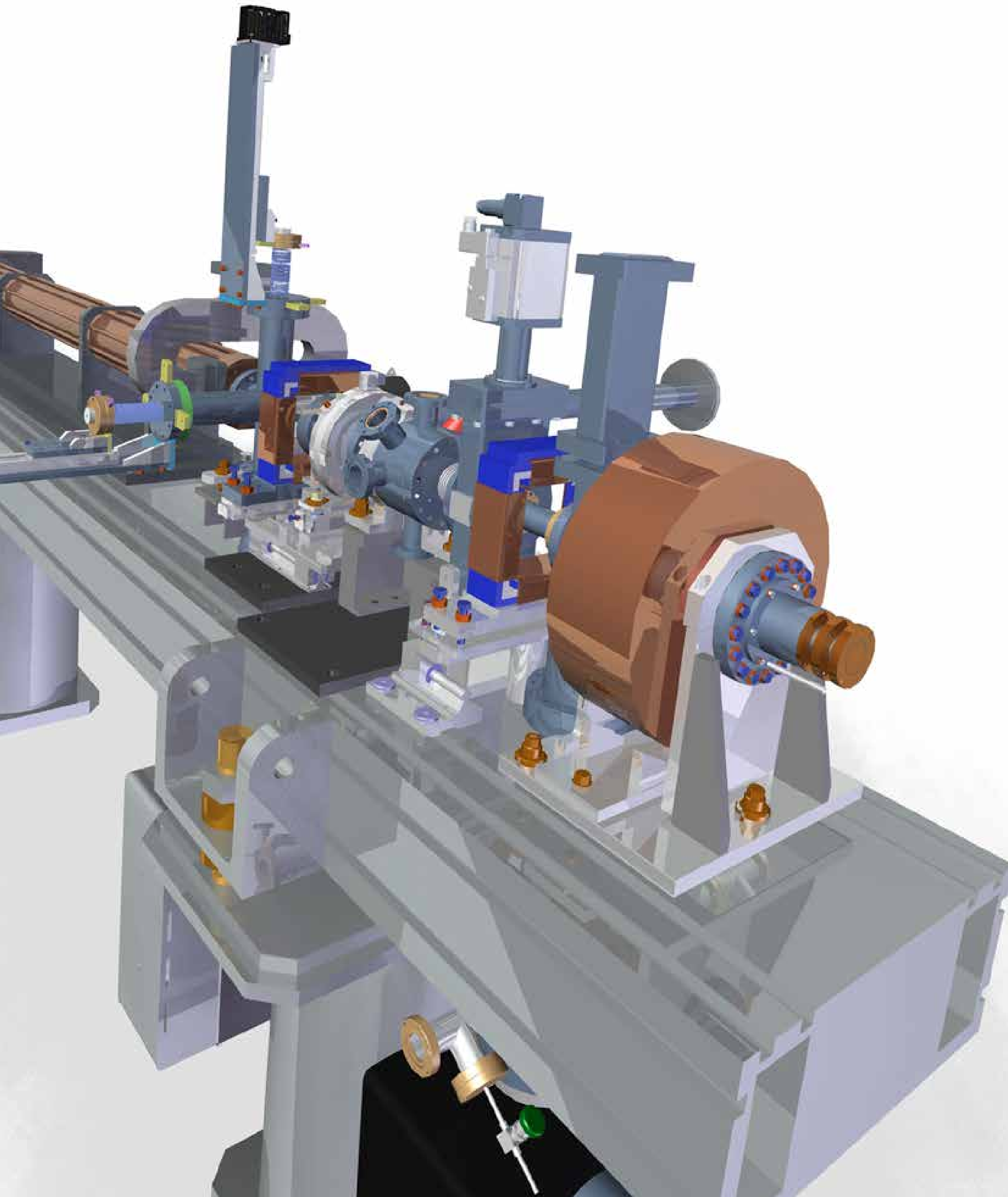
The OLAV workshop has been taking place every three years since 2005. The first OLAV was held in 2005 by CERN in Switzerland, the second one in 2008 by ASTeC in the UK, and the third one in 2011 by Oak Ridge National Laboratory in the US. The OLAV series of workshops provide a periodic forum in which participants can present and compare their experiences by oral presentations and extensive discussions. In particular, the workshops are aimed at professionals in design, operation and working of all types of particle accelerators, ranging from the largest colliding beam machines to small industrial accelerators, and from those dealing with modest vacuum levels to XHV and to large fusion machines where overlapping areas of interest exist, including UHV levels of vacuum, clean pumping systems, materials, radiation hard equipment, gauging and leak detection.

OLAV IV was a very successful event and everyone looks forward to seeing one another again at OLAV V to be held by DESY in Germany in 2017.

Accelerator Community Calls for CLARA

The Institute of Physics Particle Accelerator and Beams Group sponsored a meeting of UK accelerator professionals on 13 January 2014 at the Cockcroft Institute to discuss the accelerator science and technology opportunities that would be afforded by the proposed CLARA Test Facility. Over sixty people attended the event, chaired by Jim Clarke (ASTeC), to hear presentations about the status of the project, the accelerator design, and the ideas that different groups have for making use of the high quality electron beam that would be available. Two of the talks reflected the fact that CLARA is primarily an FEL test facility, particularly focussed on ultra short pulse generation, but the others covered a wide variety of other applications from plasma acceleration, to dielectric accelerators, to advanced beam dynamics benchmarking, to a technology test bed for advanced diagnostics and high repetition rate photoinjectors, and even as an injector into novel circular accelerators. The breadth of the potential applications was truly impressive, and clearly demonstrated the enthusiasm and strength of the accelerator community. Several speakers identified that the science can start as soon as the front end is installed, which is currently scheduled for 2015, and some experiments will even be starting in 2014 utilising VELA.

For further information contact: jim.clarke@stfc.ac.uk



6 CONFERENCE WORKSHOPS & VISITS

EuCARD13

EuCARD, an integrating activity co-funded by the European Commission under Framework Programme 7 which began in April 2009 for a duration of 4 years, was concluded with a workshop at CERN.

The workshop was held on 10-14 June 2013, followed by a one day workshop on "Visions for the Future of Particle Accelerators" and the formal kick-off meeting for the new follow-on project EuCARD-2. ASTeC participated in a number of workpackages in EuCARD: assessment of novel accelerator concepts, normal conducting linac, superconducting RF and high field magnets R&D.

EuCARD-2 brings a global view to particle accelerator research, coordinating a consortium of 40 accelerator laboratories, technology institutes, universities and industry to jointly address common challenges for the future generation of accelerators. By promoting complementary expertise, cross-disciplinary fertilisation and a wider sharing of knowledge and technologies throughout academia and with industry, EuCARD-2 aims to significantly enhance the multidisciplinary R&D for european accelerators, actively contributing to the development of a european research area in accelerator science. Peter McIntosh is co-ordinating the "Innovative RF Technologies" work package and ASTeC is also contributing to the RF photocathodes and CLIC crab cavities task within this WP.

As LHC was shutdown ASTeC participants:
Deep Angal-Kalinin, Peter McIntosh and Boris Militsyn had an opportunity to visit the LHC tunnel to see the CMS detector.

3rd EUCARD-2 Steering Committee Meeting

Over 12 & 13 December 2013, ASTeC hosted the 3rd EUCARD-2 Steering Committee Meeting, bringing together each of the 12 workpackage coordinators from across Europe. EUCARD-2 is coordinated by Maurizio Vretenar from CERN, who reviewed activity progress in areas encompassing: catalysing innovation, energy efficiency, accelerator applications, extreme beams, low emittance rings, novel accelerators, ionisation cooling test facility, high radiation materials and MagNet testing, future magnets, collimator materials, innovative RF technologies and novel concepts. The meeting also provided ASTeC with an opportunity to highlight priority research being performed at Daresbury on test facilities, photocathode R&D and UK contributions towards the HL-LHC programme, whilst also providing the Steering Committee with a tour of the ALICE, EMMA and VELA accelerator facilities.

EUCARD-2 is an integrating activity project for coordinated research and development on particle accelerators, co-funded by the European Commission under the FP7 Capacities Programme. This project will contribute to positioning European accelerator infrastructures at the forefront of global research.

For further information contact: peter.mcintosh:stfc.ac.uk

3rd Annual Meeting of the HiLumi LHC-LARP Collaboration

The joint HiLumi LHC-LARP collaboration held its 3rd annual meeting 11-15 November 2013, hosted by ASTeC, Daresbury Laboratory and the Cockcroft Institute. The international meeting brought together 180 physicists and engineers from all three continents to address the luminosity upgrade of the Large Hadron Collider (LHC) at CERN, which will provide an unprecedented rate of proton-proton collisions to the four LHC experiments in the 2020s. The meeting addressed key issues of accelerator design, scheduling and the exploitation of novel technologies to deliver the challenging project goals.

The week began with the kick-off meeting of the LHC upgrade project, which was attended by the CERN directorate, senior management of STFC and senior management of the US DoE (Dr Bruce Strauss).

The main workshop covered plenary and parallel sessions addressing various aspects of the LHC machine upgrade. The packed programme allowed a few hours during one lunch break to take a tour of the accelerator facilities ALICE, EMMA and VELA. The collaboration board dinner at the famous Old Trafford football stadium and the workshop dinner at Ruthin Castle in Wales with a medieval banquet and entertainment, provided the backdrop for further discussion and relaxation.

The intense but enjoyable long week provided the perfect environment for productive scientific discussion and collaboration building. Many thanks to the local and CERN organisers who ensured a smooth running of the workshop.

HEPTech Academia meets Industry: Environmental Applications of Accelerators

With an increasing industrial focus on resource savings, and the adoption of good environmental practises backed by ever-tightening regulatory requirements, accelerator-based solutions for environmental clean-up and production efficiencies are now transferring from the high energy physics laboratory to the industrial workplace.

This HEPTech event on 8-9 July 2013 brought together industry experts, scientists, application engineers, supply chain manufacturers and a range of funding bodies to discuss the potential requirements, limitations and opportunities that cutting edge advances bring to a broad range of environmental applications. The event looked to clarify industry's needs, and foster collaborations which accurately target these requirements with innovative and cost effective solutions.

The main focus of the day was on water and wastewater treatment, for both municipal and industrial applications. Keynote presentations from United Utilities, Black and Veatch and Microbial Solutions Ltd outlined the main industrial challenges – in particular, the issue of dealing with specific contaminants, which are costly to remove, or indeed not treatable at all, with current technologies. The main requirements on technology solutions were also identified, with capital cost, operating cost, ease of integration and energy efficiency being amongst the main priorities. The breakout sessions in the afternoon offered an opportunity for accelerator experts to further explore the applicability of accelerator technology, identifying several routes for more in-depth collaborative work. The meeting concluded that there were significant opportunities in this area and that the technology solution development would require expertise from a range of scientific and engineering disciplines. The meeting organisers will be following up on these opportunities with the help of the meeting participants.

Final Annual TIARA Preparation Phase Review

From 25-28 November ASTeC hosted the final annual review meeting of the EC-funded TIARA Preparation Phase, whose remit has been to substantiate integration of national and international accelerator R&D infrastructures into a single distributed European accelerator R&D facility, with the goal of developing and strengthening state-of-the-art research, competitiveness and innovation in a sustainable way in the field of accelerator science and technologies across Europe. With 52 attendees from across Europe's leading laboratories, the main purpose of this concluding meeting was to review the progress within the various TIARA work packages and finalise the results of the TIARA Preparatory Phase. For the past 3 years, ASTeC has played coordinating roles as part of collaborative work package teams, with Peter McIntosh representing ASTeC in WP3 to develop Accelerator R&D Infrastructures and Susan Smith in WP4 to assess Joint R&D Programming.

ASTeC Visit to the Institute of Semiconductor Physics, Novosibirsk

In September 2013, Dr Tim Noakes from ASTeC's Accelerator Physics group visited the Institute of Semiconductor Physics in Novosibirsk, which is part of the Siberian Branch of the Russian Academy of Sciences. This visit marks the latest meeting in a long running collaboration between the two institutes which dates back to 2006. The main focus of this collaboration over the years has been the development of high quantum efficiency photocathodes based on semiconductor technology for use in Energy Recovery Linacs (ERLs), such as the ALICE accelerator. One of the key developments to have come from this collaboration has been the Photocathode Preparation Facility (PPF) originally designed for the ALICE photoinjector upgrade and currently used as an important research tool for photocathode research within ASTeC. More recently, an ISP scientist (Dr Heinrich Schiebler) played an important role in the commissioning of the Transverse Electron Energy Spread Spectrometer (TESS) at Daresbury, an instrument designed to allow the detailed characterisation of the properties of electrons emitted from a photocathode.

Whilst at the ISP Dr Noakes toured the laboratory, which includes extensive facilities for the preparation and characterisation of semiconductor photocathodes; along with accelerator science applications these materials can be used in other areas such as image intensifiers and photomultiplier tubes. He also took part in an experiment to characterise the longitudinal energy distribution of electrons emitted from a GaAs(111)B photocathode using some of the unique equipment at ISP. The results of this work may form part of a larger study of these materials, which could ultimately be published. Work was also begun on a draft version of a paper based on results taken on a previous visit by ASTeC staff to ISP (Dr Boris Militsyn and Dr Lee Jones).

In addition, extensive discussions were held with Dr Alexander Terekhov, the leader of the photocathode research activity at ISP, on the future direction of this collaboration. More visits between the institutions are planned in the next year or so to carry out further collaborative experiments. In particular, these experiments will exploit the state-of-the-art capabilities (represented by the PPF and TESS) which are now in place in the Vacuum Science Laboratory here at Daresbury. It is hoped that much more interesting and useful science, including publications in high profile journals will come from this collaboration.

Whilst in Novosibirsk, Dr Noakes also took the opportunity to visit the Energy Recovery Linac at the Budker Institute of Nuclear Physics, which is one of the few other such machines in the world besides the ALICE accelerator at Daresbury.

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8 FINANCE

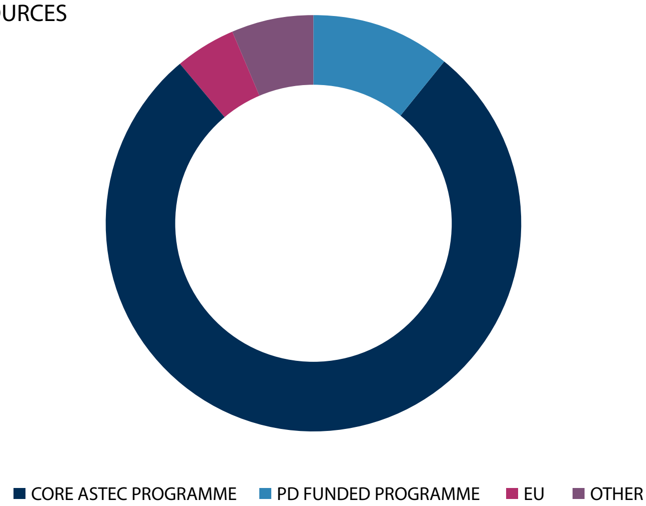
ASTeC ACTIVITIES 13/14

INCOME SOURCES 13/14	£K
CORE ASTeC PROGRAMME	7443
PROGRAMME DIRECTORATE (PD) FUNDED PROGRAMME	1036
EU	427
OTHER	607
	9513

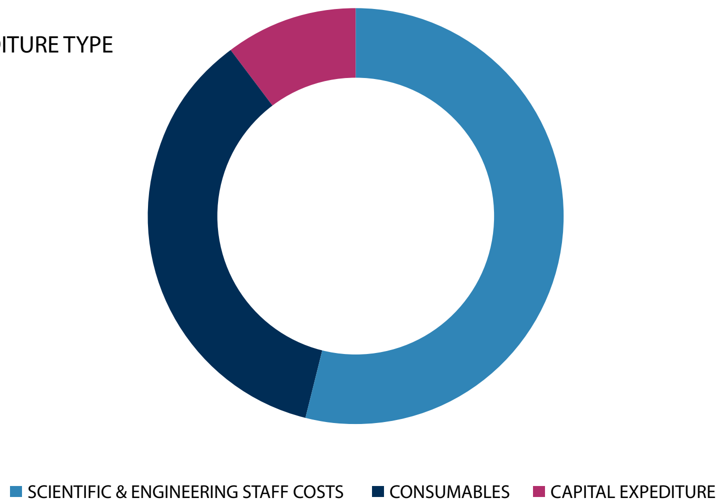
EXPENDITURE 13/14	£K
SCIENTIFIC & ENGINEERING STAFF COSTS	5130
CONSUMABLES	3427
CAPITAL EXPENDITURE	956
	9513

EXPENDITURE BY PROGRAMME 13/14	£K
CLARA PROJECT	2169
VELA PROJECT	1353
HIGH BRIGHTNESS ELECTRON ACCELERATORS	2547
HIGH POWER PROTON ACCELERATORS	924
COCKCROFT INSTITUTE AND NEW INITIATIVES	585
UNDERPINNING RESEARCH	565
EU	526
UK_NF PROGRAMME	426
PHOTON STUDIES	139
OTHER REPAYMENT WORK	279
	9513

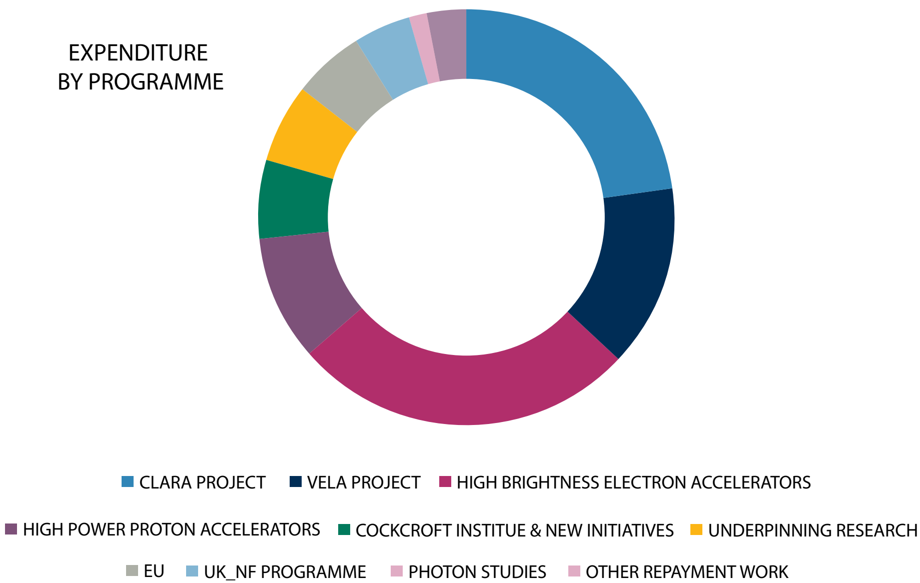
INCOME SOURCES



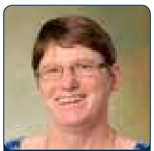
EXPENDITURE TYPE



EXPENDITURE
BY PROGRAMME

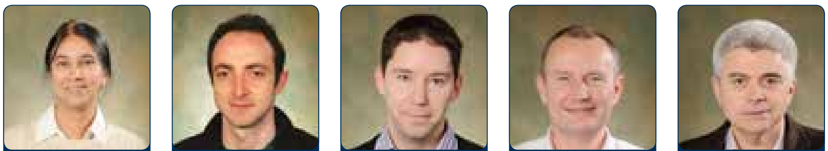


Science & Technology
Facilities Council



Susan Smith
Director

ACCELERATOR PHYSICS



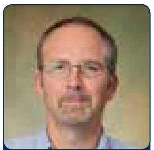
Deepa Angal-Kalinin
Group Leader

Frank Jackson
Accelerator Physicist

James Jones
Senior Accelerator Physicist

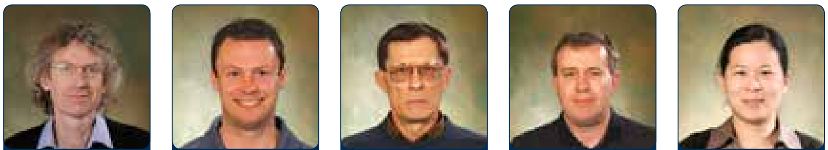
Lee Jones
Senior Accelerator Physicist

Tim Noakes
Senior Scientist



Peter McIntosh
Technical Division Head

DIAGNOSTICS & LASERS



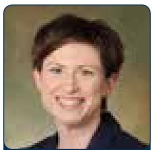
Steve Jamison
Group Leader

Stephen Buckley
Senior Diagnostics Engineer

Alex Kalinin
Senior Diagnostics Engineer

Rob Smith
Senior Diagnostics Engineer

Trina Thakker
Laser Scientist



Katherine Robertson
Business Development Manager

INTENSE BEAMS

Chris Prior
Group Leader

David Kelliher
Accelerator Physicist

Shinj Machida
Senior Accelerator Physicist

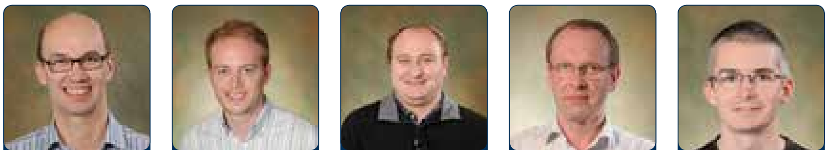
Ciprian Plostinar
Accelerator Physicist

Graeame Rees
Consultant

Mandy Brookes
Personal Assistant

Adele Cook
Management Accountant

MAGNETICS & RADIATION SOURCES



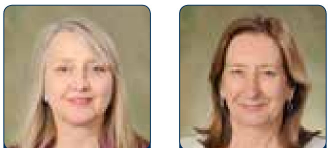
Jim Clarke
Group Leader

David Dunning
Physicist

Kiril Marinov
Physicist

Mark Roper
Senior Optics Scientist

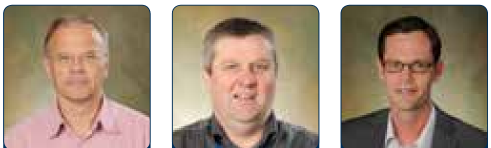
Ben Shepherd
Physicist



Janis Davidson
Admin Support

Liz Kennedy
Personal Assistant

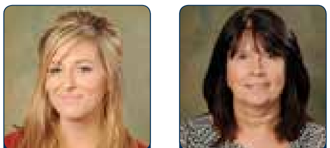
PROGRAMMES & FACILITIES



Greg Diakun
Programme Manager

Andy Goulden
Accelerator Ops. Manager

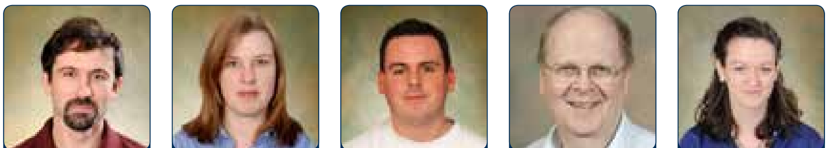
Anthony Gleeson
Business Development



Aimee Telfer
Admin Support

Sue Waller
Events & Admin Manager

RADIO FREQUENCY & CRYOGENICS



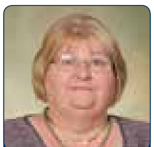
Alan Wheelhouse
Group Leader

Rachel Buckley
RF & Croyogenics Engineer

Peter Corlett
RF Engineer

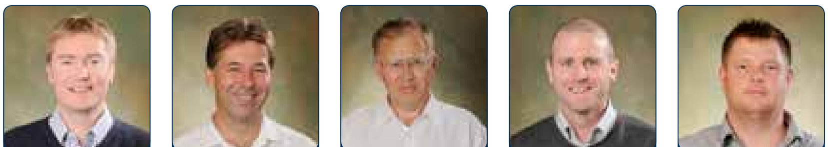
Tim Stanley
RF Engineer

Louise Cowie
RF Scientist



Marie White
Personal Assistant

VACUUM SCIENCE



Joe Herbert
Group Leader

Adrian Hannah
Vacuum Engineer

Oleg Malyshev
Senior Vacuum Scientist

Keith Middleman
Senior Vacuum Scientist

Mark Pendleton
Vacuum Engineer

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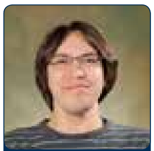
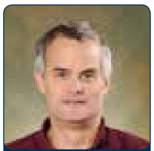
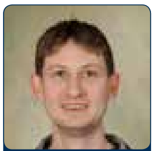
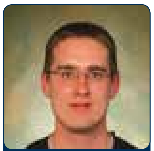

Julian McKenzie
Accelerator Physicist

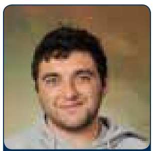

Boris Militsyn
Senior Accelerator Physicist

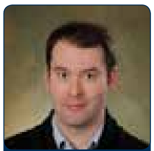

Bruno Muratori
Senior Accelerator Physicist

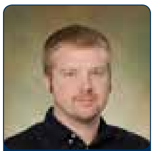

Yuri Saveliev
Senior Accelerator Physicist


Peter Williams
Senior Accelerator Physicist

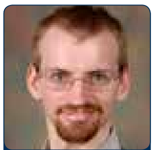

Duncan Scott
Senior Accelerator Physicist

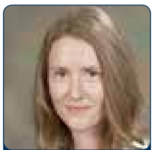

Alex Brynes
Accelerator Physicist


Edward Snedden
Laser Physicist

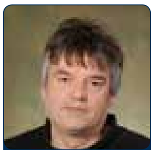

David Walsh
Senior Laser Scientist

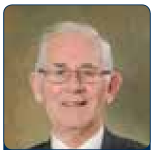

Rui Pan
Laser Scientist

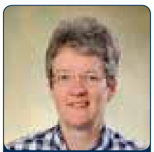

Chris Rogers
Senior Accelerator Physicist


Suzie Sheehy
Research Fellow

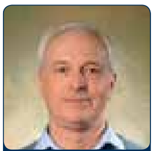

Mark Surman
Senior Scientist


Neil Thompson
Senior Physicist

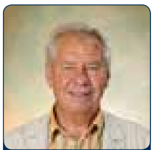

Neil Marks
Consultant


Elaine Seddon
Consultant

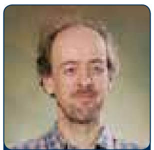
HONORARY SCIENTISTS


David Holland


Mike Henderson

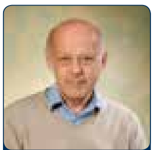

Ian Munro


Mike Poole

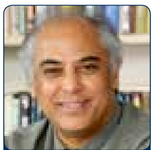

Andy Smith

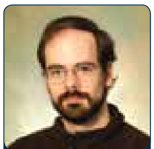

David Shaw


Ray Jones

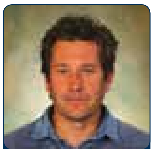

John West


Michelle Siggel-King

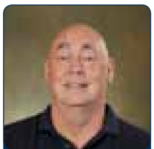

Swapan Chattopadhyay

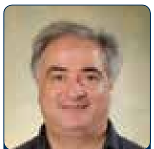

Philippe Goudket
RF Scientist


Lili Ma
Diagnostics Engineer

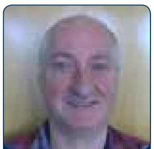

Andy Moss
Senior RF Engineer

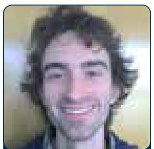

Shrikant Pattalwar
Croyogenics Engineer


Paul Gannicliff
Technical Support Officer


Reza Valizadeh
Senior Materials and Surface Scientist

ASSOCIATE APPOINTMENTS


Brian McNeil
University of Strathclyde


Lawrence Campbell
University of Strathclyde

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Establishments at Rutherford Appleton Laboratory, Oxfordshire; Daresbury Laboratory, Cheshire;
UK Astronomy Technology Centre, Edinburgh; Chilbolton Observatory, Hampshire; Isaac Newton Group, La Palma;
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