ASTeC

World class science

Science Highlights 2011 - 2012

Accelerator Science and Technology Centre

Science & Technology Facilities Council

ASTeC studies all aspects of the **science and technology of charged particle accelerators**, ranging from large scale international and national research facilities through to specialised industrial and medical applications.

Science Highlights
2011 – 2012

This report covers the work accomplished by the Accelerator Science & Technology Centre (ASTeC) for the financial year 2011 – 2012

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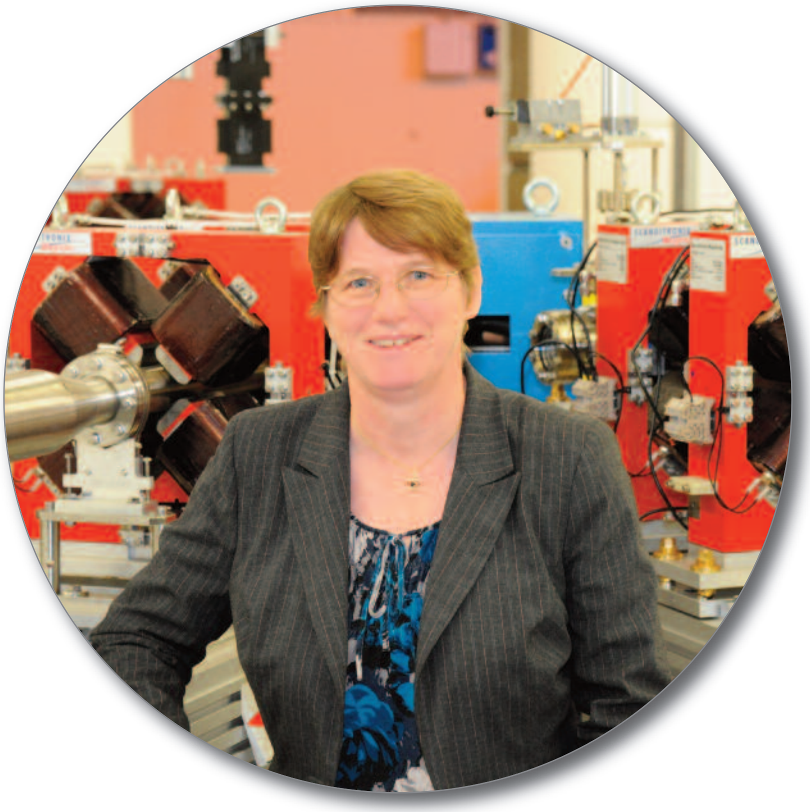
ISSN 2049-7512

www.stfc.ac.uk/astec

ASTeC

Foreword



This annual report reviews the activities of the ASTeC department across my first full year as its Director. This was also a year which saw ASTeC celebrate its 10th anniversary, an event that encouraged us to look back over a decade of highlights which included delivery of the Diamond technical design, the final photons of the SRS and growth of ASTeC leadership internationally in areas such as The International Linear Collider and Neutrino Factory. During this decade the energy recovery linac prototype (ERLP) grew into ALICE an advanced accelerator test facility delivering a diverse science programme.

This year's ASTeC programme for ALICE included two important contributions internationally. The EMMA study of acceleration in the world's first non-scaling FFAG accelerator and the SNOM cancer diagnostic programme led by Liverpool University as well as a number of accelerator physics studies of the energy recovery linac processes.

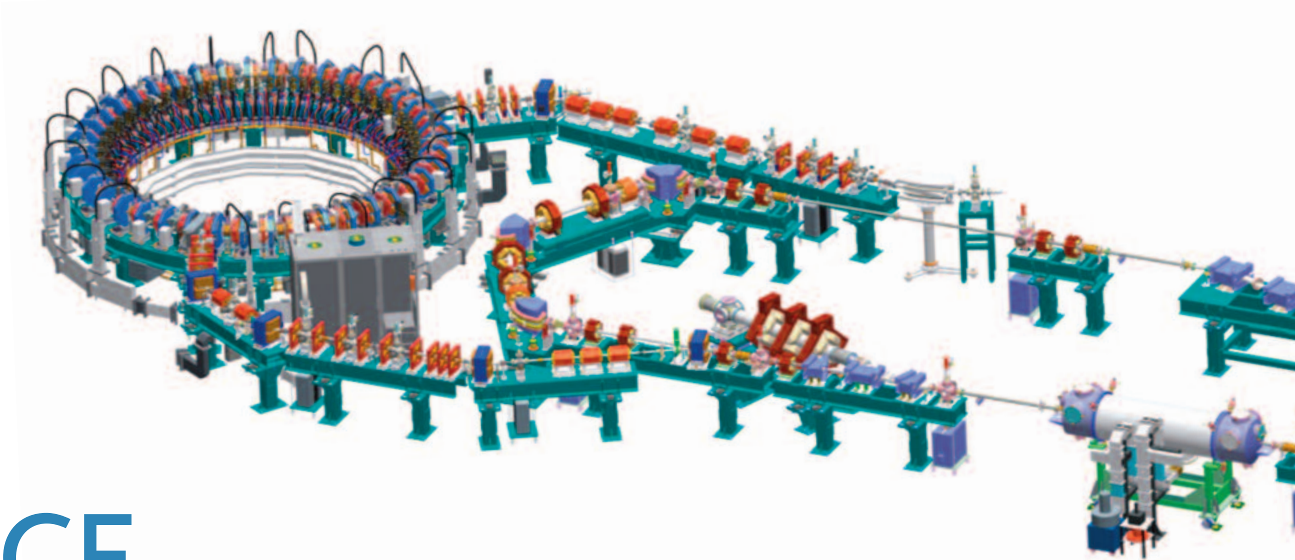
The announcement of a £2.5M investment in August, in the Electron Beam Test Facility (EBTF), has enabled us to commence the delivery of an entirely new facility. This will open up exciting opportunities for industry to apply the latest particle accelerator technology to its most critical commercial challenges. We are also developing the concept of CLARA which will develop and demonstrate technological advances to substantially enhance the performance of XUV and x-ray Free Electron Lasers (FEL).

The articles in this report highlight the breadth of accelerator science and technology activities currently being pursued within the department. These included the development of superconducting and permanent magnet accelerator designs, photoinjector and photocathode research programmes, superconducting RF module delivery, and fundamental aspects of vacuum science all centred on our facilities.

International collaborations are an intrinsic part of our delivery, and this year has again proved important for interest and participation in Daresbury based facilities and projects. Our internationally outward focussed programmes this year have included the development of an interlock system for the ITER, a number of studies supporting the SwissFEL facility and an innovative design for permanent magnet quadruples for the CLIC.
Our interactions with the national and international accelerator community are also developed and enhanced through our active participation in, and the hosting of, a number of workshops and visits improving both our capabilities and our impact.

Finally, I would like to recognise the efforts of the ASTeC staff which have delivered such a highly diverse programme of research pushing the capabilities of the next generation science facilities and positioning the UK to unlock the potential of these technological advances for the benefit of UK industry and the national economy.

Projects



ALICE

From a Prototype to a Multifunctional Facility

ALICE (Accelerators and Lasers In Combined Experiments) has evolved from being an energy recovery linac prototype for a fourth generation light source (4GLS), to a multifunctional facility hosting a wide range of projects from accelerator physics to life sciences.

Past achievements include a successful demonstration of the Compton Backscattering experiment in 2009, and start of the biological experiments using powerful broadband THz radiation from ALICE in 2010. In the same year, the first in the world non-scaling FFAG accelerator EMMA had accomplished injection of the electron beam generated by ALICE and demonstrated thousands of turns of the beam circulation in the EMMA ring. The end of 2010 was highlighted by commissioning of the first (in the UK) infra-red free electron laser (IR FEL).

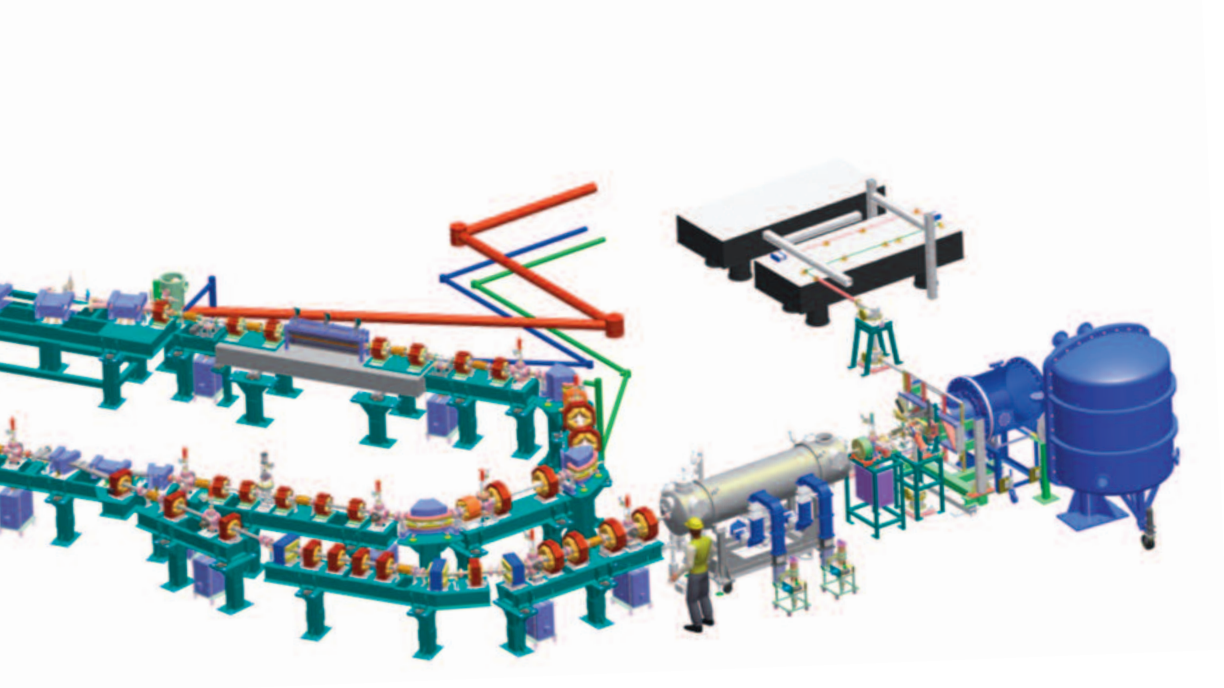
The year 2011-12 also proved to be successful in ALICE operation and achievements. The THz radiation was transported via a dedicated optical line to the Tissue Culture Laboratory thus enabling biological experiments in a perfectly controlled environment. Beam acceleration in EMMA was achieved, thus demonstrating proof-of-principle for this novel type of particle accelerator.

Finally, the IR SNOM (Scanning Near-field Optical Spectrometer) was commissioned on ALICE using its IR FEL.

Since the beginning of operations in 2006, ALICE demonstrated a steady nearly exponential growth in a number of important scientific milestones achieved. This trend, albeit not exactly "scientific" by itself, continued throughout the year 2011-12.

ALICE Accelerator

ALICE is an energy recovery linac (ERL) based accelerator. The HV DC photoelectron gun with GaAs photocathode injects an electron beam into the first superconducting accelerator module, the booster that provides the exit beam energy of 6.5 MeV. The main linac accelerates the beam to the energy required for particular projects, e.g. 26 MeV for IR FEL operation and generation of THz radiation or 12 MeV to inject the beam into the EMMA ring. After acceleration, the beam is transported to the magnetic compression chicane and then back to the main linac for energy recovery, where after the spent beam is dissipated in a dump load.

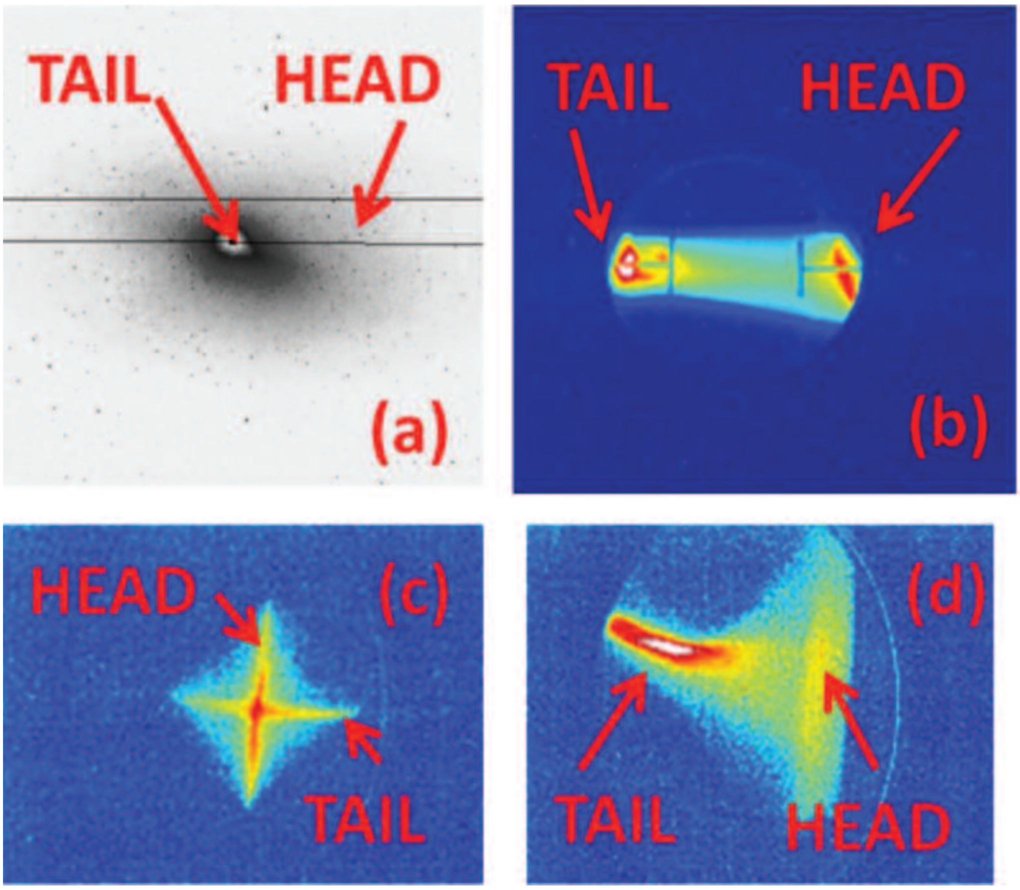


In 2011-12, two major developments took place on ALICE. Firstly, a significant improvement has been made to the hour-to-hour phase stability to within approximately 1° of the fundamental 1.3 GHz operating frequency of both of the linacs. Temperature dependent effects in the master oscillator were identified and corrected with a specially designed system that measures the RF phase continuously and keeps it constant with a feedback loop. This development greatly improved machine stability while delivering the beam to various scientific projects and allows optimisation of ALICE performance with greater efficiency.

Secondly, a larger diameter photoelectron gun ceramic was installed at the end of 2011. The gun was successfully high voltage conditioned to 420 kV for a design operational voltage of 350 kV. This allowed the gun voltage to be increased greatly from a very low 230 kV to 325 kV limited this time by the field emission effects from the cathode rather than by the ceramic itself. The electron beam quality has improved as a result, but the physics of the electron beam generation and formation has changed dramatically, which necessitated a full resetting of the machine for the various applications. Investigation and optimisation of these new machine settings is currently underway.

ALICE Science Programme

An oscillator FEL operating in the infra-red 5.5-9 μm range of wavelengths is a centrepiece of the ALICE facility. It has operated successfully since October 2010 and delivers short and powerful IR radiation pulses for several scientific applications, most notably, for SNOM. In the past year, an infra-red beamline has been commissioned to transport the radiation to a diagnostic room for detailed characterisation and applications experiments. A real time FEL gain measurement system and a spectrometer for recording single macropulse spectra have been commissioned, along with the integration of the FEL output with the SNOM which has enabled studies to make cross-correlation measurements of the FEL pulse duration to be undertaken.

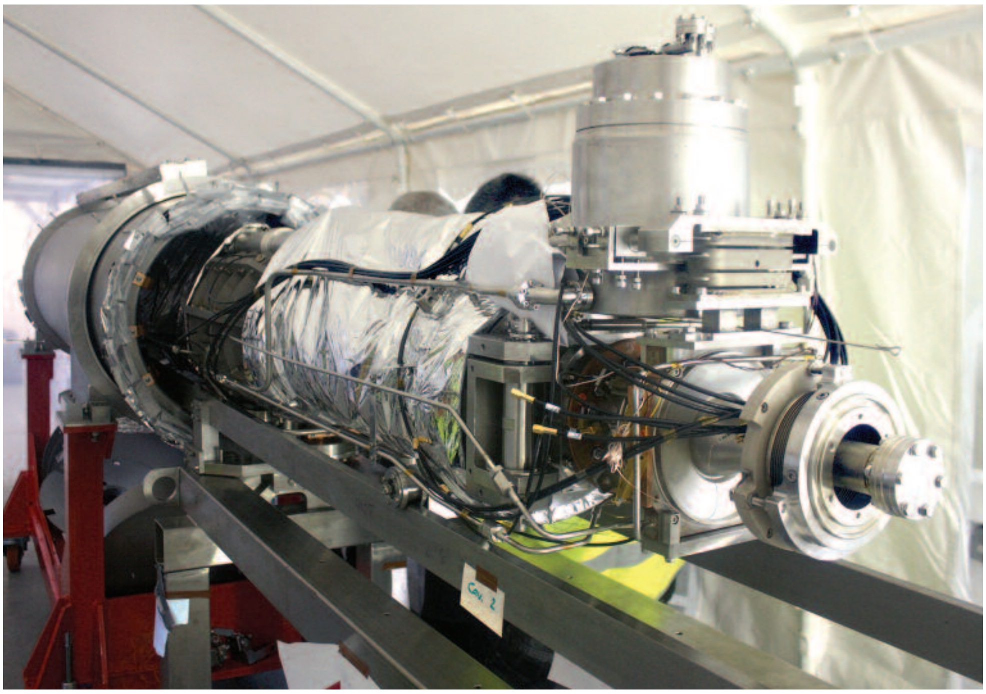


Some images of the electron beam from investigation of the bunch structure at low 230 kV gun voltage.

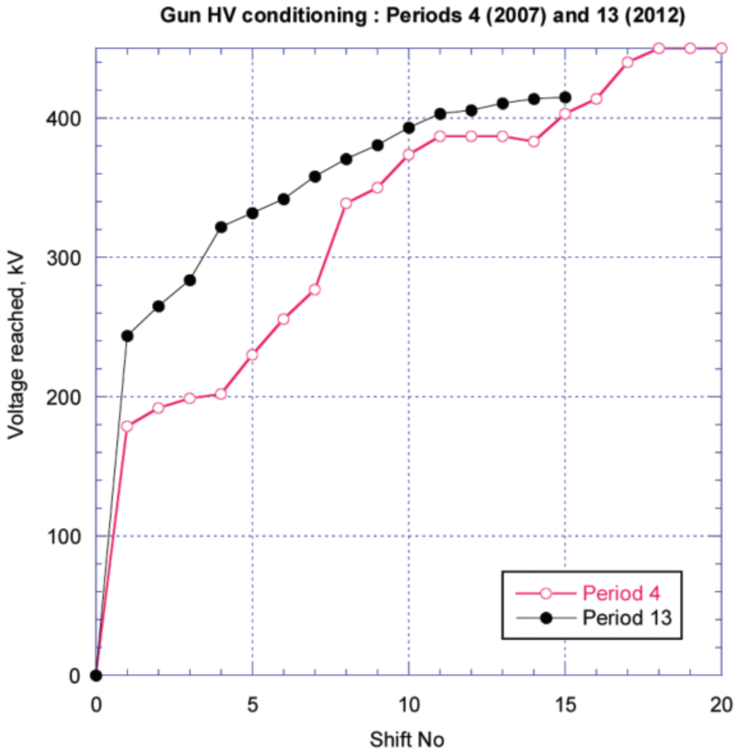
The ALICE IR FEL tuning range is matched to the molecular fingerprint region, i.e. that part of the mid-infrared spectrum in which characteristic molecular vibrations occur. A collaborative project with the Universities of Liverpool and Rome to develop SNOM for sub-diffraction biochemical imaging of human tissue has been initiated. The research programme described in a separate article of this issue aims at development of diagnostics and understanding of the mechanism and drug action in oesophageal cancer.

The coherent THz emission from ALICE was initially utilised for biological studies using an in-situ shielded incubator, close to the accelerator. In June 2011, the THz radiation was transported to a Tissue Culture Laboratory (TCL) with ~20% efficiency, close to the modelled value. In TCL, the living cells are irradiated under a strict biologically controlled environment. In part, this research aims to determine the safe level of human exposure to THz radiation. The TCL satisfies the requirements for research on live human tissue. Human stem cells are particularly sensitive to their environment and are ideal specimens for assessing the safe level of human exposure to THz radiation. In these experiments human stem cells have been exposed to peak powers of THz radiation in the range 3–11 kW for several hours. The time structure of ALICE, in which THz power is delivered in 100 μsec bursts with a 10 Hz repetition rate, is ideally suited to these experiments since the corresponding average powers are in the range 0.4–1.2 mW which makes it possible to eliminate thermal effects. Several other smaller scale studies using THz radiation from ALICE have been also conducted.

The ALICE ERL is a very rich machine in terms of accelerator physics. Over the last year, the emphasis was made on studies of the beam dynamics at relatively low beam energies (4-12 MeV) and in a presence of space charge effects. The longitudinal beam dynamics was studied in the ALICE injection line using zero-phase measurements of bunch length. Additionally the transverse dynamics were also investigated using a beam tomography section in the EMMA injection line. The longitudinal structure of electron bunches generated with the DC photoelectron gun and the effects of the gun voltage were evaluated in detail with a conclusion that the structure developed in the bunch is a result of complex processes during the initial acceleration at low beam energy (several 100s of keV), where the beam is non-relativistic. This conclusion is of great significance to all machines employing relatively low voltage (<500 kV) DC photoelectron guns.



International ERL Cryomodule



Gun HV conditioning progress in March 2012 (black) and earlier with a similar ceramic (red).

Excellent progress was made in developing the accelerator superconducting RF technology. In particular, an international collaboration comprising STFC, Cornell and Stanford Universities, LBNL, DESY, HZDR-Rossendorf and TRIUMF have developed an optimised cryomodule design for ERL application. All cavity string sub-components have now been qualified and the cryomodule has been fully assembled at Daresbury and is currently undergoing final cold testing prior to installation on ALICE in late 2012.

Work also continues on an upgrade programme to provide a digital low level RF control system for the ALICE cavities. On bench tests, the system achieved 0.03° RMS error and 0.04% amplitude error. The system is currently being tested using the ALICE RF buncher cavity.

Overall, it was another successful year 2011-12 for ALICE and for all projects that utilise its electron beam and light sources. It demonstrated that ALICE has reached a good level of maturity as a smaller scale experimental test bed for performing high impact proof-of-principle experiments in a wide range of applications.

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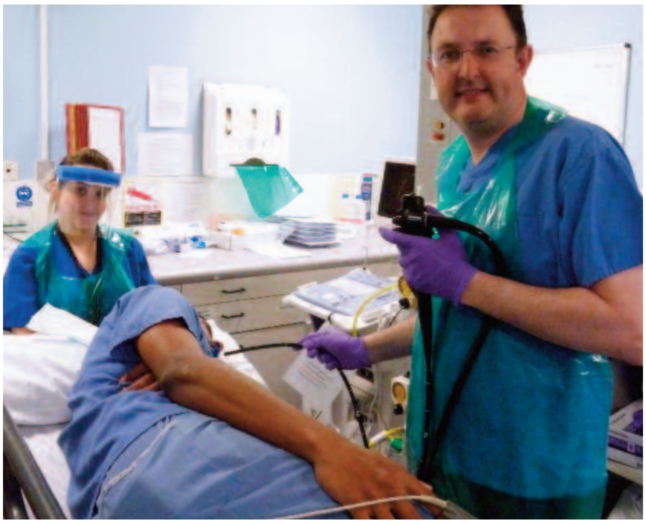
Projects

SNOM

Clinicians Exploit ALICE: Medical Research at Daresbury


Professor Mark Pritchard is able to devote time to experiments on ALICE to develop better understanding of the cancer care he provides in clinic.

Clinicians are working side by side with physicists to exploit the Free Electron Laser (FEL) light from ALICE (Accelerators and Lasers in Combined Experiments) for nanoscopic chemical mapping of tissue for medical research. Fundamental questions on the role of the environment in tumour growth, understanding why spectroscopic differences can be observed in cancer tissue – what components are responsible for these differences – and monitoring drug interactions can all be addressed by Scanning Near-field Optical Microscopy (SNOM).

The SNOM technique was pioneered on the FEL at the Vanderbilt University in the US by Antonio Cricenti and colleagues. Now working in collaboration with Peter Weightman's group from the University of Liverpool Department of Physics and a team of clinicians led by Mark Pritchard at the Royal Liverpool and Broadgreen Hospitals, they have moved the technique on to address real clinical problems.

The ALICE FEL tuning range of 5.5 – 9 μm is matched to the molecular fingerprint region in the mid-infrared spectrum in which characteristic molecular vibrations occur. These "fingerprint vibrations" are used routinely in analytical chemistry and commercial infrared microscopes, when coupled to bright synchrotron radiation sources such as Diamond, allow very high quality spectra to be recorded with a few micron spatial resolution, limited by the diffraction limit of infrared wavelengths. Now, with the intensity available from a FEL it is possible to break through this diffraction limit by orders of magnitude, locally sensing the absorption using probes much smaller than the wavelength of the light.

ALICE

ALICE operated for 35 weeks in 2011-12.

ALICE normally operates 16 hours a day in two 8 hour shifts

Why was ALICE Chosen for this Work?

There are a host of infrared FELs across the world covering the mid-infrared range so why choose ALICE? The pulse structure is ideally matched to the requirements of the highly sensitive instrument developed by Cricenti. The ALICE superconducting linac is able to support long 100 μS macropulses which are readily captured with very high signal to noise by box car integration of signals detected from an MCT detector fibre coupled to the SNOM tip. A high average infrared intensity can be obtained during this 100 μs without having to resort to extreme high peak power which would damage the sample.

The location of the ALICE accelerator close to the international centre of excellence in oesophageal cancer at Liverpool, makes this accelerator very attractive in this important healthcare programme.

Oesophageal cancer is the ninth most common cancer in the UK and around 8000 new cases are diagnosed every year. It is of a highly aggressive nature and so early diagnosis is the most important factor for improving the prognosis for patients with oesophageal cancer.

This research will give better understanding of the mechanism of disease development, how drugs interact with tumours and healthy cells, and what causes differences in the infrared spectra which will bring new diagnostic techniques into the operating theatre.

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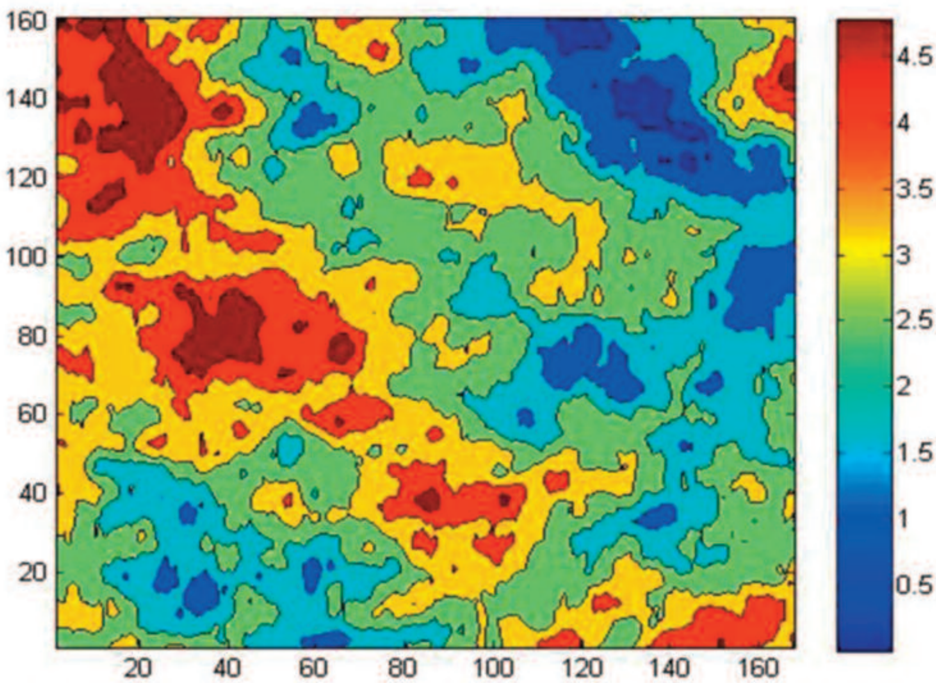

Tissue mapped by SNOM using 8.05 μm light where DNA has strong contribution to the absorption.
As with all experiments on fourth generation light sources, the data is only as good as the diagnostics available on the beamline. We have implemented real time spectral analysis with a custom pyro array on a spectrometer allowing diagnostics of the spectrum and intensity of each FEL macropulse.

DICC

The Daresbury International Cryomodule Collaboration

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

The culmination of an expansive engineering and technology development of a new type of SRF cryomodule is nearing its critical stage of hardware completion. The preferred technology solutions for this cryomodule which include: 7-cell 1.3 GHz cavities, ferrite beam-pipe HOM absorbers, high power adjustable input couplers and triple independent layers of magnetic shielding, are all intended to achieve an overall performance of >20 MV/m at a Qo of >1010, in what has been a truly collaborative venture.

Assembly of the cryomodule has been completed and it has successfully passed the first phase of off-line cryogenic tests. Thermal management characterisation has demonstrated improved performance compared to the original specifications. Installation of the cryomodule on the ALICE ERL facility will occur in late 2012, including integration to the new COOL-IT heat exchanger system, which will provide innovative, high pressure gaseous cooling of the 80K and 5K intermediate temperature circuits.

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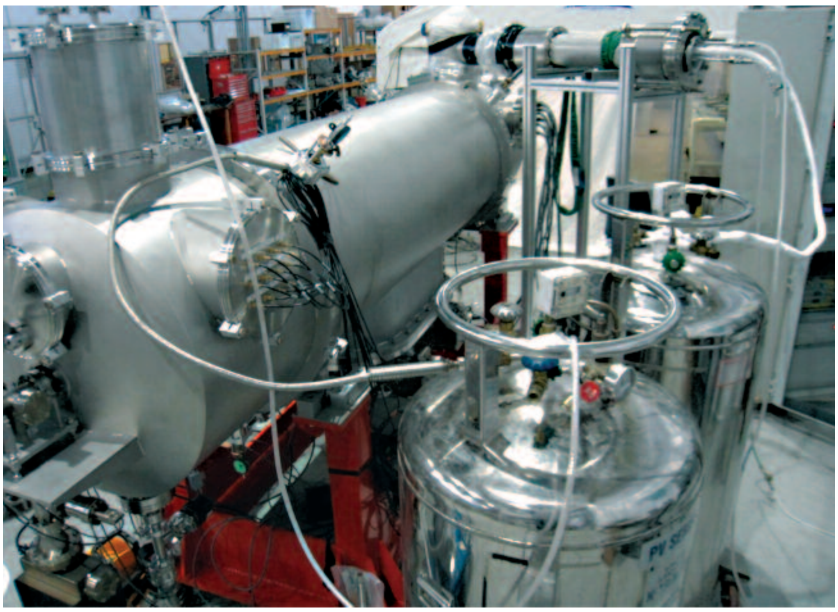
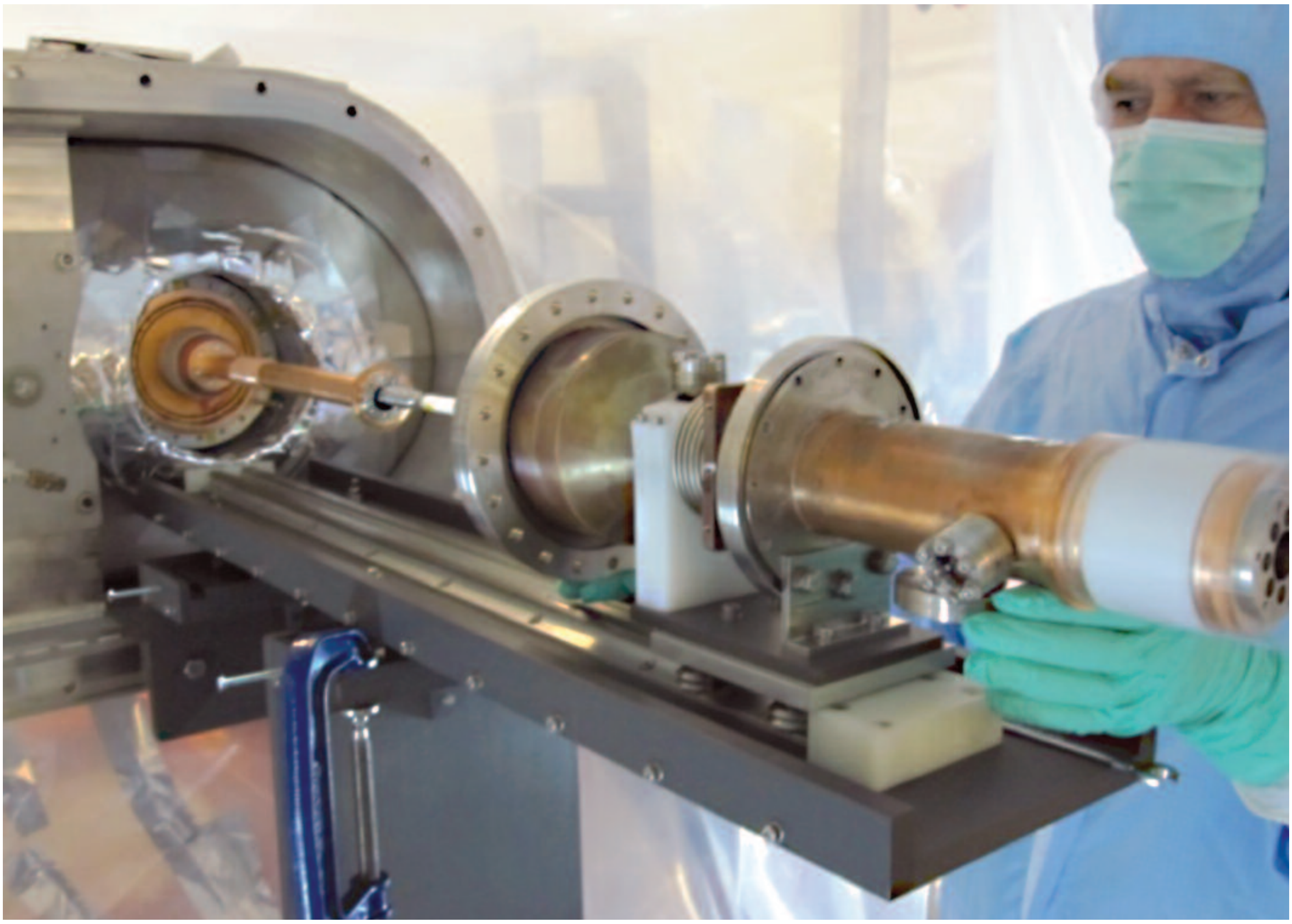


Cryomodule undergoing cryogenic tests

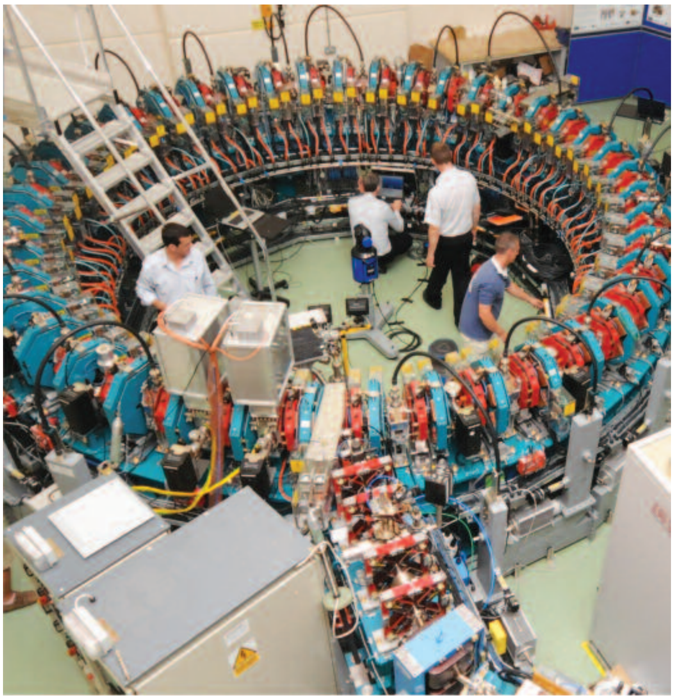


Installation of a warm RF coupler

Projects

EMMA

Electron Model of Many Applications



EMMA

EMMA is the world's first non-scaling fixed field alternating gradient (ns-FFAG) accelerator and represents a proof-of-principle of a novel transport concept as well as a new accelerating technique. The main motivation for this type of machine is that it would be the first to allow for the transport of a heavily disordered beam as well as being able to accelerate it, and all of this would be done at low cost. This means EMMA has a large acceptance, both longitudinally and transversely. There are many uses for ns-FFAGs ranging from medical applications such as hadron therapy to accelerator driven systems (ADSRs), muon colliders and a neutrino factory.

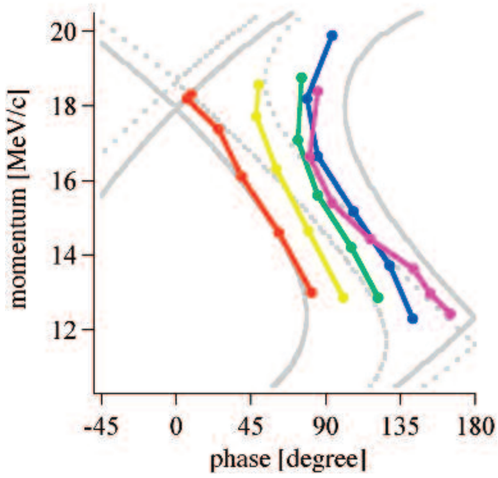
The Accelerator Physics group contributions to the EMMA project have been many in the past year, ranging from commissioning to result analysis. In March 2011 the first indications of acceleration in the serpentine channel were seen and these were subsequently confirmed in April of the same year.

Measurement of orbit position and cell tune as a function of energy gave the information required to calibrate beam momentum when the beam was accelerated. Hence, by linking the injection energy and the initial RF phase, it was possible to show that serpentine acceleration had taken place as illustrated.

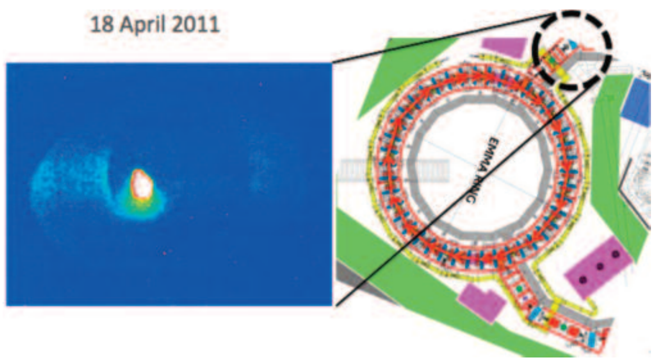
A complete calibration of the energy gain was achieved by extracting the beam and hence measuring the energy via the proportional increase in dipole strength. The set-up used, together with the extracted beam, is shown.

The conclusion was that an electron beam injected at 12 MeV/c was accelerated beyond 18 MeV/c in the serpentine channel. The energy measurement for the extracted beam using a dipole and two screens before and after the dipole confirmed the acceleration as well. The beam momentum was estimated as 18.4 +/- 1.0 MeV/c.

A précis of the results was published in Nature Physics at the start of 2012 and a picture of the novel serpentine acceleration technique made it to the front cover. The results constitute a proof of principle that non-scaling FFAGs work. Resonances in this type of machine also exit, just like in any machine where the beam goes around to the same place more than once. However, in a ns-FFAG, the resonances are crossed so quickly that the beam does not have sufficient time to become unstable. This property was also demonstrated in the Nature Physics article.



Serpentine acceleration: the various curves show the beam being injected and accelerated at different RF phases.



EMMA ring together with location of extracted beam and screen image.

As well as showing that ns-FFAGs can operate in principle, several dedicated experiments were started as part of the EMMA programme to show the large transverse acceptance of the machine. The first is the PRISM (Phase Rotated Intense Slow Muon source) experiment. This is a next generation muon-to-electron conversion experiment to obtain intense quasi-monochromatic muon beams by performing RF phase rotation in an FFAG ring. Preliminary experiments have been performed using EMMA in which a bunch is allowed to undergo a quarter of a synchrotron oscillation (over 3 turns), as would be the case in PRISM (over 6 turns); this is accomplished by injecting a bunch of known energy into the centre of an RF bucket, and then extracting 3 turns later to measure the longitudinal phase space.

As serpentine acceleration was shown to accelerate the beam fast enough not to become unstable, whilst still crossing resonances, the natural question arises of whether there exists a threshold in the speed of resonance crossing below which the beam becomes unstable. Therefore, slow integer tune crossing was studied by tune variation during synchrotron oscillation within an RF bucket, at speeds that are up to a factor of 10 smaller than the nominal EMMA serpentine channel acceleration rate. The standard deviation of the beam orbit in a window sliding over 21 of the 42 ring BPMs was taken to be the size of the beam oscillations. For motion close to the separatrix where the rate of tune change is minimum, the beam experiences large oscillation amplitude growth and complete beam loss; nearer to the stable fixed point where the rate of tune change is higher, crossing an integer gives oscillation growth which is reversed.

Dedicated experiments to explore the acceptance of EMMA, both longitudinal and transverse are currently under way. This is because ns-FFAGs with only linear magnetic elements should have a very large dynamic aperture that can therefore accommodate a huge emittance (entropy) beam, for example to allow acceleration of a muon beam from a target.

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VELA

Versatile Electron Linear Accelerator

Recent UK government funding has facilitated the construction of a unique accelerator test facility which can provide enabling infrastructures targeted at the development and testing of novel and compact accelerator technologies, specifically through partnership with industry and aimed at addressing applications in medicine, health, security, energy and industrial processing. The infrastructure provision on Sci-Tech Daresbury will permit research into areas of accelerator technologies which have the potential to revolutionise the cost, compactness and efficiency of such systems. The main element of the infrastructure will be a high performance and flexible electron beam injector facility, feeding customised state of the art testing enclosures, and associated support infrastructure.

The VELA machine consists of an S-band RF gun photoinjector, delivering 5 MeV, low emittance, short pulse electrons to two separate user areas. The machine is housed inside a 2 m thick concrete enclosure designed to provide shielding for future higher energy upgrades. Inside the accelerator vault the air temperature is controlled to ± 1°C for the optimum performance of the accelerator components and RF signalling cables. Adjacent to the shielding are three rooms to house the photoinjector laser, synchronisation equipment and instrumentation racks, which are also temperature controlled to ± 1°C. The photoinjector laser room is a designated clean area, with HEPA MACH 10 laminar air flow units located directly above the laser table. The synchronisation room, which contains the master oscillator for the accelerator, is constructed such that a Faraday cage is formed around the room to remove noise created by potentially harmful external electro-magnetic fields.

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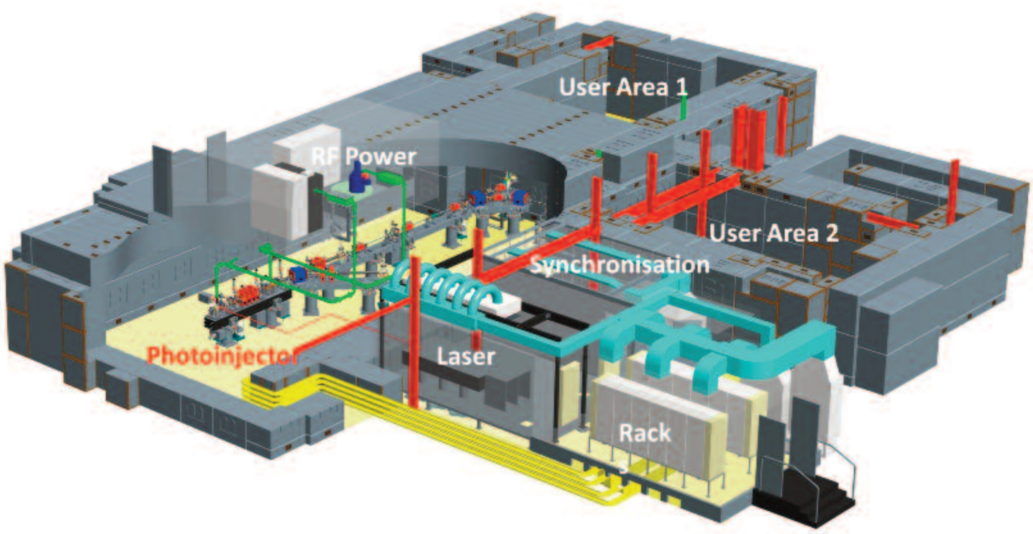
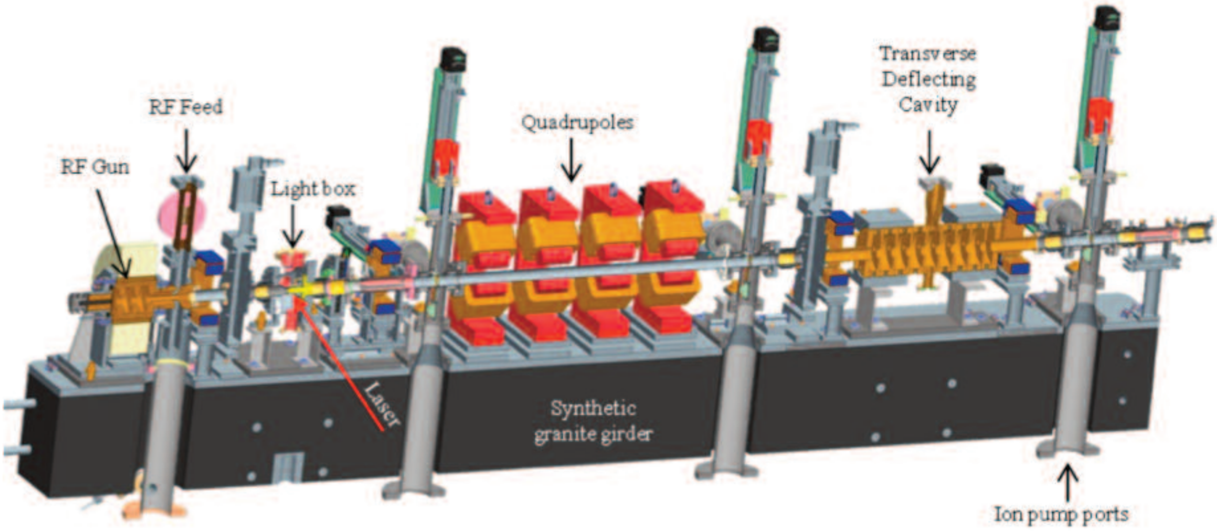




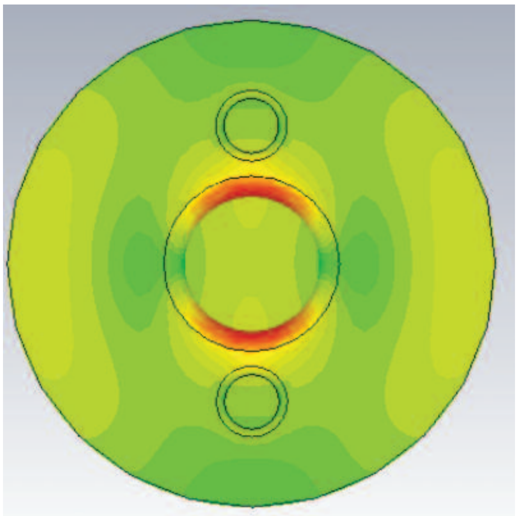
The VELA construction team

VELA Beam Parameters*

Beam Energy	4 - 6 MeV
Bunch Charge	10 - 250 pC
Bunch length ($\sigma_{t,rms}$)	1 - 10 ps
Normalised emittance	1 - 4 μm
Beam size ($\sigma_{x,y,rms}$)	1 - 5 mm
Energy spread ($\sigma_{e,rms}$)	1 - 5 %
Bunch repetition rate	1 - 10 Hz (ALPHA-X gun) 1 - 400 Hz (with high rep. rate gun in the future; klystron & laser specified for 400 Hz)

*Not all beam parameters are possible to achieve simultaneously. Some beam parameters vary along the beam line.

Transverse Deflecting Cavity for VELA



Magnetic field magnitude in the cavity showing low field near the coupling holes. Red is high field locations.

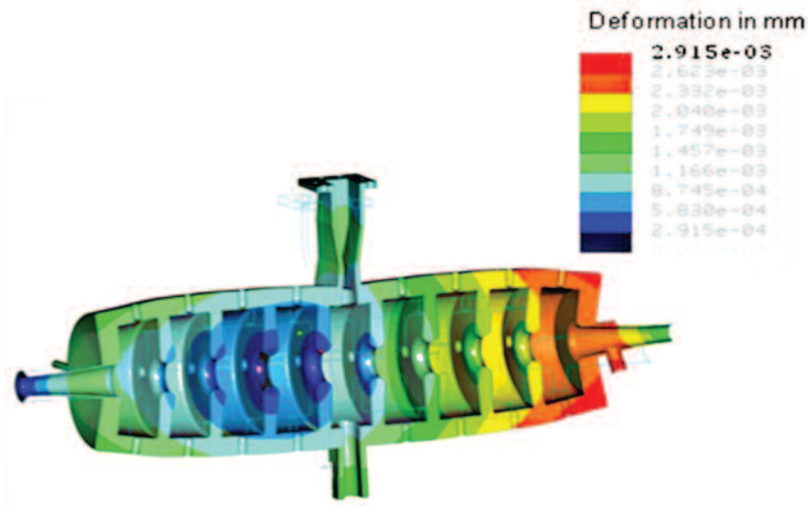
As part of the diagnostic section for the Versatile Electron Linear Accelerator (VELA) at Daresbury Laboratory a Transverse Deflecting Cavity (TDC) is required to enable slice emittance measurements to be performed, in order to longitudinally profile the 5-6 MeV, short (40 fs RMS) electron bunches from the S-band RF gun. A transverse kick of around 5 MV is required, so as to provide the required resolution of 10 fs and for this an S-band 9-cell TDC has been designed by members of the ASTeC RF group, Technology department and Lancaster University (Cockcroft Institute). The cavity was designed around the requirement that the available space was restricted to 40 cm and that an existing 6 MW, 3 GHz klystron was to be used as an RF source.

The specification meant that a high shunt impedance was required, hence a large number of cells. A 9-cell cavity design was chosen and has been modelled using CST Microwave Studio. The iris radii between cavity cells was optimised to maximise the separation between the electrical and magnetic dipole modes, and separation of the horizontal and vertical dipole mode frequencies was achieved by coupling slots in the iris walls. The design incorporates a central input coupler which aids the separation of modes, but also introduces a monopole mode, so it was necessary to add a matching section opposite the coupler to add symmetry and reduce the monopole component.

Additionally due to the fact that the beam energy is very low, care and attention was taken during the beam dynamics modelling to minimise the energy spread caused by the deflecting mode and to minimise the transverse offset of the beam. The deflection is corrected by the use of small steering magnets before and after the cavity.

A Finite Element Analysis (FEA) was performed on the cavity to evaluate the mechanical design and to ensure that deformation due to fluctuations in cavity temperature do not cause phase variations which cannot be corrected.

To ensure that the design meets the specification, a 3-cell cavity with the end cell and a central cell without an input coupler has been ordered from Research Instruments. It is proposed to perform perturbation measurements on this cavity so as to verify the design before procuring the final 9-cell cavity.



Deformation in the cavity due to the 0.7 °C temperature rise

As part of the programme of work for the TDC a klystron modulator is being designed by the Electrical Engineering Group, which will incorporate a Thales TH2056 and high voltage pulse transformer previously used to power the 11 MeV injector linac for the SRS at Daresbury Laboratory.

It is anticipated that the measurements on the prototype will be concluded in July 2012, and that any design changes will be completed the following month, so that Research Instruments GmbH, Germany can manufacture and deliver a 9-cell cavity before the end of 2012. The TDC and RF system will then be installed, and commissioned during the first planned shutdown of VELA after the first beam has been achieved.

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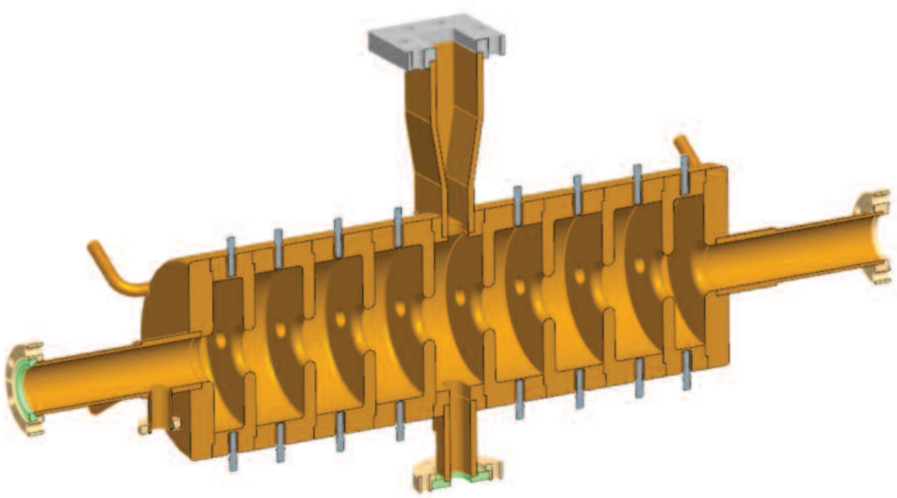
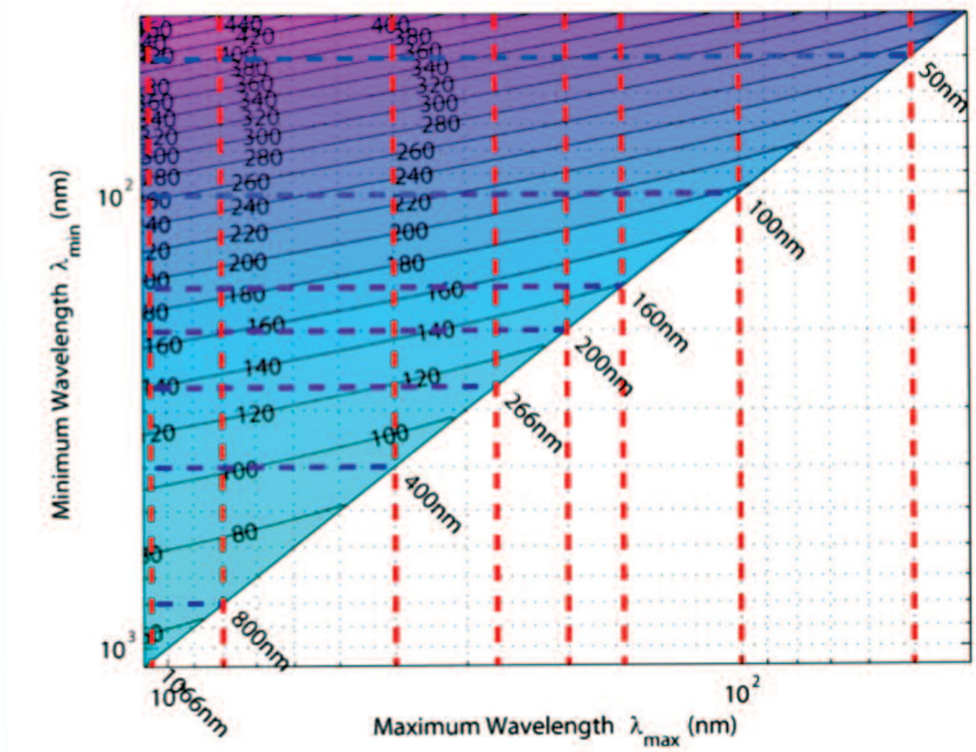


Final cavity geometry including tuners and cooling pipes

CLARA

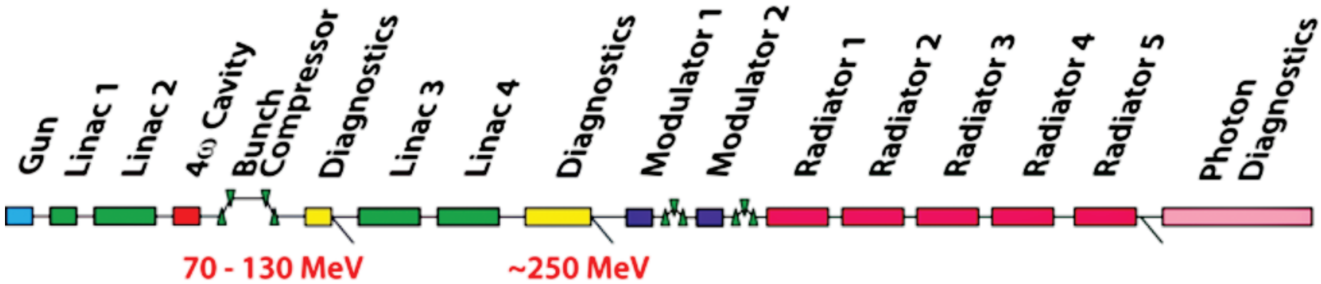
Compact Linear Accelerator for Research and Applications



Contour plot of electron beam energy (in MeV) for different CLARA tuning ranges

CLARA (Compact Linear Accelerator for Research and Applications) is a proposed major upgrade to VELA (Versatile Electron Linear Accelerator) which was funded by the UK government in 2011. The facility would serve two goals – as a prototype test accelerator for a future Free Electron Laser (FEL) light source which might be built as a major international facility in the future, building on our experience with the ALICE (Accelerator and Lasers in Combined Experiments) accelerator; and secondly as a facility for the development of novel particle accelerator applications for both academia and industry, extending the capabilities of VELA dramatically. Innovative accelerator technologies and concepts are expected to open up new possibilities for the creation of clean and safe energy, for more effective and efficient cancer therapy, for advanced security scanning systems and for coherent x-ray sources at the leading edge of photonics.

The science focussed goal of CLARA is to be an internationally leading particle accelerator test facility, specifically focussed on generating intense light with a FEL. This type of light source is the next generation beyond existing facilities such as Diamond. However, FEL technology is still immature and there are many areas where improvements can be made enabling even higher quality science to be carried out on them. Whilst the UK is not ready yet for the scale of investment needed to build a major new facility of similar scale to Diamond, it is an ideal time to build a modest test facility, which can try out many of the new untested ideas for improving the



Schematic of the possible layout of CLARA

quality of the light generated by FELs and also prove new hardware technologies currently being developed so as to actually reduce the final price tag of any future full scale facility. The unique feature of CLARA will be the ability to generate ultra-short pulses of light, orders of magnitude less than any generated so far. There are many alternative paper design schemes showing how this could be achieved but there is no international test facility capable of testing them at present. In addition, CLARA will target improved shot to shot stability and timing synchronisation as these are key areas which will directly impact on all science exploitation of such facilities.

ASTeC is currently developing the design of CLARA in collaboration with a number of UK and international partners. The electron energy has been selected to be 250 MeV and the repetition rate of the normal conducting accelerator to be up to 400 Hz. The other parameters will continue to be refined during the coming year.

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BACKSTAGE SCIENCE

Lee Jones and Peter Williams have been interviewed for 'Backstage Science', a project aiming to communicate to the general public the scientific work of STFC.

Superconducting Undulators

ASTeC has a strong track record in the field of superconducting undulators and is taking this to the next level in collaboration with Technology Department and Diamond Light Source. A design has been developed which pushes the technology to the limit and if successful will have built the most advanced undulator ever. The parameters of the device have been selected carefully to give the best possible output for Diamond photon scientists in the hard x-ray region of the spectrum, outperforming their existing in-vacuum undulator by up to a factor of twenty.

A key feature of the undulator is that it is designed to operate at 1.8 K rather than the usual atmospheric liquid helium temperature of 4.2 K. A novel cryogenic scheme has had to be developed and this will be proven in isolation prior to full magnet fabrication. This system is housed within the turret section of the cryostat and once proven in isolation it will be able to be relocated as one piece onto the final magnet cryostat. This turret section has been procured this year and is now being assembled for cryogenic tests.

In parallel, a short test undulator is being constructed and tested to prove the engineering concept. The steel formers have been manufactured and the all important superconducting wire procured. It is anticipated that the final 2 m long undulator will be installed in Diamond in 2014.

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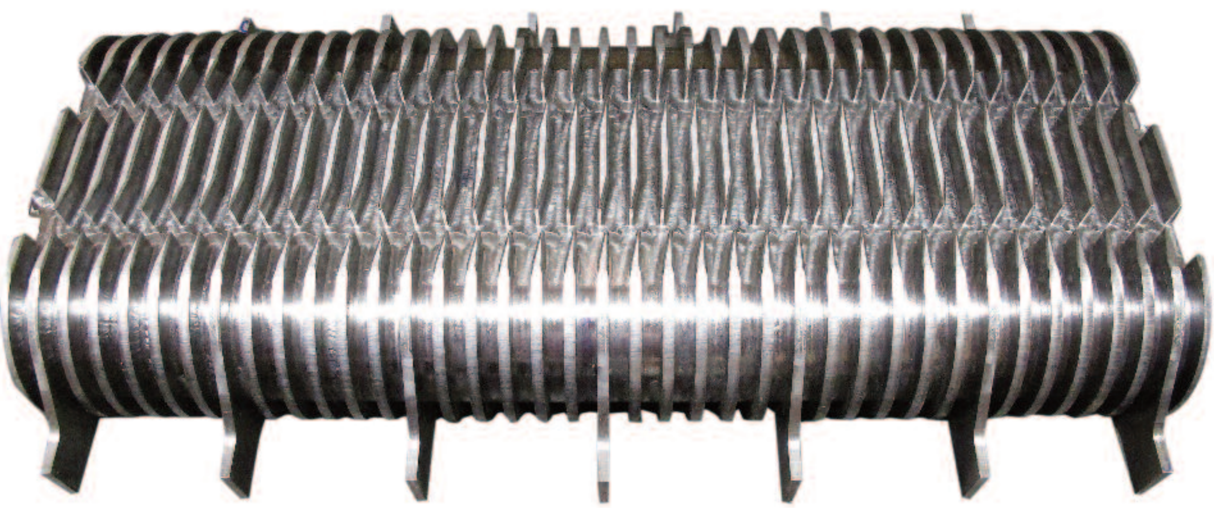


First steel former, which will be wound with superconducting wire, to prove the engineering concept

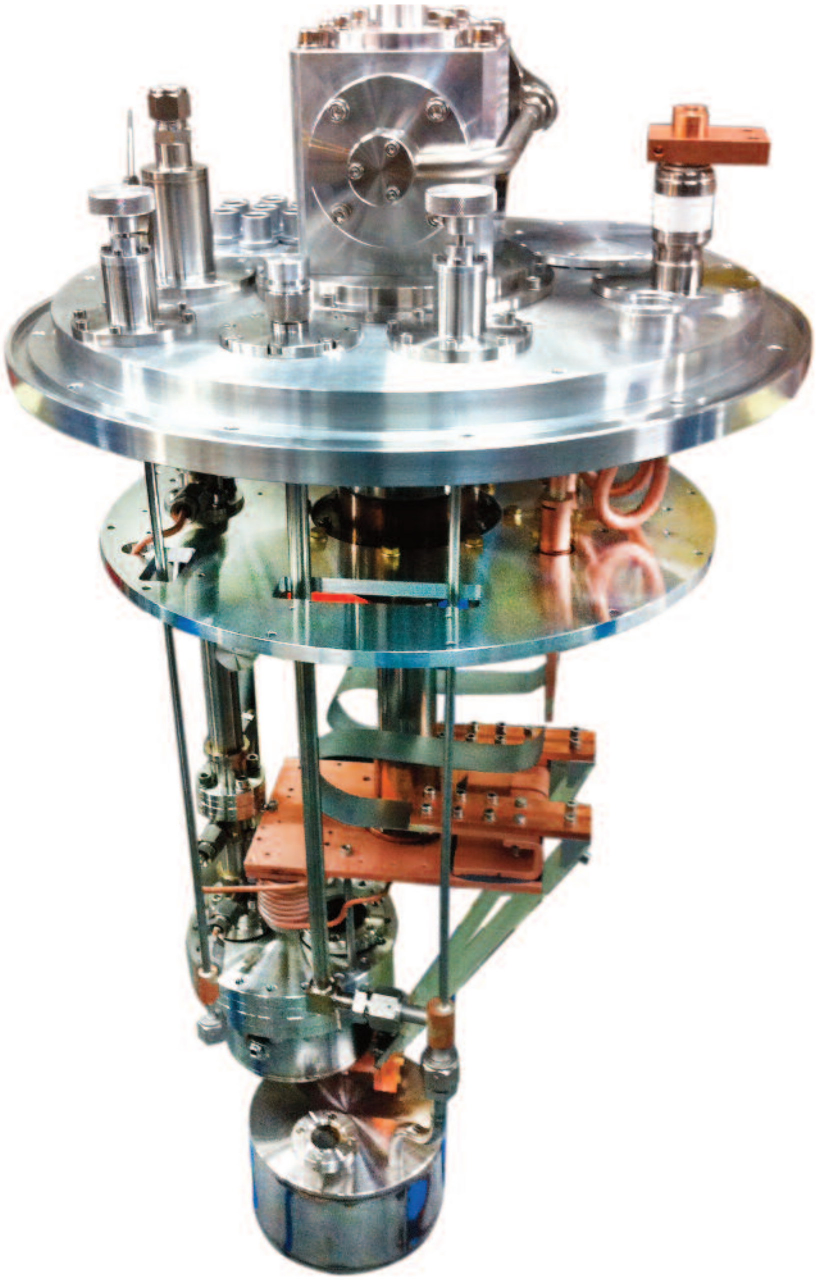
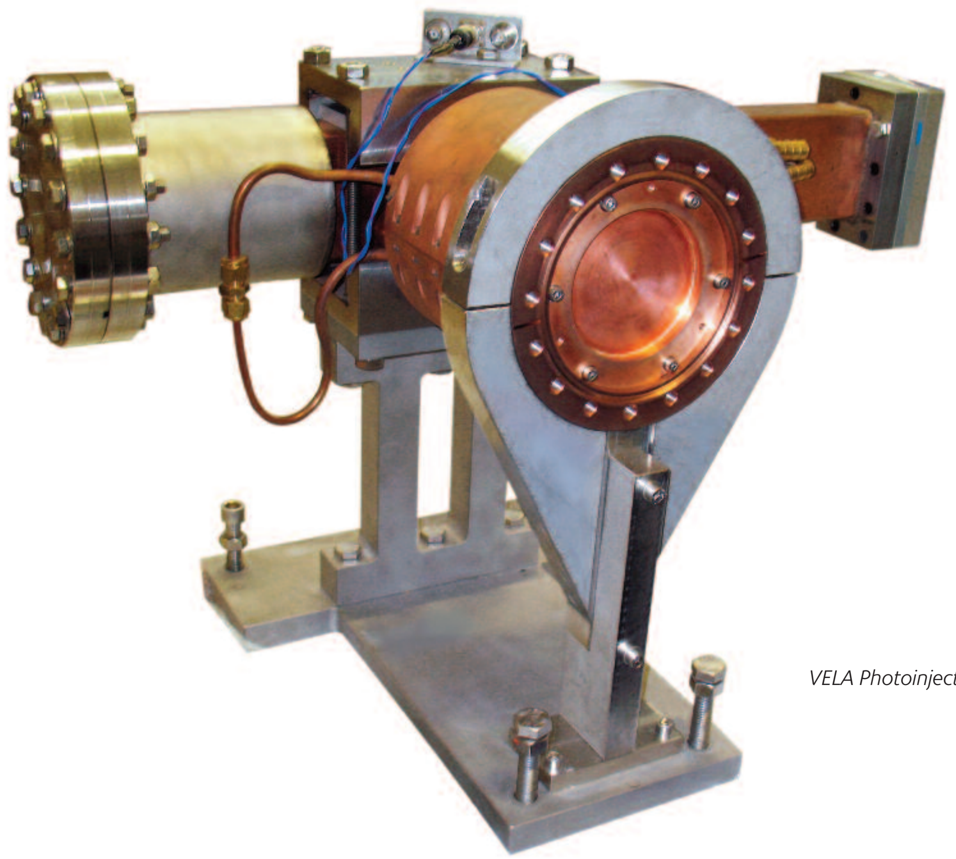


Photo of the turret section, which is being assembled prior to cryogenic testing to prove that 1.8 K can be reliably achieved

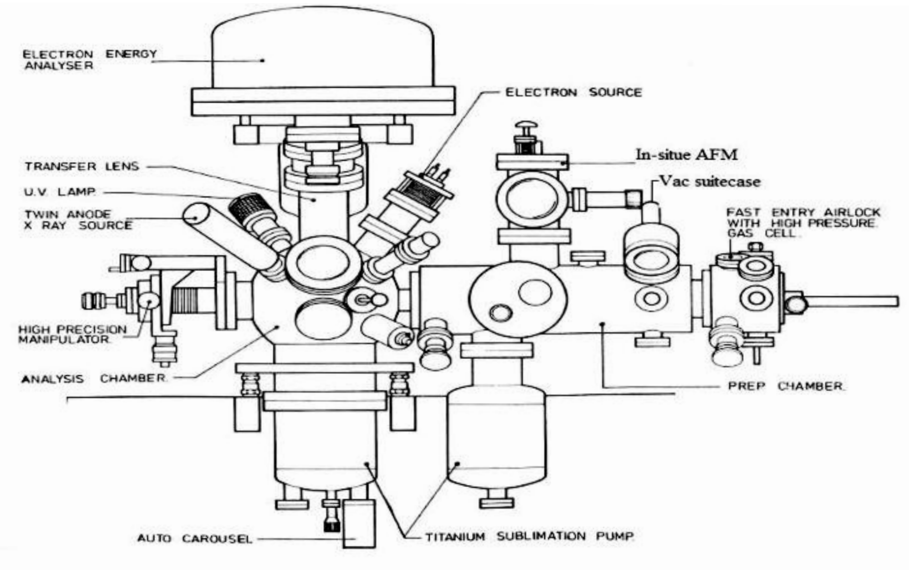
Projects

Photoinjector R&D and Photocathode Research

One of the key activities at ASTeC is the development of unique electron sources for accelerator applications which are able to deliver high quality electron beams with extra high brightness and ultra-short bunch length and/or with high average current depending on the application. During 2011-2012, ASTeC's photoinjector and photocathode development team have concentrated their effort on developing the photoinjectors for Versatile Electron Linear Accelerator (VELA) currently under development, and for the proposed CLARA project. In addition to the photoinjector design, the team's efforts have focussed on the investigation of photocathode emission properties which are core elements of photoinjectors. Photocathode research activity has been concentrated in two major areas – development of ultra-fast, ultra-bright metal photocathodes, and an investigation of the emission properties of III-V (GaAs family) high average current and polarised photocathodes.



VELA Photoinjector



Photocathode

The VELA Photoinjector

The first stage of the VELA photoinjector, designed at ASTeC, is based on an S-band 2½ cell gun cavity, originally developed for the ALPHA-X laser-driven plasma wakefield acceleration project at the University of Strathclyde. The cavity has been loaned to ASTeC, and commissioned at low RF power. Beam dynamic simulations have shown that the photoinjector design is able to deliver femtosecond-scale electron pulses with energies up to 6 MeV and bunch charge of 200 pC, which meets the design requirements for operation of VELA and/or CLARA experiments, though the operational repetition rate of the gun cavity is restricted by 10 Hz due to its cooling capacity.

The second stage of the VELA/CLARA photoinjector is currently under development, and its aim is to reach an operational repetition frequency of 400 Hz. In order to deliver a beam with the required energy, the gun will need to be fed with 10 MW of RF power. This will be delivered by a Thales klystron, powered by a ScandiNova K2 modulator which was recently delivered and commissioned. The VELA photoinjector uses a copper photocathode which is driven by 2 mJ, 180 fs FWHM ultraviolet light pulses generated by a frequency-tripled Ti:Sapphire laser.

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Preparation and Investigation of Metal Photocathodes with the ESCALB-II Facility

In the last year, the metal photocathode research program has focused on the development of a photocathode preparation and characterisation facility featuring extensive surface analysis tools which enable R&D work with different types of metal cathode. The facility is based on the ESCALB-II surface science system whose pumping capacity has been upgraded to achieve extremely high vacuum conditions. This has involved replacing the diffusion pump with a dry turbo pump, a scroll pump and an ion pump. During this renovation, the hemispherical electron energy analyser was upgraded to provide higher sensitivity by adding two additional channeltrons, and re-designing the entrance and exit apertures.

Following these upgrades, the system comprises the following surface analysis tools:

- X-ray Photoelectron Spectroscopy (XPS) with both normal and monochromatic x-ray sources: to determine surface and near-surface (9 nm) chemical state
- Auger Electron Spectroscopy (AES) / mapping: to determine surface and near-surface composition

- Ultraviolet Photoelectron Spectroscopy (UPS): to determine the valence band electronic structure of solids, and study the adsorption of relatively simple molecules on metals
- Low-magnification (5000) Scanning Electron Microscope (SEM)
- Ar- and H- ion gun: for photocathode cleaning by surface ion bombardment
- White light source with monochromator: to determine the quantum efficiency of different metal surfaces in the UV region

Several high purity single- and poly-crystalline copper photocathode samples will be investigated. The photocathode preparation system has been successfully commissioned, and is ready for the first photocathode to be studied.

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Characterisation of Photocathodes with the Transverse Energy Spread Spectrometer (TESS)

TESS is the Transverse Energy Spread Spectrometer: an experimental system currently under construction within ASTeC. The transverse energy distribution of electrons emitted from photocathode sources is one of several physical quantities which fundamentally limits the ultimate brightness of the electron beam. With the users of future light sources calling for shorter and brighter pulses, the drive to generate shorter and brighter electron pulses is clear.

The TESS detector combines a retarding field analyser with a micro-channel plate electron multiplier and phosphor readout screen. By progressively increasing the retarding voltage, the transverse energy component of electrons emitted from a photocathode dominates the electron motion, changing the overall transverse beam size and electron distribution. A highly sensitive CCD camera will record the beam footprint registered on the phosphor screen, and analysis of the size and intensity distribution of these images will yield information on the transverse energy of the source electrons.

By carefully controlling the photocathode source quantum efficiency (QE), we will be able to measure how the transverse energy spread changes as a function of QE, building on previous work with the Institute of Semiconductor Physics in Novosibirsk, Siberia. We will also study the effects of photocathode illumination with lasers at different wavelengths to better understand how the energy of the incident photons driving electron emission from the cathode affects the ultimate beam brightness. TESS also includes cryogenic cooling to investigate how energy spread changes as a function of photocathode temperature.

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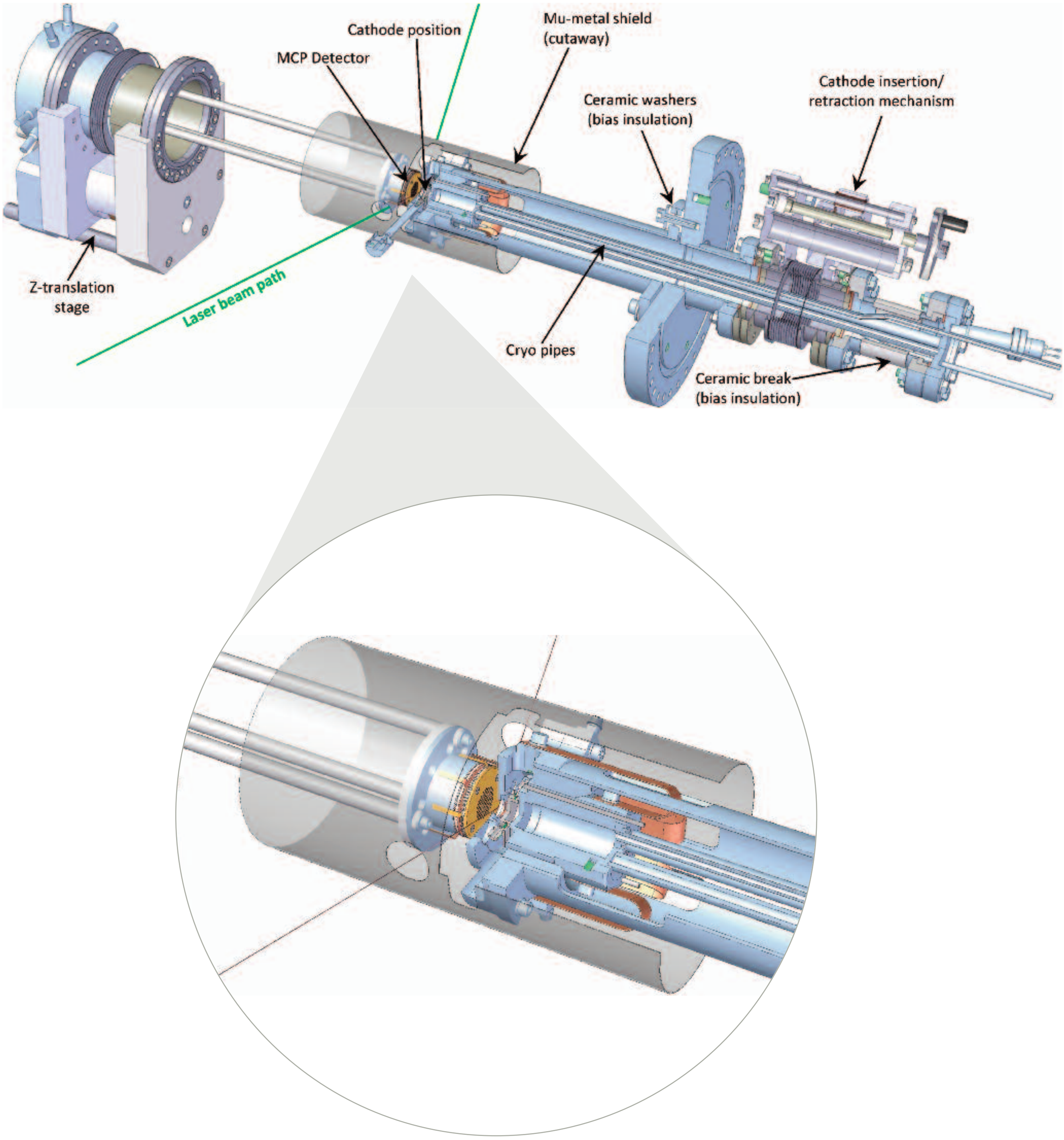

Transverse Energy Spread Spectrometer (TESS)

Electron Stimulated Desorption Stainless Steel

One of the questions discussed during the design of particle accelerator vacuum chambers is: 'What is the optimum operational temperature for the vacuum chamber?'. When the accelerator vacuum chamber is designed to operate at room temperature this usually means that it is at ambient temperature or at the temperature of cooling water. During the operation of the accelerator some power from the beam is deposited on the vacuum chamber walls and components, due to synchrotron radiation, electron multipacting, impedance losses, RF losses, etc. This power is not evenly distributed on the vacuum chamber walls and leads to non-uniform temperatures on different parts of the vacuum chamber. Other factors acting on the temperature of the vacuum chamber are specific requirements for components inside and outside the chamber that have defined operating or the conditions dictated by a particular accelerator experiment. The design of the vacuum system needs to consider how such a variation in temperature affects the outgassing from vacuum chamber walls and whether it compromises the performance of a vacuum system. To answer these questions the studies have been performed analysing electron simulated desorption (ESD) yields as a function of electron dose for three identical samples kept at different temperatures of –5, +20 and +70 °C. Results from the samples were found to be very similar. The temperature of each sample was then varied between –15 and +70 °C. These results showed that desorption yields increase with temperature, this dependence is small for H_2 but increases with atomic mass number reaching the maximum difference of factor 3 for CO_2. The main practical conclusion is that the vacuum chamber temperature in the range between –15 and +70 °C is not critical in most cases for accelerator vacuum system design. The change in ESD yield with temperature is relatively small compared to desorption yield uncertainties and the significant reduction observed with an accumulated electron dose. The results of this work will contribute to the input data required for the successful design of a next generation accelerator and provide confidence to the design team in the expected performance of the vacuum system under different conditions.

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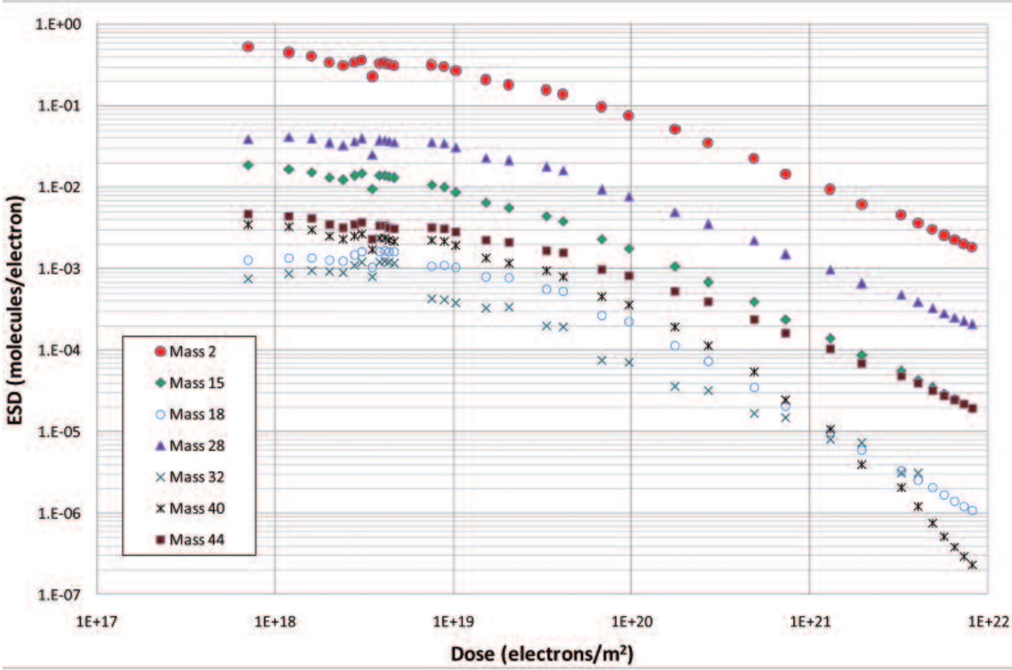
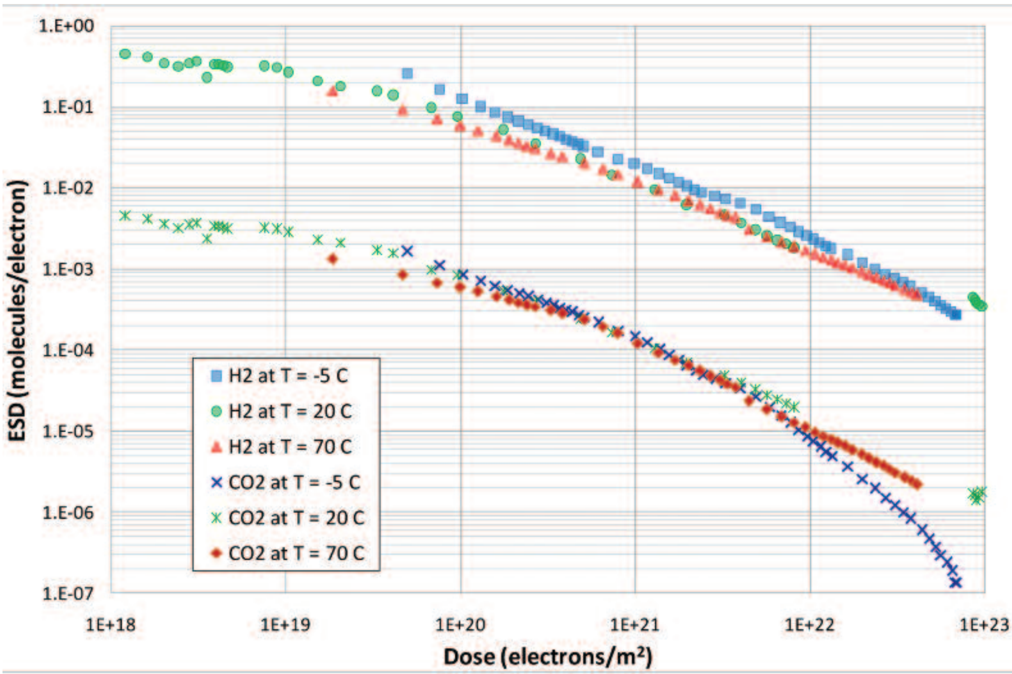
ALICE

14 scientific projects, big and small, ranging from accelerator physics to bio sciences were pursued on ALICE



The ESD yield at E=500 eV as a function of dose for the sample measured at room temperature



Comparison of the H2 and CO2 ESD yield at E=500 eV as a function of dose for the samples measured at different temperatures

Projects

UK Gauge Calibration Facility

The ASTeC Vacuum Science Group has recently upgraded their vacuum gauge comparison facility to a secondary gauge calibration standard. This will enable gauges to be compared in the range between 10-5 and 10-9 mbar to an extractor gauge calibrated against a primary standard at the Physikalisch-Technische Bundesanstalt in Germany, which is renewed every twelve months.

The facility was primarily upgraded for engineers and scientists who carry out research and development on a variety of programmes aimed at large vacuum systems for particle accelerators. When measuring qualitative data and publishing results for experimental research programmes, it is paramount that all gauges used must be verified; therefore all gauges are compared to a primary standard calibrated gauge where an individual certificate is produced for each gauge highlighting the average correction factor across the cited range of pressures.

Although the facility plays an important role in the laboratory for high accuracy and consistent pressure measurements, the facility is now available to all external collaborators, research institutes and commercial companies that require this level of accuracy. Recent developments of collaborating with SS Scientific Ltd show positive prospects for the future to enable the possibility of commercial contracts, providing additional funding for STFC and also being the number one UK facility replacing the now discontinued service previously offered by National Physical Laboratory.

A recent programme of work has included the use of the facility to perform calibrations on a number of gauges that will be used on the new research facility VELA (Versatile Electron Linear Accelerator) at Daresbury. The machine operates at a low beam energy (4-6 MeV) and it has been challenging for the engineers to design the facility as magnetic materials cannot be used within close proximity to the beam. The nature of the vacuum equipment used on VELA, mainly ion pumps and inverted magnetron gauges (IMG's) introduces potential design issues regarding influence of the magnetic fields on the electron beam path, and measurements performed on an IMG has proven that its permanent magnetic field will have a significant influence on the electron beam. Therefore, shielding was required to reduce the stray magnetic fields within acceptable levels. Although this shielding resolved the stray magnetic field issue it created further problems as it influenced the operation of the gauge. The two main problems were the IMG indicated a lower pressure than the real pressure across the full range, and the difference in the low pressure reading from the 'real' reading was non-linear across the pressure range. As a result numerous calibrations have now been performed and correction factors can now be incorporated into the software for the respected areas of the machine so as to provide accurate pressure readings and to enable operational interlocks to be set.

Members of the Vacuum Science group have attended the European Metrology Research Programme (EMRP), IND12 workshop to discuss future development work, which includes RGA calibration techniques. Additionally the European Vacuum Conference was attended where presentations were made to highlight the new facility. This generated future ideas and potential upgrade options as well as promoting the facility for commercial work.

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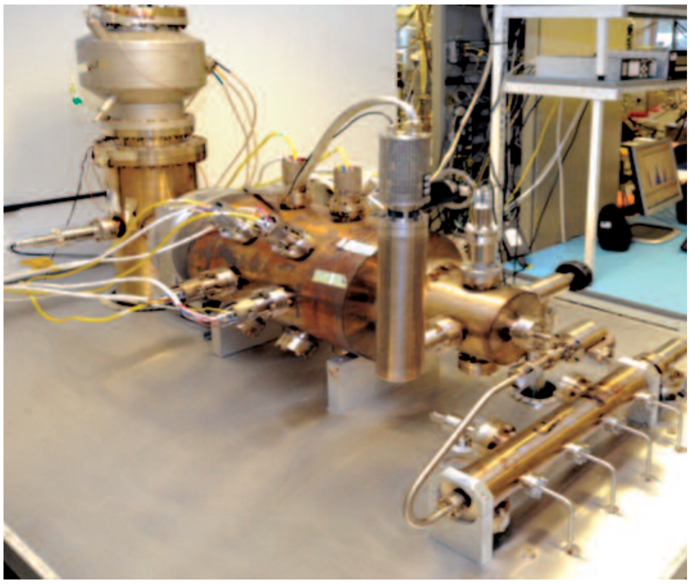

New Vacuum Gauge Calibration Facility

IMG with shielding

ALICE

10 accelerator and FEL physicists operate ALICE for various projects

ITER Interlock System

International Thermonuclear Experimental Reactor (ITER) is a large scale scientific experiment that aims to demonstrate that it is possible to produce commercial energy from fusion. ITER is based on the 'Tokamak' concept of magnetic confinement, in which the plasma is contained in a doughnut shaped vacuum vessel.

Interlocks are the instrumented functions of ITER that protect the machine against failures of the plant system components or incorrect machine operation. Regarding the I&C, the Interlock Control System (ICS) ensures that no failure of the conventional ITER controls can lead to serious damage of the machine integrity or availability.

A two layer architecture has been adopted as the best solution for implementing the interlock functions:

- The central interlock functions are coordinated by the Central Interlock System (CIS) via the Central Interlock Network (CIN) and implemented together with the Plant Interlock System (PIS) of the affected plant systems.

- The local interlock functions are implemented and coordinated by the PIS of the affected plant system using only its own network, sensors and actuators. The CIS is not directly involved in the performance of the protection function and it is only informed of the plant system change of state.

ASTeC was in charge of the follow up and management of the construction of several interlock system prototypes: slow (for functions requiring more than 100 ms response time), fast (for functions that require a response in less than 100 ms) and hardwired (for functions requiring an integrity level equivalent to SIL-4). The slow interlock prototype was constructed and sent to India to be tested during the coming year. The hardwire interlock prototype, officially called Discharge Loop, will be a current loop with triple redundancy (2003 logic) that would open a switch signalling the Fast Discharge Units (FDUs) to send the current from the superconductive magnets to the dump resistors, as well as switching off the power converters. This loop can be opened by the quench detectors or by the FDUs, in case of accidental discharge, or the power converters themselves, in the case that there is a malfunction that could lead to damage. Several prototypes have been constructed and will be tested next year in China together with the ITER current leads and the quench detectors. For the fast interlock controllers, research is still underway.

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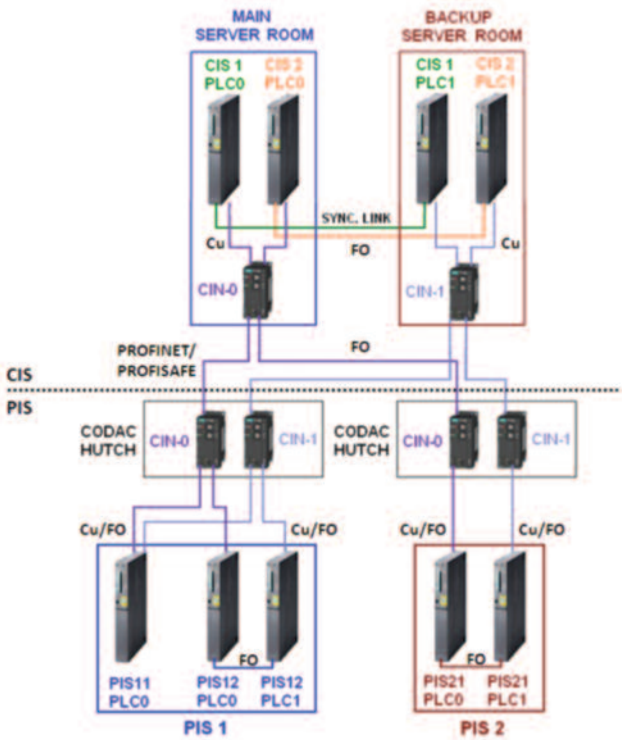
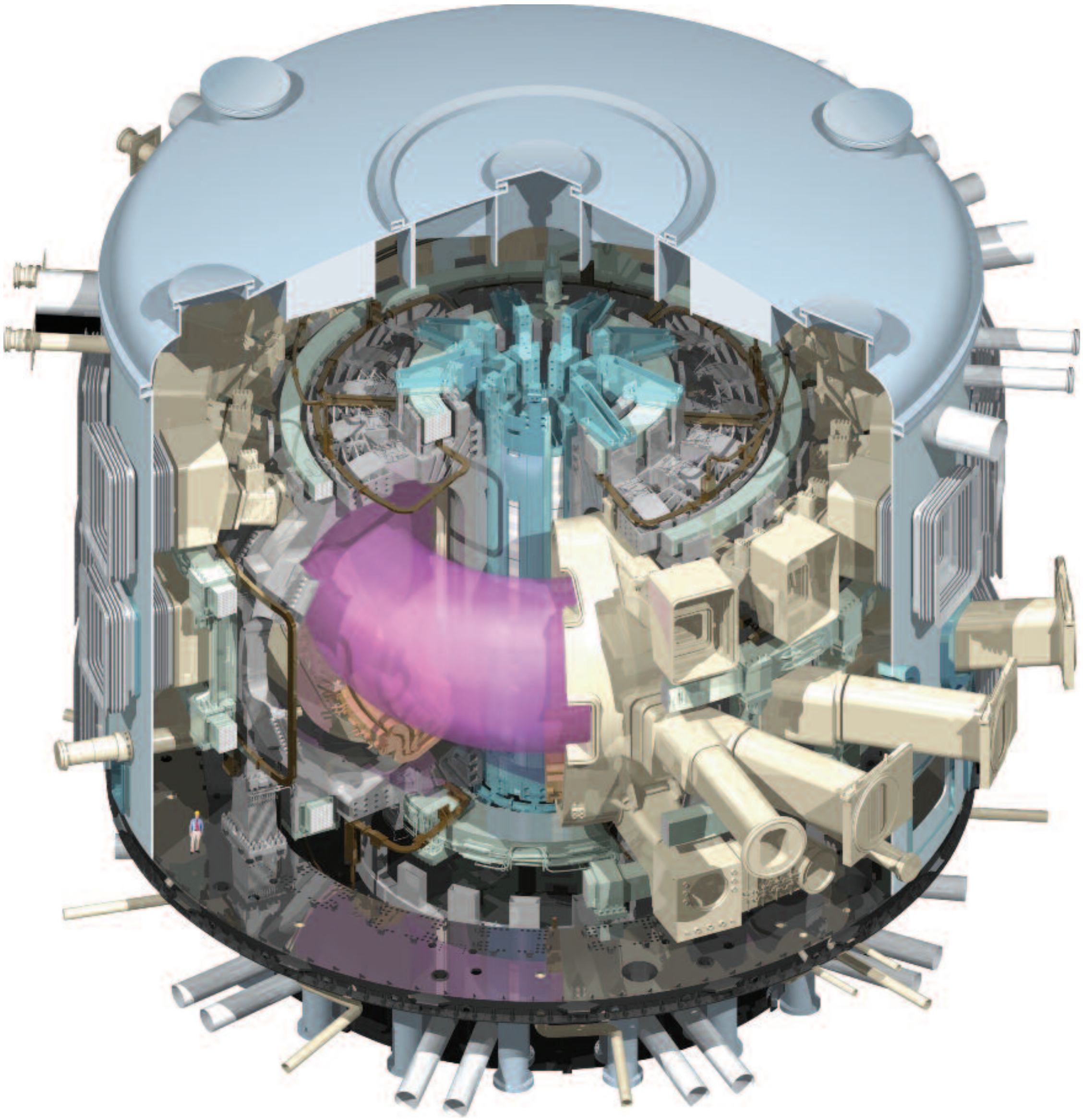
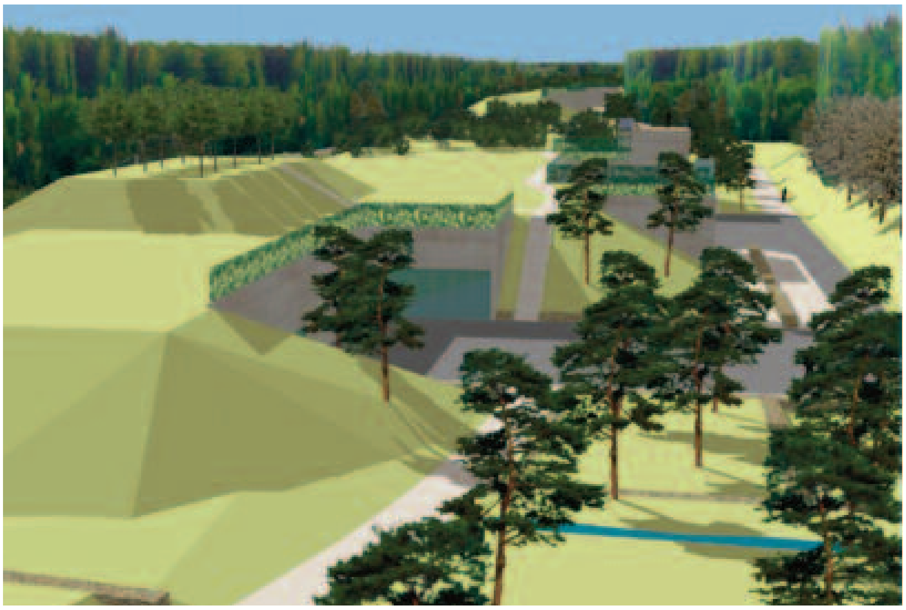


Example of slow (for functions slower than 100 ms) interlock architecture using PLCs



A cut-away view of the ITER Tokamak, revealing the doughnut shaped plasma inside the vacuum vessel

SwissFEL



Artist's impression of the SwissFEL facility (courtesy of Paul Scherrer Institute)

SwissFEL is a proposed x-ray Free Electron Laser (FEL) facility 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, signed in November 2011, ASTeC is now contributing to the SwissFEL design in four different areas in which ASTeC scientists have specific expertise.

Collimation System

In any FEL stray electrons striking the undulator can quickly cause significant demagnetisation leading to a loss of performance. The SwissFEL accelerator provides 200 pC electron bunches with maximum energy 5.8 GeV at a repetition rate of 100 Hz. The beam power is therefore only around 100 W, low compared to other FEL facilities, but undulator damage could still occur if the beam halo is not properly removed by collimation. ASTeC staff have studied the proposed collimation design for the Aramis FEL using expertise they developed on the International Linear Collider (ILC) and New Light Source (NLS) projects. The collimation system comprises of transverse collimators in the final accelerating section followed by an energy collimator in a double dogleg section upstream of the undulator. The performance of the system was studied in simulations to optimise the transverse collimator gap along the linac, evaluate the transverse collimation for various beam energies and calculate the spectrum of grazing particles on the energy collimator. The result of this work is that the system is now expected to work effectively for all the envisaged operating modes of the SwissFEL accelerator.

Self-Seeding Scheme

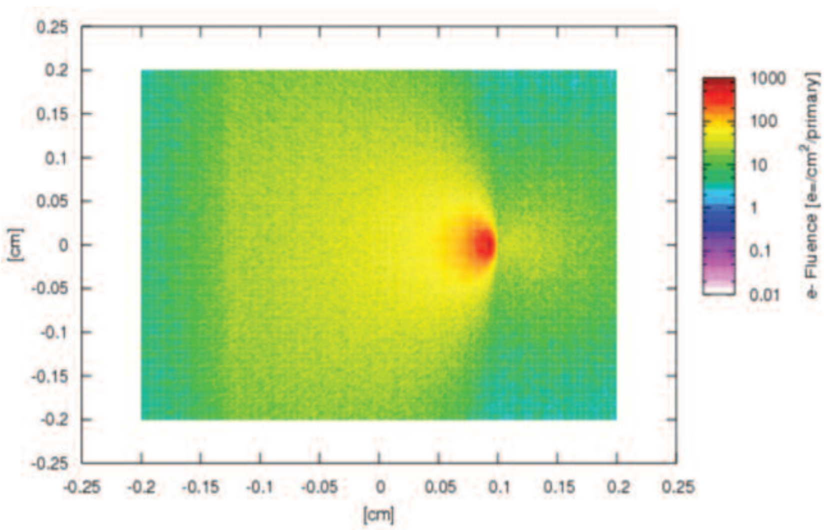
One option for improving the spectral stability and brightness of the Aramis FEL, compared to operating in a self amplified spontaneous emission (SASE) mode, is to incorporate a self-seeding scheme, as proposed by Geloni et al from Deutsches Elektronen Synchrotron (DESY) in Germany and recently successfully demonstrated at the hard x-ray Linac Coherent Light Source (LCLS) in the USA. The idea is to use a single crystal to spectrally filter the FEL radiation developing in the first section of the undulator before amplifying it to saturation in the final section of the undulator. An initial study at PSI had indicated that the scheme was feasible for Aramis, and space had been allowed in the facility layout, but there were still many questions to be answered. ASTeC scientists have now evaluated the scheme in more detail to determine the level of performance that can be expected and find the optimum position for the crystal. ASTeC has also been studying a modification of the scheme in which two separate crystals are used. In this scheme the FEL output radiation comprises two distinct spectral lines making it uniquely valuable for some scientific applications. First simulation results indicate very good performance as shown.

Afterburner for Aramis

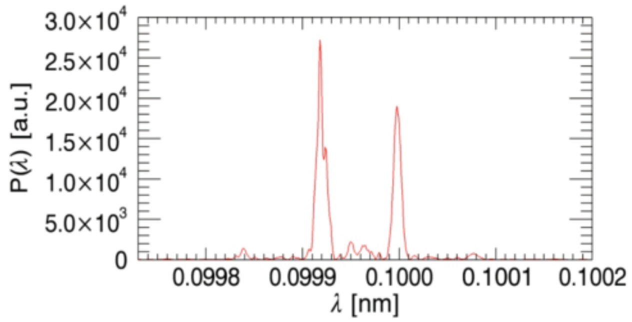
To extend the wavelength reach of the Aramis FEL beamline to shorter wavelengths it is proposed to incorporate a short `harmonic afterburner' after the main FEL undulator. The electron beam entering the afterburner is strongly microbunched at the FEL wavelength due to the FEL interaction, but this microbunching also has significant components at higher harmonics. The afterburner is therefore tuned to the second harmonic of the FEL so that the electron bunch emits a strong burst of coherent radiation at this shorter wavelength. As the FEL-induced energy spread in the electron bunch is significant, the afterburner cannot produce lasing and the power level is significantly lower than at the fundamental, but the photon flux is still sufficient to be used in many applications. ASTeC scientists employed their experience in the design and development of undulators for many previous projects to evaluate the different technology choices for the afterburner. The options considered were a superconducting undulator (similar to that being developed at STFC for the Diamond Light Source) in which the magnetic field is generated by windings of superconductor carrying a high current, an in-vacuum hybrid undulator in which the magnetic field is generated by pieces of permanent magnet and enhanced via the inclusion of Vanadium Permendur pole pieces, and finally a cryogenically cooled in-vacuum hybrid undulator in which the field is further enhanced by cooling the undulator to 77 K. It was found in simulations of the Aramis afterburner that the very best performance was obtained with the superconducting undulator but that the alternative technologies also delivered acceptable results. The final decision will be made in consulation with PSI in which the integration of the afterburner with the existing SwissFEL infrastructure will be evaluated along with its predicted photon output.

Laser Heater Undulator

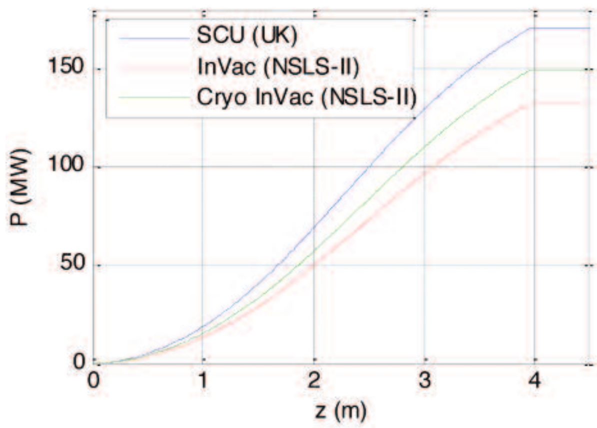
Short wavelength FELs require a high quality electron bunch to lase. One quality factor is the energy spread within the bunch which must be very small. An issue identified in similar FEL designs to SwissFEL, is that small intrinsic density modulations in the electron bunch can cause the strong emission 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 outcome is that the small energy spread in the bunch can be amplified enough to degrade the performance of the FEL.



Collimation system: Electron fluence at 1 cm downstream from collimator.



Self Seeding Scheme: simulation results of two crystal two colour self seeding scheme showing the two distinct wavelengths of the output.



Afterburner for Aramis: growth of radiation power in the afterburner undulator for the three technology options.

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 `laser heater undulator'. The electron bunch then passes through a magnetic dogleg in which the artificially smeared energy spread is converted into a longitudinal density smearing, helping to damp the intrinsic 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. ASTeC's responsibilty is the design, procurement, manufacture, testing and delivery of the laser heater undulator. The magnetic modelling is nearly complete and the engineering design is now progressing in consultation with PSI to ensure seamless integration of the undulator into the SwissFEL accelerator. The undulator will be constructed at the Daresbury Engineering Technology Centre and tested at the ASTeC magnet measurement laboratory before delivery to PSI in 2014.

The work described will be completed by the agreed dates for each work package which range from Summer 2012 to Autumn 2013. A presentation and discussion of progress made so far was given by ASTeC at the SwissFEL Advisory Committee Meeting in Spring 2012. At this meeting some other interesting topics were identified which would extend the work, taking advantage of recent FEL research undertaken by ASTeC. The outlook is promising for a long and fruitful collaboration between PSI and ASTeC.

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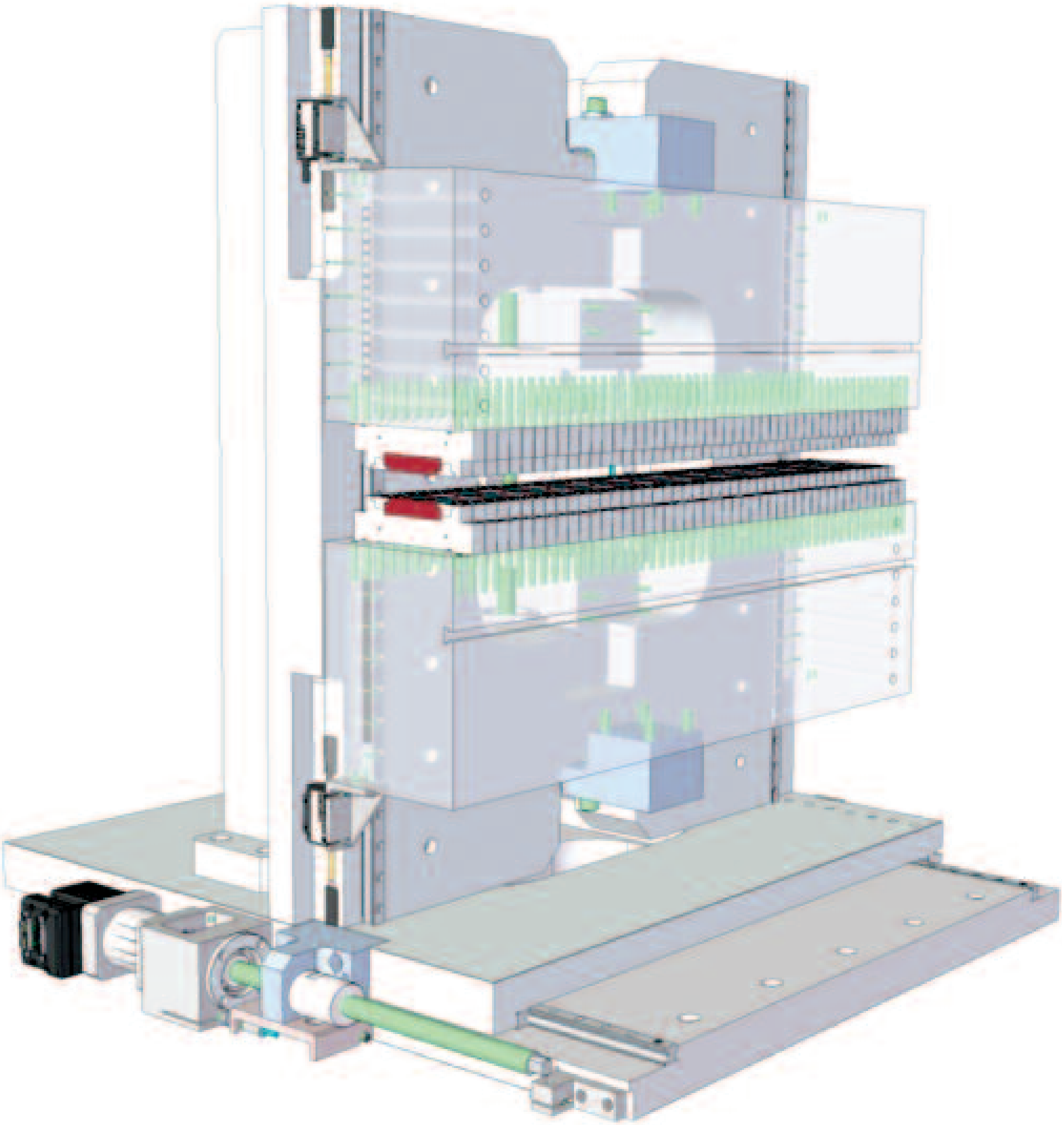

Laser Heater Undulator: draft engineering design

CLIC Drive Beam Quadrupoles

ASTeC's Magnetics and Radiation Sources (MaRS) group have been working on an innovative concept for quadrupole magnets. This concept uses permanent magnets (PMs) to generate the field instead of coils. The PMs can be moved up and down to adjust the magnetic field experienced by the beam. This reduces the power requirement of the magnet almost to zero.

This work has been undertaken in collaboration with CERN as part of the CLIC project. CLIC – the Compact Linear Collider – is a project to design a 42 km long electron positron collider, based on the principle of 'two-beam' acceleration. A low energy, high current drive beam is decelerated, and in the process transfers its energy to the high energy, low current main beam. The quadrupoles are designed for the decelerator section of the drive beam. The CLIC tunnel heat load requirements are very stringent (150 W/m), which is the main motivation for investigating the possibility of permanent magnet quadrupoles. Another is the sheer number of magnets required – one placed every metre means over 41,000 will be required! For a machine of this scale, permanent magnet technology represents a vast saving in power consumption.

The drive beam decelerator energy goes from 2.4 GeV to 240 MeV, and the baseline magnet strength (in terms of gradient x length) goes from 12.2 T to 1.2 T. There are some operating scenarios envisaged which require different magnet strengths, and so each magnet must have some adjustment built in. Since the magnets are designed around PMs, they cannot be 'switched off' like conventional electromagnets, but instead have a fixed range of strengths. Two different magnet designs have been produced, one for the high energy end and one for the low energy end.

The high strength magnet has been fully designed, magnetically and mechanically. Production of a prototype is in progress. The PMs, the most challenging and critical component, have been ordered from a specialist PM manufacturer, one that ASTeC has previously dealt with when buying PMs for undulators and wigglers. The prototype quadrupole magnet will be tested in ASTeC's magnet measurement laboratory, to ensure it meets the demanding specification in terms of field strength, range and quality. The motion system must control the position of the PMs to an accuracy of less than 10 μm, while holding them in place against forces of up to 16 kN – equivalent to the weight of a BMW 3 Series car!

The low strength magnet has gone through the initial magnetic modelling process. The constraints on this design are similar, but the strength is lower and the range of adjustment must be greater. A mechanical design is being produced in collaboration with the Technology Department. The design may undergo several iterations in 2012 before a prototype of this version can be built. The design was presented at the Magnet Technology conference in Marseille, where it garnered considerable interest. With energy costs increasing, this technology could become very attractive for future generations of accelerators to keep operating costs to a minimum. ASTeC has filed a patent covering these ideas.

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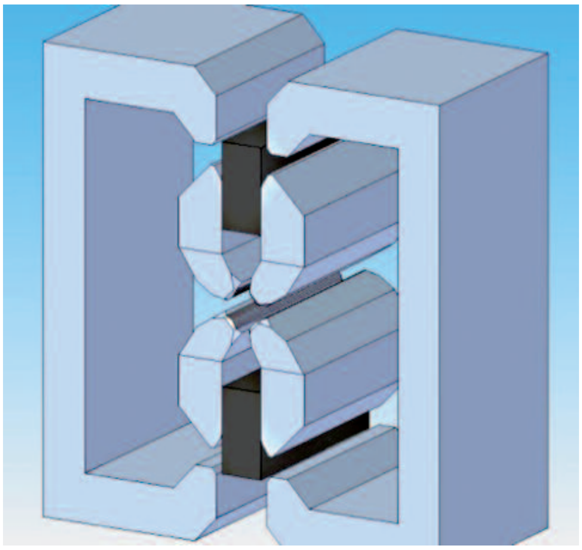
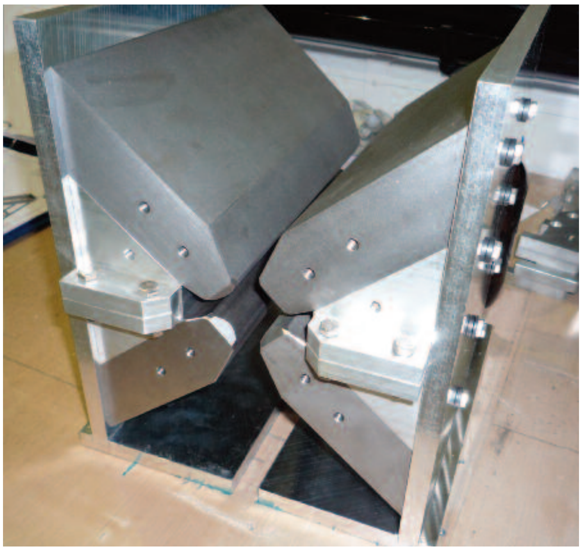
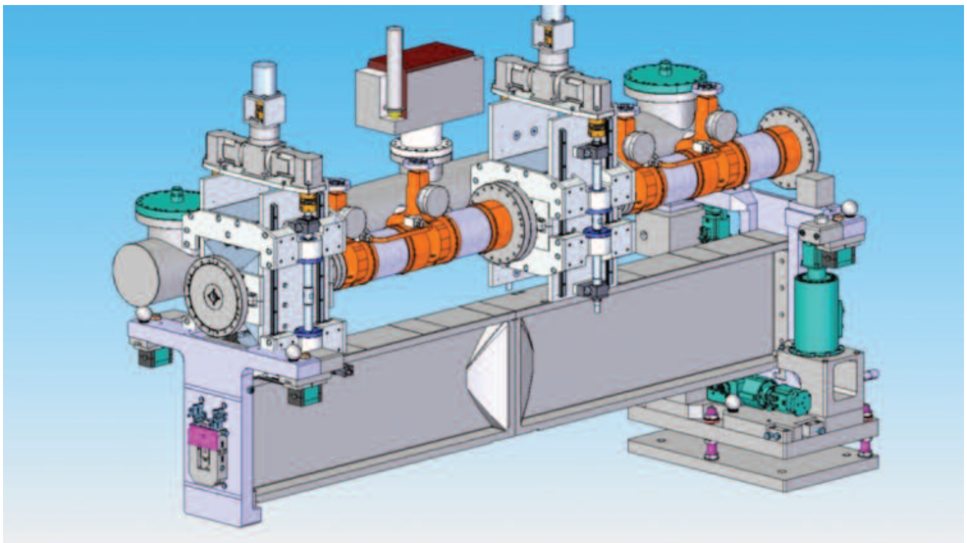


A CAD model showing the design concept of the low strength version. The PMs (in black) are magnetised horizontally, and move between the steel poles and the steel outer shell. In the fully extended position, the outer shell acts as a short circuit, further reducing the field seen by the beam and extending the operating range of the magnet



Assembly of the high strength version is under way. This picture shows the pole pieces – the PMs will be mounted above and below this, and the beam tube would go through the centre. The magnet is 230 mm long and approximately 200 mm wide, with a central bore diameter of 27.2 mm



Two of the quadrupoles as they would be installed on the CLIC module

Outreach

Accelerator Masterclass

The annual masterclass reached new heights in what has been heralded as our most successful accelerator masterclass to date. Students from five schools attended over two days, and participated in a mixture of activities which included a 3D flythrough of the unique ALICE accelerator, and an exciting hands-on experiment to estimate the injection beam energy. ASTeC's vacuum science group gave a series of demonstrations showing such things as the effect of vacuum on balloons and marshmallows, and some more serious things such as the famous Magdeburg Spheres and the triple point of water, where water can be seen to both boil and freeze at the same time.

The Space Cryogenics group demonstrated the Meissner effect in which a conductor cooled below its critical temperature expels magnetic field lines, and can be seen to levitate above a superconducting magnet. The programme also included talks on developments in particle physics, and the worldwide computing network setup to address the mammoth task of data analysis for the Large Hadron Collider. It was clear from feedback immediately after the event that the mixture of practical activities, demonstrations and talks had really stimulated the imagination of the visiting students.

ASTeC staff at the Big Bang Event

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 was run over three days at the NEC in Birmingham, and saw nearly 55,000 visitors. The exhibition stand included two Van de Graff generators, one of which provided the high voltage needed to drive the cyclotron model accelerator, and the other generally had a queue of children (plus some parents) waiting to have their hair raised by placing a hand on the dome and allowing themselves to be charged to high voltage. Another extremely popular demonstration was the permanent magnetic accelerator – a simple device whose operation surprised and delighted everyone (including teachers) and elegantly demonstrated several basic and very important aspects of physics. 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.

Visits and Work Experience Students

ALICE and EMMA continue to attract many visits, such as the Knutsford SciBar group, Congleton High School's German exchange students, Altrincham Grammar School for Boys, and professional bodies such as the local branches of the Institute of Physics and the Institute of Engineering Technology, to name but a few. ASTeC's work experience student scheme has expanded significantly over the last year, and we have hosted a record breaking number of students in a range of technical areas over the last year. The feedback from these students is overwhelmingly positive, with many stating that they would like to return again next year to continue where they left off – clear evidence of the impact of our science.

ALICE in Filmland

ALICE has been the subject of several films during the last year. STFC commissioned a film maker, Brady Haran, to make a series of 'back stage science' films, one of which focussed on ALICE's photocathode electron gun, and the other on ALICE itself. ALICE also featured in the BBC's 'History Hunt' series when a group of school children learning about John Cockcroft visited to see the Cockcroft Walton high voltage power supply which drives the photocathode electron gun. A publicity film made by Mannmade productions focuses on the unique qualities of the light pulses generated by ALICE, and how they are being used to support a range of unique scientific research programmes.

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

Van de Graff generator at the Big Bang event

Big Bang

56,000 people attended the Big Bang event of which 49,000 were young people, parents or teachers.

The Meissner Effect as demonstrated at the Accelerator Masterclass

Students

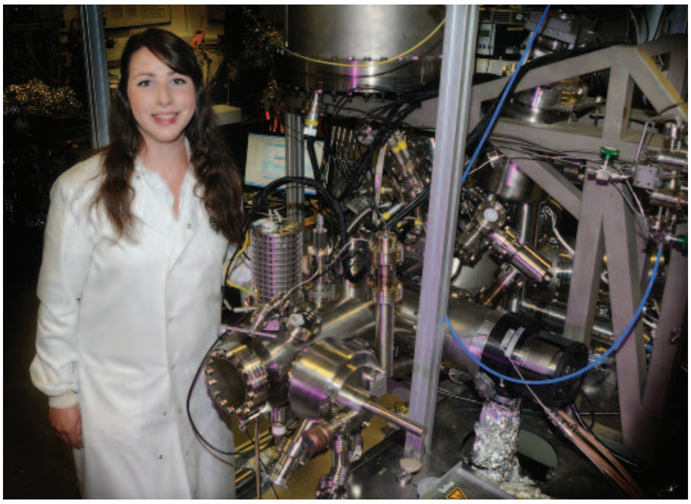
ASTeC offers several positions within the Sandwich Student placement programme which are advertised through STFC. This offers undergraduate students the opportunity to work with ASTeCs highly skilled and knowledgeable staff and its large range of high tech facilities within a world leading scientific environment.

A personal statement from one Sandwich Student, Rebecca Jones:-

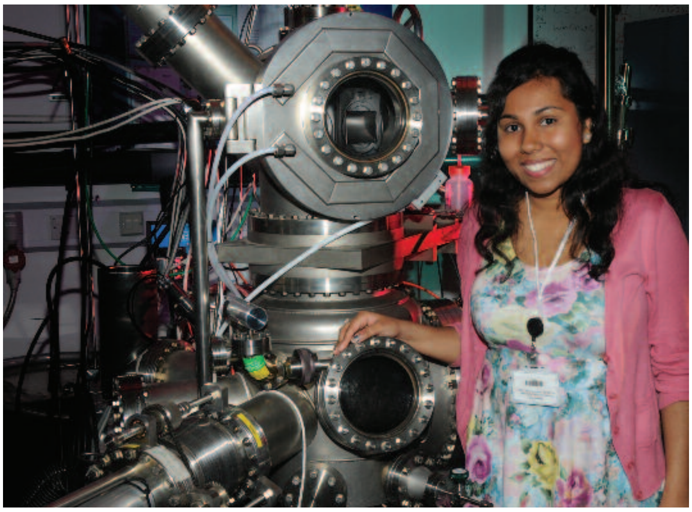
"Working for ASTeC's Vacuum group has given us a fantastic insight as to what it's really like working within a world leading laboratory on up and coming research. During my time within ASTeC I have not only put into practice our knowledge base gained at university but also have had the opportunity to work in a practical environment with world class facilities, an experience that is just not available within universities. As well as working on scientific projects within the lab, I have also had the opportunity to attend and take part in conferences, scientific exhibitions, talks by guest speakers and training courses. I have even managed to publish my work in scientific journals!

ASTeC's friendly nature has allowed me to gain independence and confidence along with an advanced knowledge within my relative field. This is an invaluable experience that is considered crucial to today's job market.

The only downside to the programme is that if you enjoy it as much as I have, you may never want to leave!!! Thank you ASTeC!"



Sandwich Student Rebecca Jones



Sandwich Student Madushani Kuruppu Achchige

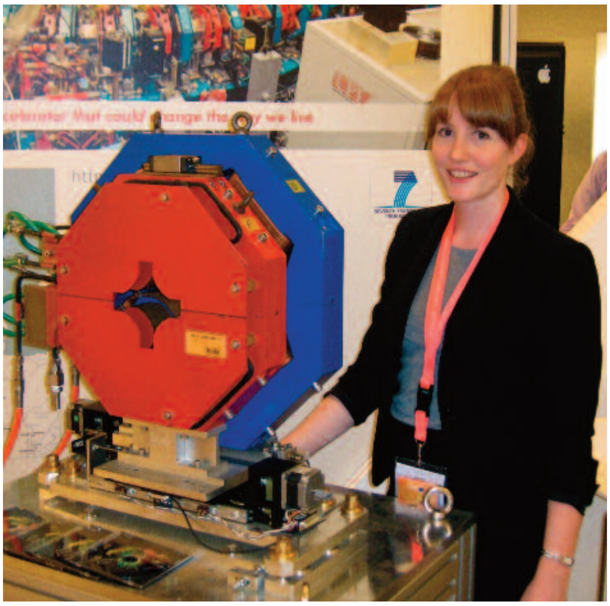
EMMA features at EU Innovation Convention

Brussels was buzzing with around 1200 policy makers, CEOs, top researchers and innovators who gathered for the first ever European Commission Innovation Convention.

A central component of the convention was an impressive exhibition designed to showcase European funded research and innovation. EMMA (the Electron Model with Many Applications) was featured as part of this exhibition, with a stand entitled "Novel Accelerators for our Future", which was selected as one of just 48 entries from a competitive field of around 450 applications.

Visitors to the stand were wowed by the visually impressive pair of EMMA quadrupole magnets, learned of the difference between EMMA and existing accelerators, and enjoyed the hands-on experience of using a real EMMA beam position monitor. Many delegates were amazed at the range of potential applications of this type of accelerator - from medical applications such as proton therapy to energy applications such as high power proton accelerators for accelerator driven systems.

For more information contact: suzie.sheehy@stfc.ac.uk



Suzie Sheehy at the European Commission Innovation Convention

ALICE

More than 40 scientists are actively involved in the ALICE science programme

Workshops & Visits

100 Years of superconductivity

Professor Dirk van Delft, Director of the Museum Boerhaave, the Dutch National museum for the history of science and medicine, located in Leiden, was on a two day visit to STFC to mark the closing ceremony of the centennial celebrations of the discovery of superconductivity.

On 17th November he visited Daresbury Laboratory and was a given a tour of ALICE - the UK's first superconducting accelerator built at Daresbury Laboratory. He also signed a copy of 'Freezing Physics', a biography of Heike Kamerlingh Onnes, authored by him. The following day he visited the cryogenics laboratory at STFC's Rutherford Appleton Laboratory (RAL), and witnessed the assembling of the cryogenic components of Atacama Large Millimetre Array (ALMA) and the Diamond Light Source. He delivered a special lecture 'The Discovery of Superconductivity and Leiden Cryogenics Laboratory' to a late evening gathering co-hosted by ASTeC, the Cockcroft Institute and IOP Merseyside branch, in the Merrison Lecture Theatre at Daresbury Laboratory and to the members of RAL and the Cryocluster group at the Pickavance Lecture Theatre at RAL.

The discovery of superconductivity was made in a moment of serendipity, three years after helium had been liquefied in the same laboratory, in a meticulously planned operation, 'Big Science' in its first appearance. In addition to the description and chronology of events, Professor van Delft brought to life the personalities and intense rivalry between Onnes and competing scientists of the day (such as James Dewar), illustrating his talk with some wonderful examples of paintings and photographs of the time.

For those who attended the lectures, there was the double treat of being addressed by Martin Wilson, who introduced the Professor and himself deserves the accolade of 'Rutherford Legend' for his work at STFC on superconducting magnets.

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£10M investment for Daresbury Laboratory

£10M investment was confirmed by Prime Minister David Cameron when he visited the Daresbury Science and Innovation Campus on 17 August.

The £10M investment will position the UK at the cutting edge of computer development and enable a new testing facility for accelerator technology.

Professor Susan Smith, Director of ASTeC said, "Until now, high energy particle accelerators have been very large machines, with linear accelerators being up to 3 km in length and synchrotron's being many tens of metres in diameter. We knew that these machines had the potential to address a wide range of challenges from cancer therapy to security screening, but the size and associated costs were prohibitive. Our focus now is to engage with industry to develop compact accelerators which are cheaper to build and cheaper to operate."

33rd International Free Electron Laser Conference

ASTeC staff Steve Jamison and David Dunning attended the 33rd International Free Electron Laser (FEL) Conference, held in Shanghai from 22nd - 26th August 2011. David Dunning gave a presentation on the first lasing of the ALICE IR-FEL.

The programme included many interesting presentations covering experiences with current FEL facilities, and proposals for future developments. The poster sessions provided opportunity for discussion, and members of ASTeC took part in useful exchanges with other delegates.

64th IUVSTA Workshop

The 64th IUVSTA workshop on Practical Applications and Methods of Gas Dynamics for Vacuum Science and Technology was jointly organised by Dr Oleg Malyshev (ASTeC/STFC), Professor F Sharipov (Parana University, Brazil) and Dr C Day (KIT, Germany). The workshop was endorsed and sponsored by the International Union for Vacuum Science, Technique and Applications (IUVSTA) and held at Hotel Leinsweiler Hof, near Karlsruhe, Germany on 16-19th May 2011.

The motivation behind this workshop was to bring together for the first time in such a framework three communities, namely theoretical and experimental physicists in the area of rarefied gas dynamics (RGD), vacuum scientists working in the field of vacuum flow simulation in all flow regimes, and representatives of vacuum industry with applications in the gas dynamics area. The purpose was to promote the recent progress in vacuum gas dynamics and to foster a better communication between these communities so as to create an increased awareness of the views and issues of the different communities.

The workshop attracted more than 60 scientists from 19 countries. Participants across the communities were reasonably well represented with about half from vacuum science (mainly from accelerator and fusion vacuum groups), a quarter from the RGD academics and the rest from industry. During the workshop there were 49 oral presentations covering 9 topical areas: vacuum metrology; vacuum pumps; experimental activities; numerical modelling; benchmark problems; vacuum system design; transient problems; accelerator vacuum systems; ITER (International Thermonuclear Experimental Reactor).

This three–community focused meeting was found to be very useful by the participants and it was recommended to bring these communities together on a regular basis every 3–4 years.

Another important outcome of the workshop was the announcement to compile a special issue of the journal Vacuum, devoted to Vacuum Gas Dynamics. It was edited by Felix Sharipov and Oleg Malyshev and was open for papers to all researchers working in the vacuum gas dynamics area. This Issue was published in Vacuum 86 (11) 2012.

ASTeC 10 Years On

To mark the 10th anniversary of its formation ASTeC hosted a Celebration Symposium with nearly 100 attendees, dedicated to a review of a decade of highlights.

Ex-Director Mike Poole recalled the early history of UK accelerator activities, leading up to the ASTeC launch in 2001, and explained its strategic objectives. The impact of ASTeC on operations and development of the Daresbury Synchrotron Radiation Source (SRS) in its later years was described by Paul Quinn (retired Associate Director) and on ISIS upgrade planning by current Accelerator Division head David Findlay.
This was followed by a series of talks on successful ASTeC collaborations and Richard Walker paid tribute to its role in the delivery of the Diamond Light Source (DLS) design (in 2002) and the more recent New Light Source (NLS) study.

A senior member of the global International Linear Collider (ILC) design team, Nick Walker from DESY, pointed out the leadership roles played by ASTeC staff on that project, and Ken Long covered a similar review of their contributions to the Neutrino Factory studies. An example of an academic partnership, in vacuum science, was given by John Colligon (MMU) and an industrial one by Ed Morton (Rapiscan). Elaine Seddon reminded the meeting about the innovative Fourth Generation Light Source (4GLS) programme and its major prototype test activity, since renamed ALICE (Accelerators and Lasers In Combined Experiments), was described by Yuri Saveliev.

The various R&D programmes now underway on ALICE were covered, and this included a review by Rob Edgecock of progress on EMMA (Electron Machine of Many Applications). The impact of ASTeC on the formation and evolution of the Cockcroft Institute was highlighted by its current Director, Swapan Chattopadhyay.

Finally, current ASTeC Director Susan Smith presented the vision and planning for the future of ASTeC, including the very recently announced £2.5M infrastructure investments. The meeting finished with a dinner, sponsored generously by industrial partners e2v Technologies and Shakespeare Engineering, that included some remarks by ASTeC Founding Director Vic Suller.

Delegation from King Abdulaziz City for Science and Technology

On 26th - 27th September a delegation from King Abdulaziz City for Science and Technology (KACST) visited Daresbury Laboratories and Cockcroft Institute (CI). KACST is both the Saudi Arabian national science agency and its national laboratories. This organisation is interested in establishing a compact light source and, following the signing of an MOU with STFC at the end of last year, they undertook this specific visit to Daresbury to investigate the potential to develop a collaboration with UK scientists and engineers which would help to realise such a project within their institute.

During the visit they were able to hear about the new £2.5M accelerator investment at Daresbury, visit ALICE (Accelerators and Lasers In Combined Experiments) and EMMA (Electron Machine of Many Applications) and discuss the challenges of accelerator projects with technical experts from both ASTeC and Technology departments.

Cockcroft Institute university staff outlined the extensive opportunities for education and training through the CI educational programme and in partnership with ASTeC and STFC.

ERL 2011

Four members of ASTeC attended the 50th ICFA Beam Dynamics Workshop on Energy Recovery Linacs. The workshop, which is held every two years was hosted at KEK, Japan on the 16th to 21st October and attracted 140 participants.

ASTeC operates ALICE (Accelerator and Lasers In Combined Experiments), Europe's first energy recovery linac based free electron laser, as a test bed for accelerator science and technology research. The participating group presented talks to the workshop based on the studies and experience of operating ALICE and studying the technologies involved in energy recovery accelerators. There are only three energy recovery linac facilities in operation, although a number of test facilities are under construction or planned in the USA, Asia and Europe.

The workshop consisted of a series of plenary session talks complemented by five parallel working groups covering the major aspects important to energy recovery accelerators. During the beam dynamics session Yuri Saveliev presented studies of ALICE which included experience of a complex "two beam" phenomena observed on the ALICE accelerator. He also presented material from the ASTeC RF group on the ALICE superconducting accelerating systems including an update on the status of the International Cryomodule which is due to replace the current ALICE linac module in the coming months.

Boris Militsyn participated in the photoinjector session and provided talks on the experience with the ALICE photoinjector as well as an overview of science studies of photocathodes being carried out within ASTeC which characterise the photoemission process under different conditions.

Julian McKenzie contributed a talk outlining simulation studies which showed the challenging dynamics involved in operating the ALICE injector at the present nominal gun voltage of 230 kV. During the next ALICE shutdown the current ceramic which is limiting the injector energy will be replaced and it is expected that the ALICE beam quality will be improved through operating the new ceramic at higher voltage.

Finally, Susan Smith participated in the combined instrumentation and beam loss working group sessions and used material supplied by Steve Buckley to present the experience on ALICE of using the beam loss monitor system.

ICFA Seminar

During 3rd -6th October 2011, Susan Smith attended the ICFA seminar on "Future Perspectives in High Energy Physics" at CERN, which is held every three years and is a four-day international exchange of information concentrating on plans for future facilities in the field of particle physics.

This year there were 212 attendees including directors of most of the world's major laboratories in our field, senior particle and accelerator physicists, and government science officials from several countries.

In addition to discussing future facilities and prospects in particle physics, this seminar reviewed the exciting recent results from current facilities which will be decisive for the future direction of the field. One highlight was the elusive hunt for the Higgs particle and the prospects for either discovery of a low energy standard model Higgs or its exclusion by LHC within a year.

At the end of the seminar Susan took the opportunity to visit the magnet test area and the Atlas control room. During the tour the process of developing and installing the LHC superconducting magnets was outlined together with ambitious future plans to develop the compact superconducting magnets required for the high luminosity upgrades of LHC. Also discussed was the R&D which will step towards the very high fields required for a future high energy LHC upgrade.

ALICE

60 tours of ALICE took place during this reporting year

Institute of Physics Conference Highlights

ASTeC was well represented at the IOP Nuclear and Particle Physics Divisional Conference, 4th -7th April 2011, hosted by Glasgow University, which incorporated the important Annual Meeting of the Particle Accelerators and Beams (PAB) Group.

This was a showcase event with hundreds of UK physicists present, many of whom make use of accelerator based facilities. Invited talks by ASTeC staff included ASTeC director, Susan Smith, who presented the latest EMMA commissioning results, and Peter McIntosh providing an overview of accelerator technology R&D programmes. Another highlight was Chris Prior being selected to summarise progress at the intensity frontier, a cross-group talk requested by the particle physicists and given to a large audience.

As well as the plenary programme, the PAB Group had its own parallel and poster sessions which featured more ASTeC presentations. The health of the discipline in the UK was illustrated by the breadth of talks and enthusiasm of speakers, both from ASTeC and other national centres (including Cockcroft Institute contributions).

Those attending also had the chance to participate in the STFC 'Town Meeting' at the end of the conference, when current national strategy was debated.

SUSAN SMITH ON BBC RADIO 4

Susan Smith, ASTeC Director, and Bob Cywinski from University of Huddersfield were interviewed recently when Julian Rush and his production team visited ALICE and EMMA. The programme 'Nuclear power without the nasties' was broadcast on BBC Radio 4.

IPAC11

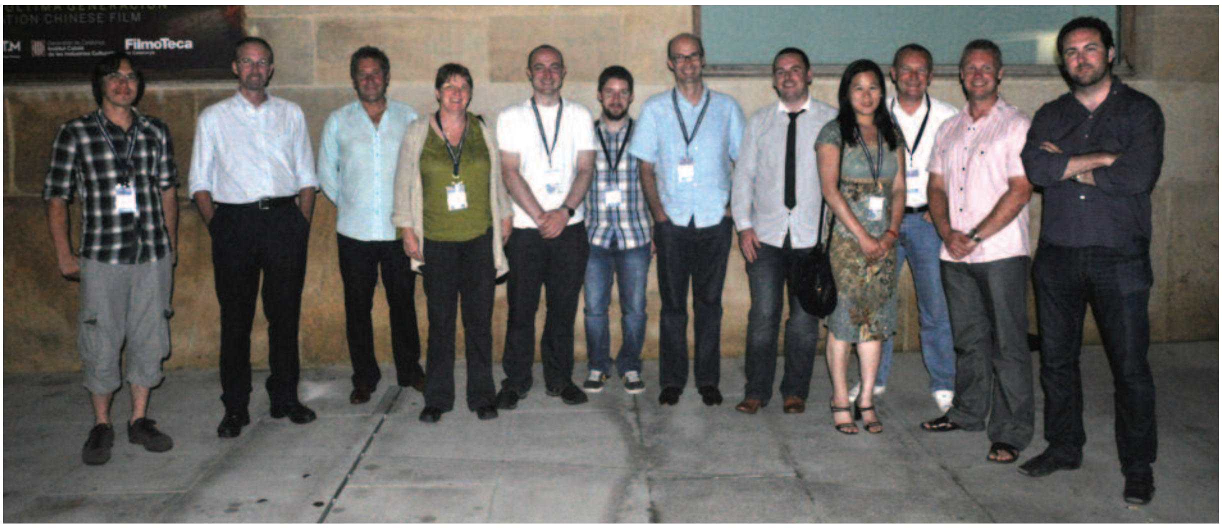
Staff from ASTeC attended IPAC11 in San Sebastian between 4th – 9th September 2011.

IPAC 2011 is the largest international conference on the latest developments in particle accelerators. ASTeC's achievements in the past year were well represented by two oral presentations. Shinji Machida of the Intense Beams Group gave a talk 'First Results from the EMMA Experiment' detailing the milestone achievement of acceleration in a non-scaling FFAG, and Frank Jackson of the Accelerator Physics Group gave a talk' The Status of the ALICE Accelerator R&D Facility at Daresbury Laboratory' including details of the first lasing of the ALICE infra red free electron laser.

The MaRS group presented two papers, both related to the application of superconducting devices within light sources. The first discussed an international experiment called COLDDIAG, which will be installed into Diamond Light Source (DLS) in November with the aim of accurately measuring for the first time the heat load from the electron beam due to wakefields and other interactions. The second paper presented the status of an ASTeC led project to design and manufacture a very advanced superconducting undulator that will also be installed into DLS in the future.

As part of IPAC there was the handover of the luminosity baton' from the Tevatron at Fermilab to the LHC at CERN as LHC had steadily increased its peak luminosity, and on the 22nd April 2011 had passed the Tevatron to become the world's highest luminosity machine. To mark this achievement a baton and a plaque documenting the increase in machine luminosity over the last 6 decades or so, was formally passed on by Vladimir Shiltsev of Fermilab to Lucio Rossi from CERN.

Mike Poole (ex-Director of ASTeC) was awarded a fellowship for key early contributions to novel synchrotron operation leading to new photonuclear investigations, lasting contributions to the realisation of second, third and fourth generation light sources, pioneering work on the development of Free Electron Laser facilities internationally, and life long services to the field of accelerator science and technology.
Sue Waller was part of the editorial team with responsibility for the JACOW repository.

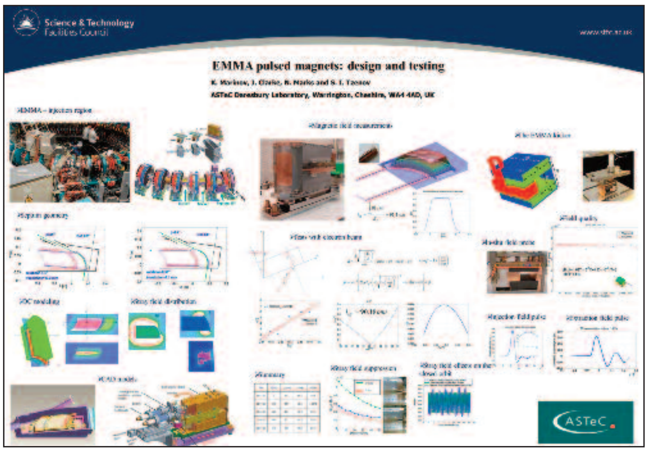


Workshops & Visits

Magnet Technology Conference

Scientists from ASTeC attended the 22nd Magnet Technology conference (MT-22), held in Marseille in September 2011. The conference aimed to highlight recent developments in the field of resistive and superconducting magnets, and there were interesting presentations from many different institutions across the world. The ITER (International Thermonuclear Experimental Reactor) fusion project was particularly well represented, and the conference included a tour of the ITER construction site at Cadarache.

Ben Shepherd presented a poster on his work on the CLIC permanent magnet quadrupoles, and Kiril Marinov presented his work on the design and testing of pulsed magnets for EMMA (Electon Model of Many Applications). Both posters generated a great deal of interest from the community.



For further information contact:
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EPS Accelerator Board

Deepa Angal-Kalinin who has been elected to join the Board of the EPS Accelerator Group. The election is for 6 years and will cover the organisation of IPAC14 and IPAC17.

Photocathode Electron Source R&D collaboration

Left to Right: Dr. Heinrich Scheibler (ISP Senior Scientist), Boris Militsyn (STFC Senior Scientist), Professor Alexander Terekhov (ISP Director), Lee Jones (STFC Scientist).

ASTeC has a long standing collaborative agreement with the Institute of Semiconductor Physics (ISP) at Novosibirsk, part of the Siberian Branch of the Russian Academy of Sciences. The ISP group headed by Professor Alexander Terekhov specialise in high efficiency photocathodes, primarily for use in image intensifiers (a technology used in night vision glasses), but the same technology underpins high performance photocathode electron sources in particle accelerators. A cathode is an electron source, and a photocathode emits electrons when illuminated by light. When used as an accelerator electron source, a photocathode is illuminated with a high power pulsed laser system to stimulate emission of extremely short bursts of electrons. This is the basis of the electron gun on the ALICE (Accelerators and Lasers In Combined Experiments) Energy Recovery Linear accelerator at Daresbury Laboratory.

The ISP is a world leader in the academic community in a number of semiconductor photocathode families, particularly the III-V group of semiconductors. Gallium arsenide (GaAs) is a member of the III-V group, and is the photocathode material in the ALICE gun. There have been a series of contracts with the ISP dating back to 2007 under which the ISP contributed to the design of the high average current electron source required for the 4GLS (Fourth Generation Light Source) project. ASTeC have also benefited immensely from their input during the design and commissioning of the Photocathode Preparation Facility (PPF) and its photocathodes, both of which were developed as part of an upgrade to the existing ALICE electron gun. The PPF routinely delivers photocathodes for research purposes with quantum efficiencies (QE) as high as 20% at 635 nm wavelength, where QE is defined as the number of electrons emitted by the photocathode per incident (rather than absorbed) photon, and depends on many factors such as photocathode material, laser wavelength, accelerating field and vacuum environment. The typical QE levels in the PPF are many times higher than the best achieved in the current ALICE gun, a testament to the quality of the PPF.

The PPF supports on-going R&D into GaAs photocathodes, and will be used to provide photocathodes for use in the TESS experiment. TESS is the Transverse Energy Spread Spectrometer, an experiment currently under construction to characterise the performance of photocathode electron sources by measuring the transverse energy spread. The goal is to increase beam brightness by reducing the source energy spread, a requisite for fourth generation accelerator based light source applications.

Recently, Boris Militsyn and Lee Jones visited the ISP to carry out several experiments, and to discuss future collaborative work. The visit was marked by exceptionally good weather for Siberia at that time of year, with clear blue skies and the temperature reaching nearly 20°C by the end of the week. The visit also saw the signing of a renewed memorandum of understanding, ensuring close links with the ISP will continued for at least a further 3 years.

It snowed the following week, marking the beginning of the Siberian winter ……

Proton Accelerators for Science and Innovation

ASTeC staff participated in the "Proton Accelerators for Science and Innovation" Workshop that was held at the Fermi National Accelerator Laboratory on the 12th - 14th January 2012 to bring together leading members of the user, developer, and consumer communities from the UK and the US.

The aim was to review and discuss the issues related to the development of technologies and accelerator facilities capable of expanding the horizons of the world's scientists, but, which could also be applied to revolutionise the health care, clean energy, and security agendas. The ambition was that this workshop would lay the foundations on which an appropriately coordinated programme for the development of the proton accelerators of the future could be built.

At the workshop on the 14th January, STFC signed a Letter of Intent with Fermilab in which the two organisations agreed joint goals and activities in the development of high intensity proton accelerators. It is also planned that STFC and Fermilab hold another workshop in 12 months to review progress and explore additional areas of collaboration.

Jim Clarke and Neil Marks from ASTeC with Giorgio Apollinari from FNAL in front of a 9 cell superconducting ILC RF cavity

Rolf Heuer Visit

Professor Rolf Heuer fifth from left with ASTeC staff members

The growing relationship between CERN, the European Organization for Nuclear Research, and the accelerator science and technology community in the UK's North West, has been marked with a visit to the Daresbury Science and Innovation Campus by CERN's Director General, Professor Rolf Heuer, on 19th July 2011. Hosted by Professor Swapan Chattopadhyay, Director of the Cockcroft Institute, Professor Heuer toured the major research facilities at the Campus, including the Vacuum and Surface Science Laboratory and the RF and Diagnostics Laboratory in the Cockcroft Institute, and STFC's Engineering Technology Centre and the ALICE (Accelerators and Lasers In Combined Experiments) and EMMA (Electron Model of Many Applications) accelerators.

Professor Chattopadhyay said: "Professor Rolf Heuer's visit to Daresbury testifies the emerging collaborations and growing strong links between CERN, Europe's largest collaborative scientific laboratory in Geneva and the accelerator science and technology enterprise in the North West".

Professor Susan Smith, Director of Accelerator Science and Technology for STFC added, "STFC has enjoyed a long standing and mutually beneficial relationship with CERN. As the UK sponsor of particle physics, our scientists and engineers continue to be closely involved in many of the experiments on the Large Hadron Collider. We look forward to developing the relationship further through the development of technology for the next generation of particle accelerators."

Ultra High Bright Electron Sources Workshop

The Ultra High Brightness Electron Sources was held at the Cockcroft Institute, Daresbury Science and Innovation Campus from 29th June – 1st July 2011. The workshop was jointly organised by the Cockcroft Institute, Diamond Light Source Ltd, John Adams Institute, Institute of Physics, DITANET and STFC ASTeC. The workshop was attended by 47 participants from 16 different institutes around the world.

The primary purpose of this workshop was to explore the possibility of generating electron beams with fs-range bunches whose emittance is at least one order of magnitude lower than the current state-of-the-art. The scope of subjects covered in the workshop programme included the complete range of processes involved in the production of electron bunches, starting with electron emission from traditional and novel electron sources, primary acceleration of electrons in the gun, transportation and manipulation of space-charge-dominated beams, and the use of diagnostics in their characterisation. A crucial aspect of this workshop was consideration and discussion of the problems encountered in simulations of beam dynamics.
The workshop brought together several international experts and researchers working on these issues and discussed common areas of interest, advancing current technological limits by fostering and encouraging collaboration.

The participants of the workshop also had the opportunity to tour ALICE (Accelerators and Lasers In Combined Experiments), EMMA (Electron Model of Many Applications) and the photoinjector development facilities at ASTeC.

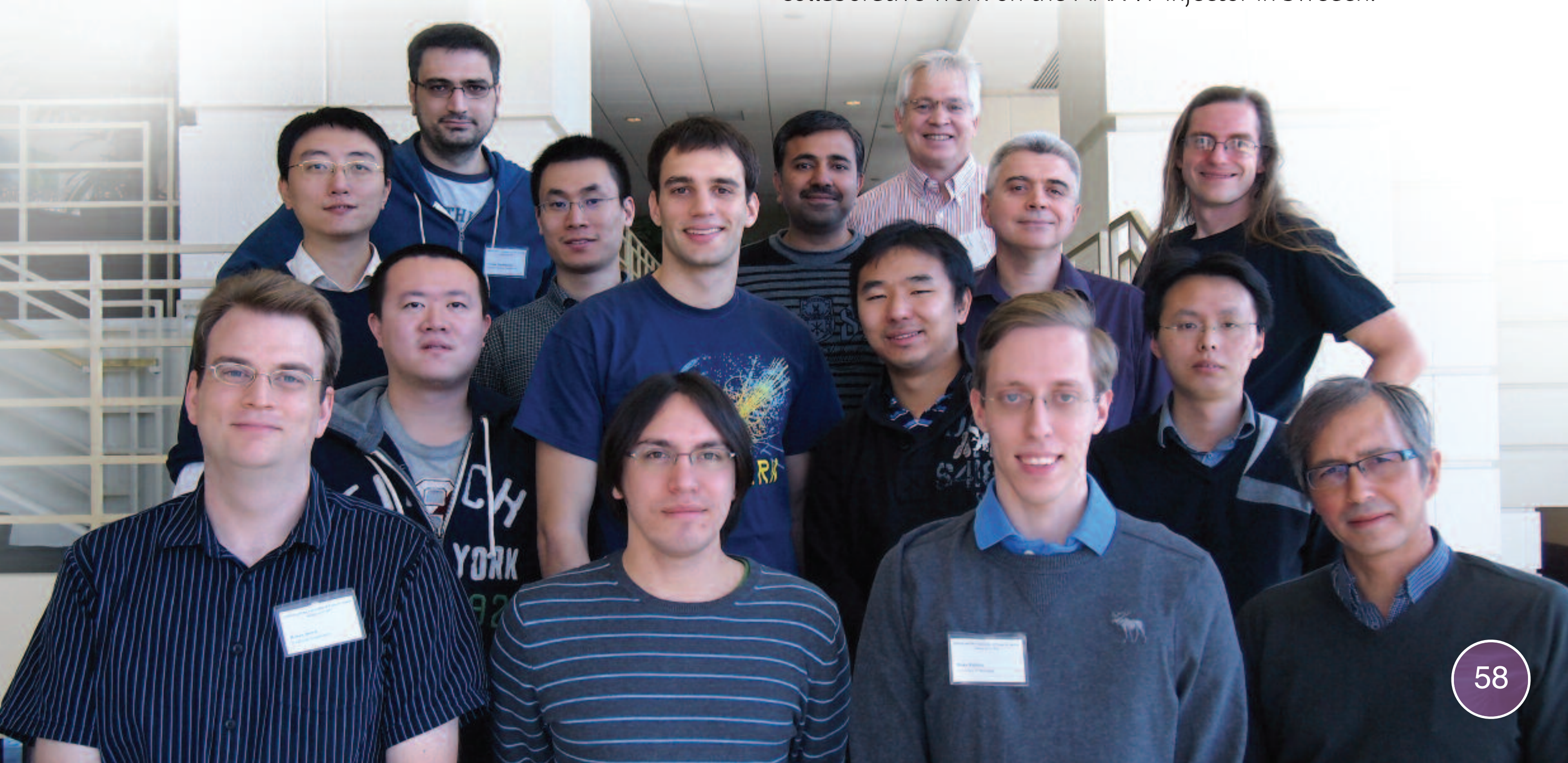
United States Particle Accelerator School (USPAS) Cathode Physics

Tim Noakes and Julian McKenzie attended the USPAS (United States Particle Accelerator School) on Cathode Physics held in Austin, Texas. The course was an opportunity to delve into the theoretical aspects of photoemission from a variety of cathode sources as well as learn about the practical aspects of operating such devices. Tim followed that week with a further course of photoinjector beam dynamics.

Photoinjectors have been a key element in ASTeC's R&D activities since first operation of the DC high voltage gun with ALICE (Accelerator and Lasers In Combined Experiments) in 2006. Since then, the photocathode programme has led to the successful development and operation of a dedicated GaAs photocathode preparation facility in the Cockcroft Institute in 2009. This allows photocathodes to be activated to quantum efficiencies as high as 20%, many times the best achieved in the ALICE gun.

Work on GaAs is continuing in collaboration with the Institute of Semiconductor Physics at Novosibirsk, with a high resolution device to measure the energy spread of the emitted electrons at both room and liquid nitrogen temperatures currently under construction. A test beamline to measure the intrinsic emittance and response time of photocathodes is also under development.

Photoinjectors are a critical component of future Free Electron Laser (FEL) based light sources -Versatile Electron Linear Accelerator (VELA) currently under construction at Daresbury Laboratory will contain a suite of diagnostics to accurately characterise RF photoguns, and will be ASTeC's first experience with copper cathodes. ASTeC's photoinjector design skills have been necessary for completion of the Conceptual Design Reports of both the 4GLS (Fourth Generation Light Source) and NLS (New Light Source) projects, and have recently led to collaborative work on the MAX-IV injector in Sweden.

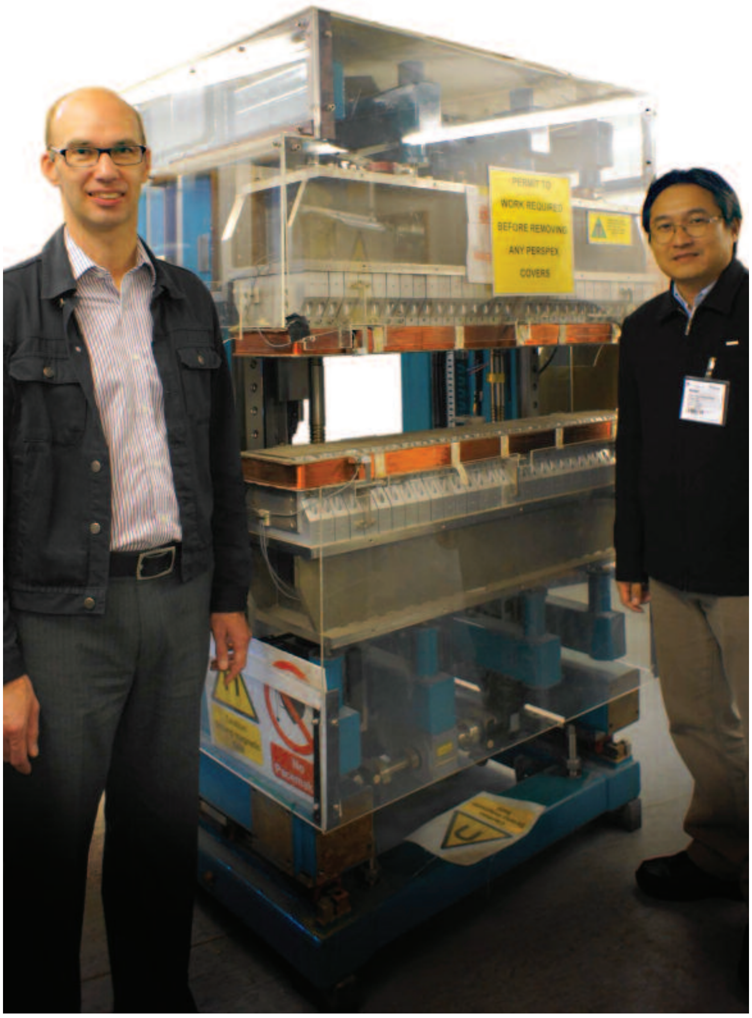


Visit by Thailand Light Source

On 4th August 2011 the Acting Director for the Thailand Synchrotron Light Research Institute, Dr Prayoon Songsiriritthigul, and colleague Dr Supat Klinkhieo, visited ASTeC and Technology Department to discuss the loan of a multipole wiggler to the Siam Photon Source. The multipole wiggler was originally designed and manufactured by ASTeC and Technology Department for the SRS in 2002. It was installed on the flagship beamline 10 and provided high quality x-ray output for the SRS light source users until the SRS facility was closed in 2008. When it was first constructed it held the world record for the highest magnetic field for a permanent magnet-based multipole wiggler, 2.4 T, at the operating gap of 20 mm. It is thought to still hold that record today.

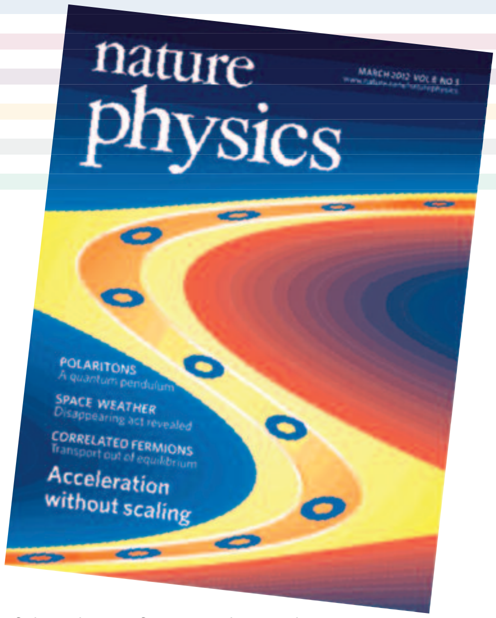
Fruitful discussions were held between Jim Clarke, Clive Hill, Andy Gallagher, Ian Mullacrane, and the visitors from Thailand and it is hoped that the magnet will be on its way to Thailand in early 2012 before installation into the Siam Photon Source in Summer 2012. It is hoped that the wiggler will serve the users in Thailand as well as it did those in the UK!

The loan is expected to last for about three years, giving the Thailand team time to design and build their own similar in-house device.



Dr Prayoon Songsiriritthigul and Jim Clarke standing next to the 2.4 T multipole wiggler which should be on its' way to Thailand next year

Publications



Cover of the edition of Nature Physics showing serpentine acceleration

Journal and conference papers

- In 2011-12 ASTeC published 45 Journal articles including works on free electron lasers, beam tomography studies and fixed field alternating gradient accelerators. These were published in a wide range of journals such as Nuclear Instruments and Methods in Physics Research, Nature Physics, Physics of Plasmas, Vacuum, and Physical Review Letters.

- There were 64 conference papers, which included papers at IPAC, PAC and FEL amongst others and covered various subjects from ALICE, EMMA, MICE and non-scaling fixed field alternating gradient proton drivers, to design work on photocathode electron guns, undulators and beam loss monitor systems.

- Peter Williams from the Accelerator Physics group, together with Hywel Owen of the University of Manchester published a paper entitled "A Modular Path Length Corrector for Recirculating Linacs" published in Nuclear Instruments & Methods in Physics Research Section A. The paper described a novel modular magnetic system that can introduce a variable path length difference in recirculating linacs without simultaneously altering beam characteristics. Such a system is widely applicable in the many proposed scientific facilities worldwide based on recirculating linacs. The paper is available on the Science Direct website

- ASTeC staff Peter Williams, Deepa Angal-Kalinin, David Dunning, James Jones and Neil Thompson have had their paper entitled "Recirculating Linac Free-Electron Laser Driver" published in Physical Review Special Topics - Accelerators and Beams. The paper describes the design of a recirculating linac as a driver for the suite of seeded free-electron lasers proposed in the UK New Light Source project. The paper is available on the American Physical Society website.

- ASTeC physicists Jim Clarke and Duncan Scott have had a paper published in 'Physical Review Letters'. The article was entitled "Demonstration of a High-Field Short-Period Superconducting Helical Undulator Suitable for Future TeV-Scale Linear Collider Positron Sources", and the work describes the first demonstration of a key piece of equipment needed to produce the intense positron beams required for the next generation of particle accelerators. The work was carried out in collaboration with STFC's Technology Department at the Rutherord Appleton Laboratory (RAL) and Argonne National Laboratory in the United States, a prototype undulator was designed, constructed and studied. The prototype successfully produces the magnetic fields needed to generate circularly polarized photons. The paper has been selected by the American Physical Society to appear in their periodical "Physics", intended to spotlight exceptional research.

Press Highlights

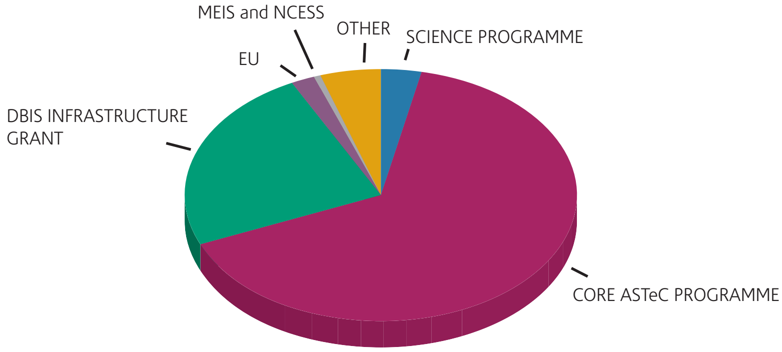
- An article written by David Rose appeared in the Mail on Sunday LIVE magazine. The story featured EMMA, PAMELA and potential applications including accelerator driven reactors in thorium fuelled power stations and accelerator developments to cure cancer more effectively.

- In February 2012 the BBC Radio 4 Today Programme featured Peter Weightman and an article on the work being performed on ALICE into oesophageal cancer diagnostic research.

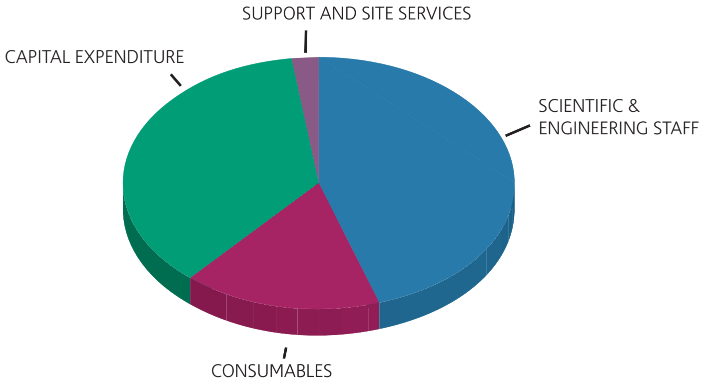
Finance

Financial Summary

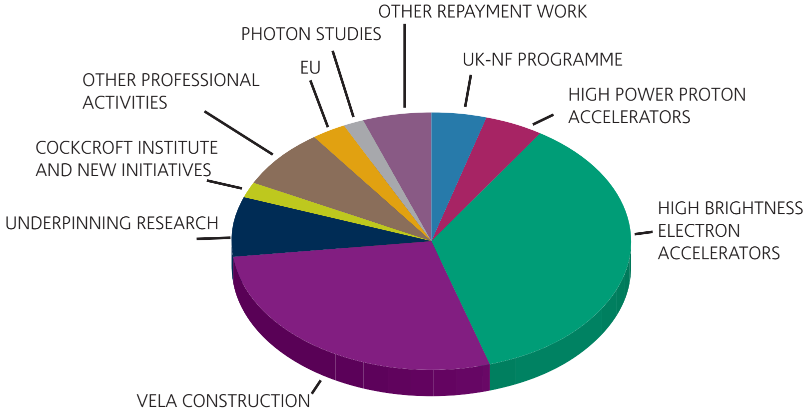
INCOME SOURCES 11/12	£K
SCIENCE PROGRAMME	363
CORE ASTeC PROGRAMME	6844
DBIS INFRASTRUCTURE GRANT	2500
EU	210
MEIS and NCESS	44
OTHER	521
	10482



EXPENDITURE 11/12	£K
SCIENTIFIC & ENGINEERING STAFF COSTS	4720
CONSUMABLES	1715
CAPITAL EXPENDITURE	3826
SUPPORT AND SITE SERVICES	221
	10482



EXPENDITURE BY PROGRAMME 11/12	£K
UK-NF PROGRAMME	484
HIGH POWER PROTON ACCELERATORS	501
HIGH BRIGHTNESS ELECTRON ACCELERATORS	3778
VELA CONSTRUCTION	2911
UNDERPINNING RESEARCH	796
COCKCROFT INSTITUTE AND NEW INITIATIVES	193
OTHER PROFESSIONAL ACTIVITIES	788
EU	297
PHOTON STUDIES	169
OTHER REPAYMENT WORK	565
	10482



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UK Astronomy Technology Centre, Edinburgh; Chilbolton Observatory, Hampshire; Isaac Newton Group, La Palma;
Joint Astronomy Centre, Hawaii.

Science & Technology Facilities Council