Accelerator Science and Technology Centre

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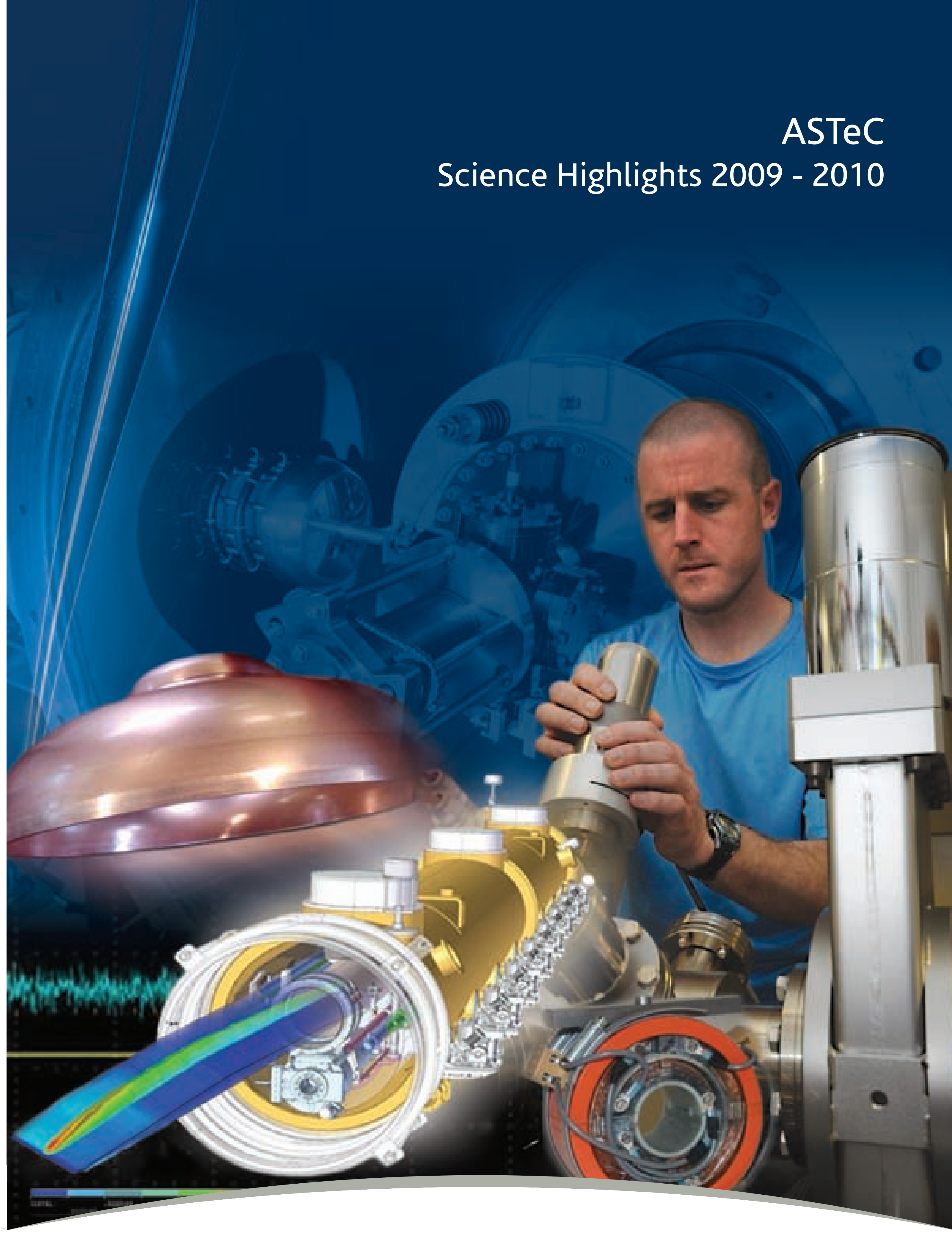
ASTeC
Science Highlights 2009 - 2010



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Accelerator Science and Technology Centre

Science Highlights
2009 – 2010

This report covers the work accomplished by the Accelerator Science & Technology Centre (ASTeC) for the financial year 2009 – 2010.

Designed & produced by: Media Services, Daresbury Laboratory.
Editors: Sue Waller and Alan Wheelhouse
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Foreword

Having taken on the role of Director in July 2010, it is a great privilege for me to present the outstanding range of scientific and technical achievements of the ASTeC department delivered under the inspiring stewardship of Mike Poole.

I would like to recognise the efforts of the ASTeC staff which has delivered a highly diverse programme of research under pining future accelerator facilities and applications in the areas of health, energy and security. The ALICE energy recovery light source delivers a broad programme of accelerator R&D, a highlight was the successful production of short pulsed x-rays through Compton backscattering. The ALICE team and their national and international collaborators worked intensively to conclude this experiment successfully.

One frontier of science is to measure structural dynamics in real time, *i.e.* to make movies of the motions of atoms and molecules as they undertake the changes that underpin physical, chemical and biological processes. ASTeC played a fundamental role in the New Light Source conceptual design which was based upon a new class of free electron lasers (FELs) designed to deliver such science. The NLS project was very positively endorsed by all who reviewed it but was put on hold due to financial considerations. ASTeC intends carry out future R&D to enable the efficient delivery of an optimal light source for UK scientists in the future.

ASTeC has continued to contribute to international collaborations tackling the immense challenge of pushing the frontiers of fundamental physics. This research has taken our scientists around the world participating in the design studies and test facility activities and we have further strengthened our collaborations with CERN. Bringing businesses and ASTeC together to undertake collaborative research enhances our impact. As part of a Mini-IPS KE enterprise, ASTeC will be working closely with Shakespeare Engineering Ltd to fabricate a superconducting structure, the first bulk-niobium accelerating structure to be fabricated in the UK, opening up a new scientific market sector for UK industry.

Research into accelerator science and technology received a boost with the announcement of nearly £20m of funding to The Cockcroft and John Adams Institutes. The Cockcroft Institute, which was awarded a £16.4m grant until 2017, is a partnership between STFC Daresbury Laboratory and the Universities of Lancaster, Liverpool and Manchester. ASTeC played a fundamental role in the establishment of this Institute and our scientists and engineers are proud to be recognised as having driven core aspects of the scientific programme which secured this additional funding. We look forward to productive partnerships with both Institutes to develop the future UK accelerator programme.

Sue Smith

Contents

ALICE

ALICE (Accelerators and Lasers In Combined Experiments) is an R&D testbed for forefront accelerator technologies at Daresbury Laboratory.

In 2009 ALICE achieved an important milestone in the production of short-pulsed Compton-backscattered x-rays. ALICE is currently utilised as a powerful source of terahertz radiation, an injector to the EMMA accelerator, and is commissioning the UK's first free electron laser.

Introduction

ALICE is a globally unique facility, pursuing R&D at the cutting edge of accelerator science. The main ALICE accelerator is a prototype for next-generation light sources, which operates in a way that minimises the energy consumption. This allows it to be used as an intense source of particles and radiation that would otherwise require a small power station to generate. ALICE is the first particle accelerator in Europe to demonstrate this 'energy recovery' technique which greatly reduces the amount of energy needed for particle acceleration. Energy recovery machines may be used for very high power sources of radiation or particle beams, leading to new opportunities in all areas of science and technology - biology, chemistry, engineering, pure and applied physics.

ALICE is currently used as a source of powerful coherent terahertz radiation, not readily available at other facilities worldwide. ALICE's next goal is to commission an infra-red free electron laser, which will demonstrate the technology needed for the next generation of UK light sources. ALICE also serves as an injector to the EMMA machine, a novel proof-of-principle experiment in accelerator technology.

ALICE Machine Developments

In 2009/10, detailed studies have driven significant improvements to accelerator performance. The fundamental parameters of electron bunch charge and beam energy were both increased to towards the ideal design values.

Achieving high charge bunches is particularly important for production of intense terahertz radiation, and necessary to drive the infra-red free electron laser. The operating charge was doubled to 40 pC, an improvement achieved through careful characterisation and optimisation of the accelerator beam transport system.

In addition, much effort was directed at enhancement of the accelerating performance of the machine. ALICE is the first facility in the UK to use high gradient superconducting radio frequency (SRF) beam acceleration. ALICE incorporates two SRF cryomodules, a booster and a main linac, each composed of two identical 1.3 GHz 9-cell niobium cavities. Important experience gained with the SRF technology allowed modifications to the system to allow the beam energy to be significantly increased during the year. The machine was tuned to maintain high efficiency of energy recovery at this new improved regime by minimising beam losses and other disruptive effects.

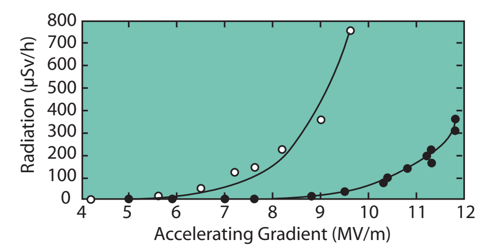
The improvement in machine acceleration performance was achieved in several ways. The first step was to tackle a power limitation of the booster two-cavity accelerator. This was overcome by finding the optimum balance power between the cavities which overcame the limitation while ensuring the whole system delivered high quality beam from the ALICE injector.

The next step was to address the so-called 'field emission' from the main energy recovery linac module – strong unwanted radiation which limits the maximum gradient at which the cavities could operate. To reduce this emission the RF pulse width was reduced to the minimum required for uniform stable acceleration over the whole ALICE beam pulse. This successfully allowed the gradient to be raised far beyond the previous limit and enabled energy recovery to be achieved at 30 MeV. Another step was to use a technique called 'helium processing' to clean the linac accelerating structures. In this process the cavity surface is cleaned by exciting the cavities with a high RF field in the presence of a small amount of helium gas. Improvements were seen in both the gradient at which field emission was seen and the level of radiation in the first linac cavity.

These improvements in the SRF have allowed ALICE to operate at 30 MeV compared to a previous limit of 21 MeV, and substantially reduced the cryogenic heat load in the system.

The ALICE electron source, the DC photo-electron gun, presented significant technological and operational challenges in previous years. However the system now performs well within the beam parameter specification, with 40 pC bunches being routinely delivered.

Helium processing at ALICE in March 2010



Reduction in radiation emitted from first linac cavity after helium processing

Cathode re-caesiation is performed once or twice a month, when the quantum efficiency decreases from initial ~3% to below ~0.5%.

In 2009-10 a systematic study and development of ALICE beam transport was undertaken. Optimisation of beam focussing and steering around the whole transport path was carried out, and these developments have lead to a reliable and routine mode of operation, with full energy recovery and very little beam loss. Efforts continue to improve the beam transport to a "turn-key" system with minimal set-up time required.

Compton Backscattering X-ray Source

ALICE continues to successfully achieve its major goals and the highlight of the

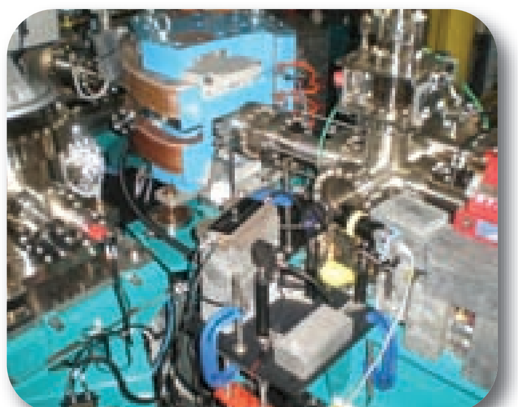
ALICE

year was undoubtedly the production of Compton backscattered x-rays (CBS) by interacting a powerful (multi-terraWatt) short-pulse laser with the ALICE electron beam. This was the first time this had been achieved in the UK.

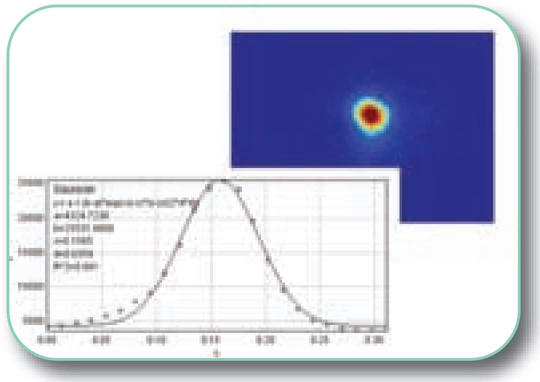
CBS x-ray sources are an attractive alternative to conventional x-ray sources (synchrotron accelerators) since they require much lower energy electron beams and the x-ray energy produced is more easily tunable.

X-ray detector

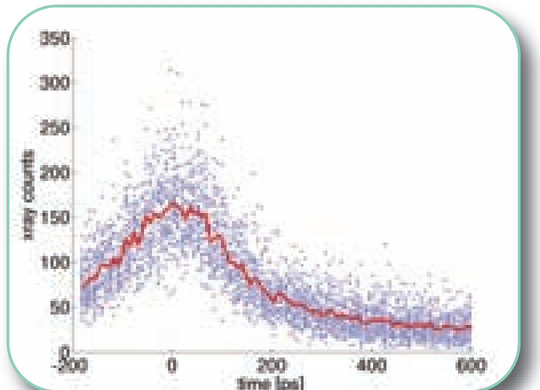
The experiment was conducted with a ‘head-on’ geometry, colliding the 70 fs, 800 nm, 500 mJ Ti:sapphire laser beam with an electron beam of 29.6 MeV energy and 40 pC bunch charge.



Focusing of laser and electron beams & transverse alignment



X-ray images



Temporal scan of laser-electron collision point

Terahertz Radiation Source Developments

ALICE as a source of powerful terahertz (THz) radiation was established in 2008, opening up an exciting area of scientific application and exploitation.

The source of the THz radiation is the ALICE bunch compression chicane where the electron bunches are reduced significantly in length. The short bunches emit pulses of high power THz radiation. This radiation serves as a diagnostic for ALICE beam physics, and is also a key area of photon science exploitation of the machine.

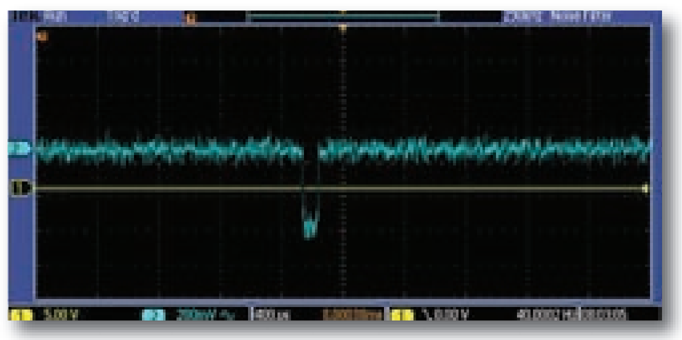
There is considerable interest in the interaction of THz radiation with biological systems, of which very little is known. A programme for the use of the THz source in biological experiments has been planned, using a beamline to transport THz radiation from ALICE to a tissue culture facility.

The THz radiation is being used in two research programmes; to determine the safe limits of human exposure to THz radiation, and to investigate the effect of THz radiation on mechanisms of biological organisation. The ALICE source is suited to these studies since it is a broadband source of high peak power and low average power, making it possible to separate the effects of THz radiation from thermal effects. First experiments are planned in a small shielded hutch close to the source in the accelerator hall.

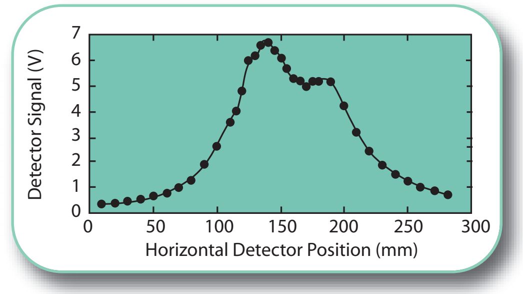
The characteristics of the THz radiation emerging from the accelerator have been measured, in particular to ensure the maximum efficiency in transporting of the radiation.

Free Electron Laser Progress

One of the main goals of ALICE is the operation of an infra-red free electron laser. This light source is of a new type of unprecedented brilliance – a so-called “fourth generation” source. These new sources are beginning to be exploited worldwide but have not yet been demonstrated in the UK.
Work progressed on this goal in



Oscilloscope trace showing spontaneous radiation signal from the IR-FEL detected by an infra-red detector. The negative going pulse is generated by the undulator radiation making multiple round trips within the laser cavity.



The horizontal terahertz beam profile at 1.1 m from the diamond exit window

2009/2010; the undulator was installed in December 2010 and operating with a 30 MeV, 20 pC electron beam, the first spontaneous radiation was achieved in February 2010. The cavity-type FEL reflects the 6 mm wavelength IR radiation from the beam backward and forward using mirrors, and the radiation is emitted through a hole in one of the mirrors where it is detected on a sensitive mercury-cadmium-telluride detector. The remaining challenges are to improve beam quality, particularly the bunch length and energy spread, so as to meet the conditions required for lasing.

Future Developments

One significant application of the ALICE machine is to provide beam for EMMA (Electron Machine with Many Applications). In March 2010 beam from ALICE was transported through the EMMA injection line for the first time. This is the very first step towards full commissioning of the EMMA machine, expected in 2010-2011.

In addition to its core research programme of THz and FEL, ALICE continues to explore interesting areas of application. One such area is a micro-bunching experiment, designed to study the effect of small scale perturbations to the ALICE bunch structure.

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The ALICE Photocathode Preparation Facility (PPF)

Work on the design of a Photocathode Preparation Facility (PPF) to upgrade the ALICE photoinjector electron gun has continued throughout this year, in collaboration with the Institute of Semiconductor Physics (ISP) in Novosibirsk, Russia.

Construction and commissioning of the 3-chamber vacuum system (also known as a load-lock) lead quickly to a GaAs photocathode with a quantum efficiency of 15%, with a high degree of reproducibility.

During this last year, the focus has moved to the practicalities of integrating the PPF with the ALICE photoinjector gun to permit the rapid exchange of photocathodes. A mock-up of the redesigned cathode ball has been constructed, and a vacuum chamber procured to allow testing of the transfer and loading/withdrawal mechanism. This step is crucial to ensure that the process works flawlessly before committing to an upgrade of the actual ALICE gun. The process will be tested in the near future, and the experience used to produce the final design of the cathode ball, optimising its performance in terms of both cathode loading/withdrawal and high voltage stability during gun operation.

ASTeC has invested a significant amount of time in fine tuning our handling and activation process, and the investigation of how sensitive an activated cathode is to a variety of gaseous species known to 'poison' photocathodes. These are basically oxygen-containing species, and lifetime measurements of the photocathode on exposure to precisely controlled doses of a range of poisonous and inert gases, with a view to gaining a better understanding of the resilience of various activation processes, have been undertaken. The delivery of a nitrogen-filled glove box for cathode handling now permits our custom-made cathodes to be chemically etched and moved into a transfer vessel for loading into the PPF without them being exposed to the air. This capability preserves the maximum quantum efficiency achievable from the cathodes.

Significant progress on the development of the control software used when creating a photocathode has been made during the year and it is expected that this process will eventually become fully automated. Further planned upgrades are the addition of a contactless temperature measuring system to give accurate control and best performance when carrying out atomic hydrogen cleaning on the GaAs cathodes, and the inclusion of a palladium membrane filter to provide ultra-pure hydrogen during this crucial cleaning process.

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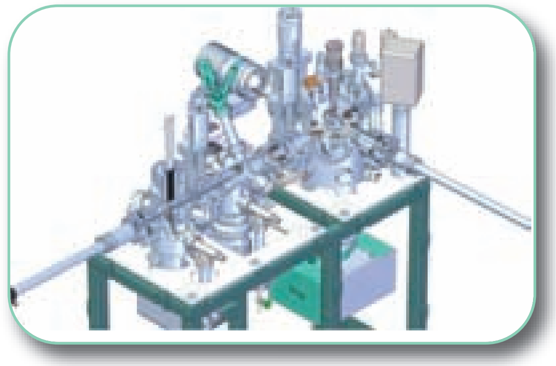
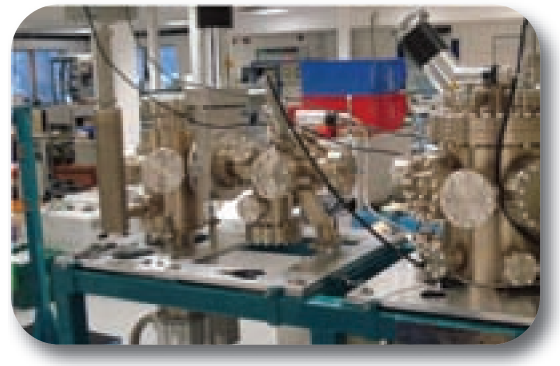
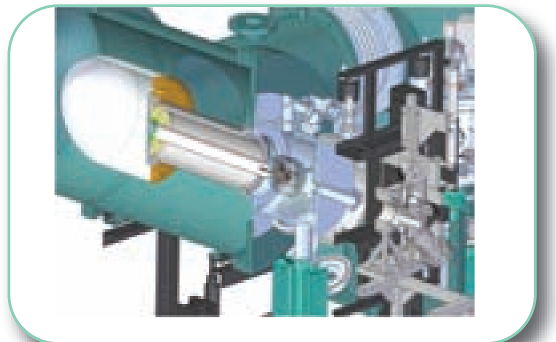


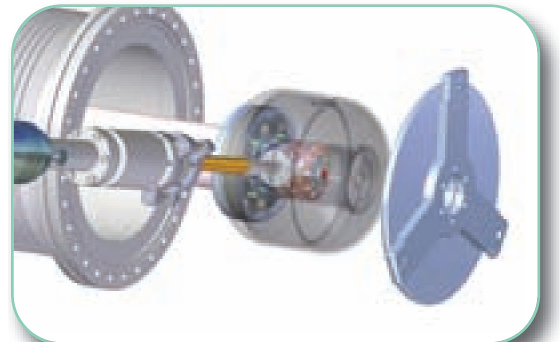
Preparation rig design



Photocathode rig



ALICE gun upgrade



ALICE gun upgrade

The Daresbury International Cryomodule Collaboration (DICC)

ASTeC, Stanford and Cornell Universities, Lawrence Berkeley National Laboratory in the USA, FZD-Rossendorf and DESY in Germany and TRIUMF in Canada are all part of the Daresbury International Cryomodule Collaboration (DICC).

ASTeC, within this collaboration has taken on the responsibility for pushing the superconducting RF technology development of a superconducting cryomodule for optimised operation on energy recovery facilities and other high duty cycle accelerators.

Through this project, ASTeC has established the necessary infrastructure for the development of Superconducting RF technology: from ISO-4/5/6 clean rooms for assembly, to a highly complex test stand to high power condition the SRF input couplers, through cryogenic tests with super-fluid helium to final performance tests with accelerated beams on the ALICE-ERL test facility (expected in April 2011). During the initial cavity qualification tests, conducted at Cornell University, the two superconducting cavities have met the performance target of 15 MV/m at Q_O of 5 x 10^9 required for ALICE operations. Specially developed high power RF power couplers have been tested successfully to withstand input powers of 30 kW in pulsed mode and 10 kW in CW mode. higher order mode (HOM) absorbers, the key components for high beam current operation, are undergoing a rigorous quality control process in readiness for being assembled with the cavities and couplers into the cryomodule vessel.

An in-house developed cryogenic system, 'COOL-IT' has been installed in readiness for the new cryomodule, to provide cooling for the radiation screens at intermediate temperatures (5 K and 80 K) using gaseous helium instead of the existing liquid nitrogen. By replacing liquid nitrogen the microphonic levels within the cavity will be reduced as there will be no boil off of gas.
A new instrumentation and control system has also been developed to facilitate the operation of the new cryomodule, which is scheduled to be installed and commissioned on ALICE during the summer of 2011.

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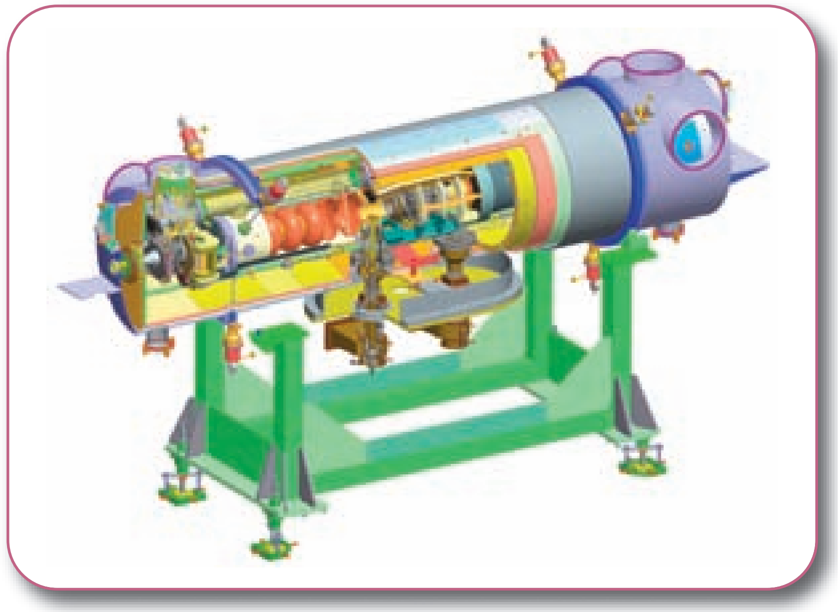
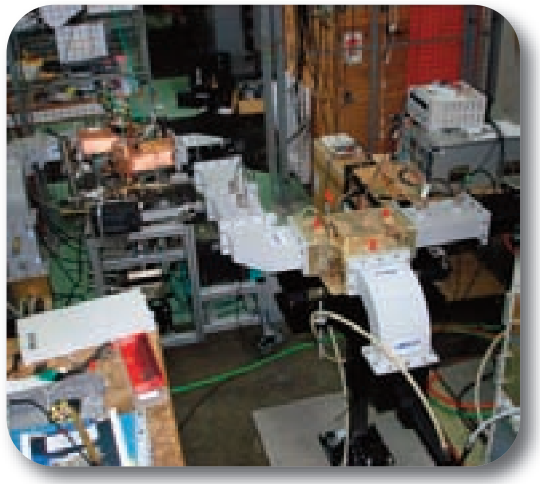
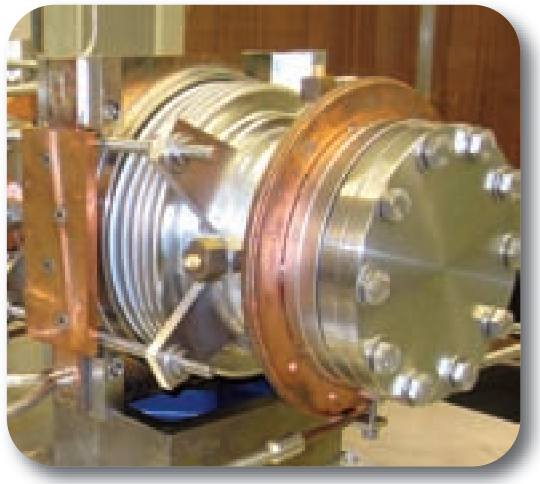


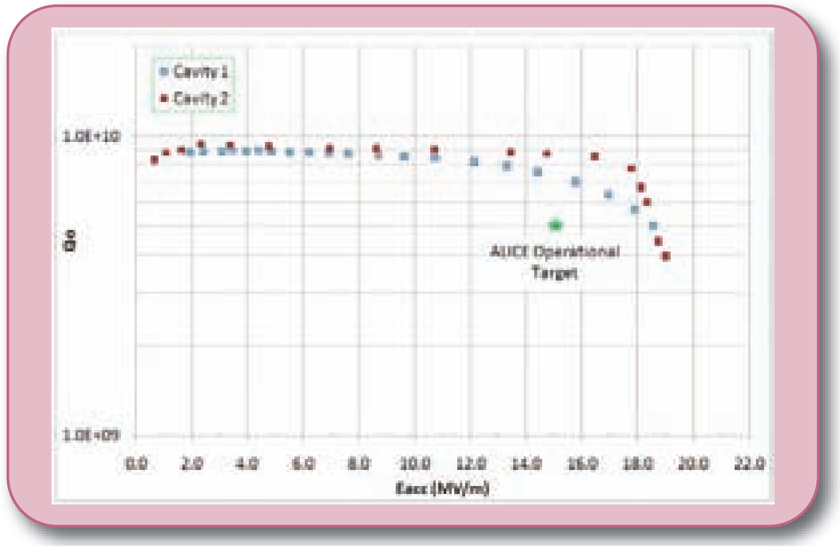
Cavity module



High Power RF coupler undergoing final tests



HOM absorbers



Results of the initial performance tests with the SRF Cavities

EMMA

Non-scaling FFAGs are currently being studied for a variety of applications, including hadron therapy, Accelerator Driven Systems and for the rapid acceleration of muons for a Neutrino Factory and a muon collider.

The unique features of these machines, however, mean that detailed development for these applications requires the construction of a proof-of-principle accelerator to fully explore the beam dynamics, gain experience in non-scaling FFAG design and construction along with the ability to benchmark the computer codes employed in the studies.

This proof-of-principle machine is called EMMA – the Electron Model for Many Applications – and its construction should be completed in the summer of 2010 at the STFC Daresbury Laboratory in the UK.

EMMA has been designed to demonstrate and study in detail all the features of non-scaling FFAGs. To do this, while keeping costs down, it was decided it should accelerate electrons from 10 to 20 MeV. The machine has been designed to be very flexible and it incorporates many diagnostic devices so as to enable detailed measurements of the beam parameters. It is built from 42 magnetic cells, each about 40 cm long, making the circumference 16.5 m. Each of these cells has two ring magnets and almost every other cell has an RF cavity. The cells in between have vacuum pumps or diagnostic devices. There is also a dedicated injection line where as much as possible the full 6-dimensional phase space of the incoming electron bunch from ALICE is measured. Further diagnostics will be mounted in an extraction diagnostics beam line, which it is planned to install at a later date. The purpose of all these diagnostics is to enable as precise as possible a determination of the effect of a non-scaling FFAG on an electron bunch.

Status

EMMA has been under construction since April 2007. The injection line was completed in March 2010 and commissioning of this has already started. The ring is built on 7 girders and 4 of these have been complete and in place since before Christmas. Two further girders will be put in place in the middle of May. The last girder is due for installation in the middle of June and will be closely followed by the start of commissioning of the ring. The diagnostics beam line will follow later in the year.

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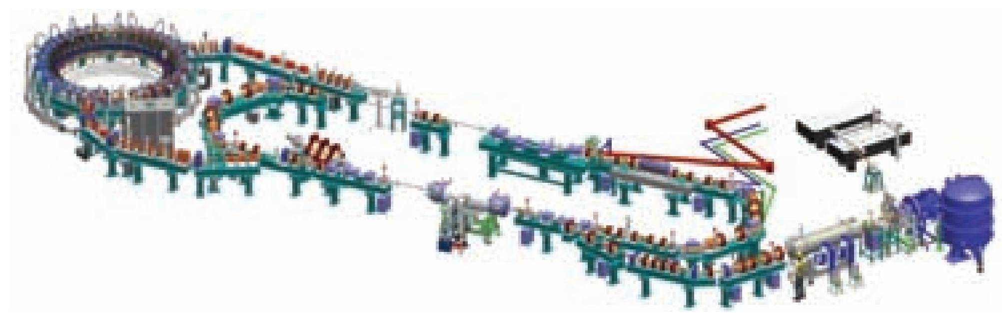
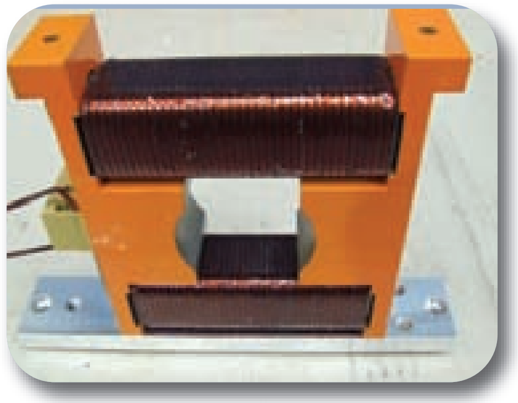


The ALICE and EMMA accelerators at the Daresbury Laboratory

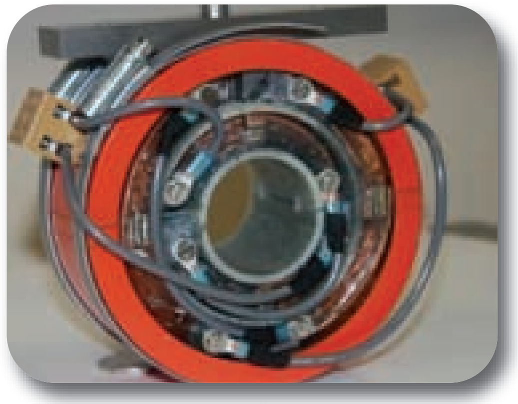
DC Magnets

All 84 quadrupole magnets for the EMMA ring have now been delivered to Daresbury, having undergone extensive testing at the factory. In order to meet EMMA's demanding requirements, the magnets must all produce the same integrated field to within 0.1%. This was achieved by fractionally adjusting the longitudinal position of the clamp plate attached to each magnet. For the dipoles and quadrupoles on the diagnostic beamline, some ex-SRS magnets were used, and some new magnets were procured. The new magnets were completed and delivered to Daresbury in June 2009. They will be assembled onto modules in 2010 in time for full ring commissioning.



A vertical corrector magnet

Horizontal and vertical correctors for EMMA will be used in the injection line, ring and diagnostic line. In the ring especially, space is very limited and so the magnet length was restricted to only 38 mm. ASTeC collaborated with Tesla Engineering, a UK magnet supplier, to produce designs for vertical and combined correctors that would meet the required specification in terms of field strength, field quality and overall footprint. Following manufacture and testing at Tesla's factory, the magnets have been delivered to Daresbury. Most of the correctors, including all of the injection line correctors, have now been installed onto the EMMA modules.



A combined (horizontal and vertical) corrector magnet

EMMA

Pulsed Magnets

Construction of the EMMA pulsed magnets – septa and kickers – was successfully completed. These magnets have been constructed entirely in-house as no commercial suppliers were prepared to submit a bid due to the very high technical complexity of the task. The magnets and their power supply units have been subjected to a rigorous performance testing and optimization process.

The maximum required kicker field strength of 7 mTm has been successfully demonstrated (a). Field quality was found to be very good with maximum variation across the horizontal aperture within the 1.5% limit.

The septum field strength and quality were measured as well, and here no sign of saturation was found at fields exceeding 1 T, which is 125% of the required strength. A detailed three-dimensional map of both the septum gap field and stray field regions has been produced (c). Since septum stray fields can severely disturb the circulating beam, a considerable amount of effort has been invested into their suppression (d-f). During this investigation it was discovered that ensuring a continuous electric contact between the various components of the eddy-current shield is crucial. In addition by trying various configurations and adding extra shielding where possible, it was possible to reduce the stray field strength by almost a factor of three. The achieved maximum stray field strength is of the order of 0.4 mTm (measured with a field probe in contact with the front part of the eddy-current screen) at 0.7 T gap field.

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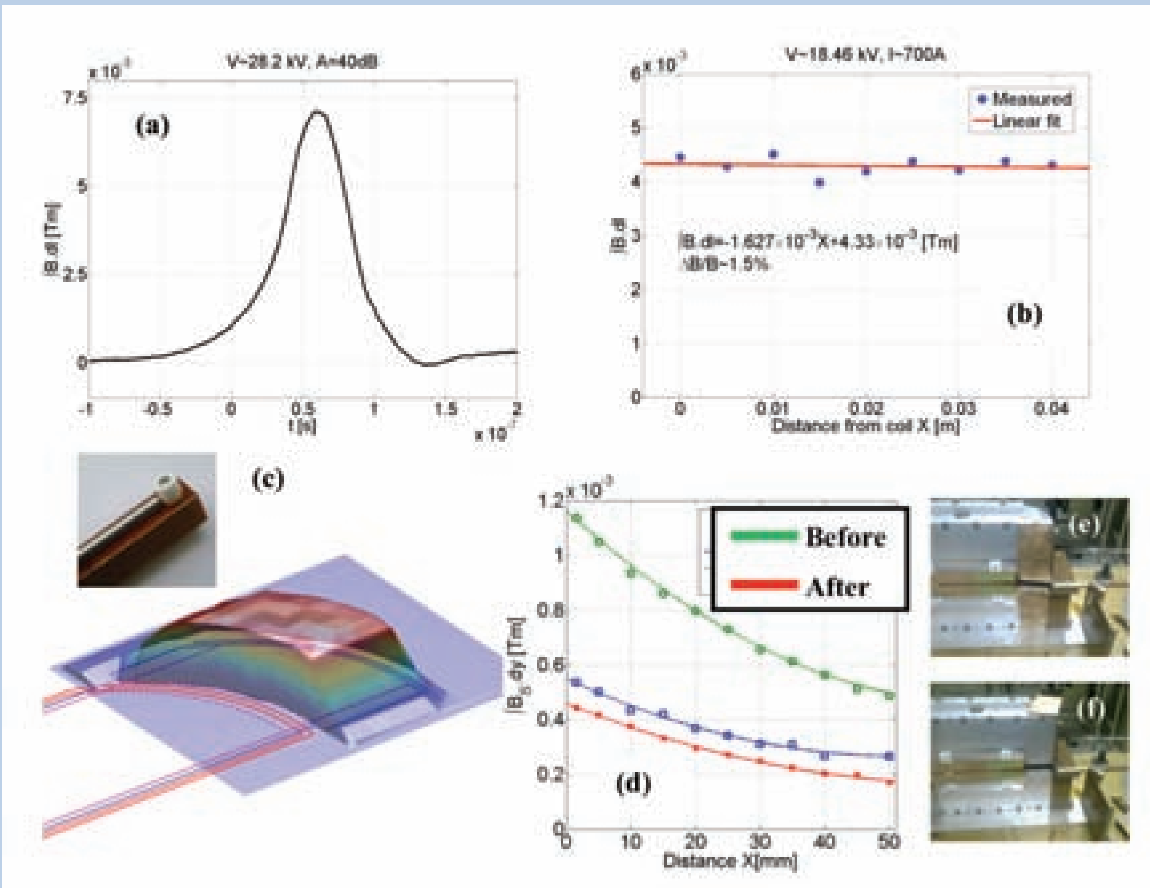

Results from the EMMA pulsed magnet tests (a) Kicker pulse at peak field/current (b) Kicker field variation across the aperture (c) Septum field map. The inset shows the 6 mm field probe (d) Different stages of septum stray field minimization (e) and (f) Various shield configurations tested.

Vacuum

After completing the EMMA vacuum system design, tender and purchasing process the past year has focussed on the vacuum preparation of the many EMMA modules. Nearly all modules were installed and thus far the vacuum system performs in line with what the Monte Carlo models predicted. The most challenging aspects of the vacuum system design were the injection and extraction modules. Out-gassing experiments were performed to ensure the out-gassing rate met the design specification before installation on the machine.

The vacuum system installation will be completed within a few months and it is anticipated that EMMA commissioning will be underway by the summer.

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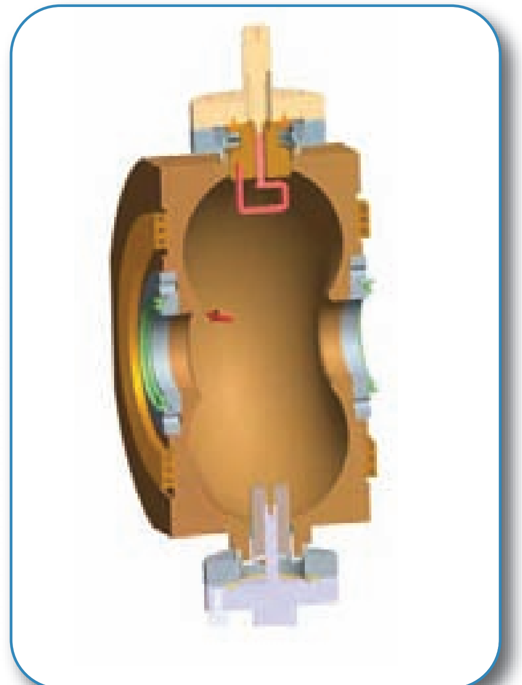
RF and Diagnostics

The EMMA RF system consists of 4 main sections; 19 1.3 GHz normal conducting cavities, a high power RF amplifier, a waveguide distribution system and a digital low level RF (LLRF) control system. The orders for these systems had already been placed the previous year and their design and manufacture were all well under way.



EMMA RF Cavity

The cavities were manufactured and delivered by Niowave Inc. During verification testing of the cavities a number of cavities were further optimised to meet the desired operating conditions of EMMA. A number of cavities were high power conditioned to the required operating levels without any gas events, giving confidence that the remaining cavities could be conditioned in-situ on the EMMA ring. The cavities have all been installed onto girders and the first 4 out of 7 girders have been positioned within the EMMA ring.

EMMA

The high power RF system has been designed and manufactured by CPI. The installation and commissioning of the system into a dummy load took place at the end of September 2009 with the RF peak power requirements being met across the frequency range required (1.2960 – 1.3015 GHz).

Q-par Angus have designed and manufactured a bespoke RF waveguide distribution system for EMMA that allows the RF amplitude to be evenly distributed to each of the 19 RF cavities whilst also allowing the phase of each cavity to be controlled. The system has been delivered and the first half of the ring is currently being installed around the outside of the first 4 sections of girders. The second half of the RF distribution ring will be installed once the final 3 girders have been positioned in the EMMA ring.

The design, development and manufacture of the digital LLRF system (Libera) are being undertaken by Instrumentation Technologies. The Libera system is tasked with performing the synchronisation with the ALICE injector, setting initial cavity conditions and then controlling the cavity amplitude and phase to promote stable acceleration in the EMMA machine. It is anticipated that the system will be delivered in Summer 2010, to enable commission of the complete RF system and then commissioning of the complete EMMA ring with beam.

The EMMA ring is designed with a large number of diagnostics instruments to understand the electron beam and its properties. Most of these systems have now been defined and are in production, or already being installed onto girders.

Optical diagnostic systems incorporating a YAG Ce crystal mounted on 'pop-in' actuators are installed in the injection line, whilst a novel 'edgeless' design is used on motorised stages within the ring. Since the beam traverses horizontally across the vacuum chamber, this motorised screen provides imaging and positional information through encoders, allowing it to be inserted into the beam aperture until it intercepts the turn required.

High Power RF Amplifier Commissioning Tests

EMMA RF Waveguide Distribution System

ASTeC in collaboration with Fermi National Accelerator Laboratory in the USA have been developing a wide bandwidth wall current monitor. The design of this novel 'in-flange' device is now complete and manufacture is on-going. Three monitors are required for EMMA installation, and these are scheduled for installation during the winter 2010 shutdown.

The Electron Beam Position Monitoring system is complex due to the orbit time of EMMA and the desire to measure the position of each turn in order to fully characterise each orbit. The signals available from 89 pickups will be pre-processed by locally mounted 'front-end' modules. These incorporate amplifiers and time delay stripline couplers, which take two opposite position signals from the BPM head (e.g. north and south or east and west). These signals are then separated out in time such that each signal can be multiplexed onto a single outgoing coax, which is connected to bespoke sensitive detection electronics in the EMMA plant room. Here VME (Virtual Machine Environment) based cards incorporating fast clocking, ADC and local memory storage digitise each pickup signal and store it locally, ready to be read-back and post processed after the circulating beam within EMMA has been extracted or dumped.

This system has required considerable design effort, and orders have been placed for the front end modules. Design work on the VME base cards is being completed at a local specialist company, whilst the daughter board electronics consisting of ADC boards and a clock generator to step the readings into memory is close to completion. All VME system crates and processor cards have been procured for this installation, and the system will be installed in two tranches, with the aim of the first set of 50 VME cards being installed by Autumn 2010.

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Commissioning and Modelling

As the commissioning date in Spring / Summer 2010 draws nearer intensive preparations are underway and as part of this two major planning workshops were held at Daresbury, hosted by the Cockcroft Institute and with attendance from university groups plus a number of overseas experts. The first was held in May 2009 and the second in December of the same year. These highly successful meetings updated progress since previous reviews and addressed outstanding scientific and technical issues. Subsequently, these workshops were extended to regular fortnightly commissioning meetings where the latest results, either from modelling or from experiment, are extensively discussed and the resulting course of action planned. The modelling has concentrated on trying to compensate for the ringing (undesired oscillatory remnant field) of the power supply for the kickers as well as the stray fields coming from both septa. All aspects of commissioning work involve an extensive collaboration, both local and international.

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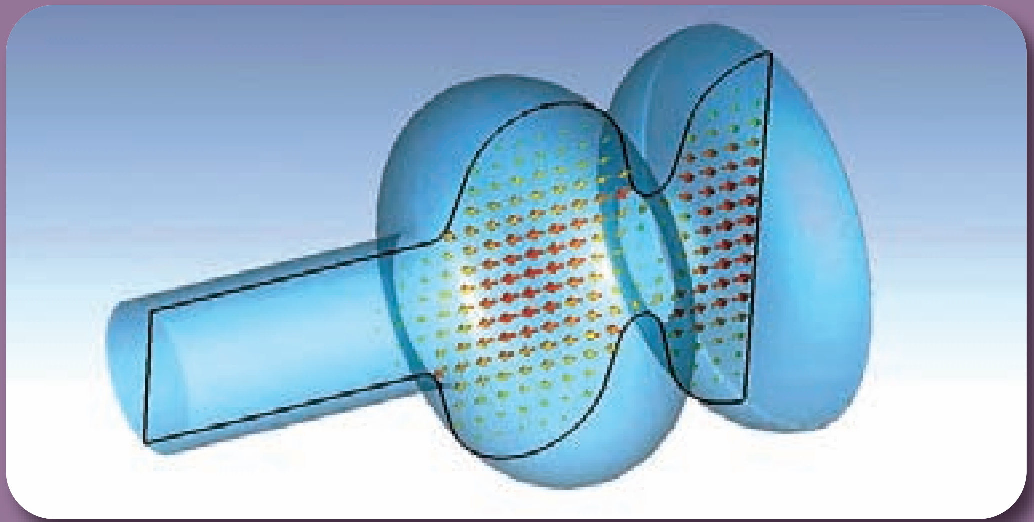
NLS Design Studies

ASTeC staff has completed the design of high repetition rate injector, beam transport system including beam dumps to deal with high repetition rate beam and a complete start-to-end design of the re-circulation linac.

Injector

The New Light Source (NLS) science case calls for a suite of FELs, with the electron bunches provided at repetition rates up to 1 MHz. However, the electron source in the baseline design will only operate up to 1 kHz.

An electron gun which can deliver low emittance bunches at a repetition rate up to 1 MHz is beyond the current state of the art. One of the main issues facing a high repetition rate electron gun is cavity cooling. ASTeC have been investigating two electron gun designs which have the potential to achieve the aims. The first is a normal conducting gun operating in the VHF regime. The relatively low frequency of 187 MHz (compared to the standard 1.3 GHz) means a large copper cavity can be employed. The large size means an overall low energy density on the cavity walls, allowing operation at high repetition rates. Such a cavity can only be operated at low electric fields, leading to a slice emittance double that of the baseline electron gun. The second option under investigation is a superconducting RF gun, operating at 1.3 GHz, as shown below. This is based on the similar technology to the accelerating cavities used in the main NLS linac and hence can operate at high repetition rates as the operational temperature is 2 K. Such a gun should be able to operate with high peak electric fields leading to a slice emittance comparable to that of the baseline electron source. Start to end simulations of NLS, included in the CDR, have been performed with this superconducting gun which show similar FEL performance to that of a low repetition rate baseline electron gun.



Re-circulation Linac Design

The high repetition rates demanded by the NLS science case have led to a decision that the facility be based on a superconducting linac. The capital and operational cost of superconducting infrastructure makes it prudent to consider recirculating the beam through a lower energy linac multiple times in order to reach full energy. Consequently, ASTeC staff members have undertaken a design study into a two-pass recirculating linac to determine whether beam quality is able to be preserved in such a scheme. The selected layout includes many novel design features and optimisation techniques. Simulations show that the recirculating linac will produce a beam of comparable quality to the baseline design.

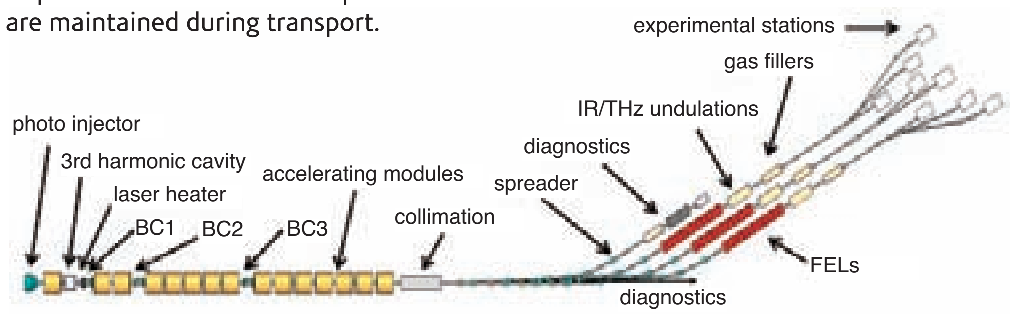
Beam Transport

The baseline design of straight-through linac and an alternative design of the re-circulation linac have been optimised to deliver high quality bunches to the FELs. The post linac beam transport includes collimation of beam halo to protect the undulators from demagnetisation, beam spreader to switch the bunches to three FEL and one diagnostics lines, straight on beam diagnostics to characterise the transverse as well as longitudinal bunch parameters and beam dumps at the end of each FEL line. These designs need to ensure that the slice bunch properties required for the seeded FEL operations are maintained during transport.

A 40 m long collimation section has been proposed to collimate the beam in transverse and the energy planes. To ensure that beam halo gets well collimated in the dedicated collimation sections, a simulated beam halo is tracked through the spreader and the undulator. These studies define the required collimator half gaps of 2.1 mm in both the transverse planes and 2.4 mm at the energy collimator to completely stop beam halo at the collimators. These gaps may be required to further reduce if the sextupoles in the spreader are switched on.

The spreader design adapted from LBNL FEL design has been optimised to achieve first order momentum compaction to be zero in each arc of the spreader. The beam passes off-axis by approximately 53 mm in the quadrupole after the septum, which reduces the need for an additional kick from the septum. However, such an offset poses problems to achieve the gradient in given FODO length as well as any adverse effects from the quality of the magnetic field. An optics solution to replace this with a compact quadrupole has been proposed to overcome this problem.

Two diagnostics sections have been proposed to characterise bunches in 6D. A straight on diagnostics line uses the FODO of the spreader for initial commissioning and tuning of the machine. A dedicated tomography section with deflecting cavities located in the first branch of the



NLS facility layout showing post-linac collimation, beam spreader, and straight-on diagnostics.

NLS Design Studies

spreader will provide identical electron bunch profiles to that seen in the FEL lines and thus in principle reduces the need of having approximately 30 m extra diagnostics section in each FEL Line.

The future upgrade bunch repetition rate proposed for NLS is 1 MHz. With 200 pC bunch charge at 2.25 GeV this needs a beam dump to absorb a power of 450 kW. The requirements of such a beam dump need to be included in the facility design from the beginning. In order to avoid risks and problems associated with a beam dump based on water, a detailed analysis was undertaken to evaluate whether a solid dump similar to the X-FEL project can be used for NLS parameters.

The steady state and transient studies carried out using ANSYS indicate that careful choice of beam sweeping in a beam dump based on graphite core embedded in a copper shell and cooled by water keep the temperature rise as well as stress within the accepted limits.

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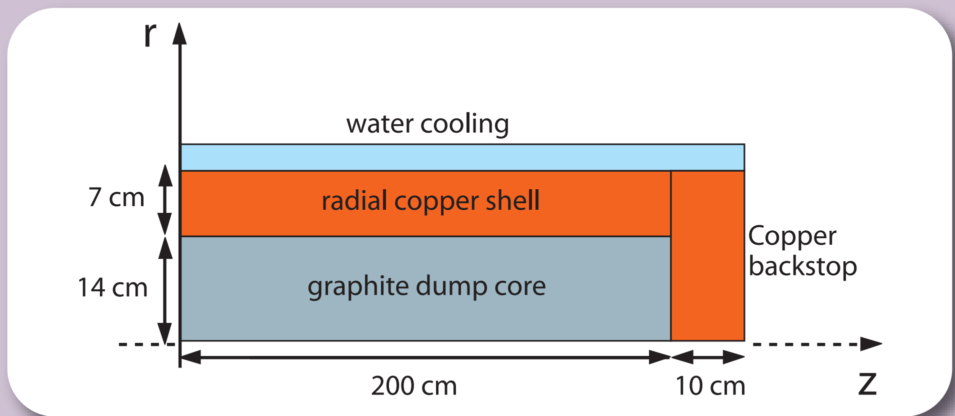
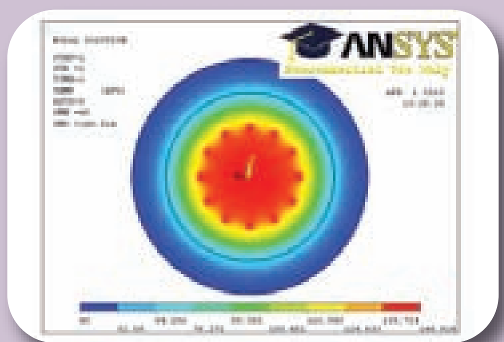
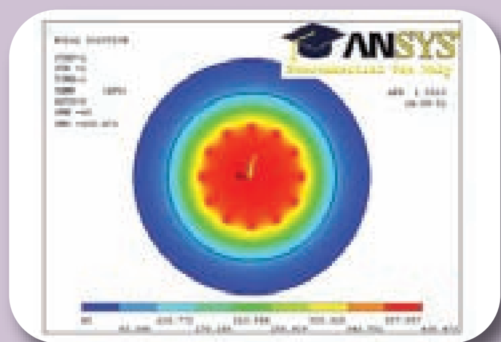


Schematic cylindrical layout of the proposed dump solution





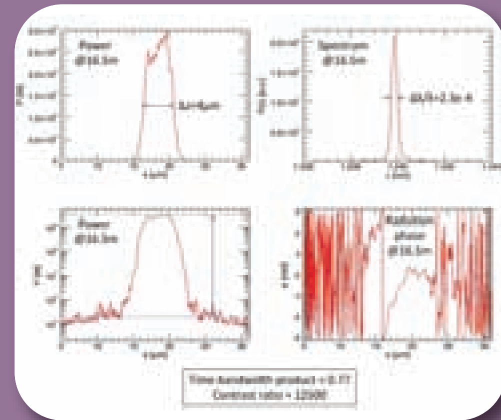
Left : Steady state calculation of the temperatures, achieved in the impacting surface of the 200 cm graphite/Cu beam dump using a beam sweep radius if 9 cm with 12 beam spots.
Right : Temperatures achieved in the section of the dump where the electromagnetic shower degenerated by the beam is at maximum intensity.

NLS FELs: Advanced Simulation Studies

Over the past year ASTeC physicists have worked closely with physicists from Diamond Light Source Ltd to validate the outline designs for the NLS Free Electron Lasers (FELs) using full three-dimensional simulations of the NLS electron bunch.

Such simulations are known as Start-to-End (S2E) Simulations because the entire life cycle of the electron bunch is modelled, from the bunch's creation in the photocathode gun, through its acceleration in the RF accelerating cavities, its temporal compression in the magnetic chicanes and finally its passage through the free electron laser undulators – here, due to the FEL interaction, it gives up some of its kinetic energy which is converted into the optical power in the FEL output pulse.

Different simulation packages are used for different stages of the process, and part of the skill is transferring data from one stage to the next without introducing numerical errors which would ruin the validity of the physical modelling. Such modelling is numerically intensive, so physicists within ASTeC took advantage of high performance parallel computing capability at Daresbury Laboratory and Diamond Light Source. Thus the modelling provided end results that give the best possible predictions of the output performance of the Free Electron Laser. A good example of these predicted outputs is those for NLS FEL-3. Once the S2E model was established it was used to see how any small errors in the system would affect the FEL performance. For example, tiny fluctuations in the timing of the radio frequency fields used to accelerate the electrons, or in the fields of the magnets in the beam transport system, can lead to successive electron bunches taking slightly different trajectories through the FEL undulator or arriving out of synchronization with the injected laser which is used to seed the FEL interaction. This would all cause fluctuations in the output of the FELs, potentially restricting their application in scientific experiments. Through this work it was established that for sufficiently stable FEL output, the tolerances on the accelerating system were extremely challenging, but not beyond state-of-the-art.



Results of Start-to-End simulations of NLS FEL-3, with output at 1.24 nm. Top left and bottom left show the temporal profile of the output pulse, top right shows the radiation spectrum, and bottom right shows the radiation phase.

The full results of this work, including predictions of the FEL output for the three different NLS FELs, were examined by the NLS International Advisory Committee and submitted for publication in the NLS Conceptual Design Report.

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NLS Magnet Design Study

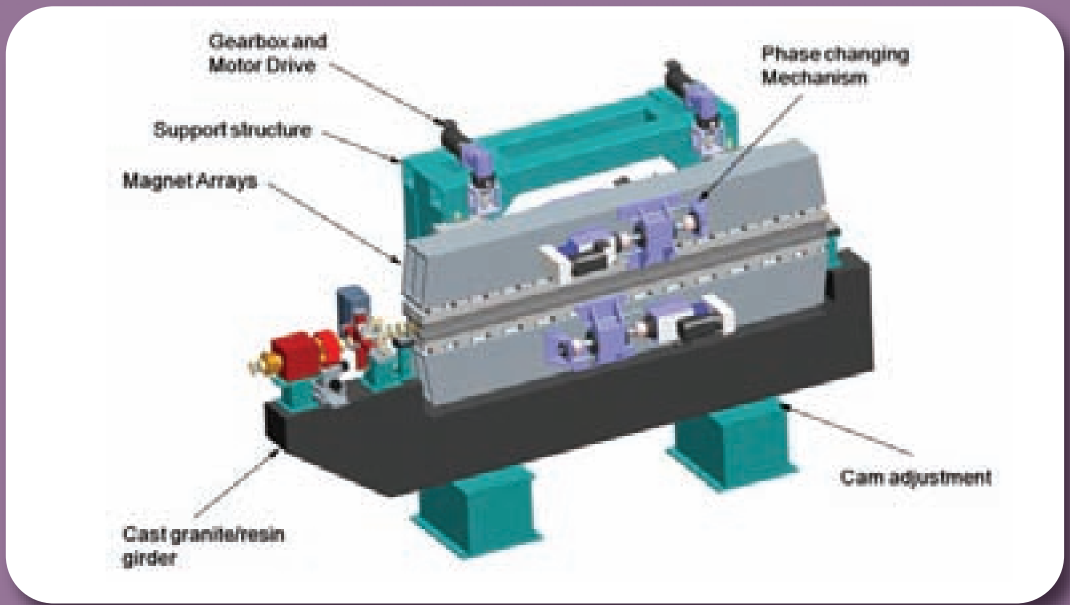
Undulator magnets are at the heart of the NLS FELs and it is essential that they perform to the required specification for the optimum performance of the facility.

There are a number of choices that have to be made regarding the undulators, such as the choice of magnet design, the minimum gap, the vacuum vessel geometry, and so on. In addition the undulator section will introduce wakefield effects on the electron bunches and these can interfere with the FEL process.

It is important that these effects are carefully simulated to ensure any detrimental effects are tolerable. Members of the MaRS group within ASTeC have been responsible for optimising the undulators for NLS whilst taking into consideration the potential wakefield issues.

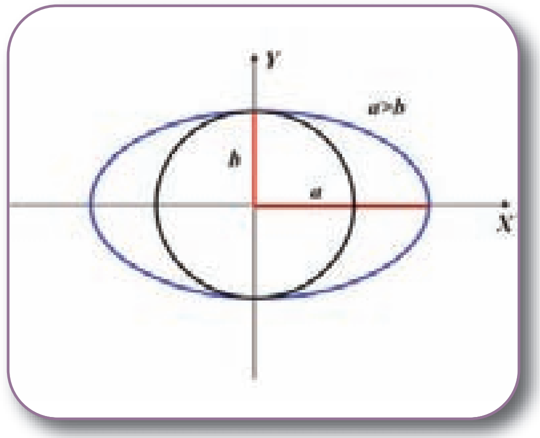
A key specification for the NLS photon output is that it has adjustable polarisation state. This means that the undulator has to generate horizontal and vertical fields which are independently adjustable in field amplitude and also in phase with respect to each other. There are a number of undulator designs which can generate such fields and so these have all been carefully compared this year to assess the advantages and disadvantages of each one.

Finally, a design was selected (so-called APPLE-2) which meets the requirements of NLS in the most effective way.



Mechanical design of an NLS undulator module mounted on a synthetic granite girder alongside a number of other key components (primarily additional magnets and diagnostics).

The design of efficient undulators and FELs requires beam transport through the narrowest possible beam pipes in order to maximize the available magnetic field strength. However, in the latter case resistive wall wakefields, caused by the close proximity of the metal vacuum vessel surface, could induce prohibitively large energy spreads which would prevent the FEL from operating correctly. This results in the existence of a fundamental lower limit for the beam pipe radius that can be implemented in such facilities. Apart from using a metal with the highest available conductivity the choice of an optimum pipe cross-section size and shape is essential to mitigate this undesirable effect.



Comparison between elliptical (semi-axes a and b) and circular (radius b) beam pipes

By changing the circular cross-section metallic beam pipe to an elliptical cross-section pipe, as shown below, then the resistive wall wakefield effect on the bunch of electrons travelling along the axis should decrease. This is because the walls of the elliptical cross-section pipe (semi-axes *a* and *b*) are further away from the bunch than the walls of the circular pipe of radius *b*. In addition it is anticipated that if *b* is fixed then increasing *a* beyond a certain limit will result in no further improvement. This suggests that pipes with sufficiently large aspect ratios *a/b* should have the smallest impact on the beam. The studies performed have shown that this is in fact not always the case and the effects depend critically on the length of the electron bunch, which is travelling through the vessel. For the NLS beam parameters there is no advantage between the elliptical vessel and the circular one. This surprising result is due to the NLS bunch length (FWHM of 45 μm) lying in exactly the region where the wakefield effect of the two different vessel cross sections are equal.

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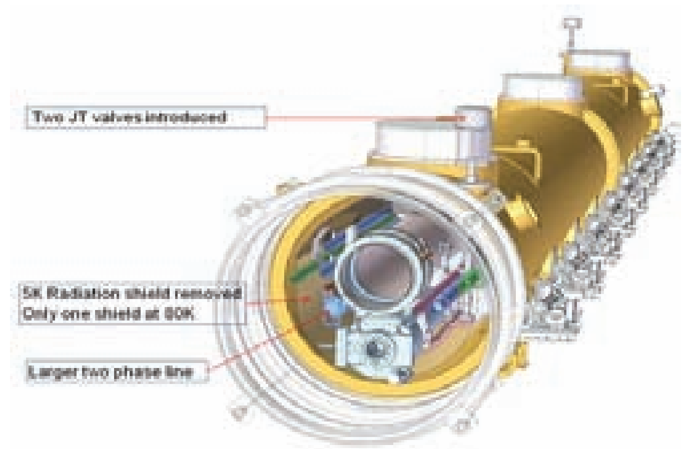
NLS: Superconducting Linac Design Study

The design requirement for the New Light Source (NLS) is based on a 2.25 GeV single pass superconducting RF (SRF) linac consisting of 144, 1.3 GHz cavities, operating at 1.8 K.

This design evaluation was undertaken by the ASTeC RF and Diagnostics group and the proposed solution from the study was based on the available technology, demonstrated performance, and reliability as well as the anticipated capital and operational expenditure.

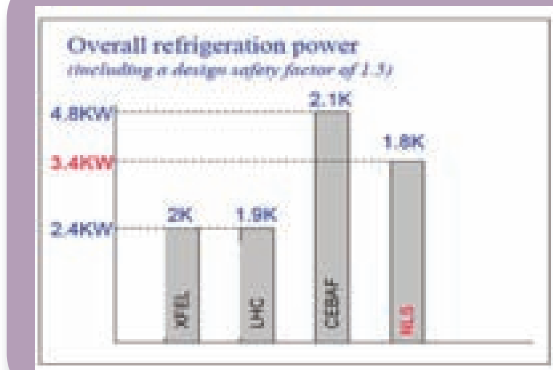
The initial phase of the design study highlighted the benefits of SRF over normal conducting RF cavities. The study showed that the lower RF power requirements for SRF cavities and the reduced level of trapped higher order modes (HOM) lead to improved beam stability providing the best means of meeting the technical and cost challenges posed by the NLS requirements. An evaluation of a number of operating frequencies was performed, whilst also considering the optimum accelerating gradient and operational cryogenic temperature. The process identified that a system incorporating 18 cryomodules; each operating at 1.3 GHz and providing an accelerating gradient of 15.5 MV/m at 1.8 K would meet the NLS performance requirements with good reliability whilst providing an acceptable level of redundancy.

For the cryogenic design, the cryomodule for XFEL was chosen as a baseline design. However, due to the CW mode of operation for NLS, the heat load experienced and the consequent helium mass flow rates to be handled by the cavities is about 10 times larger. This situation demanded major changes to the design of the cryomodule. ASTeC has undertaken a preliminary study to understand the key issues and to identify appropriate solutions and developed a cryomodule concept design to meet the requirements for NLS operation.



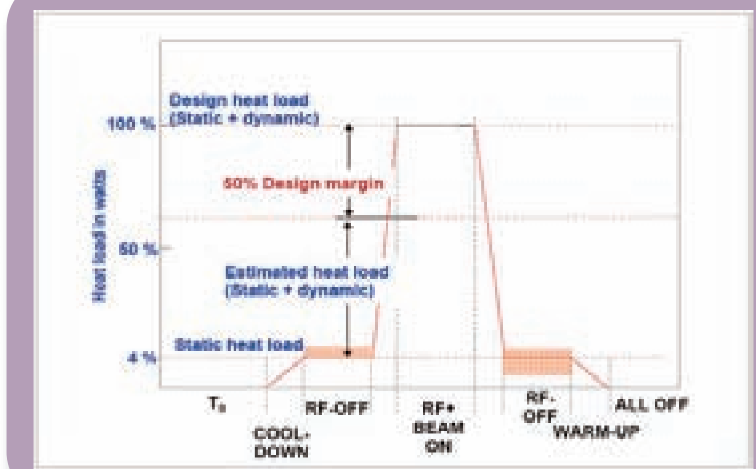
Concept design of the NLS cryomodule

The refrigeration power required by the NLS-linac would be one of the largest in the world. The most crucial feature of the refrigerator system would be the ability for it to respond to the large changes in the operational cryogenic load. ASTeC, in collaboration with industry, has developed a solution by utilising a combination of refrigerator cycles to meet this demanding requirement.



Comparison of NLS-refrigerator with some of the largest in the world

The RF system for the cavities was designed to provide the required CW power for the gradients required whilst maintaining the amplitude and phase stability to within 0.01% and <0.01°, respectively. To provide the best level of beam stability, the RF system architecture chosen for NLS was to have one amplifier system for each SRF cavity, thus allowing the low level RF (LLRF) control system to provide optimum control through individual control loops with feedback and feedforward. For the high power RF part of the system both inductive output tubes (IOTs) and solid state amplifiers were considered as suitable options to provide the required CW power levels of around 5 kW to the cavities. This would be distributed via waveguide incorporating motorised 3 stub tuners and power monitoring. A review of existing LLRF control systems identified a number of areas such as the signal to noise level on the weakly coupled cavity probes and microphonic stabilities which would need additional investigation before a design could be concluded.



Large changes in the heat load between the two operating modes

Overall the design study highlighted that critical R&D was required for a fully integrated cryomodule performance demonstrator and LLRF system development to meet NLS jitter study requirements.

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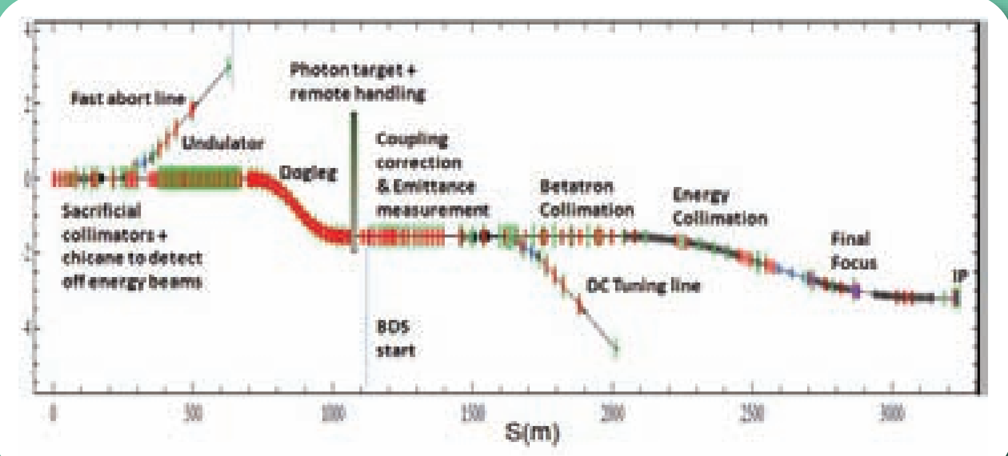
Linear Collider Design Study

ASTeC staff has contributed to the required lattice design changes for the proposed central integration for the International Linear Collider (ILC) as well as to the CLIC beam delivery system (BDS) and the ATF2 test facility at KEK.

International Linear Collider

One of the proposed options in the technical design phase of the ILC is to combine all the sources in the same central integration region.

This requires moving the undulator based positron source to the beginning of the beam delivery system. This configuration needs a dogleg on the electron side to provide a transverse offset of 1.5 m in about 400 m distance to accommodate the photon target, with a constraint to keep the emittance growth due to incoherent synchrotron radiation to a few percent level. ASTeC staff has proposed a dogleg design based on Theoretical Minimal Emittance lattice which satisfied these constraints with an emittance growth of less than 4% at 1 TeV centre of mass.



Layout of electron side beam delivery system including the undulator based positron source in the beginning of the BDS.

CLIC

The review of the CLIC BDS done by ASTeC staff at the CLIC 09 workshop indicated the required major changes in the CLIC BDS layouts designed for two different layouts at 500 GeV and 3 TeV centre of mass. This has been addressed by the CLIC team at CERN with modifications to the 500 GeV layout to accommodate it in the same tunnel. ASTeC staff has proposed better collimation optics solutions for CLIC which should improve collimation efficiency of CLIC BDS.

The CLIC collimators are designed to protect the accelerator components from a mis-steered beam and they have to be able to resist a full bunch train hit.

Additionally in any design the wakefields generated by the collimators need to be minimised as these would otherwise degrade the luminosity of the machine. These are the two main constraints in the collimator design. Thus beam optics calculations have been used to set the taper angle geometry needed to reduce wakefields to acceptable levels and a thermo-mechanical study being performed at ASTeC will summarise the feasibility of the different geometries and materials, leading to a final design.

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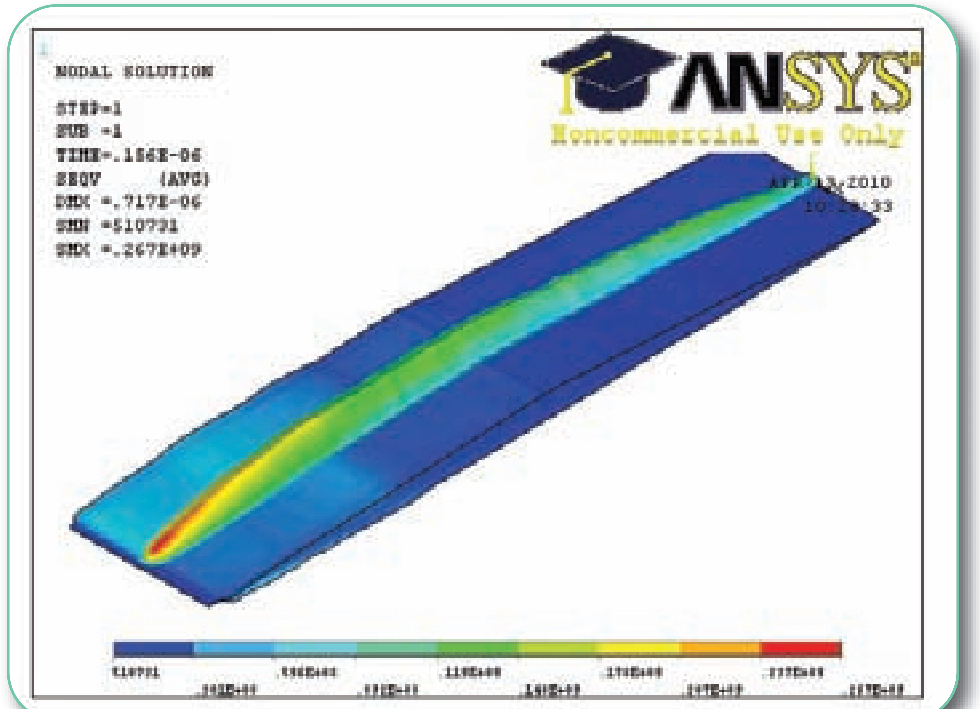

ANSYS simulations showing stress estimates in CLIC collimator

Muon Ionisation Cooling Experiment (MICE)

As part of the Muon Ionisation Cooling Experiment (MICE) at the Rutherford Appleton Laboratory it is planned to use normal conducting copper cavities to re-accelerate a muon beam after it has been retarded by liquid hydrogen absorbers.

These cavities operate at 200 MHz and require 1 MW of RF power in a 1 ms pulse at a repetition rate of 1 Hz. In order to provide this power, an RF system incorporating a Thales TH116 triode, driven by a Burle 4616 tetrode has been designed. Each amplifier chain can provide approximately 2.5 MW and this power is then split between 2 cavities.

In the past year the first high power RF amplifier for the MICE experiment has been successfully refurbished and the commissioning process has now begun. Electrical testing of individual systems is being performed to ensure everything is fully functioning before switching on the complete system. All the ancillary systems including cooling water/air, filament and controls have been tested to the required design specifications and the RF circuit is undergoing tests to ensure it can hold off the 40 kV that will be applied to the cathode during operation. The RF amplifier has been fitted with the high power triode valve, and the system connected up using 6 inch coax to a high power test load. The pre-driver amplifier has already been re-tested in readiness for operation and will allow the amplifier system to reach the level of 1 MW with the triode installed. Additionally, new triode and tetrode tubes have been delivered, and these will replace the original old tubes allowing future testing to achieve the full power requirement of 2 MW at 201 MHz.

Further commissioning of the system is planned for the Autumn.

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SRF Cavity Fabrication with Industry

A collaboration project has been set up with Shakespeare Engineering to develop the capability of UK industry to produce superconducting RF (SRF) cavities.

The aim of the project is to produce and test a 1.3 GHz single cell SRF cavity.

However, the overall objective of the project is to transfer the knowledge of the skills and processes required to manufacture a SRF cavity. As such Shakespeare Engineering is responsible for the manufacturing of the cavity, whilst both parties are responsible for the processing and validation of the fabricated cavity.

The long term goal is to develop UK industry, so that it has the opportunity to bid for the construction of SRF systems in future particle accelerators. This first stage will be to provide a technology demonstrator and the plan for the future is to continue the collaboration to produce a 7-cell cavity. Technical assistance and support is being provided by Jefferson Laboratory, who will also be doing the welding of the first cavity.

The project is well under way with the design and the drawings for the cavity having been completed. Shakespeare Engineering has manufactured the pressing tools and has successfully performed a trial press using copper to produce the first cavity cups. The next stage is the pressing of the cavity cups from niobium sheets, which is about to be undertaken shortly. Additionally preparations are underway to develop the outer hall in readiness for testing the RF cavity in October 2010.

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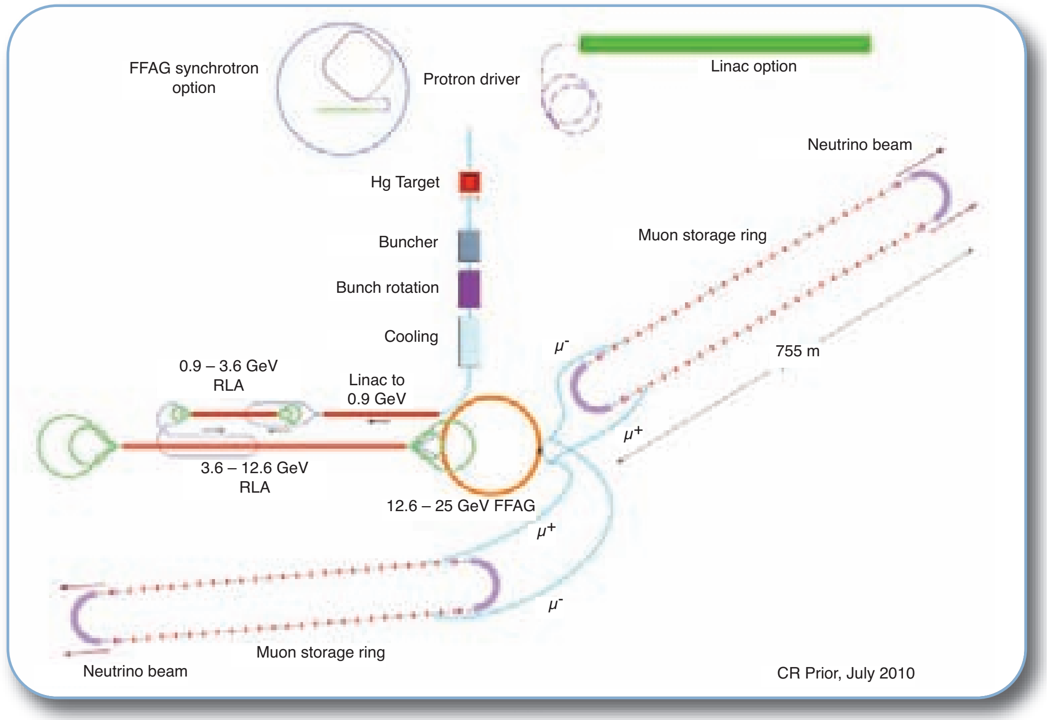
Neutrino Factory Studies

The neutrino is, perhaps, the most mysterious of the particles that make up the Standard Model of Particle Physics.

The American writer John Updike sums them up nicely in his poem* Cosmic Gall.
**From Telephone Poles and Other Poems by John Updike, ©Knopf 1963*:

“Neutrinos they are very small.
They have no charge and have no mass
And do not interact at all.
The earth is just a silly ball
To them, through which they simply pass,
Like dustmaids down a drafty hall
Or photons through a sheet of glass.
They snub the most exquisite gas,
Ignore the most substantial wall,
Cold-shoulder steel and sounding brass,
Insult the stallion in his stall,
And, scorning barriers of class,
Infiltrate you and me! Like tall
And painless guillotines, they fall
Down through our heads into the grass.
At night, they enter at Nepal
And pierce the lover and his lass
From underneath the bed – you call
It wonderful; I call it crass.”



The problem is that Updike got it wrong and neutrinos do have mass. It has been known for some time that neutrinos carry spin ½ and occur in three flavours: νe, $\nu\mu$, and $\nu\tau$. However, recently it was discovered that neutrinos produced in a particular state of flavour (say $\nu\mu$) may evolve (oscillate) into a different state (say $\nu\tau$). This can only be explained if the Standard Model is extended to include neutrino mass and mixing between the flavour states. It also opens up the possibility that neutrinos violate the matter-antimatter symmetry, and suggests that neutrinos may even be responsible for the matter-dominated Universe. How can we investigate this? The answer is the Neutrino Factory, in which intense, high-energy neutrino beams are produced from the decay of stored muon beams and transmitted through the Earth to detectors thousands of kilometres away.

An idea of how this might be done is illustrated. A high intensity driver directs a multi-megawatt proton beam onto a pion production target. Charged pions are captured in a focusing channel at low energy and quickly decay to muons, whose phase space is controlled and reduced in size by ionisation cooling. The resulting muon beam is then accelerated rapidly to an energy of 25 GeV. Finally the muons are stored in designated storage rings with long straight sections, where the neutrinos produced by their decay can be directed towards the detector sites.

Neutrino Factory Studies

The UK has been involved in Neutrino Factory accelerator studies from the outset, initially through work on the proton accelerator that drives the complex, and then developing into ideas for muon capture and acceleration schemes. Members of ASTeC's Intense Beams Group form the core team for the UK Neutrino Factory R&D activity and work in collaboration mainly with the group at Imperial College London. In the UK scenario, the proton driver might be a development of the ISIS accelerators at RAL, or a green-field accelerator designed for the Neutrino Factory and other high power applications. The production target represents a formidable engineering challenge. The preferred design utilises a liquid mercury jet; however this carries a high level of technical risk, so work in the UK has concentrated on a moving solid target or a powder-jet made up of tiny tungsten balls.

A prototype powder-jet target has recently been built and operated at RAL.

Since the initial muon distribution is very diffuse, a special section, known as the front-end, captures and controls the particles through a process of phase rotation, RF manipulation and ionisation cooling. The MICE experiment on ISIS is a proof-of-principle test of the cooling concept. The resulting muon beam is then accelerated in a solenoid linac to 0.9 GeV after which its phase space has been reduced adiabatically to the point at which it can be accelerated in two dogbone re-circulators, with 3½ passes in each, producing up to 12.6 GeV. Final muon acceleration to 25 GeV will be achieved in a non-scaling FFAG, for which EMMA serves as a test machine and will tell us a lot about FFAG beam dynamics.

Intense bursts of neutrinos and anti-neutrinos are generated by the muon beams decaying in the long straight sections of dedicated storage rings according to

$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu \qquad \mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

Two racetrack structures pointing into the Earth at angles of 18° and 36° direct the neutrino beams to detectors at distances of about 3000 km and 7500 km respectively. Such rings would penetrate to a depth of about 450 m, represent a fantastic engineering challenge and impose major geological demands on any site proposed.

Looking ahead, the proton driver, target station, and muon front end of the Neutrino Factory have been proposed as part of the accelerator facility required to deliver multi-TeV lepton-antilepton collisions at the Muon Collider.
The Neutrino Factory may therefore be seen as a step on the way to a Muon Collider, conceivably the next big particle accelerator project after the LHC.

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CLIC Drive Beam Quadrupoles

ASTeC and CERN are collaborating on a project to design quadrupole magnets for the Compact Linear Collider (CLIC) Drive Beam Decelerator.

A total of more than 40,000 quadrupoles are required in two 21 km decelerator lines, each of which transports a drive beam from 2.4 GeV to 0.24 GeV.

The magnets are demanding in terms of field strength and quality, but the real challenge comes from the space and heat load constraints in the CLIC tunnel. The CERN group are looking at a conventional electromagnetic design, while ASTeC's MaRS group are investigating alternative options – including a novel moving permanent magnet design which promises to be higher in field strength and also with virtually zero power consumption.

In line with this, ASTeC is working with Technology Department to create from the start a cost-effective design that will be suitable for mass production. A design study will be ready for the CLIC CDR in late 2010. Prototypes of the quadrupoles will be built in 2010/11 for use on the accelerator test facility, CTF3.

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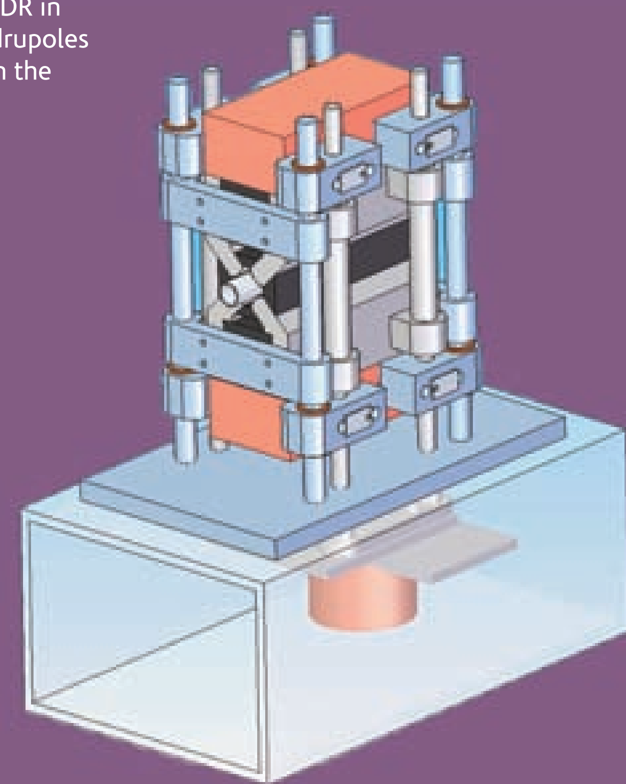


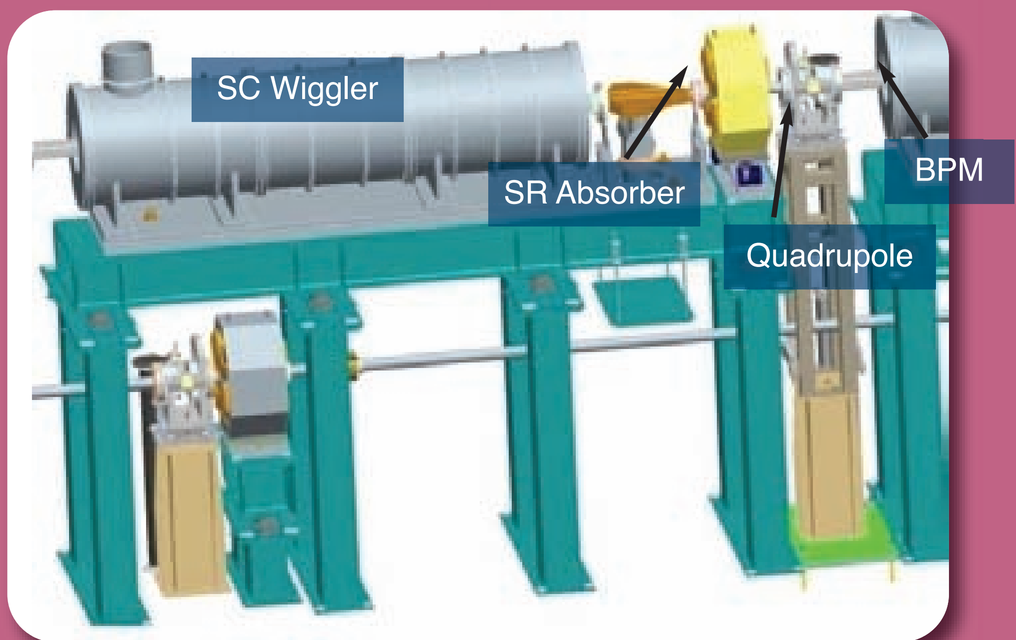
Vacuum Design of ILC Damping Rings

A collaboration team including staff from STFC (ASTeC and ETC), and Cockcroft Institute Universities have been working on the ILC Damping Ring (DR) design for a number of years. This year the mechanical and vacuum design of the ILC DR has been finalised.

Mechanical and Vacuum Wiggler Section Design

The design of the vacuum vessel for the wiggler sections of the ILC damping rings should meet a number of challenging specifications. The photon induced gas desorption is the main source of residual gas in both rings.

The electron ring vacuum specifications are driven by the ion induced beam instability. In the positron damping ring the vacuum vessel design should include the means of electron cloud mitigation and provide sufficient pumping to avoid ion induced pressure instability. One of the most challenging parts of the damping rings was a design of wiggler section. A long wiggler section is required in each ILC damping ring to provide short radiation damping times. Synchrotron Radiation (SR) power of about 40 kW is generated in each wiggler. The expanding fan of SR reaches the beam vacuum chamber walls in the following wiggler and may cause the following problems: large power dissipation on vacuum chamber walls inside the cryogenic vessel; radiation damage of superconducting coils; high photo-electron production rate causing electron cloud to build up to an unacceptable level. Therefore, the power should be absorbed in places where these effects are tolerable or manageable. The design proposed provides a possible solution for tackling all SR related problems as well as the vacuum design.

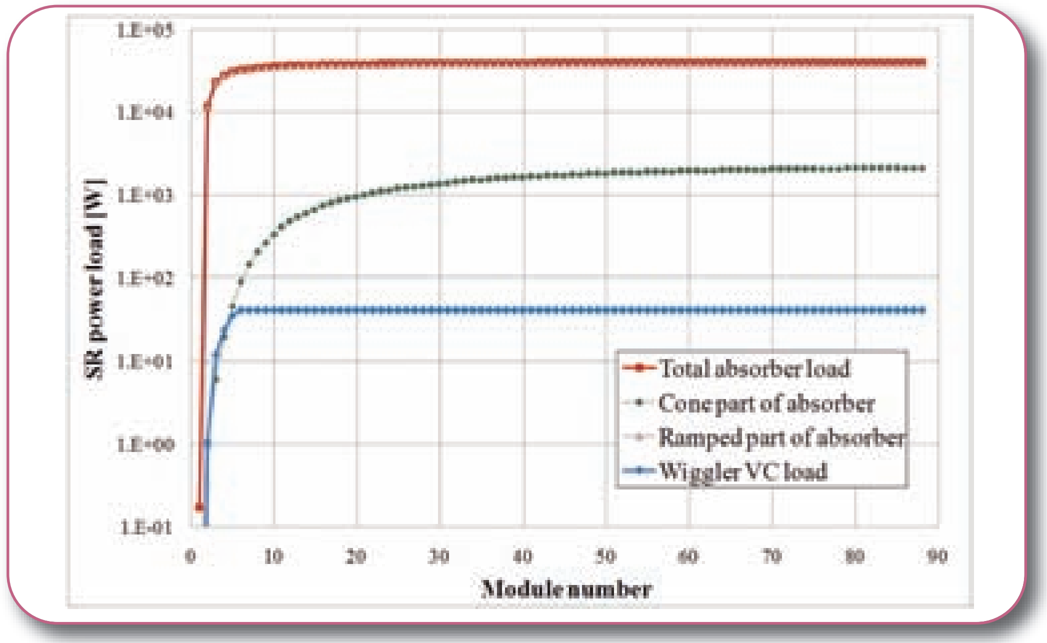


Wiggler module in the positron damping ring.

Synchrotron Radiation Power Distribution.

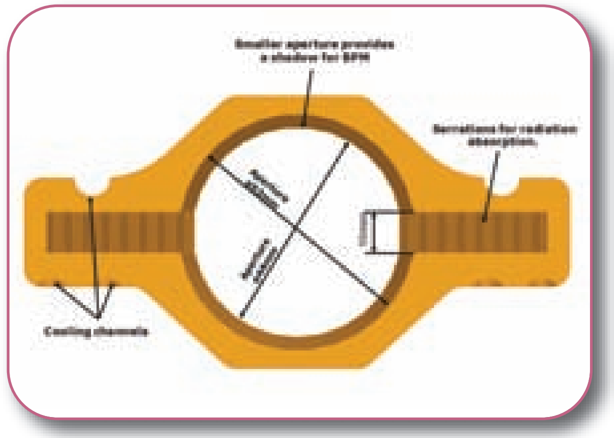
SR generated by the beam in the wigglers must be absorbed by different components of the vacuum vessel, including specially designed absorbers. The optimisation of the mechanical design, vacuum system and electron cloud mitigation requires accurate calculation of the SR power distribution. The angular power distribution from a single wiggler was calculated with software developed at BINP (Novosibirsk, Russia), using the latest lattice design. Then the superposition of SR from all wigglers allows calculation of the power distribution for all components along the wiggler section and the downstream straight section.

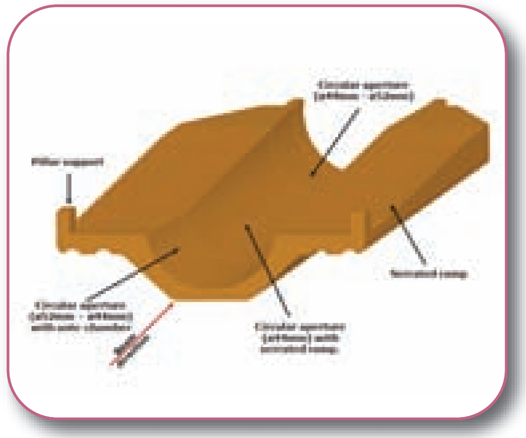
The power dissipation model for the ILC DR wiggler section was generated and the results from the model were applied to the mechanical design. Ideally, there must be no significant SR power dissipation inside the beam vacuum chamber of the wiggler, i.e. most of the SR power must be absorbed with a specially designed SR absorber. A few iterations of mechanical design and calculations of the corresponding of SR power dissipation were performed until the results given showed that the wiggler, quadrupole and BPM vacuum chamber could be efficiently screened with an SR power absorber. The absorber design needs to be capable of absorbing up to 40.3 kW of SR power. SR flux with a power of 256 kW following the wiggler section axis should be absorbed with a special high power absorber near the first arc dipole.



Power dissipation wiggler vacuum chamber and SR power absorbers along the wiggler section.

Vacuum Design of ILC Damping Rings





SR power absorber

Electron Cloud

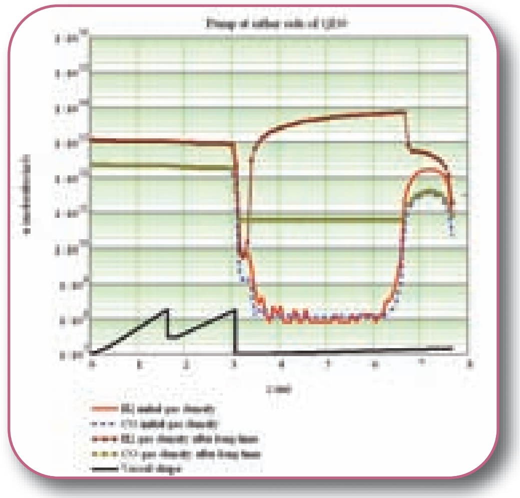
Electron cloud is a problem limiting the performance of the positron damping ring. The ASTeC vacuum group as part of the ECLOUD collaboration provided experimental input for e-cloud modelling, calculated the impact of electron multipacting and reviewed e-cloud mitigation techniques on vacuum system performance and mechanical design. This is a multi-iteration process that includes numerous meetings, discussions, drawing modifications and vacuum calculations.

Ion Induced Pressure Instability

Ion induced pressure instability is a potential problem for the ILC positron damping ring (DR) if the chosen pumping scheme does not provide sufficient pumping. The ion induced pressure instability effect results from ionisation of residual gas molecules by the beam particles, which are then accelerated in the field of the beam towards the vacuum chamber walls, causing ion induced gas desorption from vacuum chamber walls. In turn these gas molecules can also be ionised, accelerated and cause further gas desorption. If the pumping is insufficient, this effect may cause a pressure instability, in which the pressure in the beam chamber grows rapidly to an unacceptable level.

To analyse the ion induced pressure instability in the ILC positron DR the energy gained by ions was calculated for the appropriate beam parameters and it was found that the energy gain of ions will be about 300 eV. The ion induced gas desorption was estimated, and pumping solutions to avoid the ion induced pressure instability are suggested. The cheapest and most efficient solution is to use a NEG coated vacuum chamber.

The analysis of vacuum stability against ion induced desorption in the ILC positron DR was performed. It is found that gas species ionized by the beam can be accelerated in the field of the beam to impact the vacuum chamber walls with energies of about 300 eV. Due to the lack of experimental data, the gas desorption yields were estimated from experiments with higher ion energy. These results were used to model the pressure instability in the ILC positron DR and it was discovered that the ion induced pressure instability is a potential threat to the positron DR if the pumping speed is insufficient. An analysis of the possible solutions to avoid the ion induced pressure instability showed the most cost efficient method was to incorporate a TiZrV NEG coating. In this case, a distance of 40 m between UHV pumps with an effective pumping speed of 20 l/s is found to be adequate.



The gas density evolution along IR

Vacuum Studies for BDS and IP

The design of detectors for the ILC does not allow much space for pumping arrangements close to the Interaction Region (IR). ASTeC Vacuum Science group participated in the IR vacuum design, discussing and modelling different options. A Molflow program based on the Test Particle Monte Carlo method was used for the modelling, so as to define the evolution of gas density along the IR.

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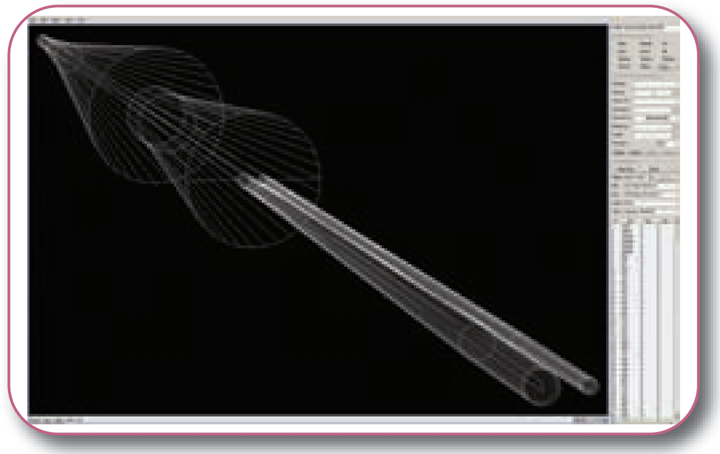

An example of an IR model in a Molflow program based on the Test Particle monte carlo method

Vacuum Science Laboratory – Surface Analysis Facility

Throughout the past year the surface analysis facility has been instrumental in the developments of NEG coatings and photocathode research.

The XPS technique has been used to demonstrate the activation of NEG coatings at 150°C – 160°C which is some 20°C – 30°C lower than the previous best result around the world.

The technique is used to detect small shifts in Binding Energy which determine the surface changes that are occurring during activation.

The system has also made significant contributions in the understanding of GaAs physics. Greater understanding of surface behaviour during surface preparation has been achieved and these results have been transferred and used on ALICE. Vacuum lifetime studies of the GaAs photocathode have produced some interesting results which have a real impact on future photoinjector vacuum design and results will be published next year.

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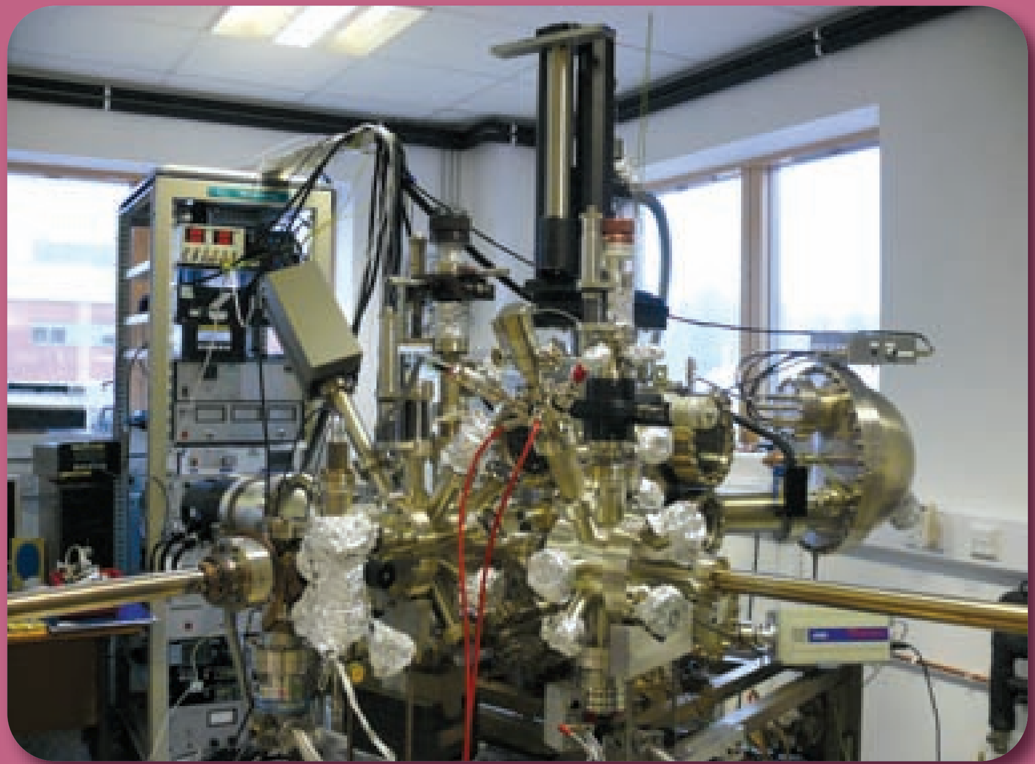

An example of an IR model in a Molflow program based on the Test Particle Monte Carlo method

Digital Low Level RF Developments

Low level radio frequency (LLRF) systems are responsible for stabilising the amplitude and phase of radio frequency fields within accelerating cavities.

This is a key task in modern accelerators where RF stability has a crucial impact on beam energy jitter and hence the quality of synchrotron light or the luminosity of collisions.

Engineers and scientists within the ASTeC Radio Frequency and Diagnostics group have been designing state of the art LLRF systems using digital techniques. These techniques involve the use of field programmable gate arrays (FPGAs) to create software reconfigurable control systems.

Systems based upon digital technology have the advantage of being capable of being rapidly reprogrammed, allowing a user to quickly tailor the LLRF system to the beam conditions. Adaptive and predictive algorithms can be used to anticipate exactly when to increase the RF power or to adjust the RF phase to overcome difficult beam loading conditions within a cavity.

In the short term, these new systems will enable the ALICE team to achieve a more stable beam, particularly where adaptive feed forward algorithms can help in the presence of high beam loading, and it is planned to test the system on ALICE in the Summer of 2010. Beyond ALICE, these systems can be reconfigured for use on many other accelerators, and promise to deliver more and more stable beam conditions as the technology matures.

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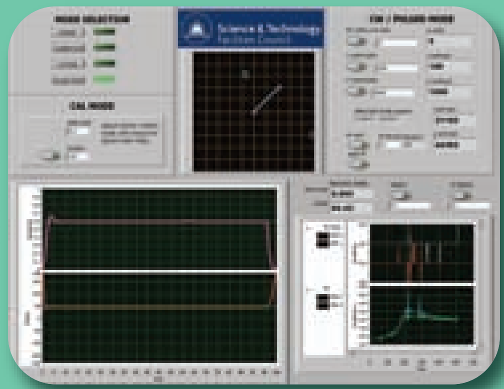
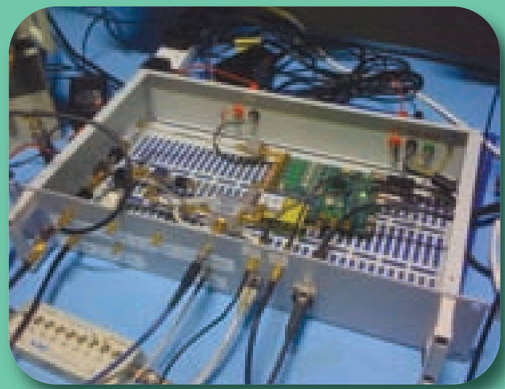


LLRF GUI



LLRF hardware

Conferences, Workshops, Meetings and Visits

Numerous conferences and workshops have been attended by ASTeC staff throughout the year. In addition ASTeC has undertaken the organisation of a number of workshops and the successful running of the FEL'09 conference.

EMMA Commissioning Workshops

EMMA (Electron Model for Many Applications) will be the first demonstration of a revolutionary new type of particle accelerator, the world's first non-scaling FFAG.

This exciting proof of principle trial, now under construction at Daresbury Laboratory, is an important step towards possible future applications in neutrino research, hadron therapy or even energy generation from sub-critical reactors. The project is part of a larger project called CONFORM (COnstruction of a Nonscaling FFAG for Oncology, Research, and Medicine) run by the BASROC association and is funded by a Basic Technology grant with additional funding provided by ASTeC. EMMA relies on the ALICE facility for its injected electron beams.

Intensive preparations are being undertaken to meet the planned Spring 2010 commissioning date and as part of this there were two major planning workshops held at Daresbury, hosted by the Cockcroft Institute and with attendance from universities plus a number of overseas experts. A wide range of topics were discussed from beam dynamics, magnets and their power supplies, RF and timing, beam diagnostics and commissioning of the machine. Both meetings were highly successful showing great progress since the previous reviews. Additionally the meetings allowed the outstanding scientific and technical issues to be discussed and addressed. Everyone now looks forward to the difficult challenges ahead.

Emma Commissioning Workshop attendees 2009

The Royal Society Summer Science Exhibition

ASTeC and the Cockcroft Institute were involved in collaboration with the John Adams Institute and CERN in the presentation of an exhibit at the highly prestigious Royal Society Summer Science Exhibition.

The exhibit concentrated on the LHC (The Large Hadron Collider, CERN, Switzerland) and ALICE (Accelerators and Lasers in Combined Experiments) accelerators, but also included EMMA (Electron Model of Many Applications), PAMELA (Particle Accelerator for Medical Applications) and the Diamond Light Source. The group's intention was to demonstrate the range of applications for particle accelerator technology from fundamental particle physics, through light sources to medical imaging and cancer therapy. This aspiration was reflected in the exhibit's title: Accelerators everywhere: from the big bang to curing cancer.

The exhibition took place at the Royal Society in London from June 30th until July 4th, 2009. During this period, nearly 5,000 members of the public visited the exhibition to experience the cutting-edge of UK science, and to meet the scientists responsible for these achievements. The group's exhibit was eye-catching, exciting, interactive and tactile, and featured as the backdrop for a news article on the Summer Science Exhibition by the BBC on their website.

Visitors were able to experience a virtual reality 3D fly-through of the ALICE and EMMA accelerators, or to control a virtual LHC to try and find the Higgs boson. A real pair of magnets from the EMMA accelerator featured prominently at the front of the exhibit, prompting many questions about particle accelerators and their applications. This served as the ideal basis to explain how accelerator technology can be applied to advanced medical imaging, and for proton or ion therapy in the treatment of certain in-operable cancers. The exhibit was even visited by medical professionals, curious to learn more about the potential application of particle accelerators in their field and overall the event was a huge success.

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Conferences, Workshops, Meetings and Visits

FEL 09

In August 2009 ASTeC hosted the 31st International Free Electron Laser Conference (FEL 09) at the new Liverpool Arena and Convention Centre, with over 250 scientists from around the world visiting to discuss new developments in the field of free electron lasers (FELs).

31st International Free Electron Laser Conference (FEL 09) – 2009

The programme was organised into a number of sessions ranging from FEL technology, to new and emerging concepts, to the use of FEL radiation in experiments, with interesting talks and productive poster sessions. ASTeC staff made a substantial contribution, with the UK's proposal for a New Light Source being centred on cutting-edge free electron laser designs. The undoubted highlight of the scientific programme were results from the Linac Coherent Light Source (LCLS) facility in Stanford, USA, which had demonstrated the world's first delivery of hard x-rays from a free electron laser earlier in the year and the programme featured a number of talks on this hugely impressive feat.

The Conference Reception was held in the grand setting of Liverpool's Anglican Cathedral. Refreshments were served and the delegates were treated to an organ recital. The Conference Banquet was held in the equally impressive venue of St George's Hall, where the delegates were welcomed to the Banquet with a short set from the Mersey Beatles, performing several of the Fab Four's hits resplendent in Sergeant Pepper outfits! Dinner was served and speeches followed, with scientists from the LCLS being recognised with prizes for their achievements. Mike Poole presented a special certificate to the LCLS team to commemorate its success. The Mersey Beatles returned to play a longer set, and there was the first ever occurrence of delegates dancing at an FEL conference as the community celebrated the successful culmination of decades of work!

The conference programme featured a visit to Daresbury Laboratory, with a tour around the prototype next generation accelerator-based light source ALICE, featuring its own free electron laser. Many ASTeC staff, plus others from the laboratory, were on hand to discuss the development of these advanced machines. Interesting presentations were given on other projects at the Laboratory, including EMMA and SuperStem.

Members of ASTeC took on the key roles in the organisation and running of the conference. Mike Poole and Jim Clarke co-chaired the conference while Neil Thompson was chair of the local organising committee and Sue Waller was conference secretary. They were joined on the local organising committee by Stuart Eyres and David Dunning, and many other ASTeC staff made important contributions to the successful delivery of the conference.

As the conference closed the community looked ahead to building on its considerable achievements, and to Malmo, Sweden where the next conference will be held in August 2010.

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Conferences, Workshops, Meetings and Visits

Particle Physics Master Class

Daresbury Laboratory held its annual Particle Physics Masterclass on the 15-16th March 2010. Around 80 A-level students visited the Laboratory to take part, and to learn about particle accelerators and their application as a research tool in a host of scientific disciplines.

Similar activities are run by universities, but the Daresbury event has the distinct advantage of directly showcasing the ALICE (Accelerators and Lasers in Combined Experiments) and EMMA (Electron Model of Many Applications) machines as part of the students' experience.

They were given talks, practical demonstrations and various challenges relating to particle accelerators, with the focus on the ALICE accelerator (an R&D prototype for the next generation of accelerator-based light sources). Students experienced a 3D virtual reality fly-through of this unique machine before

taking a short tour of the facility prior to carrying out a hands-on experiment to measure the electron beam energy in the ALICE accelerator.

This activity was delivered by ASTeC in collaboration with university colleagues through the Cockcroft Institute. The interest level of the students involved was high throughout the day, and feedback from teachers was good. It is planned to expand this event further next year, and to formally shift the focus to make this an accelerator physics Masterclass, the only such event in the UK.

For further information contact:
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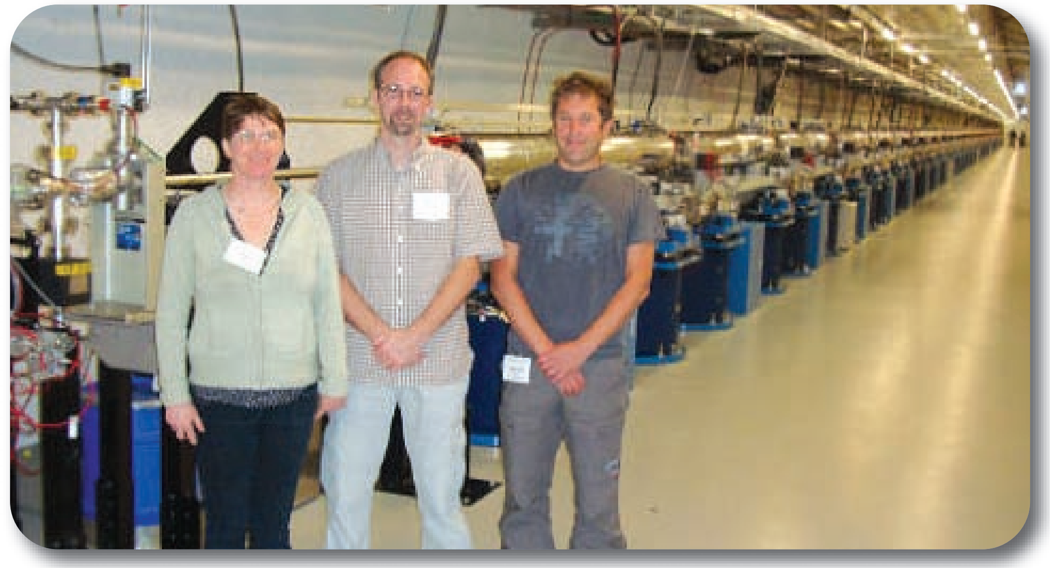

Susan, Peter and Andy visiting the LCLS Undulator Hall.

48th ICFA Advanced Beam Dynamics Workshop on Future Light Sources.

In March 2010, Peter McIntosh, Andy Moss and Susan Smith from ASTeC attended the 48th ICFA Advanced Beam Dynamics Workshop on Future Light Sources at SLAC National Accelerator Laboratory, California.

The workshop series, on future light sources, reviews and discusses modern accelerator-based light sources for wavelengths ranging from the infrared to x-rays. Working groups were dedicated to critical issues of ERL, FEL, storage ring and novel light source concepts, as well as to essential technologies like linacs, undulators, synchronization, electron sources, beam diagnostics and numerical simulations.

ASTeC presented an update of the advances in accelerator science taking place in the UK at the ALICE R&D facility, including the latest commissioning results from the UK's first FEL. In a combined ERL/FEL session, new results from simulations done at Daresbury of a seeded FEL driven by the recirculation option for NLS were used to make a unique comparison between the challenging recirculation design and the more straight forward but costly single pass FEL design. The encouraging recirculation results fuelled a lively debate on the merits of the two options. Additionally Alan Gillespie from Dundee University presented state of the art R&D from a collaborative project with ASTeC which is pushing the forefront of electro-optic beam diagnostic techniques, critical to the operation of future short pulsed light source.

Further information can be found at:
http://www-conf.slac.stanford.edu/icfa2010/

Conferences, Workshops, Meetings and Visits

1st Vacuum Symposium UK and RGA9 Meeting

ASTeC hosted the first Vacuum Symposium UK, which was held in the Cockcroft Institute Building at Daresbury Laboratory on the 10th and 11th February 2010.

The meeting was jointly organised by the RGA User Group, Institute of Physics Vacuum Group and British Vacuum Council with a local organising committee chaired by the ASTeC Vacuum Science Group Leader, Joe Herbert.

The meeting was a great success bringing together more than 150 representatives from the vacuum community including academia, industry, national laboratories and representatives of equipment suppliers/manufacturers. A number of delegates had travelled overseas to attend the meeting and commented on the meeting's success. The programme included an equipment exhibition (26 hi-tech companies), technical programme (18 oral presentations), facility visits (on the campus) and a training school for students and new users of vacuum (approx 50 received training through two different courses).

The technical programme was divided over the two days into two sections. On day one the RGA User Group organised a programme (RGA9) dedicated to those interested in Residual Gas Analysers and their applications. The programme began with an invited talk delivered by Dr Janez Setina (Institute of Metals and Technology, Ljubljana, Slovenia) describing recent advances in the techniques and requirements for the calibration of quadrupole mass spectrometer instruments. A talk by Dr Steve Taylor (University of Liverpool) on the advances in using Ion Traps for RGA was met with considerable interest as this new technology promises to deliver a new range of advanced instruments. The second day of the programme was organised by the Vacuum Group of the Institute of Physics to cover a broader range of topics. The programme began with an invited talk delivered by Prof. Manfred Leisch (Institute of Solid State Physics, Graz University of Technology, Austria) reviewing advances in the understanding of Hydrogen Outgassing from stainless steel. A further highlight was a talk by Dr Oleg Malyshev (ASTeC) reviewing the use of non-evaporable getter coatings for vacuum systems including some significant advancements made in the ASTeC vacuum science laboratory.

Following the success of the 1st Vacuum Symposium UK a second meeting is being organised to take place on the Harwel Science and Innovation Campus in March 2011.

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PAC '09

The 23rd Particle Accelerator Conference (PAC '09) took place in the port city of Vancouver, Canada on 4-8th May 2009.

The 23rd Particle Accelerator Conference (PAC '09) took place in the port city of Vancouver, Canada on the 4-8th May 2009. The conference was held jointly in the Fairmont and Hyatt Regency hotels and was attended by over 1300 delegates. ASTeC contributed 59 papers to the proceedings covering a large number of accelerators such as ALICE, EMMA, NLS, the Neutrino Factory, ISIS, CLIC and ILC and with a vast range of topics including accelerator machine designs, magnet design, photo injectors, RF systems, muon storage rings and superconducting undulator development. ASTeC's work on EMMA (Electron Machine of Many Applications) and FFAG (Fixed Field Alternating Gradient) accelerators was recognised with oral presentations from Neil Marks and Susan Smith on 'Non-scaling FFAG Magnet Challenges' and 'EMMA, the World's First non-scaling FFAG Accelerator', respectively.

Further information can be found at:
http://www.triumf.info/hosted/PAC09/

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PALS visit 7th May 2009

ASTeC Science Highlights 2009 - 2010

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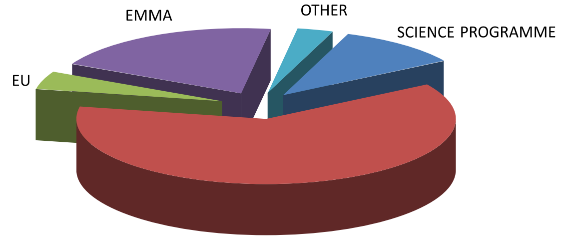
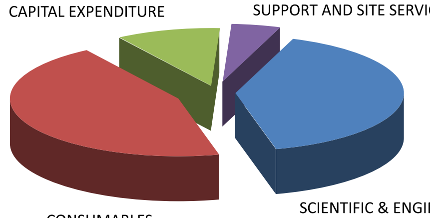
Financial Summary

ASTeC ACTIVITIES 09/10

INCOME SOURCES 08/09	£K
SCIENCE PROGRAMME	1090
CORE ASTeC PROGRAMME	6404
EU	478
EMMA	2076
OTHER	302
	10350



EXPENDITURE 08/09	£K
SCIENTIFIC & ENGINEERING STAFF COSTS	4200
CONSUMABLES	4623
CAPITAL EXPENDITURE	1050
SUPPORT AND SITE SERVICES	477
	10350



EXPENDITURE BY PROGRAMME 08/09	£K
LC-ABD PROGRAMME	745
UK-NF PROGRAMME	901
HIGH POWER PROTON ACCELERATORS	759
HIGH BRIGHTNESS ELECTRON ACCELERATORS	2850
UNDERPINNING RESEARCH	1264
NEW INITIATIVES	202
OTHER PROFESSIONAL ACTIVITIES	637
EU	280
EMMA	2409
OTHER REPAYMENT WORK	303
	10350