Science and Technology Facilities Council

ASTeC Highlights 2021–23

Accelerators in a New Light

Contents

Director's Foreword

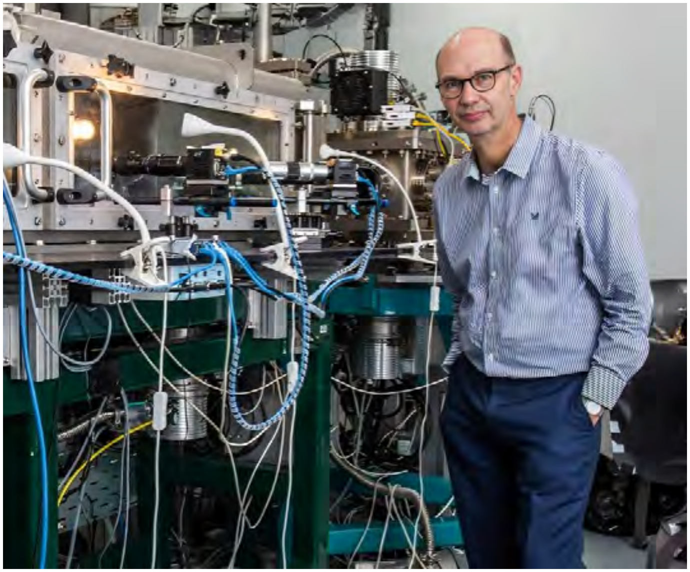
The past two years have been the most exciting period in ASTeC's history. We have been finalising the assembly and installation phases of our ambitious upgrade of CLARA, making the UK's largest ever accelerator-system in-kind contributions to new world leading user facilities, carrying out highly impactful research and development that will make future accelerators far more sustainable, and enabling leading industries to make societal and economic impacts for the UK.

As I write this, the final components are being installed into the CLARA facility that will enhance the energy by a factor of five, the brightness by a factor of hundred, the repetition rate by a factor of ten, and the laser power at the experiments by a factor of twelve. All together, these enhancements will make CLARA Europe's premier accelerator test facility and I look forward to future reports highlighting the successful beam commissioning and the many impactful experiments which our user community are preparing for now.

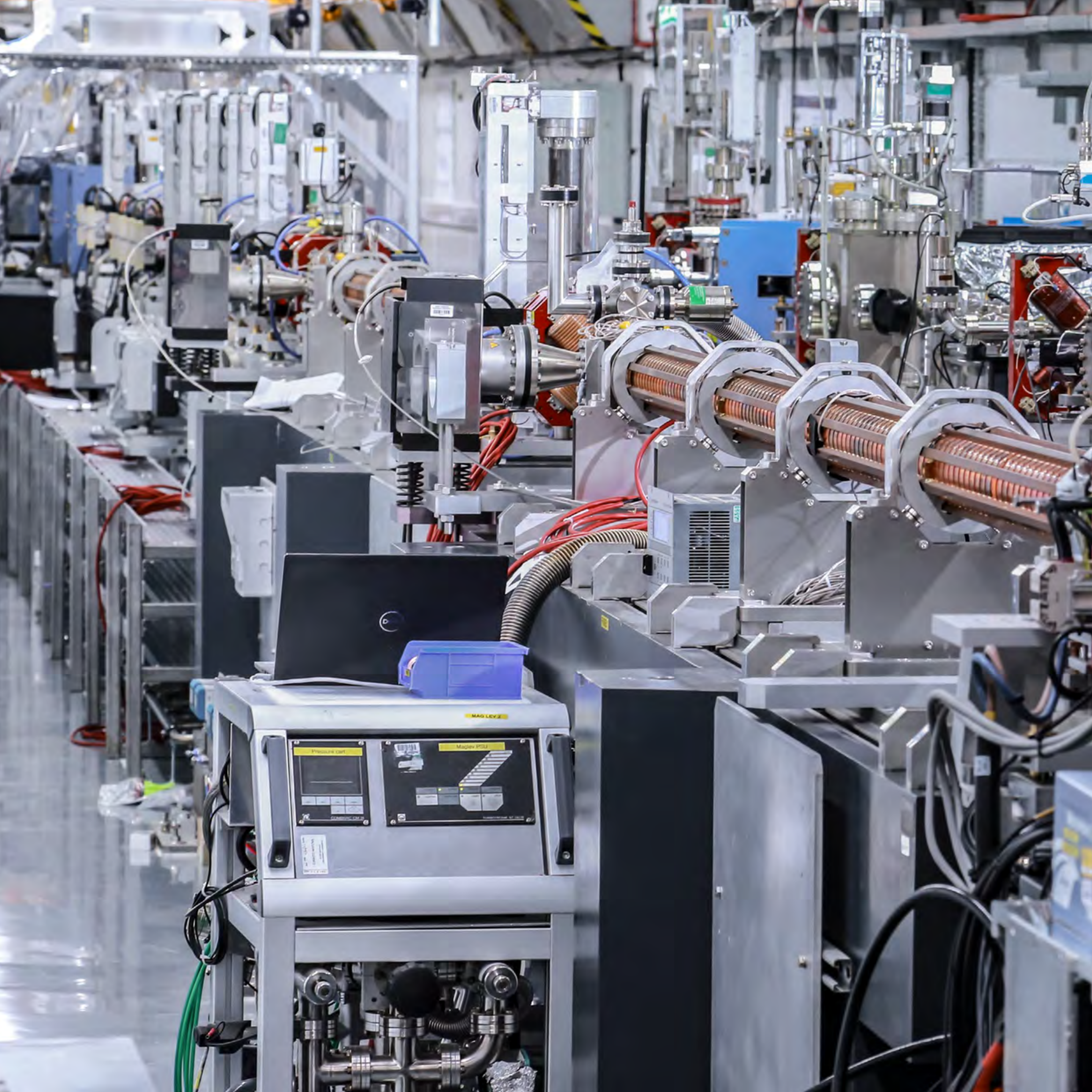
The scale of ASTeC's in-kind contributions to leading new international facilities has never been greater. Over the last two years our superconducting RF cavity delivery to the European Spallation Source has changed from preparation and commissioning into full scale factory mode. Our SuRF Lab facility has been preparing, testing, and where necessary re-cleaning RF cavities, non-stop and we have delivered the majority of these now to the team in France which assembles them into the cryomodules. This is a meticulous process and requires a very high level of quality assurance and documentation. Our hard work has meant that our French colleagues have always had plenty of cavities to hand to keep them busy! As this activity now concludes, the SuRF Lab will transition into the area that not just qualifies superconducting RF cavities for the Proton Improvement Plan-II at Fermilab in the US, but also the area where we assemble the long cryomodules that house these cavities. An enormous amount of preparation for this activity, including initiating the procurement of the materials and cavities, has already taken place to get us to this point. Elsewhere at Daresbury Laboratory, ASTeC has been leading on the delivery of the shorter crab cavity cryomodule prototype for the High Luminosity upgrade of the Large Hadron Collider. This will be immediately followed by the assembly of the production modules. Again, this has been an intense activity which will have tremendous impact internationally.

The UKRI investments into new infrastructures have highlighted just how important particle accelerators are to the 'big science' that UKRI supports. Many of the top priority new infrastructures which UKRI have selected for funding have accelerators at their heart. Naturally, the design and development of most of these new accelerator based user facilities falls to ASTeC to deliver, which we are very well equipped to do. We are playing a leading role in; RUEDI, an exciting new electron diffraction and imaging facility, ITRF, a facility which plans to revolutionise ion based radiotherapy treatments, and UK XFEL, a design study and options analysis which will offer UK researchers access to the brightest X-ray source on the planet. In addition we have been supporting, with our unique skills and capabilities, the delivery of the Extreme Photonics Applications Centre and Diamond-II at the Harwell Campus.

Further details regarding all of these activities and our people which make them possible are provided in this Highlights report. The increasing volume of our activities has been tremendously exciting but has also brought many challenges for my staff. I am incredibly proud of the 'can do' attitude which is intrinsic to ASTeC and it is great credit to my staff that we deliver successfully on all fronts and our reputation continues to grow!



Professor Jim Clarke, Director of ASTeC.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CLARA Our Flagship Test Facility

The Compact Linear Accelerator for Research and Applications (CLARA) is an advanced electron accelerator test facility at Daresbury Laboratory. CLARA's major objectives are to be the European test bed for accelerator research and development, to enable the UK academic, industrial, and health sectors to develop new accelerator-based technologies and to pave the way towards the building of a next-generation UK X-ray Free-Electron Laser.

A series of milestones have been reached through CLARA's successful programmes of commissioning and user exploitation and the development of diagnostics based on machine learning. Meanwhile CLARA continues its evolution towards Full Energy Beam Exploitation (FEBE) which will maximise the research impact CLARA can deliver.

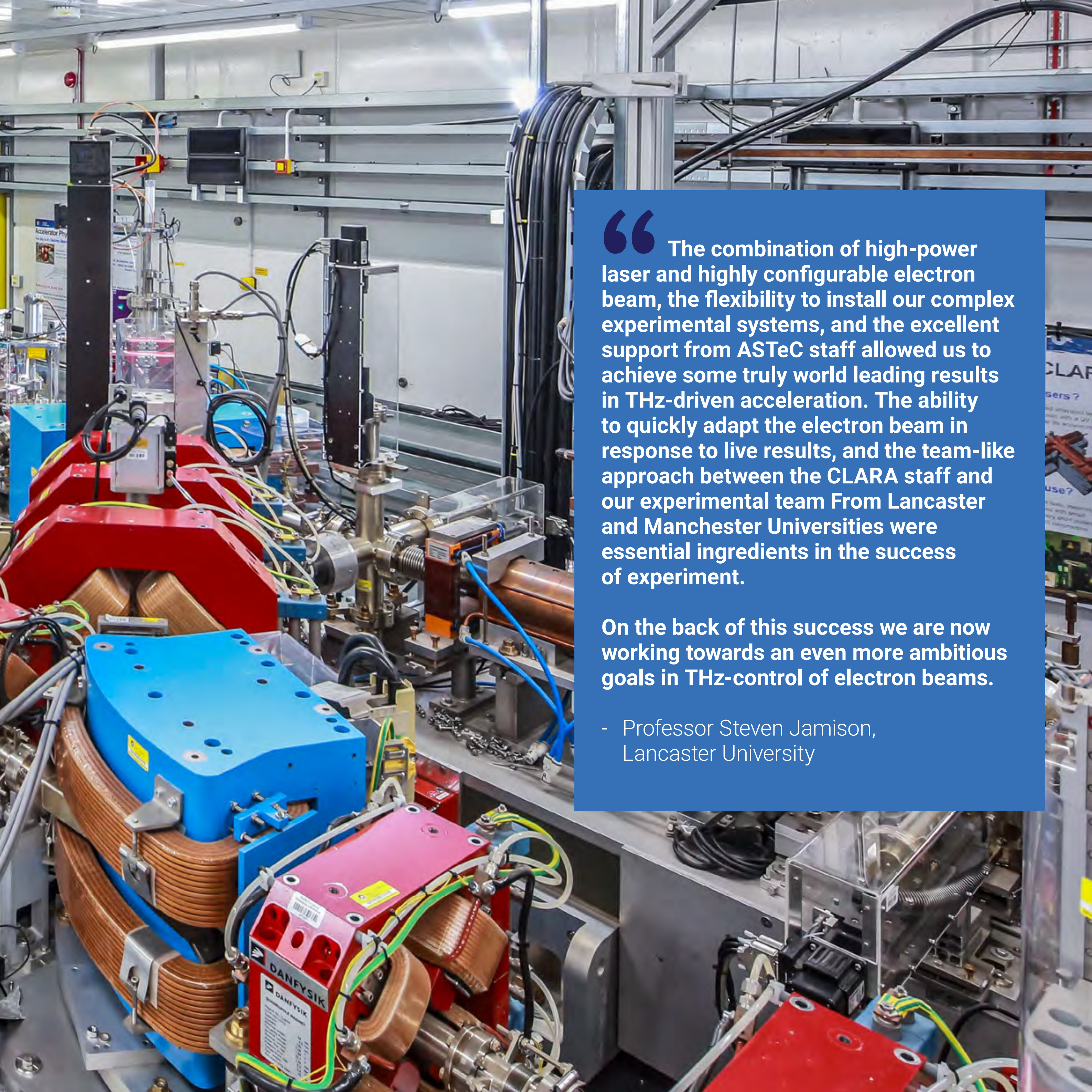
CLARA Exploitation Highlights

CLARA's beam was delivered to nine experiments during October 2021 to April 2022, with the vast majority of these being very successful. An extremely diverse programme of research was carried out, featuring alternative acceleration techniques including laser induced plasma wakefield, dielectric wakefield and THz based acceleration, in addition to novel diagnostics and detector development, medical physics and radiation biology. Several of these experiments were the next step forward from the previous successful CLARA exploitation user programme in 2018-19, including two transnational accesses through the Horizon 2020 ARIES programme.

Out of nine experiments, five experiments required combination and synchronisation of CLARA's terawatt laser and electron beams in a dedicated user chamber. Beams ranging between 4 – 35 MeV/c were delivered along CLARA's straight-on beamline to two user experiments. Longitudinally manipulated 35 MeV/c beams were also delivered along the CLARA to VELA line to the dedicated user area to perform several challenging experiments. Responses from a feedback survey issued after the user programme indicated high levels of satisfaction from all the experimental teams.

A follow up CLARA User meeting was subsequently held in July 2022, where users communicated their results and plans for publications. The CLARA team has presented plans for completion of 250 MeV CLARA and a timeline for future exploitation in early 2025 at various forums.

> **"We had a highly successful run and were able to show - for the first time - how indirect damage is the main contributor to DNA bond breaks under irradiation with a 35 MeV electron beam. We achieved this exciting result through irradiating plasmid DNA samples with the highly stable repeatable beam delivered at CLARA. This was a seamless collaboration between ASTeC, the Christie NHS Trust, and the University of Manchester.**
>
> - Professor Roger Jones, University of Manchester



“ The combination of high-power laser and highly configurable electron beam, the flexibility to install our complex experimental systems, and the excellent support from ASTeC staff allowed us to achieve some truly world leading results in THz-driven acceleration. The ability to quickly adapt the electron beam in response to live results, and the team-like approach between the CLARA staff and our experimental team From Lancaster and Manchester Universities were essential ingredients in the success of experiment.

On the back of this success we are now working towards an even more ambitious goals in THz-control of electron beams.

- Professor Steven Jamison,
  Lancaster University

> **CLARA is one of the very few places in the world it is possible to study the interaction of a well controlled electron beam with a high power laser and plasma. This near-unique capability enabled our experimental team to study the injection of electrons into a laser driven plasma wakefield - for only the second time in the world – and demonstrate that these electrons were accelerated. This exciting result has led to the development of a major new collaborative research proposal to fully exploit the upgraded CLARA facility and drive research into novel high gradient, collider quality particle accelerators.**
>
> - Dr Laura Corner, University of Liverpool

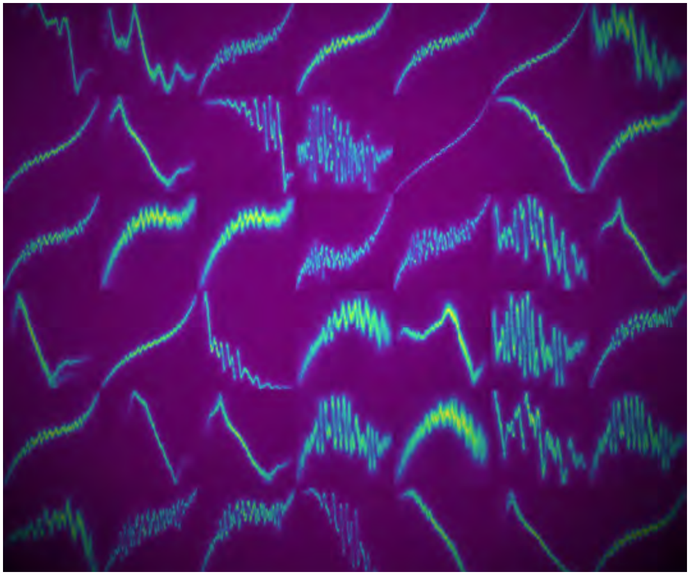
> **Through exploiting the flexible beam delivery and high fidelity diagnostics at CLARA we were able to investigate in detail transverse beam dynamics in Dielectric Wakefield Accelerators. This world first study revealed the limitations of one of the proposed methods to suppress beam break-up instabilities in high gradient Dielectric Wakefield Accelerators. Suppression of beam break up in high gradient wakefield accelerators is vital for realising sustainable high energy accelerators in the future. These results have been published and have attracted the attention of the international scientific community.**
>
> - Dr Yuri Saveliev, ASTeC , STFC

Machine Learning Developments

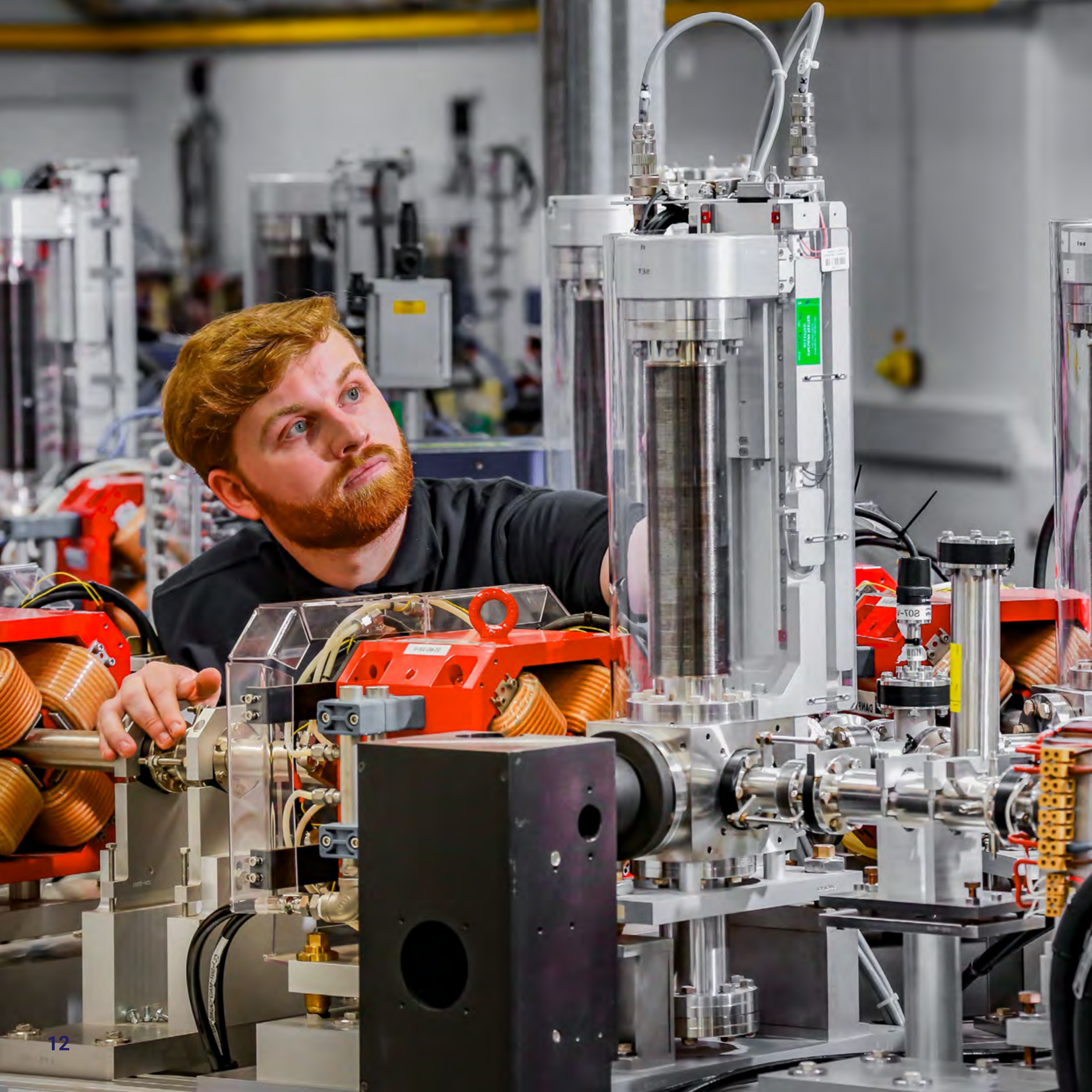
Machine Learning (ML) is extremely useful for extracting patterns and relationships within data and therefore for making predictions about new data. At the CLARA facility, we aim to use ML to deliver an efficient, automated accelerator with rapidly customisable beam properties. Over recent years, ASTeC staff and collaborators have developed a number of projects to realise these aims.

We have carried out two related projects on customisable electron bunch shaping to date – the first of which is a simulation-based example to apply temporal bunch shaping to the whole of CLARA, while the second is an experimental demonstration of the same idea on a smaller part of the machine. The simulation-based example uses ML to learn the relationship between the settings of CLARA's parameters (e.g. accelerating gradients/phases) and the resulting electron bunch shape. The result is a model that can be used for various applications, for example as a 'virtual diagnostic', which predicts the bunch shape in cases where real diagnostics can't be used. Our work also includes a feature where CLARA users can draw their desired electron bunch shape, which is then delivered by using the model as part of an optimiser to find the required settings.

The second project applies the same approach in practice to a smaller part of CLARA used in generating the initial electron bunch – the photoinjector laser. In this case, ML is used to learn the relationship between the spectral phase properties of a laser pulse (which can be controlled with a waveform generator) and its resultant temporal shape. Both simulations and experimental data are used to train the model, and the model has been successfully applied on the real laser. The aim is that by shaping the laser pulse, we will be able to customise the bunch shape in future. This will be further enhanced by work with collaborators at the University of Liverpool to develop advanced ML-based diagnostics.



Various examples of simulated longitudinal phase space of electron bunches, each with different accelerator settings. We used machine learning to find the relationship between settings and images, to allow us to create custom images.



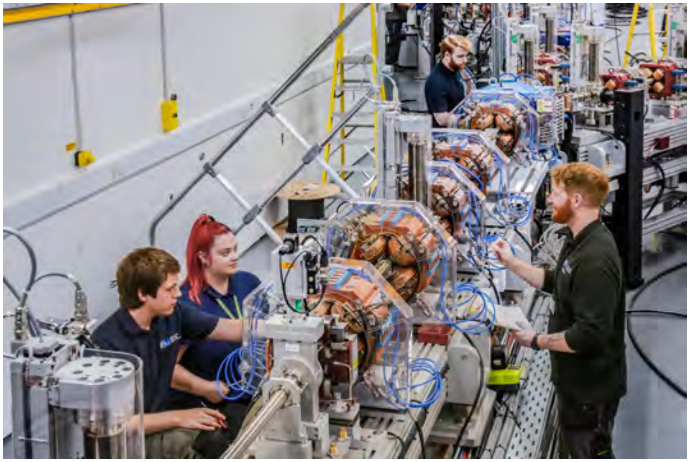
CLARA Construction April 2021 To March 2023

April 2021 to March 2023 was the main installation period for the Phase 2 section of the CLARA accelerator. It was the culmination of many years of conceptual, technical and detailed design, followed by procurement and offline construction challenges. COVID-19 had a huge impact on every task throughout this period, which contributed to the decision to prioritise additional exploitation time (using the temporary shielded Phase 1 area providing 35 MeV/c beam to users) over maintaining the second shutdown schedule; ultimately delaying this until March 2023.

In March 2021, two new RF rooms were built and basic infrastructure was put in place, ready for the RF infrastructure to be installed and tested. The Phase 2 accelerator hall build progressed well, despite resource conflicts and consistent disruptions due to COVID-19. Downstream of the temporary shield wall, the accelerator modules were installed as they became available from the offline build/test processes in the Engineering Technology Centre (ETC). FEBE Arc modules also progressed through the building and testing phase.

By April 2023, accelerator shielding infrastructure for Phase 2 is complete and all RF infrastructure has been tested but has not yet been optimised for operation. All accelerator modules except for the FEBE hutch modules are installed, with services installation underway. The construction and offline testing of the FEBE hutch modules continues in the ETC. Services installation for the hutch is also progressing, the removable shield door is installed and the FEBE laser room suite has been constructed.

This highly productive period has concluded with the start of the final shutdown in which the temporary Phase 1/Phase 2 shielding will be removed, Beam Area 1 will be dismantled and the separate areas of CLARA will be joined by the installation of the accelerator modules in the Phase 1 area.



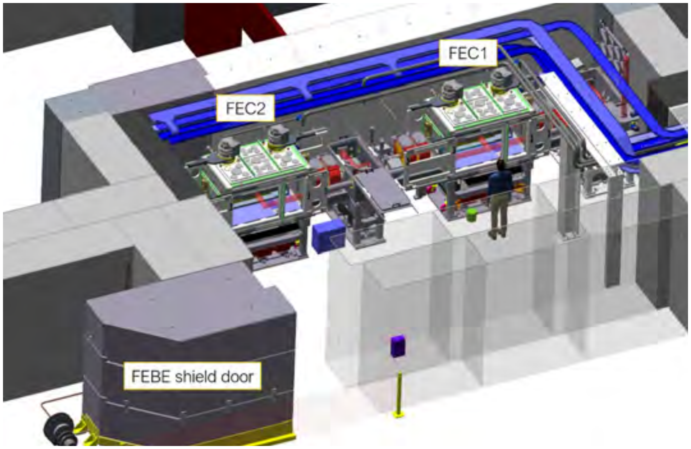
Building CLARA in the accelerator hall.

Full Energy Beam Exploitation Of CLARA

Phase 2 of CLARA will provide maximum beam energy of 250 MeV in a Full Energy Beam Exploitation (FEBE) shielded hutch. Phase 2 will increase beam energy by a factor of 6, beam brightness by a factor of 100 and pulse repetition rate by a factor of 10. This will facilitate many novel proof-of-principle experiments to be demonstrated. Two large experiment chambers – FEC1 and FEC2 – are being prepared in the Engineering Technology Centre at Daresbury Laboratory, ready for installation on CLARA during 2023. Over one metre in height, their design will make it easier for users to install equipment in and around CLARA's beam path.

The chambers sit in a large concrete bunker, which users can access while CLARA is running into a beam dump in an adjacent hall. This will help ASTeC experts maintain the electron beam while experiments are being set up. The bunker is currently assembled and in position, including the sixty-ton shield door which can be opened and closed using a cushion of air.

A large room has been constructed above the bunker to house a 120 TW laser. Incredibly intense pulses of laser light will be directed into the bunker and combined with the electron beam for a variety of purposes, including acceleration beyond 250 MeV using plasma generated by ionization of gas particles. The room will be fully prepared in advance of the laser arriving in August 2024, with the first full energy beam exploitation of CLARA beginning early 2025.

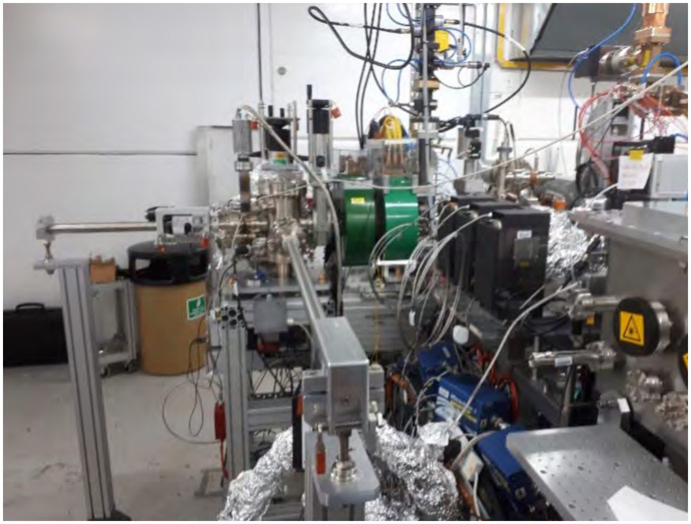


3D view of the FEBE hutch, including the sixty-ton shield door (lower left) and two FEBE experiment chambers – FEC1 and FEC2 – each approximately two metres long and one metre tall. The electron beam from the main CLARA accelerator travels through the hutch from right to left, first entering FEC1 before travelling through to FEC2.

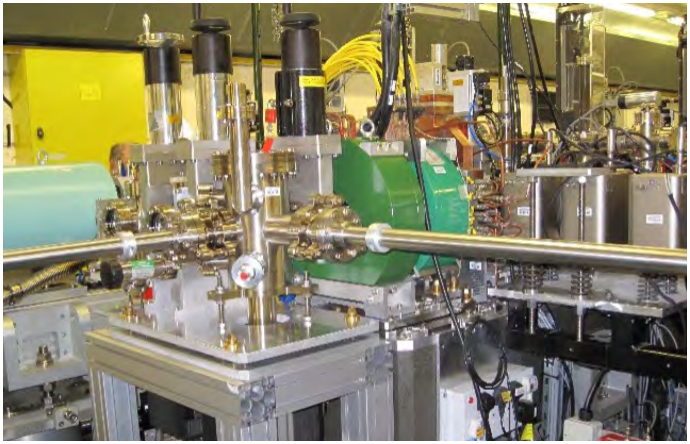
Upgrading CLARA's Electron Source

Significant work has been dedicated towards the optimisation of CLARA's upgraded 10 Hz electron gun, including the selection of an appropriate photocathode and transverse and longitudinal optimisation of the photoinjector laser profile generating the electron beam. Further efforts have been directed towards commissioning the upgraded 10 Hz gun with a 'load-lock system', which allows the photocathode to be rapidly changed without having to go through the lengthy process of opening up the vacuum chamber and conditioning the gun to sustain high RF fields. Upon achieving a bunch charge of more than 100 pC with the required beam properties, CLARA's user programme was suspended due to effects of the COVID-19 pandemic and subsequently resumed in October 2021, running until April 2022. The gun provided ultrabright electron beam throughout the user run satisfactorily.

On successful completion of the user exploitation programme, a programme was undertaken to prepare for the commissioning of a High Repetition Rate Gun (HRRG) designed in-house. The gun was conditioned using an automated RF conditioning script developed in-house. A beam with 100 pC bunch charge at 100 Hz repetition rate was successfully demonstrated in early March 2023. The gun is now ready to be swapped to CLARA line in the planned shutdown to meet CLARA specification of 100 Hz.



10 Hz gun upgraded with load lock photocathode system installed on CLARA line.



High Repetition Rate Gun with photocathode load lock system installed on the VELA line for commissioning.

Designing New National Infrastructures

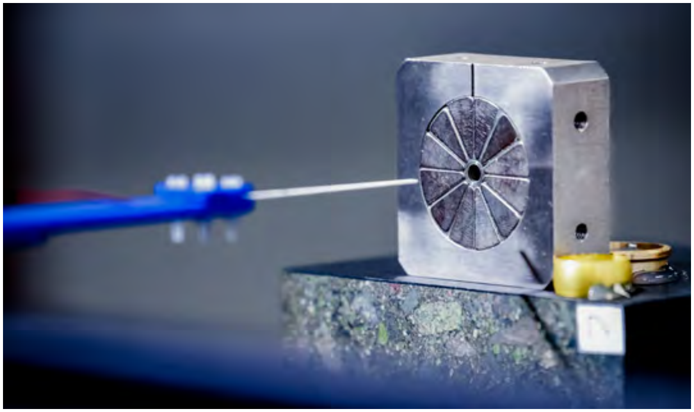
ASTeC has a rich history of designing, implementing, and operating accelerator test facilities at Daresbury Laboratory over the past 20 years. These facilities (ALICE and EMMA in the past, VELA and CLARA currently) have been instrumental in validating novel and innovative accelerator concepts and technologies, as well as new modalities of radiotherapy. Many of the results of these activities are being exploited for larger scale national infrastructure facilities such as Diamond-II, EPAC, ITRF, RUEDI, and UK XFEL.

EPAC

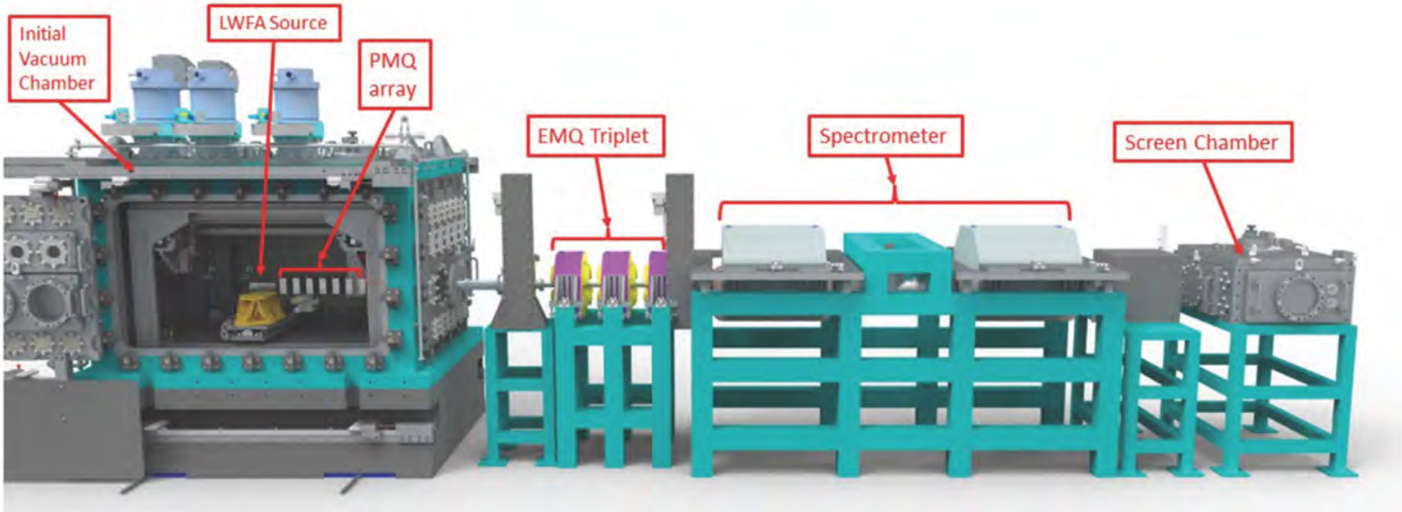
ASTeC is contributing to the Extreme Photonics Applications Centre (EPAC) that is currently under construction at the STFC Rutherford Appleton Laboratory site. A collaboration between UKRI, MoD, academia, and industry, EPAC aims to progress ultracompact novel laser-driven electron accelerators. These new electron accelerators can produce photon beams with unique properties for scientific and industrial applications. One example is the replication of extreme astrophysical events (high pressures, temperatures and so on) to further a fundamental understanding of stellar processes. Another example is for the production of high-energy X-rays and gamma-rays by a range of methods; such femtosecond-scale sources of highly-penetrating radiation give imaging capabilities essential for many applications in industry (particularly the nuclear industry) and for defence.

ASTeC have recently designed a unique modular beamline to capture the electron beam generated by laser acceleration, and to focus for a range of user experiments at multiple electron energies (from 1 to 5 GeV). The laser-plasma interaction generates a very high energy GeV electron beam which is inherently divergent and requires a beamline to capture and condition it. This includes a novel modular, adjustable permanent magnet quadrupole (PMQ) capture array using in-house-designed shimmable 500 T/m Halbach quadrupoles. Following capture and conditioning, a further series of conventional electromagnetic quadrupoles (EMQs) directs the electrons either to a variety of experimental interaction points or through a wide-bandwidth electron energy spectrometer. The bespoke spectrometer is a unique double-dipole large aperture instrument operating up to 1.4 T. It is an essential instrument that will allow the EPAC project to diagnose and improve the production of the high-energy, monochromatic electron beams.

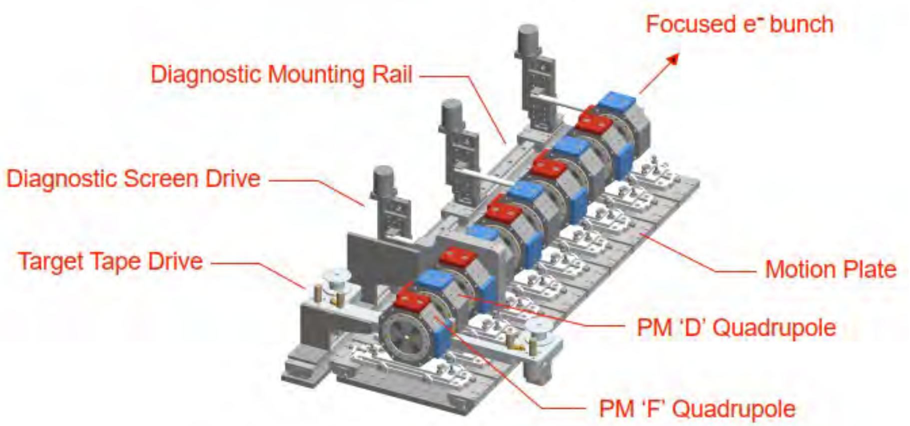
As well as being responsible for the electron beam conditioning, ASTeC are also responsible for ensuring that sufficiently low pressures are obtained in this highly complex environment which simultaneously combines intense lasers, gas jets and high-vacuum electron transportation. Collaborating across several departments and the Hartree centre, ASTeC is implementing an advanced nozzle separation design to separate the gas-jet laser-plasma beam generation from the downstream electron beam exploitation areas.



Field measurement of a novel permanent magnet quadrupole.



Engineering concept for the EPAC laser-plasma electron generation chamber (left), showing the gas jet source and PMQ array for 1 GeV operation. Once captured, the electron bunches are transported here through the EMQ system and spectrometer to both monochromate and diagnose the electron spectrum.



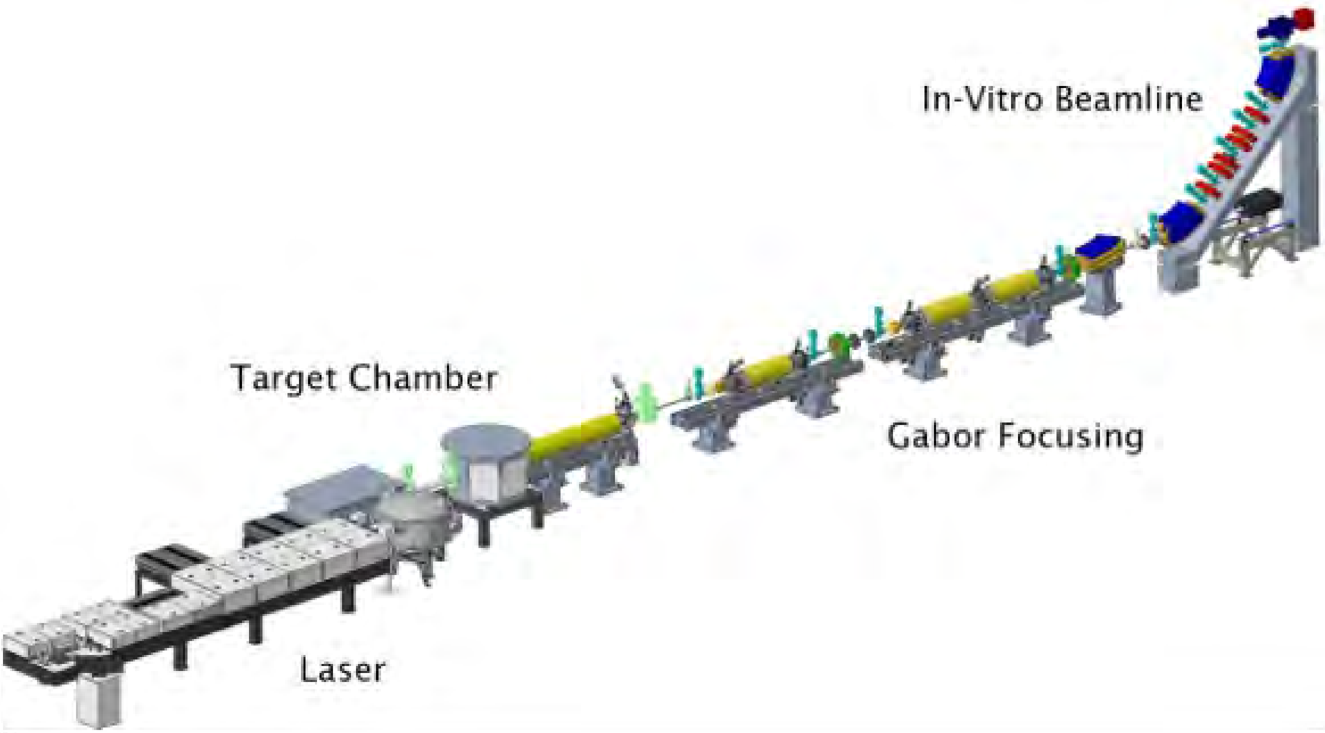
Engineering concept for the EPAC PMQ (permanent magnet quadupole) capture array, incorporating tape-drive target and diagnostic screens. Each quadrupole can be independently aligned to the electron bunch transport axis, and the array flexibly reconfigured for different energies and focal properties.

ITRF

2022 saw the commencement of a 2-year project funded by the UKRI Infrastructure Fund to develop the conceptual design of a groundbreaking new facility for biology and medicine – the Ion Therapy Research Facility (ITRF). ITRF aims to provide researchers with a flexible ion beam research platform that will develop basic understanding of the interaction between different ions and biological systems; one key motivation is to understand which patients will most benefit if ion radiotherapy is brought to the UK. ASTeC staff are leading STFC's involvement with the ITRF project, a partnership between the UK's world-leading plasma and accelerator physics research community and STFC's expertise in building user research facilities.

Ion therapy uses heavy particles such as protons, helium and carbon ions to deliver a directed radiotherapeutic dose to a treated region such as a tumour. Using ions instead of conventional X-rays allows the treatment to better avoid certain organs at risk. Protons are already in clinical use in the UK, but heavier ions may give a better therapeutic benefit due to their higher radiobiological effectiveness in some cell and cancer types. Also, recent results with very high (so-called FLASH) dose rates indicate a benefit to delivering ion therapy very quickly; mini-beams or other spatio-temporal ion schemes may also offer benefits. ITRF aims to study these potentially groundbreaking effects in model cell systems.

The key first element for ITRF is a flexible intense plasma acceleration stage using experience gained from a number of UK plasma groups working in the LhARA collaboration (Laser-hybrid Accelerator for Radiobiological Applications). In this first 2-year project stage, the design of the plasma source will be developed along with how to capture and select the generated ions using a novel Gabor lens system and fixed field alternate gradient (FFA) ring. ASTeC and STFC Technology Department staff are responsible for helping the component developments into an overall facility design, building on the experience gained in the pioneering EMMA FFA accelerator previously built at Daresbury Laboratory. We look forward to publishing a conceptual design report in 2024.



One concept for the 1st stage of ITRF, which envisages a foil target to generate ions such as protons with very short bunch lengths at around 15 MeV. A strong-focusing Gabor lens system captures and selects ions from the target within a desired energy bandwidth and delivers them to one of the user beamlines, here a vertical in-vitro line for cell irradiation studies.

RUEDI

The Relativistic Ultra-fast Electron Diffraction and Imaging (RUEDI) project seeks to develop an EPSRC funded facility for ultra-fast science at Daresbury Laboratory. The overall project is led by the University of Liverpool and the other main project partner is the Rosalind Franklin Institute (RFI) at Harwell. The project is funded as a preliminary activity under the UKRI Infrastructure Fund with the goal to produce Conceptual and Technical Design reports.

A Science case has been developed with five themes: ‘Energy materials’, ‘Materials in Extreme Conditions’, ‘Bio-sciences’ ,‘Dynamics of Chemical Change’ and ‘Quantum Materials’. A series of workshops were held across various sites in the UK to identify interested academic partners and refine the RUEDI instrument requirements.

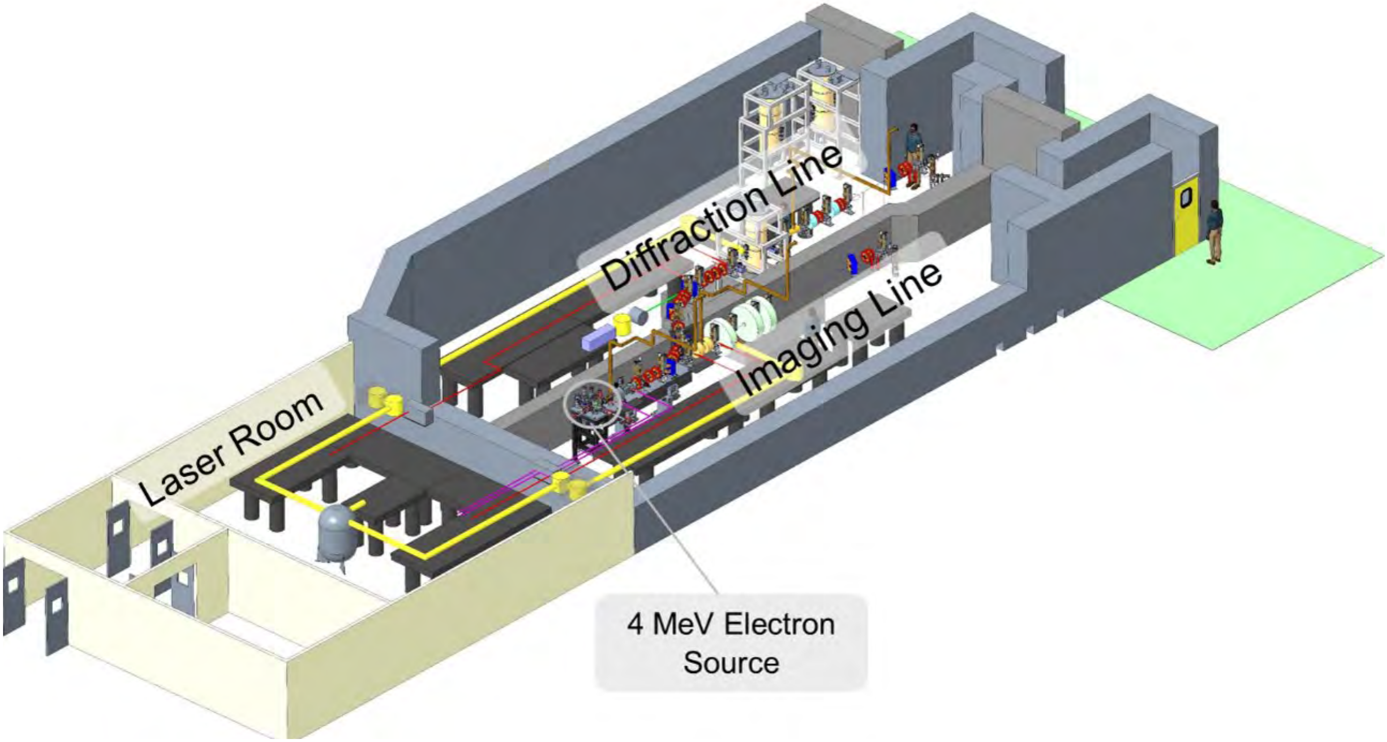
ASTeC’s main role in the project is the design of an instrument to allow both ultra-fast diffraction (10-30 fs temporal resolution) and imaging (5 - 10 ps temporal resolution, 1 - 100 nm imaging resolution) to be achieved. The design has evolved with two different beamlines each optimised for the particular application due to the very different electron beam requirements.

For Diffraction experiments, ultra-short electron pulses are required, and a magnetic bunch compression arc has been identified as the favoured solution to achieve this. An interchangeable sample chamber is proposed that will allow a wide range of sample types and environments to be achieved including liquid and gas samples and ultra-low temperature environments. Electron optics then transport the diffracted electrons to a detector with single electron sensitivity.

On the Imaging line, low energy spread, small spot size and short pulse length are all required at the sample. To achieve low energy spread an RF cavity is used which also controls the final energy of the beam. Carefully designed optics will provide a small round beam at the desired bunch length. The main lens of the imaging system also acts as the sample interaction point and several other lenses are additionally required to form the image on the detector.

The facility will also require a very large number of dedicated laser systems to carry out the intended pump/probe experiments. Short ultra-violet pulses must be provided to the electron source - an S-band RF Photoinjector – and a wide range of wavelengths must also be directly deliverable to the samples. These pulses act as a pump to affect some physical or chemical change that can then be characterised both structurally (diffraction), compositionally and topographically (imaging). By altering the delay between pump and probe these changes can be witnessed in real time.

The RUEDI project is an exciting opportunity for the UK to take a leadership role in the field of ultra-fast science, which is the new frontier in terms of understanding the key mechanisms that take place in chemical reactions and biological processes which effectively define the real world performance of advanced materials and the mechanisms behind diseases and their potential treatments. A positive outcome for the funding bid to build the whole facility is hoped for in the near future.



RUEDI facility design showing the layout of the Diffraction and Imaging beamlines, flanked by the facility laser systems.

Diamond-II

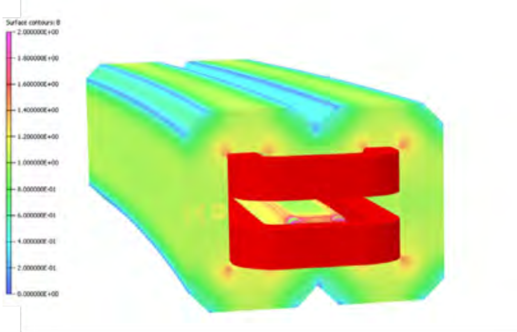
Diamond is the UK's national facility for X-ray science that operates at the Harwell campus, next to the STFC Rutherford Appleton Laboratory site. Diamond is a circular ring that stores electrons at an energy of 3 GeV; as the electrons circulate through the 560 m circumference they emit intense bursts of X-rays which are used by scientific and industrial researchers - from both the UK and abroad - to investigate a range of scientific problems. Diamond was designed in partnership with ASTeC staff and has been operating as a cutting-edge research tool since 2007. Since 2020 preparations have been made for an upgrade that will help ensure it continues to support world-class UK science in the coming years. This is the Diamond-II project.

The Diamond-II upgrade aims to increase both output X-ray brightness and the transverse coherence, both of which are important for X-ray imaging in biology and other studies. This will be achieved by improving the beam quality and increasing the beam energy from 3.0 GeV to 3.5 GeV. Both changes require a new booster synchrotron – a smaller accelerator which accelerates and injects electron bunches into the main storage ring.

In collaboration with Diamond staff, ASTeC scientists optimised the electron beam dynamics of the new booster as well as designing the new multifunction dipole magnets that will be used. The dipole magnet generates a complex field pattern that bends, focuses, and corrects the electron beam trajectories during the acceleration process.

The new booster design produces ultra-small electron bunches that can be injected into the new main storage ring with almost no losses. ASTeC physicists have also helped to optimise the entire injection chain and provided guidance for the final engineering design. To allow efficient acceleration the booster must maintain an extremely low beam pipe pressure; this is complicated by the small apertures required within the new booster dipoles.

ASTeC vacuum scientists, who have played a key role in modelling and optimising Diamond vacuum system, are working in a collaboration with the Diamond team to evaluate a non-evaporable getter coating (NEG) solution to meet tighter vacuum specifications required for future light source upgrade projects. An ASTeC-coated vacuum chamber prototype will be tested shortly at a dedicated beamline on Diamond.



3D field profile of one of the multifunction booster synchrotron dipole magnets. The magnet is used to bend, focus, and correct the beam as it is accelerated. The magnet is compact with a high peak field and small aberrations, allowing the booster to achieve very high performance.

UK XFEL

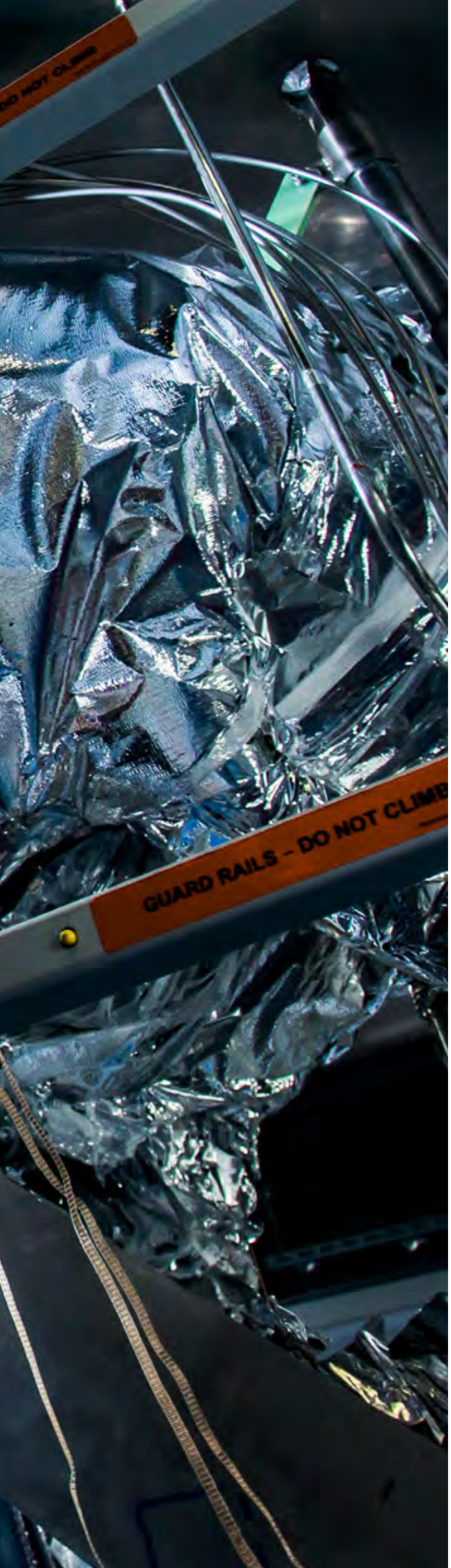
UK Research and Innovation has approved and funded a UK XFEL Conceptual Design and Options Analysis (CDOA) as part of a major investment in future UK research and innovation infrastructures. This new study, which started on 1st October 2022 and will run for three years, will evaluate a number of options that will enable UK researchers' access to next generation XFEL capability as articulated in the UK XFEL Science Case. As well as evaluating a new facility based in the UK, the study will also evaluate the options of investing in overseas facilities to enhance their current capabilities and capacity.

Following the announcement, the project team, largely from ASTeC, has developed a detailed plan and timeline. The science team, which drafted the Science Case, has already been expanded and engagement with the facility designers has stepped up to discuss in detail the capabilities that UK researchers require from a next generation XFEL. The project was formally launched at a public event at the Royal Society in London on 30th January 2023. The event caught the imagination of science reporters, with full length articles being published in both Physics World and Chemistry World.

A series of workshops on the science and technology that will be enabled by a next generation XFEL, will be held around the UK over the next two years, supported by ASTeC staff, to inform researchers of the science case and to ensure the facility designers fully understand the user requirements.

A primary objective of this 3-year study is to develop options for how to deliver a world-leading ultrashort X-ray facility for science, with new capability compared to what is currently available or planned, through a UK-based machine or substantial upgrade to an overseas facility. Several meetings have already been held with overseas facilities as part of an initial fact finding, including a face-to-face event at European XFEL. ASTeC staff are now assessing the new capabilities required by the Science Case and focussing attention short term on those most challenging to achieve. The two areas currently receiving the most attention are; how to deliver transform limited pulses across the full wavelength range and how to maximise usage of the facility by addressing multiple FEL provision and user throughput issues.


GUARD RAILS



Delivering For New International Facilities

ASTeC has been at the forefront of accelerator development for over 20 years, conceptualising novel ideas and concepts, and leading the practical verification of new accelerator processes, technologies, and facilities. Through close partnerships with Technology Department and Cockcroft Institute universities, Daresbury Laboratory has become a world-renowned centre of excellence for accelerator science and technology development and delivery. ASTeC's capabilities have been recognised through engagements with world-leading international facilities and programs, where it has secured lead responsibility for critical accelerator systems as national in-kind contributions. ASTeC is either activity leading or strongly provisioning a wide range of complex accelerator technologies. This includes novel undulators, integrated magnet, vacuum and diagnostics systems, superconducting crab cavities, and superconducting accelerators for facilities like the CompactLight design study, the High Luminosity Large Hadron Collider (HL-LHC) upgrade at CERN, the European Spallation Source (ESS) in Sweden and the Proton Improvement Plan II (PIP-II) at Fermilab in the USA.

PIP-II

Were there a unit of measurement for how compelling a project title is, “Phase 2 of the Proton Improvement Plan” would barely cause the dial to flicker. Yet this underwhelming description belies one of the most exciting accelerator-build projects in which ASTeC has a leading role. PIP-II, a billion-dollar undertaking led by colleagues at Fermilab and supported by institutions across the globe, will deliver a proton accelerator with a beam energy of 800 MeV to power the Deep Underground Neutrino Experiment (DUNE). ASTeC and Technology Department staff at Daresbury Laboratory are delivering three cryomodules to provide the final boost in beam power and accelerate protons to 84% of the speed of light.

The cryomodules will use super-cooled cavities working under vacuum to store and shape the rapidly oscillating electrical field at 650 MHz that accelerates the positively charged protons. These cavities are geometrically complex structures made of niobium which offers almost zero resistance to electrical current when operating at 2 degrees kelvin.

In 2022 we signed a contract with Zanon (Italy) for the supply of twenty superconducting cavities. Zanon have already produced copper mock-ups of the half-cells that will be welded together to form the cavities. Copper is used to test dies and formers for deep drawing as its physical properties closely resemble those of niobium.

Anna Shabalina (ASTeC) with Ambra Gresele (Zanon) holding copper half-cell mock-ups for the superconducting cavities.

In October 2022 Daresbury Laboratory functioned as the turn-around point for the transportation test of a dummy cryomodule from Fermilab. Similar in weight and centre of gravity to the cryomodules themselves, this heavily-instrumented mass was shipped by road, air and train between the two laboratories. The purpose of the test was to assess how well the transport frame designed by STFC's Technology Department would protect the delicate, but heavy, cryomodule from the shock loads on such a long journey. The results were excellent with Fermilab declaring high confidence in the frame's ability to protect our precious cargo.

2023 promises to be another busy year here at Daresbury Laboratory as we source components for cryomodules and begin to test cavities. PIP-II has long been a hugely significant project and 2023 is the year that we expect to launch cryomodule construction work on site.

Daresbury and Fermilab staff with the dummy cryomodule in its transport frame.

ESS Beam Transport Modules

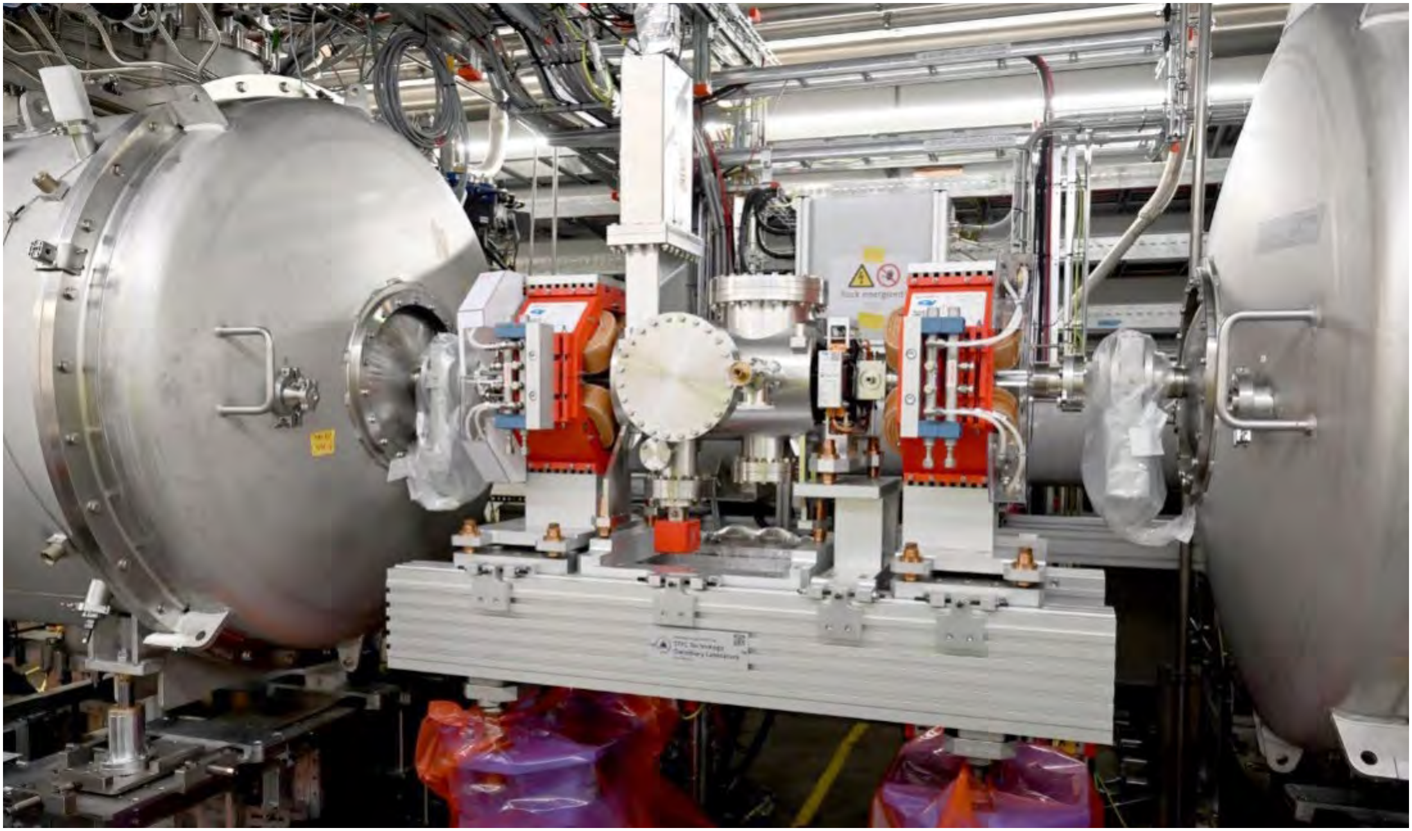
The European Spallation Source (ESS) is a new multi-billion Euro scale research facility under construction in Lund, Sweden, which when finished, will be the world's most powerful source of neutrons. This facility will provide intense beams of these subatomic particles to probe material in search of answers to new questions across a vast range of sciences including: fundamental questions about the nature of sub-atomic particle models, understanding electromagnetic behaviour in technology such as solar panels and fuel cells, and understanding biological processes necessary to develop new treatments for cancer and other diseases.

STFC has been responsible for overseeing the UK's 10% contribution to the construction of ESS, as one of around 18 Institutes providing 42 In-Kind Contribution work packages supplying significant scientific hardware to the ESS programme.

One of the critical delivery activities has been for the Beam Transport Modules (BTM) which began way back in 2015, utilising the relationship that the ASTeC Vacuum Solutions Group had established with the ESS Vacuum group in 2013, which led to STFC's first contribution of vacuum preparation and test facilities in the summer of 2015. Working then extensively with Technology Department, the remit was to deliver 74 of the Linac Warm Units which go in-between the superconducting cryomodules of the ESS Linac. The project expanded in its early days to also include vacuum beam pipes, to be used in place of the superconducting cryomodules prior to them being available for installation. As a result, it meant the BTM project would essentially deliver over 80% of the ESS beamline vessels.

The function of the ESS linac is to accelerate the proton beam close to the speed of light. It is extremely important for the operators to know where the proton beam is at all times and be able to manipulate it accordingly. The BTM systems allow this to happen as the modules include magnets to help steer and focus the proton beam, whilst also including a range of diagnostics to allow the operators to measure where the beam is at any point along the ESS linac transport. This is all done under Ultra-High Vacuum conditions to ensure the proton beam can reach the target whilst minimising any interaction with residual gas in the vacuum system.

The project has been a great success and the ESS vacuum group have since successfully tested all of the BTM modules. In the spring of 2022, a team of Daresbury Laboratory staff visited ESS for the first time in over 2 years - due to the COVID pandemic - to see the ESS linac in Sweden and it was a magnificent experience. The majority of the BTM contribution had already been installed, with only a few items left to implement. This was a fantastic achievement for all involved and brought to an end almost 9 years of hard work and dedication from the Daresbury Laboratory teams.



One of the first three Linac Warm Units in place between spoke cryomodules (Image: Ulrika Hammarlund/ESS).

ESS High Beta Cavities

In addition to the Beam Transport Modules, the ESS High Beta Cavities project is one of the biggest elements within the UK's contribution and ASTeC is responsible for providing 84 "SRF cavities" which are used to give the protons their final boost from 80% to 95% of the speed of light. Each of these cavities has to be fabricated by specialists in industry, from ultra-high purity Niobium material, before being tested and qualified for installation into cryomodule vessels.

Prior to April 2021, STFC's Superconducting Radio Frequency Laboratory (SuRF Lab) team had completed the first few tests on cavities produced for the ESS, including the successful test of 3 cavities in the same test assembly. This was a key result necessary to be able to test cavities at the desired throughput.

The programme has not been without setbacks though: in May 21, a cavity being used to crosscheck and benchmark STFC's test facility against another European laboratory was damaged beyond repair in a road traffic incident. At the same time, initial test results on other cavities being produced showed a much higher than expected failure rate.

With perseverance from the project team and industrial cavity supplier, these issues were both effectively solved: first by expediting preparation of an alternative cavity for correlated tests, then by modifying the final steps of the cavity cleaning during manufacture and arranging to retrospectively apply this on any cavities which had already been processed and cleaned.

July 2021 marked the start of the 'steady state' test campaign within SuRF Lab, which was anticipated to last ~24 months and conduct upwards of 36 test cycles each of 3 cavities.

Both production and testing of ESS cavities has continued at a regular cadence since 2021, and to date the project has conducted 142 individual cavity tests across 86 of the 89 cavities being produced in total, with testing performed both at STFC's SuRF Lab and at the Deutsche Elektronen Synchrotron (DESY) Accelerator Module Test Facility in Hamburg, Germany. In total, over 70 cavities have been qualified and delivered (or in final preparation before delivery), and around 11 of the 21 high-beta cryomodules needed by the ESS have been assembled by CEA Saclay in France.

The ESS High Beta Cavities project is now in its final stage of cavity testing, with plans well underway for managing SuRF Lab's transition from testing ESS cavities to the somewhat larger PIP-II cavities, as well as preparing for other SRF and cryogenic projects.

Some of the Daresbury SuRF Lab team with a High Beta Cryomodule at ESS after assembly by CEA Saclay.

Daresbury Laboratory Team Celebrate High Pressure Rinse (HPR) Facility

The HPR facility is housed in the SuRF Lab, inside the ISO-4 cleanroom suite next to the vertical test facility (VTF). The entire suite has been designed and commissioned for the reprocessing of superconducting radiofrequency (SRF) cavities and is the only one of its kind in the UK.

SRF cavity qualification is a critical and somewhat unique capability amongst the world's accelerator laboratories. As a result of such leading responsibility and working in close partnership with Technology Department, ASTeC is enabling UKRI to make significant in-kind contributions to many major international facilities at an unprecedented scale.

> **"Teams from Technology and ASTeC have been involved in the commissioning of the HPR facility and it has involved months of hard work from them all. When testing for ESS is complete, the facility will be utilised for the PIP-II high beta cavities. This is a key piece of infrastructure and will be an important factor when bidding for new work for many years to come.**
>
> - Mark Pendleton, SuRF Lab Operations Manager

Recertification of ISO 9001 QMS at STFC Daresbury Laboratory

In January 2022, the Technology/ASTeC Daresbury Laboratory Quality Management System (QMS) successfully passed an ISO 9001 external audit by the national standards body BSI, allowing it to continue with its long-running accreditation. This accreditation allows us to demonstrate to our customers that quality is of utmost importance within our projects.

Hi-Lumi LHC: Upgrading The Large Hadron Collider

The Large Hadron Collider (LHC) will remain the most powerful accelerator in the world for at least the next two decades. To extend its discovery potential, the LHC is being upgraded to achieve the integrated luminosity goal by a ten-fold increase from the nominal design value.

The new machine configuration for the High Luminosity LHC (Hi-Lumi LHC or HL-LHC), will rely on a number of key innovative technologies, each representing exceptional technological challenges. These include: cutting-edge 11 - 12 Tesla superconducting magnets, new technology for beam collimation, novel techniques for suppression of electron cloud processes, high-power superconducting links with zero energy dissipation and compact superconducting Crab Cavities for beam rotation.

ASTeC, Technology Department at Daresbury Laboratory and the University of Lancaster in collaboration with CERN have already previously collaborated to design, install and demonstrate first operation of a prototype Crab Cavity Cryomodule at the Super Proton Synchrotron (SPS) at CERN in May 2018. This prototype test consisted of using two Double Quarter Wave (DQW) Crab Cavities operating in superfluid liquid helium at 2 Kelvin.

A second prototype cryomodule is being prepared at Daresbury Laboratory, incorporating two RF Dipole (RFD) cavities with its cold RF couplers, being successfully integrated in a purpose-built ISO-4 clean room in October 2022. This new capability to assemble crab cavities is a major step for the laboratory in its vision to be competitive with other leading organisations engaged in developing SRF technologies.

STFC Team inside SPS tunnel during the installation of Crab Cavity Cryomodule.

The HL-LHC project team is now in the process of integrating the SRF cavity string with the vacuum vessel and other key components like thermal and magnetic shielding, associated instrumentation, and cryogenic piping. The completed cryomodule is scheduled to be shipped to CERN in the summer of 2023. Following which, the project team is preparing to construct four more cryomodules each consisting of two DQW crab cavities, which will be delivered to CERN for final installation for the HL-LHC upgrade.

Successfully integrating the Crab Cavity String in the ISO-4 Clean room.

CompactLight

X-Ray Free-Electron Lasers (XFELs) are lasers driven by electron beams which have been accelerated using radio waves inside Linear Accelerators (Linacs). The electrons then travel through ‘undulator’ magnets which cause them to undulate from side to side and emit X-rays. The X-rays emitted act back on the electrons and stimulate them to emit even more X-rays. The end result is that XFELs produce X-ray radiation a billion times brighter than that produced in Synchrotrons such as the Diamond Light Source on the Harwell Science and Innovation Campus.

The XFELs in operation worldwide, in the USA, Japan, Germany, South Korea and Switzerland, are very large, and hence expensive, facilities. They are large because the electron beam must be accelerated to a very high energy to produce the required X-rays, meaning the linac must be several hundred metres long. If it was possible to increase the accelerating gradient of the linac, so that the electrons could reach the required energy in a shorter distance, this would reduce the size of the linac. If it was possible to also reduce the energy to which the electrons had to be accelerated, this would reduce the linac size even further.

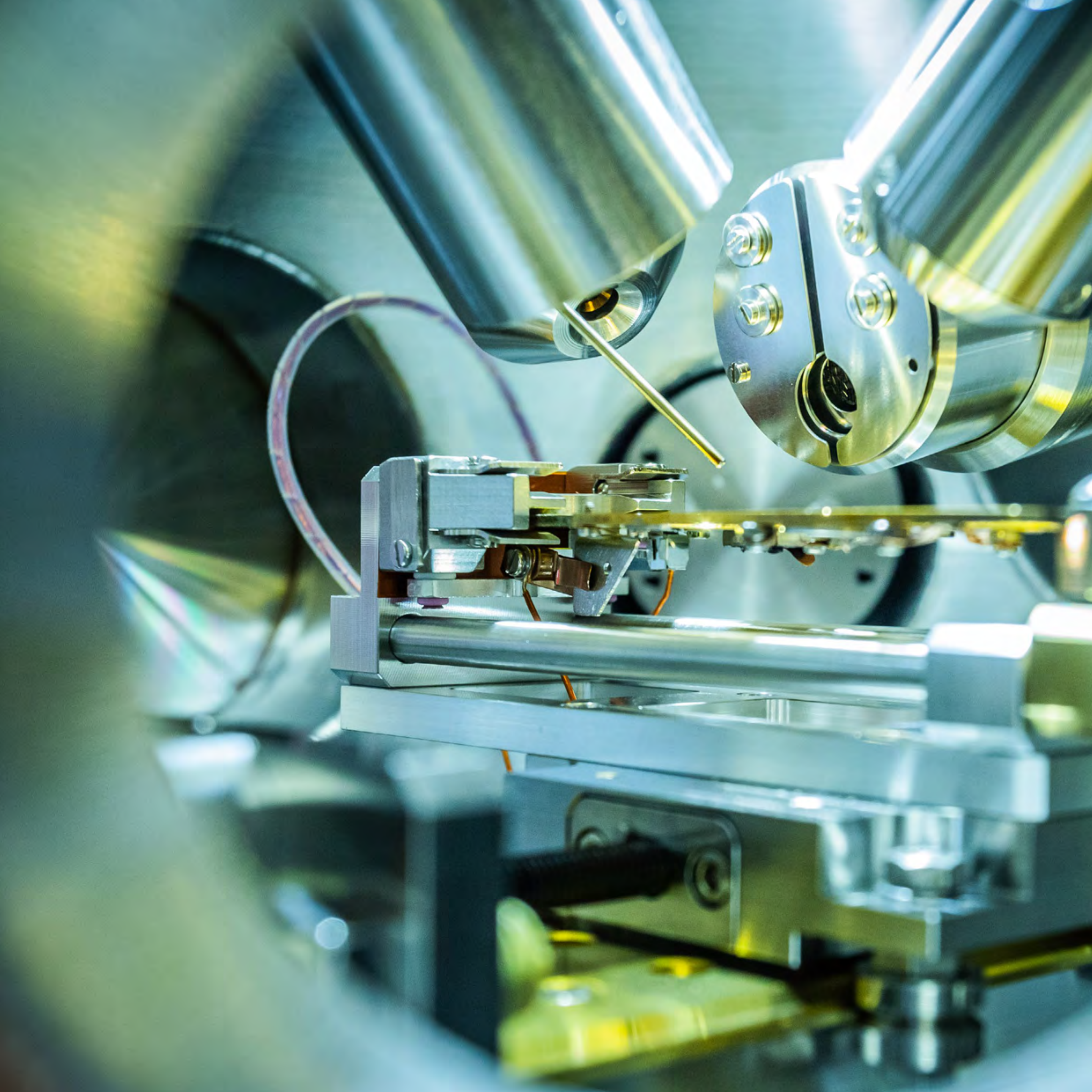
These two aspirations were tackled by the CompactLight Project. This was an EU funded project and a collaboration of 25 universities and national laboratories from Europe and beyond. The main goal was to re-imagine the XFEL to make it more compact and affordable. ASTeC led the overall facility design.

The first innovation was to use a new type of linac developed at CERN, called an X-Band linac, which uses higher frequency radio waves. This means the accelerating gradient is much higher. The second innovation, proposed by ASTeC, was to use a superconducting undulator with a very strong magnetic field that can produce X-rays using a lower electron beam energy. The end result was that the facility length could be several hundred metres shorter than existing XFEL facilities.

ASTeC’s next idea was to use two undulators side-by-side and to split the electron beam into two, one beam going into each undulator. In this way each undulator can independently produce X-rays of different wavelengths which can then be combined together in a single user experiment, opening up new areas of scientific discovery.

The final conceptual design was published at the end of 2021. The innovative ideas generated by the project have found their way into the designs of several future projects, such as UK XFEL, and a number of hardware prototypes are under construction across Europe.

A prototype of the superconducting undulator under construction.



Sustainable Accelerators

The world is experiencing unprecedented environmental changes and swift action is required to cut carbon emissions. UKRI has the ambition to be net zero by 2040 and ASTeC is leading the way for STFC by making particle accelerators far more sustainable in the future. This section highlights several ASTeC initiatives tackling the challenge - the ZEPTO research project delivering more energy efficient machines, the Sustainable Accelerators Task Force undertaking an Accelerator Impact Review and the development of a UK Centre of Excellence in Sustainable Accelerators.

Sustainable Accelerators Task Force Overview

ASTeC has set up a Sustainable Accelerators Task Force to investigate ways in which accelerators can be made more sustainable. Climate change is at a critical point and a sustained reduction in carbon emissions is required to keep global temperatures from rising significantly. The vital research science carried out at many accelerators contributes to both the understanding of climate change and the means to combat it. However, accelerators are by their nature very energy-hungry facilities; larger accelerators can consume many megawatts of power when in use, equivalent to the entire energy demand of a small town. The Task Force aims to bring together research and development into technologies that can make accelerators more energy efficient, so they can deliver the same cutting-edge science whilst drastically cutting their carbon emissions.

ASTeC already has research programmes which can deliver reduced operating emissions for accelerators. The Task Force brings them under the same banner and looks to secure coordinated funding for all of them.

ASTeC's Task Force is also investigating the overall carbon footprint of accelerators. These are complex systems involving many different interacting components: RF, lasers, vacuum, magnets, controls, diagnostics, shielding, heating and cooling. Many of these systems use a large amount of energy and/or materials; the task force aims to look at the carbon footprint of the whole lifecycle of an accelerator, from procurement and construction, through operation and maintenance, right up to decommissioning, disposal and recycling. RUEDI will be a case study, though the findings will be equally applicable to other accelerator facilities such as CLARA and UK XFEL.

Inaugural Sustainable Accelerators Workshop 2022 hosted at Daresbury Laboratory.

Centre of Excellence In Sustainable Accelerators

Particle accelerator facilities are essential to STFC's research portfolio, yet they consume very large amounts of electrical power and impact other valuable resources. The UKRI Infrastructure Roadmap has supported the development of several new accelerator-based facilities and there is an ambition within Europe for a new particle physics collider facility at CERN. It is essential that these potential new facilities are as sustainable as possible and ASTeC has been leading a Sustainable Accelerators activity for several years to ensure that STFC is a world leader in this area. The next step for ASTeC and STFC is to ramp up activities in this area to ensure the most impactful new technologies are ready for implementation in a timescale compatible with these new facilities. This is our motivation for developing the Centre of Excellence in Sustainable Accelerators (CESA).

The mission of CESA will be to host and enable world class R&D that will enable particle accelerators to be much more sustainable and help STFC achieve net zero by 2040. Furthermore, CESA will become a hub for training the next generation of accelerator scientists and engineers, providing them with the knowledge to deliver sustainable designs.

ASTeC has been actioned by STFC to develop the Outline Business Case for CESA and so we are engaging and consulting with the wider UK accelerator community now and assessing which of the possible delivery options is optimal to ensure that CESA meets the needs of the UK.

Selim Dönmez, Getty Images.

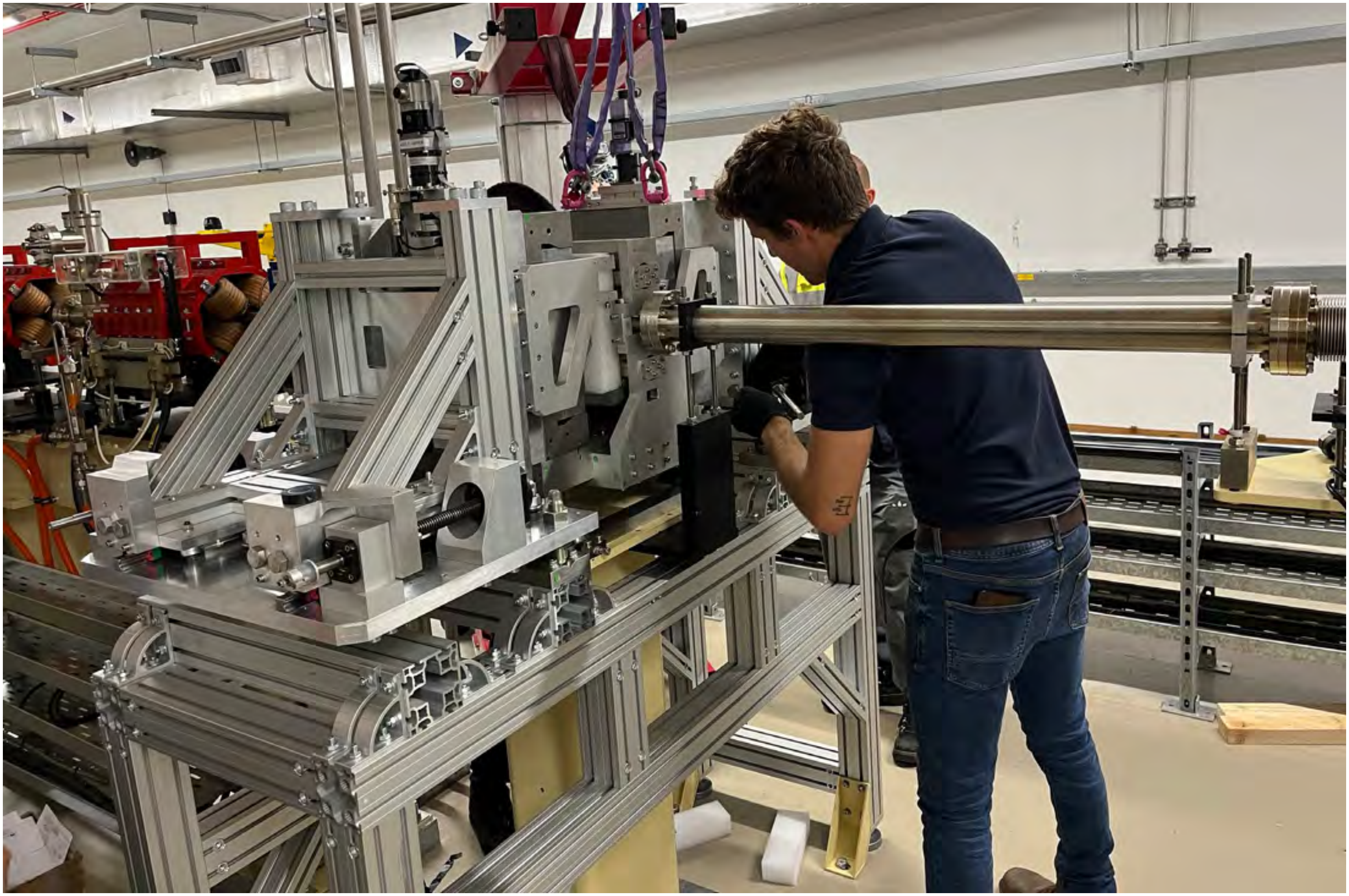
ZEPTO Installation At Diamond Light Source

The ZEPTO (Zero Power Tunable Optics) project has been a flagship research activity for the Magnetics and Radiation Sources Group since the ASTeC-CERN collaboration on the Compact Linear Collider (CLIC) project began in 2011. The particle accelerator community as a whole is pushing for more energy-efficient machines. One way to achieve this is to replace traditional resistive electromagnets, which require constant power draw to operate, with permanent magnet (PM) systems that require no electricity to produce their field. A key limitation of PMs is that they produce a fixed field strength, yet accelerator magnets often need to be adjustable. The ZEPTO project aims to resolve this, by creating PMs that can adjust their field strength, by moving the PM material relative to fixed steel structures. The position of the PM material determines the strength and the shape of the fixed steel structures determines the field shape.

The project is now a key part of the sustainability drive within ASTeC. The goal is to demonstrate that ZEPTO technology can be used beyond the CLIC prototype, as a drop-in replacement for electromagnets on other accelerators. ASTeC therefore entered into a collaboration with Diamond Light Source (DLS) to develop a new ZEPTO quadrupole version for the DLS booster to storage ring transfer line.

This new version was built and measured in 2021, but measurements revealed a critical asymmetry in the assembly procedure. The magnet was re-assembled and re-measured at Daresbury Laboratory during the summer of 2022, with results showing that it was suitable for installation on DLS. Installation proceeded in August/September 2022, proving that the PM can be installed around a beam pipe without breaking vacuum.

Results to date are promising. The DLS electron beam is passing through the magnet during facility user time, with the replaced electromagnet switched off, saving approximately 136 kg of CO2 per year. DLS beam measurements have confirmed that the injection efficiency whilst using the ZEPTO quadrupole is at least as good as a traditional electromagnet. DLS beam experiments have also shown that the prototype fixes a key problem in previous versions – movement of the magnetic centre as the strength is adjusted. The magnet will continue to operate over the course of the next year, with the performance being monitored for degradation over time.



Installation of the new ZEPTO magnet for testing on Diamond Light Source.

Generating Impact With Industry

Many companies use STFC facilities and expertise to develop their technologies, grow their presence in the UK and generate UK jobs. Daresbury Laboratory is a site where this can be seen first-hand. The combination of ASTeC and Technology Department knowledge with Daresbury Laboratory's significant particle accelerator infrastructure has helped the well-known companies Varian Medical Systems and PsiQuantum advance their activities in the UK.

Varian Medical Systems

For more than a century radiotherapy has been used to treat cancer. Ionizing radiation kills malignant cells by damaging the DNA of cancerous tissue and shrinking the tumour. These cells are vulnerable because of their high rate of division and reduced ability to repair DNA damage.

In the UK, on average someone is diagnosed with cancer every 90 seconds. UK cancer incidence has risen by 19% in the last decade. These stark statistics highlight the importance of supporting the development of cancer treatment in the UK.

Varian and STFC open the radiation test facility for Halcyon™ at Daresbury Laboratory.

Varian Medical Systems is a World leading manufacturer of medical devices and software for treating cancer. Varian wanted to increase their commercial resilience by setting up a manufacturing and testing site for their Halcyon™ system within the UK. The challenge lay in finding a suitable location, and the relevant expertise, to allow Varian to generate the radiation needed for final stage testing of the systems before shipping to their destination hospital around the world. Due to the amount of X-ray radiation produced during operation, the testing must take place within a carefully shielded environment to protect those working in the surrounding area.

Daresbury Laboratory has been pioneering particle accelerators (plus the associated radiation protection) since the 1960s when the first accelerator was built on the site. Particle accelerators are the heart of radiotherapy systems and as such ASTeC are perfectly placed to support industry with such challenges. ASTeC and Technology Department (TD) staff worked with Varian to adapt a current radiation test facility to their specific requirements and support Varian to set up and operate the facility for their Halcyon™ system.

Based upon the success of the first test facility Varian wanted to further expand their capability. ASTeC and TD staff also worked with Varian to design and build a second bespoke test facility with a sliding concrete door which could speed up the turnaround time between testing cycles.

By finding a facility to test their Halcyon™ systems, Varian could expand their manufacturing capability. By utilising the expertise of ASTeC and TD staff, Varian were able to set up and operate the new facility quickly and safely and the skill levels of their employees were increased. By creating a bespoke test facility Varian saved one day per test cycle, therefore generating more income from a faster turnaround time of systems from order to delivery. Over a 3.5 year period Varian tested 117 Halcyon™ systems, using the STFC test facilities and support, which could go on to deliver over 20 million cancer treatments around the world.

> **“By working with STFC’s Daresbury Laboratory, Varian were able to produce and test Halcyon™ radiotherapy systems within the UK. This work has led to increased productivity, upskilling our workforce, the creation of new jobs and supporting the development of cancer treatment. The unique facilities, bespoke project support and associated expertise on site made this possible and I would like to thank ASTeC and TD for their support**
>
> **- Steve Pullen, Manufacturing Manager, Varian Medical Systems**

PsiQuantum

Quantum computers are anticipated to solve problems that would otherwise be impossible to solve on any supercomputer now or in the future.

Working in a different way to a classical computer, a quantum computer will be capable of solving computational problems that might otherwise require a billion years to calculate on today's fastest supercomputers.

Where classic computers work in 'bits', a quantum computer uses quantum bits, known as 'qubits'.

Scientists can already build quantum computers with a few hundred qubits, but for a quantum computer to be commercially useful and solve real world problems, qubits are needed in the millions. These devices operate at temperatures just a few degrees above absolute zero, equivalent to the temperature of deep space (in the region of -270°C). Operating in such an environment reduces the thermal noise, improves the quantum coherence, enabling better control and reliability.

Cryogenics is the branch of physics dealing with the production and effects of very low temperatures.

Within particle accelerators cryogenic temperatures are used for superconducting magnets to steer particles and superconducting RF cavities to accelerate them. A superconductor is a material that achieves superconductivity (no electrical resistance) when they are cooled below a critical temperature.

Daresbury Laboratory is already home to one of the UK's largest cryogenic cooling facilities for research and development (R&D). It develops cryomodules for large-scale research facilities across the world. ASTeC and Technology Department have the expertise in these fields leading to a collaboration between STFC and Silicon Valley start-up PsiQuantum. This collaboration will enable PsiQuantum to gain access to the advanced cryogenic systems that are critical in its mission to build the world's first useful quantum computer.

PsiQuantum has subsequently opened its first advanced R&D facility outside of the US at Daresbury Laboratory in March 2023, supported by a £9 million UK government investment. PsiQuantum's collaboration with STFC will ultimately overcome the scaling challenges facing 'fault tolerant' quantum computing.

Image right: Quardia, iStock, Getty Images Plus via Getty Images.

“We are very excited to be setting up a lab in the UK in collaboration with the STFC’s Daresbury Laboratory. The UK has a long history in quantum technologies and a talent pool of exceptional quantum engineers. The STFC team and facilities are absolutely world class, with a deep history of accomplishments in large-scale scientific infrastructure. Access to existing cryogenic infrastructure and expertise accelerates PsiQuantum’s mission to deliver a large-scale quantum computer.

- Mark Thompson, Chief Technologist and Co-Founder at PsiQuantum

People, Events and Awards

ASTeC staff continue to support major events from conferences to massive outreach activities. Meanwhile, staff members past and present are receiving prestigious awards and recognition for their remarkable work. This section focuses on ASTeC events, staff and the continuous improvement of the department.

Accelerator & Particle Physics Masterclass

ASTeC hosted the Accelerator & Particle Physics Masterclass (APPMC), our flagship annual outreach event in collaboration with the other Cockcroft Institute members and the Daresbury Laboratory public engagement team, on 29th March 2023. This event is traditionally done by inviting visitors to the laboratory, but the uncertainty over COVID led to it being organised as an online event once again.

Whilst doing online-only events does restrict our ability to show off our work and facilities, it also presents opportunities. It makes it possible to introduce new interactive activities that students can "play along" with and learn at home, and these are powerful tools for making learning about particle accelerator technology engaging for teenagers. The online delivery also provides scope for greater reach, both in numbers and geographically, as participation is no longer limited to those close enough to travel to Daresbury Laboratory or restricted to the numbers that can be safely accommodated on site. It also allows us to bring in virtual tours from other facilities such as Diamond Light Source.

This year we hosted the event in direct conjunction with schools, with students joining during the school day as complete class groups. In total, we welcomed 477 students and 24 teachers from around the country, making this our largest ever masterclass event.

The day included talks on the history and purpose of synchrotron radiation, the physics of electromagnetism, and an ASTeC produced video explaining vacuum. We brought in collaborators from Diamond Light Source who gave their virtual tour, and from Boulby underground laboratory who delivered a live walk-round of the experiments taking place deep under the north sea. We also guided the students through the Lancaster Particle Physics Package and Liverpool Surfatron, interactive activities that explain how particle acceleration works. The day ended with students submitting questions that were answered live by staff, students and apprentices from across ASTeC and the CI.

Screenshot from the online masterclass, showing James Conlon (ASTeC) performing vacuum demonstrations.

Continuous Improvement: Daresbury Site Induction Project

The continuous improvement project, led by Alison Cooper, ASTeC's Departmental Safety Lead focussed on reducing the time spent by staff, contractors and users completing the site induction, a mandatory requirement to work at the Daresbury Laboratory (DL). The existing induction process took visitors ~45+ minutes to complete, costing £25,000 in lost time alone. From a safety perspective, between 17 June 2020 and 10 February 2022 the compliance scores for users were, on average, 47.5%, putting individuals and others at risk by not meeting the minimum requirements whilst on site.

The changes implemented have made a big impact, outperforming the original targets, resulting in the following benefits:

- Increasing safety compliance of individuals working on our site.
- Focussing succinctly on the dos, don'ts, safety, and emergency procedures and recognising that everyone has a mobile phone has reduced the time to complete the induction from 43.33 mins to 13.10 mins, a cost saving of approximately £17,500 each year.
- Increasing customer satisfaction and the reputation of STFC by sharing updated and relevant training.
- Introducing mobile authentication has enabled individuals without a company email address the opportunity to complete induction training without delay.

Alison Cooper (ASTeC) presenting her storyboard.

Daresbury Laboratory Concept Image

The concept image for Daresbury Laboratory was created by Kieran Belshaw, who was a concept artist on Game of Thrones. Helen Cattell and Anthony Gleeson (Business Development for ASTeC) worked with Kieran during dark winter lockdown evenings to help build a picture of what Daresbury is all about.

The resulting image highlights some of the fantastic work that has taken place on the site over the past 60 years from the Nuclear Structure Facility in the tower to solving the structure of the foot and mouth virus using the SRS.

Concept image of Daresbury Laboratory site, created by Kieran Belshaw.

Vacuum Symposium Success At Daresbury Lab

Vacuum Symposium UK is an annual event aimed at bringing together academic and industrial users of vacuum science and technology along with its many applications.

The very first event was held at Daresbury Laboratory in 2010 and, due to the hard work of colleagues in ASTeC, it returned for the first time since in July 2022 for Vacuum Symposium 11.

LINAC2022

The 31st International Linear Accelerator Conference, the first in-person Linac conference since Beijing in 2018, was hosted by STFC, the Cockcroft Institute and the John Adams Institute. The conference was chaired by Peter McIntosh (ASTeC).

LINAC2022 WISE Session

A Women in Science and Engineering (WISE) session was conducted which comprised the eminent Professor Averil Macdonald OBE, who gave the keynote address for the topic of 'Reclaiming the Authority Gap'. In addition, an illustrious panel discussed with the audience possible solutions to dealing with this problem in scientific and educational organisations. Anna Shabalina (ASTeC) and Steve Jamison (Lancaster University), together with Tessa Charles (University of Liverpool) who was also in charge of the overall EDI aspects of the conference, deserve significant credit for the coordination and delivery of this impactful session which received extensive acknowledgement from the LINAC2022 participants. It is hoped that the recent addition of a WISE session to both the Virtual LINAC2020 and this LINAC2022 can be maintained for future conferences.

Anna Shabalina (far right) chairing the panel discussion at the Women in Science and Engineering session.

Faye Taylor Wins Institute Of Physics Technical Skills Award

Faye Taylor has achieved extraordinary things in her time as an apprentice. She has commissioned and programmed a controls system for CLARA, STFC's next generation research and development particle accelerator; she has designed dynamic system requirements for the LINAC Water Stability System, to ensure that the exceptional beam stability that is demanded is achieved; and she has supported the development of the electrical infrastructure within the European Spallation Source currently under construction in Sweden.

Peter McIntosh Recognised By Lord Mayor of Liverpool

As Conference Chair of the 31st Intentional Linear Accelerator Conference (Linac2022) held at the Liverpool Arena and Convention Centre (ACC) in September, Peter McIntosh (ASTeC) was recognised by the Lord Mayor of Liverpool for bringing £990k of investment to the city.

Susan Smith Awarded OBE

Susan Smith, former Head of Daresbury Laboratory and former Director of ASTeC, has been awarded an OBE (Officer of the Order of the British Empire) by Her Majesty The Queen in the 2022 New Year Honours for services to Science and Technology.

WiSTEM Event Stats

As a non-funded staff network, run by volunteers at DL, the DL WiSTEM committee organised the first in-person network event in over 2 years back in May 2022. Since then, the 3 members of the committee, 2 of whom are from ASTeC, organised 4 significant events for the DL WiSTEM network. The events visibly consisted of significant numbers of ASTeC people!

Summary of network events:

1. **WiSTEM Coffee Morning 18.05.22**
   First in-person DL WiSTEM event in over 2 years!

2. **WiSTEM network meets STFC Council & Exec Board 21/09/2022**

3. **WiSTEM talks menopause: Agile Life Sciences 25/10/2022**

4. **WiSTEM Innovation talk with Yupar Myint 02/02/2023**

5. **WiSTEM coffee meet up - Innovation Team Talk with BID 23/03/2023**

New DL WiSTEM Lead

The new DL WiSTEM Lead is none other than our very own Lauren Hamblett, who volunteered for the role in March 2023 and hit the ground running, organising and leading the WiSTEM coffee meet up with the Innovation team within a week!

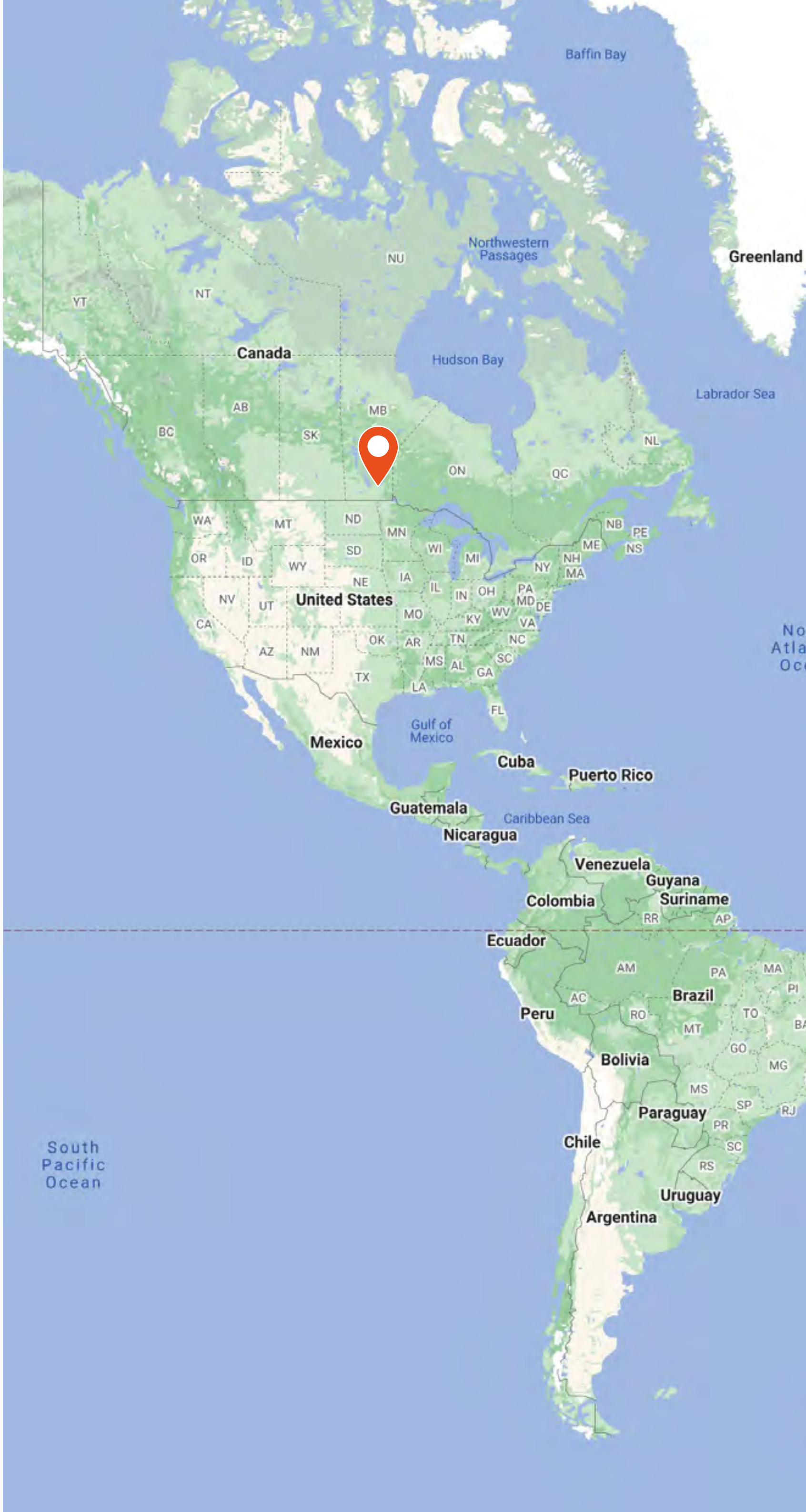
Remarkable Leadership

Members of the STFC WiSTEM network were given the exciting opportunity to apply for fully funded places on the extremely popular “Remarkable Leadership” training course. We are proud to say that 3 of the 10 coveted places when to members from ASTeC! This course is funded across STFC by BID.

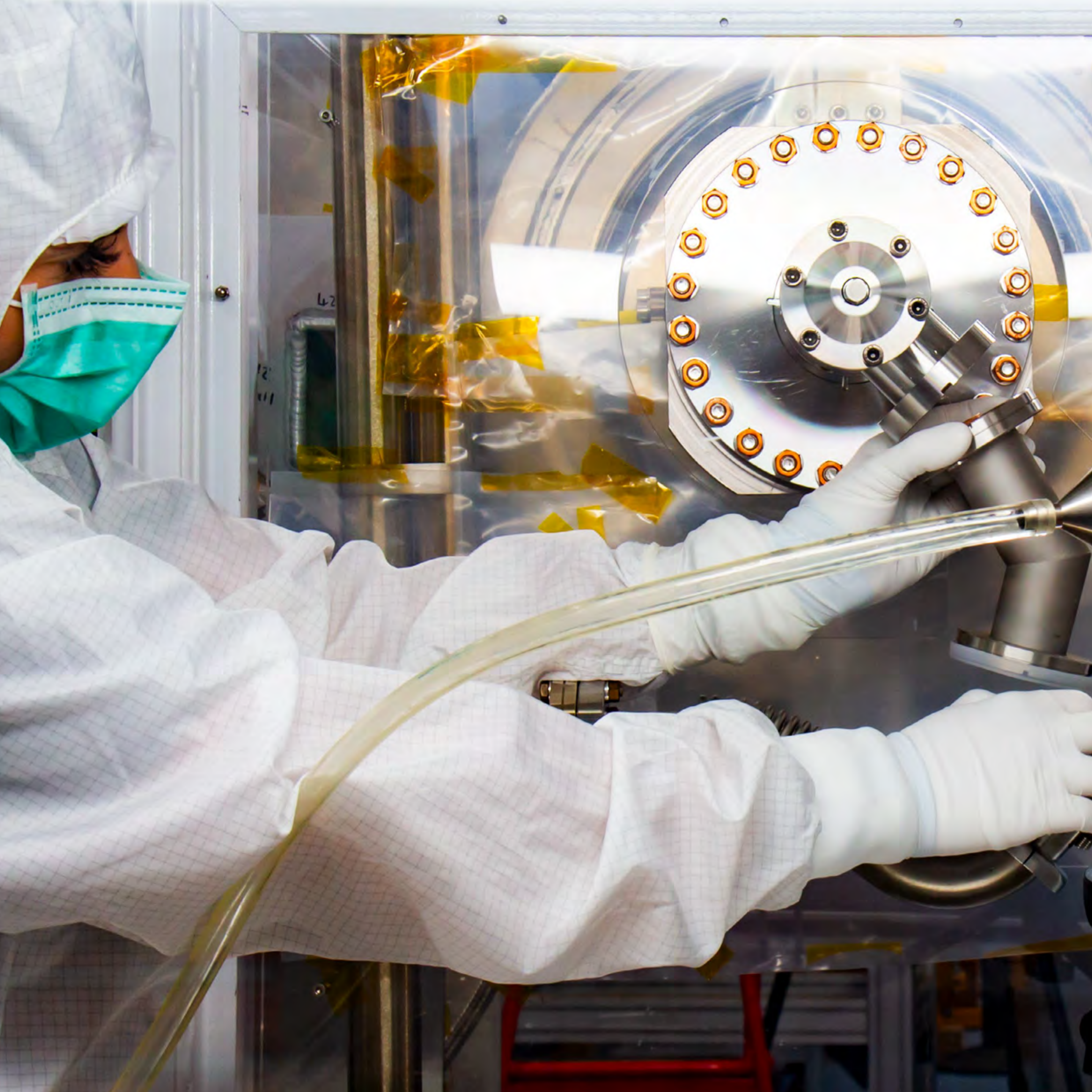
ASTeC's ED&I Place Of Birth Map

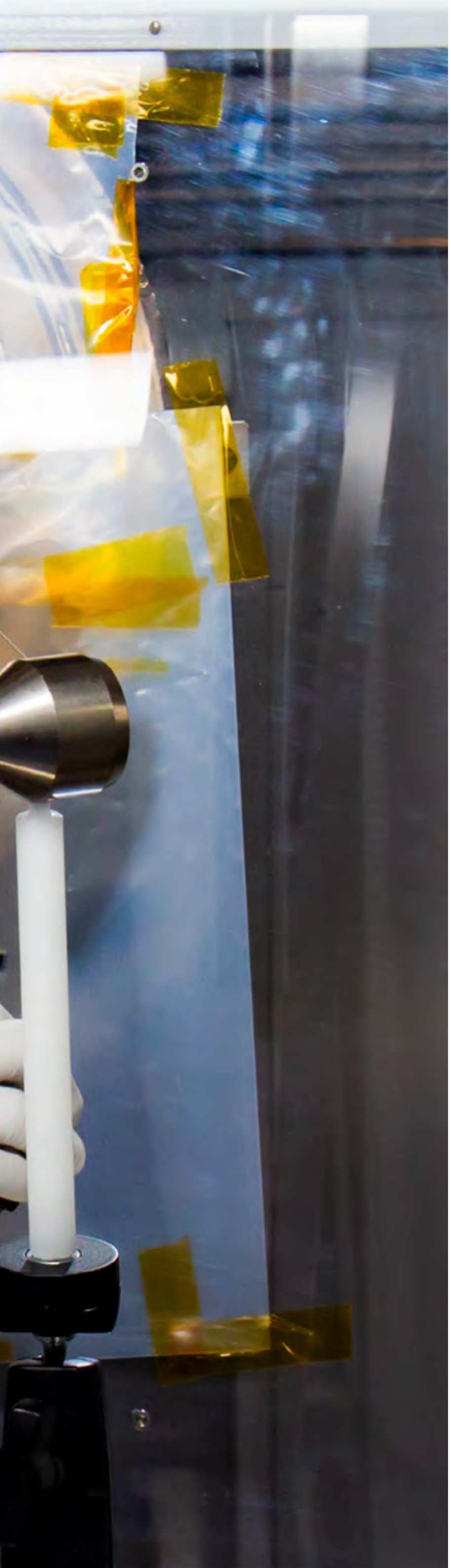
As part of an initiative to help us think about diversity within our department, ASTeC's ED&I team asked staff to fill out a simple form with their town/city and country of birth. This information has been turned into a diversity map showing where we all come from and gives us a broader understanding of the different nationalities present within our department.

Map showing the birthplaces of ASTeC staff.



Barents Sea
Kara Sea
Norwegian Sea
Iceland
Sweden
Norway
Russia
Denmark
Belarus
Poland
Ireland
Germany
Ukraine
Kazakhstan
Mongolia
Austria
France
Romania
Italy
Kyrgyzstan
Portugal
Türkiye
Turkmenistan
Sea of Japan
China
South Korea
Japan
Tunisia
Syria
Iraq
Afghanistan
Morocco
Iran
Pakistan
Nepal
Algeria
Libya
Egypt
East China Sea
Western Sahara
Saudi Arabia
India
Myanmar (Burma)
Oman
Philippine Sea
Mauritania
Mali
Niger
Sudan
Chad
Yemen
Thailand
South China Sea
Burkina Faso
Gulf of Aden
Arabian Sea
Bay of Bengal
Vietnam
Guinea
Ghana
Nigeria
Ethiopia
Gulf of Thailand
Laccadive Sea
Malaysia
Gulf of Guinea
Somalia
Kenya
Gabon
DRC
Indonesia
Tanzania
Banda Sea
Papua New Guinea
Arafura Sea
Angola
Zambia
Mozambique
Namibia
Zimbabwe
Madagascar
Indian Ocean
Botswana
South Atlantic Ocean
Australia
South Africa
Great Australian Bight
Sea of Okhotsk





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ASTeC Science Highlights 2021-2023

This report covers the work accomplished by the Accelerator Science & Technology Centre (ASTeC) for the years 2021 - 2023

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