Science and Technology Facilities Council

ASTeC Highlights 2019–20

Accelerators in a New Light

Contents

Professor Jim Clarke

Director's Foreword

This report highlights some of our most prominent achievements during 2019-20. As noted in the article on CLARA, as we ended the financial year we entered into a national lockdown caused by the COVID-19 pandemic. The international science community has rapidly responded to this crisis and it is inspiring and motivating to see the amazing research being carried out using the Diamond Light Source that was designed by ASTeC twenty years ago. A feature of accelerator research and development is that the eventual impact of our work is impossible to predict. The pandemic has reminded us all that major investments in national science facilities are essential to meet the challenges of the future. Our recent work on radiotherapy systems for low and middle income countries also make it clear that our research can have lifesaving impact using modest accelerators too.

This report highlights some of the activities that have been made possible with the CLARA accelerator facility. New methods have been proven for the first time to generate light and to accelerate electrons. These new techniques may open up new applications for accelerators or make light sources and accelerators more affordable in the future.

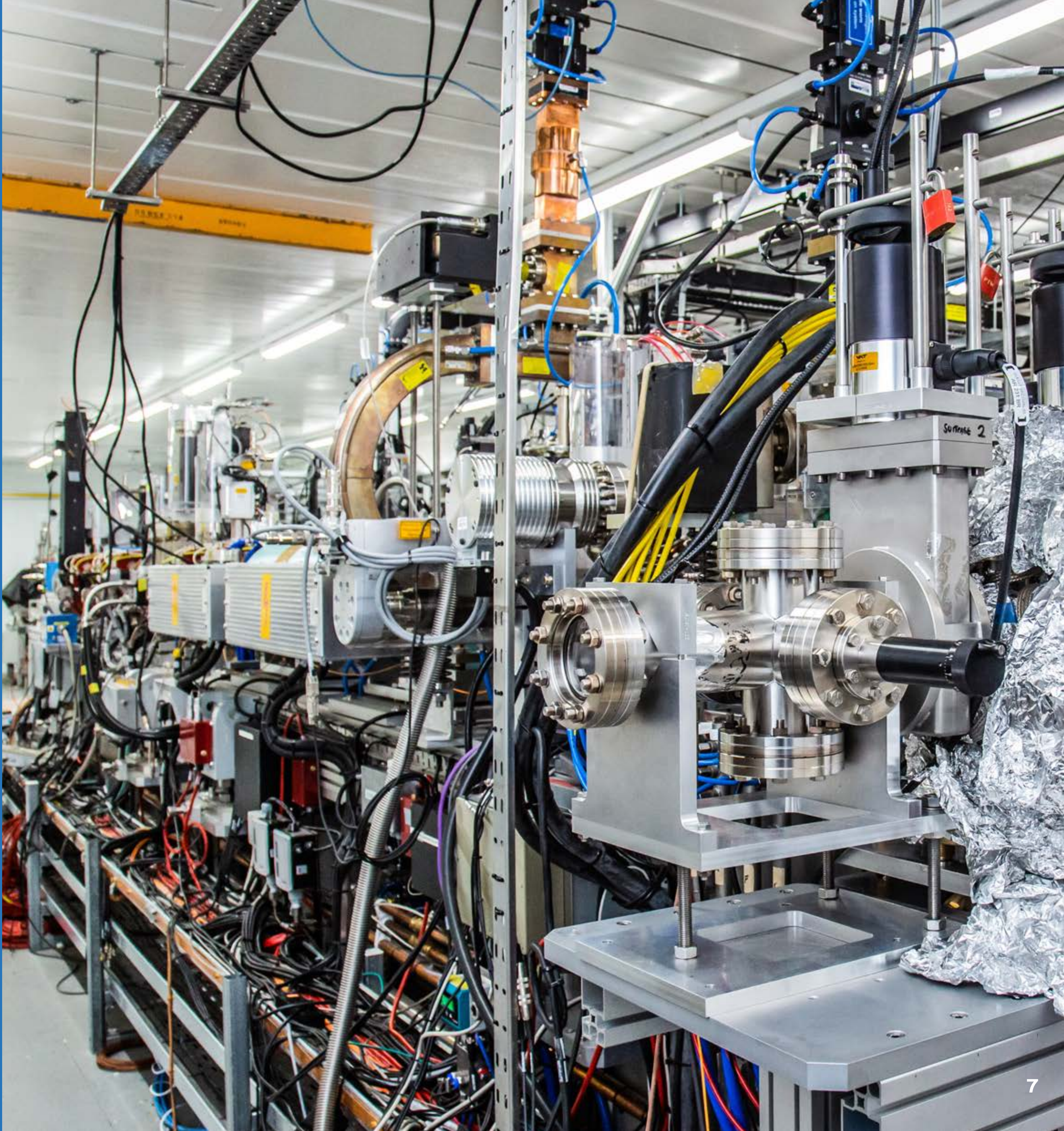
It is important that we don't stand still and continuously look to enhance our capabilities to ensure that we are able to make meaningful contributions internationally. In recent years we have established new capabilities in vacuum and surface science, cryogenic testing of accelerator components, and in the application of lasers. Some of our most exciting developments are explained here together with the impact that they are already having.

Finally, it is wonderful to share some of the very public successes of our staff in this edition and to hear their stories. All of their achievements are fully deserving of public recognition and celebration. Our success depends completely on all of our staff and their accumulated experience, it is gratifying to know that our skills are appreciated so widely.

CLARA Successes

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 for the UK to build a next-generation X-ray Free-Electron Laser user facility.

This year a lot of work has been done to 'commission' CLARA – this is the process of making sure that CLARA's performance meets the demanding specification. There have also been excellent results from users of the CLARA electron beam who have for example demonstrated a new type of radiation source and made a pocket-sized accelerator. In parallel ASTeC scientists and engineers have designed FEBE, a planned extension to CLARA where users can do experiments using high-energy electron bunches combined with high power lasers.



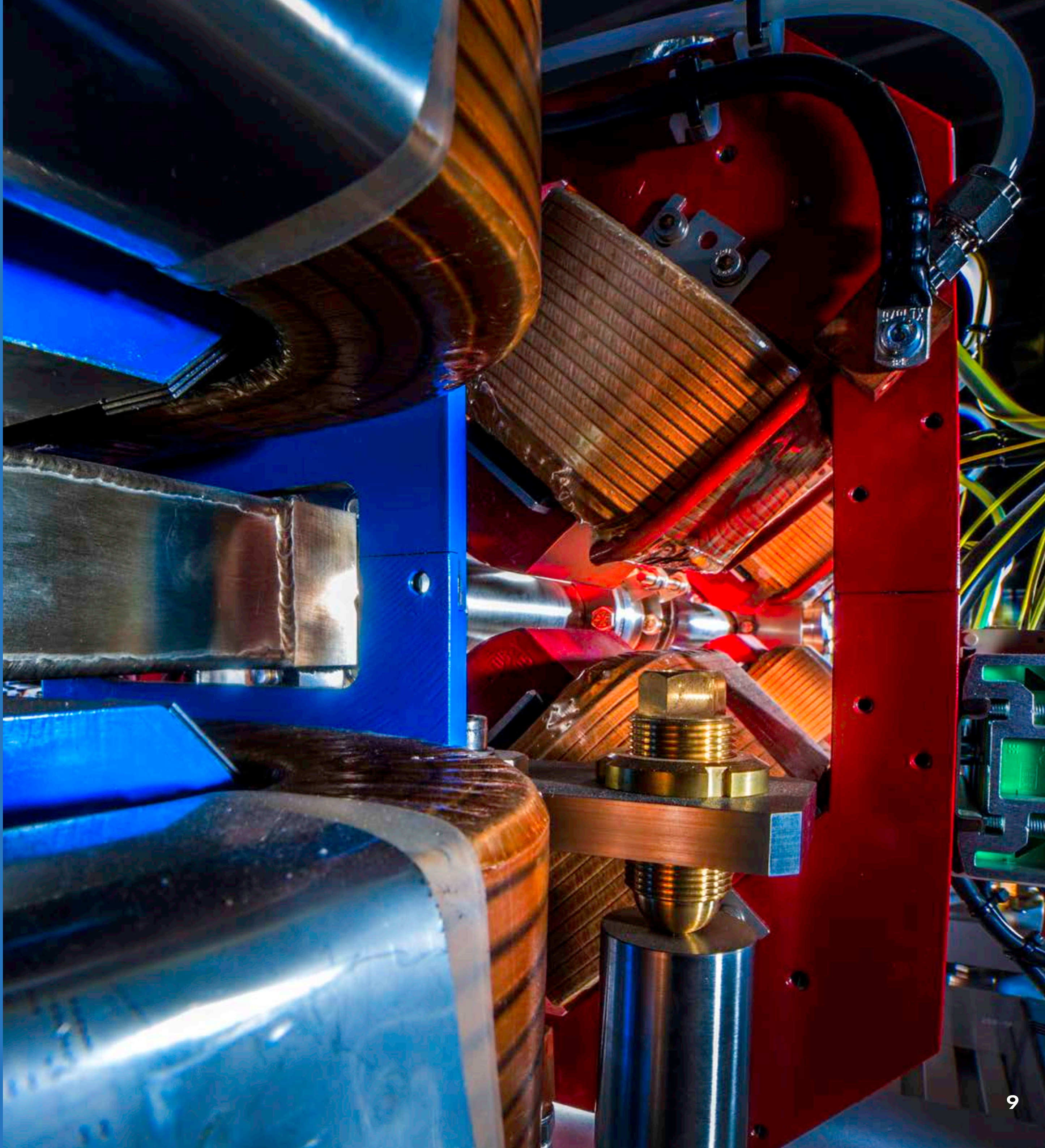
Commissioning CLARA – from Shutdown to Lockdown

After the end of a successful user run in March 2019, CLARA was shut down temporarily to improve the radiation shielding so that the next phase of CLARA could be built up in the accelerator hall. Once this is done the beam energy can be increased from 50 MeV to 250 MeV – this higher energy beam will be sent down the FEBE user beamline and could eventually be used to drive a Free-Electron Laser.

During the shutdown the 10 Hz electron gun was upgraded. First, ASTeC scientists used their photocathode expertise, built up over the last few years of R&D in this area, to prepare a selection of promising photocathodes using different materials and surface treatments. The 'candidates' were measured for surface roughness in our optical metrology lab and then tested in the electron gun to see how they responded to the high power accelerating fields. After that a 'load lock system' was installed on the gun to allow the photocathode to be rapidly changed without having to go through the lengthy process of opening up the vacuum chamber. This will ensure that the gun is always available to produce high charge electron bunches. Finally, the photon beamline which transports the photoinjector laser from its source in the laser room and steers and focusses it onto the cathode itself, was modified to give a higher quality laser beam – this in turn improves the quality of the electron beam.

The next step was to 'RF condition' the upgraded gun. This is the process of gradually increasing the strength of the radio-frequency (RF) electric accelerating field inside the gun. If this is done too quickly then huge sparks are created which damage the inside surface and limit the maximum field. If it's done slowly, however, the inside surface gets gradually smoother and higher fields can be reached. Because the quality of the electron bunches is better for higher accelerating fields, this is an important but time consuming process. To speed things up, ASTeC scientists developed the intelligent No-Operator Automatic RF Conditioning (NO-ARC) code which allows unmanned RF conditioning overnight and on weekends, making the process a lot quicker and more effective than doing it manually.

The results of the gun upgrade were quickly seen when CLARA was turned on again after the shutdown – the bunch charge could be increased to over 400pC, much higher than the design value of 250 pC. But it wasn't all good news – this high charge quickly degraded again. Work is ongoing to solve the problem. However, beam was transported successfully to the user area. ASTeC scientists were getting on with the detailed measurements used to characterise the beam before the start of the user program when suddenly all work was suspended due to the COVID-19 lockdown.



A New Type of THz Radiation Source

Terahertz (THz) is a region of the electromagnetic spectrum between infrared (used in TV remotes) and microwave (used in ovens). There are applications of THz radiation in material science, medical research, and many other fields. One source of high power, narrowband, THz radiation is Coherent Cherenkov Radiation (CCR) which is given off when an ultra-short electron bunch - shorter than the wavelength of the THz radiation – passes through a 'structure' specifically designed to resonate at a given THz frequency. CLARA is one of the few places in the world where ultra-short electron bunches can be used to explore this concept.

An ASTeC-led experiment on CLARA demonstrated the world's first continuously tunable, narrowband CCR source. This experiment was a collaboration between ASTeC, RAL Space, The University of Manchester, Royal Holloway University of London, and Lancaster University. Electron bunches with a charge of 100 pC and duration 300 femtoseconds were sent to the experimental area called Beam Area 1. Here, the bunches were carefully focussed and steered through a novel rectangular dielectric lined waveguide (DLW), made of precision machined copper lined with ultra-thin (25 um) quartz wafers. The CCR was quickly detected then the gap between the dielectric wafers was varied using picomotor actuators - this changed the frequency. The CCR produced was transported to a bespoke Martin-Puplett interferometer which measured the frequency and bandwidth. It was found that the CCR was smoothly tunable over a wide range from 0.6 THz to 1 THz, with a bandwidth of less than 0.05 THz, in excellent agreement with the computer simulations and theoretical predictions! The experimental results were published in Physical Review: Accelerators and Beams in 2019 and were among the first to be published from the inaugural CLARA user run.

CCR sources are of great interest to developers of new accelerator-based light sources. This is partly because they are compact, but also the light given off is exactly synchronised with the electron bunch used to generate it. Scientists can therefore do experiments where the CCR is used in combination with radiation at other wavelengths generated by the same electron bunch using, for example, a free-electron laser. In such 'pump-probe' experiments, where one pulse of radiation is used to excite (pump) a sample and another pulse of radiation is used to study (probe) how the sample then rapidly changes over ultra-short timescales, exact synchronisation of the two pulses would allow extremely precise timing measurements to be made of the processes studied. The CCR pulse can be further controlled - the THz pulse energy can be increased by making the DLW structure longer, and the peak power can be increased by turning up the bunch charge. These results showed the scientific community that CLARA is a great place to do novel and world leading experiments.

The interaction chamber inside Beam Area 1

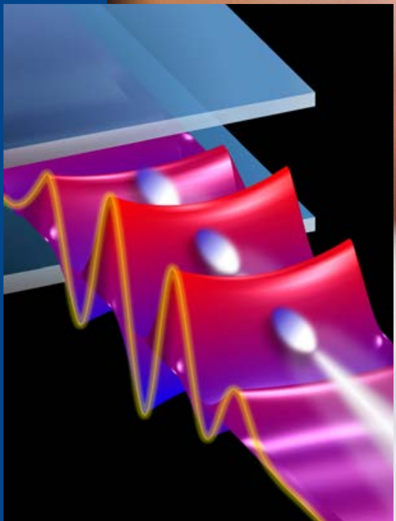
Creating a Pocket-Sized Accelerator

This year ASTeC scientists created a new type of pocket-sized accelerator. They collaborated with their colleagues from the Cockcroft Institute to develop a new way of using lasers to generate THz light pulses. These were focussed into a dielectric structure at the same time as ultra-short CLARA electron bunches were injected – the result was that the electron bunches were accelerated to more than 99.99% of the speed of light! The THz was created by exciting a nonlinear crystal with a high power femtosecond laser producing an accelerating gradient of 1 GV/m - this is ten times higher than a 'traditional' RF accelerating cavity so particles reach higher energies over much shorter distances - this is why the accelerator is pocket sized.

The wavelength of THz is around a millimeter. At this scale it is easy to make suitable accelerating structures which can completely capture and accelerate ultrashort bunches with high charge. This makes it possible to measure and manipulate particle bunches on time scales of less than 10 femtoseconds. In the future, THz accelerators could be used to track atomic motion in samples and construct so-called molecular movies for materials characterisation.

The research was published in Nature Photonics. Lead author on the paper Dr Morgan Hibberd from The University of Manchester said: "The main challenge was matching the velocity of the accelerating THz field to the incoming electron beam velocity, while also preventing the inherently lower velocity of the THz pulse envelope propagating through our accelerating structure from significantly degrading the length over which the driving field and electrons interact. We overcame this problem by developing a unique THz source which produced longer pulses containing only a narrow range of frequencies, significantly enhancing the interaction. Our next milestone is to demonstrate even higher energy gains while maintaining beam quality. We anticipate this will be realised through refinements to increase our THz source energy, which are already underway."

Professor Steven Jamison of Lancaster University, who jointly leads the programme, explained: "The controlled acceleration of relativistic beams with terahertz frequency laser-like pulses is a milestone in development of a new approach to particle accelerators. In using electromagnetic frequencies over one hundred times higher than in conventional particle accelerators, a revolutionary advance in the control of the particle beams at femtosecond time scales becomes possible."



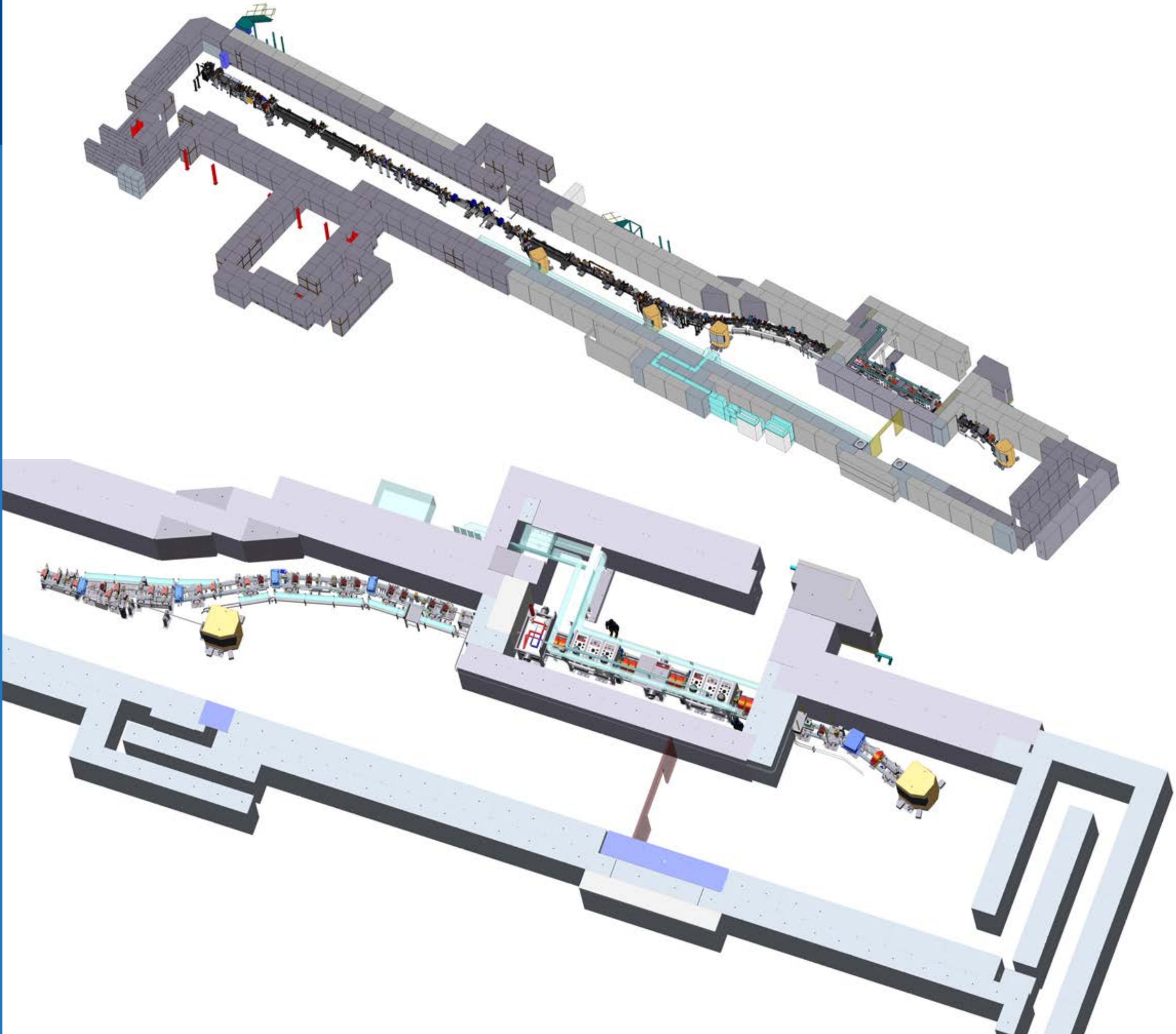
Schematic illustration of electron bunches being accelerated by waves of THz

Designing a High-Energy Electron Beam User Facility

This year the design work for FEBE, the Full Energy Beamline for Exploitation, has reached an advanced stage and construction of components has begun. FEBE is a planned extension to CLARA, where users will be able to do experiments using CLARA's high-quality, electron bunches at an energy five times higher than is currently possible. Making FEBE as useful as possible for scientific and industrial users is essential, so the design priorities were to give users maximum flexibility at the same time as the highest quality electron bunches. The provision of a 100 TW-class laser (about ten times more powerful than the laser currently used in experiments with the electron beam) and advanced novel diagnostics extend FEBE's appeal and will enable world-leading research in novel acceleration and plasma-based concepts.

The design has benefitted from the experience of planning, commissioning and operating CLARA's Beam Area 1 (BA1) user facility which has clearly shown the need for an electron-beam user facility in the UK. Because FEBE is an extension to CLARA it had to be designed to fit inside the existing building. User feedback from experimental runs in BA1 had highlighted the benefits of keeping the user station in a separate enclosure (hutch) to the main machine, with user teams able to install and commission their experimental equipment without the electron beam present but whilst the accelerator is still being optimised, saving both time and staff effort.

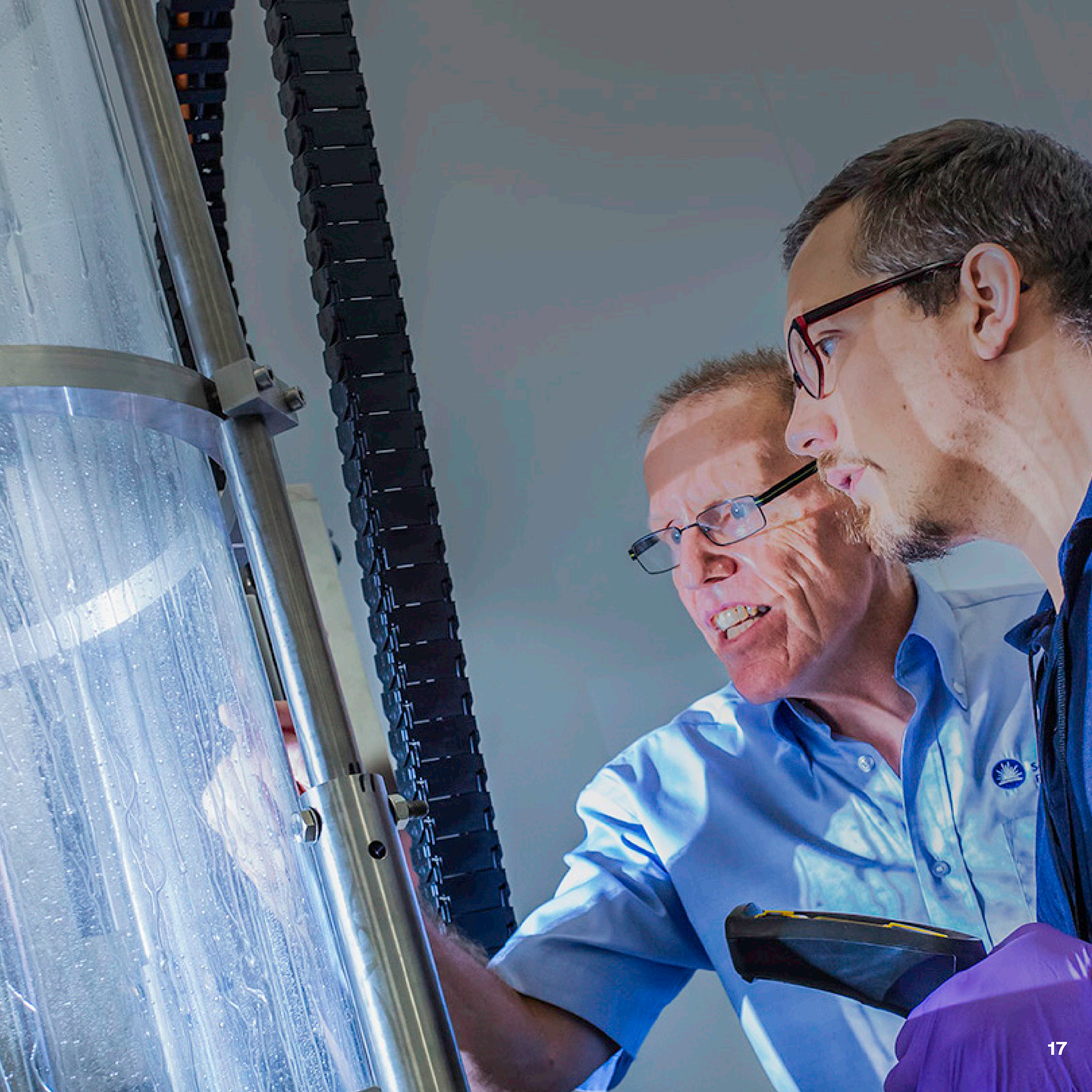
FEBE is offset transversely from the main CLARA beamline, linked by a 4-dipole arc containing alternating focussing and defocussing quadrupole magnets. Strong non-linear collective effects, in which the electrons in the bunch interact with each other, occur in the beam transport line from CLARA to FEBE, but by designing the beamline carefully using the latest techniques in accelerator physics the degradation in the quality of the bunch due to these effects has been minimised. The design must also minimise any potential impact on the CLARA FEL which will be built in the 'straight ahead' position next to FEBE, so the final layout is the optimal compromise between this constraint and the need for high-quality beams at the FEBE experimental stations.



Engineering layouts of (top) CLARA, showing how the electron bunches will be diverted into the FEBE beamline, and (bottom) a closer view of the FEBE beamline showing the shielded user experimental area

Infrastructure Developments For New Capability

ASTeC scientists and engineers continue to develop the infrastructure to enable the research and development that will expand the capabilities of future accelerators. Highlights enabled this year include the demonstration of a novel method of particle acceleration using the LATTE Lab in combination with CLARA, success in advancing new thin-film technologies for superconducting cavities in the VISTA Lab, and progress in developing the SuRF Lab for series production of superconducting RF cavities for large international accelerator facilities.



The LATTE Lab

Despite its name the LATTE Lab does not serve coffee! In fact, within the lab drinking is forbidden. LATTE stands for LAsers, Terahertz (THz) and Terrawatt Experiments and the laboratory is ASTeC's dedicated facility for the research and development of new laser applications. It is home to a number of powerful, pulsed laser systems, the largest of which is capable of 20 Terawatt pulses (that's 20,000,000,000,000 Watts) that are less than 50 femtoseconds (0.00000000000005 seconds) long. This system is so powerful that the light must be transported in vacuum to avoid turning the air into a plasma and distorting the pulses. The LATTE Lab lasers can be synchronised in intricate combinations with each other, and are also used to do experiments with the CLARA accelerator beam which is housed next door.

The generation and detection of THz radiation is one of the core research tools of the lab. It lies in the frequency range between microwaves and infrared light and has a wavelength of about 100 micrometres – the width of a human hair - similar in length to an electron bunch in a particle accelerator, meaning that the bunch's electric field can be measured in similar ways to THz radiation. This is one of the lab's main research topics, and a new high resolution bunch profile diagnostic is currently being tested on CLARA that could be applied to accelerators around the world.

A growing use of the lab is to provide reliable high energy laser pulses for CLARA exploitation activities. This has attracted great interest as the combination of a terawatt laser and a relativistic electron beam is rare and provides great opportunities in laser-plasma acceleration, direct laser acceleration, and diagnostics development. A highlight this year has been using the lasers in the LATTE Lab in the first demonstration of direct acceleration of relativistic electron bunches with THz radiation. This is a ground-breaking result, which earned a Nature group publication and may pave the way for future miniaturisation of particle accelerators. The experiment is described in more detail in the CLARA section of this publication. This work was done by the DATA group - a collaboration of ASTeC and Cockcroft Institute scientists and students.

The lab is also used to conduct R&D for other CLARA purposes, such as testing systems that will be eventually installed on the CLARA photoinjector laser. This laser is required to run all the time that CLARA is accelerating electrons, so chances to work directly on it are limited. There is also work on high precision laser synchronisation schemes with a target to match laser pulses and electron bunches with a precision of one femtosecond. To do this the lasers must be controlled using sophisticated in-house designed and built electronics systems in a very stable environment.

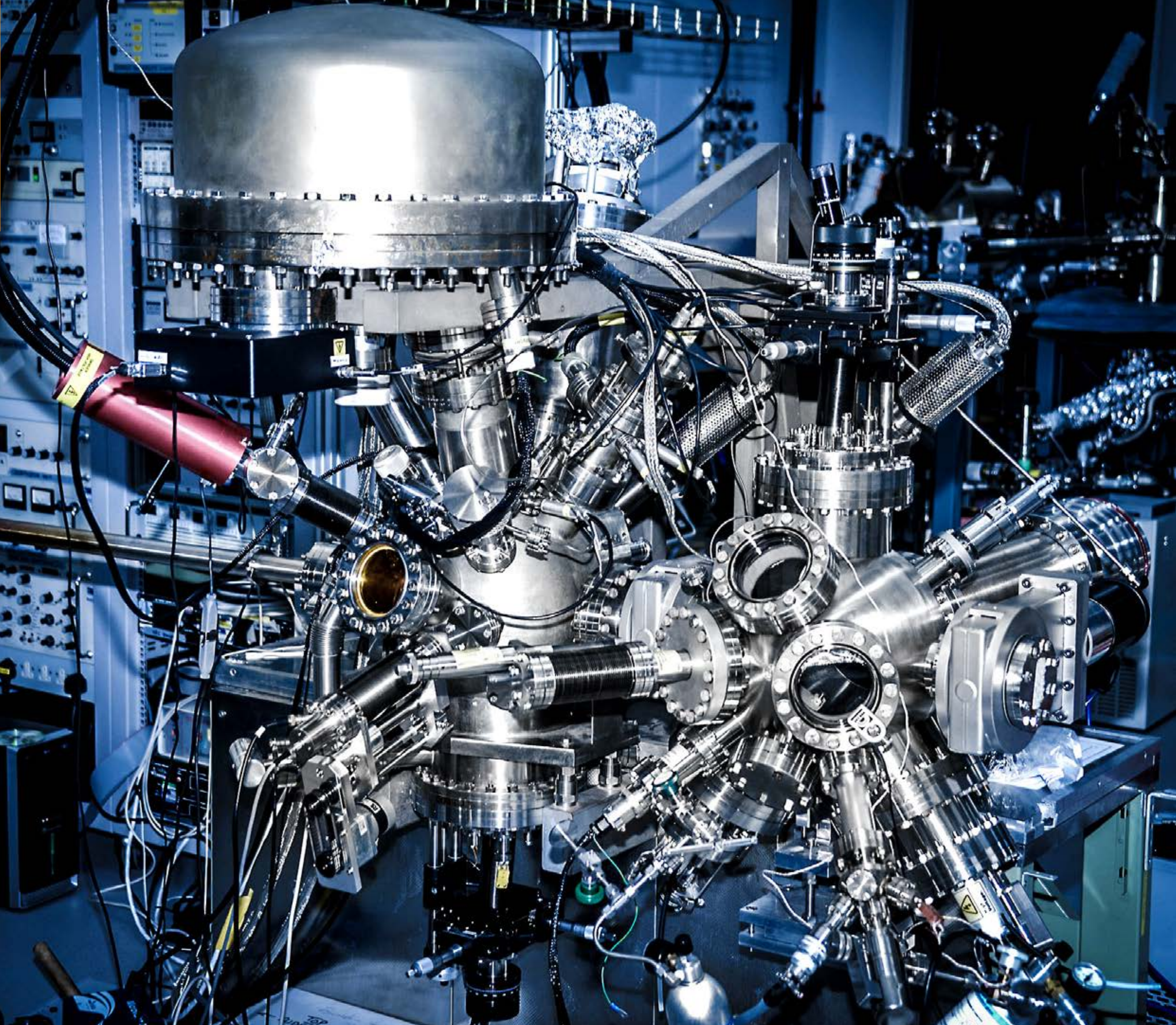
The VISTA and Cryogenics Labs

The ASTeC Vacuum Solutions Group (VSG) manage the Vacuum Interface & Surface Technologies for Accelerators (VISTA), Cryogenics and Vacuum Processing Labs. These are used for research on photocathodes, vacuum technologies and thin film coatings for next-generation accelerators such as an upgraded Diamond Light Source near Oxford, PETRA IV in Hamburg, an upgraded Large Hadron Collider at CERN and a new X-ray Free-Electron Laser in the UK.

One area where the team are making significant contributions is superconducting radiofrequency (SRF) thin film development. SRF accelerating cavities can accelerate millions of electron bunches per second because they are built from niobium which becomes superconducting if cooled to about minus 270 C - this means there is no electrical resistance in the cavity walls so they don't heat up due to the high electrical currents on the inside surfaces. However, niobium is expensive so ASTeC scientists are researching the idea of using a very thin superconducting film deposited on the inside of a much cheaper copper cavity. Within the VISTA lab a comprehensive facility which uses a technique called physical vapour deposition is used to make superconducting films such as niobium, niobium nitride and niobium tin. Other deposition techniques, such as Chemical Vapour Deposition (CVD), Plasma Enhanced CVD and High Power CVD can be used for more complex shapes and more challenging materials such as magnesium boride. The films are analysed for structure, morphology and composition using different techniques, including, for example, imaging the surface with a Scanning Electron Microscope. The superconducting properties are then studied at low temperatures in the cryogenics lab - but this can only be done at very low RF powers.

However, through an international collaboration called ARIES (in which ASTeC coordinates one of the work packages) superconducting films can now be tested at higher RF powers. This year the team deposited niobium films onto a quadrupole resonator (QPR) – a cavity specially designed for testing flat films at high RF power. The films were prepared by collaborators overseas, then sent to Daresbury for deposition on the QPR in a specially built facility. The QPR was then forwarded to further members of the collaboration for testing. This was a challenging operation because the films had to be kept as particle free as possible as the different stages of the process were carried out across Europe. The final test results showed the superconducting performance of the thin film was very promising. The team will continue with future tests, moving to more complex layered thin film structures which may improve the performance of SRF cavities even further.

This development of this technology maps onto the cavity testing available in the SuRF Lab where the current European Spallation Source (ESS) and future Proton Improvement Plan II (PIP-II) projects are doing production tests on bulk niobium cavities. In future, ASTeC scientists will be able to deposit full cavities and test them using this infrastructure to validate the technology for the next generation of accelerators.



The metal photocathode preparation
facility in the VISTA Lab

The SuRF Lab

This year ASTeC and the Technology departments have been developing and commissioning their Superconducting RF facilities which can be used to accurately measure the performance of SRF cavities in their operating conditions. As a result Daresbury is set to become one of only a few laboratories throughout the world that can qualify series production cavities for large scale SRF accelerator programmes.

The Superconducting RF Laboratory (SuRF Lab) comprises two technical facilities. The first is the Vertical Test Facility. Here up to three cavities can be cooled to minus 271 C (nearly absolute zero temperature) in a large 2m diameter, 4m deep cryostat. At the same time their performance and behaviour is measured as they are filled with high power RF waves. The second facility is a bespoke cleanroom equipped to perform a High Pressure Rinsing cleaning process on the inner surface of the cavities to maximise their performance.

SuRF Lab is heavily engaged in delivering 'In-Kind Contributions' to two very large-scale world-class research facilities – the ESS and Fermilab's PIP-II. For the ESS, ASTeC must fabricate, qualify and supply 84 high-performance SRF cavities. Since first operations of the Vertical Test Facility in 2019, work has been going on to ensure the facility is ready and fully validated. For the PIP-II project, 18 SRF cavities will be procured from industry, qualified at Daresbury, and then integrated into 3 cryomodules which will later be installed in the final accelerator site. For this, a Cryomodule Assembly Area is being designed and will be built to dovetail with the existing ESS cleanroom and test facilities.

Partnering with industrial suppliers is also underway to develop and use the Vertical Test and Cryomodule Assembly facilities as part of a full UK capability, incorporating the design, fabrication, qualification, and integration of SRF cavities into complete cryomodules. This will be vital for future UK accelerators and the UK's contribution to global accelerator programmes. For instance, UK-XFEL will likely use SRF technology to reach the high repetition rates identified in the recently published UK-XFEL Science Case. Future ISIS upgrades may also rely on this technology, and the UK capability will support ASTeC's thin films research programme – which aims to reduce costs and increase performance of superconducting cavities – by allowing ASTeC scientists to test novel cavity manufacturing concepts.

Special Report: Addressing the Lack of Radiotherapy in Challenging Environments

From 2017 onwards, ASTeC has worked with the ICEC (International Cancer Expert Corps), CERN, the universities of Lancaster, Oxford and Swansea and collaborators from Sub-Saharan Africa to address the shortfall of Radiotherapy systems for cancer treatment in Low- and Middle-Income Countries (LMICs).

Delegates at the STFC-sponsored workshop in Botswana

The annual global incidence of cancer is projected to rise in 2040 to 27.5 million cases, with two thirds of these in LMICs. In these countries there is a severe shortfall in the availability of one of the most effective treatments – radiotherapy (RT). RT typically uses x-rays, produced by colliding an electron beam from a linear accelerator (linac) into a target, to destroy or damage tumour cells - the x-rays damage the DNA in the cancer cells so they cannot function or replicate normally. In high income countries, RT is used to treat more than 50% of patients. However, in LMICs patients often face long delays for treatment or can't get treated at all.

There are many reasons for the shortfall. Linacs are expensive to buy, but even more expensive to service and maintain. Sometimes the physical environment itself is challenging – to operate stably and reliably, RT linacs require a constant ambient temperature and supplies of clean cooling water. This can be difficult in countries with extremes of climate. Sometimes local infrastructure is both weak and limited, with frequent power and water outages which severely reduce the available up-time for therapy. Finally, there are often not enough trained clinicians, accelerator scientists, engineers and technicians to maintain and operate the machines. All these factors, combined with the growing demand for RT, mean that mortality rates will continue to worsen unless something can be done to mitigate these challenges.

Motivated by this, and the sustainable development goals of the UN, the multidisciplinary collaboration Project STELLA (Smart Technologies to Extend Lives with Linear Accelerators) was initiated. ASTeC's involvement in the project started after participation in the workshop sponsored by ICEC and STFC at CERN in 2017. Based on the recommendations from that workshop, STFC provided seed funding to start developing some real solutions. In 2019, ASTeC and Cockcroft Institute staff participated in a workshop sponsored by STFC in Botswana to discuss and share their progress.

Specific areas where improvements can be made include making servicing and replacement of parts more efficient, identifying improvements and efficiencies in power supplies to improve reliability, and to improve machine diagnostic capabilities incorporating cloud-based operating systems.

The outcome for STELLA will be a new, transformative, RT technology for patient treatment. This will immediately benefit LMICs, but can also be applied to improve access to high quality treatment in High Income Countries.

STFC Physicist Deepa Angal-Kalinin (left) visiting a radiotherapy treatment facility in Botswana

Personal Achievements

In the past year the high-quality work of a number of ASTeC staff has been recognised and rewarded. Here they tell their stories, in their own words.

Faye Taylor

Electrical Apprentice, who was a finalist in the National Apprenticeship Awards' Apprentice of the Year

I'm an ASTeC electrical apprentice based in the Engineering Technology Centre and this year I was nominated for the National Apprenticeship Awards' Apprentice of the Year. This was for my apparently 'excellent attitude and enthusiastic approach to everything I do'! There were around 30 nominations from over 30,000 apprentices around the country, so it was a great honour! The black tie awards evening was held in London at the House of Commons and I went along with my supervisor.

At the time I was in the third year of my four year apprenticeship. I'd already worked on many ASTeC projects and collaborations, including the radiation safety interlock systems for the Advanced Oncotherapy prototype Proton Cancer Therapy machine and the European Spallation Source (ESS) high beta SRF cavity project. I've also provided project and operational support for ASTeC's suite of Radiation test facilities, working on the electrical and control infrastructure for the CLARA project and the Linac Test Facility.

Another aspect of my job I enjoy is helping with ASTeC's public engagement work. We aim to inspire the public using fun outreach activities. This also helps sustain the UK STEM skills pipeline which is an important objective for the department.

I'm now in the fourth year of my apprenticeship. The next steps are to complete my Level 4 and HNC then go on to Level 6/ degree when I'll be able take up my position with ASTeC full time.

Rachael Buckley

Senior Process Engineer, who was awarded Honourary Fellow of the Institute of Physics

This year the IOP introduced a new award section specifically to recognise the role Technical staff have in the field of physics and to show how the Science that we do in our establishments and facilities around the country would not be possible without the commitment and expertise of technicians.

I feel very honoured to be one of the first recipients of this award and have been given the prestigious title of Honorary Fellow of the institute. This puts me within a cohort that also includes some very eminent Scientists, which from my perspective is somewhat overwhelming. That said, I believe that my recognition by the institute, is also a recognition for the numerous technical and scientific staff who have influenced, guided and supported my career development over the last 30+ years.

The award came as a total shock as I had no idea that I had been nominated and my first knowledge of this was an email from the IOP congratulating me and inviting me to join the institute as an Honorary Fellow. As it happens, I had been a nominee and it wasn't a "scam".

The award ties in nicely with the STFC Apprentice scheme also receiving an award from the IOP and STFC launching its involvement in the Technician Commitment, which aims to elevate the visibility and recognition of its own technical staff. As an ex-apprentice, still involved in the recruitment and training of today's apprentices and a member of the STFC Technician Commitment Steering Group the award came at a very appropriate time.

Andy May

Cryogenics Engineer, who was awarded the Harry Jones Prize by the British Cryogenics Council

This year I was very honoured to be awarded the Harry Jones Prize by the British Cryogenics Council. The prize is named in memory of Harry Jones, Professor of Condensed Matter Physics at the Clarendon Laboratory at Oxford, who led the High Magnetic Fields and Superconductivity group for nearly 30 years and was recognised internationally as an expert on superconducting magnets.

The prize is given annually by the BCC for experimental work involving cryogenics, and I am very grateful to have been recognised by the board for my doctoral research at Manchester University on cryogenics for experimental cosmology. The work was the design, modelling, development, testing, delivery, and integration of a number of novel millikelvin systems for several forthcoming Cosmic Microwave Background polarization observatories. I am very fortunate to have had fantastic support in this work from my supervisor Prof Lucio Piccirillo, as well as a number of close collaborators across Europe, North America, and Japan.

I was presented with the award by Peter McIntosh and Shrikant Pattalwar on behalf of the BCC board, and was given a great opportunity to talk about my work in a lecture following the presentation.

Cryogenics is a fundamentally enabling technology for superconducting RF (SRF) in particle accelerators. Key projects for Daresbury with significant cryogenic work include the ESS high-beta cavities, the HL-LHC crab cavity cryomodules, and the PIP-II HB650 cryomodules. For me, cryogenics has always been a fascinating area to work in, mostly due to its highly interdisciplinary nature. With such exciting projects in SRF, I really look forward to continuing to work in this area for a long time.

Ben Shepherd

Leader of the Magnetics and Radiation Sources Group, who was invited to give a plenary talk at the International Particle Accelerator Conference

IPAC is the International Particle Accelerator Conference with typically well over a thousand attendees. It's our chance to hear about all the exciting developments that are happening in the field, to contribute something of our own work, and to network and socialise with international colleagues. I've been attending these big conferences regularly since I started working at ASTeC, and it's always an exciting and inspiring event. I've presented many posters during the (always extremely crowded) poster sessions, but until now I've never given a talk at such a big conference.

Towards the end of 2019 I received a letter inviting me to give a talk at IPAC'20 on the subject of using permanent magnets for particle accelerators. And not just during one of the later specialised parallel sessions, but during the opening plenary session! This was a hugely exciting opportunity for me – and more than a little daunting.

At the beginning of 2020, I'd just started to put together the slides for my talk when I heard something on the news about a new virus that had been found in China. As it spread across the world it became increasingly clear that the conference season this year was going to be very different. In late 2020, online talks and seminars are now the norm – but it was a big effort for the organisers to switch to a virtual format at such short notice, and they did a fantastic job.

Recording the talk from home was actually pretty easy. We've got three children, who were all being homeschooled at the time, but fortunately I've got a space I can use for an 'office' where there's no distracting background noise. I wrote a script for the talk and read from it rather than just talking around the bullet points. That seemed to be the best way to ensure I got across everything I wanted to say without too much hesitation or stumbling.

The conference format was to put one whole day of videos up at a time and leave them up for two weeks, with questions submitted as moderated comments on the video's page. It seemed to work really well, and as well as my talk being the most popular of the week I got loads of great questions – a good sign that people were engaged with the talk and found it interesting. Another advantage of the virtual format – you can see who's asking questions, and it was a good opportunity to communicate with other people working in the same field. Perhaps best of all, I got plenty of time to respond to each question – rather than having to try to come up with an intelligent response on the spot!

Compared to a traditional face-to-face conference, the virtual format felt very different – less sense of being part of a big community, no poster sessions and (worst of all) no conference dinner. But there were a lot of positives – a good Q&A session and no time spent waiting in airport lounges. After this pandemic we should rethink how we do conferences, with remote attendance more common. This will make it easier for more people to be involved, and reduce the carbon footprint of our science activities.

End Note: Reflections on my time as ASTeC Director

Professor Susan Smith

ASTeC Director Professor Susan Smith has now retired and handed over the reins to Professor Jim Clarke. Her significant achievements were recognised by the Institute of Physics - they awarded her the Particle Accelerators and Beams Group 2020 Prize for 'major contributions, innovation and leadership in accelerator and light source science, including in operations and upgrades of the SRS at Daresbury Laboratory, in leading the accelerator design for the Diamond facility at RAL, and leading the construction of the ERL ALICE, EMMA and CLARA facilities at Daresbury. In the last decade Susan has simultaneously been the Director of ASTeC and Head of Daresbury Laboratory, roles which recognise her exceptional scientific expertise and managerial abilities'. Here Susan reflects on her time as Director.

My directorship started in the midst of austerity so I needed courage and conviction to take the helm and steer towards a brighter future, but I was confident we would get through this darker period. My priority was to ensure ASTeC could deliver the next generation of accelerator driven science facilities. I caught a favourable wind with impetus funding for the Versatile Electron Linear Accelerator (VELA) facility, delivering next generation technologies in the context of supporting industrial and societal applications.

I kept the momentum up by leading a concept for a world leading free electron laser (FEL) test-bed, CLARA. With Technology Department, I had fantastic opportunities to bid simultaneously for significant involvement in two big European accelerator projects, ESS and ELI-NP. Both came off, together with initial CLARA accelerator funding. With more success than we dreamt of, and thanks to our brilliant staff who worked their socks off, we have grown in strength whilst simultaneously delivering these challenging projects. Today, CLARA has delivered an impressive breadth of accelerator-based research from very high-energy electron cancer therapy to industrialisation of accelerator components. The completion of Phase 2 is an exciting prospect for 2022 which will allow unprecedented research in techniques promising to miniaturise particle accelerators. Perhaps the accelerator physicist of the future will not be researching using such "big" science facilities in the future!

Our international endeavours also paved the way for a big involvement in the LHC upgrade and the injector upgrade for the DUNE project in the USA. With the solutions to global challenges demanding advanced analytic facilities to probe matter at ultra-short timescales, our FEL expertise has never been more relevant to the UK's future research needs.

Now under Jim Clarke's leadership, I am confident that ASTeC will be at the vanguard of delivering a brighter future through advanced accelerators in years to come.

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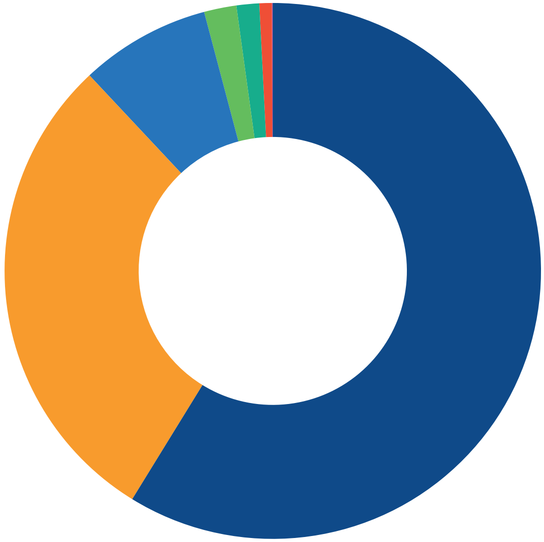
Financial Summary

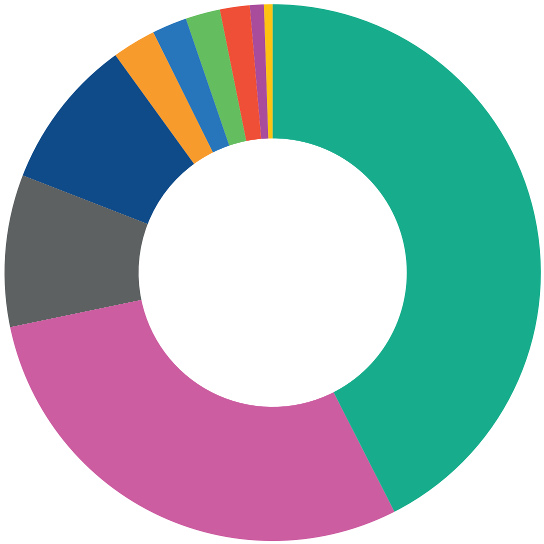
ASTeC Activities 19/20

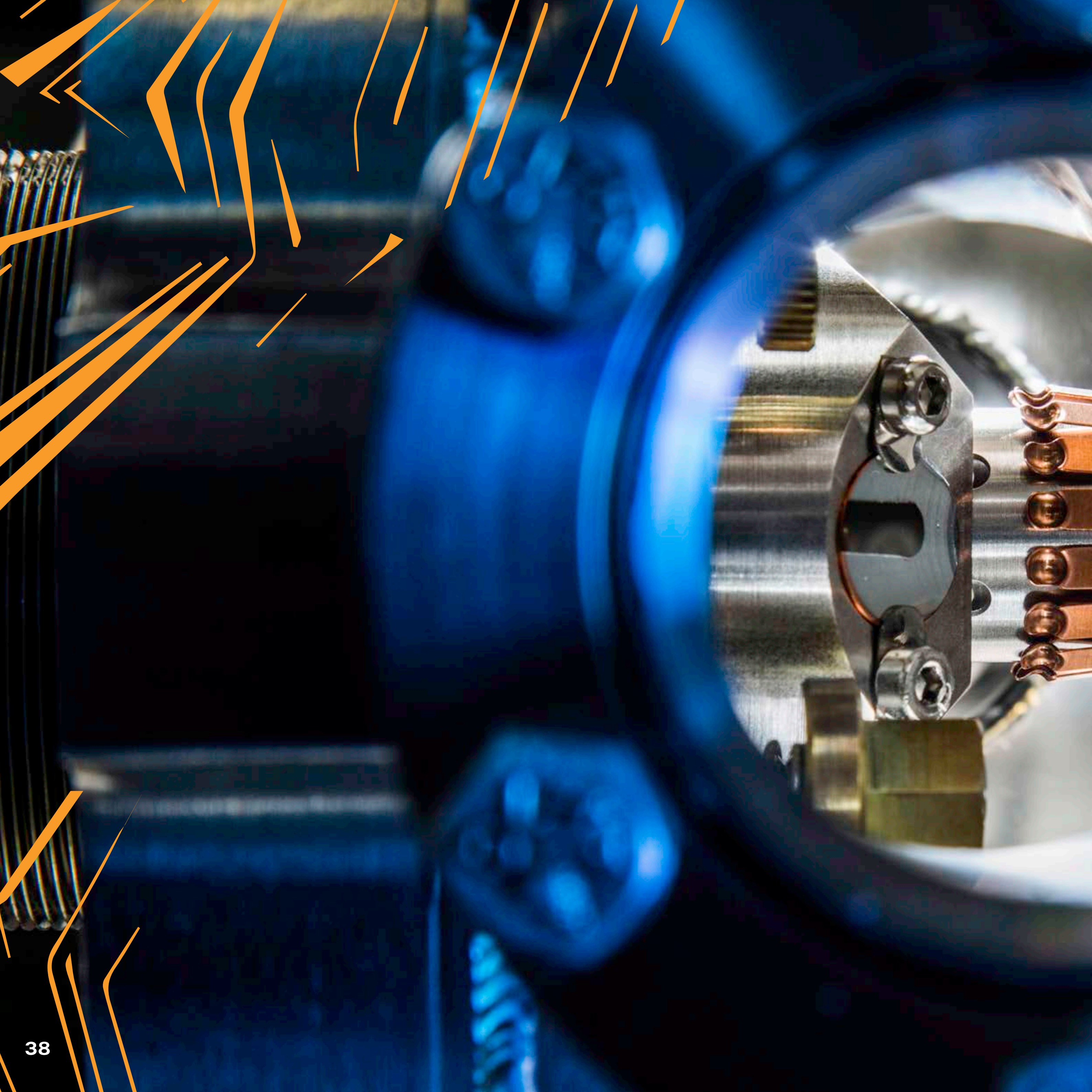
Income sources	£K
STFC ASTeC core	£9,676
STFC PD funding	£124
EU	£225
International Laboratories	£8
Industry	£1,293
ESS/PIP II - STFC Programmes	£4,814
Other (CI Grant and events)	£321
Total	**£16,462**

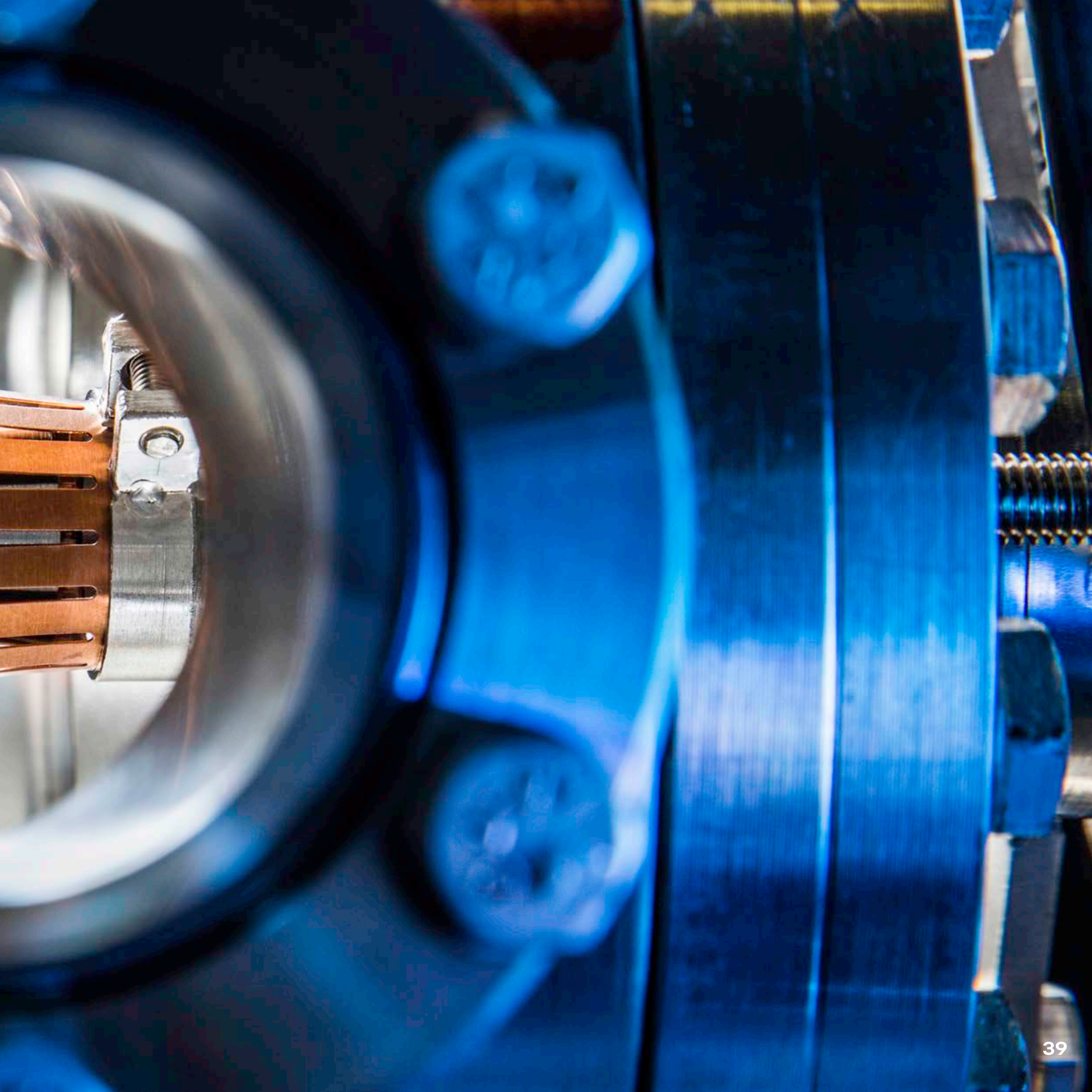


Expenditure Type	£K
Scientific & Engineering Staff Costs	£7,760
Non-Staff Resource	£6,392
Capital Expenditure	£2,310
Total	**£16,462**

Expenditure by Programme	£K
High Brightness Electron Accelerators	£1,502
EU Programmes	£296
CLARA Projects	£6,996
CLARA/VELA Exploitation	£139
Cockcroft Inst & New Initiatives	£346
Underpinning Research	£433
UK_NF Programme	£343
Photon Studies	£86
High Power Proton Accelerators	£4,814
Other Repayment Work	£1,508
Total	**£16,462**







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