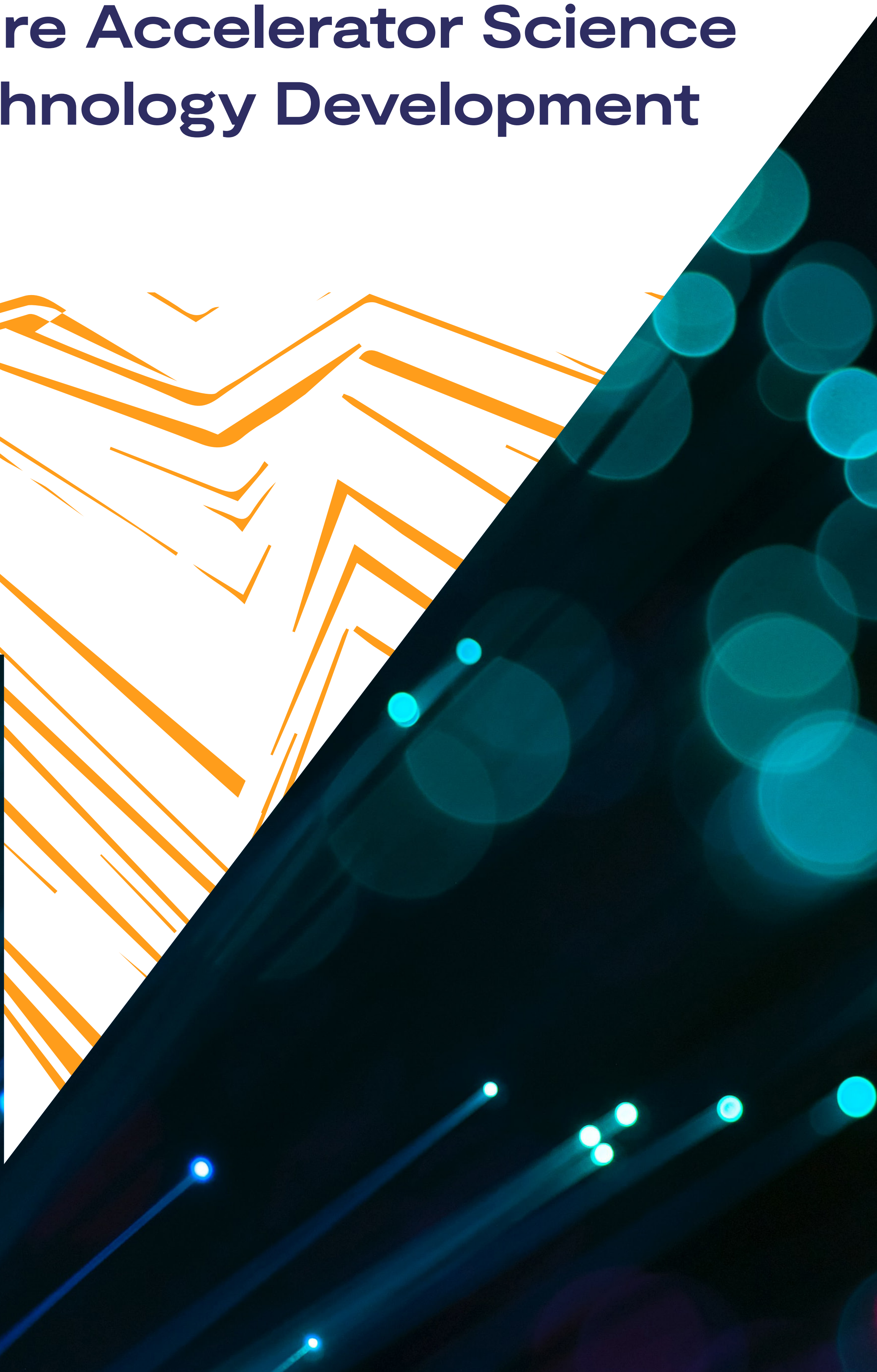
Science and Technology Facilities Council

STFC Strategic Framework for Future Accelerator Science and Technology Development



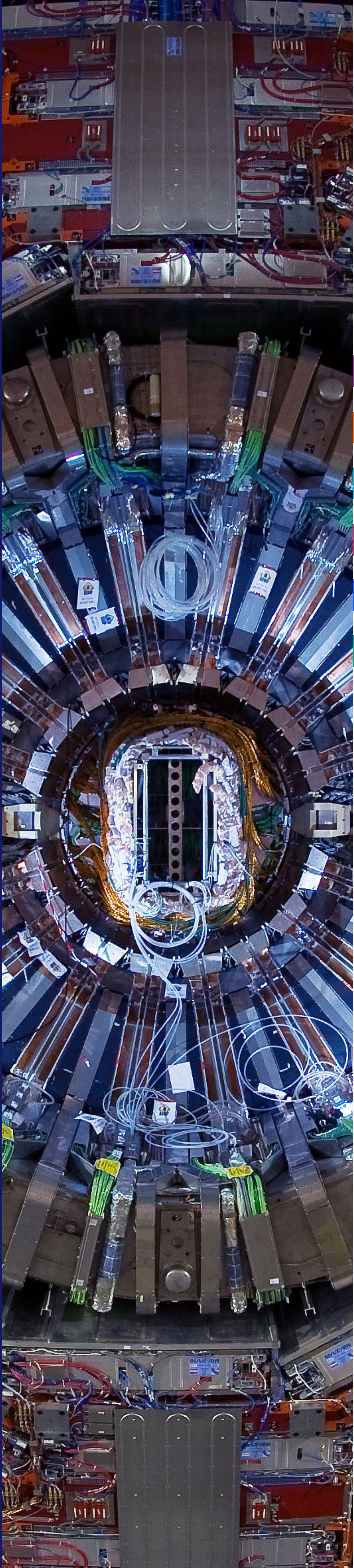


Image credit: CERN

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Foreword

Accelerators are a key underpinning capability which enable large parts of our Science and Technology Facilities Council (STFC) core programme as well as the broader UK research and innovation community to succeed, both nationally and internationally.

The UK remains a strong player in accelerator science research and development, contributing to major international projects including the European Spallation Source, HL-LHC at CERN and PIP-II at Fermilab in the US. The next generation of research infrastructures both here in the UK and internationally will have ever more challenging performance specifications, continuing to drive innovation. The advancement of accelerator technology has the potential to have impacts for the UK economy and broader society, including medical applications of accelerators; maintaining the UK's capacity and capability in accelerator research and development is of key strategic importance for the UK. We also recognise that performance of the next generation of accelerators must be sustainable and low carbon in construction and operation.

This refreshed Strategic Framework for STFC's accelerator science and technology capability will ensure we continue to have the right tools and skills to drive progress across many important areas of science and innovation, directly benefitting the nation and helping to make the UK a science superpower.

We look forward to working with our colleagues and stakeholders across all the UK science and technology communities including academia, industry and our international partners as we begin to implement the measures set out in this Strategic Framework.

I hope you find this report an informative and exciting presentation of the opportunities that lie ahead.

Professor Mark Thomson

Executive Chair
Science and Technology Facilities Council

ISIS Target Station 2 at Rutherford Appleton Laboratory

Executive Summary

Accelerator science and technology and the application of accelerators is a critical component of STFC's capabilities, enabling us to deliver world-leading national and international research and innovation capabilities and, through those, discover the secrets of the Universe. STFC's investment in underpinning accelerator research and machine development is realised through a range of different delivery functions and has resulted in a strong UK accelerator capability in STFC's national facilities and laboratories and in the higher education institute (HEI) communities.

Addressing the next science challenges in high energy and particle physics, and the many other science areas supported by STFC at the national and international user facilities, will require a new generation of accelerator driven research infrastructures with higher performance requirements. These new machines will have to meet their performance goals at the lowest possible capital and operating cost while also minimising the environmental impact.

This Strategic Framework for Future Accelerator Science and Technology Development aims to:

1. set out how STFC will take forward and prioritise its work in the accelerator fields
2. enhance the coordination of accelerator activities across all of STFC's delivery functions
3. ensure that the resources directed to accelerator science and technology achieve the best outcomes possible

This framework outlines a single set of priorities that will be used to guide the future strategic direction of accelerator science and technology across the whole suite of activity funded by STFC. The primary ownership of the framework and the actions that it will drive are the Executive Directors for Programmes and the National Laboratories. The STFC Technology and Accelerator Advisory Board (TAAB) will monitor progress and provide strategic advice. Since many accelerator activities can be decades long in their realisation and operation, the Framework, and its implementation actions, will be reviewed and refreshed every 3-5 years.

The principal elements of the Framework are summarised in the box on the following page.

STFC's Vision and Mission Statement for accelerators (section 2) identifies 4 themes: meeting the operational needs of current and future accelerator infrastructures; research to achieve the performance and sustainability goals of future accelerators; enabling the wider application of accelerators; and building the pipeline of specialist skills.

The UK's accelerator capability and strategic landscape (section 3 and 4) is outlined. Maintaining this capability in the context of the broader strategic landscape is key to delivering on national goals and securing international leadership.

The overarching implementation factors (section 5) include:

- Giving priority to infrastructures that support the science mission needs
- Promote coordination and collaboration across the accelerator portfolio
- Ensure that international programme commitments are aligned with the UK's strengths and leverage our accelerator facilities and infrastructures
- Retain capacity to support some blue skies research
- Embedding sustainability considerations in all new developments
- Align STFC funded Accelerator Institute activities with the Strategic Framework
- Encourage greater collaboration with industry - across all TRLs
- Explore opportunities to attract external funding to apply accelerator technologies to wider applications

Meeting the short-term infrastructure needs (section 5.1) actions include:

- Maintain the operational capabilities of the national user facilities
- Ensuring the business cases for new infrastructures are deliverable
- Encourage UK groups to secure contracts at international experiments, facilities or both

Targeted research to support longer-term needs (section 5.2) actions include:

- Exploit the investments made in world-class research accelerator R&D facilities
- Programmatic research calls aligned with the European Roadmap and Particle Physics Technology Advisory Panel report
- Developing more sustainable acceleration techniques
- Ensure that critical technologies are developed for future infrastructures

Wider application of accelerators (section 5.3) actions include:

- Facilitating access to STFC supported research facilities and expertise
- Work with partners including industry to raise awareness and support securing external funding

Training scientists and engineers (section 5.4) actions include:

- Train the next generation of specialist accelerator scientists and engineers
- Provide interesting and impactful work and fully embraces equality and diversity
- Promote opportunities for career development and sharing skills across projects

The responsibilities for overseeing implementation and reporting (section 6) include:

- Clear ownership and responsibility for delivery and coordination by STFC's Executive Directors
- An annual reporting process by STFC management to TAAB and Science Board
- A strong role for TAAB to review and assess progress and oversee the regular review and updating of the Framework

1 Introduction

Devices to generate, accelerate and manipulate beams of particles have been important scientific tools since the late 19th century, enabling our growing understanding of the nuclear structure of matter, high energy physics and the world of quantum mechanics. The UK has long been at the forefront of accelerator technology development and application. In 1932 Cockcroft and Walton, working with Rutherford, built the world's first high energy (400kV) accelerator and were awarded the Nobel Prize for accelerating protons to collide with lithium and transmute it into helium.

The importance of accelerator technologies is not declining with many new requirements driving a need for continued innovation in the next generation of machines. These include:

- A growing range of new research infrastructures, such as high brightness synchrotron radiation sources and Free Electron Lasers (FEL), that rely upon powerful and efficient accelerators
- Challenging performance requirements for the next generation of high energy physics machines that could follow the High Luminosity Large Hadron Collider (HL-LHC), potentially achieving energies in the region of 100TeV
- The potential of new accelerator technologies, such as laser and electron driven plasma wave techniques, that may be able to achieve high particle energies in much more compact designs
- The increasing application of particle accelerators in medical imaging and treatment, for example proton and ion therapies to treat cancer
- The need to reduce the carbon footprint of research machines so that the infrastructure is recognised as being environmentally responsible as the world seeks to achieve net zero in carbon emissions

These new requirements, challenges and opportunities for accelerator technology make it timely to formulate a refreshed strategic approach to future STFC accelerator activities so that resources can be directed to the most beneficial impacts and outcomes and we can ensure there is an appropriate balance between transformative and incremental developments.

This Strategic Framework is for **future STFC investments and priorities** whilst recognising that there are other UK interests (EPSRC, HEIs, Industry) and important international dimensions. It builds on the Strategic Review[1] produced in 2017 that researched the high priority drivers and needs for future particle accelerators.

The Framework sets out: the **themes that align with STFC's mission**; the **drivers that are determining requirements** that STFC will need to meet; steps that can help achieve a coherent programme of activities that **builds technical capability and strengthens the skills pool**; and oversight and governance processes that will ensure an **appropriate balance of priorities and funding** to meet the evolving needs and achieve the necessary outcomes. The diversity of accelerator activities, from relatively short duration research projects to decades long multi-million-pound new research infrastructures, means that the timescale for the Framework is medium term (5 years) and that the theme areas, the projects within them and priorities, will evolve over time.

1. ukri.org/publications/stfc-accelerator-strategic-review-report

2 STFC's Accelerator Vision

The Science and Technology Facilities Council (STFC), as part of UK Research and Innovation (UKRI) is tasked with[2]:

"carrying out, facilitating, encouraging and supporting research into science, technology and new ideas in the fields of astronomy, particle physics, space science, and nuclear physics; and the provision and operation of research facilities in relation to any area of UKRI's activity: arts and humanities, biotechnology and biological sciences, social sciences, engineering and physical sciences, medicine and biomedicine aimed at improving human health, environmental and related sciences."

STFC (and its predecessor bodies) has supported a strong national capability in accelerator technology research and application. The early university-based machines led to major breakthroughs in the UK; however, the scale needed for the next generation of large machines meant that these outgrew universities to be sited in national and international facilities.

The science and technology behind accelerators and the wide-ranging outcomes that they enable researchers and technologists to achieve, support several of the strategic objectives in the UKRI Strategy 2022 to 2027[3] including:

- Advancing the frontiers of human knowledge and innovation by enabling the UK to seize opportunities from emerging research trends, multidisciplinary approaches and new concepts and markets
- Securing the UK's position as a globally leading research and innovation nation with outstanding institutions, infrastructures, sectors and clusters across the breadth of the country
- Focusing the UK's world-class science and innovation to target global and national challenges, create and exploit tomorrow's technologies, and build the high-growth business sectors of the future

2.1. A Vision for Accelerators

Building on this heritage, and in response to the emerging requirements, **STFC's vision for accelerators is:**

"To strengthen our world leading capabilities in accelerator science and technology so that the UK can design, build and operate the accelerators of tomorrow"

This vision can be turned into a series of themes that together form a coherent mission statement for STFC's accelerator research and implementation actions.

2.2. Accelerator Mission Statement themes

STFC will promote, develop and enhance UK accelerator capability to enable world-class science, recognising that particle accelerators are vital components of our current and future large facility portfolio, nationally and internationally. This will be achieved by:

- Ensuring short term capability to operate existing infrastructure and to design and build future accelerator facilities
- Conducting long-term research and development aligned with future infrastructure priorities
- Promoting the wider application of accelerators for the benefit of UK society and economy
- Training scientists and engineers to meet the needs of users and beneficiaries of accelerator research

2. Higher Education and Research Act 2017
3. ukri.org/publications/ukri-strategy-2022-to-2027

3 The UK's accelerator capability

Particle accelerators are complex technologies. The systems that are employed in large research infrastructures need cutting edge capabilities in the diverse technologies employed and in the skilled workforce needed to design, build and operate them.

3.1. A multi-facetted capability

The UK capability has been built up over many years and includes:

- STFC's Accelerator Science and Technology Centre (ASTeC)
- The two accelerator Institutes, John Adams and Cockcroft, and the wider HEI community
- STFC's national laboratories (including expertise in accelerator engineering, controls, plasma acceleration, cryogenics and instrumentation) and the operational teams in the UK's accelerator driven user facilities (ISIS Neutron and Muon Source and Diamond Light Source)
- The strong links to expertise and access to test facilities located at international facilities (such as CERN, Fermilab and J-PARC)
- Industry

Accelerator Science and Technology Centre

The Accelerator Science and Technology Centre (ASTeC) within STFC is a centre of excellence which brings together all the skills and expertise required to develop world class accelerators for the UK's future research needs. ASTeC studies all aspects of the science and technology of charged particle accelerators, ranging from large-scale international and national research facilities through to specialised industrial and medical applications. ASTeC is also a partner in the Cockcroft Institute.

Accelerator Institutes

The Cockcroft Institute (CI) and John Adams Institute (JAI), both for accelerator science and technology were established in 2004. The creation of the institutes was a response to the need to rejuvenate accelerator science and technology in the UK. Both institutes are composed of university groups with an accelerator focus and both have increased their membership since their formation.

Each institute has developed a unique identity of individual strengths that complement each other and build UK capability. These identities are reinforced via the geographic coordination and collaboration around the institutes' activities with STFC's National Laboratory infrastructure: CI, the Accelerator Science and Technology Centre (ASTeC), and the wider-Daresbury Laboratory (DL) in the north-west, and the JAI and the Rutherford Appleton Laboratory (RAL) in the south-east. The institutes collaborate with each other to contribute to national and international projects.

Aerial view of Rutherford Appleton Laboratory

The UK's accelerator-based facilities

ISIS Neutron and Muon Source is a world-class spallation neutron and muon source that has been operating since the mid-1980s. The accelerator system delivers 800MeV protons to two spallation targets. In 2021 an upgrade replaced one of the original linear accelerator (linac) tanks.

Diamond Light Source is the UK's national synchrotron and began operations in 2007. The linac delivers 100MeV electrons into the storage ring which are then boosted to 3GeV.

CLARA (Compact Linear Accelerator for Research and Applications) is an advanced electron accelerator test facility enabling the UK academic, industrial and health sectors to explore new accelerator-based technologies, treatments, and carry out frontier research. **FEBE** (Full Energy Beam Exploitation) is an expansion of CLARA to enable access and exploitation of the full energy electron beam, with the option of high power laser interaction as well for more complex experiments.

EPAC (Extreme Photonics Applications Centre) construction began in 2019 and science experiments are expected to begin in 2024. The facility includes a dedicated plasma acceleration experimental area.

All these elements work together to fulfil the mission statement requirements. This diversity is particularly important as it gives a breadth of opportunity to train the necessary specialist expertise and build and retain a critical mass to support the next generation of projects.

Accelerator developments and experiments emerge from collaborations built in academic, national and international laboratories. Significant impacts can be achieved by building on strengths and cross-fertilisation between activities and on the expertise and experience from past infrastructure developments. Underpinning capabilities (such as skills, instrumentation, magnets and beam diagnostics) are developed through, and can be applied to, many different projects.

Accelerator test facilities are an important element of the technical capability. Previous test facilities that have built UK leadership in specific technology areas include ALICE (energy recovery linacs, ERLs), EMMA (fixed field alternating gradient accelerators, FFAs) and MICE, which gave the first demonstration of ionisation cooling. The Front End Test Stand (FETS) facility at the Rutherford Appleton Laboratory (RAL) was built to prototype and test subsystems, for example radiofrequency quadrupoles and beam chopping, with novel features that could potentially be used with a high energy pulsed proton driver. The CLARA test facility at ASTeC enables a range of cutting-edge accelerator science and technology investigations. This includes being a test bed for future X-ray Free Electron laser developments. A facility access arrangement enables CLARA to be made available to users from across the community, including use by industry.

3.2. An International Player

The UK's technical capabilities and expertise and skills means that we can influence and contribute to significant projects worldwide. For example, in 2021 experts from across the STFC national laboratories and HEIs led elements of the Laboratory Directors Group (LDG) European Strategy for Particle Physics Update research and development (R&D) road mapping panels. The table below shows some of the recent and current international facilities with a strong UK involvement.

Project	UK Contributions
EU Horizon 2020 Projects	iFAST (Innovation Fostering in Accelerator Science and Technology) and CompactLight (X-band FEL Design Study)
European Spallation Source	SRF cavity testing, RF waveguide distribution systems, linac warm units, vacuum test equipment
HL-LHC (CERN)	Design and build of SRF crab cavity cryomodules, instrumentation for injector chain, background studies, coldboxes for cold powering, beam diagnostics hardware, and collimation studies
LBNF/DUNE (US)	Three six-cavity high-beta 650MHz PIP-II SRF cryomodules, and the 2.4MW-capable neutrino production target development, remote handling, and helium cooling plant
Hyper-Kamiokande	Neutrino production Target and beam window upgrade development to 1.3MW capability
AWAKE (CERN)	Design and optimisation of the witness electron bunch, measuring the properties of the electron bunches, and a scalable plasma cell and diagnostics
ILC/CLIC	Instrumentation, controls, feedback, beam dynamics, simulations
EuPRAXIA	Instrumentation, plasma acceleration, simulations. Input to the Conceptual Design Report around plasma photocathodes and high-performance diagnostics, targetry and applications
MICE	Beam, integration, liquid-hydrogen delivery system, focus-coil module and superconducting solenoids, RF power, and software and computing

4 The accelerator strategic landscape

The UK's accelerator expertise is making strong contributions to many international collaborations such as the High Luminosity upgrade to the Large Hadron Collider at CERN. The next generation of particle physics machines that will be needed for future research will have very challenging performance goals. In 2021 the European Particle Physics Strategy Update[4] highlighted these challenges and recommended that:

The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. A roadmap should prioritise the technology, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry. Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes.

The CERN management board commissioned a multi-national expert group to produce an accelerator R&D roadmap report[5] (and a complementary detector roadmap). The European accelerator roadmap identified several technology areas for future focused research – see box.

STFC formed the Particle Physics Technology Advisory Panel (PPTAP) task and finish group in 2021 to consider how the UK particle physics and associated accelerator and detector R&D activities could respond to the challenges in the European Strategy, taking account of the current level of expertise and relevant activity within the UK. PPTAP[6] concluded that the UK has broad ranging accelerator expertise across many of the areas identified in the European Roadmap, these are considered against the broader scientific priorities in section 5.

European strategy for particle physics accelerator R&D roadmap research areas

- High field magnets. The magnet technology needed for future particle colliders will need new materials including high temperature superconductors that can achieve magnetic field strengths at least 50% greater than those in the HL-LHC.
- High gradient radiofrequency (RF). New material technologies including thin film techniques are needed together with advanced cooling and control systems that can also minimise energy consumption.
- High gradient laser/plasma acceleration. Proving the feasibility of developing a high energy collider system using plasma acceleration with the necessary beam characteristics, reliability and reproducibility.
- Muon accelerators. Development of a high energy (>10TeV) muon collider concept that can help confirm the potential benefits over conventional acceleration techniques.
- Energy recovery linacs (ERLs). Developing novel high energy ERL technologies that have application in particle colliders and more widely in other applications including free electron lasers and photolithography.

4. home.cern/sites/default/files/2020-06/2020%20Update%20European%20Strategy.pdf
5. cds.cern.ch/record/2800190/files/146-138-PB.pdf
6. ukri.org/publications/particle-physics-technology-advisory-panel-pptap-report

5 A strategic approach to meet future needs

The approach to managing the STFC led accelerator science and technology activities has evolved over the past decade and successfully supported a strong portfolio of scientific research and technology application. There are exciting opportunities to build on this capability to meet the needs and challenges of emerging major new national and international facilities that will rely on accelerators to achieve their goals. At the same time, the demands on the research and innovation budgets held by UKRI are increasing and accelerator resources and capital projects have to be considered alongside many other opportunities, including detector technologies and computing (as noted in the European Roadmaps and the PPTAP report).

The findings of expert groups in the UK and internationally have begun to determine the primary areas of future focus for STFC's accelerator R&D and operations activities. However, full clarity and the timelines for actions will take time to evolve.

Delivering on these opportunities will need a robust strategic approach that ensures that all the parts of the UK's accelerator capability are effectively coordinated to meet the emerging new priorities. The factors that will influence how funding on accelerators should be determined and balanced against other needs include:

- **Giving priority to developments that support the science mission needs related to new and upgraded national and international infrastructures, including the nuclear and particle physics projects.**
- **Ensuring that international programme commitments are aligned with the UK's strengths, and seek international partnerships that can help leverage the gains from our accelerator facilities and infrastructures.**
- **Ensuring that sustainability issues related to accelerator technologies are adequately addressed for all new infrastructure developments and projects.**
- **Retaining the capacity in the overall STFC accelerator resourcing to support some blue skies research (coordinated with EPSRC activity where appropriate).**
- **Ensuring the main Accelerator Institute activities funded by STFC continue to be aligned with the Strategic Framework themes.**
- **Promoting coordination and collaboration across all the STFC accelerator portfolio so that knowledge and skills sharing is enhanced.**
- **Encouraging greater collaboration with industry - across all TRLs - to increase the UK capability in key technologies and skills and facilitate the exploitation of research investments.**
- **Exploring opportunities to support activities that attract external funding to apply STFC accelerator technologies to wider applications with societal benefits.**

The following sections provide an outline of how the Framework steps will be implemented. As these steps progress and in response to further input from the UK community and international partners, the planning for future actions will be refined and updated. These steps are grouped into the Mission Statement themes as follows:

- **Theme 1. Ensuring short term capability to operate existing infrastructure and to design and build future accelerator facilities.** Supporting the delivery of STFC's science mission activities including maintaining and operating the current national facility accelerator systems and responding to the emerging accelerator-based research infrastructure and particle physics programme needs (Section 5.1).
- **Theme 2. Conducting long-term research and development aligned with future infrastructure priorities.** Carrying out the underpinning research and development needed for the new technologies that will help meet the future machine performance and sustainability goals (Section 5.2).
- **Theme 3. Promoting the wider application of accelerators for the benefit of UK society and economy.** Supporting other accelerator applications, including medical applications, broadening the benefits from the primary science mission investments (section 5.3).
- **Theme 4. Training scientists and engineers to meet the needs of users and beneficiaries of accelerator research.** Developing and retaining the expertise and skills needed now and for the future accelerator project pipeline (section 5.4).

5.1 Theme 1. Ensuring short term capability to operate existing infrastructure and to design and build future accelerator facilities

STFC must enable the continued efficient operation of the UK national facilities that have accelerator technologies as a core part of their operation, including incremental upgrades and achieving performance gains in support of their multidisciplinary science programmes. As part of this effort, STFC should encourage knowledge-sharing between the facilities, securing the benefits of a single operator of the national infrastructures.

The UK government's Research and Development Roadmap[7] sets out an ambition to "Provide long-term flexible investment into infrastructure and institutions. This will allow us to develop and maintain cutting-edge research, development and innovation infrastructure, with agile and resilient institutions able to play their fullest role." In support of this, UKRI has developed the research infrastructure roadmap[8] and implemented a process to identify opportunities to provide a long-term, flexible pipeline of research and innovation infrastructure investment priorities for the next 10 to 20 years[9].

The infrastructure programme has already identified the following priority future research infrastructures with significant accelerator elements (see box) and it is likely that additional infrastructures will be identified in future rounds.

Theme 1 Implementation steps

- **Maintain the operational capabilities of the national user facilities (ISIS and Diamond), enabling incremental accelerator upgrades for performance and reliability enhancements within the established mechanisms for facility planning and capital and resource allocations.**
- **Ensure that the accelerator elements of the business cases for new research infrastructure opportunities are technically feasible and deliverable through robust review mechanisms.**
- **Encourage UK groups to secure contracts for accelerator developments at international experiments and facilities where this helps maintain and develop key technical capabilities and skills without adversely affecting other parts of the programme.**

Live UK research infrastructure projects

Diamond II. A major upgrade to the UK's national synchrotron, the Diamond Light Source. The plans include increasing the electron beam energy to 3.5GeV and implementing new magnet technologies in the storage ring to increase the source brightness and coherence.

Endeavour. Endeavour will provide new instruments and significant upgrades of several others at ISIS.

Live UK infrastructure scoping studies

Ion Therapy Research Facility. This scoping study will develop the specification and costs for a pioneering, national radiobiology facility intended to conduct the basic research needed to develop and apply the next generation of ion beams for radiotherapy.

X-ray Free Electron Laser (XFEL). This conceptual design study will explore different options to provide access to a second generation XFEL capability for UK science and innovation.

ISIS II. This scoping project will explore new accelerator, storage ring and target technologies that can deliver beam energies in excess of 1GeV and beam powers of over 1MW in a future pulsed neutron source.

RUEDI. This project will investigate the design of a Relativistic Ultrafast Electron Diffraction and Imaging facility for structural dynamics studies on the femtosecond timescale. The RUEDI imaging facility will be unique in the UK (and globally) and produce electron bunches at energies up to 5MeV, at a repetition rate of 100Hz.

7. assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/896799/UK_Research_and_Development_Roadmap.pdf
8. ukri.org/wp-content/uploads/2020/10/UKRI-201020-UKinfrastructure-opportunities-to-grow-our-capacity-FINAL.pdf
9. ukri.org/what-we-offer/creating-world-class-research-and-innovation-infrastructure/funded-infrastructure-projects

5.2 Theme 2. Conducting long-term research and development aligned with future infrastructure priorities

There needs to be continued investment to support and conduct accelerator research and development where it is aligned to future national priorities and STFC science strategies. This will ensure that the accelerator capabilities needed to meet the science mission requirements can be maintained and grown. Considering the strengths identified in the PPTAP report against the current broader scientific priorities (proposed and approved projects) suggests several priority areas for UK investments, as outlined in the table below.

Priority technology areas	Secondary technology areas
Plasma accelerator technologies	High field magnets
THz driven and dielectric wakefield accelerators	Muon accelerators
Thin film SRF	High temperature SC magnets
Permanent Magnets	Energy recovery linacs
Beam instrumentation, manipulation and control systems	

Building on these priority technology areas, we will prioritise supporting research focused on the three pillars of:

- LHC and its upgrades, exploiting UK strengths aligned with the European Roadmap
- Novel acceleration technologies (exploiting CLARA, EPAC and similar facilities)
- The route to UK FEL capabilities

Work towards a UK FEL capability is being supported through the UK-FEL preliminary infrastructure project funded through the UKRI Infrastructure Fund. Innovative and cutting-edge technologies necessarily have an element of risk and it must be accepted that not all research will result in deployable acceleration technologies. The provision of test facilities such as CLARA and EPAC can enable new techniques to be rigorously explored to determine their potential for successful application.

Example research topics: Plasma Acceleration

Plasma wave driven acceleration using lasers or proton/electron beams to achieve very high electric field gradients that can accelerate particles to high energies over short distances is an exciting area of accelerator research. Pioneering work in laser driven acceleration has been carried out at STFC’s Central Laser Facility . The new Extreme Photonics Applications Centre (EPAC) will be a powerful research capability that will enable further cutting-edge research in these new acceleration techniques. Similarly, CLARA is being used for electron driven plasma acceleration and externally injected laser plasma acceleration research. STFC, therefore, has two world-leading complementary facilities for novel acceleration research and will leverage this investment. The UK are also part of the EuPRAXIA consortium to develop a future plasma-acceleration infrastructure and this is now included on the ESFRI roadmap.

Sustainable accelerator technology

High carbon technologies are not well aligned with national and global net zero policies. This is a significant challenge for large accelerator driven research machines as the established technologies are typically energy intensive in their construction and operation. Addressing the challenge of designing more sustainable accelerator systems requires a holistic approach across all the machine elements, including items like shielding structures as well as the electrical and magnetic systems. STFC's Sustainability Action Plan sets out a framework for addressing sustainability challenges across all activities.

Cost reduction has always been a driver, for example to reduce electricity consumption and decrease the use of expensive consumables (such as, capturing and recycling helium). The need for future research infrastructures to embrace net zero carbon ambitions and wider sustainability aims for water, energy and material efficiency are bringing an increased emphasis to this area of work, helping to embed them into every aspect of our accelerator activity.

Theme 2 Implementation steps

- **Ensure that the critical technology developments needed for future infrastructures are addressed.**
- **Refine the longer-term priorities for the UK building on the findings of the PPTAP report.**
- **Prioritise exploiting our investment in the UK's world leading accelerator R&D facilities (CLARA and EPAC) to test both high-risk and incremental developments, with any new UK accelerator research facilities paused in the short term (~3 years).**
- **Prioritise developing techniques that will make significant improvements in the sustainability of future accelerators**
- **Support targeted R&D programmes that can reinforce developing UK strengths directly aligned with future infrastructures, new accelerator technologies and the European Roadmap and PPTAP findings.**

Sustainable Accelerator Research

STFC is supporting work on more sustainable technologies including new designs for magnets, RF systems, and other components. Energy recovery linacs have been highlighted for their sustainability credentials by the ESPP Accelerator R&D Roadmap. Other technologies being investigated include replacing electromagnets with adjustable permanent magnets with no power or cooling water requirements and superconducting radiofrequency cavities made from copper coated with a superconducting film, which is expected to have superior RF performance and be able to operate at the higher temperature of 4K compared to the traditional solid niobium cavities which operate at 2K.

5.3 Theme 3. Promoting the wider application of accelerators for the benefit of UK society and economy

In addition to underpinning the facilities supporting scientific research, accelerator technologies themselves have widespread applications that can have direct benefits to society and industry most notably in the areas of healthcare, security, and material modification. The accelerator skills and technology developed through STFC's core science activities can play a role in further developing these areas. While STFC investment has been modest, it has still resulted in some vibrant collaborations, including some supported through the Global Challenges Research Fund (GCRF). The accelerator institutes and ASTeC continue to exploit and develop these activities, for example with the STELLA project.

Accelerator activity outside the core science mission work is important to STFC because:

- The technology needed by future large science facilities will have spin-off applications and benefits to other sectors and industry. This adds to the cost-benefit ratio and helps justify the often-significant cost of future research facilities
- The additional funding streams that can support wider accelerator applications helps maintain the "critical mass" of capability to the benefit of both core and non-core activities
- The links forged with industry and other partners helps mutual development and skills transfer

Industrial collaboration

The unique skills and capabilities that STFC has enabled via long term investments (for example, thin films technology, quantum computing etc) are of value to industry, both for accelerator related projects and for wider commercial activities that can benefit from these capabilities. Similarly, industry skills in design and manufacturing are a key element of the supply base that supports STFC's research and infrastructure accelerator projects in the UK and in international programmes. Industry also collaborates with and funds some work at the accelerator Institutes and the wider HEI community.

A tangible outcome of this collaboration is the strong industry presence that has been realised at the Daresbury campus including Advanced Oncotherapy and Varian.

Case study: benefits of industrial collaboration at STFC's Daresbury Laboratory

STFC and Teledyne e2v, a leading supplier of technologies and components for industry, have formed a strategic relationship to advance the world's next generation of particle accelerator technologies and bring exciting new opportunities for UK industry. Through this agreement Teledyne e2v gain access to the Compact Linac accelerator and radiation enclosure at STFC's Daresbury Laboratory, supporting the development of new products and integrated RF and X-ray systems. Meanwhile, for STFC, the agreement delivers specialist technical support for the Compact Linac, provided by Teledyne e2v, which manufactured several of the original components.

Theme 3 Implementation steps

- **Facilitate access to our unique accelerator R&D capabilities and expertise to work in partnership and add value across other disciplines**
- **Maximise access to our accelerator beam test facilities in the UK as well as supporting access to international beam facilities through enhanced outreach and awareness raising**
- **Work with partners including industry to secure funding to support developments out with STFC's direct responsibilities.**

5.4 Theme 4. Training scientists and engineers to meet the needs of users and beneficiaries of accelerator research

Tackling accelerator science and technology challenges needs diverse skill sets that can take many years to acquire. Attracting and retaining people whilst they build and practice these skills needs a career path that provides a combination of opportunities and rewards. It is essential to build and retain a sufficient pool and pipeline of skilled staff to maintain, operate and develop the current and future national and international accelerator facilities. The resource pool exists in STFC's national laboratories, and national and international facilities, and partner HEI's as well as in industry. Our accelerator institutes and national laboratories are key to ensuring the continued pipeline of skills.

Training is a high priority to ensure that the expertise needed is nurtured to provide an agile workforce at all levels, from apprentices and graduates through to senior scientists and technicians. Given the wider applicability of the skills developed in the accelerator science and technology workforce, some turnover is both inevitable and desirable as this promotes opportunities and strengthens links with other organisations and industry.

STFC is taking steps across a range of job and career types including developing plans for a Skills Academy to help tackle the national technical skills gap.

Theme 4 Implementation steps

- **Train the next generation of specialist accelerator scientists and engineers:**
  - **Attract high calibre apprentices, graduates, technicians, doctoral candidates and postdoctoral researchers and fellows**
  - **Develop and maintain the scientific and technical skills required to support current facilities and deliver the priority future projects.**
  - **Continue to support the accelerator institutes to provide a focus for training the next generation of accelerator experts in areas where there is a recognised international skills shortage.**
- **Seek to attract and retain the best talent by providing interesting and impactful work in a stimulating environment that fully embraces equality and diversity.**
- **Promote opportunities for skills gained in projects to be shared and used across the portfolio of activities and foster career development, including making use of all the UKRI training mechanisms.**

Apprentices - STFC has a strong and successful apprenticeship programme in the national laboratories and national facilities. We will ensure that skills relevant to accelerators continue to feature strongly in the training opportunities provided.

Technicians - Technicians play a key part in maintaining STFC's leading edge in research excellence and driving solutions to technological challenges. In 2019, STFC joined with 84 other universities and research institutions to become a signatory of the Technician Commitment initiative. The Technician Commitment has now been embraced by UKRI and an action plan has been published.

Fellowships - STFC funds several fellowship schemes to support talented early career researchers including the Ernest Rutherford Fellowships which enable early career researchers with clear leadership potential to establish a strong, independent research programme.

6 Implementation monitoring and reporting

6.1 Ownership and coordination

The portfolio of STFC's accelerator activities is spread across many aspects of STFC's delivery functions. An important aim of the Strategic Framework is to enhance the coordination across these areas so that the resources directed to accelerator science and technology achieve the best outcomes possible.

This spread of activity is a challenge within STFC's management structures. The primary ownership of the Framework and the actions that it will drive are:

- The Executive Director, Programmes
- The Executive Director, National Laboratories

As the new generation of accelerator driven UK facilities are instigated, there will be an increasing need for involvement of the Executive Director, Large Scale Facilities in the relevant Framework actions (Figure 1).

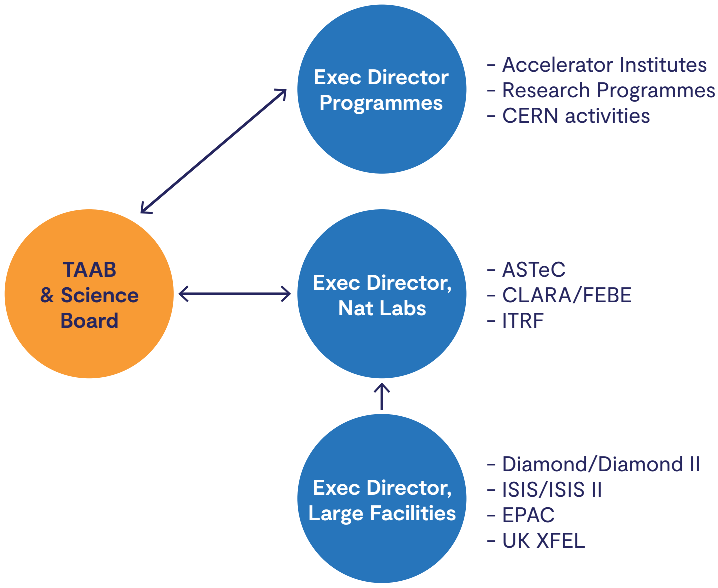

Figure 1: Ownership and reporting structure for the Framework

6.2 Progress reporting

Implementation of the steps set out in section 4 will be informed by consultation with TAAB and Science Board. This will include seeking advice on aspects including:

- Achieving the right balance of activities across the accelerator portfolio
- Identifying where top-down priorities need to be given to complement community driven research proposals
- Reviewing progress and advising on any changes in priority or aims
- Identifying opportunities for a greater level of join-up between activities

STFC will prepare a high-level report to TAAB for review and critical assessment of the progress made. This will contain a clear and concise summary of current STFC activities across the facilities, national laboratories, accelerator institutes and other funded activities. It will also include details of activities where STFC is a partner with some or all the funding coming from other sources. The plan will indicate the principal activities and outcomes forecast for the next year and outline the likely longer-term actions.

The activity report will include the following points:

- Show the status of the activities related to the key theme actions
- Highlight how the activities make use of and build our capabilities and strengths
- Highlight how coordination between activities is being achieved so that knowledge and capabilities are being effectively disseminated and exploited
- Report any monitoring data including outcomes and impacts achieved by both STFC based activity and grant funding
- Provide a summary breakdown (operation, construction projects, R&D, training) of funding across the STFC portfolio
- Highlight any new risks and opportunities

An in-depth review of the strategy implementation and achievements will be carried out after 3 years, led by a sub-group appointed by TAAB. The findings of this review will be used by TAAB to provide comment to STFC's Council and Executive Board on the status and health of the accelerator programme, highlighting any concerns, risks and opportunities.

Glossary

ALICE	A Large Ion Collider Experiment
ASTeC	Accelerator Science and Technology Centre
AWAKE	Advanced Proton Driven Plasma Wakefield Acceleration Experiment
CERN	European Organisation for Nuclear Research
CI	Cockcroft Institute
CLARA	Compact Linear Accelerator for Research and Applications
DL	Daresbury Laboratory
EMMA	Electron Machine with Many Applications
EPAC	Extreme Photonics Applications Centre
EPSRC	Engineering and Physical Sciences Research Council
ERL	Energy Recovery Linac
ESPP	European Strategy for Particle Physics
FEBE	Full Energy Beam Exploitation
FEL	Free Electron Lasers
FETS	Front End Test Stand
FFA	Fixed Field Alternating Gradient Accelerator
GCRF	Global Challenges Research Fund
HEI	Higher Education Institution
HL-LHC	High-Luminosity - Large Hadron Collider
iFAST	Innovation Fostering in Accelerator Science and Technology
ILC/CLIC	International Linear Collider / Compact Linear Collider
ITRF	Ion Therapy Research Facility
JAI	John Adams Institute
J-PARC	Japan Proton Accelerator Research Complex
LBNF/DUNE	Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment
LDG	Laboratory Directors Group
LHC	Large Hadron Collider
Linac	Linear accelerator
MICE	Muon Ionization Cooling Experiment
PIP-II	Proton Improvement Plan II
PPTAP	Particle Physics Technology Advisory Panel
R&D	Research and Development
RAL	Rutherford Appleton Laboratory
RF	Radiofrequency
RUEDI	Relativistic Ultrafast Electron Diffraction and Imaging
SC	Superconducting
SRF	Superconducting Radiofrequency
STELLA	Smart Technologies to Extend Lives with Linear Accelerators
STFC	Science and Technology Facilities Council
TAAB	Technology and Accelerator Advisory Board
TRL	Technology Readiness Level
UKRI	UK Research and Innovation
XFEL	X-ray Free Electron Laser

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