Statement of Interest Submission Form

Science and Technology Facilities Council

Additional supporting information, such as letters of support, are not required and will not form part of the Science Board PPAN consideration.

Please submit this form to the Science Board PPAN Secretariat by emailing SBPPAN@stfc.ukri.org.

Project title:	Uncommon Sense: Detector Research & Development for particle, astro-particle and nuclear physics
Project lead and contact email:	Chris Parkes, chris.parkes@manchester.ac.uk
STFC contact:	Sarah Verth

Institutes and groups involved in project

- List the institutes and groups involved, including STFC National Laboratories

University of Birmingham, University of Bristol, Brunel University London, University of Cambridge, University of Edinburgh, University of Glasgow, Imperial College London, King's College London, University of Lancaster, University of Leicester, University of Liverpool, University of Manchester, University of Oxford, Queen Mary University of London, Royal Holloway University of London, STFC Daresbury, STFC Particle Physics Department, STFC Technology Department, STFC ISIS, University of Sheffield, University of Sussex, University College London, University of York, University of Warwick.

Anticipated project start date	**FY 25/26**	**April**
Project end date	**FY 29/30**	**March**

One line project description:

Community wide strategic technology development to enable our future science goals

Project description **(maximum 500 words)**

Include:

- High level science case and key questions that the project will address

Particle physics is entering a new era as ATLAS and CMS phase II R&D ends. The detector R&D for the next decade is focussed on providing the innovative technologies, infrastructure and staff skills that will enable a set of medium and smaller scale projects with more diverse aims and that will potentially lay the path for a major future collider project on the 20+ year horizon. The science goals of these future projects include the understanding of the Higgs boson; the search for new particles and forces from beyond the Standard Model; the exploration of flavour and fundamental symmetries in the quark and lepton sectors; the quest for dark matter; the understanding of the strong force and extreme states of matter.

- Specific UK project deliverables

An international programme of strategic R&D in detector systems is being setup, known as DRD[1]. The UK community (particle, astro-particle and relevant nuclear physics) is fully engaged in this process, which it has helped shape, and provides several of the international leaders of the DRD process and collaborations.

DRD is organised across eight collaborations covering 1-gaseous detectors; 2-liquid detectors (for neutrinos and dark matter); 3-semiconductor detectors; 4-particle identification; 5-quantum sensors and technology; 6-calorimeters; 7-electronic systems; 8-challenges of large scale systems. The UK is prioritising its specific deliverables in this international process. Here we give three illustrative thematic technology examples from amongst DRD-UK interests.

- Development of CMOS detector systems (DRD3,6,7,8). The next generation of high-precision tracking detector systems and also potentially digital calorimetry will be based on monolithic active pixel sensors (where the sensor and readout chip is a single electronic system). This industry standard process (e.g. used in mobile phone cameras) offers the potential for low-cost and high-volumes for large area coverage.

- Development of 4D detector systems (DRD1,3,4,6,7). The next generation of collider-detectors will add time stamping at the *O(*10) ps level, reducing the effective multiplicity of the analysed events, and provide particle identification.
- Development of low-background light and charge collection systems (DRD2,4). The next generation of neutrino, neutrinoless double beta-decay and dark matter search experiments require higher efficiency sensor systems with ultra-low radioactive backgrounds. This capability will underpin the UK's aspirations to host world-class science in the Boulby underground laboratory.

- What success looks like for the project?

The costs involved in developing cutting-edge technologies are rising while the field remains – by commercial standards – a low-volume, niche market. Increasingly, costs can be met only through a significant pooling of resources. The new DRD structures will have the necessary critical mass to meet these challenges while ensuring that creativity is maintained. This strategic R&D programme will:

- deliver the novel technologies that will underpin the next generation of experiments and facilitate long-term developments through UK and international coordinated activity.
- Provide instrumentation training and skill development for the next generation of experimental particle physicists, engineers and technical staff.
- Construct and support specialised facilities (design, build and test) supporting international capability in detector development and construction.
- Provide methods of establishing meaningful longer-term relationships with UK industrial partners.

[487 words]

The following areas are based on the STFC assessment criteria for SOIs.
Please use the bullet points provided as a guide for the content of your answers.

Scientific excellence and timeliness **(maximum 500 words)**

- Scientific justification of the project

The delivery of world-class science in particle physics, astro-particle physics and nuclear physics research is foundational to the purpose of STFC. This programme is enabled by the development of novel instrumentation. The benefits to the wider society of the development of such instrumentation and the associated skills training are central to why fundamental physics is funded from public resources.

- Scientific competitiveness of the project within the national and international landscapes

The DRD programme is the internationally agreed route to deliver the instrumentation for the next generation of experiments. The UK has traditionally played a key role in the development and construction of key detector systems for major international experiments. The support requested for strategic R&D, will leverage the strong expertise and excellent infrastructure developed over many years, enabling the UK to continue to make leading contributions.

The European Particle Physics Strategy 2020 Update concluded that *"Success…relies on innovative instrumentation and state- of-the-art infrastructures....The community should define a global detector R&D roadmap."* This roadmap [1] was prepared, under the auspices of the European Committee for Future Accelerators (ECFA) and approved by CERN Council. This led to an implementation document [2] to form the collaborations with CERN as host institution. Many UK staff now hold positions in the international DRD collaborations and the chair of the ECFA detector panel that organised the process was from the UK. A parallel detector development process is being setup by US particle physics community with DOE. The UK national project has been formed over the past year.

- Outcomes of any related projects and previous investment

In the 1990s, post LEP construction and pre-LHC, a similar process occurred which enabled the detector technology for the successful realisation of the LHC. More recently the CERN RD collaborations have existed to facilitate information exchange and common developments in specific areas. The largest of these has been the RD50 collaboration whose breakthroughs enabled the radiation hard vertex and semiconductor tracking detectors of the LHC and HL-LHC. The long-term co-leader of RD50 has been from the UK. The RD53 collaboration has developed the common pixel chip utilised by both the ATLAS and CMS Phase II experiments. The RD collaborations will be replaced by the new DRD structure, which will have a new strategic project based structure and the wider technology range that is needed for the next era.

- Why is now the right time for the project to take place? Include any external drivers of project timing

Currently four of the eight DRD collaborations have been approved by the Detector Research and Development Committee (DRDC) and started operation in January 2024. The other four are in various stages of pre-approval and all are expected to start operation by the end of 2024.

CERN has approved its funding (7M CHF/annum) and the other leading European countries are seeking their funding for the programme. The UK needs to provide specific funding to secure a leading role in the development of next-generation technology. The support will operate in three / four year cycles.

With the end of the R&D phase for major instrumentation projects (ATLAS/CMS) the UK has the opportunity to engage in DRD for the benefit of the future programme, and without this programme risks losing expertise and leadership.

[498 words]

Strategic drivers and prioritisation **(maximum 500 words)**

- How will the project contribute to the delivery of STFC and UKRI strategic priorities?

DRD is the agreed community project that will deliver instrument development to meet the following priorities of the STFC Strategic Delivery Plan 2022–2025 [3]:
1.1. Delivering world-class training;
2.1 International Research Infrastructure;
2.2 Maintaining our National Facilities as Centres of Excellence;
2.3 Next Generation World-Class Capabilities;
3.1 Leveraging our international investments;
3.2 Strategic investment in our science areas;
4.1 Exploiting discoveries;
4.2 Accelerating commercialisation;
5.2 Building a Green Future (see Environment section below);
5.3 Investing in transformative technologies

- How has the project been prioritised within the research community (e.g., community engagement, discipline or technology roadmap/strategy, government or UKRI strategy)?

The DRD programme is the outcome of a four-year process in the international community as described above. All eight collaborations have held consultations and workshops. Engagement with the workshops has been remarkable with several having 500-1000 participants. The leaders of the collaborations, and PI for the UK, have been (or will be) elected by a vote for all contributing groups. The DRD-UK process has been discussed in a dedicated session of the STFC particle physics advisory panel (PPAP) and the first full community DRD-UK meeting was held after the IOP particle astro-particle and nuclear physics conference in April 2024.

An international survey has been conducted through ECFA and the Lab Director's Group on the available major infrastructure for particle physics instrumentation development. Existing major UK infrastructure of relevance includes the Diamond light source, ISIS neutron and muon source, Birmingham Cyclotron and Boulby underground laboratory. The lack of underpinning national UK facilities for R&D silicon detector fabrication is a notable omission compared with international competitors and DRD-UK has engaged with STFC to highlight this limitation to the DSIT UK government consultation on the UK semiconductor strategy [4].

- Level of community support (scale and the potential of the community to grow if the project is funded)

This proposal is signed by all particle and astro-particle physics groups in the UK and the nuclear physics groups engaged in the largest scale projects. Internationally the engagement is also high, for example the DRD3 (semiconductors) and DRD2 (liquid detectors for neutrino and dark matter) Collaborations currently have 132 institutes from 28 countries and 99 institutes from 15 countries, respectively. Given the participation of all major international groups in the process, further growth is likely to be primarily from the engagement of less developed areas of the world (e.g. Africa, South America).

- Fit of the project within the national and international landscapes

This is the nationally and internationally agreed collaborative structure for particle, astro-particle and related nuclear physics technology development for the foreseeable future.

- Synergies with other discipline areas

The development of cutting-edge instrumentation has a proven track record in providing some of the strongest STFC engagements with other discipline areas. This includes benefits to national facilities (ISIS, Diamond, RAL Space) and medical and security applications.

[416 words]

Benefits **(maximum 300 words)**

- Scientific benefits

DRD will enable the future experimental programme of our fields. For example, the development of 4D detectors and development of low-cost CMOS pixel detectors (3D space) to replace silicon strips (2D) will both, figuratively and literally, open a new dimension in collider detectors that is needed for the order of magnitude higher data rates expected at some future collider detectors; the next generation of dark matter and neutrinoless double-beta decay experiments will be simply unachievable without the development of new technologies with ultra-low background rates; developing the applications of quantum technologies offer entirely new science opportunities from dark matter to gravitational waves.

- Wider benefits beyond scientific results such as economic (including benefits to UK industry or a particular UK region), health, cultural, security, or public service impacts, cost efficiencies, policy improvement.

Particle physics technology development is recognised as one of the key economic benefits that accrue from the STFC programme, notably in the medical and security fields [3].

DRD-UK offers a unique opportunity for establishing a combined UK particle physics engagement programme with UK industry, to address our poor economic return from CERN through a competitive supply chain in line with the aims of the recent DSIT Policy paper on CERN engagement [5]. Unlike individual project funds, it will allow long-term cross-community industrial relationships to be built. With this in mind we seek to:

- Establish an industry programme board, to provide industrial awareness and advice on the DRD-UK programme.
- Develop a core technology requirements roadmap and identify the mutually beneficial technology developments that are possible with UK industry.
- Provide funding for technology trials with industry to allow proof of concept projects.

This programme has been developed with the STFC head of UK CERN industrial liaison.

[256 words]

Step change **(maximum 300 words)**

- How will the project deliver a step change in capability from what is currently available? This could be addressing a gap in UK capability (knowledge, people, infrastructure), or steps to maintain a current advantage.

The project will deliver step changes in technology that will facilitate the next generation of experiments. Just as the UK contributions to the LHC and HL-LHC experiments would not have been possible without the breakthroughs in radiation hard electronics and semiconductors, the roadmap [1] has identified the range of capability requirements for the 2030s and 2040s. These include low-cost and low-material highly segmented devices, some with unprecedented timing precision; ultra-low-background materials and devices; electronics with embedded intelligent processing capabilities.

Some of our competitor countries (notably France, Germany, Italy, Spain) have had long-term strategic R&D funding that has continued technology development in parallel to the construction of the current large-scale detector systems. In the UK in recent years this development has happened through R&D inside single-experiment focussed projects. This has inevitably led to the UK falling behind in some areas of technology development, while still maintaining an excellent record in the delivery of largescale projects as a consequence of the UK investments in technology in previous decades.

There is a lack of younger expertise in the development of detector technology and difficulties in recruitment and retention are encountered. We will address this for the next generation of leaders in large-scale fundamental science instrumentation by establishing an instrumentation training programme and a Centre of Doctorate Training linked to the DRD projects and UK experimental programme. This is described further below under studentships. Many UK academic staff in experimental groups in the past decade have been recruited through fellowships, a process currently favouring those engaged in the data analysis and production of final physics results. We will engage with STFC around addressing the shortcomings of the fellowship process for the progression of the cohort that will be trained by this CDT programme.

[289 words]

Risk **(maximum 300 words)**

- State key project risks

The DRD structure provides the necessary critical mass to realise step-changes in technology and long-term strategic thinking which is not available in individual funding calls. However, R&D is about realising benefits from creativity, the projects must thus remain agile and able to respond to new opportunities. For this reason, critical periodic reviews of the programme will be held.

The next large-scale collider programme is more than twenty years away, thus specific devices developed at this time are highly unlikely to be directly used in those detectors. Instead, these long-term needs need to be embedded in the programme through the delivery of technologies for medium term experiments and dedicated demonstrators. The medium-term experiments have a wide-array of competing needs, this requires prioritisation in collaboration with STFC and the UK community. The programme is thus best considered a partnership with the universities, national labs and funding agency requiring more joined-up thinking than a typical funding award.

- Impact of not beginning/participating in the project
- Impact of delayed funding decision

The lack of UK R&D funding in recent years has led to the UK falling behind our international competitors in some key areas. However, the successes in delivery of high profile instrumentation construction in the UK gives a strong technology base from which to rebuild. All international DRD collaborations are expected to be operational by the end of 2024, thus knowledge of the expected future funding level will allow the UK to target its involvement.

- Is the project scalable? Provide any alternative options for ambition/cost/schedule

As described in [6] the UK community has expressed aspirations in all eight DRDs (though at very different levels), training, industry and new major infrastructure. The prioritisation of these interests will be dictated by the level of funding we choose to invest. This investment will in turn determine the level of UK leadership in the next generation of experimental programmes. Given current funding constraints a minimum level programme is described here.

[300 words]

Deliverability **(maximum 200 words)**

- Involvement of formal project management; how embedded is project management in the project?
- Project management approach
- Feasibility of project delivery

A UK steering board has been actively meeting since summer 2023, comprising one representative for each of the 20 UK particle physics groups and with further smaller groups associated. UK coordinators have been appointed for all eight DRD collaborations, and for work packages for training and industrial engagement. The institutions involved in each area have been identified. The UK PIs of most major future experiments in this field have addressed the steering meetings over the past months. The programme has the support of all UK groups.

The project team involves leading members from all recent and current large particle, astro-particle and nuclear construction projects and as such have full knowledge of current project management practice in the field. Realistic goals for project delivery will be set and reviewed. The PI led the LHCb Upgrade I project, nationally and internationally, the largest particle physics construction project to have completed installation and started operation in the past decade and which was delivered on-budget and in-time for LHC operations. The DRD-UK project is supported by STFC PPD, with a PPD leadership member as budget holder, and will consult PPD project office to include professional project management commensurate with the project scale.

[198 words]

Environmental sustainability **(maximum 200 words)**

- How have environmental sustainability considerations been embedded into the project design?
- Any actions planned to mitigate and measure/estimate the impact of implementation and contribution to the UKRI's Environmental Sustainability Strategy (example areas; carbon, procurement, efficient use of resources, living environment, physical environment)
- If and how the project or its outputs directly enhance or benefit the environment

The international scientific community has a responsibility to limit the negative environmental impacts of basic research. The next generation of large particle physics projects must be delivered to comply with the UK's net-zero law [7]. Several members of the project team are engaged in considering sustainability issues in particle physics and dedicated discussions have been held amongst interested members of the community and with STFC. The community report [8] recommends "Assessing, reporting on, defining targets for, and undertaking coordinated efforts to limit our negative impacts on the world's climate and ecosystems must become an integral part of how we plan and undertake all aspects of our research."

Significant quantities of highly damaging greenhouse gases (GHGs) are used for particle detection technologies and cooling systems across HECAP+ and we identify this as the aspect in which this DRD could make the largest impact. Gases are used in a variety of detectors, such as time projection chambers, ring-imaging Cherenkov detectors, multi-wire proportional chambers, and most notably resistive plate chambers (RPCs). Scope 1 direct emissions made up about 25% of CERN's carbon footprint in 2019, 92% of these Scope 1 emissions are related to the activities of the large LHC experiments. To put the emissions into context, CERN's PFC emissions are roughly the same size as the Swiss emissions.

We identify the following three initial priority areas for DRD-UK activities, for which dedicated resources will be requested.

- Development of low-global warming potential (GWP) gases for use in existing and future gas detector systems. The large areas of RPC muon detector systems in the ATLAS and CMS detectors are the dominant contributors to emissions. Several future detector projects still plan to use RPCs or other gaseous systems (DUNE, SHIP, Anubis, Codex-b). The challenge in finding replacement gases originates from having to satisfy several factors: safety (non-flammable and low toxicity) and low environmental impact (minimising GWP), while maintaining their detector performance (detection efficiency, timing precision, ageing resistance, good quenching capabilities, and radiation-hardness).
- Development of low-GWP and non-PFAS (per-and poly fluoroalkyl "forever chemical") coolants for detector systems. The UK plays a particularly major role in the development and construction of large-scale tracking systems and thus has particular responsibilities in this area. The adoption of CO_2 based cooling systems is significantly reducing emissions. However, these systems are large, operate at high-pressure and recirculating systems are expensive. Liquid coolant systems based on chemicals with lower GWP than the fluorocarbons typically were starting to be implemented. However, these replacements (brand-name Novec) are PFAS chemicals and will be phased out, and thus alternatives must be identified.
- Development of low-GWP radiators and/or leak free systems for Ring imaging Cherenkov (RICH) systems. The UK is one of the leading countries in RICH development. Promising tests have been performed replacing one gas, CF_4, with CO_2 which has a similar refractive index though somewhat lower light yield. However, for lower momentum particles an alternative to C_4F_{10} gas needs to be identified, either through alternative gases, novel-radiators, or leakless systems.

[495 words].
The number of words for this section has been increased following guidance from the STFC office, given the particular relevance of the topic to this project.

Project information

Long term project implications **(maximum 200 words)**

- Longer term commitments such as maintenance and operations (M&O)

None.

- Potential call for exploitation staff effort on the Consolidated Grant/Astronomy Standard Grants

This project facilitates for the first time a coordinated and strategic use of the considerable R&D funds that have long been requested and awarded by STFC to the UK groups. STFC modified the rules of the 2024 CG round to include such strategic R&D initiatives and invited a dedicated submission from the DRD-UK Collaboration [6]. This DRD-UK

CG document gives the wide range of UK interests. Once the funding level resulting from this SOI is known, the individual projects and areas will be shaped around the UK and internationally agreed priorities. The CG funds will then be focussed in support of this DRD-UK prioritised programme.

[107 words]

Project partners **(maximum 200 words)**

- Principle partners/collaborators and level of commitment

All particle and astro-particle physics groups in the UK, and the nuclear physics groups engaged in the largest scale projects, are part of this programme. All UK particle physics groups have deployed resources from their consolidated grants on DRD activities in their bids [6]. These resources are typically small fractions for core and academic staff, they will be deployed on supporting the specific projects that are funded following this SOI process.

- Project fit within international collaboration (if applicable)

All elements of the UK project are part of the international DRD proposed projects that have been approved or are being reviewed by the international DRD committee. The number and level of engagement with the specific projects will, of course, depend upon the level of new resource allocated to DRD-UK through this SOI process.

- Industrial partners

Wide engagement with UK industry will be sought. Partners already identified in the DRD-UK CG submission [6] include: BOC/Linde; MIRION (Canberra); Agilent; XIA; Calder Lead; Micron semiconductors; Teledyne e2v; Quantum Detectors; Photek; Torr Scientific; Kurt J. Lesker; Europractice.

- Any other funding sources

The major international partners are currently seeking funding with their funding agencies. There have been previous European union instrumentation projects (e.g. the AIDA network, currently nearing the end of its 3rd generation) with significant UK involvement.

[199 words]

Associated studentships (if applicable) **(maximum 100 words)**

- List any studentships included in the project.

We seek a Centre of Doctorate Training linked to DRD and the UK detector programme. Co-funding will be sought with private sector partners. In addition to R&D intensive firms, companies in the areas of public engagement, communication and managerial skills will be engaged. The training programme will consist of: a mix of online and face-to-face lectures tailored to PhD students doing instrumentation work; residential laboratories and workshops focused on hardware; networking events; soft-skills training; and industry placements. The residential instrumentation laboratory element will be modelled on the long-running STFC particle physics summer school and bid for in the STFC call.

[100 words]

Ethics and responsible research and innovation (RRI) **(maximum 100 words)**

a) Does the research in this application relate to any of the 17 sensitive areas of the economy identified in the NS&I Act? This project includes advanced materials, technologies with potential dual use and quantum technologies. The project team is experienced in managing such issues.	Yes
b) Does the research in this application include international collaboration? The international project has been approved by the 23 member countries of CERN council (including STFC). CERN has a further 13 associated member countries and around 50 country cooperation agreements.	Yes
c) Is this application part of an experiment at an international facility? It is not part of any individual experiment but will develop technology to the stage where it can then branch-off to be further tailored to application in many experiments.	No

If answering 'yes' further guidance will be provided if a full proposal is invited.

- Applicants are expected to consider UKRI's trusted research and innovation work programme aimed at protecting all those working in our collaborative international research and innovation sector.

- What are the ethical or RRI implications and issues relating to the proposed work? If the proposed work is not thought to raise any ethical or RRI issues, explain why.

The project will be conducted in line with best practice on EDI, open science and the FAIR principles.

[98 words]

Estimated project costs

- An estimate of the total project cost to STFC (80 or 100% FEC, please specify). STFC laboratory costs should be provided at 100% FEC
- Staff costs must include overheads at both universities and national laboratories.
- Include the capital construction phase
- Costs should be broken down by heading and must be sufficiently detailed to show that estimates are reasonable

The STFC strategic review of particle physics (Dec. 2022) [9] recommended "There should be an increase in resources available for generic R&D for detectors & accelerators. An indicative goal would be to approach a minimum of 5% of the core programme".

The Particle Physics Technology Advisory Panel (summer 2022) [10] recommended "The UK must respond to..[DRD roadmap]… by undertaking an STFC-funded programme" and that this is "in addition to funding allocated to current and future activities".

Consequently, in line with these, we propose the minimal recommended level of ~£3M/annum new funding for this DRD programme. This will be supplemented by the CG R&D funds, dedicated STFC R&D project calls, and the funds for the CDT programme that are also estimated here.

We assume 50% funding in the first year for the DRD programme to account for project ramp-up.
Staff costings at mid-grade are assumed. Inflation is included at 3%.
Working allowance at a typical appropriate level is included.
Studentships are assumed to be 3.5 year studentships starting six months into the project.

DRD-UK Research programme

Cost heading	FY 1 £k	FY 2 £k	FY 3 £k	FY 4 £k	Total £k
Staff effort (university)	995	2050	2112	2175	7333
Staff effort (STFC labs)	142	293	302	311	1047
Equipment	196	538	440	293	1467
Travel and consumables	98	245	203	140	685
Working allowance	143	313	306	292	1053
Total	**1574**	**3438**	**3362**	**3211**	**11584**

Centre for Doctoral Training

Cost heading	FY 1 £k	FY 2 £k	FY 3 £k	FY 4 £k	Total £k
Fees	57	118	122	126	423
Maintenance	231	476	490	505	1701
RTSG	615	1230	1230	1230	4305
Total	**288**	**594**	**612**	**630**	**2124**

STFC-funding involvement

- Will the project utilise any staff effort from any Consolidated Grant/Astronomy Standard Grants?

Yes. Please see the Particle Physics 2024 Consolidated Grant submission for FTE breakdown [6].

- Will the project utilise any STFC National Laboratories baseline staff effort (**NOT project posts**)?

Yes. Please see the Particle Physics 2024 Consolidated Grant submission for FTE breakdown [6].

- Will the project have any STFC-funded computing involvement (e.g., DiRAC, GridPP)?

GridPP resources are likely to be used for the analysis of data taken during instrumentation development, for example in simulation and in testbeam analysis but at a minimal level compared with existing experimental activities. This proposal complements Swift-HEP, which addresses the future software and algorithmic needs of the community with some synergy at the intersection of the projects for example in embedded processing in intelligent detectors.

References

[1] ECFA Detector R&D Roadmap Process Group, The 2021 ECFA detector research and development roadmap , Geneva, 2020. doi: 10.17181/CERN.XDPL.W2EX. https://cds.cern.ch/record/2784893?ln=en

[2] ECFA Detector R&D Roadmap Process Group, The 2022 ECFA detector research and development roadmap implementation plan , Geneva, 2022. https://indico.cern.ch/event/1197445/contributions/5034860/attachments/2517863/4329123/spc-e-1190-c-e-3679-Implementation_Detector_Roadmap.pdf

[3] Science and Technology Facilities Council Strategic Development Plan 2022-2025. https://www.ukri.org/wp-content/uploads/2022/09/STFC-100123-StrategicDeliveryPlan2022.pdf

[4] Department for Science Innovation and Technology, National Semiconductor Strategy , UK, 2023. https://assets.publishing.service.gov.uk/media/646626780b72d3001334476d/national_semiconductor_strategy.pdf

[5] Department for Science Innovation and Technology, UK Strategy for Engagement with CERN , UK, 2023. https://assets.publishing.service.gov.uk/media/6516a9bb6a423b0014f4c604/uk_strategy_for_engagement_with_cern.pdf

[6] DRD-UK Consolidated Grant Submission 2025-2029, 2024

[7] The Climate Change Act 2008 (2050 Target Amendment) Order 2019 https://www.legislation.gov.uk/uksi/2019/1056/contents/made

[8] Environmental sustainability in basic research a perspective from HECAP+ https://sustainable-hecap-plus.github.io/Sustainability_in_HECAPplus.pdf

[9] STFC Review panel, Strategic Review of Particle Physics, 2022. https://www.ukri.org/wp-content/uploads/2023/01/STFC-03012023-SRPP-Final-Report_Dec-22.pdf

[10] Particle Physics: Towards a UK Technology R&D Roadmap for Accelerators, Detectors, and Software and Computing, 2022. https://www.ukri.org/wp-content/uploads/2022/08/STFC-220822-ParticlePhysicsTowardsUKTechnologyRDRoadmapAcceleratorsDetectorsSoftwareComputingReport.pdf