UK Strategic Detector R&D Programme

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This position paper is being submitted to PPAP and PAAP in response to the call for proposals for Infrastructure Fund preliminary activities, after consultation with the relevant STFC programme managers. Although it is not yet clear to what extent non-project-specific R&D aligns with the goals of the IF, we invite the advisory panels to consider this initiative alongside project-specific proposals in the first instance, and then provide feedback on the relative prioritisation of this work, and the appropriate next steps.

This document describes the intent, scope and organisation of a UK programme of Strategic R&D in detector systems for particle physics and particle astrophysics, in the first instance within the context of the proposed European Roadmap for detector R&D.

Justification and Purpose

The next major construction projects for both collider physics and low-background physics are a decade or less away, and require significant R&D activities in preparation. These will be followed by the design of yet-more-challenging detectors with ultra-high background conditions, or at very large scale, for which cost-effective technological solutions do not yet exist and must be invented. New classes of sensors (some using quantum technologies) are being developed at low TRL, and must be developed into complete systems.

The capability to design, develop, and scientifically exploit advanced detector technologies underlies practically all STFC experimental research. Sustaining such capability requires access to appropriate laboratories and facilities, and a well-trained workforce across all career levels. The costs of access to cutting-edge technologies are now such that cooperative work at European and international scale is mandatory, as is efficient and coordinated use of expensive and specialised facilities at laboratories. Detector technology should be a key impact-generating output of the STFC research programme, and there is proven scope for interdisciplinary and industrial use of both particle physics detectors and the related data-processing systems.

In recognition of the points above, a new R&D programme in detector systems was proposed in the 2020 update of the European Strategy for Particle Physics, and the need for a corresponding UK activity was highlighted in the most recent UK PPAP and PAAP roadmaps. A European Detector R&D Roadmap has now been developed, published, and approved by CERN Council. This roadmap makes clear recommendations on the need to begin new sustainable long-term R&D programmes (GSR6) and to establish a system of fully distributed R&D based around centralised facilities (GSR5). The UK PPTAP has made commensurate recommendations on STFC strategy in this area, fully endorsed by the TAAB in its recommendations to the STFC Executive. Each of these roadmaps or reports calls for the ramp-up of a coordinated R&D programme in the context of the wider European activities, with the intention of securing and sustaining UK leadership in key areas of capability.

Detector R&D usually takes place in three stages:

1. ‘Blue-skies R&D’ R&D (low TRL), develops new concepts at laboratory scale, and provides fundamental proof-of-principle of new techniques. It is typically carried out by small research teams with access to local facilities, potentially with industry involvement.
2. ‘Strategic R&D’ (mid TRL), addresses systems-oriented and scaling issues, demonstrating long-term performance of detectors, and investigating engineering trade-offs and realistic costs. It requires dedicated and specialised facilities and technical support, and is carried out within a specific RD project or collaboration, and ideally as a co-development with industry.
3. ‘Project-oriented R&D’ (high TRL), produces demonstrators and prototypes for specific experiments or facilities. It is carried out in the context of an established experiment as the first phase of a construction programme, and with industry as suppliers.

STFC currently supports project-oriented R&D via pre-production grants, and has recently called for proposals for blue-skies R&D. However, beyond minimal participation in a few CERN RD projects, there is little activity in the strategic R&D area that is currently the most relevant for the next generation of science projects.

Scope and Objectives

The scope and breadth of necessary detector R&D has been examined in detail during the European Roadmap process, with UK input and overall leadership. The Roadmap therefore provides an appropriate supporting structure for UK planning, and also makes a number of relevant recommendations on organisation and coordination.

In a UK context, the objectives of the strategic R&D programme should be to:

- Develop and sustain a world-leading capability for advanced detector technology R&D in the STFC research community
- Facilitate continued UK leadership in the European R&D programme, and subsequent resulting leadership in next-generation experiments
- Construct and support specialised facilities at UK institutes, supporting international capability in detector development and construction
- Identify routes for rapid application of new detector technologies across national facilities, academic disciplines, and industry
- Support co-development of technologies with UK companies, leading to enhanced economic return from international investments
- Transform skills development, training and career prospects for technology-focussed early career researchers in STFC core science areas.

The UK has strength across its institutes in detector development, including specialised capabilities, facilities, and support at both universities and national laboratories. The R&D programme must therefore support staff time and infrastructure across a full range of UK participants, but also pay heed to the 'hub-and-spoke' model allowing a concentration of investment in centralised technical facilities where needed. In the UK case, this would largely involve allocation of funding for shared facilities used across a range of national and international projects, in many cases leveraging existing infrastructure at institutes.

The 'off-ramps' from strategic R&D, leading to accomplishment of the objectives will include:

- Proposals via the STFC Visions process for follow-up project R&D and construction of new instruments
- Supply of high-technology deliverables to international projects, either as UK buy in or via contracts
- Interdisciplinary proposals for application of technology in non-STFC areas, either via the UK's national facilities or within institutes
- Exploitation of IP within industry via licenses and other agreements
- Direct employment of trained people in industry.

The scope of the European Roadmap is wide, including technologies relevant to both collider physics, low-background physics and particle astrophysics. However, the balance of community activity will naturally be steered by the demands of future experiments with strong UK interest, and with particular regard to building up and sustaining capability in areas where future specific contributions are foreseen. This should include an appropriate combination of short-term R&D towards (e.g.) future e+e- and dark matter experiments for the 2030s, and longer-term R&D towards (e.g.) subsequent high-background collider experiments, new large-scale neutrino experiments, or advanced quantum detectors.

Organisation and Strategy

Whilst strategic by definition, the R&D programme must also be responsive in the sense that it should accept self-organised proposals from the community, and prioritise them based on both excellence and relevance to the objectives outlined above. However, some consideration of strategy and structural issues is needed in order to ensure sufficient concentration of resources (i.e. establishment of critical mass) in priority areas. The priorities set for the R&D programme should be driven by and respond to future UK science priorities. It may be useful to maintain a UK-specific 'R&D roadmap' building on the work of PPTAP and providing a framework for decisions on priorities within the strategic R&D programme.

A mechanism to ensure this would be to direct funding primarily in the first instance to supporting UK participation in the European R&D programme, both via the CERN DRD collaborations and the ECFA e+e- detector initiative. Additional European or international programmes will be relevant for some science areas (e.g. quantum technology). This would allow recognition of current or potential areas of UK international leadership, and provide assurance of an appropriately structured and managed overall project.

There should also be provision for:

- Follow-up of the outputs of the UK ‘blue-skies’ R&D programme
- Work primarily focussed on interdisciplinary or industrial applications
- Career support for ECRs with a technology focus, via studentships and fellowships

The creation of a large-scale CDT in detector technology and data-handling, and / or a centre for industrial engagement with particle physics, should be considered. The case for the former rests upon (a) the need to sustain an indigenous skilled workforce at all career stages, noting that many leading UK detector experts received their primary training in the 1990s; (b) exploitation of opportunities to interact with a range of relevant companies via the proven CDT model. The development of coherent ‘access point’ for industrial collaboration is a model that has worked well in other disciplines and other areas, and which can in principle bring benefits beyond the R&D programme itself (i.e. enhanced return on international investments via contracts).

The CERN DRD collaborations are expected to be long-lived and to evolve and expand their programme over the next decade. In order to ensure an appropriately agile programme, the UK programme should ideally be structured as a succession of medium-term projects (e.g. three years duration) with clear objectives and deliverables, and with the possibility of follow-up funding. For medium-scale projects, normal oversight procedures should be followed, not least as a vehicle for exposing a number of new PIs to the STFC project management and governance framework. For small-scale projects, a lighter touch regime may be appropriate. Funds should in principle be available to support researcher time, technicians, engineering services, materials, and operational costs. The regime for support of capital purchases should be discussed, since UKRI rules may preclude funding major equipment at full cost.

The timeline for the European R&D initiative indicates that the new DRD collaborations will be operational in early 2024, with concrete R&D proposals and subsequent discussions around structure, organisation and responsibilities in Spring 2023. It is therefore necessary to make decisions on likely future funding levels on a commensurate time scale, allowing UK bids for responsibilities. However, it must also be recognised that a large part of the UK community (and the European community more widely) is substantially occupied with LHC upgrade R&D or construction at present. Many of these projects will wind down from 2024 onwards, and so a ramp-up in engagement and funding should take place over a similar time scale, allowing the expertise developed in the LHC upgrades to be retained and harnessed for the next generation of projects.

Resources

The R&D programme is naturally scalable, but also requires critical mass to be established in areas where the UK wishes to take leadership or make rapid progress towards nearer-term projects. Since this is intended as a national programme applicable to a wide range of future projects, there needs to be scope to support at least three to four substantial developments across multiple institutes, in addition to (potentially) a number of smaller projects. In addition, resources will be needed to support the skills- and industry-related aspects, and to put in place any necessary specialised new facilities at national laboratories and universities.

On one hand, it is clear that a substantial portion of the relevant UK community are currently engaged in detector upgrade or construction activities for a range of projects. On the other, there is strong motivation for an early start to the programme, supporting UK ambitions for leadership within the DRD programme. It is therefore natural to consider a ramp-up of resources for this programme, starting at a sufficient level to support initial UK involvement, and culminating at a sustainable level sufficient to support an internationally-competitive programme over the long term, including the efforts of experts currently supported through detector construction projects. In this sense, the progressive increase of funding does not require exclusively 'new money' but may represent a shift of emphasis from construction projects to R&D, along with a corresponding transition of key individuals. In addition, early funding for an increased level of students and postdocs in the short term will ensure (a) a trained workforce for the later stages of the project, and (b) a successful transfer of skills and knowledge from current experts to future generations.

As an initial proposal, a starting expenditure of around £3M per annum would be sufficient to support a number of medium scale projects, ensure the opportunity for most UK groups to become involved in the DRD programme, and allow the startup of the CDT and industry engagement. This should rise progressively to a sustained level of around £10M per year by the late 2020s, comparable with the level of investment in R&D for LHC upgrades in the 2010s, and putting the UK on a par with programmes in other countries.

Author list

P. Allport (Birmingham), H. Araujo (Imperial), G. Barker (Warwick), A. Barr (Oxford), A. Bevan (QMUL), S. Biller (Oxford), D. Bortoletto (Oxford), J. Brooke (Bristol), C. Buttar (Glasgow), P. Burrows (Oxford), D. Costanzo (Sheffield), G. Davies (Imperial), M. D'Onofrio (Liverpool), J. Dopke (PPD), J. Evans (Manchester), S. Farrington (Edinburgh), H. Fox (Lancaster), M. Gersabeck (Manchester), T. Gershon (Warwick), V. Gibson (Cambridge), J. Goldstein (Bristol), L. Gonella (Birmingham), C. Gwenlan (Oxford), N. Harnew (Oxford), S. Harper (PPD), J. Hays (QMUL), P. Hobson (QMUL), L. Hommels (Cambridge), D. Hynds (Oxford), M. John (Oxford), R. Jones (Lancaster), H. Kraus (Oxford), C. Lazzeroni (Birmingham), C. Leonidopoulos (Edinburgh), R. MIddleton (PPD), J. Monroe (RHUL), P. Newman (Birmingham), R. Farrow (STFC), P. Majewski (PPD), **D. Newbold** (PPD, corresponding author), A. Oh (Manchester), A. Reichold (Oxford), A. Robson (Glasgow), S. Paling (PPD), K. Palladino (Oxford), D. Petyt (PPD), A. Pilkington (Manchester), R. Plackett (Oxford), D. Sankey (PPD), C. Sawyer (PPD), P. Scovell (PPD), C. Shepherd-Themistocleous (PPD), I. Shipsey (Oxford), A. Tapper (Imperial), A. Thea (PPD), G. Viehauser (Oxford), T. Vickey (Sheffield), I. Vivarelli (Sussex), D. Waters (UCL), N. Watson (Birmingham), T. Weidberg (Oxford), G. Wilkinson (Oxford), F. Wilson (PPD), S. Wotton (Cambridge), S. Zenz (QMUL)