UK Particle Physics Technology Centre

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Project Outline

Innovation in particle detection and data-handling technologies unpins the entire STFC science programme. It is clear that the most exciting future science projects will critically depend on technologies that do not exist today, but which must be developed over the next decade. However, UK funding for detector R&D has fallen to the lowest level for many years, and we risk losing international leadership.

We propose a new model for the funding and coordination of detector development activities at a national scale. Based on the success of past initiatives such as ASTEC, UKATC, and the accelerator institutes, the UK Particle Physics Technology Centre will combine the efforts of research groups across the UK. New investment in people and facilities, combined with new initiatives in doctoral training and industry engagement, will directly enable future international leadership, and will ensure a direct return to UK industry from the international particle physics programme.

The key deliverables of the centre, over a five-to-ten-year time scale, will be:

- A **detector R&D research programme**, comprising a range of projects at different scales of investment, ranging from flagship themes at the multi-year, multi-million level, through mid-sized focussed R&D of the type previously funded via the STFC PRD scheme, to small startup grants or summer studentships for new ideas.
- A major **Centre for Doctoral Training** in detector technologies, with a substantial number of students hosted across UK institutes. Cohort-based training in basic and advanced skills will be a central function, offered by experts drawn from across the community. As with other CDTs, students will typically be expected to complete an industrial placement as part of their PhD.
- Establishment of a **focal point for industrial engagement** with UK particle physics, via: technology co-development and joint training; industrial take-up of existing particle physics technologies; and identification of current and near-future opportunities for contracts within the UK programme, and from CERN and other major facilities.

The UK-PPTC will be a distributed project, rather than a single physical facility. It will harness expertise and facilities from the UK university groups, alongside current and new facilities at the national labs. Together, we will seek to develop not only new detector systems, but also to develop a new generation of technology-focussed particle physicists, with appropriate training and experience to maintain UK participation in the next international particle physics experiments.

Scientific Case

UK particle physics currently focuses on large experiments at the CERN LHC, at accelerator-driven neutrino beams, and at dark matter observatories. Each of these international programmes uses state-of-the-art detectors, their design and construction depending heavily on UK expertise. Examples of specific UK strengths include: precise silicon sensor systems and calorimetry; very high performance electronics for triggering and readout; and techniques for construction of ultra-low-background detectors. These capabilities *directly* enable the scientific output of major facilities; without cutting-edge detectors, the science is simply not accessible.

All progress in experimental particle physics depends on advances in detector and data-handling technology. Each new generation of experiments imposes increasingly challenging conditions, and requires improved capabilities in data recording and processing. Although particle physics and allied subjects are not unique in requiring high-performance detector systems, they are distinguished by (a) level of detector complexity, (b) extremely large data rates, (c) challenging environments in terms of accessibility, radiation hazards, and communications, and (d) the need for scientists and engineers to work seamlessly together to deliver complete systems. Each of these aspects is of direct relevance to industry and to other scientific disciplines, as has been demonstrated by past technology spin-offs.

The field is now starting to define a number of major future projects for the era after the LHC, designed to discover and investigate physics beyond the Standard Model. These include:

- High-energy and high-luminosity e^+e^- machines for precise investigation of LHC discoveries, including measurement of the Higgs boson couplings. Exceptionally complex new tracking and calorimetry systems will be required, well beyond the current state of the art.

- High-energy hadron colliders, producing as much as twenty times the collision rate of the LHC at ten times the energy. New data-processing technologies, some embedded into the detector itself, will be required to handle data rates orders of magnitude beyond any current systems in science or industry

- A future generation of ultra-low-background detectors, capable of measuring the distribution and properties of dark matter, and requiring brand new detection techniques combining efficient coverage of kiloton volumes with low background contributions.

The technologies to enable these projects does not exist today. Moreover, it is also critical for the affordability of future facilities that new approaches are found to improve the efficiency and cost-effectiveness of detector systems.

Maintaining international leadership requires continuous investment in R&D. The UK's success in driving the LHC experimental programme rested on decades of prior work carried out by generations of physicists and engineers. That expertise has now been successfully transferred to new projects such as DUNE. However, in recent years, it has become difficult to sustain a coherent national programme of detector R&D. STFC currently has no funding scheme directly targeting detector development; the funding which is available is almost exclusively via ERC, and has an uncertain future. Despite best efforts, UK industrial engagement in particle physics, and the return from international subscriptions, remains low. Most importantly of all, there is no new generation of young physicists with basic technology expertise ready to carry the programme forward; this gap is starting to be felt as we approach new construction projects.

Our partners elsewhere in Europe are addressing this issue through investment in new centres of expertise. Examples include nationally-funded institutes in Karlsruhe, Trento, Amsterdam and Vilnius (to name only a few of those with whom the UK is already collaborating), plus of course CERN and national labs. It is clear that our current facilities and level of investment cannot equal theirs. Key characteristics of these centres include an explicit mission in training and industry engagement, and a close coupling between basic R&D, systems development and testing, and exploitation of technology as part of the national and international science programme. If the UK wishes to maintain its historical leadership in the development of new science facilities, we need to be able to work with such institutes as equal partners.

The UK-PPTC will act as the coordination layer for a national programme of detector systems development. It will not supplant existing centres of expertise in Universities and labs, but instead consolidate and harness them across a number of coherent projects, whilst ensuring adequate and stable funding, in some cases jointly with Universities and industry. The research programme should be driven by proposals, and ‘owned’ by the community. We highlight below some potential areas of activity. Each technology is relevant to a number of future large-scale science projects, but also has direct applications in the commercial world. They are at very different technology readiness levels, but each offers the potential for the UK to become a world leader.

- Monolithic silicon pixel detectors are a semi-mature technology, in which the UK has until recently had a strong record in innovation. These sensors will be key to the development of new high performance low power tracking detectors (e.g. for linear collider detectors), and are also finding use in a range of industrial and medical areas. The emphasis will be in both improvements to basic sensor technology, and system-scale developments.

- The UK has strength in high speed digital and analogue electronics for trigger and DAQ, with increasingly novel approaches being taken to real-time data processing for experimental data. Here, the need is for development of skilled people with expertise in both physics and advanced pattern recognition and machine learning techniques. Collaboration with data scientists in academia and industry on future projects will be essential.

- Large area photon detectors with precise timing capability will be a key enabling technology in future generations of dark matter and neutrino detectors. There are clear industrial applications, e.g. in improved LIDAR sensors, and there is a small but established UK industry in high performance photodetectors. Although candidate sensors exist, their use in particle physics is untested, and much more development is needed.

- Advanced communication technologies, both photonic and >50GHz radio, are likely to play a major role in future detector systems (e.g. for future colliders or large-scale distributed detectors), since they can provide huge bandwidths at low power. However, these systems are ‘in the lab’ at present. Here, particle physics detectors can form a excellent technology test bed, working to solve basic technology problems before commercial applications are realistic.

- Quantum technologies (e.g. superconducting nanowire sensors for single photon detection) offer routes to extremely high-performance detector systems in the long term, across a range of science areas. Devices of suitable scale have not yet been perfected, and are not commercially available, and yet share many basic properties with existing particle detection systems. Other countries (e.g. the USA) are now funding co-development of new quantum detectors as a pump-primer for their ‘quantum technologies’ industry.

All of these topics, plus several others, were highlighted within the context of the current call for ‘big ideas’. There is general agreement in the UK community that a rational balance and connection between these areas, under the umbrella of the UK-PPTC, would be desirable and achievable. Each will eventually require access to construction and test facilities at significant scale, and the UK-PPTC will depend on high quality infrastructure at Universities and labs. We anticipate that part of the project budgets would be in the form of capital investment, thereby triggering co-investment by Universities. We do not budget for national-level infrastructure, but are aware of the current initiatives for investment in new facilities at RAL and elsewhere. The UK-PPTC has a potentially valuable role in cementing the relationship between the particle physics community and providers of facilities and expertise at the labs (e.g. RAL TD and SCD).

Leadership

The UK has maintained a strong international standing in experimental particle physics by balancing capabilities in technology and detector construction with those in science exploitation, theory, and computing. Over the last few years, this balance has become increasingly one-sided, and there is a risk as we enter an era of new facilities in the next decade that the UK will be marginalised. Although individuals have leadership in some key areas of R&D (e.g. CLIC, LAr-DM, SiD for ILC, FCC-hh design studies), there is no significant UK funding available to support a more substantial programme in any of these areas. Funding of the UK-PPTC, acting in support of these areas, will therefore play directly into sustained UK influence during the critical early design phase of each these and other projects, and then into scientific leadership. This will ensure, as it has done in the past, a successful scientific return on UK investment.

Societal and Economic Impact

Delivery of future projects will require a new generation of trained scientists with detector and technology expertise. A natural focus over the last decade on exploitation of running experiments has led to a generational gap, with the majority of new postdoctoral detector experts now coming from abroad. STFC science programmes should provide a key part of the UK skills pipeline, and physicists with practical expertise in high technology systems will be in high demand as the UK economy diversifies from the current focus on services.

We anticipate the training mission of UK-PPTC happening in three ways:

- Funding of PDRAs within research projects (representing the bulk of the cost), providing a sustainable career path for technology-focussed researchers.

- Establishment of a CDT with a cohort of around five students per year, building up to a steady state of around 20 students.
- Appointment of a number of UK-PPTC fellows, addressing the difficulty of detector experts in obtaining Rutherford Fellowships. The Fellows would be expected to drive their own projects, and to work flexibly across national labs, universities, and industry.

It is clear that, despite current efforts, much more needs to be done to bring about sustainable engagement between particle physics and UK industry. There are no ’quick wins’ here. A realistic long-term route to UK industrial provision of high technology products and services for major new projects is to start at grass-roots level with co-development of the basic technologies and systems. The recent success of the industrially-sponsored STFC DTCs in Big Data shows that this is a viable approach, and that industry is keen to engage. However, such an engagement will need to take place over a decade-long time scale, with significant new investment, and driven by the community ‘bottom-up’, complementing a traditional ‘top-down’ approach to KT.

Public engagement with particle physics rests on two aspects. There is a great deal of interest in the depth and significance of the science itself. However, there is an equal level of interest in the sheer scale and complexity of the machinery of particle physics. UK-PPTC will have a valuable role in showcasing STFC technology capabilities for both the public and for industry

There have been many industrial collaborations with particle physics, though those in detector development have often tended to be of a customer-client nature, or based around use of a specific product or a specific knowledge transfer target. Several of the recent tranche of STFC CDTs have found new ways to collaborate with industry. In particular, new co-funding models for PhD students have been successful in attracting industry investment; this could be extended to co-funding of PDRAs on suitable projects. We will also seek to obtain industrial income against any use of facilities for product development.

Scale of Investment

In order for the new approach to be effective, an initial programme of 5–10 years is required. This will allow sufficient time for the first products of the R&D programme to be taken up in science projects, and also sufficient time for 2–3 cohorts of UK-PPTC fellows to be trained and enter the field. Based on the level of support for current ERC-funded projects and past PRD projects, a budgetary requirement of around £5M per year could be anticipated, not including the participation of existing national lab or University CG-funded staff. A rough breakdown of costs is given below, which we assume would be covered by a combination of existing STFC funding and new direct funding from government (targeted at the training and industrial engagement components).

Commercial Case

The UK-PPTC will not expect to make substantial capital purchases. Where such investment in good or services is made, it will take place within the context of individual projects, and within

Item	Number	Unit cost	Annual cost
UK-PPTC Fellows	10	£100k	£1M
Students	20	£30k	£600k
Large project costs	2	£1M	£2M
Small project costs	4	£300k	£1.2M
Startup project costs	8	£30k	£240k
PPTC staff			£200k
Facility costs / support			£200k
Events / industrial engagement			£100k
Total			£5.54M

Table 1: Outline budget

existing UKRI and university frameworks.

Management Case

The UK-PPTC should have a full-time director and industrial engagement officer, plus administrative support. Significant work will be needed to establish the training and industrial collaboration aspects of the project, in addition to ensuring correct scientific and financial oversight, provide the necessary reporting to funders, and providing strategic direction.

Governance should be via a panel of senior UK and international academics, plus industry representatives. It may be appropriate for the UK-PPTC management to be embedded directly within the existing STFC national lab management structures. Since the centre will need to carry out a lightweight peer-review and oversight function, it will need to appoint independent panels in accordance with best practice.

Financial and scientific management of individual projects will be delegated to PIs, who (as recipients of STFC grants) will need to follow the usual reporting and oversight regime in the case of the larger projects. Conversely, it is also important that the ‘startup’ projects be allowed to proceed efficiently without heavyweight review and reporting – though unlike in previous schemes, follow-up of achievements and results is vital.