Detector Research & Development Collaboration - Briefing document

For circulation to Graham Blair, Sarah Verth, Karen Kirkby
Prepared on behalf of all UK particle physics groups by: DRD-UK Steering Board and coordinators, contact: Chris.Parkes @cern.ch
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"The success of particle physics experiments relies on innovative instrumentation and state-of-the-art infrastructures. To prepare and realise future experimental research programmes, the community must maintain a strong focus on instrumentation...The community should define a global detector R&D roadmap."
European Particle Physics Strategy 2020 Update

1. Introduction

Particle physics detector R&D is entering a new era with the major projects of ATLAS and CMS Phase II now in their construction phase. R&D for the next decade is focussed on a set of medium and smaller scale projects and will potentially lay the path for a major future collider project on the 20+ year horizon.

Consequently, a programme of Strategic R&D in detector systems for particle physics, particle astrophysics, and related nuclear physics activities is being setup under the auspices of ECFA. These replace the existing CERN RD collaborations and significantly expand their remit. The UK community is fully engaged in this process, which it has helped shape, and provides four of the sixteen international leaders of the DRD collaborations.

The costs involved in exploiting, adapting, and further developing cutting-edge technologies are rising rapidly while the field remains – by commercial standards – a low-volume, niche market. Increasingly, costs can be met only through a significant pooling of resources, particularly given the growing complexity and degree of specialisation required of those involved in device design and the need to negotiate with vendors as larger-scale organisations. The new DRD structures will have the necessary critical mass to meet these challenges while ensuring that creativity is maintained. These long-term strategic funding programmes will sustain research and development in order for the technology to mature and to be able to deliver the experimental requirements.

This strategic R&D programme will:

- Provide international coordination to identify and target common technological goals that will underpin the next generation of experiments facilitating long-term developments
- Provide and coordinate instrumentation training and skill development for the next generation of experimental particle physicists, engineers and technical staff
- Provide methods of establishing meaningful longer-term relationships with industrial partners

The DRD collaboration aims to develop a programme over the next years to meet these goals. in this new international framework the UK is well placed (infrastructure, expertise, leadership) to further build, or in some cases rebuild, strong international leadership if supported through appropriate investment.

2. Structure

A set of DRD Collaborations are being formed these are given in Tab. 1, covering most major areas of relevant R&D, with CERN as host. The process has been steered by the ECFA detector panel, under the chairmanship of Phil Allport (Birmingham), through a roadmap [1] and implementation document [2]. A Detector Research and Development Committee (DRDC), analogous to the LHCC, has started work to receive proposals and review them for approval. The overall structure is given in Fig. 1. MoUs for the 1st phase (3-4 years) will be prepared in 2024 for agreement with FAs. The operational model will be similar to experimental collaborations, thus allowing strategic priorities to be determined and cross-institution and international collaboration to be performed. The funding agencies are expected be involved through a dedicated Resources Review Board (RRB).

These DRD collaborations will address the needs of strategic R&D to underpin future experimental programmes. The will build upon and expand from the success of CERN RD collaborations, such as RD50 (which underpinned most of the silicon developments that enabled LHC detctors and beyond, and the UK had the long-term co-spokesperson) and RD53 (where a common ATLAS/CMS Upgrade II pixel chip basis was developed). Blue-Sky R&D or experiment-specific R&D are primarily covered by other funding mechanisms.

The DRD collaborations are expected to ramp-up over the first 3-4 years cycle, benefitting from the development of the programme and new structure and the availability of additional people and resources as the ATLAS/CMS Phase II construction completes.

No.	Primary area of interest	Relative UK interest
DRD-1	Gaseous detectors	4%
DRD-2	Liquid detectors	14%
DRD-3	Semiconductors	29%
DRD-4	PID and Photon Detectors	10%
DRD-5	Quantum and emerging technologies	7%
DRD-6	Calorimeters	5%
DRD-7	Electronics & Data Processing	22%
DRD-8	Large scale detector systems - infrastructure	8%

Table 1: The eight international DRD collaborations that are currently progressing through formation and approval. The relative size of the UK interest in each of the eight areas was estimated from input from UK institutions, weighted by group size. This is likely to continue to evolve as some areas, for example DRD-8, are still in an early stage of formation.

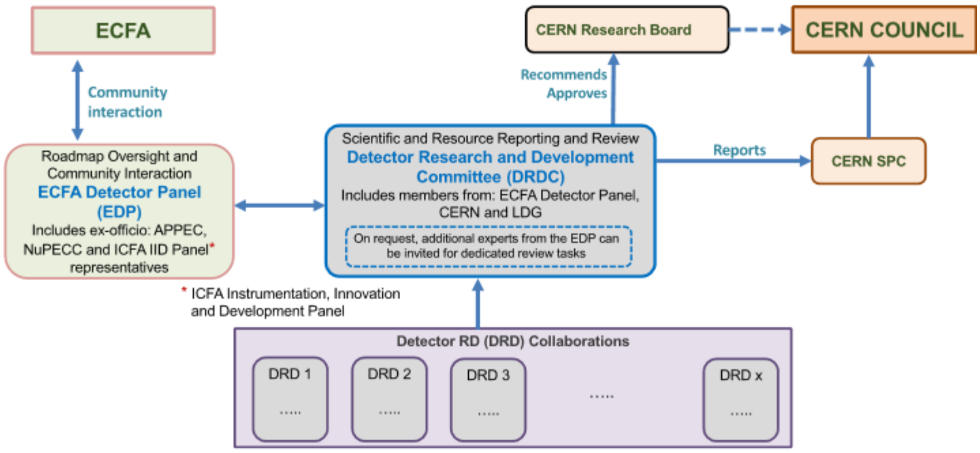

Fig. 1: Organisational structure for the DRD collaborations, where the arrows indicate the reporting lines.

A UK structure has been setup to coordinate the activities. A steering board has been appointed with representatives from each of the 20 UK particle physics groups (see Appendix A) and UK coordinators appointed for the DRD collaborations (see Appendix B). UK community meetings have been held and the coordinators are working with the international community to shape the overall projects. The UK particle and particle astro-physics community are fully engaged and the relevant elements of the UK nuclear physics community have also been contacted.

3. UK Strategy

In the past years, particle physics detector system construction has been a significant UK strength with major international projects having been delivered and currently in construction. However, the development of new technologies has lagged behind other leading nations in some important areas. The extensive expertise and infrastructure in the UK, established through our involvement in major build and development programmes, can be leveraged to enable a fast and cost-effective rebuilding of technology R&D leadership.

The DRD collaborations provide the opportunity for the UK to coordinate and target its R&D programme on the key technologies in which it wishes to play a leading for the next decades, developing appropriate infrastructure and working with UK industry. Establishing this generic R&D was a recommendation of the recent STFC Strategic review of particle physics [3]. Training in instrumentation and industrial engagement can be further strengthened in the UK, and these are both areas that can benefit from this initiative.

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 DRD programme will give the opportunity for students to develop a skill set for experimental particle physics and of benefit to the UK economy.

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. The international coordination of activities gives the opportunity for UK industry to reach a wider pool of researchers from which future orders for the experimental programme will emerge.

The scope of the European Roadmap is wide, including technologies relevant to particle and nuclear collider physics, non-collider precision physics, low-background physics, and particle astrophysics. However, the UK programme will be led by the demands of future experiments with strong UK interest, and with particular regard to building up and sustaining capability in areas where specific UK detector contributions are foreseen. The future environmental impact of the field must also be considered. With these points in mind, PIs from a range of future UK projects are discussing directly with the UK DRD collaboration leaders and members of many projects are involved in the UK DRD structure.

Consequently the UK goals for the DRD collaborations will be:

- 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 (design build and test) at UK institutes, supporting international capability in detector development and construction
- 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.

4. Funding arrangements

Following discussions with Sarah Verth, Grahame Blair, it is agreed that submission for the 2025-2028 Consolidated grant will be made on behalf of the UK DRD collaboration. DRD activities will be listed as an option in the 2024 Consolidated grant submission Form X. The UK activities will be organised in a series of work-packages, aligned with the international DRD collaborations, with their goals specified, effort estimated, infrastructure requirements, and capital estimates given. We welcome this as it has the potential for the longterm support to meet the strategic goals of the programmes. Bridging funds will likely be required for the initial period as the first DRD collaborations will start in January 2024. The prospect of bids to the STFC call for the development of basic technologies or larger bids through the PPRP process for specific aspects were also discussed.

The major European partners are going through a similar process, and first discussions have been held between the UK, France, Germany and Italian scientific PIs. A parallel process is also being organised in the US. Germany is the most advanced currently with funding submissions having made to BMBF this summer. CERN's EP R&D process, now starting its second period, is integrated into this development. For the international DRD programme to be successful all major nations will need to play their role, and the UK can seize the opportunities of this initiative to put ourselves at the forefront of R&D developments for the future.

5. Selected Case Studies

In order to illustrate the range of project goals we provide here three example studies. These are examples of initiatives from different areas that have emerged as areas of common interest from the UK community discussions and are aligned with the international DRDs and the requirements of future experiments.

Case Study 1 : Common interface ASIC for detector readout, timing, and control

Issue: ASIC development has consistently been the major source of schedule slippage in particle physics experiments. ASIC design, manufacture and test cycles inevitably have a long iteration time of the order 12-18 months. The situation is now worsened with increasingly high production costs as smaller feature size ASICs become industry standard. Future experiments will struggle to afford the time, cost and access the skilled personnel to perform their own developments for all subsystems, necessitating a common design that can serve as an off-the-shelf solution with broad community support.

Aim: We aim to develop a specific ASIC family & common block which can be operated in the front-end chain or incorporated in future front-end ASICS, serving as a known interoperable quantity. Features of such a design include: Intelligence/Processing capability; the ability to distribute precision timing**;** Single Eevent Upset tolerance at low cost**;** High-speed, high reliability output to commercial-off-the-shelf devices and standardised short-haul data links for on-detector communication.

UK DRD Activity: The UK has many decades of experience in the design and build of DAQ systems, and is home to the EUROPRACTICE Microelectronics Support Centre. UK Leadership of this project and national-level activities across the DRD7 remits in Engineering design, emulation, simulation, and testing are expected, as part of co-developments with CERN and the international DRD consortia.

Case Study 2 : Increased light detection in liquid detectors

Issue: Increased light detection and reduction of both energy thresholds and backgrounds would be transformative for future neutrino and dark matter experiments. This requires R&D efforts to develop new and improved solutions for light detection, hand-in-hand with improved background rejection techniques. A step change in technologies to measure and control trace radioactivity and particulate contamination is also essential.

Aim: We aim to increase, improve and combine the light signals recorded, underpinned by ultra-low background developments. A coherent R&D effort includes: development and characterisation of light sensors; increased collection and detection efficiency over a broad wavelength range; development of charge-to-light and charge+light readouts; and background reduction with improved material screening techniques and use of novel low-background materials.

UK DRD Activity: The UK community spans noble liquid detectors targeted at dark matter searches and neutrino physics, water Cherenkov detectors for neutrino physics and liquid scintillator detectors to search for neutrinoless double beta decay. The programme will benefit all these and builds on previous investments in world-class facilities at the Boulby underground laboratory, which will boost industrial engagement. Developing UK global leadership in light detection for liquid detectors and collaborating with international partners will improve the prospects for the UK hosting world-leading large-scale science projects in this area.

Case Study 3 : Monolithic pixel sensors for future trackers

Issue: Current pixel technology will not meet the need of future experiments where radiation hardness requirements will be a few orders of magnitude higher than currently, and precision timing measurements are giving rise to new opportunities complementing the high resolution spatial coordinates for pattern recognition – a true 4D tracking.

Aim: We aim to deliver, and fully characterise, high performance pixel sensors from which the solutions for deployment in medium term future experiments can be based. These will be implemented as fully functional monolithic sensors, with sensor and electronics integrated in one object and use commercial CMOS technologies with large volume, low-cost production. High granularity (25x25 μm) and high radiation tolerance (10^{17} 1 MeV n_{eq}/cm^2) will be targeted in one device, with a modest time resolution. While a second device will incorporate the proven time-resolution of LGAD devices, aiming to deliver an innovative combined LGAD MAPS detector, with a time resolution of order 10 ps.

UK DRD Activity: The proposal builds on existing UK expertise on LGAD and CMOS sensor development and digital CMOS design to put the UK back at the forefront of what will be the leading technology for the next decade. We will work with the leading international groups, steering the development of a common activity.

6. Summary

An international organisation for strategic R&D activities is being setup to serve the needs of the future experimental programmes in particle, particle astro-physics and related nuclear physics areas. The necessary national infrastructure, training and industrial support will form part of this activity. The UK is fully engaged in this process and is currently organising its activities, in alignment to the international DRD collaboration and major international partners.

References

[1] ECFA Detector R&D roadmap process group, The 2021 ECFA Detector Research and development roadmap. https://cds.cern.ch/record/2784893

[2] ECFA Detector R&D roadmap process group, European Strategy for Particle Physics Implementation of the Detector Research and Development Roadmap, CERN/SPC/1190, https://indico.cern.ch/event/1197445/contributions/5034860/attachments/2517863/4329123/spc-e-1190-c-e-3679-Implementation_Detector_Roadmap.pdf

[3] STFC Strategic Review of Particle Physics, https://www.ukri.org/wp-content/uploads/2023/01/STFC-03012023-SRPP-Final-Report_Dec-22.pdf, recommendations 73 and 77

Appendix A: DRD-UK Steering Board

Members of the DRD-UK steering board representing all UK particle physics groups. The nuclear physics community has also been contacted.

Institution	Representative
Birmingham	ALLPORT, Philip Patrick
Bristol	GOLDSTEIN, Joel
Brunel	KHAN, Akram
Cambridge	WILLIAMS, Sarah

Edinburgh	GAO, Yanyan
Glasgow	BATES, Richard
Imperial	TAPPER, Alex
King's	DI LODOVICO, Francesca
Liverpool	VOSSEBELD, Joost
Manchester	PARKES, Chris (UK PI)
Oxford	BORTOLETTO, Daniela (UK Steering board Chair)
QMUL	HOBSON, Peter
RAL - PPD	WILSON, Fergus
RAL - TD	FRENCH, Marcus Julian
RHUL	MONROE, Jocelyn
Sheffield	VICKEY, Trevor
Sussex	HARTNELL, Jeffrey John
UCL	THOMAS, Jenny
Warwick	RAMACHERS, Yorck

Appendix B: DRD-UK Coordinators

UK coordinators for each of the DRD activities. DRD5 and 8 coordinators have not yet been appointed as these areas are at an earlier stage of formation.

Institution	**Representative**
DRD-1 [Gas]	BRANDT, Oleg; MAJEWSKI, Pawel;
DRD-2 [Liquid]	GUENETTE, Roxanne; MONROE, Jocelyn; SAAKYAN, Ruben; SCOVELL, Paul;
DRD-3 [Si]	DOPKE, Jens; GONELLA, Laura; HYNDS, Daniel; VILELLA FIGUERAS, Eva
DRD-4 [PID]	BLAKE, Thomas; ROMANO, Angela
DRD-5 [Quantum]	TBC
DRD-6 [Calo]	SALVATORE, Fabrizi; WATSON, Nigel
DRD-7 [Electronics]	FITZPATRICK, Conor; FRENCH, Marcus; POTAMIANOS, Karolos; PRYDDERCH, Mark; ROSE, Andrew
DRD-8 [Systems]	TBC
Training	LAZZERONI, Cristina; BATES, Richard
Industry Engagement	FARROW, Richard