Letter of Intent: DRD8

R&D Collaboration for Mechanics & Cooling of Future Vertex and Tracking Systems

Dr Thomas Bergauer, Chair
DRDC

19 February 2024

Dear Thomas,

The undersigned institutes intend to submit to the DRDC a proposal for a new CERN DRD collaboration to develop mechanics and cooling for vertex and tracking systems at future particle physics experiments.

Mechanics and cooling are core aspects of a vertexing and tracking system, and a critical part of the material optimisation for these systems. As tracking detectors get larger and more complex, it is essential to invest early and decidedly on mechanics and system integration aspects, building a strong community and developing the necessary tools and know-how to face future challenges of tracker design. Technologies in this field are closely related to design choices for sensors, front-end electronics, and electrical and readout services, and are driven by environmental factors, including the radiation environment. The full potential of advances in sensor technologies and readout can only be exploited if they are supported by aggressively optimised mechanics and cooling that need to go beyond already proven solutions.

This field profits from ongoing advances in materials and manufacturing techniques. These advances are driven by commercial applications in the aerospace, automotive and refrigeration industries, which often have very different optimisation goals than particle physics. To that aim we do think that there is room for an R&D collaboration, which we intend to explore. However, advances in the aforementioned fields will be critical in achieving our goals. To benefit of those requires to closely follow these developments and evaluate new materials and technologies for applications in particle physics.

Challenges awaiting the mechanics community in the future include:

- find solutions to make the implementation of aggressive and innovative layouts possible;
- tackle the obvious scalability challenges associated with the construction of detectors two or three times the size of the ATLAS and CMS trackers, which will likely require higher levels of industrialisation for the HEP community;
- adopt comprehensive life-cycle approaches for detectors to cope with extremely harsh environments and ever-growing environmental impact awareness.

Initially, we plan to group our activities into four working groups coordinated by a DRD8 steering group:

- WG 8.1: Global/System Design and Integration:
  - Mechanics for advanced layouts, including curved and tilted sensors, low radii vertex systems and retractable detectors;
  - Service integration;
  - Environmental and structural health monitoring;
  - Life-Cycle design of trackers;
  - Fostering links with the accelerator community to understand the Machine Detector Interface (MDI) for future colliders;
  - Robotics and remote operation, maintenance and handling;
  - Scalability and industrialisation.
- WG 8.2: Low Mass Mechanics and thermal management of Silicon sensors:
  - Novel materials for structural and thermal management applications, including qualification for operation in harsh environments;
  - Advanced manufacturing techniques, including additive manufacturing;
  - Support structures with integrated cooling circuits, including silicon or ceramic substrates with embedded microchannels, composite substrates with embedded pipe-less networks and cold plates with thin-walled pipes;
  - Modular, scalable designs for detectors with large surface areas;
  - Vacuum-tight composite structures.

- WG 8.3: Detector Cooling
    - Evaporative and liquid cooling for both low and warm temperatures, based on natural or eco-friendly refrigerants and new cycles;
    - Gas cooling solutions for detectors, including flow design and heat transfer through porous media.
    - Connection technologies for cooling circuits, including leak repair methods;
    - Instrumentation, including flow measurements for gases and liquids.
- WG8.4 Design and Qualification Tools:
    - Open-source software and high-performance parallel computing numerical simulation tools for structures and fluids;
    - Machine learning enhanced topology optimisation;
    - Virtual reality aided design;
    - Methods for using 3D design of complex service geometries and linking of schematics and 3D models;
    - Connection of CAD tools and GEANT.

A common concern for all efforts will be reduction of environmental impact, minimising carbon footprint and global warming potential by appropriate choice of materials and manufacturing methods, taking into account the full life cycle of the detector.

Because of the dependence on design choices for sensors, front-end electronics, and electrical and readout services, the work on mechanics and cooling is highly reliant on the system specifications. To enable targeted and collaborative R&D work in our field, we propose to focus on solutions within two application frameworks.

- Low intensity (LI): In this framework the mechanics and cooling will support sensors and electronics that have been designed for low power densities, possibly involving pulsed powering. The number and cross-section of electrical services will be small. Radiation damage levels will be low, and thus there will be no need to operate these systems cold (< 15 °C). Where possible, gas cooling will be an appealing solution. Radiation hardness levels of materials will be moderate.
  This will be the framework that will target, although not exclusively, experiments at future lepton colliders.

- High intensity (HI): Detector systems within this framework will have to cope with high particle densities of signal and background particles. The high channel density and complexity of the front-end electronics will result in high power densities, which will need to be supplied (likely by advanced powering systems like serial powering or DC-DC conversion), and removed by potent evaporative cooling systems. Significant radiation damage will require cold (< -35 °C) operation to keep leakage currents under control. Materials will need to be qualified for the high radiation environment.
  This will be the framework that will aim for experiments at future hadron machines.

Material minimisation and a good thermal connection between local heat sources and sinks will be major goals in both cases, but the optimisation will be different. Nevertheless, we do expect that some of the solutions we will develop will be of benefit for both frameworks.

To verify and benchmark the performance of the solutions developed in this R&D effort, and as physical deliverables, we propose the construction of demonstrators which take into account the specifications defined in the context of other DRD efforts like DRD3 or DRD7. These demonstrators should be exercised in realistic environments, in a test-beam and/or real physics experiments, where possible.

To prepare and organise such a cross-disciplined effort, a steering group will be needed. At the beginning, this will involve interaction with other DRD collaborations, to define the system specifications, scope and timeline of the demonstrators. In later stages this programme has to include system design and performance verifications by simulation and prototypes, and finally construction and operation of the demonstrators.

The collaboration currently comprises xxx contributing institutes in xxx countries, and we are developing a work plan for an initial three-year R&D phase. We aim to submit a detailed proposal for the first tranche of projects before the end of 2024, including a description of the organisation for the DRD. The xxx collaborating institutes intend to contribute to xxx projects with an aggregated yearly effort of over xxx FTEs. The collaboration will remain open to new participants and projects and is intended to continue and evolve in the long term.

On behalf of the collaboration,

DRD8 Steering Committee
(C. Gargiulo, A. Jung, A. Mussgiller, P. Petagna, B. Schmidt, G. Viehhauser)

Annexes:
1. List of contributing institutes
2. List of contributions to working groups, per country and institute

Annex 1: List of contributing institutes

Country/Institute	Contact
France	
IPHC Strasbourg	baudot@in2p3.fr
CPPM Marseille	vigeolas@cppm.in2p3.fr
Germany	
DESY	andreas.mussgiller@cern.ch
GSI Darmstadt	m.teklishyn@gsi.de
Italy	
INFN Ferrara	gramigna@fe.infn.it
INFN Perugia	cristiano.turrioni@pg.infn.it
United Kingdom	
UKRI-STFC Rutherford Appleton Laboratory	fergus.wilson@stfc.ac.uk
University of Bristol	Joel.Goldstein@bristol.ac.uk
Bristol Composites Institute	laura.pickard@bristol.ac.uk
National Composite Centre (NCC)	Matt.Scott@nccuk.com
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University of Manchester	oscar.augusto@cern.ch
University of Oxford	georg.viehhauser@physics.ox.ac.uk
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Switzerland

CERN Burkhard.Schmidt@cern.ch

University of Geneva franck.cadoux@unige.ch

Annex 2 : List of contributions to working groups per country and institute

Country/Institute	Contr.WG1	Contr.WG2	Contr.WG3	Contr.WG4	Total
France					
IHPC Strasbourg					
CPPM Marseille					
Germany					
DESY					
GSI Darmstadt					
Italy					
INFN Ferrara					
INFN Perugia		0.25	0.25	0.5	1
Switzerland					
CERN	1	2	1	1	5
Univ. of Geneva					
United Kingdom					
UKRI-STFC RAL					
University of Bristol		0.5			0.5
Bristol Comp. Inst.		1.5	0.25		1.75
Nat. Comp. Centre					
Univ. of Manchester		1	1		2
Univ. of Oxford		0.75			0.75
Univ. of Sheffield					
Univ. of Liverpool		0.25			0.25
USA					
Purdue University					
LBNL					
Grand Total	1	6.25	2.5	1.5	**11.25**