Proposal DRD8: Mechanics & Cooling of Future Vertex and Tracking Systems

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Introduction

- DRD8 community is significantly smaller than other DRD collaborations: currently 38 participating institutes
  - Set up a simple management structure for DRD8
- DRD8 has grown out of annual Forum on Tracking Detector Mechanics
  - Existing community with well-functioning regular networking
- Collaborating institutes are already involved in activities fitting within the DRD8 portfolio on funded projects that are linked to specific experiments (ALICE, LHCb, Mu3e, ePIC etc.)
  - No need for additional management structure for that

→ DRD8 strategy: Focus on a limited number of core projects that promise a significant leap of capability and would otherwise not be pursued

- Programme is only viable if new funding for DRD can be obtained

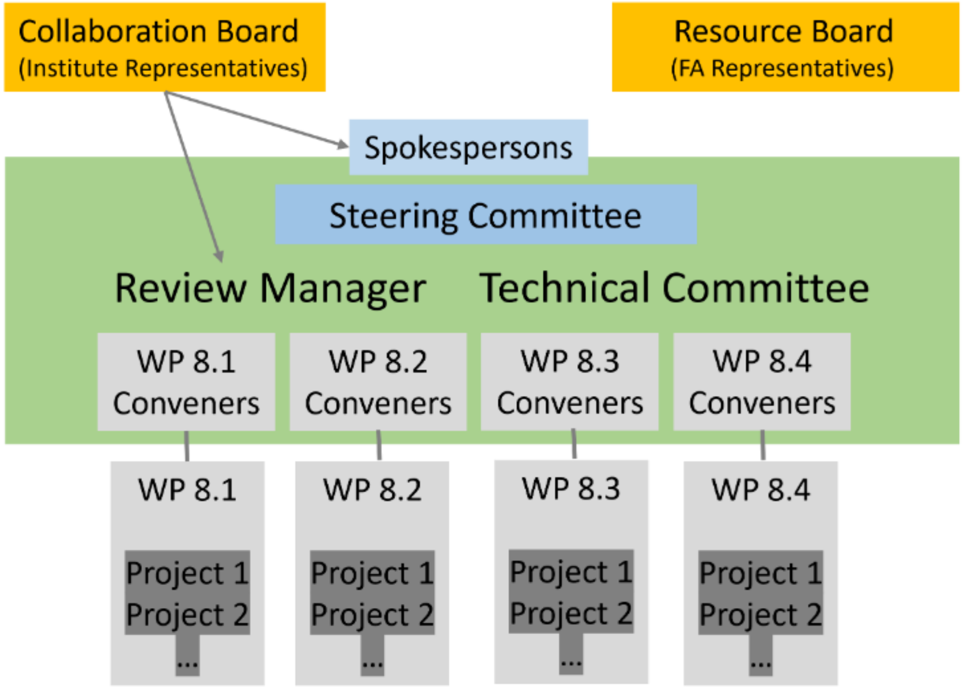
Work packages

- DRD8 will be divided into four work packages
  - WP1: Global system design and integration
  - WP2: Low-mass mechanics and thermal management
  - WP3: Detector cooling
  - WP4: Design and qualification tools
- Each WP will cover three aspects
  1. Each WP comprises two research projects
     - Two for now, can be increased in the future
  2. As most of the groups in the collaboration are already in funded projects: Improve opportunities for networking, information exchange and access to equipment and/or facilities
     - No specific R&D projects are defined in this proposal for these rather well defined existing detector projects
  3. Research activities undertaken by member groups that will not be managed by the DRD8 organisation, but address research goals within the DRD8 portfolio
     - These are typically small collaborations or single institutes
     - For endorsement by the DRD8 Steering Committee, to strengthen their case when applying for funding
     - DRD8 will organize reviews if requested

Projects

- Projects have been chosen by WP coordinators based on suggestions from the community
  - Project 1.1: The Vertex Region of Future Particle Physics Experiments
  - Project 1.2: Robots in the HEP Experimental Caverns
  - Project 2.1: Advanced Mechanical Tracker Structures
  - Project 2.2: Characterisation of Material Properties and Database Development
  - Project 3.1: New Evaporative Cooling Fluids and Systems
  - Project 3.2: Microchannel Cooling Substrates
  - Project 4.1: Extended Reality (XR) Development
  - Project 4.2: Connection of Engineering Design Tools with Physics Simulation Software
- Interesting range of topics from tools with very clear focus, to blue skies creative thinking with a wide open field of possible solutions
- Currently between 3 and 16 participating institutes per project
  - Depending on breadth of anticipated activities

Governance



- Work Packages led by **Conveners** (two per WP) who manage the R&D projects
- **Steering Committee** (SC) guides collaboration and represents it to outside world
- Chaired by **spokesperson** and **deputy**
- WP Conveners and SC collectively form the **Technical Committee** (TC)
- The **Collaboration Board** (CB) is the scientific and technical representation of the collaborating institutions
  - Each contributing institute sends one representative to the CB
- The **Review Manager** (RM) sets up regular technical reviews of the projects
- The **Resources Board** (RB) represents funding agencies supporting the projects in the collaboration

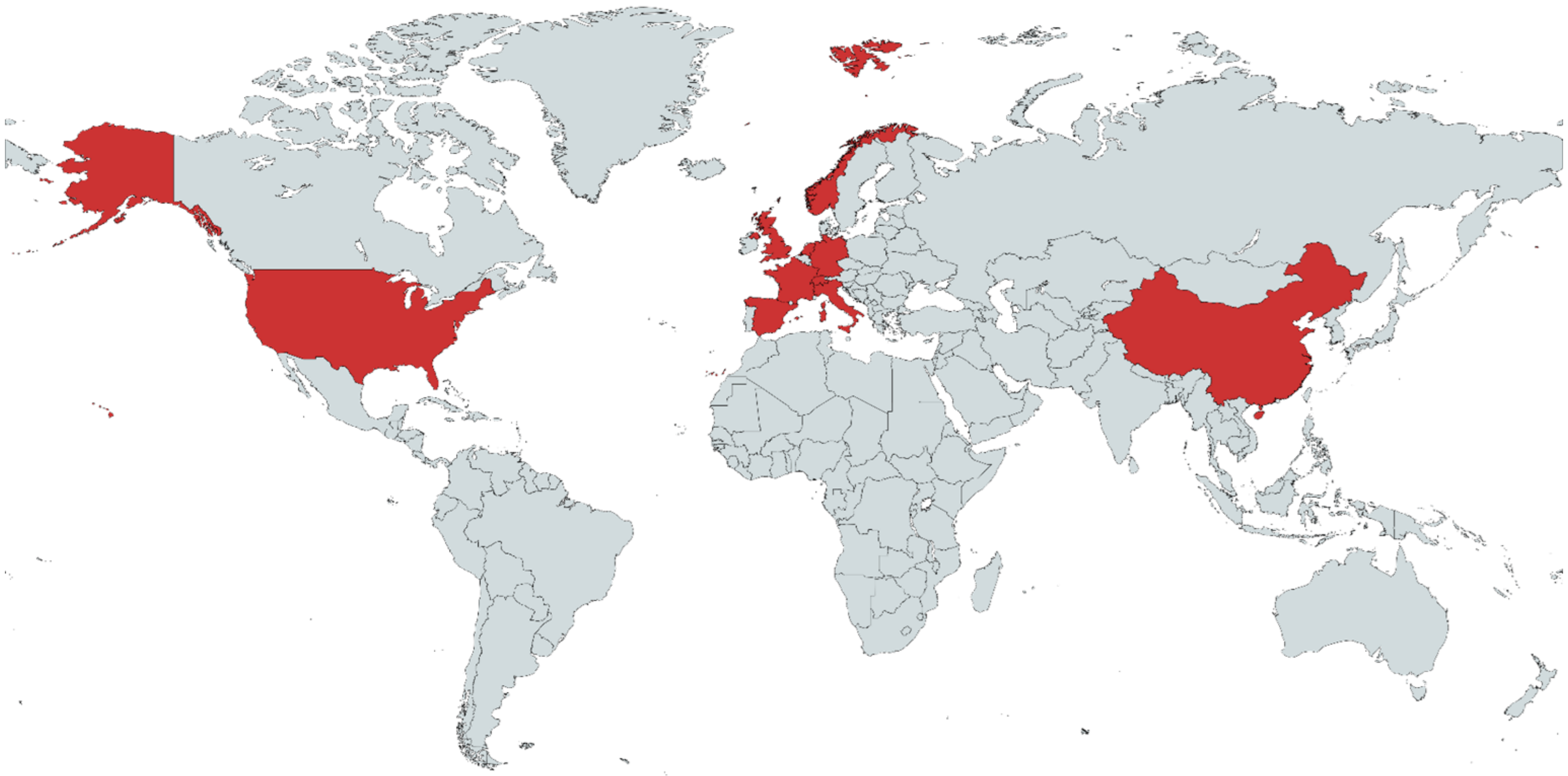
Milestones and deliverables

Month	Label	Topic
6	M2.1.1	Design specifications
	M2.2.1	Identification of community needs
9	D3.2.1	New round of 3D printing prototypes exploring different geometries
12	M1.1.1	Curved and tilted sensors
	M1.2.1	Mobile mesh network in cavern
	M2.1.2	Pre-Concept Design Report
	M2.2.2	Standardised test protocols & lab infrastructure archive
	M3.1.1	Krypton system demonstration
	M4.1.1	Market survey report
	M4.2.1	Specification of transfer system
15	M3.1.2	Krypton component development
	M3.2.1	Ceramics feasibility tests
18	M3.1.3	sCO_2 properties
	M3.2.2	Prototypes bonded with thermo-compression or hyperbaric process characterisation
	D4.1.1	Purchase of hardware and software
24	D1.1.1	Carbon beam pipe
	D1.2.1	Legged robots and robotic airships in magnetic field
	M2.1.3	Concept Design Report
	D2.1.1	Production of simple prototypes for NDT Testing
	M2.2.3	Database GUI and back-end selection
	D2.2.1	Updated test protocol documentation
	M3.2.3	3D printing
27	D3.2.2	Fluidic and thermal results from integrated system
30	D2.2.2	Database Beta Version release
	D3.1.1	Krypton system development
36	M1.1.2	Retractable detectors
	D1.1.2	Mock-up & integration
	D1.2.2	Legged robots and robotic airships in cavern
	M1.2.2	Legged robots and robotic airships control system
	M1.2.3	Mobile mesh network cavern inspection
	M2.1.4	Critical Design Report (CrDR)
	D2.2.3	Public database release
	M3.1.4	Krypton cooling performance
	D3.1.2	sCO_2 system development
	M3.2.4	Bi-phase CO_2 thermo-fluidic models
	M4.1.2	Application of XR technologies to detector projects
	D4.1.2	Project reports
	M4.2.2	Simplified 3D models
	M4.2.3	Export from physics simulation software

- For now DRD8 proposal for 3 years
  - But we hope that we can continue this programme beyond this time
- Each project has between 4 and 6 milestones/deliverables spread over the duration of the programme to allow to monitor progress of the research project

Participating institutes

Country/Organisation	Institute
CERN	CERN
China	IHEP
France	CPPM Marseille IJCLab Orsay LPNHE Paris IPHC Strasbourg
Germany	DESY Freiburg University GSI Darmstadt Halbleiterlabor of the Max-Planck-Society Fachhochschule Offenburg
Italy	FBK Trento INFN Ferrara INFN LNF Frascati INFN Genova INFN Perugia INFN and University of Pisa University of Rome La Sapienza
Netherlands	Nikhef
Norway	NTNU Trondheim
Spain	CNM Barcelona IFIC Valencia
Switzerland	University of Geneva
United Kingdom	UKRI-STFC Rutherford Appleton Laboratory University of Bristol Bristol Composites Institute National Composite Centre (NCC) University of Liverpool University of Manchester University of Oxford University of Sheffield
USA	Cornell University University of Arizona Fermilab Florida Institute of Technology LBNL Purdue University SLAC



- Open to additional collaborators (some already under negotiation)
- Encouraging industrial partners (one industrial partner already part of proposal)

Relations to other DRDs

- Research activities in DRD8 cover non-active supporting aspects for future tracking systems
- Requirements & specifications for DRD8 will be heavily influenced by needs & opportunities of future sensor & readout technologies
- Close interactions with DRD3 and DRD7 will be an important aspect
- In the long run, success of the DRD8 research programme will require the construction of one or more demonstrator(s)
  - Large enough, representative advanced sensors and electronics prototypes, operation in a realistic environment
  - Currently can conceive of two such demonstrators
    - One for low-power (LP) operation (future e^+e^- collider)
    - The other for a future high-intensity (HI) tracker (future hadron collider)
  - Will require common participation of DRD3, DRD7 and DRD8
  - Near-term task will be the creation of management and planning structure with DRD3 and DRD7 and development of specifications for demonstrator(s)

Resources

Project	Effort [FTE/year]		Material budget [kCHF]	
	available	required	available	required
Project 1.1	9.7	15.4	650	1530
Project 1.2	3.0	4.0	120	220
Project 2.1	7.7	13.0	190	500
Project 2.2	4.5	8.5	85	245
Project 3.1	3.0	4.5	30	200
Project 3.2	5.5	10.5	285	1030
Project 4.1	0.4	1.7	0	80
Project 4.2	1.5	4.7	0	20
Grand total	**35.3**	**62.3**	**1360**	**3825**

- Available resources are resources on activities within the DRD portfolio
  - Typically funded for specific experiments
  - Technically these are not DRD8
  - Will focus on the completion of their projects and proceed under any circumstances
  - Exact assignment difficult, but probably a reasonable estimate of the this effort
- Required resources are what we think will achieve a credible scientific programme that will realise our research goals
  - Not guaranteed, contingent on funding
- The difference constitutes the added value that DRD8 will bring

Miscellaneous

- Meetings
  - DRD8 collaboration meetings twice a year
    - Once in conjunction with the Forum on Tracking Detector Mechanics (abroad)
    - The other likely to be at CERN
  - WP meetings will be organised by WP conveners regularly as useful for advancing the research programme
- Education and training
  - DRD8 too small and its research topics too narrow to justify stand-alone schools or similar
  - Will identify lecturers for lecture courses on relevant topics, and facilitate exchange of educational material among these lecturers
  - Lecturers are ready to participate in schools within the DRD collaborations and outside (e.g. CERN summer school, ECFA summer school, EDIT)

Next steps

- Attract additional collaborators, also from industry
- Write and agree on MoU, which will detail the role of participating institutes and companies
- Most important: Acquire funding
  - Due to the nature of the work we should be open for unusual (non-PP) funding streams
  - Making sure that the participating institutes pursue this aggressively will be the first task for the DRD8 management
- Collaboration meeting in May/June 2025 in conjunction with Forum on Tracking Detector Mechanics 2025 in Bristol
  - 2d DRD8, 3d Forum

Further material

Project 1.1: The Vertex Region of Future Particle Physics Experiments

- New design solutions for future beam pipes and vertex systems
  - Challenges: minimum material budget, mechanical stability, and proximity to the beamline, integration of inner vertex layers with accelerator optics
  - Crucial for preparing the ambitious design of future beam pipe and detector mechanics
- Research topics
  - Curved sensors: Reduce the material budget significantly and bring first hit point outside the beam pipe closer to the interaction point
  - Ultra-thin beam pipes: Alternative beam pipe materials like alloys of beryllium and aluminium (Albemet), and carbon composites
  - Retractable detectors: Bring first layer closer to interaction point, while addressing apertures, impedance and vacuum stability which are important for the beam
  - Integration of accelerator and vertex detectors: cope with tight positioning requirements to guarantee high luminosity, and at the same time allow operations and maintenance of detector elements difficult to access
  - Low-mass hardware alignment systems for future tracking detectors: Develop solutions that are complementary to that available through track-based alignment algorithms (weak modes) and that is low-mass and radiation-hard
- CERN, IHEP/CAS, GSI Darmstadt, INFN Pisa, INFN Perugia, INFN Frascati, Nikhef, IPHC Strasbourg, IFIC Valencia, University of Geneva, University of Liverpool, University of Oxford, University of Bristol, University of Freiburg

Project 1.2: Robots in the HEP Experimental Caverns

- Develop robotic systems for access and maintenance in underground particle detector areas consisting of large semi-structured caverns with high magnetic fields and radiation levels
  - Autonomous and on-demand inspections and 3D environmental mappings to reduce accelerator down-time, prevent unnecessary beam dumps due to false alarms, detect anomalies at an early stage, monitor operation of experiments
  - In future, will also aim at developing robotic manipulation systems for first intervention, and detector maintenance or removal
- Ground and aerial platforms
  - Legged ground robotic platforms
  - Robotic airships
  - Mobile mesh network (swarm of mini robots)
- CERN, IHEP/CAS, Roma I (La Sapienza), University of Arizona

Project 2.1: Advanced Mechanical Tracker Structures

- Challenge particle physics tracking detector design paradigms with an unhindered and blue-sky approach
  - Make use of modern materials as well as design and manufacturing techniques
  - Pursue new, unconventional geometries
- Research topics:
  - Orthotropic materials: optimise mechanical and thermal performance in critical directions
  - Non-planar structures, and complex geometries: utilise Advanced Digital Manufacturing (ADM) techniques such as Additive Manufacturing (AM), Hybrid Manufacturing and tow-steering
  - Integration of services into mechanical structures
  - Tools to help predict and optimise the performance of detector support structures featuring orthotropic materials, complex geometries and/or integrated services produced with advanced manufacturing techniques
  - Non-Destructive Testing (NDT) and other forms of Quality Assurance/Quality Control (QA/QC) that will guarantee quality of non-traditional, homogeneous or isotropic structures
- CERN, DESY, GSI Darmstadt, Nikhef, Purdue University, University of Oxford, University of Liverpool, Bristol Composites Institute, UK National Composites Centre, STFC-RAL, INFN PISA

Project 2.2: Characterisation of Material Properties and Database Development

- Development of centralized database with validated material data
  - To optimise the resources allocated to material testing
  - Avoid redundancies
  - Standardised procedures for testing and reporting material properties
  - Make data available for thermo-mechanical simulations and informed detector designs
- Research topics
  - Material testing protocols: Identify ISO / ASTM standard test procedures, document step-by-step testing procedures including specimen preparation, testing equipment, environmental conditions, and measurement techniques that can be recreated across the laboratories using controlled environmental conditions
  - Documentation and database development: Development of database, covering material characterisation data and offering a standardised documentation of testing campaigns across the participating laboratories
- CERN, DESY, University of Oxford, Bristol Composites Institute, INFN Perugia, Purdue University, Cornell Laboratory, Florida Institute of Technology

Project 3.1: New Evaporative Cooling Fluids and Systems

- Develop sustainable cooling solutions in both the warm and cold domain
  - Cold (cooling temperatures in the range of -90°C / -50°C): Krypton
    - Transcritical cooldown in a compressor cycle
    - Requires specific components to be developed or modified from standard
  - Warm (above 0°C): Supercritical carbon dioxide (sCO2):
    - Electrically non-conductive fluid with much lower viscosity than water and allowing for higher heat transfer coefficients operating at high pressure and temperatures above 31.7°C
- CERN, NTNU, DESY, FH Offenburg, University of Sheffield, Cornell University, DORIN (industrial partner)

Project 3.2: Microchannel Cooling Substrates

- Covering different manufacturing techniques and materials
  - Silicon microchannels via buried channels:
    - Development of a microchannel cooling technology fully compatible with (CMOS) sensors in the same substrate
    - Development of ”active interposers” which hold mechanical support and buried micro-channels to provide local, high-efficient, together with interconnection capabilities to cover the electrical connection between detector and front-end electronics with the back-end electronics and rest of the system to provide re-distribution of the I/O signals (readout, control signals), plus power lines
  - Silicon microchannels via thermocompression
    - Set up a dedicated cooling test bench
    - Fabrication of cooling plates with micro-channels of various geometrical and surface form factors
    - Development of numerical 3D models and implementation in numerical simulation tools
    - Development of low-cost silicon cooling-platesfabrication process, based on hyperbaric bonding (uses a thin layer of gold - similarly to thermo-compression - and is performed at room temperature inside a hyperbaric chamber)
    - Development of cooling-plates interconnects to allow fabrication of heat exchangers covering large areas
  - Low-temperature co-firing ceramic (LTCC) and high-temperature co-firing ceramic (HTCC):
    - Different ceramic layers to enclose the channels, offers possibility to integrate high conductivity materials between layers
  - 3D metal printing
    - High level of design flexibility, fast turn-around processing time, and cost-effectiveness, especially in electronics-dense areas with limited space
    - Surface finishing and potential of the material budget improvement will be explored via post-processing techniques
- University of Manchester, French Collaboration, IMB-CNM, IFIC and DESY, CERN, Nikhef, MPG HLL, University of Sheffield, Italian Consortium

Project 4.1: Extended Reality (XR) Development

- Bridge the gap between the physical and digital world
  - Technologies that are being adopted by leading industries and institutions
- Research topics
  - Augmented Reality (AR): Enhances the physical world by overlaying digital content onto real-world environments, can display in real-time digital working instructions or safety instructions in physical equipment
  - Virtual Reality (VR): Full immersion into digital environment, can be used for virtual interventions in experimental and accelerator areas while these are not accessible
  - Mixed Reality (MR): Interact with both virtual and physical worlds simultaneously, for example allows for connecting remotely with colleagues located in a collaborating institute
- CERN, GSI Darmstadt, University of Sheffield

Project 4.2: Connection of Engineering Design Tools with Physics Simulation Software

- Communication between CAD design tools, used for designing and integrating particle physics equipment, and physics simulation software (e.g. GEANT)
  - Automatise the transfer of simplified engineering models, including geometry and material metadata, from engineering design software to physics simulation tools (e.g. Geant4, FLUKA)
- Phase 1: Define data exchange requirements by identifying the inputs and outputs of both engineering design and physics simulation software
- Phase 2: Develop tools to generate essential geometry data and material metadata in the engineering design software, ensuring compatibility and seamless transfer with physics simulation software
- CERN, IHEP, GSI Darmstadt, Oxford University, INFN-LNF Frascati, Purdue University

Governance details

- WP conveners
  - Organise regular meetings of their WP
  - Chair WP sessions during DRD8 collaboration meetings
  - Aggregate material for annual DRD8 progress report
  - Ensure that results and data of general interest are stored in DRD8 repository
  - Usual term 3 years
- SC
  - Follows progress and activities of WPs
  - Updates R&D vision of the collaboration
  - Calls regular DRD8 meetings to report publicly on progress of the R&D effort
  - Issues annual DRD8 progress report and presents it to CB
  - Consists of six to eight members
    - Term of membership in SC is normally three years, renewable once
    - Each year up to two members of the SC will be replaced
    - Two places within SC should be reserved to junior members of the community
  - Nominates WP Conveners and proposes chairperson and deputy (both to be approved by CB)
- Spokesperson and deputy
  - Term one year, rotation among SC members is desired
- TC
  - Tracks projects
  - Organises internal reviews and monitors progress
  - Issues recommendations to projects
  - Drafts the annual DRD8 progress report.
  - Will approve presentations and publications
- CB
  - Scientific and technical representation of the collaborating institutions
  - Each contributing institute sends one representative to CB
  - Meets at least once per year to discuss progress and vision
  - Approves annual DRD8 progress report, proposals for new projects, work packages and contributors
  - Appoints SC members and endorses the Spokesperson & Deputy Spokesperson and the WP Conveners
  - Members of the CB should not be members of the TC
  - CB elects chairperson from among its members
  - Chairperson will serve for a period of two years
- RM
  - Sets up review panel (with some participation of experts outside DRD8 encouraged) and its chair
  - Defines together with the WP conveners the remit for each review
  - Sets the time and place of the review in coordination with all parties involved
  - After the review the RM will ensure that a written report of the findings of the panel is distributed to the parties involved
  - The RM can supply funding agencies with the review reports on request
  - On request by the involved parties, the RM will provide the same support for the review of other research activities within the framework of DRD8
- CB
  - Meets at least annually
  - Approves annual DRD8 progress report and proposals for new projects and contributors
  - Representation can be through representatives of collaborating institutions, or delegated to a body acting on behalf of one or several institutions