Detector Research and Development projects for future High Energy Physics experiments

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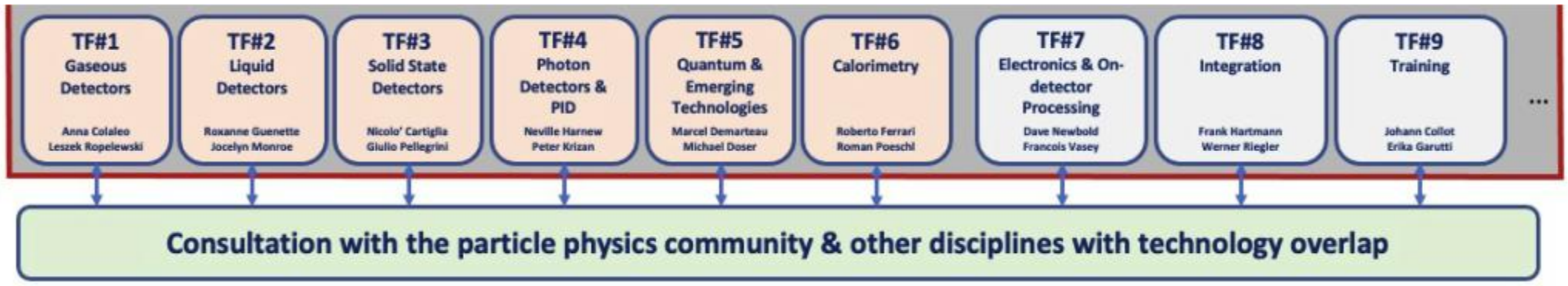
ECFA Detector Roadmap

European Committee for Future Accelerators (ECFA) released in 2021 a full document (200 pages) and synopsis (~10 pages) based on a community-driven effort

The full document can be referenced as DOI: 10.17181/CERN.XDPL.W2EX

- Overview of future facilities (EIC, ILC, CLIC, FCC-ee/hh, Muon collider) or major upgrades (ALICE, Belle-II, LHC-b,…) and their timelines
- Ten “General Strategic Recommendations”
- Nine Technology domains with Task Forces areas
  - The most urgent R&D topics in each domain identified as Detector R&D Themes (DRDTs)



Detector R&D Themes

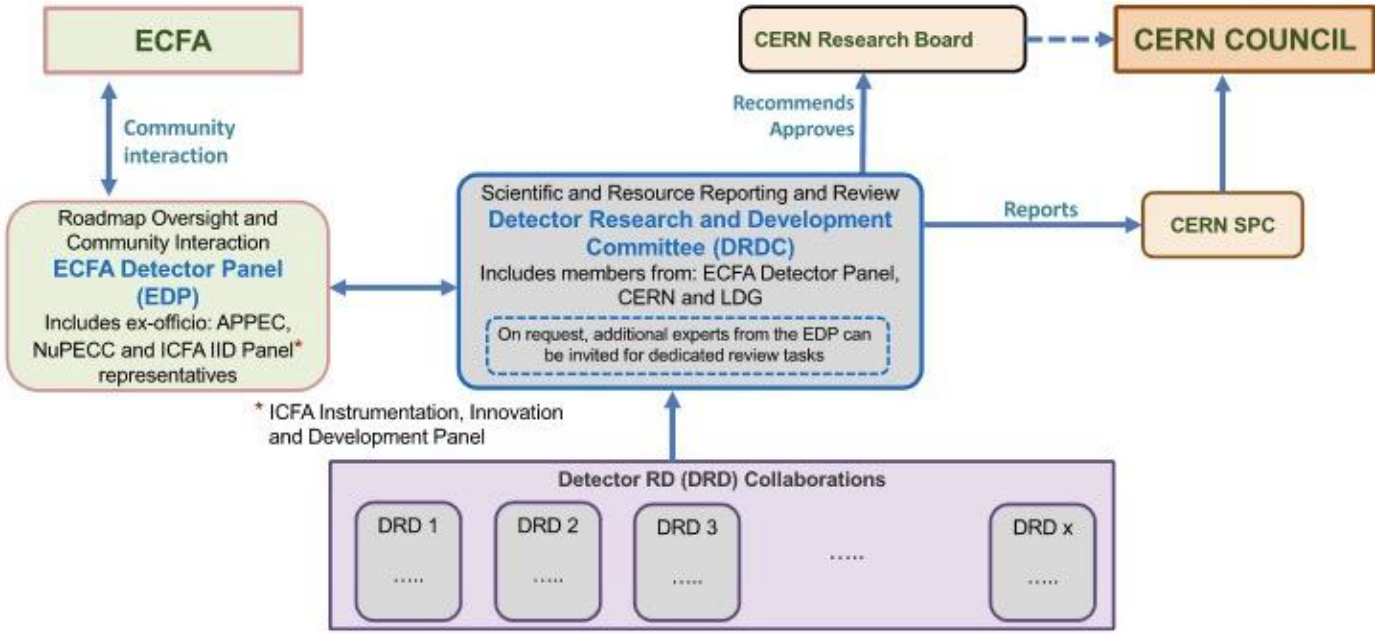
high-level deliverables

Detector Community Themes

Roadmap implementation plan

- Approved by CERN SPC and Council in fall 2022 (CERN/SPC/1190 ; CERN/3679)
- CERN will host DRD collaborations
  - ✦ Interaction between DRD collaborations and committees through DRDC
  - ✦ Interface to ECFA via ECFA Detector panel (EDP): https://ecfa-dp.desy.de

- Distinction between reviewing body (DRDC) and advisory body (EDP)
- DRDC reviews DRD progress, monitor milestones & deliverables, and reports to CERN Research Board
- ECFA Detectot Panel (full mandate to be found here)
  - organizes "**DRD managers forum**"
  - provides input to the next Strategy update



Committee Members

ECFA Detector Panel (EDP):

- Co-chairs: ***Didier Contardo*** *(Lyon),* ***Felix Sefkow*** *(DESY)*
- Scientific secretary: *Jens Dopke (STFC RAL)*
- Gaseous Detectors: *Silvia Dalla Torre (Torino)*
- Liquid Detectors: ***Inés Gil Botella*** *(CIEMAT)*
- Solid State Detectors: *Susanne Kuehn (CERN)*
- PID & Photon Detectors: ***Roger Forty*** *(CERN)*
- Quantum & emerging Tech.: *Steven Hoekstra (Groningen)*
- Mechanics and integration: *Jens Dopke (STFC RAL)*
- Calorimetry: ***Laurent Serin*** *(IJCLab)*
- Electronics: *Valerio Re (Bergamo)*
- Ex Officio: *ECFA Chair (Paris Sphicas), ICFA Detector Panel (Ian Shipsey), DRDC chair (**Thomas Bergauer**), APPEC & NuPECC observers*

Detector R&D Committee (DRDC):

- ***Thomas Bergauer*** (HEPHY Vienna), Chairperson
- *Jan Troska* (CERN), scientific secretary
- *Stan Bentvelsen* (NIKHEF; LDG contact)
- *Shikma Bressler* (Weizmann)
- *Dimitry Budker* (Mainz)
- ***Roger Forty*** (CERN; RB contact)
- *Claudia Gemme* (INFN and U. Genoa)
- ***Inés Gil Botella*** (CIEMAT)
- *Petra Merkel* (Fermilab; US contact)
- *Mark Pesaresi* (Imperial College)
- ***Laurent Serin*** (IJCLab)
- Ex-officio: **D. Contardo, F. Sefkow** (EDP)

Names in bold in both committees

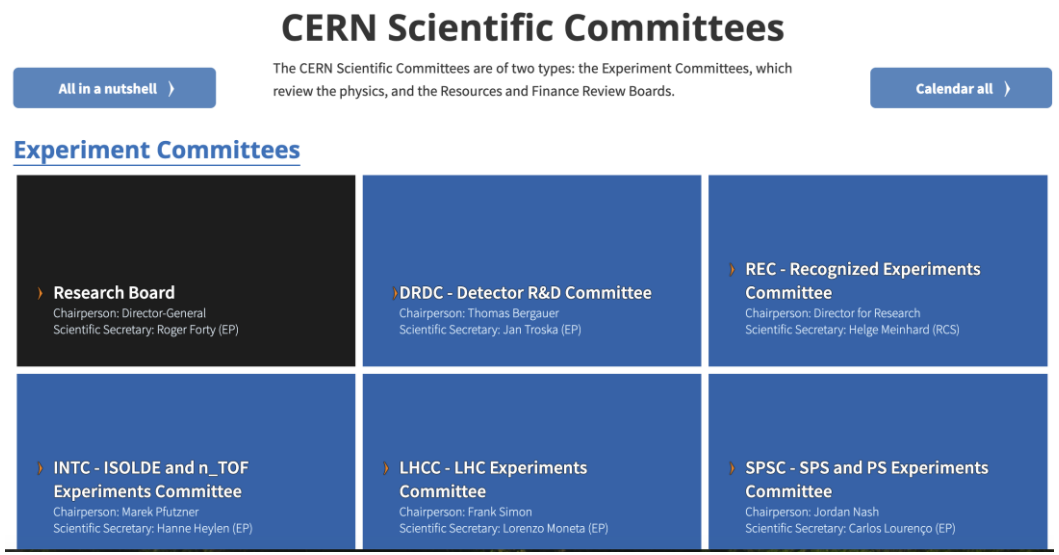
DRD Managers Forum

- https://ecfa-dp.desy.de/drd_managers_forum/
- The DRD Collaborations Managers Forum (DCMF) is an informal body (in the sense of not being a committee of either CERN or ECFA) set up by the ECFA Detector Panel (EDP) at the request of the DRD Collaboration managements to provide a forum for communications and discussions of common issues among DRD Collaborations.
  - ✦ Two representatives per DRD collaboration
  - ✦ EDP members; DRDC members only if cross-membership
- Meetings so far: Indico: https://indico.cern.ch/category/12772/
  - ✦ 11 March: introduction, DRD8 LoI
  - ✦ 29 April: focus on AIDA-successor
  - ✦ 18 July on MoU
  - ✦ 14 October on MoU

DRD Committee (DRDC)

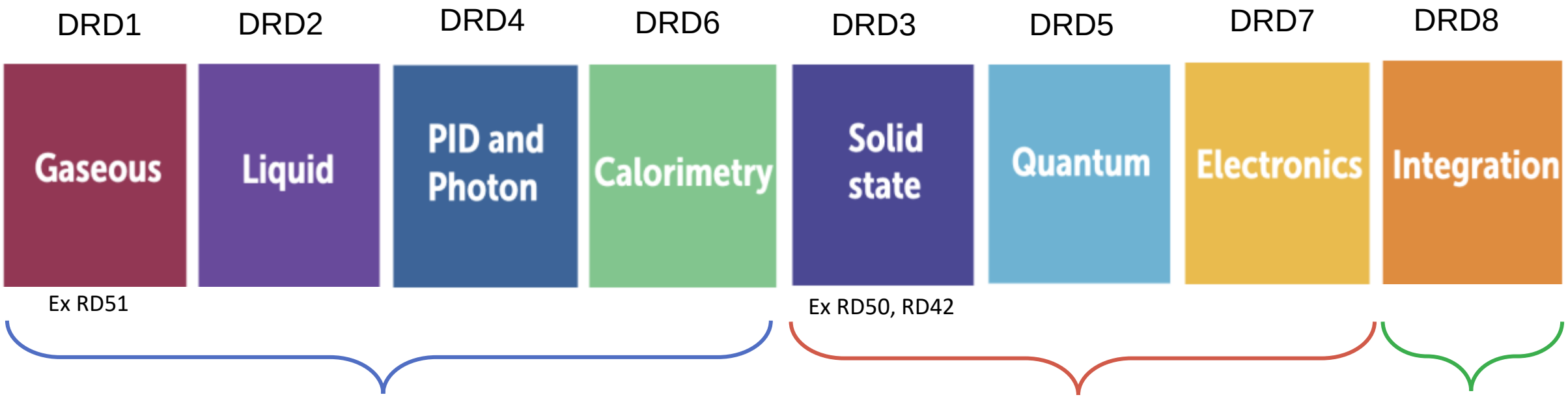
- Detector R&D Committee is a CERN committee
  - ✦ Established in autumn 2023 following ECFA Detector Roadmap Process
  - ✦ http://committees.web.cern.ch/drdc
- Mandate of DRDC:
  - ✦ Reviews DRD proposals and suggests recommendations to **CERN Research Board**
  - ✦ Requests annual status reports of running DRD collaborations and conducts reviews of their progress
- DRDC meetings (5th meeting in Feb 24-25):
  - ✦ https://indico.cern.ch/category/17132/
  - ✦ Open and closed sessions
- **Indico DRDs**: Category “Experiments / R&D”

  https://indico.cern.ch/category/6805/



DRD1 Development of Gaseous Detectors	170 eventos
DRD2 Liquid Detectors	18 eventos
DRD3 Solid State Detectors	105 eventos
DRD4 Photon Detectors and Particle ID	389 eventos
DRD5 Quantum and Emerging Technologies	2 eventos
DRD6 Calorimetry	73 eventos
DRD7 Electronic Systems	57 eventos
DRD8 Tracking Detector Mechanics	3 eventos
DRD National Coordination	9 eventos

Status of DRD collaborations



Fully approved for 3 years
by CERN Research Board in **December 2023**

Fully approved for 3 years
by CERN Research Board in **June 2024**

Fully approved for 3 years by CERN RB in **Dec 2024**

MoU template by CERN

- CERN has provided a **template** for the **Memorandum of Understanding between all institutes of each DRD collaboration (and CERN)**
  - ✦ To agree with CERN's *General Conditions for the execution of experiments*, legal service, KT office
  - ✦ Should be almost identical for all DRD collaborations
- **Main MoU** is the only one which is physically/electronically **signed by each collaborating institution/Funding Agencies**; Contains: Obligations of CERN as host laboratory, industrial involvements, common fund, definitions of work packages, working groups. Meant to be unchanged during the whole collaboration lifetime.
- **Annexes**: everything that can change over time
  - ✦ Does not necessarily need a physical signature by funding agencies, but agreement/vote at Resource Board (with representatives of funding agencies)

- Annex 1: Collaborating Institutions and their Contact Persons
- Annex 2: Funding Agencies and their Representatives
- Annex 3: Equipment Structure and Technical Participation of the Collaborating Institutions
- Annex 4: The Organisational Structure of the Collaboration
- Annex 5: Overview of the Financial Participation of the Funding Agencies
- Annex 6: Specific Obligations and Responsibilities of CERN as the Host Laboratory of the DRDn Collaboration
- **Annex 7: Work Packages**
- **Annex 8: Working Groups**
- Annex 9: Other Work Entities
- Annex 10: Included Background IP
- Annex 11: Conflict of Interest Disclosure Form
- Annex 12: CERN General Conditions Applicable to Experiments

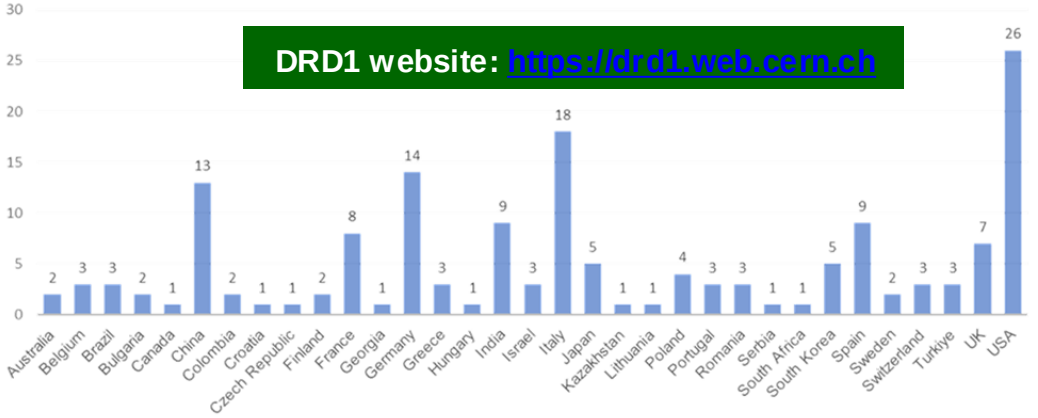
MoU template by CERN

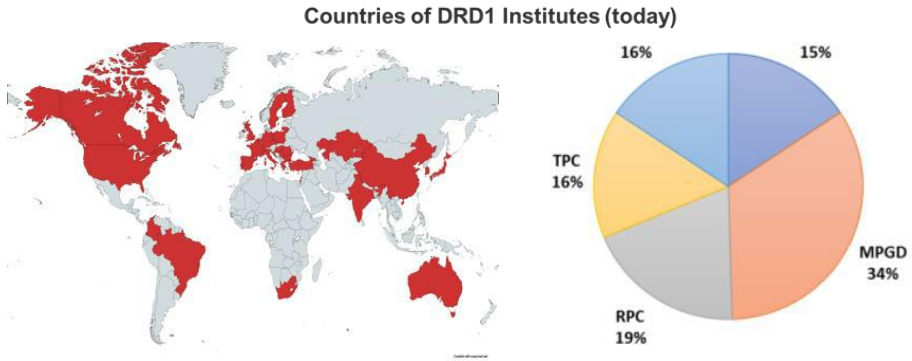
- Various meetings over the last months between DRDs management and CERN management to converge on a final Memorandum of Understanding (MoU) document
  - ✦ First MoU draft received from the CERN management end of June
  - ✦ Update in July on MoU annexes
  - ✦ Documents updated in September and October
- Current status:
  - ✦ Most collaborations voted on constitution a.k.a. by-laws to the MoU
  - ✦ WPs finalized the definition of “Deliverables”, that have been included in the tables of Annex 7
  - ✦ First draft of the MoU documents with full tables sent to the CERN management on November 8th
  - ✦ Some DRD collaborations submitted the annexes (some not yet)

Detector R&D Collaborations

Gaseous Detectors (DRD1)

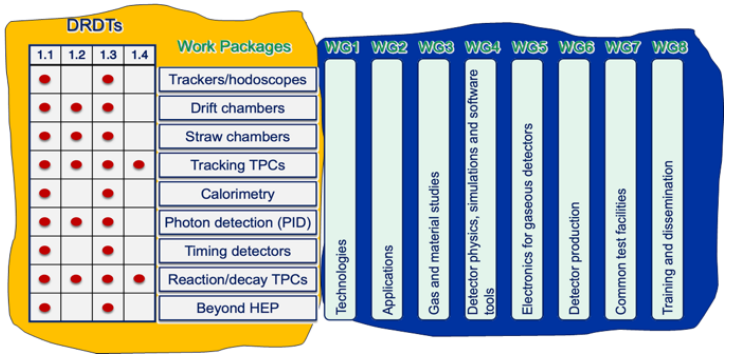
- ***More than 165 Institutes***
- ***5 Industrial, Semi-Industrial and Research Foundations***
- ***More than 30 Countries*** ***(UJ from SA)***
- ***More than 700 members***





Organized in:

- ***Working Groups:*** ***serve as the backbone of R&D:*** provides a platform for sharing knowledge, expertise & efforts by supporting strategic detector R&D directions, facilitating the establishment of joint projects between institutes
- ***Work Packages:*** ***reflect the ECFA DRDTs:*** long-term projects addressing strategic R&D goals, outlined in the ECFA Detector R&D roadmap with dedicated funding lines
- ***Common Projects:*** ***enhance synergies in "blue sky" and genericR&D between institutes:*** short-term blue-sky R&D or common tool development with limited time and resources, supported by the Collaboration



✓ ***DRD1 Activities are advancing in 2024:*** three collaboration meetings (Feb., Jun., Dec.), topical WG discussions and workshops, MPGD2024 & RPC2024 conferences & Straw Tracker workshop 2024, three DRD1 test-beams, DRD1 School in December

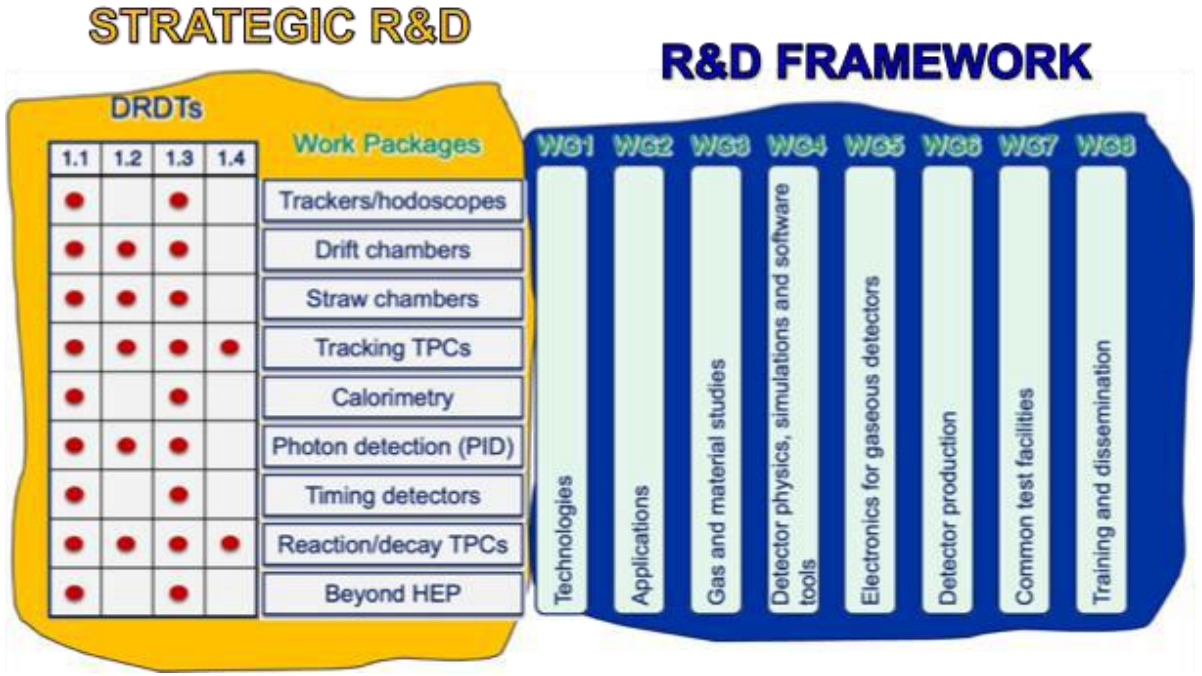
Highlights from DRD1

- ***WG3: Gas and Material Studies***
  - Kick-off meeting to introduce the members
- ***WG4: Detector physics, simulations and software tools***
  - Tutorial on numerically calculating the induced signal in resistive detectors
- ***WG5: Electronics***
  - Ongoing discussions on future SRS Activities
  - Topical workshop on electronics (Jun. 2024)
- ***WG7: Common Test Facilities***
  - Organisation of several test-beam in Prevessin
  - Large participation and use of common infrastructure (for example beam telescope)
- Strategic R&D in Work Packages not yet started due to resources requested via MoU

DRD1 Website
https://drd1.web.cern.ch

Gaseous

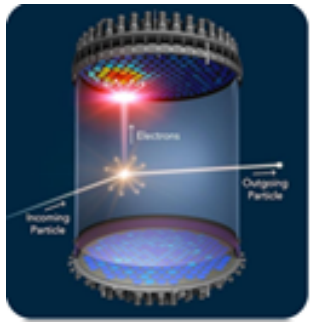
DRDT 1.1 Improve time and spatial resolution for gaseous detectors with long-term stability
DRDT 1.2 Achieve tracking in gaseous detectors with dE/dx and dN/dx capability in large volumes with very low material budget and different read-out schemes
DRDT 1.3 Develop environmentally friendly gaseous detectors for very large areas with high-rate capability
DRDT 1.4 Achieve high sensitivity in both low and high-pressure TPCs



DRD2 (Liquid Detectors) Technology domains

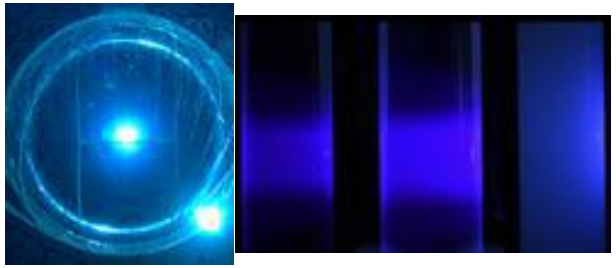
Noble Elements

- Argon & Xenon
- Ionisation charge & transport
- VUV Scintillation, light propagation & detection



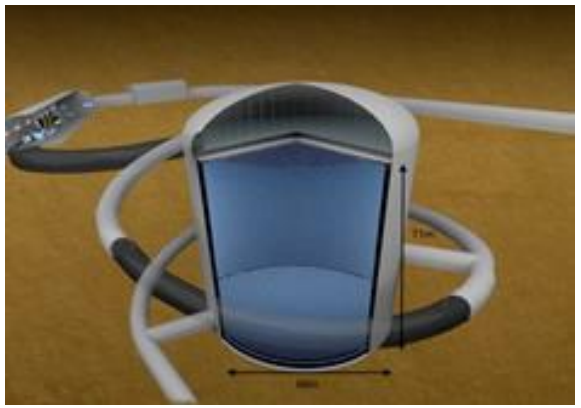
Liquid Scintillators

- Visible Scintillation, light propagation
- Scintillator properties
- Isotope loading



Water Cherenkov

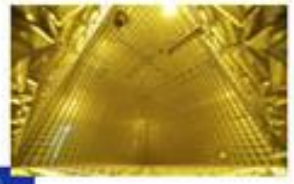
- Cherenkov light, light propagation
- Doping for n-capture

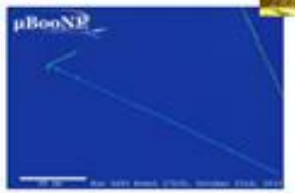


DRD2 scientific communities

Neutrinos

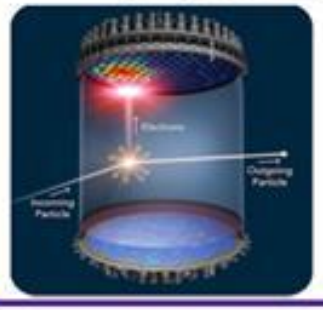
- Oscillation precision measurements (δ_{CP}, mass ordering, θ_{23} octant, sterile νs)
- Neutrino interactions (from CEvNS to DIS)
- Astro neutrinos





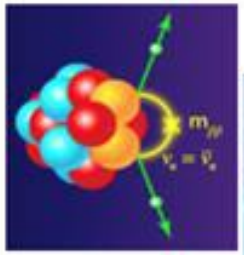
Dark Matter

- Direct detection (WIMPs, …)



0νββ

- Search for Majorana neutrinos

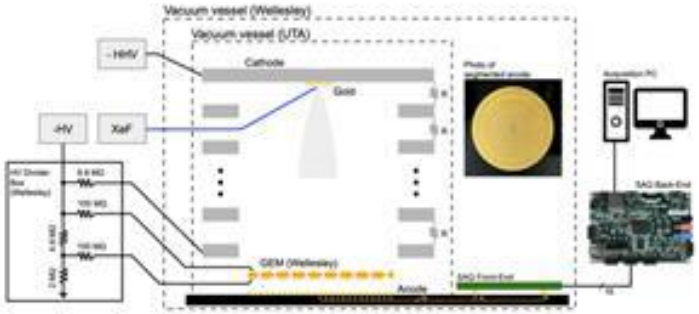


DRD2 scientific progress

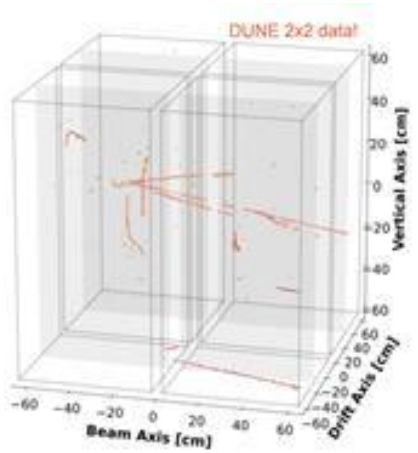
WP1.1 Pixels & charge+light
(J. Asaadi & E. Gramellini)

D1.1 First operation of a multi-channel Q-Pix prototype with COTS component

(JINST 19 (2024) 06, P06007)



D1.2 Deployment and operation of the LArPix readout concept in the 2x2 demonstrator on the NuMI beam

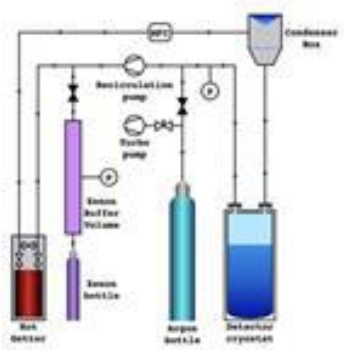


From Andrew Cudd at NuFact

WP3.2 Target properties and isotope loading of noble elements

- EUV scintillation from xe-doped LAr
  - P.Agnes et al., X-ArT

https://arxiv.org/abs/2410.22863



D3.1: Progress at ton-scale on hybrid (water-based) scintillators detectors:

BNL prototypes: 1-ton → 30-ton
- production, purification and characterization of WbLS
- status: construction of 30-ton prototype is on-going

ANNIE (FNAL): SANDI Acrylic Vessel
- hybrid reconstruction of beam neutrinos (GeV range)
- recent deployment of SANDI vessel with 365kg of Gd-loaded WbLS

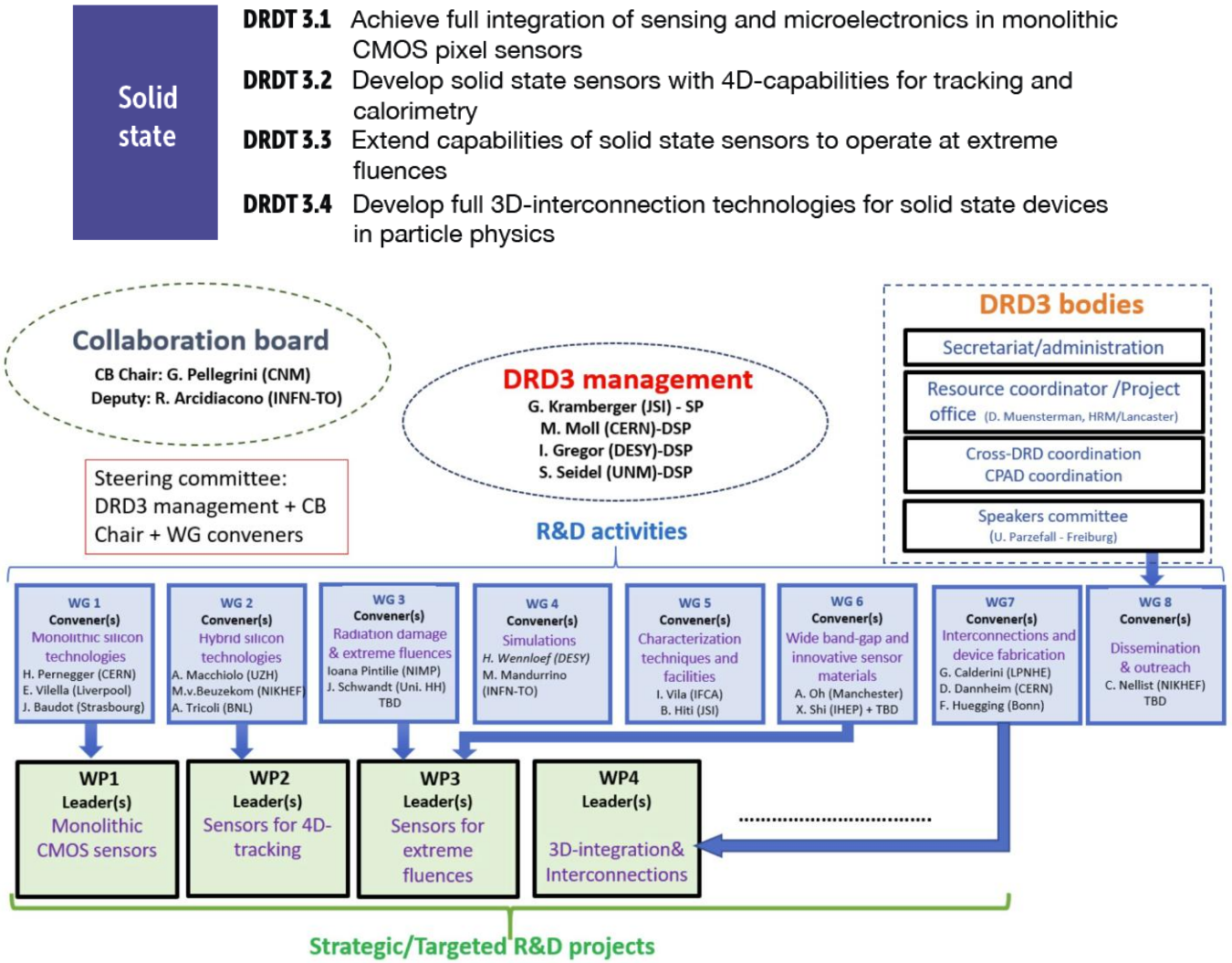
→ detection of final-state neutrons
→ Cherenkov/scintillation separation with PMTs & LAPPDs

EOS (Berkeley)
- hybrid detection at MeV energies
- detector complete, final preparations for filling with WbLS

→ coordinated program of German/US groups

DRD3: Solid State Detectors

- DRD3 benefits from existing RD50 collaboration
  - ✦ Extended by diamonds (RD42) and 3D integration
  - ✦ Large interest in CMOS (DMAPS) sensors
- Large Collaboration: 143 institutes, 28 countries, ~900 interested people
  - ✦ ~ 70% are from Europe, 15% from North America,
  - ✦ Compare: RD50: 65 institutes and 434 members
- Collaboration website: https://drd3.web.cern.ch
- 1st DRD3 collaboration meeting (17-21 June 2024); 2nd collaboration meeting (3-6 Dec 2024)



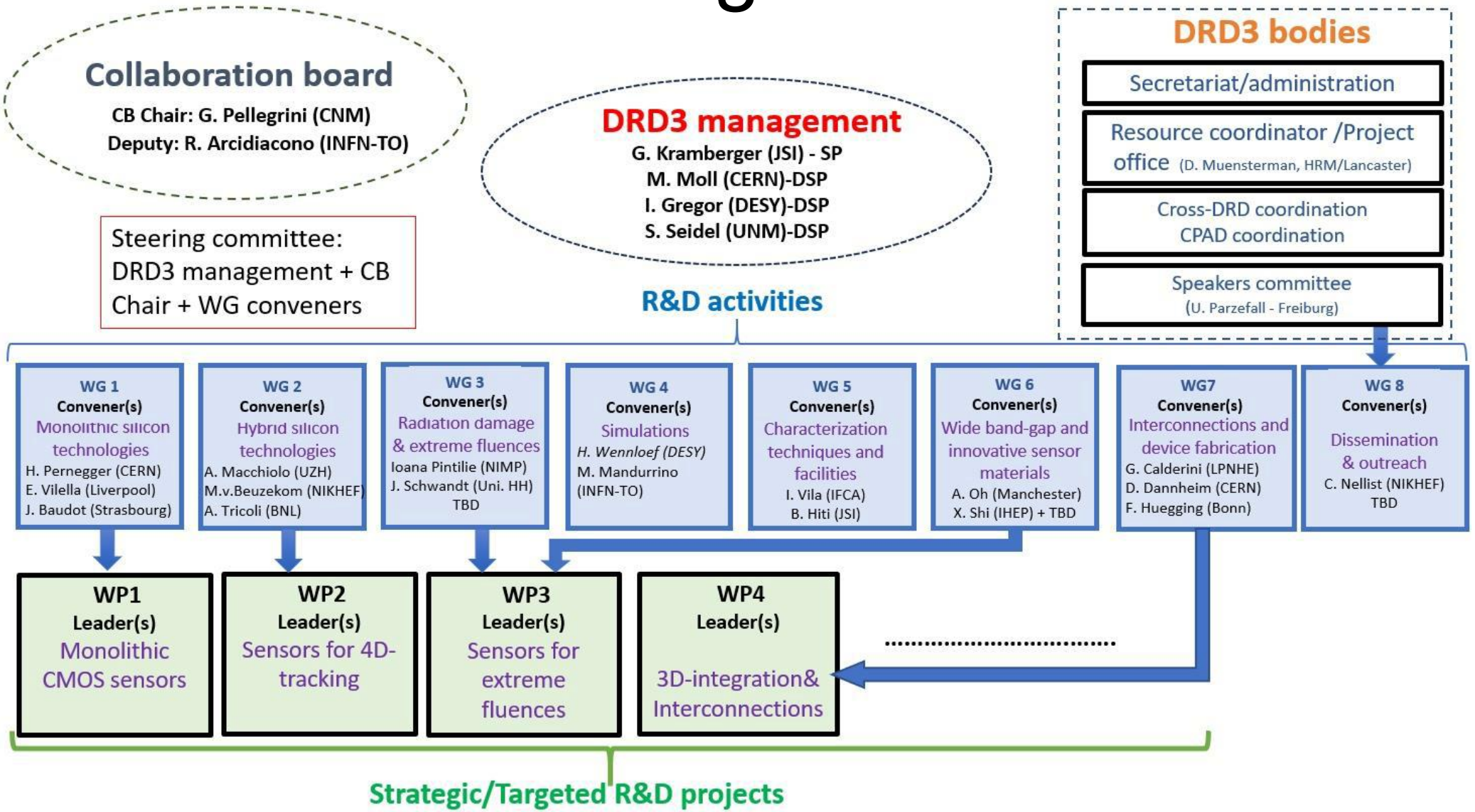
DRD3: Semiconductor Detectors

- DRD3 benefits from existing RD50 collaboration, extended by diamonds (RD42) and 3D integration
  - Focus widened from pure radiation hardness (HL-LHC Ph-2 upgrades) to lepton collider needs
  - Large interest in CMOS (DMAPS) sensors
- Large Collaboration: 143 institutes from 28 countries
  - ~900 interested people
  - ~ 70% are from Europe, 15% from North America,
  - Compare: RD50: 65 institutes and 434 members
- Budget: ~5 MCHF/y (existing), ~8 MCHF/y (additional needed)
  - 327/170 FTE (existing / additional needed)

- CB Board chair : Giulio Pellegrini (CNM Spain)
- Spokesperson: Gregor Kramberger (JSI Slovenia) with deputies (Sally Seidel, Michael Moll, n.n.)
- Webpage: https://drd3.web.cern.ch/

- 1st DRD3 collaboration meeting (17-21 June 2024); 2nd collaboration meeting (3-6 Dec 2024)

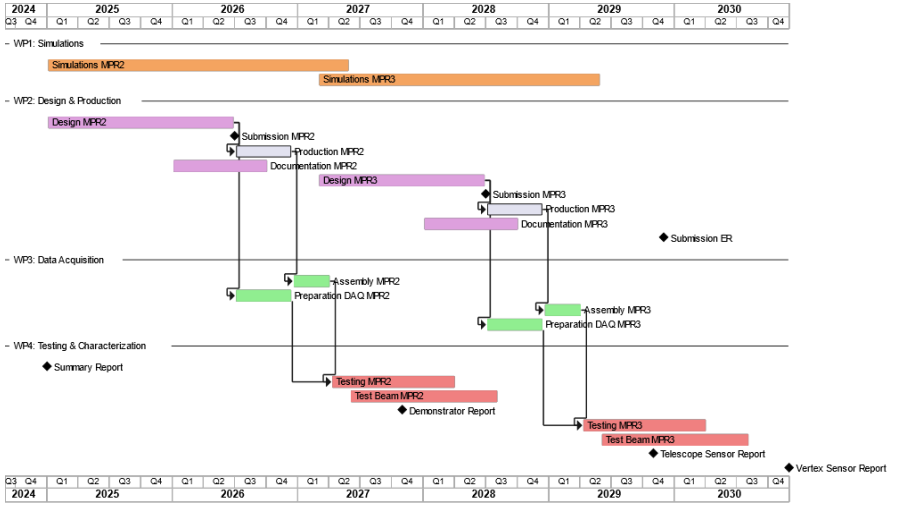
DRD3: Organization



DRD3: Monolithic CMOS Sensors

- R&D program divided into three phases
  - the initial stepping stones developments of ALICE-3, LHCb-2, EIC, Belle-3, ATLAS, CMS, and HGCAL (DRD6);
  - the subsequent further developments for e+e− colliders;
  - and, lastly, the R&D for MC and FCC-hh.
- Several complementary CMOS processes are accessible to HEP community:
  - TPSCo 65 nm, LFoundry 110 nm, IHP 130 nm, LFoundy 150 nm, AMS/TSI 180 nm, TJ 180 nm,
  - large-area passive CMOS
  - Stitching (ALICE), 3D stacking
- 32 project proposals currently under consideration;
  - Cover sensor optimization simulations (TCAD), ASIC design, DAQ Systems, testing & characterization, demonstrators
  - project timelines synchronized to MPW submission schedules (synergy with DRD7 for several processes, e.g. TPSCo 65nm

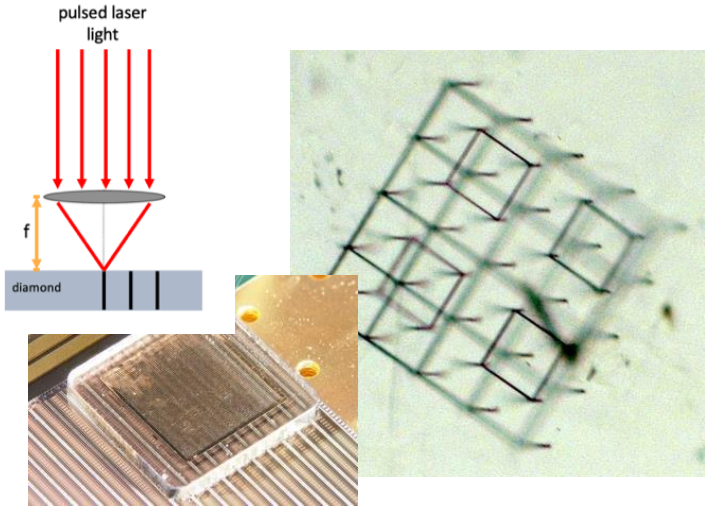
WG1 research goals <2027	
	Description
RG 1.1	Spatial resolution: ≤3 µm position resolution
RG 2.2	Timing resolution: towards 20 ps timing precision
RG 1.3	Readout architectures: towards 100 MHz/cm^2, 1 GHz/cm^2 with 3D stacked monolithic sensors, and on-chip reconfigurability
RG 1.4	Radiation tolerance: towards 10^{16} n_{eq}/cm^2 NIEL and 500 MRad
RG 1.5	Low-cost large-area CMOS sensors

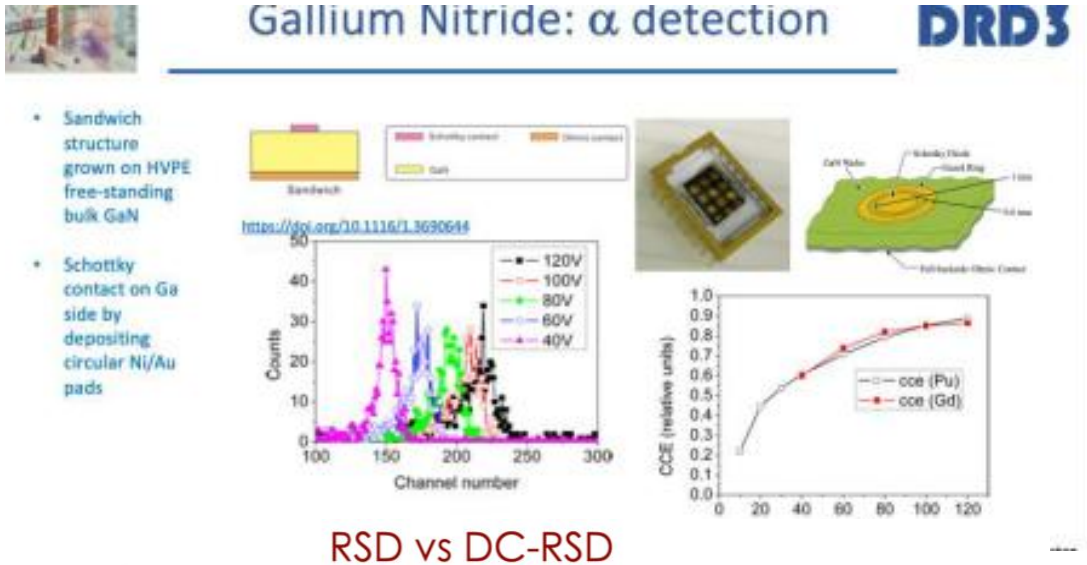


DRD3: Wide Band gap and LGADs

Materials under investigation: Diamond, Silicon Carbide, Gallium Nitride

3D Diamond:

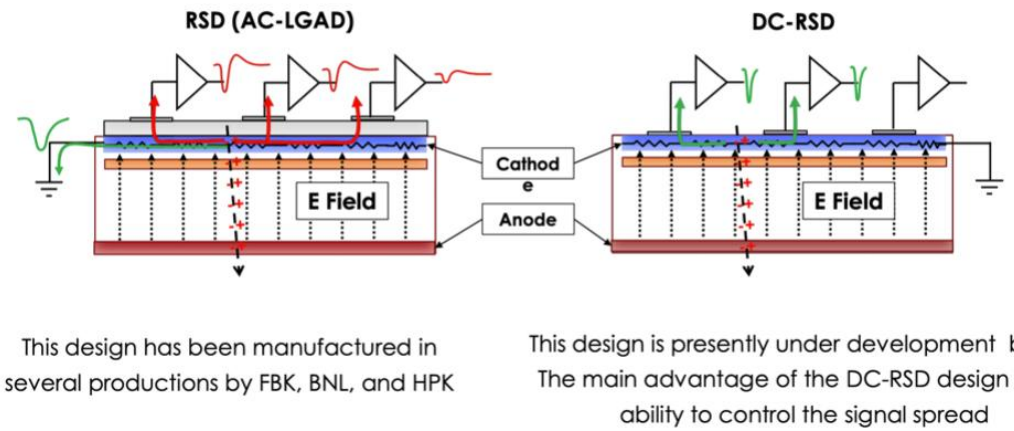




R&D on new LGAD technology:

- **4D-tracking**
  - **Resistive silicon detector: AC-RSD and DC-RSD**

- **Sensors for extreme fluences (10^{16} – 10^{17} n^{eq}/cm^2)**
  - **Compensated LGADs**

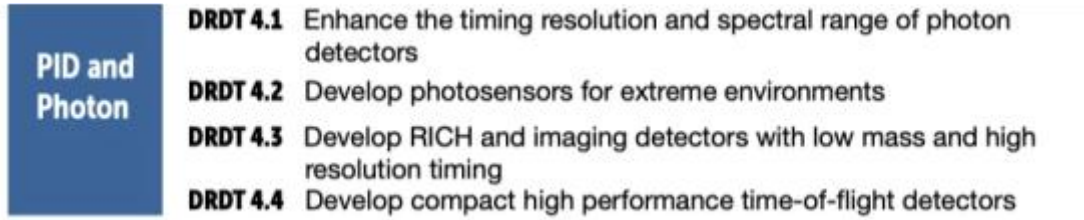


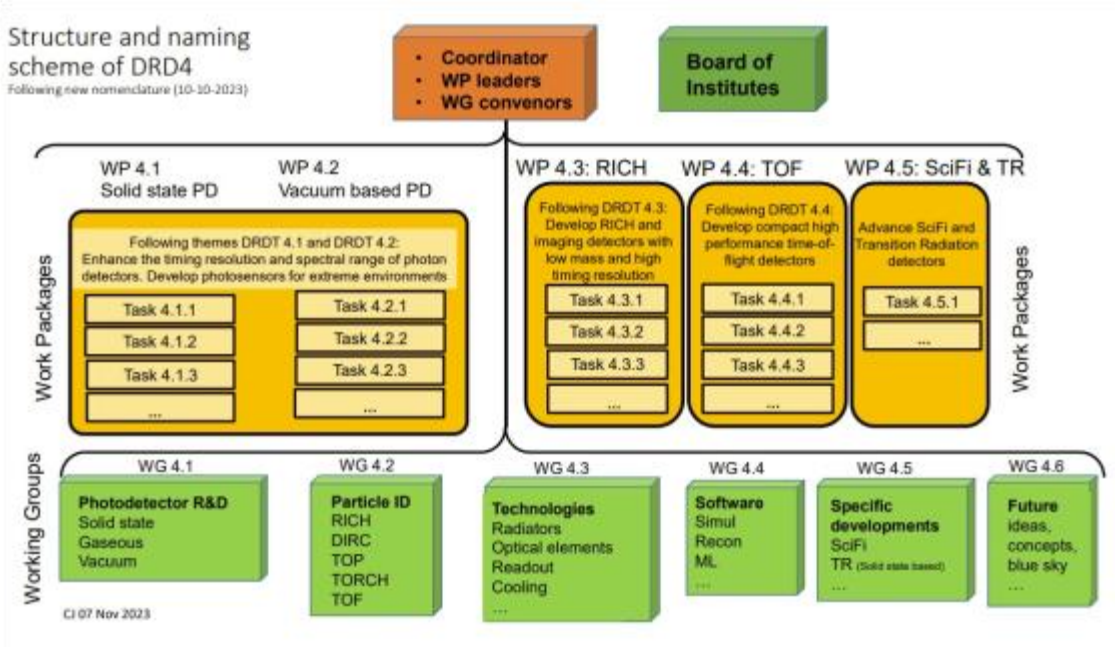
This design has been manufactured in several productions by FBK, BNL, and HPK

This design is presently under development by FBK
The main advantage of the DC-RSD design is the ability to control the signal spread

DRD4: Photon Detectors & Particle ID

- Main goal: bundle and boost R&D activities in photodetector technology and Particle Identification (PID) techniques for future HEP experiments and facilities
- DRD4 covers the following topics:
  - ✦ Single-photon sensitive photodetectors (vacuum, solid state, hybrid)
  - ✦ PID techniques (Cherenkov based, Time of Flight)
  - ✦ Scintillating Fiber (SciFi) tracking
  - ✦ Transition Radiation (TR) using solid state X-ray detectors
- Collaboration: 74 institutes from 19 countries, 7 (semi-) industrial partners
  - ✦ 6 Working Groups (WGs) reflecting the main areas of R&D
  - ✦ 5 Work Packages (WPs) reflecting the main ECFA roadmap themes and goals
- Collaboration website: https://drd4.web.cern.ch
- **DRD4 collaboration meetings:** constitutional meeting (CERN, 23-24 January 2024),1st DRD4 Collaboration meeting (CERN, 17 -20 June 2024), 2nd DRD4 Collaboration meeting (CERN, 21 -25 October 2024)
- First WG meetings started in May (indico)





DRD4 Scientific Progress

ÖAW ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN · HEPHY · RWTH AACHEN UNIVERSITY

SiPM Single Photon Timing Resolution

Stefan Gundacker [1, 2]

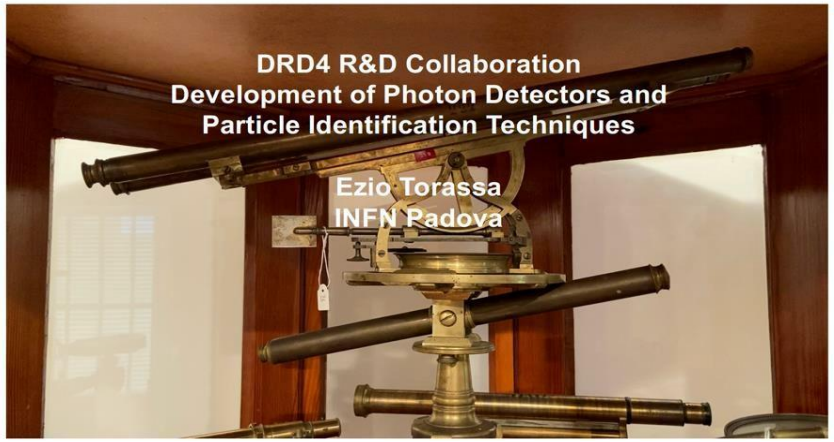
[1] Institute of High Energy Physics (HEPHY), Austrian Academy of Sciences (OEAW), Vienna, Austria
[2] Department of Physics of Molecular Imaging Systems (PMI), RWTH Aachen University, Aachen, Germany

stefan.gundacker@cern.ch

Belle II

MCP-PMT performance for Belle II and future developments for upgrades

INFN PADOVA



FONDAZIONE BRUNO KESSLER
FUTURE BUILT ON KNOWLEDGE

FBK NUV-BSI SiPM Update

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Adapting the CBM's RICH electronics readout to SiPMs

2nd DRD4 Collaboration Meeting. CERN.

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DRD5: Quantum Sensors

Quantum

- **DRDT 5.1** Promote the development of advanced quantum sensing technologies
- **DRDT 5.2** Investigate and adapt state-of-the-art developments in quantum technologies to particle physics
- **DRDT 5.3** Establish the necessary frameworks and mechanisms to allow exploration of emerging technologies
- **DRDT 5.4** Develop and provide advanced enabling capabilities and infrastructure

- Quantum Technologies are a rapidly emerging area of technology development to study fundamental physics
  - ✦ Development of HEP detectors on the long term
- Full proposal developed in the last year (approved in June 2024)
  - ✦ Two community workshops [link]
- Re-structured the Roadmap topics into WPs
  - ✦ Many reports and documents as deliverables, but this is in the nature of this proposal (early TRL)
- Signed by 94 institutions, 338 persons, with (rough estimate of 20 FTE per WP)
- Quantum Sensing autumn school (4-8 Nov 2024)

Roadmap topics

Proposal WP's

Sensor family → / Work Package ↓	clocks & clock networks	superconduct-ing & spin-based sensors	kinetic detectors	atoms / ions / molecules & atom interferometry	opto-mechanical sensors	nano-engineered / low-dimensional / materials
WP1 *Atomic, Nuclear and Molecular Systems in traps & beams*	X			X	(X)	
WP2 *Quantum Materials (0-, 1-, 2-D)*		(X)	(X)		X	X
WP3 *Quantum super-conducting devices*		X				(X)
WP4 *Scaled-up massive ensembles* (spin-sensitive devices, hybrid devices, mechanical sensors)		X	(X)	X	(X)	X
WP5 *Quantum Techniques for Sensing*	X	X	X	X	X	
WP6 *Capacity expansion*	X	X	X	X	X	X

WP-2 (0-,1- and 2-D materials)

WP-2a (application-specific tailoring)	characterization protocol	database definition	populated db
	protocol	*Database prototype*	*Functional database*
WP-2ab (extended functionalities)	workshop/conference	device designs	novel hybrid devices
	Device concepts	*Prototype devices*	*Functional devices*
WP-2c (simulations)	status & desiderata	prototype model	benchmarked simulations
	Report	*Simulation SW designs*	*Validation report*

DRD6: Calorimetry

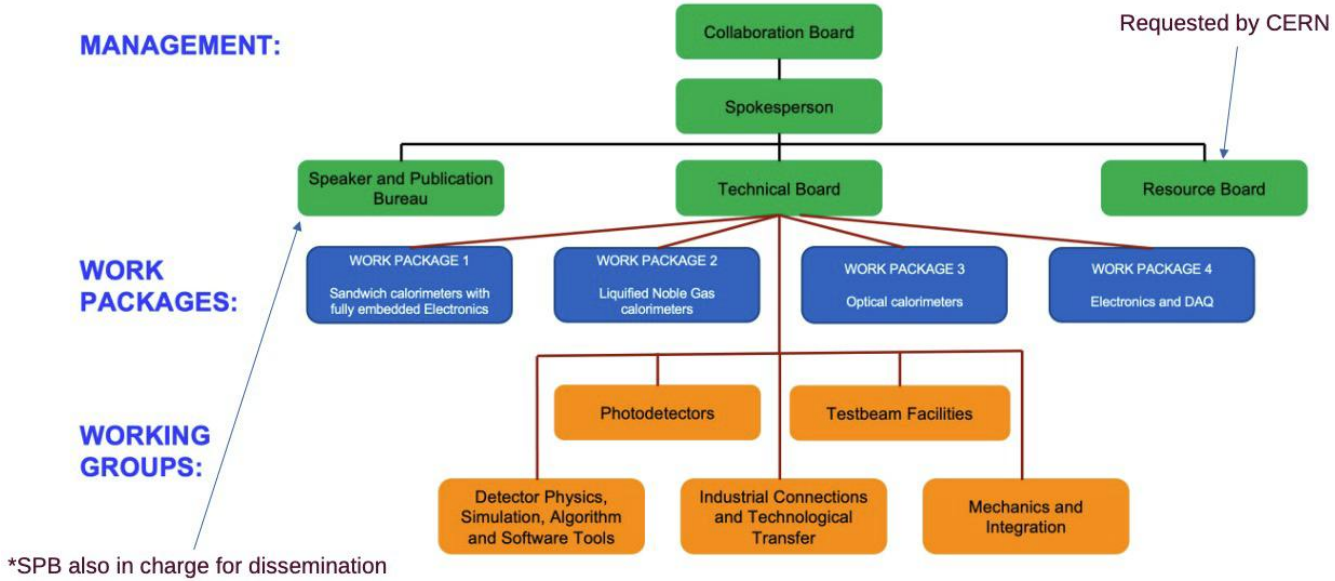
- Collaboration emerged from several collaborations like CALICE and CrystalClear (RD18), 135 institutions
- Targets: high granularity, timing resolution, hadronic energy resolution
- 1st Community Meeting 12/1/23 https://indico.cern.ch/event/1212696/
- 2nd Community Meeting 20th April 2023 https://indico.cern.ch/event/1246381/
- **1st DRD6 Collaboration Meeting** at CERN (9-11 April 2024) https://indico.cern.ch/event/1368231/, 2nd Collaboration Meeting at CERN (30 Oct 2024) https://indico.cern.ch/event/1449522/

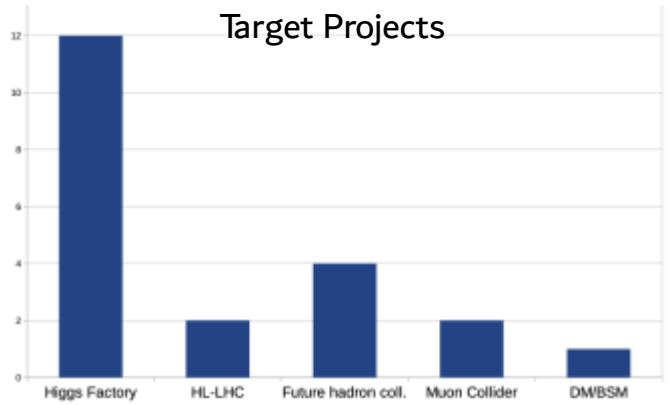
Calorimetry

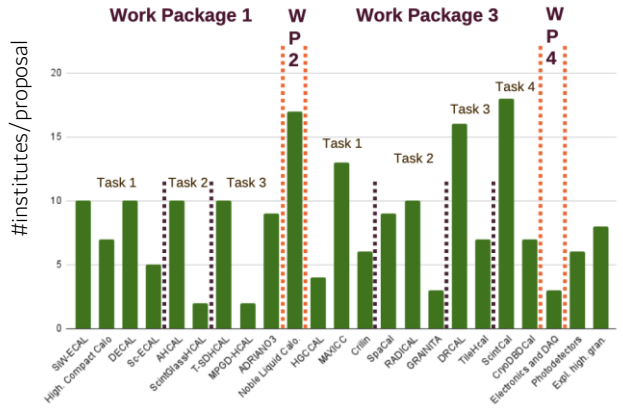
DRDT 6.1 Develop radiation-hard calorimeters with enhanced electromagnetic energy and timing resolution

DRDT 6.2 Develop high-granular calorimeters with multi-dimensional readout for optimised use of particle flow methods

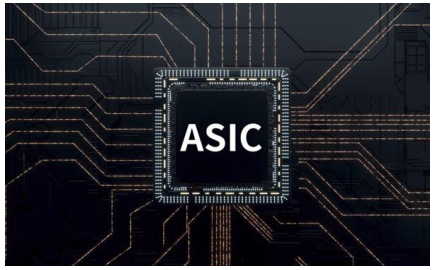
DRDT 6.3 Develop calorimeters for extreme radiation, rate and pile-up environments







DRD7: Electronics



- Approved **in June 2024**
- Objectives: Carry out strategic R&D in electronics, fulfilling DRDTs, Coordinate cross-European access to technologies, tools and knowledge, Interface with other DRDs (No orthogonal "Service-Provider" for other DRDs)
- Collaboration website: https://drd7.web.cern.ch/
- Organization: 19 countries, 68 institutes
  - ✦ 1st workshop March, 2nd workshop Sept 2023, 1st collab meeting (Sept 2024)

Electronics

DRDT 7.1 Advance technologies to deal with greatly increased data density

DRDT 7.2 Develop technologies for increased intelligence on the detector

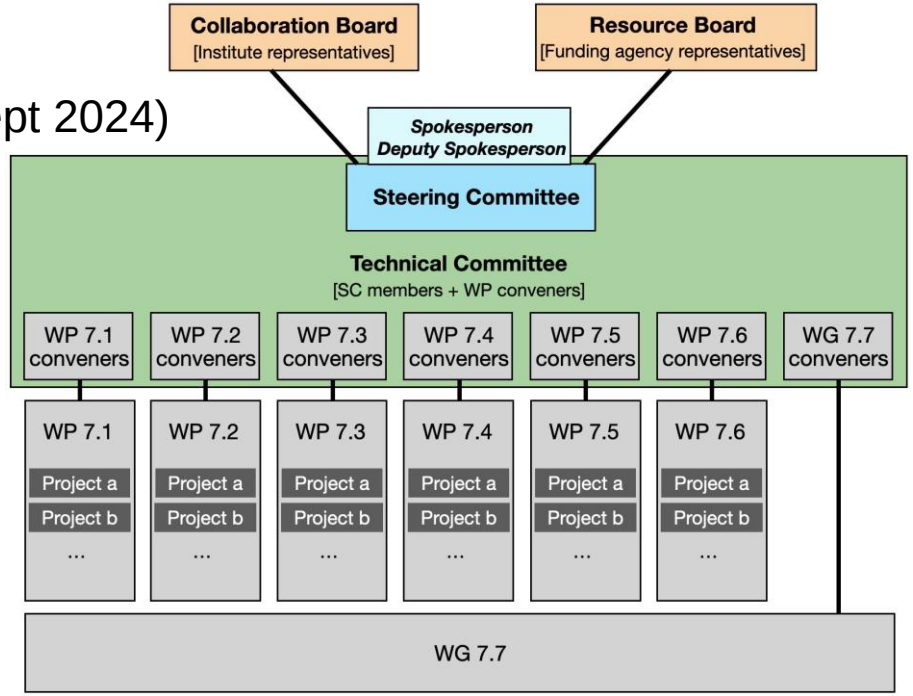
DRDT 7.3 Develop technologies in support of 4D- and 5D-techniques

DRDT 7.4 Develop novel technologies to cope with extreme environments and required longevity

DRDT 7.5 Evaluate and adapt to emerging electronics and data processing technologies

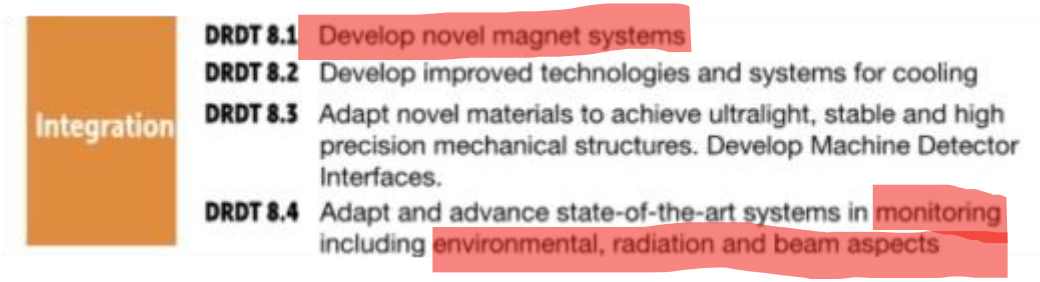
WP 7.6 Complex imaging ASICs and technologies

WG 7.7. Transversal Tools and Technologies

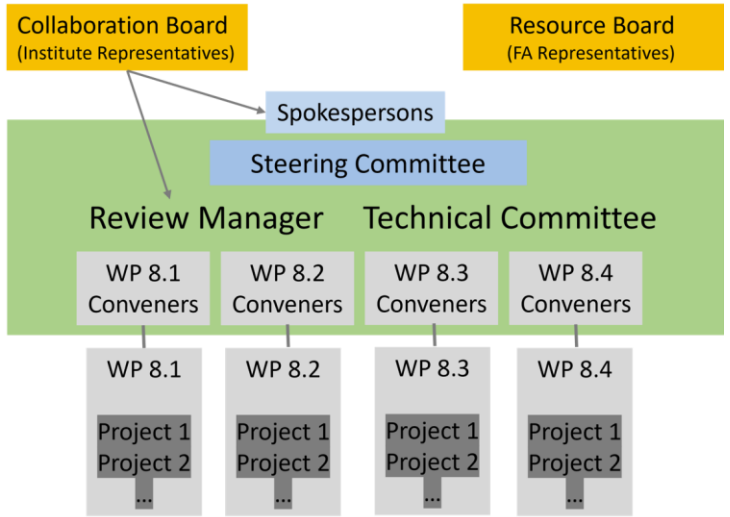


DRD8: Mechanics & Integration

- Initial TF convenors did not continue as proposal preparation team
- New proponents had to be searched for, which were found by the group around the “Forum on Tracker Mechanics” workshop organizers
- Community survey resulted in an interest in going forward
- Community Meeting on December 6, 2023
- LoI received by end of February 2024 with full proposal submitted in Oct 2024 and **approved in Dec 2024**
  - ✦ LoI does not cover all DRDTs, as they are quite diverse
  - ✦ Focus on vertex detector mechanics and cooling
  - ✦ 38 institutes in 7 countries, 32 FTEs at the moment



- WP1: Global System Design and integration
- WP2: Low-mass Mechanics and Thermal Management
- WP3: Cooling
- WP4: Design and Qualification Tools



Summary

- New CERN-hosted Detector R&D (DRD) collab. are currently being set up following ECFA Detector roadmap to work on strategic R&D
  - All DRD collaborations completed their organization structure and started to work
- Now: re-defining deliverables and work packages towards MoU, signatures of MoU's; negotiate with funding agencies to develop funding programs for DRD projects
- 2026: written status reports "prolongation request" are expected, as approval period is 3 years
- DRDs offer many opportunities to South Africa HEP community to get involved in high-end technology R&D in detector instrumentation.
  - It would help developing local expertise, students training, and more crucially, to be part of future HEP programs
  - Open numerous opportunities for application in other fields (Medical, signal processing, MC, ML/IA,…)

Overview

R&D Research Programme

Experiments | Teams | Participations

Search criteria: Search

Name	Synonym	Title	Program	Date of Approval	Status
DRD1		Detector R&D Collaboration for Gaseous detectors	R&D	06-12-2023	Preparation
DRD2		Detector R&D Collaboration for Liquid detectors	R&D	06-12-2023	Preparation
DRD3		Detector R&D Collaboration for Solid-State detectors	R&D	06-12-2023	Preparation
DRD4		Detector R&D Collaboration for Photon detectors and Particle ID	R&D	06-12-2023	Preparation
DRD5		Detector R&D Collaboration for Quantum Sensors for particle physics	R&D	05-06-2024	Preparation
DRD6		Detector R&D Collaboration for Calorimeters	R&D	06-12-2023	Preparation
DRD7		Electronics and On-Detector Processing	R&D	05-06-2024	Preparation
DRD8		Mechanics & Cooling of Future Vertex and Tracking Systems	R&D	04-12-2024	Preparation

Started December 2023:	Started June 2024:
DRD1: Gaseous Detectors	**DRD3**: Solid State Detectors
DRD2: Liquid Detectors	**DRD5**: Quantum & Emerg. Tech.
DRD4: PID & Photon Detectors	**DRD7**: Electronics
DRD6: Calorimetry	

Starting End 2024/Beginning 2025: DRD8 (Mechanics and Integration)