Detector R&D for future experiments

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(INFN and University of Ferrara)

European Strategy for Particle Physics Town Hall Meeting

Ferrara, November 6th 2024

European Strategy on Particle Physics

http://europeanstrategy.cern

Continuous process driven by the community

- First defined **2006**
- **Update 2013** brought us HL-LHC decision
- **Update 2020** brought us decisions for post-HL-LHC times:
  - *Europe, together with its international partners, should investigate the technical and financial feasibility of **a future hadron collider at CERN** with a centre-of-mass energy of at least **100 TeV** and with an **electron-positron Higgs and electroweak factory** as a possible **first stage**.*
  - ***Detector R&D programmes** and associated infrastructures should be supported at CERN, national institutes, laboratories and universities. **Synergies** between the needs of different scientific fields and **industry should be identified** and exploited to boost efficiency in the development process and increase opportunities for more **technology transfer benefiting society** at large. [... The community should define a global detector R&D roadmap that should be used to support proposals at the European and national levels..*
  - Successful completion of High-Luminosity LHC must remain key focus
- **Update 2026** on the horizon with input proposals by spring 2025

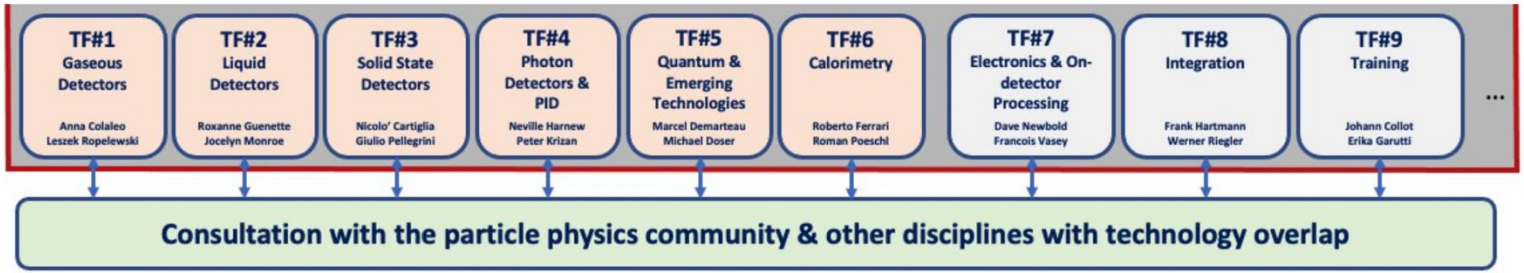
http://dx.doi.org/10.17181/CERN.JSC6.W89E

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

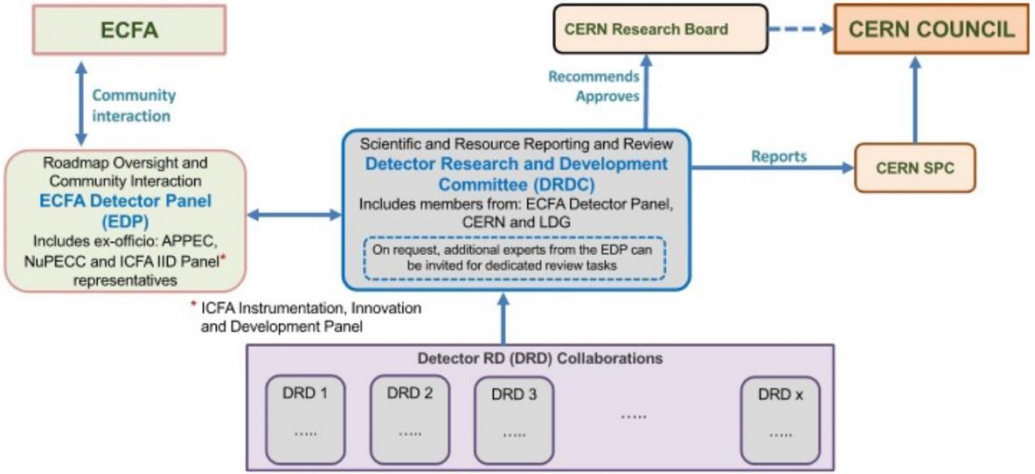
- Overview of **future facilities** (EIC, ILC, CLIC, FCC-ee/hh, Muon collider) or major **upgrades** (ALICE, Belle-II, LHC-b,…) and their **timelines**
- Ten "**General Strategic Recommendations**" (full list in backup slides)
- **Nine Technology domains** with **Task Forces** areas
  - The **most urgent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



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

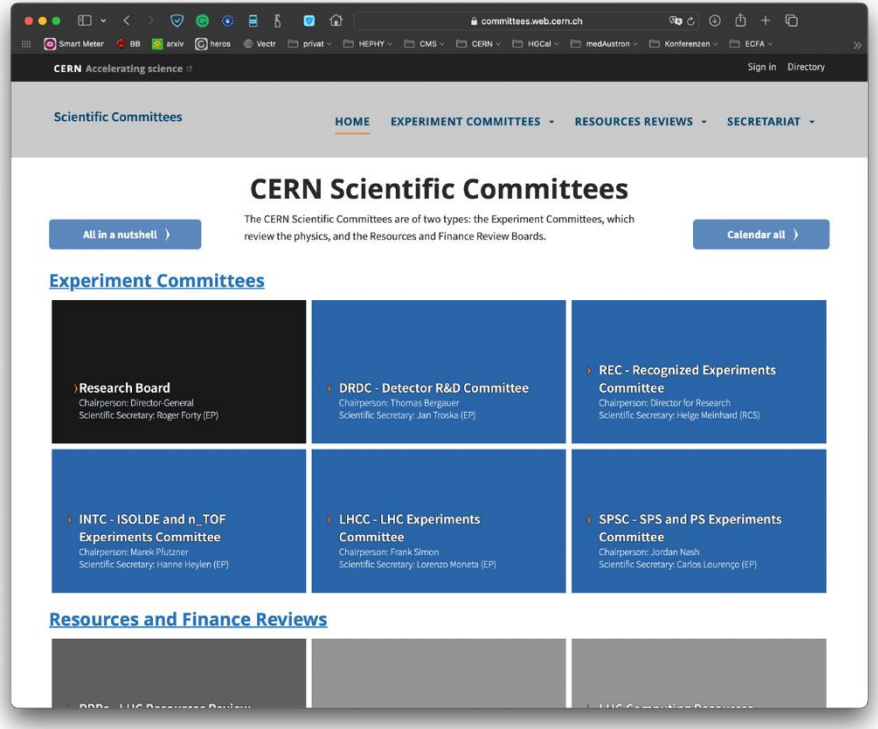
- Distinction between reviewing body (DRDC) and advising body (EDP)
- ECFA Detector Panel (EDP) interfaces to ECFA
  - Organizes "DRD managers forum"
  - provides input to the next Strategy update



DRD Committee (DRDC) at CERN

- Detector R&D Committee is a new committee on the same level as SPSC and LHCC
  - Established 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

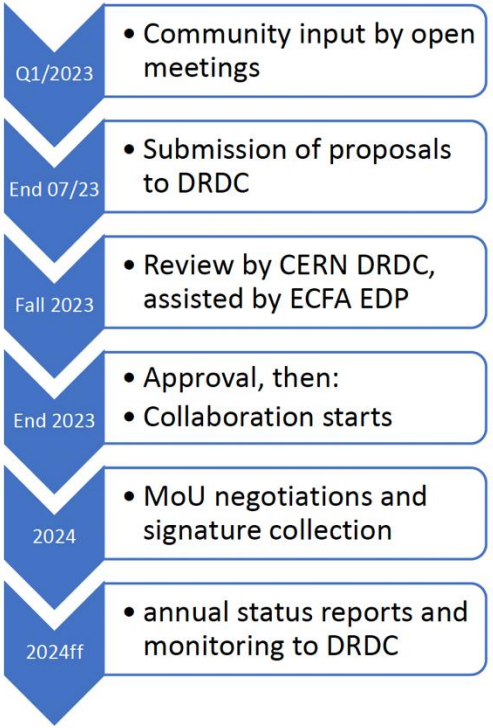


From ECFA Task forces to DRD collaborations

- Chapters convenors (Task Force) from ECFA Roadmap became part of Proposal Writing Teams for new DRD collaborations
- Collected input from the communities in open meetings happening in the beginning of 2023

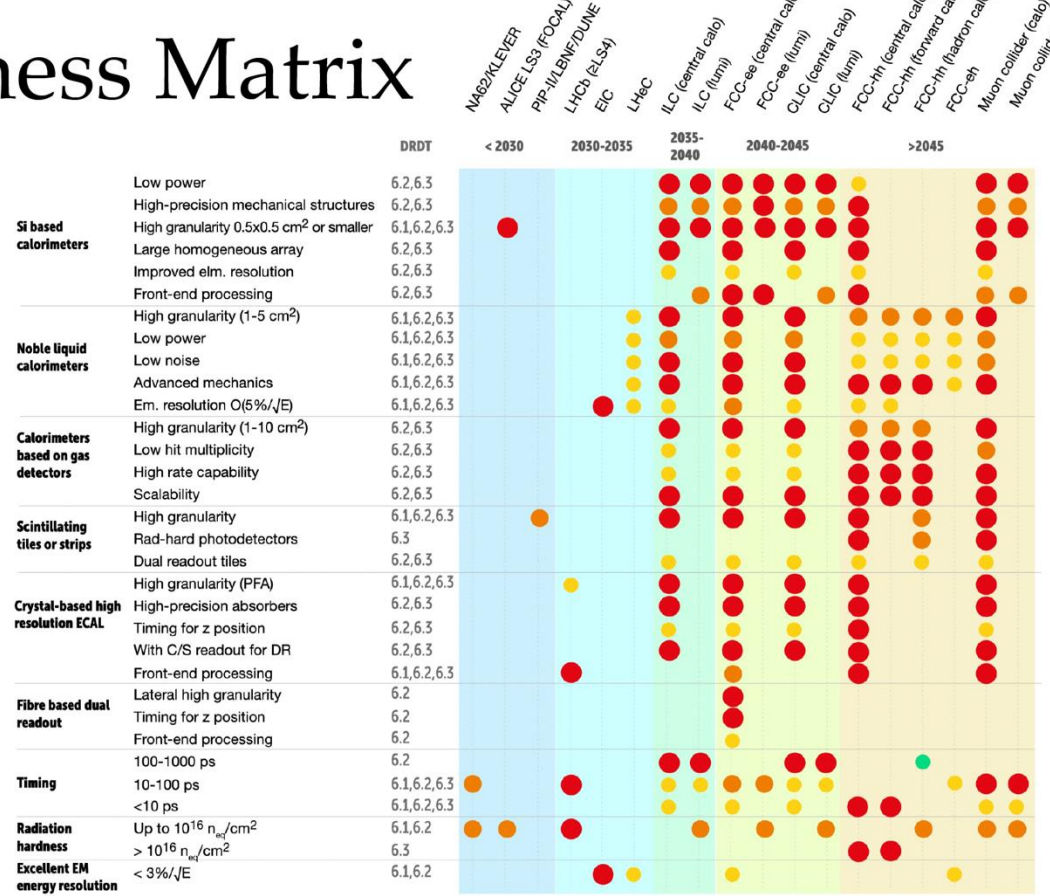
- Summer 2023: **Submission deadline of DRD proposals**
  - The DRDC (DRD Committee) was appointed at the same time only
  - Review of first DRD proposals by DRDC in autumn 2023
  - Intense phase of work as also DRDC mandate and tasks had to be defined first

- **Approval of first DRD collaborations in December 2023 RB**
- Once approved, DRD collaborations started in 2024
  - Collaborations have kick-off meetings, elect management positions,…
  - Setting up MoU and collecting signatures from Funding Agencies



Detector Readiness Matrix

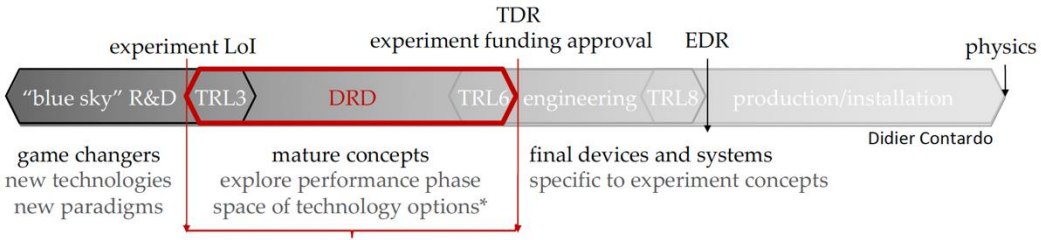
- Lists the **strategic R&D needs** of different topics in a traffic-light style system
- Used to define work packages, projects, deliverables in proposals written by proto-collaboration
  - Submitted for review to DRDC and approval by CERN RB
  - Progress tracked by annual DRDC review



Strategic R&D

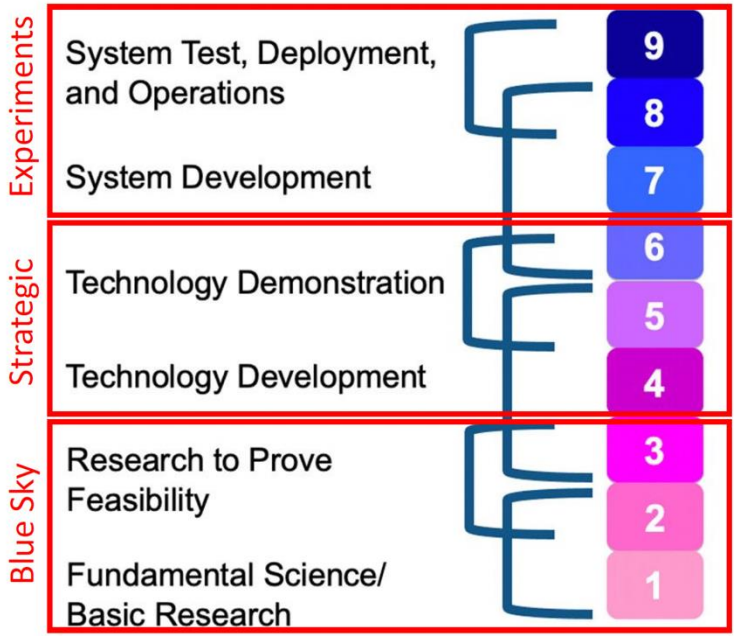
Strategic R&D bridges the gap between the idea (“**blue sky research**”, TRL 1-3) and the **deployment and use in a HEP experiment** (TRL 8-9)

- Detector R&D Collaboration should address TRLs from 3 to 7, before experiment-specific engineering takes over
- Covers the development and maturing of technologies, e.g.
  - Iterating different options
  - Improving radiation hardness
  - Scaling up detector area, number of layers,..
- Backed up by **strategic funding**, agreed with funding agencies



Technology Readiness Levels (TRLs) 1-9:

Method for estimating the maturity of technologies



Blue Sky R&D

- Blue Sky R&D is basic research where "real-world" applications are not immediately apparent.
  - Covers very low TRLs (Technology Readiness Levels)
  - Starting point of development
- **EU-funded and national programs** play an important role in enabling and supporting generic R&Ds in Europe: AIDA/2020/innova, ATTRACT, ERC grants
  - Not existing in other parts of the world to this extent
  - Successor to AIDAinnova planned
- **Common fund** of RD50/RD51 was used to fund "common projects" which can be seen as blue sky
  - RD50 rules: minimum 3 institutes; financial contribution is doubled by RD50
  - MoU has a paragraph about common fund; can or cannot be used by DRD collaborations, but allows to start collecting money by simple CB vote, without having formal update of MoU

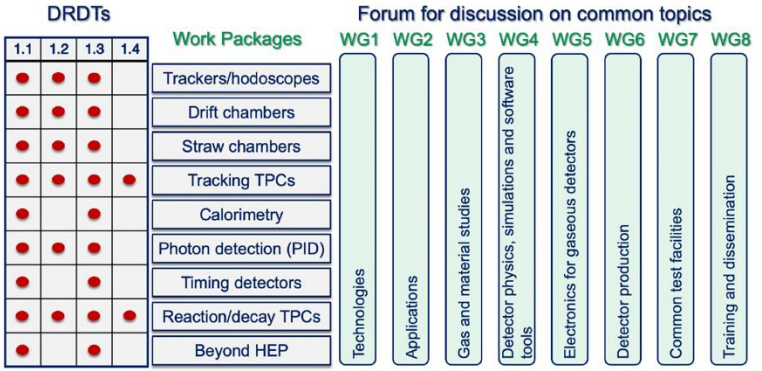
Detector R&D collaborations

Highlights of organization and structure

DRD1: Gaseous Detectors

Gaseous

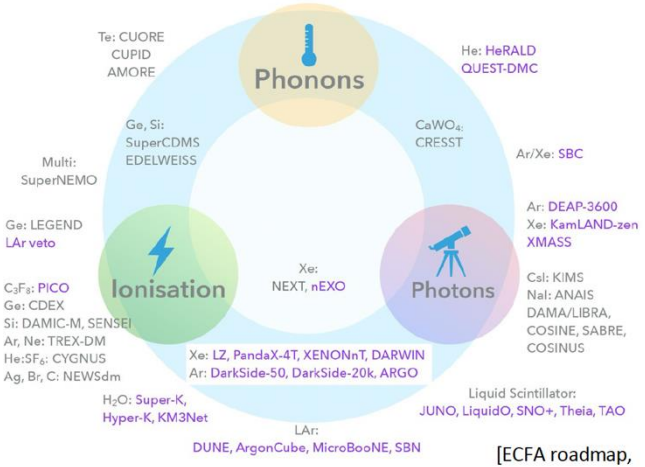
- **DRDT 1.1** Improve time and spatial resolution for gaseous detectors with long-term stability
- **DRDT 1.2** Achieve tracking in gaseous detectors with dE/dx and dN/dx capability in large volumes with very low material budget and different read-out schemes
- **DRDT 1.3** Develop environmentally friendly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



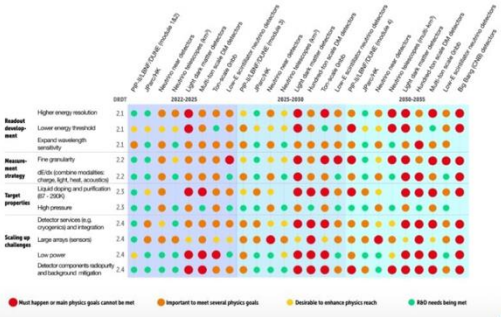
- Organized in
  - **Working Groups:** serving as the backbone of R&D
  - **Work Packages:** will reflect the DRDTs,
  - and **Common Projects** (blue sky) financed by fixed yearly fee (Common Fund)
- Large community of 161 institutes, 700 members, 33 countries based on previous RD51 collab.
- Anticipated budget: 3 MCHF/y existing, additional 3 MCHF/y needed, 270/100 FTE
- CB board chair : Anna Colaleo; Spokespersons : Eraldo Oliveri, Maxim Titov
- A collaboration website exists: https://drd1.web.cern.ch
- Collaboration meetings: 29.1. to 2.2.2024: link, 2nd Collaboration Meeting June 17-21; 3rd Collaboration Meeting December (tbc) + regular WG meetings
- Requested six weeks of beamtime at CERN SPS for 2024 already

DRD2: Liquid detectors

- Covers **Dark Matter** and **Neutrino** experiments, accelerator and non-accelerator-based
- Several large-scale and many small-scale experiments running or foreseen with liquid detectors
  - Underground Dark Matter Experiments: small and rare signals
- Technology: **Noble Liquids** (e.g. DUNE), **Water Cherenkov** (e.g. Super/Hyper-K) and **Liquid Scintillator** with light and ionization readout
- R&D for multi-ton scale noble liquids:
  - Target doping and **purification**
  - Detector components **radiopurity** and background mitigation
- Feb. 5-7, '24: inaugural DRD2 Collaboration Meeting at CERN https://indico.cern.ch/event/1367848/
  - 156 participants, 91 contributed talks, from 71 institutes in 15 countries
- CB Board chair election 1 March 2024 resulted in CB board chair W. Bonivento
- Developments in this field are rapid and it is not possible today to reasonably estimate the dates for projects requiring longer-term R&D

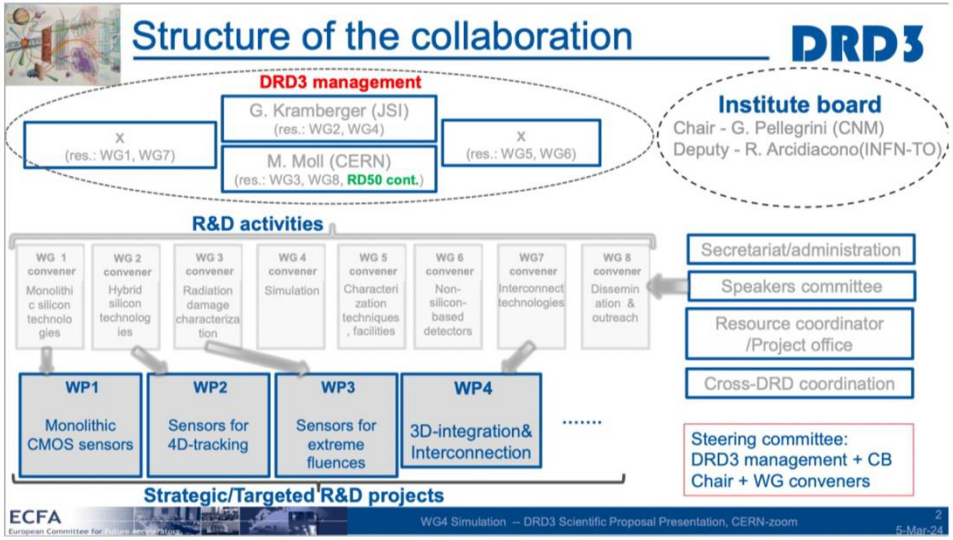


[ECFA roadmap, Modified from L.Baudis]



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: 132 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/

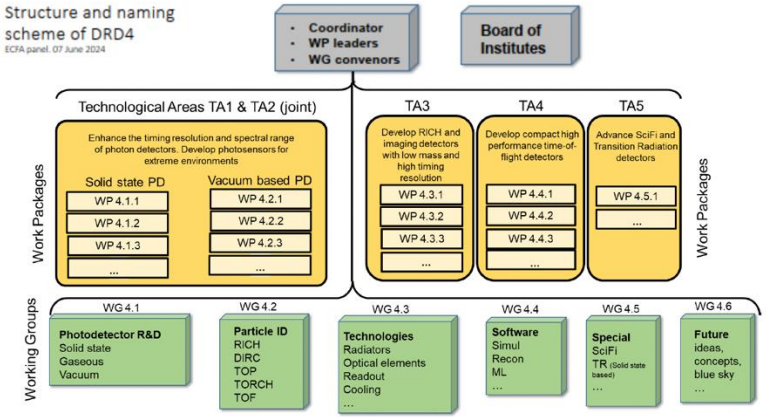
- Recently started with WG/WP meetings to organize work towards 1st DRD3 collaboration meeting (17-21 June 2024)

DRD4: Photodetectors & Particle ID

- **Developments** on PMTs, MCP-PMTs, SiPMs, APD, HPD, quantum devices, SciFi,
  - Challenges for example for SiPMs: rad hard, dark rate, timing
- **Applications** in Ring Imaging Cherenkov Detectors (RICH), Time-of-Flight (ToF), TRD
- Connection to almost every other DRD collab. (gas, Silicon, Calo, electronics, SiPM at cryogenic temp.)

- **Collaboration**: 74 institutes from 19 countries, 7 (semi-) industrial partners

- **DRD4 constitutional meeting** 23-24 January: https://indico.cern.ch/event/1349233/
  - CB board chair: Guy Wilkinson
  - Spokespersons: Massimiliano Fiorini
  - WP/WG chairs elected as well
- Next meetings 17-21 June 2024 ; 21-25 October 2024



PID and Photon

DRDT 4.1 Enhance the timing resolution and spectral range of photon detectors

DRDT 4.2 Develop photosensors for extreme environments

DRDT 4.3 Develop RICH and imaging detectors with low mass and high resolution timing

DRDT 4.4 Develop compact high performance time-of-flight detectors

DRD5: Quantum Sensors

- Quantum Technologies are a rapidly emerging area of technology development to study fundamental physics
  - Targeting a lower TRL than the other DRDs
  - Development of HEP detectors on the long term

- Full proposal developed in the last year
  - Effort driven by Michael Doser (CERN) and Marcel Demarteau (Oak Ridge)
  - 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)

- Final proposal was submitted to DRDC last week **Aim to be approved in June**

Roadmap topics

Proposal WP's

Sensor family → / Work Package ↓	clocks & clock networks	superconducting & 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 superconducting 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)

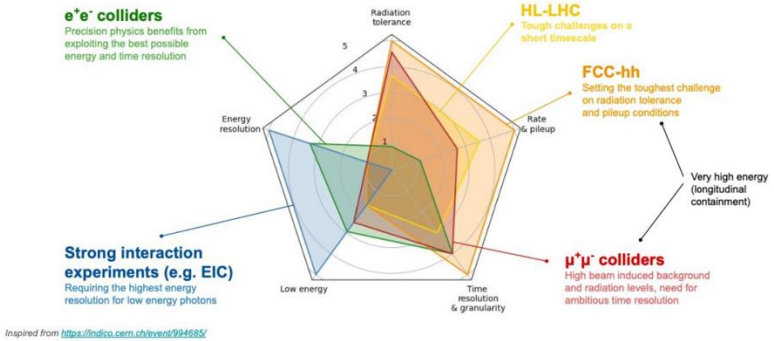
WP-2a →	characterization protocol →	database definition →	populated db
(application-specific tailoring)	*protocol*	*Database prototype*	*Functional database*
WP-2ab →	workshop/conference →	device designs →	novel hybrid devices
(extended functionalities)	*Device concepts*	*Prototype devices*	*Functional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

DRD6: Calorimetry

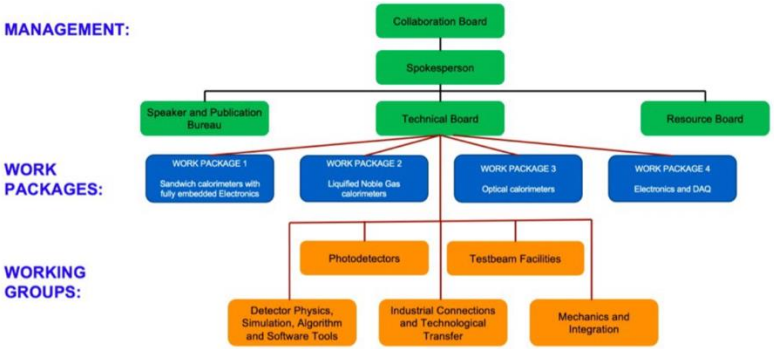
- R&D in calorimetry has a particularly long lead-time
  - Many technology developments (gas, scintillator or Silicon-based readout) done in other DRDs
  - Large and challenging prototype setups even in early stages
  - Dedicated calorimeter test beam line at SPS requested (H8?)

- Collaboration emerged from several collaborations like CALICE and CrystalClear (RD18)
  - 23 input proposals were collected from existing collaborations, boiled down to four WPs and five Working Groups
- Size : 131 institutes;
  - 183 FTE/y (existing), 100 FTE/y additional needed
  - Anticipated Budget ~3.2M€/y existing, ~1.4 to 2.4M€/y additional needed (2024-2026)
  - Little (extra) need at the beginning (2024-2026)

- 1st Collaboration Meeting happened 9-11 April and marked the end of the transition phase



Inspired from https://indico.cern.ch/event/994685/



DRD7: Electronics

- Full proposal received by 21 May 2024; **aiming approval 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
- Organization:
  - 19 countries, 68 institutes
  - 1st workshop in March, 2nd workshop in Sept. 2023; 1st collaboration meeting planned 9-10 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

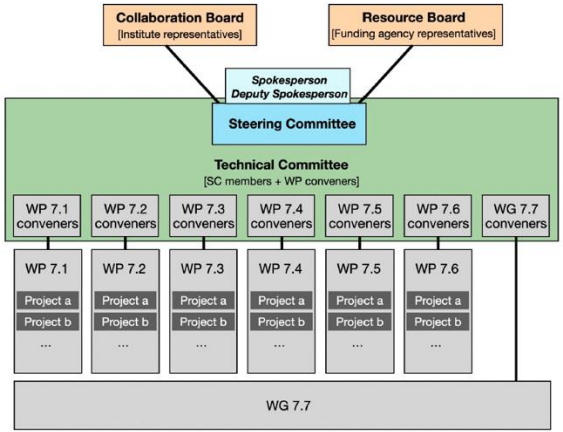
DRDT 7.3 Develop technologies in support of 4D- and 5D-techniques

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

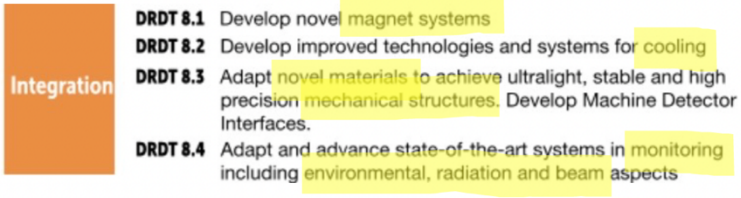
WG 7.7. Transversal Tools and Technologies



DRD8: 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
  - Burkhard Schmidt (CERN) and Andreas Mussgiller (DESY)

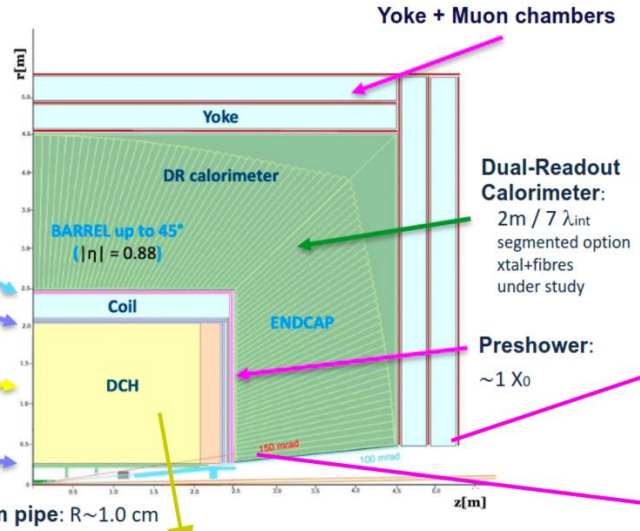
- Community survey resulted in an interest in going forward
- Community Meeting on December 6, 2023
- LoI received by end of February 2024 with the **aim to write a full proposal by the end of this year**
  - LoI does not cover all DRDTs, as they are quite diverse
  - Focus on vertex detector mechanics and cooling
  - 22 institutes in 7 countries, 32 FTE at the moment



Ferrara groups involvement in the DRD Collaborations

DRD1 for future colliders

IDEA detector baseline layout



Superconducting solenoid coil:
2 T, R ~ 2.1-2.4 m
0.74 X_0, 0.16 λ @ 90°

Outer Silicon wrapper:
Si strips /LGAD options

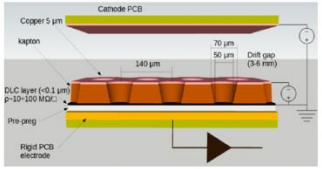
Drift Chamber: 112 layers
4 m long, R = 35-200 cm

Vertex:
5 MAPS layers
R = 1.37-31.5 cm

Dual-Readout Calorimeter:
2m / 7 λ_{int}
segmented option
xtal+fibres
under study

Preshower:
~1 X_0

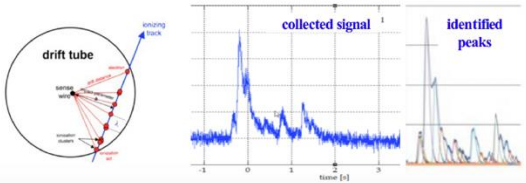
Beam pipe: R~1.0 cm

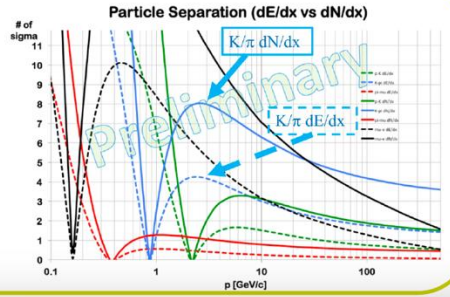


µRWELL for preshower and muon detector, expecially for long lived particles.

Crucial technological transfer to industry

Ultra-light drift chamber with cluster counting to improve PID capabilities





6 persone
4.5 FTE

WP2: light readout

- Task 2.1: Increased sensor quantum efficiency.
  - This effort is targeted at efficiency in the VUV and at cryogenic temperatures.
  - Overlap-complementarity with WP1 of DRD4, which focuses on
    - - radiation hardness
    - - timing performance
- Goals:
  1. Design of sensors and strategies to maximize QE efficiency in the VUV
  2. Fabrication of integrated devices
  3. Network of facilities for the **operational characterization in the VUV**

Ferrara: 0.8 FTE, 4 staff + 2 early career

DRD4: Photon Detectors

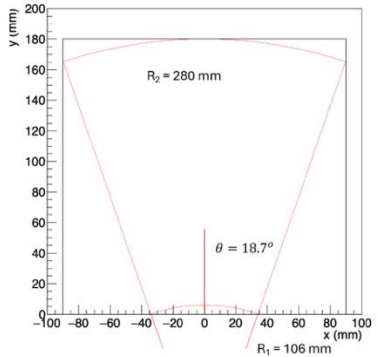
- WP1 (Solid-state photodetectors)
  - Development of Back-Side Illuminated (BSI) SiPM at FBK
  - Development of radiation-hard SiPM for future experiments in harsh environments
- WP2 (Vacuum-based photodetectors)
  - MCP longevity and high-rate capability studies, to find a candidate photodetector for the LHCb RICH Upgrade 2
  - Develop an MCP-PMT with combined excellent timing resolution and good spatial resolution, to find a candidate photodetector for the LHCb RICH Upgrade 2

14 persone
11.5 FTE

4.3.1 Optimized aerogel:

Characterization and development of tiles of excellent optical quality and large area suitable for future experiments

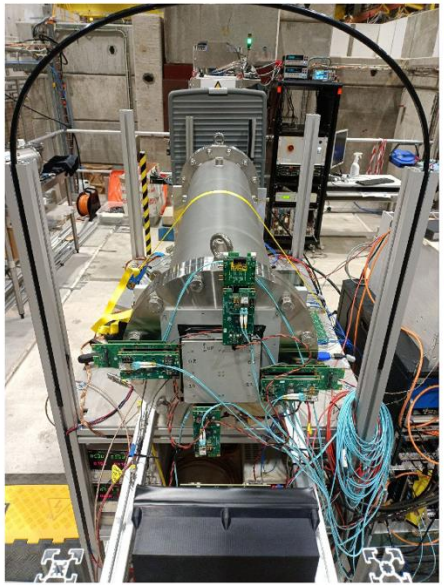
Small tiles being studied in lab and with prototypes
Large and shaped tiles under production (Aerogel Factory)

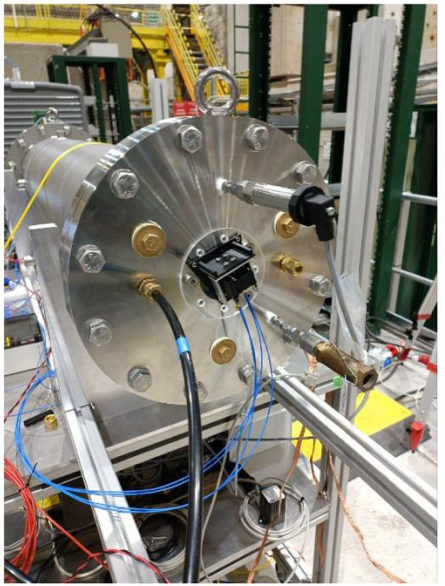


4.3.2 Pressurized RICH:

Feasibility study of the usage of pressurized inert gas (i.e. Argon) as alternative to greenhouse fluorocarbon gases.

3.5 bar certified chamber under realization
(preliminary validation done at CERN)





5 persone
1.5 FTE

DRD 6 CALORIMETRY

The "OREO" ORiEnted calOrimeter project

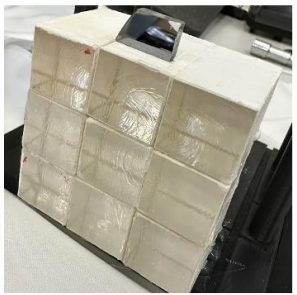
Objective: Development of an **ultra-compact** and **ultra-fast electromagnetic calorimeter** with oriented crystals.

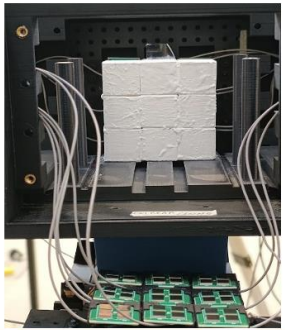
OREO is the subtask 3.1.4 in WP3 Optical Calorimeters
INFN Units (total 6.5 FTE, 26 people): FE (12 people, 2 FTE), LNL, LNF, MiB
Subtask coordinator and member of DRD6 CB: **Laura Bandiera**

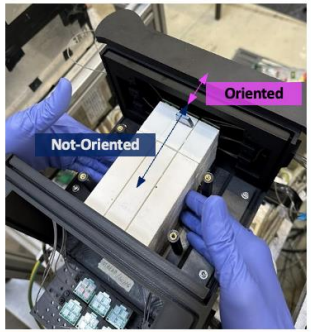
2024: First prototype construction and test at CERN

3x3 matrix of PWO-ultrafast

(PWO is one of the most common crystal scintillators used in HEP)

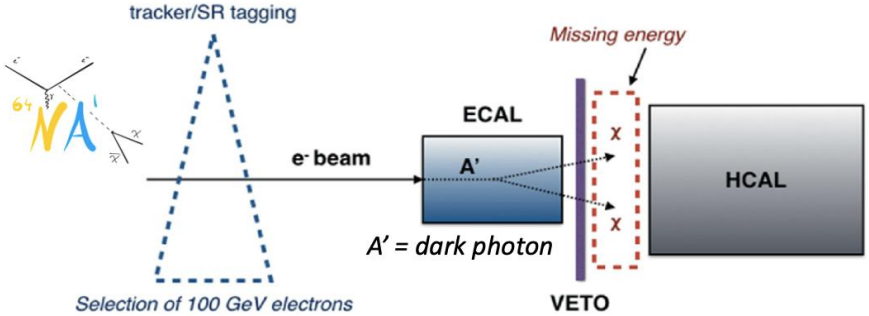






Applications:

- in **light dark matter search** to realize **compact active beam dump or target** with an **increased sensitivity** (started collaboration with **NA64 @CERN SPS**) and future experiments **at the FCC-ee injector**



- **Longitudinally segmented ECAL**
  - **compact high-resolution ECAL** in forward geometry (e.g. HIKE SAC or **forward collider region**)
  - In **isotropic calorimeters** (e.g. MAXICC for FCC-ee or CRILIN for muon collider) -> **control the crystal orientation**