Implementing the ECFA Detector R&D Roadmap:

Towards International Detector R&D Collaborations

Anna Colaleo (University and INFN Bari

15/1/2024

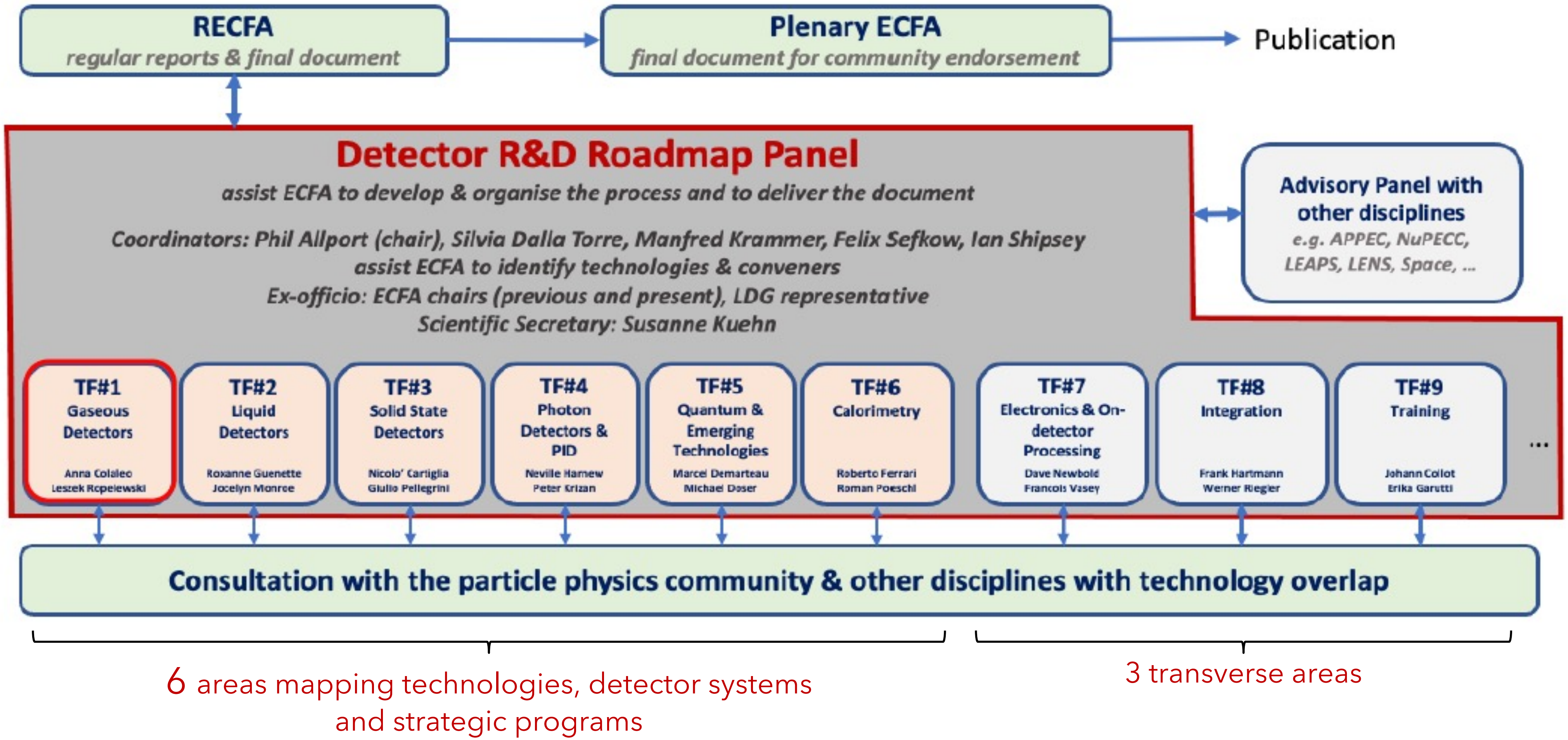
Steps toward a long term detector R&D program

- **2019** — Granada Symposium: WGs and Physics Briefing Book
- **2020** — ESPP update*: HEP strategic projects
- **2021** — ECFA detector R&D roadmap: TF & community workshops
- **2023** — ECFA DRD proposals
- **2024** — DRD MoUs: collaborations active
- **2026-27** — ESPP update

***Deliberation document:** **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. **Collaborative platforms and consortia** must be adequately supported to provide coherence in these R&D activities. The community should define a **global detector R&D roadmap** that should be used to support proposals at the European and national level*

ECFA Detector Roadmap preparation

9 Task Forces organizing wide consultation of the community* through questionnaires and symposia



** Nuclear Physics and AstroParticle (including Gravitational Wave) not considered in the roadmap, but NuPPEC and ApPEC invited to follow the process, also joint ECFA - NuPECC - ApPEC seminars in 2019 - 2022 to develop common instrumental projects*

Report and timeline

- Timescale of future projects as approved by European Lab Director Group (LDG) in “Accelerator R&D Roadmap”

- The Detector R&D Roadmap has identified
  - Set of detector R&D areas which are required if the physics programmes of experiments at these facilities are not to be compromised.
  - Detector R&D Themes (DRDT)
  - General Strategic Recommendations (GSR)

Guiding principle: Project realisation must not be delayed by detectors R&D

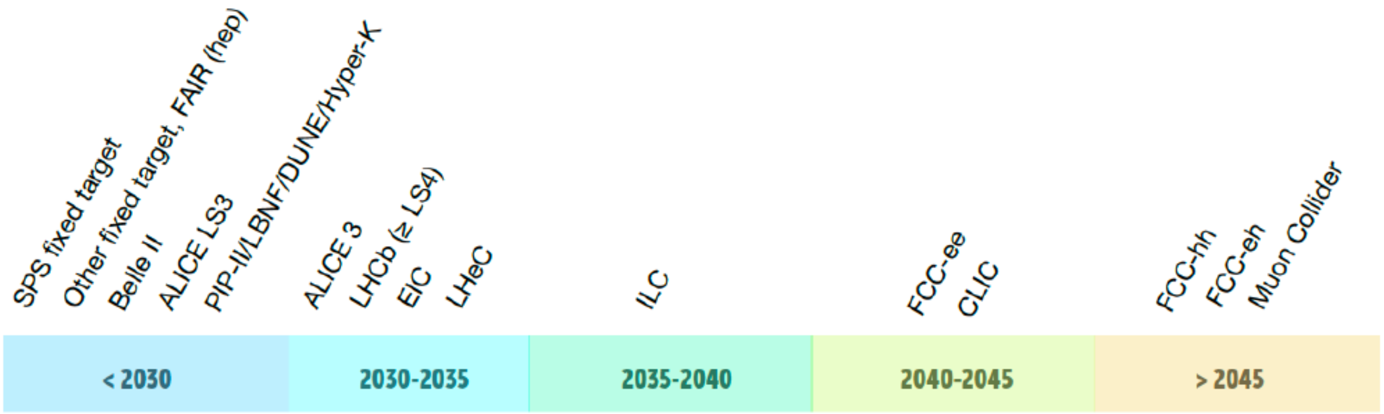


Figure 3: Large Accelerator Based Facility/Experiment Earliest Feasible Start Dates.

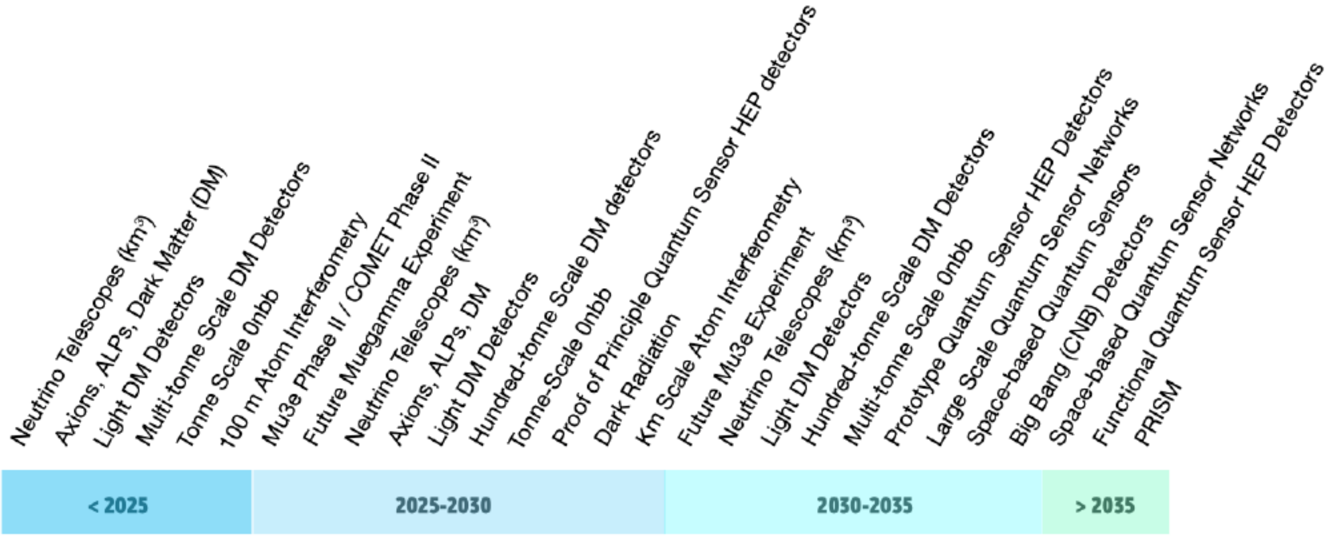
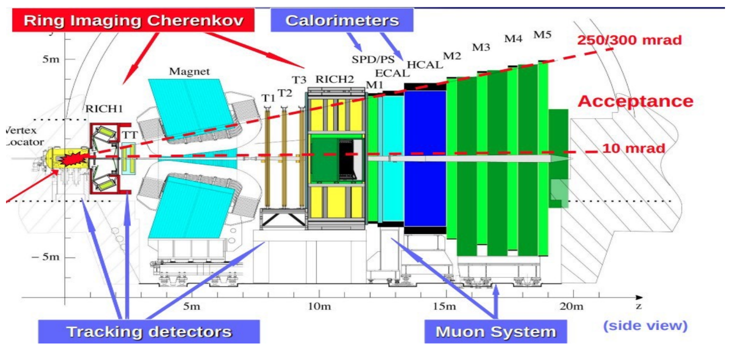


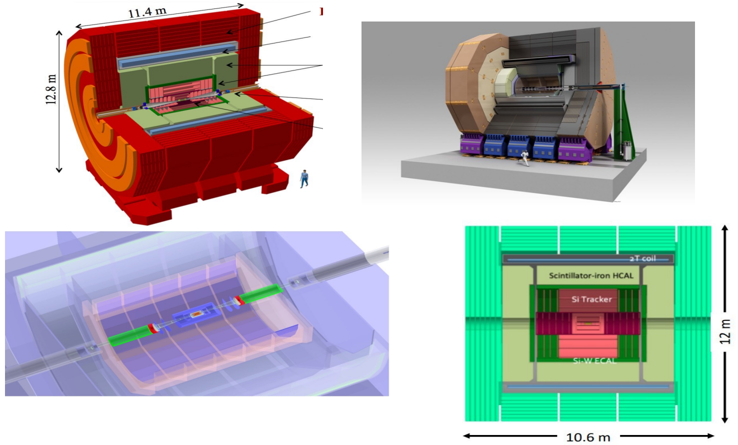
Figure 4: (Representative) Smaller Accelerator and Non-Accelerator Based Experiments Start Dates (*not intended to be at all an exhaustive list*).

Main target projects of Gaseous Detector R&Ds

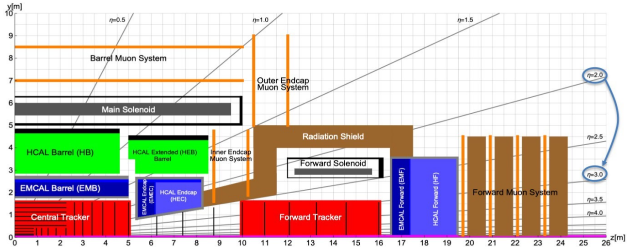
HL-LHC after LS4



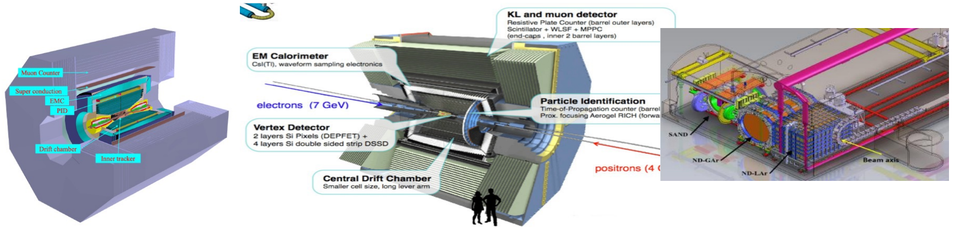
Higgs Factories



Future hadron colliders (FCC-hh/eh colliders)

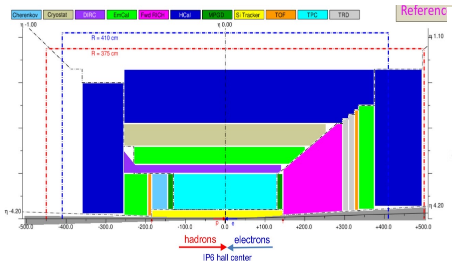


BELLE, DUNE ND, SCTF

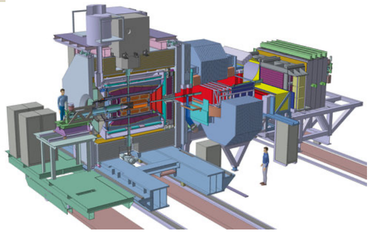


Hadron physics

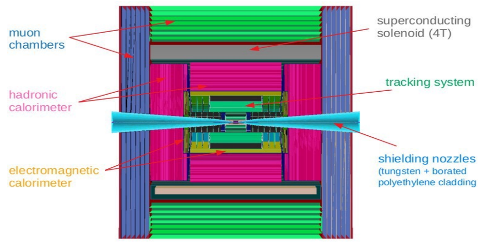
EiC



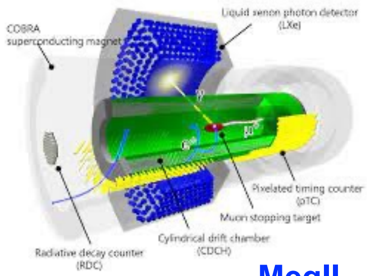
PANDA



Muon Collider

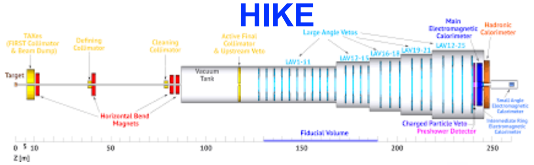


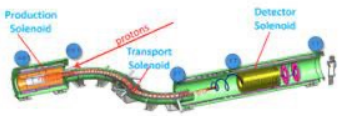
Rare event search, fixed target (LFV, Kaon physics)



MegII

HIKE





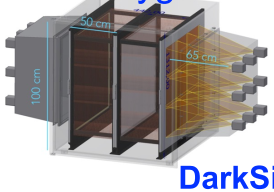
MU2E

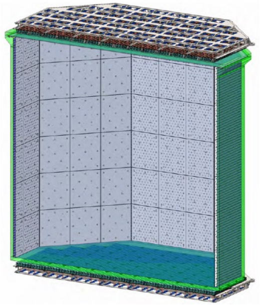
DM, solar axions, ββ0ν-decay, neutrino, nuclear

MIGDAL
Migdal In Galactic Dark mAtter expLoration

Darksphere

Cygnus





DarkSide20 and ARGO

A. Colaleo

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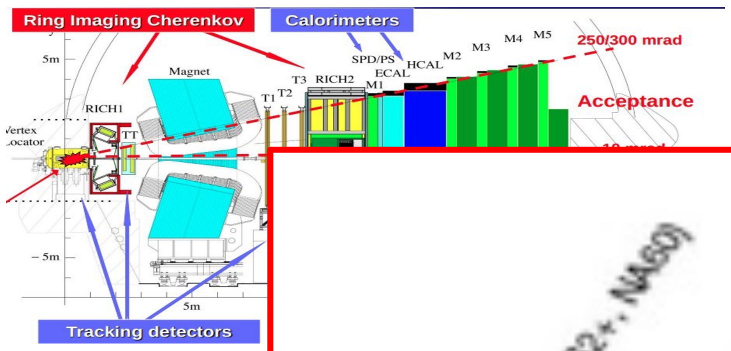

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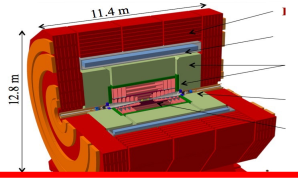

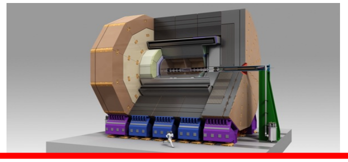

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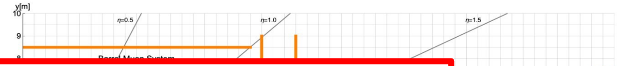

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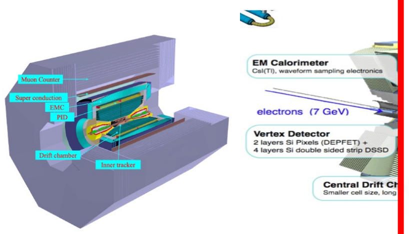

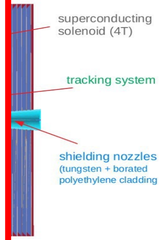

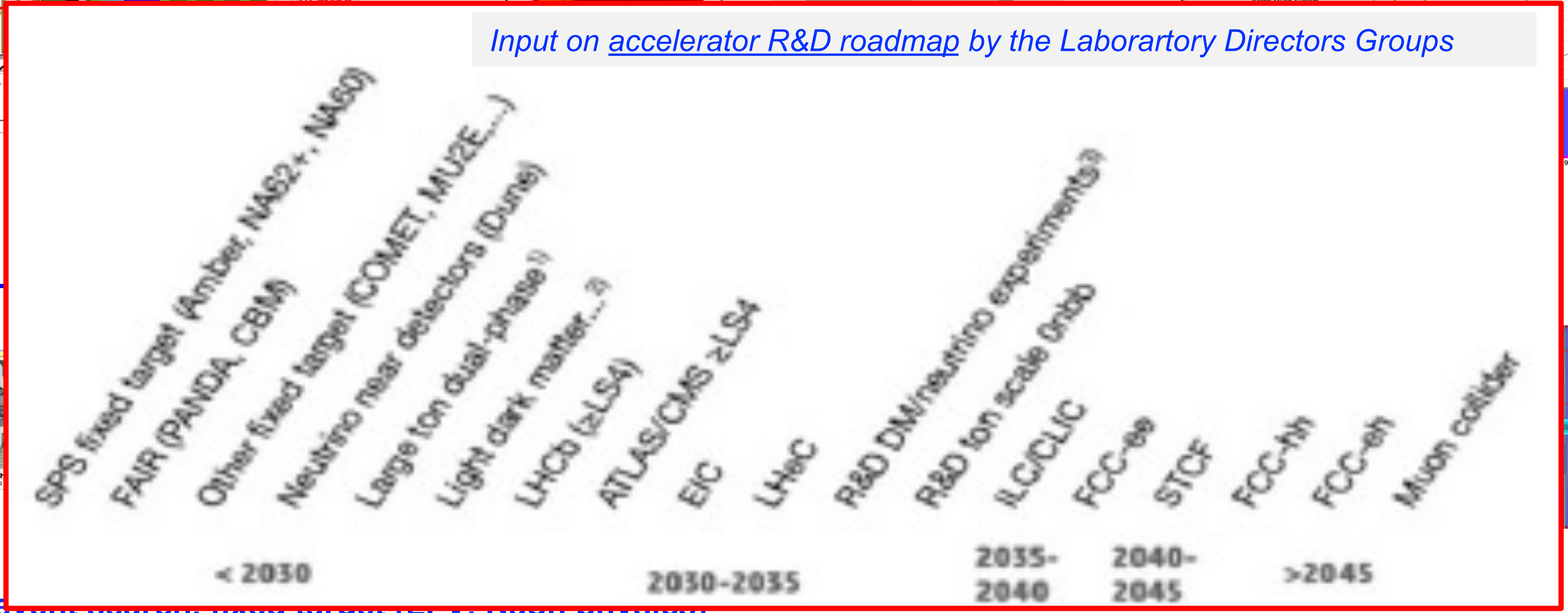

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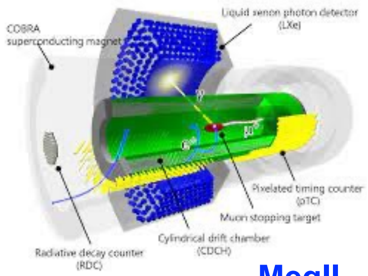

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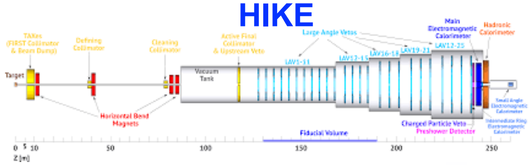

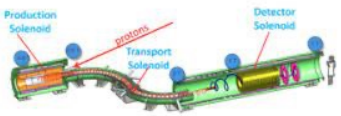

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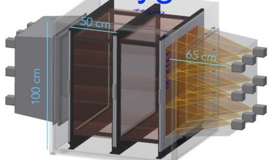
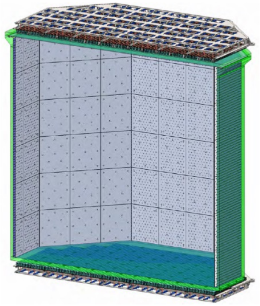




DarkSide20 and ARGO

ECFA Detector R&D Roadmap content

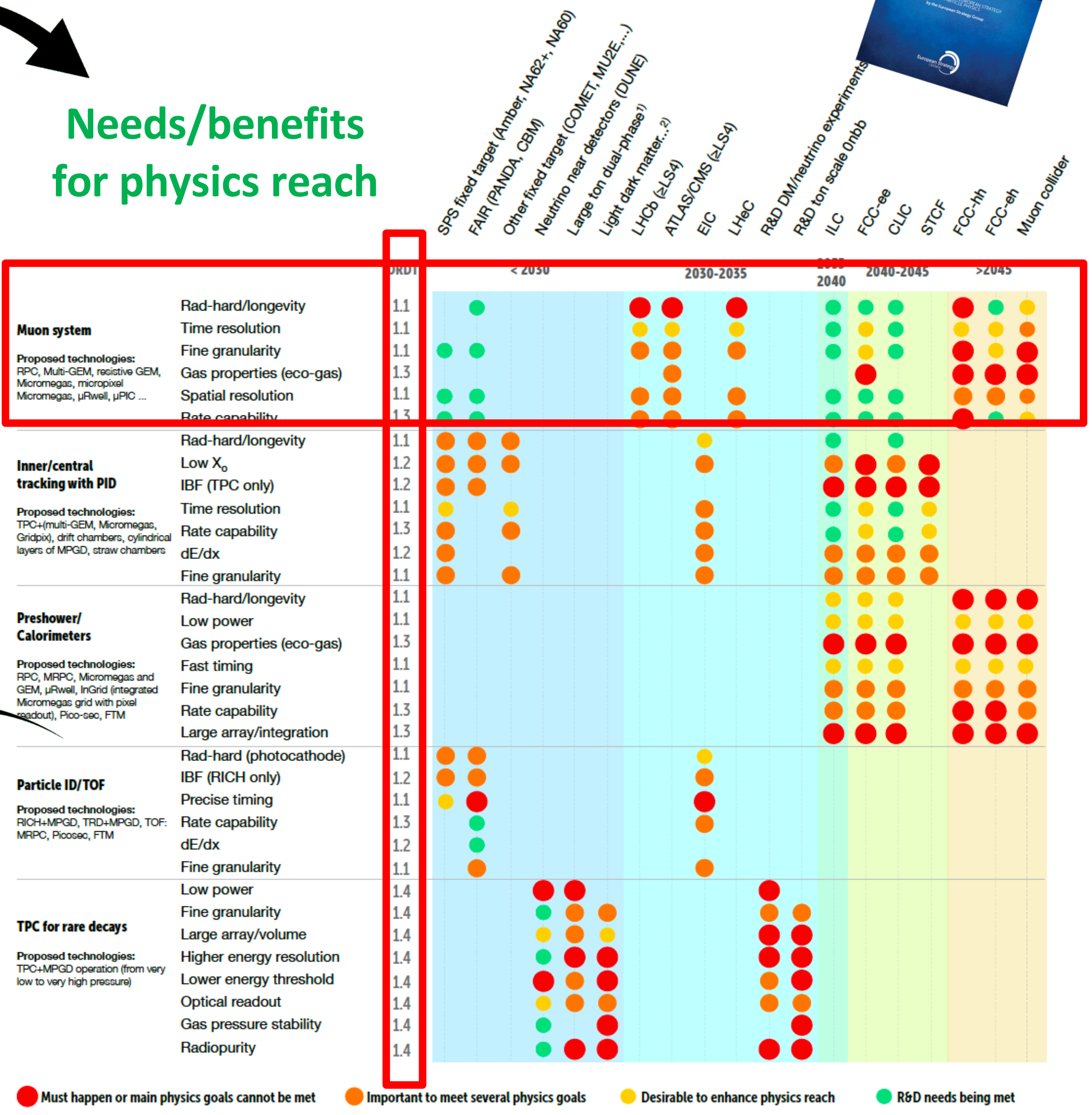
Performance targets and main drivers from facilities

Example: Muon systems

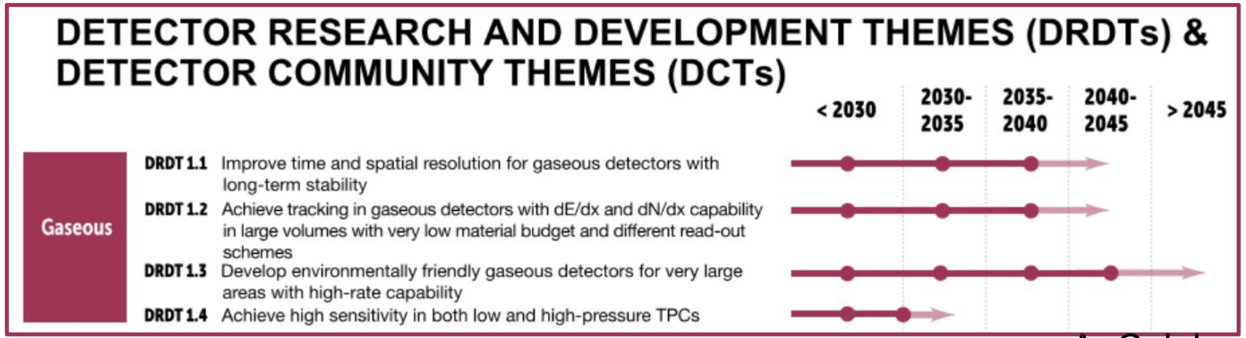
Facility	Technologies	Challenges	Most challenging requirements at the experiment
HL-LHC	RPC, Multi-GEM, resistive-GEM, Micromegas, micro-pixel Micromegas, µ-RWELL, µ-PIC	Ageing and radiation hard, large area, rate capability, space and time resolution, miniaturisation of readout, eco-gases, spark-free, low cost	**(LHCb)**: Max. rate: 900 kHz/cm² Spatial resolution: ~ cm Time resolution: O(ns) Radiation hardness: ~ 2 C/cm² (10 years)
Higgs-EW-Top Factories (ee) (ILC/FCC-ee/CepC/SCTF)	GEM, µ-RWELL, Micromegas, RPC	Stability, low cost, space resolution, large area, eco-gases	**(IDEA):** Max. rate: 10 kHz/cm² Spatial resolution: ~60-80 µm Time resolution: O(ns) Radiation hardness: <100 mC/cm²
Muon collider	Triple-GEM, µ-RWELL, Micromegas, RPC, MRPC	High spatial resolution, fast/precise timing, large area, eco-gases, spark-free	Fluxes: > 2 MHz/cm² ($\theta<8^0$) < 2 kHz/cm² (for $\theta>12^0$) Spatial resolution: ~100µm Time resolution: sub-ns Radiation hardness: < C/cm²
Hadron physics (EIC, AMBER, PANDA/CMB@FAIR, NA60+)	Micromegas, GEM, RPC	High rate capability, good spatial resolution, radiation hard, eco-gases, self-triggered front-end electronics	**(CBM@FAIR):** Max rate: <500 kHz/cm² Spatial resolution: < 1 mm Time resolution: ~ 15 ns Radiation hardness: 10¹³ neq/cm²/year
FCC-hh (100 TeV hadron collider)	GEM, THGEM, µ-RWELL, Micromegas, RPC, FTM	Stability, ageing, large area, low cost, space resolution, eco-gases, spark-free, fast/precise timing	Max. rate 500 Hz/cm² Spatial resolution = 50 µm Angular resolution = 70 µrad (η=0) to get Δp/p≤10% up to 20 TeV/c

Gaseous Detector Example!

Needs/benefits for physics reach

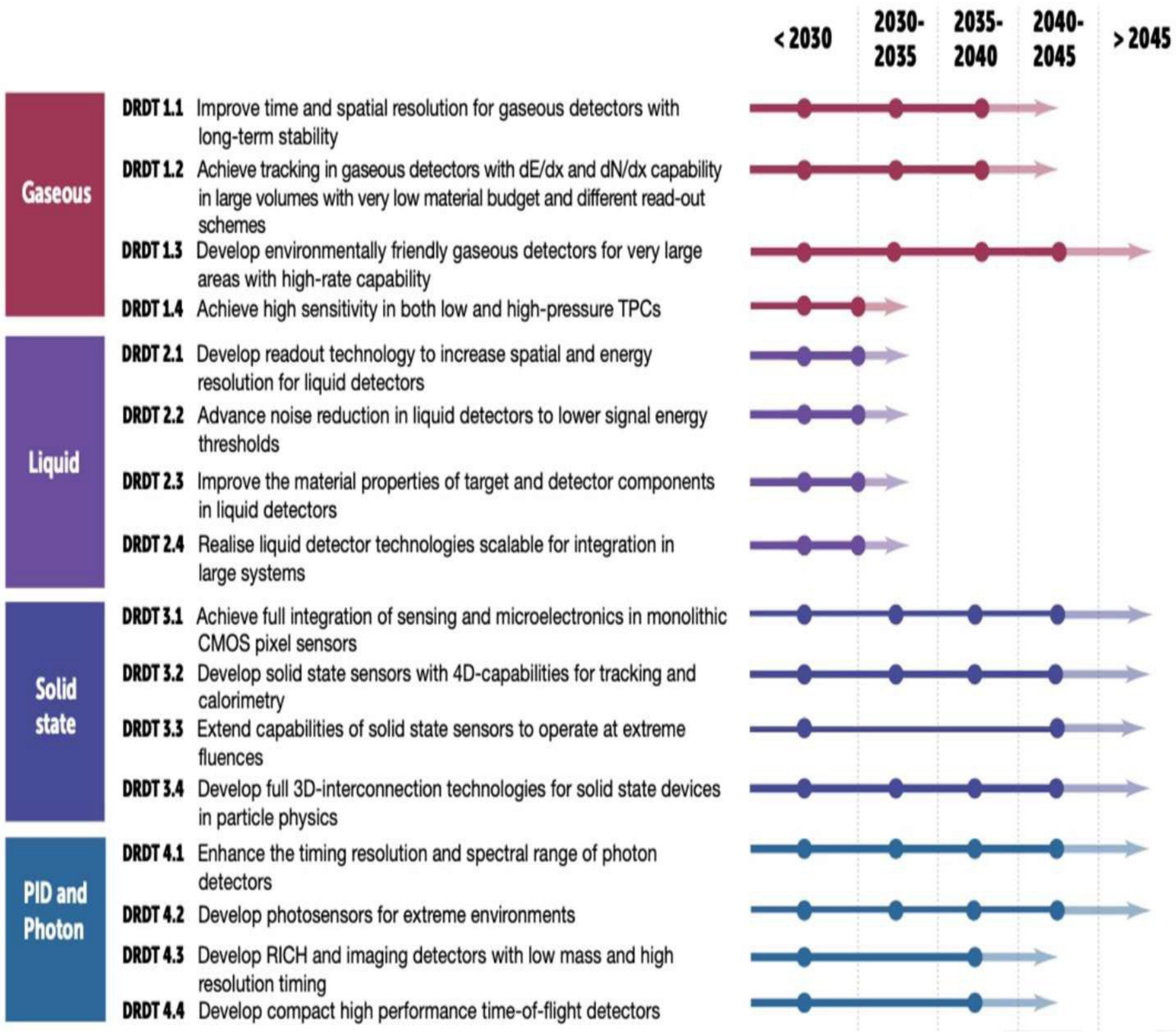


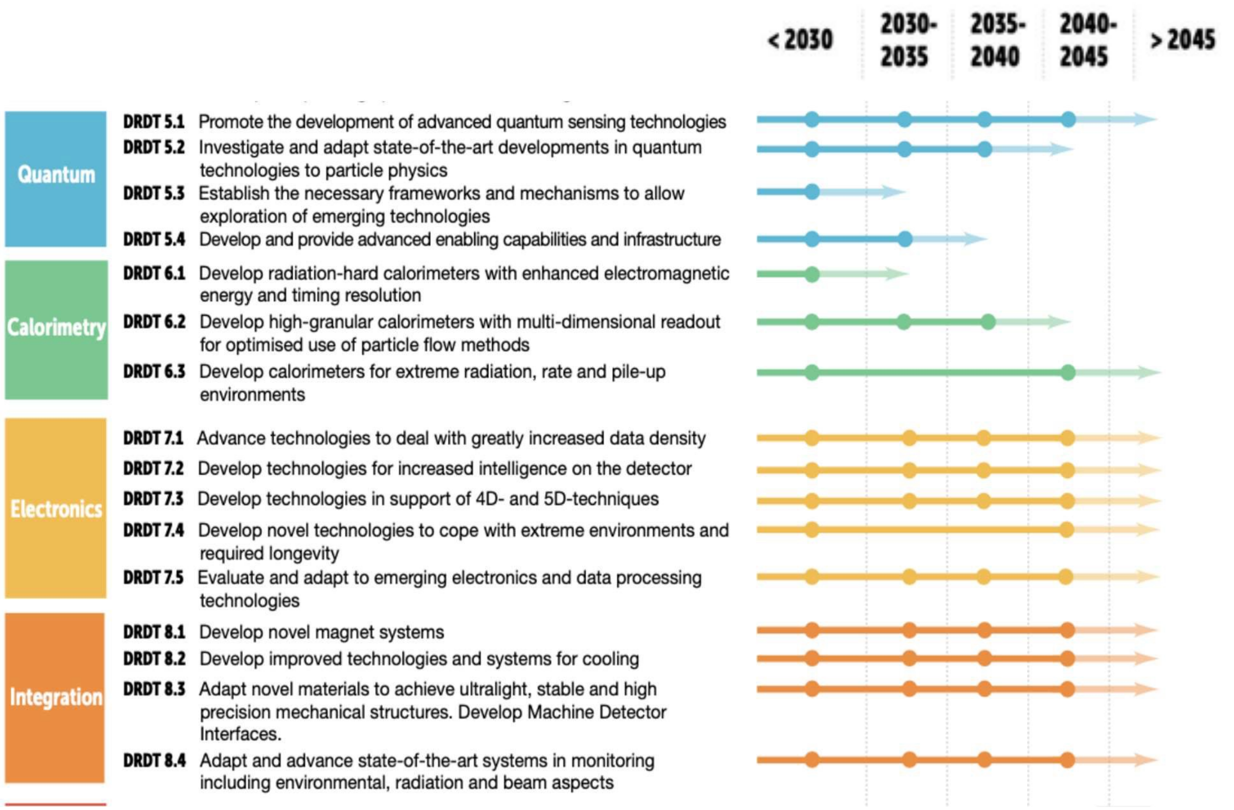
Detector R&D themes



Detector R&D Themes and timelines

For each Task Force, the summarizing timelines are also based on the needs of the future facility/experiments





The faded region acknowledges the typical time needed between the completion of the R&D phase and the readiness of an experiment at a given facility

General Strategic recommendations

In addition to the Detector R&D Themes the following General Strategic Recommendations, also in line with indication of the ESPP:

GSR 1 - Supporting R&D facilities

GSR 2 - Engineering support for detector R&D

GSR 3 - Specific software for instrumentation

GSR 4 - International coordination and organisation of R&D activities

GSR 5 - Distributed R&D activities with centralised facilities

GSR 6 - Establish long-term strategic funding programmes

GSR 7 - Blue-sky R&D

GSR 8 - Attract, nurture, recognise and sustain the careers of R&D experts

GSR 9 - Industrial partnerships

GSR 10 - Open Science

See description in backup slides

CERN Council has mandated ECFA to work out a detailed implementation plan (in close collaboration with the SPC, the funding agencies and the relevant research organisations in Europe and beyond).

General Strategic recommendations

In addition to the Detector R&D Themes the following General Strategic Recommendations, also in line with indication of the ESPP are made under the following headings.

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Implementation started through the setting up of DRD collaboration

"Implementation roadmap"

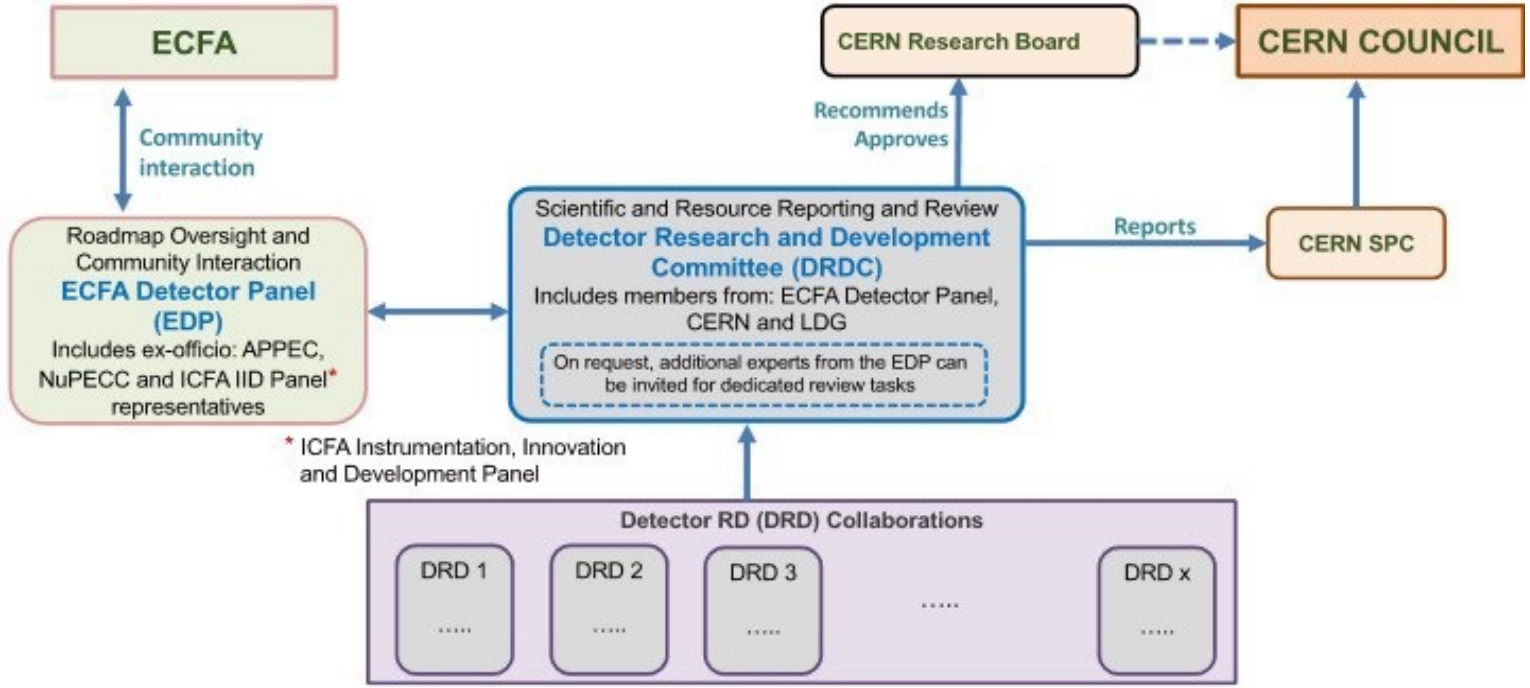
CERN Council has mandated ECFA to work out a detailed implementation plan (in close collaboration with the SPC, the funding agencies and the relevant research organisations in Europe and beyond).

Roadmap Implementation plans

- Approved by CERN SPC and Council in fall 2022 (CERN/SPC/1190 ; CERN/3679)

➔ Form DRD international collaborations, anchored at CERN with a status similar to experiments:

- Two bodies review and evaluate DRD proposals:
  - DRD committee (DRDC) : http://committees.web.cern.ch/drdc established
  - ECFA Detector Panel: https://ecfa-dp.desy.de
- Interaction between DRD collaborations and CERN **only through DRDC***



** Review frequency will de defined by the DRDC, it could typically be every 2 years*

From ECFA Task Forces to DRD Collaborations

	Q4-2022/Q1-2023	Q2-2023	Q3-2023	Q4-2023	2024
DRD TEAM	▪ Formation of the DRD proposal team ▪ Collection of interest from the institutes (survey) ▪ Community Workshops and shaping the direction of RD.	▪ **Writing the proposal** (scientific and organization) that includes conclusion and feedback from the workshop and survey ▪ Collect feedback by institutes in contact with their funding agencies about the best funding schema	**End July –submission of the proposal,** **Collect information about:** ▪ resources needed ▪ resources available ▪ Interest of institutes/FA to contribute to specific tasks	• DRD organization and scientific programs defined. • More feedback from FA and institutes about activities, milestones, deliverable • **Final submission of the proposal**	▪ New structures operational and new R&D programmes underway • Through 2024, collection of MoU signatures with defined contribution areas per institute.
DRDC	▪ DRDC mandate reviewed and agreed with CERN management and EDP	▪ Mechanisms agreed with funding agencies for country specific DRD funding request.	▪ DRDC set, start the review (scientific, milestones, feasibility, financials)	▪ Follow the review revisions and upon green light from DRDC, **CERN research board approves the formation of the collaboration**	• Start monitoring progress in organization

- **Ramp up of new strategic funding and R&D activities 2024-2026**

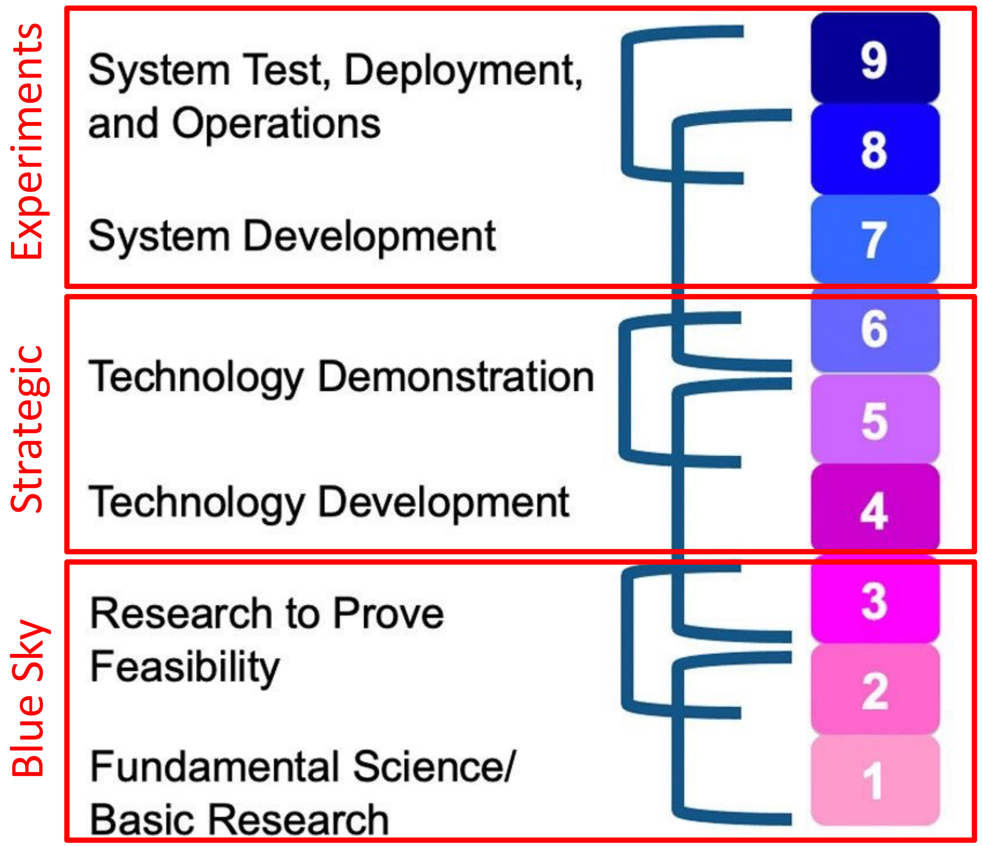
A. Colaleo

Areas of Detector R&D: Strategic vs Blue-Sky

Strategic R&D towards **necessary technologies to build future experiments** and **blue-sky R&D**

- **Strategic R&D projects (Work Packages) a**ddresse the DRDTs in ECFA roadmap by defining suitable deliverables and milestones
  - Technology Readiness Levels (TRL) 3-6
  - Backed up by **strategic funding (remaining in the institutes)**, agreed with funding agencies
- DRD collaborations should also contain a small "**blue-sky**" section (TRL 1-3)
  - Allow new developments to emerge
  - Possibly financed by **common fund** + institute contributions (RD50/51 scheme)

T. Bergauer (DRDC chair)



DRD Proposal content

- **Scientific organization and programme**
    - Scientific organization (different for each DRD)
    - Breakdown in **Work Packages (WP)** with Deliverables and Milestones to reach the research goals
    - Interplay with other DRDs for the shared developments of similar components or applications but with different specifications or operating conditions
- Current planning is focused on first R&D period of 3 years with prospect for longer term
- **Human resources and funding** at the level of WPs to demonstrate that programs can reasonably be achieved
    - **in public document**
        - list of institute wishes to contribute
        - estimate of human and funding resources required for each WP
        - sums of the available/additional expected resources for each WP
        - management, committees and scientific working group organization
    - **confidential at the level of institutes**
        - human and funding resources expected to be available/prolongated
        - new resources being requested to achieve the strategic scope
        - Initial money matrix of contribution for Funding Agency

The DRD1 Proposal

Great DRD1 community teamwork, allowed to shape the "legacy document" for the gaseous detectors domain for decades to come

I Executive summary (35 pages)

- Introduction
- Scientific organization of the DRD1 Collaboration
- Collaboration Organization
- Resources and Infrastructure
- Partners and Their Fields of Contributions
- Steps towards the formation of DRD1 Collaboration
- DRD1 Implementation Team

II Scientific Proposal and R&D Framework (102 pages)

- Research topics and Work plan
  (8 sections, one per Working Group)

CERN

DRD1

DRD1 EXTENDED R&D PROPOSAL
Development of Gaseous Detectors Technologies
v1.5

Abstract

This document, realized in the framework of the newly established Gaseous Detector R&D Collaboration (DRD1), presents a comprehensive overview of the current state-of-the-art and the challenges related to various gaseous detector concepts and technologies. It is divided into two key sections.

The first section, titled "Executive summary", offers a broad perspective on the collaborative scientific organization, characterized by the presence of eight Working Groups (WGs), which serve as the cornerstone for our forthcoming scientific endeavours. This section also contains a detailed inventory of R&D tasks structured into distinct Work Packages (WPs), in alignment with strategic R&D programs that funding agencies may consider supporting. Furthermore, it underlines the critical infrastructures and tools essential for advancing us towards our technological objectives, as outlined in the ECFA R&D roadmap.

The second section, titled "Scientific Proposal and R&D Framework," delves deeply into the research work and plans. Each chapter in this section provides a detailed exploration of the activities planned by the WGs, underscoring their pivotal role in shaping our future scientific pursuits. This DRD1 proposal reinforces our unwavering commitment to a collaborative research program that will span the next three years.

On-line version: https://cernbox.cern.ch/s/PP7BZroM3NYS2Vh
DRD1 Website: https://drd1.web.cern.ch/

Geneva, Switzerland
January 9, 2024

https://cds.cern.ch/record/2885937

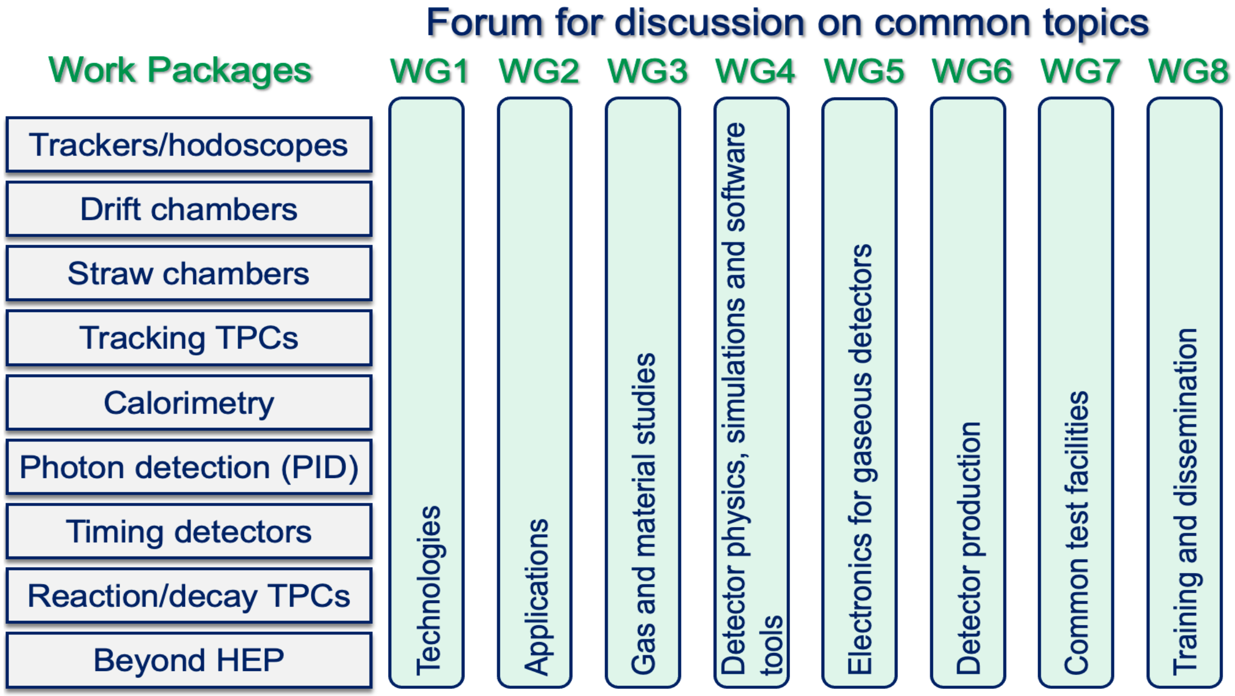
Approved by CERN Reasearch board on 6th December!

DRD1 Collaboration implementation

R&D FRAMEWORK

- **Collaboration type: Community-driven** with the **R&D environment:** common infrastructures (labs, workshops), common R&D tools (software and electronics), cross-disciplinary exchanges

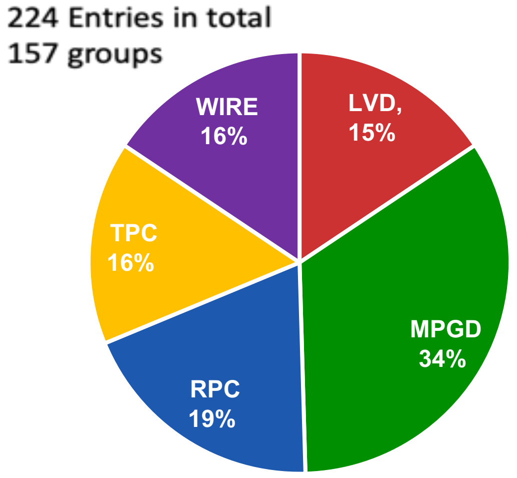
- **Scientific organization in 8 Working Groups:** forum of discussion, provides a platform for sharing knowledge, expertise, and efforts



R&D PROJECTS

- **9 Work Packages (WP):** long-term project addressing strategic R&D goals, outlined in ECFA Roadmap, with dedicated funding lines.

- **Common Projects (CP):** short-term blue-sky R&D or common tool development with limited time and resources, supported by the Collaboration Common funds.



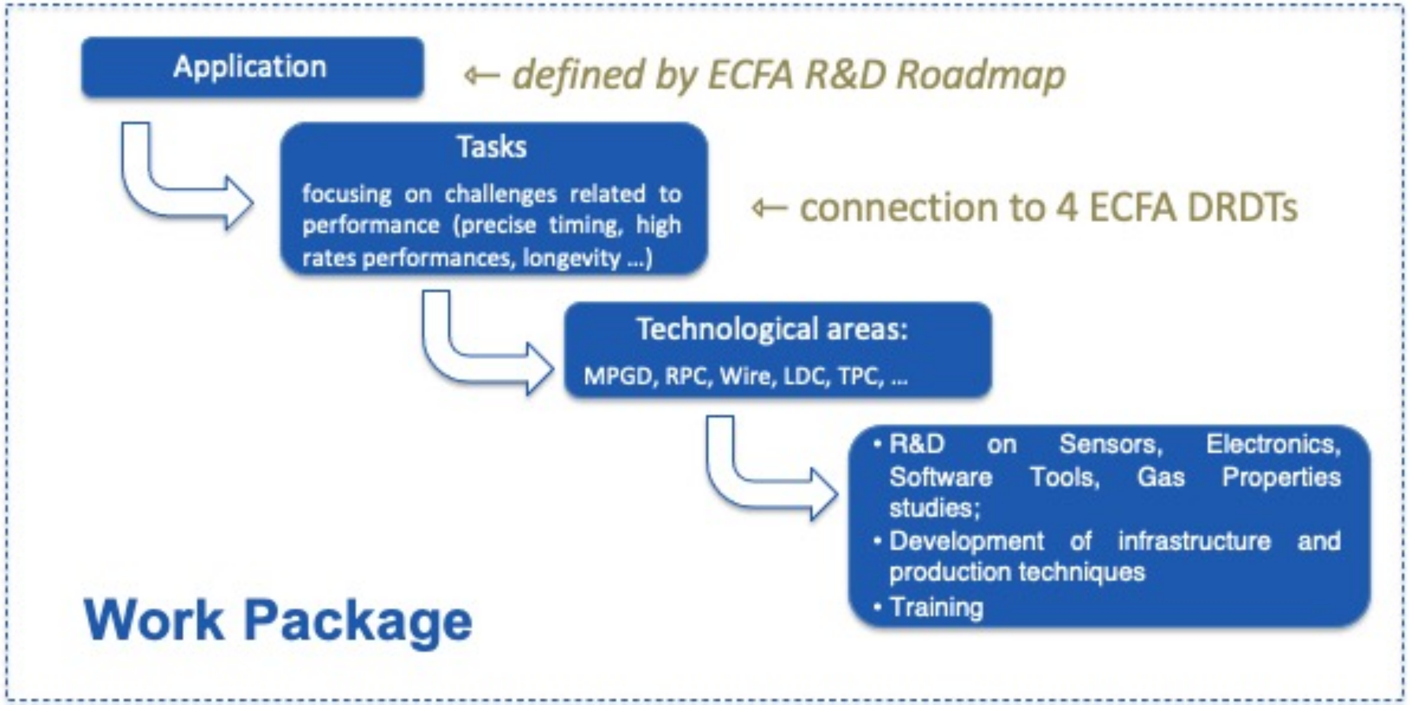
>700 participants from 157 institutes in 33 countries

+ 4 Industrial, Semi-Industrial partners and Research Foundations

A. Colaleo

DRD1 Strategic R&D = Work Package

Group together institutes research interests around **Applications** with a focus on a **specific task(s)** devoted to a specific challenge (Detector R&D theme), typically related to specific **Detector Technologies** and to the development of **specific tool or infrastructure. Dedicated funding line are envisage for each WP***



- WP1: trackers/hodoscopes
- WP2: Drift Chambers
- WP3: Straw Chambers
- WP4: Tracking TPCs
- WP5: Calorimetry
- WP6: Photon detectors
- WP7: Timing detectors
- WP8: Reaction/Decay TPCs
- WP9: Beyond HEP

- Detailed documents describing each WP, including scientific goals, deliverables, milestones, and resources, is currently under preparation by the interested institutions.
- Cumulative information for each WP has been preliminary reported in the proposal.
- Institutes will have entered into negotiations with their FA to ensure that assumptions on additional strategic support can be confirmed in future MoU Annexes agreements.

Muon system @ future colliders

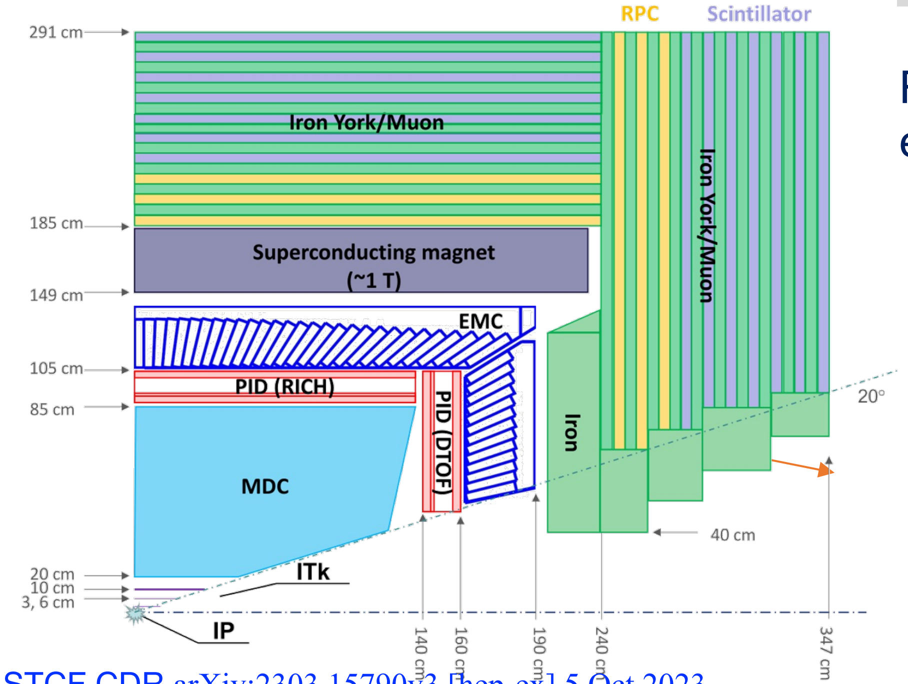
- Large area coverage, cost effective, high efficiency@ high background and high radiation environment
- Trigger, tracking and time-tagging particles from rare-event decays and long-lived particles over large detection volumes.

Challenges requirements at future facilities

3-6 Muon Stations: large single detector area
Space resolution, σx, of O(100)μm
Efficiency ~ 98-99%
Time resolution: <1 ns: trigger/BX-id, background rejection
Rate: few kHz/cm2 – MHz/cm2
Low GWP gas mixture

Technologies

- RPC -30 × 30 mm^2 cells @CLD/CEPC
- MPGD/RPC@ Muon collider/SCTF
- μRWell 50x50 cm^2 (tiles) also for pre-shower @FCC



STCF CDR arXiv:2303.15790v3 [hep-ex] 5 Oct 2023

Muon Detector @ SCTF

R&D on MUD performance in a high rate and high radiation environment to explore the dependence of muon-ID abilities with a high background level.

MUD: **RPC 3 layers** (+ 7 scint. layers)

- Rate up to 100 kHz/channel;
- Module size > 0.5 m^2 /length > 1 m
- Electronic suitable for both RPC and SiPM signal processing, low power consumption, high efficiency, radiation resistance
- Precision timing (< 100 ps);

DRD1 WP1: tracker/hodoscope

Challenges

- Extend the state-of-the-art rate capability by at least one order of magnitude
  - Improve time resolution ~sub-ns for RPC /O(ns) for MPGD
  - Enable reliable and efficient operation with suitable low-GWP gas mixtures
  - Establish large-scale serial production and cost reduction procedures
- ➢ ECFA R&D themes are all covered

Goals

- Develop and validation of RPC and MPGD-based prototypes with advantage solutions for extensive surface coverage and optimized for medium-high flow rates with associated fine granularity readout, precise tracking and timing
- Develop a new frontend and readout systems that push the detector boundaries in terms of timing, radiation resistance, and performance

One project include different technologies

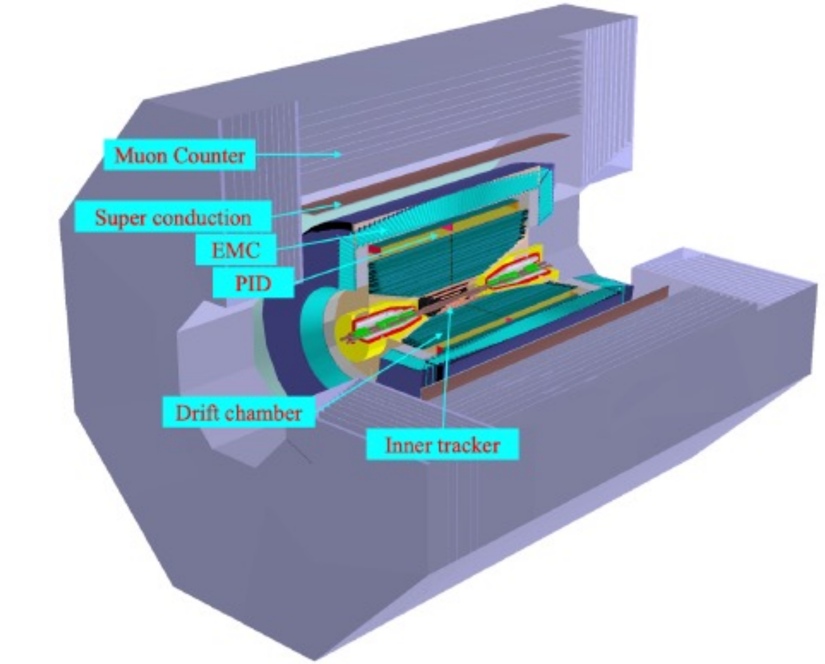
➔ collaborative effort

#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Milestones/Deliverable 12M	Milestones/Deliverable 24M	Milestones/Deliverable 36M	Institutes
T1	New RPC structures	- Develop low-cost resistive layers - Increase rate capability from 10 kHz to 1 MHz per cm^2 - Improve timing resolution from sub-ns to ps levels	WG1, WG2, WG3, WG4, WG5, WG6, WG7, WG8	1.1, 1.2, 1.3	**M1.1** **Review of Detector Prototypes:** examining the current status and future prospects of innovative resistive materials, novel structures, and challenges in hybridizing Resistive Plate Chambers (RPC) and Micro-Pattern Gas Detectors (MPGD). This evaluation includes compiling of a comprehensive report highlighting comparative performance, along with the respective advantages and disadvantages of available technologies. **[T1, T2, T5, T6, T7, T8]** **M1.2** **Review of the status of the art of ASICs and DAQ systems,** and definition of the requirements for next-generation large area muon systems. **[T3, T4]**	**M2.1** **Detector Prototypes Enhancement:** building upon the insights from M1.1. Proof of rate capability above 100 kHz/cm^2, assessing the status and potential improvements of RPC and MPGD detectors, informed by feedback from the previous phase. **[T1, T2, T5, T6, T7, T8]** **M2.2** **Design and Simulation studies of new ASIC:** Building blocks for MPGD and RPC and technical note(s) about the chips expected performance. **[T3]** **M2.3** **Design of a novel readout system for Gaseous Detectors:** assessment of performance achievements based on DAQ modelling. **[T4]**	**D1** **Large area RPC and MPGD prototypes:** design, construction, and test of RPC and MPGD-based prototypes **[T1, T2]** with advanced solutions for extensive surface coverage **[T6]**, optimized for medium-high flow rates (range tens kHz/cm^2 – few MHz/cm^2), precise tracking (100 µm) and timing (ns and sub-ns time resolution). This includes considerations for the compatibility of eco-friendly gases. **[T5, T7]** **D2** **New frontend and DAQ systems:** completion of the innovative ASICs' final design; compilation of comprehensive production documentation; if applicable, initiation of the engineering run for the first chip, should it be in an advanced stage **[T3]**. DAQ system prototyping for gaseous detectors, aiming to push the boundaries in terms of timing, radiation resistance, multi-channel high rate acquisition and performance, for large systems **[T4]**.	INFN-BA, UniBA, PoliBA, INFN-LNF, INFN-RM2, UniRomaTOV, INFN-BO, INFN-FE, INFN-NA, INFN-RM3, INFN-TO, IRFU/CEA, IFIN-HH, Istinye U, CERN, CIEMAT, LMU, WIS, Wigner, U Kobe, U Cambridge, USTC, U Oviedo, UNSTPB, UTransilvania, VUB and UGent, U Genève, U Hong Kong, MPP, BNL, FIT, JLab, MSU, Tufts, UC Irvine, U Florida, U Massachusetts, Amherst, U Michigan, UW–Madison, IGPC
T2	New Resistive MPGD Structures	- Stable up to gains of $\mathcal{O}(10^6)$ - High gain in a single multiplication stage - High rate capability (1 MHz/cm^2 and beyond) - High tracking performance (100 μm) - Development of low-granularity 2D-readout with high-tracking performance						
T3	New Front-end electronics	- New front-end - 1 fC threshold - High-sensitivity electronics to help achieve stable and efficient operation up to ≈MHz/cm^2 - High granularity detector capability						
T4	Optimization of scalable multichannel readout systems	- Front-end link concentrator to a powerful FPGA with possibilities of triggering and ≈20 GBit/s to DAQ for high-rate experiment -Develop robust, compact, and low power DAQ for low-rate experiment						
T5	Eco-friendly gases	- Guarantee long-term operation - Explore compatibility and optimized operation with low-GWP gases						
T6	Manufacturing	- Technological transfer for cost-effective production of high-quality, high-performance large area resistive MPGD. - Reliable production of homogeneous resistive large DLC foils with the CERN-INFN sputtering machine						
T7	Longevity on large detector areas	- Study discharge rate and the impact of irradiation and transported charge (up to C/cm^2) - Study the impact of low-GWP gases and new materials on high radiation hardness environment						
T8	New Hybrid-multi-technologies Structures	- Development of new ideas of detector structures and hybridization						

Inner Tracking system @ SCTF

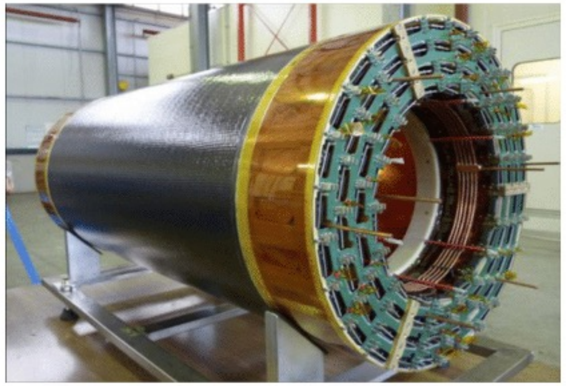
Main tasks of the STCF inner tracker are to detect particle hits of charged particles, especially those with momentum <100 MeV/c, detect secondary vertices from the decays of short-lived particles, and to facilitate the reconstruction of charged particle tracks with the Drift Chamber at high particle flux@10^{35}

STCF CDR arXiv:2303.15790v3 [hep-ex] 5 Oct 2023

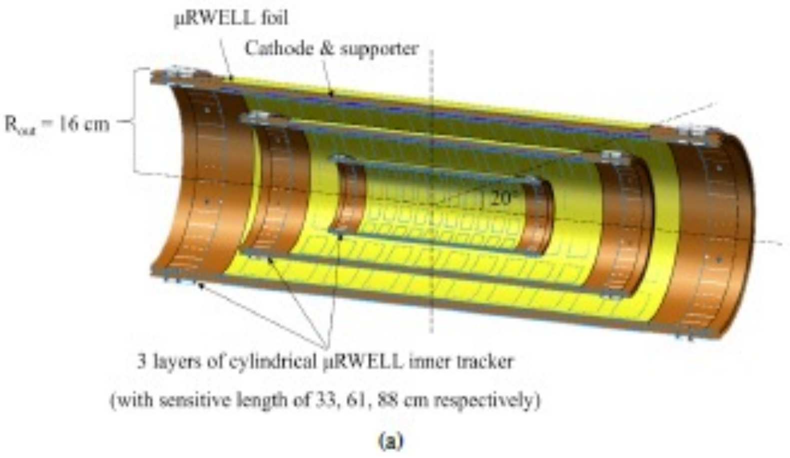


Cylindrical µRWELL:

- Modular roof-tile detector
- 3 layers: inner radii of 60 mm, 110 mm and 160 mm,



Flexible RWELL +readout PCB



Cylindrical MPGDs has been also developed & used: GEMs (KLOE, BESIII), Micromegas (CLAS12)

Specification	Requirement
Material Budget	0.25% X0 for each detector layer
Spatial Resolution	Single-hit spatial resolution better than 100 µm in the r − ϕ direction
Detector Occupancy	Not exceeding a few percent

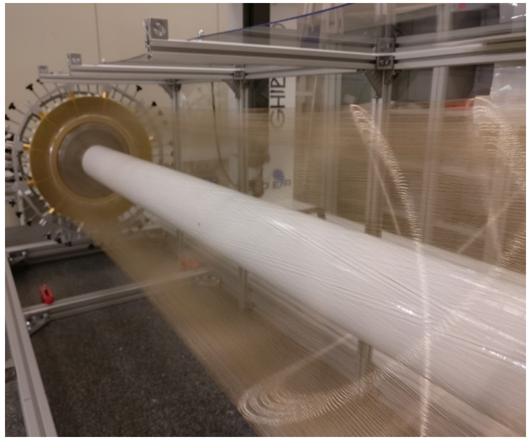
- **The TPC is also an attractive option:**
  - ➢ More hits per track;
  - ➢ More reliable dE/dx – measurement;

✓ TPC capability to reconstruct the tracks under investigation with full simulation.

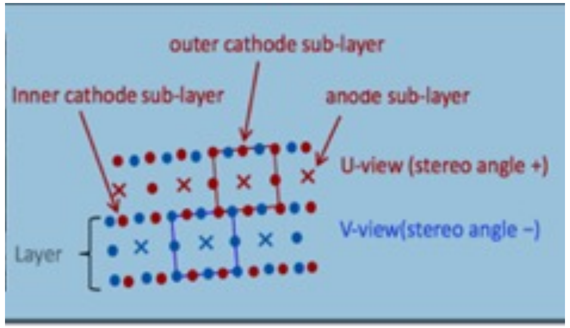
A. Colaleo

Drift chambers@ future collider

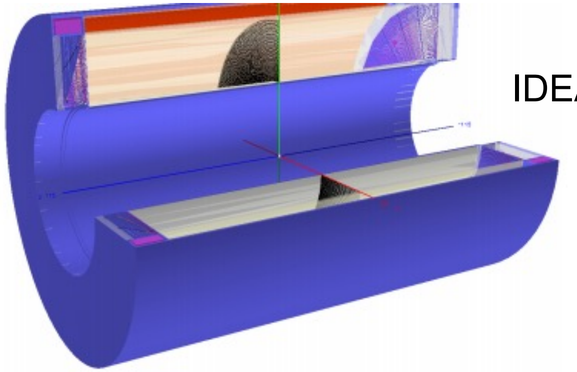
FCC-ee and CEPC Drift Chamber: ultra-light drift chamber (DC) equipped with cluster counting readout techniques.
high transparency in terms of multiple scattering to the momentum measurement and the **very precise PID** capabilities.



Inspired by MEGII DC



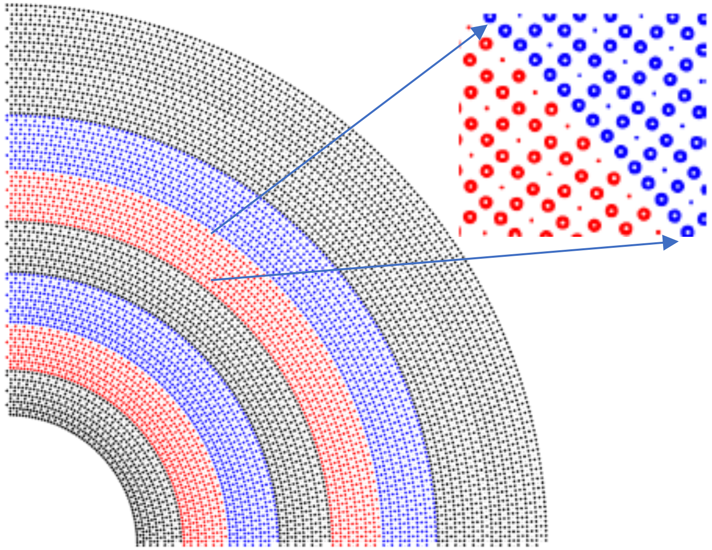
- The dE/dx < 3% σ(pT)/pT ≈ 0.40% at 100 GeV/c with cluster counting,
- Large number of channels,
- gas gains ~**5×10⁵**
- long drift times (slow drift velocity),
- trigger rate (Z_0-pole at FCC-ee) = 25 kHz/cm²



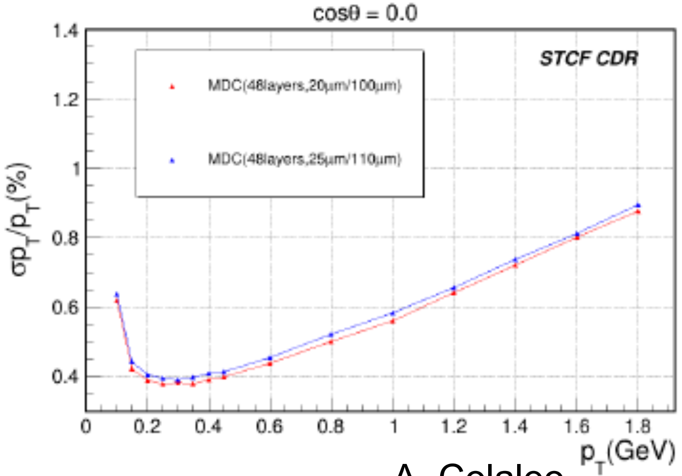
- GAS: 90% He – 10% iC_4H_{10}
- Radius 0.35 – 2.00 m
- Total thickness: 1.6% of X_0 at 90°

Main Drift Chamber @ SCTF

STCF CDR arXiv:2303.15790v3 [hep-ex] 5 Oct 2023



Sense wire : 20μm (W), 0.5μm (Au)
Field wire: 100μm (Al), 0.5μm (Au)



A. Colaleo

Configuration inspired by BESIII and Belle II

- 48 layers of drift cells
- Radius: 200 mm - 850 mm.
- He/C3H8 (60/40) gas mixture

Performance

- momentum resolution: σpT /pT < 0.5%@1 GeV/c.
- dE/dx resolution ~ 6% can be achieved

DRD1 WP2: Drift Chambers

Challenges:

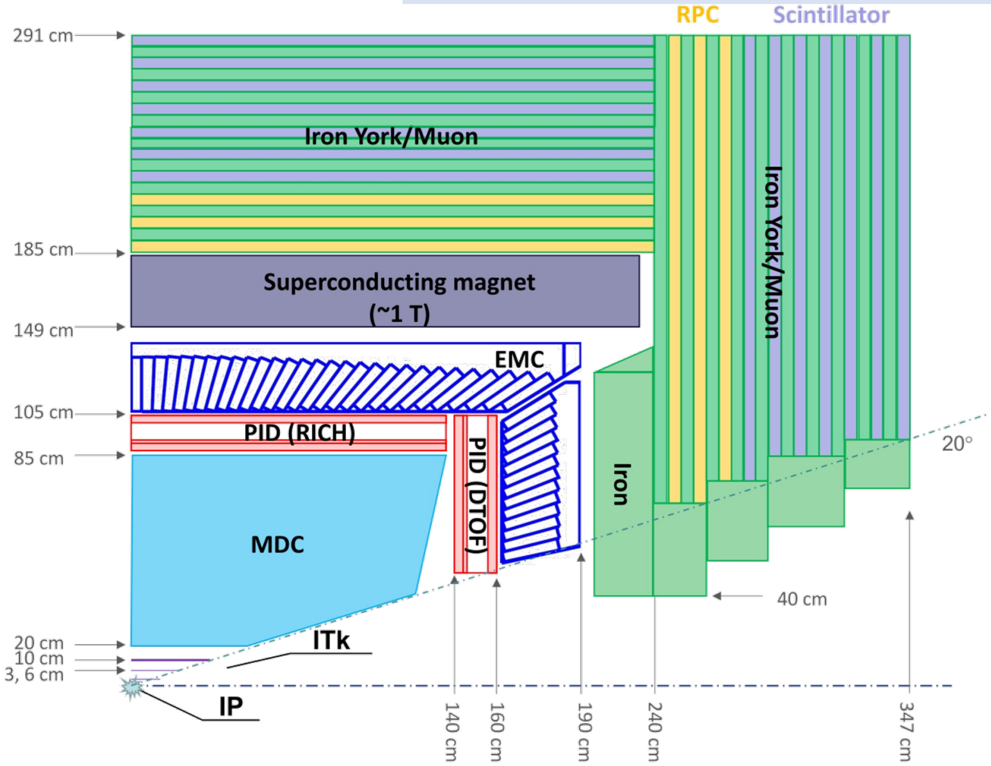
- Development of front-end ASIC for cluster counting/a scalable multichannel DAQ board
- New wiring procedures and new endplate concepts
- Consolidation of new wire materials and wire metal coating / ageing phenomena
- Increase of the rate capability and granularity
- Optimization of gas mixing, recuperation, purification and recirculation systems

Goals:

- Achieving efficient cluster counting and cluster timing performances by using FPGA based architecture
- Completion of a cylindrical sector of a full length drift chamber prototype aimed at testing all mechanical properties.
- Performance of K-π separation in the momentum range from 2 to 30 GeV/c based on a scalable front-end/digitizer/DAQ electronics chain for cluster counting.

#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Milestones/Deliverable			Institutes
					12M	24M	36M	
T1	Front-end ASIC for cluster counting	- High bandwidth - High gain - Low power - Low mass	WG1, WG2, WG3, WG4, WG5, WG7	1.1, 1.2, 1.3	**M1.1** **At least 80% efficiency** of the cluster counting/timing with resolution in dn/dx smaller than 30% for a single hit. [T1] **M1.2** **Design of the frontend ASIC** optimized for cluster counting. [T1]	**M2.1** **Completion of the mechanical design** of the full length drift chamber prototype. [T3] **M2.2** **Validation of the tension recovery scheme.** [T3]	**D1** **Realization of a scalable front-end/digitizer/DAQ** electronics chain for cluster counting/timing. [T1-T2] **D2** **Performance of *K*-*π* separation** in the momentum range from 2 to 30 GeV/*c*. [T1-T2]	CNRS-IN2P3/IJCLab, INFN-BA, UniBA, PoliBA, INFN-LE, INFN-RM1, U Massachusetts, Amherst, U Michigan, UC Irvine, Tufts, BNL, FIT, U Florida , UW–Madison, U Nankay, U Tsinghua, IHEP CAS, U Wuhan, U Jilin, USTC, IMP-CAS, Bose
T2	Scalable multichannel DAQ board	- High sampling rate - Dead-time-less - DSP and filtering - Event time stamping - Track triggering						
T3	Mechanics: wiring procedures, new end-plate concepts	- Feed-through-less wiring procedures - More transparent end-plates ($X < 5\% X_0$) - Transverse geometry						
T4	High rate High granularity	- Smaller cell size and shorter drift time - Higher field-to-sense ratio						
T5	New wire materials and wire metal coating	- Electrostatic stability - High YTS - Low mass, low Z - High conductivity - Low ageing						
T6	Study ageing phenomena for new wire types	- Establish charge-collection limits for carbon wires as field and sense wires						
T7	Optimize gas mixing, recuperation, purification and recirculation systems	- Use non-flammable gases - Keep high quenching power - Keep low-Z - Increase radiation length - Operate at high ionization density						

PID and gaseous Photon detector@ STCF



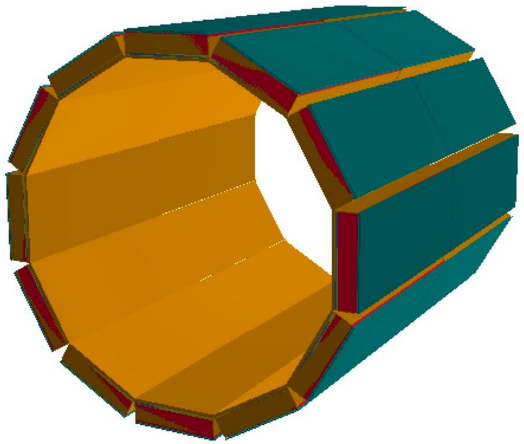
Interplay with DRD4

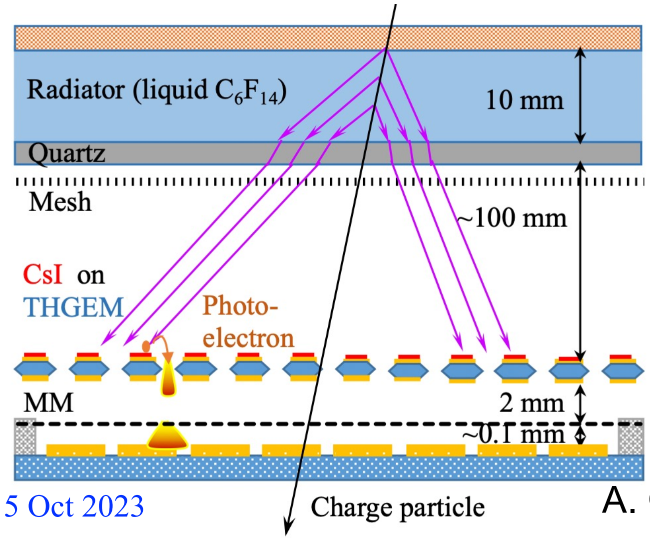
STCF PID Barrel Detector:

- efficiency > 97%, mis-id π/K < 2% (p ≤ 2.0 GeV/c)
- Thickness: ~20 cm
- Material budget < 0.5 X_0
- Expected Res: 2.5 mrad

Large Area Gaseous UV-Photon Detector: MPGD based RICH

- Rate: <5kHz/cm^2
- C_6F_{14} as radiator (10mm)
- THGEM with CsI-coated photocathode+MM: 10^5 gain, IBF: 10^{-3}
- Pad:0.5x0.5cm^2
- Number of readout channel: 10^6





R&D:

- Verify RICH detector performance and PID capabilities
- Alternative radiators (photonic crystals, silicon aerogels)
- Studies on CsI quantum efficiency, working gases, extraction fields
- High amplification, low ion backflow, expandability

STCF CDR arXiv:2303.15790v3 [hep-ex] 5 Oct 2023

A. Colaleo

DRD1 WP6: Photon detectors

Interplay with DRD4

- Increase photocathode efficiency, robust photoconverters
  - Longevity improvement
  - Enhance Quantum Efficiency (QE)
  - Extend response to the visible range
  - Rad-hardness up to 10^{11} neq/cm²
- Ion Backflow (IBF) suppression/discharge protection
  - Reduce IBF down to 10^{-4} and below
  - Achieve stable, high gain operation up to 10^5-10^6
  - Enable operation in magnetic fields
- Gas Studies
  - Develop environmentally friendly gas radiators
  - Explore alternatives to CF_4
- Enhance Front-End Electronics (FEE)
  - Ensure stability at high input capacitance
  - Minimize noise levels
  - Provide a large dynamic range
- Strengthen Mechanical Aspects:
  - Enable high-pressure operation, Improve gas tightness

#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Milestones/Deliverable			Institutes
					12M	24M	36M	
T1	Development of robust UV photoconverters for gaseous photon detectors	- Robustness against accumulated charge dose: < 20% deterioration of quantum efficiency for 100 mC/cm^2	WG1, WG2, WG3, WG4, WG5, WG6, WG7	1.1, 1.2, 1.3	**M1** **Design and production of small-size photon detector prototypes**, e.g. THGEM + Micromegas equipped with hydrogenated nanodiamond photocathode **[T1]**, PICOSEC Micromegas equipped with novel photocathodes **[T6]**, Double Micromegas photon detectors **[T3]**, etc. to test the proposed technological improvements.	**M2** Results of simulations and measurements of IBF suppression **[T7, T3]**, photocathode robustness **[T1]**, a test of small-size prototypes **[T2, T5]** and new readout development, with low noise at low input capacitance **[T9]**.	**D1** **Demonstrator prototypes** for Large area Double Micromegas **[T8]**, Space resolution < 1 mm **[T5]**, Time resolution < 200 ps **[T6]**, IBF < 1%. **Test bench** for visible sensitive photocathodes studies **[T4]**. **D2** **Report** on novel robust photocathode performance **[T1]** and PDE achievements **[T2]**. **D3** **New ASIC chip** prototype integration **[T9]**.	AUTH, USTC, NISER Bhubaneswar, CERN, WIS, INFN-PD, DFA-UNIPD, INFN-TS, HIP, U Aveiro, MSU, TUM
T2	Increase the photon detection efficiency	- Photoelectron efficiency in gas ≥ 75% of that under vacuum						
T3	Suppression of ion feedback to the photocathode, increase of stability and longevity	- Stable detector operation at 10^5 gain. - IBF reduction down to 10^{-4} - Stable operation in harsh environment (10^{11} n_{eq}/cm^2)						
T4	Develop gaseous photon detectors sensitive to visible light	- Sustained photosensitivity to visible light in gaseous photon detectors						
T5	Increase spatial resolution and readout granularity	- Spatial resolution ≤ 1 mm						
T6	Increase time resolution	- Time resolution ≤ 100 ps						
T7	Modelling and simulation of gaseous photon detectors	- Accurate simulation of IBF to the photocathode, gain and stability						
T8	Large area coverage	- Gain and QE variation ≤ 10% over 1 m^2 area with ≤ 10% dead area.						
T9	Readout electronics for single photon signals	New frontend ASIC chip with 64 channels, ENC 0.5 fC at 20pF						

Summary and outlook

New Detector R&D (DRD) collaborations are being set up following the ECFA Detector roadmap to pave the way for the next decades.

R&D Recognition and Sustainability:

- The DRD collaboration status, akin to experiments, acknowledges the pivotal role of detector instrumentation and innovation.
- Preparation of the DRD proposals has fostered vibrant, global communities, uniting diverse expertise and facilitating large-scale worldwide contributions to advance R&D.
- Establishes crucial mechanisms for sustained funding, providing access to and fostering the development of cutting-edge technologies.

Current status and Key Achievements (more info 113th Plenary ECFA Meeting DRDC chair report and minutes of 1st DRDC meeting)

- DRD1, DRD2, DRD4, and DRD6 Collaborations approved at the CERN Research Board meeting on Dec. 6
- DRD3 Collaboration approval is anticipated in March 2024.
- DRD5 white paper and DRD7 LoI documents expected for approval at the March Research Board

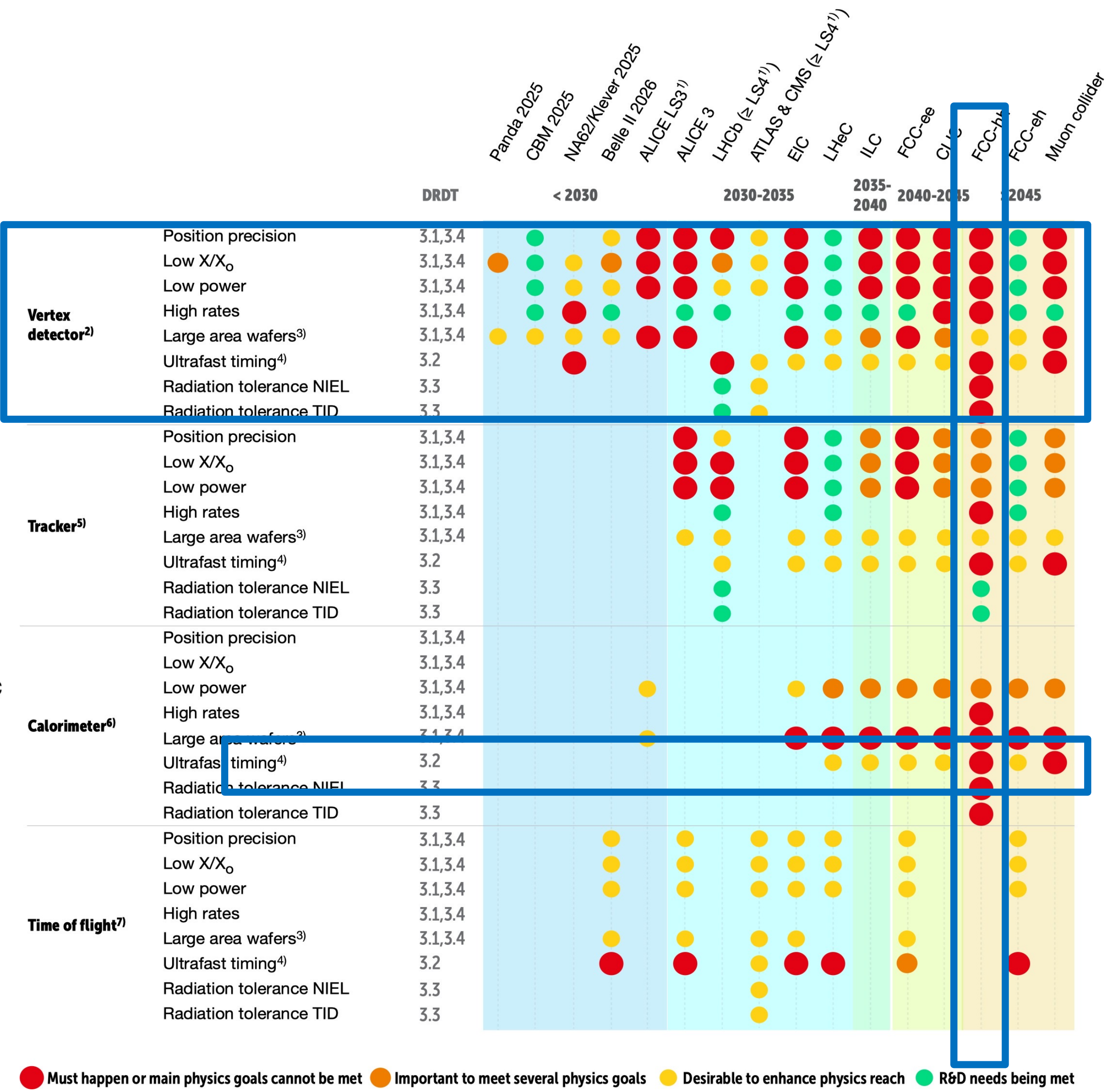
Next steps

Collaborations are ready to start activities in January 2024, with MoUs in preparation for the summer of 2024

- Forming their organizational structure.
- Consolidating the scientific program and resource needs in preparation for agreements with FAs.

ECFA DETECTOR R&D ROADMAP CONTENT

- The most urgent R&D topics in each Task Force area are identified by **Detector Readiness Matrix**
- **Detector R&D Themes (DRDTs)** were formulated as high-level deliverables and described in each TF chapter



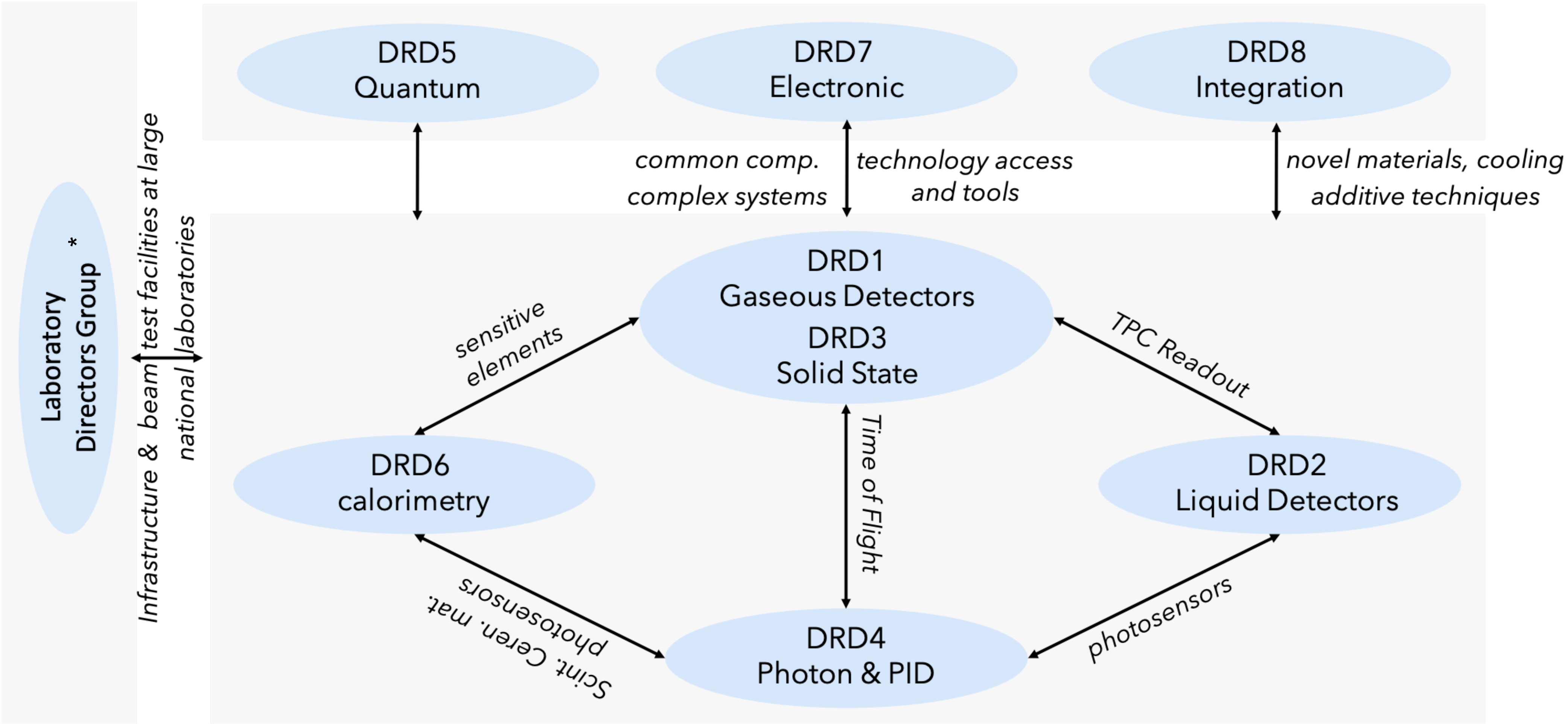
Solid state	**DRDT 3.1** Achieve full integration of sensing and microelectronics in monolithic CMOS pixel sensors
	DRDT 3.2 Develop solid state sensors with 4D-capabilities for tracking and calorimetry
	DRDT 3.3 Extend capabilities of solid state sensors to operate at extreme fluences
	DRDT 3.4 Develop full 3D-interconnection technologies for solid state devices in particle physics

Semiconductor Example!

Proposed DRD collaborations and cross links

interplay between DRDs

D. Contardo.



* LNF - Italy, STFC/Daresbury - UK, CIEMAT - DESY, Germany, STFC/RAL - UK , LNGS - Italy, F.CEA/Irfu – France, IJCLab – France, Nikhef - Netherlands, PSI - Switzerland

DRD1 Collaboration framework: Working Group

The collaborative structure of DRD1 keeps RD51 structure in Working Groups: core of the scientific organization. Platform for sharing knowledge, expertise, and efforts, crucial in identifying, guiding, and supporting strategic common R&D directions, facilitating the establishment of joint projects between institutes

WG 1	WG 2	WG 3	WG 4	WG 5	WG 6	WG 7	WG 8
Technologies	Applications	Gas and material studies	Detector physics, simulations, and software tools	Electronics	Detector production	Common test facilities	Training and dissemination
Large Volume Detectors (Drift chambers, TPCs)	Trackers/Hodoscope	Measurement of Gas Properties	Garfield++	Front-End Electronics for Gaseous Detectors	Common Production Facilities and Equipments	Detector Laboratories Network	Knowledge Exchange and Facilitating Scientific Collaborations
MPGDs	Inner and Cenral Tracking with PID Capabilities: - Drift Chambers - Straw tubes - TPC	Studies on Eco-friendly Mixtures	Simulation of Large Charges and Space Charge	Modernised Readout Systems (DAQ): high performances	QA/QC	Test Beam Common Facilities	Training and Dissemination Initiatives
RPCs, MRPCs	Calorimetry	Ageing and Outgassing studies	Simulation of Detectors with Resistive Elements	Modernised Readout Systems (DAQ); FE Integration	Collaboration with Industrial Partner	Irradiation Common Facilities	Career Promotion
TPC	Photon Detector (PID)	Gas sytems	Modelling and Simualtion of Eco-friendly Mixtures	Modernised Readout Systems (DAQ): portability	Gaseous Detector FORUM (know-how)	Specialized laboratories (outgassing/ageing, gas analysers, photocathodes)	Outreach and Education
Straw tubes, TGC, CSC, drift chambers, and other wire detectors	Timing Detectors (PID & Trigger)	Materials studies: - novel material (nanomaterial) - new material for wire - new converter	Optimization of Simulations (time, hw/sw resources)	Instrumentation (e.g. HV,LV, monitoring)		Common instrumentation and sofware	
New amplifying structures	TPC as reaction and decay chambers	Photocathodes	Specific Proceses (e.g. Electroluminescence)				
	Beyond HEP - Medical Application - Neutron Science - Muography - Space Applicatios - Oher (Dosimetry, Beam Monitoring, Cultural Heritage, Homeland Security,..)	Precision Mechanics					

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Detector R&D Roadmap: General Strategic Recommendations

GSR 1 - Supporting R&D facilities

It is recommended that the structures to provide **Europe-wide coordinated infrastructure in the areas of: test beams, large scale generic prototyping and irradiation be consolidated and enhanced to meet the needs of next generation experiments** with adequate centralised investment to avoid less cost-effective, more widely distributed, solutions, and to maintain a network structure for existing distributed facilities, e.g. for irradiation

GSR 2 - Engineering support for detector R&D

In response to ever more integrated detector concepts, requiring holistic design approaches and large component counts, the R&D should be supported with **adequate mechanical and electronics engineering resources**, to bring in expertise in state-of-the-art microelectronics as well as advanced materials and manufacturing techniques, to tackle generic integration challenges, and to maintain scalability of production and quality control from the earliest stages.

GSR 3 - Specific software for instrumentation

Across DRDTs and through adequate capital investments, the availability to the community of **state-of-the-art R&D-specific software packages must be maintained and continuously updated**. The expert development of these packages - for core software frameworks, but also for commonly used simulation and reconstruction tools - should continue to be highly recognised and valued and the community effort to support these needs to be organised at a European level.

GSR 4 - International coordination and organisation of R&D activities

With a view to creating a vibrant ecosystem for R&D, connecting and involving all partners, there is a **need to refresh the CERN RD programme structure and encourage new programmes for next generation detectors**, where CERN and the other national laboratories can assist as major catalysers for these. It is also recommended to revisit and streamline the process of creating and reviewing these programmes, with an extended framework to help share the associated load and increase involvement, while enhancing the visibility of the detector R&D community and easing communication with neighbouring disciplines, for example in cooperation with the ICFA Instrumentation Panel.

Detector R&D Roadmap: General Strategic Recommendations

GSR 5 - Distributed R&D activities with centralised facilities

Establish in the relevant R&D areas a distributed yet connected and supportive tier-ed system for R&D efforts across Europe. Keeping in mind the growing complexity, the specialisation required, the learning curve and the increased cost, consider more focused investment for those themes where leverage can be reached through centralisation at large institutions, while addressing the challenge that distributed resources remain accessible to researchers across Europe and through them also be available to help provide enhanced training opportunities.

GSR 6 - Establish long-term strategic funding programmes

Establish, additional to short-term funding programmes for the early proof of principle phase of R&D, also **long-term strategic funding programmes to sustain both research and development of the multi-decade DRDTs** in order for the technology to mature and to be able to deliver the experimental requirements. Beyond capital investments of single funding agencies, international collaboration and support at the EU level should be established. In general, the cost for R&D has increased, which further strengthens the vital need to make concerted investments.

GSR 7 – "Blue-sky" R&D

It is essential that **adequate resources be provided to support more speculative R&D** which can be riskier in terms of immediate benefits but can bring significant and potentially transformational returns if successful both to particle physics: unlocking new physics may only be possible by unlocking novel technologies in instrumentation, and to society. Innovative instrumentation research is one of the defining characteristics of the field of particle physics. "Blue-sky" developments in particle physics have often been of broader application and had immense societal benefit. Examples include: the development of the World Wide Web, Magnetic Resonance Imaging, Positron Emission Tomography and X-ray imaging for photon science.

Detector R&D Roadmap: General Strategic Recommendations

GSR 8 - Attract, nurture, recognise and sustain the careers of R&D experts

Innovation in instrumentation is essential to make progress in particle physics, and R&D experts are essential for innovation. It is recommended that ECFA, with the involvement and support of its Detector R&D Panel, continues the study of **recognition with a view to consolidate the route to an adequate number of positions with a sustained career in instrumentation R&D** to realise the strategic aspirations expressed in the EPPSU. It is suggested that ECFA should explore mechanisms to develop concrete proposals in this area and to find mechanisms to follow up on these in terms of their implementation. Consideration needs to be given to creating sufficiently attractive remuneration packages to retain those with key skills which typically command much higher salaries outside academic research. It should be emphasised that, in parallel, society benefits from the training particle physics provides because the knowledge and skills acquired are in high demand by industries in high-technology economies.

GSR 9 - Industrial partnerships

It is recommended to **identify promising areas for close collaboration between academic and industrial partners**, to create international frameworks for exchange on academic and industrial trends, drivers and needs, and to establish strategic and resources-loaded cooperation schemes on a European scale to intensify the collaboration with industry, in particular for developments in solid state sensors and micro-electronics.

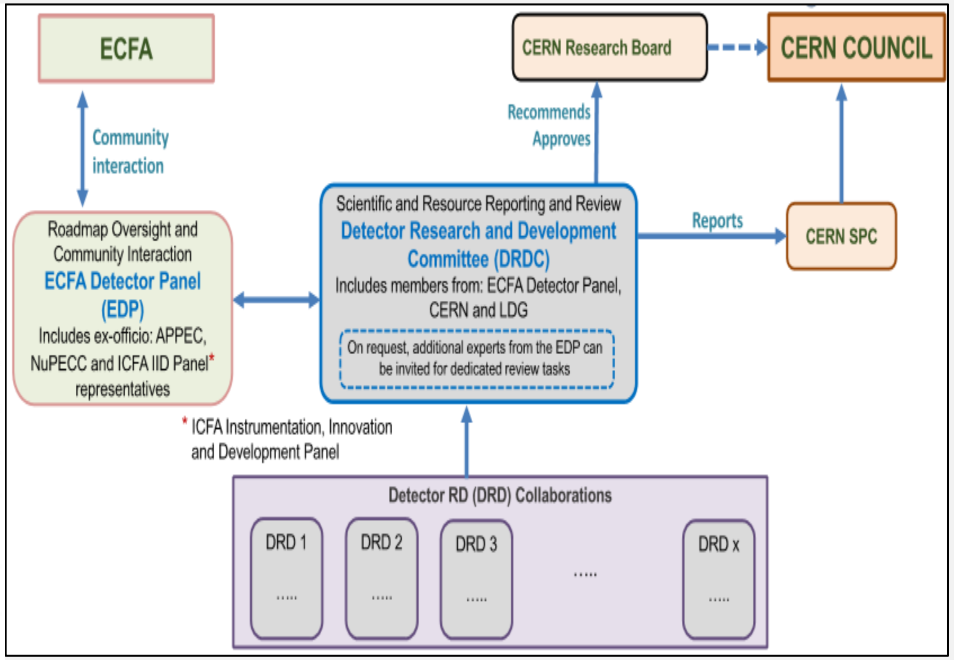
GSR 10 – Open Science

It is recommended that the concept of **Open Science be explicitly supported in the context of instrumentation**, taking account of the constraints of commercial confidentiality where these apply due to partnerships with industry. Specifically, for publicly-funded research the default, wherever possible, should be open access publication of results and it is proposed that the Sponsoring Consortium for Open Access Publishing in Particle Physics ($SCOAP^3$) should explore ensuring similar access is available to instrumentation journals (including for conference proceedings) as to other particle physics publications.

Framework of the DRD Collaborations

In alignment with the general conditions for experiment execution at CERN, a dedicated Detector R&D Review Committee (DRDC) has been put in place, along with formalized MoUs with various Funding Agencies.

Co-chairs:	Phil Allport (Birmingham) Didier Contardo (IP2I Lyon)
Scientific secretary:	Doris Eckstein (DESY)
Gaseous Detectors:	Silvia Dalla Torre (Torino)
Liquid Detectors:	Inés Gil Botella (CIEMAT, Madrid)
Solid State Detectors:	Doris Eckstein (DESY) Phil Allport (Birmingham)
PID & Photon Detectors:	Roger Forty (CERN)
Quantum and emerging Technologies.:	Steven Hoekstra (Groningen)
Calorimetry:	Laurent Serin (IJCLab)
Electronics:	Valerio Re (Bergamo)
Ex Officio:	Karl Jakobs (ECFA Chair) Ian Shipsey (ICFA Detector Panel)
Observer for APPEC	Aldo Ianni (INFN, LNGS)
Observer for NuPECC	Eugenio Nappi (INFN, Unit of Bari)



ECFA Detector Panel

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