
# Plans for Detector Research and Development of international Collaborations

Claudia Gemme (INFN Genova)

INFN
Istituto Nazionale di Fisica Nucleare


# Outline

First Part: Introduction to the Detector R&D

Second Part: The Detector R&D collaborations

- Detector R&D for the future: the next decades
- Status and near future in the setting up

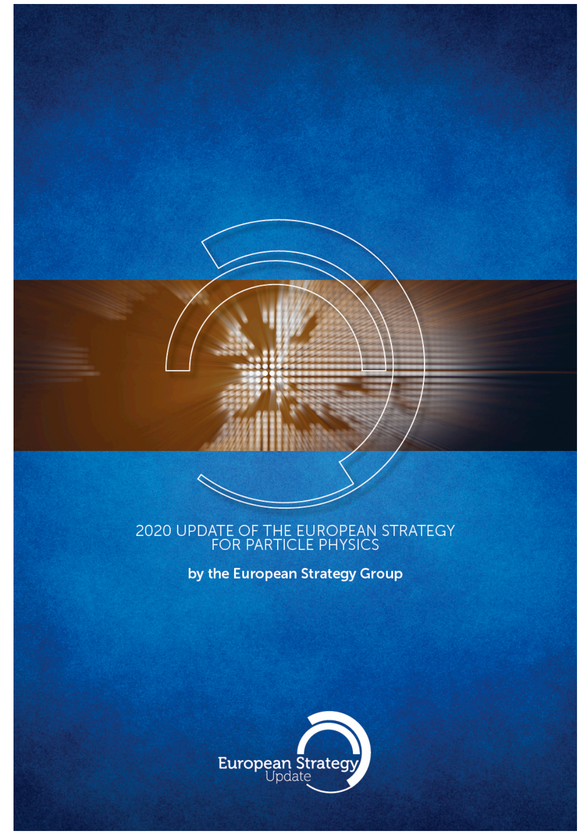
Final considerations


# Introduction to the Detector R&D

# European Strategy on Particle Physics

http://europeanstrategy.cern

- Strategy first defined in 2006
- **Update in 2013** to launch the HL-LHC decision
- **Update in 2020** to envisage 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**.*
  - *The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. A **roadmap should prioritise the technology**, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry. **Deliverables for this decade should be defined** in a timely fashion and coordinated among CERN and national laboratories and institutes.*
  - ***Successful completion of High-Luminosity LHC must remain key focus***



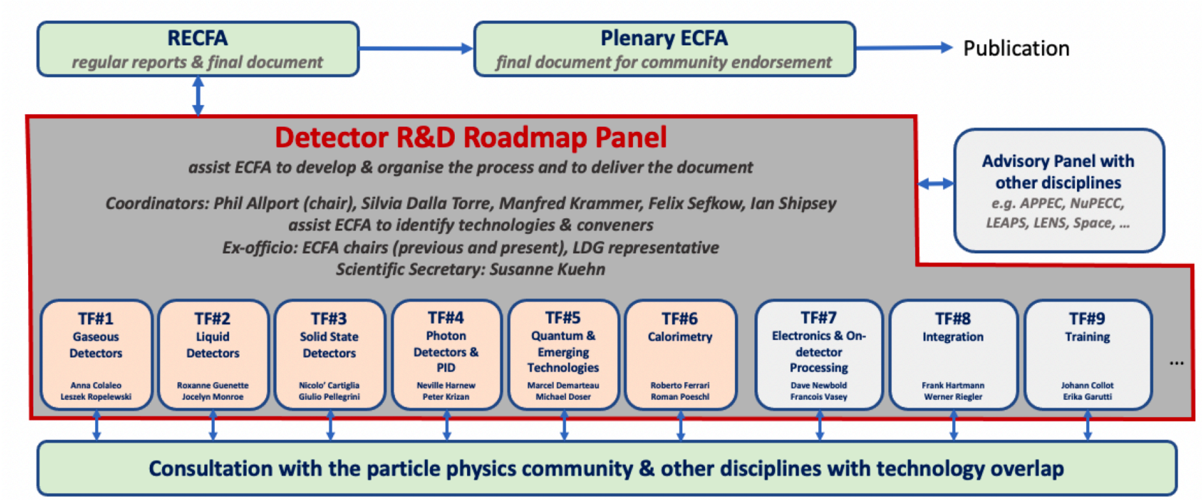

http://dx.doi.org/10.17181/CERN.JSC6.W89E

# ECFA detector roadmap

The 2021 ECFA detector research and development roadmap: full doc , synopsis

- A **Detector R&D Roadmap Panel** was formed to define areas & organise wide community consultation.

*The ECFA Detector R&D Roadmap Panel Organisation*



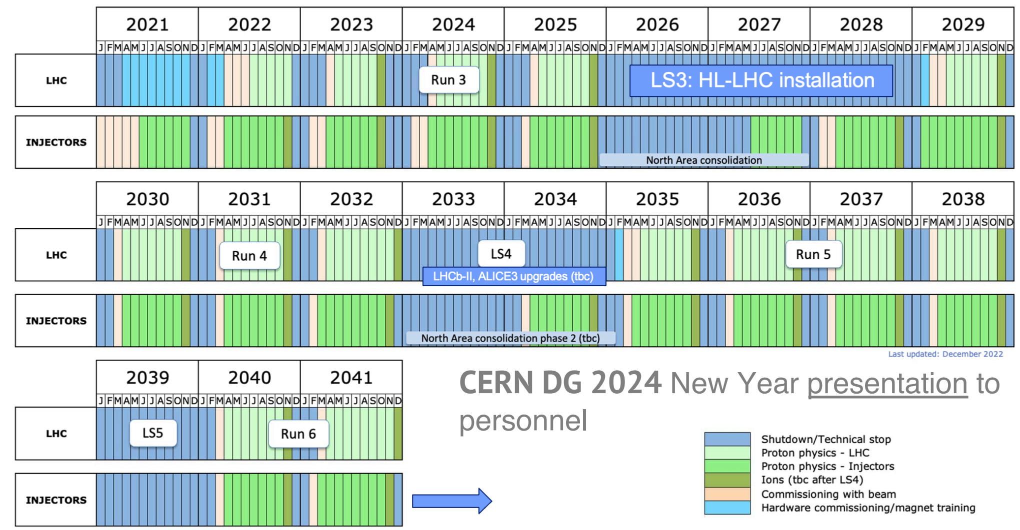


- The Roadmap was approved by Plenary European Committee for Future Accelerators (**ECFA**) **in November 2021**. It contains:
  - Overview of **future facilities** (EIC, ILC, CLIC, FCC-ee/hh, Muon collider) or major **upgrades** (ALICE, Belle-II, LHC-b,…) and **timeline**
  - Nine Technology domains based on **Task Forces** areas (Gaseous detectors, Liquid, etc …)
    - The **most urgent R&D topics** in each domain identified as **Detector R&D Themes** (DRDTs)
  - Concludes with ten "**General Strategic Recommendations**"

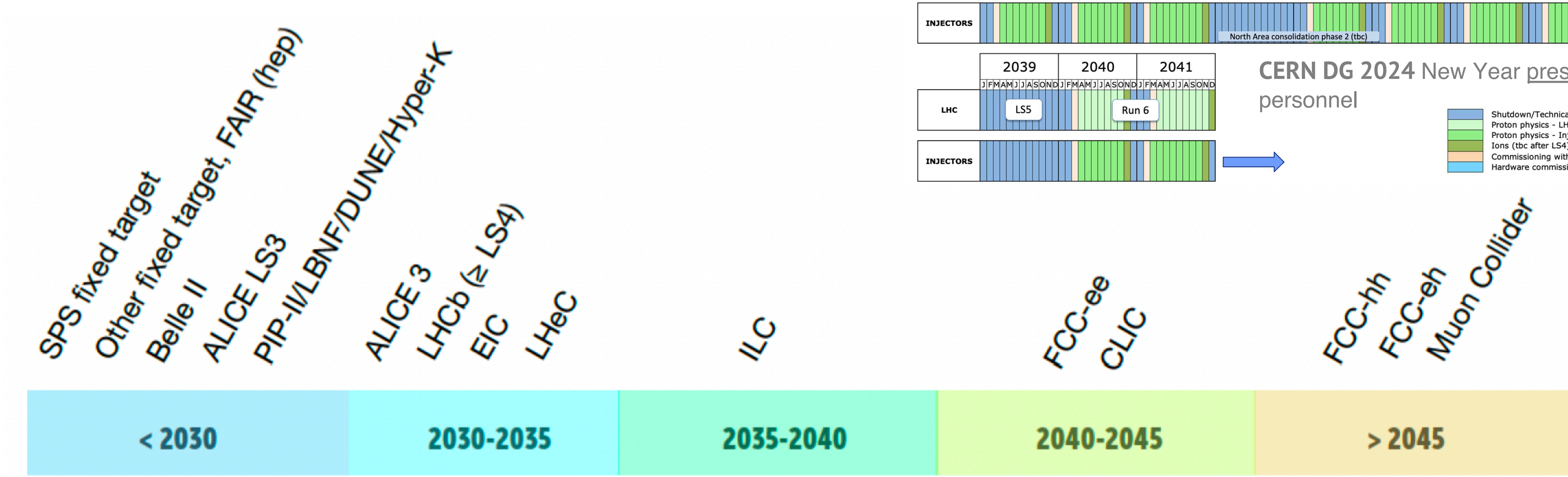
# ECFA detector roadmap: Timeline

- Five time periods defined, from now to 2045 and later.
  - the **Future Large Experiments**

**Indicative timeline out to 2041** for **(HL)-LHC Schedule**



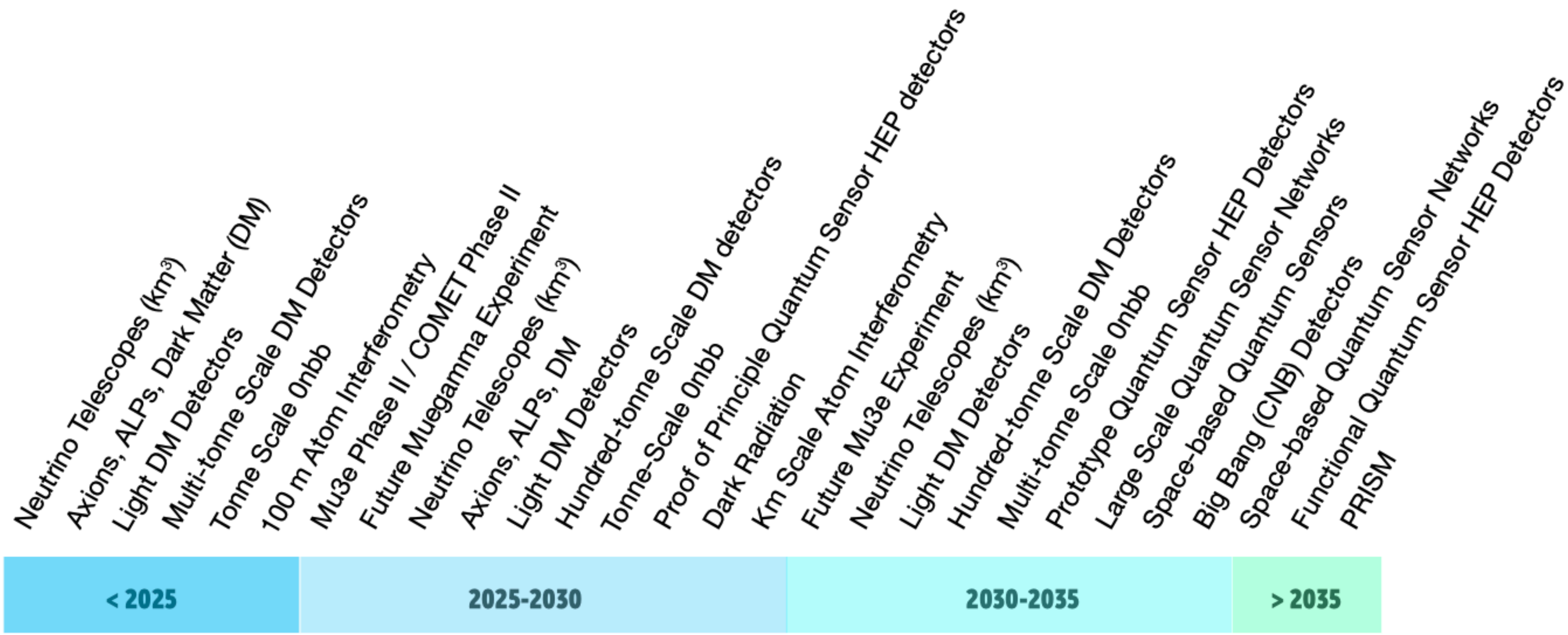

**CERN DG 2024** New Year presentation to personnel




**LHC LS3** **LHC LS4** *Large Accelerator Based Facility/Experiment Earliest Feasible Start Dates*

# ECFA detector roadmap: Timeline

- Different time periods defined
  - the **Future Smaller Experiments** at smaller accelerator and non-accelerator based




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

# ECFA detector roadmap: R&D topics and Themes

- The most urgent R&D topics in each Task Force area are identified as **Detector R&D Themes** (DRDTs) and visualized at high level by a **Detector Readiness Matrix.**

- **Detector R&D Themes (DRDTs)** were formulated as high-level deliverables:

**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

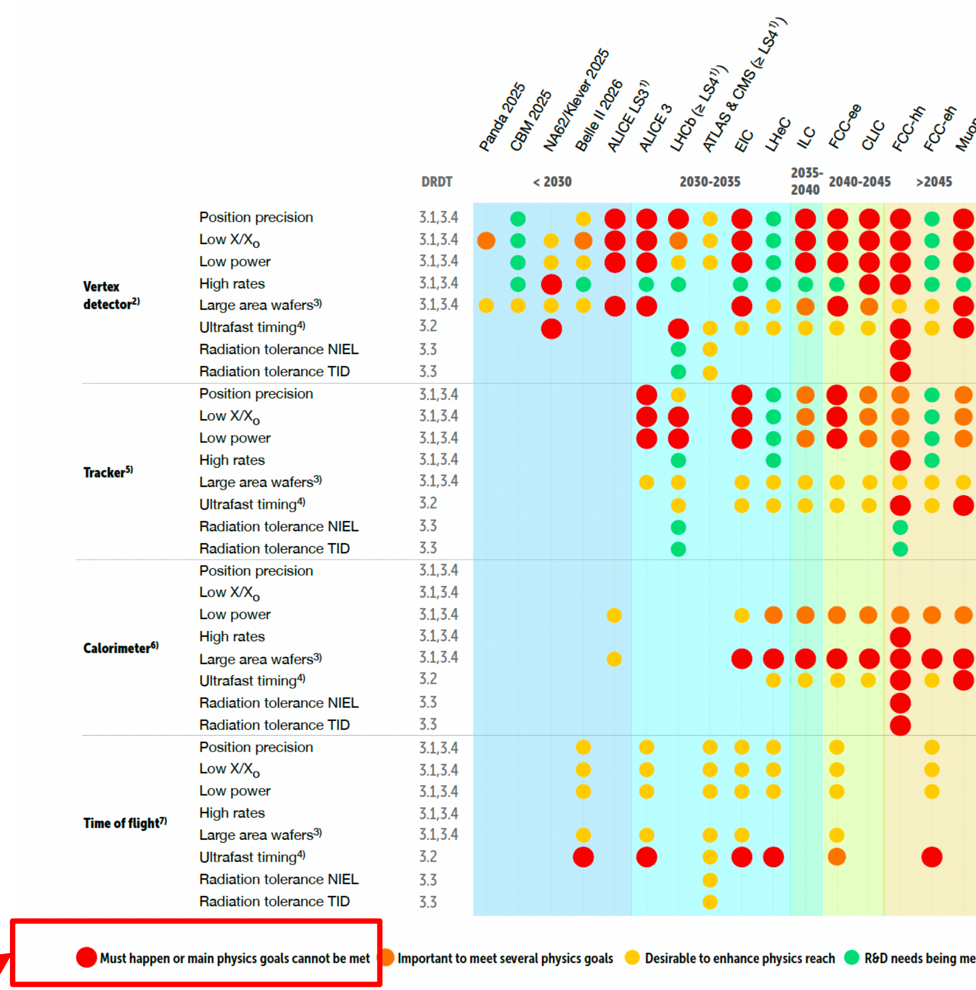



Figure 1.1: Schematic timeline of categories of experiments employing GDs together with DRDTs and R&D tasks. The colour coding is linked not to the intensity of the required effort but to the potential impact on the physics programme of the experiment: Must happen or main physics goals cannot be met (red, largest dot); Important to meet several physics goals (orange, large dot); Desirable to enhance physics reach (yellow, medium dot); R&D needs being met (green, small dot); No further R&D required or not applicable (blank).

**Examples for Solid State Detectors!**

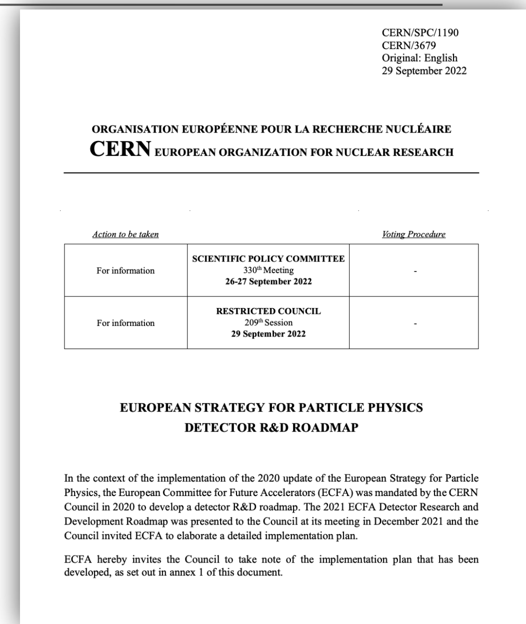
# ECFA detector roadmap: GSR

- The **General Strategic Recommendations** (GSR) topics are:
  - Supporting R&D facilities: **test beams, large scale generic prototyping and irradiation**
  - **Engineering support** for detector R&D
  - Specific **software** for instrumentation
  - **International coordination** and organisation of R&D activities
  - Distributed R&D activities with **centralised facilities**
  - Establish long-term **strategic funding programmes**
  - "**Blue-sky**" R&D
  - Attract, nurture, recognise and **sustain the careers of R&D experts**
  - **Industrial** partnerships
  - **Open Science**

# Roadmap implementation plan

*The 2022 ECFA detector research and development roadmap Implementation plan: ([CERN/SPC/1190; CERN/3679](CERN/SPC/1190; CERN/3679))*

- ECFA **implementation proposal** was endorsed by Council in **Sep. 2022**: proposed that the long-term R&D efforts be organised into **Detector R&D (DRD) collaborations hosted at CERN**.
  - following the model of the RD collaborations established in the early 1990s to address the huge challenges posed by the construction of the LHC detectors (RD1, … , RD42, RD50, RD51, … RD53)
- Interaction between DRD collaborations and CERN committees is via the **DRDC**, which will regularly review them



CERN/SPC/1190
CERN/3679
Original: English
29 September 2022

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

| *Action to be taken* | | *Voting Procedure* |
|---|---|---|
| For information | SCIENTIFIC POLICY COMMITTEE 330th Meeting 26-27 September 2022 | - |
| For information | RESTRICTED COUNCIL 209th Session 29 September 2022 | - |

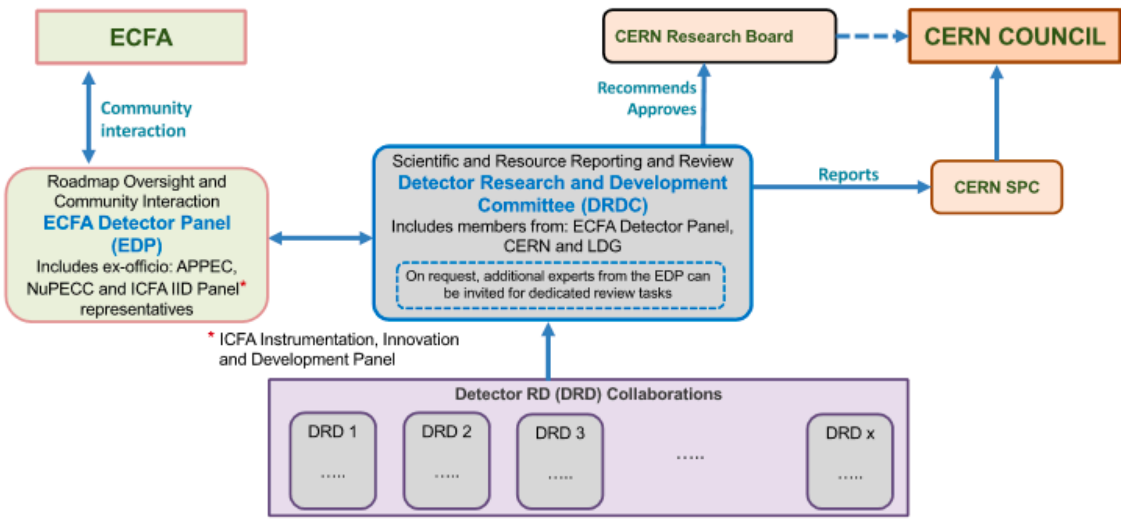
EUROPEAN STRATEGY FOR PARTICLE PHYSICS
DETECTOR R&D ROADMAP

In the context of the implementation of the 2020 update of the European Strategy for Particle Physics, the European Committee for Future Accelerators (ECFA) was mandated by the CERN Council in 2020 to develop a detector R&D roadmap. The 2021 ECFA Detector Research and Development Roadmap was presented to the Council at its meeting in December 2021 and the Council invited ECFA to elaborate a detailed implementation plan.

ECFA hereby invites the Council to take note of the implementation plan that has been developed, as set out in annex 1 of this document.

**ECFA Detector Panel (EDP):**

- Co-chairs: ***Phil Allport*** *(Birmingham),* ***Didier Contardo*** *(Lyon)*
- Scientific secretary: *Doris Eckstein (DESY)*
- Gaseous Detectors: *Silvia Dalla Torre (Torino)*
- Liquid Detectors: ***Inés Gil Botella*** *(CIEMAT)*
- Solid State Detectors: *Doris Eckstein, Phil Allport*
- PID & Photon Detectors: ***Roger Forty*** *(CERN)*
- Quantum and emerging Technologies.: *Steven Hoekstra (Groningen)*
- Calorimetry: ***Laurent Serin*** *(IJCLab)*
- Electronics: *Valerio Re (Bergamo)*
- Ex Officio: *ECFA Chair (Karl Jakobs), ICFA Detector Panel (Ian Shipsey), DRDC chair (**Thomas Bergauer**), APPEC & NuPECC observers*




**Detector R&D Committee (DRDC):**

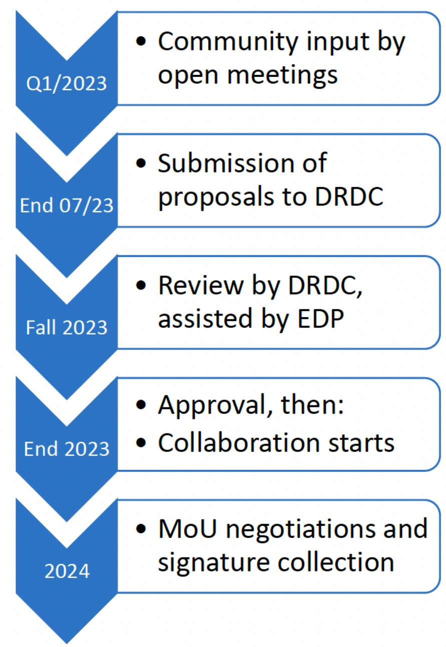
- ***Thomas Bergauer*** (HEPHY Vienna)
- Scientific secretary: *Jan Troska* (CERN)
- *Stan Bentvelsen* (NIKHEF, **LDG**)
- *Shikma Bressler* (Weizmann)
- *Dimitry Budker* (Mainz)
- ***Roger Forty*** (CERN)
- *Claudia Gemme* (INFN and U. Genoa)
- ***Inés Gil Botella*** (CIEMAT)
- *Petra Merkel* (Fermilab, US)
- *Mark Pesaresi* (Imperial College)
- ***Laurent Serin*** (IJCLab)
- Ex-officio: ***P. Allport, D. Contardo*** (EDP)
- Ex-officio: CERN DRC, EP dep. head, KT head

*DRD Committee: http://committees.web.cern.ch/drdc*
*ECFA Detector Panel: https://ecfa-dp.desy.de*

# Roadmap implementation plan: Collaborations

- The new DRD collaborations:
  - ~ matching the **Task Forces** areas
  - A similar organization like a HEP experiment, general conditions
  - **Strategic funding** of deliverables agreed with funding agencies via MoUs
  - As for past RD50,RD51, collection of small common funds to finance **Blue-Sky** common projects
- Timeline:
  - In 2023 community input (via existing R&D bodies where possible), then a written short **proposals** for each TF topic, review by DRDC, aiming to **approval** by the end of 2023 so that DRD collaborations can officially start beginning of 2024 with **MoU** setup and collecting signatures from FAs
- In the proposal:
  - Breakdown in **Work Packages** with Deliverables due to achieve research goals Milestones, along the RD Themes.
  - Focused on first R&D period of 3-4 years with prospect for longer term
  - Analysis of **human resources and funding** at the level of WPs to evaluate feasibility
    - Basis to establish Funding Agency commitments to WP deliverables in MoUs

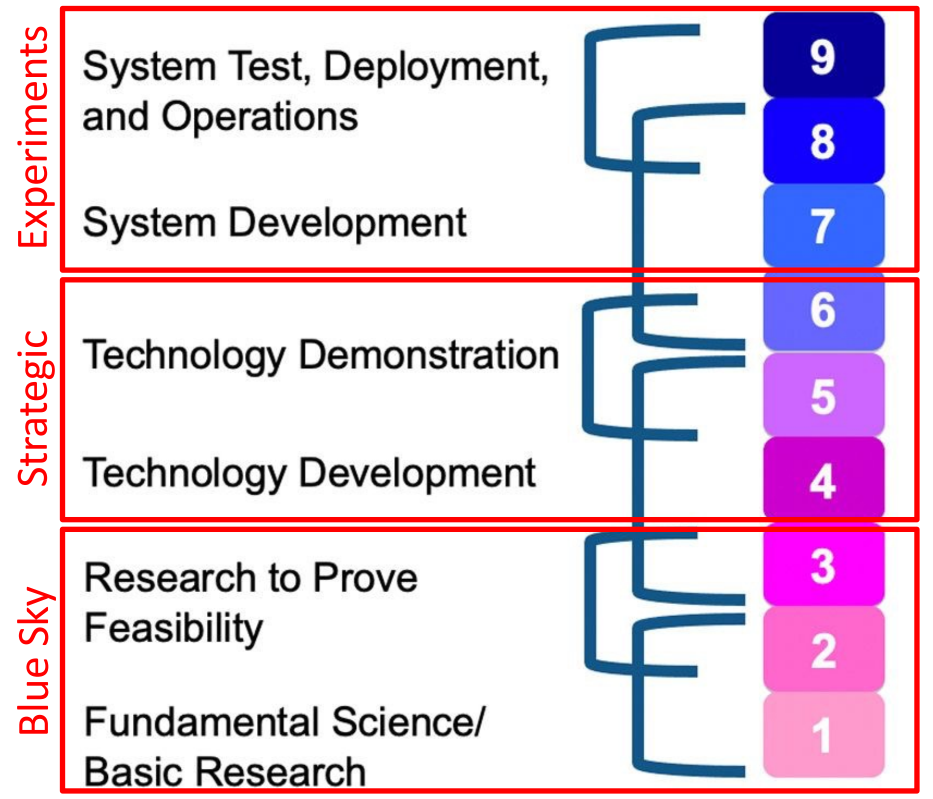
Approval timeline



# Roadmap implementation plan: Strategic vs Blue-Sky

- Strategic R&D bridges the gap between the **idea** (so-called **Blue Sky**, TRL 1-3) and the deployment and use in a HEP experiments (TRL 8-9)
  - **Detector R&D Collaboration should address Strategic R&D (TRL 3-6),** before experiment-specific engineering takes over.
  - Covers the development and maturing of technologies, e.g.
    - •Improving radiation hardness
    - •Speeding up readout
    - •Simplification of designs
    - •Iterating different options
  - Backed up by **strategic funding**, agreed with funding agencies  (MoUs)
- DRD collaborations should also contain a small **Blue Sky** section
  - Allow new developments to emerge
  - Possibly financed by common fund + institute contributions (RD50/51 scheme)

***Technology Readiness Levels (TRLs)*** *defined by NASA: Method for estimating the maturity of technologies*



# R&D in other countries/contexts

- In US, result from Snowmass: recommendation to **create Detector R&D collaborations in the US**
  - Organized by **CPAD** (Coordinating Panel for Advanced Detectors) of the APS/DPF (one chairperson from CPAD is in DRDC)
  - They created **11 RDCs** (R&D Collaborations) and appointed coordinators (see CPAD website)
  - Recently started to reach out to the community and work on detailed planning
  - Overlap to DRDs through people/groups involved in both and liaisons

- **EU-funded** grants play an important role in enabling and supporting generic R&Ds, and fostering collaboration: AIDA/2020/innova, ATTRACT, ERC grants

| RDC# | TOPIC |
|---|---|
| 1 | Noble Element Detectors |
| 2 | Photodetectors |
| 3 | Solid State Tracking |
| 4 | Readout and ASICs |
| 5 | Trigger and DAQ |
| 6 | Gaseous Detectors |
| 7 | Low-Background Detectors |
| 8 | Quantum and Superconducting Sensors |
| 9 | Calorimetry |
| 10 | Detector Mechanics |
| 11 | Fast Timing |


# The Detector R&D collaborations

Status, Composition, Scientific highlights

# R&D Collaborations being setup

*Targeting mostly HEP*

- Gaseous Detectors (DRD1)
- Semiconductor Detectors (DRD3)
- Calorimetry (DRD6)

*Targeting "smaller experiments"*

- Photodetectors & Particle ID (DRD4)
- Liquid Detectors (DRD2)
- Quantum Sensors & emerging technologies (DRD5)

*Transversal topics necessary for all activities*

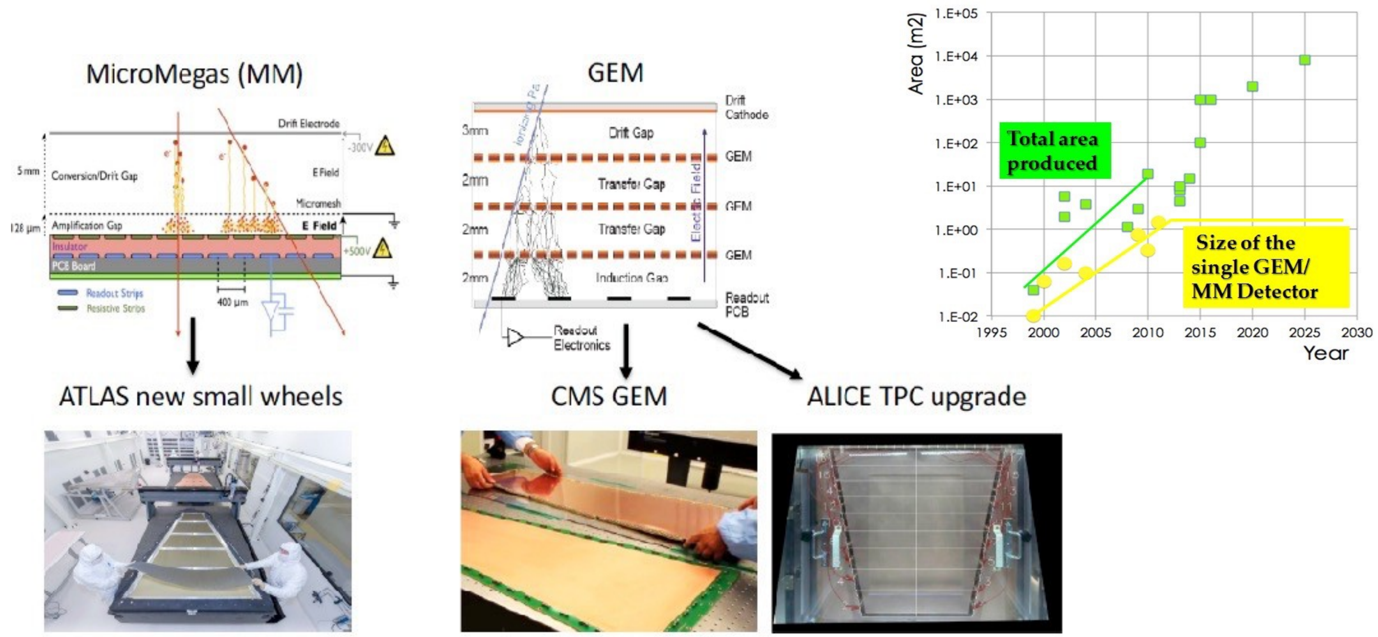
- Electronics (DRD7)
- Integration (DRD8)
- Training (TF9)

Topics at the boundary between areas have been clarified in the proposals, however liasons between DRDs are in place whenever needed.

| Collaboration | Topic | Proposal Submission | Approval | Comment |
|---|---|---|---|---|
| *DRD 1* | *Development of Gaseous Detectors* | *July 2023* | *Dec. 2023* | *Former RD51* |
| *DRD 2* | *Liquid Detectors* | *July 2023* | *Dec. 2023* | |
| *DRD 3* | *Solid State Detectors* | *October 2023* | *Exp. June 2024* | *Former RD50* |
| *DRD 4* | *Photon Detectors and PID Techniques* | *July 2023* | *Dec. 2023* | |
| *DRD 6* | *Calorimetry* | *July 2023* | *Dec. 2023* | *CALICE, Crystal Clear* |
| *DRD 5* | *Quantum and Emerging Technologies* | *December 2023* | *Exp. June 2024* | *Low TRLs* |
| *DRD 7* | *R&D for Electronic Systems* | *December 2023* | *Exp. June 2024* | *Coordination with other groups* |
| *TF 8 → DRD8* | *Integration* | *LoI submitted* | *later* | *Workshop on 6th Dec.* |
| *TF 9* | *Training* | *-* | *-* | *ECFA panel* |

# DRD1: Gaseous detectors

- The panorama of GDs makes them adequate for a variety of applications, despite the operational complexity (high voltage and gas supplies)
  - GDs are the primary choice for **large-area coverage** with **low material budget** & **dE/dx** measurement (TPC, Drift chamber) & **fast timing** (multigap RPC, PICOSEC).




- Effort in improving their spatial and time resolution, along with high-rate capability performance, and in developing eco-friendly GD for large areas/high rate.

**Gaseous**

**DRDT 1.1** Improve time and spatial resolution for gaseous detectors with long-term stability

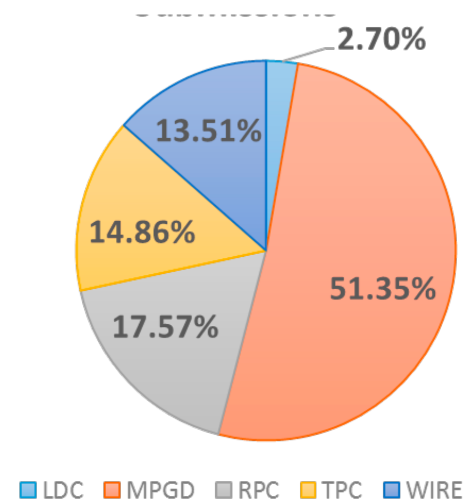
**DRDT 1.2** Achieve tracking in gaseous detectors with dE/dx and dN/dx capability in large volumes with very low material budget and different read-out schemes

**DRDT 1.3** Develop environmentally friendly gaseous detectors for very large areas with high-rate capability

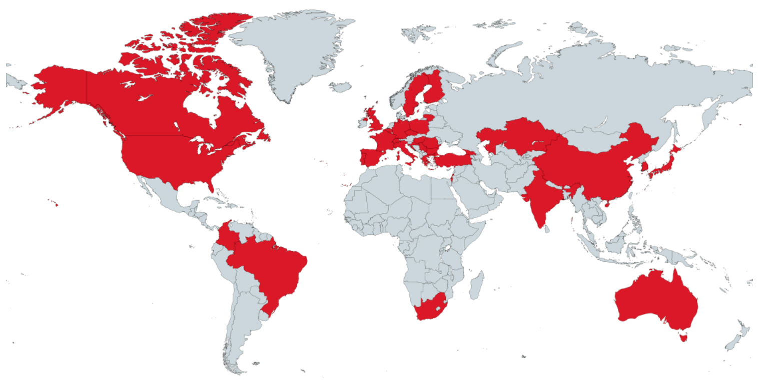
**DRDT 1.4** Achieve high sensitivity in both low and high-pressure TPCs

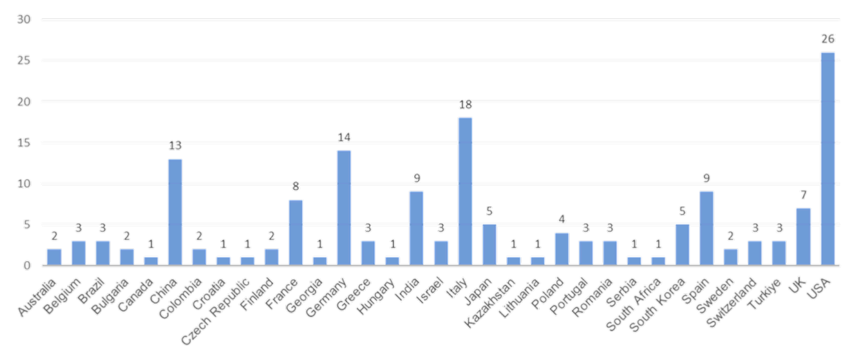
# DRD1: Gaseous detectors - collaboration status

- **Status**: Proposal (link), collaboration approved in December 2023
- **History**: DRD1 is the successor and extension of RD51 (MPGD)
- **Collaboration** setup:
  - **Chair Collaboration Board**: Anna Colaleo (Ba)
  - **Spokepersons**: Eraldo Oliveri, Maxim Titov
  - **Website** : *https://drd1.web.cern.ch/*
  - **Collaboration Meetings**
    - 1st DRD1 COLLABORATION MEETING, 29 January - 2 February, 2024
    - 2nd DRD1 COLLABORATION MEETING, 17-21 June 2024
  - **Participants:** *>700 participants from 161 institutes in 33 countries + 5 Industrial, Semi-Industrial partners and Research Foundations*
  - **Budget**: 3 (3) MCHF/y and 270 (100) FTE existing (additionally requested)



Technology interests





**Countries of DRD1 Institutes (today)**

**Italy:** *BA, BG, BO, FE, GSSI, LE, LNF, LNS, MIB, NA, PD, PV, PI, RM1, RM2, RM3, TO, TS*

MPGD: Micro Pattern Gas detector

# DRD1: Gaseous detectors - collaboration status

- As other DRDs, DRD1 is Organized in **Working Groups** (serving as knowledge and technology hub) and two types of joint projects: **Common Projects** (CP), short term, limited funding, Blue Sky projects, and **Work Packages** (WP) which encompass long-term projects with significant strategic R&D goals and corresponding funding lines.

| DRDTs 1.1 | 1.2 | 1.3 | 1.4 | Work Packages |
|---|---|---|---|---|
| ● | | ● | | Trackers/hodoscopes |
| ● | ● | ● | | Drift chambers |
| ● | ● | ● | | Straw chambers |
| ● | ● | ● | ● | Tracking TPCs |
| ● | | ● | | Calorimetry |
| ● | ● | ● | | Photon detection (PID) |
| ● | | ● | | Timing detectors |
| ● | ● | ● | ● | Reaction/decay TPCs |
| ● | | ● | | Beyond HEP |

Forum for discussion on common topics

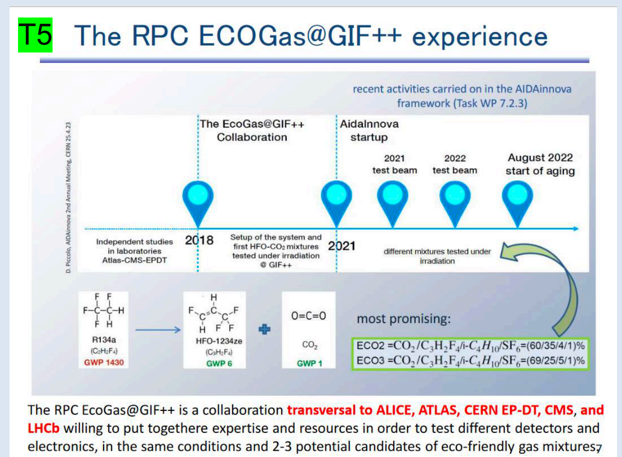
| WG1 | WG2 | WG3 | WG4 | WG5 | WG6 | WG7 | WG8 |
|---|---|---|---|---|---|---|---|
| Technologies | Applications | Gas and material studies | Detector physics, simulations and software tools | Electronics for gaseous detectors | Detector production | Common test facilities | Training and dissemination |

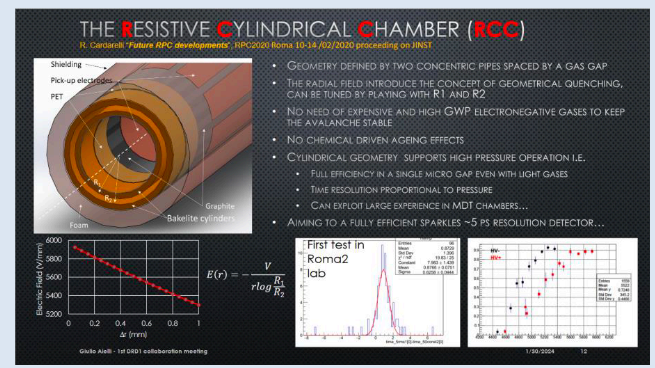
Example

## WP1: Genuine trackers/hodoscopes (large area muon systems, inner tracking/vertexing)

The goal is to strengthen their stability, robustness, and long-term performance, as well as to optimize a cost-effective manufacturing together with industrial partners.

T1: New RPC Structures
T2: New Resistive MPGD Structures
T3: New Front-end electronics
T4: Optimization of scalable multichannel readout systems
**T5: Eco-friendly gases**
T6: Manufacturing
T7: Longevity on large detector areas
**T8: New detector structures**




T8

# DRD3: Solid State detectors

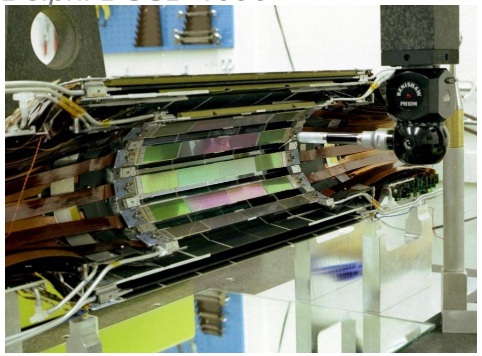
Remarkable success in HEP enabled by significant advancements **in chip industries**

- **Detector area** increased by one order of magnitude each decade (1 $m^2$ ➔ 10 $m^2$ ➔ 200 $m^2$ ➔ 600$m^2$ )
- **Radiation hardness** at levels not imagined decades ago
- **Endcap Timing detectors** for ATLAS and CMS (4D tracking)

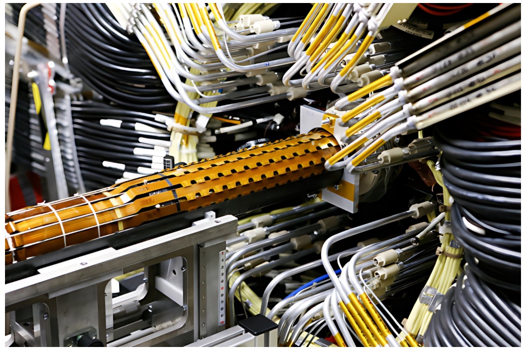
Next stepping stones in R&D are upgrades in ALICE, LHCb, EIC, Belle-3, ATLAS, CMS, and HGCAL; subsequently $e^+e^-$ colliders; and, lastly, the R&D for MC and FCC-hh.

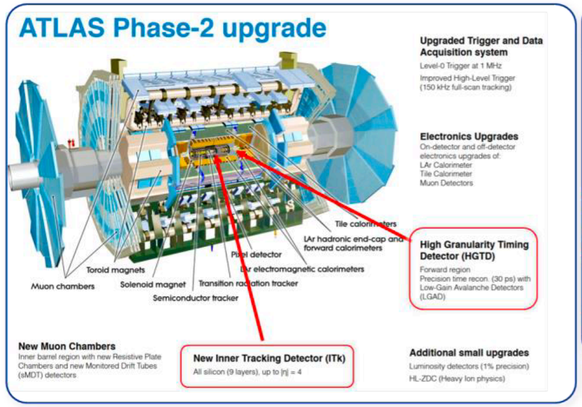
- **FCC-ee:** Vertex detectors with low mass, high resolution (target per layer spatial resolution of ≤ 3 $\mu$m and x/x0≤ 0.05%),
- **FCC-hh:** low power and high radiation hardness (up to $8{\cdot}10^{17}\ n_{eq}cm^{-2}$)
- Pile-up mitigation by ultra-fast timing in O(10-100ps)
- Low mass with fully integrated with electronics, mechanics, services
- Large area sensors at low cost for calorimetry

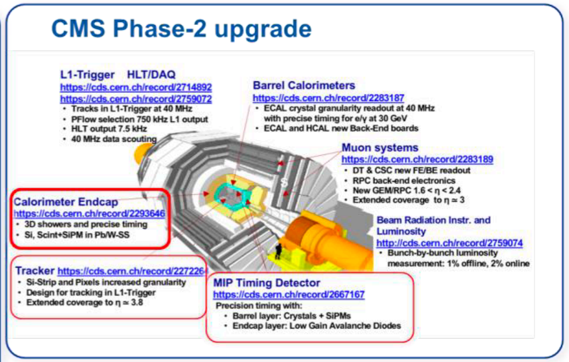
*Delphi DSSD 1996*



*ATLAS IBL 2014*





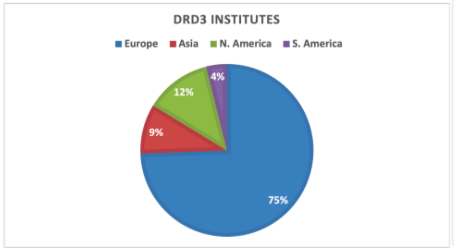

*...also very close collaboration with LHCb!*

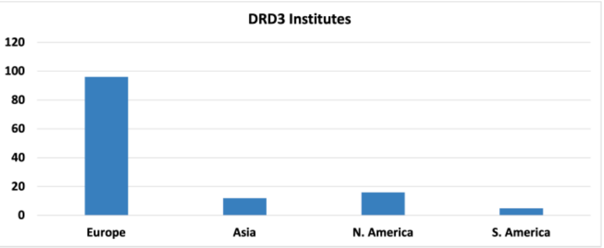
**Solid state**

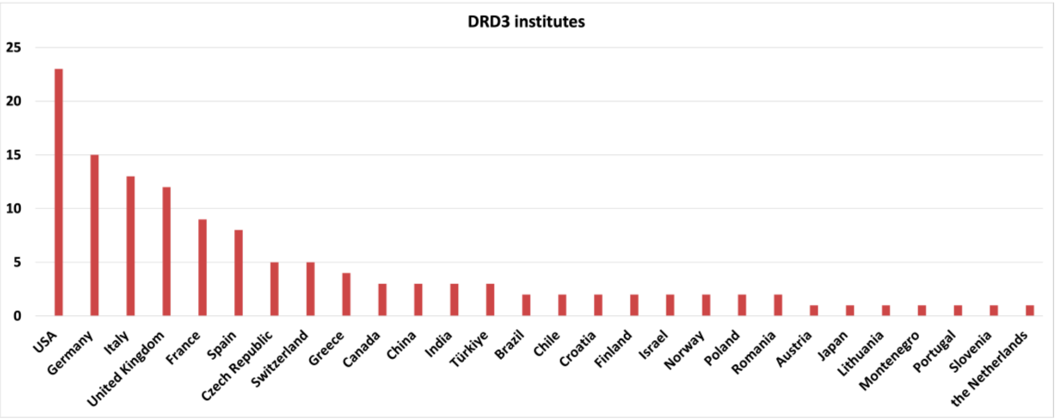
| | |
|---|---|
| **DRDT 3.1** | Achieve full integration of sensing and microelectronics in monolithic CMOS pixel sensors |
| **DRDT 3.2** | Develop solid state sensors with 4D-capabilities for tracking and calorimetry |
| **DRDT 3.3** | Extend capabilities of solid state sensors to operate at extreme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

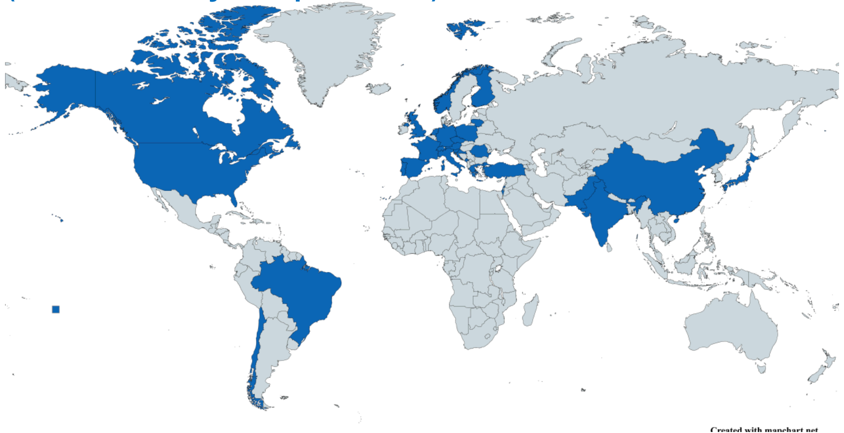
# DRD3: Solid State detectors - collaboration status

- **Status**: Proposal submitted in October, Conditionally approved
- **History**: DRD3 is the successor and extension of RD50 (Rad-hard sensors)
- **Collaboration** setup:
  - **Chair Collaboration Board**: Giulio Pellegrini (CNM) (deputy Roberta Arcidiacono (To))
  - **Spokeperson**: Gregor Kramberger, JSI
  - **Website**: [https://drd3.web.cern.ch/](https://drd3.web.cern.ch/)
  - Collaboration **Meetings:**
    - Coming soon: 1st DRD3 COLLABORATION MEETING, June 2024
  - **Participants:** *> 500 participants from 132 institutes in 28 countries*
  - **Budget**: 5 (8) MCHF/y  and 327 (170) FTE existing (additionally requested)



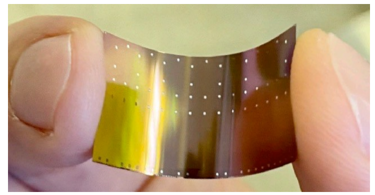



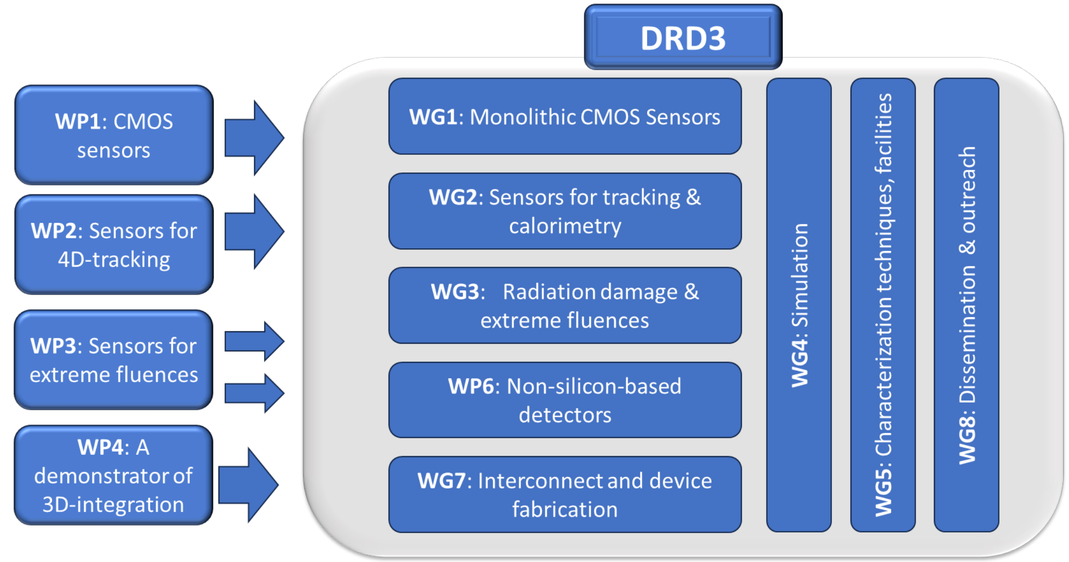
***Italy:*** *BA, GE, PG, TO, TS, PD, FI, PI, LE, MI, MIB, TN, FBK*

# DRD3: Solid State detectors - collaboration status

- CMOS Monolithic sensors: combining sensing and readout elements
  - Sensor development becomes chip development, but typically with modifications to standard process
  - overlap with DRD7 electronics

*CMOS MAPS for ALICE ITS3*

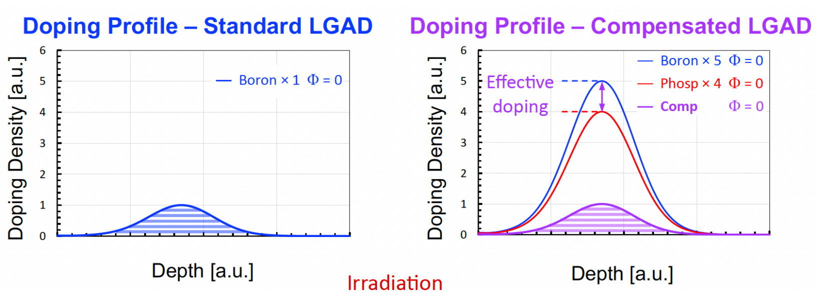




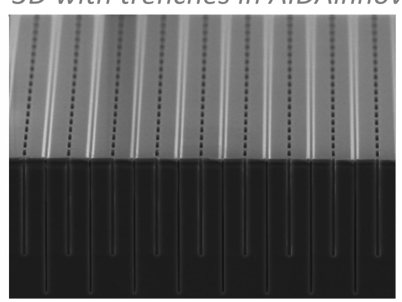

- 4D Tracking/ToF: Timing using 3D/LGAD sensors
  - Suppression of pile-up
  - Foundries CNM, FBK, HPK
  - Timing performance ( <30 ps for 50 µm sensors)
  - LGAD: Radiation hardness limited by loss of gain

| WP | Task | Title |
|---|---|---|
| 1 | 1.1 | DMAPS: spatial resolution |
| 1 | 1.2 | DMAPS: timing resolution |
| 1 | 1.3 | DMAPS: read-out architectures |
| 1 | 1.4 | DMAPS: radiation tolerance |
| 2 | 2.1 | 4D tracking: 3D sensors |
| 2 | 2.2 | 4D tracking: LGAD |
| 3 | 3.1 | Extreme fluence: wide band-gap materials (SiC, GaN) |
| 3 | 3.2 | Extreme fluence: diamond-based detectors |
| 3 | 3.3 | Extreme fluence: silicon detectors |
| 4 | 4.1 | 3D Integration: fast and maskless interconnect |
| 4 | 4.2 | 3D Integration: in house post-processing for hybridization |
| 4 | 4.3 | 3D Integration: advanced interconnection techniques for detectors |
| 4 | 4.4 | 3D Integration: mechanics and cooling |

*Compensated LGAD concepts: COMPLEX ERC*



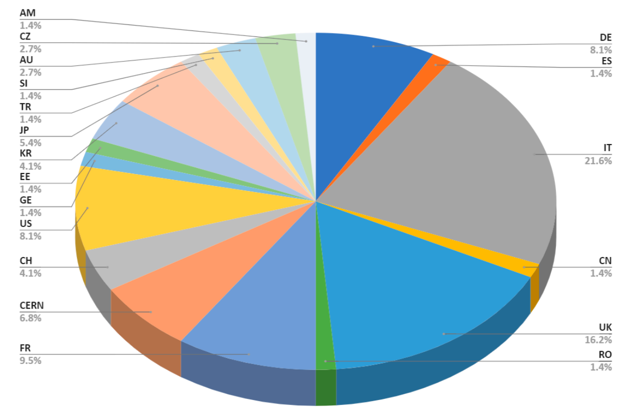

*3D with trenches in AIDAinnova*



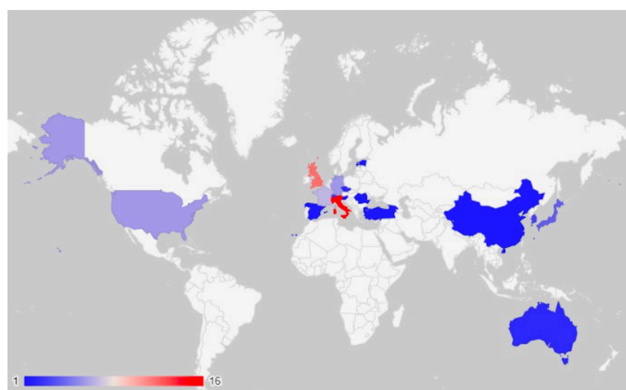
# DRD4: Photon and PID detectors – collaboration status

Photon detections and Particle Identification (PID) are essential in the majority of particle physics experiments

- **Status**: Proposal (link), collaboration approved in December 2023
- **History**: no precursor, *many with no prior experience in large R&D collaborations*
- **Collaboration** setup:
  - **Chair Collaboration Board**: Guy Wilkinson
  - **Spokepersons**: Massimiliano Fiorini (Fe)
  - **Website** : [https://drd4.web.cern.ch/](https://drd4.web.cern.ch/)
  - DRD4 **Meetings**
    - DRD4 constitutional meeting happened at CERN (23-24 January)
  - **Participants:** *74 institutes in 19 countries, 7 industrial partners*
  - **Budget**: 1.5 (1.8) MCHF/y and 100 (60) FTE existing (additionally requested)

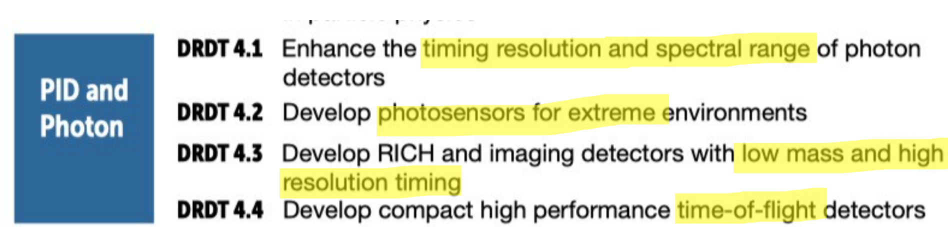



**Italy:** *BA, BO, FE, GE, MI, MIB, PD, PV, PG, TN, TS, FBK*

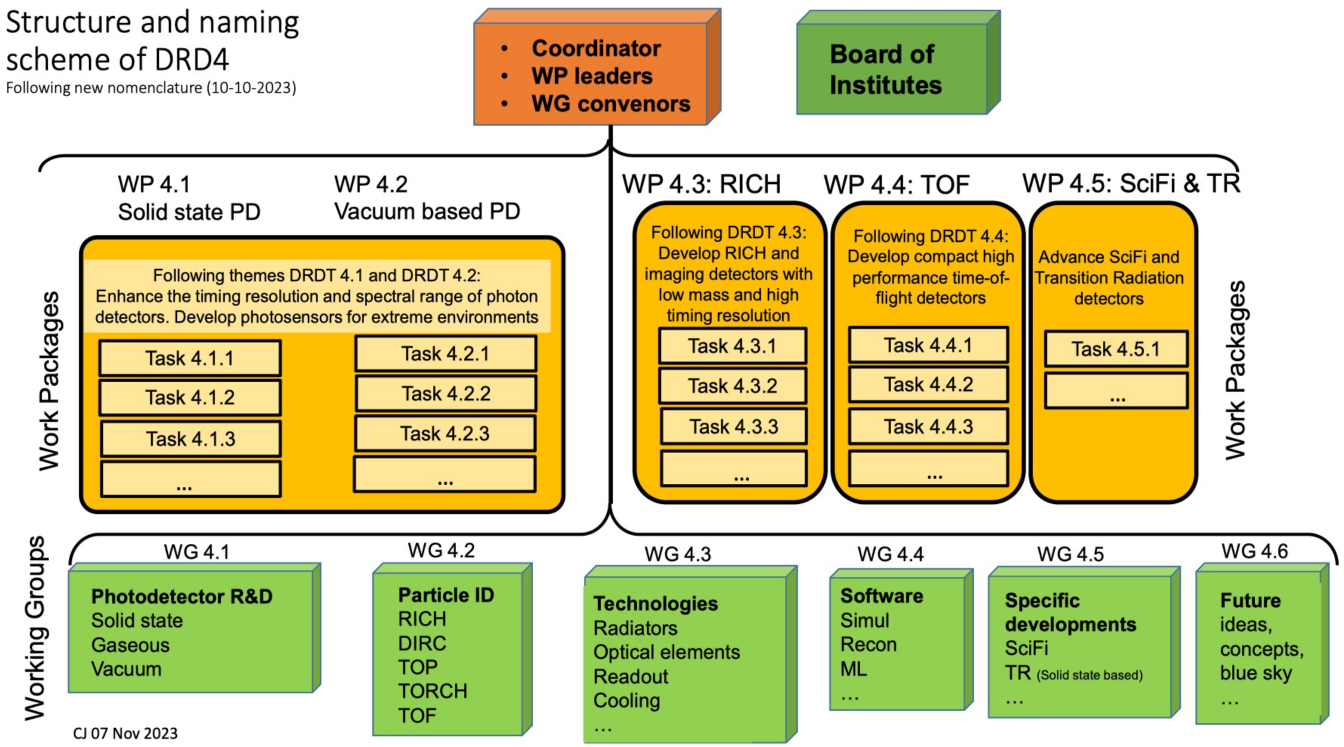


# DRD4: Photon and PID detectors – collaboration status

- **Developments** on PMTs, MCP-PMTs, SiPMs, APD, HPD, quantum devices, SciFi
  - Challenges for example for SiPMs: rad hard, dark rate, fast timing
- **Applications (and WPs)** Solid state PD, Vacuum based PD, Ring Imaging Cherenkov Detectors (RICH), Time-of-Flight (ToF), Transition Radiation detectors



| 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 |

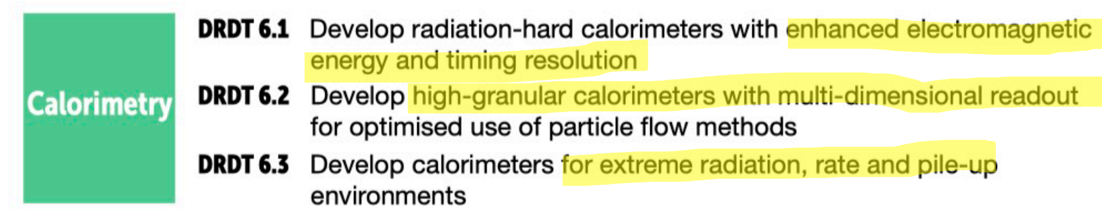


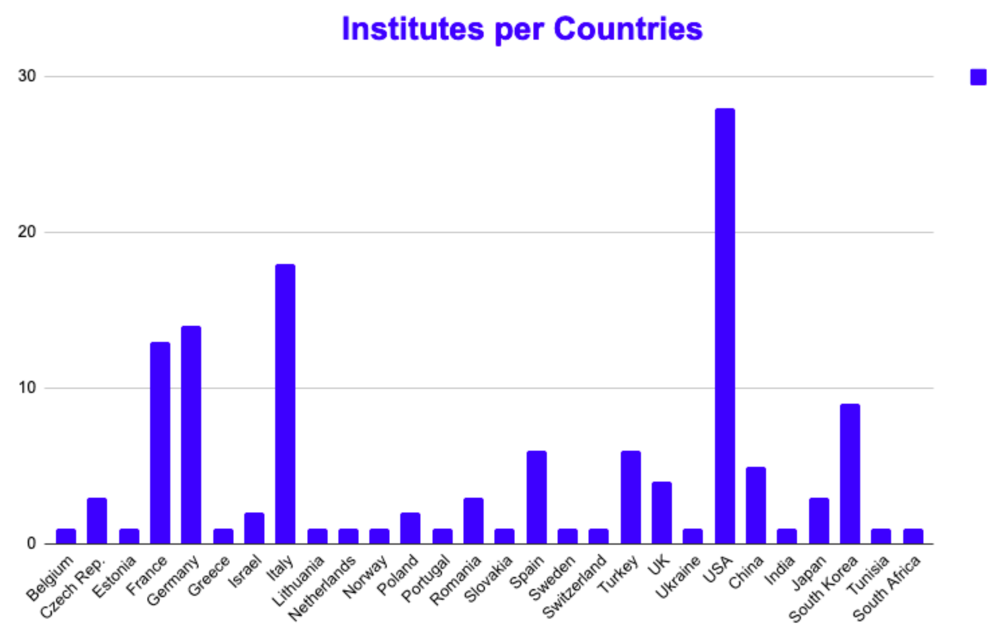

DRD4 has a dual structure

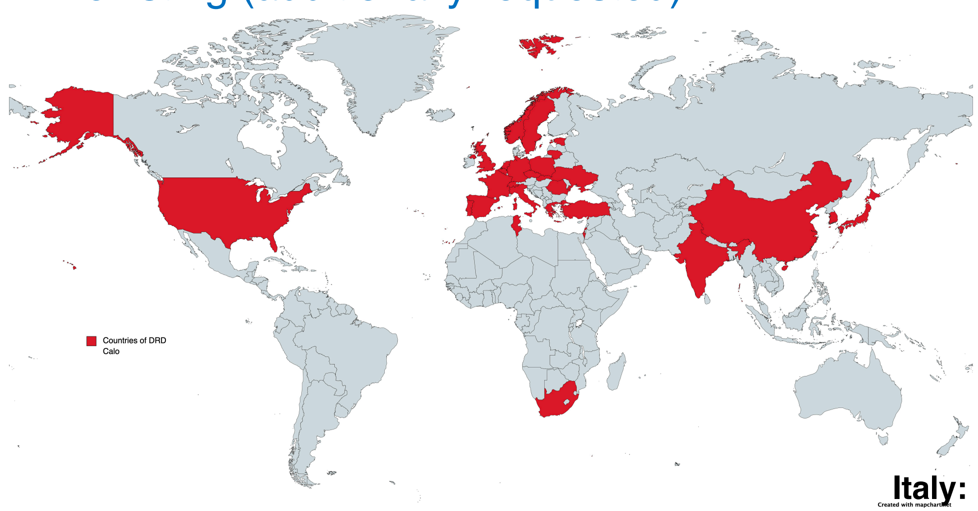
- 6 Working Groups (WGs) reflecting the main areas of R&D and serve as scientific forums
- 5 **Work Packages (WPs)** reflecting the main themes and goals described in the ECFA roadmap. WPs are **run like projects**: divided in tasks, with agreed goals, milestones, deliverables, and are jointly funded by the resources of the participants

# DRD6: Calorimetry - collaboration status

- **Status**: Proposal (link), collaboration approved in December 2023
- **History**: DRD6 emerged from CALICE and Crystal Clear (RD18) and other R&D groups
- **Collaboration** setup:
  - **Chair Collaboration Board**: Roberto Ferrari (Pv)
  - Spokesperson: Roman Poeschel
  - **Website** : *https://drd6.web.cern.ch/*
  - DRD6 **Meetings** 1st DRD6 Collaboration meeting 9-11 April link
  - **Participants:** *131 institutes in 28 countries*
  - **Budget**: 3.2 (2.4) MCHF/y and 188 (100) FTE existing (additionally requested)



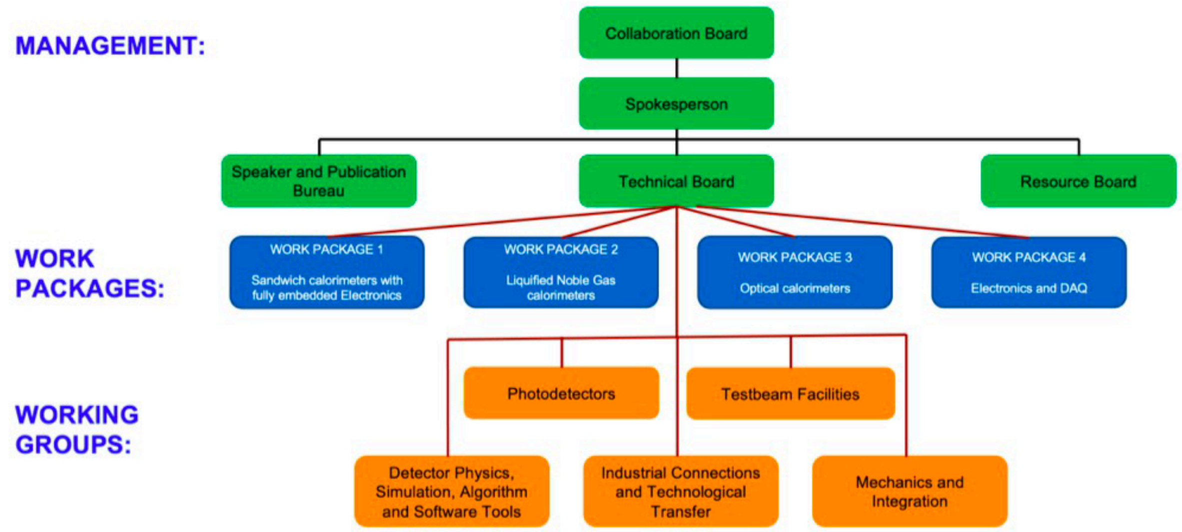



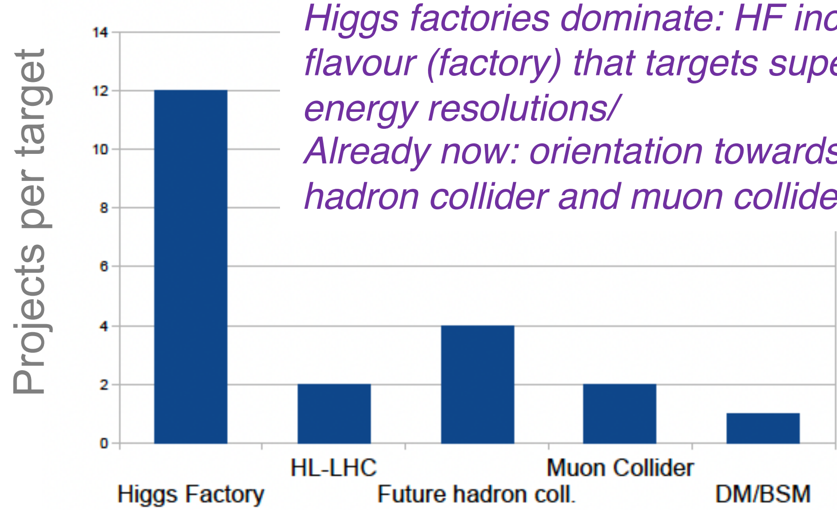

**Italy:** BA, BO, CT, FE, *LNGS, LNF, LNL, MI, MIB, NA, PD, PI, PV , RM1, TO, TS, FBK*

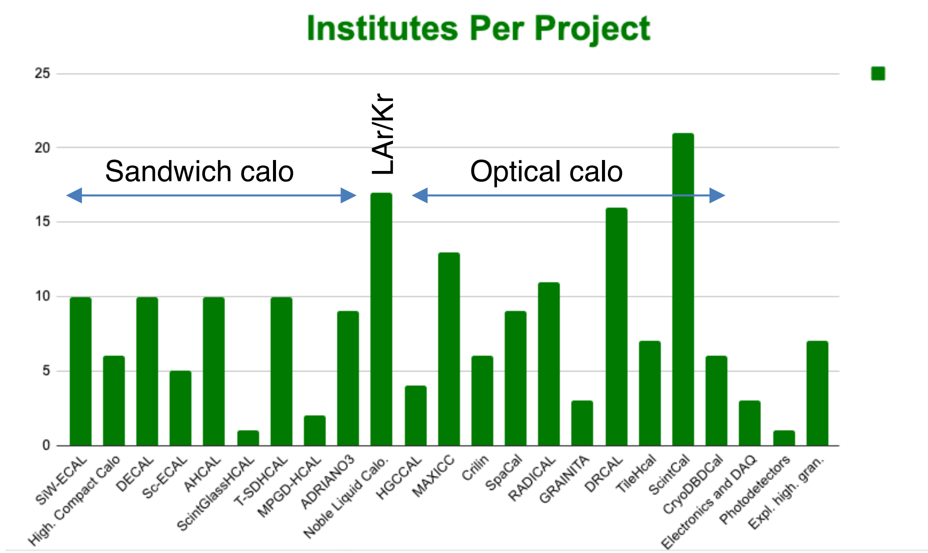
# DRD6: Calorimetry - collaboration status

- Light-weight organization structure organized in four Work Areas
  - Several projects coming from pre-existing collaborations or frame-works to cover options in configurations of elm. and hadr. segments, for different target applications and in different technologies
  - particle flow in all concepts evolving to 5D
- Several transversal activities, including dedicated calorimeter test beam line.



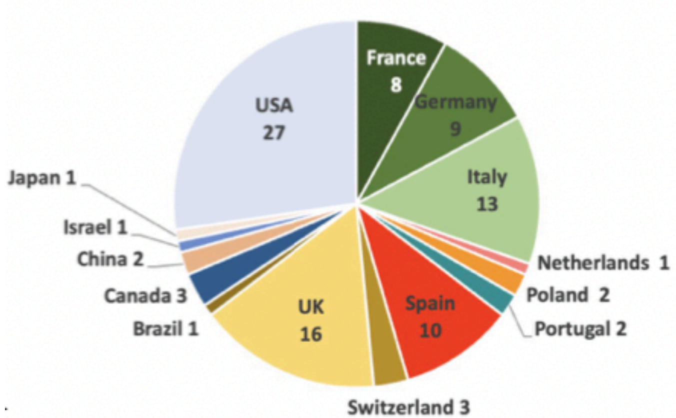

*Higgs factories dominate: HF includes heavy flavour (factory) that targets superb elm. energy resolutions/*
*Already now: orientation towards future hadron collider and muon collider*

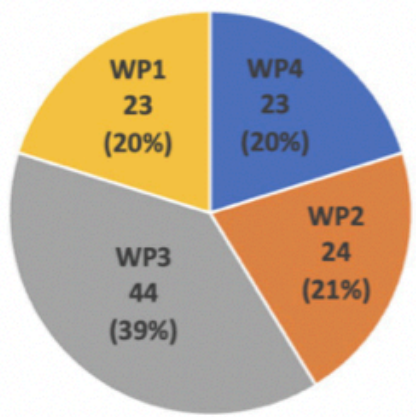


# DRD2: Liquid detectors

- Status: Proposal (link), collaboration approved in Dec. 2023.
- Collaboration setup:
  - **Chair Collaboration Board**: Walter Bonivento (Ca)
  - **Spokepersons**: --
  - **Website** : *https://drd2.web.cern.ch/*
  - DRD2 **Meetings:** February 2024 (link)
  - **Participants:** ***99*** *institutes in 15 countries.* Close coordination with CPAD in US
  - **Budget**: 2.6 (5.2) MCHF/y and 148 (157) FTE existing (additionally requested)




***Italy:*** *BO, CA, GE, GSSI, LNS, LNL, MI, NA, PD, RM3, TO, FBK*

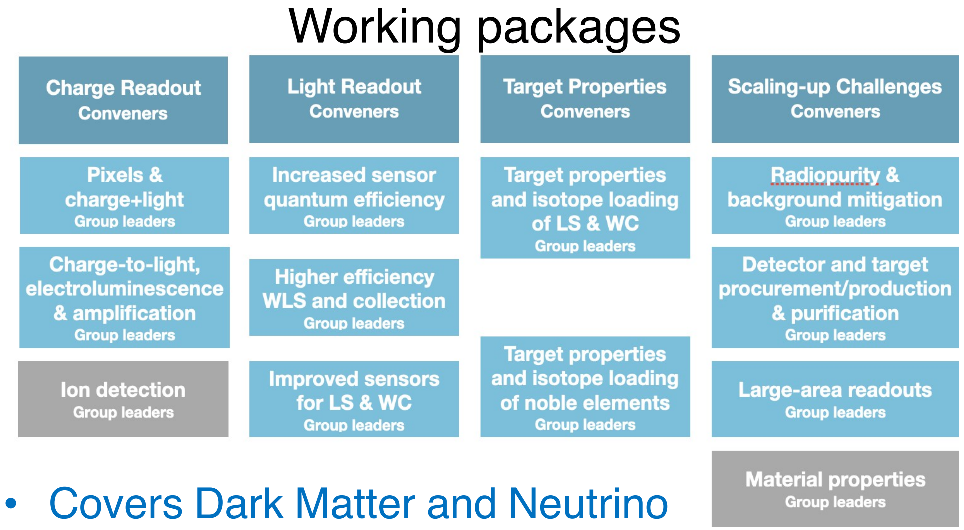
**Liquid**

**DRDT 2.1** Develop readout technology to increase spatial and energy resolution for liquid detectors

**DRDT 2.2** Advance noise reduction in liquid detectors to lower signal energy thresholds

**DRDT 2.3** Improve the material properties of target and detector components in liquid detectors

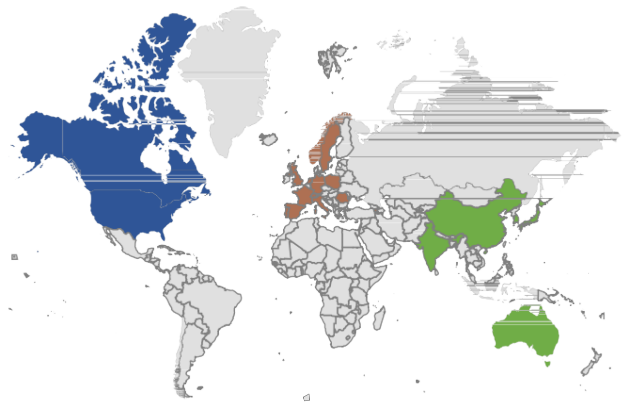
**DRDT 2.4** Realise liquid detector technologies scalable for integration in large systems



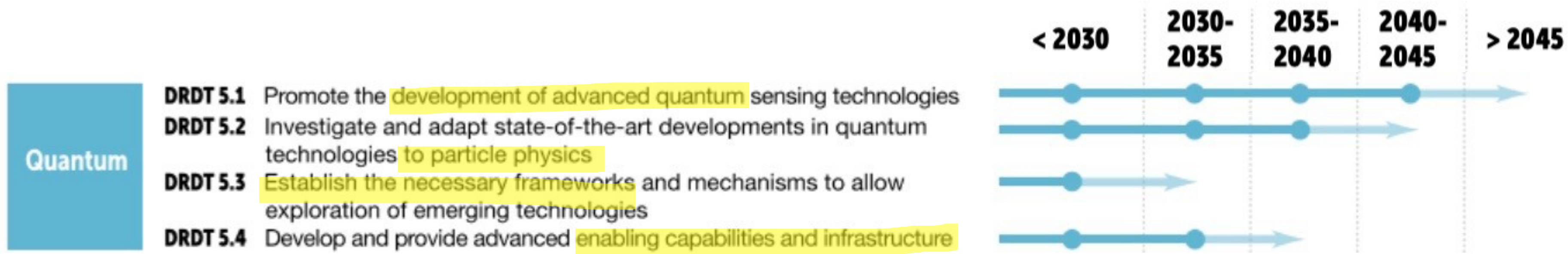

- Covers Dark Matter and Neutrino experiments, accelerator and non-accelerator-based
- Several large-scale and many small-scale experiments running or foreseen with liquid detectors
- Technology: Noble Liquids (e.g. DUNE), Water Cherenkov (e.g. Super/Hyper-K) and Liquid Scintillator with light and ionization readout
- Underground Dark Matter Experiments – small and rare signals R&D for multi-ton scale noble liquids

# DRD5: Quantum Technologies

- Quantum Technologies are a **rapidly emerging area** of technology development to study fundamental physics.
- Considering **community building** to promote developments and investigate adaptations to HEP. DRD5 may just have a platform/hub organization.
- Many different sensor and technologies being investigated: clocks and clock networks, kinetic detectors, spin-based, superconducting, optomechanical sensors, interferometry, atoms/molecules/ions, … Relatively **low TRL**.
  - Targeting Gravitational Wave, Axion, DM detection
  - Development of HEP detectors on the long term



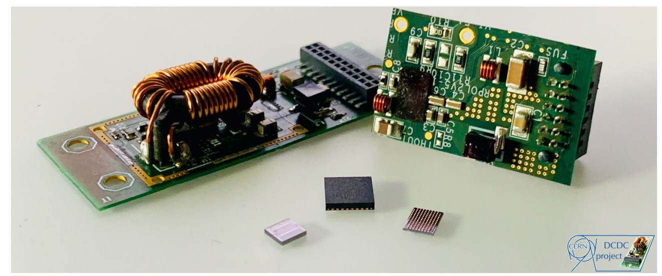
- **Status**: Proposal submitted in March, seeking for approval in June
- **Participants:** ***40 institutes in 15 countries***
  - 25 proposed contributions
  - conveners: Marcel Demarteau, Michael Doser
  - Information on personal web page of M. Doser



# DRD7: Electronics systems

- Electronic systems may be **a limiting factor** in the scientific reach of future experiments, unless significant R&D, new organisational structures, new relationship with industry are put in place.
- New R&D techniques (ultra-high granularity, precise timing information for triggering and reconstruction, more data) call for **more sophisticated** data handling, processing, low-material faster links and power dissipation.
  - → R&D must identify **an affordable compromise** between performance, complexity, power consumption and flexibility.

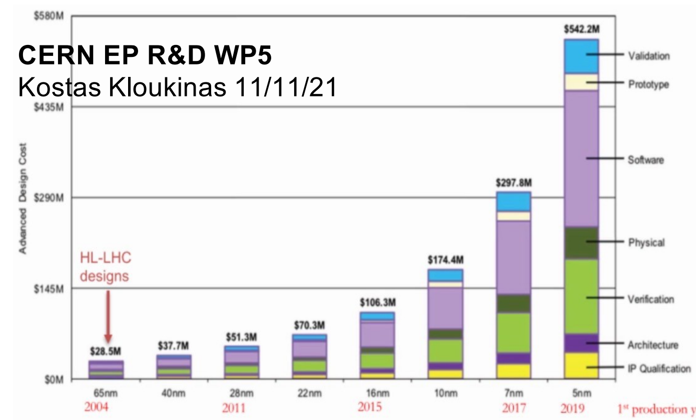
| Electronics | | |
|---|---|---|
| | DRDT 7.1 | Advance technologies to deal with greatly increased data density |
| | DRDT 7.2 | Develop technologies for increased intelligence on the detector |
| | DRDT 7.3 | Develop technologies in support of 4D- and 5D-techniques |
| | DRDT 7.4 | Develop novel technologies to cope with extreme environments and required longevity |
| | DRDT 7.5 | Evaluate and adapt to emerging electronics and data processing technologies |




Thousands of FEAST ASICs and FEASTMP modules delivered to the experiments (ATLAS ITk, New Small Wheel, CMS, Belle-II SVD,...)

- Strategic developments necessary **for systems to be used in large-scale experiments**, with synergy across many domains:
  - Already used for **example in HL-LHC** (*data links, power conversion, RD53 ASIC*) and beyond (MediPix, etc)
  - New smaller node imposes **significantly higher funds** necessary
  - **Legal topics** (NDAs, design sharing agreements, sw licenses,..)

**CERN EP R&D WP5**
Kostas Kloukinas 11/11/21

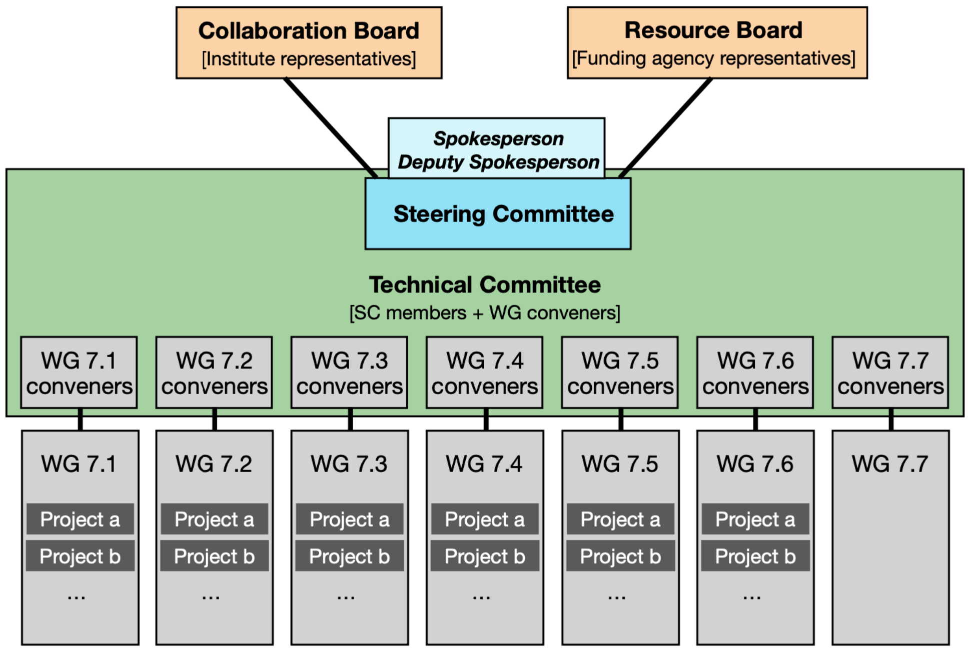


Chip Design and Manufacturing Cost under Different Process Nodes: Data Source from IBS*

NDA: non disclosure agreement

# DRD7: Electronics systems – Collaboration status

- **Status**: Proposal in discussion with the DRDC, to be approved in June 2024
- **Collaboration** being set up, for the time being:
  - **DRD7 Steering Committee**: F. Simon [KIT] (co-chair), F. Vasey [CERN] (co-chair), J. Baudot [IPHC Strasbourg], M. French [STFC RAL], R. Kluit [NIKHEF], A. Rivetti [INFN TO]
  - DRD7 **Meetings**
    - 1st workshop happened in March, 2nd workshop 25-27 September 2023
  - **Participants:** *68 institutes in 19 countries (*additional institutes have shown interest)




R&D in electronics often revolves around **major laboratories that can provide a backbone of expertise** (in particular engineering) and resources (production, expensive hardware) → Reflected in composition of Steering Committee as central executive body.
Research activities defined bottom-up by institutes coming together in Projects, grouped thematically in Working Groups.

# DRD7: Electronics systems – Collaboration status

| | | DRDT |
|---|---|---|
| **Data density** | High data rate ASICs and systems | 7.1 |
| | New link technologies (fibre, wireless, wireline) | 7.1 |
| | Power and readout efficiency | 7.1 |
| **Intelligence on the detector** | Front-end programmability, modularity and configurability | 7.2 |
| | Intelligent power management | 7.2 ↻ |
| | Advanced data reduction techniques (ML/AI) | 7.2 |
| **4D-techniques** | High-performance sampling (TDCs, ADCs) | 7.3 |
| | High precision timing distribution | 7.3 |
| | Novel on-chip architectures | 7.3 ↻ |
| **Extreme environments and longevity** | Radiation hardness | 7.4 |
| | Cryogenic temperatures | 7.4 |
| | Reliability, fault tolerance, detector control | 7.4 ↻ |
| | Cooling | 7.4 |
| **Emerging technologies** | Novel microelectronic technologies, devices, materials | 7.5 |
| | Silicon photonics | 7.5 |
| | 3D-integration and high-density interconnects | 7.5 |
| | Keeping pace with, adapting and interfacing to COTS | 7.5 |

- WG 7.1 - Data Density and Power Efficiency
- WG 7.2 - Intelligence on the Detector
- WG 7.3 - 4D and 5D Techniques
- WG 7.4 - Extreme Environments
- WG 7.5 - Backend Systems and commercial off-the-shelf Components
- WG 7.6 - Complex imaging ASICs and Technologies

WG 7.7 Tools and Technologies

↻ topics currently not explicitly addressed by projects

- **Projects in a bottom-up** approach, but ensured above threshold and fit the WGs
  - With slight remapping of activities to maximize synergies within working groups
  - Backend systems & COTS as an independent topic
  - **Transverse WG on Tools and Technologies (spare slide)**
- For each project, milestones and deliverables spelled out for 2024-26 and perspectives beyond that term
- Development of **specific electronics** covering need of R&D projects covered in respective DRDs. **Contacts defined** to interface with DRD7.

| WG7.1 | PROJECTS |
|---|---|
| Data density and power efficiency | **7.1a** Silicon Photonics transceiver development<br>**7.1b** Powering next generation detector systems<br>**7.1c** Wireless Data And Power Transmission (WADAPT) |
| **WG7.2** Intelligence on the detector | **7.2b** Radiation tolerant RISC-V SoC<br>**7.2c** Virtual electronic system prototyping |
| **WG7.3** 4D and 5D techniques | **7.3a** High performance TDC and ADC blocks at ultra-low power<br>**7.3b1** Strategies for characterizing and calibrating sources impacting time measurements<br>**7.3b2** Timing distribution techniques |
| **WG7.4** Extreme environments | **7.4a** Device modelling and development of cryogenic CMOS PDKs and IP<br>**7.4b** Radiation resistance of advanced CMOS nodes<br>**7.4c** Cooling and cooling plates |
| **WG7.5** Backend systems and COTS components | **7.5a** DAQOverflow<br>**7.5b** From FE to BE with 100GbE |
| **WG7.6** Complex imaging ASICs and technologies | **7.6a** Common access to selected imaging technologies<br>**7.6b** Shared access to 3D integration |
| **WG7.7** Tools and Technologies | **7.7** A Hub-based structure for ASICs developments |

# DRD8: Mechanics and integration

- **Target**: Mechanical support and structures, cooling, magnets and management of radiation environment
  - DRDTs are quite diverse
  - Some topics are very closely connected to the genuine DRDs, where the technology is developed (DRDT 8.3)

- **LoI sent,** proposal for the next 3-4 years in preparation:
  - First meeting on December
  - 22 contributing institutes in 7 countries
- Currently investigating opportunities for a joint effort on common aspects, such as materials, assembly techniques, cooling:
  - WG 8.1 Global/System Design and Integration
  - WG 8.2 Low Mass Mechanics and thermal management
  - WG 8.3 Detector Cooling
  - WG 8.4 Design and Qualification Tools

Integration

**DRDT 8.1** Develop novel magnet systems

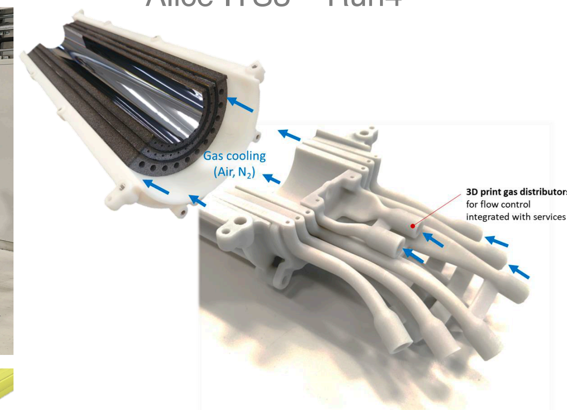
**DRDT 8.2** Develop improved technologies and systems for cooling

**DRDT 8.3** Adapt novel materials to achieve ultralight, stable and high precision mechanical structures. Develop Machine Detector Interfaces.

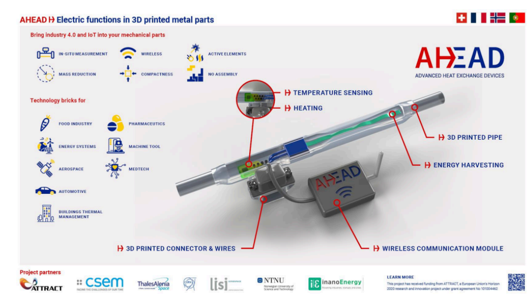
**DRDT 8.4** Adapt and advance state-of-the-art systems in monitoring including environmental, radiation and beam aspects

Cold detectors: Kr / sKr facility

Warm detector: air cooling
Alice ITS3 – Run4

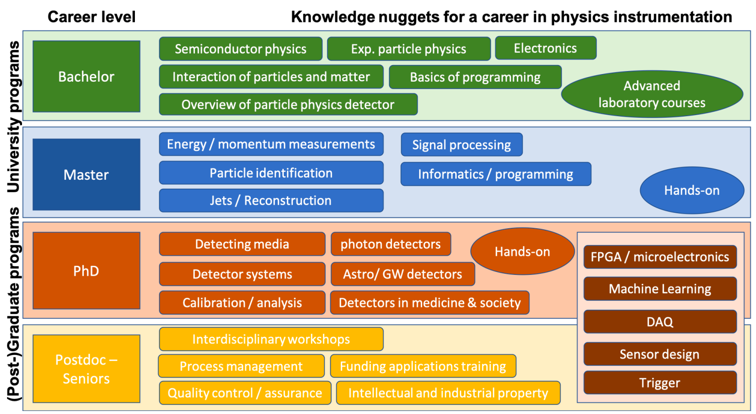



Tracker in the beam pipe
Alice Iris – HL-LHC




Additive Manufacturing (3D printing)

# TF9 on Training





- One of the Recommendation of the detector R&D roadmap stresses the need to **train and maintain a work force** in instrumentation for Particle Physics, targeting primarily graduate students and Early Career Researchers (ECR).
  - Increase **participation of young scientists** in leading-edge instrumentation R&D
  - **foster growth of** future HEP instrumentation **experts** who can compete for permanent positions, **mandatory to the success** as well as the long-term health **of experimental particle physics as a whole**.

- **ECFA training panel** (link) has been setup (chairs: E. Garutti and J. Collot) with Goals:
  - Enhance the **synergies** between existing training programmes
  - creation of a **European master's degree program in HEP instrumentation**

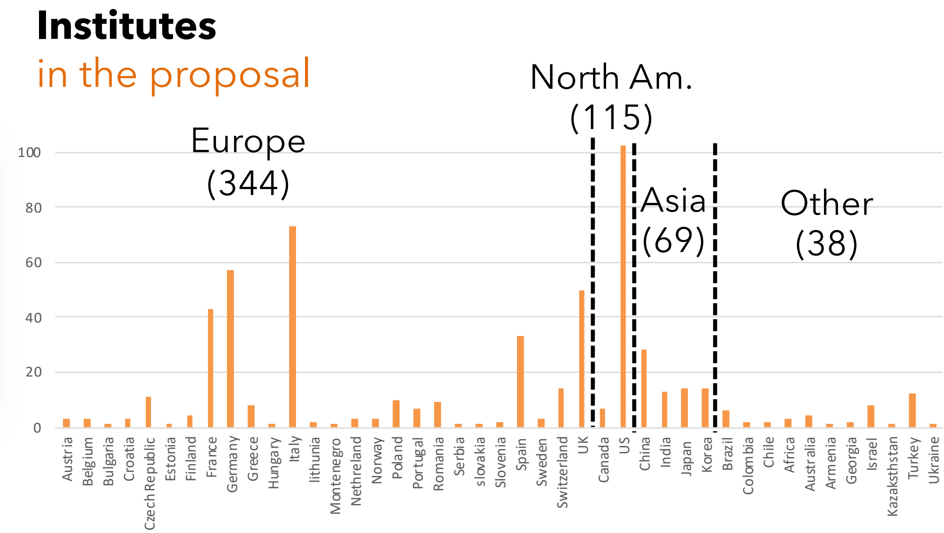

# Final considerations

What's next; future is now!

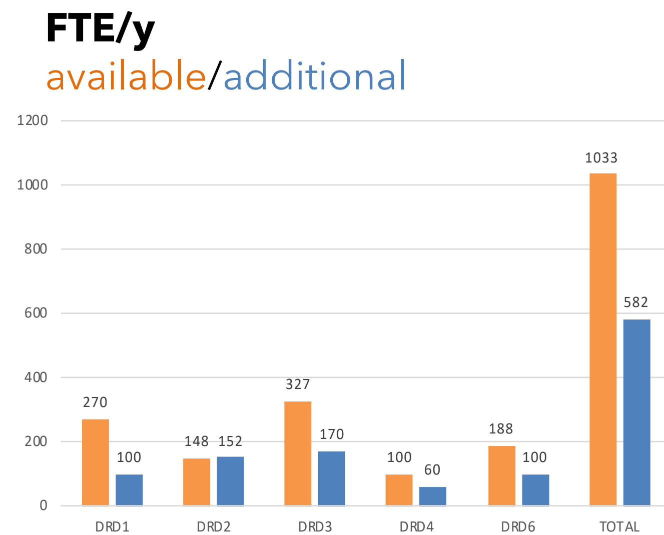
# DRDs: Summary of contributions

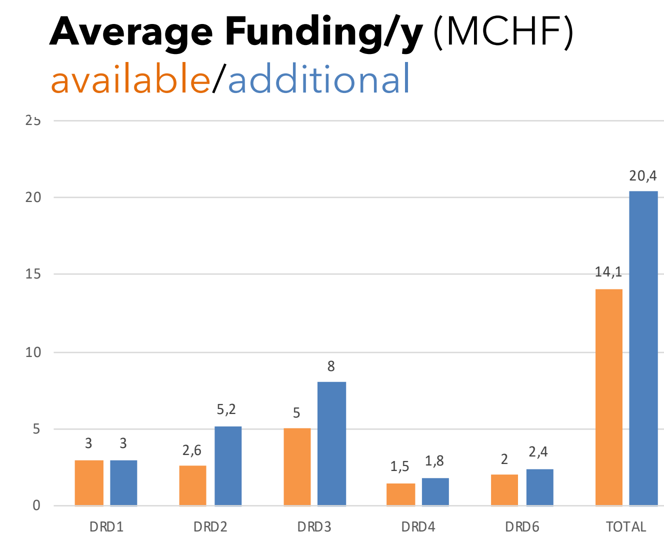
- Participating institutes in DRD1-2-3-4-6
  - same institutes can contribute in different DRDs
  - **Italy between 10-20%**

| | % Italian Inst. |
|---|---|
| DRD1 | 0.11 |
| DRD2 | 0.13 |
| DRD3 | 0.10 |
| DRD4 | 0.22 |
| DRD6 | 0.14 |




- Expected FTE/y & Funding/y
  - available ≃ current funding, average over 3 first years
  - additional ≃ requested to fulfil program, based on a survey → uneven answers from institutes, not a commitment
- Need consolidation in the MoUs



FYI-only

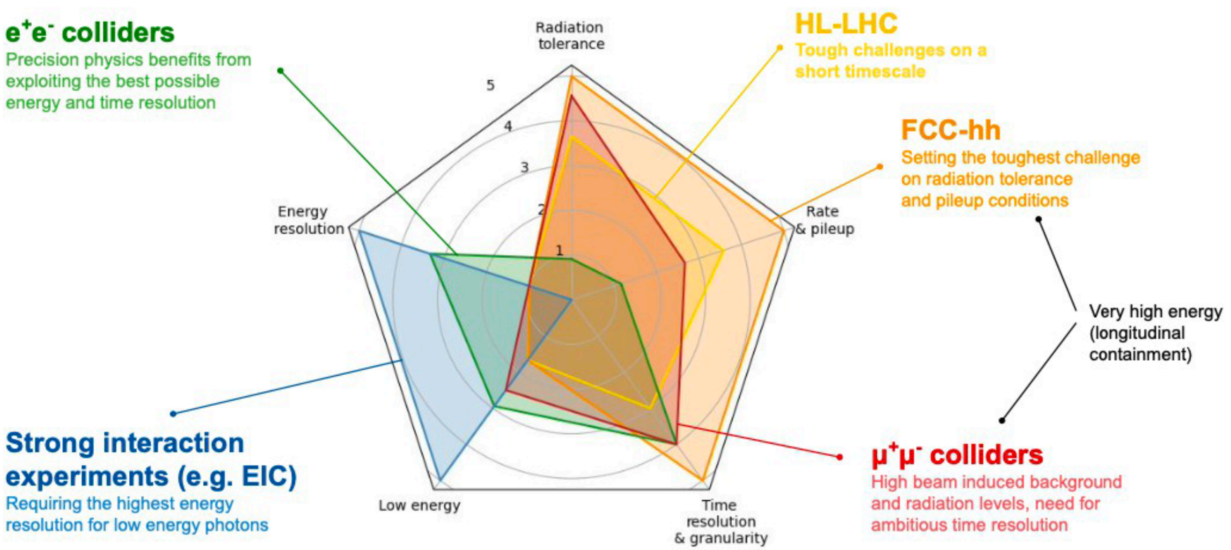
# DRDs: Memorandum of Understanding

- All institutes of one DRD collaboration shall sign a **“light-weight” MoU**
  - Does not contain commitments to strategic funds
  - Defines **Common Fund**, if agreed by the respective DRD Collaboration
  - Covers **IP topics**, how to handle involvement of industry (In that case very similar as the current existing MoUs of RD50/51)
  - MoU Template will be provided by CERN (currently being negotiated with legal office, KT, DRC,..)

- **Strategic funding** will be agreed upon in **Annexes** to this light-weight MoU
  - One Annex per Work Package, signed by the FAs of the institutes involved in the respective WP

# Conclusions

- New **Detector R&D (DRD) collaborations** are now in place* to pave the way for the next decades.
  - The main goal is **instrumentation not to be the limiting factor** to meet the needs of the long-term particle physics program.
  - Collaborations will bring to **maturity a spectrum of techniques** where experiments will follow-up to their own needs.




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

* **Quantum sensors** (DRD5), **Electronics** (DRD7) in approval **Integration** (DRD8) at LoI

# Conclusions

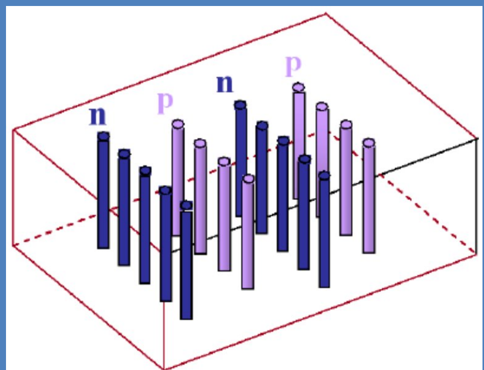
- Is too early to engage in such a huge R&D plan?

  *[i.e. maybe worrisome for the success of Phase2 upgrades running late??]*

# From R&D to HEP: one example

## Concept – Proof of principle

Late 90's




S. Parker et. Al. NIMA 395 (1997) 328, https://doi.org/10.1016/S0168-9002(97)00694-3

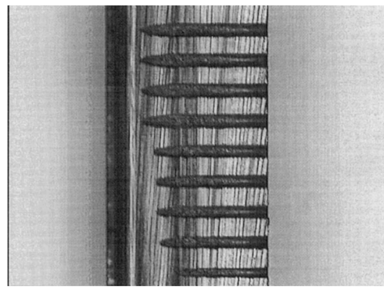
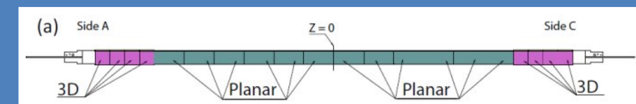


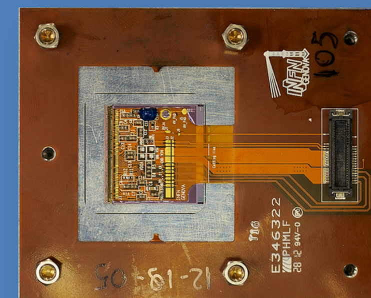
Fig. 4. A view of part of a set of etched holes, showing the increased depth reached by holes of larger diameters. The wafer was 540 μm thick and the etch time was 5 h. The photo-mask hole diameters from top to bottom are: four holes at 30 μm, four at 25 μm, and one at 20 μm.

C. Kenney, S. Parker, J. Segal and C. Storment,, IEEE Trans. Nucl. Sci. 46 (1999) 1224.

## First applications in HEP

2014-18



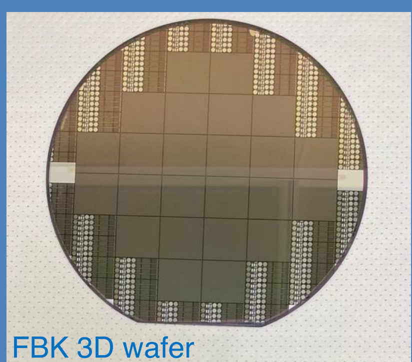



**ATLAS Innermost layer,** large eta,
B. Abbot et al, *JINST 13 (2018) no.05, T05008*

*Forward detectors in Phase–I*
- ***AFP in ATLAS***
- ***PPS in CMS***

## Key detector in HEP

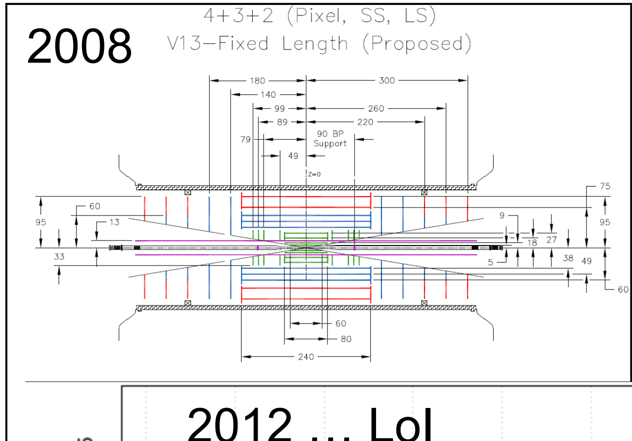
2024-2028

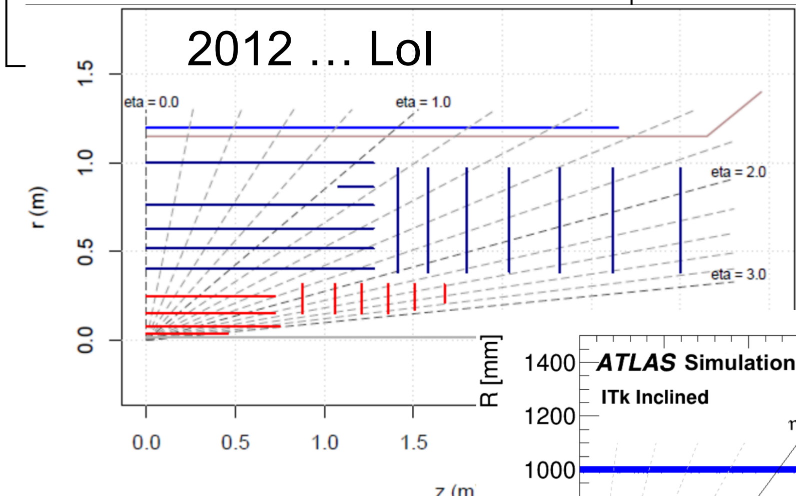




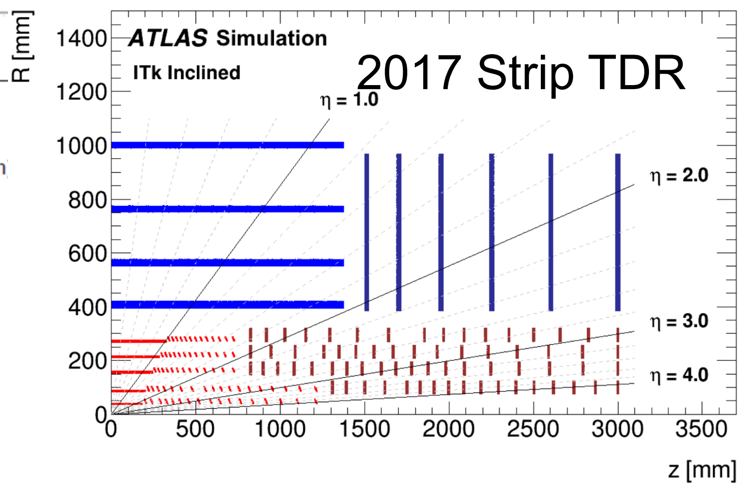
3D sensor technology:
A very long way between first ideas and key applications in an experiment!

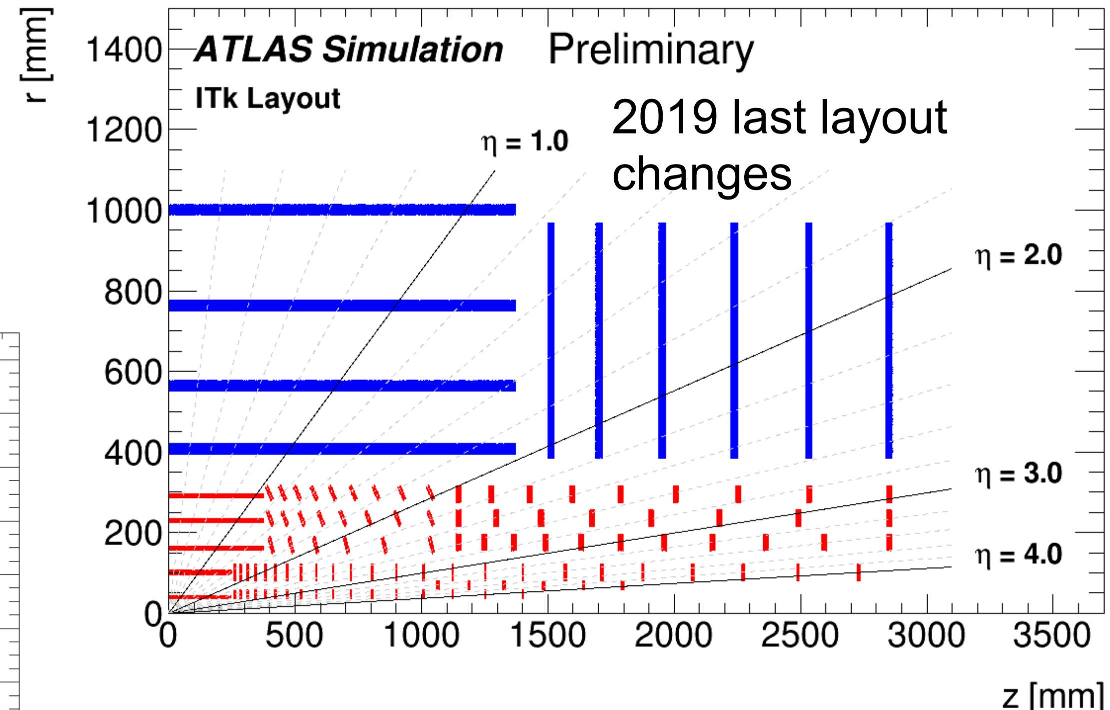
# From ideas to HEP: one example




- ATLAS Inner tracker layout for Phase-2 had a very long story (intrinsically connected to technology, bkg…):
  - Discussion started in (at least) 2006 → Layout Advisory Committee → UTOPIA → Upgrade Layout TF, up to the ITk Layout Task force (2016) to finalize Layout for TDRs. Last minimal changes in 2019.



# Conclusions

- Is too early to engage in such a huge R&D plan?
  - **Not really, it takes years (decades) to bring ideas into reality!**

- A key message from the ECFA recommendations is to **sustain the careers of R&D experts:** " *Attract, nurture, recognise and sustain the careers of R&D experts*"**.** There are several competing fields outside HEP!
  - No instrumentation → no "Physics" reach

- To get people engaged, in particular the Early career scientists, it is important also to get **intermediate experimental setups** where the new technologies in their infant status may be tested.
  - HL-LHC LS3+ is certainly part of the experimental setting where ideas can be tested
  - Other setups are certainly welcome!

# References


- [1] T. Bergauer, TIPP 2023
- [2] D. Cotardo, 13th ICFA Seminar on Future Perspectives in HEP, 2023
- [3] N. Pastrone, CSN1 March 24
- [4] DRDC open session,  March 2024, *https://indico.cern.ch/event/1356910/*

SPARE

# Roadmap implementation plan: Review Roles

- Detector R&D Committee (**DRDC**) functions:
  - The **DRDC reviews proposals in terms of their scientific scope**, **milestones and technical feasibility, with the help of topic-specific experts from the EDP**, and critically examines all financial aspects of the strategic R&D part of the DRD programme.
    - **evaluate the initial request for DRD resources** with a focus on the required effort and how it matches the pledges by participating institutes (paying particular attention to justification and to existing staff, infrastructures and funding streams);
    - **decide whether to recommend approval**
  - **conduct reviews of the progress of the DRD collaborations by asking for annual status reports**
  - be the single **body that interacts with the existing CERN committee structure** for the purposes of approvals, reporting, etc.

- ECFA Detector Panel (**EDP**) expanded role would:
  - provide direct input on DRD proposals, **through the appointment of members to the DRDC**
    **→ Three members and respective chairmen (ex-officio) in both EDP and DRDC**

SPARE

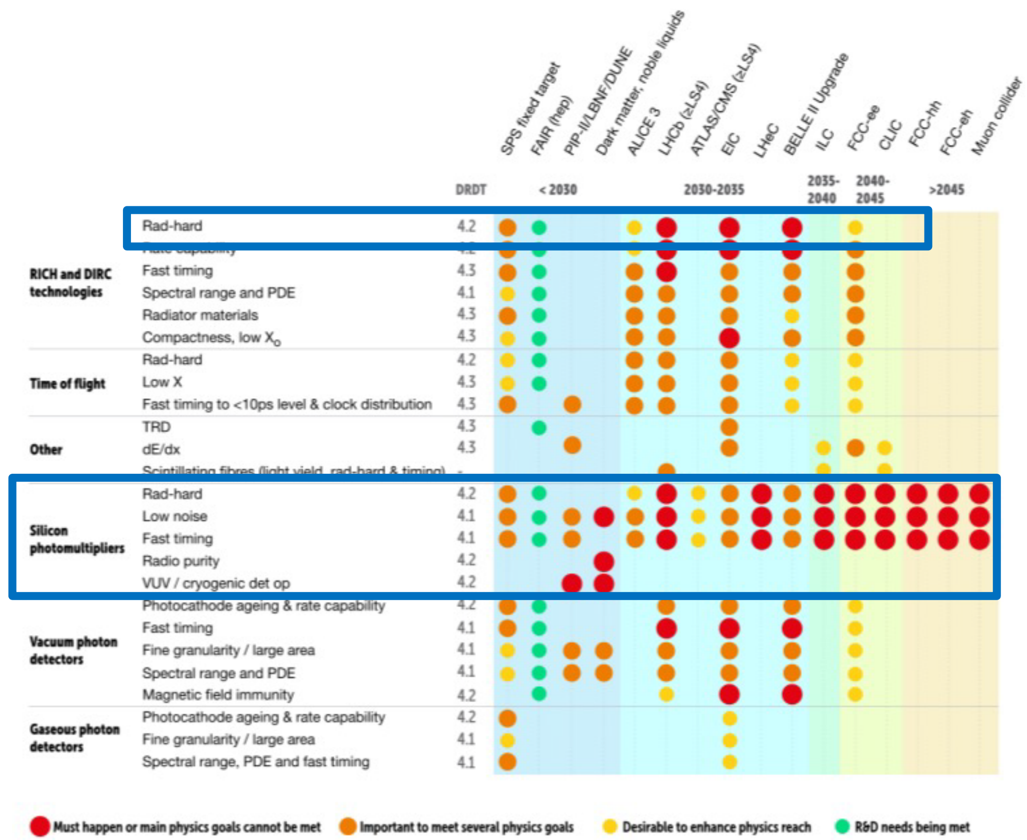
# DRD7: Electronics systems – Collaboration status

- **Need for collaboration** is particularly acute for micro-electronics technologies, where the complexity and cost of development are extremely high and continue to increase for every new generation. → This has shown to **be critical in several ASICs for Phase-2** projects.

- DRD7 will set up a task force that will propose an implementation solution for a **Hub-based structure for ASICs developments in the HEP community** (top-down approach for this area)
  - To establish and maintain access, for the DRD community, to state-of-the art microelectronics **technologies and EDA software** tools through regional collaboration and coordination (the Hubs)
  - To ensure a **professional approach to prototyping** and production fabrication cycles by delivering best practice in design, verification and foundry submission
  - To facilitate collaborative work across **distributed design teams** establishing the necessary infrastructure for IP block sharing,
  - To ensure that projects follow **rigorous project review and submission** processes to manage risks and control changes in projects

# DRD4: Photon and PID detectors

- Photon detections and Particle Identification (PID) are essential in the majority of particle physics experiments
  - Domain of application and PID performance is growing with the available photodetectors (SiPM may revolutionize the field)
  - As for other detectors, the inclusion of precise timing information may bring a breakthrough in performance
- **Developments** on PMTs, MCP-PMTs, SiPMs, APD, HPD, quantum devices, SciFi
  - Challenges for example for SiPMs: rad hard, dark rate, fast timing
- **Applications** in Ring Imaging Cherenkov Detectors (RICH), Time-of-Flight (ToF), Transition Radiation detectors
- Connection to almost every other DRD collab. (gas, Silicon, Calo, electronics, SiPM at cryogenic temp.)




| 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 |

# DRD6: Calorimetry

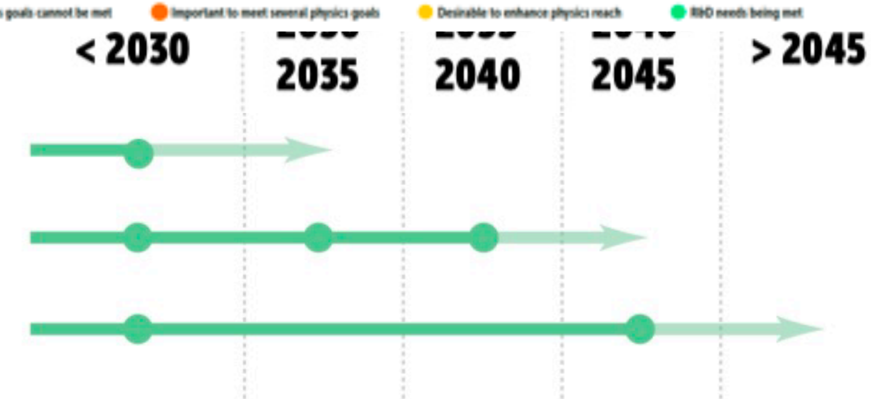
- R&D in calorimetry has a particularly long lead-time due
  - Many technology developments (gas, scintillator or Silicon-based readout)
  - Large and challenging prototype setups even in early stages
  - Enhance 5D reconstruction techniques


**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

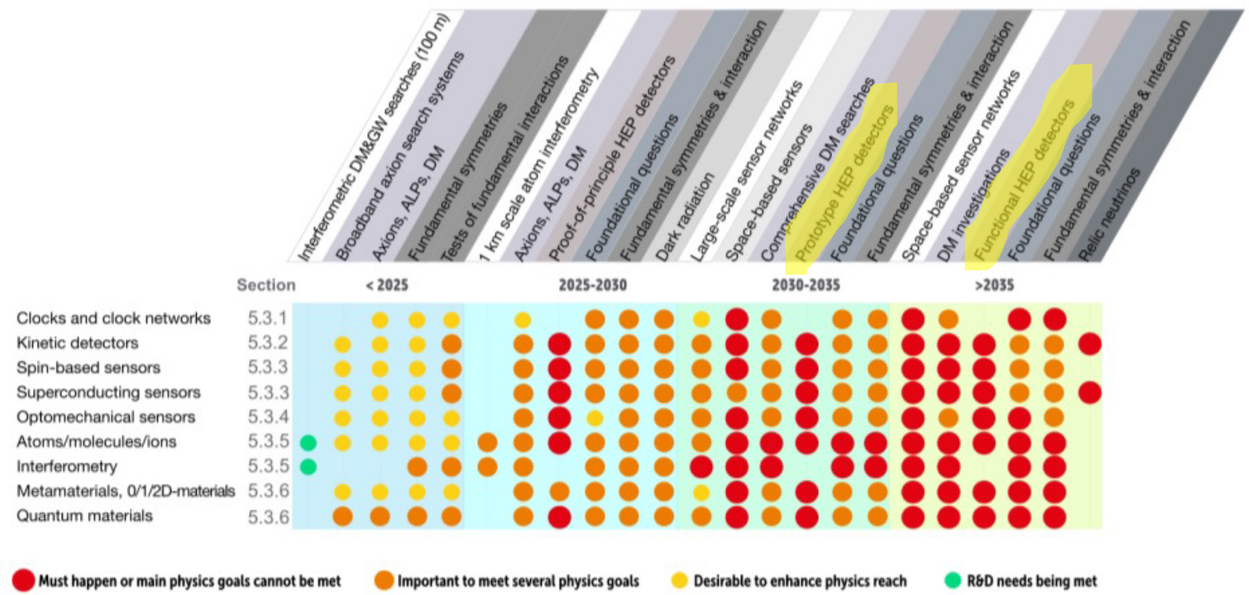


# DRD5: Quantum Technologies

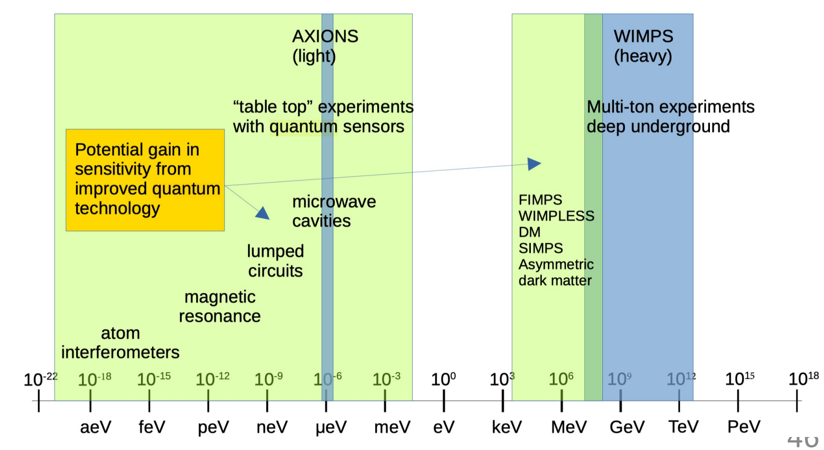
- Quantum Technologies are a **rapidly emerging area** of technology development to study fundamental physics
  - Targeting Gravitational Wave, Axion, DM detection
  - development of HEP detectors on the long term

- Many different sensor and technologies being investigated: clocks and clock networks, kinetic detectors, spin-based, superconducting, optomechanical sensors, interferometry, atoms/molecules/ions, …

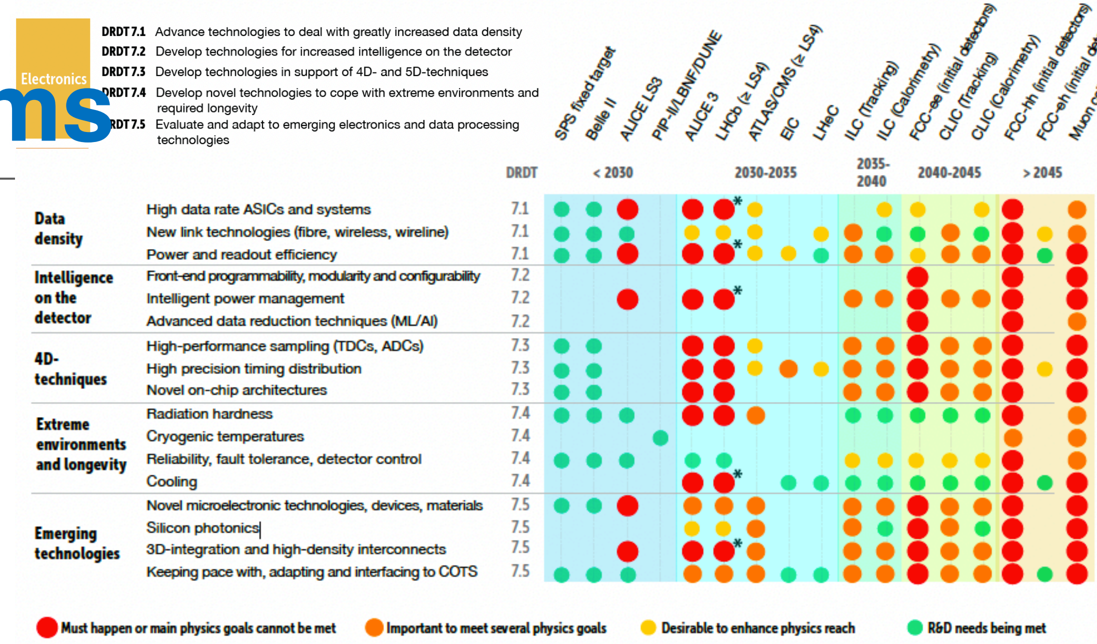
- Several initiatives started at CERN, DESY, UK,…



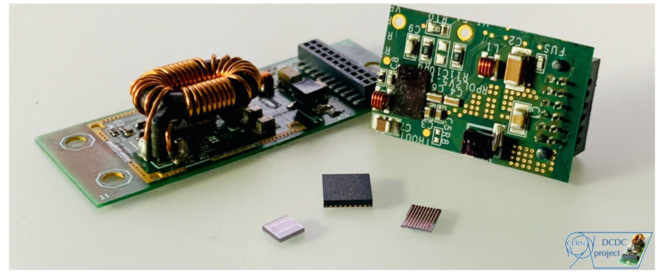

Example: potential mass ranges that quantum sensing approaches open up for Axion searches (from: ECFA roadmap)



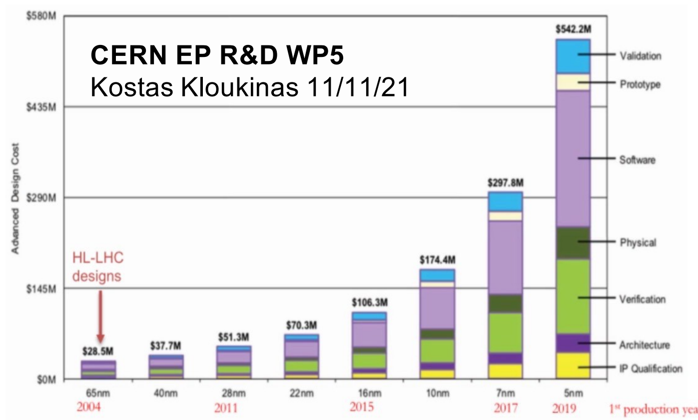
# DRD7: Electronics systems




- Next generations of electronic systems performance may be **a limiting factor** in the scientific reach of future experiments, unless significant R&D, new organisational structures, new relationship with industry are put in place.
- New techniques (ultra-high granularity, precise timing information for triggering and reconstruction, more data) need **more sophisticated data handling, processing, low-material faster links and power dissipation.**
  - Additional HEP requirements: **radiation and magnetic fields** (niche and low volume market only)
  - Data selection and reduction will increasingly be addressed by intelligent processors close to the front end, reducing data movement.
  - → R&D must identify **an affordable compromise** between performance, complexity, power consumption and flexibility.
- Strategic developments necessary **for systems to be used in large-scale experiments**, with synergy across many domains:
  - Already used for example in HL-LHC (*data links, power conversion, RD53 ASIC*) and beyond (MediPix, etc)
  - New smaller node imposes **significantly higher funds** necessary
  - Legal topics (NDAs, design sharing agreements, sw licenses,..)




Thousands of FEAST ASICs and FEASTMP modules delivered to the experiments (ATLAS ITk, New Small Wheel, CMS, Belle-II SVD,...)




Chip Design and Manufacturing Cost under Different Process Nodes: Data Source from IBS*