

# ECFA detector R&D roadmap for HEP

9.9.2022

Susanne Kuehn, CERN

CENTRO DE CIENCIAS DE BENASQUE PEDRO PASCUAL

**XLIX International Meeting on  
Fundamental Physics (IMFP22)**

*BENASQUE (SPAIN), 5-10 SEPTEMBER 2022*

# Overview



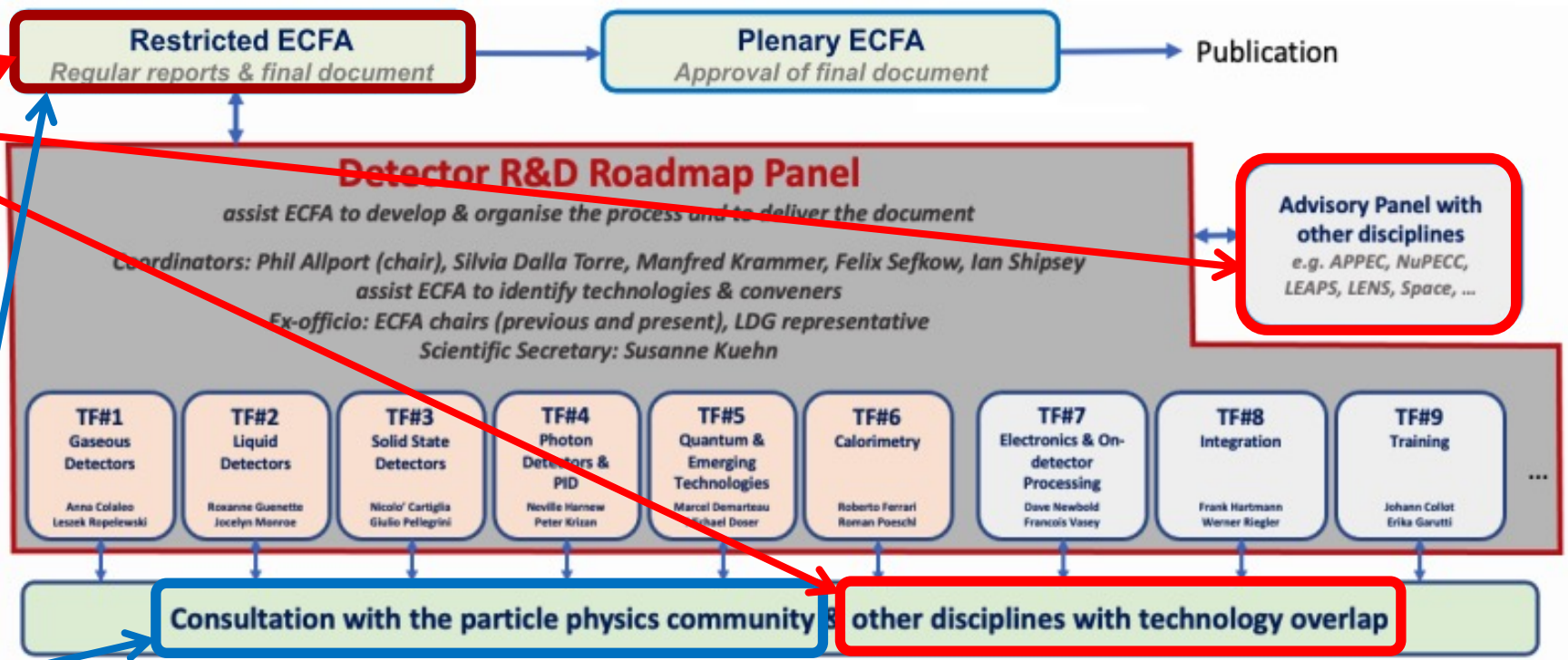
- The ECFA Detector R&D Roadmap process
- Overview of future facilities considered in the Roadmap
- Examples on R&D of several detector technologies
  - Gaseous, Liquid and Solid State Detectors
  - Calorimetry, Particle identification and photon detectors, Quantum and emerging technologies
  - Microelectronics, Integration, Training
- Observations – General Strategic Recommendations
- Implementation plan
- Summary



# ECFA Detector R&D Roadmap process

“Organised by ECFA, a roadmap should be developed by the community to balance the detector R&D efforts in Europe, taking into account progress with emerging technologies in adjacent fields” \*

The community should define a global detector R&D roadmap that should be used to support proposals at the European and national levels” \*



ECFA Detector R&D Roadmap Panel web pages at:  
<https://indico.cern.ch/e/ECFADetectorRDRoadmap>

\* 2020 European Particle Physics Strategy Update  
<https://europeanstrategyupdate.web.cern.ch/>



Process organised by Panel and nine Task Forces with input sessions and open symposia, surveys with wide community consultation



# ECFA Detector R&D Roadmap: All involved



**Process involved: 67 authors; 12 expert Input Session speakers; ECFA National Contacts; respondents to the Task Force surveys; 121 Symposia presenters; 1359 Symposia attendees and 44 APOD TF topic specific contacts.**

**ECFA** European Committee for Future Accelerators

Two Days of Input Sessions

Input Session speakers provided detailed specifications and continued giving support for the process ... particularly for checking if there were any unmet detector R&D needs for the ESPP identified programme which may have been overlooked in the symposia programmes.

Speaker	Presentation Topic
1 Chris Parkes	Detector R&D requirements for HL-LHC
2 Luciano Musa	Detector R&D requirements for strong interaction experiments at future colliders
3 Johannes Bernhard	Detector R&D requirements for strong interaction experiments at future colliders
4 Frank Simon	Detector R&D requirements for future linear high energy e+e- machines
5 Mogens Dam	Detector R&D requirements for future circular high energy e+e- machines
6 Martin Aleksa	Detector R&D requirements for future high-energy hadron colliders
7 Nadia Pastrone	Detector R&D requirements for muon colliders
8 Marzio Nessi	Detector R&D requirements for future short and long baseline neutrino experiments
9 Maarten De Jong	Detector R&D requirements for future astro-particle neutrino experiments
10 Laura Baudis	Detector R&D requirements for future dark matter experiments
11 Cristina Lazzeroni	Detector R&D requirements for future rare decay processes experiments
12 Alexandre Obertelli	Detector R&D requirements for future low energy experiments

**ECFA National Contacts**

Country	Name	Country	Name
Austria	Manfred Jeitler	Finland	Panja Lukka
	Gilles De	France	Didier Contardo
Belgium	Lentdecker	Germany	Lutz Feld
	Venelin	Greece	Dimitris Loukas
Bulgaria	Koshuharov	Hungary	Dezso Varga
Croatia	Tome Anticic	Italy	Nadia Pastrone
Cyprus	Panos Razis	Israel	Erez Etzion
Czech Republic	Tomáš Davidek	Netherlands	Niels van Bakel
Denmark	Mogens Dam	Norway	Gerald Eigen
		Poland	Marek Idzik
		Portugal	Paulo Fonte
		Romania	Mihai Petrovici
		Serbia	Lidija Zivkovic
		Slovakia	Pavol Striznec
		Slovenia	Gregor Kramberger
		Spain	Mary-Cruz Fouz
		Sweden	Christian Ohm
		Switzerland	Ben Kilminster
		Turkey	Kerem Cankocak
United-Kingdom	Jacopo Vivarelli		
Ukraine	Nikolai Shulga		
CERN	Christian Joram		

Thank you for all input, contributions and comments!

- Task Force convenors, Task Force expert member*  
*Detector R&D Roadmap members of the ECFA*
- Task Force 1 Gaseous Detectors:** Anna Colaleo<sup>1</sup>, Leszek Leszek<sup>2</sup>, Klaus Dehmelt<sup>3</sup>, Barbara Liberti<sup>4</sup>, Maxim Titov<sup>5</sup>, Joao Veloso<sup>6</sup> (*Expert Members*)
- Task Force 2 Liquid Detectors:** Roxanne Guenette<sup>7</sup>, Jocelyn Monroe<sup>8</sup> (*Conveners*)  
Auke-Pieter Colijn<sup>9</sup>, Antonio Ereditato<sup>10,11</sup>, Ines Gil Botella<sup>12</sup>, Manfred Lindner<sup>13</sup> (*Expert Members*)
- Task Force 3 Solid State Detectors:** Nicolo Cartiglia<sup>14</sup>, Giulio Pellegrini<sup>15</sup> (*Conveners*)  
Daniela Bortoletto<sup>16</sup>, Didier Contardo<sup>17</sup>, Ingrid Gregor<sup>18,19</sup>, Gregor Kramberger<sup>20</sup>, Heinz Pernegger<sup>2</sup> (*Expert Members*)
- Task Force 4 Particle Identification and Photon Detectors:** Neville Harnew<sup>16</sup>, Peter Krizan<sup>20</sup> (*Conveners*)  
Ichiro Adachi<sup>21</sup>, Eugenio Nappi<sup>1</sup>, Christian Joram<sup>2</sup>, Christian Schultz-Coulon<sup>22</sup> (*Expert Members*)
- Task Force 5 Quantum and Emerging Technologies:** Marcel Demarteau<sup>23</sup>, Michael Doser<sup>2</sup> (*Conveners*)  
Caterina Braggio<sup>24</sup>, Andy Geraci<sup>25</sup>, Peter Graham<sup>26</sup>, Anna Grasselino<sup>27</sup>, John March Russell<sup>16</sup>, Stafford Withington<sup>28</sup> (*Expert Members*)
- Task Force 6 Calorimetry:** Roberto Ferrari<sup>29</sup>, Roman Poeschl<sup>30</sup> (*Conveners*)  
Martin Aleksa<sup>2</sup>, Dave Barney<sup>2</sup>, Frank Simon<sup>31</sup>, so Tabarelli de Fatis<sup>32</sup> (*Expert Members*)
- Task Force 7 Electronics:** Dave Newbold<sup>33</sup>, Francois Vasey<sup>2</sup> (*Conveners*)  
Niko Neufeld<sup>2</sup>, Valerio Re<sup>29</sup>, Christophe de la Taille<sup>34</sup>, Marc Weber<sup>35</sup> (*Expert Members*)
- Task Force 8 Integration:** Frank Hartmann<sup>35</sup>, Werner Riegler<sup>2</sup> (*Conveners*)  
Corrado Gargiulo<sup>2</sup>, Filippo Resnati<sup>2</sup>, Herman Ten Kate<sup>36</sup>, Bart Verlaet<sup>2</sup>, Marcel Vos<sup>37</sup> (*Expert Members*)
- Task Force 9 Training:** Johann Collot<sup>38</sup>, Erika Garutti<sup>18,39</sup> (*Conveners*)  
Richard Brenner<sup>40</sup>, Niels van Bakel<sup>9</sup>, Claire Gwenlan<sup>16</sup>, Jeff Wiener<sup>2</sup>, ex-officio Robert Appleby<sup>41</sup> (*Expert Members*)

**ECFA** European Committee for Future Accelerators

Full-day Public Symposia

Following these symposia as the main topic...

Task Force	TF7	TF8	TF2	TF5	TF3	TF1	TF4
Dates	25/3/21	31/2/21	9/4/21	12/4/21	23/4/21	29/4/21	30/4/21
Unique users	309 + 123 (webcast)	154 + 17 (webcast)	187 + 5 (webcast)	220	504	339	105
Max. number of concurrent viewers	230 + 123 (webcast)	76 + 17 (webcast)	130 + 5 (webcast)	100	275	191	59

Common registration for the symposia had logged 1359 participants by the end of the last one.

Received extensive feedback during symposia and after by email.

Surveys were also employed to receive direct inputs from individuals and via RECCA delegates or their National Contacts.

APOD appointed experts consulted where needed by Task Force convenors for advice on developments in their disciplines.

19<sup>th</sup> November 2021 ECFA Detector R&D

ECFA Detector R&D Roadmap Symposium of Task Force 6 Calorimetry  
ECFA Detector R&D Roadmap Symposium of Task Force 4 Photon Detectors and Particle Identification Detectors  
ECFA Detector R&D Roadmap Symposium of Task Force 9 Training  
ECFA Detector R&D Roadmap Symposium of Task Force 1 Gaseous Detectors  
ECFA Detector R&D Roadmap Symposium of Task Force 3 Solid State Detectors  
ECFA Detector R&D Roadmap Symposium of Task Force 5 Quantum and Emerging Technologies  
ECFA Detector R&D Roadmap Symposium of Task Force 2 Liquid Detectors

March 2021  
31 Mar ECFA Detector R&D Roadmap Symposium of Task Force 8 Integration  
25 Mar ECFA Detector R&D Roadmap Symposium of Task Force 7 Electronics and On-detector Processing

ECFA European Committee for Future Accelerators

Advisory Panel with Other Disciplines

APPEC: Astro-Particle Physics European Consortium  
ESA: European Space Agency  
LEAPS: League of European Accelerator-based Photon Sources  
LENS: League of advanced European Neutron Sources  
NuPECC: Nuclear Physics European Collaboration Committee

The Task Force Convenors join those listed below to compose the Detector R&D Roadmap Panel.

Panel coordinators: Phil Allport<sup>42</sup> (Chair), Silvia Dalla Torre<sup>43</sup>, Manfred Kramer<sup>2</sup>, Felix Sefkow<sup>18</sup>, Ian Shipsey<sup>16</sup>

Ex-officio Panel members: Karl Jakobs<sup>44</sup> (Current ECFA Chair), Jorgen D'Hondt<sup>45</sup> (Previous ECFA Chair), Lenny Rivkin<sup>46</sup> (LDG Representative)

Scientific Secretary: Susanne Kuehn<sup>2</sup>

ECFA European Committee for Future Accelerators

Organisation name	Contact name
APPEC	Andreas Haungs (Chair)
NuPECC	Mark Levintowicz (Chair)
LEAPS	Caterina Biscari (Chair)
LENS	Helmut Schober (Chair)
ESA	Guenter Hasinger (Director of Science) Franco Ongaro (Director of Technology, Engineering and Quality)

Named expert contacts

Named expert contacts	Named contacts for each TF where appropriate
APPEC	191 Jennifer L. Raaf (Germany)
	192 Manfred Lindner (DIPN Heidelberg)
	193 Michael Doser (Germany)
	194 Helmut Schober (DIPN Heidelberg)
	195 Tino Pollmann (Mikrot)
	196 Harald Link (Munich)
	197 Federico Petrucci (DIPN Munich)
	198 Alex Hether (UK)
	199 Aldo Ianni (ENEA)
	200 Matteo Lodi (LAPD)
NuPECC	191 Laura Eibonero (EUM Munich)
	192 Bernhard Kuber
	193 Luciano Musa (CERN)
	194 Michael Doser
	195 Eugenio Tassi (DIPN Bari)
	196 Jochen Kohn (Munich)
	197 Christian Lins (Heidelberg)
	198 Thomas Bunn (Germany)
	199 Linka Thoma (Bonn)
LEAPS	197 David Blazynski (Lund)
	198 Christian Schmidt
	199 Werner Riegler (CERN)
LENS	197 Lars Schmitt
	198 Michael Doser
LENS	197 Bernd Schmitt (PSI)
	198 Robert Orlin
	199 Steve Agin (European Neutron Source)
	200 Peter Giffels (PSI)

Named expert contacts	Named contacts for each TF where appropriate
LENS	191 Bruno Guardà (ILL)
	192 Manfred Lindner (DIPN Heidelberg)
	193
	194
	195 Helmut Schober (DIPN Heidelberg)
	196
	197 Bruno Guardà (ILL)
	198
	199
ESA	191 Nick Helms
	192 Brian Shortt
	193 Nick Helms
	194
	195 Alexander Santini
	196 Alessandra Constantino Mucio
	197 Brian Shortt
	198 Peter Schmitt
	199 Sarah Wittig
	Nick Helms
	Christina Santini
	195 Peter Verhoeve
	196 Sarah Wittig
	197 Nick Helms
	198 Nick Helms
	199 Jörg Ter Haar
	Christophe Homwath
	Nick Helms
	198 Alessandra Constantino Mucio
	199 Massimo Breglio
	Christophe Homwath



# Overview of future facilities

- Many different future facilities proposed/foreseen based on accelerators and non-accelerators
- Focus on the technical aspects of detector R&D requirements given the [2020 EPPSU deliberation document](#) listed “*High-priority future initiatives*” and “*Other essential scientific activities for particle physics*” as input

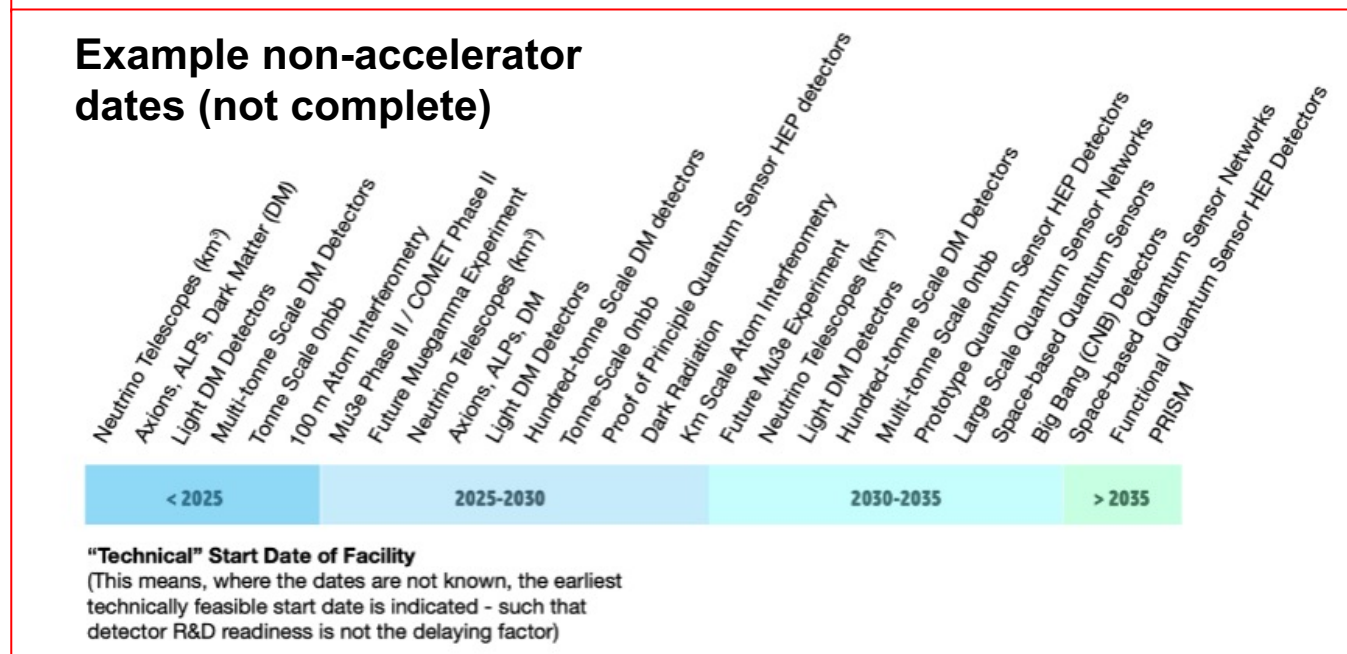


The dates used in these diagrams have a deliberately low precision, and are intended to represent the earliest ‘feasible start date’ (where a schedule is not already defined), taking into account the necessary steps of approval, development and construction for machine and civil engineering. They do not constitute any form of plan or recommendation, and indeed several options presented are mutually exclusive.

Furthermore, the projects mentioned here are usually limited to those mentioned in the 2020 EPPSU, although it should be noted that detector R&D for other possible future facilities is usually aligned with that for programmes already listed.

The facilities are aligned with Accelerator R&D Roadmap <http://arxiv.org/abs/2201.07895>

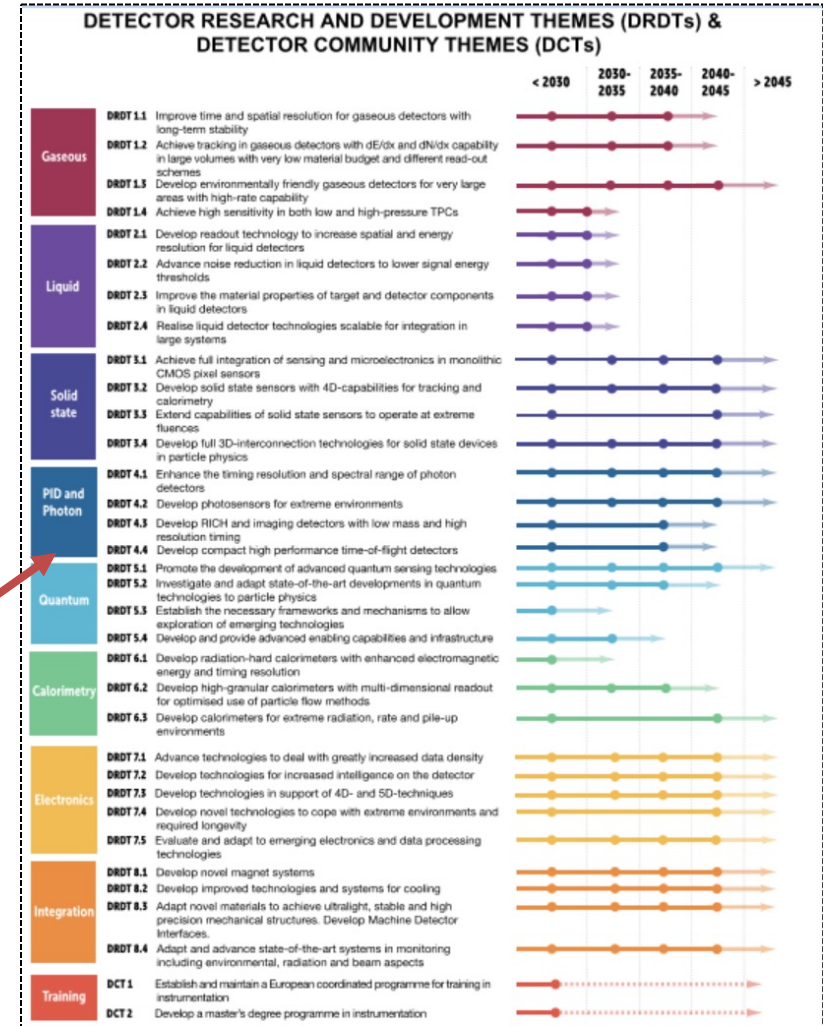
→ Many detector concepts at different future facilities



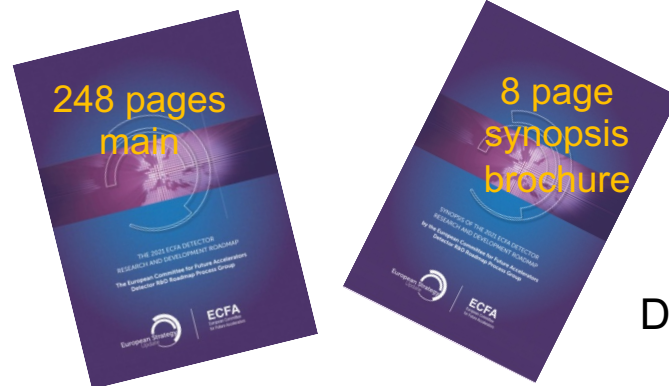
# ECFA Detector R&D Roadmap



- Task Forces **started from the future science programme to identify main detector technology challenges** to be met (both mandatory and highly desirable to optimise physics returns) and estimated the period over which the required detector R&D programmes may be expected to extend.
- Within each Task Force created a **time-ordered technology requirements driven R&D roadmap in terms of capabilities not currently achievable**. It is also noted that in many cases, the programme for a nearer-term facility helps enable the technologies needed for more demanding specifications later, providing **stepping stones** towards these.
- **Developed and defined “Detector R&D Themes” (DRDTs) to highlight the most important drivers for research in each technology area and “Detector Community Themes” (DCTs) in the context of the training area (TF9).**
- **General strategic recommendations for our field** are collected in the chapter of general observations and considerations.



**Main Document published** (approval by RECFA at [19/11/21](#)) and 8 page **synopsis brochure** prepared for less specialists audience



ECFA Detector R&D Roadmap Panel web pages at:  
<https://indico.cern.ch/e/ECFADetectorRDRoadmap>  
 Documents: CERN-ESU-017 [10.17181/CERN.XDPL.W2EX](https://cds.cern.ch/record/2784893),  
<https://cds.cern.ch/record/2784893>



## Building the Foundations

"Strong planning and appropriate investments in Research and Development (R&D) in relevant technologies are essential for the full potential, in terms of novel capabilities and discoveries, to be realised."

The field of particle physics builds on the major scientific revolutions of the 20th century, particularly on the experimental discoveries and theoretical developments which culminated in the Nobel Prize-winning discovery of the Higgs boson at CERN in 2012. The ambitions for the field going forward are set out from a European perspective in a global context in the European Strategy for Particle Physics (ESPP) which was updated in 2020. This strategy lays down a vision for the coming half-century, with a science programme which, in exploring matter and forces at the smallest scales and the Universe at earliest times, will continue to provide answers to questions once thought only to be amenable to philosophical speculation, and has the potential to reveal fundamentally new phenomena or forms of matter never observed before.

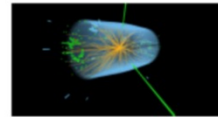
The ESPP recognises the huge advances in accelerator and detector technologies since the world's first hadron collider, the Intersecting Storage Rings, started operation at CERN 50 years ago. These advances have not only supported, and in turn benefited from, numerous other scientific disciplines but have spawned huge societal benefits through developments such as the World Wide Web, Magnetic Resonance Imaging, Positron Emission Tomography and 3D X-ray imaging.



Installation of the CMS Central Tracking Detector with 10 million read-out channels and using silicon detectors covering an area of over 200 m<sup>2</sup>. (© CERN)

The far-reaching plans of the ESPP require similar progress over the coming decades in accelerator and detector capabilities to deliver its rich science programme. Strong planning and appropriate investments in Research and Development (R&D) on relevant technologies are essential for the full potential, in terms of novel capabilities and discoveries, to be realised.

The 2020 update of the ESPP called on the European Committee for Future Accelerators (ECFA) to develop a global Detector R&D Roadmap defining the backbone of detector R&D required to deploy the community's vision. This Roadmap aims to cover the needs of both the near-term and longer-term programmes, working in synergy with neighbouring fields and with a view to potential industrial applications.



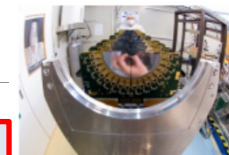
3D plot showing of a simulated Higgs boson decaying into two photons as observed by the CMS experiment. (© CERN)



ATLAS gas detector based muon spectrometer, which covers a large area of the solid angle of a hadron field and measures the paths of the muons that pass through it to an accuracy of better than a tenth of a millimetre. (© CERN)

## Setting the Priorities

"To fully explore the properties of the Higgs boson many of the other deepest questions in physics the development of a roadmap for the required technologies."



Vertex Locator (VELO) of the LHCb experiment allowing short lived particles (bottom) to be measured with precision of a twentieth of a picosecond. (© CERN)



Insertion of Lead Tungstate crystals (over three times the density of conventional glasses) into the high granularity electromagnetic calorimeter of the ALICE detector giving percent scale energy measurements. (© CERN)



ProtonLHC: three hundred cubic metre volume prototype Liquid Argon Muon(s) Detector being constructed at CERN. (© CERN)

## Identifying the Tools

"It is vital to build on Europe's world-leading capabilities in sensor technologies for particle detection."

The figure opposite illustrates the "Detector R&D Themes" (DRDTs) and "Detector Community Themes" (DCTs) identified in the roadmap process, grouped according to the areas addressed by the nine task forces set up by ECFA to develop a strategy for future detector R&D priorities. All the themes are critical to achieving the science programme outlined in the ESPP and are derived from the technological challenges that need to be overcome for the scientific potential of the future facilities and projects listed in the ESPP to be realised. It is important to ensure that, for each of the future facilities mentioned in the ESPP, detector readiness should not be the limiting factor in terms of when the facility in question can be realised. In many cases, less demanding developments are required for experiments scheduled in the medium term, which can then act as "stepping stones" (illustrated by the in-between dots) towards achieving the final specifications.

The R&D priorities are outlined for the key detector types: those based on gaseous, liquid or solid sensing materials; along with those required for sensing aspects specific to photon detection, particle identification (PID) or energy measurement (calorimetry). In addition, quantum sensors are already offering radically new opportunities to particle physics, and their further development will widen their applicability to the field. Sophisticated read-out technologies are essential to all detector types and are often the limiting factor when very large numbers of channels are to be instrumented, especially given the ever more demanding sensitivity and robustness required for operation in the extreme conditions of many particle physics experiments. Unique advanced engineering solutions are needed to complement all these detector developments and, as with accelerators, the field drives many aspects of progress in magnet technology. Last but not least, environmental sustainability is a central requirement for all future research and innovation activities.

Given the vital importance of expertise in a wide range of cutting-edge technologies, the Detector R&D Roadmap also contains specific recommendations in terms of training, Detector Community Themes with emphasis on providing better coordination between the many different training schemes available across Europe, and exploring mechanisms to establish a core syllabus for a Masters qualification in particle physics instrumentation that brings together the crucial elements from the large number of diverse existing courses. Given the uneven access to training in the area of instrumentation in all regions of the world, a key focus is to greatly improve the inclusivity of future programmes, workshops and schools, encouraging the widest possible diversity of participants.

While defining the priorities within particle physics, as outlined above, the ECFA Detector R&D Roadmap also emphasises the vital importance of benefiting from synergies with adjacent research fields, knowledge institutions and high-technology industries.

The highest priority laid down Higgs factory to thoroughly: a new type of particle, which is understanding of how the Higgs boson, every known particle was either a "matter" or a "force" particle, describing the world in terms of fundamental entities and their interactions without being able to accommodate the fact that particles also have mass. In the ESPP, the vision for the future facilities to fully explore the properties of the Higgs boson and study many of the other deepest questions in physics necessitates the development of a roadmap for the required detector technologies (in much the same way as the LHC and its upgrades significantly guided R&D planning for previous decades). The ECFA Detector R&D Roadmap addresses this need whilst highlighting synergies with other projects on nearer timescales and showing how they are also embedded in the longer-term context.

In the area of detector development, it is vital to build on Europe's world-leading capabilities in sensor technologies for particle detection, using gas and liquid-based or solid-state detectors, as well as energy measurement and particle identification. Also required are cutting-edge developments in bespoke microelectronics solutions, real-time data processing and advanced engineering. Adequate resourcing for such technology developments represents a vital component for future progress in experimental particle physics. Talented and committed people are another absolutely core requirement. They need to be enthused, engaged, educated, empowered and employed. The ECFA Detector R&D Roadmap brings forward concrete proposals for nurturing the scientists, engineers and technicians who will build the future facilities and for incentivising them by offering appropriate and rewarding career opportunities.

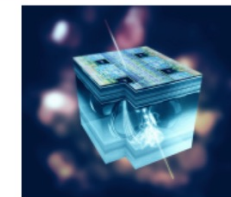


Illustration of microelectronic circuitry integrated with a detecting medium as a single monolithic active-state detector. (© ALICE collaboration)



Paul Scherrer Institute (Switzerland) facility for delivering high targeted radiotherapy with beams of accelerated protons (Proton Therapy). (© Scandinavian Super Proton Therapy)



Detector assembly facility for detector R&D, testing and assembly (targeting LHC upgrades, future collider facilities and medical applications). (© BLPA, University of Birmingham)



Students and young scientists working on the construction of prototype detector modules. (© CERN)

8 page synopsis brochure prepared for less specialist audience

## SYNOPSIS OF THE 2021 ECFA DETECTOR RESEARCH AND DEVELOPMENT ROADMAP

by the European Committee for Future Accelerators Detector R&D Roadmap Process Group



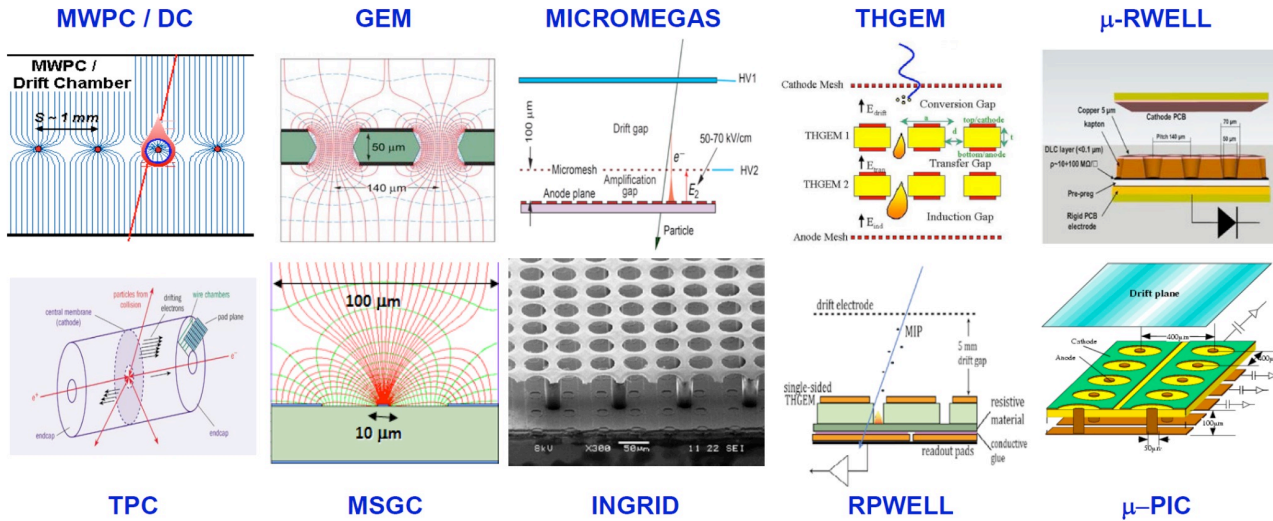
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for Future Accelerators



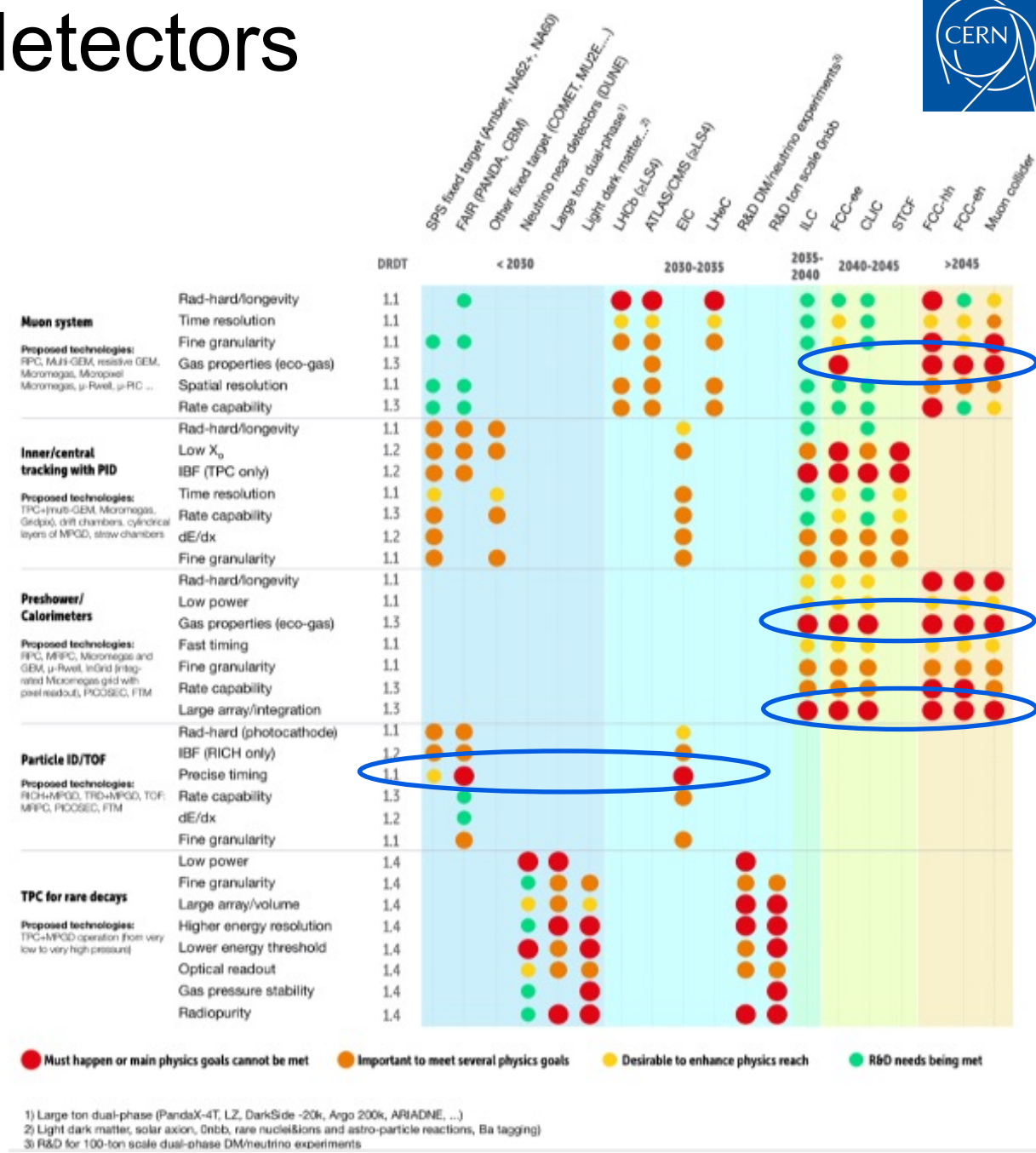
# Gaseous detectors



- Gaseous detectors: from Wire/Drift Chamber → Time Projection Chamber (TPC) → Micro-Pattern Gas Detectors
- Primary choice for large-area coverage with low material budget & dE/dx measurement (TPC, Drift chamber) & TOF functionality (MRPC, PICOSEC)



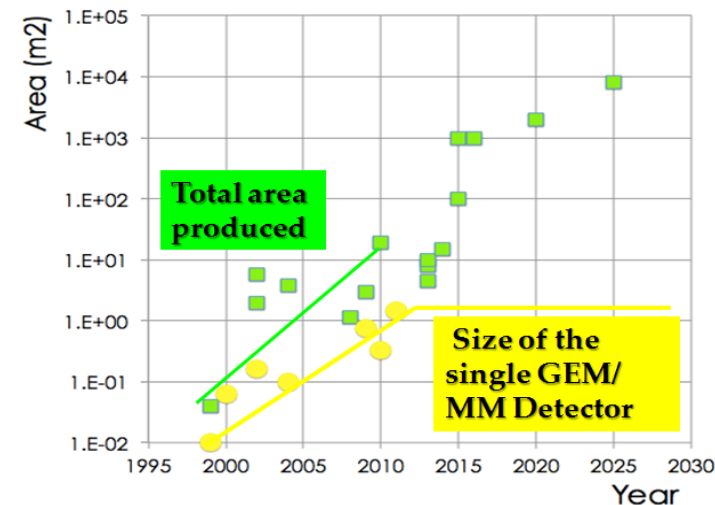
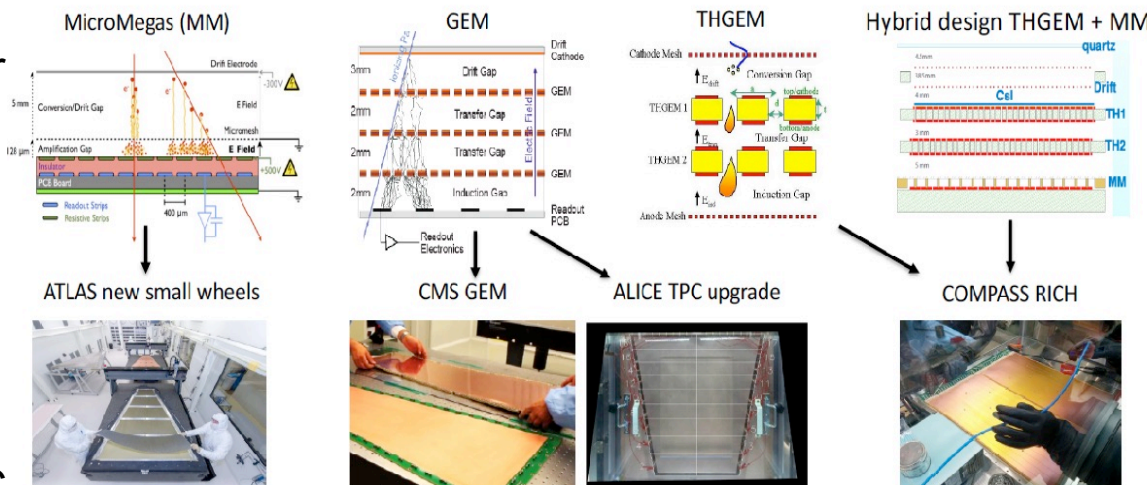
- **Detector Readiness Matrices of each Task Force chapter** focus on the extent to which the R&D topic is *mission critical* to the programme than the intensity of R&D required
  - Must happen or main physics goals cannot be met
  - Important to meet physics goals
  - Desirable to enhance physics reach
  - R&D need being met



1) Large ton dual-phase (PandaX-4T, LZ, DarkSide-20k, Argo 200k, ARIADNE, ...)  
 2) Light dark matter, solar axion, Dnbb, rare nuclei/ions and astro-particle reactions, Ba tagging)  
 3) R&D for 100-ton scale dual-phase DM/neutralino experiments

# Gaseous detectors: area and timing

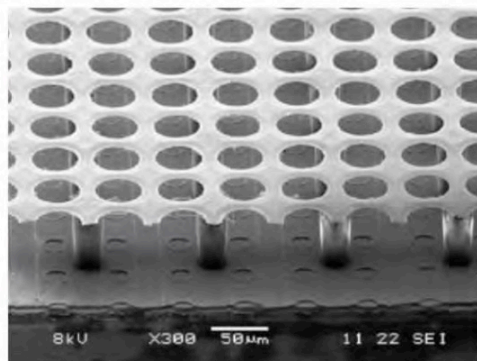
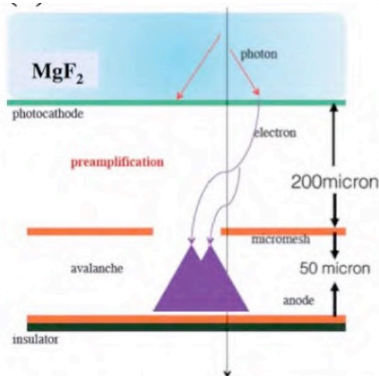
- **Upgrades to a number of systems used at the LHC for tracking, muon spectroscopy and triggering have taken advantage of the renaissance in gaseous detectors (esp MPGDs)**
- **New generation of TPCs use MPGD-based readout:** e.g. ALICE Upgrade, T2K, ILC, CepC



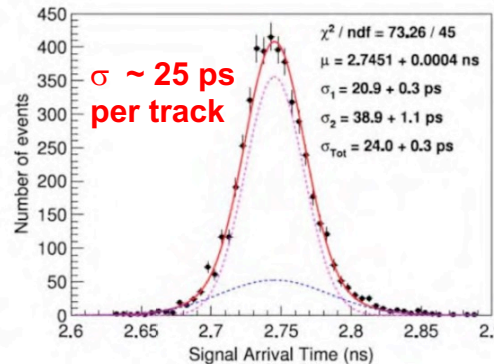
- **Gaseous detectors offer very competitive timing through e.g.**
  - **Multi-gap Resistive Plate Chambers** (down to 60 ps time resolution) (ALICE TOF Detector, Z.Liu, NIM A927 (2019) 396)
  - An enabling emerging R&D: **Micromegas with timing** (PICOSEC concept)

J. Bortfeldt, NIM A903 (2018) 317

Cherenkov radiator + Photocathode + MM



Timing (MIP test-beam):

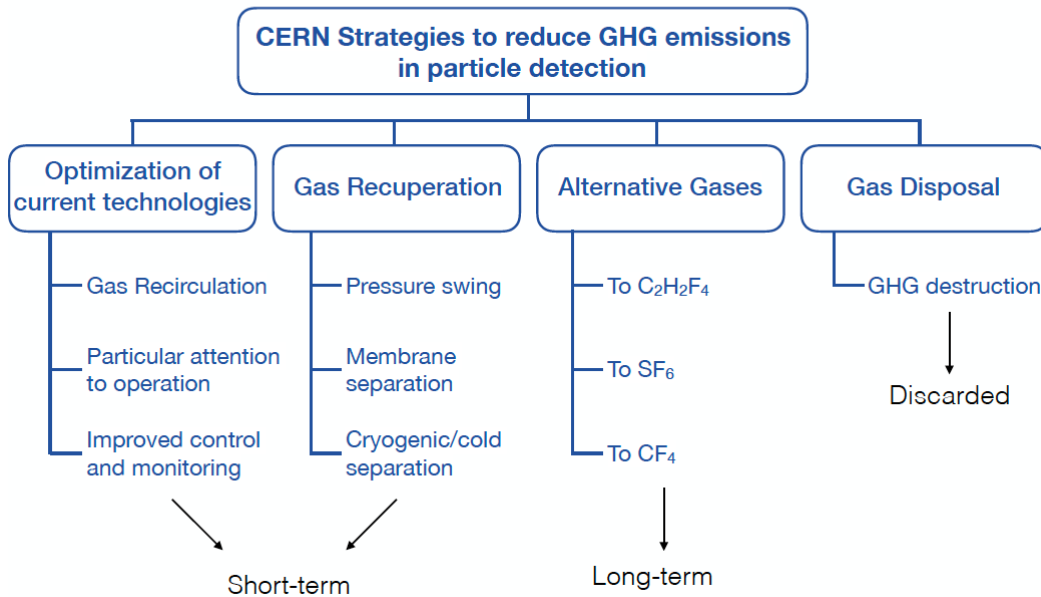


→ Many developments emerged from the R&D studies within the RD51 Collaboration

# Gaseous Detectors: eco-friendly gases

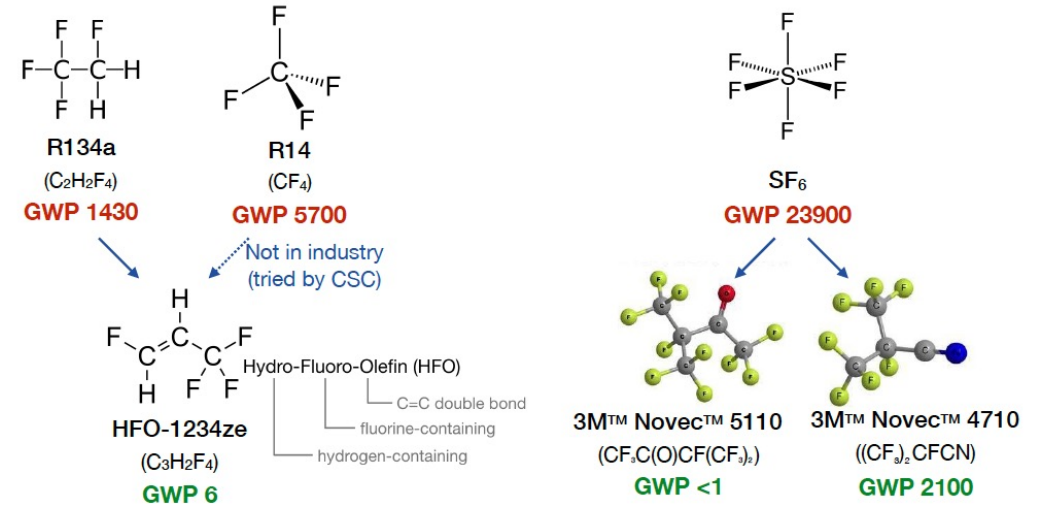
- 92% of emission at CERN related to large LHC experiments
- Thanks to gas recirculation GHG emission already reduced by > 90% wrt. to open mode systems!
- Many LHC gas systems with gas recuperation

## CERN strategies for GHG reduction



## Possible alternatives to GHG gases

*New eco-friendly liquids/gases have been developed for industry as refrigerants and HV insulating medium... ionisation properties in particle detection not well known*



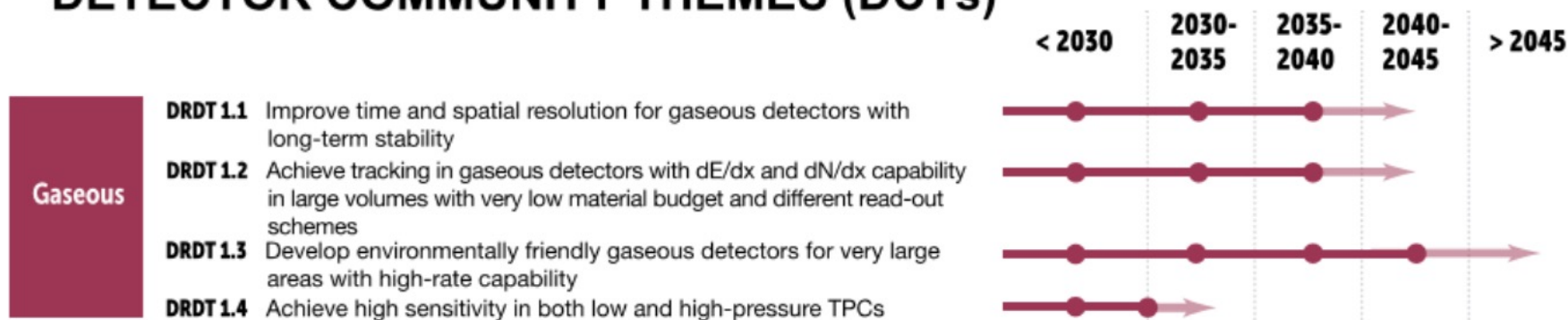
- Alternative gases:
  - A lot of work especially in RPC community to search for alternative to C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>
  - Not an easy task to find new eco-friendly gas mixture for current detectors



# Gaseous detectors

→ The DRDTs of Task Force 1 Gaseous detectors

## DETECTOR RESEARCH AND DEVELOPMENT THEMES (DRDTs) & DETECTOR COMMUNITY THEMES (DCTs)



To highlight the most important drivers for research in each technology area

To not limit a feasible start date of a future facility

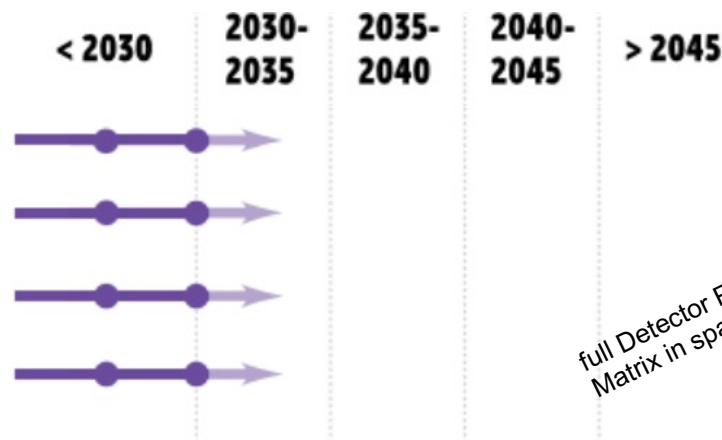
- The faded region acknowledges the typical time needed between the completion of the R&D phase and the readiness of an experiment at a given facility.
- Stepping stones are shown to represent the R&D needs of facilities intermediate in time.
- It should be emphasised that the future beyond the end of the arrows is simply not yet defined, not that there is an expectation that R&D for the further future beyond that point will not be needed.

# Liquid detectors

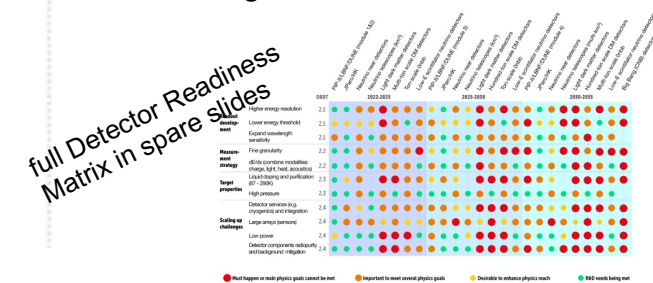
- The DRDTs are

Liquid

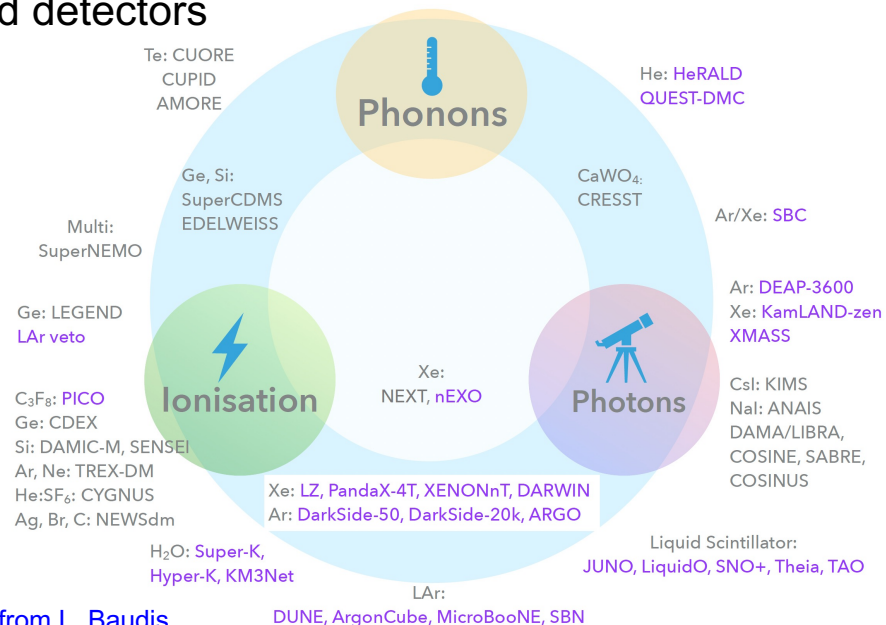
- DRDT 2.1** Develop readout technology to increase spatial and energy resolution for liquid detectors
- DRDT 2.2** Advance noise reduction in liquid detectors to lower signal energy thresholds
- DRDT 2.3** Improve the material properties of target and detector components in liquid detectors
- DRDT 2.4** Realise liquid detector technologies scalable for integration in large systems



Note: Developments in this field are rapid and it is not possible today to reasonably estimate the dates for projects requiring longer-term R&D



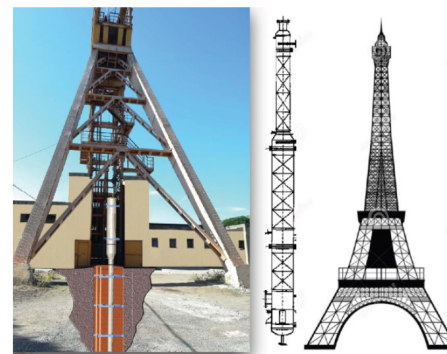
- Several large-scale and many small-scale experiments running or foreseen with liquid detectors



Modified from L. Baudis

## Underground Dark Matter Experiments – small and rare signals

- Target doping and purification
- Detector components radiopurity and background mitigation



ARIA underground purification system for argon (DarkSide-20k)

Low-radioactivity argon: extraction (Urania plant, 330 kg/d), purification (ARIA facility, 10 kg/d)

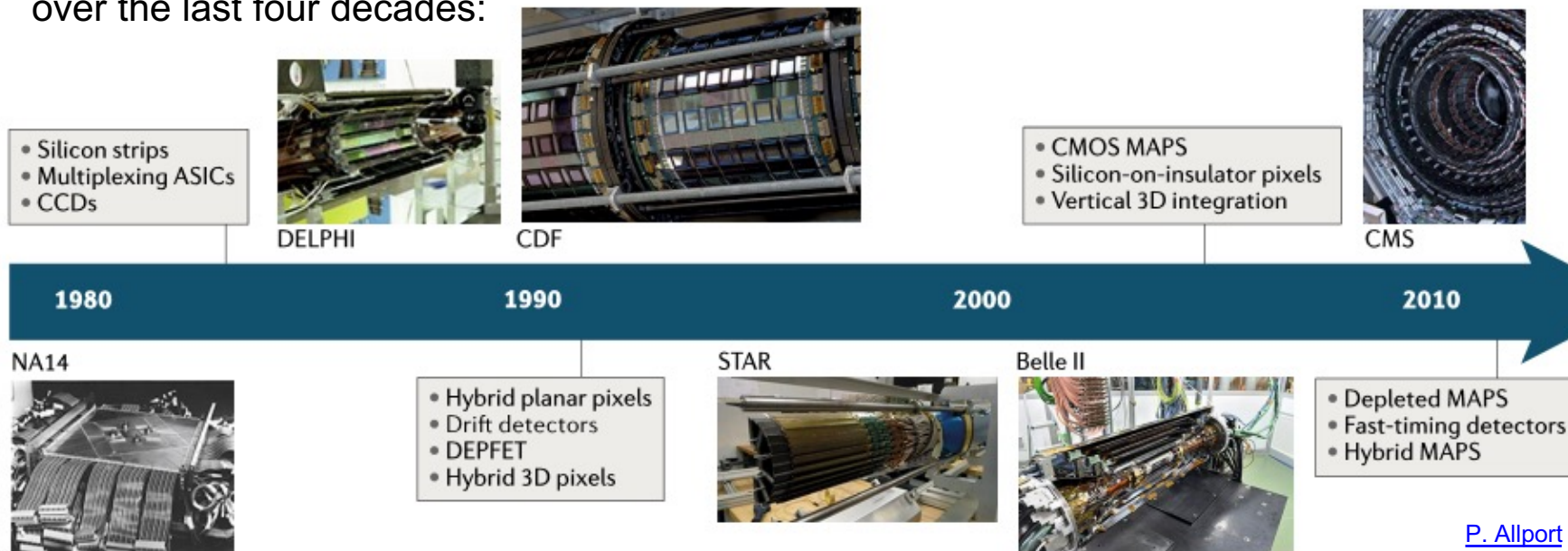


Distillation columns for krypton and radon, material screening and selection, radon emanation

Rn distillation column for XENONnT (reduce <sup>222</sup>Rn - hence also <sup>214</sup>Bi - from pipes, cables, cryogenic system)

# Solid State Detectors

- Many different silicon detector technologies for **particle tracking** have been developed over the last four decades:

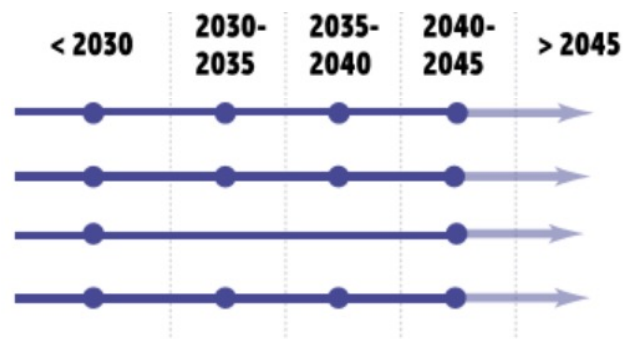


Remarkable: **every decade** the instrumented areas have increased by **a factor of 10** while the numbers of channels in the largest arrays have increased by **a factor of 100**

- Solid state detectors more and more used for **calorimetry and time-of-flight**

## They lead to these DRDTs:

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



**New Challenges** (see Detector Readiness Matrix in spare slides):

- Vertex detectors with low mass, high resolution** (Target per layer spatial resolution of  $\leq 3 \mu\text{m}$  and  $X/X_0 \leq 0.05\%$  for FCC-ee), **low power and high radiation hardness** (up to  $8 \times 10^{17} \text{ n}_{\text{eq}}/\text{cm}^2$  for pp-colliders)
- Trackers: **affordable sensors** with low mass, high resolution, **low power**
- Large area and granular** devices for calorimeters
- Detectors with **ultra-fast timing** ( $O(10-100 \text{ ps})$ ) for PID, TOF
- Fully integrated with electronics, mechanics, services, ...





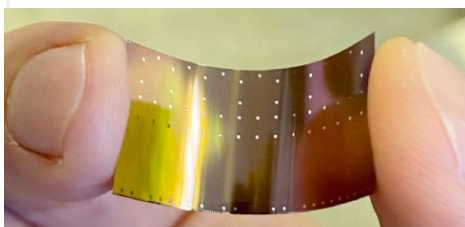
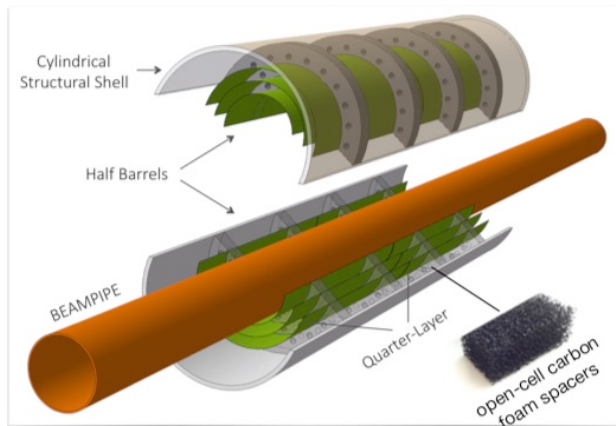
# CMOS MAPS

- **Monolithic sensors combining sensing and readout elements (DRDT 3.1)**
- Example: For FCC-ee vertex detector targeting spatial resolution per layer of  $\leq 3\mu\text{m}$  and  $x/x_0 \leq 0.05\%$ , essential to have low power. Plus radiation-hardness up to  $8 \times 10^{17} \text{ n}_{\text{eq}}/\text{cm}^2$  for pp-collider.

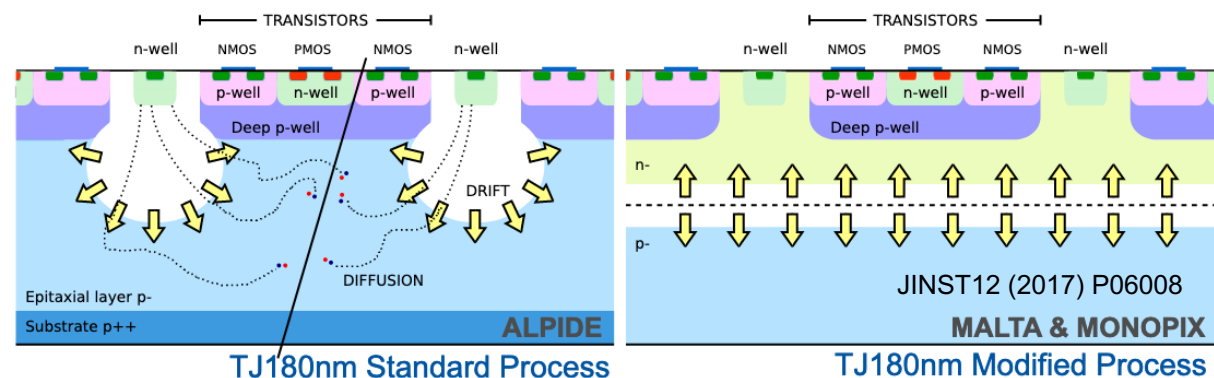
## CMOS MAPS for ALICE ITS3 (Run 4):

(LOI: CERN-LHCC-2019-018, [M. Mager](#))

- Three fully cylindrical, wafer-sized layers based on curved ultra-thin sensors (20-40  $\mu\text{m}$ ), air flow cooling
- Very low mass,  $< 0.02\text{-}0.04\%$  per layer



## Radiation hardness of MAPS: From ALPIDE to MALTA/Monopix with modified Tower Jazz 180 nm process



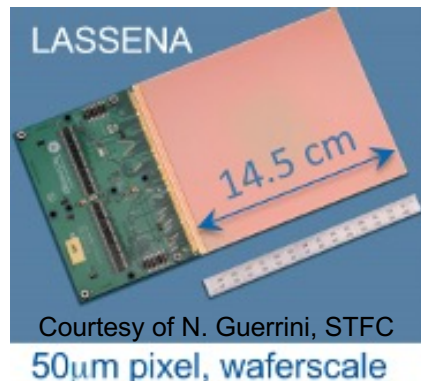
→ Up to 97% efficiency after fluence of  $1 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$  [H. Pernegger](#)

## MIMOSA @ EUDET BeamTest

Telescope → 3  $\mu\text{m}$  track resolution achieved



Large area:  
**stitching**  
INMAPS process



Courtesy of N. Guerrini, STFC  
50 $\mu\text{m}$  pixel, waferscale

## To achieve higher radiation hardness (DRDT 3.3):

Hybrid technologies with thin, 3D-structures (columns/trenches) silicon and/or high bandgap materials (e.g. diamond) are mostly considered for really high radiation environments.

# Silicon timing detectors

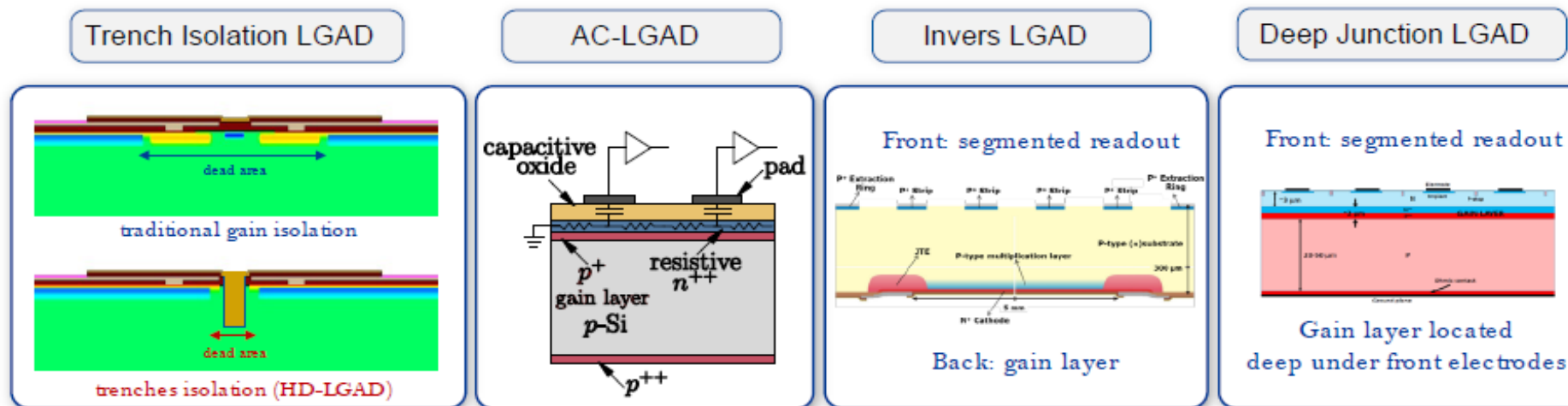


**Sensors for 4D-Tracking: position and time resolution (DRDT 3.2) → Development of Radiation Hard Timing Detectors (Low Gain Avalanche Detectors)**

- For LGADs, three main foundries (CNM, FBK, HPK) and more producers
- Time information hugely beneficial to suppress pile-up in pp-collisions

## LGAD: Fill factor & performance improvements

- Two opposing requirements:
  - Good timing reconstruction needs homogeneous signal ( i.e. no dead areas and homogeneous weighting field)
  - A pixel-border termination is necessary to host all structures controlling the electric field
- Several new approaches to optimize/mitigate followed:



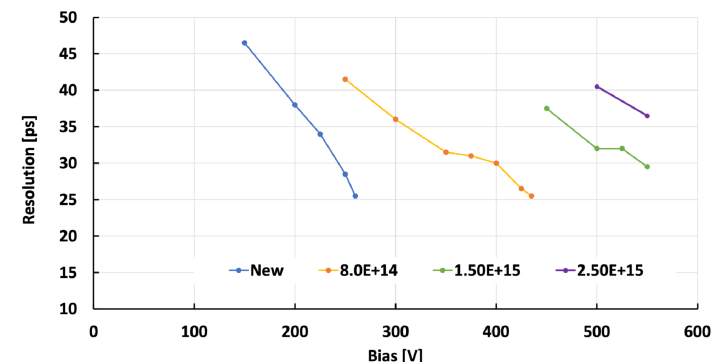
Concepts simulated, designed, produced and tested in 2018/19

..new concept 2020

Areas of LGAD developments within RD50 Collaboration:

- Timing performance ( ~ 25 ps for 50 μm sensors)
- Fill factor and signal homogeneity
- Position resolution is about 5% of the distance between electrodes O(5-15 μm) (AC-LGAD)
- Radiation Hardness (~2x10<sup>15</sup> n<sub>eq</sub>/cm<sup>2</sup>)
- Performance Parameterisation Model

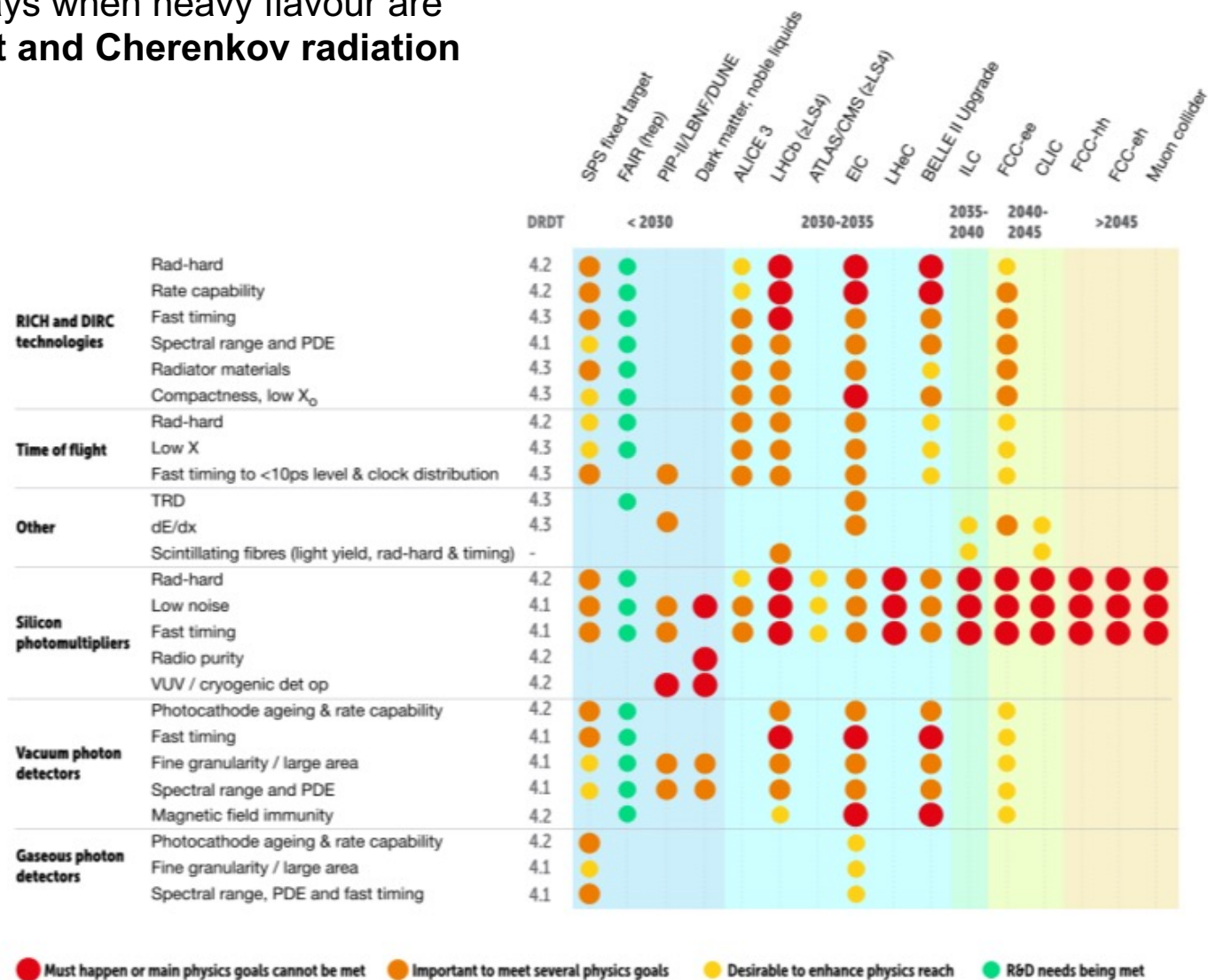
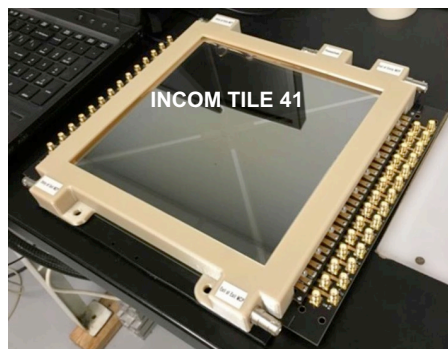
FBK 45-micron UFS3.2 W13



N. Cartiglia

# PID and Photon Detectors

- **Particle Identification (PID)** essential to identify decays when heavy flavour are present: everywhere. **Used are  $dE/dx$ , Time-of-Flight and Cherenkov radiation**
- **Many developments on vacuum photon detectors, solid state, gas-based and superconducting photon detectors**
- Challenges for example for **SiPMs**: the high dark count rate and moderate radiation hardness prevented their use in RICH detectors where single photon detector required at low noise
- Challenges for **MCP-PMTs** is their price and they are not tolerant to magnetic fields, similarly **Large-Area Picosecond Timing Detectors (LAPPD)** which are promising but need in addition pixellation

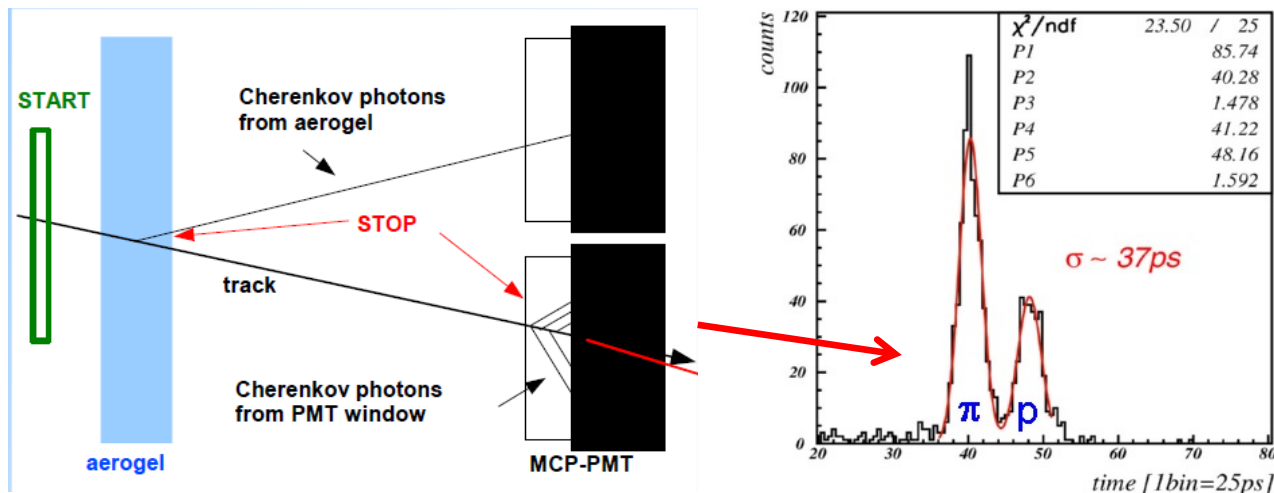




# PID and Photon Detectors: RICHes

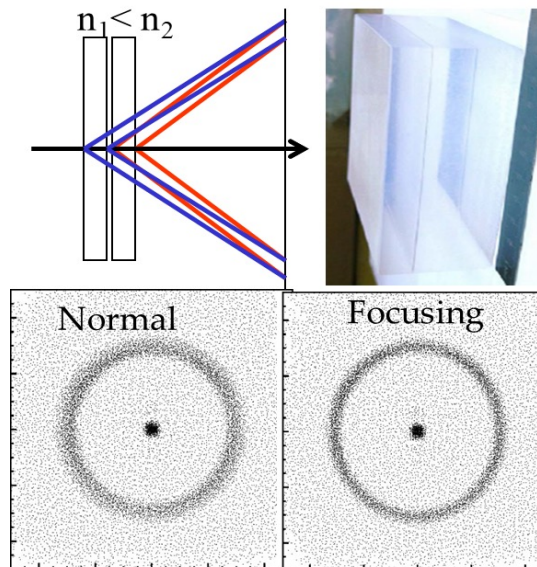
Examples of trends in proximity focusing aerogel radiator RICHes:

- **Combination of proximity focusing RICH + TOF with fast new photon-sensors** → MCP-PMT or SiPM using Cherenkov photons from PMT window
- Use of focusing configuration, e.g. ARICH (Belle), Forward RICH (Panda)



Cherenkov photons from PMT window can be used to positively identify particles below threshold in aerogel

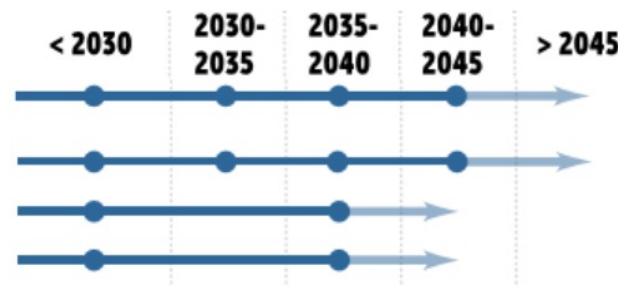
P. Krizan @INSTR2020  
T. Credo, 2004 IEEE NSS/MIC Conference Record



- RICHes with proximity focusing: thin radiator (liquid, solid, aerogel) and low momenta
- Time-Of-Flight (TOF) detectors: use prompt Cherenkov light, fast gas detector
- RICHes with focalisation: extended radiator (gas), mandatory for high momenta

DRDTs:

PID and Photon	DRDT 4.1	DRDT 4.2	DRDT 4.3	DRDT 4.4
	Enhance the timing resolution and spectral range of photon detectors	Develop photosensors for extreme environments	Develop RICH and imaging detectors with low mass and high resolution timing	Develop compact high performance time-of-flight detectors



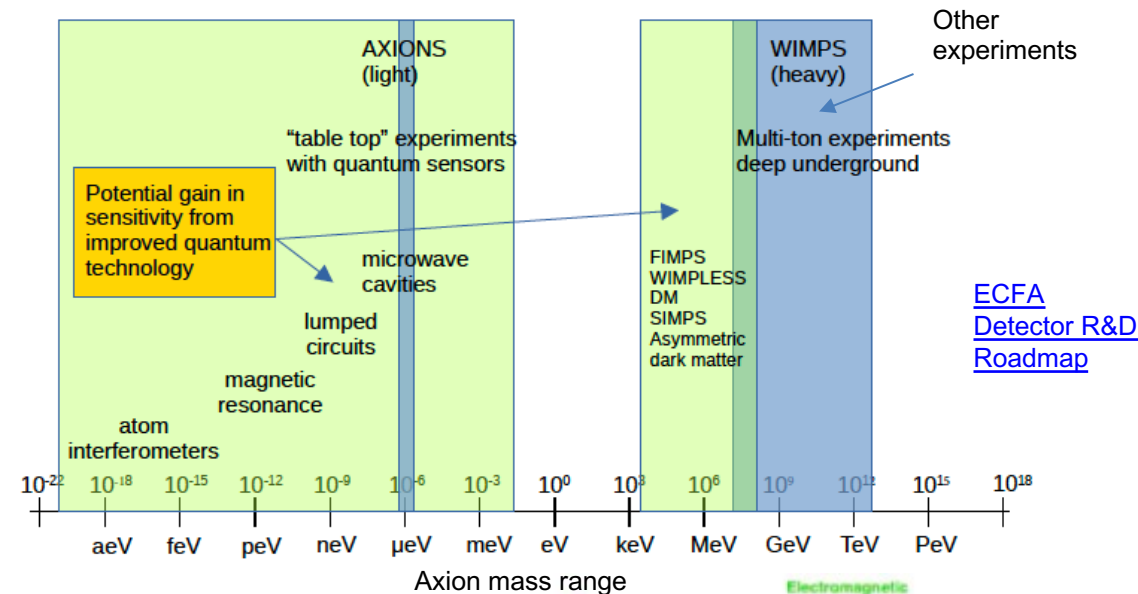
# Quantum and emerging technologies



- **Quantum Technologies** are a rapidly emerging area of technology development to study fundamental physics
- The ability to engineer quantum systems to improve on the measurement sensitivity holds great promise
- **Many different sensor and technologies being investigated:** clocks and clock networks, kinetic detectors, spin-based, superconducting, optomechanical sensors, atoms/molecules/ions, interferometry, ...
- Several initiatives started at CERN, DESY, UK, ...

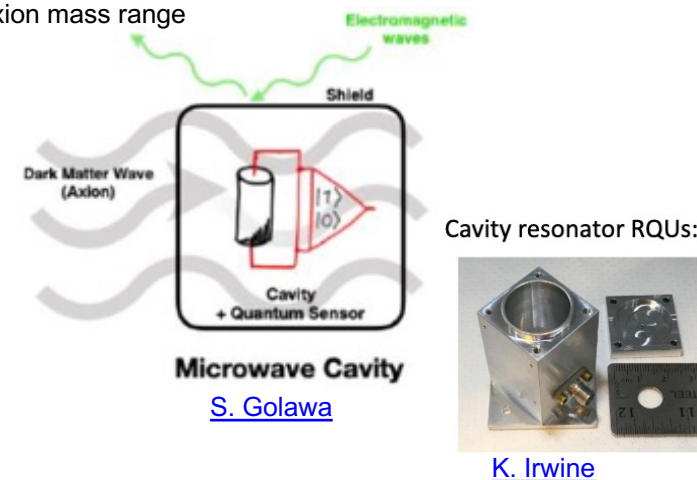
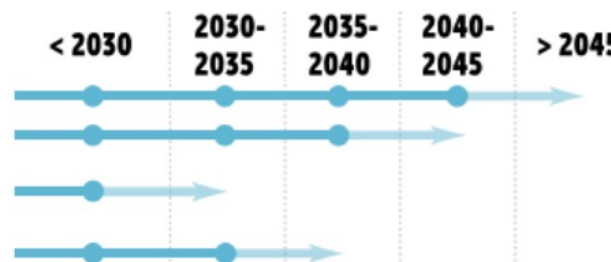


Example: potential mass ranges that quantum sensing approaches open up for Axion searches



## DRDTs

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

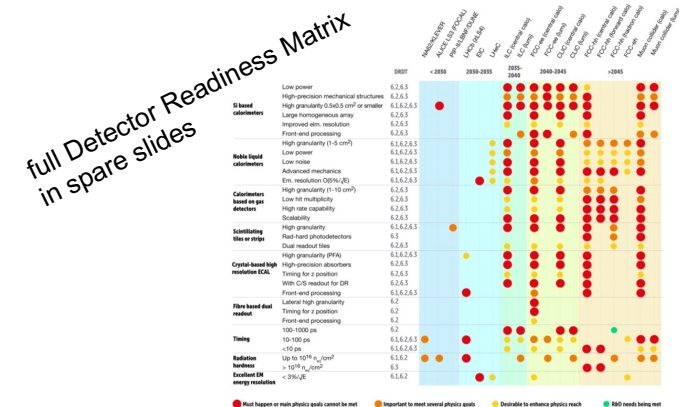
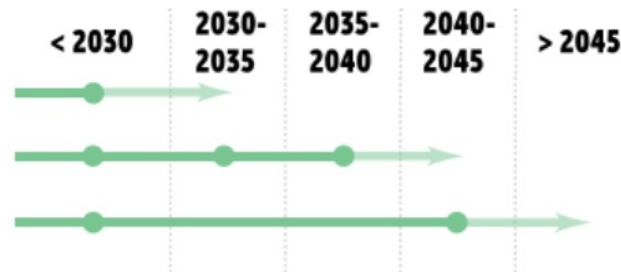


# Calorimetry

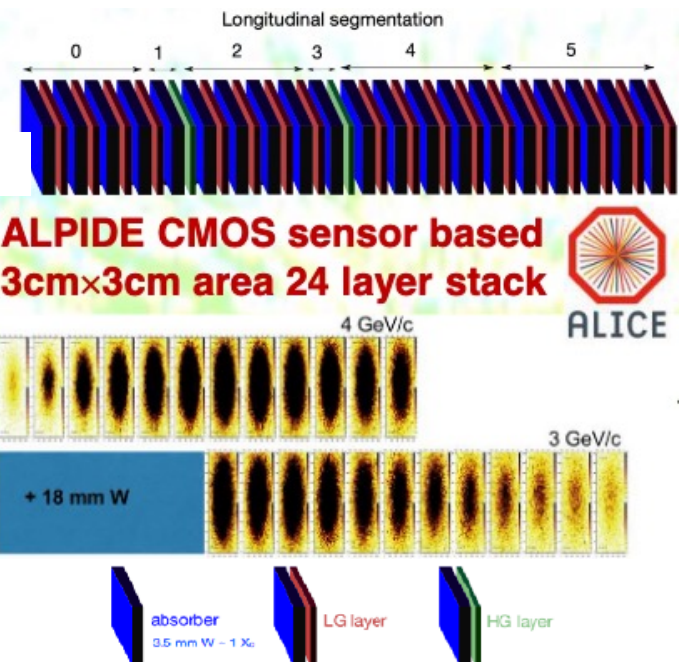
- **R&D in calorimetry has a particularly long lead-time** due to the duration of the stage for experiment specific final prototyping, procurement, production, assembly, commissioning and installation
- DRDTs:

## 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



### ALICE FoCAL



**DRDT 6.1:** The enhanced electromagnetic energy and timing resolution most relevant in next decade for upgrades of ALICE and LHCb.

Example: MAPS based SiW ECALs

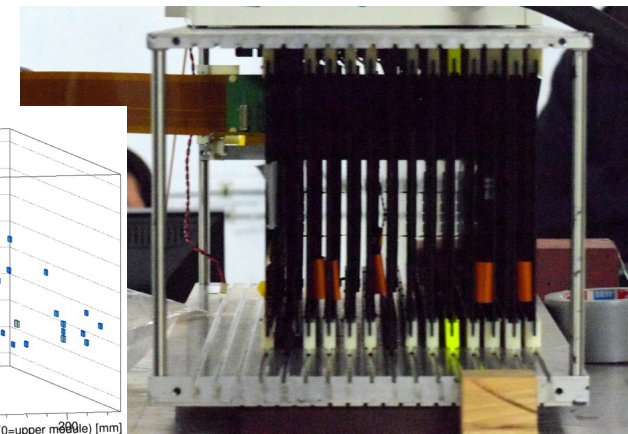
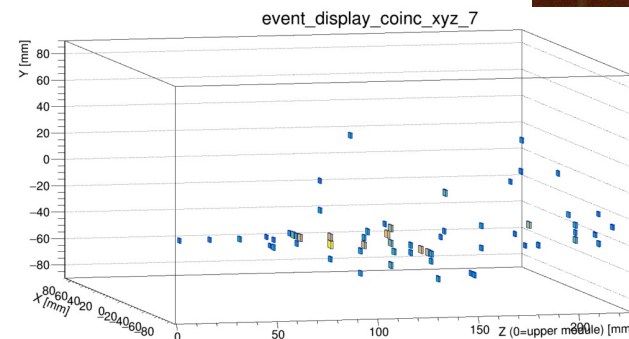
Good energy resolution

[T. Peitzmann](#), H. Yokoyama: "Test beam performance of a digital pixel calorimeter",  
 T. Rogoschinski: "Simulation of a SiW pixel calorimeter": TIPP 26/5/21

### CALICE

Integrated front-end and digital electronics  
 15 layers with 15360 channels  
 2.1 mm (x11) and 4.2 mm (x3) tungsten  
 Culmination of 10 years of prototyping

<https://aitanatop.ific.uv.es/aitanatop/siwecal-tb2021/>



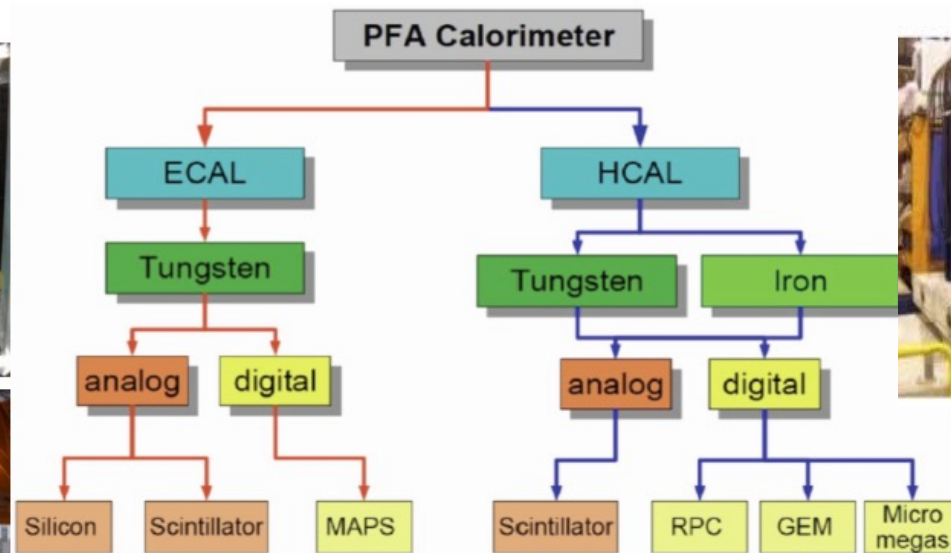
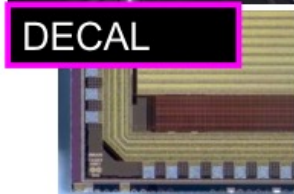


# Calorimetry

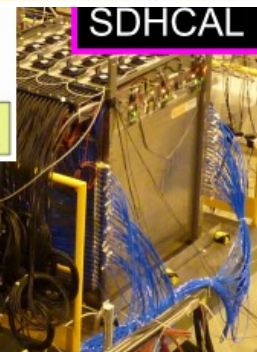
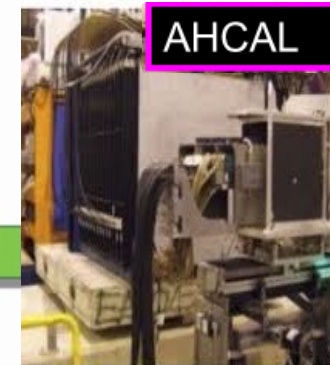
**DRDT 6.2: Particle Flow based on high granularity calorimeters** particularly important for  $e^+e^-$  Higgs-EW-top factories and to be considered for EIC. Separation of signals by charged and neutral particles in **highly granular calorimeters**.

Options are:

- **Dual-readout** (e.g. DREAM/RD52 Collaboration, [FCC-ee IDEA](#)):  $f_{EM}$  from absorber with combined scintillator parallel plates for non-relativistic (hadronic) component and Cherenkov for relativistic (EM) component (PMMA fibres);
- High granularity **LAr/LKr**: LAr proven technique but high granularity challenging;
- Finely segmented **crystals** ([RD18](#) Collaboration);
- **Particle Flow based “tracking calorimeter”** concept with very fine sense element segmentation for precise reconstruction of each particle within the jet. Up to  $\sim 100M$  channels and  $10000\text{ m}^2$  active elements



From P. Allport

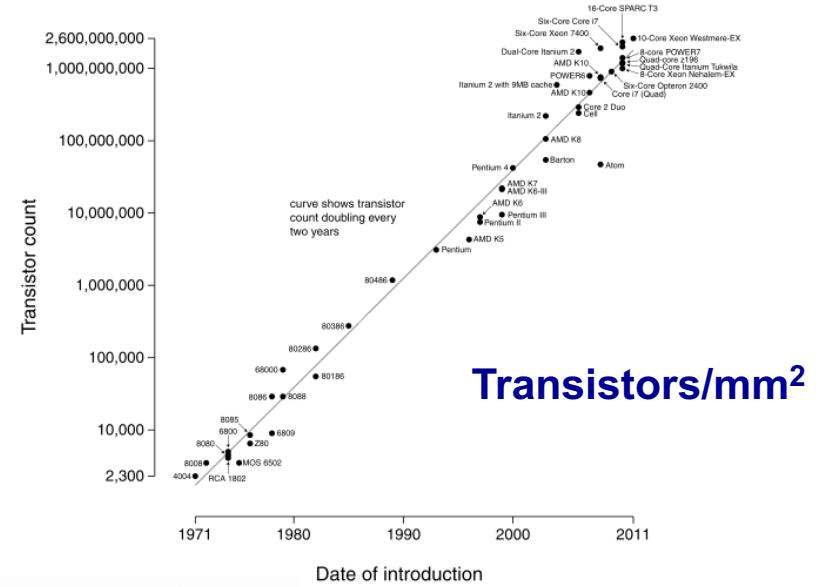


With thanks for help to Roman Pöschl, Fabrizio Salvatore and Nige Watson

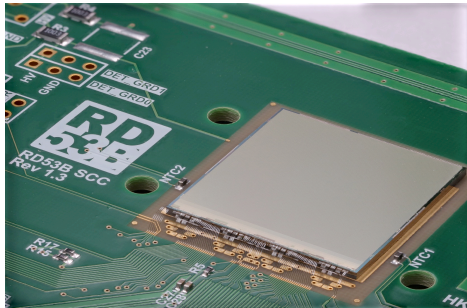
**DRDT 6.3: Extreme radiation hardness and pile-up rejection** critical for FCC-hh in particular

# Electronics

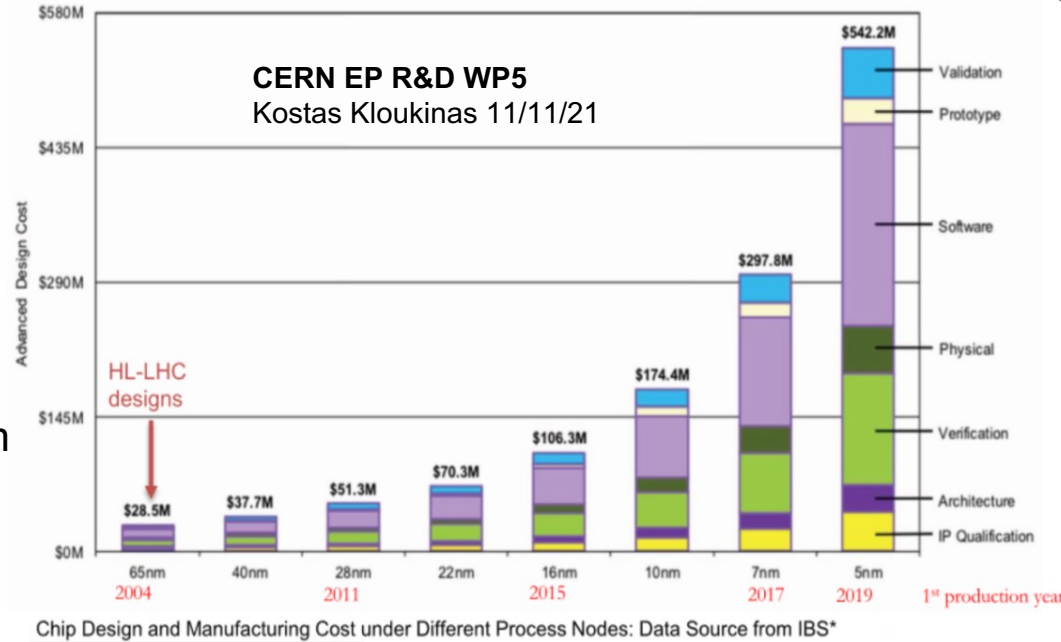
Microprocessor Transistor Counts 1971-2011 & Moore's Law



- **Main challenges: precision timing** (ToF; 4D tracking), **high granularity** and **resolution** imply a **cost** in terms of **data handling, processing, complexity and power**.
- Need **latest advances in commercial microelectronics** and **high-speed links** (DRDT 7.1, 7.4, 7.5)
- However, very specific needs for HEP in e.g. **radiation hardness** or **operation in magnetic fields** with HEP at best a niche low volume market.
- For example: Long time to develop radiation tolerance in 65 nm O(GRad) and large cost → technology is not straightforward;

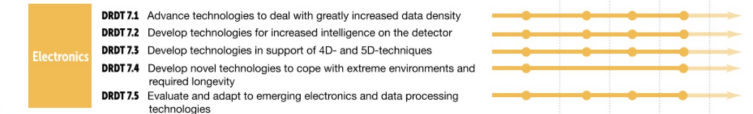


RD53 Collaboration (65 nm ASIC for HL-LHC)



Increasing sophistication, entry **cost** and **complexity**  
 → call for a **change of approach** from the past with **increased coordination around Europe**

→ **DRDTs of TF7:** (see spare slides)



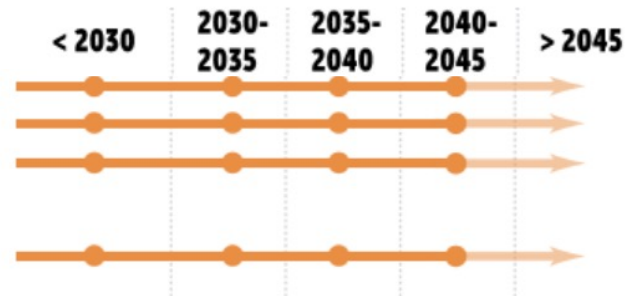
- HEP Community looks into 28 nm for the future and dedicated 130/65 nm technologies for monolithic pixels (DRDT 7.1)

# Integration

- DRDTs:



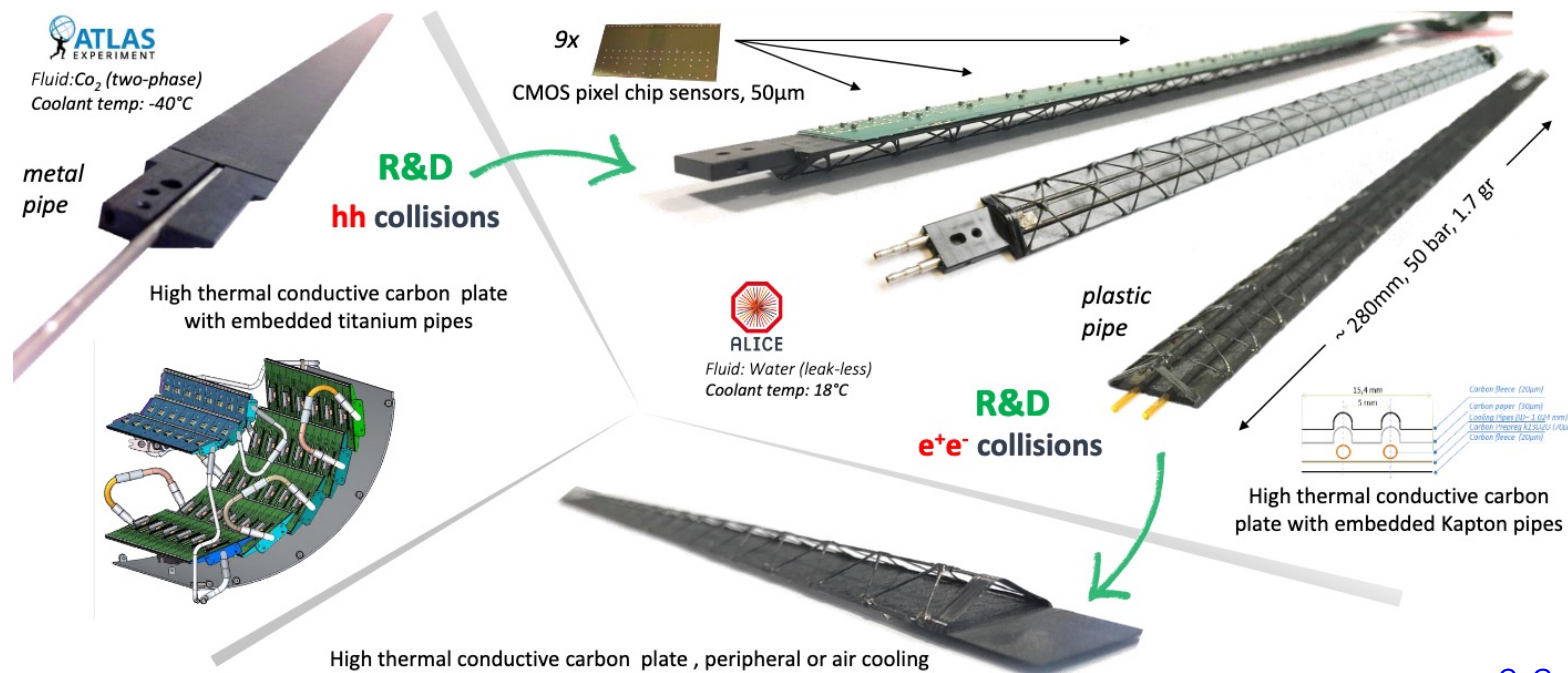
- DRDT 8.1** Develop novel magnet systems
- DRDT 8.2** Develop improved technologies and systems for cooling
- DRDT 8.3** Adapt novel materials to achieve ultralight, stable and high precision mechanical structures. Develop Machine Detector Interfaces.
- DRDT 8.4** Adapt and advance state-of-the-art systems in monitoring including environmental, radiation and beam aspects



- Investigation of **novel superconductors for magnet systems** as well as support of expert design capabilities and modelling software for future experiments is vital.
- Cooling technologies** for cryogenics and low-mass heat removal from on-detector electronics and semiconductor sensors require dedicated R&D activities.

- Ultra low mass, stable, precision mechanics and machine detector interface design** are major topics

- Example: Pipe design

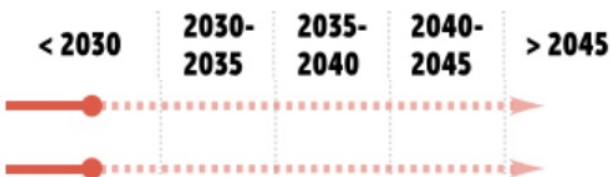




# Training for instrumentation

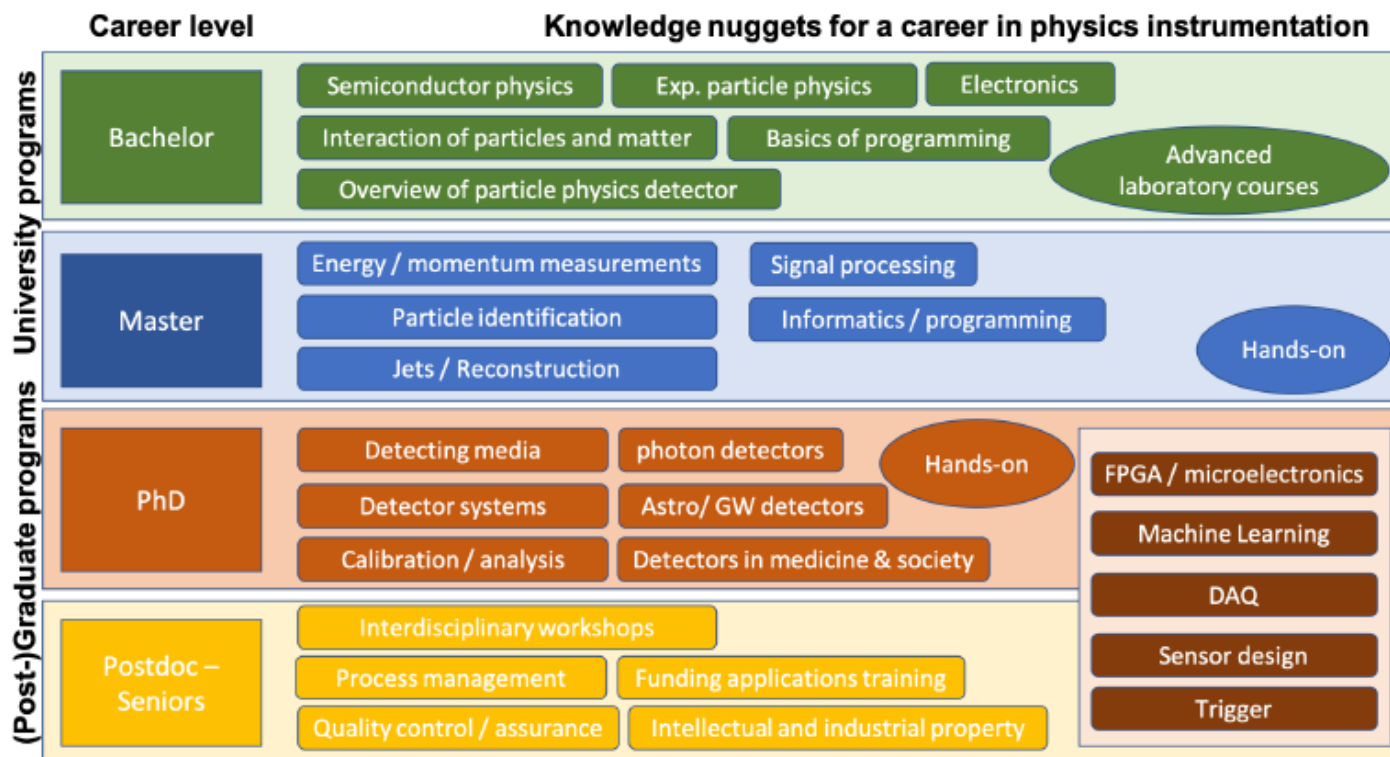
Training\*

- DCT 1** Establish and maintain a European coordinated programme for training in instrumentation
- DCT 2** Develop a master's degree programme in instrumentation



\* See "Results of the 2021 ECFA Early-Career Researcher Survey on Training in Instrumentation" [ECFA ECR Panel arXiv:2107.05739](#)

- A structured training programme shall support the scientists in their career
- Increase participation of young scientists, in particular graduate students, in leading-edge instrumentation R&D, and to foster growth of future HEP instrumentation experts who can compete for permanent positions



Possible structure of a training plan recommendation

Personnel, retention and training of detector experts are detailed in the [ECFA Detector R&D Roadmap](#) as mandatory to the success as well as the long-term health of experimental particle physics as a whole.

# 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.

# 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.



# 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<sup>3</sup>) should explore ensuring similar access is available to instrumentation journals (including for conference proceedings) as to other particle physics publications.

# ECFA Detector R&D Roadmap

Main Document published and approval by RECFA at 19/11/21 and 8 page synopsis brochure prepared for less specialists audience (<https://cds.cern.ch/record/2784893>)



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→ The Roadmap has been presented to the CERN Scientific Policy Committee and Council and has been very well received, with the SPC congratulating the Roadmap Panel and endorsing the recommendations, **creating significant support and momentum for following up on its key recommendations.**

# Implementation of the Roadmap

- **Next step is the implementation of the Roadmap:** CERN Council has mandated ECFA to work out a detailed implementation and review plan (in close collaboration with SPC, the Funding Agencies and the relevant research organisations in Europe and beyond)
- **Roadmap Panel Coordination Group has worked out a proposal which was discussed in RECFA and presented to SPC and Council** in March and June 2022
- **Discussions have been going on with the Funding Agencies** and proposed implementation plans were presented to them in April 2022 in [Plenary RRB](#)
- Discussions with existing RD collaborations like RD50, RD51, CALICE
- Presentation to community by P. Allport in [Plenary ECFA in July 2022](#)
  - **ECFA regards the first stage, that needs the longest lead-time, as being to work out funding structures that would meet the recommendations **GSR4**, **GSR5** and **GSR6** to define a long-term framework for strategic R&D detector funding in Europe.**
  - It was realised that the only viable model to fund future R&D Collaborations to deliver programmes to sustain the multi-decadal requirements, identified as the DRDTs in the Roadmap, was to **utilise the existing understood framework for funding long-term investments in particle physics experiments at CERN.**

→ **The formation of new Detector R&D (DRD) collaborations**

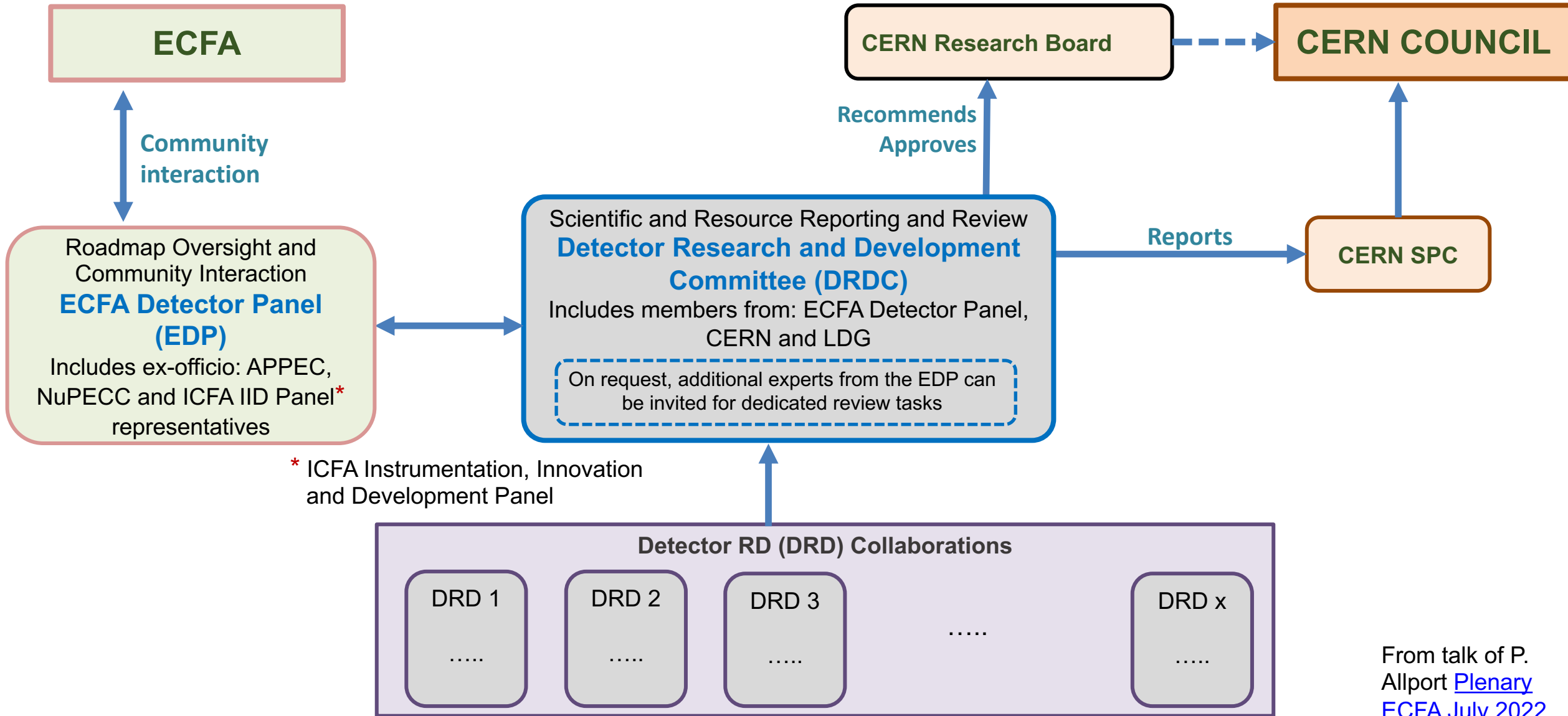


# Implementation of the Roadmap

- It is proposed that the **DRD Collaborations** should be anchored at CERN → CERN recognition; World-wide participation
- **The new DRDs should take full account of existing, well-managed and successful ongoing R&D collaborations and other existing activities** (current RDs, CERN EP R&D programme, EU-funded initiatives, collaborations exploring particular technology areas for future colliders, ... ).
- The **formation of the new DRD collaborations** should clearly adopt a **community-driven approach**;
  - propose this could be supported by existing ECFA Detector R&D Roadmap Task Forces;
  - existing CERN RDs, or other collaborations, covering several DRDT topics can help nucleate the process;
  - aim to initiate this year, with full process established over the coming year.

→ setting these up is foreseen to follow a bottom-up approach, coordinated by the ECFA Task Force leaders with strong involvement of managements of existing RD collaborations
- Research topics, budget, milestones, etc., would have to be **adapted as rolling grants for long-term R&D lines** with flexibility for adapting to the changing international landscape and new R&D opportunities (for example coming from “*blue-sky*” R&D funded through resources outside those awarded for DRDT-specific strategic R&D). Funding of Strategic R&D anticipated to be additional to both Blue-Sky R&D and to the very Experiment-Specific R&D that should be covered within the corresponding experiment funding envelope.
- Resources are expected to be awarded to and held at the participating institutes

# Implementation and Review

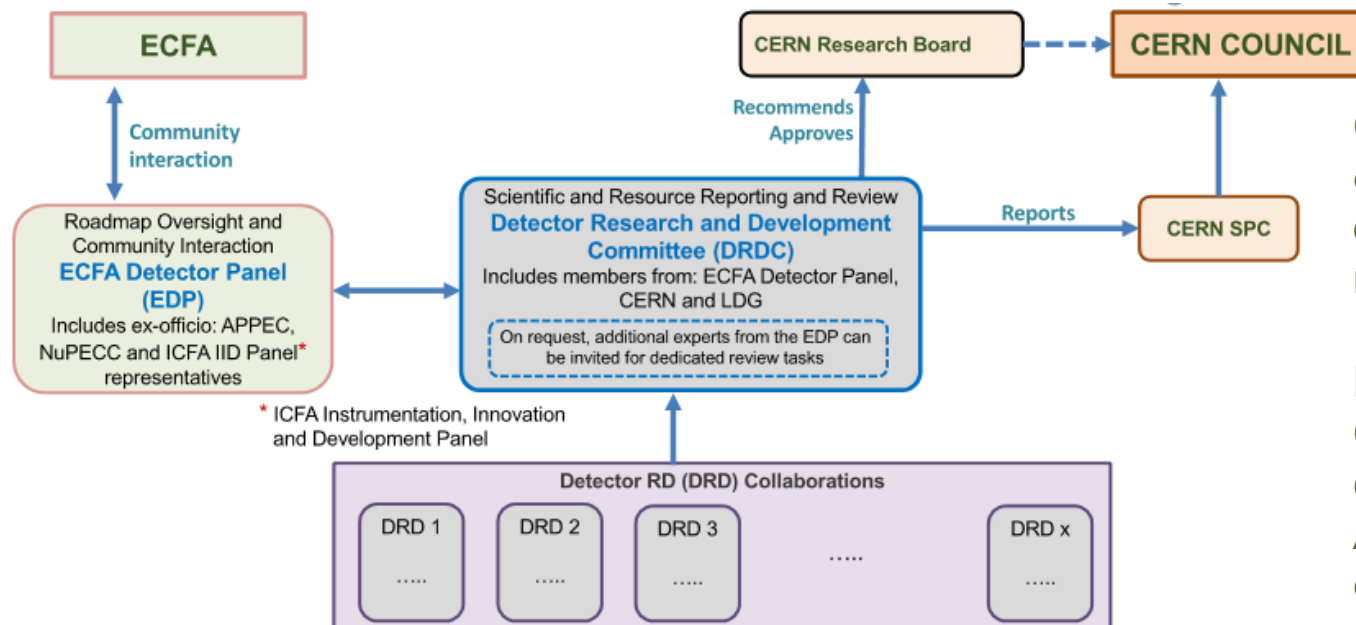


From talk of P. Allport [Plenary ECFA July 2022](#)

# Implementation and Review

**ECFA (through RECFA and PECFA) maintains broad links to the wider scientific community.**

**EDP engages with other scientific disciplines and also communities outside Europe through close links with the ICFA IID Panel.**



**CERN provides rigorous oversight through well-established and respected reviewing structures.**

**DRDs able to benefit from CERN recognition in dealings with Funding Agencies and corporations.**

## EDP:

- provides direct input, through appointed members to the DRDC, on DRD proposals in terms of Roadmap R&D priorities (DRDTs);
- assists, particularly via topic-specific expert members, with annually updated DRDC scientific progress reviews of DRDs;
- monitors overall implementation of ECFA detector roadmap/DRDTs;
- follows targets and achievements in light of evolving specifications from experiment concept groups as well as proto-collaborations for future facilities;
- helps plan for future updates to the Detector R&D Roadmap.

## DRDC:

- provides financial, strategic and (with EDP) scientific oversight;
- evaluates initial DRD resources request with focus on required effort matching to pledges by participating institutes (including justification, given existing staff, infrastructures and funding streams);
- decides on recommending approval;
- conducts progress reviews on DRDs and produces a concise annual scientific summary encompassing the full detector R&D programme;
- be the single body that interacts for approvals, reporting etc with the existing CERN committee structure.



# Implementation of the Roadmap

- It has been strongly recommended that the setting up of this proposed organisational structure proceeds immediately with concrete plans. The final **implementation and review plan will be presented to Council at the end of September** (after discussion within RECFA, Task Force leaders and RD Collaboration managements and CERN management).
  - The aim is for DRDs to be up and running as entities by **2024** and to be ready for having a ramp up of the proposed resources awarded for “**Strategic R&D**” through **2025** to a steady state by **2026**.
- There will be of course a transition but the main target is that the DRDs will be able to address the high-priority items defined in the Roadmap via the DRDTs in this timeline

# Foreseen Timeline

- The Detector R&D Roadmap **Task Forces** will need to start **organising open meetings to establish the scope and scale of the communities wishing to participate in the corresponding new DRD activities** from **Autumn of this year**.
- (Where the broad R&D topic area has one or more DRDTs already covered by existing CERN RDs or other international collaborations these need to be fully involved from the very beginning and may be best placed to help bring much of the relevant community together around the proposed programmes.)
- **Through 2023**, **mechanisms** will need to be **agreed with funding agencies**, in parallel to the below, for country specific DRD collaboration funding requests for Strategic R&D and **for developing the associated MoUs**.
- **By Spring 2023**, the **DRDC mandate** would need to be formally defined and agreed with CERN management; Core DRDC **membership** appointed; and **EDP mandate** plus **membership** updated to reflect additional roles.
- To allow sufficient time for **reviewing** and iteration, **DRD proposals** will need to be submitted by **early Summer 2023**.
- Formal **approval** should be given by the CERN Research Board **in Autumn 2023**.
- New **structures operational** and new **R&D programmes underway** from **beginning 2024**.
- **Through 2024**, **collection of MoU signatures** will need to take place, with defined areas of interest per institute.
- **Ramp up of new strategic funding and R&D activities** **2024-2026** in parallel to completion of current deliverables.

# Summary

- The [ECFA Detector R&D Roadmap](#) has been prepared by a large team of internationally recognised leaders in this area with access to a much wider pool of other instrumentation experts. It has been the **product of wide community consultation with very broad participation**.
- The results of all the feedback have been implemented in the **final 248 page version and additional non-expert 8 page synopsis which was formally approved by Plenary ECFA on 19<sup>th</sup> November 2021**.
- Many technological challenges and several examples were presented in this talk → **Highlighting the need for a lot of further Detector R&D**
- **The Roadmap has been presented to the CERN Scientific Policy Committee and Council** and has been very well received, with the SPC congratulating the Roadmap Panel and endorsing the recommendations, **creating significant support and momentum for following up on its key recommendations**.
- **Detailed plans for the implementation of the Roadmap have been developed during 2022**.
- **New DRD collaborations, one per Task Force are proposed and a related review structure** to set up an overall framework to secure longer-term R&D resources and taking advantage of the multiple synergies across different fields of detector development.



# Thank you!

## **Acknowledgment**

Phil Allport, Kerstin Borrás, Maxim Titov, Roman Pöschl, Karl Jakobs, Christian Joram, Laura Baudis, Corrado Gargiulo, Thomas Peitzmann, Ian Shipsey, Frank Simon, Sunil Gowala, and the ECFA Roadmap Panel

# SPARE



# Implementation and Review

- The aim is for DRDs to be up and running as entities by 2024 and to be ready for having a ramp up of the proposed resources awarded for “Strategic R&D” through 2025 to a steady state by 2026.
- The timescales are set by the necessity to prioritise HL-LHC deliverables and to allow a timely completion or transfer of existing funded R&D into this new framework.  
(Note existing CERN RD collaborations will need to put in proposals for continuation beyond the end of 2023.)
- Strategic funding is here intended to be additional to continued funding opportunities to support of more exploratory Blue-Sky R&D through shorter-term “responsive mode” schemes (often nationally organised with broader peer review looking across applications in a range of scientific communities).
- Such funding should be expected to continue being sought by participating researchers where it is more appropriate for speculative ideas whose impact is much wider than that defined by the currently understood detector R&D needs of the future particle physics programme (as encapsulated in the DRDTs).
- As currently, highly Experiment Specific R&D is expected to be covered within the funding envelope for approved projects where detailed specifications call for a much more targeted approach.
- Mechanisms should be established to maximise flow of ideas and experience between these three different modes of R&D.

[Talk P. Allport Plenary ECFA July 2022](#)



# European Particle Physics Strategy Update



**“Main report:** *“Recent initiatives with a view towards strategic R&D on detectors are being taken by CERN’s EP department and by the ECFA detector R&D panel, supported by EU-funded programmes such as AIDA and ATTRACT. Coordination of R&D activities is critical to maximise the scientific outcomes of these activities and to make the most efficient use of resources; as such, there is a clear need to strengthen existing R&D collaborative structures, and to create new ones, to address future experimental challenges of the field beyond the HL-LHC. Organised by ECFA, a roadmap should be developed by the community to balance the detector R&D efforts in Europe, taking into account progress with emerging technologies in adjacent fields.”*

**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 levels.”*

Extracted from the documents of 2020 EPPSU, <https://europeanstrategyupdate.web.cern.ch/>

More roadmap process details at: <https://indico.cern.ch/e/ECFADetectorRDRoadmap>

# Detector R&D organisation

- Looking in the past:

## Detector R&D

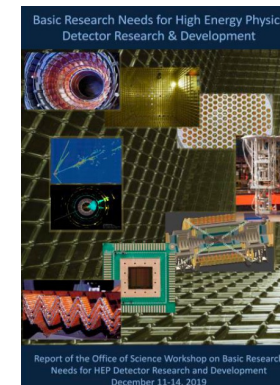
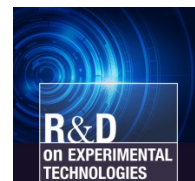
- From 1986, vigorous CERN programme with 40 MCHF funding from Italian government (Zichichi's LAA Project)
- CERN Detector R&D Committee set up mid 1990. By March 1992: 35 proposals, 24 approved – involving 800 people in 170 institutes

## Detector Research and Development Committee (DRDC), 1990 - 1995

The Detector Research and Development Committee (DRDC) was set up in July 1990. It received proposals for detector R&D involving people from Member States, other countries, and CERN itself. The committee operated in the same way as the other experimental committees of CERN, and forwarded its recommendations to the Research Board for final decision. It held its last meeting in January 1995. Its role was taken over by the [LHC Committee \(LHCC\)](#).

- Several processes conducted/ongoing to organise the Detector R&D (more details in spare slides)

- Technology oriented RD Collaborations: [RD18](#), [RD42](#), [RD50](#), [RD51](#), [RD53](#), ...
- US [Basic Research Needs](#) report and [Snowmass Instrumentation Frontier](#) process
- [CERN EP R&D](#)
- [AIDAInnova](#)
- [ECFA Detector R&D Roadmap](#) ([Slides](#), [Webpage](#))
- ....

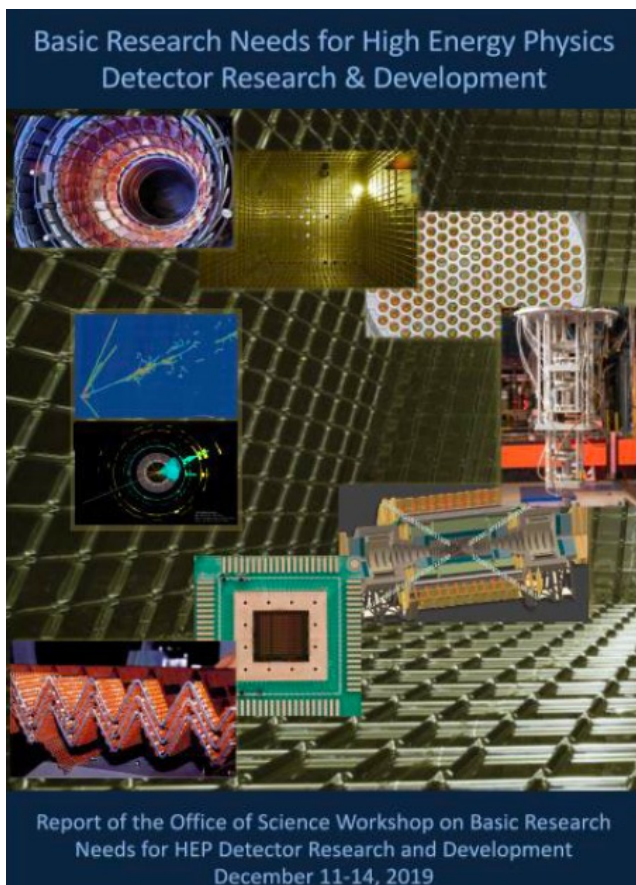


**Detector R&D readiness should not be the determining factor in the future of particle physics**

# US: Basic Research Needs Report, Snowmass Process

DOE-BRN Report published (Sep. 2020)

<https://science.osti.gov/hep/Community-Resources/Reports>



**Snowmass Instrumentation Frontier:** The Snowmass Process is organized by the DPF of the American Physical Society: <https://snowmass21.org>

- Identify and document a vision for the future of particle physics (PP) in the US in a global context
- Communicate opportunities for discovery in PP to broader community and to the (US) government.
- Aim for Snowmass Book and online archive by end of 2022
- <https://snowmass21.org/instrumentation/start> Conveners: P. Barbeau, P. Merkel, J. Zhang

- **Snowmass Summary for Public**
  - 2 pages

- **Snowmass Summary Report**
  - ~50 pages

- **Snowmass Book**
  - ~500 pages

- **Topical Group Reports**

- **Reports of Multi-Frontier Topics**

- **Contributed Papers**  
= **White Papers**

**Snowmass Report**  
**« Community-Driven »:**

- Executive Summary: ~10 pages
- Introduction
- 10 Frontier Executive Summaries
- Executive Summaries of Multi-Frontier Topics
- Conclusion

- Snowmass Summary Report (~50 pages)
- Frontier Summaries (~400 pages with 10 Frontiers)
- Multi-Frontier Topic Summaries (~50 pages)

**IF Frontier Summary:**  
**40 pages**

(Written by TG members including early careers)

- Topical Group Reports: short reports

- Multi-Frontier Topics spanning multiple Frontiers.
- Each Multi-Frontier Topic Summary: ~10 page

(Written by the community including early careers)

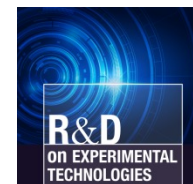
- References



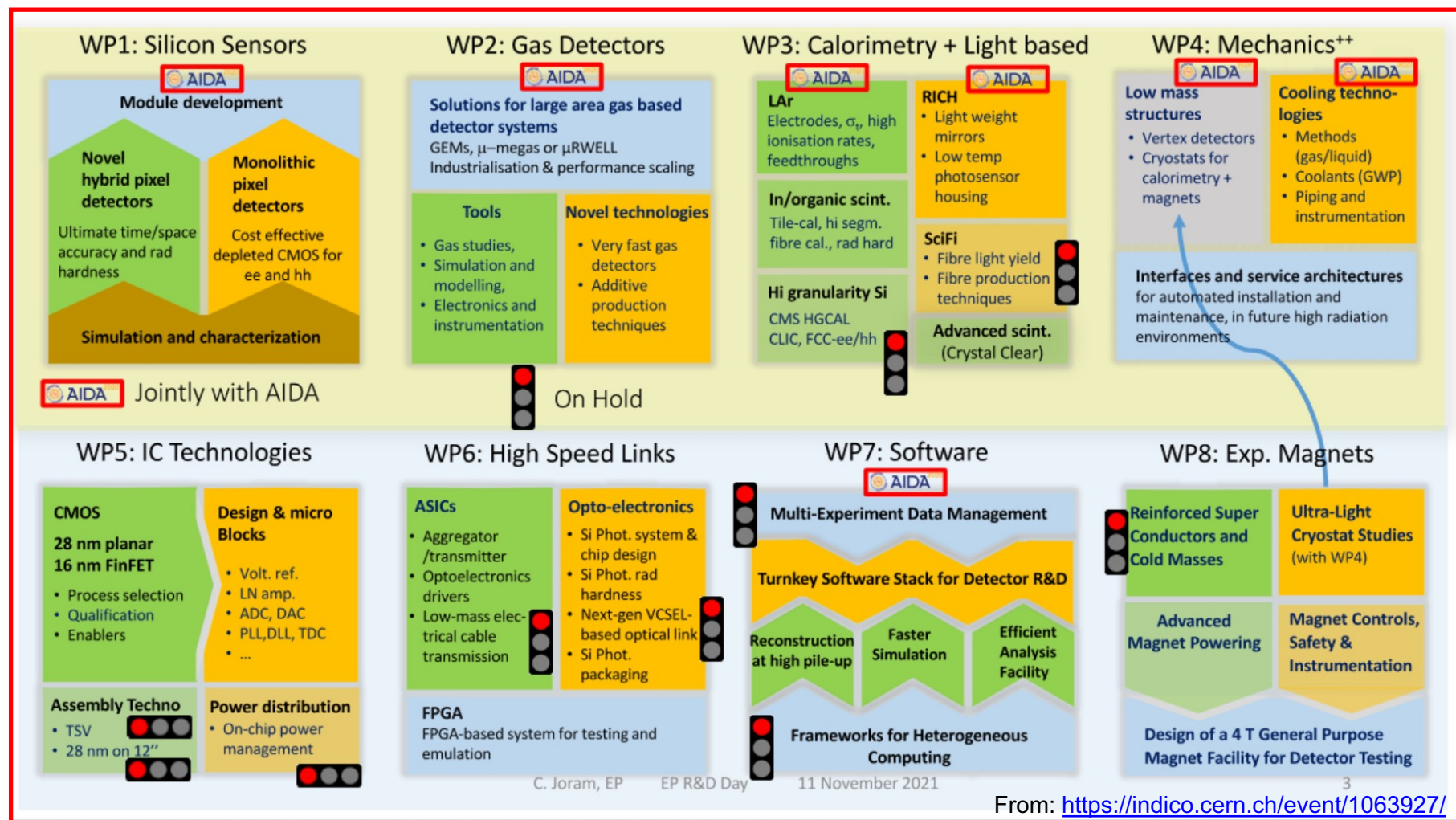
# CERN EP R&D



- Following tradition of **DRDC** (LHC Phase-0), White Paper R&D (LHC Phase-I)
- Target **beyond approved LHC upgrades**: e.g. FCC-ee/eh/hh
- Strong links/overlap with RD50, RD51, RD18 and AIDAInnova



- See materials at <https://ep-rnd.web.cern.ch>



From: <https://indico.cern.ch/event/1063927/>



# EU: AIDAInnova Project and Detector R&D for Higgs Factories



## New AIDAInnovaCall / Objectives:

- Support research **infrastructure** networks developing and implementing a **common strategy/ roadmap** including technological development required for improving their services through **partnership with industry**
- Support **incremental innovation** and cooperation with industry
- Complementarity to ATTRACT
- Increased focus on industrial partners
- No Transnational Access Proposed
- Funding 10 M€ for 4 years

## Some targeted applications:

- Higgs Factories
- ATLAS, CMS LS4, ALICE, LHCb LS3 pre-TDR
- Accelerator-based neutrino experiments

## Higgs Factory Detector R&D



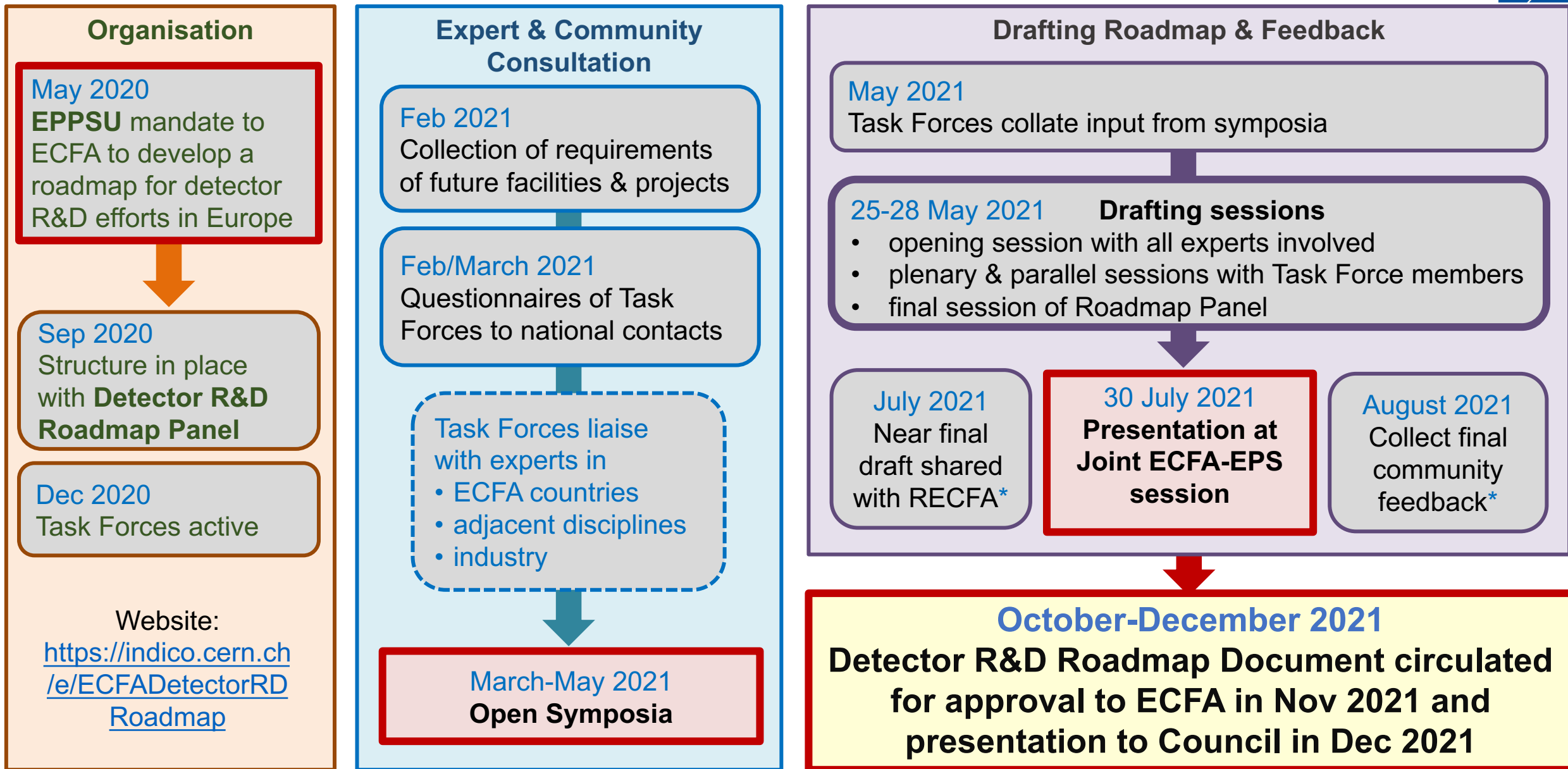
Detector Technology	Linear & Circular Colliders common R&D	Differences
All	test infrastructure prototype electronics software for reconstruction and optimisation	readout rates power and cooling requirements
Silicon Vertex and Track Detectors	highest granularity and resolution, timing ultra-thin sensors and interconnects simulation and design tools low-mass support structures cooling micro-structures	emphasis on timing (background) and position resolution
Gaseous Trackers and Muon Chambers	ultra-light structures for large volumes industrialisation for large area instrumentation eco-friendly gases	DC and TPC presently considered only at some colliders
Calorimeters and Particle ID	highly compact structures and interfaces advanced photo-sensors and optical materials ps timing sensors and electronics	emphasis on granularity and stability DR and LAr presently only considered for circular

F. Sefkow: <https://indico.cern.ch/event/932973/contributions/4066737/attachments/2140131/3606033/Ainnova-HiggsF-FSefkow20201110.pdf>

# Technology oriented R&D Collaborations

- Originally: "Cell" approach, oriented to select the different LHC experiment detector technologies within CERN DRDC program (90's): <http://committees.web.cern.ch/Committees/obsolete/DRDC/Projects.html>
- **Today: Successful approach to streamline efforts/resources, handle new techniques and common components to on-going detector engineering challenges/production:**
  - RD42 Diamond detectors
  - RD50 Silicon radiation hard devices
  - RD51 Micropattern gas detectors
  - RD53 Pixel readout chip for ATLAS and CMS (65 nm)
- In general, large collaborations of interacting institutes, mostly EU-based with world-wide participation
- Good model, allows to consolidate resources, especially people
- CERN is central, but support needed from other labs and agencies
- **Detector R&D Programs –originally focused on ILC and CLIC Linear Colliders** to exploit complementary/ commonalities of technological developments for different facilities
- **CALICE high granularity electromagnetic and hadronic calorimeters (since 2001 for ILC)**
  - CALICE enabled high granularity calorimetry for CMS HL-LHC upgrade

# Process and Timeline



# Links for Roadmap Process

<https://indico.cern.ch/event/957057/page/21633-mandate> (Panel Mandate document)

<https://indico.cern.ch/event/957057/page/21653-relevant-documents>

<https://home.cern/resources/brochure/cern/european-strategy-particle-physics>

<https://arxiv.org/abs/1910.11775> (Briefing Book)

[https://science.osti.gov/-/media/hep/pdf/Reports/2020/DOE\\_Basic\\_Research\\_Needs\\_Study\\_on\\_High\\_Energy\\_Physics.pdf](https://science.osti.gov/-/media/hep/pdf/Reports/2020/DOE_Basic_Research_Needs_Study_on_High_Energy_Physics.pdf)

<https://ep-dep.web.cern.ch/rd-experimental-technologies> (CERN EP R&D)

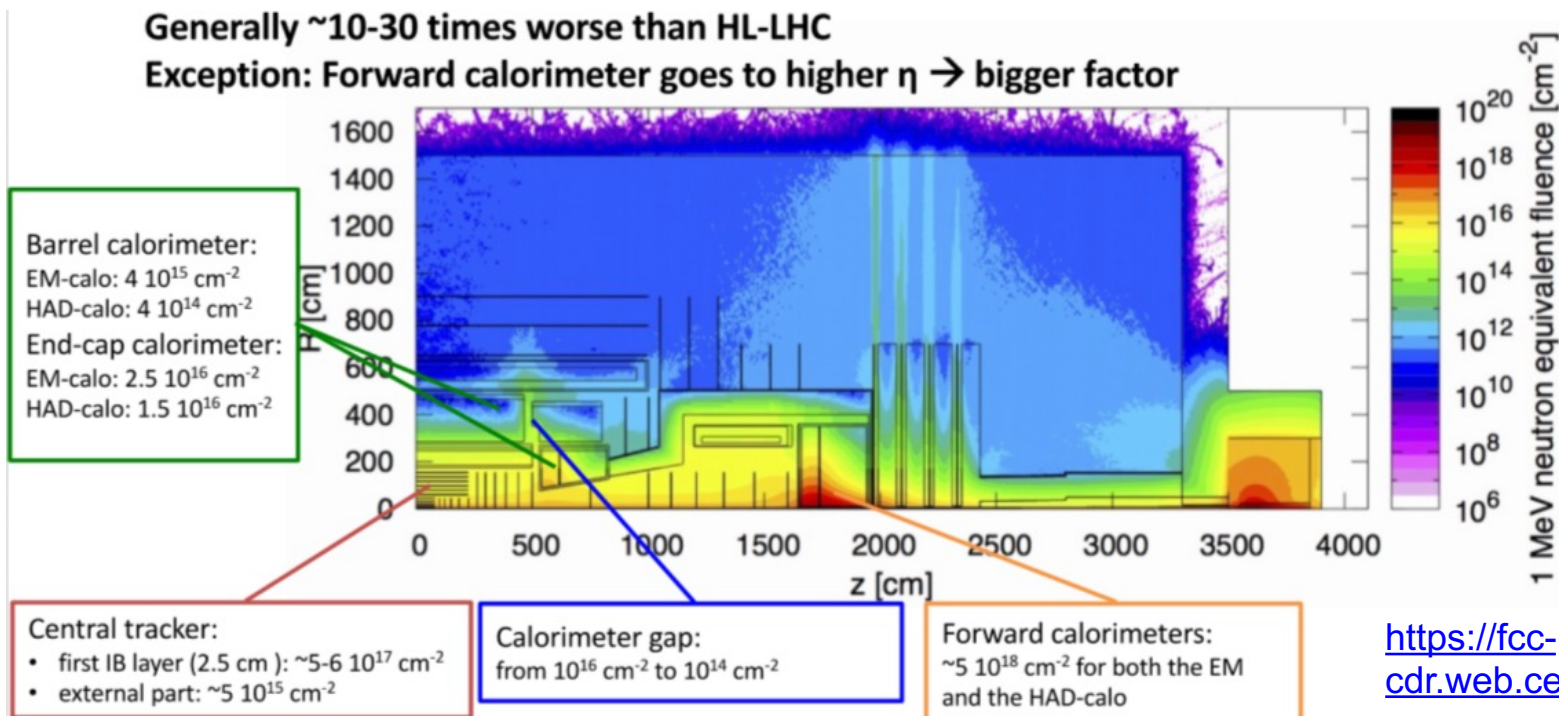
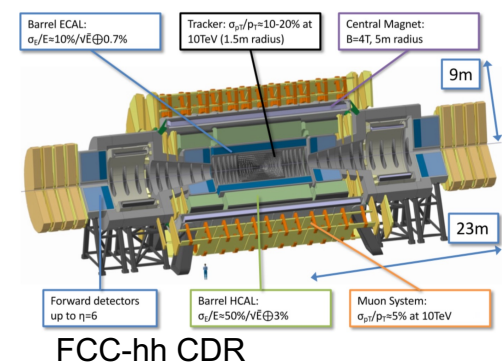
<https://aidainnova.web.cern.ch> (linking research infrastructures in detector development and testing)

<https://attract-eu.com/> (ATTRACT: linking to industry on detection and imaging technologies)

[https://ecfa-dp.desy.de/public\\_documents/](https://ecfa-dp.desy.de/public_documents/) (Some useful documents from the ECFA Detector Panel)



# Example of future detectors at accelerators

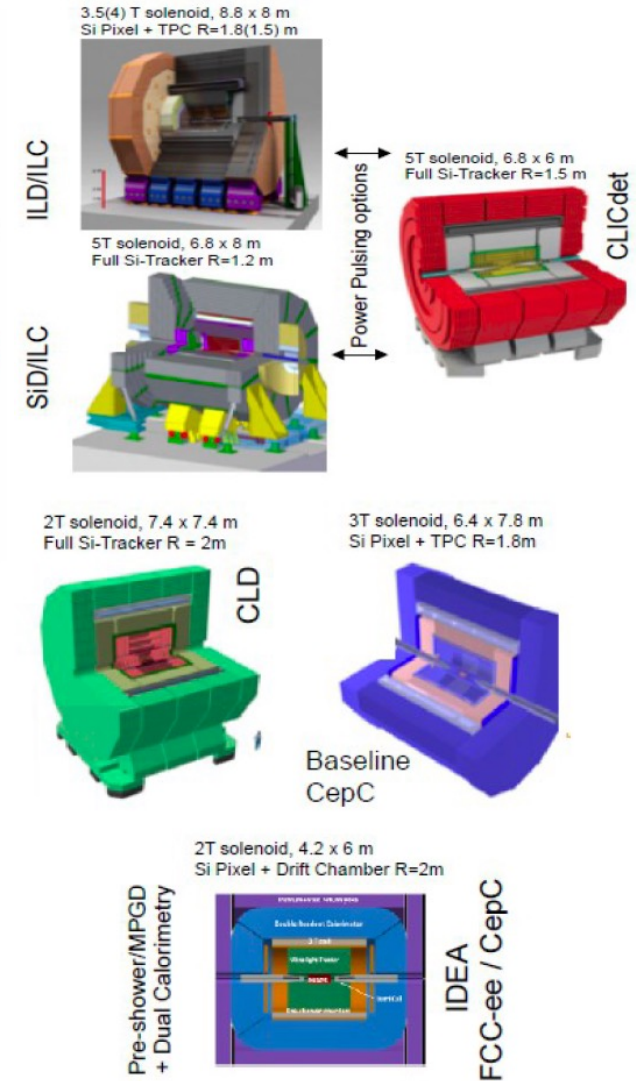
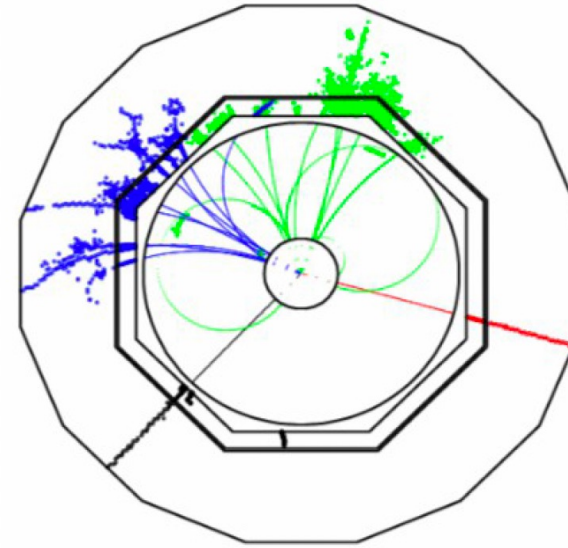
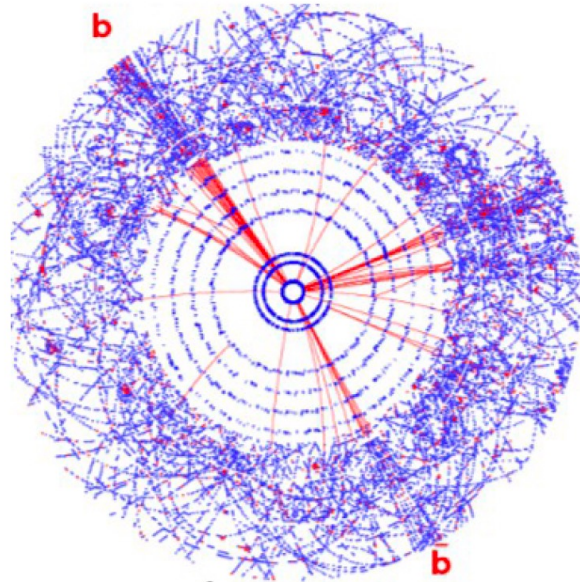


Largest challenge is that radiation levels go well beyond what any currently available microelectronics can survive ( $\lesssim$  MGy) and few sensor technologies can cope beyond  $\sim 10^{16} n_{\text{eq}}/\text{cm}^2$  (HL-LHC vertex layers)

# Example of future detectors at accelerators

Hadron-hadron collisions e.g. LHC

$e^+e^-$ -collisions

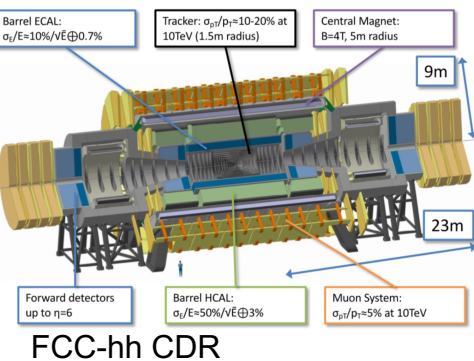


- Busy events
- Require hardware and software triggers
- High radiation levels

- Clean events
- No trigger
- Full event reconstruction

- One of the many challenges: radiation hardness. Radiation levels of e.g.  $300 \text{ MGy}/5\text{-}6 \cdot 10^{17} n_{\text{eq}}/\text{cm}^2$  in first tracker layers go well beyond what any currently available microelectronics can survive ( $\lesssim \text{MGy}$ ) and few sensor technologies can cope beyond  $\sim 10^{16} n_{\text{eq}}/\text{cm}^2$

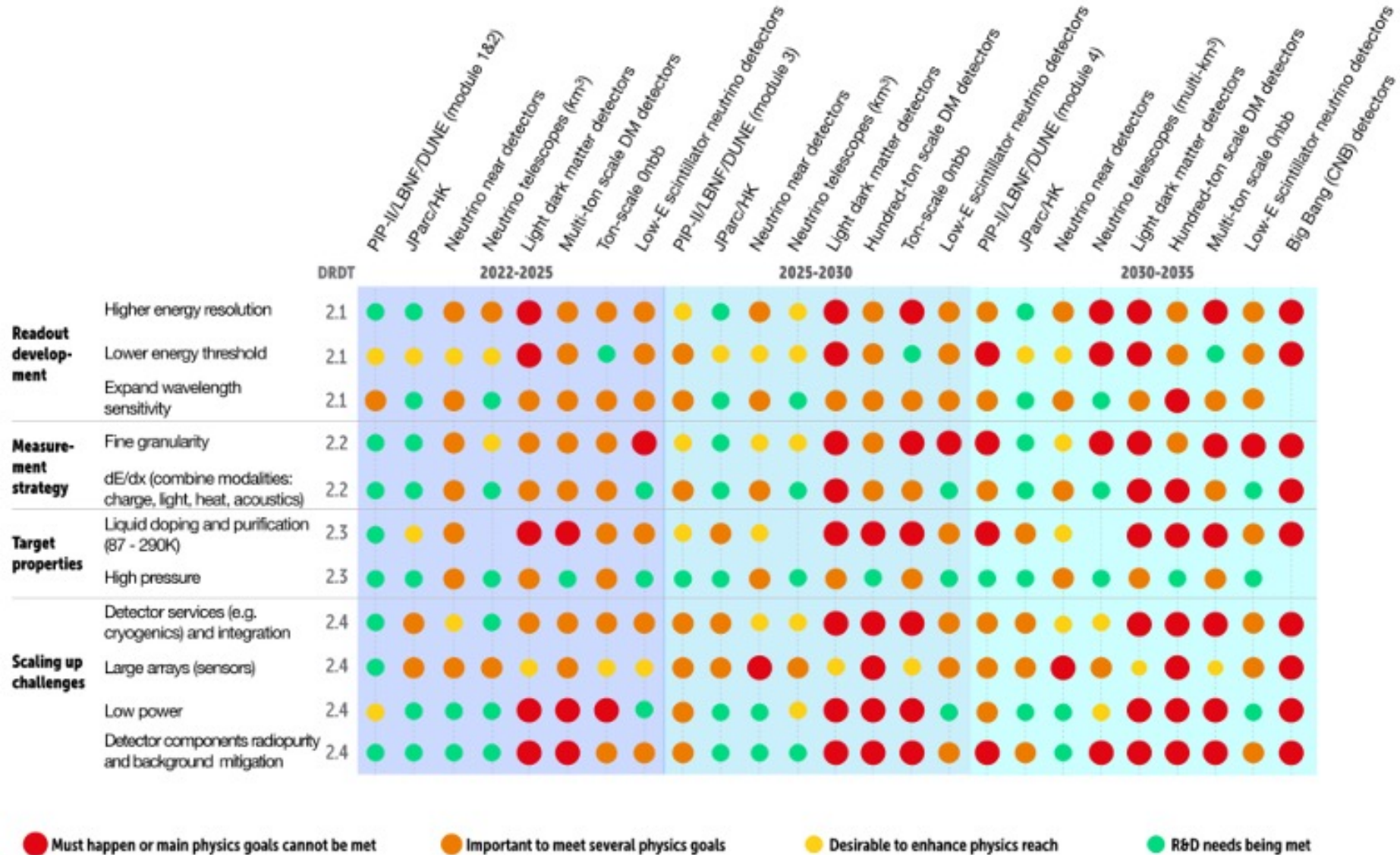
→ Detector R&D essential



FCC-hh CDR



# Liquid detectors

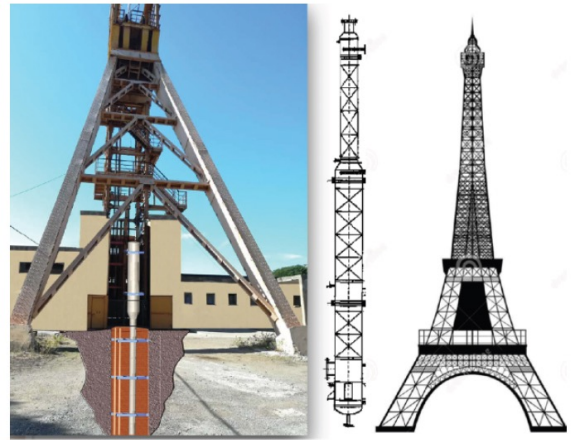


# Liquid detectors: Underground Dark Matter experiments

- Variety of DM experiments with small and rare signals need extreme control of background sources (radiopurity) coupled with high sensitivity and discrimination of signal from residual backgrounds
- R&D for multi-ton scale noble liquids: **Target properties**
  - Low-radioactivity argon: extraction (Urania plant, 330 kg/d), purification (ARIA facility, 10 kg/d)
  - Fast purification in liquid phase for large e-lifetime (removal of O<sub>2</sub> and H<sub>2</sub>O impurities) → high light and charge yield; radon-free filters
- R&D for multi-ton scale noble liquids: **Detector performance and background control**
  - Single phase versus two-phase TPCs
  - Distillation columns for krypton and radon, material screening and selection, radon emanation

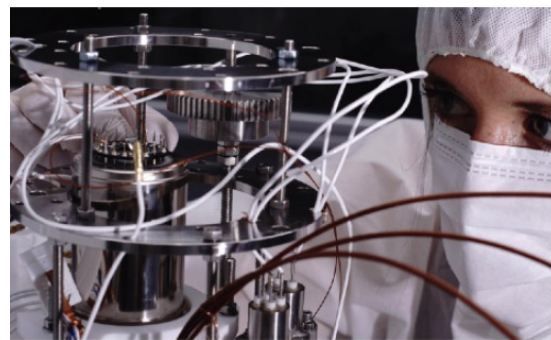
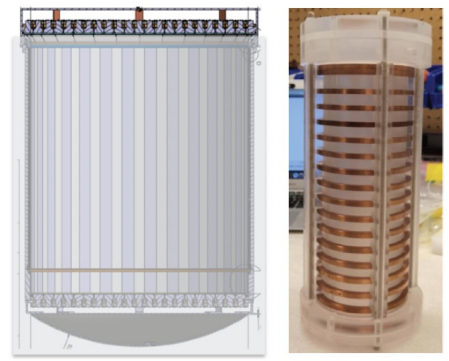


LXe purification system (5 L/min LXe, faster cleaning; 2500 slpm) for XENONnT

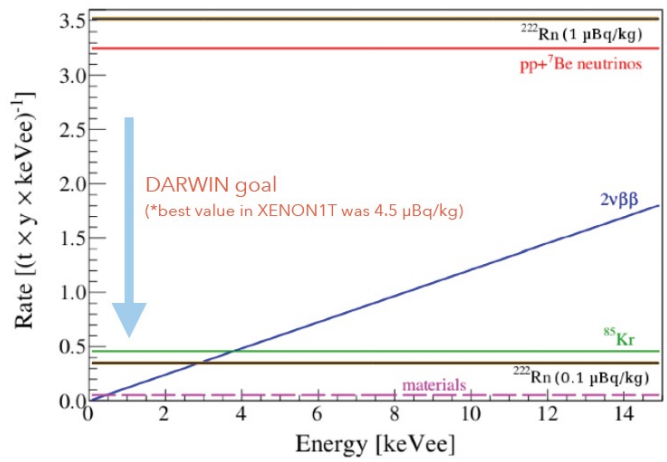


ARIA underground purification system for argon (DarkSide-20k)

R&D on sealed TPC for DARWIN; JINST 16 P01018 (2021)



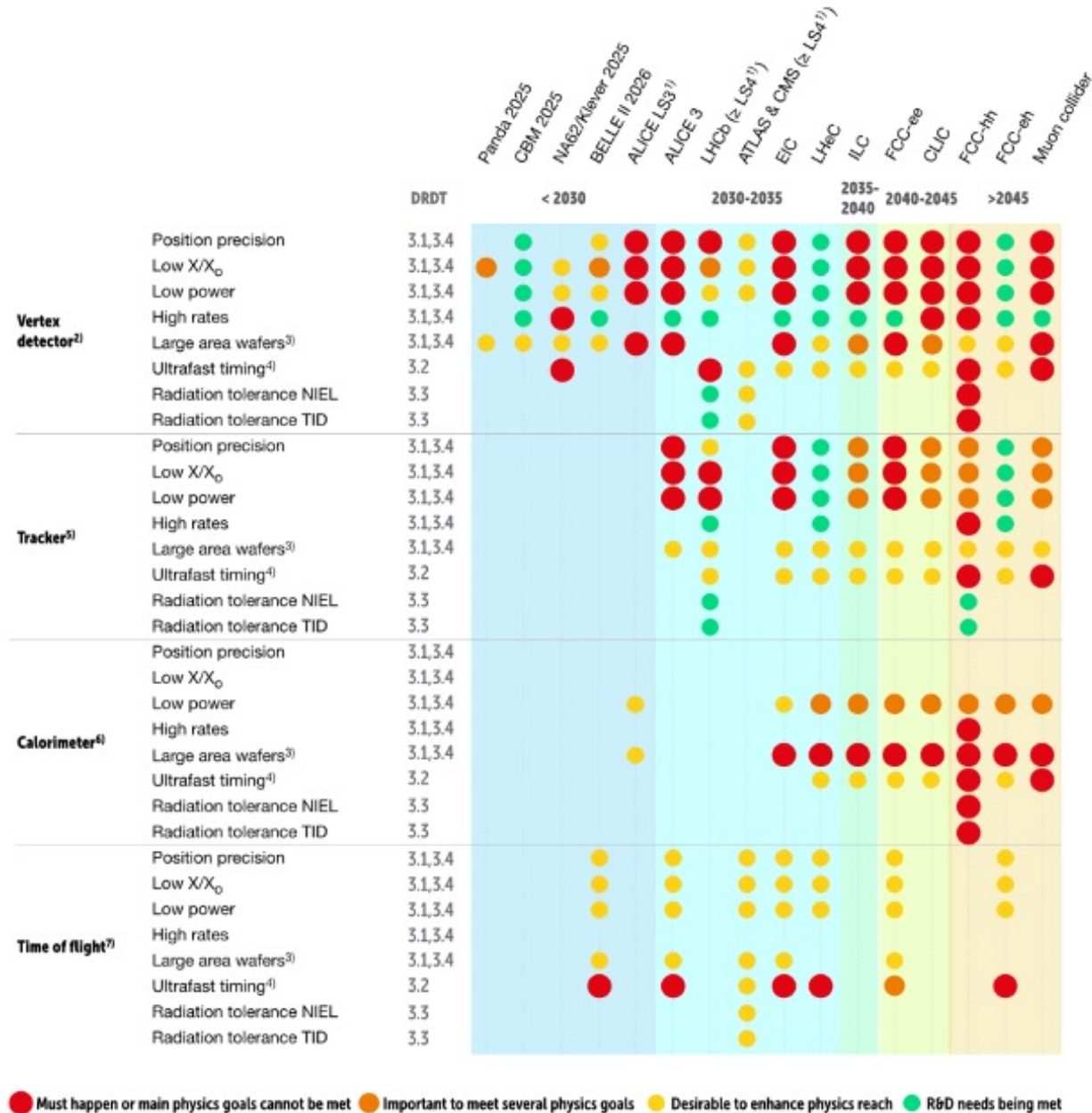
Hermetic TPC R&D for DARWIN



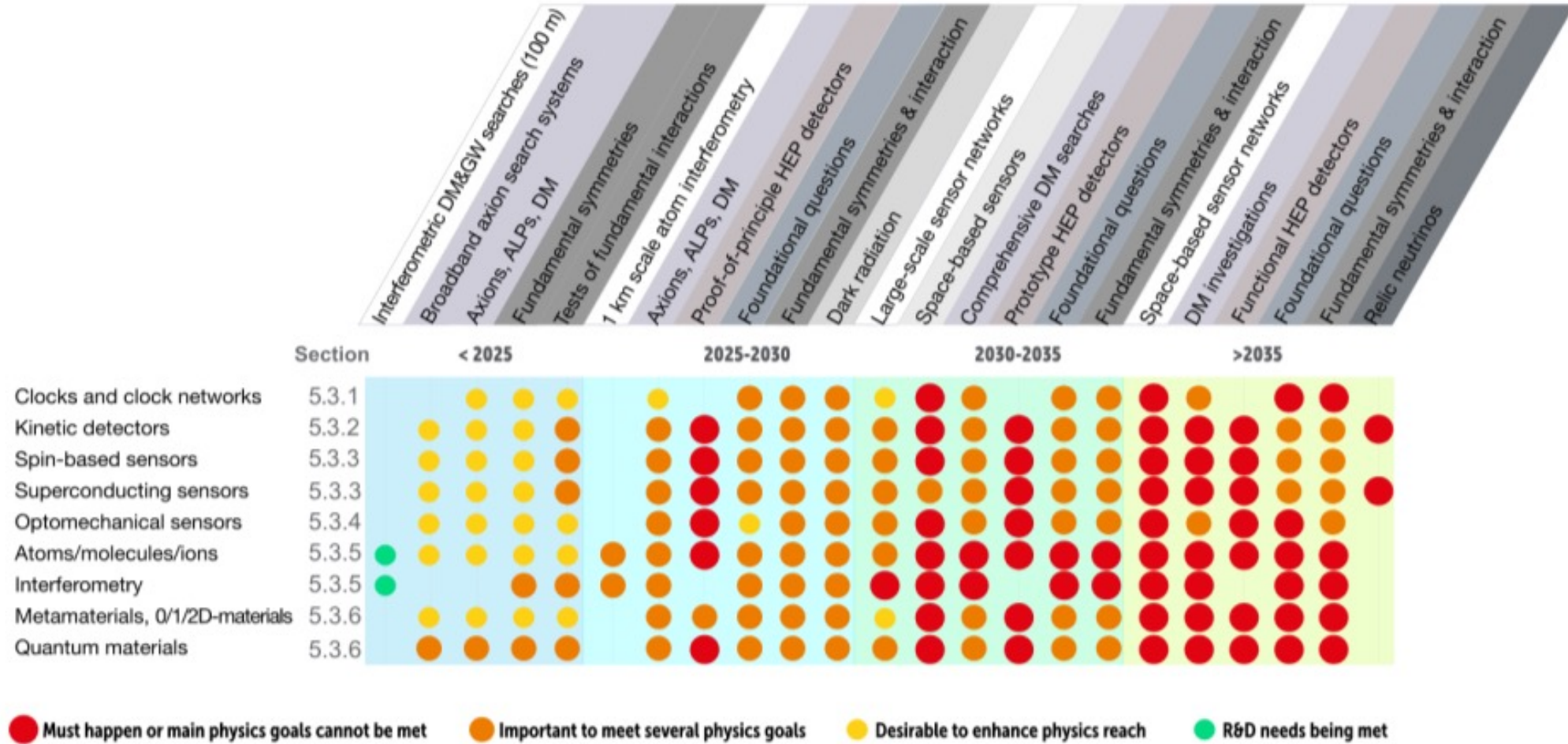
Rn distillation column for XENONnT (reduce <sup>222</sup>Rn - hence also <sup>214</sup>Bi - from pipes, cables, cryogenic system)



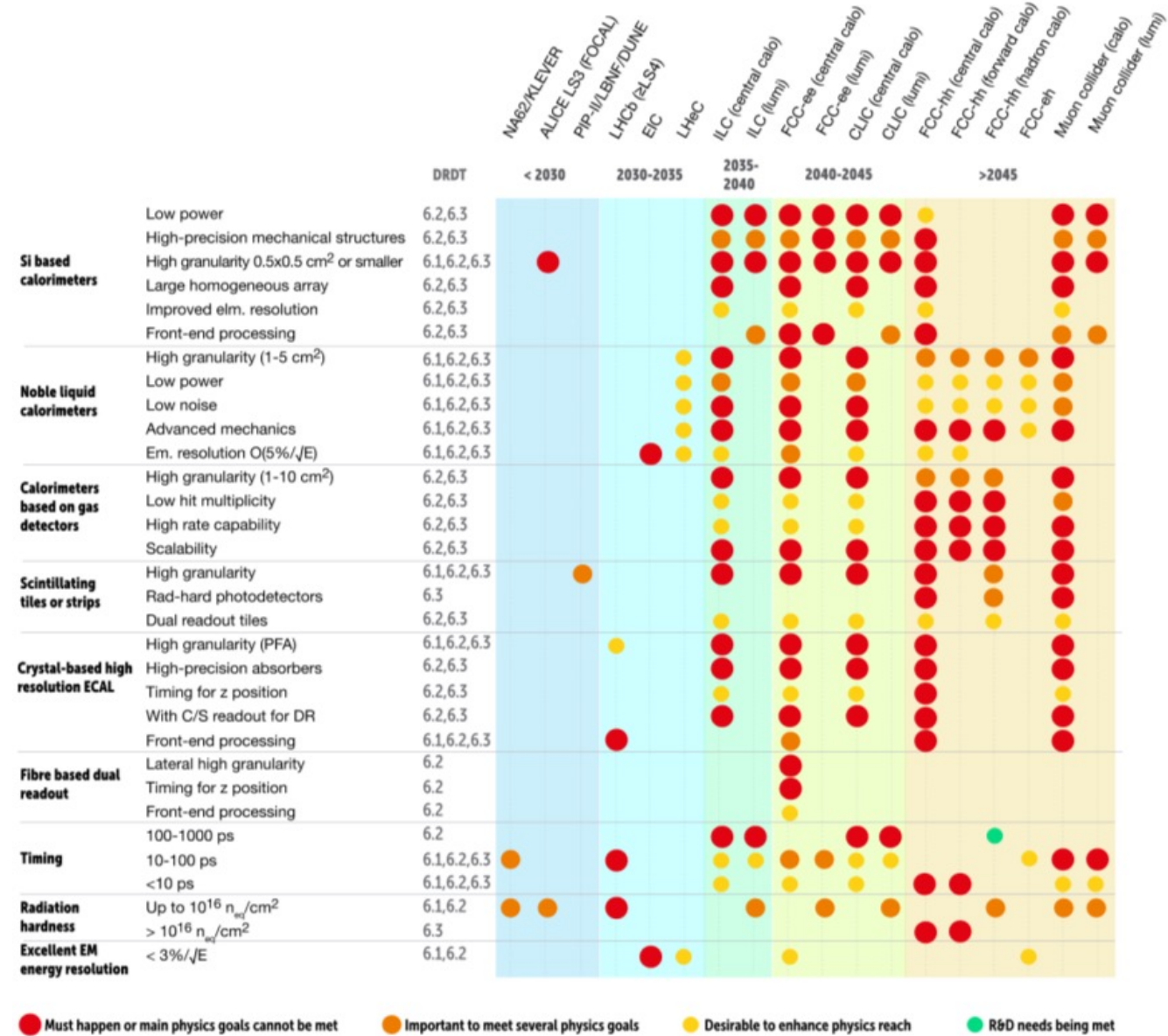
# Solid State Detectors



# Quantum and emerging technologies

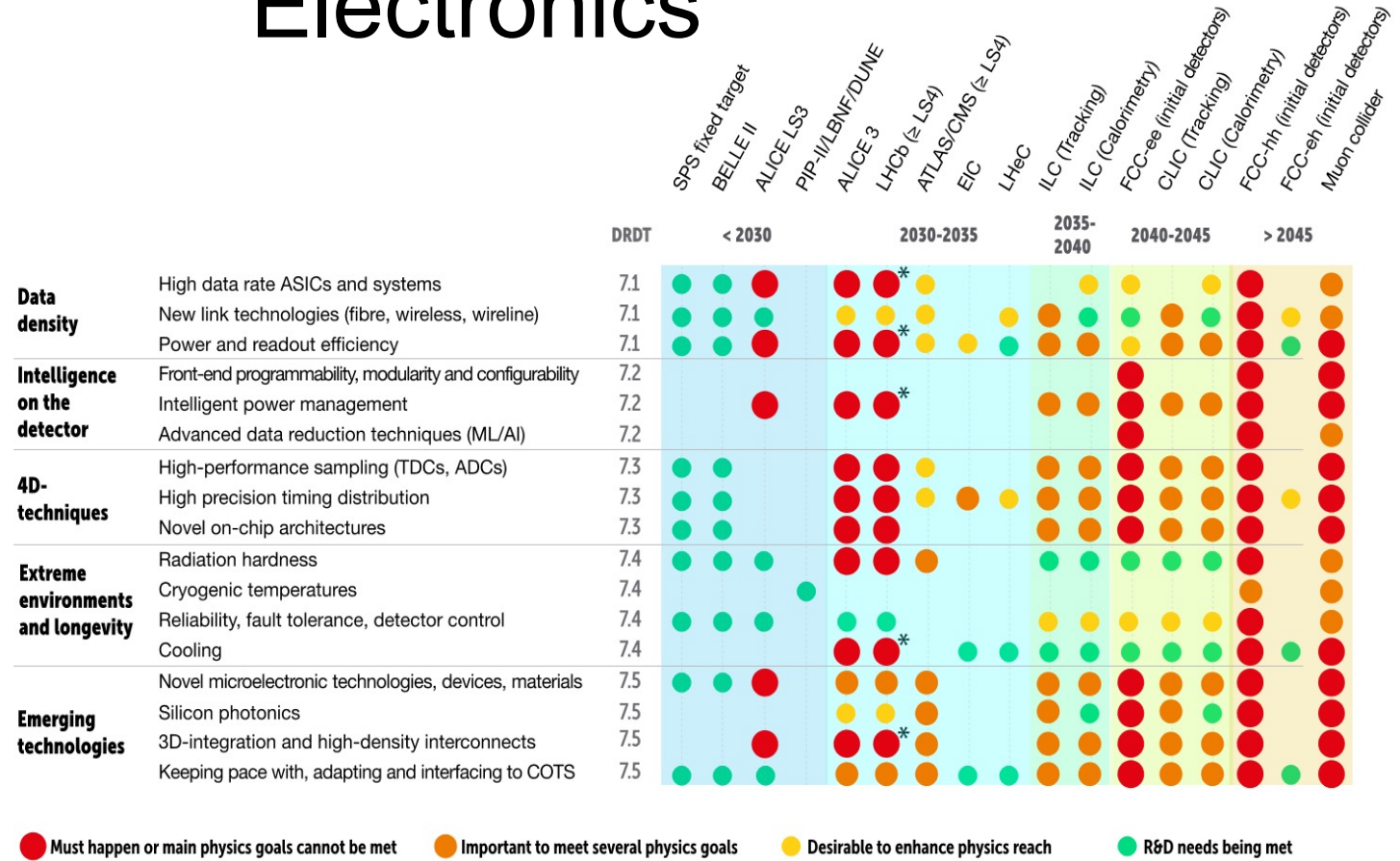


# Calorimetry





# Electronics



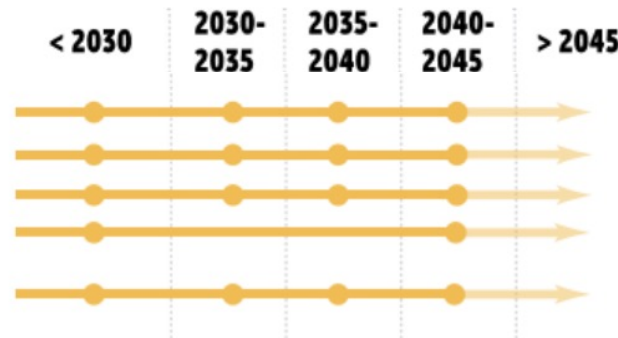
● Must happen or main physics goals cannot be met    ● Important to meet several physics goals    ● Desirable to enhance physics reach    ● R&D needs being met

\* LHCb Velo

The DRDTs are

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





# Integration

- Detector Readiness Matrix

