The ECFA Detector R&D Roadmap and its implementation

4.5.2023
LIP Lisbon Seminar

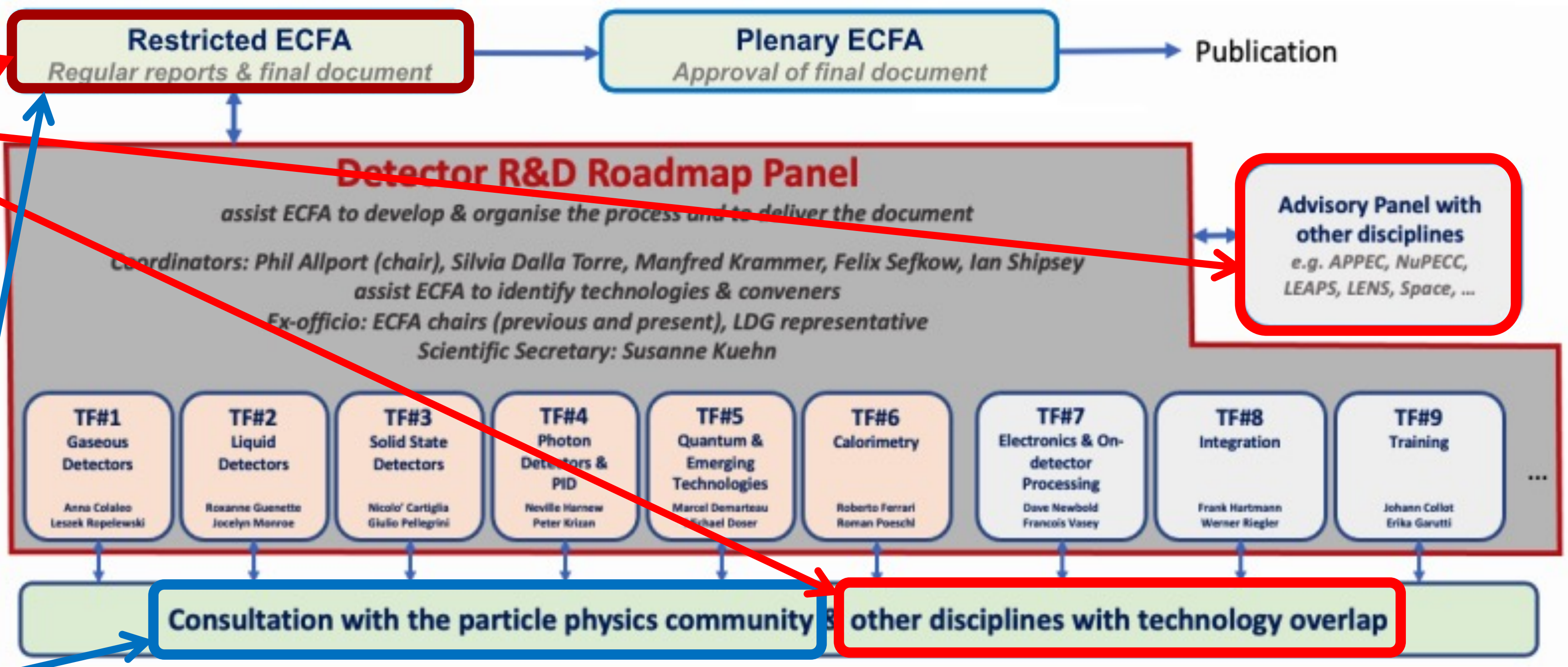
Susanne Kuehn, CERN

Overview

- The ECFA Detector R&D Roadmap process
- Overview of future facilities considered in the Roadmap
- Examples on R&D of several detector technologies with a focus on Gaseous Detectors and Calorimetry
- Observations – General Strategic Recommendations
- Implementation process
- Summary and next steps of the implementation

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.

Thank you for all input, contributions and comments!

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
Austria	Manfred Jeitler
Belgium	Gilles De Lentdecker
Bulgaria	Venelin Koshuharov
Croatia	Tome Anticic
Cyprus	Panos Razis
Czech Republic	Tomáš Davídek
Denmark	Mogens Dam

Country	Name
Finland	Panja Lukka
France	Didier Contardo
Germany	Lutz Feld
Greece	Dimitris Loukas
Hungary	Dezso Varga
Italy	Nadia Pastrone
Israel	Erez Etzion
Netherlands	Niels van Bakel
Norway	Gerald Eigen
Poland	Marek Idzik
Portugal	Paulo Fonte
Romania	Mihai Petrovici
Serbia	Lidija Zivkovic
Slovakia	Pavol Strizenec
Slovenia	Gregor Kramberger
Spain	Mary-Cruz Fouz
Sweden	Christian Ohm
Switzerland	Ben Kilminster
Turkey	Kerem Cankocak
United-Kingdom	Iacopo Vivarelli
Ukraine	Nikolai Shulga
CERN	Christian Joram

Task Force convenors, Task Force expert membe… …d members of the ECFA Detector R&D Roadm…

Task Force 1 Gaseous Detectors: Anna Colaleo[1], Leszek… Klaus Dehmelt[3], Barbara Liberti[4], Maxim Titov[5], Joao Veloso[6] *(Exp…)*

Task Force 2 Liquid Detectors: Roxanne Guenette[7], Jocelyn Monroe[8] *(Conveners)* Auke-Pieter Colijn[9], Antonio Ereditato[10,11], Ines Gil Botella[12], Manfred Lindner[13] *(Expert Members)*

Task Force 3 Solid State Detectors: Nicolo Cartiglia[14], Giulio Pellegrini[15] *(Conveners)* Daniela Bortoletto[16], Didier Contardo[17], Ingrid Gregor[18,19] Gregor Kramberger[20], Heinz Pernegger[2] *(Expert Members)*

Task Force 4 Particle Identification and Photon Detectors: Neville Harnew[16], Peter Krizan[20] *(Conveners)* Ichiro Adachi[21], Eugenio Nappi[1] Christian Joram[2], Christian Schultz-Coulon[22] *(Expert Members)*

Task Force 5 Quantum and Emerging Technologies: Marcel Demarteau[23], Michael Doser[2] *(Conveners)* Caterina Braggio[24], Andy Geraci[25], Peter Graham[26], Anna Grasselino[27], John March Russell[16], Stafford Withington[28] *(Expert Members)*

Task Force 6 Calorimetry: Roberto Ferrari[29], Roman Poeschl[30] *(Conveners)* Martin Aleksa[2], Dave Barney[2], Frank Simon[31], …o Tabarelli de Fatis[32] *(Expert Members)*

Task Force 7 Electronics: Dave Newbold[33], Francois Vasey[2] *(Conveners)* Niko Neufeld[2], Valerio Re[29] Christophe de la Taille[34], Marc Weber[35] *(Expert Members)*

Task Force 8 Integration: Frank Hartmann[35], Werner Riegler[2] *(Conveners)* Corrado Gargiulo[2], Filippo Resnati[2], Herman Ten Kate[36], Bart Verlaat[2], Marcel Vos[37] *(Expert Members)*

Task Force 9 Training: Johann Collot[38], Erika Garutti[18,39] *(Conveners)* Richard Brenner[40], Niels van Bakel[9] Claire Gwenlan[16], Jeff Wiener[2], ex-officio Robert Appleby[41] *(Expert Members)*

ECFA – Full-day Public Symposia

…the future facilities and… Following the… symposia as the main fora…

Task Force	TF7	TF8	TF2	TF5	TF3	TF1	[illegible]	[illegible]	[illegible]
Dates	25/3/21	31/3/21	9/4/21	12/4/21	23/4/21	29/4/21	30/4/21	6/5/21	7/5/21
Unique users	369 + 123 (webcast)	154 + 17 (webcast)	197 + 5 (webcast)	220	504	339	105	207	201
Max. number of concurrent viewers	230 + 123 (webcast)	76 + 17 (webcast)	130 + 5 (webcast)	100	275	191	59	110	115

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 RECFA delegates or their National Contacts.

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

19th November 2021 ECFA Detector R&D…

May 2021

- 07 May ECFA Detector R&D Roadmap Symposium of Task Force 6 Calorimetry
- 06 May ECFA Detector R&D Roadmap Symposium of Task Force 4 Photon Detectors and Particle Identification Detectors
- …dmap Symposium of Task Force 9 Training
- …dmap Symposium of Task Force 1 Gaseous Detectors
- 23 Apr ECFA D… …oadmap Symposium of Task Force 3 Solid State Detectors
- 12 Apr ECFA Detector R&D Roadmap Symposium of Task Force 5 Quantum and Emerging Technologies
- 09 Apr 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

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

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[42] *(Chair)*, Silvia Dalla Torre[43], Manfred Krammer[2], Felix Sefkow[18], Ian Shipsey[16]

Ex-officio Panel members: Karl Jakobs[44] *(Current ECFA Chair)*, Jorgen D'Hondt[45] *(Previous ECFA Chair)*, Lenny Rivkin[46] *(LDG Representative)*

Scientific Secretary: Susanne Kuehn[2]

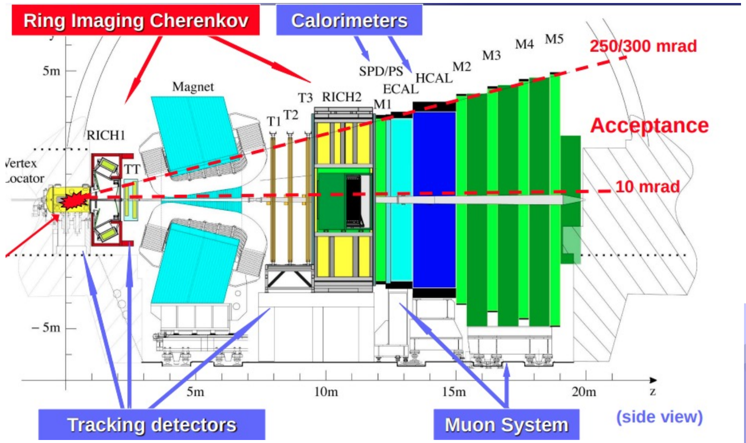
Named contacts for each TF where appropriate

Named expert contacts		
APPEC	TF1	Jennifer L Raaf (Fermilab)
	TF2	Manfred Lindner (MPI Heidelberg)
	TF3	Fabrice Retiere (TRIUMF)
	TF4	Tina Pollmann (Nikhef)
	TF5	Harald Lück (Hannover)
	TF6	Federica Petricca (MPI Munich)
	TF7	Marc Weber (KIT)
	TF8	Aldo Ianni (LNGS)
	TF9	Katrin Link (APPEC)
NuPECC	TF1	Laura Fabbietti (TUM Munich)
		Bernhard Ketzer
	TF2	
	TF3	Luciano Musa (CERN)
		Michael Deveaux
	TF4	Eugenio Nappi (INFN Bari)
		Jochen Schwiening
	TF5	: Christian Enss (Heidelberg),
	TF6	Thomas Peitzmann (Utrecht)
		Ulrike Thoma (Bonn)
	TF7	David Silvermyr (Lund)
		Christian J. Schmidt
	TF8	Werner Riegler (CERN)
		Lars Schmitt
	TF9	Michael Deveaux,
LEAPS	Bernd Schmitt (PSI)	
	Fabienne Orsini	
	Steve Aplin (European	
	Heinz Graafsma (DESY)	

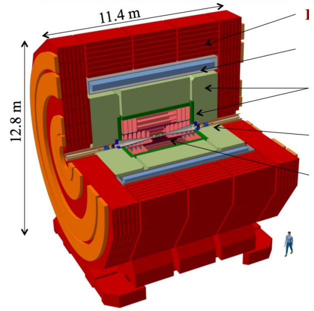
LENS	TF1	Bruno Guerard (ILL)
	TF2	Manfred Lindner (MPI Heidelberg)
	TF3	
	TF4	
	TF5	Helmut Schober (ILL)
	TF6	
	TF7	Bruno Guerard (ILL)
	TF8	
	TF9	
ESA	TF1	Nick Nelms
	TF2	
	TF3	Brian Shortt
		Nick Nelms
		Giovanni Santin
		Alessandra Constantino Mucio
	TF4	Brian Shortt
		Peter Verhoeve
		Sarah Wittig
		Nick Nelms
		Giovanni Santin
	TF5	Peter Verhoeve
		Sarah Wittig
		Nick Nelms
	TF6	Nick Nelms
	TF7	Joerg Ter Haar
		Christophe Honvault
		Nick Nelms
		Alessandra Constantino Mucio
	TF8	Massimo Braghin
	TF9	Christophe Honvault

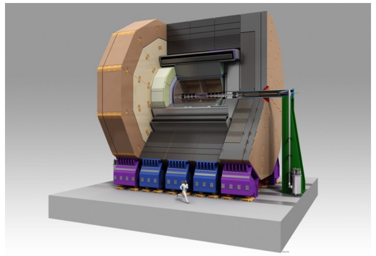
Target projects with Detector R&D

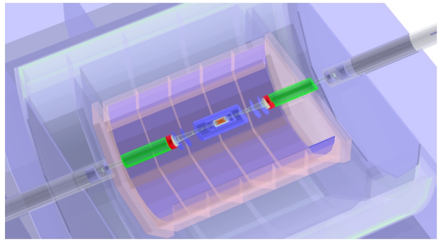
HL-LHC after LS4

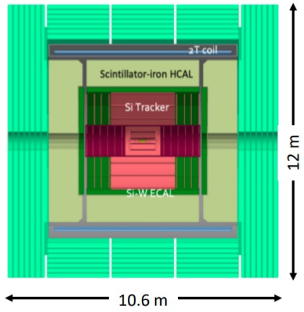


Higgs Factories

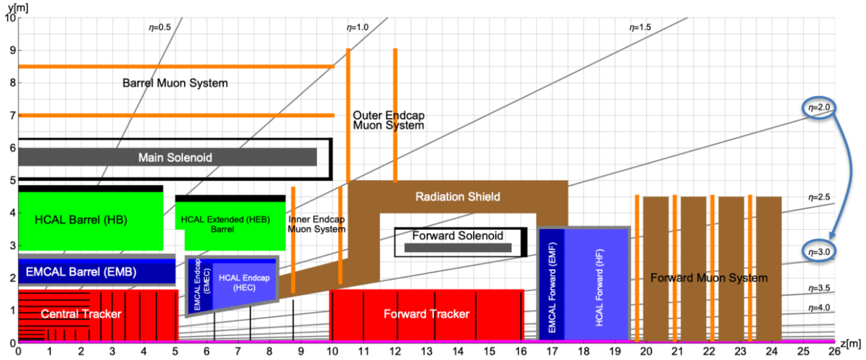




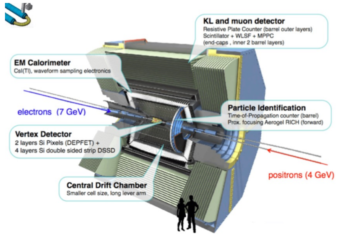


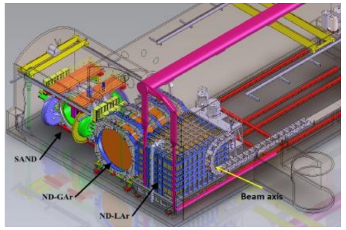


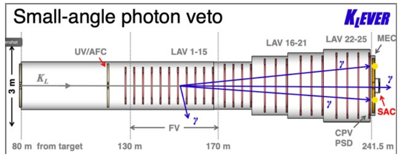
Future hadron colliders (including eh colliders)



SuperKEKB, DUNE ND and Fixed Target

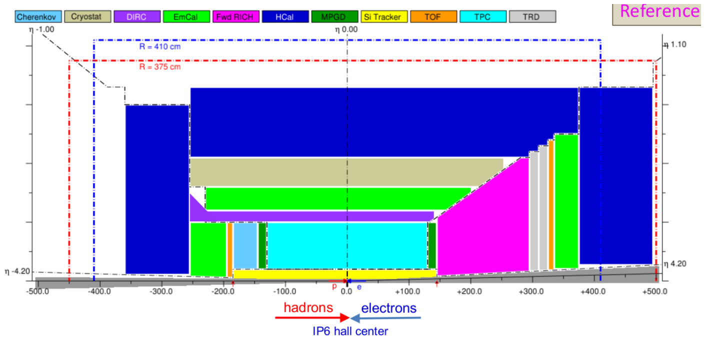




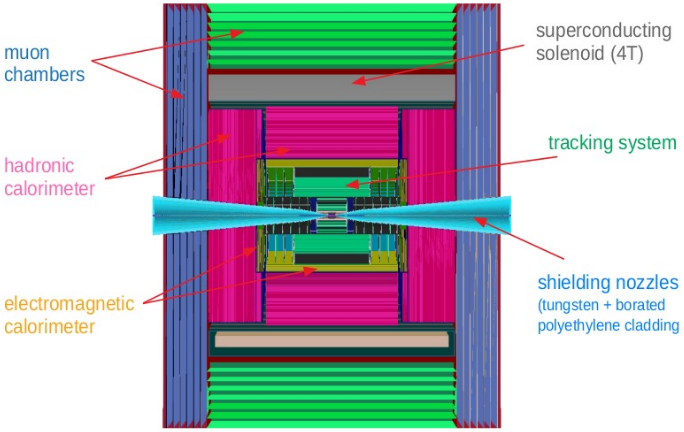


From Roman Pöschl

EiC

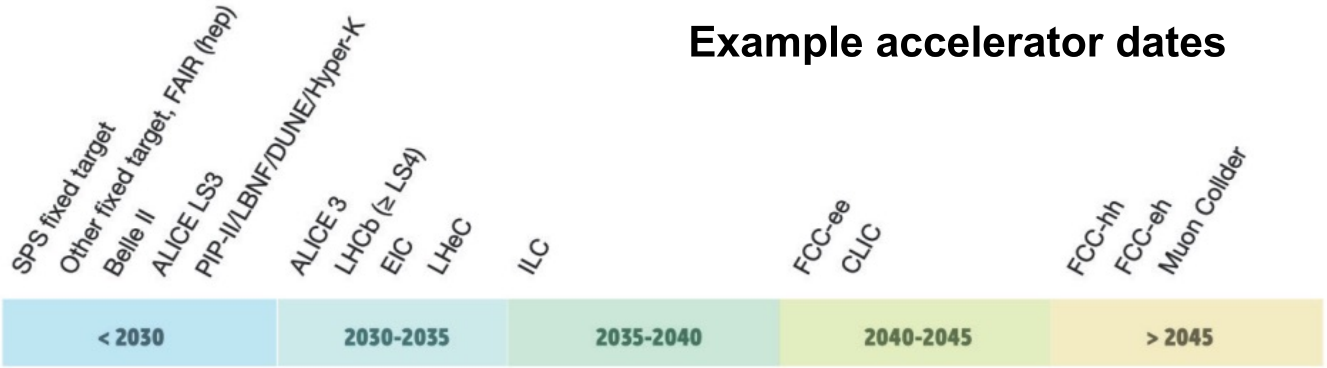


Muon Collider

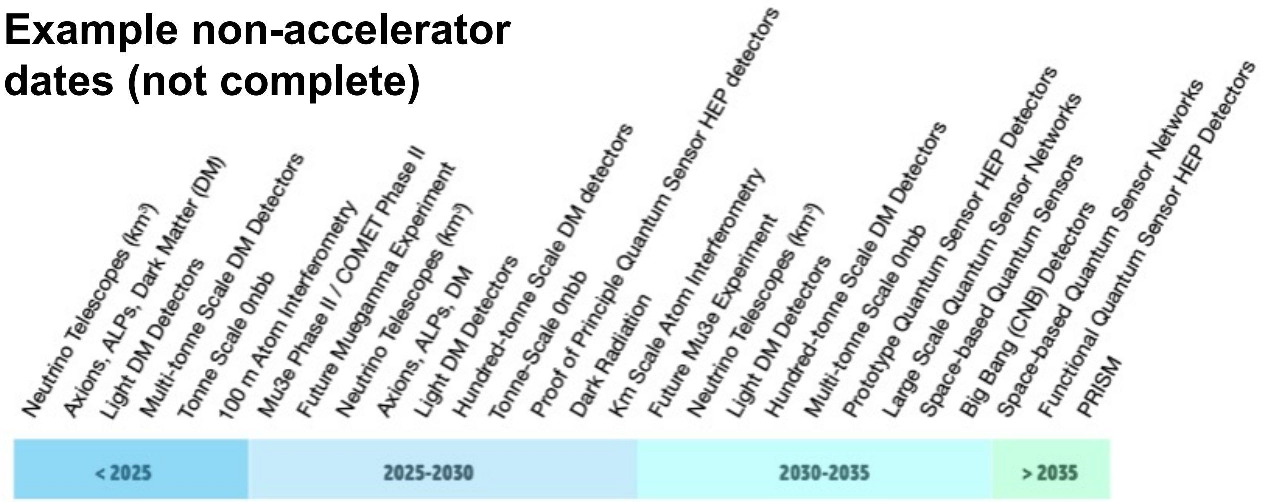


Overview of future facilities

- 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**



Example non-accelerator dates (not complete)



"Technical" Start Date of Facility
(This means, where the dates are not known, the earliest technically feasible start date is indicated - such that detector R&D readiness is not the delaying factor)

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.

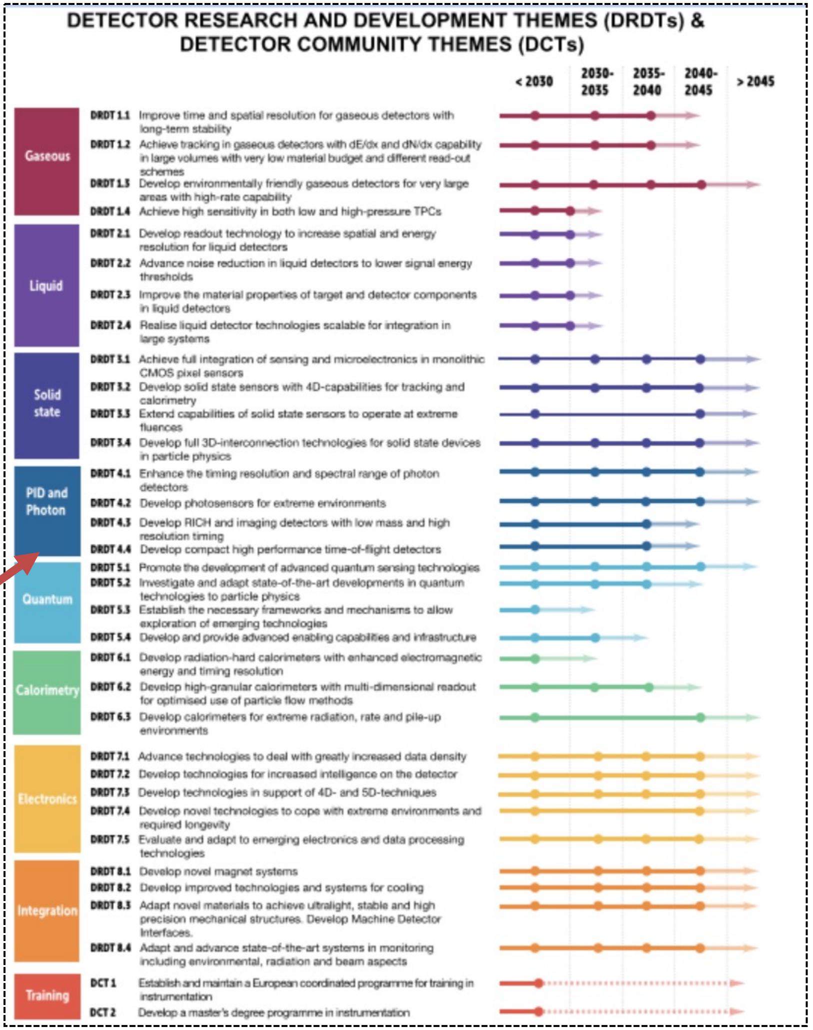
Furthermore, the projects mentioned here are usually limited to those mentioned in the 2020 EPPSU, although it should be noted that detector R&D for other possible future facilities is usually aligned with that for programmes already listed.

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

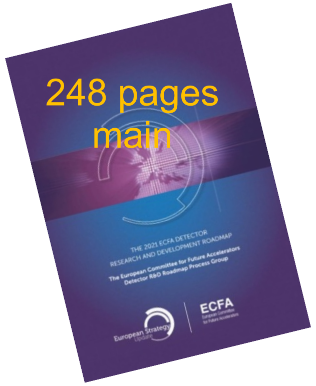
→ Many detector concepts at different future facilities

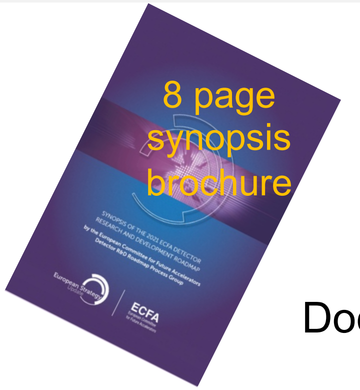
ECFA Detector R&D Roadmap

- 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.

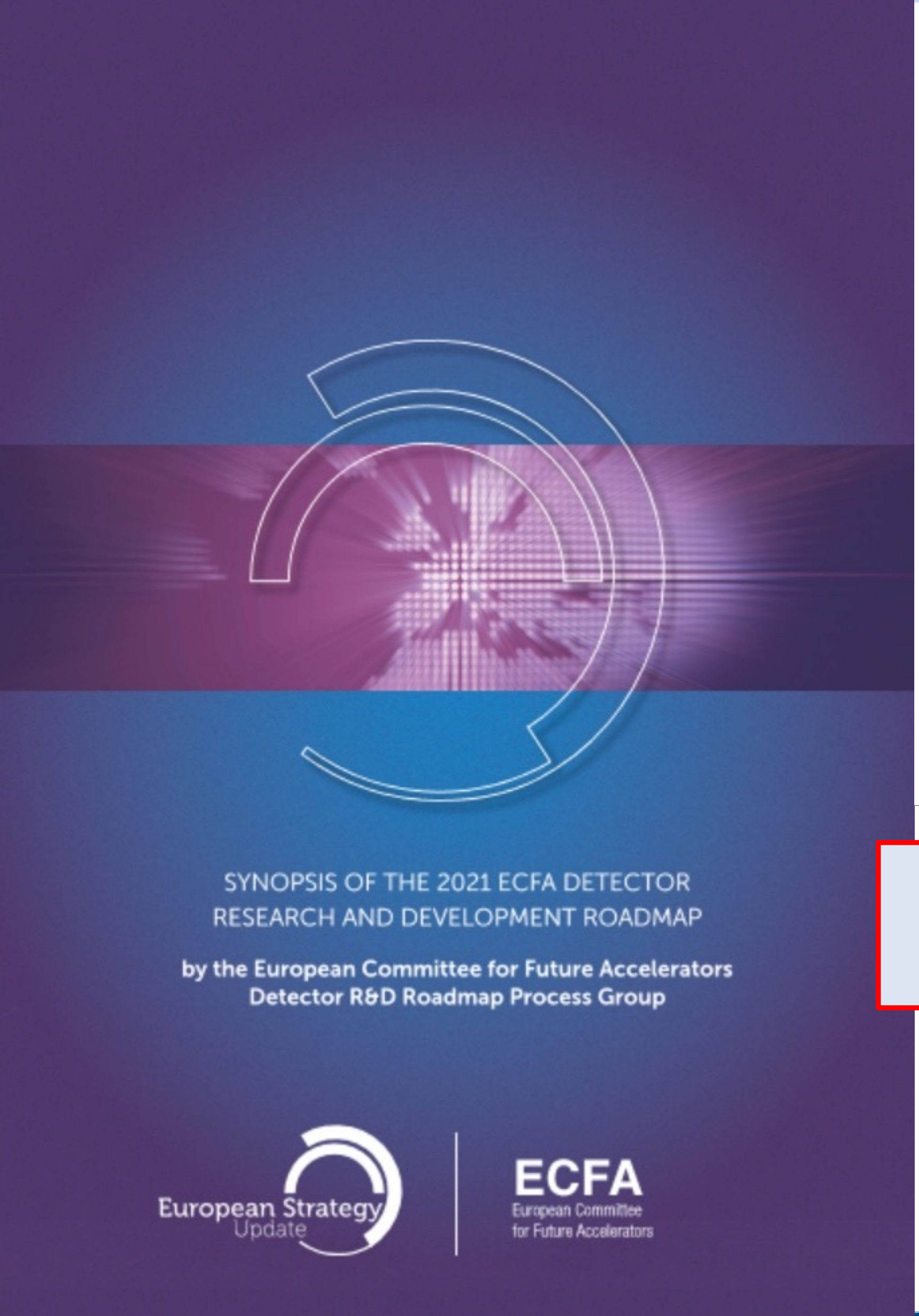


Main Document published (approval by RECFA at 19/11/21) and 8 page **synopsis brochure** prepared for less specialists audience





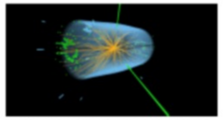
ECFA Detector R&D Roadmap Panel web pages at:
https://indico.cern.ch/e/ECFADetectorRDRoadmap
Documents: CERN-ESU-017 10.17181/CERN.XDPL.W2EX, https://cds.cern.ch/record/2784893



_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.


Event display of a candidate Higgs boson decaying into two photons as recorded by the CMS experiment. (© CERN)

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 m². (© CERN)

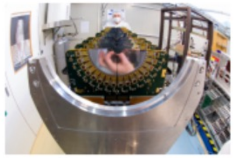

ATLAS gas detector based muon spectrometer, which covers a total area the size of a football field and measures the paths of the muons that pass through it to an accuracy of better than a tenth of a millimetre. (© CERN)

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 programme, working in synergy with neighbouring fields and with a view to potential industrial applications.

_Setting the Priorities

"To fully explore the properties of the Higgs bos[on and study] many of the other deepest questions in physics [necessitates] the development of a roadmap for the required [detector] technologies."


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

The highest priority laid down ... Higgs factory to thoroughly e... new type of particle, which is ... understanding of how the Uni... 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.


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)

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.


ProtoDUNE: three hundred cubic metre volume prototype Liquid Argon Neutrino 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.


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

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.


Paul Scherrer Institute (Switzerland) facility for delivering highly targeted radiotherapy with beams of accelerated protons (Hadron Therapy). (© Scanderbeg Sauer Photography/PSI)


Bespoke cleanroom facility for detector R&D, testing and assembly targeting LHC upgrades, future collider facilities and medical applications. (© B/LPA, University of Birmingham)

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.


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

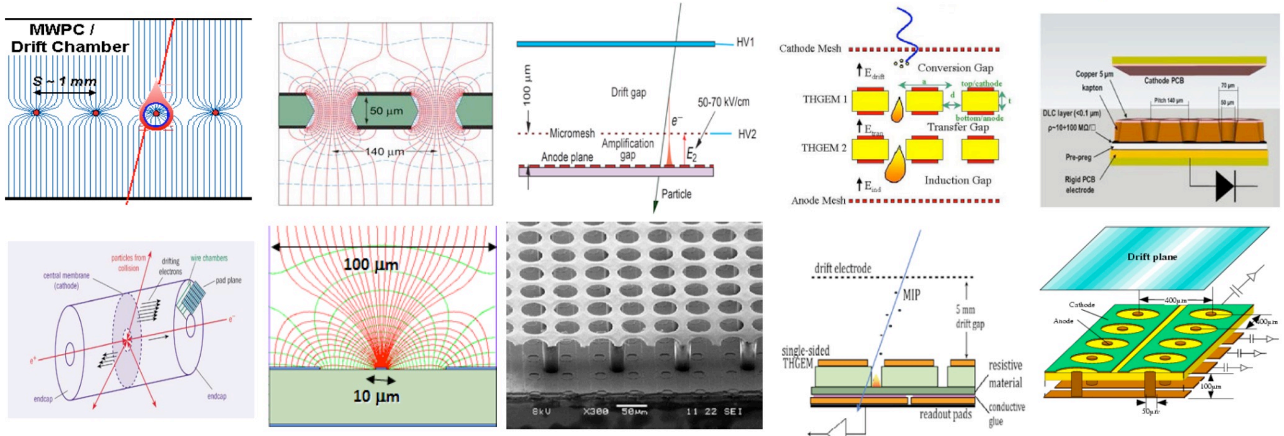
While defining the priorities within particle physics, as outlined above, the ECFA Detector R&D Roadmap also emphasises the vital importance of benefiting from synergies with adjacent research fields, knowledge institutions and high-technology industries.

8 page synopsis brochure prepared for less specialist audience

Gaseous detectors (TF1)

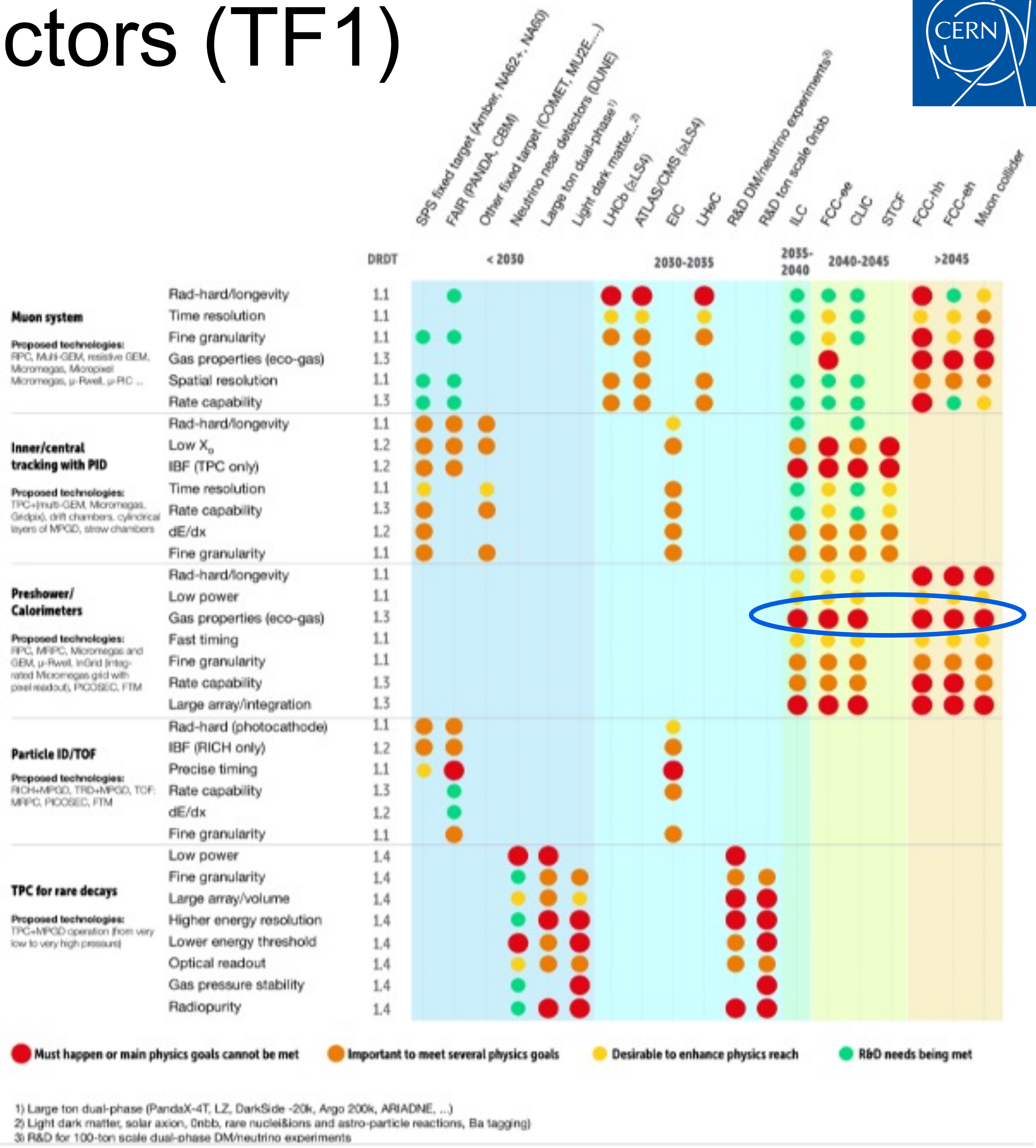
- Gaseous detectors: from Wire/Drift Chamber → Time Projection Chamber (TPC) → Micro-Pattern Gas Detectors
- Primary choice for large-area coverage with low material budget & dE/dx measurement (TPC, Drift chamber) & TOF functionality (MRPC, PICOSEC)

MWPC / DC | GEM | MICROMEGAS | THGEM | μ-RWELL



TPC | MSGC | INGRID | RPWELL | μ–PIC

- **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

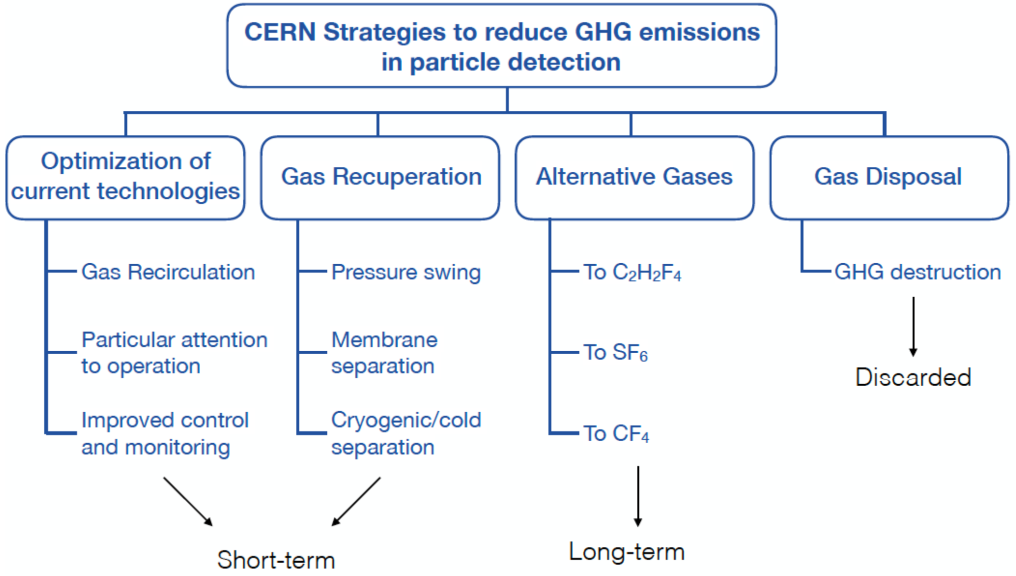


Gaseous Detectors: eco-friendly gases

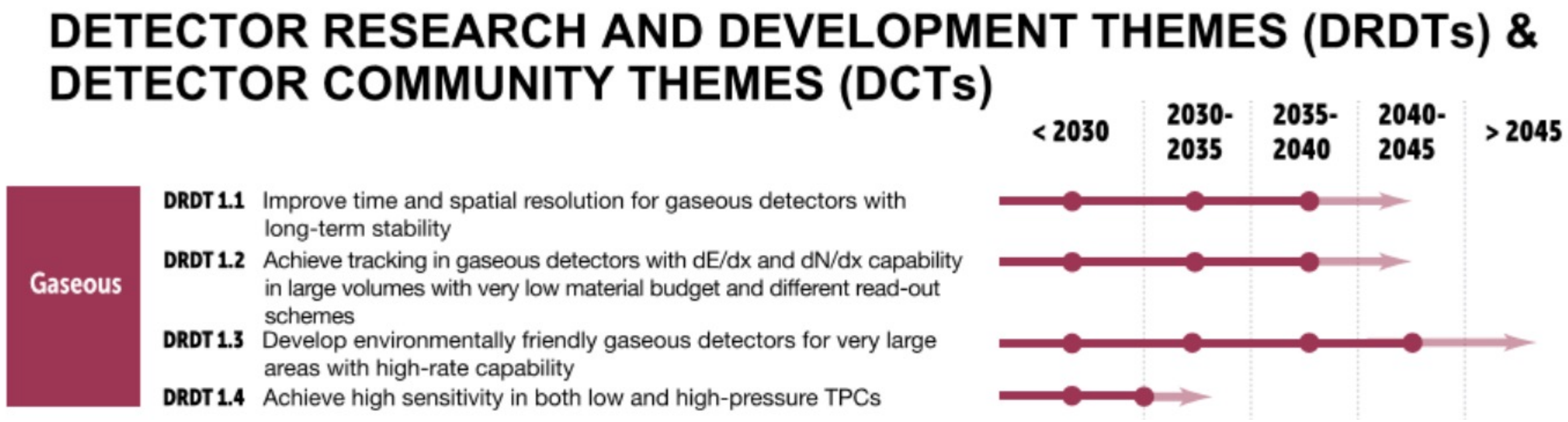
- 92% of emission at CERN related to large LHC experiments
- Thanks to gas recirculation GHG emission already reduced by > 90% wrt. to open mode systems!
- Many LHC gas systems with gas recuperation
- Not an easy task to find new eco-friendly gas mixture for current detectors

CERN strategies for GHG reduction

[B. Mandelli](#)



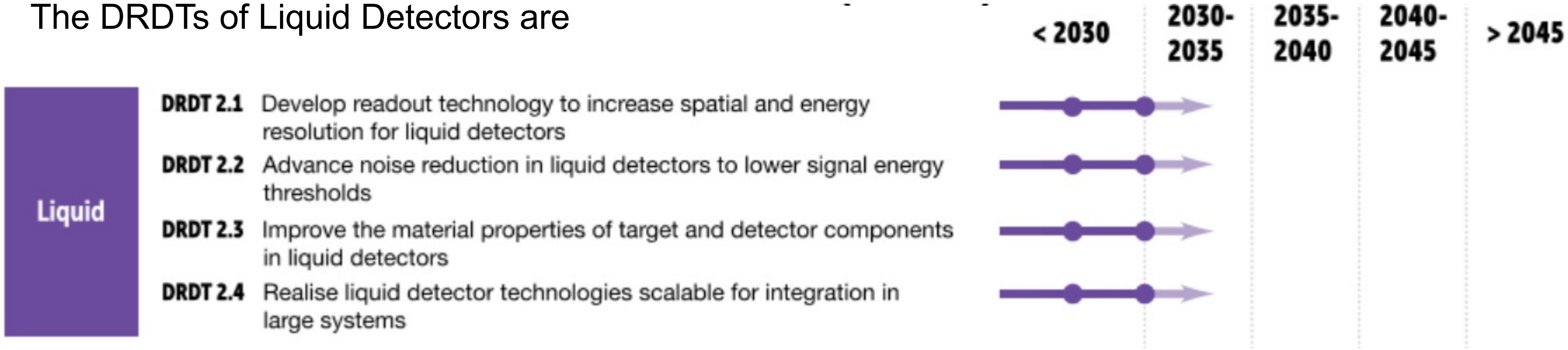
→ **The DRDTs of Task Force 1 Gaseous detectors**



- 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 (TF2)

- The DRDTs of Liquid Detectors are



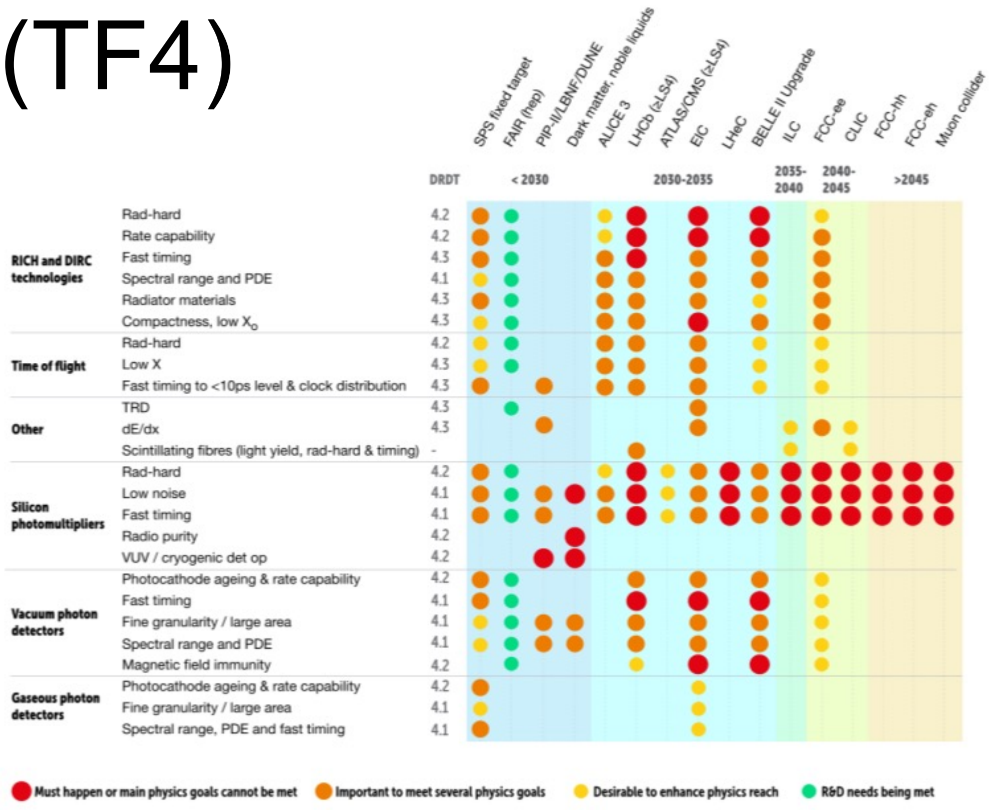
- Full Detector Readiness Matrix and more details in spare slides

Solid State Detectors (TF3)

- Many different silicon detector technologies for **particle tracking** have been developed over the last four decades.
- Solid state detectors more and more used for **calorimetry and time-of-flight.**
- **New Challenges** (see Detector Readiness Matrix in spare slides):
  - **Vertex detectors with low mass, high resolution** (Target per layer spatial resolution of ≤ 3 µm and $X/X_0 \leq 0.05\%$ for FCC-ee), **low power and high radiation hardness** (up to 8×10^{17} n_{eq}/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 ps)) for PID, TOF
  - Fully integrated with electronics, mechanics, services, …

PID and Photon Detectors (TF4)

- **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
- Important to progress in development of Silicon Photomultipliers



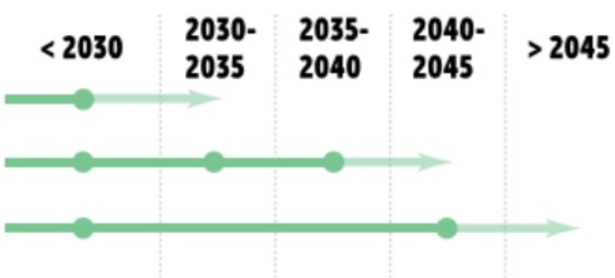
Quantum and emerging technologies (TF5)

- **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 → **R&D required to transfer it to HEP applications**
- **Many different sensor and technologies being investigated**: clocks and clock networks, kinetic detectors, spin-based, superconducting, optomechanical sensors, atoms/molecules/ions, interferometry, …

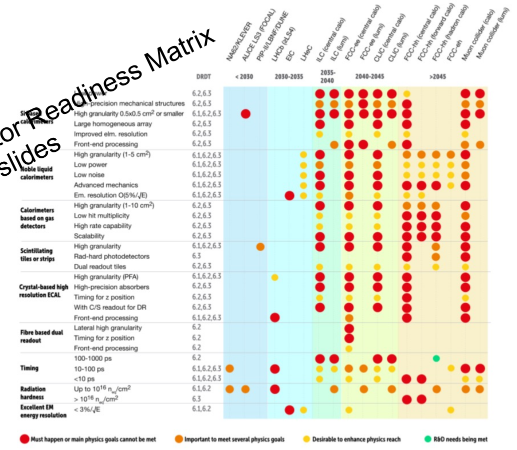
Calorimetry (TF6)

- **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:

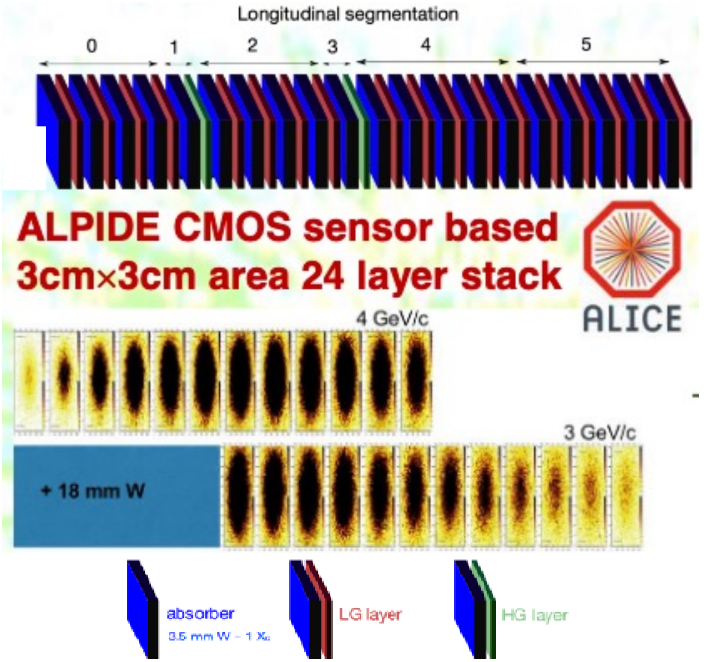
Calorimetry	DRDT 6.1	Develop radiation-hard calorimeters with enhanced electromagnetic energy and timing resolution
	DRDT 6.2	Develop high-granular calorimeters with multi-dimensional readout for optimised use of particle flow methods
	DRDT 6.3	Develop calorimeters for extreme radiation, rate and pile-up environments



full Detector Readiness Matrix in spare slides



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

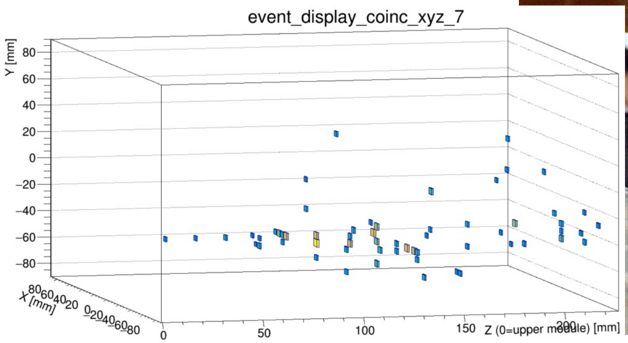
Good energy resolution

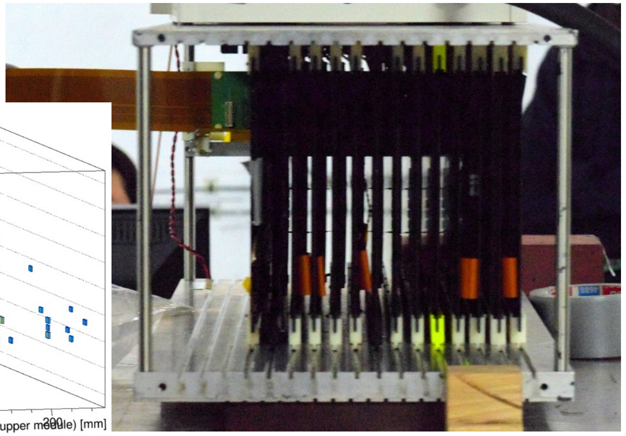
T. Peitzmann, H. Yokoyama: "Test beam performance of a digital pixel calorimeter", T. Rogoschinski: "Simulation of a SiW pixel calorimeter": TIPP 26/5/21

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/





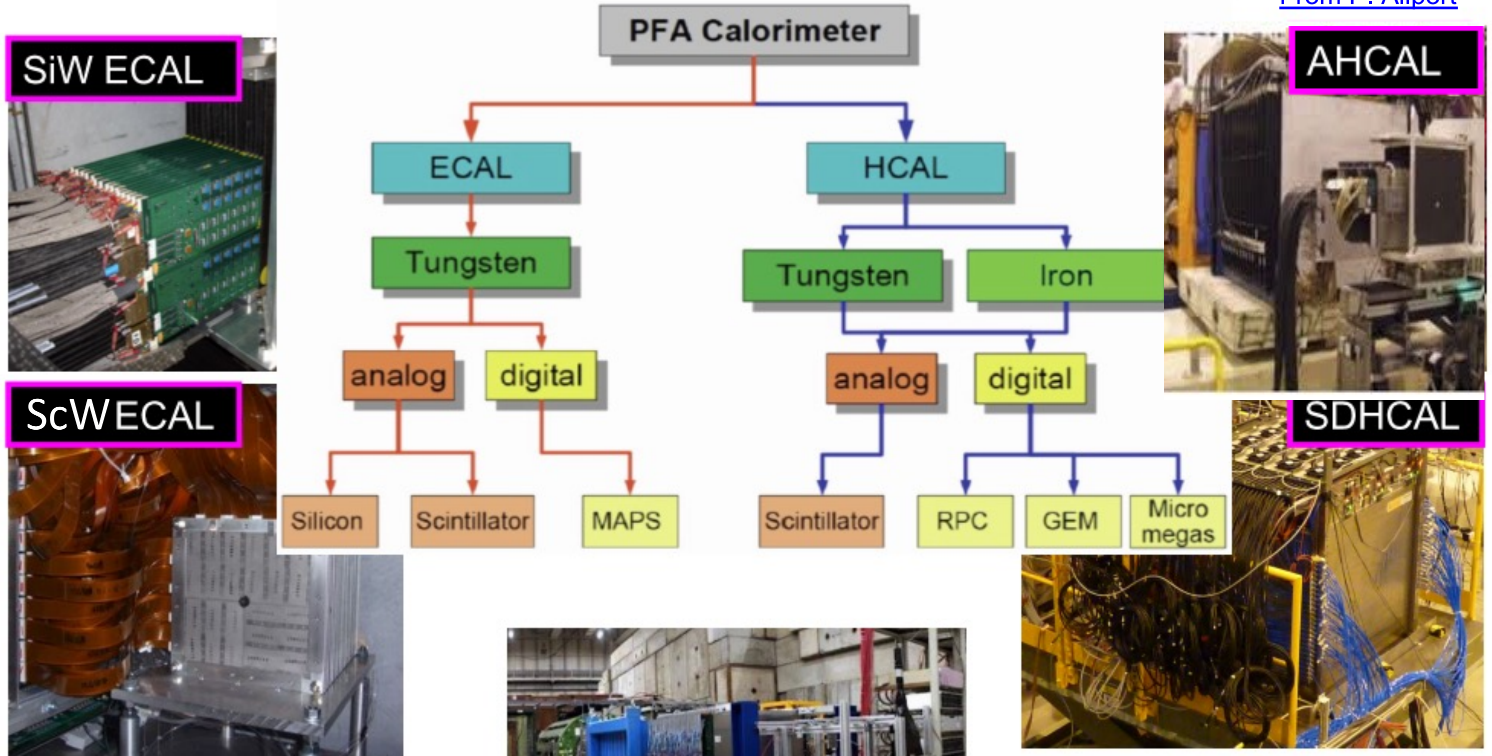
Calorimetry

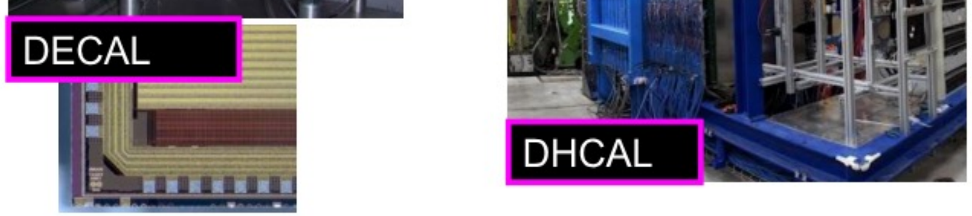
DRDT 6.2: Particle Flow based on high granularity calorimeters particularly important for e^+e^- Higgs-EW-top factories and to be considered for EIC. Separation of signals by charged and neutral particles in highly granular calorimeters.

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 ~100M channels and 10000 m^2 active elements

From P. Allport





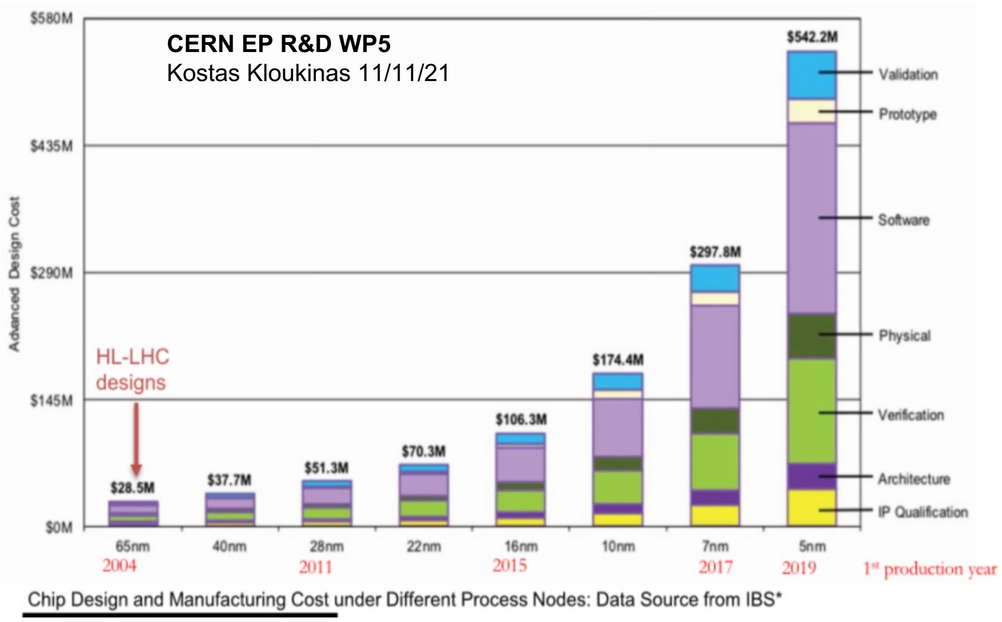
With thanks for help to Roman Pöschl, Fabrizio Salvatore and Nige Watson

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

Electronics (TF7)

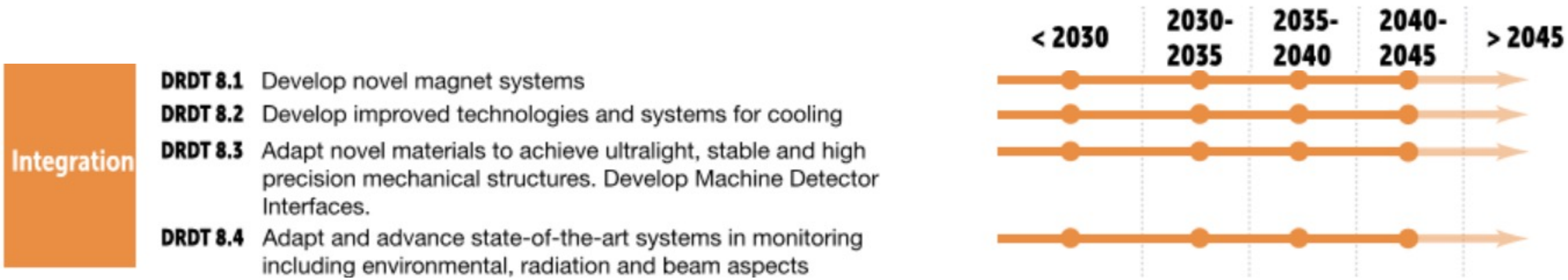
- **Main challenges: precision timing** (ToF; 4D tracking), **high granularity** and **resolution** imply a **cost in terms of data handling, processing, complexity and power.**
- Need **latest advances in commercial <u>microelectronics</u> and <u>high-speed links</u>** (DRDT 7.1, 7.4, 7.5, see also spare slides)
- 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.

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



Integration (TF8)

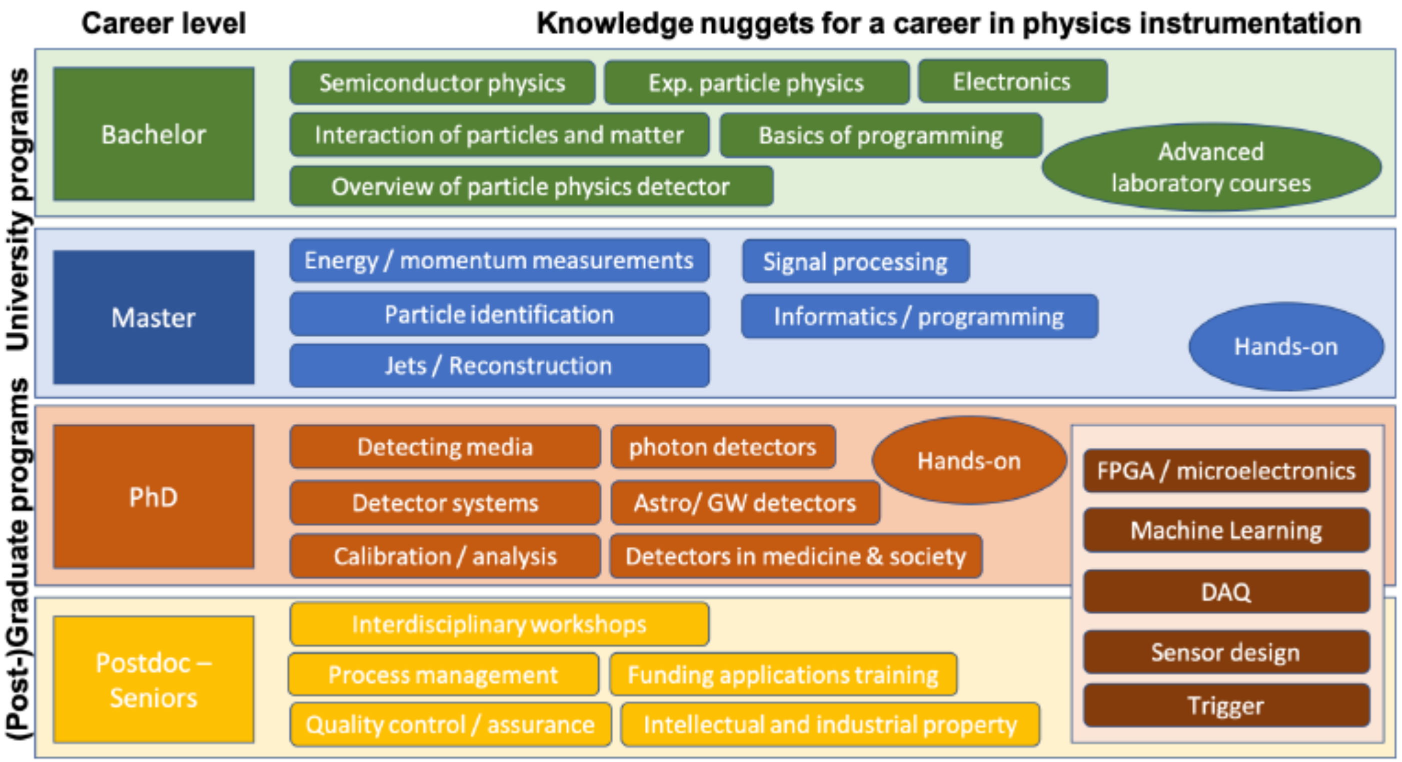
- DRDTs:



Training for instrumentation (TF9)

* 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^3) 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)

→ **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.**

SPC – CERN Scientific Policy Committee

Implementation of the Roadmap

- **Ongoing 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
- Proposal summarized in document which was discussed within RECFA, Task Force leaders, RD Collaborations and CERN management → **Sent to and endorsed by CERN Council in September 2022 (CERN/SPC/1190)**

  - **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

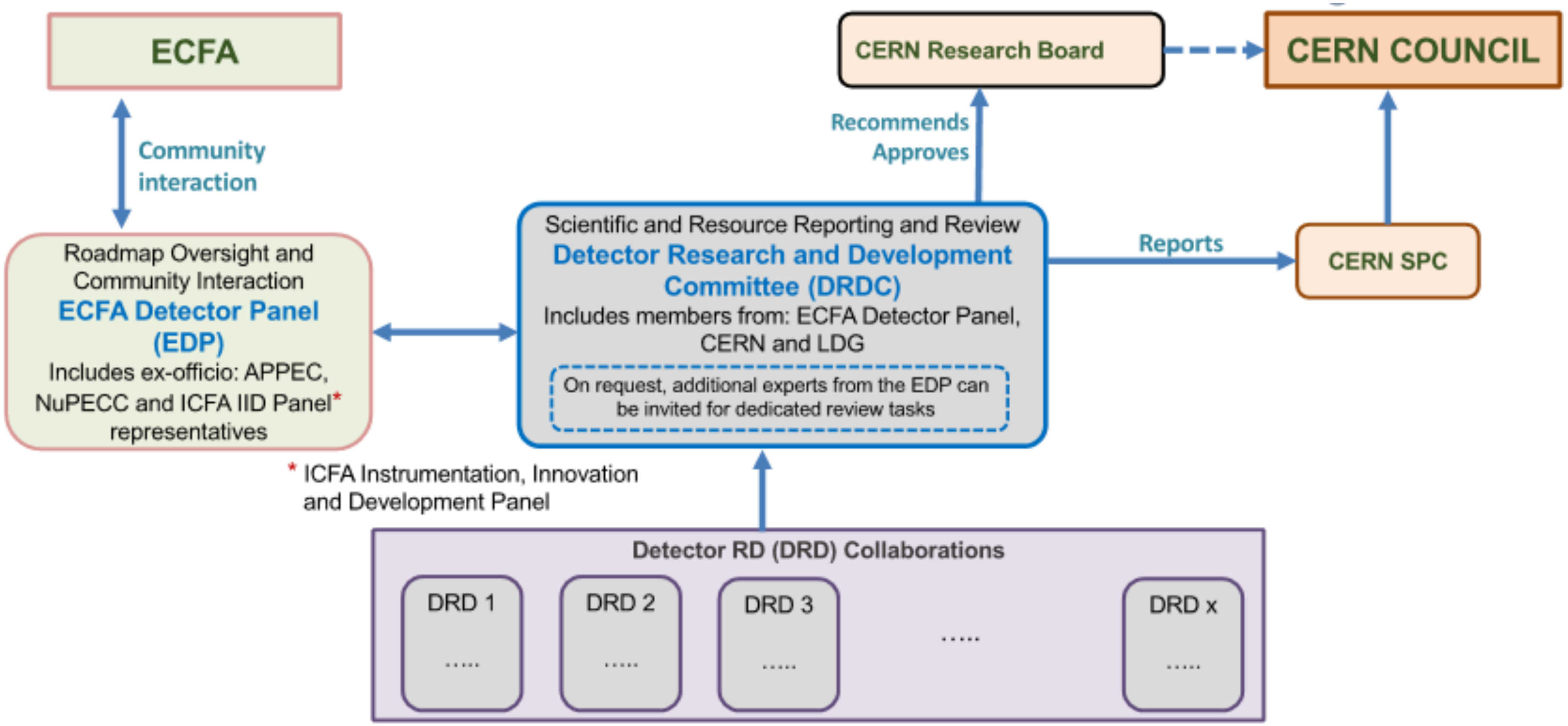
Implementation of the Roadmap

- 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;
  - proceeding using existing ECFA Detector R&D Roadmap TFs due to their extensive contacts with the community;
  - are engaging existing CERN RDs, and other collaborations covering several DRDT topics, to help nucleate the process;
  - Inviting the different communities to sign up to the topics where they wish to be involved at https://indico.cern.ch/event/957057/page/27294-implementation-of-the-ecfa-detector-rd-roadmap

- 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.

Implementation and Review



Detailed slides can be found at Plenary ECFA meeting in July 2022: Plenary ECFA July 2022 and Plenary ECFA Nov 2022

- Scientific and Resource Reporting and Review by a Detector Research and Development Committee (DRDC)
- Assisted by the ECFA Detector Panel (EDP): the scope, R&D goals, and milestones should be vetted against the vision encapsulated in the Roadmap. (EDP: http://cds.cern.ch/record/2211641/files/, exists, hosted at DESY)
- DRDs base for R&D in different areas. Contributions from non-European groups very welcome.
- Funding Agency involvement via a dedicated Resources Review Board (~once every two years).
- Yearly follow-up by DRDC → report to SPC → Council

Timeline

- Since end of 2022, the Detector R&D Roadmap **Task Forces started organising open meetings to establish the scope and scale of the communities wishing to participate in the corresponding new DRD activities** (see later slide).
- 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 end of 2022, outline structure and review mechanisms agreed with CERN Council.
- Q1/2023, **DRDC mandate formally defined** and agreed with CERN management; Core DRDC membership appointed; and EDP mandate plus membership updated to reflect additional roles.
- Q1-Q2/2023, **Develop the new DRD proposals** based of the detector roadmap and community interest in participation, including light-weight organisational structures and resource-loaded work plan for R&D programme start in 2024 and ramp up to a steady state in 2026.
- Q3/2023, **Review of proposals by DRDC** leading to recommendations for formal establishment of the DRD Collaborations.
- Q4/2023, DRD Collaborations receive formal approval from CERN Research Board.
- Q1/2024, New structures operational for ongoing review of DRDs and R&D programmes underway.
- Through 2024, **collection of MoU signatures.**

Ongoing steps of implementation - how to take part

- Building of new Detector R&D (DRD) Collaborations
  - Organised by Task Forces, involving managements of existing RD Collaborations.
  - Some starting with surveys, smaller group meetings and evolving to the community meetings; or community meeting to kick-start the process; or a mixture of both in parallel → Participation by everybody encouraged and welcome!
  - ECFA Roadmap Coordination Group continuing to meet and guiding process.
- Status of DRDs:

DRD1: 1st-3rd March 2023 https://indico.cern.ch/event/1245751/
(Organisation and workplan at https://indico.cern.ch/event/1214405/)

DRD2: 20th April 2023 https://indico.cern.ch/event/1214404/timetable/#20230420
(Organisation and workplan at https://indico.cern.ch/event/1214404/)

DRD3: 22nd-23rd March 2023 https://indico.cern.ch/event/1214410/timetable/#20230322.detailed
(Further background at https://indico.cern.ch/event/1214410/)

DRD4: 16th-17th May 2023 https://indico.cern.ch/event/1263731/ (surveys currently launched)
(Further background at https://indico.cern.ch/event/1214407/)

DRD5: planning proceeding along different lines given the very large and diverse community: see Ian Shipsey's slides (requires DESY-indico account) and sign-up of interest on https://indico.cern.ch/event/1214411/

Ongoing steps of implementation - how to take part

- Status of DRDs continued:

  DRD6: 12th January 2023 https://indico.cern.ch/event/1212696/ and 20th April 2023 https://indico.cern.ch/event/1246381/
  (Organisation, workplan and proposal status at https://indico.cern.ch/event/1213733/)

- Transversal Task Forces need to be different. See for example the in the DRD7 proposed organisation below.

DRD7: 14th-15 March 2023 https://indico.cern.ch/event/1214423/timetable/#20230314
(Organisation and planning are detailed in the draft "Organisation of the DRD7 Collaboration. Version 5" which could be a useful guide for other DRDs and also contains a blueprint for how a transversal DRD can interact with the other topic areas)

TF8: Survey launched to gauge community appetite for DRD in the areas discussed during the TF8 community meeting on 31st March 2021 at ECFA Detector R&D Roadmap Symposium of Task Force 8 Integration (31 March 2021) · Indico (cern.ch)
(Note also: Forum on Tracking Detector Mechanics 2023 but this only covers some of the aspects of TF8 interests)

TF9: Has become the topic of a dedicated new **ECFA Training Panel.** Members encompass that of the detector roadmap R&D TF9 group, plus two more experts on training in accelerators, and one representative of ICFA, APPEC, NuPECC and of the ECFA ECR Panel.
Kick-off meeting on 7th March 2023 with agenda at ECFA Training Panel - Kick-off Meeting (7 March 2023) · DESY-Konferenzverwaltung (Indico) Web pages etc are being constructed here with help from ECFA secretariat.

Further ongoing steps of implementation

- Light-weight guidelines for DRD proposal writing were provided to preparation teams of DRDs.
- CERN management (Research Director J. Mnich) is preparing setting up the DRDC.
- The ECFA Detector Panel (EDP) has been re-activated, mandate and composition have been updated (more in spare slides).

<u>The ECFA Detector Panel</u>

Updated Mandate

- provides direct input on DRD proposals, through the appointment of members to the DRDC, in terms of the Roadmap's R&D priorities (as encapsulated in the Detector R&D Themes);
- assists, particularly via topic-specific expert members, in the conduct of annual DRDC reviews of the scientific progress of DRD collaborations;
- monitors the overall implementation of the ECFA detector roadmap and the specific DRDTs;
- follows up targets and achievements in the 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.

The membership of the EPD reflects the needs to provide expertise in each of the key detector areas identified in the Roadmap

- 2 Co-Chairs, scientific secretary and nine members
- Terms three years, once renewable

- Implementation of GSR 1: Supporting R&D facilities (irradiations, testbeams, infrastructures) with a LDG-ECFA working group. Group being set up throughout 2023, Co-Chairs are Stan Bentvelsen (LDG, ECFA, the Netherlands), Marko Mikuz (ECFA Slovenia). Working group meetings started (see e.g https://indico.cern.ch/event/1270324/contributions/5335653/attachments/2620117/4529835/LDG-ECFA-infra-20230329.pdf)

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 19th 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 its **implementation** was trusted to **ECFA to organise** by CERN Council
- **The implementation builds on the well understood and successful model** for making long-term investments in support **of experimental collaborations at CERN** for which many mechanisms already exist with Funding Agencies which can be translated into similar arrangements for providing resources for the new DRD Collaborations.
- **New DRD collaborations, one per Task Force and a related review structure** is being set up for an overall framework to secure longer-term R&D resources and taking advantage of the multiple synergies across different fields of detector development.

- **The implementation process with the community is actively happening during 2023.**

Thank you!

Acknowledgment
Phil Allport, Kerstin Borras, 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

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

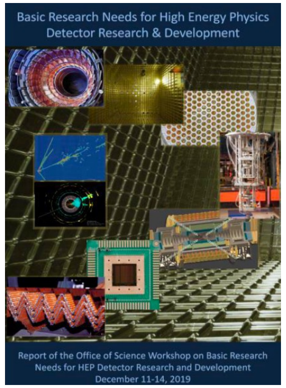
Detector Research and Development Committee (DRDC), 1990 - 1995

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)
  - ….

Snowmass 2021

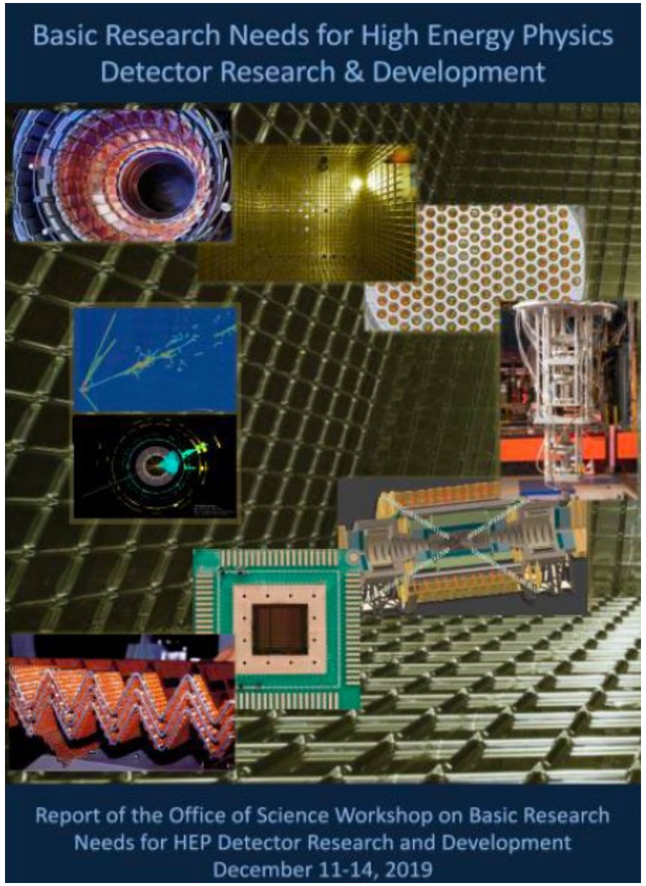
AIDA innova



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 2023
- https://snowmass21.org/instrumentation/start Conveners: P. Barbeau, P. Merkel, J. Zhang

Snowmass Report « Community-Driven »:

- **Snowmass Summary for Public**
  - 2 pages
- **Snowmass Summary Report**
  - ~50 pages
    - Executive Summary: ~10 pages
    - Introduction
    - 10 Frontier Executive Summaries
    - Executive Summaries of Multi-Frontier Topics
    - Conclusion
- **Snowmass Book**
  - ~500 pages
    - Snowmass Summary Report (~50 pages)
    - Frontier Summaries (~400 pages with 10 Frontiers)
    - Multi-Frontier Topic Summaries (~50 pages)
- **Topical Group Reports**
  - Topical Group Reports: short reports
- **Reports of Multi-Frontier Topics**
  - Multi-Frontier Topics spanning multiple Frontiers.
  - Each Multi-Frontier Topic Summary: ~10 page
- **Contributed Papers = White Papers**
  - References

IF Frontier Summary: 40 pages

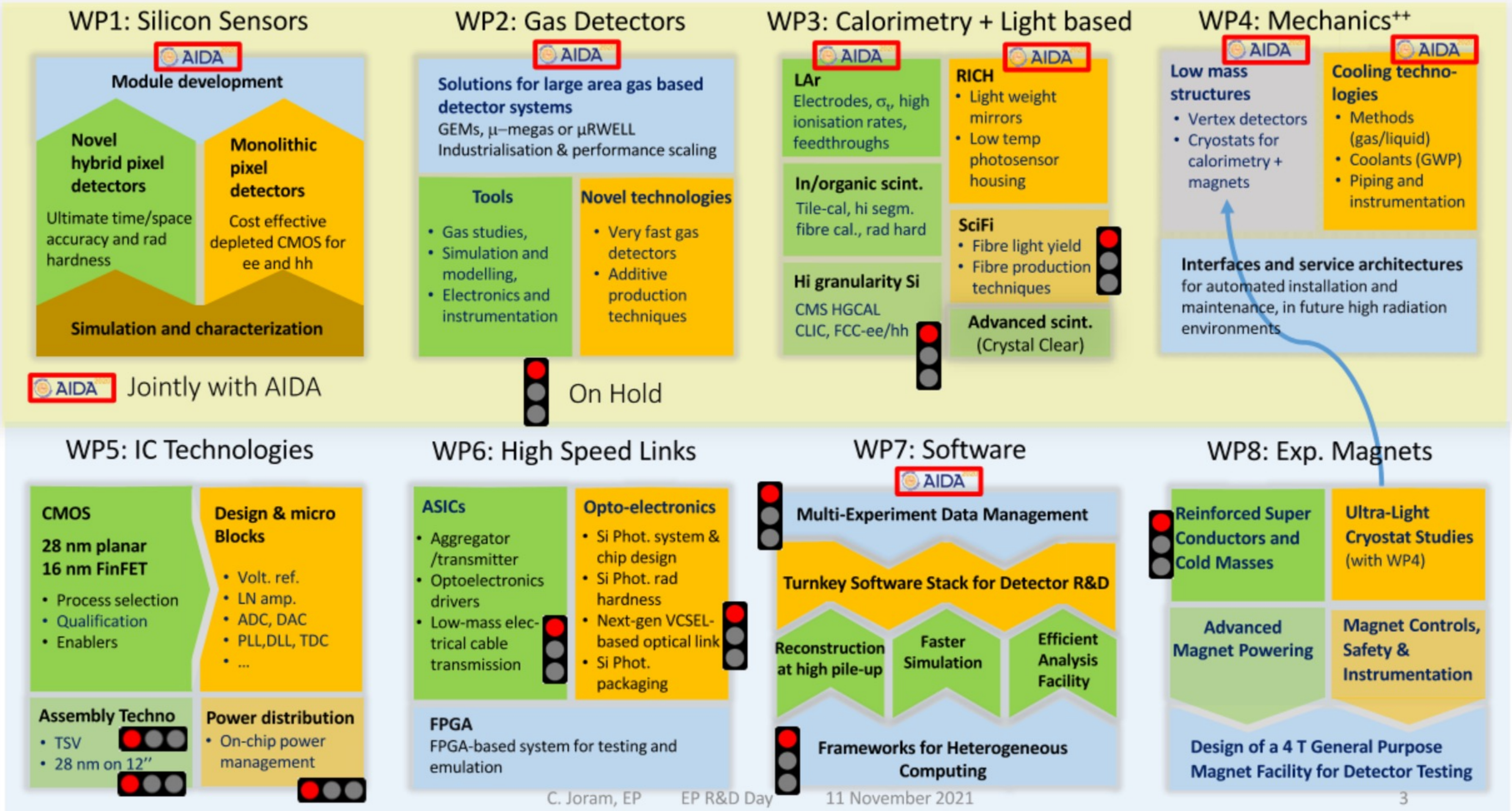
(Written by TG members including early careers)

(Written by the community including early careers)

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 pesresently 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

Organisation

May 2020
EPPSU mandate to ECFA to develop a roadmap for detector R&D efforts in Europe

Sep 2020
Structure in place with **Detector R&D Roadmap Panel**

Dec 2020
Task Forces active

Website:
https://indico.cern.ch/e/ECFADetectorRDRoadmap

Expert & Community Consultation

Feb 2021
Collection of requirements of future facilities & projects

Feb/March 2021
Questionnaires of Task Forces to national contacts

Task Forces liaise with experts in
- ECFA countries
- adjacent disciplines
- industry

March-May 2021
Open Symposia

Drafting Roadmap & Feedback

May 2021
Task Forces collate input from symposia

25-28 May 2021 **Drafting sessions**
- opening session with all experts involved
- plenary & parallel sessions with Task Force members
- final session of Roadmap Panel

July 2021
Near final draft shared with RECFA*

30 July 2021
Presentation at Joint ECFA-EPS session

August 2021
Collect final community feedback*

October-December 2021
Detector R&D Roadmap Document circulated for approval to ECFA in Nov 2021 and presentation to Council in Dec 2021

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

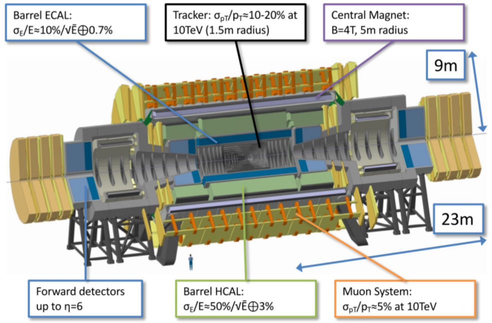
https://ep-dep.web.cern.ch/rd-experimental-technologies (CERN EP R&D)

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

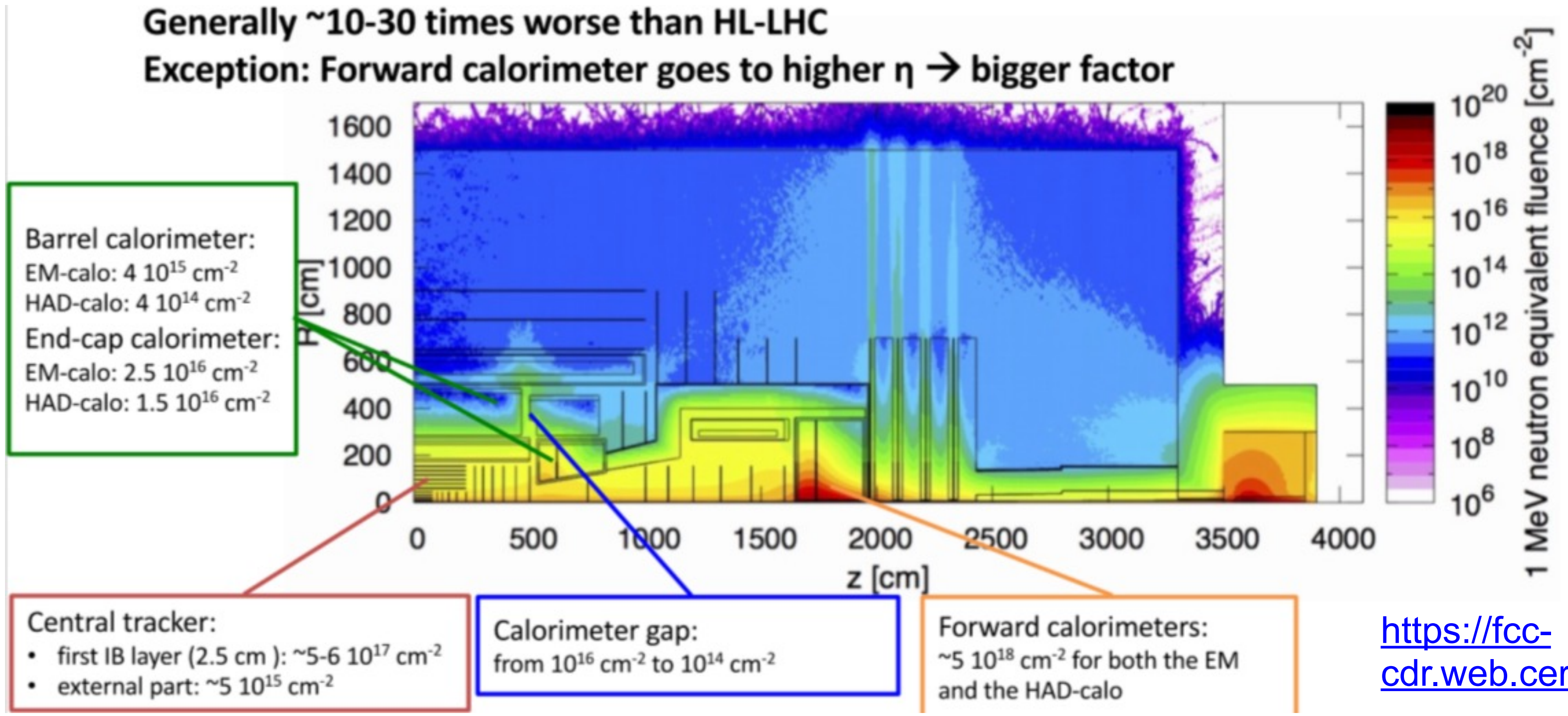
https://attract-eu.com/ (ATTRACT: linking to industry on detection and imaging technologies)

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

Example of future detectors at accelerators



FCC-hh CDR

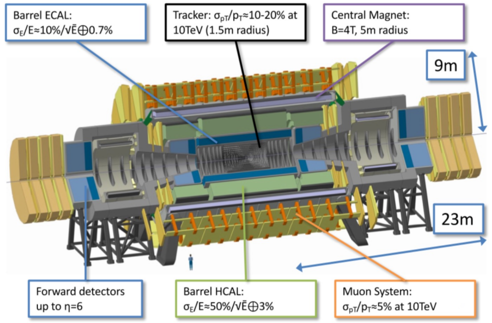


https://fcc-cdr.web.cern.ch/#FCCHH

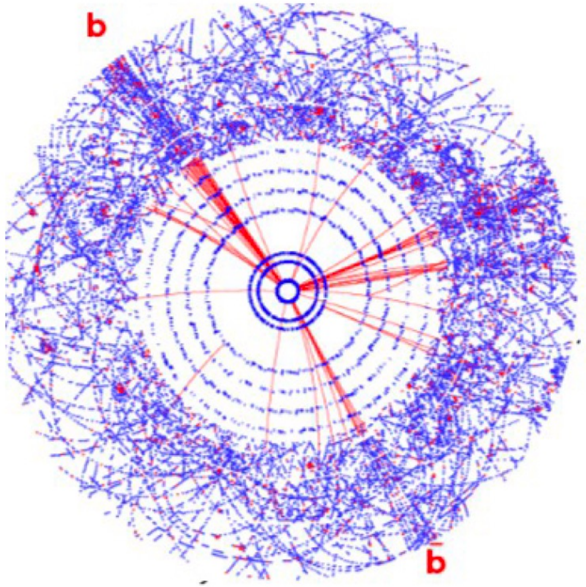
Largest challenge is that radiation levels go well beyond what any currently available microelectronics can survive (≲ MGy) and few sensor technologies can cope beyond ~$10^{16} n_{eq}/cm^2$ (HL-LHC vertex layers)

Example of future detectors at accelerators

Hadron-hadron collisions e.g. LHC

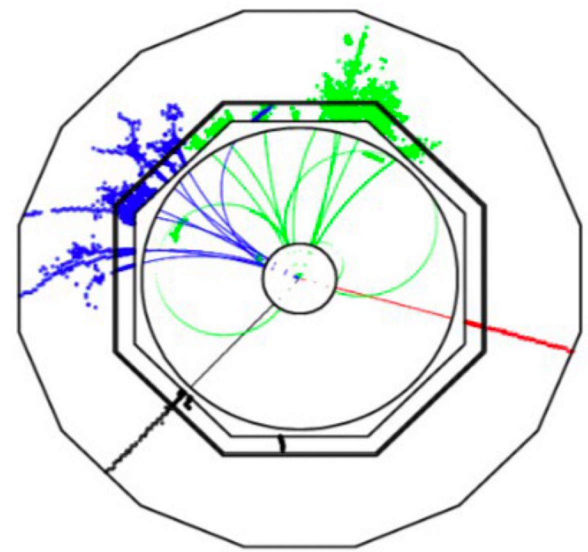


FCC-hh CDR

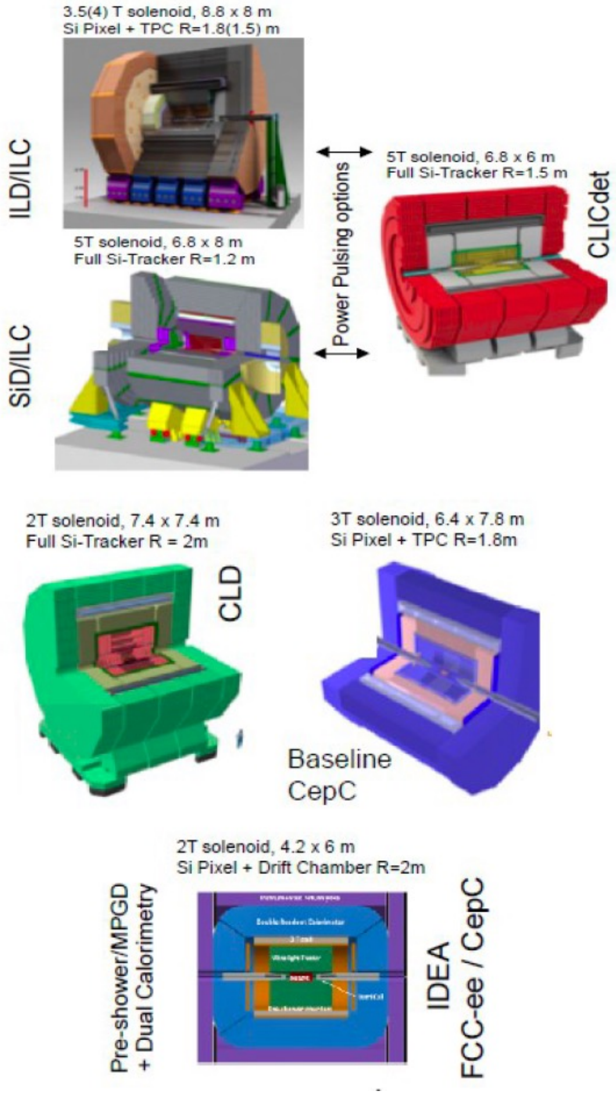


- Busy events
- Require hardware and software triggers
- High radiation levels

e^+e^--collisions



- Clean events
- No trigger
- Full event reconstruction



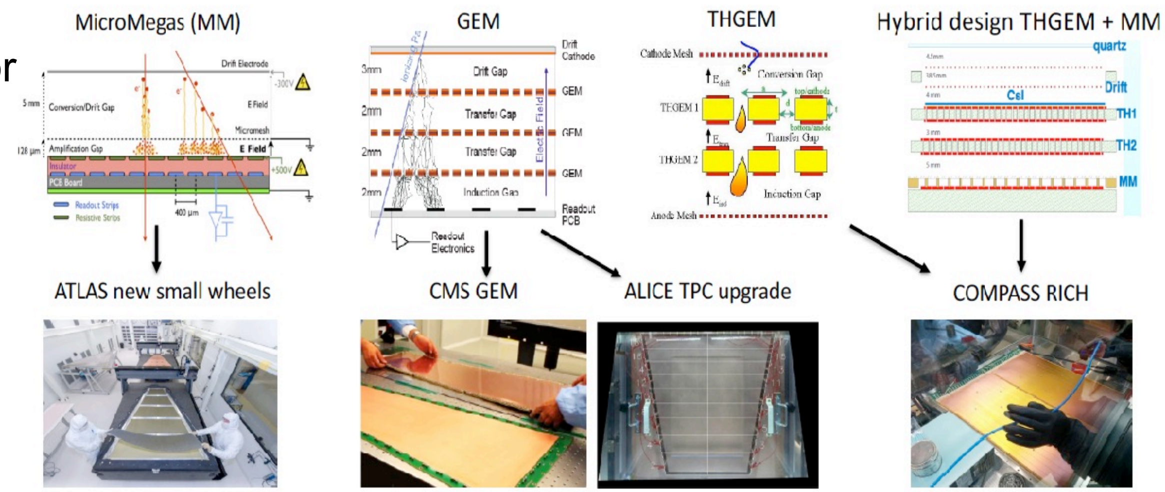
- One of the many challenges: radiation hardness. Radiation levels of e.g. 300 MGy/5-6 10^{17} n_{eq}/cm^2 in first tracker layers go well beyond what any currently available microelectronics can survive (≲ MGy) and few sensor technologies can cope beyond ~10^{16} n_{eq}/cm^2

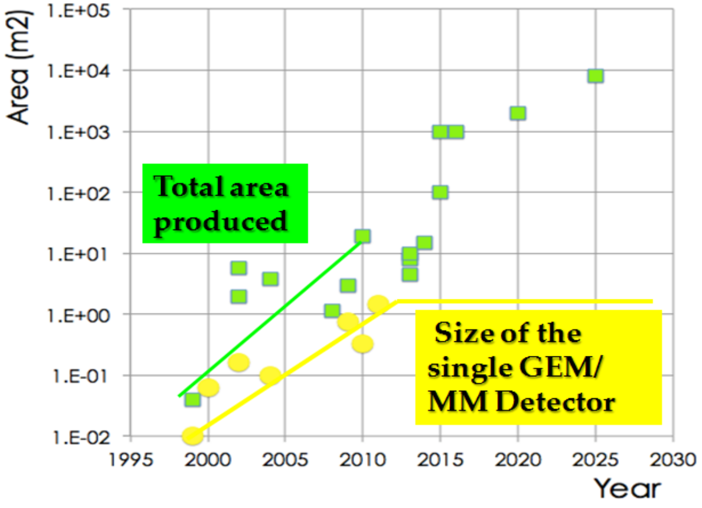
→ Detector R&D essential

Gaseous detectors: area and timing

[M. Titov](https://)

- **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. T2K, ILC, CepC

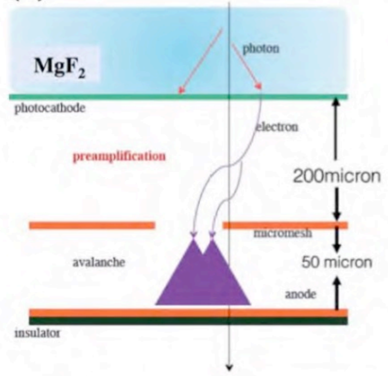


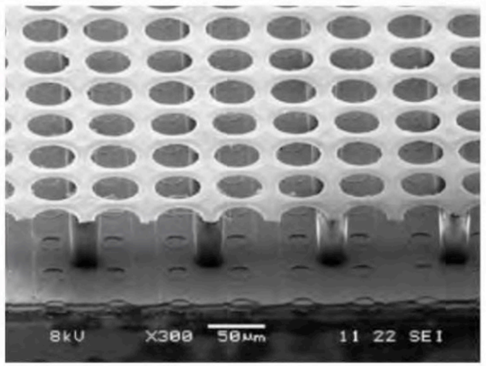


- **Gaseous detectors offer very competitive timing** through e.g.
  - **Multi-gap Resistive Plate Chambers** (down to 60 ps time resolution) (ALICE TOF Detector, Z.Liu, NIM A927 (2019) 396)
  - An enabling emerging R&D: **Micromegas with timing** (PICOSEC concept)

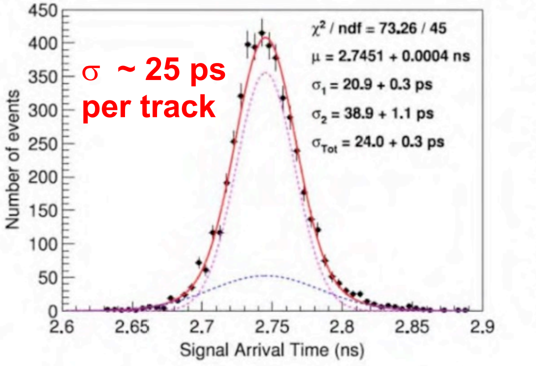
Cherenkov radiator + Photocathode + MM

J. Bortfeldt, NIM A903 (2018) 317





Timing (MIP test-beam):



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

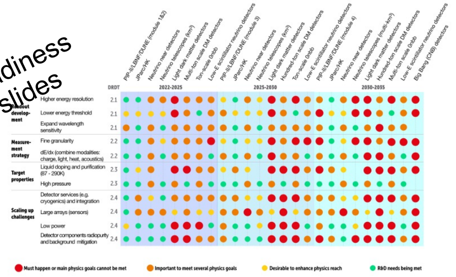
Liquid detectors

- The DRDTs are

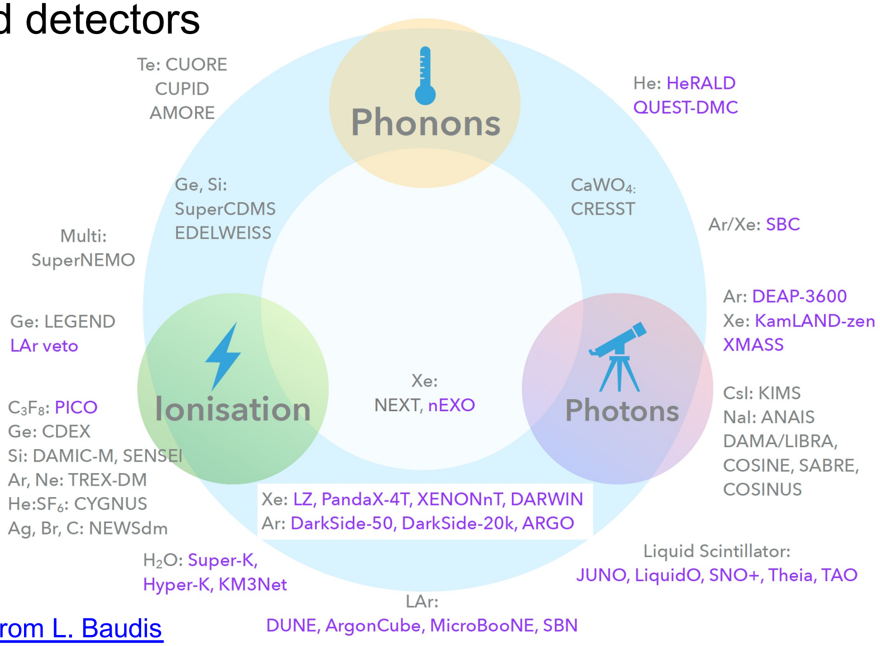
Liquid		< 2030	2030-2035	2035-2040	2040-2045	> 2045
DRDT 2.1	Develop readout technology to increase spatial and energy resolution for liquid detectors					
DRDT 2.2	Advance noise reduction in liquid detectors to lower signal energy thresholds					
DRDT 2.3	Improve the material properties of target and 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

full Detector Readiness Matrix in spare slides



- 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

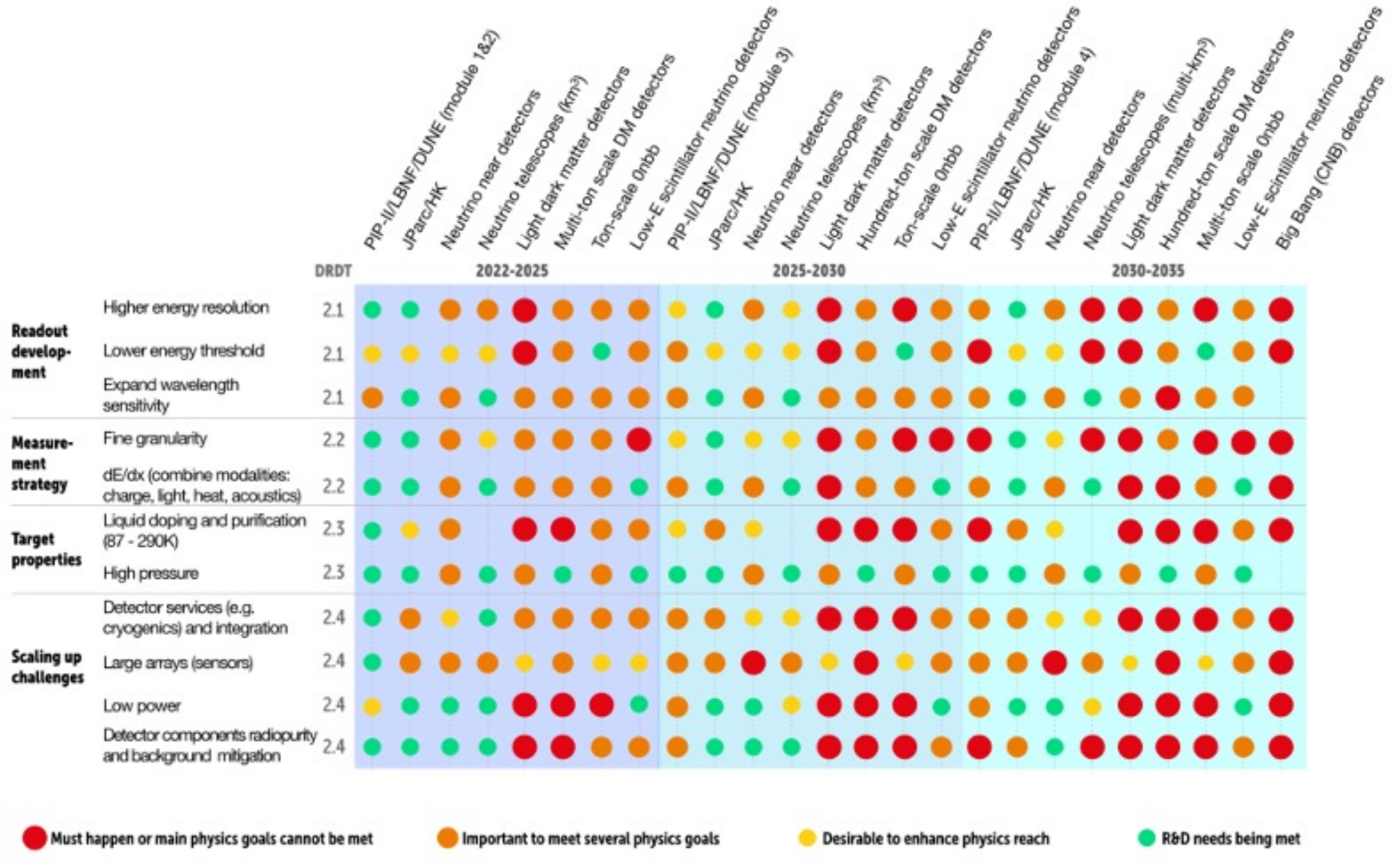
R&D for multi-ton scale noble liquids:

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

Rn distillation column for XENONnT (reduce ^{222}Rn - hence also ^{214}Bi - from pipes, cables, cryogenic system)

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

Liquid detectors

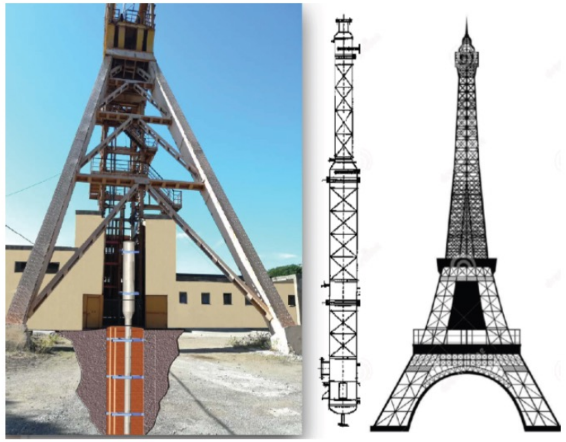


Liquid detectors: Underground Dark Matter experiments

- **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_2 and H_2O impurities) → high light and charge yield; radon-free filters

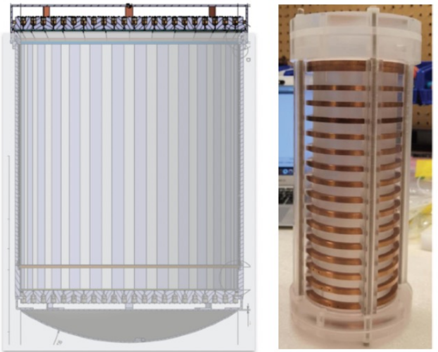
LXe purification system (5 L/min LXe, faster cleaning; 2500 slpm) for XENONnT

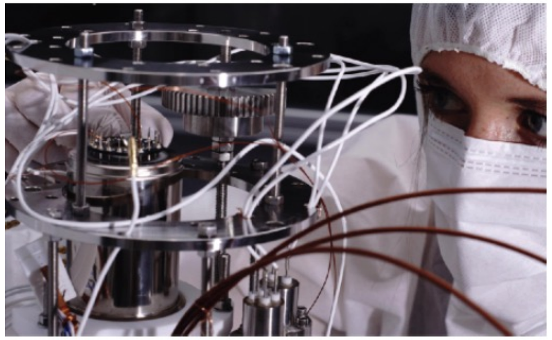


ARIA underground purification system for argon (DarkSide-20k)

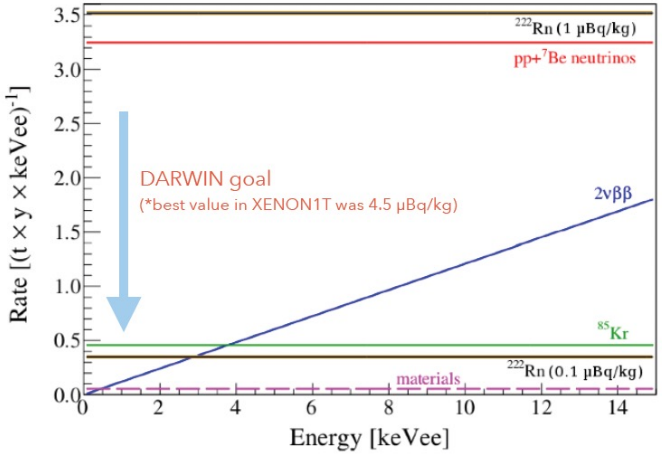
- R&D for multi-ton scale noble liquids: **Detector performance and background control**
  - Single phase versus two-phase TPCs
  - Distillation columns for krypton and radon, material screening and selection, radon emanation

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





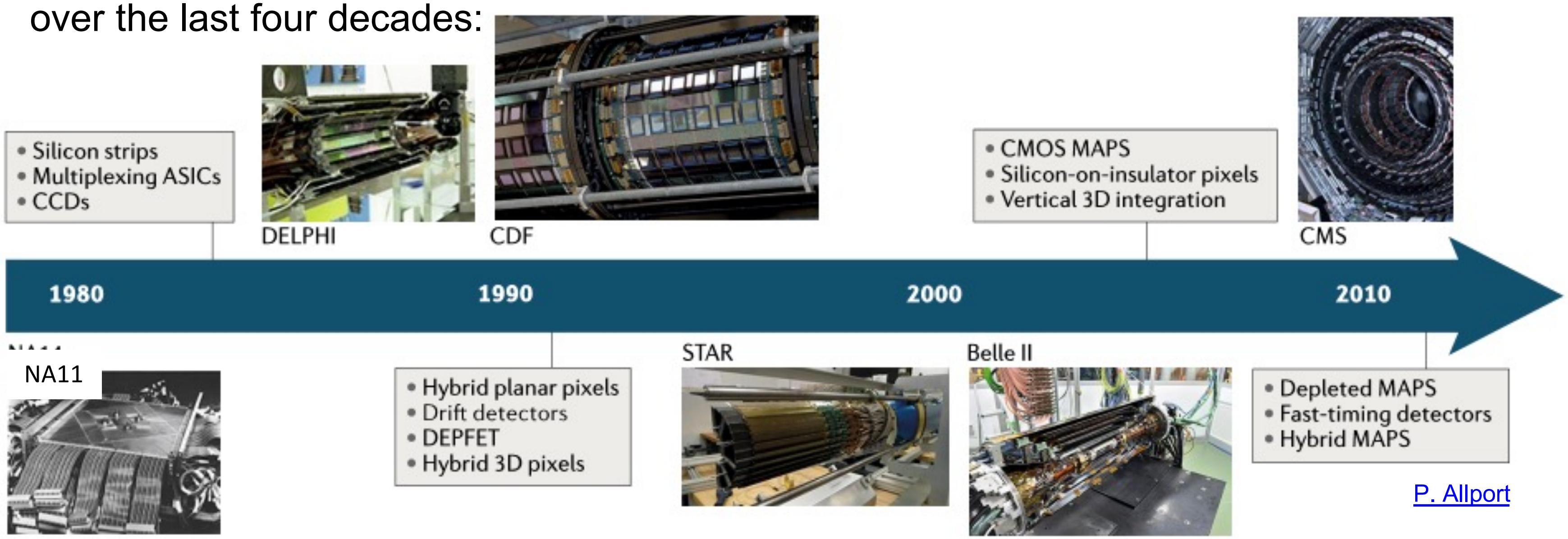
Hermetic TPC R&D for DARWIN



Rn distillation column for XENONnT (reduce ^{222}Rn - hence also ^{214}Bi - from pipes, cables, cryogenic system)

Solid State Detectors (TF 3)

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

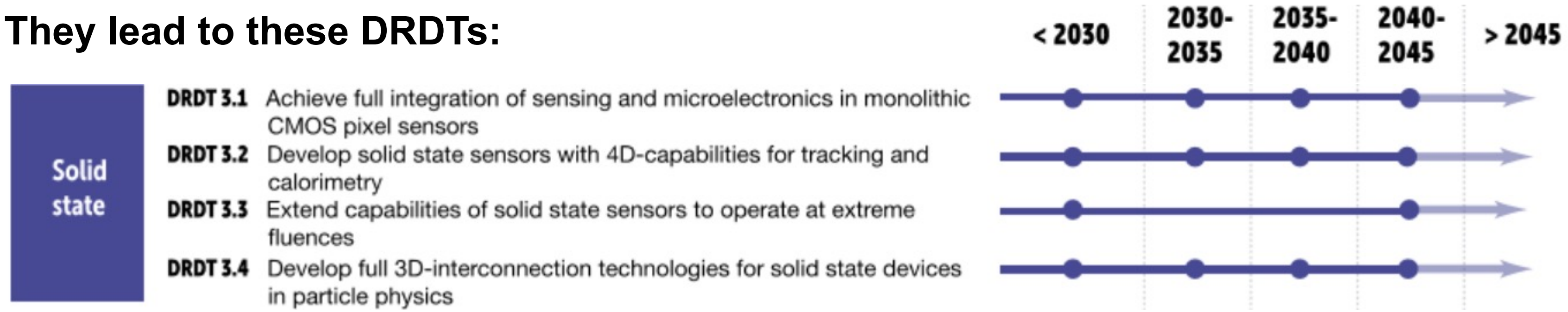


P. Allport

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:



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

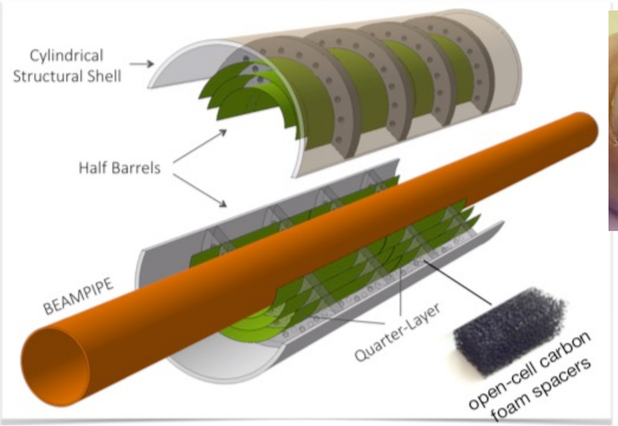
- **Vertex detectors with low mass, high resolution** (Target per layer spatial resolution of ≤ 3 μm and X/X_0 ≤ 0.05% for FCC-ee), **low power and high radiation hardness** (up to 8×10^{17} n_{eq}/cm^2 for pp-colliders)
- Trackers: **affordable sensors** with low mass, high resolution, **low power**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

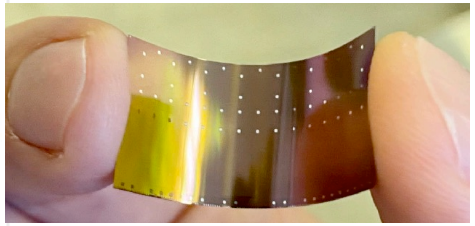
CMOS MAPS

- **Monolithic sensors combining sensing and readout elements (DRDT 3.1)**
- Example: For FCC-ee vertex detector targeting spatial resolution per layer of ≤ 3μm and X/X_0 ≤ 0.05%, essential to have low power. Plus radiation-hardness up to $8\times10^{17} n_{eq}/cm^2$ for pp-collider.

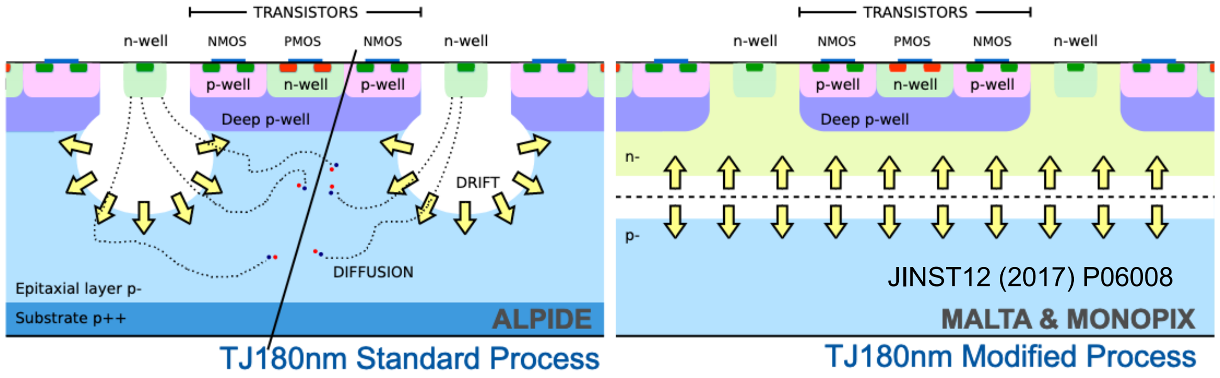
CMOS MAPS for ALICE ITS3 (Run 4):
(LOI: CERN-LHCC-2019-018, M. Mager)

- Three fully cylindrical, wafer-sized layers based on curved ultra-thin sensors (20-40 μm), air flow cooling
- Very low mass, < 0.02-0.04% per layer





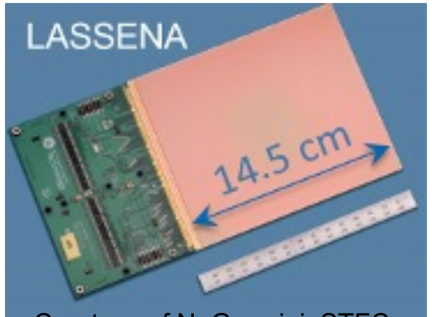
Radiation hardness of MAPS: From ALPIDE to MALTA/Monopix with modified Tower Jazz 180 nm process



→ Up to 97% efficiency after fluence of $1\times10^{15} n_{eq}/cm^2$ H. Pernegger

MIMOSA @ EUDET BeamTest
Telescope → 3 μm track resolution achieved

Large area: stitching
INMAPS process



Courtesy of N. Guerrini, STFC
50μm 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)

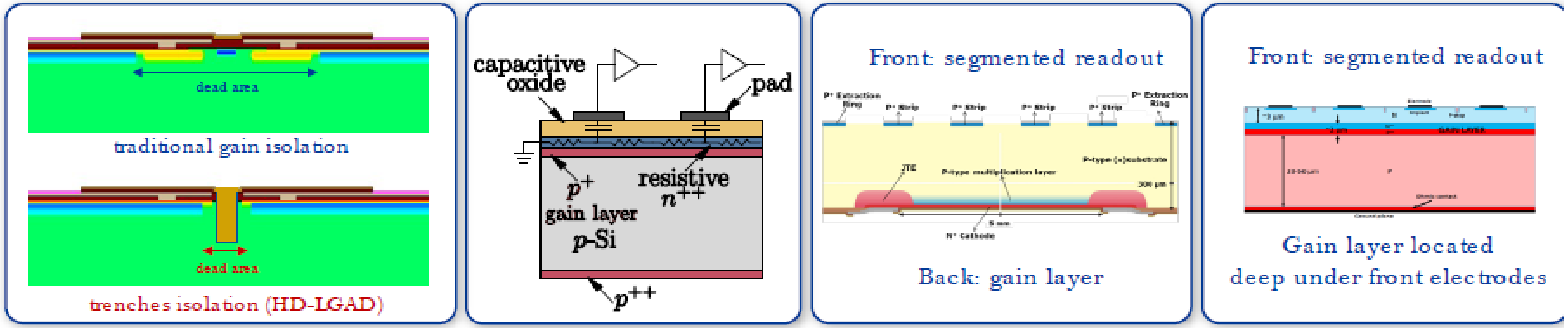
- For LGADs, three main foundries (CNM, FBK, HPK) and more producers
- Time information hugely beneficial to supress pile-up in pp-collisions

LGAD: Fill factor & performance improvements

RD50

- 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:

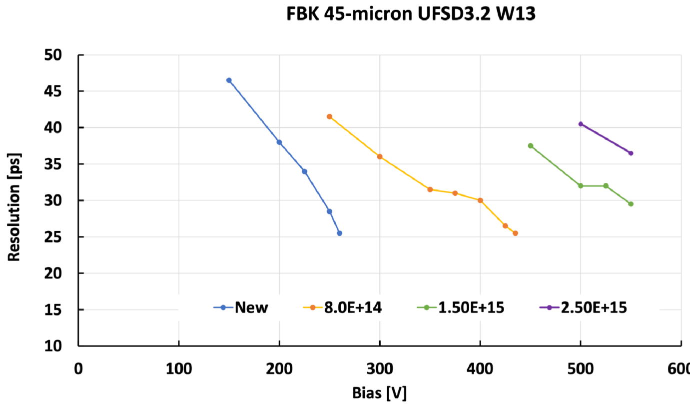
Trench Isolation LGAD | AC-LGAD | Invers LGAD | Deep Junction LGAD



Concepts simulated, designed, produced and tested in 2018/19 ..new concept 2020

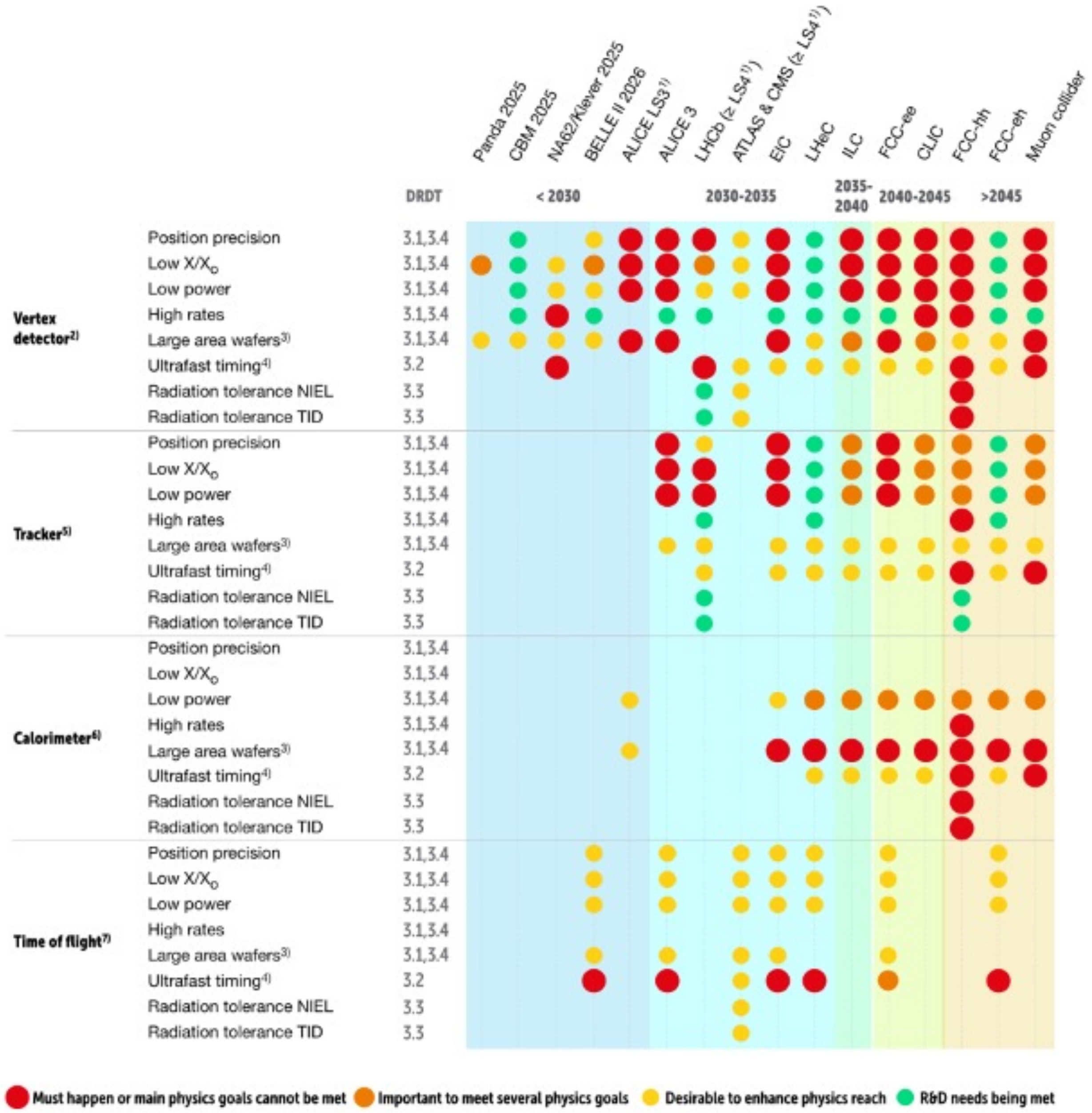
Areas of LGAD developments within RD50 Collaboration:

- 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 (~$2x10^{15}$ n_{eq}/cm^2)
- Performance Parameterisation Model



N. Cartiglia

Solid State Detectors

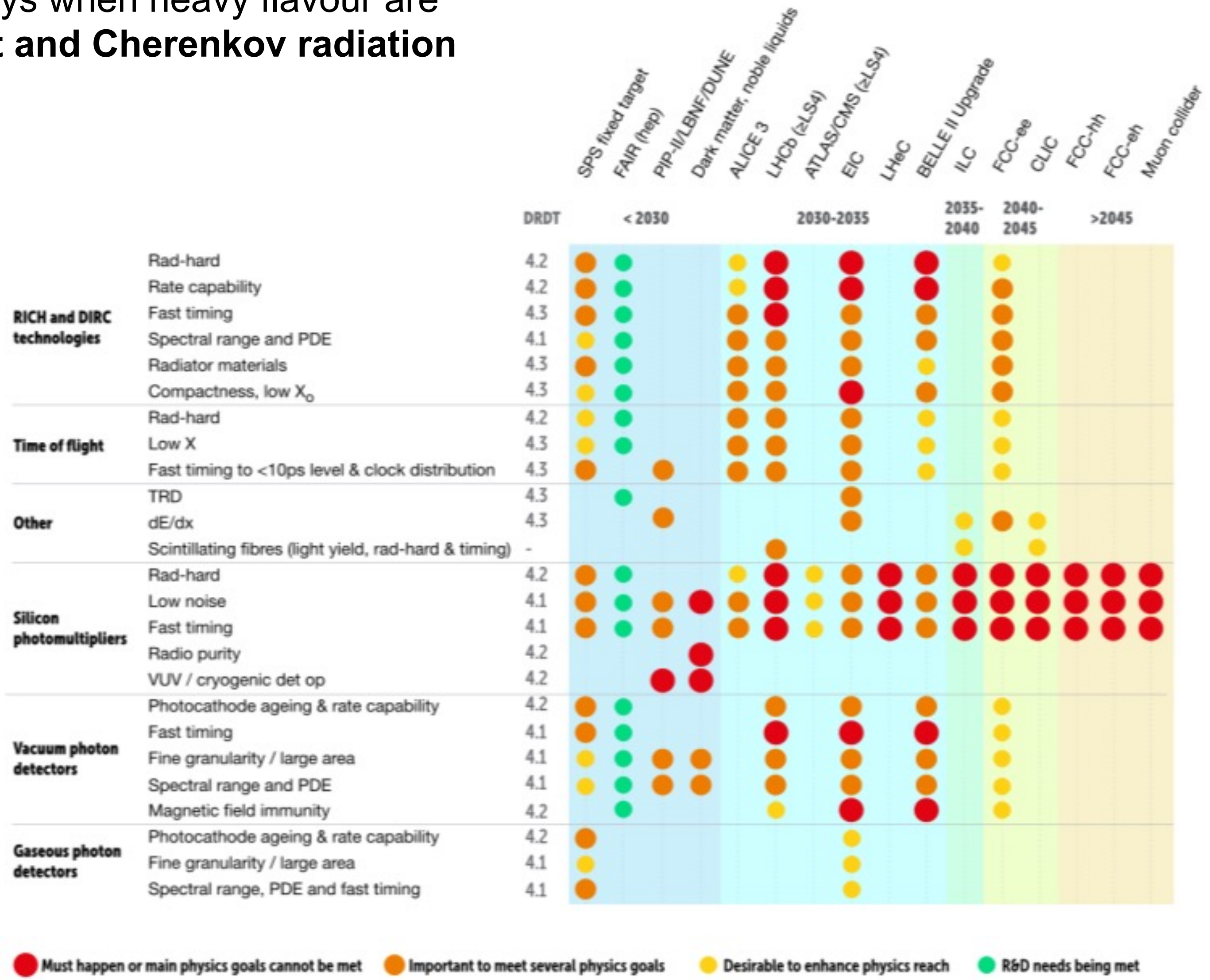


PID and Photon Detectors

- **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**

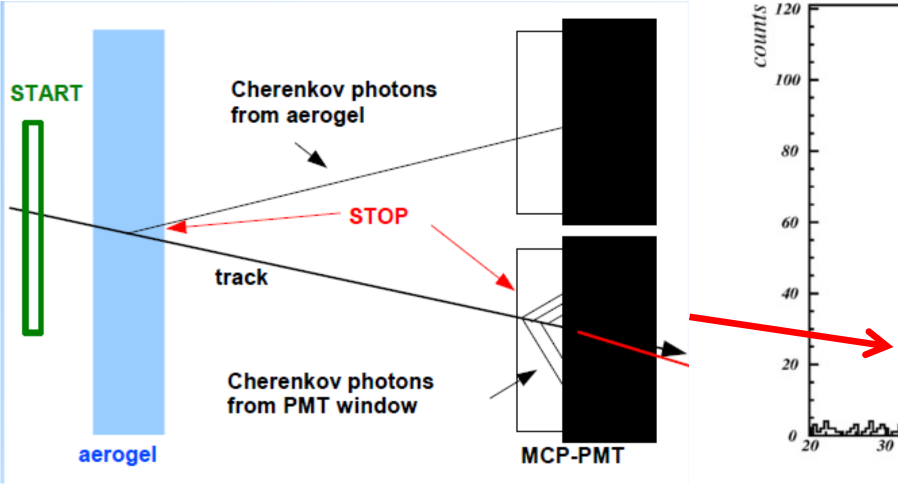
- Challenges for example for **SiPMs**: the high dark count rate and moderate radiation hardness prevented their use in RICH detectors where single photon detector required at low noise
- Challenges for **MCP-PMTs** is their price and they are not tolerant to magnetic fields, similarly **Large-Area Picosecond Timing Detectors** (LAPPD) which are promising but need in addition pixellation

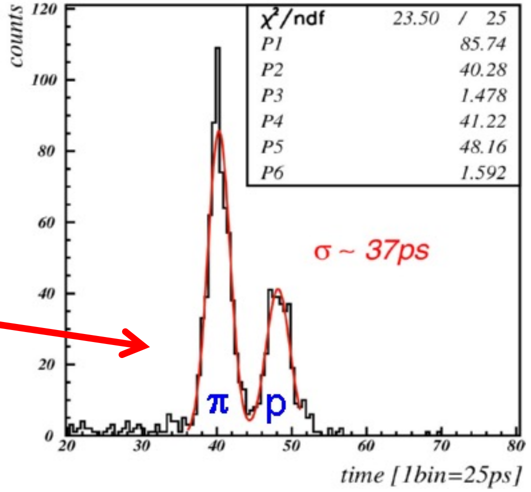


PID and Photon Detectors: RICHes

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





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

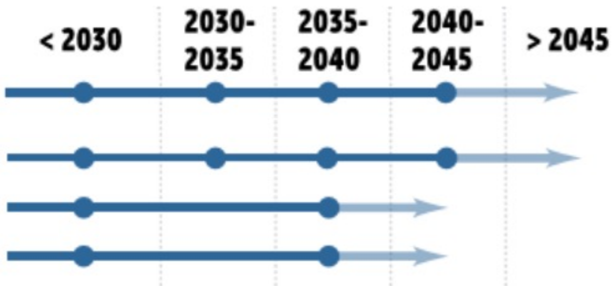
P. Krizan @INSTR2020
T. Credo, 2004 IEEE NSS/MIC Conference Record

- 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 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

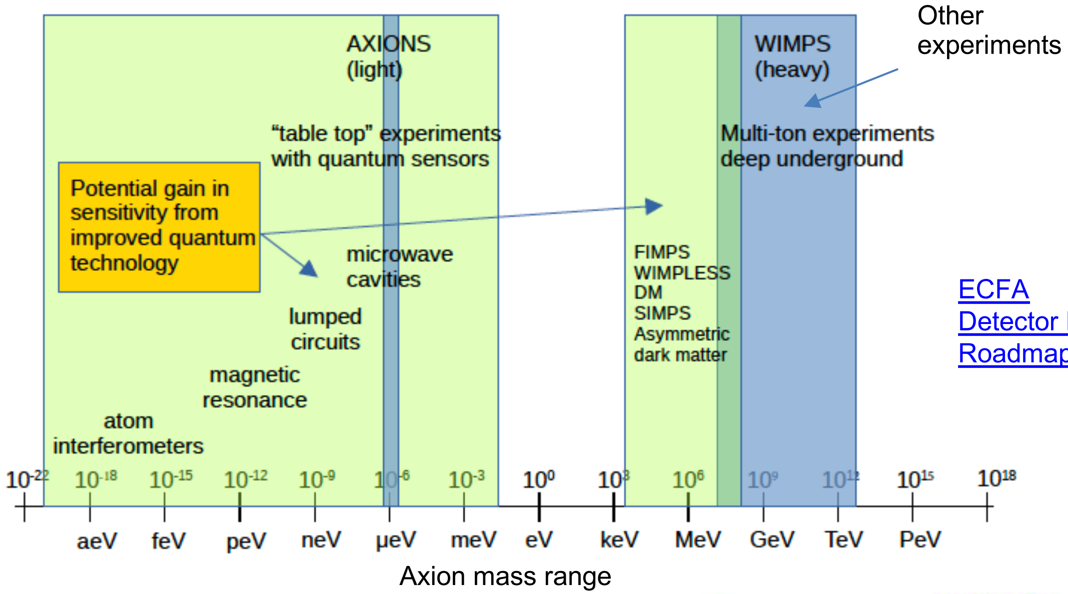


Quantum and emerging technologies

- **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, …

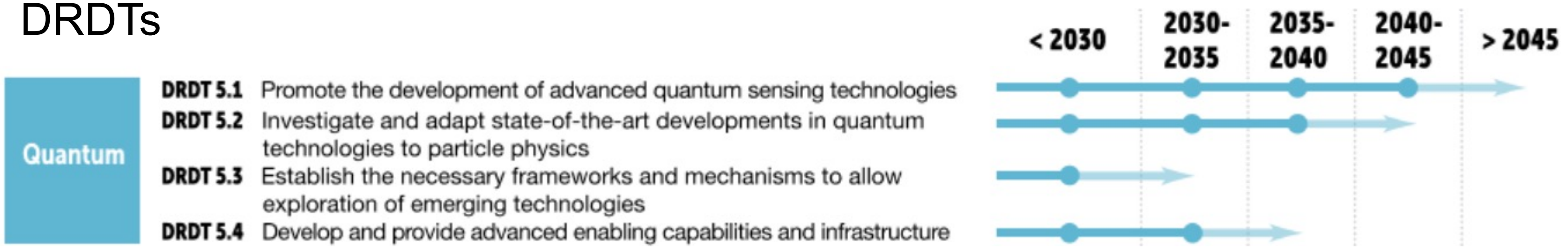
QUANTUM TECHNOLOGY INITIATIVE

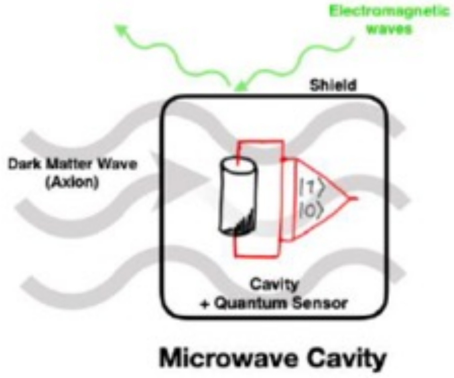
Example: potential mass ranges that quantum sensing approaches open up for Axion searches



ECFA Detector R&D Roadmap

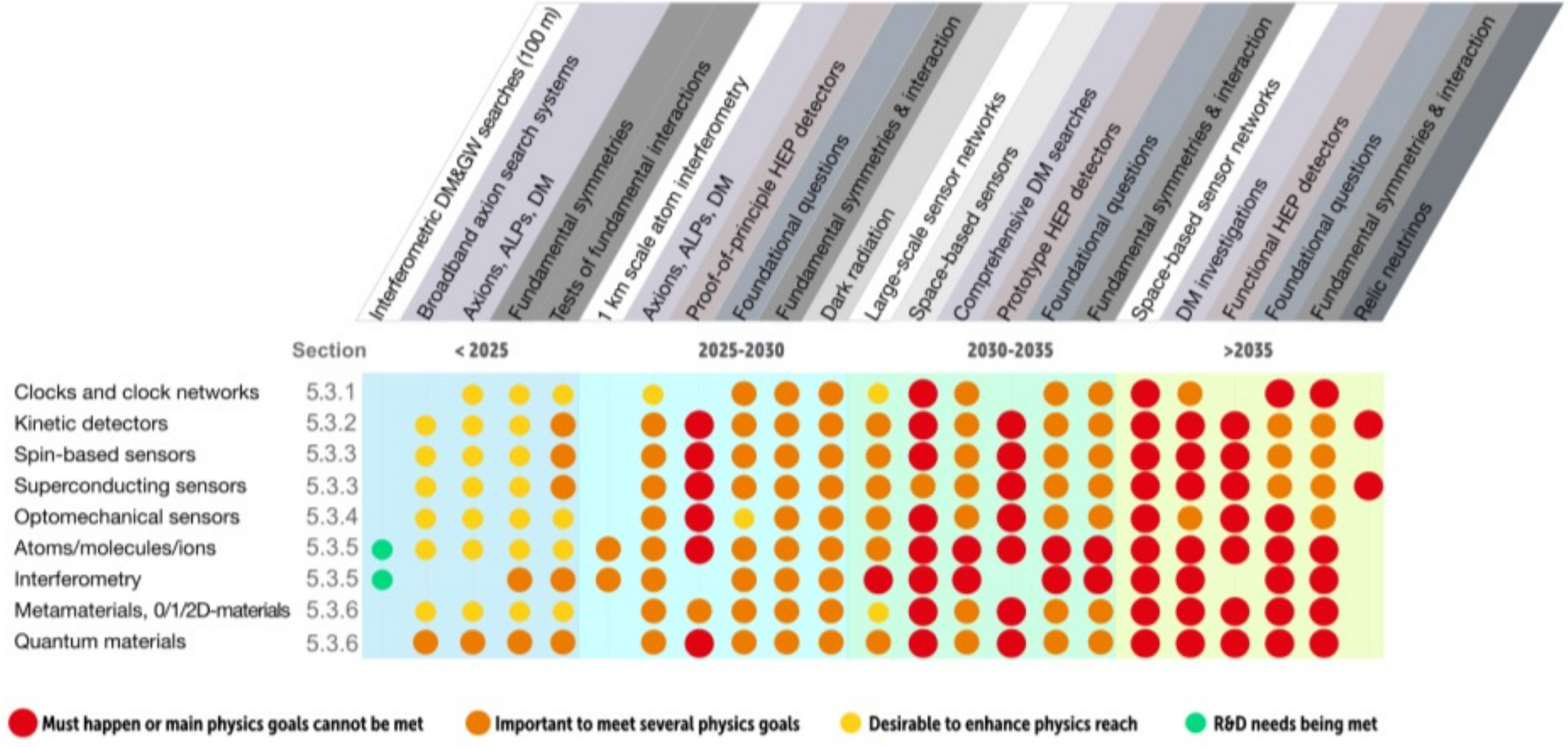
DRDTs



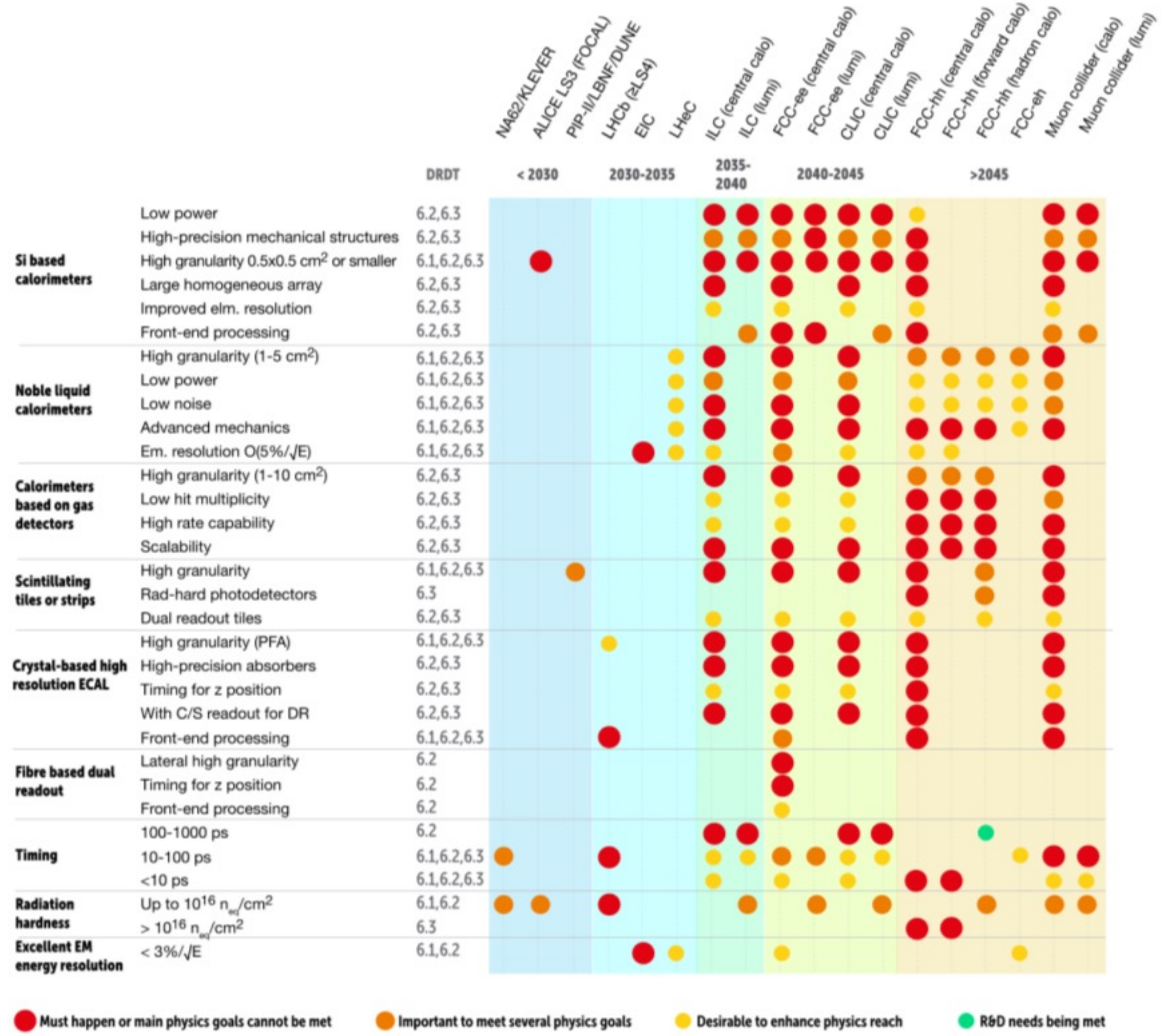


S. Golawa

Quantum and emerging technologies

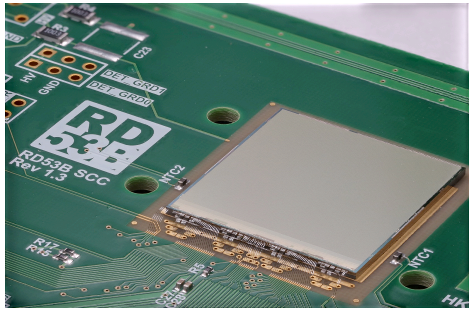


Calorimetry



Electronics

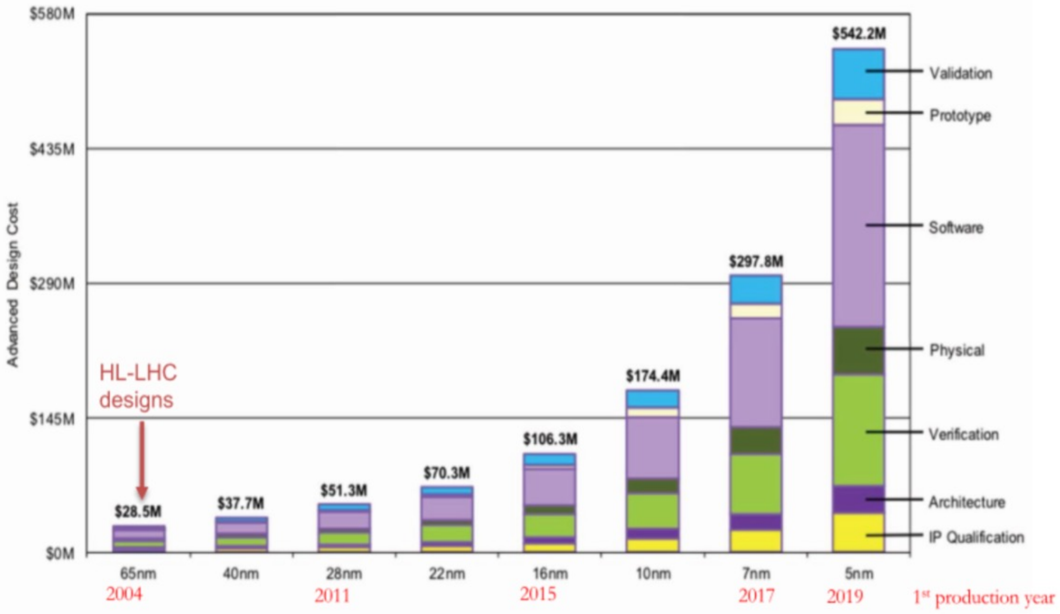
- **Main challenges: precision timing** (ToF; 4D tracking), **high granularity** and **resolution** imply a **cost in terms of data handling, processing, complexity and power.**
- Need **latest advances in commercial microelectronics and high-speed links** (DRDT 7.1, 7.4, 7.5)
- However, very specific needs for HEP in e.g. **radiation hardness or operation in magnetic fields** with HEP at best a niche low volume market.



RD53 Collaboration (65 nm ASIC for HL-LHC)

For example: Long time to develop radiation tolerance in 65 nm O(GRad) and large cost → technology is not straightforward;

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

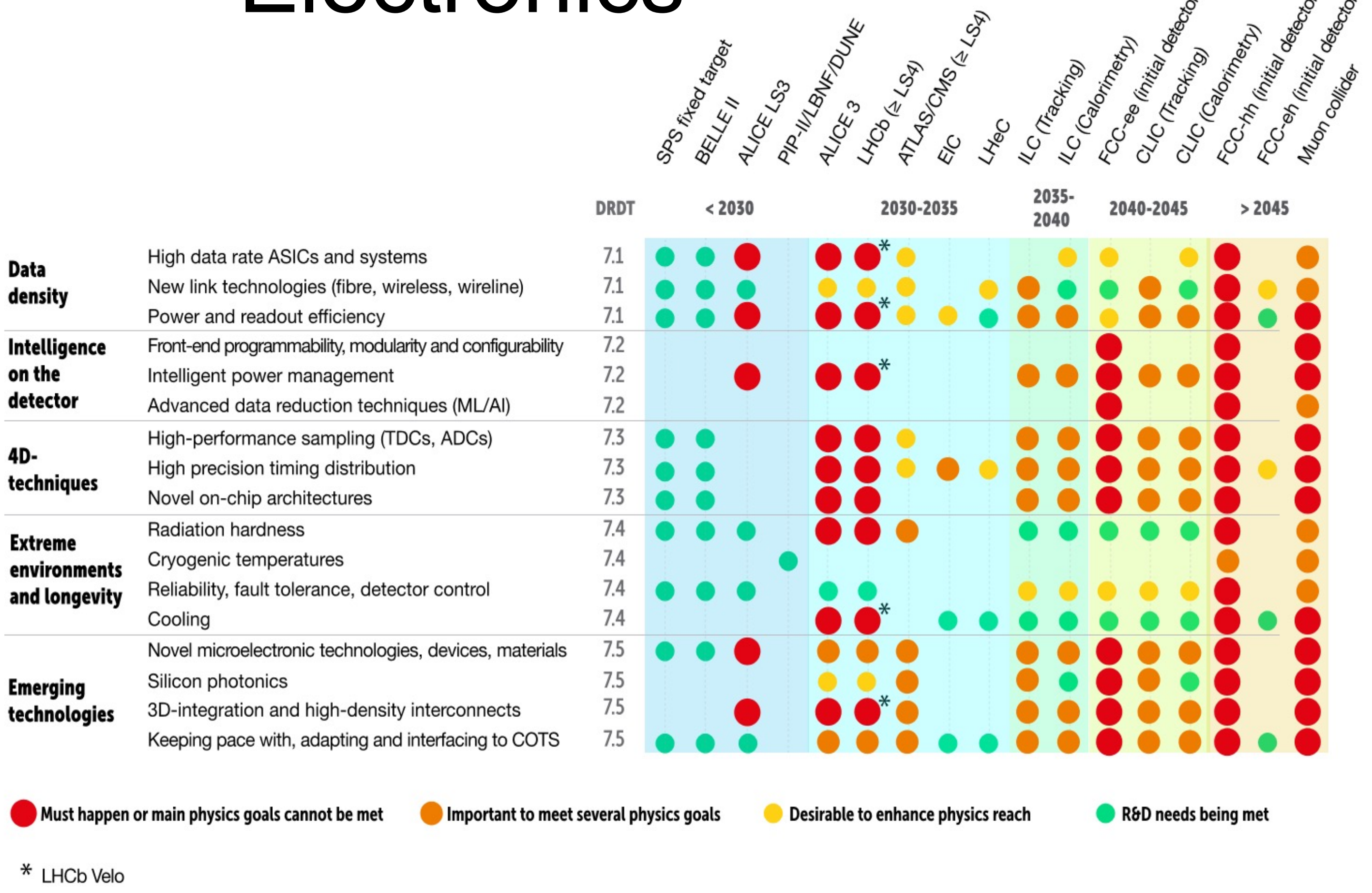


Chip Design and Manufacturing Cost under Different Process Nodes: Data Source from IBS*

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

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

Electronics



The DRDTs are

Electronics

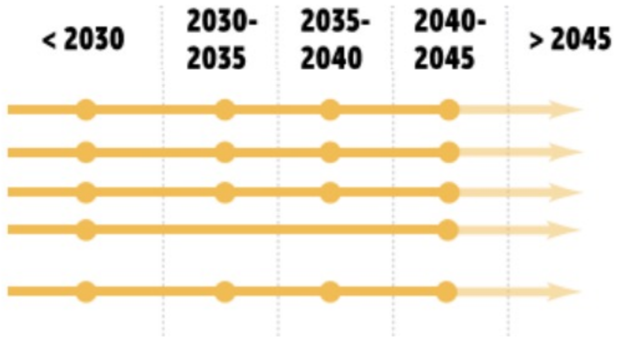
DRDT 7.1 Advance technologies to deal with greatly increased data density

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

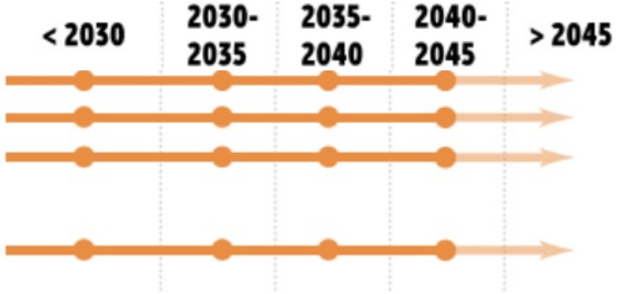
DRDT 7.5 Evaluate and adapt to emerging electronics and data processing technologies



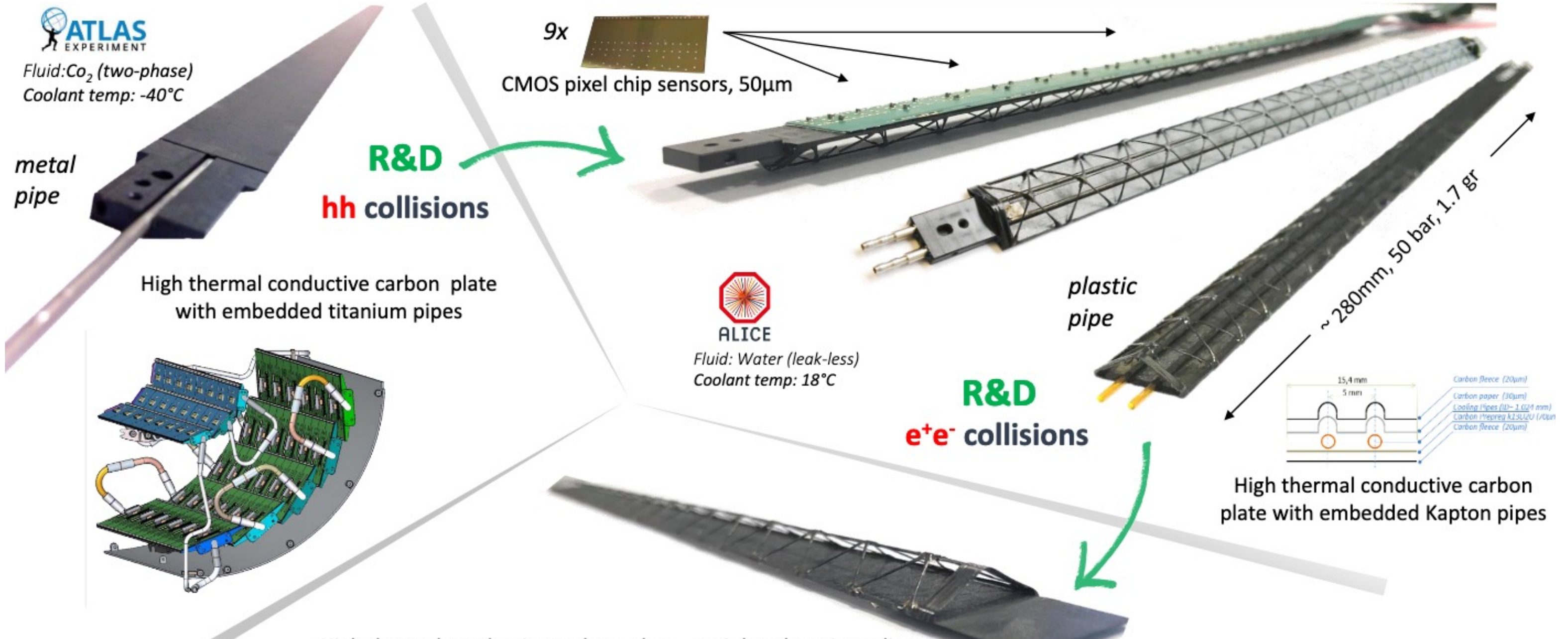
Integration

- DRDTs:

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



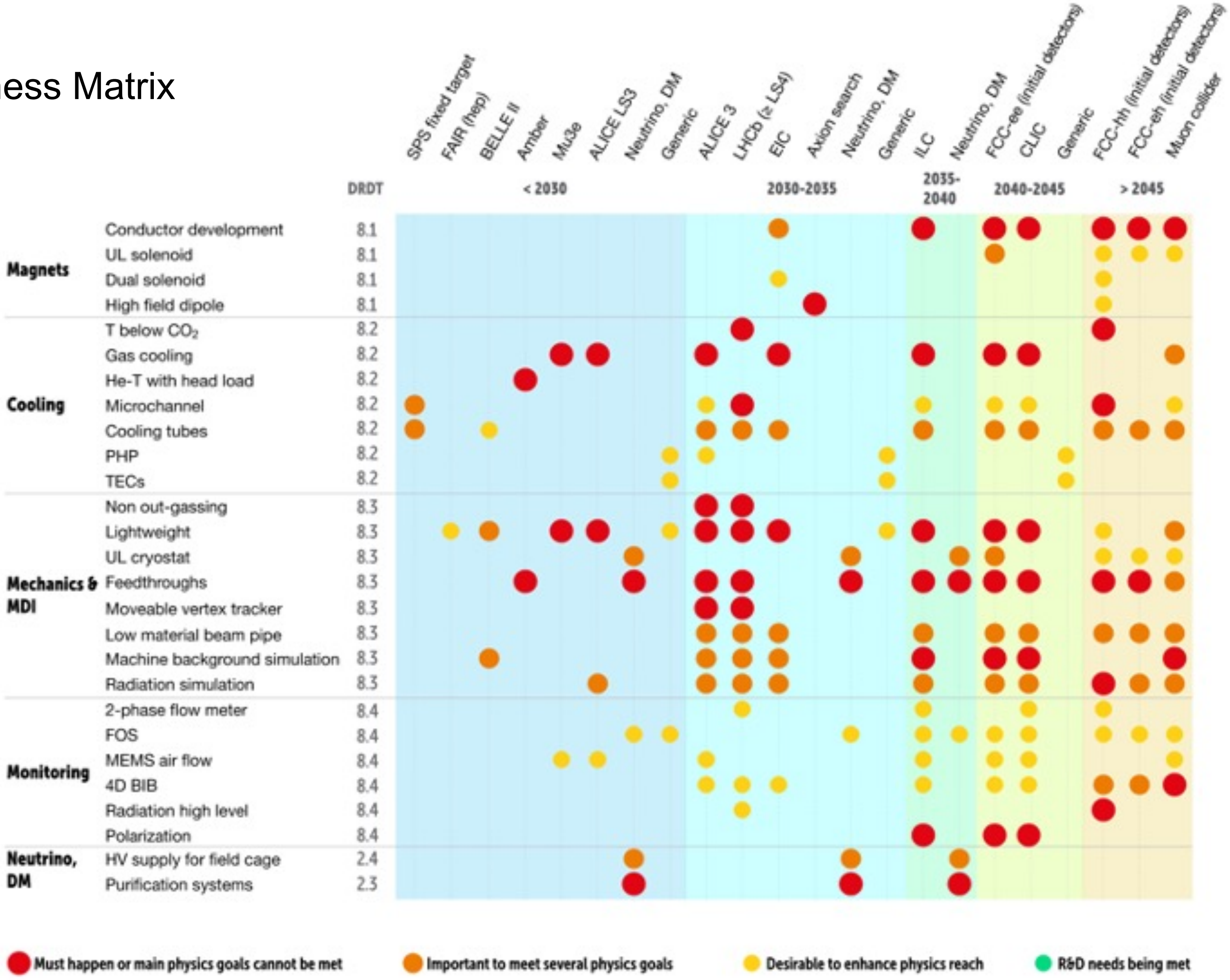
- Investigation of **novel superconductors for magnet systems** as well as support of expert design capabilities and modelling software for future experiments is vital.
- **Cooling technologies** for cryogenics and low-mass heat removal from on-detector electronics and semiconductor sensors require dedicated R&D activities.
- **Ultra low mass, stable, precision mechanics** and **machine detector interface design** are major topics
  - Example: Pipe design



C. Gargiulo

Integration

- Detector Readiness Matrix

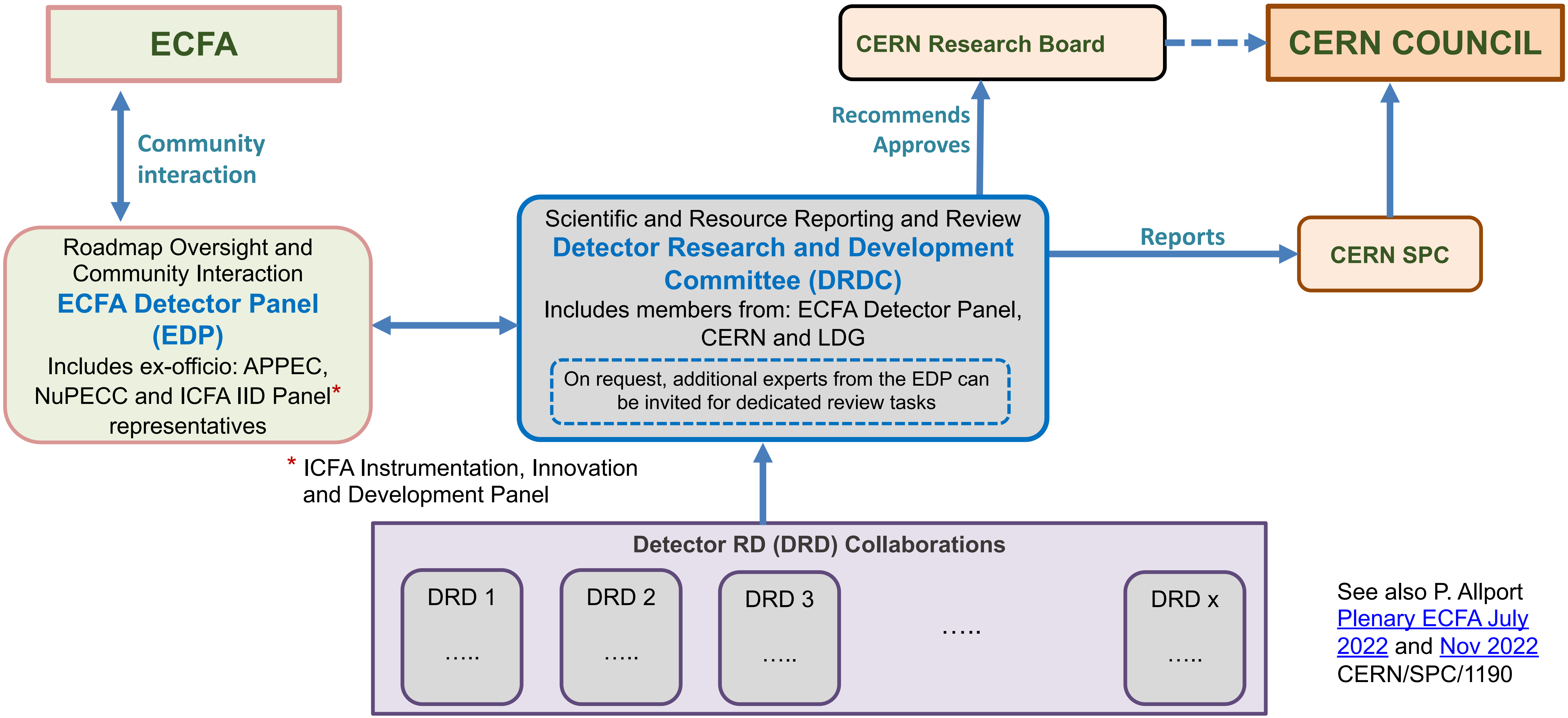


Implementation and Review

- 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

Implementation and Review

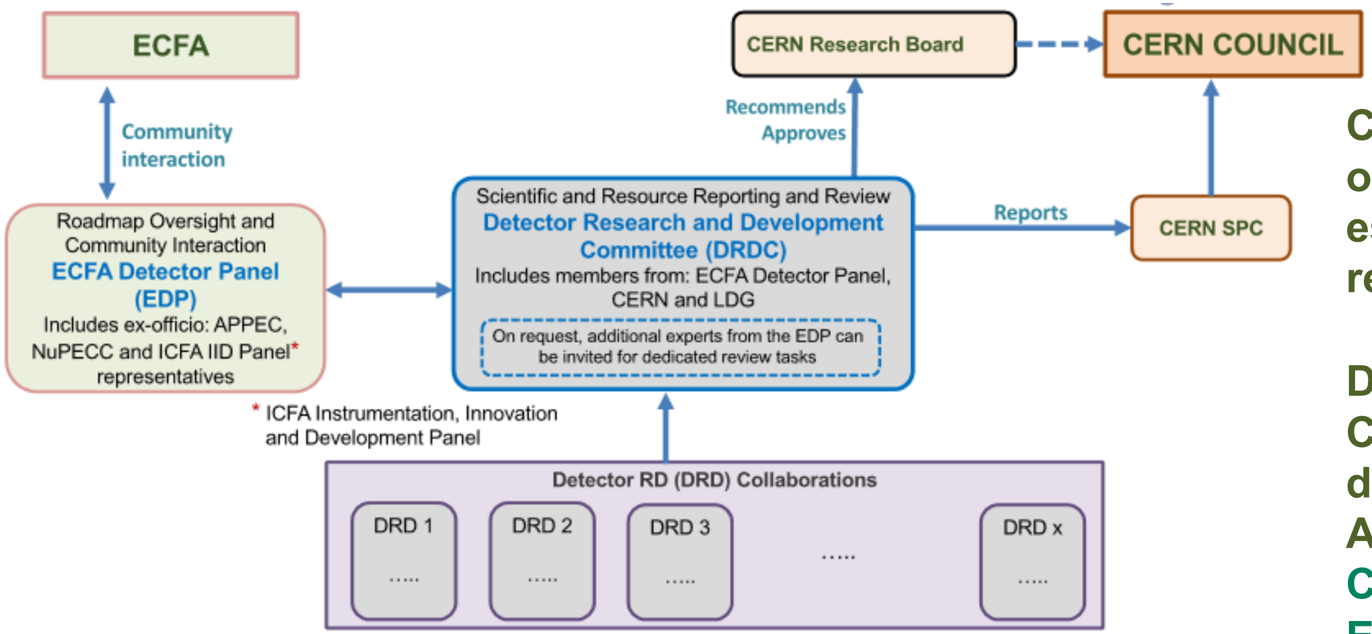


See also P. Allport Plenary ECFA July 2022 and Nov 2022 CERN/SPC/1190

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. Contribution from non-European groups welcome!

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.

See also P. Allport Plenary ECFA July 2022 and Nov 2022
CERN/SPC/1190

Next steps of implementation – the EDP

- The membership of the EPD reflects the needs to provide expertise in each of the key detector areas identified in the Roadmap: Gaseous Detectors; Liquid Detectors; Silicon Detectors; Photon Detectors and Particle Identification; Quantum and Emerging Technologies; Calorimetry; Electronics and On-detector Processing; and Integration. (The area of Training now being addressed by the dedicated ECFA Training Panel.)
- Two Co-chairs (Phil Allport, Birmingham and Didier Contardo, IP2I Lyon) who are also permanent members of the DRDC to advise and regularly report on EDP deliberations, as well as a Scientific Secretary (Doris Eckstein, DESY, Solid State Detectors).
- Members:
  - Silvia Dalla Torre (INFN Trieste) Gaseous Detectors;
  - Inés Gil Botella (CIEMAT) Liquid Detectors;
  - Roger Forty (CERN) PID & Photon Detectors;
  - tbc Quantum and Emerging Technologies;
  - Laurent Serin (Orsay LAL) Calorimetry;
  - Arno Straessner (Dresden)* Electronics;
  - Valerio Re (Bergamo) Electronics;
  - Karl Jakobs (Freiburg) ex-officio (ECFAChair);
  - Ian Shipsey (Oxford)† ex-officio ICFA IIDP Chair;
  - APPEC and NuPECC appointed Observers.

* Leaving 2023
†Quantum and Emerging Technologies expertise

- It is proposed that the terms of the Co-chairs be defined as three years with periods in office to run eighteen months out of phase with each other to provide continuity. The mandate of each co-chair can be renewed once, for a maximum period of six years.
- It is proposed that the positions of Scientific Secretary and Member have terms of three years, renewable once, but also staggered in time to ensure reasonable overlaps of experience when terms come to an end.