ECFA
European Committee for Future Accelerators

ECFA Detector Roadmap

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on behalf of TENMAK
PECFA Representative of Türkiye

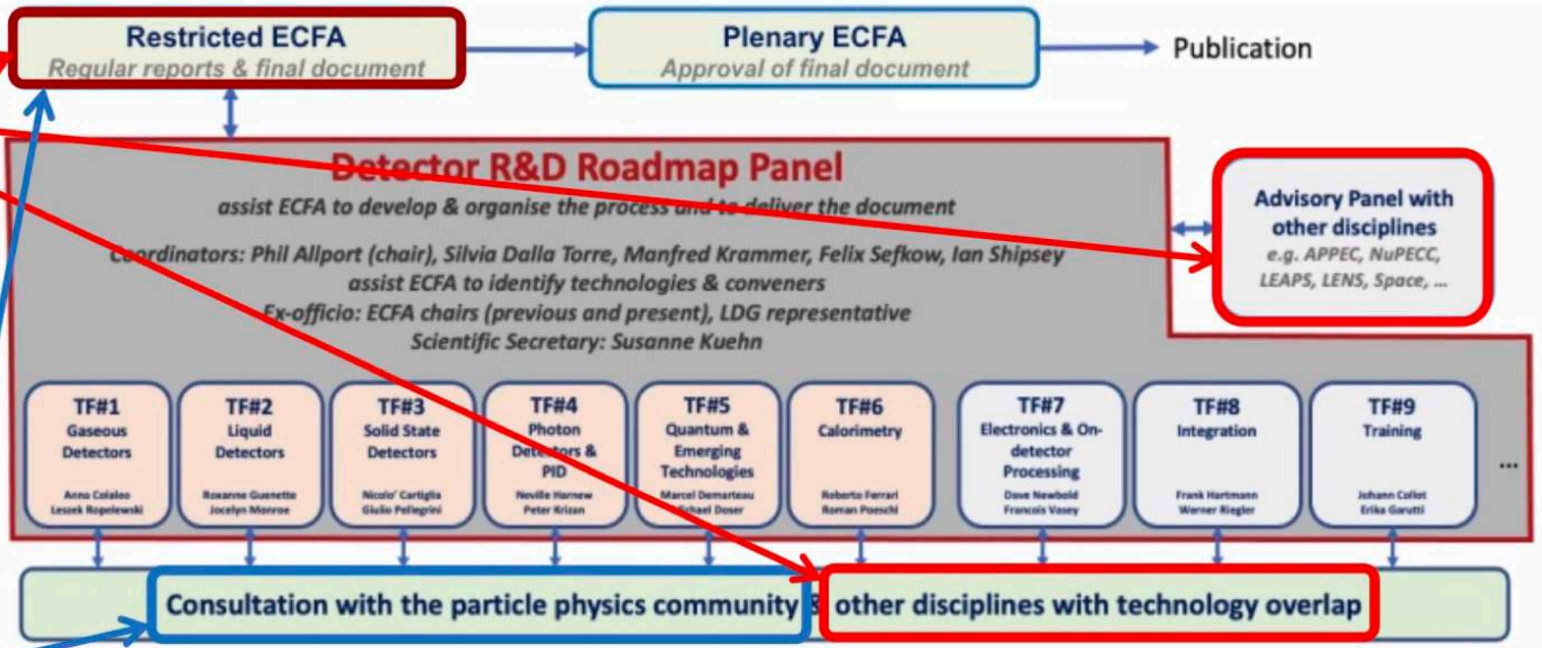
heavily based on or directly using slides by Phil Allport, Susanne Kuehn, Felix Sefkow, and Karl Jakobs

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" *

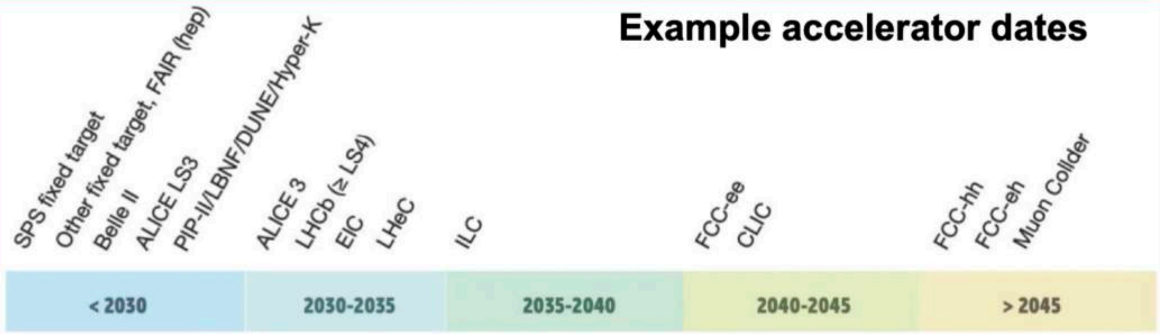
ECFA Detector R&D Roadmap Panel web pages at:
https://indico.cern.ch/e/ECFADetectorRDRoadmap

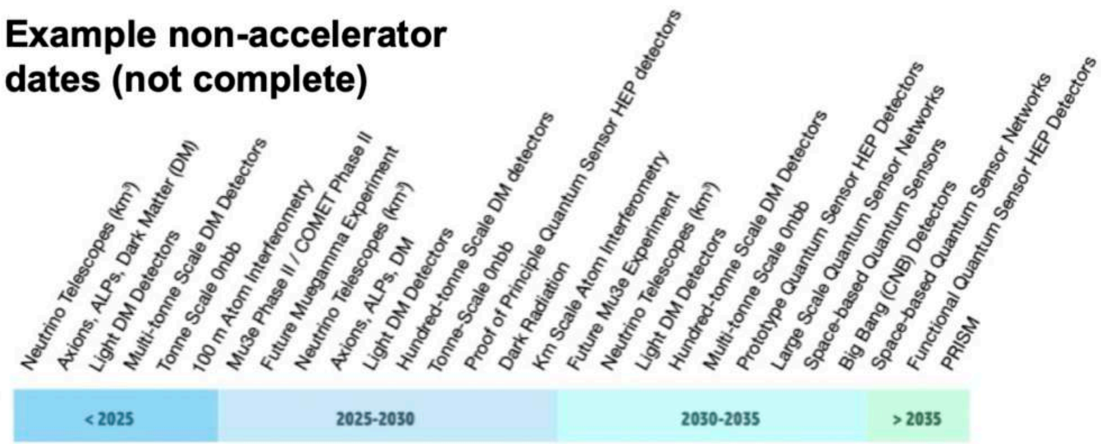
*** 2020 European Particle Physics Strategy Update**
https://europeanstrategyupdate.web.cern.ch/

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

Overview of future facilities

- Many different future facilities proposed/foreseen based on accelerators and non-accelerators
- Overview from ECFA Detector R&D Roadmap Document (CERN-ESU-017, 10.17181/CERN.XDPL.W2EX)





"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.

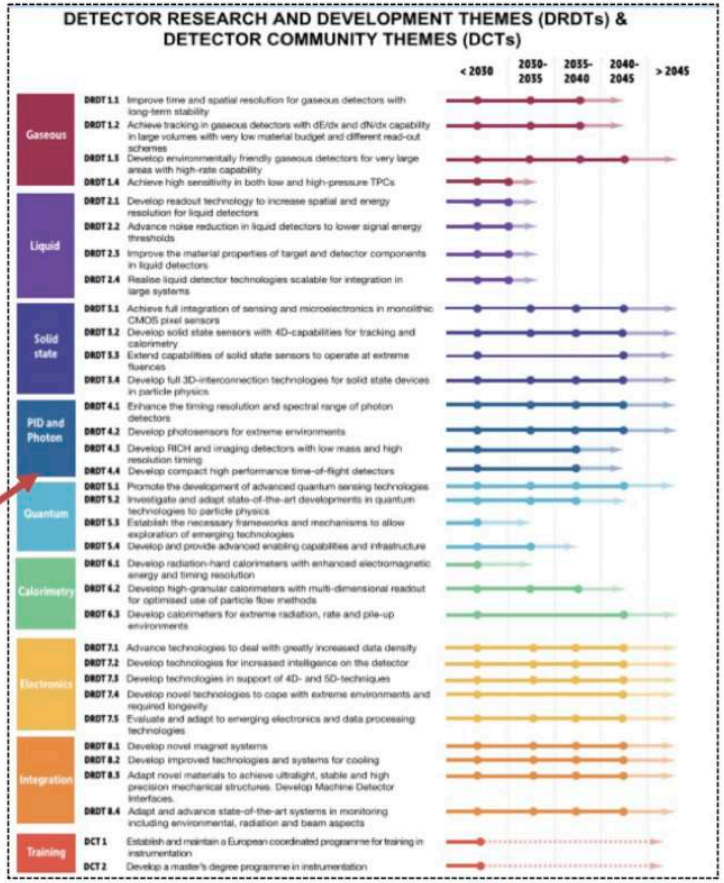
Furthermore, the projects mentioned here are usually limited to those mentioned in the 2020 EPPSU*, although it should be noted that detector R&D for other possible future facilities is usually aligned with that for programmes already listed.

→ Many detector concepts at different future facilities

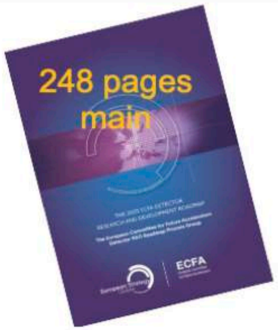
*** 2020 European Particle Physics Strategy Update**
https://europeanstrategyupdate.web.cern.ch/

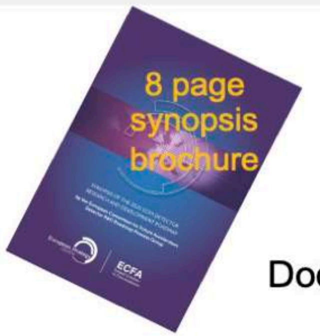
ECFA Detector R&D Roadmap

- 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





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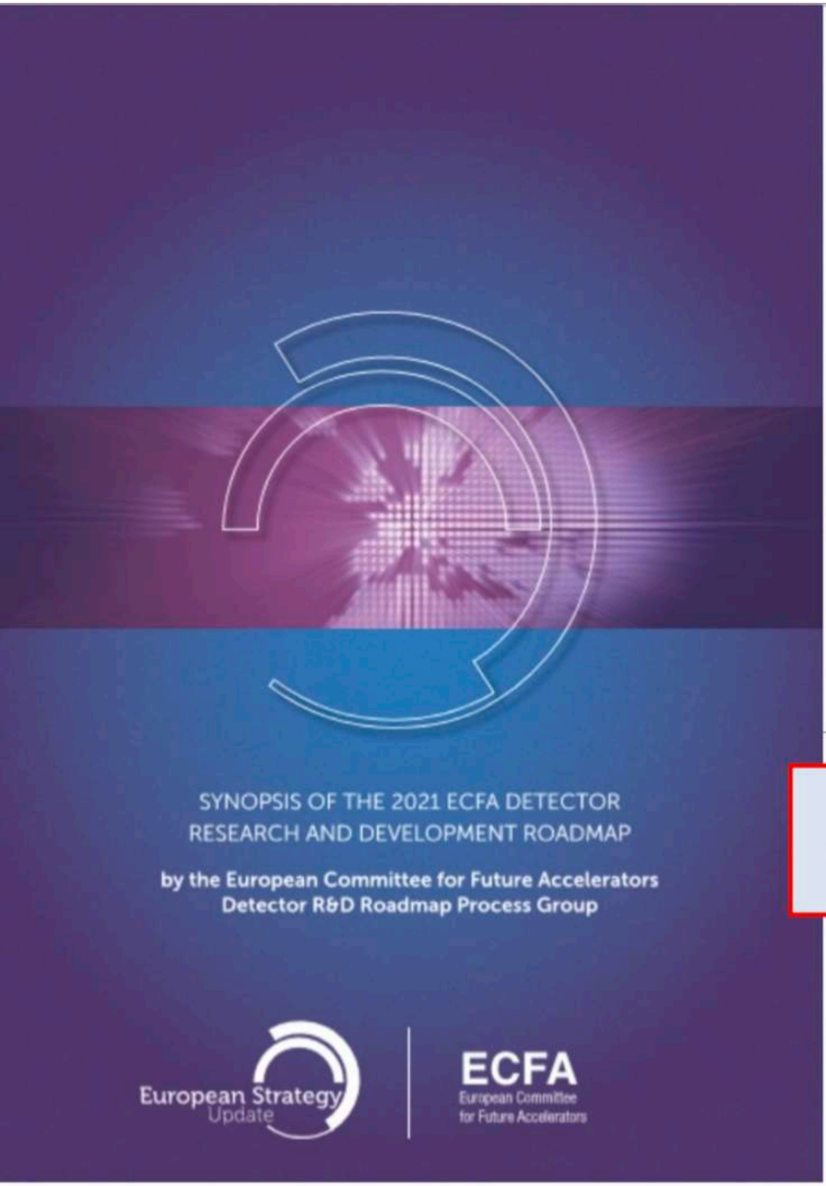
Documents: CERN-ESU-017 10.17181/CERN.XDPL.W2EX, https://cds.cern.ch/record/2784893

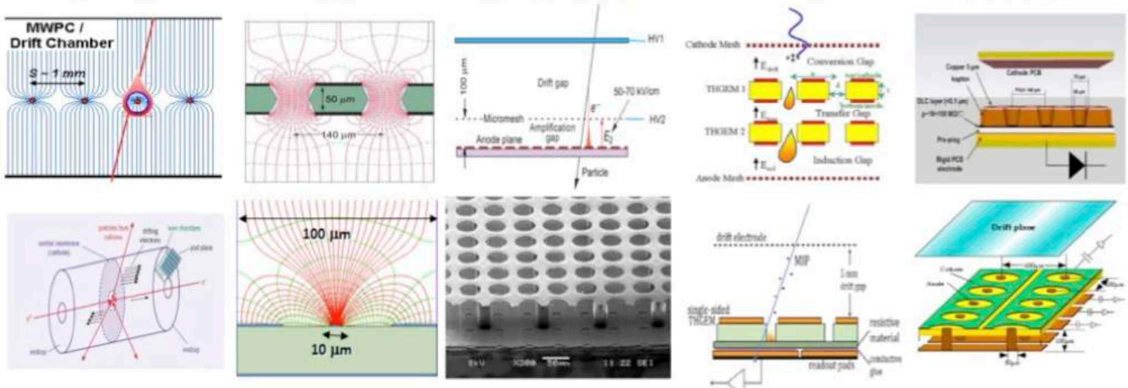


8 page synopsis brochure prepared for less specialist audience

Gaseous detectors

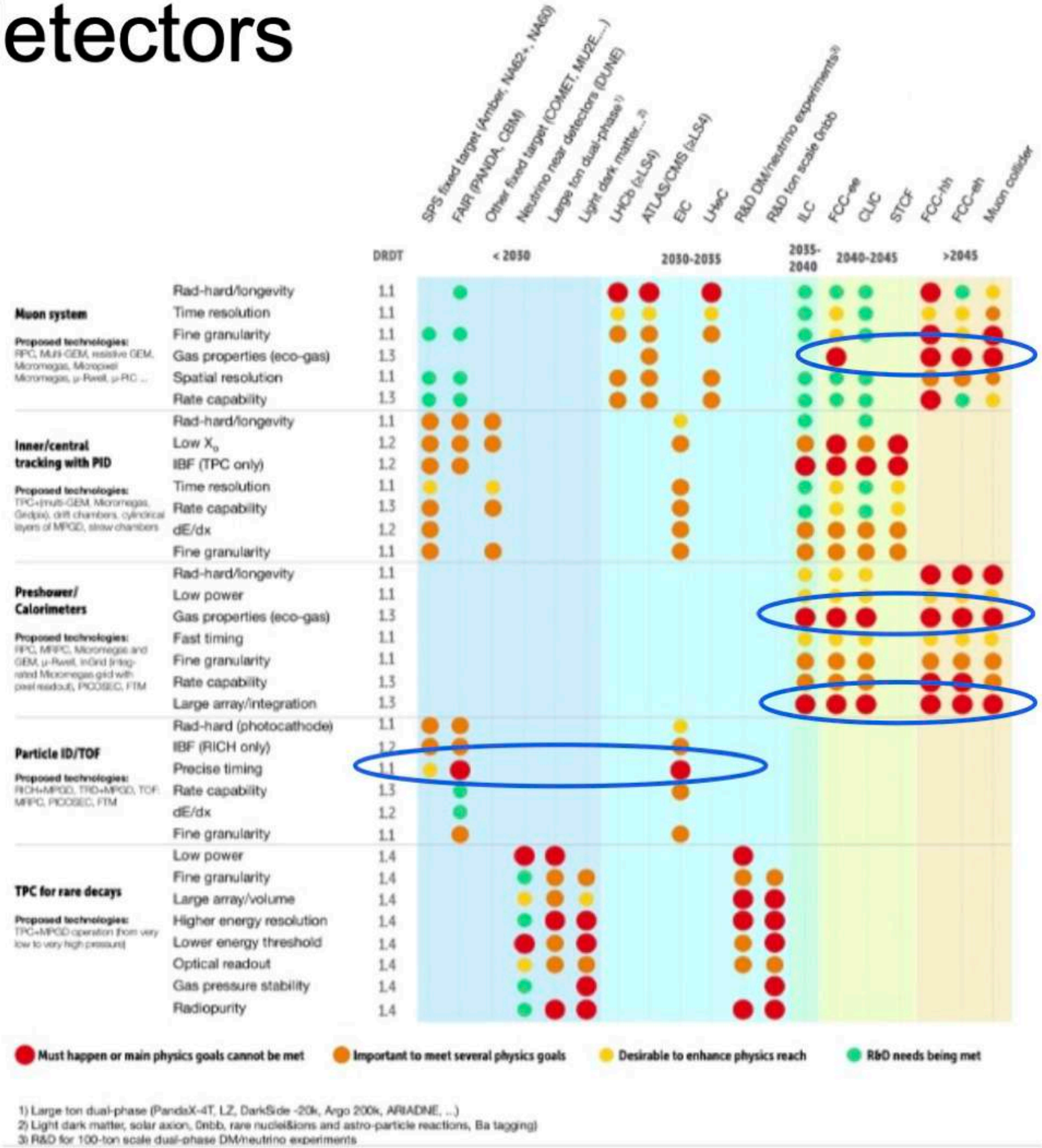
- Gaseous detectors: from Wire/Drift Chamber → Time Projection Chamber (TPC) → Micro-Pattern Gas Detectors
- Primary choice for large-area coverage with low material budget & dE/dx measurement (TPC, Drift chamber) & TOF functionality (MRPC, PICOSEC)

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



TPC | MSGC | INGRID | RPWELL | μ–PIC

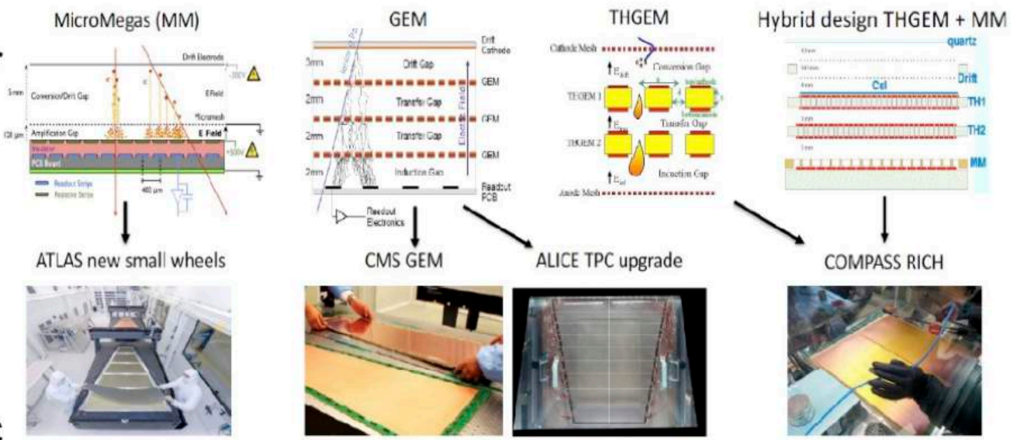
- **Detector Readiness Matrices of each Task Force chapter** focus on the extent to which the R&D topic is *mission critical* to the programme than the intensity of R&D required
  - Must happen or main physics goals cannot be met
  - Important to meet physics goals
  - Desirable to enhance physics reach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

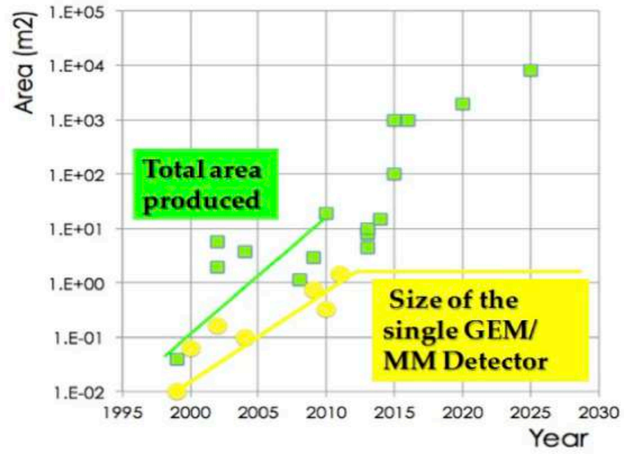


Gaseous detectors: area and timing

M. Titov

- **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

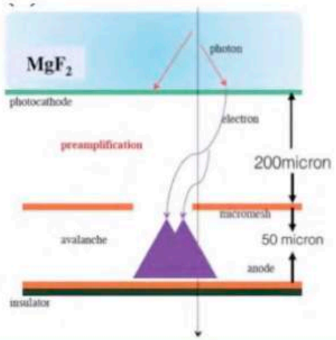


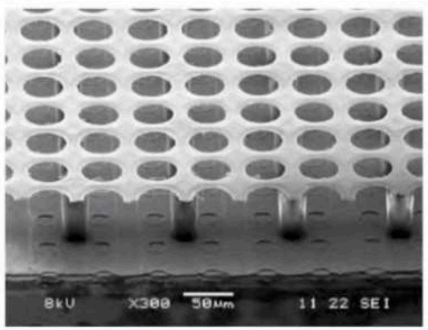


- **Gaseous detectors offer very competitive timing** through e.g.
  - **Multi-gap Resistive Plate Chambers** (down to 60 ps time resolution) (ALICE TOF Detector, Z.Liu, NIM A927 (2019) 396)
  - An enabling emerging R&D: **Micromegas with timing** (PICOSEC concept)

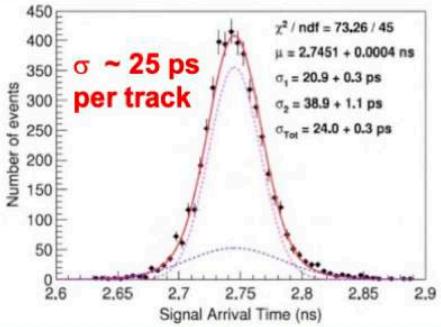
Cherenkov radiator + Photocathode + MM

J. Bortfeldt, NIM A903 (2018) 317





Timing (MIP test-beam):

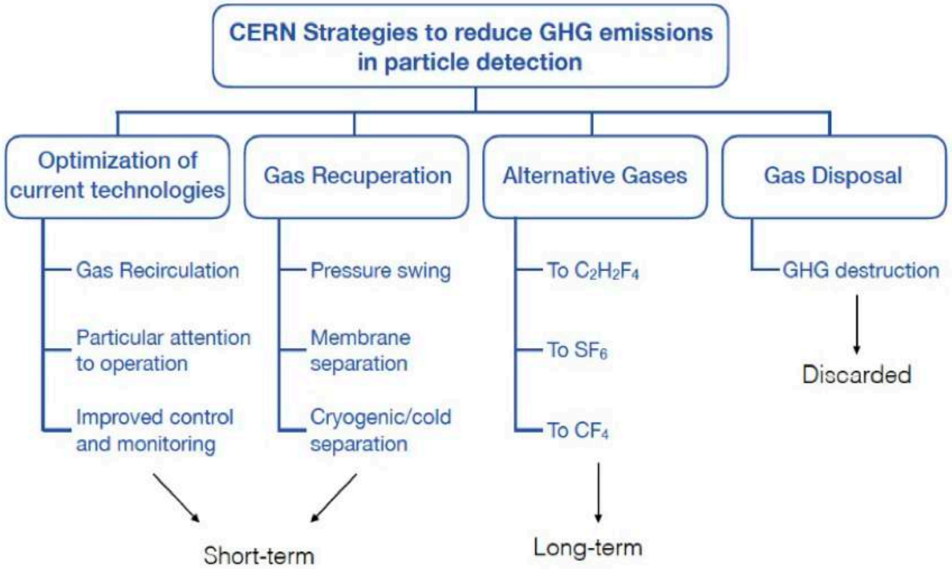


→ Many developments emerged from the R&D studies within the RD51 Collaboration

Gaseous Detectors: eco-friendly gases

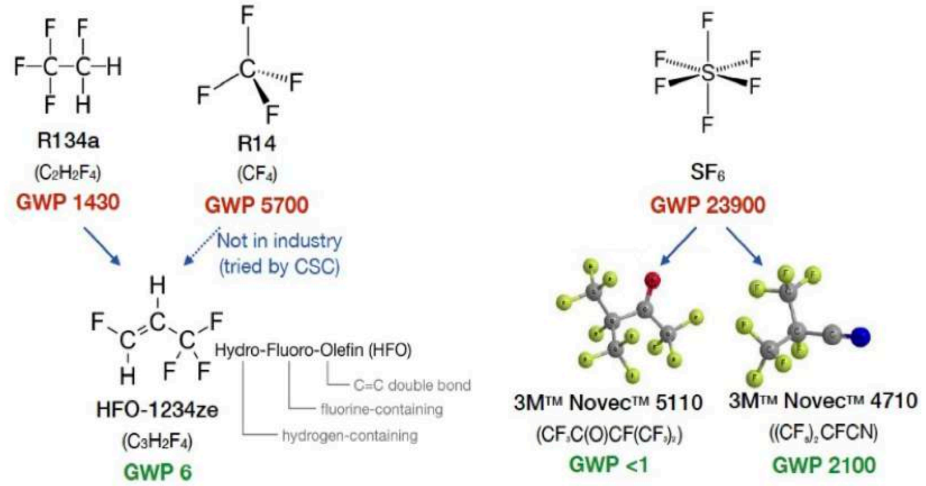
- 92% of emission at CERN related to large LHC experiments
- Thanks to gas recirculation GHG emission already reduced by > 90% wrt. to open mode systems!
- Many LHC gas systems with gas recuperation

CERN strategies for GHG reduction



Possible alternatives to GHG gases

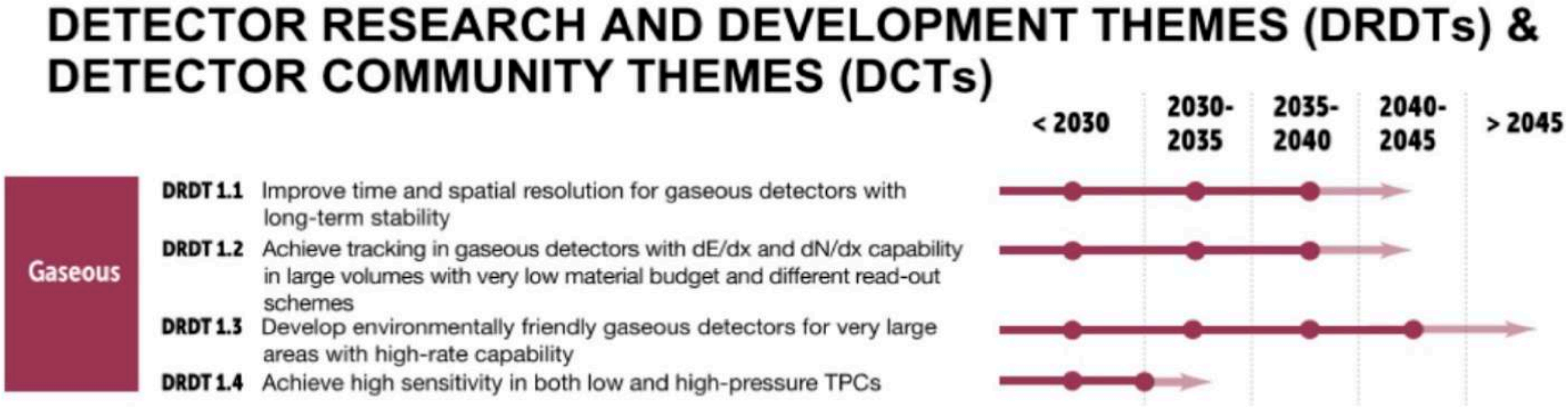
New eco-friendly liquids/gases have been developed for industry as refrigerants and HV insulating medium... ionisation properties in particle detection not well known



- Alternative gases:
  - A lot of work especially in RPC community to search for alternative to $C_2H_2F_4$
  - Not an easy task to find new eco-friendly gas mixture for current detectors

Gaseous detectors

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



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

To not limit a feasible start date of a future facility

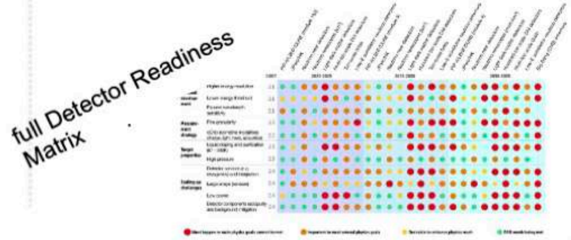
- The faded region acknowledges the typical time needed between the completion of the R&D phase and the readiness of an experiment at a given facility.
- Stepping stones are shown to represent the R&D needs of facilities intermediate in time.
- It should be emphasised that the future beyond the end of 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

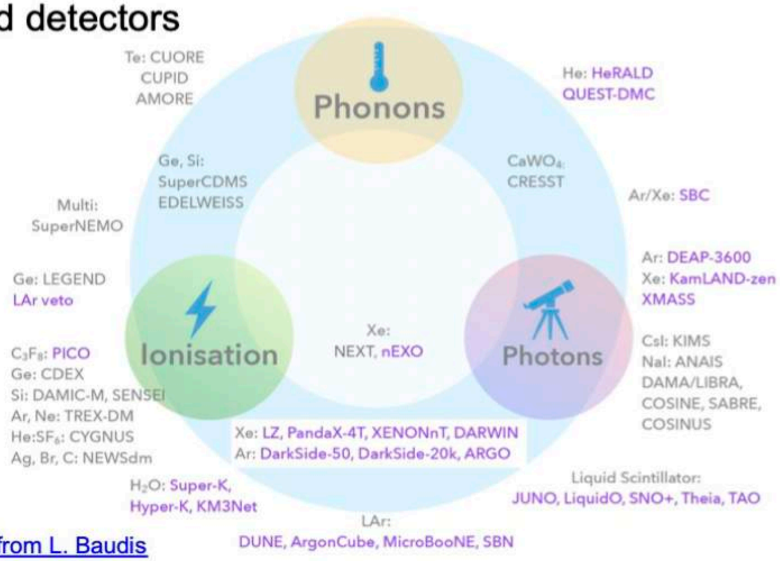
- The DRDTs are

Liquid		< 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



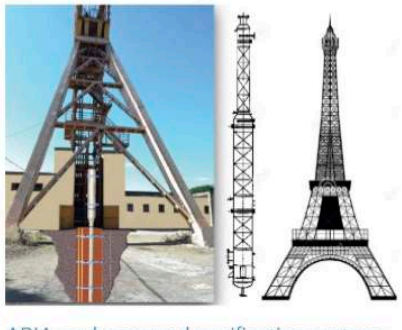
- Several large-scale and many small-scale experiments running or foreseen with liquid detectors



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



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

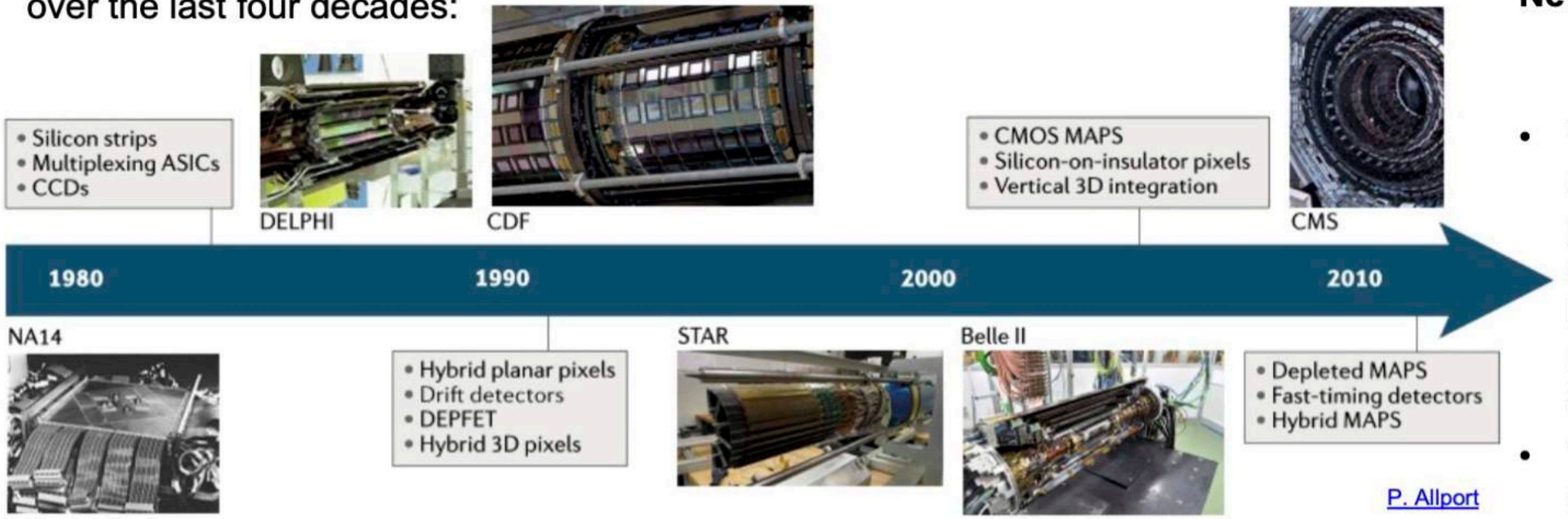
Low-radioactivity argon: extraction (Urania plant, 330 kg/d), purification (ARIA facility, 10 kg/d)

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

Solid State Detectors

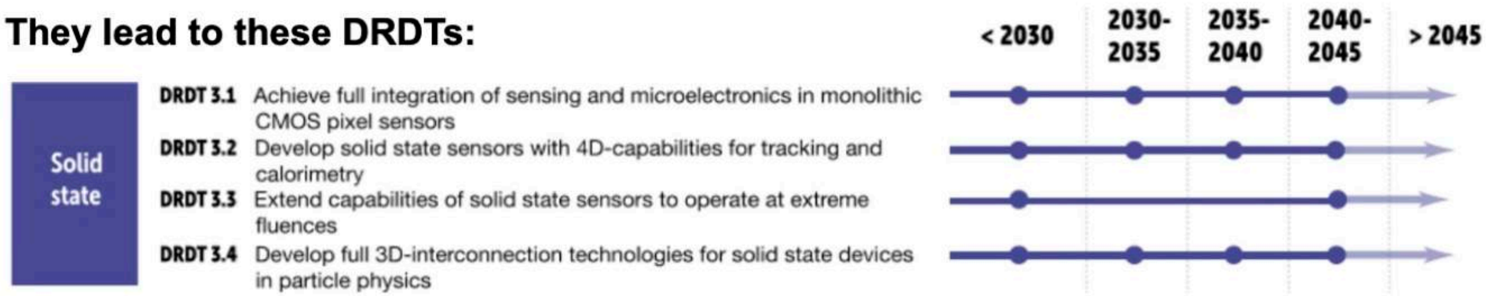
- Many different silicon detector technologies for **particle tracking** have been developed over the last four decades:



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:



New Challenges

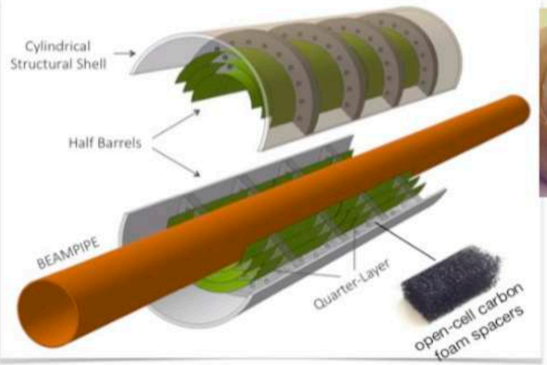
- **Vertex detectors with low mass, high resolution** (Target per layer spatial resolution of ≤ 3 μm and X/X_0 ≤ 0.05% for FCC-ee), **low power and high radiation hardness** (up to 8×10^{17} n_{eq}/cm^2 for pp-colliders)
- Trackers: **affordable sensors** with low mass, high resolution, **low power**
- **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, …

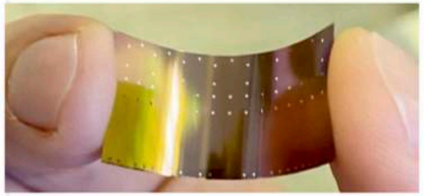
CMOS MAPS

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

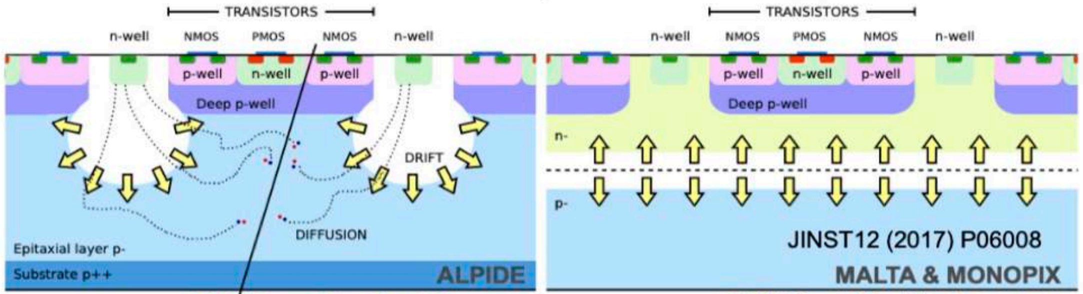
CMOS MAPS for ALICE ITS3 (Run 4):
(LOI: CERN-LHCC-2019-018, M. Mager)

- 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



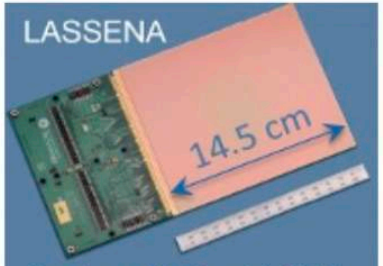
TJ180nm Standard Process

TJ180nm Modified 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)

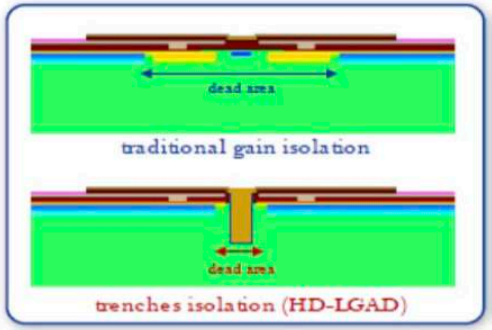
- For LGADs, three main foundries (CNM, FBK, HPK) and more producers
- Time information hugely beneficial to supress pile-up in pp-collisions

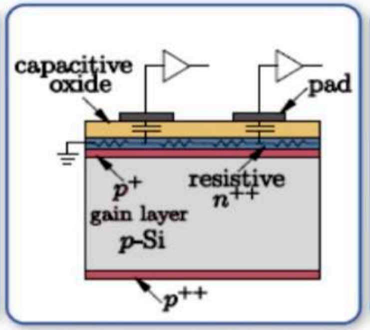
LGAD: Fill factor & performance improvements

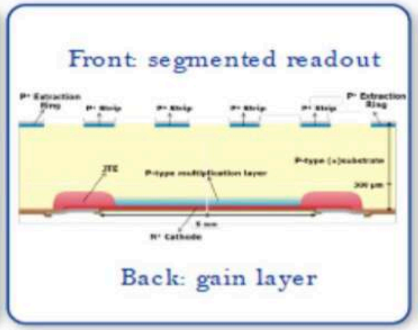
RD50

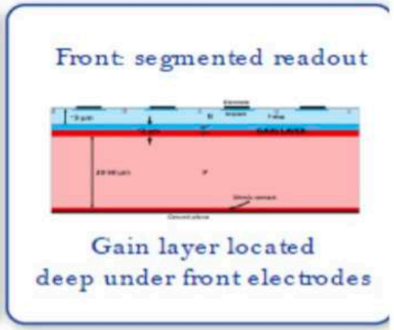
- Two opposing requirements:
  - Good timing reconstruction needs homogeneous signal (i.e. no dead areas and homogeneous weighting field)
  - A pixel-border termination is necessary to host all structures controlling the electric field
- Several new approaches to optimize/mitigate followed:

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



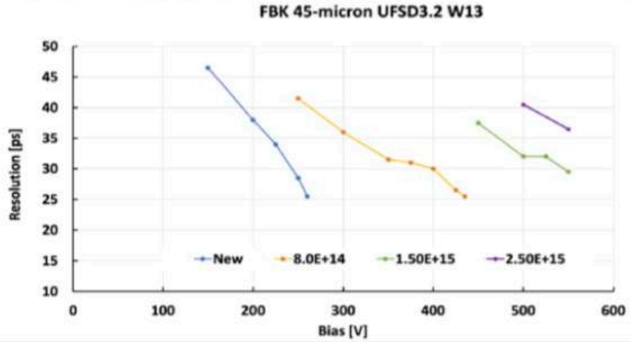






Concepts simulated, designed, produced and tested in 2018/19

..new concept 2020



N. Cartiglia

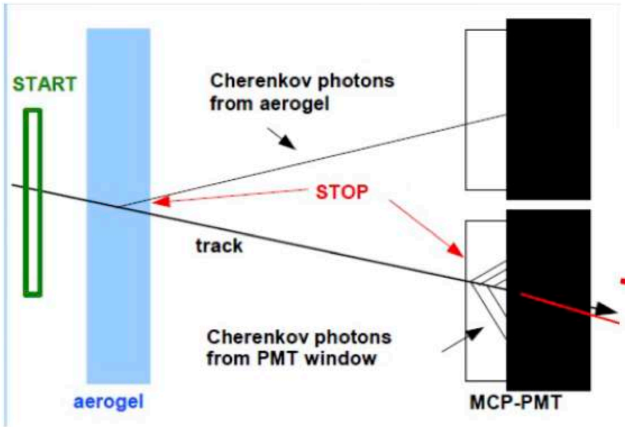
Areas of LGAD developments within RD50 Collaboration:

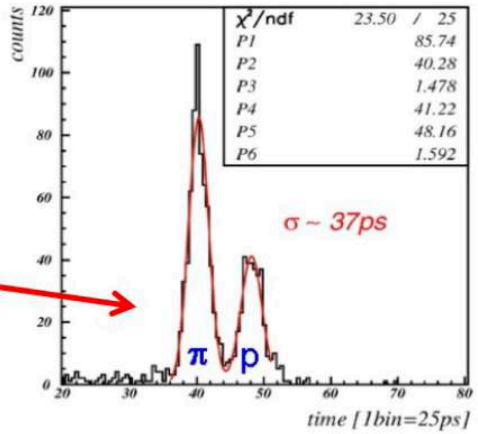
- Timing performance (~ 25 ps for 50 μm sensors)
- Fill factor and signal homogeneity
- Position resolution is about 5% of the distance between electrodes O(5-15 μm) (AC-LGAD)
- Radiation Hardness (~2×10^{15} n_{eq}/cm^2)
- Performance Parameterisation Model

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

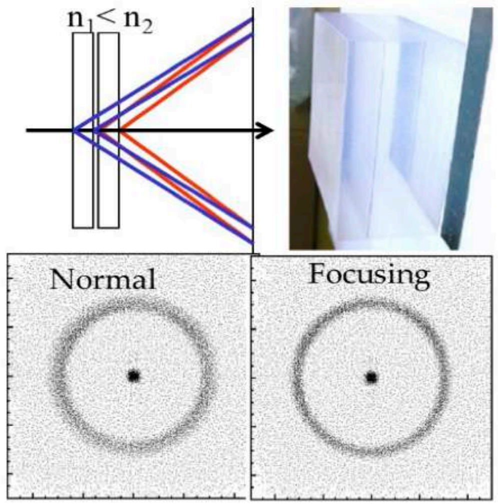




Cherenkov photons from PMT window can be used to positively identify particles below threshold in aerogel

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

- Use of focusing configuration, e.g. ARICH (Belle), Forward RICH (Panda)

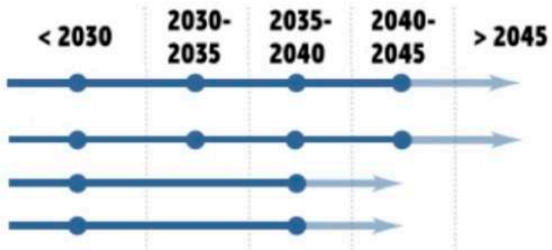


- RICHes with proximity focusing: thin radiator (liquid, solid, aerogel) and low momenta
- Time-Of-Flight (TOF) detectors: use prompt Cherenkov light, fast gas detector
- RICHes with focalisation: extended radiator (gas), mandatory for high momenta

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



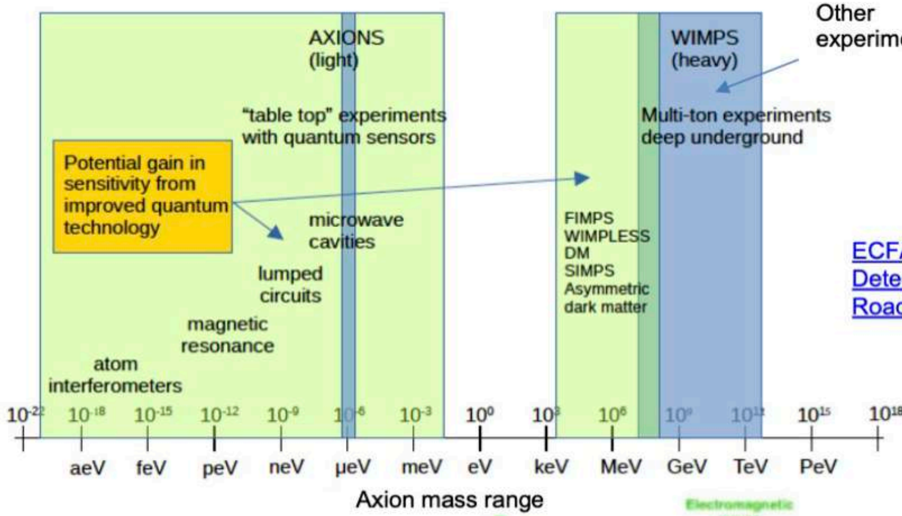
Quantum and emerging technologies

- **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

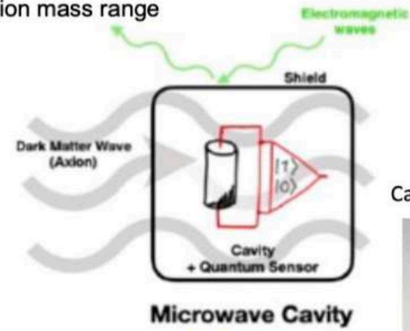
- **Many different sensor and technologies being investigated**: clocks and clock networks, kinetic detectors, spin-based, superconducting, optomechanical sensors, atoms/molecules/ions, interferometry, …

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

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

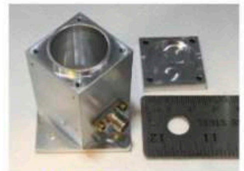


ECFA Detector R&D Roadmap



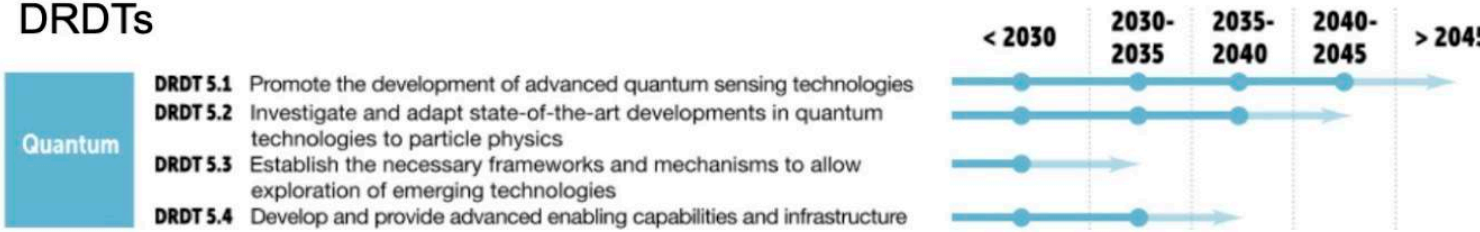
S. Golawa

Cavity resonator RQUs:



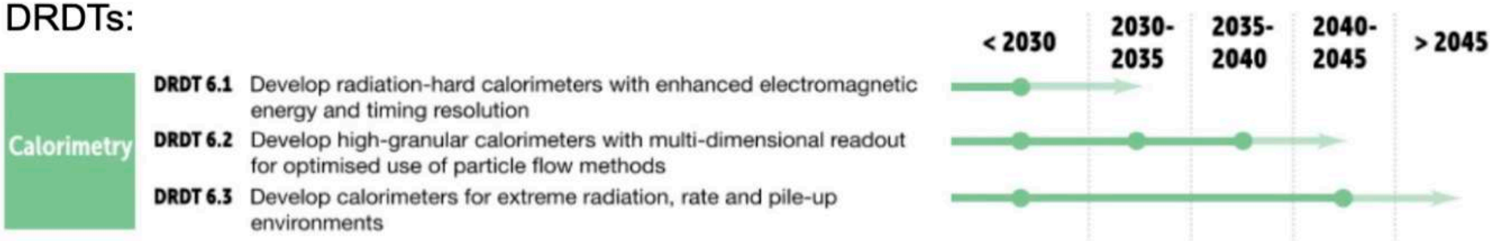
K. Irwine

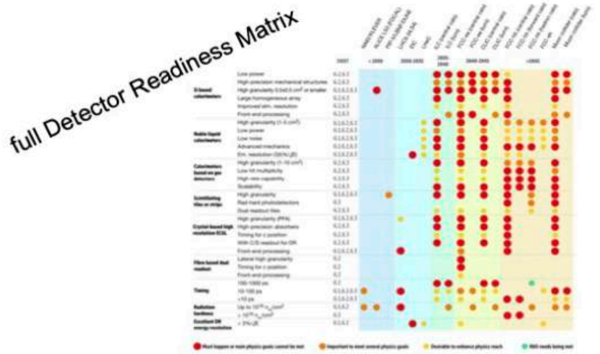
DRDTs



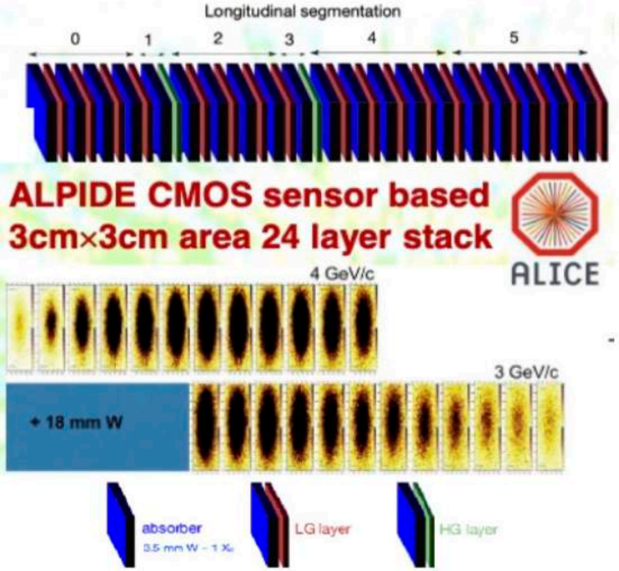
Calorimetry

- **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:





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

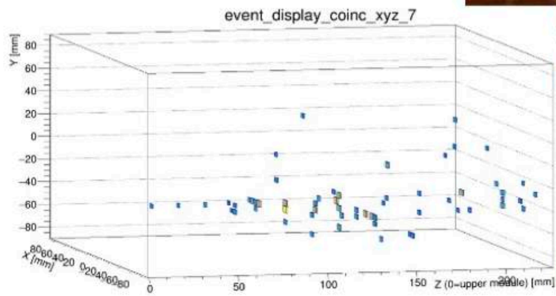
Good energy resolution

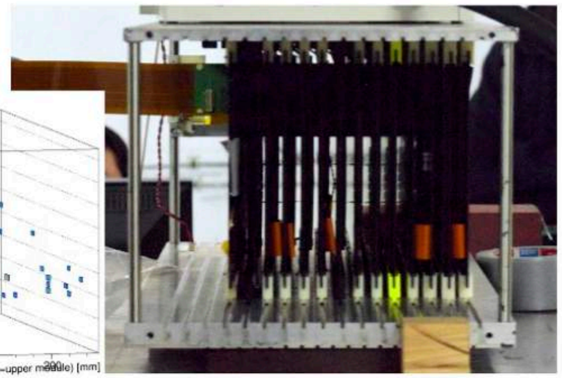
T. Peitzmann, H. Yokoyama: "Test beam performance of a digital pixel calorimeter", T. Rogoschinski: "Simulation of a SiW pixel calorimeter": TIPP 26/5/21

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/





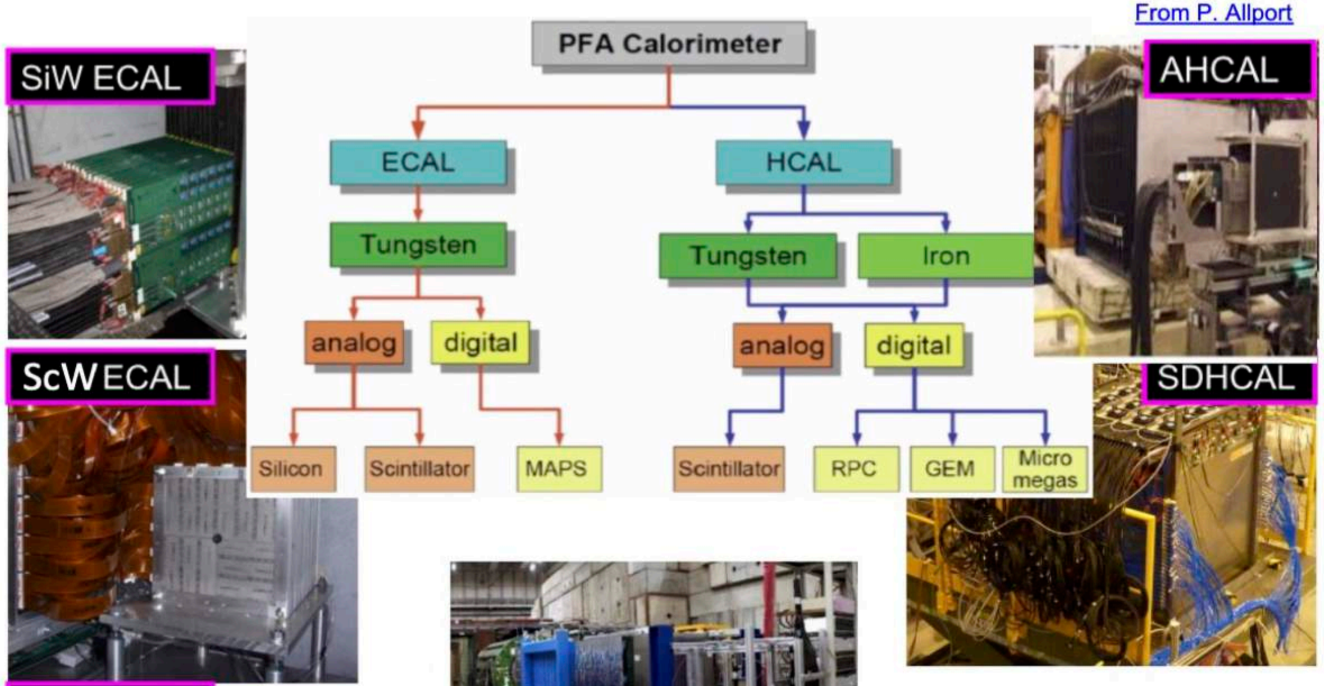
Calorimetry

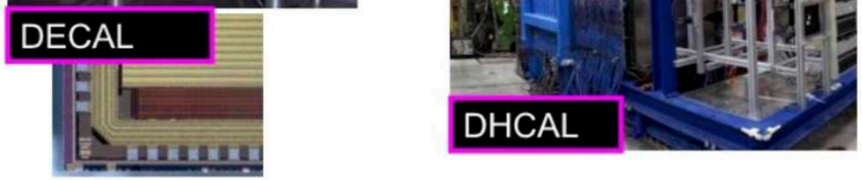
DRDT 6.2: Particle Flow based on high granularity calorimeters particularly important for e^+e^- Higgs-EW-top factories and to be considered for EIC. Separation of signals by charged and neutral particles in highly granular calorimeters.

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





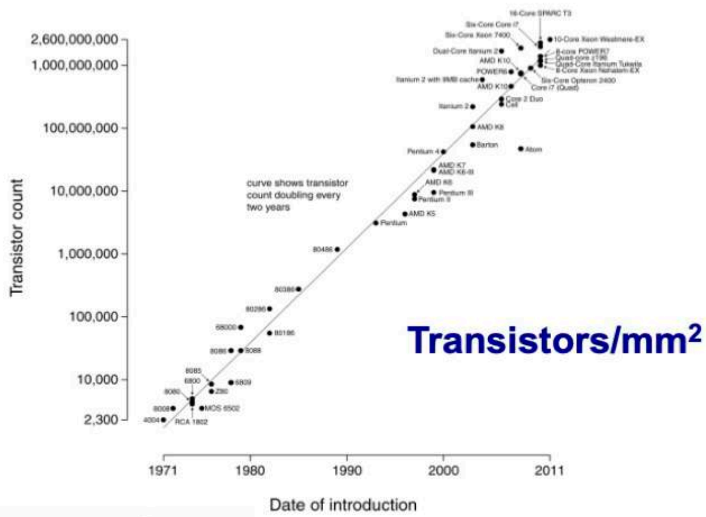
With thanks for help to Roman Pöschl, Fabrizio Salvatore and Nige Watson

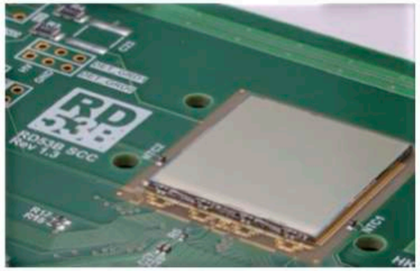
DRDT 6.3: Extreme radiation hardness and pile-up rejection critical for FCC-hh in particular

Electronics

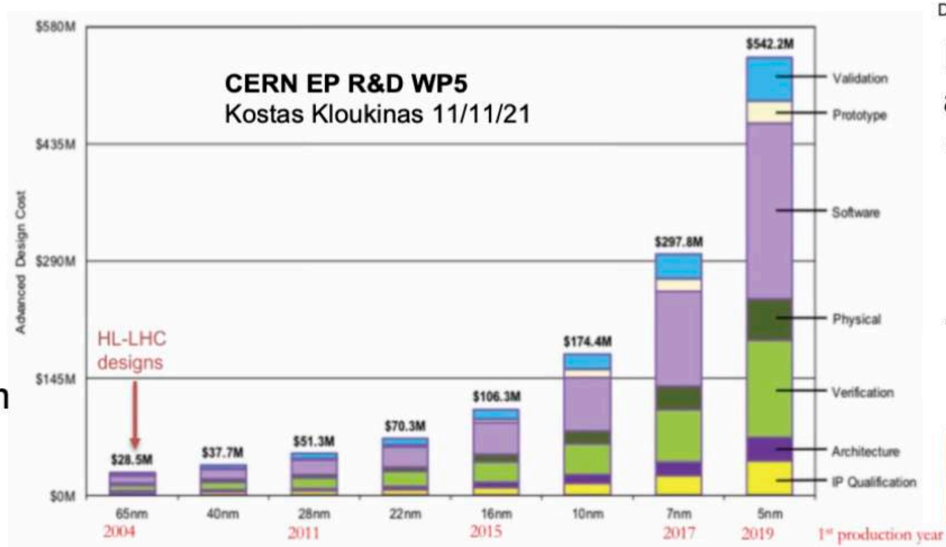
- **Main challenges: precision timing** (ToF; 4D tracking), **high granularity** and **resolution** imply a **cost in terms of data handling, processing, complexity and power.**
- Need **latest advances in commercial <u>microelectronics</u> and <u>high-speed links</u>** (DRDT 7.1, 7.4, 7.5)
- However,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

Microprocessor Transistor Counts 1971-2011 & Moore's Law





RD53 Collaboration (65 nm ASIC for HL-LHC)



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

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

Increasing sophistication, entry **cost and complexity**

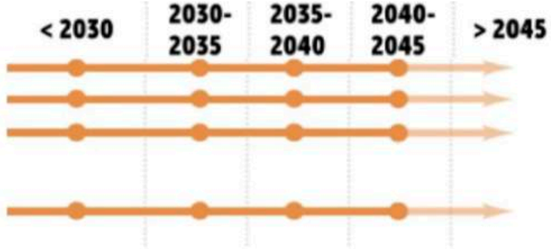
→ call for a **change of approach from the past with increased coordination around Europe**

→ **DRDTs of TF7**

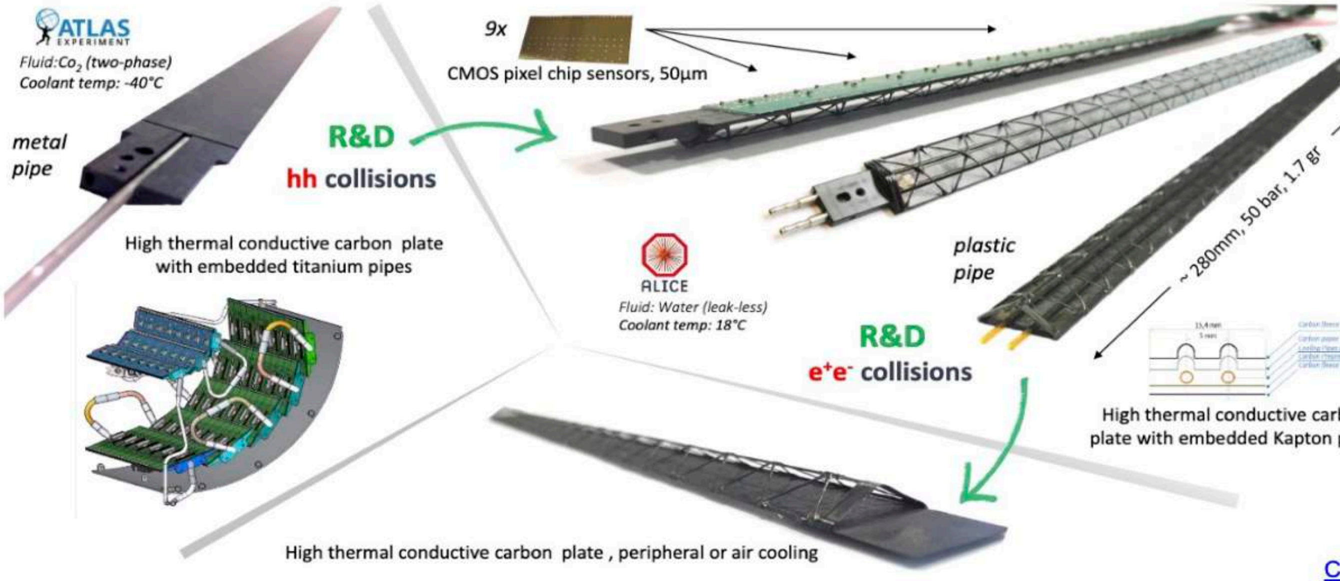
Integration

- 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

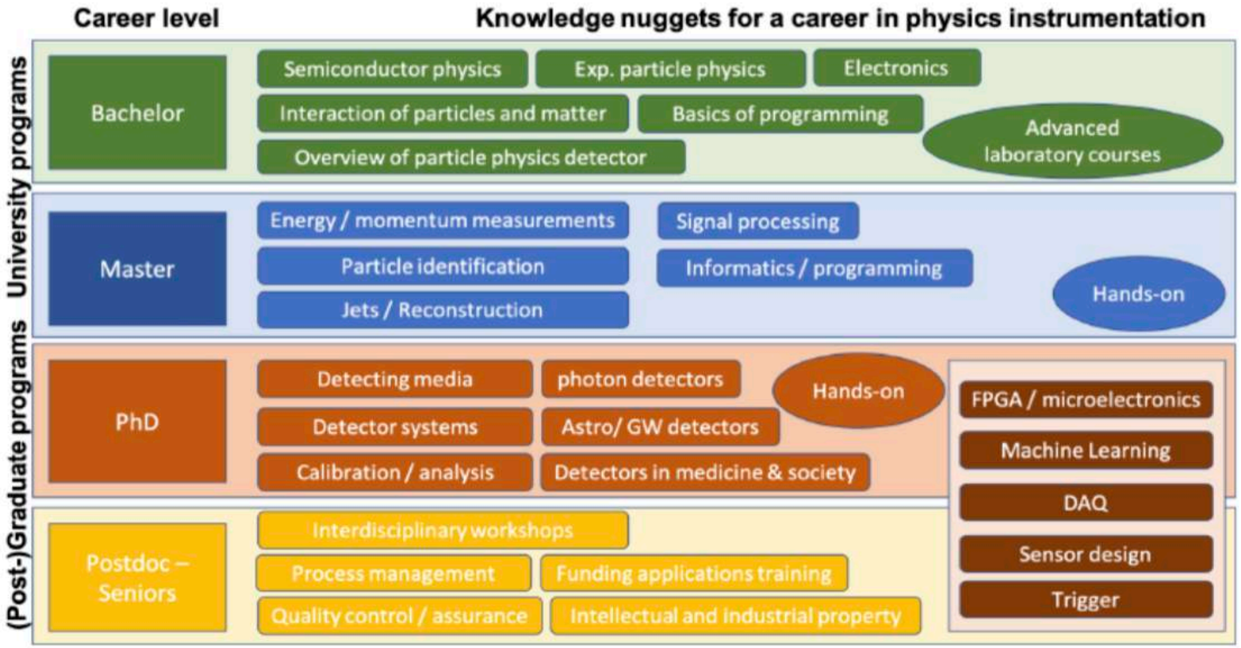


C. Gargiulo

Training for 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.

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 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 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 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

Back-Up

General Strategic Recommendations

GSR 1 - Supporting R&D facilities

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

GSR 2 - Engineering support for detector R&D

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

GSR 3 - Specific software for instrumentation

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

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

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

Detector R&D Roadmap

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Testbeam!

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ASIC Design, advanced mechanics

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GEANT4, Pandora, key4HEP

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R&D collaborations

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.

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Detector R&D Roadmap

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.

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