ÖAW AUSTRIAN ACADEMY OF SCIENCES

HEPHY INSTITUTE OF HIGH ENERGY PHYSICS

Detectors R&D Roadmap

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Content

- First Part:
  - European Strategy on Particle Physics
  - ECFA Detector Roadmap and its implementation plan
  - Detector R&D for the future: the next decades
    - Example of usefulness on strategic R&D

- Second Part:
  - Brief look to planned Detector R&D collaborations

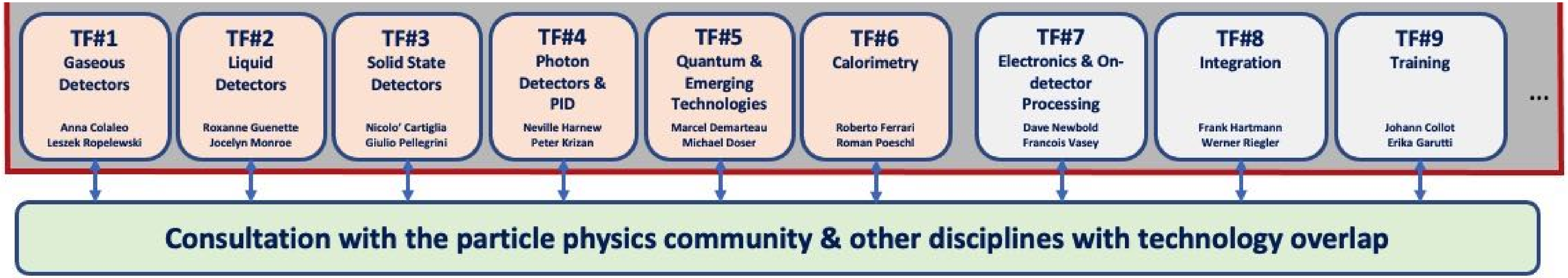
Disclaimer: I am from the Silicon community and I will use this on several occasions as an example

ECFA Detector Roadmap

European Committee for Future Accelerators (ECFA) released in 2021 a full document (200 pages) and synopsis (~10 pages) based on a community-driven effort

The full document can be referenced as DOI: 10.17181/CERN.XDPL.W2EX

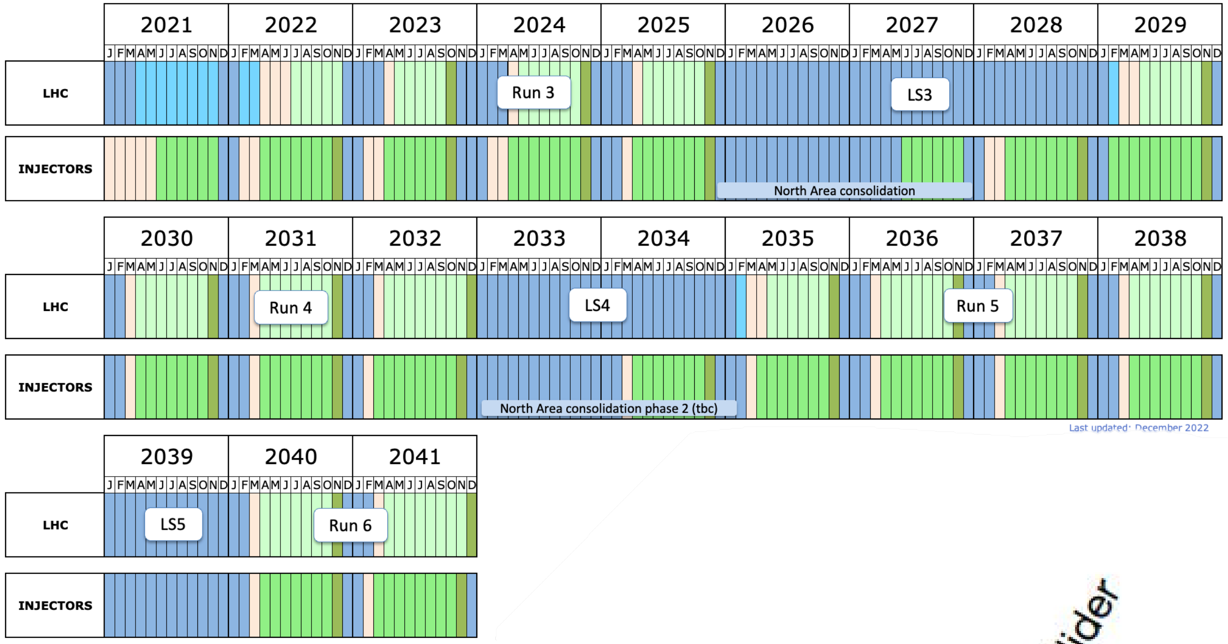
- Overview of **future facilities** (EIC, ILC, CLIC, FCC-ee/hh, Muon collider) or major **upgrades** (ALICE, Belle-II, LHC-b,…) and **timeline**
- **Nine Technology domains** with **Task Forces** areas
  - The **most urgent R&D topics** in each domain area identified as **Detector R&D Themes** (DRDTs)
- Concludes with ten "**General Strategic Recommendations**"

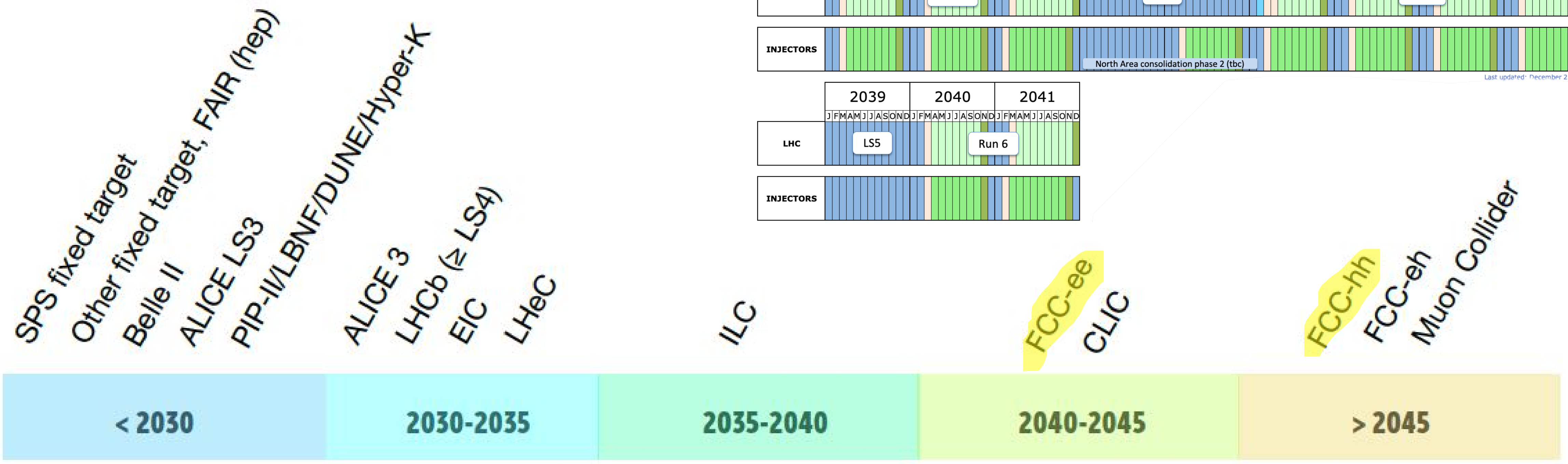


Future Large Experiments

- Five Time periods defined

(HL-)LHC timeline:



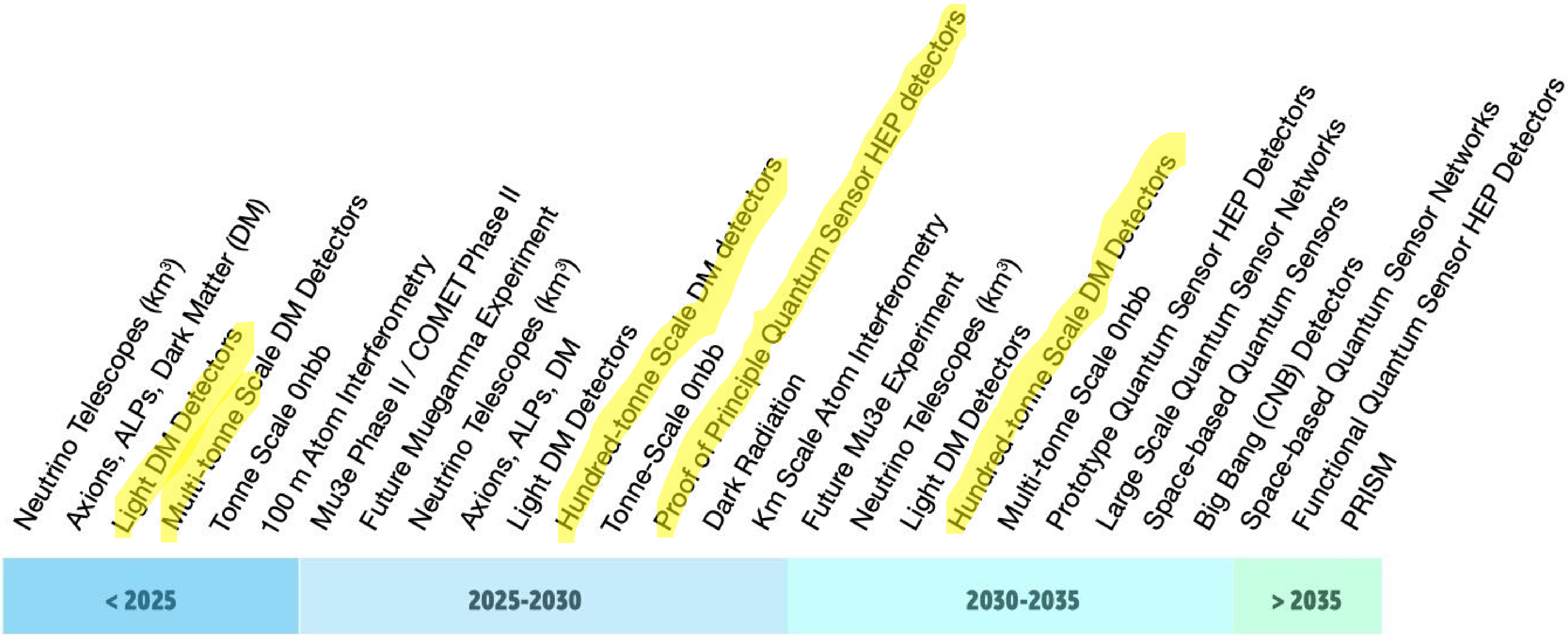


LHC LS3

LHC LS4

Future "Smaller" Experiments

- Different time periods as for large experiments:



General Strategic Recommendations

The General Strategic Recommendations (GSR) topics are:

- GSR 1: Supporting R&D facilities (**test beams, large scale generic prototyping and irradiation)**
- GSR 2: **Engineering support** for detector R&D
- GSR 3: Specific **software** for instrumentation
- GSR 4: **International coordination** and organisation of R&D activities
- GSR 5: Distributed R&D activities with **centralised facilities**
- GSR 6: Establish long-term strategic **funding programmes**
- GSR 7: "**Blue-sky**" R&D
- GSR 8: Attract, nurture, recognise and sustain the **careers of R&D experts**
- GSR 9: **Industrial** partnerships
- GSR 10: **Open Science**

comprehensive explanation to each GSR in backup slides

R&D Topics and DRDTs

- The most urgent R&D topics in each Task Force area are identified by **Detector Readiness Matrix**
  - Tables with much more details exist in roadmap (contains also target numbers for different experimental needs, e.g. ALICE 3: 0.05% X/X_0 (per layer)

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

Solid state

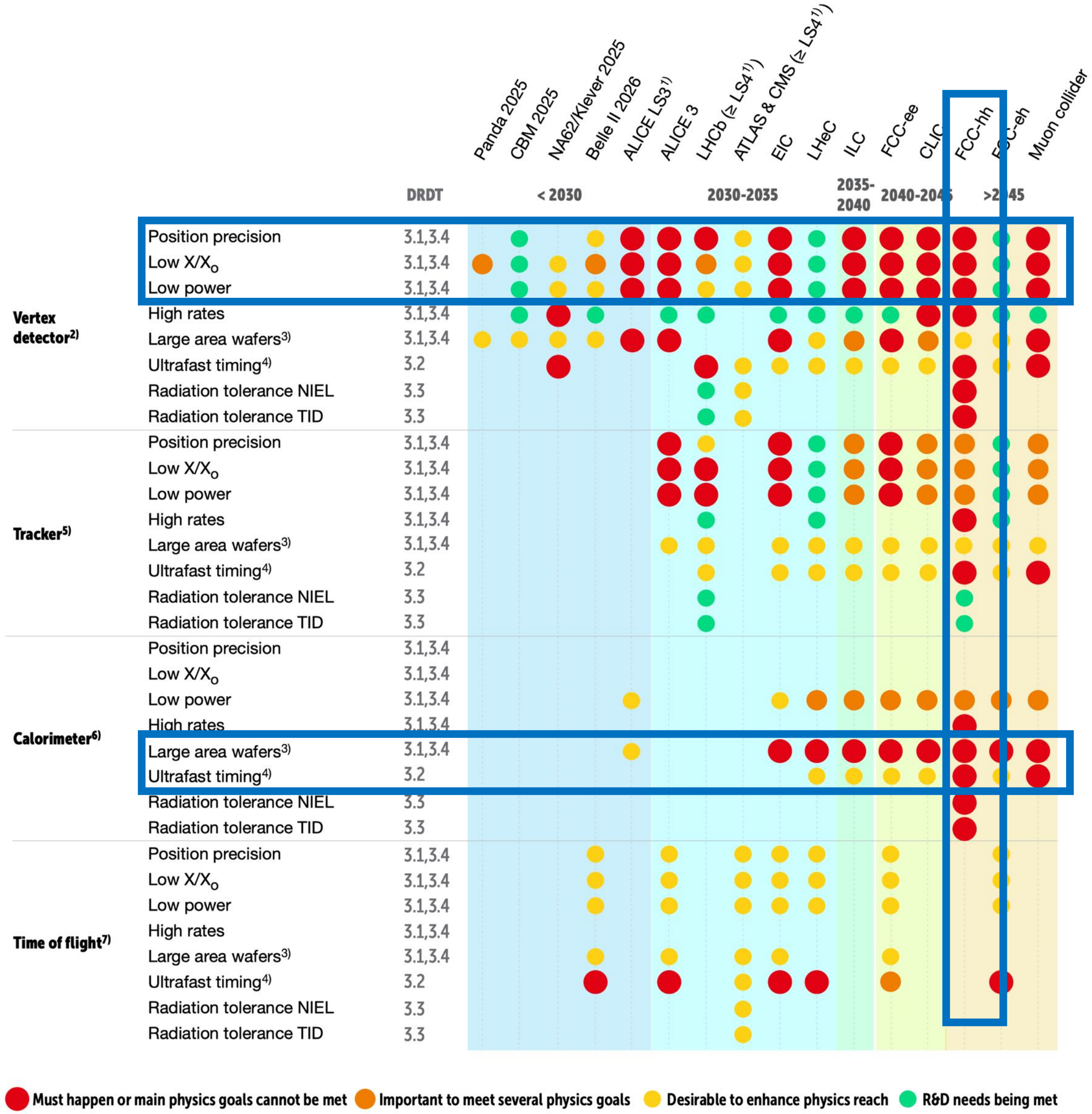
DRDT 3.1 Achieve full integration of sensing and microelectronics in monolithic CMOS pixel sensors

DRDT 3.2 Develop solid state sensors with 4D-capabilities for tracking and calorimetry

DRDT 3.3 Extend capabilities of solid state sensors to operate at extreme fluences

DRDT 3.4 Develop full 3D-interconnection technologies for solid state devices in particle physics

Semiconductor Example!

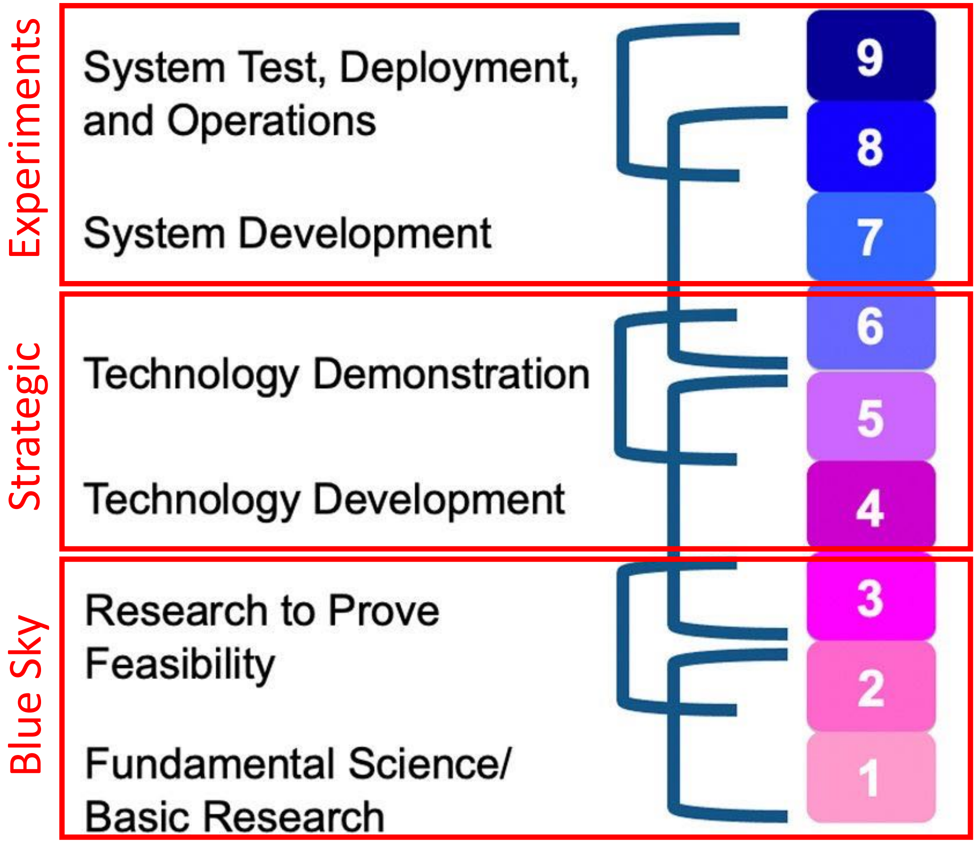


Strategic R&D vs. Blue Sky

Strategic R&D towards **necessary technologies to build future facilities** and experiments

- Addresses the DRDTs in ECFA roadmap by defining suitable deliverables and milestones
  - Technology Readiness Levels (TRL) 3-6
  - Backed up by **strategic funding**, agreed with funding agencies (MoUs)

- DRD collaborations should also contain a "**blue-sky**" section (TRL 1-3)
  - Allow new developments to emerge
  - Possibly financed by common fund + institute contributions (RD50/51 scheme)



Example for the need of strategic funding

My group worked for almost a decade with European semiconductor industry to find a “second source” for large-area planar Si sensors (targeting Phase-II Upgrades)

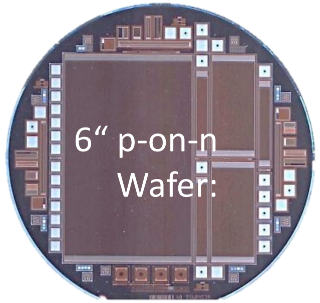
- Attracted a lot of attention
- Pushed HPK into developing 8” process
  → now being used for CMS HGCal
- Milestones:
  - 2009: re-produce 6” p-on-n strip sensors
  - 2015: First AC-coupled strip sensors on 8” wafers
  - 2016/17: production of first 8” hexagonal HGCal sensors
  - 2018: **program stopped due to economic reasons**

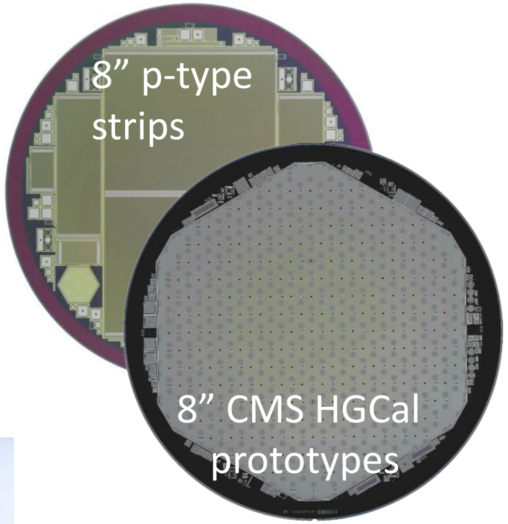
Reason for termination of program before series production:

- O(10) more wafer runs (~150k€ each) would have been necessary to mature the technology
- Strategic R&D funding for R&D costs → reduction of series production costs

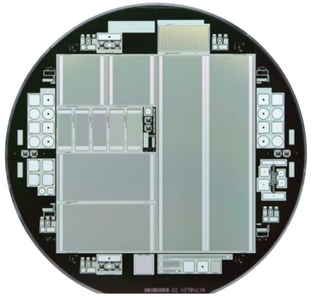
Former CERN DG R. Heuer with Infineon manager and HEPHY staff

Infineon CEO together with HEPHY and CERN representatives



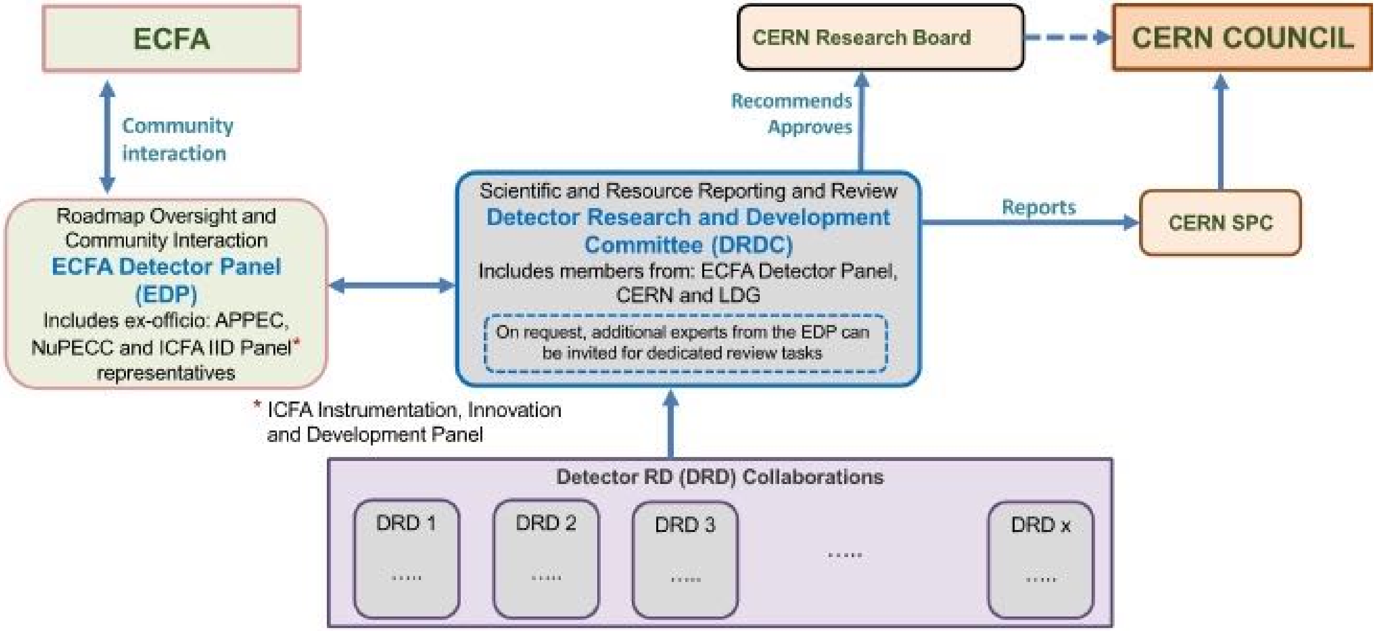


6” CMS PS-S prototypes



Roadmap implementation plan

- Approved by CERN SPC and Council in fall 2022 (CERN/SPC/1190 ; CERN/3679)
- Two bodies review and evaluate DRD proposals:
  - DRD committee: http://committees.web.cern.ch/drdc
  - ECFA Detector Panel: https://ecfa-dp.desy.de
- Interaction between DRD collaborations and committees **only through DRDC**



Status in the US and elsewhere

- Result from US Snowmass process: recommendation to **create Detector R&D collaborations in the US**
  - Organized by CPAD (Coordinating Panel for Advanced Detectors) of the APS/DPF (one chairperson from CPAD is in DRDC)
  - They created 11 RDCs (R&D Collaborations) and appointed coordinators (see https://cpad-dpf.org/?page_id=1549)
  - Recently started to reach out to the community and work on detailed planning
  - Overlap to DRDs through people/groups involved in both and liaisons
- **EU-funded programs** play an important role in enabling and supporting generic R&Ds: AIDA/2020/innova, ATTRACT
- **Other collaborations**: e.g. CALICE (ILC), CrystalClear,..
- **CERNs R&D Program**: RD18, RD42, RD50, RD51, RD53,…

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

From ECFA Task forces and RD collaborations to DRD collaborations

Follow the successful model of R&D collaborations at CERN, e.g. RD50 and RD51:
- Reviewed 5-year work plans containing milestones and deliverables
- MoU with all participating institutes and CERN (RD50 signed only in 2019)
- Collection of small common fund (~2k€ per year and institute) to keep the organization running (organization of meetings) and to fund common projects

Goals for new DRD collaborations:
- A similar organization like a HEP experiment (collaboration board as decision body)
- **Strategic funding of deliverables** agreed with funding agencies via MoUs

Timeline:
- community input (via existing R&D bodies where possible) by **Q1 2023**
- Written short (~20 pages) proposals for each TF topic **by July 2023** (with some exceptions, see later)
- Review by DRDC **this fall**, with iterations (e.g. re-submission after clarification requests)
- **Approval by the end of 2023** → DRD collaborations can officially start beginning of 2024
  - Essential for RD50/RD51 to allow seamless continuation
- MoU setup and collecting signatures from FA starting in 2024

- Annual status reports to DRDC

Q1/2023
- Community input by open meetings

End 07/23
- Submission of proposals to DRDC

Fall 2023
- Review by DRDC, assisted by EDP

End 2023
- Approval, then:
- Collaboration starts

2024
- MoU negotiation and signature collection

Proposed Detector R&D collaborations

Highlights of scientific programs, organization and community contributions

Proto-Detector R&D Collaborations

Targeting mostly HEP

- Gaseous Detectors (DRD1) [ex RD51]
- Semiconductor Detectors (DRD3) [ex RD50]
- Calorimetry (DRD6)
- Photodetectors & Particle ID (DRD4)
- Liquid Detectors (DRD2)

Targeting "smaller experiments", e.g. rare event searches, DM

Targeting low TRL ←

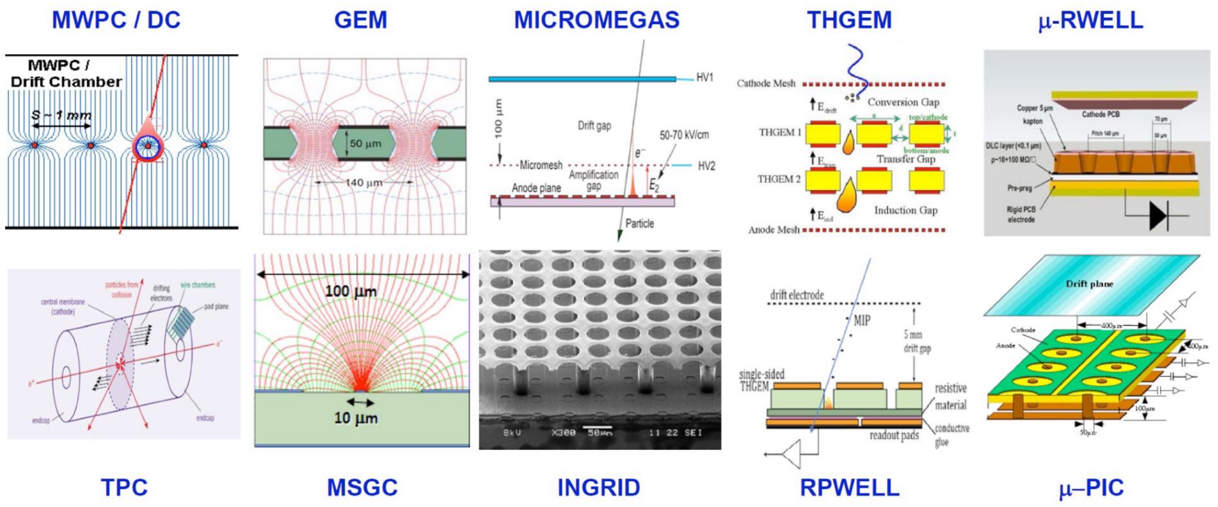
- Quantum Sensors (DRD5)

Orthogonal topics necessary for all activities

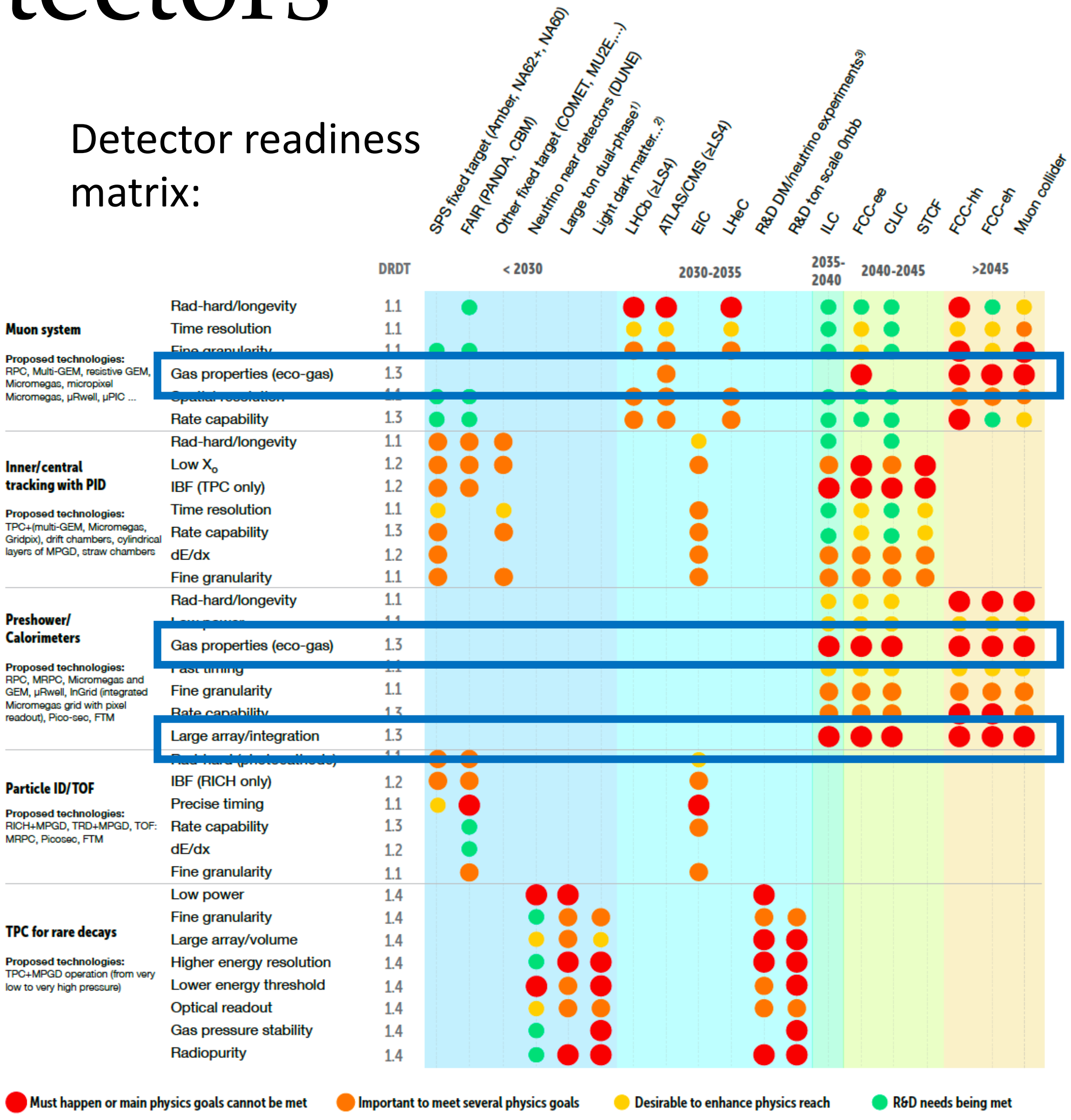
- Electronics (DRD7)
- *Integration (TF8)*
- *Training (TF9)*

Gaseous Detectors

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



Detector readiness matrix:



Gaseous Detectors

Large Areas:

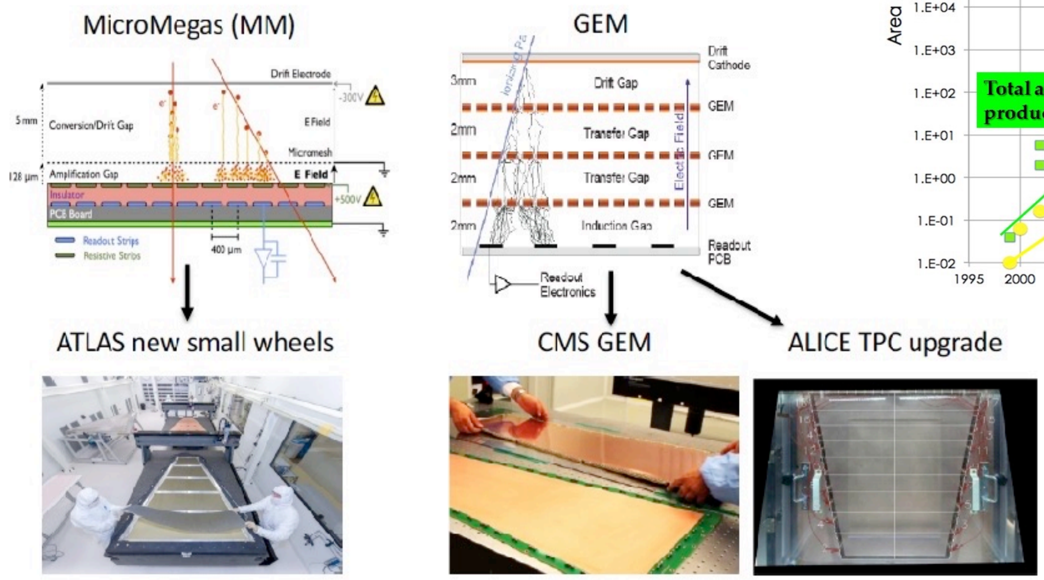
- Systems developed for LHC experiments led to unprecedented large systems, mostly based on MPGDs

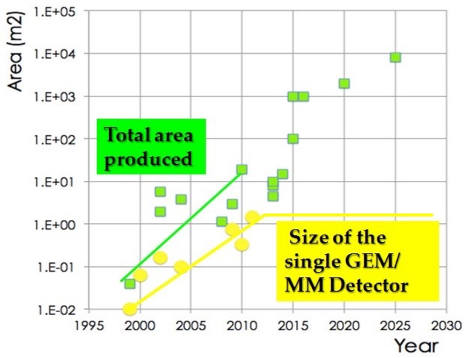
Fast Timing:

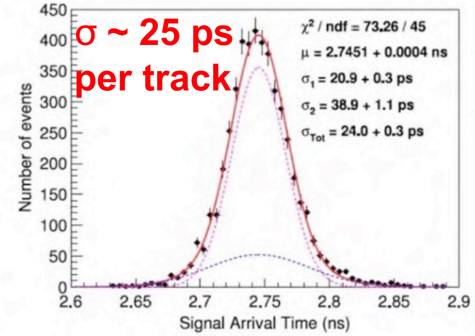
- Fast timing with Multi-Gap RPCs: achieved ~60ps time resolution (ALICE TOF Detector, Z.Liu, NIM A927 (2019) 396)
- Micromegas with timing (PICOSEC concept): 25ps

Eco-friendly gas mixtures

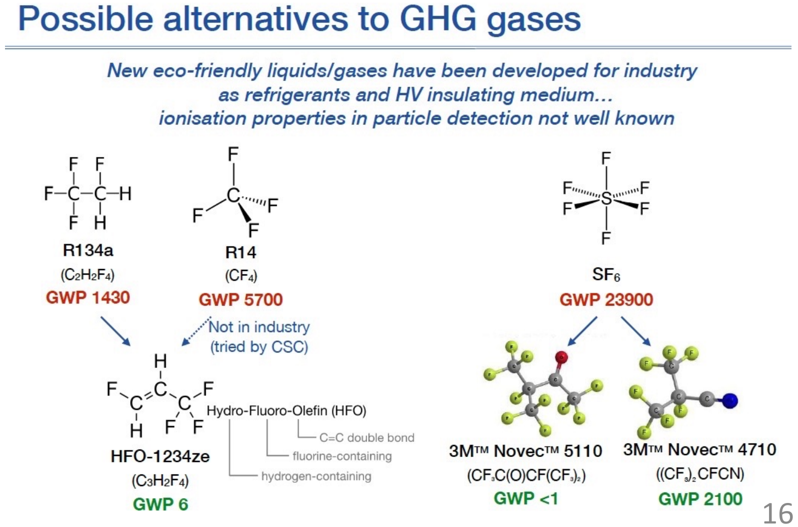
- 92% of emissions at CERN are related to LHC experiments
- Gas re-circulation: GHG emission reduced by >90%
- Alternatives to $C_2H_2F_4$ for TPCs with lower Global Warming Potential (GWP)







PICOSEC: NIMA903 (2018) 317



Gaseous Detectors

DRD1: Successor and extension of RD51

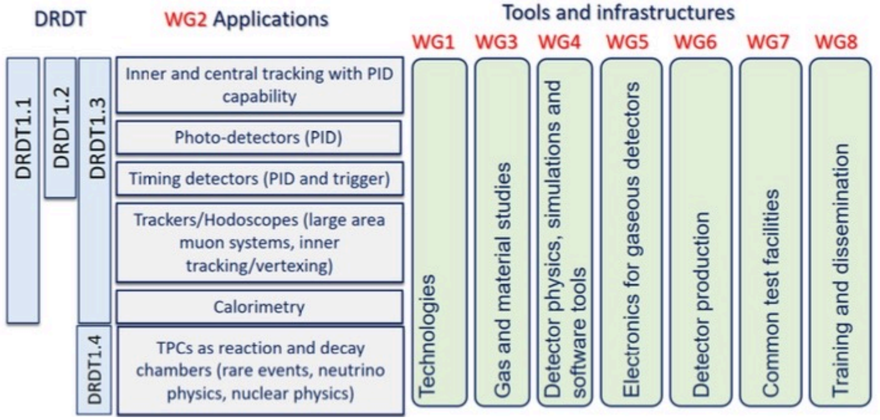
Gaseous

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

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

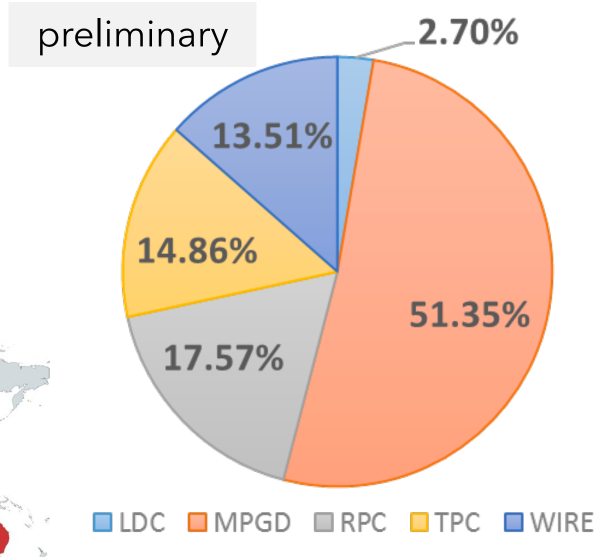
DRDT 1.3 Develop environmentally friendly gaseous detectors for very large areas with high-rate capability

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



- Organized in **Work Packages** (deliverables), **Working Groups** (knowledge and technology hub) and **Common Projects** (blue sky)
- Convenors: TF1: Anna Colaleo (Bari), Leszek Ropelewski (CERN)
  - RD51 Co-Convenors: Eraldo Oliveri (CERN), Maxim Titov (CEA Saclay)
- Proposal status: Extended proposal (100p) submitted, under review by DRDC (executive summary in preparation)
- Large community of 118 institutes
- Community meeting: most recent June 23
- Web page: https://drd1.web.cern.ch/

Technology interests in DRD1



Semiconductor Detectors

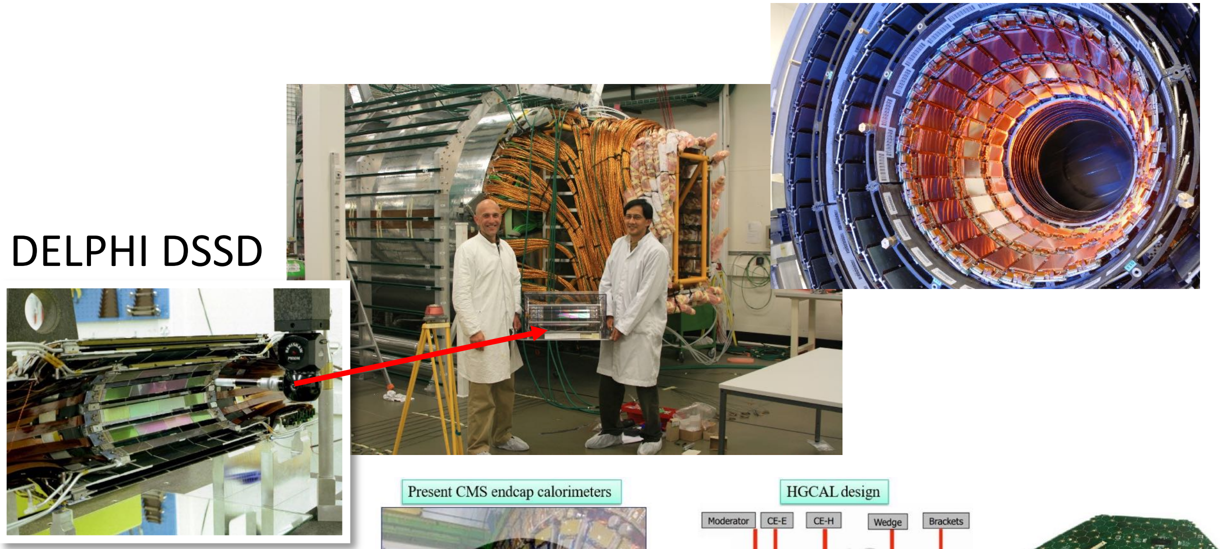
Remarkable success in HEP enabled by significant advancements in chip industries:

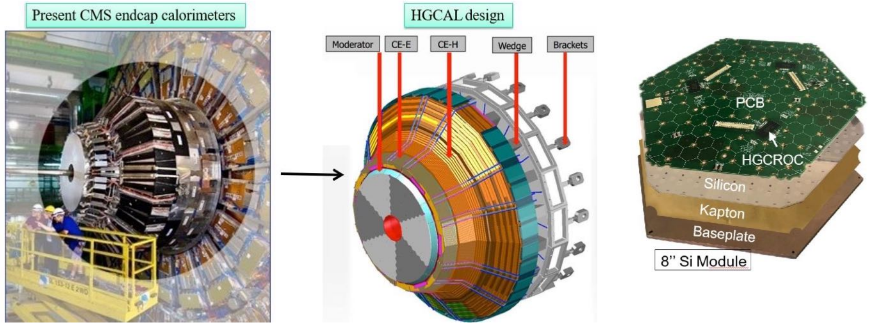
- **Detector area** increased by one order of magnitude each decade (1 m^2 → 10 m^2 → 200 m^2 → 600m^2)
- **Radiation hardness** at levels not imagined decades ago
- **Endcap Timing detectors** for ATLAS and CMS (4D tracking)

New Challenges:

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

DELPHI DSSD





Solid state

DRDT 3.1 Achieve full integration of sensing and microelectronics in monolithic CMOS pixel sensors

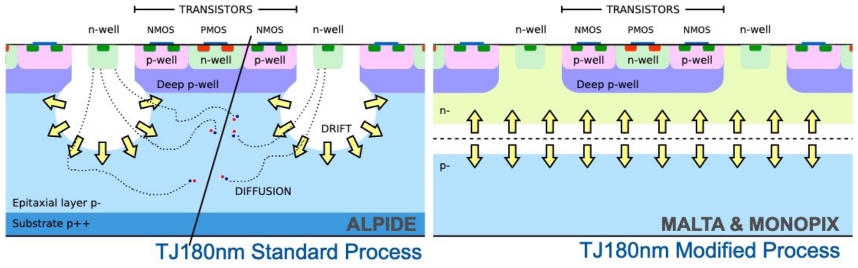
DRDT 3.2 Develop solid state sensors with 4D-capabilities for tracking and calorimetry

DRDT 3.3 Extend capabilities of solid state sensors to operate at extreme fluences

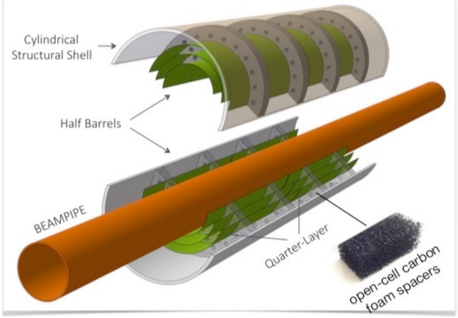
DRDT 3.4 Develop full 3D-interconnection technologies for solid state devices in particle physics

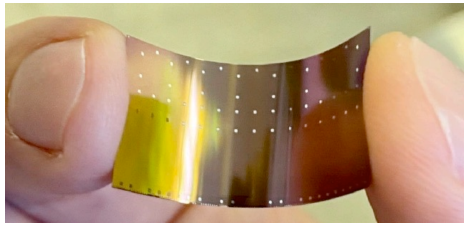
Semiconductor Detectors

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



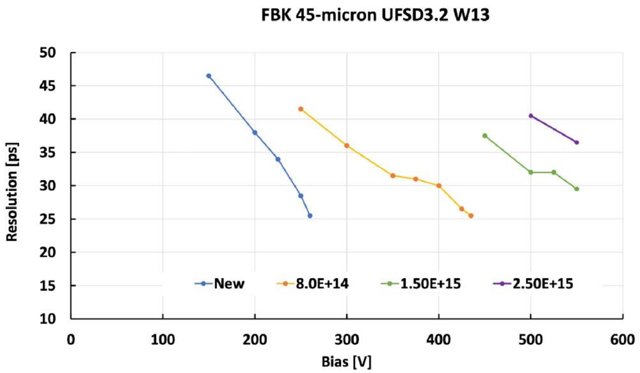
- 4D Tracking / ToF: Timing using LGAD sensors
  - Suppression of pile-ups
  - Foundries CNM, FBK, HPK
  - Timing performance (~ 25 ps for 50 µm sensors)
  - Radiation hardness limited by loss of gain

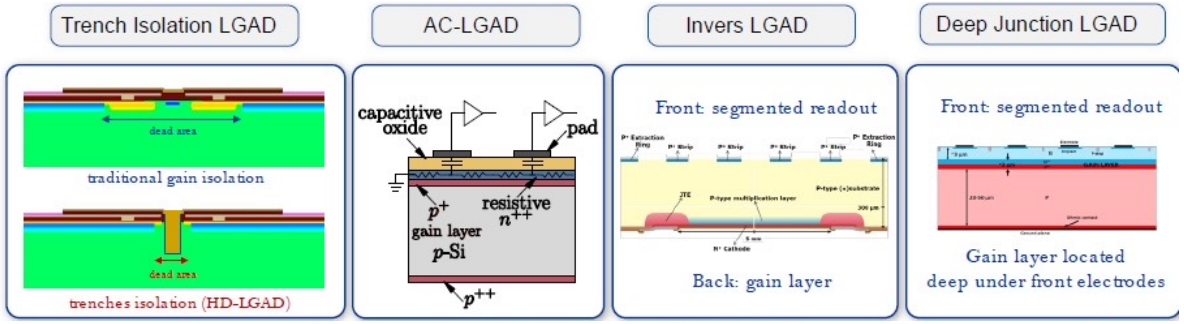




CMOS MAPS for ALICE ITS3 (Run 4)
(LOI: CERN-LHCC-2019-018, M. Mager)

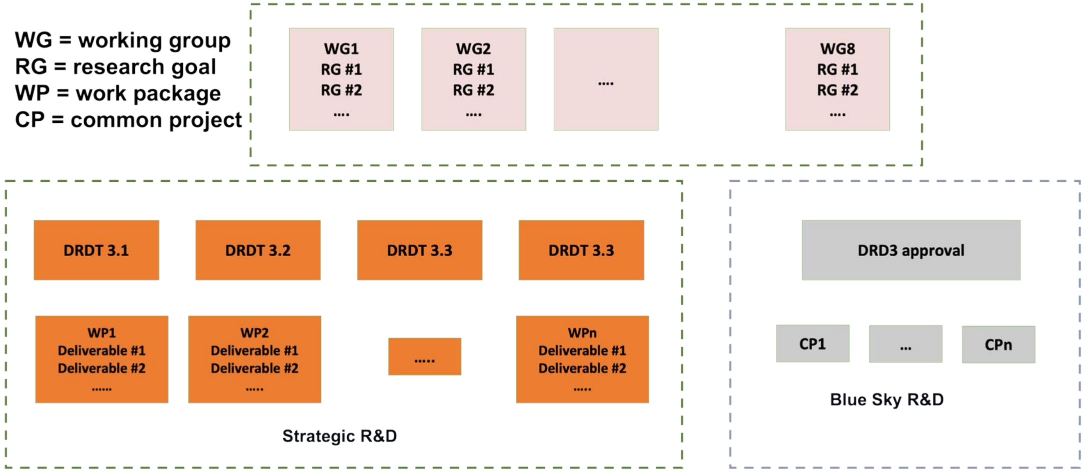
- Radiation hardness
  - Wide bandgap

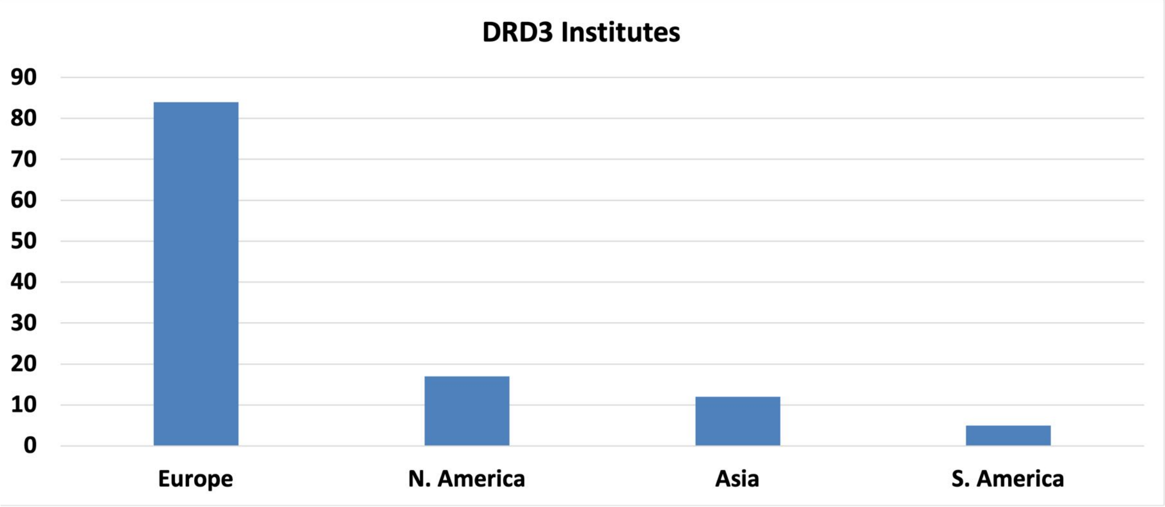


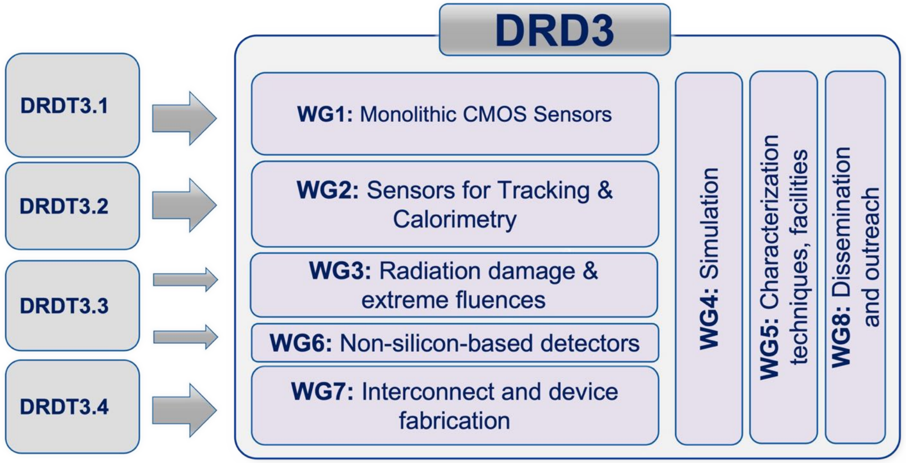


DRD3: Semiconductor Detectors

- DRD3 collaboration benefits from existing RD50 collaboration
  - Extended by diamonds (RD42) and 3D interconnects
  - Convenors: TF3: Nicolo Cartiglia, Giulio Pellegrini
    - RD50: Michael Moll, Gianluigi Casse
  - Organized in Work Packages, Working Groups and Common projects
  - 118 institutes, 28 countries

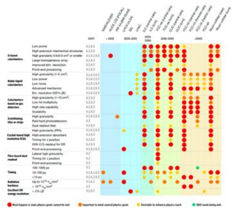


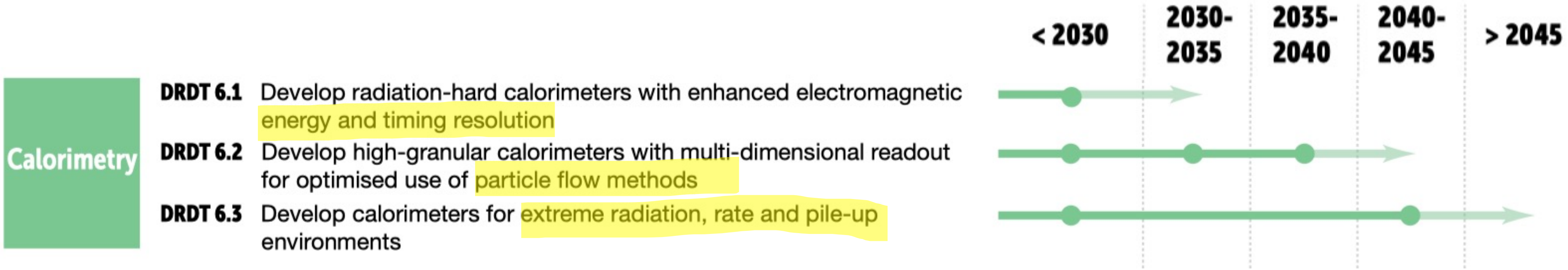


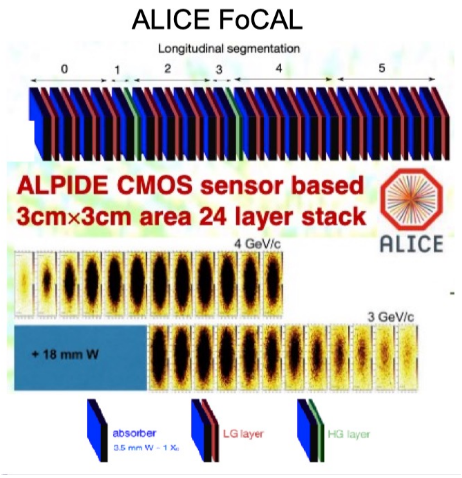


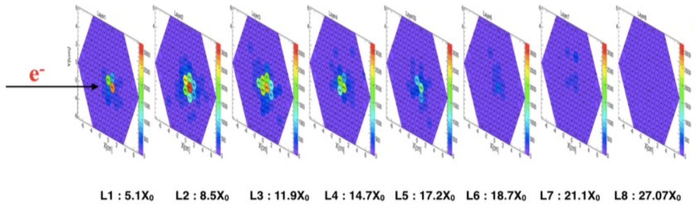
Calorimetry

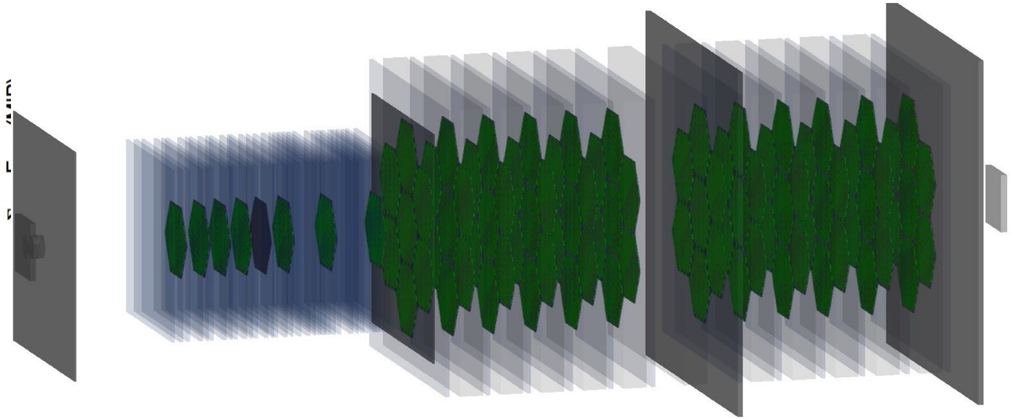
- R&D in calorimetry has a particularly long lead-time due
  - Many technology developments (gas, scintillator or Silicon-based readout)
  - Large and challenging prototype setups even in early stages





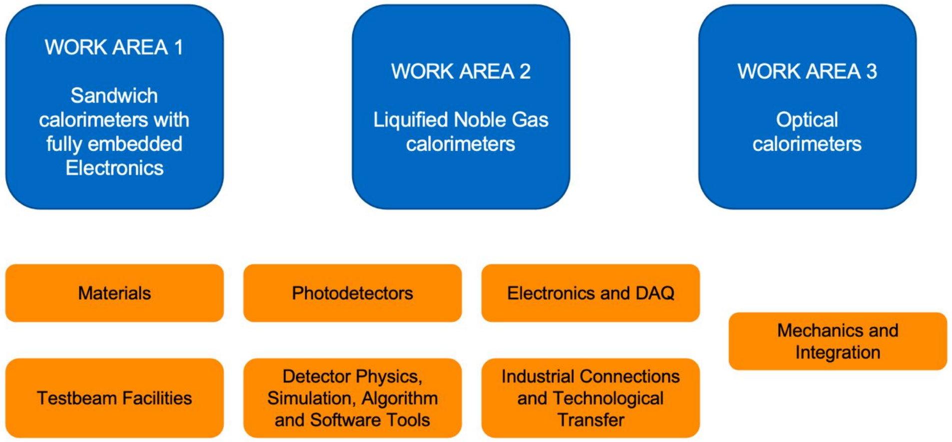






DRD6 Collaboration

- Collaboration emerged from CALICE and CrystalClear (RD18)
  - Convenors: Roberto Ferrari, Roman Pöschl
  - 24p proposal received and under review by DRDC
- Light-weight organization structure organized in three Work Areas
  - Several projects for different target application and calorimeter types
- Several transversal activities
  - Dedicated calorimeter test beam line



Target applications : e+e- collider FCC-hh Muon collider other

Calorimeter types : Electromagnetic Hadronic Electromagnetic + Hadronic

Project maturity : +++ exists a large prototype ++ exists a small prototype + at level of proof of principle

WA1		WA2		WA3	
SiW Ecal	(+) ++	EM LAr Calo	+	EM HGCAL	+
DECAL	++			EM MAXICC	+
Highly compact calorimeter	+			EM CRILIN	+
Sc Ecal	++			EM GRAINITA	+
AHCAL	+++			EM SPACAL (LHCb Phase 2)	++
ScintGlassHCAL	+			EM RADICAL	+
T-DHCAL	+++			EM + HAD DRCAL	(+)++
MGPD-HCAL	+			HAD TILECAL	+
ADRIANO3	++				

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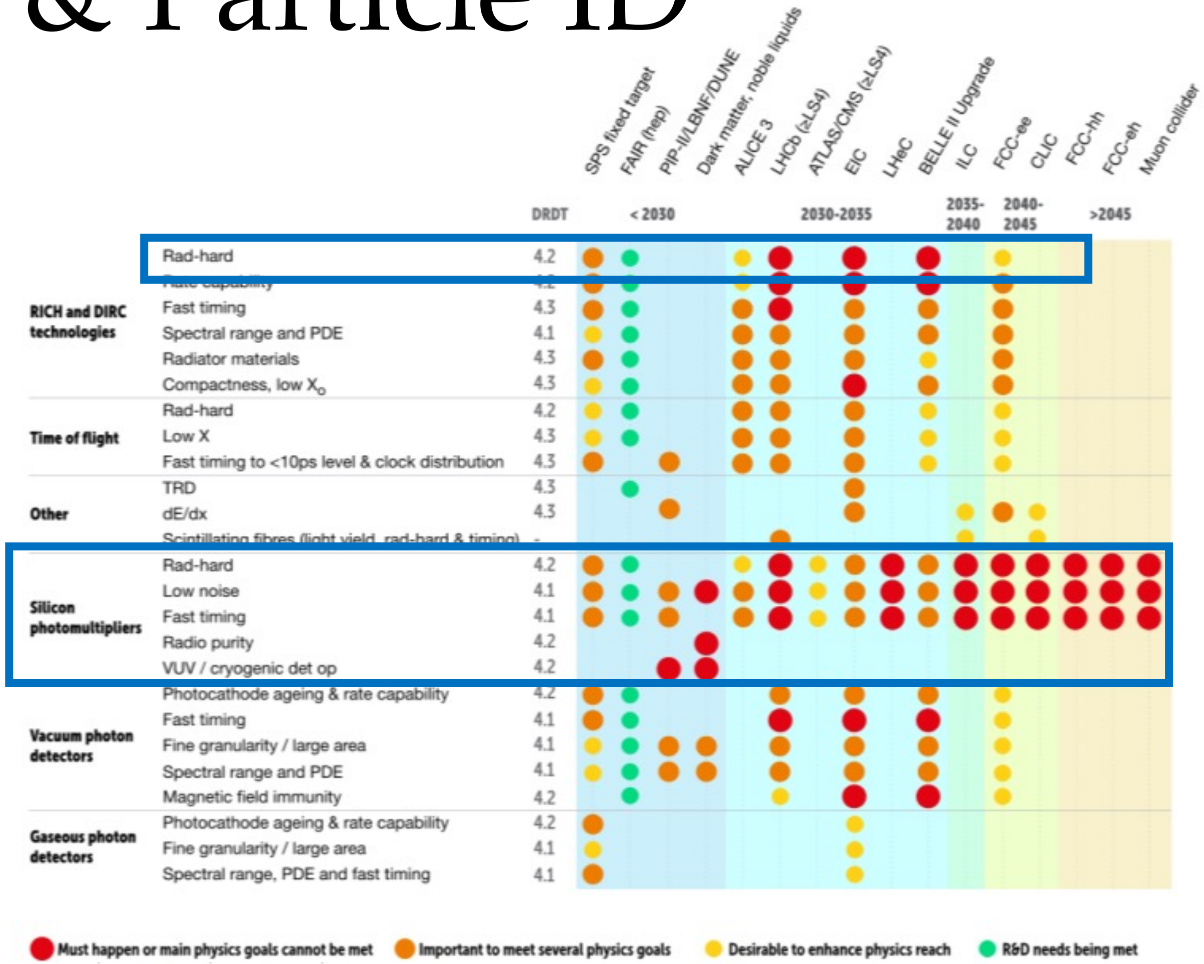
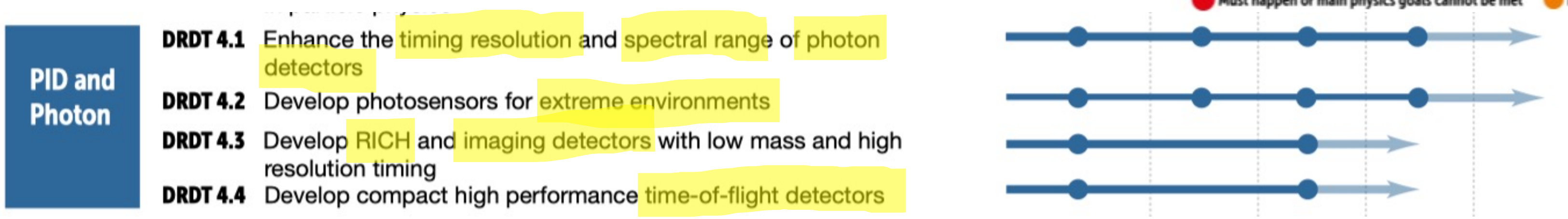
Photodetectors & Particle ID

- Particle Identification (PID) essential to identify decays when heavy flavor are present

- **Developments** on MCP-PMTs, SiPMs, Vacuum and gaseous photon detectors
- **Applications** in Ring Imaging Cherenkov Detectors (RICH), Time-of-Flight (ToF), TRD

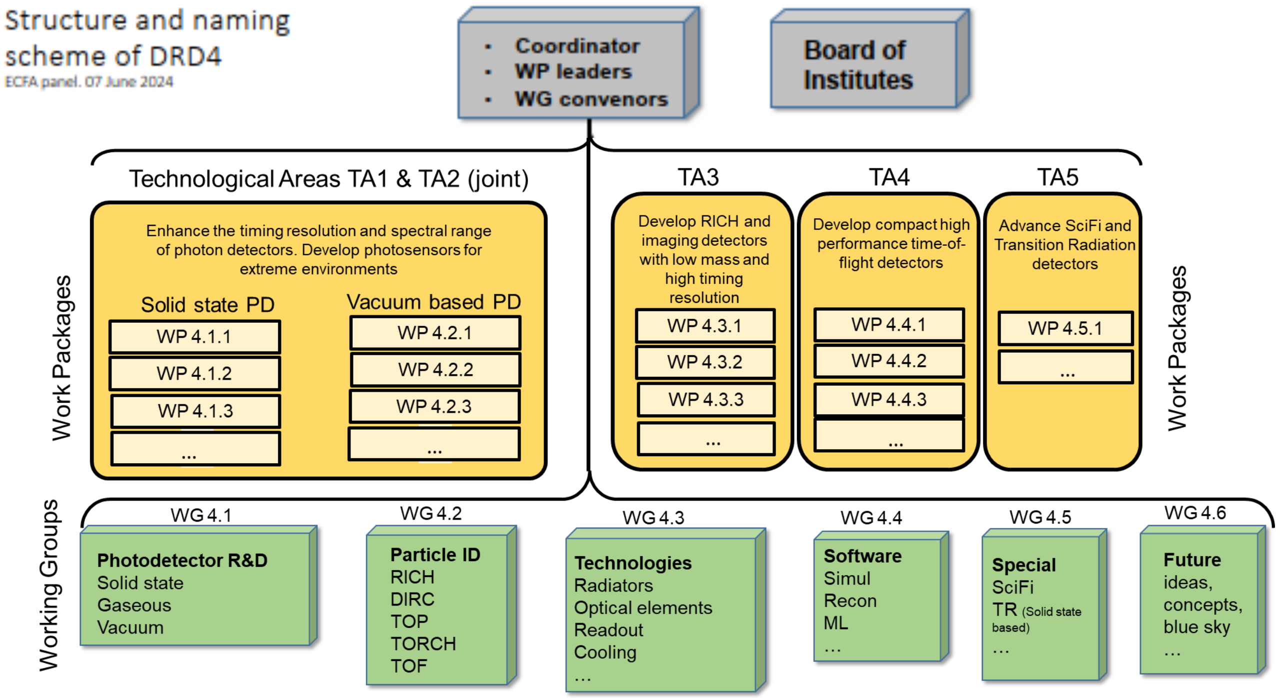
- Challenges for example for SiPMs: the high dark count rate and moderate radiation hardness prevented their use in RICH detectors where single photon detector required at low noise, but also new ideas emerge (e.g. backside illumination)





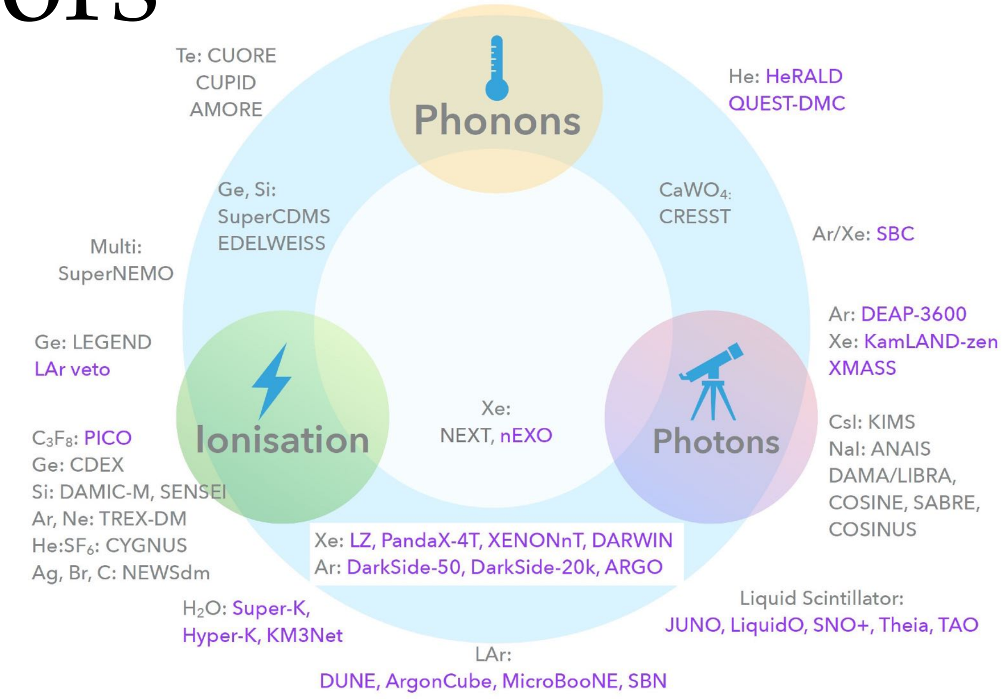
DRD4: Photodetectors & PID

- Collaboration currently led by Christian Joram (CERN) + Peter Krizan (Ljubljana) + team of 12 others
  - election of management when collaboration officially constituted in 2024
- About 50 institutes
  - EU + 6 US, 2 China, 2 Japan, 2 Australia, 1 S.Korea, 1 Armenia
- 7 industrial partners
- Connection to almost every other DRD collaboration (gas, Silicon, calo, electronics, SiPM at cryogenic temp.)

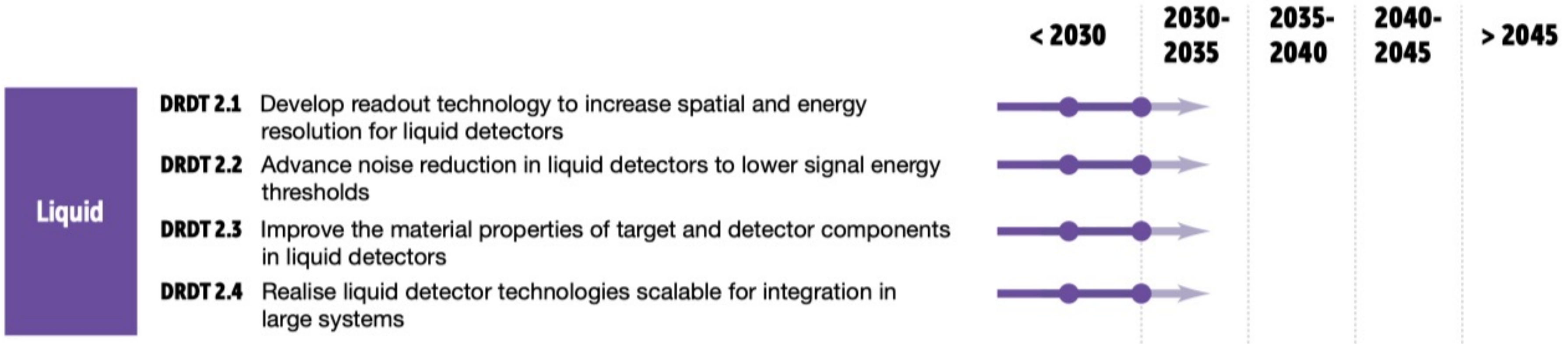


Liquid detectors

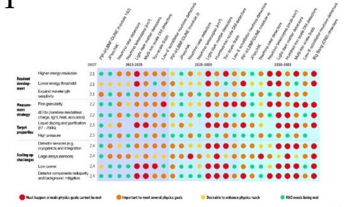
- Covers **Dark Matter and Neutrino experiments**, accelerator and non-accelerator-based
- Several large-scale and many small-scale experiments running or foreseen with liquid detectors, several in the US
- Technology: **Noble Liquids** (e.g. DUNE), **Water Cherenkov** (e.g. Super/Hyper-K) and **Liquid Scintillator** with light and ionization readout
    - Target doping and purification
    - Detector components radiopurity and background mitigation
- CERN Neutrino Platform should be exploited by DRD2



[ECFA roadmap, Modified from L.Baudis]

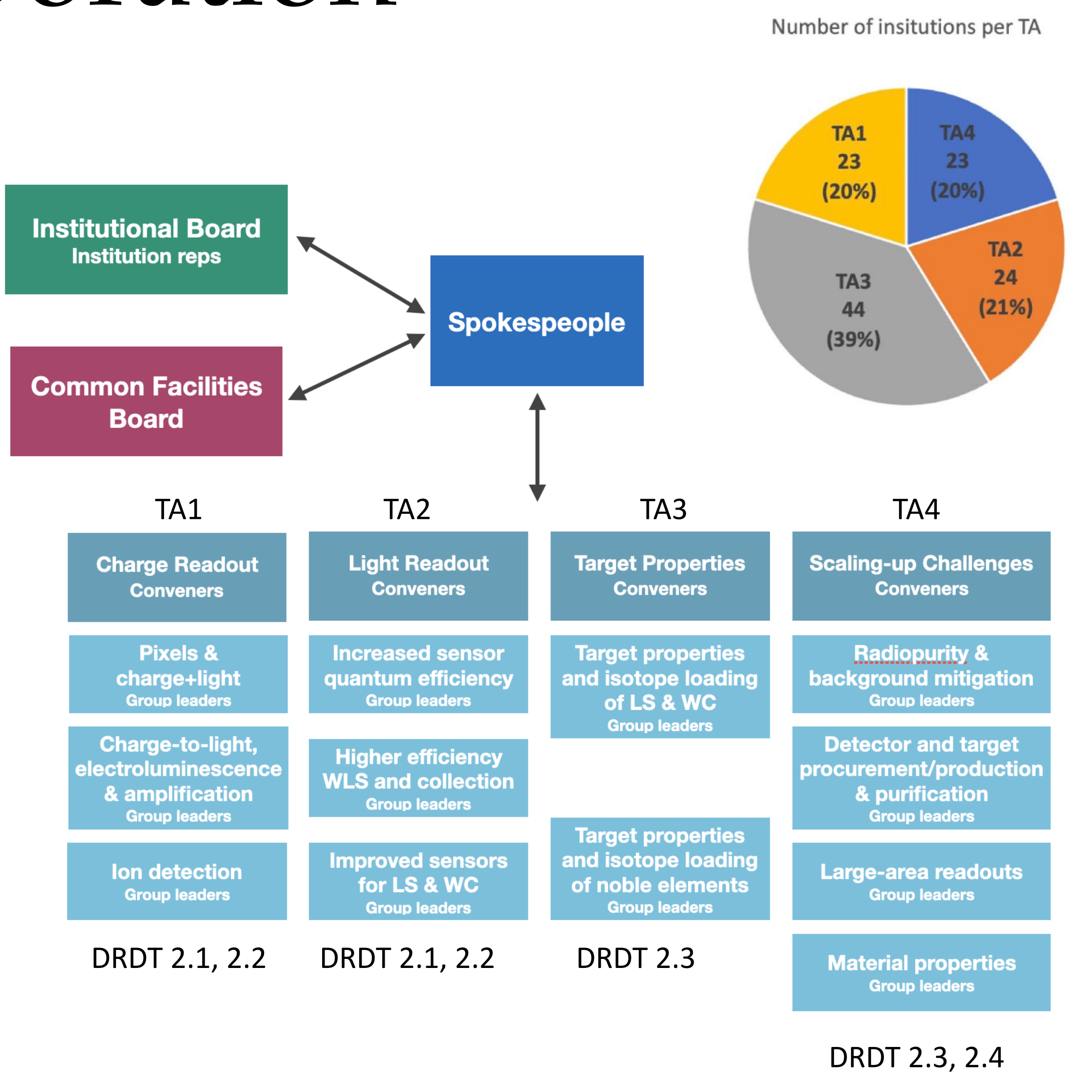


Note: Developments in this field are rapid and it is not possible today to reasonably estimate the dates for projects requiring longer-term R&D



DRD2 Collaboration

- Conveners: Roxanne Guenette, Jocelyn Monroe
- DRD2 proposal (26p), divided in four Technology Areas (TA), well aligned to DRDTs
  - Proposal currently under review by DRDC
- DRD2 Collaboration from 114 institutes in 15 countries
  - Significant US contribution (1/4)
  - Nominated liaisons to DRD1,4 and 7
  - A list of companies associated to different TA is included
- Detailed funding request (available/required) for both funds and FTE given in proposal

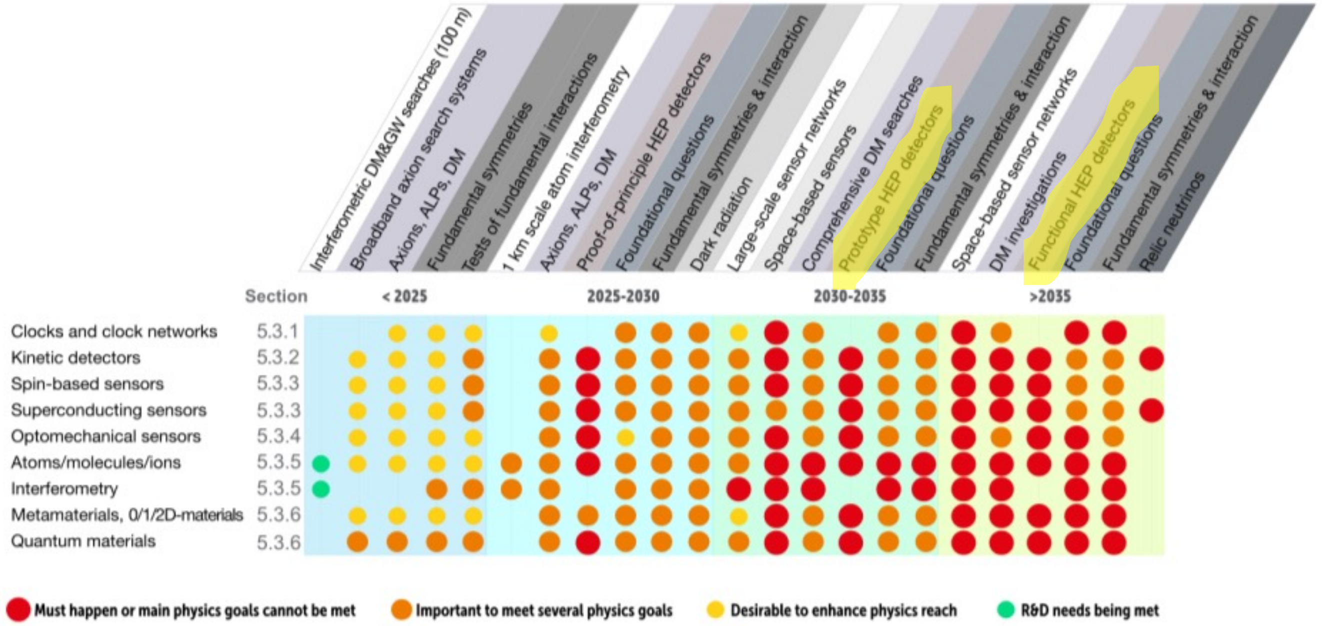


Quantum Sensors

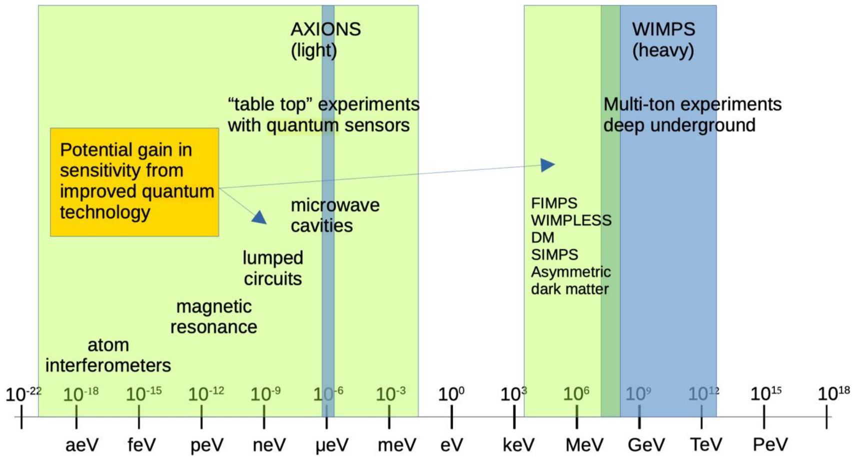
- Quantum Technologies are a **rapidly emerging area** of technology development to study fundamental physics
  - Targeting Gravitational Wave, Axion, DM detection
  - development of HEP detectors on the long term

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

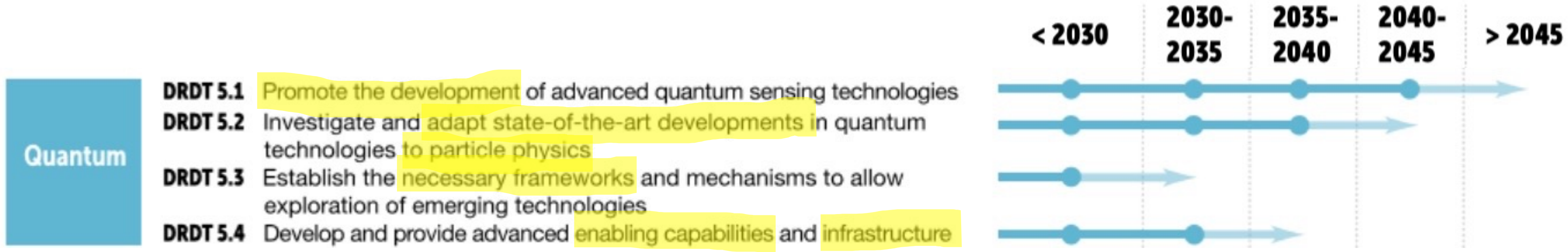
- Several initiatives started at CERN, DESY, UK,…



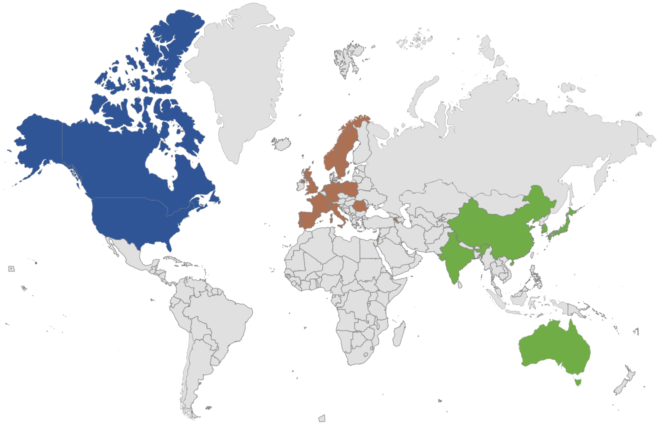
Example: potential mass ranges that quantum sensing approaches open up for Axion searches (from: ECFA roadmap)



DRD5 Collaboration



- 40 institutes in 15 countries
- 25 proposed contributions
- conveners: Marcel Demarteau, Michael Doser
- White Paper / LoI being submitted to DRDC
  - Information on personal web page of M. Doser



- A workshop to prepare the proposal for submission by the end of the year was held at CERN from Oct. 2-4.

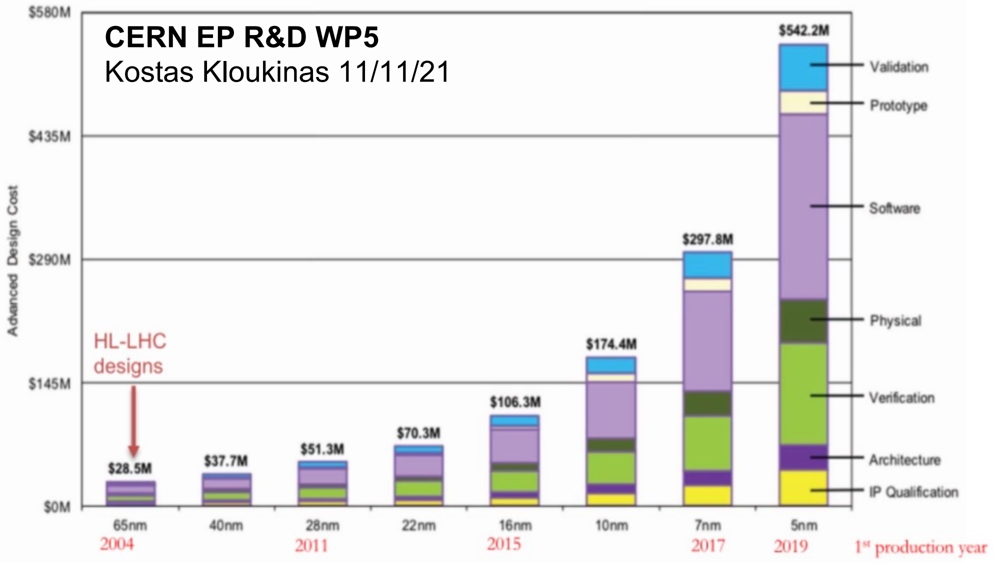
Micro-Electronics

- **All new techniques** (Precision timing, ultra-high granularity and improved signal resolution) need **more sophisticated data handling, processing, complexity and power.**
  - Requires exploiting the **latest advances in commercial microelectronics** and **high-speed links**.
  - Additional HEP requirements: **Radiation and magnetic fields** (niche and low volume market only)

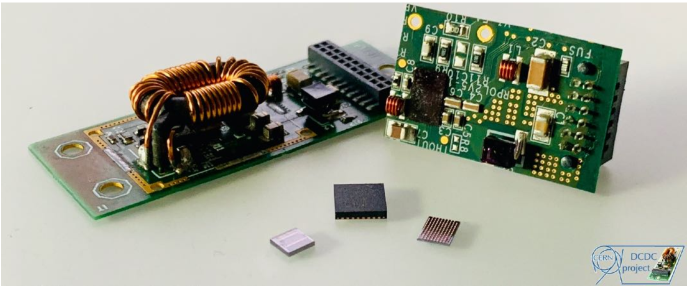
- Core topic: **ASIC development**
  - Community now looks into 28 nm CMOS nodes for the future and dedicated 130 /110/65 nm technologies for monolithic pixels (**DRD3 overlap**)
  - Each new node imposes **significantly higher funds** necessary
  - Legal topics (NDAs, design sharing agreements, software licenses,..)
  - Organization of multi-project wafer runs

- Strategic developments necessary **for systems to be used in large-scale experiments**, with synergy across many domains (e.g. DC-DC powering, FMC boards like FC7, GLIB)
  - All DRD collaborations have demands in electronics, from ASICs specific to certain detector technologies to small-scale readout systems

  → expert persons needed to be members of both, original DRD collaboration and electronics (see Annex B in this document)



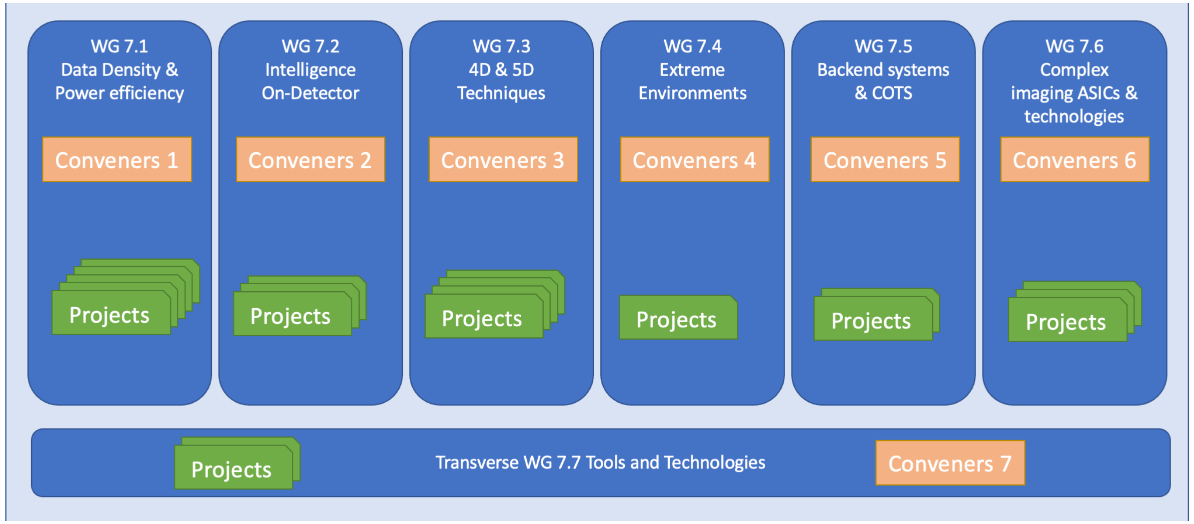
Chip Design and Manufacturing Cost under Different Process Nodes: Data Source from IBS*

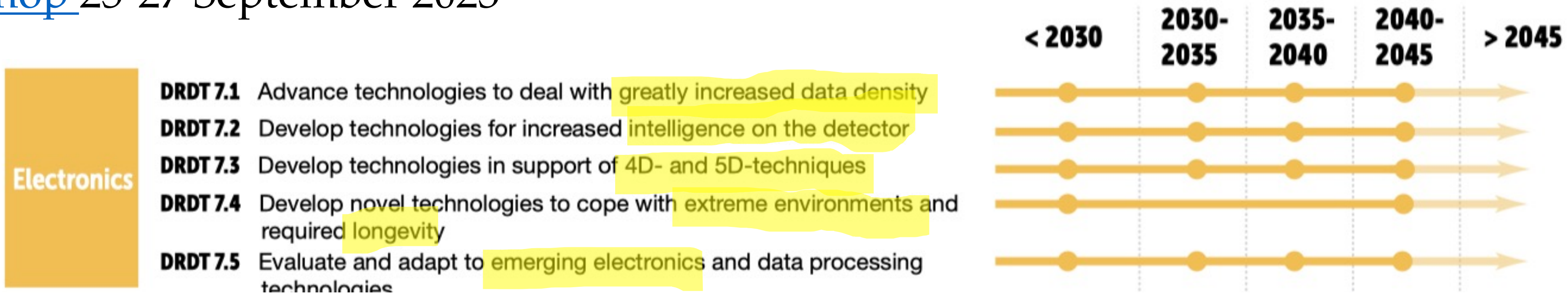


~40000 FEAST ASICs and ~47000 FEASTMP modules have been/are being delivered to the experiments (ATLAS ITk, New Small Wheel, CMS, Belle-II SVD,...)

DRD7: Electronics

- LoI exists, full proposal to be submitted by the end of this year
  - To ensure no duplication and foster cooperation between different DRDs
- Organization:
  - ~50 Institutes, 18 countries
  - Conveners: Francois Vasey, and others
  - Six Development areas (WG)
  - 1st workshop happened in March, 2nd workshop 25-27 September 2023





Projects in DRD7

16 projects in a bottom-up approach, but ensured that all are above certain threshold and fit the WGs

- 7.1a: Silicon Photonics Transceiver Development
- 7.1b: Powering Next Generation Detector Systems
- 7.1c: Wireless Allowing Data and Power Transmission

- 7.2a: eFPGA - Programmable Logic Array
- 7.2b: Radiation Tolerant RISC-V processor
- 7.2c: Virtual electronic system prototyping

- 7.3a: High performance TDC and ADC blocks at ultra-low power
- 7.3b-1: Data-driven impact studies and calibration strategies for time measurements
- 7.3b-2: Timing distribution techniques and systems

- 7.4a: Modeling and development of cryogenic CMOS PDKS
- 7.4b: Radiation resistance of advanced CMOS nodes
- 7.4c: Cooling and cooling plates

- 7.5.a COTS architectures, tools and IP
- 7.5b: No backend, full 100GbE solutions from FE to DAQ

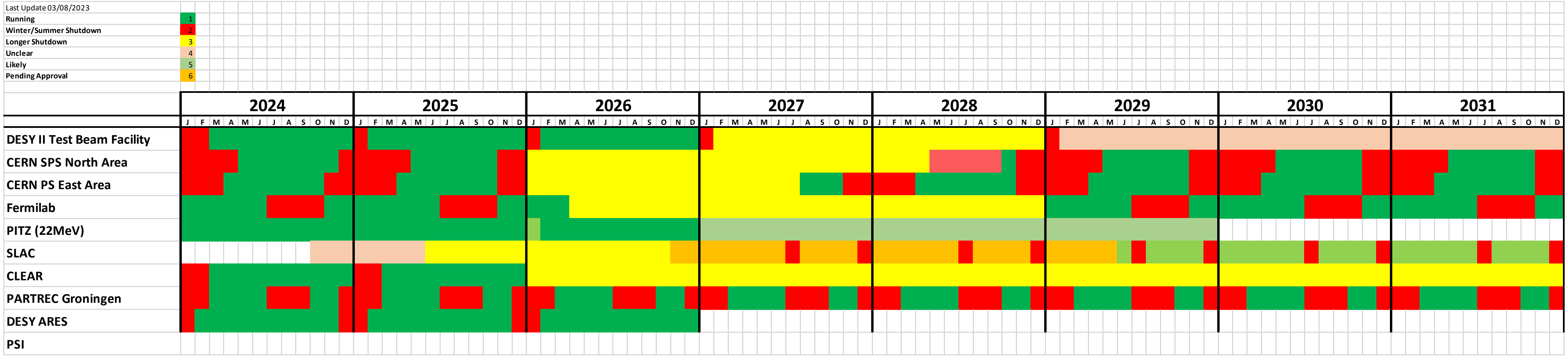
- 7.6a: Common access to selected imaging technologies and IP blocks
- 7.6b: Common access to 3D and advanced integration

Status of DRD Proposals

- **Collaboration-building for communities that have not worked together before** (DRD2, DRD4, DRD5),
  - Very **positively seen** to foster collaboration
- **Large spread of focus and/or level of details of the submitted proposals**
  - Presumably caused limited time given to communities to work on it
  - Community still very busy with Phase-II Upgrades of HL-LHC experiments (DRD1, 3, 6)

- **DRD Committee (DRDC) started to review proposals**
  - Proposals were prepared under the supervision of a different body (ECFA)
  - Required and available funds are difficult to estimate and therefore subject to a high level of uncertainty
- What might be missing?
  - A coherent picture of **resources across all DRDs** so that funding agencies get the total demand
  - Better **coordination between different DRDs** to **reduce duplications**, especially for electronics
  - Coordinated approach on how **to involve industry (IP):** MoU template prepared by CERN
  - Several groups complain about **missing beam test possibilities** from 2026 onwards

Beam test possibilities



https://cern.ch/international-facilities

Summary

- New Detector R&D (DRD) collaborations are currently being set up following ECFA Detector roadmap to pave the way for the next decades.
- **Instrumentation must not the limiting factor to meet the needs of the long-term European particle physics program**
- Beam test possibilities are an essential tool for it
- Status of DRD collaborations: 5 proposals currently under review:
  Gas detectors (DRD1), **Liquid Detectors** (DRD2), **Semiconductor Detectors** (DRD3), **Photodetectors & Particle ID** (DRD4), **Calorimetry** (DRD6)

DRD collaborations will become operational in 2024

The End.

– Acknowledgments: Phil Allport, Didier Contardo, Roger Forty, Susanne Kühn, Felix Sefkow, Maxim Titov and many others

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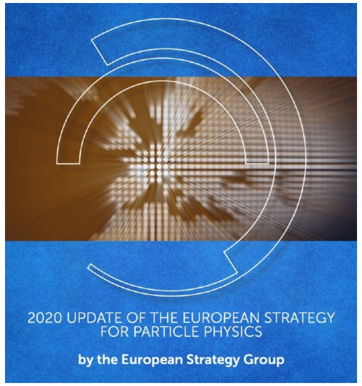
European Strategy on Particle Physics

http://europeanstrategy.cern



Continuous process driven by the community

- First defined 2006
- **Update 2013** brought us HL-LHC decision
- **Update 2020** brought us decisions for post-HL-LHC times:
  - *Europe, together with its international partners, should investigate the technical and financial feasibility of* ***a future hadron collider at CERN*** *with a centre-of-mass energy of at least* ***100 TeV*** *and with an* ***electron-positron Higgs*** *and electroweak* ***factory*** *as a possible* ***first stage****.*
  - *The European particle physics community* ***must intensify accelerator R&D*** *and* ***sustain it with adequate resources****. A* ***roadmap should prioritise the technology****, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry.* ***Deliverables for this decade should be defined*** *in a timely fashion and coordinated among CERN and national laboratories and institutes.*
  - Successful completion of High-Luminosity LHC must remain key focus

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

History of Detector R&D in Europe

- First Detector R&D collaborations have been created at CERN starting in 1990 with the LHC on the horizon:
  RD-1 (est. 1990): *Scintillating fibre calorimetry at the LHC (SPACAL)*
- Last R&D collaboration approved:
  RD53 (est. 2013): *Pixel readout ASIC for HL-LHC*

- Still active (among several others) and relevant for this talk:
  - **RD50** (est. 2002): Radiation Hard Semiconductor Devices for Very High Luminosity Colliders (with predecessors RD20, RD48)
  - **RD51** (est. 2008): Development of Micro-Pattern Gas Detectors Technologies

- Reviewed by a first DRDC (1990-1995), later by the LHCC
  - Work programs and key achievements documented in a 5yrs work plan 2018-23 RD50: [LHCC-SR-007]

Information about RD collaborations:
- CERN experimental program webpage
- CERN Greybook

Timeline ECFA Roadmap

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

2 July 2021
Near final draft shared with RECFA*

30 July 2021
Presentation at Joint ECFA-EPS session

Until Sep 2021
Collect final community feedback*

Oct 2021
Detector R&D Roadmap Document submission to RECFA and afterwards to PECFA and Council

*community feedback via RECFA delegates and National Contacts

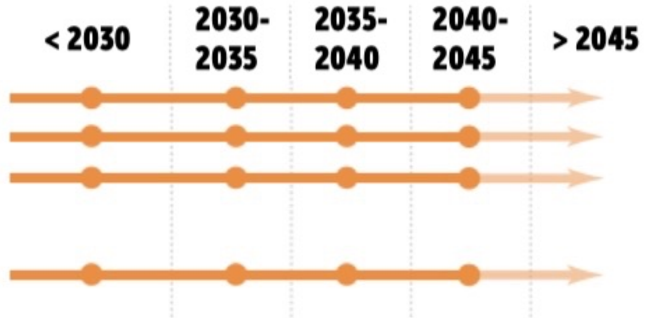
DRDC mandate
according to CERN council document

CERN/SPC/1190 ; CERN/3679

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

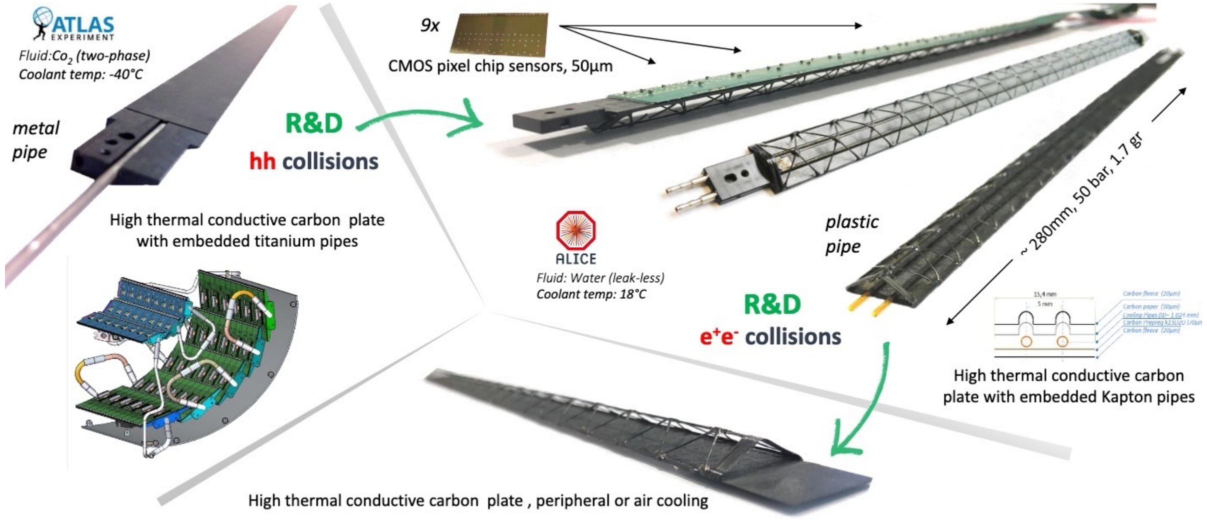
Task Force 8: Integration

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



- Target: Mechanical support and structures, cooling, magnets and management of radiation environment
- **No DRD collaboration has been proposed at this stage**
  - DRDTs are quite diverse
  - Some topics are very closely connected to the genuine DRDs, where the technology is developed (DRDT 8.3)

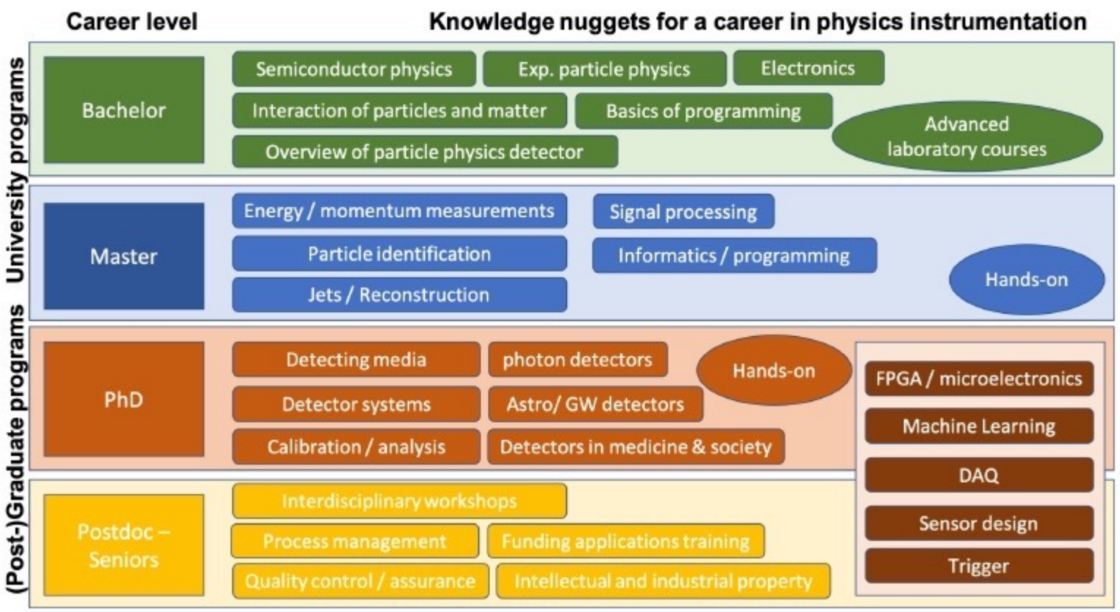
➢ nevertheless a community survey is on-going to investigate opportunities for a joint effort on common aspects, such as materials, assembly techniques, cooling,..



Task Force 9: Training

- A structured **training program** 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
- 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**.

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



Committee Members

ECFA Detector Panel (EDP):

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

Detector R&D Committee (DRDC):

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

Names in bold in both committees

Checklist for proposal evaluation

1. Check if the proposal format matches guidance document from EDP (tables, layout,..)
   - Document linked here and here (if not accessible at Indico)
2. Milestone and Deliverables match ECFA detector roadmap
3. Committed resources (FTE / funds) match the demand given by the scientific program
4. Collaboration structure exists (institution board, conference board, decision-making bodies,..)
5. Common fund and its usage (for small bottom-up projects, but also for administration?)
6. Overlap/transition from existing collaborations explained
   - DRD1/3: RD51/50: common projects, common fund
   - DRD6: Calice, CrystalClear
   - DRD5: CERN quantum initiative
7. Interconnections
   - Explanation of scientific topics which overlap with other DRDs, especially electronics
   - Liaisons nominated to other DRDs and the US DRC groups
   - Industry participation

Draft DRD Proposal Guidance

(16th February 2023)

Updated 29th June 2023 following discussion with DRDC Chair

2. Main Proposal:

To keep the process manageable for both proponents and reviewers, it is recommended that the DRD proposal document should not exceed 20 pages, following a common outline template as suggested below:

- Introduction (objectives of the DRD collaboration)
- Planning technology area 1 (including a task/deliverable synoptic, resources and list of contributing institutes)
- …
- Planning technology area n (including a task/deliverable synoptic, resources and list of contributing institutes)
- Interfaces to other DRD proposals - including particularly the links to DRD7 as a transversal Detector R&D topic area
- Common simulation tools and test facilities
- Partnerships (industrial, other research areas, other applications)
- Networking and training
- Proposal for the collaboration structure
- Resources (as discussed below) both existing and anticipated
- Summary (high level planning synoptic by DRDT broken-down to sub-areas)

Draft DRD Proposal Guidance

(16th February 2023)

Updated 29th June 2023 following discussion with DRDC Chair

Timeline of milestones and major deliverables per DRDT and technology					
Deliverables or milestones in appropriate years	**2024**	**2025**	**2026**	**2027-2029**	**≳ 2030**
DRDT 1					
Technology 1	List of deliverables in year due (if any)				
...					
Technology n	List of deliverables in year due (if any)				
...					
DRDT n					
Technology 1	List of deliverables in year due (if any)				
...					
Technology n	List of deliverables in year due (if any)				

Timeline of FTE per DRDT and technology					
Total FTE estimated to be required to deliver the outlined R&D programme	**2024**	**2025**	**2026**	**2027-2029**	**≳ 2030**
DRDT 1					
Technology 1	Total required FTE				
...					
Technology n	Total required FTE				
...					
DRDT n					
Technology 1	Total required FTE				
...					
Technology n	Total required FTE				

Timeline of Materials and Services (non-FTE) Funding per DRDT and technology					
Total non-FTE funds estimated to be required to deliver the outlined R&D programme	**2024**	**2025**	**2026**	**2027-2029**	**≳ 2030**
DRDT 1					
Technology 1	Total requried funds				
...					
Technology n	Total requried funds				
...					
DRDT n					
Technology 1	Total requried funds				
...					
Technology n	Total requried funds				

List of deliverables per technology and DRDT				
List of Contributing Institutes	**Technology 1**	**...**	**...**	**Technology n**
DRDT 1	List of contributors			
...				
DRDT n	List of contributors			

Timeline of FTE per DRDT and technology				
Estimate of expected total FTE from existing sources (not requiring new "strategic" support)	**2024**	**2025**	**2026**	**≳ 2027**
DRDT 1				
Technology 1	Total estimated FTE from existing sources			
...				
Technology n	Total estimated FTE from existing sources			
...				
DRDT n				
Technology 1	Total estimated FTE from existing sources			
...				
Technology n	Total estimated FTE from existing sources			

Timeline of Materials and Services (non-FTE) Funding per DRDT and technology				
Estimate of expected total non-FTE funds from existing sources (not requiring new "strategic" funding)	**2024**	**2025**	**2026**	**≳ 2027**
DRDT 1				
Technology 1	Total estimated funds from existing sources			
...				
Technology n	Total estimated funds from existing sources			
...				
DRDT n				
Technology 1	Total estimated funds from existing sources			
...				
Technology n	Total estimated funds from existing sources			

Timeline of FTE per DRDT and technology				
Estimate of total R&D programme FTE (sum of existing and hoped for given realistic assumptions)	**2024**	**2025**	**2026**	**≳ 2027**
DRDT 1				
Technology 1	Total number of FTE proposed			
...				
Technology n	Total number of FTE proposed			
...				
DRDT n				
Technology 1	Total number of FTE proposed			
...				
Technology n	Total number of FTE proposed			

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.

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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**.

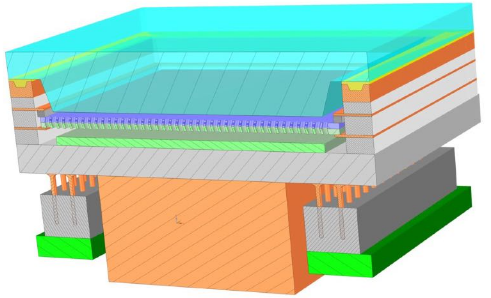
GSR 10 – Open Science

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**.

DRD4: Photodetectors

- MCP-PMTs: Under evaluation for LHCb RICH, TORCH, PANDA, HIKE, etc.
  - Extremly good time resolution <70ps, custom pixelisation possible
  - R&D on lifetime improvements and rate capabilities

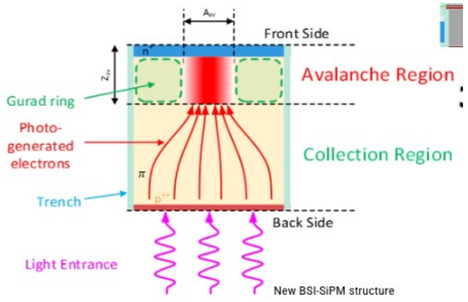
MCP with 64 x 64 anode pads (Photek)



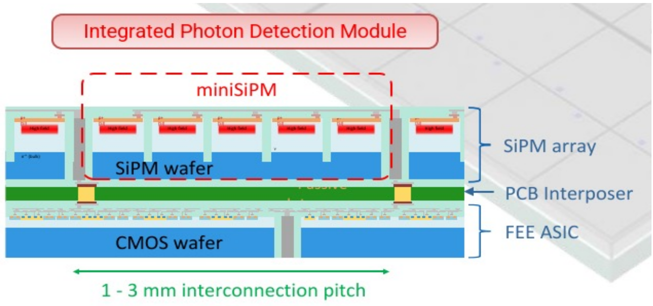
R&D to develop an MCP with integrated Timepix4 chip (55 x 55 μm^2 pixels)

Massimiliano Fiorini

- SiPMs:
  - Pros: High detection efficiency, low cost
  - Cons: High noise (DCR), neutron damage
  - Many R&D lines being followed: back-side illuminiation, sensor+electronics integration



FBK

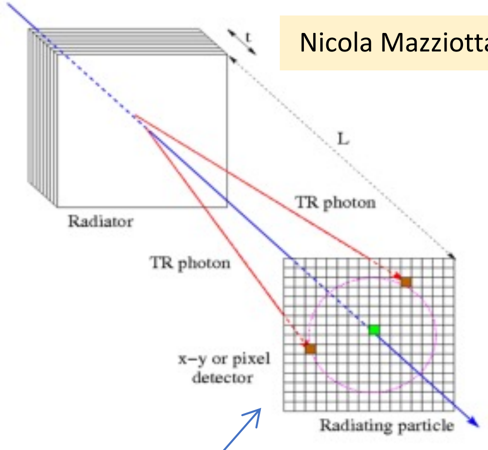


FBK

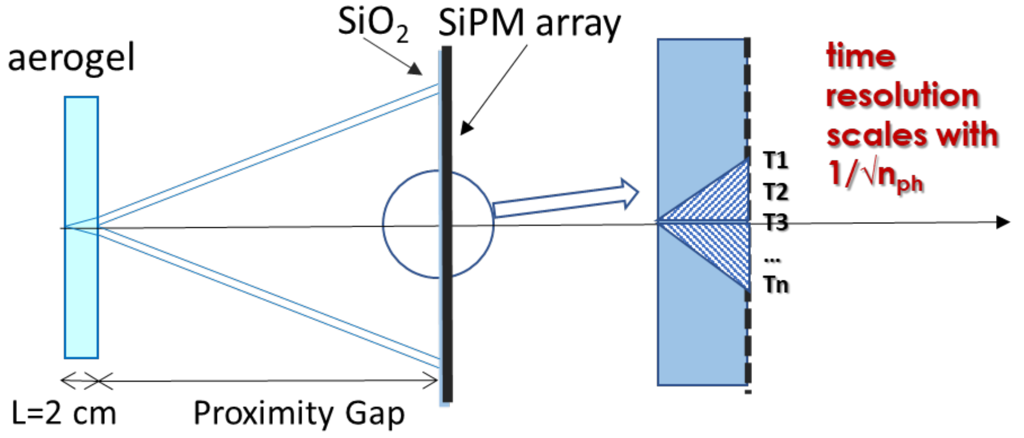
DRD4: Particle ID

- **RICH** detectors
  - Proximity focusing aerogel development
  - Possible combination with TOF measurement
  - Environmentally friendly RICH radiator gases (replacement for fluorocarbons)
  - Compact RICH with dual aerogel + gas radiators
- **TOF** detectors
  - SiPMs detecting Cherenkov light from their entrance window
  - DIRC-style: TORCH (10 ps resolution per track over large areas) LHCb-TDR-023
- **TR** detectors
  - Solid-state detection of Transition Radiation

Nicola Mazziotta



GaAs sensor + Timepix3 readout chip



DRD6: Particle Flow

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 m2 active elements