ECFA Detector RoadMap

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Assemblea di Sezione

What are ECFA Research and Developement (DRD)

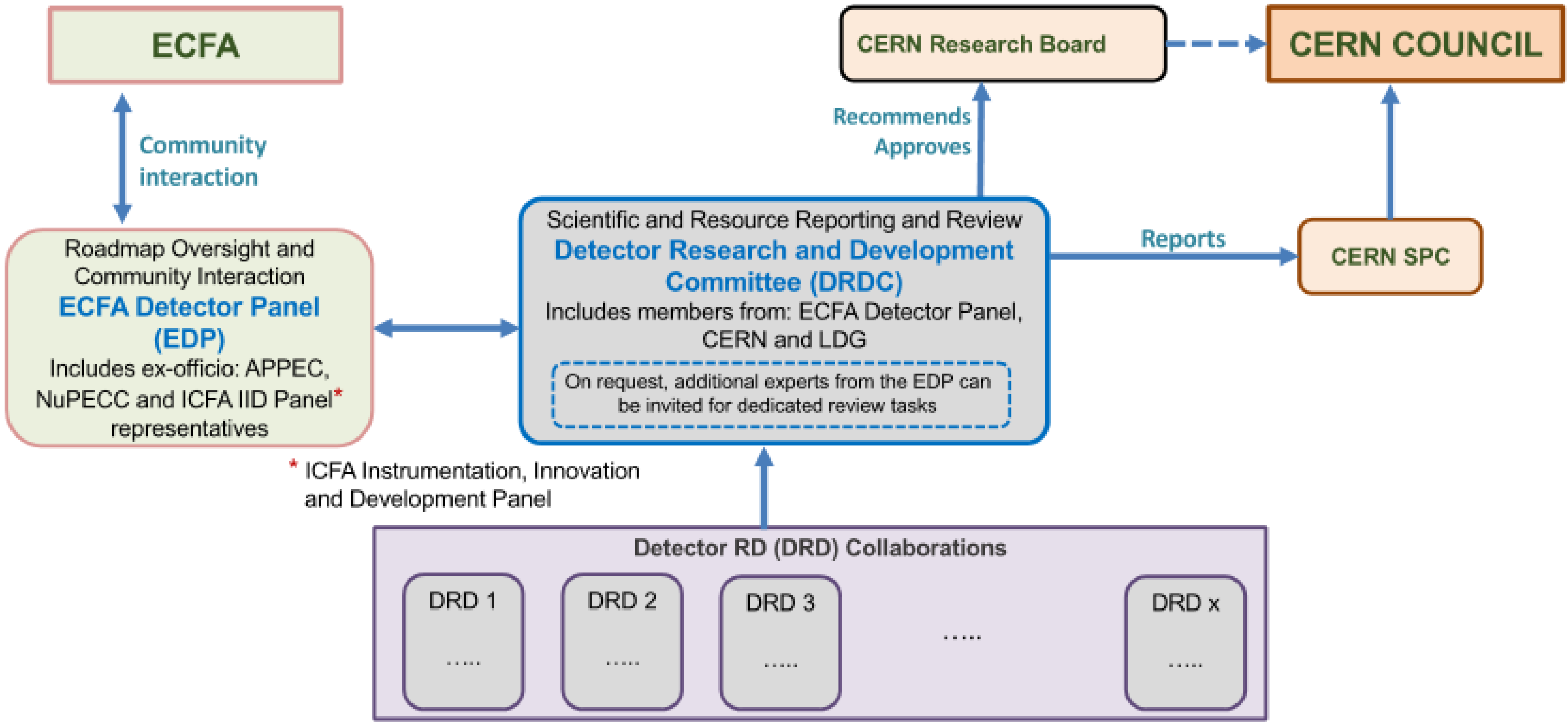
Organization involving European Union (ECFA) and hosted by CERN.

Goal: having a shared roadmap for future detector R&Ds

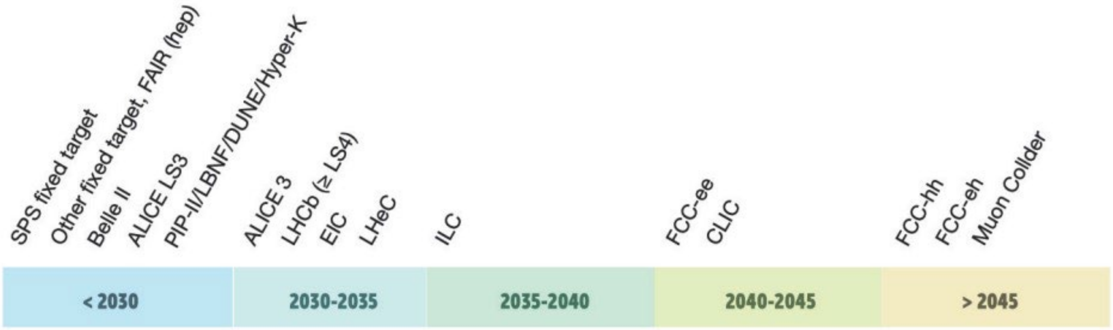
There is no financial autonomy for the Research and Development projects.

Past experiences (RD projects) worked in strong synergy with present and near-future experiments, allowing an easy flow of resources..

Today we do not have a strong push for upgrades which helped building a strong R&D program, however….



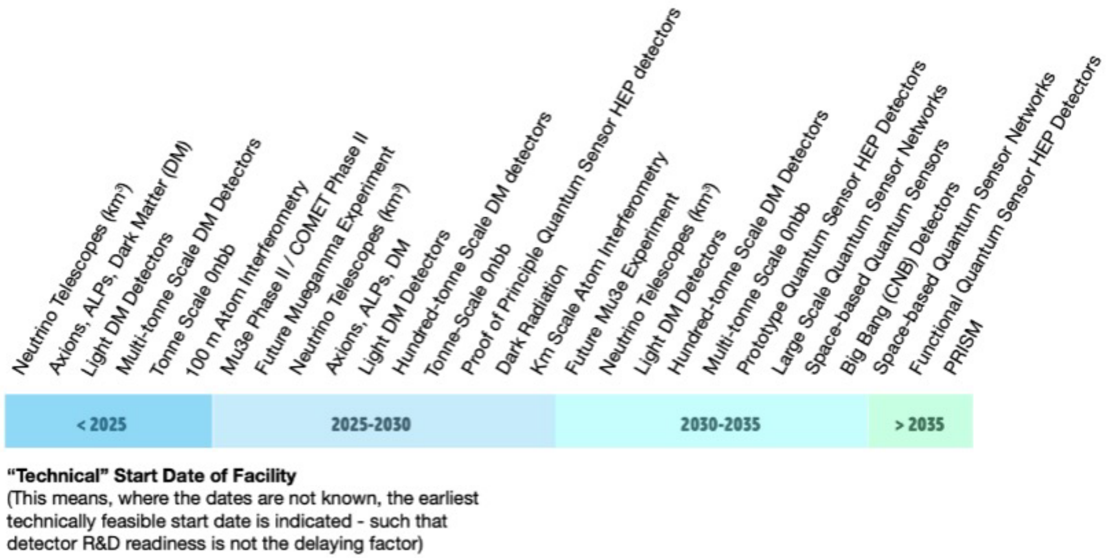
New Detectors for New Initiatives



Previous ECFA R&D projects (RD5*) strongly driven by LHC needs. Now there is no strong workhorse pushing for a focused R&D, however there are plenty of future projects brewing up both on accelerator and non-accelerator physics.

Different Physics goals call for different detectors, experience from current experiments can be brought to new projects and new fields.

Different timelines for the new project will shape the R&D efforts in the coming years



What is in DRD projects

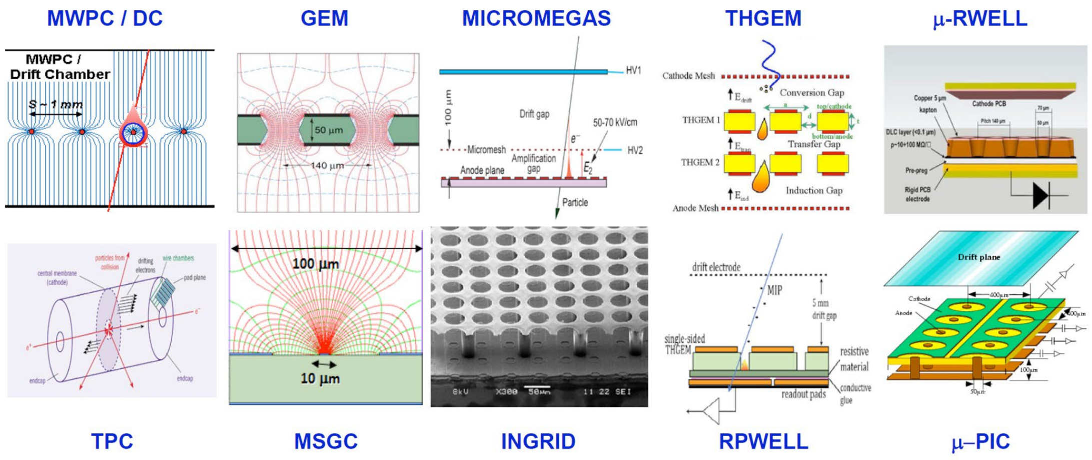
- DRD – 1 : Gas Detectors
- DRD – 2 : Liquid Detectors
- DRD – 3 : Solid State Detectors
- DRD – 4 : Particle Identification
- DRD – 5 : Quantum Technologies
- DRD – 6 : Calorimetry
- DRD – 7 : Electronics
- DRD – 8 : Integration

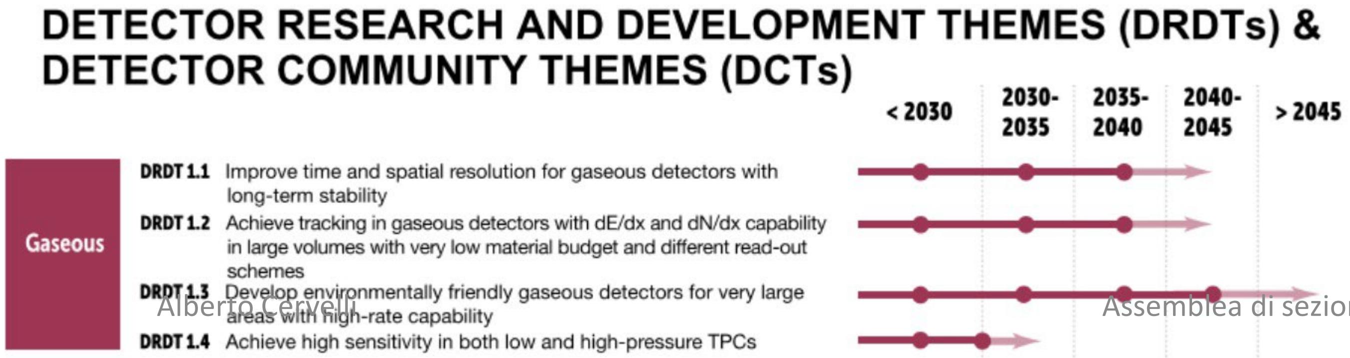
General Recomendations

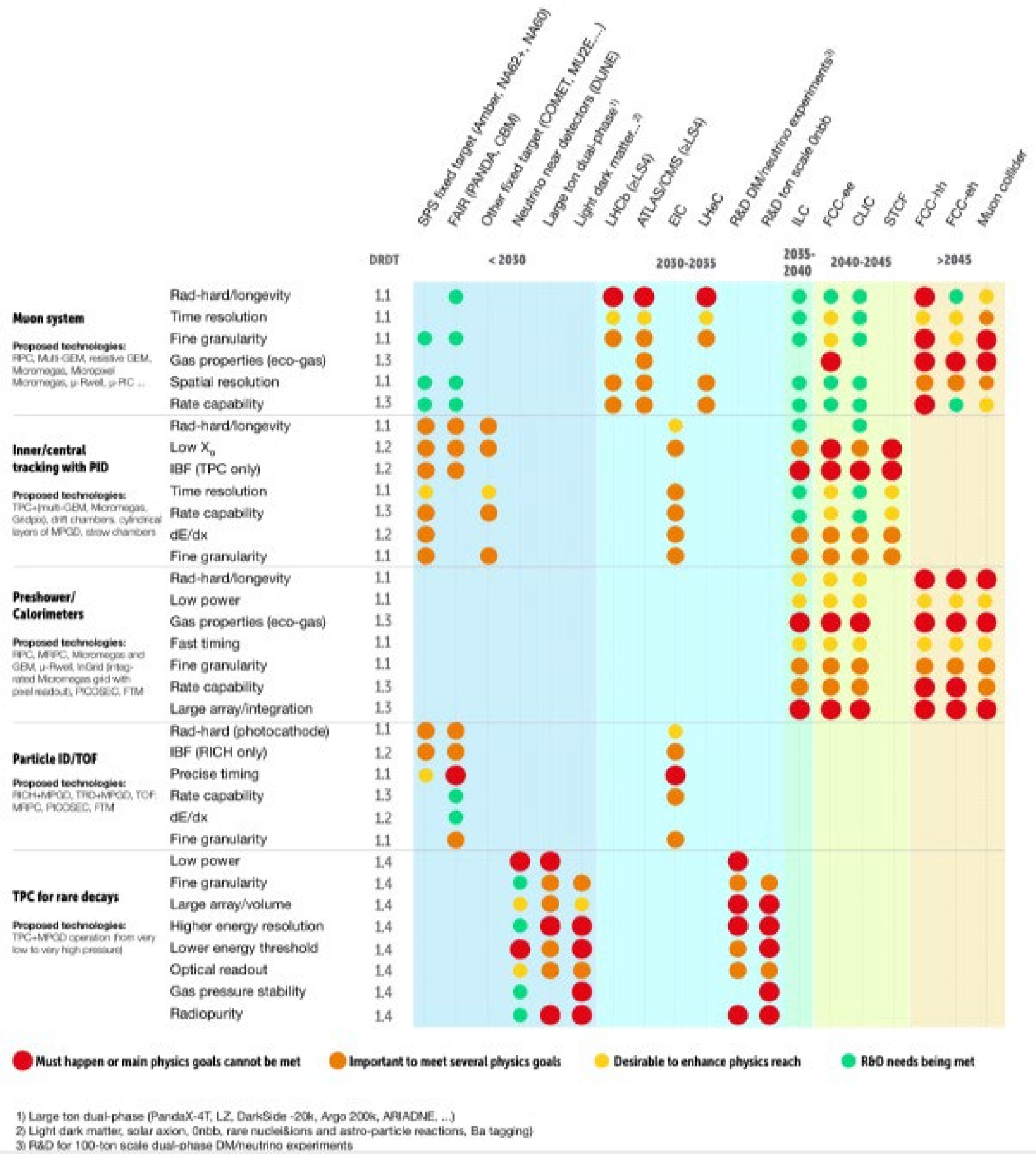
1. **Supporting R&D facilities :** coordinated infrastructure for Test-Beams, irradiation, large scale prototyping
2. **Engineering support for detector R&D:** electrical and mechanical engineering support for ever-growing integrated systems
3. **Specific software for instrumentation:** state-of-the-art R&D-specific software packages must be maintained and continuously updated
4. **International coordination and organisation of R&D activities**: connecting and involving all partners, there is a need to refresh the CERN RD programme structure and encourage new programmes for next generation detectors
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 acrossEurope
6. **Establish long-term strategic funding programmes**: long-term strategic funding programmes to sustain both research and development of the multi-decade DRDTs
7. **"Blue-sky" R&D:** "Blue-sky" developments in particle physics have often been of broader application and had immense societal benefit.
8. **Attract, nurture, recognise and sustain the careers of R&D experts:** Training programs and an adequate number of positions with a sustained career in instrumentation R&D
9. **Industrial partnerships**
10. **Open Science**

Gas Detectors - DRD1

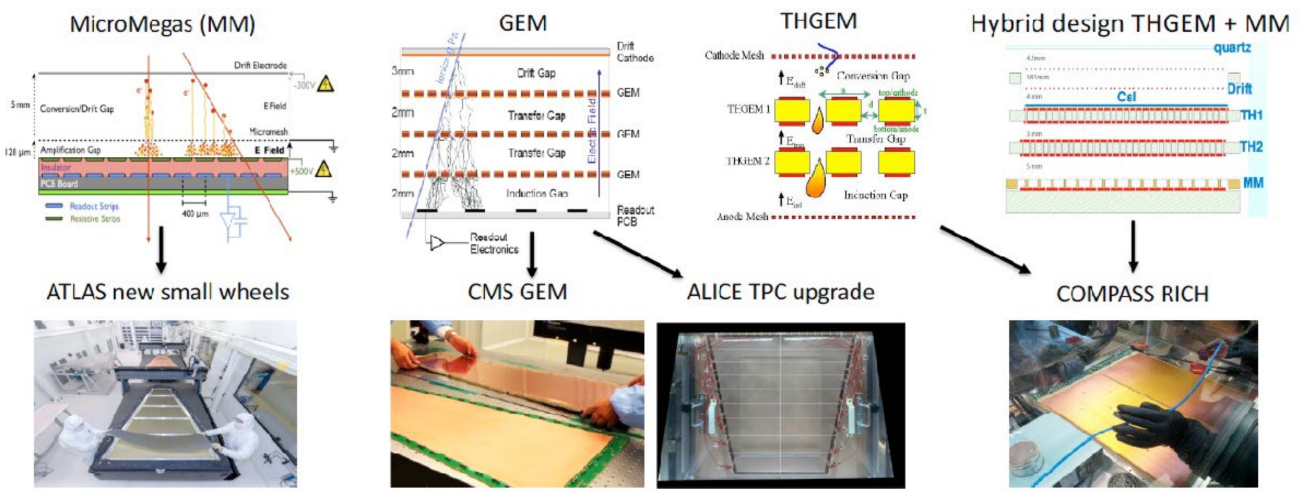
Best Choice for large detectors with low material budget:
→ Focus on speed: TOF systems
→ Focus on tracking: drift chambers , TPC







Gas Detectors - DRD1



LHC upgrade led to a wide array of new developments for tracking, muon spectrometry and triggering

New development for TPC development (ALICE)

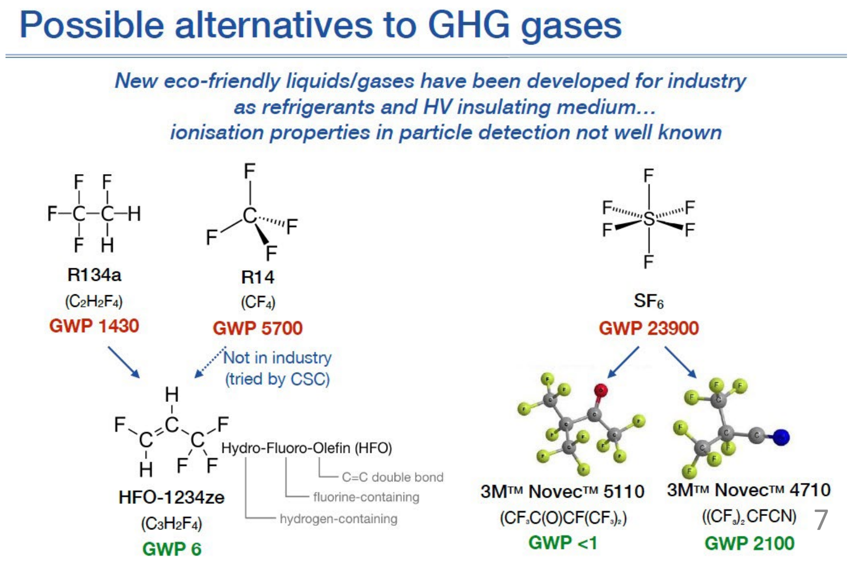
Timing with multi-gaps RPCs (ALICE)

Enabling technology for future detector Timing GEMSs

92% of emission at CERN related to large LHC experiments

Important R&D (ATLAS):
A lot of work especially in RPC community to search for alternative to C2H2F4

Not an easy task to find new eco-friendly gas mixture for current detectors



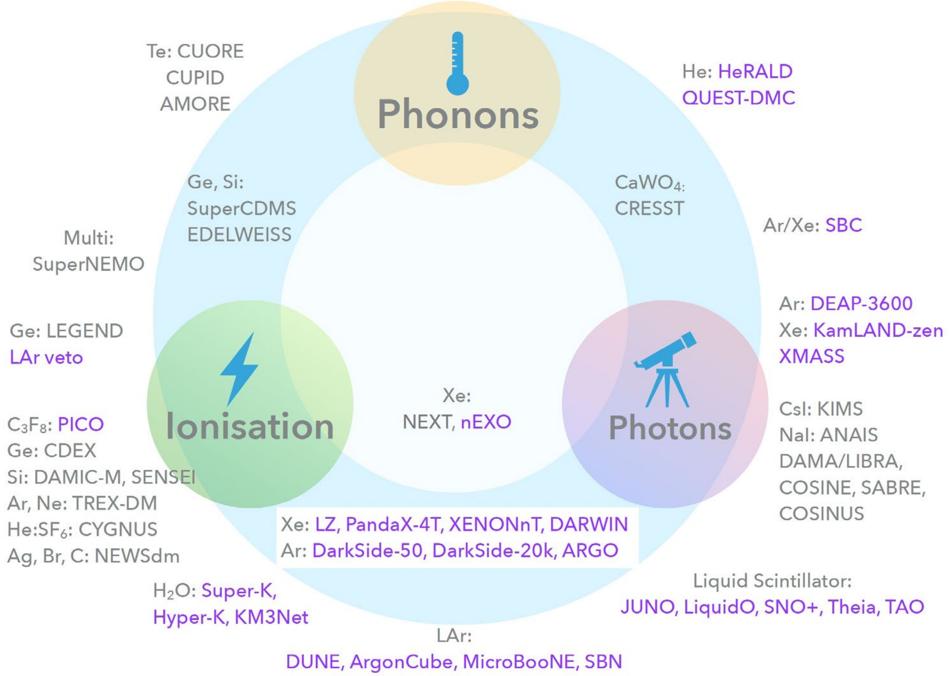
Local Groups involved: XENON, DUNE, DARKSIDE

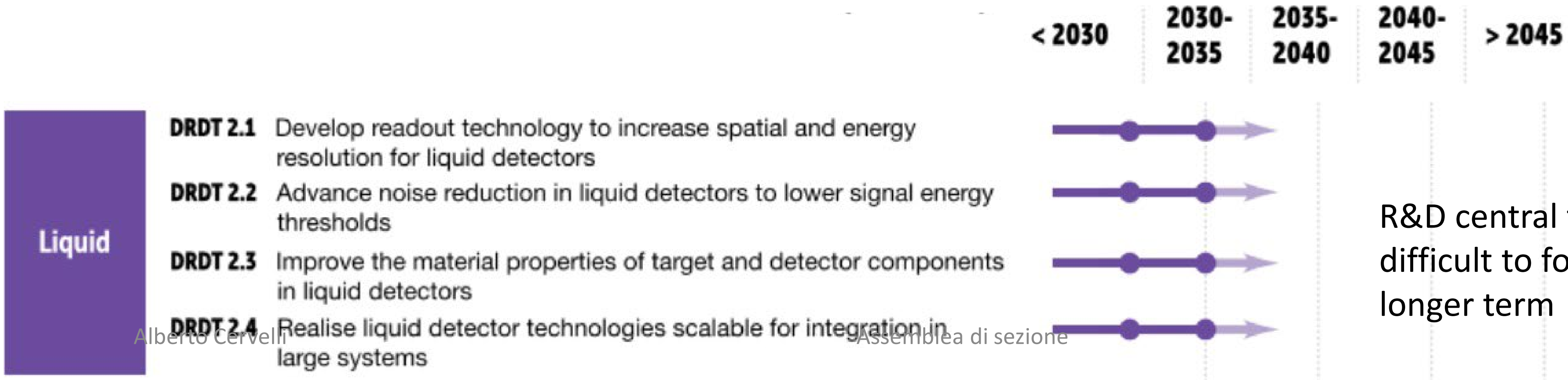
Liquid Detectors - DRD2

Many detectors in advanced design phases will use liquid detectors, both in large- and small-scale experiments

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
New readout technologies for liquid detectors

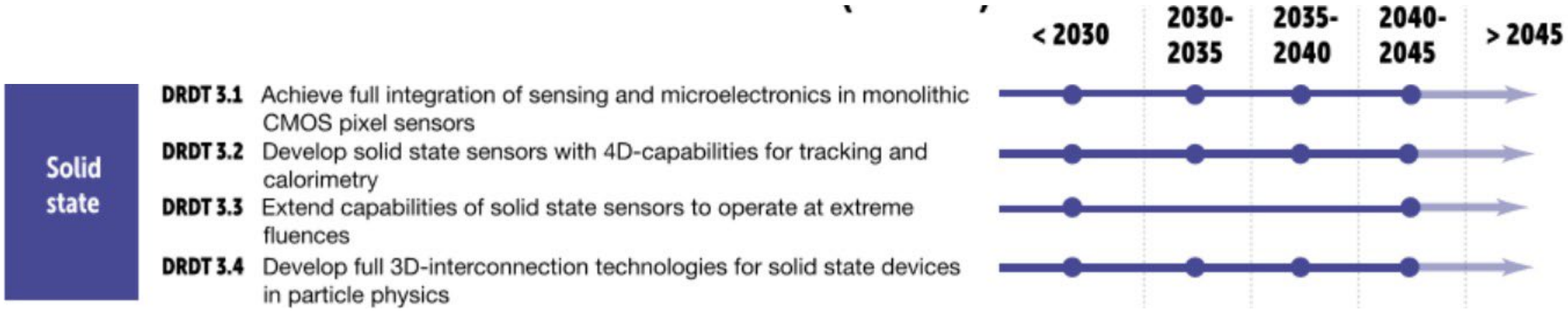




R&D central for new experiments, difficult to foresee the timeline for a longer term

Local Groups involved: ATLAS, TIMESPOT, ALICE

Solid State Detectors - DRD3



Fun Fact: 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 detector now used more and more in Calorimetry and TOF detectors

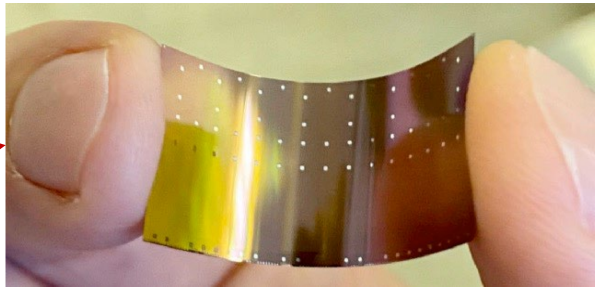
Main Challenges for Future R&D:

→ Vertex detectors **with low material budget** (Target per layer spatial resolution of ≤ 3 µm and thickness ≤ 0.05% X_0) (FCC-ee)
→ **affordable sensors** with low mass, high resolution, **low power** (FCC-hh, large area detectors)
→ **Large area and granular devices for calorimeters**
→ Detectors with ultra-fast timing (O(10-100 ps)) for PID, TOF

Solid State Detectors - DRD3 - Tracking

2 (+1) Great development paths for different physics goals:

→ radiation hard detectors with high spatial resolution (FCC-hh)



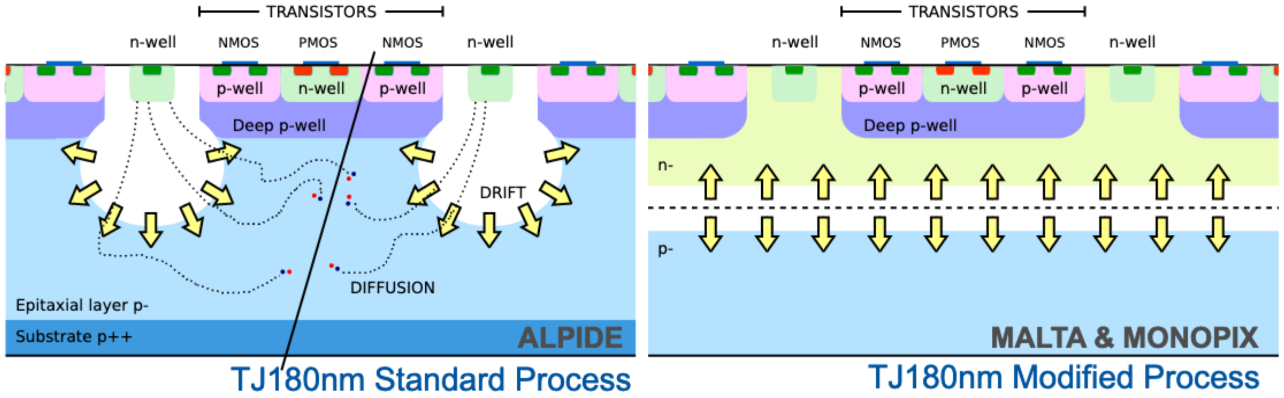
Three fully cylindrical, wafer-sized layers based on curved ultra-thin sensors (20-40 μm), air flow cooling

Very low mass, < 0.02-0.04% per layer

→ Monolithic CMOS for low material budget and large area detector

Telescope → 3 μm track resolution achieved

→ Radiation hard monolithic detectors



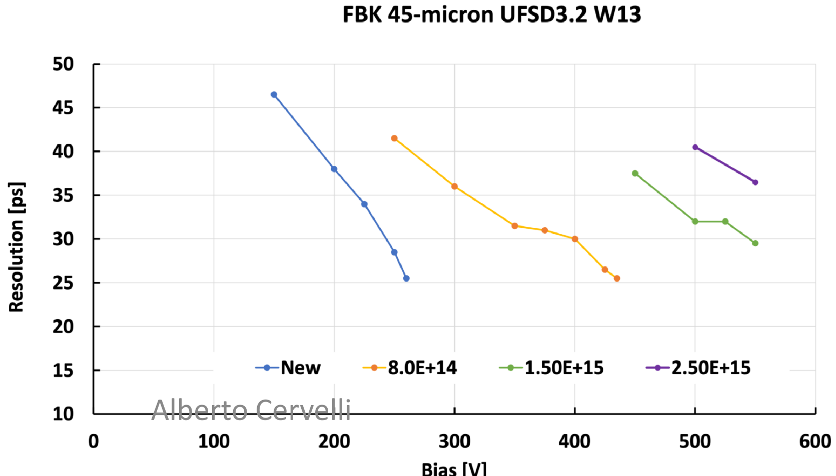
Up to 97% efficiency after fluence of 10^{15} n_{eq}/cm^2

Solid State Detectors - DRD3 – Timing

4D tracking is getting more and more reliable: first large area detector should be ready in the near future

LGAD produced by FBK (and other producers).

Crucial for high pile-up environments, such as FCC-hh and future hadronic facilities

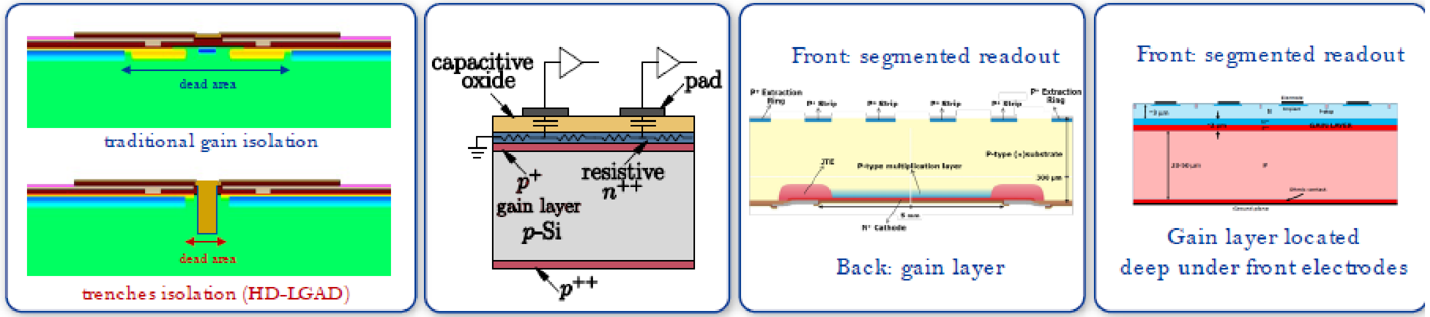


LGAD: Fill factor & performance improvements

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

Development stemming from RD50 (involvement from Bologna - ALICE)

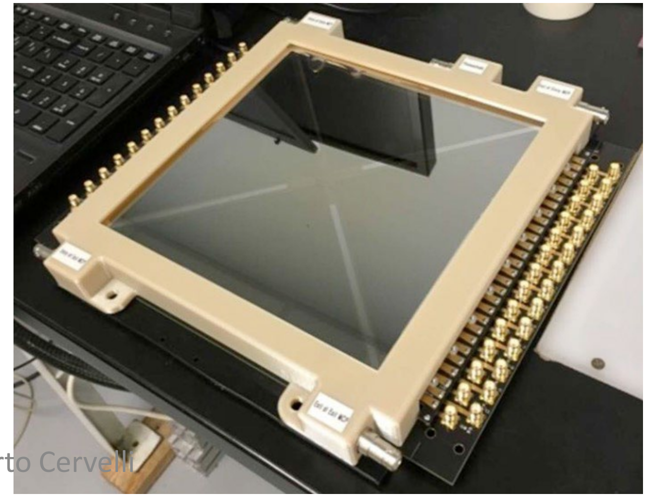
Future goals:
Improve timing, fill factor, radiation hardness, charge drift simulation and knowledge

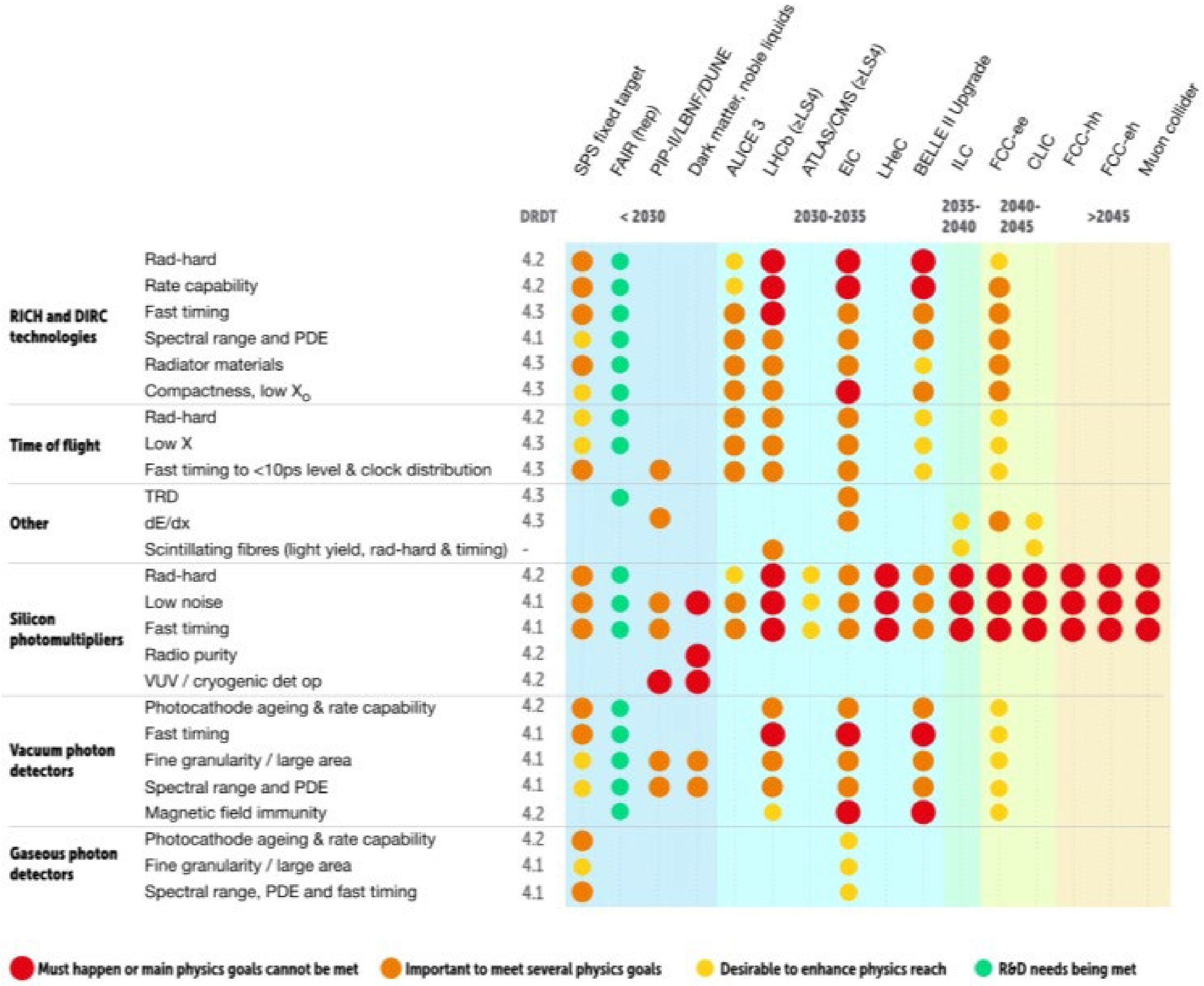
Particle Identification - DRD4

PID methods:dE/dx, TOF, Cherenkov light detection

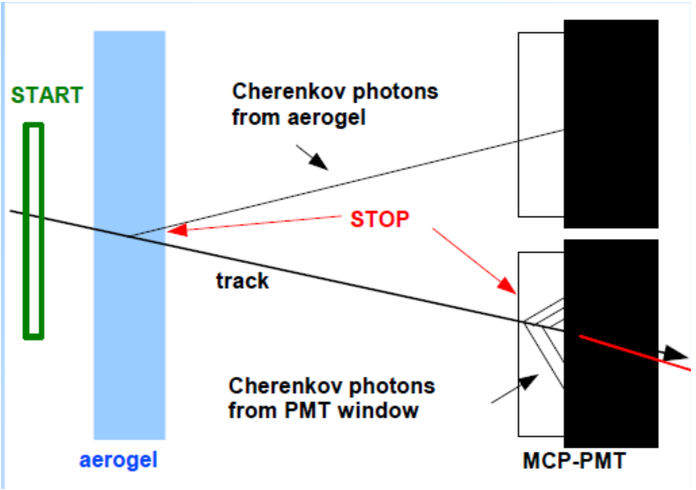
→Challenges for **SiPMs**: high dark count rate and moderate radiation hardness prevented their use in RICH detectors where single photon detector required at low noise

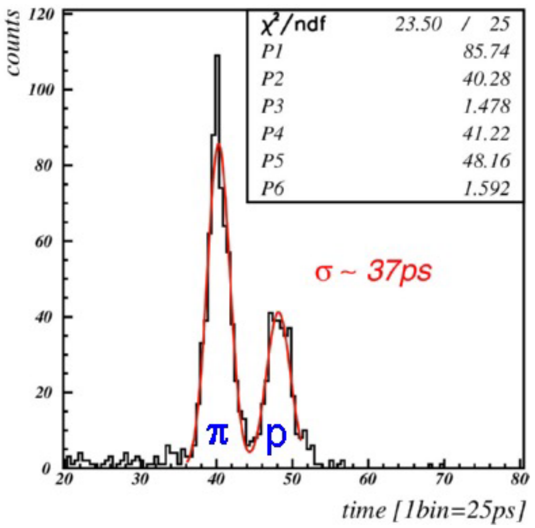
→ Challenges for **MCP-PMTs** reduce price and sensitivity to B fields, similarly **Large-Area Picosecond Timing Detectors** (LAPPD) promising, but need higher granularity and pixellation

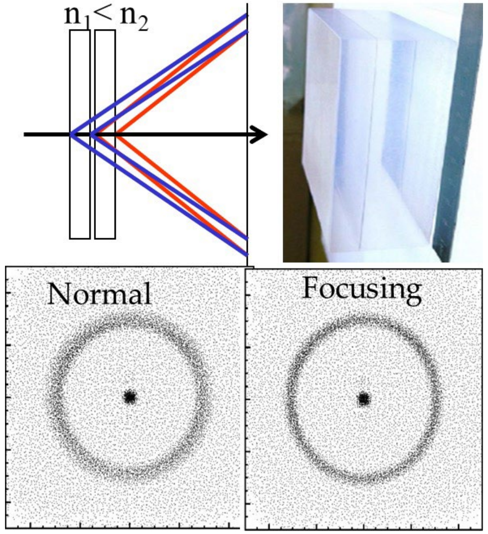




Particle Identification - DRD4



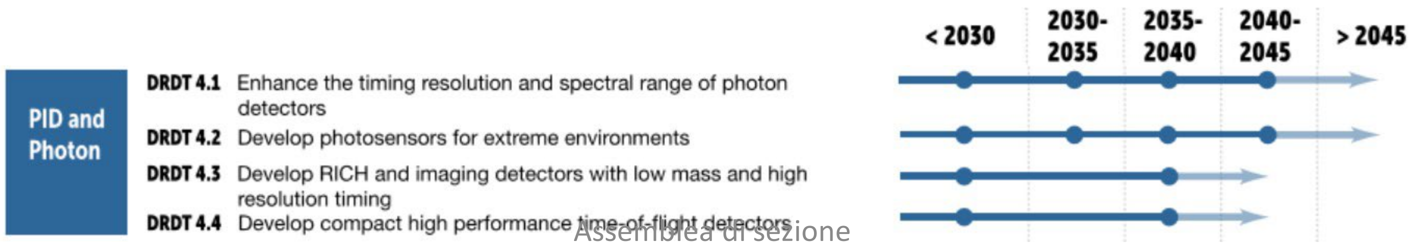




RICHes with proximity focusing: thin radiator (liquid, solid, aerogel) and low momenta

Time-Of-Flight (TOF) detectors: use prompt Cherenkov light, fast gas detector

RICHes with focalisation: extended radiator (gas), high momenta

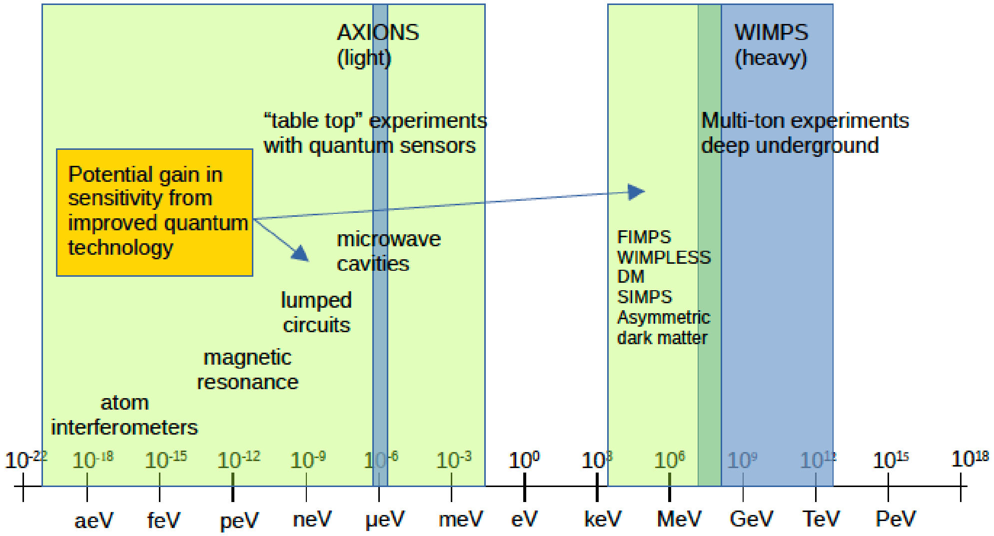


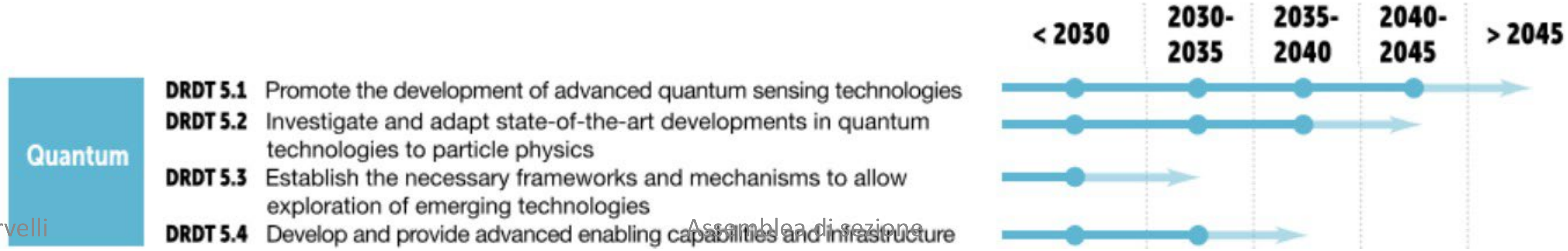
Quantum Technologies -DRD5

Rapidly emerging area of technology development to study fundamental physics

Use quantum systems to improve 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, …





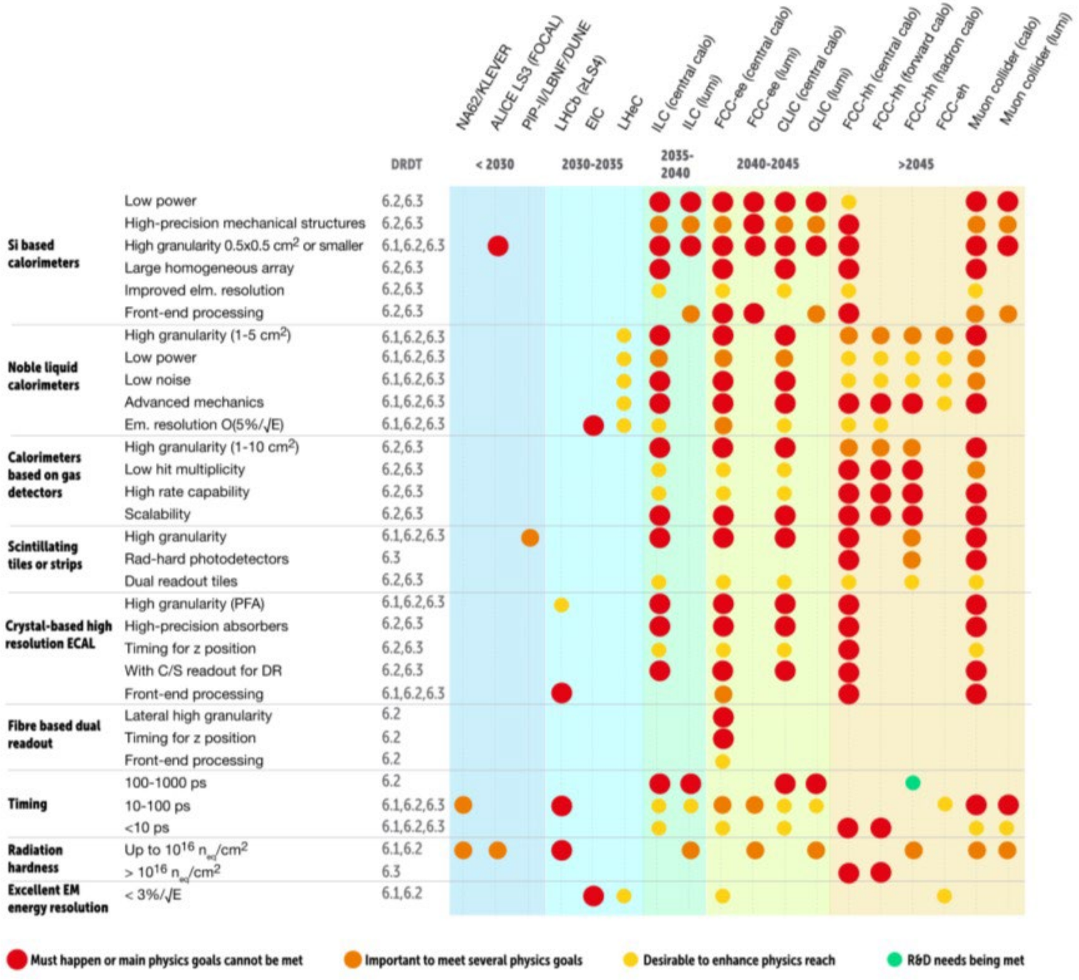
Calorimetry - DRD6

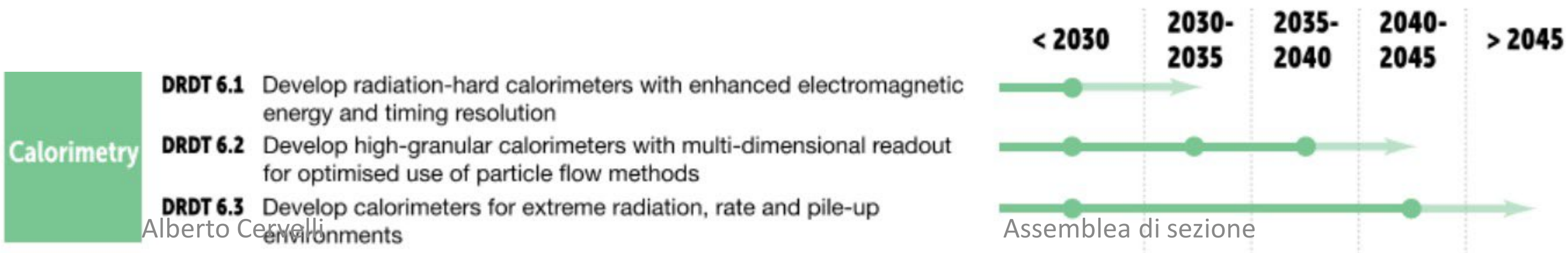
The enhanced electromagnetic energy and timing resolution most relevant in next decade for upgrades of ALICE and LHCb.

Particle Flow based on high granularity calorimeters:

- Dual-readout (e.g. DREAM/RD52 Collaboration, FCC-ee IDEA)
- High granularity LAr/LKr: LAr proven technique but high granularity challenging
- Finely segmented crystals
- Particle Flow based "tracking calorimeter" concept with very fine sense element segmentation

Extreme radiation hardness and pile-up rejection (FCC-hh)



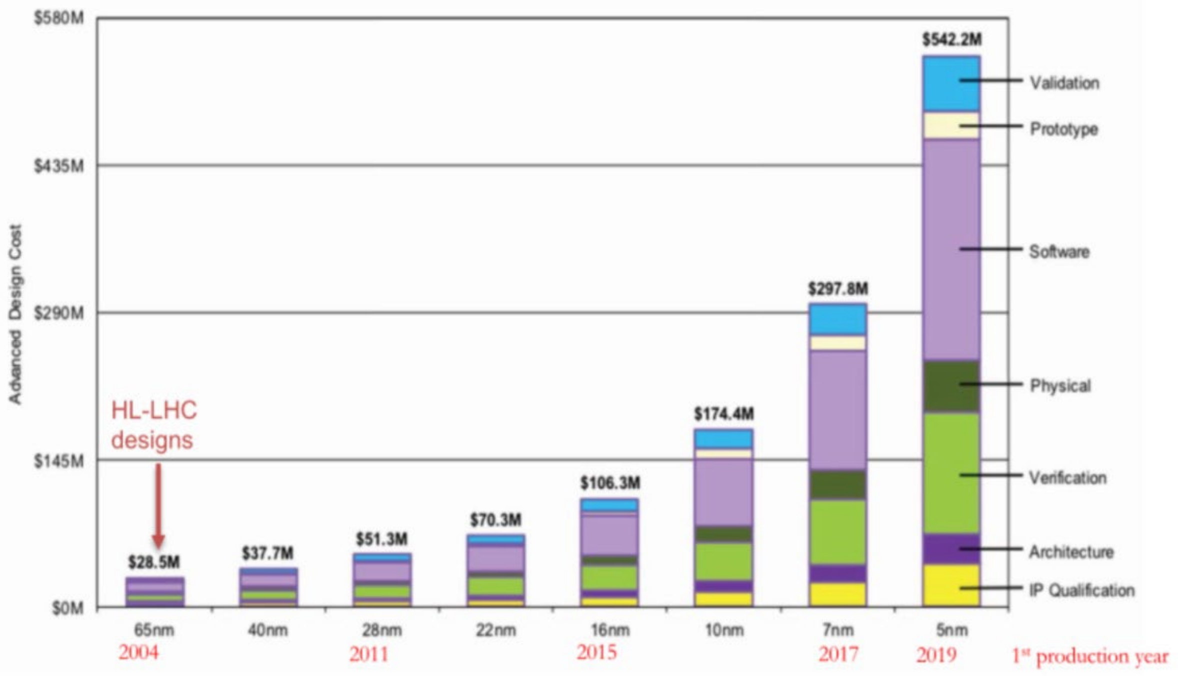


Electronics - DRD7

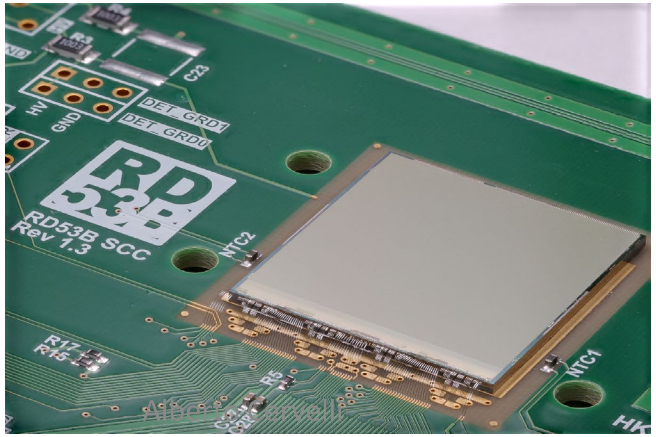
Main challenges:
- **precision timing** (ToF; 4D tracking),
- **High granularity** and **resolution** imply a **cost in terms of data handling, processing, complexity and power.**
- **Low consumption electronics** → no need for cooling

Need **latest advances in commercial microelectronics and high-speed links**

specific needs for HEP in e.g. **radiation hardness or operation in magnetic fields** with HEP at best a niche low volume market
→Long time to develop radiation

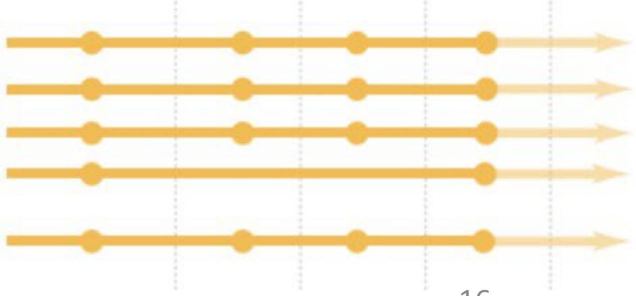


Chip Design and Manufacturing Cost under Different Process Nodes: Data Source from IBS*



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



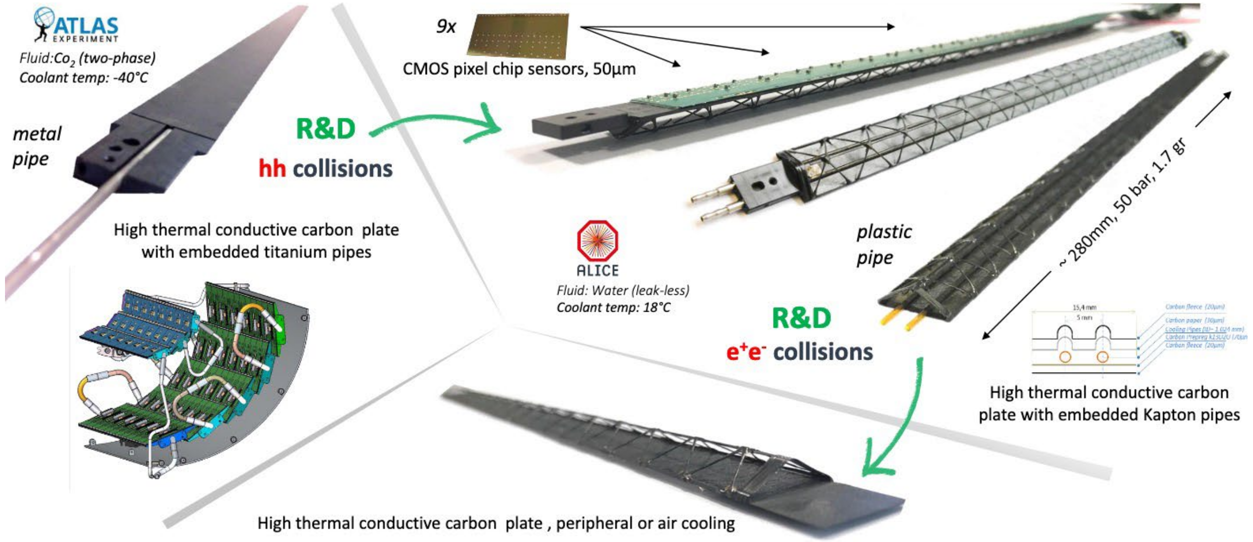
Integration – DRD 8 [Includes Luminometry]

Investigation of novel superconductors for magnet systems as well as support of expert design capabilities and modelling software for future experiments is vital.

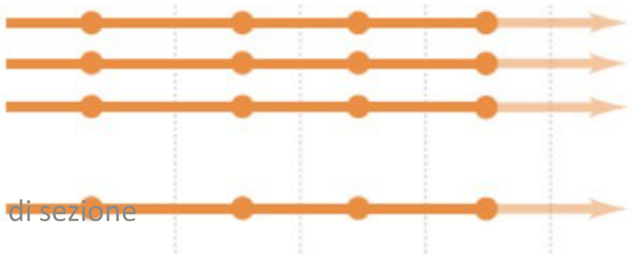
Cooling technologies for cryogenics and low-mass heat removal from on-detector electronics and semiconductor sensors require dedicated R&D activities.

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

Monitoring for environmental radiation and beam aspects



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



Oportunities

- Many R&D projects are already ongoing in Bologna! We should join the new R&D projects bringing our own expertise while seeking for synergies and collaborations with other groups working on similar developments

- Lots of different areas of experties are already available, together with a great amount of infrastructures and instrumentation.

- The Technincal and Technological areas of Bologna are already involved and well prepared for new and difficult challenges.

- Despite not having a focused project for this R&D efforts, the development of new detectors is crucial for any new project, and so we need to jump on this opportunity in order to be in the best shape to have leading roles in the future

Conclusions

- Bologna is involved in several R&D developments already. These activities should be reflected also in the new DRDs.
- The new DRDs might provide synergies and collaborations with other groups.
- We should participate to the formation of DRD groups and shape them such that they reflect our ongoing interests
- INFN has ongoing activities in basically all the DRD groups and in the general recommendations. It is therefore important to properly coordinate the various contributions to make sure that INFN' strong role in detector R&D is recognised.