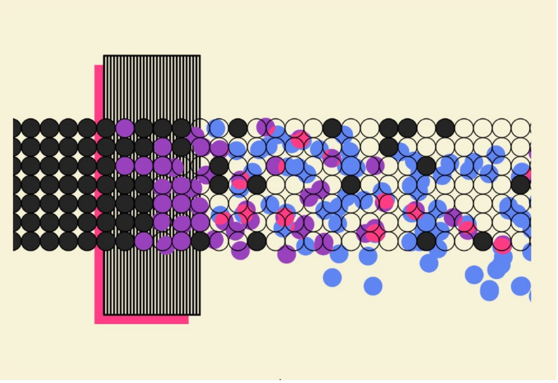


University of Chicago – *August 7, 2025*

2nd Annual US Muon Collider Meeting

Instrumentation R&D Directions

towards an experiment design a @ 10 TeV Muon Collider

Nadia Pastrone

Setting the framework

- Discoveries and new measurement results in HEP (as well in any scientific field) require and are strongly linked to sophisticated tools – **particle detectors, electronics** and **software/AI** – to identify, collect and analyse full information of all the final state particles

- Experimental environment and physics goals demand for
  different enabling technologies to face challenging requirements
  rigorous developments requiring adequate time and resources (people and funding)
  to reach the level of maturity reliable and feasible to build dedicated detectors

infrastructures
resources
plans
industry engagement

technology R&D
including "blue sky"

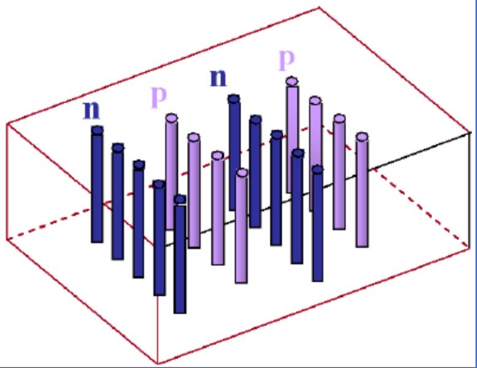
trained experts
continuous training

EU & US Strategy: Focused R&D for accelerator and detector components are MANDATORY

From R&D to HEP: one example on technology

Concept – Proof of principle

Late 90's



S. Parker et. Al. NIMA 395 (1997) 328, https://doi.org/10.1016/S0168-9002(97)00694-3

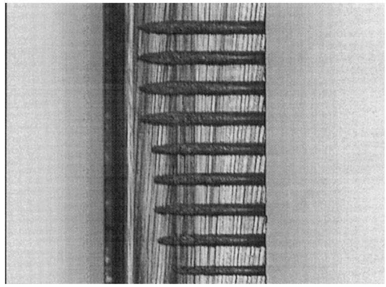
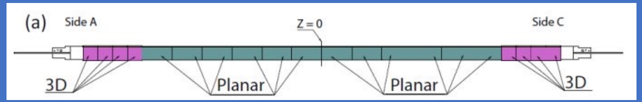


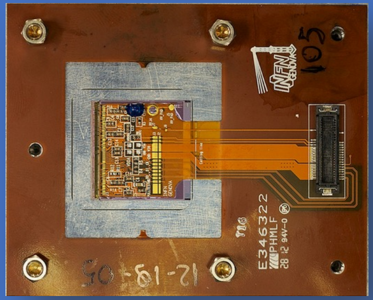
Fig. 4. A view of part of a set of etched holes, showing the increased depth reached by holes of larger diameters. The wafer was 540 μm thick and the etch time was 5 h. The photo-mask hole diameters from top to bottom are: four holes at 30 μm, four at 25 μm, and one at 20 μm.

C. Kenney, S. Parker, J. Segal and C. Storment,, IEEE Trans. Nucl. Sci. 46 (1999) 1224.

First applications in HEP

2014-18



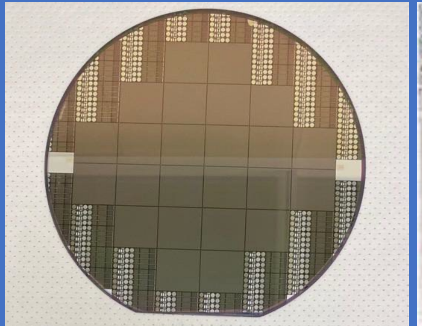


ATLAS Innermost layer, large eta, B. Abbot et al, *JINST 13 (2018) no.05, T05008*

Forward detectors in Phase–I
- ***AFP in ATLAS***
- ***PPS in CMS***

Key detector in HEP

2024-2028



FBK 3D wafer

Modules for the innermost layer in ATLAS –CMS Phase2

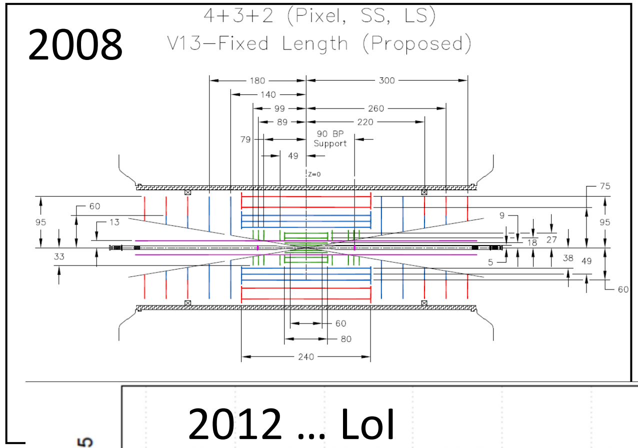
3D sensor technology

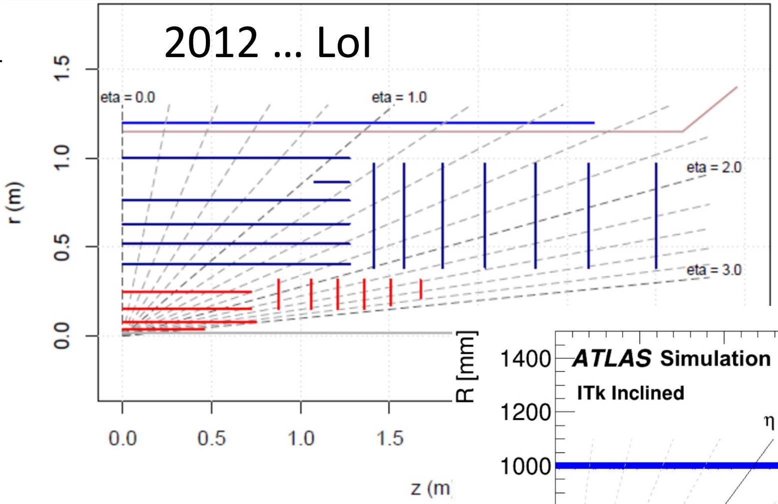
A very long way between first ideas and key applications in an experiment!

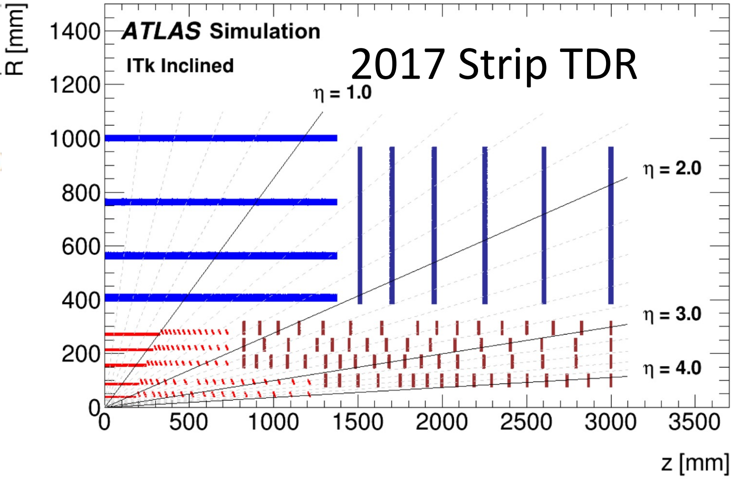
From ideas to HEP: one example on design

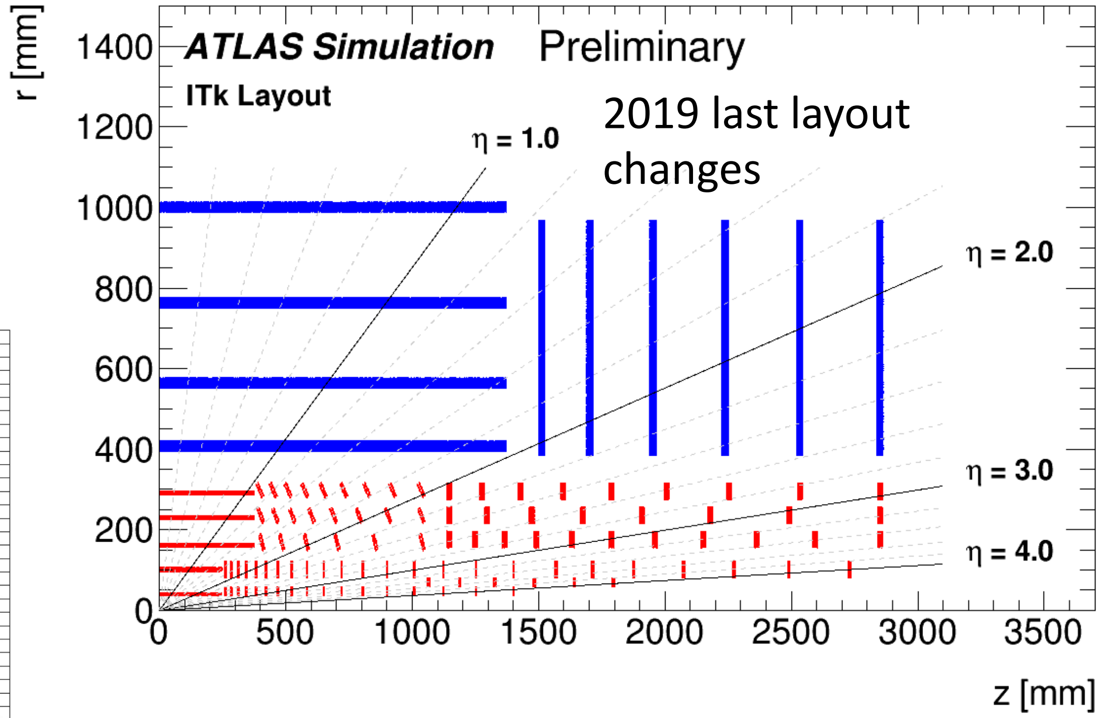
ATLAS Inner tracker layout for Phase-2 had a very long story (intrinsically connected to technology, bkg…)

- Discussion started in (at least) 2006 → Layout Advisory Committee → UTOPIA → Upgrade Layout TF, up to the ITk Layout Task force (2016) to finalize Layout for TDRs.
- Last minimal changes in 2019!







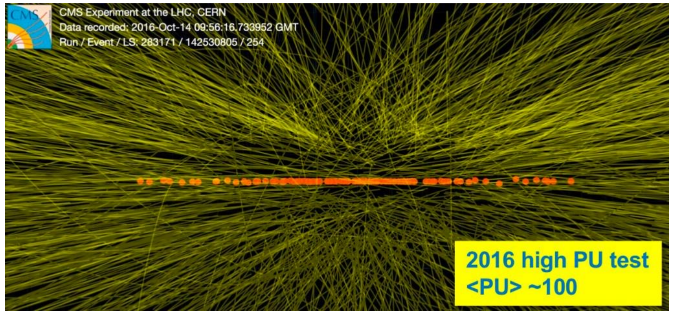


HL-LHC ATLAS and CMS upgrades - timeline

Typical Development Cycles: 20–30 years

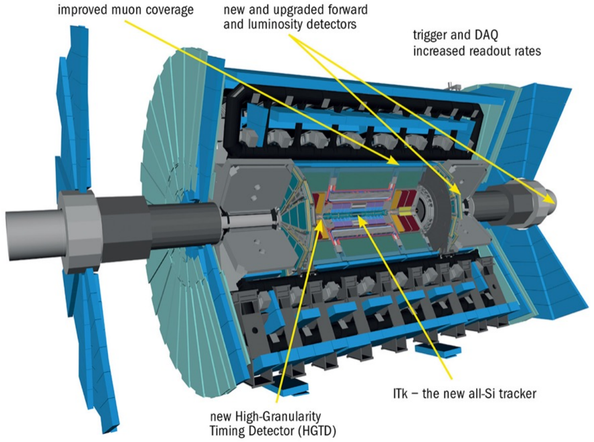
Ulrich Husemann - ESPPU

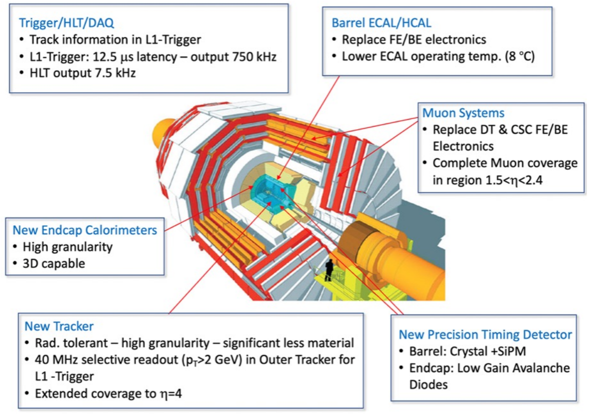
- First ideas and workshops — Early 2000s
- Letters of Interest/ Technical Proposals — 2012–2015
- Technical Design Reports — 2017–2021
- Production & Commissioning — 2022–2030

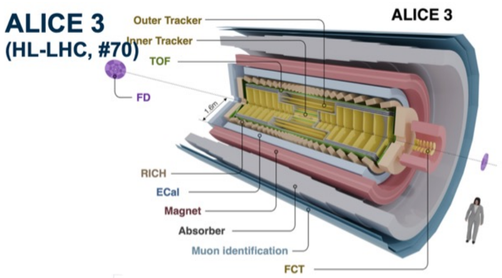


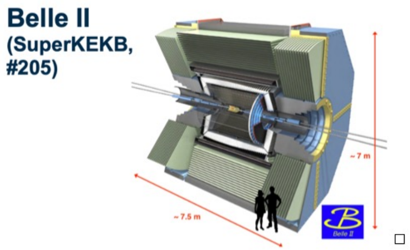
Detector technology R&D and design

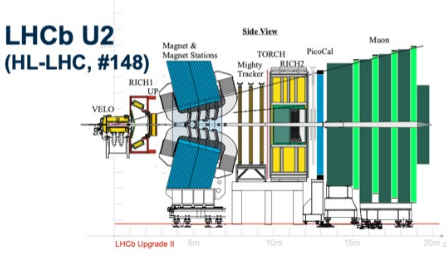
- new ideas are stemming from present implementation
- new plans for ALICE, LHCb, BELLE2 and ePIC @ EIC

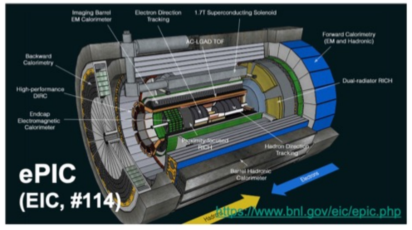




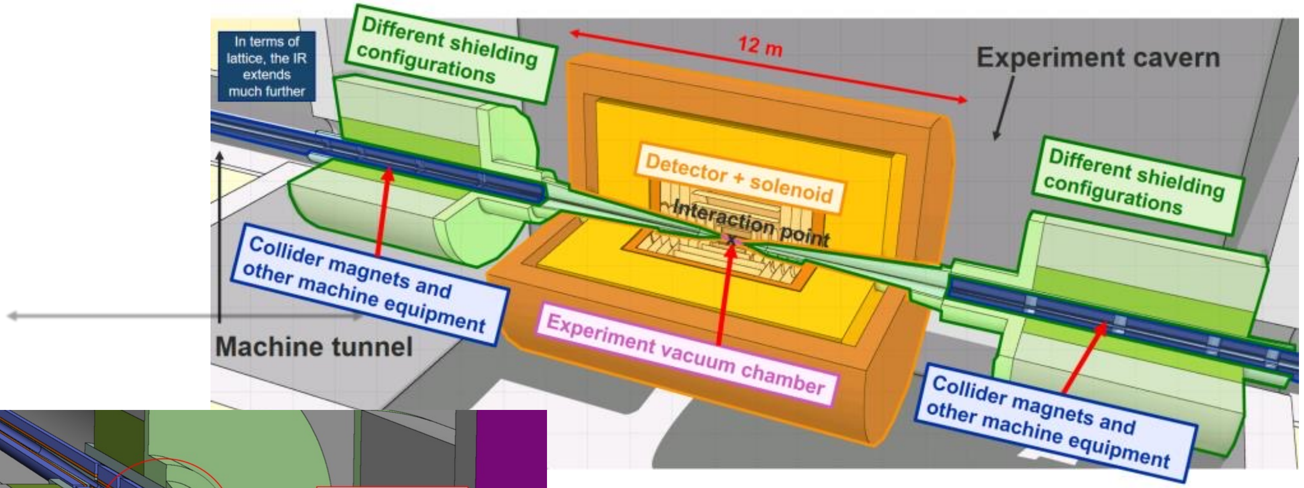






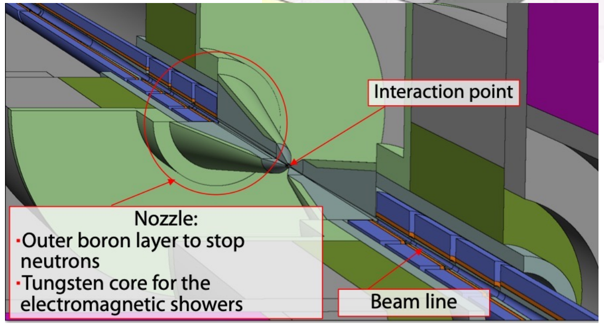


Experiment design @ 10 TeV Muon Collider

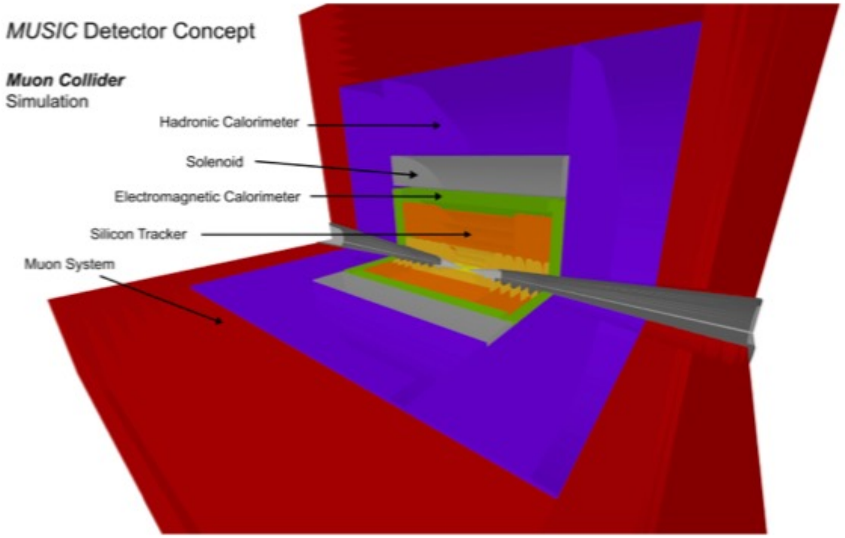


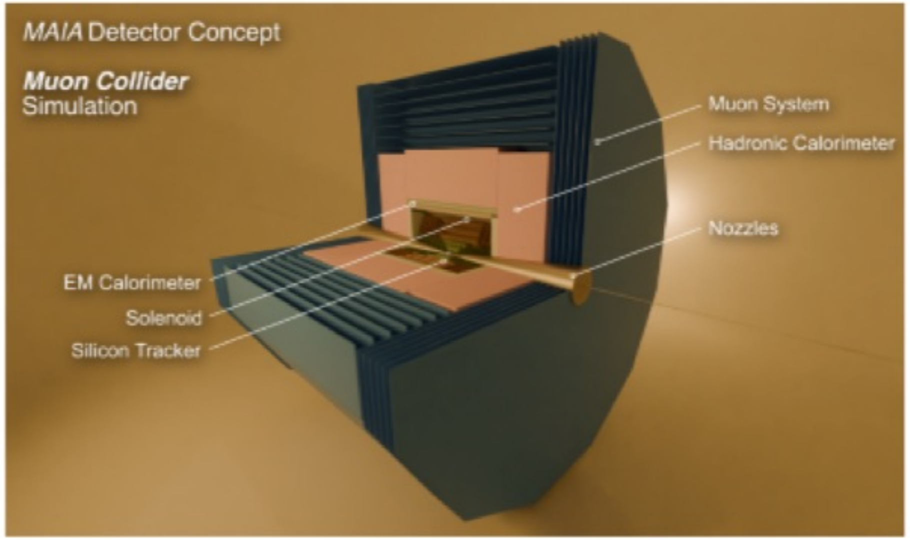
photons, electrons, positrons

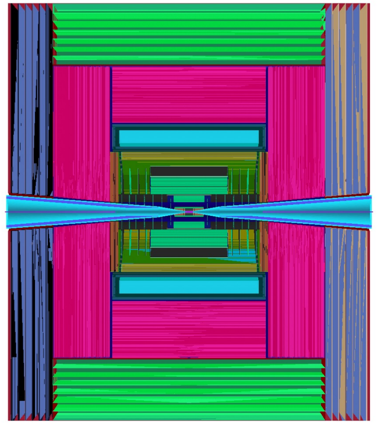
(0.0003% of a BIB event)



Simone Pagan Griso
USMCC talk







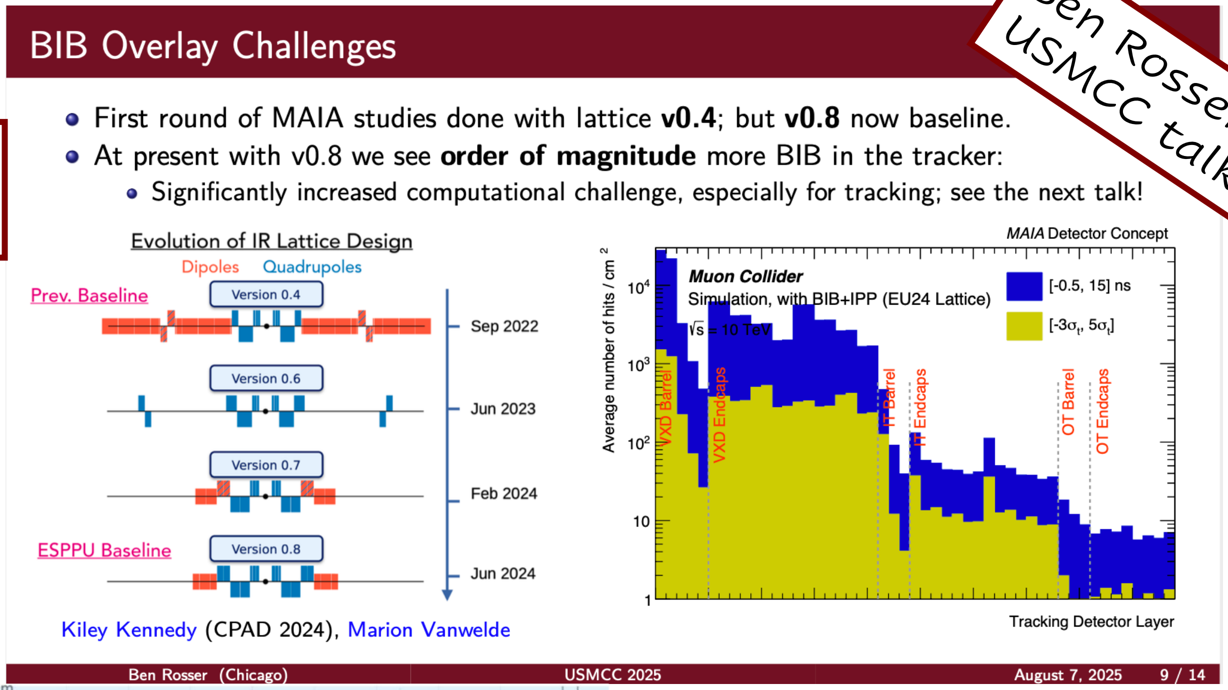
Backgrounds: *beam induced (BIB)-incoherent e^+e^- pairs production*

beam halo

Crucial ingredients:

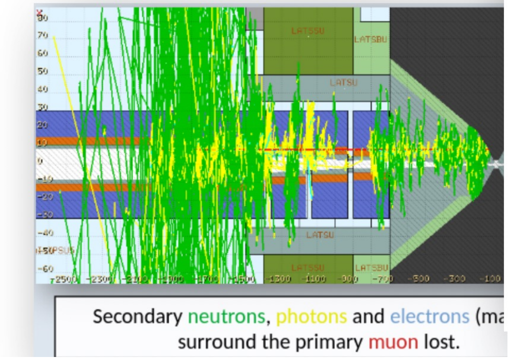
- Machine Lattice @ 10 TeV
- Machine detector interface (MDI)
- Nozzle structure
- Detector magnet

Donatella Lucchesi
USMCC School talk

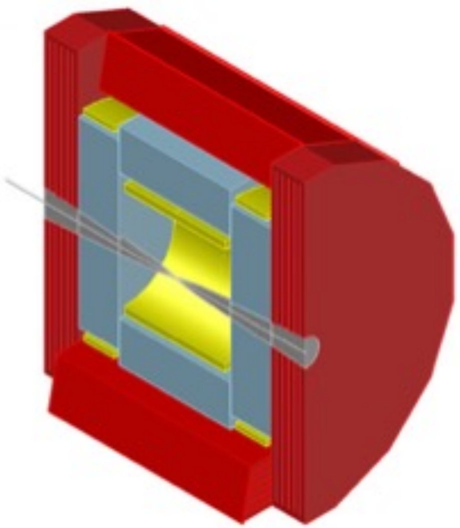


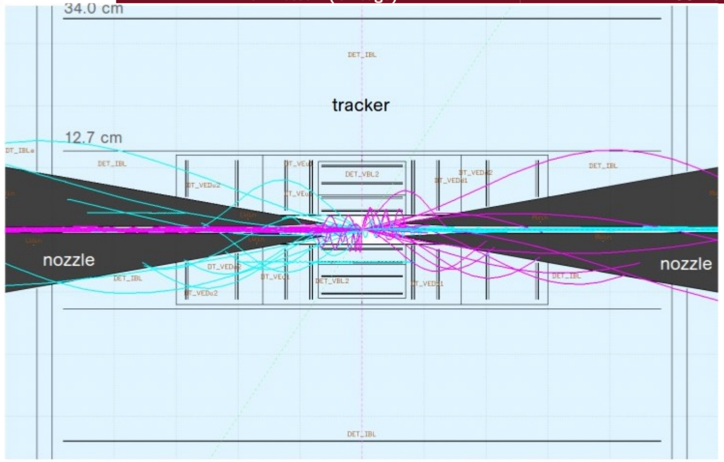
Ben Rosser
USMCC talk

First IMCC halo-induced background studies for 10 TeV:



Daniele Calzolari - ICHEP 2024





John Dervan
USMCC talk

neutron BIB
on ECAL studies

Detector requirements: @ 10 TeV

Requirement	Baseline	Aspirational
Angular acceptance $\eta = -\log(\tan(\theta/2))$	$\|\eta\| < 2.5$	$\|\eta\| < 4$
Minimum tracking distance [cm]	~ 3	< 3
Forward muons ($\eta > 5$)	tag	$\sigma_p/p \sim 10\%$
Track σ_{p_T}/p_T^2 [GeV^{-1}]	4×10^{-5}	1×10^{-5}
Photon energy resolution	$0.2/\sqrt{E}$	$0.1/\sqrt{E}$
Neutral hadron energy resolution	$0.4/\sqrt{E}$	$0.2/\sqrt{E}$
Timing resolution (tracker) [ps]	$\sim 30 - 60$	$\sim 10 - 30$
Timing resolution (calorimeters) [ps]	100	10
Timing resolution (muon system) [ps]	~ 50 for $\|\eta\| > 2.5$	< 50 for $\|\eta\| > 2.5$
Flavour tagging	b vs c	b vs c, s-tagging
Boosted hadronic resonance identification	h vs W/Z	W vs Z

STRONG INTEREST IN DEVELOPING:

- 4D vertex and tracker sensors
- new calorimeters 4D or 5D ideas
- sustainable muon detector
- front-end electronics with on-board intelligence
- powerful reconstruction algorithm
- AI simulation and analysis tool

Maximum values

ionizing dose **1 MeV neutron-eq fluence**

Component	Dose [kGy]		1 MeV neutron-equivalent fluence (Si) [10^{14} n/cm^2]	
	MAIA	MUSIC	MAIA	MUSIC
Vertex (barrel)	1000		2.3	
Vertex (endcaps)	2000		8	
Inner trackers (barrel)	70		4.5	4
Inner trackers (endcaps)	30		11.5	10
ECAL	0.58	1.4	0.15	1

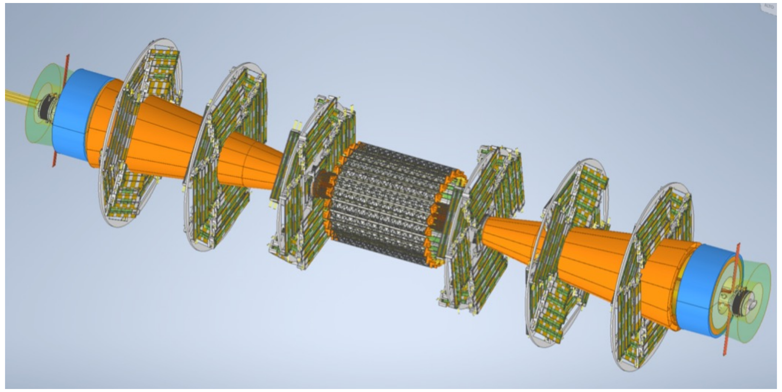
Other future projects requirements - vertexing

	ITS3	ALICE 3 VTX	ALICE 3 TRK	ePIC	FCC-ee
Single-point res. (μm)	5	2.5	10	5	3
Time res. (ns RMS)	2000	100	100	2000	20
In-pixel hit rate (Hz)	54	96	42		few 100
Fake-hit rate (/pixel/event)	10^{-7}	10^{-7}	10^{-7}		
Power cons. (mW / cm^2)	35	70	20	<40	50
Hit density (MHz/cm^2)	8.5	96	0.6		200
NIEL (1 MeV n_{eq}/cm^2)	$4 \cdot 10^{12}$	$1 \cdot 10^{16}$	$2 \cdot 10^{14}$	few 10^{12}	10^{14} (/year)
TID (Mrad)	0.3	300	5	few 0.1	10 (/year)
Material budget (X_0/layer)	0.09%	0.1%	1%	0.05%	˜0.3%
Pixel size (μm)	20	10	50	20	15-20

Key technology: MAPS – monolithic active pixel sensors

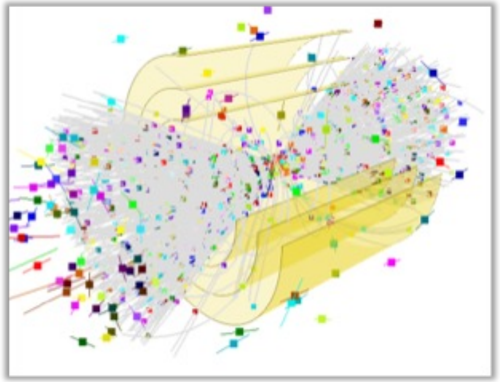
- Integration of sensitive elements and logic on a **single chip**
- Leveraging industry **standard CMOS** processes, modified for particle physics

Vertex detector - IDEA detector



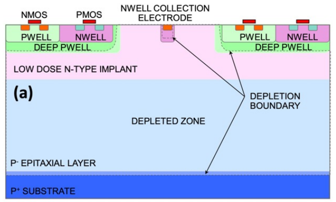
On-going R&D on tracking sensors – DRD3

	Vertex Detector	Inner Tracker	Outer Tracker
Cell type	pixels	macropixels	microstrips
Cell Size	$25\,\mu m \times 25\,\mu m$	$50\,\mu m \times 1\,mm$	$50\,\mu m \times 10\,mm$
Sensor Thickness	$50\,\mu m$	$100\,\mu m$	$100\,\mu m$
Time Resolution	30 ps	60 ps	60 ps
Spatial Resolution	$5\,\mu m \times 5\,\mu m$	$7\,\mu m \times 90\,\mu m$	$7\,\mu m \times 90\,\mu m$

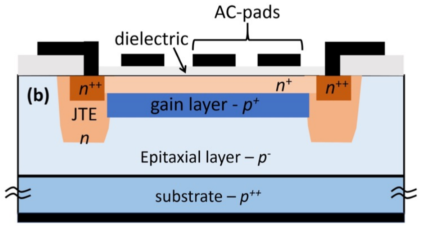


Sinergy with timing sensors development for HL-LHC

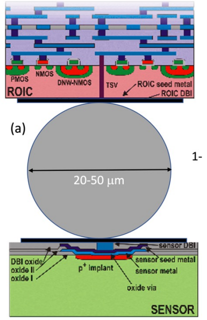
Promising technologies



Monolithic devices (CMOS):
Good timing and spacial resolution, but radiation hardness to be improved



Low Gain Avalanche Detectors (LGAD):
Large and fast signal (20-30 ps resolution), moderate radiation hardness

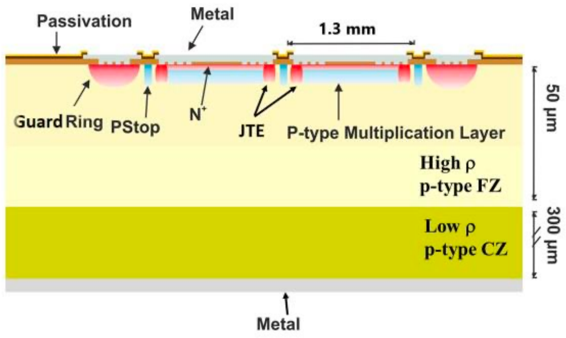


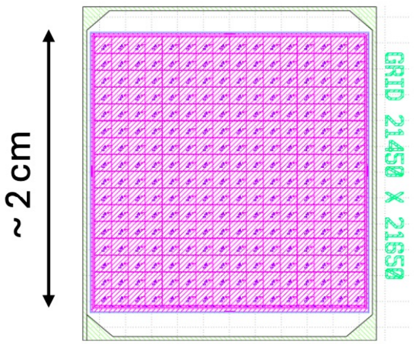
Hybrid small pixel devices:
No gain but fast timing (20-30 ps resolution) and good position resolution. Intrinsically radiation hard

Silicon LGAD sensors for 4D tracking up to very high fluence:

V. Sola et al., Nucl. Instrum. Meth. A 1040 (2022) 167232.

LGAD: timing resolution for high radiation environments





ETL sensor (Similar to HGTD sensor)**:**

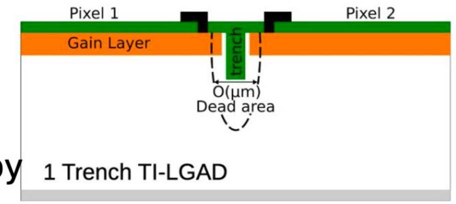
- Pixel pitch: 1.3 mm
- **Inter-pixel distance: < 100µm** (determined by segmentation technology based on JTE and p-stop)
- **Fill Factor** ~ 90%

LGAD technology is relatively young, with plenty of room for improvement and new ideas

Marco Ferrero – IMCC 2025

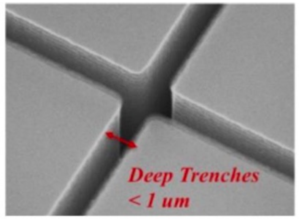
LGADs evolution toward 4D-tracker

Trench-isolated LGADs (TI-LGADs)



The traditional JTE and p-stop are replaced by trench etched into the silicon sensor

- Smaller dead area: trench width ~1µm
- Small pixels with better fill factor



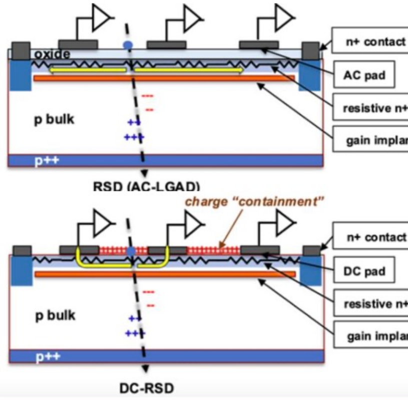
R&D ongoing in DRD3 collaboration

Resistive silicon detector (RSD)

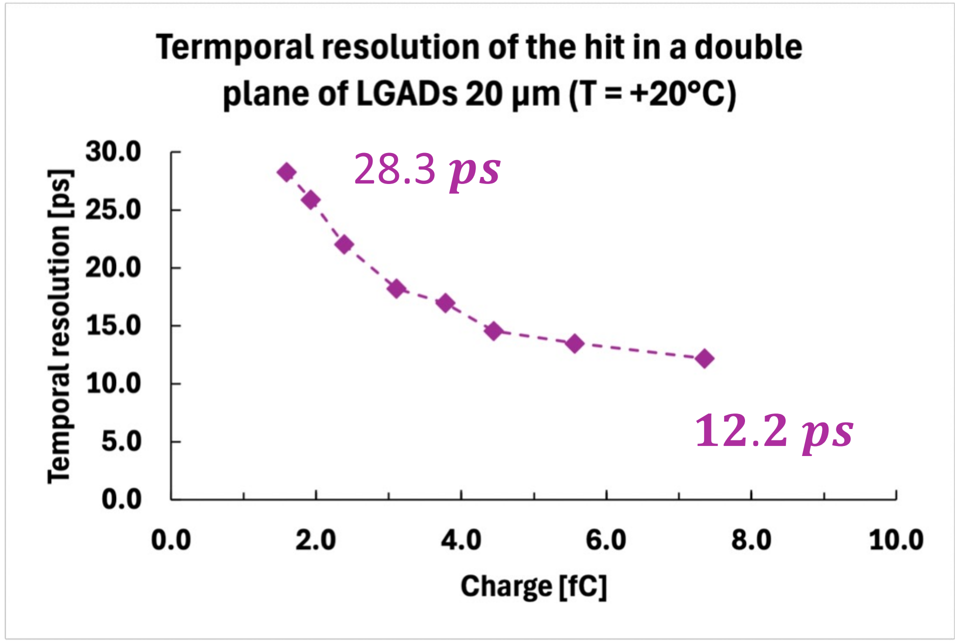
- Fill factor close to 100%
- Space resolution: ~ 3-5% of the pitch
- Timing resolution of 30-40 ps

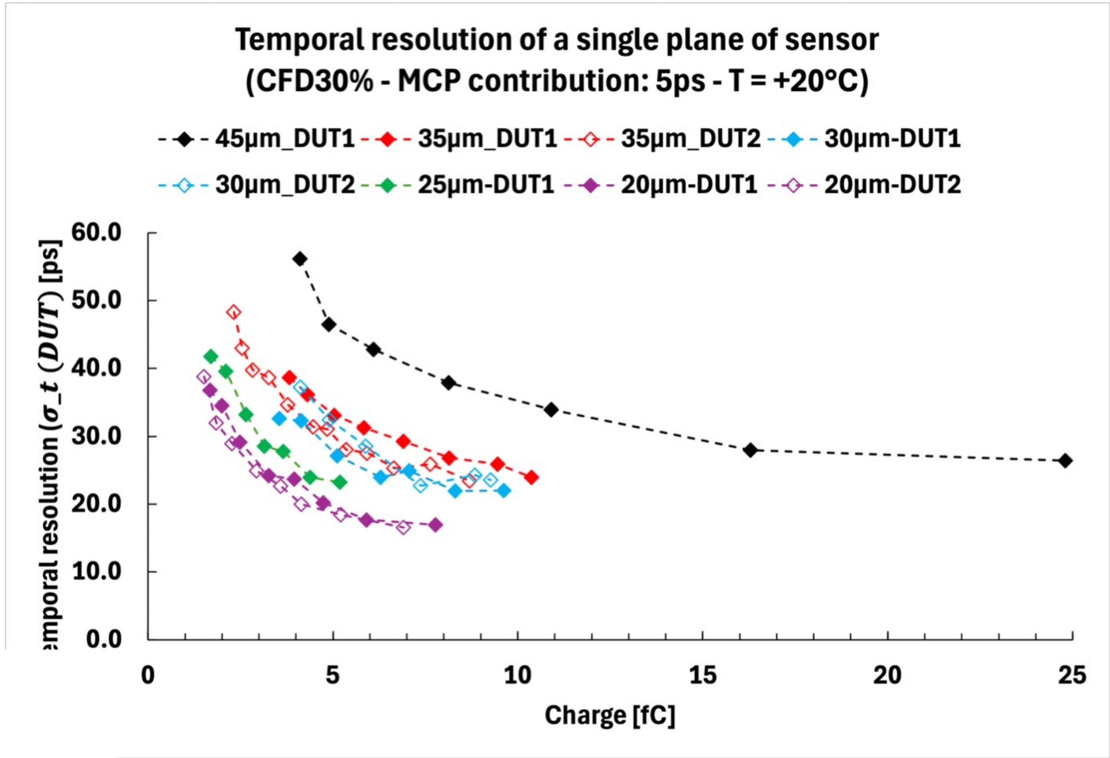
RSD is a technology suitable for:

- low density, low power read-out architectures (approximately x100 fewer channels than standard pixel sensors)
- Environment with low-medium event rate



LGAD: timing resolution for irradiated sensors



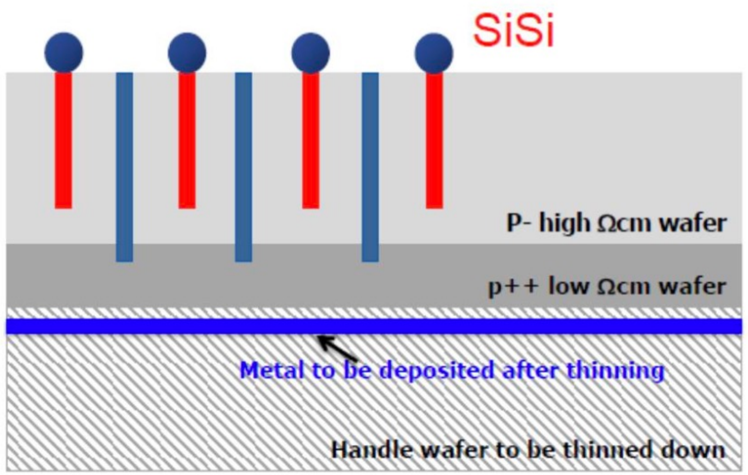


- Timing resolution of unirradiated thin LGADs 35, 30, 25 and 20 μm-thick has been measured
  - **35, 30 and 25 μm-thick LGADs** can achieve timing resolutions **below 25 ps**
  - **20 μm- thick LGADs** can achieve a resolution of **17 ps**
- The risetime of the signal and the landau contribution to the timing resolution decrease in thinner LGADs leading to better timing resolution in thinner ones.
- The minimum charge to reach a fixed value of timing resolution decreases as a function of LGAD thickness.
- A timing resolution of **12.2 ps** has been measured with a **double plane of 20 μm-thick LGAD.**
- **Irradiated 30 μm-thick LGADs** can reach a timing resolution of **18 ps (20 ps)** up to an irradiation fluence of $1.5 \cdot 10^{15}\ n_{eq}/cm^2$ ($2.5 \cdot 10^{15}\ n_{eq}/cm^2$).

Marco Ferrero – TREDI 2025

3D sensors for 4D tracking

Marco Ferrero – IMCC 2025

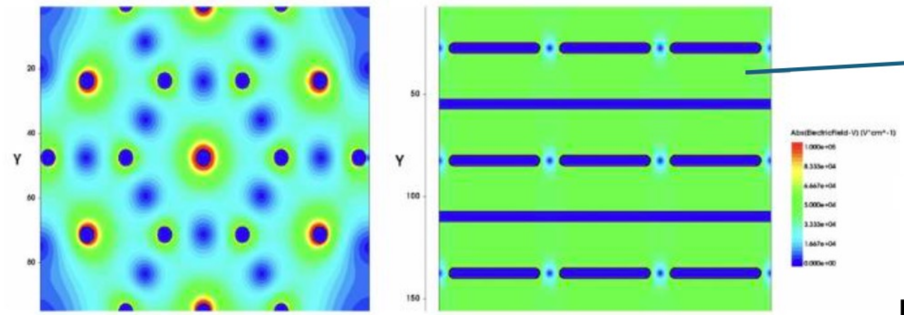


3D sensors technology:

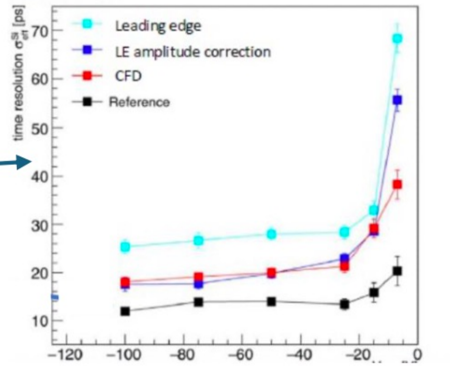
- Well-suited for environments with very **high event rates** and **pile-up**
- Ideal for use in vertex detectors
- Design based on column and trench electrodes (able to achieve **~10 ps resolution**)
- **~99% efficiency** (when operated tilted)
- Excellent **radiation resistance** ($>10^{16}$ n_{eq}/cm^2)

Column

Trench



Suitable for timing



From [A. Lampis et al 2023 JINST 18C01051]

3D sensors technology was chosen for the LHCb 4D VELO

Calorimeters - DRD6

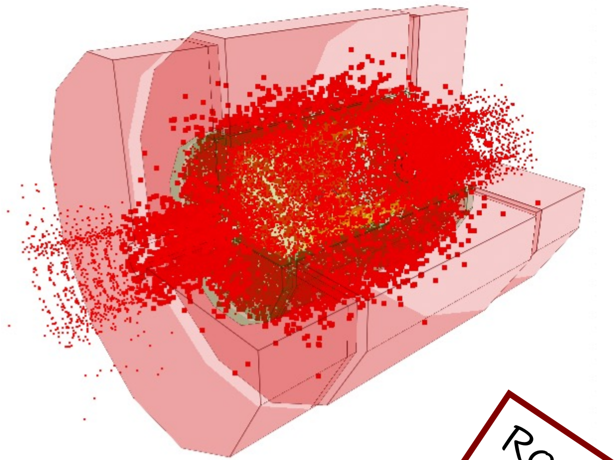
Key requirements:

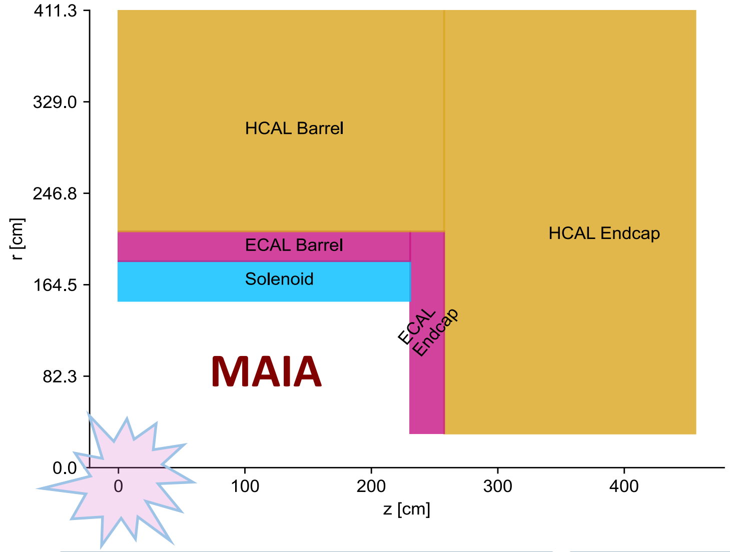
- **Energy resolution (3-4% at 100 GeV)** and compensation of different response to electrons and hadrons
- Suited for modern algorithms: **particle flow, machine learning**
- New: **5D calorimetry** (energy, 3D position, time)

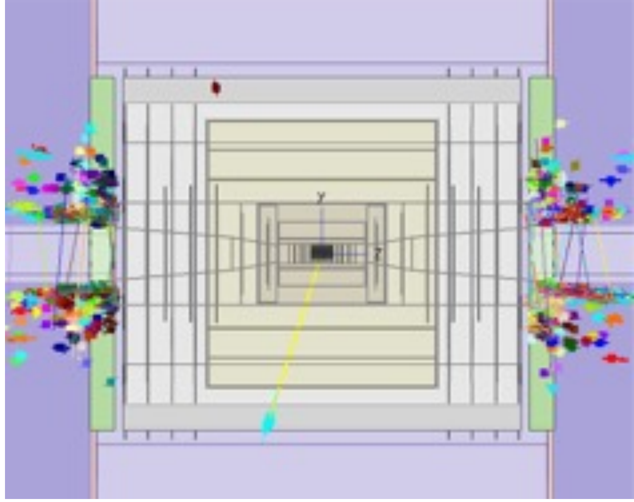
Key technologies:

- Main types: sandwich, optical (crystal, fiber), noble liquids
- High granularity imaging calorimeters high lateral and longitudinal segmentation
- Dual-readout calorimeters: scintillation and Cherenkov effects
- Optical calorimeters: efficient photon detectors

Calorimeters







Rose Powers
USMCC talk

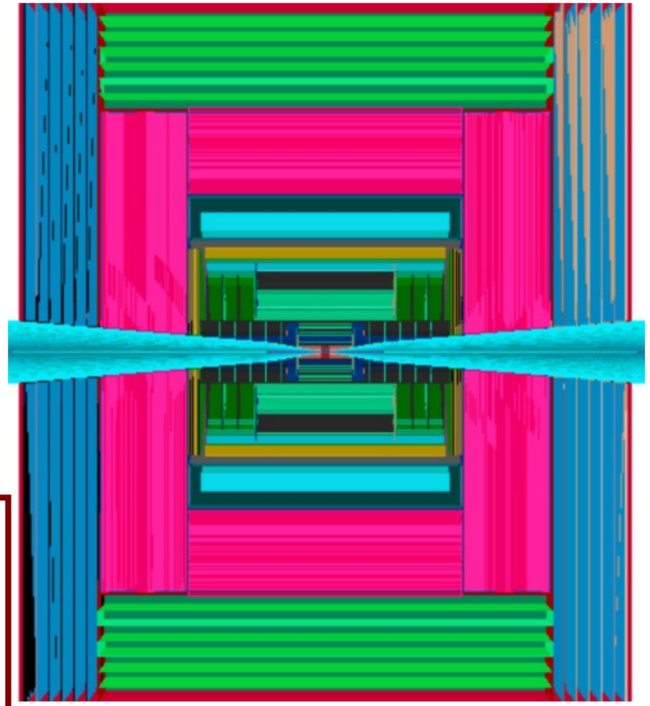
CALIBRATION - MAIA

Particle behavior in the solenoid

ECAL:
- Silicon and Tungsten
- 5x5 mm^2 cells
- 50 layers

HCAL:
- Iron and scintillator
- 30x30 mm^2 cells
- 75 layers

MUSIC design @ 10 TeV



Donatella Lucchesi et al. – IMCC

Gregory Penn
USMCC talk

RECONSTRUCTION

Particle Flow @ $\mu\mu$ environment

Pandora Algorithm excellent starting tool, but needs to operate under BIB environment

MUSIC

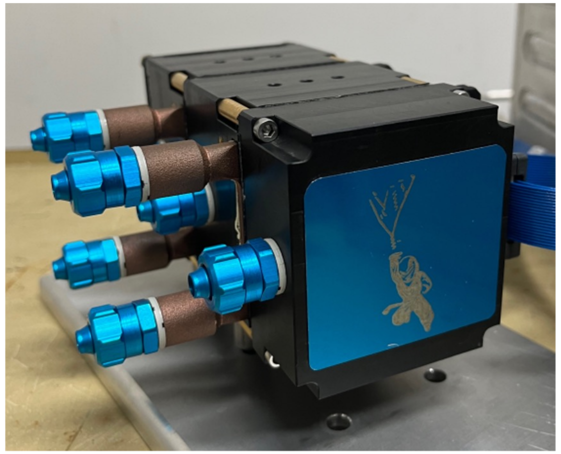
moving the solenoid between the calorimeters

On-going R&D in e.m. calorimeters – DRD6

Crilin, *JINST* **17** P09033

Crilin – CRystal calorImeter with Longitudinal InformatioN –

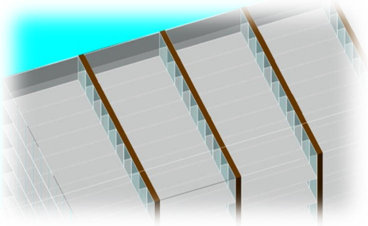
semi-homogeneous electromagnetic calorimeter based on **Lead Fluoride Crystals** (PbF_2) matrices where each crystal is readout by 2 series of 2 UV-extended surface mount **SiPMs**

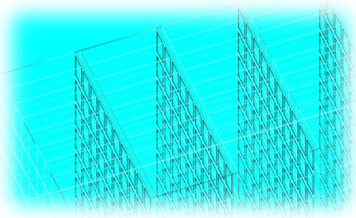


2-layer 3x3-crystal Crilin prototype

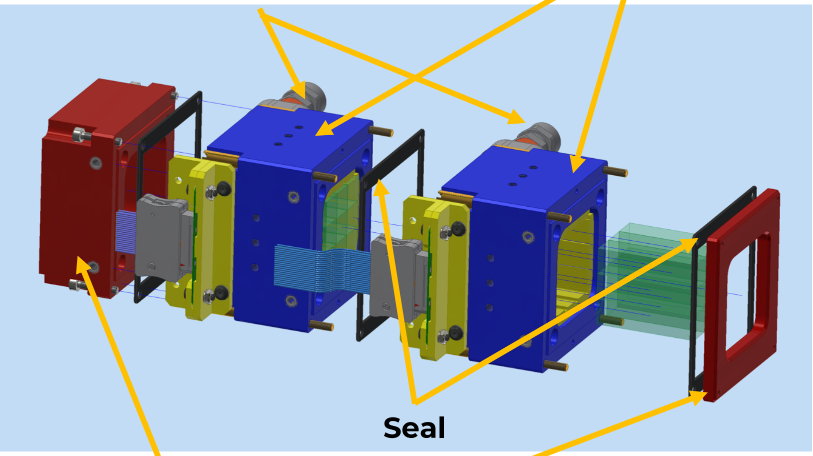
High-density crystal:
need for increased layer numbers with space constraints
Speed response:
Cherenkov crystals, ensuring accurate and timely particle detection
Semi-homogeneous:
strategically between homogeneous and sampling calorimeters
Flexibility:
able to modulate energy deposition for each cell and adjust crystal size
Compactness:
Unlike segmented or high granularity calorimeters it can optimize energy detection while staying compact

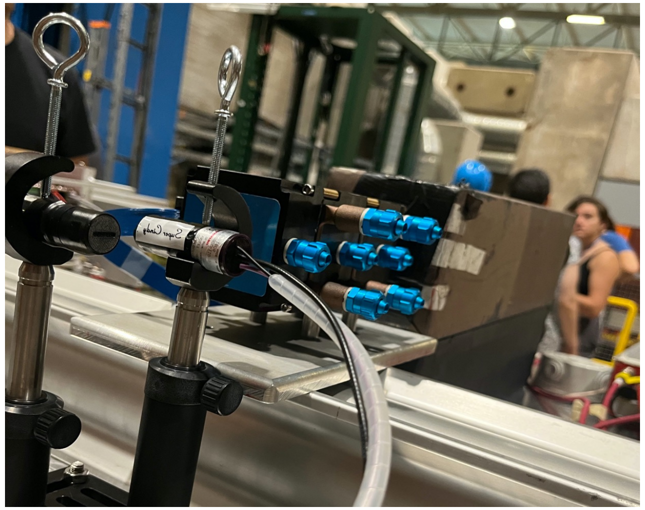
- O(100-1000) particles/cm^2 at ECAL surface
- >200 TeV deposited energy per event
- >1 kGy/year TID, 10^{14} neq(1 MeV)/cm^2 year





Results from a 3 layers prototype of test beams





Crystal	PbF_2	PWO-UF
Density [g/cm^3]	7.77	8.27
Radiation length [cm]	0.93	0.89
Molière radius [cm]	2.2	2.0
Decay constant [ns]	-	0.64
Refractive index at 450 nm	1.8	2.2
Manufacturer	SICCAS	Crytur

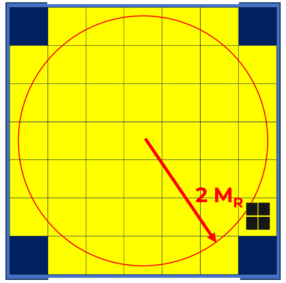
For the expected radiation level **the choice for SiPMs was 10 µm Hamamatsu SMD** for minor dark current contribution

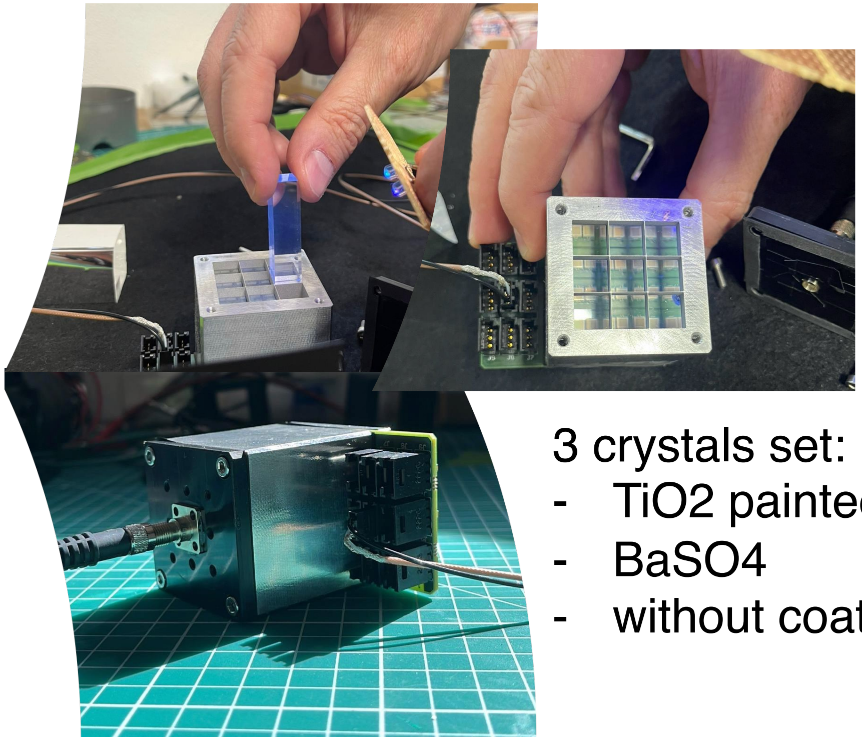
- **Time resolution**: < 40 ps for single crystals, for E_{dep} > 1 GeV
- **Radiation resistance:**
  PbF_2(PWO-UF) robust to > 35(200) Mrad
  SiPMs validated up to 10^{14} n_{1MeV}/cm^2 displacement-damage eq. fluence

IRRADIATION STUDIES

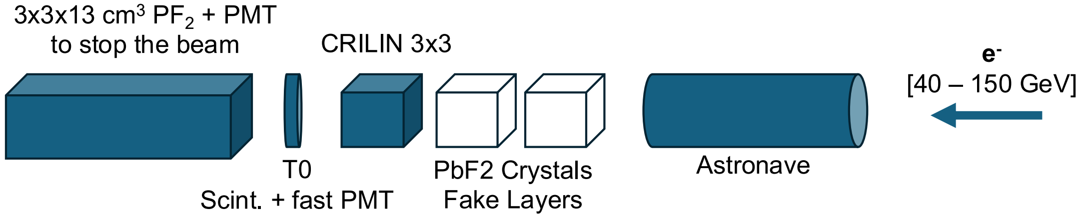
- **PbF_2:**
  - **after a TID > 350 kGy no significant decrease** in transmittance observed
  - Transmittance after neutron irradiation showed no deterioration
- **$PbWO_4$-UF:** for first layer
  - **after a TID > 2 MGy no significant decrease** in transmittance observed

CRILIN: 2025 test beam and 2026 plans



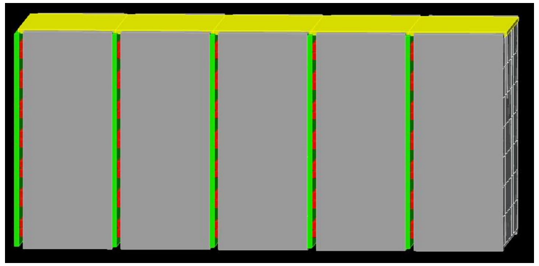


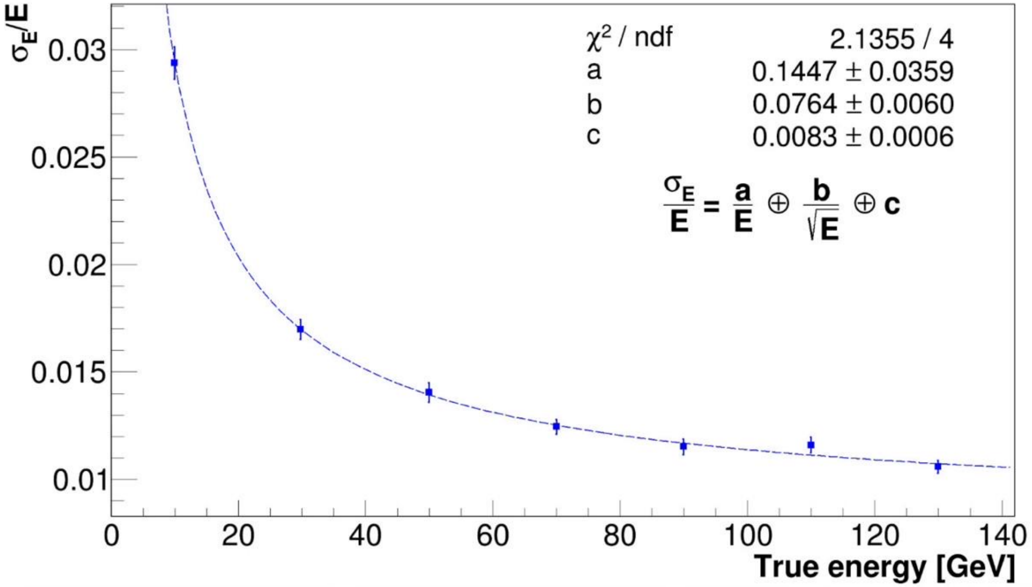
3 crystals set:
- TiO2 painted
- BaSO4
- without coating



FINAL PROTOTYPE
5 layers, 7x7 crystals, ~ 250 channels

- slightly wider crystals (PbF2 1.3x1.3 cm2 with 0.1mm tolerance)
- 100 μm printing per side
- Aluminum matrix support
  - → max 200 μm inter-crystal thickness
  - → max 2mm external envelope thickness
  - → max 5mm between layers





- 0.2 P.E./MeV per crystal
- gaussian noise σ = 10 MeV
- 30 MeV energy threshold per crystal

Simulation: Energy Resolution ~ 7.5%/√E

On-going R&D in hadronic calorimeters – DRD6

[MPGD-based hadronic calorimeter, Nucl. Instrum.Meth. A 1047 (2023) 167731]

MPGD-HCAL

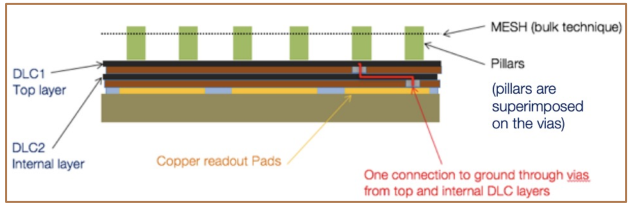
based on **resistive Micro-Pattern Gaseous Detectors** as **readout layers for a sampling hadronic calorimeter**

MPGD features:

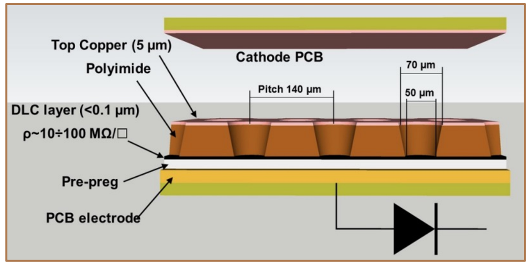
- **cost-effectiveness** for large area instrumentation
- radiation hardness up to several **C/cm²**
- **discharge rate** not impeding operations
- rate capability O (**MHz/cm²**)
- high granularity
- time resolution of **few ns**

one of the goals of such R&D is to choose the best technology for calorimetry @ Muon Collider

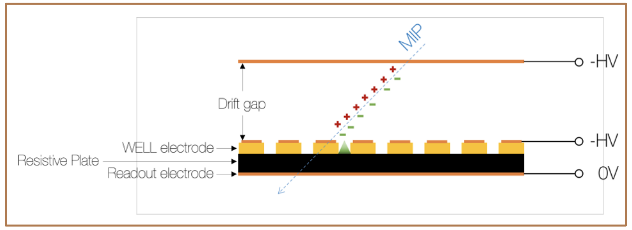
Micromegas (MM)



µRWELL



RPWELL



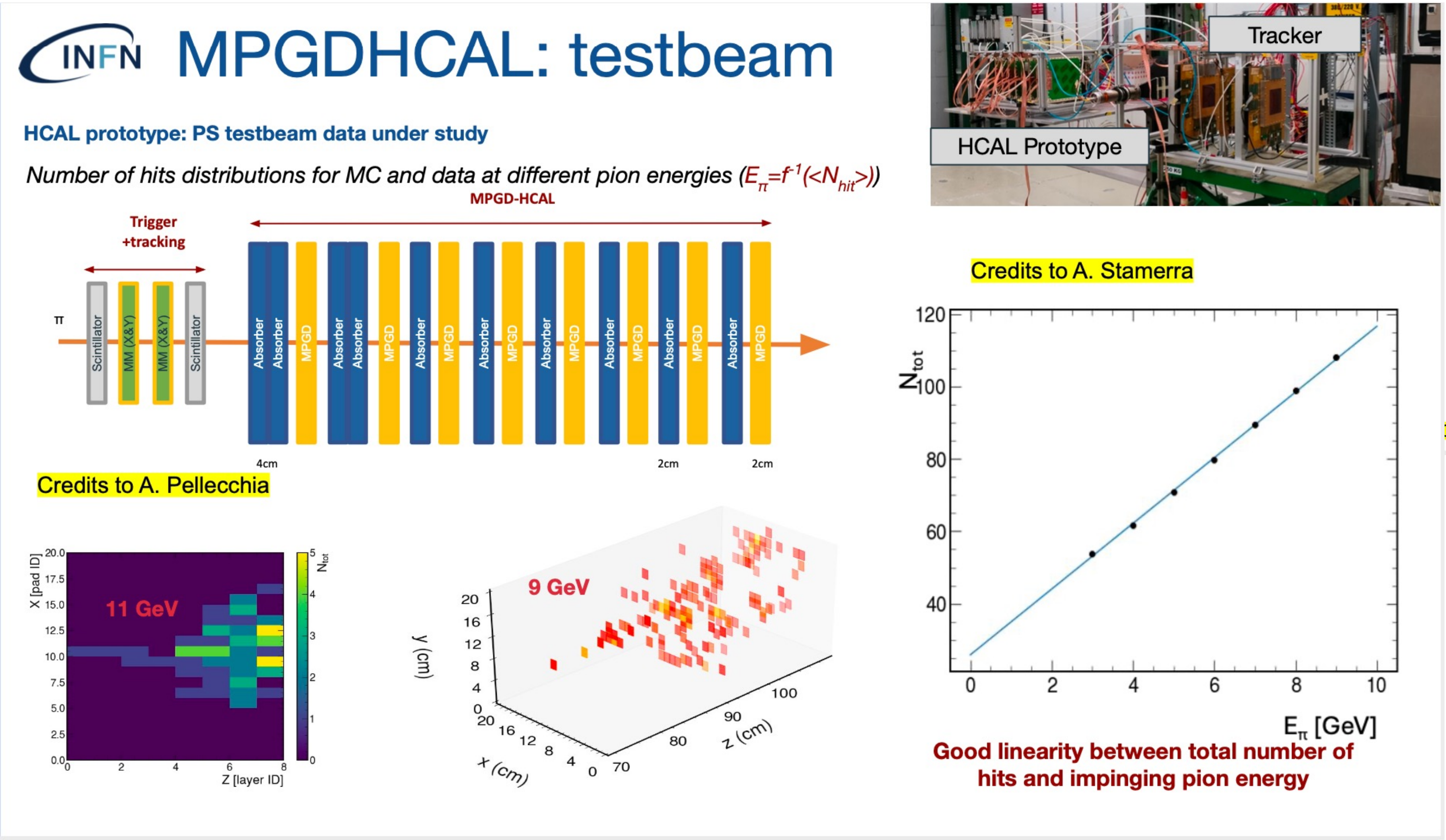
Past work:

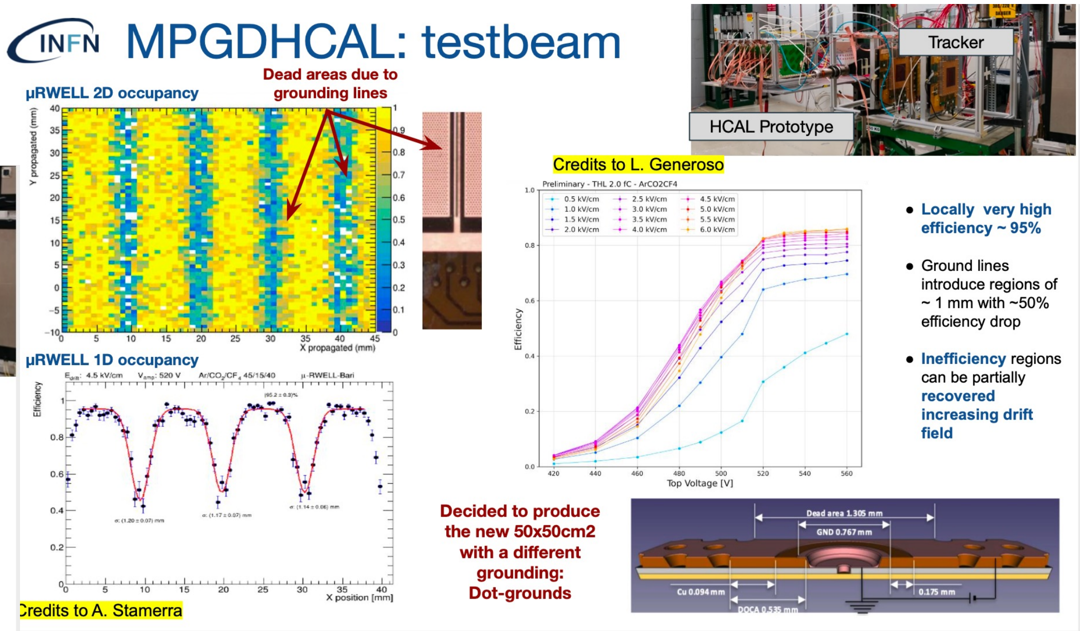
- [CALICE collaboration]: a sampling calorimeter using **gaseous detectors** (RPC) but also tested MicroMegas
- [SCREAM collaboration]: a sampling calorimeter combining RPWELL and resistive MicroMegas

R&D plan → systematically **compare** three MPGD technologies for hadronic calorimetry: resistive MicroMegas, µRWELL and RPWELL, while also investigating **timing**

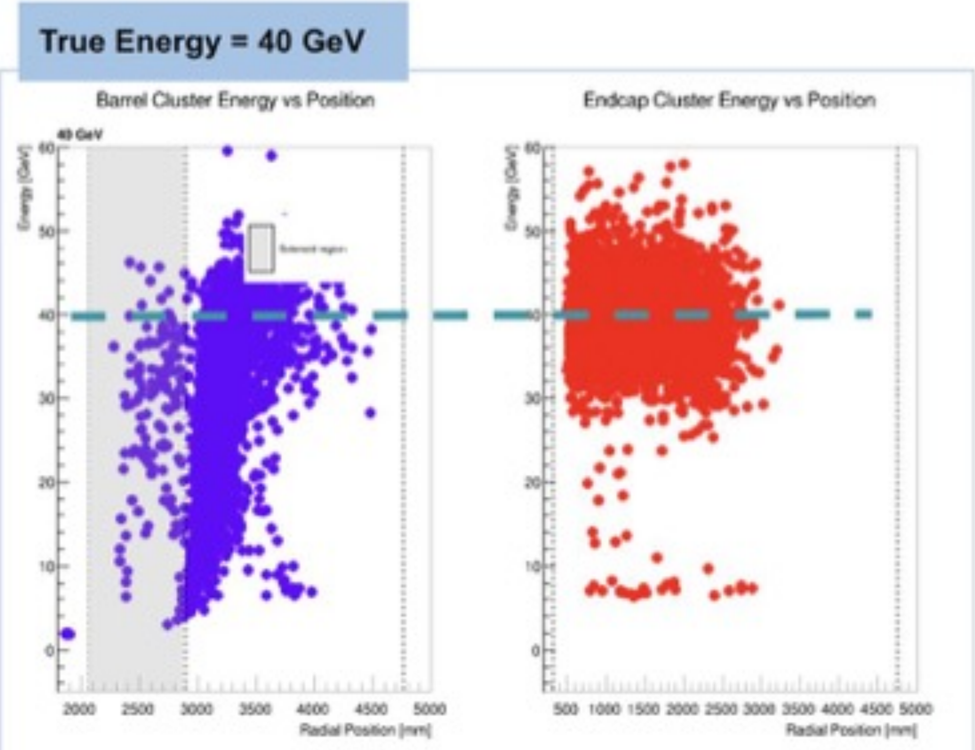
Hadronic calorimeter

testbeam





Simulation - 10 TeV



Evaluated the impact of the MUSIC detector concept
on a MPGDHCAL
Solenoid between ECAL and HCAL

Muon systems - DRD1

Key requirements

- **Resolution** (momentum: 0.1% at 45 GeV, time)
- **Particle identification** (dE/dx or dN/dx in gaseous detectors:
π/K separation up to 100 GeV; muon ID)
- **New: 4D tracking** (3D position: < 30 μm, time: < 30 ps)

Key technologies

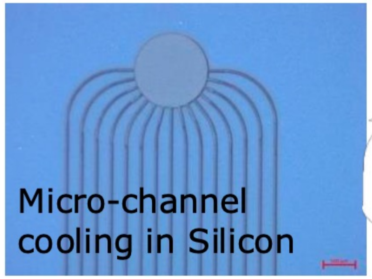
- **Gaseous** detectors:
parallel plates, wire chambers, micro-pattern detectors, drift chambers, time projection chambers
- **Silicon** detectors:
hybrid and monolithic pixels, ultrafast timing, strips *(FCC-ee: gaseous tracker enclosed with silicon "wrapper")*
- **Scintillating (fiber)** detectors

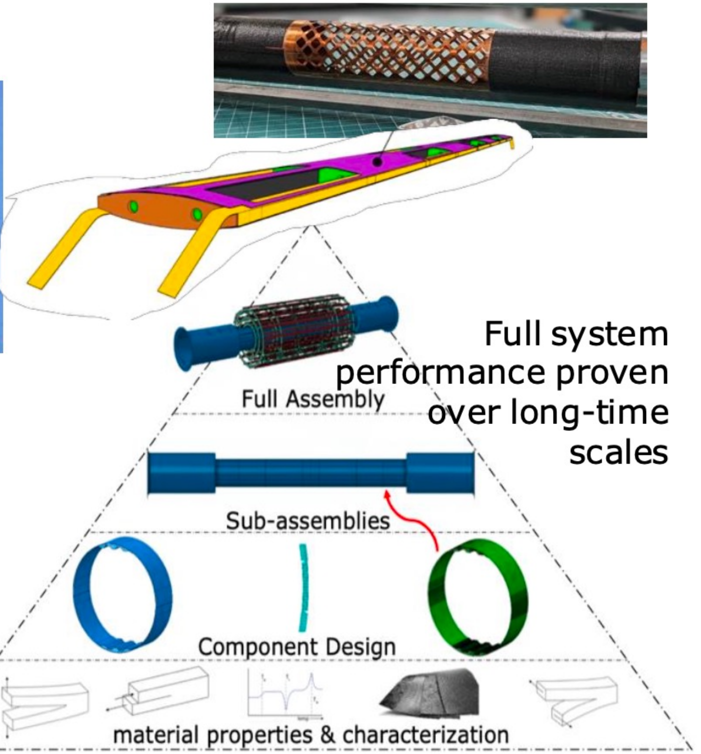
Mechanics and Integration - DRD8

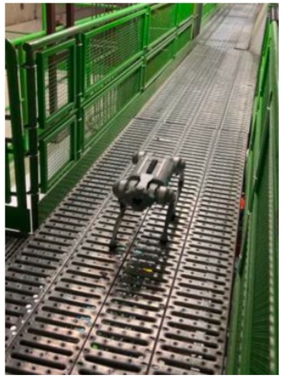
- DRD8 proposal approved by Dec 2024
  - Does not cover all DRDTs, as they are quite diverse
  - Focus on vertex detector mechanics and cooling as emerged from "Forum on Tracker Mechanics" workshop series

- **Advanced materials** and structures for **vertex detectors:**
  - Mechanics for curved sensors, Thin beam pipe, Retractable detectors, MDI, Low-mass hardware, alignment
  - Characterization of Material properties and database
- **Cooling**: Airflow, Evaporative CO_2 and new fluids (Krypton), Microchannel cooling in Si, Cooling tubes welding and material investigations
- **Robots** and **Virtual reality** to simulate/remote control access in restricted areas
- **Software** tools to connect engineering design with physics simulation (e.g. connect GEANT4 with CAD)

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







Electronics, Trigger and Data Acquisition - DRD7

ELECTRONICS

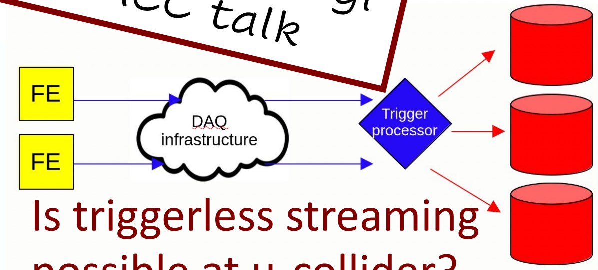
Requirements:

- **Dedicated chips (ASICs) and programmable logic (FPGAs)** on detector frontend and in the "counting room"
- New development: **"intelligent" frontends smart pixels**, embedded FPGAs
- Low-noise, cryogenic, superconducting electronics (e.g. SQUIDs, parametric amplifiers, ...)
- Packaging, interconnects, system integration

Challenges:

- Special requirements compared to industry —> high costs
- Increasing gap to industry state of the art (e.g. feature size)

Angira Rastogi USMCC talk



Is triggerless streaming possible at μ-collider?

TRIGGER and DATA ACQUISITION

Requirements:

- High-rate electrical/optical data transmission, photonics
- Traditional approach: triggered readout
- **New trend: triggerless/streaming readout with (ML-enabled) "intelligent" backend processing**
- Heterogeneous trigger farms: **CPU/GPU/FPGA**

Challenges:

- Maintain versatile heterogeneous frameworks (no vendor lock-in)
- Avoid bottlenecks between ASIC and DAQ

ECFA Detector R&D Roadmap

Thomas Bergauer - ESPPU

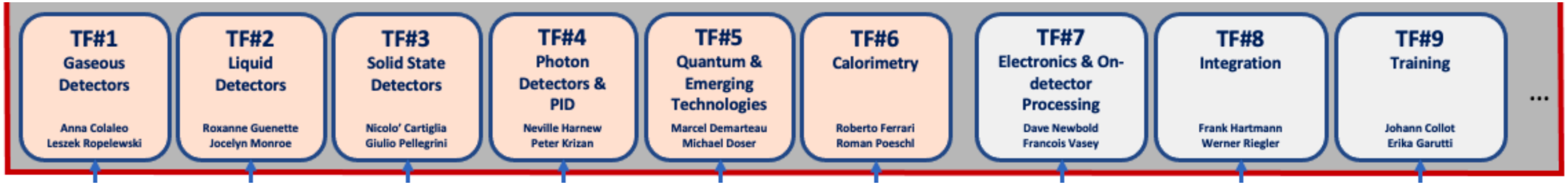
The community should define a global detector R&D roadmap that should be used to support proposals at the European and national levels. ***ESPPU 2020***

ECFA detector roadmap released in 2021 with full document (200 pages) and synopsis (~10 pages) based on a **community-driven effort** with many community meetings

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

Document contains:

- Overview of **future facilities** (EIC, ILC, CLIC, FCC-ee/hh, Muon collider) or major **upgrades** (ALICE, Belle-II, LHC-b,…) and their **timelines**
- Ten "**General Strategic Recommendations**" (GSRs) see next slide….
- **Nine Technology domains** with **Task Forces (TF)** areas:
  - The **most urgent R&D topics** in each domain, identified as **Detector R&D Themes** (DRDTs)



IMPLEMENTATION PHASE since 2022 - COLLABORATIONS APPROVAL on-going since 2024

DRD international collaborations

Thomas Bergauer - ESPPU

Eight DRD collaborations have been approved for an initial period of 3 years (extendable) with different histories and “maturity”:

- Based on previous R&D collaborations:
  - **DRD1: Gaseous detectors** (based on RD51): *161 institutes, 700++ people*
  - **DRD3: Semiconductor Detectors** (previously RD42, RD50): *145 institutions / 700++ people*
  - **DRD6: Calorimetry** (CALICE, other proto-experiment collabs.): *135 institutes*

- Completely new: (community building, building trust, and finding benefit of being “CERN hosted”)
  - **DRD2: Liquid Detectors:** *86 institutes, 205 members*
  - **DRD4: Photodetectors & PID:** *74 institutes*
  - **DRD5: Quantum Sensors and emerging technologies:** *112 involved groups*

- Transversal activities: no service provider, but with genuine R&D interest (TF9 → ECFA Training Panel)
  - **DRD7: Electronics:** *67 Institutes*
  - **DRD8: Mechanics & Integration:** *38 institutes*

US R&D Collaborations – RDCs

CPAD – Coordinating Panel for Advanced Detectors

Instrumentation R&D is inherently necessary to our scientific future

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 Detectors
9	Calorimetry
10	Detector Mechanics
11	Fast Timing

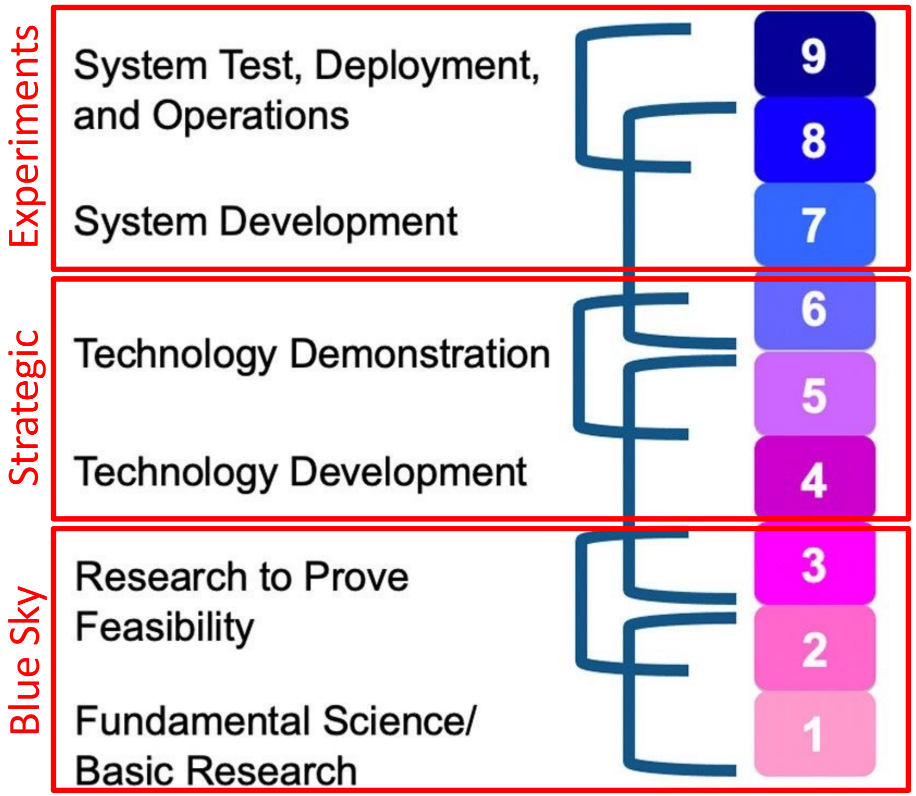
RDCs initiated after Snowmass recommendation

RDC#	TOPIC	COORDINATORS	MAILING LIST
1	Noble Element Detectors	Jonathan Asaadi, Carmen Carmona	cpad_rdc1@fnal.gov
2	Photodetectors	Shiva Abbaszadeh, Flavio Cavanna	cpad_rdc2@fnal.gov
3	Solid State Tracking	Anthony Affolder, Sally Seidel	cpad_rdc3@fnal.gov
4	Readout and ASICs	Angelo Dragone, Mitch Newcomer	cpad_rdc4@fnal.gov
5	Trigger and DAQ	Zeynep Demiragli, Jinlong Zhang	cpad_rdc5@fnal.gov
6	Gaseous Detectors	Prakhar Garg, Sven Vahsen	cpad_rdc6@fnal.gov
7	Low-Background Detectors	Daniel Baxter, Guillermo Fernandez-Moroni, Noah Kurinsky	cpad_rdc7@fnal.gov
8	Quantum and Superconducting Sensors	Rakshya Khatiwada, Aritoki Suzuki	cpad_rdc8@fnal.gov
9	Calorimetry	Marina Artuso, Minfang Yeh	cpad_rdc9@fnal.gov
10	Detector Mechanics	Eric Anderssen, Andreas Jung	cpad_rdc10@fnal.gov
11	Fast Timing	Gabriele Giacomini, Matt Wetstein	cpad_rdc11@fnal.gov

Roadmap implementation plan: Strategic vs Blue-Sky

- Strategic R&D bridges the gap between the **idea** (so-called **Blue Sky**, TRL 1-3) and the deployment and use in a HEP experiments (TRL 8-9)
  - **Detector R&D Collaboration should address Strategic R&D (TRL 3-6),** before experiment-specific engineering takes over
  - Covers the development and maturing of technologies, e.g.
    - Improving radiation hardness
    - Speeding up readout
    - Simplification of designs
    - Iterating different options
  - Backed up by **strategic funding**, agreed with funding agencies (MoUs)
- DRD collaborations should also contain a small **Blue Sky** section
  - Allow new developments to emerge
  - Possibly financed by common fund + institute contributions (RD50/51 scheme)

Technology Readiness Levels (TRLs) *defined by NASA: Method for estimating the maturity of technologies*



Final remarks and next steps

Advances in detector and accelerator pair with the opportunities of the physics case

- A key message ALWAYS is to **sustain the careers of R&D experts:**
  "Attract, nurture, recognise and sustain the careers of R&D experts"

No instrumentation → no "Physics" reach

- To get people engaged, in particular the Early career scientists, it is important also to get **intermediate experimental setups/goals and synergies** where the new technologies in their infant status may be tested

→ Muon Collider Demonstrator with physics cases

MORE in the following:

- Deep Dive on Timing Detectors
- Detector and Accelerator Synergies
- Bluesky R&D

Murtaza Safdari
USMCC talk

Sridhara Dasu
USMCC talk

Cristian Pena
USMCC talk

References - recent

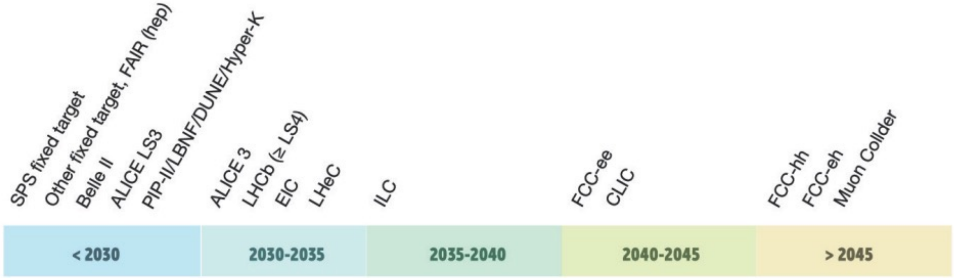
46. Tools for Discovery – Instrumentation Requirements for Future Projects
Ulrich Husemann - KIT Karlsruhe
47. From ECFA Detector Roadmap to DRD Collaborations and beyond
Thomas Bergauer (HEPHY Vienna)
and many others….

From Requirements to Construction: R&D for Detectors at Future Colliders
Lorenzo Sestini (INFN-FI)
@ Physics At The Highest Energies With Colliders - GGI Florence

- *Synergies for enabling technologies opens new opportunities in the coming years*
- *Level of complexity requires to plan ahead evaluating needs with an open mind*
- *Detector field is a great playground to deeply understand Nature and benefit Society*

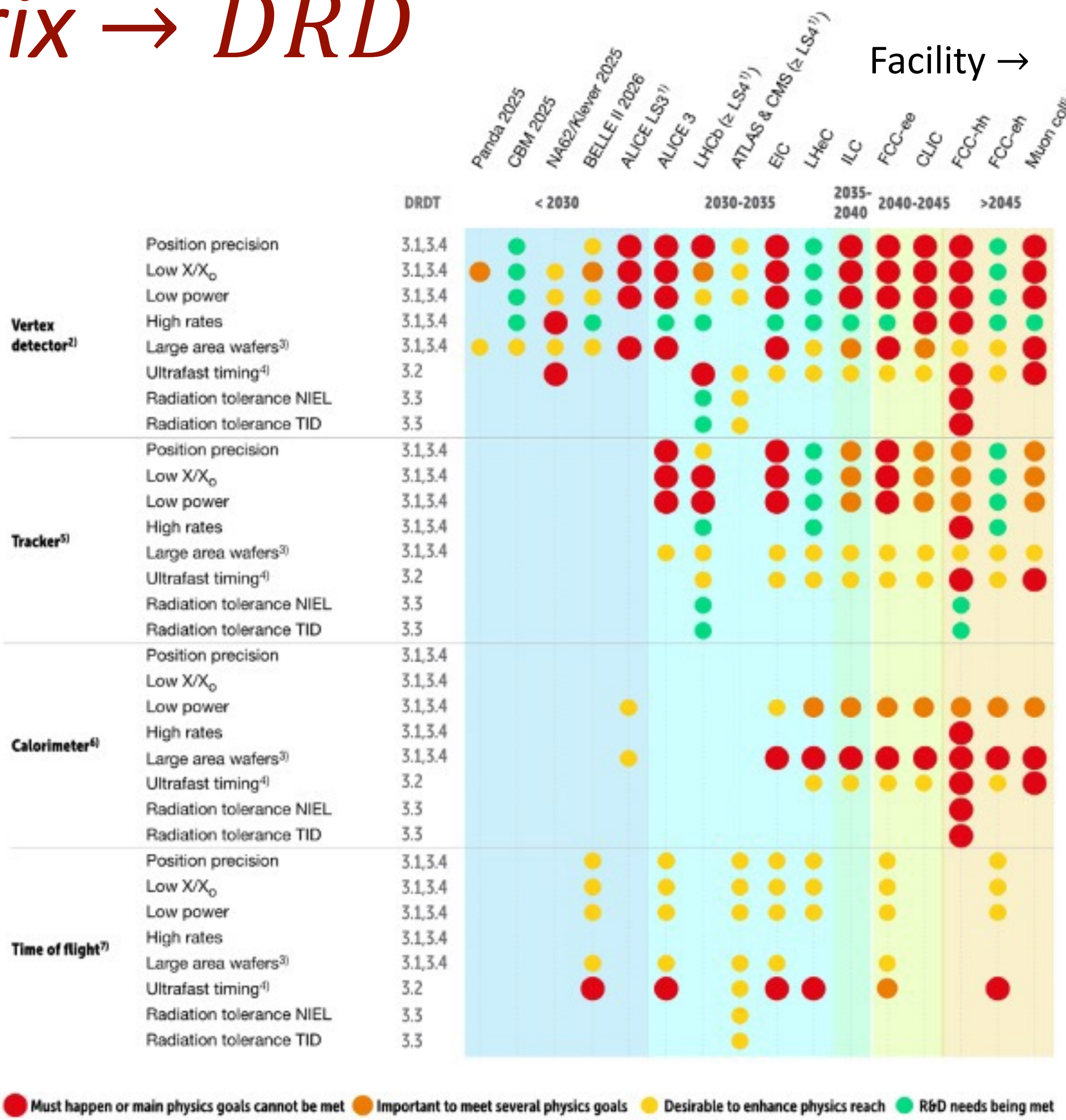
Thanks for the attention!

Detector Readiness matrix → DRD



Focus on the technical aspects of R&D requirements given the EPPSU list of "High-priority future initiatives" and "Other essential scientific activities for particle physics"

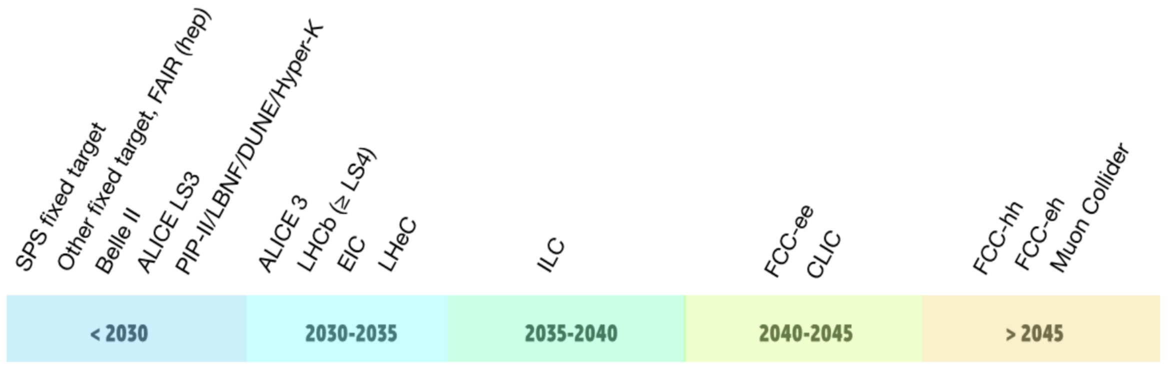
- Must happen or main physics goals cannot be met
- Important to meet physics goals
- Desirable to enhance physics reach
- R&D need being met



HEP projects for Detector Research & Development

upgrades and future large accelerators projects

small accelerators, nuclear reactors, cosmic rays second and third generation of experiments



DRD1 gaseous | DRD3 solid state | DRD4 photon & PID | DRD6 calorimeter

DRD2 liquid | DRD5 quantum & emerging techno.

DRD7 electronics and on-detector processing - DRD8 integration (?) - Training Panel

Strategic DRD programmes cover evolving TRLs* between 3 to 6

Didier Contardo @ ICFA Seminar 2023

* *Technology Readiness Level defined by NASA, low TRL < 3 also often referred as "blue sky" , TRL > 6 are experiment specific engineering*

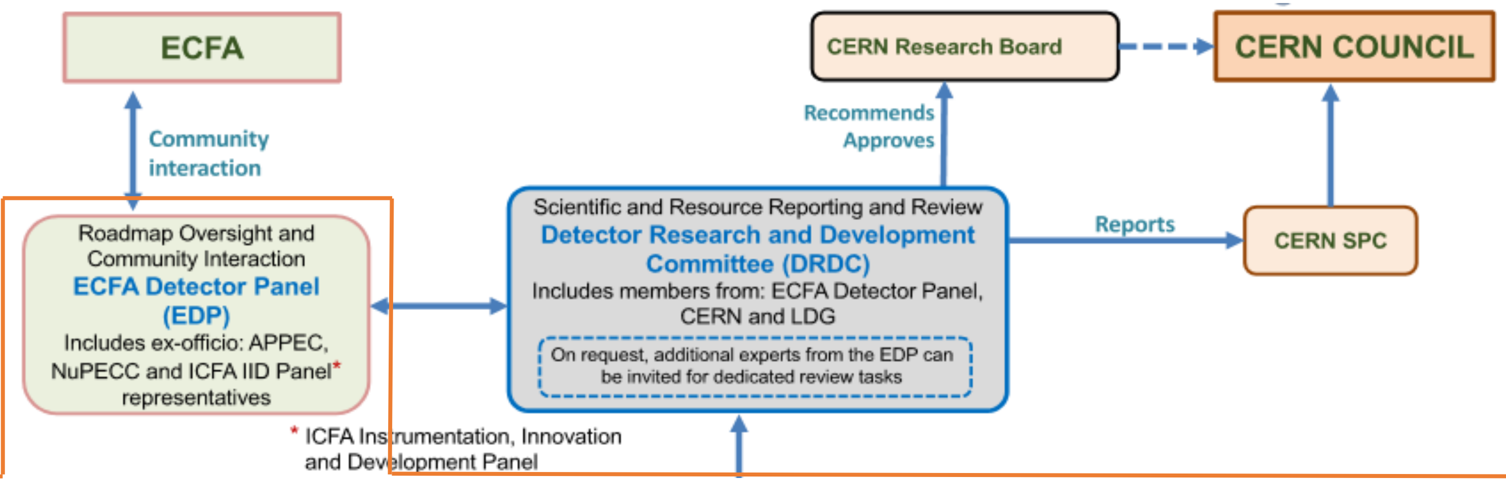
** *Planning of projects is for physics start at the time of the roadmap, end of strategic R&D must consider project engin., constr. and instal. time*

DRD collaborations hosted at CERN (framework)

follows general conditions for execution of experiments at CERN

EDP web page
- contact point for the community

EDP/DRD Managers Forum mandate
- common issues



DRD1 ✓	Gaseous Detector	M. Titov, E. Oliveri
DRD2 ✓	Liquid Detector	R. Guenette, G. Fiorillo
DRD3 ✓	Solid State Detector	G. Kramberger, G. Pellegrini
DRD4 ✓	Photon det. and PID	M.Fiorini, G. Wilkinson
DRD5 ✓	Quantum, emerging techno.	M. Demarteau, M. Doser
DRD6 ✓	Calorimetry	R. Poeschl, R. Ferrari
DRD7 ✓	Electronics on-detector processing	F. Simon, F. Vasey
DRD8 ✓	Mechanics and Integration	B. Schmidt, A. Mussgiller

✓ Approved by CERN RB*, ✓ DRD8 LoI submitted to DRDC, proposal aims end-2024

Didier Contardo @ PECFA July 2024

DRDC wep page, presentations of DRDs at open sessions

* approvals cover a period of three years – to be renewed