Status of DRD-on-Calorimetry

Roman Pöschl
On behalf of the DRD Calo Collaboration

Seminar Universität Kaiserslautern/Landau RPTU - July 2025

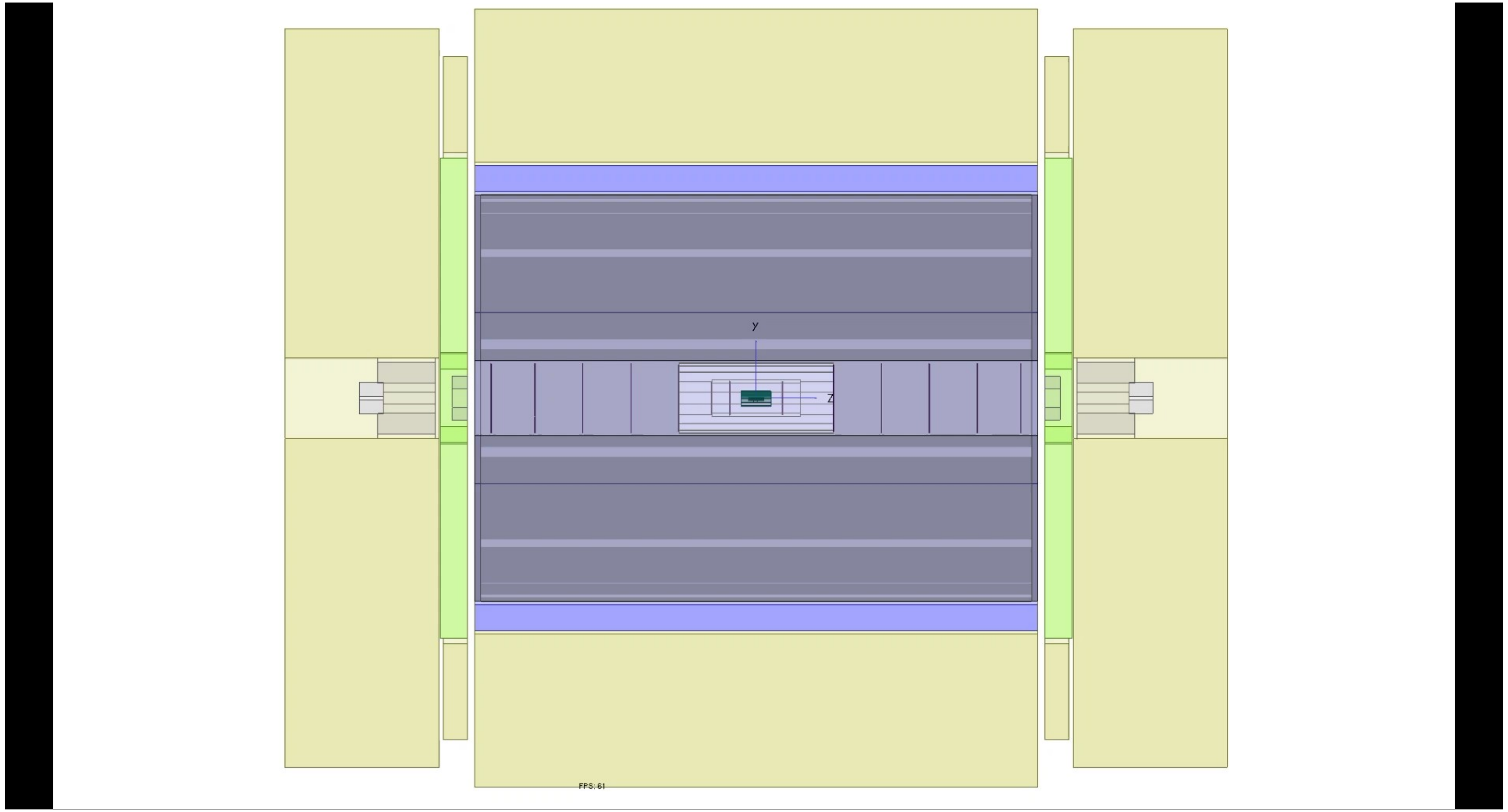
Most slides provided by G. Gaudio, L. Masetti, G. Marchiori, M. Mlynarikova, C. De la Taille, W. Ootani
For a full overview please consult: https://indico.ijclab.in2p3.fr/event/11400/

Collider Detector – A HEP Event

Vertex Detectors
Reconstruction of interaction point and decay vertices

Tracking Detectors
Reconstruction of charged particles in central and forward part

Calorimetry
Energy measurement in the outer (and forward) part
Subdivided in electromagnetic (ECAL) and Hadronic (HCAL) Calorimeters



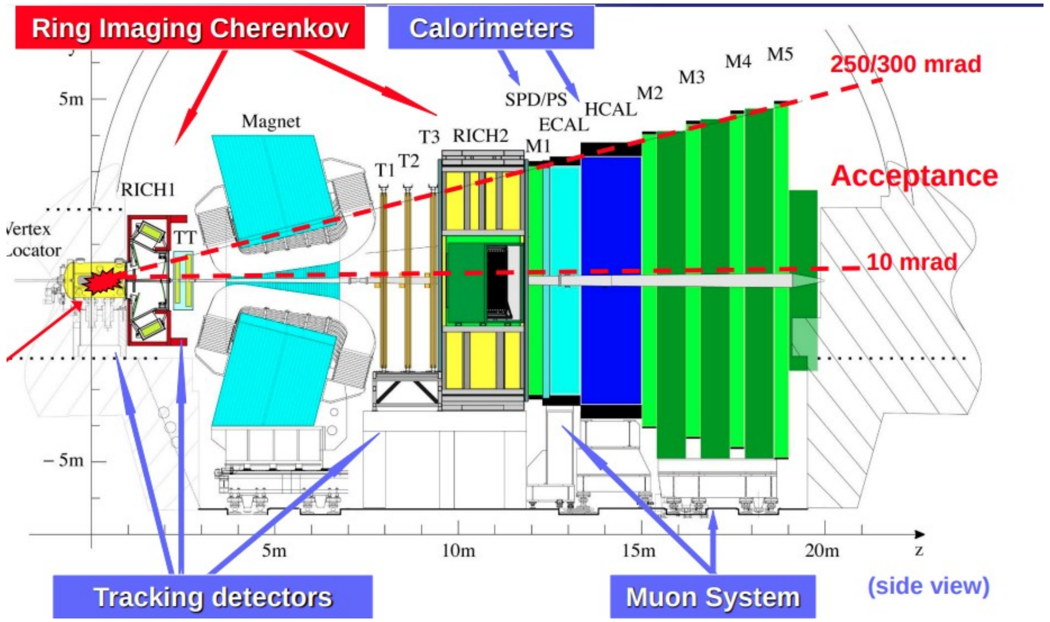
Typical jet energies between 50 and several 100 GeV
Typical particle energies between 1 and 100 GeV

B. Dudar

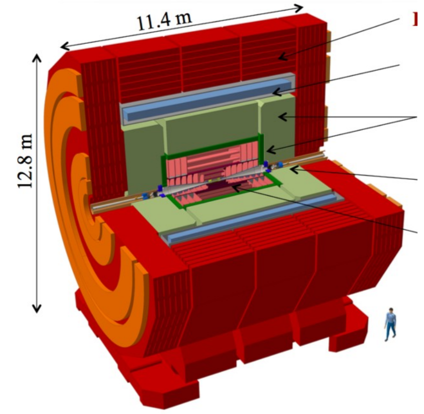
Main Target Projects of Detector R&D in HEP

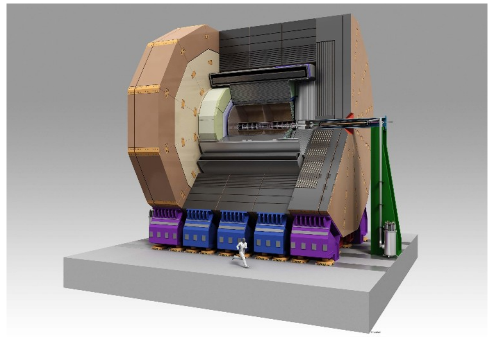
DRD Calo

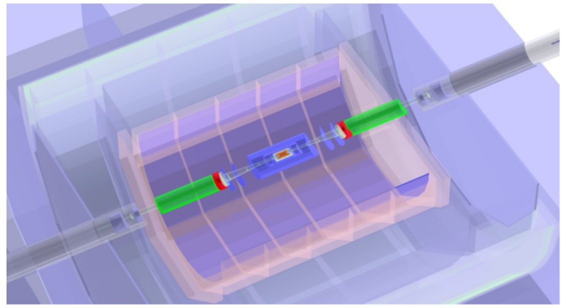
HL-LHC after LS4

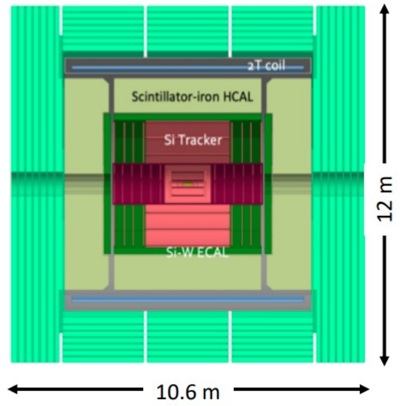


Higgs Factories

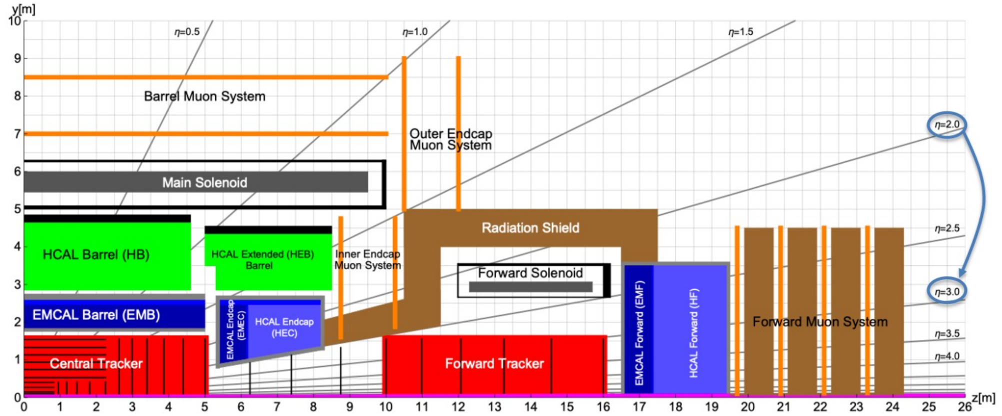




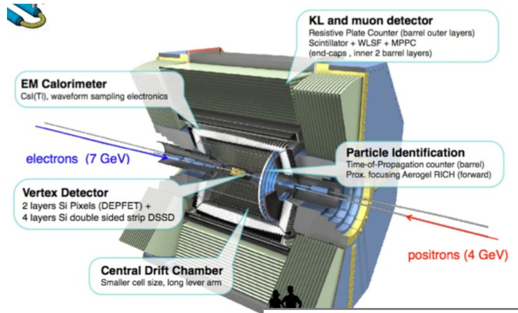


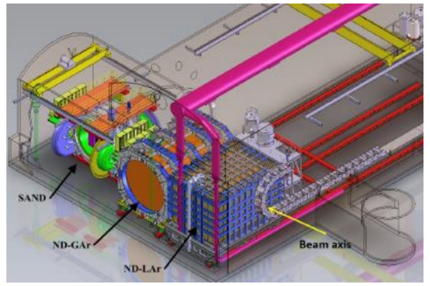


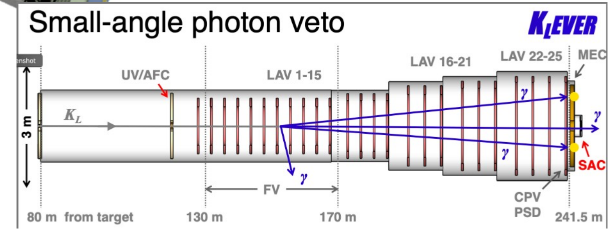
Future hadron colliders (including eh colliders)



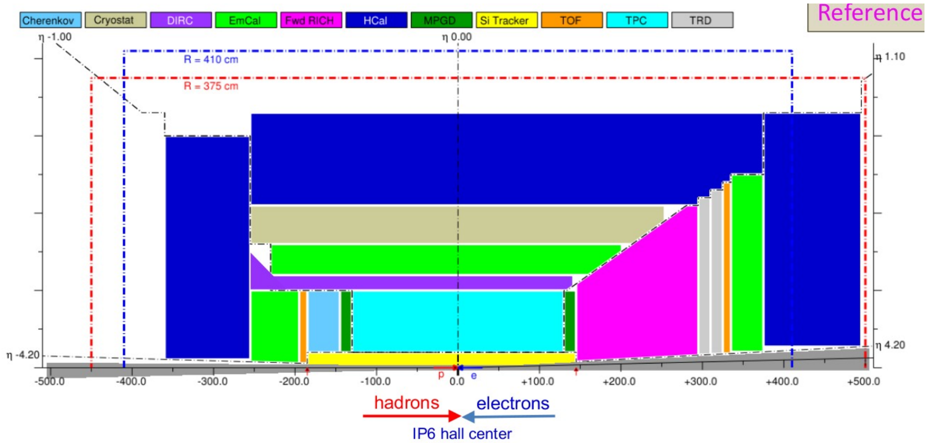
SuperKEKB, DUNE ND and Fixed Target



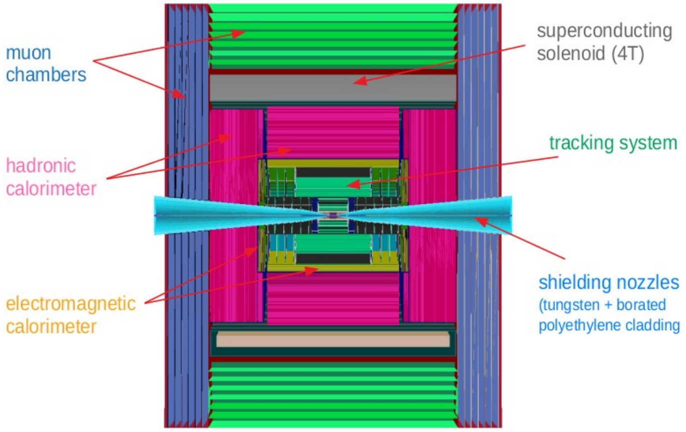




EiC



Muon Collider



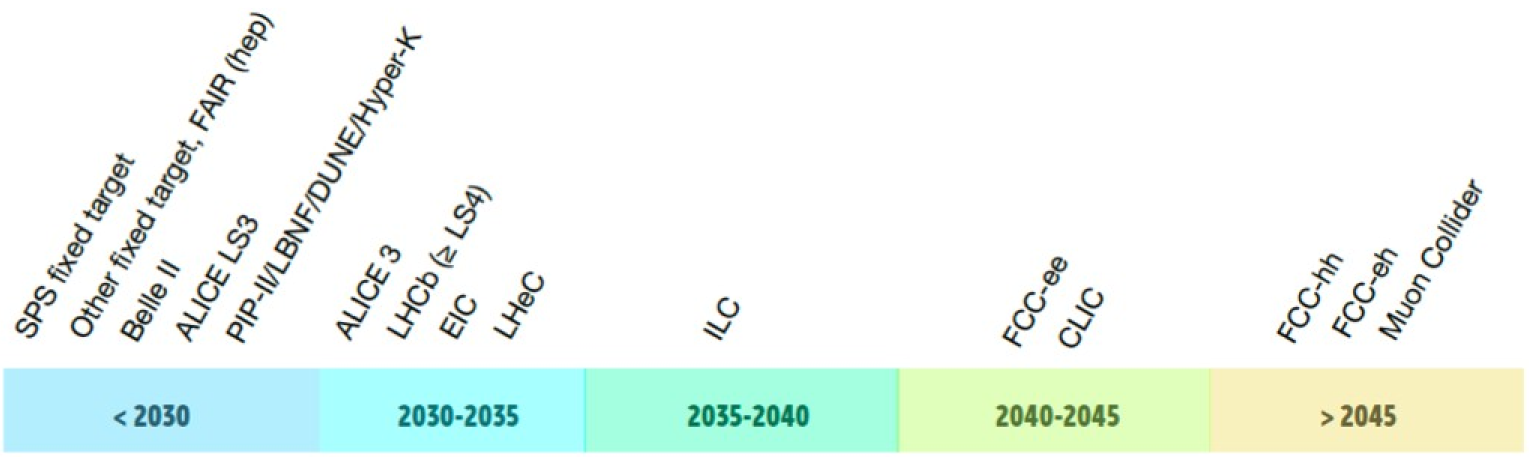
The roadmap document(s)

- ECFA R&D Roadmap
  - CERN-ESU-017 https://cds.cern.ch/record/2784893
  - 248 pages full text and 8 page synopsis

- Endorsed by ECFA and presented to CERN Council in December 2021

The Roadmap has identified
  - General Strategic Recommendations (GSR)
  - Detector R&D Themes (DRDT)
  - Concrete R&D Tasks

- Timescale of projects as approved by European Lab Director Group (LDG)



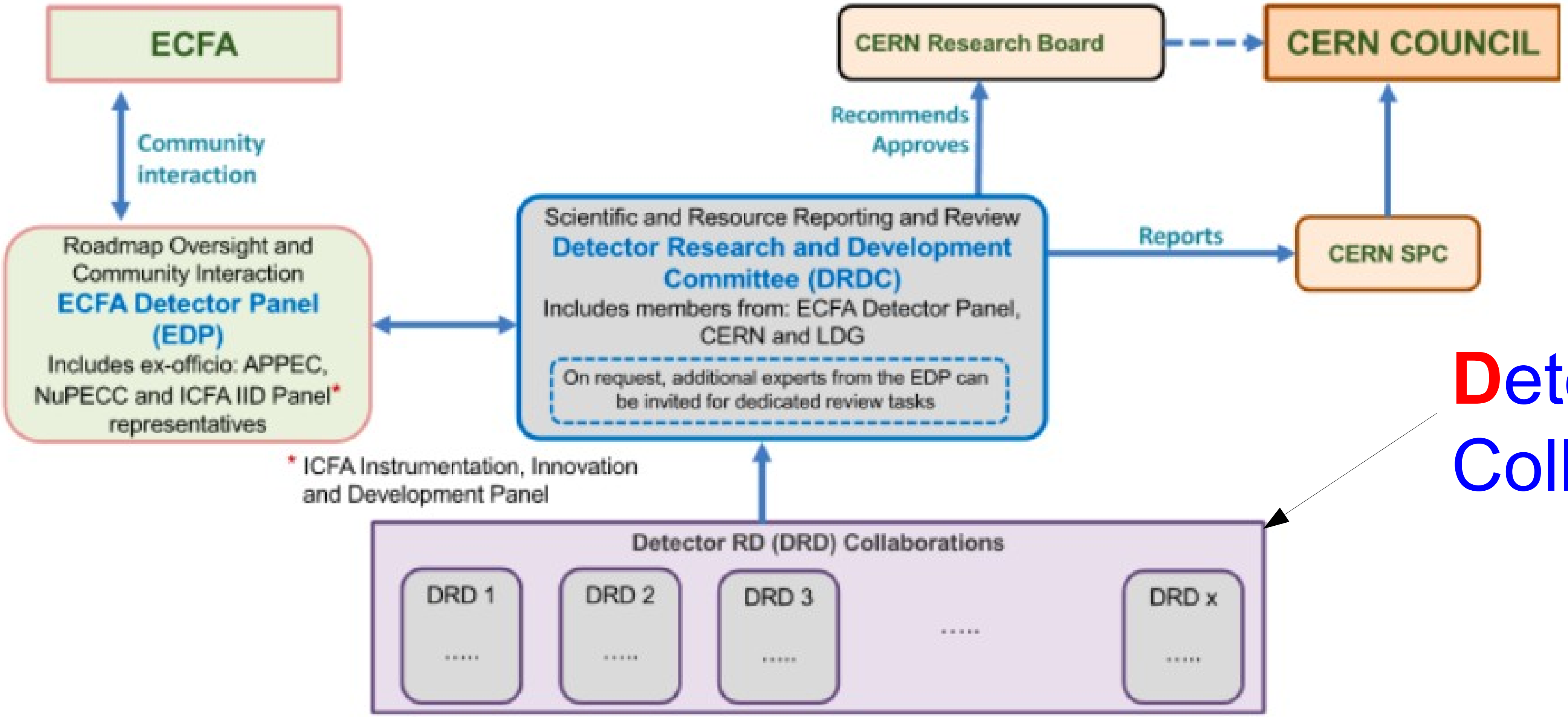
Guiding principle: Project realisation must not be delayed by detectors

From Roadmaps to DRDs

- ***Roadmap implementation plan*** defined that CERN will host the DRD collaborations
  - Approved by CERN SPC and Council in fall 2022 (CERN/SPC/1190 ; CERN/3679)
  - New committee created as reviewing body, the DRDC at the same level as LHCC, SPSC and others
- Most of the chapter's convenors ("Task Forces") from ECFA Roadmap process became part of *Proposal Writing Teams* for new DRD collaborations
  - Collected input from the communities in open meetings happening in the first half of 2023
- **Approval of DRD collaborations** by CERN Research Board:
  - DRD1,2 4 & 6 in December 2023
  - DRD3, 5 and 7 in June 2024
  - DRD 8 in December 2024

Future Organisation of Detector R&D (in Europe)

DRD Calo



Detector R&D Collaborations

- DRD are hosted by CERN and are therefore legally CERN collaborations
  - Significant participations by non-European groups is explicitly welcome and needed => World wide collaborations!
- The progress and the R&D will be overseen by a DRDC that is assisted by ECFA
  - Thomas Bergauer of ÖAW/Austria appointed as DRDC-Chair
- The funding will come from national resources (plus eventually supranational projects)

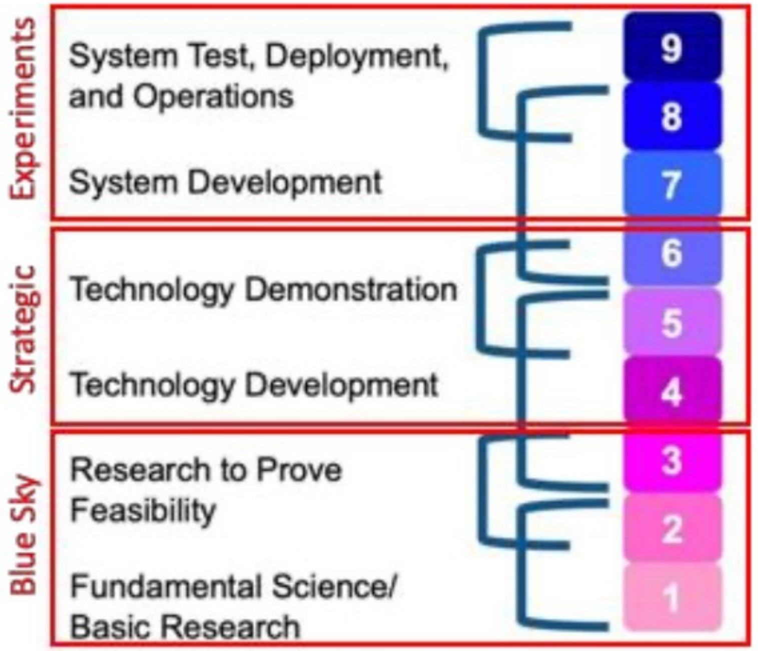
DRDs should cover strategic R&D

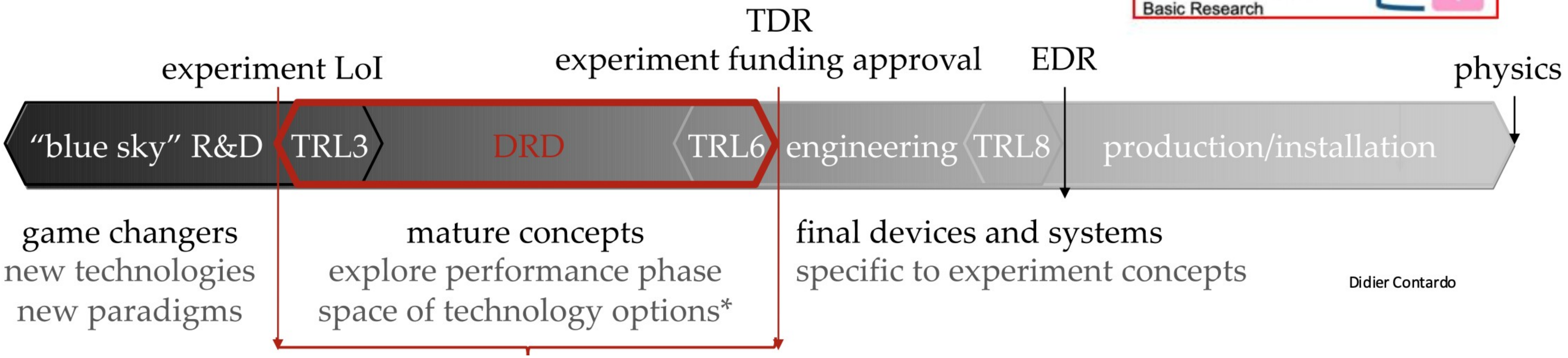
Strategic R&D bridges the gap between the idea (“**blue sky research**”, low TRLs) and the **deployment and use in a HEP experiment** (TRL 8-9)

Covers the **development and maturing of technologies**, e.g.

- Iterating through different options
- Improving radiation hardness
- Scaling up challenges: detector area, number of channels, layers,..
- …

„NASA“ TRL levels:



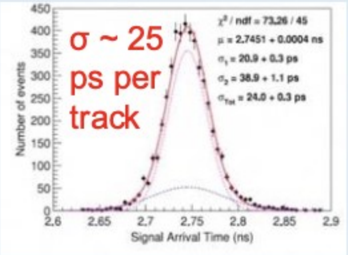


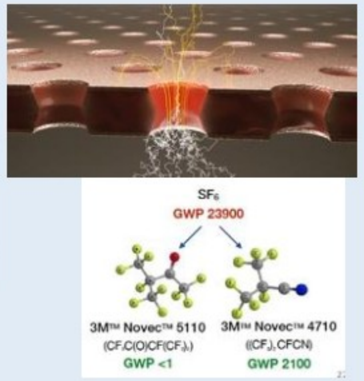
Didier Contardo

The DRDs in a nutshell

DRD1: Gaseous Detectors

Large · Fast · eco-friendly gases · MPGD, e.g. GEMs

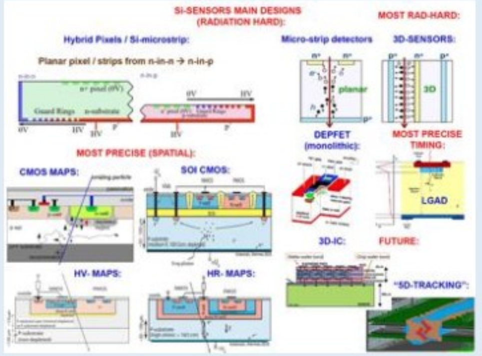




PICOSEC: NIMA903 (2018) 317

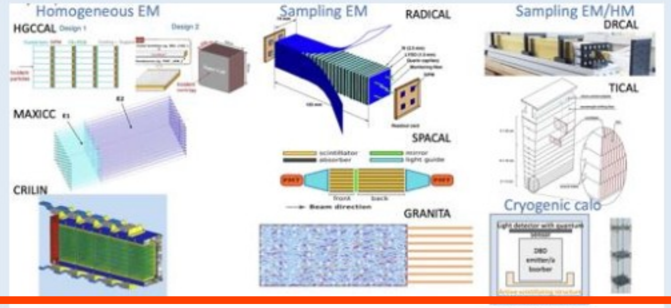
DRD3: Semiconductor Det.

Monolithic CMOS · LGADs · radiation hardness · interconns.



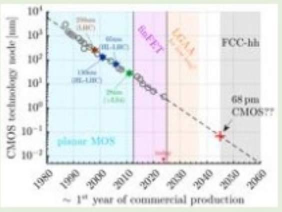
DRD6: Calorimetry

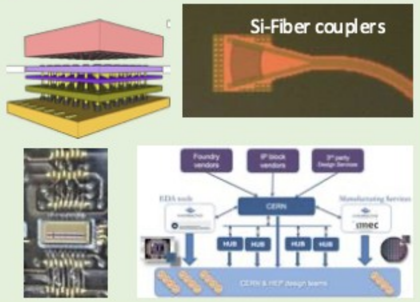
Energy resolution · High granularity · dual readout · particle flow · sandwich · optical



DRD7: Electronics

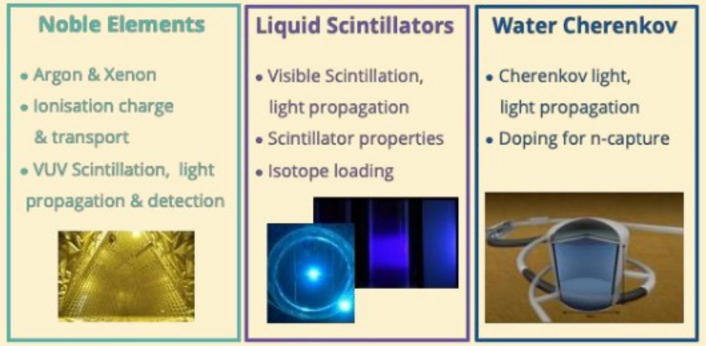
ADC/TDC IP Blocks · Opto-electronics · packaging · power · extreme environments · COTS · intelligence on detector · foundry access





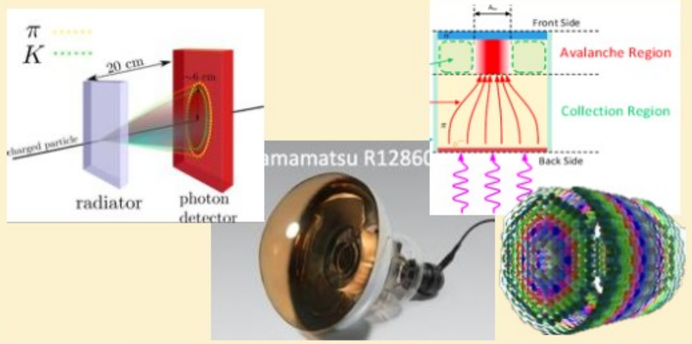
DRD2: Liquid Detectors

for Neutrinos · Dark Matter · 0vbb



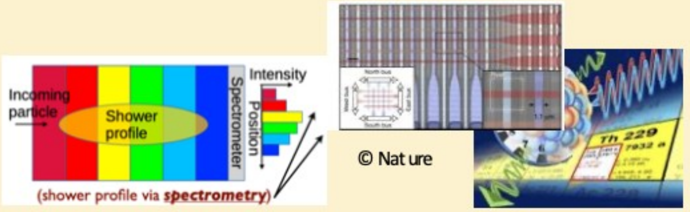
DRD4: Photon detectors

vacuum, solid-state (SiPM), hybrid single-photon and SciFi detectors · applications in PID, RICH, tracking



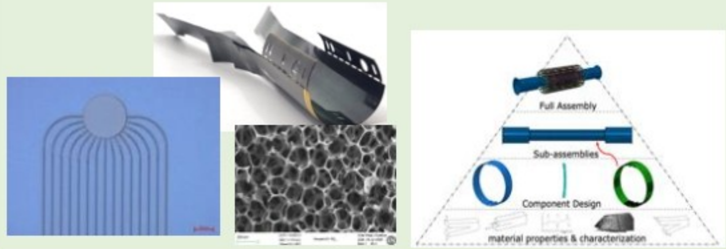
DRD5: Quantum Sensors

Quantum dots · superconduct. nanowires · bolometers · TES · MMC · nuclear clocks
Applications in LEPP, first projects in HEPP happening

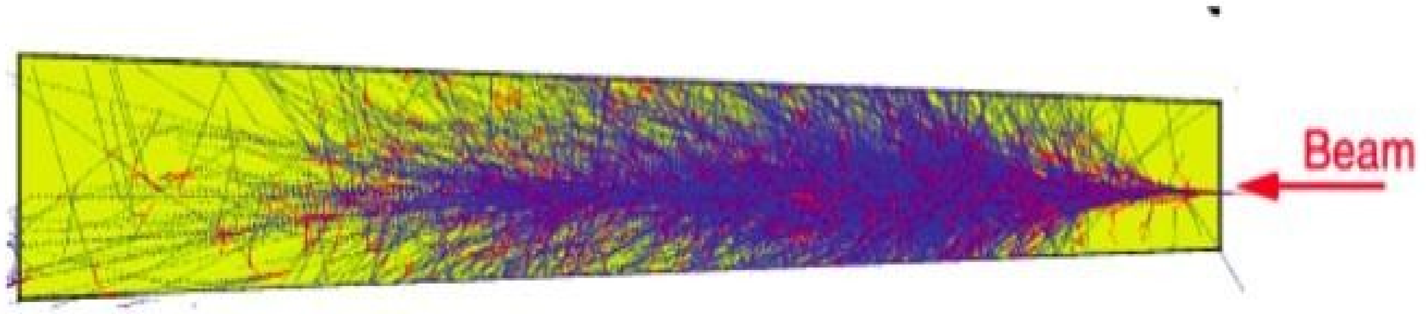


DRD8: Mechanics

Ultra-thin beam pipes · CF foam and new materials · curved, retractable sensors · air & micro-channel cooling · eco-friendly cooling fluids · robots · augmented reality

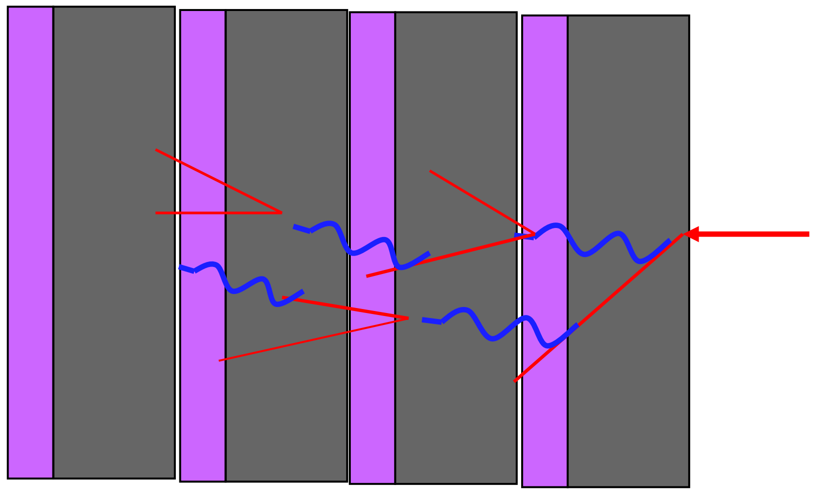


Homogenous Calorimeters



Entire shower passes active medium
Active medium = absorber medium
Typically inorganic crystals with high photon yield
with N_{photon} (t) ~ E $\Rightarrow$ σ(E) ~ $\sqrt{E}$

Sampling Calorimeters



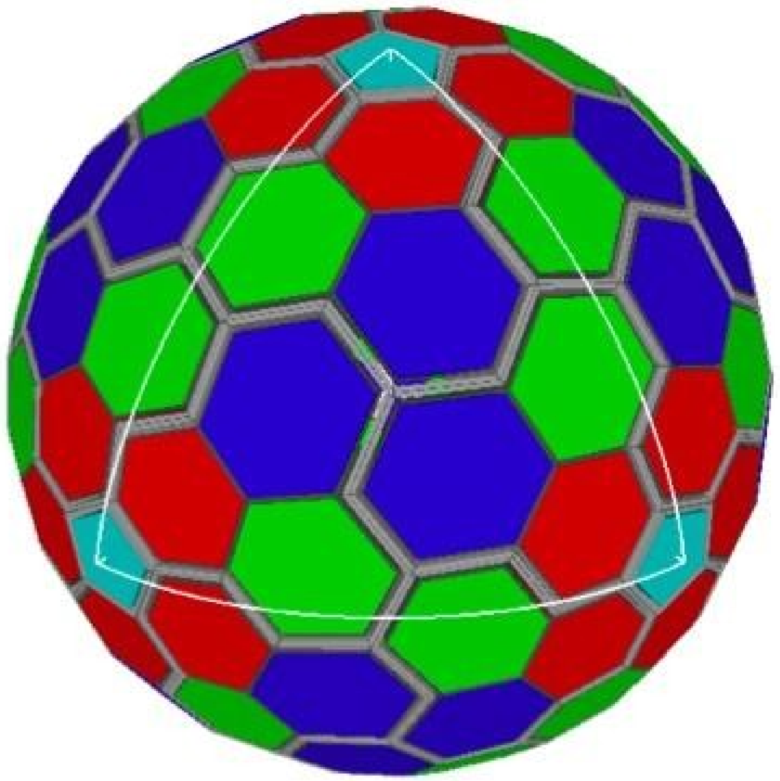
Only sample of shower passes active medium
Typically scintillating tiles from organic materials
(alternatives semi-conductor, gas counters)
Production of shower particles is statistical process
with N (t) ~ E $\Rightarrow$ σ(E) ~ $\sqrt{E}$

$$\boxed{\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E\,[\mathrm{GeV}]}} \oplus b \quad [\%]}$$

Master formula of calorimetry

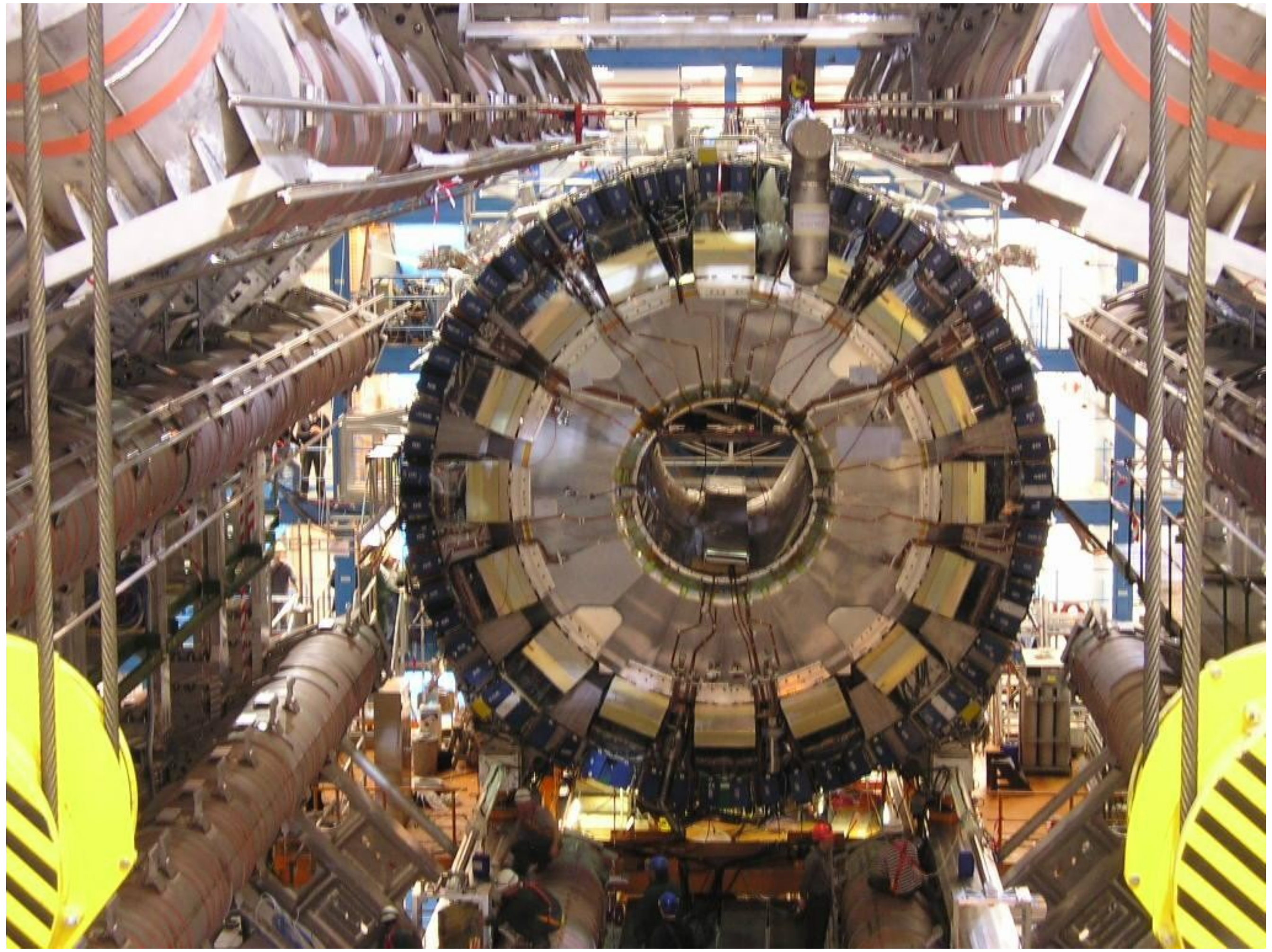
Calorimeters in Nuclear and Particle Physics

4π 'Germanium Ball' of
AGATA Experiment



1m

ATLAS Detector



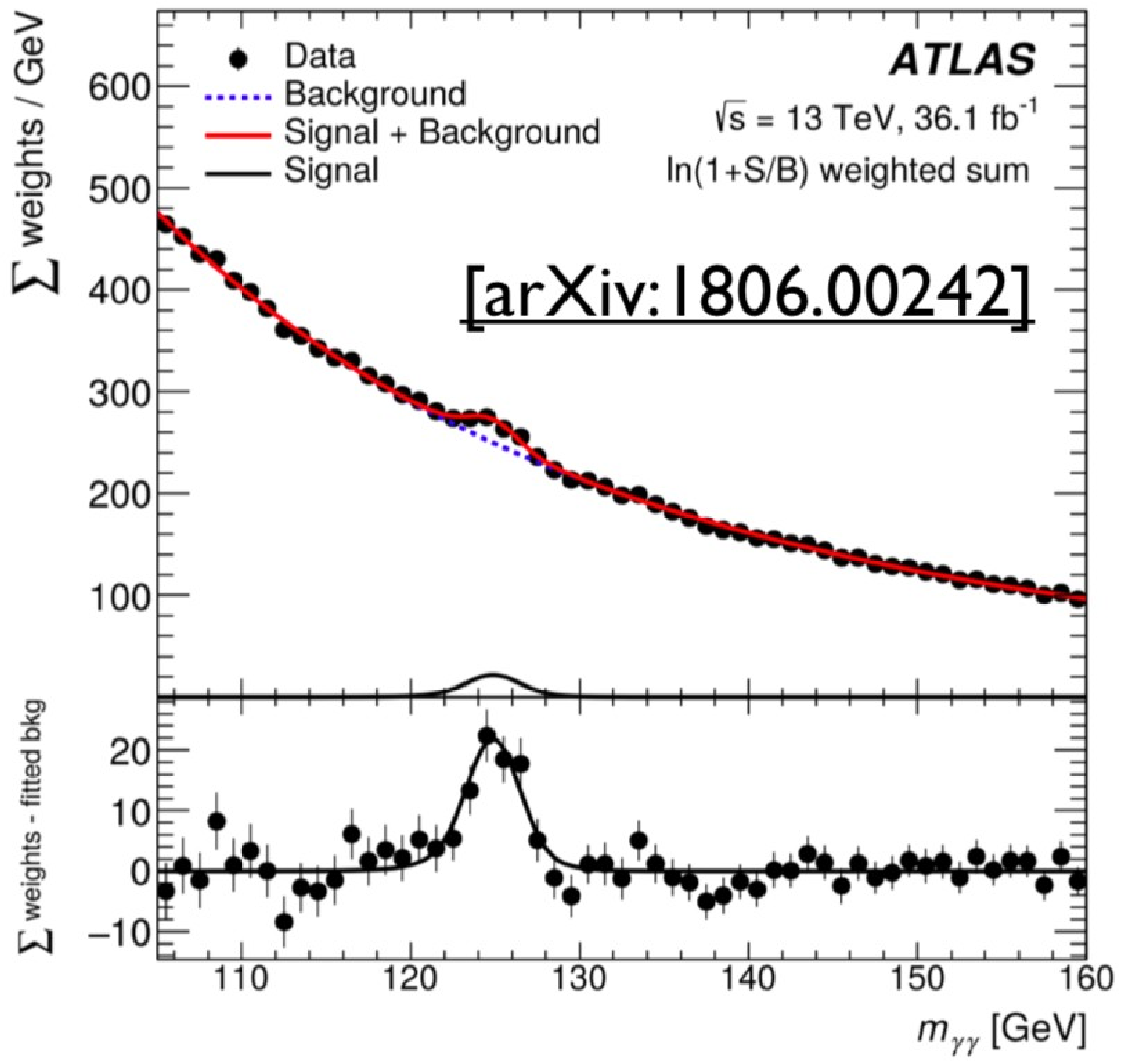
~10m

Calorimeters are employed in 'table top' experiments and in huge experimental apparatuus

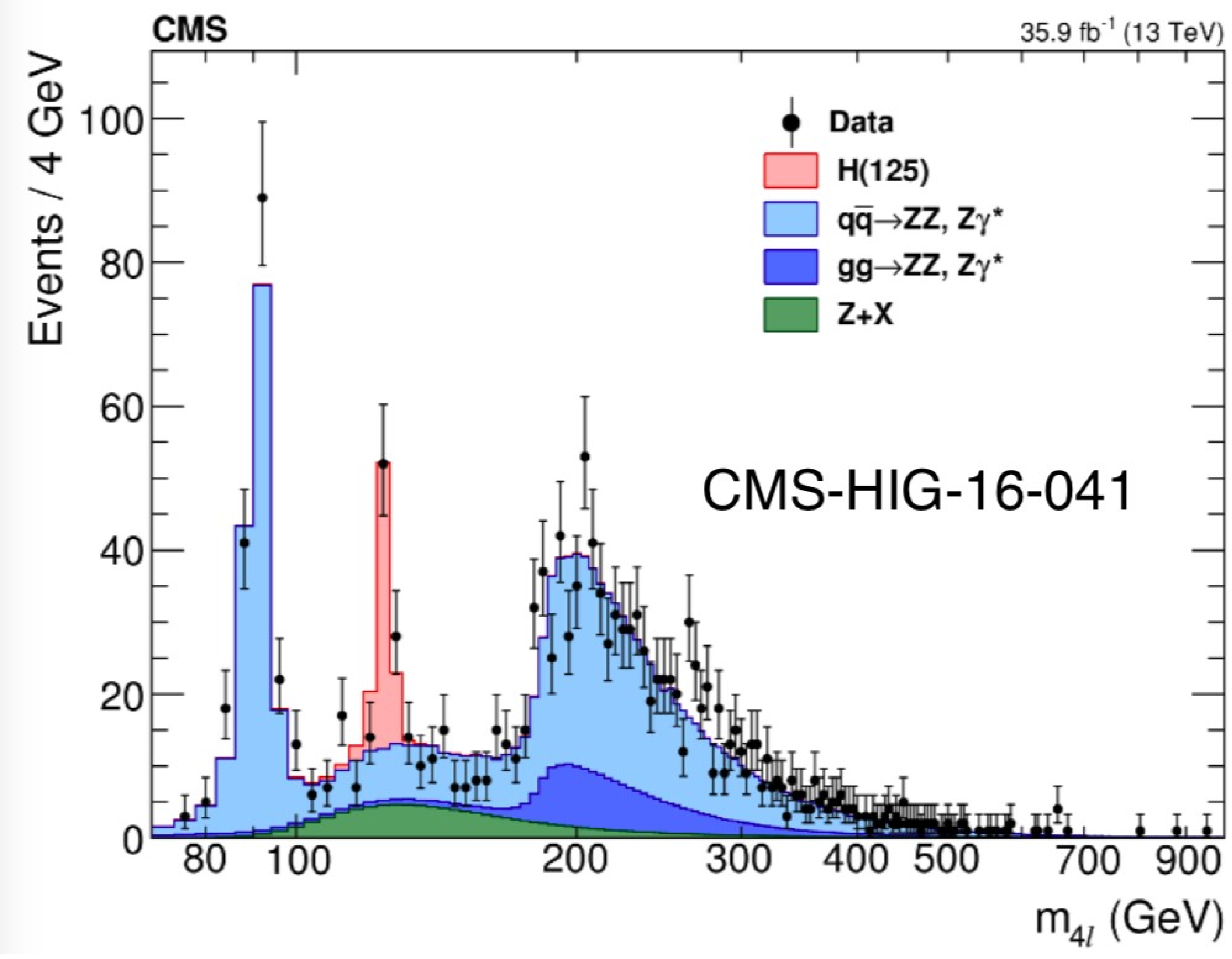
Calorimeters @ LHC - Examples

DRD Calo

H→γγ



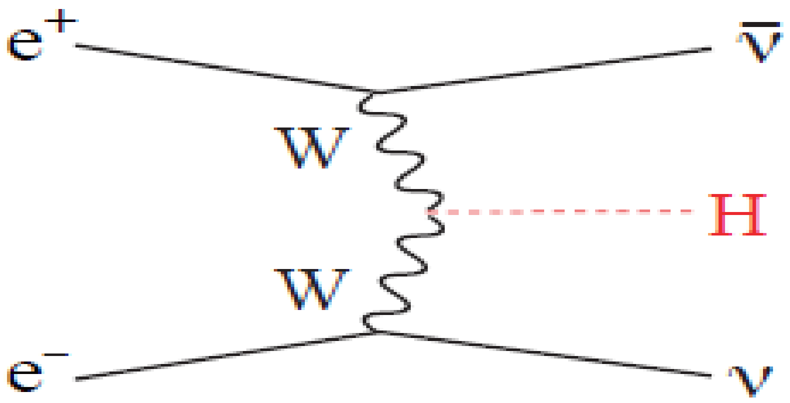
H→ZZ→llll

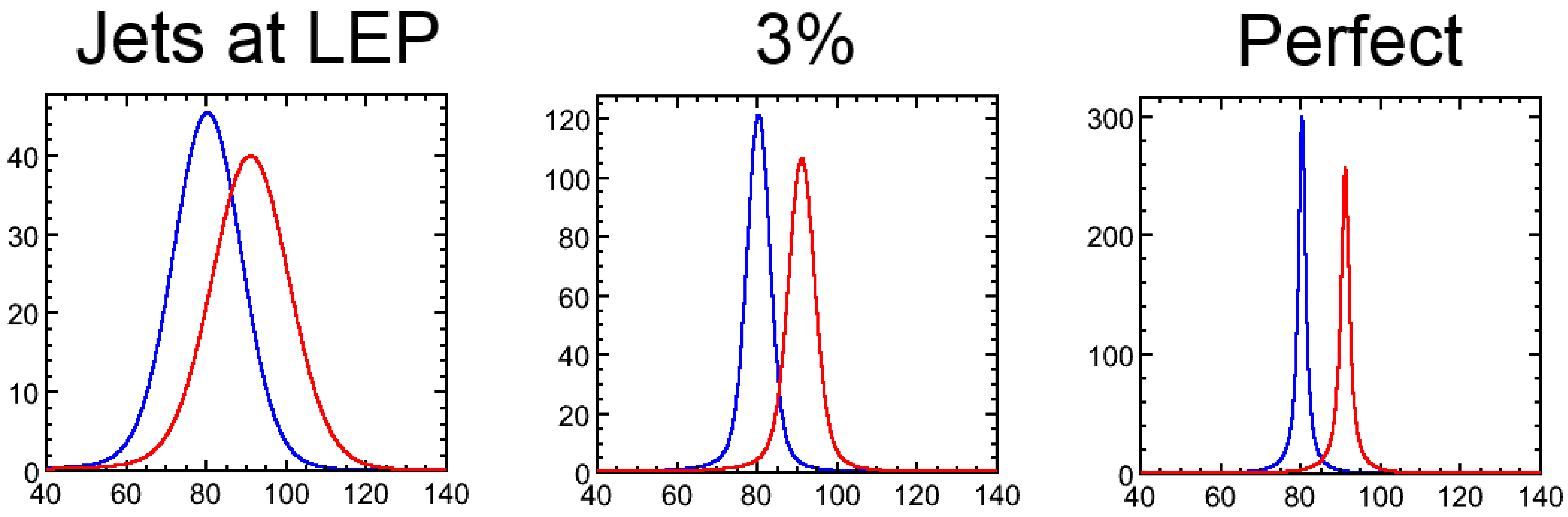


Examples:

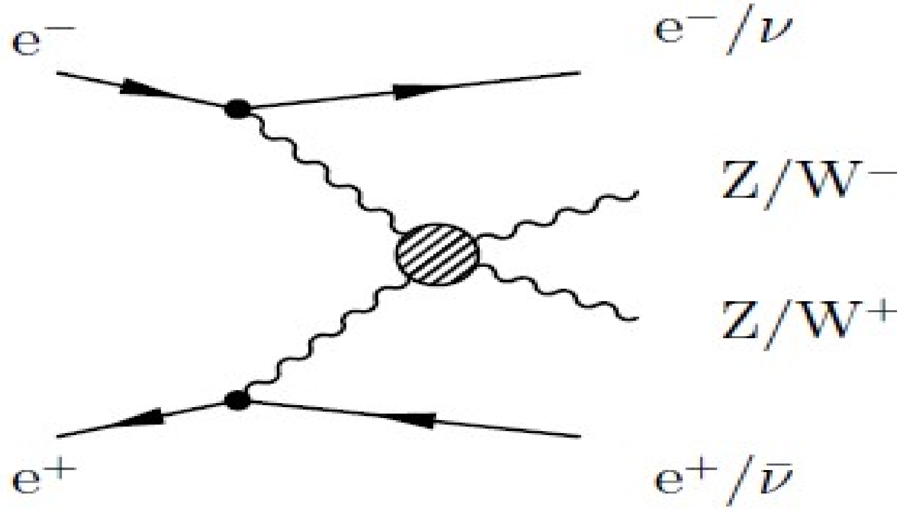
W Fusion with final state neutrinos requires reconstruction of H decays into jets

Jet energy resolution of ~3% for aclean W/Z separation





M. Thomson



Slide: F. Richard at International Linear Collider – A worldwide event

DRD Calo - Mission

- The DRD-on-Calorimetry develops calorimeter concepts required for future high-energy physics experiments.
- The DRD-on-Calorimetry shares the development of tools and infrastructure of common interest among the different projects.
- Electromagnetic and hadronic calorimeters are developed in a unified approach.
- The DRD-on-Calorimetry carries out test beam campaigns with prototypes of different sizes.
  - The maturity of a concept will have to be demonstrated with full-scale prototypes.
- The Collaboration organises the task sharing between the prototype projects, to benefit from synergies between them and maximise the use of common infrastructures, building blocks and frameworks, as well as simulation code and data samples.
- It also aims at enabling common test beams with electromagnetic and hadronic calorimeters.

From Proposal to Reality

DRD 6: Calorimetry

Proposal Team for DRD-on-Calorimetry

July 31, 2024

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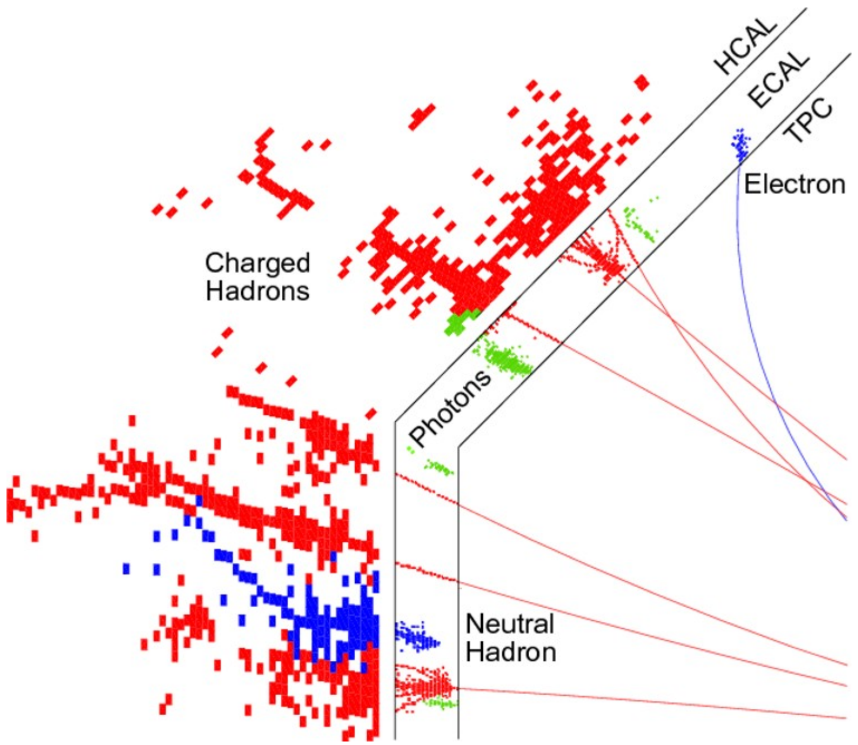
Contents

- Proposal: CERN-DRDC-2024-004; DRDC-P-DRD6: http://cds.cern.ch/record/2886494
- Proposal defines 40 Milestones (MS) and 39 deliverables (D)
  - MS and D are resource loaded
- MS and D and the associated resources will be subject to revision
  - New D can be added
- Revision kicked-off at recent Collaboration Meeting

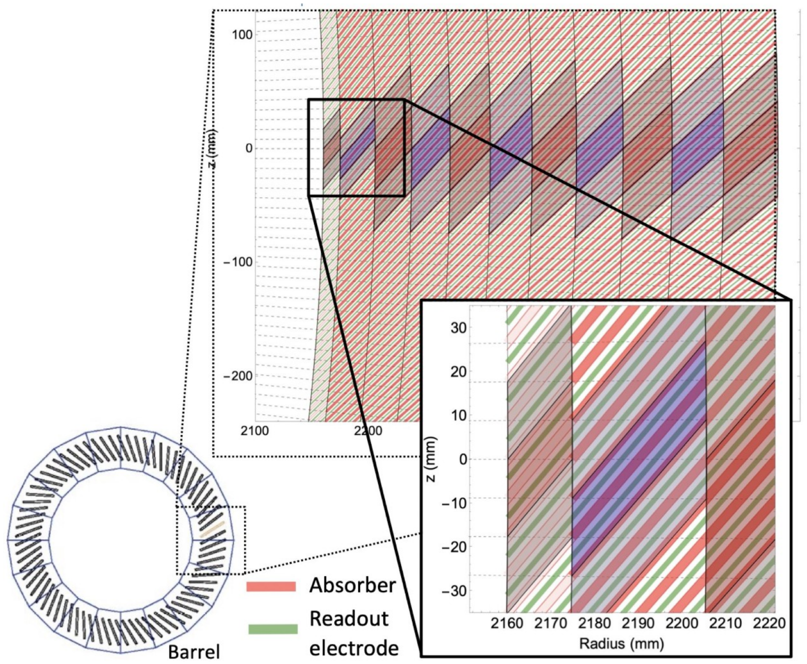
DRD Calo in a nutshell

- Calorimeters are key devices in each future HEP Experiments
- Collaboration comprises 128 institutes from 28 countries
- Scientific programme organised around four Work Packages

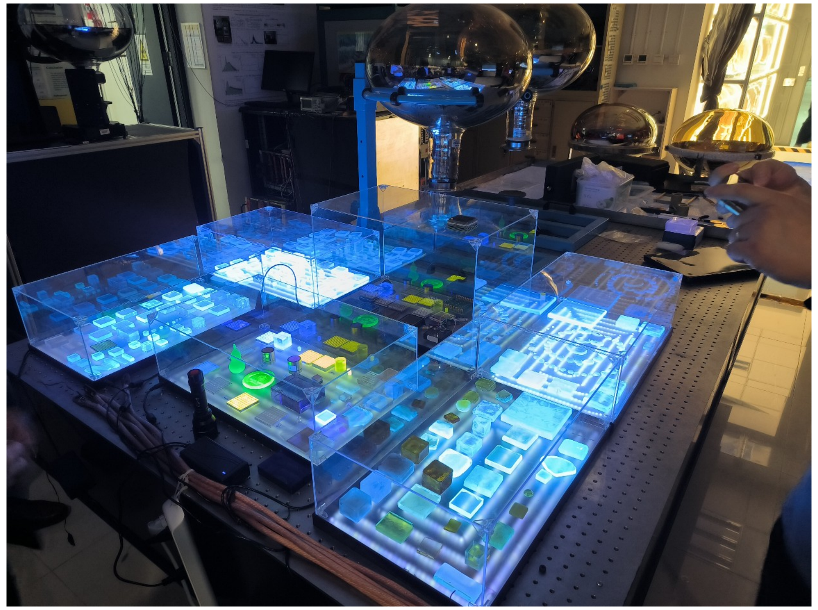
Sandwich calorimeters
With embedded electronics



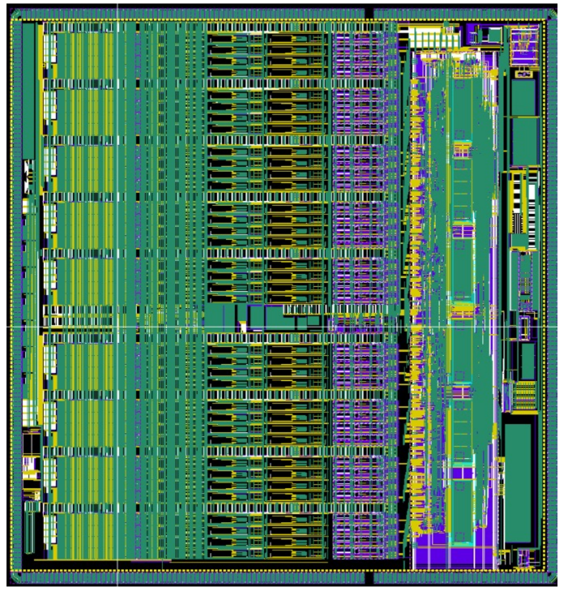
Liquid Noble Gas Calorimeters



Optical Calorimeters

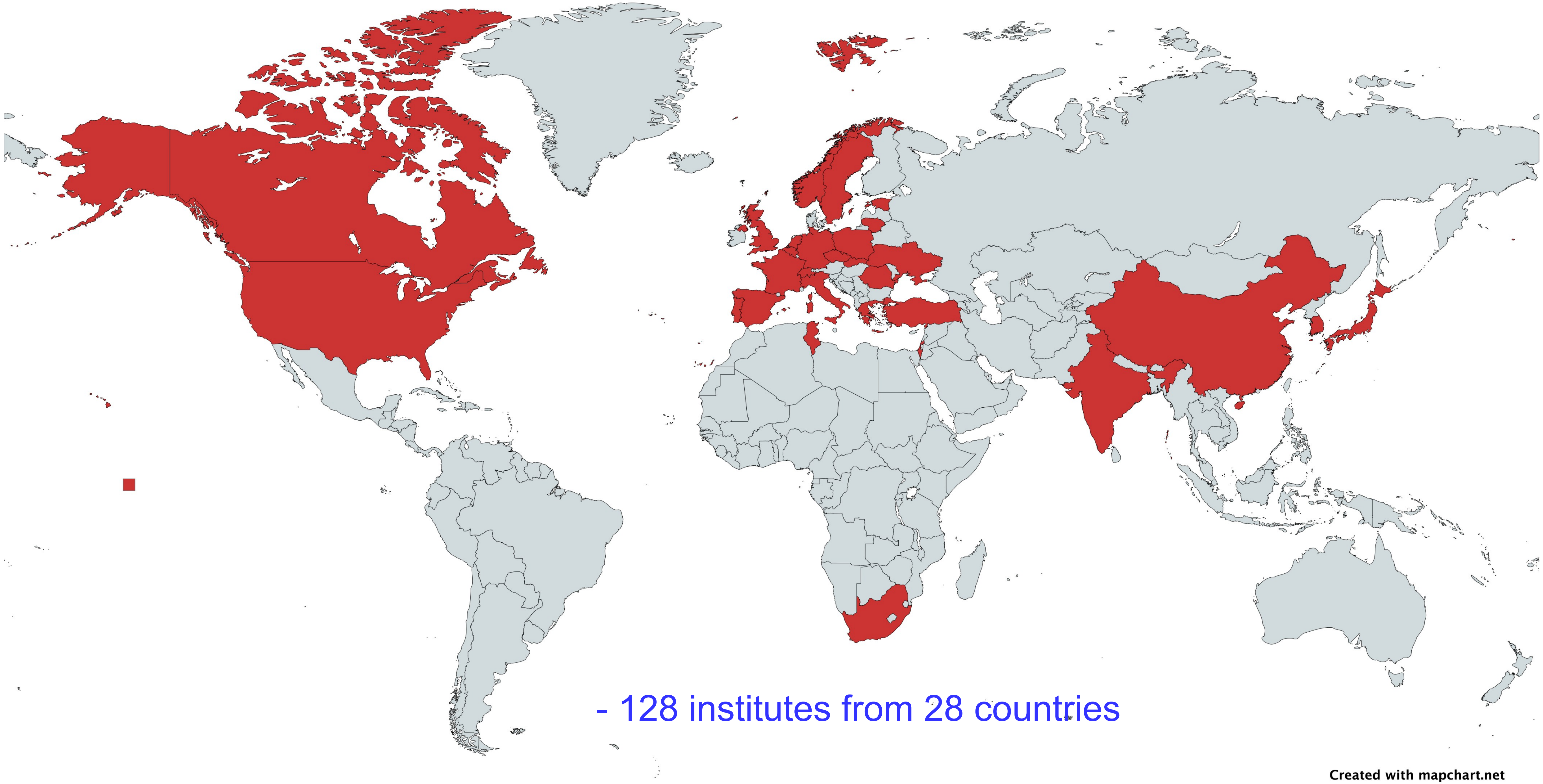


Front end electronics



- Coherence ensured by five working groups
  - Recent highlight software tutorial

DRD Calo – Who and where we are



- 128 institutes from 28 countries

Collaboration Meeting(s)

3rd Collaboration Meeting at IJCLab Orsay (April 2025)

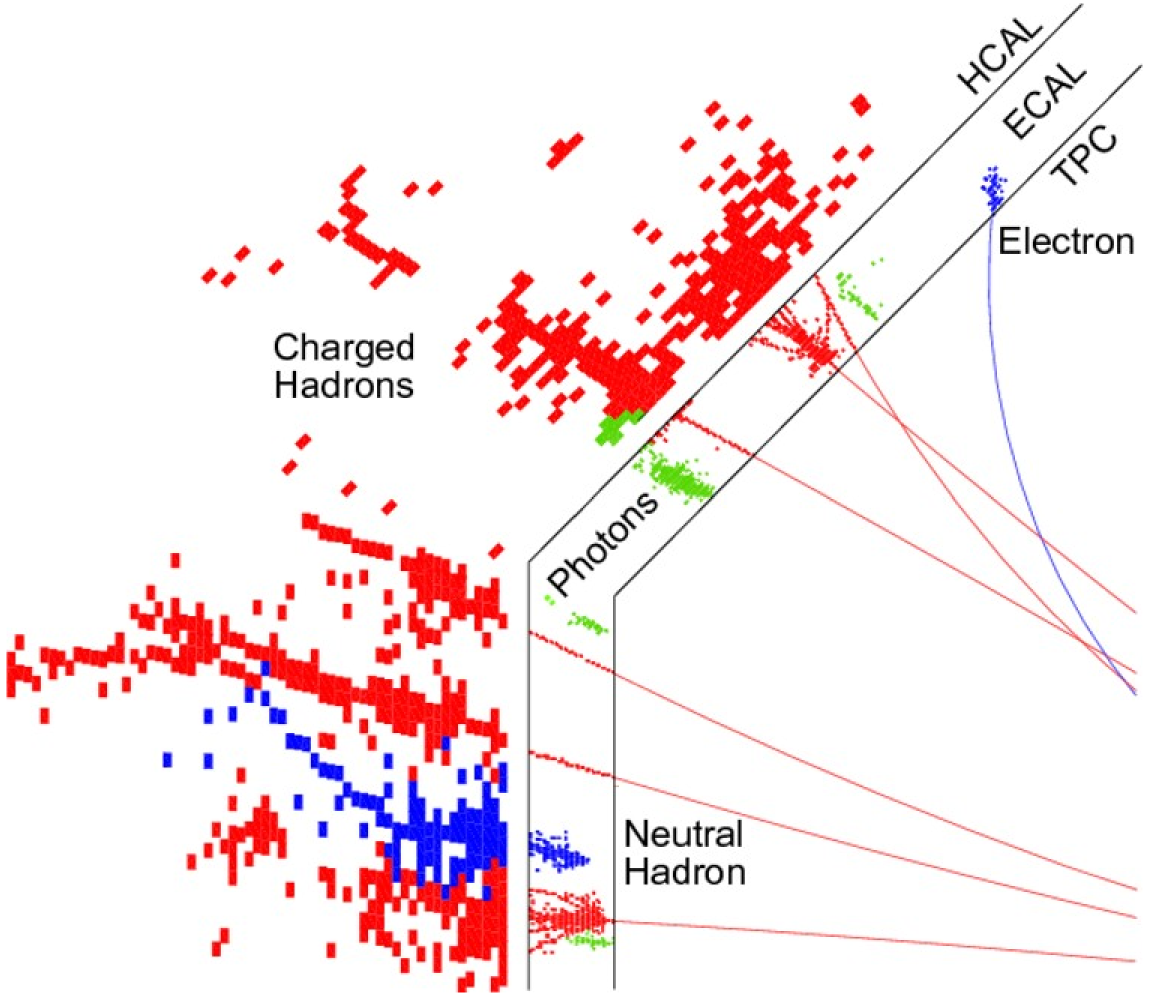
https://indico.ijclab.in2p3.fr/event/11400/

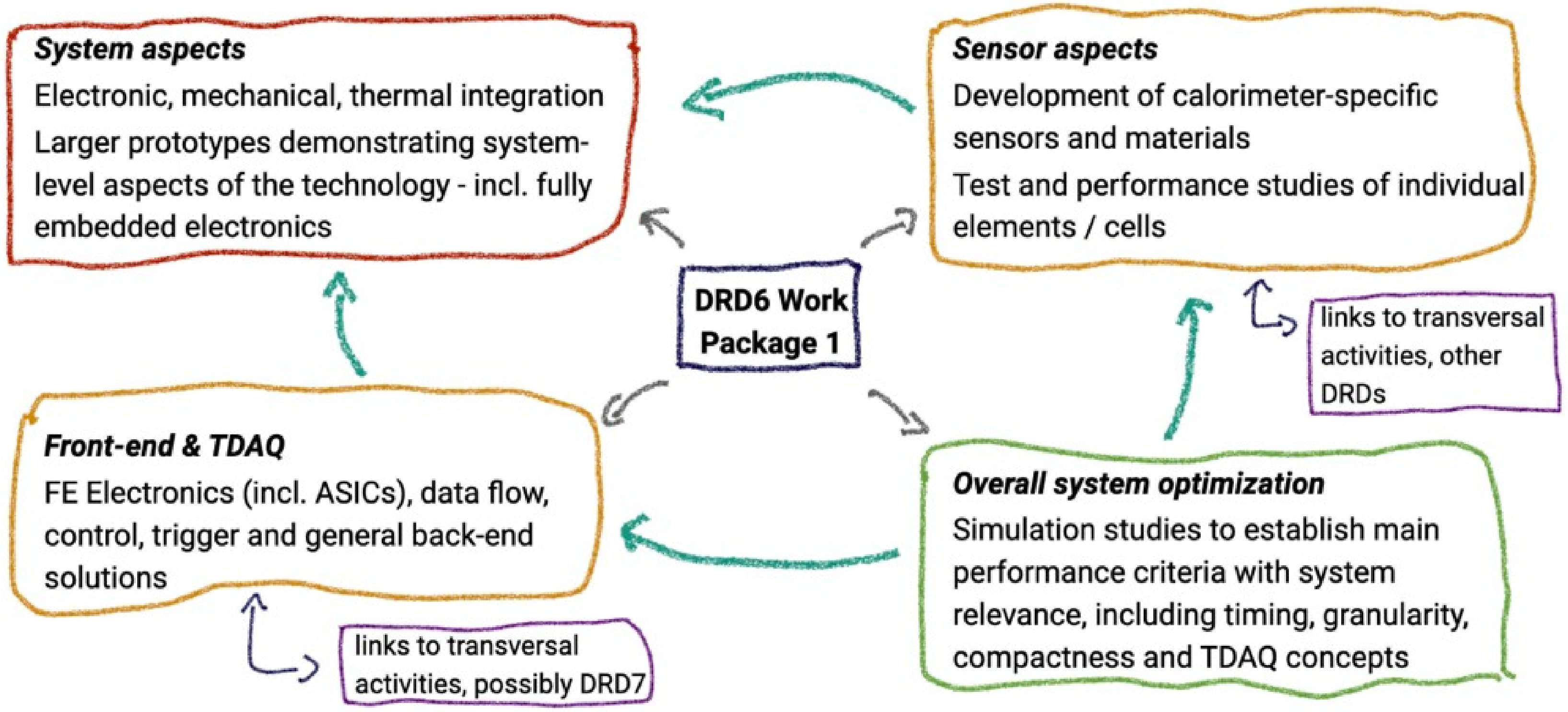
4th Collaboration Meeting at Ancona (Sept. 2025)

https://indico.cern.ch/event/1551941/

Work Package 1 in a nutshell

DRD Calo





- Challenges:
  - High pixelisation, 4π hermetic -> little room for services
    - Detector integration plays a crucial role

- New strategic R&D issues
  - Detector module integration
  - Timing
  - High rate e+e- collider (such as FCC-ee)

- Imaging calorimeters live on the high separation power for Particle Flow
- One calorimeter - Subdivided into electromagnetic and hadronic sections

Work Package 1 - Tasks

DRD Calo

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

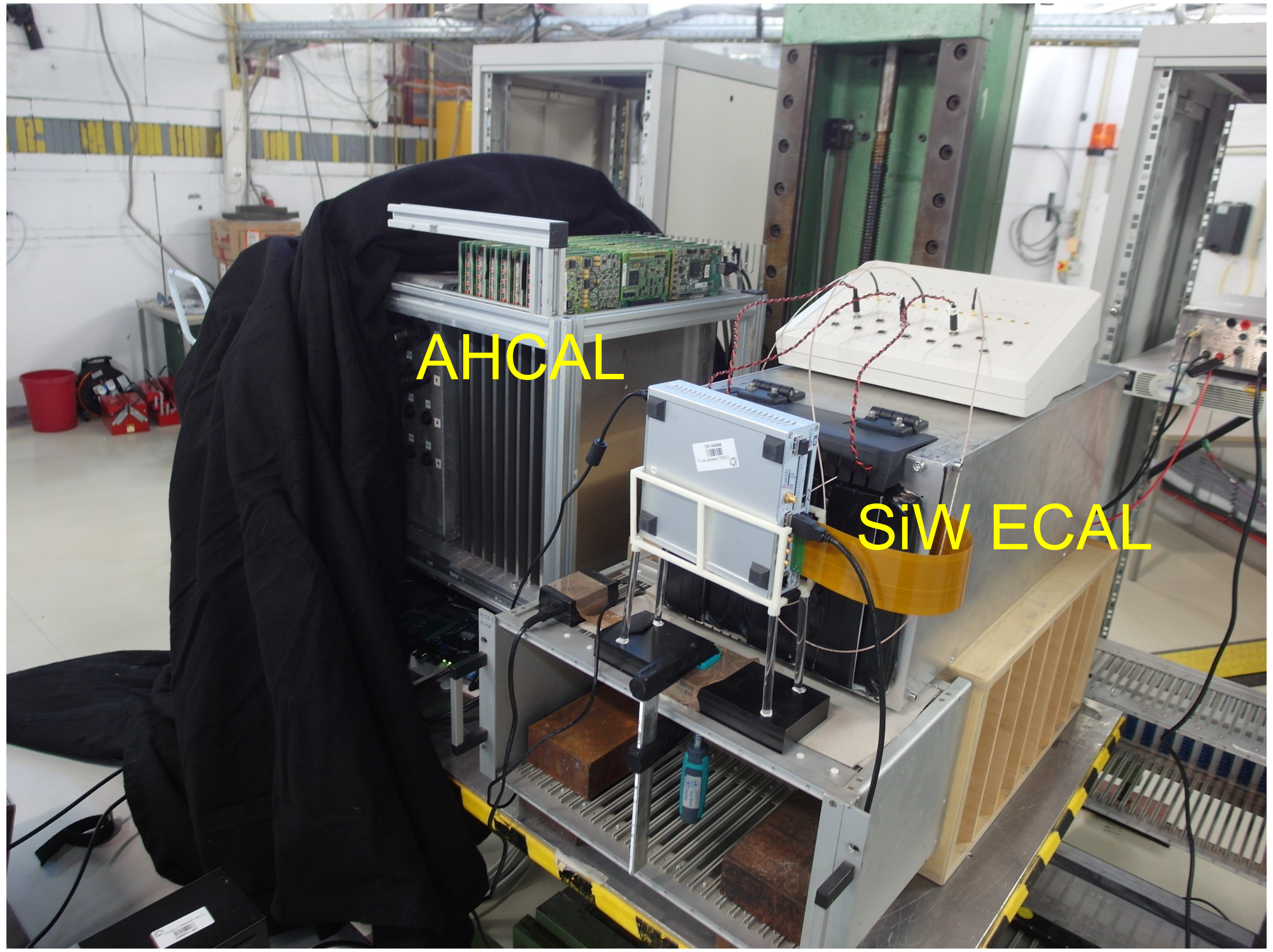
Elm. sections

Hadronic sections

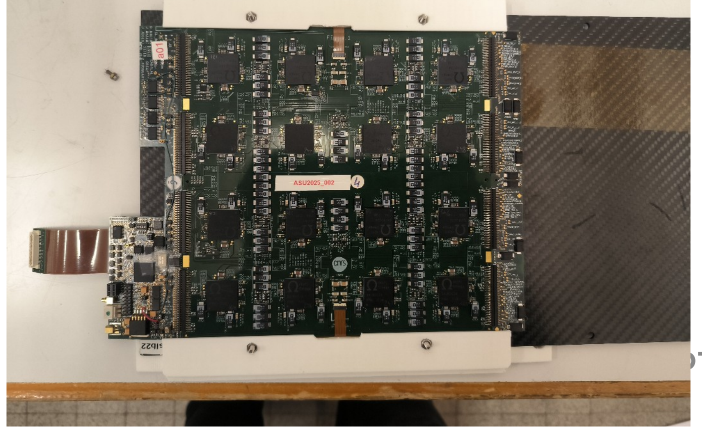
Task/Subtask	Sensitive Material/ Absorber	DRDT
Task 1.1: Highly pixelised electromagnetic section		
Subtask 1.1.1: SiW-ECAL	Silicon/ Tungsten	6.2
Subtask 1.1.2: Highly compact calo	Solid state (Si or GaAs)/Tungsten	6.2
Subtask 1.1.3: DECAL	CMOS MAPS/Tungsten	6.2, 6.3
Subtask 1.1.4: Sc-Ecal	Scintillating plastic strips/Tungsten	6.2
Task 1.2: Hadronic section with optical tiles		
Subtask 1.2.1: AHCAL	Scintillating plastic tiles/Steel	6.2
Subtask 1.2.2: ScintGlassHCAL	Heavy glass tiles/Steel	6.2
Task 1.3: Hadronic section with gaseous readout		
Subtask 1.3.1: T-SDHCAL	Resistive Plate Chambers/Steel	6.2
Subtask 1.3.2: MPGD-HCAL	Multipattern Gas Detectors/Steel	6.2, 6.3
Subtask 1.3.3: ADRIANO3	Resistive Plate Chambers+Scintillating plastic tiles/ Heavy Glass	6.1, 6.2, 6.3

WP1 – Subtask 1.1.1 and 1.1.2 – SiW ECAL and AHCAL

Common testbeam March 2025 at DESY



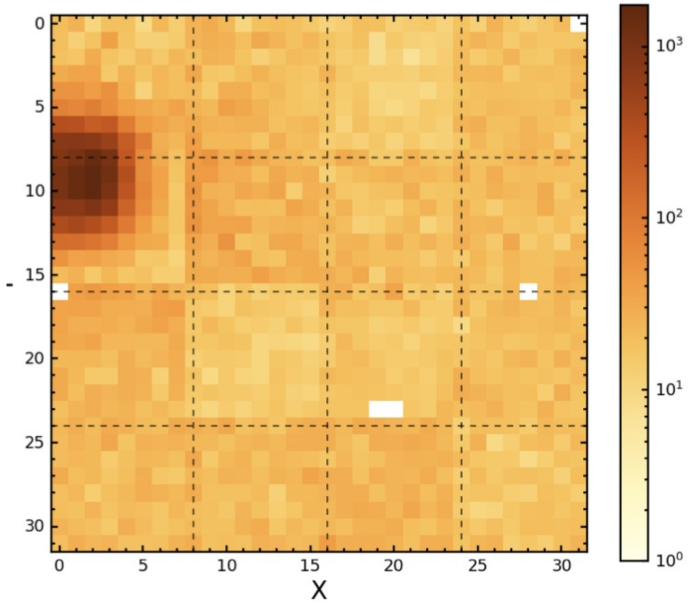
18x18cm^2, 1024 (Si) Channels



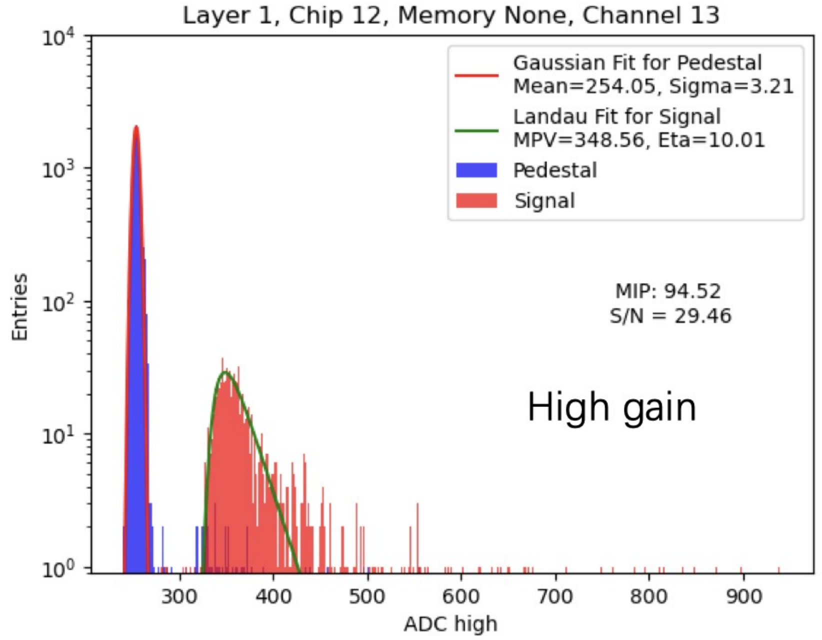
New SiW Ecal modules

SiW ECAL Modules - Performance

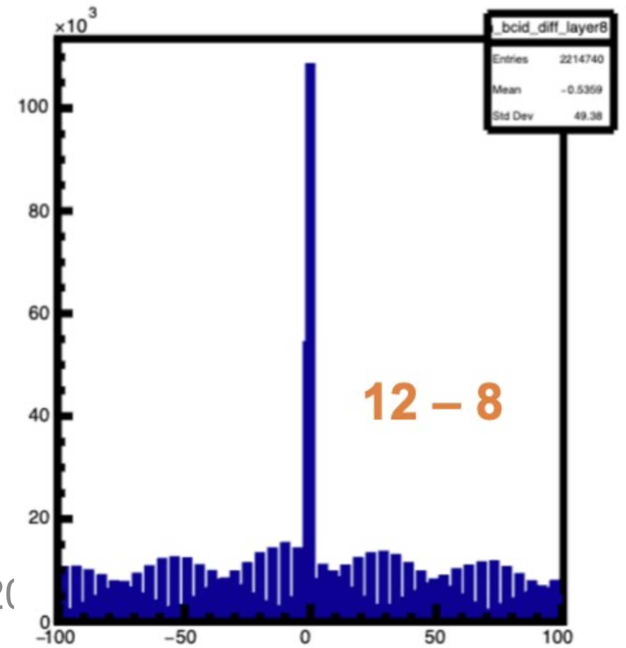
(Almost) no noisy cells

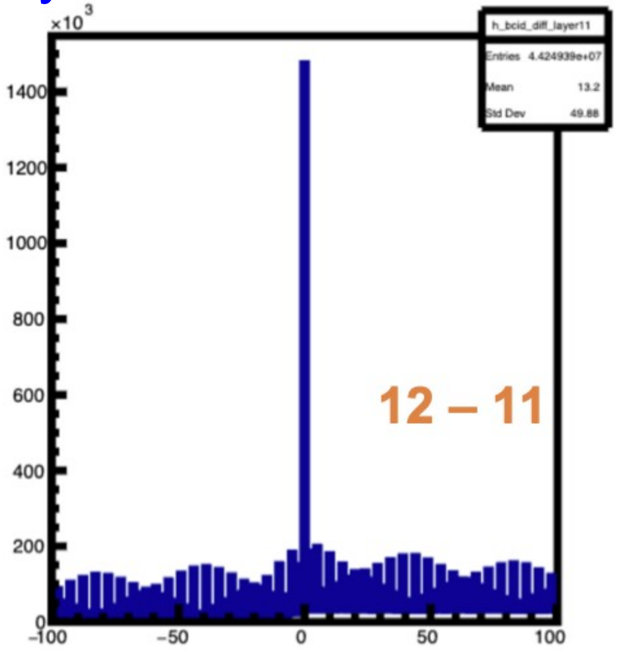


Clear S/N Separation



Detectors in sync

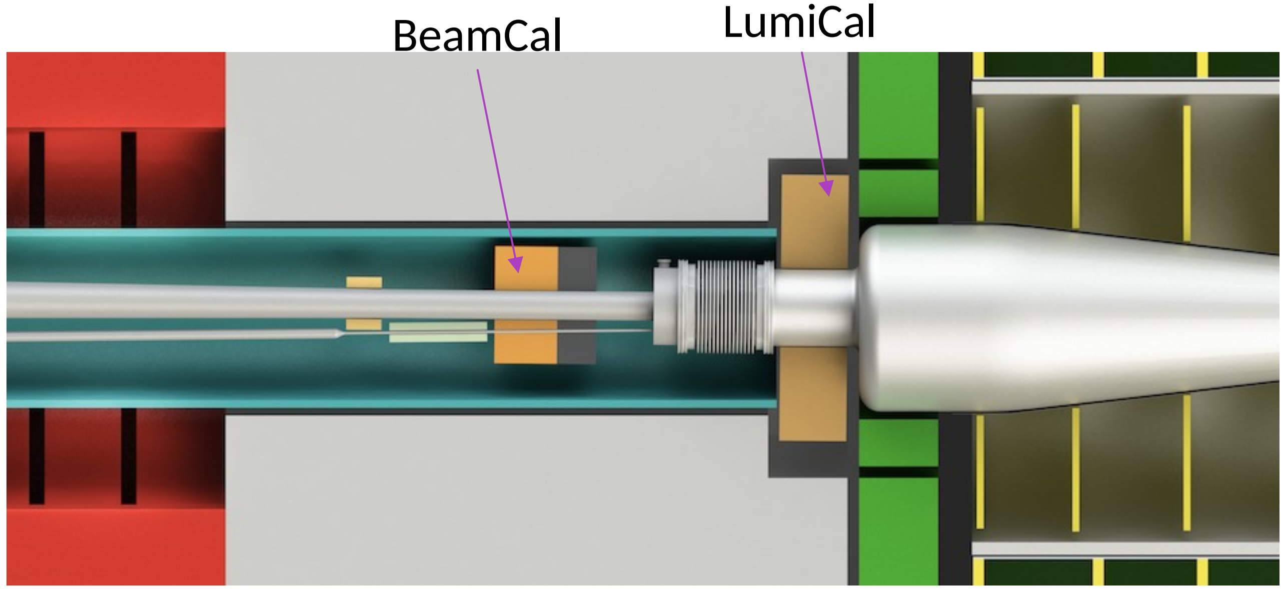




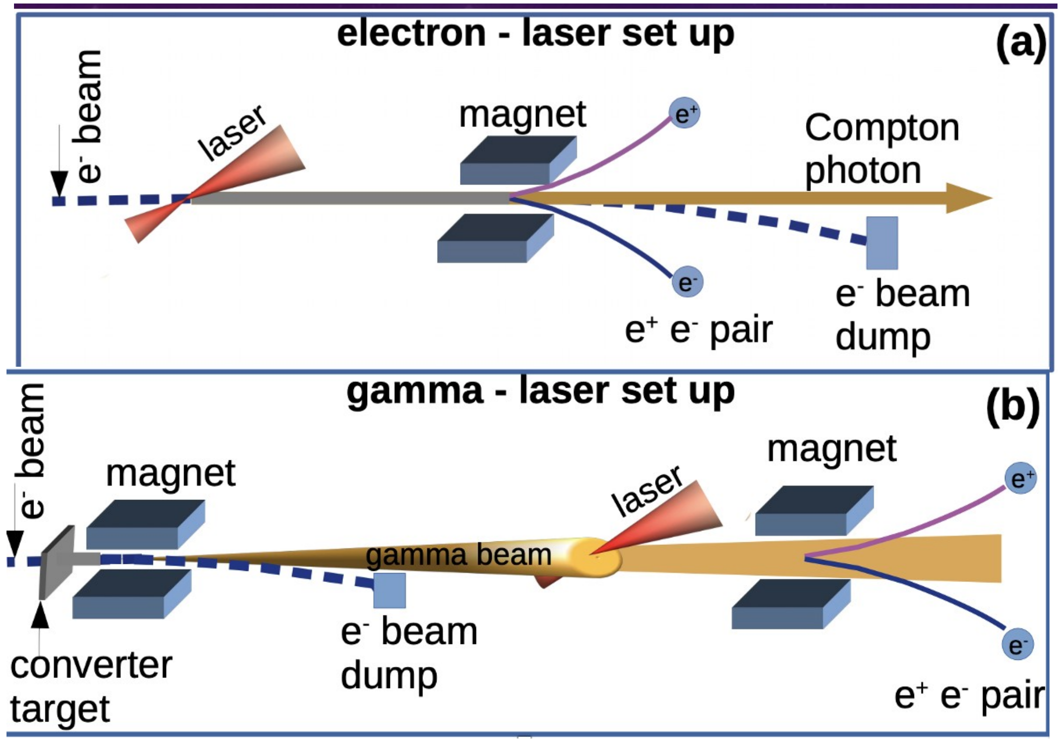
WP1 – Subtask 1.1.2 – Highly Compact Calo

DRD Calo

Longstanding R&D for forward calorimeters

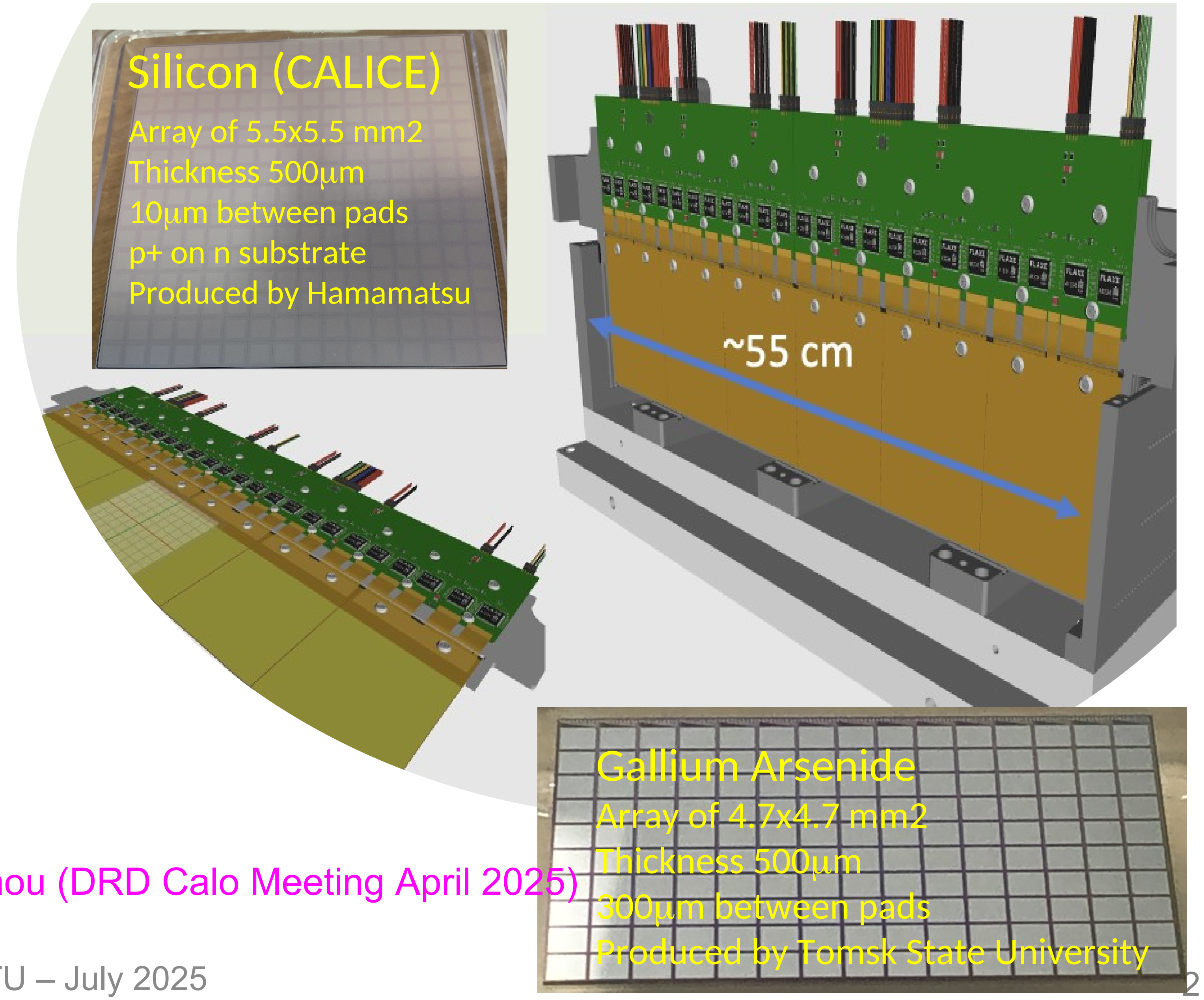


Applied to LUXE (DESY Experiment, extreme QED)



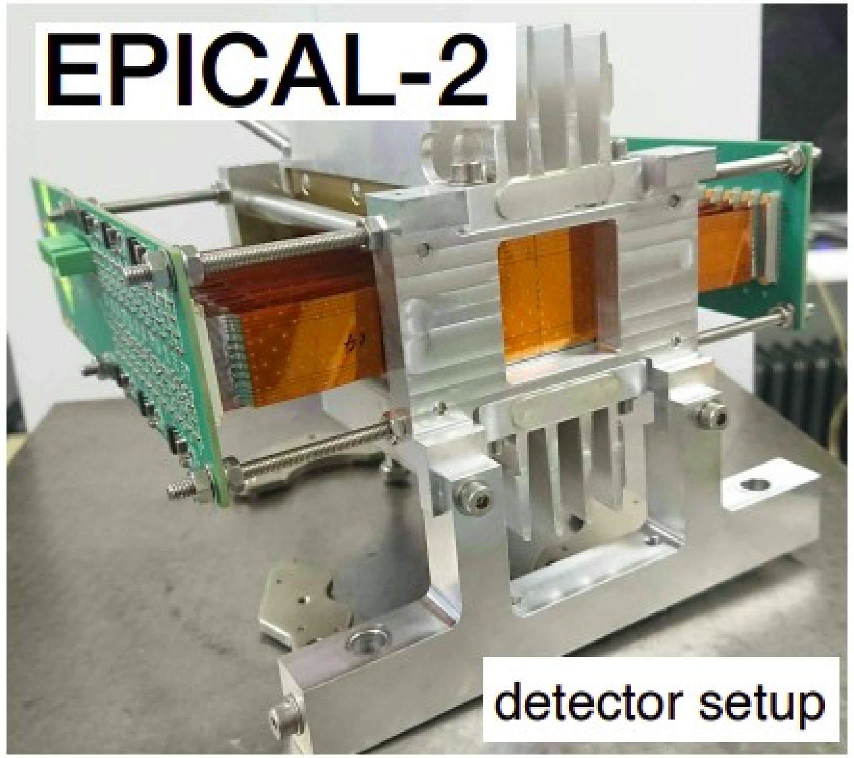
LUXE

- Realisation of compact mechanical structures
- Sensor R&D

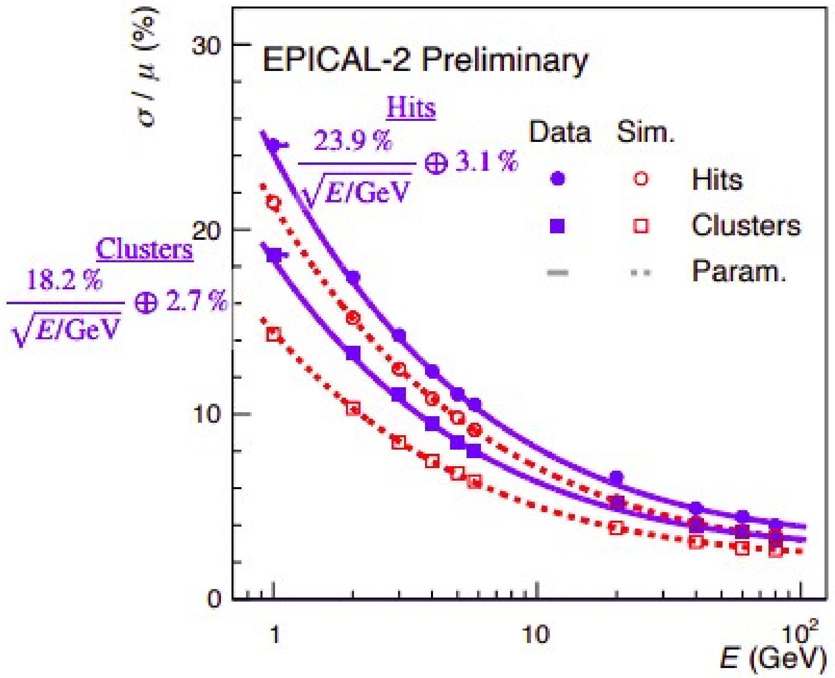


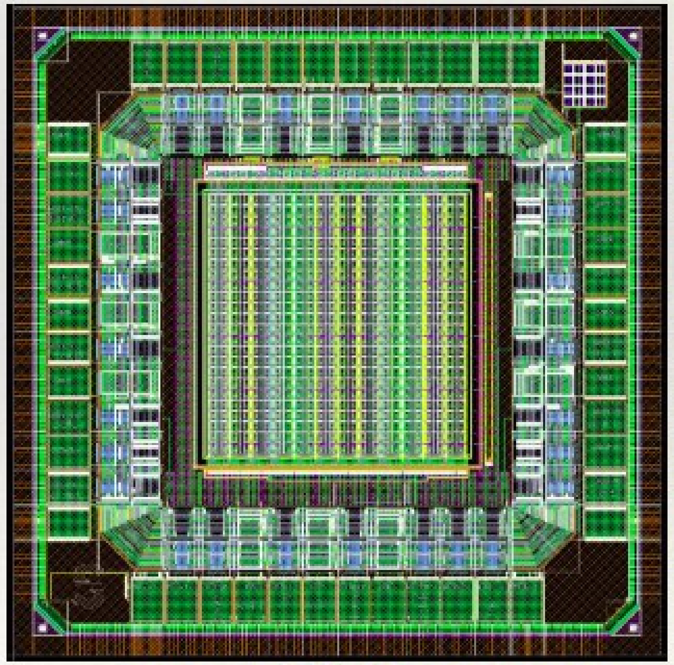
Yan Benhammou (DRD Calo Meeting April 2025)

WP1 – Subtask 1.1.3 – DECAL

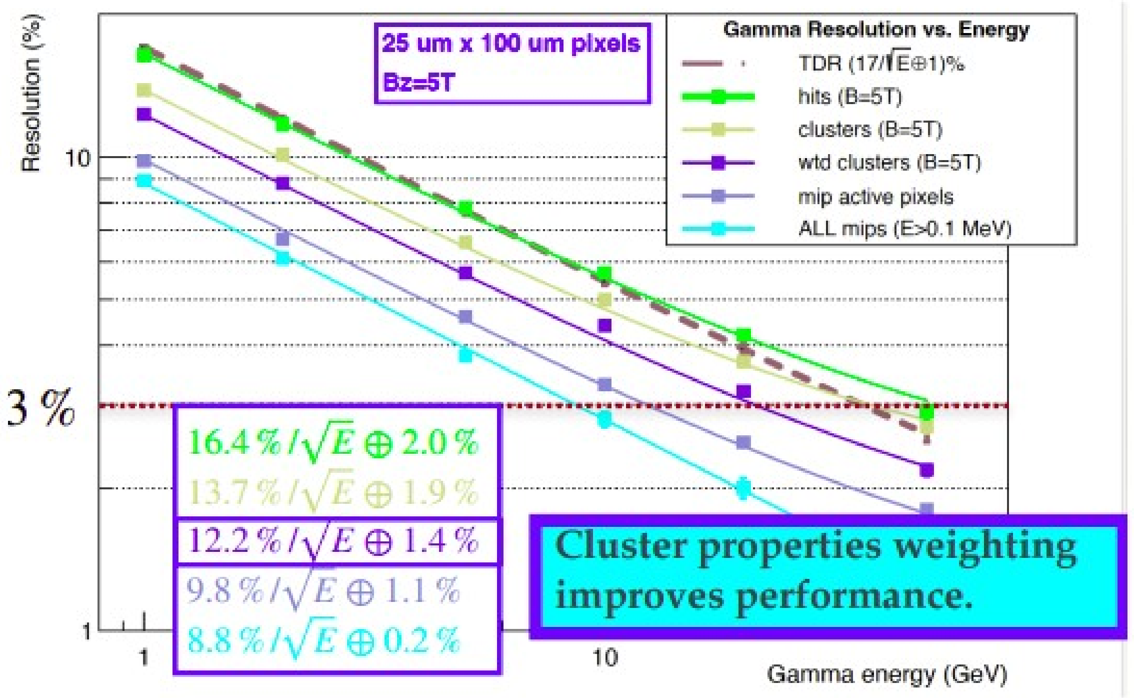


- Major challenges
  - Development of dedicated sensor
    - Local dynamic range: optimise granularity and bit depth
    - Power consumption, rate capabilities, data reduction, radiation, trigger capability(?), timing(?)
  - Integration: preserve compactness for small R_M
    - Cooling, cabling, etc.

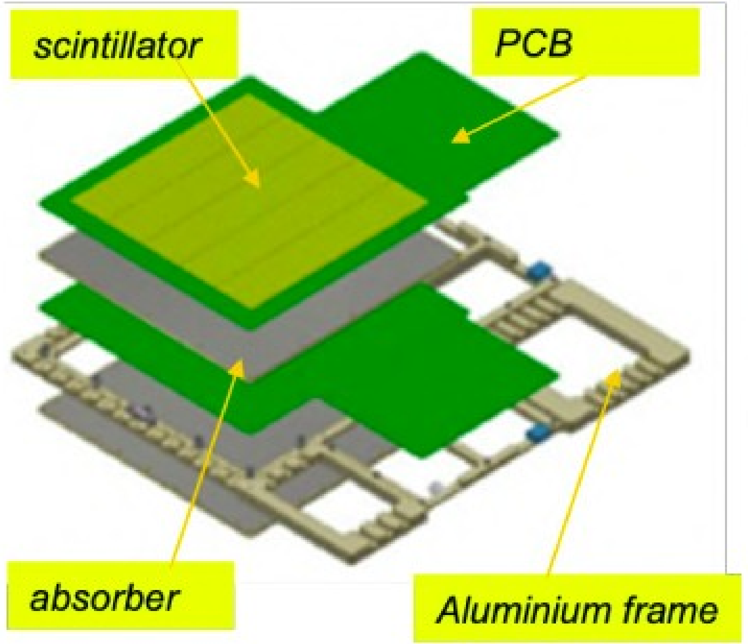




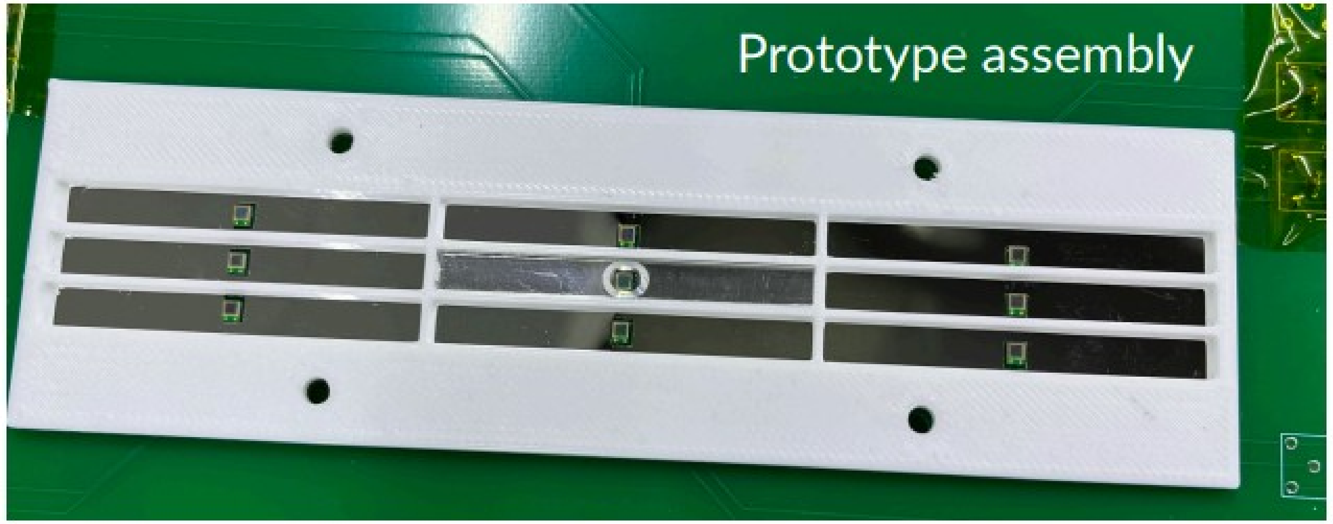
Layout of SLAC prototype
for WP1.2 2022
shared submission
on TowerSemi 65nm

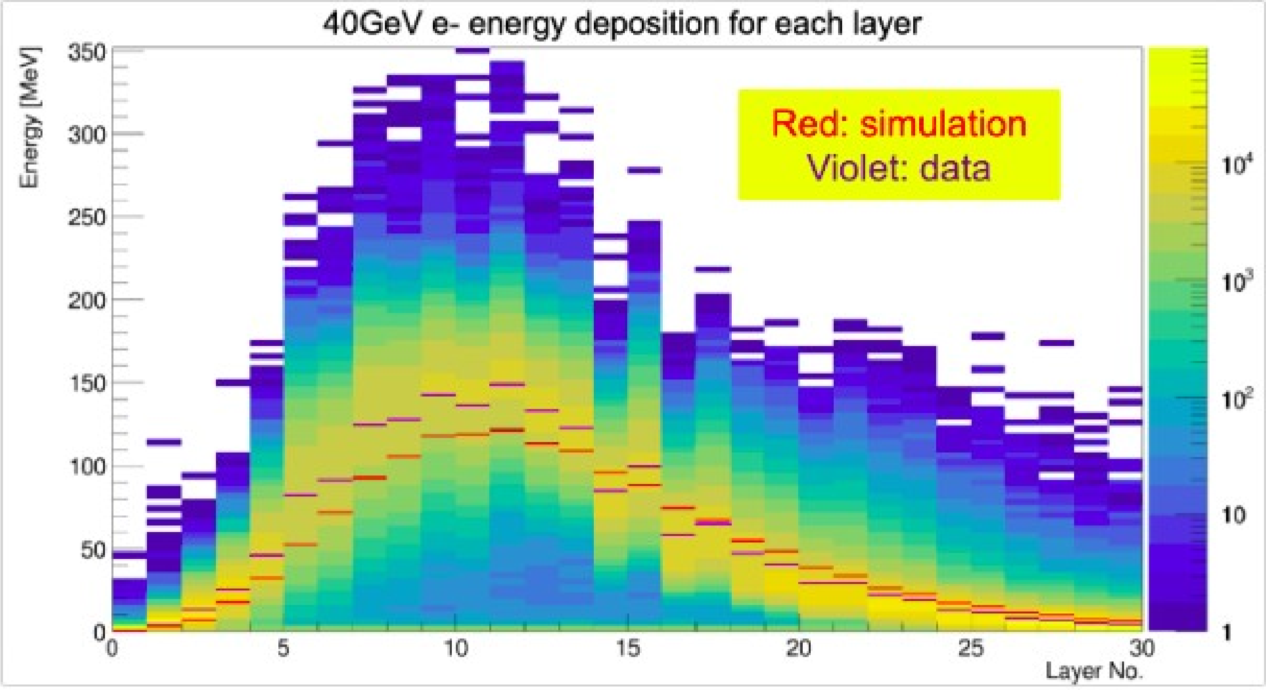


WP1 – Subtask 1.1.4 – ScECAL



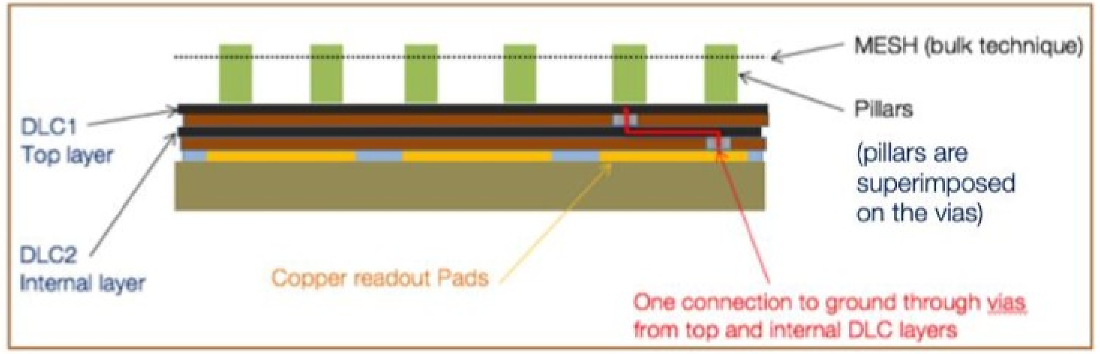
- ScW-ECAL **technological prototype**
  - Full layers (32 layers)
    - Detection layer of 210×225mm² with 210 scintillator-strips
      - 30 layers with single SiPM readout
      - 2 layers with double SiPM readout
    - Absorber plate (3.2mm-thick 15%-85% Cu-W alloy)
    - Total material thickness $23.4\,X_0$
- Beam test campaign at CERN in 2022/2023 (combined test with CEPC-AHCAL)

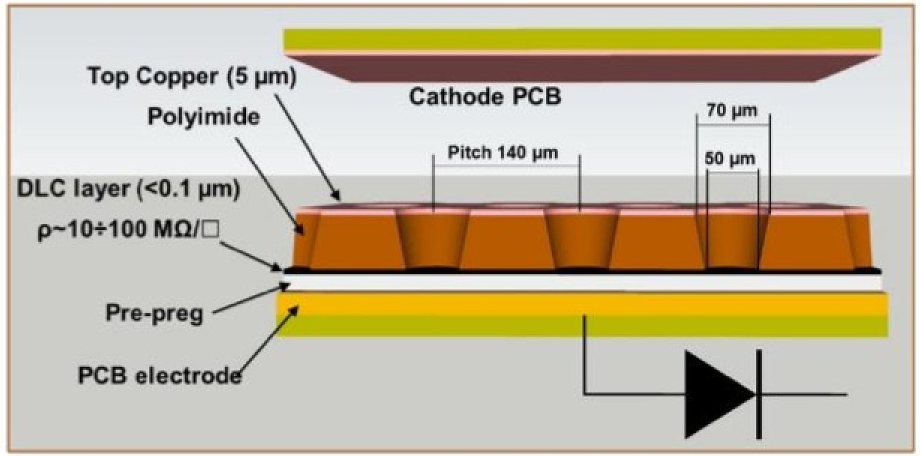




WP1 – Subtask 1.3.2 – MPGD-HCCAL

Micromegas (MM)

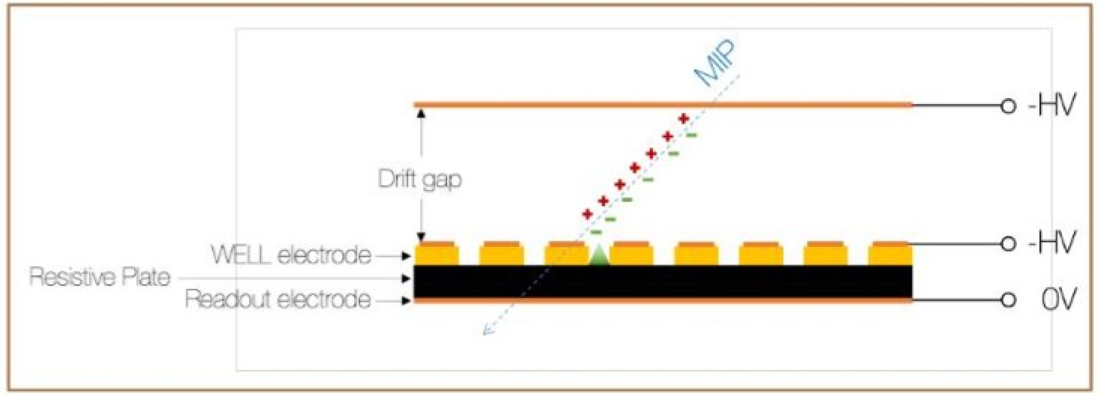




µRWELL

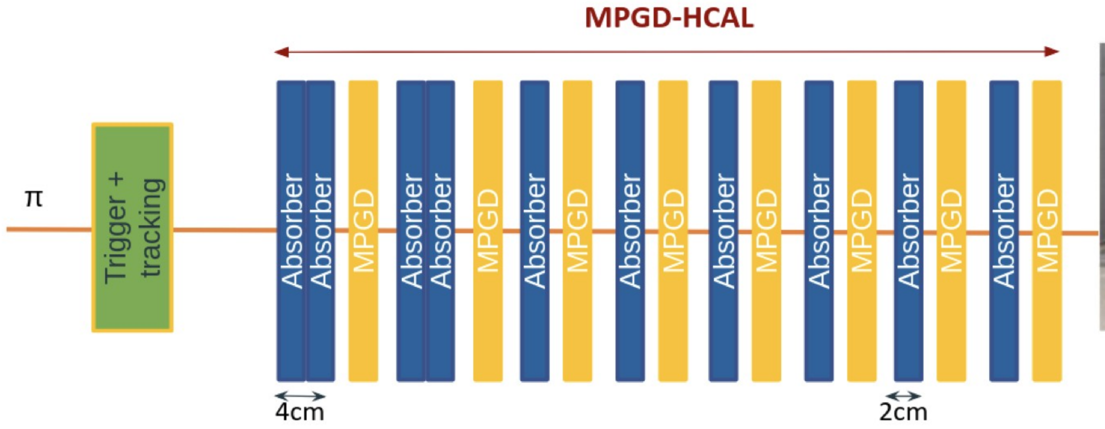
S

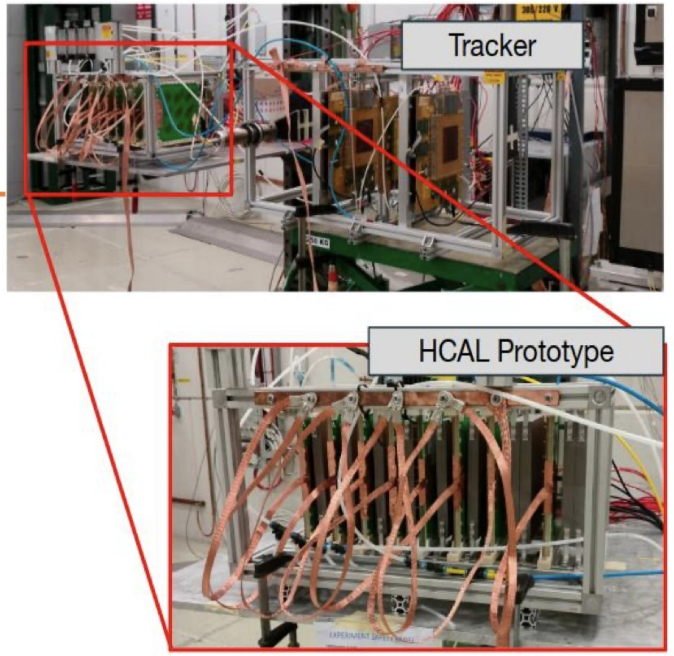
RPWELL



MPGD-HCAL prototype

With absorbers

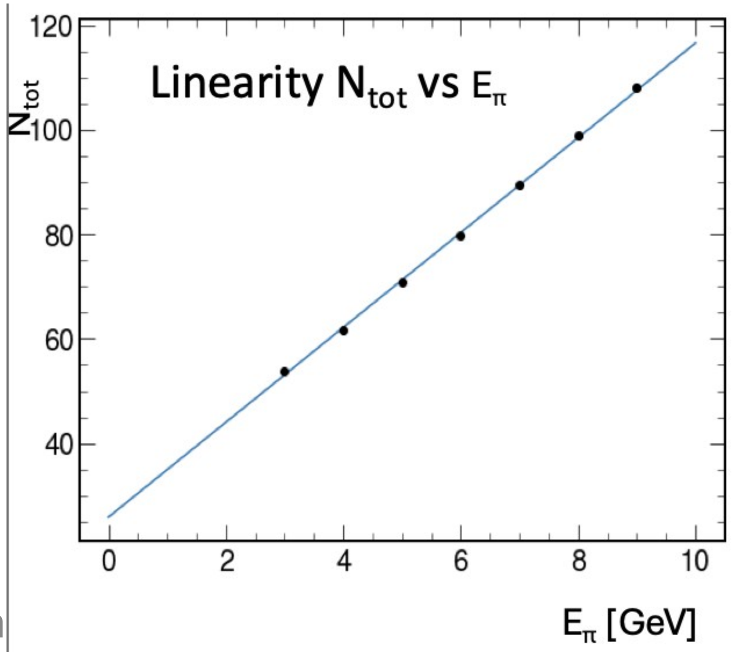


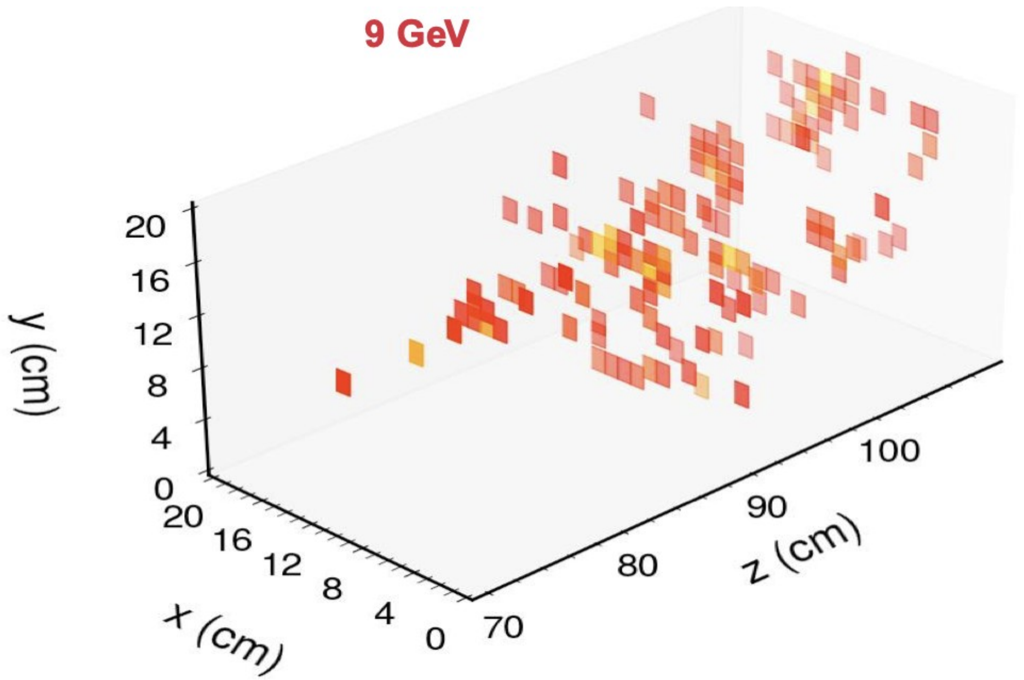


HCAL prototype ~ 1 λ_I (8 active layers) tested under pion beam at PS
Data taking based on analog FE (APV25 + SRS)

Runs at different π^- energy (up to 11 GeV)

- Two TB campaigns: August 2023, July 2024
- Data analysis **ongoing**
- Developed G4 simulation for comparison with TB prototype

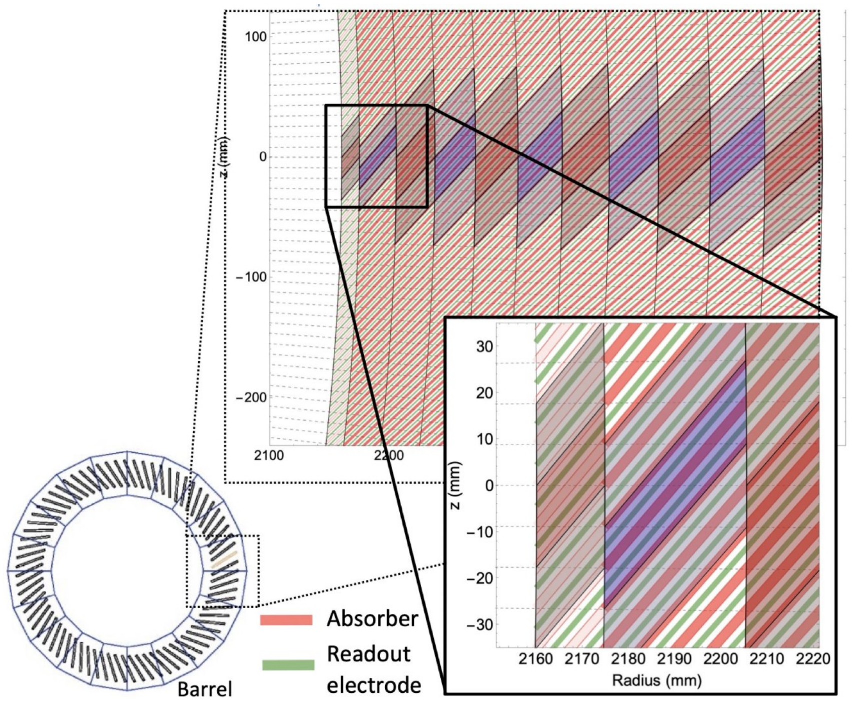




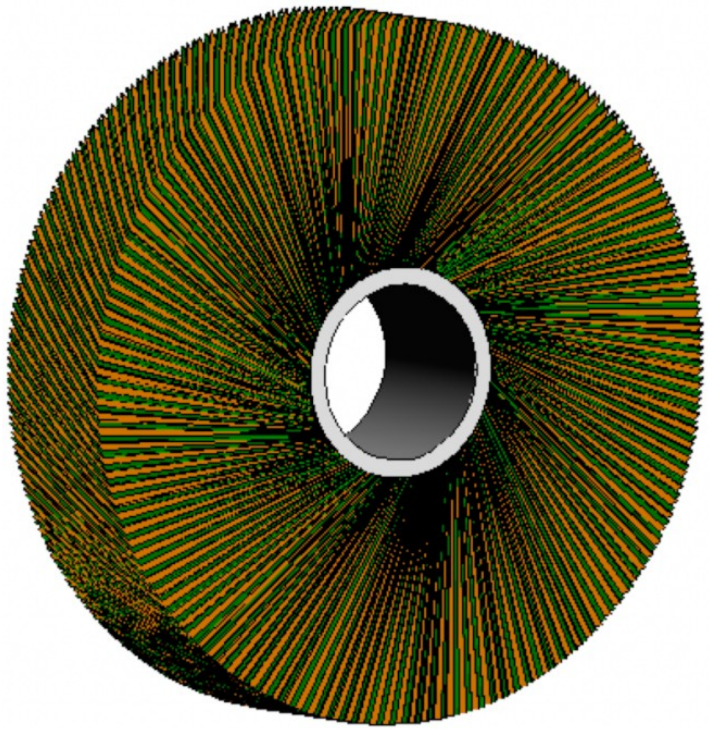
Sem

WP2 – Overview

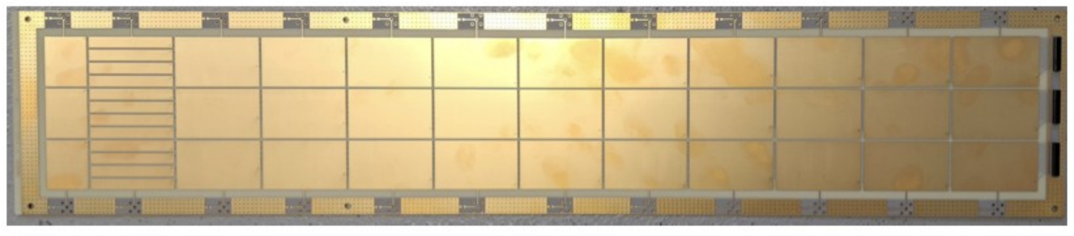
- Focused on R&D on noble-liquid calorimetry
- Main target on foreseeable future: sampling EM calorimeter for e+e- factories - one of key features of “ALLEGRO" detector concept for FCC-ee (https://allegro.web.cern.ch/)
  - highly granular calorimeter with absorber planes inclined in r-phi (barrel) / arranged in turbine-like structure (endcap)
  - readout by segmented PCB planes alternated to Pb (or W) absorbers, gaps in between filled with LAr (or LKr)



barrel



endcap

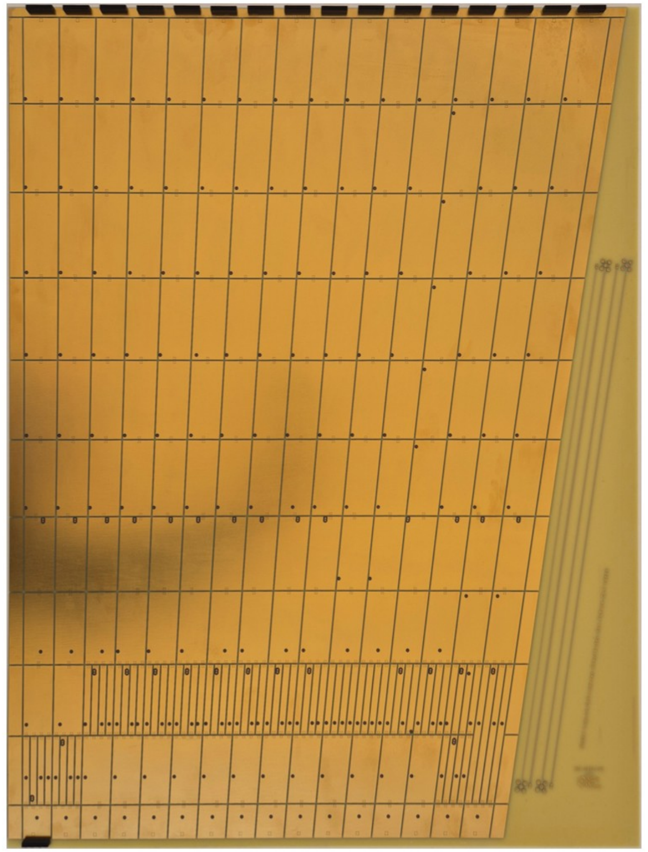


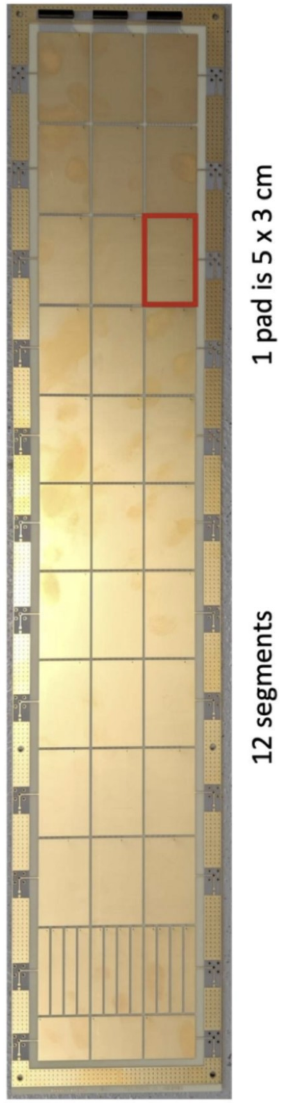
PCB (readout)
Current main focus of
Hardware development

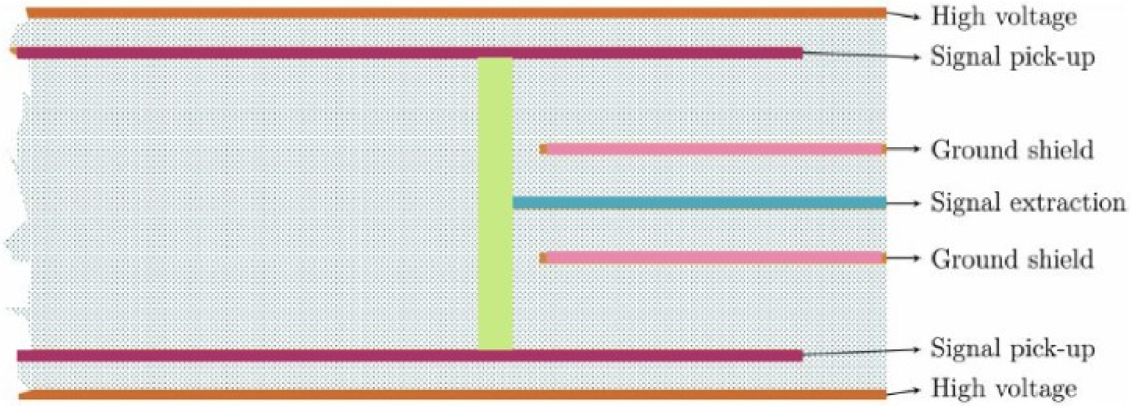
WP2 – R&D on readout electrode

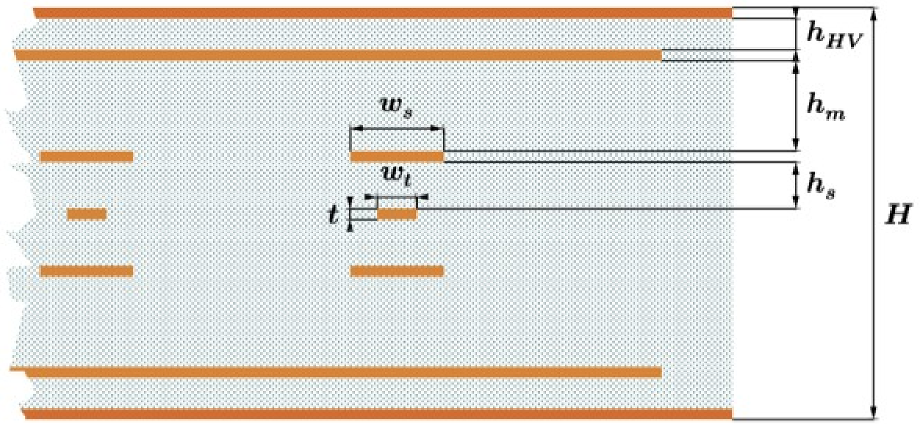
- Signal traversing under other cells induces *cross-talk* (x-talk) that worsens resolution
- Can be mitigated by sandwiching signal traces between grounded shields*
- **Trade-off between x-talk and electronics noise**
  - Shields reduce x-talk but increase capacitance to ground and hence noise
- In latest prototype PCBs baseline is 2x width shields above and below each signal trace
  - Various other configurations being tested also

Readout electrode prototypes



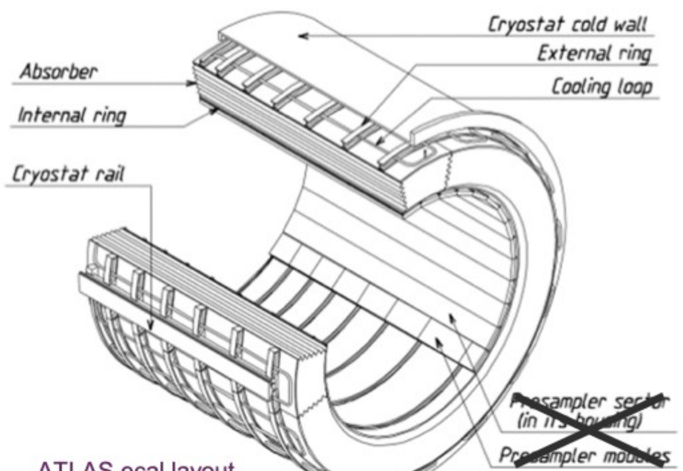




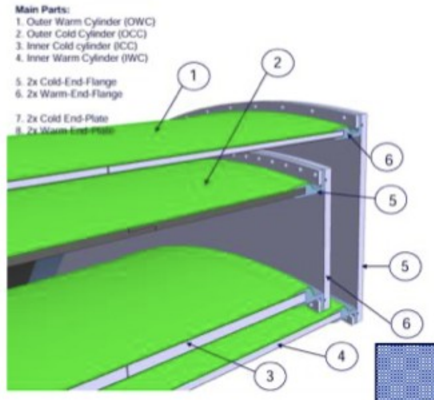


*For details see https://in2p3.hal.science/in2p3-04914287v1/document

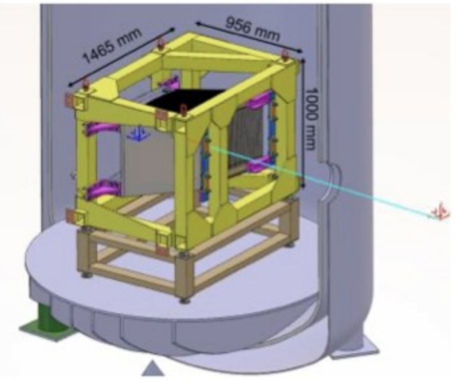
WP2 – R&D on Mechanics

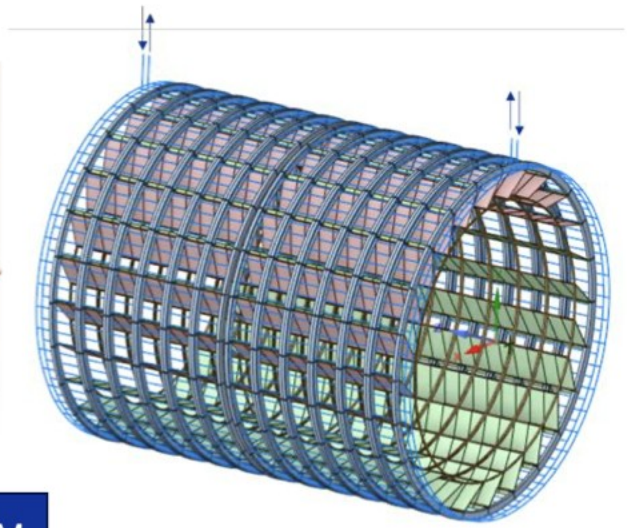


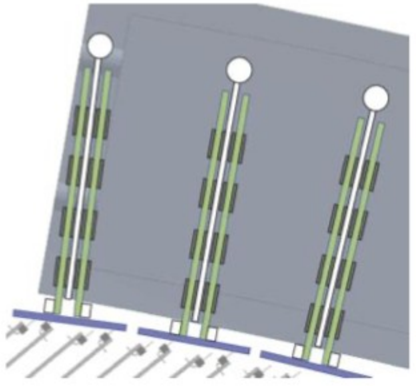
ATLAS ecal layout



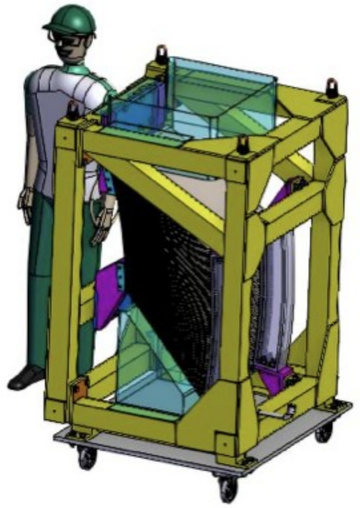
María Soledad Molina González
Carbon composite cryostat



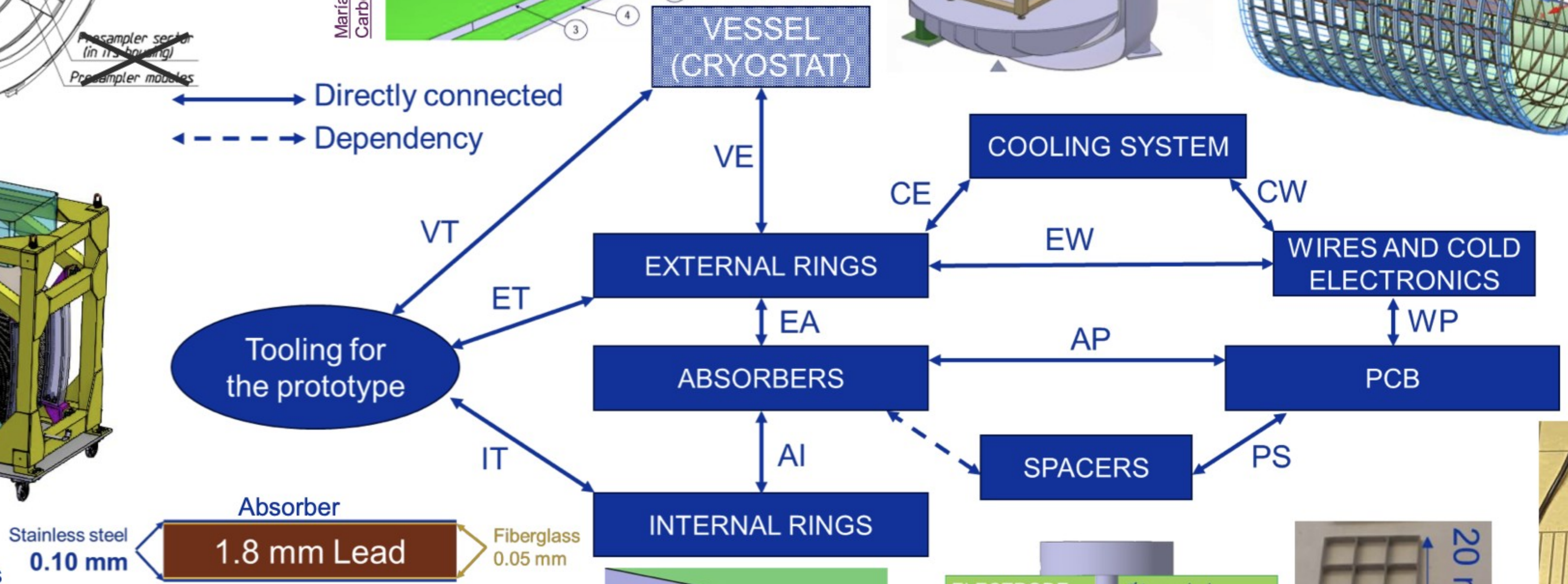


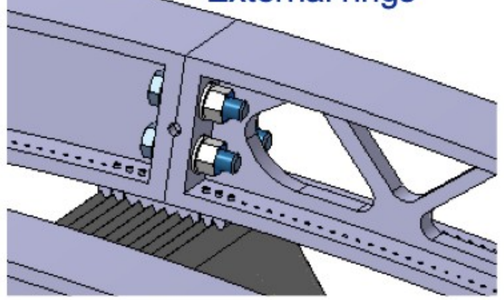


BNL: Cable routing in ALLEGRO

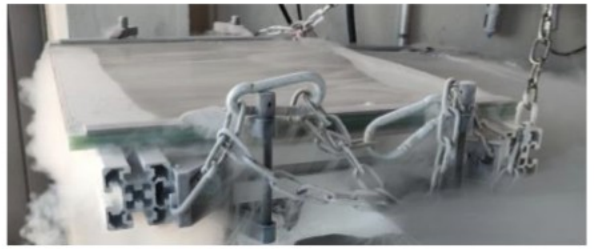


Pierre Karst (ST2410245_01)

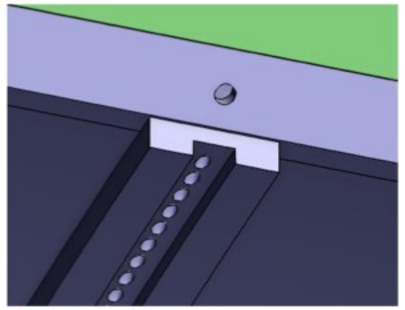




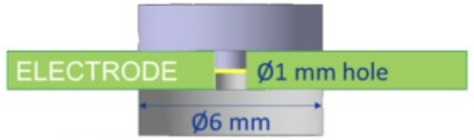
External rings

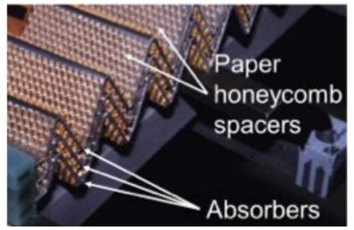


Absorber cold test



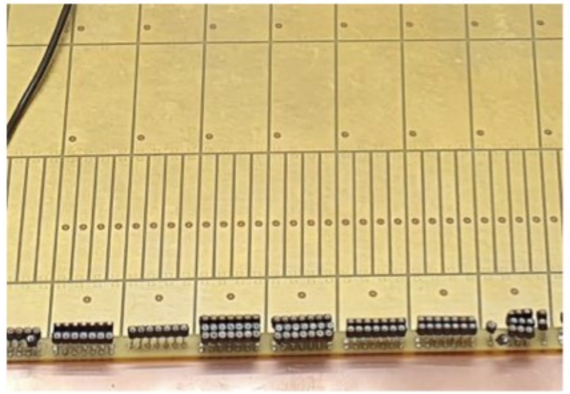
Internal ring





Spacers will be pins, 3D printed mesh or paper honeycomb, as in ATLAS experiment

https://cernbox.cern.ch/s/1oWw7zzxiB0DV7L

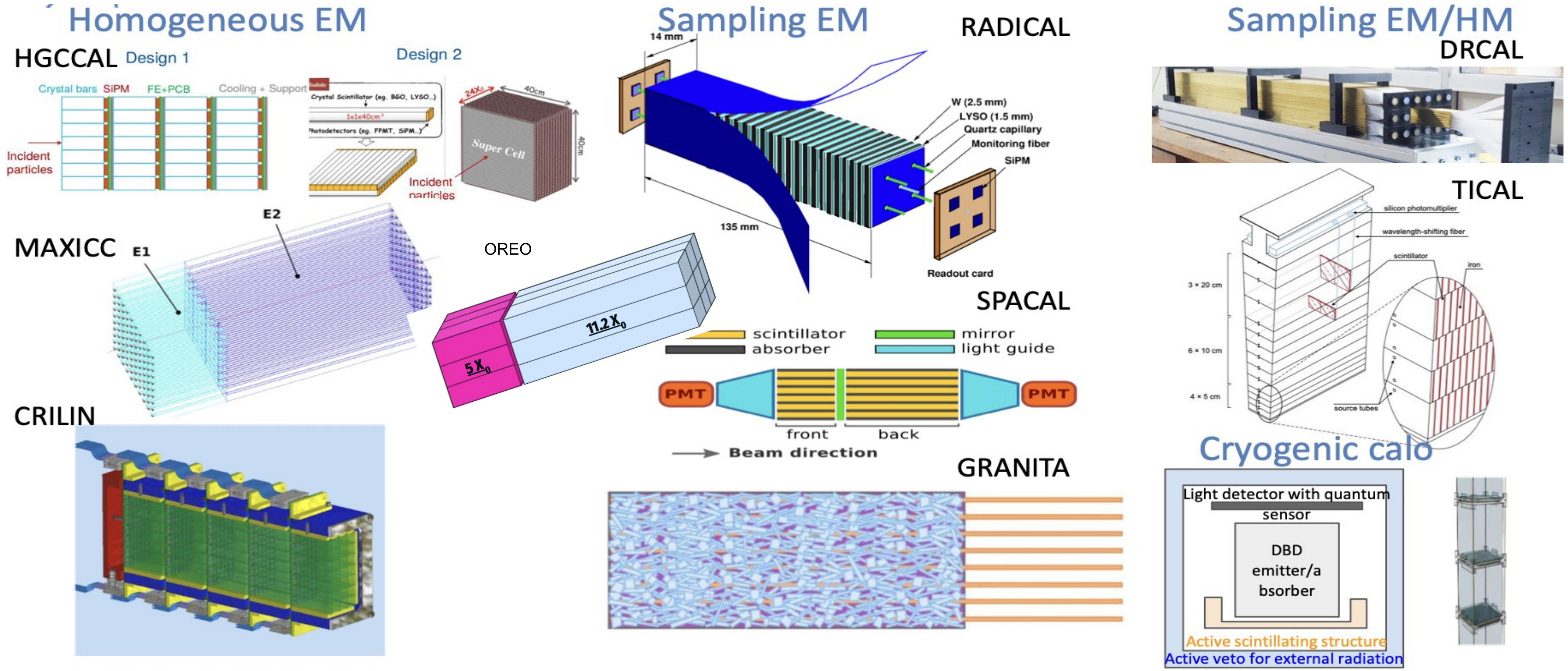


https://allegro.web.cern.ch/plots/ecal_barrel/ecal_barrel/

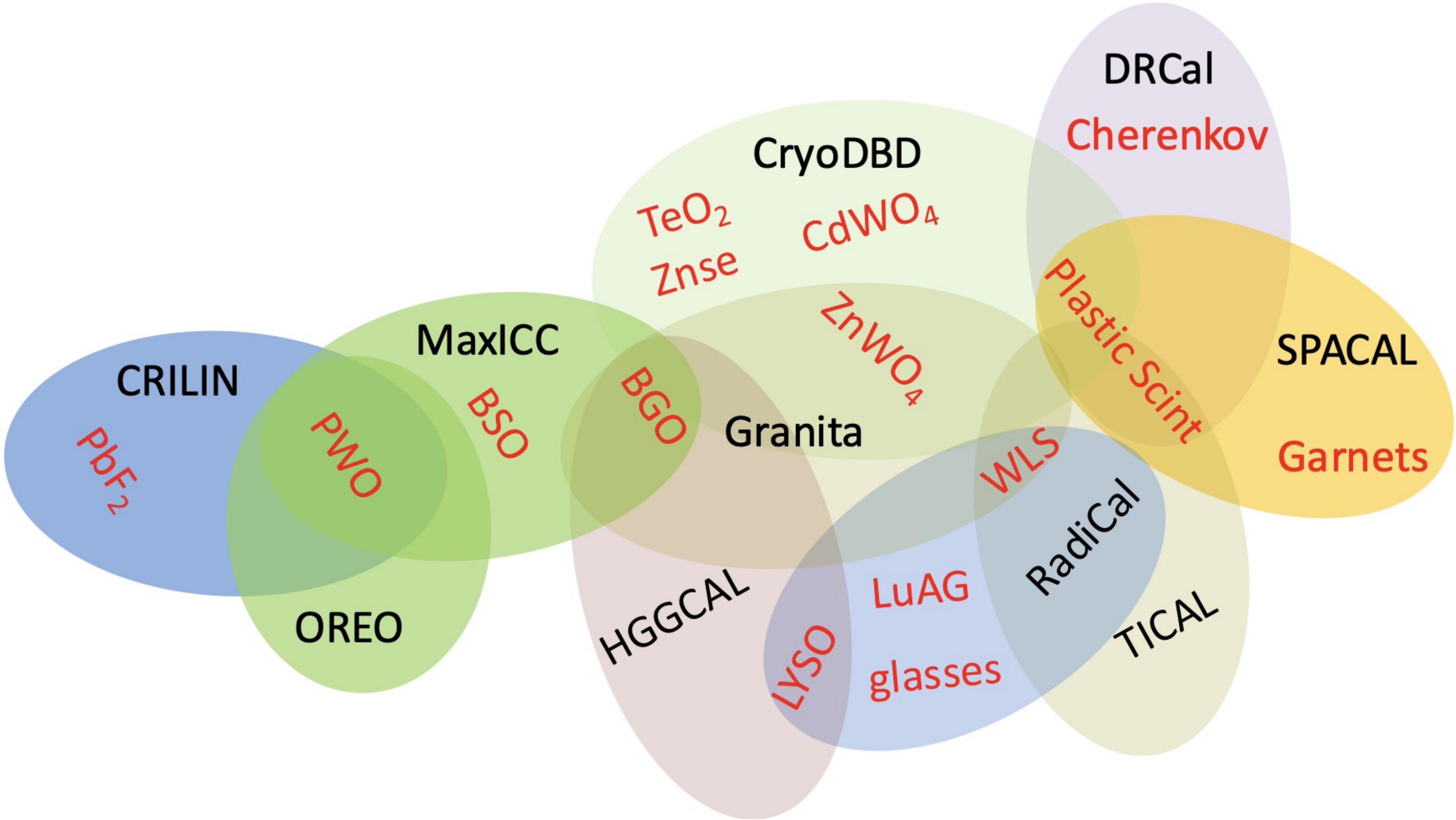
F. A. Zarate, DRD Calo Collaboration Meeting

Work Package 3 – Overview

- Involvement from ~70 institutes working on 11 different projects
- **The goal**: explore, optimise and demonstrate with full shower-containment prototypes, new concepts of sampling and homogeneous calorimeters based on scintillating materials

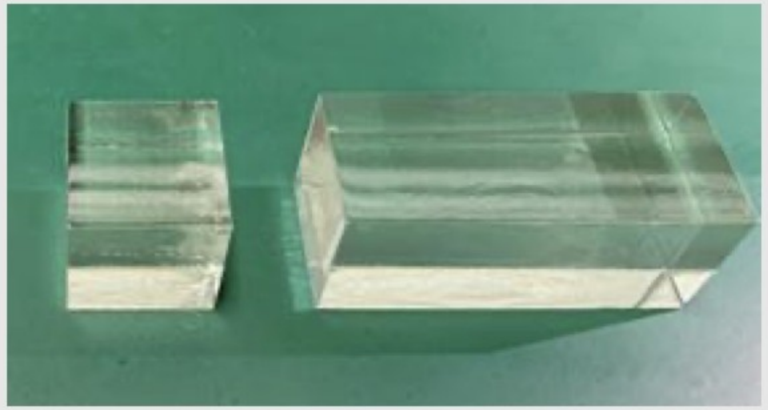


Common scintillating materials between projects



Work Package 3 – Comparison of optical materials

Plastic Scintillator



Glass Scintillator

Crystal Scintillator

Large density	★	Large density	★★	Large density	★★★
High light yield	★★	High light yield	★★	High light yield	★★★
Energy resolution	★	Energy resolution	★★	Energy resolution	★★★
Low cost	★★★	Low cost	★★	Low cost	★
Fast decay	★★★	Fast decay	★★	Fast decay	★★
Large size	★★★	Large size	★★	Large size	★★

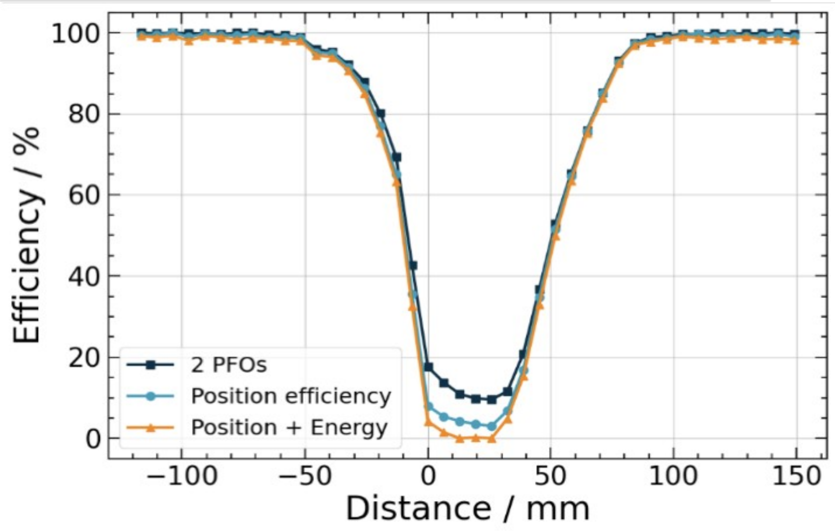
S. Qian, DRD Calo Meeting April 2025

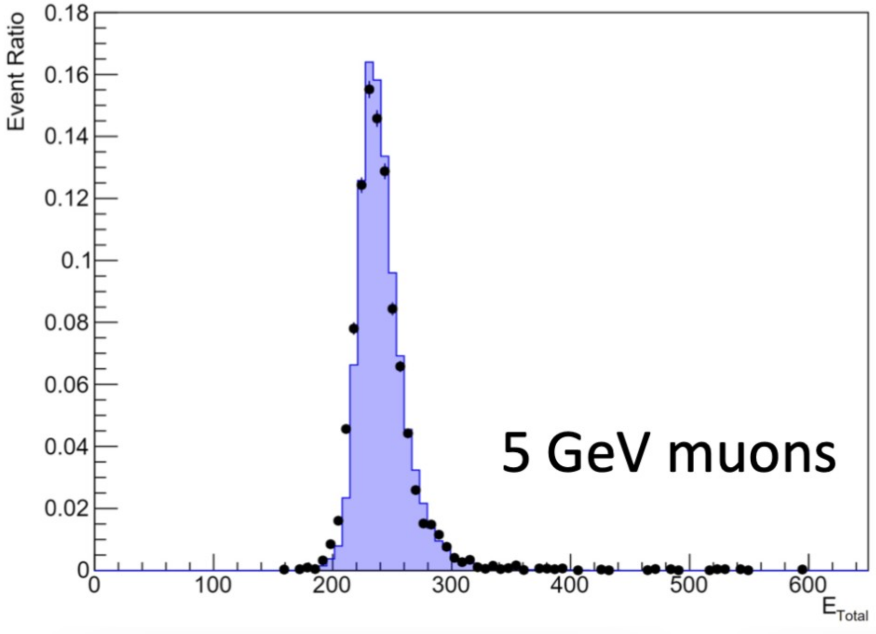
WP3 – Subtask 3.1.1 – HGCCAL

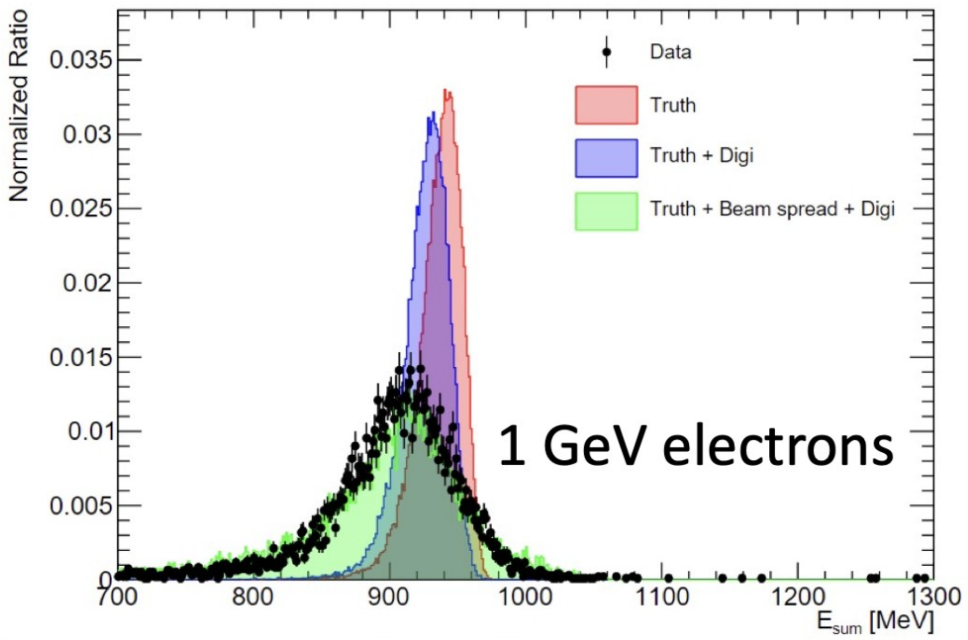
DRD Calo

- Crystal bars arranged in a grid structure
  - Optimal EM resolution: 2-3%/√E
  - Fine segmentation for particle flow algorithms
- Some of 2024 highlights
  - Well on track for (not only) 2024 milestones and deliverables
  - A full HGCCAL physics prototype developed and tested
  - New PFA reconstruction software for the long-bar design

$\gamma - \pi$ separation for 5 GeV γ and π^-



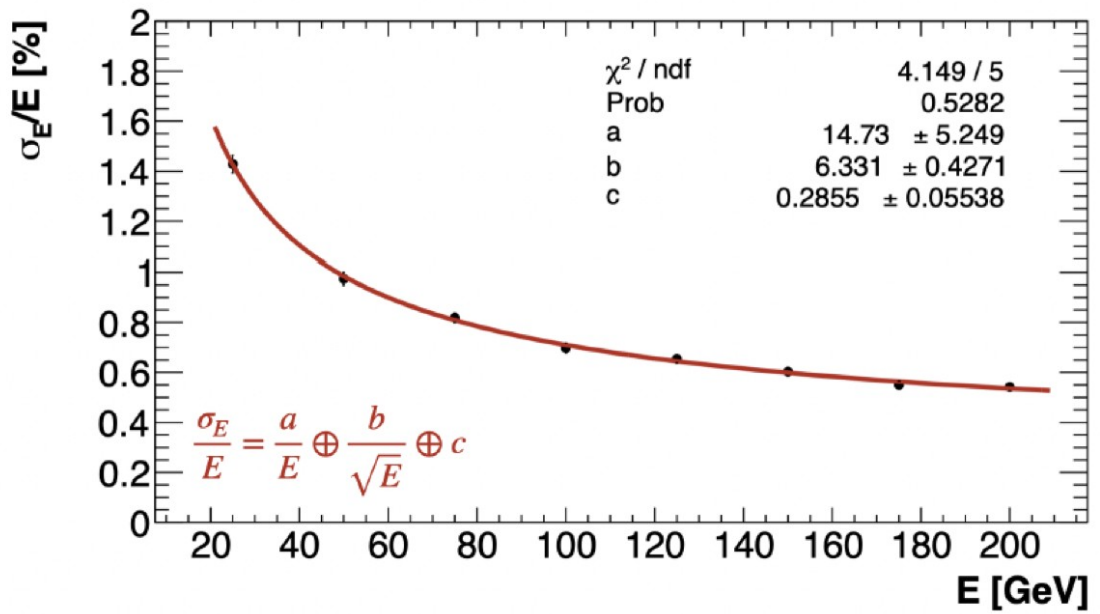


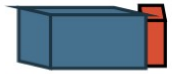


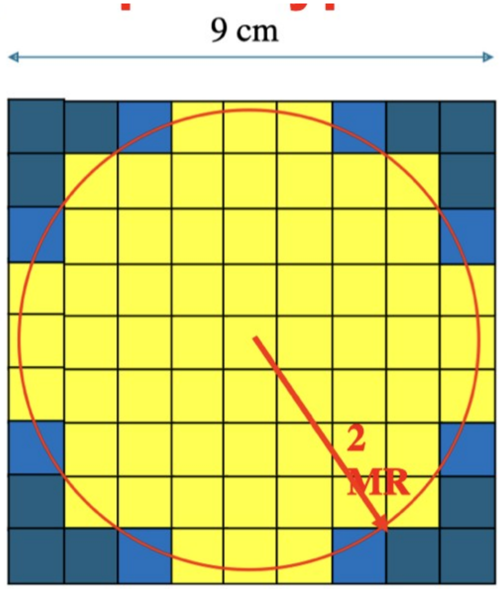
WP3 – Subtask 3.1.3 – CRILIN

DRD Calo

- A CRystal calorimeter with Longitudinal InformatioN for the future Muon Collider
  - EM calorimeter: semi-homogeneous based on Lead-Fluorite (PbF_2) crystals and SiPMs
- Targets EM resolution: 5-10%/√E
  - Limited by beam induced background (BIB) and SiPM noise (due to radiation damage)
- First prototypes tested in beam tests
- Some of 2024 highlights
  - Optimised number of crystals and layers using Geant4 simulations
  - Work ongoing towards a large scale prototype
    - Completion may be delayed due to delays in the funding







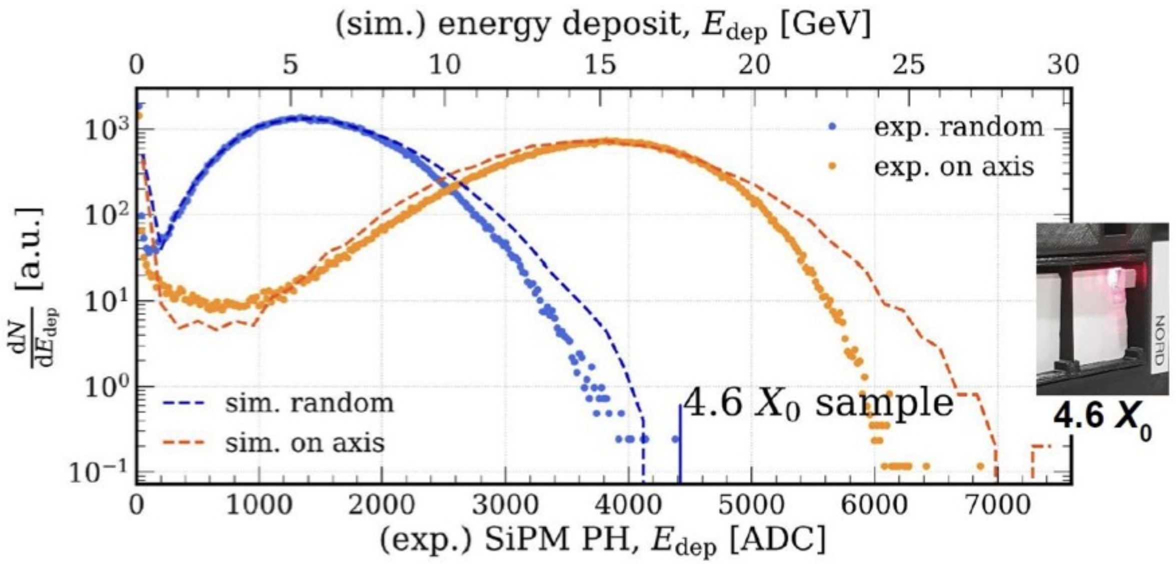
publication

L. Bandiera, V.V.Haurylavets, V. Tikhomirov NIM A 936 (2019) p.124-126
L. Bandiera et al., Front. Phys. 2023 11:1254020. doi: 10.3389/fphy.2023.1254020
M. Soldani et al., arXiv:2404.12016v1

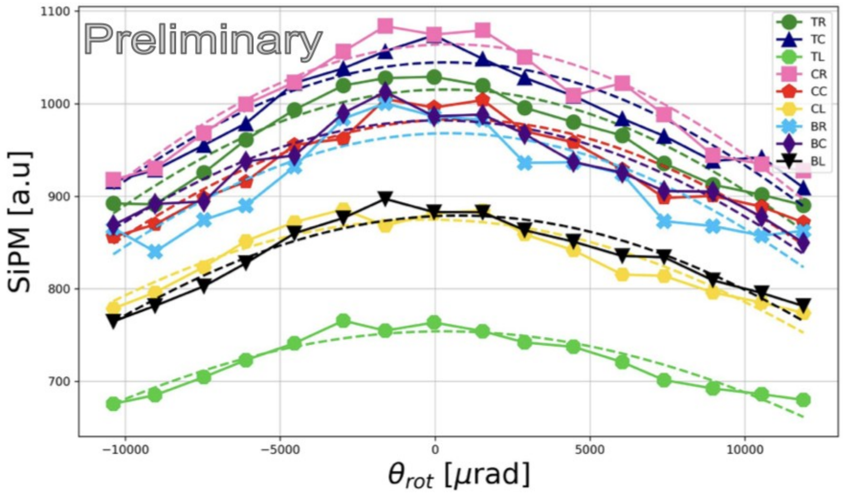
D3.18 achieved

OREO joined DRD Calo during 2024

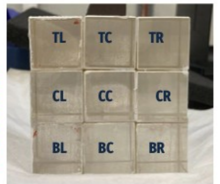
- Idea: Use oriented crystals
  - The input photon or electron/positron showers can fully develop in a much shorter depth with respect to the current state-of-the-art detectors, with the same light yield
- Some of 2024 highlights
  - Two layer PWO-UF prototype fully assembled
  - First experimental tests at CERN and data analysis



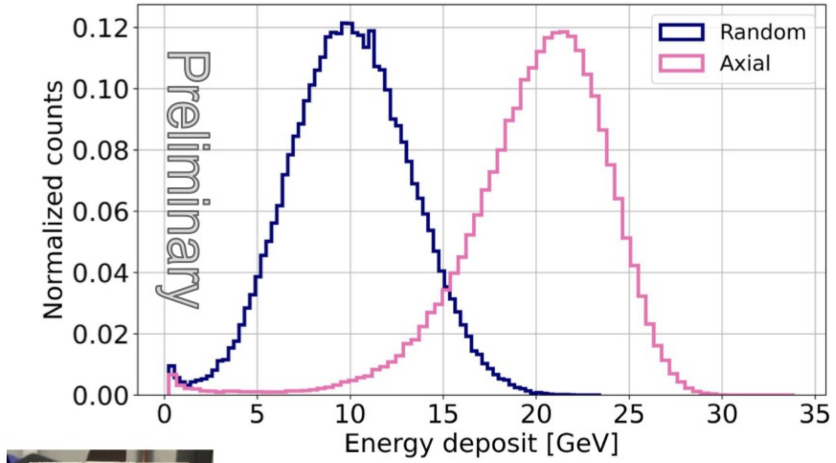
6 GeV electrons @ T9 PS



The crystals are well inter-aligned!



120 GeV electrons @ H4 SPS



Alessia Selmi

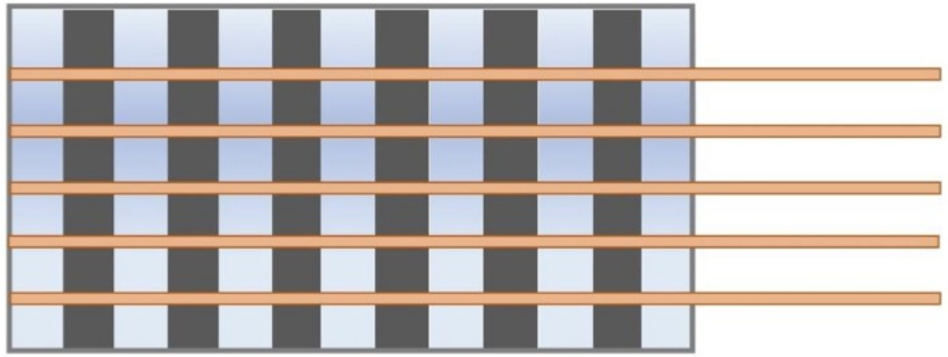
Typical sampling calorimeters:

$$\frac{\sigma_E}{E} \sim \frac{10\%-15\%}{\sqrt{E}}$$

Crystal calorimeters :

$$\frac{\sigma_E}{E} \sim \frac{1\%-2\%}{\sqrt{E}}$$

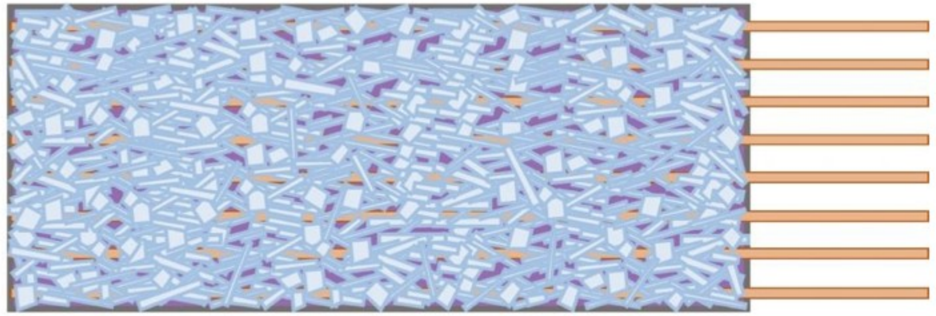
Shashlyk-type calorimeter



Requirements:

- fine sampling
- scintillation light locally contained

GRAiNITA



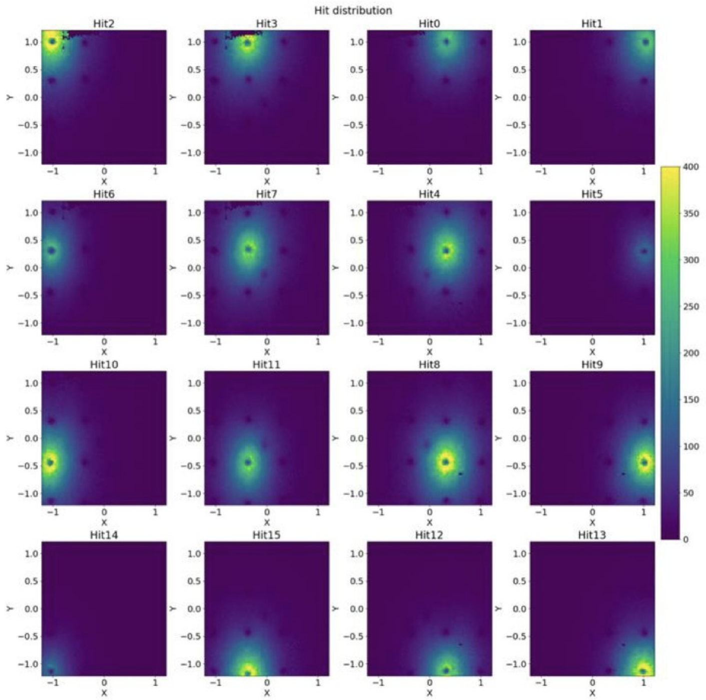
Main components :

- Scintillating grains(e.g. $ZnWO_4$)
- WLS fibers
- Heavy liquid

Inspired by LiquidO (Commun. Phys. 4, 273 (2021))

Testbeam:

Light is confined to fibre regions

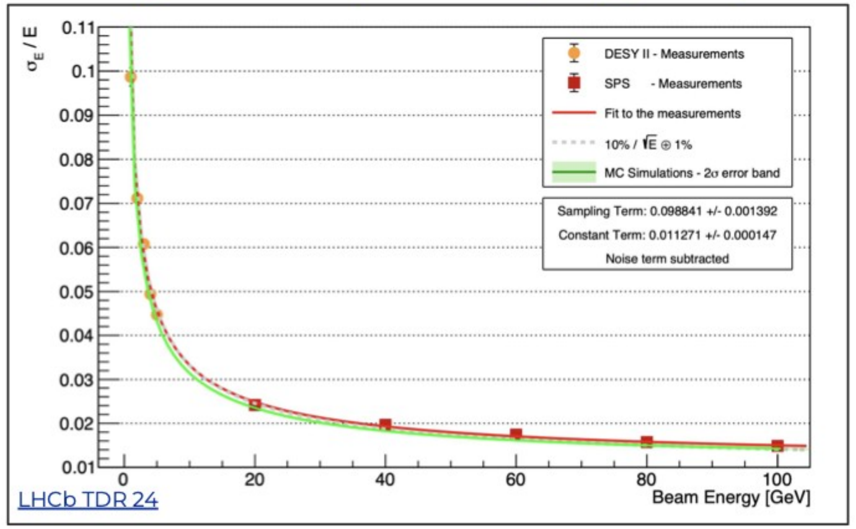


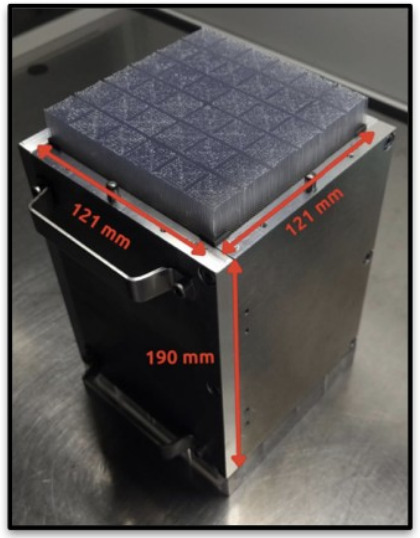
WP3 – Subtask 3.2.2 – SpaCal

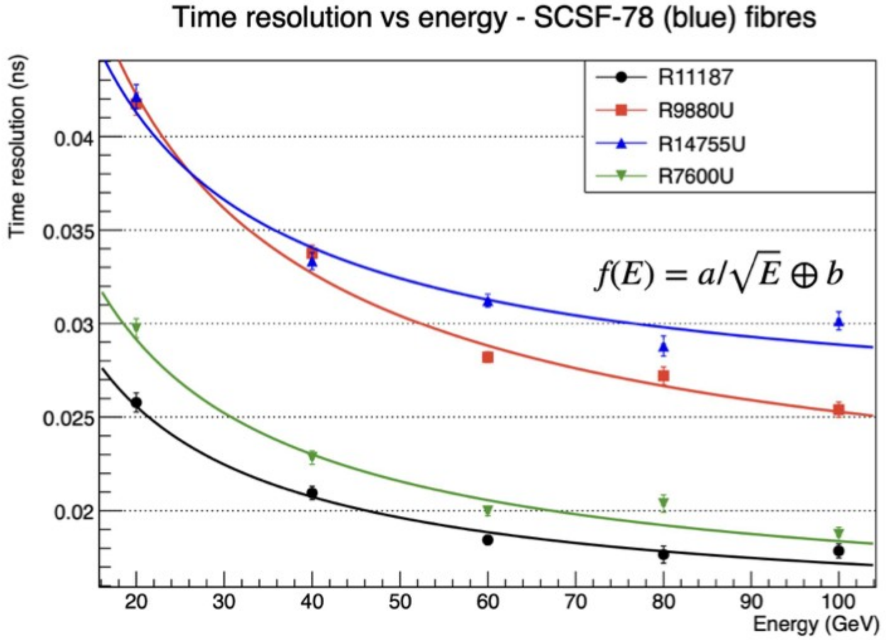
arxiv:2205.02500

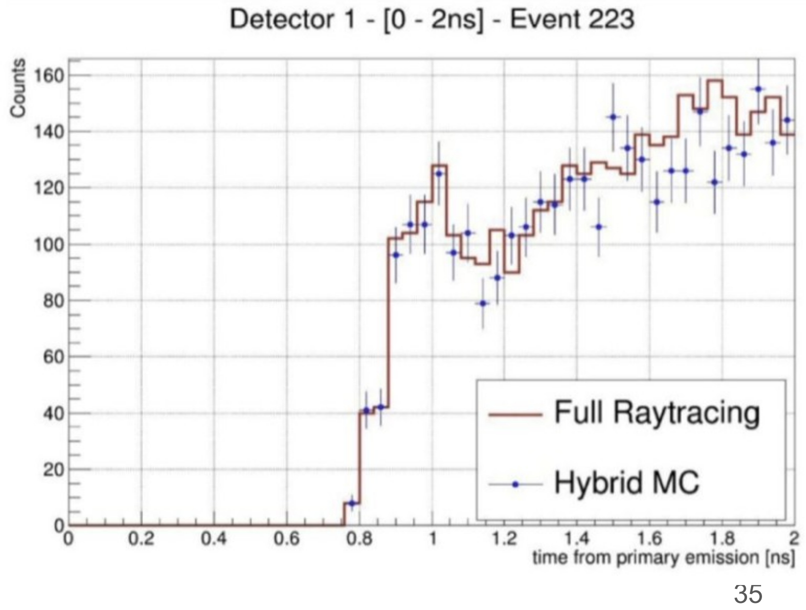
- Sampling EM calorimeter: scintillating fibres inserted in a high-density absorber material
  - Tunable energy resolution and time resolution of O(10-20) picoseconds
- Some of 2024 highlights
  - Tested prototypes with tungsten and lead absorbers
    - Deliverable D3.7 achieved!
  - **Time resolution** better than 20 ps for high-energy electron beams

Energy Resolution (DESY & SPS, R14755U-100)





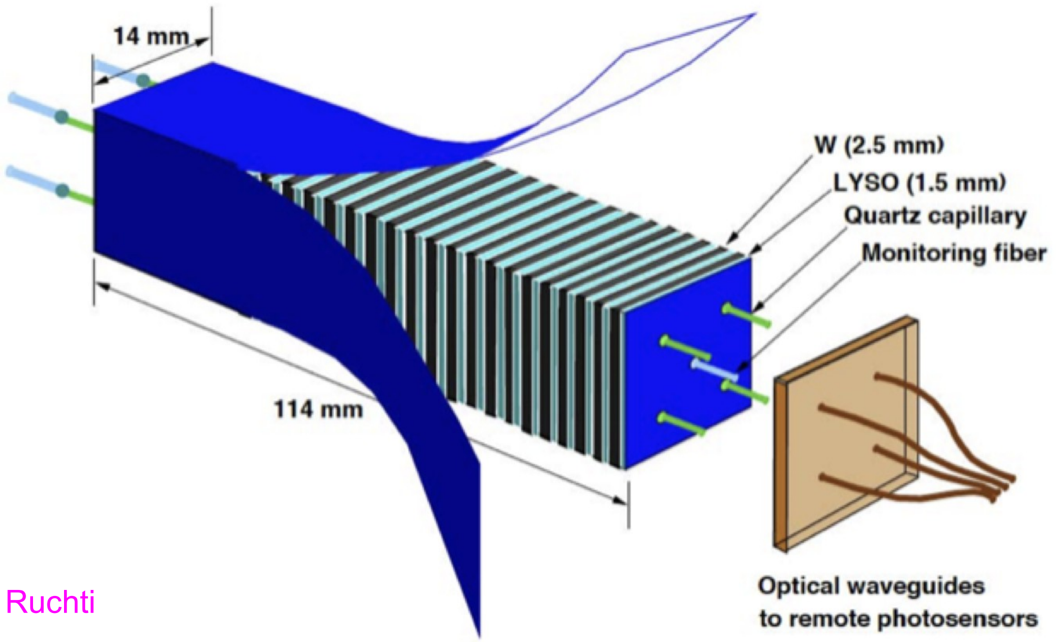


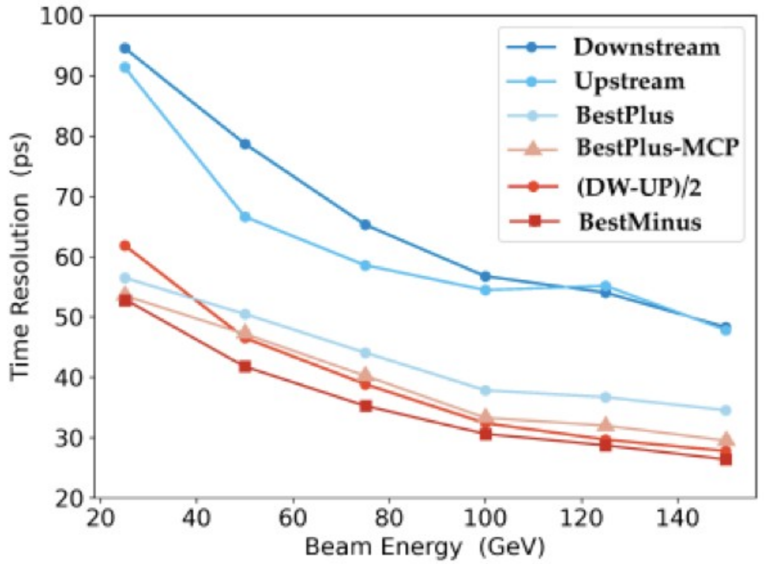


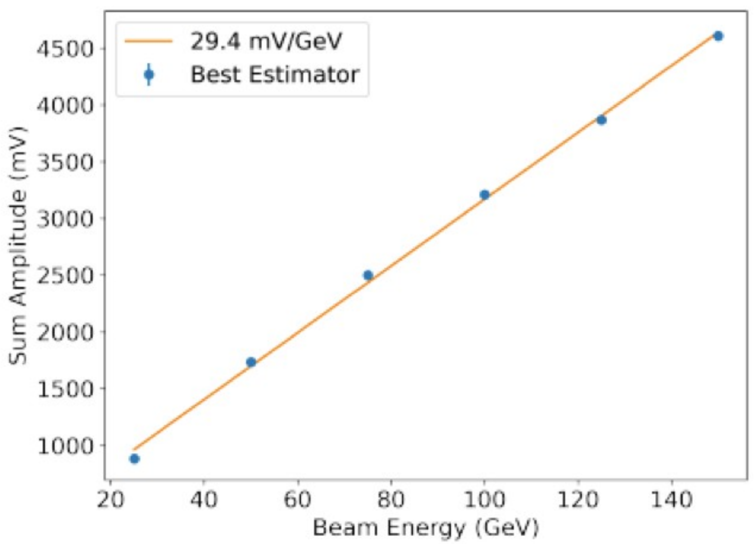
WP3 – Subtask 3.2.3 – RADICAL

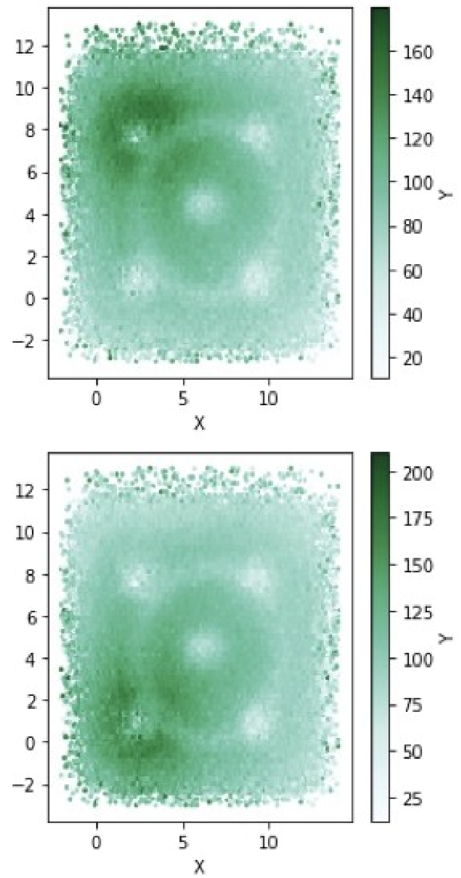
https://doi.org/10.1016/j.nima.2024.169737

- Shashlik-type: crystal plates, tungsten plates, quartz capillaries with WLS material
  - Uses the scintillation and Cherenkov light
  - Compact EM calorimeter with fast-timing
- Some of 2024 highlights
  - Prototypes successfully measured at beam tests
  - Tested different wavelength shifters for timing measurements at shower max







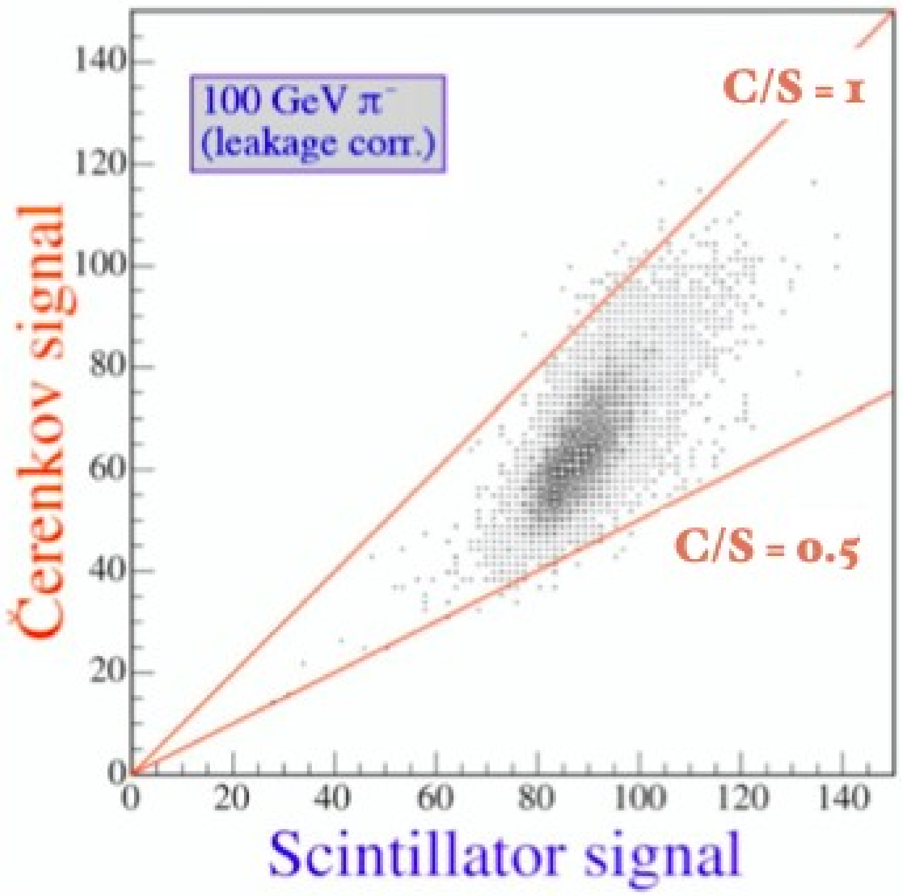


Randy Ruchti

Subtask 3.3.1: Dual Readout Calorimeter – The principle

- The **Dual-readout** concept: do not spoil em resolution to get **e/h=1** but **measure f_{em}** event by event → **eliminate effects of fluctuations in f_{em} on calorimeter performance**

- Use 2 different sampling processes: **Cherenkov light** (produced by relativistic particles and dominated by the e.m. shower component) and **scintillation light production** (for the total deposited energy):



$$C = E\left[f_{em} + \frac{1}{(e/h)_C}(1-f_{em})\right]$$

$$S = E\left[f_{em} + \frac{1}{(e/h)_S}(1-f_{em})\right]$$

e.g. if: (e/h) = **1.3(S)** vs **4.7(C)**

$$\frac{C}{S} = \frac{f_{em} + 0.21(1-f_{em})}{f_{em} + 0.77(1-f_{em})}$$

$$\boxed{E = \frac{S - \chi C}{1-\chi}}$$

Universally valid!

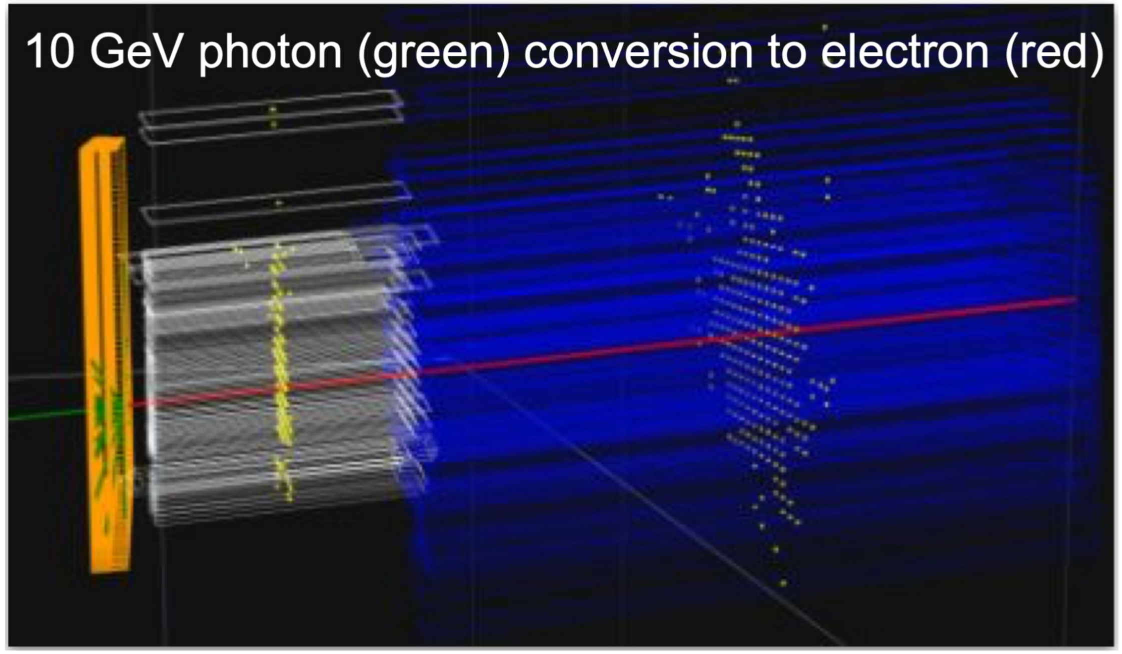
with: $\chi = \dfrac{1-(h/e)_S}{1-(h/e)_C}$

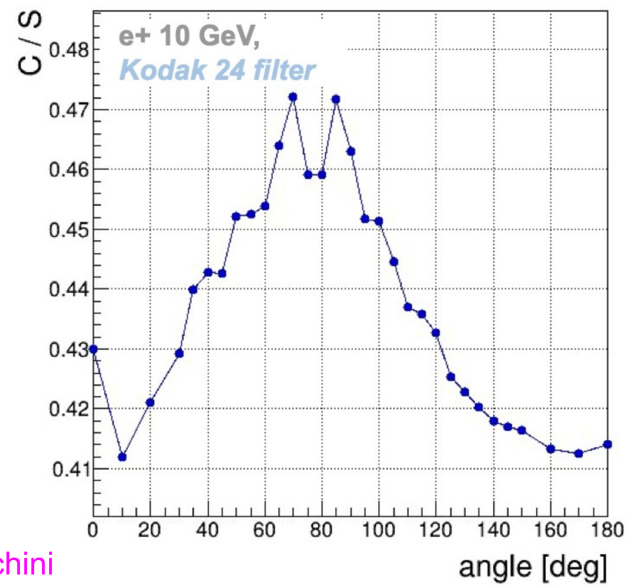
χ is independent of both:
- Energy
- Type of hadron

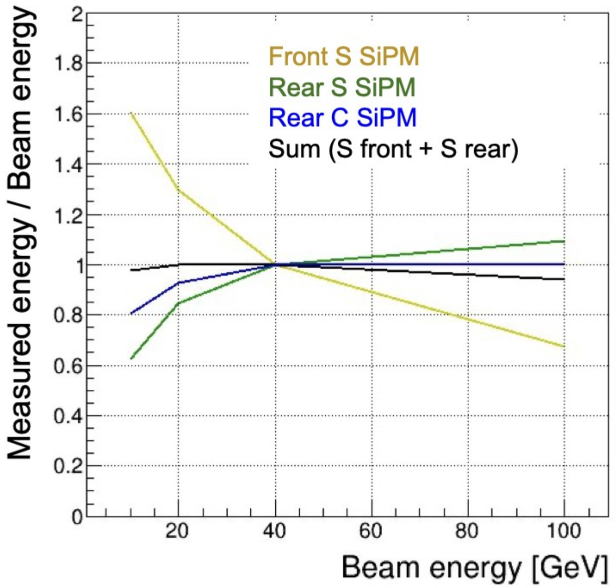
M. Antonello, FCC-Week 2018

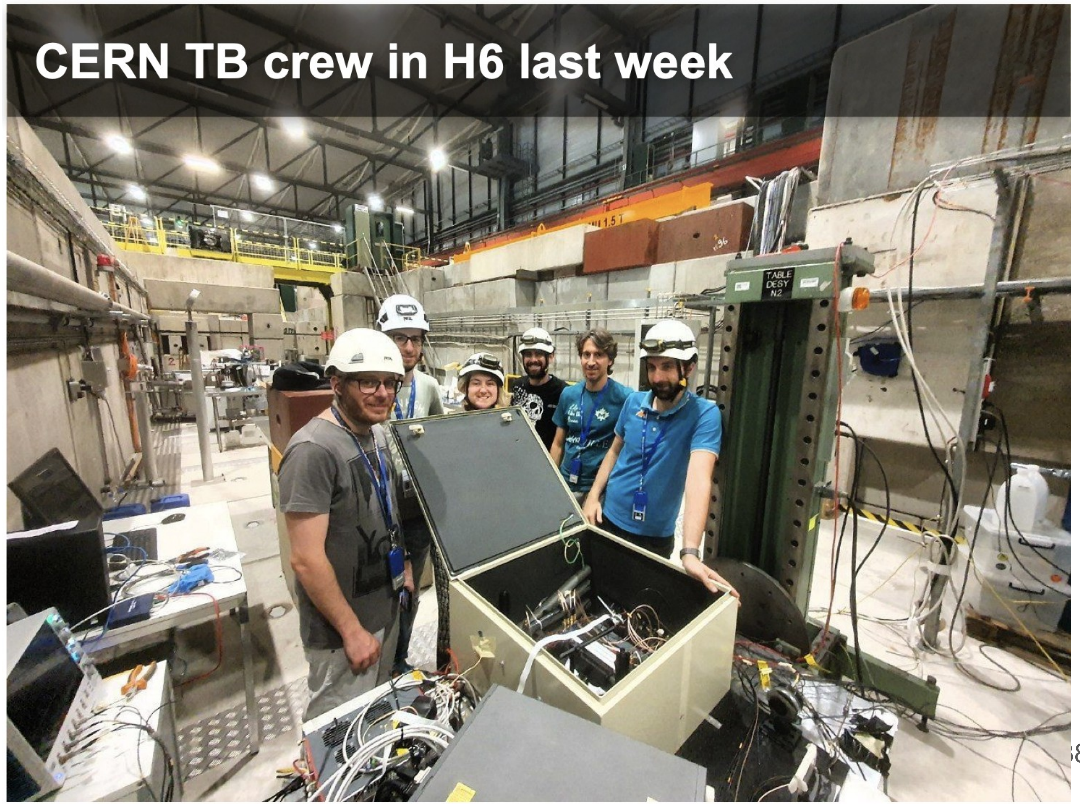
WP3 – Subtask 3.1.2 – MAXICC

- Homogeneous EM calorimeter based on segmented crystals with dual-readout
  - High density scintillating crystals with good cherenkov yield
  - Promise 3%/√E + DR capability
- Some of 2024 highlights
  - Implementation in key4hep gearing up
  - **R&D to optimize dual-readout** in scintillating crystals using optical filters and SiPM **progressing well** thanks to successful beam tests in 2024









Marco Lucchini

Dual readout calorimetry – Building Blocks

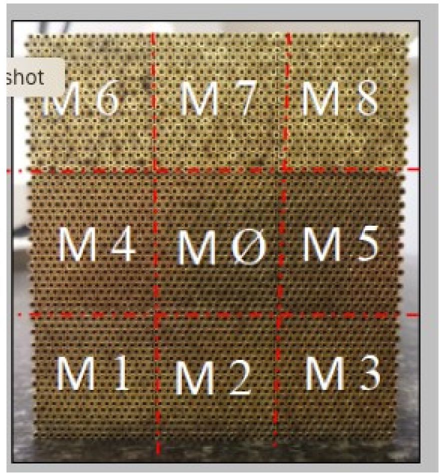
Fast signals

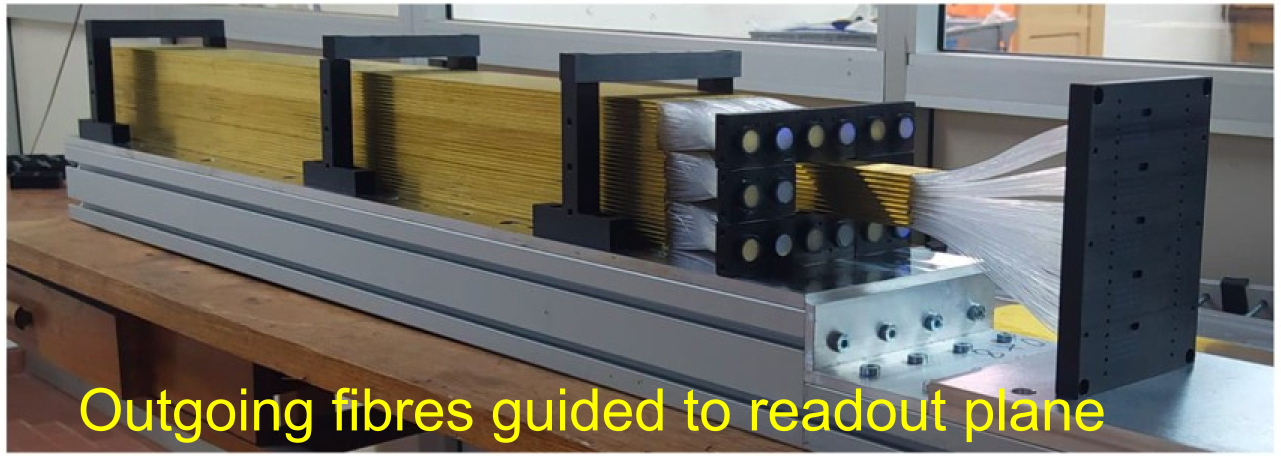
Slow signals

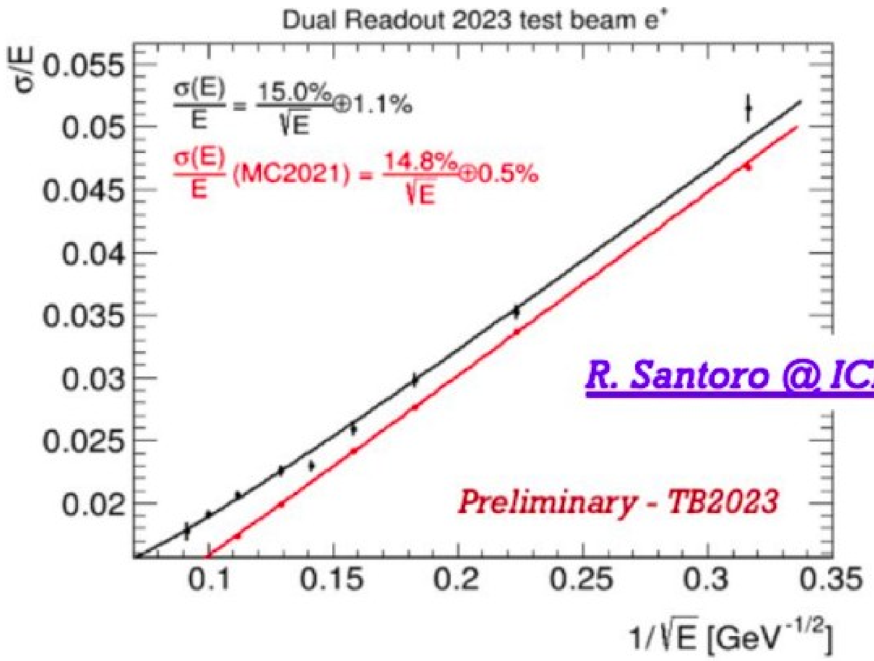
Dual readout to capture Electromagnetic and hadronic components of shower

Prototype development

- First step "electromagnetic prototype" 10x10x100cm^3
  - Qualification of
    - Assembly procedure
    - Readout systems





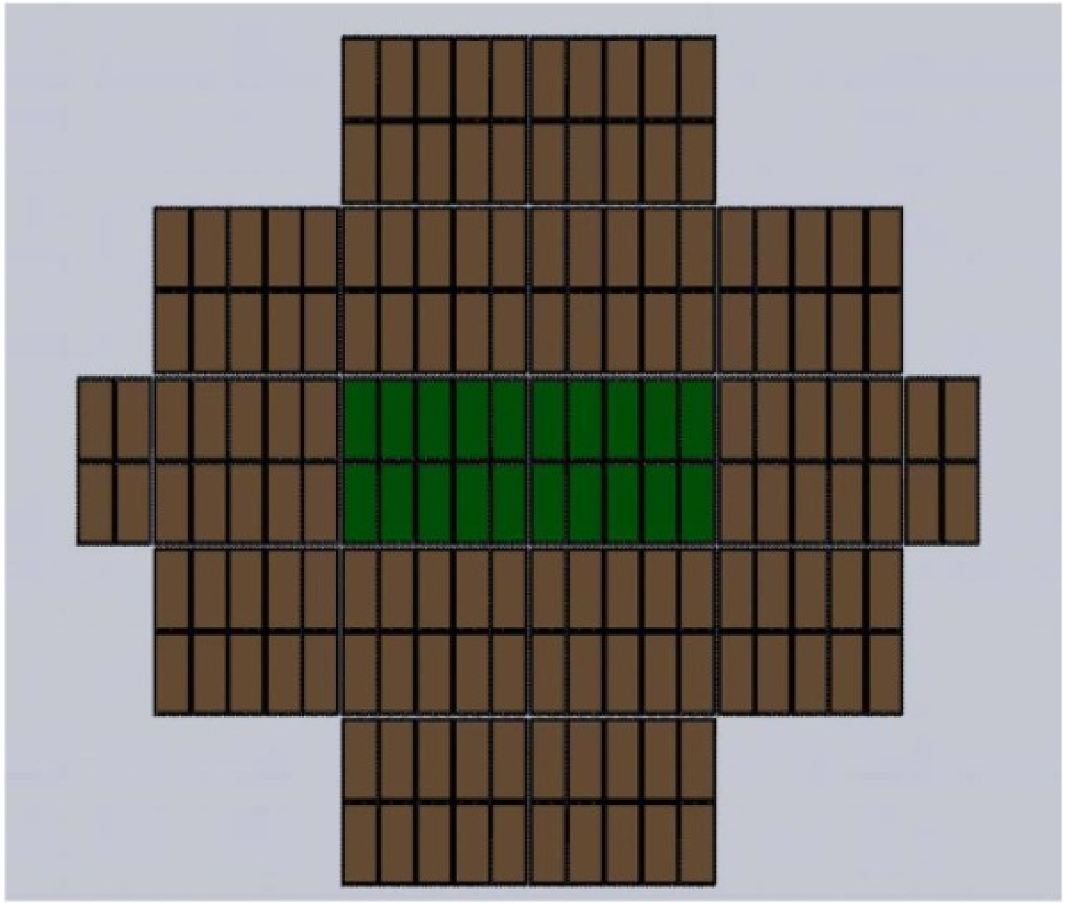


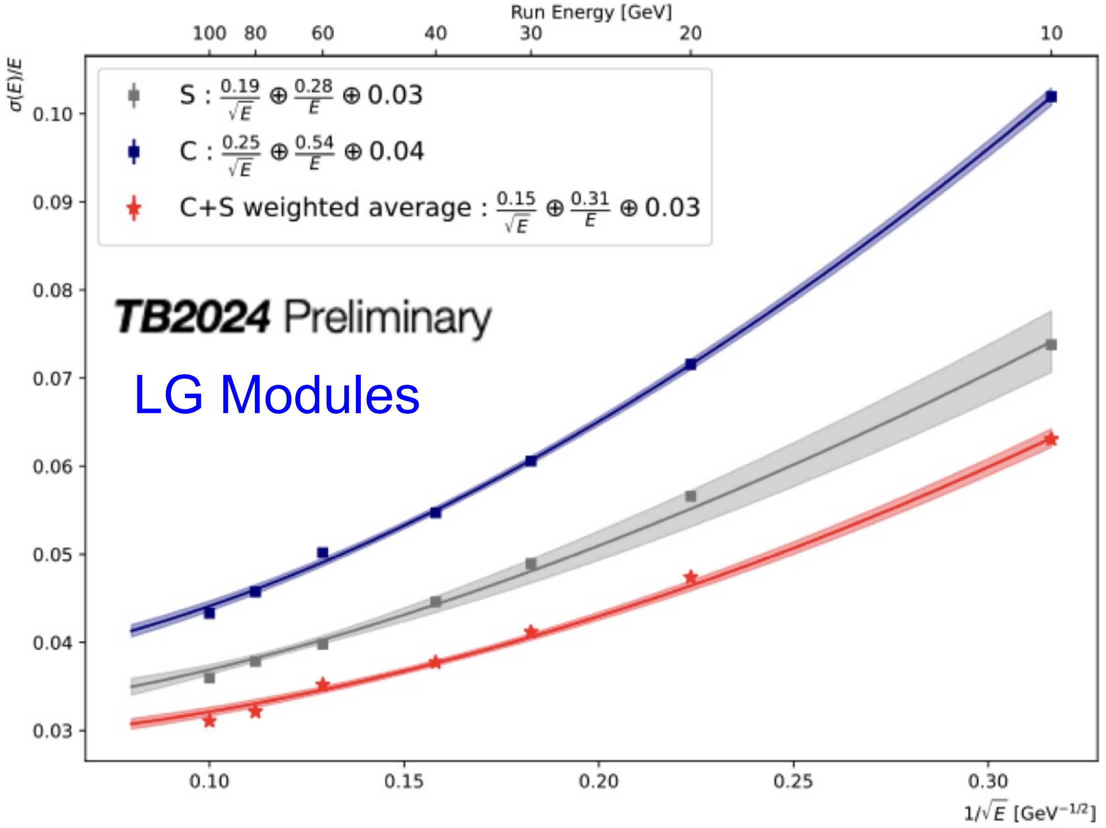
Electromagnetic energy resolution
In beam test

$$\frac{\sigma}{E} = \frac{15\%}{E} \oplus 1.1\%$$

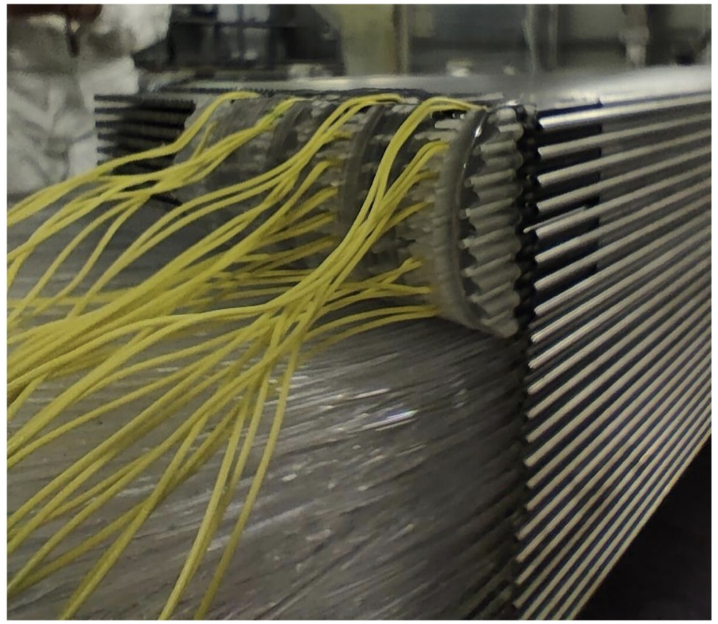
Dual readout calorimetry – Towards large prototype

Prototype with hadronic containment



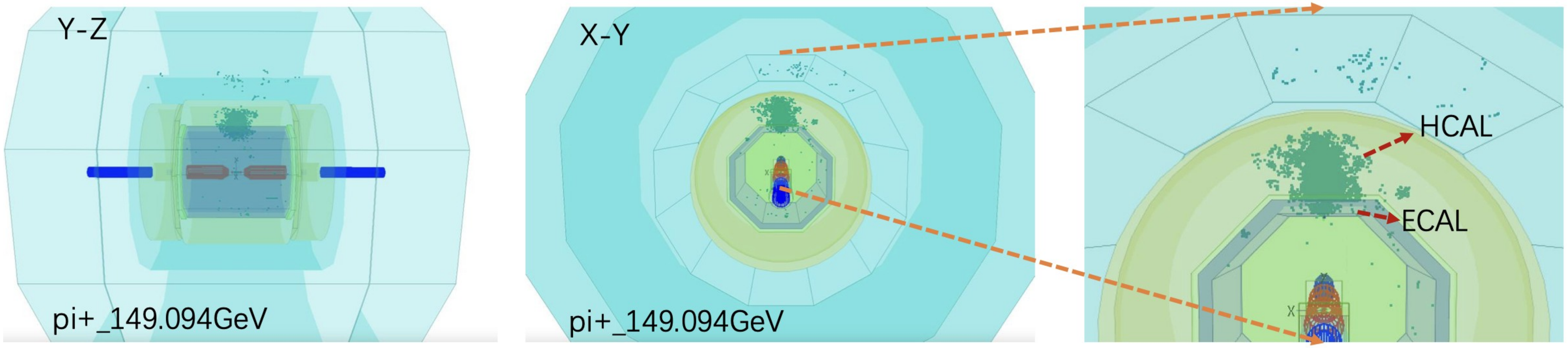


- $65x65x200$ cm^3
- 17 modules in total
- 15 low granular (LG) modules equipped with PMTs
- 2 central high granular modules equipped with SiPMs

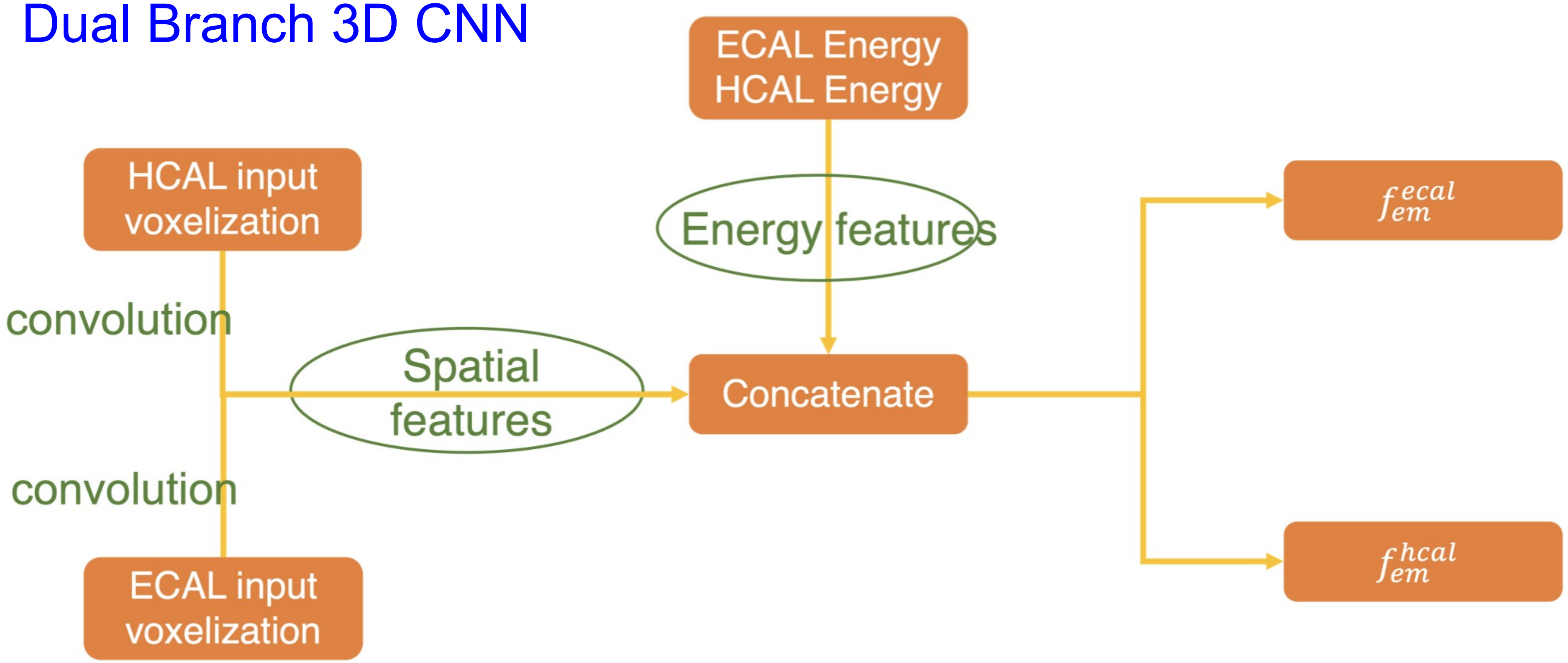


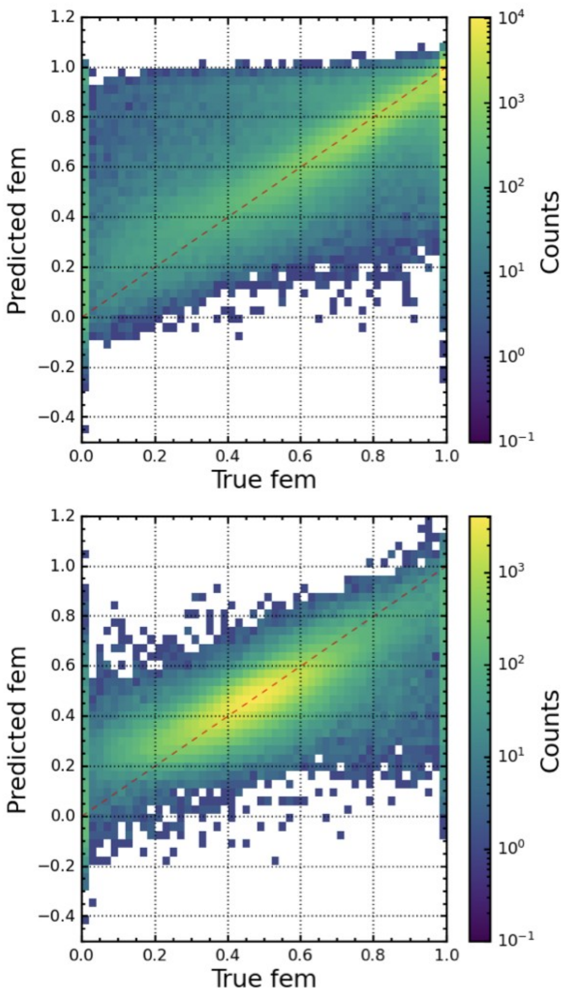
Intermezzo Catching f_{em} with Machine Learning - WIP

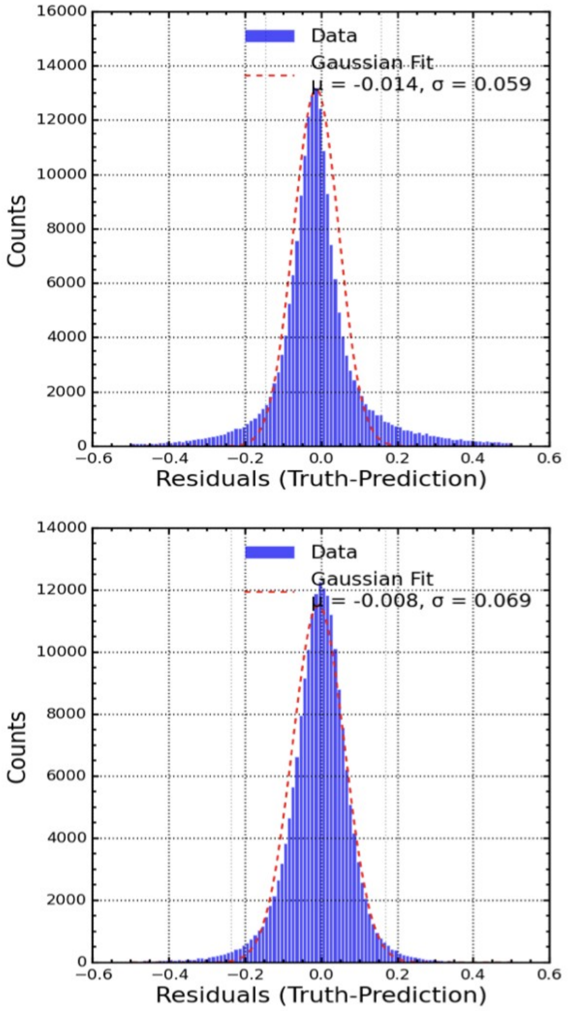
Calos à la WP1



Dual Branch 3D CNN



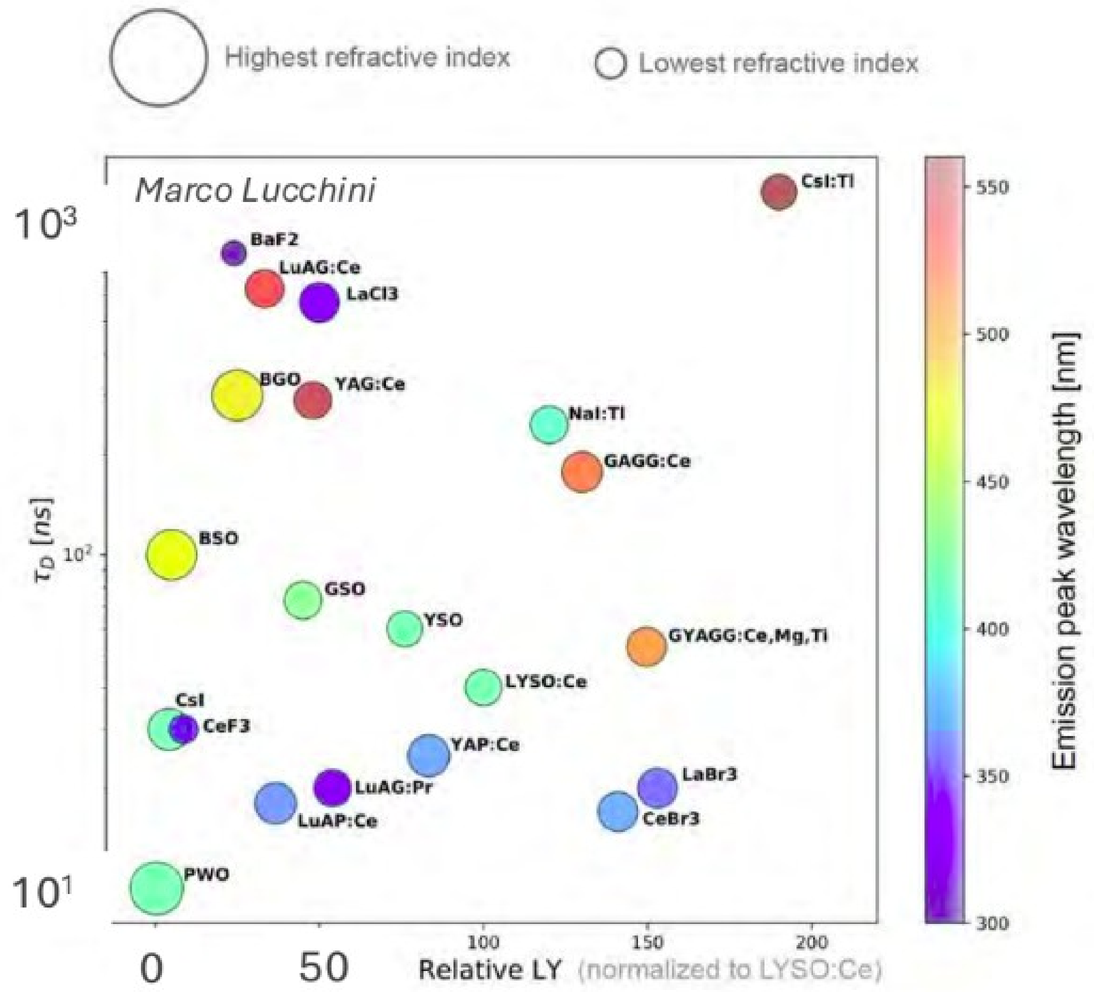


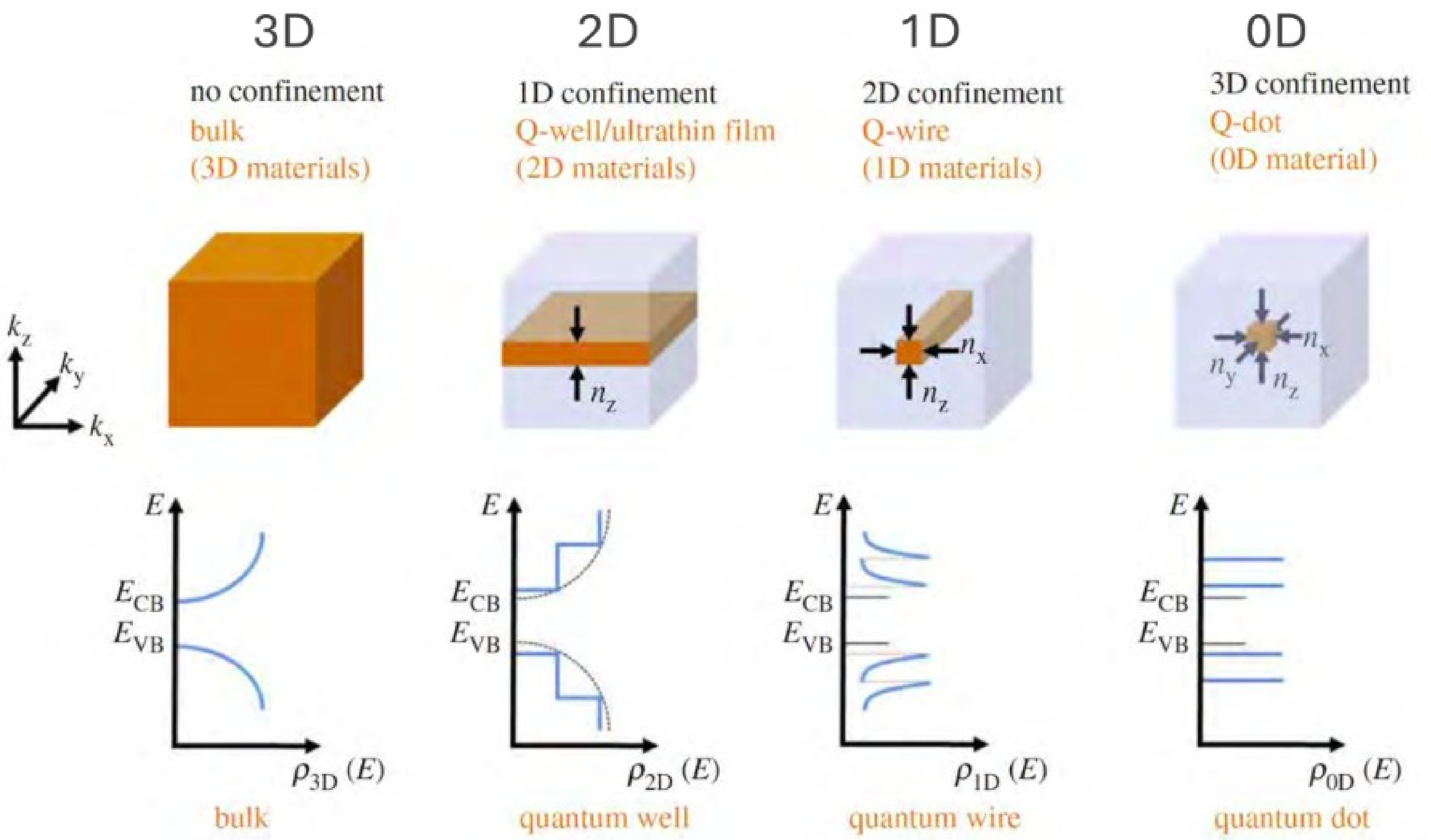


X. Xia, PhD Thesis; IJCLab (WIP)

Quantum Dots

- Traditionally crystal - fully absorbing calorimetry - has obtained the best energy resolution

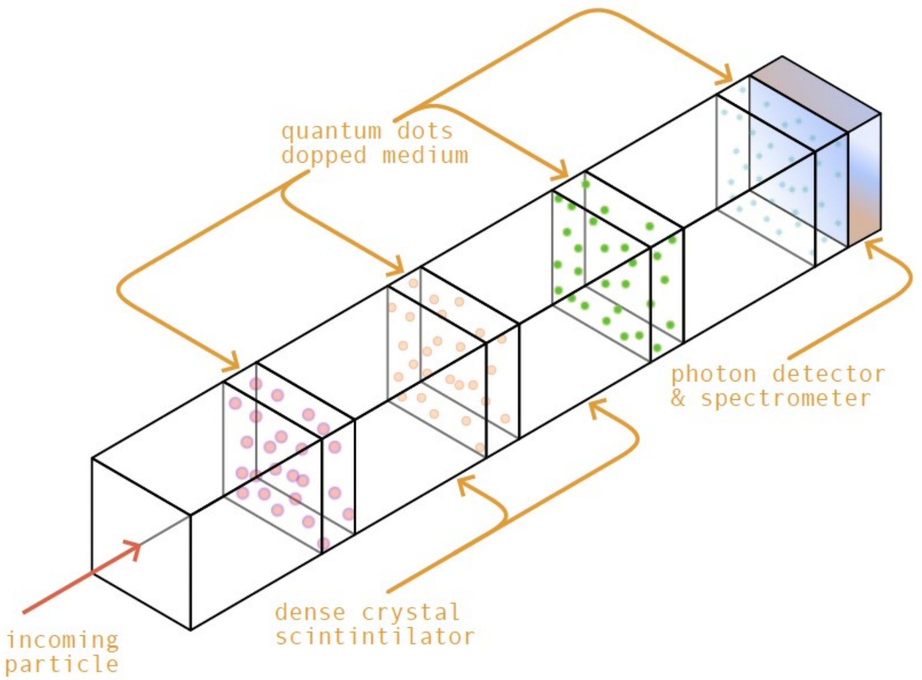


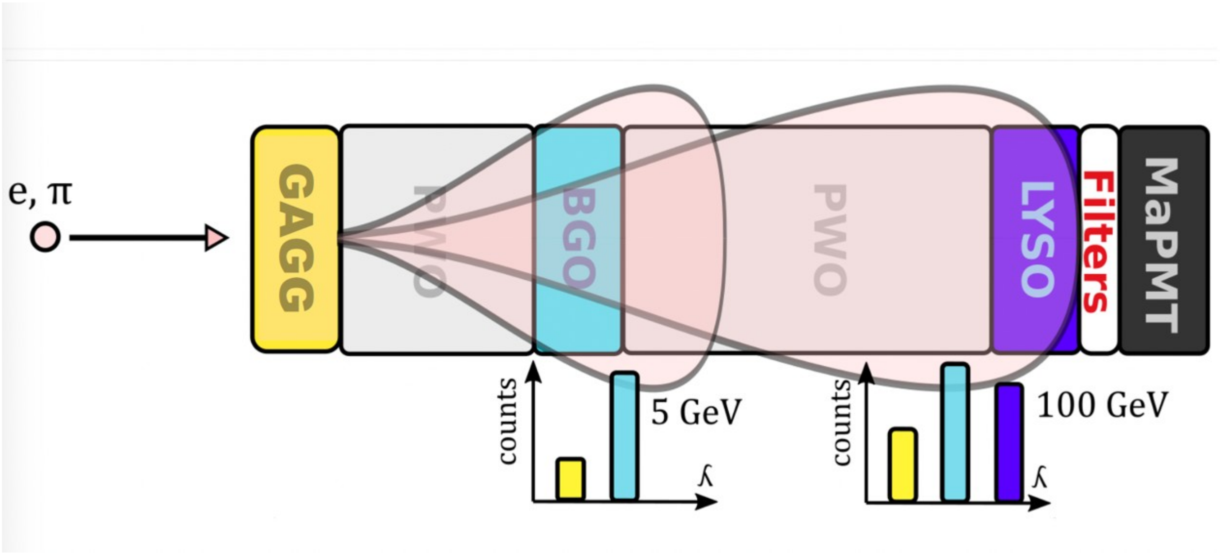


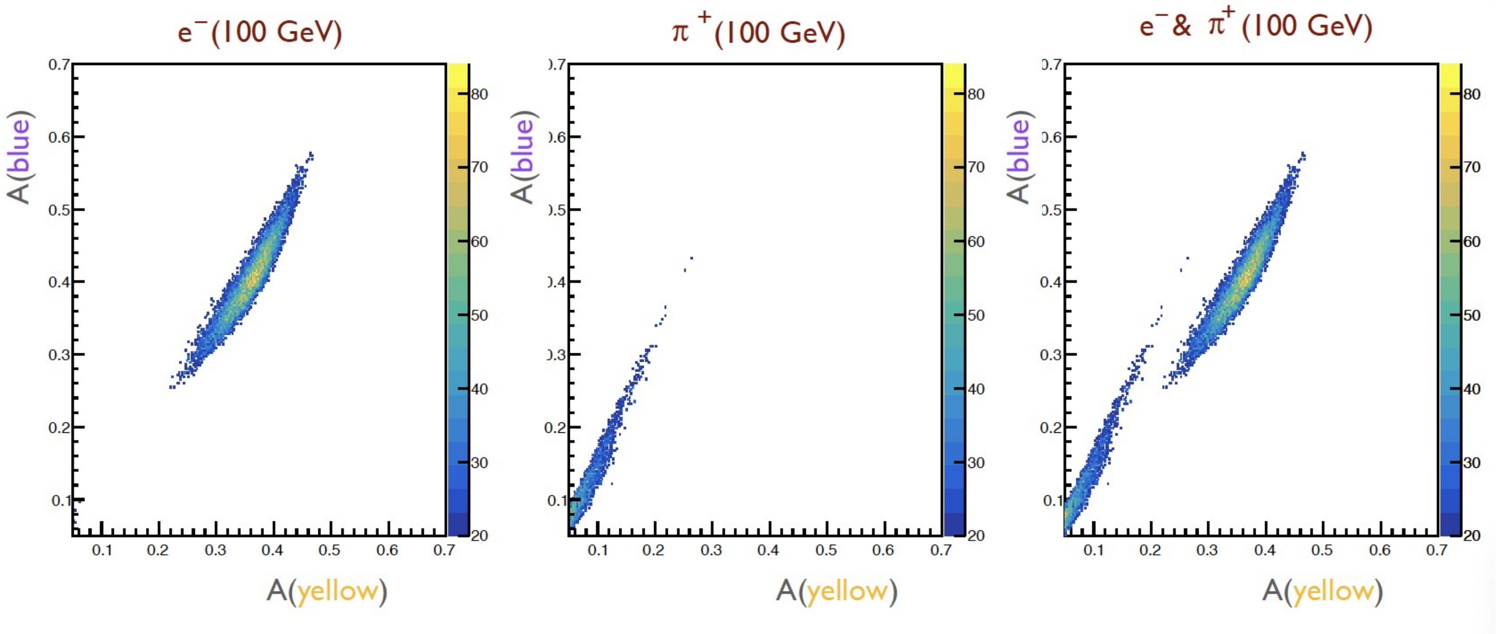
- Huge range of possibilities through **quantum engineering** of materials

M. Demarteau, DRD Calo Meeting

Quantum Dot Crystal Calorimetry







Chromatic Calorimetry

From: Devanshi Arora, CALOR'24

WP4 – Electronics and DAQ

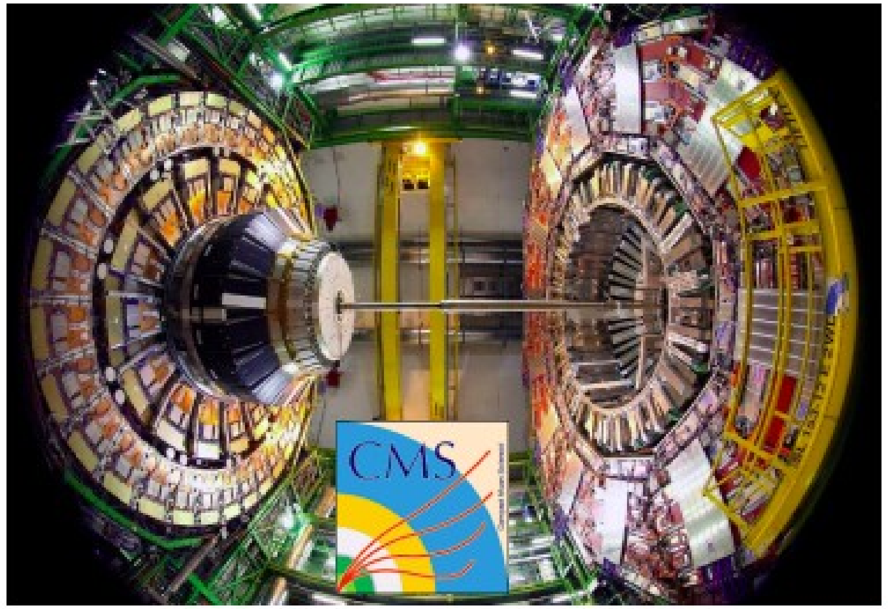
H2GCROC for the endcap calorimeter – Phase II

6M of Silicon channels
(+ 240k of SiPM)

Radhard (200 Mrad)
Low Power (15 mW per chn)
Precise timing (25 ps)

Total of 150k ASICs needed
Pre-prod this year

CALOROC for EIC



Same ASIC structure (floorplan)
Same ADC and TDC
Same readout

Common interfaces

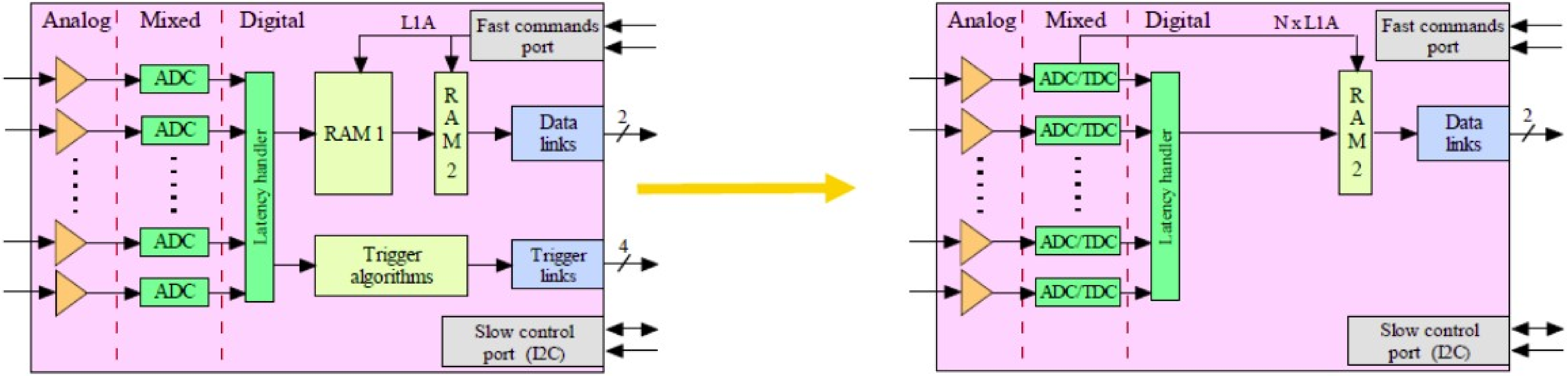
HEP trend => imaging calorimetry
- High number of channels
- Charge and precise timing (<100 ps)
- Low power + System-On-Chip

Based on H2GCROC, CALOROC will provide a versatile and low-power solution for SiPM readout

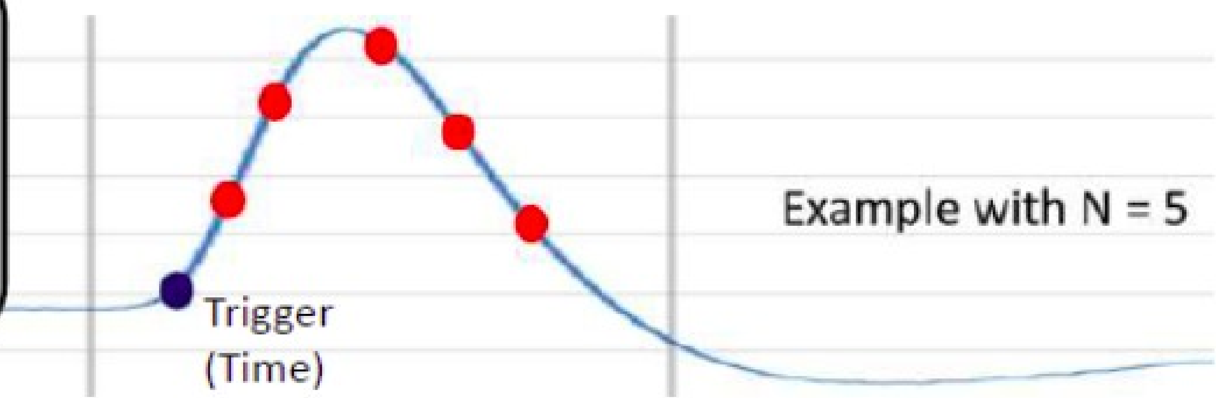
C. de la Taille, DRD Calo Meeting

WP4 – From pp -> eA, pp

- No more LVL1 : data streaming => auto-trigger and zero-suppress
  - very interesting for future DRD6 readout ASICs !



- Each event passing the threshold is readout
- Auto-trigger with N “samples” (1 to 7)
- Can be exercised with present HGCROC (multiple L1A-triggers)

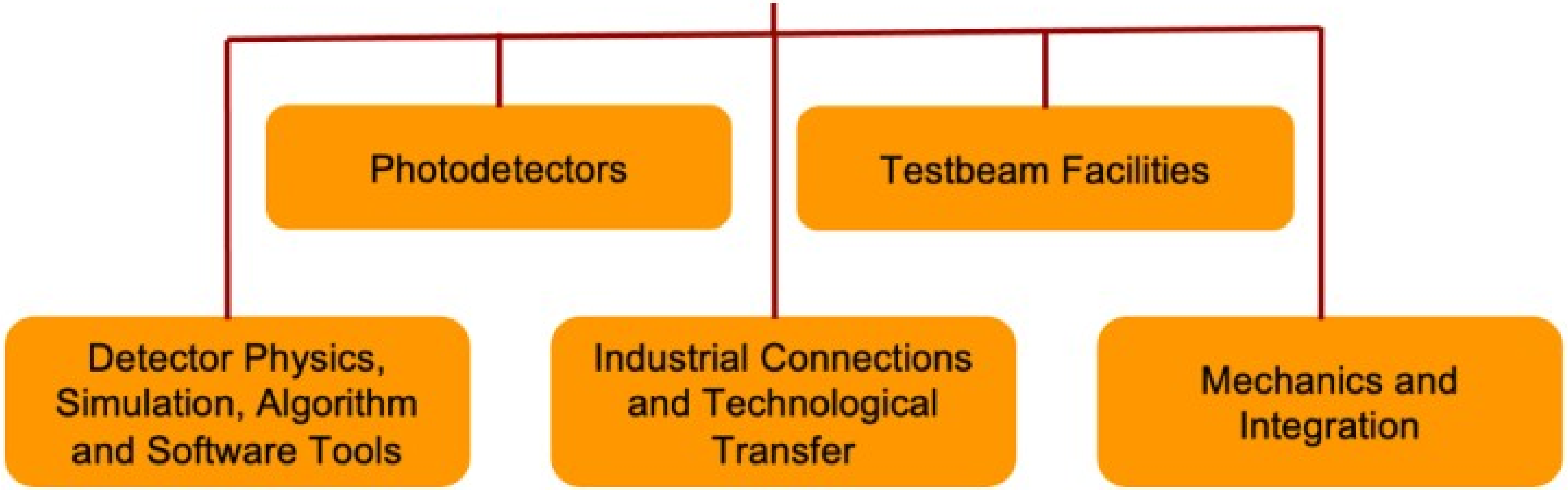


Working Groups

Our (DRD6) definition:

transversal activities needed by all the sub-tasks in the DRD6 collaboration

- Avoid duplications (=> Save time and money)
- Share experience (=> Progress faster and better)
- Built the collaboration (=> connect people from different groups, projects, institutes)
- WGs are established progressively



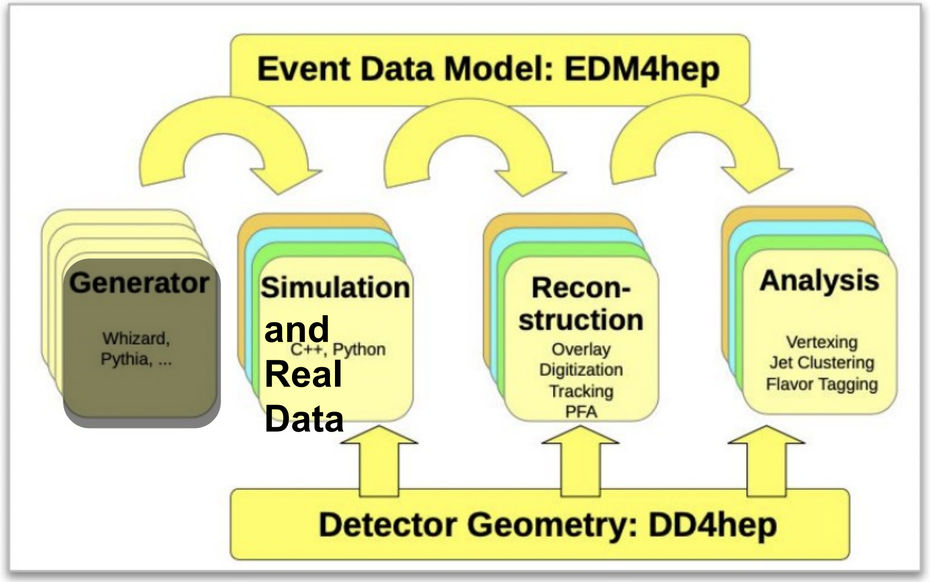
Working Groups – Software

Data Acquisition and Monitoring

EUDAQ +

ots otsdaq@FNAL

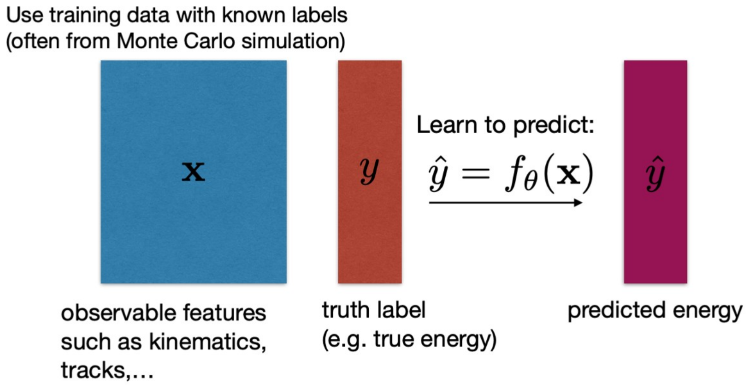
Data/Event Processing (key4hep)

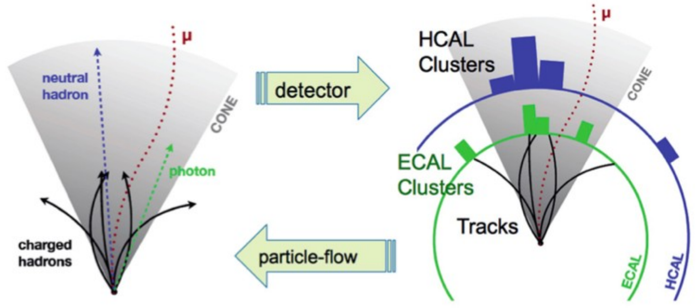


Your favorite
Calo Prototype(s)

Exploitation:

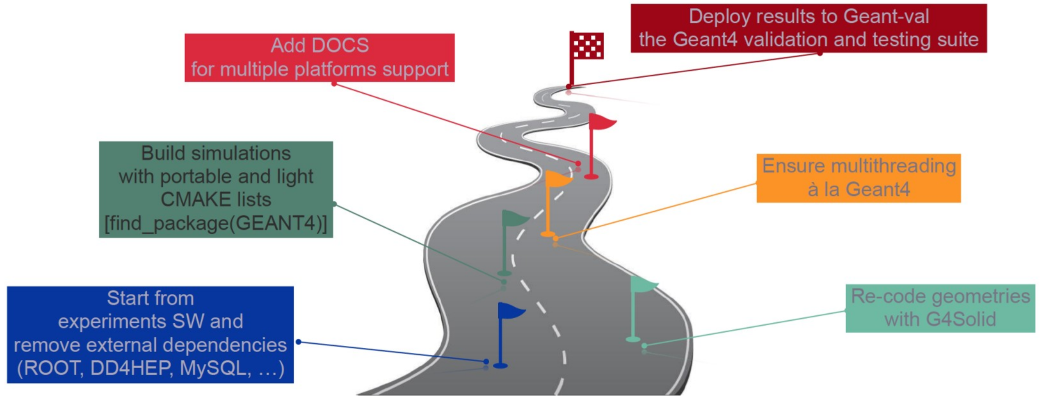
Pattern recognition, s/w compensation



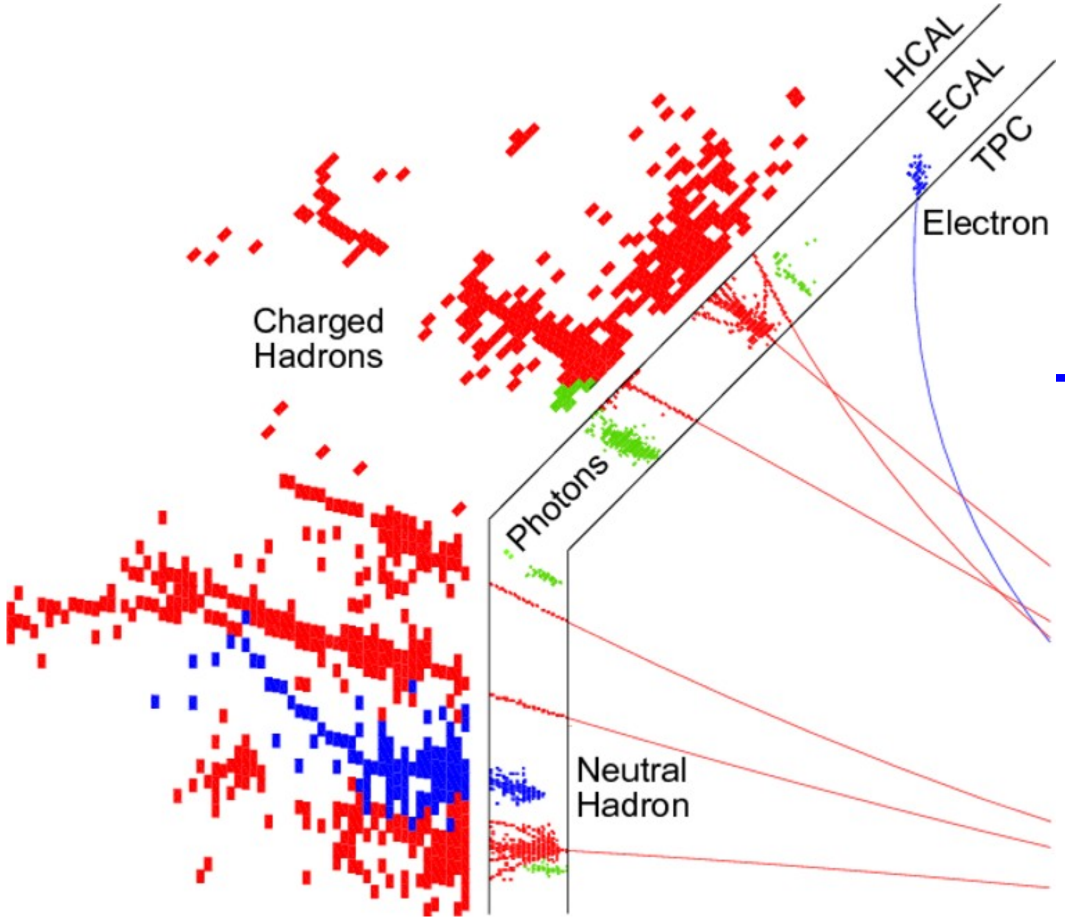


Physics output

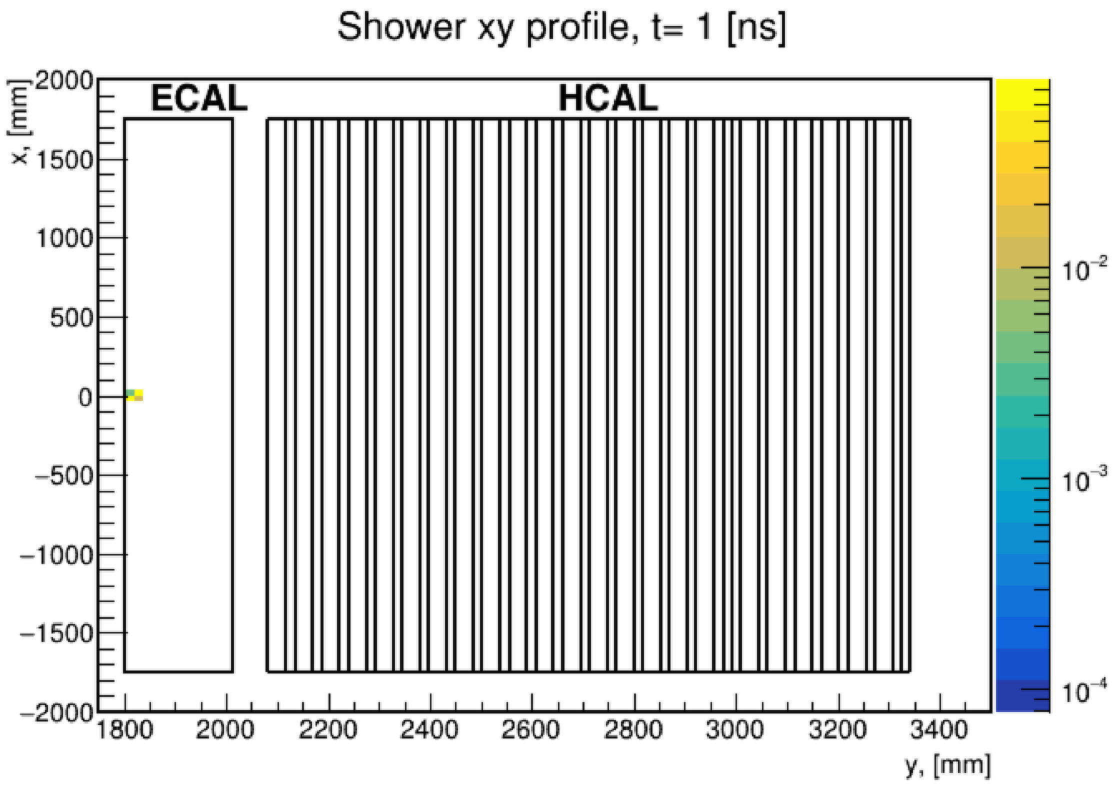
From experiments to geant-val, a winding road G4



Software – Co-design for detectors



From static pictures to movies



Y. Padniuk, Master student Technical University of Kiyv

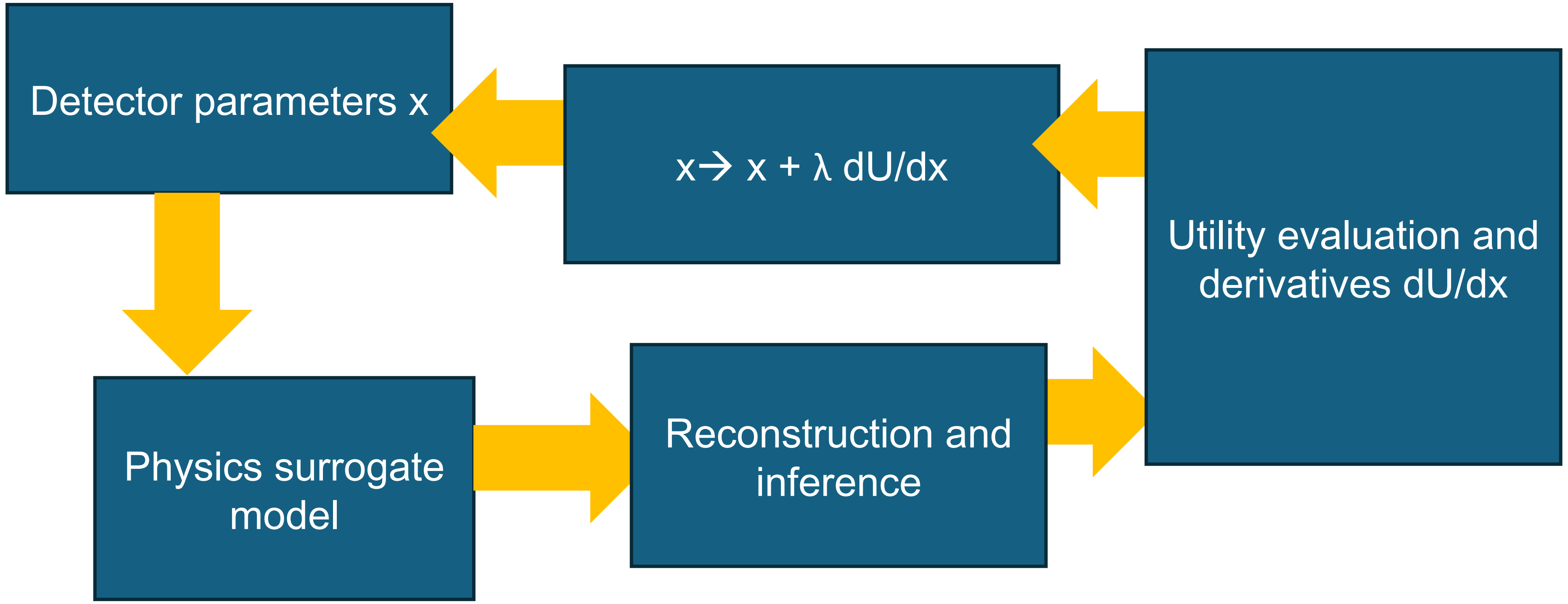
- Raw reconstruction (raw signals to energy deposition) : NN on FPGA (hls4ml), GPU
- AI in pattern recognition with timing as additional variable
- Jet tagging, particle identification
- Event identification
- Data Quality Monitoring

David Rousseau + R.P.

What does it mean in practice?

It means creating a full parametric model of the detector, plugging in a surrogate model of the physics, and a differentiable model of the data reconstruction and inference extraction

Then you can iteratively modify the detector parameters following the gradient of the utility function – like in a NN



Dumbed down version of an optimization pipeline

Tommaso Dorigo, DRD Calo Meeting, April 2025

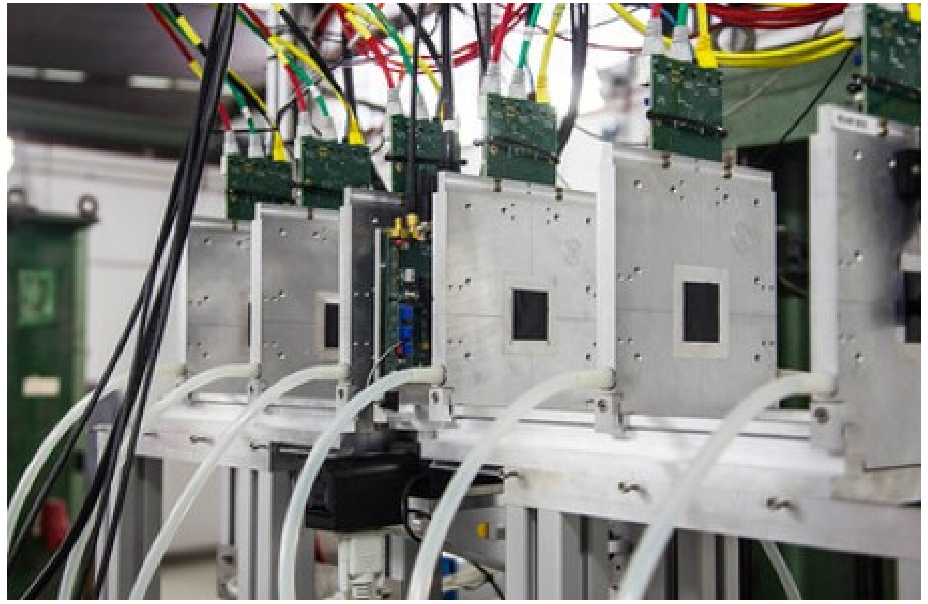
Working Groups – Testbeams ...

Generic Equipment and Tools

Overall Planning

Your favorite
Calo Prototype(s)

Beam Line Infrastructure



Communication with Operators

- Many items are common to all projects
- Common coordination will streamline beam test programme

WG2 – Photodetectors
March 2025 Survey – Common topics

Detector technologies: SiPMs are listed in most answers, but several groups are also working with PMTs and MCP-PMT or on all technologies

Segmentation: pixels size down to?

Standard characterization methods and how to compare photodetectors: in particular, linearity, timing PDE, radiation tolerance. Relevant topics: standardization, readout for low-gain detectors, VUV setup availability.

Radiation tolerance: in certain applications → which levels?

Readout of photodetectors: several readout options, usually ASICs, are employed. Are they optimal? How to choose between them?

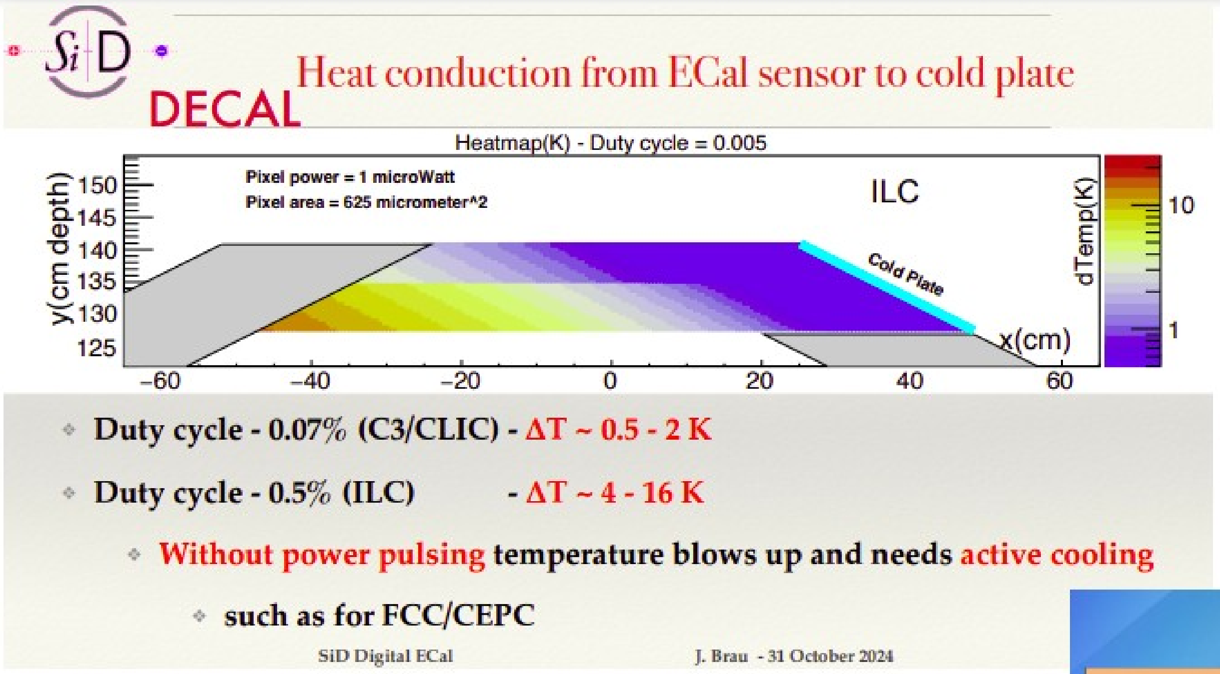
Analog vs. Digital output: pros/cons?

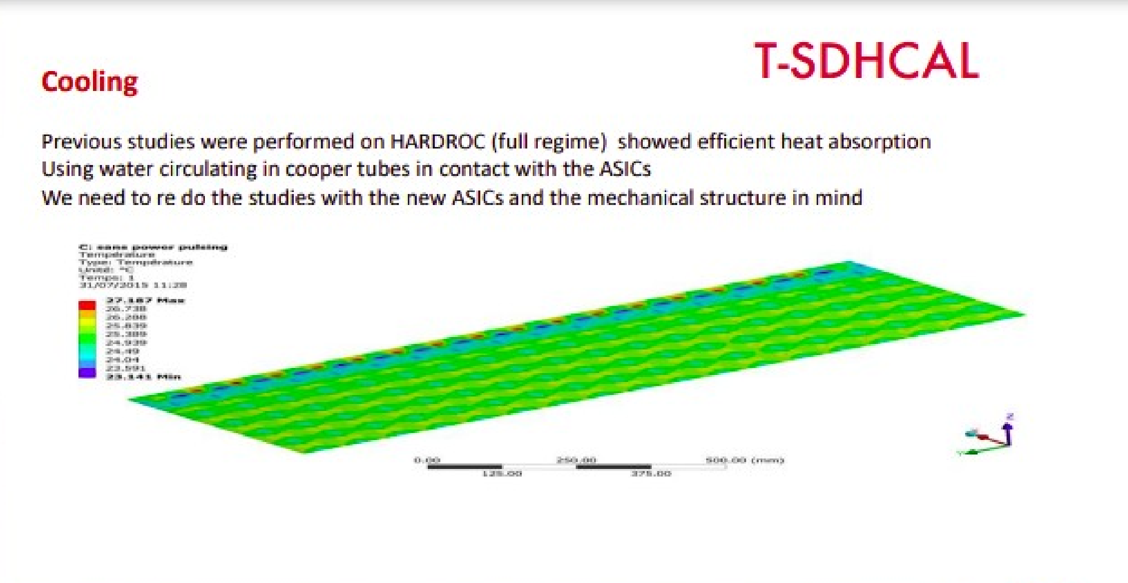
Integration, packaging: what are the challenges / opportunities for the integration of sensor and readout and for packaging, especially for large photon-sensitive areas? Light filter in package.

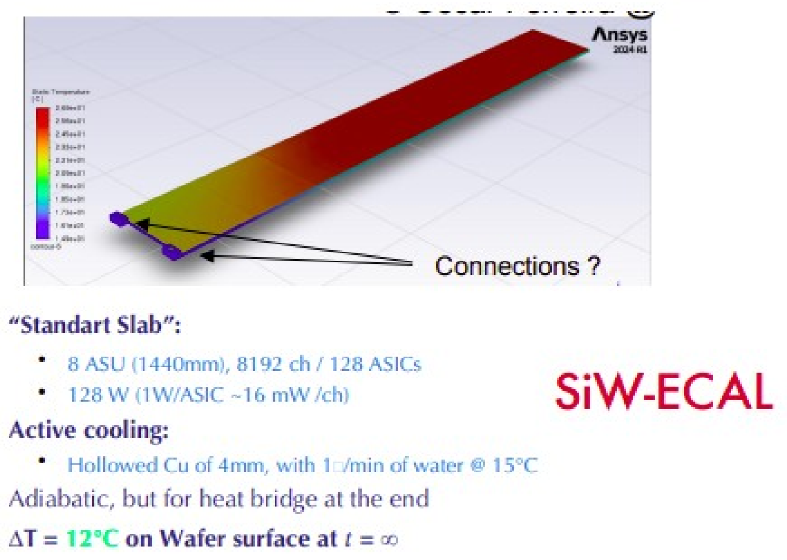
Scale-up and cost comparison: in volumes. Uniformity, reliability. COTS vs. custom technologies.

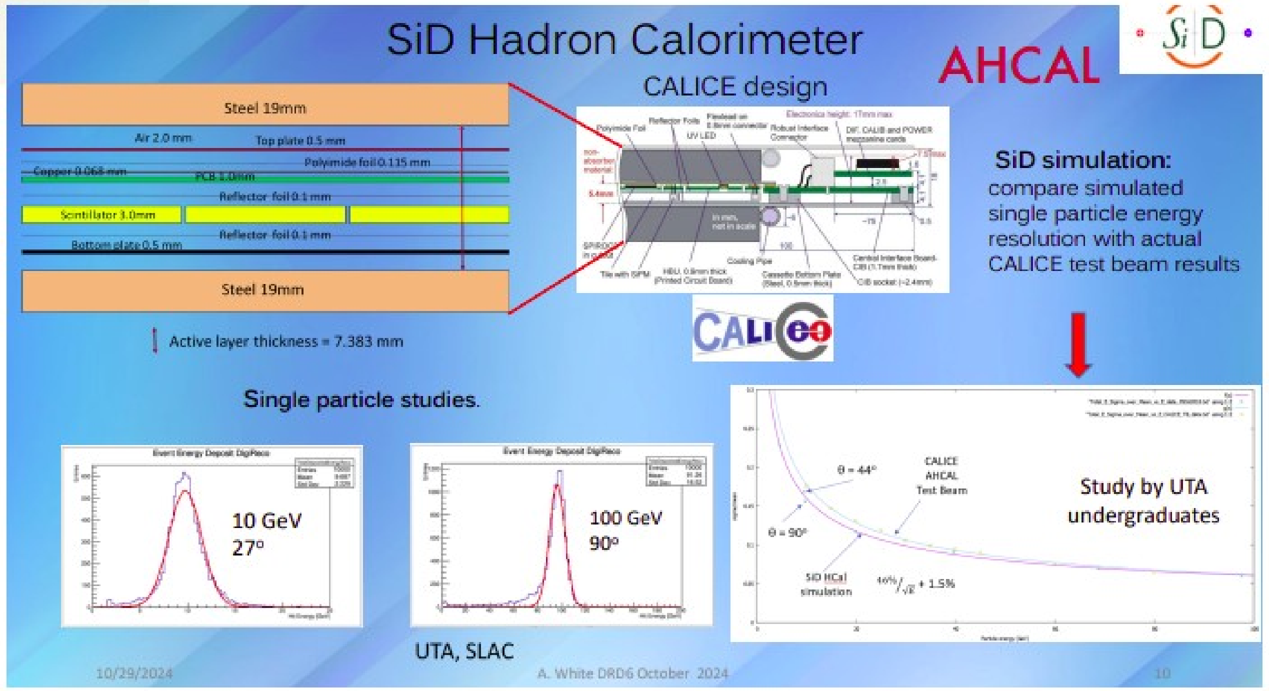
A. Gola, DRD Calo Meeting April 2025

WG on Mechanics (?)





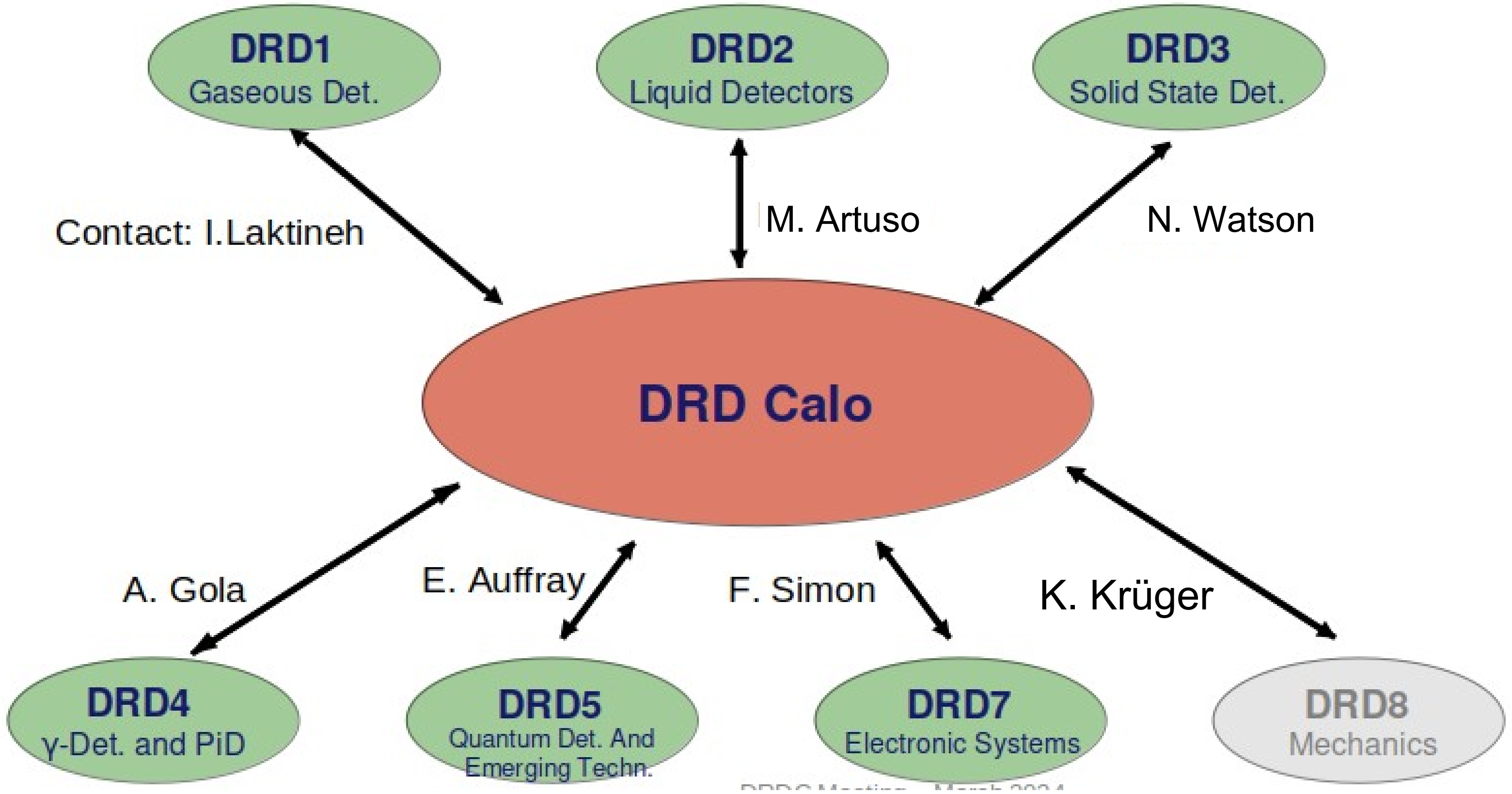




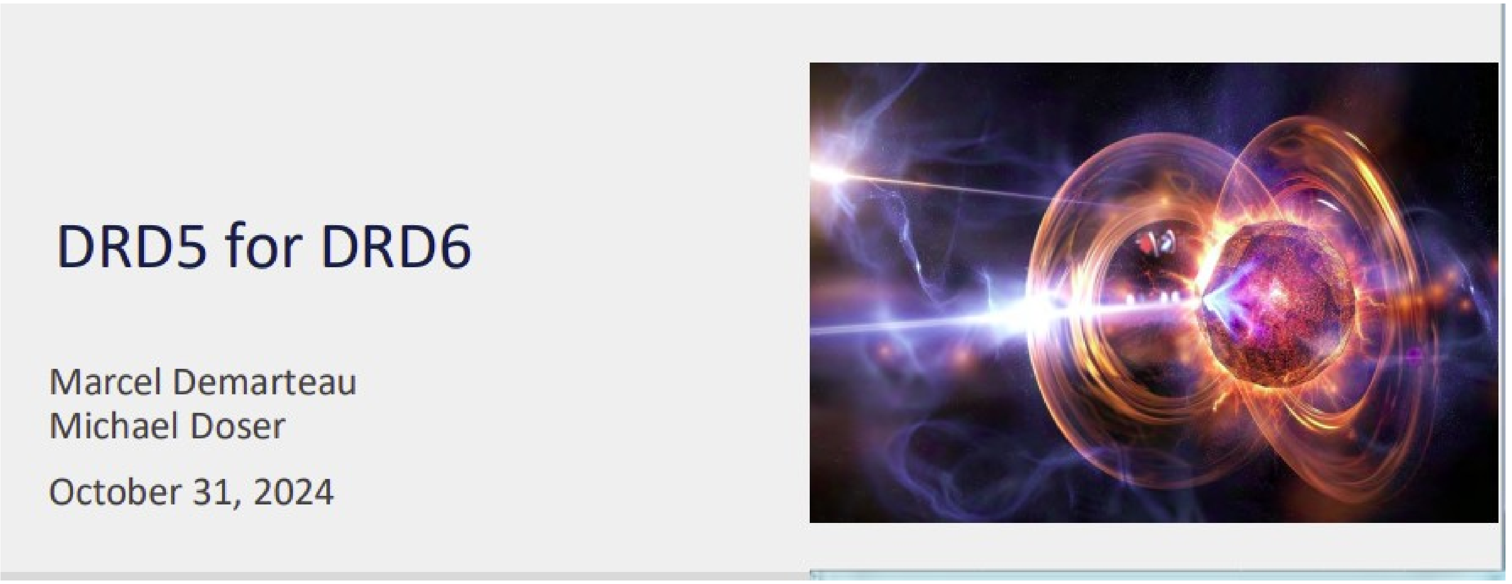
- Cooling seems to be a common topic for many projects (here WP1 but also relevant for WP3)
- Could be used to kick-off WG5

Cross Talk

Link Persons to other DRD



DRD5 talk at DRD Calo Meeting



DRD7 talk at DRD Calo Meeting

Conclusions

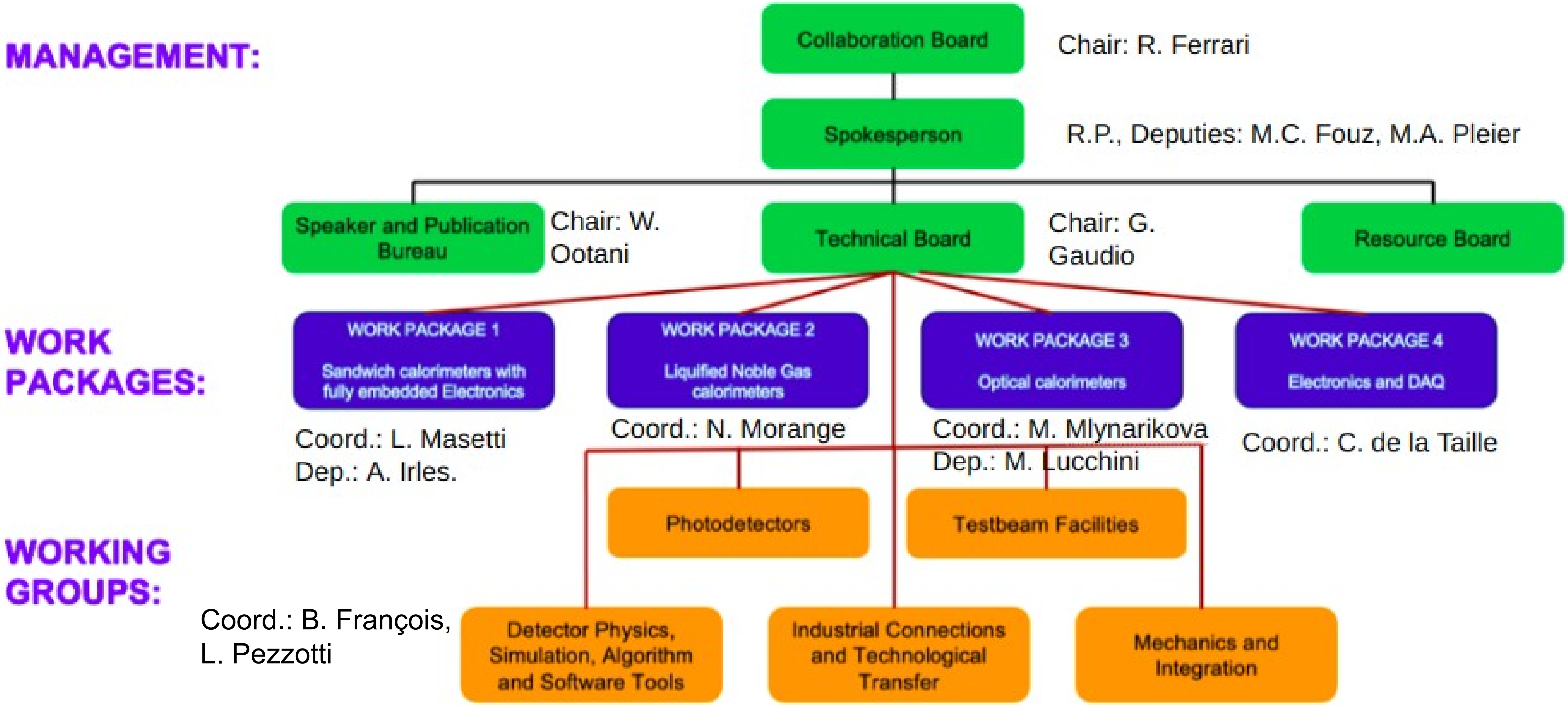
- DRD-on-Calorimetry pursues strategic R&D for calorimeters for future colliders
  - Partially new efforts, partially capitalising on existing activities

- Scientific Programme has started
  - All four work packages fully active
  - First deliverables either completed or in sight
  - Working Groups are about being formed

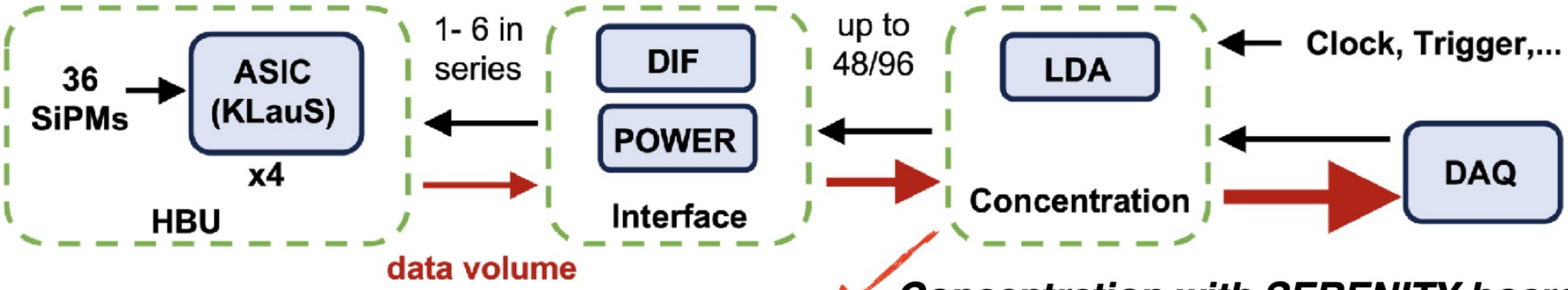
- The main goal is that everyone feels the added value of being member of the DRD
  - Great importance to mutual support to realise R&D goals

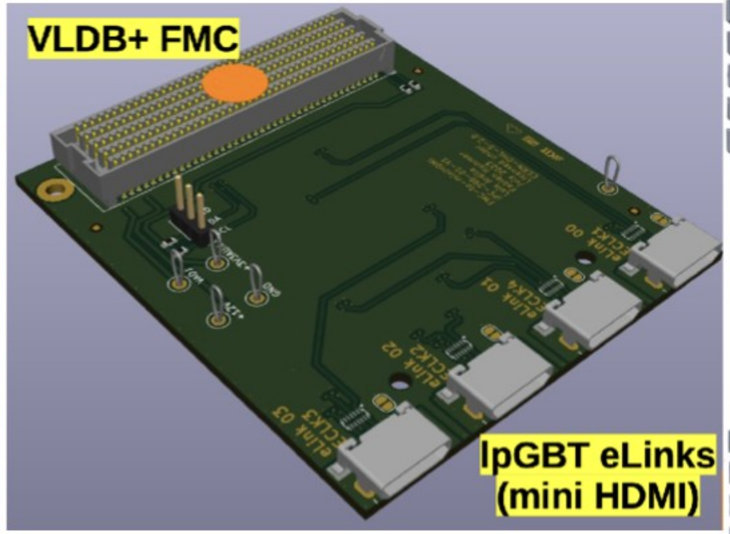
Backup

Current structure

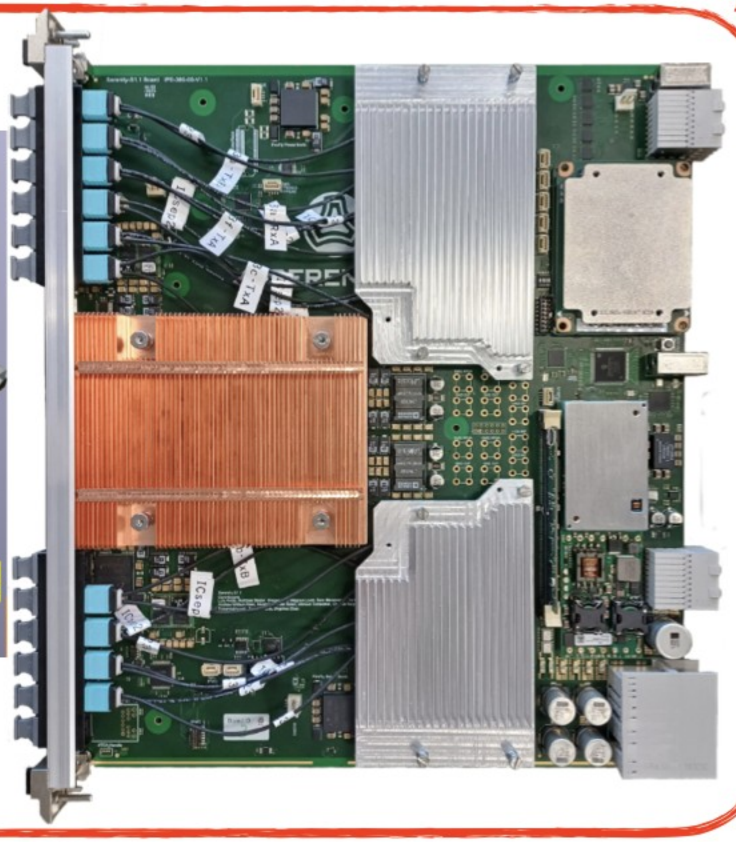


WP1 – Intermezzo – Adapting granular calos to continous r/o





VLDB board for design new DIF module



Concentration

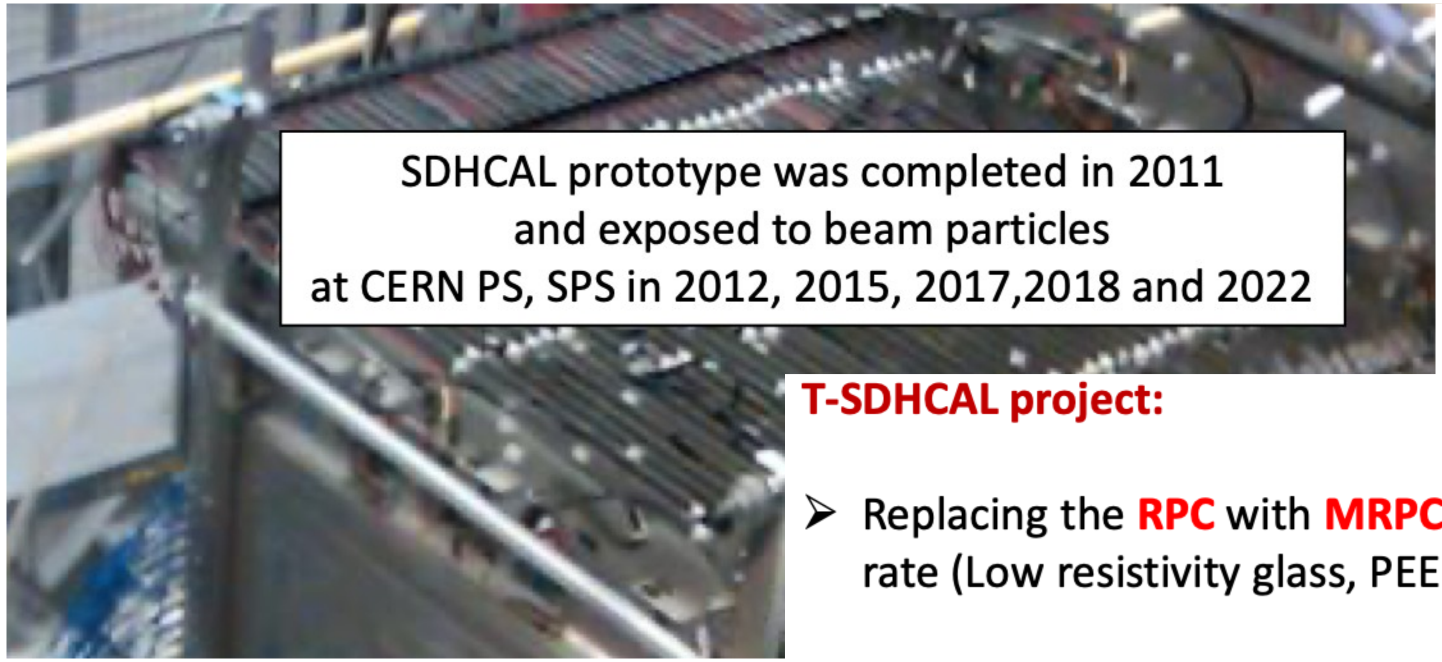
Concentration with SERENITY board:

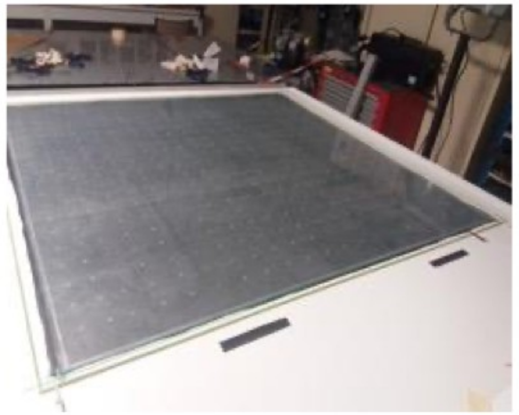
- A carrier card for the Phase-2 upgrade of the CMS experiment at the LHC at CERN.
- High throughput data processing (acting as a data engine) up to 3 Tb/s with 128 (up to 192) 25 Gb/s links
- lpGBT provides I²C (3 I²C masters), GPIOs, ADCs, DACs to tileboards.
- Versatile Link Development Board (VLDB), lpGBT and VTRx+ on VLDB+

The DIF module will need to be redesigned to communicate with Serenity.

Frank Simon, DRD Calo Meeting April 2025

WP1 – Subtask 1.3.1 – T-SDHCAL





T-SDHCAL project:

- Replacing the **RPC** with **MRPC**. Low resistive materials could be used to increase the rate (Low resistivity glass, PEEK doped with Carbon Nanoparticles)

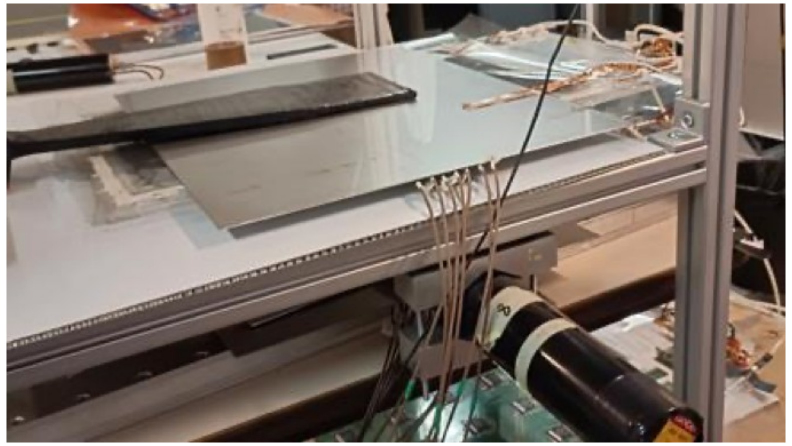
  →We need to study how many gaps are needed to reach **100 ps** taking into account the cost on the cassette thickness.

- Replacing the **HARDROC** ASIC with a new ASIC

  →We started with **PETIROC** as a first step but we will go for **CALOROC** in the near future.

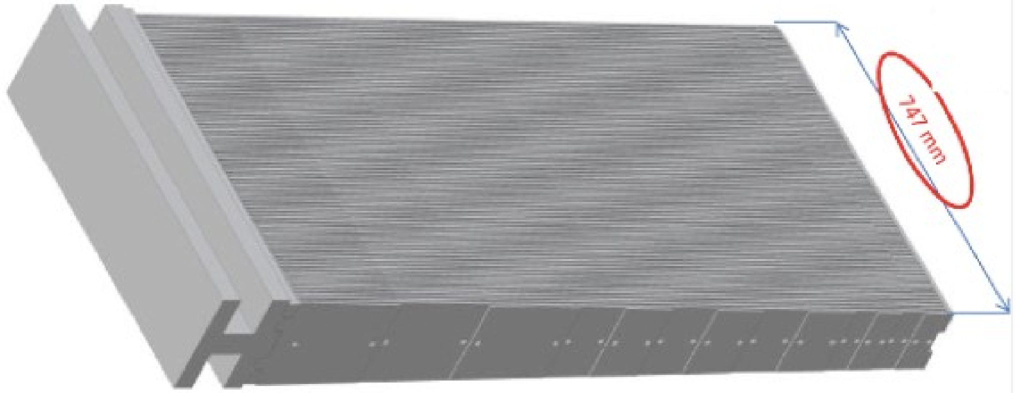
- Developing a **cooling system**.
  The cooling system should not add too much dead zone. Could we use it with the present SDHCAL mechanical with limited efforts?

  → we have done already some studies on this topic



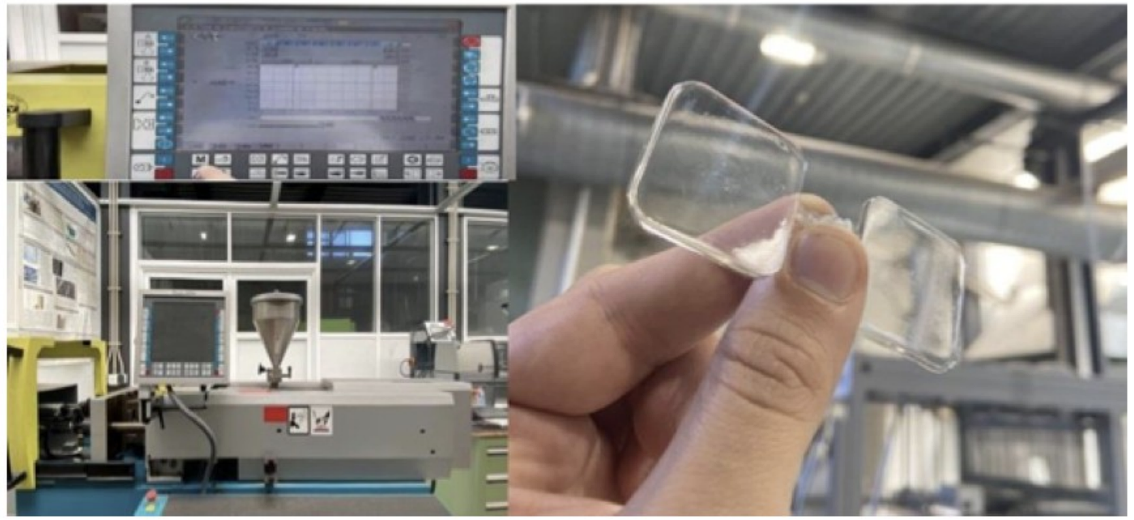
WP3 – Subtask 3.3.2 – TileCal

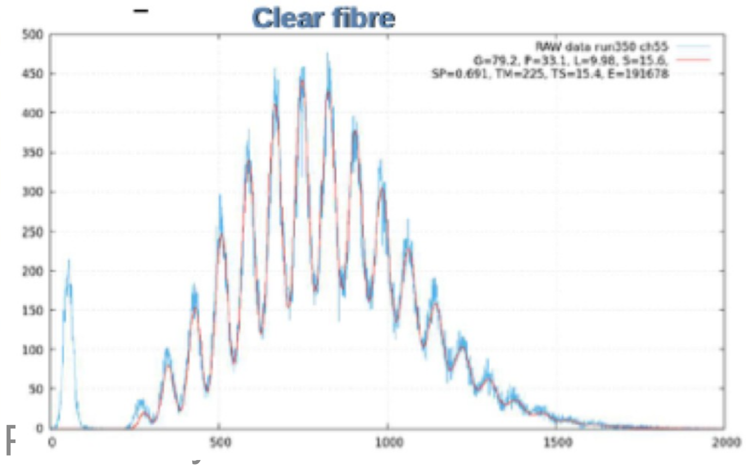
Henric Wilkens

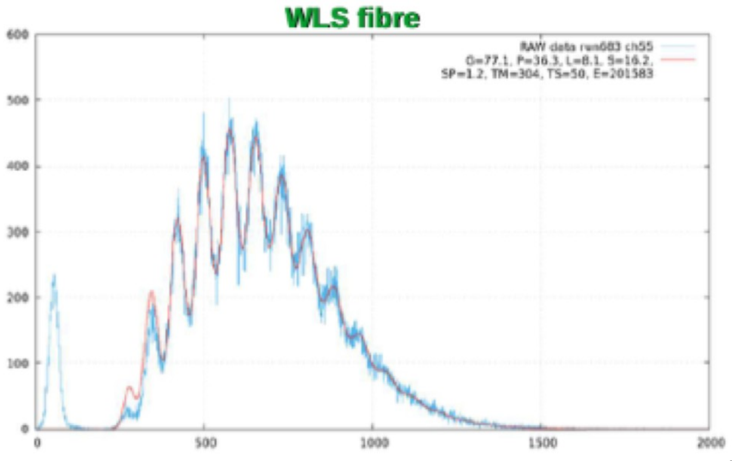


- High-granularity version of ATLAS TileCal hadronic calorimeter
  - 5mm steel absorber plates alternating with 3mm scintillators
  - SiPM readout through WLS
  - Part of ALLEGRO → close collaboration with WP2

- Some of 2024 highlights
  - Exploration of new scintillator materials
  - Optimisation of WLS and SiPMs for readout efficiency
  - Mechanical studies of the testbeam module
    - First period of master and filler plate produced

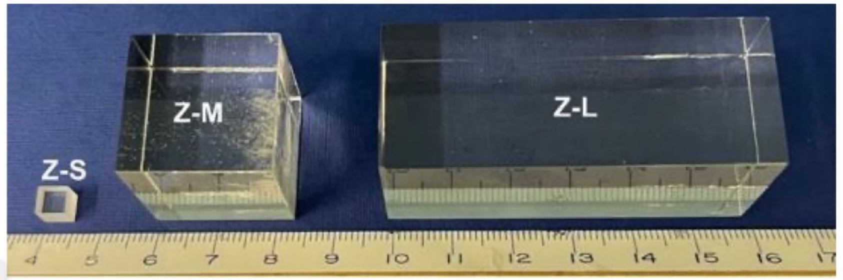




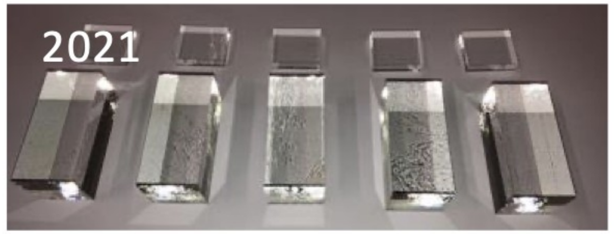


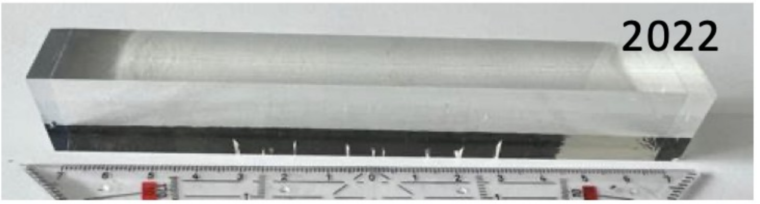
Scintillating Materials – Glasses around the world

Development in Caltech/Calvision

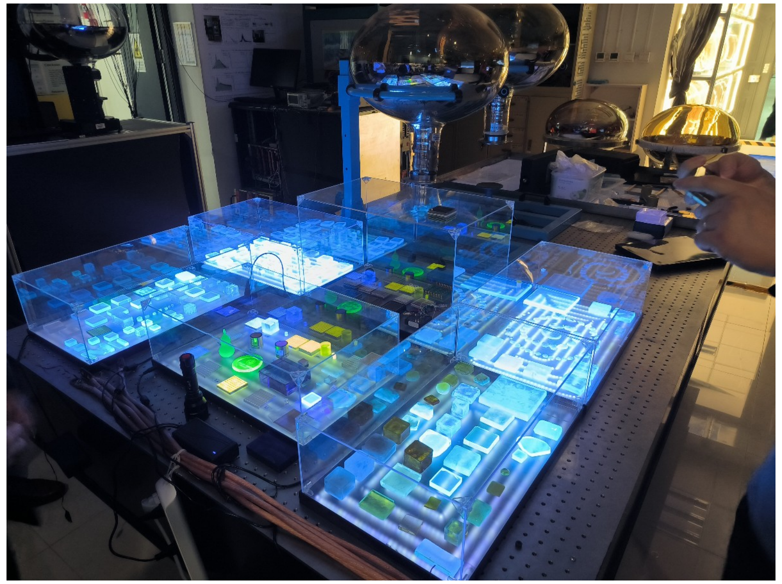


Development in Giessen with Schott company

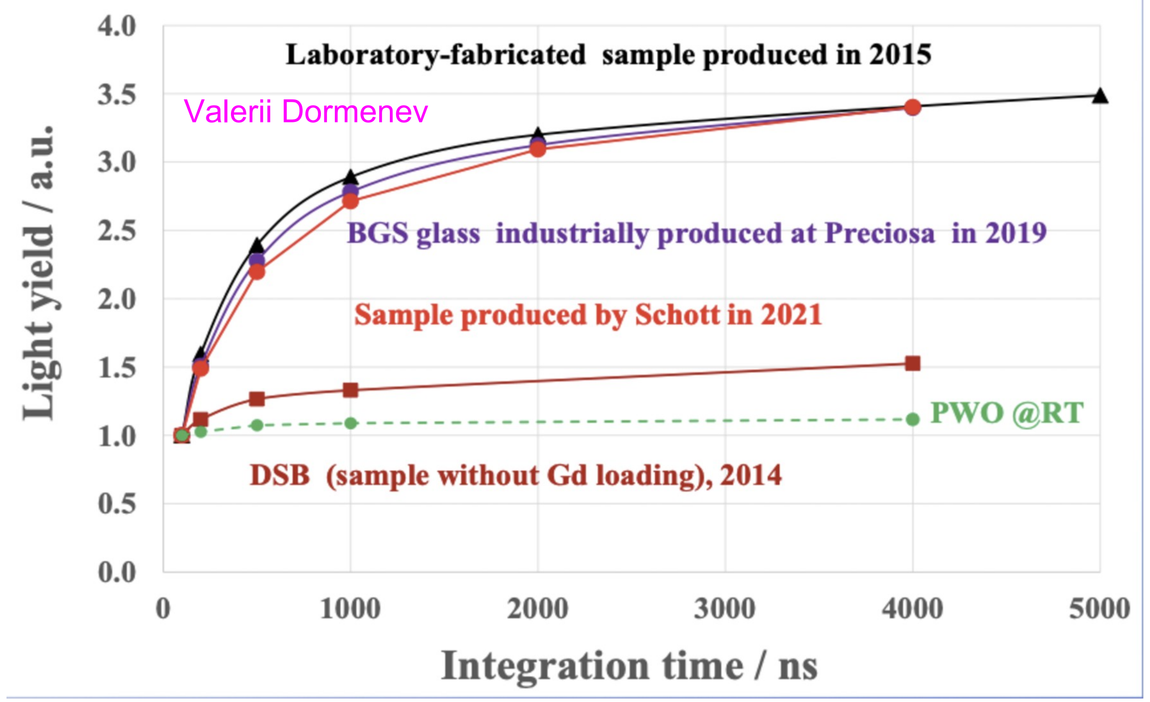




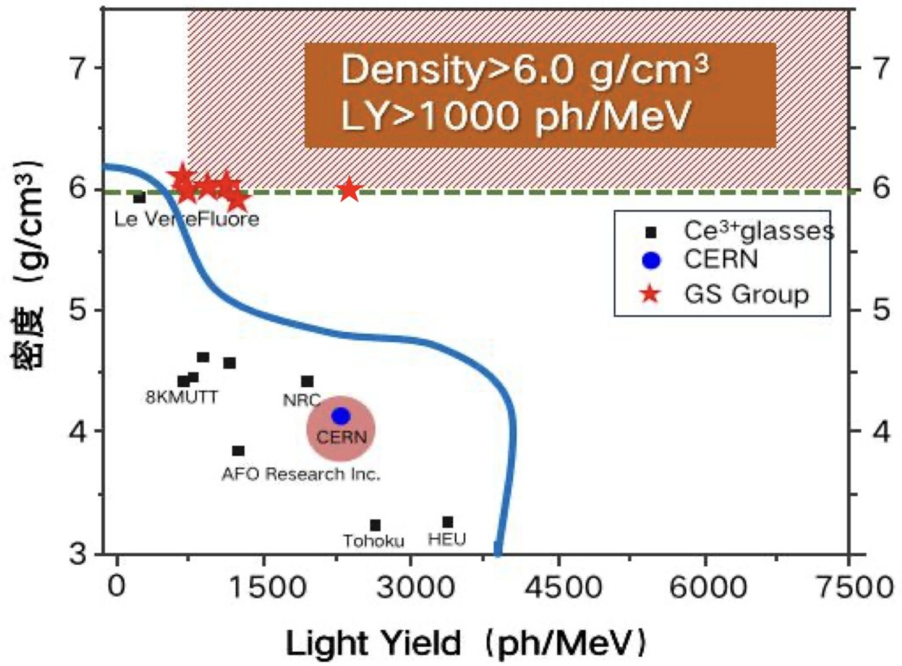
GS Collaboration (China)



Main R&D Topic Light Yield



E. Auffray
Sen Qian
DRD Calo Meeting
April 2025



WP4 – Electronics and DAQ

CALOROC is a 36 chip to read out SiPMs for EIC calorimetry

– Streaming readout

– will pave the way for DRD6

• 2 variants

– CALOROC1A : conservative « à la H2GCROC » (SiPM)

– CALOROC1B : innovative « à la SPIROC » with auto-gain

• Study of a possible variant « à la HGCROC » for Si and LAr

• R&D proposal by ADRIANO3 collaboration to develop R/O with CALOROC and FPGA concentrator (to be followed up)

C. de la Taille, DRD Calo Meeting

Testbeam Facilities

- Test beam dedicated area
  - Resource optimisation
  - Both HW and SW setting up
- Starting from CERN NA
  - Discussion starting with SPS coordinator
  - extend to other facilities?
- Test beam request organization
  - coordinating requests among different projects and different facilities
  - => find needed time for anyone
  - exploit synergies
  - combined ECAL+HCAL performance

Testbeams at CERN in 2025

Task	Name	TB-AREA	Detail	Prototype	Dates
1.3.2	MPGD-HCAL	PS	T10	8layer 20x20 cm^2 + 4 layer 50x50 cm^2	15-29.10
3.1.1	HGCCAL	PS	T9	4 tile 4x4x1 cm^3 + few layers 3x3 tiles	26.6 - 8.7
3.1.2	MAXICC	SPS	H6	full EM proto	17-30.9
3.1.3	CRILIN	SPS	H2	3x3x2 crystal prototype: final mechanics and SiPM RO	7-13.5 and 17-23.9
3.1.4	OREO	SPS	H4	3x3x2 crystal prototype PWO-UF + PMT	6-19.8
3.2.3	RADICAL	SPS	H6	LYSO:Ce and LuO:Yb tiles+ DSB1, LUAG:Ce and flavonol WLS	10-16.9
3.3.1	DRCAL	SPS	H8	3 fibers prototypes	6-19.8 and 24.9 -7.10

To this adds testbeams at DESY, KEK, FNAL and other localtions

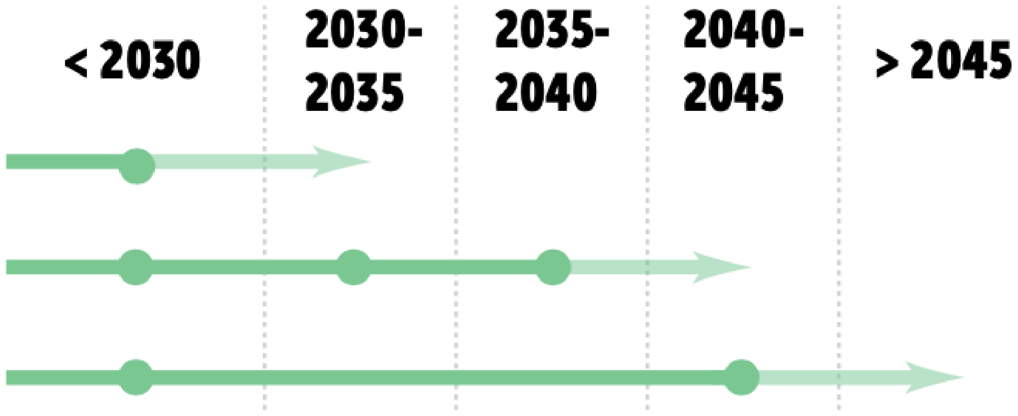
Future Facilities and DRDT for Calorimetry

Calorimetry

DRDT 6.1 Develop radiation-hard calorimeters with enhanced electromagnetic energy and timing resolution

DRDT 6.2 Develop high-granular calorimeters with multi-dimensional readout for optimised use of particle flow methods

DRDT 6.3 Develop calorimeters for extreme radiation, rate and pile-up environments



- The Detector R&D Themes and the provisional time scale of facilities set high-level boundary conditions
  - See backup slides for detailed R&D tasks

WP3 – Projects

Project	Scintillator/WLS	Photodetector	DRDTs	Target
Task 3.1: Homogeneous and quasi-homogeneous EM calorimeters				
HGCCAL	BGO, LYSO	SiPMs	6.1, 6.2	e^+e^-
MAXICC	PWO, BGO, BSO	SiPMs	6.1, 6.2	e^+e^-
Crilin	PbF_2, PWO-UF	SiPMs	6.2, 6.3	$\mu^+\mu^-$
Task 3.2: Innovative Sampling EM calorimeters				
GRAiNITA	$ZnWO_4$, BGO	SiPMs	6.1, 6.2	e^+e^-
SpaCal	GAGG, organic	MCD-PMTs,SiPMs	6.1, 6.3	e^+e^-/hh
RADiCAL	LYSO, LuAG	SiPMs	6.1, 6.2, 6.3	e^+e^-/hh
Task 3.3: (EM+)Hadronic sampling calorimeters				
DRCal	PMMA, plastic	SiPMs, MCP	6.2	e^+e^-
TileCal	PEN, PET	SiPMs	6.2, 6.3	e^+e^-/hh
Task 3.4: Materials				
ScintCal	-	-	6.1, 6.2, 6.3	$e^+e^-/\mu^+\mu^-$/hh
CryoDBD Cal	TeO, ZnSe, LiMoO NaMoO, ZnMoO	n.a.	-	DBD experiments

+ OREO in Task 3.1

Collaboration Meetings 2024

- 9th - 11th of April 2024 at CERN
- https://indico.cern.ch/event/1368231/overview
- 133 participants, 67 on-site

- 30th of October - 1st of November 2024 at CERN
- https://indico.cern.ch/event/1449522/
- 184 participants, 54 on-site

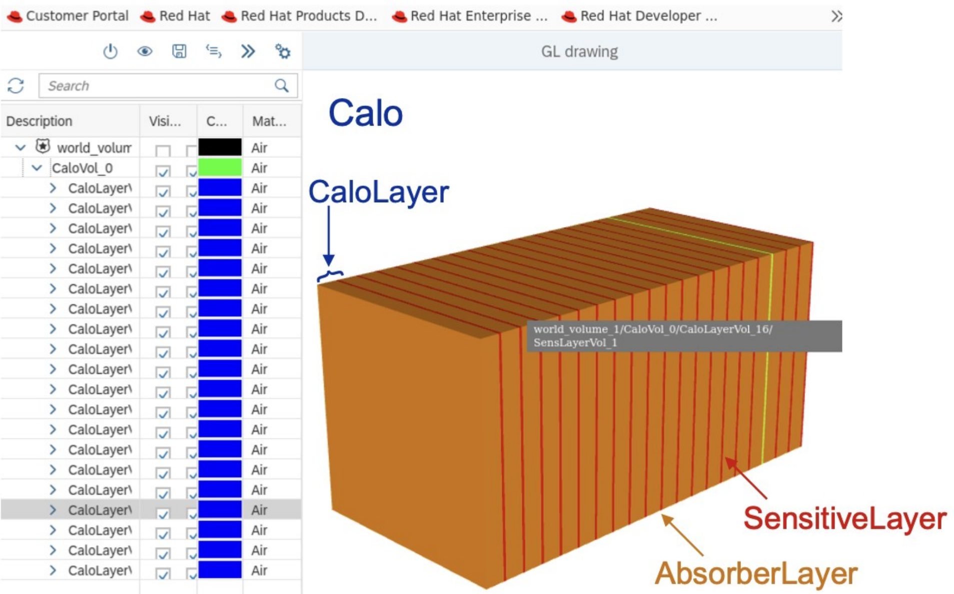
Software WG - Tutorials

DRD Calo

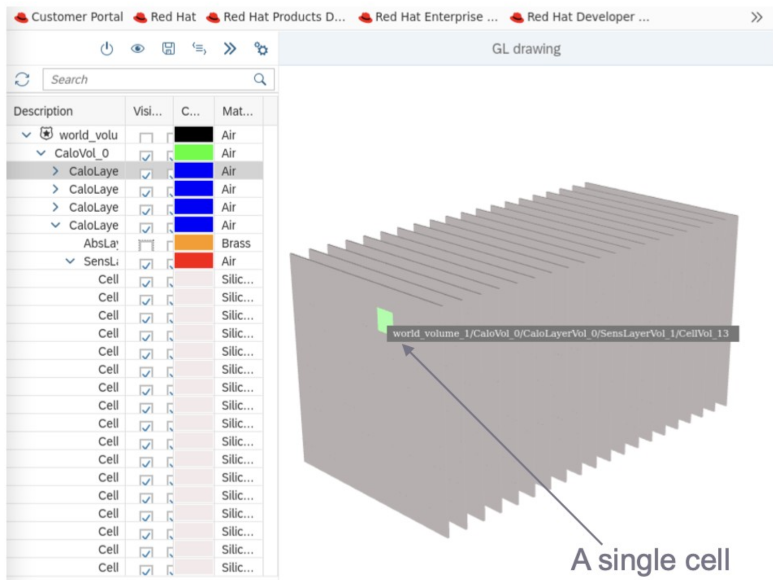
Organised by Brieuc and Lorenzo during last collaboration meeting

Detector implementation with DD4HEP

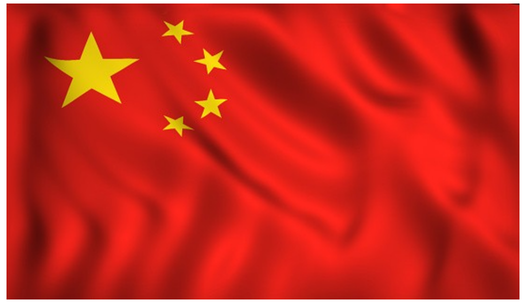
simplecalo1



simplecalo2



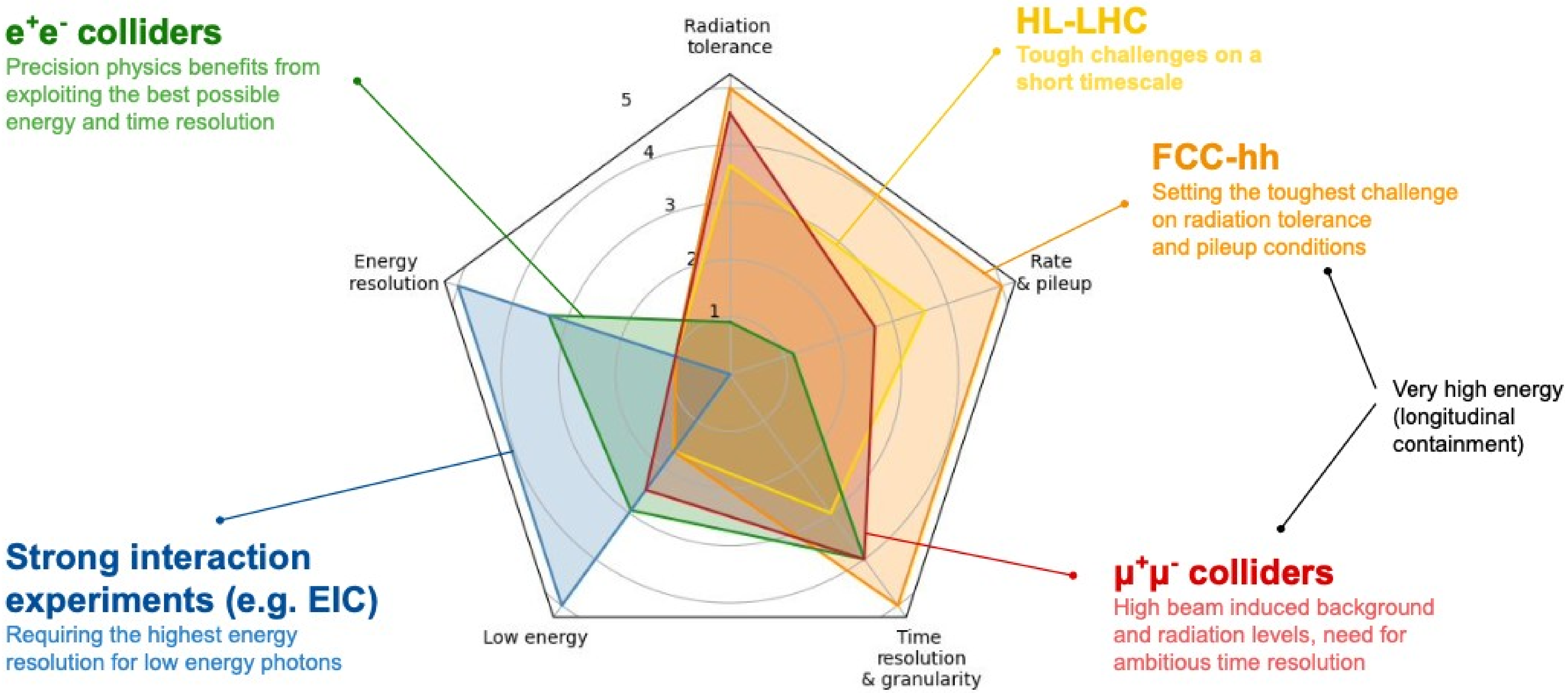
The bigger picture



- DRD implements and/or connects to strategies in Europe, US and Asian Countries
- Interlink with US programme see next pages

Requirements for calorimetry at future colliders

DRD Calo



Inspired from https://indico.cern.ch/event/994685/

Categories of R&D

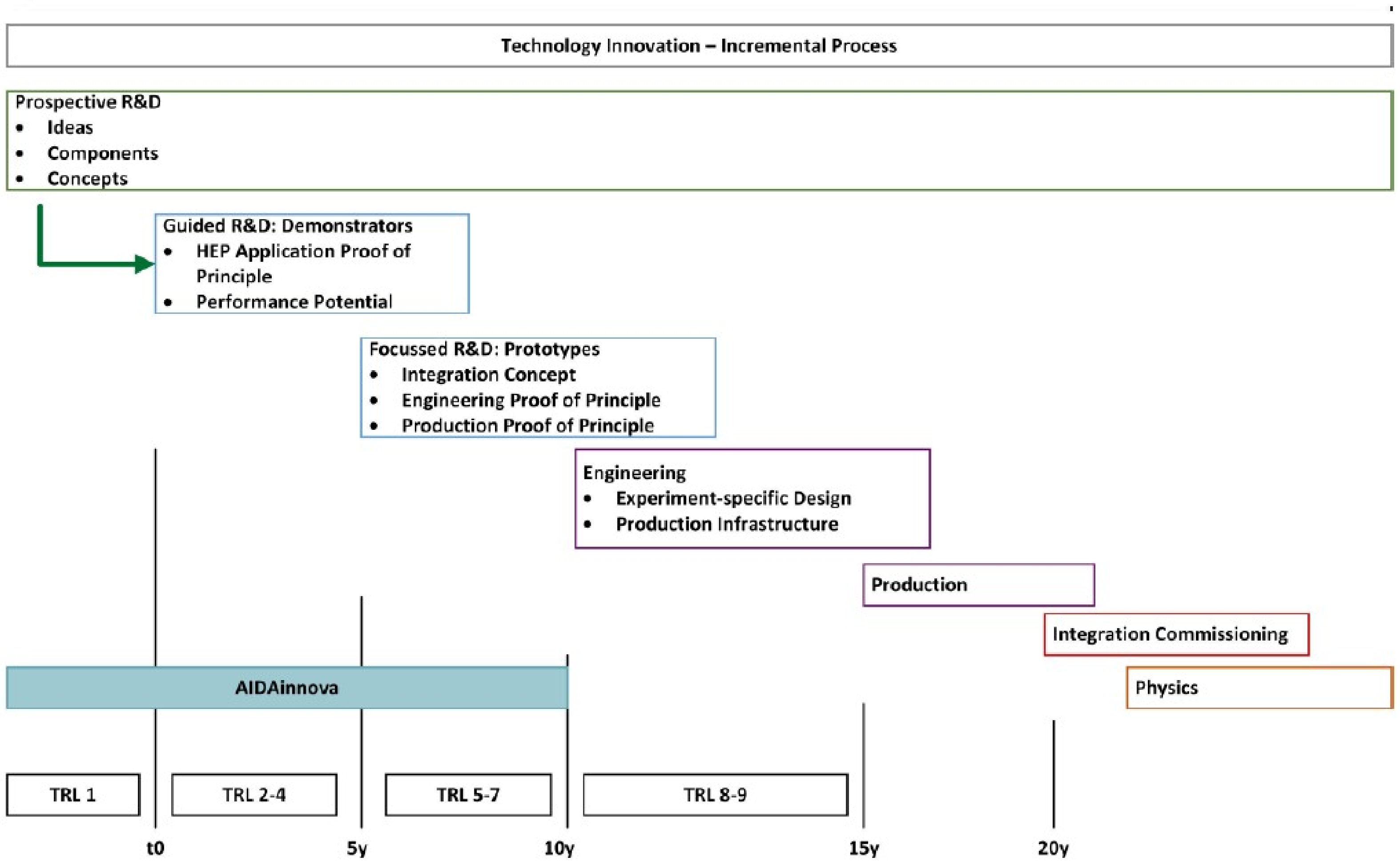
1. Strategic R&D via DRD Collaborations
   (long-term strategic R&D lines)
   (address the high-priority items defined in the Roadmap via the DRDTs)
2. Experiment-specific R&D
   (with very well defined detector specifications)
   (funded outside of DRD programme, via experiments, usually not yet covered within the projected budgets for the final deliverables)
3. "Blue-sky" R&D
   (competitive, short-term responsive grants, nationally organised)

vision

focus

agility

Transitions Blue-sky → Strategic → Specific expected
Cross-fertilisation desired



F. Sefkow, CALICE Meeting and ECFA Higgs/top/EW Factory Meeting

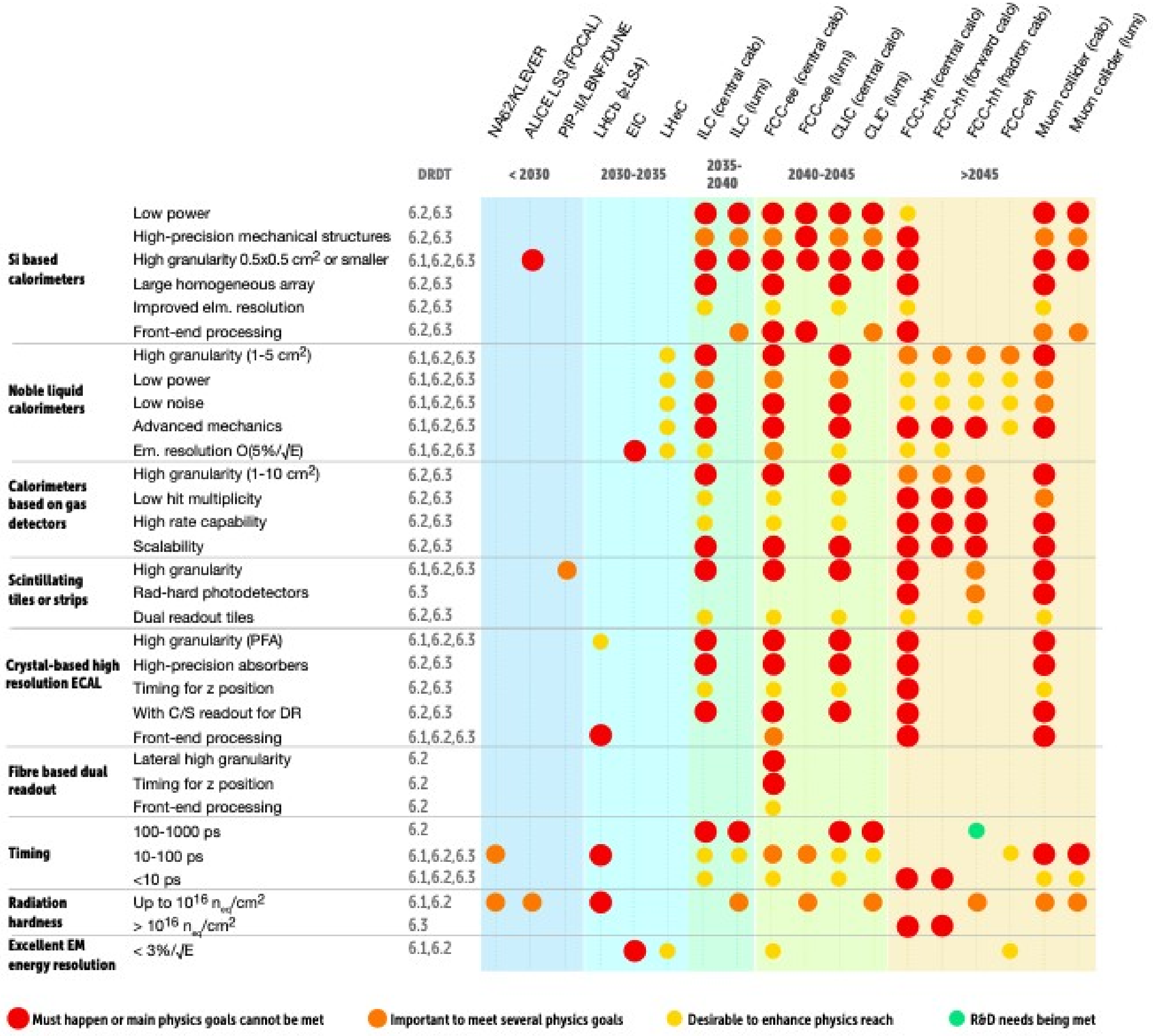
Calorimetry- Identified Key Technologies and R&D Tasks

DRD Calo

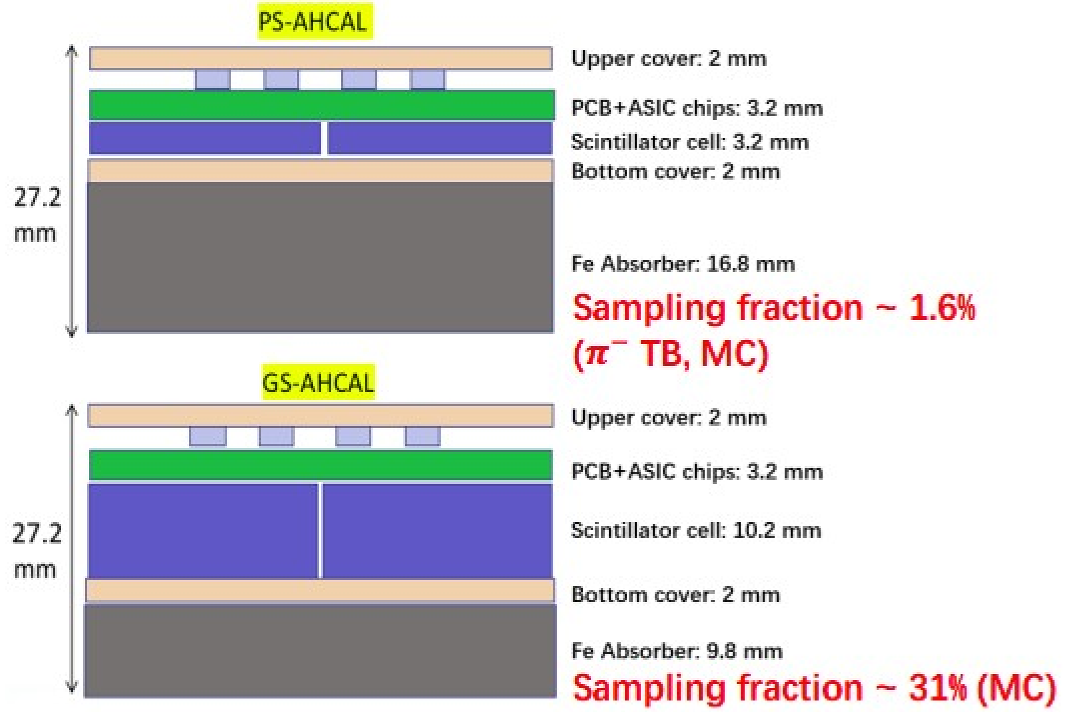
- Key technologies and requirements are identified in ECFA Roadmap
  - Si based Calorimeters
  - Noble Liquid Calorimeters
  - Calorimeters based on gas detectors
  - Scintillating tiles and strips
  - Crystal based high-resolution Ecals
  - Fibre based dual readout

- R&D should in particular enable
  - Precision timing
  - Radiation hardness

- R&D Tasks are grouped into
  - Must happen
  - Important
  - Desirable
  - Already met

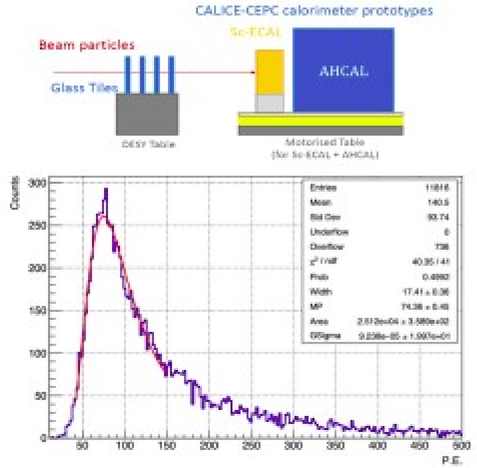


WP1 – Subtask 1.2.2 – ScintGlassHCAL



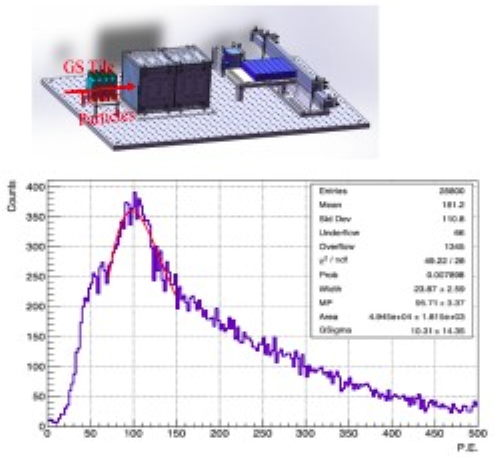
Glass scintillator R&D: Light yield

CERN Muon-beam (10 GeV muon)
11 glass tiles tested at CERN (2023/5)



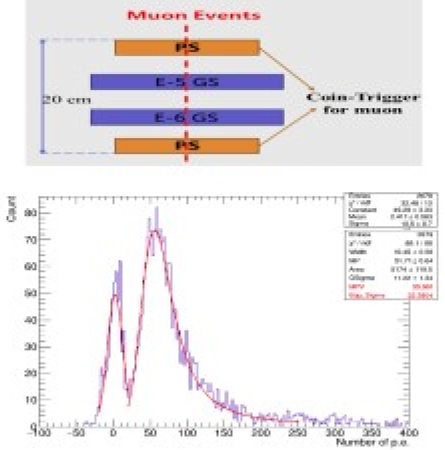
- Typical Light Yield: 500 – 600 ph/MeV
- Typical MIP response: 60 – 70 p.e./MIP

DESY Electron-beam (5 GeV electron)
9 glass tiles tested at DESY (2023/10)



- Typical Light Yield: 600 – 700 ph/MeV
- Typical MIP response: 70 – 80 p.e./MIP

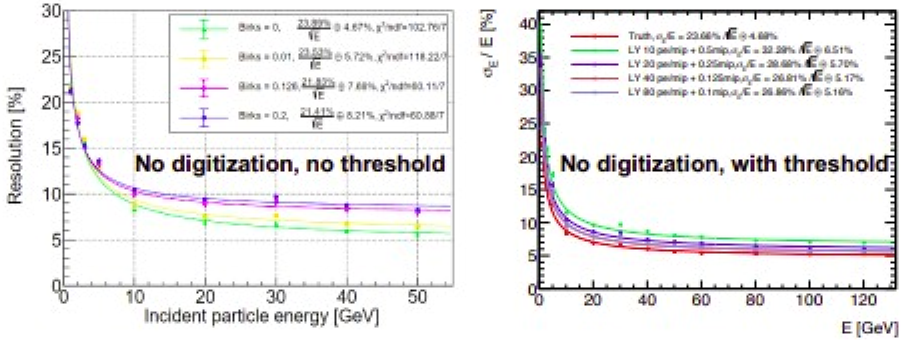
IHEP Cosmic Muon (3 GeV muon)
4 glass tiles tested at IHEP (2024/4)



- Typical Light Yield: 500 – 700 ph/MeV
- Typical MIP response: 60 – 80 p.e./MIP

GS-HCAL performance simulation

- Key parameters to energy resolution are studied: light yield, threshold, Birks constant, attenuation length.



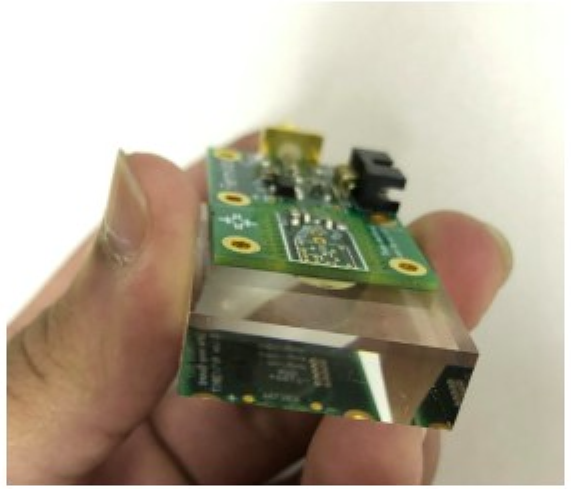
- **Plan in next years: follow DRD6 and CEPC Ref-Det TDR timeline.**
  - 2024 - 2025: detector design and optimization, $4\times4\times1\ cm^3$ tile R&D, SiPM and electronics performance test
  - 2026 - 2027: prototype construction and test.

WP1 – Subtask 1.3.3 – MPGD-HCCAL

- Cerenkov radiator: 3x3x2 cm^3 lead-glass tiles (typical size)
- Scintillator component: 3x3x 0.5 cm^3 scintillating tiles (typical size)
- Neutron component: 10x10x1 cm^3 doped RPC
- Tiles readout: on-tile sipm
- RPC readout: pads

Presentation in April

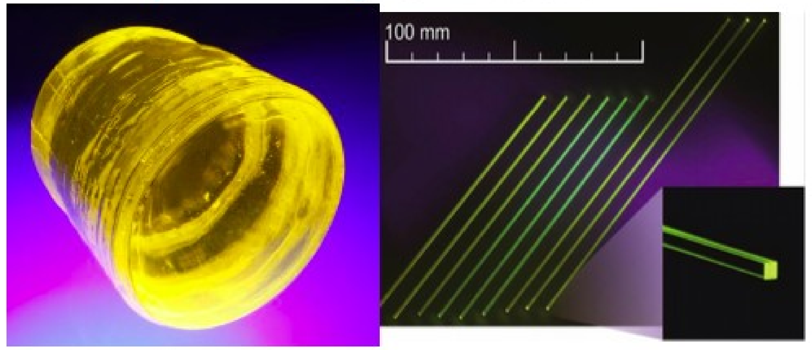
Since then: funding application submitted to DOE



Novel optical materials

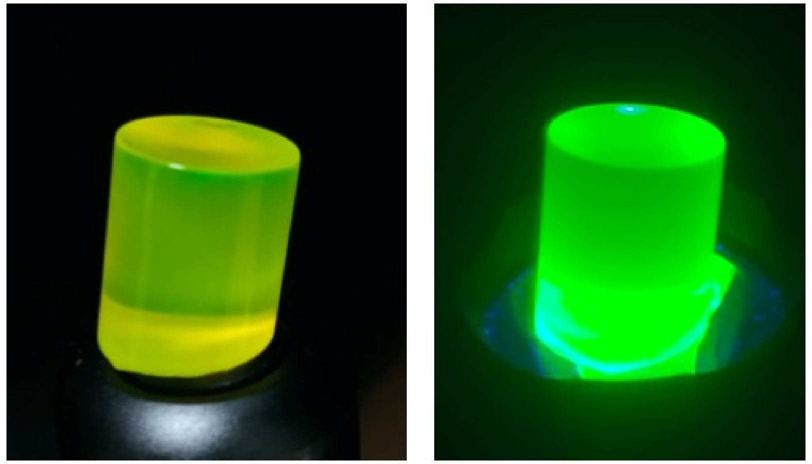
- Radiation hard optical materials with ultrafast timing response are required for new detectors in HEP, nuclear medicine and industry
- A time resolution below 30 ps or even in the sub ps domain requires a better understanding of the fast signal production mechanisms in detection materials
- Innovative test suites required for the combination of fast timing and radiation tolerance will be developed for the characterisation and classification of materials
- Scalable and cost effective production techniques for the novel materials have to be explored together with the industrial partners

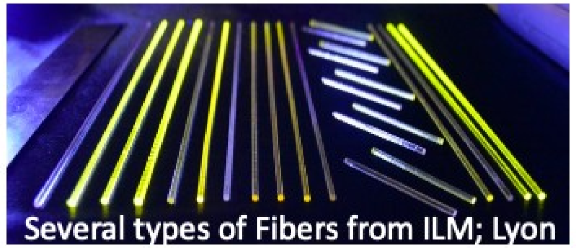
Crytur YAG ingots => fibers



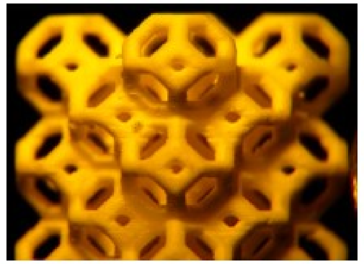
Crytur PWO crystals

GlasstoPower development on quantum materials





3 D printed garnet Crystals



Courtesy G. Dosovitskyi, Kurchatov Institute