ALLEGRO
Noble-Liquid-based calorimeter for FCC-ee

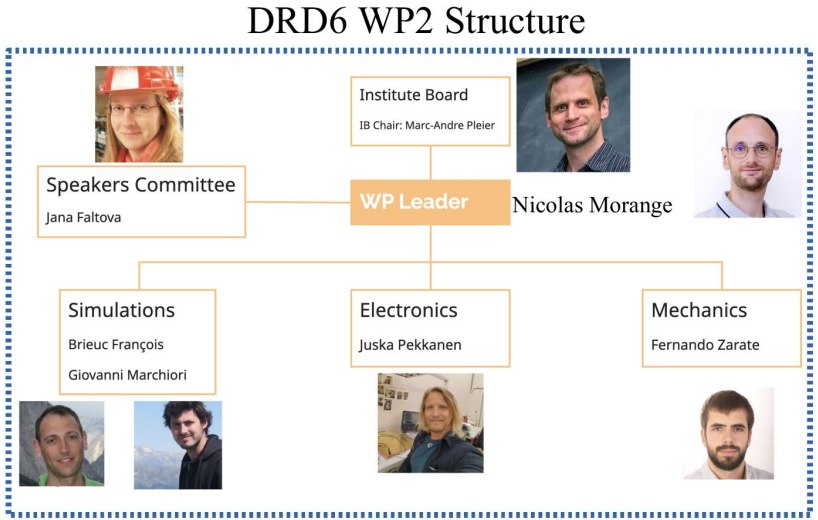
Martina Koppitz - on behalf of the ALLEGRO team

ILC - Workshop 28.06.2024

ALLEGRO Workforce Organization

Organized within ECFA “Detector R&D on calorimetry” (DRD6) collaboration

Workpackage 2: Noble Liquid Calorimeters
20 institutes from 7 countries



DRD6 Calorimetry Collaboration Meeting April 2024

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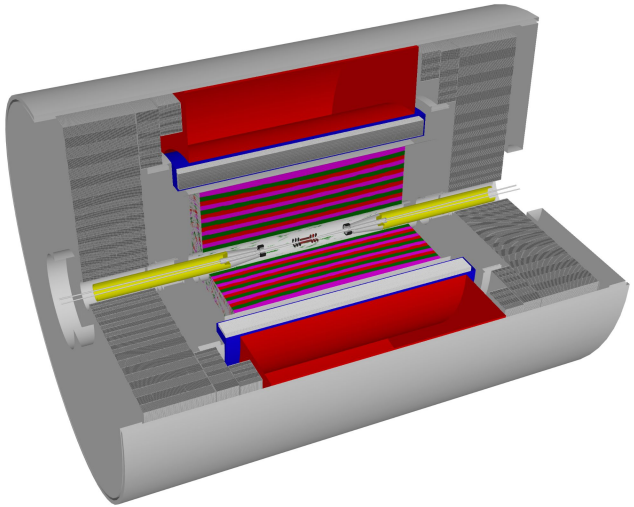
A **L**epton **L**epton collider **E**xperiment with **G**ranular **R**ead-**O**ut

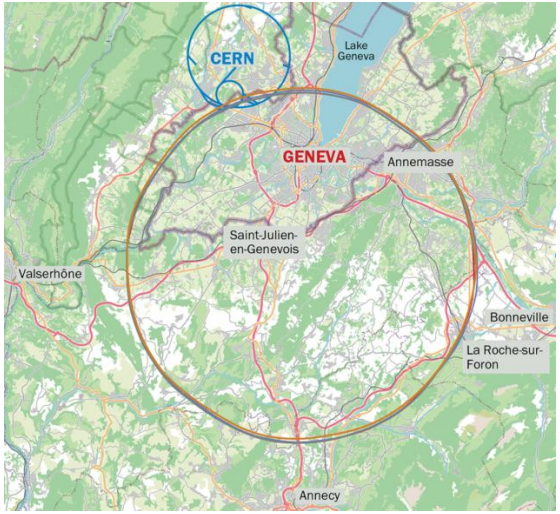
Outline:

1. FCC-ee
2. Detector concept
3. Noble Liquid ECAL with high granularity

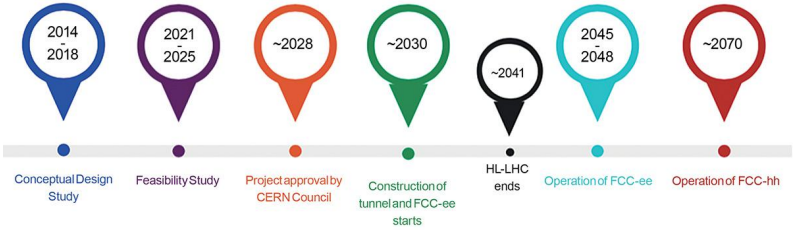


Future Circular Collider - Overview

- 90.7 km circumference, up to 4 interaction points possible
- Stage 1: FCC-ee (up to 356 GeV) as Higgs factory, electroweak & top factory at highest luminosities
- Stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier



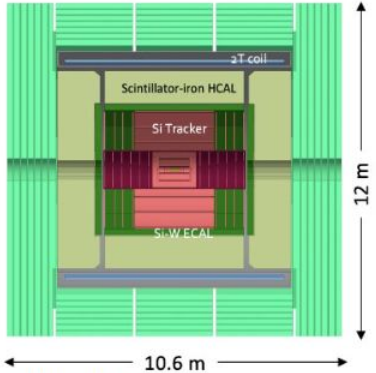
Midterm review very positive, no show-stoppers identified so far



R&D ongoing to optimize detectors for ambitious physics programme (particle flow, particle identification → high granularity)

Detector Concepts

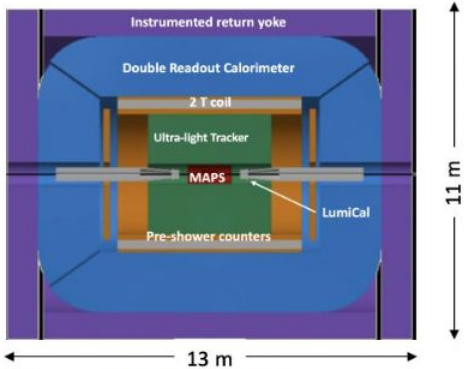
CLD



- Well established design
  - ILC -> CLIC detector -> CLD
- Full Si vtx + tracker
- CALICE-like calorimetry;
- Large coil, muon system
- Engineering still needed for operation with continuous beam (no power pulsing)
  - Cooling of Si-sensors & calorimeters
- Possible detector optimizations
  - σ_p/p, σ_E/E
  - PID ($\mathcal{O}$(10 ps) timing and/or RICH)?

CDR

IDEA



- A bit less established design
  - But still ~15y history
- Si vtx detector; ultra light drift chamber with powerful PID; compact, light coil;
- Monolithic dual readout calorimeter;
  - Possibly augmented by crystal ECAL
- Muon system
- Very active community
  - Prototype designs, test beam campaigns, …

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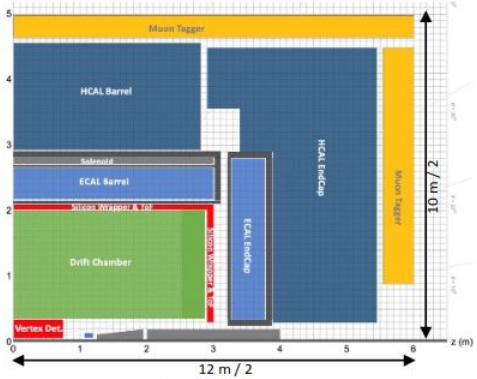

- The “new kid on the block”
- Si vtx det., ultra light drift chamber (or Si)
- High granularity Noble Liquid ECAL as core
  - Pb/W+LAr (or denser W+LKr)
- TileCal-like HCAL;
- Coil inside same cryostat as LAr, outside ECAL
- Muon system.
- Very active Noble Liquid R&D team
  - Readout electrodes, feed-throughs, electronics, light cryostat, …
  - Software & performance studies

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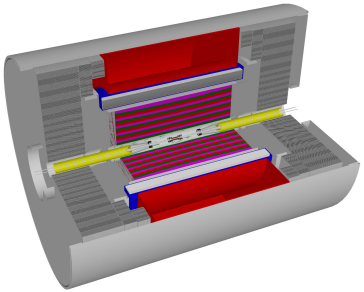
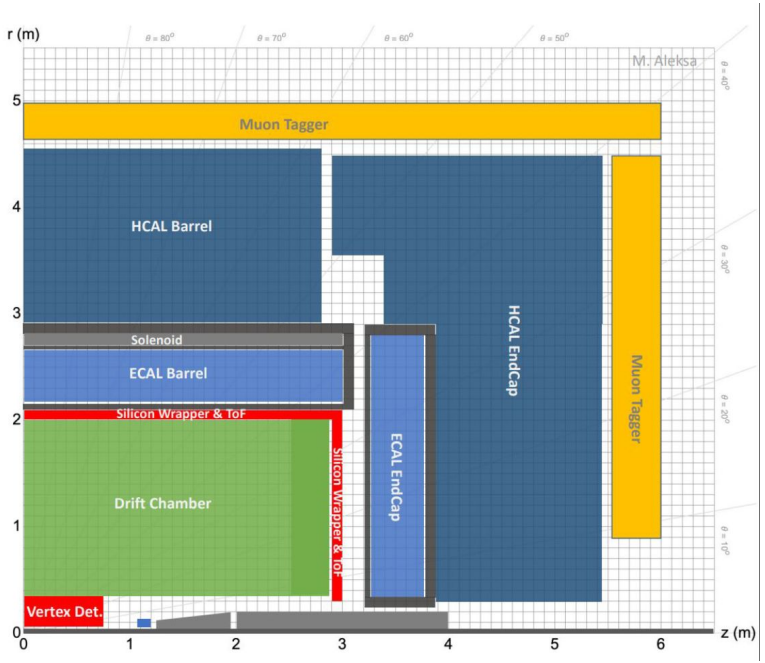
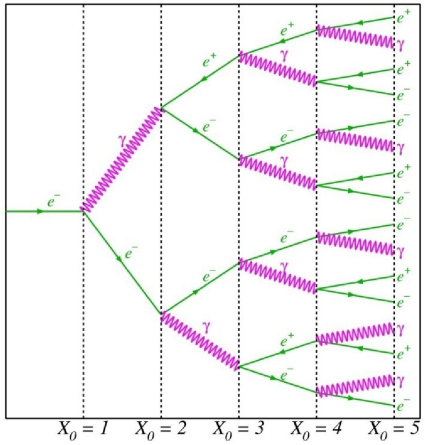


A **L**epton **L**epton collider **E**xperiment with **G**ranular **R**ead-**O**ut

- Ultra-light tracking system with PID capabilities
- Noble liquid electromagnetic (ECAL) and scintillator based hadronic calorimeter (HCAL)
- Ultralight carbon fiber cryostat
- 2 T solenoid between ECAL and HCAL



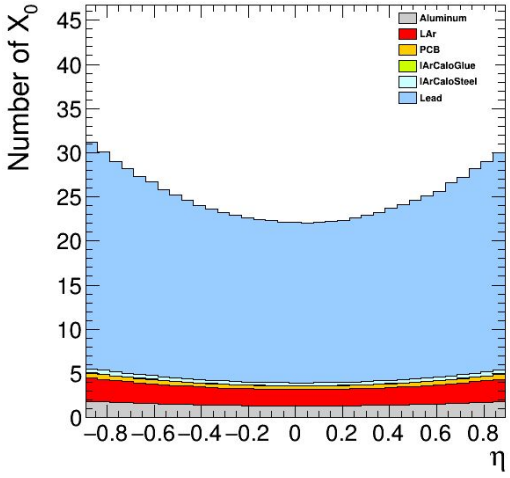
Calorimetry Basics



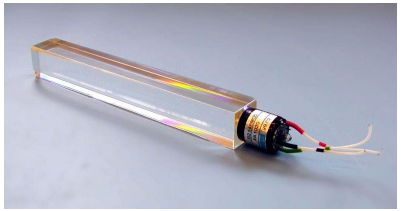
Energy measurement via absorption of particle

Dense absorber material (shower development), active material to induce signal

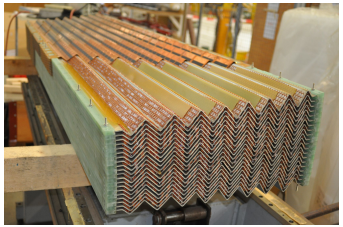
Material choice: longitudinal shower containment determined by radiation length, lateral spread important for shower separation and position



Homogeneous vs. Sampling Calorimeter



CMS - PbWO



ATLAS - Lead + Liquid Argon

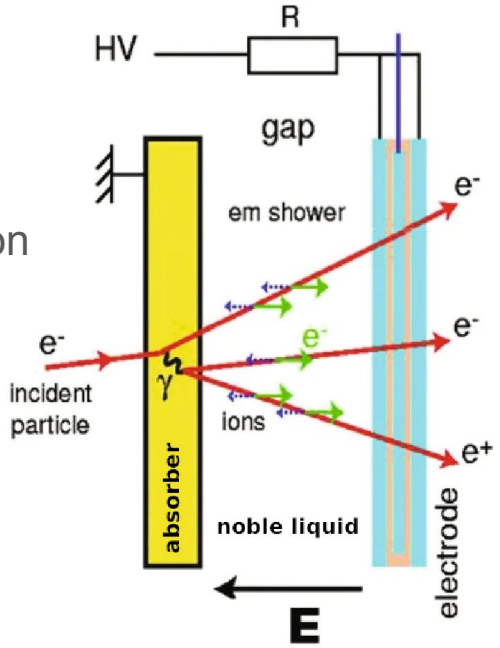
Noble Liquid Electromagnetic Calorimeter

Why noble liquids?

- Intrinsic stability, scintillation and ionization properties, linearity, good timing properties, radiation hardness
- Ionization by incident particle
- Drift towards electrode induces signal

Challenges:

- Cryostat structure, signal feed-through

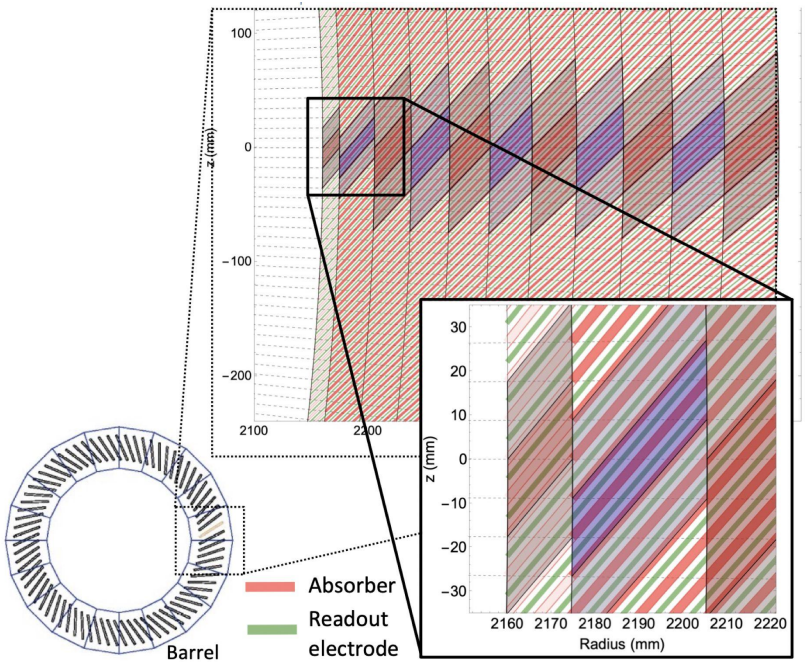


Noble liquid based calorimetry successful in several high energy physics experiments!

Noble Liquid Electromagnetic Calorimeter

Baseline geometry:

- Liquid argon as active material, lead absorbers
- 1536 plates inclined by 50˚ (phi uniformity)
- 22 X_0(40cm), 11 longitudinal layers
- Lightweight carbon fibre cryostat
- Granularity: $\theta \times \phi \times r \sim 2 \times 1.8 \times 3\ cm^3$

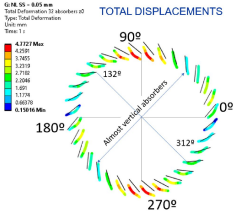


Prototypes

Absorbers

1.8 mm lead + 50 μm steel

Structural analysis

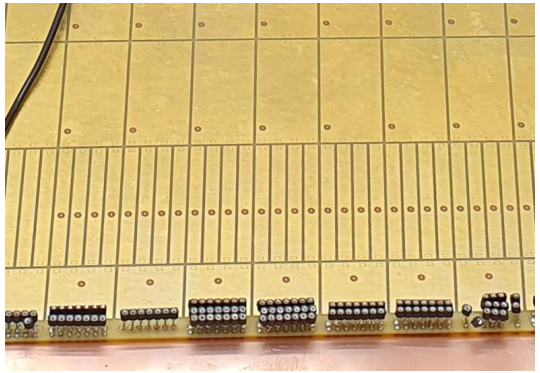


Thermo-mechanic tests in liquid nitrogen

Printed Circuit Board

Designed and tested at CERN

Strips in front layer with 4x finer segmentation for π^0



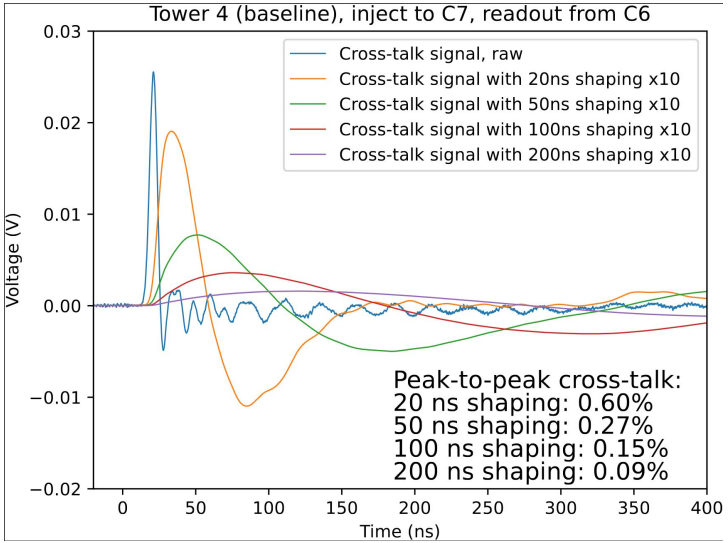
Towards High Granularity - Multilayer PCB

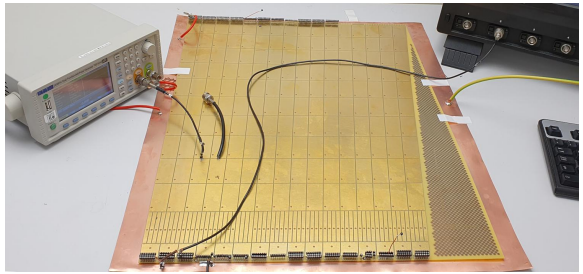
Finding the sweet spot between high granularity, cross talk and electronics noise:

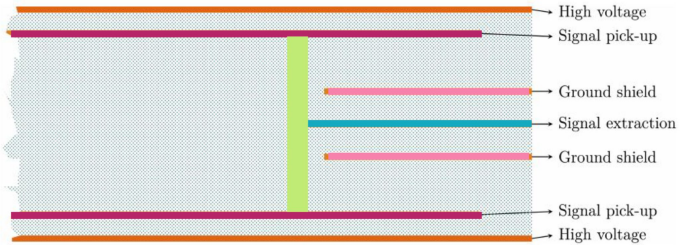
Cross talk: signal traversing below other cells

Reduced by shielding, but increased capacitance to ground results in noise

Longer shaping times possible for FCC-ee





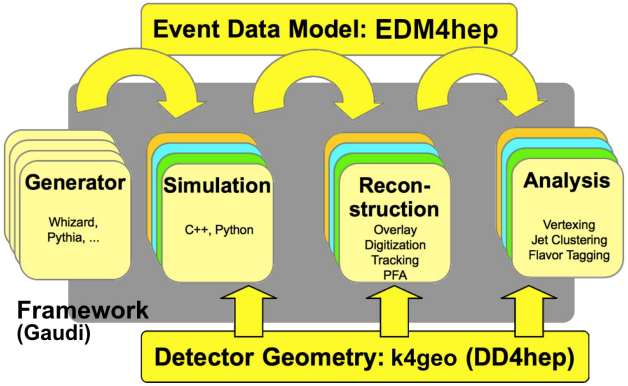


Side-view

Performance Studies

Simulations of ECAL barrel using FCC-Software:

- based on **Key4Hep** framework, software meant to support all future collider studies
- Detector description with **DD4hep**

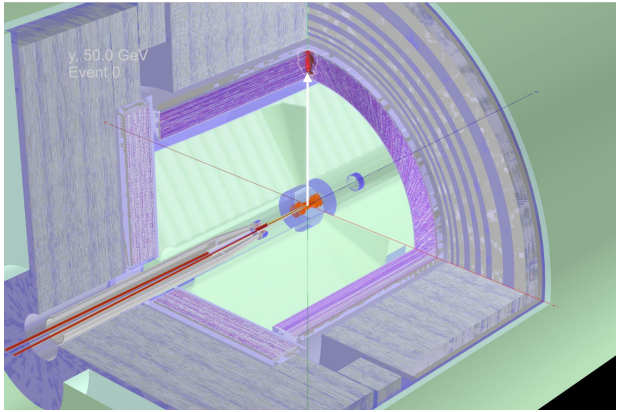


Simulation flexible, enable studies of different configurations

Improving accuracy with constant implementations (cross-talk)

Study of physics performance

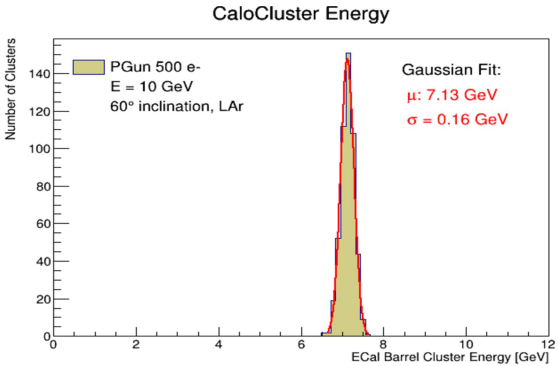
Optimization of detector design

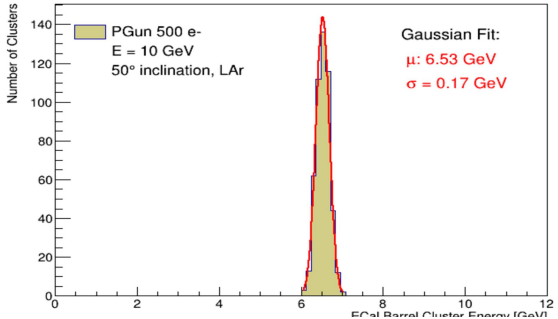


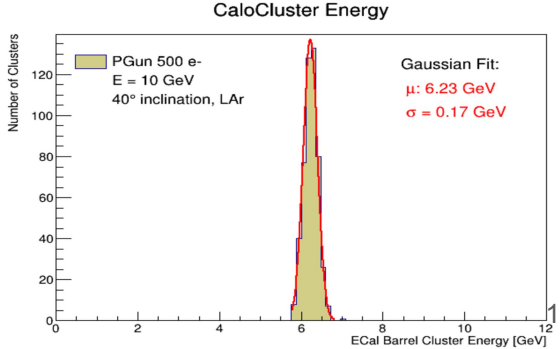
Performance Studies

Study impact of geometry modifications of ECAL barrel:

- Inclination/number of layers: limit LAr gap widening to keep constant term low, length of layers and angle chosen to obtain a projective geometry in phi
- Choice of material: investigate LAr/LKr and Pb/W
- Segmentation: cells on PCB enables freedom on granularity in each layer

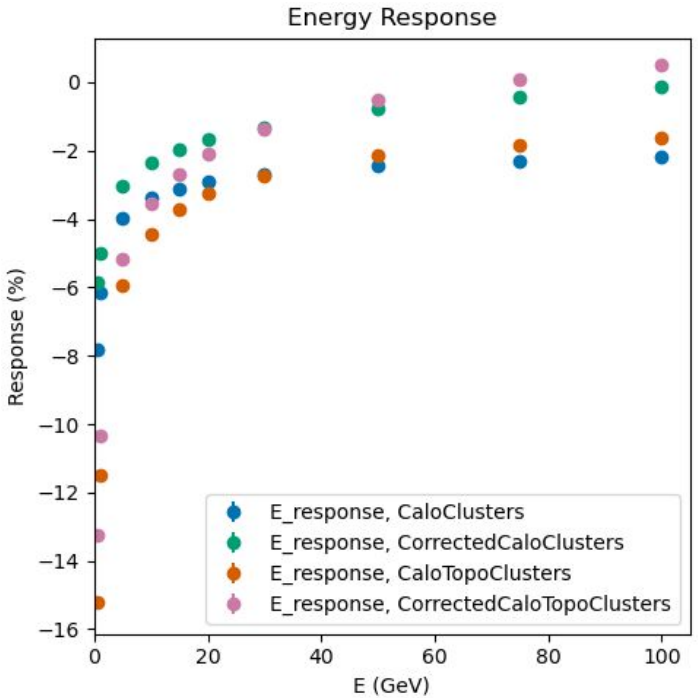






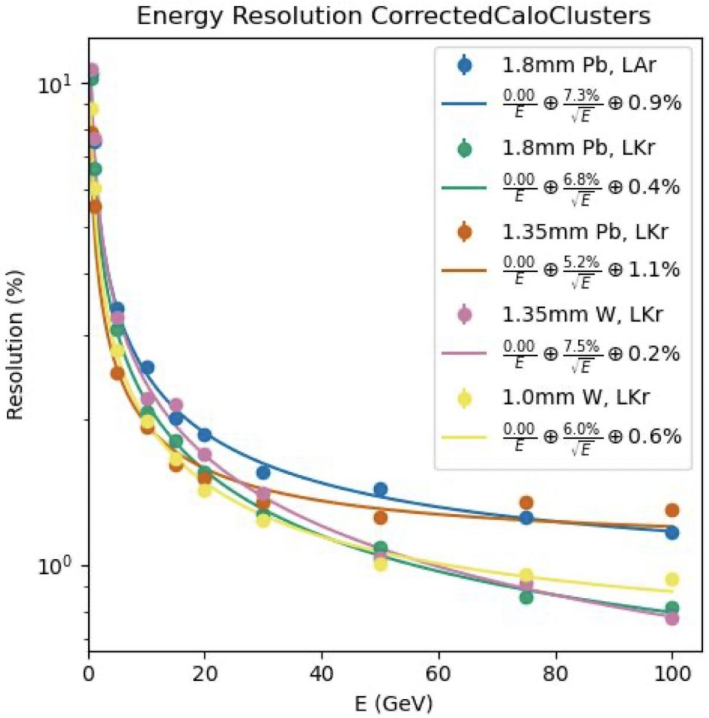
- Energy response:

$$\frac{E_{rec} - E_{truth}}{E_{truth}}$$



- Energy resolution:

$$\frac{\sigma}{E} = Noise\ term \oplus stochastic\ term \oplus constant\ term$$

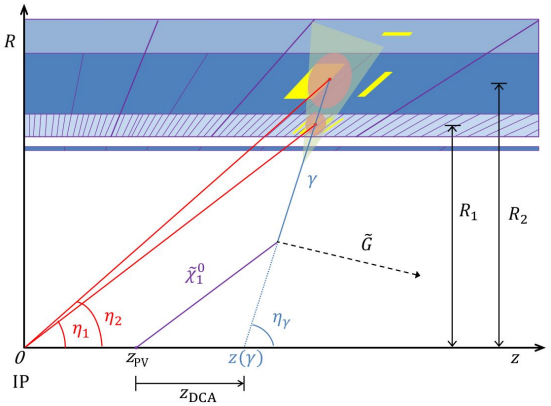


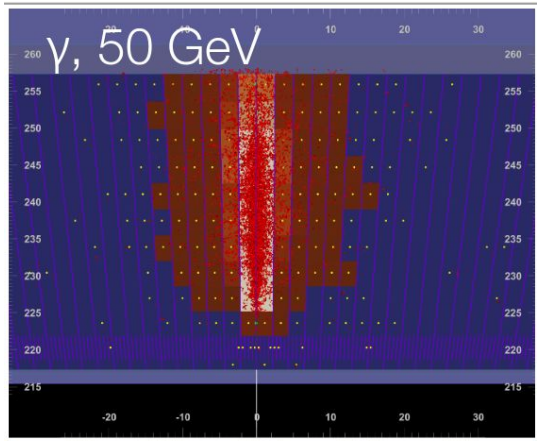
π^0/γ identification

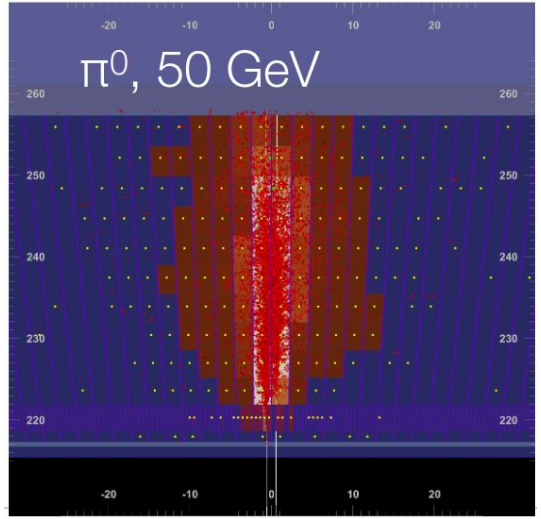
- $\pi^0 \rightarrow \gamma\gamma$, little angular separation towards high energies:

$$\theta = 2arc\tan\left(\frac{mc^2}{2E}\right)$$

- Which granularity for optimal π^0 rejection?
- Study shower shape variables
- Enabling searches for long lived particles





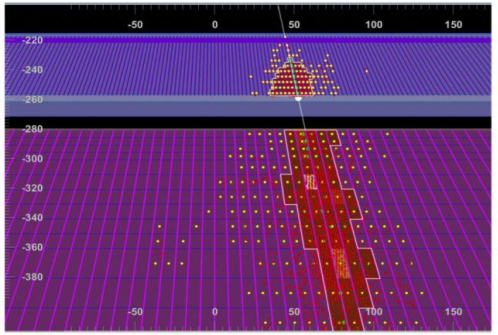


The Quest for the Optimal Granularity

First studies have shown that shower has not fully evolved yet up to strip layer

→ Improved and updated PCB design, strips shifted further to the back

More than one strip layer?



Shower generated by 50 GeV π^+

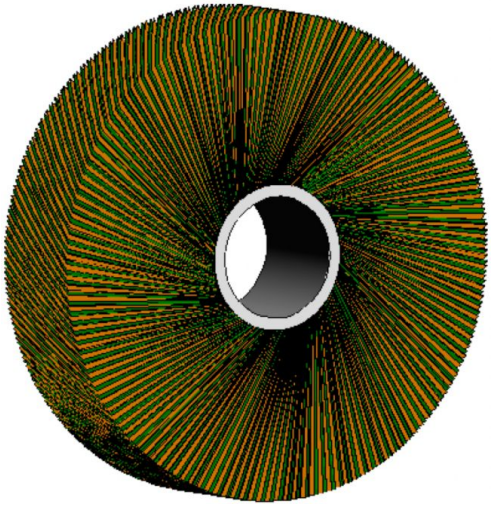
Crucial for Particle Flow (matching of tracks)

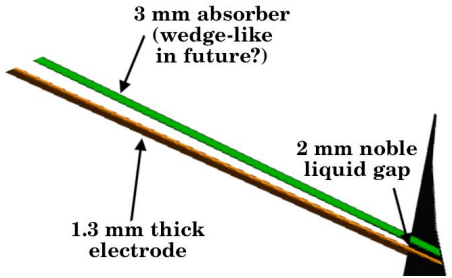
PF implementation ongoing in FCC software

ECAL Endcap design

Current idea being implemented in the simulation: “Turbine design”

- Thin Pb absorber plates, similar to ECAL barrel
- Symmetry in ϕ
- Challenge: size ob Noble liquid gap increases

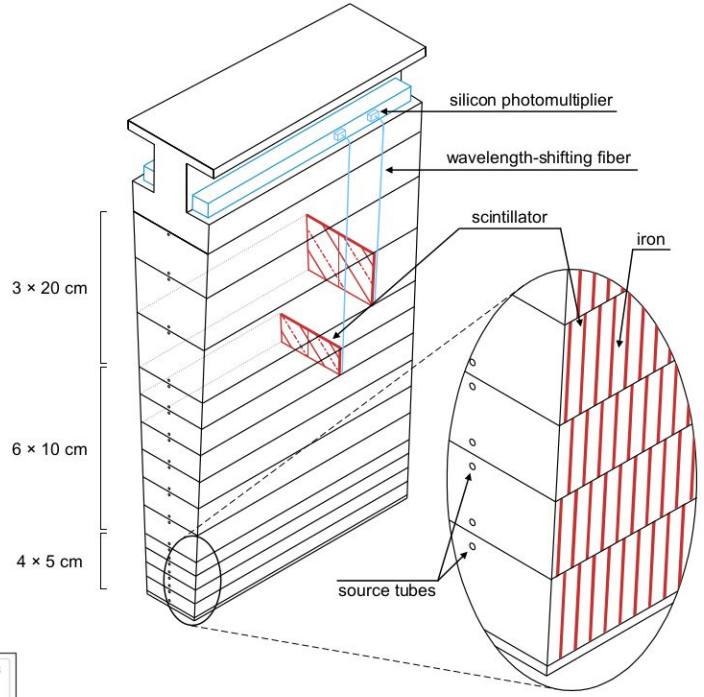




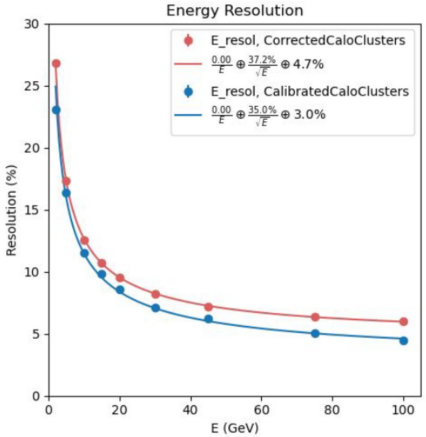
HCAL

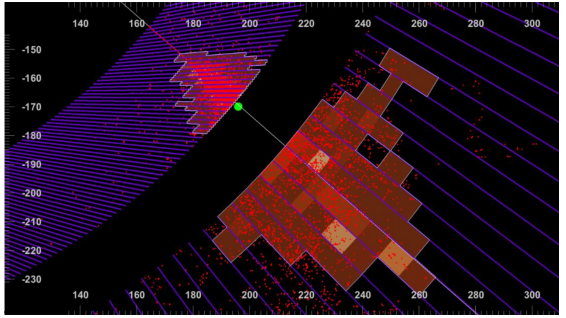
Inspired by ATLAS TileCal

- 5mm steel absorbers and 3mm scintillator plates, oriented perpendicular to the beam line
- 13 longitudinal layers
- Light readout through wavelength shifting fibres



Topological clustering implemented recently to study combined ECAL+HCAL performance

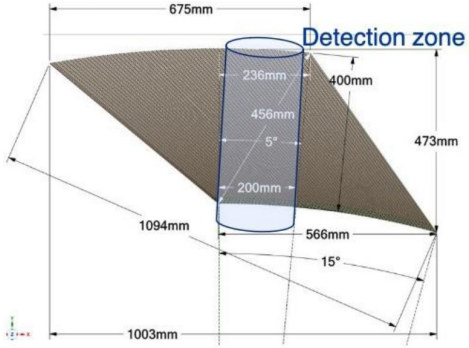




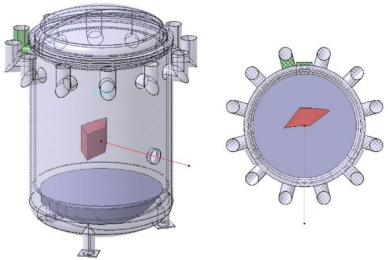
Test Beam Model

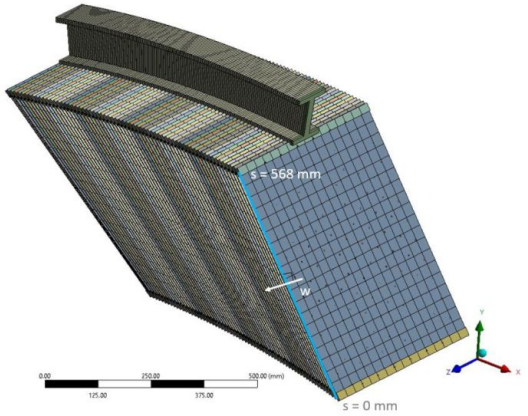
Planning for a testmodule in 2028

- Mechanical designs for module with 64 absorbers
- Working on adapting testbeam cryostat

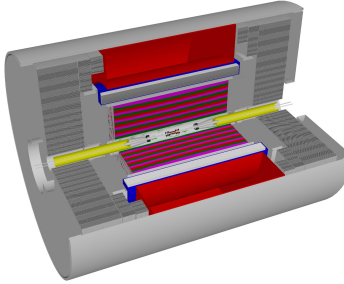


The cryostat available to make the test beam is the CRRP-00563.





Summary



ALLEGRO - General purpose detector for FCC-ee with ECAL based on Noble Liquid Technology

High granularity, optimized for e+e- collider programme (Particle Flow, PID)

Particle identification properties under study, focus in particular on π^0/γ rejection

First prototypes (readout PCBs & absorbers) are being tested and new designs elaborated

Testbeam module expected by 2028

Happy to welcome new collaborators!

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