ALLEGRO simulated performance

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https://indico.in2p3.fr/event/33434/

FUTURE CIRCULAR COLLIDER

NUCLÉAIRE & PARTICULES

ALLEGRO concept

- ALLEGRO = A Lepton coLlider Experiment with Granular calorimetry Read-Out
- A Noble-Liquid ECAL Based, general-purpose detector concept for FCCee

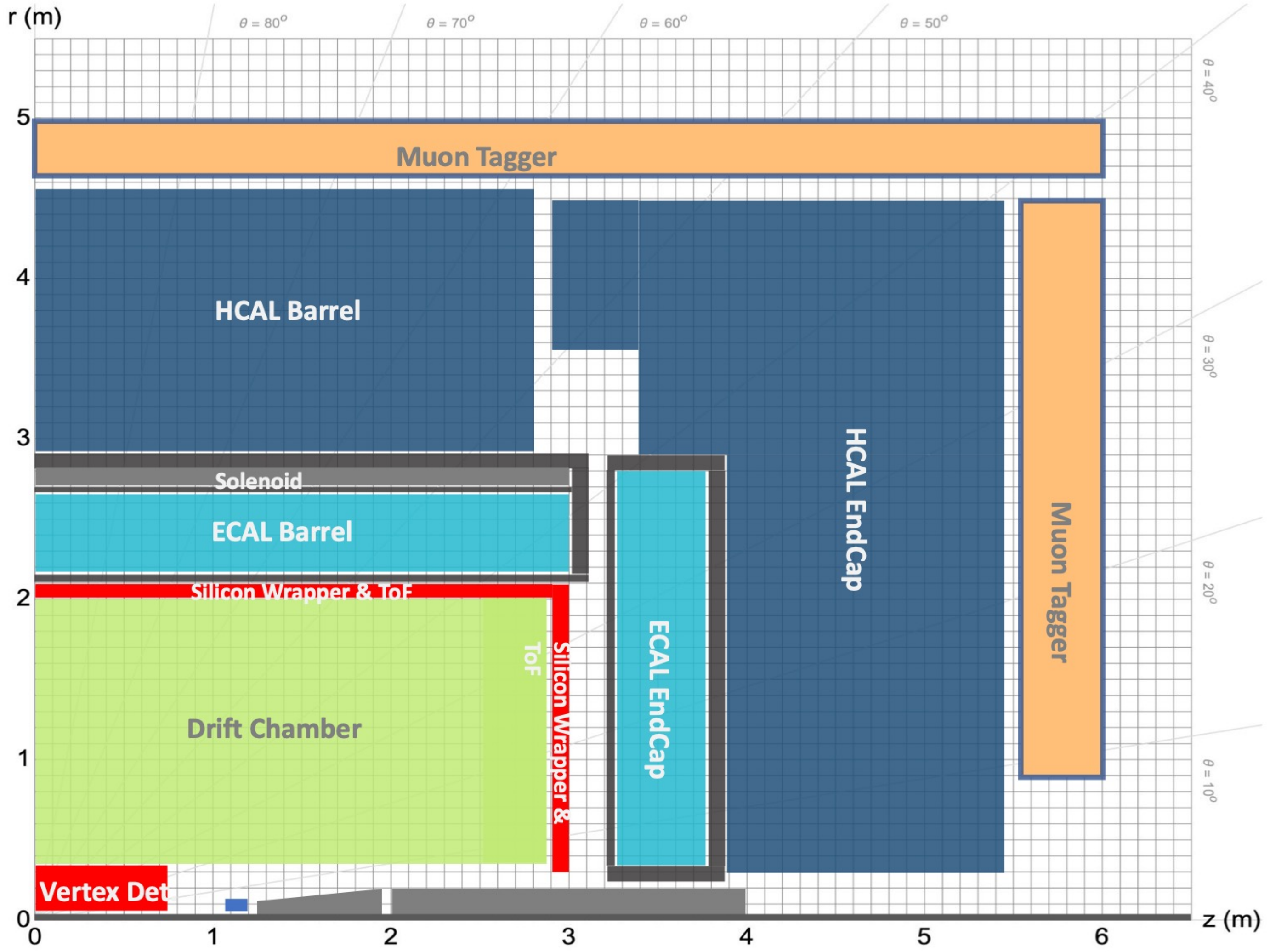
- Vertex Detector
- Drift Chamber (± 2.5 m active)
- Silicon Wrapper + ToF
- Solenoid B = 2T, sharing cryostat with ECAL
- High Granularity ECAL:

- Noble liquid + Pb or W
- Multi-layer PCB as read-out electrode

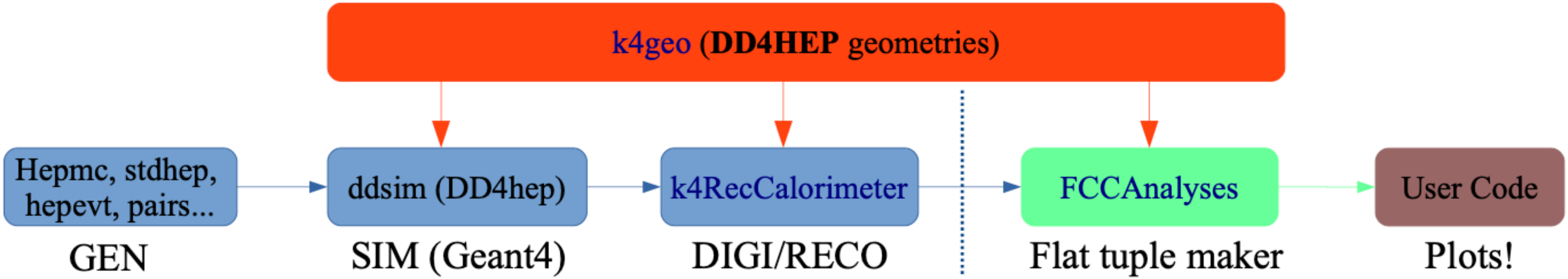
- High Granularity HCAL / Iron Yoke:

- Scintillator + Iron
- SiPMs directly on Scintillator or
- TileCal: WS fibres, SiPMs outside

- Muon Tagger



ALLEGRO software



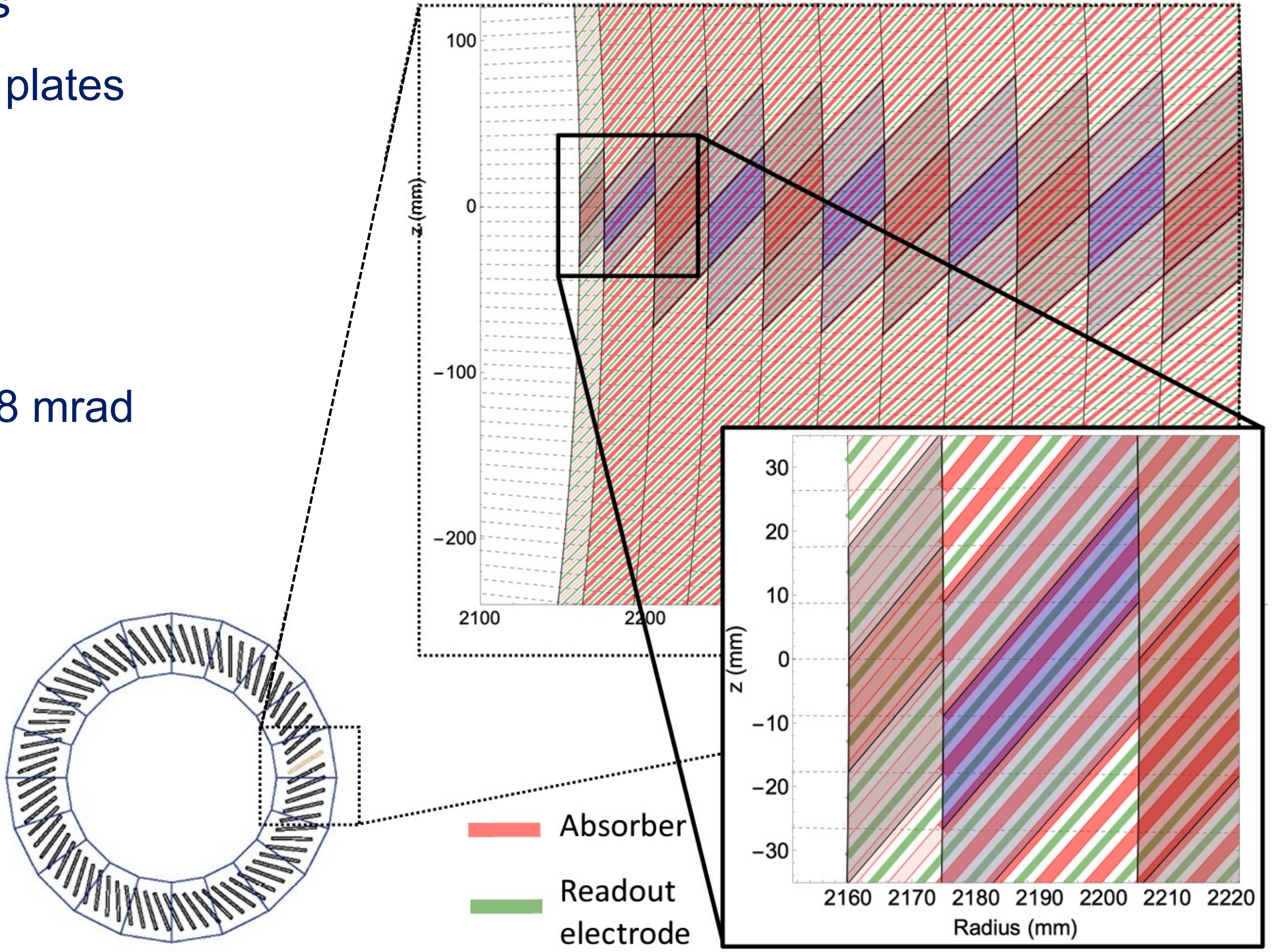
- Part of the ALLEGRO calorimeter software written for FCC-hh
  - Already using Gaudi for algorithms development, but based on the `fcc::edm` data format

- Decided to migrate from k4SimGeant4 to ddsim for the Geant4 interface
  - Align with other FCC sub-detectors choices and with future colliders in general
    - A must for plug-and-play
  - Profit from the maturity of ddsim

ALLEGRO ECAL barrel design

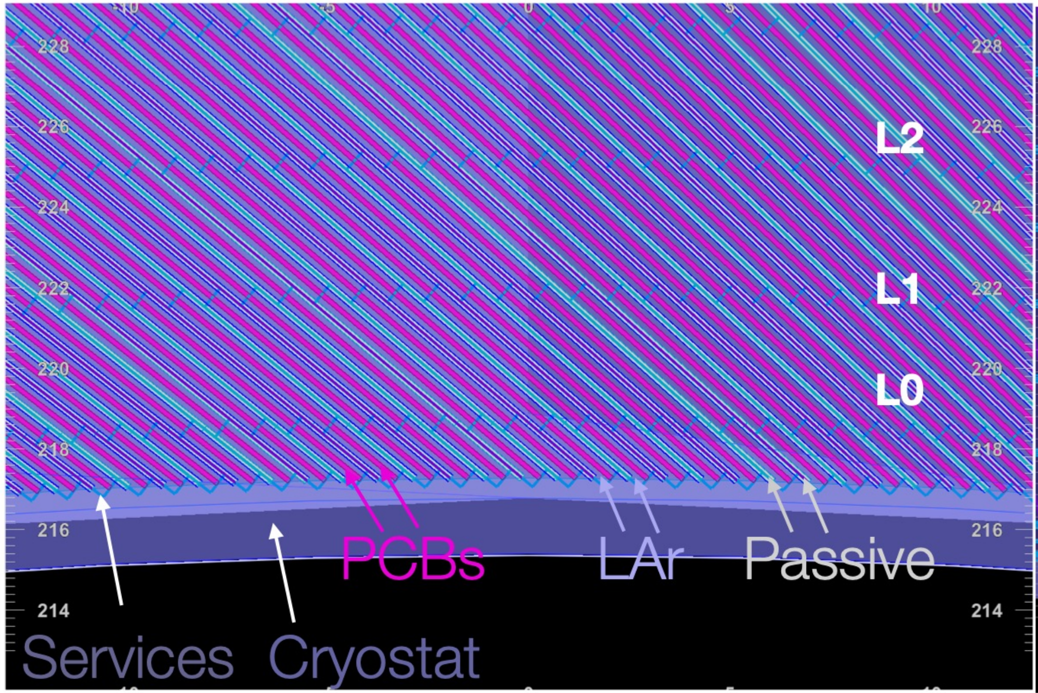
- Design driven by the solution used for electrodes
  - 1536 straight inclined (50°) 1.8 mm Pb absorber plates
  - Multi-layer PCBs as readout electrodes
  - 1.2 - 2.4 mm LAr gaps (LKr considered)
  - 40 cm deep (22 X_0)
  - $\Delta\theta$ = 10 (2.5) mrad for regular (strip) cells, $\Delta\phi$ = 8 mrad

- Copper electrodes
  - Number of layers and granularity of layers fully optimizable
  - Projective cells

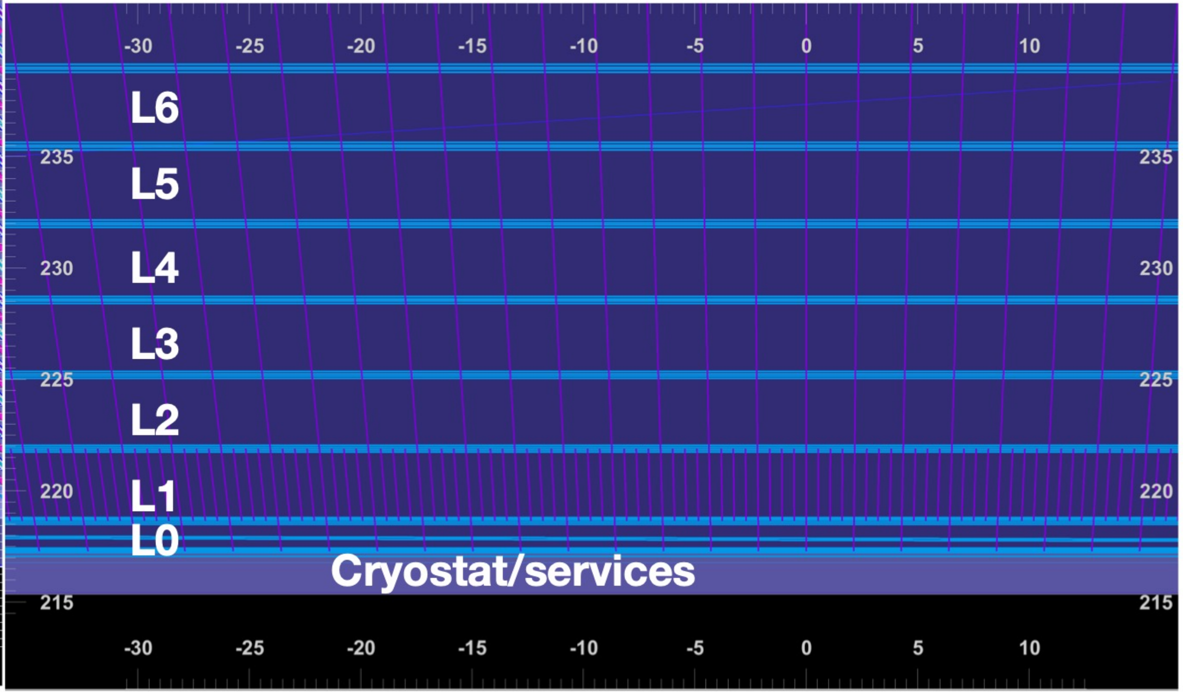


ECAL barrel simulation

- A nice event display tool developed
- Detector model now evolved to the third version: ALLEGRO V03
  - 11 layers in ECAL barrel
  - L1 as strip layer, 4 times finer granularity in theta

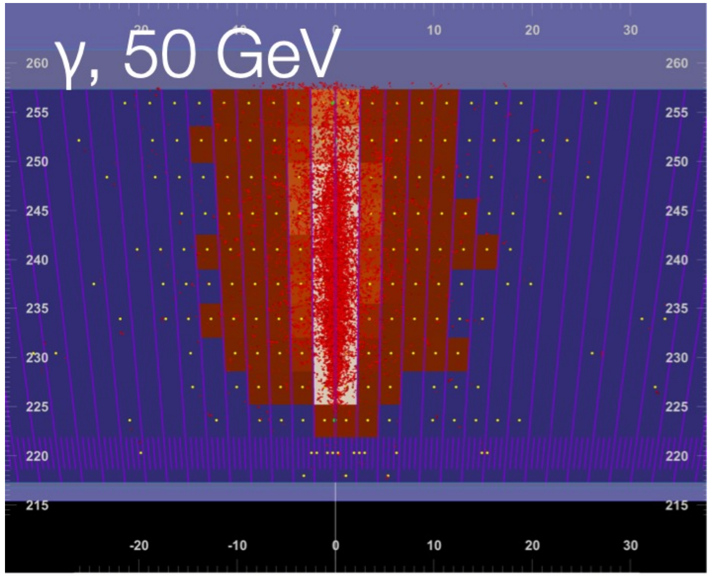


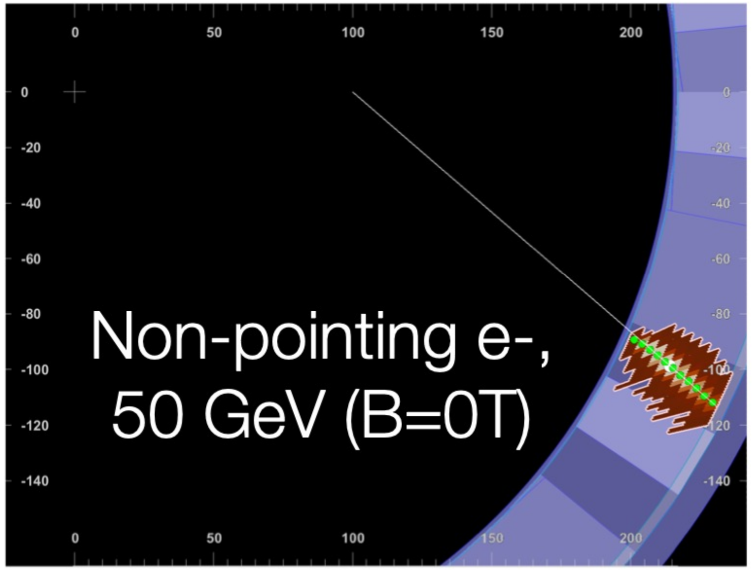
Geant4 geometry (r-ϕ)

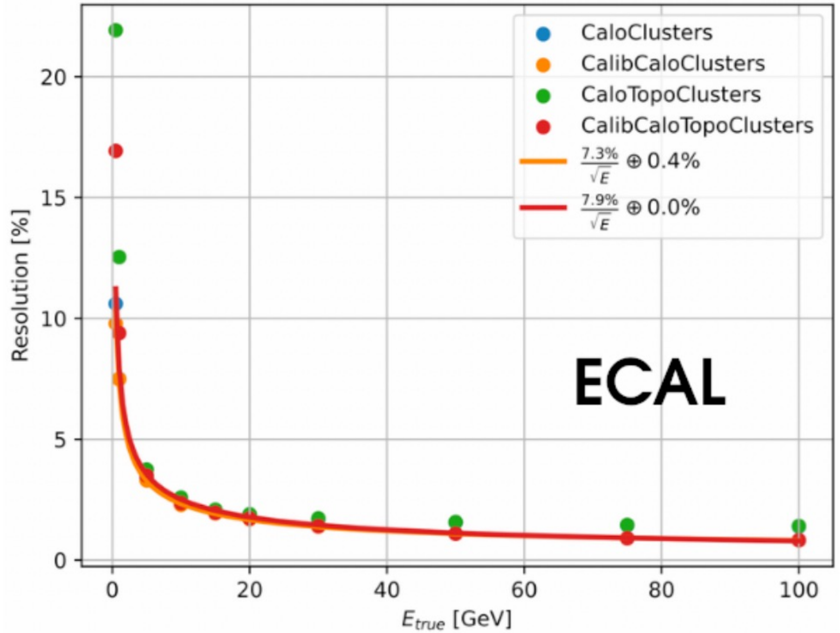


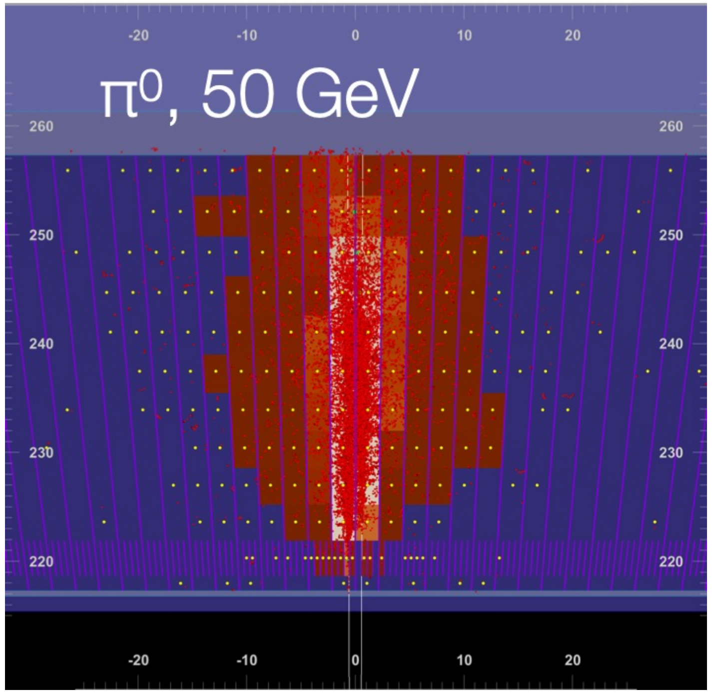
θ segmentation (r-z)

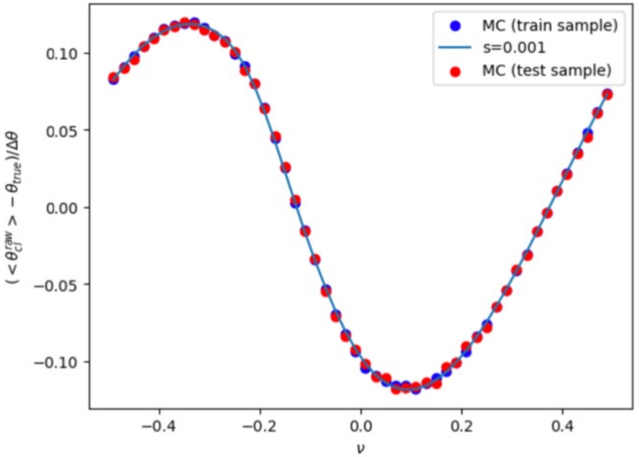
ECAL barrel simulation

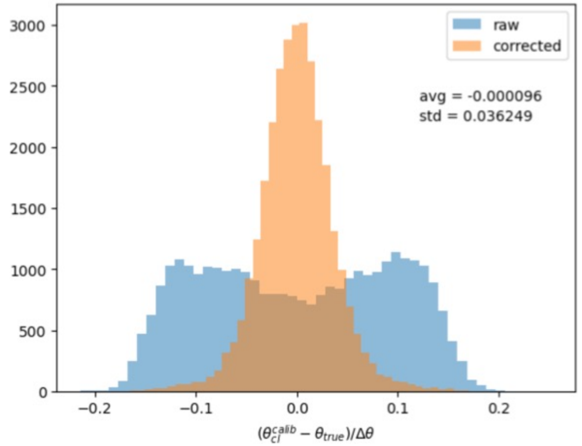








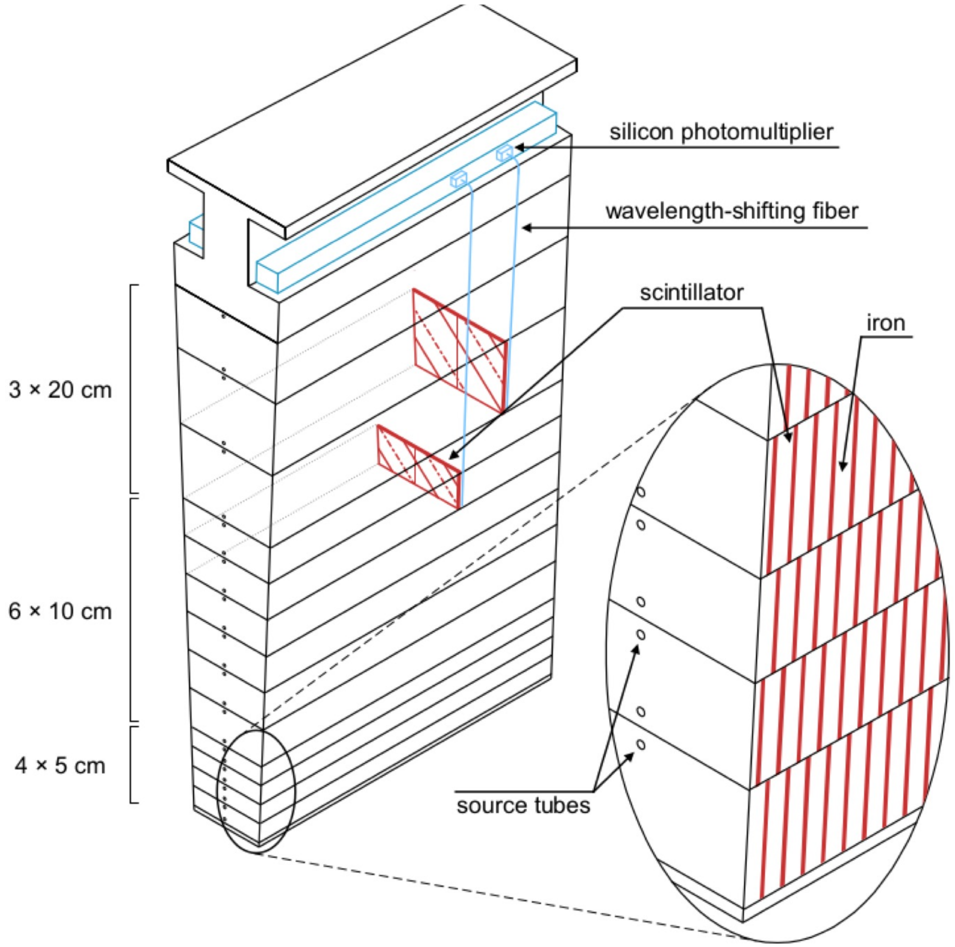




Position/direction reconstruction: S-curve
θ correction and resolution

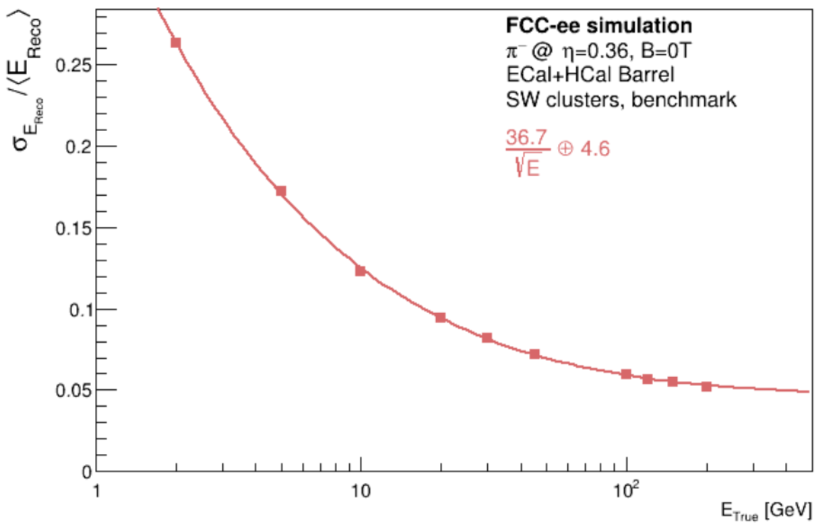
ALLEGRO HCAL design

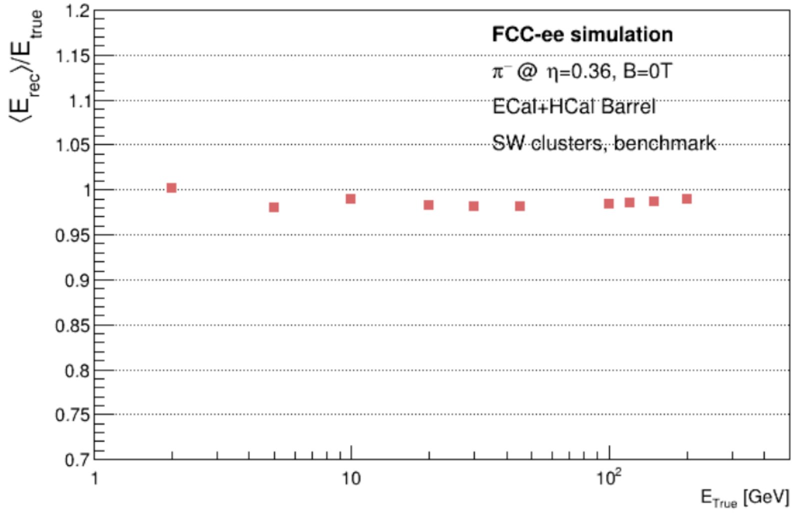
- HCAL design based on alternating steel and scintillator layers
- Well studied and tested design (similar to ATLAS TileCal)
- 5 mm steel absorber plates alternating with 3 mm scintillator plates
- 13 radial layers (4 x 5 cm, 6 x 10 cm, 3 x 20 cm)
- 128 modules in φ, 2 tiles per module → $\Delta\varphi = 0.025$
- $\Delta\theta \sim 0.022$ (grouping 3 - 4 tiles)
- Also acts as return yoke for solenoid

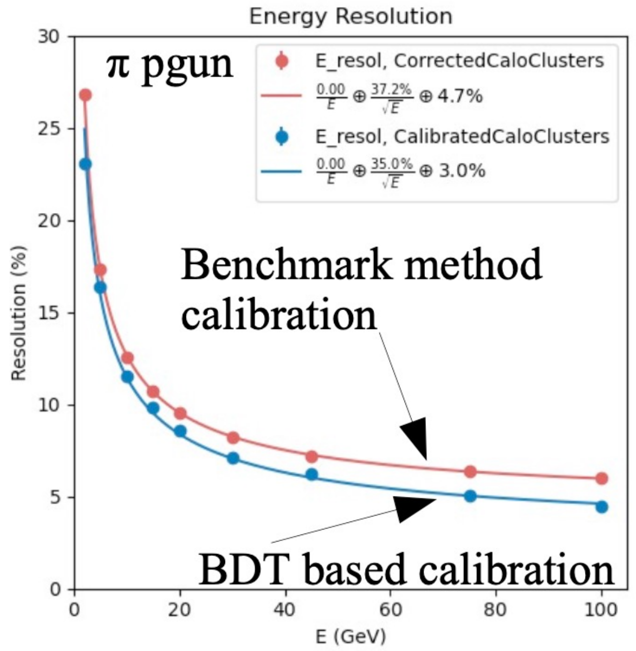


HCAL simulation

- HCAL barrel ready for physics as well
  - Detailed DD4hep geometry description, calibration, noise
- Implement together ECAL + HCAL for reconstruction
- Performance studies with the barrels (sliding window clusters)
  - Benchmark method calibration: linearity ~ 1%
  - BDT calibration improved the resolution

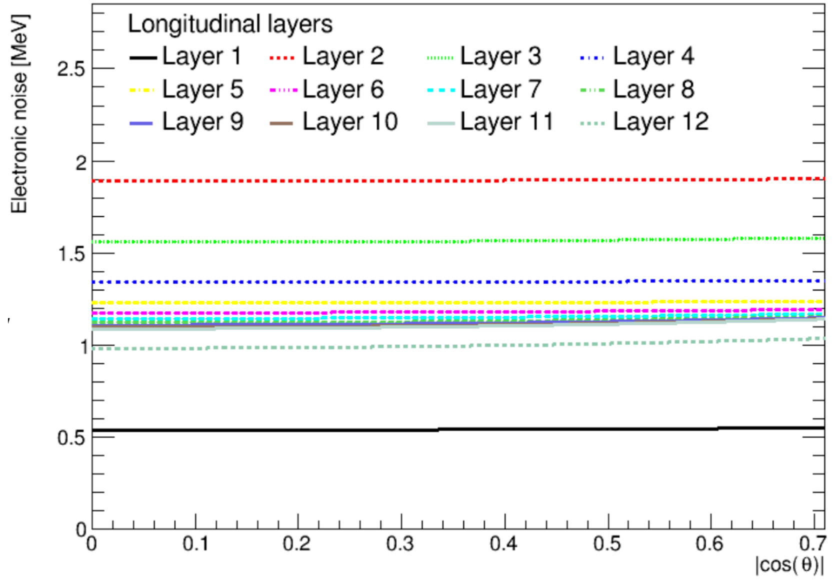


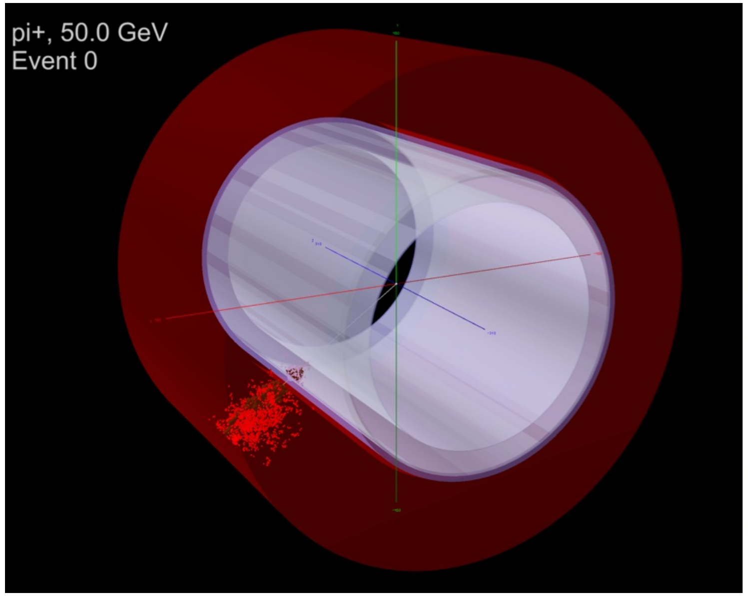


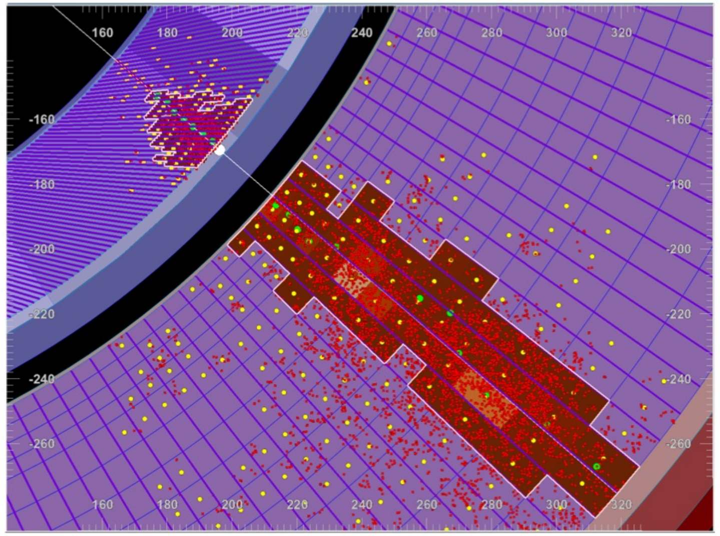


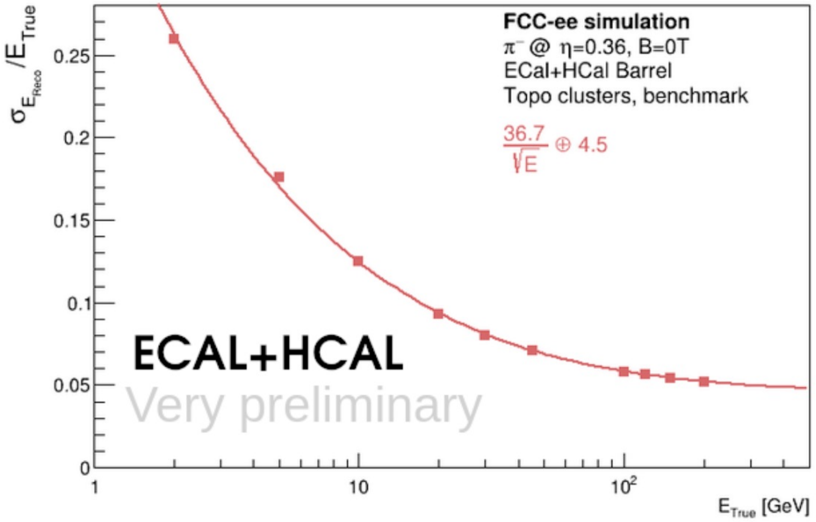
ECAL + HCAL combination

- Define neighboring relation between ECAL/HCAL
- Find seeds and iteratively collects cells in several steps of Signal/Noise thresholds (topo clustering)
- Require expected noise per cell
- Benchmark method calibration applied

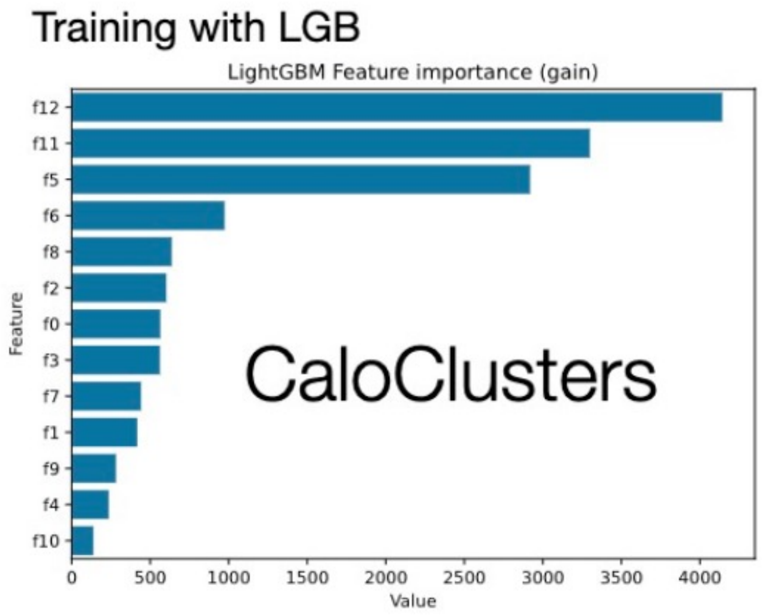


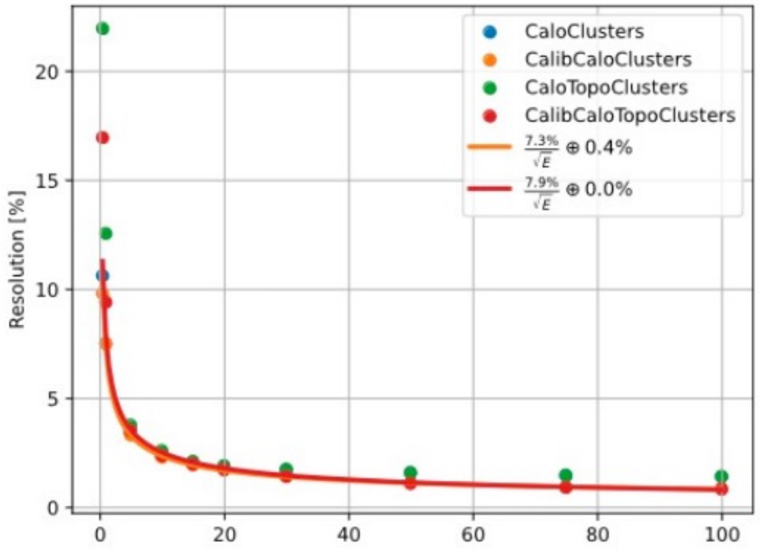






MVA based e/γ calibration






```
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    numLayers=[11],
    firstLayerIDs=[0],
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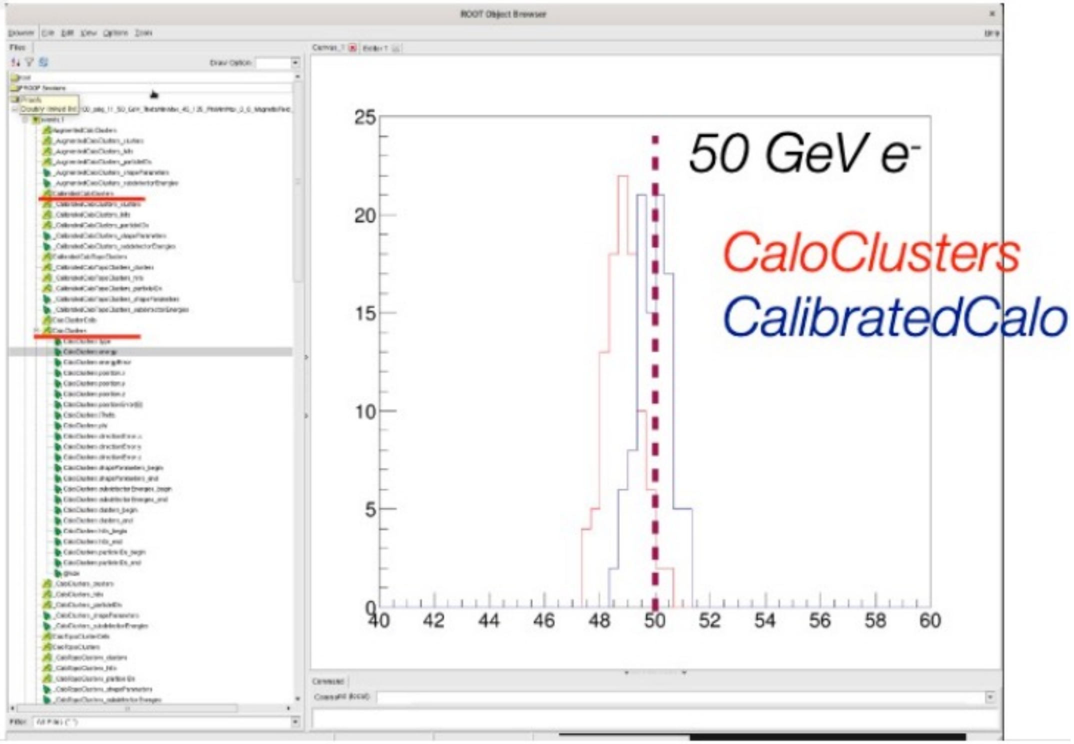
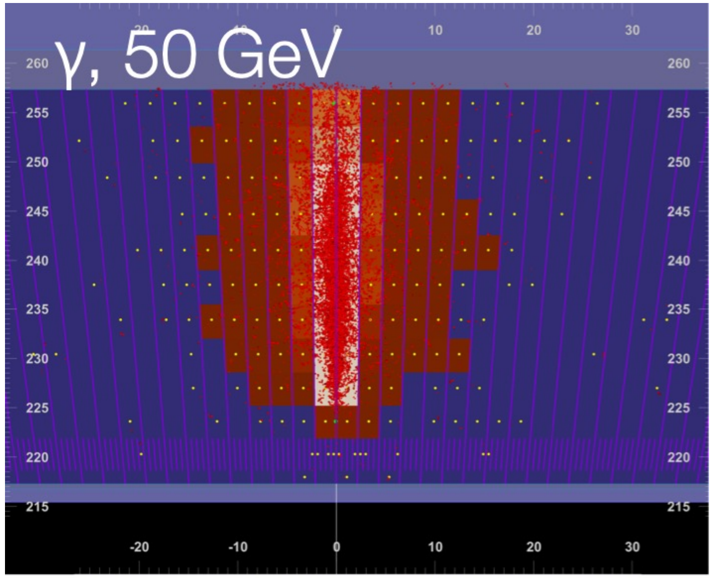
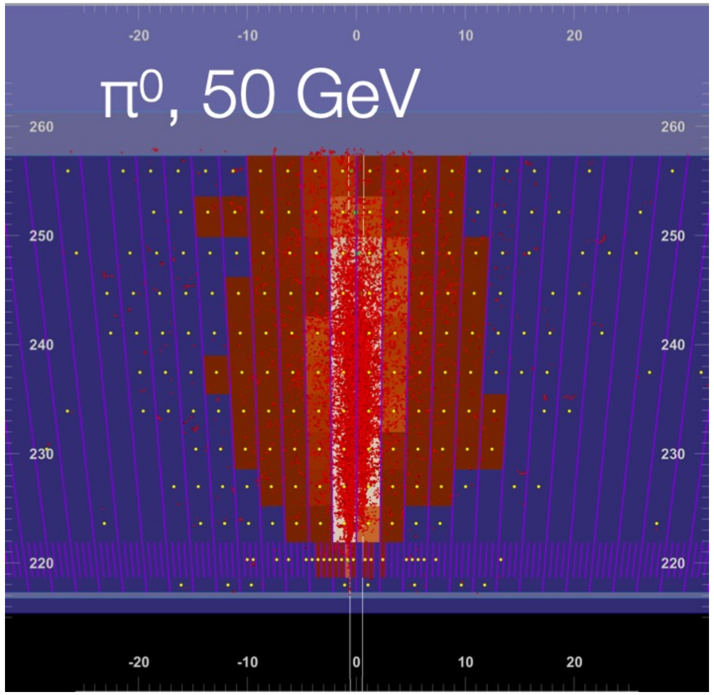
    OutputLevel=INFO
)
```



Photon identification

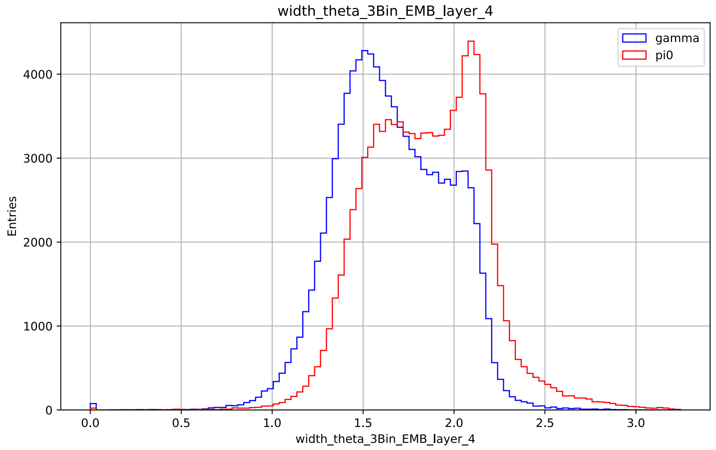
- Photon and pi0 behave similarly in detectors
- Photon:
  - Form concentrated, symmetric electromagnetic showers
  - Showers are elliptical with a regular transverse profile
- Pi0:
  - Decay into two photons, creating closely spaced or merged showers
  - Showers are complex with possible tails or multiple peaks.
- Series of shape parameters calculated for photon ID
  - as inputs of BDT / NN

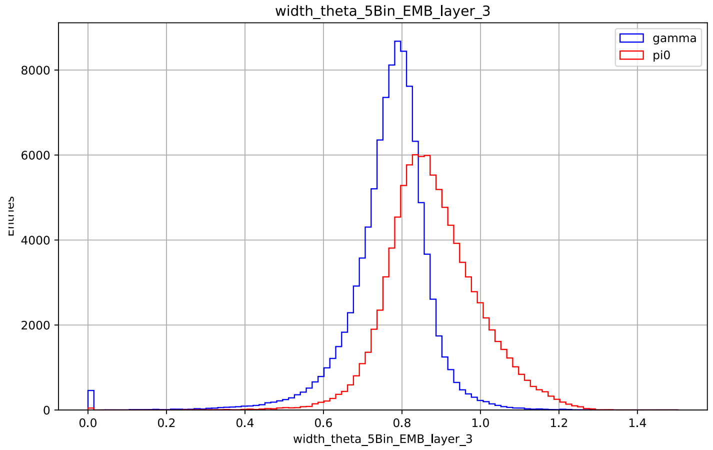


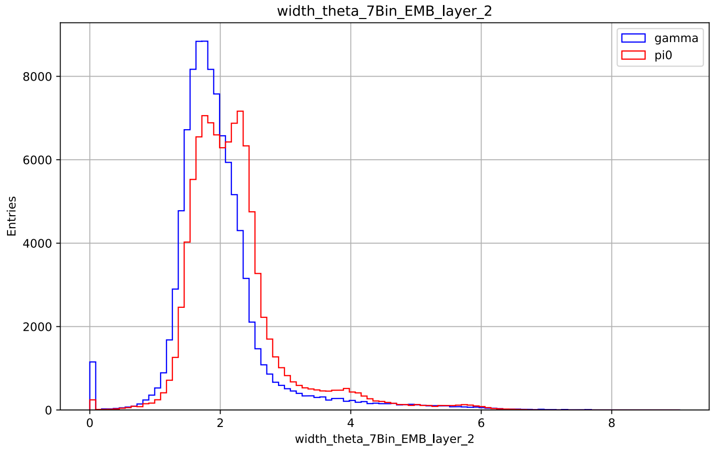


Photon/pi0 shape parameters

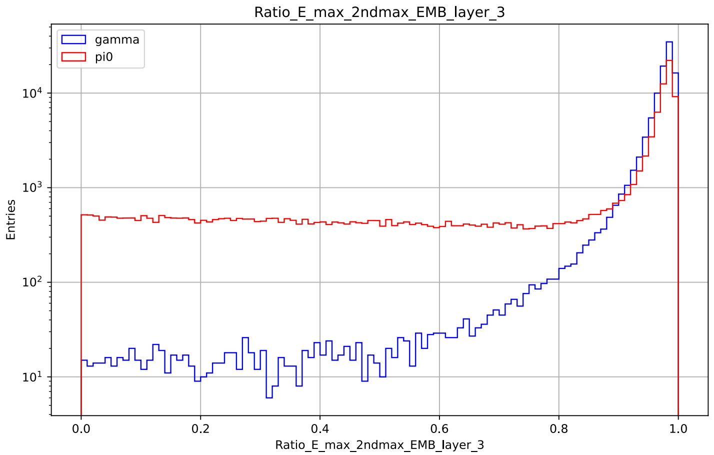
- Width in theta calculated from 3, 5, 7 cells in L4, L3, L2

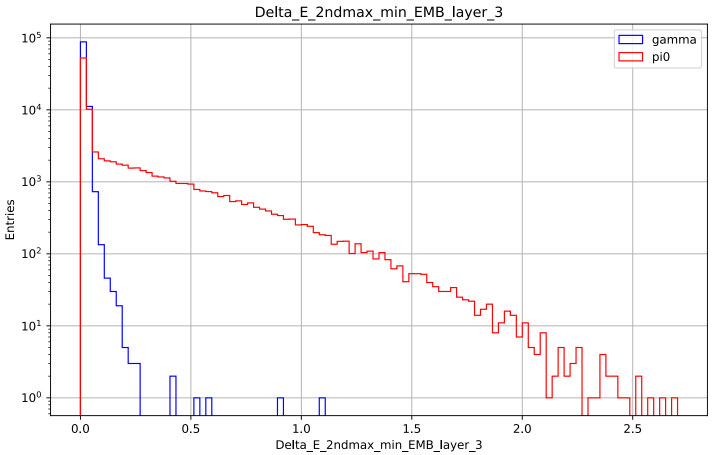






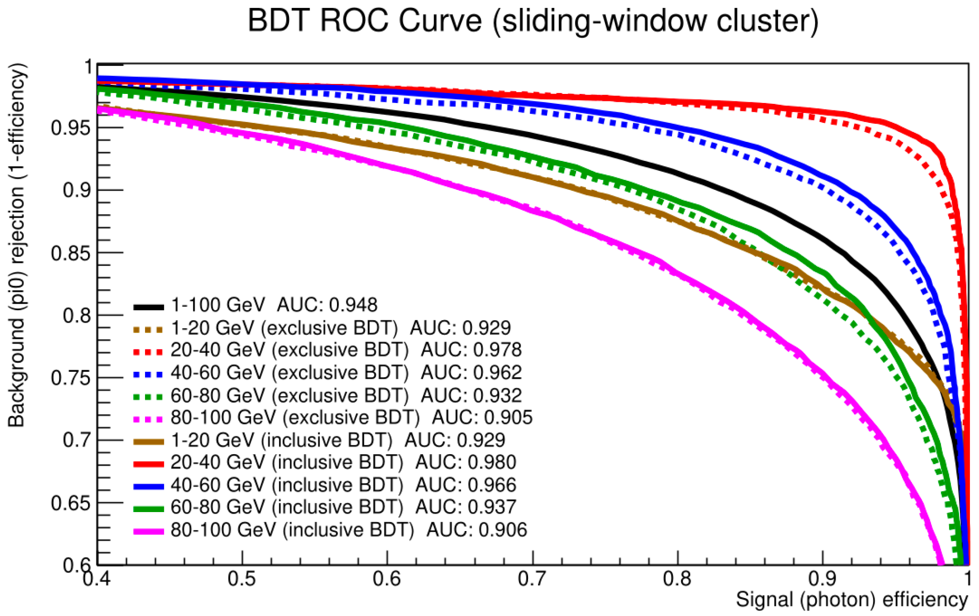
- Ratio_E and Delta_E vs. theta in L3

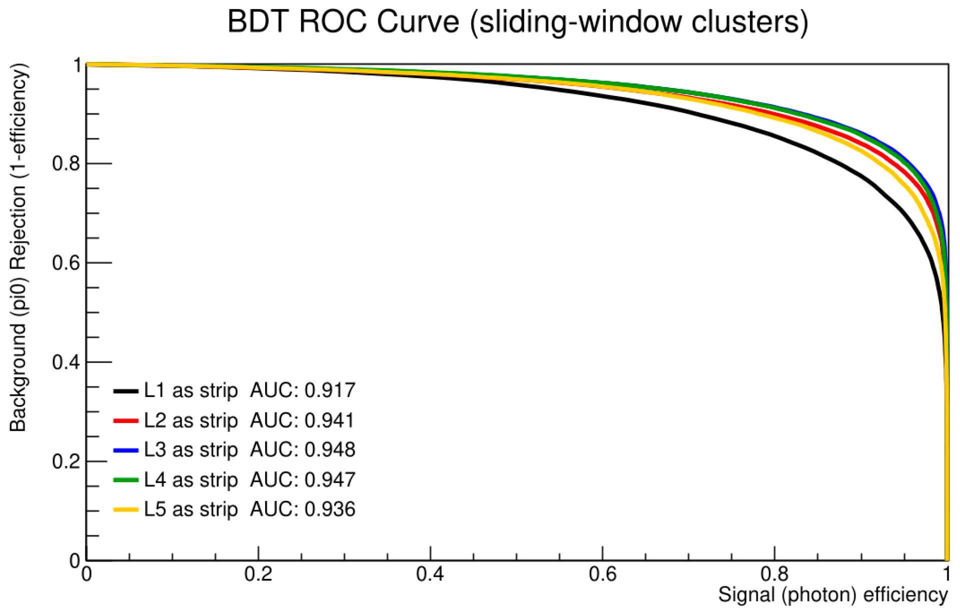




Photon/pi0 separation

- Train inclusive BDT (1-100 GeV) and exclusive BDTs in 5 E_cluster intervals
- Inclusive BDT as good as exclusive BDTs
- Test custom detector versions
  - Shift strip layer to L2, L3, L4, L5
  - 100k events for photon / pi0 each
- From the ROC curve:
  - L3 has the best performance (AUC 0.948)
    - L4 is very close (AUC 0.947)

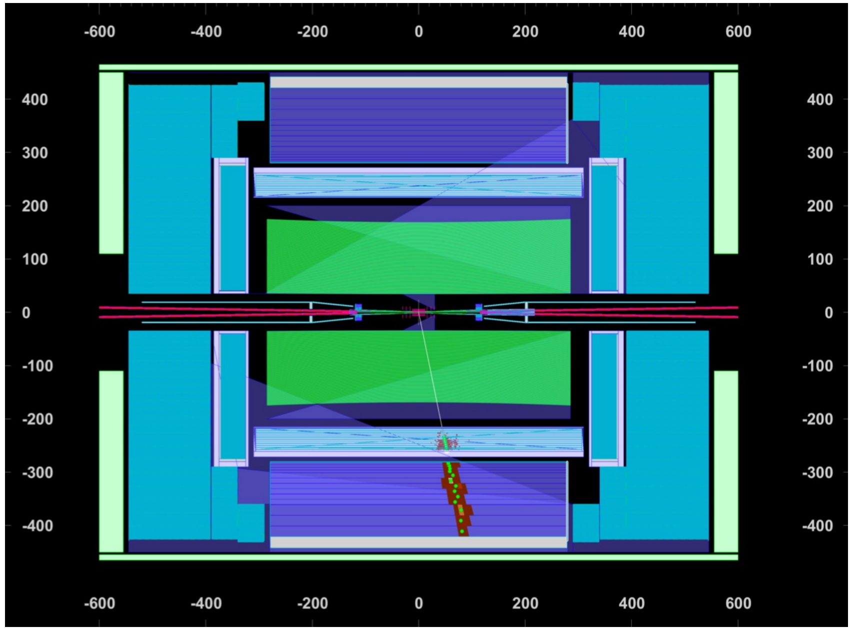




Summary & Outlook

- A first complete geometry implementation of the ALLEGRO benchmark is available
  - Some detectors still place holders (muon system, endcaps)

- Calorimeters digitization and reconstruction well advanced, enables optimization studies
  - New detector segmentation
  - (Topo and sliding-window) clustering
  - Energy calibration
  - Photon ID
  - …



- Outlook
  - To complete ALLEGRO geometry and reconstruction
    - Enables optimization of the whole detector benchmark based on physics analyses

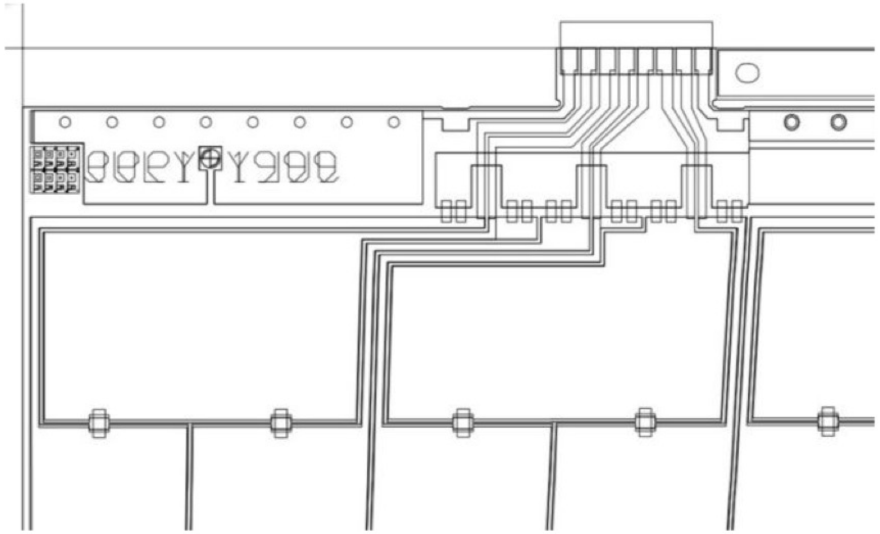
Back Up

Granularity of Noble Liquid Calorimeters

- Calorimeter design:
- Granularity of the calorimeter ⇔ granularity of the electrodes

- ATLAS: copper / kapton electrode
- Traces to read out middle cells take real estate on back layer
- Cannot really increase granularity

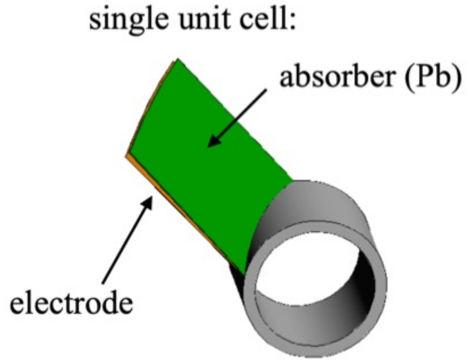
- FCC-ee requirements
- High jet energy resolution needed
- Particle flow algorithms take advantage of much finer granularity

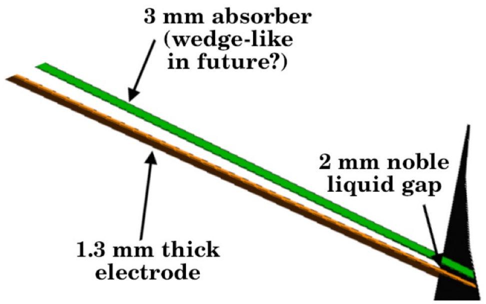


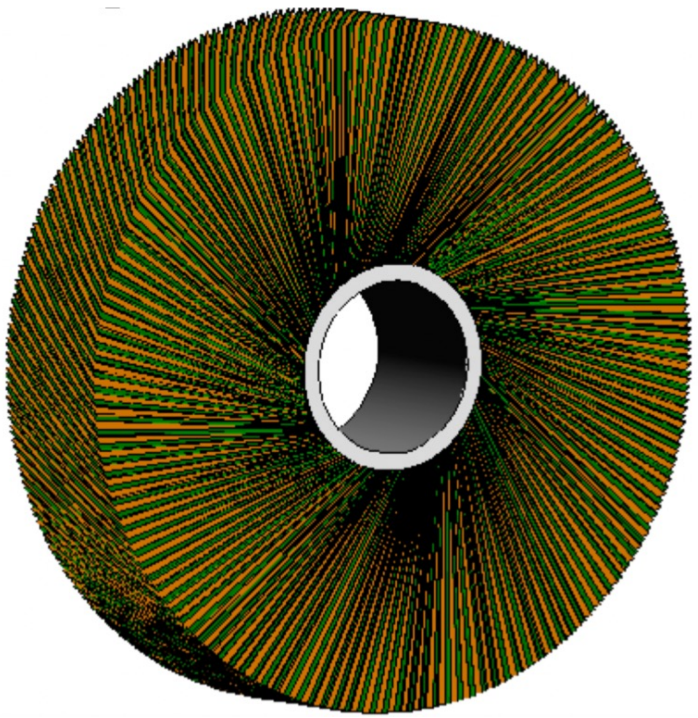
✓ Solution for Noble Liquid calo for FCC
  - Multi-layer PCB to route signals inside

ALLEGRO ECAL endcap design

- Endcap design more complex than barrel
- A few preliminary ideas on the table. Showing here the one being implemented in the simulation at the moment ("Turbine design")
- Similar to barrel design, with many thin absorber plates
- Symmetric in ϕ
- Readout from high-|z| face
- Issue: increase in the size of the LAr gaps
  - Mitigated stacking several cylinders







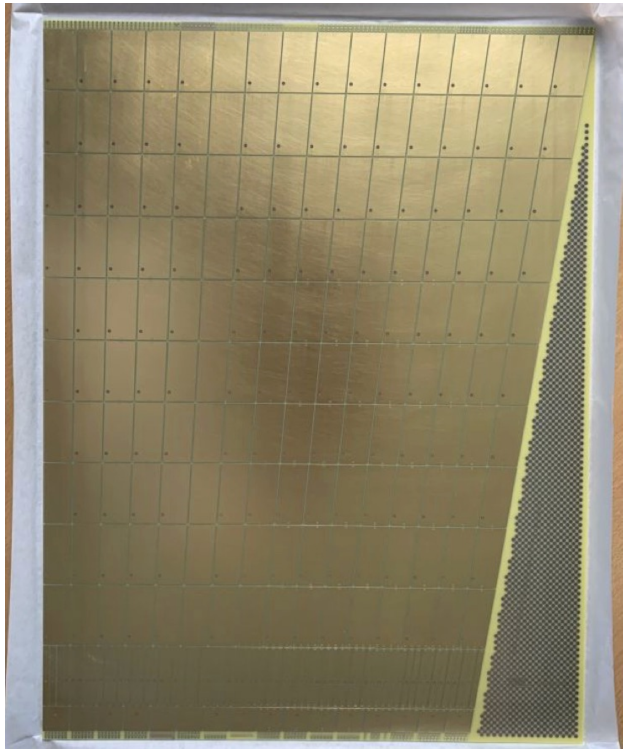
Electrodes prototypes

➢ Explore tradeoffs between max granularity / capacitance (noise) / cross-talk

- First large-scale prototype at CERN *
- Explore many options for grounding, for shields
- First-layer readout at the front
- Few per-mille cross-talk achievable with long shaping

- Next prototype at IJCLab **
- All layers readout at the back
  - Best for material budget, worse for noise and cross-talk
- Use of connectors for easier measurements
- Development of system for automated measurements

*



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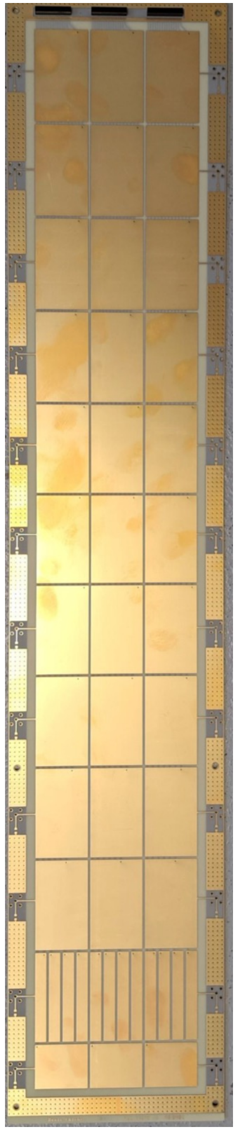

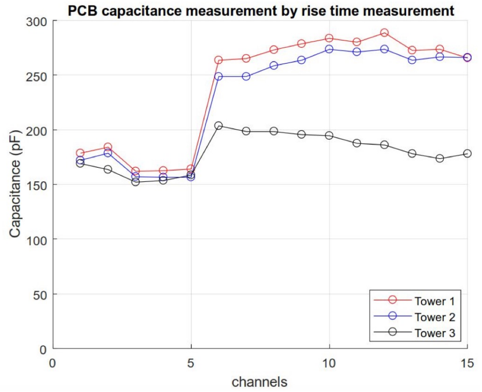

Shape parameters (1/2)

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*Baskets :       30 : Basket Size=     120320 bytes  Compression=  50.20     *
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*         | UInt_t collectionID[_AugmentedCaloClusters_clusters_]            *
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*............................................................................*
```

- Cluster level:
  - Energy
  - Mass
  - Number of cells
- Calculated in each layer:
  - Maximum energy of cell
  - Energy fraction: E(i) / E
    - E(i) is energy in layer i, E is cluster energy
  - Width in theta: sqrt(sum(theta_i^2*E(i))/sum(E(i))-(sum(theta_i E_i)/sum(E_i))^2)
    - theta_i is theta ID of cell
  - Width in phi (module): sqrt(sum(module_i^2*E(i))/sum(E(i))-(sum(module_i E_i)/sum(E_i))^2)
    - module_i is module ID of cell

Shape parameters (2/2)

➢ Calculated in each layer, expected to have good separation especially in the strip:

- Ratio_E vs. theta: (E_max - E_2ndmax) / (E_max + E_2ndmax)   [will be 1 if no E_2ndmax found]
- Delta_E vs. theta: E_2ndmax - E_min
  - E_max and E_2ndmax found in 1-D theta spectrum
  - E_min found in the theta range of E_max and E_2ndmax
- Ratio_E vs. phi and Delta_E vs. phi, similarly as in theta:
  - E_max and E_2ndmax found in 1-D module spectrum
- Width in theta, taking account only N cells around the cell with E_max
  - N = 3, 5, 7, 9
- E fraction side: E(within up to +- N cells around E_max) / E(within up to +-1 cells around E_max) - 1.0
  - N = 2, 3, 4
  - Performed with 1-D theta spectrum