Design and performance of the calorimeter system for the ALLEGRO FCC-ee detector concept

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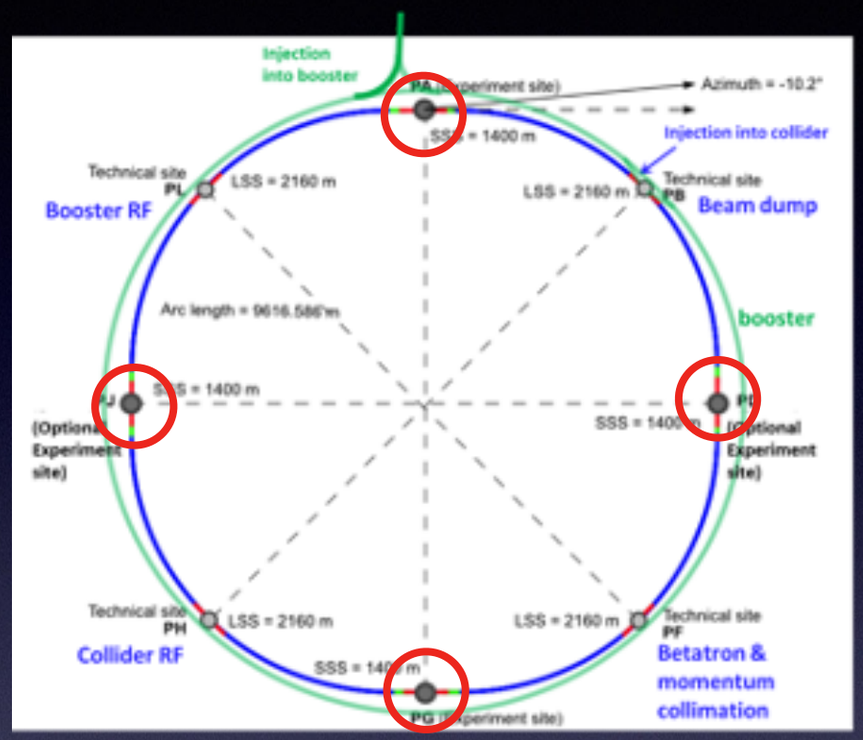
ALLEGRO and the FCC-ee

- FCCee design allows for four interaction regions



- Ideally populated with complementary detectors
  - subject to different systematic effects
- Defining feature of ALLEGRO is noble-liquid EM calorimetry

- Noble liquid calorimetry has several features that match well with the demands of the FCCee program
  - e.g. linearity and stability → potential for small systematics
- Successfully used in several HEP experiments (SLD, MarkII, DØ , H1, NA48/62, ATLAS)

ALLEGRO and the FCC-ee

- Quarter view of ALLEGRO concept
  - to be understood as a platform for testing ideas; all details subject to change

2 T solenoid shares cryostat with barrel ECal

±2.5 m active region in *z* similar to IDEA detector concept

MAPS/DMAPS similar to ALICE3?

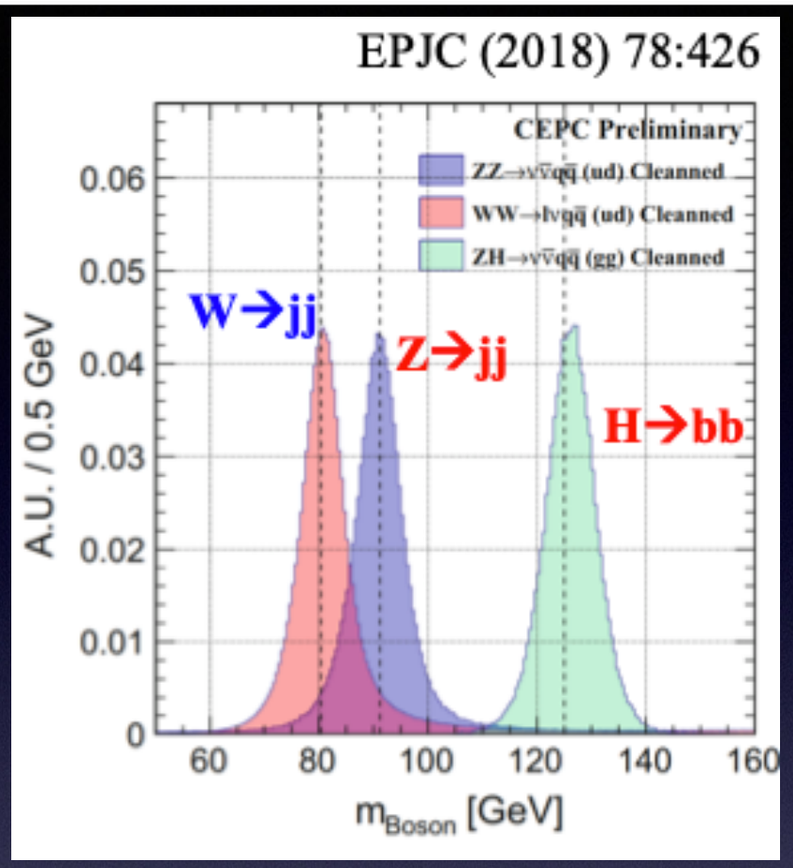
Drift chambers, RPCs, and/or micromegas

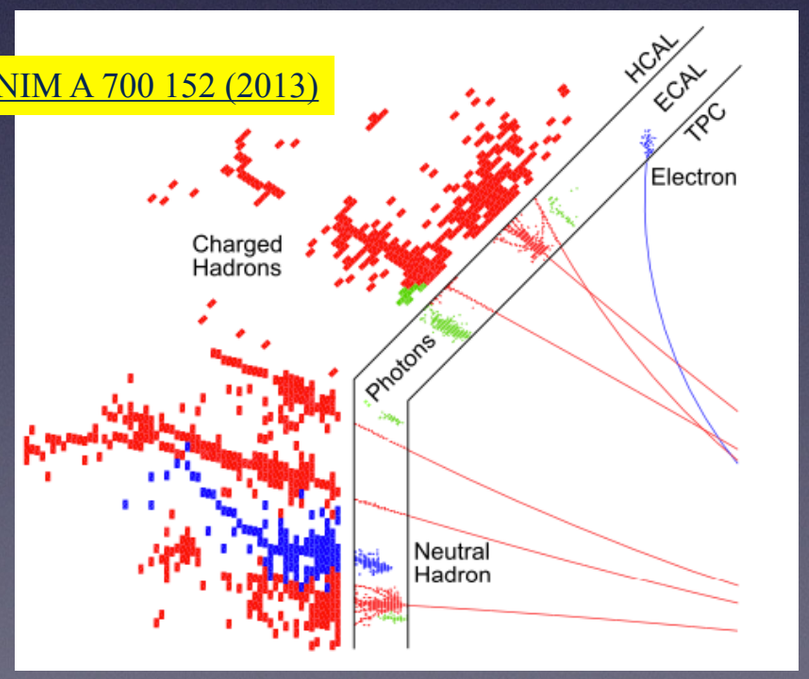
Studies organized by ECFA Calorimetry Detector R&D collaboration (DRD6)

Remainder of the talk will focus on the calorimeters

Calorimeter Requirements

- Precision physics program at FCC-ee places stringent demands on calormeters:
  - Separation of $W/Z \rightarrow jj$ (e.g. in Higgs decay)
    - requires $\frac{\sigma}{E} \sim \frac{30\,\%}{\sqrt{E}}$ for jets
  - Achieved through a combination of hadronic calorimetry and "particle flow" reconstruction

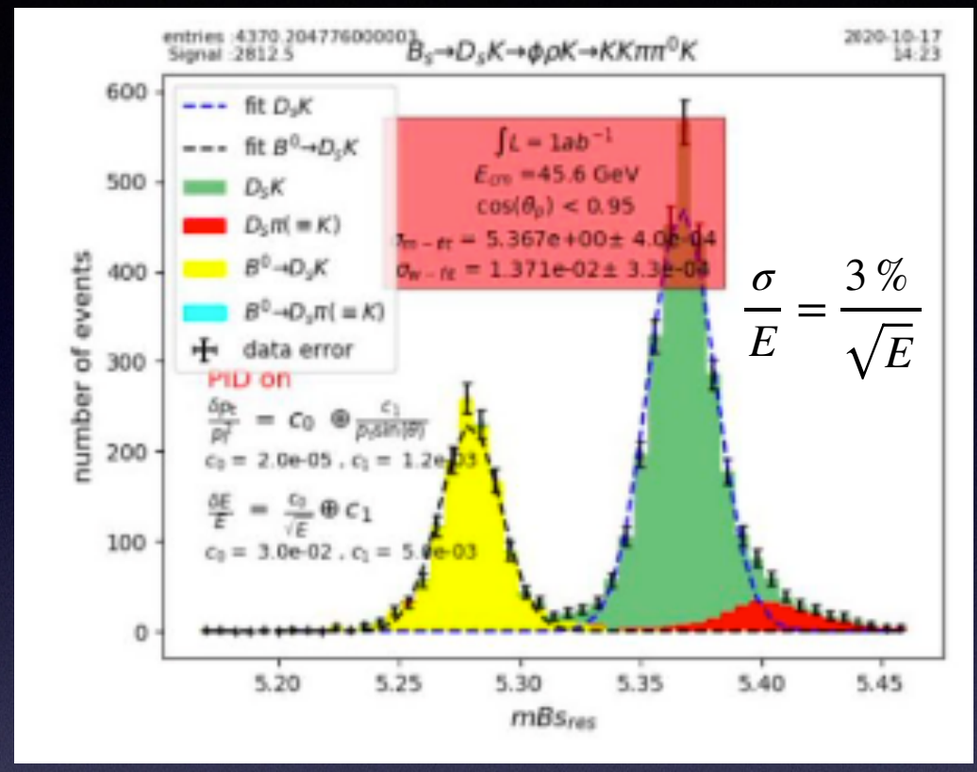




250 GeV jet (CLIC_ILD)

Calorimeter Requirements

- EM calorimeter requirements are driven by Higgs and flavor physics programs
  - Higgs:
    - ✦ recover brem γs from recoil to improve mass resolution
  - Flavor:
    - ✦ distinguish e/single $\gamma/\pi^0 \rightarrow \gamma\gamma$
    - ✦ separate B^0 and B_S decays to same final state



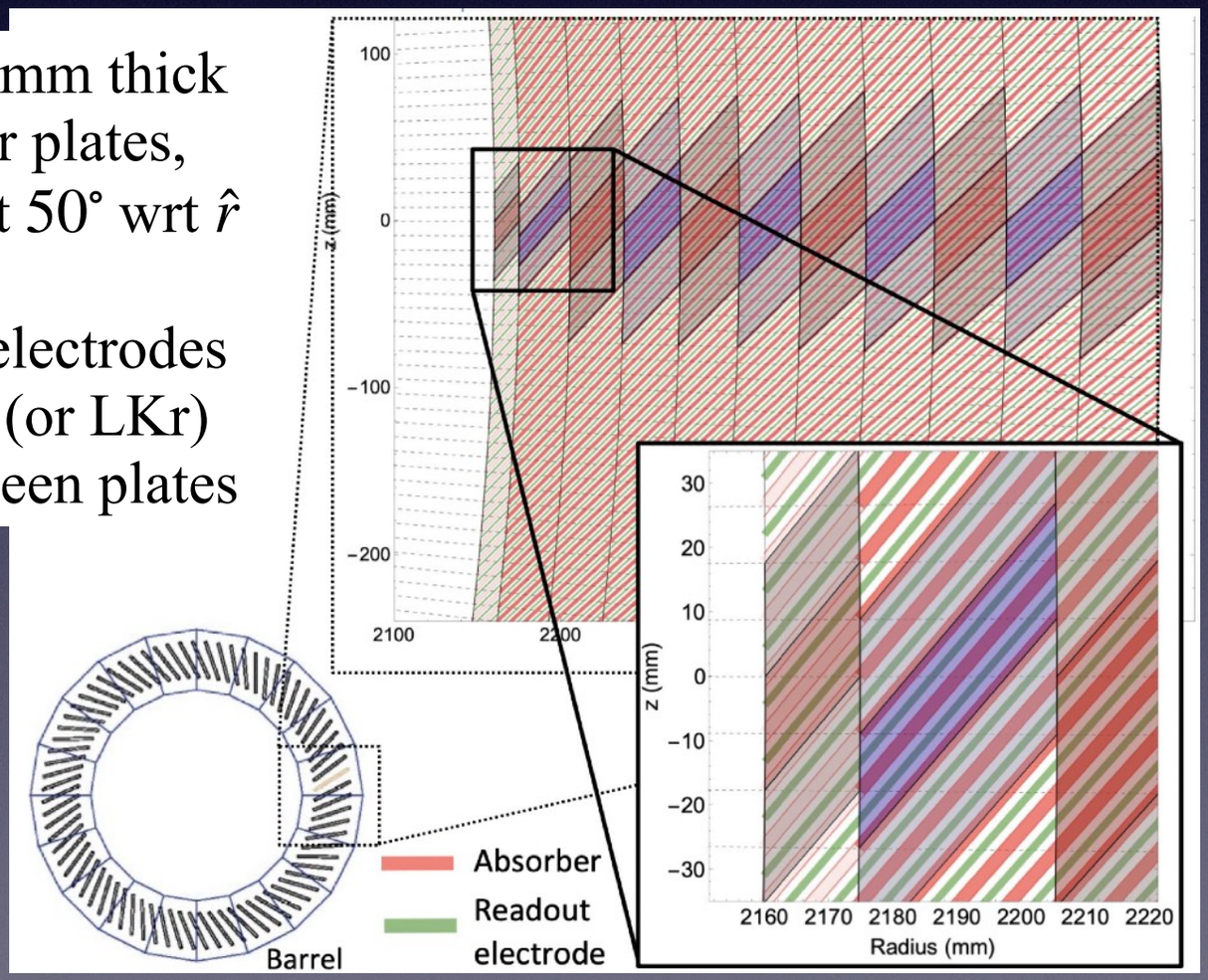
Both HCal and ECal must have high granularity and excellent resolution

Calorimeter Design (EM barrel)

- Resolution requirements demand frequent shower sampling
  - many thin absorbers
  - uniformity in ϕ, possibility to read out from high-r side, use of many copies of a few components lead to an "inclined planes" design

1536 1.8-mm thick absorber plates, inclined at 50° wrt $\hat{r}$

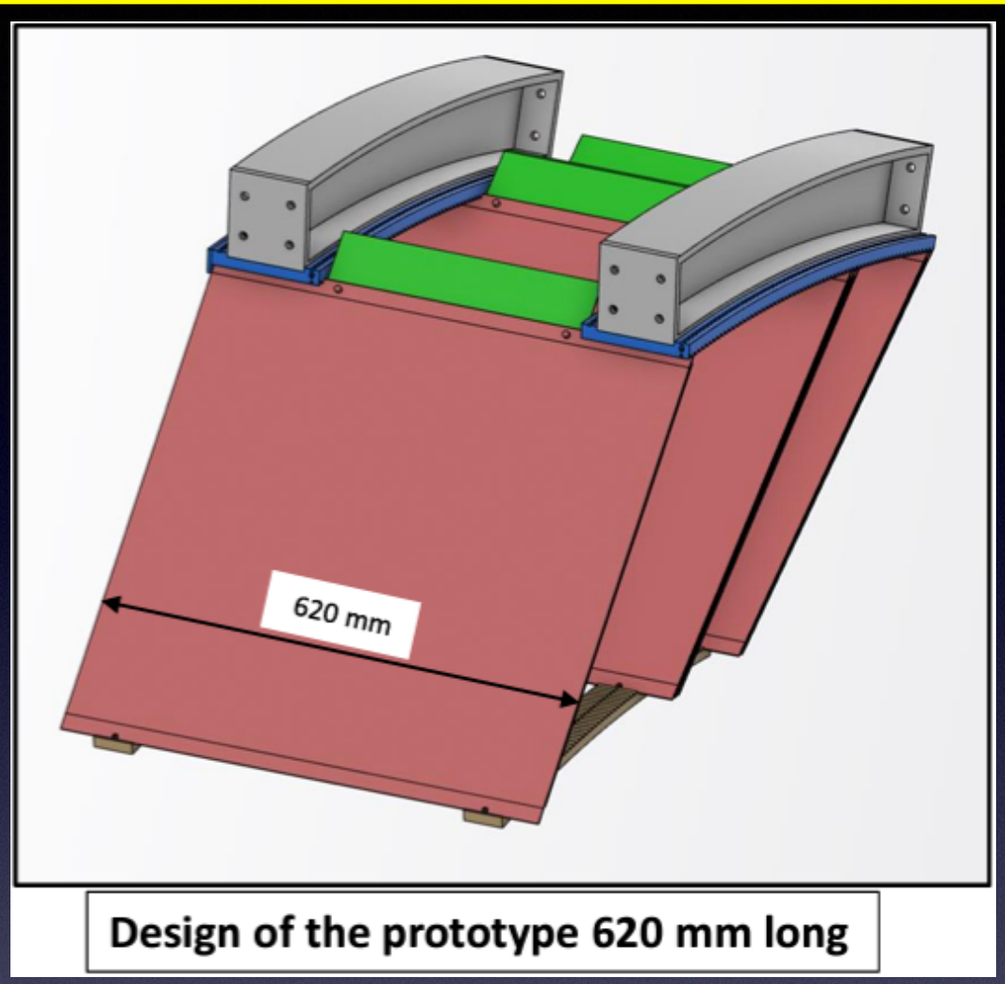
Readout electrodes and LAr (or LKr) gaps between plates



Electrodes are multi-layer PCBs with internal signal routing

Granularity in the dimensions along the absorber is determined by segmentation of readout electrode

Calorimeter Design (EM barrel)

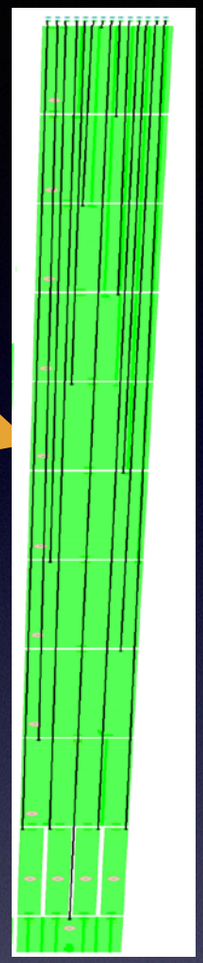


Design of the prototype 620 mm long

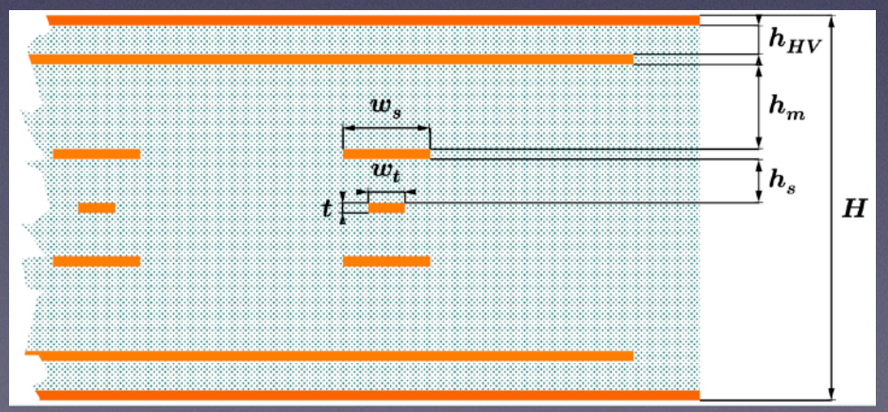
Potential mechanical design

Prototype absorbers and electrodes are currently being tested — see Zhibo Wu's talk for details!

Electrode readout scheme…



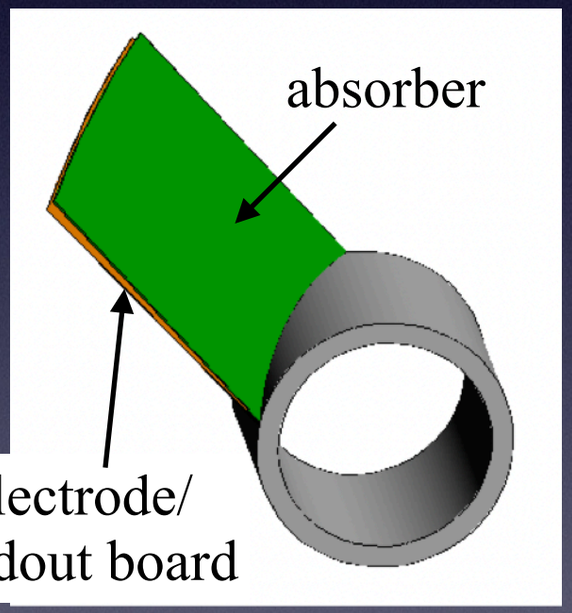
…and internal structure



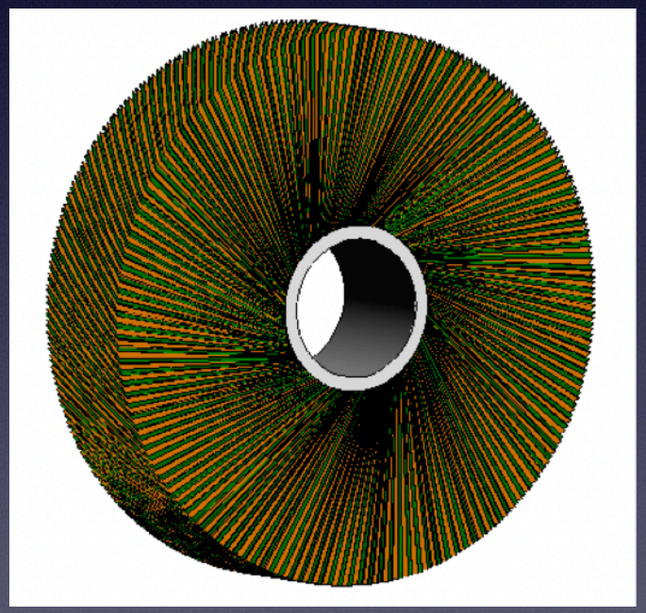
Calorimeter Design (EM endcap)

- One concept is for a ~direct translation of the EM barrel design to the endcap
  - the inclined planes become "blades" in a turbine-like structure:

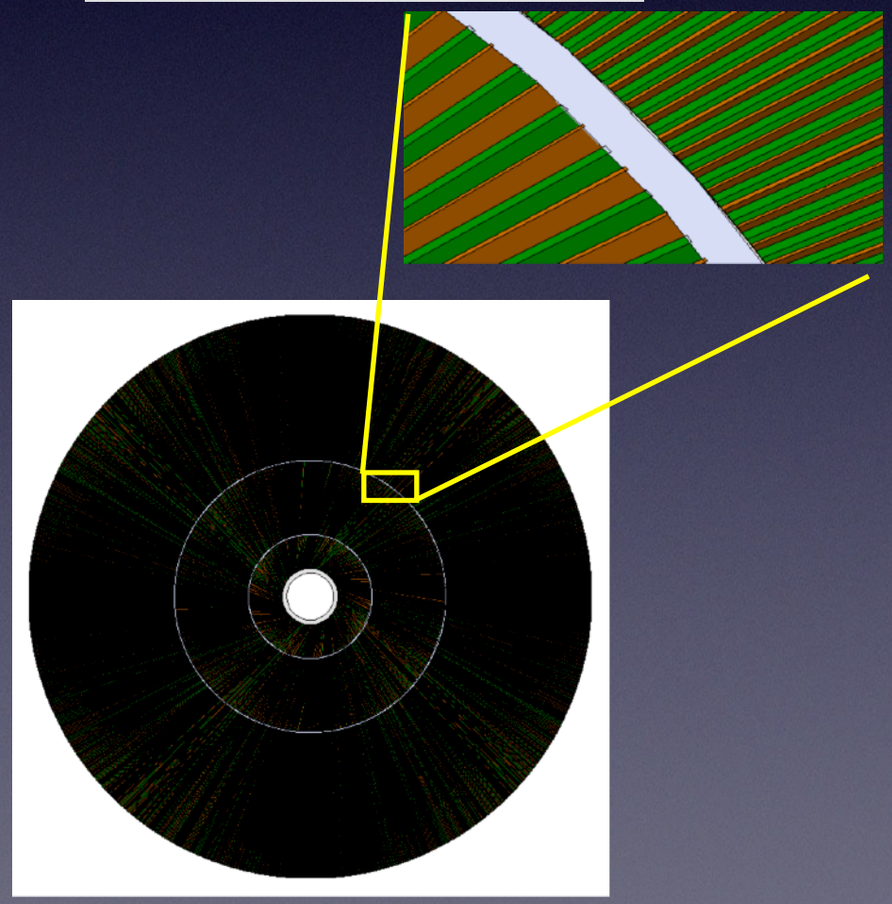
Single unit cell



Full set of blades around inner radius



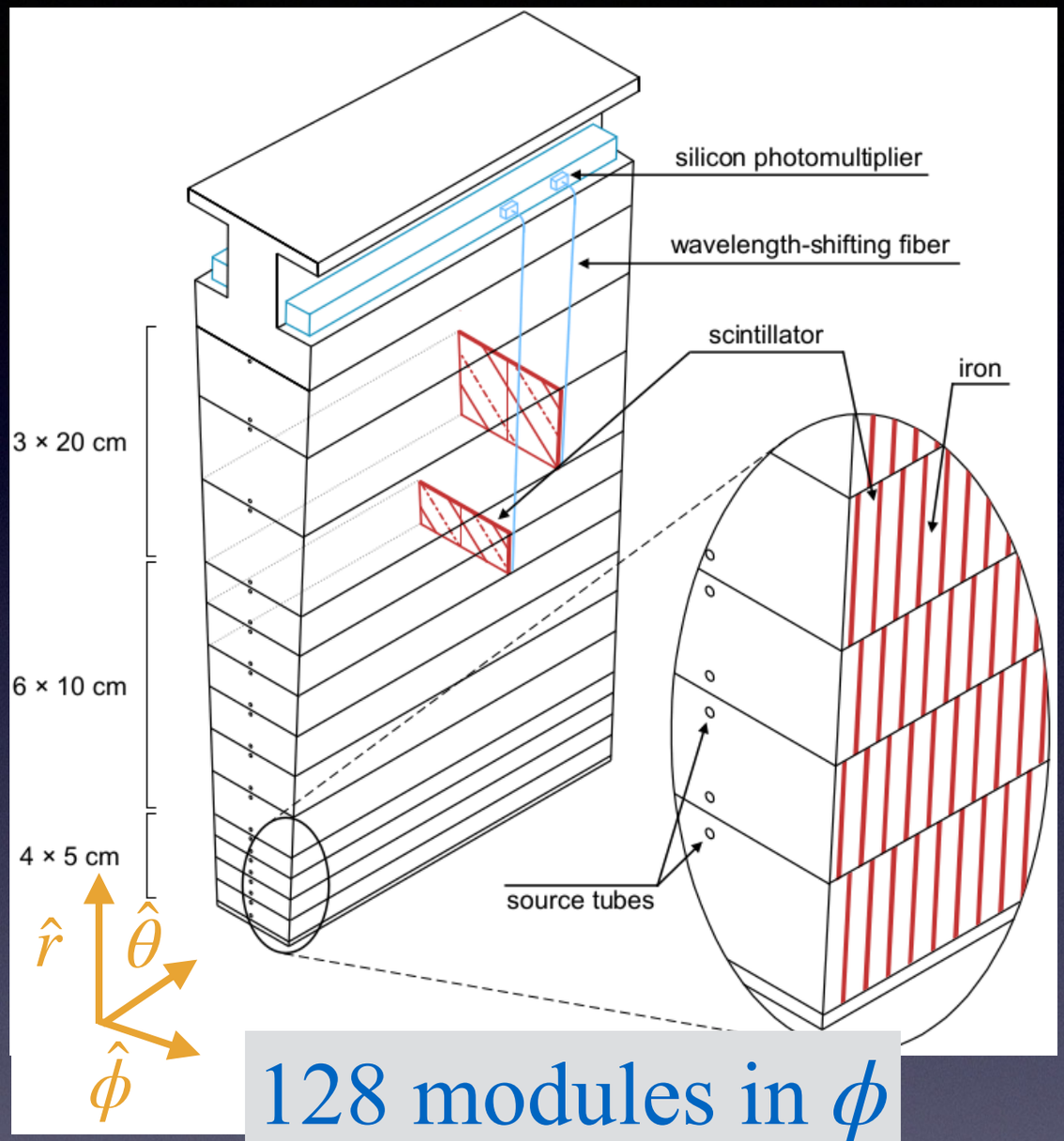
Complete endcap with nested wheels



Tapering the absorbers to be thicker with increasing *r* may be necessary

Calorimeter Design (HCal Barrel)

- To keep the detector compact, an iron/scintillator design is used for the HCAL
  - current implementation simulation is similar to the ATLAS TileCal
- Granularity in r/ϕ determined by size of scintillating tiles
  - 3-4 tiles ganged in θ
  - detailed PFlow studies planned to determine optimal granularity

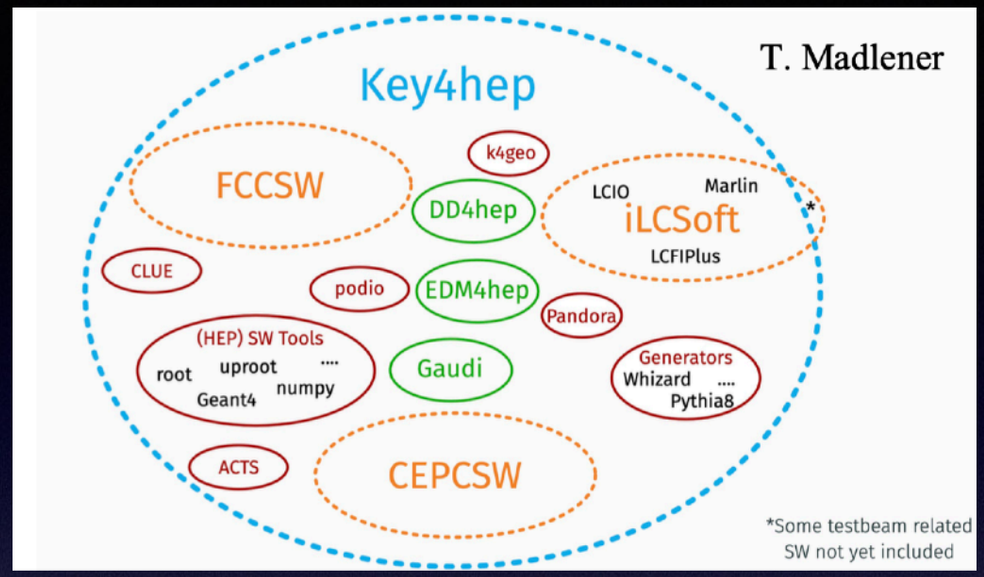


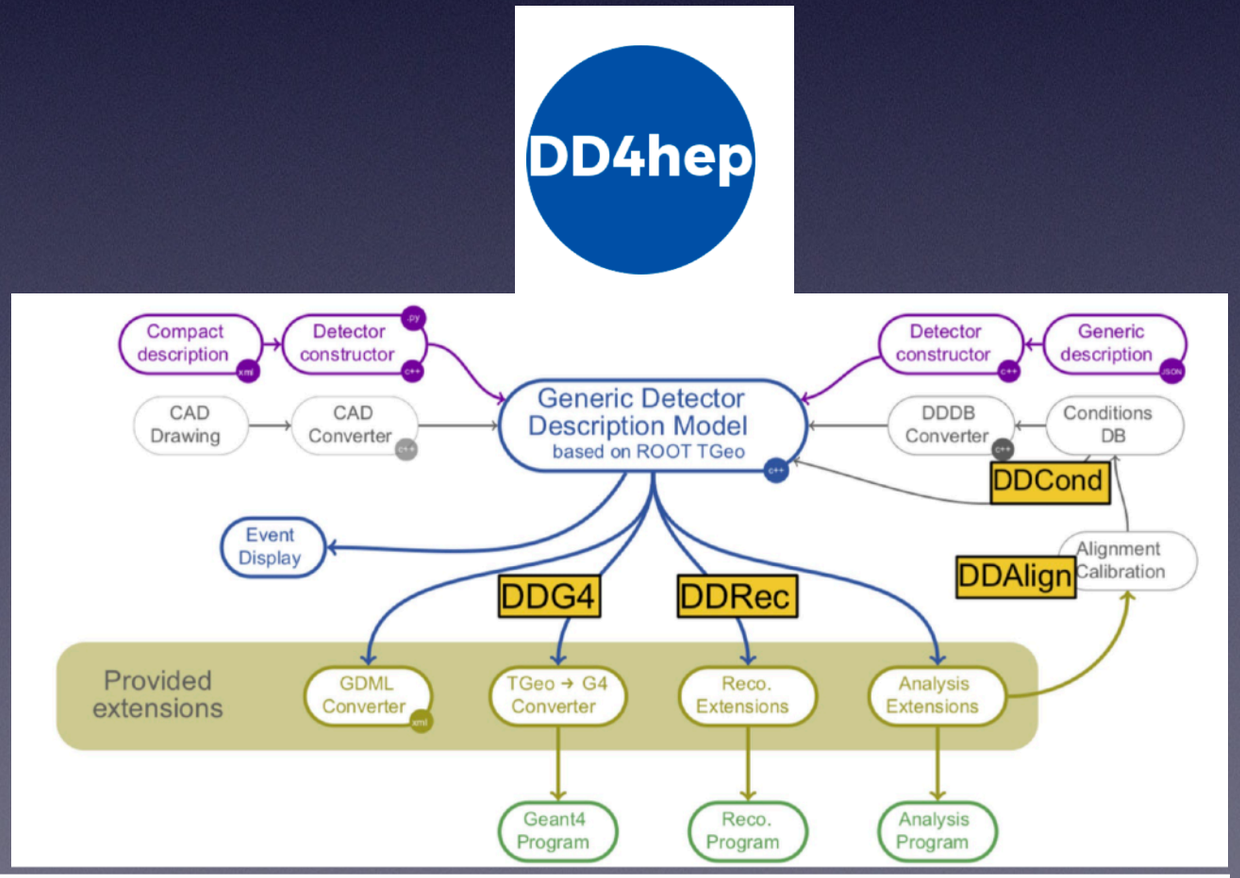
128 modules in ϕ

CALICE-like detector also under consideration

Simulation

- Detailed (Geant4-based) simulation is required to evaluate and optimize detector designs
- For ALLEGRO, this is done with the key4hep SW ecosystem
  - used by many future collider experiments
- Geometry defined with DD4hep
- C++ code defines structure, with parameters taken from xml files
  - simple to make modifications, swap in/out detector systems, etc.

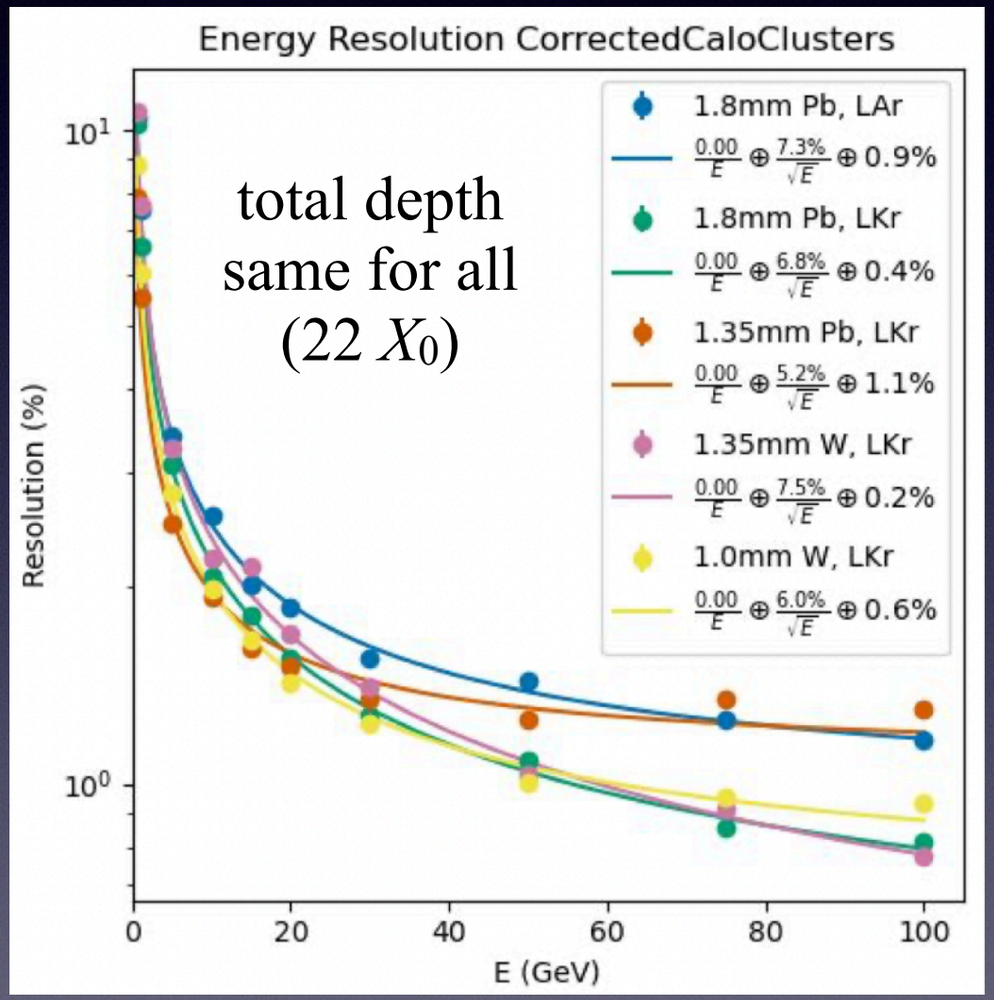




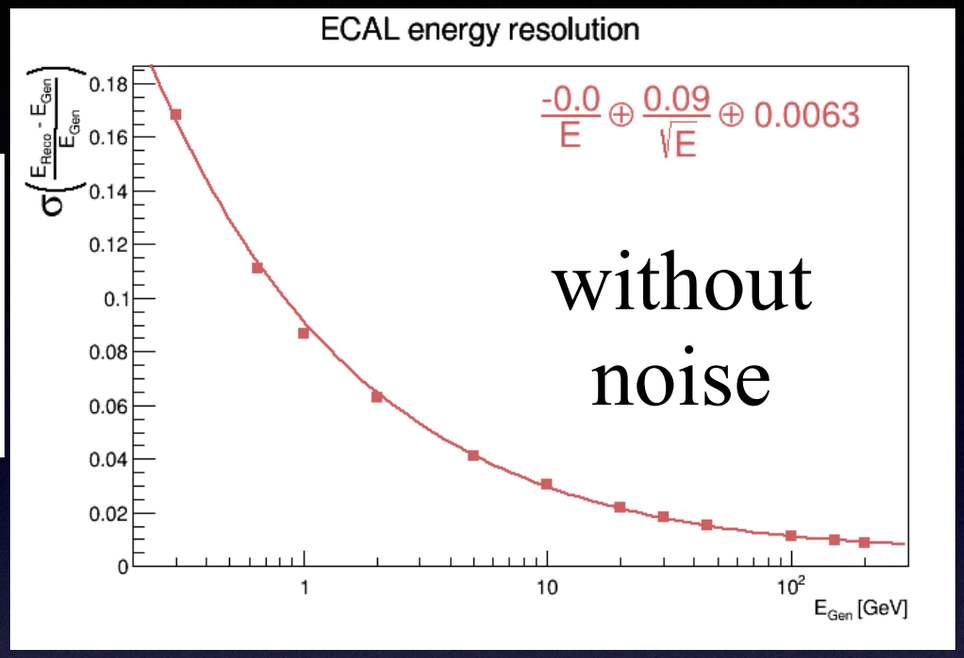
Simulation Results (ECal Barrel)

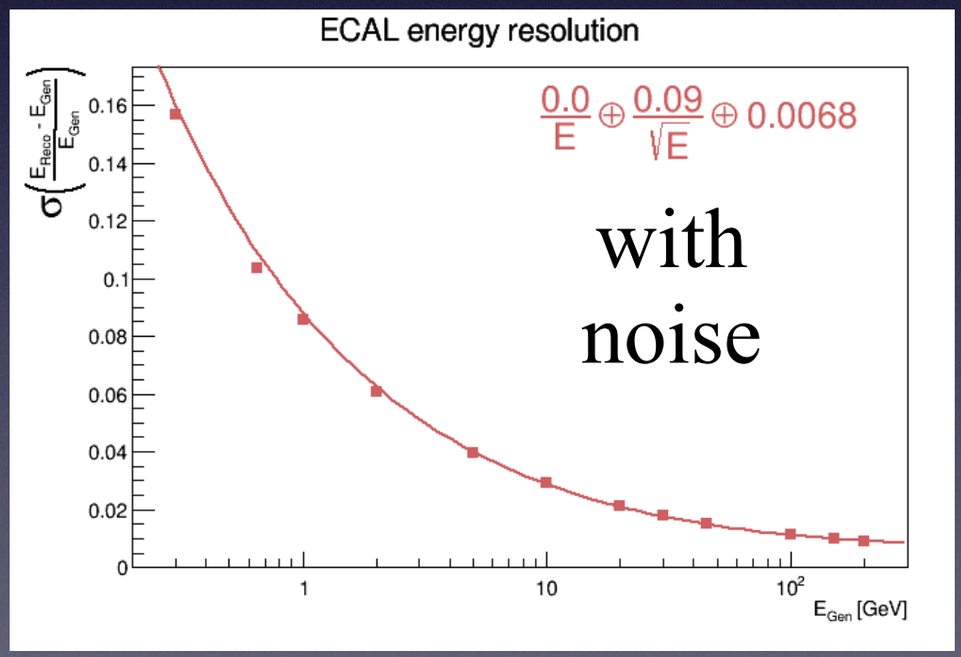
- Single electrons used to:

study material choices



assess impact of noise



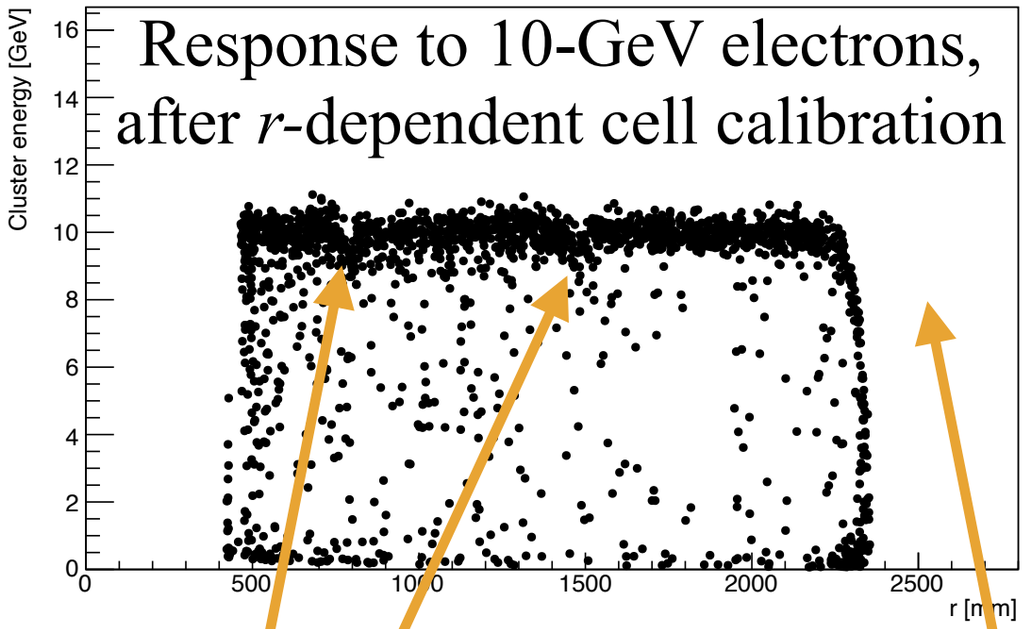


Performance is consistent with requirements

Simulation Results (ECal Endcap)

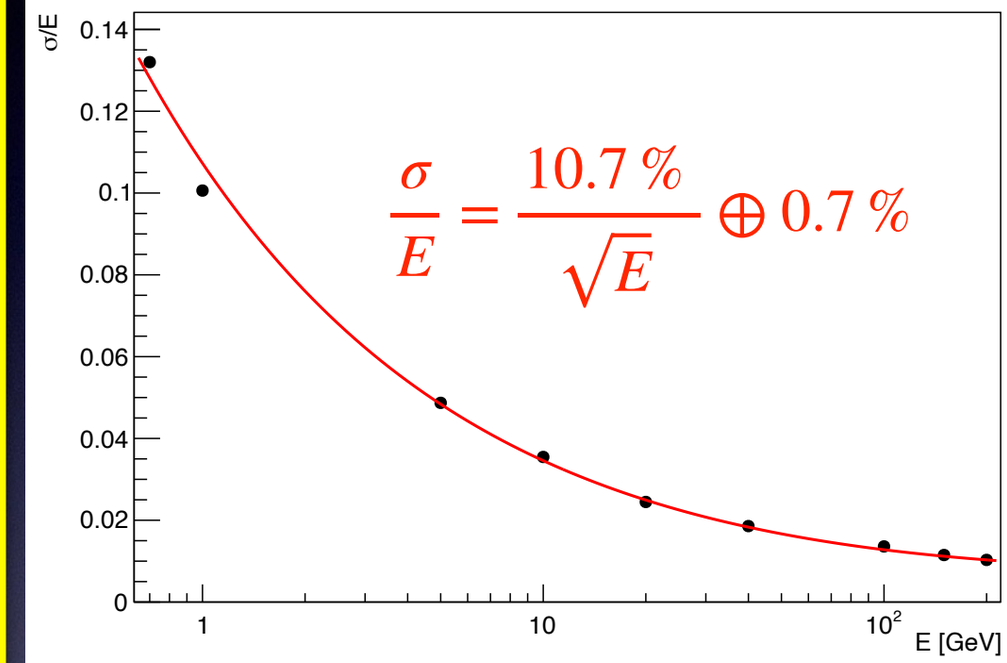
- Initial single-electron studies, with sliding-window reconstruction

LAr + tapered Pb absorbers



Transitions between wheels

Region shadowed by barrel ECal



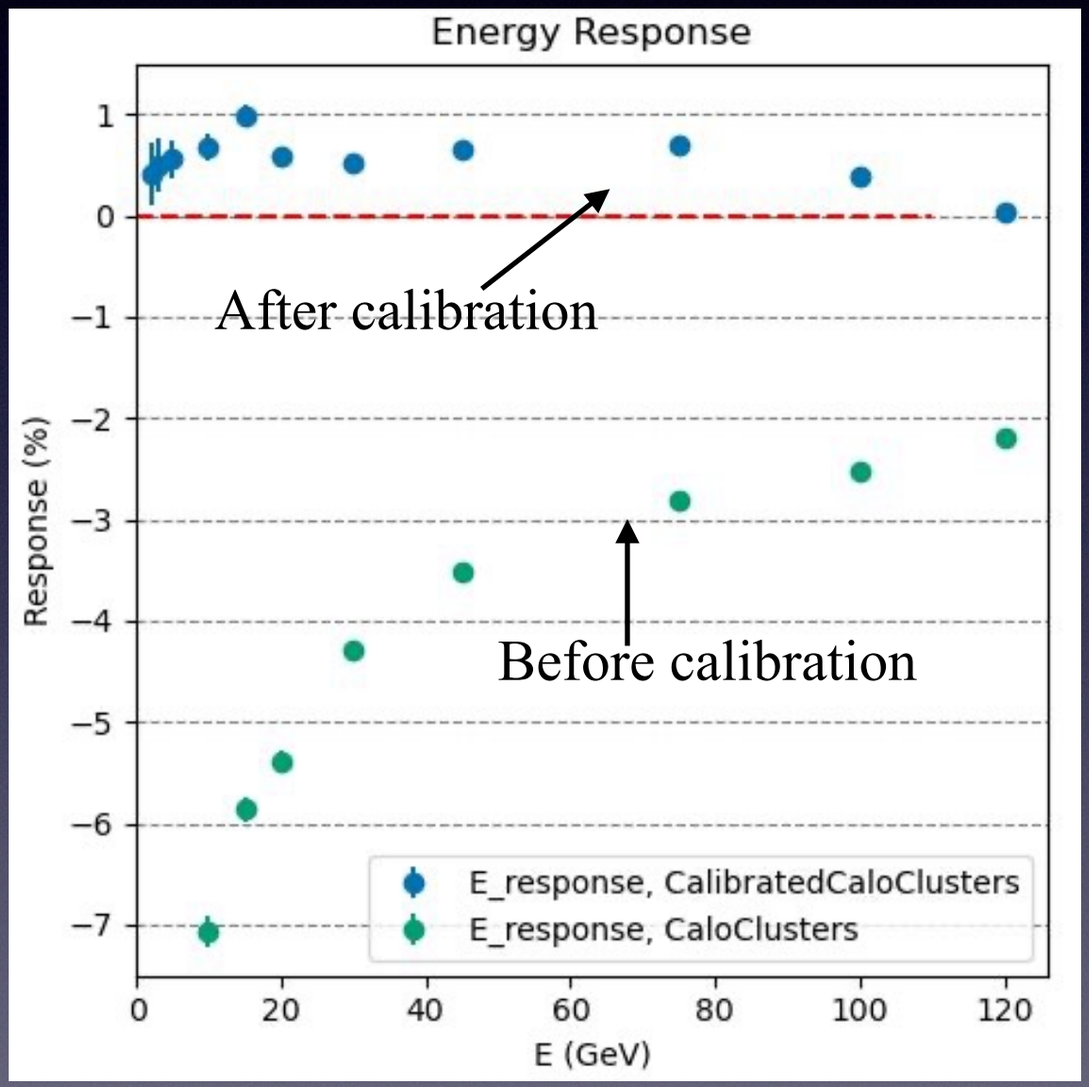
Resolution similar to barrel ECal

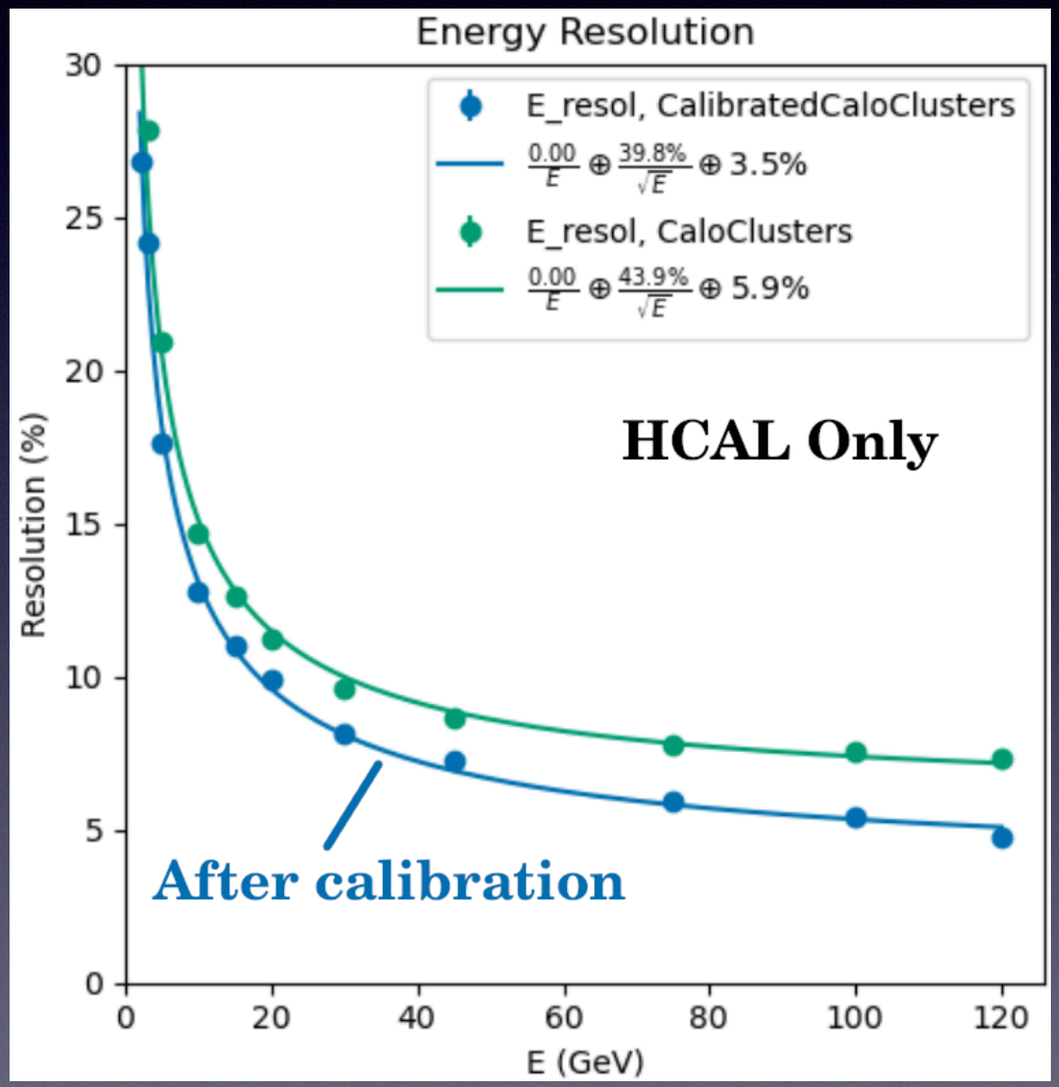
Many possible optimizations to be studied

Simulation Results (HCal Barrel)

- Single pion studies

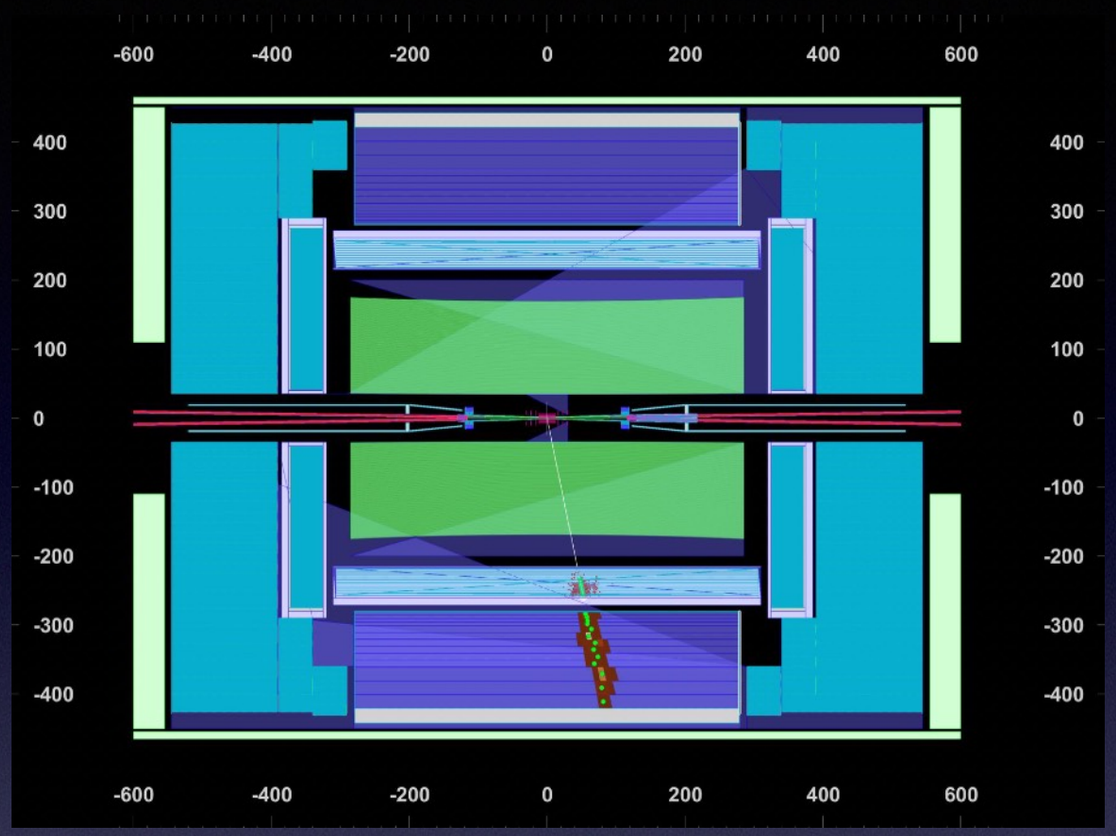
Linearity of response

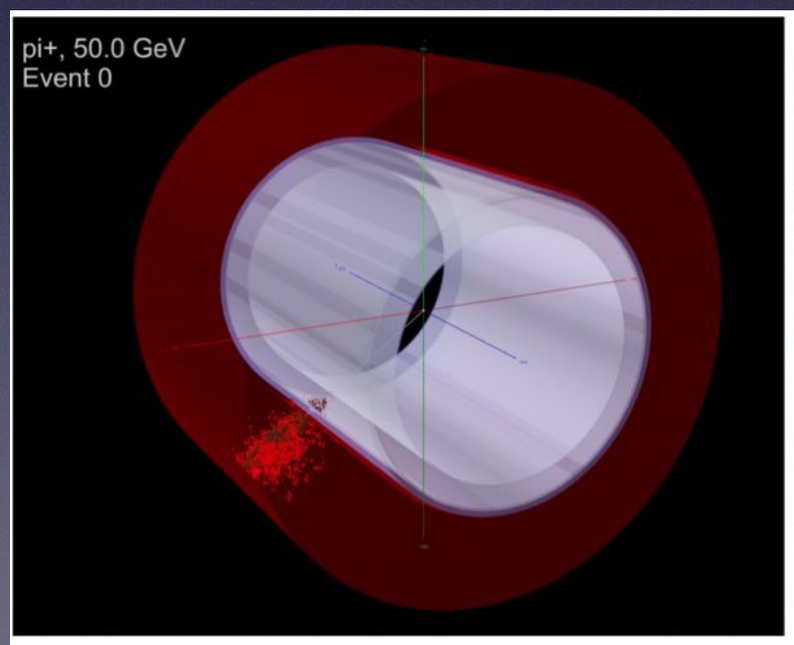


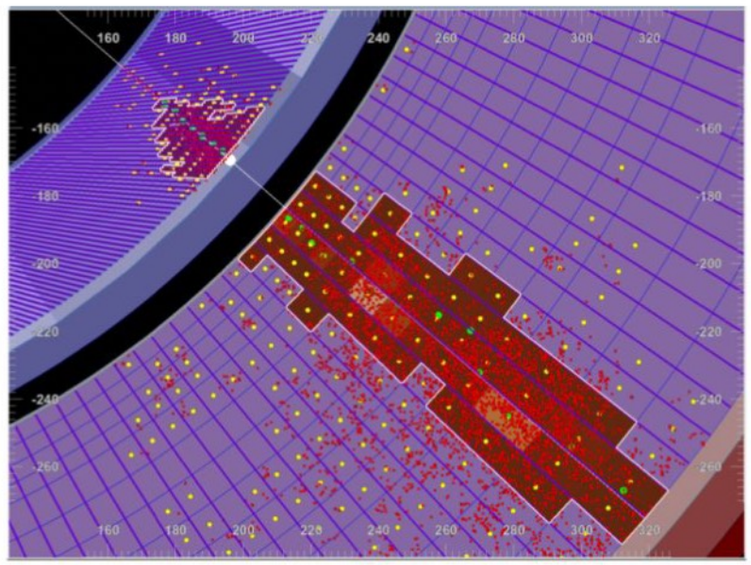


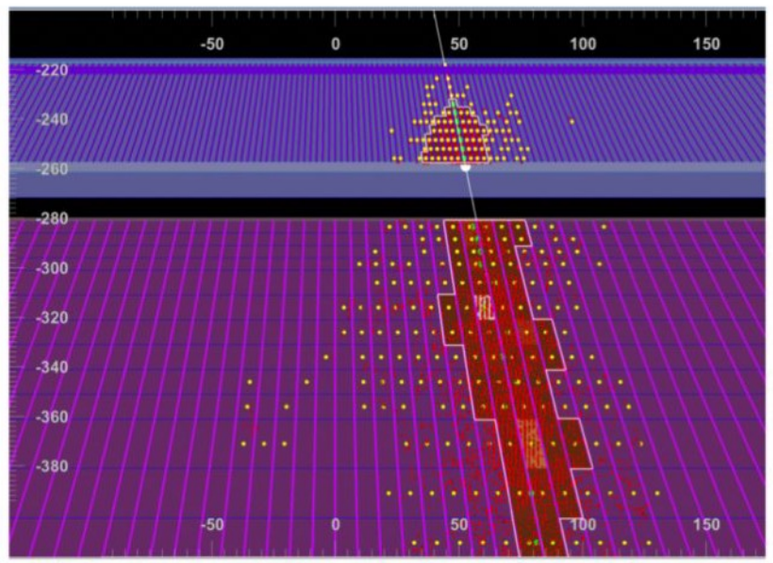
Combined ECal + HCal Response

- Reconstruction can combine signals from ECal and HCal barrels
- Example shown is a single 50-GeV pion
  - topological clustering used for reconstruction



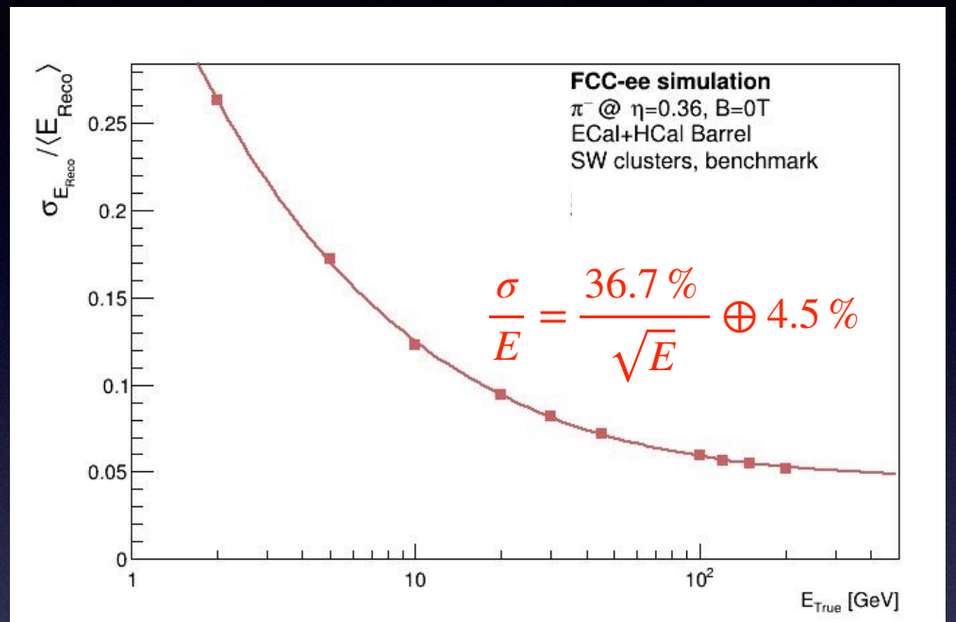


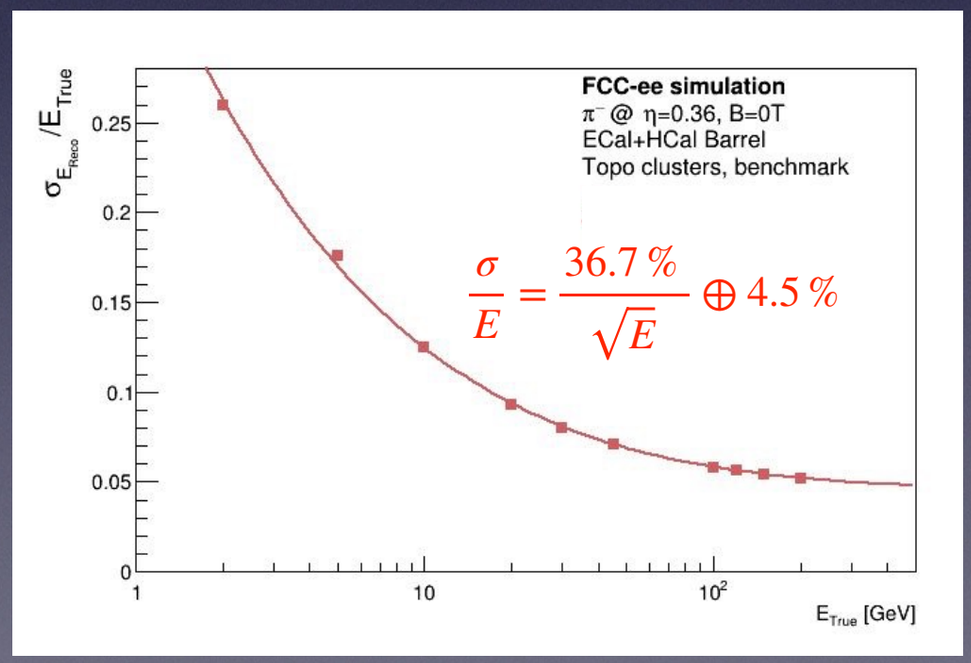


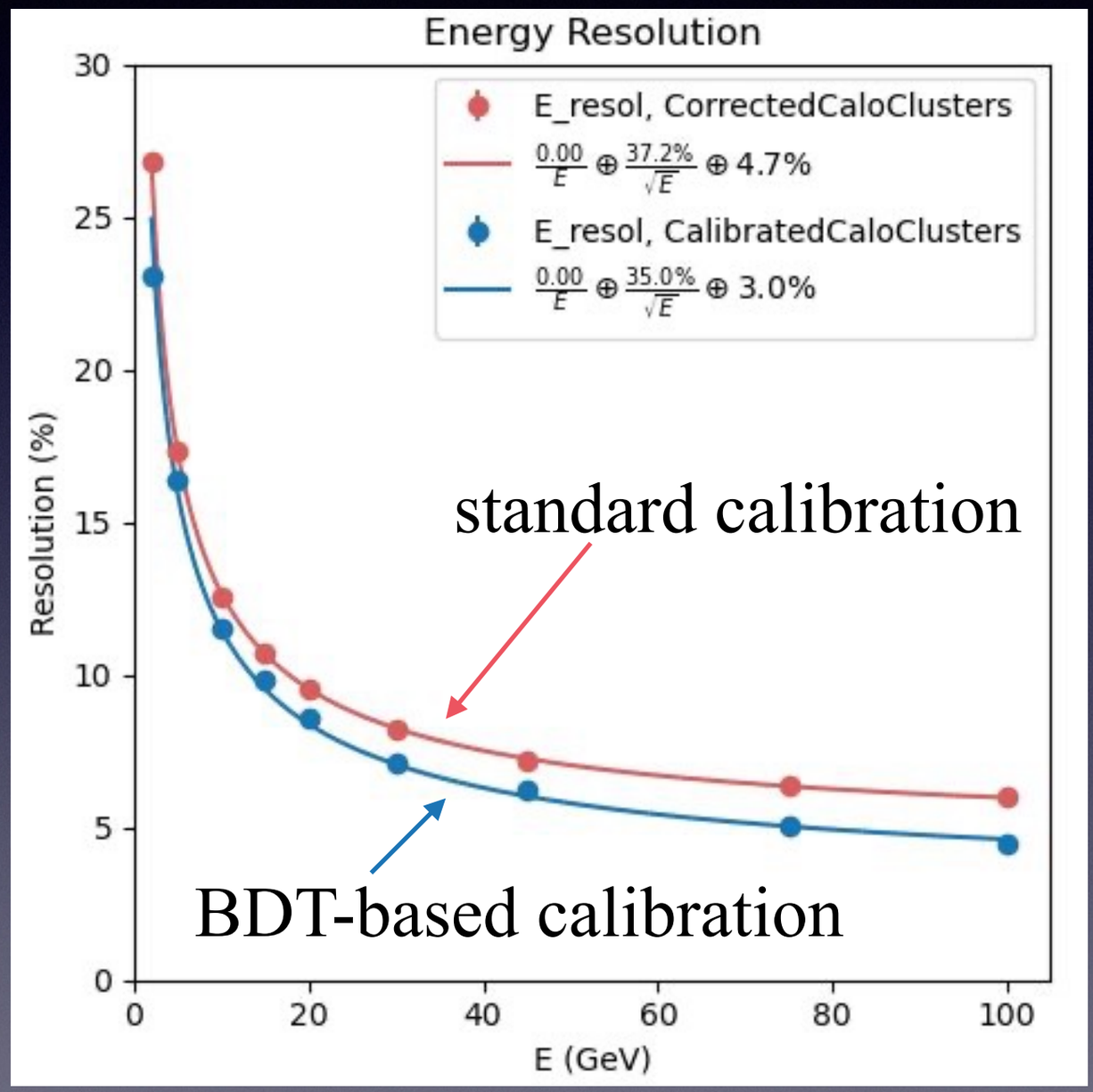


Combined ECal + HCal Response

- Effect of different reconstruction algorithms and calibration methods (single pions used in all cases):







Summary

- The ALLEGRO concept serves as a testbed for potential FCC-ee detectors (calorimeters in particular)
  - defining features are noble-liquid EM and iron/scintillator hadronic calorimeters
- Simulation studies show that this calorimeter system could meet the demands of the FCC-ee program
  - lots of exciting work ahead in optimization and in converting the concept to an actual detector
    - see Zhibo Wu's talk on R&D studies for noble-liquid calorimeters

Plenty of room for new ideas
(and new collaborators!)

Backup