ALLEGRO detector concept with Noble-liquid calorimeter

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on behalf of ALLEGRO ECal team

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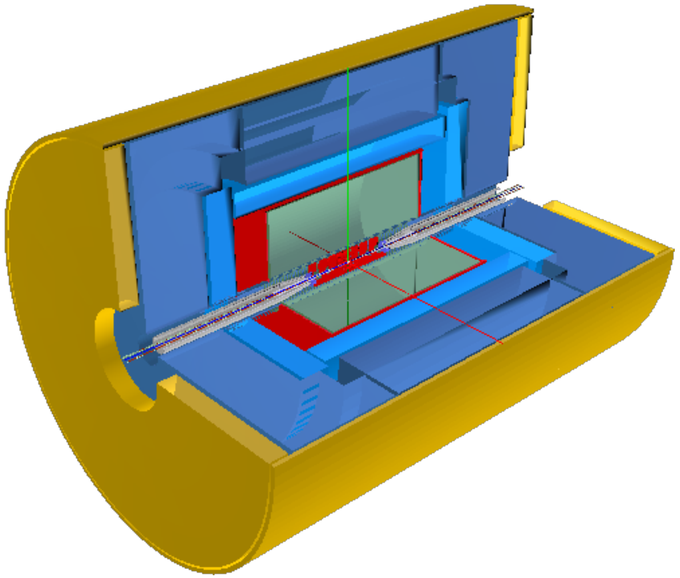
ALLEGRO

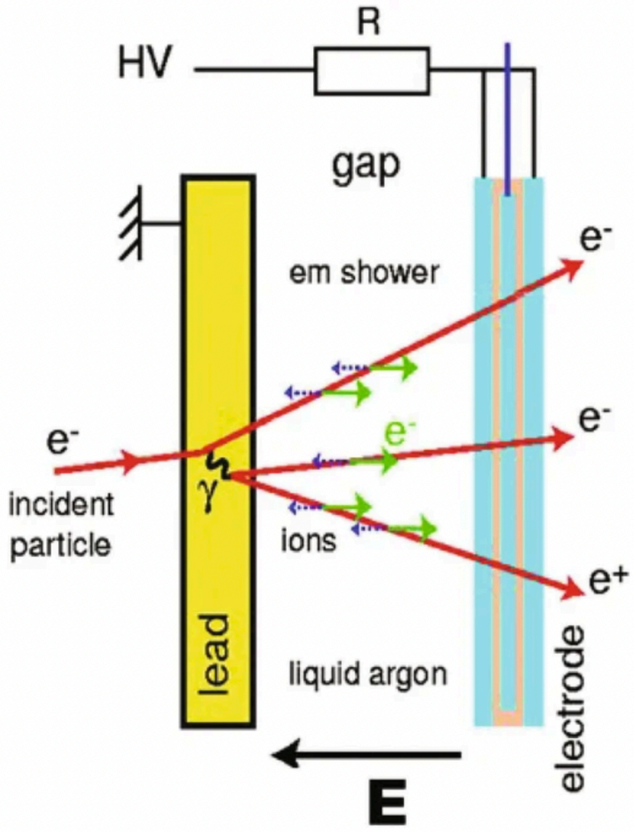
- **A L**epton co**L**ider **E**xperiment with **G**ranular calorimetry **R**ead-**O**ut
- Highly-granular noble liquid EM calorimeter (ECal) inside solenoid
  - LAr/LKr with Pb/W
  - inside 2T solenoid sharing the cryostat
- Part of DRD6 collaboration as Work Package 2 (WP2)



- General purpose detector concept for full FCC-ee programme
- Focus on particle identification with particle flow
- Other sub-detector systems
  - vertex detector, drift chamber, Tile-Cal hadronic calorimeter and muon tagger

Noble-liquid calorimetry

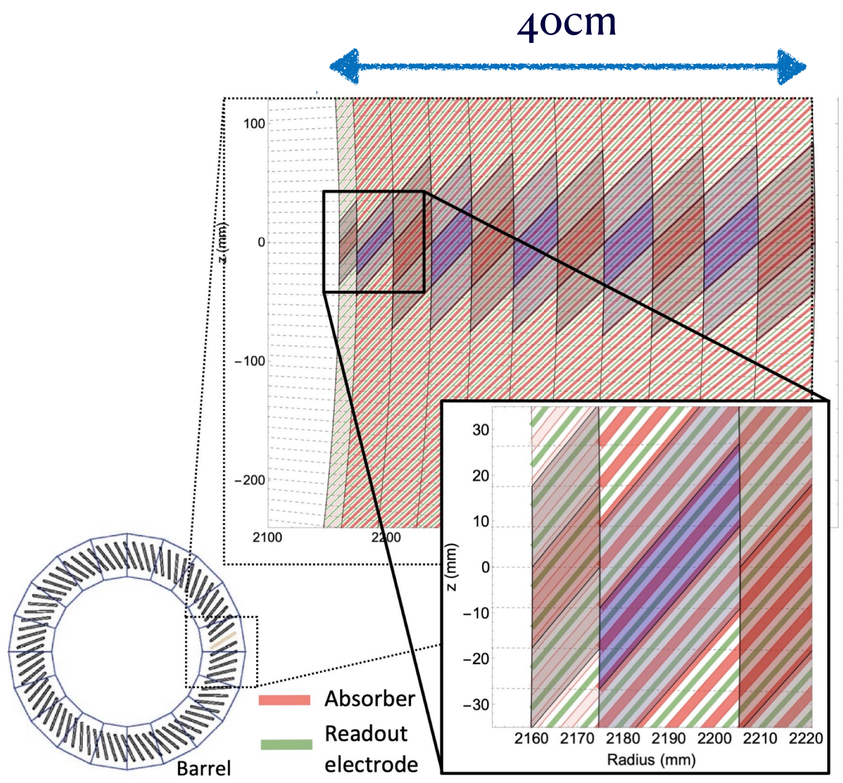
- Sampling calorimeter technology - alternating layers of absorber, noble liquid and read-out electrode
- EM showers start in absorber
- Electrons produced in the showers ionize the liquified noble gas and induce signal
- Decade of success at particle physics experiments: D0, H1, NA48/63, ATLAS,...
- Advantages
  - good energy resolution, stable, uniform
  - easy to calibrate
- Challenges
  - signal extraction and complex mechanical structure inside the cryostat



Barrel design

Baseline geometry

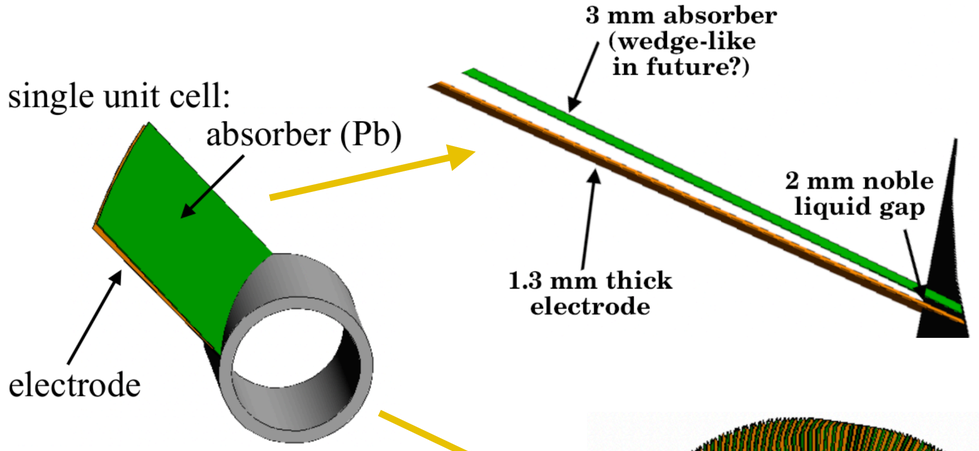
- 1536 straight inclined (50°) 1.8mm Pb absorbers
- gaps between absorbers and electrode maintained by spacers
  - LAr gaps from 1.2 to 2.4 mm
- 40cm in thickness, or 22 X_0
- multi-layer PCBs as read-out electrodes
- segmentation
  - $\Delta\theta$~ 10 mrad
  - $\Delta\phi$~ 8 mrad
- 11 longitudinal layers
- the second layer with narrow strips segmented in θ for π^0 detection

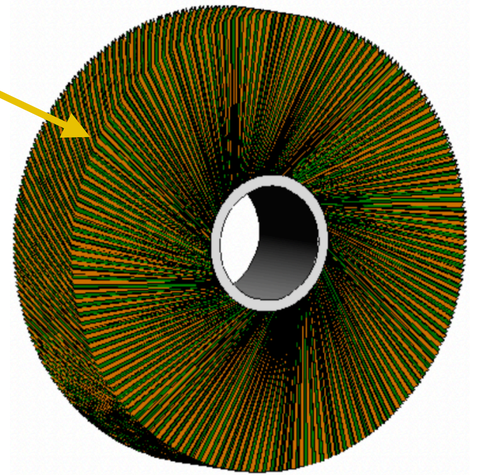


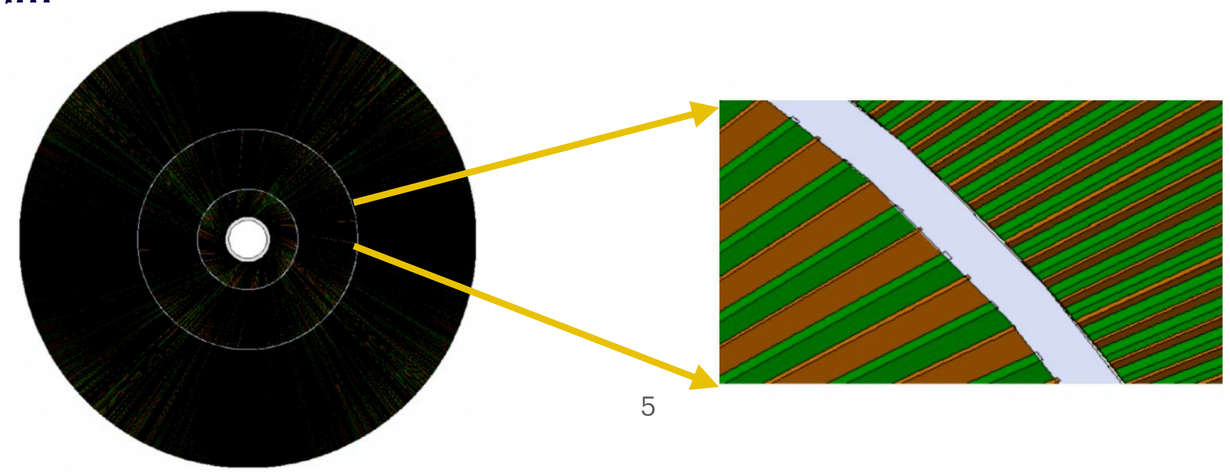
- LKr or LAr as active medium
- W or Pb as absorbers

Endcap design

- Similar concept to the barrel
- Particles should traverse many thin absorber/sampler electrode unit cells
- 3 nested wheels with turbine-like layout
  - similar to barrel design with many thin absorbers
  - tapered absorber thickness
  - 420 mm < R < 2750 mm



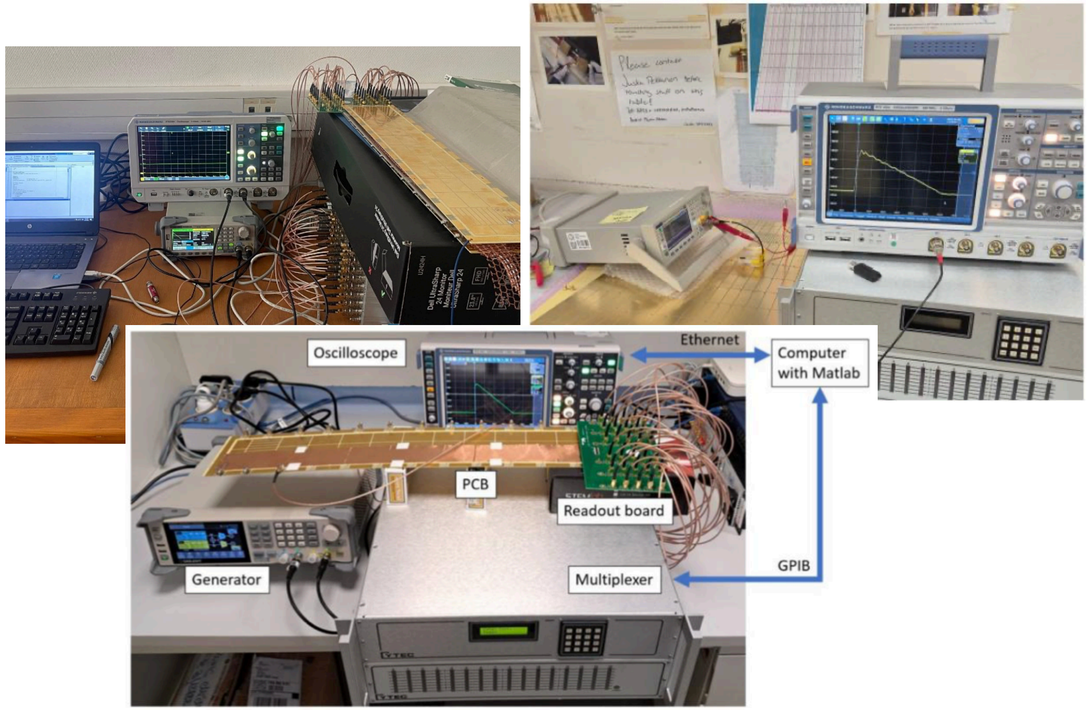




Read-out electrodes

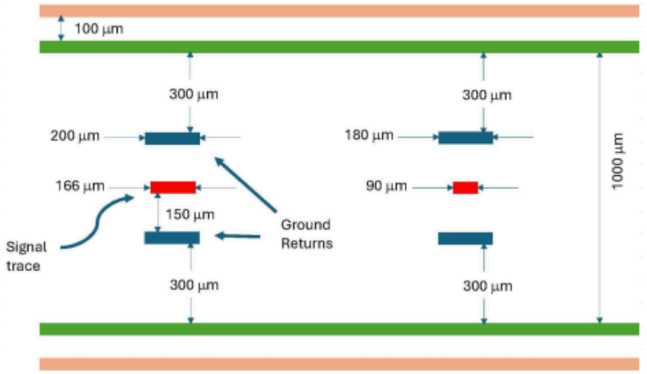
Barrel

- Printed circuit board (PCB) technology allows high granularity
  - signal traces inside the electrode
  - allows for ~10× ATLAS granularity
  - first versions of prototype were tested

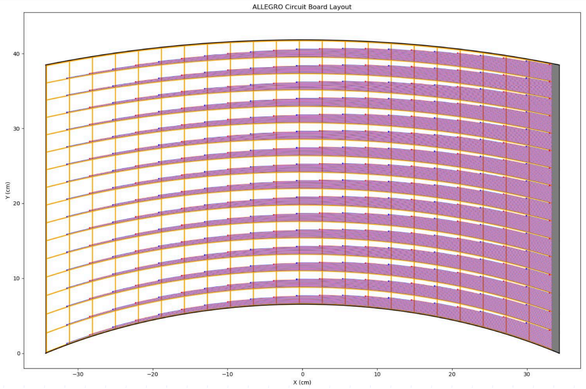


End-caps

- Dedicated PCB design in Arizona
  - flat PCB with shape adapted to the turbine-like design
  - signal read-out from high-|z| edge
  - study of transfer line characteristic impedance
- Prototype design in progress



Xsection of two different embedded transmission lines

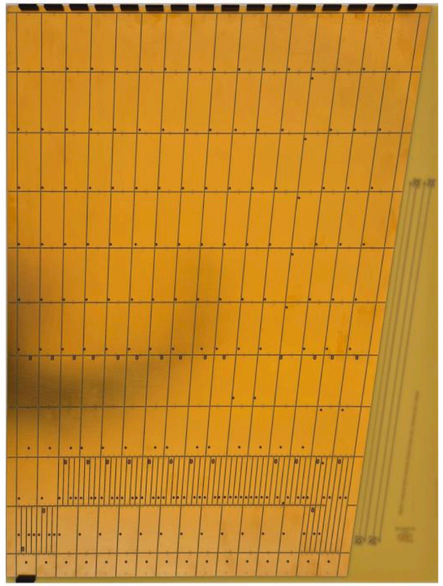


turbine inner wheel readout board

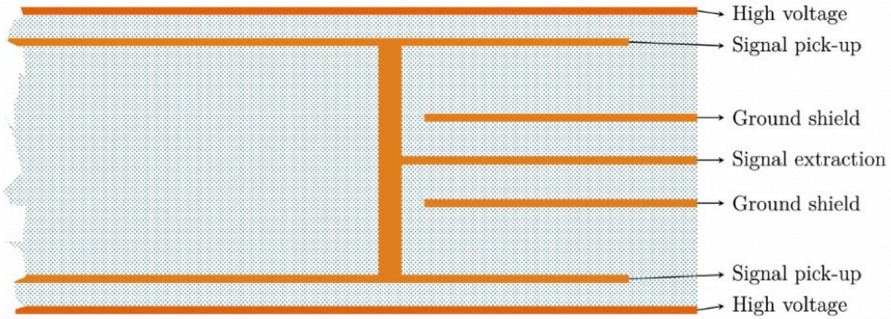
Barrel read-out electrode prototypes

PCB prototype

- 11 longitudinal compartments , 16 θ-towers with unique configurations
- readout from the outer edge
- strip segments in 3rd row + variations
- 7 layers

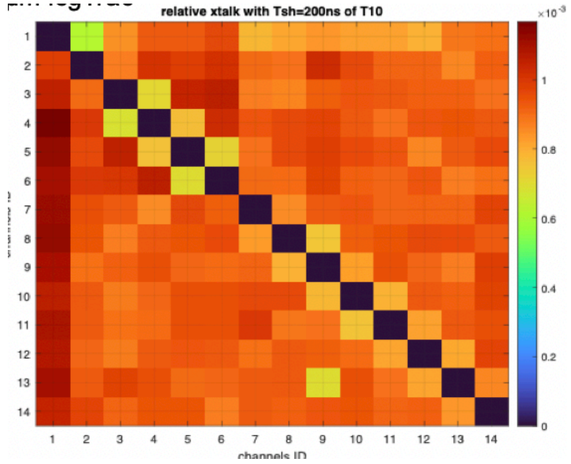


side view

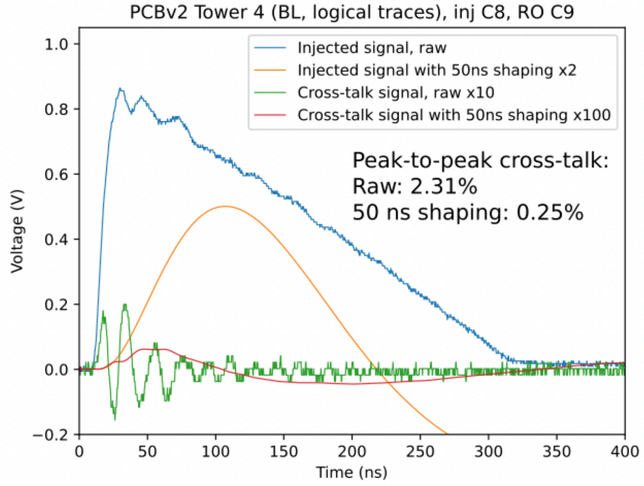


Measurements

- CERN, IJCLab, BNL
- relative cross-talk is less <0.1% with 200 ns pulse shaping



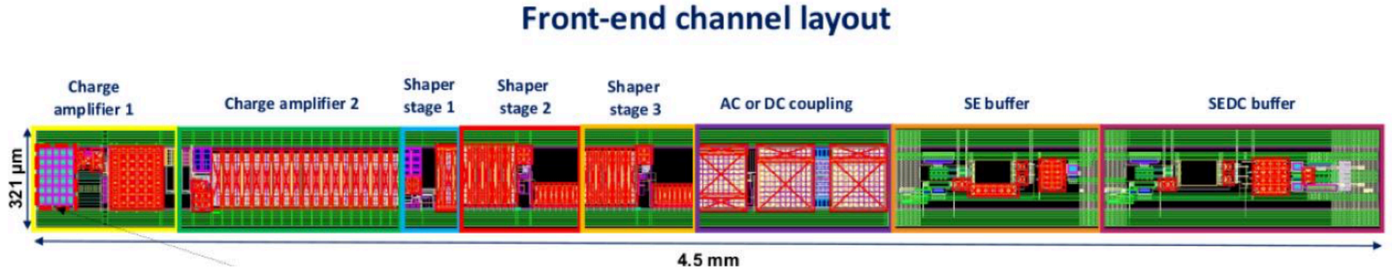
- Cross-talk reduced to 0.25% level with 50 ns pulse shaping
- results reproduced in simulation



Cold read-out electronics

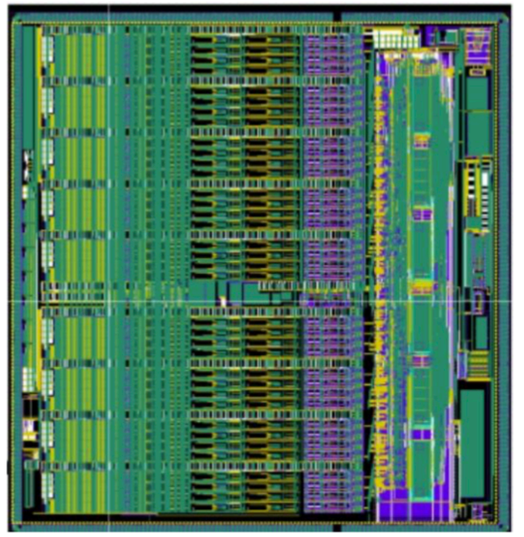
- ECal barrel contains ~2M channels
- Outside cryostat: warm electronics requires routing of signal cable
- Cold electronics needs room for board+HV, powering and cables
- First design of cold front-end preamplifiers (BNL, OMEGA)
- Initial design of cold front-end readout chain

Brookhaven National Laboratory



CHARMS250 cryogenic analog front-end ASIC @ BNL

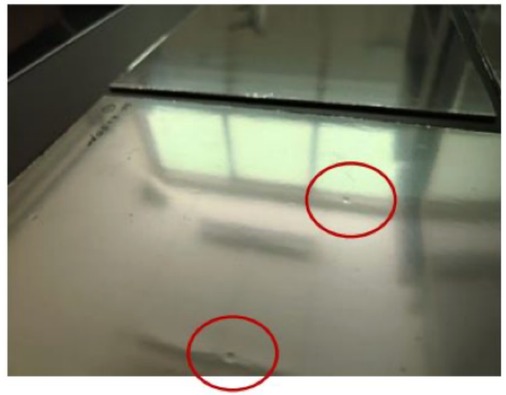
OMEGA Microelectronics

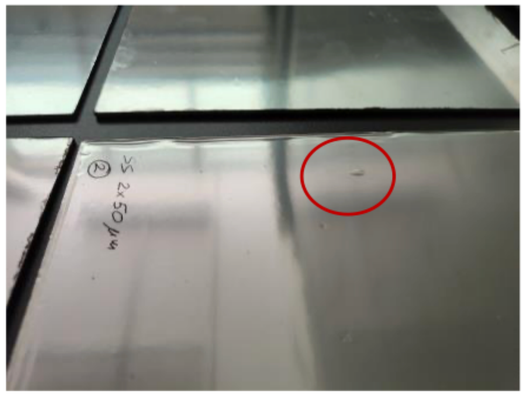


CALOROC1C chip for ALLEGRO ECal @ Omega Labs

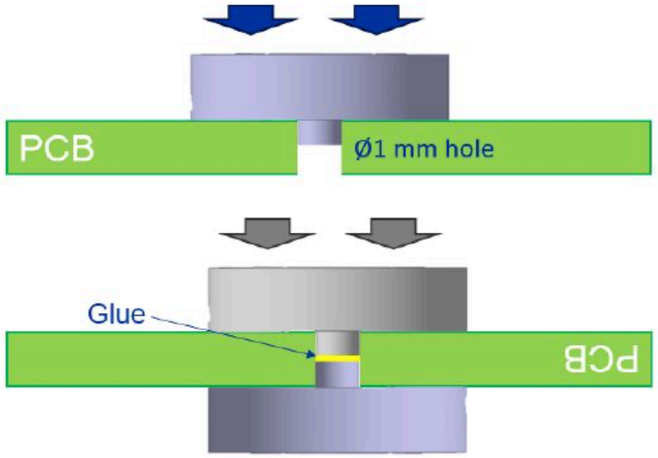
Absorbers & Spacers

- **Absorbers** are 1.8mm lead plates sandwiched between stainless steel sheets
  - two designs - 0.1mm and 0.05mm stainless steel sheets
  - tests performed with liquid nitrogen bath of 77K
    - deformation appear in tests with 0.05mm steel
      - differences in thermal expansions
- Absorber with 0.1mm stainless steel sheets is now default





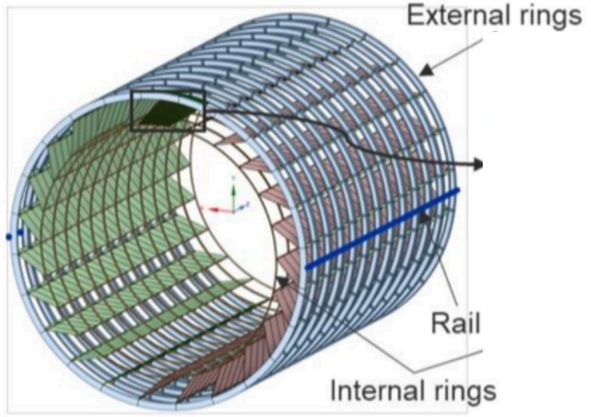
- Need to control LAr gap between absorbers and electrode
- First studies on **cylindrical spacers**
  - at least ⌀6mm
  - placed in the edges of readout cells
  - at most 200 mm between spacers
  - total volume occupied is 0.15% of the total LAr gap
- Other studied options
  - 3D printed mesh
  - Honeycomb paper

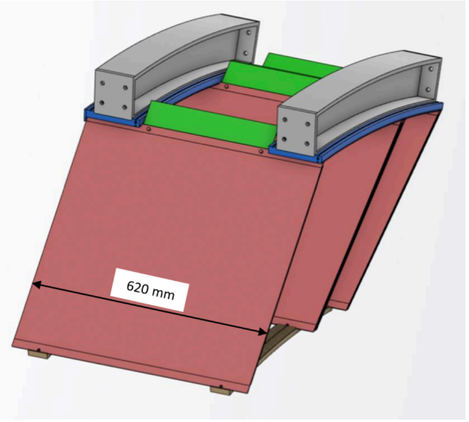


Barrel support structure

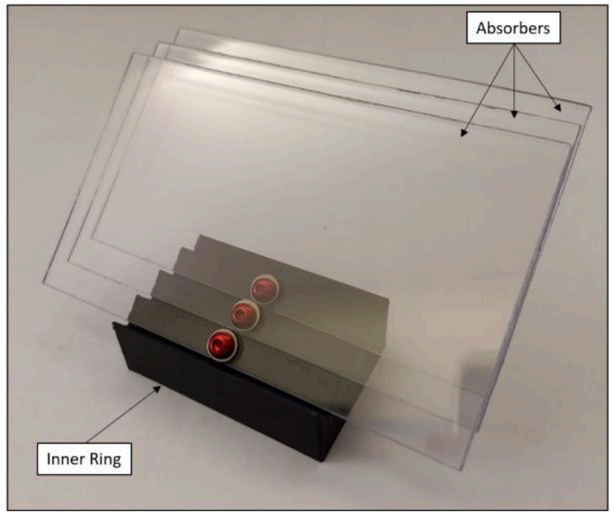
Main components

- internal ring - positioning
- external ring - support
- absorbers are positioned and fixed on the rings

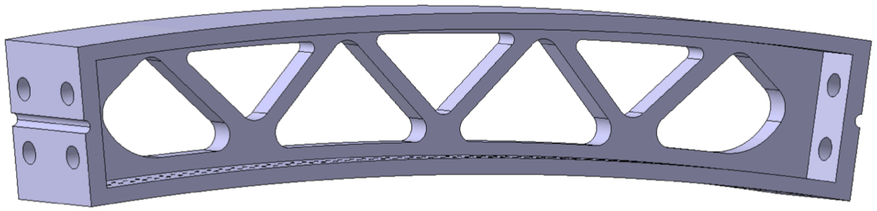




- 3D printed prototypes to check the assembly between absorbers and rings

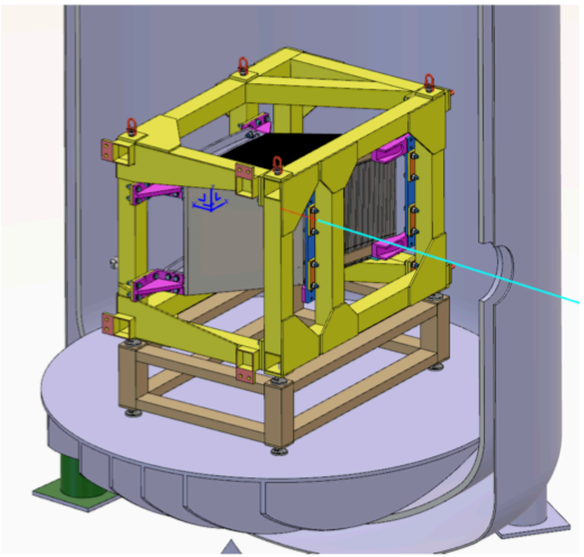


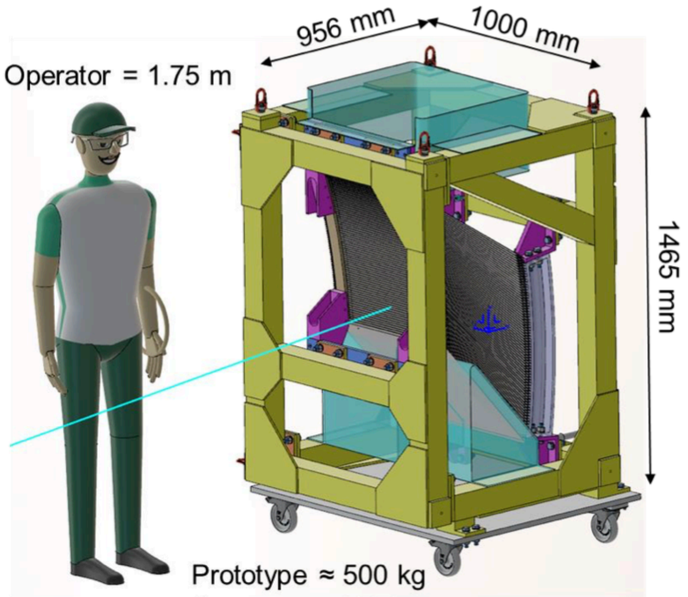
- Need space in external ring for cables and cooling pipes



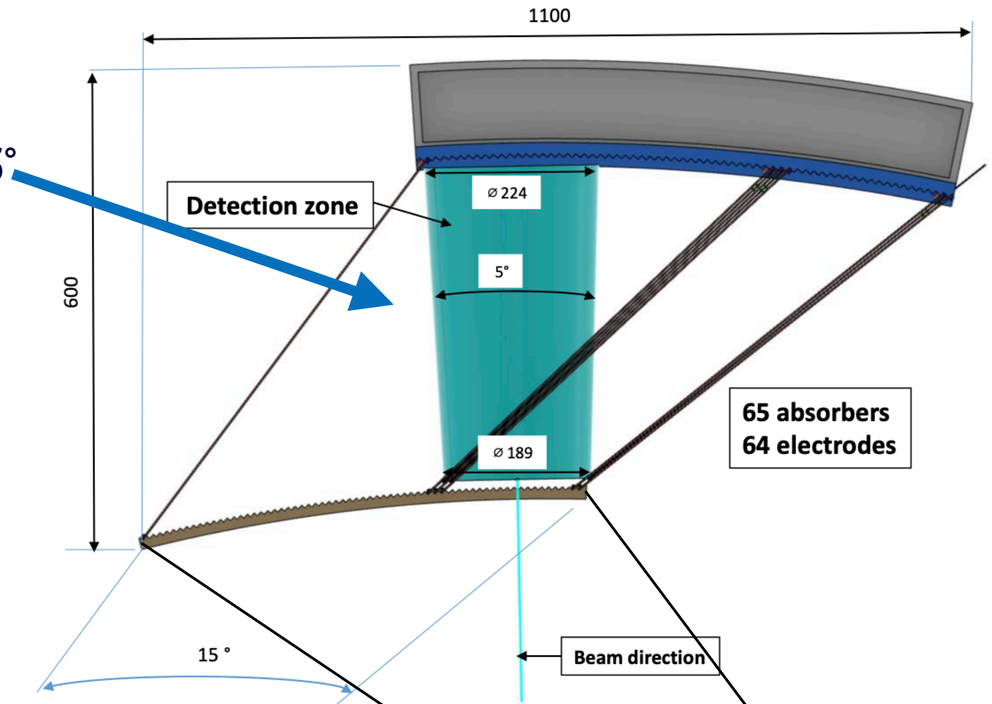
Test beam prototype

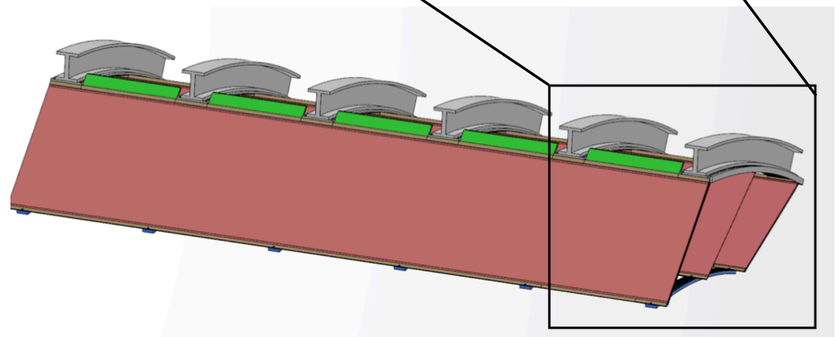
- Preparation of the ECal barrel test beam prototype
- Dimension is a sector of 15° and it corresponds to a detection zone of 5°
- Design with 65 absorbers and 64 electrodes





Pierre Karst
(ST2410245_01)

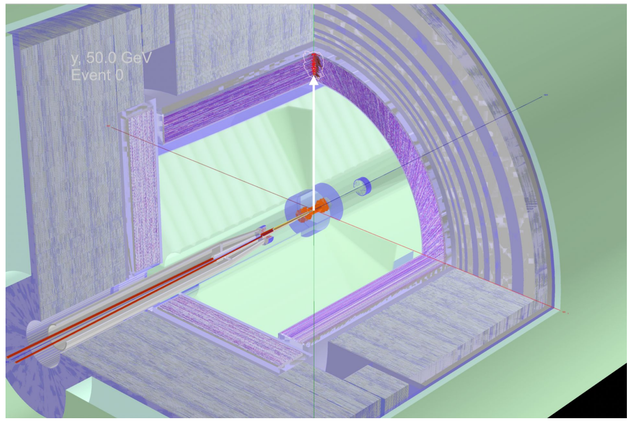




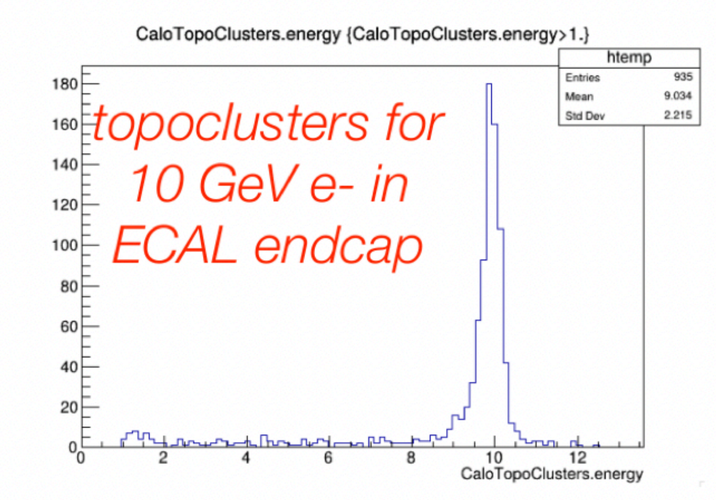
Concept of the Barrel – 3 meters long

Full simulation

response to 50 GeV photon

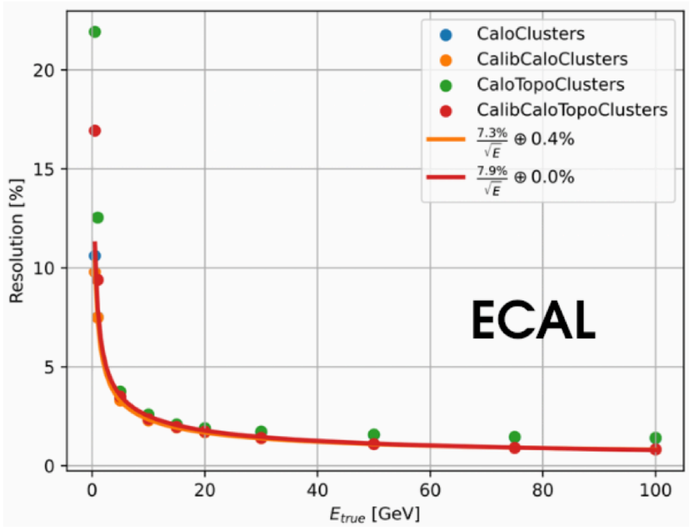


- Geometry description of ALLEGRO detector concept implemented in Key4hep
- Simple digitization as a sum of Geant4 energy deposit, corrected by pre-calculated sampling fraction for each layer, also handle noise addition and cross-talk emulation
  - realistic digitization on-going
- Clustering is available for fixed-size sliding window cluster and topocluster



- Clustering with topoclustering using ECal+HCal barrel and ECal endcap
- Fixed-size sliding window clustering available for both barrel and endcap

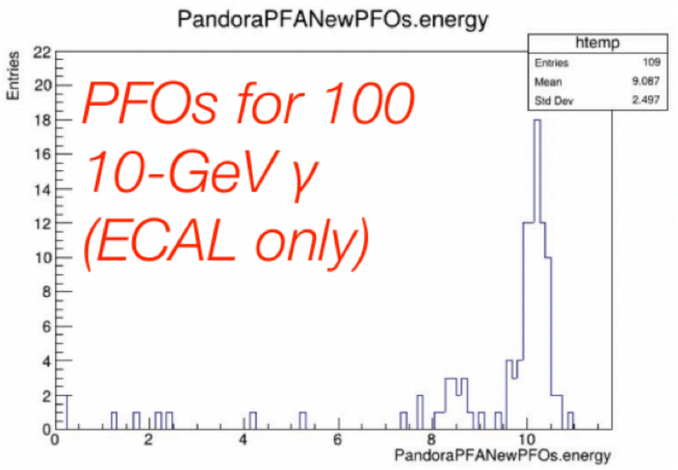
- EM resolution with a sampling term of 7-8% in simulation

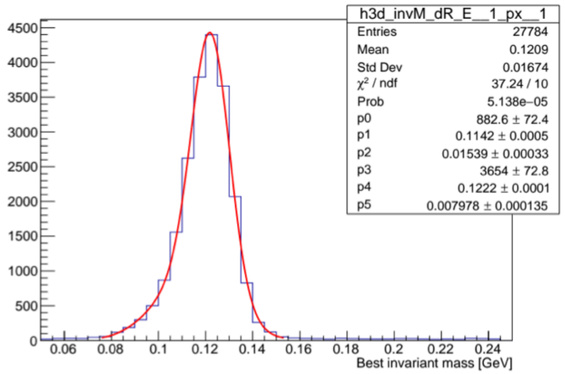


Full simulation

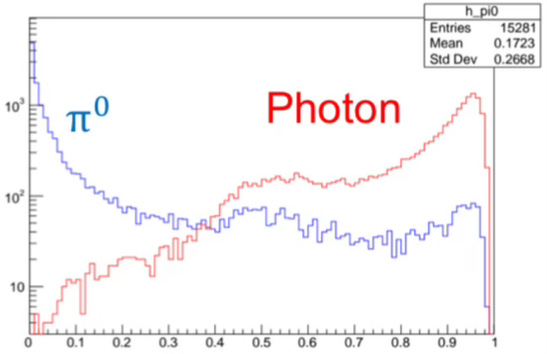
Particle Flow

- integration of information from other subdetectors (tracking) essential for best reconstruction of charged particles (electrons)
- progress towards PandoraPFA reconstruction in ALLEGRO





π^0 invariant mass reconstructed by ALLEGRO ECal



BDT score of photon-π^0 separation trained with cluster energy and shower shapes

Photon-π^0 separation

- reconstruction of resolved π^0 by pairing clusters in the π^0 invariant mass window
- unresolved π^0 are separated from photons via machine learning method
- identification of tau decay mode by counting number of reconstructed π^0 in ALLEGRO ECal

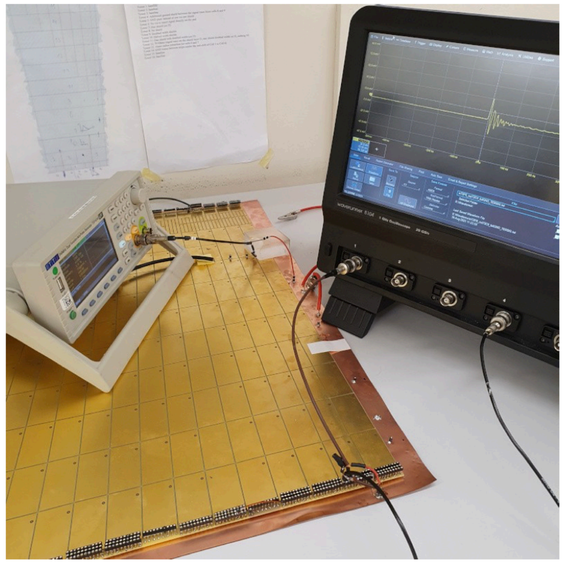
Conclusions

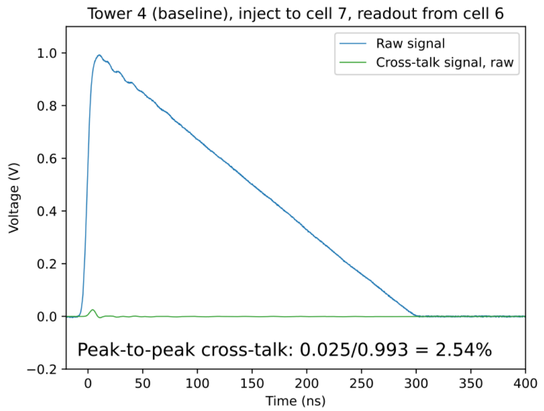
- **ALLEGRO** is realistic general-purpose detector concept for Higgs factory
- Progress in almost all aspects of ECal calorimetry
- Exploring turbine-like Endcap geometry
- Barrel electrode prototype is tested, endcap electrodes are developing
- Working on mechanics for our test beam prototype
- A lot of progress towards the full detector simulation

Backup

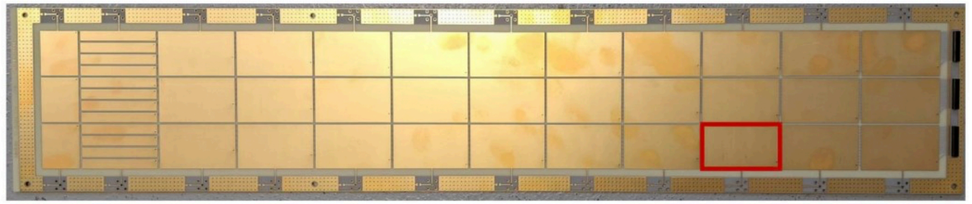
Read-out electrode prototypes

- **PCB v1** prototype at **CERN**
  - Full-depth 16-tower PCB produced at CERN
  - 12 longitudinal compartment, presampler and strip segment front
  - 7-layer PCB; including HV pads
  - read-out of 4 inner layer from front, 8 layers from back

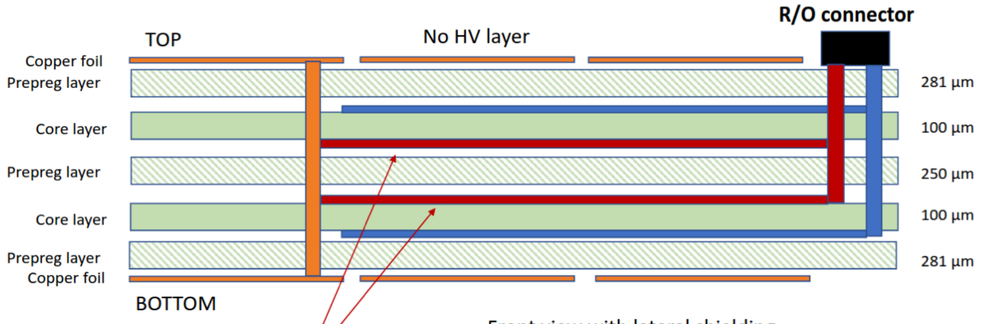




- **PCB v3** prototype at **IJCLab**
  - 12 longitudinal segments, all pads have same size (except presampler and strip segment)
  - readout from the outer edge
  - 3 towers with different ground shielding

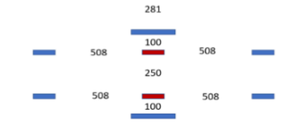


12 segments 1 pad is 5 x 3 cm



Double signal trace to be completely symmetric and have an even number of conductor layers
=> it's easier to manufacture

Front view with lateral shielding and distances in µm



Widths:
Signal: 127µm
Top/bottom shielding: 254µm
Lateral shielding: 127µm

Documented in HAL:
https://in2p3.hal.science/in2p3-04914287v1/document