7th FCC Physics Workshop

ALLEGRO Detector Concept & Noble-Liquid ECAL Development

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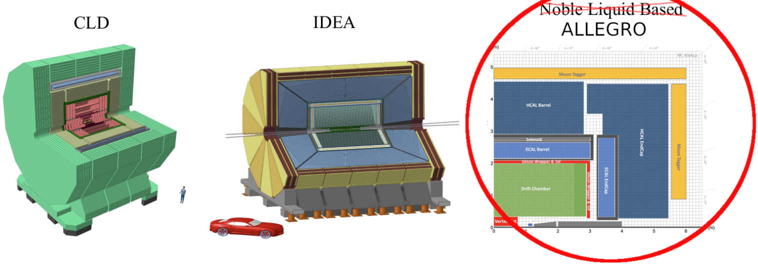
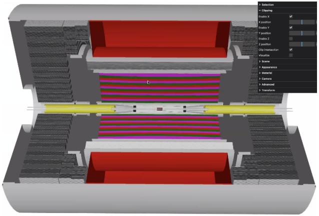
Outline

- The ALLEGRO detector concept
- Hadronic calorimeter
- End-cap EM calorimeter
- Barrel EM calorimeter
  - Read-out electrode prototype & cross-talk studies
  - Mechanical design
- Conclusions & outlook



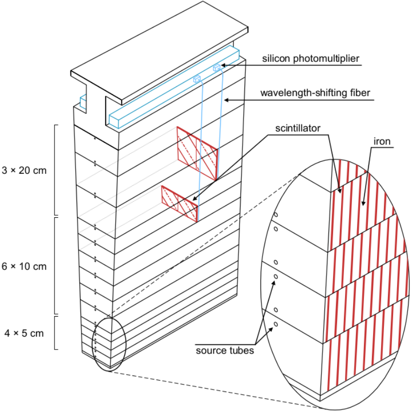
ALLEGRO detector concept

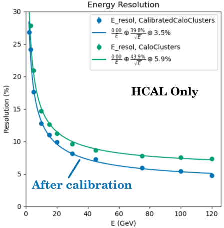
- General-purpose detector for FCC-ee
- Recently coined as ALLEGRO
  - A Lepton coLlider Experiment with Granular calorimetry Read-Out
- Highly-granular noble liquid ECAL a central and most studied feature
  - LAr or LKr with Pb or W absorbers
  - Multi-layer PCB as read-out electrode
- Vtx detector, drift chamber and ECAL inside 2 T solenoid, sharing cryostat
- HCAL and muon system outside solenoid
- Optimized for full FCC-ee physics program
  - Focus on PFlow & particle ID performance



Hadronic calorimeter

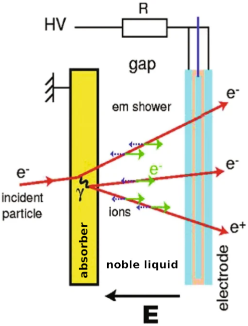
- HCAL design based on alternating steel and scintillator layers
  - Well studied and tested design (CALICE & ATLAS)
  - 5 mm absorbers, 3 mm scintillators
- 13 radially thickening layers
- 128 modules in ϕ, 2 tiles per module $\rightarrow \Delta\phi$ = 0.025
- $\Delta\eta$ = 0.025 (grouping 3-4 tiles)
- Doubles as return yoke for solenoid
- Geometry optimisation & calibration studies ongoing

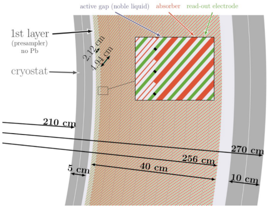




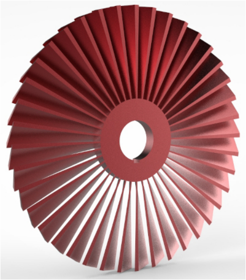
Refresher on noble liquid calorimetry

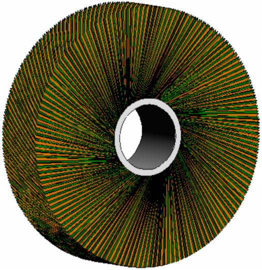
- Sampling calorimetry relying on ionization
- Based on alternating layers of absorbers, noble liquid and read-out electrodes
  - Voltage applied over noble-liquid gap
  - Incident particle ionizes noble liquid
  - e^- drift to electrodes for signal pick-up
- Successfully applied in a number of HEP experiments
  - MarkII, DØ, H1, NA48/62, ATLAS
- Excellent E resolution, linearity, stability and uniformity, good timing properties
- Challenges: complex mechanical structure inside cryostat, signal feed-thru, granularity





Wake-up riddle





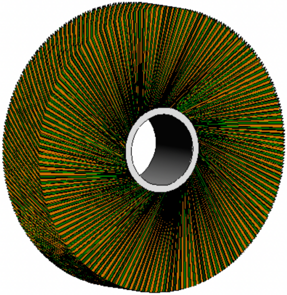
What does any of the above have to do with future collider experiments?

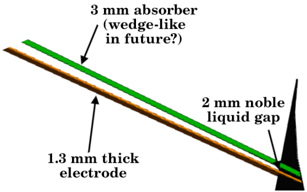
Endcap EM calorimeter

- Noble-liquid based sampling calorimeter
- ECAL endcap designed to feature:
  - Thin absorbers (high granularity)
  - Readout from outside faces only (no dead material)
  - Uniformity in ϕ

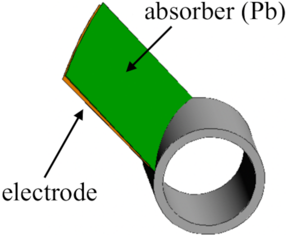
$\Rightarrow$ **Turbine-like geometry**

- $\sim$240 absorbers and electrodes each
- Geometry ported to FCC-SW for FCC-ee simulations





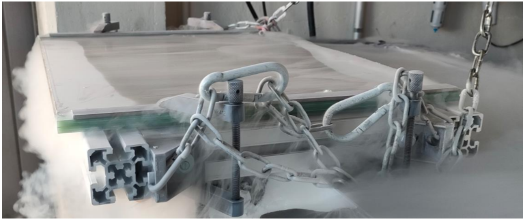
single unit cell:

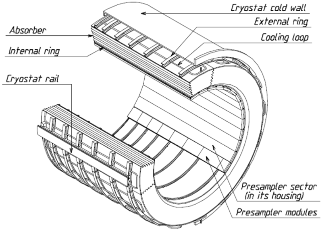


drawings by Rob Walker

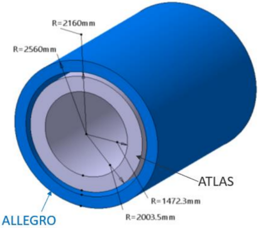
Barrel ECAL - mechanical design

- ATLAS LAr ECAL used as reference
  - Larger radius, new electrode geometry
- Finite element analysis used for structural element design (strenght, size)
- First prototype of two absorbers and one electrode built in 2023
  - Tested in liquid nitrogen bath





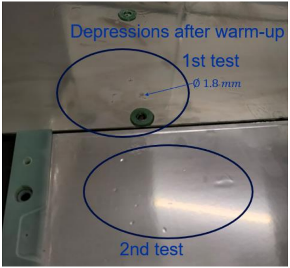
ATLAS liquid argon calorimeter general layout

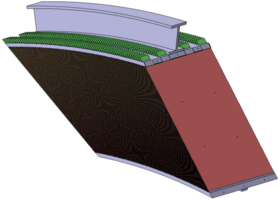


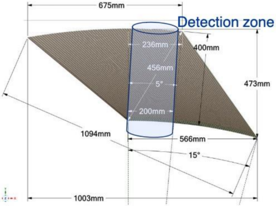
Calorimeter size comparison

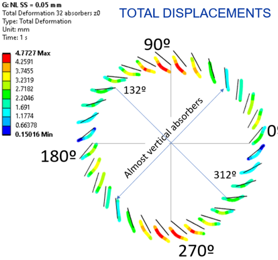
Absorbers & test-beam prototype

- First absorber prototypes produced with 1.8 mm of lead with 50 μm steel layers
- Small depressions seen after cold test
  - Origin being investigated
  - May need thicker steel layer
- Mechanical properties studied with FEM
- Design of a test beam prototype to be frozen by September 2024
  - 64 electrodes and absorbers
  - Placed in a cryostat for beam tests



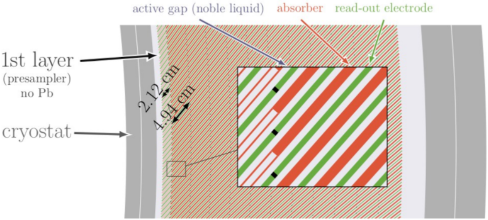


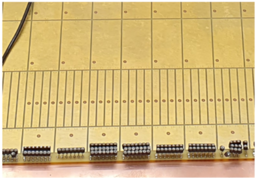


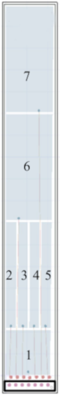


Highly granular noble-liquid calorimeter

- Printed circuit board (PCB) technology allows "arbitrarily" high granularity
  - Signal traces inside the electrode
- Prototype PCB 58 cm $\times$ 44 cm $\rightarrow$
  - 50° inclination, 40 cm (22 χ_0) thick
  - Split to 16 θ-towers & 12 depth layers
  - Narrow strips in front for π^0 detection
- 7-layer PCB, complex internal structure
- 240 cells in total in the first prototype
- Read-out from inner and outer edge

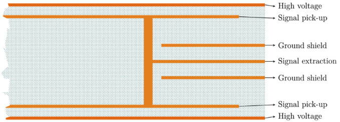


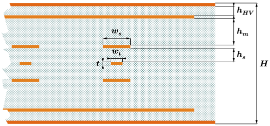


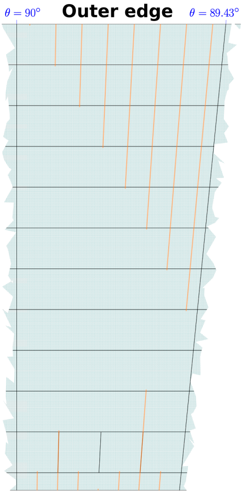


Readout electrode structure & shielding

- Signal traversing under other cells induces *cross-talk* (x-talk) that reduces main signal
- Can be mitigated by shielding signal traces with grounded strips
- **Trade-off between x-talk and electronics noise**
  - Shields reduce x-talk but increase noise
- In PCB v0 baseline is 2x width shields above and below each signal trace
  - Other configurations implemented for studies

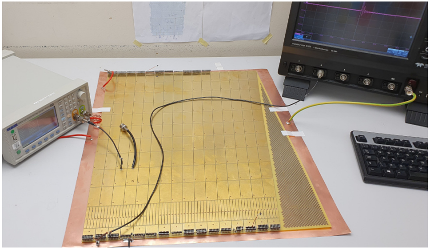


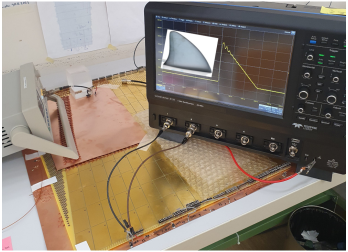




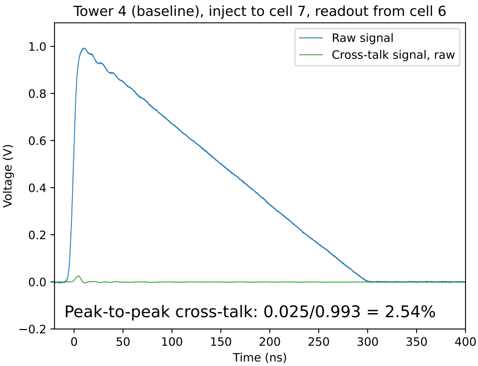
PCB measurement setup

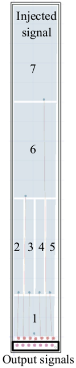
- Electrical properties measured with a table-top setup
- Copper sheet as grouding and "absorber" above and below
- Function generator used for injecting shark-fin signal
  - 300 ns wide 1 V peak at 5 ms intervals
- Signal read with oscilloscope and analyzed offline
- Extra care needed for good quality measurements
  - Short cables, thorough grounding, impedance matching





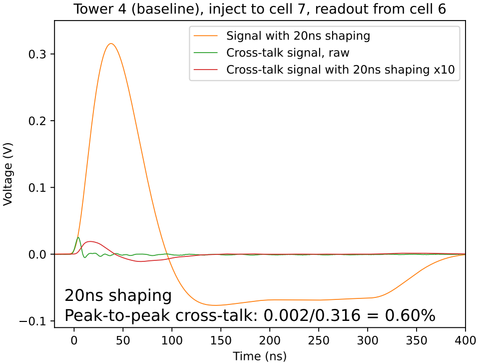
PCB measurements

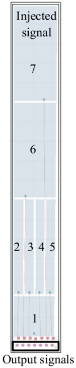




- Compare main signal magnitude to x-talk signal
- X-talk measured as "peak-to-peak" ratio
- X-talk ratio of <1% is needed and achieved with *shaping* $\rightarrow$

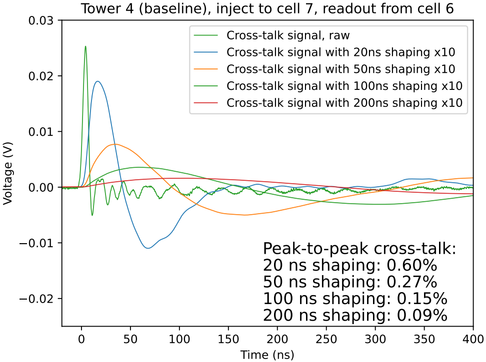
PCB measurements





- Shape signals with ATLAS-style CR-RC^2 shaper
  - Here modeled by an analytical function
  - In reality implemented with electronics
  - Other shaping functions will be studied
- After shaping x-talk signal too small to see $\rightarrow \times 10$

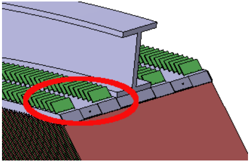
Cross-talk and shaping time

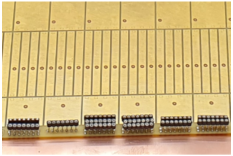


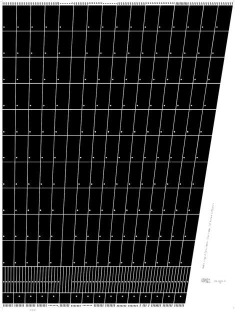
- Longer shaping time gives lower x-talk in e^+e^- conditions
  - At LHC long shaping times not good due to pileup
- X-talk down to 0.1% and less with long shaping time
- Low x-talk seen also in other shielding configurations

Plans for next PCB prototype

- Simulation studies underway for optimizing granularity
- Readout from outer edge only for minimizing dead material
  - X-talk of strip layer a challenge due to smaller signal
  - Singnal traces need to be "funneled" thru support structure
  - Read-out pins become tiny
- Would only one shield per signal strip be sufficient?
  - 6-layer PCB cheaper to manufacture and thinner $\rightarrow$ increased sampling ratio
- Need to re-design readout connections
  - Industry standard connector?
  - Soon results from Paris prototype!

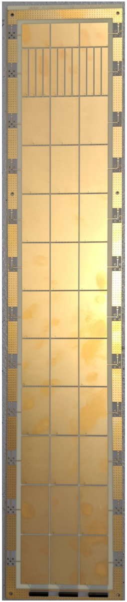




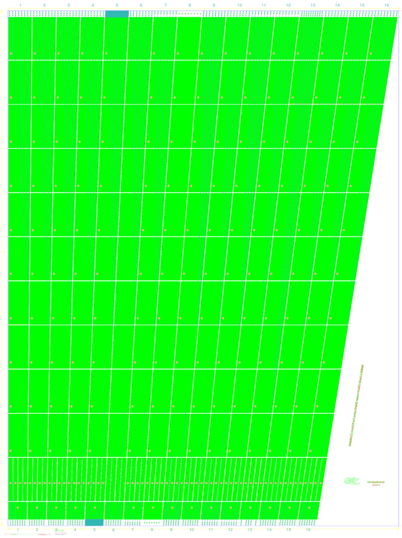


Conclusions & Outlook

- ALLEGRO is general-purpose FCC-ee detector concept
- High-granularity NL ECAL with multi-layer PCB
  - Good option for future e^+e^- experiments
  - Also excellent choice for hadron colliders
- New prototype PCB to be produced by summer
  - Smaller prototype arrived last week to IJCLab ⇒
- Test-beam prototype with 64 layers in development
  - Design frozen by 9/2024, then need to build it...
- ALLEGRO web page to be released soon
- Talk on relevant SW development this afternoon
  - Brieuc François, `https://indi.to/XVHgN`



Back-up



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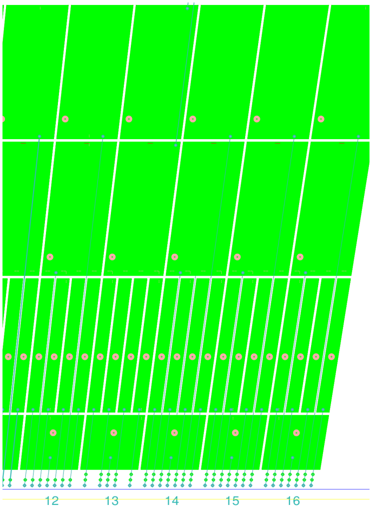

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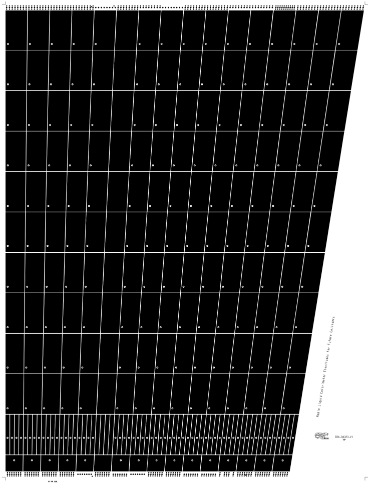
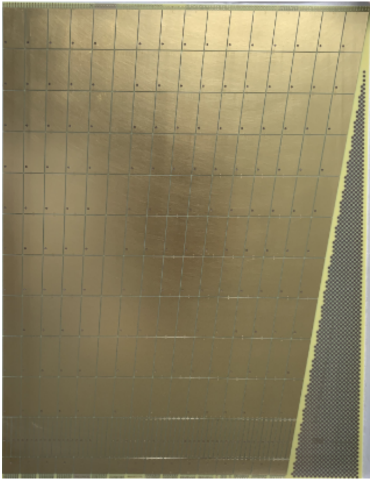
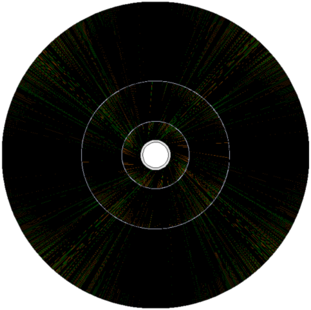

Noble Liquid Calorimeter Electrodes for Future Colliders
EDA-04323-V1



- Another consideration is the variation of the gap with radius
  - means that response is very different at the inner and outer radii (41 cm and 275 cm)
- To mitigate this, the detector can be subdivided into a set of nested cylinders:



Tradeoff between minimizing variation in gap width vs. minimizing transitions/dead areas

In this example, each cylinder has $r_o/r_i \approx 1.9$