Second ECFA Workshop on e+e- Higgs/EW/Top Factories

Noble Liquid Calorimetry for Future Collider Experiments

a.k.a. ALLEGRO detector concept & ECAL development

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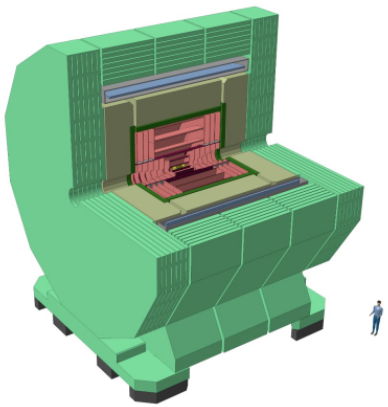
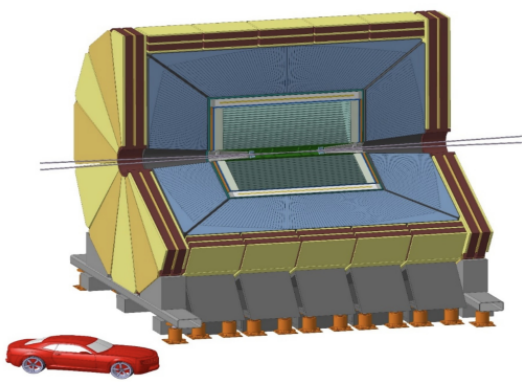
Outline

- ALLEGRO detector concept
- Noble liquid calorimetry
- Read-out electrode prototype & cross-talk studies
- Mechanical design
- Software & performance studies
- Conclusions & outlook

CLD



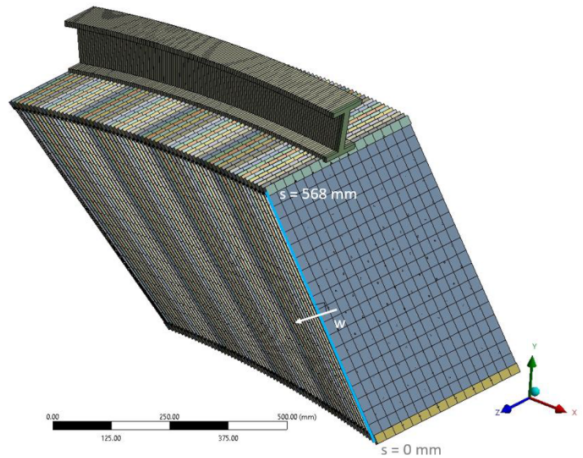
IDEA



~~Noble Liquid Based~~
ALLEGRO

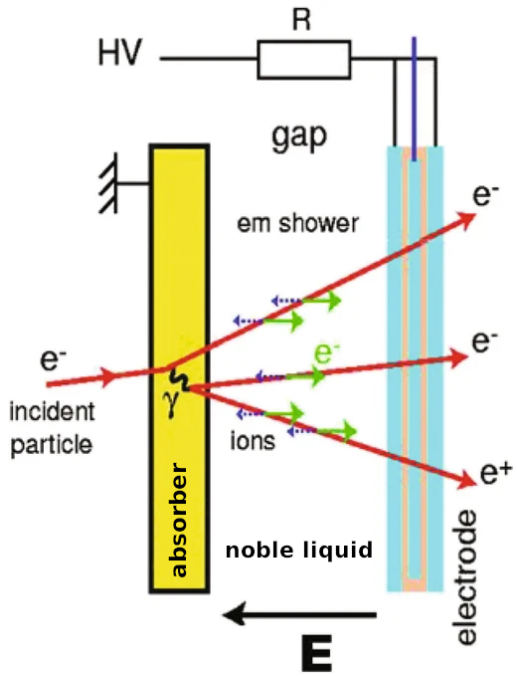
ALLEGRO detector concept

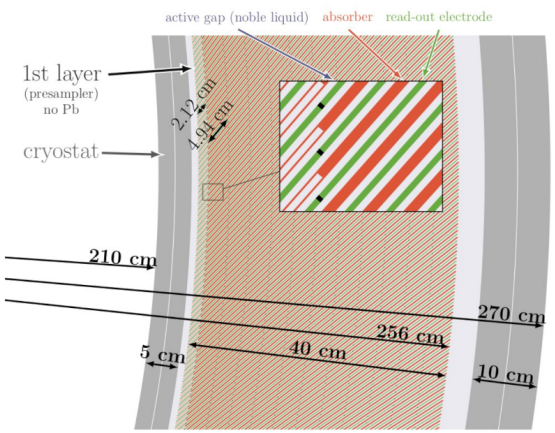
- General-purpose detector for FCC-ee
- Recently coined as ALLEGRO by a vote
  - A Lepton coLlider Experiment with Granular calorimetry Read-Out
- Concept built around a highly-granular noble liquid ECAL
  - LAr or LKr with Pb or W absorbers
  - Multi-layer PCB as read-out electrode
- Vtx detector, drift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



Refresher on noble liquid calorimetry

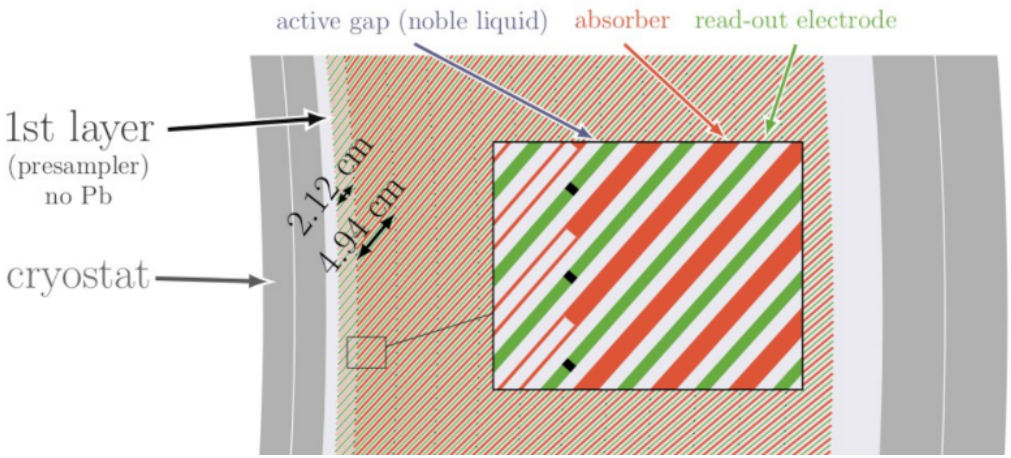
- Sampling calorimetry relying on ionization
- Based on alternating layers of absorbers, noble liquid and read-out electrodes
  - Voltage applied over noble-liquid gap
  - Incident particle ionizes noble liquid
  - e^- drift to electrodes for signal pick-up
- Successfully applied in a number of HEP experiments
  - 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

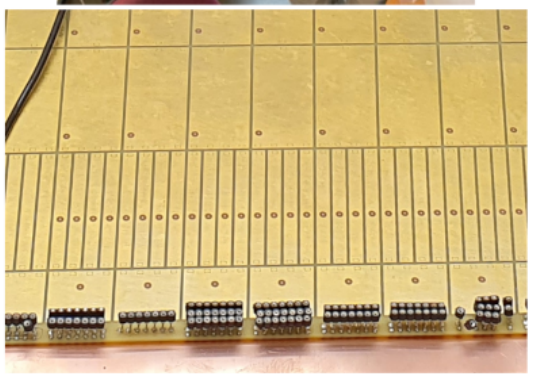


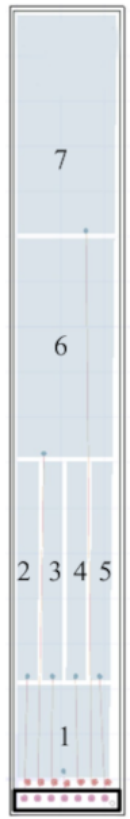


Highly granular noble-liquid calorimeter

- 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

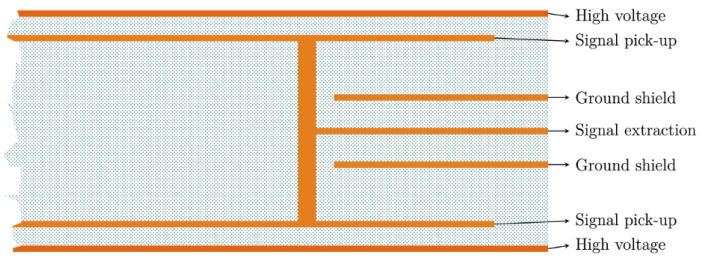


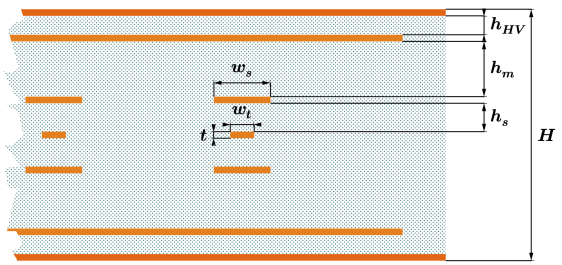


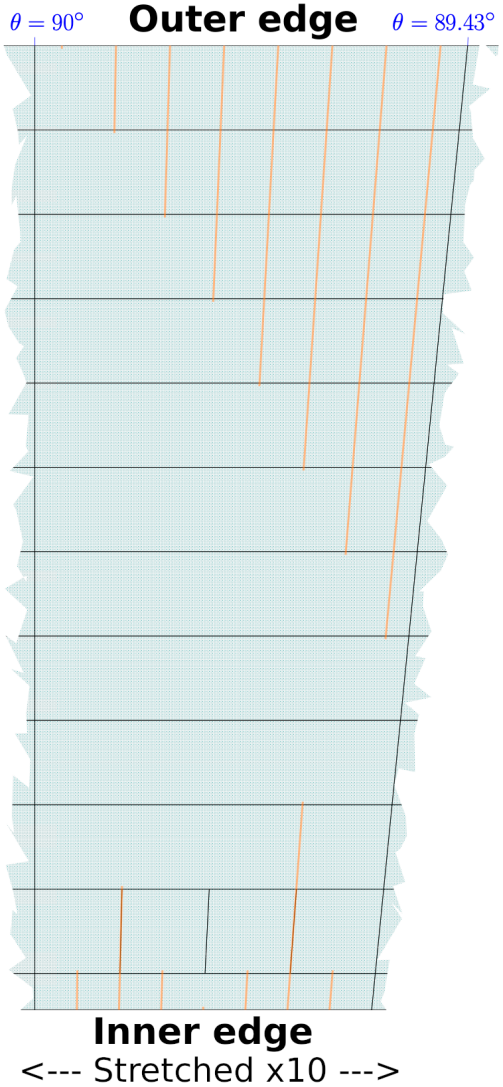


Readout electrode structure & shielding

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

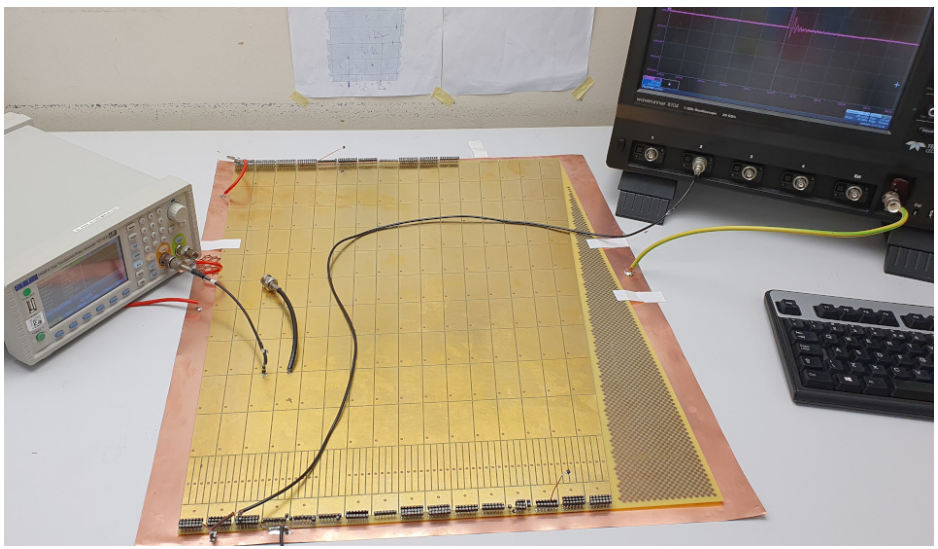


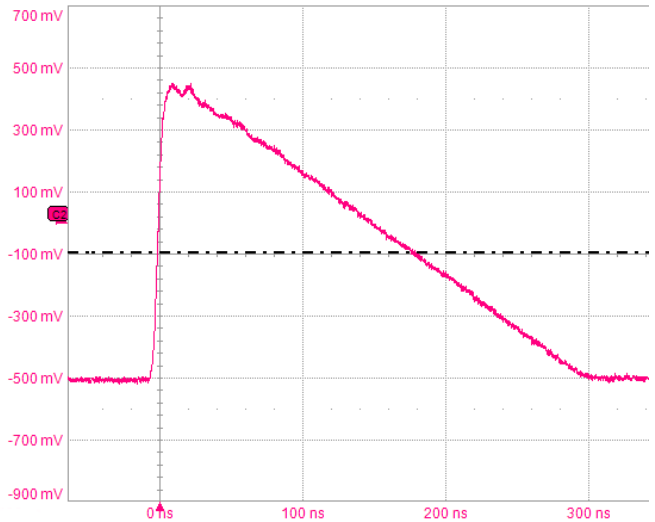




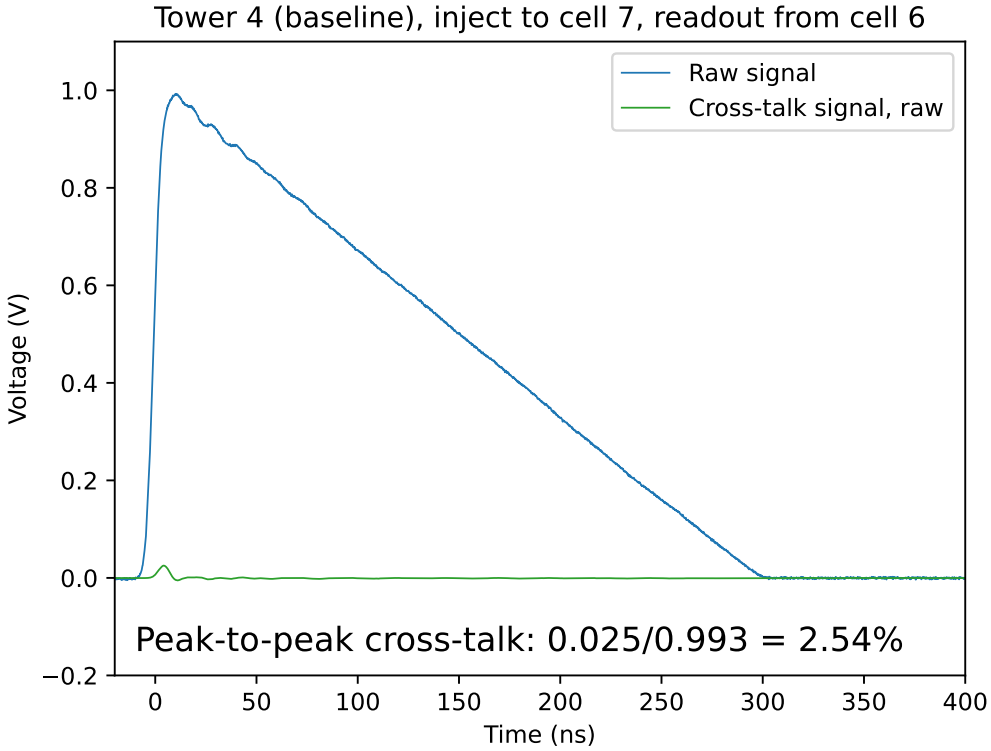
PCB measurement setup

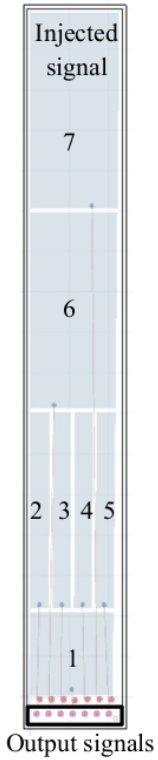
- Electrical properties of the PCB measured with a simple table-top setup
- Function generator used for injecting sharp-edged triangular signal
  - 300 ns wide 1 V peak with long (5 ms) period
- Signal read with oscilloscope, analyzed offline
- Extra care taken for ensuring good quality measurements
  - Short cables, thorough grounding, termination of signal strip, impedance matching





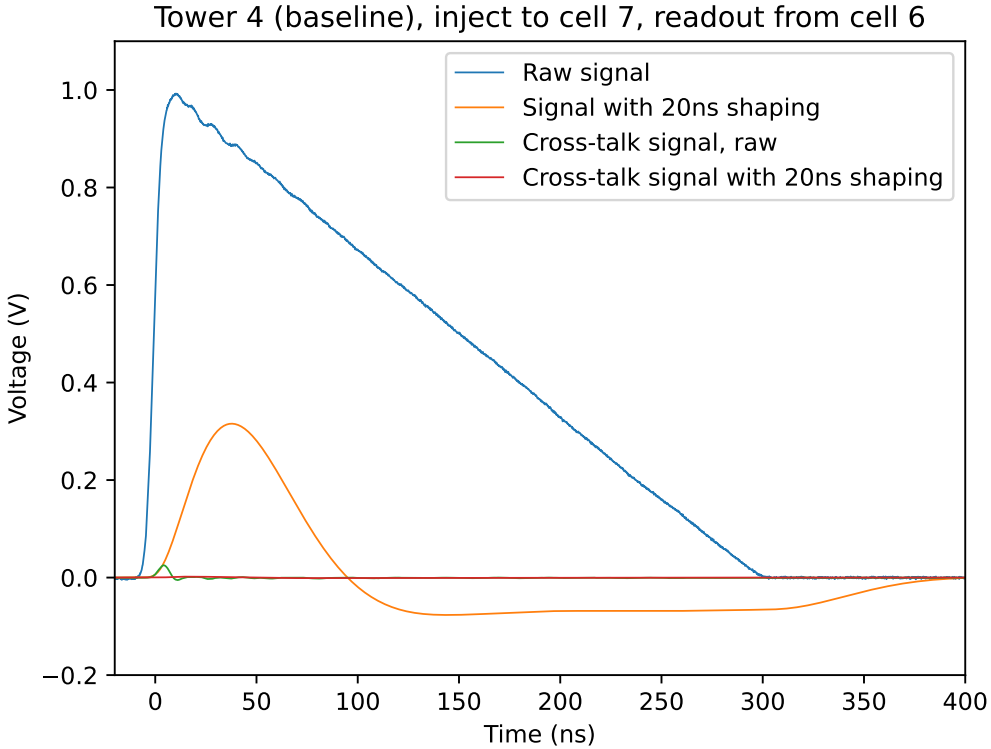
PCB measurements

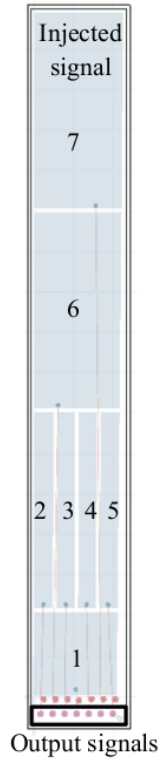




- Compare main signal magnitude to x-talk signal
- X-talk measured as "peak-to-peak" ratio
- X-talk ratio of <1% is needed and achieved with *shaping* →

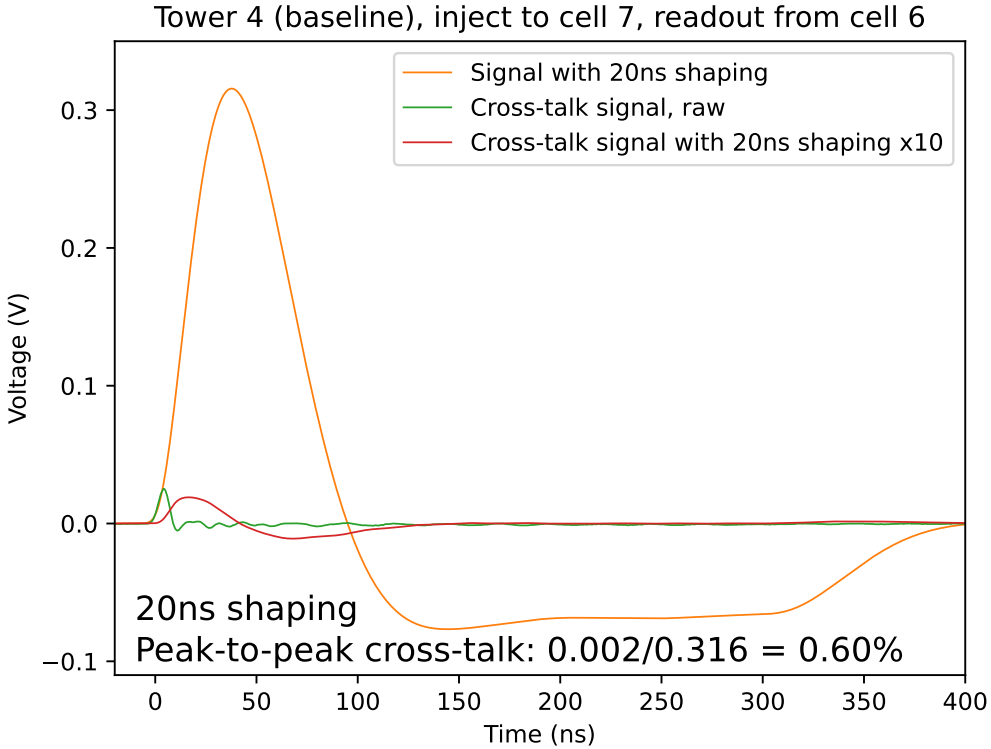
PCB measurements

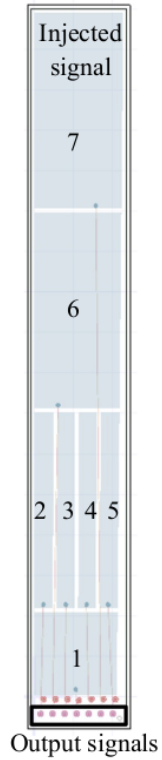




- Shape signals with ATLAS-style CR-RC^2 shaper
  - Here modeled by an analytical function
  - In reality implemented with electronics
  - Other shaping functions will be studied
- After shaping x-talk signal too small to see

PCB measurements





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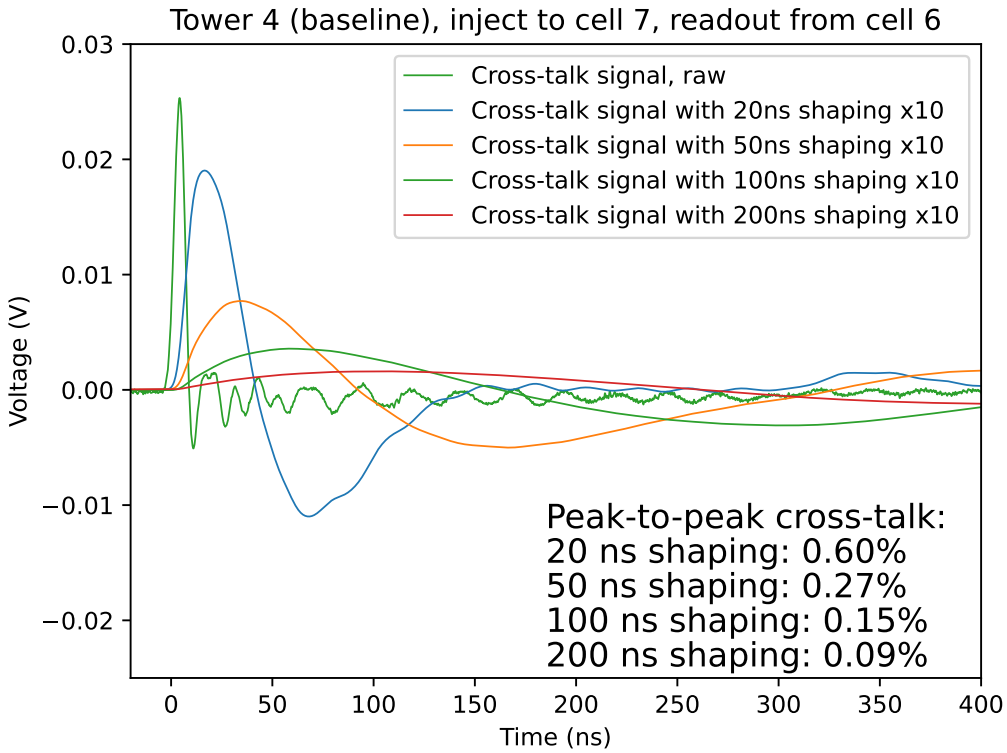
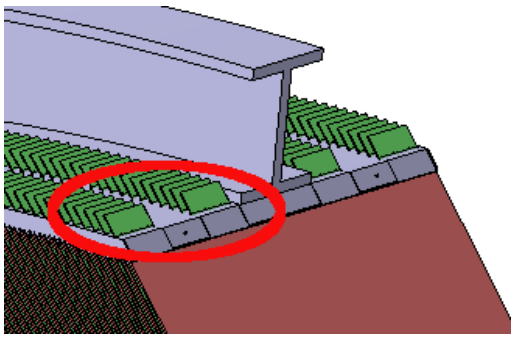
Cross-talk and shaping time

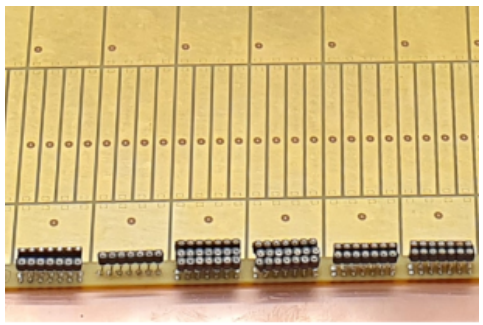


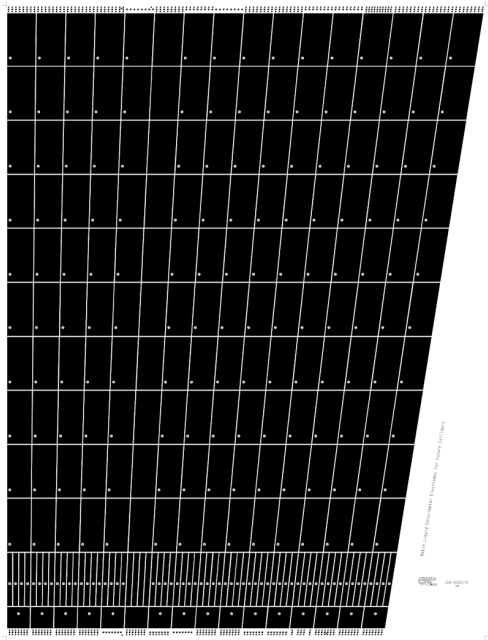
- Longer shaping time gives lower x-talk in e^+e^- contitions
  - At LHC long shaping times not good due to pileup
- Cross-talk goes down to 0.1% with 200 ns shaping
- Here only one pair of cells, more studies to be done

Plans for next PCB prototype

- Simulation studies underway for optimizing granularity
- Read-out from outer edge only for minimizing material bulk
  - Signal-to-cross-talk ratio of narrow strip layers a challenge due to smaller main signal
  - Singnal traces need to be "funneled" thru support structure
  - Will increase "trace-to-trace" cross-talk
- Would only one shield per signal strip be sufficient?
  - 6-layer PCB cheaper to manufacture
  - Thinner PCB increases sampling ratio
- Better solution to read-out connection
  - Industry standard connector?

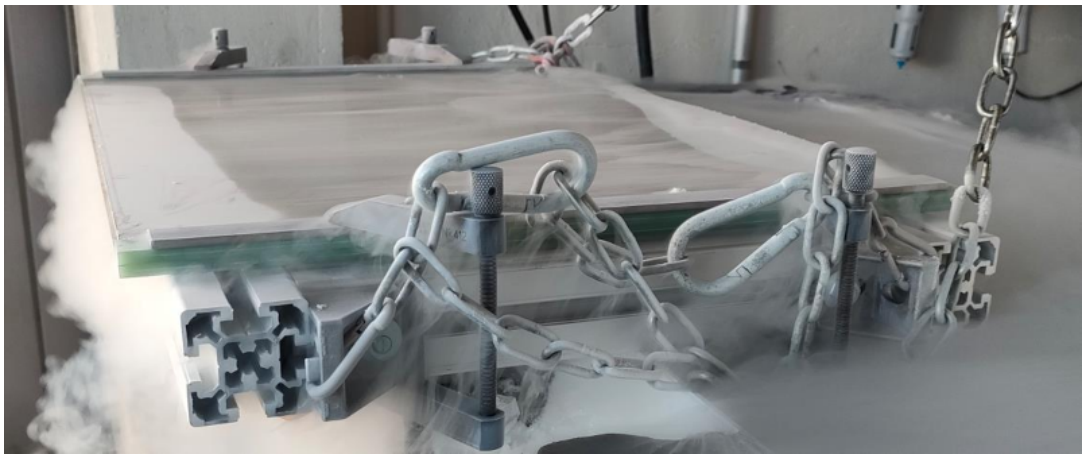


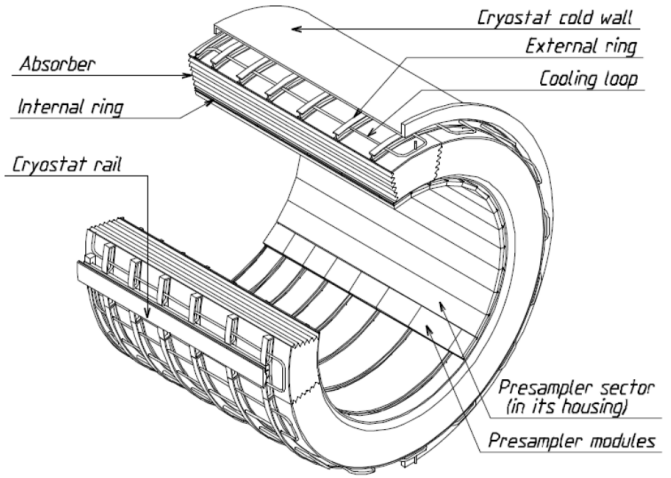




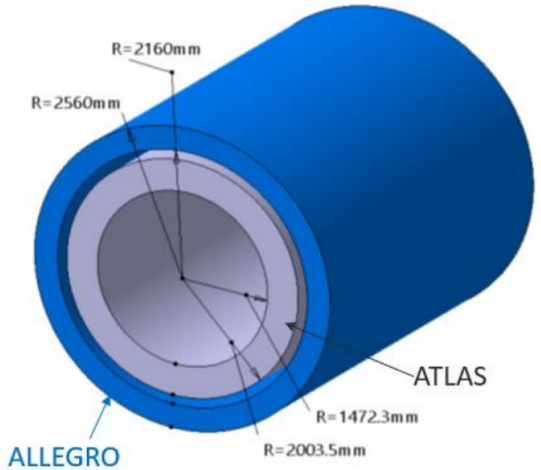
Mechanical studies

- 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 was built
  - Tested in liquid nitrogen bath, no permanent damages found





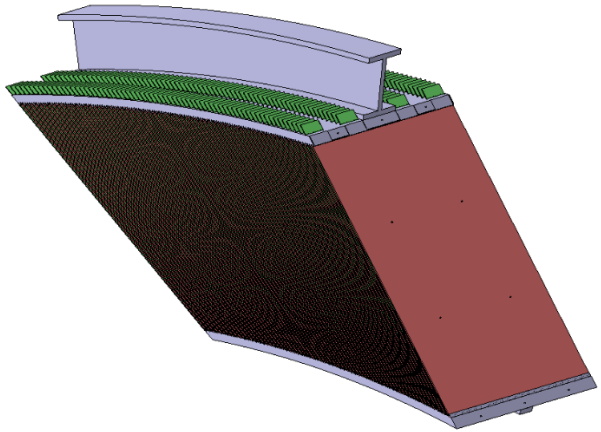
ATLAS liquid argon calorimeter general layout

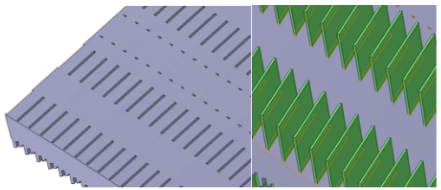


Calorimeter size comparison

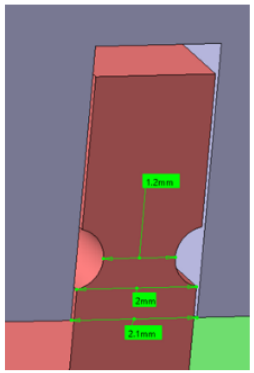
Test-beam prototype

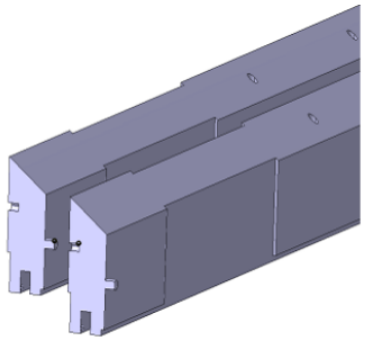
- Design of a test beam prototype to be frozen by September 2024
  - 64 electrodes and absorbers
  - Placed in a cryostat for beam tests
- 3D-printed prototype in development
  - Easy to produce and improve test parts
  - Design can be used as basis for real parts
  - Helps also in visualizing complex structure

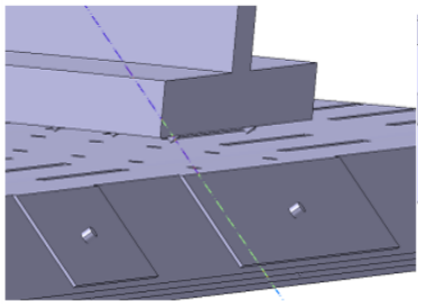


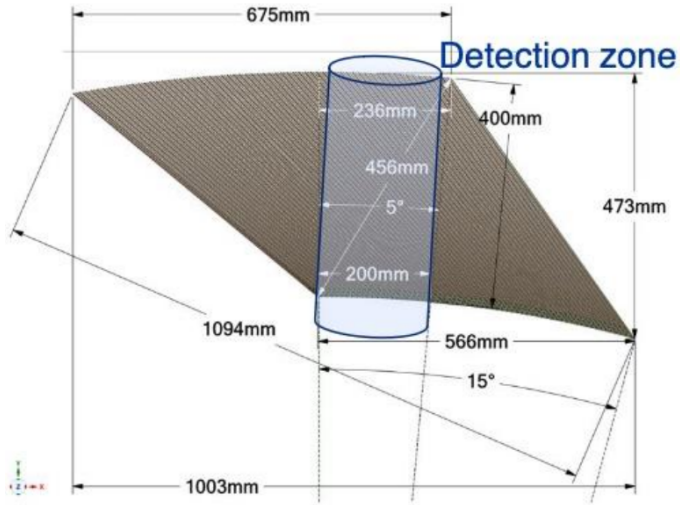


Gaps for readout



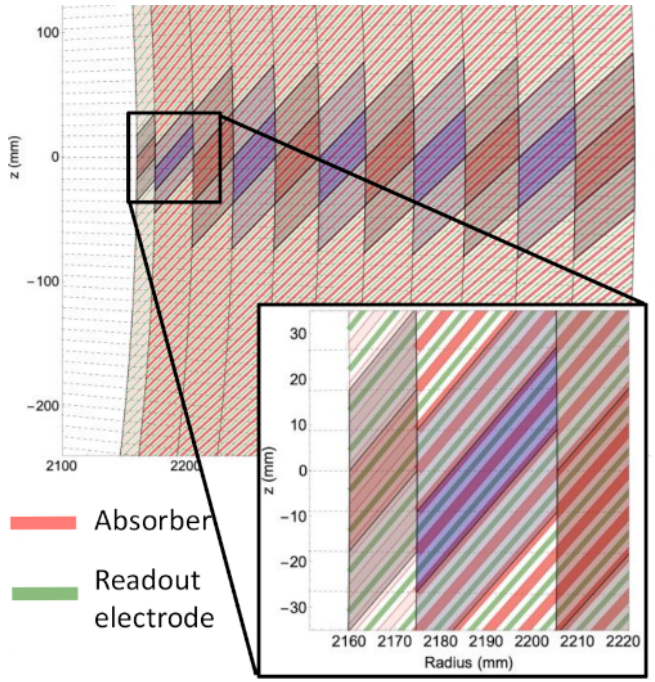


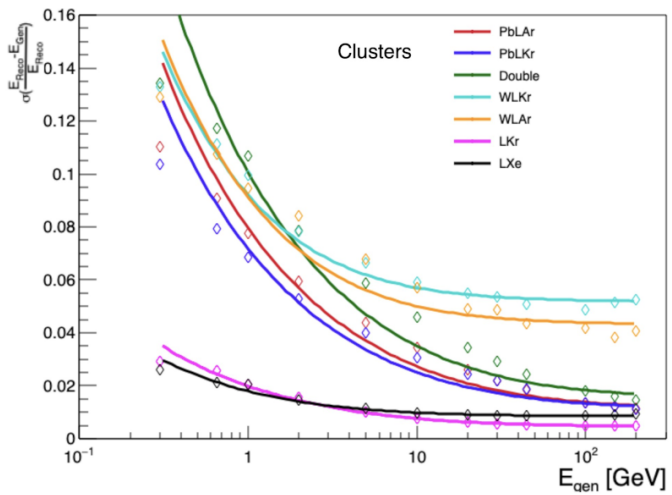


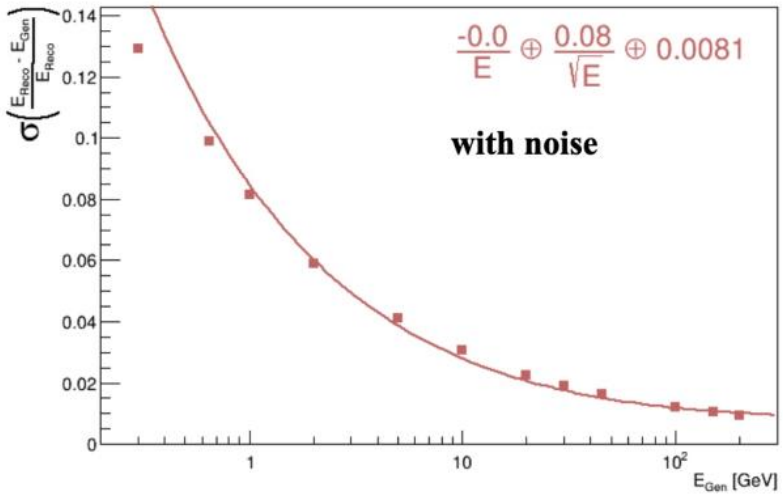


Software & Performance studies

- Full detector simulation in development in the FCC-SW in the Key4hep framework
  - Crucial already in early planning state for performance studies before test beam
- More on SW today at 4pm & Friday at 9am
  - Talks by Alvaro Delgado & Brieuc François
- Some performance studies already done, much more to be done
  - Materials, inclination, granularity, ...

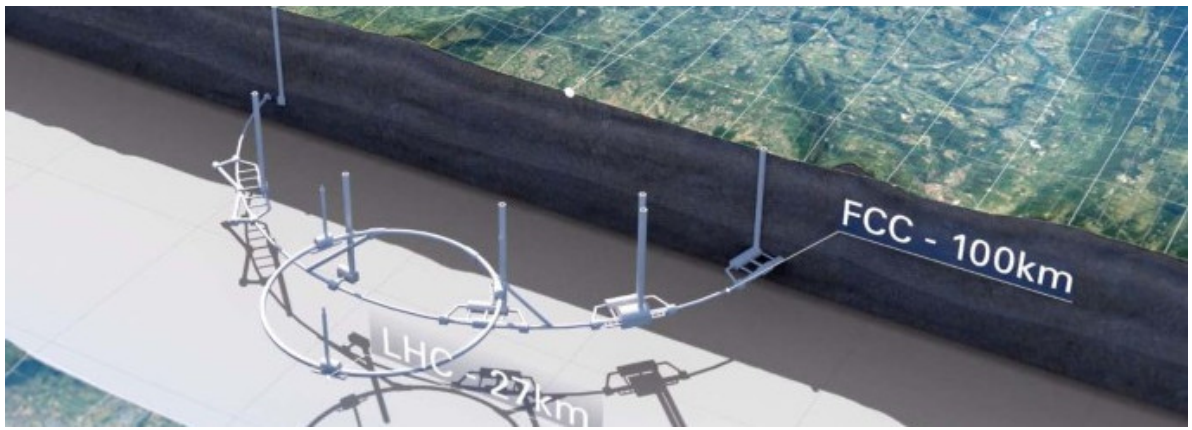




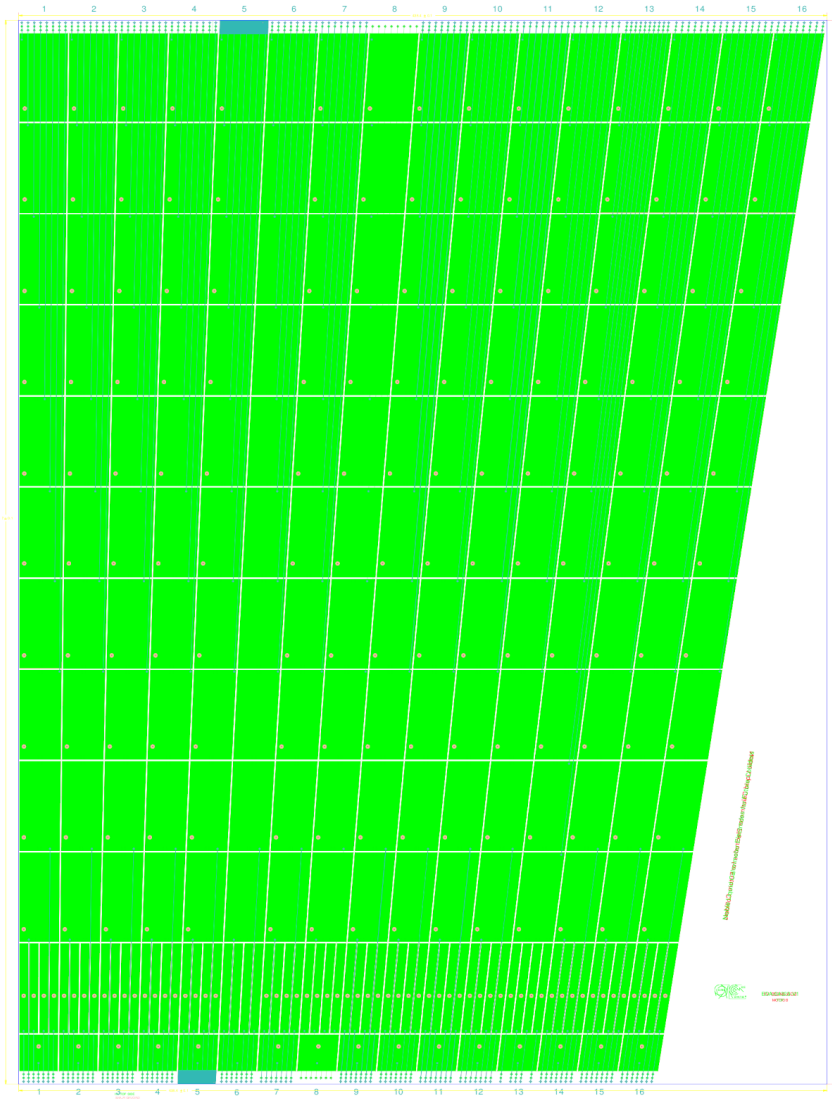


Conclusions & Outlook

- ALLEGRO is a multi-purpose detector concept for FCC-ee
- Multi-layer PCB allows high-granularity NL calorimetry
  - Good option for future e^+e^- experiments
  - Also excellent choice for hadron colliders
- New prototype PCB design in 3-4 months
  - Smaller prototype PCB coming earlier to IJCLab in Paris
- Test-beam prototype with 64 layers in development
  - Design ready by 9/2024, then need to build it...
- Draft web page done, to be published within next months
- Team is growing fast, more people always welcome!



Back-up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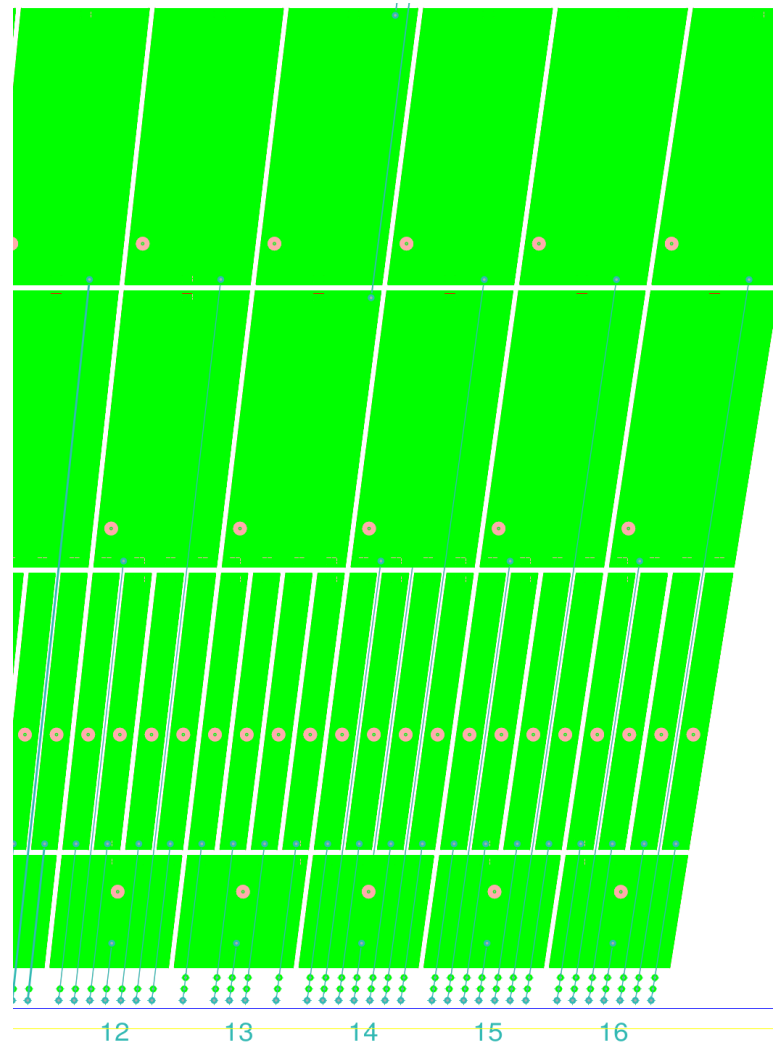
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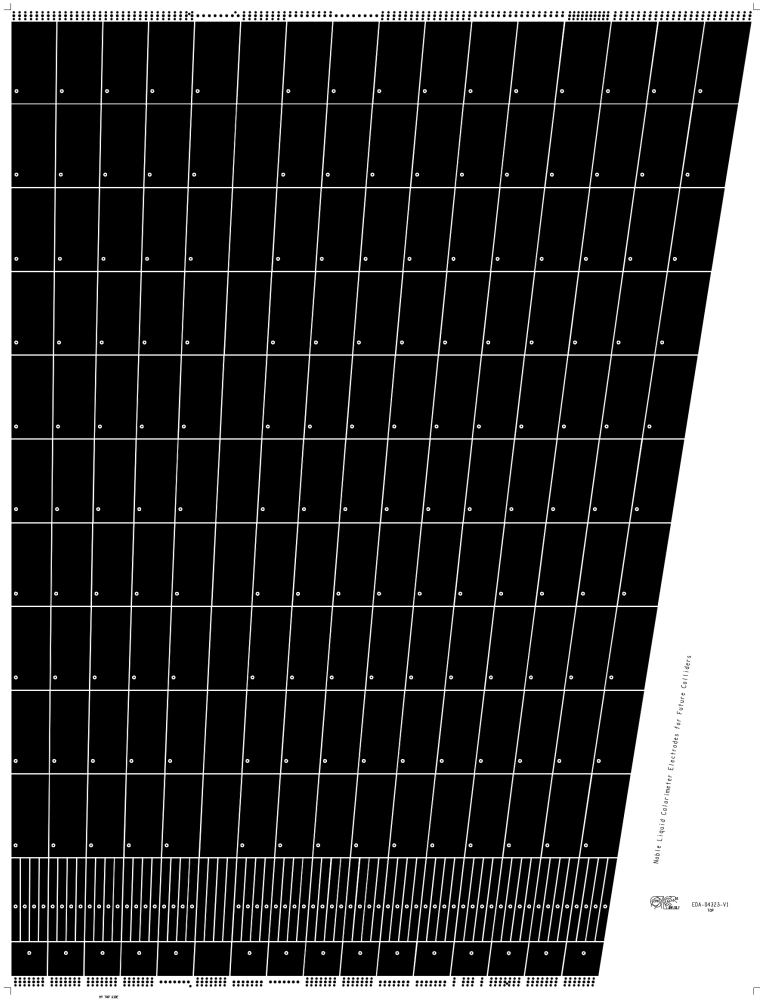
Multi-Layer Printed Circuit Boards for Liquid Calorimeter Electrodes for Future Colliders
EDA-04323-V1