# WP2:
# Liquified Noble Gases Calorimeters

Nicolas **Morange**, *IJCLab*

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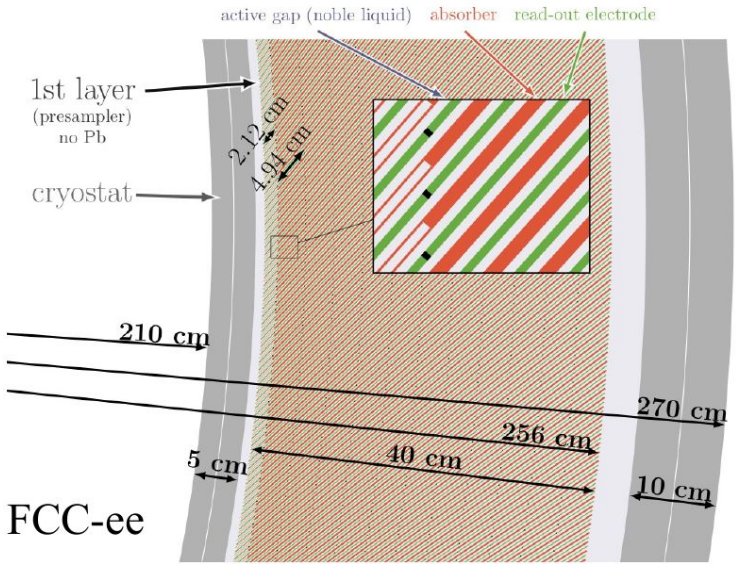
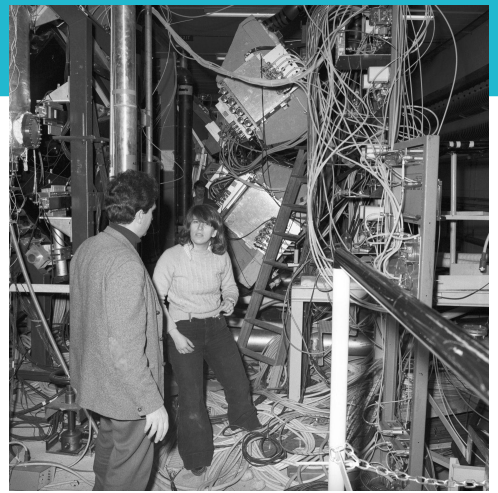
# WP2: a One-Project Work Package

**WP2 == ALLEGRO Ecal**

- R&D for next generation liquified noble gas calo started as (only ?) viable solution for FCC-hh detector
  - Goal: high-granularity (~ ATLAS ×10) for good PFlow reconstruction in high pile-up environment
- Switched to an R&D project towards an $e^+e^-$ Higgs factory detector
  - Same basic concept
  - $e^+e^-$ environment allows for significant design optimisations towards ultimate noble liquid calo performance

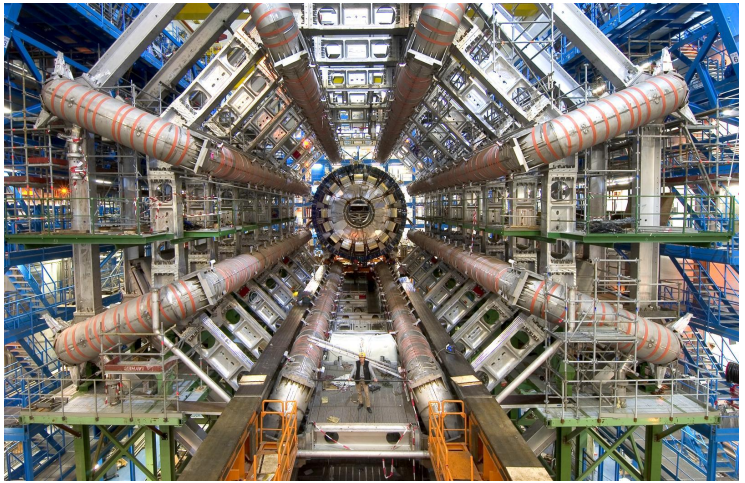


# Noble liquid based Ecal



- Decades of success at particle physics experiments: from R806 to ATLAS
  - Mostly LAr, a bit of LKr
- An appealing option for FCC-ee
  - Good energy resolution
  - High(-ish) granularity achievable
  - Linearity, uniformity, long-term stability
  - Easy to calibrate

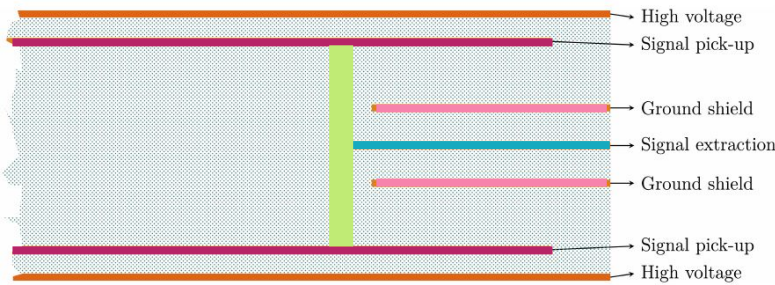
**Excellent solution for small systematics**



- Lots of interesting studies / R&D to do
  - Optimization for PFlow reconstruction
  - Achieving very low noise
  - Lightweight cryostats to minimize $X_0$
  - Designing for improved energy resolution

# Granularity of Noble Liquid Calorimeters

- Calo 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



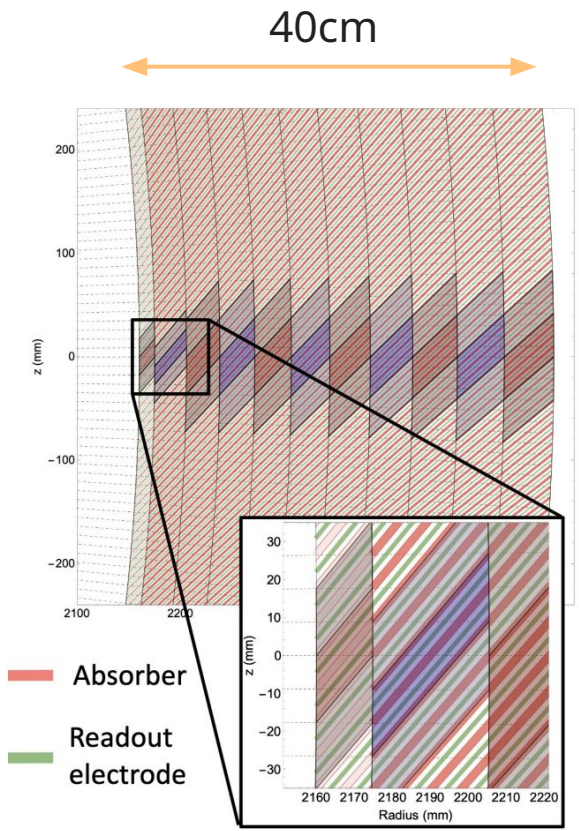
# Allegro Ecal Barrel Design

## Design driven by the solution used for electrodes

- 1536 **straight inclined** (50°) 1.8mm **Pb** absorber plates
- Multi-layer PCBs as readout electrodes
- 1.2 – 2.4mm **LAr** gaps (**LKr** seriously considered)
- 40cm deep (22 $X_0$)
- $\Delta\theta$ = 10 (2.5) mrad for regular (strip) cells, $\Delta\phi$ = 8 mrad,
  12 longitudinal layers

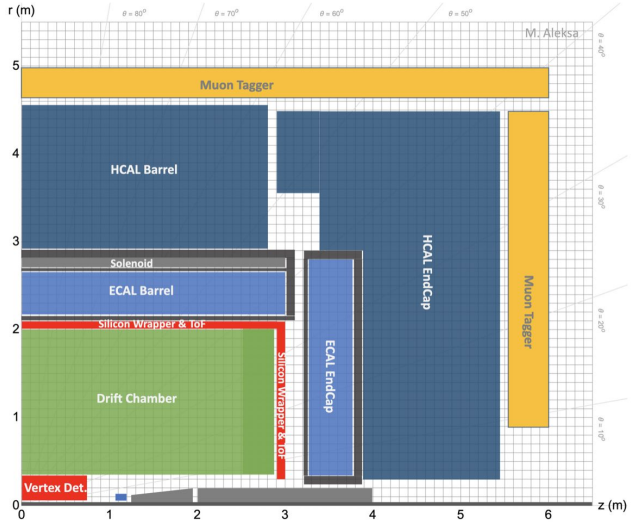
## Copper electrodes: lots of flexibility

- Number of layers and granularity of layers fully optimizable
- Projective cells
- ➢ Lots of room for optimisation !



# Main goals of the project

- Develop the calo design
  - Study design solutions for endcaps
  - Study general performance in simulation, in combination with some HCAL concept
  - Optimize granularity
- Build a first prototype and measure performance in testbeam
  - Need to design and optimize electrodes, absorbers
  - Readout electronics
  - Can then be refined to test further developments / new ideas




**4 Main Tasks**

1. General design and expected performance
2. Readout electrodes
3. Readout electronics
4. Mechanical studies and prototype

# Participating institutes

**New partners are always welcome !**



















# Work Package 2 Organization

- Have setup an Institute Board (IB)
- Following an election process, Marc-Andre Pleier (BNL) has been elected IB Chair, and N.M. is WP2 Leader
- More details on the organization will be discussed tomorrow in the WP2 2nd parallel session

**Please join the WP2 parallel session if you are curious about the project !**

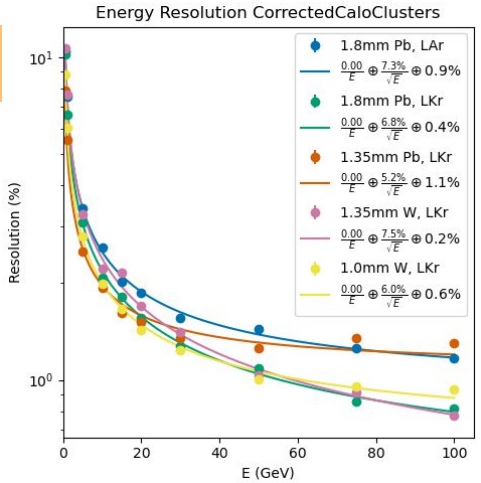
# And now for the fun part !

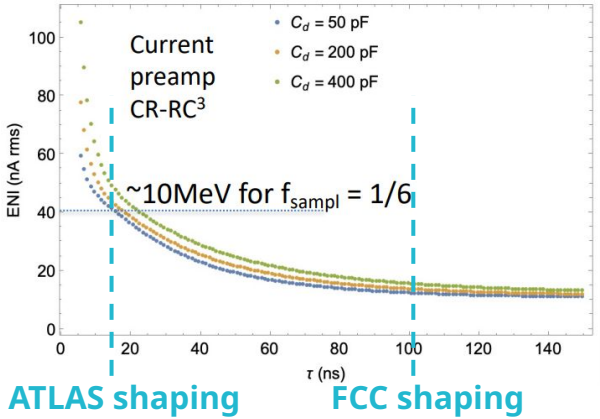
# Energy resolution: design options and noise

**Energy resolution: σ(E)/E = a/E + b/√E + c ⇒ 3 terms to optimise !**

- Constant term
  - Hermeticity, low dead material, uniformity
- Sampling term: improve sampling fraction
  - Optimise gap size, sampling fraction, active and passive material
  - Explore LAr ⇒ LKr, Pb ⇒ W
    - between 5% and 7.5%
- Noise term: readout electronics
  - Want: measurement of 200 MeV photons, S/N>5 for MIPs
  - Longer shaping time wrt ATLAS (200 ns) helps a lot
  - Cold frontend electronics in the cryostat would provide noiseless readout

$$N \sim C_d \sqrt{\frac{4kT}{g_m \tau_p}}$$

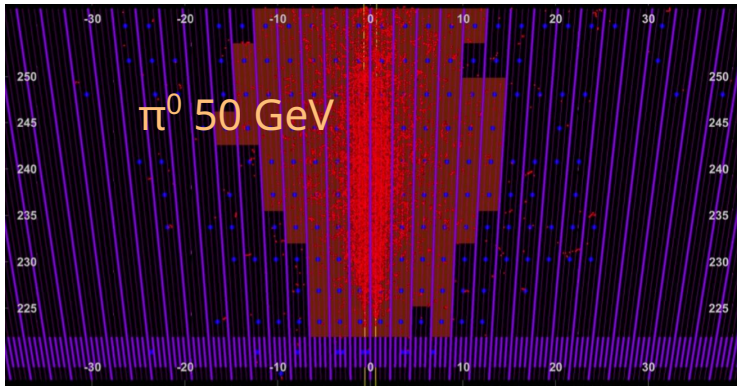


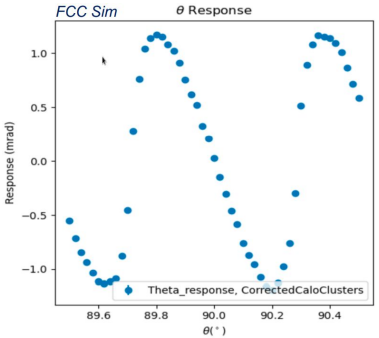



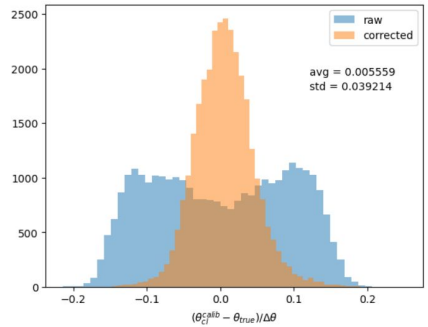
# PID/PFlow: granularity optimisation

**2023: important groundwork. ⇒ 2024: granularity optimisation studies possible**

- Flexible geometry implemented in Full sim
  - Can study EM shower shapes
  - Benchmark: photon / $\pi^0$ separation
  - Ongoing: implementation of cross-talk effects
- Calibrations of reconstruction
  - Simple MVA energy regression of EM clusters
  - Cluster position calibration per layer
    - Allows pointing studies (⇒ ALPs)
- Particle Flow on its way
  - Using Pandora toolbox
  - For technical reasons, pioneered in detector sim with Allegro Ecal + CLD Tracker
  - Hope for first results in 2024 !



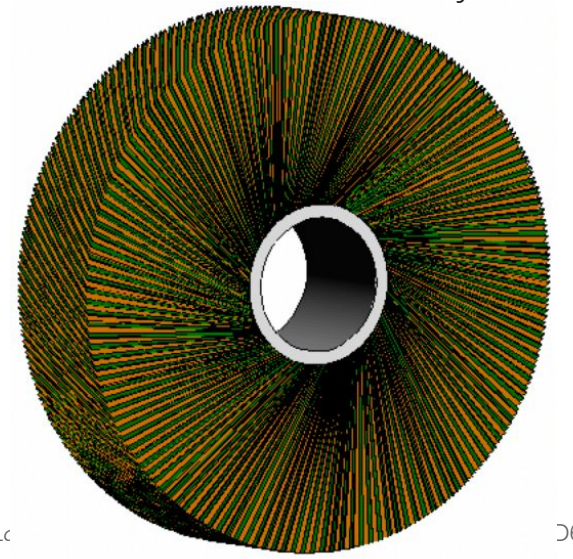



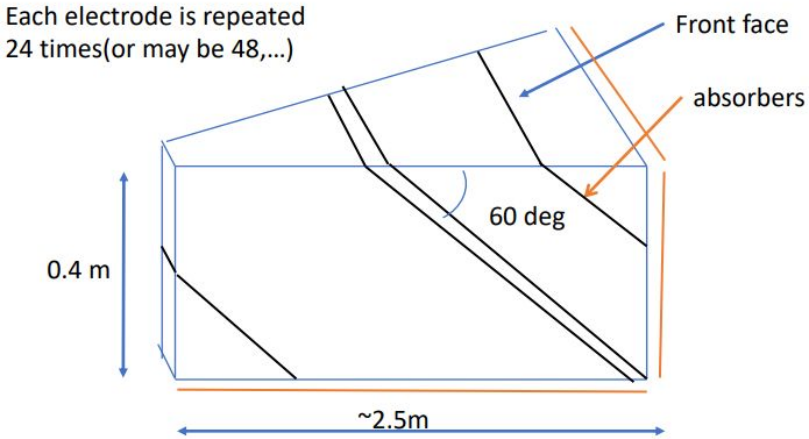
# Designs for the endcaps: first ideas

**Endcaps designs more complex than that of the barrel: very preliminary ideas !**

- "Turbine" design
  - More similar to barrel design
  - Symmetric in ϕ
  - Issue: increase in the size of the Noble liquid gaps
  - Need to stack several cylinders

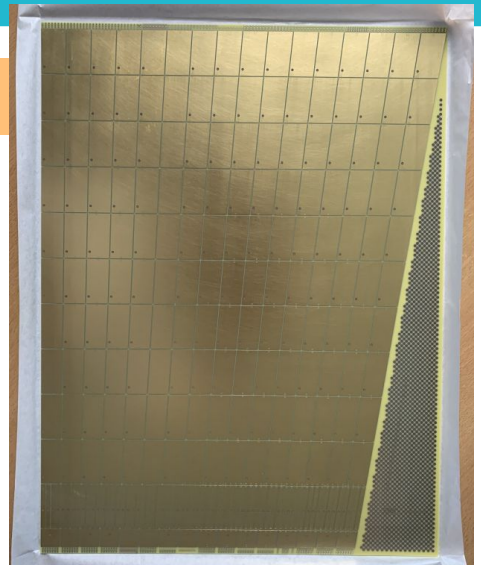


- XY / Pie wedge designs
  - Less symmetry in ϕ
  - Increase of LAr gaps under control
  - Many types of electrodes to draw and produce

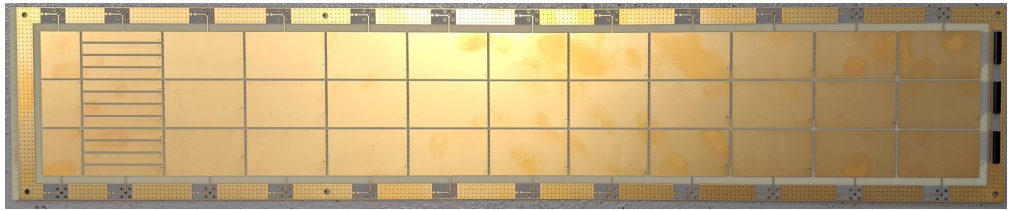


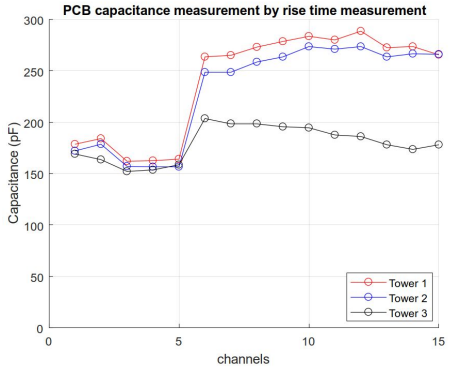
# Electrodes prototypes

**Explore tradeoffs: max granularity / capacitance (noise) / cross-talk**



- First large-scale prototype at CERN
  - Explore many options for grounding, for shields
  - First layers 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
  - New shielding ideas
  - Development of system for automated measurements

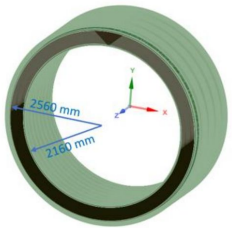


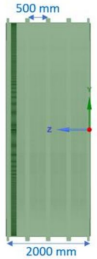


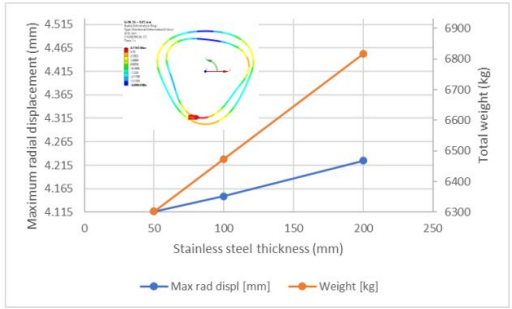
# Mechanical studies

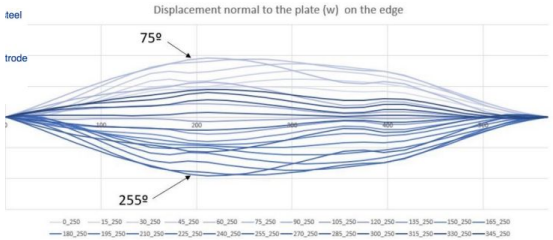
## Simulation studies

- Model the full barrel
  - Define support structures, spacers
  - Study thickness of steel sheet
  - Simulations in warm and in cold



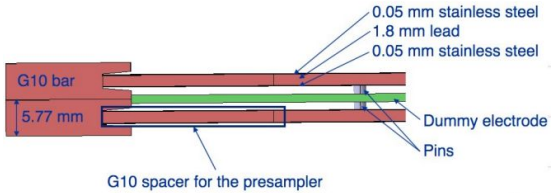



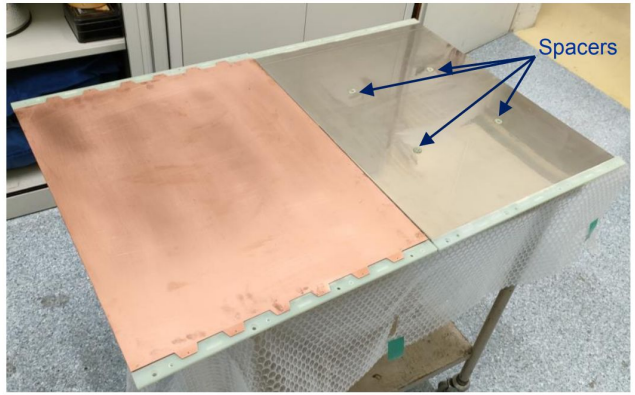




## Absorbers prototypes

- First feasibility prototypes
  - Verify assumed rigidity
  - Thermo-mechanical tests in liquid nitrogen

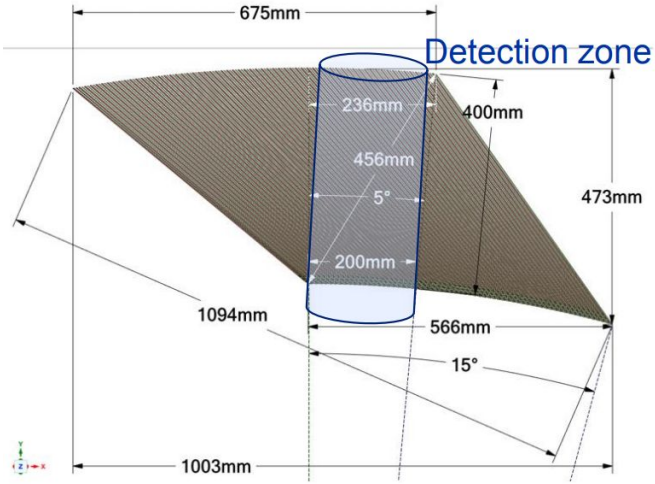


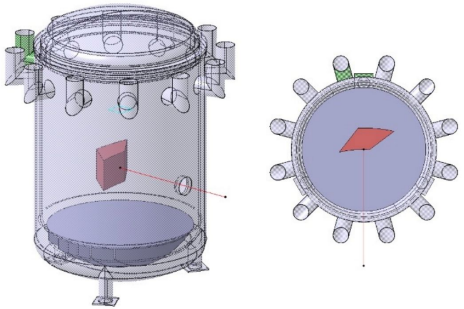
# Towards a testbeam module

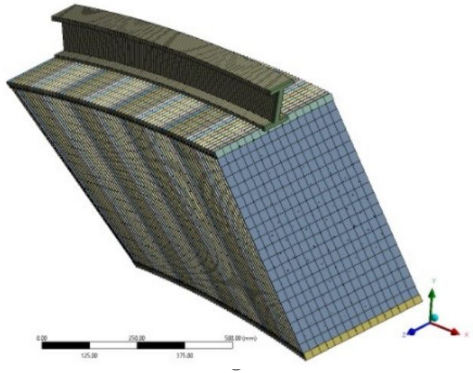
**Plan to produce test module in the next four years**

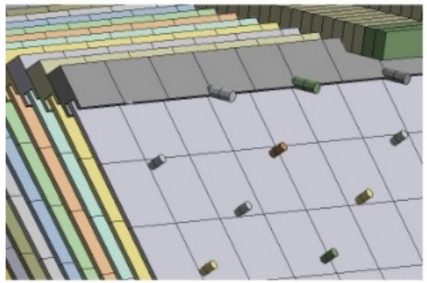
- Mechanical design of module (64 absorbers) has started
  - First finite element calculations performed
- Work on finding / adapting testbeam cryostat
- Common tools (e.g EUDAQ) should facilitate integration in testbeam facility




The cryostat available to make the test beam is the CRRP-00563.







# Conclusions

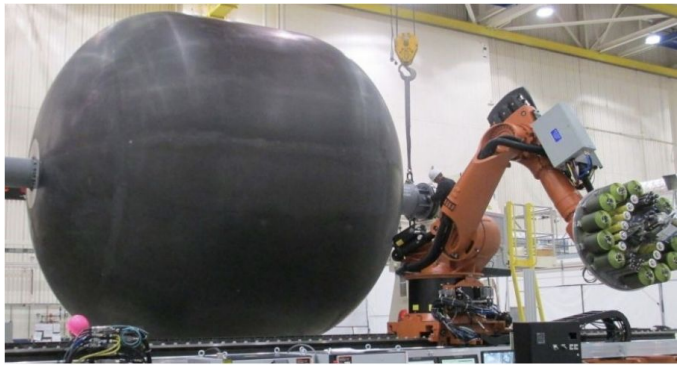
- WP2 is a one-project work package
- Goals of ALLEGRO Ecal R&D well defined
- Exciting studies going on / starting
- Internal organization of the work package being defined

# Supplementary Material

# Cryostat and feedthroughs

## Low mass cryostats

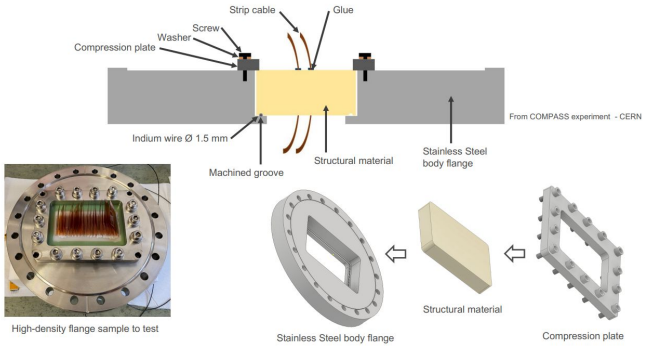
- Minimise dead material in front
  - Use of sandwiches with carbon fiber + Al honeycomb
  - Synergy with progress in aerospace
- CERN R&D: address CFRP/Metal interfaces
- Promises for **"transparent" cryostats**: few % of $X_0$ !

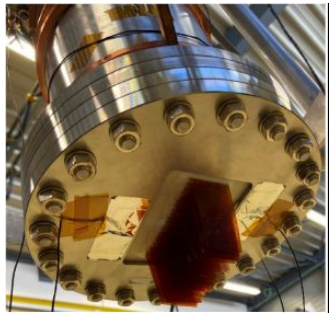


NASA's lineless cryotank

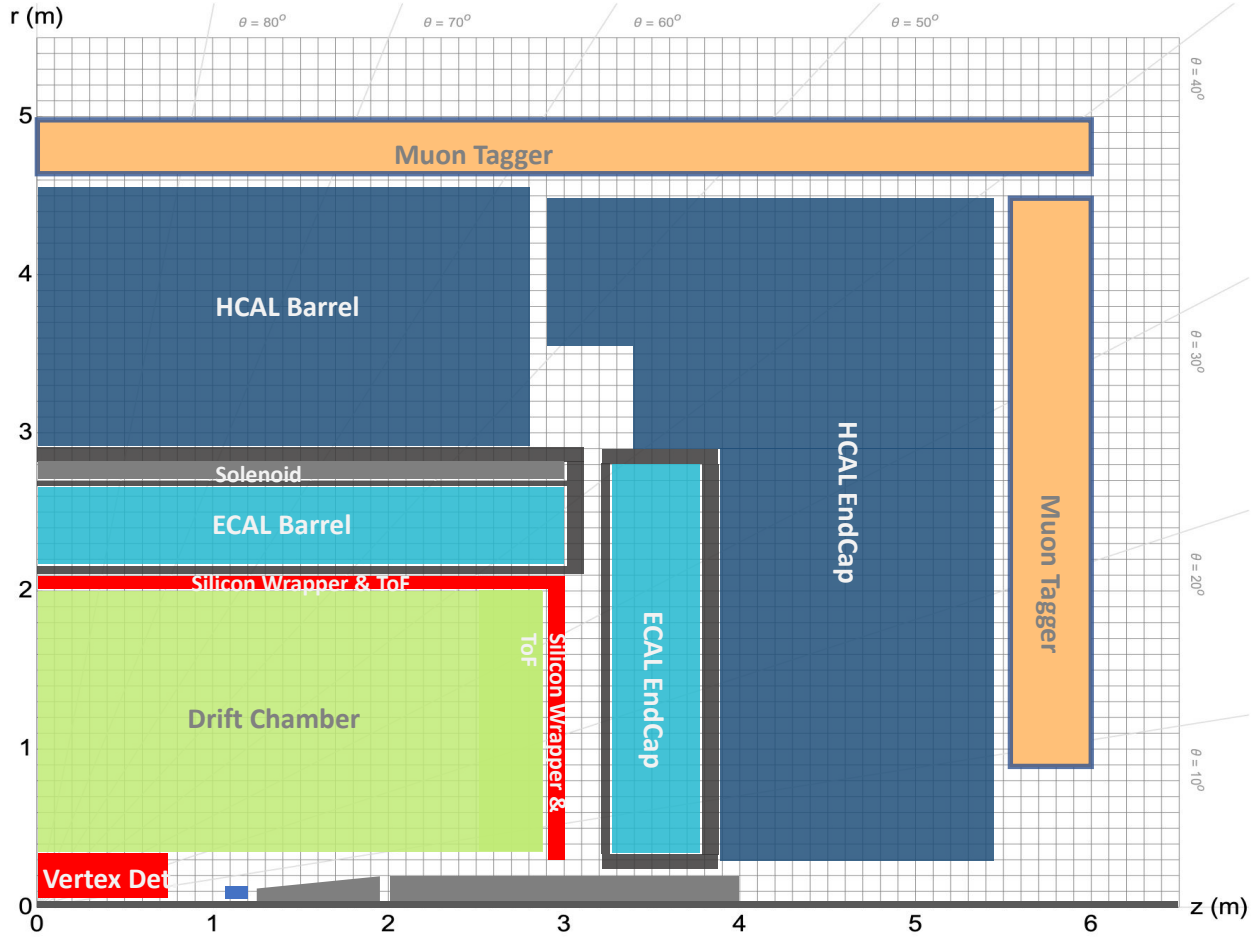
## High-density feedthroughs

- Aim for ~ ×5 density and ~ ×2 area wrt ATLAS
- Successful R&D on connector-less feedthroughs at CERN
  - 3D-printed epoxy resins structures with slits for strip cables, glued to the flange
  - Leak tests and pressure tests at 300 K and 77 K



# Allegro detector concept




**A** Lepton co**L**lider **E**xperiment with **G**ranular **R**ead-**O**ut

- **Vertex Detector**:
  - MAPS or DMAPS possibly with timing layer (LGAD)
  - Possibly ALICE 3 like?
- **Drift Chamber** (±2.5m active)
- **Silicon Wrapper + ToF**:
  - MAPS or DMAPS possibly with timing layer (LGAD)
- **Solenoid B=2T**, sharing cryostat with ECAL, outside ECAL
- **High Granularity ECAL**:
  - Noble liquid + Pb or W
- **High Granularity HCAL** / Iron Yoke:
  - Scintillator + Iron
    - SiPMs directly on Scintillator or
    - TileCal: WS fibres, SiPMs outside
- **Muon Tagger**:
  - Drift chambers, RPC, MicroMegas