NEWS FROM THE ALLEGRO DETECTOR CONCEPT

Nikiforos Nikiforou (CERN)

ALLEGRO DETECTOR CONCEPT

A **L**epton-**L**epton collider **E**xperiment with **G**ranular **R**ead-**O**ut: high-performance, general-purpose detector concept

Built around a noble liquid ECAL (DRD6 WP2) and scintillator based HCAL (DRD6 WP3)

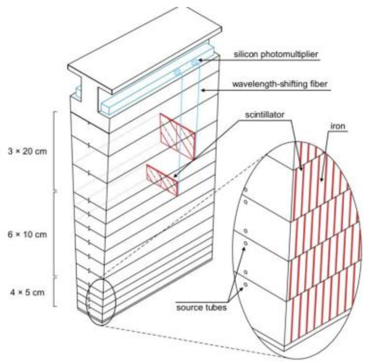
- Expanding and adapting work done for calorimetry at FCC-hh (see arxiv:1912.09962)
- Taking advantage of experience in successful construction and operation of the ATLAS Calorimeters at the LHC

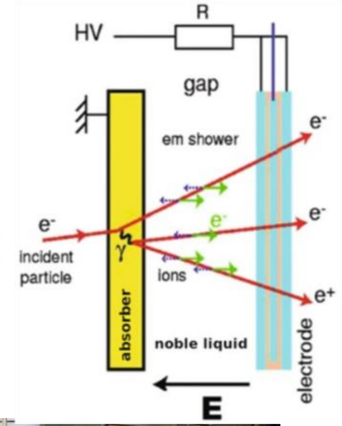
R&D of Noble-Liquid calorimeter for future colliders ongoing since a few years now

- **Now part of DRD Calo forming WP2**

This is the work of a relatively small team of people which is growing!

Quick reminder of the concept today and updates mainly from ECAL Mechanics and Electrode design efforts





ALLEGRO

https://allegro.web.cern.ch/

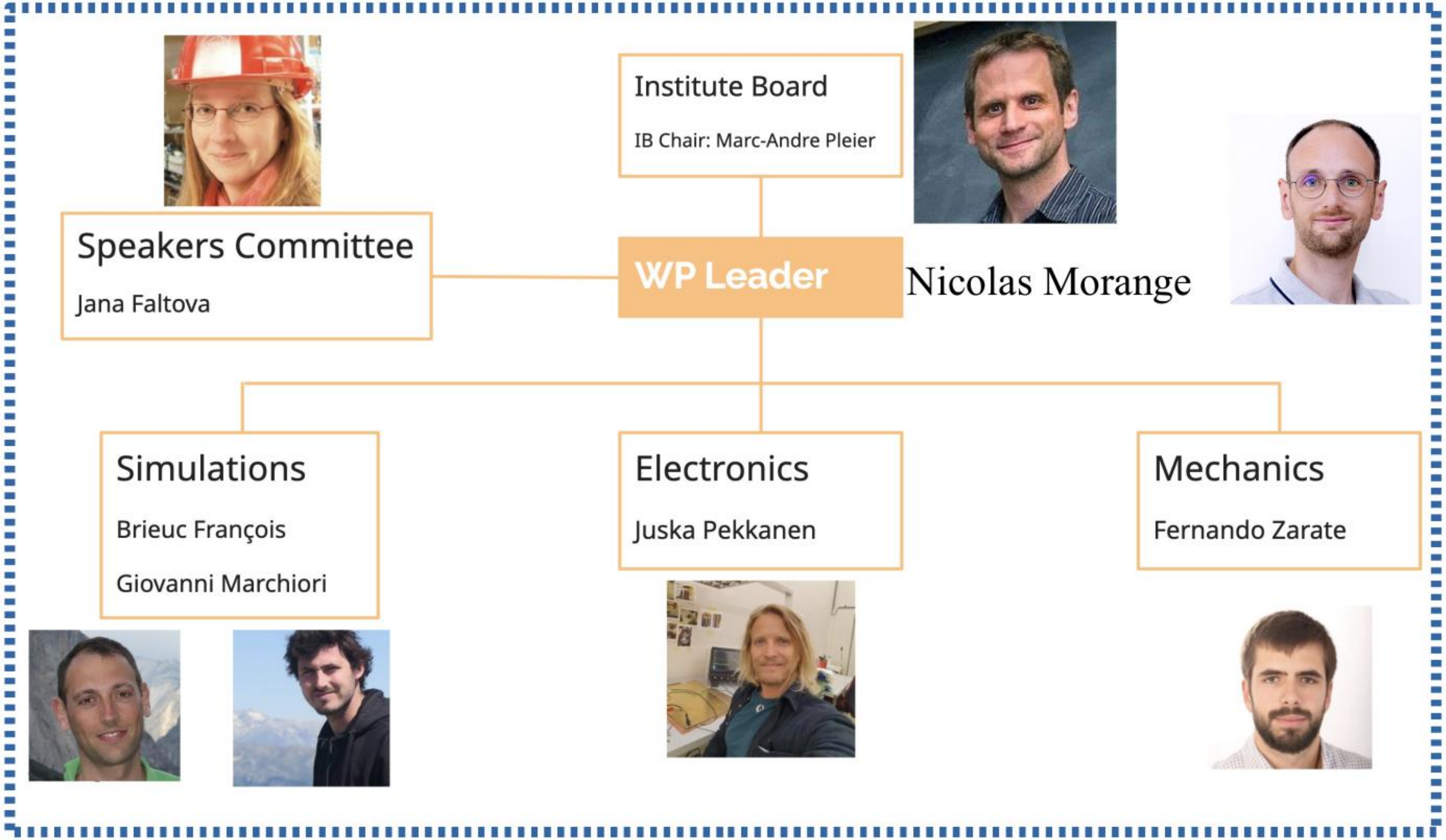
DRD6 WP2

21 Institutes from 7 countries

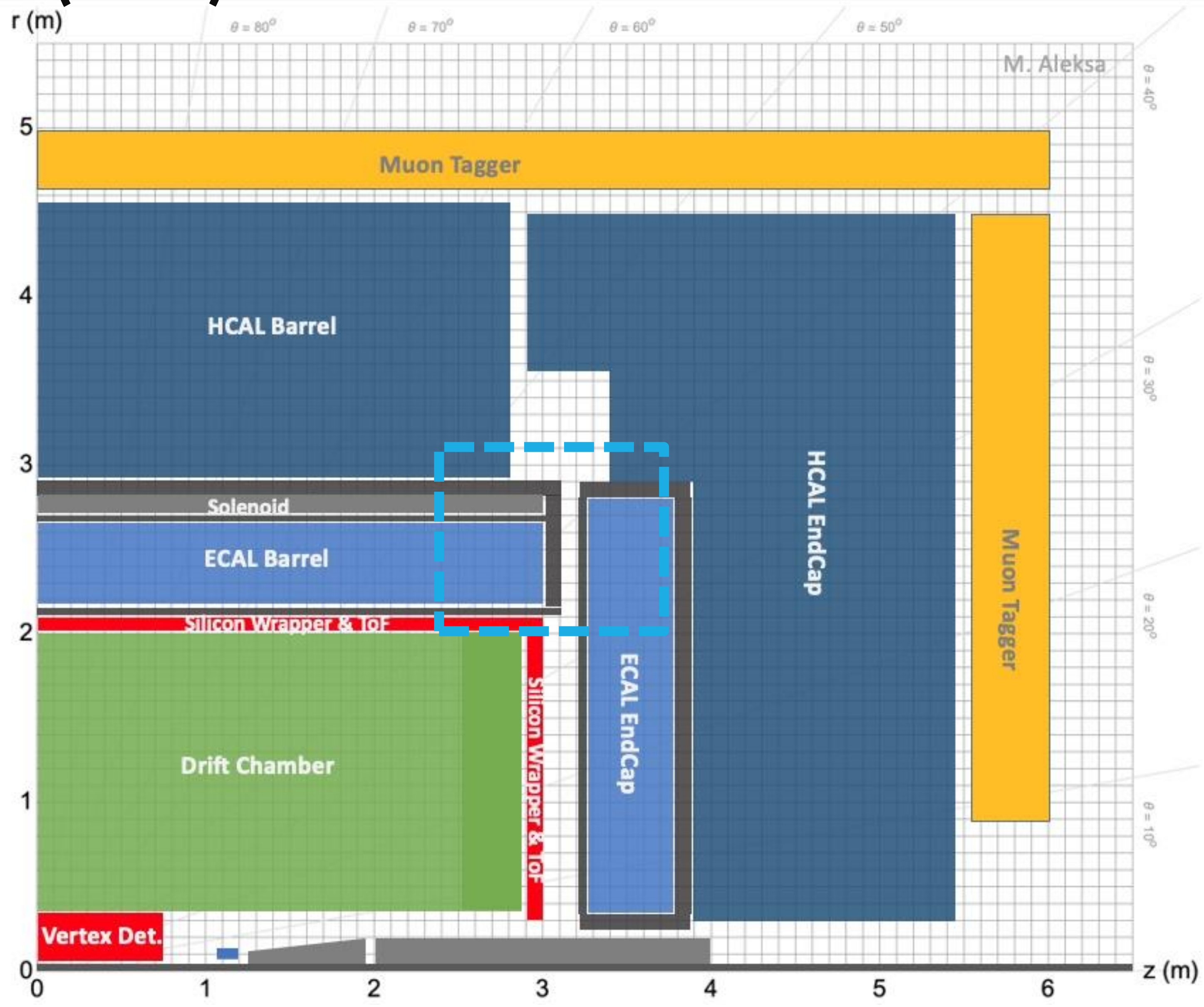
Many opportunities for contributions!

Regular monthly meetings on Indico

DRD6 WP2 Structure



(ONE) ALLEGRO DETECTOR CONCEPT



Vertex Detector:
- MAPS or DMAPS possibly with timing layer (LGAD)
- Possibly ALICE 3 like?

Drift Chamber or Straw Tracker (±2.5 m active)

Silicon Wrapper + ToF:
- MAPS or DMAPS possibly with timing layer (LGAD)

High Granularity ECAL:
- LAr + Pb (or LKr?)
- Particle Flow reconstruction

Solenoid B=2 T, sharing cryostat with ECAL, outside ECAL
- **Light solenoid coil ≈ 0.76 X_0**
- **Low-material cryostat < 0.1 X_0**

High Granularity HCAL / Iron Yoke:
- Scintillator + Iron (particle flow reconstruction)
  - SiPMs directly on Scintillator or
  - TileCal: WS fibres, SiPMs outside

Muon Tagger:
- Drift chambers, RPC, MicroMegas

Nothing set in stone, open to any suggestions
- **e.g Different tracker technologies**
- **Different endcap layout ("plugs")?**
  - **How to accommodate services**

HIGH GRANULARITY NOBLE-LIQUID CALORIMETER

Baseline design

1536 straight inclined (50.4°) 1.8mm Pb absorber plates

Multi-layer PCBs as readout electrodes

1.2 – 2.4 mm LAr gaps

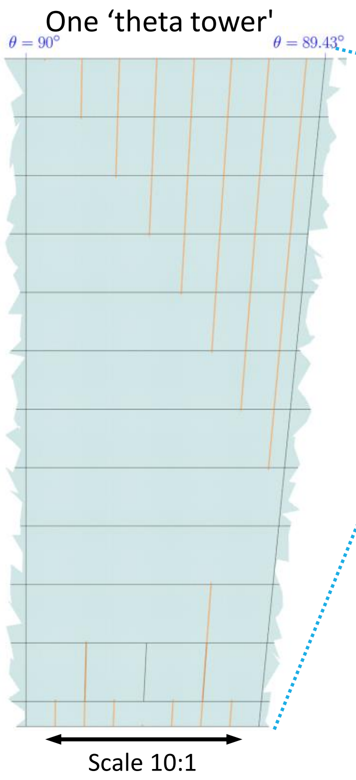
40 cm deep (≈ 22 X_0)

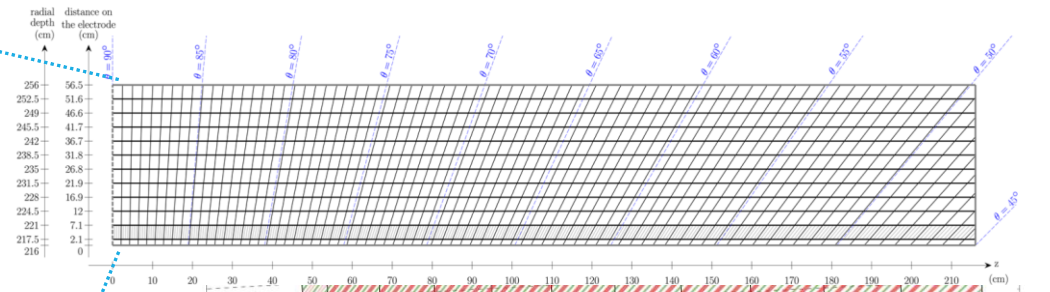
Segmentation:

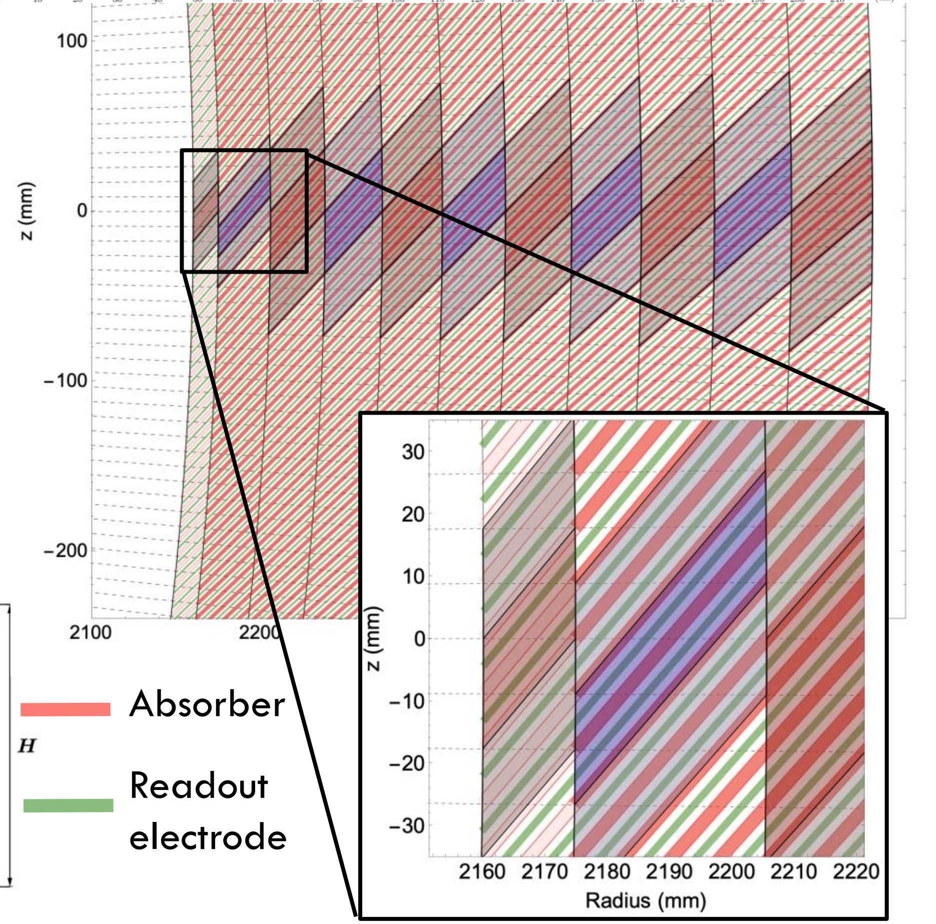
- $\Delta\theta$ = 10 (2.5) mrad for regular (1st comp. strip) cells,
- $\Delta\phi$ = 8 mrad
- → cell size in strips: 5.4 mm x 17.8 mm x 30 mm

11 layers

Implemented in FCC-SW Fullsim



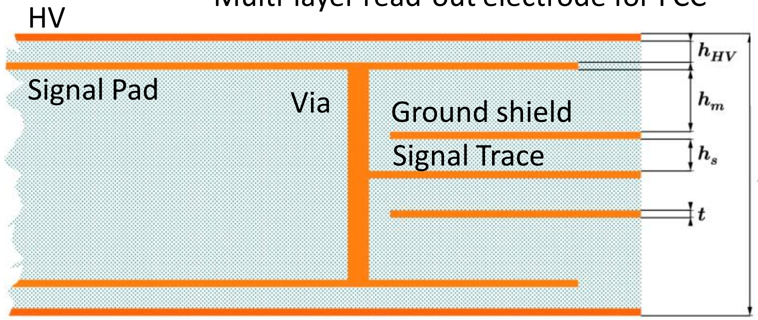




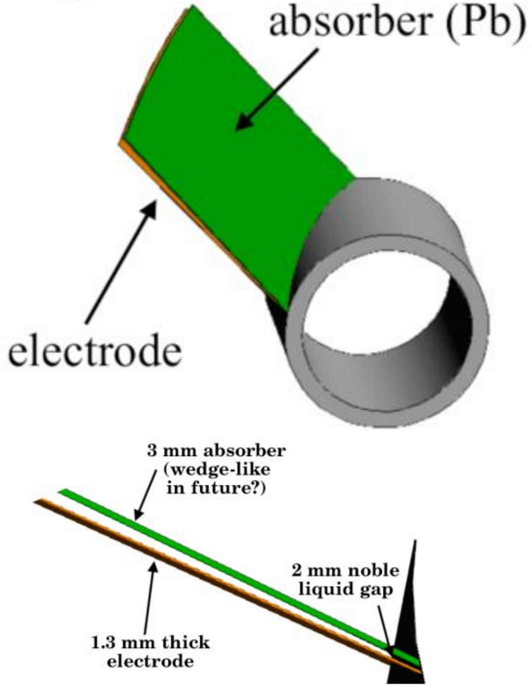
Possible Options

- LAr or LKr, W or Pb absorbers,
- Absorbers with growing thickness
- Granularity optimization
- Al or carbon fiber cryostat
- Warm or cold electronics

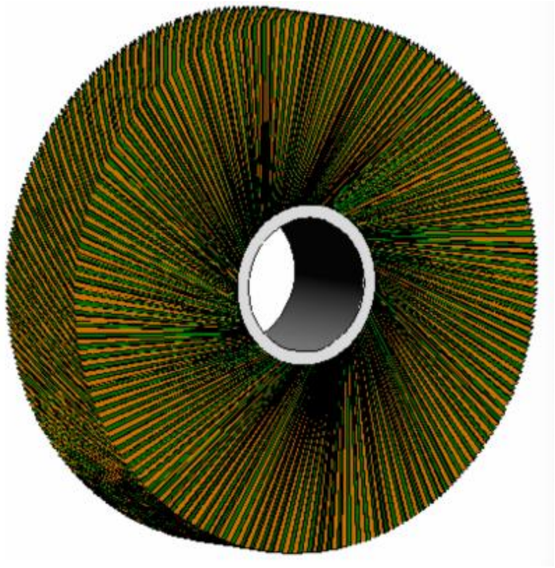
Multi-layer read-out electrode for FCC



EM ENDCAP DESIGN: TURBINE-LIKE

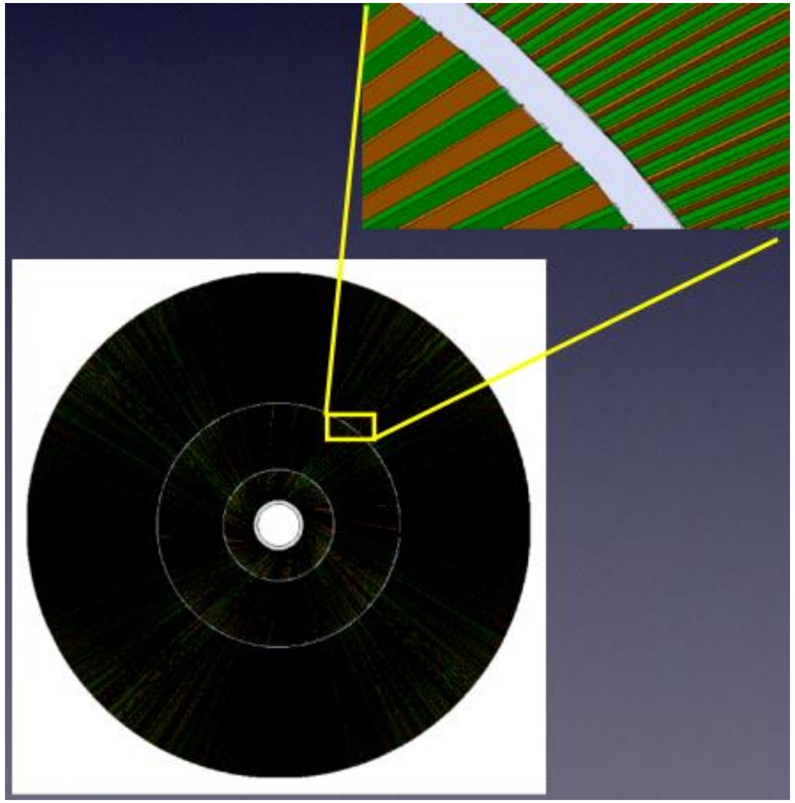


Inclined and rotated electrode/plate assemblies



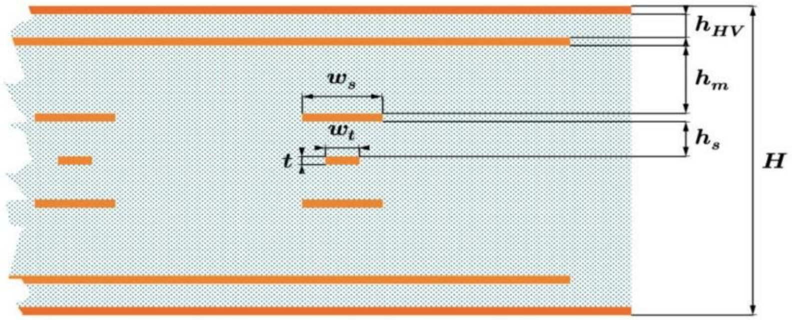
Implemented in full simulation

In dd4hep/key4hep

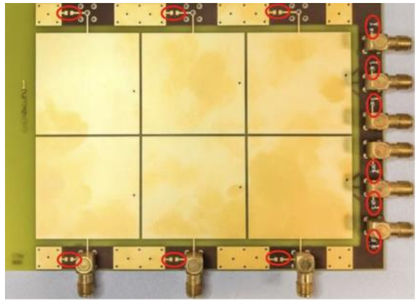


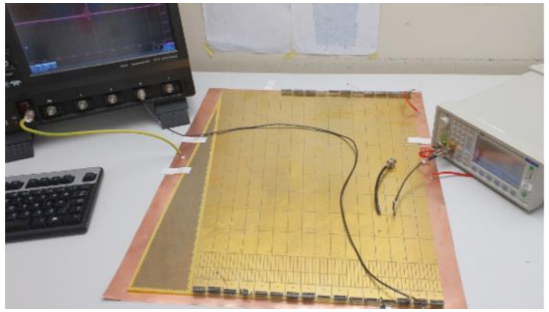
Can limit radial increase of gap by using concentric independent wheels

E. W. Varnes
R. Walker



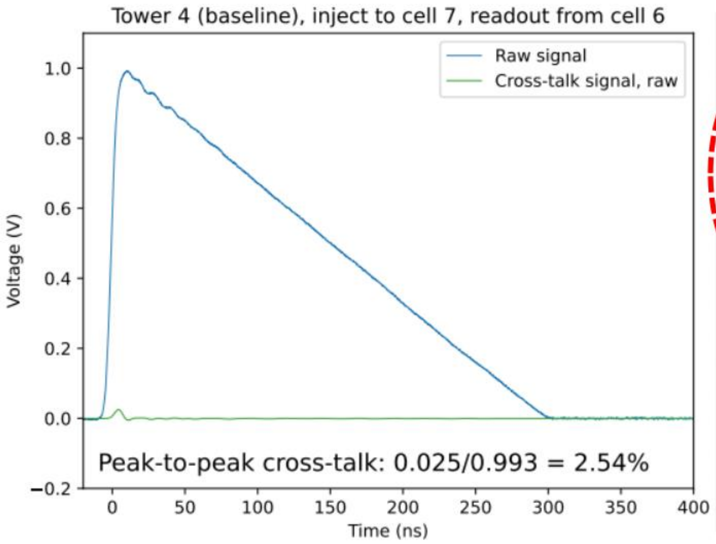
READOUT ELECTRODES ON MULTI-LAYER PCBS





A few prototypes already designed and constructed at IJCLAB and CERN and under test

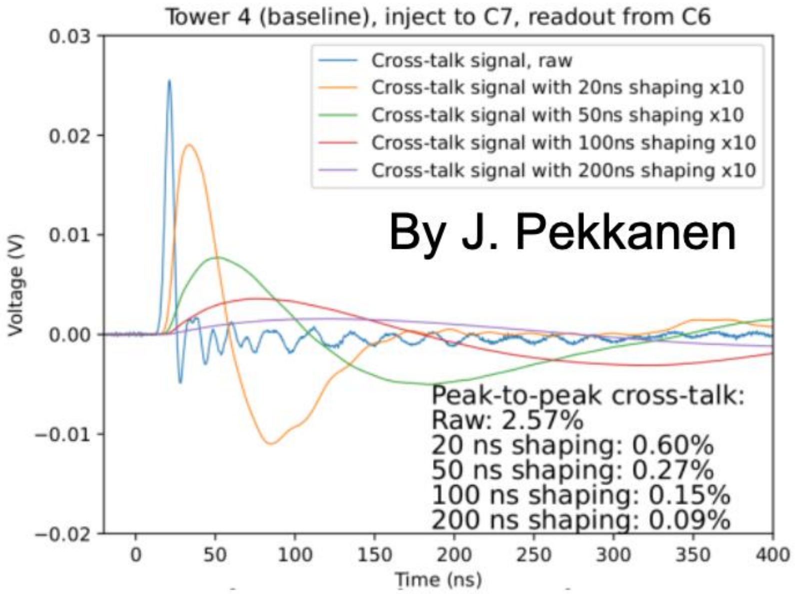
- Measurements of x-talk, capacitance and other cell properties
- Comparing lab results with Finite Element simulation (ANSYS)



Inject in one cell, readout in other

With reasonable shaping, the x-talk can be reduced significantly, <<1% x-talk target

X-talk now modelled in full detector simulation (slides by Z. Wu)



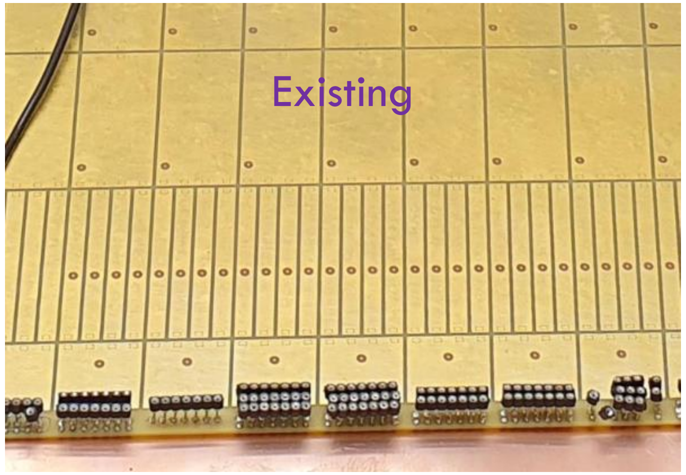
NEW PCB PROTOTYPE

New design being finalized to test properties of different cell granularity arrangements and trace/shielding configurations:

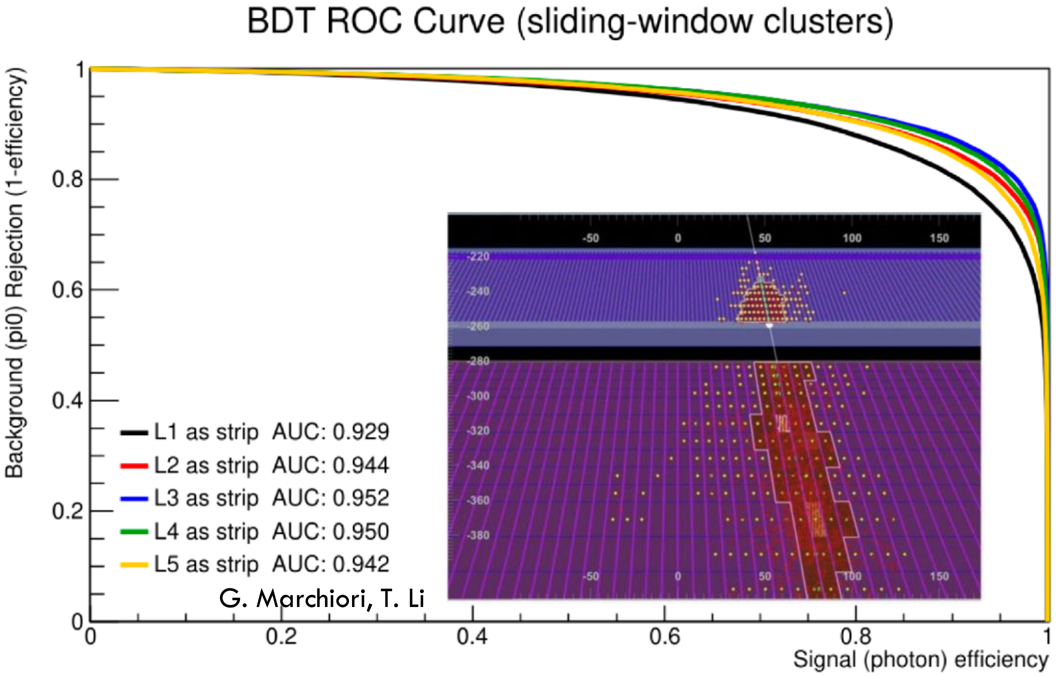
- Readout from back, Industry connectors, projective geometry
- Effect of putting “strips” further back
- lateral shields (single and double), optimized trace ordering
- Shields grounded in PCB

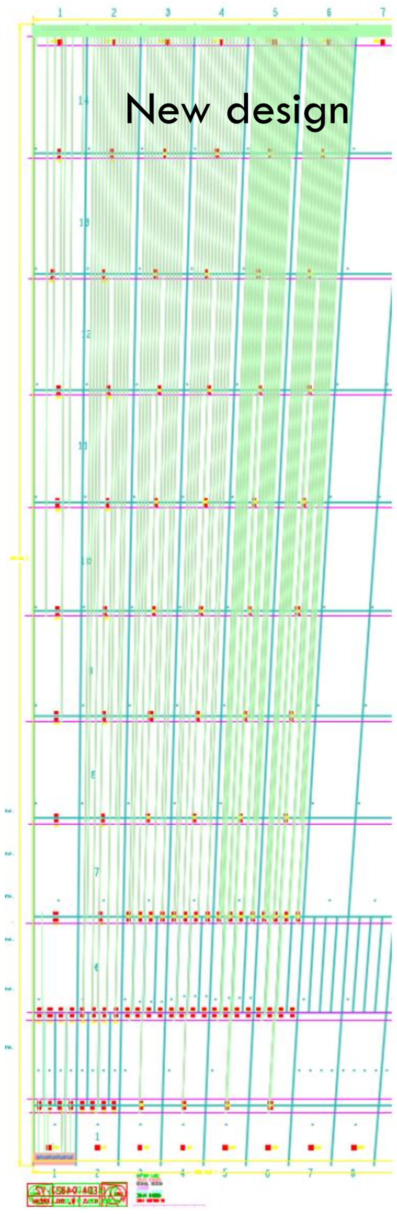
Will produce copies for BNL, CERN, IJCLAB

Target before the end of the year



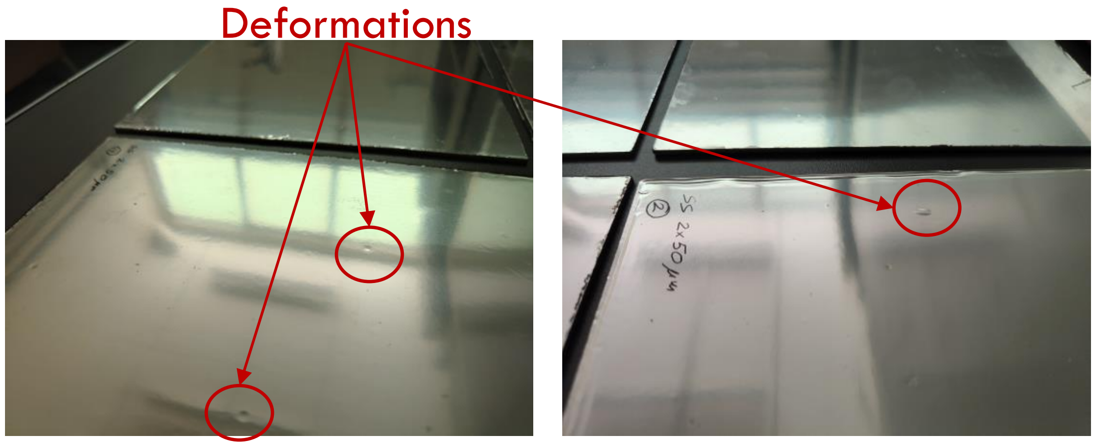
- Strips for γ/π^0 separation only in the front (but shower may not be developed until e.g. layer 3)
- Connectors hand-soldered





J. Pekkanen

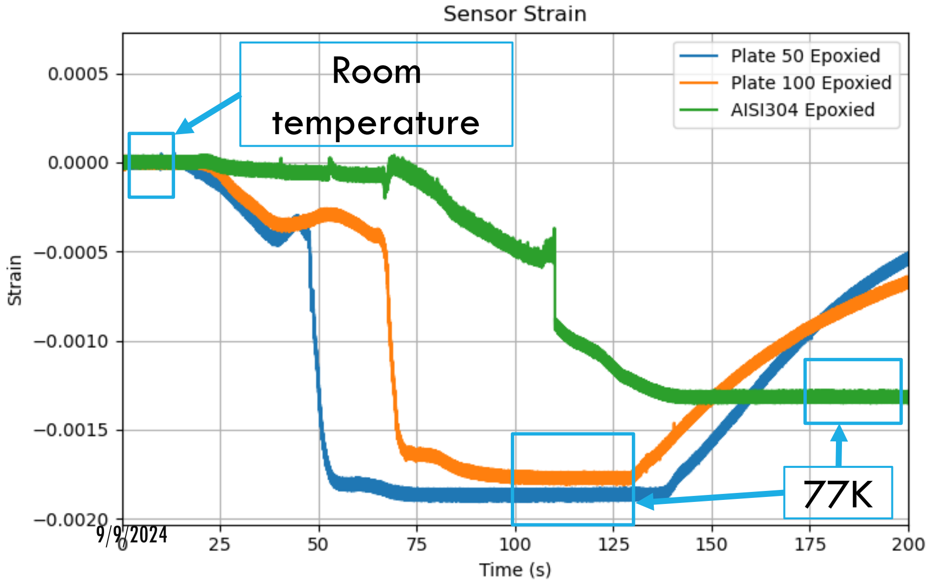
ABSORBER CONTRACTION TESTS



Tested absorber plate assemblies with 100 µm and 50 µm stainless steel sheets

- 50 µm present some deformations (depressions) that are not in the 100 µm plates.
- CTE of the absorbers has been measured using strain gauges and taking a stainless-steel bar as reference.
- The results are similar than the ones obtained in the tests using displacement sensors ($15.6 \cdot 10^{-6}$ 1/K).

$$CTE_{absorber} = \frac{\varepsilon_{absorber} - \varepsilon_{AISI}}{\Delta T} + CTE_{AISI}$$



	ε AISI	CTE AISI
AISI 304	-1.32E-03	1.326E-05

	εabs	εa-εAISI	CTE abs	CTE abs*
Absorber 50um	-1.87E-03	-5.53E-04	1.582E-05	1.563E-05
Absorber 100um	-1.83E-03	-5.13E-04	1.563E-05	

Fernando Aretio Zárate

ASSEMBLY DESIGN UPDATES

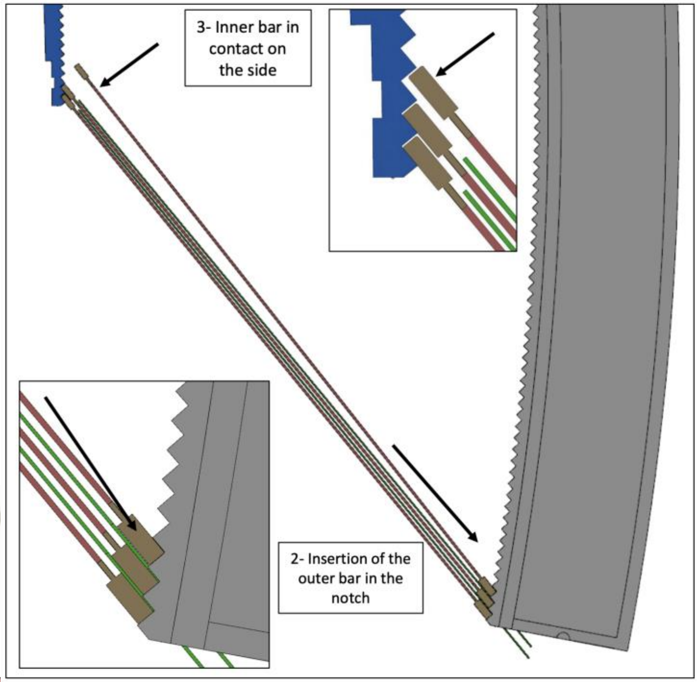
3D printed parts produced by Pierre Karst (CPPM) to check the assembly.

Aluminium bolts with Torx head have been ordered to test the maximum torque and compare it versus the Allen hex bolts (0.35 Nm).

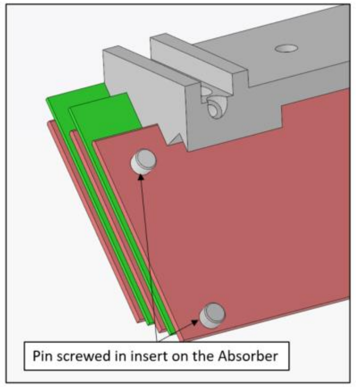
Finite elements model, to analyse the thermomechanical behavior of this new design, is ongoing.

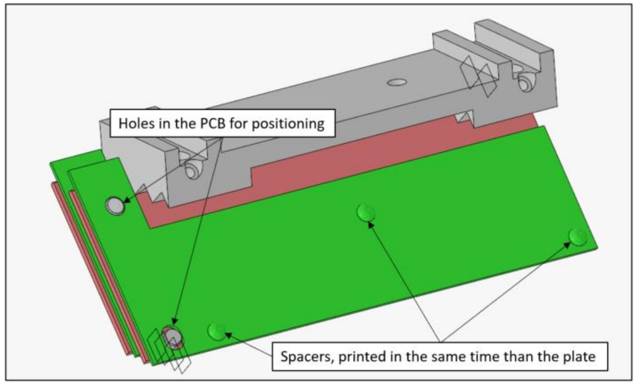
Allen

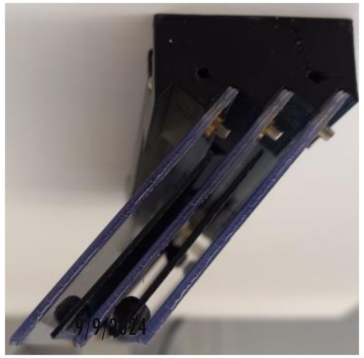
Torx



Joints to the external ring







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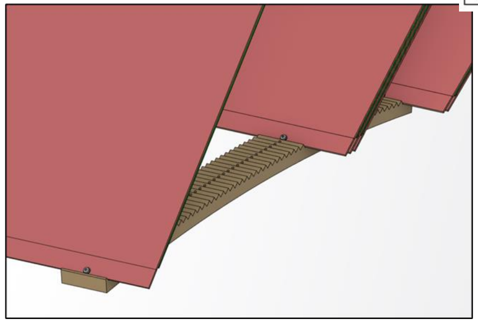
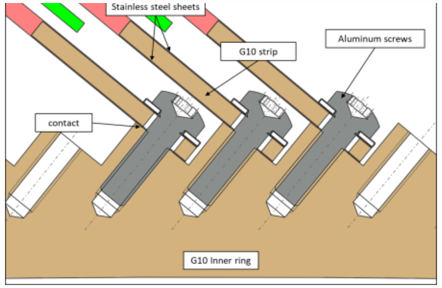
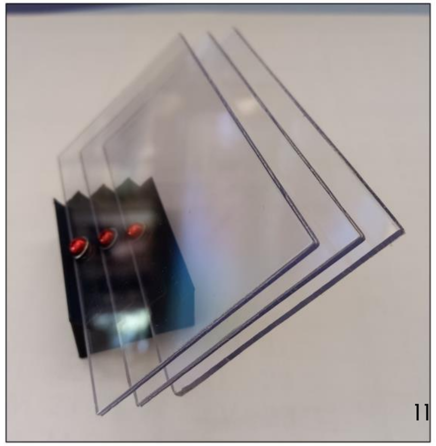
Joints to the internal ring







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ESTIMATION OF THE NOBLE LIQUID NEEDED

In the context of the study of the possibility of use other noble liquid, the total volume has been estimated.

ATLAS BARREL DIMENSIONS

r_ext	2140 mm		
r_int	1390 mm		
Long	3267 mm		
Volume_tot	27.2 m3		
V_detection_material	5.4		
Volume_tot - V_material	21.8 m3	Barrel =	43.5 m3
m_LAr	30.5 ton	Barrel =	60.9 ton

ALLEGRO BARREL DIMENSIONS

r_ext	2710 mm		
r_int	2140 mm		
Long	3267 mm		
Volume_tot	28.4 m3		
V_detection_material	8.8		
Volume_tot - V_material	19.5 m3	Barrel =	39.1 m3
m_LAr	27.3 ton	Barrel =	54.7 ton

Table 4-3 Maximum mass of parts supported by the calorimeter.

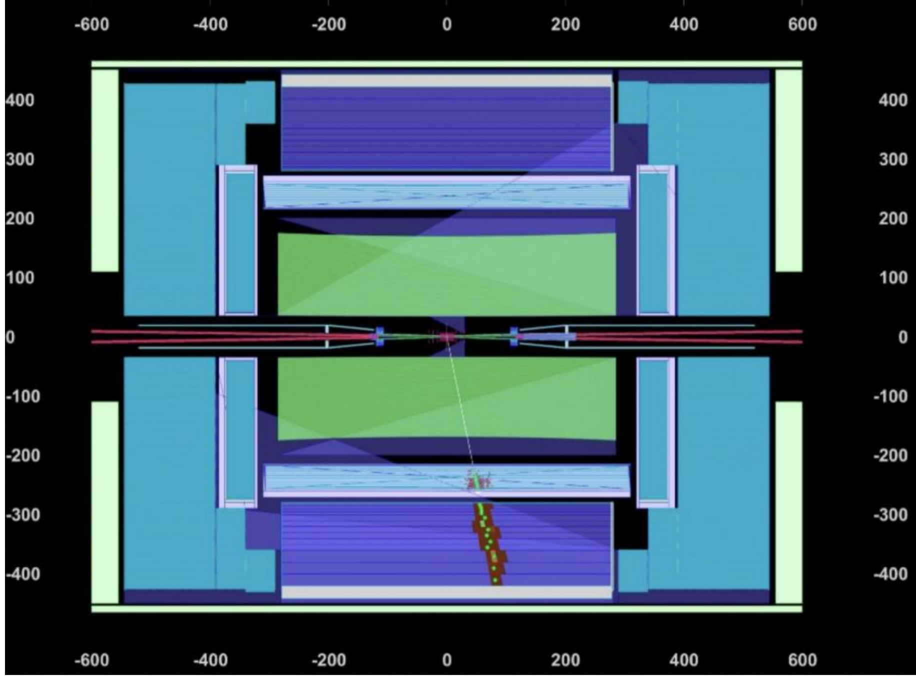
Object	Mass (tons) (upper limit)
EM calorimeter	110
Liquid argon	62
Coil	5.5
Inner detector (incl. cables)	5
Cold vessel	12
Warm vessel	13

The estimation returns 39.1m^3 for the ALLEGRO barrel, instead of 43.5 m^3. As it's a rough calculation, we can take the same numbers than ATLAS, where 62 tons of LAr was the upper limit.

Each end cap was estimated to enclose 26 tons of LAr in ATLAS.

5.4.1 Specifications and mass table of cryostat materials

The total mass of the cryostat of 23.6 tons plus the mounted detectors of 218.6 tons (without liquid argon) amounts to 242 ± 2 tons. For the crane load one has to add the mass of the crane adapter of 10 ±2 tons. The mass of the liquid argon filling is 26 tons. A detailed list of the masses is given in Table 5-3 for the detector masses and in Table 5-4 for the cryostat masses. All materials used to build the cryostat are given in Table 5-6.



PUTTING IT ALL TOGETHER

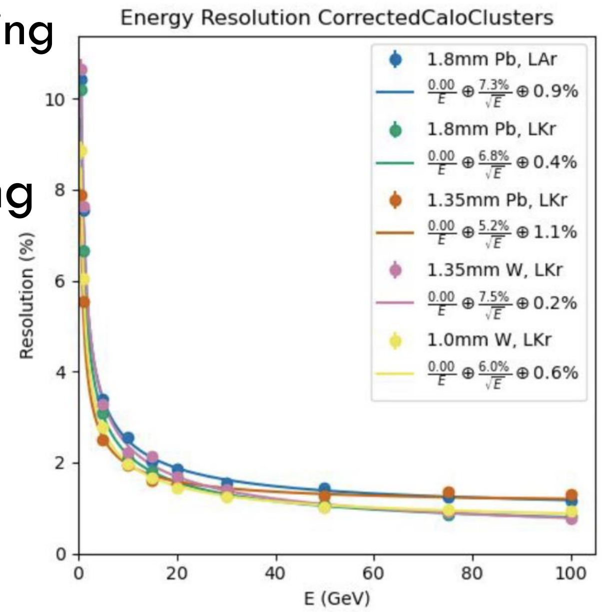
Model implemented in full simulation and (full) reconstruction chain in key4hep

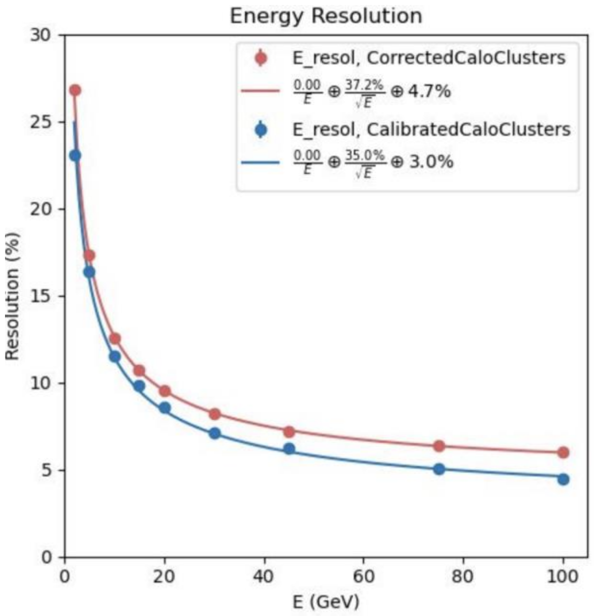
Reconstructing, calibrating clusters in both ECAL and HCAL

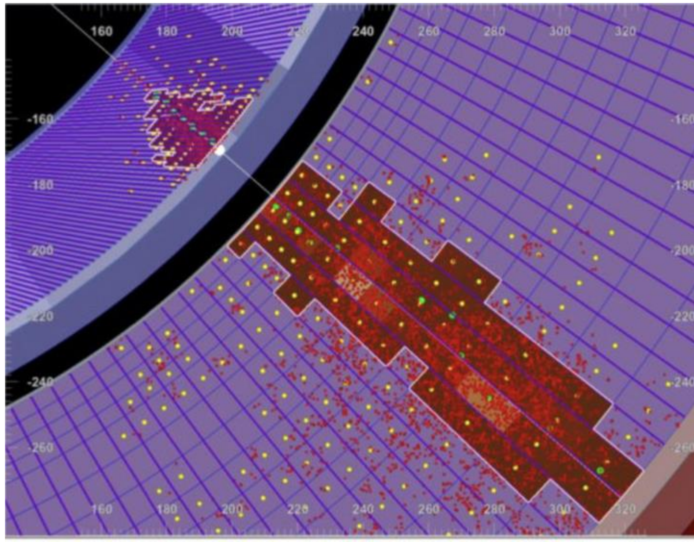
- E.g. single pions
- Energy resolution for single π^- with a sampling term of 35% and a constant term of 3% achieved

Work on particle ID ongoing

Flexibility in key4hep allows to keep exploring options (e.g. LKr)







J. Faltova

CONCLUSIONS

ALLEGRO is a proposal for a general-purpose, high-performance detector concept at FCCee with a high-granularity Noble-Liquid Calorimeter ECAL and Tile-based HCAL

Growing collaboration with new institutes recently joining the effort

- Interests of institutes still evolving

More contributions and ideas welcome!

Simulation work to define and optimize design

New electrode prototypes expected soon for more measurements in the lab

Mechanics studies of assembly methods, stresses, thermal properties, … well underway

First module prototype in test beam by 2028

- **Challenging, but exciting work ahead!**

BACKUP MATERIAL

READOUT ELECTRONICS

HGROC in cold bath

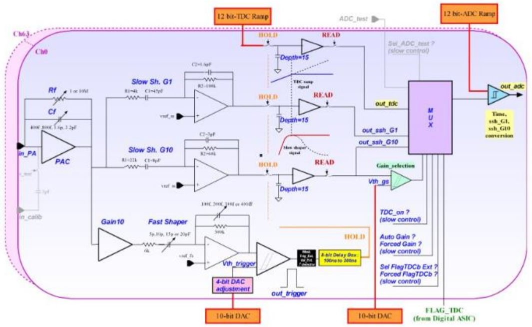
On-detector Electronics: two options under consideration

- Warm option (outside cryostat)→ requires work on cables inside the cryostat and feedthroughs to get the many signals out
- Cold option (inside cryostat) → very appealing, but also requires work
  - Noise reduction up to factor ~5
  - If all the electronics are inside the cryostat, it is easier to extract the signals
  - Power consumption is a huge challenge

Intention to reuse/adapt existing readout chips and/or exploit synergies for the test module

- E.g. ATLAS LAr, CMS HGCAL, DUNE, … SKIROC
- Significant interest/work planned at OMEGA, BNL, …

SKIROC



Timing? Requirements not fully defined yet/performance not fully explored

- But heavily depends on choices on the electronics

Off-detector electrons/DAQ: requirements not yet defined

- Also try to reuse available electronics for the test-beam

WHY USE NOBLE LIQUID CALORIMETRY

Proven technology with successful operation in several experiments

- e.g. ATLAS, D0, H1, NA48/62

Inherently radiation-hard

Suitable for experiments at various machines

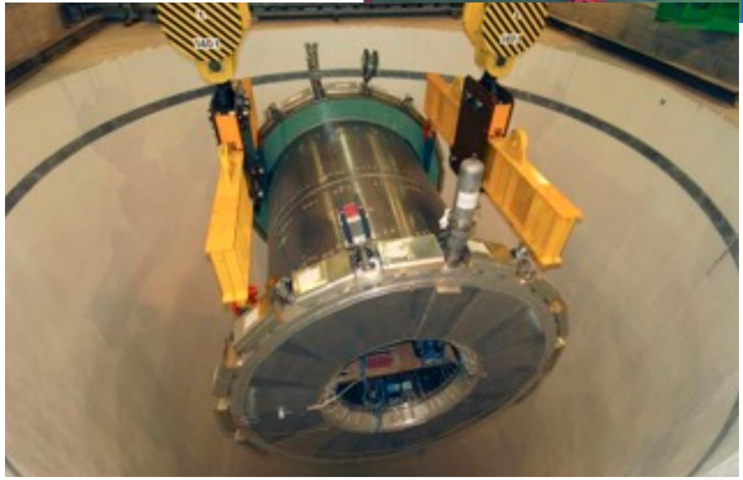
Very good energy resolution

- Sampling term of ~10%

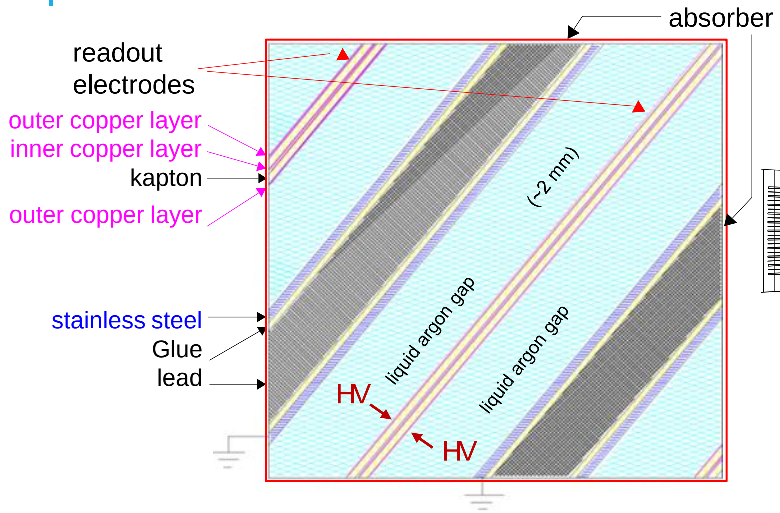
Linearity, uniformity and stability of the response

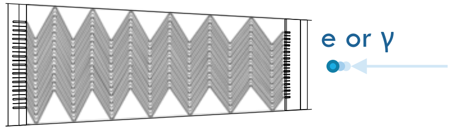
- Easy to calibrate
- Good control of systematic uncertainties

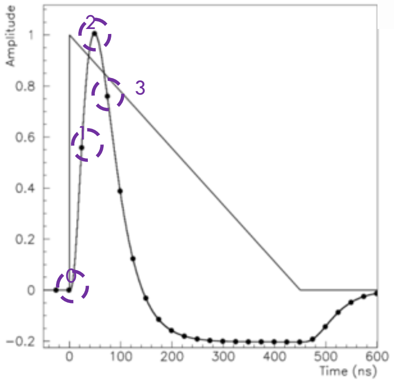


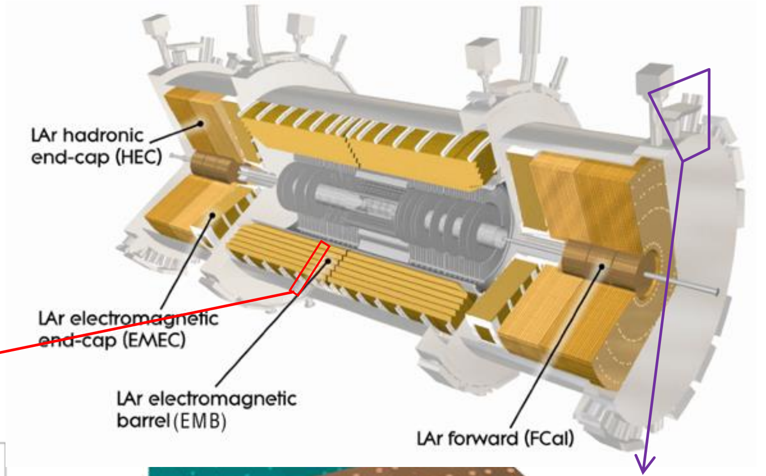



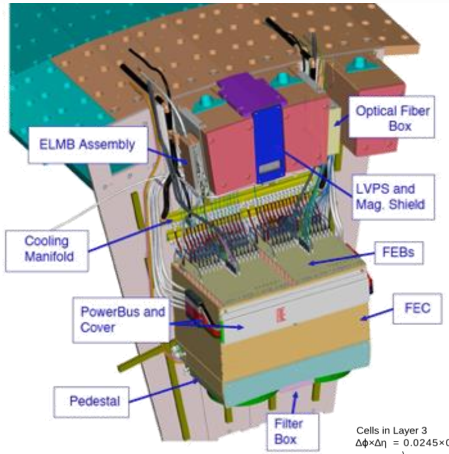
THE ATLAS LAR CALORIMETER

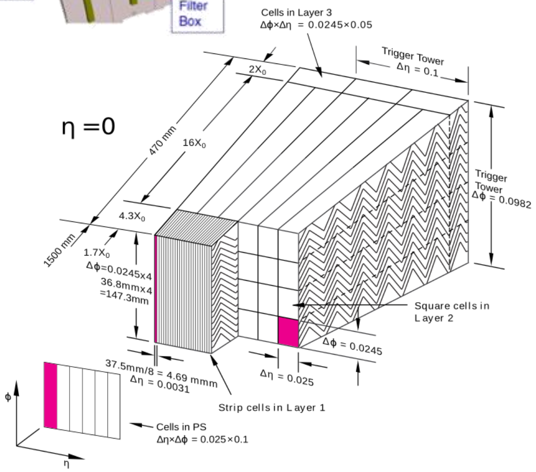












- **On-detector** electronics shape LAr ionization signal and **sample in 4 positions 25 ns** apart in 3 gain scales → **Only one of the gains** digitized and transmitted via optical fibers to **Off-detector Electronics**
  - ***Optimal Filtering Technique*** used to calculate deposited cell energy and pulse peaking time (requires good knowledge of pulse shape)
- **Can we make this technology work with the Particle Flow paradigm?**

HIGH DENSITY FEEDTHROUGHS

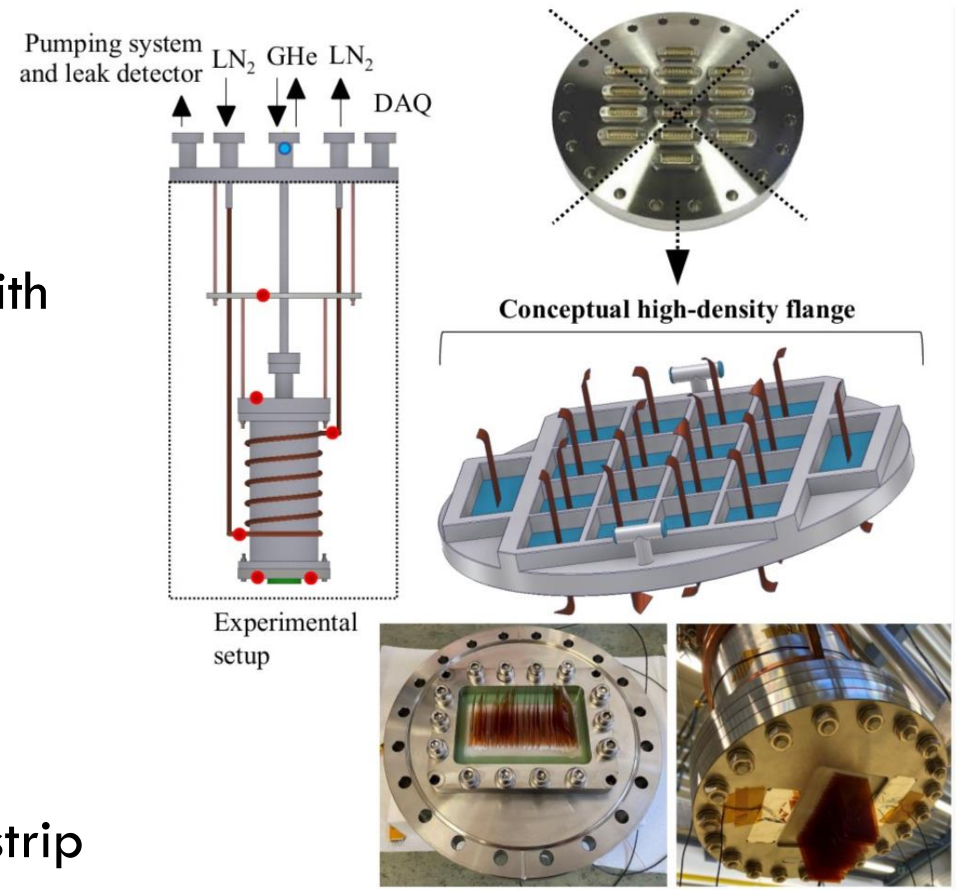
Factor of 10-15 more channels wrt ATLAS (ECAL barrel with ~2 M channels)

Innovative connector-less feedthroughs

- High density flange
- Higher area dedicated to signal extraction
- 20 000 wires per feedthrough
- Leak and pressure (3.5 bar) tests at 300 and 77 K

Identified a solution surviving several thermal cycles (G10 structure with slits + indium seal + Epo-Tek glued Kapton strip cables)

To be done: design and test a full flange



THE WAY FORWARD

Further develop the overall design and study is performance in full simulation

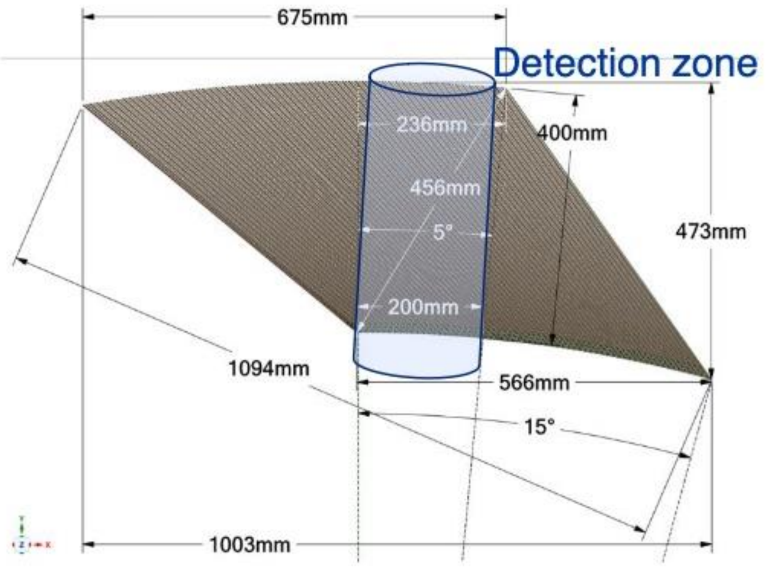
Determine required granularity

Develop and freeze readout electrode design

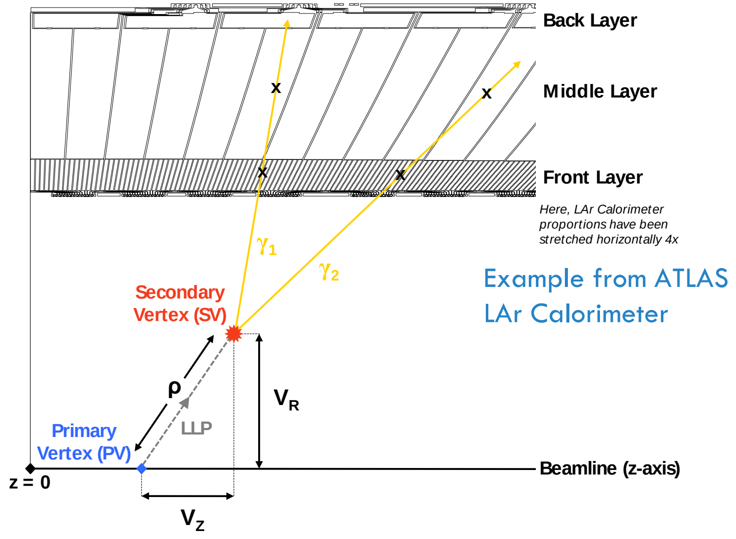
Investigate and decide on readout electronics (cold vs warm?)

Study mechanics, structural/assembly aspects of calorimeter

Build a prototype module in cryostat and study it in test beam some time in **2028**



GRANULARITY



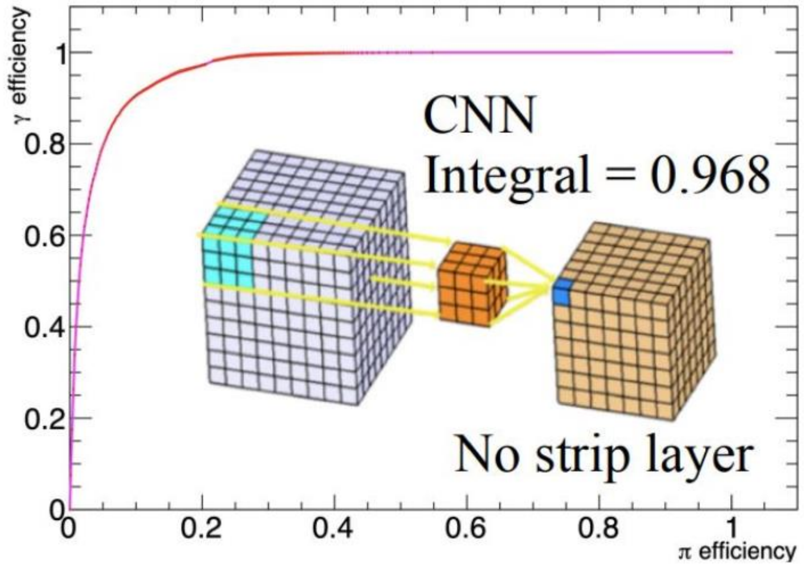
Example from ATLAS LAr Calorimeter

Need to understand the required granularity

- Study pion ID (tau physics)
- Axion-like particle searches
  - Including Long-lived signatures → Employ pointing/diphoton vertex reconstruction
- Jet energy reconstruction
- Using 4D imaging techniques, ML, PFlow

Optimize design for EM resolution

- Electron and photon resolutions
- Pions, b-physics
- Gap size, sampling fraction, active and passive material…



TEST MODULE

Mechanical design of testbeam module (64 absorbers) has started

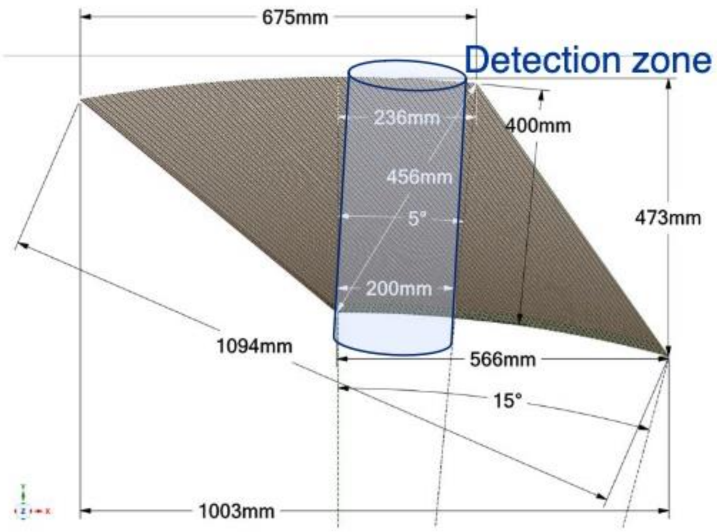
Finite element calculations including

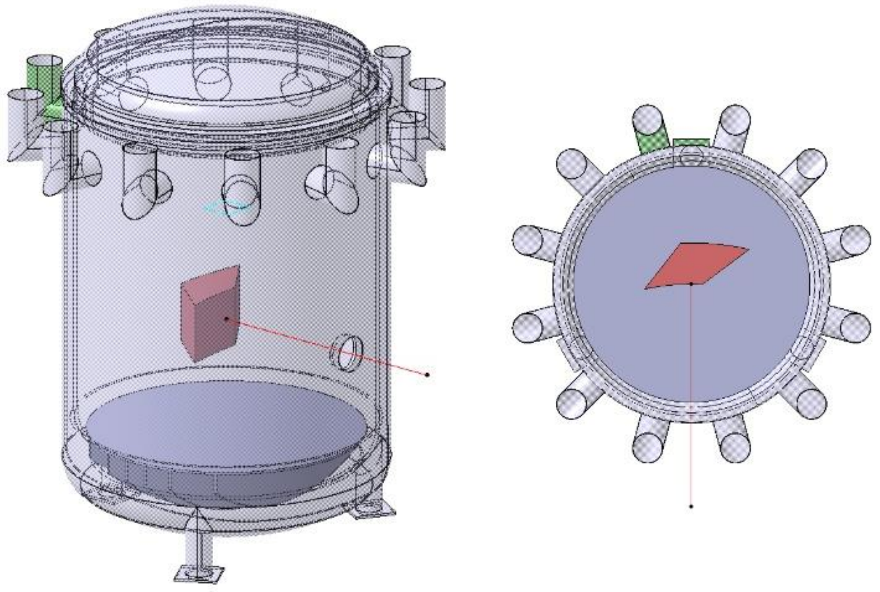
- Rings and G10 bars
- Absorbers and electrodes as shell (2D) elements using layers
- Distance pins
- Six M5 beams join electrodes and absorbers in each side (inner-outer)

Plan to place module into cryostat available at CERN

- But looking into thin carbon-fiber cryostats

Assembly and first tests at warm ~2027, cold tests and test-beam in 2028





CALORIMETRY – JET ENERGY RESOLUTION

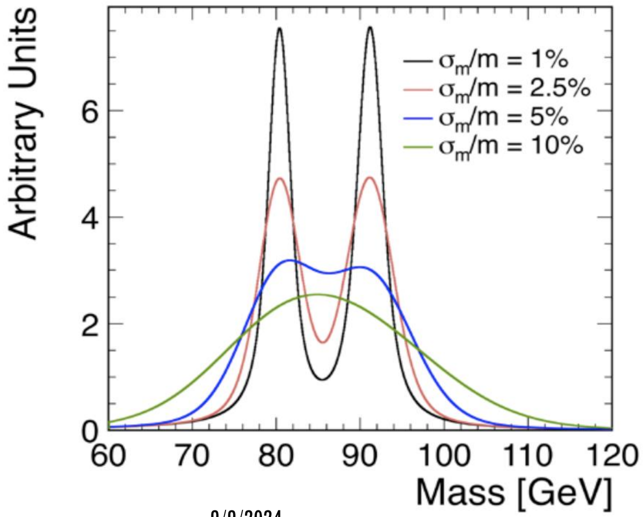
Energy coverage < 300 GeV : 22 X_0, 7λ
Precise jet angular resolution

Jet energy: $\sigma(E_{jet})/E_{jet} \simeq 30\% / \sqrt{E}$ [GeV] **?**

⇒ Mass reconstruction from jet pairs

Resolution important for control of (combinatorial) backgrounds in multi-jet final states

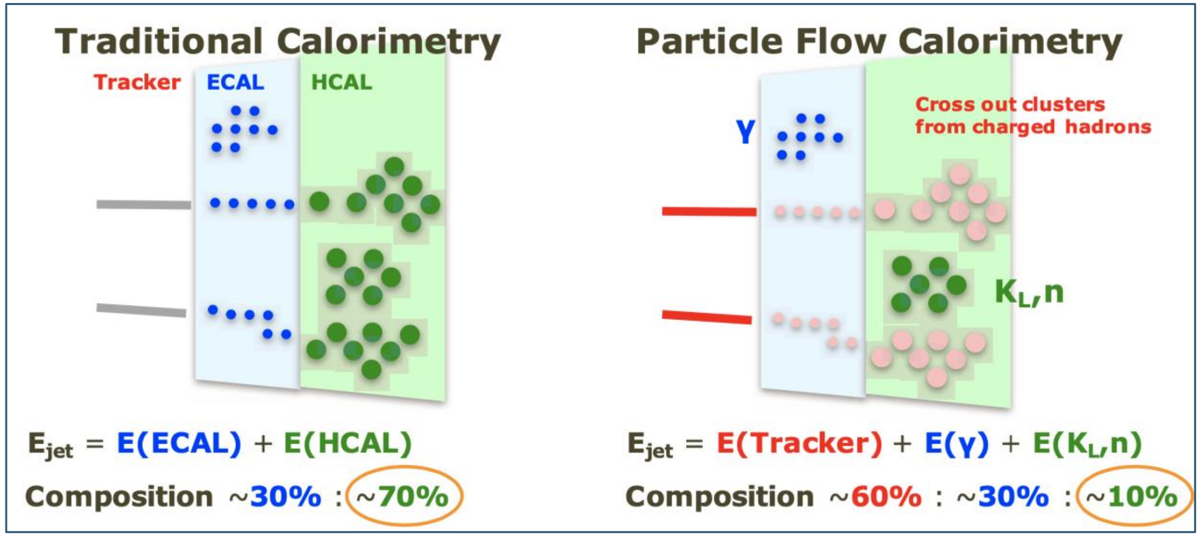
- Separation of HZ and WW fusion contribution to ννH
- HZ → 4 jets, tt events (6 jets), etc.



- At $\sigma E/E \simeq 30\% / \sqrt{E}$ [GeV], detector resolution is comparable to natural widths of W and Z bosons

How to achieve jet energy resolutions of ~3-4% at 50 GeV:

- **Highly granular calorimeters**
- **Particle Flow reconstruction and possibly in addition techniques to correct non-compensation (e/h≠1), e.g. dual read-out**



→ High granularity and/or dual read-out

TARGETS FOR CALORIMETRY

Detector technology (ECAL & HCAL)	E.m. energy res. stochastic term	E.m. energy res. constant term	ECAL & HCAL had. energy resolution (stoch. term for single had.)	ECAL & HCAL had. energy resolution (for 50 GeV jets)	Ultimate hadronic energy res. incl. PFlow (for 50 GeV jets)
Highly granular Si/W based ECAL & Scintillator based HCAL	15 – 17 % [12, 20]	1 % [12, 20]	45 – 50 % [45, 20]	≈ 6 % ?	4 % [20]
Highly granular Noble liquid based ECAL & Scintillator based HCAL	8 – 10 % [24, 27, 46]	< 1 % [24, 27, 47]	≈ 40 % [27, 28]	≈ 6 % ?	3 – 4 % ?
Dual-readout Fibre calorimeter	11 % [48]	< 1 % [48]	≈ 30 % [48]	4 – 5 % [49]	3 – 4 % ?
Hybrid crystal and Dual-readout calorimeter	3 % [30]	< 1 % [30]	≈ 26 % [30]	5 – 6 % [30, 50]	3 – 4 % [50]

Table 1. Summary table of the expected energy resolution for the different technologies. The values are measurements where available, otherwise obtained from simulation. Those values marked with "?" are estimates since neither measurement nor simulation exists.

For references and more information see https://link.springer.com/article/10.1140/epjp/s13360-021-02034-2

MECHANICS

Challenge: assemble electrodes and absorbers in a rigid structure with relatively light-weight support

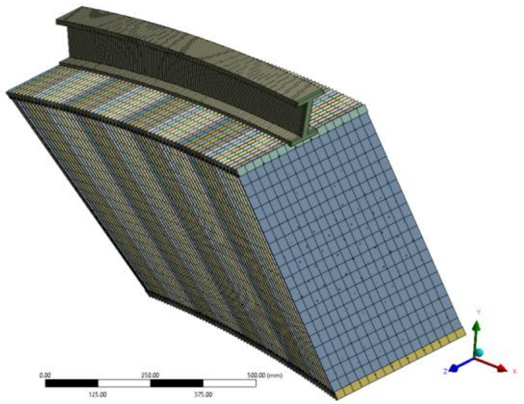
- Successful example with ATLAS LAr
  - Though accordion structure contributes to rigidity. On the other hand, assembly of straight plates should be easier

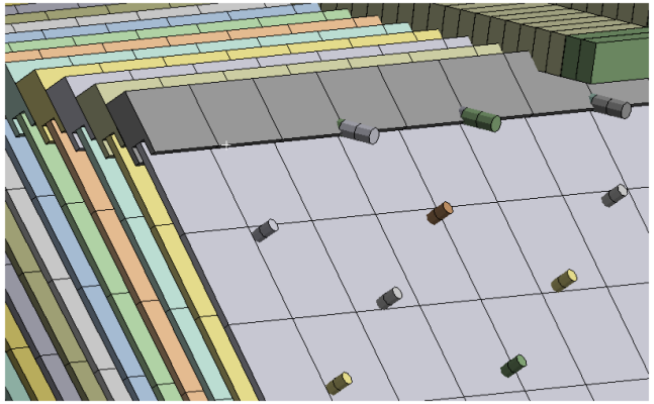
Work recently started in earnest but quite encouraging

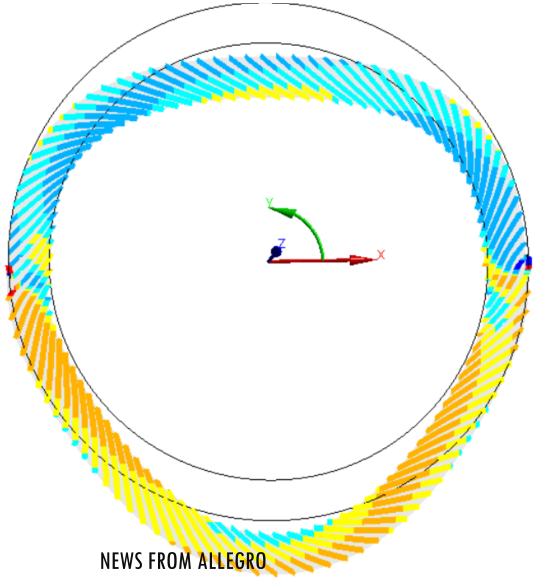
- FE analysis, deformation under own weight

But also studying feasibility of additional ideas:

- Trapezoidal absorbers
- 3D-printed pins for precision spacing/maintaining gaps





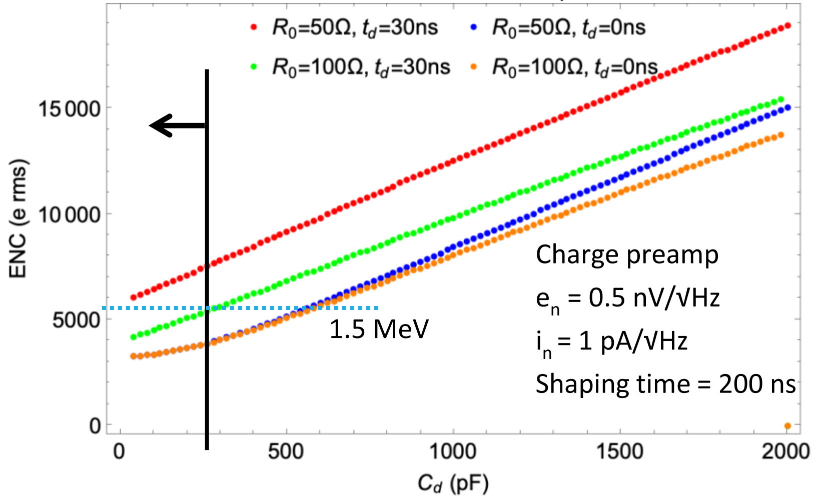


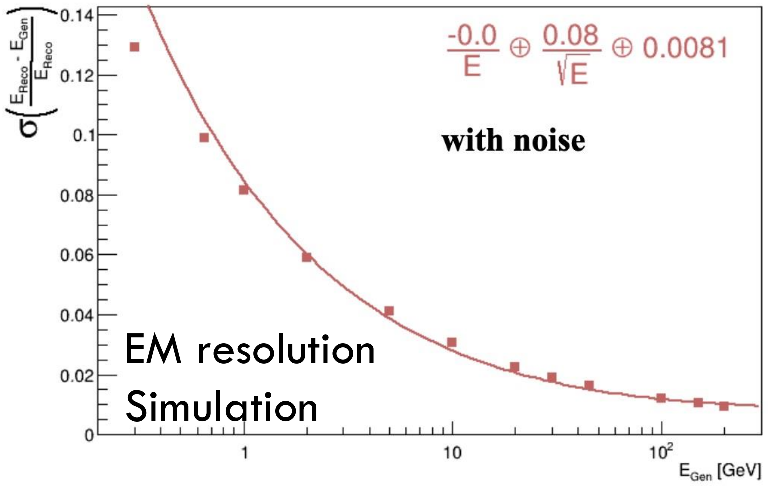
CHALLENGES: RESOLUTION, NOISE AND CROSSTALK

EM resolution with sampling term of 8 to 9%

- **Noise vs cross-talk challenge:** traces need to be shielded to minimize cross-talk → grounded shields increase detector capacitance and hence noise → need to find best compromise – **prototype electrode produced & measured**
  - **Noise** of < 1.5 MeV per cell for warm electronics and transmission lines of R_0 = 100 Ω and τ = 200 ns (C_d ≤ 250 pF)
    - → MIP S/N > 5 reached for all layers
  - **Cross-talk** of < 1% for shaping times τ ≥ 20 ns

Noise vs detector capacitance





Simulated cross-talk 2 shields < 1% for τ ≥ 20 ns confirmed by measurements on prototype

Cross-talk (%) / Shaping time (ns) ↓	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
No shaper	0.54	0.85	0.85	2.31	2.62	9.11
20	0.03	0.04	0.01	0.09	0.11	0.75
50	0.01	0.02	0.0	0.04	0.05	0.37
100	0.01	0.01	0.0	0.02	0.03	0.23
150	0.0	0.01	0.0	0.02	0.02	0.18
200	0.0	0.01	0.0	0.01	0.02	0.15
300	0.0	0.0	0.0	0.01	0.01	0.13