High Granular Noble Liquid Calorimeter

J. Faltova (Charles University)
on behalf of Noble liquid calorimetry group

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Current Noble Liquid Calorimeters

Well understood concept with good experience from HERA, D0, NA31, ATLAS

Advantages

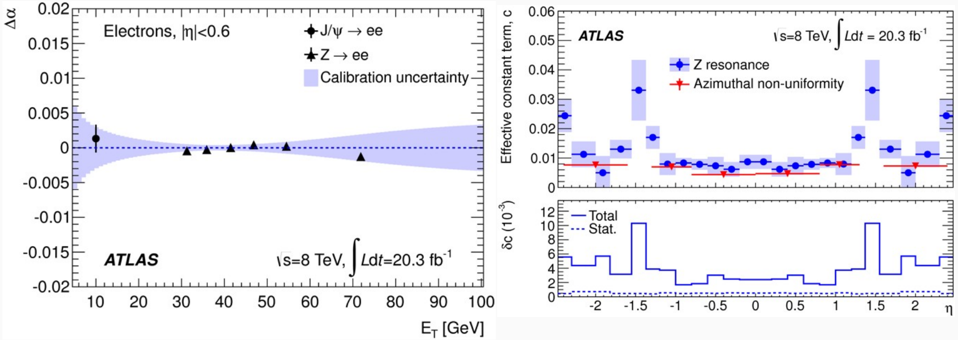
– Very good energy resolution
– Excellent linearity and stability of response
– Radiation hardness
– Very good timing and position resolution
– Particle identification capabilities (e, γ, π^0)
– Cost effective solution

Current design of the noble liquid calorimeters has limited granularity

Alternative to silicon calorimeters

ATLAS LAr calorimeter

arXiv:1407.5063



Future Noble Liquid Calorimeters

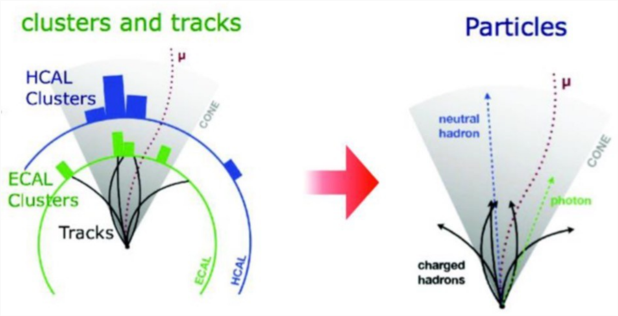
Future calorimeters has to be optimised for advanced reconstruction techniques such as particle flow algorithm or machine learning

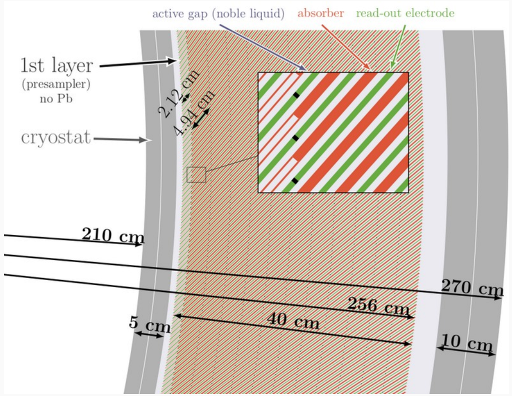
- Energy resolution
- Particle identification

“Smooth” connection between the tracker and calorimeter

-> High granularity is the key ingredient

High granularity possible with usage of multi-layer PCBs ($\Delta\eta$ x $\Delta\varphi$ ≈ 0.01 x 0.01, 8-12 longitudinal layers)
– Good performance achieved using MC simulations (CERN-FCC-PHYS-2019-0003)
– Considered as a benchmark for FCC-hh detector and an option for FCC-ee detector





R&D projects on noble liquid calorimeters

1/ Carbon composite cryostat (CERN)
-- Low material budget in front of the calorimeter crucial for e.g. energy resolution

2/ High density feed through design (CERN)

– 10 x # channels compared to ATLAS, up to 50 cables/cm^2

3/ Read-out electrode design and performance optimisation (CERN, CNRS-IJCLab)

– Important e.g. for keeping the electronic noise low

4/ Software development (CERN, Charles Uni)

R&D projects supported by: CERN EP R&D, H2020 (AIDAinnova)

More details about the project will be shown at ECFA TF6 Calorimeters session by B. Francois (https://indico.cern.ch/event/999820/)

BACKUP

How to achieve high granularity

Full granularity of 10 x ATLAS LAr calorimeter granularity

- Few millions of cells to be read out

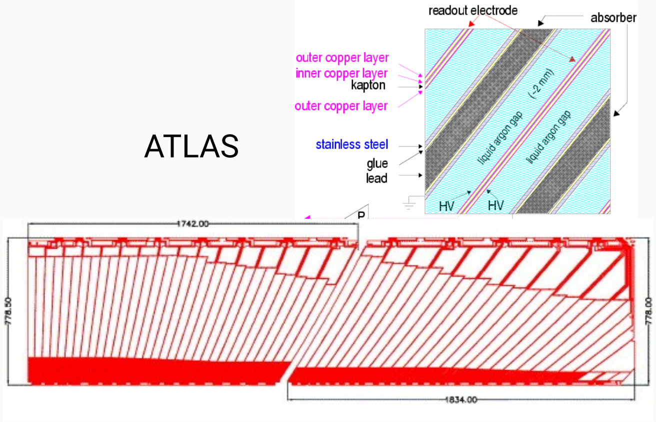
ATLAS read-out not possible

- Traces to route the signals to the front or back of the electrode take space, not possible to read out more longitudinal compartments

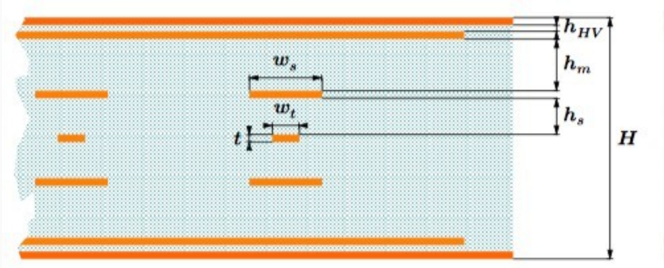
Multi-layer PCBs

- Signal routed in a deep layer
- Design with 7 layers considered
  - High voltage, read-out, signal traces, shielding of the traces
- Electronic noise proportional to the capacitance of the cells
  - Higher granularity -> more shields -> capacitance between shields and signal pads increases

ATLAS



FCC calorimeter read-out, side view (perpendicular to the signal traces)



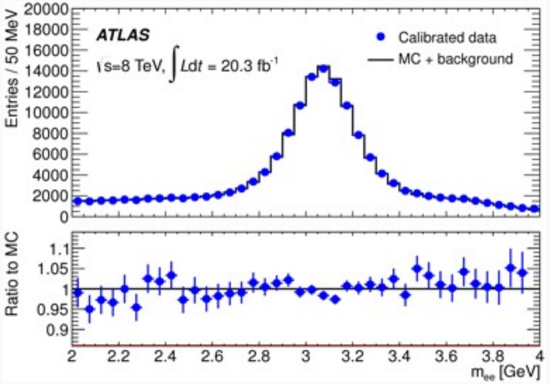
Performance of ATLAS LAr calorimeter

Results using LHC Run 1 data

Validated and measured with J/ψ and Z boson peak

Energy resolution

- Sampling term *a* of 10%
- Noise term of *b* ~250 MeV per cluster (without pile-up)
- Measured constant term of *c* of 0.7% in the central barrel



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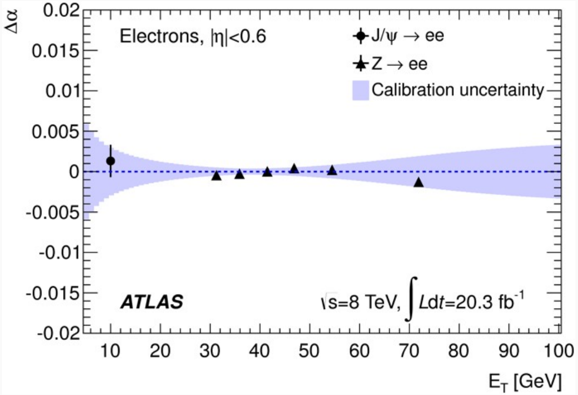
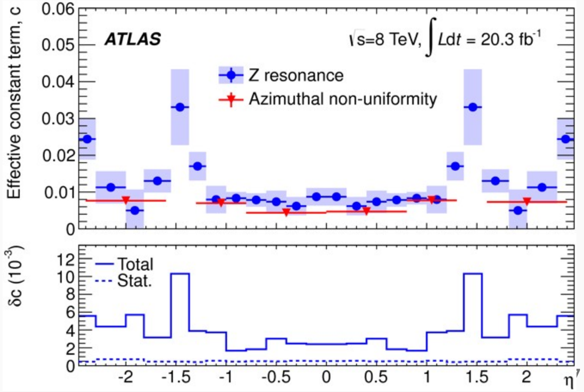
Linearity of 10^{-3} over large E_T range

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c.$$





LAr ECAL for FCC-hh

LAr calorimeter is a part of the FCC-hh reference detector

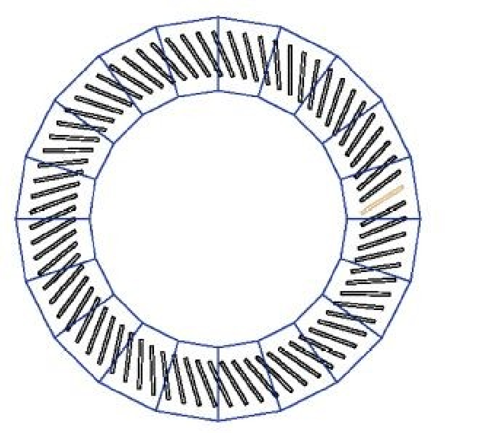
Tilted Pb planes around the barrel as a consequence of the choice of multi-layer PCBs

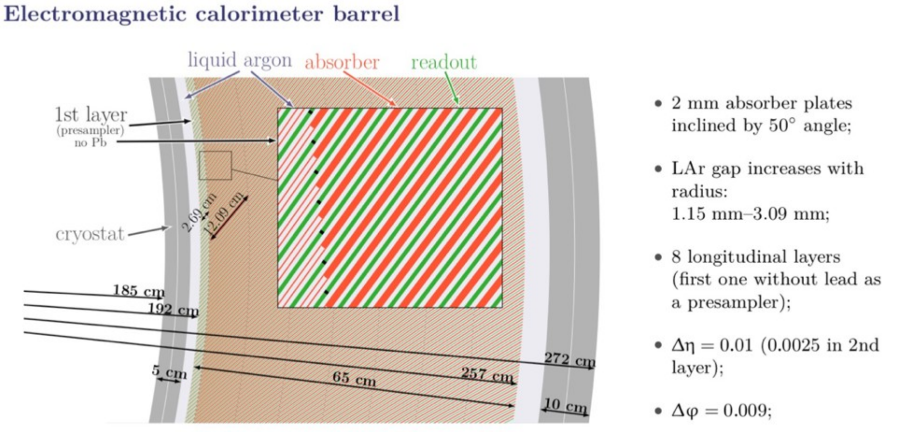
Fine longitudinal and lateral granularity

- Optimized for particle flow
- Needed for the efficient pile-up suppression
- 8 longitudinal compartments, fine lateral granularity
  - Granularity: $\Delta\eta \times \Delta\varphi \approx 0.01 \times 0.01$;
    2nd layer $\Delta\eta \times \Delta\varphi \approx 0.0025 \times 0.02$
- ~2.5M channels

Sampling fraction (SF) changes with depth

- SF ≈ 1/7 to 1/4 (LAr gap 2 x 1.15 mm to 2 x 3.09 mm





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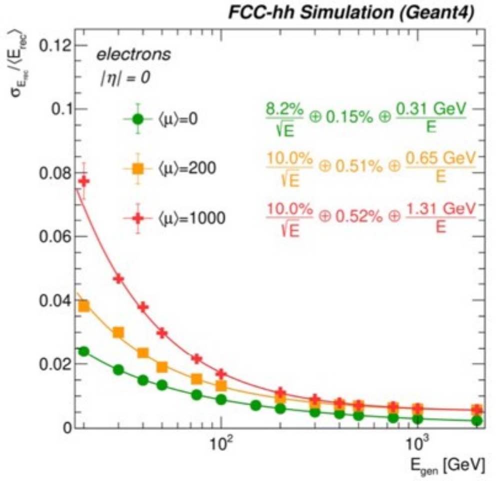
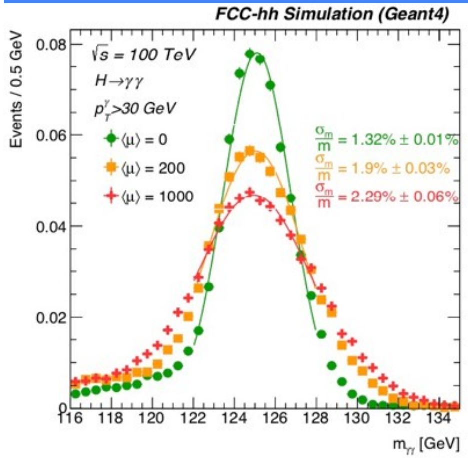
Performance of FCC-hh LAr ECAL

Required energy resolution achieved

- **Sampling term ≤ 10%/√*E***
- **Only ≈300 MeV electronic noise** with multilayer electrodes (comparable with ATLAS)
- Impact of in-time pile-up at <*μ*> = 1000 of ≈ 1.3 GeV pile-up noise

-> Efficient in-time pile-up suppression will be crucial (using the tracker)





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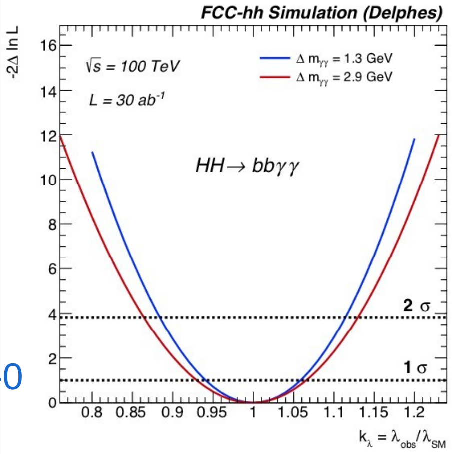
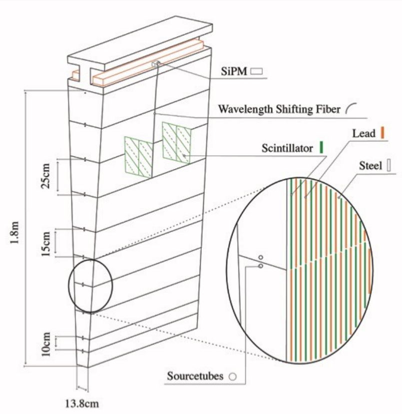


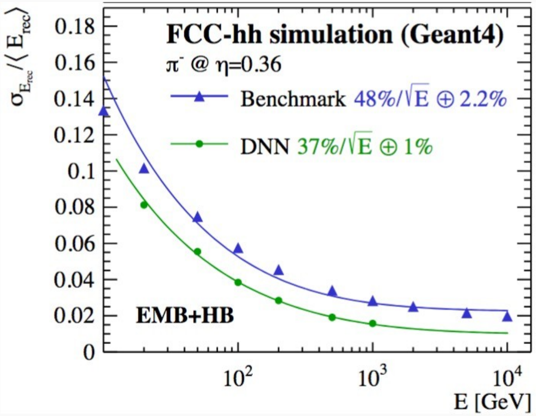
Performance for hadrons

Combined performance of LAr ECAL and fine granular scintillating Tile HCAL ($\Delta\eta \times \Delta\varphi \approx 0.025 \times 0.025$)

Very good energy resolution obtained using deep neural network with calorimeter information only

- Sampling term of **37%/√*E*** achieved (without tracker)





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