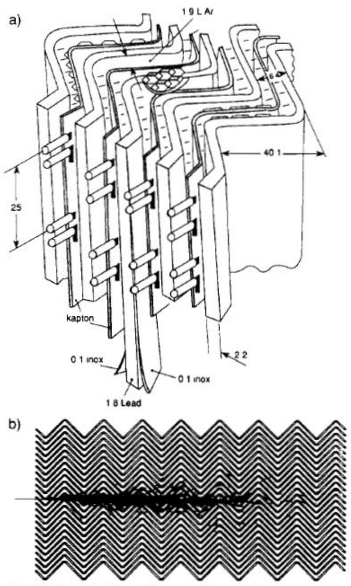
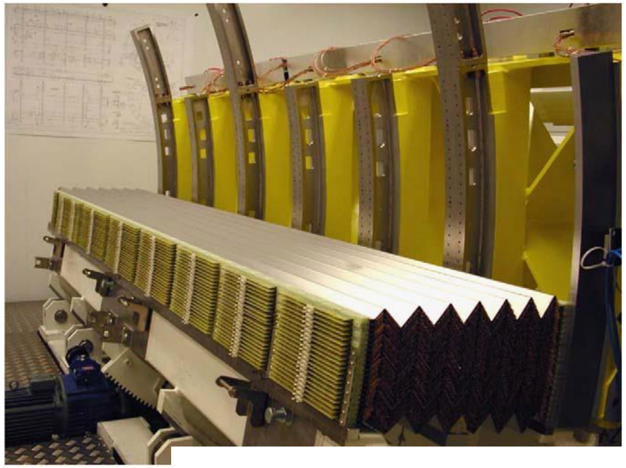
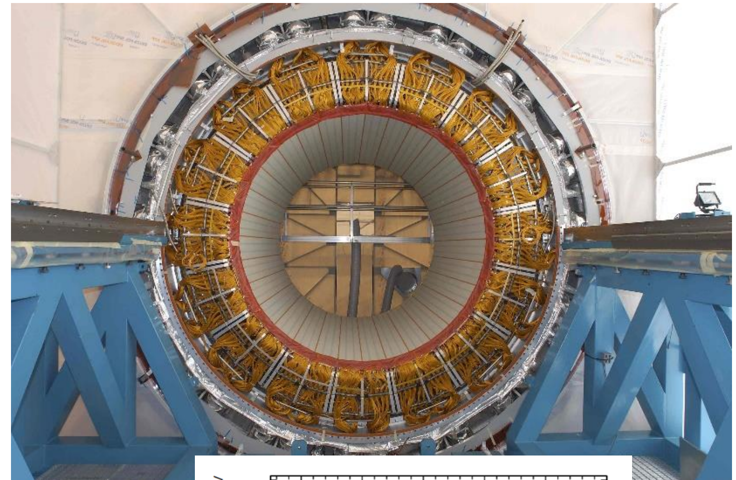
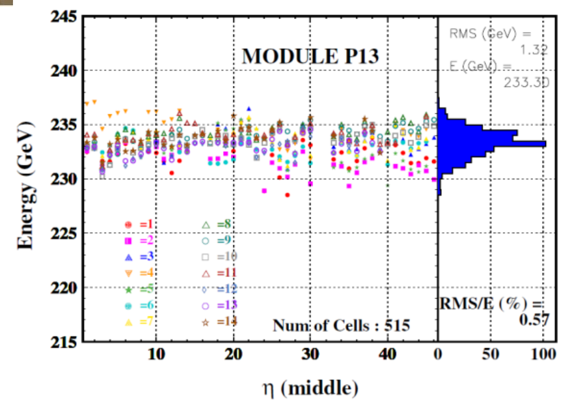
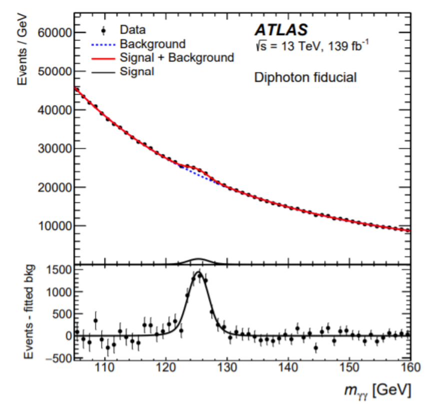
Design / construction / operation of the ATLAS LARG EM calorimeter
a personal view











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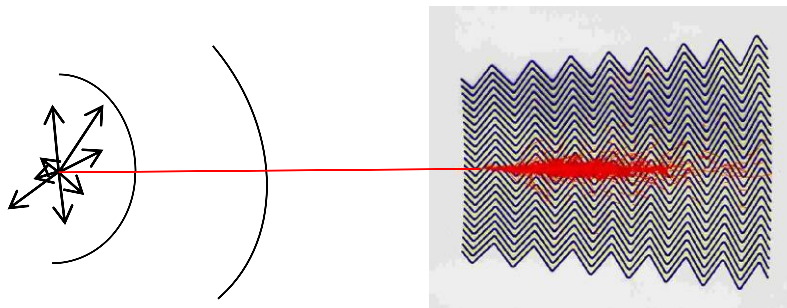
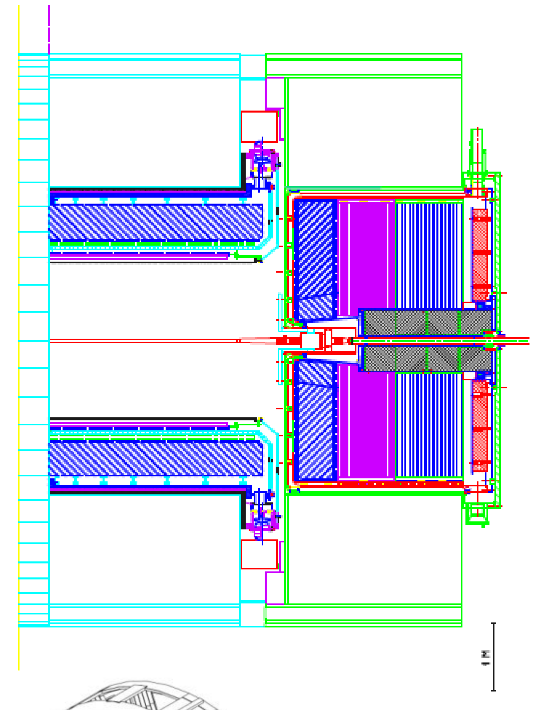
based at CERN

Brief description





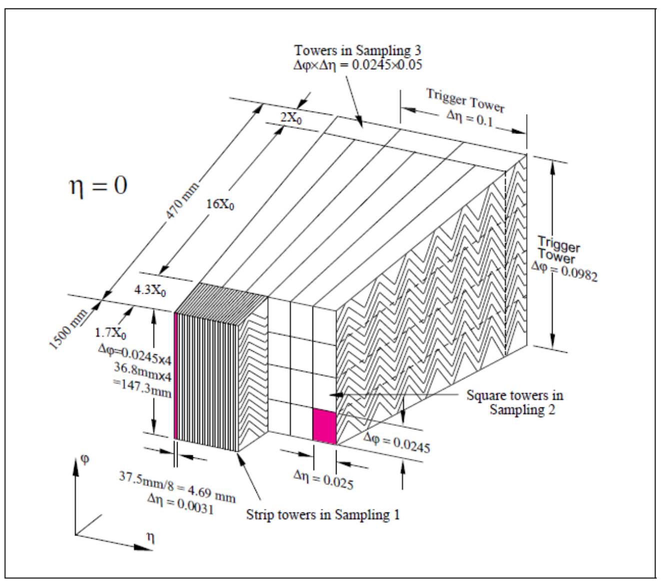


Figure 1-2 Sketch of the accordion structure of the EM calorimeter.

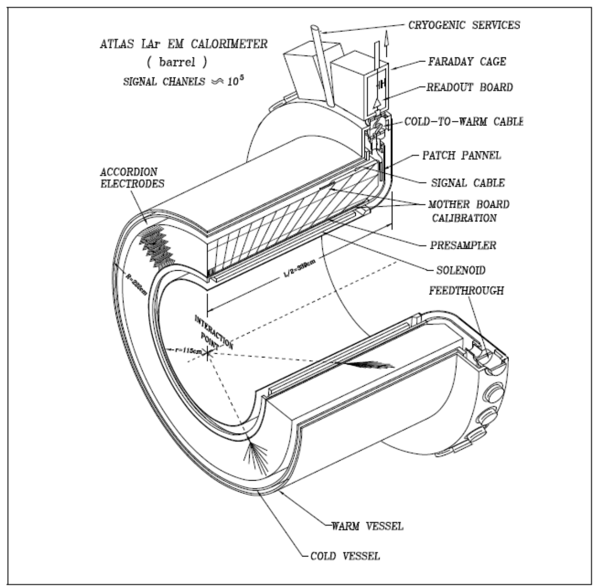
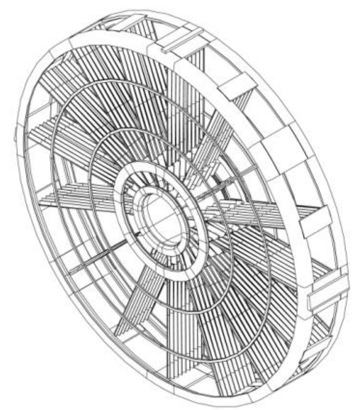
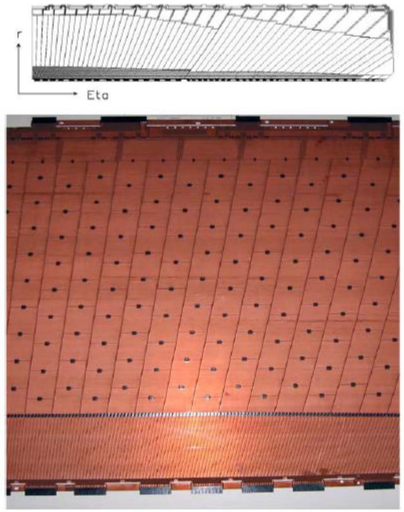


Figure 1-1 Perspective view of one half of the barrel cryostat.



EM Barrel

- **Calorimeter mechanics: CERN, LAL-Orsay, LAPP-Annecy, CEA-Saclay, Milano**



2 half-barrels
16 modules each
64 absorbers/gaps per module

- **Presampler: Grenoble, Stockholm, Morocco**

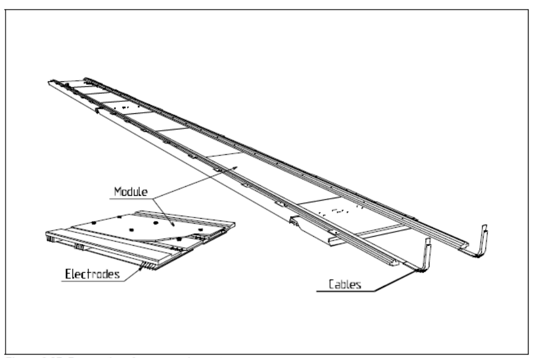
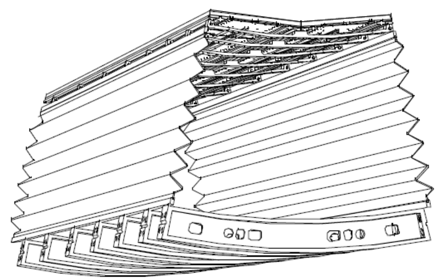


Figure 6-27 Perspective of a presampler sector.



Readout

- **Typical signal: ionization current in 2mm gap @ 2000V**

  No amplification: 2-3 μA/GeV

Total drift time 450 ns

Bunch crossing : 25 ns

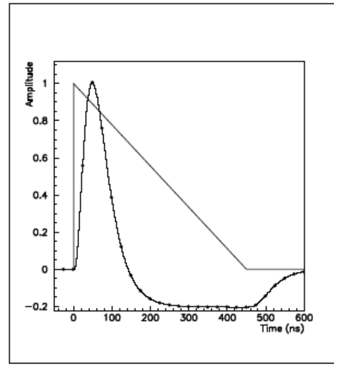
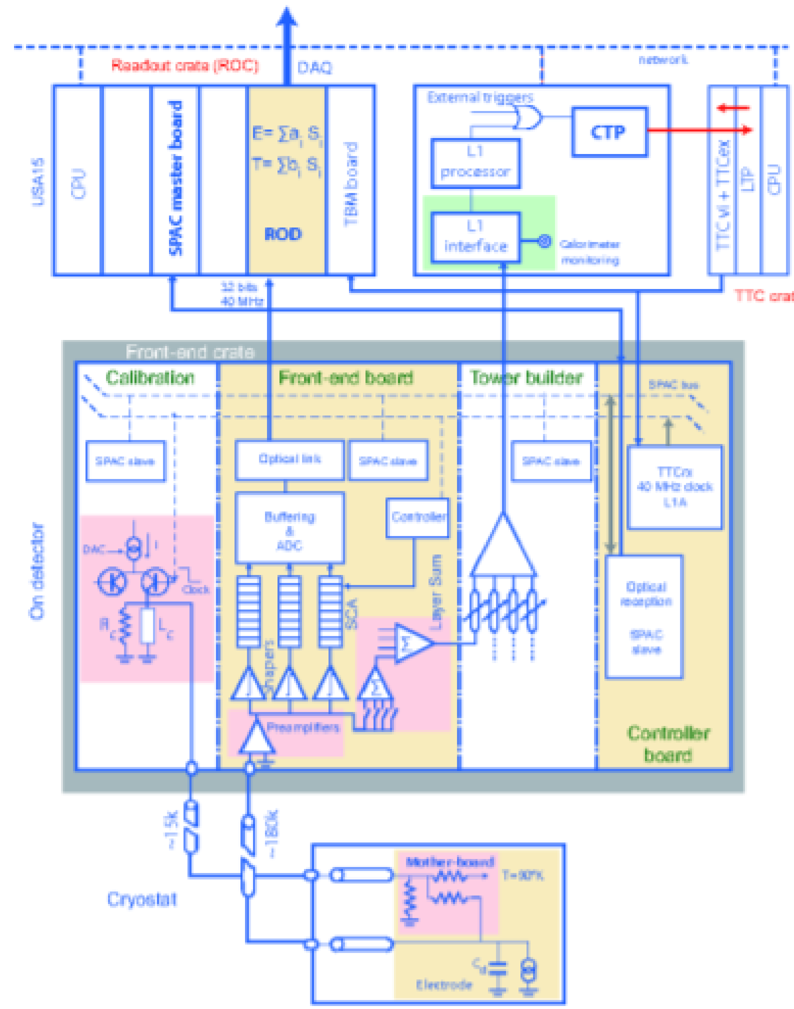


Figure 1-6 Signal shape as produced in the detec (triangle), and after shaping (curve with dots). The d represent the position of the successive bunch cro ings.

- **Shaping essential: optimize pile-up vs noise**
  - **Bipolar asymmetric**

- **Readout: 190 000 channels, 14 bits, 3 ranges**

  pipelined for 2 μs by analog memory
- **Trigger: ~5000 channels, 10 bits, 25 ns**
- **Calibration to ~ 0.1%**



Main design guidelines

- ***Two permanent references:***
  - ***H-$\gamma\gamma$ simulation: estimate impact of each decision: design, procurement, QC…***
  - ***Test beams: realistic setups. Fast analysis / feedback***

- **Principle**
  - **Accordion (Daniel Fournier): fast signal extraction, granularity, hermeticity (in phi)**
    - **Absorber thickness and detailed geometry**
  - **Noble liquid detection: rad-resistance, stability. Choice of liquid: Ar/Kr/ (Xe)**

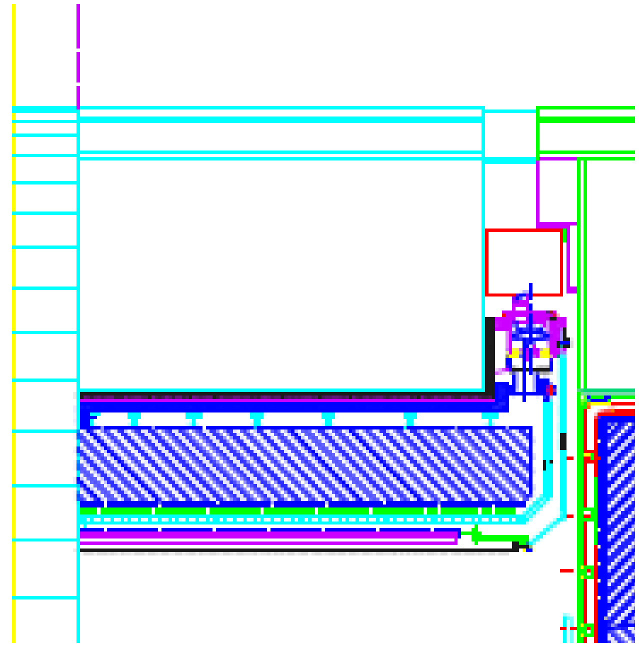
- **Cryostat**
  - **Low dead material, homogeneity**

- **Signal formation and transport : detailed understanding**

- **Quality control : rather strict , well implemented and documented**
  - **(once in the cryostat: almost like a satellite…)**

Cryostat

- Central solenoid in front of the ECAL
  - *integrated in the cryostat isolation space*
  - minimize coil thickness and supports
- Aluminum, minimize wall thicknesses, dead material and dead space
- Design multi-channel feedthrus , cables (no cold elect)
  - 1920 lines feedthrus
- Liquid purity : 29 probes (9 in barrel)
  - Effect of purity studied
- Temperature: 96 probes (32 in barrel)
  - Effect of temperature studied. Thermal simulations of cryostats

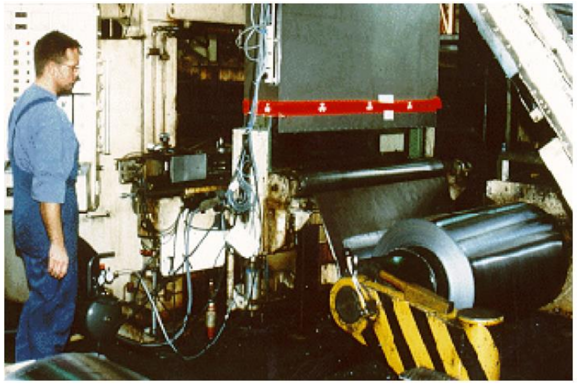


Signal processing

- **Grounding: Radeka's scheme. Strictly imposed (design, construction)**
    - ***LAr very sensitive to coherent noise (triggers: ΣE_T , E_T miss…)***
- **cold part: only passive, but *needs to be understood in detail (inductance…)***
- **Front-End Crates**
    - **Trigger sums (LTDB), output on cables. *Beware of saturation/non-linear cases***
    - **Calibration boards: very important, *not easy (offsets…)***
    - **Front-End Boards: Hybrid preamps + Analog memories (DMILL rad-hard tech)) , ADC**
        - **1524 FEB's…**
- **Radiation resistance: a lot done by ourselves*, documentation not always reliable…***
- **Commissioning: timings, calibration, etc. : Lots of work but OK.**
- **Data quality *[channels with no or reduced HV, noise-bursts, etc…]***
- **Calibration from data: very fine understanding *(never ending*)**

EM mechanics

- **Careful design: simple, simple fabrication processes, built-in accuracy**
  - **Of course careful with ΔT between ambient and LAr for all designs (SS: 3mm/m)**



- **Absorbers**
  - **Lead plates:**
    - **measurement during production at milling factory (home-made X-ray system)**
    - **measurement of all plates (ultra-sound)**
    - **pairing of plates to minimize constant term. Impact estimated real-time**
  - **Prepreg : careful QC at factory**
  - **Steel: careful selection of surface treatment**
  - **Bending machine: clever design for good accuracy (*thanks JL Chevalley*!)**
  - **QC: 3D measurement of all absorbers**

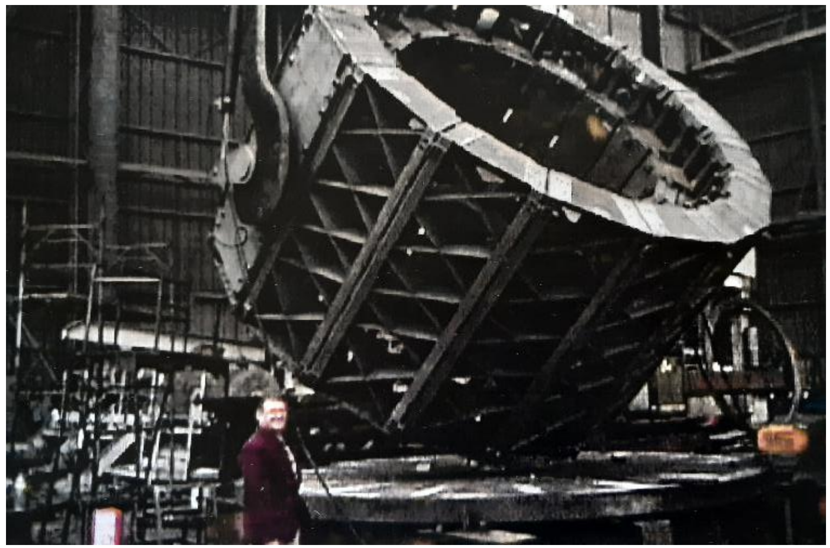
- **G10 bars and internal rings**
  - **Designed to take care of (strange) thermal behavior of accordions (asymmetric contraction coefficient)**
  - **Very stringent geometry criteria => *difficulties in procurement***
  - **QC: thickness measurement of all bars. ΔT behavior on samples (all plates)**

- **Support rings, tooling**
  - **geometry accuracy ⇔ large weight ?**

    one half-barrel: 57 tons

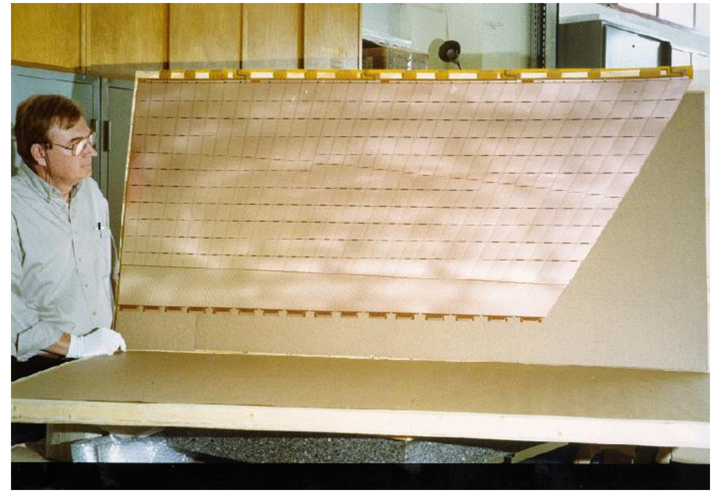
    typ accuracy: 0.2 mm

  - **strong impact of assembly plan on tooling and machining specs…**

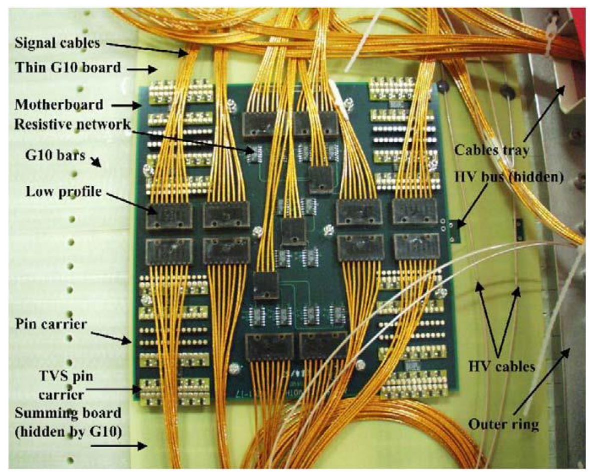


Electrodes, cold boards, cables

- **Multilayer " kapton" electrodes**
  - **Large printed circuit, high accuracy, "low" price:**
    - **difficult to get accuracy at factory**
  - **Protection resistors: carbon ink**
    - **bending/damage, difficult to get right R value**
  - **Accordion bending:**
    - **difficult to get correct geometry (elastic material)**
  - **QC: geometry , all resistors**
  - **Design: needed to understand real signal propagation: inductance, ground returns (" springs ") , cross-talk.**



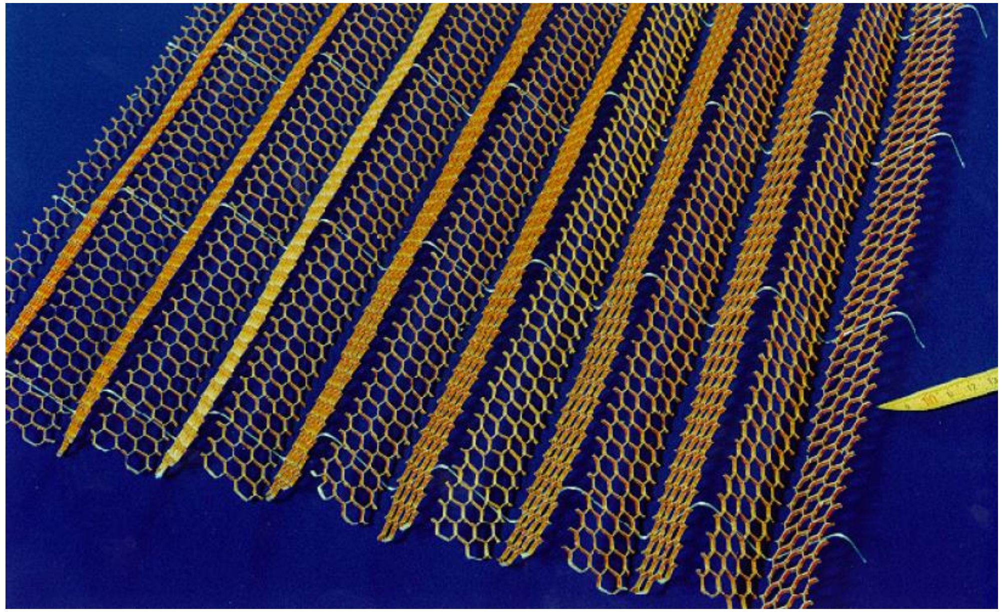
- **Cold boards: OK**
- **Cables: OK. Take skin effect into account**
  - **Beware of dielectric / porosity to LAr**



Spacers (HEXCEL honeycomb sheets)

- **Not easy to get the thickness tolerance (1.75 mm +- 0.1)**

- **Big problems with cleanliness at start => HV problems**
  - **Shorts from start, or short appearing later (complete module, in LAr, etc.)**
  - **Never really identified**
    probably metallic dust
  - ***Protection resistors do not allow to***
    "burn" the shorts

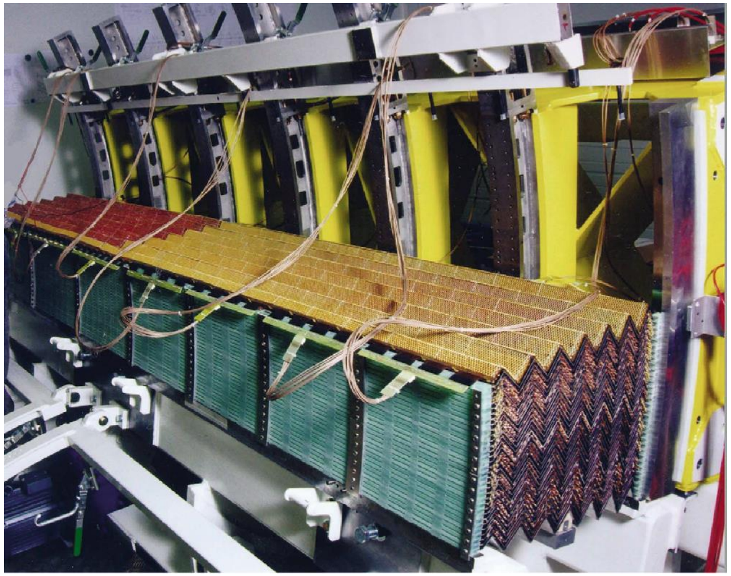


- **Cured by thorough cleaning**
  - **Alcohol bath + blowing**
  - **Large personpower load**

- **QC: each spacer HV-conditioned/tested before assembly**

Module assembly

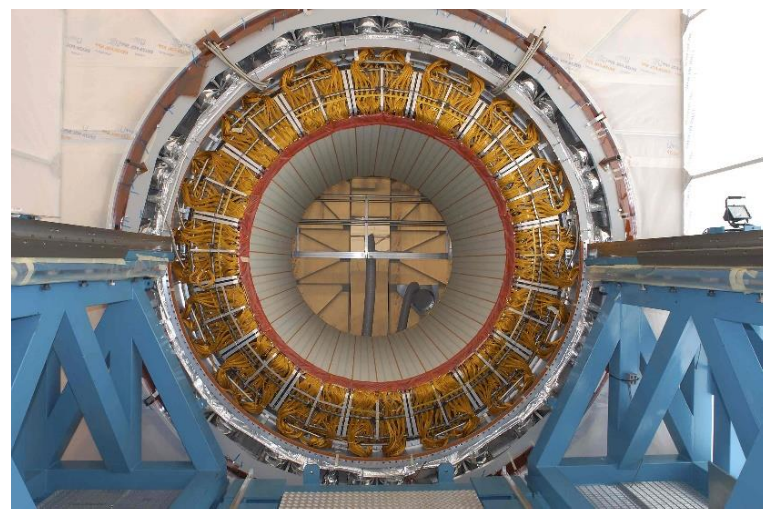
- **Barrel: 3 sites (CERN, LAPP, Saclay) , each with a cryostat to test one module in LAr (End-Caps : 2 sites: Madrid, Marseilles)**
- **Clean rooms : “reasonable quality” ~100 000 class, *strict rules enforced***
- **Identical assembly benches and process**
- **Identical QC measurements and tests**
  - **Each gap: measure assembly thickness, test HV**
  - **Module: measure overall geometry, test HV, measure all gap capacitances**
  - **Fast exchange of info, procedures, and pieces**
  - **Integrate mod measurements into “virtual barrel” to ensure safe assembly**



- **Cold test of module in each lab, 4 in beam-test**

Overall assembly at CERN

- **Mechanical assembly of modules into ½ barrel: OK**
- **Insertion of presampler modules**
- **Measure all channels on barrel:**
  - **capacitance/inductance, TDR**
    tedious, *very useful*



- **½ barrel rotation and insertion into cryostat: spectacular but easy.**
- **Connexion of cables to Feed-thrus.**

Beam tests

- **1990 small prototype (front face 40x40 cm)**
  - **Square geometry**
  - **Idem, with cylindrical geom**

- **1992 large prototype module: 2m x 0.7 m**
  - **Several granularities and electronics schemes**

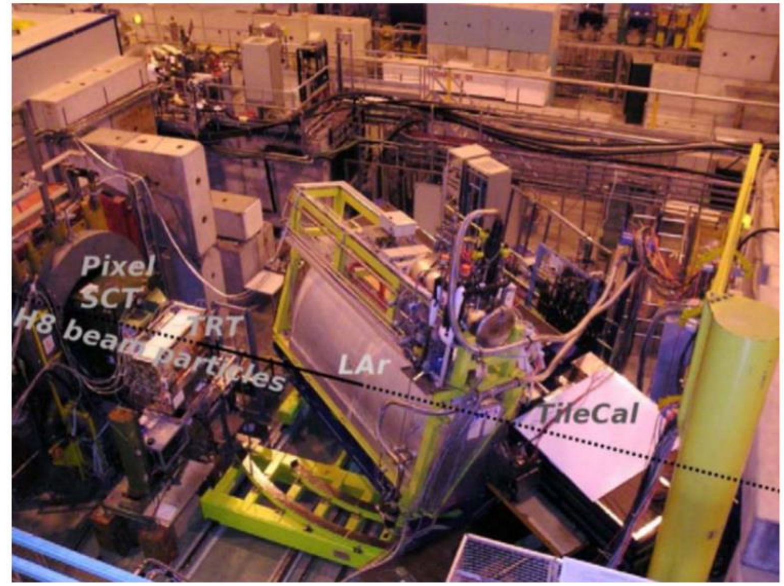
- **Module 0**

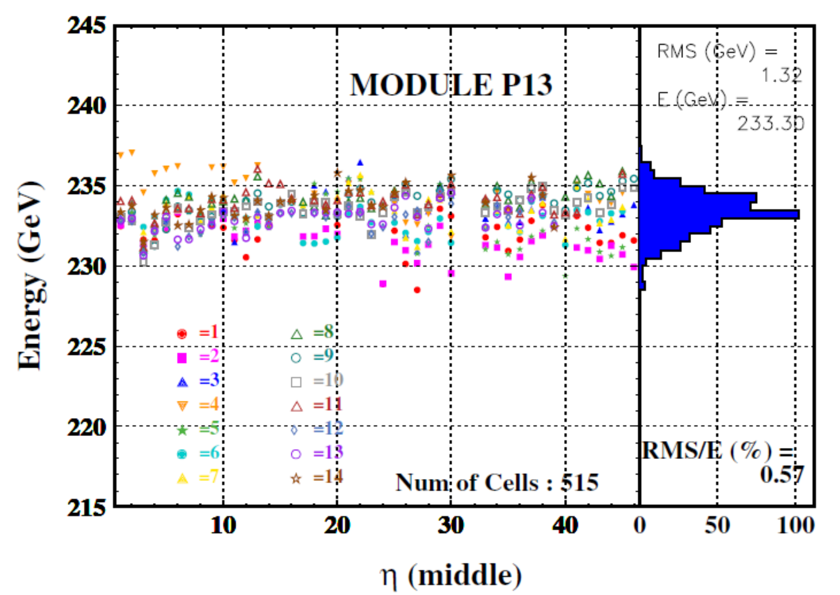
- **Series modules: 4 (/32) tested in beam**

  Very important to do large scans

  local tests do not bring much info.

- **Combined tests (IDET, HAD)**





Performance in ATLAS: operation

- **Purity, temperature OK**

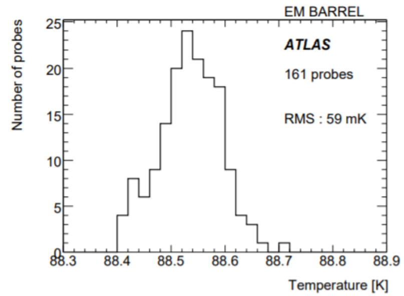
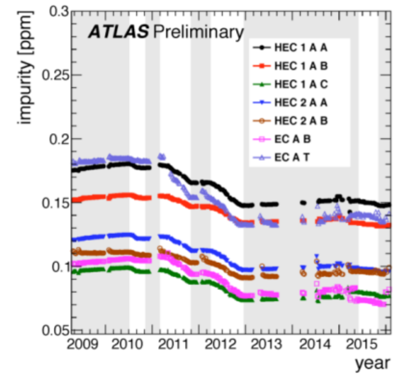


Fig. 7. Distribution of the average temperature measured over ten days for temperature probes within the EM Barrel cryostat [10].



- **Dead, Reduced HV's**
  - **< 1/1000 dead channels (2-sides/gap)**
  - **Few 1000's reduced HV**
  - **HV trips ~0.4 % data loss (2015)**

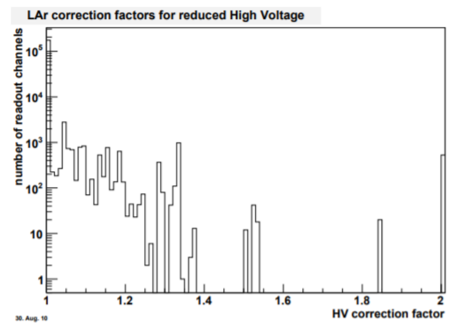
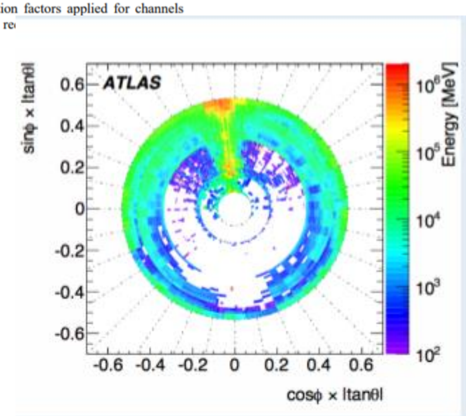


Fig. 10. Distribution of cell energy correction factors applied for channels serviced by at least one HV line operated at re

- **Normal coherent noise very small**

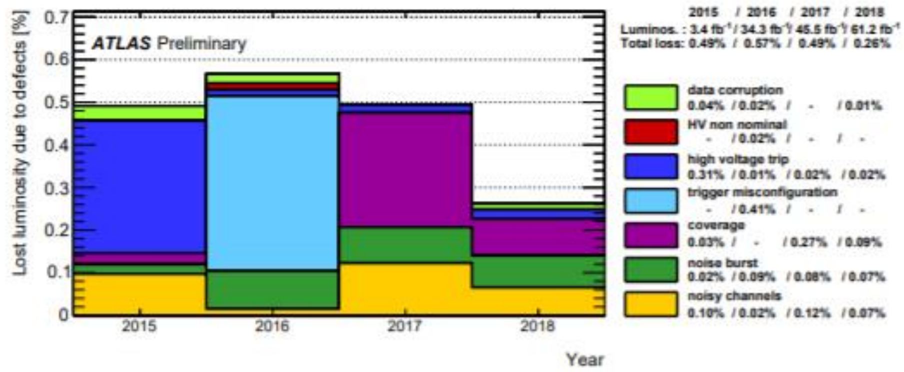


- **Noise bursts**
  - **Mainly in EMC (end-caps)**
  - **Cause not clear. Related to Purity probes(?)**
  - **Removed by Data Quality: 0.02% data loss (2015)**

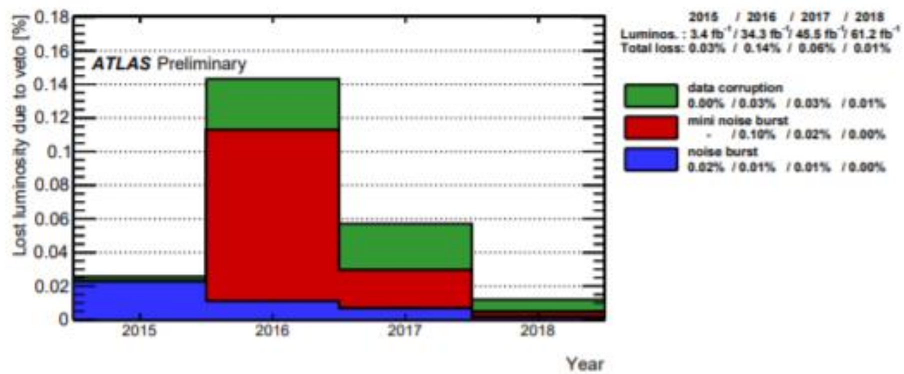
Data quality inefficiency

- **Inefficiency in Run2**

  Well below 1%



(a)

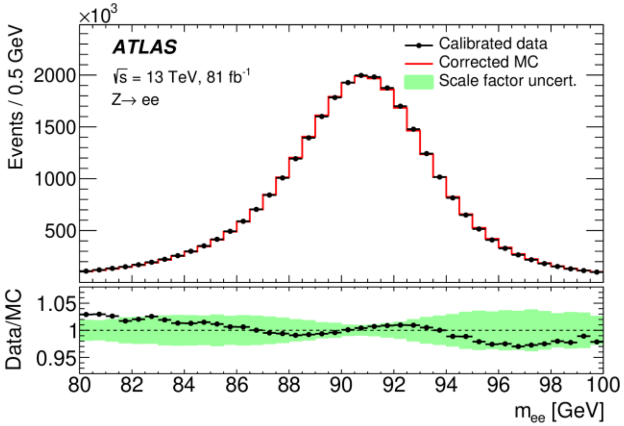


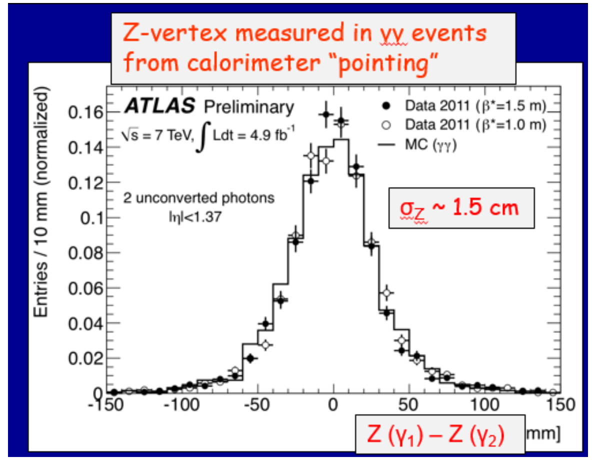
(b)

Ar data quality inefficiency in Run 2 [3]. a) Luminosity block defect rejection. b) Time
n.

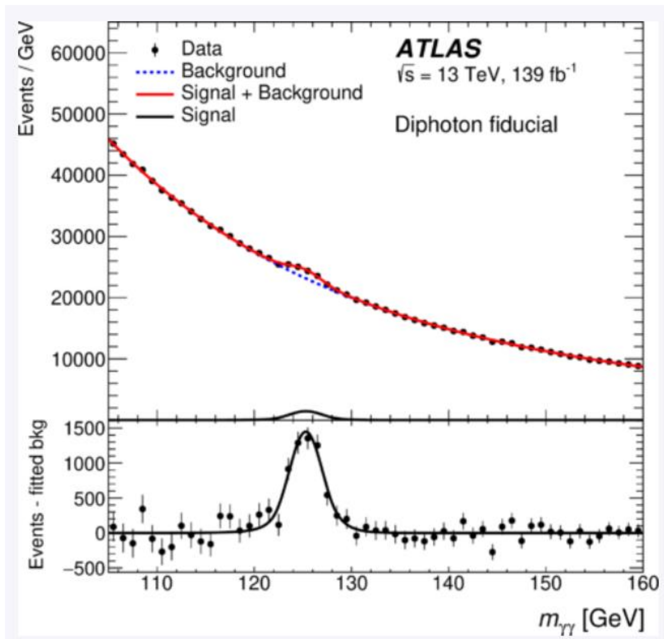
Performance: Physics

- **Constant term, Pointing**





- **Hgg**



Conclusion

- **ATLAS Liquid Argon calorimeters**
  - **A very large scale project**
  - **Many difficulties, but reached the specs**

  - **Well organized**
    - **Strong, no-nonsense management by D. Fournier.**
    - **Early installation + cryostats => strong incentive to be rigorous**
    - **Powerful labs and teams (cryo experience, QC culture, handling exp…)**

- **Besides design and construction, importance of:**
  - **Simulations and large-scale test-beams**
  - **Commissionning and data-quality work**