EP R&D Day 2021

Status of Noble Liquid Calorimetry WP3.1

11/11/2021

Maria Asuncion Barba Higueras(TE)
Brieuc François (EP)
Martin Aleksa (EP)
Michel Chalifour (TE)
Johan Bremer (TE)

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Part 1: PCB electrodes design with noise and cross-talk mitigation

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- Multilayer PCB electrodes
- PCB electrode design
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- Cross-talk studies
- Performance studies
- Plans

Part 2: Signal extraction from the cryostat → development of high-density feedthroughs

- Introduction
- Solution studied
- Selection of components
- Experimental tests
- Mechanical simulations

Part 1: PCB electrodes design with noise and cross-talk mitigation

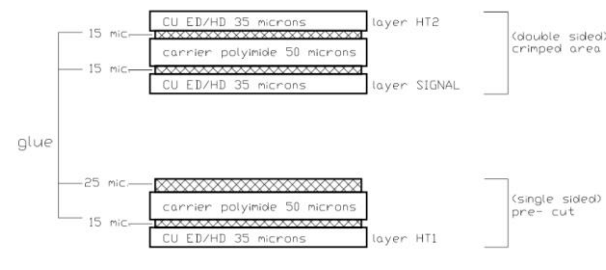
Introduction

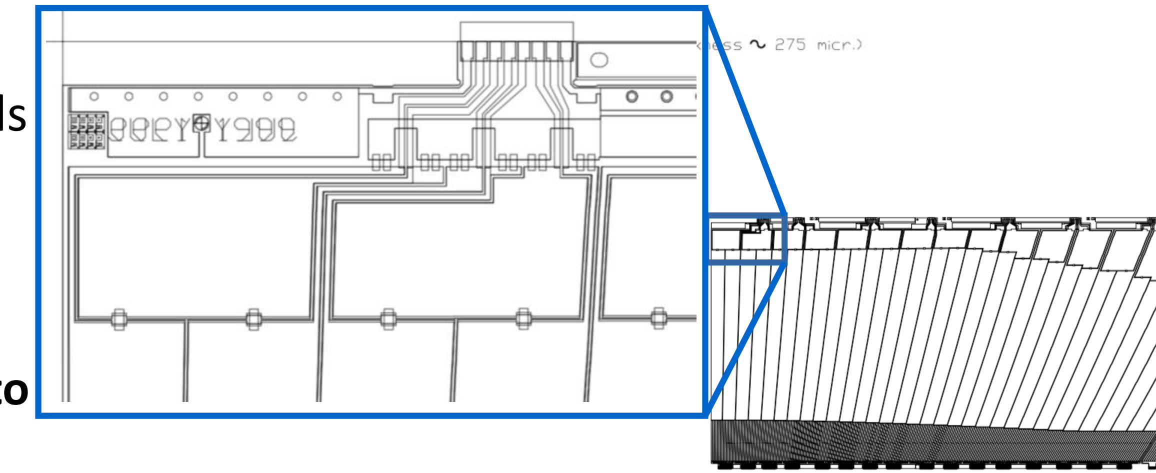
- Noble Liquid calorimetry is a well proven technology
  - Successfully operated/operating in D0, H1, NA48/62, ATLAS, …
- Key features
  - Radiation hardness, long term stability
  - Linear response, uniformity, high control over systematics
  - Good energy/timing resolution

- Very promising candidate to meet future experiment's requirements
  - Proposed as the **baseline for FCC-hh ECAL + Hadronic Endcap/Forward and LHeC ECAL**
  - **Adapted to an e^+e^- experiment** (FCC-ee), leading to a **very interesting option**
- R&D direction: optimization for particle flow reconstruction on top of conventional calorimetry
  - **Higher granularity: PCB electrodes design with noise and cross-talk mitigation + signal extraction from the cryostat**

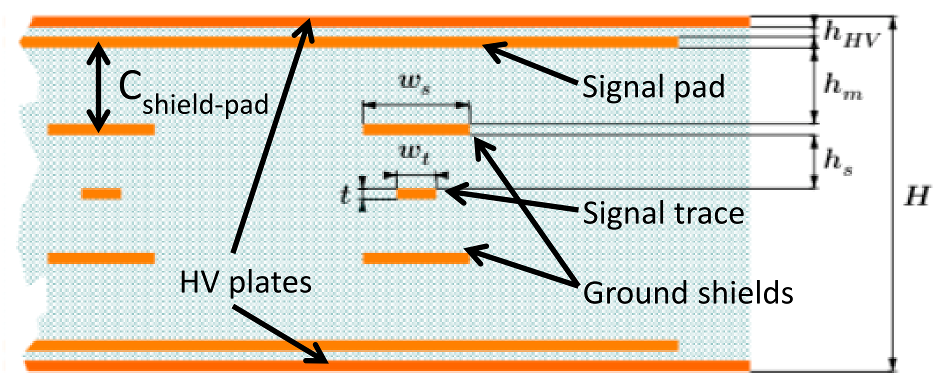
Multilayer PCB electrodes

- ATLAS signal extraction: first longitudinal layer read from inner radius, middle and back layers read from outer radius
  - Kapton electrode implementation
    - 3 layers glued together
    - 2 HV layers + 1 signal layer
  - Signal routed via traces in the same layer as the pad, alongside other cells
  - Longitudinal granularity limited by by trace density/cross-talk





- **Higher granularity can be achieved thanks to multilayer PCB electrode**
  - Traces can run beneath other cells, inside the PCB
  - Prevent cross talk with ground shields
  - Ground shields increase the capacitance → noise
    - $C_{cell} = C_{shield\text{-}pad} + C_{detector}$
    - $C_{detector}$: signal pad – absorber ground
    - Careful optimization

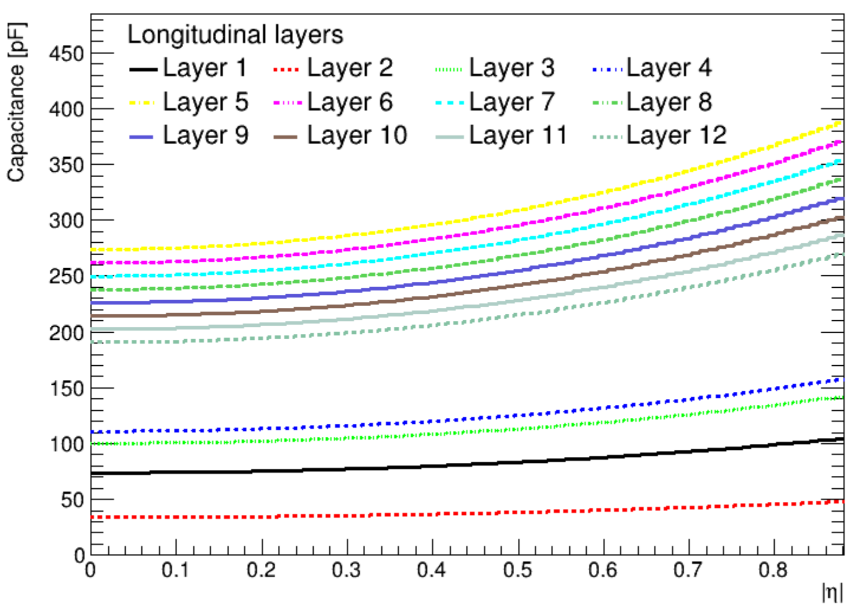


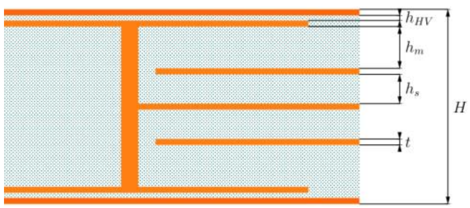
PCB Electrode Design

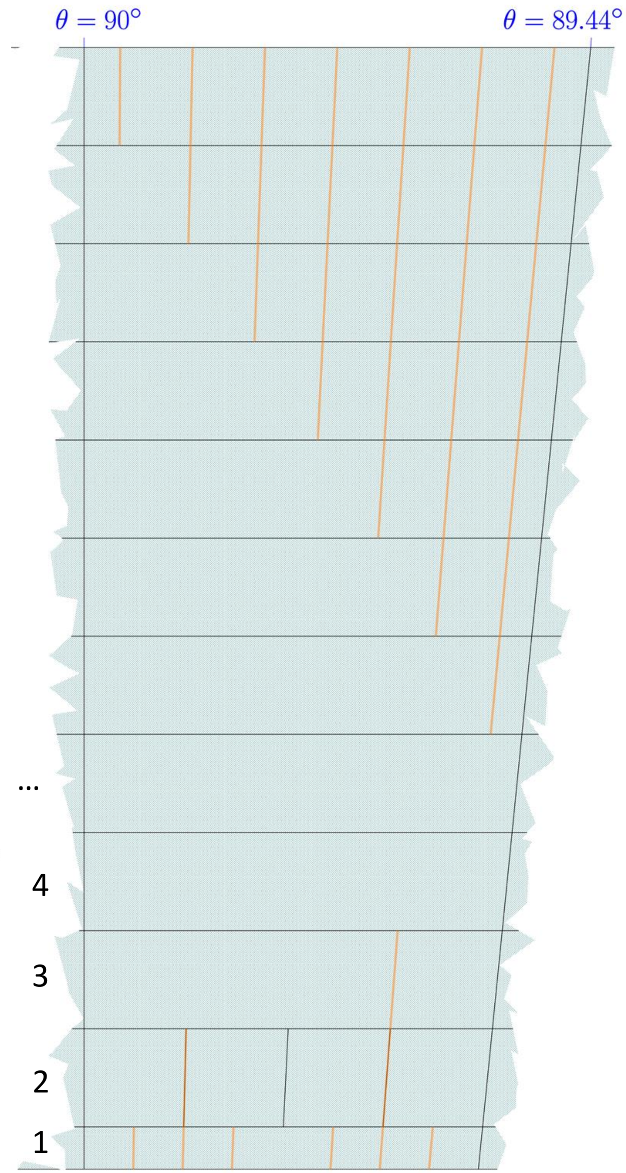
- Implementation of the PCB electrode in CAD (Cadence Allegro®)
  - Lower the number of signal traces/ground shields by reading two signal pads with one trace and maximize spacing between traces
  - Keep the number of traces extracted from front low
    - Noise term dominate for low energy particles which deposit their energy mostly in early longitudinal layers

- Derived cell capacitance from Finite Element Method tools (Ansys Maxwell®): 30 – 400 pF depending on the cell

Total capacitance



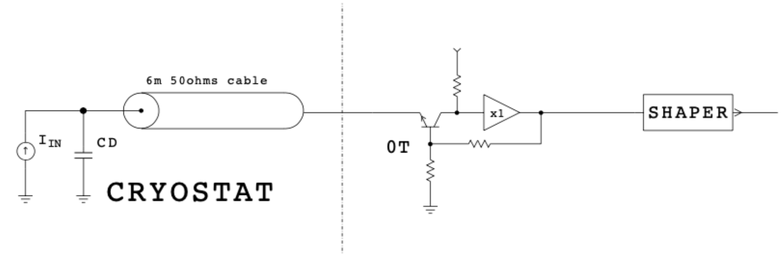


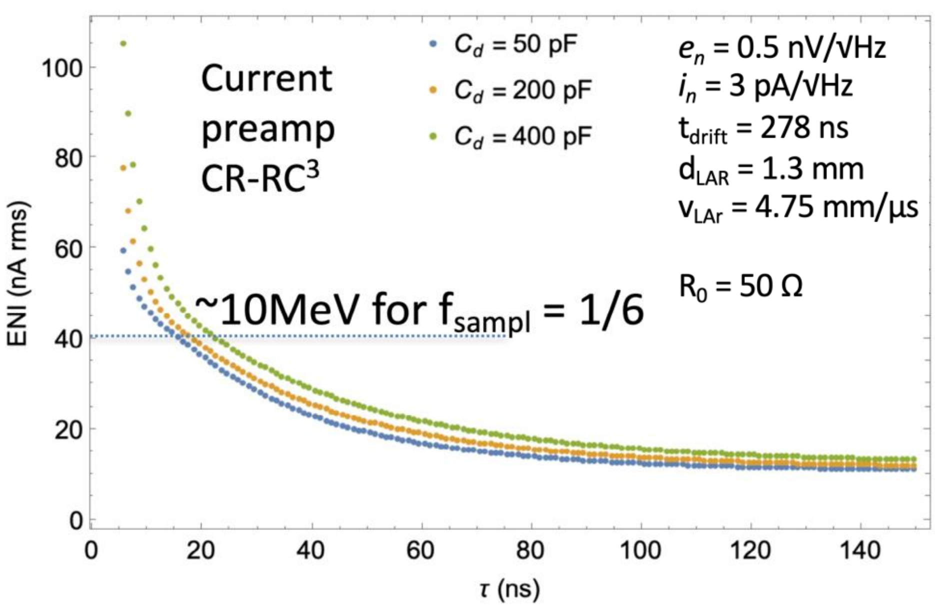


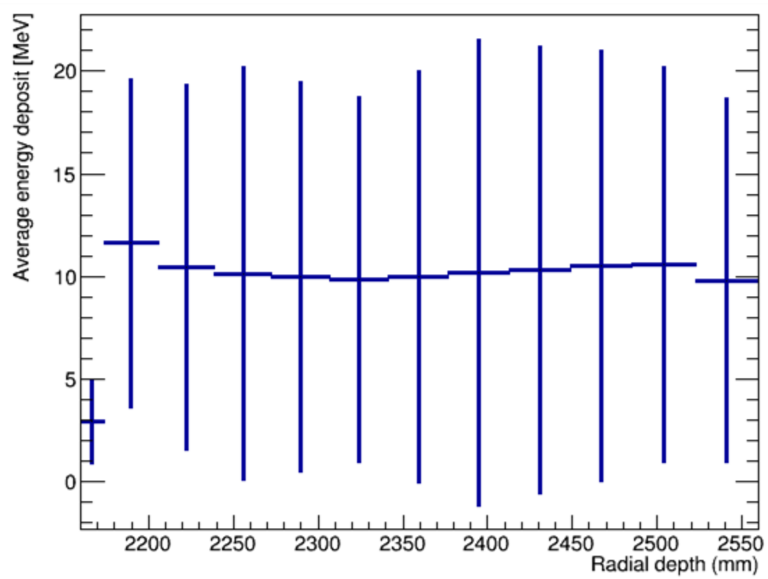
Horizontal axis expanded by a factor 10

Noise studies

- The noise has been estimated with an analytical implementation of the whole readout chain assuming ATLAS like electronics
  - Signal extracted by 5 meters coaxial cables feeding the pre-amplifier and shaper
  - Noise level below 5 MeV can be achieved for shaping time above 80 ns
  - Single MIPs can be measured with signal over noise (S/N) ratio of ≥ 3



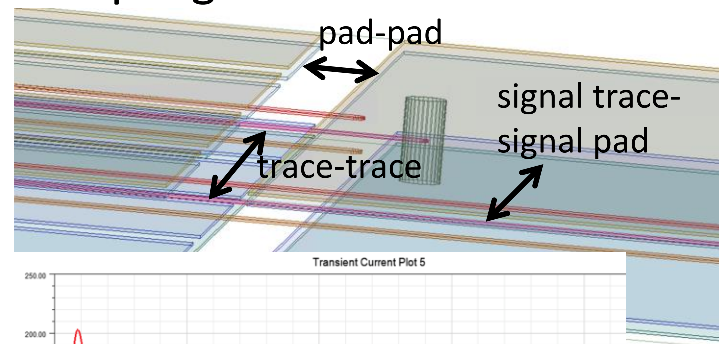


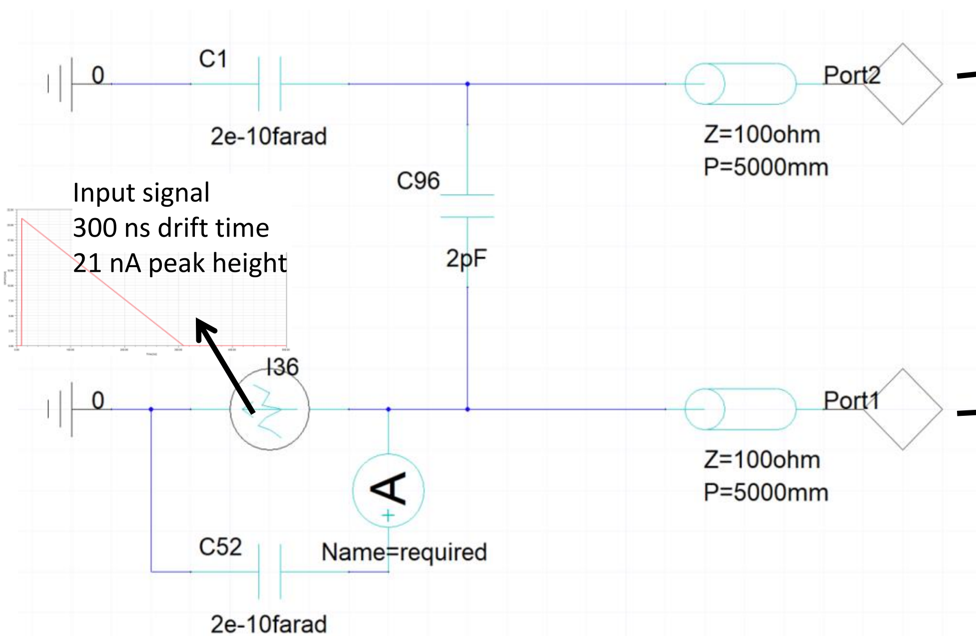


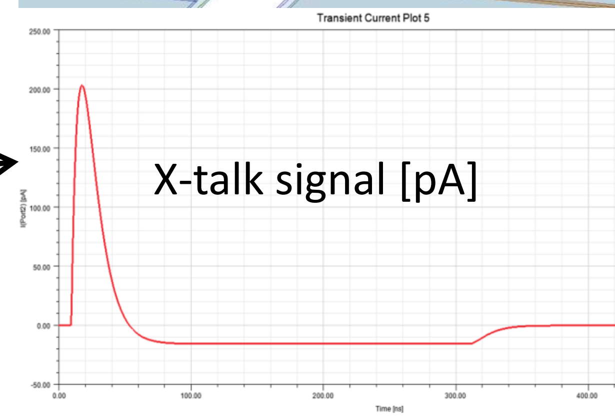
Average MIP energy deposit per layer

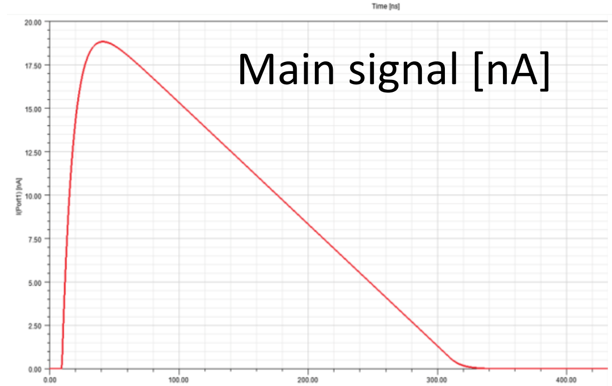
Cross-talk studies

- Cross talk occurs between cells mainly due to capacitive coupling
  - Capacitance values extracted from Ansys Maxwell® (total capacitive coupling of 2.2 pF for the outer radius cells)
  - Cross-talk equivalent circuit implemented in Ansys Circuit®





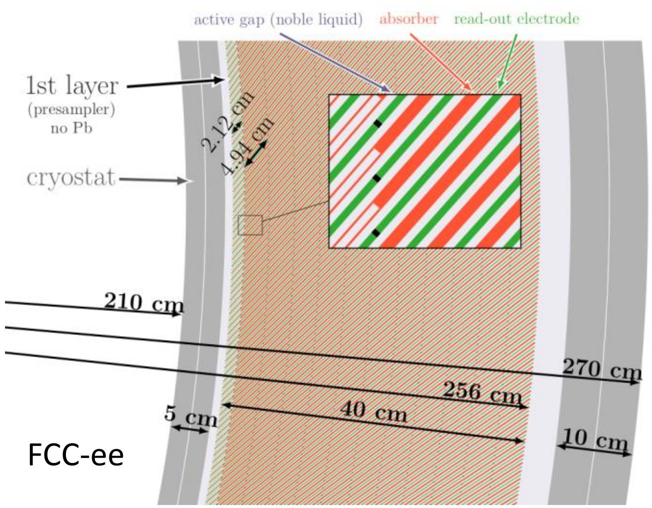


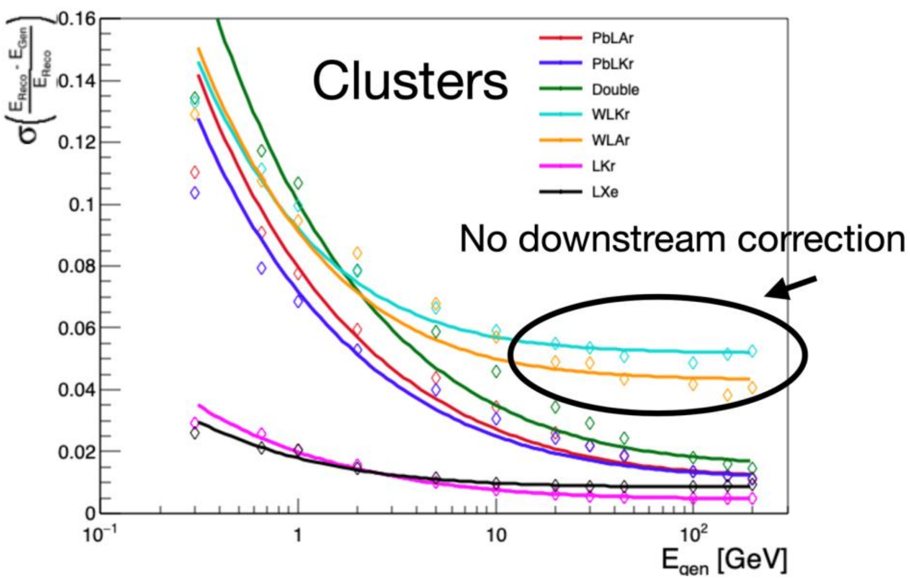


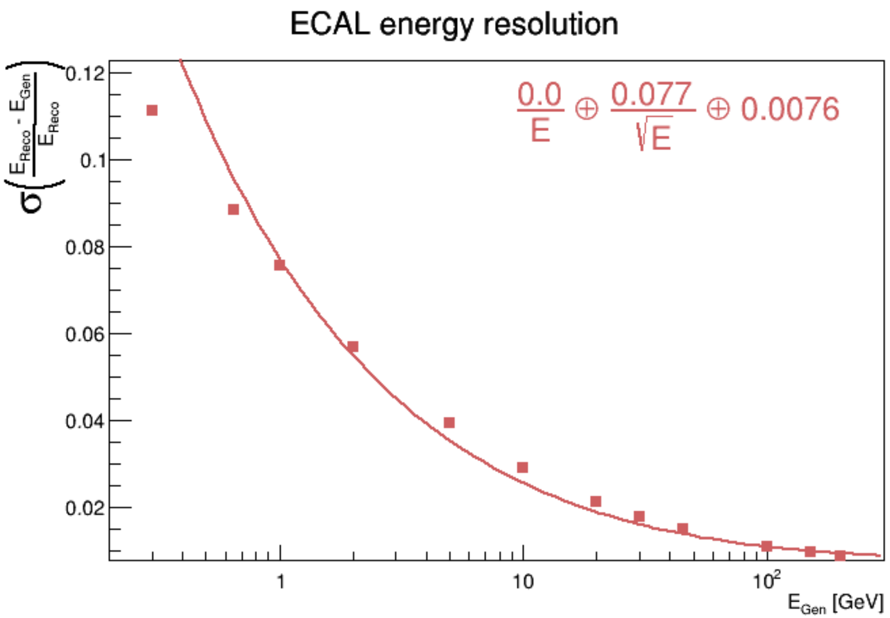
- Observed cross-talk ~1% (only capacitive source considered)
- Results currently being cross-checked with full FEM tools (Ansys HFSS 3D layout®) and scattering parameters

Performance studies

- Geometry with inclined plate implemented in FCCSW
- Baseline scenario: 2 mm Pb absorber, 1.2 mm LAr gap, 1.2 mm PCB electrodes, 50 degrees inclination, 12 longitudinal layers, ΔΘ = 0.560, 1536 plates in phi, 1 readout cell = 2 physical cells (ΔΦ = 8 mrad)
- Performances have been evaluated from particle gun (no noise – no cross-talk)
- Various scenarios for the absorber material and noble liquid are under study

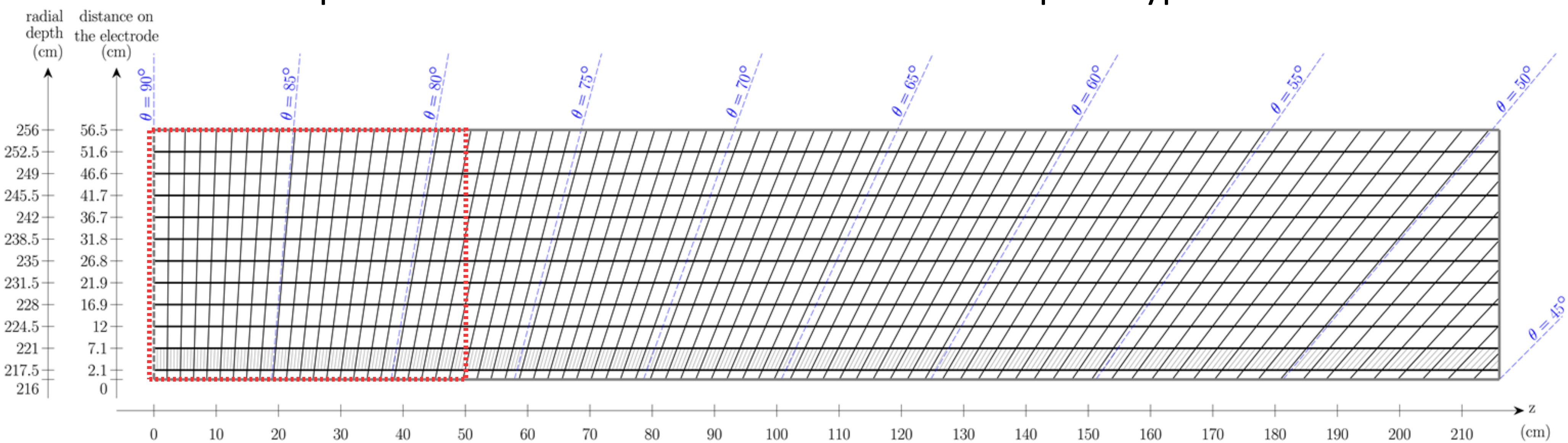






Plans

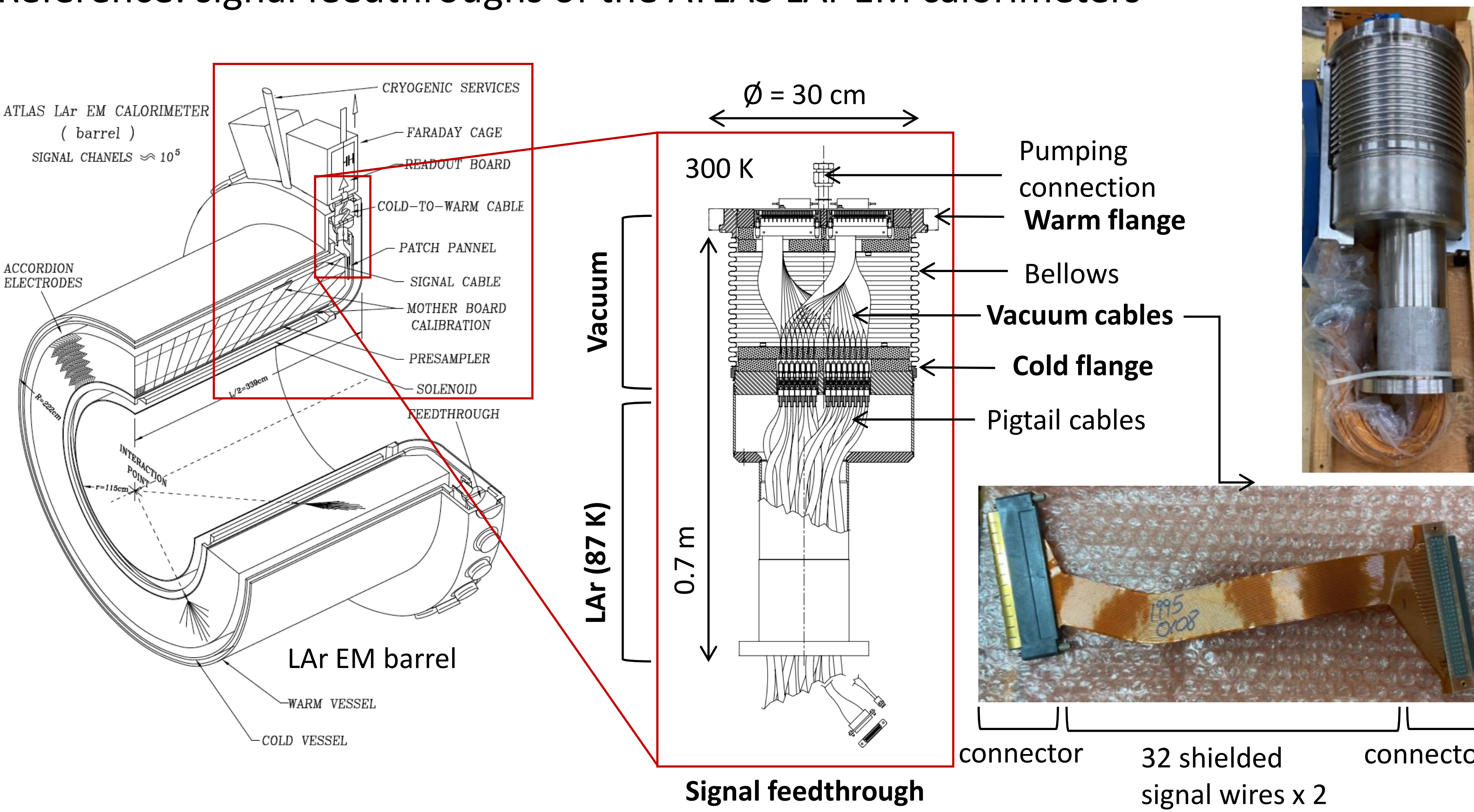
- End of 2021: finalization of the FEM PCB study
- Early 2022: Implementation of a new PCB CAD for a first prototype
  - 1:1 scale dimensions
  - Several theta towers in one prototype (~ 20)
    - Maximize the number of scenarios tested per prototype production while staying in 'standards' dimensions
- Mid-end 2022: production and characterization of the PCB prototype



Part 2: Signal extraction from the cryostat: development of high-density feedthroughs

Introduction

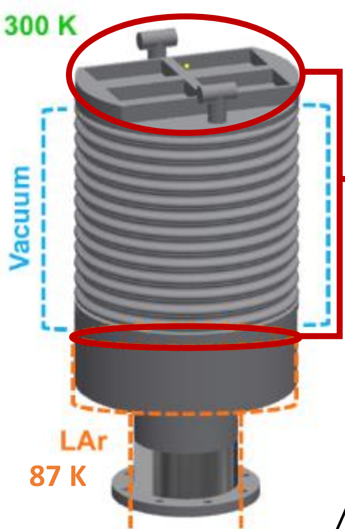
➢Reference: signal feedthroughs of the ATLAS LAr EM calorimeters

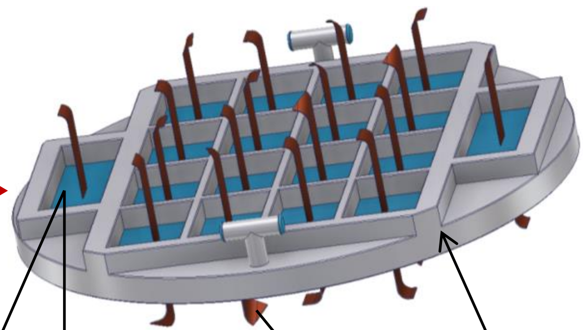


➢GOAL: **~20 000 signal wires/feedthrough** (x10 ATLAS FT: 1920 wires/feedthrough)

Solution studied

➢ High-density flanges: get rid of the use of connectors



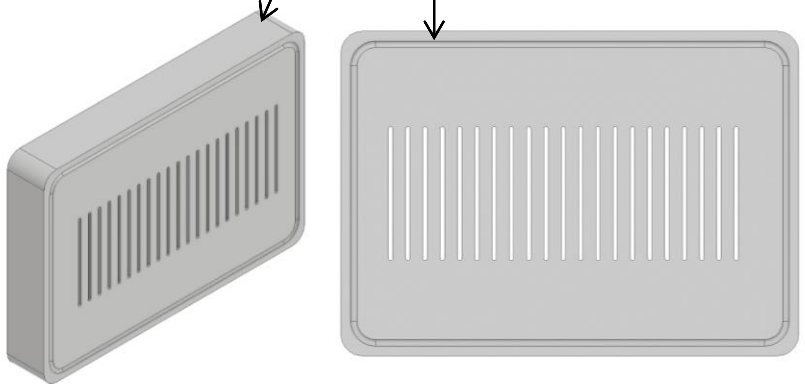


Main components:

1. **Structural material**
2. **Glue to fill the slits**
3. **Sealing solution to the SS flange**

Stainless Steel body:

- Ø = 600 mm, thickness 20 mm
- Space for heaters
- 2 pumping connections



Kapton strip cable

Structural material with slits:

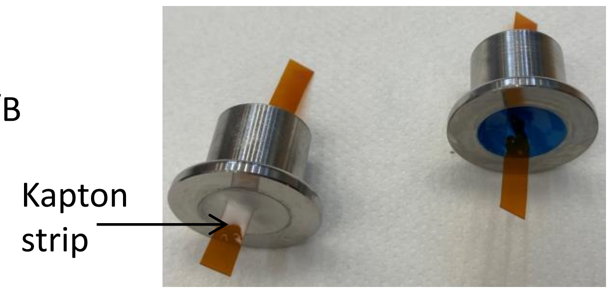
- Thickness 15 to 17 mm
- Slits (1 mm width) + 2 to 3 mm between slits + 30 mm length

Selection of components

➢Glue selection:

Samples (welding couplings): **thermally shocked and leak tested at room T°**

- Epo-tek T7110
- Araldite 2011 A/B

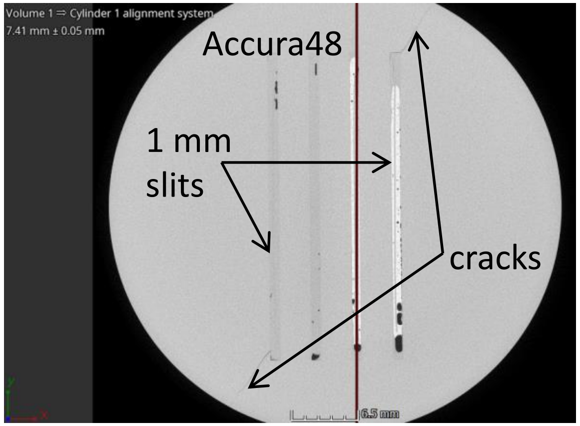


(7 candidates from literature and CERN experiments)

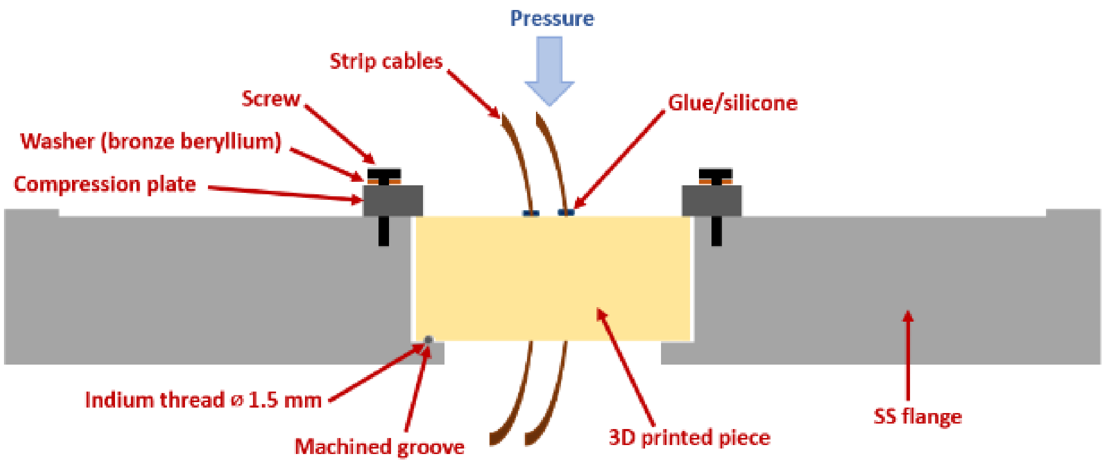
➢Structural material selection:

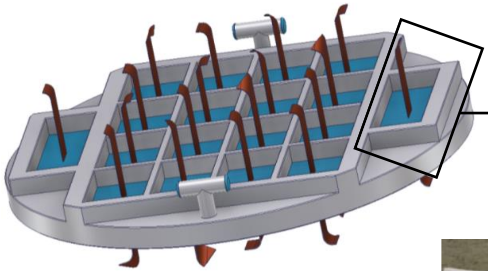
Samples: **thermally shocked + 3D CT scan before and after**

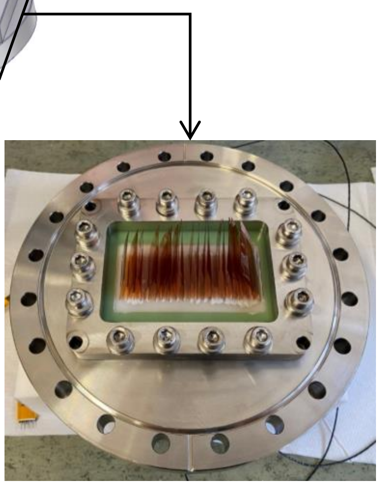
- Accura25 (3D-printed)
- SilasticM (rubber)
- MY750 (resin)
- G11
- G10



➢Sealing solution: indium seal + compression plate

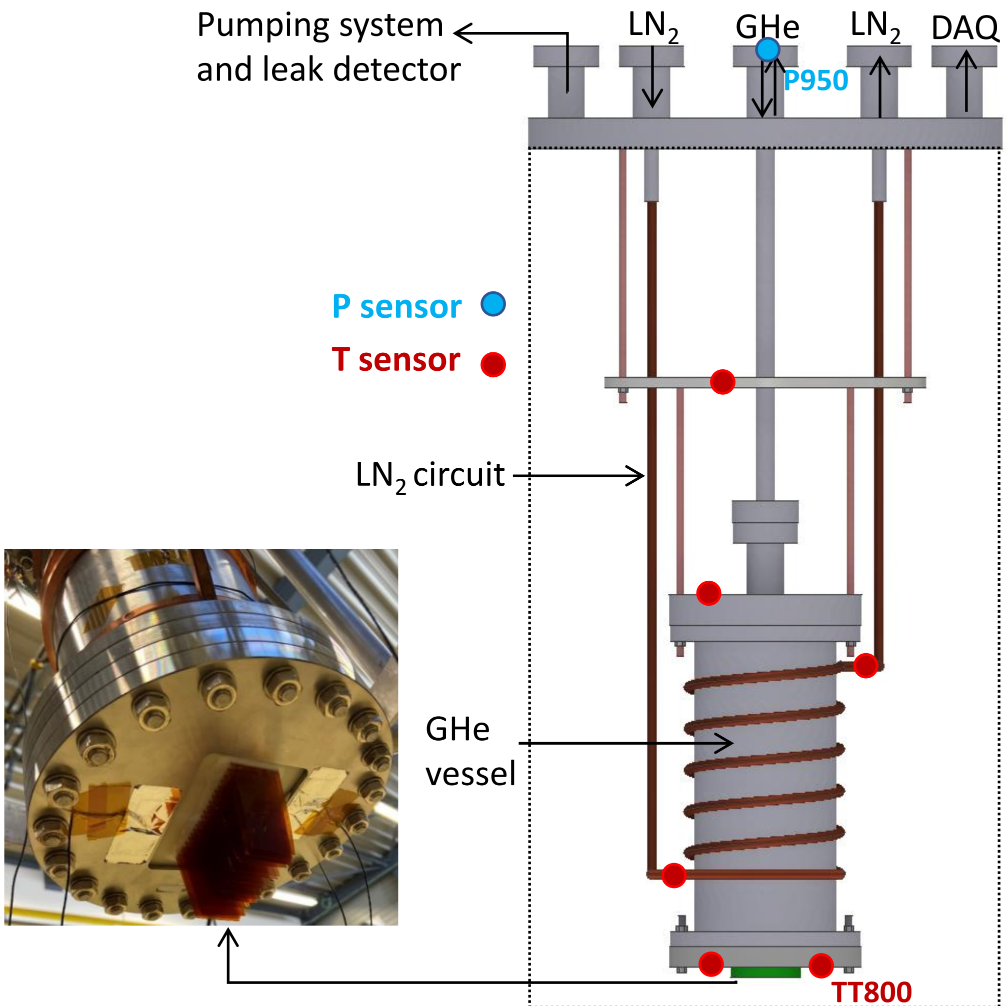






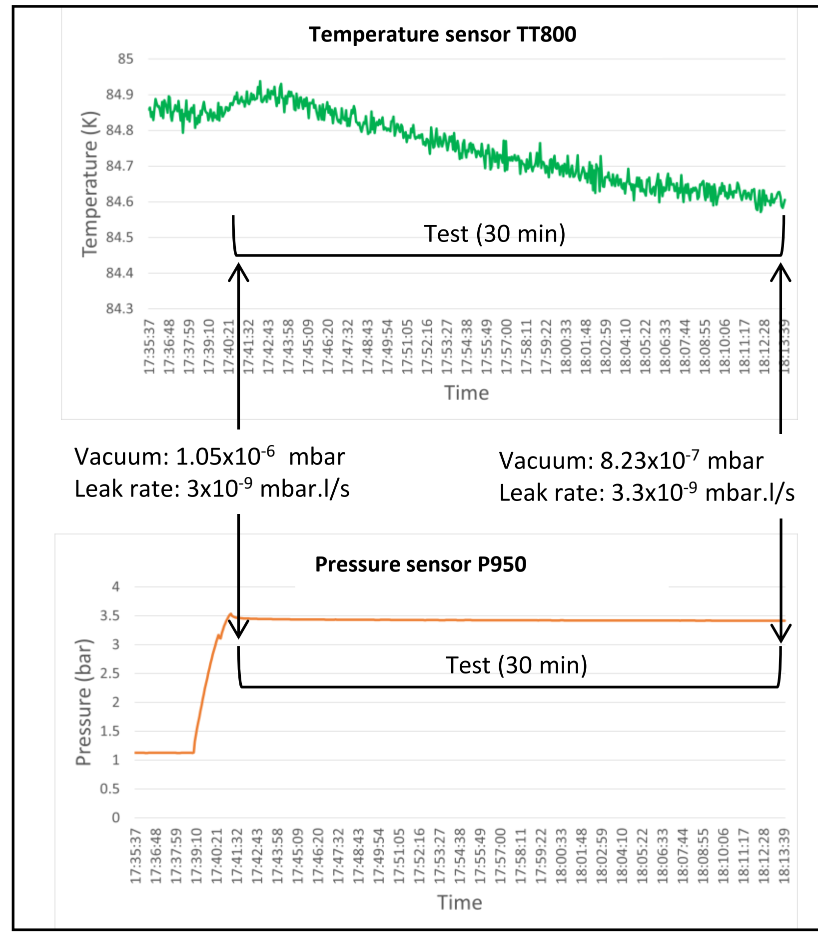
Experimental tests

- Experimental results: ex.: G10 + epo-tek (glue) + Kapton strips + indium seal



Pressure and leak test at room temperature
Cooling down: leak measurements every hour (+ P, T°, Vacuum)
Warming up: leak measurements every hour (+ P, T°, Vacuum)

Pressure test low T°



Mechanical simulations

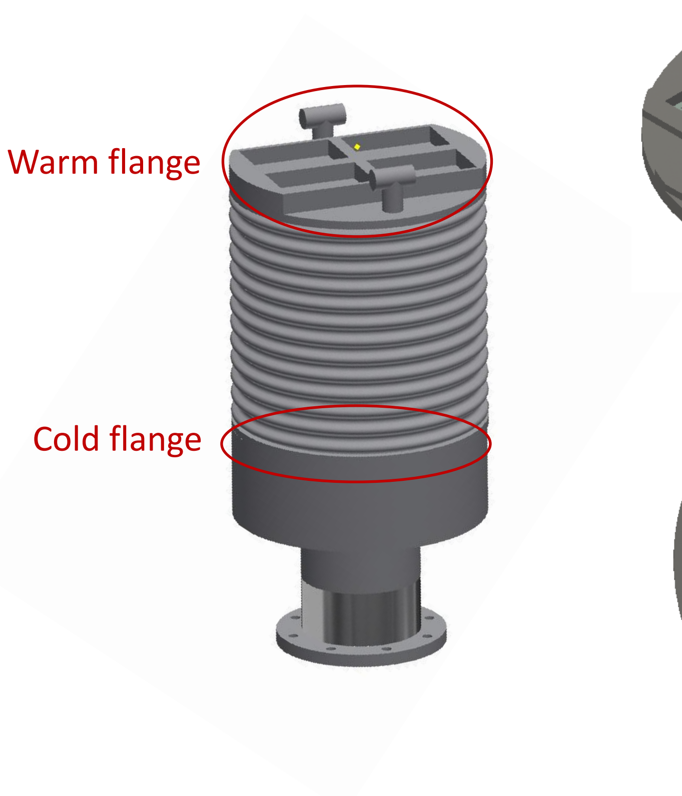
➢Study of different designs of the final feedthrough flange and mechanical stress simulations

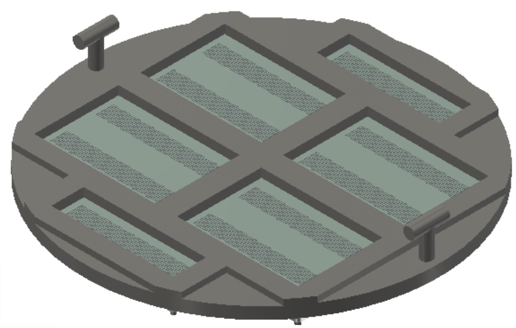
4 designs studied: 16 000 – 20 000 signal wires/flange

Mechanical simulations at room and low temperature with Autodesk Inventor:

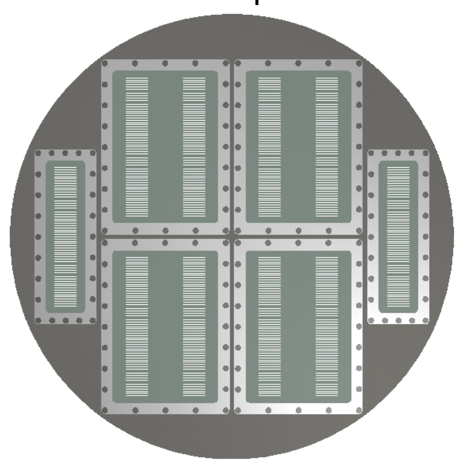
Max. deflection: 0.79 mm (ATLAS FT 0.68 mm)

Max. Von Mises Stress: 143 MPa (below yield and tensile strength of components)

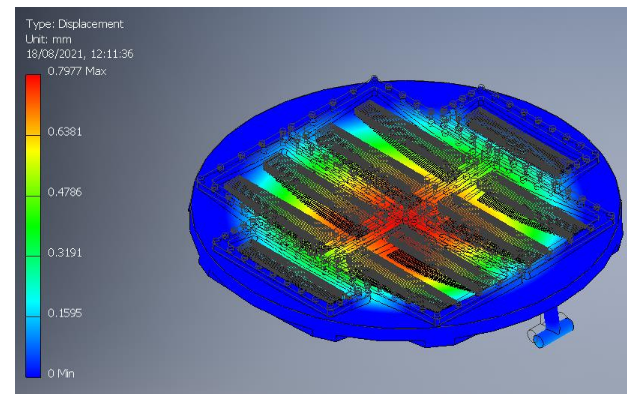


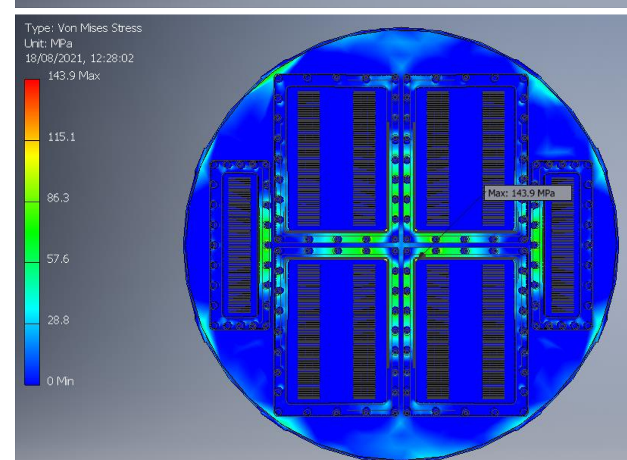


Outer part



Inner part





Thank you for your attention!

Questions?

brieuc.francois@cern.ch

maria.asuncion.barba.higueras@cern.ch