Noble Liquid Calorimetry: Input proposals in Track 2

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2nd DRD Calorimetry community meeting, 20/04/2023

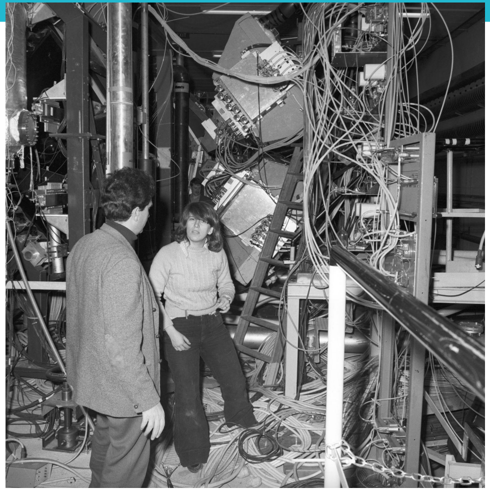
Input proposal(s)

In the end only 1(+1) proposals submitted in Track 2

	ID	Title	State	Accepted type	Reviewed
☐	13	Common Readout AS...	Awaiting Review	n/a	
☐	34	Noble Liquid Calorim...	Awaiting Review	n/a	

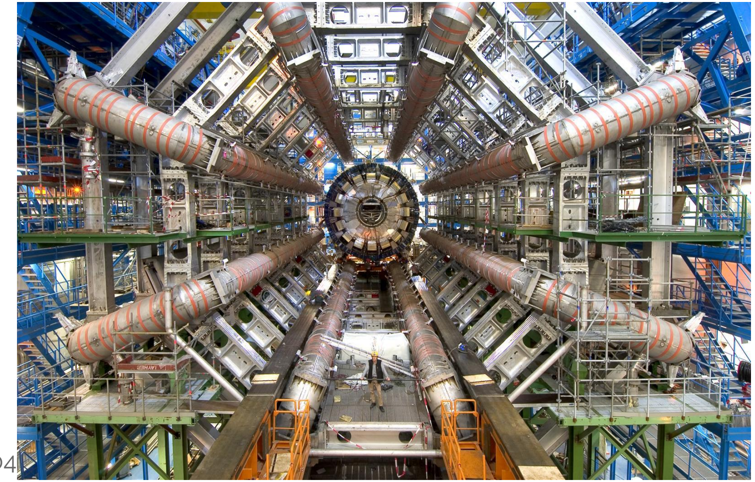
- “*Noble Liquid Calorimetry for Future Accelerator Experiments*”, by M. Aleksa, M.-A. Pleier and N. M.
- + transverse proposal on “*Common Readout ASICs for DRD6 calorimeter prototypes*” by C. de la Taille, M. Idzik and O. Gevin

Noble Liquid Calos for Future Accelerator Experiments



- Decades of success at particle physics experiments: from R806 to ATLAS
  - Mostly LAr, a bit of LKr
- An appealing option for precision measurements
  - Good energy resolution
  - High(-ish) granularity achievable
  - Radiation hardness for hadron colliders
  - Linearity, uniformity, long-term stability

Excellent solution for small systematics



- Ambitious R&D plans
  - High granularity noble liquid calo
  - Optimization for PFlow reconstruction
  - Designing for improved energy resolution
    - Achieving very low noise
    - Lightweight cryostats to minimize X_0
  - Goal: build a small test module and do testbeam

Participating institutes

A Growing Collaboration

Areas of interests of the groups are still evolving

CERN

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

Brookhaven National Laboratory

Charles University

Centre de Physique des Particules de Marseille CPPM

APC

LPNHE Paris

Arizona

Stony Brook University

Nevis Laboratories Columbia University

Technische Universität Dresden

Ústav experimentálnej fyziky SAV, v. v. i. 1969

The University of Texas at Austin

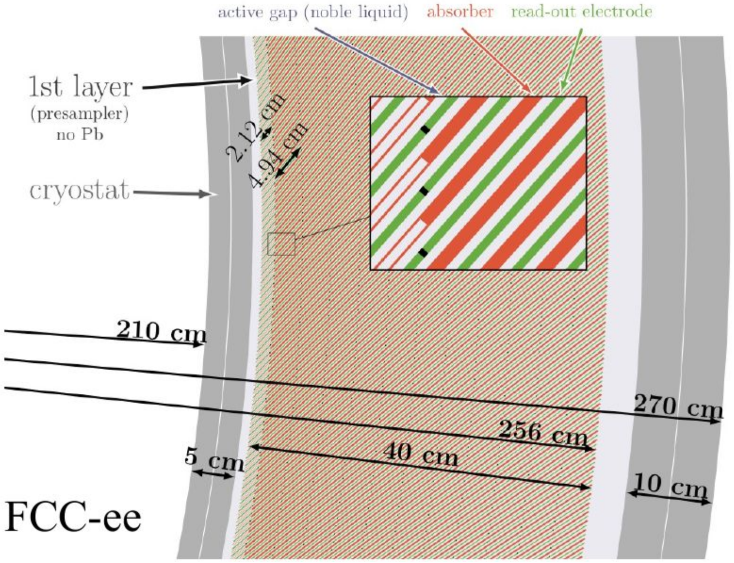
Omega Microelectronics

Main idea of the concept: straight PCBs as readout electrodes

Design driven by readout electrodes

Baseline (conservative) FCCee ECAL barrel design

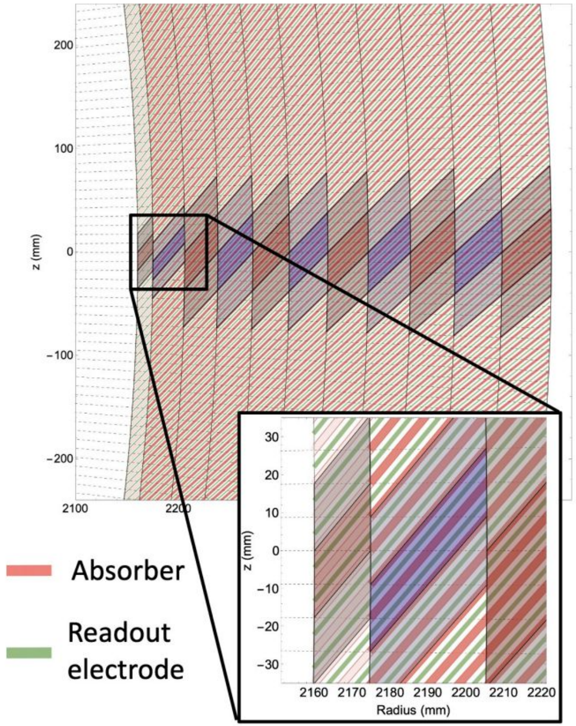
- 1536 **straight inclined** (50°) 1.8mm **Pb** absorber plates
- Multi-layer PCBs as readout electrodes
- 1.2 – 2.4mm **LAr** gaps
- 40cm deep (22 X_0)
- $\Delta\theta$ = 10 (2.5) mrad for regular (strip) cells, $\Delta\phi$ = 8 mrad,
  12 longitudinal layers
- **Solid aluminum** cryostat
- Implemented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



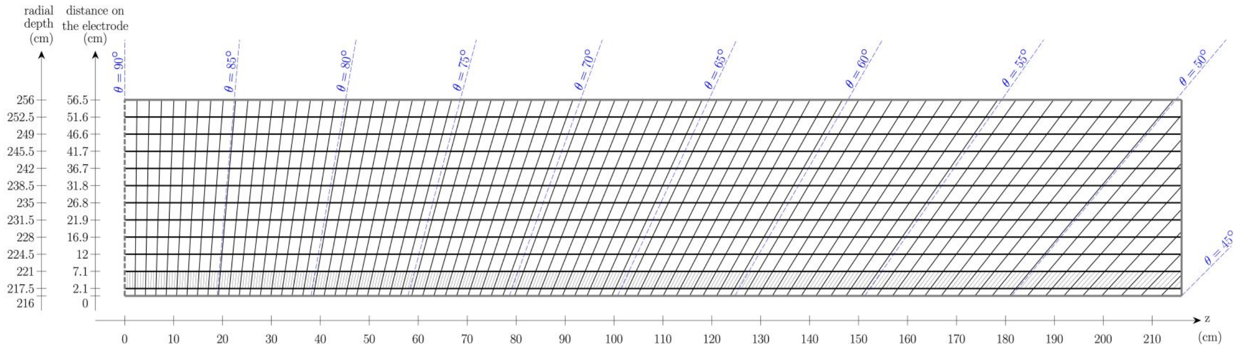
Lots of room for optimization and improvements

Geometry

Transverse

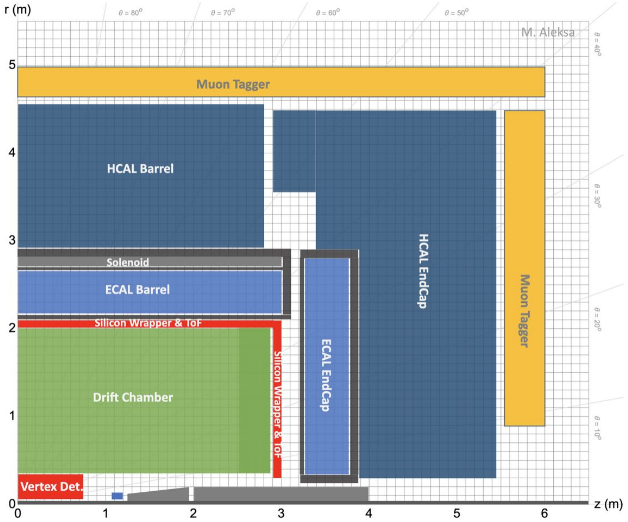


Longitudinal



Main goals of the proposal

- 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

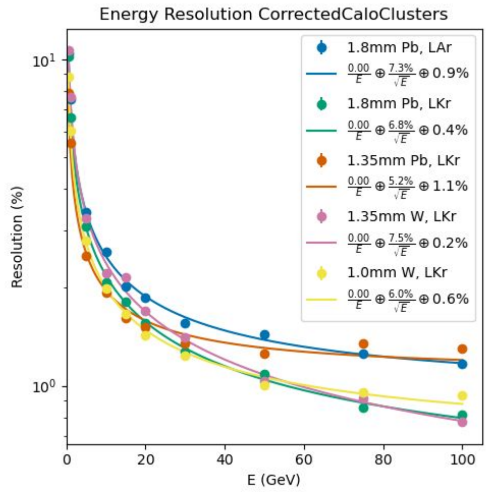


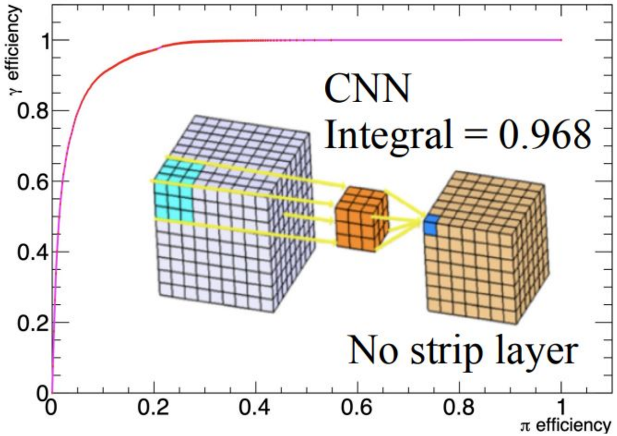
4 Work Areas

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

1. General design and expected performance

- Full simulation integrated in FCC software chain is a big asset
- First EM physics studies performed in 2022
  - Many more can be performed
  - Can guide LAr/LKr, granularity…
- Next major step will be addition of some HCAL in simulation, along with PFlow algorithms
  - Then can look at all physics performance metrics
- Performance in endcaps also has never been looked at
- Many opportunities for software development
  - Clever ML techniques for clustering / PID ?





1. General design and expected performance

Workplan

- Understand the required granularity
  - Study pion ID (tau physics)
  - Axion searches
  - 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...
- Investigate possibility to readout Cerenkov light
  - Design feasibility
  - Possible gains for timing or for DR measurements

Institutes

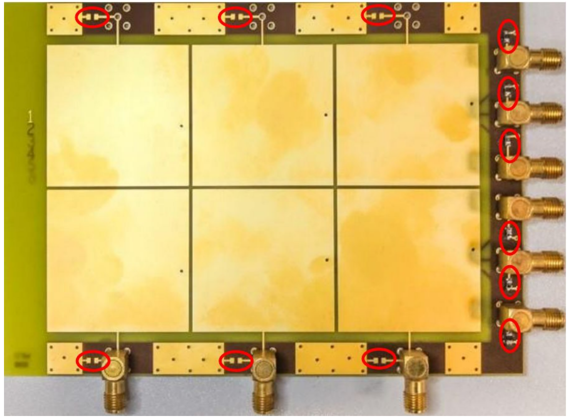
Most institutes interested to contribute to simulation studies

- Mostly CPPM interested in the Cerenkov study

2. Readout electrodes prototypes: status

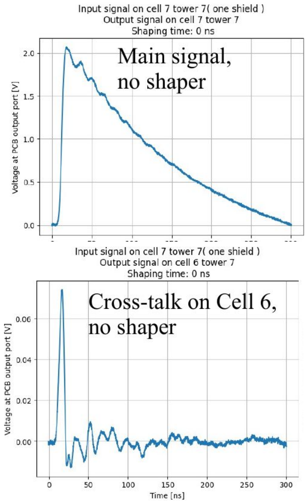
Small scale electrode @ IJCLab

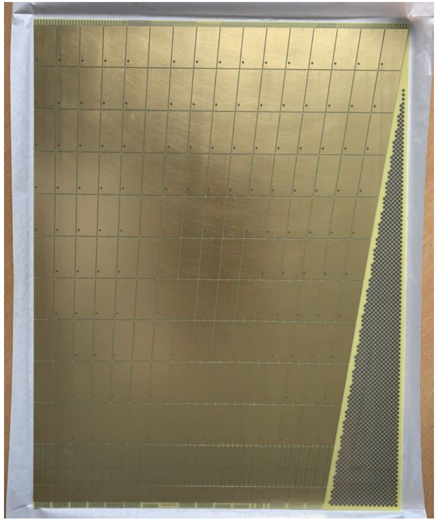
- Detailed measurements of cell properties and cross-talk effects
- Frequency behaviour
- **Good overall agreement with simulations on large frequency range**



Larger scale electrode @ CERN

- 1:1 scale θ chunk: 16 towers with different layouts
- Electrical tests with scope and software shaper
- **Sub-percent cross-talk easily achievable with > 50 ns shaping**





2. Readout electrodes

Workplan

- Barrel electrodes
  - Optimize granularity based on physics simulations
  - Minimise noise (aim for photons down to 300 MeV and S/N>5 for MIP) and cross-talk
  - Readout everything at the back
  - Connectors
  - HV layer, including resistors
  - Aim for “final” prototype end of 2024
- Endcap electrodes
  - Investigate possible geometries
  - Optimize granularity
  - Design prototypes

Institutes

- Barrel: CERN, IJCLab
- Endcaps: Arizona
- Also: BNL, Stony Brook

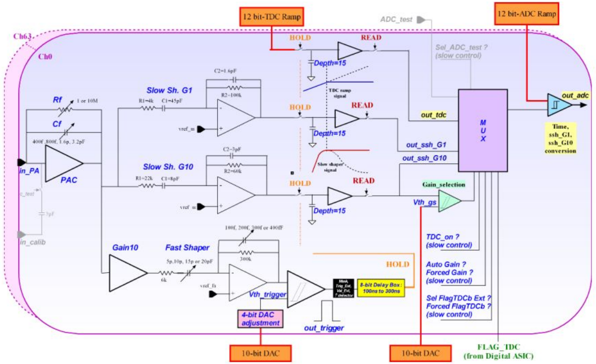
3. Readout electronics

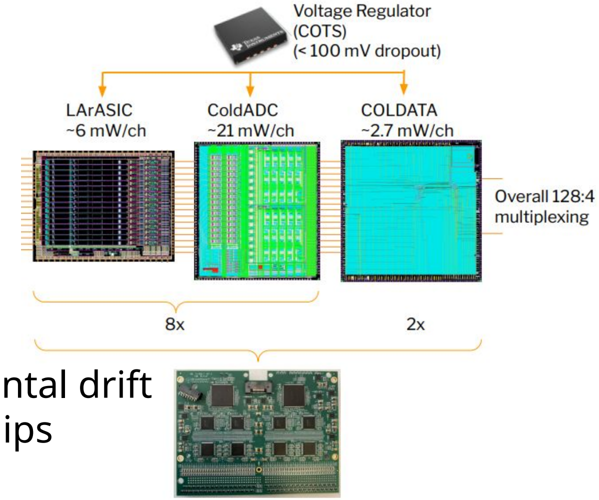
- Warm Frontend electronics option
  - Requirements similar to other calos
  - Requires work on cables inside the cryostat
- Cold Frontend electronics option
  - Very appealing option
  - Needs dedicated work
  - How much can we put in the cold ? Preamp, ADC, multiplexer ? Optical conversion ?
  - Power consumption is a huge challenge

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

- Backend electronics and DAQ
  - Requirements not yet defined

SKIROC





Dune horizontal drift front-end chips

3. Readout electronics

Workplan

- Both Frontend options
  - Take advantage of synergies with existing chips and with transverse proposal by CdIT, OG and MI
  - Develop frontend boards
- Warm Frontend electronics option
  - Specific work on cables inside the cryostat
- Cold Frontend electronics option
  - Adapt 'regular' chips to LAr temperatures, or start from Dune experience
  - Specific work on power consumption
- Backend electronics and DAQ
  - Requirements not yet defined

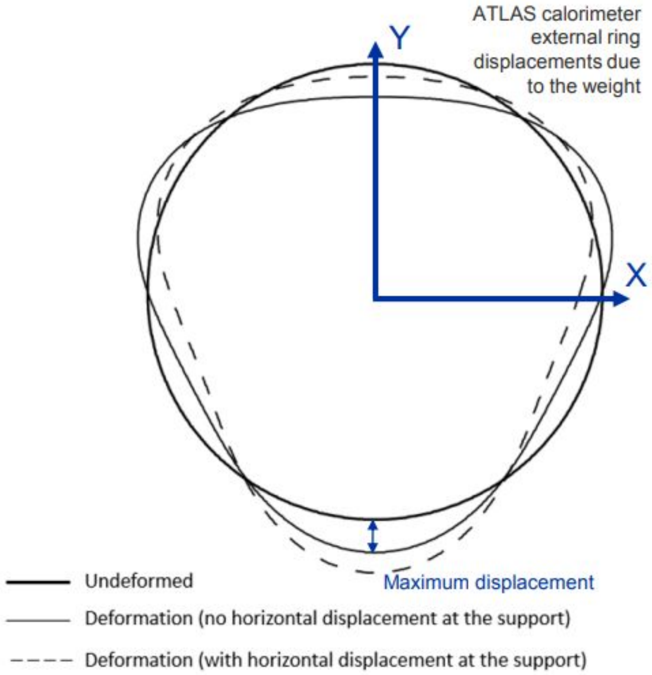
Institutes

- Frontend: BNL, Omega, IJCLab, UT Austin
- Backend: CPPM

4. Mechanical studies

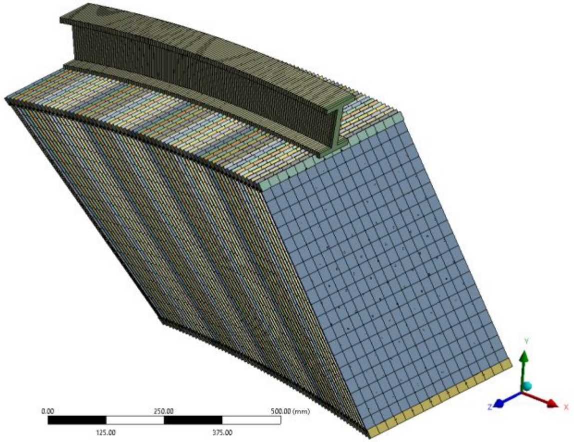
Small systematics require highly uniform and stable calorimeter

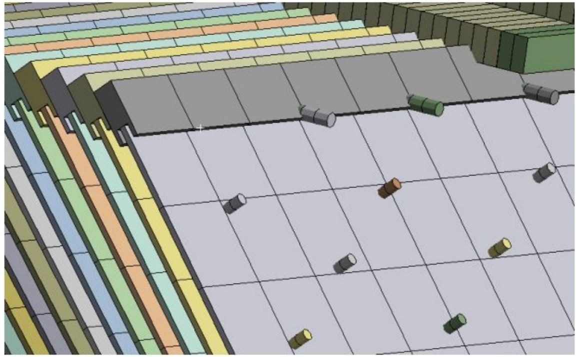
- Studies just starting
  - Identifying what are our requirements and learning from ATLAS
  - First FEM studies
- Overall challenge: make the whole structure rigid enough, while keeping light on support structures
- Lots of room for new ideas



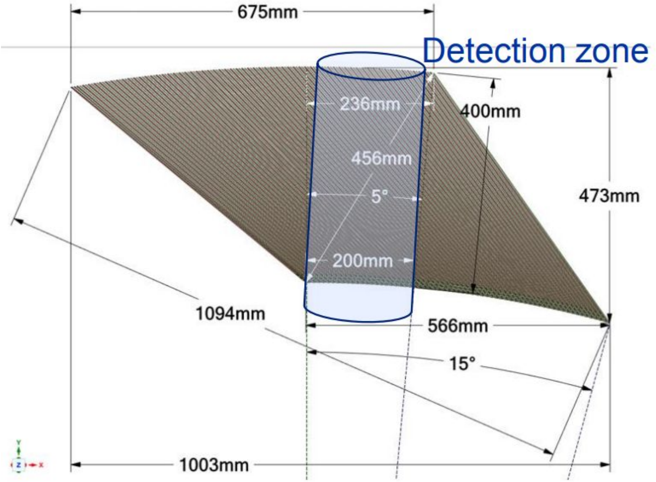
4. Absorbers and spacers

- Basic absorber design directly inspired from ATLAS
  - Can we do better ?
  - Thickness, tolerances…
- Simpler because no accordion bending
- New idea of trapezoidal absorbers
  - Can it be done, with what tolerances ?
  - Need iterations with industry
- ATLAS spacers: honeycomb
  - Including variable size in the endcaps
- Spacers: can we instead 3D-print pillars to be placed regularly ?





4. Towards a prototype



Workplan

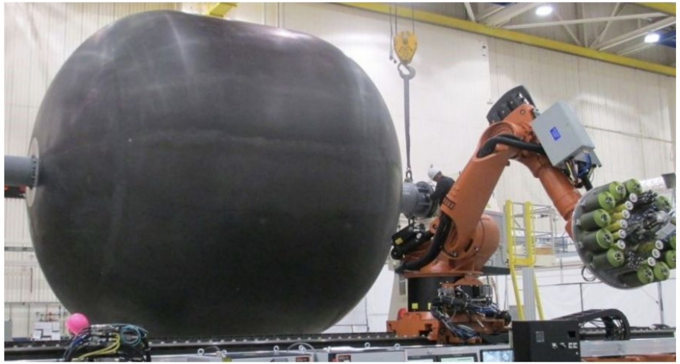
- Absorbers
  - Find best compromise in feasibility, between thickness, rigidity, support structures
  - Prototypes in 2024 and 2025
- Small module
  - Requires to put everything together
  - Design in 2024 and 2025
  - Assemble and test at warm temperatures in 2027
  - Cold tests and testbeam in 2028
- Infrastructure
  - Use of common tools (EUDAQ…) would facilitate the integration in a testbeam facility
  - Strong testbeam expertise from some institutes

Institutes

- Absorbers: CERN
- Most institutes interested to contribute to testbeam
- Contributions in construction not yet discussed

4. Cryostat for first prototype

- Carbon fiber-based cryostats show excellent perspectives for “transparent” cryostats
  - CFRP shell + Al honeycomb sandwich
  - Optimization between X_0 and mechanical properties
- Ongoing R&Ds at CERN to address CFRP / metal interfaces, and sealing methods
- Testbeam will use prototype carbon fiber cryostat, or re-use existing aluminum cryostat



NASA’s lineless cryotank

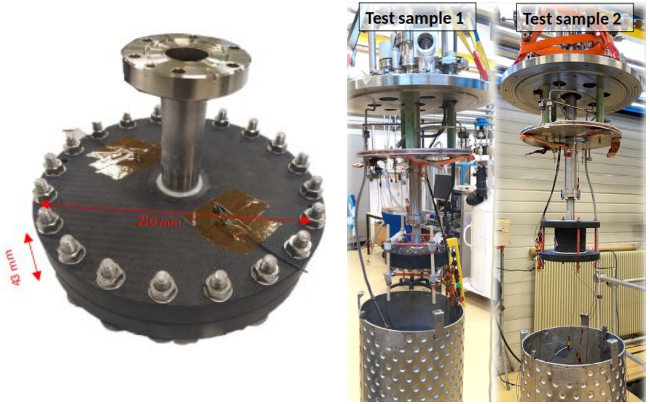
Sandwich Shell

Skin [0,45,-45,90]s
Core : Al Honeycomb
Skin [0,45,-45,90]s

Solid Shell

Radiation length X_0[mm]
Al = 88.9
HM CFRP = 260
Honeycomb Al= 6000

Criteria: Safety Factor = 2	Sandwich shell				Solid shell			
	HM CFRP		Al		HM CFRP		Al	
	OWC	ICC	OWC	ICC	OWC	ICC	OWC	ICC
Material budget X/Xo	0.03	0.043	0.094	0.17	0.092	0.12	0.34	0.44
Xo % savings	-68%	-75%	REF	REF	-2%	-29%	262%	159%
Skin Th. [mm]	3.2	4.8	3.9	7.5				
Core Th. [mm]	32	38	40	40				
Total Th. [mm]	38.4	47.6	47.8	55	24	30.4	30	39
Thickness % savings	-20%	-13%	REF	REF	-50%	-45%	-37%	-29%



Sealing with Belleville washers

Conclusions

- TF2 united behind one common input proposal
- First definition of milestones and deliverables
  - Simulation work to define and optimize designs
  - First prototype in testbeam by 2028
- Interests of institutes still evolving