EP R&D Day 2022
WP4: Detector Mechanics

CERN
21st June 2022

Act1.b: Low Mass Cryostats
for HEP experiments

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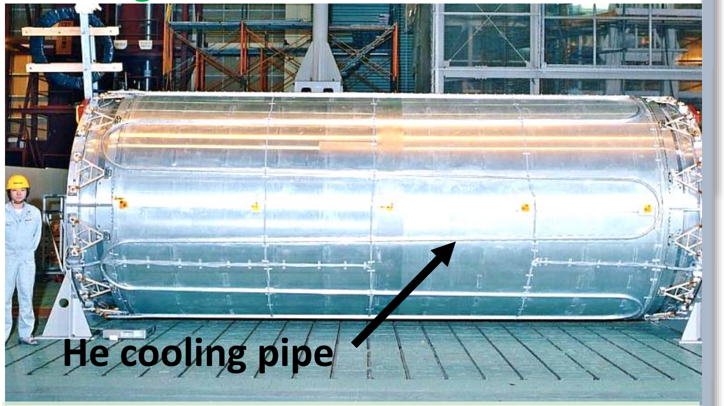
https://indico.cern.ch/event/1156197/

Main scope

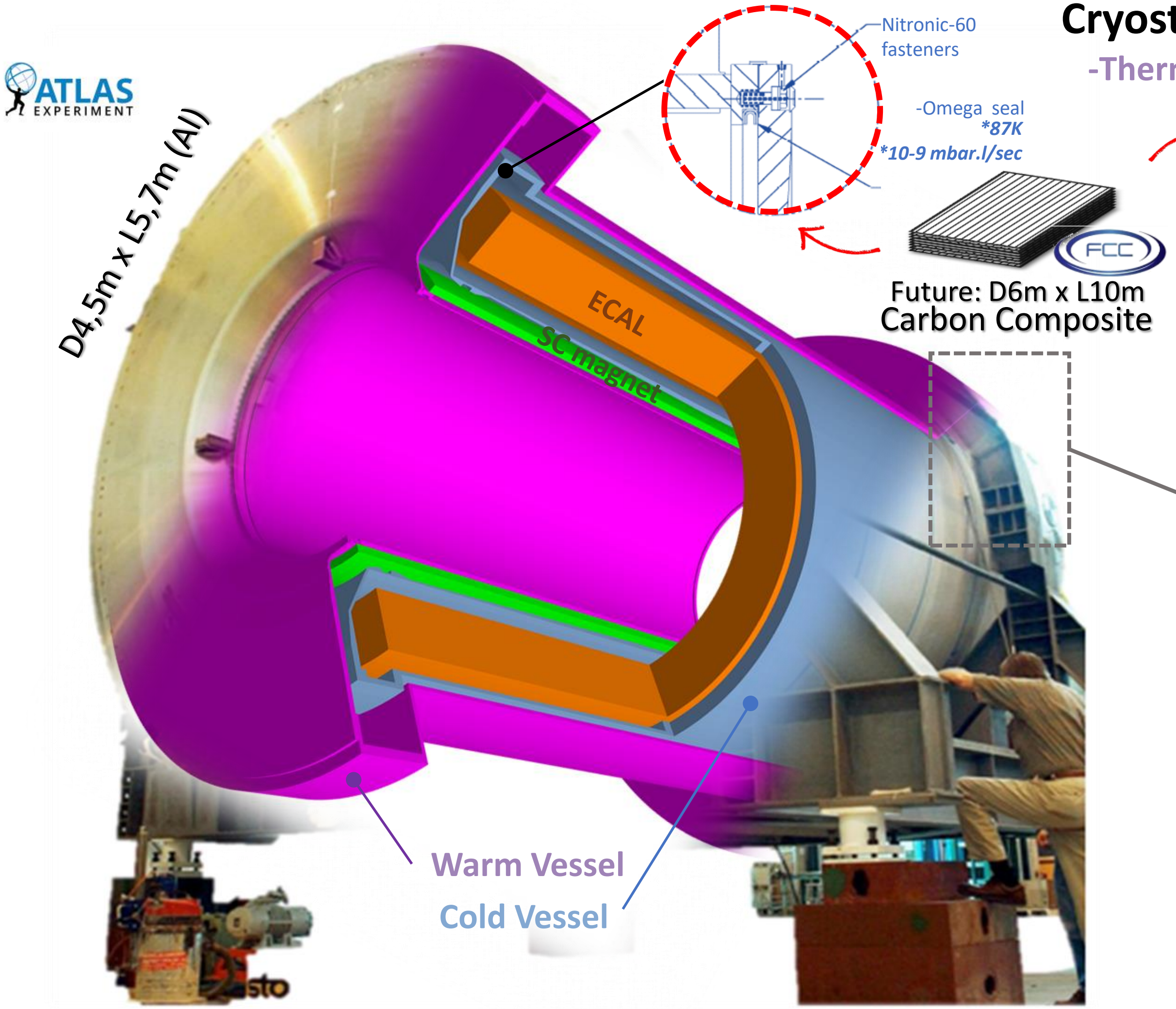
SC Magnet



Ultra-thin cryostat for compact assembly of experiments

LAr ECAL calorimeter

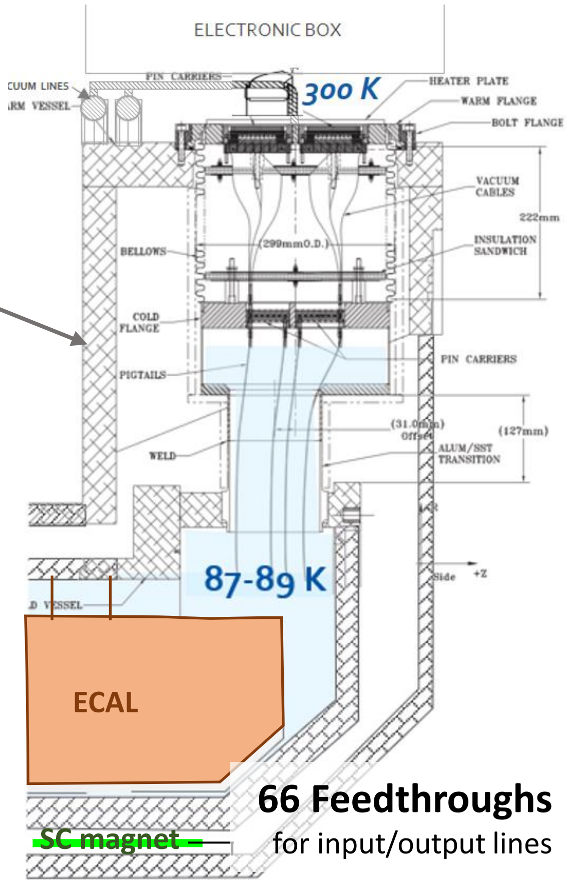
Low material budget cryostat for better detector performance



Cryostat for SC magnet and LArCal:

-Thermal insulation: 10e-5 mbar and 293 K

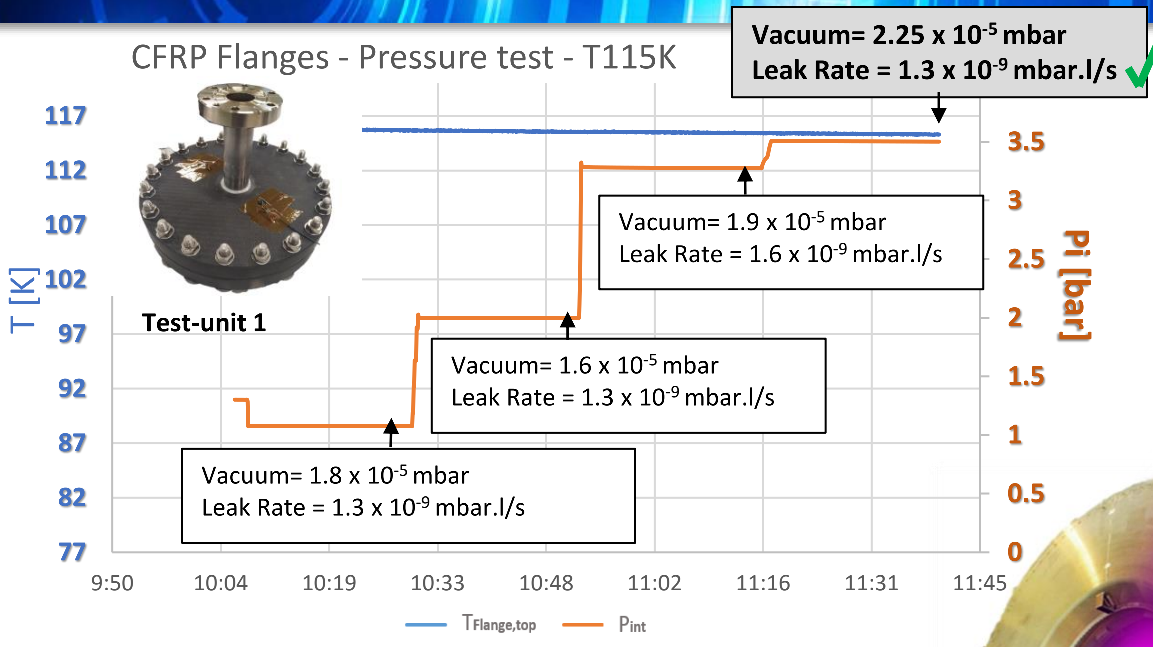
-LAr tightness: 3.5 bar and 87 K



66 Feedthroughs
for input/output lines

→ Carbon composite (CFRP) to design cryostats with lower material budget to improve future detectors performance.

Breadboard Model: Leak-tightness


CFRP Flanges - Pressure test - T115K

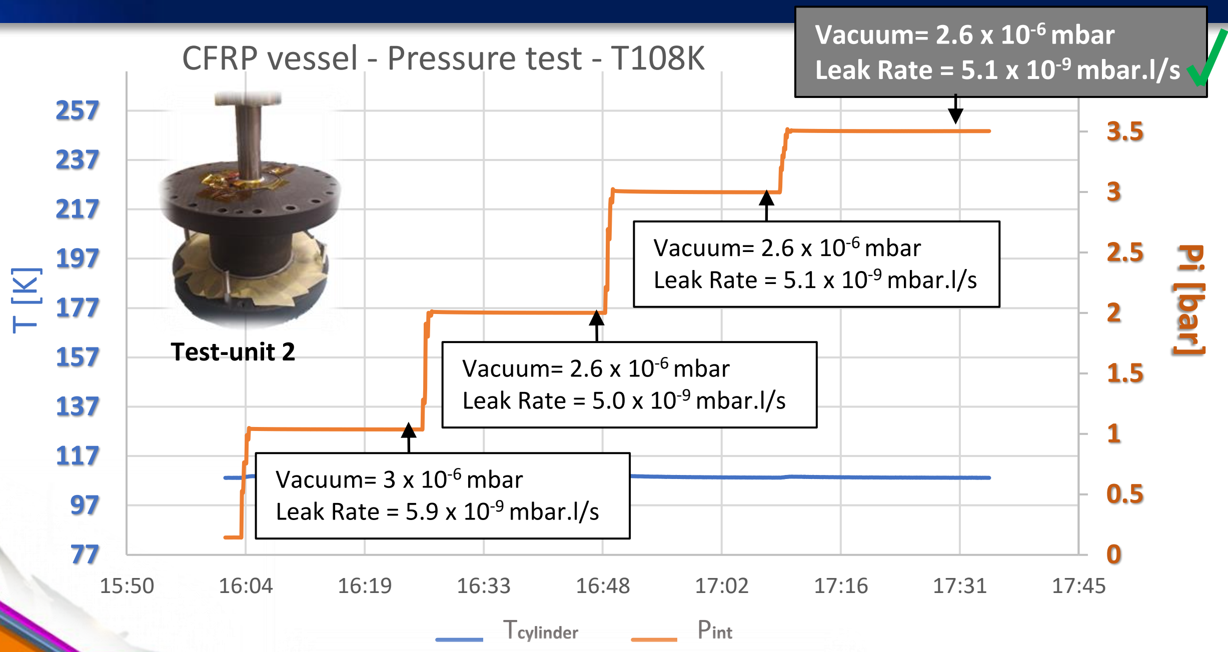
Vacuum= 2.25 x 10^{-5} mbar
Leak Rate = 1.3 x 10^{-9} mbar.l/s ✓

Vacuum= 1.9 x 10^{-5} mbar
Leak Rate = 1.6 x 10^{-9} mbar.l/s

Vacuum= 1.6 x 10^{-5} mbar
Leak Rate = 1.3 x 10^{-9} mbar.l/s

Vacuum= 1.8 x 10^{-5} mbar
Leak Rate = 1.3 x 10^{-9} mbar.l/s

Test-unit 1


CFRP vessel - Pressure test - T108K

Vacuum= 2.6 x 10^{-6} mbar
Leak Rate = 5.1 x 10^{-9} mbar.l/s ✓

Vacuum= 2.6 x 10^{-6} mbar
Leak Rate = 5.1 x 10^{-9} mbar.l/s

Vacuum= 2.6 x 10^{-6} mbar
Leak Rate = 5.0 x 10^{-9} mbar.l/s

Vacuum= 3 x 10^{-6} mbar
Leak Rate = 5.9 x 10^{-9} mbar.l/s

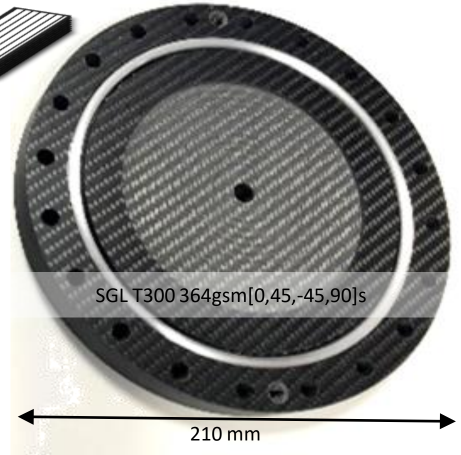
Test-unit 2

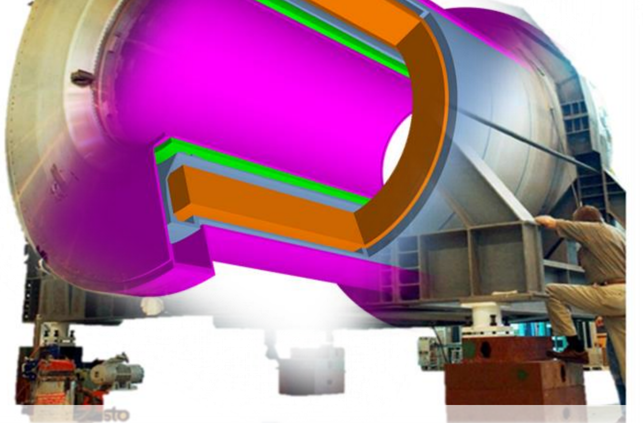
Dismountable joint for cryogenics

Helicoflex metallic seal validated at T=115K* and Pint,max = 3.5 bar

Helicoflex (UHV at CERN)

*3 K
*10-9 mbar.l/sec

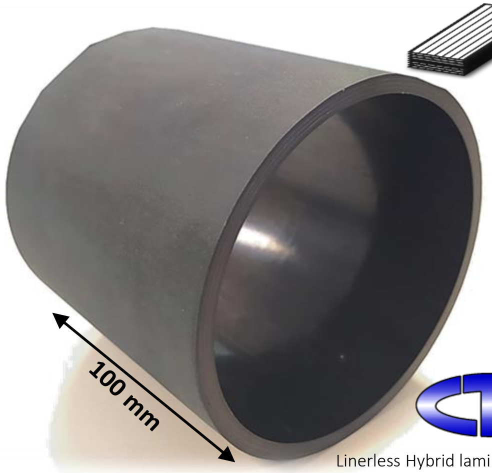


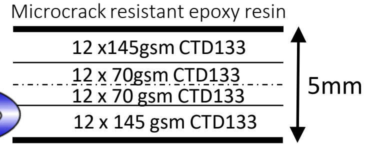


-Thermal insulation: 10e-5 mbar and 293 K
-LAr tightness (10e-9 mbar.l/s*): 3.5 bar and 87 K

Liner-less wall for cryogenics:

CTD-133 toughened resin validated at T=108K* and Pint,max = 3.5 bar





Linerless Hybrid laminate: $[0/-15/15/-30/30/-45/45/-60/60/-75/75/90]_S$

→ Two prototypes built and tested to address thin-wall tightness and sealed joint for CFRP cryostats.

Breadboard Models: Transition piece

Glass fiber + resin

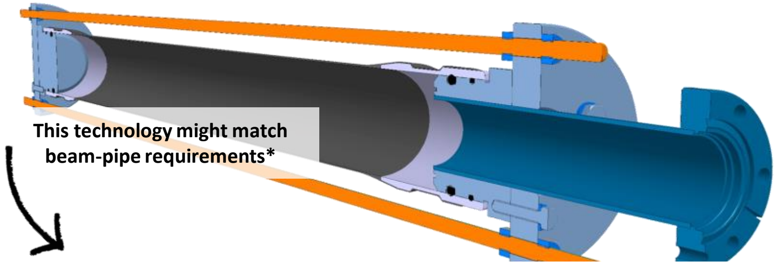
Carbon fiber + resin

Glass fiber + resin

SS end-fitting

connova

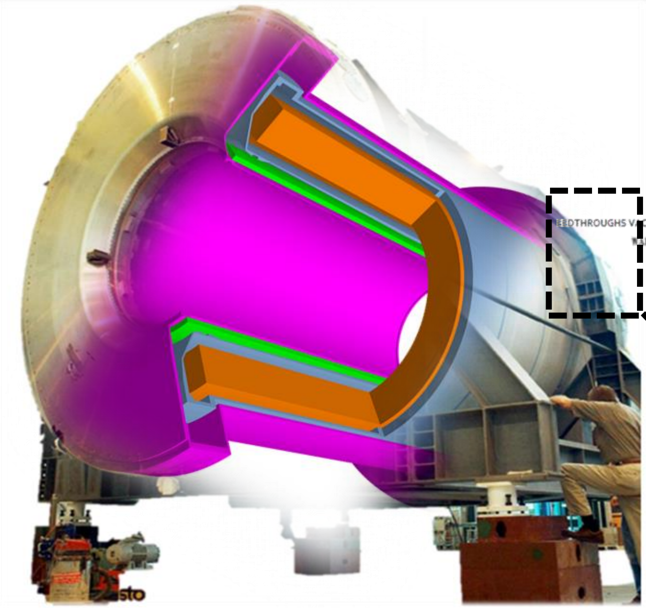
This joint is design to be optimal at cold temperatures: polymeric fibers contacts more than metal and carbon fiber)*



This technology might match beam-pipe requirements*

Tube	Resin	Fiber	Wall thickness	End-Fittings	He leak rate (Troom)
1	CTD-7.1	T800H	0.7 mm	SS 314	10e-9 mbar.l/sec
2	Araldite	T800H	1.5 mm	SS 314	10e-11 mbar.l/sec
3	CTD-7.1	T800H	1.5 mm	SS 314	10e-10 mbar.l/sec
4	Araldite	T800H	0.7 mm	SS 314	leak < 10e-7 mbar.l/sec -> interface

*Cold He-leak-test campaign starts on July 22



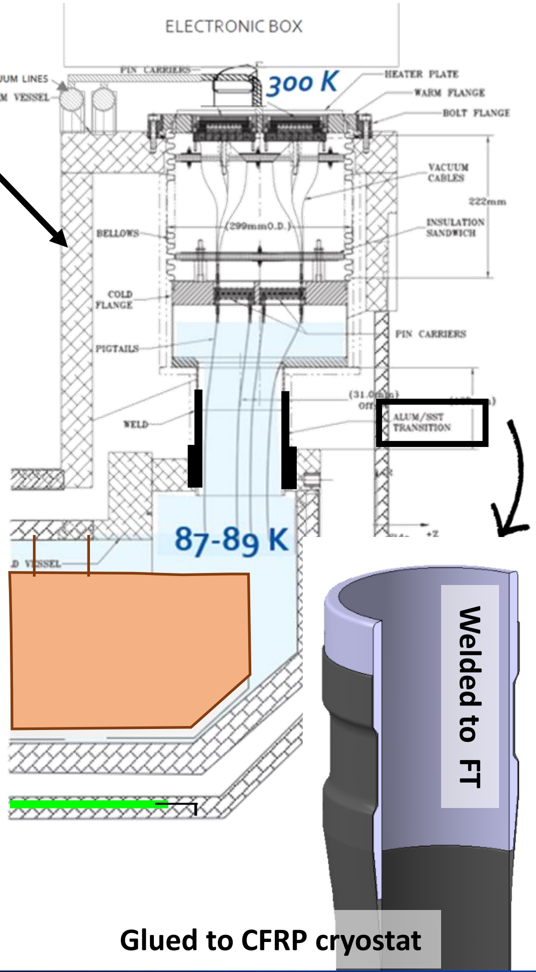
66 Metallic Feedthroughs (FTs)

for input/output lines

Cryostat for SC magnet and LArCal:

-Thermal insulation: 10e-5 mbar and 293 K

-LAr tightness: 3.5 bar and 87 K



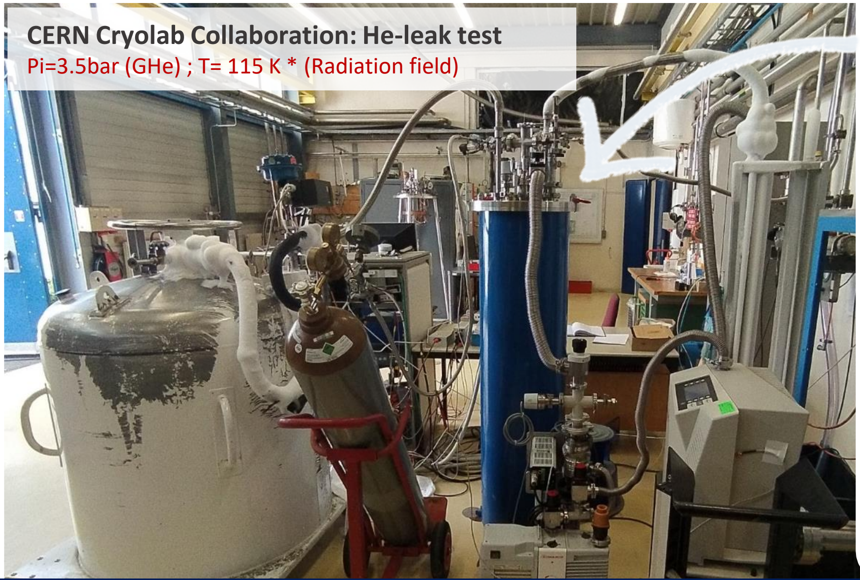
Glued to CFRP cryostat

→ Leak-tight interface between carbon composite cryostat and metallic feedthroughs is under study.

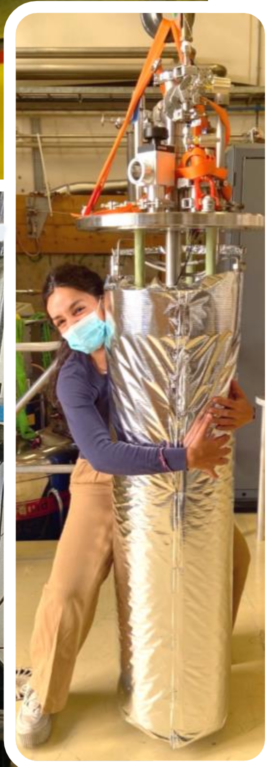
Large scale manufacturing: Engineering model

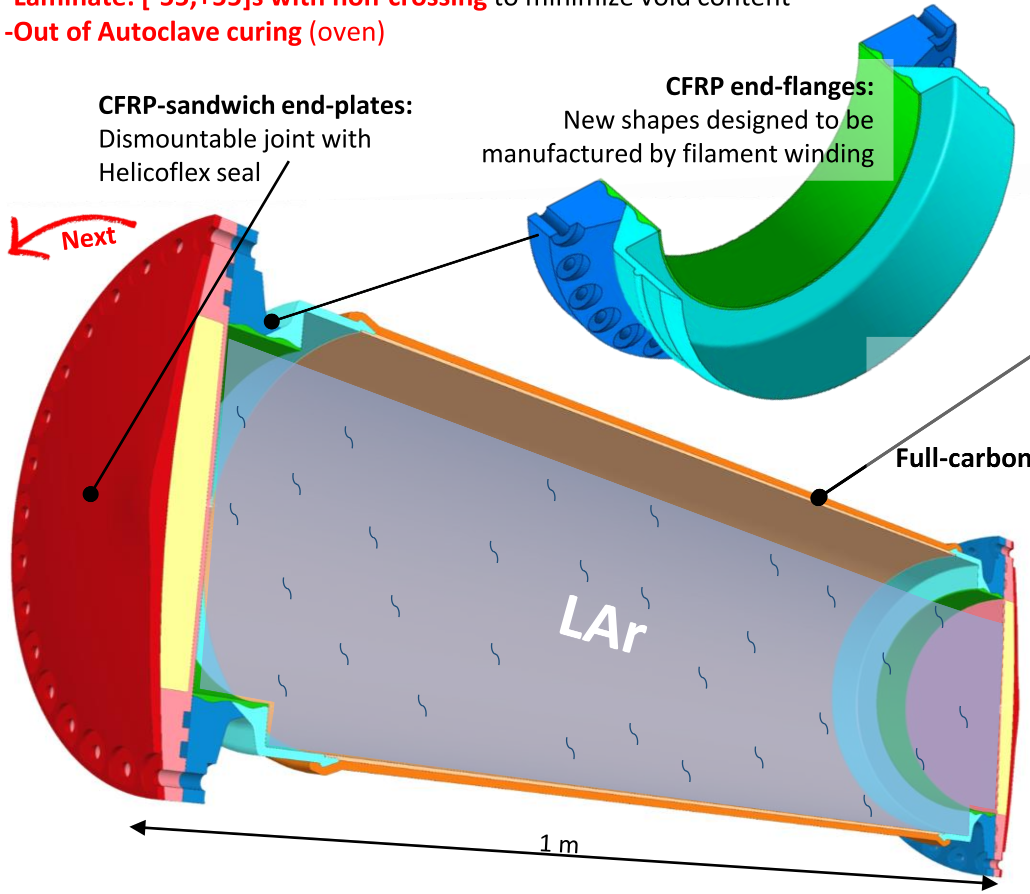
Process development for Wet Filament Winding as an alternative to RAFP tech.

-Optimize **resin bath** preparation and size to minimize void content: **CTD-7.1 and LY 556**
-Optimize **carbon fiber young modulus** (as high as the winding process allows it): **M40J**
-Optimize **carbon fiber tension** to increase cross-plies density (permeation resistance).
-Laminate: [-55,+55]s with non-crossing to minimize void content
-Out of Autoclave curing (oven)



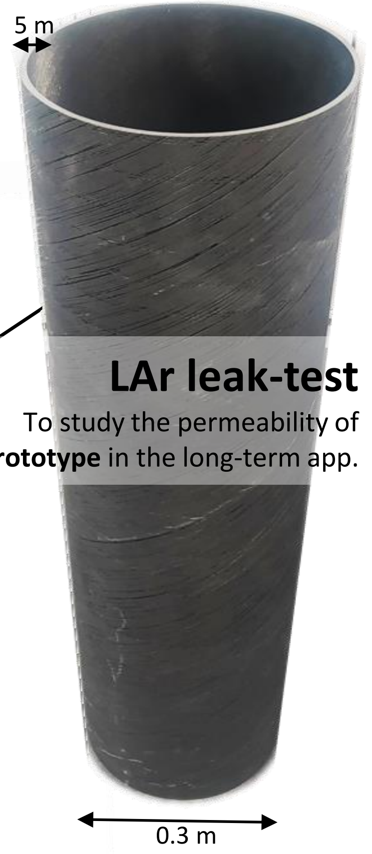
CERN Cryolab Collaboration: He-leak test
Pi=3.5bar (GHe) ; T= 115 K * (Radiation field)





CFRP-sandwich end-plates:
Dismountable joint with
Helicoflex seal

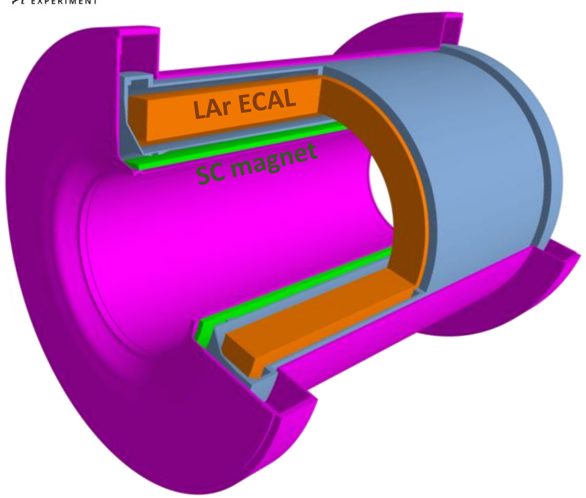
CFRP end-flanges:
New shapes designed to be
manufactured by filament winding



LAr leak-test
To study the permeability of
Full-carbon prototype in the long-term app.

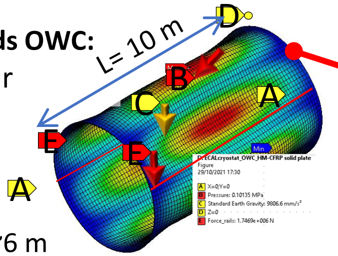
→ **Automated process for large-scale production is under development to achieve a laminate with minimal void content.**

Carbon composite profits



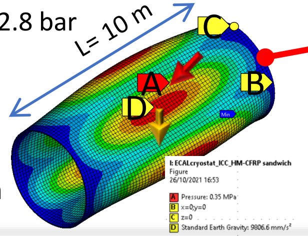
Buckling Analysis (SF=2)

FEM loads OWC:
- 1bar



D~6 m

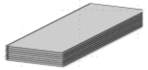
FEM loads ICC:
- 1.25x 2.8 bar



D~4 m

Sandwich Shell

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



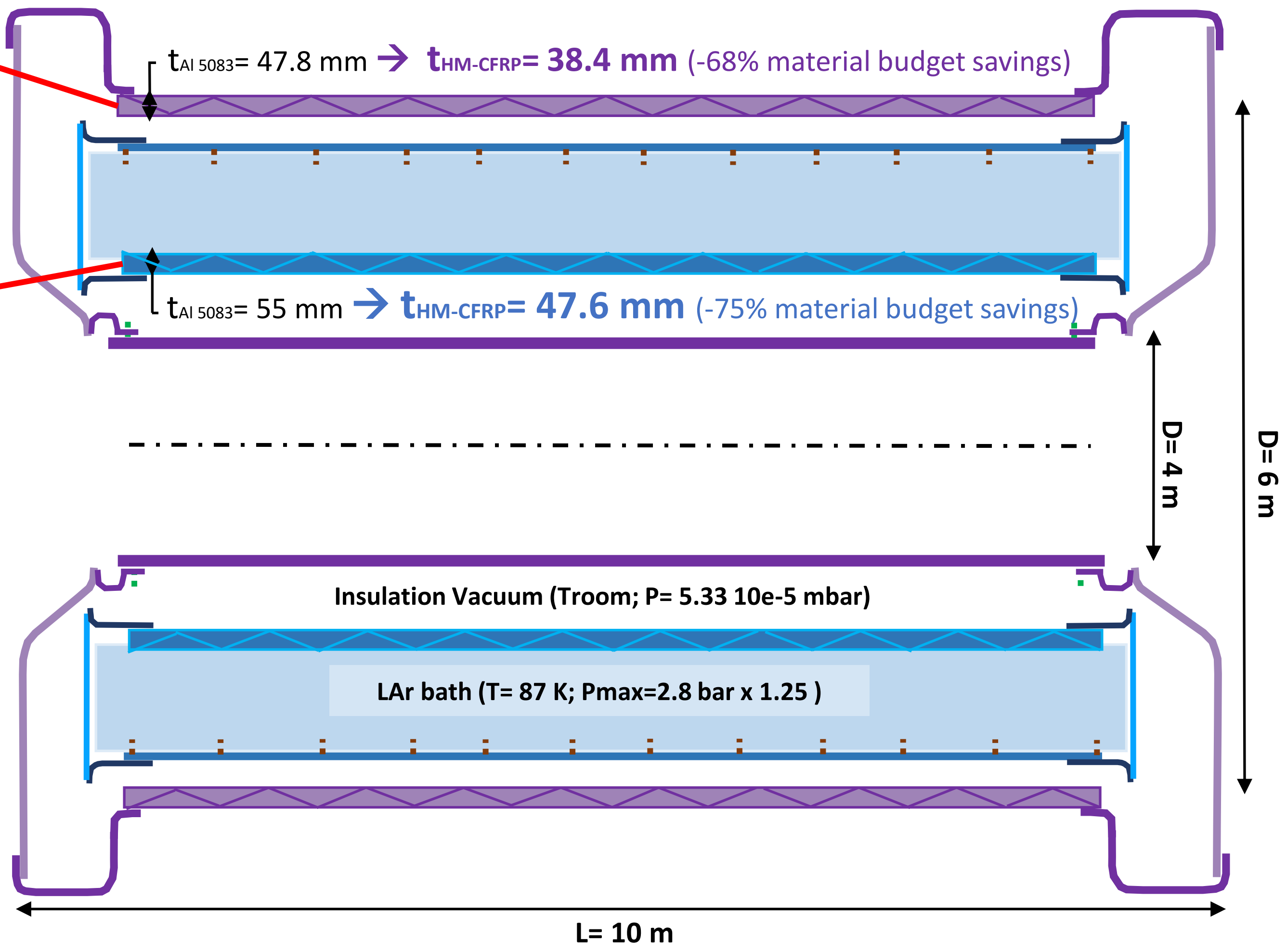
Solid Shell

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%

Sandwich wall
Solid wall

Baseline geometry FCC-hh LAr barrel ECAL



$t_{Al\ 5083}$= 47.8 mm → $t_{HM\text{-}CFRP}$= **38.4 mm** (-68% material budget savings)

$t_{Al\ 5083}$= 55 mm → $t_{HM\text{-}CFRP}$= **47.6 mm** (-75% material budget savings)

Insulation Vacuum (Troom; P= 5.33 10e-5 mbar)

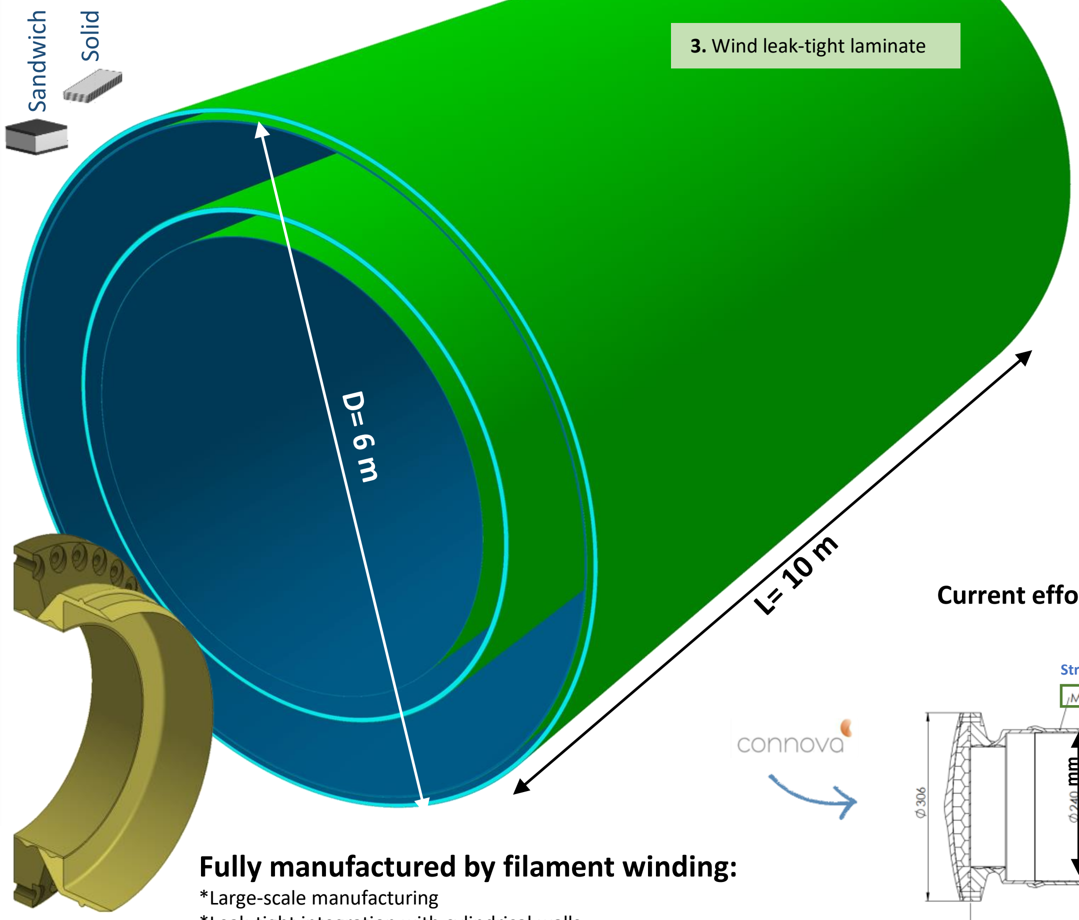
LAr bath (T= 87 K; Pmax=2.8 bar x 1.25)

→ CFRP cryostat walls will provide savings in terms of material budget/thickness with respect to an aluminum cryostat

Full-CFRP Concept Demonstrator (R&D ++)

Design criteria: Minimum material budget

- 🟩 Non-crossing laminate (leak-tight CFRP)
- 🟦 Multi-piece structural mould (CFRP)



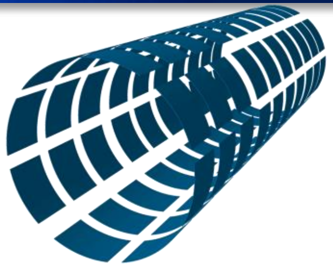
End-Flanges

Fully manufactured by filament winding:

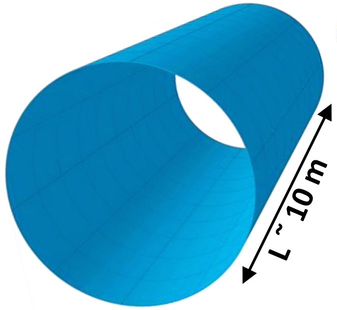
*Large-scale manufacturing
*Leak-tight integration with cylindrical walls
*Carrying axial and radial loads

Multipiece Structural Mould

To simplify production and integration due to the large dimensions expected in future detectors.



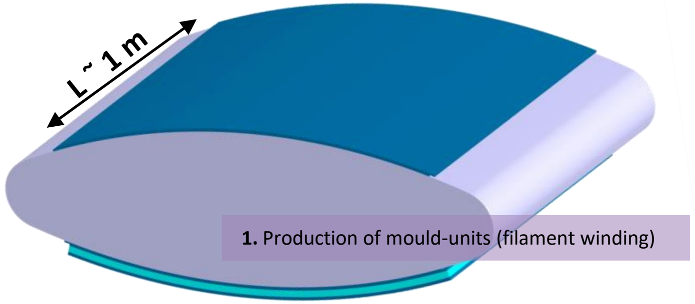
2. Assembly of the large cylindrical structural-mould



Development of a large **multifunctional carbon composite mould**

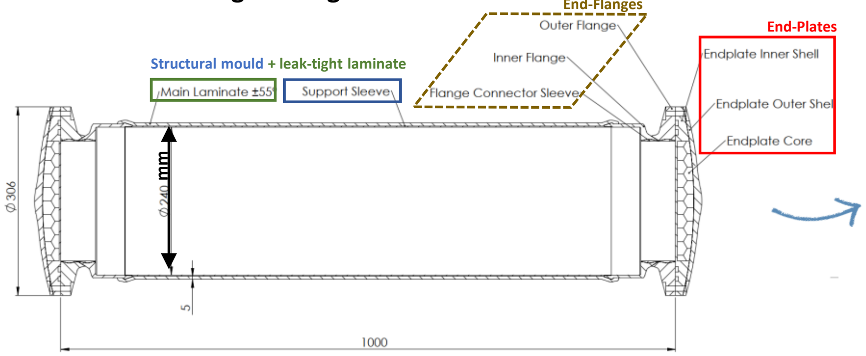
A) Tool: to wind cryostat walls (toughened epoxy resin at cryogenics)

B) Structural part: carry the loads expected in each of the cylindrical walls of future cryostats



1. Production of mould-units (filament winding)

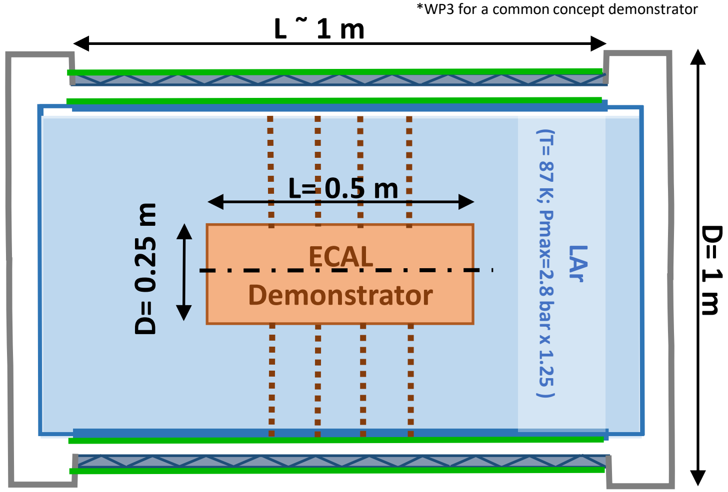
Current effort: Engineering model



FULL-CARBON LARGE-SCALE concept demonstrator (2024)

Collaboration

*CERN Cryolab for testing campaign
*WP3 for a common concept demonstrator

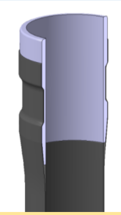


→ Full carbon composite demonstrator based on learnings from breadboard models and large-scale concept development.

R&D lines: Full carbon composite cryostat

1. What has been done?

- a) Design requirements, materials and processes
- b) CFRP liner-less wall leak-tight at cryogenics (breadboard model tested)
- c) Dismountable joint between CFRP parts at cryogenics (breadboard model tested)

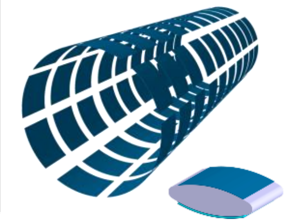


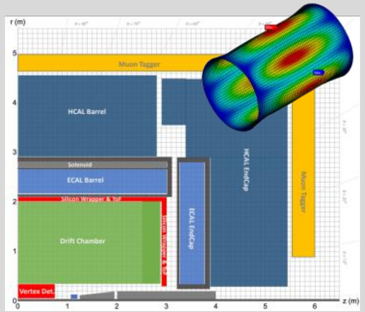
2. Ongoing …

- a) Interface between CFRP cryostat and metallic feed-throughs (samples to be tested)
- b) Automated manufacturing process for large-scale CFRP cryostat (engineering model to be tested)

3. What is next?

- a) Detailed analysis of a large CFRP cryostat for FCC Detector Concept
- b) 1m diameter concept demonstrator **(R&D ++)**





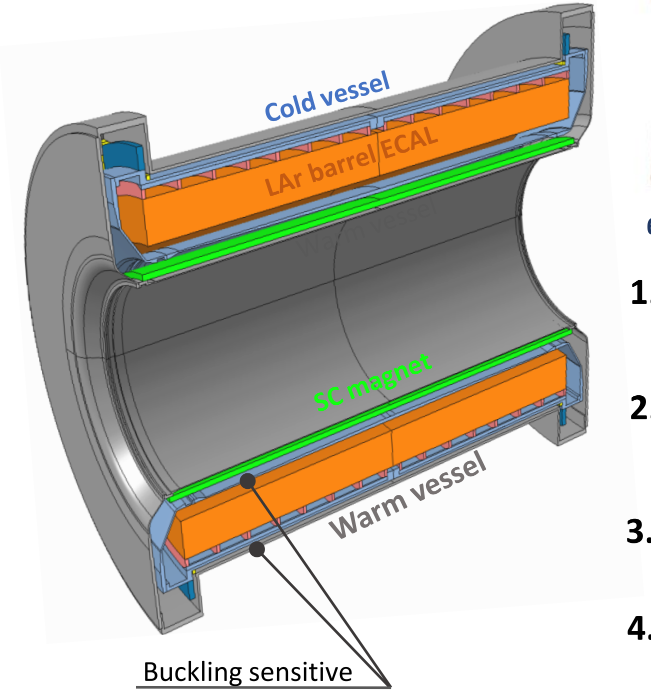
Thank you very much !

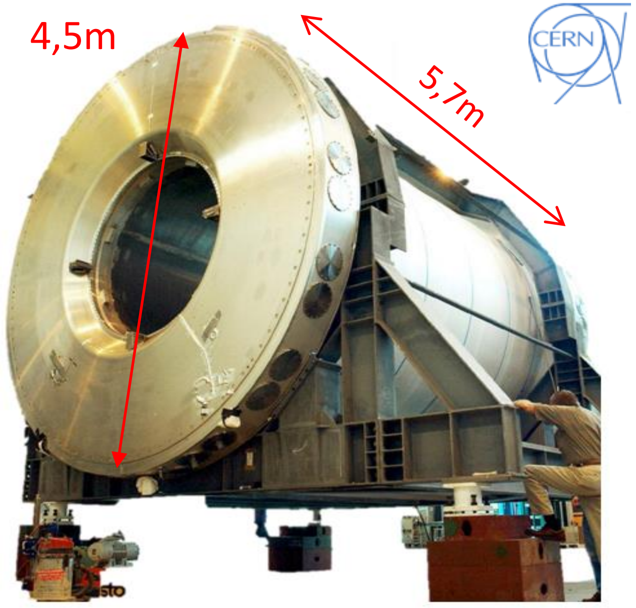
Back-Up

Main requirements

ATLAS barrel-cryostat

toroidal Al 5083 *double wall*



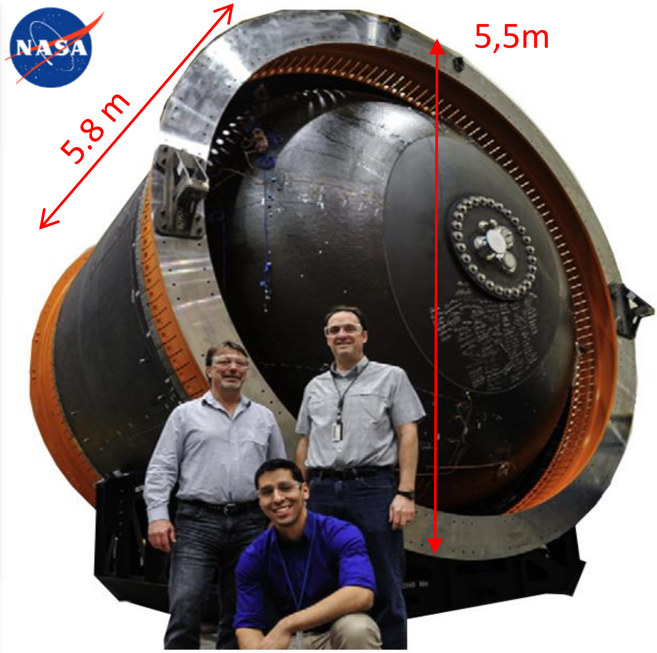


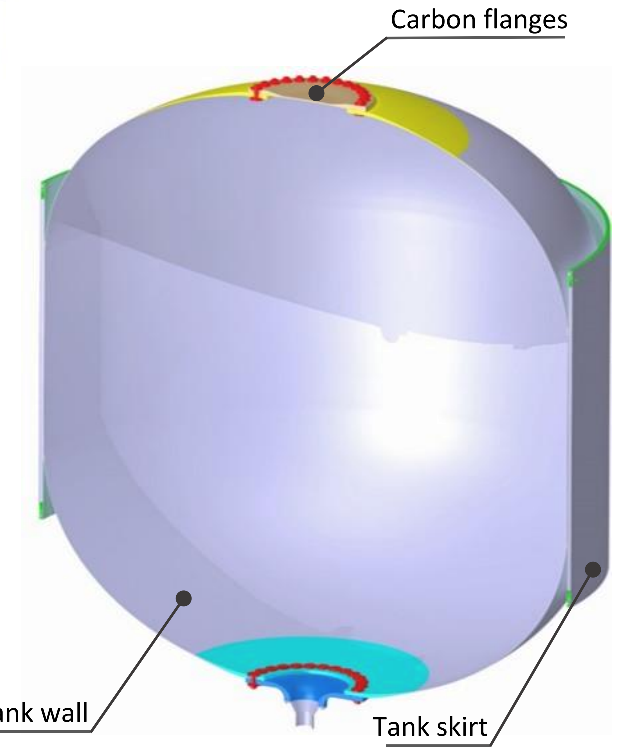
6 x 10m in future cryostats*

1. **Tightness in long term**
   Cold vessel: LAr leak-tight
   Warm vessel: Vacuum tight
2. **Operating conditions:**
   Cold vessel: T= 87 K; $P_{int,\ max}$ = 2.8 bar
   Warm vessel: T_{room} ; $P_{int} = 10^{-5}$ mbar
3. **Radiation Resistance:**
   Total lifetime dose < 0.1 MGy
4. **Minimize material budget**
   Al 5083 thin wall+ buckling resistant design *

NASA's CCTD LH2 cryotank

All carbon composite thin wall





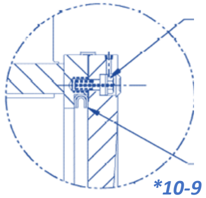
1. **Tightness in short term**
   Tank wall: LH2 (LOX) leak-tight
   Tank skirt: Vacuum tight
2. **Operating condition:**
   Tank wall: T=20 K; $P_{int,\ max}$ = 3.2 bar
   Tank skirt: T_{room} ; $P_{int} = 10^{-5}$ mbar
3. **Minimize mass**
   CFRP thin wall + stiffening skirt

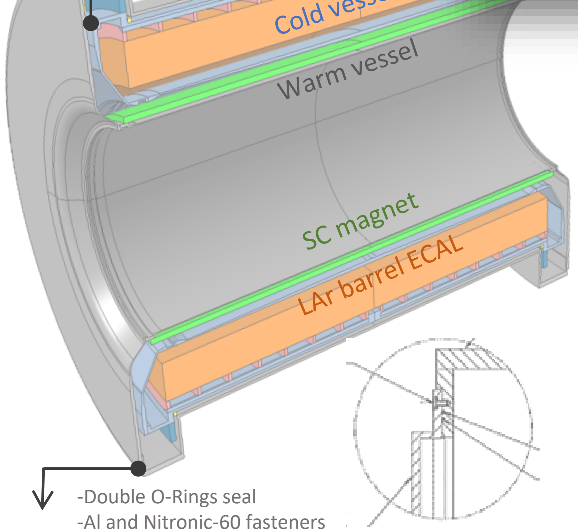
✓ Cryostats to house the SC-magnet and LAr-ECAL have similar requirements with cryotanks to storage LH2 in launch vehicles

Material and processes (State of the art)

ATLAS barrel-cryostat

toroidal Al 5083 *double wall*





1. Material:

Aluminum 5083

2. Process:

Forming, welding and machining

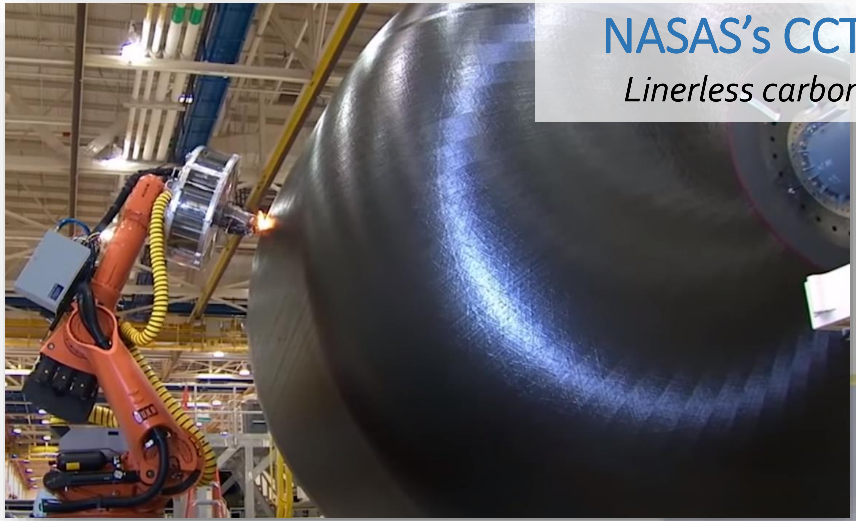
3.Joints:

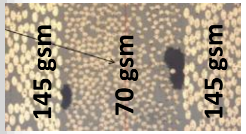
Fasteners; polymeric seals (warm)

Fasteners; metallic seal → welded (cold)

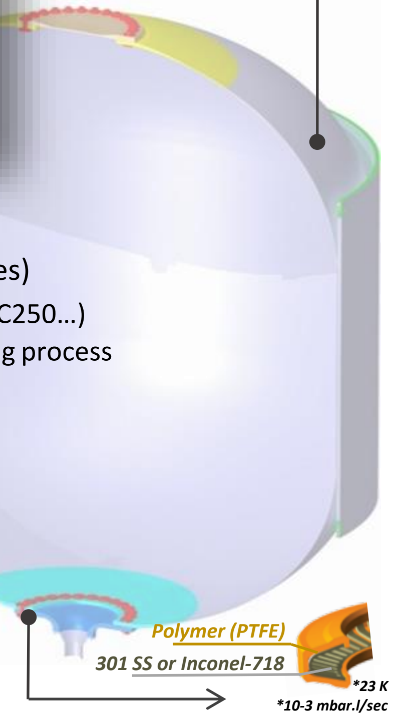
NASAS's CCTD LH2 cryotank

Linerless carbon composite thin wall





CFRP hybrid laminate



1. Material

Leak-tight linerless wall: CFRP hybrid laminate (thick and thin plies)

a) Resin: Microcrack resistant (**CTD,** 5320-1, MTM45-1, M56, TC250…)

b) Carbon Fiber: higher modulus compatible with manufacturing process

2. Process:

Robotic Automated fiber placement (RAFP)

Out of Autoclave (OoA) curing

3. Joints

Permanent: Hot-bonded and co-cured

Dismountable: Fasteners, Belleville washers and Furon Seal

✓ **R&D required to adapt aerospace technology choices to HEP low mass cryostats**

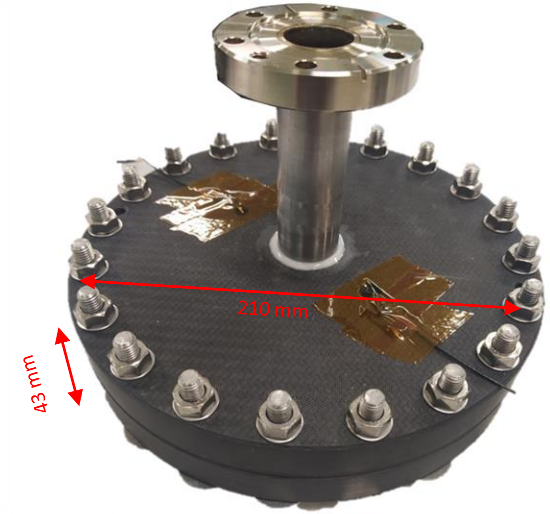
Test samples

1. Dismountable joints: sealing method for bolted composite flanges

Design criteria: He leak-rate < 10e-9 mbar.|/s at 87K and 3.5 bar (2.8 bar x 1.5 safety factor)

Helicoflex (UHV at CERN)


*3 K
*10-9 mbar.l/sec



Test sample 1

2. Leak-tight liner less wall: micro-crack and permeation resistant laminate (OoA)

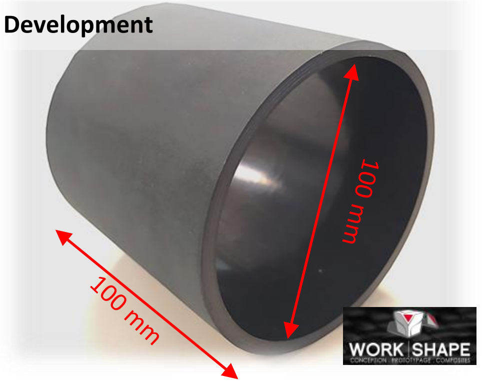
Design criteria: He leak-rate < 10e-9 mbar.|/s at 87K and 3.5 bar (2.8 bar x 1.5 safety factor)

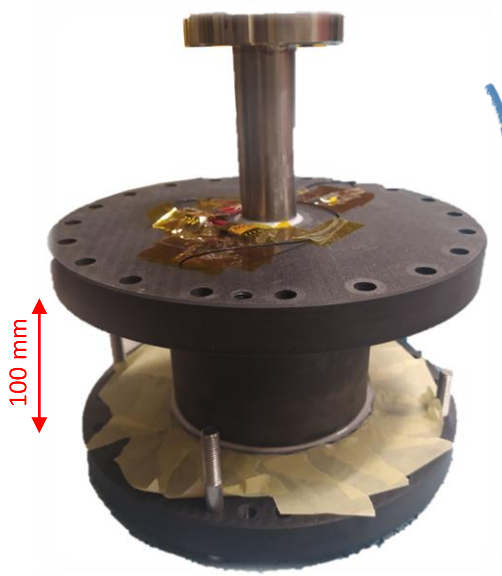
Composite Technology Development

12 thick layers
12 thin layers
12 thin layers
12 thick layers

5mm

- **Material: CTD 133P**
  -145 gsm prepreg
  -70 gsm prepreg

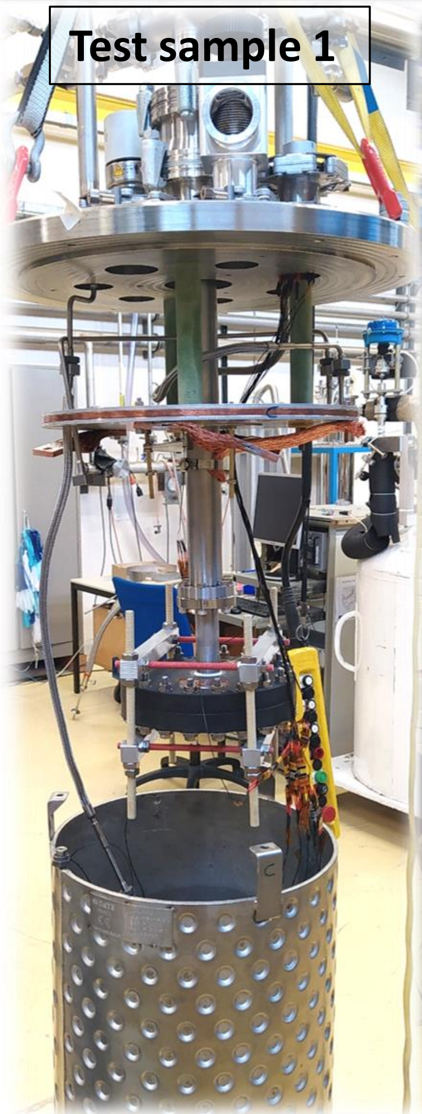




Test sample 2

→ Two prototypes have been built to address wall tightness and sealed joint for CFRP cryostats

Test performance (CERN Cryolab Collaboration)



Thanks a lot to :
Martin Aleksa
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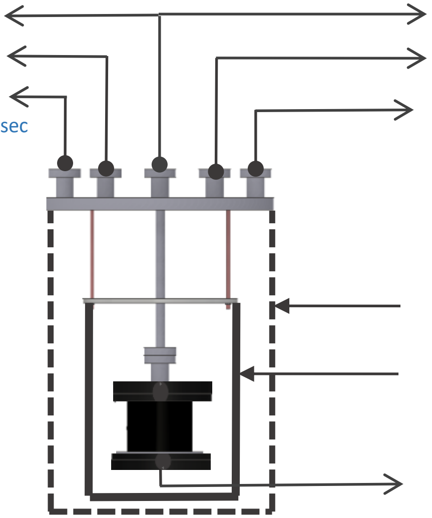
Maria A. Barba
Agostino Vacca
Laetitia Dufay-Chanat
Sebastien Prunet



Pumping System
LN2 heat exchanger
Vacuum sensor
(1x10-3 - 1x10-6) mbar.l/sec

GHe bottle (C)
LN2 dewar (D)
Pumping system (A)
He-leak detector (B)
(1x10-8 - 1x10-9) mbar.l/sec

Cryostat
(Hermetically closed)

Thermal shield by radiation
(not hermetically closed)
77K

Test-Unit
1bar-3.5bar ; 115 K *

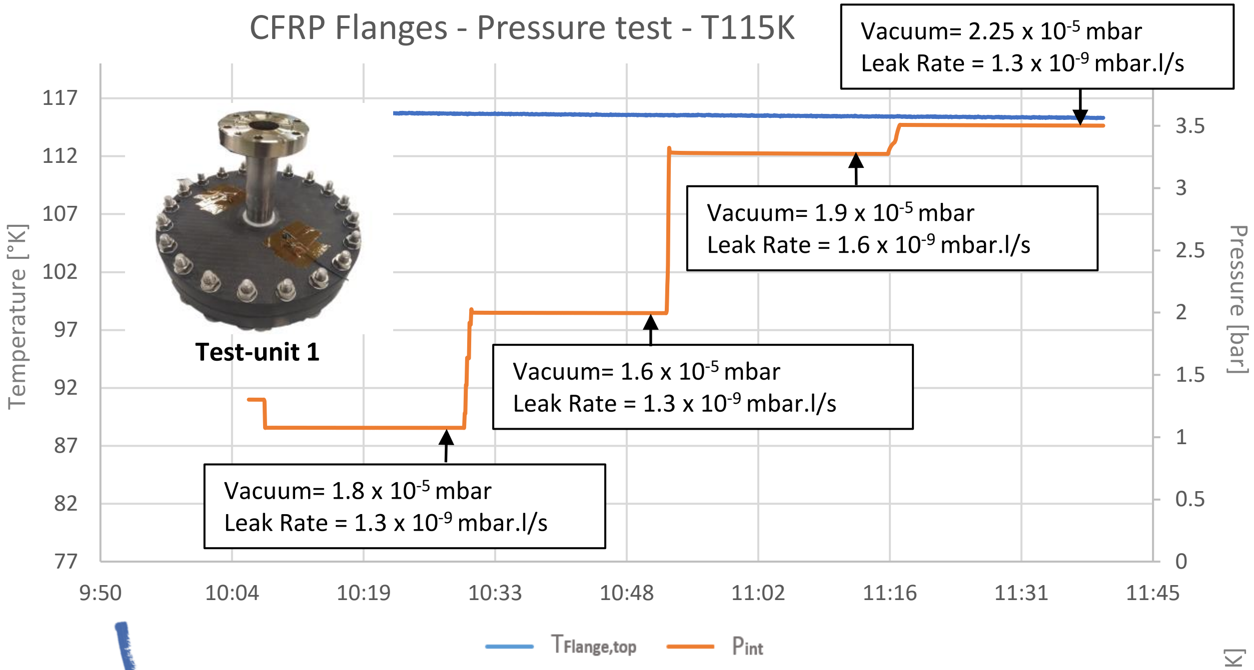
$Q_{rad} = \varepsilon \times \sigma \times (T_1 - T_2)$

Test Procedure :

1. Pressure and leak test at Troom (1h30 min)
2. Cooling down (5 days)*
3. Pressure and leak test at Tcryo (1h30min)
4. Warming up (1 week aprox.)

→ Experimental setup allowed us to check He leakage at 3.5 bar and ~110K (test setup limit)

Test results



Vacuum= 2.25 x 10^{-5} mbar
Leak Rate = 1.3 x 10^{-9} mbar.l/s

Vacuum= 1.9 x 10^{-5} mbar
Leak Rate = 1.6 x 10^{-9} mbar.l/s

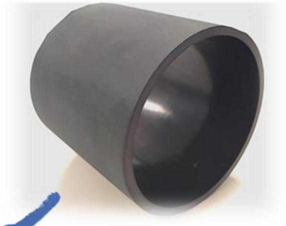
Vacuum= 1.6 x 10^{-5} mbar
Leak Rate = 1.3 x 10^{-9} mbar.l/s

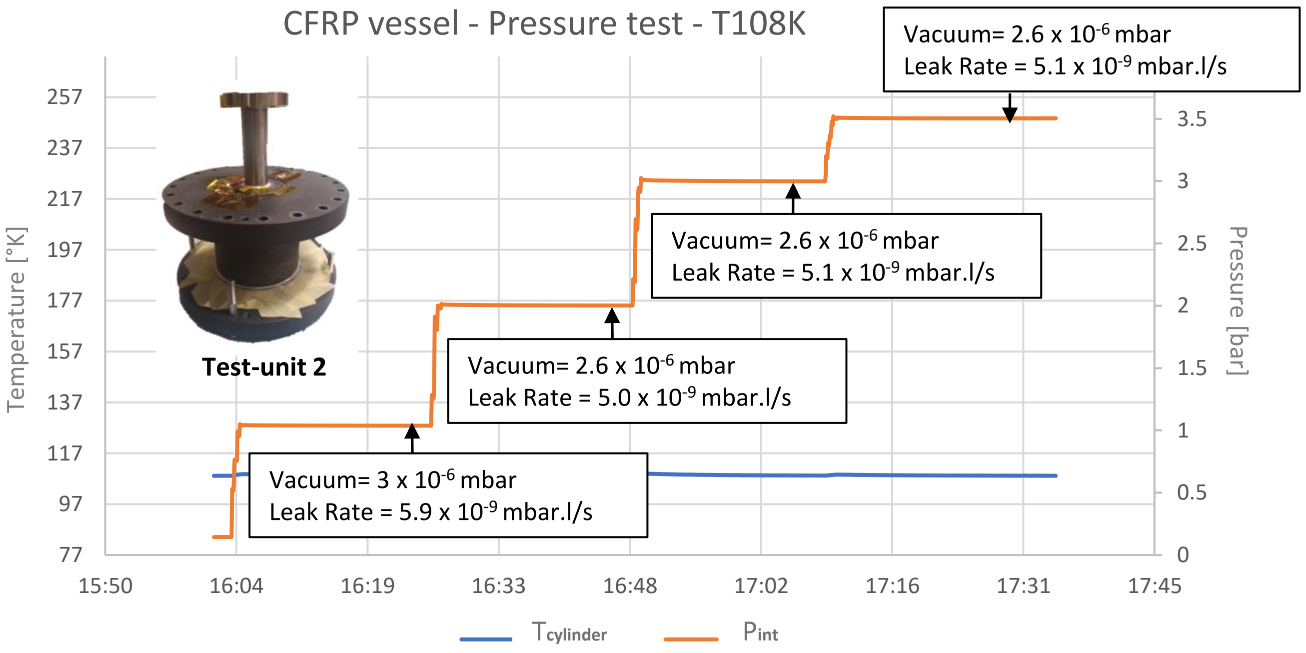
Vacuum= 1.8 x 10^{-5} mbar
Leak Rate = 1.3 x 10^{-9} mbar.l/s

Helicoflex metallic seal validated for sealing carbon composite flanges at 115K* and $P_{int,max}$ = 3.5 bar

* Minimum temperature driven by tets setup limits (LAr 87K)

CTD toughened resin validated for thin wall carbon composite shells at 108K* and $P_{int,max}$ = 3.5 bar





Vacuum= 2.6 x 10^{-6} mbar
Leak Rate = 5.1 x 10^{-9} mbar.l/s

Vacuum= 2.6 x 10^{-6} mbar
Leak Rate = 5.1 x 10^{-9} mbar.l/s

Vacuum= 2.6 x 10^{-6} mbar
Leak Rate = 5.0 x 10^{-9} mbar.l/s

Vacuum= 3 x 10^{-6} mbar
Leak Rate = 5.9 x 10^{-9} mbar.l/s

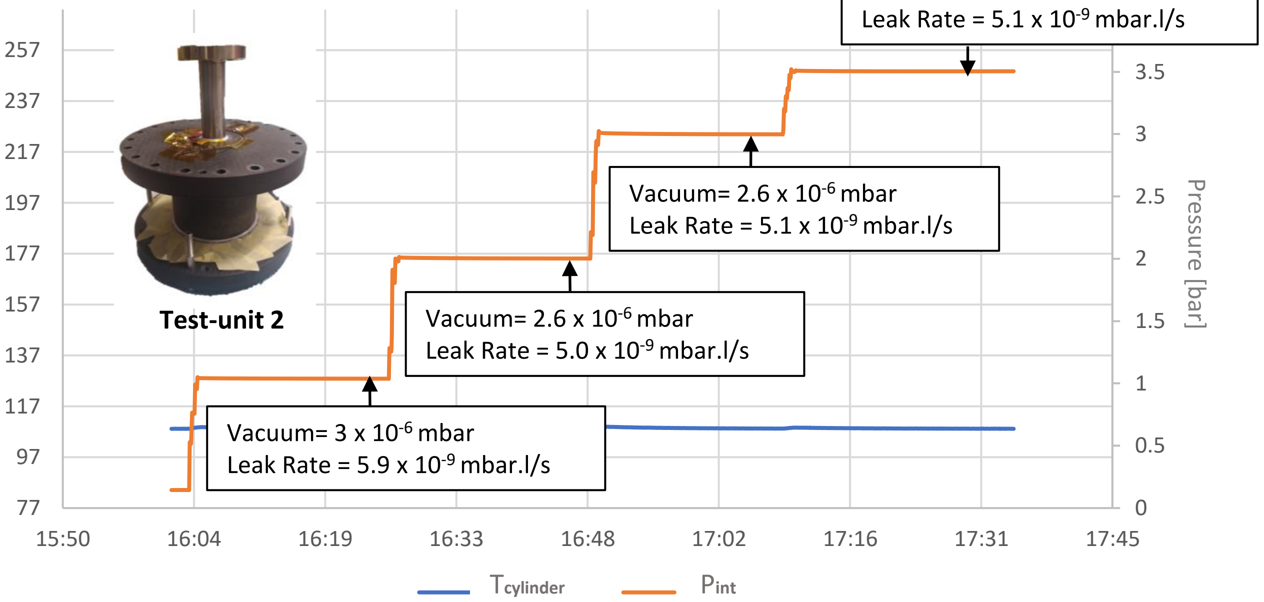
→ Non He-leakage was detected along cryo-tests up to 10e-9 mbar x l / s

Test results

* Minimum temperature driven by tets setup limits (LAr 87K)

CTD toughened resin validated for thin wall carbon composite shells at 108K* and $P_{int,max}$ = 3.5 bar

CFRP vessel - Pressure test - T108K



Vacuum= 3×10^{-6} mbar
Leak Rate = 5.9×10^{-9} mbar.l/s

Vacuum= 2.6×10^{-6} mbar
Leak Rate = 5.0×10^{-9} mbar.l/s

Vacuum= 2.6×10^{-6} mbar
Leak Rate = 5.1×10^{-9} mbar.l/s

Vacuum= 2.6×10^{-6} mbar
Leak Rate = 5.1×10^{-9} mbar.l/s

→ **Non He-leakage was detected along cryo-tests up to 10e-9 mbar x l / s**

Automated manufacturing process

Thanks a lot to:
Taylan Toprak (Connova) - Business Development Head
Thomas Leschik (Connova) - Operations Head
Tobias Hoyer (Connova) – Project Engineer
Mark Seeber (CTD) - Commercial Office Head

Visit to Connova 02.11.2021

Process development for Wet Filament Winding as alternative to RAFP

- -Optimize **CTD-7.1 resin bath** preparation and size.
- -Optimize **carbon fiber tension** to increase cross plies density (permeation resistance)
- -Laminate: **[-55,+55]s with non-crossings** to minimize void content
- - Out of Autoclave curing (oven)

Micro-crack resistant resin at cryogenics includes toughened additives. **Vacuum evacuation** of resin system is needed **to improve void content before winding** and to get high mechanical properties.

Peel-ply as final layer to compact laminate and **evacuate voids**

→ Next samples to address filament winding technology as an efficient manufacturing process for larger scale

Feedthroughs (FT): Carbon-Metal interfaces

Test samples: Carbon composite thin tubes with Stainless Steel (1.4301) end-fittings embedded into laminate, by filament winding

Carbon/Metal non-conventional joint

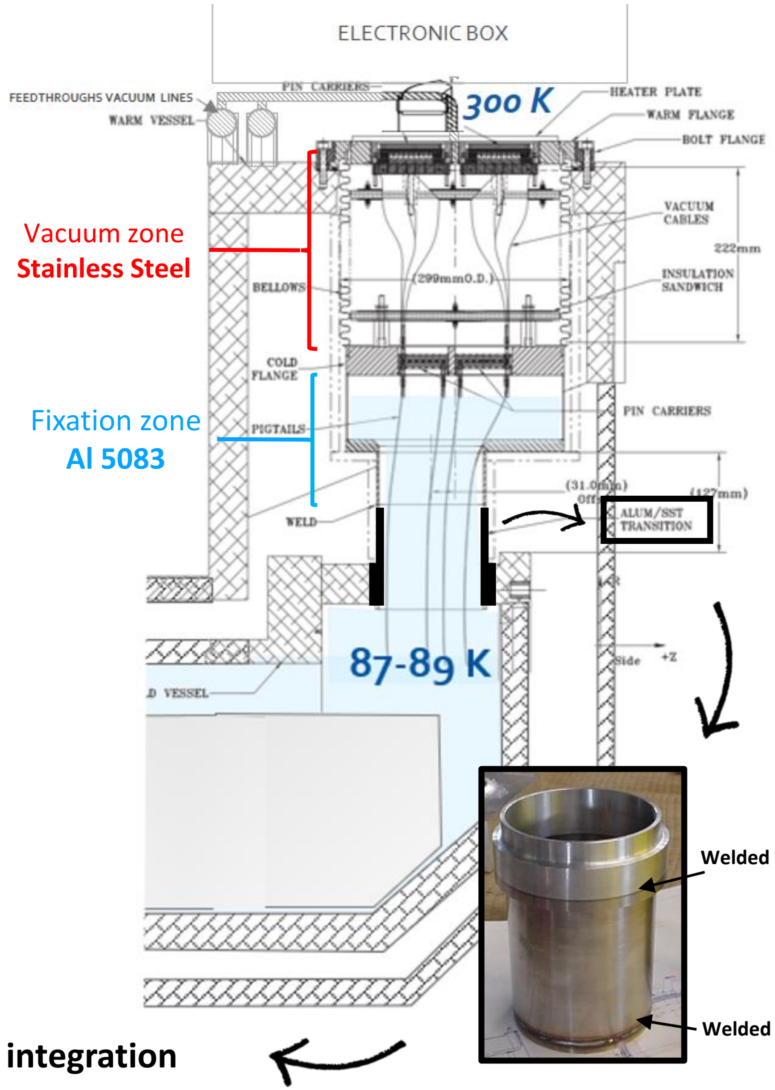
T800H/**CTD-7.1;** Di=59 mm; **t= 1.5mm**

T800H/**CTD-7.1**; Di=59 mm; **t= 0.7mm**

T800H/ **LY 556** ; Di=59 mm; **t= 1.5mm**

T800H/ **LY 556** ; Di=59 mm; **t= 0.7mm**

64 signal FT + 2 HV TF + Solenoid chimney



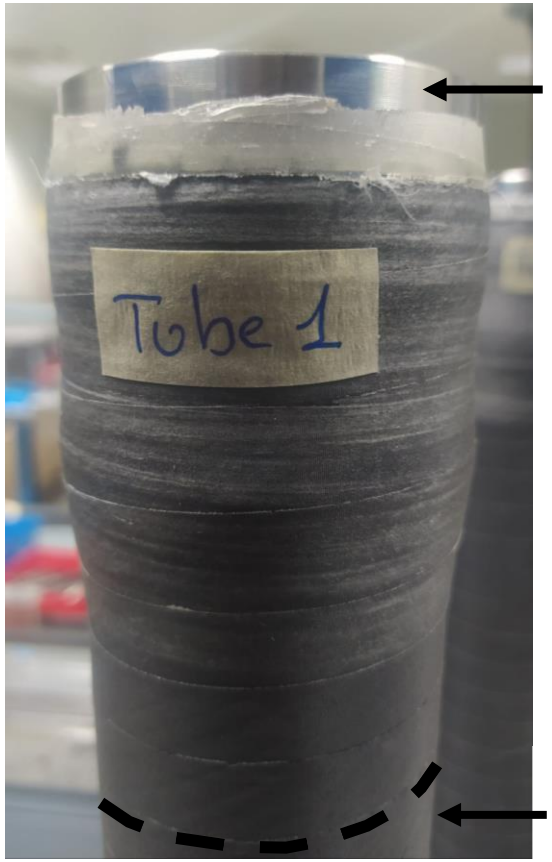
FT integration

→ A large number of FTs is expected in future detectors. A cryostat/FT interface is required to address FTs integration

Feedthroughs (FT): Carbon-Metal interfaces

Test samples: Carbon composite thin tubes with Stainless Steel (1.4301) end-fittings embedded into laminate, by filament winding

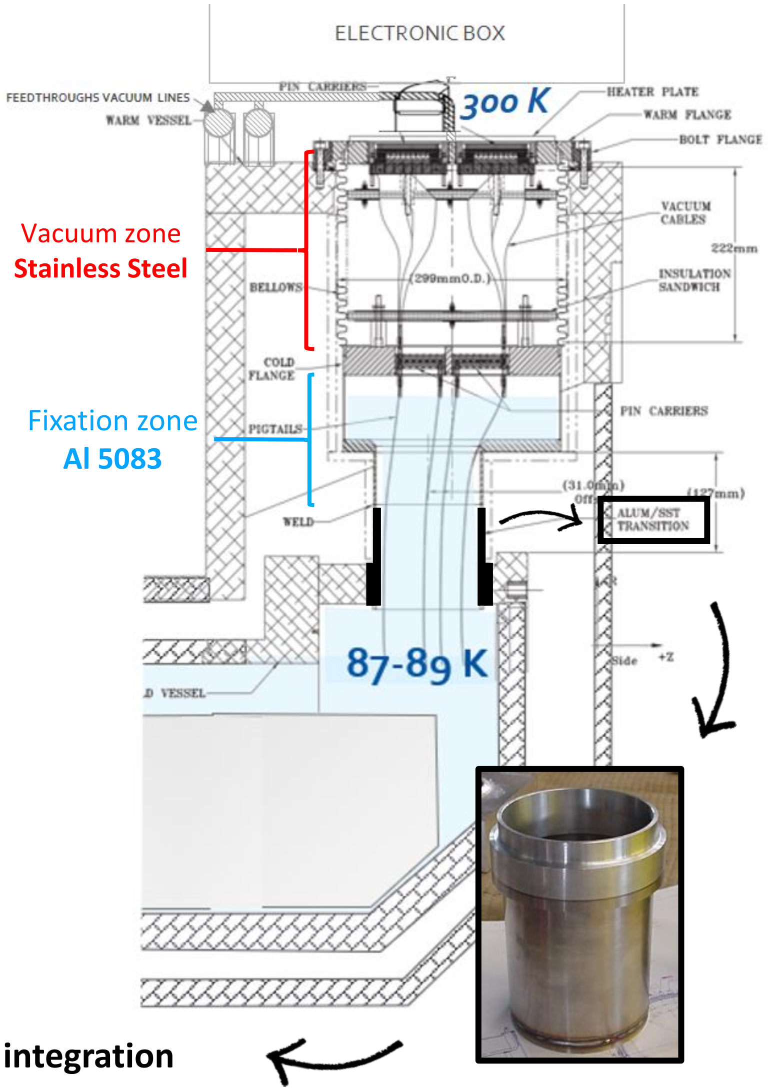
Carbon/Metal non-conventional joint



Welded to metallic Feedthrough

Glued to carbon composite Cryostat

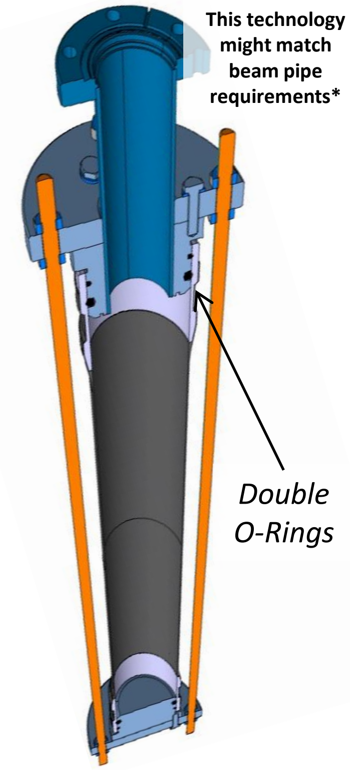
64 signal FT + 2 HV TF + Solenoid chimney



FT integration

→ A large number of FTs is expected in future detectors. A cryostat/FT interface is required to address FTs integration

Feedthroughs: Test results at Troom



This technology might match beam pipe requirements*

Tube	Resin	Fiber	Wall thickness	End-Fittings	He leak rate (Troom)
1	CTD-7.1	T800H	0.7	SS 314	10e-9 mbar.l/sec
2	Araldite	T800H	1.5	SS 314	10e-11 mbar.l/sec
3	CTD-7.1	T800H	1.5	SS 314	10e-10 mbar.l/sec
4	Araldite	T800H	0.7	SS 314	leak < 10e-7 mbar.l/sec -> interface

We are in need of collaboration to validate it this joint at 87K*

Atlas cryostat: 64 signal FT + 2 HV TF + Solenoid chimney

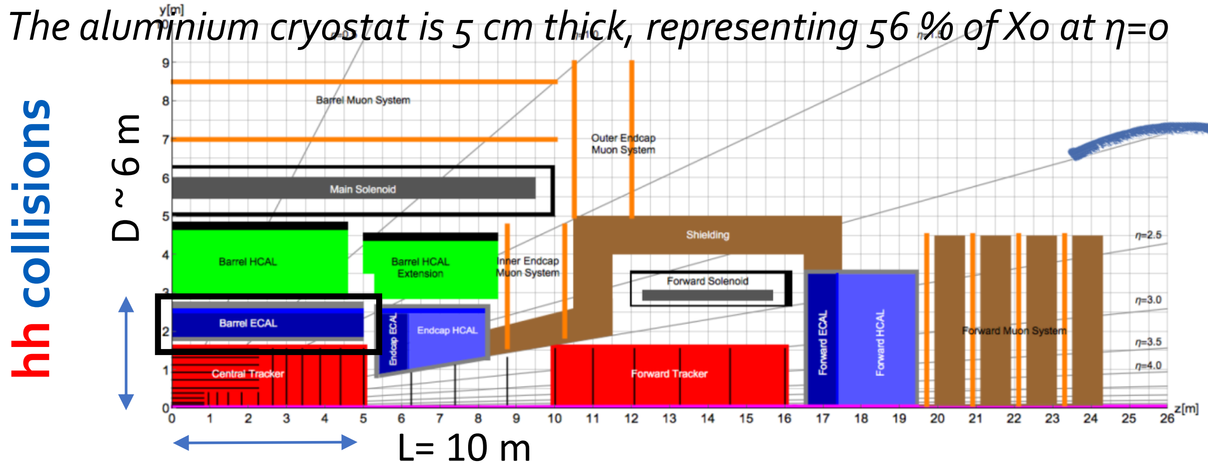
This joint is design to be optimal at cold temperatures: polymeric fibers contacts more than metal and carbon fiber)*

→ Non conventional bonding between metal-carbon parts needs to be validated at LAr temperature (87 K)

Design of CFRP cryostats for future experiments

Baseline geometry, FCC-hh LAr barrel ECAL :

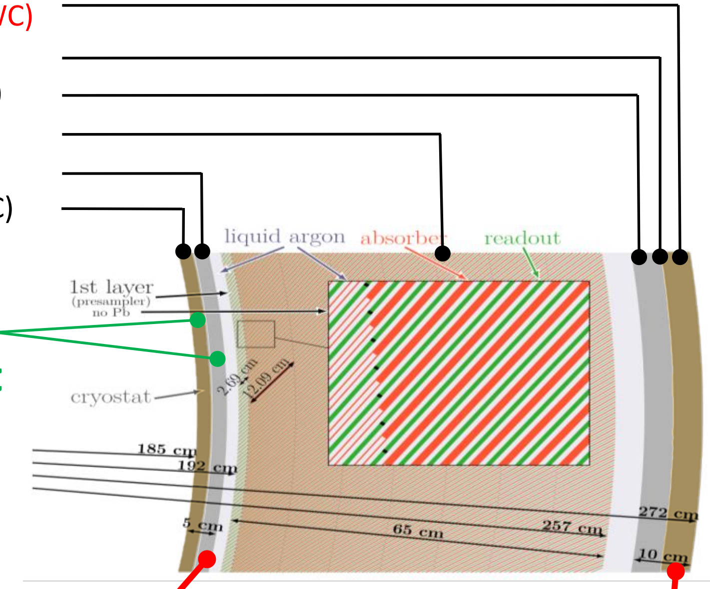
The aluminium cryostat is 5 cm thick, representing 56 % of Xo at η=0



Outer warm cylinder (OWC)
Insulation vacuum
Outer cold cylinder (OCC)
LAr ECAL
Inner cold cylinder (ICC)
Inner warm cylinder (IWC)

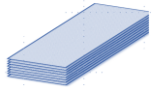
Minimum material budget

Buckling resistance



Sandwich Shell

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

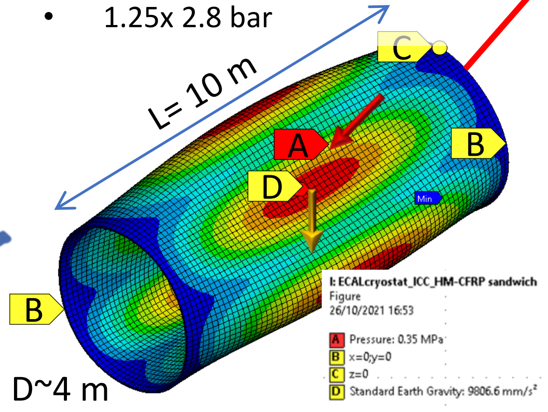


Solid Shell

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

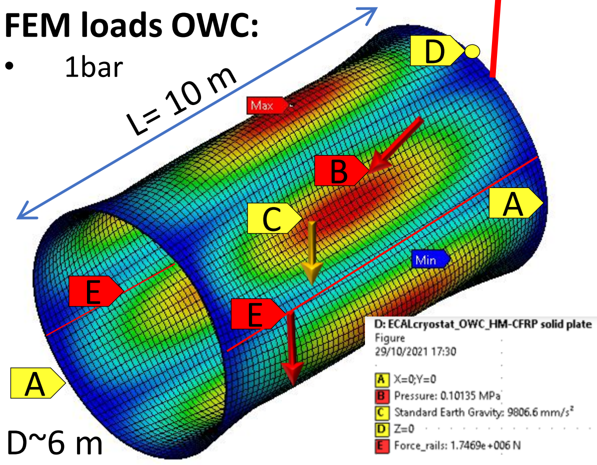
Criteria: Safety Factor = 2	Sandwich shell				Solid shell			
	HM CFRP		Al		HM CFRP		Al	
	OWC	ICC	OWC	ICC	OWC	ICC	OWC	ICC
Material budget X/Xo	0.03	0.043	0.094	0.17	0.092	0.12	0.34	0.44
Xo % savings	-68%	-75%	REF	REF	-2%	-29%	262%	159%
Skin Th. [mm]	3.2	4.8	3.9	7.5				
Core Th. [mm]	32	38	40	40				
Total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

FEM loads ICC:
- 1.25x 2.8 bar



I: ECALcryostat_ICC_HM-CFRP sandwich
Figure
26/10/2021 16:53
A Pressure: 0.35 MPa
B x=0;y=0
C z=0
D Standard Earth Gravity: 9806.6 mm/s²

FEM loads OWC:
- 1bar



D: ECALcryostat_OWC_HM-CFRP solid plate
Figure
29/10/2021 17:30
A X=0;Y=0
B Pressure: 0.10135 MPa
C Standard Earth Gravity: 9806.6 mm/s²
D Z=0
E Force_rails: 1.7469e+006 N

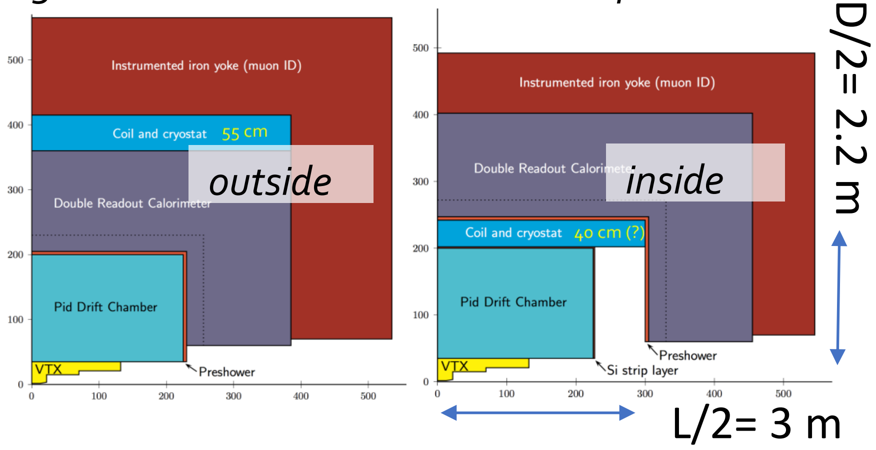
→ CFRP cryostat walls will provide savings in terms of material budget/thickness respect to Aluminum

Design of CFRP cryostats for future experiments

Baseline geometry, FCC-ee

a very challenging 2T solenoid "ultra-thin and transparent"

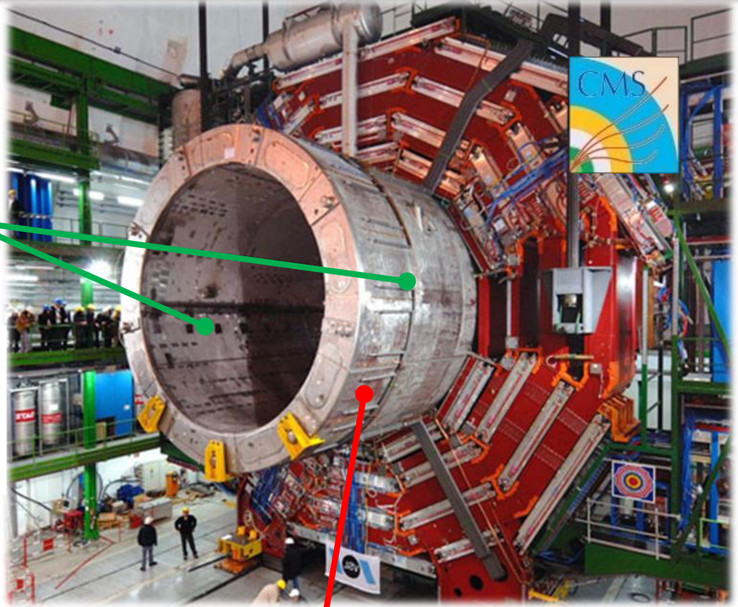
e^+e^- collisions



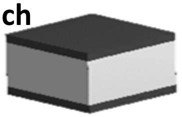
Minimum material budget

Buckling resistance

Patm → Vacuum



Sandwich

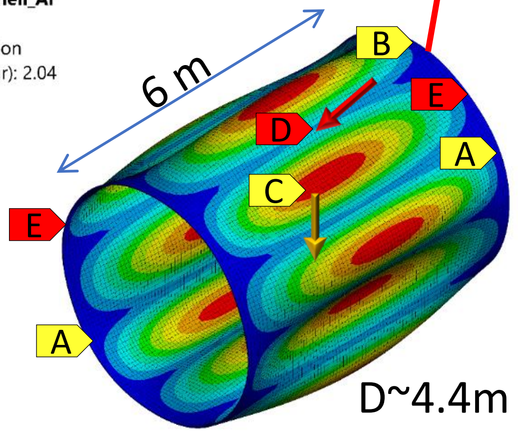


Skin [0,45,-45,90]s
Core : Al Honeycomb
Skin [0,45,-45,90]s

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

Criteria: Safety Factor = 2	Honeycomb Al		Solid shell	
	HM CFRP	Al	HM CFRP	Al
Material budget X/Xo	0.017	0.045	0.065	0.24
Xo % savings	-62%	REF	44%	433%
Skin Th. [mm]	1.6	1.7		
Core Th. [mm]	26	40		
Total Th. [mm]	29.2	43.4	16.8	20.9
Thickness % savings	-33.00%	REF	-61%	-52%

G: Buckling_Outer_shell_Al
Total Deformation
Type: Total Deformation
Load Multiplier (Linear): 2.04
Unit: mm



FEM loads OWC:

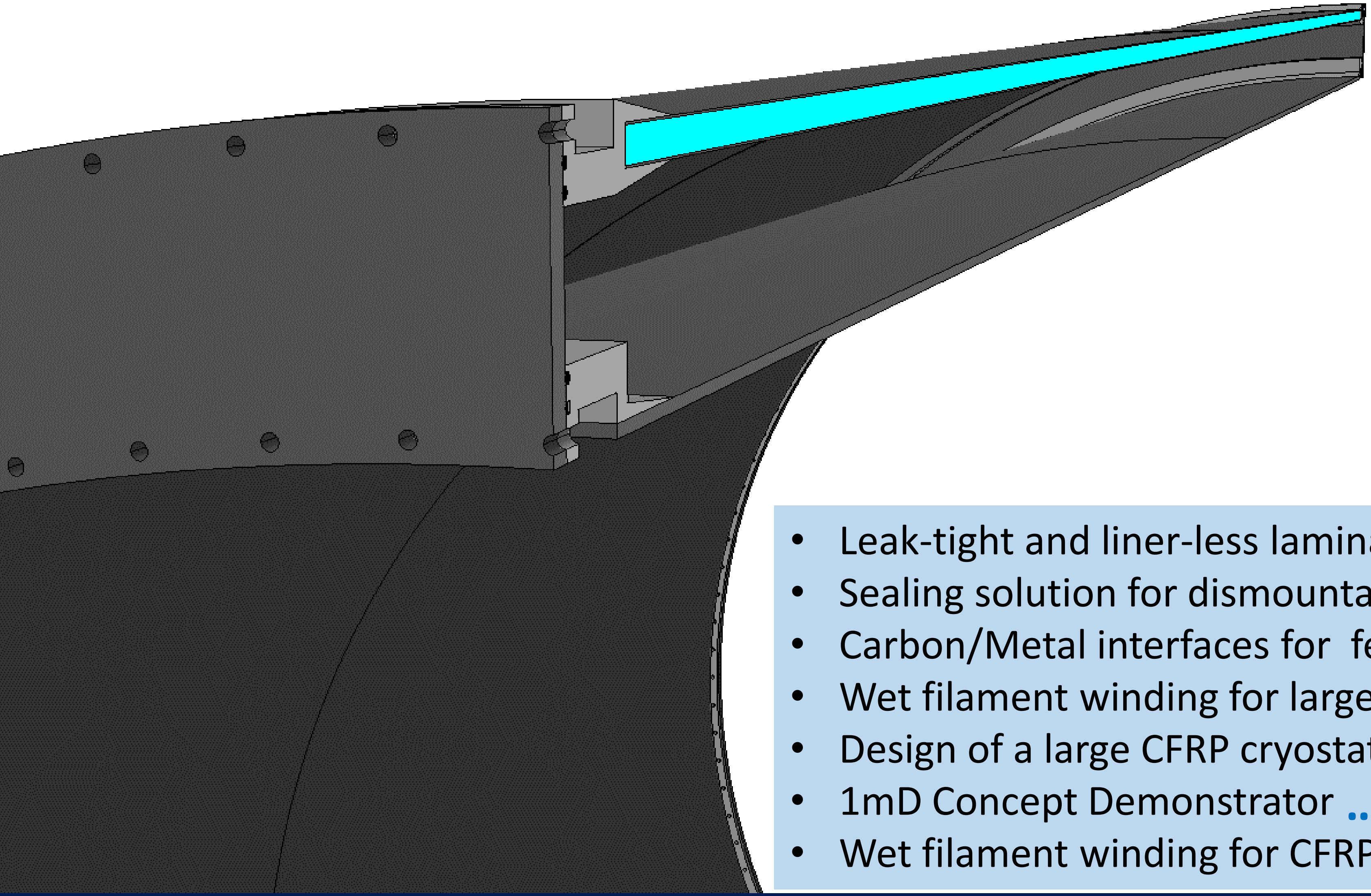
- 1 bar

A: Outer_shell_Al
Static Structural
Time: 1. s

A	X=0; Y=0
B	Z=0
C	Standard Earth Gravity: 9.81e+003 mm/s²
D	Pressure: -0.101 MPa
E	Force: 3.5e+005 N

→ CFRP cryostat wall will help to provide savings in terms of material budget/thickness respect to Aluminum

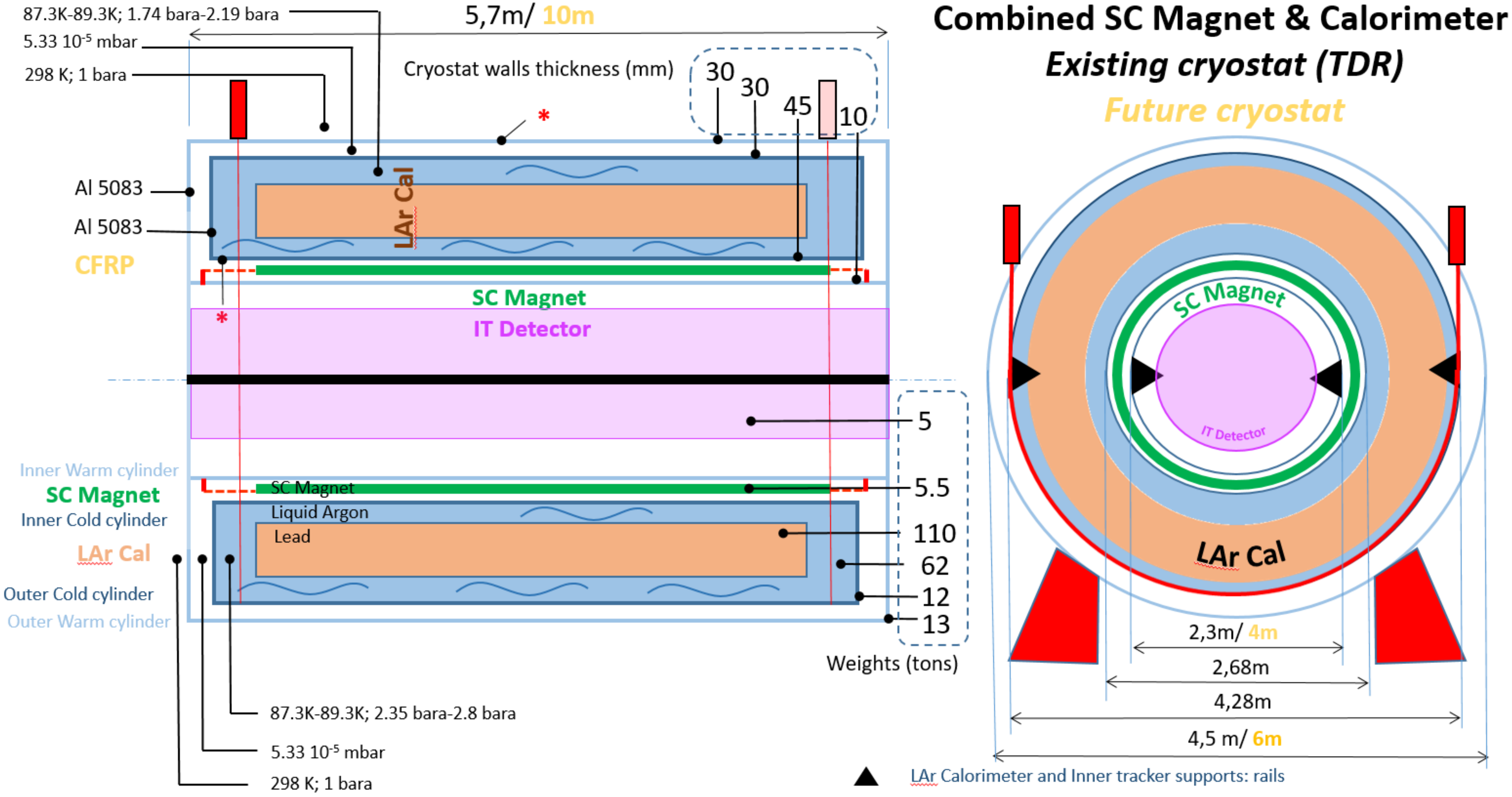
Summary



- Leak-tight and liner-less laminate. ✓
- Sealing solution for dismountable joints. ✓
- Carbon/Metal interfaces for feed-throughs (and Beam Pipe*) ...
- Wet filament winding for large scale production ...
- Design of a large CFRP cryostat based on FCChh and FCCee needs ...
- 1mD Concept Demonstrator ...
- Wet filament winding for CFRP sandwich cylinder ?

→ Carbon composite design might help to minimize material budget and weight of cryostats in HEP experiments.

ATLAS barrel cryostat - Requirements



Note:* Buckling sensitive, each shell that is subjected to an external press larger than the internal

**** SC Magnet cooled by closed circuit, He serpentine on the structural shell**

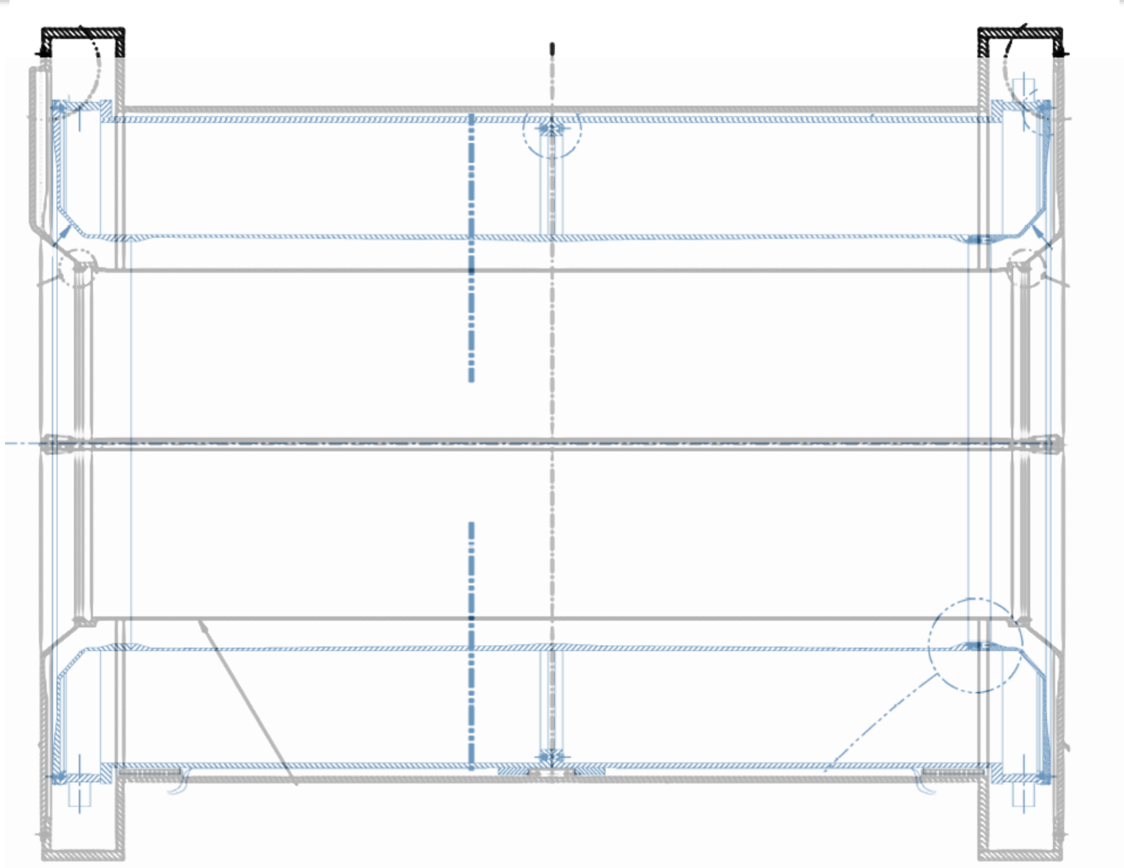
▲ LAr Calorimeter and Inner tracker supports: rails

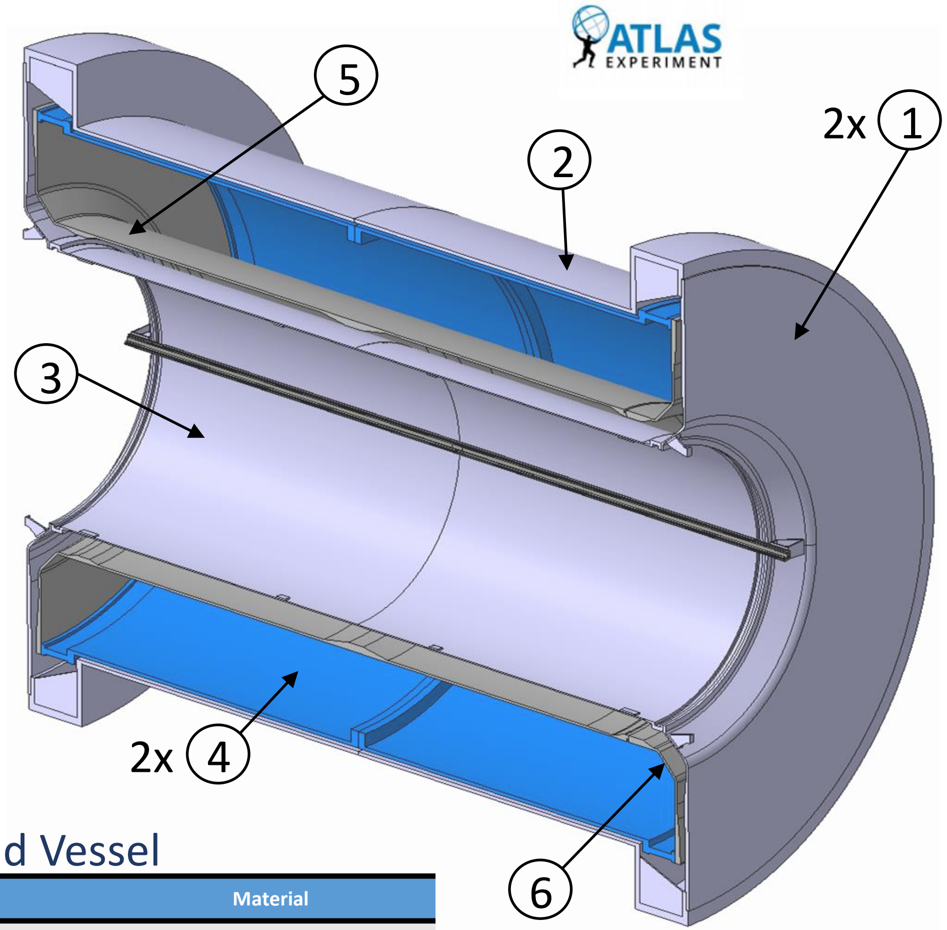
🟥 Cold Vessel supports: straps from the outer warm cylinder

┏- - - - SCM support: fixed at the end flange of the warm inner cylinder

→ The ATLAS barrel cryostat houses the LAr calorimeter and the SC magnet, supports the IT and it is supported by Tile-CAL

ATLAS barrel cryostat – Structure I





Warm Vessel

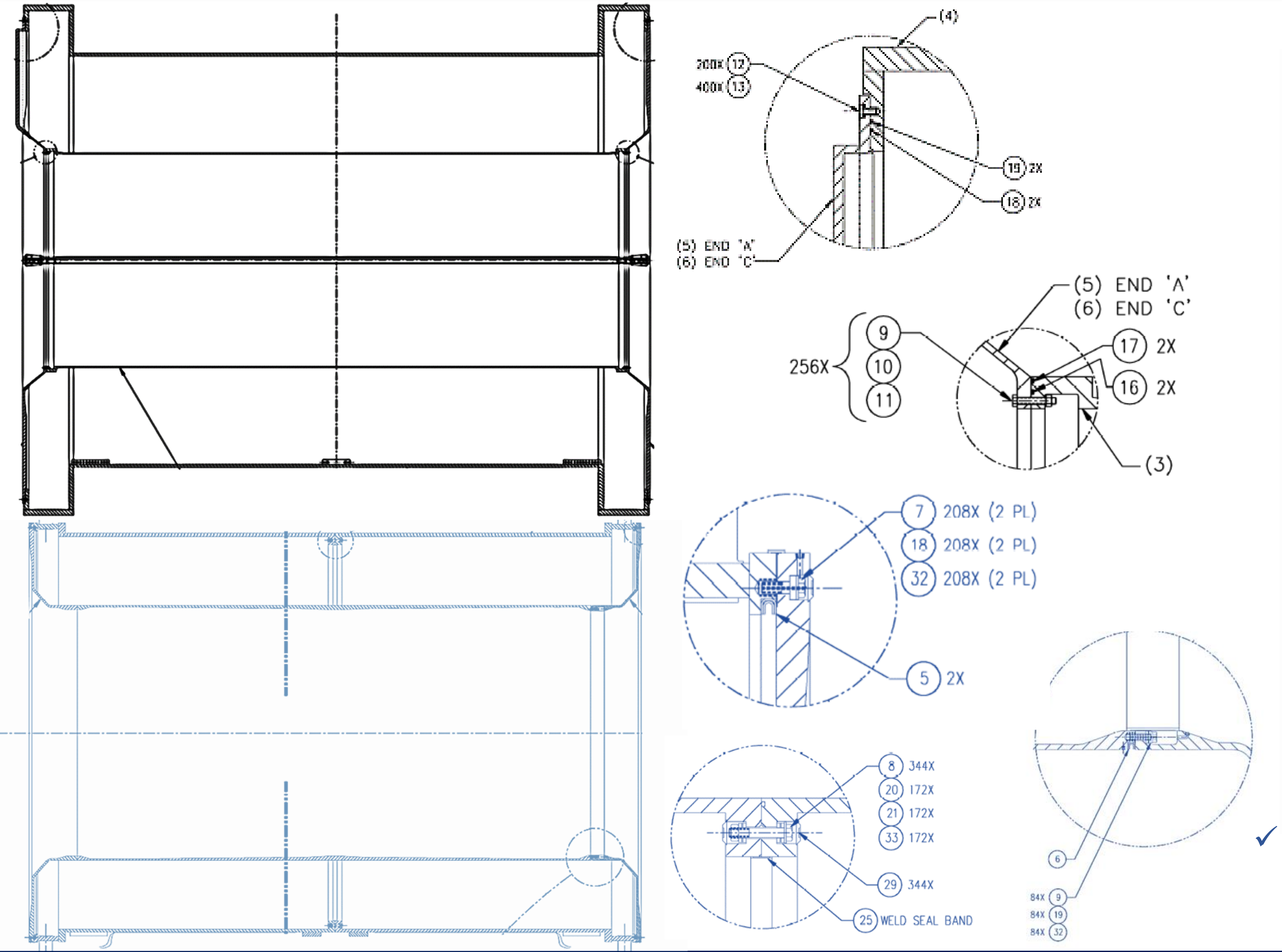
Item	Part	Material
1	Warm Bulkhead (x2)	Al 5083
2	Outer warm cylinder	Al 5083
3	Inner warm cylinder	Al 5083

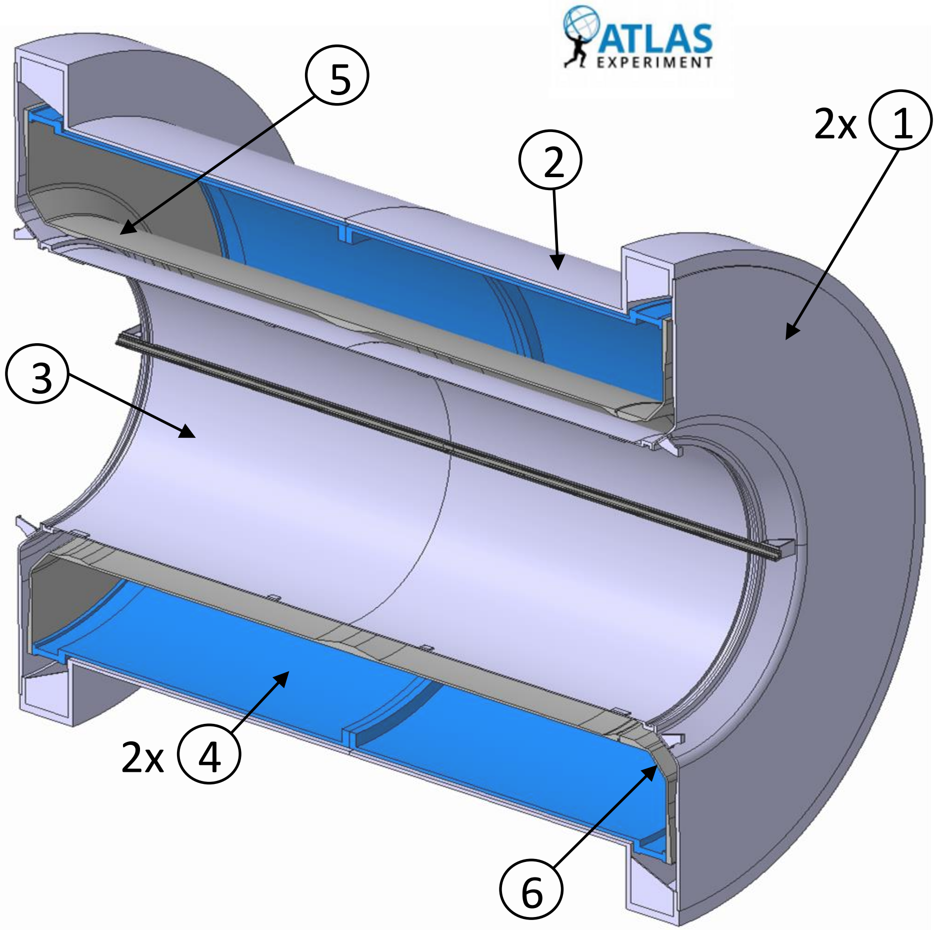
Cold Vessel

Item	Part	Material
4	Outer cold cylinder half (x2)	Al 5083
5	Inner cold cylinder + cold bulkhead A	Al 5083
6	Cold Bulkhead C*	Al 5083

→ The ATLAS barrel cryostat houses the LAr calorimeter and the SC magnet, supports the IT and it is supported by Tile-CAL

ATLAS barrel cryostat – Structure II



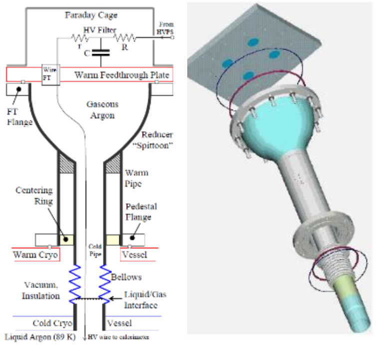


- ✓ References: Cold vessel of ATLAS cryostat was sealed by **Omega metal seals** (BEFORE WELDING) to be cold tested and accepted at a sensitivity of **10e-9 mbar.l/sec.**

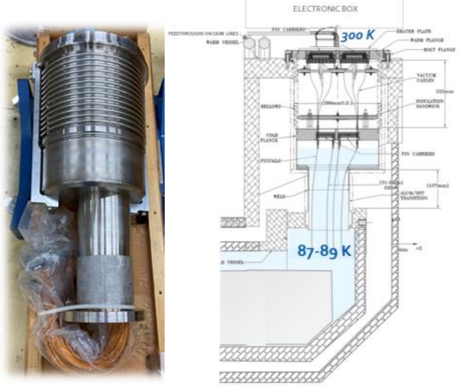
→ The ATLAS barrel cryostat houses the LAr calorimeter and the SC magnet, supports the IT and it is supported by Tile-CAL

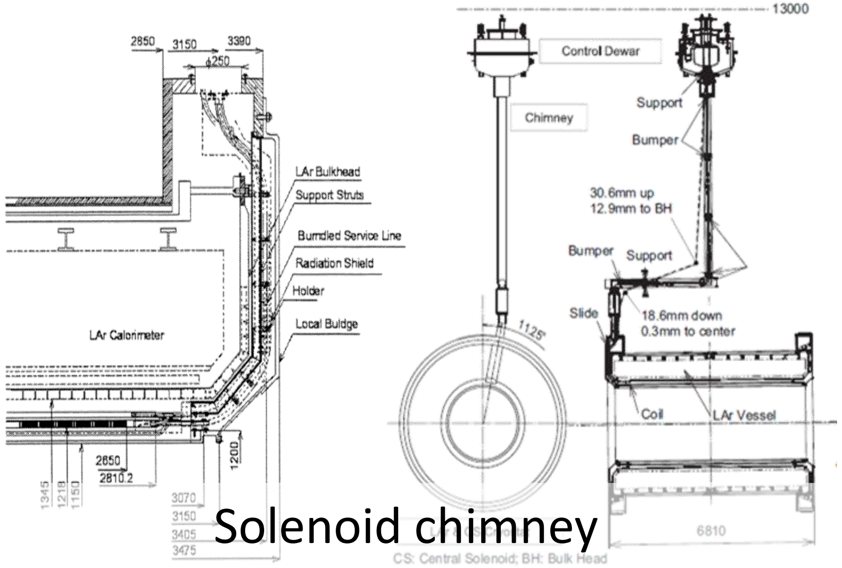
ATLAS barrel cryostat - Feedthroughs

2 HV FEEDTHROUGHS

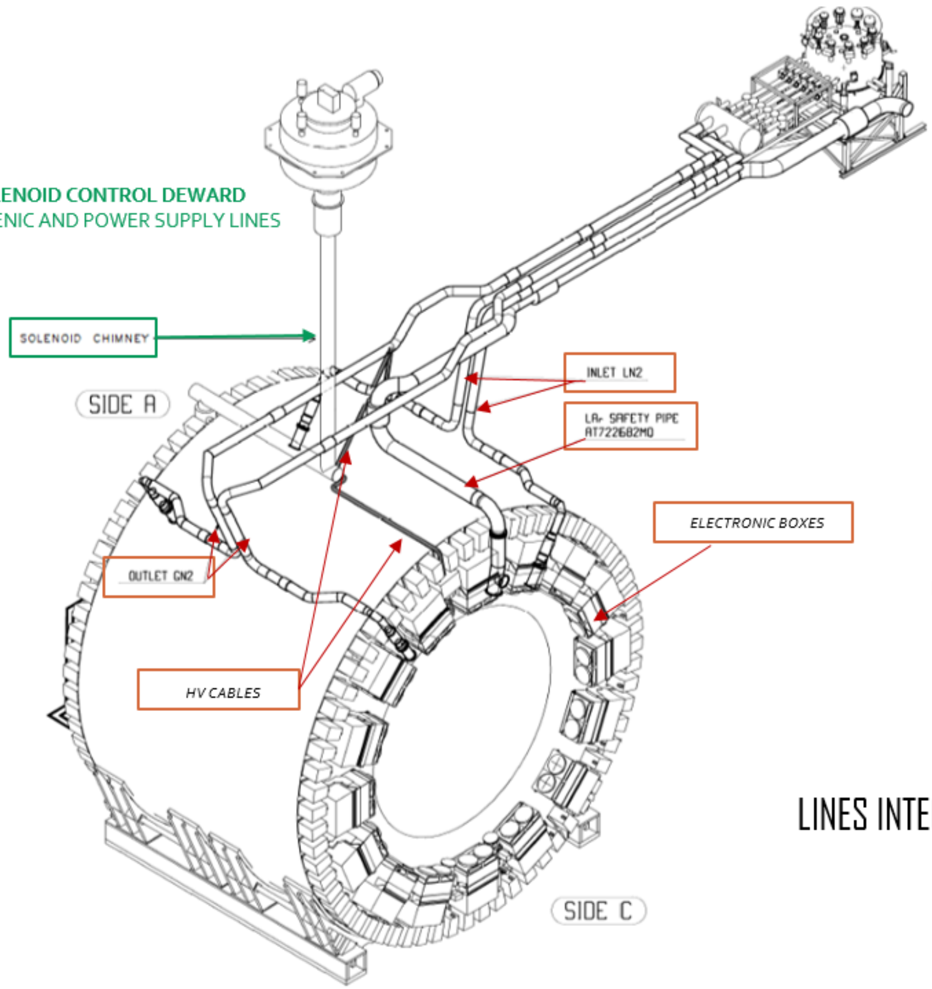


64 SIGNAL FEEDTHROUGHS





Solenoid chimney



SOLENOID CONTROL DEWARD
CRYOGENIC AND POWER SUPPLY LINES

EM CALORIMETER CRYOSERVICE LINES
COOLING LOOP:
INLET LN2 LINE-HEATEXCHANGER-OUTLETGN2

EM CALORIMETER CRYOGENIC LINE
LAr safety line

EM CALORIMETER HV LINES

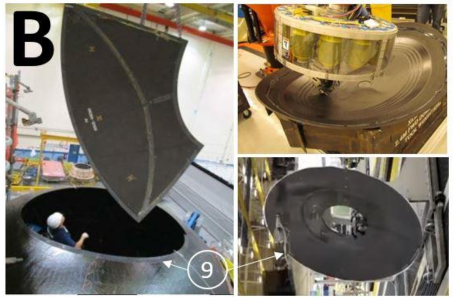
EM CALORIMETER SIGNAL AND CALIBRATION LINES

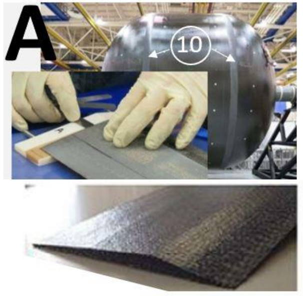
LINES INTEGRATION INTO THE ATLAS CRYOSTAT

→ Feedthroughs are allocated on both ends of the cryostat to accommodate lines supporting LAr Calorimeter and SC magnets

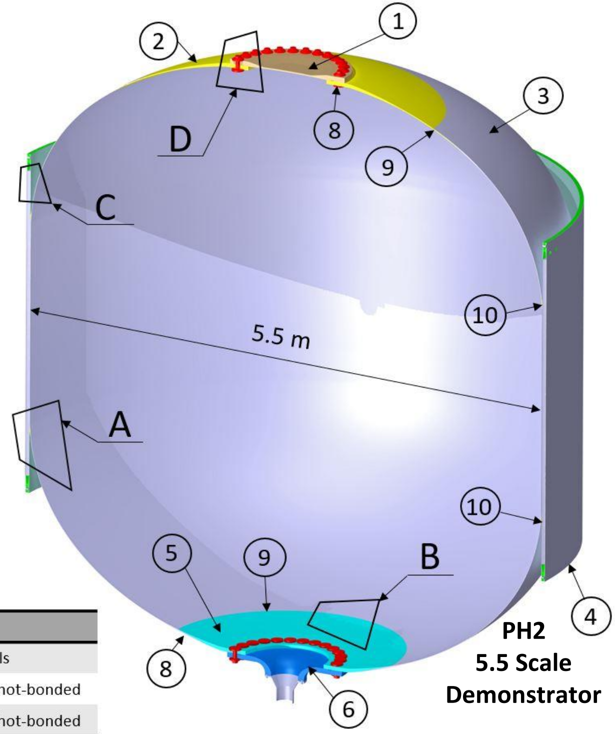
NASA's CCTD – State of the art of CFRP cryotanks

Part	Feature	2.4m in diameter Precursor Tank	5.5m in diameter Scale Demonstrator
Tank Wall	**Construction**	Monocoque wall with nominal thickness to withstand pressure load	Monocoque wall with nominal thickness to withstand pressure load
		*Pressure scaled up to achieve same stresses in tank joint than Scale Demonstrator	*Design Pressure=3 bars
	***Fiber Placement**	Robotic Automated Fiber Placement (RAFP)	Robotic Automated Fiber Placement (RAFP)
	***Curing**	Out-of-Autoclave processing (low pressure)	Out-of-Autoclave processing (low pressure)
	Layup	Hybrid laminate with centred 6 thin plies	Hybrid laminate with centred 6 thin plies
	Material	IM7/5321-1, 70 gsm and 145 gsm RAFP slit-tape tow (STT)	IM7/5321-1, 70 gsm and 145 gsm RAFP slit-tape tow (STT)
	Tooling	Multipiece C/E mandrel (24 segments), RAFP cell, Oven	Multipiece C/E mandrel (20 segments), RAFP cell, Oven
	SHM	Acoustic Emission sensor-based system	Acoustic Emission sensor-based system (20 sensors required)
	SE Y-Joint	Baseline hot-bonded softening strip	Optimized hot-bonded softening strip
	SE Scarf Joints	Scarf shape included in muiltipiece mandrel	Scarf shape included in muiltipiece mandrel
	NDI	Trough-Transmission Ultrasonic (TTU)and Pulse Echo (PE)	Trough-Transmission Ultrasonic (TTU), Pulse Echo (PE)and Flash thermography
Skirt	**Construction**	Monocoque thick skirt	Fluted core (Inner skin + flute panels + outer skin)
	***Fiber Placement**	Robotic Automated Fiber Placement (RAFP)	Robotic Automated Fiber Placement (RAFP)
	***Curing**	Out-of-Autoclave processing (low pressure)	Out-of-Autoclave processing (low pressure)
	Layup	Thick ply laminate	Inner skin thick ply laminate + flute panel laminate + Outer skin thick ply laminate
	Material	IM7/5321-1, 145 gsm RAFP slit-tape tow	Skins: IM7/5321-1, 145 gsm RAFP slit-tape tow
			Flute panel: C/E fabric (facesheets) and thin tapes (angled web members)
	Tooling	Skirt Alignment Fixture, RAFP cell, Oven	Flute layup mandrel, Skirt Alignment Fixture, RAFP cell, Oven
	SE Y-Joint	Co-bonded and hot-bonded softening strip	Co-bonded and hot-bonded softening strip
	End-Joint	None, designed to ease of handling	Load-bearing design, to vent leaks and to apply flight axial loads along tests
Forward Cover	**Construction**	Monocoque dome with nominal thickness to withstand pressure load	Monocoque dome with nominal thickness to withstand pressure load
		*Pressure scaled up to achieve same stresses in tank joint than Scale Demonstrator.	*Design Pressure=3 bars.
	***Fiber Placement**	Single-headed Robotic Automated Fiber Placement (RAFP)	Single-headed Robotic Automated Fiber Placement (RAFP)
	***Curing**	Autoclave processing (0.57 Mpa with 94.8kPa vacuum)	Autoclave processing (0.57 Mpa with 94.8 KPa vacuum)
	Layup	Hybrid laminate with centred 6 thin plies	Hybrid laminate with centred 6 thin plies
	Material	IM7/5321-1, 70 gsm and 145 gsm RAFP slit-tape tow (STT)	IM7/5321-1, 70 gsm and 145 gsm RAFP slit-tape tow (STT)
	Tooling	Forward cover mold, RAFP cell, Autoclave	Forward cover mold, RAFP cell, Autoclave
	SE Scarf Joint	Co-bonded and hot-bonded (scarf shape included in cover mould)	Co-bonded and hot-bonded (scarf shape included in cover mould)
Sump Cover	**Construction**	Monocoque dome with nominal thickness to withstand pressure load	Monocoque dome with nominal thickness to withstand pressure load
		*Pressure scaled up to achieve same stresses in tank joint than Scale Demonstrator.	*Design Pressure=3 bars.
	***Fiber Placement**	Single-headed Robotic Automated Fiber Placement (RAFP)	Single-headed Robotic Automated Fiber Placement (RAFP)
	***Curing**	Autoclave processing (low pressure)	Autoclave processing (low pressure)
	Layup	Hybrid laminate with centred 6 thin plies	Hybrid laminate with centred 6 thin plies
	Material	IM7/5321-1, 70 gsm and 145 gsm RAFP slit-tape tow (STT)	IM7/5321-1, 70 gsm and 145 gsm RAFP slit-tape tow (STT)
	Tooling	Forward cover mold, RAFP cell, Autoclave	Forward cover mold, RAFP cell, Autoclave
	SE Scarf Joint	Co-bonded and hot-bonded (scarf shape included in cover mould)	Co-bonded and hot-bonded (scarf shape included in cover mould)
Forward Flange	**Construction**	Carbon Composite thin close-out	Carbon Composite thick flange
	***Fiber Placement**	Hand layup	Hand layup
	***Curing**	Autoclave processing (0.57 Mpa with 94.8kPa vacuum)	Autoclave processing (0.57 Mpa with 94.8kPa vacuum)
	Layup	Hybrid laminate with centred 6 thin plies	Hybrid laminate with centred 6 thin plies
	Material	IM7/5321-1, 70 gsm and 145 gsm hand-lay up layers or STT??	IM7/5321-1, 70 gsm and 145 gsm hand layup layers
	Tooling	Close-out mold, ancillary cure tools and stands (Al and steel), Autoclave	Flange mould, ancillary cure tools and stands (Al and steel), Autoclave
	Joint	co-bonded and hot-bonded scarf joint	Bolted joint (torque limited bolts, Belleville washers and Furon seals)
Sump Flange	**Construction**	Carbon Composite thin close-out	Carbon Composite thick flange
	***Fiber Placement**	Hand layup	Hand layup
	***Curing**	Autoclave processing (0.57 Mpa with 94.8kPa vacuum)	Autoclave processing (0.57 Mpa with 94.8kPa vacuum)
	Layup	Hybrid laminate with centred 6 thin plies	Hybrid laminate with centred 6 thin plies
	Material	IM7/5321-1, 70 gsm and 145 gsm hand-lay up pre-preg layers	IM7/5321-1, 70 gsm and 145 gsm hand layup pre-preg layers
	Tooling	Autoclave	Autoclave
	Joint	Bolted joint (torque limited bolts, Belleville washers and Furon seals)	Bolted joint (torque limited bolts, Belleville washers and Furon seals)





Item	Component	Material (CFRP)
1	Forward Flange	5320-1 hybrid laminate
2	Forward Cover	5320-1 hybrid laminate
3	Tank Wall	5320-1 hybrid laminate
4	Skirt	5320-1 thick plies
5	Sump Cover	5320-1 hybrid laminate
6	Sump Flange	5320-1 hybrid laminate
7	Flute panel core	5320-1 Thin plies



PH2 5.5 Scale Demonstrator

Item	Joint	Material	Components	Note
8	Torque limited bolts	Metal ?	Flanges-Covers	Belleville washers and Furon seals
9	Scarf Joint	C/E	Covers-Tank wall	Structurally efficient co-bonded hot-bonded
10	Y-Joint (softening strip)	E/E	Skirt-Tank wall	Structurally efficient co-bonded hot-bonded

Equivalency Tests (PH1)	Out-of-Autoclave				Autoclave		
ATK	IM7/M56 145hlu, 70hlu		IM7/5320-1 145hlu,70hlu				IM7/8552-1 145hlu
Boeing			IM7/5320-1 145fp,70fp		IM7/BXA 145fp	IM10/8552-1 70fp	
Lockheed Martin	IM7/M56 145fp, 70hlu	IM7/ MTM45-1 145fp,70hlu		IM7/TC250 145fp,70hlu			
Northrop Grumman		IM7/ MTM45-1 70hlu			IM7/BXA 70hlu		

Ply thickness: 145= 145gsm FAW ; 70= 70gsm FAW / Manufacturing technique: hlu= hand layup ; fp= fiber placed

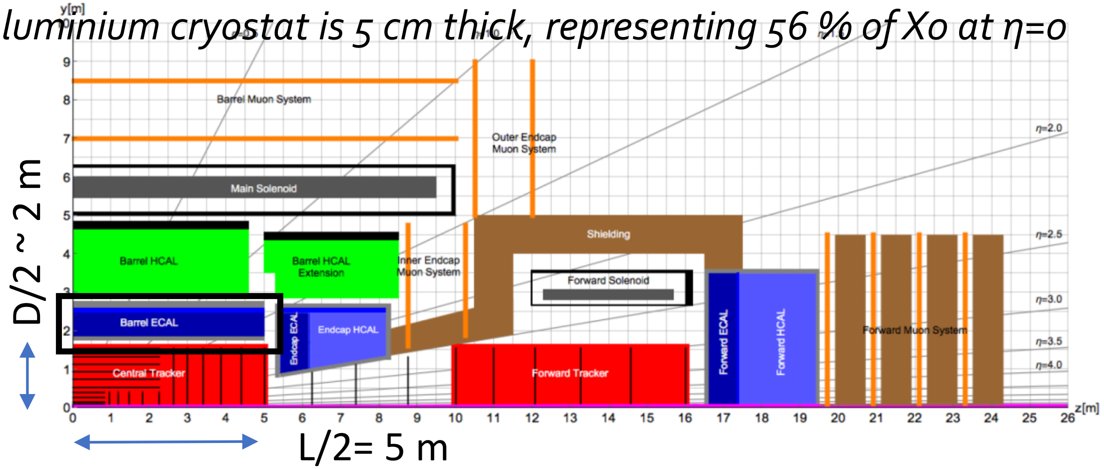
→ NASA CCTD 5.5m in diameter demonstrator is the most advanced cryotank in literature reviewed (Successfully tested)

Radiation Environment in future experiments

hh collisions

Baseline geometry, FCC-hh LAr barrel ECAL :

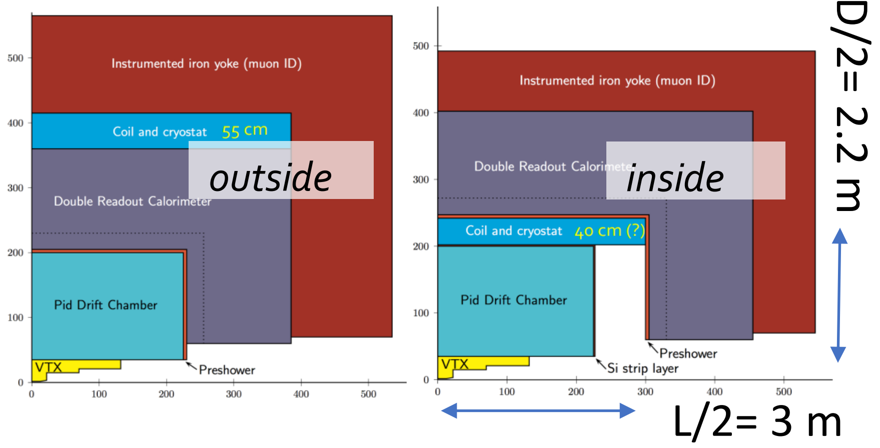
The aluminium cryostat is 5 cm thick, representing 56 % of Xo at η=0



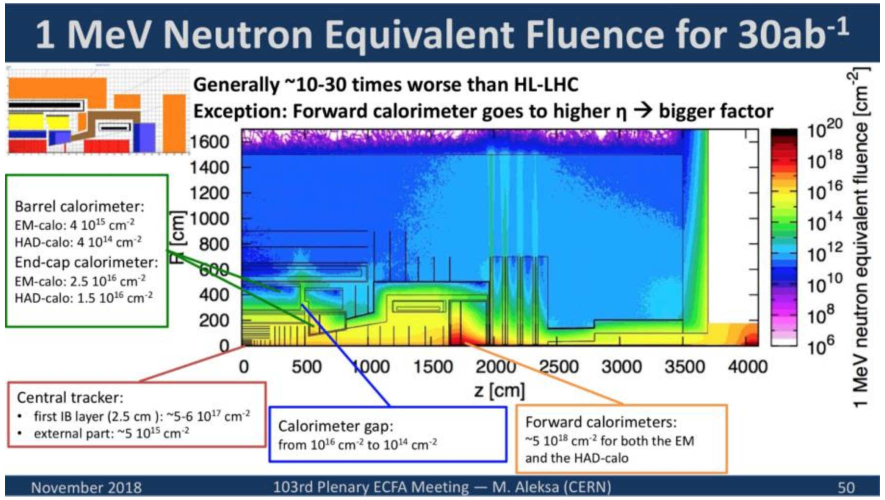
e⁺e⁻ collisions

Baseline geometry, FCC-ee

a very challenging 2T solenoid "ultra-thin and transparent"



FLUKA simulations



1 MeV Neutron Equivalent Fluence for 30ab^{-1}

Generally ~10-30 times worse than HL-LHC

Exception: Forward calorimeter goes to higher η → bigger factor

Barrel calorimeter:
EM-calo: 4 10^{15} cm^{-2}
HAD-calo: 4 10^{14} cm^{-2}
End-cap calorimeter:
EM-calo: 2.5 10^{16} cm^{-2}
HAD-calo: 1.5 10^{16} cm^{-2}

Central tracker:
- first IB layer (2.5 cm): ~5-6 10^{17} cm^{-2}
- external part: ~5 10^{15} cm^{-2}

Calorimeter gap:
from 10^{16} cm^{-2} to 10^{14} cm^{-2}

Forward calorimeters:
~5 10^{18} cm^{-2} for both the EM and the HAD-calo

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FCChh: The estimated **radiation** levels at the barrel EM-calorimeter are relevant to the **choice of resin and glue.**

FCCee: radiation level is almost **negligible.**

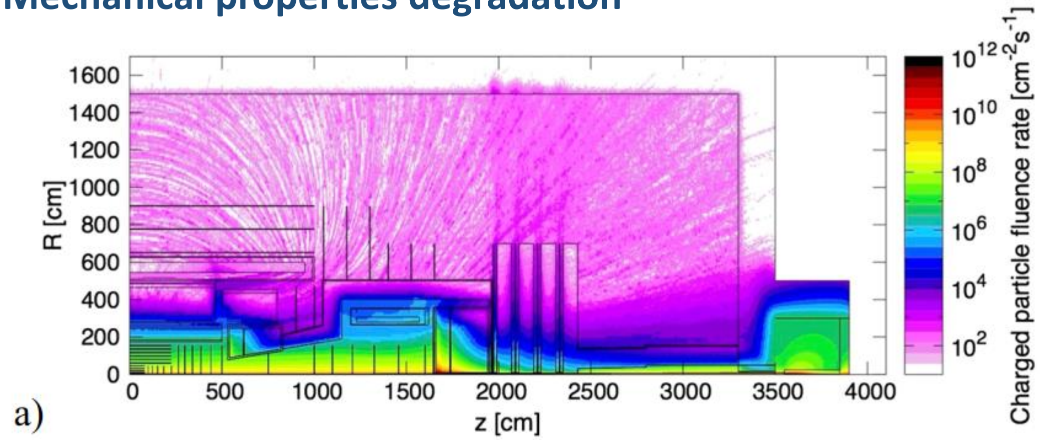
→ The CFRP cryostat for FCChh ECAL must be resistant to radiation in long term application (30ab-1 of integrated luminosity)

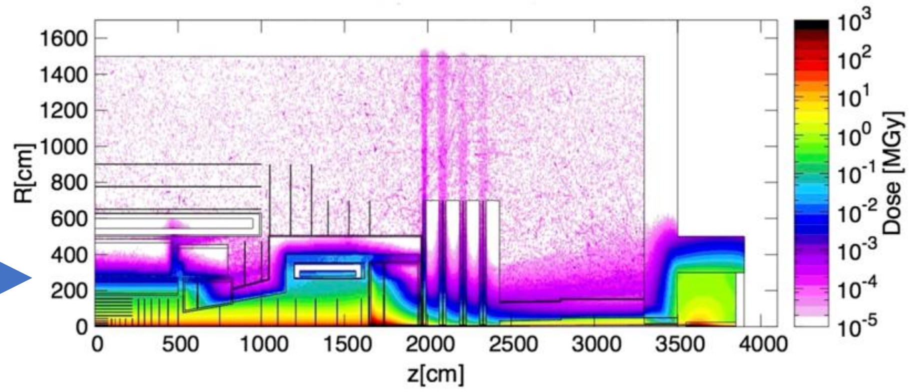
Radiation loads for Future Circular Collider

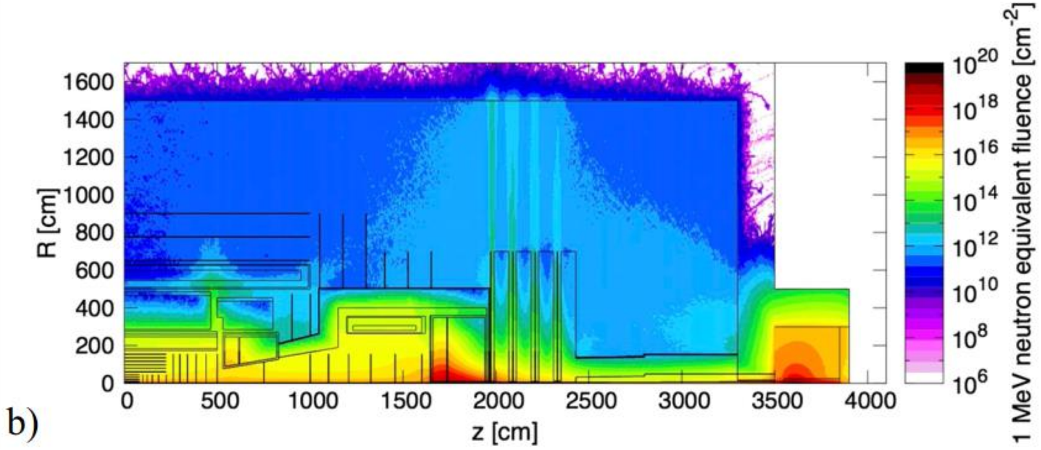
Radiation types:

- **EM waves**
- **Particle Radiation (by charged and neutral particles) → Displacement damage: changes structures of atoms → Resin becomes brittle → Mechanical properties degradation**

FLUKA simulations







Validate material to be resistant to:

a) 10e6 charged particles/ cm2.s

b) 4 x 10e15 neutrons/cm2 for 30ab-1 (~30 years)

c) 10e4 photons/cm2.s

Long term damage:
1MeV neutrons
(fast neutrons)

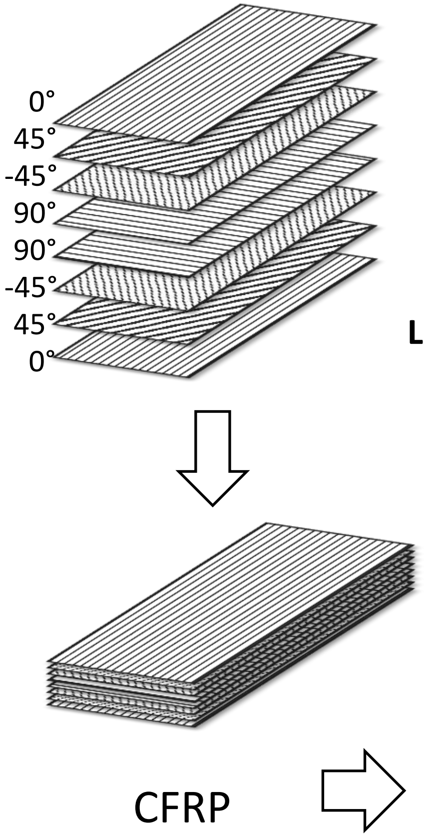
10e-1 MGy total dose

→ Total ionizing dose for 30ab-1 of integrated luminosity expected in ECAL is 0.1 MGy (max. amount of rad over its lifetime)

COURTESY OF WP4
Massimo Angeletti

Cryostat for future detectors at CERN

Stacking of plies into a composite laminate with different angles of fibre reinforcement

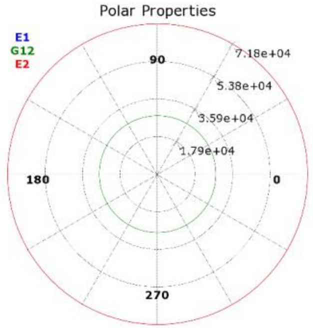


Intermediate Modulus (IM-CFRP)

Carbon fiber:
IM10, E1=310GPa

Lamina:
Carbon Unidirectional Prepreg
IM10/8552 60% Vf
E1=190GPa, Thickness=0,1mm
0° Tensile strength = 3310MPa
0° Compression strength = 1793MPa
In-plane shear strength = 128 MPa

Laminate:
Quasi-isotropic stack-up = [0,45,-45,90]s
Laminate stiffness E1=E2=71.8 GPa
Laminate shear stiffness G12=27.8GPa

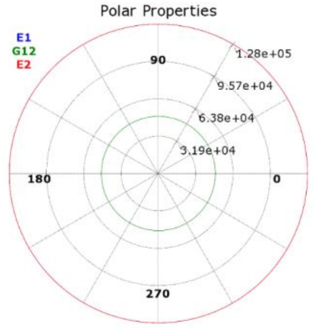


High Modulus (HM-CFRP)

Carbon fiber:
M60J, E1=588GPa

Lamina:
Carbon Unidirectional Prepreg
M60J/EX-1515 60% Vf
E1=360GPa, Thickness=0,1mm
0° Tensile strength = 2010MPa
0° Compression strength = 790MPa
90° Tensile strength = 34MPa
In-plane shear strength = 55MPa

Laminate:
Quasi-isotropic stack-up = [0,45,-45,90]s
Laminate stiffness E1=E2=128 GPa
Laminate shear stiffness G12=49GPa

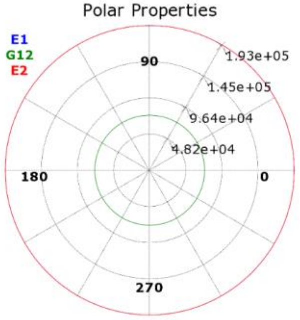


Ultra High Modulus (UHM-CFRP)

Carbon fiber:
YS-95A, E1=920GPa

Lamina:
Carbon Unidirectional Prepreg
YS-95A/EX-1515 60% Vf
E1=540GPa, Thickness=0,1mm
0° Tensile strength = 1900MPa
0° Compression strength = 340MPa
90° Tensile strength = 25MPa
In-plane shear strength = 50MPa

Laminate:
Quasi-isotropic stack-up = [0,45,-45,90]s
Laminate stiffness E1=E2=193 GPa
Laminate shear stiffness G12=73GPa



→ **Preliminary analysis showed the use of CFRP can improve metallic design for both, solid plate and sandchich structures**