CERN
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CARBON COMPOSITE IN HARSH ENVIRONMENT: CRYOSTATS

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INTRODUCTION

WHY CARBON CRYOSTAT?

HIGH RADIATION ENVIRONMENT IN DETECTORS

Main Scope of the R&D

Decrease thickness and material budget of the next generation cryostats for HEP using Carbon Fibre Reinforced Plastic.

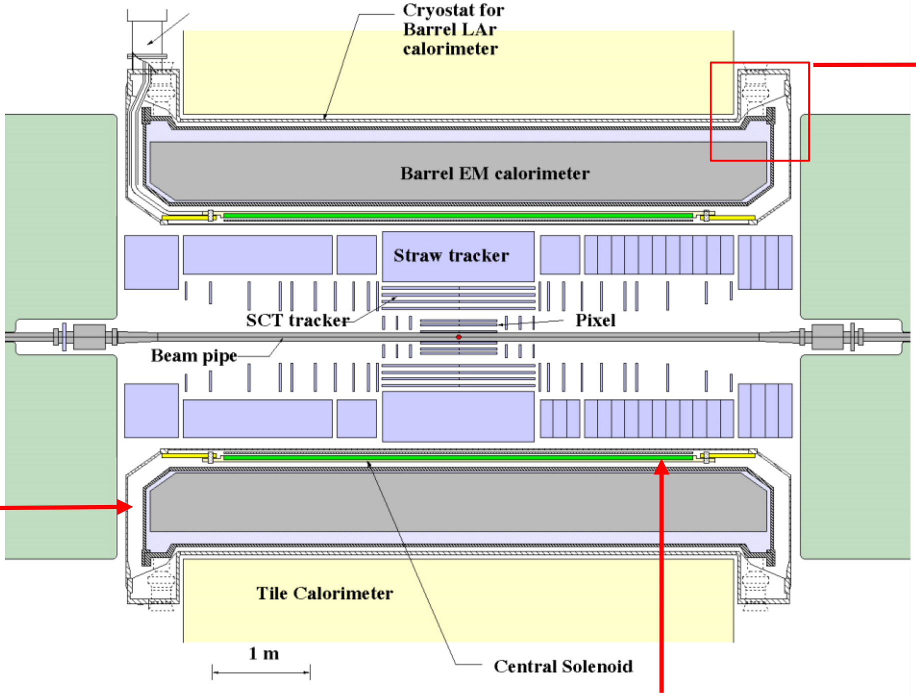
Application in spearhead technological sectors (aerospace, aeronautics, transport,...)

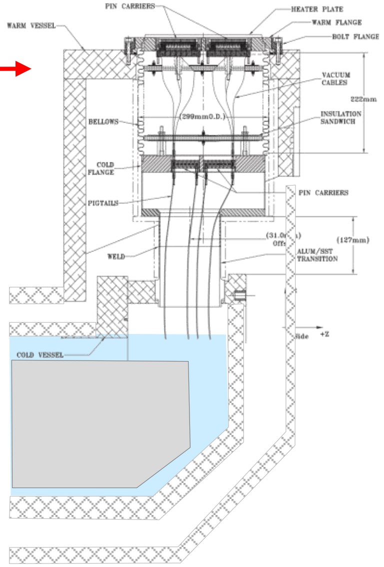
Compare with advanced metal and hybrid honeycomb structure achieving better predictions of limit state of the material and conditions in which it is safe to operate or when damage could progress. Reduce the use of functional materials (such as liners) by ensuring the airtightness through the composite structural materials.

FUTURE DETECTOR CRYOSTAT: **ULTRA-THIN**

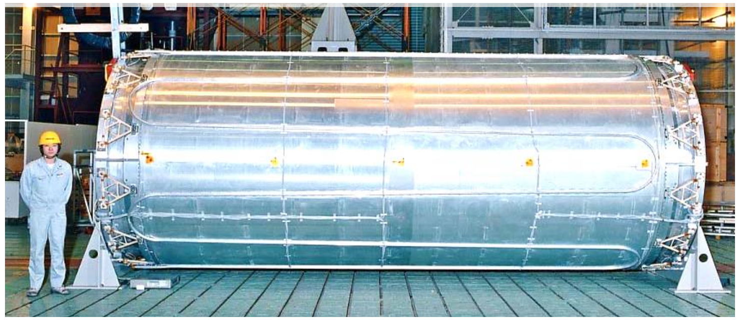
- ✓ Cryostats in HEP are still the purview of metals. New design aims to ultralight cryostats for both magnets and calorimeters

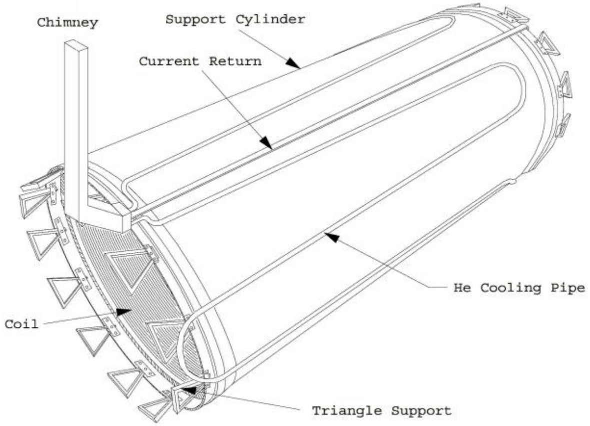
ATLAS barrel cryostat*, toroidal* Al 5083 *double wall, warm and cold vessel, with a feedthrough flange and a flexible bellows welded between them and pumped down to about* 10^{-3} *mbar vacuum.*





ATLAS Solenoid Magnet





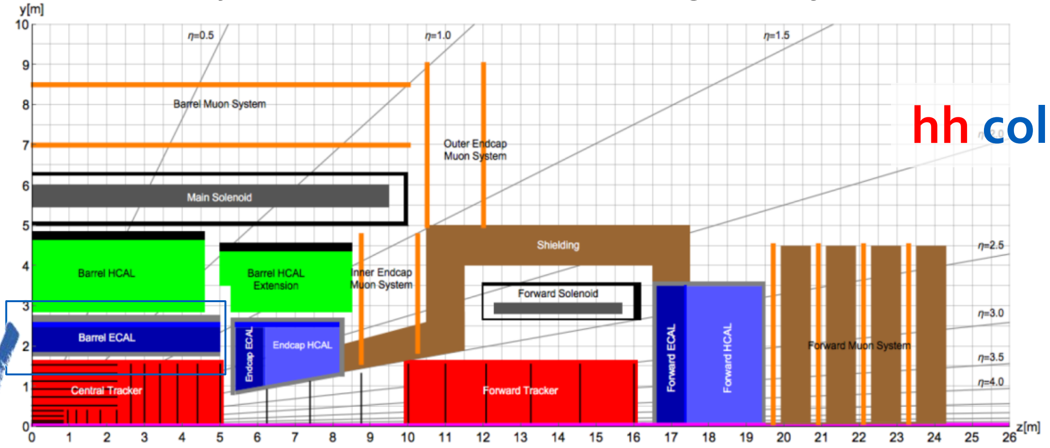
- ✓ In order to decrease the thickness and material budget, lightweight and strong composite materials will be considered

FUTURE DETECTOR CRYOSTAT: ULTRA-THIN

✓ Calorimeter and magnet requirements will drive the design of a thin carbon composite cryostat

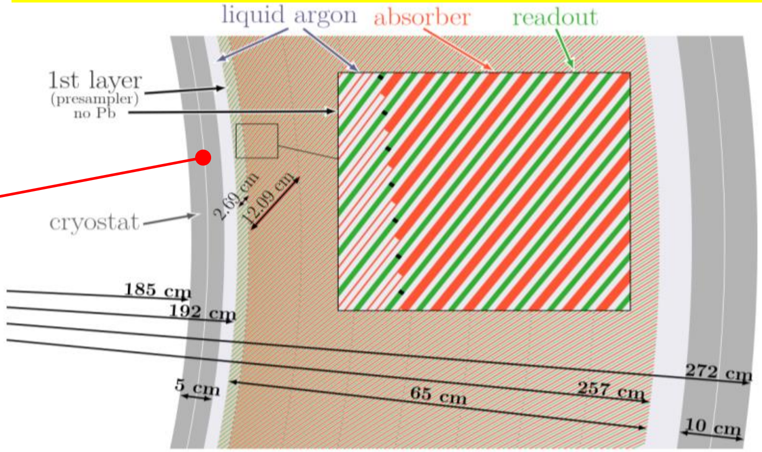
Baseline geometry, FCC-hh LAr barrel ECAL :

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



hh collisions

Cryostat calorimeter (double vessel)



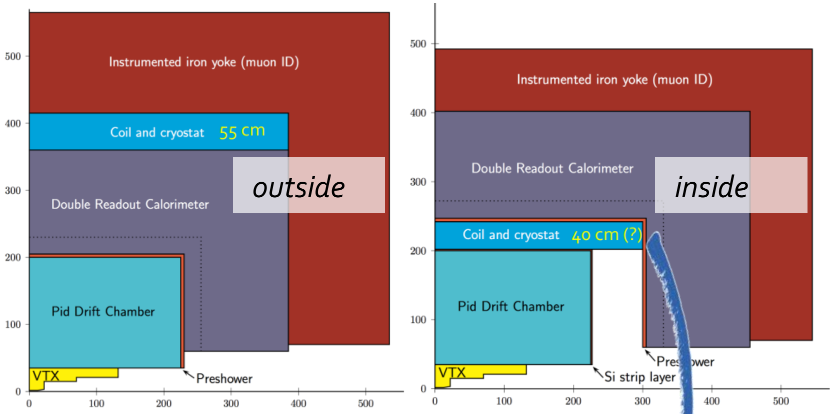
minimum material

Baseline geometry, FCC-ee :

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

e^+e^- collisions

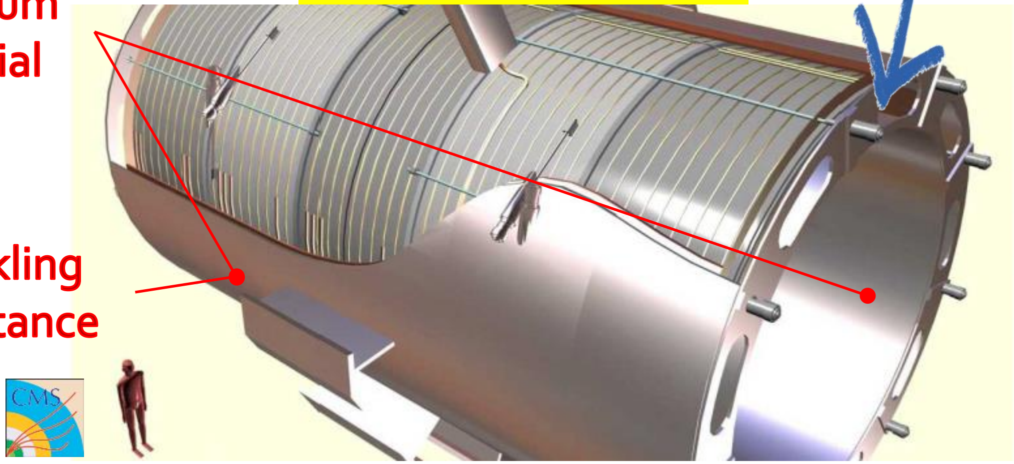
Solenoid outside or inside calorimeter



Cryostat magnet

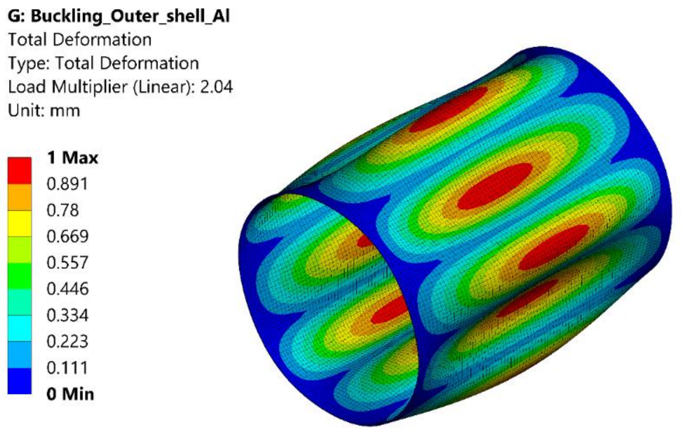
minimum material

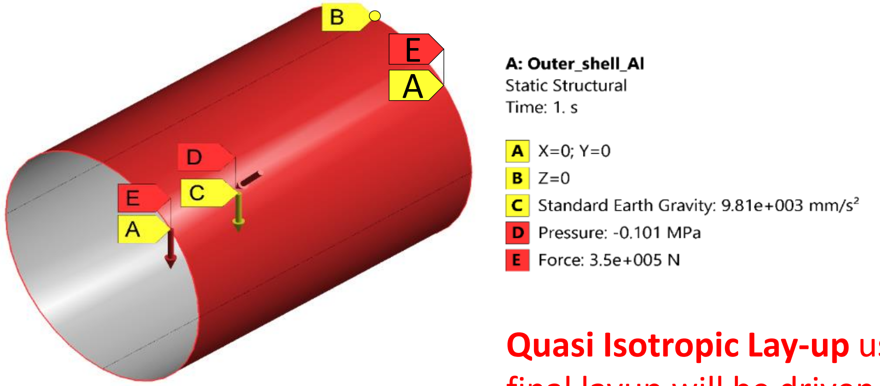
buckling resistance



✓ Design solutions based on Carbon Fibre Reinforced Plastic will be investigated to fulfil specific HEP cryostat requirements

Cryostat (Preliminary): Comparative analysis WG4





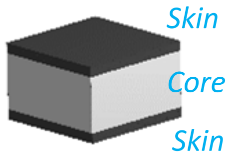
FEM loads:

- 1 atm pressure
- Rigid end flanges allowed to move axially
- Self weight
- 350 kN of force on the flanges

Quasi Isotropic Lay-up used in this analysis only **for overall considerations,** final layup will be driven by load/boundary conditions

Safety factor = 2.0

Sandwich



Radiation length X_0[mm]

Al = 88.9
Ti = 35.1
UHM/HM CFRP = 260
Honeycomb Al= 6000

	Sandwich					Solid plate				
	UHM CFRP	HM CFRP	IM CFRP	Al	Ti	UHM CFRP	HM CFRP	IM CFRP	Al	Ti
Avg. Th. [mm]				4.0	1.5	13.6	16.8	20.8	20.9	17.2
Material budget X/X_0	0.0134	0.0147	0.0189	0.045	0.034	0.052	0.065	0.08	0.24	0.49
X_0 + %	-70%	-67%	-58%	X_0	-24%	+16%	+44%	+78%	+433%	+989%
Skin Th.[mm]	1.2	1.2	1.6	1.7						
Core Th. [mm]	25	33	40	40						
Total Th. [mm]	27.4	35.4	43.2	43.4	101	13.6	16.8	20.8	20.9	17.2
Thickness + %	-37%	-18%	0%	T	+133%	-69%	-61%	-52%	-52%	-60%

LOW MASS COMPOSITE IN AEROSPACE INDUSTRY

✓ Intuitive Machines Selected by NASA for Robotic Return to the Moon in 2021.

NovaC is equipped with two liner-less cryotanks high performance cryogenic liquid oxygen (LOX) and liquid methane (LCH_4) integrated propulsion:

Intuitive Machines **close colaboration** will provide:

- FEM material properties of the single ply and the layout.
- Flat plate material samples.
- *Test performance and data analysis.*
- ***Expertise to investigate solutions and materials in HEP environment.***

MATERIALS:

- ***Microcrack resistant fibre/resin system for towpreg**: IM7/8552 epoxy,* IM7/F650 bismaleimide and IM7/5250-4 BMI .

- **Toughened epoxy prepreg resin for out-of-autoclave manufacturing**: Cytec's CYCOM 5320-1

✓ Visited Intuitive Machine on Jan 2020 (ref . Trent Martin Nasa)

✓ Cryostat in HEP detector should profit from similar development in aerospace : CHATT, CCDT, SPACE X programs, NOVA-C…

Company	Application	Fluid	Liner	Temp	Pres	Dimensions		Material		Laminate	thick	additional note	Manufacturing process	Curing	Year	Gain
				(°C)	(bar)	Diam (m)	Height (m)	Core	Ply		mm					
McDonnell Douglas	DC-XA	LH2	Liner-less	-253		2.43	4.88		IM7/8552			**Internal insulation** Skirt	Automated Fiber Placement	A	1996	
Lockheed Martin	X33	LH2	Liner-less	-253		6	8.5	KorexTM+3-pcf honeycomb	IM7/977-2		40,64	Fail: Microcracking and debounding		A	1999	
Northrop Grumman	SLI	LH2	Aluminium foil between the inner skin and the core		8.27	1.8	4.5	non-metallic honeycomb	IM7/977-2			core=thermal insulator layer	Ultrasonic Tape Lamination	OOA		
Boeing	CCTD phase 1	LH2	Liner-less					fluted core sandwich wall	IM7/977-2				Automated Fiber Placement			
Lockheed Martin	CCTD phase 1	LH2	Liner-less					External box stiffened	IM7/977-2							
Northrop Grumman	CCTD phase 1	LH2	Liner-less					honeycomb sandwich core	IM7/977-2 thin ply			(70g/m2)				
Nasa	CCTD phase 2	LH2	Liner-less	-253	4	5.5		Fluted composite core skirt	CYCOM 5320-1 Pre-peg	Hybrid. 17 ply (5 thin)		0,13mm/ 0,063mm		OOA	2014	30
Boeing	CCTD phase 2	LH2	Liner-less	-223	9.3	2.4	5,5	Fluted composite core skirt	CYCOM 5320-1 Pre-peg	Hybrid. 17 ply (5 thin)		0.137mm/ 0.064mm	Robotic Automated Fibre Placement	OOA		
DLR	CHATT		PE-liner			1	3	glass fibre/carbon	Araldite® LY 564				filament wet winding			
FOI/SICOMP	CHATT		Liner-less	-150	3				T700 h TeXtreme®t	n.4 ±45° n.20 ±25°.		thickness				
TU Delft	CHATT		liner													
ALE	CHATT		PE-liner			0.29m	0.57m		T700 24k							
NASA & Lockheed Martin		LOx	Liner-less			1.2	2.7									17
Space X		LOx	Liner-less			12			TORAY?							

In work

✓ Investigate how to tailor these new processes and materials for HEP cryostat: thermal insulation, feed through, rad loads

FUTURE DETECTOR CRYOSTAT: **ULTRA-THIN**

✓ HEP Cryostat Boundary Conditions

Cryostat radiation loads

Cryostat feed-throughs

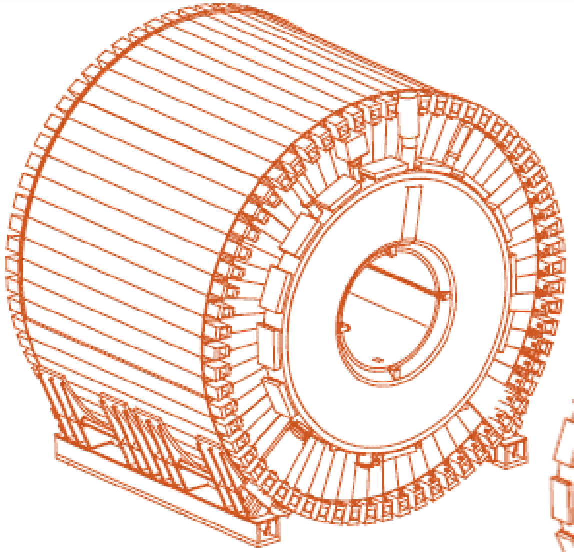
Cryostat thermal insulation

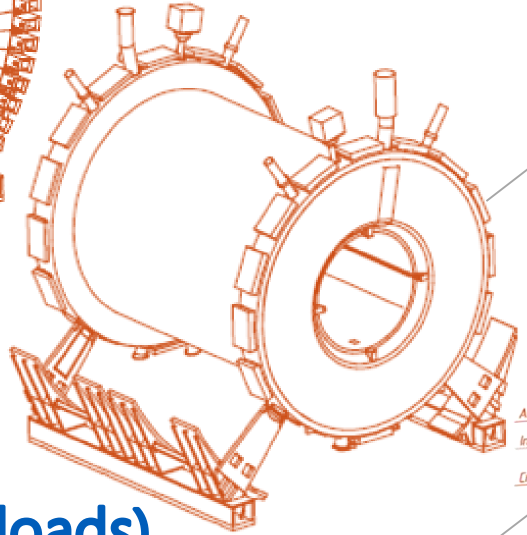
Cryostat interface to the experiment.

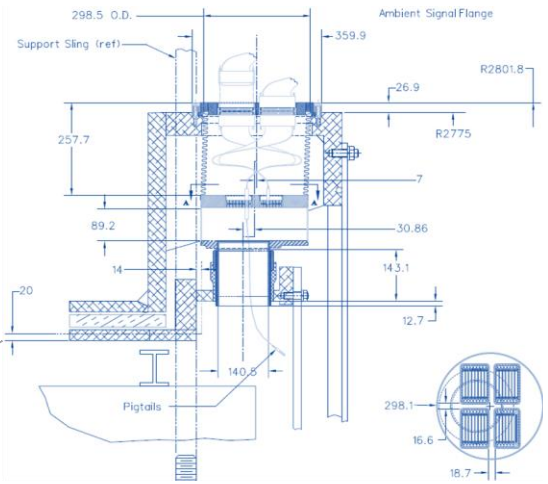
Cryostat interface to LA Cal and SC Magnets (loads).

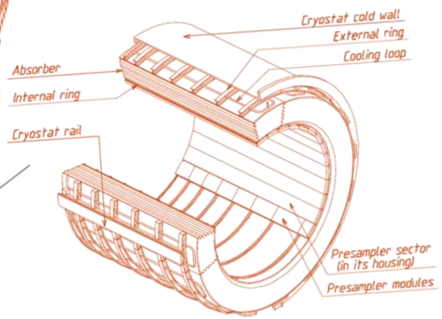
Cryostat assembly sequence

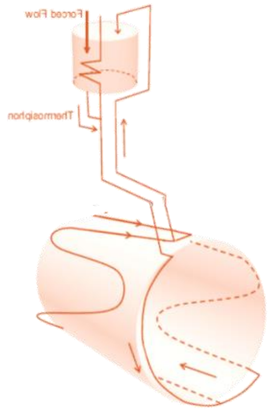
Cryostat installation sequence

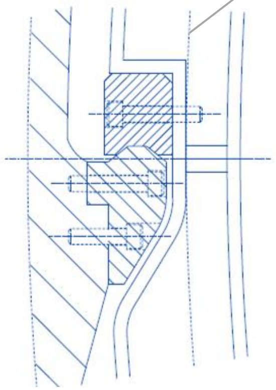


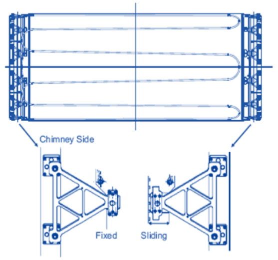












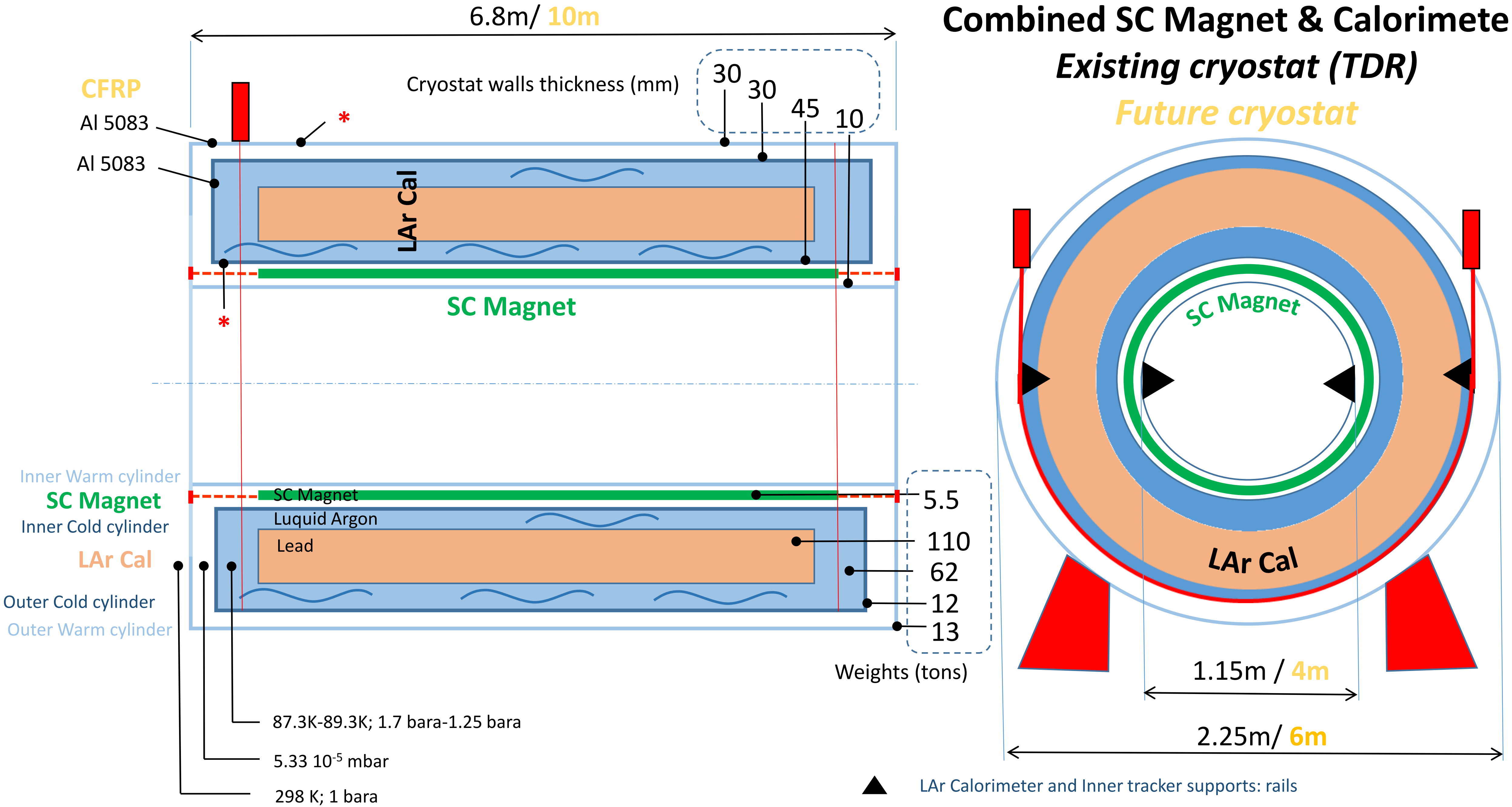
THE ATLAS CRYOSTAT LAYOUT

INTERFACES AND LINES TREATMENT

Combined SC Magnet & Calorimeter

Existing cryostat (TDR)

Future cryostat



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

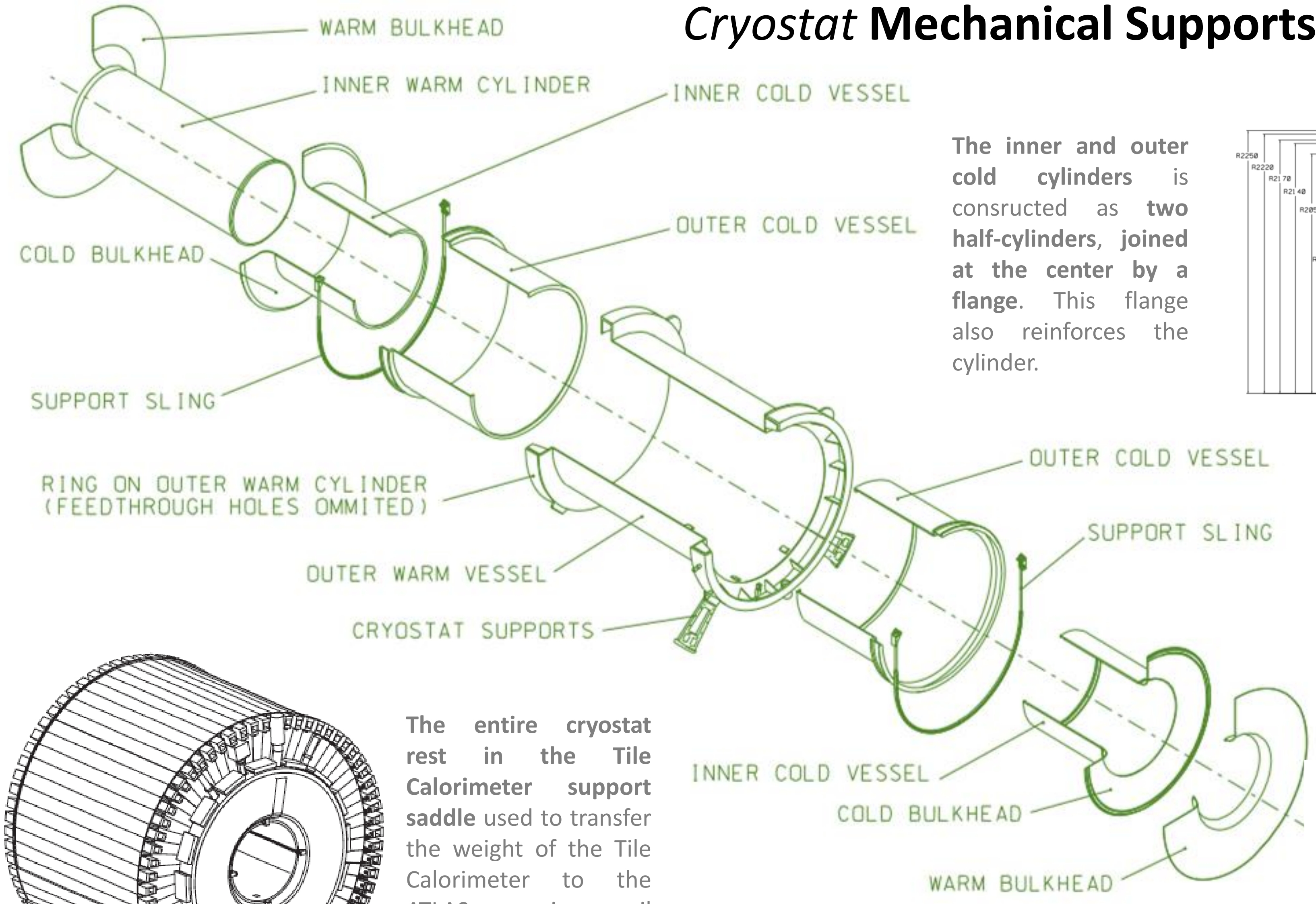
**** SC Magnet cooled by closed circuit, He serpentine on the structural shell**

▲ LAr Calorimeter and Inner tracker supports: rails

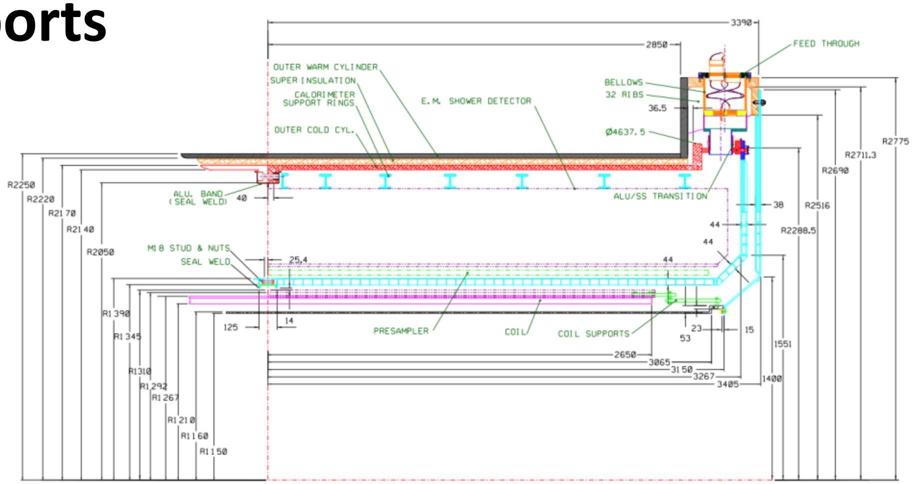
Cold Vessel supports: straps from the Outer Warm cylinder

SCM support: fixed at the end flange of the Warm tank

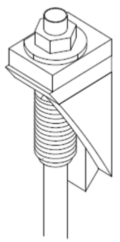
Cryostat Mechanical Supports



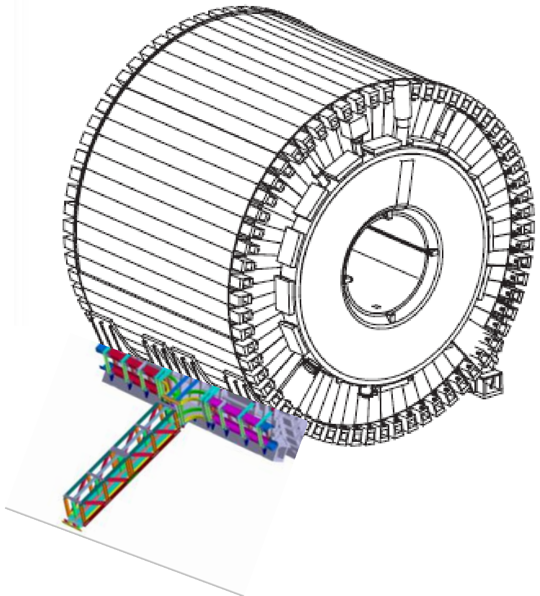
The inner and outer cold cylinders is consructed as **two half-cylinders**, **joined at the center by a flange**. This flange also reinforces the cylinder.



The whole cold vessel, is supported by **two "slings"** which wrap around the thickened end of the bulge of the **warm vessel.**

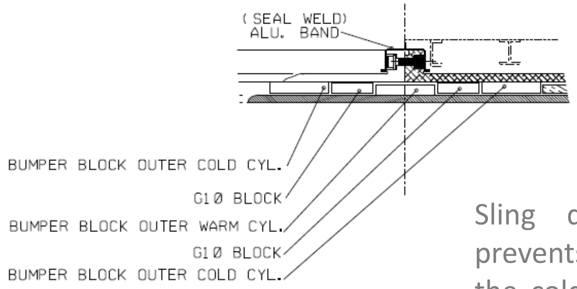


The **vertical position** of the cold vessel can be adjusted at any time by adjusting the support slings; this can be done without opening the vessel.



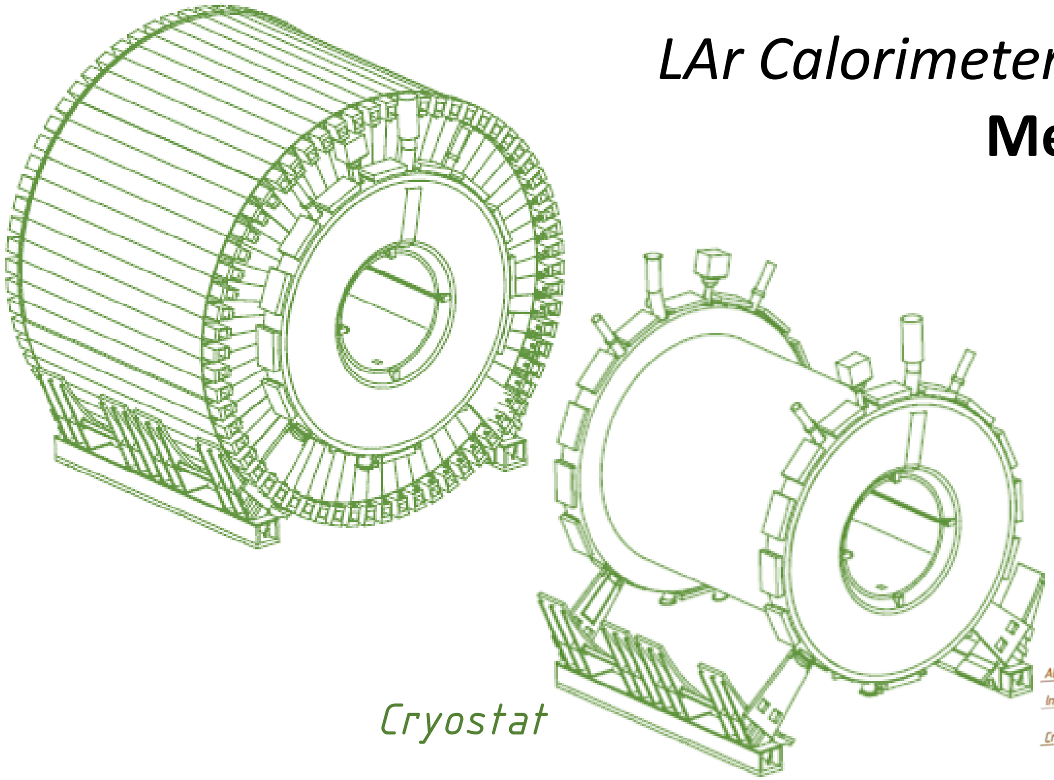
The entire cryostat rest in the Tile Calorimeter support saddle used to transfer the weight of the Tile Calorimeter to the ATLAS main rail systems.

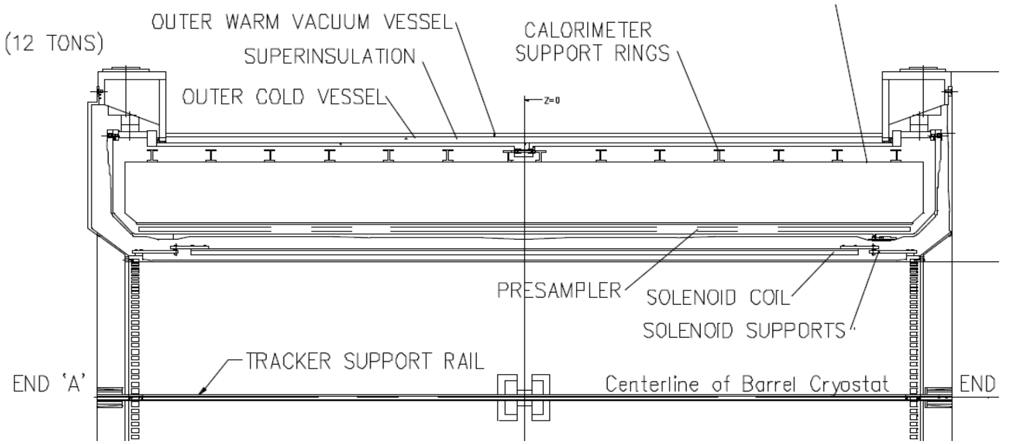
A **support plate** is **attached to the ends of the barrel Tile calorimeter** at approximately 45 degrees from the bottom vertical; this supports a reinforced section of the warm outer cylinder.

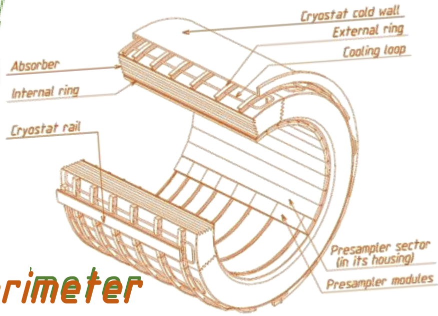


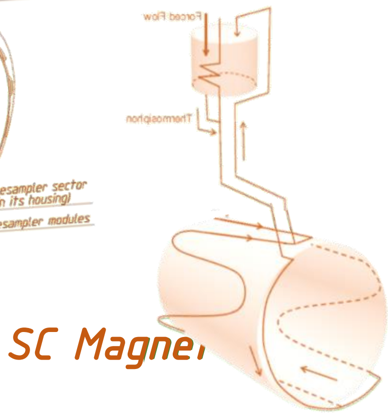
Sling don´t **prevent** prevents **motion** of the cold vessel **in the axial direction: BUMPER BLOCK**

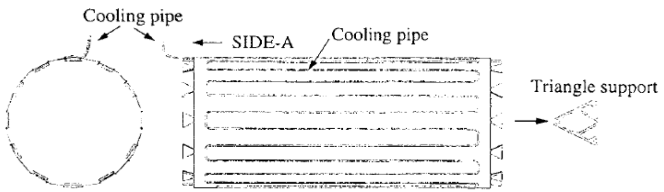
LAr Calorimeter, SC Magnet and Inner Detector
Mechanical Supports





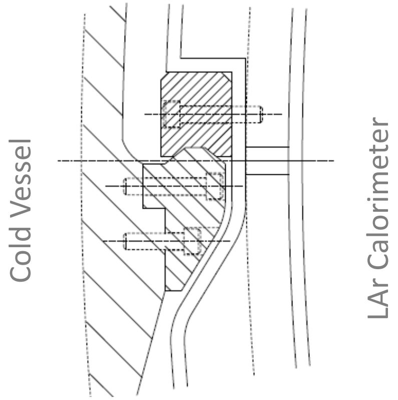




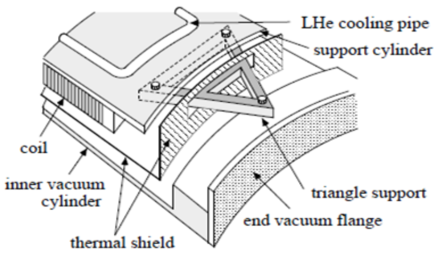


*The **EM calorimeter** is supported by **the outer cold cylinde**r **which has in its inside a ledge** where a **transition piece (**Alu 5083), is **solidly bolted** (only after the cylinder has been carefully measured, to compensate for any manufacturing tolerances of the vessel).

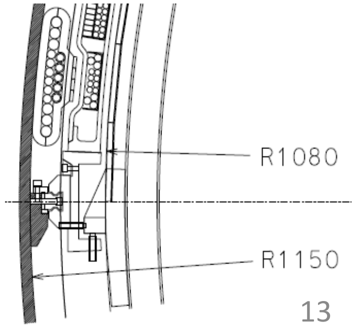
***The second transition piece** is made of stainless steel and it will slide over the Aluminium piece. It will be fixed to the cryostat ledge in a manner to keep the EM cryostat axially aligned at low temperature



The **SC Magnet coil** is attached to each flange of the **inner warm vessel** by 12 **CFRP triangles** uniformly distributed at each axial end of the coil, supporting both the radial and the axial forces



The **Inner Tracking System** seats inside the **inner warm cylinde**r on two ledge



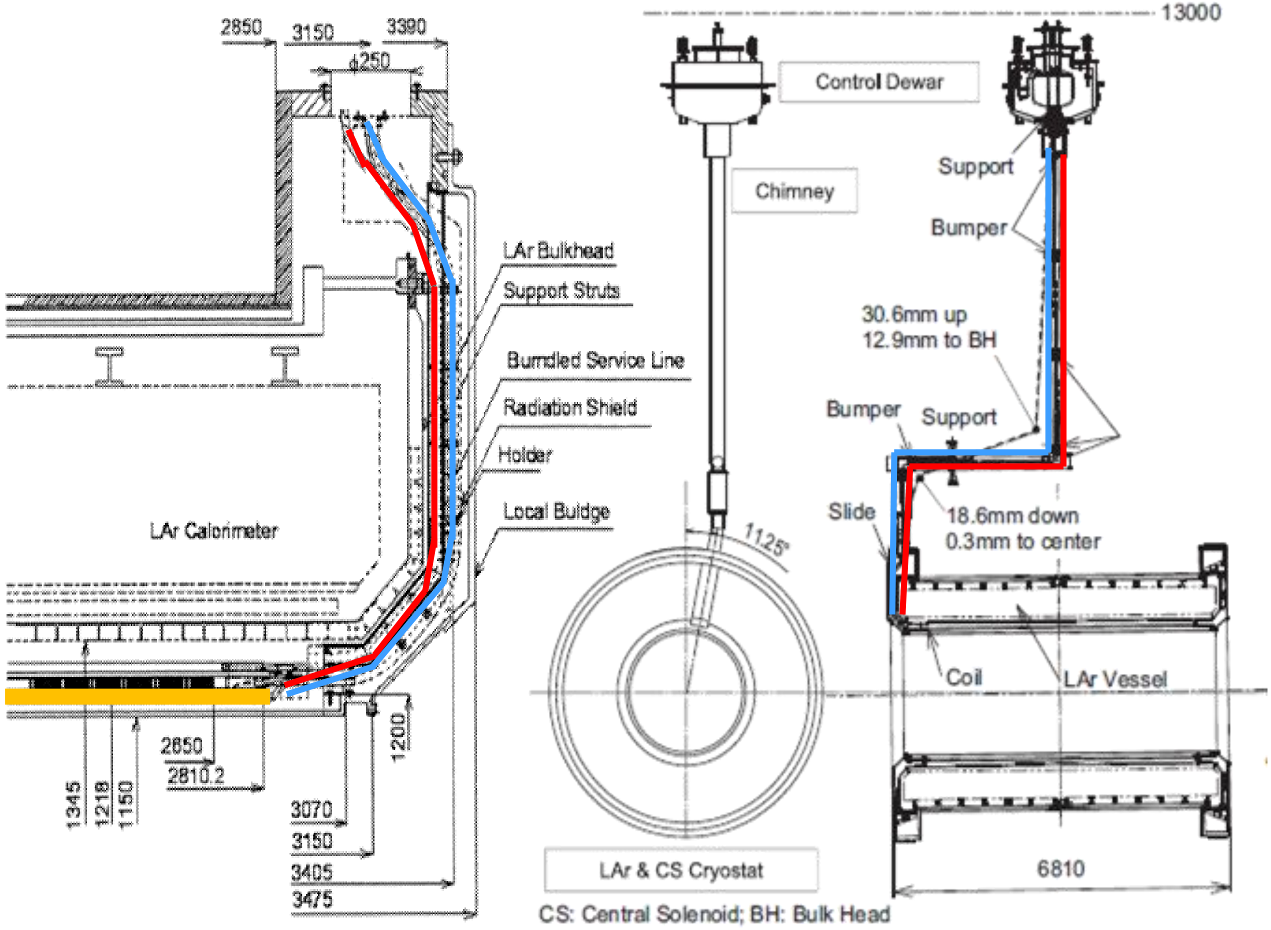
SUPERCONDUCTIVE CENTRAL SOLENOID LINES

✓ The power and cryo-service lines as well as the cryogenic lines to supply and return cooling helium are bundled together.

The different lines are connected to the top part of the coil. They **are bundled together** and brought up in the vacuum space along the wall of the cold-vessel bulkhead to the top of the cryostat.

The **superconducting bus line is brought into a chimney** connected to the **A side** of the cryostat through a 250 mm diameter flange at the top of the LAr cryostat. The flange must be fully accessible from the top and from the bottom.

Assembly of the solenoid and bus line test

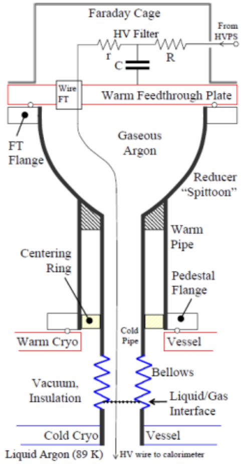


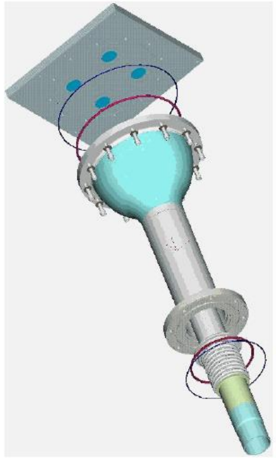
Superconducting bus line in ATLAS cavern

BARREL LAR CALORIMETER LINES

✓ The power, signal and cryo-service lines as well as the cryogenic lines are treated with dedicated systems.

❖ 2 Feedthroughs for HV lines

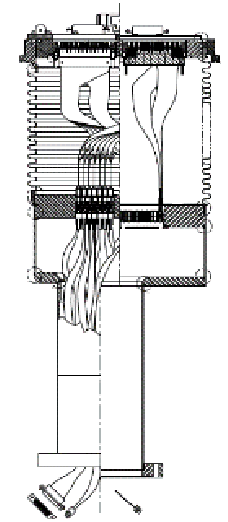




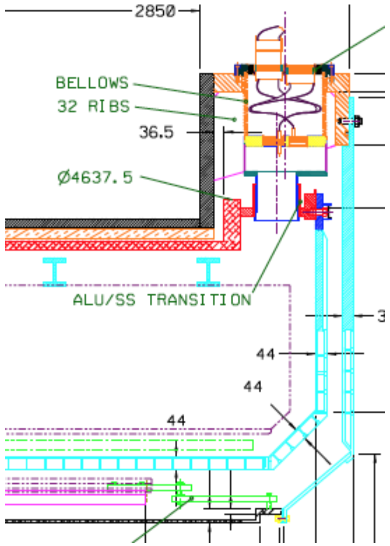
- 2k **HV lines**
- One in each end of the cryostat, **are placed at the highest point** and are **kept at room temperature**, with a buffer volume of gaseous **argon gas** directly below the wire feedthroughs separating them from the **liquid argon below**.
- Produced outside CERN (PAVE tech)

❖ 64 Feedthroughs for signal lines

- 100k **signal lines**
- **32 in each end of the cryostat**, distributed **radially in equal numbers** around each end of the barrel of 1920 signal lines each, **connecting the inside of the cold vessel to the outside**.
- Produced inside CERN.



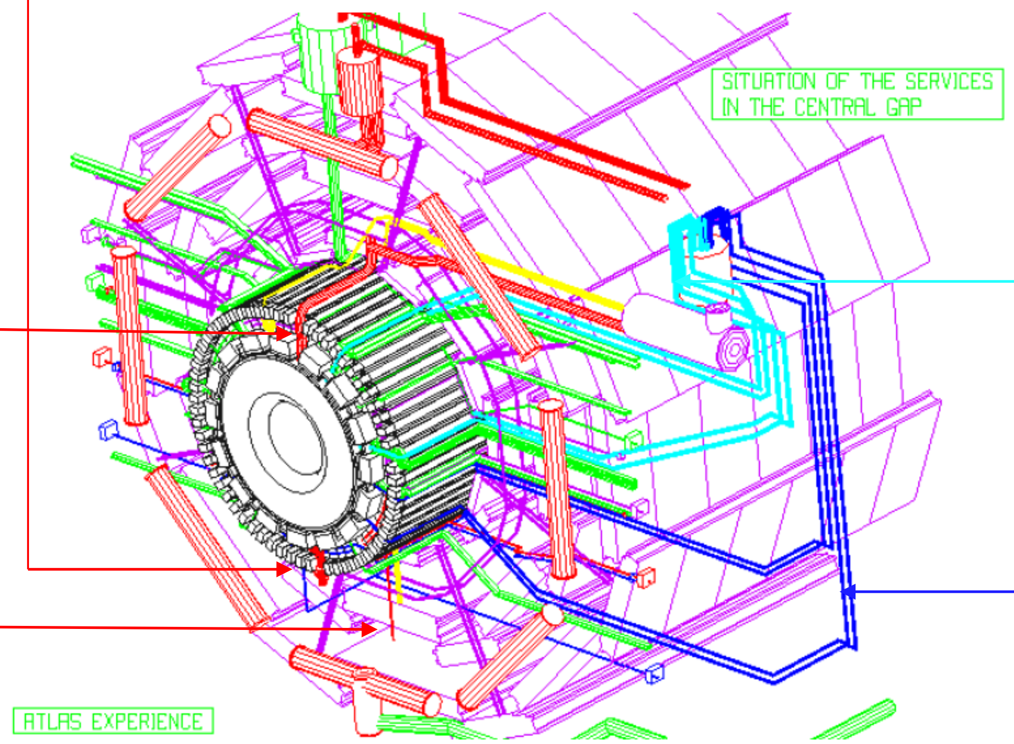
Endcap Barrel



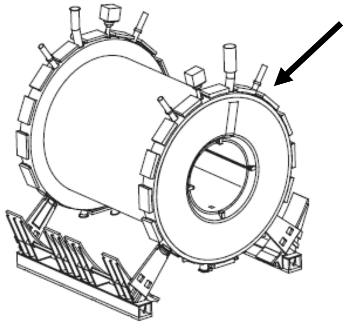
❖ Cryogenic and cryo-services lines

The cryogenic fluid used by the **cryo plant** is **nitrogen** while the **calorimeter** itself will **be charged with Ar** (or He in warming-up or cooling down phases).

LAr supply **cryogenic line (C side)**
LAr emptying **cryogenic line**
Pump out
In LN_2 **cryo-service transfer line** to heat exchangers
Out GN_2 **cryo-service transfer line** from heat exchangers

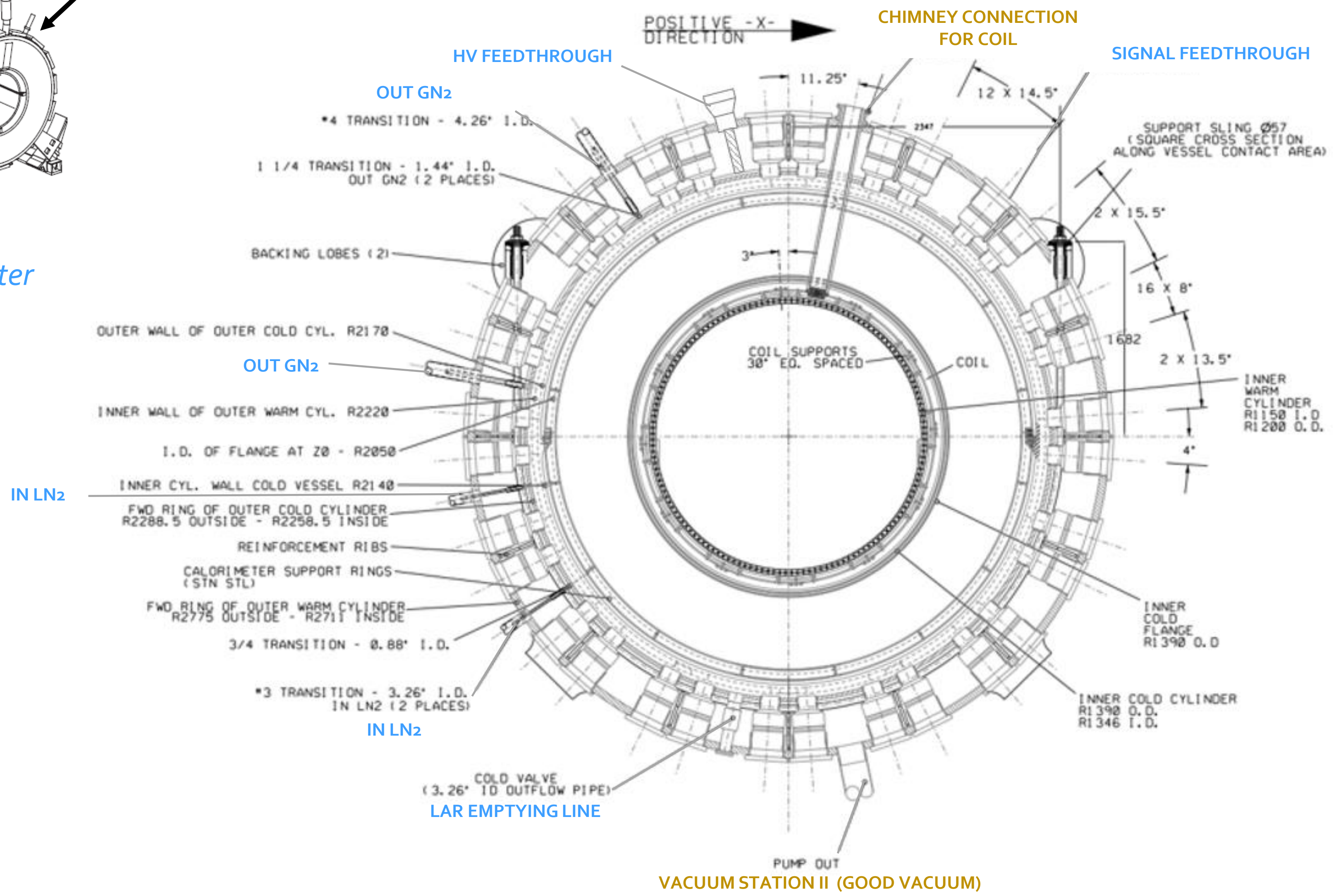


A SIDE VIEW

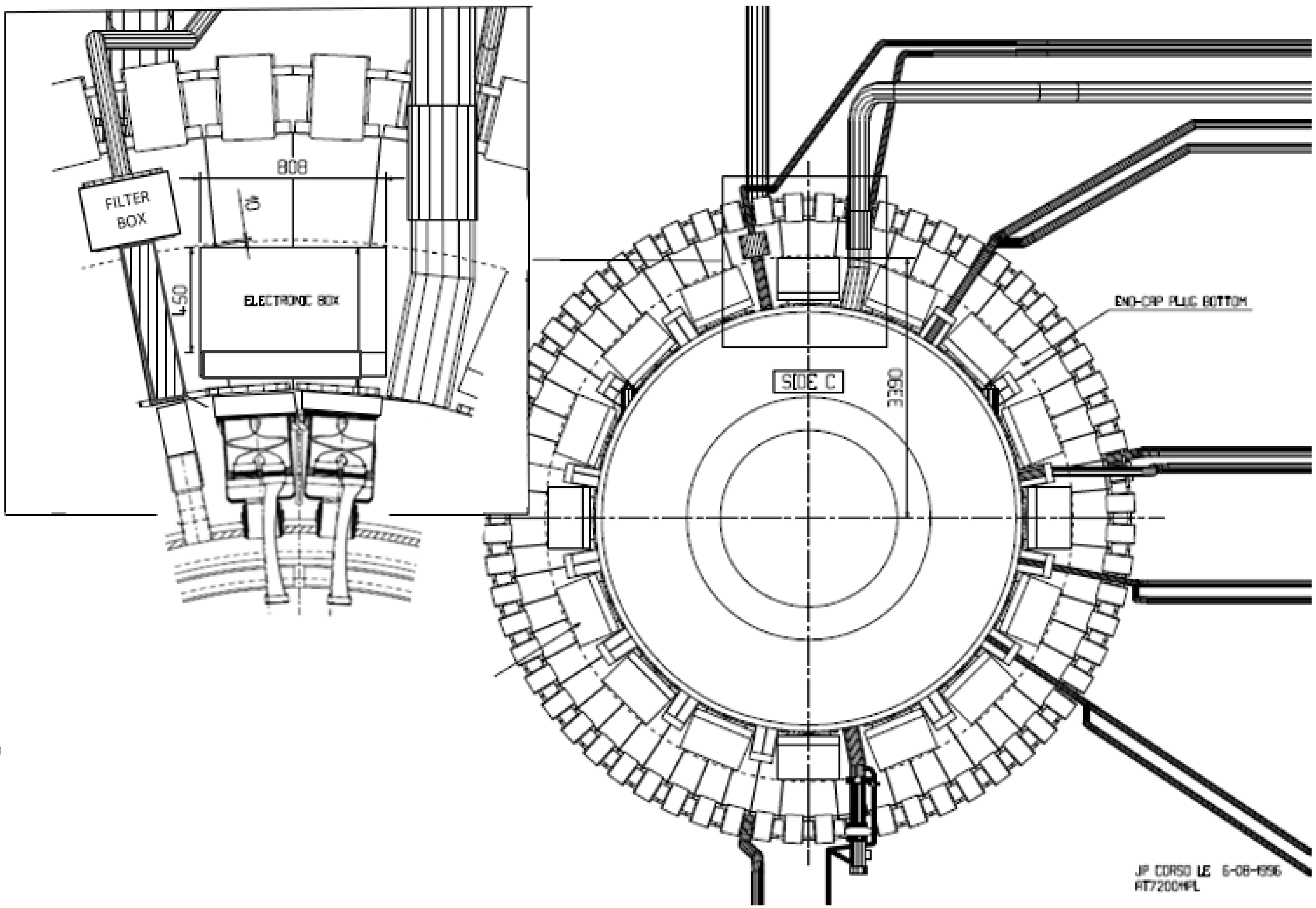


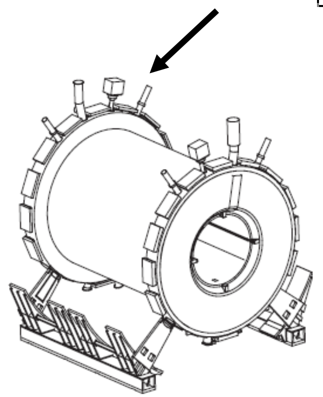
Solenoid

LAr Calorimeter



C SIDE VIEW





Solenoid

LAr Calorimeter

LN2 COOLING LOOP

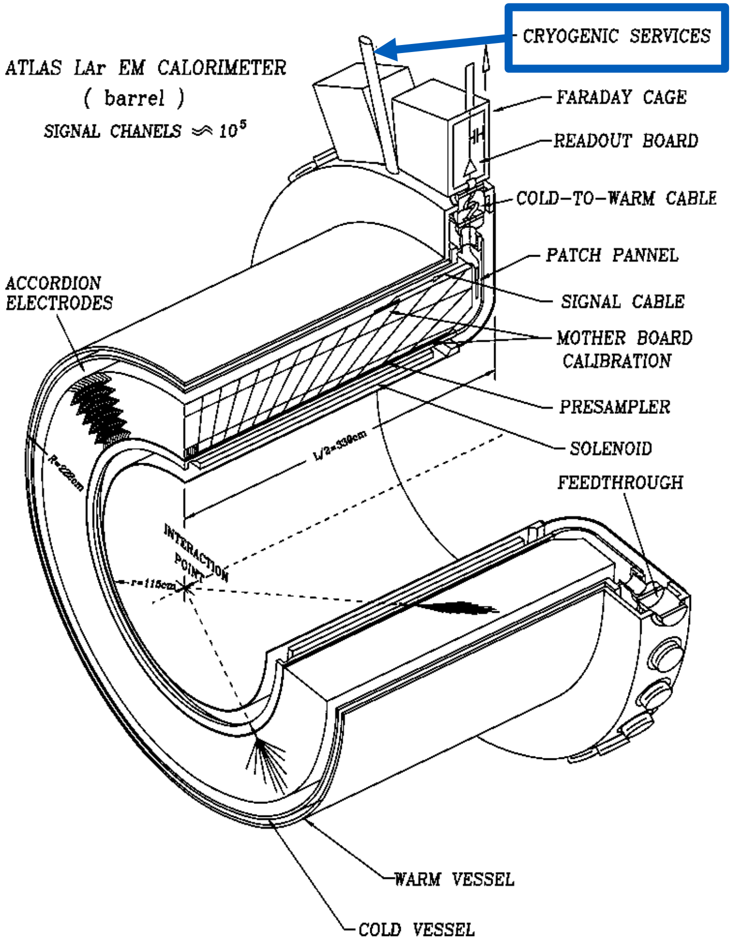
- ✓ The cooling principle is based on evaporation of satured liquid nitrogen flowing through the heat exchangers in a cooling loop placed in the LAr volumes , which will be re-liquefied in a phase separator.

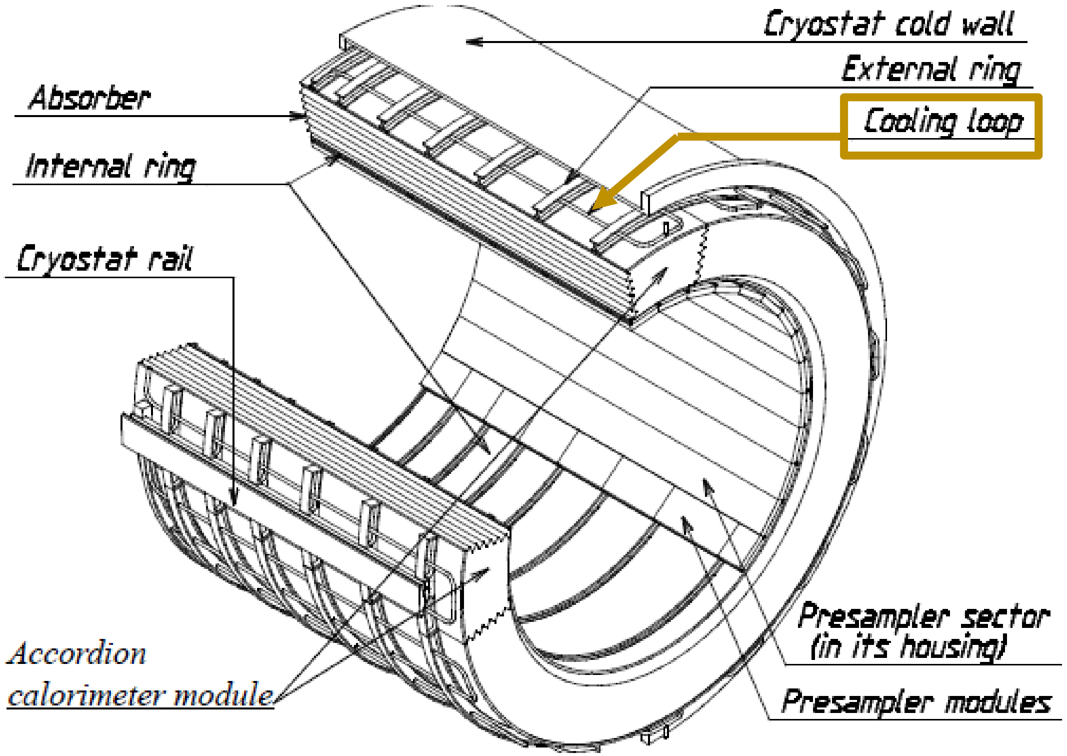
***Criogenic service** tubes will provide connection of the cooling loop with the outside at each end of the cryostat.*

Six heat exchanger tubes** (stainless steel 304) will be placed **inside the barrel cryostat:

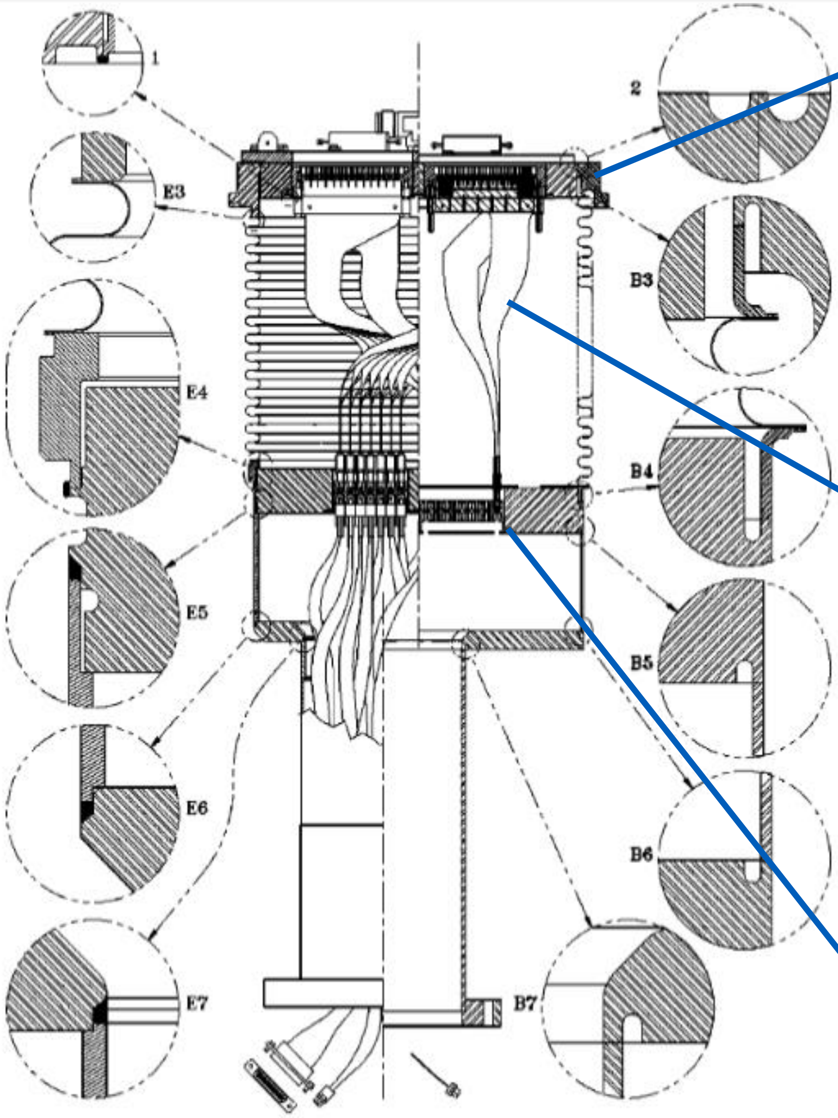
- ✓ *4 of them will **be integrated in the calorimeter modules** and run through holes in the external rings.*
- ✓ *The **2 remaining** will be situated **at each end of the barrel***

Each of the heat exchanger is equipped with two control valves

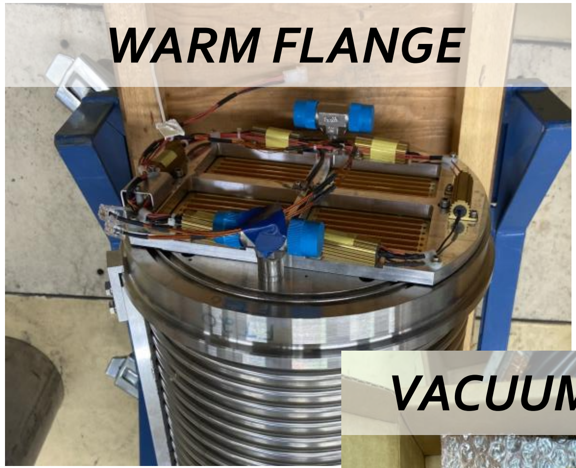


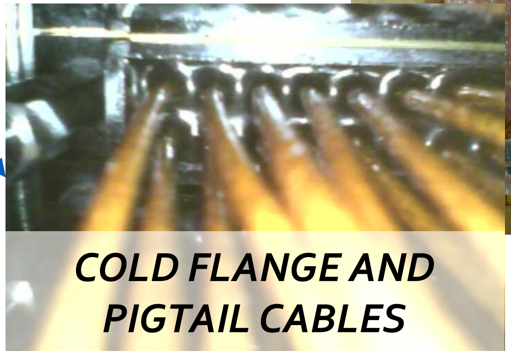


SIGNAL FEEDTHROUGHS



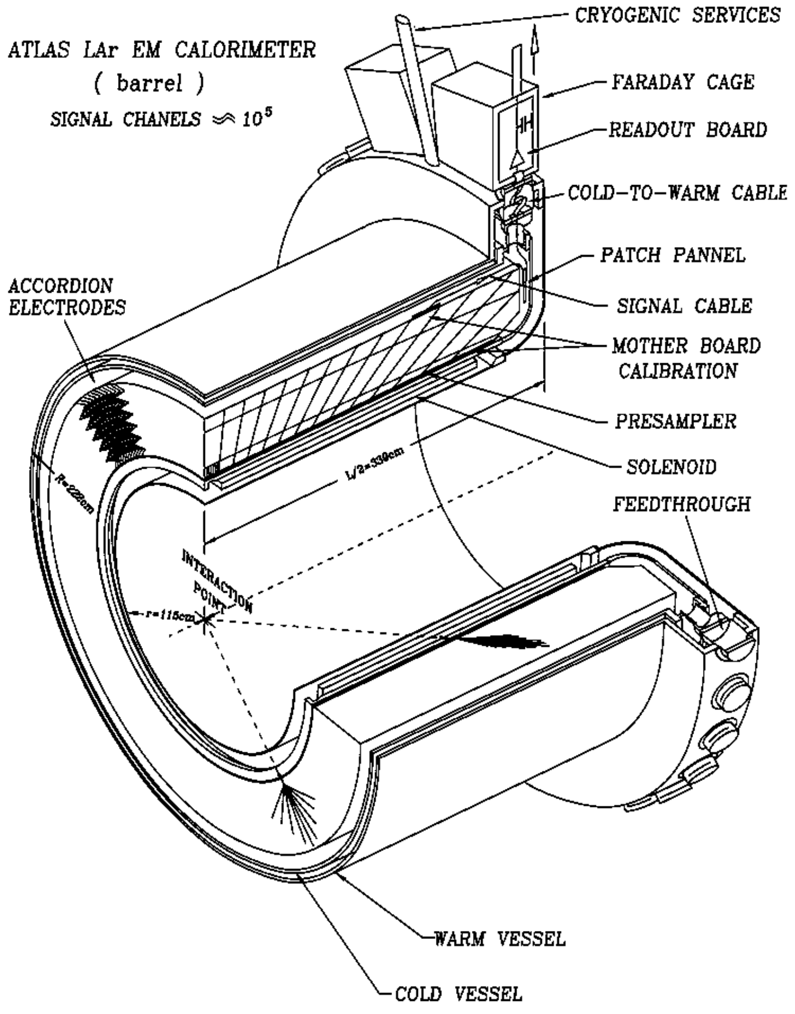
End-Cap signal FT *Barrel signal FT*

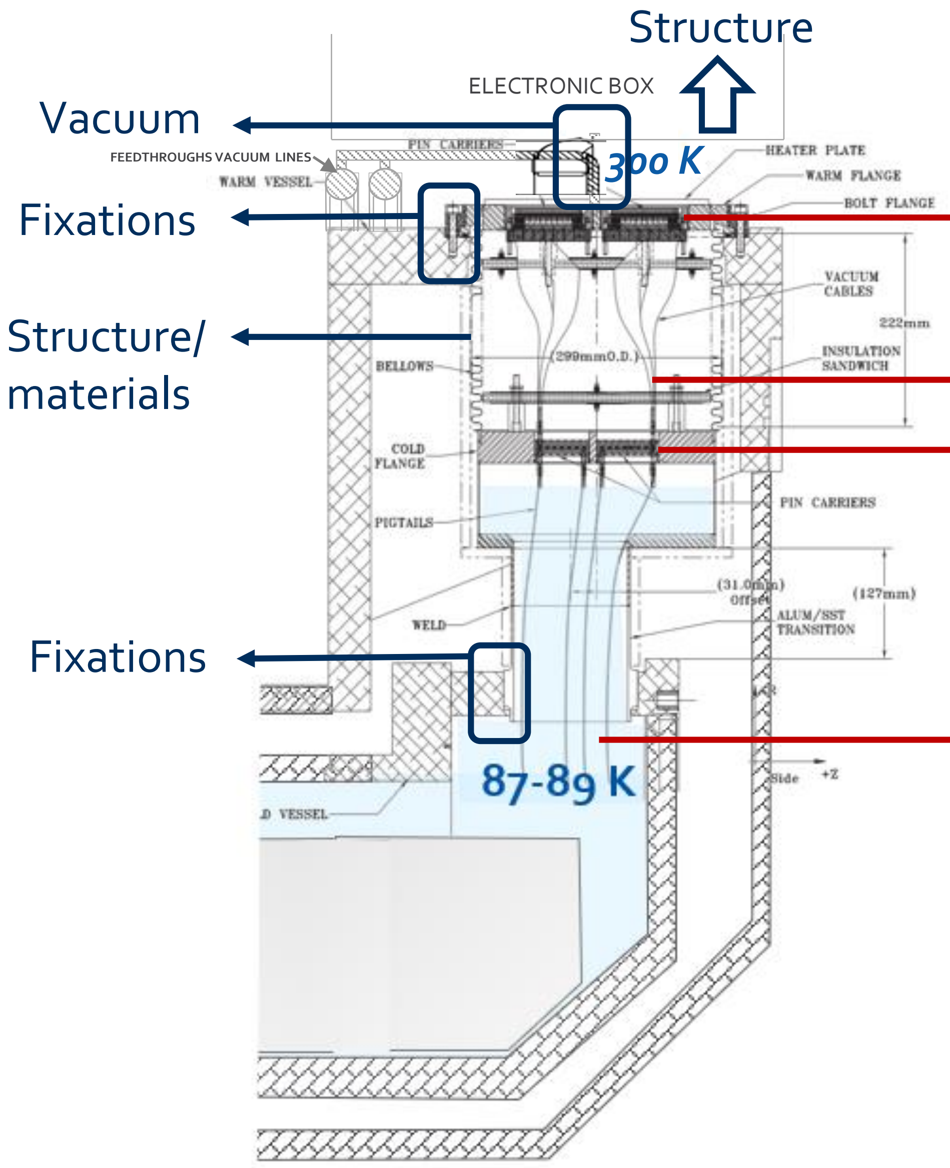




BARREL SIGNAL FEEDTHROUGHS

Main points to develop:





Flanges/ connectors

Vacuum zone
Stainless Steel

Type of cables

Flanges/ connectors

Fixation zone
Al 5083
***Coaxial cables into LAr**

Type of cables

BACK-UP

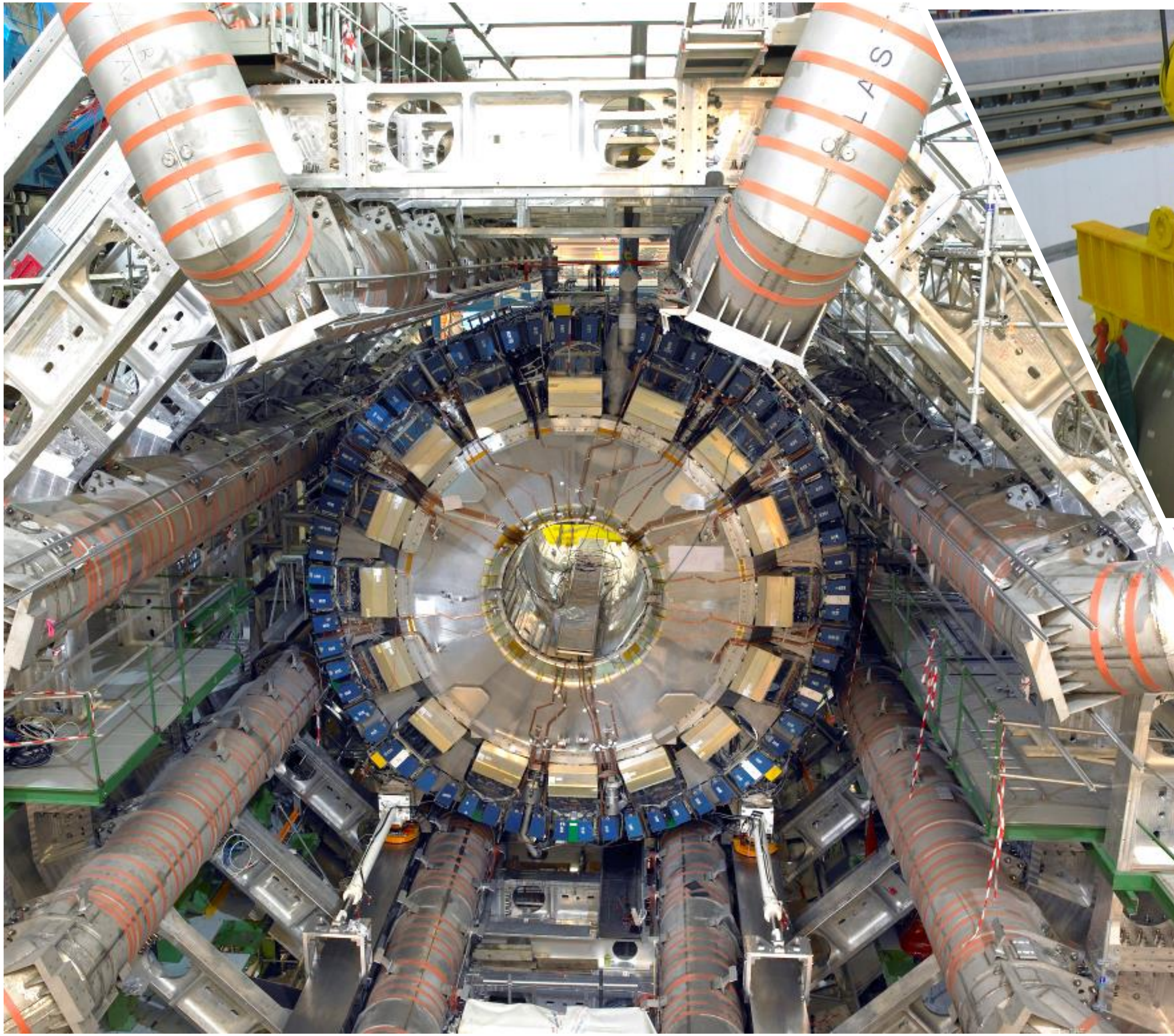
FOR DISCUSSION :

LOCATION AND NUMBER OF:

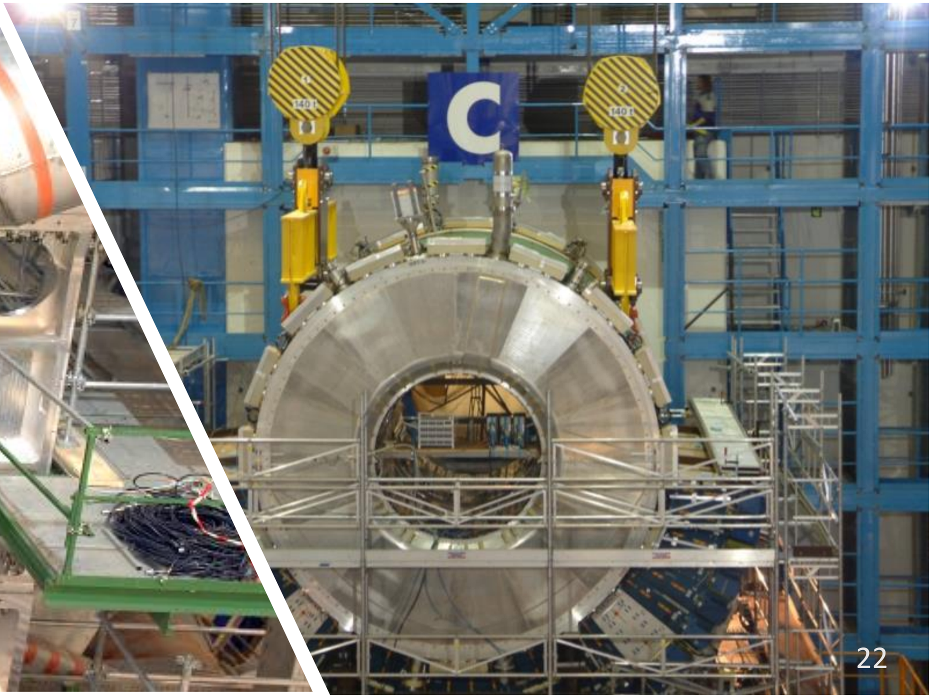
- ✓ Cryo-service lines.
- ✓ Cryogenic lines.
- ✓ Vacuum system pipes and pump outs.

INTERFACES:

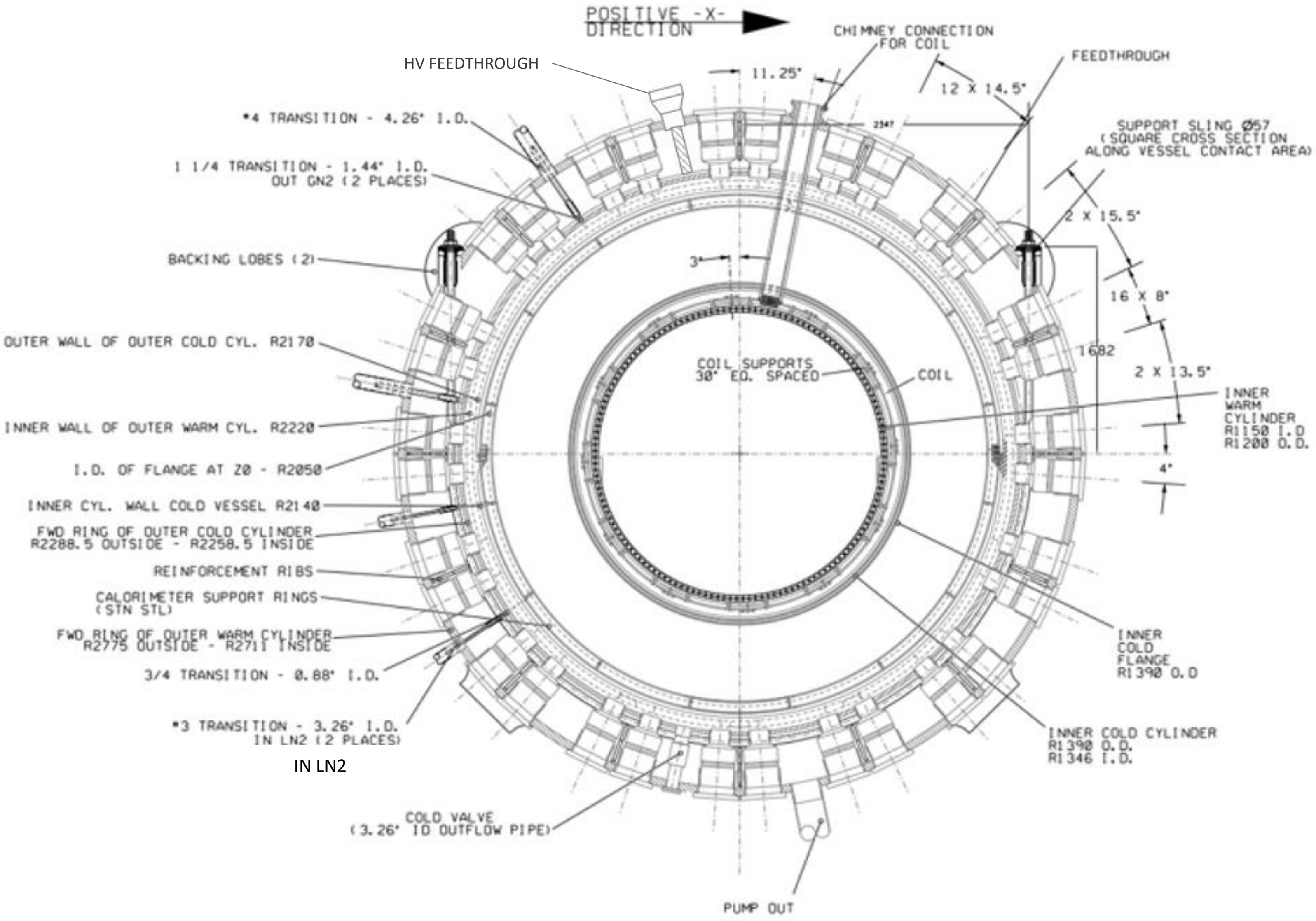
- ✓ Heat exchanger tubes through cold vessel.




1
140 t

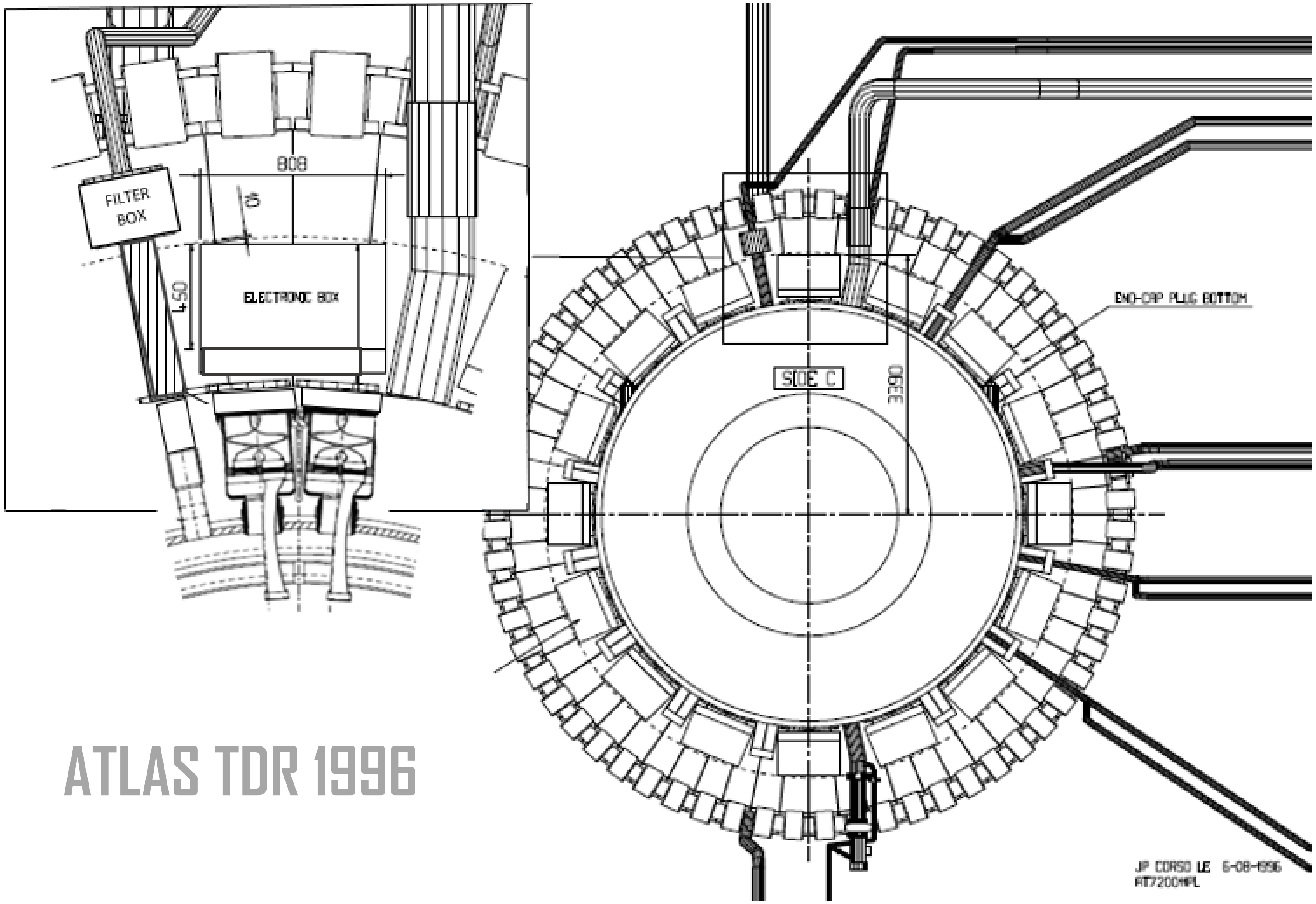

C

A SIDE VIEW


POSITIVE -X- DIRECTION
HV FEEDTHROUGH
CHIMNEY CONNECTION FOR COIL
11.25°
12 X 14.5°
FEEDTHROUGH
2347
SUPPORT SLING Ø57 (SQUARE CROSS SECTION ALONG VESSEL CONTACT AREA)
*4 TRANSITION - 4.26" I.D.
1 1/4 TRANSITION - 1.44" I.D. OUT GN2 (2 PLACES)
2 X 15.5°
BACKING LOBES (2)
3°
16 X 8°
OUTER WALL OF OUTER COLD CYL. R2170
1682
COIL SUPPORTS 30° EQ. SPACED
COIL
2 X 13.5°
INNER WARM CYLINDER R1150 I.D R1200 O.D.
INNER WALL OF OUTER WARM CYL. R2220
I.D. OF FLANGE AT Z0 - R2050
4°
INNER CYL. WALL COLD VESSEL R2140
FWD RING OF OUTER COLD CYLINDER R2288.5 OUTSIDE - R2258.5 INSIDE
REINFORCEMENT RIBS
CALORIMETER SUPPORT RINGS (STN STL)
FWD RING OF OUTER WARM CYLINDER R2775 OUTSIDE - R2711 INSIDE
INNER COLD FLANGE R1390 O.D
3/4 TRANSITION - 0.88" I.D.
*3 TRANSITION - 3.26" I.D. IN LN2 (2 PLACES)
INNER COLD CYLINDER R1390 O.D. R1346 I.D.
IN LN2
COLD VALVE (3.26" ID OUTFLOW PIPE)
PUMP OUT

C SIDE VIEW

POWER, CRYOGENIC AND CRYOSERVICE LINES FOR COIL (A SIDE)



HV FEEDTHROUGH LINES (A AND C SIDES)

LAR CRYOGENIC LINE (C SIDE)

OUT GN2 CRYOSERVICE LINES (A AND C SIDES)

OUT GN2 CRYOSERVICE LINES (A AND C SIDES)

IN LN2 CRYOSERVICE LINES (A AND C SIDES)

IN LN2 CRYOSERVICE LINES (A AND C SIDES)

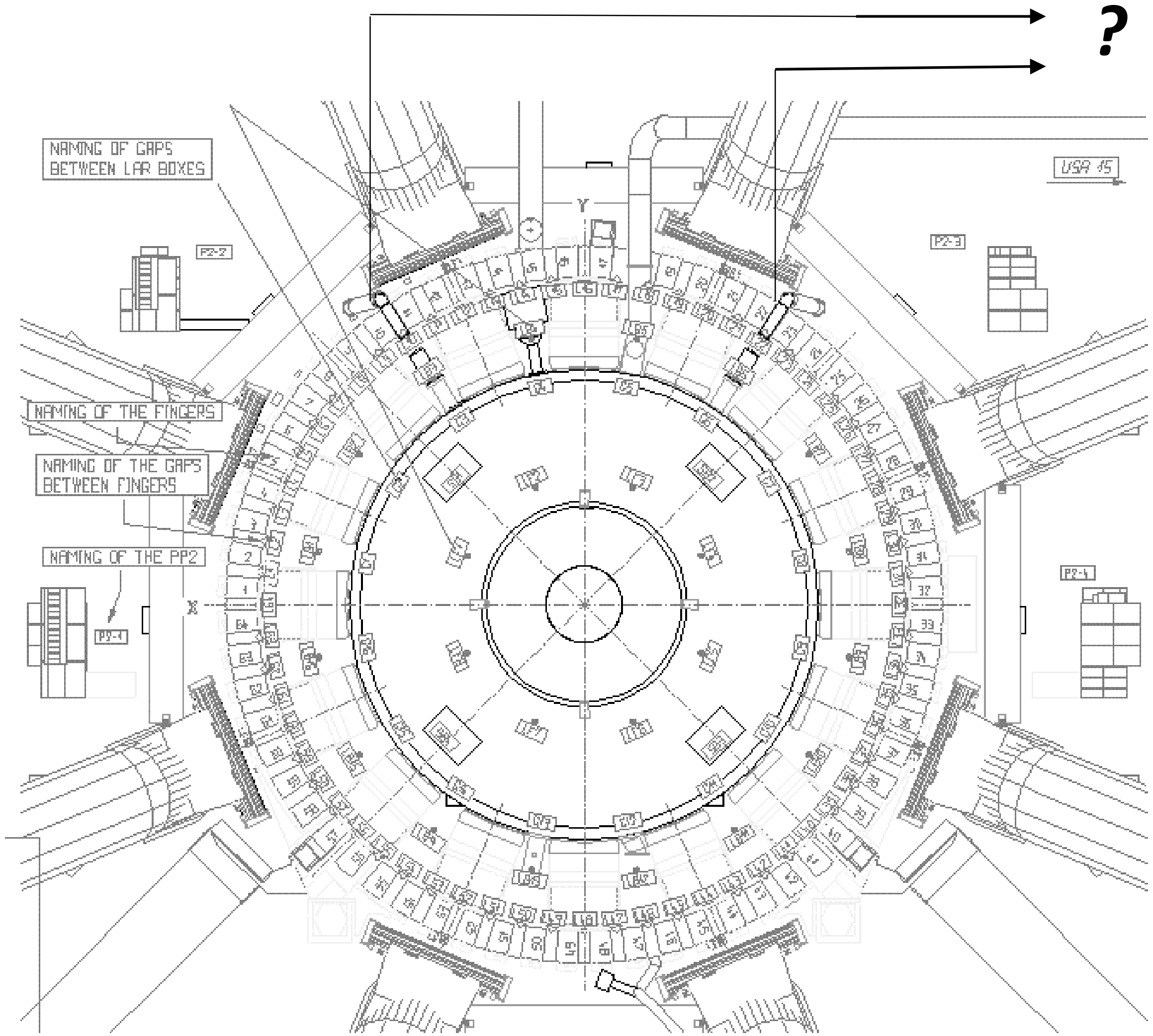
ATLAS TDR 1996

LAR EMPTYING CRYOGENIC LINE??

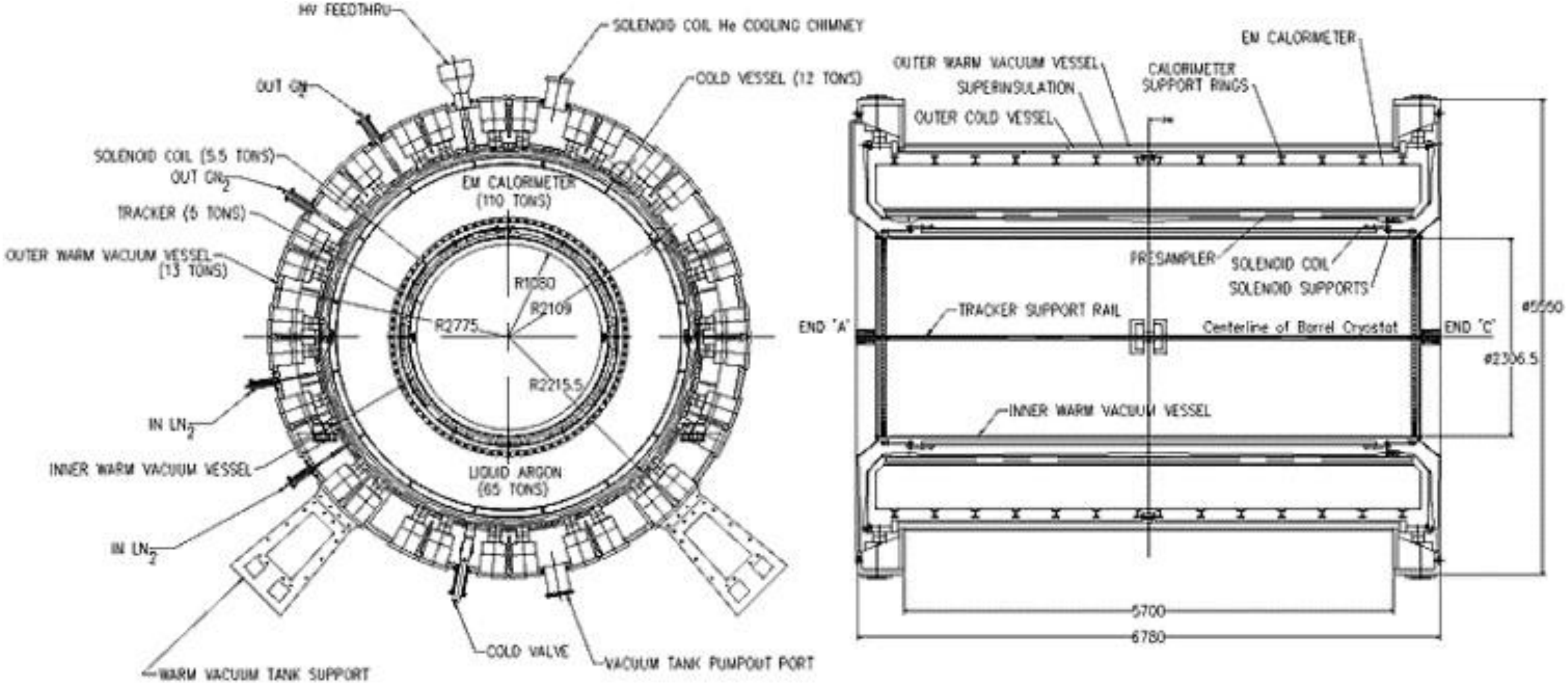
PUMP OUT
VACUUM STATION I (PURGING)

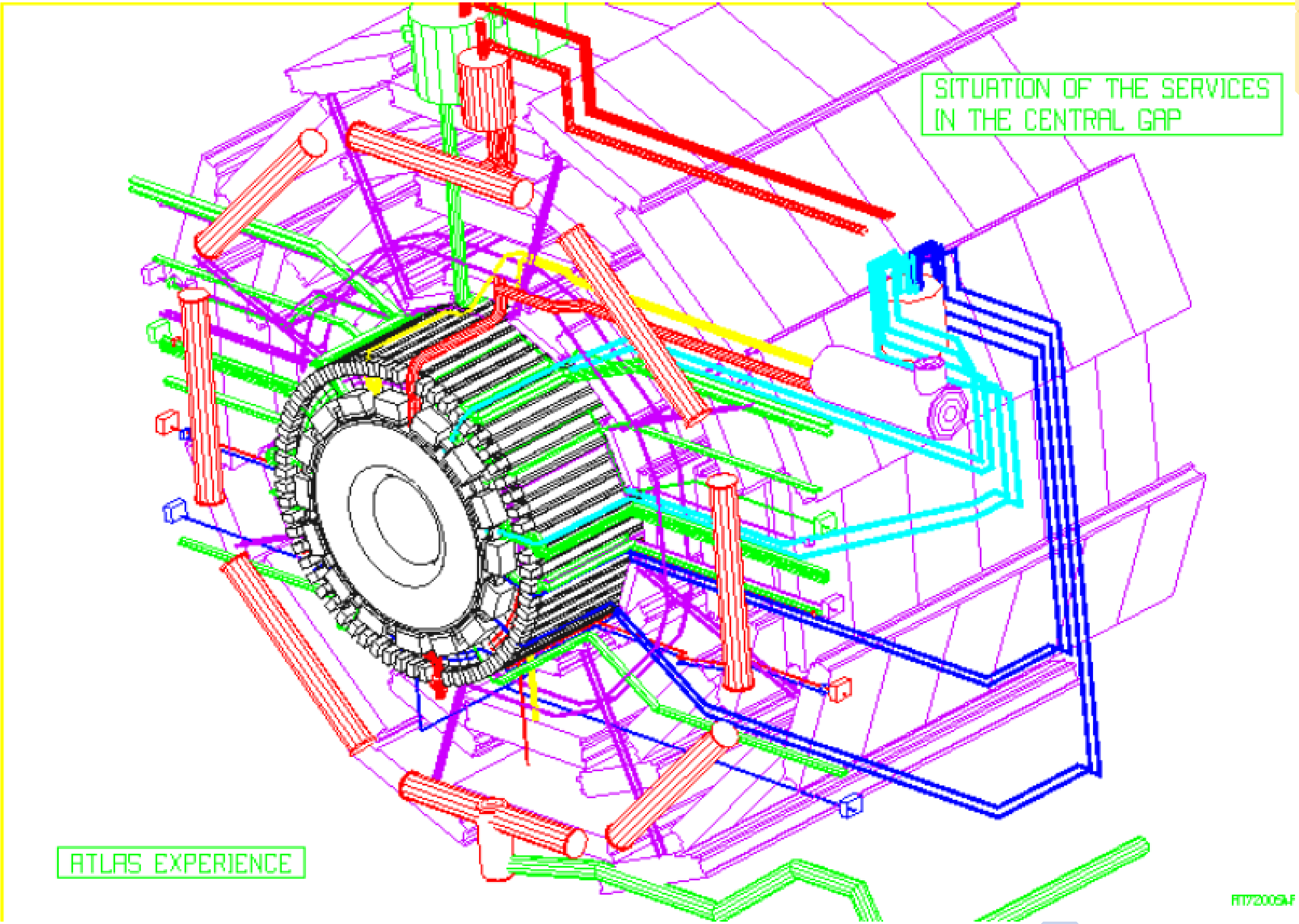
C SIDE VIEW

SOLENOID SERVICE INTEGRATION ON SUFACE, JAN 2004



ATLAS BARREL CRYOSTAT ASSEMBLY

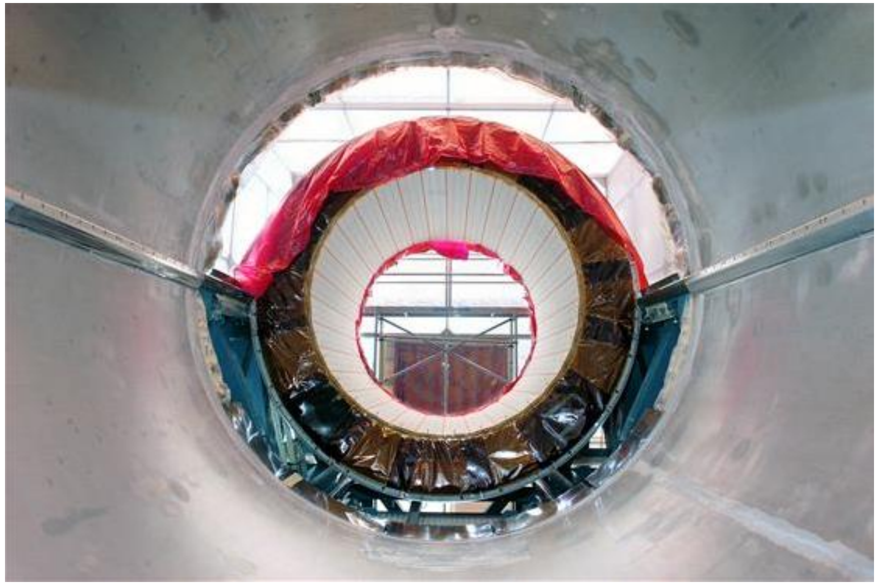


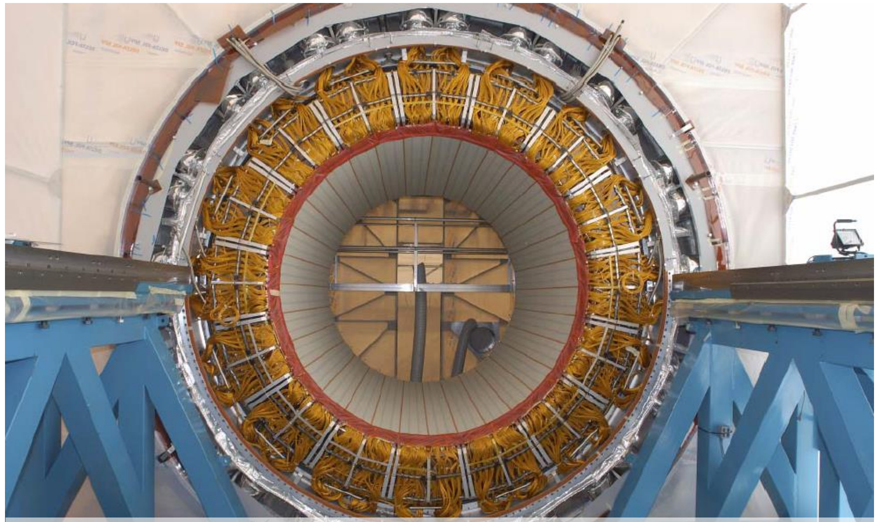


SITUATION OF THE SERVICES
IN THE CENTRAL GAP
ATLAS EXPERIENCE

✓ CRYOSTAT AND CALORIMETER

2002, ASSEMBLY CALORIMETER CRYOSTAT



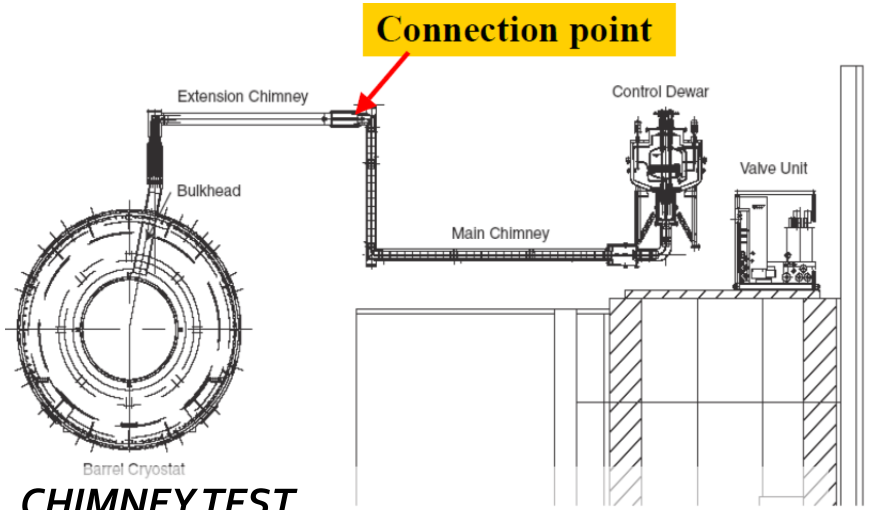


2003, INSERTION ATLAS CALORIMETER

ASSEMBLY SEQUENCE

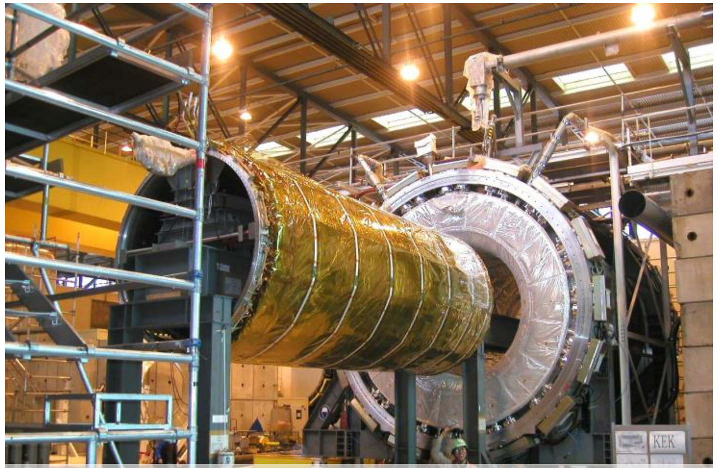
✓ SC MAGNET

1999, TOSHIBA CO, REALIZATION OF THE SOLENOID AND WELDING MACHINE



2003, CERN, CHIMNEY TEST

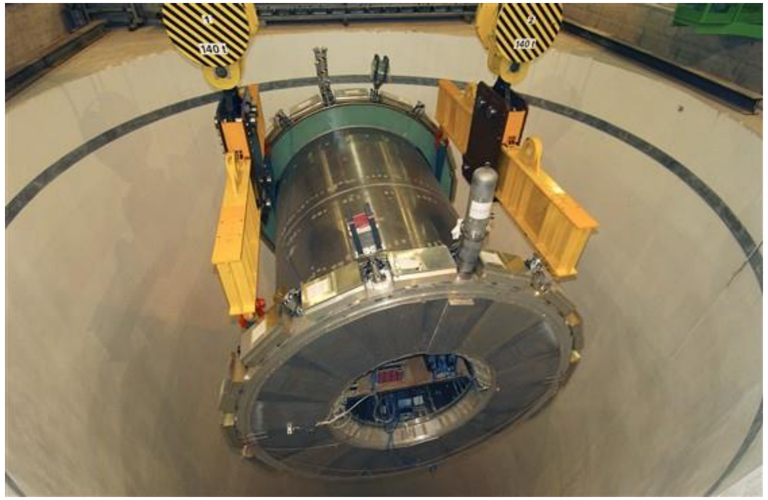
2003, KEK, DESIGN AND TEST OF THE CENTRAL SOLENOID



2004, CERN, CENTRAL SOLENOID AND SERVICE INTEGRATION. ON-SURFACE TEST

ASSEMBLY SEQUENCE

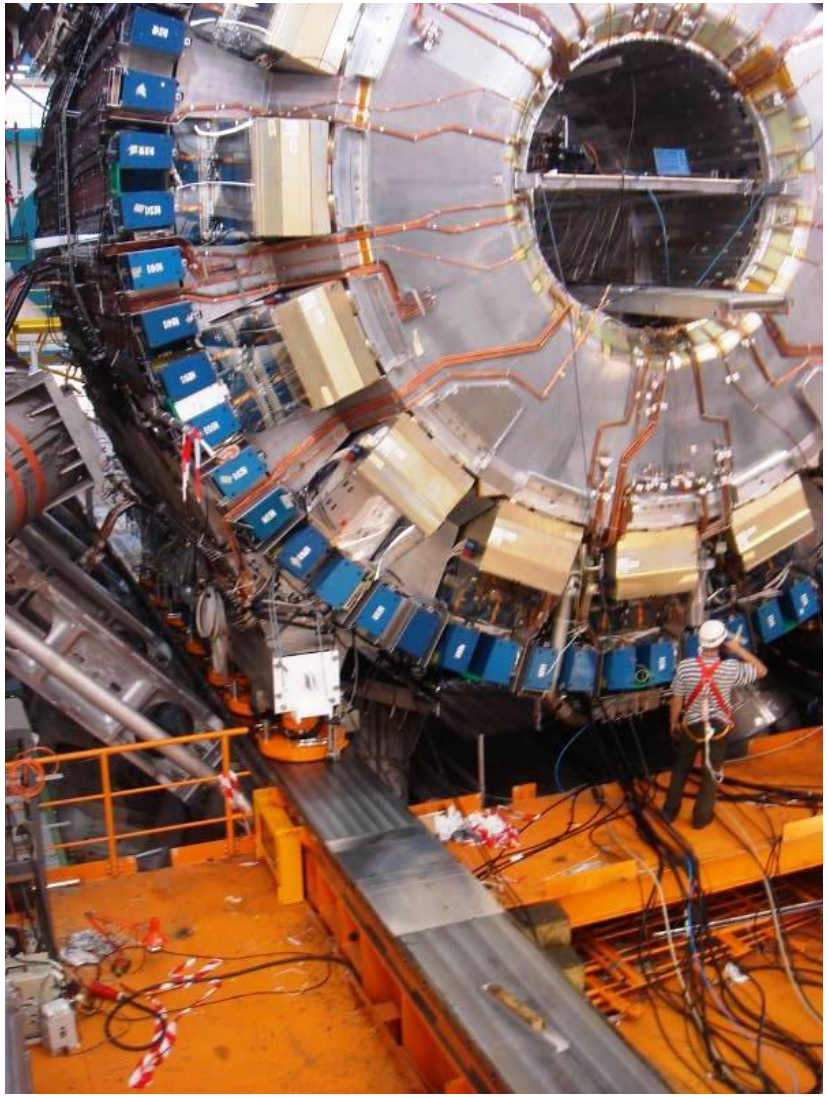
✓ ATLAS CRYOSTAT



2004, CRYOSTAT GOES ATLAS CAVERN

ASSEMBLY SEQUENCE

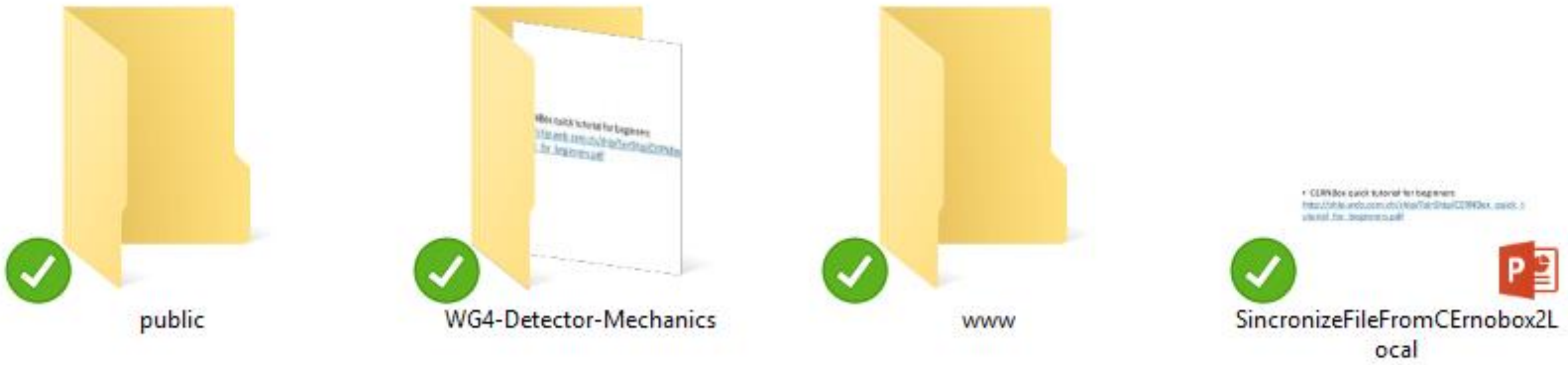
✓ ATLAS TILE CALORIMETER, CRYOGENICS AND INNER TRACKER



CERN BOX

EP-RDET

Project (10 Terabyte) created in CERN Box: EP-RDET, available to WPs
WP4 will use it for storing and sharing all files previously in EP R&D old-website



File of instruction for synchronizations
https://cernbox.cern.ch/index.php/s/gdYrsR1Be1fGeCG

Contact
corrado.gargiulo@cern.ch
massimo.angeletti@cern.ch