



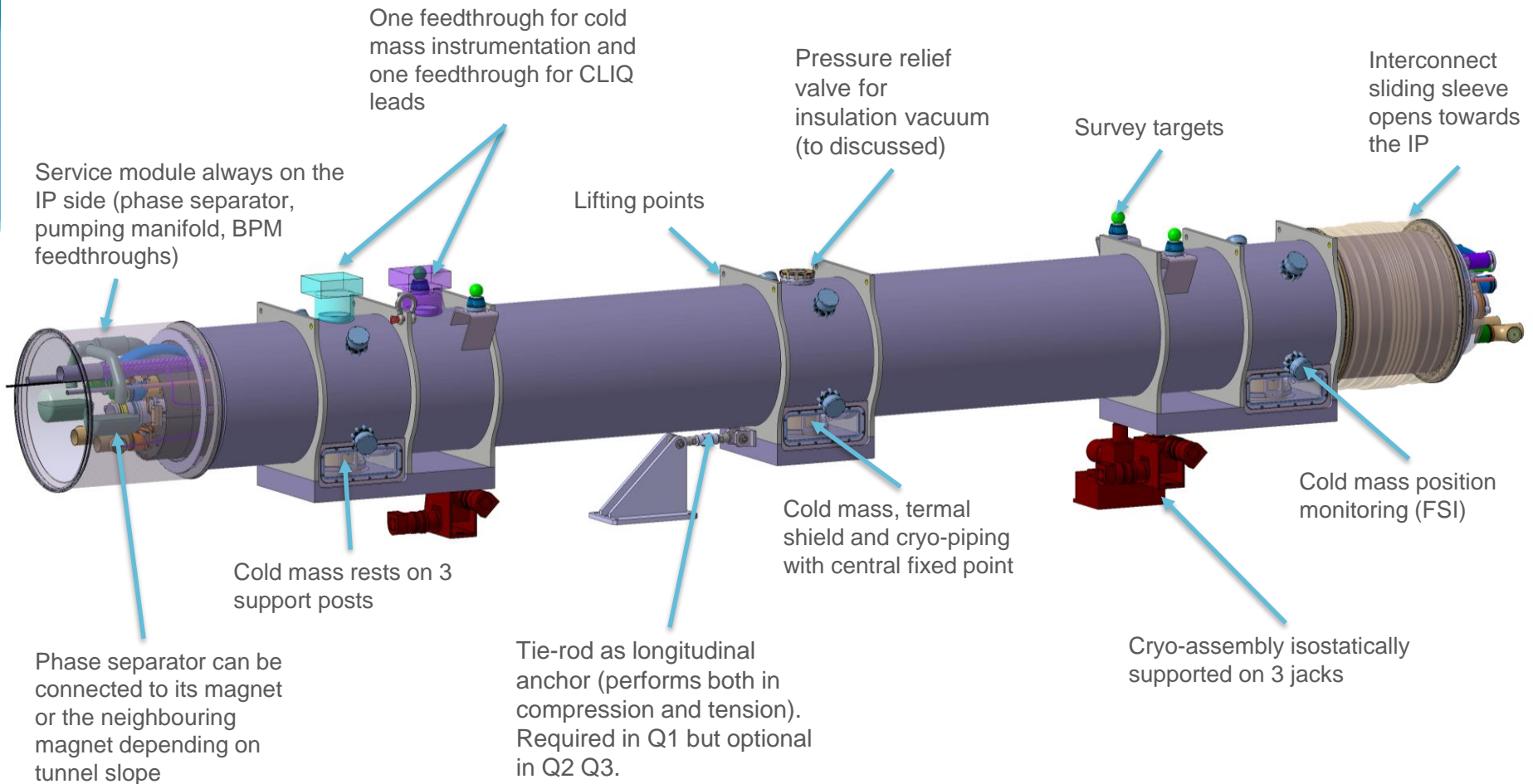
Q1-Q2-Q3 cryo-assemblies: status and plan

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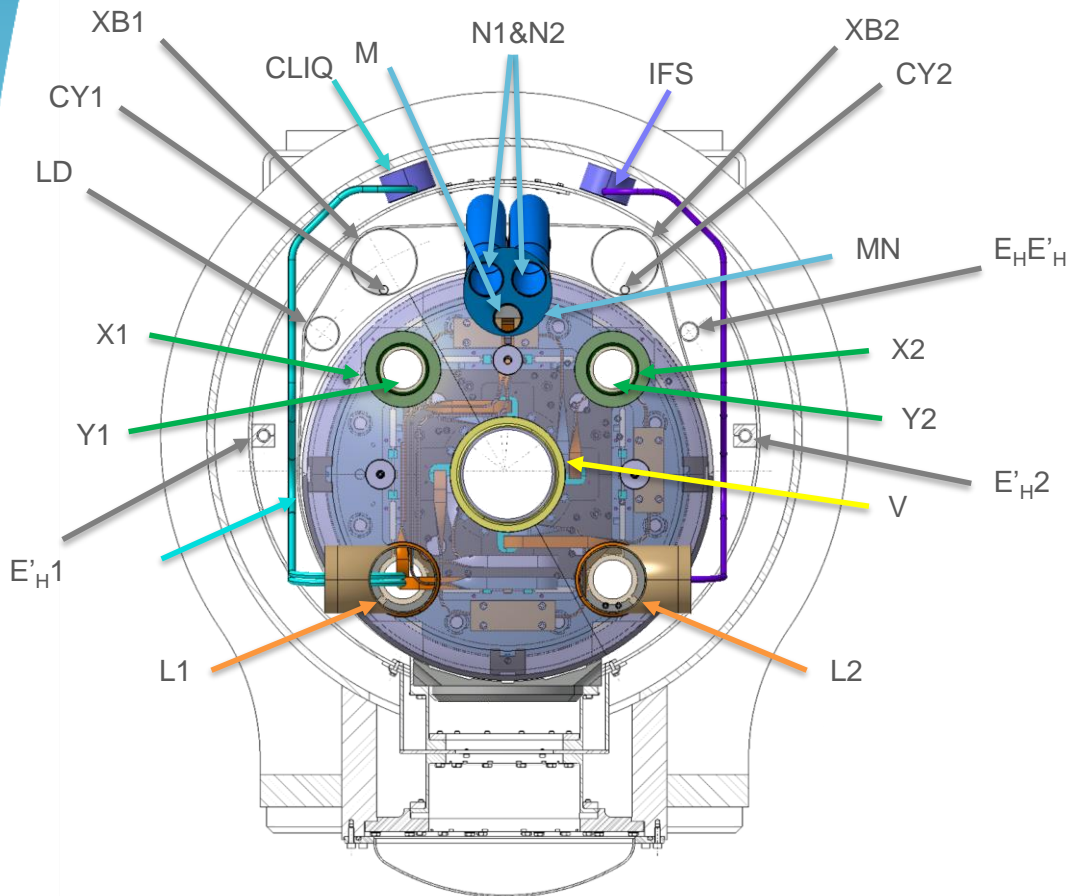


7th HL-LHC Collaboration Meeting, 13-16 November 2017

Cryostat design status (ex. Q2 IR1 Right)

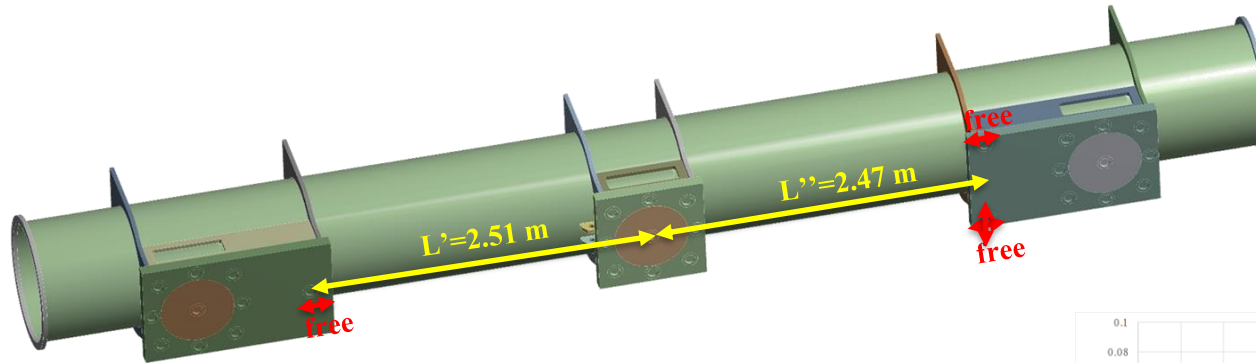


Piping nomenclature



- N1 & N2 Auxiliary lines for Trim and Correctors Busbars
- M Aperture for the cold mass busbars
- MN Busbars Interconnection line
- X1 & X2 Heat exchanger tubes
- y1 & y2 Helium inlets
- V Beam line
- L1 & L2 Conduction path for Helium (2x75cm²)
- IFS Instrumentation feedthroughs capillary
- CLIQ CLIQ feedthroughs current leads
- XB1 XB2 Pumping lines
- CY1 CY2 1.9 K inlet
- LD Cooldown and quench line
- E_HE'_H Thermal shield and beamscreen inlet
- E'_H1 E'_H2 Thermal shield cooling

Cryostat supports and vacuum vessel design



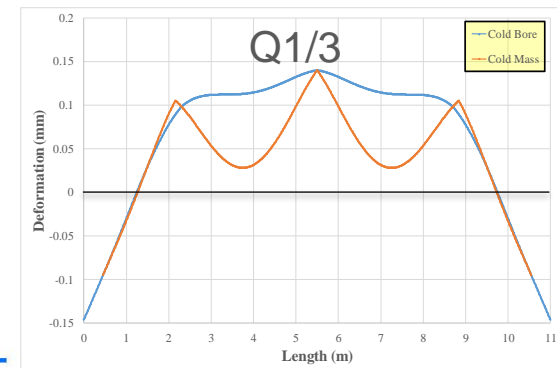
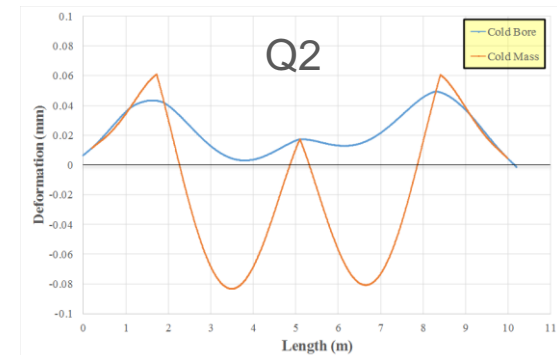
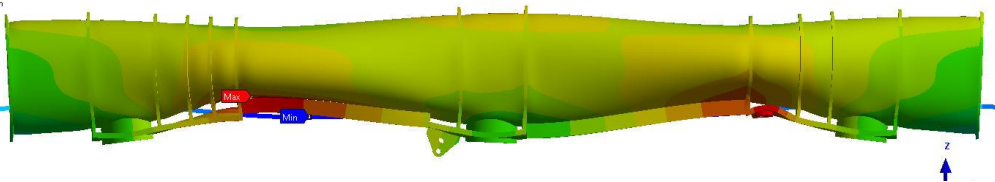
- Cryostat interface meeting 29/8/2017: decision to implement isostatic support (3 jacks instead of 4) <https://indico.cern.ch/event/661726/>
- Small difference in length between Q1/3 and Q2: same interfaces to simplify assembly tooling
- Optimisation of jack locations for minimum cold mass deformation presented at WGA#3 18/10/2017

<https://indico.cern.ch/event/666376/>

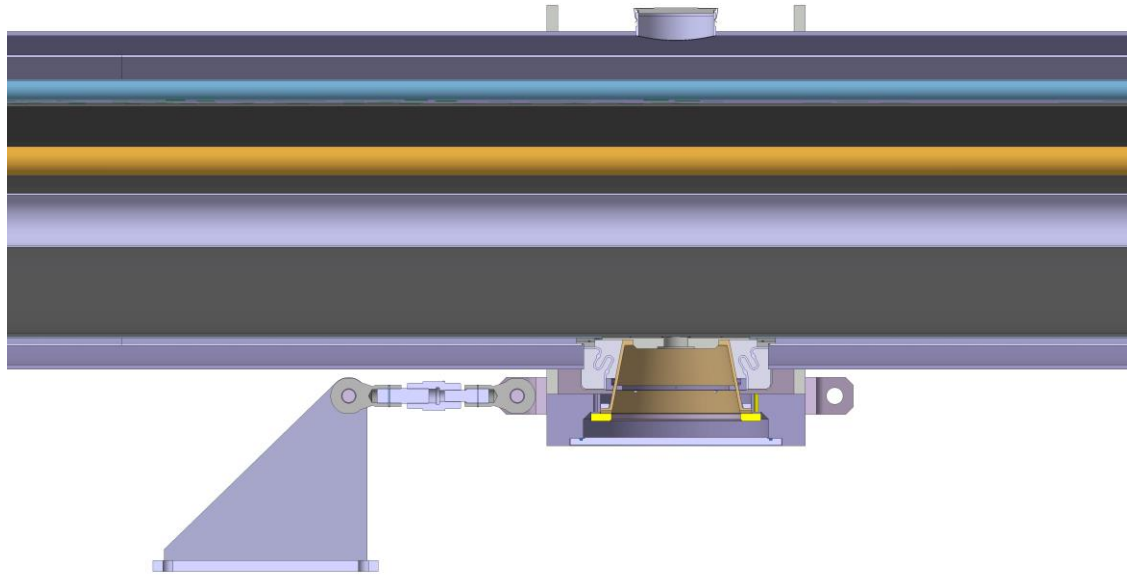
- Goal: Interface between cold mass and vacuum vessel deform evenly
- Total displacement of cold mass interfaces ~130 micron
- Contribution of vacuum vessel deformation to cold bore misalignment: < 60 micron

A: Static Structural
Z Axis - Directional Deformation
Type: Directional Deformation(Z Axis)
Unit: mm
Global Coordinate System
Time: 1
04/01/2016 20:05

0.0386 Max
-0.00333
-0.0453
-0.0872
-0.129
-0.171
-0.213
-0.255
-0.297
-0.339
-0.381
-0.423

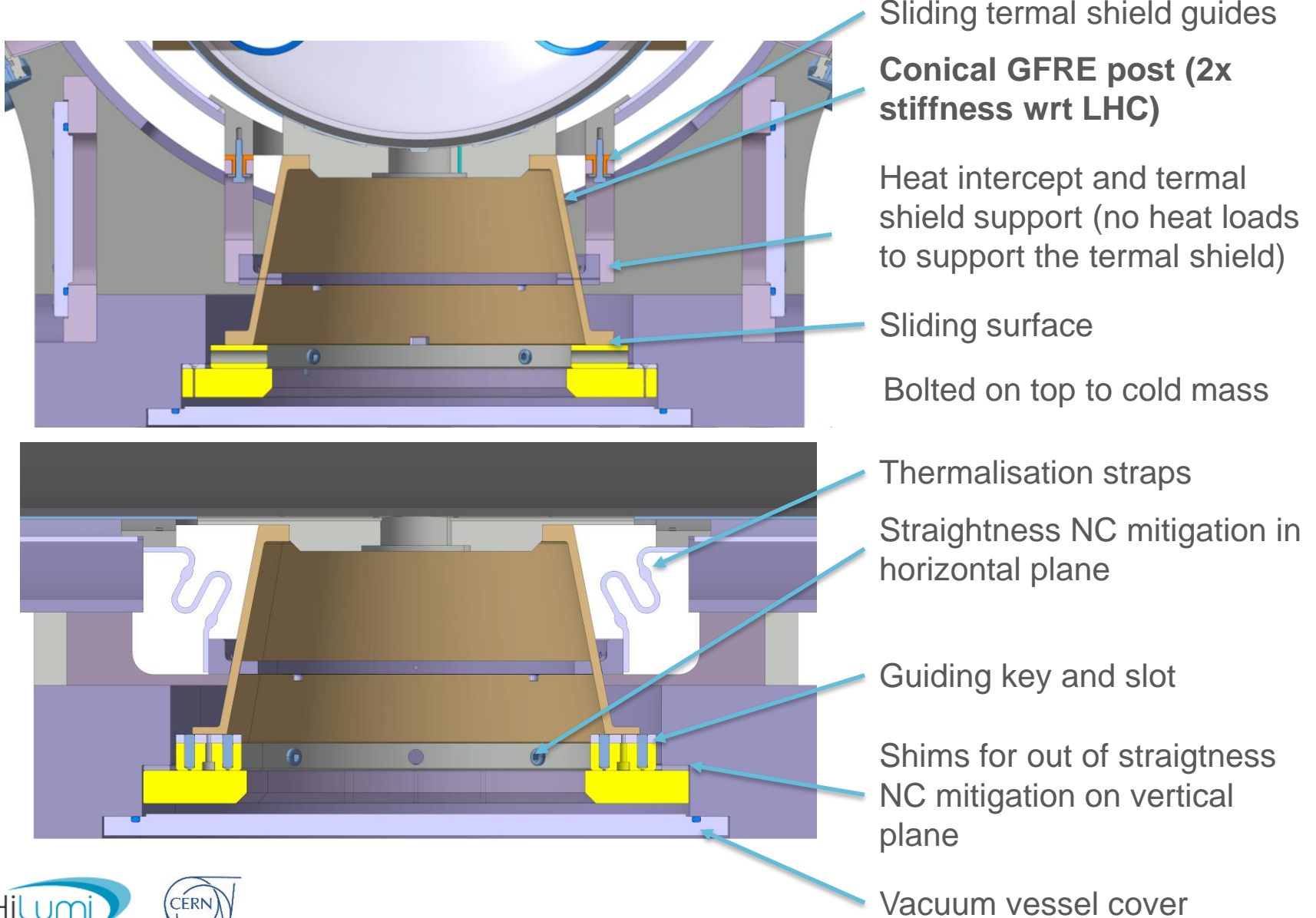


Longitudinal anchor for Q1

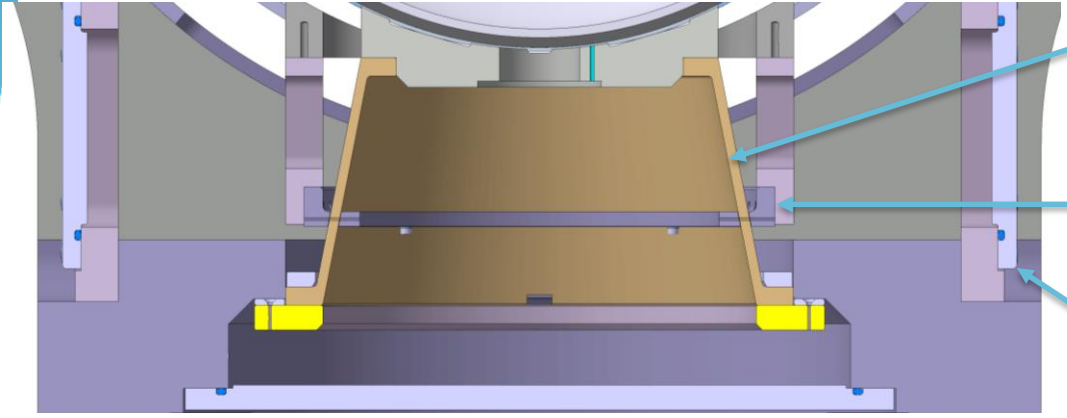


- Can be placed on either side of the central support post
- Designed to work in compression or tension
- Functional specification <https://edms.cern.ch/document/1856323/0.1>
 - **13 tonne** on either direction
 - Adjustment range +/-10 mm
 - Resolution +/- 0.1 mm with differential screw
 - No adjustment under vacuum load
 - Not remotely operated
- Validation test planned in 2018 using LHC spare triplet cryo-assemblies

Sliding support post



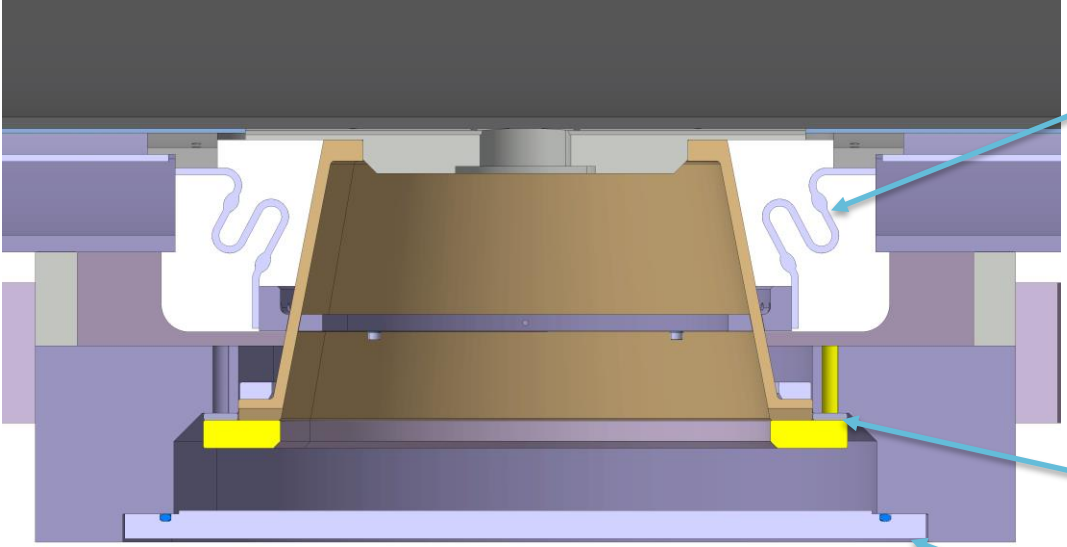
Fixed support post



Conical GFRE post (2x stiffness wrt LHC)

Heat intercept and thermal shield support (no heat loads to support the thermal shield)

Access door in vacuum vessel for assembly



Thermalisation straps

Bolted on top and bottom

Shims for out of straightness
NC mitigation on vertical plane

Vacuum vessel cover

Heat intercept location

Optimum location: **48.5 mm**

Minimum exergetic cost: 1132 W

Heat loads for 8 mm thickness

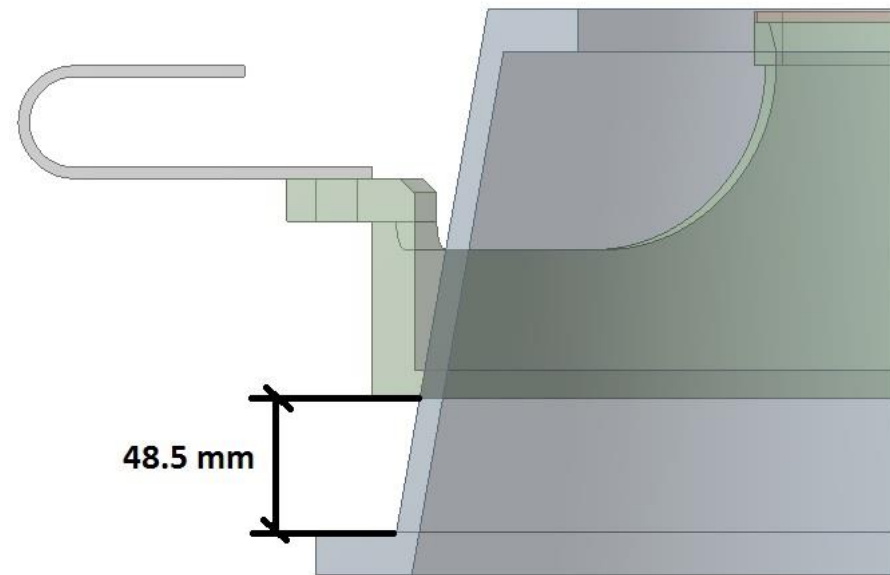
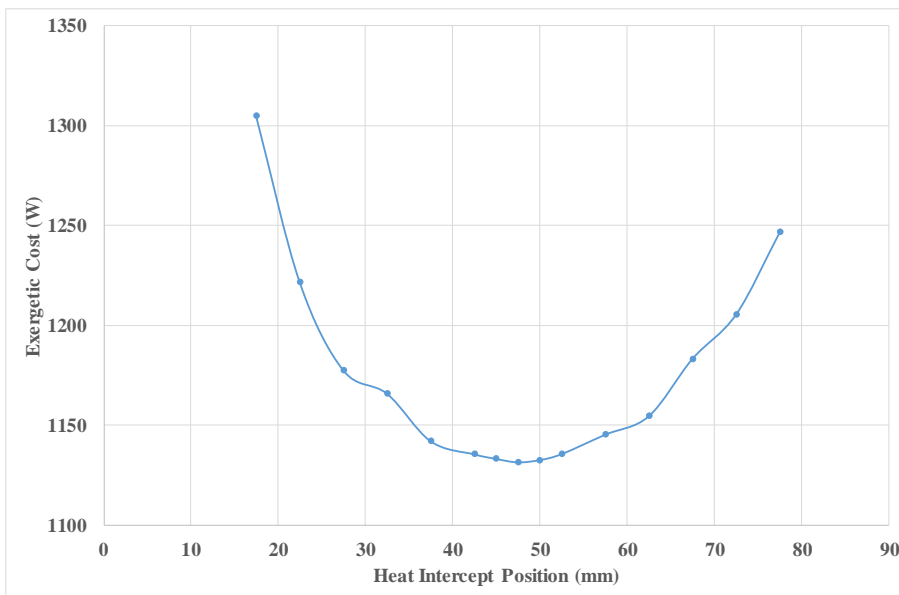
(very preliminary):

- **0.23 W** at 1.9 K level
- **3.3 W** on 60-80 K level

$$W = W_{CM}C_{CM} + W_{TS}C_{TS}$$

with the following coefficients:

$$C_{CM}: 1000 \quad C_{TS}: 17$$



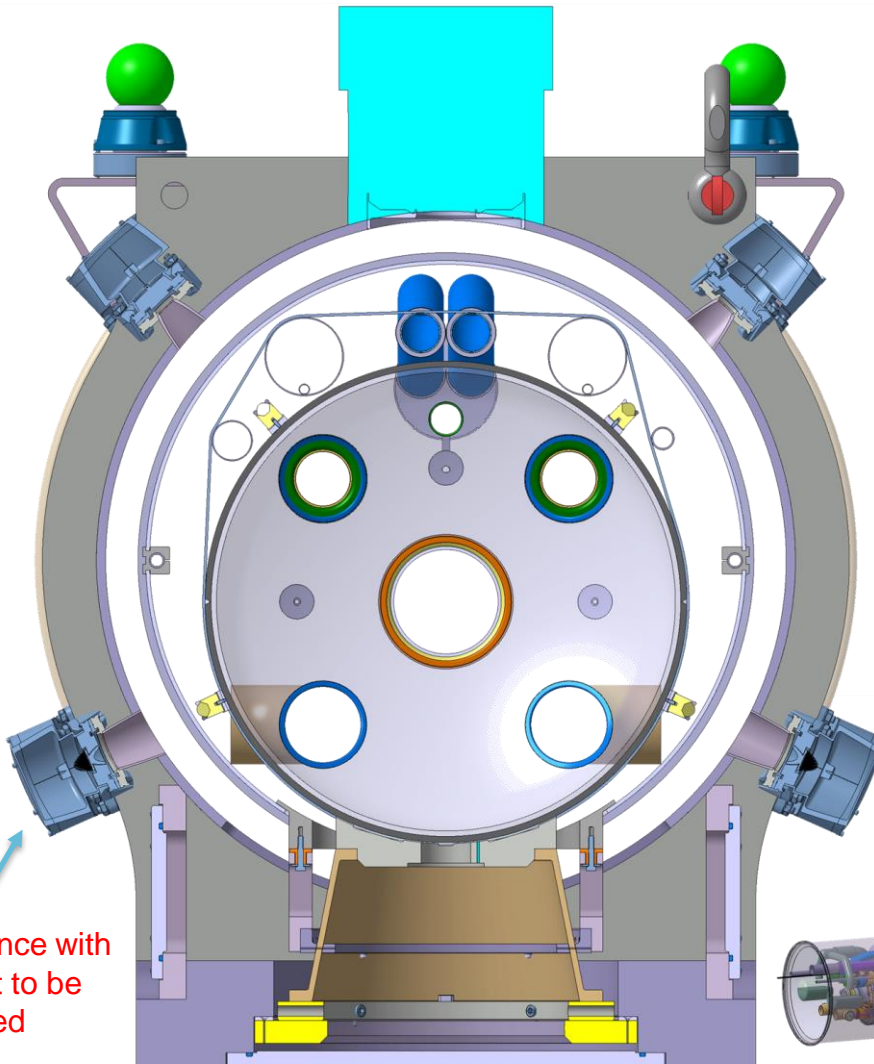
Preliminary specifications

- Design loads functional spec under approval
<https://edms.cern.ch/document/1868420/0.1>
 - LC1, room temperature, 205 kN compression, 135 kN transverse
 - LC2, cold, 142 kN compression, 125 kN transverse
- Glass fibre – epoxy composite
- Layup and autoclave (preferred by potential suppliers)
- Fibre volume fraction: 40-50%, max 2% dispersion
- Maximum void content: 1%
- Dispersion on support post stiffness: +/- 5%
- Residual deformation after load testing: 2%
- Tests done by manufacturer
 - Material property testing as input for mechanical calculations
 - Load testing 100%
 - Ultrasound testing 20% (option for 100%)
- Done by CERN
 - Thermal contraction tests at the EN-MME lab
 - Radiation hardness on samples (100 kGy)
 - Thermal performance evaluation by CERN

Integration of CM position monitoring (FSI)

Mateusz Sosin

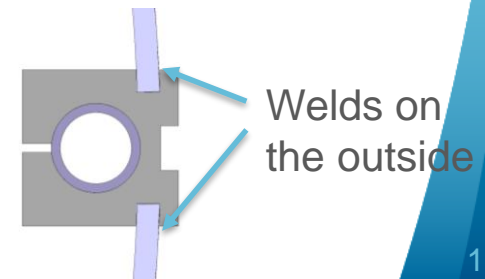
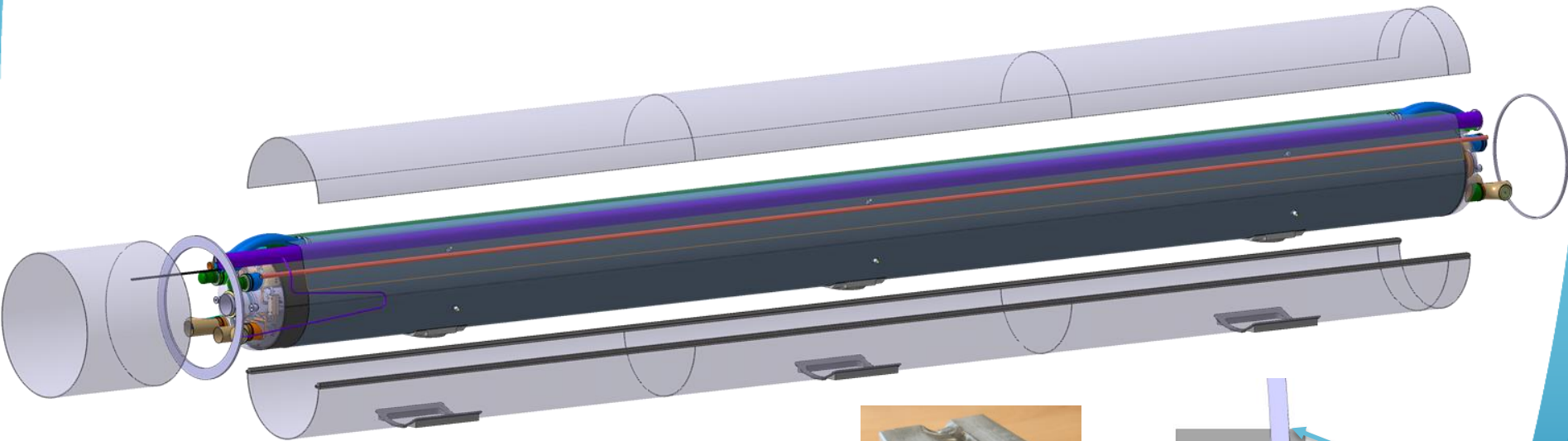
- Frequency scanning interferometry, absolute positioning
- 3 x 4 targets aligned with cold mass support posts
- Circumferential location agreed Nov 2017
- At sliding supports, mounted with an angle of 10 deg wrt vertical plane to allow measurement of longitudinal movement
- Thermals shield interfaces for minimum heat load to be specified



Interference with transport to be addressed

Thermal shield

- 5 mm thick aluminium 1050 shell with continuous longitudinal cooling on both sides
- Symmetrical cooling prevents “banana effects” during thermal transients
- The cylinder is split horizontally in two halves that are welded once the cold mass is in place
- Machined saddles at the interfaces with support posts
- Two options for the cooling pipes
 - Stainless steel tube press fitted inside aluminium bar: negligible tooling investment / more labor / inferior thermal efficiency
 - Extruded aluminium tube: investment on extrusion tooling / better for series / delicate aluminium welds / aluminium to stainless steel transitions

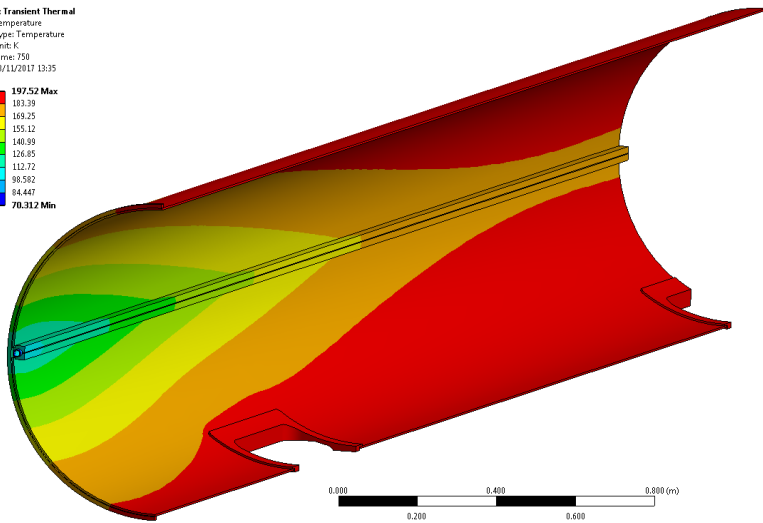


Thermal shield deformations

- Thermo-mechanical calculations on going (cryostat interface meeting 7/11/2017 <https://indico.cern.ch/event/677105/>)
 - Mass flow 7.5 g/s
 - Radiation through MLI 1.5 W/m²
 - Support post in-leak ~5 W @ 70 K per support (conservative)
 - First radiation cooled to 200 K (by radiation exchange with the 80K cooled cold mass).
 - Then gaseous helium is run in the cooling lines to further cool down the screen to 60-80K.
 - Maximum ovalisation during transients of 4 mm

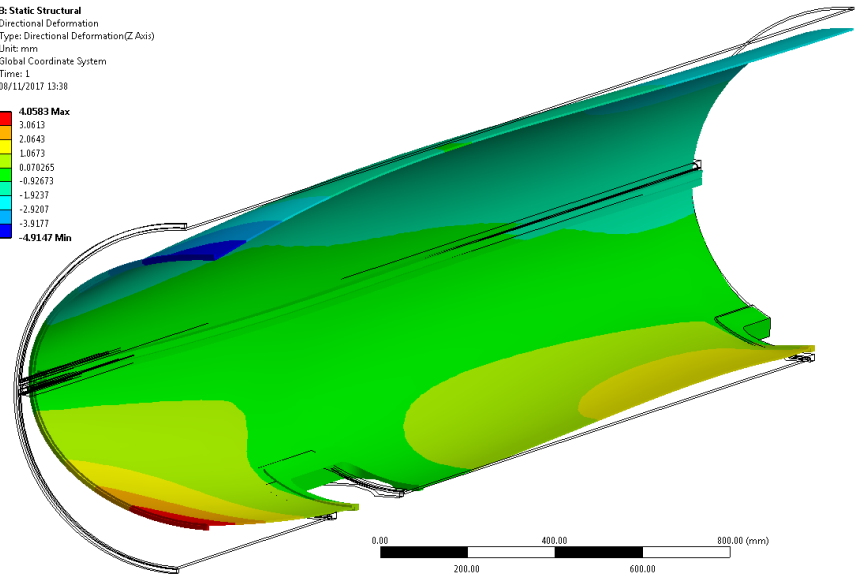
A: Transient Thermal
Temperature
Type: Temperature
Unit: K
Time: 750
08/11/2017 13:35

197.52 Max
163.39
169.25
155.12
140.99
126.85
112.72
98.582
84.447
70.312 Min



B: Static Structural
Directional Deformation
Type: Directional Deformation(Z Axis)
Unit: mm
Global Coordinate System
Time: 1
08/11/2017 13:38

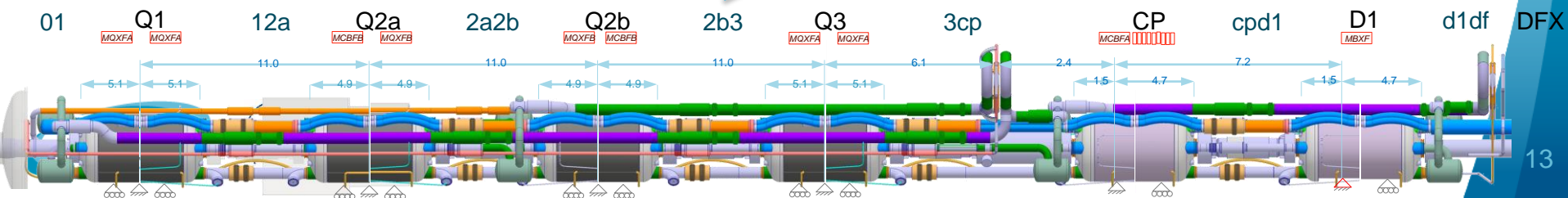
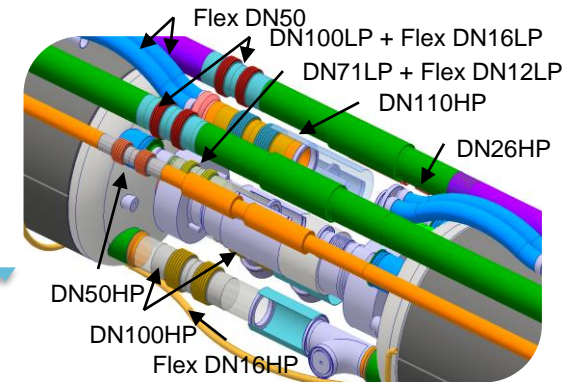
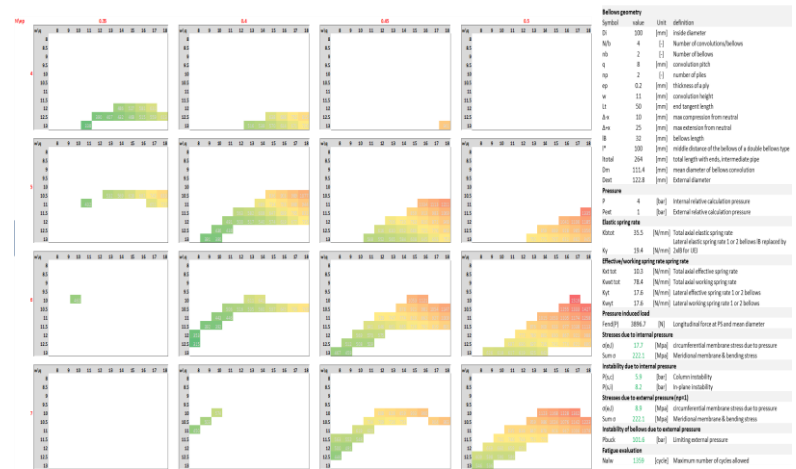
40583 Max
3.6613
2.6643
1.6673
0.670265
-0.92673
-1.9237
-2.9207
-3.9177
-4.9147 Min



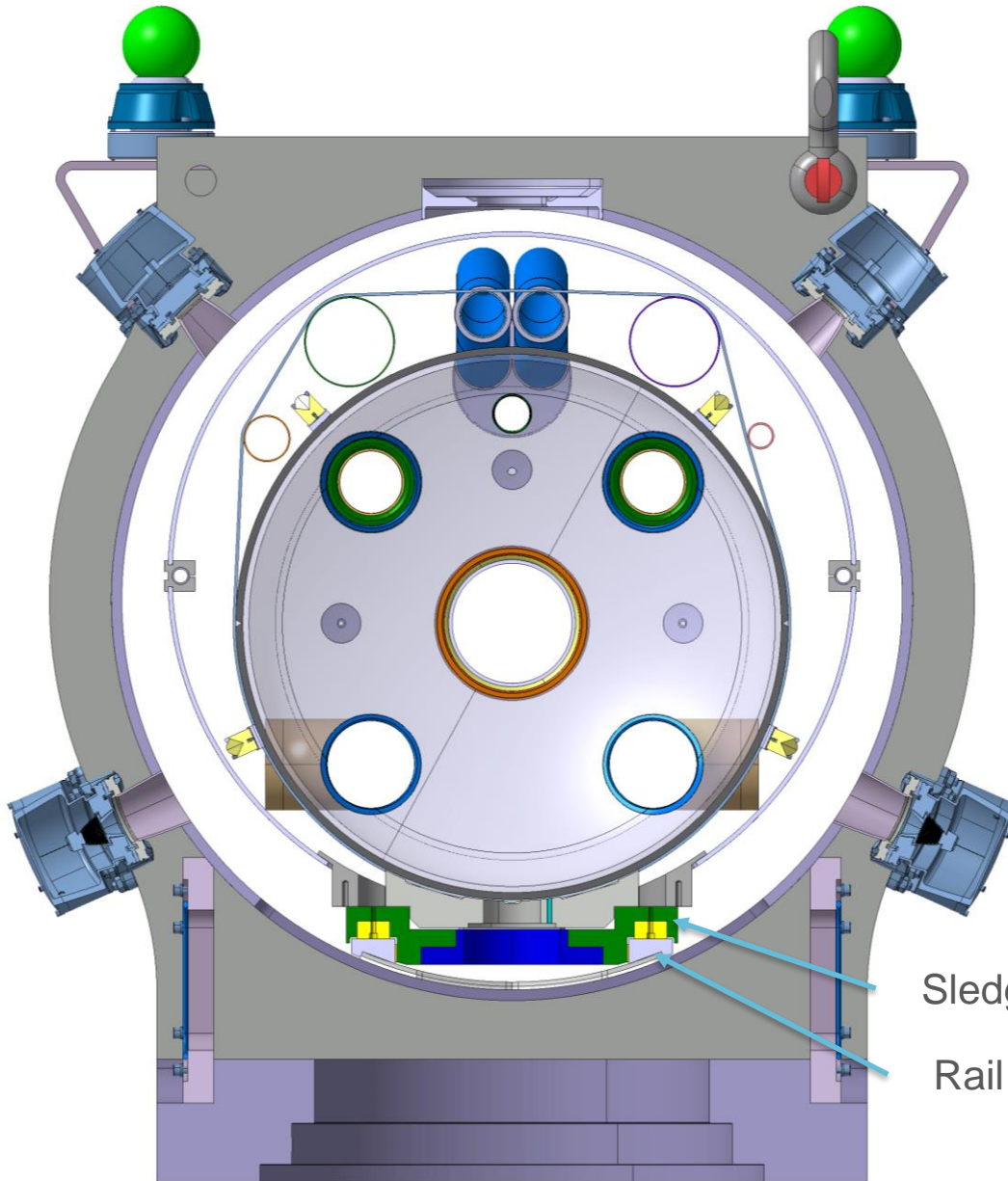
Expansion joints

- Universal expansion joints for minimum impact on alignment**
- Specifications:**
 - Design pressure (PS) : from 4 to 25 bar internal relative pressure
 - Axial cyclic movements up to 46mm (500 cycles)
 - Temperature range : [1.9 K ; 300 K]
 - Nominal diameters : from $\varnothing 10$ to $\varnothing 110$ mm
- Quantity:**
 - up to 100 bellows and flexibles per side
- Design optimisation:**
 - Minimise outer diameter for integration purposes
 - Minimise axial and lateral spring rates
 - Minimise number of plies
 - Minimise the number of different bellows
- Bellows project progress status:**
 - Dedicated pre-design software developed based on **European Pressure Directive** (EN13445 & EN14917+A1).
 - Most used bellows are pre-designed and loads evaluated
 - Axial rigidity up to 250 N/mm per universal expansion joint
 - Exceptional cases under study: End of Q1, Interconnection equipped with jumper, interface with DFX

Software interface for bellows design optimisation

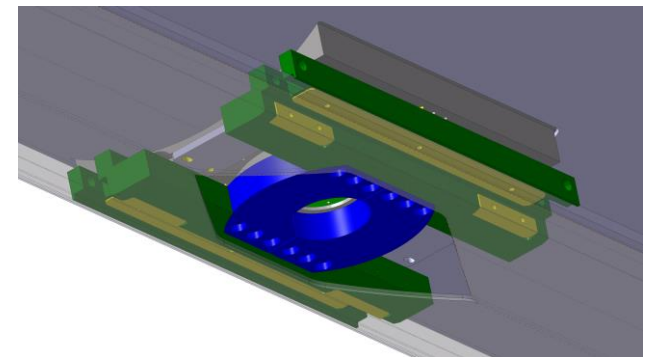
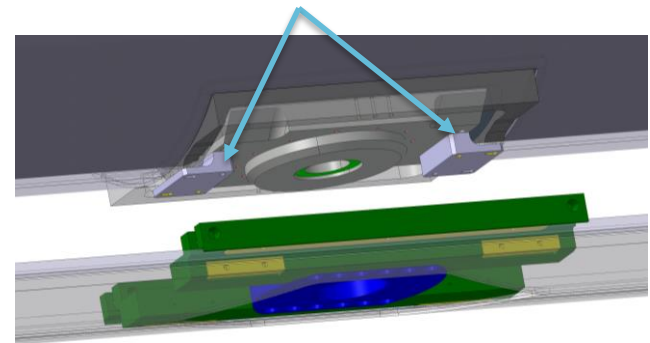


Assembly tooling: sledge on rails



Cold mass offset at -27 mm during insertion (nominal is 54 mm), up to -23 mm to remove sledges and then rails

Temporary support for thermal shield

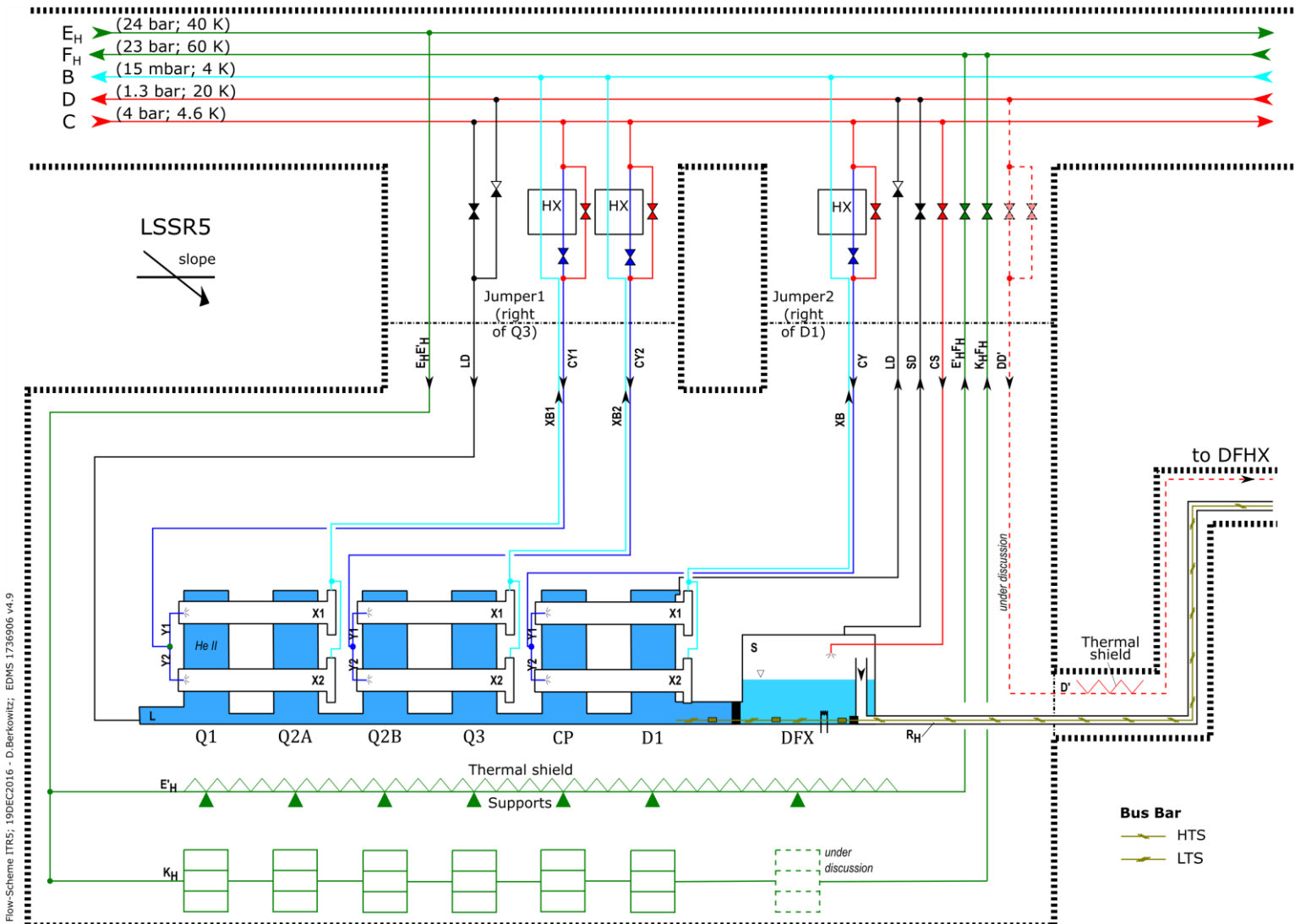


Sledge

Rail

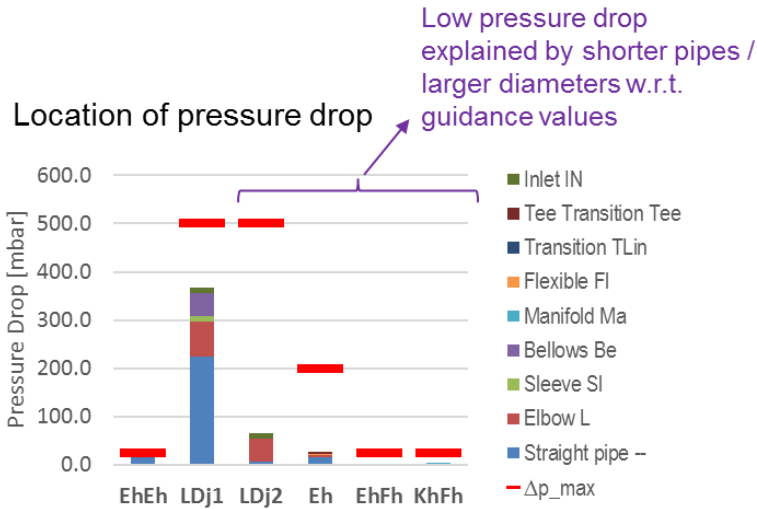
Pipe sizing and pressure drop

Edms 1573115
Edms 1710017

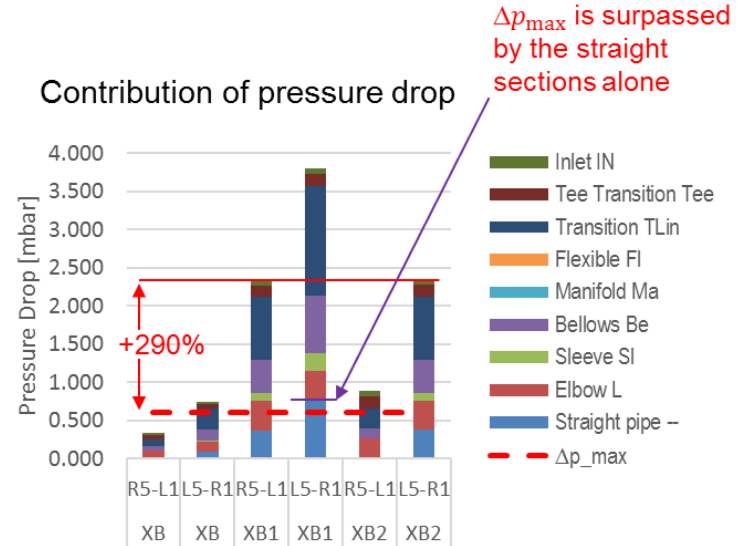


Flow-Scheme ITR5; 19DEC2016 - D.Berkowitz; EDMS 1736906 v4.9

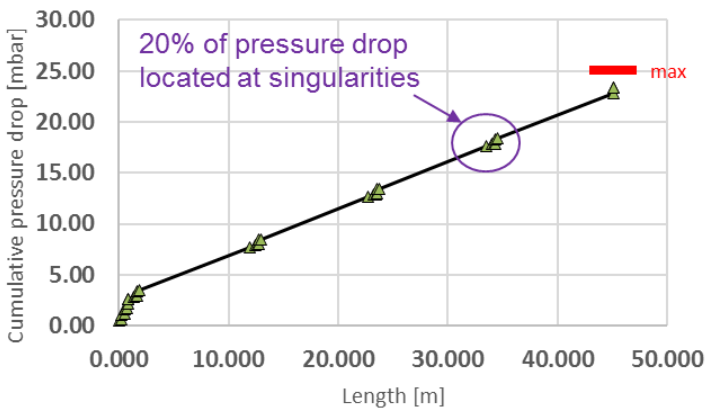
High/medium pressure lines



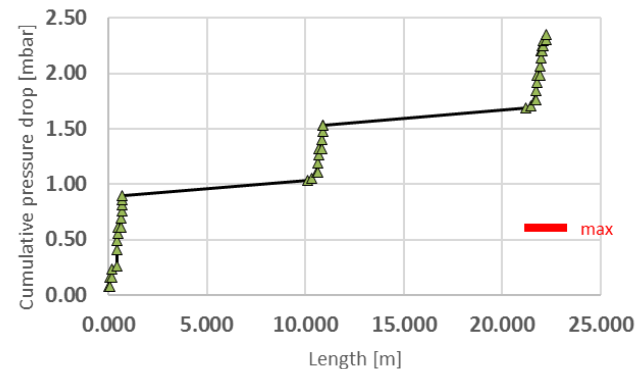
Pumping lines



Pressure drop over pipe length (E_hE_h)



Pressure drop over pipe length (XB1 on R5/L1)



Recent data. Discussions on-going.

Design and procurement road map

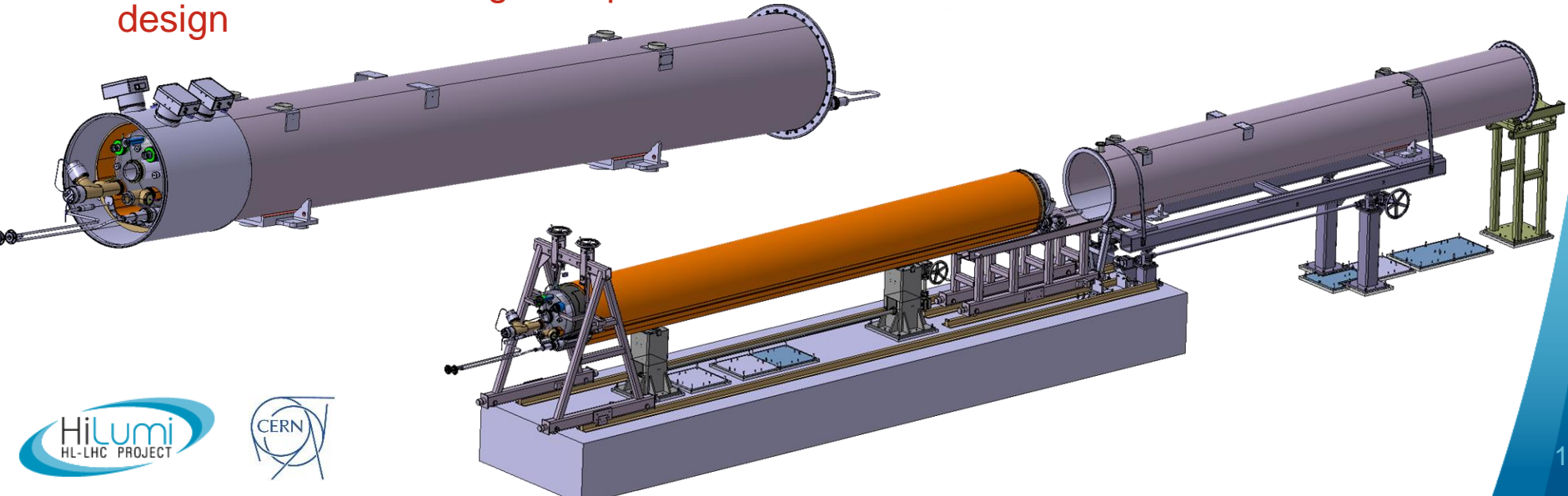
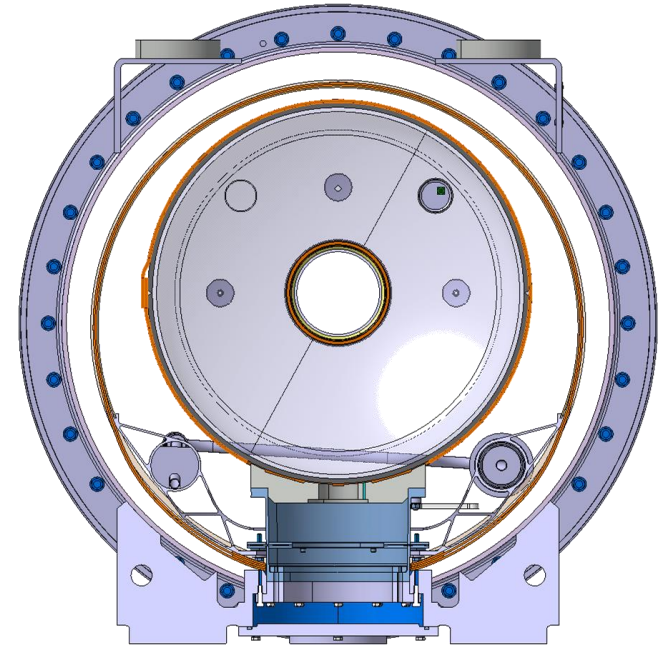
Component	Who	Design	Procurement/Assembly
Cold mass	LMF	End covers depend on interconnect detailed design Interfaces for survey FSI	Delivered with N-lines Welded plates for cryo lines (tbd)
Vacuum vessel	CMI	First design by end of year <ul style="list-style-type: none"> Opening for support post Jack interfaces Deformations under load Baseline for instrumentation and CLIQ feedthroughs Minimise welded reinforcements for stability over time Interfaces for survey FSI 	Single contract for all WP3 vacuum vessels (excl. D1). Q10 as option. Cylinder + service module with adjusted diameter <ul style="list-style-type: none"> DR Jul 2017 (price estimation as C&SR) MS before end 2017 IT spring 2018 FC June 2018, Order Jul 2018 First units Q2 & Q1 Mar 2019 Delivery over 3 years (tbd)
Support posts	CMI	First design by end of year <ul style="list-style-type: none"> Review assembly procedure Increase diameter as much as possible for stiffness Thermalisation design Assembly tooling pre-design 	Single contract for all WP3 vacuum vessels incl. D1 (must be the same in a continuous cryostat) <ul style="list-style-type: none"> As critical as vacuum vessels MS dispatch Nov 2017 IT dispatch Feb 2018 Finance committee June 2018 Order placed July 2018 Pre-series Mar 2018
Thermalizations for support posts	CMI	Idem <ul style="list-style-type: none"> Must be very compact 	Schedule OK if design done Q1 2017
Thermal shields	CMI	First design by end of year <ul style="list-style-type: none"> Thermalization and accessibility during assembly Split vertically or horizontally Temporary support during cryostating Cold mass alignment targets: approve heat loads 	Aluminium extrusions <ul style="list-style-type: none"> Tender Q1 2018 Aluminium to stainless steel transitions <ul style="list-style-type: none"> Tender Q1 2018 Plates and machining Wwith support from MME (tbd) Welding/assembly in SMI2 Bottom trays and transitions for Q4 and Q10: qty in stock to be checked.
MLI		Blankets designed by contractor	Not much to gain with scale effect. Several orders according to needs
Cryo piping and phase separators	CMI	Cross check pressure drop with TE-CRG Detailed design of phase separator manifold Design of liquid boiling solution, active or passive (with TE-CRG) Level gauges (tbc) Validate jumper design	Solution to ensure cooling at 1.9 K to be discussed Procurement strategy will depend on design Assembled after cold test: Will be not shipped to the US.

Design and procurement road map (cont.)

Component	Who's in charge	Design	Procurement/Assembly
Expansion joints and hoses	CMI	Pre-design and functional specification on going Design by contractor LHC specifications on materials are not interesting to contractors: we must revise them	Better in a single contract or we risk not being attractive to industry Conceptual specification Design by the supplier Fatigue testing of pre-series Series production Heat exchanger bellows + N Line hoses shipped to US, others welded at CERN? (tbd)
CLIQ and instrumentation feedthroughs		Local feedthroughs: <ul style="list-style-type: none"> • Can be cold tested with the magnet • Simpler test bench • Less connections if magnet must be removed • Local feedthroughs agreed for Instrumentation and CLIQ 	
Current leads <ul style="list-style-type: none"> • 35 A trim 		35 A leads after Q1 as they must go through cold diode	
<ul style="list-style-type: none"> • 16x120 A correctors • 2x200 A correctors 		Pre-study on-going. Not baseline yet	
Beam screens / BPM / Plug-in module / CWT	VSC	There is very little room for welding and cutting between beamscreen and cold mass lines: to be discussed at the level of HL-LHC integration BPM cables and feedthroughs to be routed	
Interconnects		Welding and cutting tools to be designed Mockups	Vacuum vessels sleeves ordered as single contract (needed for the string) Thermal shields and MLI to have shorter lead times Procurement of welding and cutting tools must be addressed as soon as the first design is done
Jacks		Will we need to design new jacks or can we use existing ones? Longitudinal adjustment range under discussion. Strategy to be discussed with SU	
Cryostating bench for SMI2		Will replace existing MS bench. Compatible with all WP3 cryostats + LHC MS SSS and long connection cryostats Design by contractor according to CERN functional spec.	1 tooling for CERN+ 1 tooling for US IT dispatch Nov 2017 Order placed: Feb 2018 + 12 months: Tool 1 installed and commissioned at CERN Feb. 2019 + 14 months: Tool 2 installed and commissioned at FNAL Apr. 2019

Test cryostat for MQXF proto

- Using LHC spare vacuum vessel
 - Dedicated service module for feedthroughs to be welded and cut off after the test
- New support posts required (shorter):
 - Collaboration with EP department for production in lay-up and autoclave.
 - Machined from G10 tube was studied: not ideal for transverse loads.
 - Alternative: machined from stainless steel (higher heat loads)
- Modifications to the cryostating tooling
- The vessel is too thin to support the cold mass weight: Reinforcement plates inside vacuum vessel
- **Definition of feedthroughs required to finish the design**



Thank you!