



Requirements of technical systems

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Outline:

- **Introduction**
- **Systems involved**
- **Cryogenic system**
- **Super-conducting bus bars**
- **Beam vacuum**
- **Other requirements**
- **Summary**



Introduction

- Technical Working Group for the DS collimators in pt.3
- 8 weekly meetings in last 2 months
- Chairs: A.Bertarelli+V.Parma
- Secretary: D.Ramos (minutes in <https://espace.cern.ch/dscollimator>)
- Participants: O.Aberle, R.Assmann, V.Baglin, A.Bertarelli, F.Cerutti, R.Principe, Th.Renaglia, D.Ramos, V.Parma, J.Ph.Tock, R.Van Weelderen
- Goal: review specifications, feasibility of cold and warm options for installation in the 2012 shut-down, and review integration within LHC technical systems
- Requirements in this presentation focused on the warm concept, “the 2012 option”
- Most of this content is part of an Engineering Specification under preparation (editor: Delio Ramos)



Applicable LHC documents

1. LHC-PM-ES-0002 v1.1, General Parameters for Equipment Installed in LHC, 1999
2. The LHC Quality Assurance Plan, <http://lhc-proj-qawg.web.cern.ch/lhc-proj-qawg/LHCQAP/>
3. LHC-LVW-ES-0004 v0.1, Vacuum Requirements for the LHC Collimators, 2003
4. LHC-VCC-CI-0001 v3, Supply of Seamless Austenitic Stainless Steel Tubes for the LHC Main Dipole and Quadrupole Superconducting Magnets, 2000
5. LHC-VSS-ES-0001 v1.0, Beam screens for the LHC arc magnets, 2002
6. LHC-LVI-CA-0001 v1.0, Functional Specifications for the Components of the LHC Arc Beam Vacuum Interconnects, 2001
7. LHC-VST-ES-0001 v1.0, Longitudinal cold to warm transitions for the beam vacuum system, 2002
8. Heat Load Working Group, <http://lhc-mgt-hlwg.web.cern.ch/lhc-mgt-hlwg/default.htm>
9. LHC-CRI Technical note 2002-05, Forces in the LHC interconnections, edms id: 346011 v3.
10. LHC-Q-ES-0001 v1.1, Dimensions, pressures, temperatures and sizing of valves and piping in the LHC machine cryostat and cryogenic distribution line, 2000
11. LHC-PM-ES-0001 v2.0, Voltage withstand levels for electrical insulation tests on components and bus bar cross sections for the different LHC machine circuits, 2004.
12. LHC-LI-ES-0001 v5.3, Arc cryomagnet extremities, 2005
13. LHC-GI-ES-0001 v1.0, Alignment targets, 1999.
14. LHC-LI-ES-0013 v1.0, Interconnection work package 0 – Preparation of interconnections: interconnection installation kits, 2003
15. LHC-G-ES-0007 v2.0, Alignment requirements for the jacks of the cryomagnets, 2000
16. LHC-G-ES-0009 v1.1, First positioning of the LHC cryo-magnets (Arcs and DS), 2001
17. LHC-G-ES-0010, The smoothing of the magnets of the LHC ring (final positioning), 2002

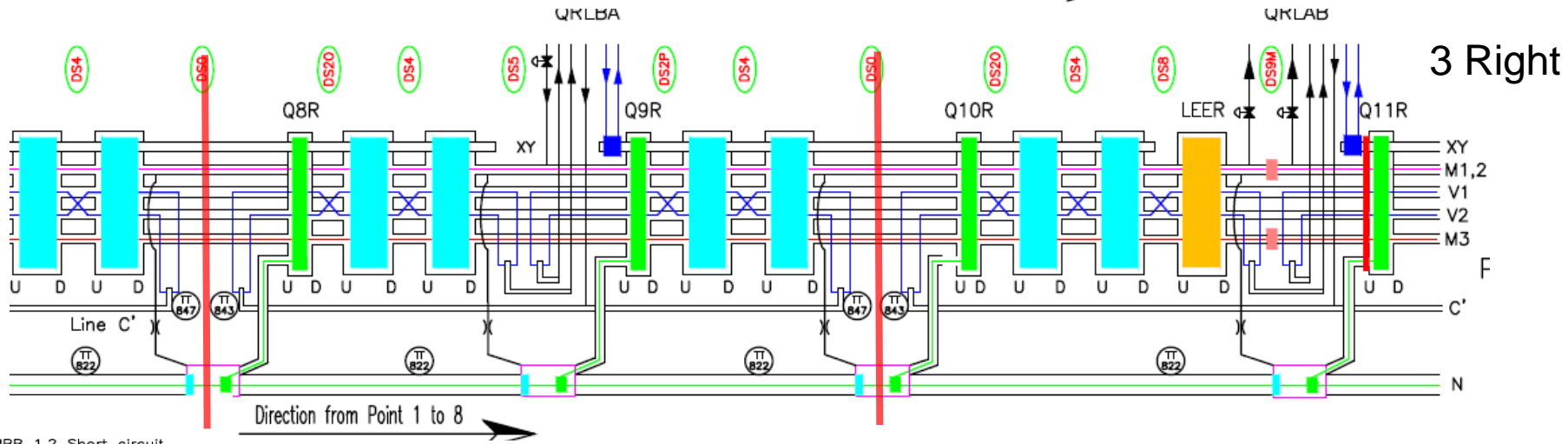
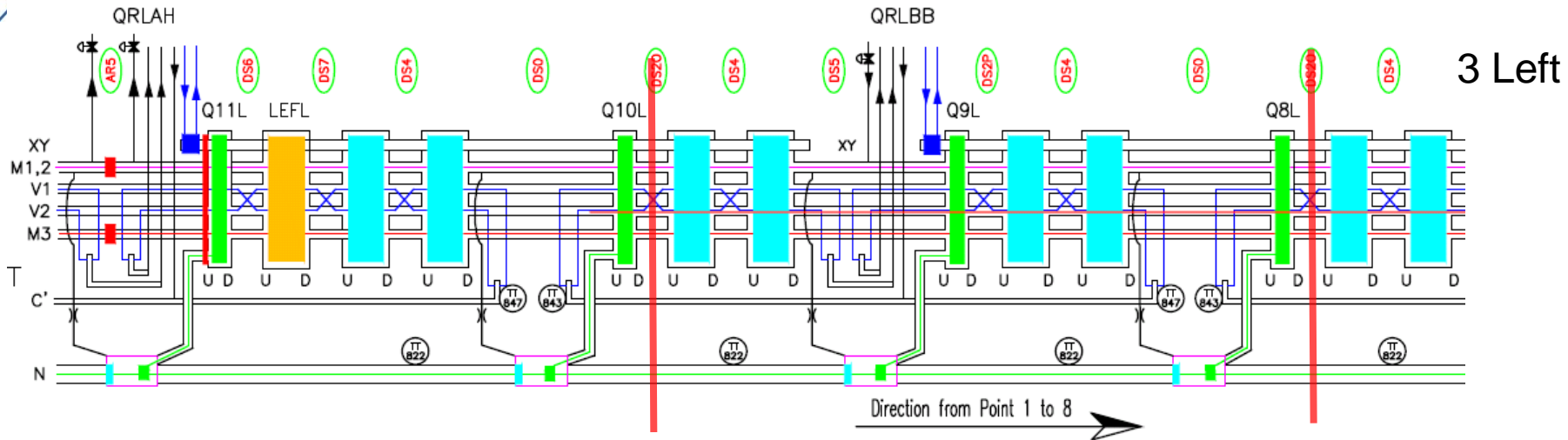


Cryostat strategy

- Reuse of all possible existing components and designs:
 - Minimise risk of unexpected problems
 - Reduce design effort and procurement lead-time
- Keep interconnects standard
 - Standard tunnel installation (tools, assembly procedures, QA)
 - Interconnection plane distance: 4'500 mm (margin included)
- Test all units in operating conditions in SM18 (power tests)
- Preparation for tunnel integration in SMI2 (as for magnets)
- Installation of collimators *in-situ* (can be staged)
- Design of cryostat should allow quick removal of faulty collimator (no sector warm up)



System integration in 3 Left and 3 Right



- MBB 1,2 Short circuit
- Main busbar plugs
- 6 kA busbar plugs (3 x 6kA)
- line-N busbar plugs (600 A)
- 6 kA connector (12/6 connections)
- 6 kA connector (3 connections)
- 600 A connector
- DFB Lambda plate(s)
- 600A Plug with restriction
- Heat-Exchanger
- Main busbars M3
- Main busbars M1 and M2
- Auxiliary busbars (600 A)
- 6 kA busbars
- X Hydraulic restrictions
- ⊕ Cooldown and fill valves
- ↗ Positive Slope
- ↘ Negative Slope
- U = UPSTREAM SIDE
- D = DOWNSTREAM SIDE

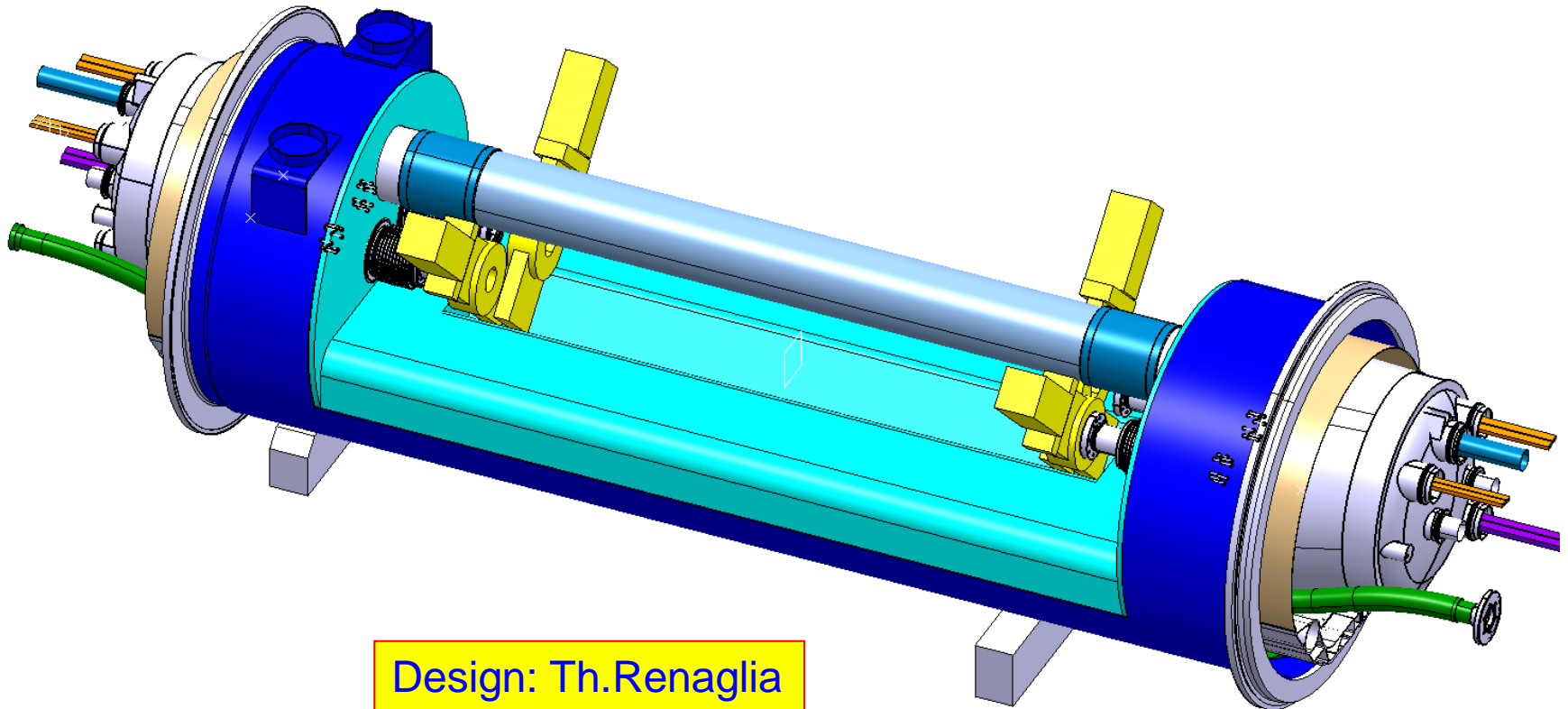


Systems to be “bridged”

Provide functional continuity to:

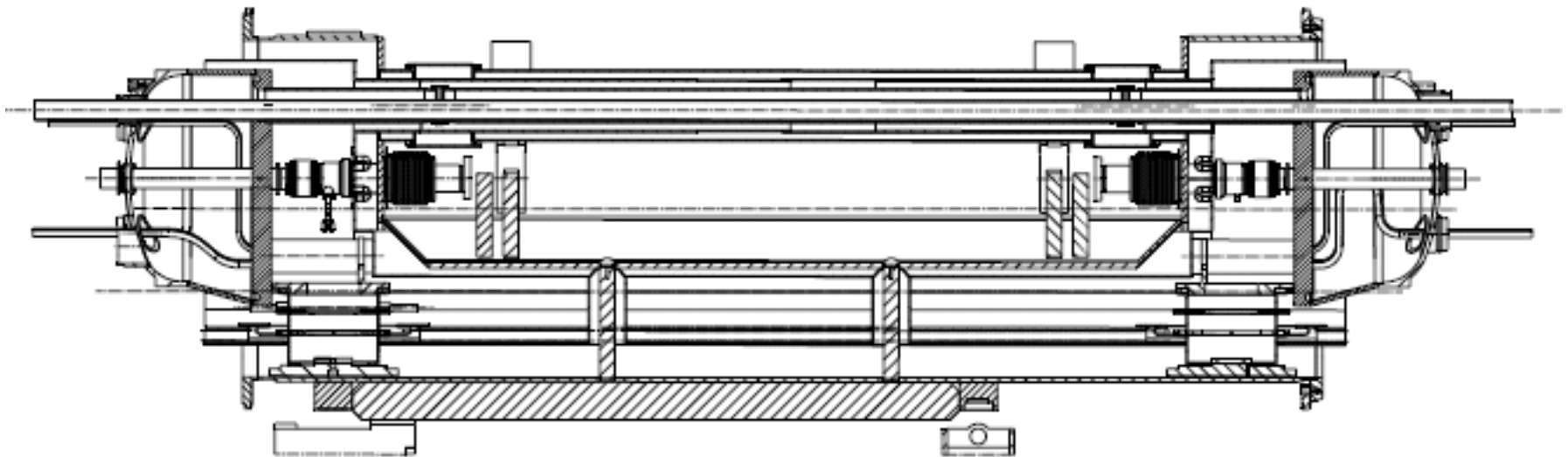
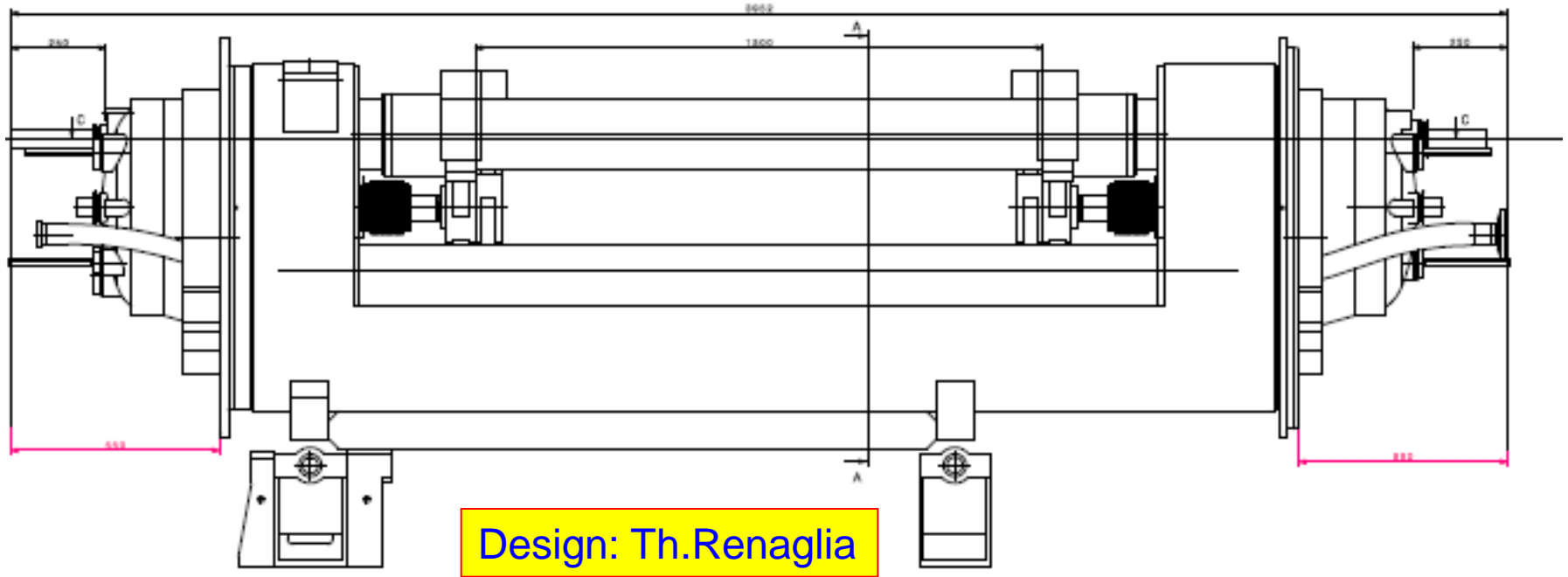
1. V1, V2 (beam lines)
2. M1, M2, M3 and corrector spools (busbar lines)
3. Aux.BB line (line N, only 600 A cables)
4. Pressurised HeII (line L)
5. Sub-cooled HeII (lines X, y)
6. C', KD1, KD2 lines (4.5 K) for IR3L; none for IR3R (but needed to thermalise cryostat components)
7. Thermal shield line (line E)
8. Insulation vacuum (line W)

The warm concept (*pre-study*)



Design: Th. Renaglia

The warm concept (*pre-study*)

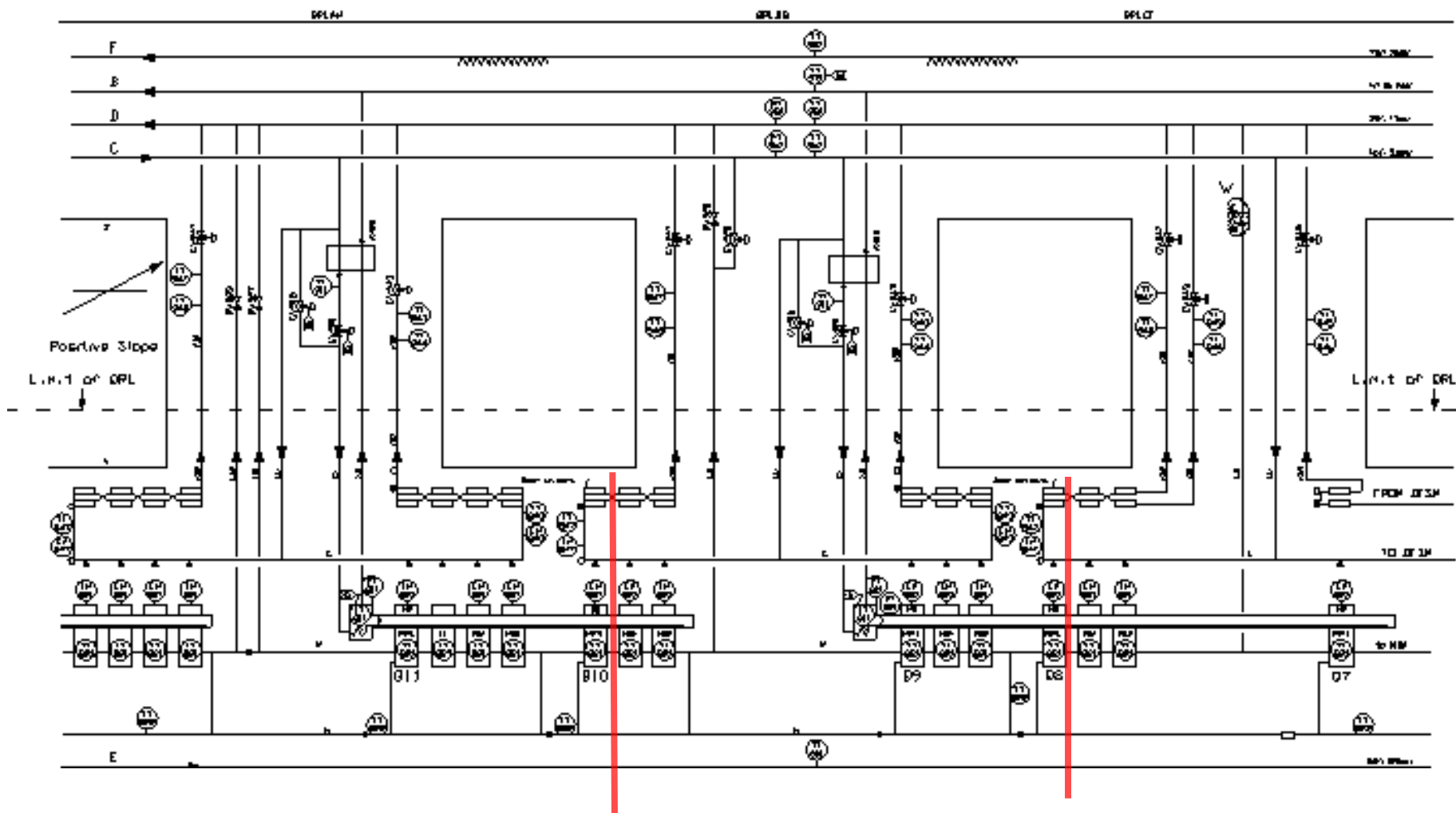


Cryogenic scheme DS3L

Cryogenic Distribution Line

See LHCLSR_0016

See LHCLSR_0039



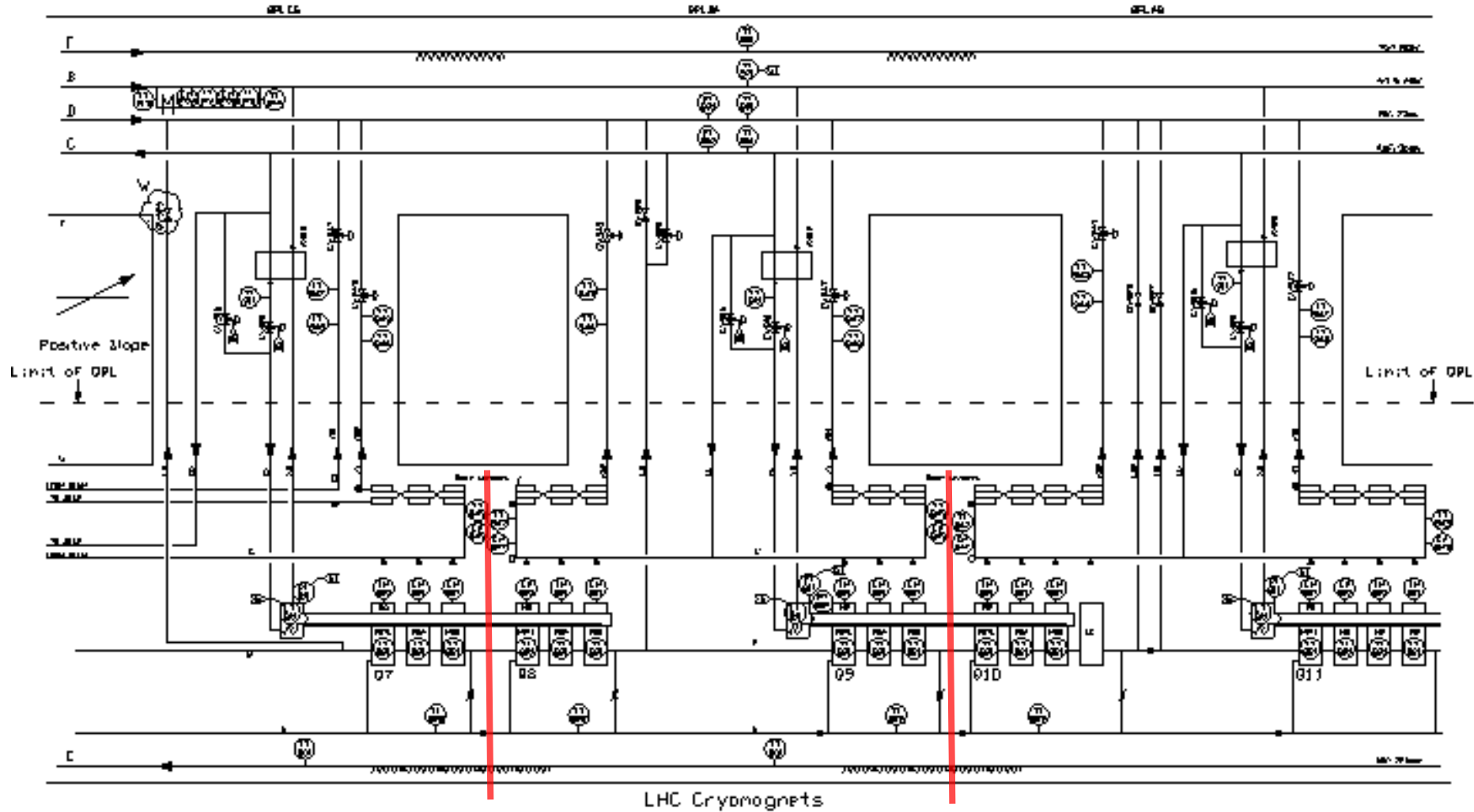


Cryogenic scheme DS3R

Cryogenic Distribution Line

See LHCLSOR_0040

See LHCLSOR_0016





Cryogenic specific requirements

(based on LHC-Q-ES-0001 v1.1)

Cold mass (envelope of pressurised static super-fluid He):

- Ensure a longitudinal total free flow passages equivalent to a frictional pressure drop less than, or equal, to the one of a single smooth circular tube of **50 mm** inner diameter
- Ensure a total free cross section of at least **60 cm²** (for T homogeneity over cell length and allow good T control)

Line X:

- Straight (no bends) to ensure continuous slope for liquid He flow
- Limit excessive local heat loads (static+dynamic) to avoid liquid dry-out
→ **HL < 0.78 W/m** (highest specific load in LHC @ ultimate)
- Not a heat exchanger in DS collimator → Cu not necessary

Lines C', KD1, KD2:

- Active cooling of supports posts and beam-screens in short cold-bores
- Different layouts in IR3L and IR3R to be coped with: **requires more detailed study**



Heat Loads budgets per cryostat (4.5 m)

The approach:

- Take specified HL budgets for DS (*ref. LHC Heat Load WG*)
- Estimate specific heat loads for DS: HL /meter
- Heat Load budgets per cryostat: HL/meter x 4.5 meters
- Add HL for for 4 Cold-to-Warm-transitions (*ref. LHC Heat Load WG*)
- Reduction of dyn. HL due to DS collimation not accounted for (conservative)

Table 4 – Heat load budget, 4.5 m long cryostat with 1.8 m long beam screen, including 4 CWT.

Design heat load [W]	Temperature levels		
	50-75 K	4.6-20 K	1.9 K LHe
LHC Nominal	45.1	14.0	2.5
% increase on DS budget	+5.6%	+3.6%	+2.6%
LHC Ultimate	45.6	21.3	3.2
% increase on DS budget	+5.5%	+2%	+2.6%



Temperatures and Pressures

(based on LHC-Q-ES-0001 v1.1)

		Cool-down/Warm-up		Normal operation		Magnet Quench	
Line	I.D. [mm]	T [K]	P [MPa]	T [K]	P [MPa]	T [K]	P [MPa]
1.9 K pressurized He vessel (Line L)	(2x80 +end vol. + vol. around line X)	293-1.9	1.2	1.9	0.13	30	2.0
Line N	50	293-1.9	1.2	1.9	0.13	30	2.0
Line X	54	293-1.9	IP = 0.2 OP = 1.2	1.8	IP = 0.0016 OP = 0.13	30	IP = 0.0016 OP = 2.0
Line Y	10	293-1.8	0.2	1.8	0.0016	30	0.0016
Line E	80	293-50	1.95	50 - 65	1.95	50-65	2.2
Line C'	15	293-4.6	1.65	4.6	0.36	4.6	0.36
Lines V1, V2	50	293-1.9	IP = vac. OP = 1.2	1.9	IP = vac. OP = 0.13	30	IP = vac. OP = 2.0
Lines K1, K2	3.7	293-4.6	1.65	4.6	0.36	4.6	0.36
Vacuum vessel W	890	293	vacuum	293	vacuum	293	vacuum

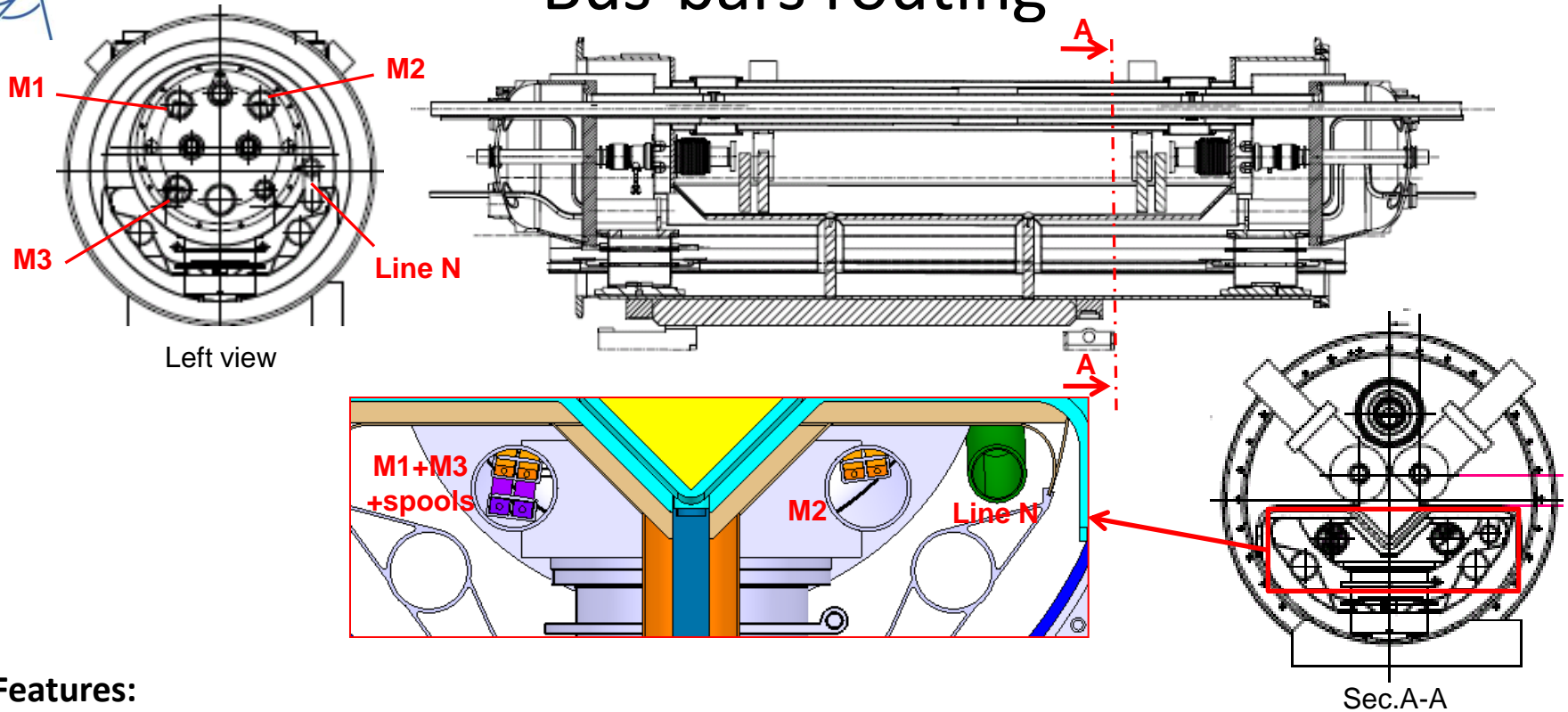


Operating, design and test pressures

(based on LHC-Q-ES-0001 v1.1)

	Normal operation	Design pressure	Test pressure	Maximum operating pressure	Safety device
Envelope	P [MPa]	P [MPa]	P [MPa]	P [MPa]	
1.9 K He vessel (and lines M)	0.13	2.0	2.5	2.0	Existing QV valves
Line N	0.13	2.0	2.5	2.0	Existing QV valves
Line X	IP = 0.0016 OP = 0.13	IP = 0.0016 OP = 2.0	IP = 0.5 OP = 2.5	IP = 0.2 OP = 1.2	
Line Y	0.0016	0.4	0.5	0.2	
Line E	1.95	2.2	2.75	1.95	
Line C'	0.36	0.36	2.5	1.65	
Lines V1, V2	IP = vac. OP = 0.13	IP = vac. OP = 2.0	IP = vac. OP = 2.5	IP = 0.1 OP = 1.2	Existing burst disks
Lines K1, K2	0.36	2.0	2.5	1.65	
Vacuum vessel W	vacuum	vacuum	N.A.	0.15	Existing DN200 valves on adjacent dipoles (longitudinal impedance to be checked)

Bus-bars routing



Features:

- Bus-bars in one piece (no intermediate connection)
- Final shaping during construction
- Limited thermal contractions to be coped with
- Supports to withstand electromagnetic forces
- Insulation to comply with spec. LHC-PM-ES-0001
- No diagnostics instrumentation required (so far)
- Stray field to beam to be further investigated. Need EM shielding?

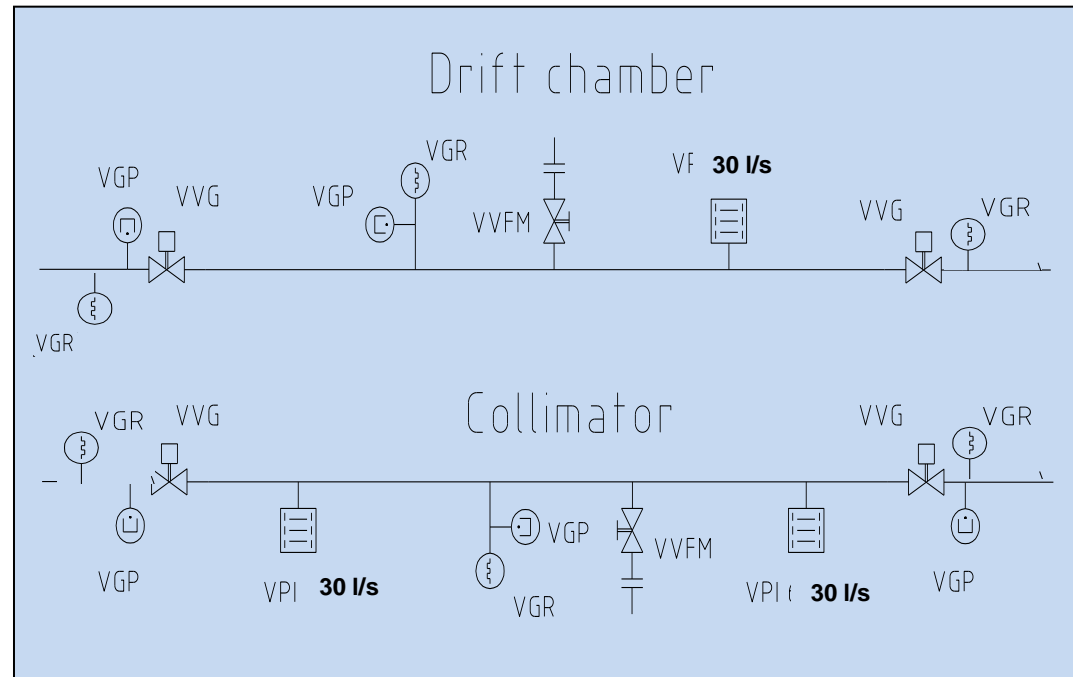
Magnet circuit	Bus bar quantity x current
MQ	4 x 13 kA
MB	2 x 13 kA
Corrector magnets in dipoles	8 x 600 A
	4 x 120A
	8 spares
Corrector magnets in SSS	42 (or 48 IR3R) x 600A



Beam vacuum

(based on LHC-LVW-ES-0004 v0.1)

- Instrumentation layout
 - 4 Sector valves (interlocked with Penning gauges)
 - Drift chamber: NEG + Ion pumping (30 l/s) ; Penning/Pirani gauges
 - Collimator: ion pumping 2x30 l/s; Penning/Pirani gauges
- Cold bores:
 - $T < 3.3$ K (H_2 cryopumping)
 - Beam-screens (5K-20K)
 - Thermal exp.compensation
- Cold-to-Warm transitions
 - Identical to LHC “standalone” SSS





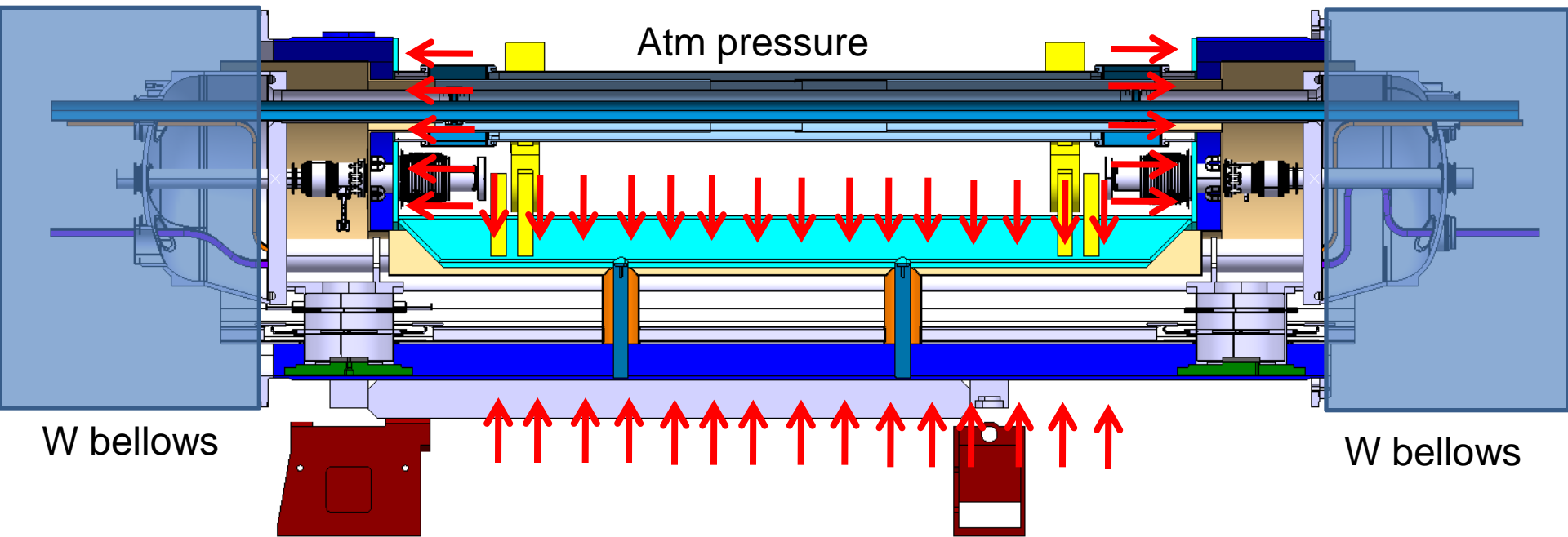
Pressure/vacuum forces and alignment

- Unbalanced pressure/vacuum forces and bellows forces must be considered
- Vacuum forces on (identical) W bellows are balanced on cryostat but effect on dimensional stability of vacuum vessel (not axial symmetric) must be checked
- Transverse positioning accuracy of the cold mass in the cryostat not very stringent ($\sim \pm 0.5\text{mm}$?)
- Transverse positioning stability in the order of few tenths of mm (TBC)
- Cryostat supporting and alignment independent from collimator alignment

Bellows forces in the interconnects (corresponding pressure in brackets [MPa]).

Bellows type	Maximum axial force [N]		Maximum transverse force [N]	
	293 K (compression)	1.9 K (extension)	293 K	1.9 K
M1, M2 & M3	2'560	6'240	910 (0) 1'360 (2.0)	1'010 (0) 1'130 (0.13)
QBX (heat exchanger bellows)	990	2'010	130	150
RF Contract	0	720	30	65
Total for the cold mass	8'670	22'170	2'920	3'310
E	0	8'775	Small w.r.t. the other forces	
W	1'870*	1'870*	2'680	2'680

*Forces resulting from 5 mm assembly tolerance, not from temperature variations.



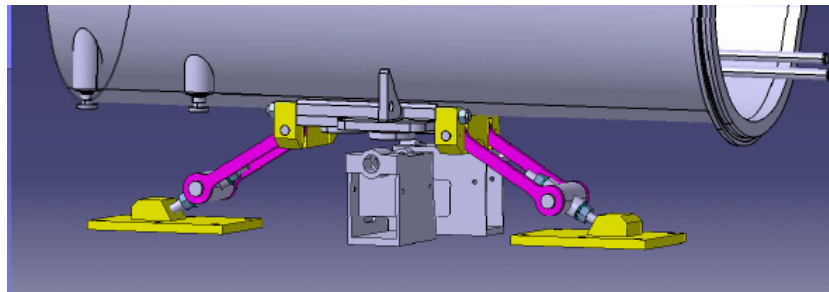


Cryostat jacks and Interconnect forces

(based on LHC-HBQ-ES-0001.00 rev. 1.0)

- Reuse jack supporting system of LHC
- Mass load of cryostat relatively low (16'000 N)
- Bellows forces at interconnects give risk of lift-off from jacks → ground anchoring needed (like SSS with vac.barriers)

Load case	Maximum forces [N]	Direction	Comment
Cryostat load	16'000	Vertical (-z)	
1 interconnect (longitudinal compression +16mm)	12'700	Longitudinal (y)	M1,M2,M3,QBX,E (W not included)
2 transverse misaligned interconnects (5mm)	8'430	Transversal (x,z)	Assembly tolerances/realignment
2 W bellows longitudinal compressed (+5mm)	3'000	Longitudinal (y)	Assembly tolerances/realignment
2 W bellows misaligned (5mm)	4'600	Transversal (x,z)	Assembly tolerances/realignment
Maximum interconnect forces	15'700	Longitudinal (y)	
	13'030	Transversal (x)	
	13'030	Transversal (z)	Risk of lift-off



SSS ground anchoring



Testing and preparation for tunnel

- Construction testing:
 - Pressure test (construction integrity)
 - Dimensional checks (mechanical interfaces)
 - Leak test
 - Electrical tests: continuity, hi-pot
- Qualification testing @ cold (SM18):
 - End return box (design/supply, *new WP not foreseen so far*)
 - Duration: 4 wks/unit (no contingency!): (1 w connect , 2 w C/D +test, 1 w W/U and disconnect)
 - Envisaged tests:
 - Leak-tightness @ cold (insulation+beam vacua)
 - Hi-pot tests
 - Powering tests (ramping cycles)
 - ...(tbd)
 - Diagnostics instrumentation (T gauges, Vtaps?...): needs to be clarified
- Preparation for tunnel (SMI2): ~ 2 wks/unit (no contingency!)
 - Preparation of cold beam tubes (cleaning, beam-screens)
 - Preparation of interconnect extremities



Other requirements

- Radiation shielding needed?
 - Lead shielding was a (tough!) requirement in the LHC CC
 - Needed in the DS cryostats? To be decided by experts
- Reliability:
 - Cryostat shall be maintenance-free
 - Collimator shall be removable in-situ and replaced by drift tubes
- ...



Summary

- The study carried out in the last two months allowed reviewing specifications and feasibility of the cold and warm options for DS collimators to be installed in the 2012 shut-down
- Warm option is the “2012 solution”
- Integration needs for the cryostats within LHC technical systems could be reviewed and have led to additional requirements
- No technical show-stoppers have been identified so far
- ...but this was only a pre-study, more work is still needed (e.g. magnetic and radiation shielding)
- An Engineering Specification for the DS collimators is in progress and will be the basis for the design of the DS collimators
- The technical challenge is certainly at reach but the engineering and construction effort is not to be underestimated
- The **cryostat should NOT be underestimated**, it is far from being an “**empty cryostat**”...

Let's not repeat the same mistakes
made on the LHC Connection Cryostats !



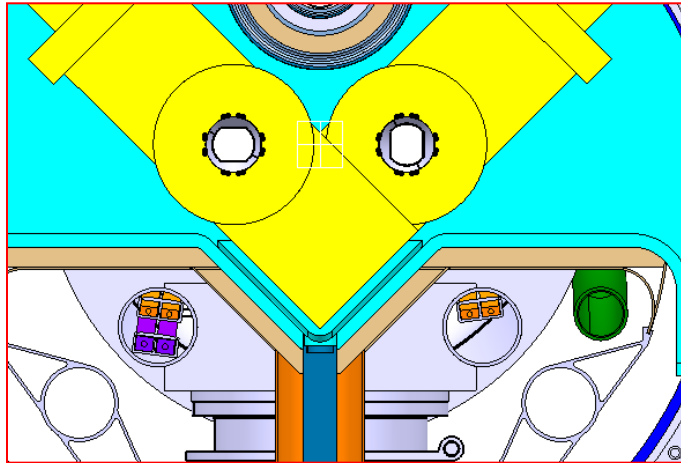
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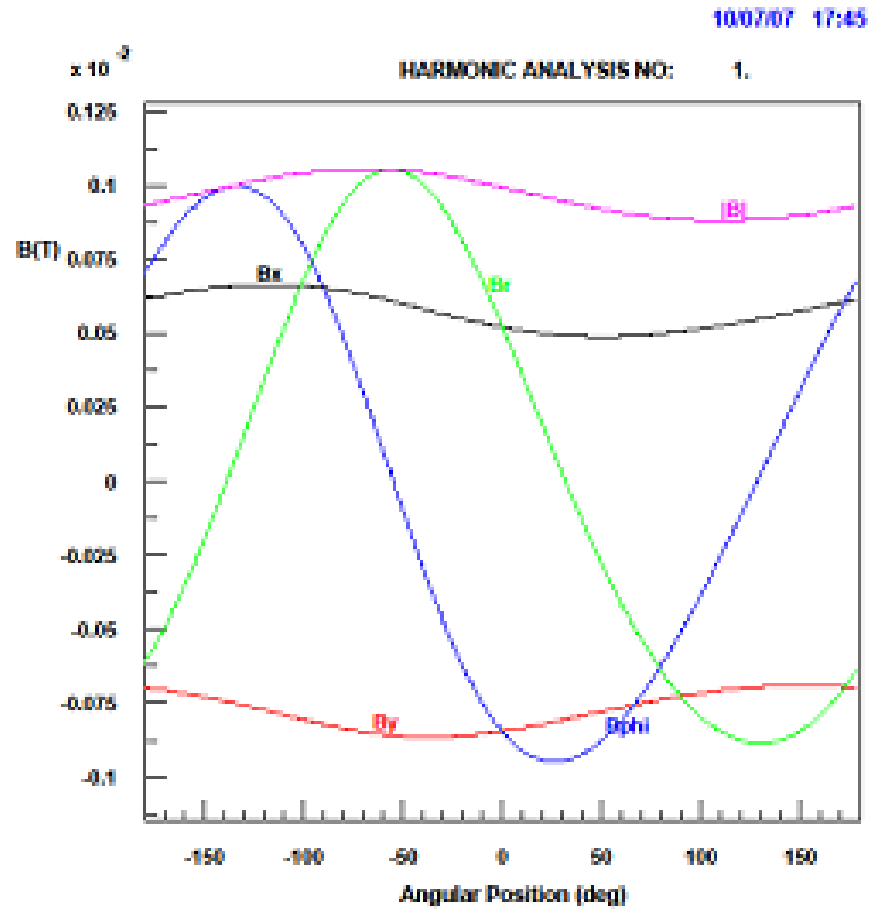
Spare slides

BB stray field to beam (*first results*)

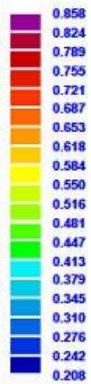
Roxie calculations: S.Russenschuck



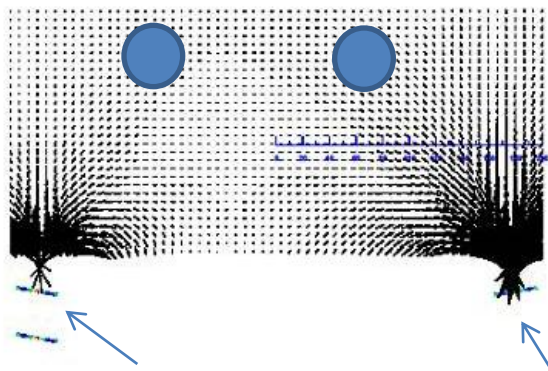
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D Quad+dipole BB

F Quad BB