RFD cryomodule design (LHC-prototype)

8th HL-LHC Collaboration Meeting -18/10/2018

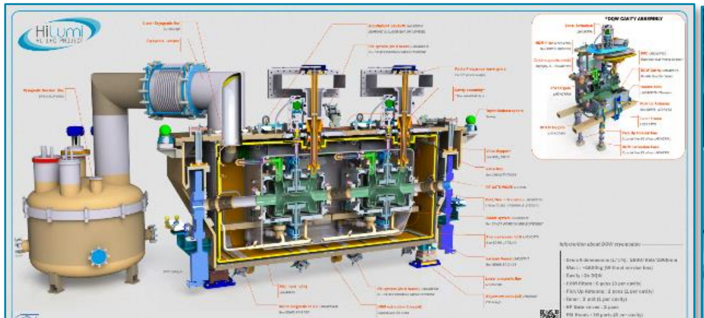
Teddy Capelli on behalf of the WP4 collaboration in particular :
STFC Daresbury, CERN EN/MME, ATS/DO, BE/RF, EN/ACE, EN/SMM, HSE, TE/CRG, TE/VSC.

Review of previous design (DQW for SPS)

Hi-Luminosity LHC
WP4 - CRAB CAVITY
Prototype DQW for SPS

- Mechanical design 
- Review and validation of manufacturability
- Redaction of technical specifications
- Manufacturing drawings
- Tests of prototype parts

- Redaction of assembly procedures
- Follow up of assembly
- Review / Bilan



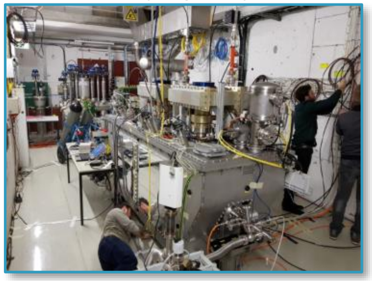
Overview of DQW Cryomodule for SPS

Cryostating - SM18 - 2017

Machining of cavity - 2017

Cavity string assembly @ SM18 - 2017

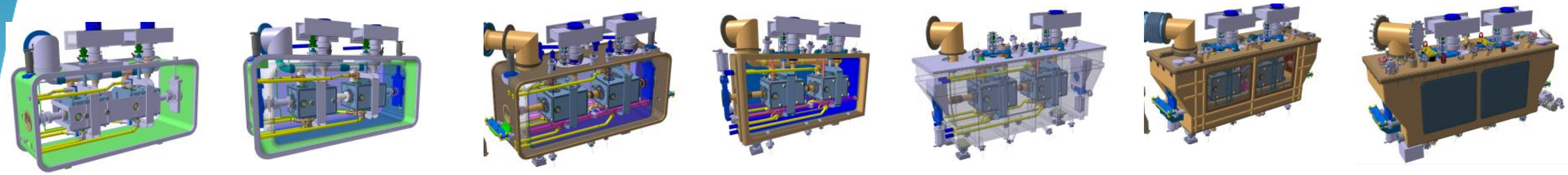
Assembly sequence - DQW Cryomodule for SPS

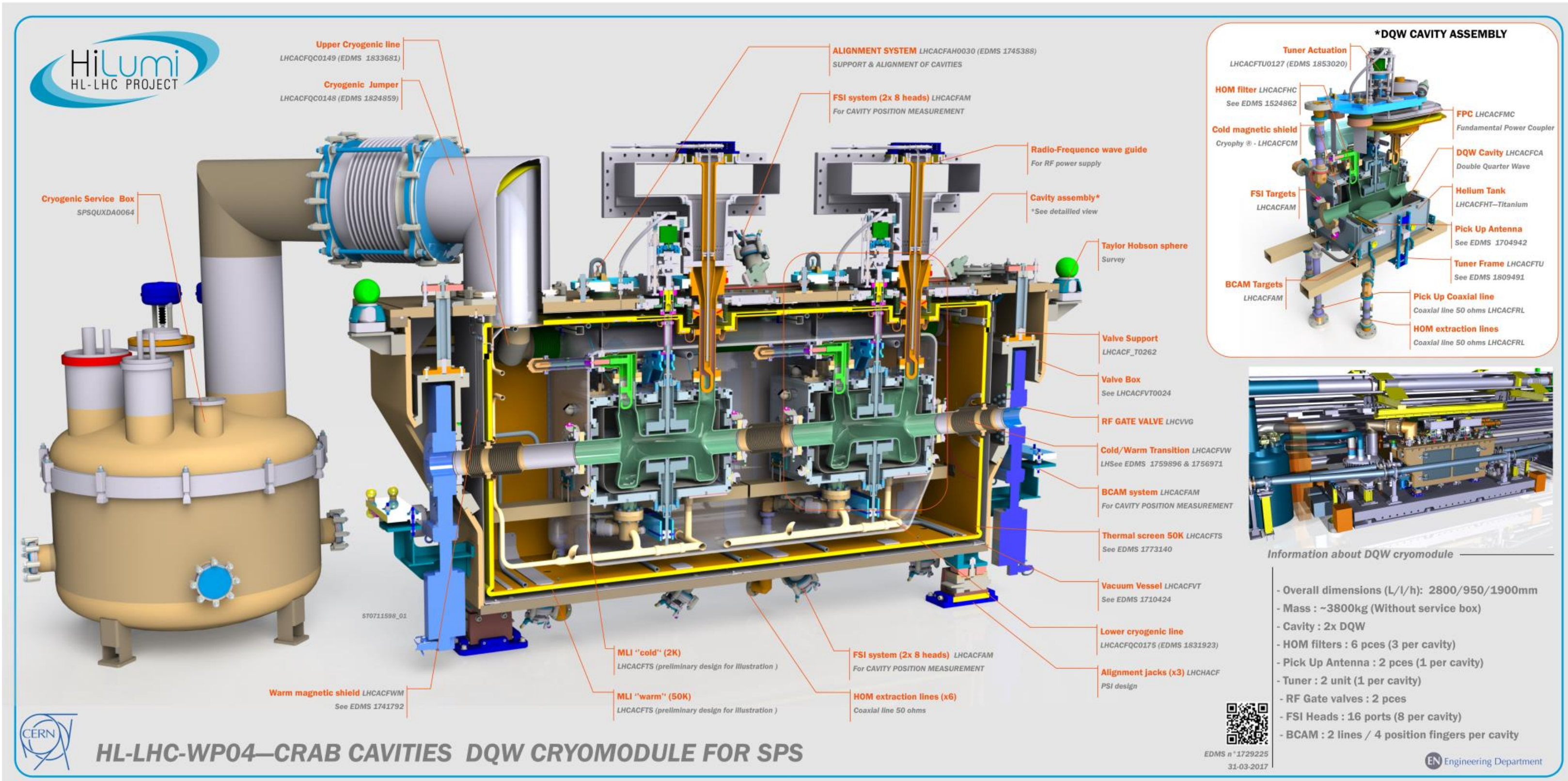


SM18 Bunker before CRAB test - 2017

Key numbers :
Total parts : ***13450*** *(without tooling)*
Quantity of unique parts : ***1043***
Quantity of drawings : ***690*** *(+220 tooling)*
*Hours spent for design : ~**15000** hours*
11 different designers over ~3 years
Over 80 people involved in the design

Review of previous design (DQW for SPS)





Modifications / differences of RFD cryomodule

- Cryomodule for RFD cavities
- LHC-Prototype
- Improvement with respect to **lesson learnt** from first DQW cryomodule
- Assembly at STFC – Daresbury (UK)

DESIGN ACTIVITIES

RFD Cavity (Raphael Leuxe / Laurene Giordanino – CERN EN/MME)
- RFD Cavity length : 919mm (SPS/DQW Cavity = 660mm) -> + 520mm !
- Tooling for forming
- Welding sequence
- ...

Cryostat vessel design
- Replace oring gasket by welded connection everywhere it is possible
- Vacuum barrier in the jumper

Beam vacuum (EN/MME – TE/VSC)
- Second beam pipe + RF valves
- Beam screen in second beam pipe
- Rf bridge for bellows
- Vacuum instrumentation definition and integration
- Vacuum chambers + bellows

Cryogenic (EN/MME – TE/CRG)
- Biphase line + New cooling lines (Beam screen cooling 4.5K, HOMs..)
- Safety devices (safety valve, pressure measurement..)
- Exchangeability of level gauges
- New thermal screen **(CERN / UKRI STFC)**
- Thermal intercepts
- Cold warm transition (definition of thermal budget and pre design)
- MLI design
- Jumper with vacuum barrier

Tooling (P.Minginette CERN EN/MME / E.Jordan UKRI STFC)
- Tooling for welding of cavity
- Definition and design of tools for RFD cryomodule assembly
- Adaptation of design to existing assembly tools

Tuner (Kurt Artoos / Joanna Swieszek – CERN BE/RF)
- Frame adapted from DQW design
- Double pipe + thermalisation – **Change of design**
- Actuation - **Modification**

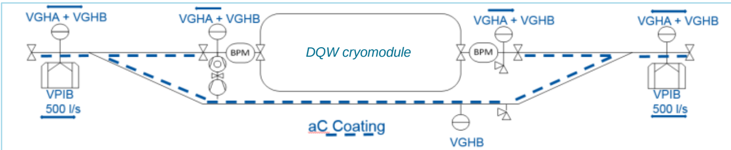
Radiofrequency equipment (Sebastien Calvo / Frida Eriksson – CERN BE/RF)
- HOMs and Antenna design for manufacturing
- RF coaxial line for HOMs and pick up

Support and alignment (EN/MME – EN/SMM - STFC)
- Cavity support and alignment system
- Cryomodule support and alignment
- FSI definition
- Temporary support for transport

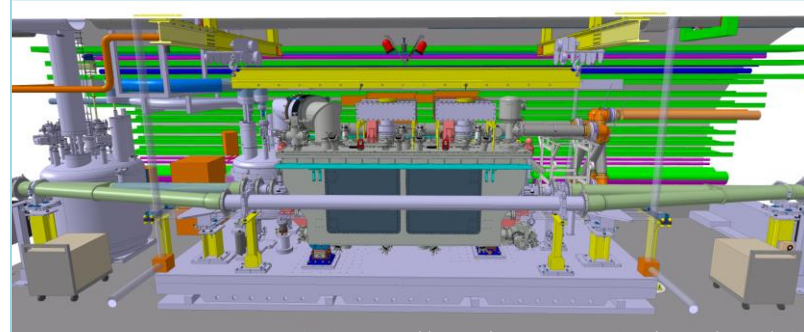
Instrumentation
- Definition and integration of instrumentation (T°, Mag sensor, ..)
- Rooting of cables.

Magnetic shield (N.Templeton UKRI STFC)
- Design and integration of cold magnetic shield
- Design and integration of warm magnetic shield

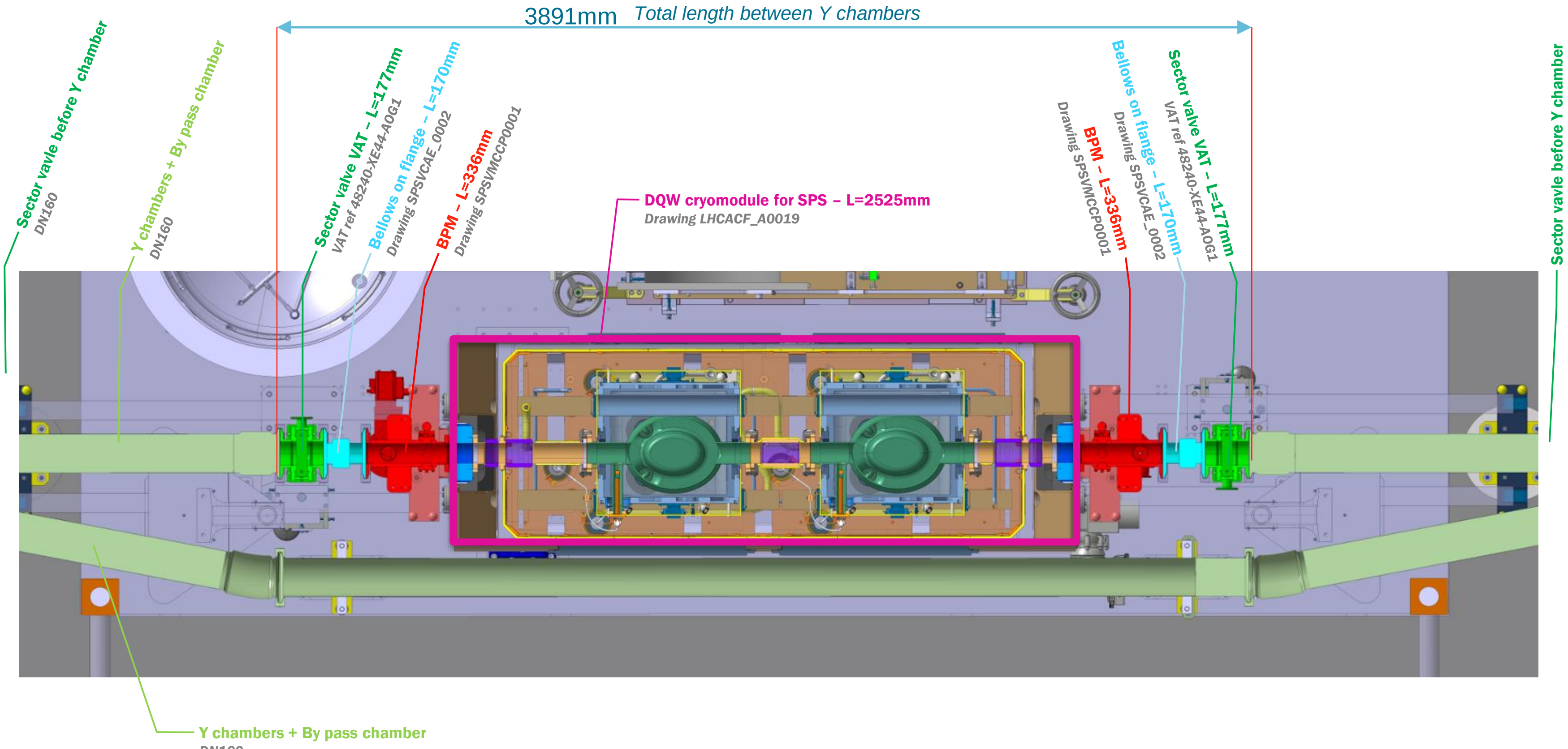
SPS test stand integration



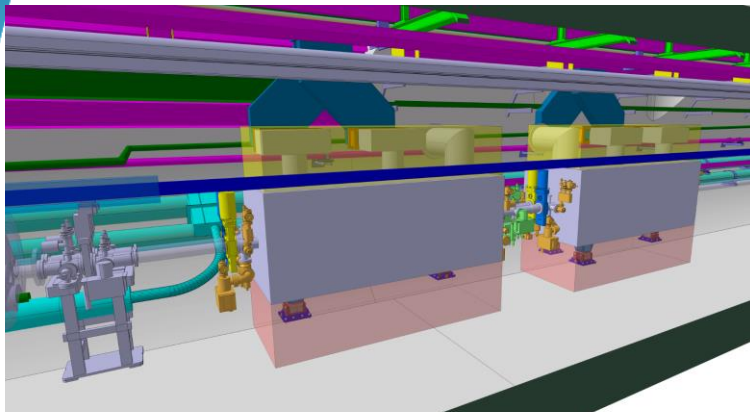
*SPS beam vacuum layout for test stand – courtesy **Chiara Pasquino TE/VSC***

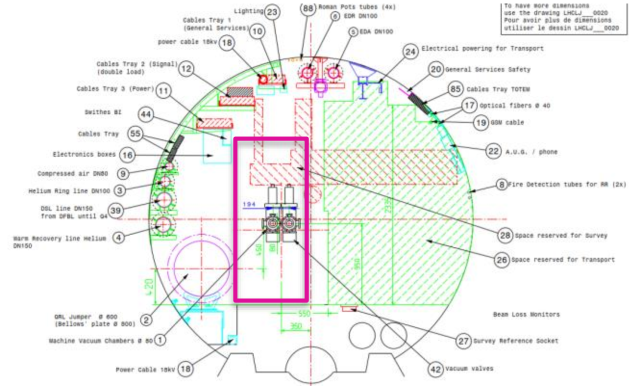


SPS test stand integration – courtesy S.Mehanneche EN/ACE

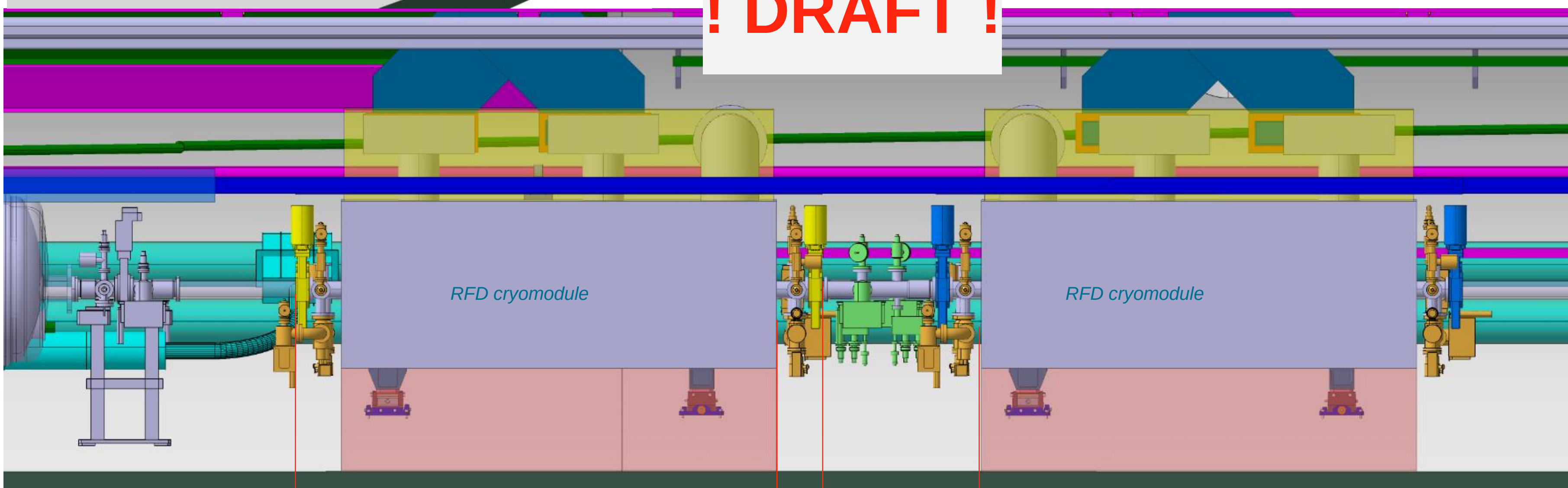


LHC integration – preliminary study





! DRAFT !



~3200 mm (valve to valve)

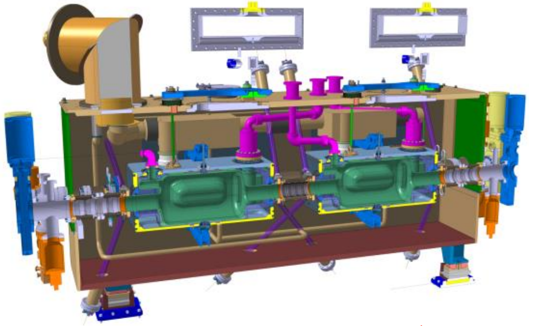
~1250 mm

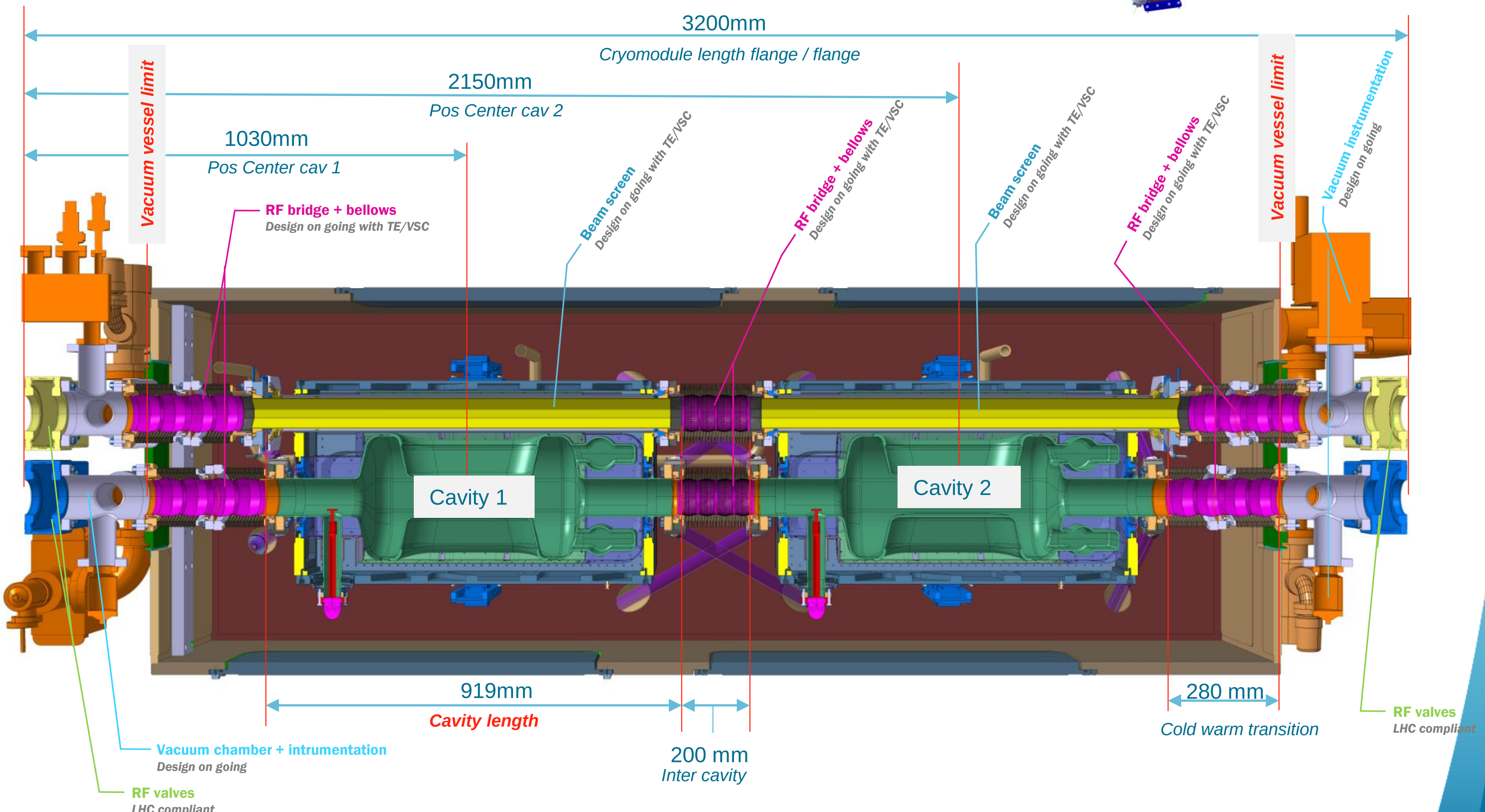
Interconnexion

See slide #10

LHC integration– courtesy ***M. Gonzalez de la Aleja – CERN ATS/DO***

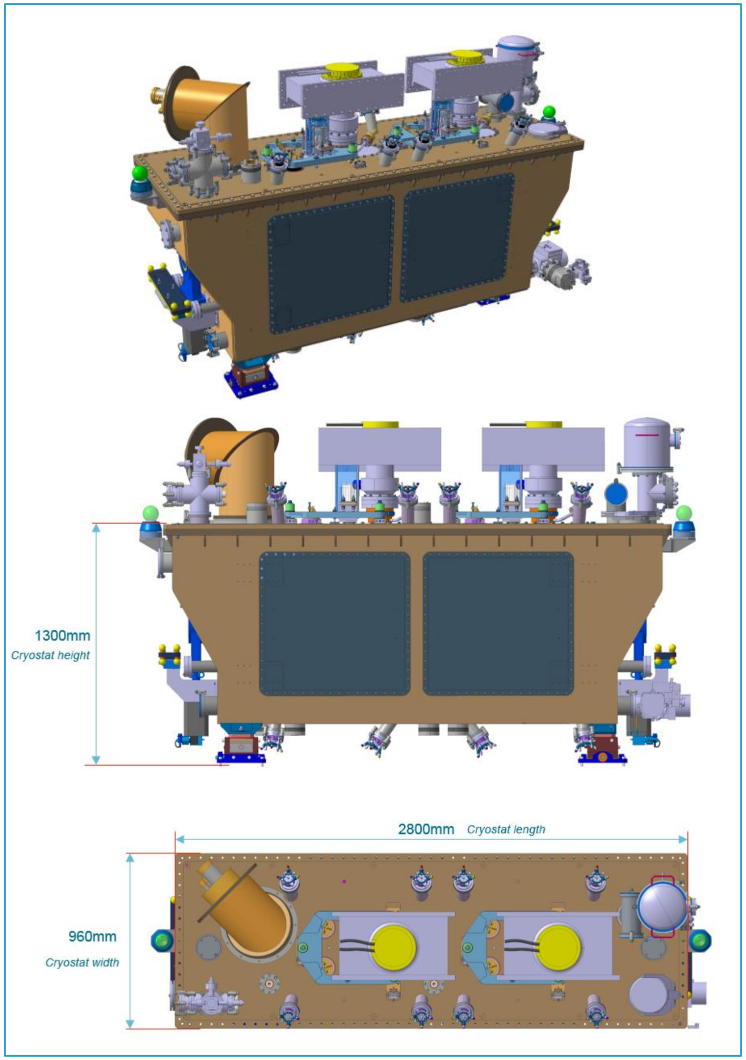
Beam section of RFD Cryomodule



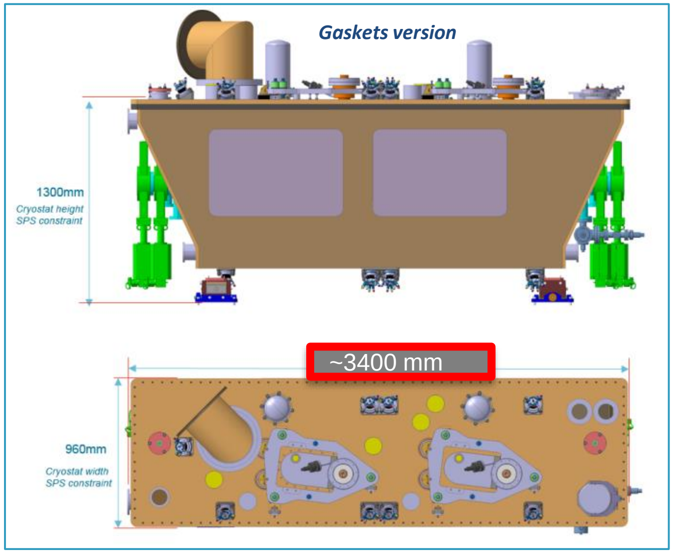


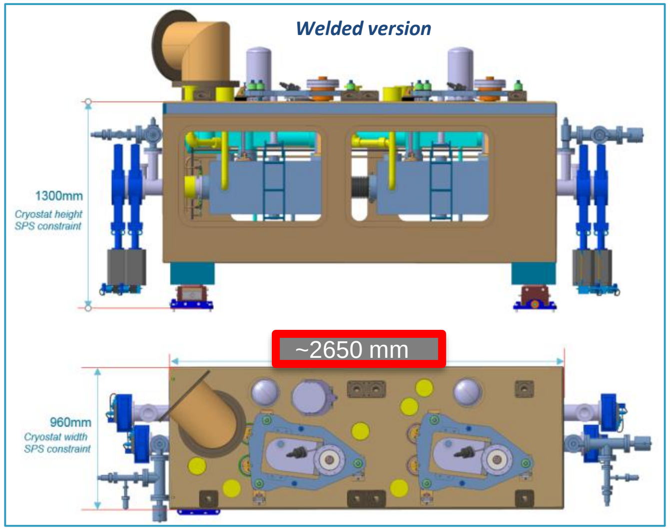
Cryostat vessel design

DQW prototype design



RFD design





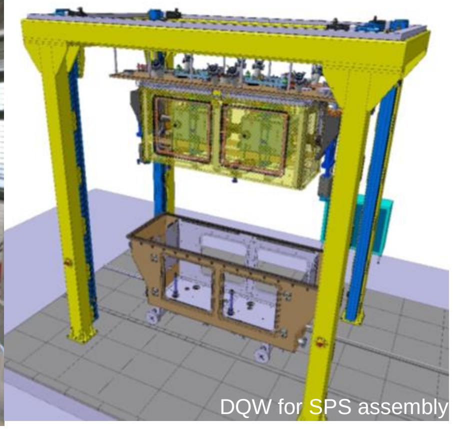
Vacuum vessel– welded concept

- Welded concept inspired from LHC DFBs
- Remove large gaskets (that cannot be repaired in the tunnel)
- Reduce the size of the VT (also improve its stiffness and reduce total weight)
- All the leak tight welds are accessible from outside

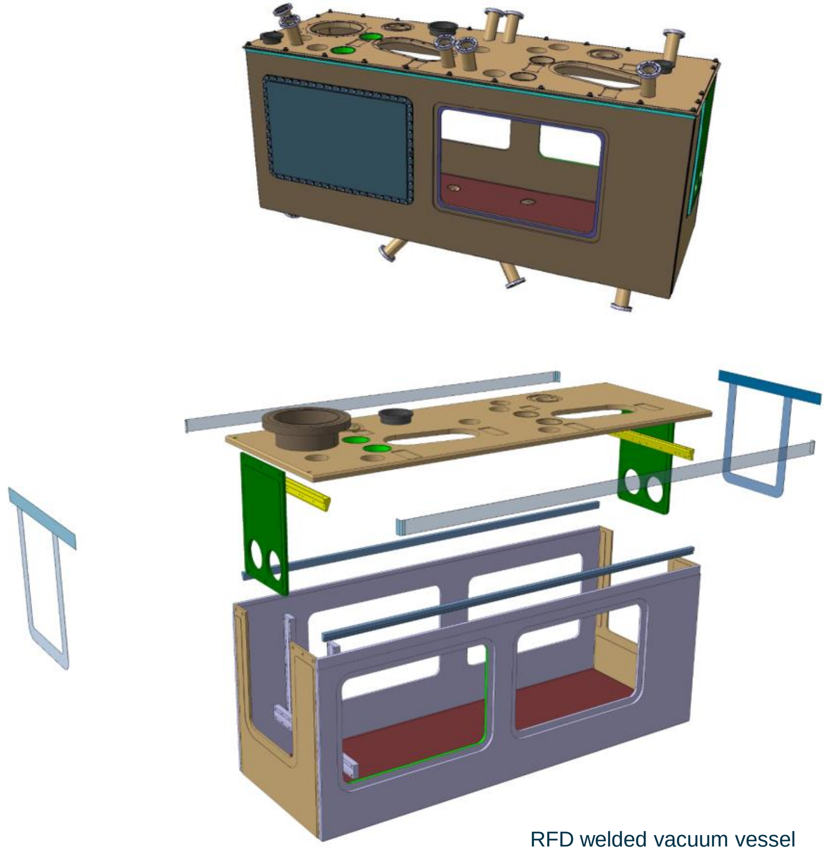
Remaining points to be studied

- Intermediate leak test really complex
  (possibility to use a gasket for test – Under study)
- Assembly sequence

DQW for SPS assembly



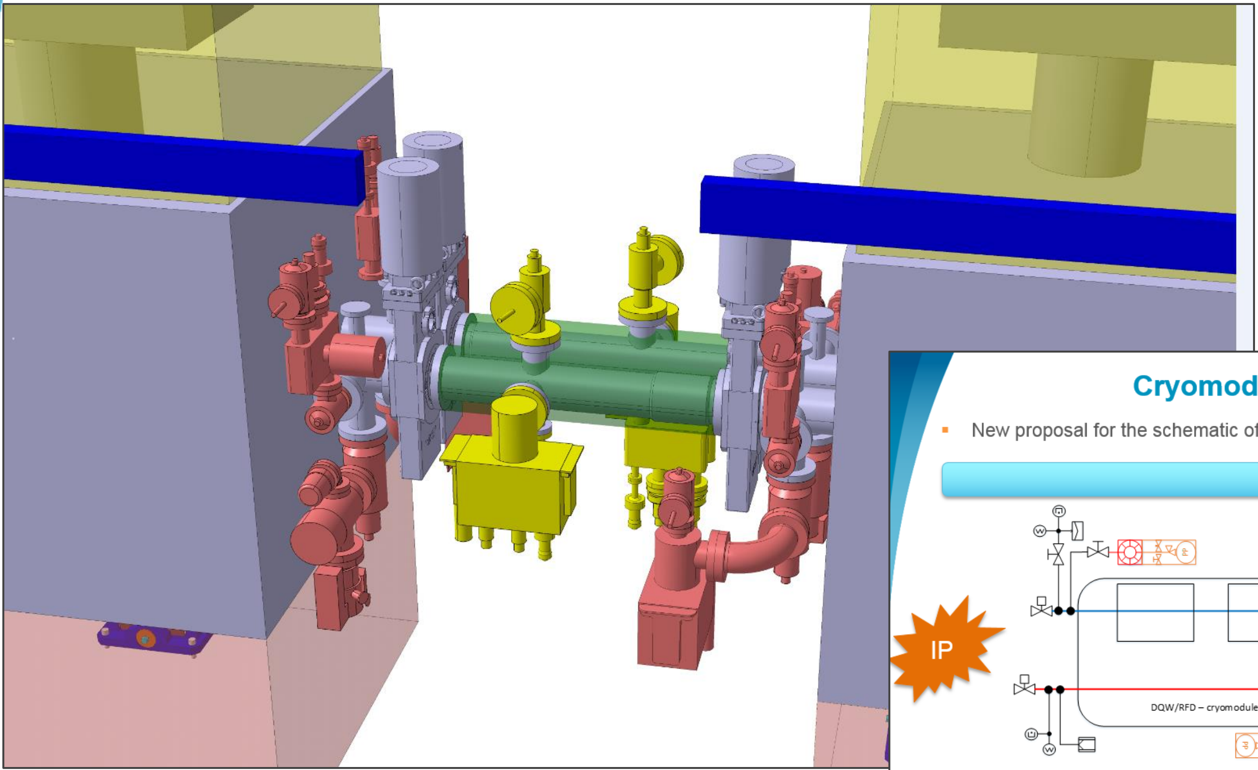
DQW for SPS assembly



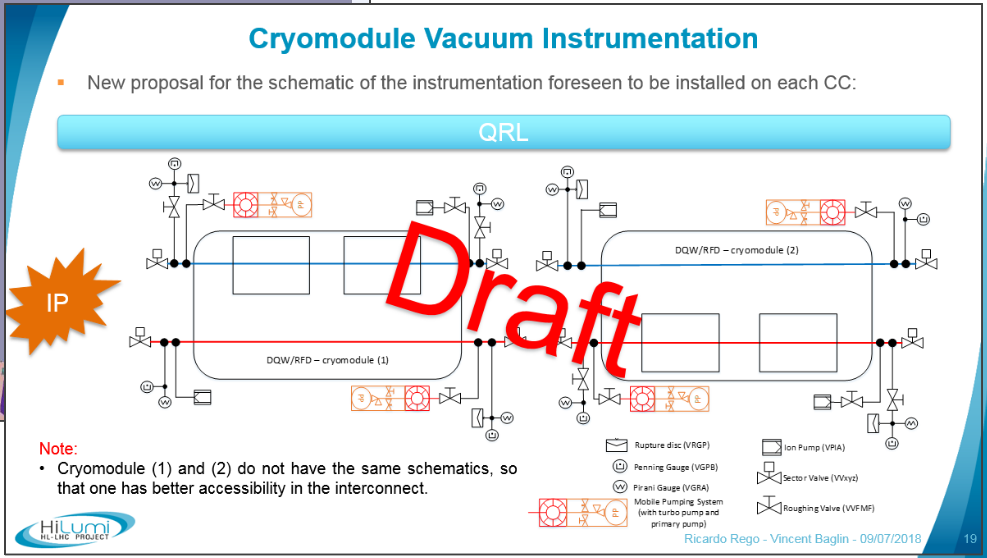
RFD welded vacuum vessel

Beam vacuum instrumentation & interconnexion

- Vacuum instrumentation to be added on both beam lines
- Interconnexion under study (R. Tavarez Rego CERN – TE/VSC)
- Support of interconnexion linked to cryomodule



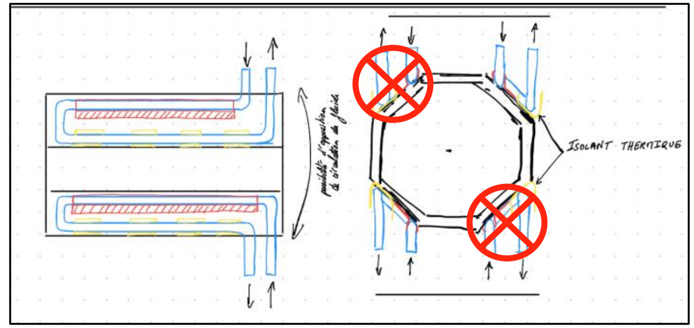
Study of CRAB Cryomodule interconnexion for LHC
Courtesy : N.Peray CERN – R.Tavarez Rego CERN

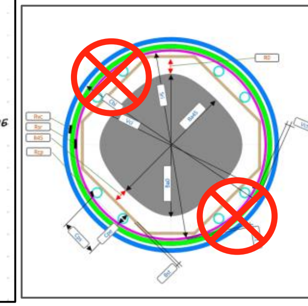


Draft of instrumentation for preliminary integration study
Vincent Baglin – Ricardo Rego CERN

Beam screen

- Cold bore <3K (for cryo pumping)
  (HL-LHC design report V.01 §12.6)
- Beam screen actively cooled (4-20K)
- Need a new cryogenic circuit
- Maximize the beam aperture
- Limited room inside the cryomodule (cold bore max aperture = 84mm)

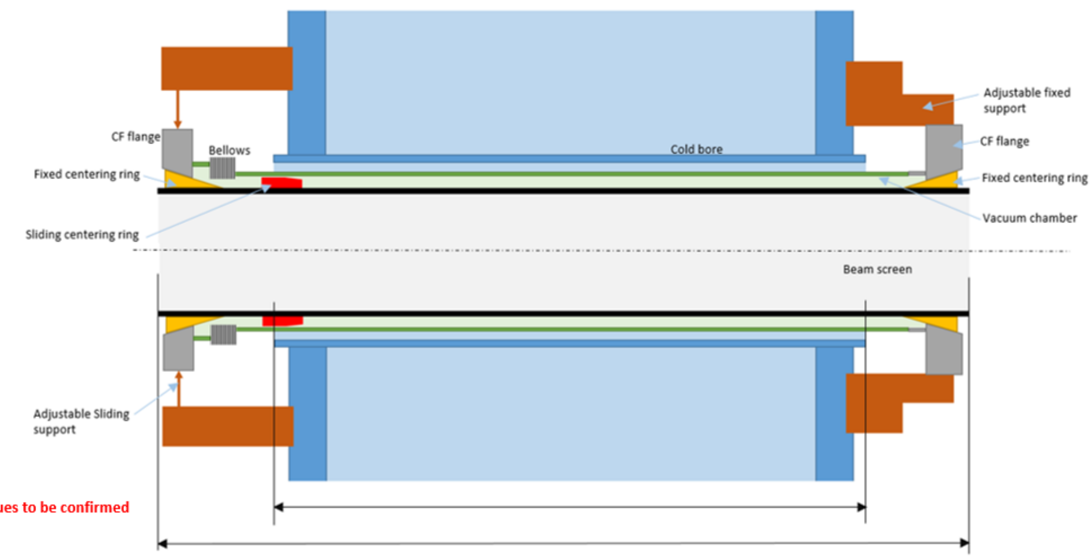




#	Name	Type	Designation	Value		
			COLD BORE			
1	Cbi	shape	Cold bore internal diameter	84	mm	
2		shape	Cold bore cylindricity	0.3	mm	
			VACUUM CHAMBER			
3	Rvc	Room	Room between Cold bore / Vacuum chamber	0.5	mm	Radius
4	Vci	Dim	Internal diameter maxi	79.3	mm	Calculated va
5	Vct	Dim	Vacuum chamber thickness	1.5	mm	Radius
6		shape	Thickness tol	0.05	mm	
7		shape	Cylindricity	0.3	mm	
8	VcNom	Dim	Internal nominal diameter (calc from VCI)	79.65	mm	Calculated va
			CF FLANGE			
9		Shape + po	Position of positionning shape WRT out pipe	0.1	mm	
10		Pos	Welding with pipe tolerance	0.5	mm	
			FIXING RING (POS BEAM SCREEN IN CF FLANGE)			
11		Shape + po	Positionning shape tolerance WRT Octogone	0.2	mm	
			SLIDING RING (in contact with cooling pipe)			
12	Rsr	Room	Minimum room with internal vacuum chamber Ø	0.4	mm	Radius Calc.
13	Sri	Auto	Sliding ring internal diameter mini	76.900	mm	Calculated va
14	Srt	Dim	Thickness	0.5	mm	
15		Shape	Shape tol	0.1	mm	
16		shape	Thickness tol	0.05	mm	
16b			Internal nominal diameter (calc from Sri)	77.050	mm	Calculated va
			COOLING PIPE (only impact 45°)			
17	Rcp	Room	Minimum room with sliding ring	0	mm	
18	Cpe	Dim	External diameter	4.76	mm	
19		Shape	Tolerance on external diameter	0.05	mm	
20		Position	Position of pipe on beam screen	0.5	mm	
21	Cps	Dim	Pipe entraxe	15	mm	
			OCTOGONAL BEAM SCREEN			
21	Bst	Dim	Thickness	1	mm	
22		Dim	Coating	0.075	mm	
23	BsH	Dim	Vertical/Horizontal aperture mini	68.267	mm	Calculated va
23b			Internal nominal diameter (calc from BsH) befo	68.967	mm	Calculated va
24	Bs45	Dim	45° aperture mini	62.732	mm	Calculated va
24b			Internal nominal diameter (calc from Bs45) befo	63.432	mm	Calculated va
25		Shape	Tol.on thickness	0.05	mm	
26		Shape	Tol.on shape	0.5	mm	
			BEAM			
27		Dim	Vertical and horizontable	57.5	mm	
28		Dim	45°	52	mm	
			Helium tank + cavity position and alignment tol			
29		Position	Position of cavity magnetic center	0.5	mm	Diameter
30		Position	Alignement tol 0.3° along beam axis	1	mm	Radius
31		Position	Cold bore position tolerance WRT Cavity magnetic center	1.75	mm	Radius
33		Position	Ground motion	0.75	mm	Radius
			tot	3.75		
			RESULTS			
34		Room	Room beam/beam screen H & V	7.016618	mm	Radius
35		Room	Room beam/beam screen 45°	6.98202	mm	Radius
36	Rvc	Room	Room between Cold bore / Vacuum chamber	0.5	mm	Radius
39		Room	Final minimal room between beam screen and beam	2.00078554	mm	Radius

Values to be confirmed

DRAFT !

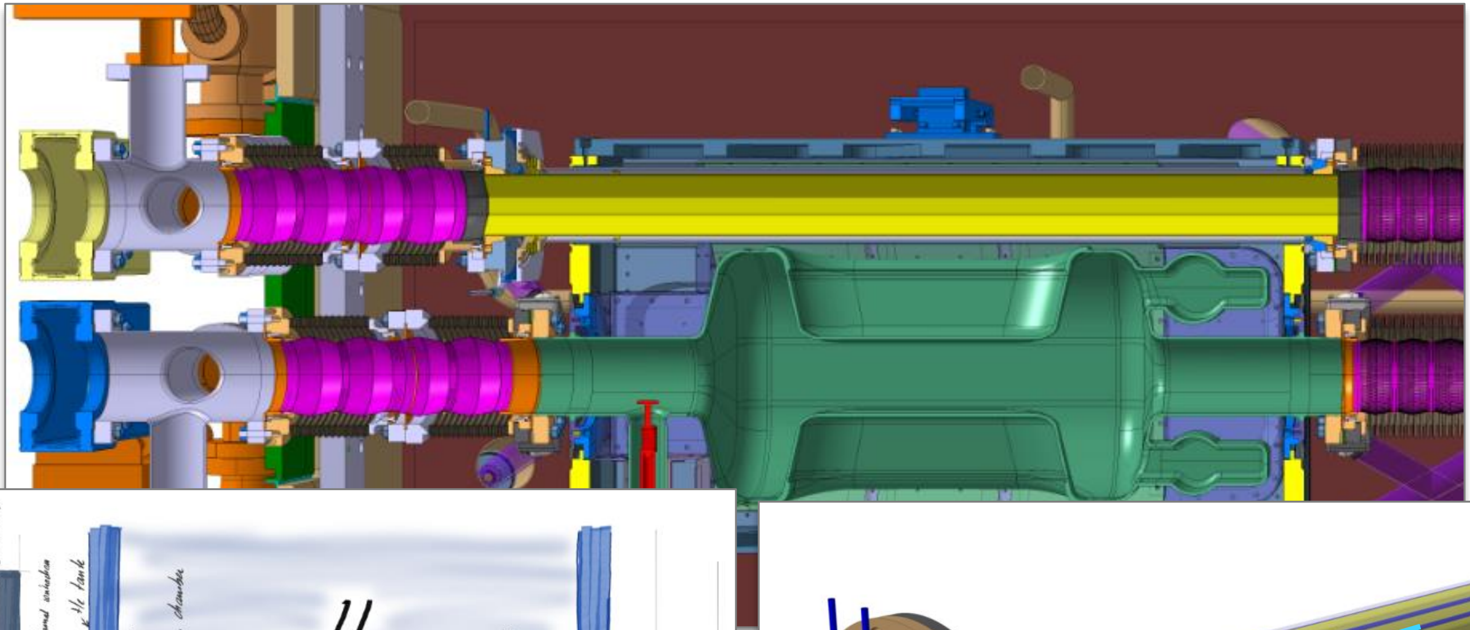


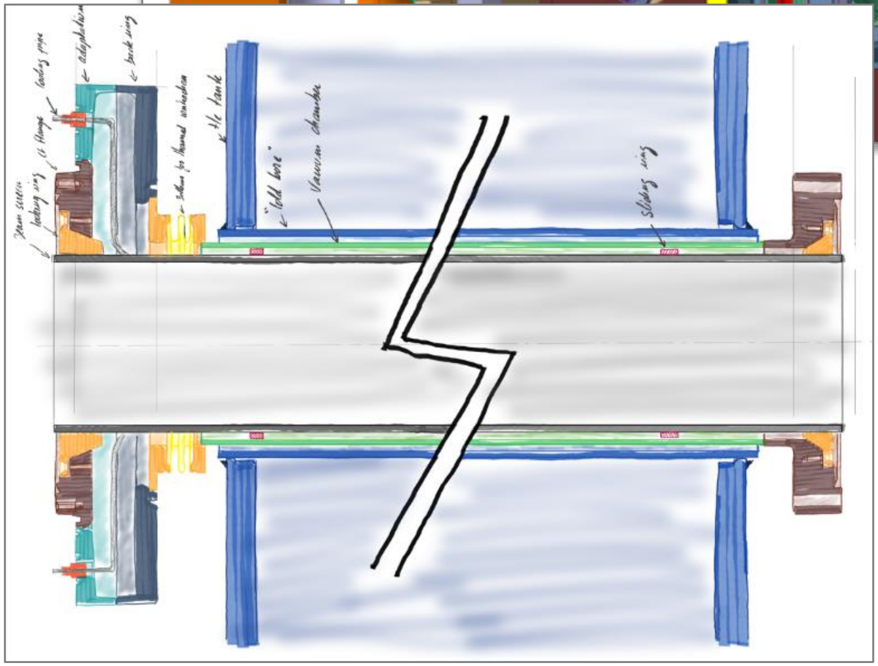
Dimensions of beam screen (nominal) :

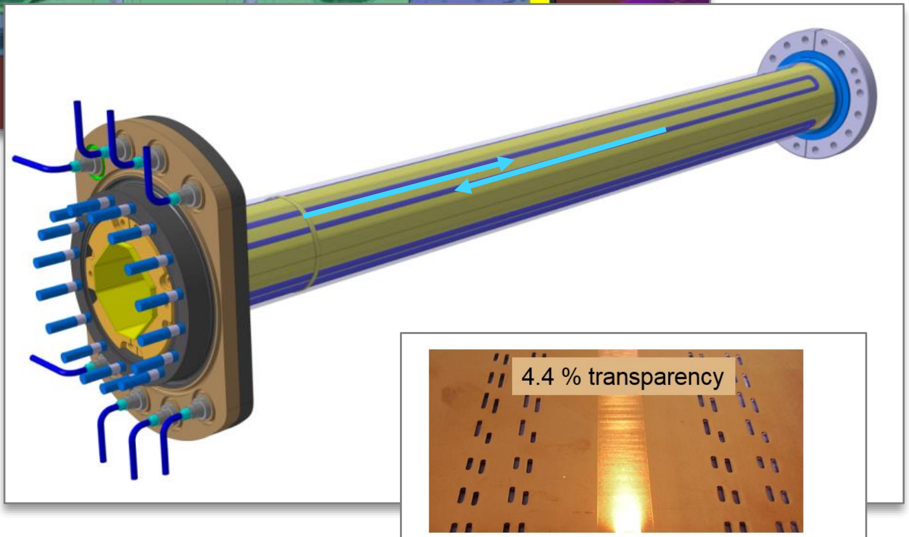
Vertical and Horizontal : 67.7 mm
45° : 62.2 mm

Under definition with experts from vacuum and cryogenics teams

Beam screen





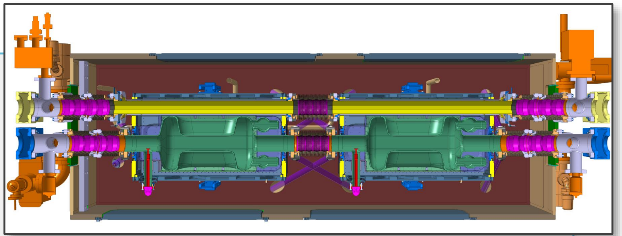


Slot: Width, W= 1.5 , length = 8 +/-2
Longitudinally spaced by 16 +/- 2 between the axes of the slots
Wall thickness, T = 1 mm

V. Baglin, HL-LHC Vacuum System, WP2 meeting, CERN, 27th June 2017

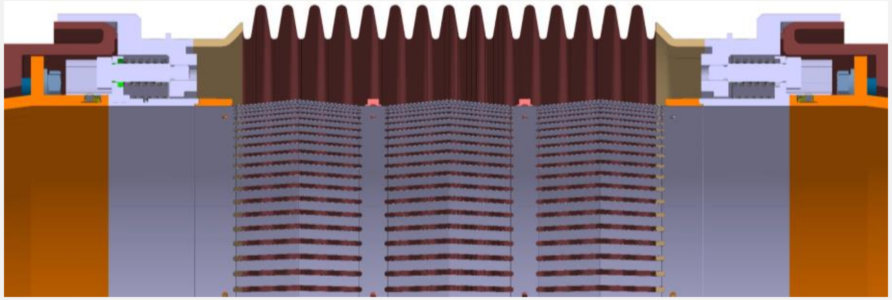
RF bridges for bellows

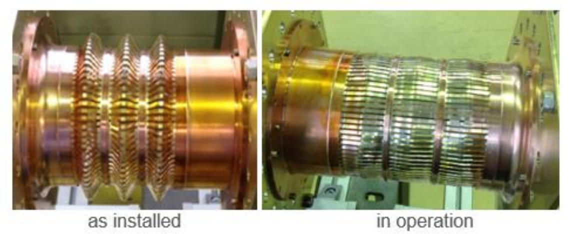
- Need to “screen” every bellows on the beam lines
- Large lateral displacement for cavity adjustment (8mm max.)
- Deformable RF fingers design from triplet area (C.Garion – J.Perez Espinos CERN TE/VSC)
- 4 configurations to be designed
- 2 configurations shall be optimized for cold/warm transition



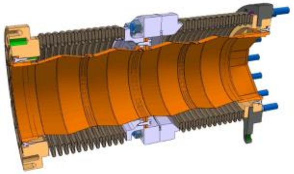
Copper Beryllium deformable RF fingers:

- Circular aperture
- C17410
- 0.1 mm thick, 3 mm width, gap: 1.4 mm
- 3 convolutions

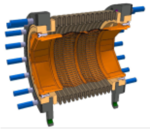




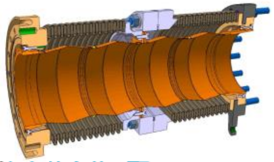
Extracted from presentation of C.Garion
33rd HL-LHC TCC– 13 July 2017



Cold-Warm Transition Circular/Octogonal



Inter-cavities Octogonal/Octogonal



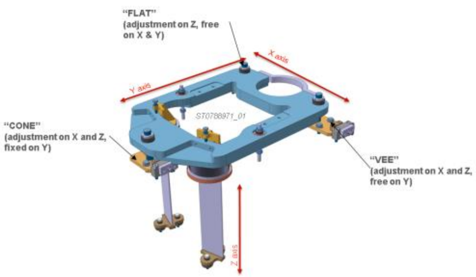
Cold-Warm Transition Circular/Circular

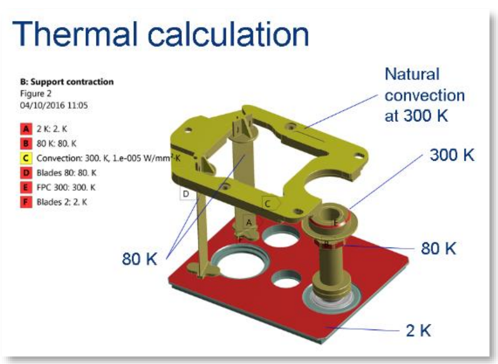
Inter-cavities Circular/Circular

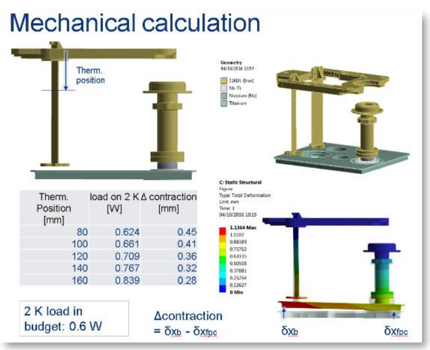
Support and alignement for RFD

Cavity support

- Design adapted from DQW
- Modification with respect to lesson learnt from DQW







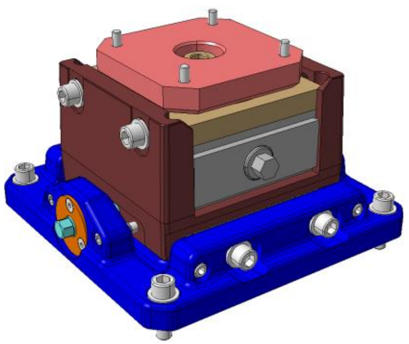
C. Zanoni EN/MME

Cryomodule support for LHC

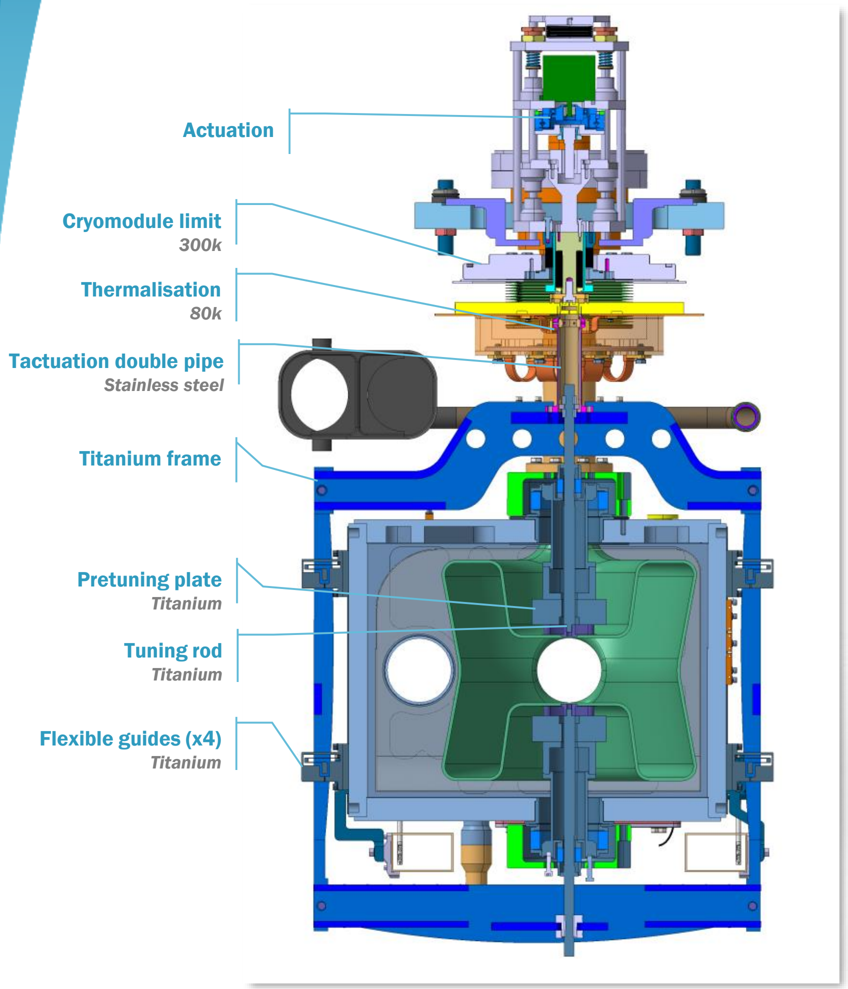
- Remote controlled support in LHC
- Design on-going (M.Sosin EN/SMM)

Cryomodule support for SPS

- Same manual supports than previous cryomodule (x3)

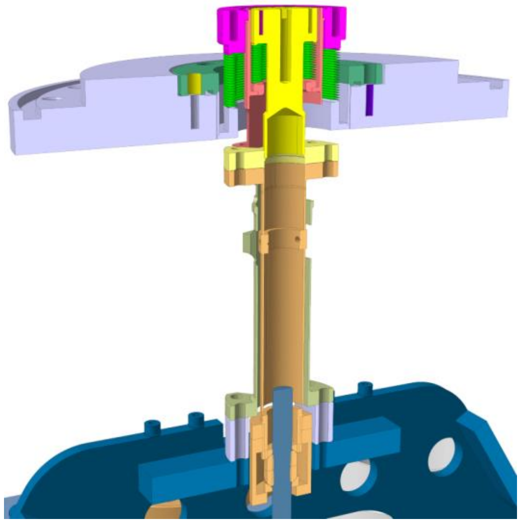


Tuning system



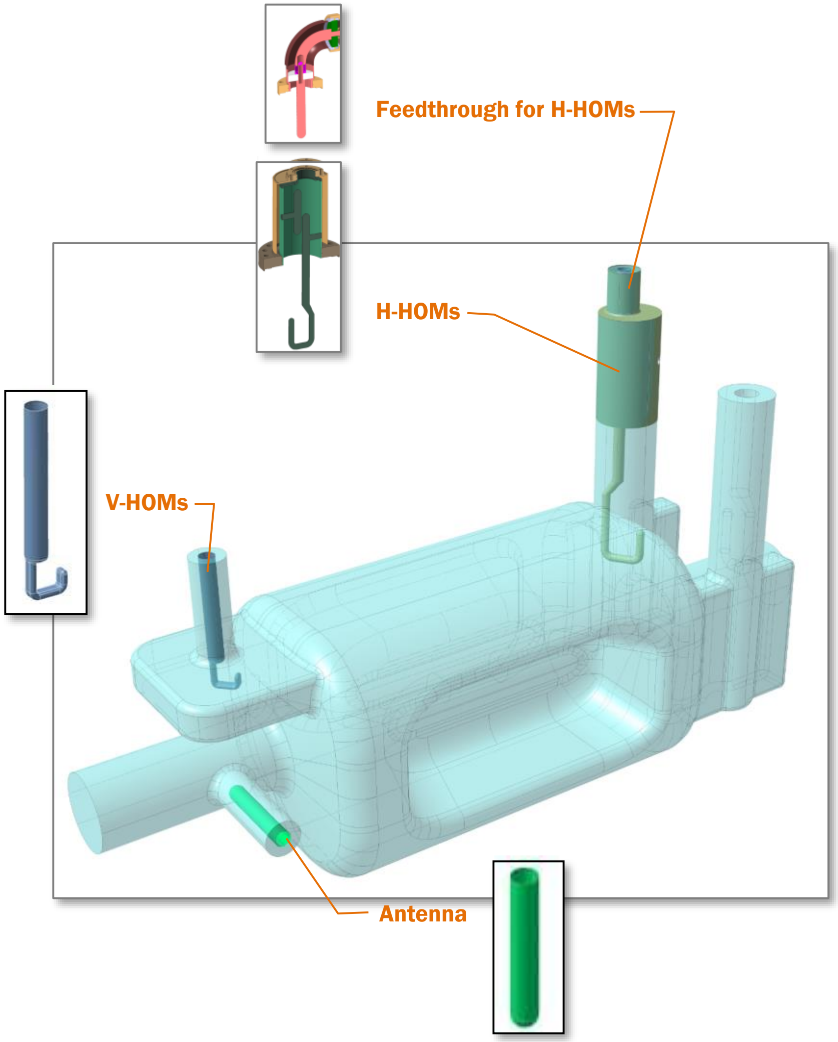
- Adaptation of DQW design
- Modification following lessons learned with DQW
- No pre tuning

See presentation J.Swieszek



DQW design overview

RF component for cavity



CERN responsible for HOMS, FPC & Pick-Up - E.Montesinos BE/RF

HOMs and Antenna for RFD prototypes, under manufacturing at CERN:

- Mechanical design in progress
- Collaboration BE/RF – CERN workshop (EN-MME)

FPC outer pipe :

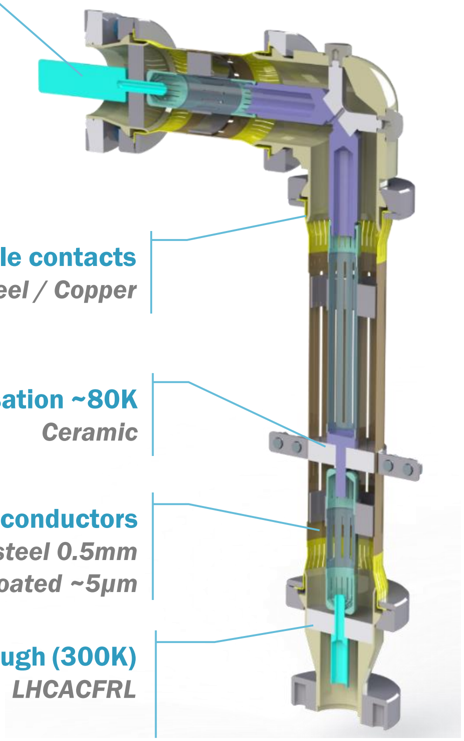
- Mechanical design to be adapted
- Definition of the coating process according to the lesson learnt from DQW
- Collaboration EN/MME – BE/RF – TE/VSC

RF COAXIAL LINES

CERN responsible for HOMS, FPC & Pick-Up - E.Montesinos BE/RF

Design constraints :

- insulation vacuum (not cooled by convection)
- RF power
- Thermal load to 2K bath
- Alignment and thermal contraction compensation
- Limited room for installation inside the cryomodule

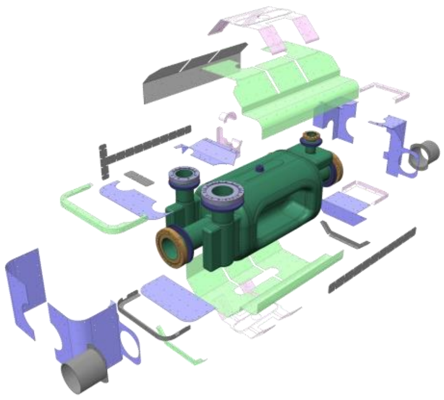


Datas

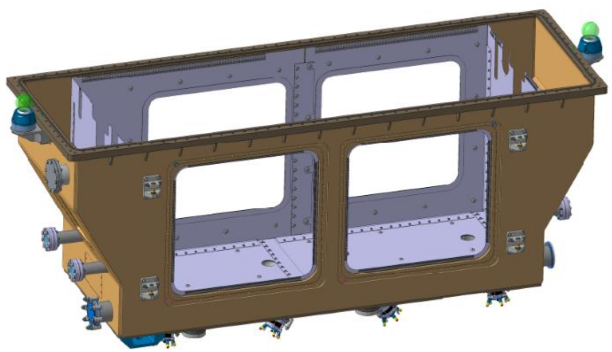
- 2 V-HOMS coaxial lines
- 2 H-HOMS coaxial lines
- 2 Antennas coaxial lines
- Size and design standardized for all lines
  - S.Steel with copper coating
  - Extremities compatible with standard connector
  - Shapal ring for thermalisation of inner line
  - Alumina for vacuum feedthrough

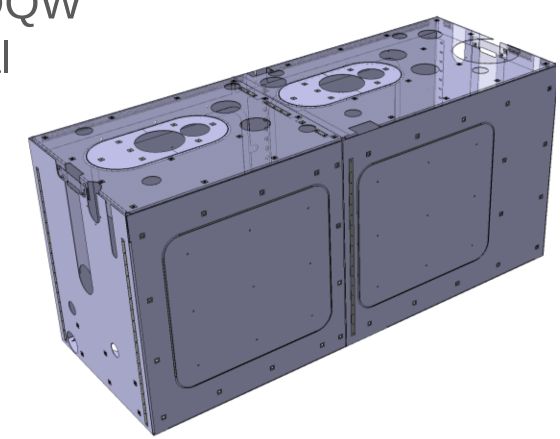
Magnetic Shield (STFC)

- **Cold magnetic shield (2K):**
  - Design under validation
  - Assembly sequence to be checked
  - Material : Cryophy



- **Warm magnetic shield (300K):**
  - Design to be done
  - Adaptation from DQW
  - Material : Mumetal

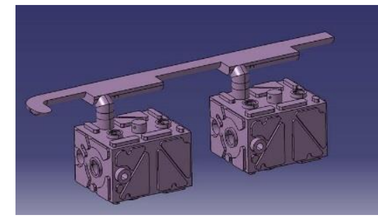


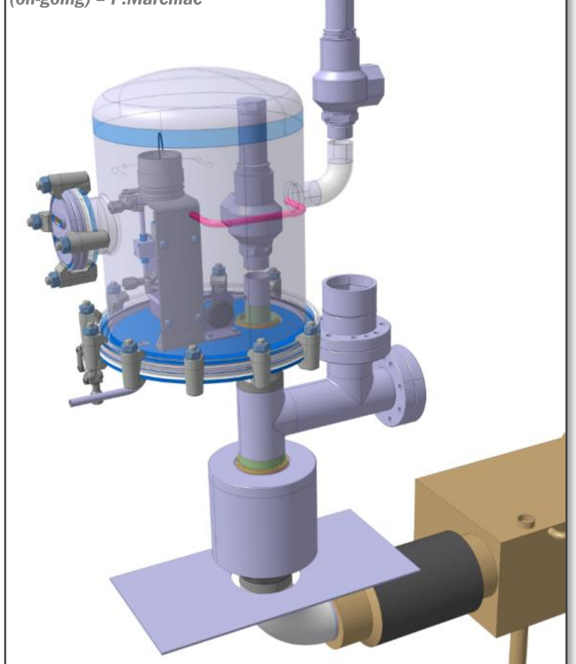


Cryogenic equipment

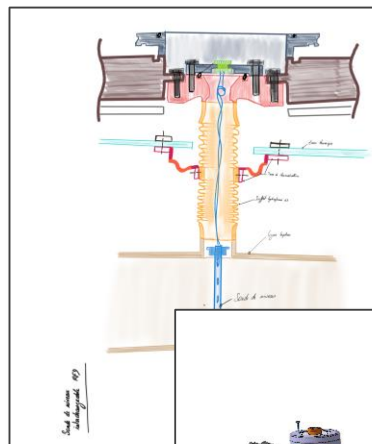
- New cooling line for beam screen
- Safety valve on cryomodule side
- Exchangeable level gauges
- Pressure measurement set up
- Bolted temperature sensors
- Distribution of pipes for cooling equilibrium
- Adaptability to LHC slope

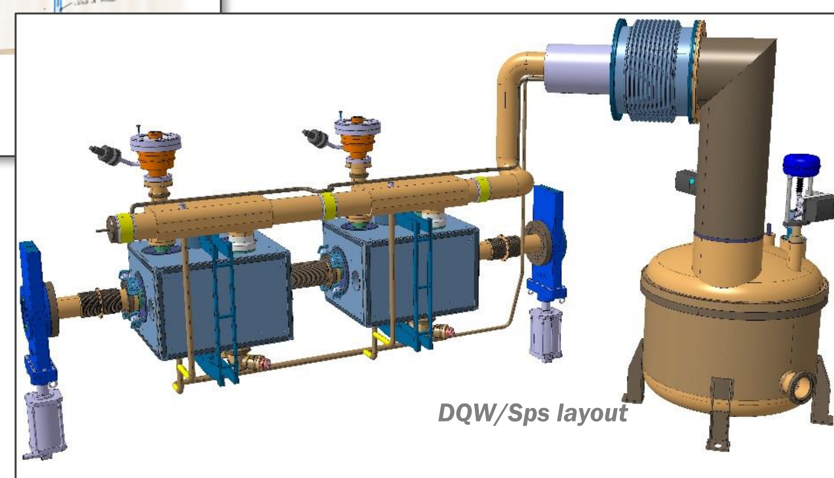
- **Datas :**
  - surface 2k / beam vacuum : ~1m2
  - surface 2k / insulation vacuum : 3.6m2
  - Volume of helium : 166L
  - Biphase inner diameter : 100mm





Cryogenic safety valve integration (on-going) – P.Marcillac

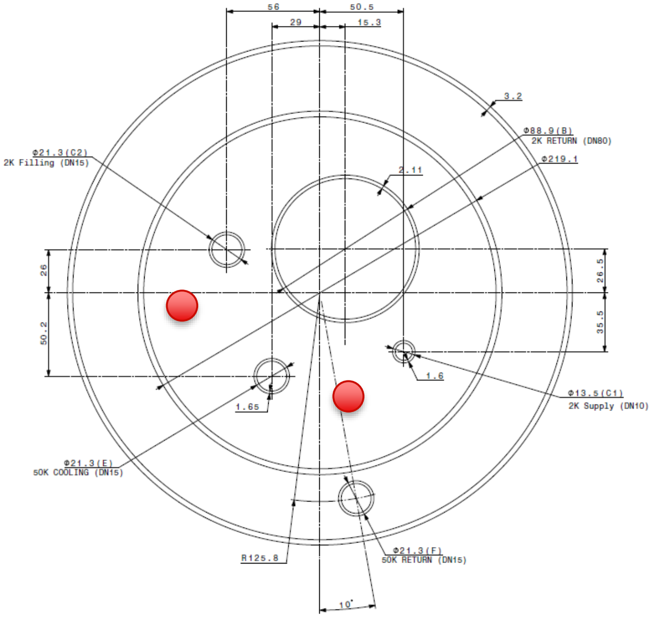




DQW/Sps layout

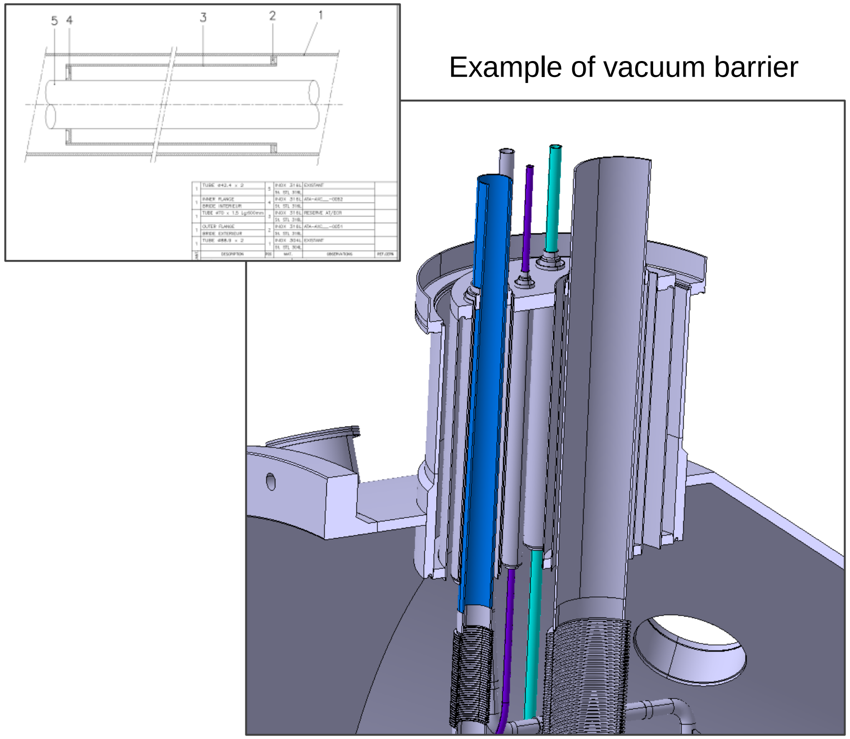
Jumper

- Design adapted from DQW
- Integration of a vacuum barrier (separate insulation vacuum of CCM from SM)
- Integration of an additionnal line for beam screen cooling (4-20K)
- Manufacturing sequence to be defined
- Adaptabibily to both SPS and LHC



SPS jumper section view – K.Brodzinski

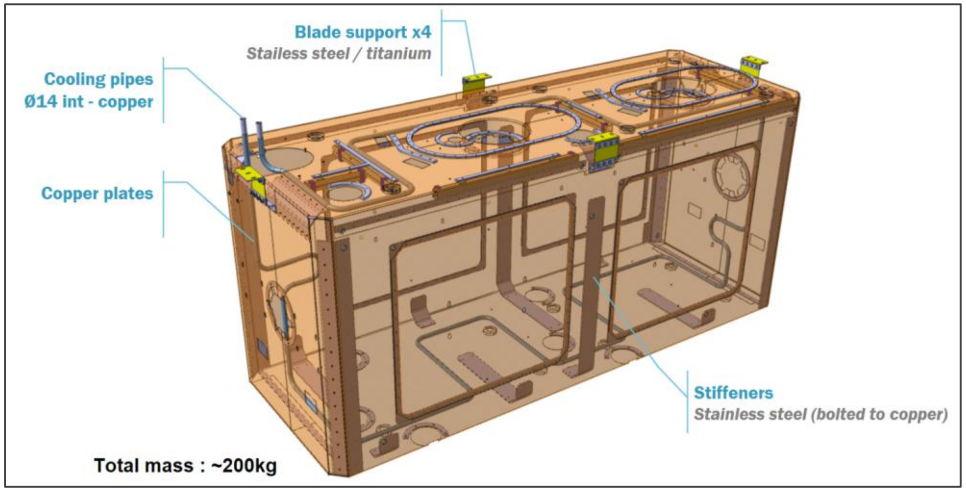
Example of vacuum barrier

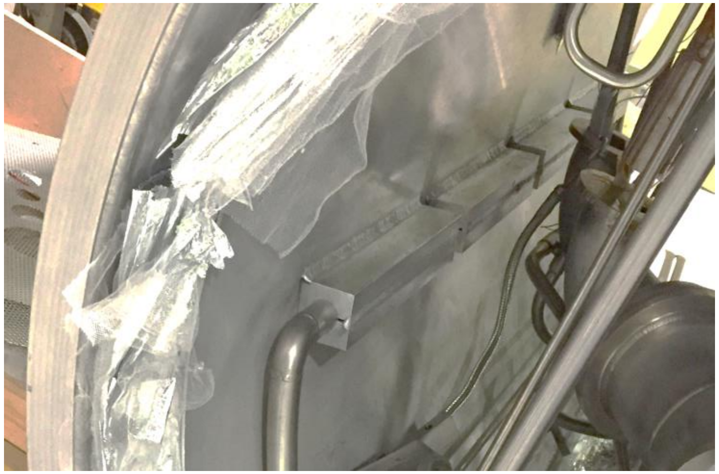


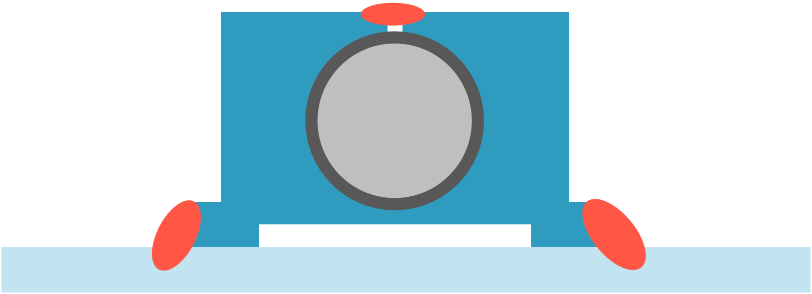
Thermal screen (STFC)

- **DQW design :**
  - Copper plates th. 3mm
  - Copper pipes brazed to plates
  - Operating pressure 18 bars
  - Transition copper/s.steel for final welds

- **Alternative design:**
  - Aluminium plates th. 3mm
  - S.steel pipes clamped to plates
  - Operating pressure 25 bars







Additionnal studies to be done

- Connexion with LHC service module
- Support of vacuum interconnexion (attached to cryomodule)
- MLI 2k and 70K
- Detailed assembly procedure + assembly tooling
- Additional locking system on cavities for transport
- Transport tooling
- ...

End

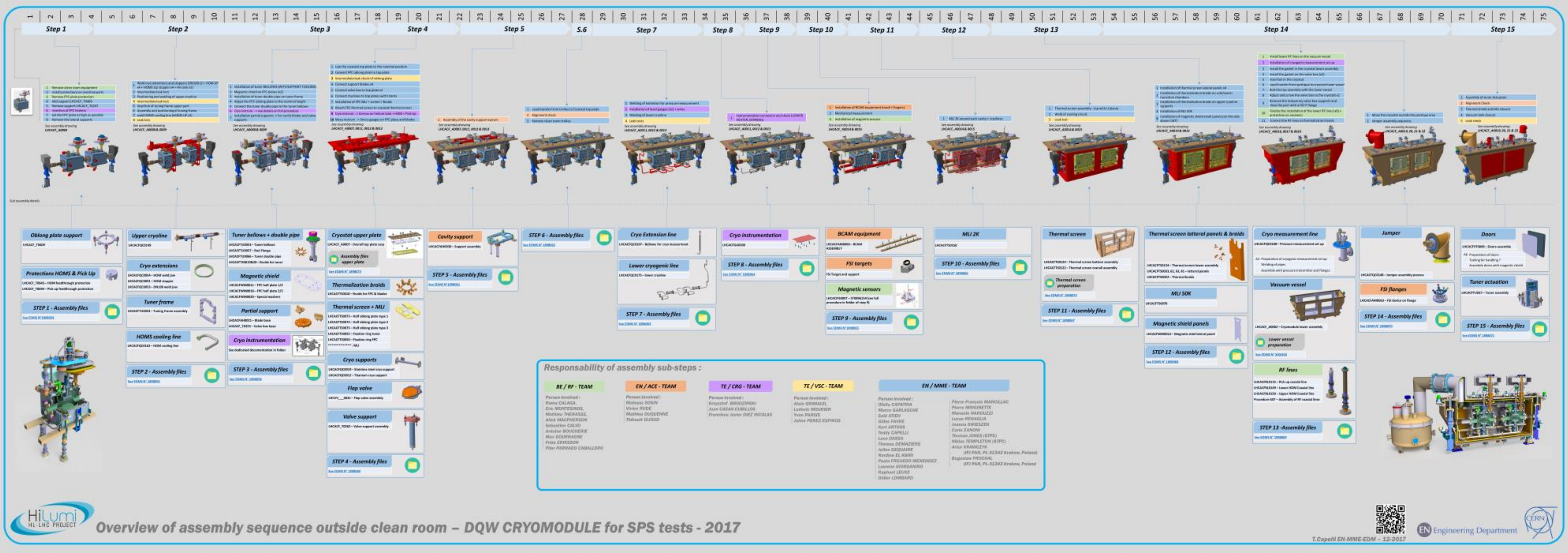
Thermal budget 2K - ! Only rough guess !!

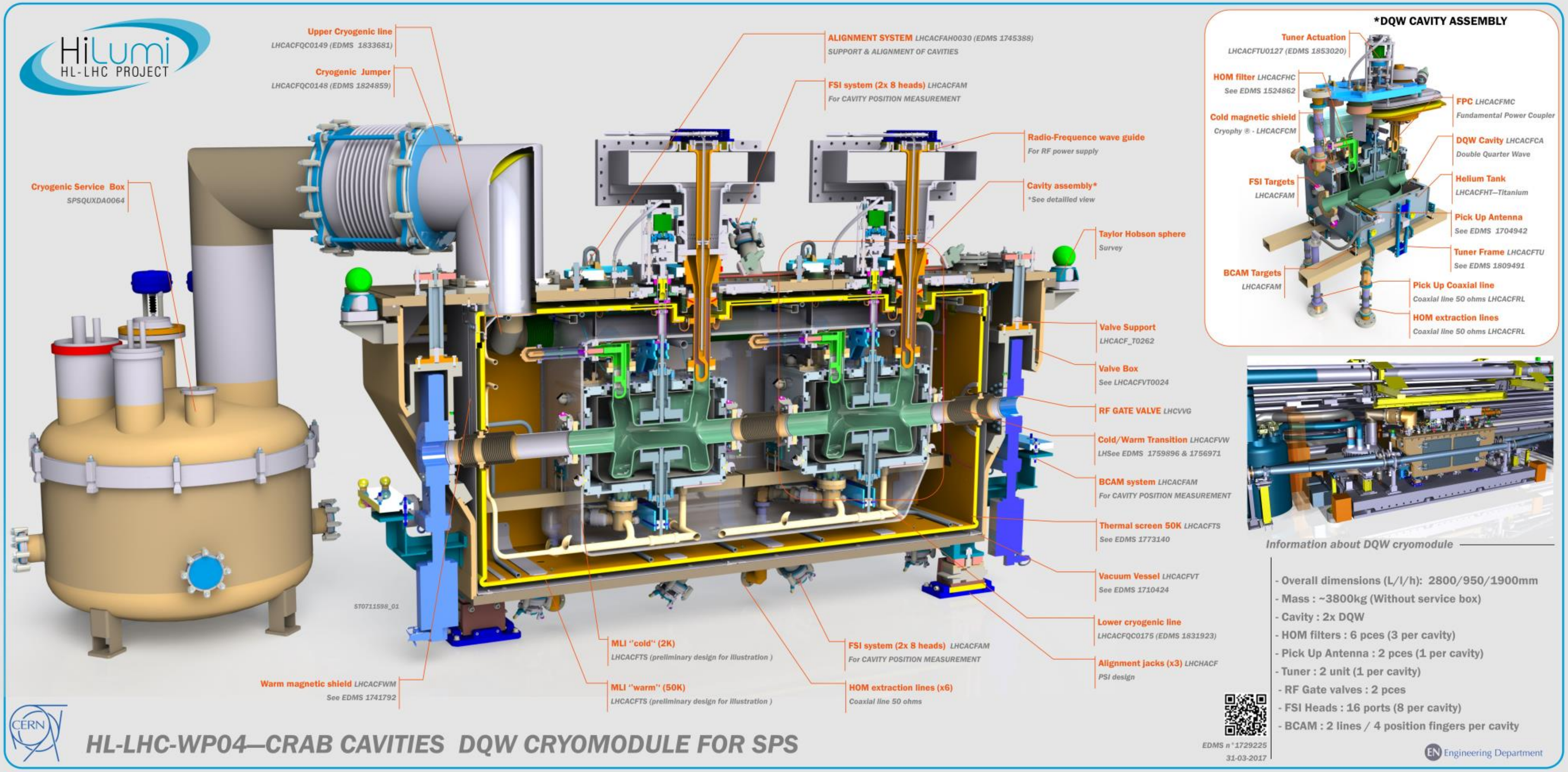
	2 K bath	
Static		
Radiation	2.8	- Less ports (no BCAMS) + two coaxial lines less
CWT	2 ?	– four CWT with RF bridges
Supports	2	– supports optimisation ?
FPC	4	– same static load
Instrumentation	3	– same load
HOM/Pickup	3	- 2 HOMS less
Tuner	1	
Beam screen cooling	????	- Beam screen cooling effect on cavity ?
Total Static	17.8	
Dynamic		
Cavity	11	– same RF load ?
FPC	5	– RF load to be calculated
HOM/Pickup	3.7	- 2 HOMS less
Beam	0.5	
Total Dynamic	20.2	
TOTAL	38	

- Less ports (no BCAMS) + two coaxial lines less
- 4 cold warm transitions with RF bridges
- Safety valve
- Beam screen cooling warm up the cavity ?

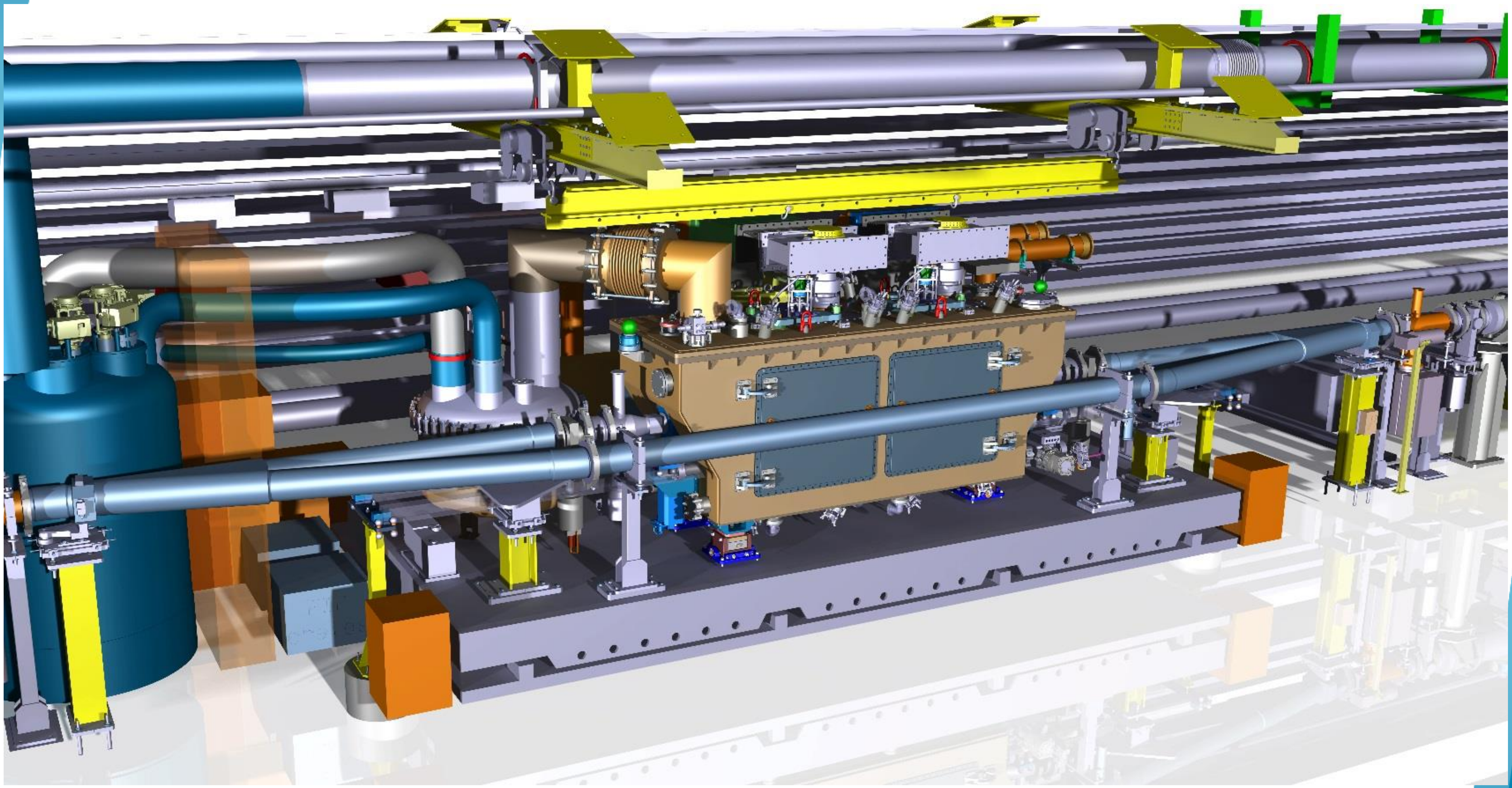
	2 K bath	80 K interceptors
Static		
Radiation [1]	3.4	30
CWT [2]	0.2	10
Supports [3],[4]	2	40
FPC [5]	4	100
Instrumentation [6]	2.3	10
HOM/Pickup [7],[8]	3.9	40
Tuner [9]	1	10
Total Static	**16.8**	**240**
Dynamic		
Cavity [10]	11	0
FPC [5]	5	10
HOM/Pickup [7],[8]	4.9	10
Beam	0.5	0
Total Dynamic	**21.4**	**20**
TOTAL	**38.2**	**260**

DQW Thermal budget (extracted from EDMS 1729079 – F.Carra)


Step 1
Step 2
Step 3
Step 4
Step 5
S.6
Step 7
Step 8
Step 9
Step 10
Step 11
Step 12
Step 13
Step 14
Step 15
Responsability of assembly sub-steps :
BE / RF - TEAM
EN / ACE - TEAM
TE / CRG - TEAM
TE / VSC - TEAM
EN / MME - TEAM
Overview of assembly sequence outside clean room – DQW CRYOMODULE for SPS tests - 2017



HiLumi HL-LHC PROJECT
Upper Cryogenic line LHCACFQC0149 (EDMS 1833681)
Cryogenic Jumper LHCACFQC0148 (EDMS 1824859)
Cryogenic Service Box SPSQUXDA0064
ALIGNMENT SYSTEM LHCACFAH0030 (EDMS 1745388) SUPPORT & ALIGNMENT OF CAVITIES
FSI system (2x 8 heads) LHCACFAM For CAVITY POSITION MEASUREMENT
Radio-Frequence wave guide For RF power supply
Cavity assembly* *See detailled view
Taylor Hobson sphere Survey
Valve Support LHCACF_T0262
Valve Box See LHCACFVT0024
RF GATE VALVE LHCVVG
Cold/Warm Transition LHCACFVW LHSee EDMS 1759896 & 1756971
BCAM system LHCACFAM For CAVITY POSITION MEASUREMENT
Thermal screen 50K LHCACFTS See EDMS 1773140
Vacuum Vessel LHCACFVT See EDMS 1710424
Lower cryogenic line LHCACFQC0175 (EDMS 1831923)
Alignment jacks (x3) LHCHACF PSI design
ST0711598_01
MLI "cold" (2K) LHCACFTS (preliminary design for illustration)
MLI "warm" (50K) LHCACFTS (preliminary design for illustration)
FSI system (2x 8 heads) LHCACFAM For CAVITY POSITION MEASUREMENT
HOM extraction lines (x6) Coaxial line 50 ohms
Warm magnetic shield LHCACFWM See EDMS 1741792
*DQW CAVITY ASSEMBLY
Tuner Actuation LHCACFTU0127 (EDMS 1853020)
HOM filter LHCACFHC See EDMS 1524862
Cold magnetic shield Cryophy ® - LHCACFCM
FSI Targets LHCACFAM
BCAM Targets LHCACFAM
FPC LHCACFMC Fundamental Power Coupler
DQW Cavity LHCACFCA Double Quarter Wave
Helium Tank LHCACFHT—Titanium
Pick Up Antenna See EDMS 1704942
Tuner Frame LHCACFTU See EDMS 1809491
Pick Up Coaxial line Coaxial line 50 ohms LHCACFRL
HOM extraction lines Coaxial line 50 ohms LHCACFRL
Information about DQW cryomodule
- Overall dimensions (L/l/h): 2800/950/1900mm
- Mass : ~3800kg (Without service box)
- Cavity : 2x DQW
- HOM filters : 6 pces (3 per cavity)
- Pick Up Antenna : 2 pces (1 per cavity)
- Tuner : 2 unit (1 per cavity)
- RF Gate valves : 2 pces
- FSI Heads : 16 ports (8 per cavity)
- BCAM : 2 lines / 4 position fingers per cavity
CERN
HL-LHC-WP04—CRAB CAVITIES DQW CRYOMODULE FOR SPS
EDMS n°1729225
31-03-2017
EN Engineering Department



Coaxial lines

Design from DQW, length/position adapted to RFD