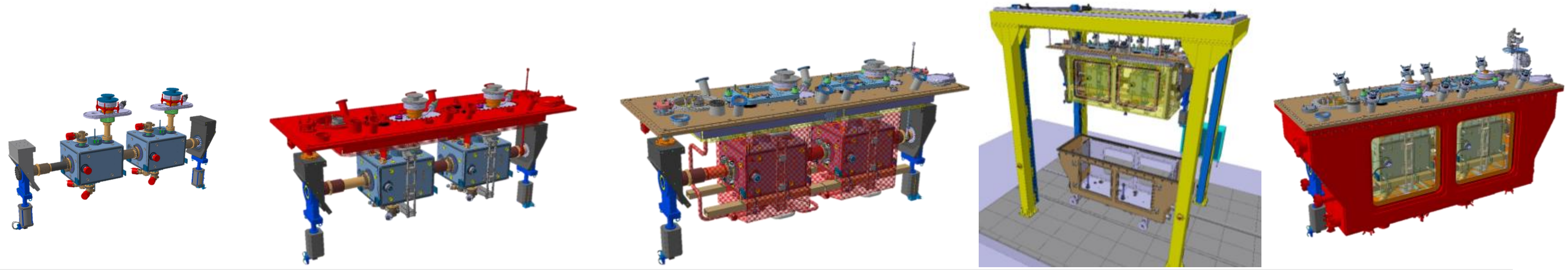
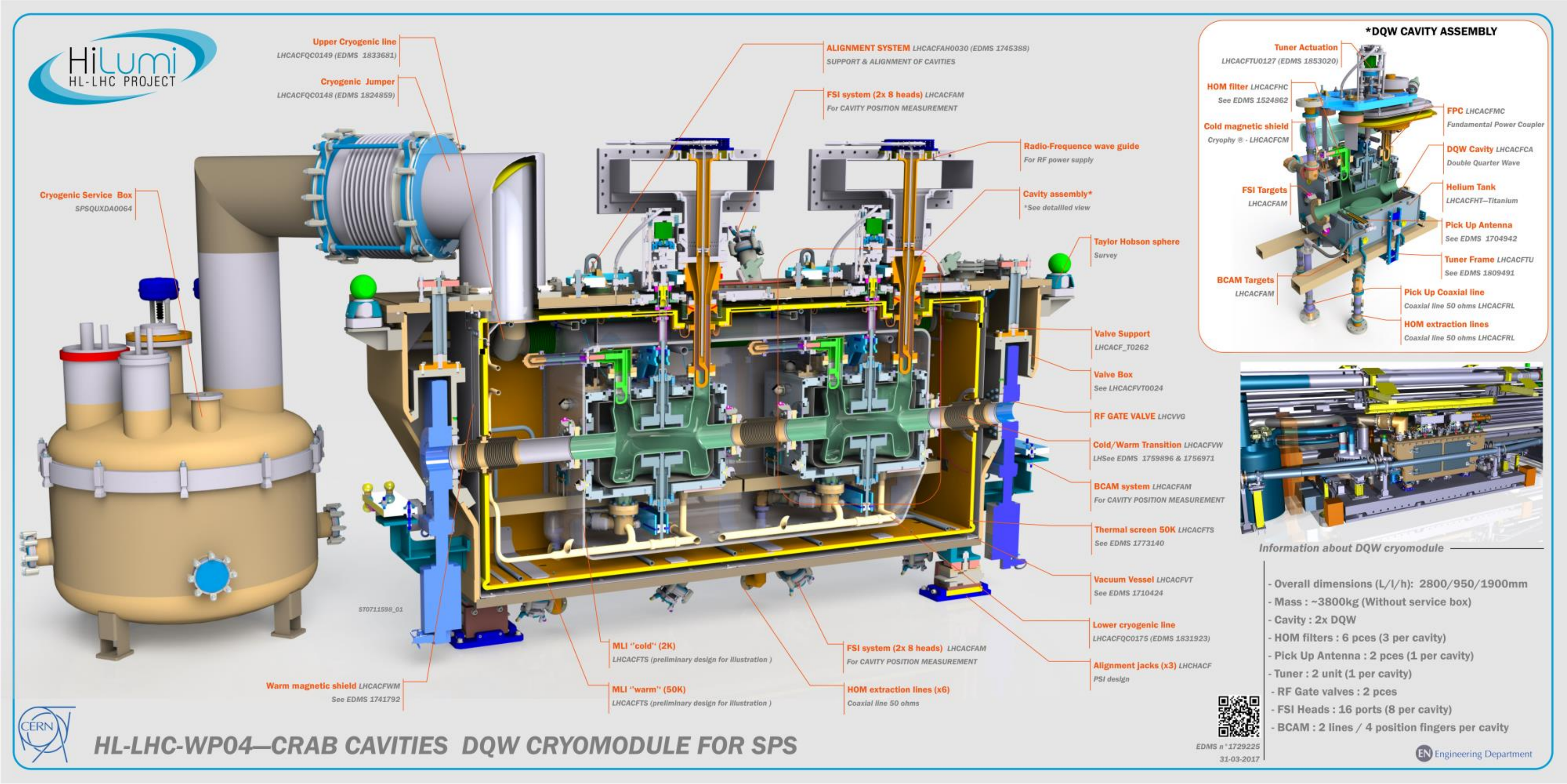
RFD cryomodule design for SPS tests

International Review of the Crab Cavity for HL-LHC -20/06/2019

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.

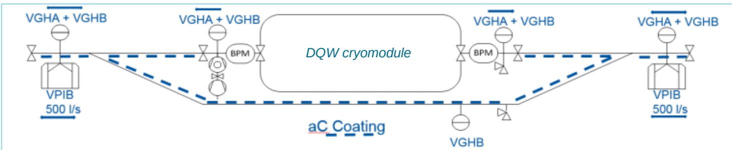
Review of previous design (DQW for SPS test)



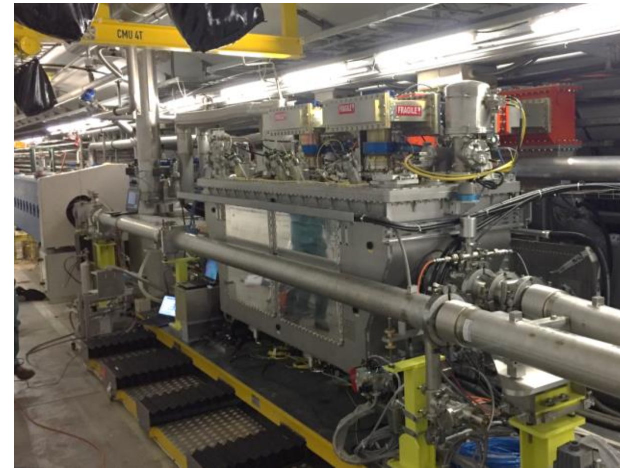


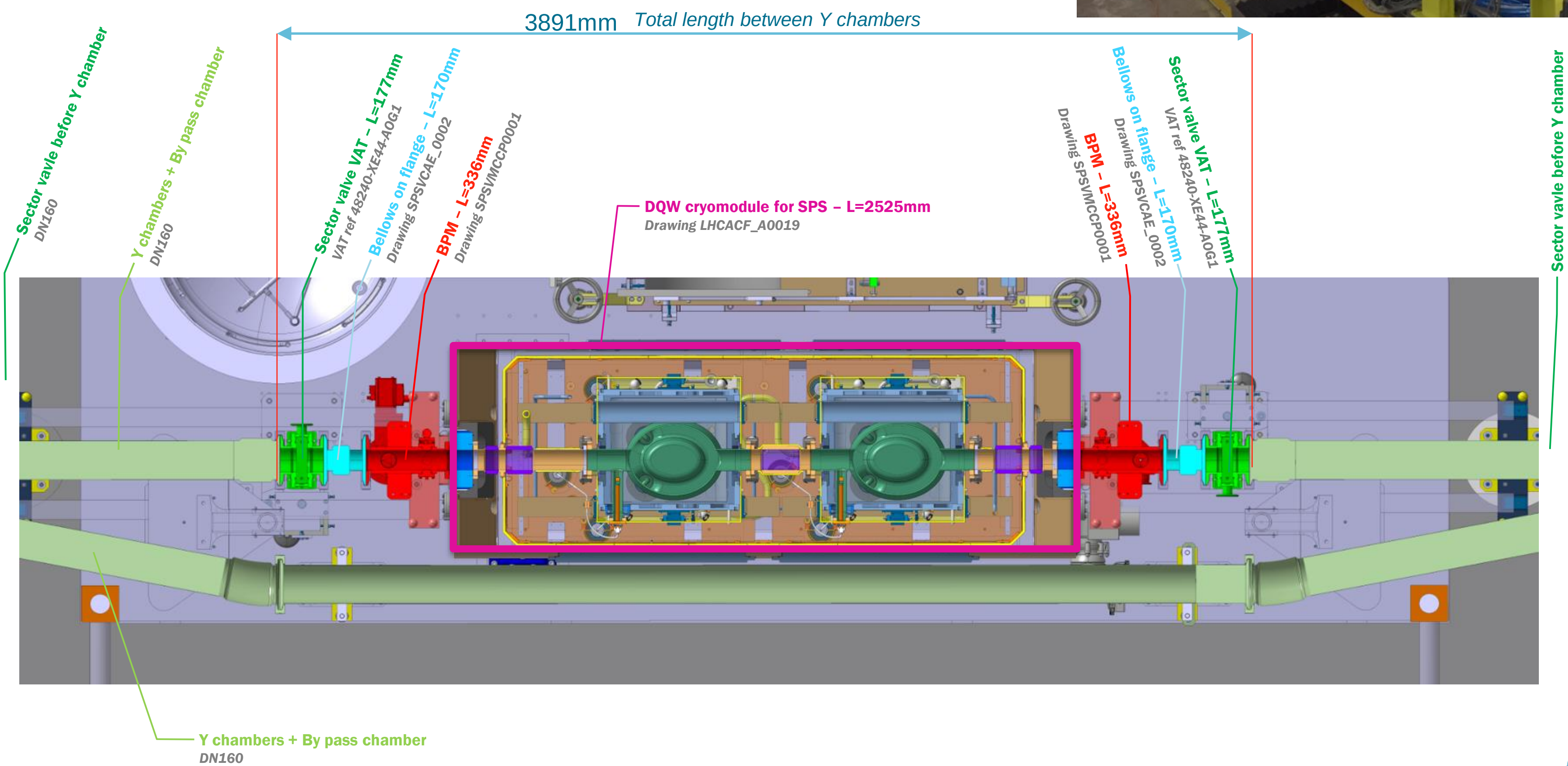
SPS test stand

See presentation of G.Vandoni



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





Modifications / differences of RFD cryomodule

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

DESIGN ACTIVITIES

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

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

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

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

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

Tuner (Kurt Artoos– CERN EN/MME)
- Frame
- Double pipe + thermalisation
- Actuation

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
- Thermal screen cooling circuit (CERN, STFC)
- Thermal intercepts
- Cold warm transition (definition of thermal budget and pre design)
- MLI design

Thermal screen and MLI (CERN, STFC)
- Aluminun design with clamped Ss pipes
- Adaptation of MLI principle

Cryostat vessel design
- Replace oring gasket by welded connection
- Vacuum barrier in the jumper on service module side

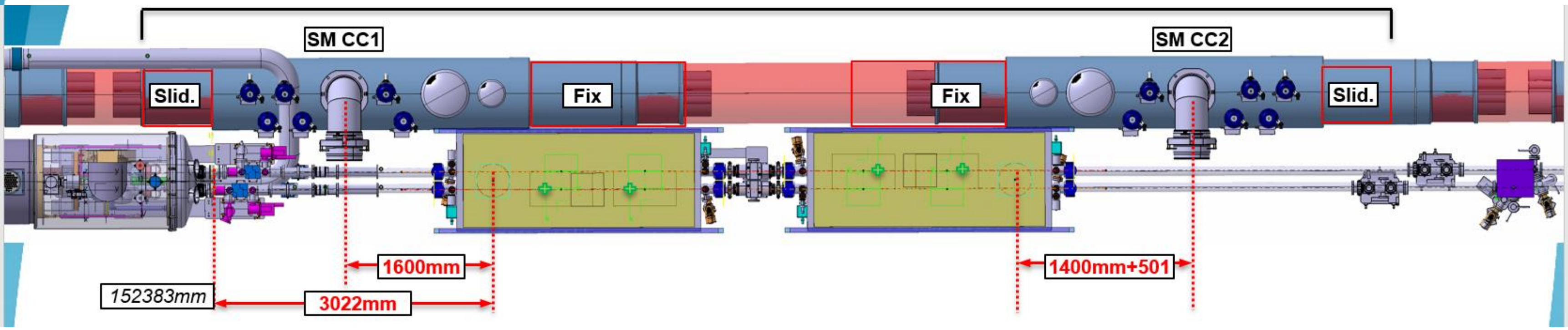
Transport of cryomodule (K.Artoos CERN, E.Jordan STFC)
- Risk analysis
- Frame for transport
- Internal locking for transport

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

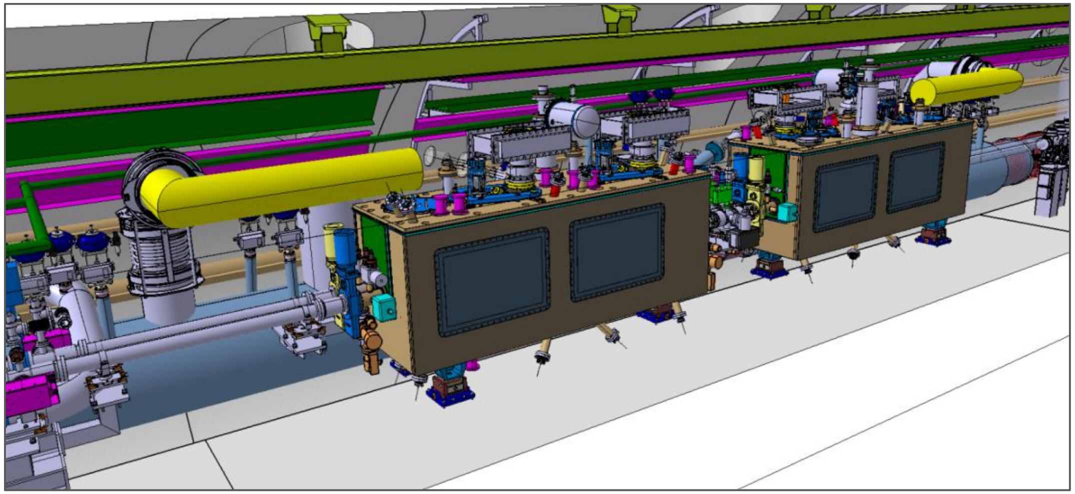
Instrumentation
- Definition and integration of instrumentation (T°, Mag sensor, ..)
- Rooting of cables.

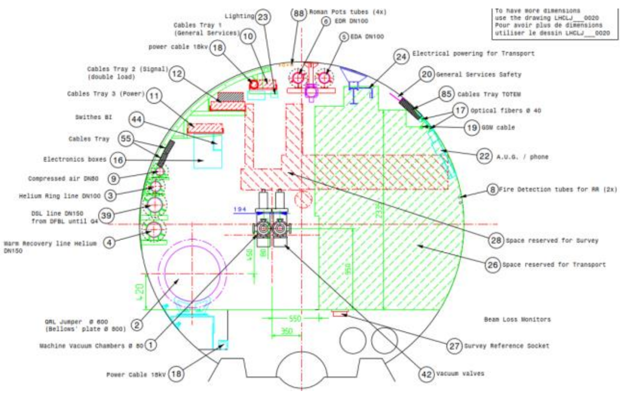
LHC integration – preliminary study

See presentation of P.Fessia



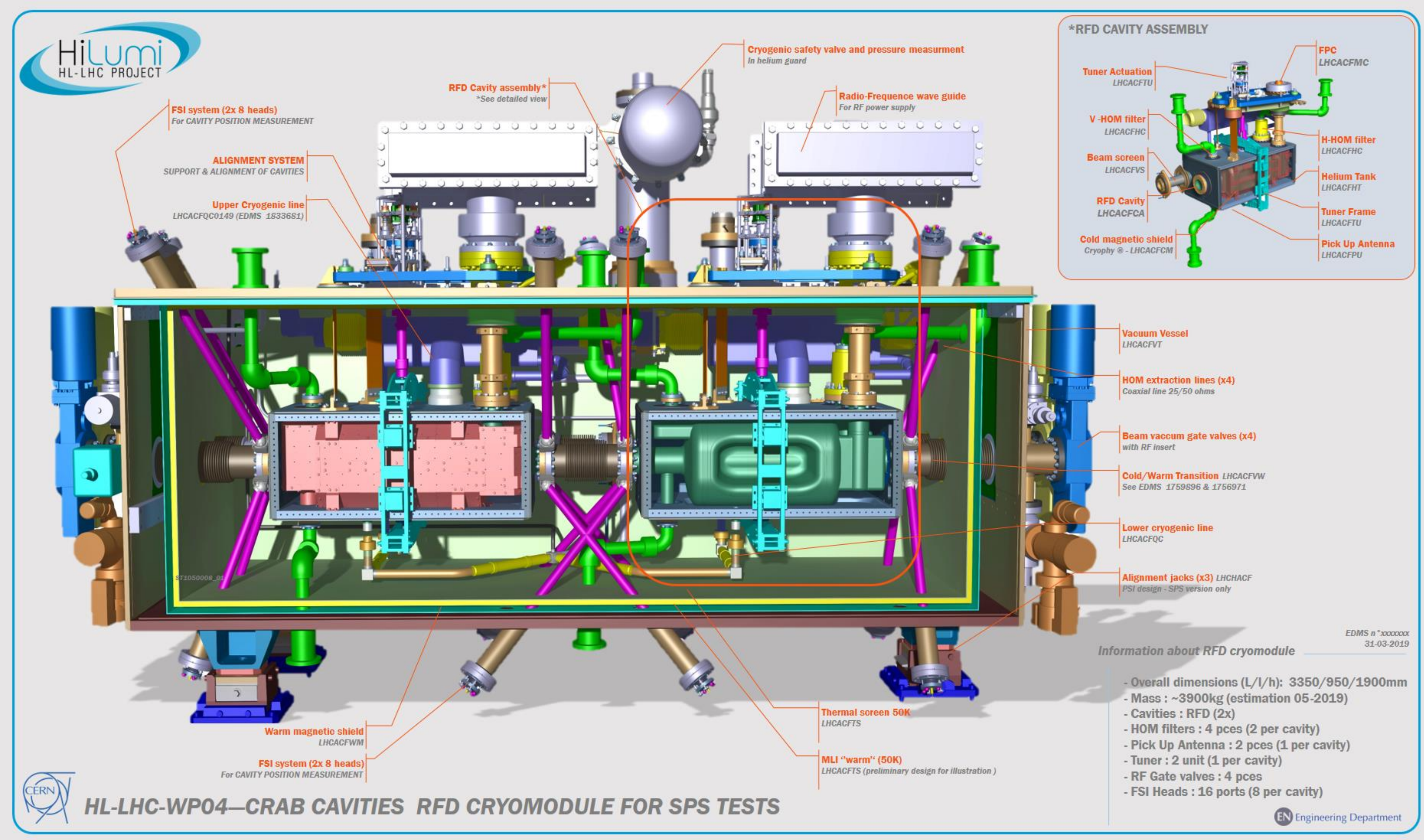
LHC integration– courtesy ***M. Gonzalez de la Aleja – CERN ATS/DO***





Section view of LHC
More details on drawing LHCLJ___0020

RFD/SPS Cryomodule overview



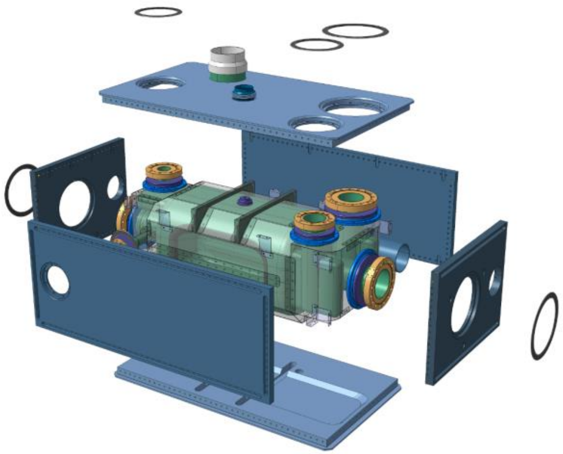
RFD Cavity mechanical design

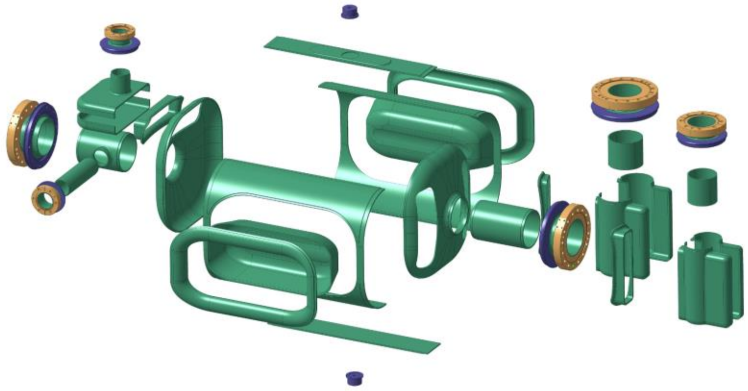
CAVITY design

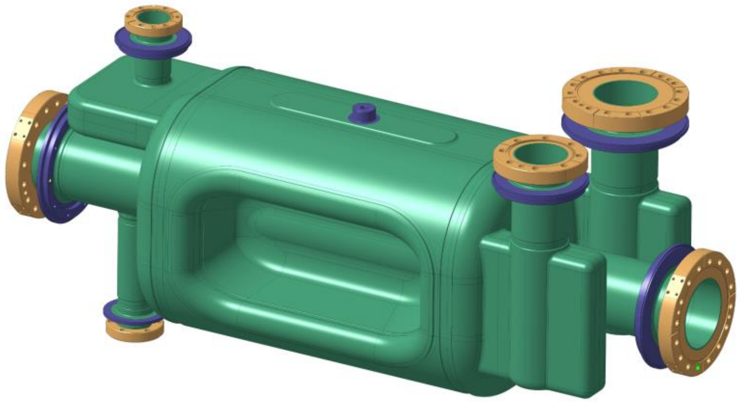
- Mechanical design done from 2K RF design
- Splitting of the cavity optimized for manufacturing

(Anticipation of deformation, thickness variation and welding shrinkage)

- Helium tank design on-going







Courtesy R.Leuxe & L.Giordanino CERN-EN/MME – cavity design & forming tooling
Courtesy P.Minginette CERN-EN/MME – tooling for machining and welding

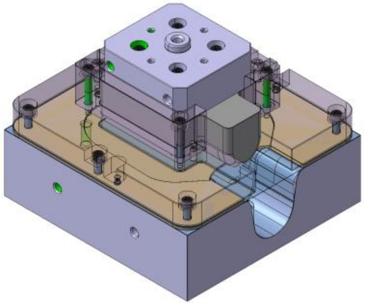
RFD Cavity tooling for manufacturing

Tooling for forming, machining and welding:

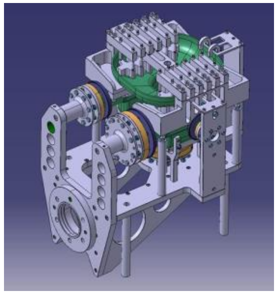
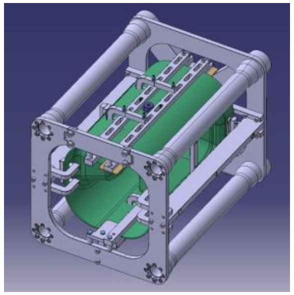
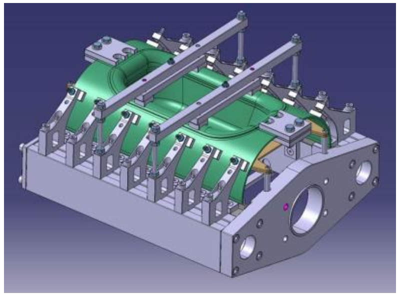
- Forming methodology adapted according to lessons learnt with DQW cavity manufacturing
- Design of forming, machining and welding tooling
- Strategy specific for each cavity type (new design needed for RFD)

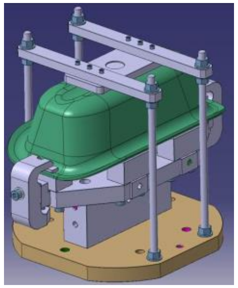
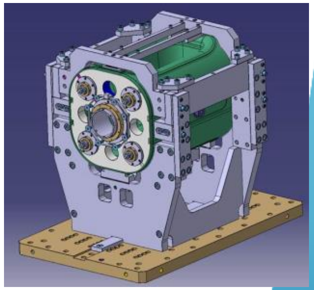
See presentation of M.Garlasche

H-HOM box forming



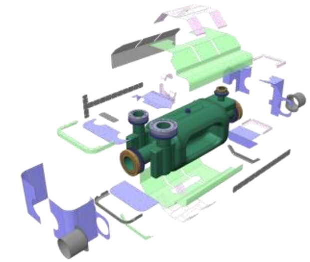
Tooling for machining and welding

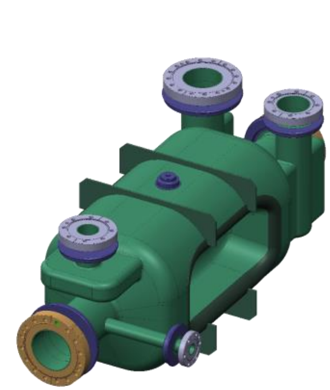
Courtesy R.Leuxe & L.Giordanino CERN-EN/MME – cavity design & forming tooling
Courtesy P.Minginette CERN-EN/MME – tooling for machining and welding

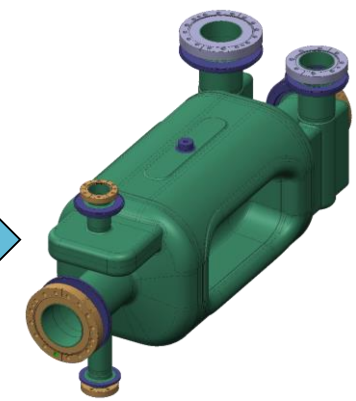
Cold Magnetic Shield (STFC)

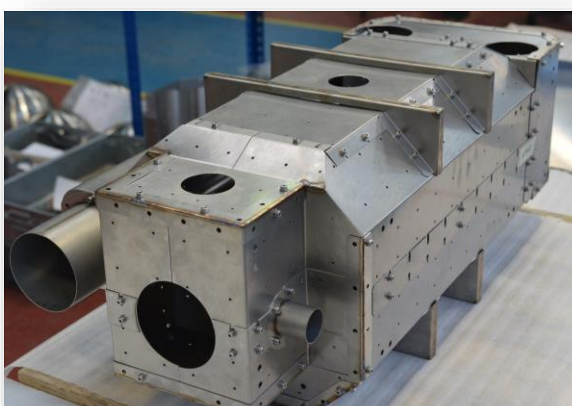


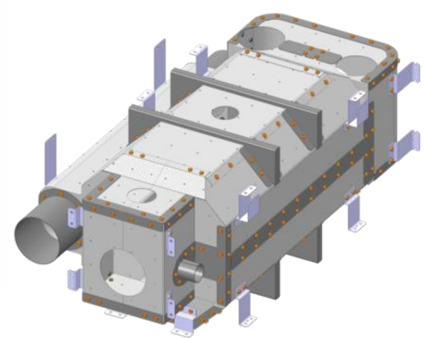
Courtesy N.Templeton - STFC

- **Cold magnetic shield (2K):**
  - RFD Cold Magnetic Shields designed & delivered to CERN in Apr ‘15
  - Changes in cavity design mean shield designs require revision
  - Approach taken to modify & reuse existing shields (as much as possible)
  - Detailed design: Complete
  - Integration checks: On-going
  - Specification & Tender: On-hold
  - Analysis for cool down stress and deformation

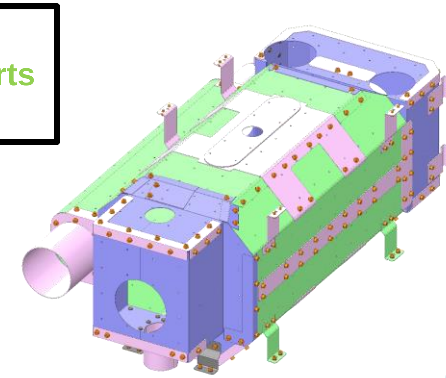






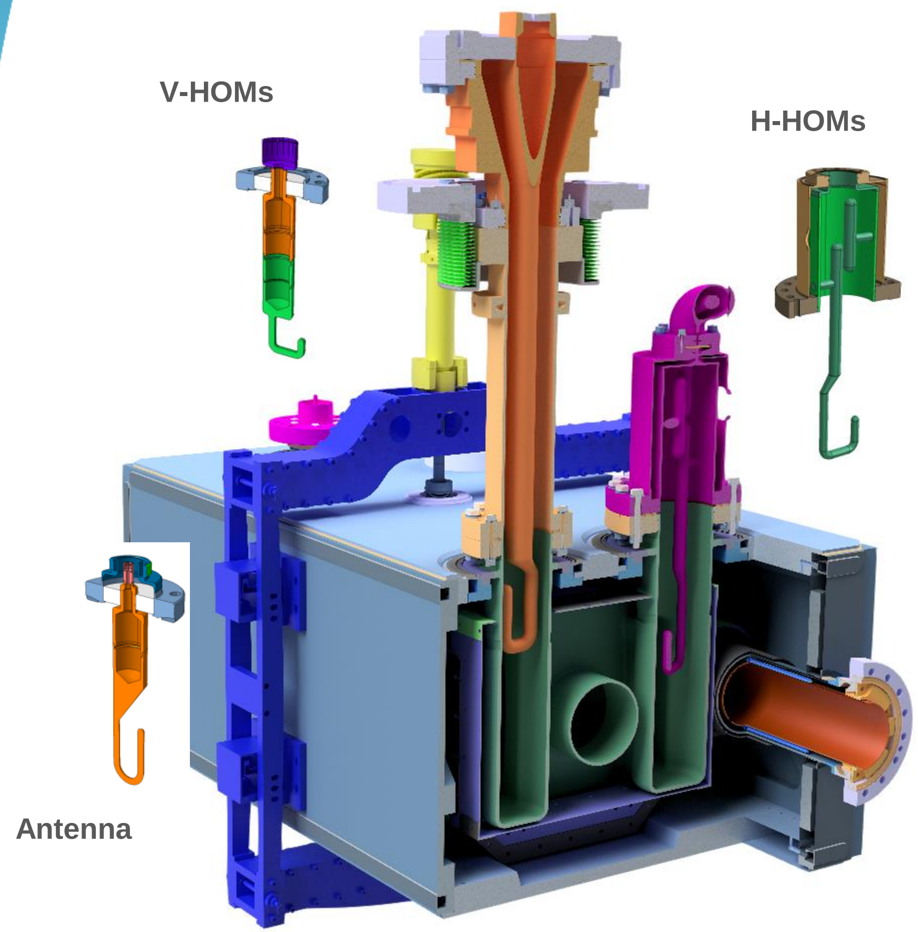


New Parts
Modified Parts
Unchanged



FPC, HOMS and Pick up

See presentation of E.Montesinos



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

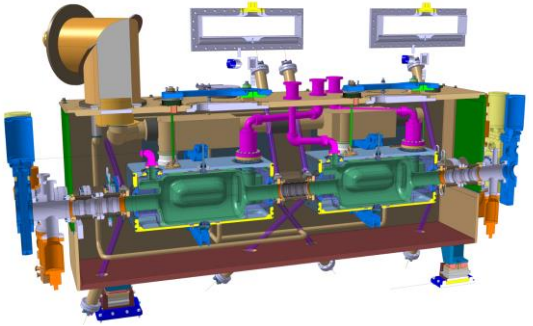
HOMs and Antenna for RFD prototypes, under manufacturing at CERN:

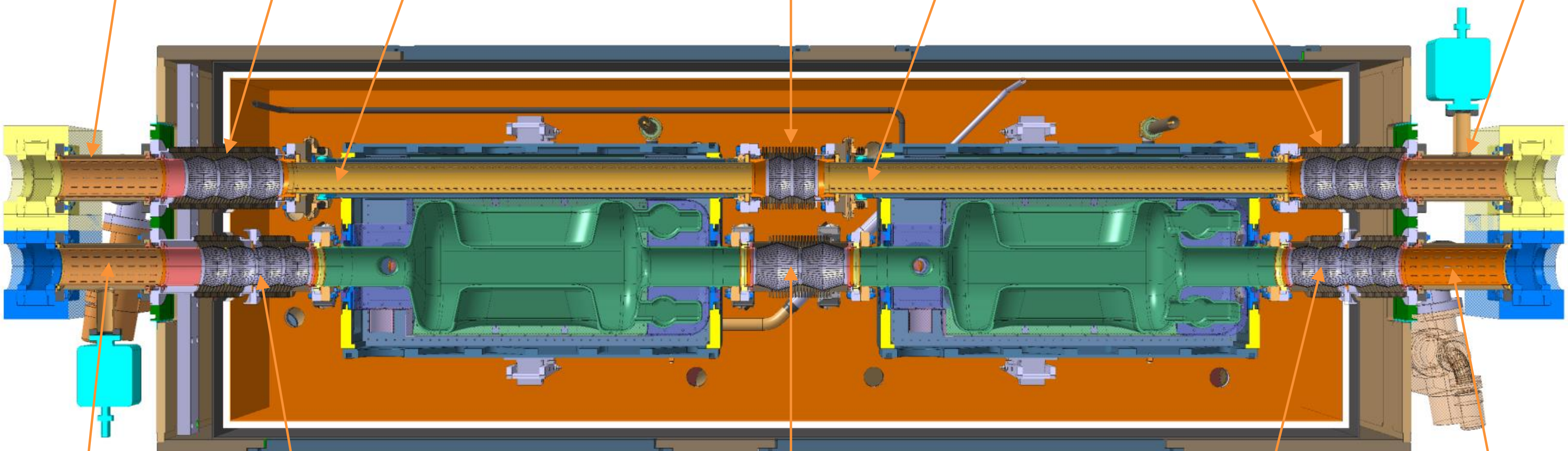
- Mechanical design in progress
- Collaboration BE/RF – CERN workshop (EN-MME)

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

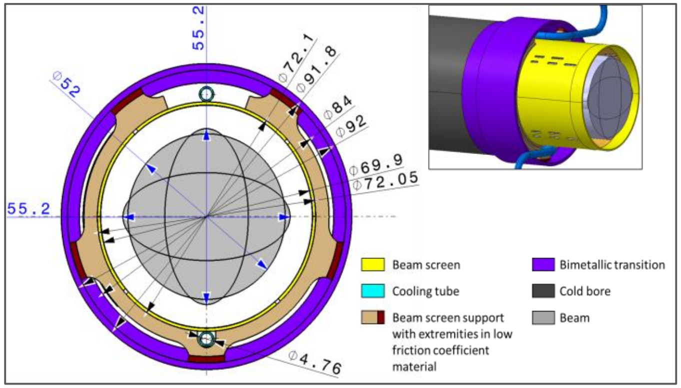
Beam section of RFD Cryomodule



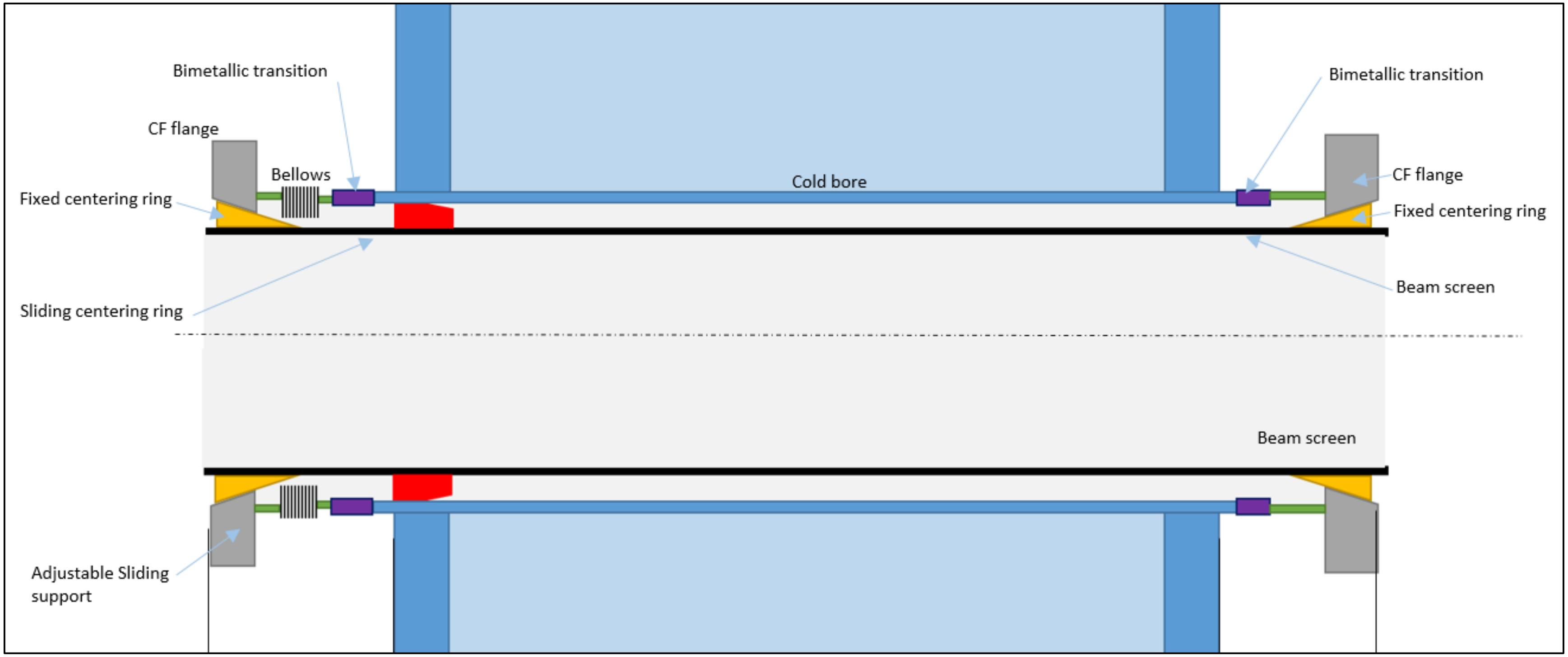


Beam screen

- 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 see EDMS 1864637
- Limited room inside the cryomodule (cold bore max aperture = 84mm)



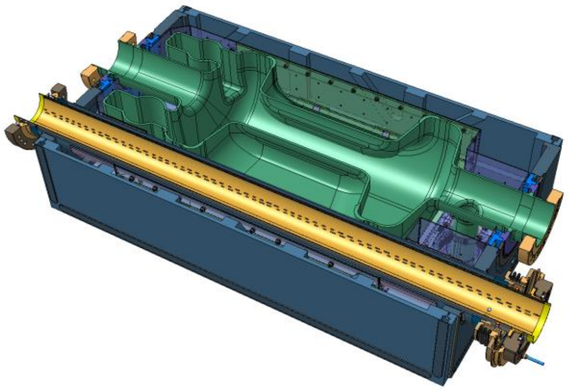
Extracted from EDMS 1864637
R.Tavares Rego



Collaboration CERN EN-MME / TE-VSC

See also the presentation of G.Riddone

Beam screen

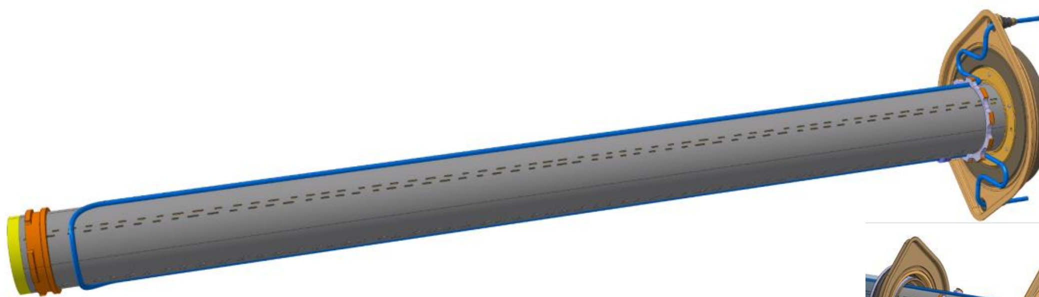


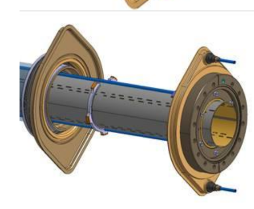
- Stainless steel screen with «random» holes for pumping
- Copper layer on the inner surface (th. 0.075mm)
- Ø4.76mm cooling pipe welded on screen (He gaz @ ~20K)
- 1 bellows for differential contraction
- Aperture calculation -> 1.5mm clearance on the radius

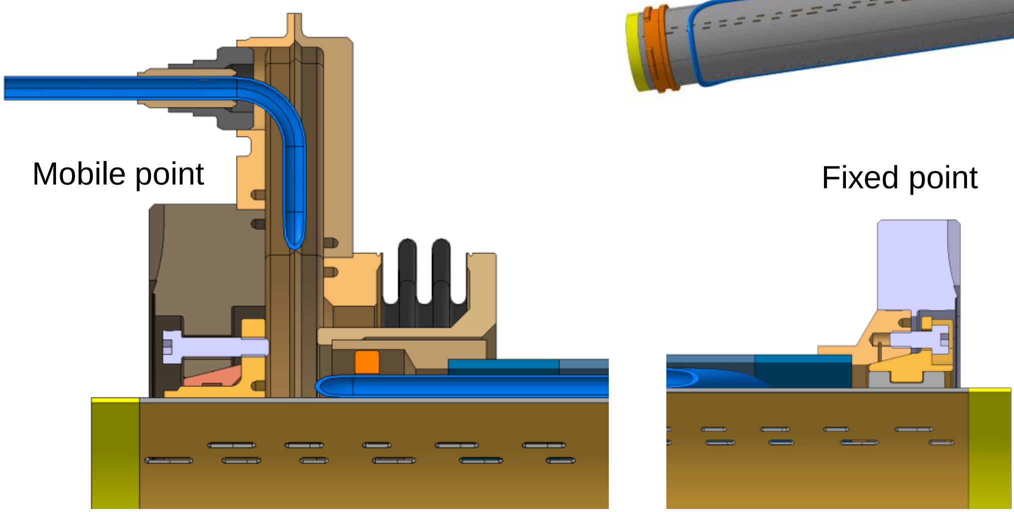
(calculation made with worse case LHC dipole method)

Remaining studies :

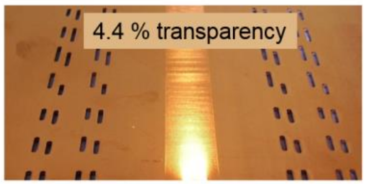
- Centering optimization
- Welding sequence to be reviewed
- Thermal calculation







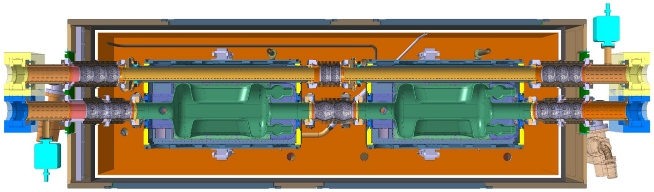
Compensation of differential contraction
(up to 1.7mm)



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

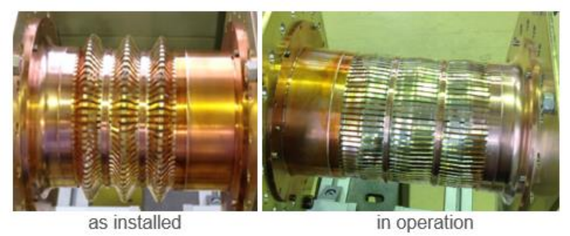
RF bridges for bellows



- Need to “screen” every bellows on the beam lines
- Large lateral displacement (6 mm max.)
- Deformable RF fingers design from triplet area (C.Garion – J.Perez Espinos CERN TE/VSC)
- 4 configurations to be designed

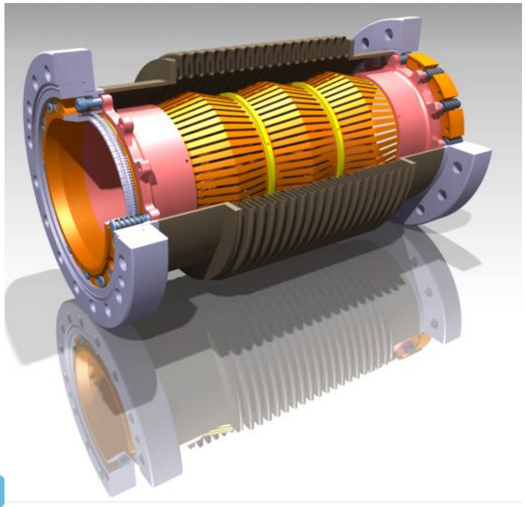
Copper Beryllium deformable RF fingers:

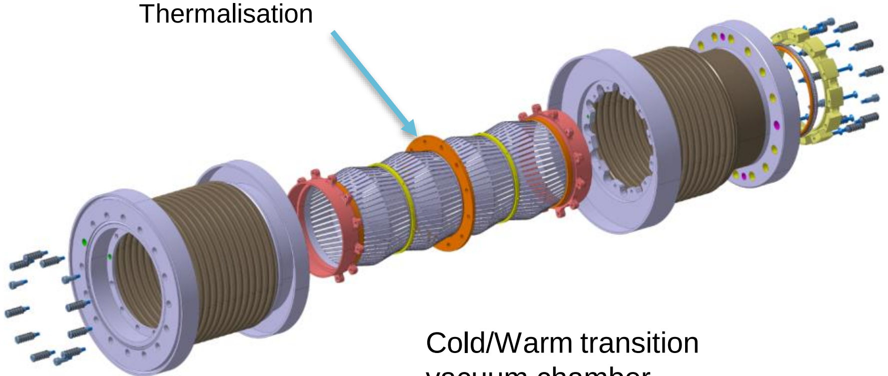
- Circular aperture
- C17410
- 0.1 mm thick, 3 mm width, gap: 1.4 mm
- 3 convolutions



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

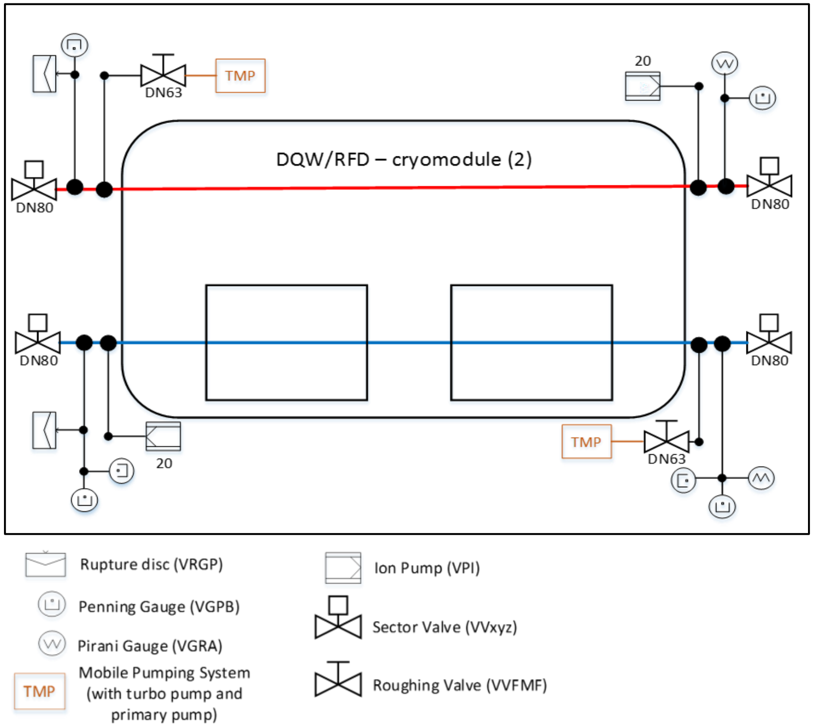
Intercavity vacuum chamber

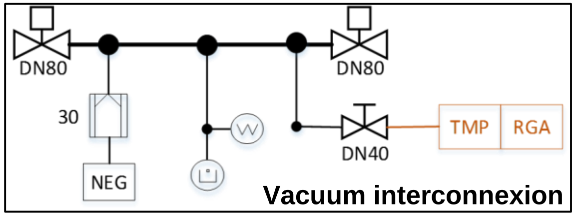




Beam vacuum instrumentation & interconnexion

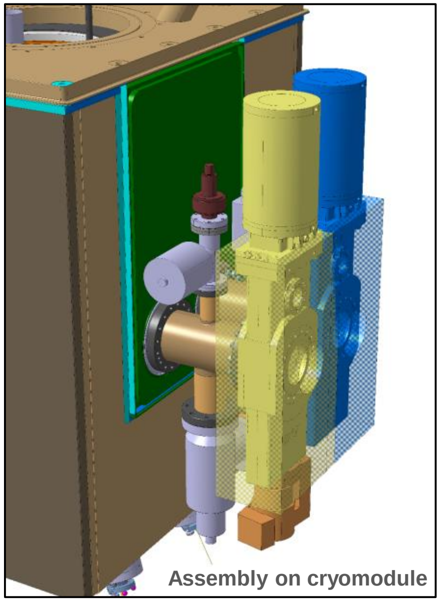
See presentation of G.Riddone



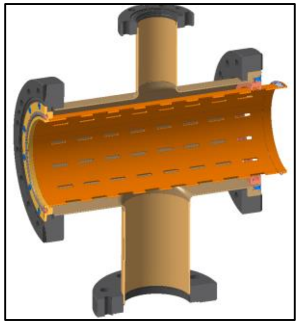


Vacuum interconnexion

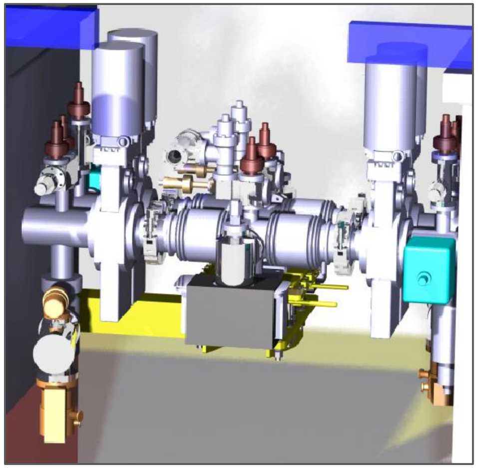
Courtesy R. Tavares Rego (TE/VSC) EDMS 1864637



Assembly on cryomodule



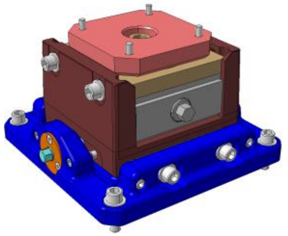
Extremity chambers



Study of CRAB Cryomodule interconnexion for LHC

Courtesy :R.Tavarez Rego CERN TE/VSC - N.PERAY CERN EN/MME

Support and alignement for RFD

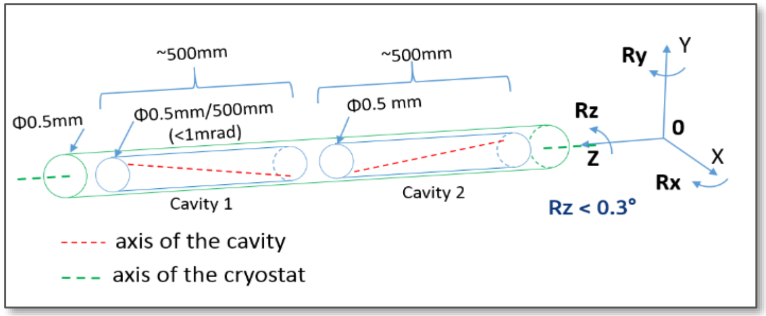


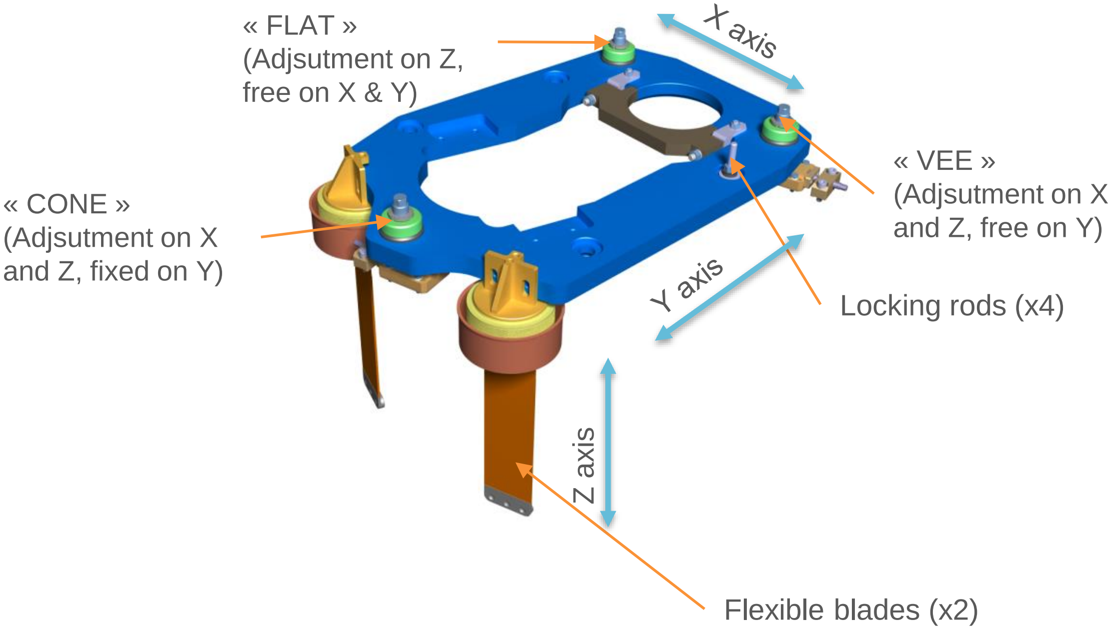
Cavity support

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

Alignement tolerances

- X-Y: **0.5mm (3σ)** for mechanical alignment + 0.5mm for operation errors
- Rz < 0.3°
- Rx, Ry (mean axis of CC inside Φ0.5mm)

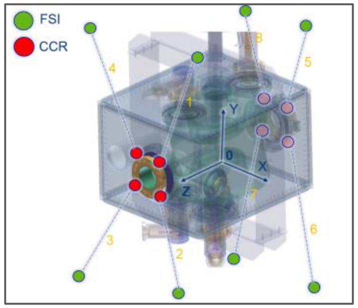


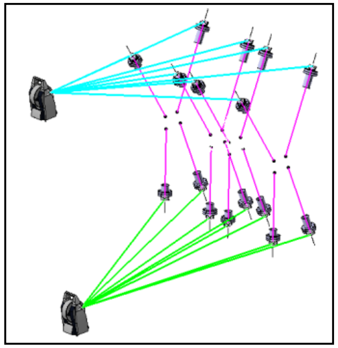


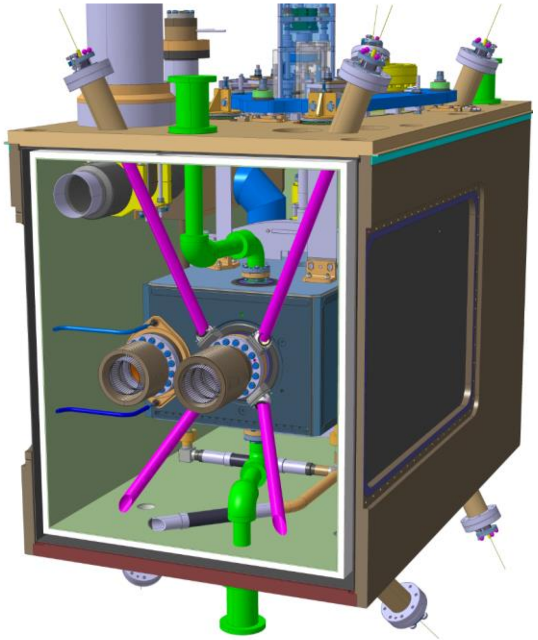
Cavities position monitoring system

See presentation of M.Sosin

- Frequency Scanning Interferometry system *(tested and validated during SPS test)*
- 8 targets per cavity
- Measure distances between FSI heads and centres of CCR targets used
- Positions of the FSI heads to be measured
- Anticipation of deformation (Thermal contraction, vacuum forces..etc)

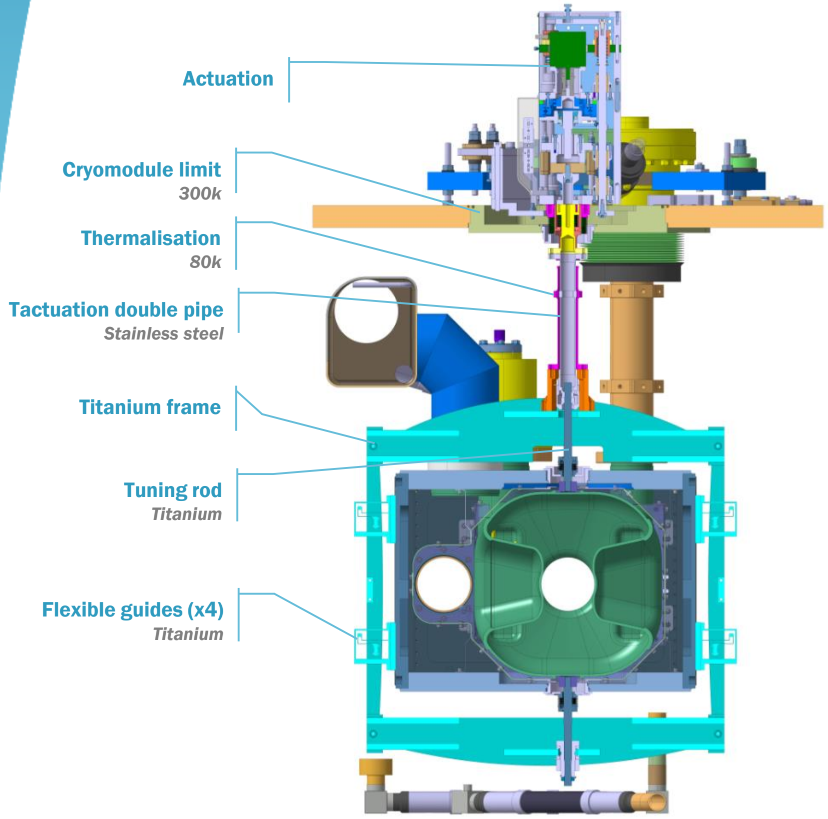






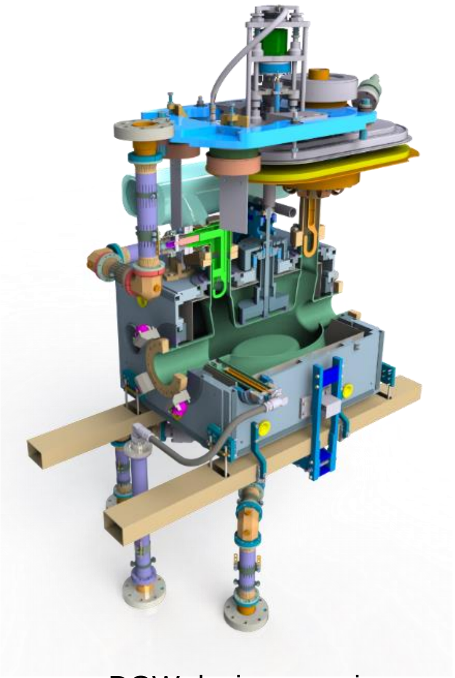
Courtesy M.Sosin – CERN EN/SMM

Cavity tuning system



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

See presentation of K.Artoos on freq. tuning



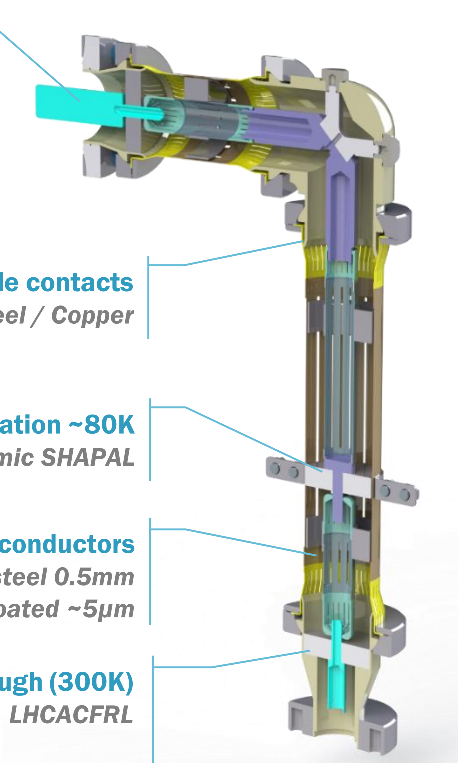
DQW design overview

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



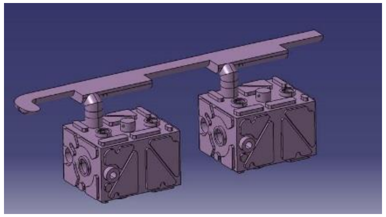
Datas

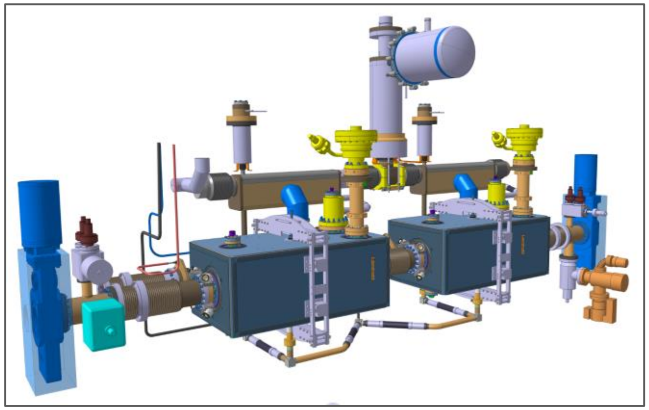
- 2 V-HOMS coaxial lines
- 2 H-HOMS coaxial lines
- 2 Antennas coaxial lines
- Size and design standardized for all lines
  - Non magnetic S.Steel with copper coating
  - Extremities compatible with standard connector
  - Shapal ring for thermalisation of inner line
  - Alumina for vacuum feedthrough

Cryogenic equipment **See presentation of K.Brodzinski**

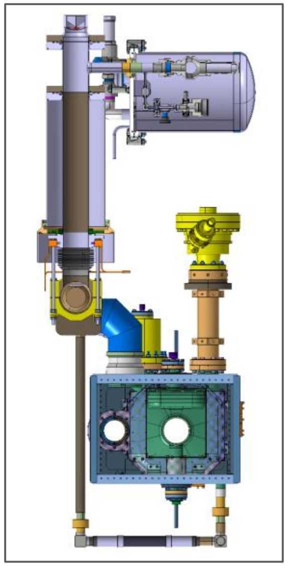
- New cooling line for beam screen
- Safety valve on cryomodule side
- Exchangeability of level gauges
- Pressure measurement set up
- Bolted temperature sensors
- Distribution of pipes for cooling equilibrium
- Adaptability to LHC slope

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

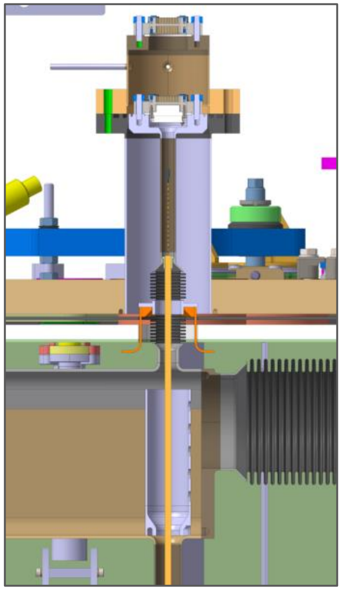




Cryogenic safety valve integration

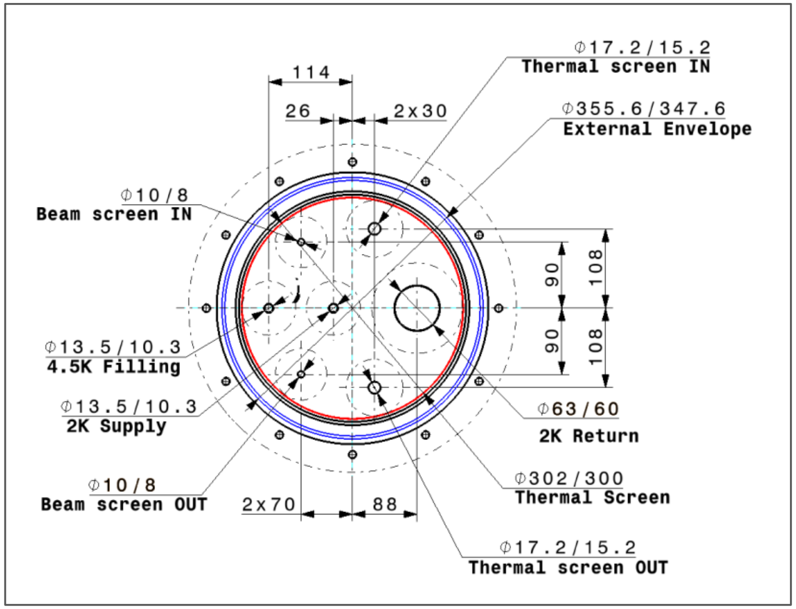


Level gauge feedthrouh (Ø12mm in.)



Cryogenic Jumper

- Integration of new beam screen line
- Stndardization of LHC interface
- Symmetrical jumper interface (allows the rotation of cryomodule)



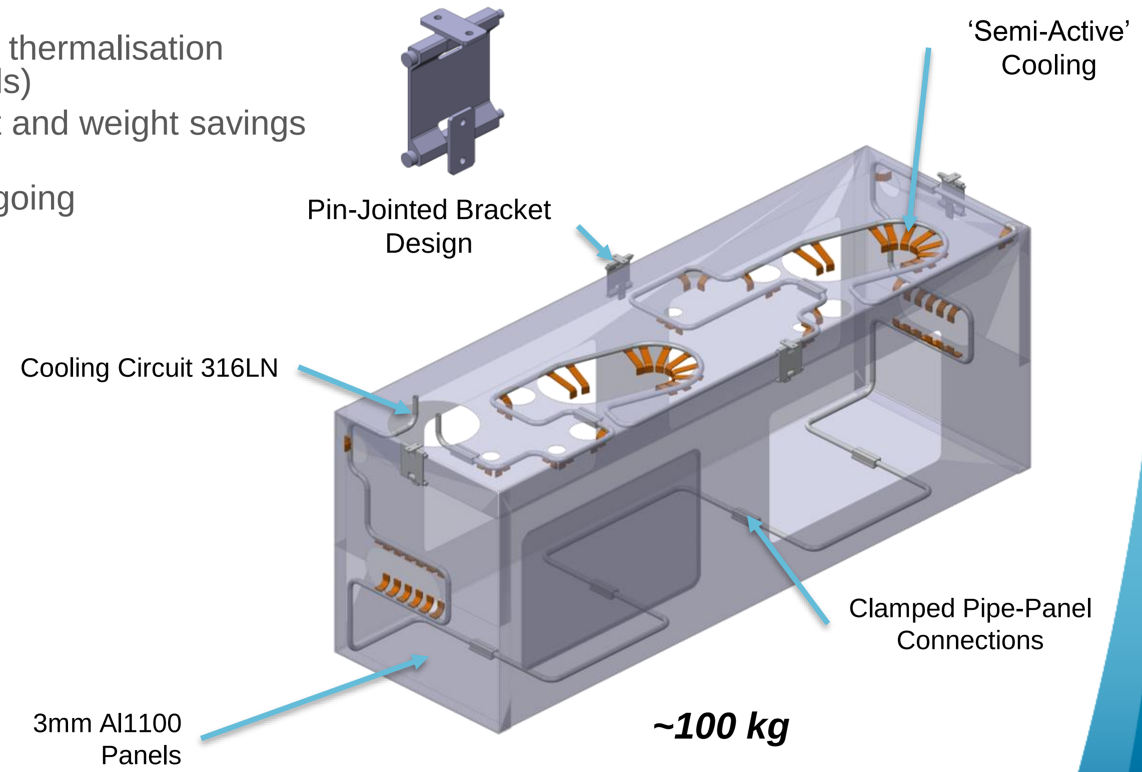
LHCACFQC0209
LHC jumper standard interface proposal

Thermal screen (STFC)

Courtesy N.Templeton - STFC

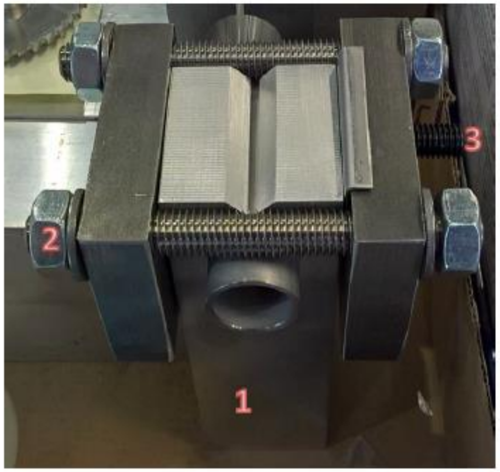
- **DQW-SPS design :**
  - Copper plates th. 3mm
  - Copper pipes brazed to plates
  - Operating pressure 18 bars
  - Transition copper/s.steel for final welds

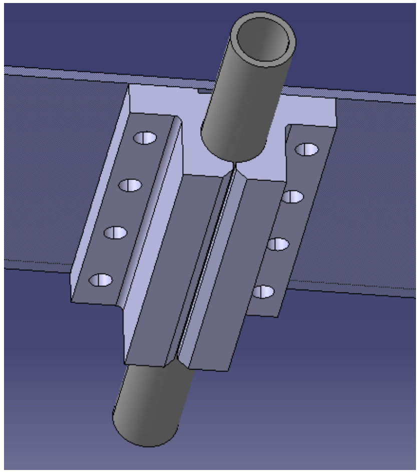
- **RFD design:**
  - Aluminium plates th. 3mm
  - SS316 Cooling circuit for cryoline integration and pressure safety
  - 'Semi-Active' cooling circuit allows thermalisation direct to pipe (brazed copper braids)
  - Al1100 panels give significant cost and weight savings for series production
  - Optimisation & detailed design ongoing



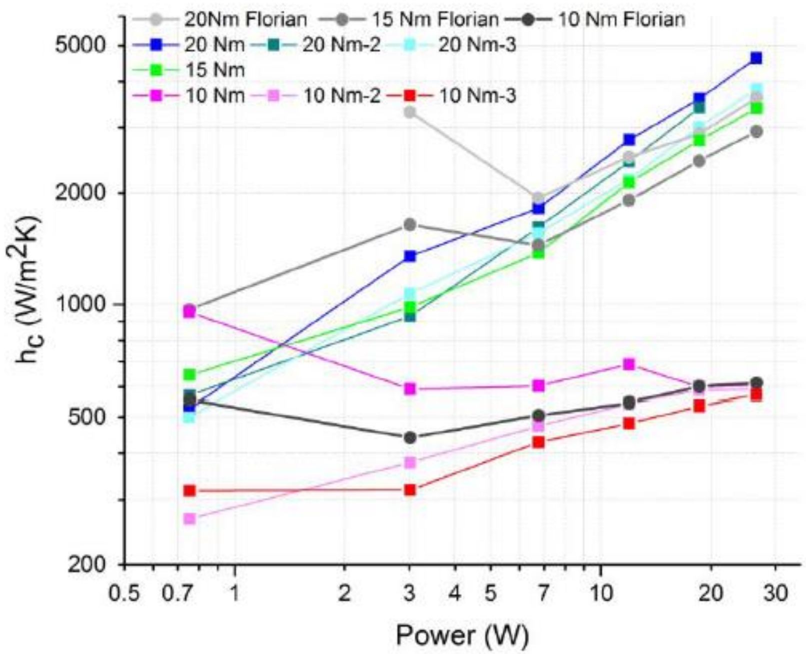
Pipe Panel Connections (STFC)

Courtesy N.Templeton - STFC





- SS 316 Pipes pre-assembled to Al block
- Pipes are pre-loaded with clamp
- Al block welded
- Pipe-block is integrated into cooling circuit
- Al blocks are fastened to panel
- Validation see ‘EDMS No. 1977794’
  - Thermal Characterisation of Stainless Steel Tube in Alluminium Block for Applications in Thermal Shield, A Nuñez Chico – EDMS 1977794
- TCC > 500 W/m2K



Analysis

Courtesy N.Templeton - STFC

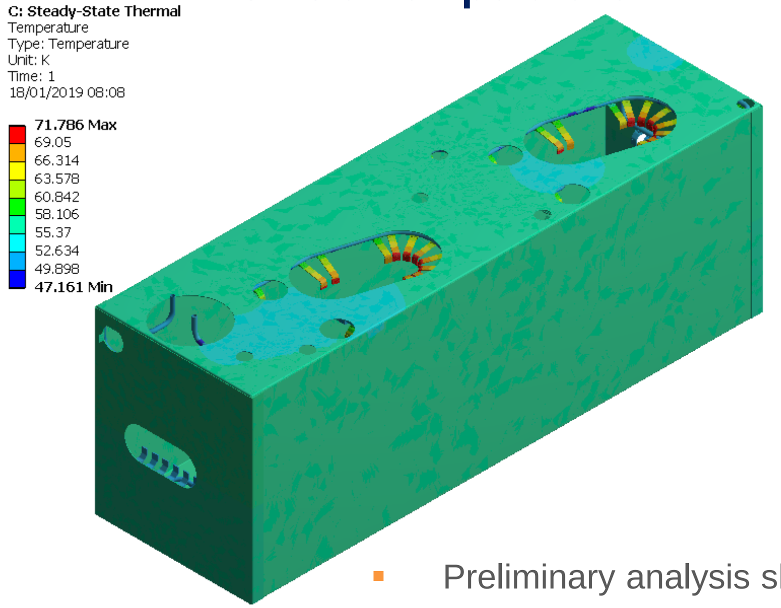
https://indico.cern.ch/event/742082/contributions/3085091/attachments/1734407/2805340/HL_LHC_Collaboration_2018.pdf

- Steady State Thermal Analysis
- Non-Linear Material properties
- Pipe Convection: 400 W/m^2 @ 50 K
- Thermal Contact Conductance: 500 W/m^{2}K
- Heat Loads (see table)

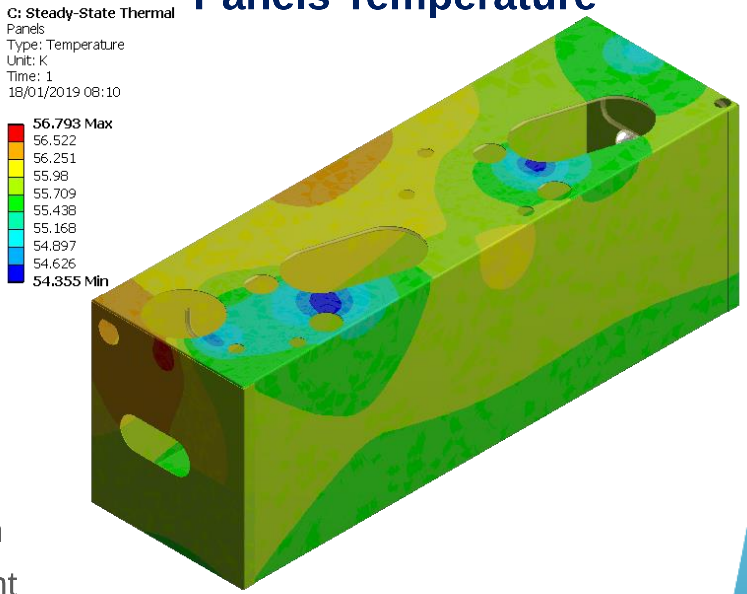
Heat Source	Heat Load (W)	QTY	Total (W)
FPC	36.0	2	72
HOM Coax	9.0	4	36
Blades	7.7	4	30.8
CWT	5.0	4	20
Tuner	7.6	2	15.2
Instrumentation	8.0	1	8
Screen Supports	2.0	4	8
BiPhase Support	2.5	2	5
Pick-ups	2.0	2	4
	Flux (W/m^2)	Area (m^2)	
Radiation	1.2	8.9	10.7
		Total:	209.7

Thermal Screen Heat Load Estimates v0.1.xlsx

Shield Temperature



Panels Temperature



- Preliminary analysis shows that design changes minimise temperature gradient across the shield
- Max dT panels: ~2 K
- Max dT Pipe, panels and braids: ~20 K

RFD Thermal Screen - Next Steps

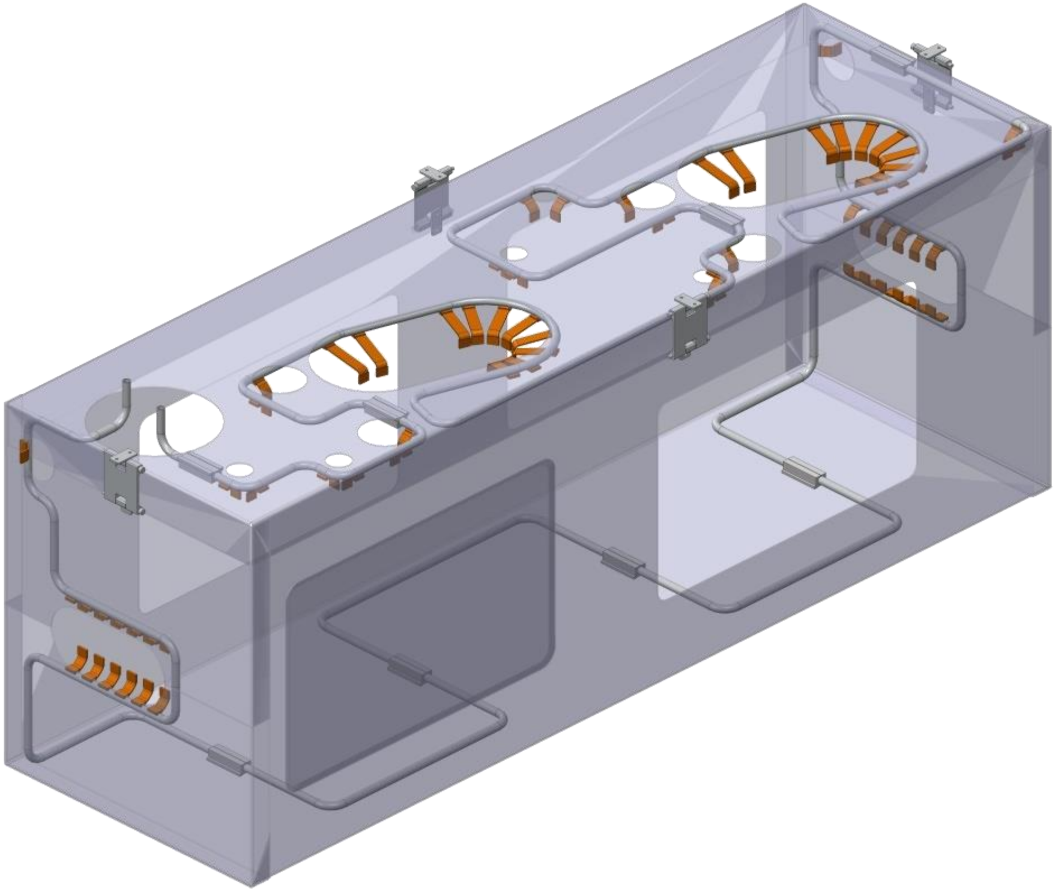
Courtesy N.Templeton - STFC

Design

- Clamp - Cooling circuit integration
- FPC cover
- Stress relief features
- Braid design & integration
- Detailed Design

Analysis

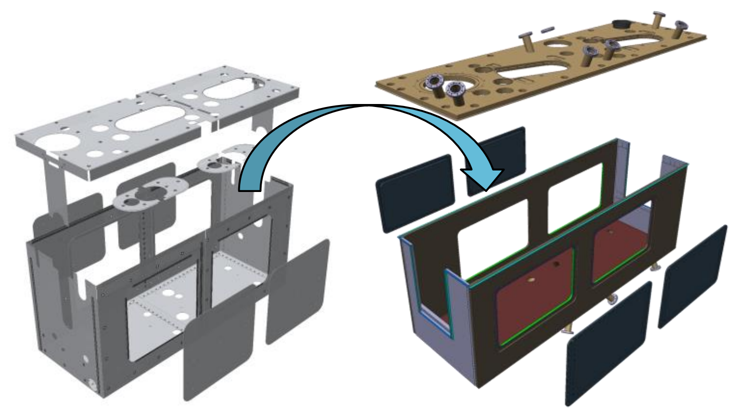
- Self weight & stiffness
- Cool down stress

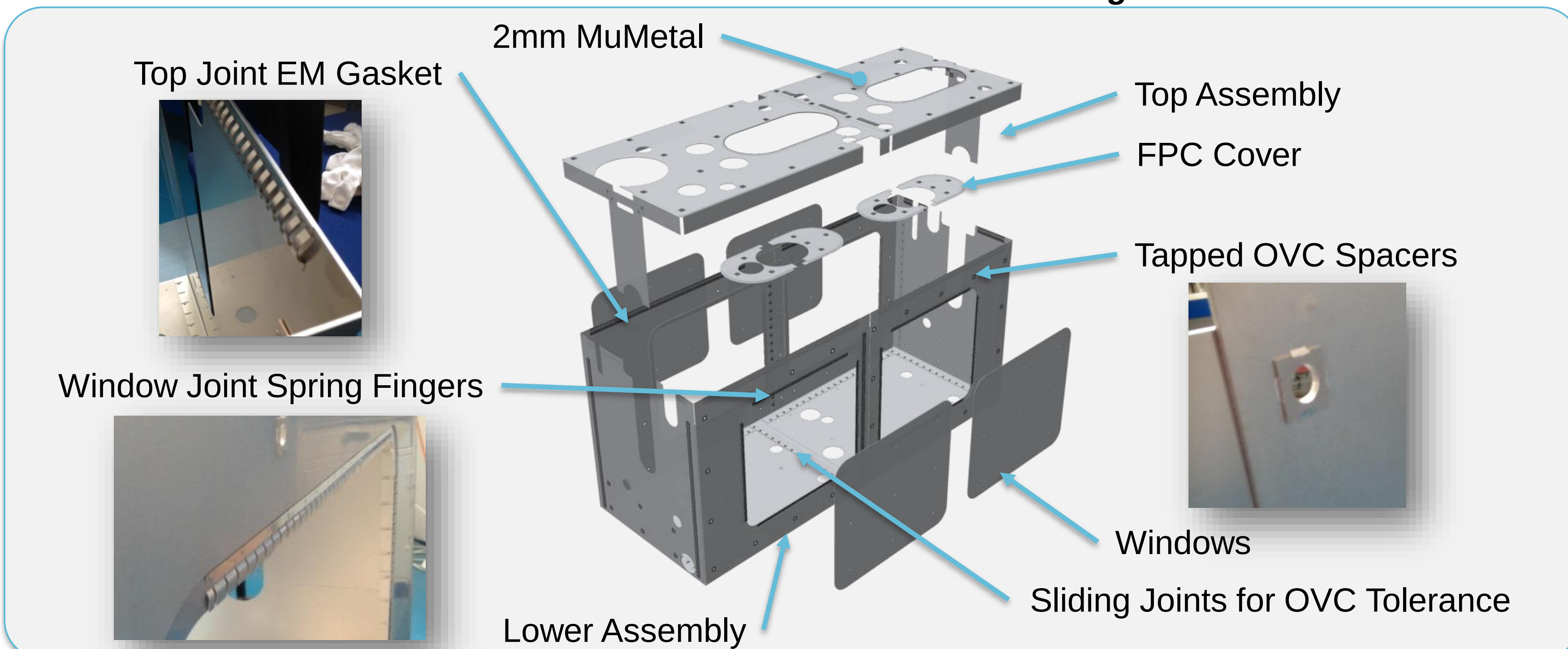


Warm Magnetic Shield (STFC)

Courtesy N.Templeton - STFC

- DQW Design to be repeated for RFD Pre-Series
- No configuration change required
- Only minor changes from DQW lessons learnt
- Warm Magnetic Shield has many interfaces!
- Design is dependant on Top Plate & Lower OVC design freeze
- Curie temperature (460 C) to be considered in design & implementation of OVC welding





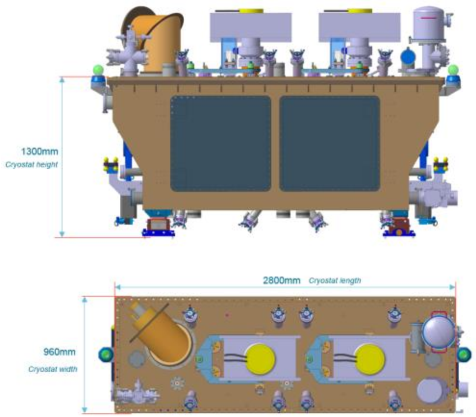
Cryostat vessel design

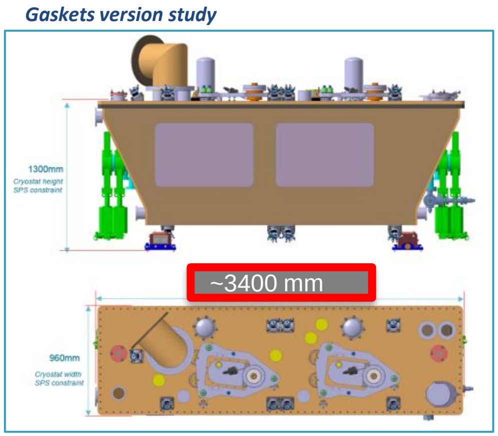
DQW outer vessel :

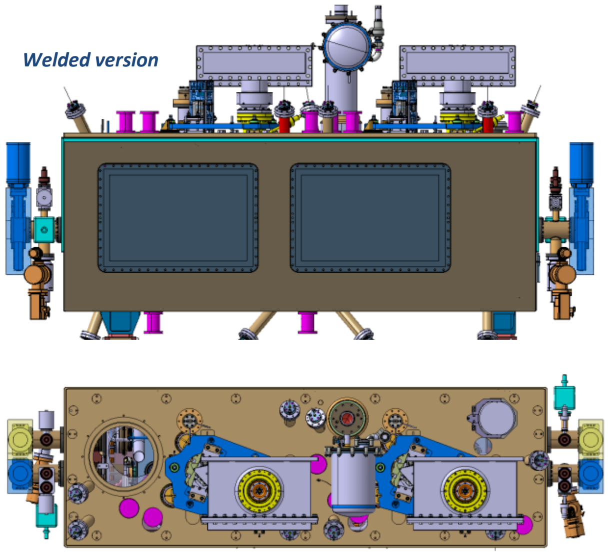
- Large gaskets
- Overall dimensions : 2800x960x1300

RFD outer vessel :

- Large gaskets removed
- Overall dimensions : 2800x950x1300

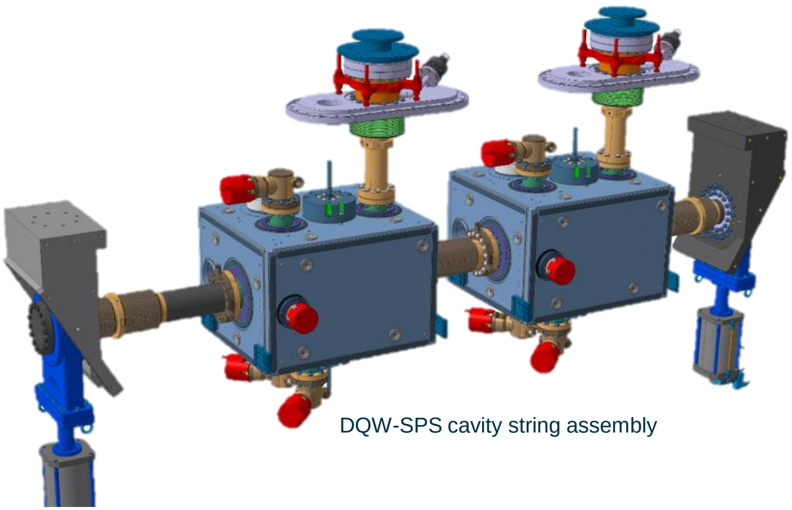




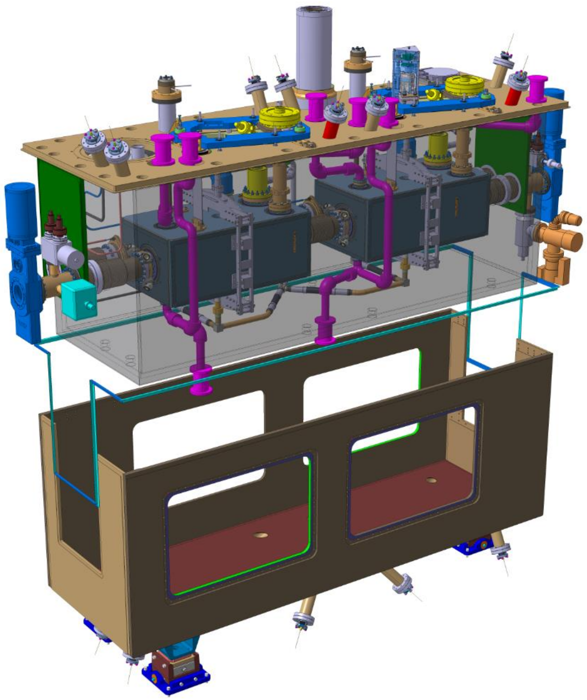


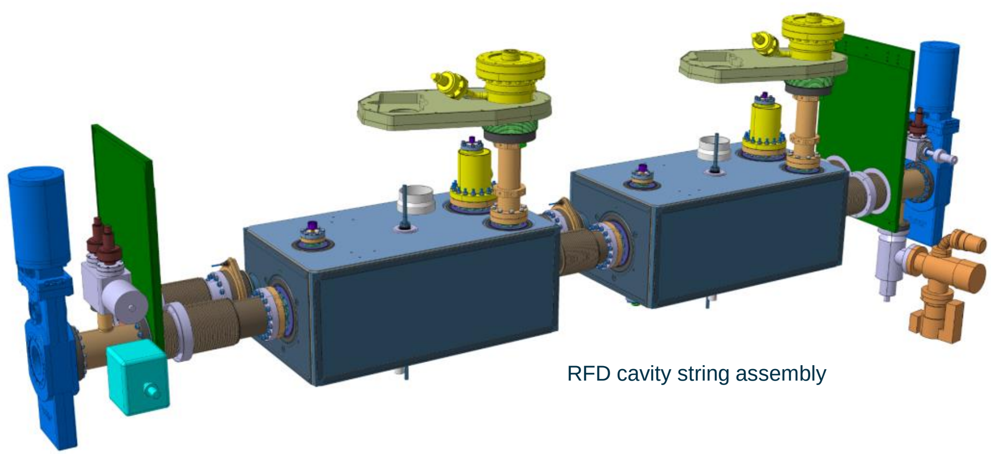
Vacuum vessel– welded concept

- Gaskets removed
- Integration of the additional vacuum instrumentation
- All the leak tight welds are accessible from outside

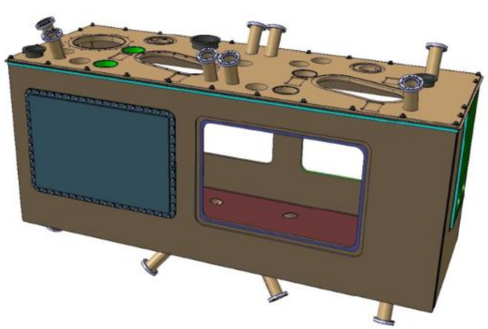


DQW-SPS cavity string assembly





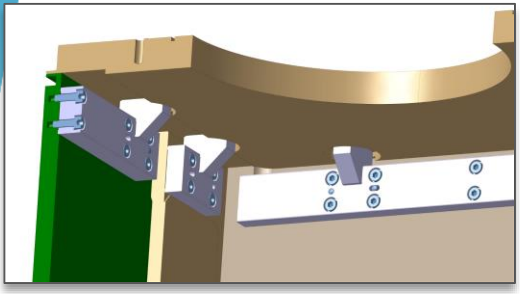
RFD cavity string assembly

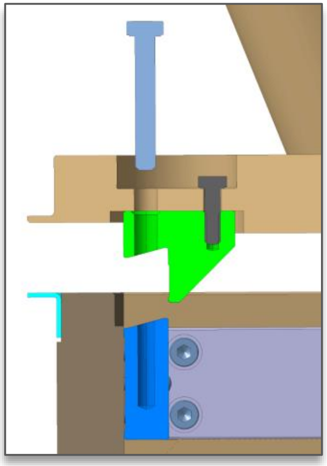


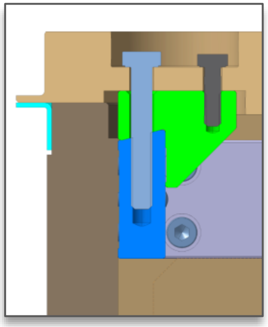
RFD welded vacuum vessel

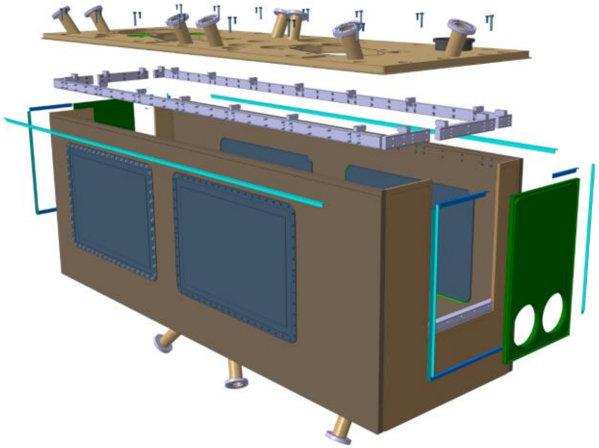
Vacuum vessel– welded concept

- Reinforcement study (on-going)



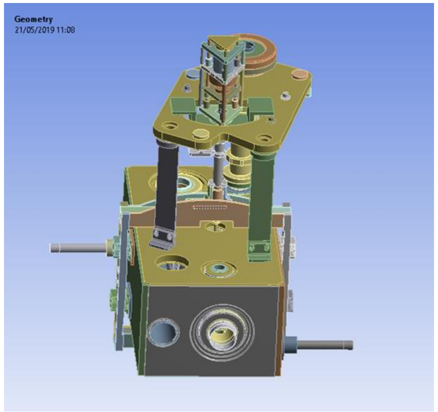


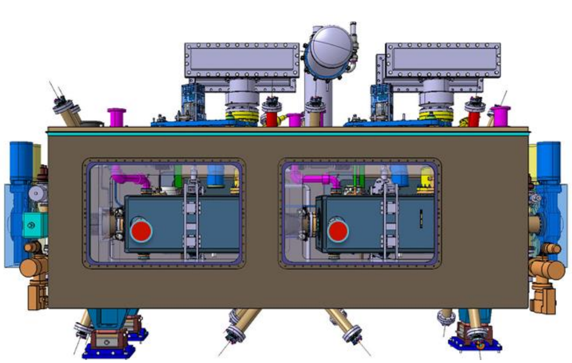


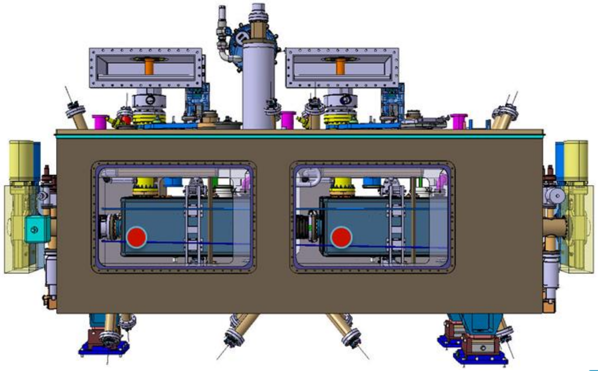


- Transport restraint (integration study to be done)

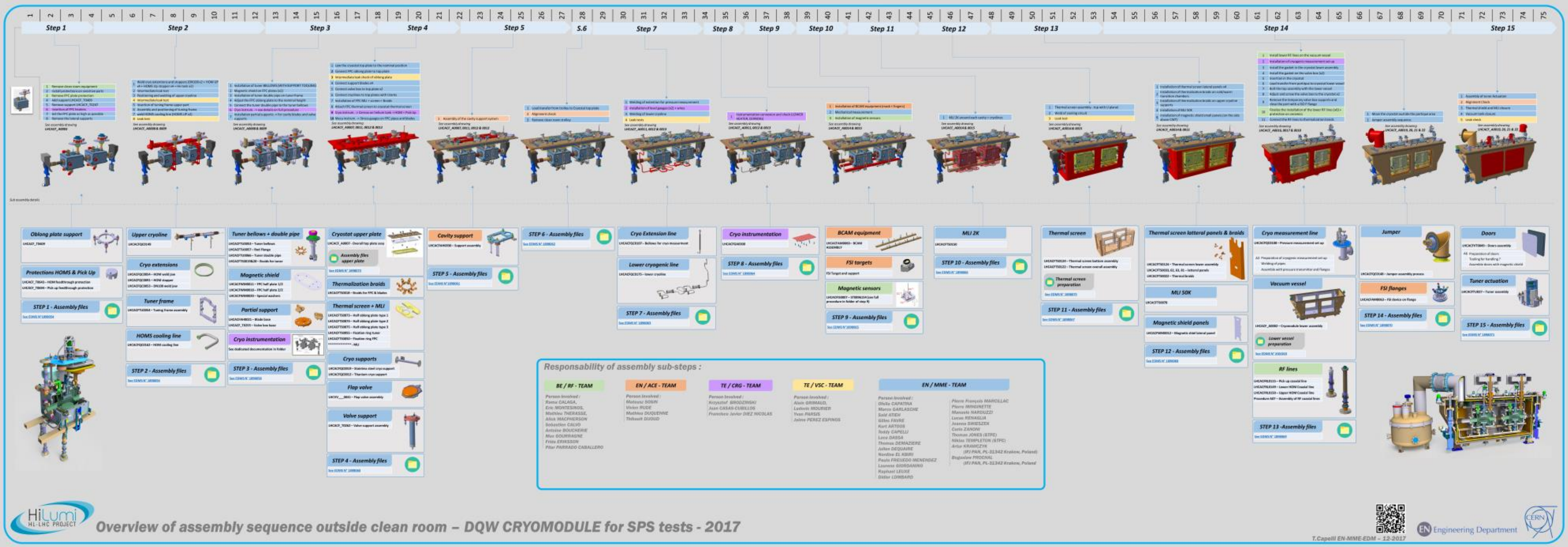
  See presentation K.Artoos

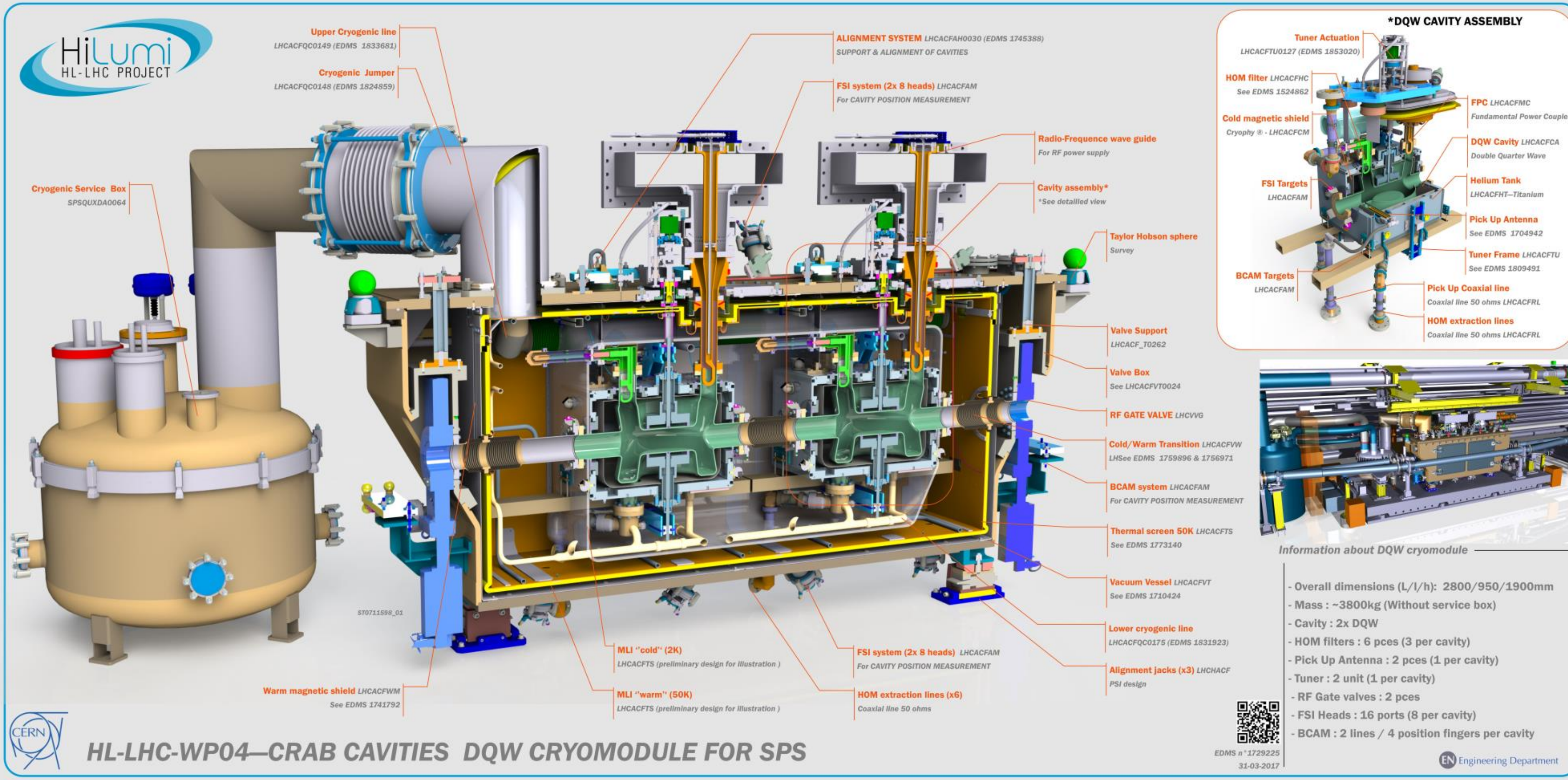




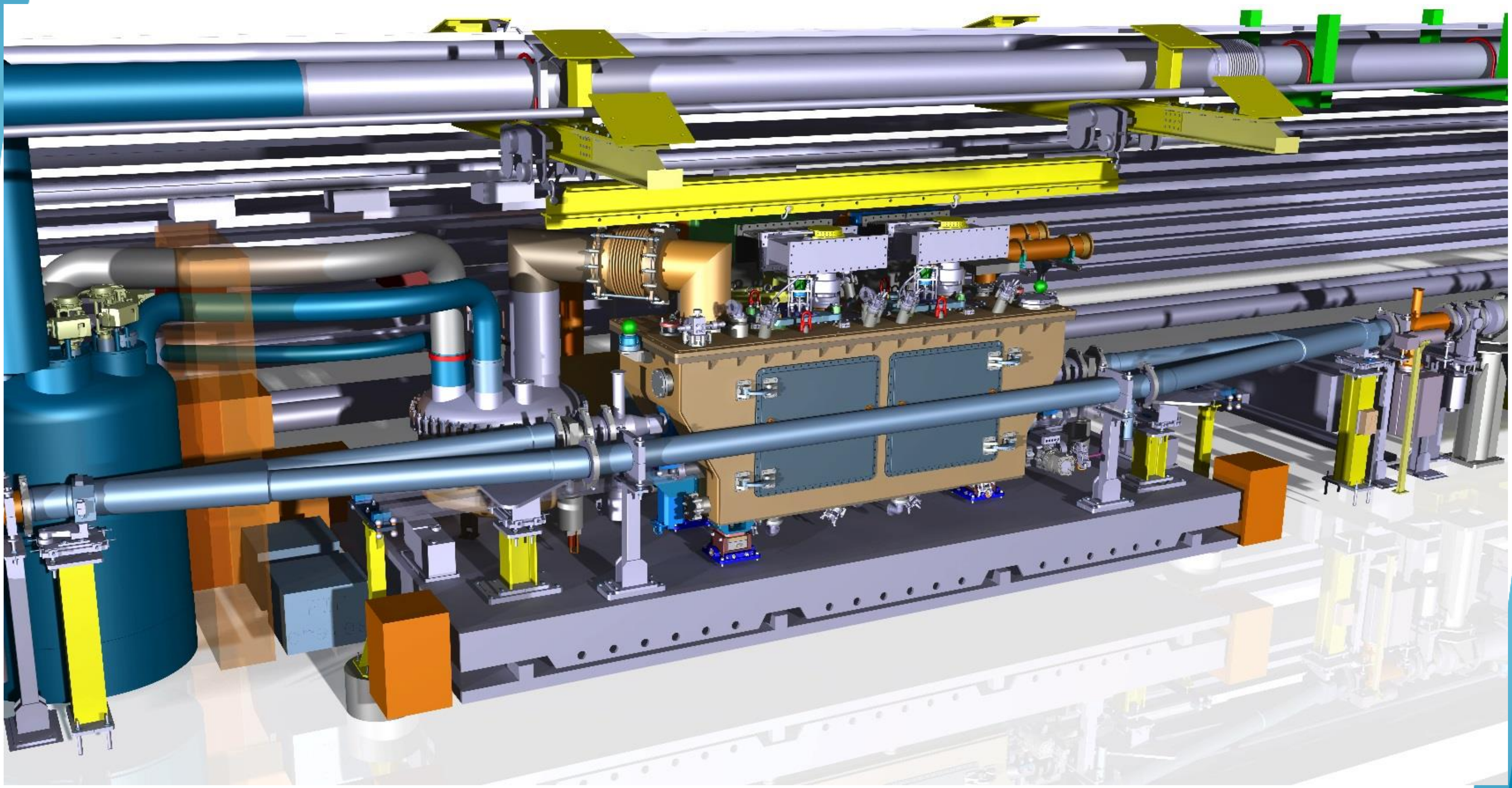


End


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

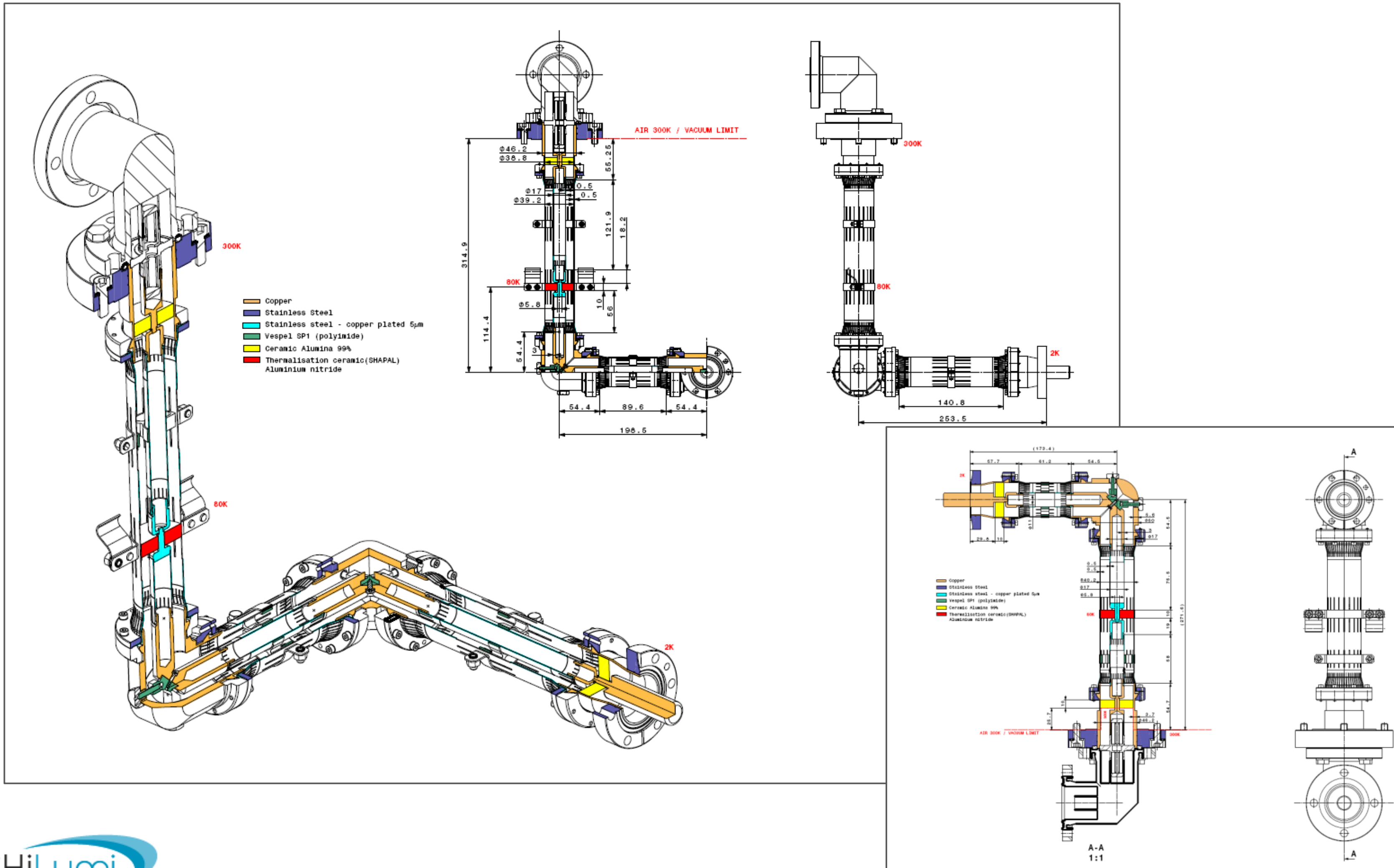


HiLumi HL-LHC PROJECT
Upper Cryogenic line
LHCACFQC0149 (EDMS 1833681)
Cryogenic Jumper
LHCACFQC0148 (EDMS 1824859)
ALIGNMENT SYSTEM LHCACFAH0030 (EDMS 1745388)
SUPPORT & ALIGNMENT OF CAVITIES
FSI system (2x 8 heads) LHCACFAM
For CAVITY POSITION MEASUREMENT
Radio-Frequence wave guide
For RF power supply
Cavity assembly*
*See detailled view
Taylor Hobson sphere
Survey
Cryogenic Service Box
SPSQUXDA0064
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)
FSI system (2x 8 heads) LHCACFAM
For CAVITY POSITION MEASUREMENT
Warm magnetic shield LHCACFWM
See EDMS 1741792
MLI "warm" (50K)
LHCACFTS (preliminary design for illustration)
HOM extraction lines (x6)
Coaxial line 50 ohms
*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

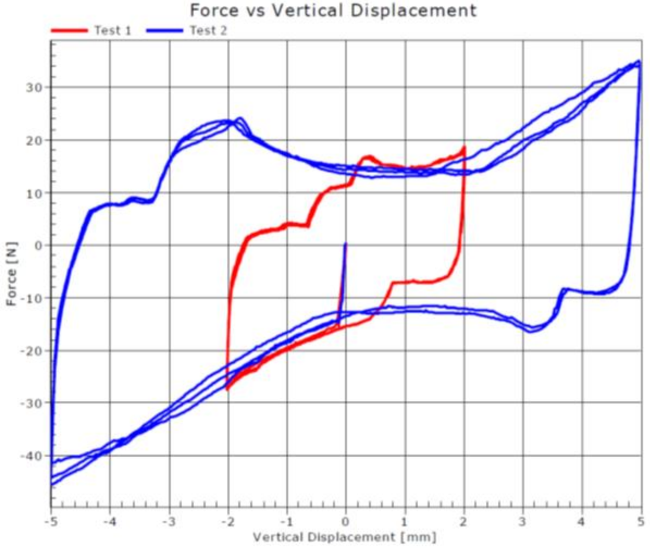


Coaxial lines

Design from DQW, length/position adapted to RFD

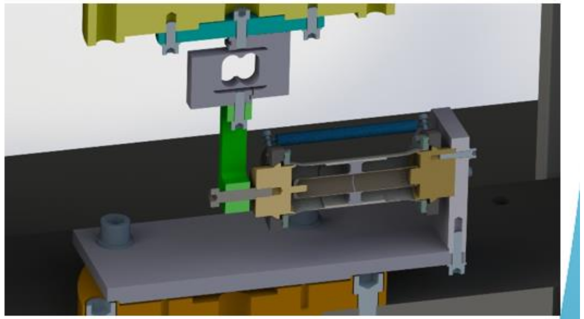


Results: tests 1 and 2



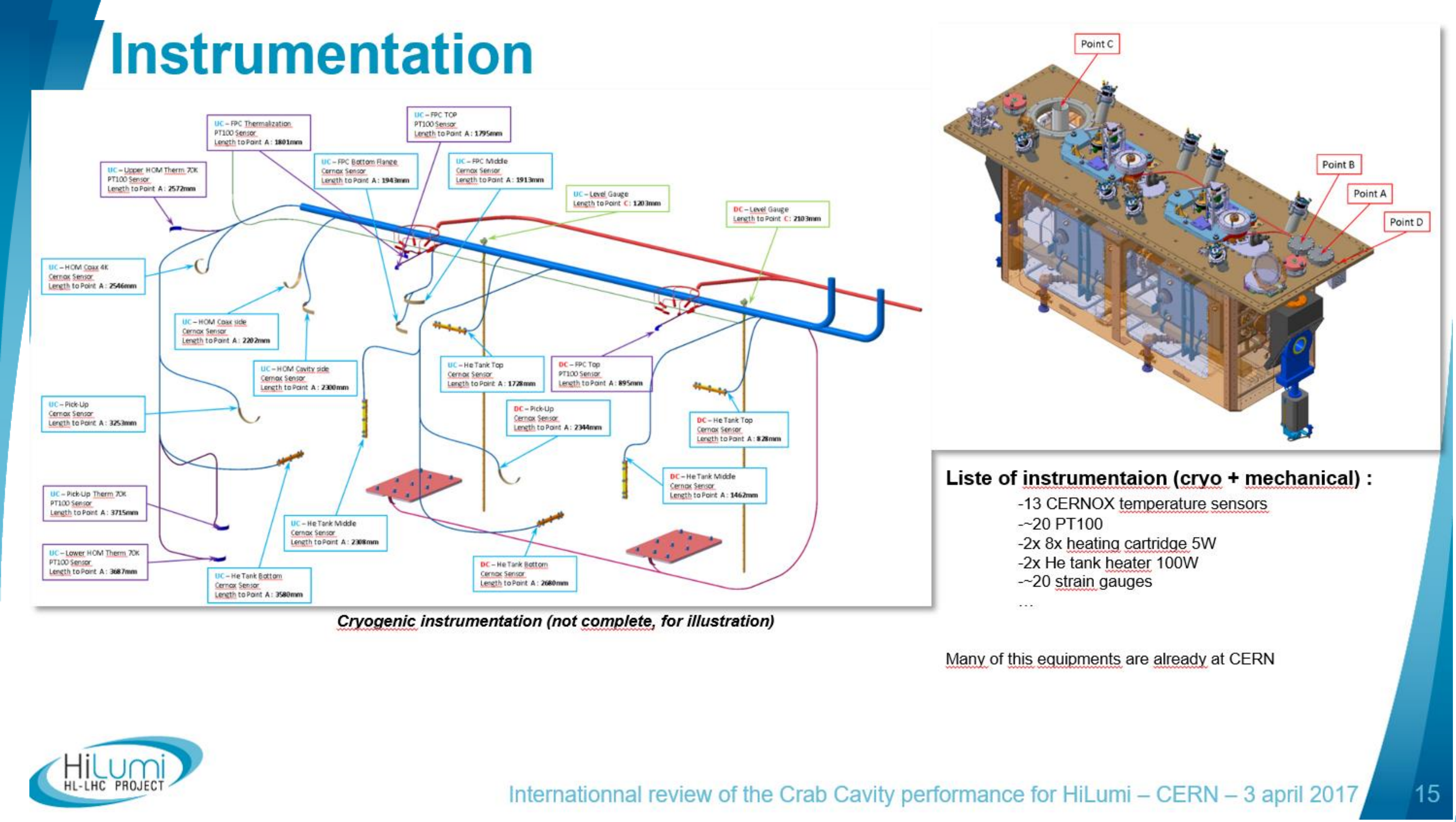
- **Test 1**: 3 cycles between +/- 2 mm at 1 mm/min
- $|F|_{max}$ = 27.7 N downward direction

- **Test 2**: 2 cycles between +/- 5 mm at 1 mm/min
- $|F|_{max}$= 47.7 N downward direction



L. BIANCHI – EDMS1737834

Test performed at Mechanical Measurment lab of CERN (L.Bianchi – M.Guinchard)



- Glue replaced by bolted connection

Pipe Convection & Parameters

		Inputs	
Internal Diameter	D (m)	**0.015**	*(15 mm)*
Mass Flow Rate	m (kg/s)	**3.80E-03**	*(3.8 g/s)*
Pressure	P (Bar)	**20**	
Temperature	T_s (K)	**50**	
	T_f (K)	**70**	
	T (K)	60	
Specific Gas Constant	R_{He} (J/kg K)	2078	
Density	ρ (kg/m³)	16.04	
Mean Fluid Velocity	U (m/s)	1.34	
Dynamic Viscosity	μ (Pa.s)	2.10E-05	Ref
Reynolds Number	Re	15,360	
Specific Heat	c_p (J/kg.K)	5188	
Fluid Thermal Conductivity	k (W/m.K)	*0.066859*	See kHe data
Prandtl Number	Pr	1.63	
Nusselt Number	Nu	89.5	Ref
Heat Transfer Coefficient	**h (W/m².K)**	**399.0**	

Thermal screen: we discussed to use ID 10 mm but I reanalyzed this circuit and changed my position to use ID 15 mm as in DQW. Diameter of 10 mm would be largely sufficient for required flow but considering the fact that we have experience about gas speed/vibrations in pipe of 15 mm which does not has influence on RF, we should not introduce such change and use ID = 15 mm. Below I give main characteristics of this circuit as information to Niklas.

Assumptions: Tin/out=50/70 K, heat load=400 W, ID=15 mm, PHe=20 bara
Output: required mass flow=3.8 g/s, gas speed=1.63 m/s, deltaP=6.5 mbar (considering 20 m line with 20 elbows).

1237-meng-cal-0011-v1.0-Thermal Screen Cooling Circuit