WP4-RFD cryomodule design for SPS tests

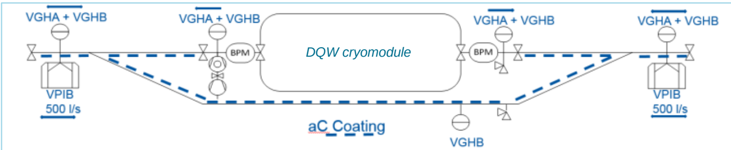
11th HL-LHC Collaboration Meeting, CERN - 19-22 October 2021

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

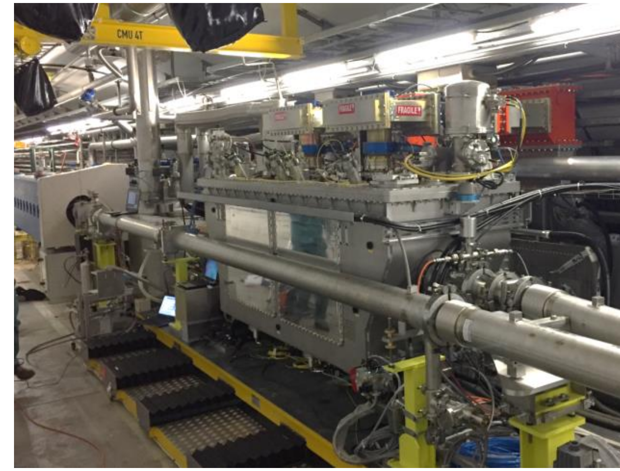
Cryomodule design

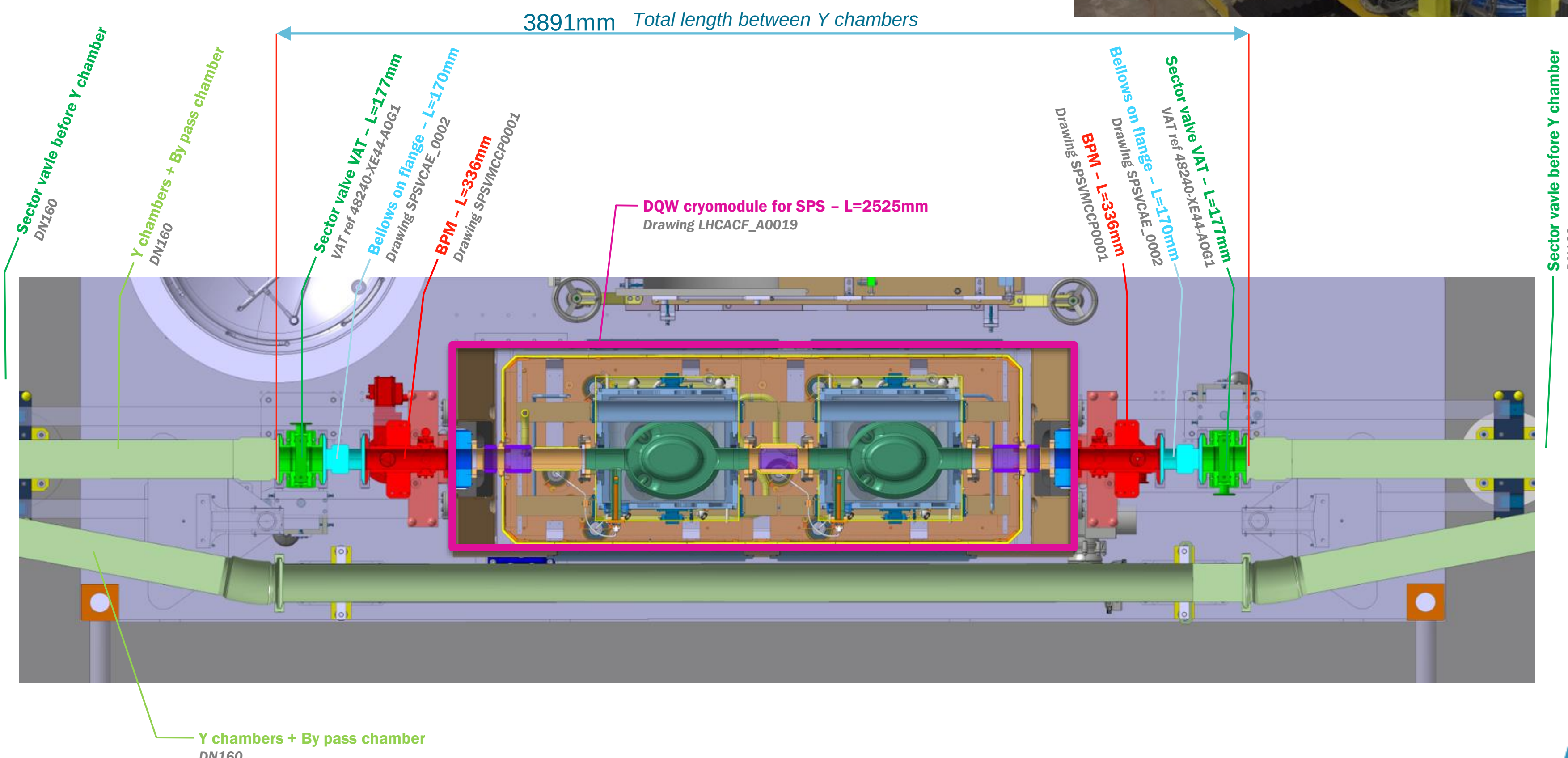
- Collaboration CERN / STFC-Lancaster (UK) / Triumf (Canada)
- Environmental constraints :
  - Space integration LHC/SPS/SM18
  - Cryogenic temperatures / Cryogenic capacities
  - Vacuum / Ultra High Vacuum
  - Radiofrequencies
  - Vibration due to transport
  - External interfaces
- Assembly constraints :
  - Assembly sequence
  - External sites for assembly – STFC / UK – Triumf / Canada
  - Interfaces for assembly tooling
  - Clean room compatibility
  - Welding compatibility
- Series production optimization:
  - Optimization of thermal performances
  - Production simplification / sub-contracting
  - Standardization of component
  - Material selection for cost reduction
  - Weight reduction

SPS test stand

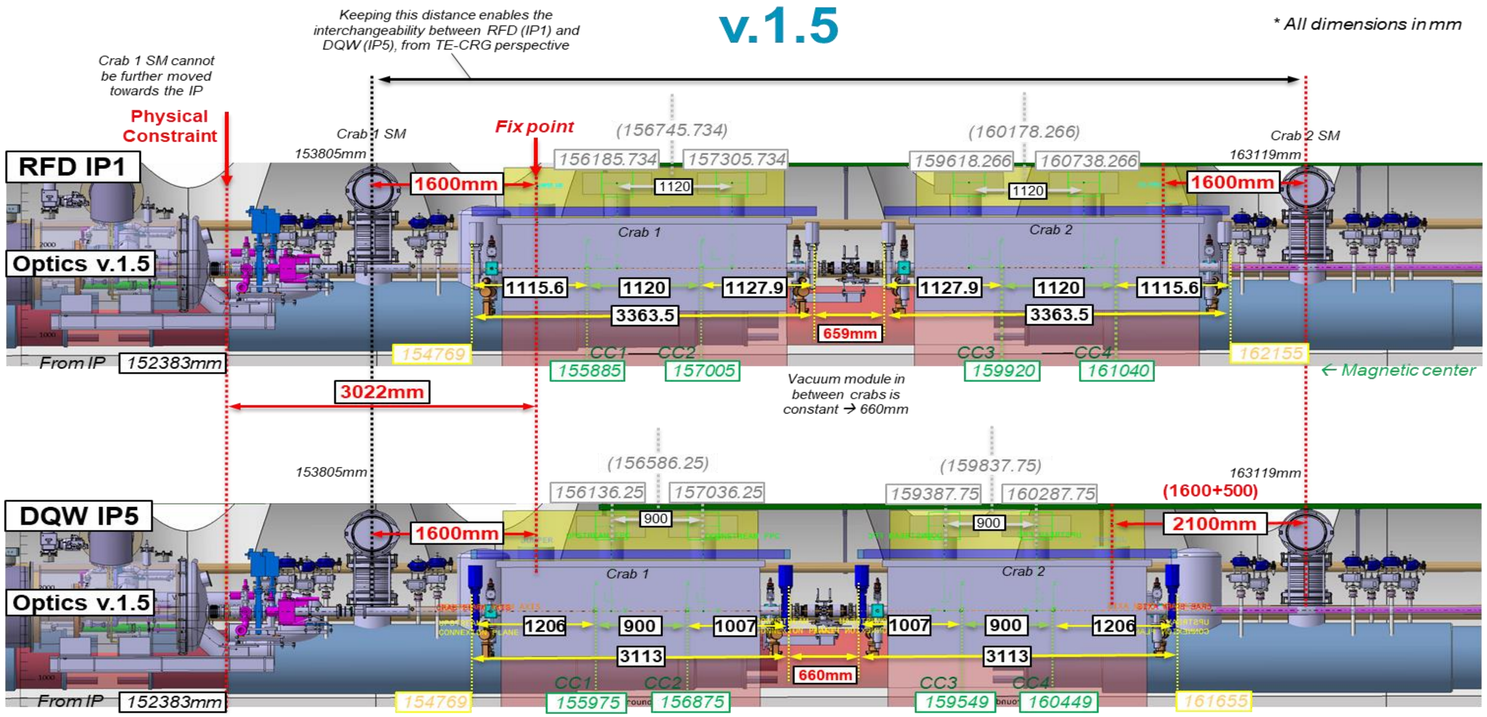


*SPS beam vacuum layout for test stand – courtesy **Chiara Pasquino TE/VSC***

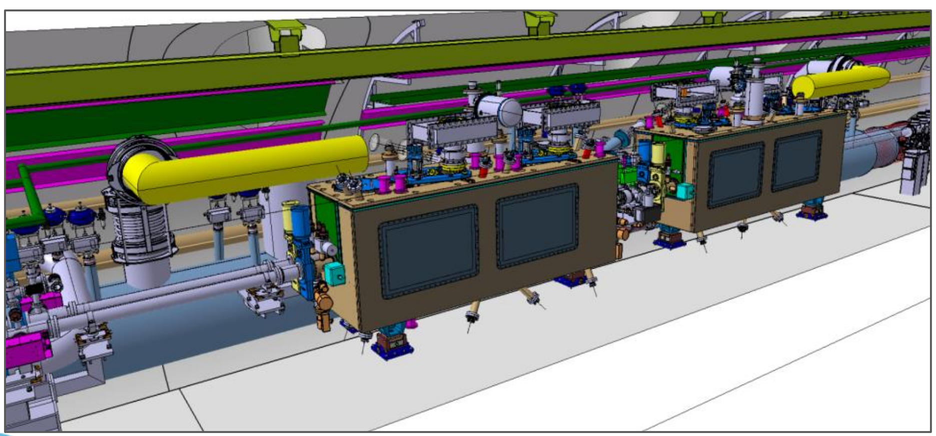


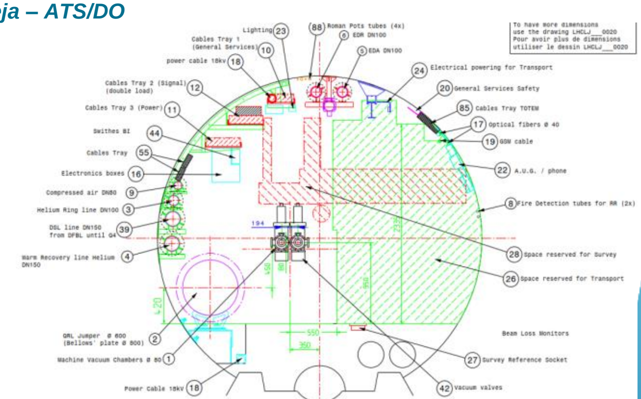


LHC integration – preliminary study



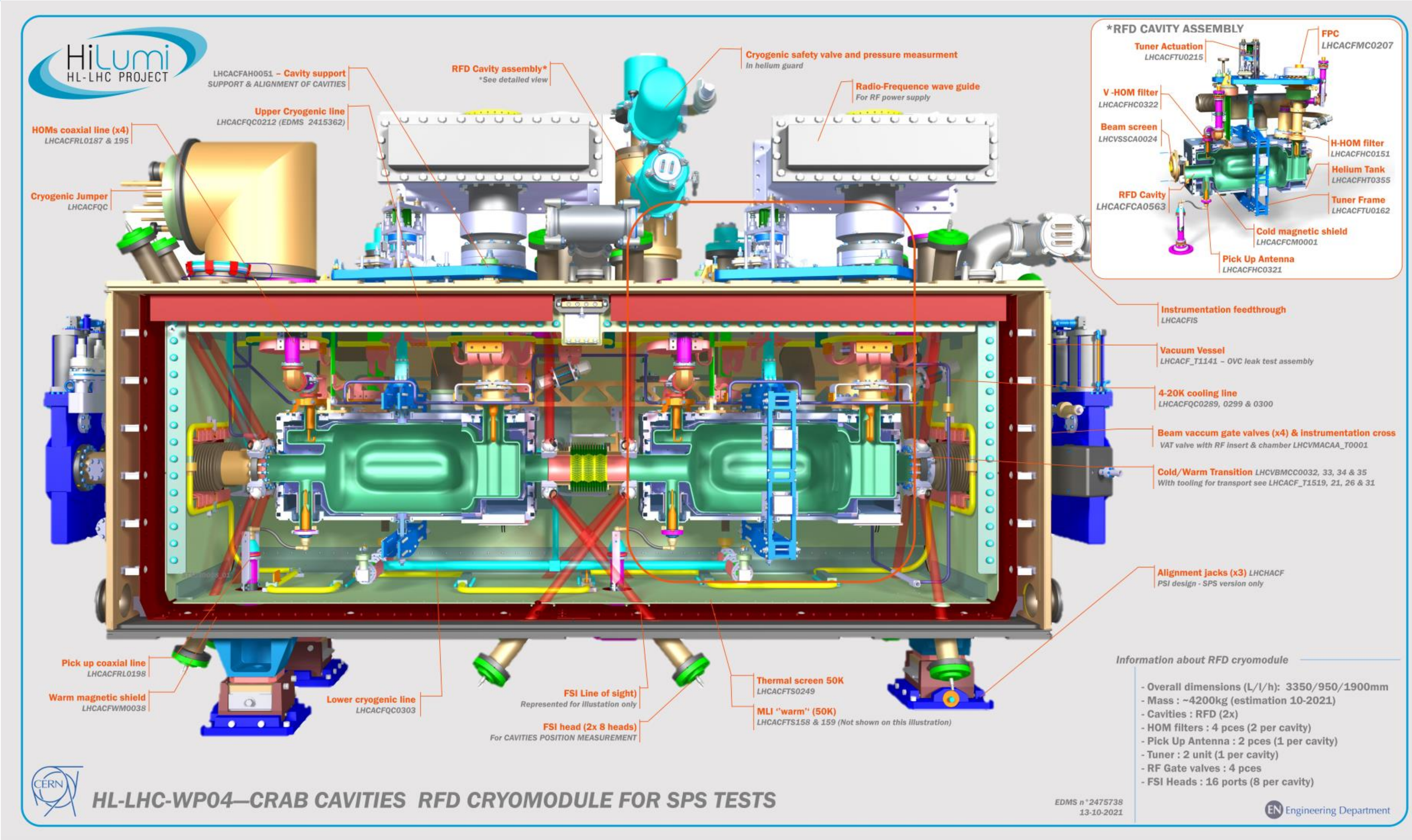
LHC integration– courtesy **M. Gonzalez de la Aleja – ATS/DO**





Section view of LHC
More details on drawing LHCLJ___0020

RFD/SPS Cryomodule overview



RFD Cavity mechanical design

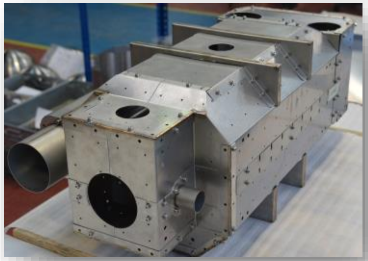
CAVITY design

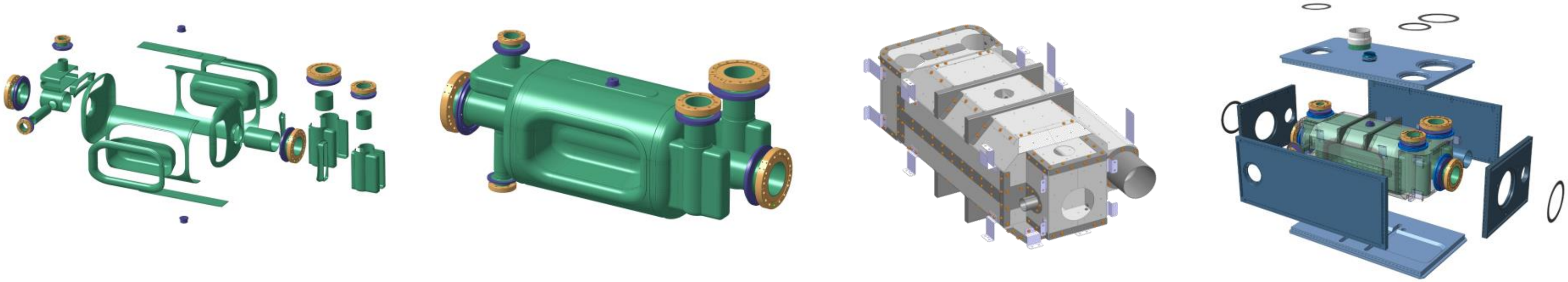
- Mechanical design done from 2K RF design
- Splitting of the cavity optimized for manufacturing

(Anticipation of deformation, thickness variation and welding shrinkage)

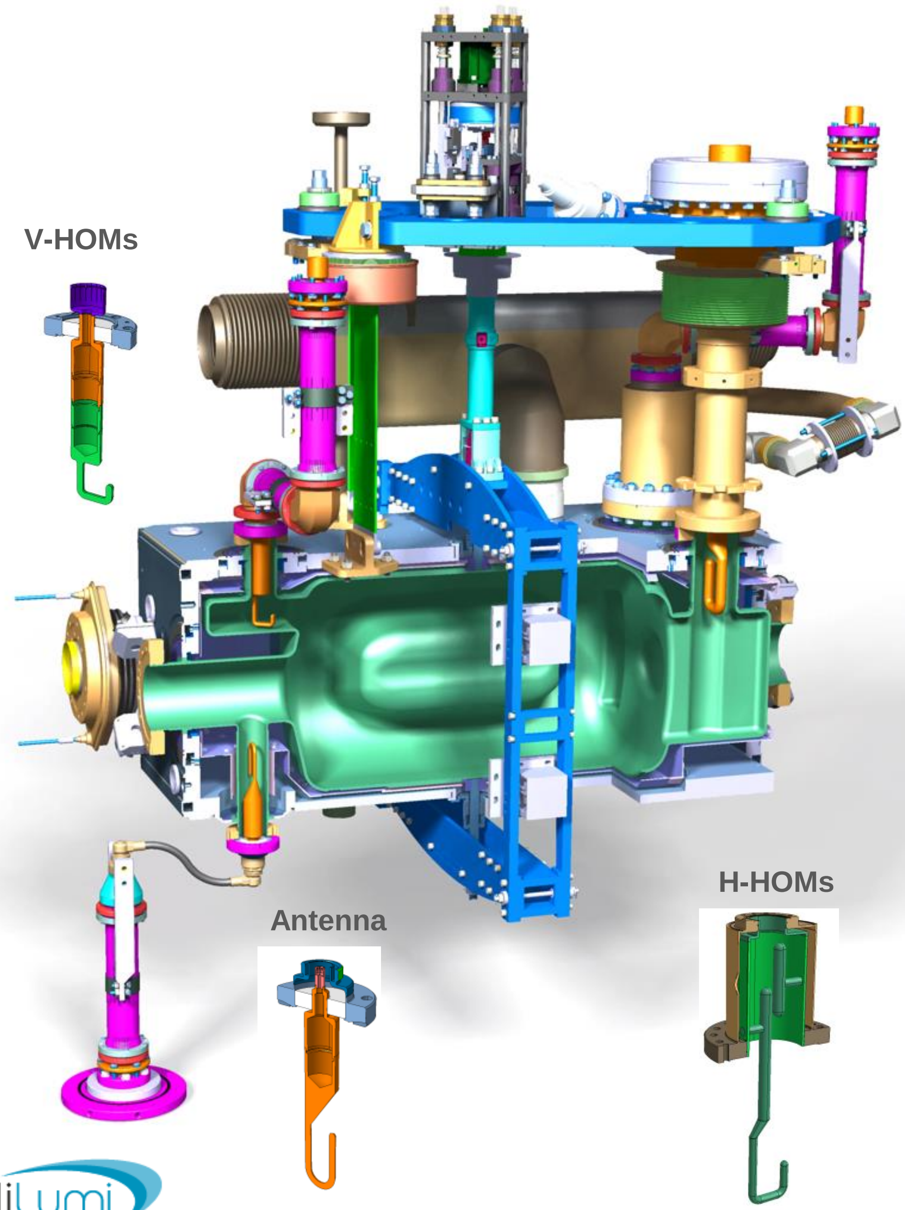
Cold magnetic shield (2K) - STFC:

- Material : Cryophy
- Installed around the cavity inside the Helium vessel
- Analysis for cool down stress and deformation





FPC, HOMS and Pick up



See presentation of E.Montesinos

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

HOMs and Antenna for RFD :

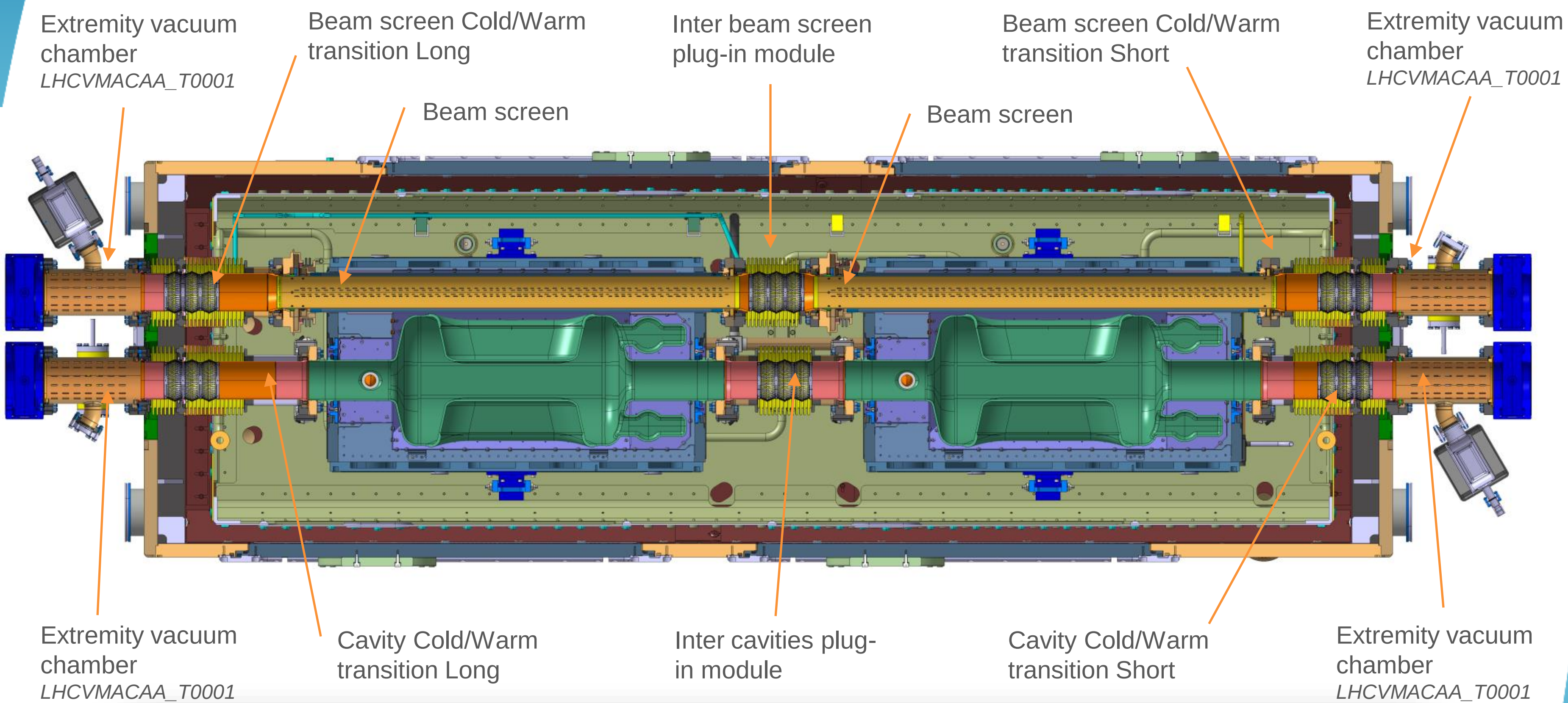
- Collaboration SY/RF – CERN workshop (EN-MME)

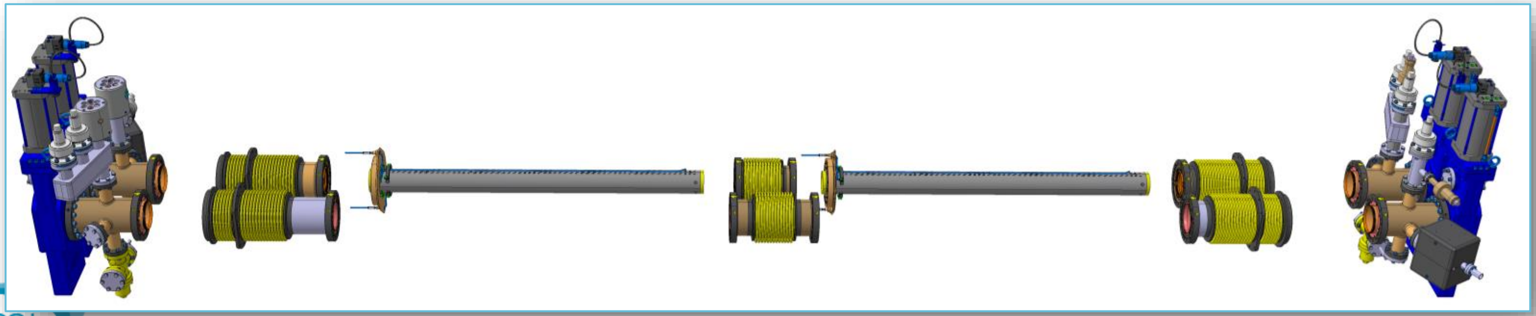
FPC outer pipe :

- Stainless Steel pipe with internal Cu coating
- Collaboration EN/MME – SY/RF – TE/VSC
- Thermal evaluation see EDMS 2218580

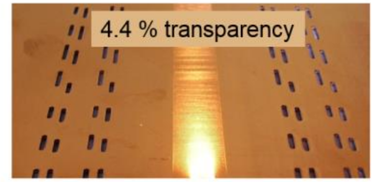
Beam section of RFD Cryomodule

See presentation of Chiara Pasquino CERN/TE-VSC and EDMS 1864637 – TE/VSC specification

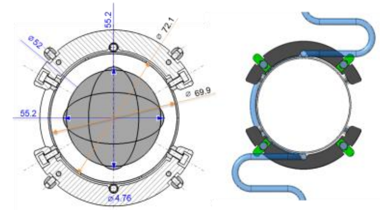




Beam screen

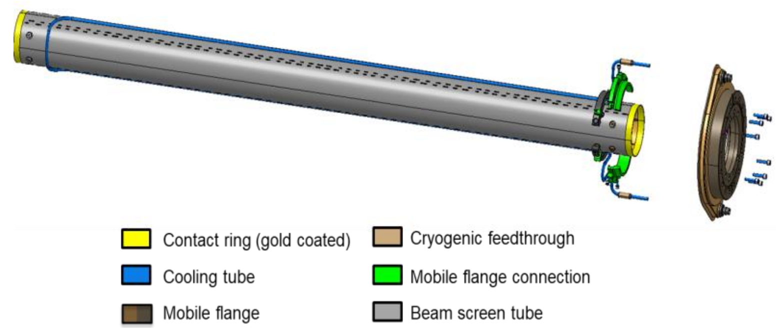


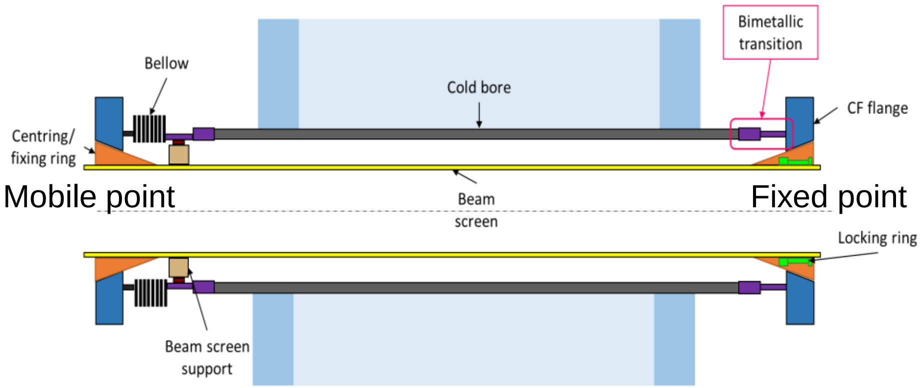
Slot: Width, W= 1.5 , length = 8 +/-2
Longitudinally spaced by 16 +/- 2 between the axes of the slots
Wall thickness, T = 1 mm



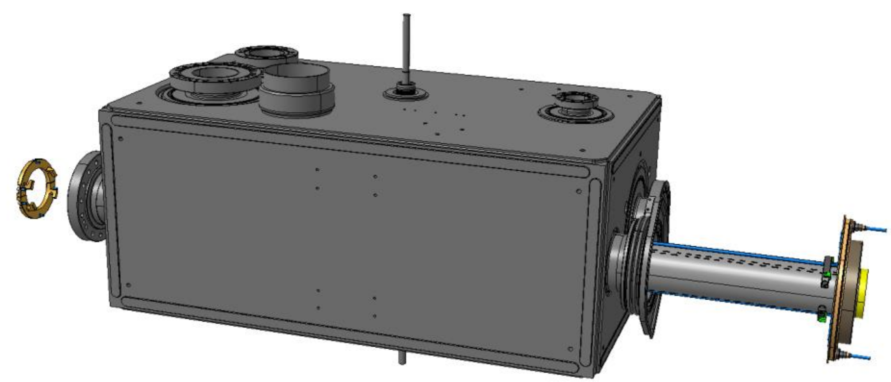
V. Baglin, HL-LHC Vacuum System,
WP2 meeting, CERN, 27th June 2017

- Stainless steel screen with «random» holes for pumping
- Copper layer on the inner surface (th. 0.075mm)
- 1 bellows for differential contraction
- Aperture analysis -> 1.5mm clearance on the radius
  (calculation made with worse case LHC dipole method see EDMS 1864637)
- Cold bore <3K (for cryo pumping)
  (HL-LHC design report V.01 §12.6)
- Beam screen actively cooled (4-20K)



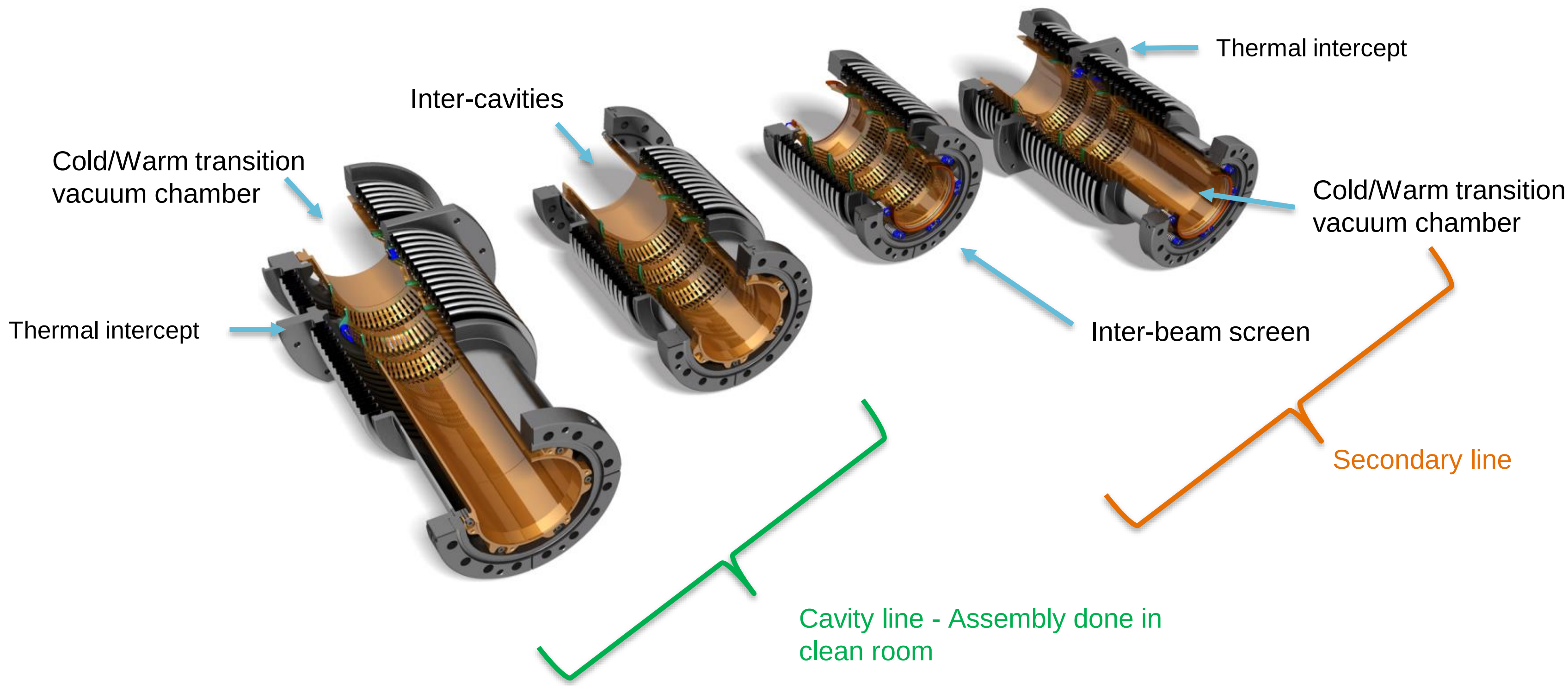


Compensation of differential contraction
(up to 1.7mm)



Bellows with internal shield (PIMS)

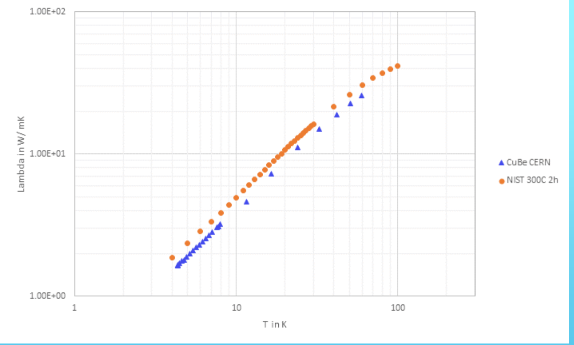
- Need to “screen” every bellows on the beam lines
- Large lateral displacement (6 mm max.) for cavity positioning & thermal contraction
- Design from triplet area (C.Garion – J.Perez Espinos CERN TE/VSC)
- 4 configurations specific for CRAB cryomodule designed



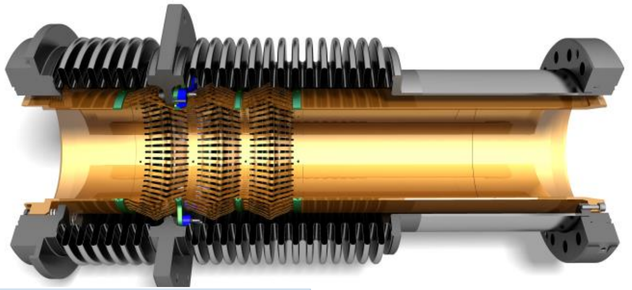
Bellows with internal shield (PIMS)

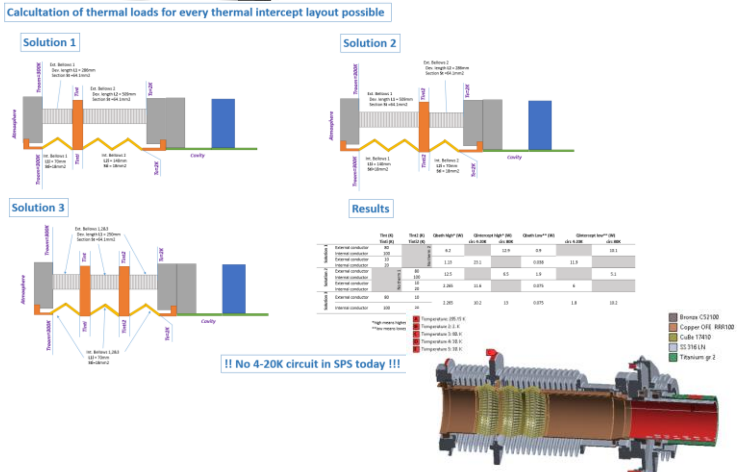
Copper Beryllium deformable RF fingers:

- Circular aperture
- C17410
- 0.1 mm thick, 3 mm width, gap: 1.4 mm
- 3 convolutions
- Thermal conductivity at low temperature checked

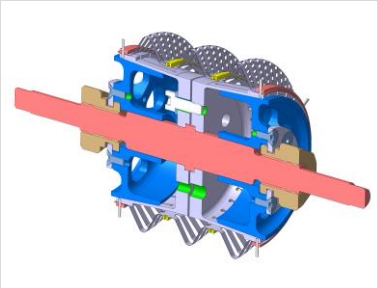


Result of low temp. conductivity measurement
By Torsten Koettig – TE/CRG

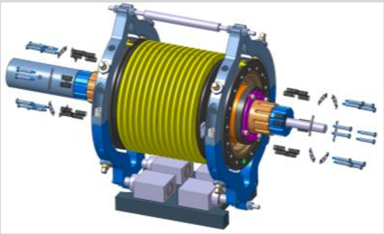




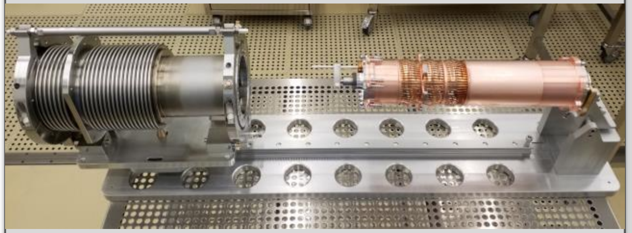
Thermal analysis cold-warm transition
<u>See EDMS 2433067 - J.Swieszek EN-MME</u>



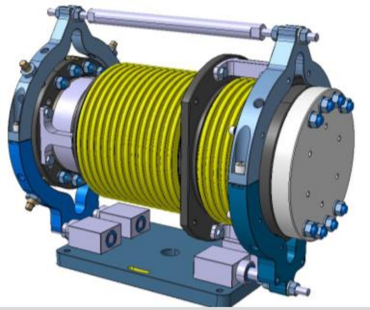
Tooling for manufacturing



Tooling for assembly
Outside clean room
<u>Secondary line</u>

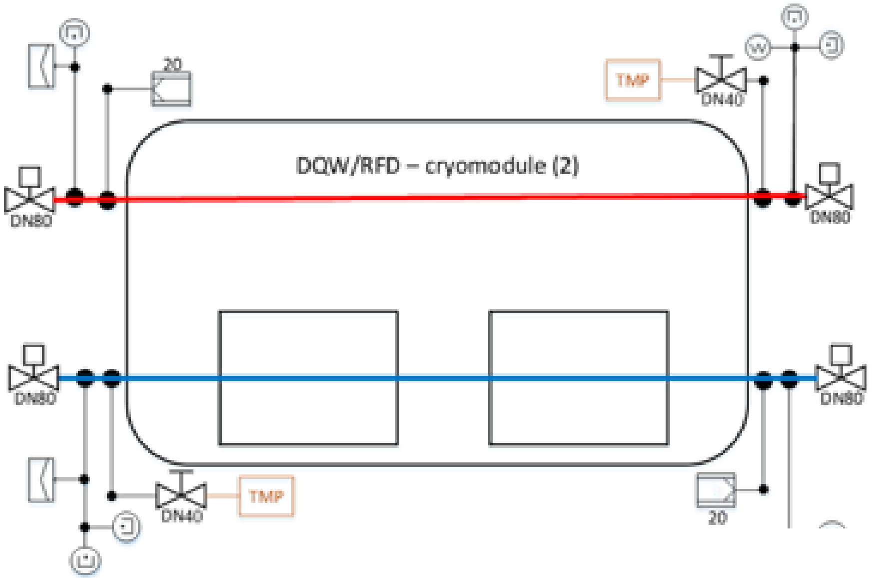


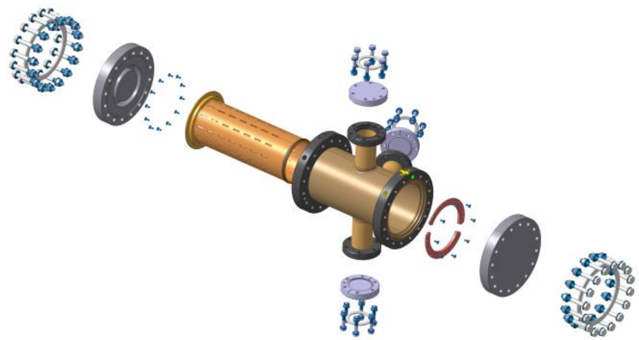
Tooling for assembly
Inside clean room
<u>CRAB line</u>



Tooling for transport

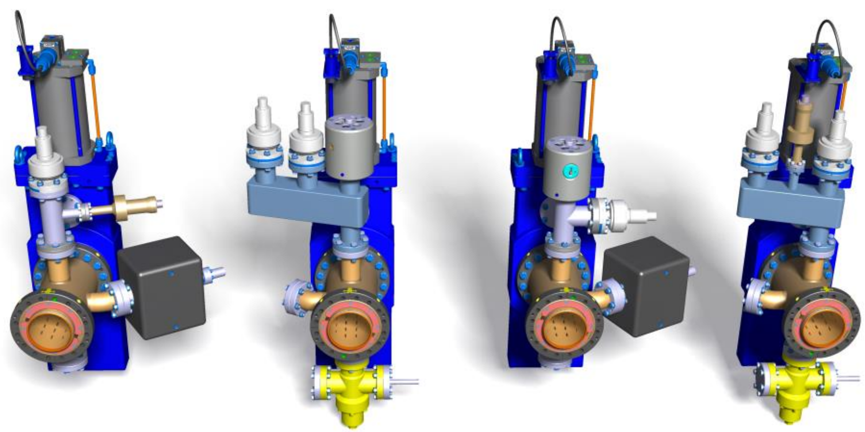
Beam vacuum instrumentation





Extremity chambers
LHCVMACAA_T0001

Rupture disc (VRGP)
Penning Gauge (VGPB)
Pirani Gauge (VGRA)
TMP Mobile Pumping System (with turbo pump and primary pump)
Ion Pump (VPI)
Sector Valve (VVxy
Roughing Valve (V



EDMS 1864637 – TE/VSC specification

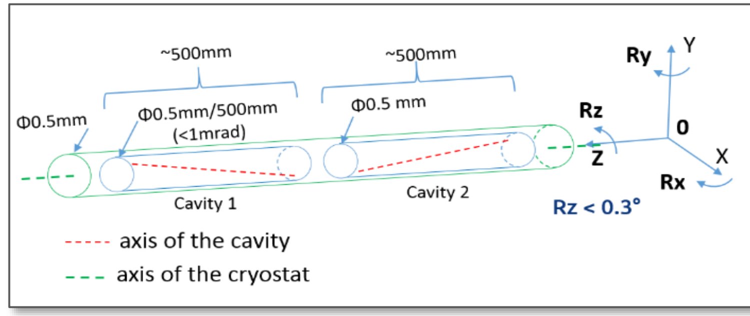
Support and alignement for RFD

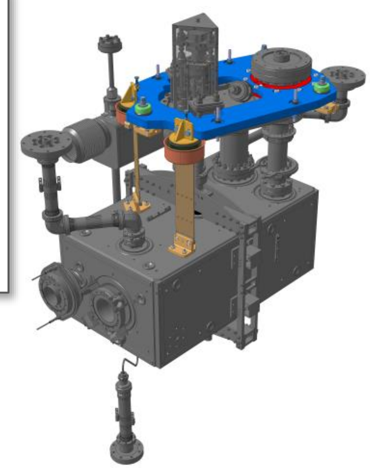
Cavity support

- Design adapted from first cryomodule
- Modification with respect to lesson learnt

Alignement tolerances

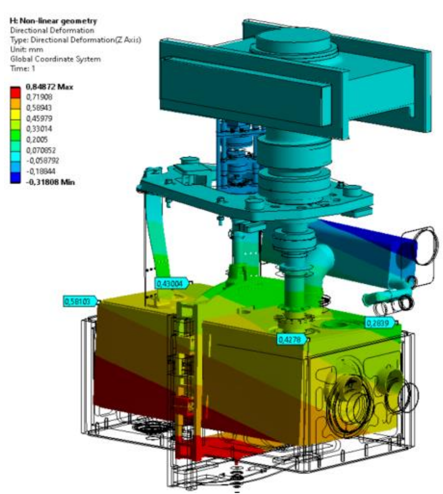
- X-Y: **0.5mm (3σ)** for mechanical alignment + 0.5mm for operation errors
- Rz < 0.3°
- Rx, Ry (mean axis of CC inside Φ0.5mm)

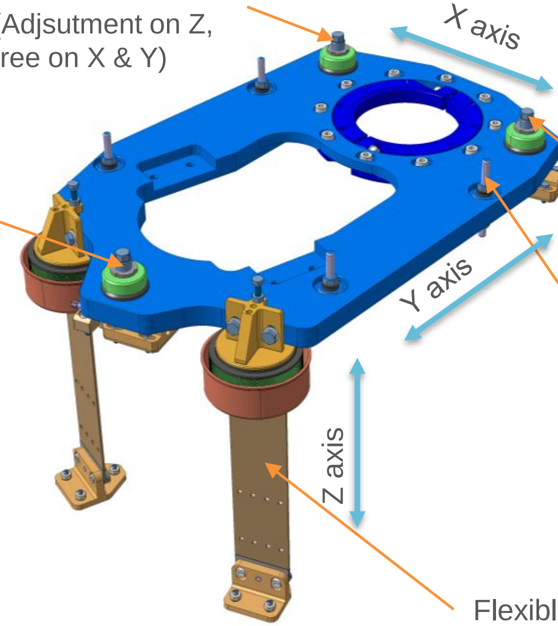




Mechanical and thermal evaluation

Report not yet on EDMS – E. Cano-Pleite

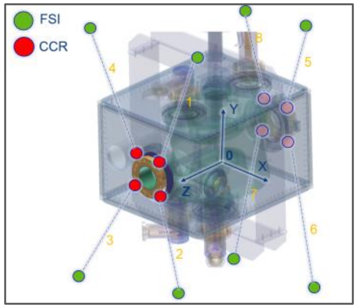


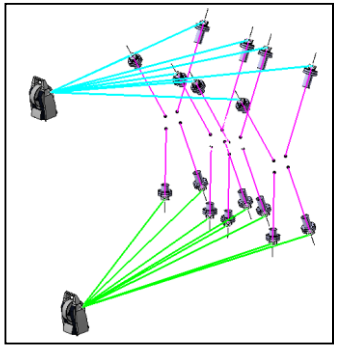


Cavities position monitoring system

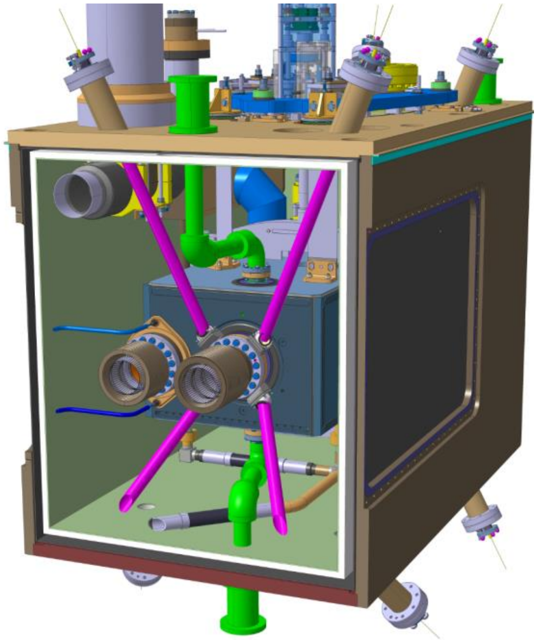
See presentation of V.Rude / M.Sosin

- 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)

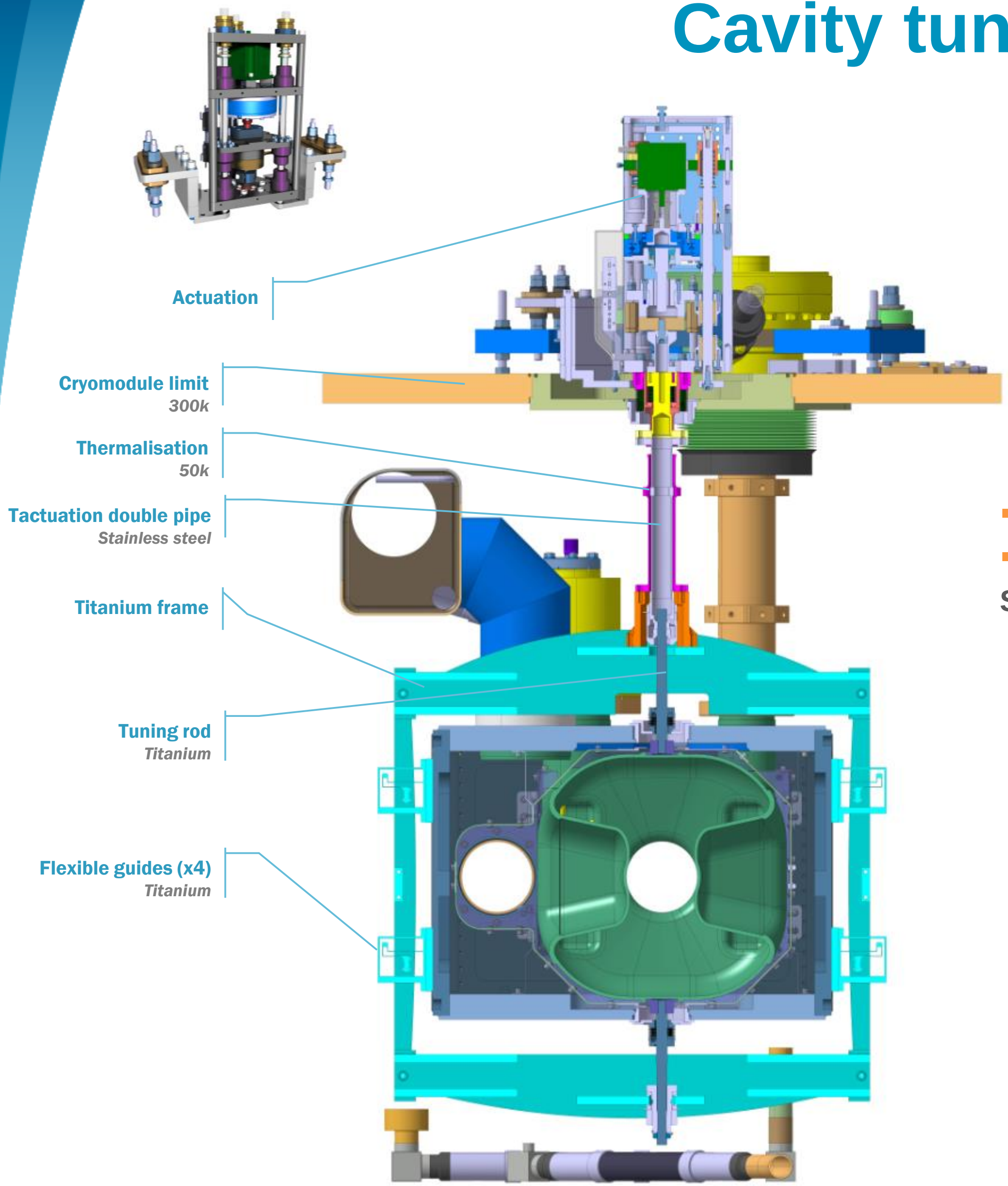




Courtesy M.Sosin – CERN EN/SMM



Cavity tuning system



- Adaptation of DQW design to RFD cavity
- Modification following lessons learned with DQW

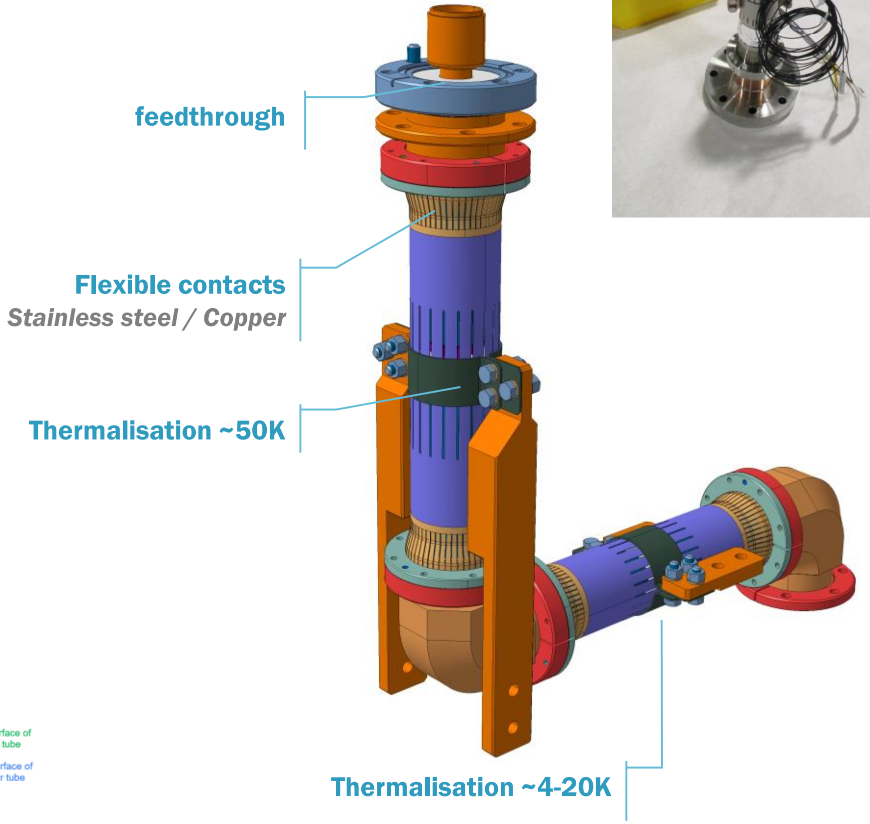
See presentation of K.Artoos on freq. tuning

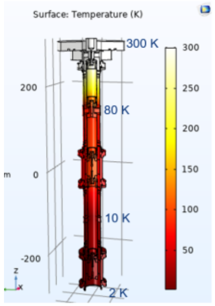
RF COAXIAL LINES

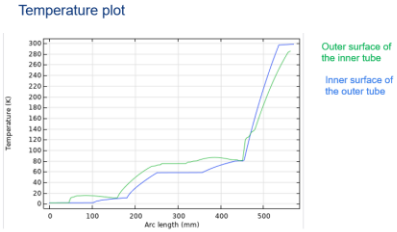
CERN responsible for HOMS, FPC & Pick-Up - E.Montesinos BE/RF

- 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
- 2 V-HOMS coaxial lines / cryomodule
- 2 H-HOMS coaxial lines / cryomodule
- 2 Antennas coaxial lines / cryomodule
- Size and design standardized for all lines
  - Non magnetic S.Steel with copper coating
  - Standardized extremities
  - Shapal ring for thermalisation of inner line
  - Alumina for vacuum feedthrough

- Thermal evaluation see : EDMS 2592079 & 2367094
  J. Swieszek EN-MME







Heat loss (per one coaxial line) [W]				
	2 K bath	10 K	80 K	300 K
Static	0.042	0.73	6.37	-7.14
Static + dynamic	0.44	1.45	7.47	-6.05

TOTAL (2x HHOM + 2x VHOM) [W]			
	2 K bath	10 K	80 K
Static	0.17	2.92	25.48
Static + dynamic	1.76	5.8	29.88

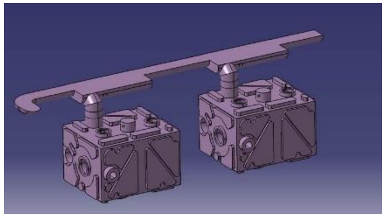
See presentation of E.Montesinos

Cryogenic lines

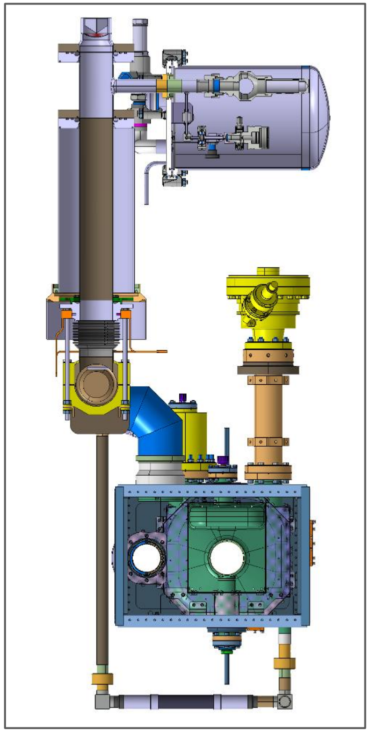
See presentation of K.Brodzinski

- 4 circuits of Helium :
  - 4-20K cooling line
  - 4.5K filling line
  - 2K supply / return
  - 40-60K thermal screen cooling line
- Safety valve and rupture disk on cryomodule side
- Exchangeability of level gauges
- Pressure measurement set up
- Distribution of pipes for cooling equilibrium
- Adaptability to LHC slope

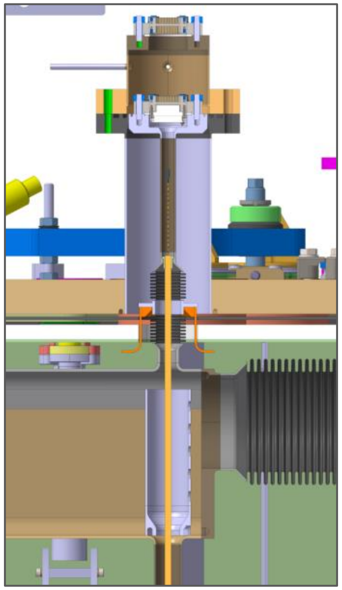
- **Datas :**
  - surface 2k / beam vacuum : ~1m2
  - surface 2k / insulation vacuum : 3.6m2
  - Volume of helium : 166L
  - Biphase inner diameter : 100mm



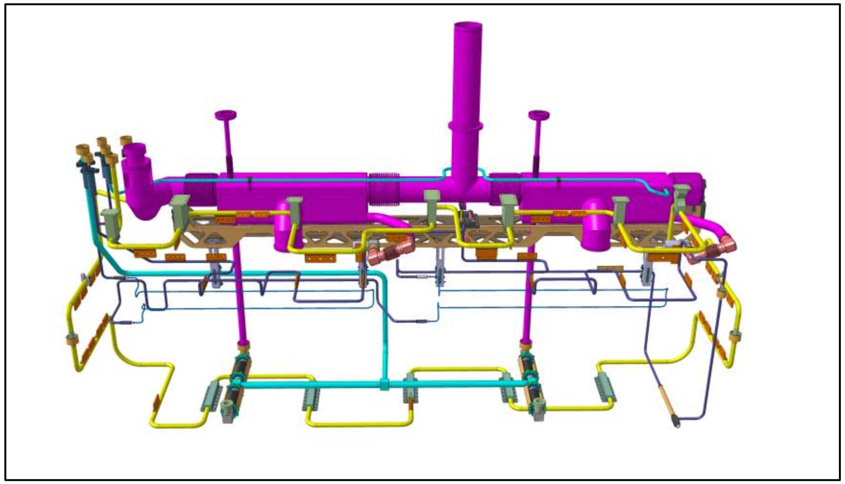
Cryogenic safety valve extension



Exchangeable Level gauge

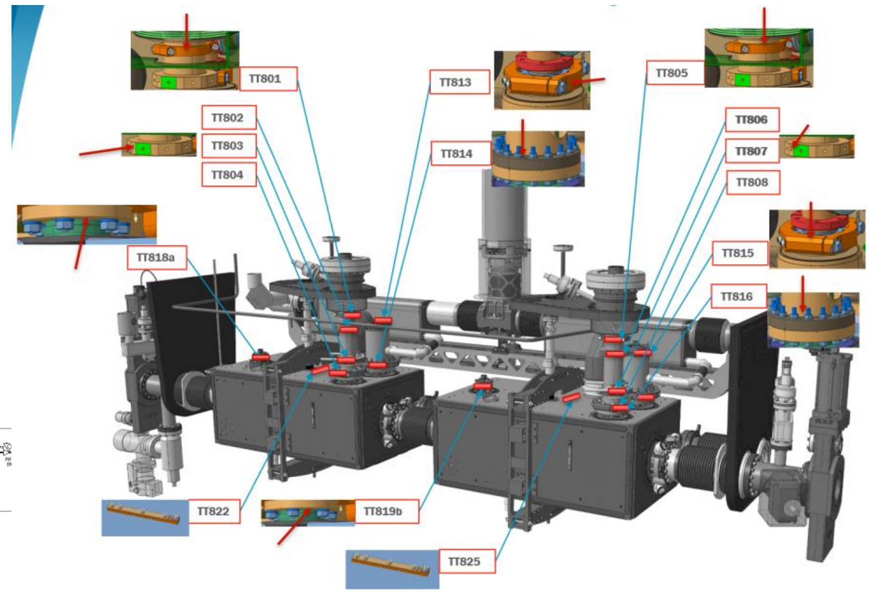


Cryogenic internal lines

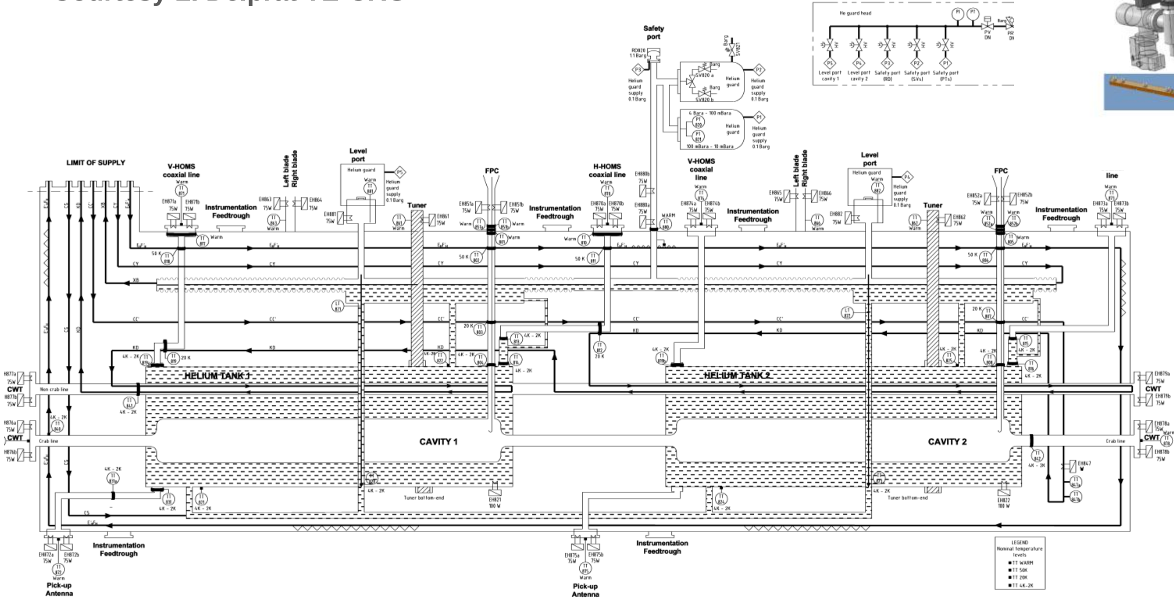


Cryogenic instrumentation

- Lots of thermal measurment during SPS test for validation of design/calculations :
  - 28 CERNOX
  - 24 PT100
  - 2 pressure transmiters
  - 2 Helium level gauges
  - 42 heaters



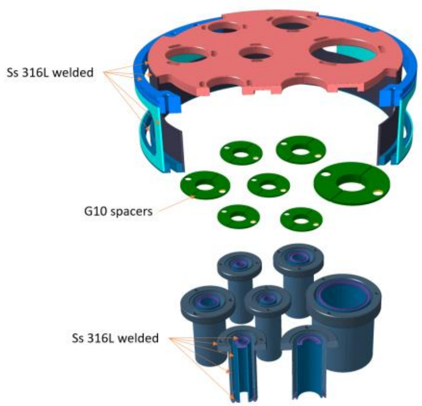
HL-LHC CRAB CAVITY P&I DIAGRAM – CRNLSQLJ0070
Courtesy L. Delpart TE-CRG

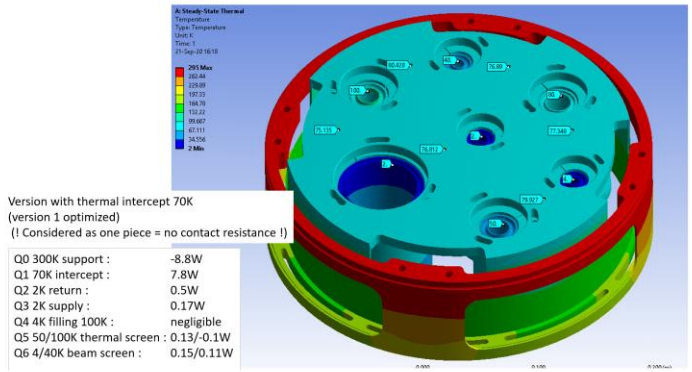


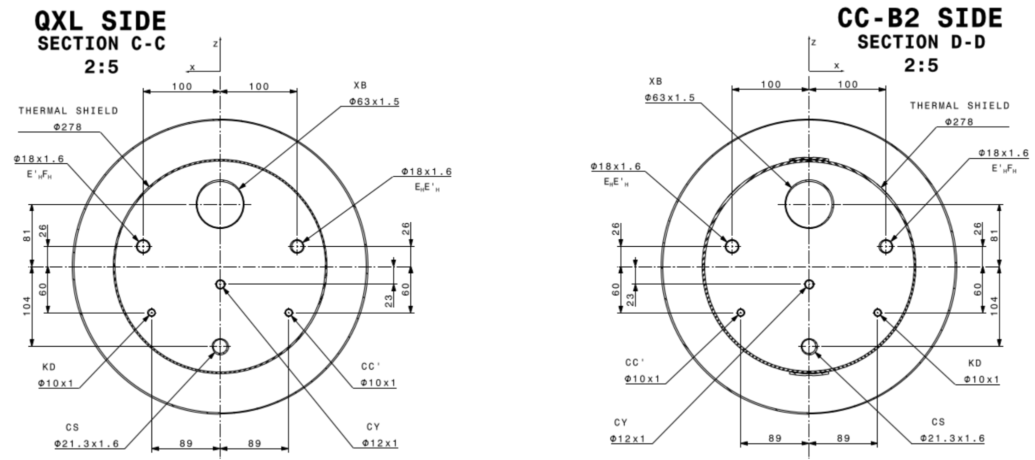
Cryogenic Jumper

- Integration of new cryoline layout
- Standardization of LHC interface
- Symmetrical jumper interface (allows the rotation of cryomodule)

Jumper internal support







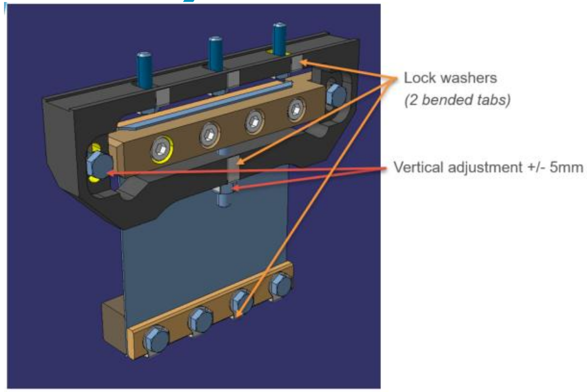
LHC QXL/CRYOMODULE connexion definition - courtesy ***M. Sisti – TE/CRG***

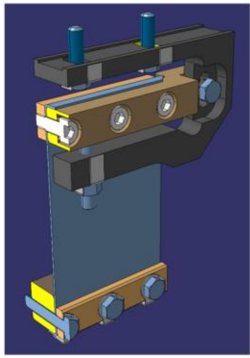
Thermal screen (STFC/CERN)

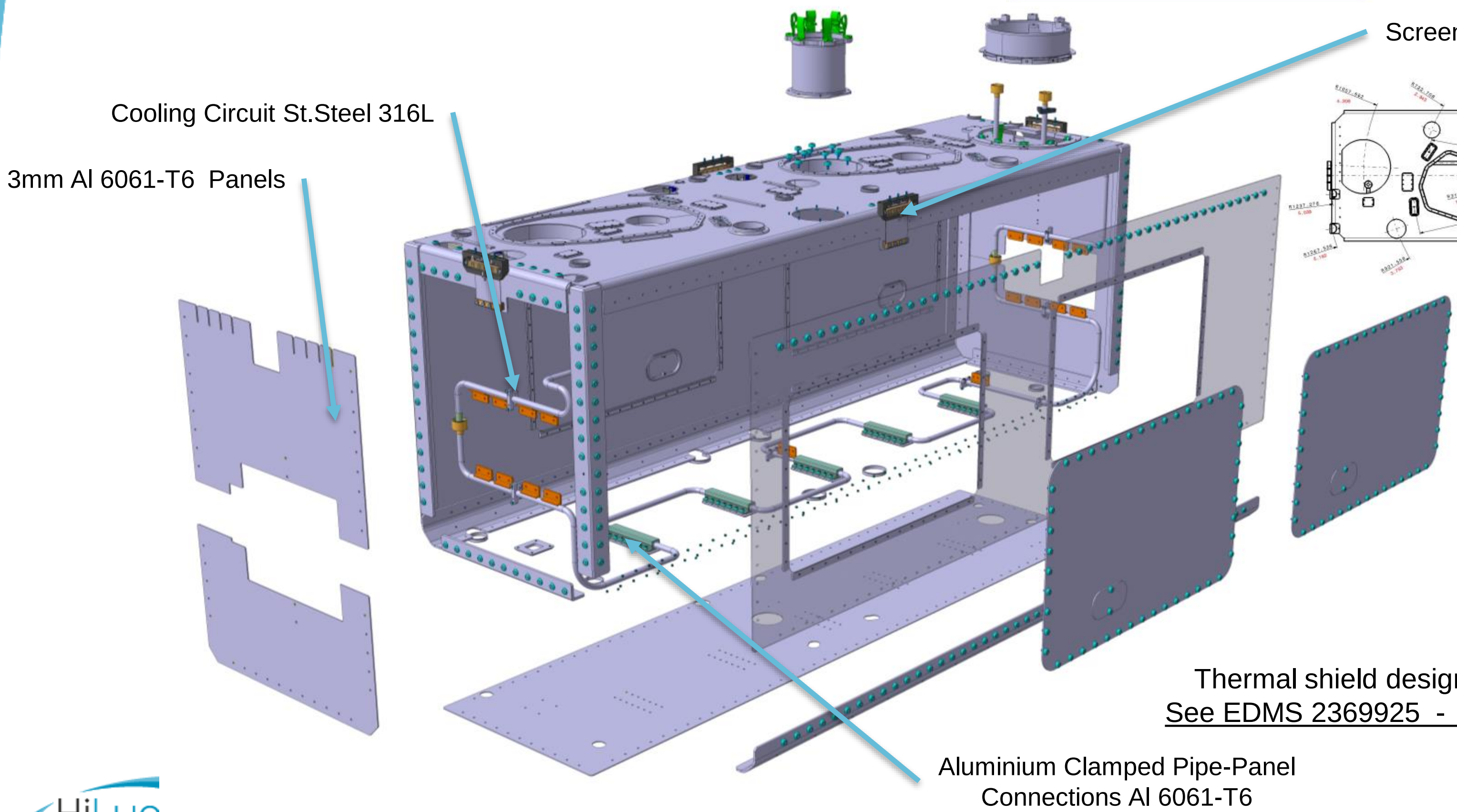
Design changes:

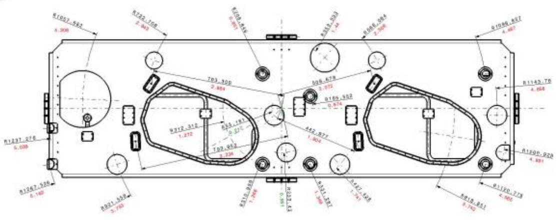
- Aluminium plates th. 3mm*
- Stainless steel Cooling circuit 316L (1.4435)
- Adjustable support

**Al 6061-T6 panels give significant cost and weight savings for series production*







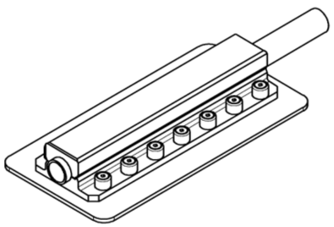


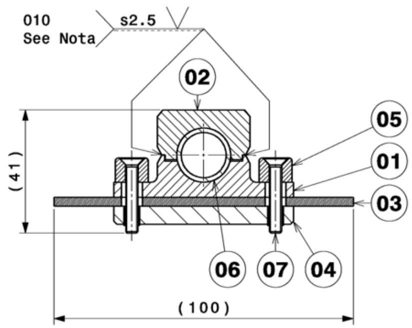
Thermal shield design report and analysis
See EDMS 2369925 - N.TEMPLETON STFC

Pipe Panel Connections (STFC/CERN)

- Ss 316 Pipes pre-assembled with Al. block (6061-T6)
- Pipes are pre-loaded with clamp
- Al block welded in sequence
- Pipe-block is integrated into cooling circuit
- Al blocks are fastened to panel

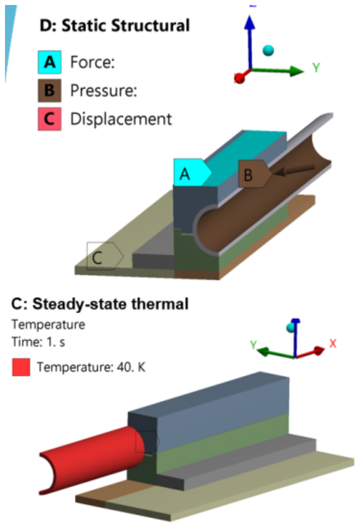
LHCACFTS0192





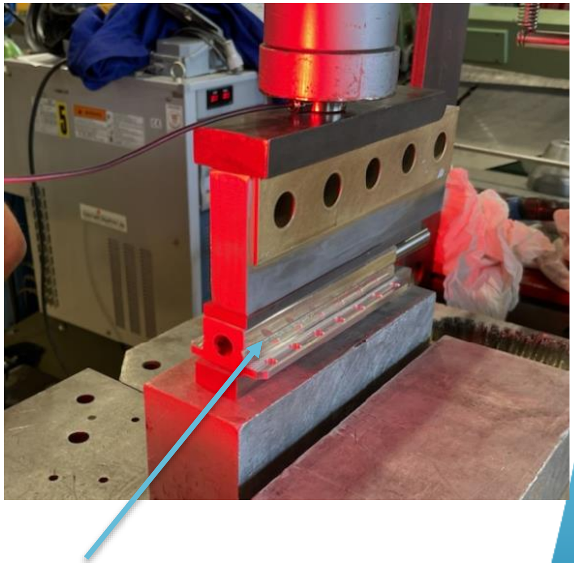
Mechanical analysis

See EDMS 2569527 - T. GUILLEN HERNANDEZ EN-MME



Load case	Preload/Force [N]	Displacement [mm]	Pressure inside pipe [MPa]	Temperature [K]
LC 1	-1625	Uz = 0	-	-
LC 2	-1625	Uz = 0	-	-
LC 3	-	Uz = 0	-	-
LC 4	-	Uz = 0	2.5	-
LC 5	-	Uz = 0	2.5	Yes
LC 6	-	Uz = 0	-	Yes

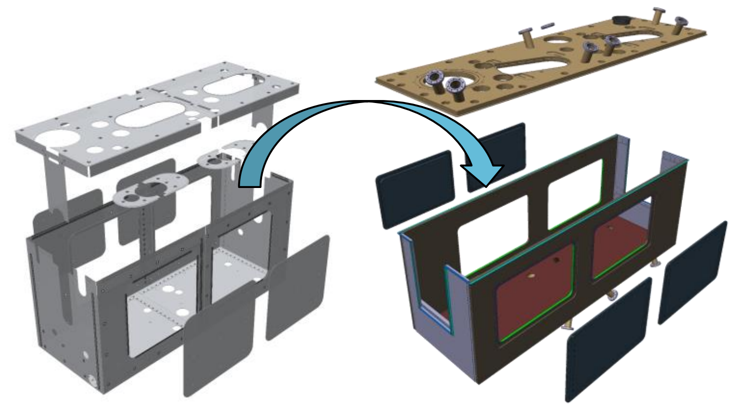
Welding test with optical mechanical measurement



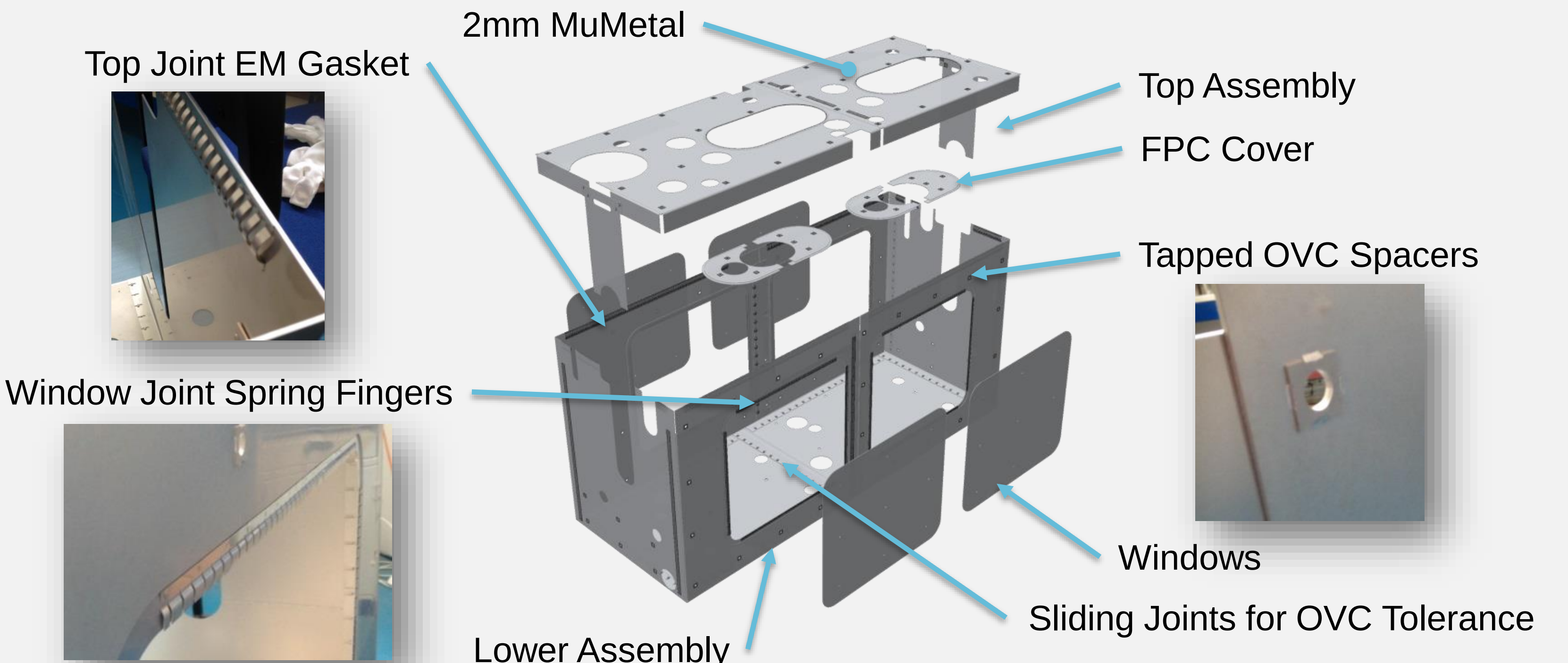
Warm Magnetic Shield (STFC)

Courtesy N.Templeton - STFC

- DQW design adapted to RFD
- Material : MuMetal Th.:2mm
- Curie temperature (460 °C) to be considered in design & implementation of OVC welding



~150 kg



Cryostat vessel design

- Large gaskets avoided
- Overall dimensions : 2800x950x1300
- Mass : 3100kg
- St. Steel welded assembly

Mechanical analysis
<u>See EDMS 2272855 - L. DASSA EN-MME</u>

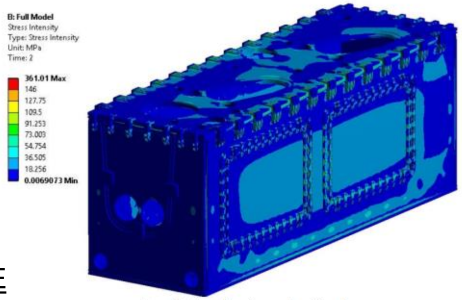
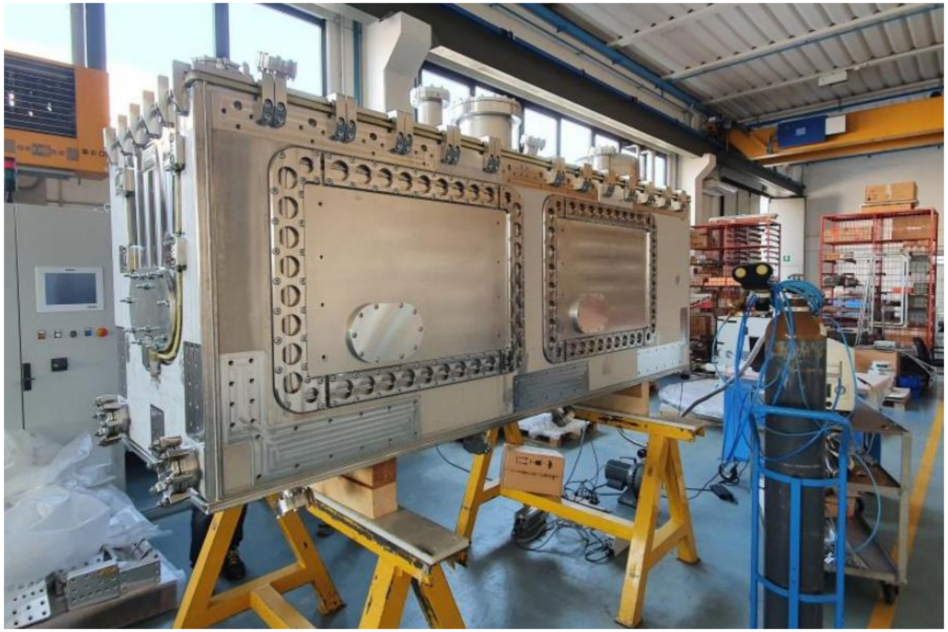
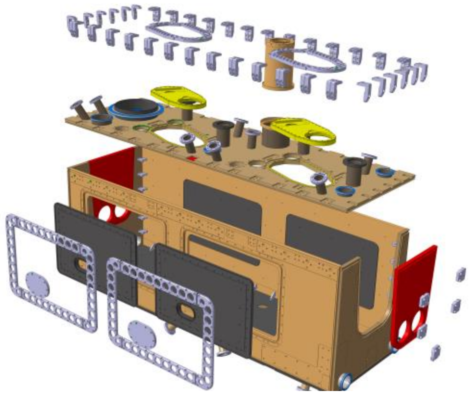


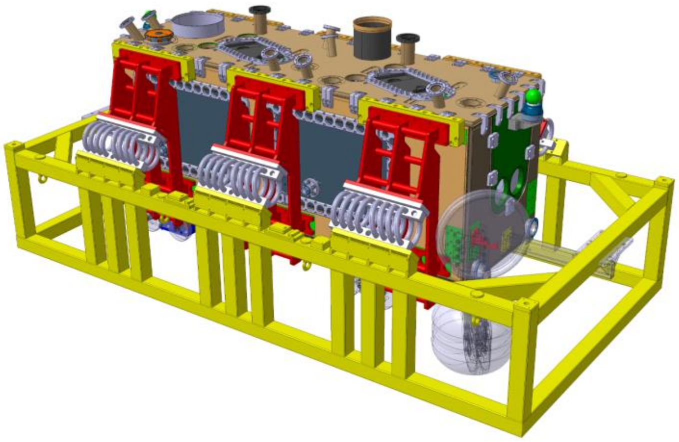
Figure 31: Von-Mises Stress – Load Case 1



RFD OVC manufacturing – Courtesy J.Sauza Bedolla - Lancaster

- Manufacturing is over and leak test has been done and validated

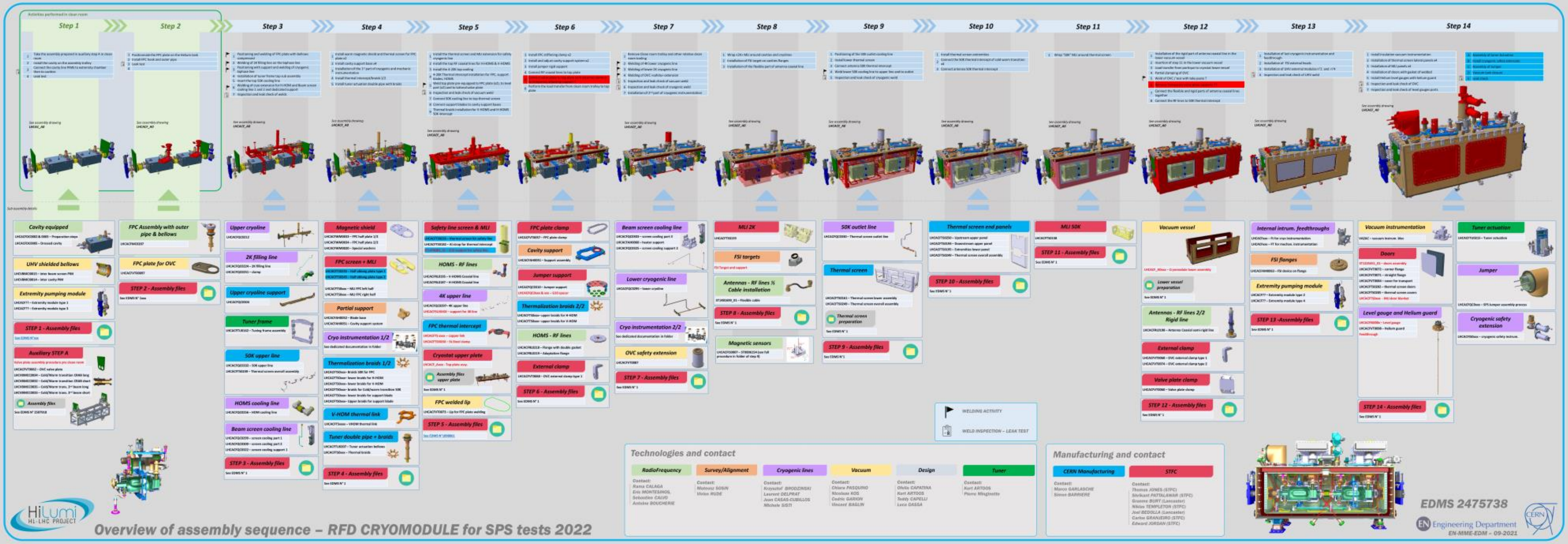




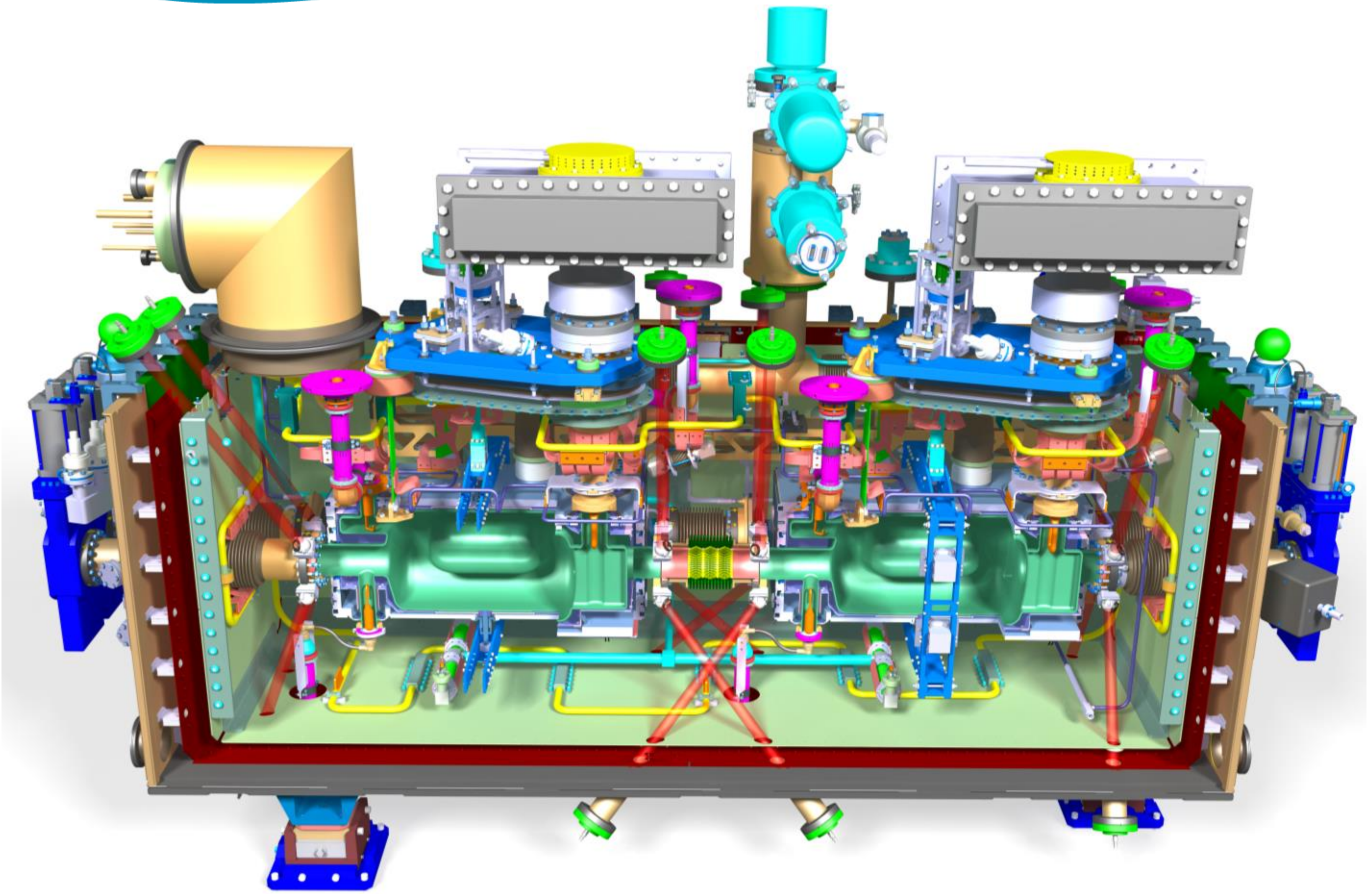
Tooling for cryomodule transport – courtesy E.Jordan - STFC

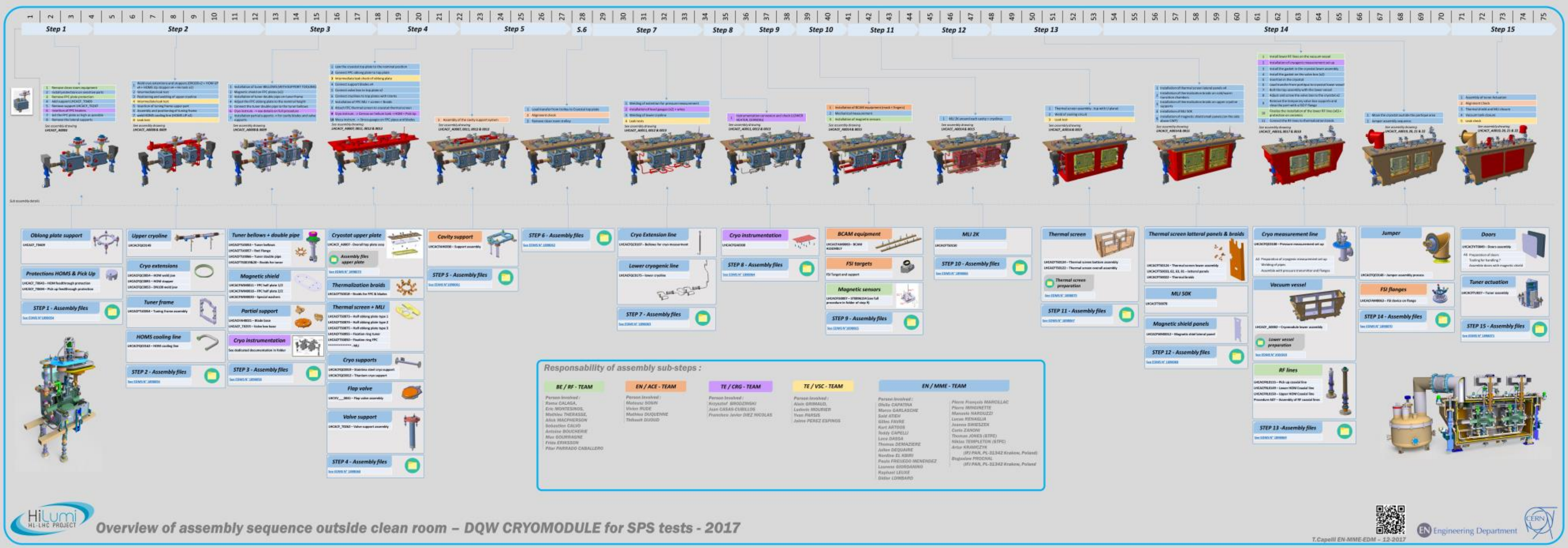
Assembly sequence overview
EDMS 2475738

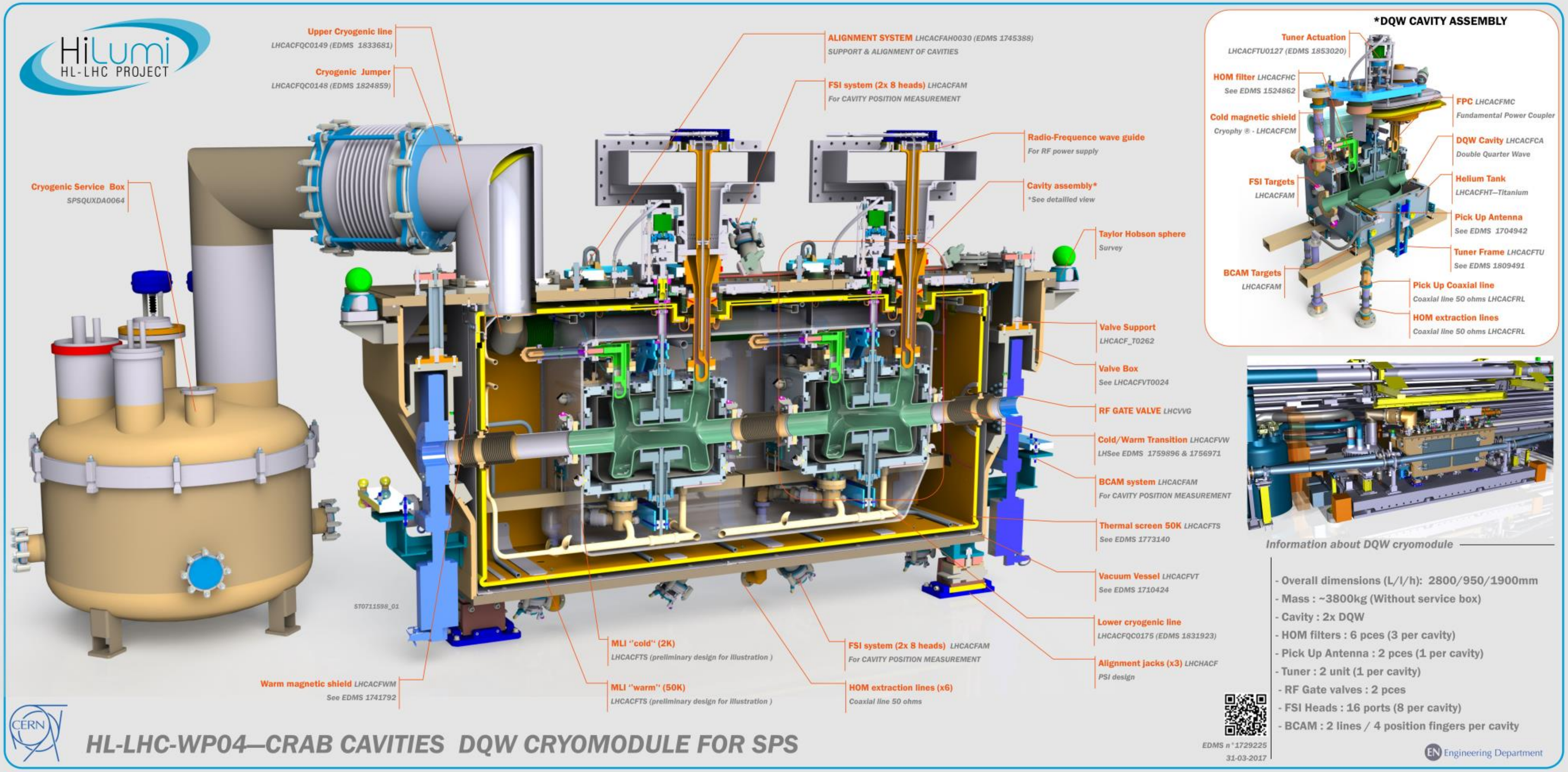
- Detailled assembly procedure under definition - STFC/CERN collaboration

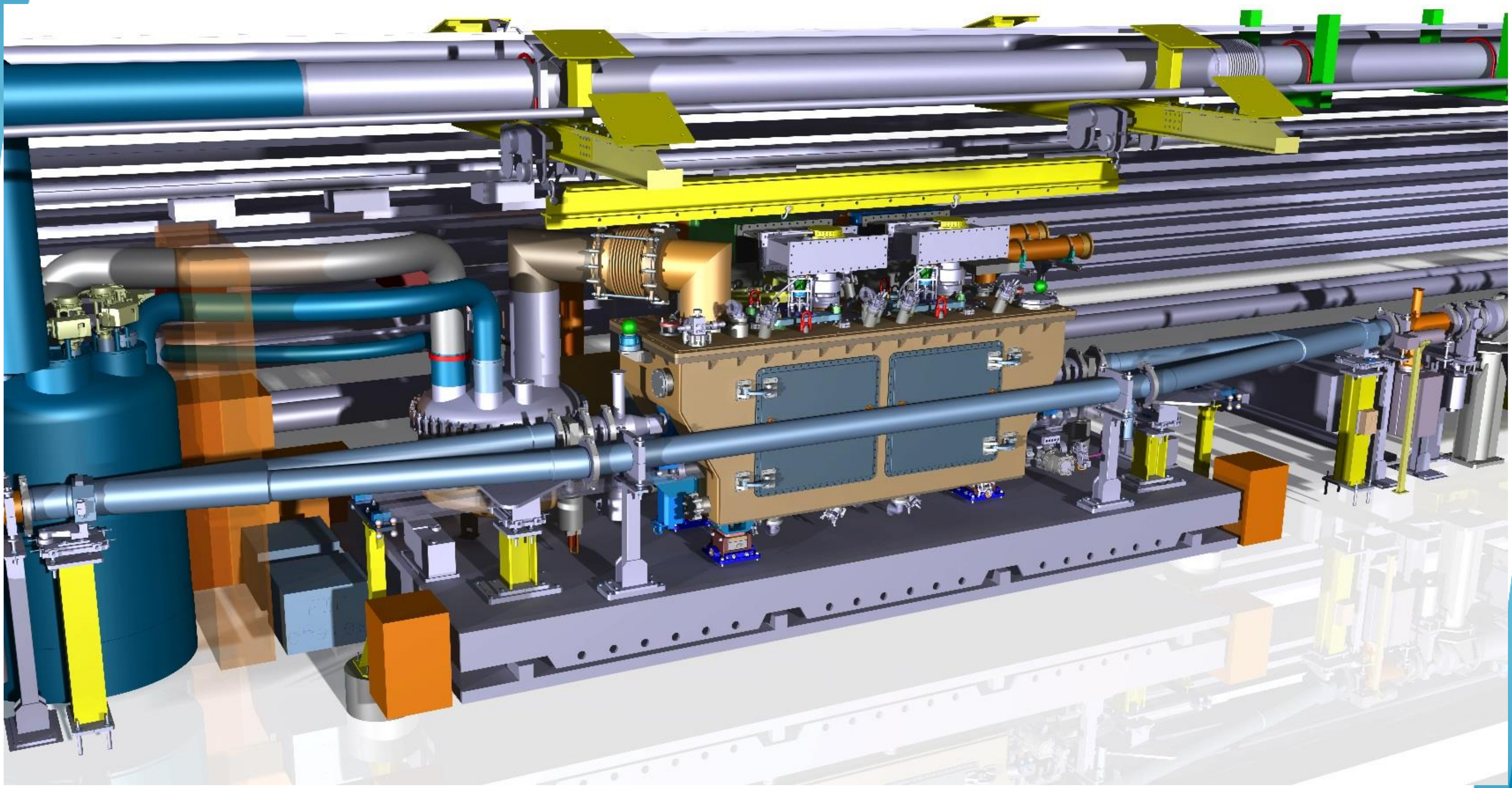


End



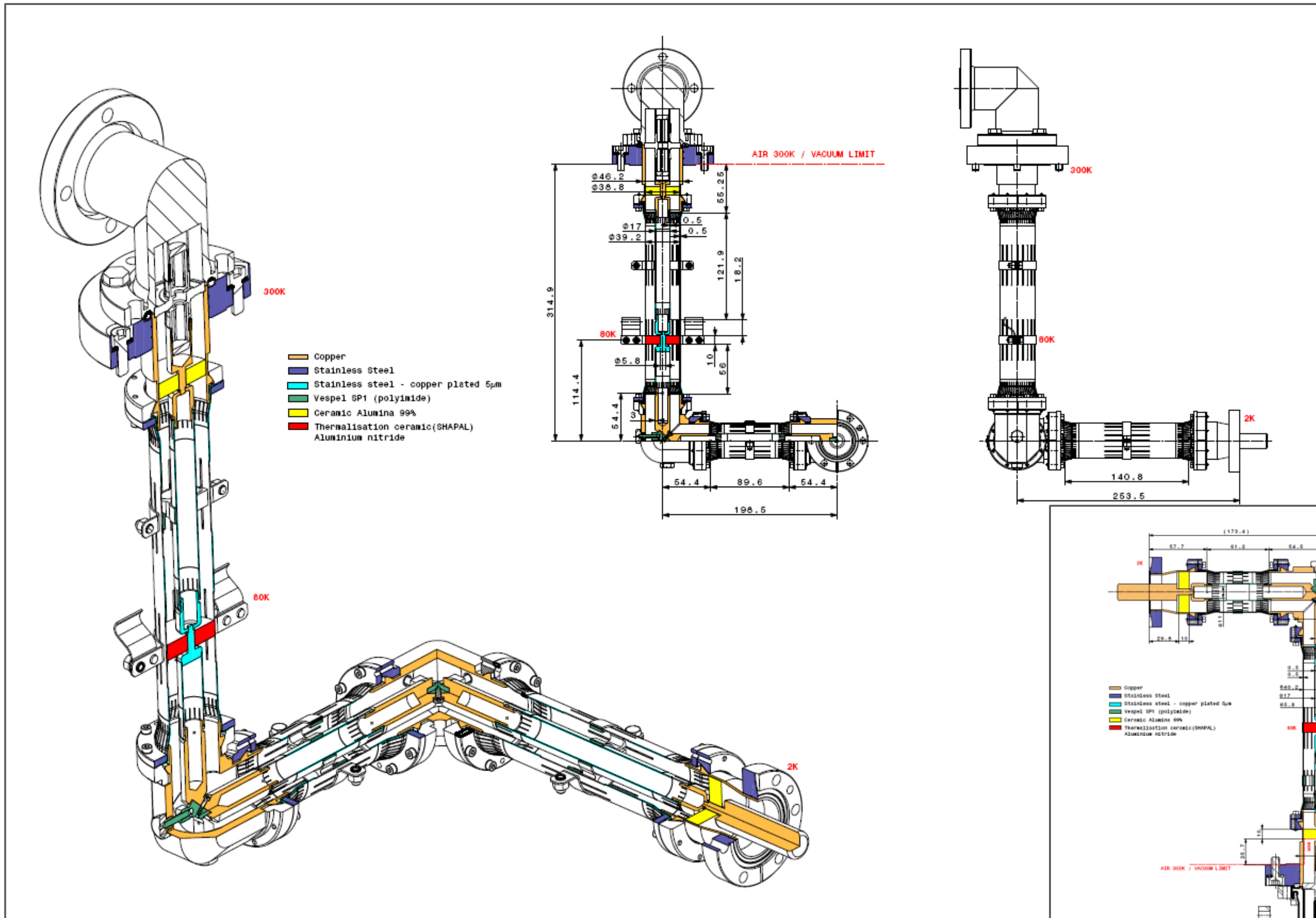

Step 1
Step 2
Step 3
Step 4
Step 5
S.6
Step 7
Step 8
Step 9
Step 10
Step 11
Step 12
Step 13
Step 14
Step 15
Oblong plate support
Protections HOMS & Pick Up
STEP 1 - Assembly files
Upper cryoline
Cryo extensions
Tuner frame
HOMS cooling line
STEP 2 - Assembly files
Tuner bellows + double pipe
Magnetic shield
Partial support
Cryo instrumentation
STEP 3 - Assembly files
Cryostat upper plate
Thermalization braids
Thermal screen + MLI
Cryo supports
Flap valve
Valve support
STEP 4 - Assembly files
Cavity support
STEP 5 - Assembly files
STEP 6 - Assembly files
Cryo Extension line
Lower cryogenic line
STEP 7 - Assembly files
Cryo instrumentation
STEP 8 - Assembly files
BCAM equipment
FSI targets
Magnetic sensors
STEP 9 - Assembly files
MLI 2K
STEP 10 - Assembly files
Thermal screen
STEP 11 - Assembly files
Thermal screen lateral panels & braids
MLI 50K
Magnetic shield panels
STEP 12 - Assembly files
Cryo measurement line
Vacuum vessel
RF lines
STEP 13 -Assembly files
Jumper
FSI flanges
STEP 14 - Assembly files
Doors
Tuner actuation
STEP 15 - Assembly files
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
Engineering Department

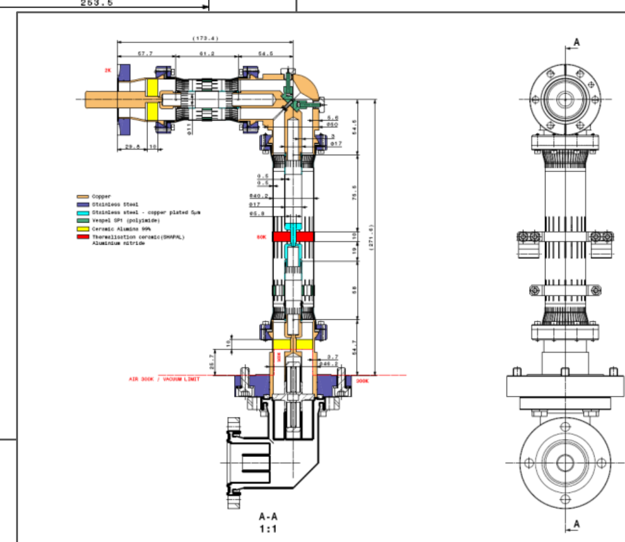

HiLumi HL-LHC PROJECT
Upper Cryogenic line LHCACFQC0149 (EDMS 1833681)
Cryogenic Jumper LHCACFQC0148 (EDMS 1824859)
ALIGNMENT SYSTEM LHCACFAH0030 (EDMS 1745388) SUPPORT & ALIGNMENT OF CAVITIES
FSI system (2x 8 heads) LHCACFAM For CAVITY POSITION MEASUREMENT
Radio-Frequence wave guide For RF power supply
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
MLI "cold" (2K) LHCACFTS (preliminary design for illustration)
FSI system (2x 8 heads) LHCACFAM For CAVITY POSITION MEASUREMENT
MLI "warm" (50K) LHCACFTS (preliminary design for illustration)
HOM extraction lines (x6) Coaxial line 50 ohms
Warm magnetic shield LHCACFWM See EDMS 1741792
ST0711598_01
*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



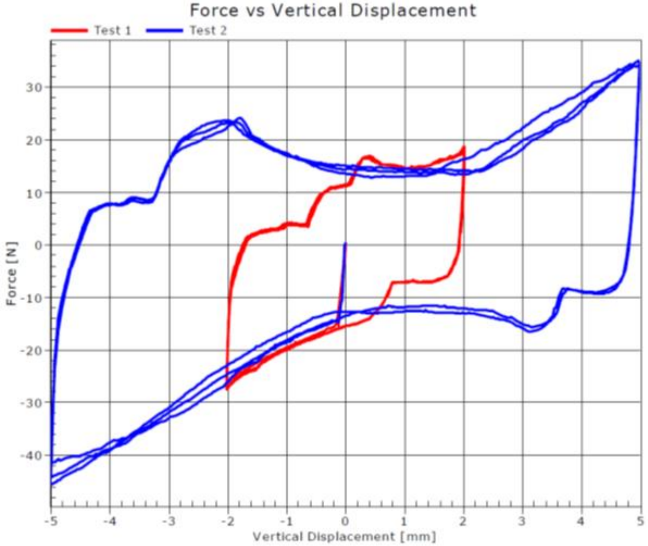
Coaxial lines

Design from DQW, length/position adapted to RFD



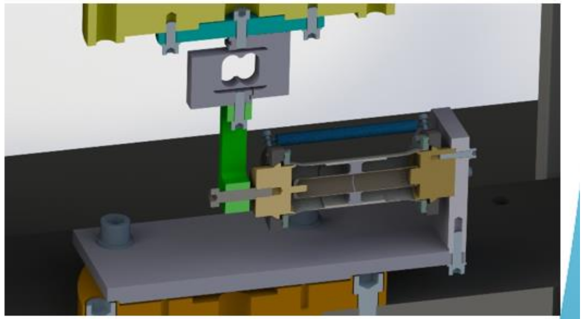


Results: tests 1 and 2



- **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

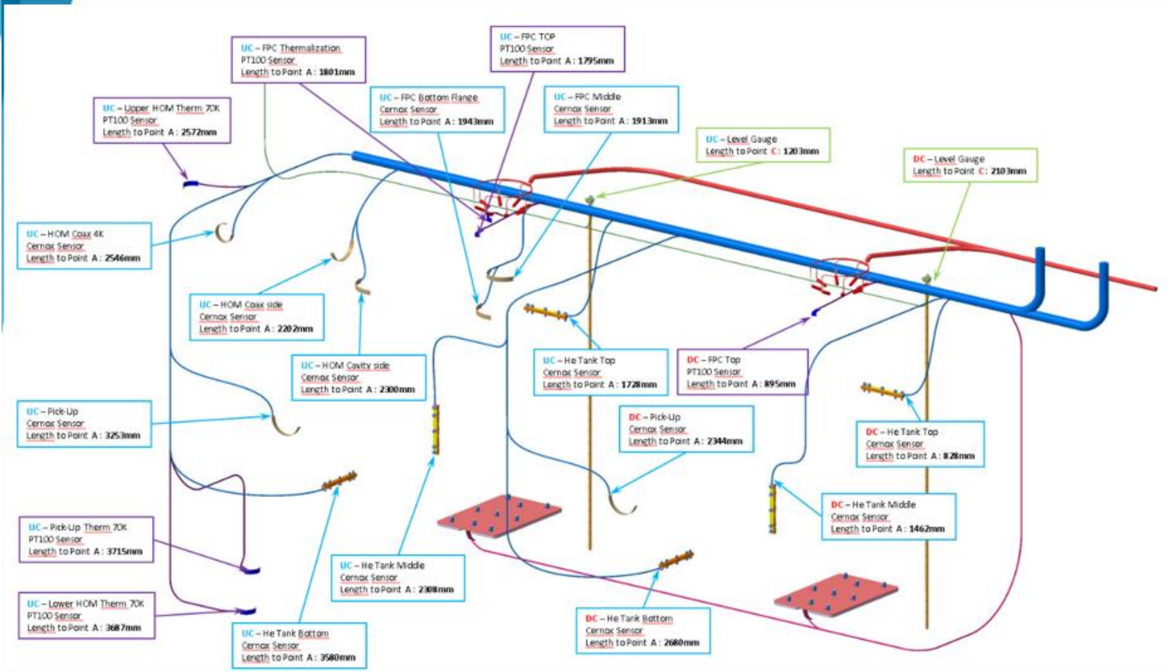


L. BIANCHI – EDMS1737834

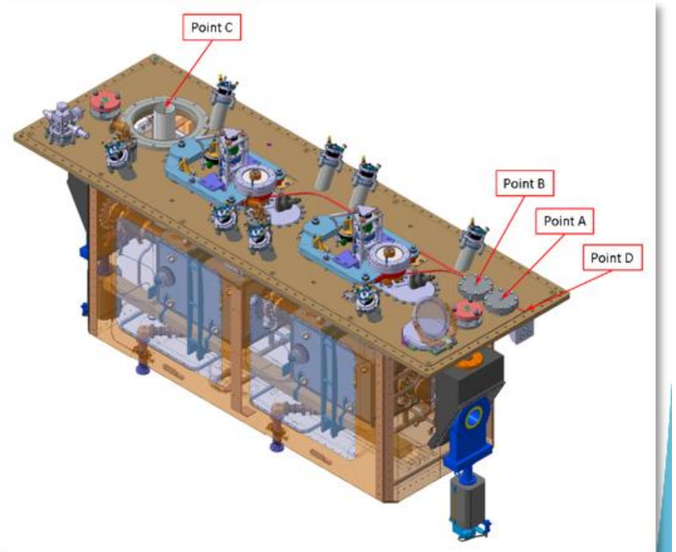
Test performed at Mechanical Measurment lab of CERN (L.Bianchi – M.Guinchard)

International review of the Crab Cavity performance for HiLumi – CERN – 3 april 2017 28

Instrumentation



Cryogenic instrumentation (not complete, for illustration)



Liste of instrumentaion (cryo + mechanical) :

- -13 CERNOX temperature sensors
- -~20 PT100
- -2x 8x heating cartridge 5W
- -2x He tank heater 100W
- -~20 strain gauges
- …

Many of this equipments are already at CERN