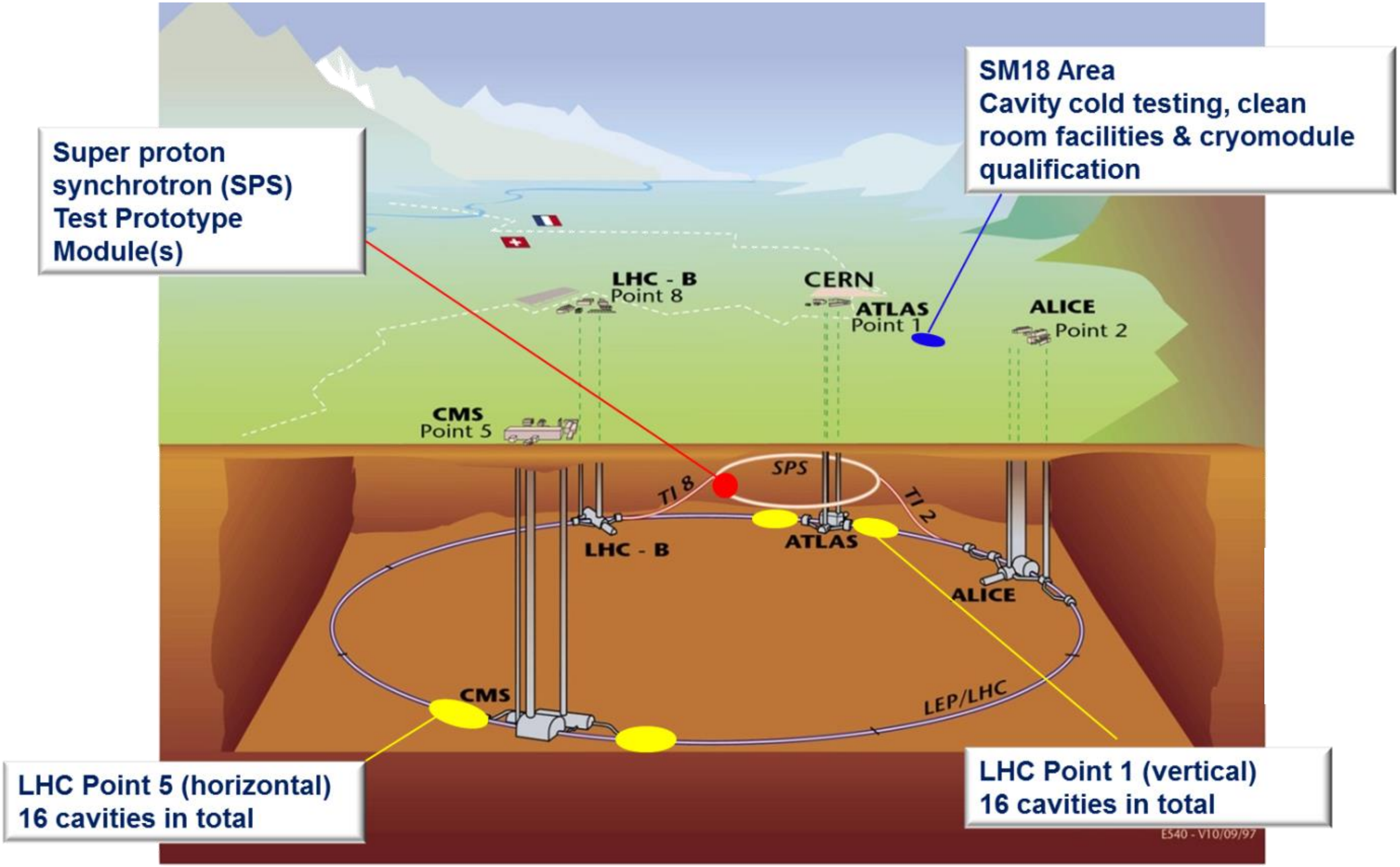
Current project Status of SPS Module
May 26, 2016

On behalf of WP4

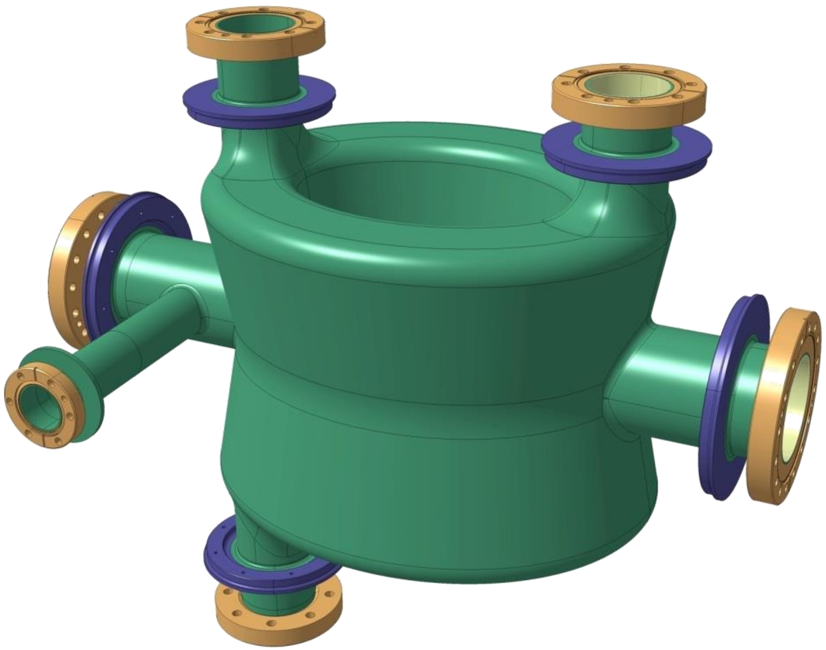


High Luminosity LHC

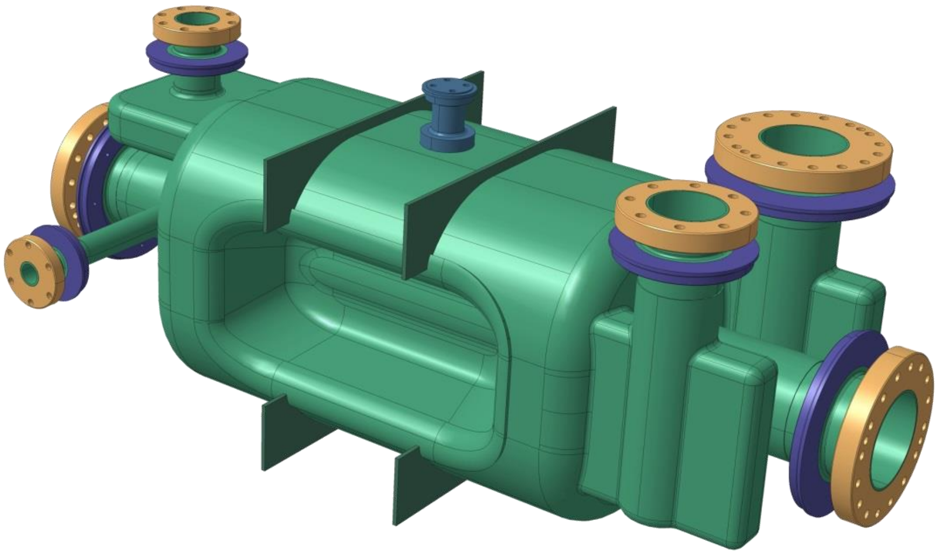
Cavities

Compact design to allow adjacent LHC beam pipe at 194 mm

Baseline : adopt both cavity types and exploit their natural RF topology



Double Quarter Wave (DQW) cavity –
Vertical – to be used in Point 1 (ATLAS)



RF Dipole (RFD) cavity –
Horizontal – to be used in Point 5 (CMS)

Dressed cavities

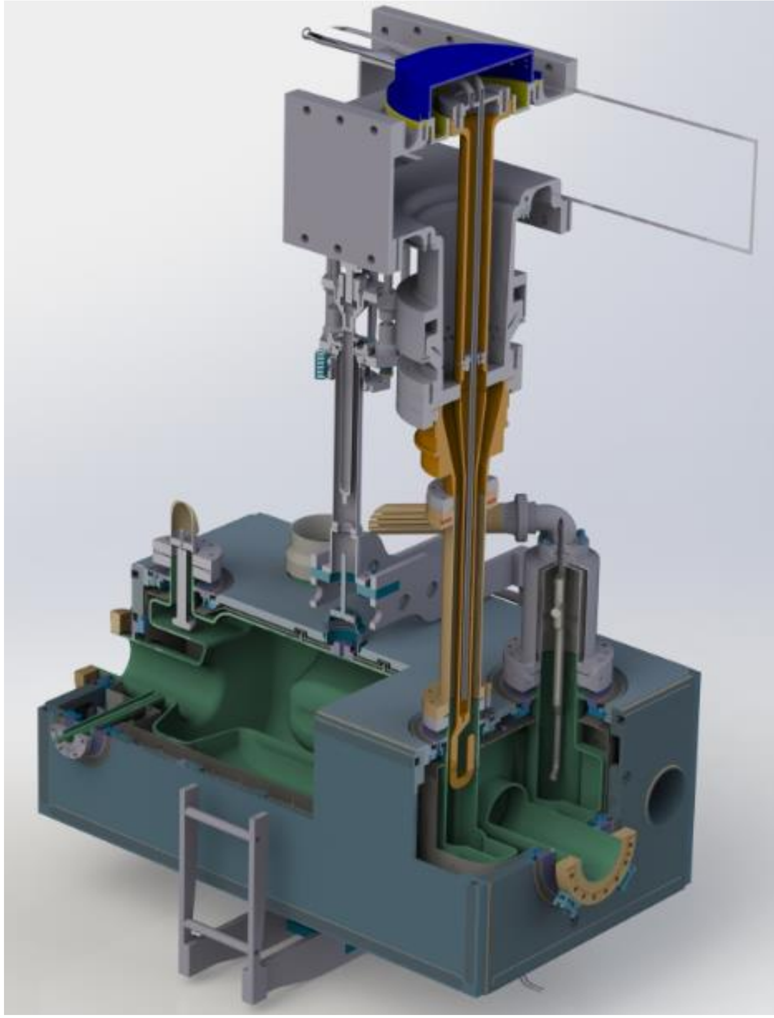
Double Quarter Wave

- Cavity Review - May 2014, BNL
- HOM Coupler Review - February 2015, JLAB
- Helium Vessel Review - May 2015, CERN

High Luminosity LHC

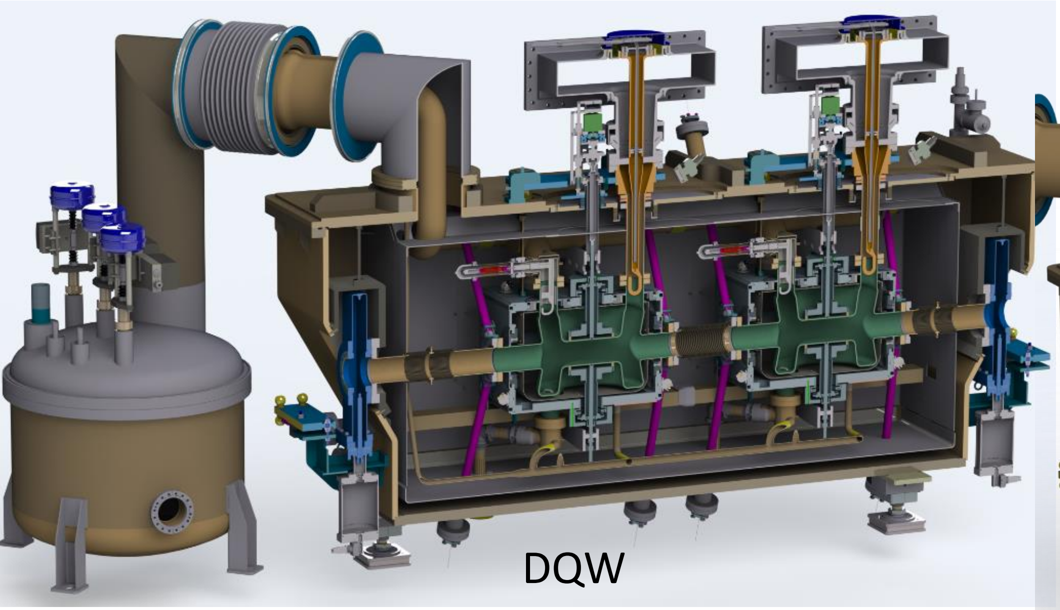
Dressed cavities

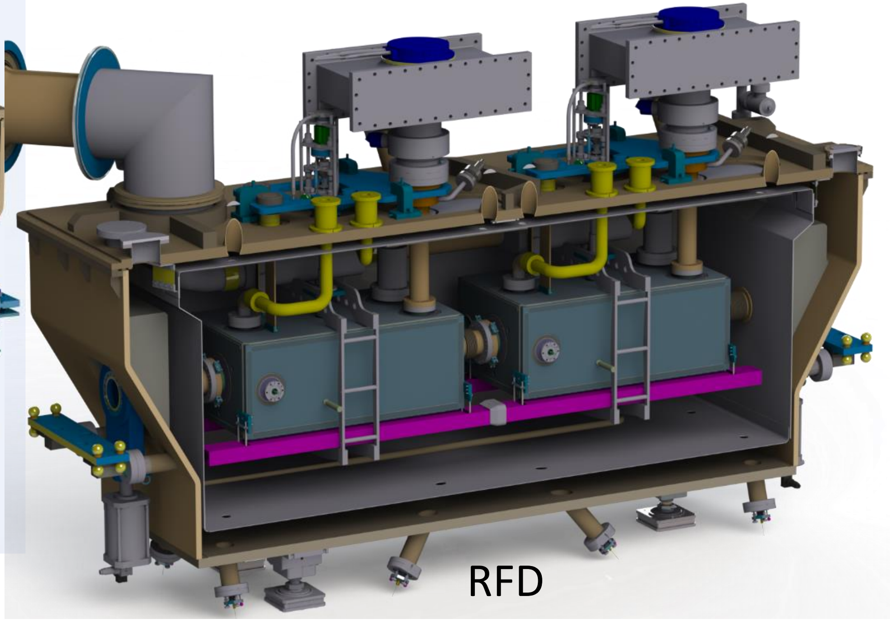
RF Dipole



- Cavity Review - May 2014, BNL
- HOM Coupler Review - February 2015, JLAB
- Helium Vessel Review - May 2015, CERN

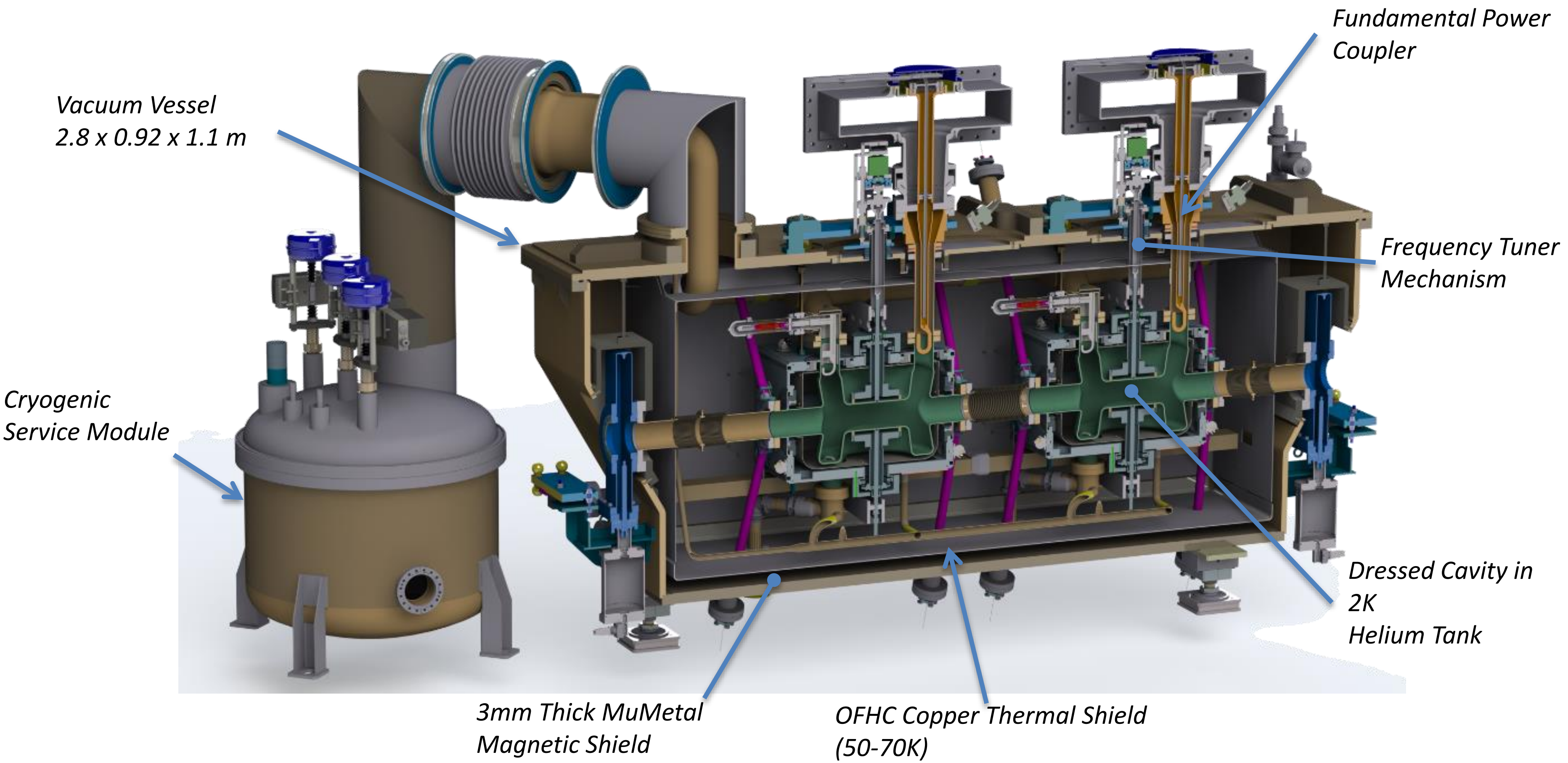
SPS Cryomodule





- CM Review, Nov 2015 (Basic design choices approved)
- SPS cryomodule DQW developed as 1st priority, RFD will follow

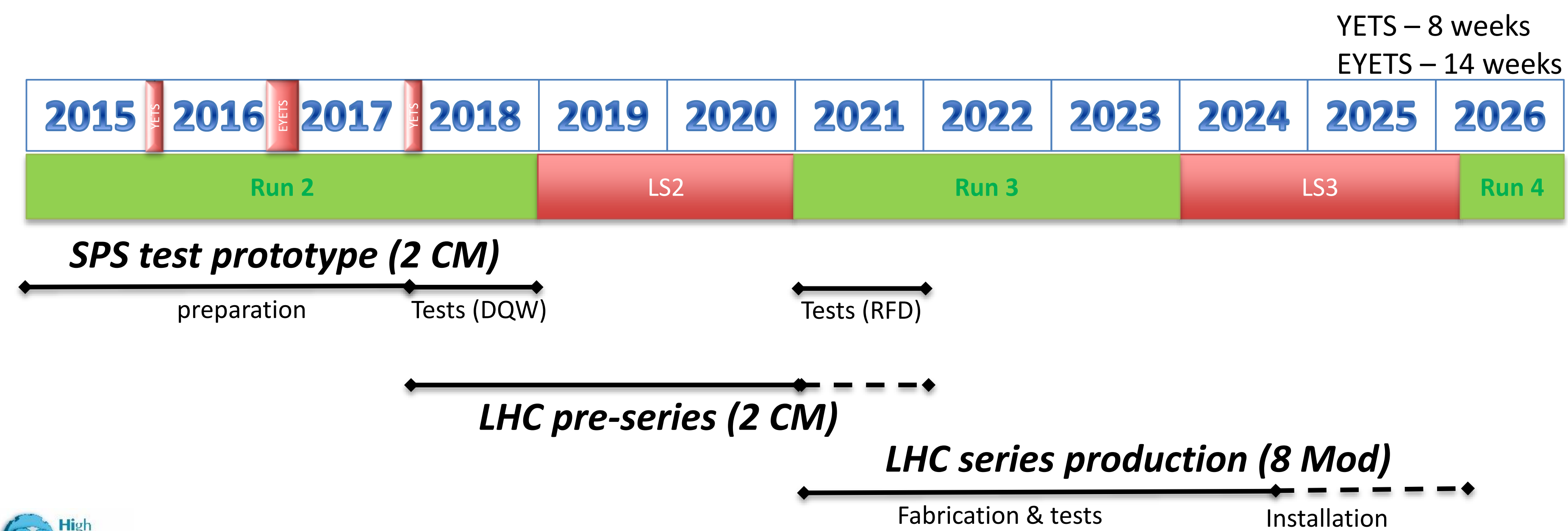
SPS Cryomodule DQW



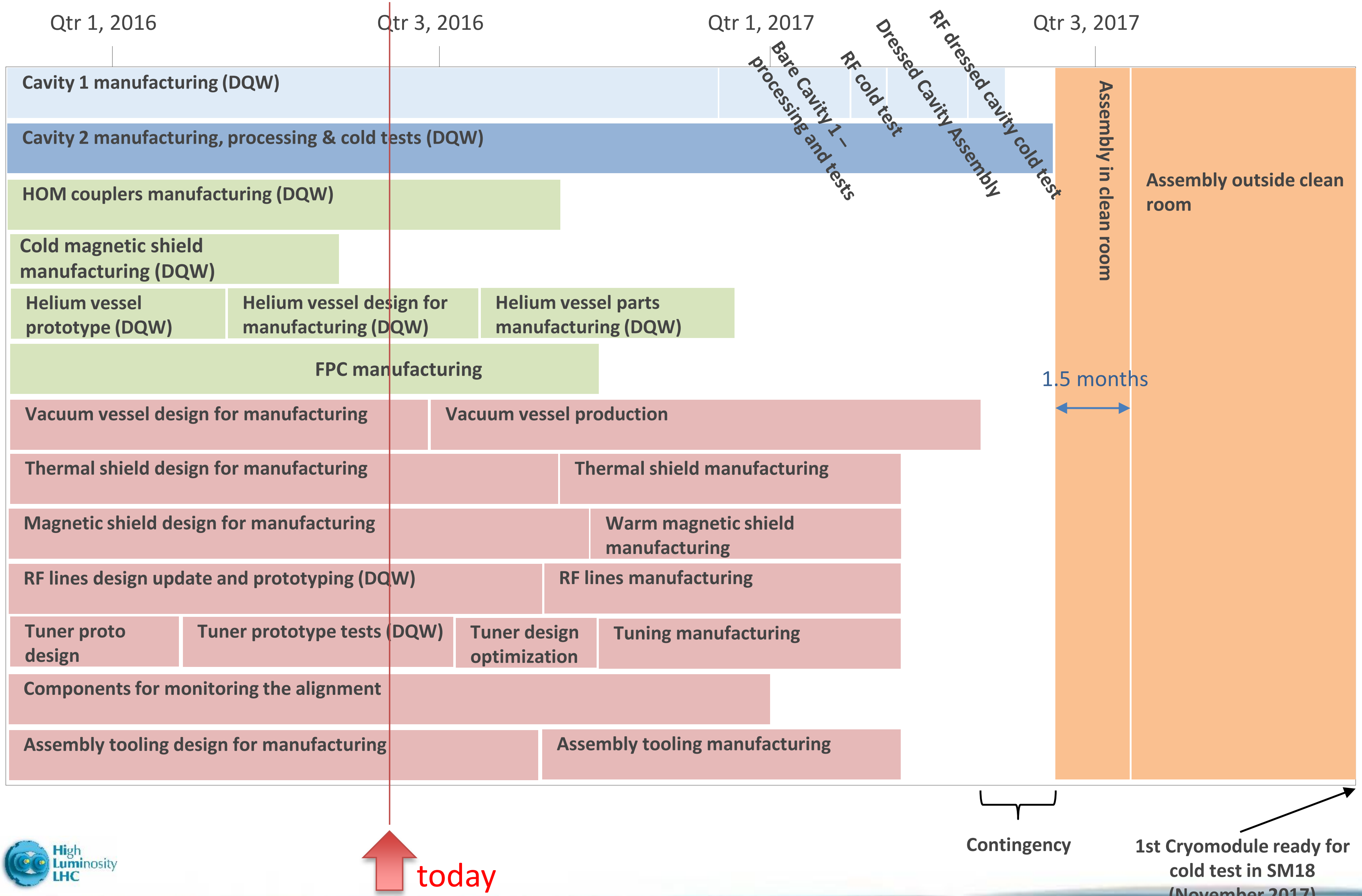
High Luminosity LHC

Revised Planning

- *First Re-Baselining after C&S Review I*
  - *US cavities delayed (+ unresolved "conformity standards")*
  - *CERN cavity production (DQW) for SPS is adopted as baseline*
- *Impact on SPS is significant*

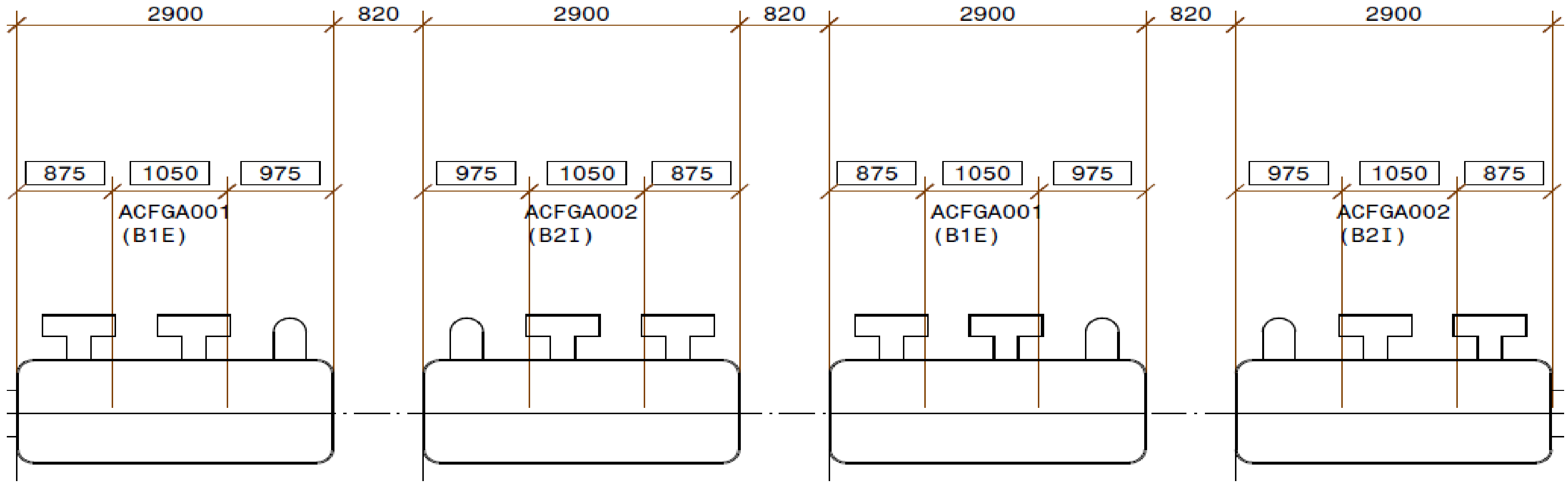


Plans for DQW SPS-CM



LHC

- LHC layout: 4 “SPS like” cryomodules x 2 cavities each / IP side



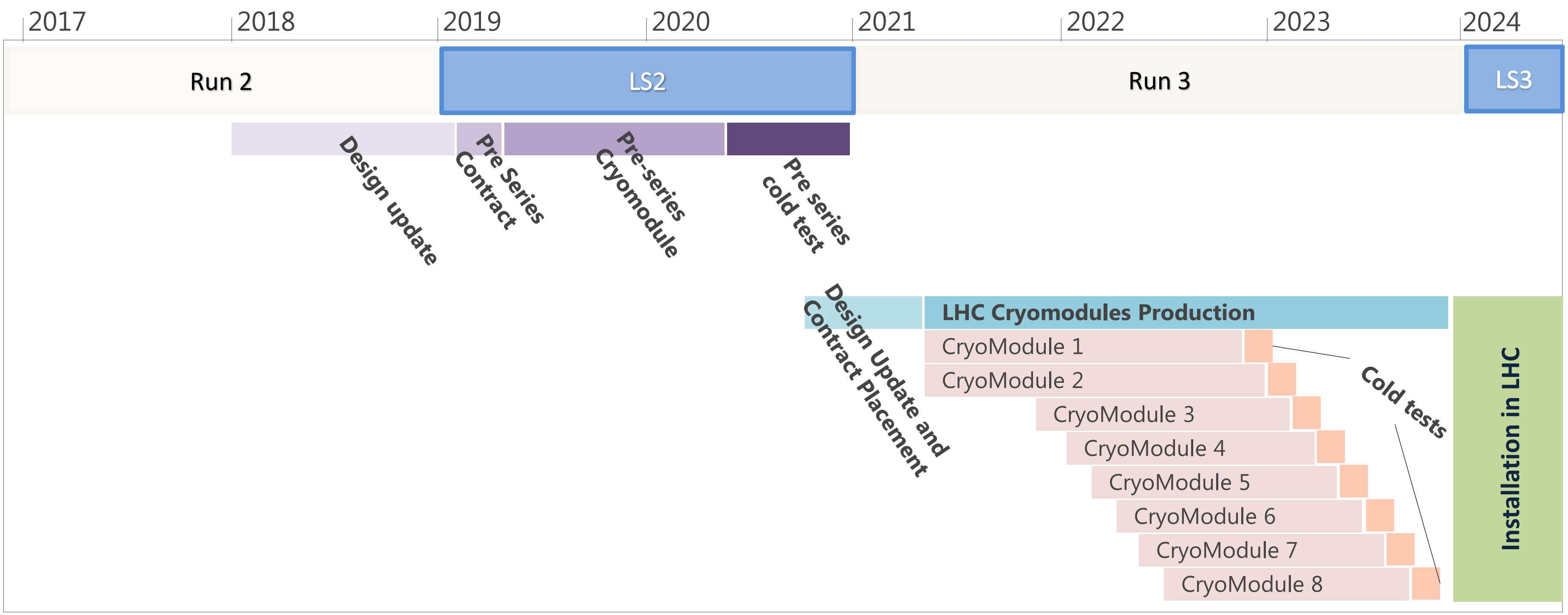
Basic choices for the design:

Maximize modularity

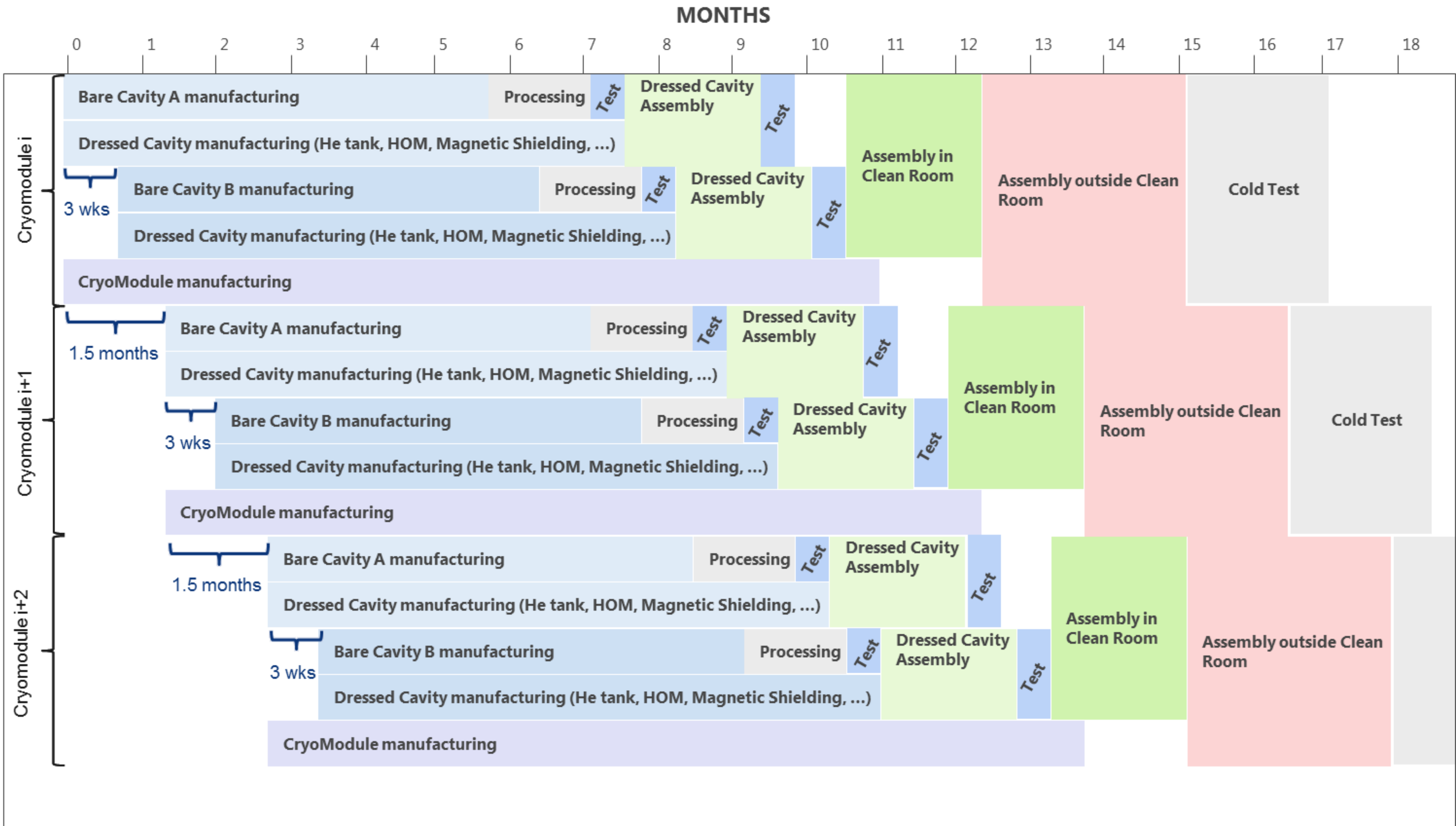
Maximize compatibility between SPS and LHC

Standardize the solutions for the 2 types of cavities

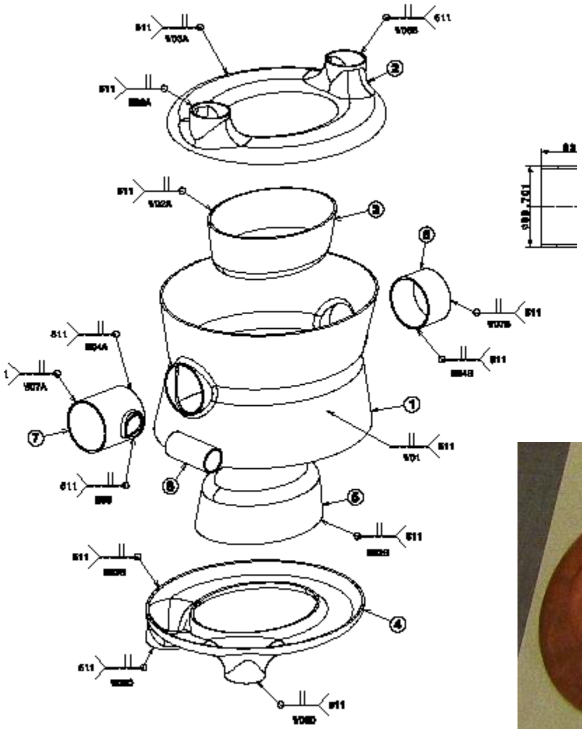
Revised Plan, LHC Series



Revised Plan, LHC Series

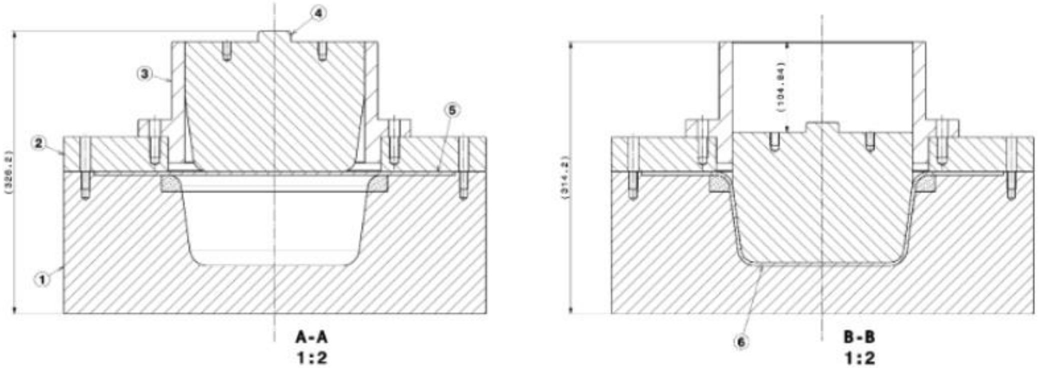


DQW Production, Circular Trials
(Lunette, Cuvette, Extrusion)

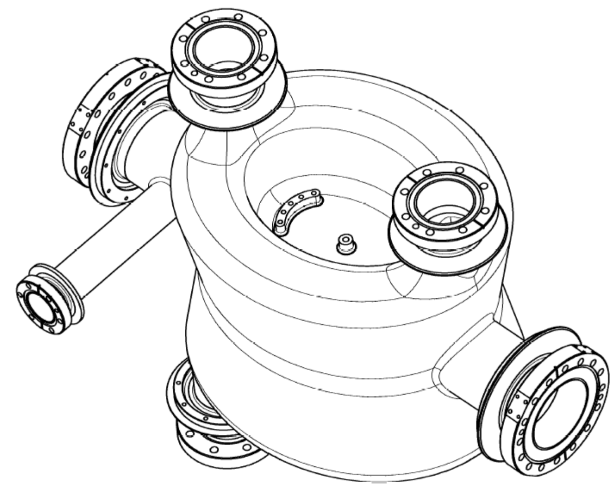


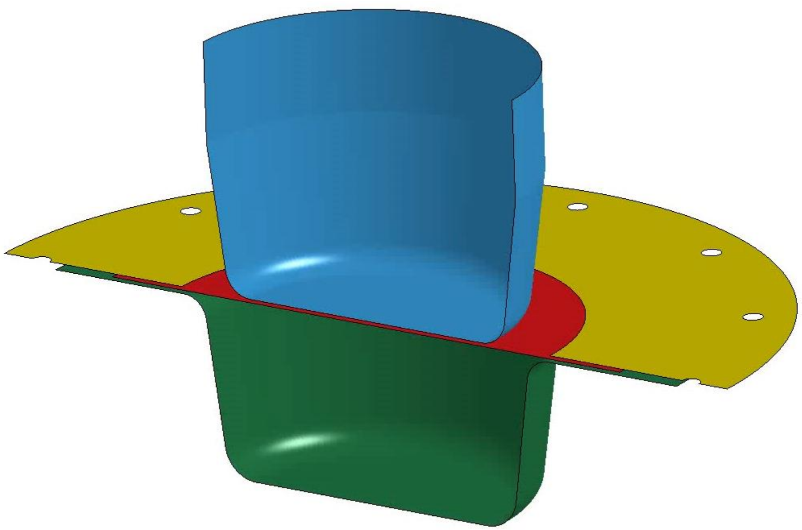
Cu tests performed to explore shaping techniques & tooling (very systematic analysis)
Circular samples show very good shape and thickness accuracies

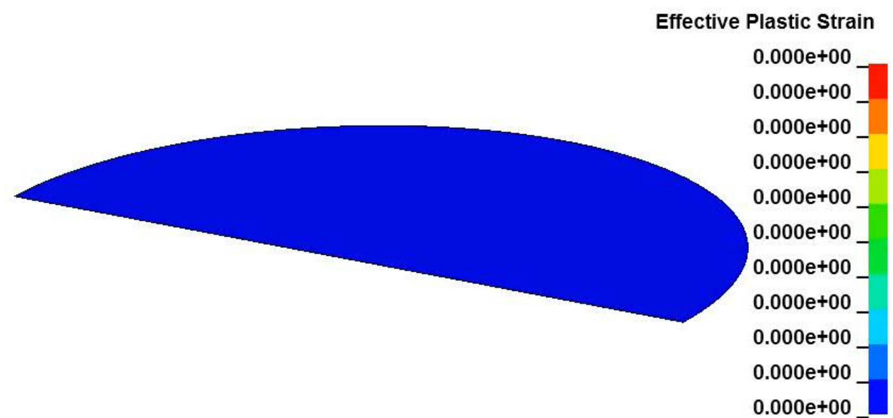
Example Shaping Simulations

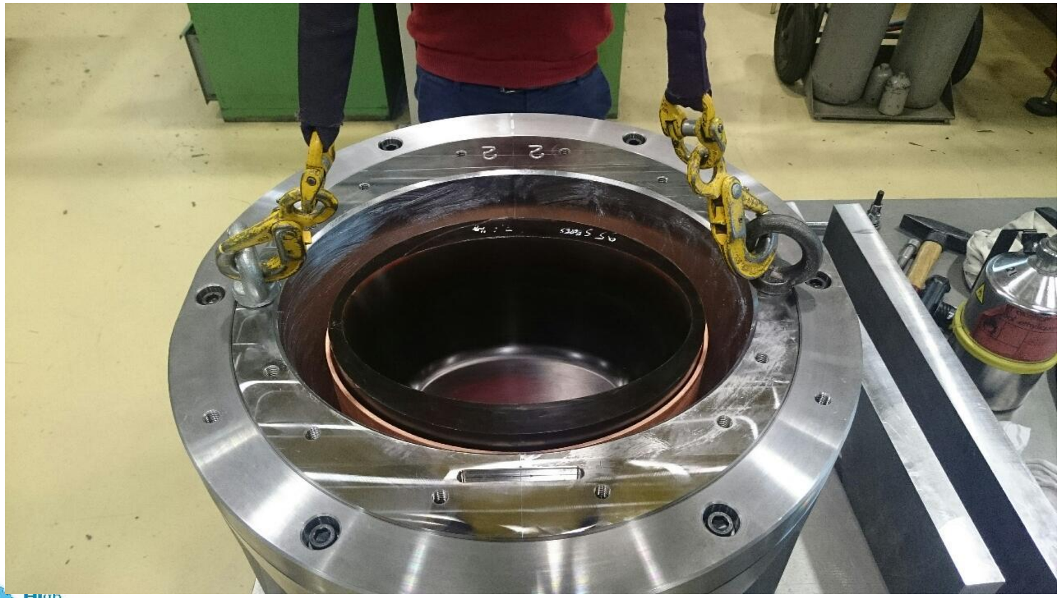


Dwg: LHCACFCA0067





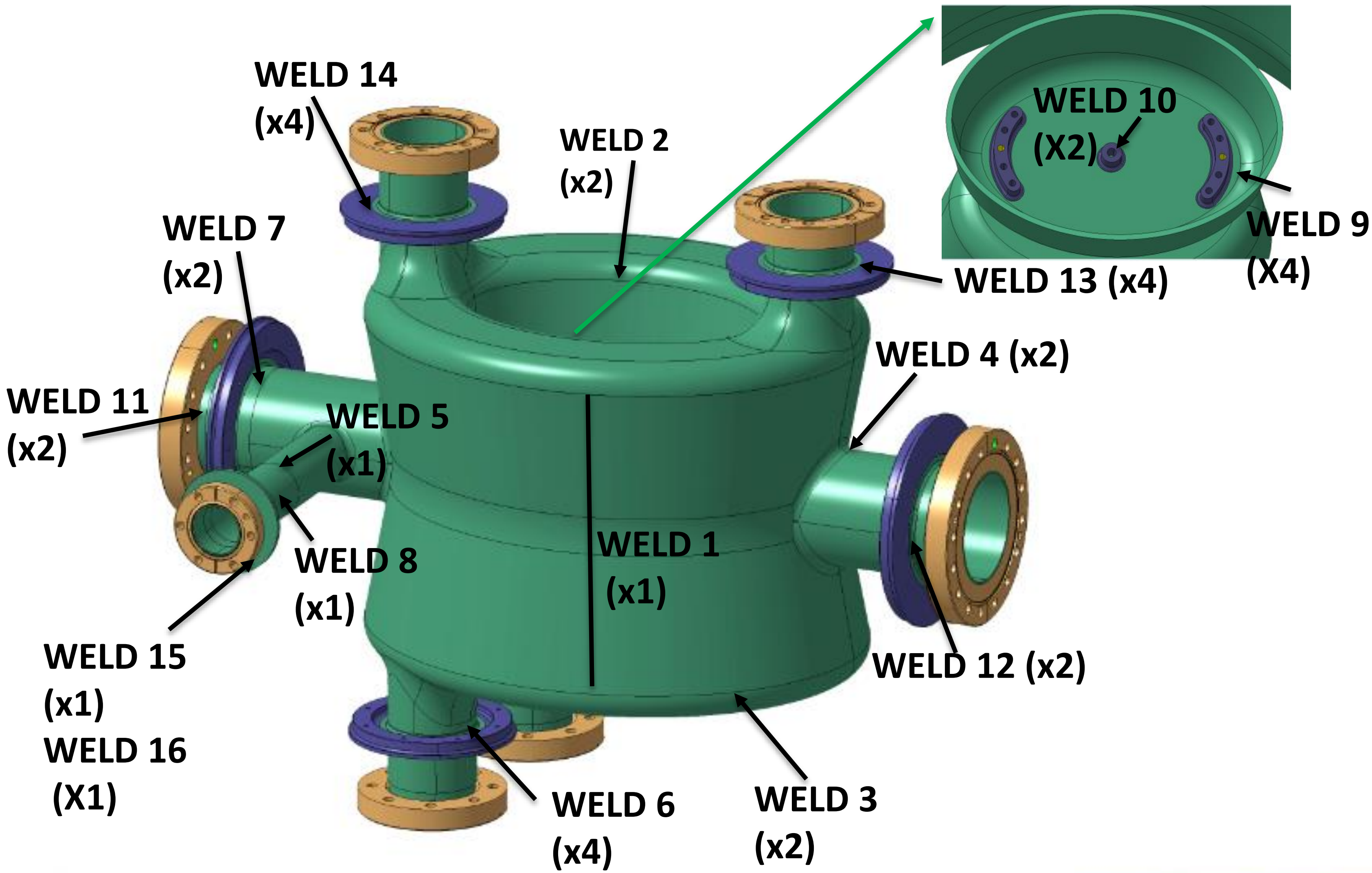




High Luminosity LHC

Weld Map

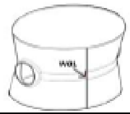
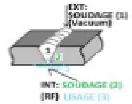
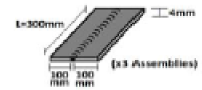
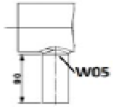
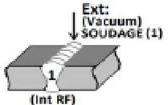
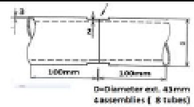
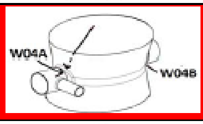
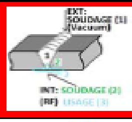
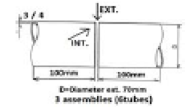
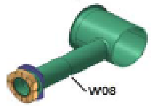
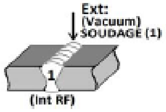
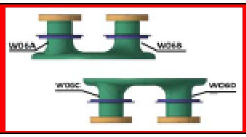
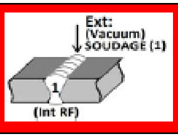
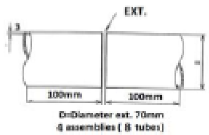
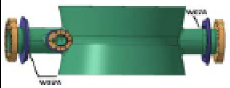
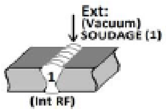
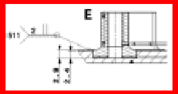
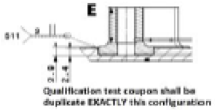
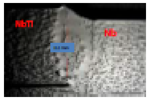
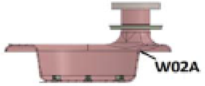
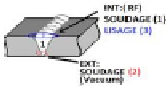
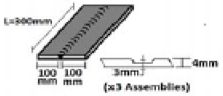
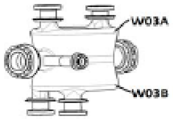
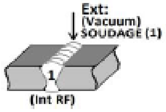
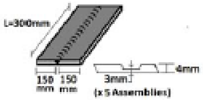
16 complex welds to qualify & perform (with tight tolerances)



High Luminosity LHC

Welding Test Qualification Flow Chart

WELDING TESTS & QUALIFICATIONS - CRAB CAVITY | DATE: 30/10/15 | Issued/Réalise: P.Freijedo & T.Tardy

Weld N. / N° soudure & SEQUENCE	Joint identification	Joint configuration	PASS	Dwg's reference / Références plans de détail	Joint Type / Type de joint	Dimension: Øint (mm)	Dimension: Esp. (mm)	Dimension: Esp.Estimé (mm)	Process / Procédé	Sample for Welding tests & Qualification (EN-15614-11) (Configuration & Dimensions)	MATERIAL NEEDED	pWPS /pDMOS Preliminaire Descriptif de Mode	REMARKS
W01			Par l'extérieur cavité: 1er pass: Soudage Par l'interieur cavité : 2nd pass- Soudage 3th pass- Lissage	LHCACFCA0023	BW with full penetration	-	4	4	511-EBW		PLATE 520X520X4 (1 Unit)		
W05			Par l'extérieur cavité: Soudage	LHCACFCA0023	BW with full penetration	37,63	3	2	511-EBW		PLATE 520X520X3 (1 Unit)		Thickness to be defined
W04A W04B			Par l'extérieur cavité: 1er pass: Soudage en deux cycles Par l'interieur cavité : 2nd pass- Lissage local interieur	LHCACFCA0023	BW with full penetration	83,7	3		511-EBW		PLATE 520X520X4 (1 Unit)		Thickness to be defined
W08			Par l'extérieur cavité: Soudage	LHCACFCA0023	BW with full penetration	37,63	3	3	511-EBW	Already qualified with circular sample for W05	-		
W06A W06B W06C W06D			Par l'exterieur cavite: Soudage	LHCACFCA0023	BW with full penetration	61,67	3		511-EBW		PLATE 520X520X4 (1 Unit)		Thickness to be defined
W07A W07B			Par l'exterieur cavite: Soudage			83,7	3	3	511-EBW				
W09A W09B W09C W09D W10A W10B			Par l'exterieur cavite: Soudage	LHCACFCA0001	BW with partial penetration		2		511-EBW		NbTi/Nb		Preliminary test performed: 
W02A W02B			Par l'interieur cavité : 1er pass-Soudage 3-Lissage Par l'extérieur cavité: 2-Soudage	LHCACFCA0023	BW with full penetration	238	4	4-3	511-EBW		PLATE 520X520X4 (3 Units)		Thickness to be defined
W03A W03B			Par l'exterieur cavite: Soudage	LHCACFCA0023	BW with full penetration	398	4	4-3	511-EBW				

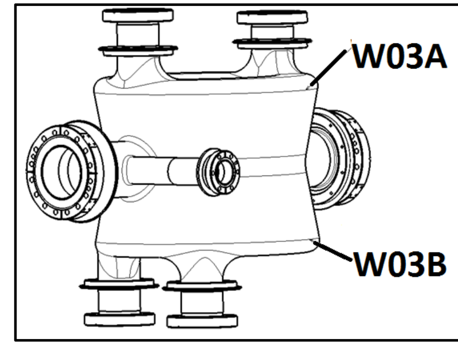
Difficult Weld

A Sample Weld

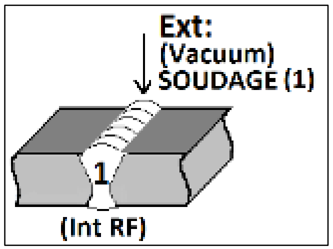
<u>Nb-Nb: W03A/B Final ellipsoidal welds :</u>

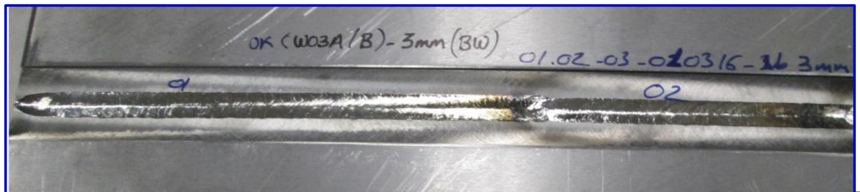
Welding in 3mm of thickness performed on 1 side.

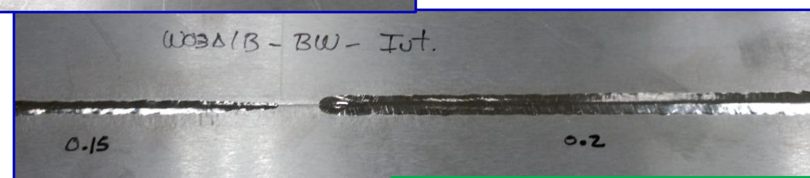
Two configurations tested: Key (Clé) and BW (Bords droits)



BW

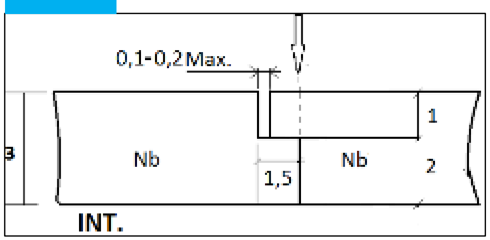


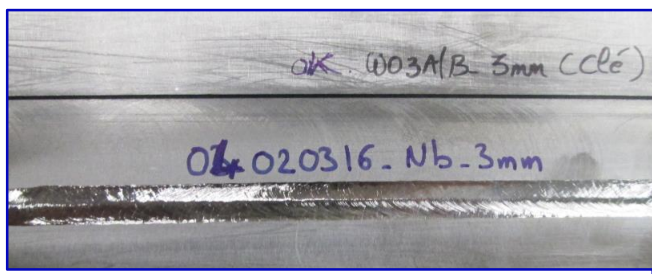


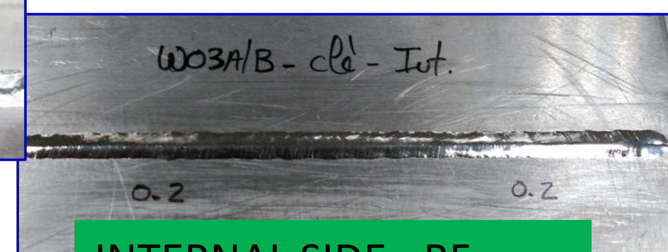


INTERNAL SIDE - RF

KEY



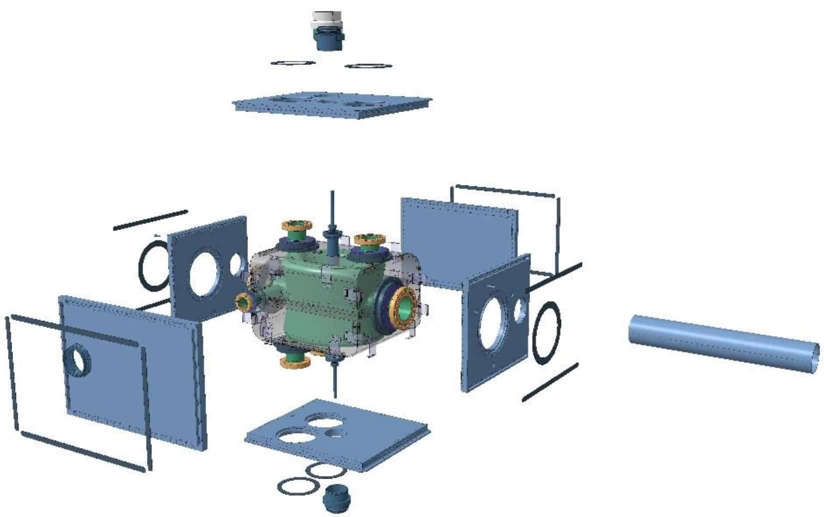




INTERNAL SIDE - RF

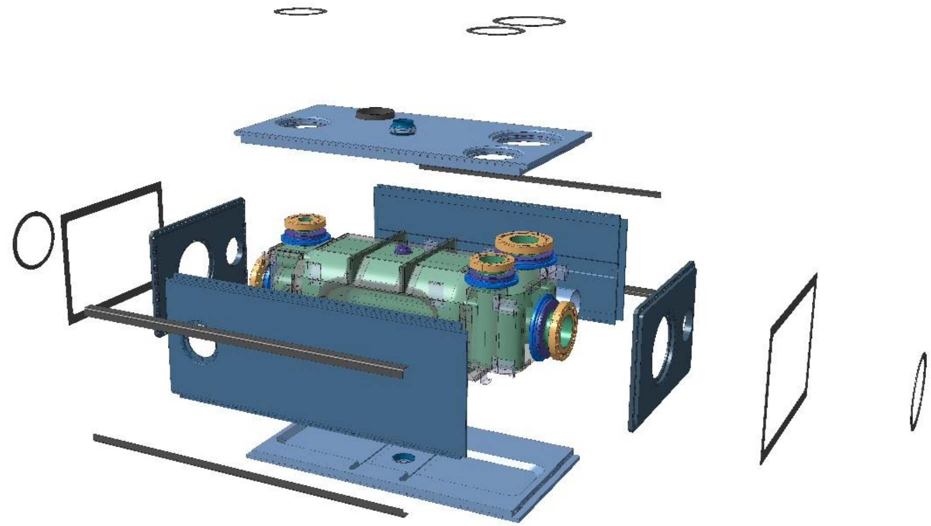
BOTH CONFIGURATIONS WITH SATISFACTORY RESULTS

Helium Vessel



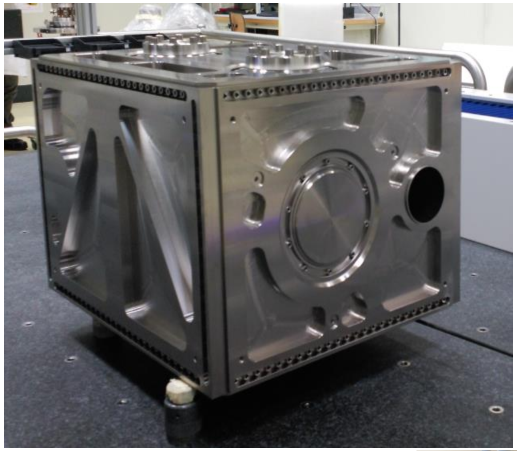
Bolted/welded concept was chosen for structural integrity & minimal stress to cavity

A dummy prototype was launched for experimental verification of assembly procedure, stress, vacuum integrity and other aspects.



They are now verified

Prototype Helium Vessel

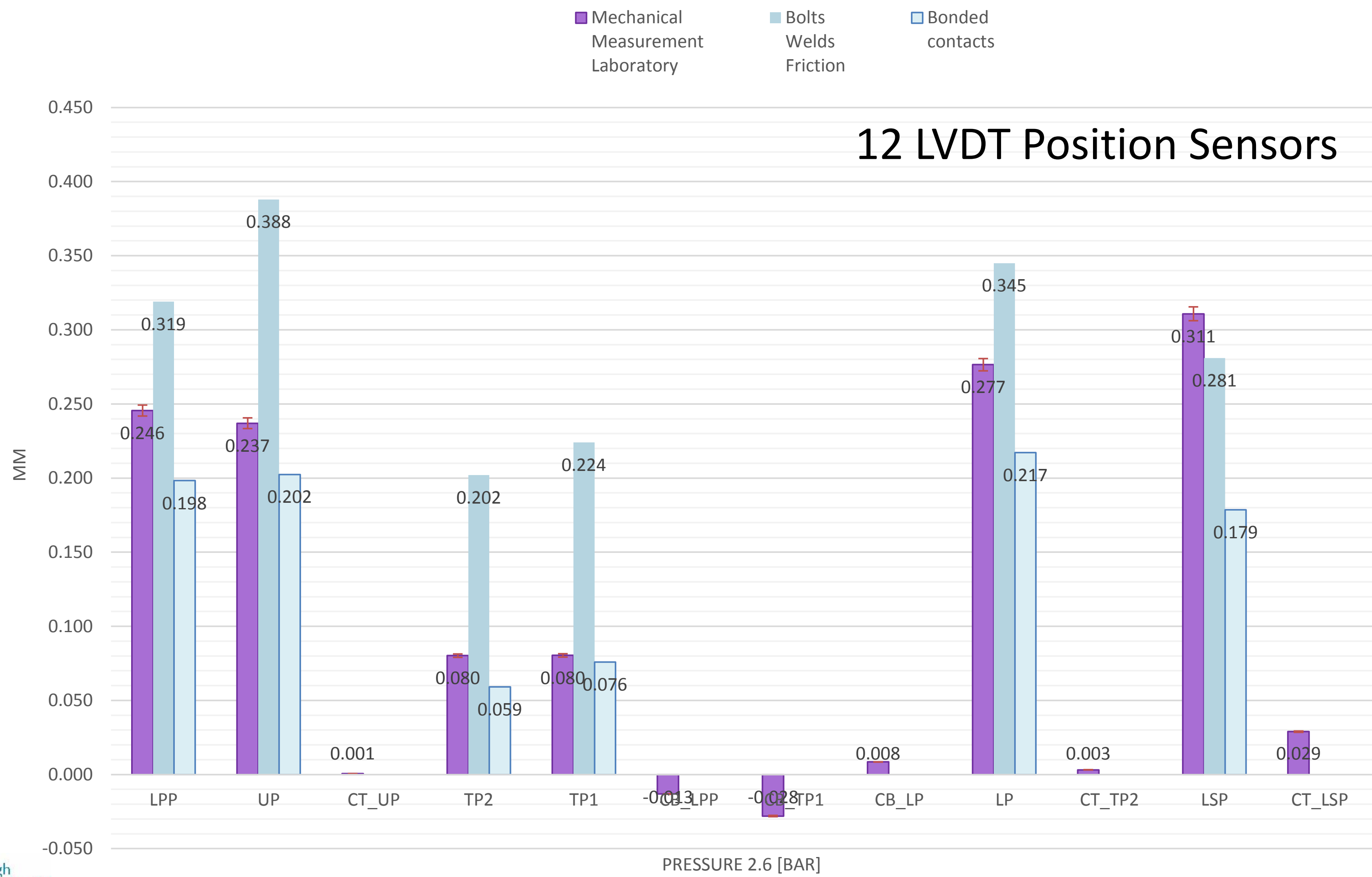


WELDING STEPS
1- Vertical welds
2- Welds around the top/bottom plate
3- Longitudinal Covers
4- Circular Covers & Beam pipe

Pressure tests (2.6 bar)

The vacuum levels remained at $\leq 10^{-9}$ mbar (5 thermal cycles)

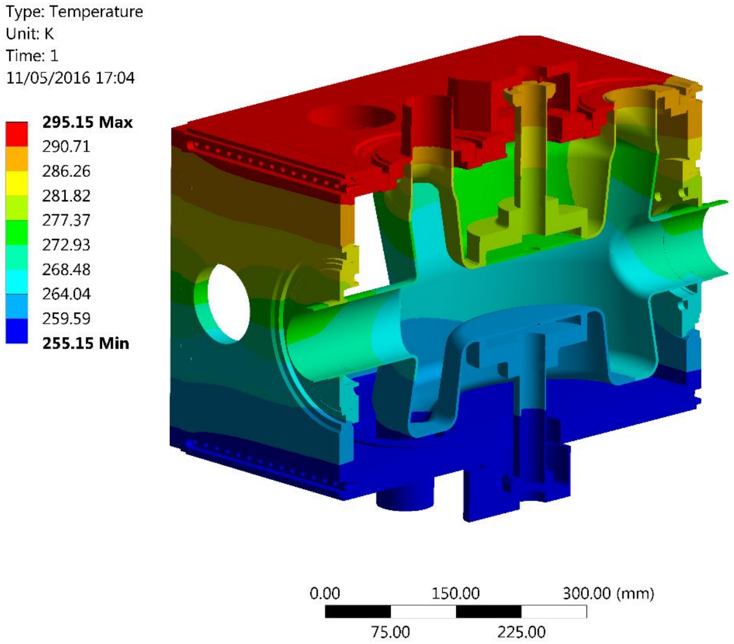
Tests vs. Simulations

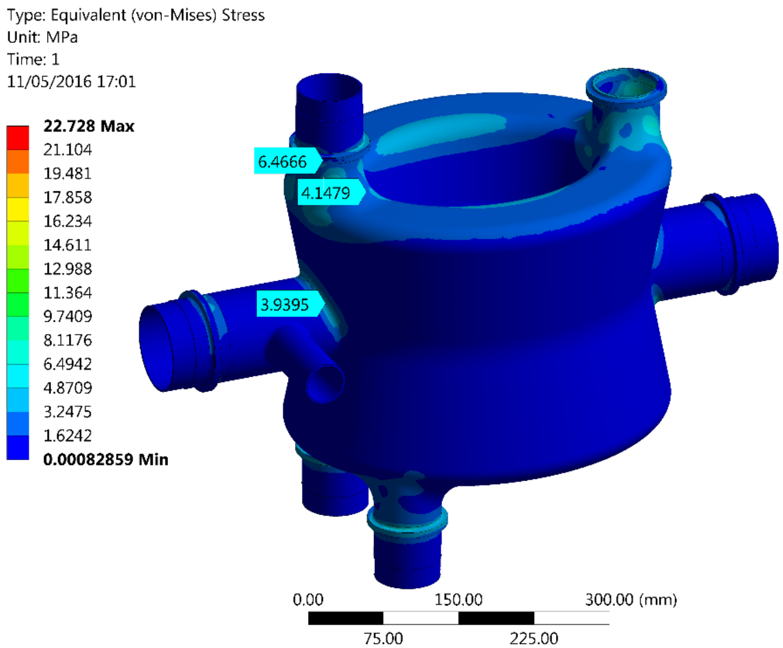


High Luminosity LHC

Cavity Stress, cool down

- $\Delta T_{max} = 40\ K$ top/bottom of tank (input constraint)

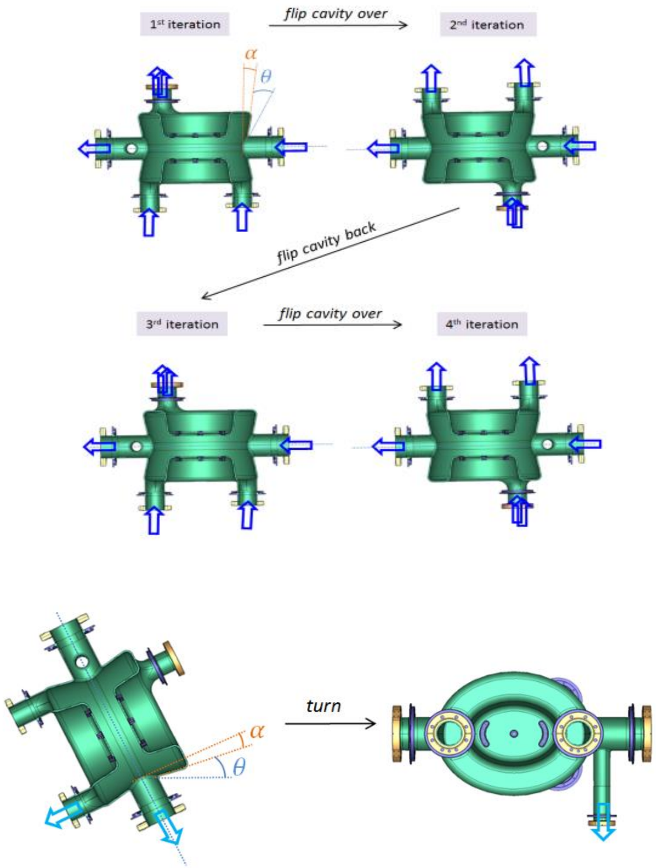




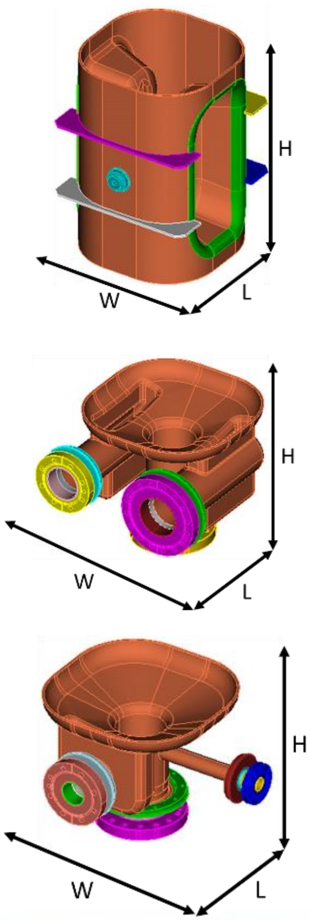
- Stress on cavity is low ($\leq 10\%$ of allowable)
- Slower cool-down rate can further reduce if necessary

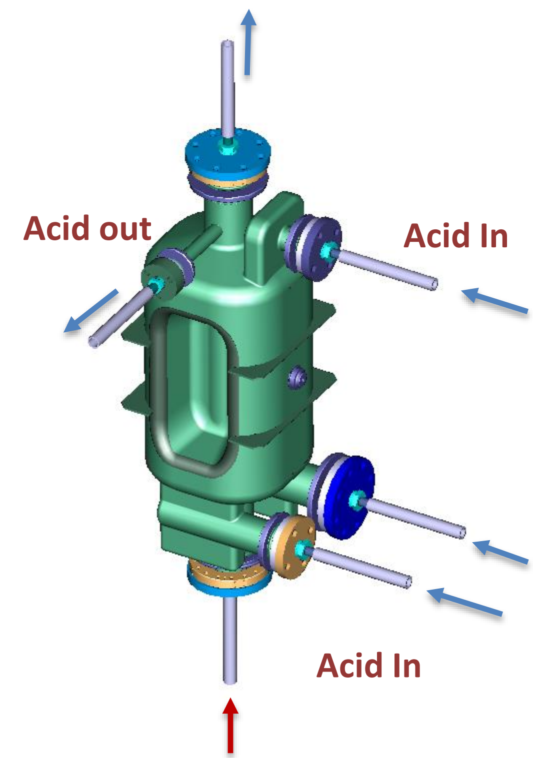
Cavity Chemistry, DQW & RFD

DQW: Very light chemistry on Parts & Bulk Chemistry on assembled cavity

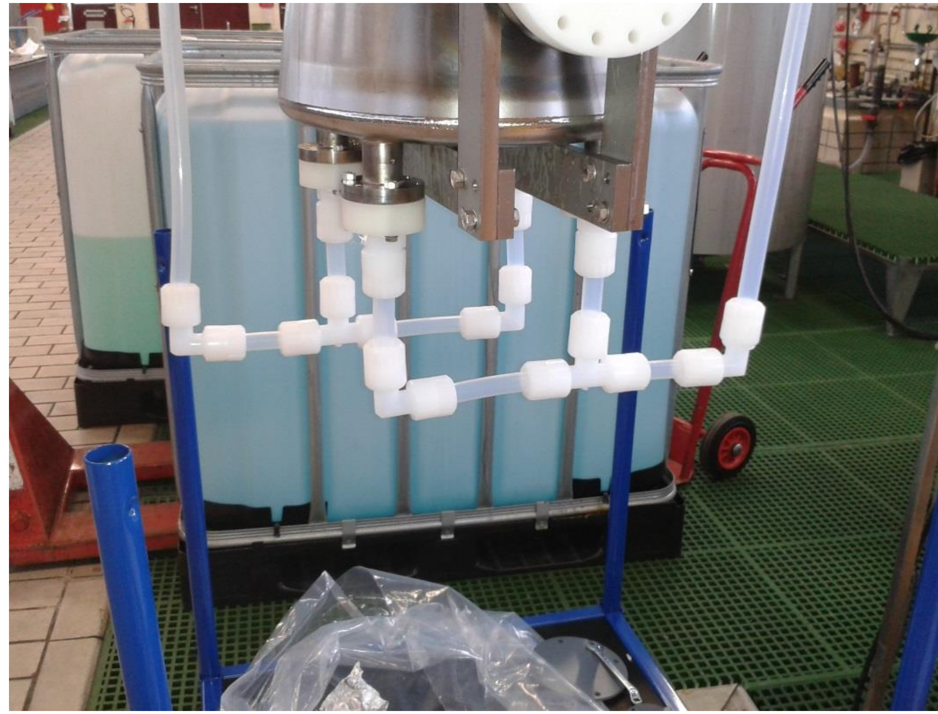


RFD: Bulk Chemistry on Parts & Light Chemistry on assembled cavity





CERN Setup, Cavity Chemistry (PoP)

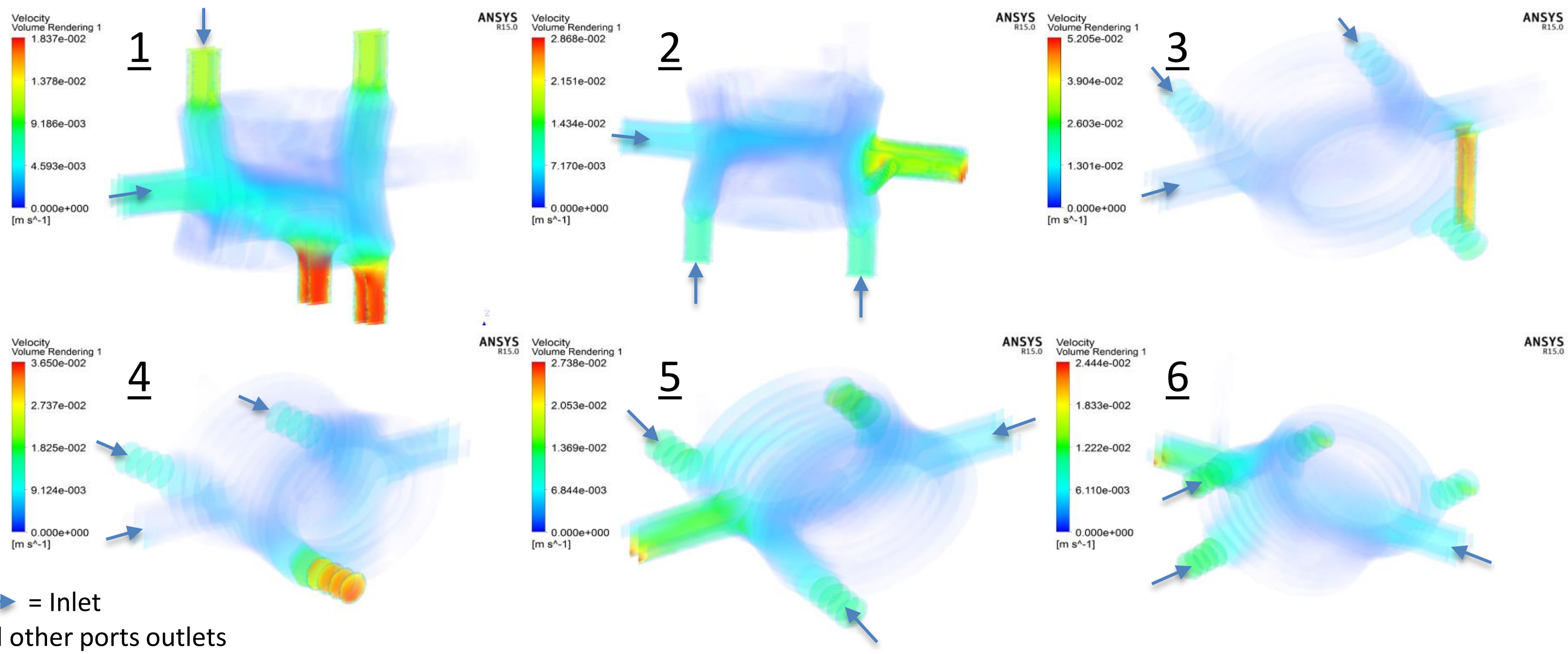


General procedure uses acid circulation between $10 - 15^{0}$ C (~ 40 min, indicative)

Small tilting for trapped gas removal

Fluid Dynamics for Chemistry

See Talk: T. Jones



→ = Inlet
All other ports outlets
Gravity acts down as shown in images

Analysis	1	2	3	4	5	6
Range (cm/s)	0.63	1.82	0.90	0.65	1.23	0.92
Standard Deviation (cm/s)	0.21	0.40	0.24	0.21	0.26	0.23
Av. Velocity (cm/s)	0.29	0.38	0.33	0.31	0.36	0.28

Data taken for 21 points throughout the cavity for each orientation

High Luminosity LHC

Frequency Tracking

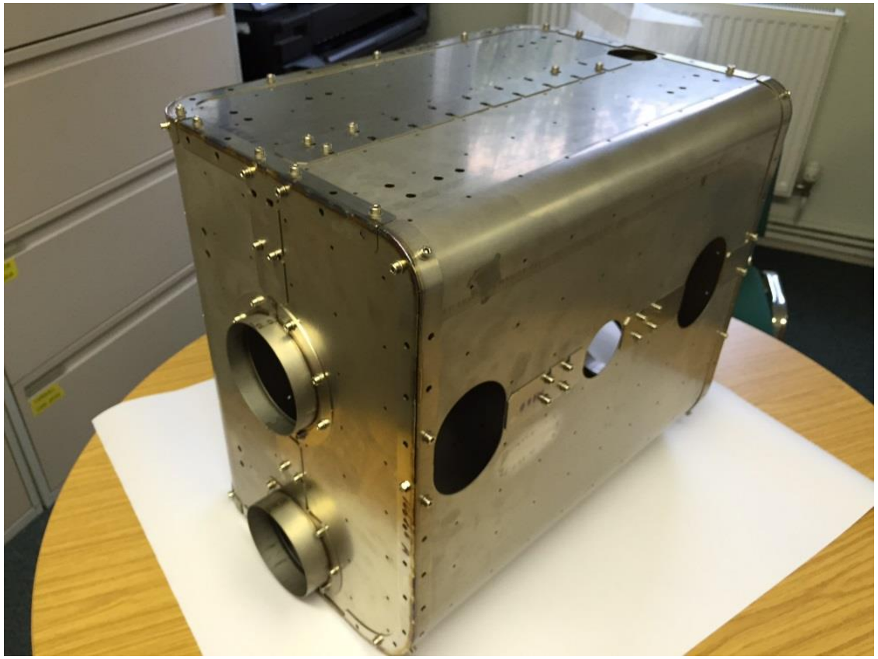
See Talk: S. De Silva, S. Verdu

FREQUENCY SHIFTS Target: 400.79 MHz (-60 kHz)

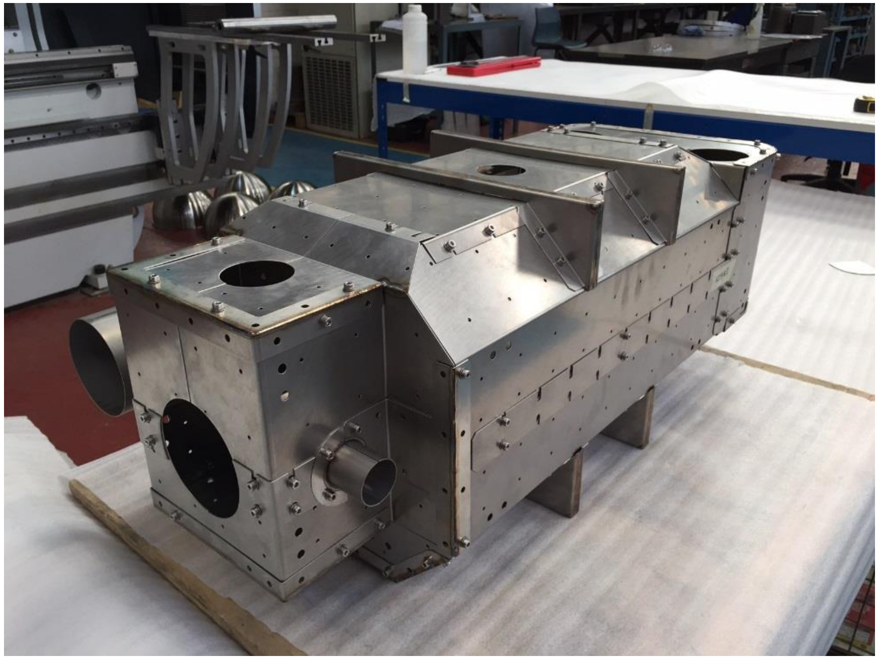
	Effect	Magnitude		Uncertainty		Unit	Premises under which value was calculated	
Fabrication	*Last weld-A shrinkage (assumed ~1 mm)*	$\Delta f_{ShrinkWeldA}$	980	-490	+980	kHz	Freq shift calculated as expected shrinkage times trim sensitivity.	Cumulative freq shift from both shrinkage and sagging of last weld-A will be known after welding the "next-to-last" weld.
	Last weld-A sagging (assumed 0.5mm-deep, 5mm-thick bead)	$\Delta f_{SaggWeldA}$	-70	-50	+70	kHz	From simulations.	
	High-T baking	Δf_{High-T}	0			kHz		
	Low-T baking	Δf_{Low-T}	0			kHz		
	BCP (210 μm)	Δf_{BCP}	-170	-50	+50	kHz	Models prepared for CST simulations.	Take about ~30% for error due to thickness removal uncertainty and unhomogenenity. Error may be reduced if BCP performed in several iterations and in rotating facility.
Assembly	*Couplers and ports (bare cavity --> baseline aseembly of cavity with couplers)*	Δf_{C}	-89	??	??	kHz		Estimate uncertainty coming from assembly error that will turn into penetration error.
	Test couplers out --> in	Δf_{TestC}	0			kHz		
	Helium vessel mounting and magnetic shield assembly	Δf_{Mount}	0			kHz		
	Welding of helium vessel	$\Delta f_{TankWeld}$	-150	-116	+416	kHz	Magnitude: form measurement of displacements in dummy tank after welding used as input for ACE3P simulations. Uncertainty: worst-case scenario for tolerance error of ±0.1 mm.	
Setup	*Frequency change from air to vacuum*	Δf_{ε}	133.3			kHz	Formula	
	Frequency sensitivity to pressure	$\Delta f_{P}/P$	-0.103			Hz/mbar	ANSYS-APDL	
	Frequency change from 300 K to 2 K	Δf_{T}	573			kHz	ANSYS-APDL	
Operation	*Lorentz detuning coefficient*	$\Delta f_{U}/(Vt)^2$	-40			$Hz/(MV)^2$	CST simulation for model including tuning system and vessel.	
	LF detuning: RF power off --> on	Δf_{LD}	-0.4			kHz		
	Beam loading	Δf_{BL}	0			kHz	Formula	

2K Internal Magnetic Shields

Double QW

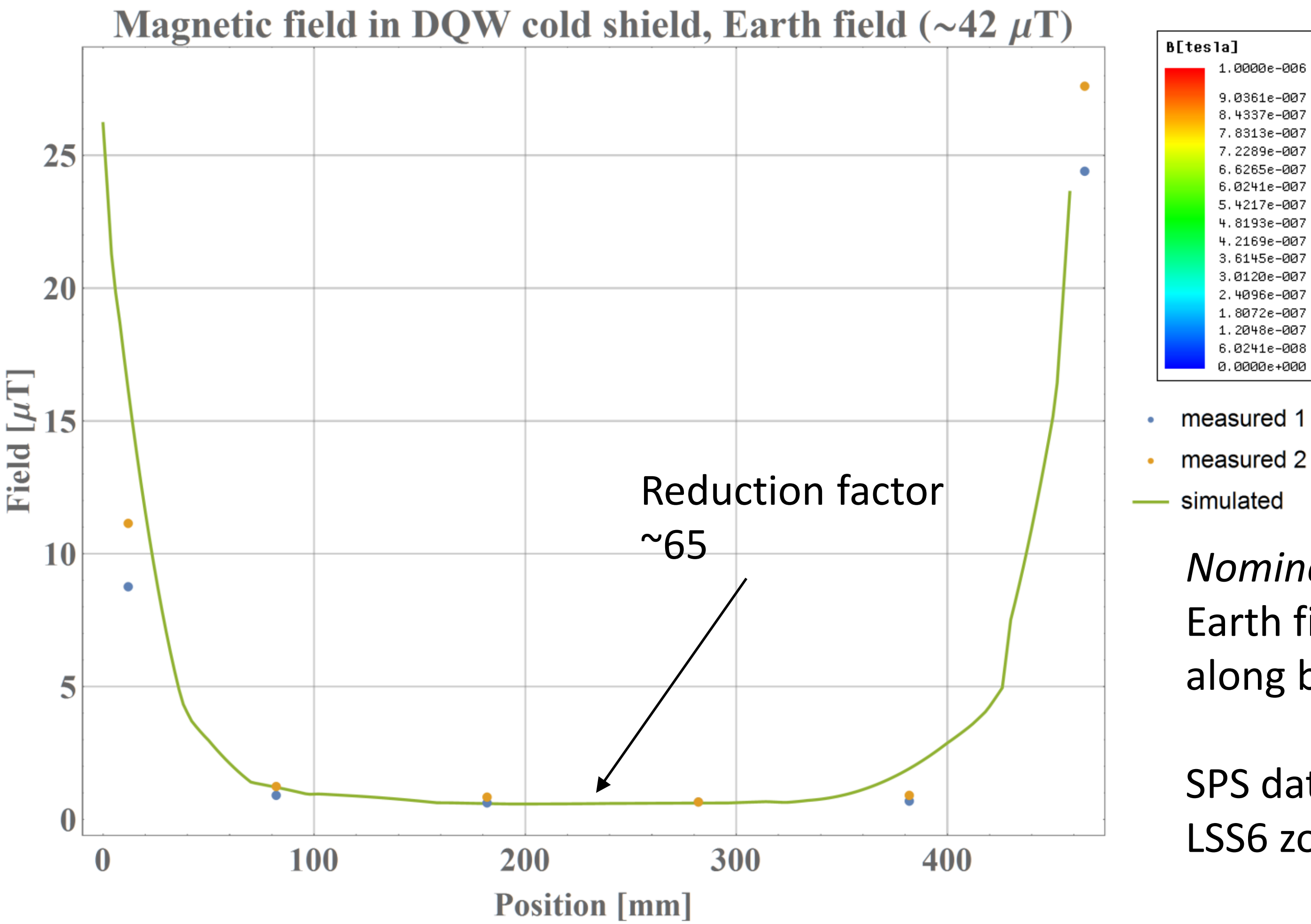


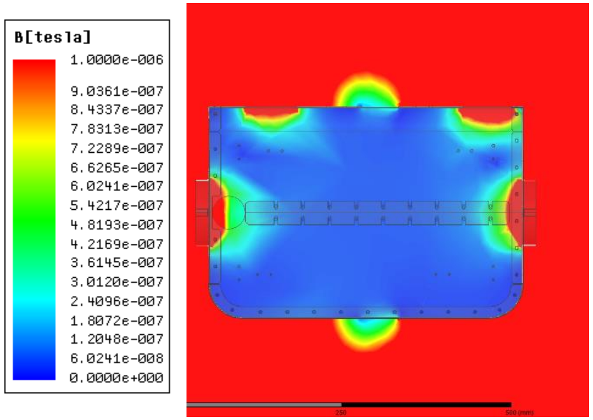
RF Dipole



- *Internal magnetic shields already integrated by STFC-UK !!*
  - *1 mm Cryophy, annealed after shaping, supported by Ti brakets*
  - *Controls done: dimensions, shielding reduction factor*
  - *At CERN waiting for cavities…*

Comparison of Data and Simulations





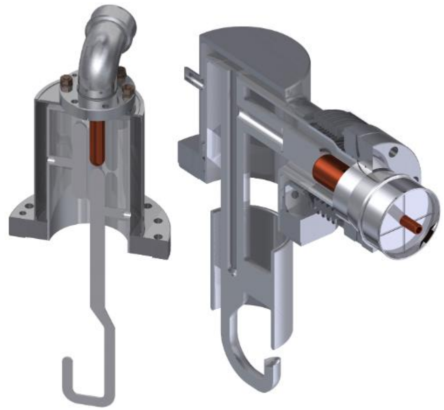
Nominal input:
Earth field (~ 42 μT) along beam axis

SPS data taken in LSS6 zone from YETS

High Luminosity LHC

HOM Couplers

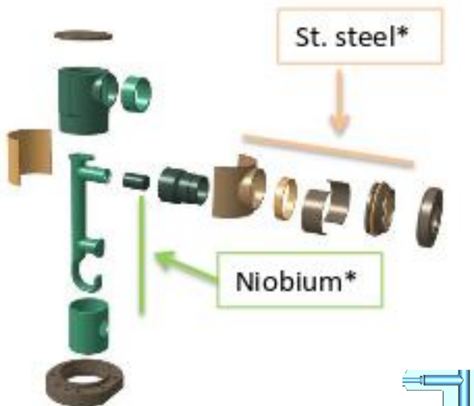
See Talk: M. Garlasche



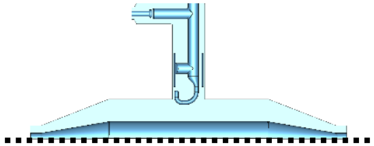
DQW Status

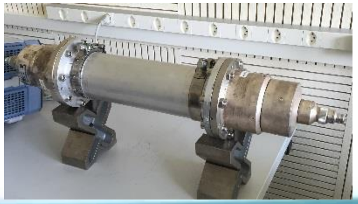
- Niobium pieces & other ancillaries produced
- Final metrology & welding tests ongoing before assembly

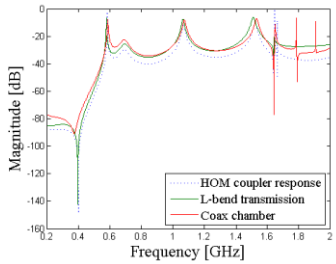
RFD material at CERN, fabrication in 2016

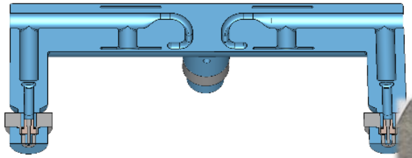


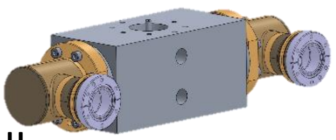
HOM Testbox







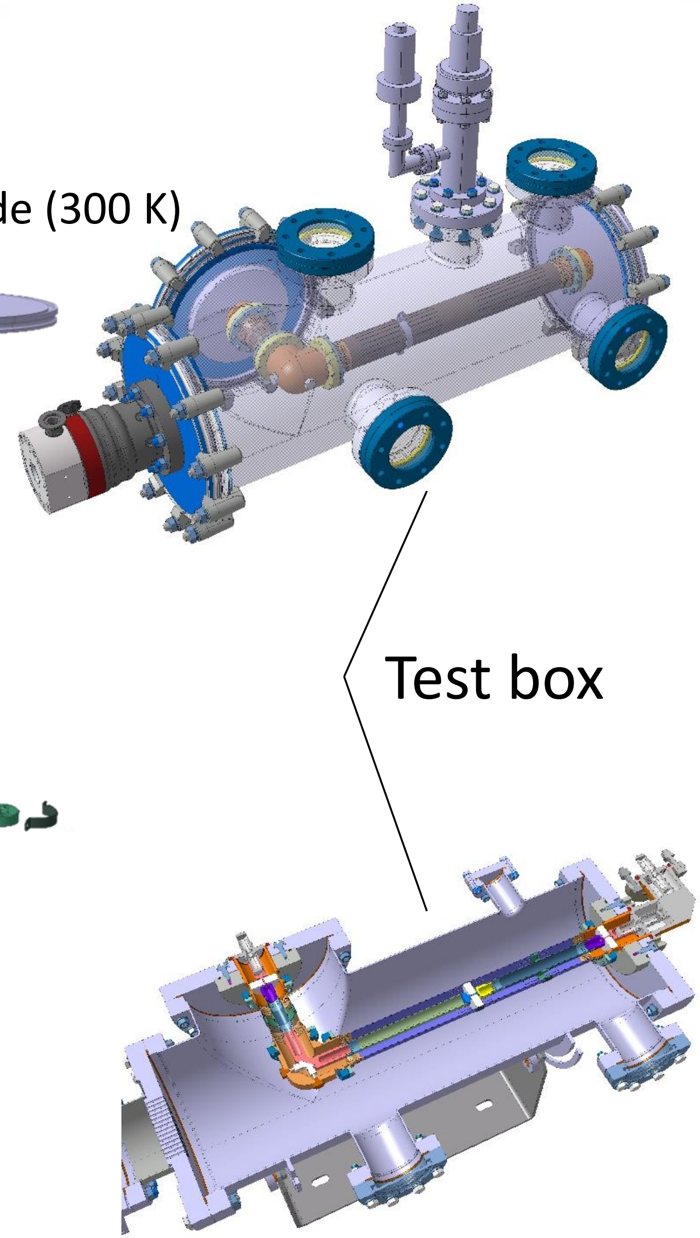




See Talk: J. Mitchell

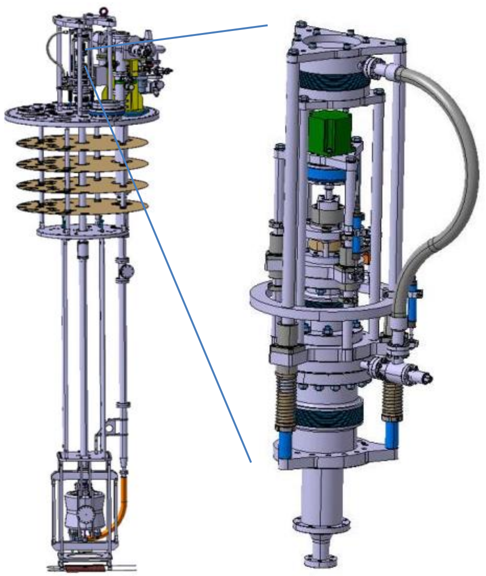
HOM Lines

- Optimized for static/dynamic heat loads to 2K
- Coax line for 1 kW, 316LN, Cu sputtered (5μm)
- Flexibility using spherical joints & themalization with alumina disk
- Destructive tests for validation 2016



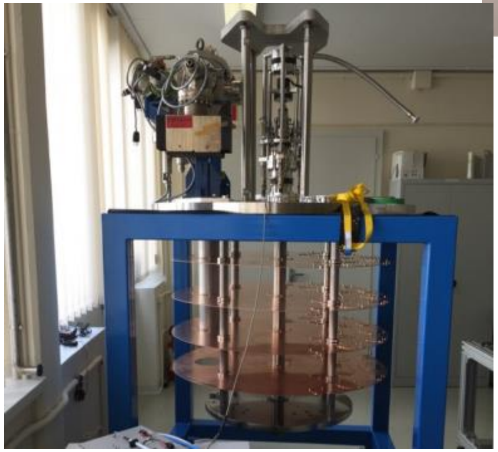
Tuner Tests (on PoP)

See Talk: A. Castilla

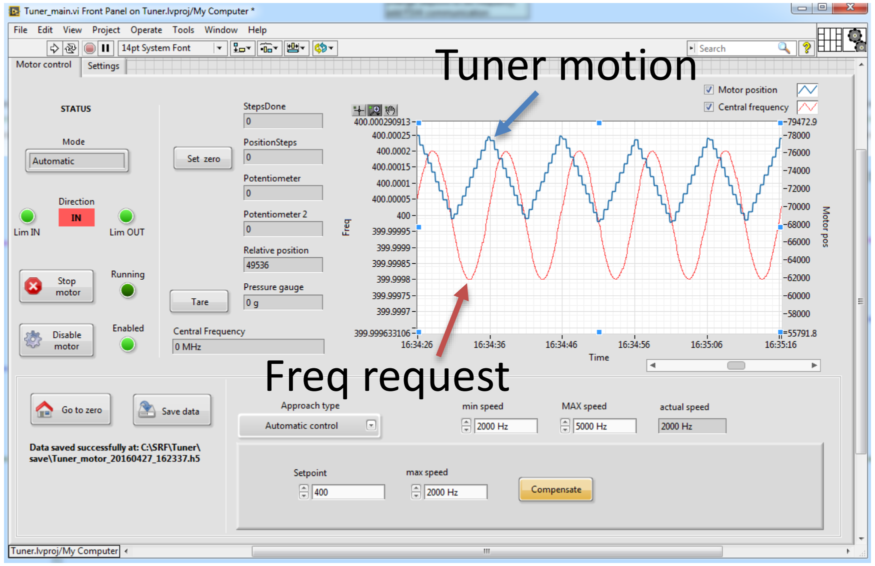


Tuner preparation for Cold Tests planned during Jun 2016

- Assembly into SM18_V3 & protection for cooldown actions ongoing
- PLC based control system successfully tested in a feedback loop



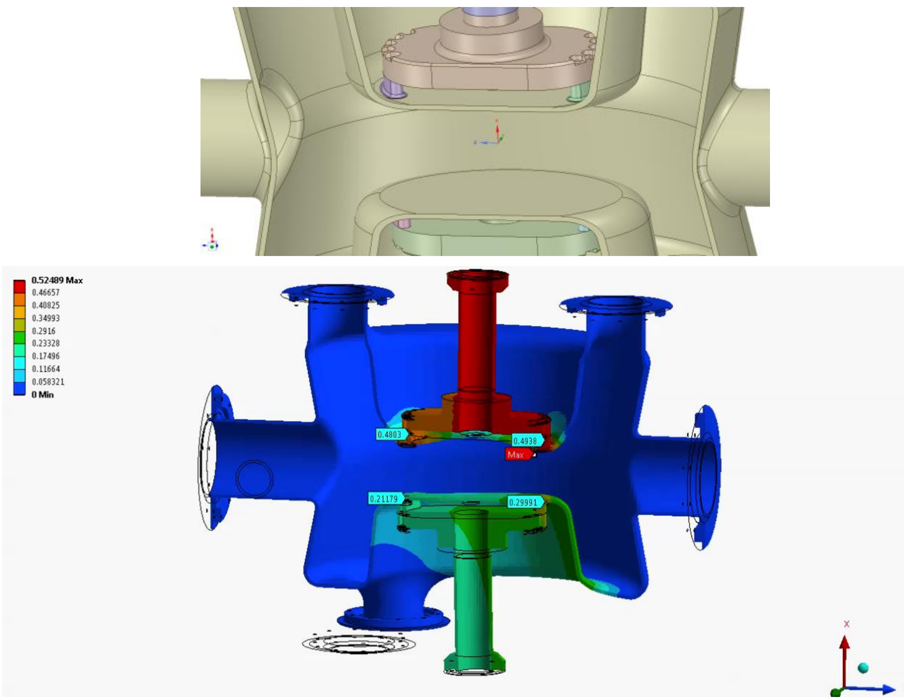
Repeatability preceision ~0.5 µm ~ 100 Hz



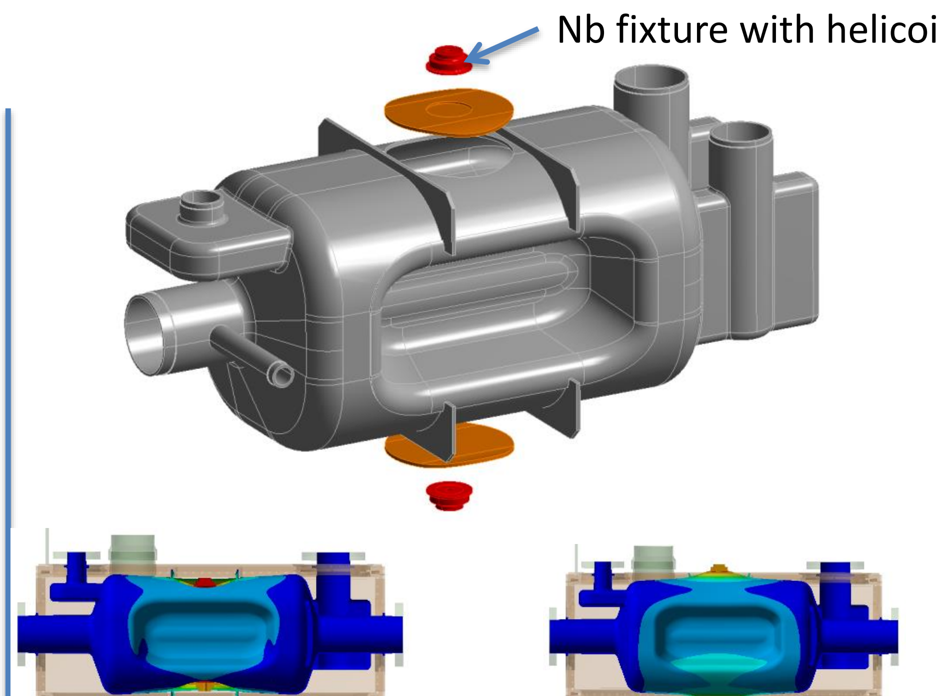
High Luminosity LHC

Tuning Fixtures

- Warm frequency tuning limited by tuning fixture
- Limiting factor is the strength of NbTi fixture and weld
  - CERN (NbTi), USLARP (Nb with reinforced shape)

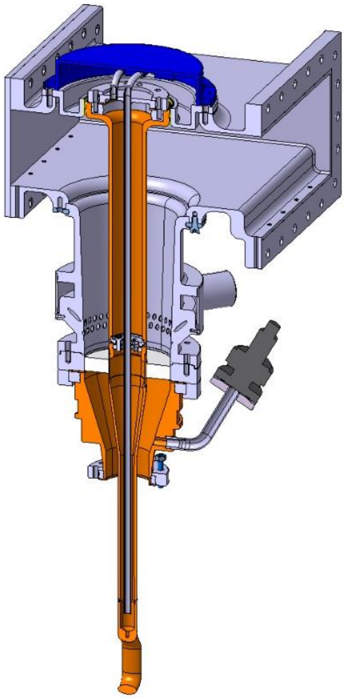


DQW Pre-tuning: ≥ 0.3 mm permanent deformation



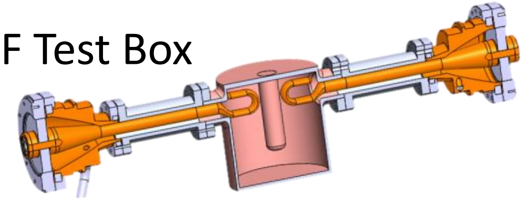
RFD: ~ 1.4 mm (7000 kN elastic limit)

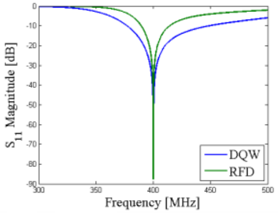
Power Coupler



Most FPC parts (+spares) completed

RF Test Box





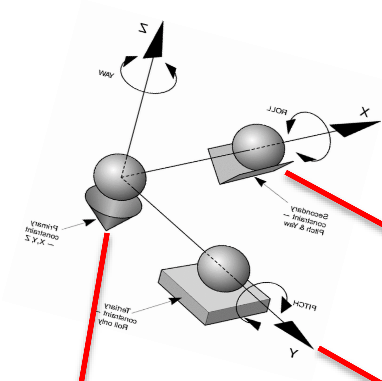
2 DQW + 2 RFD Couplers by end of May (spares in Oct)

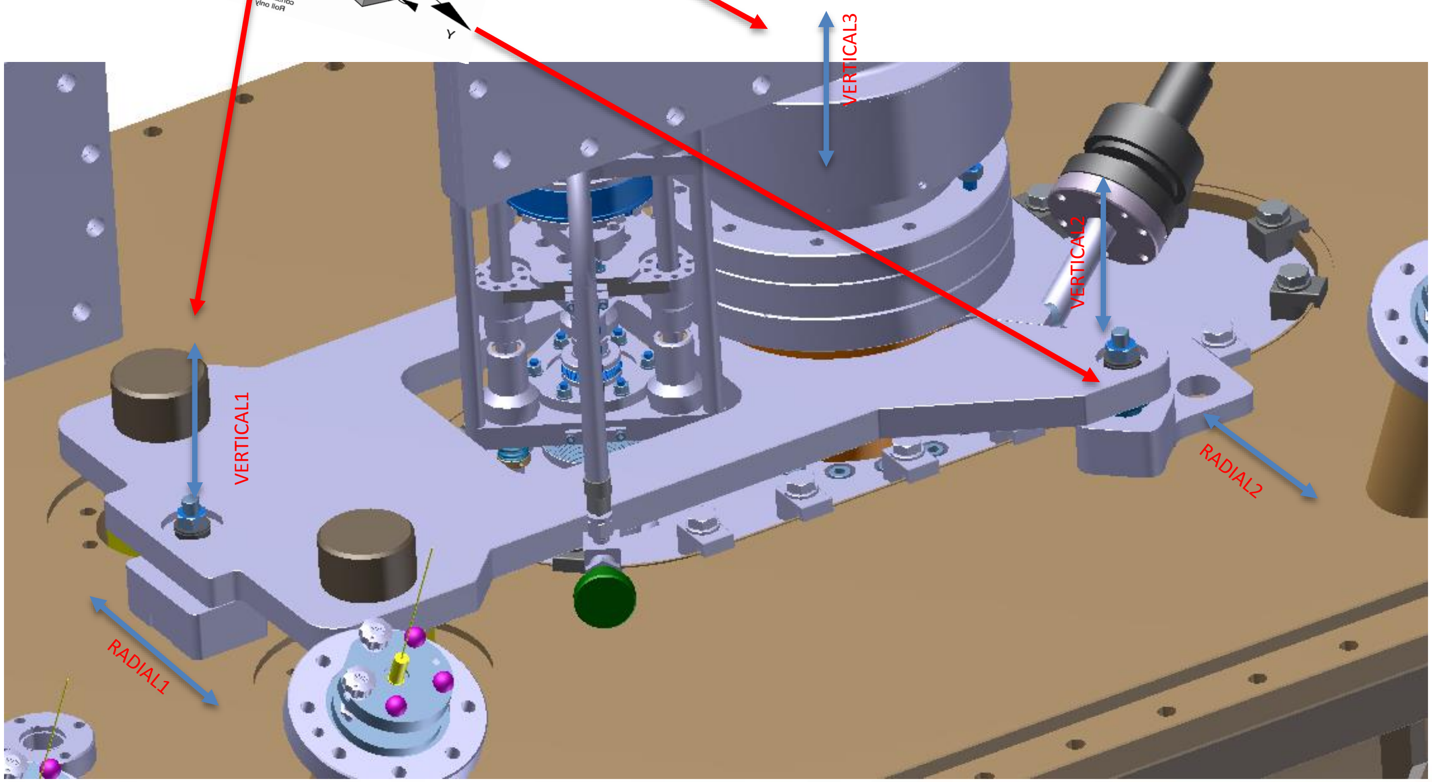
RF Test box ready by Sept. → Clean room assembly in Oct
Two DQW couplers ready April 2017

Cavity Supports & Alignment

Top plate – kinematic mount, option with levelling jacks as vertical supports

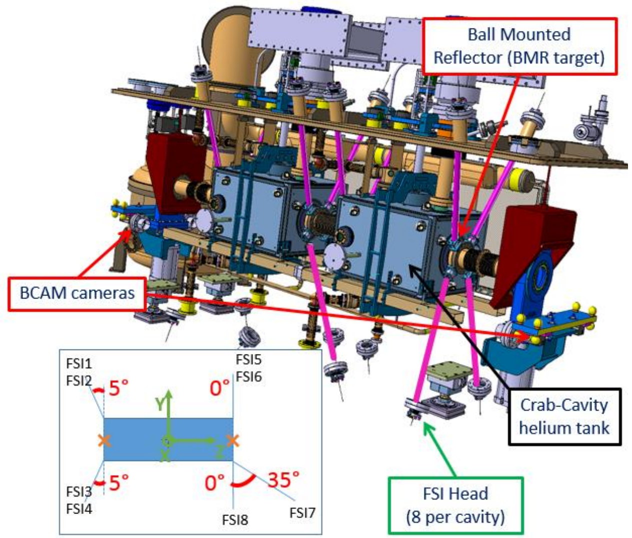
Three point alignment which are blocked after
Additional points for rigidity

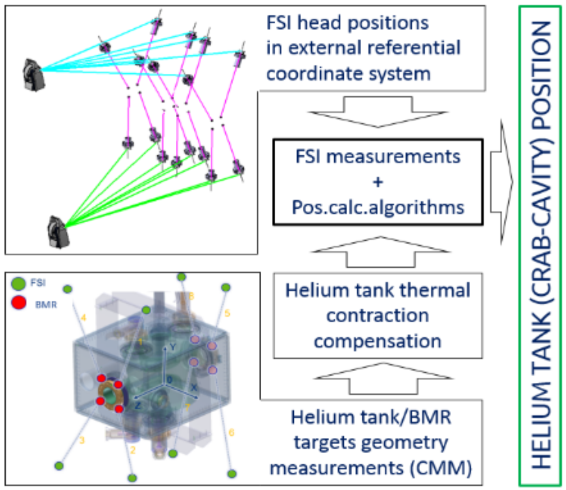




Position monitoring system (BCAM + FSI)

- BCAM + FSI (1:1) full system mock-up under construction
- Irradiation campaign of reflective targets and collimators finished
- FSI head prototypes designed and under manufacturing
- BCAM → System performance initially validated on the mock-up. Tests and calibration of camera vacuum viewports pending
- Cryogenic tests of reflective targets planned in the next 2 months



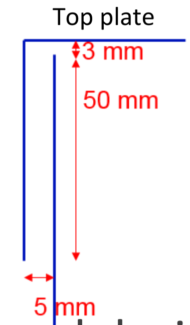


- Fiducialisation of the helium tank mock-up on CMM and laboratory verification of full system performance
- FSI head test in operation conditions (vacuum, reflector at 4K)
- Irradiation campaign of FSI heads assemblies
- SM18, SPS - DAQ and data processing software development
- Measurements in SM18 – validation of the final system

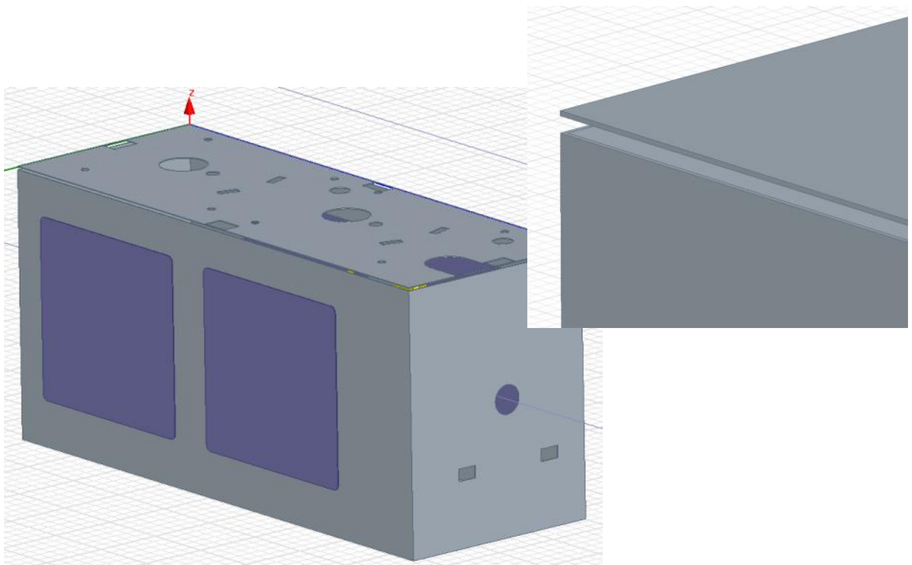
High Luminosity LHC

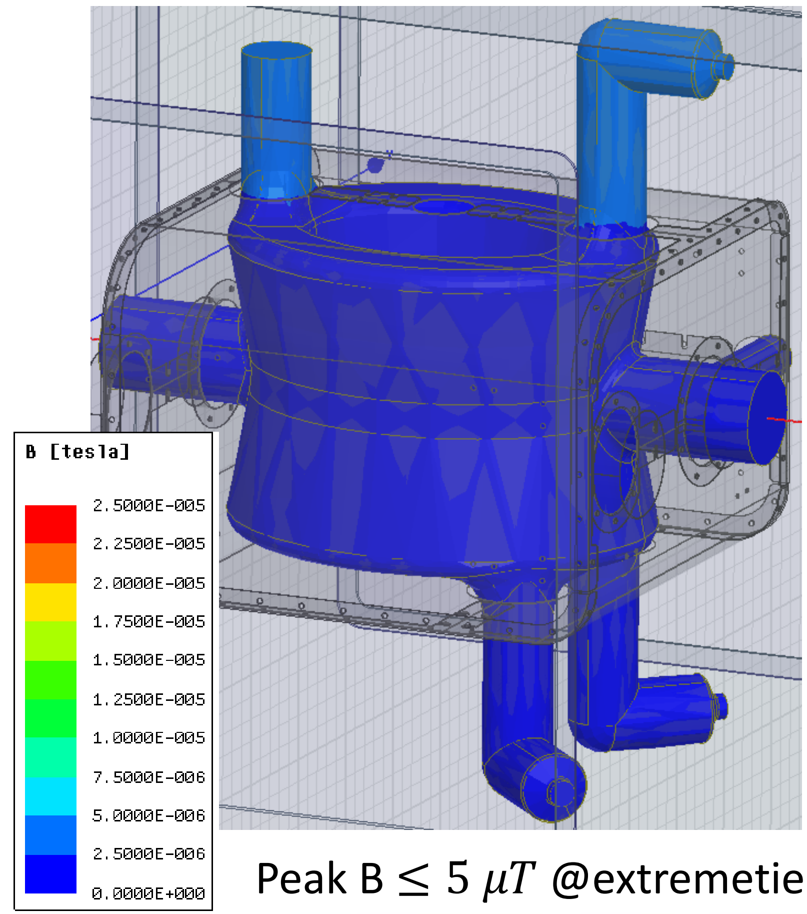
Warm Magnetic Shield

- Field measured in SPS and applied to Warm Magnetic Shield
- Gaps between plates induces field leaks, fine tuning



Results with optimal proposed design

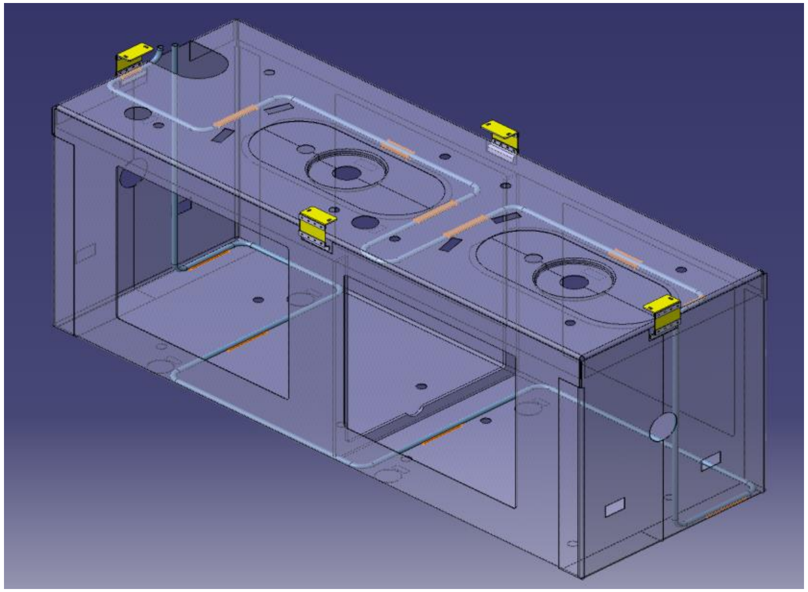


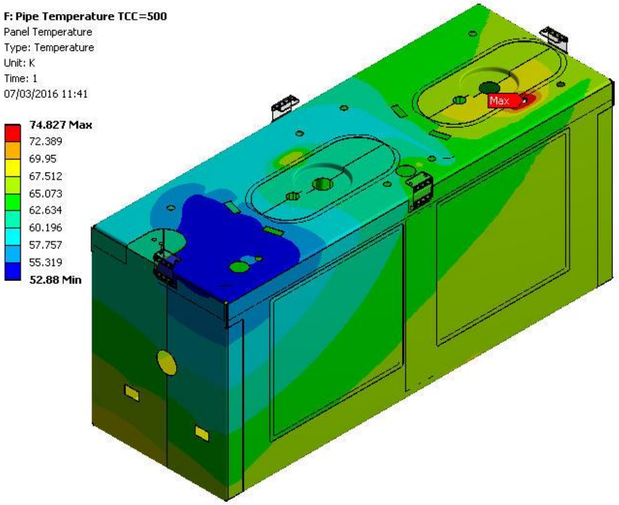


Peak B $\leq 5\ \mu T$ @extremeties

CM Thermal Shields

- After several studies, Cu chosen as baseline
- Connection between cooling pipe and plates under study
- Design & integration finishing





Result Summary		Pipe Temperature		Pipe Convection	
		T_{min} (K)	T_{max} (K)	T_{min} (K)	T_{max} (K)
Al/SS	Panels	64	81	70	87
	Pipe	50	105	50	139
Cu	Panels	53	75	55	84
	Pipe	50	70	50	75

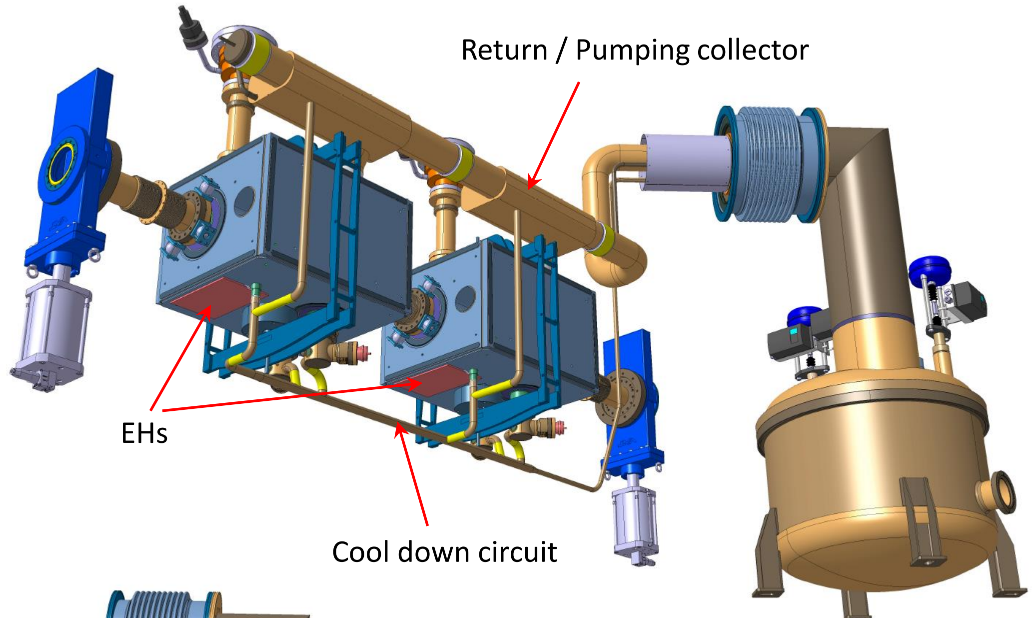
High Luminosity LHC

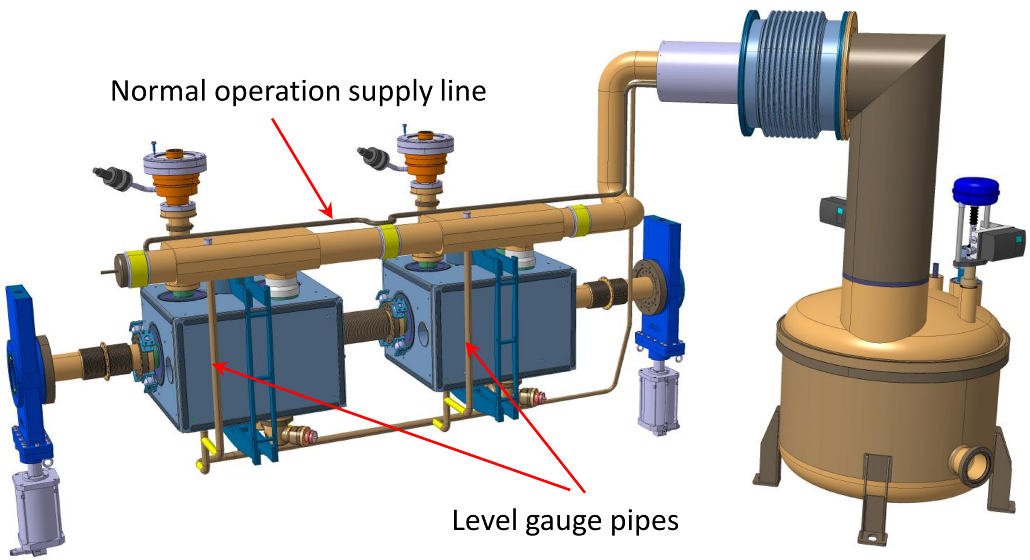
CM Cryo-Circuits

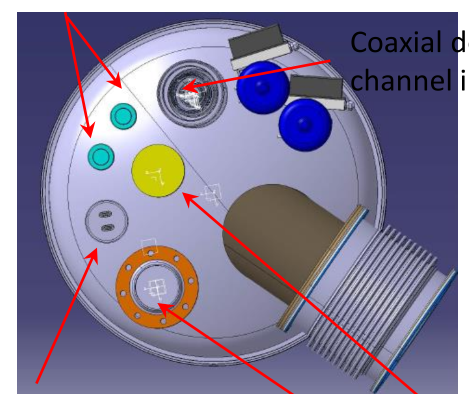
Cool down and 2 K normal operation

DQW static HL: 12.5 W
RFD static HL: 12 W

DQW dynamic HL: 18.1 W
RFD dynamic HL: 15.9 W

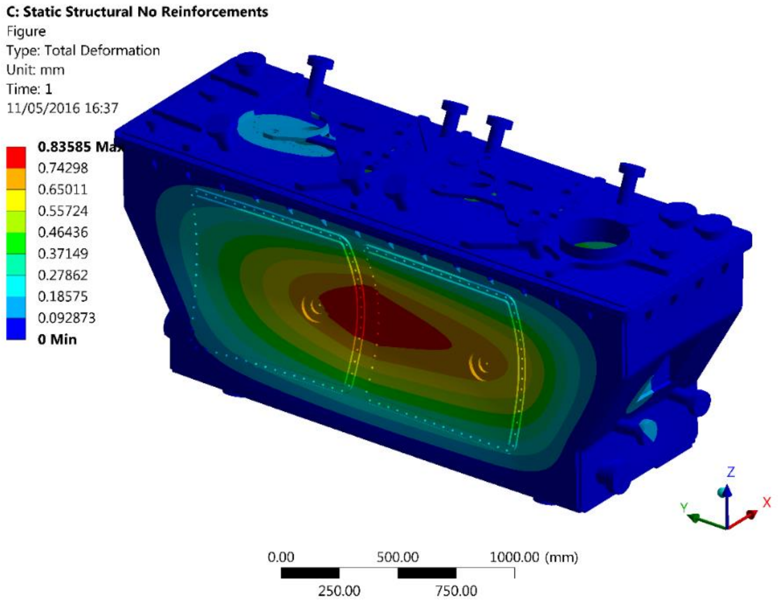


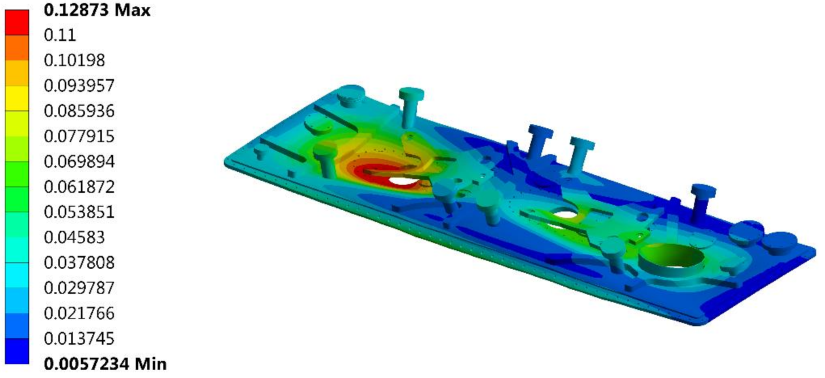




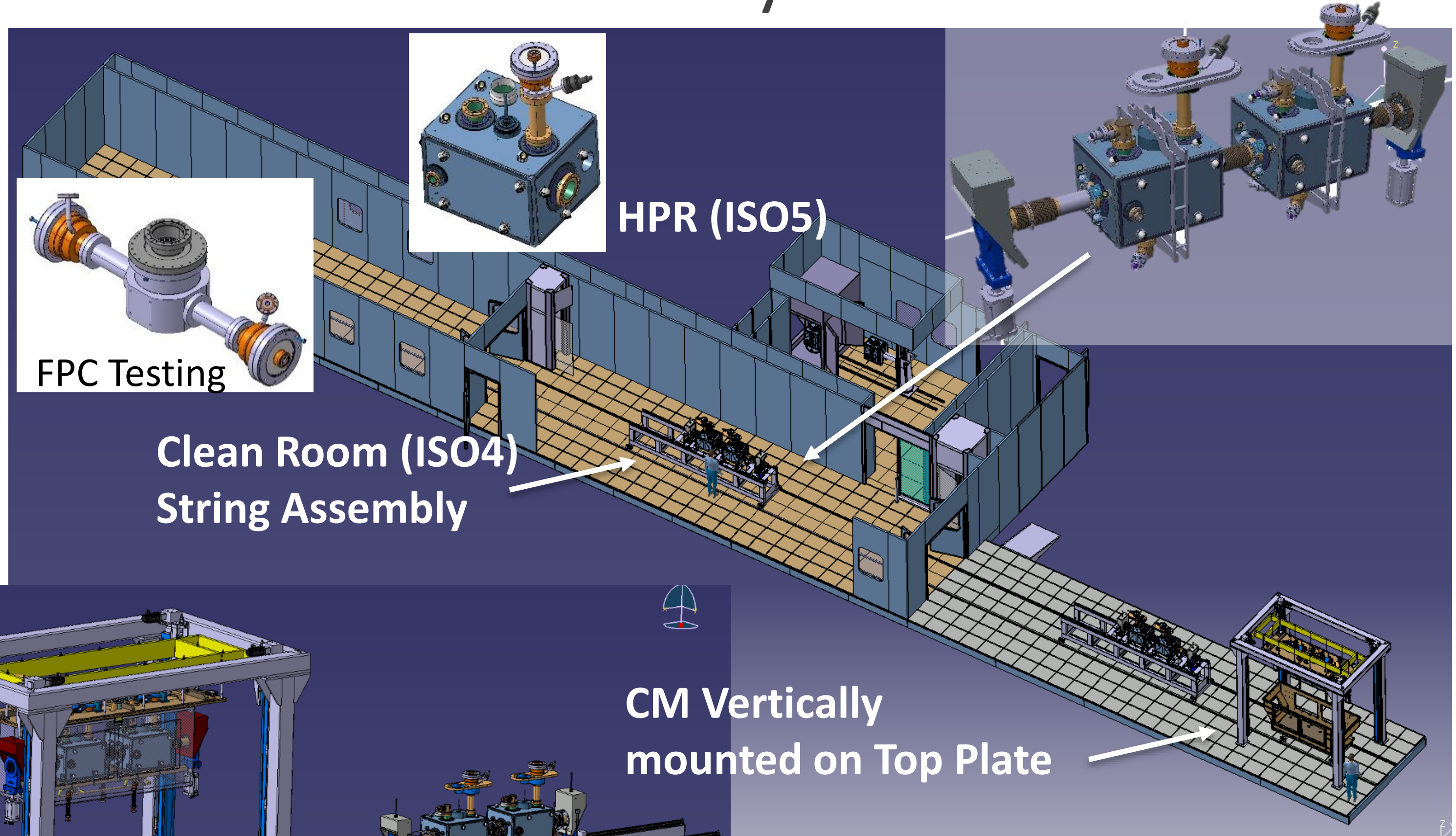
Vacuum Vessel

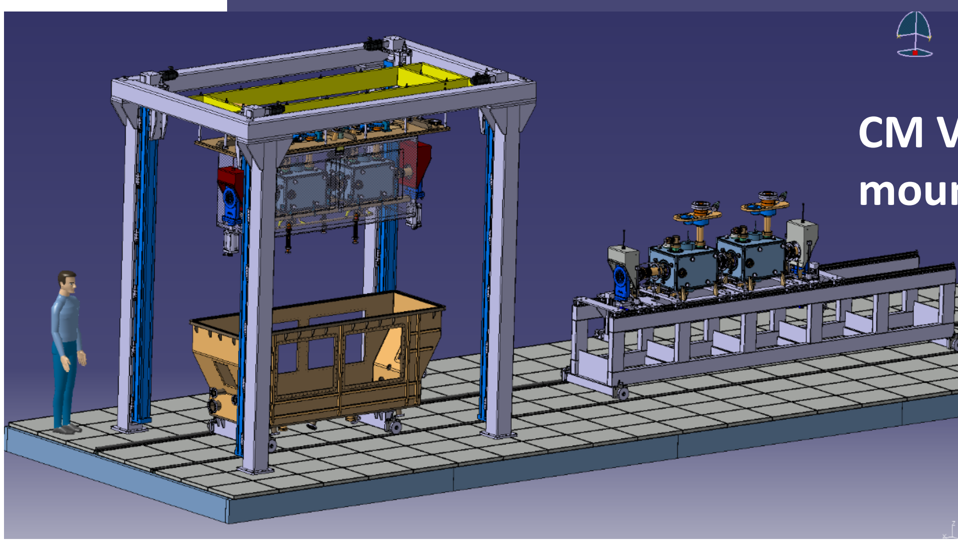
- Trapezoidal design for assembly (adopted from Triumph)
- Stainless steel with Al lateral windows (max access)
- Deformation on top must be limited to mitigate misalignments
- Deformation to be limited for vacuum integrity





SM18 Clean Room & CM Assembly



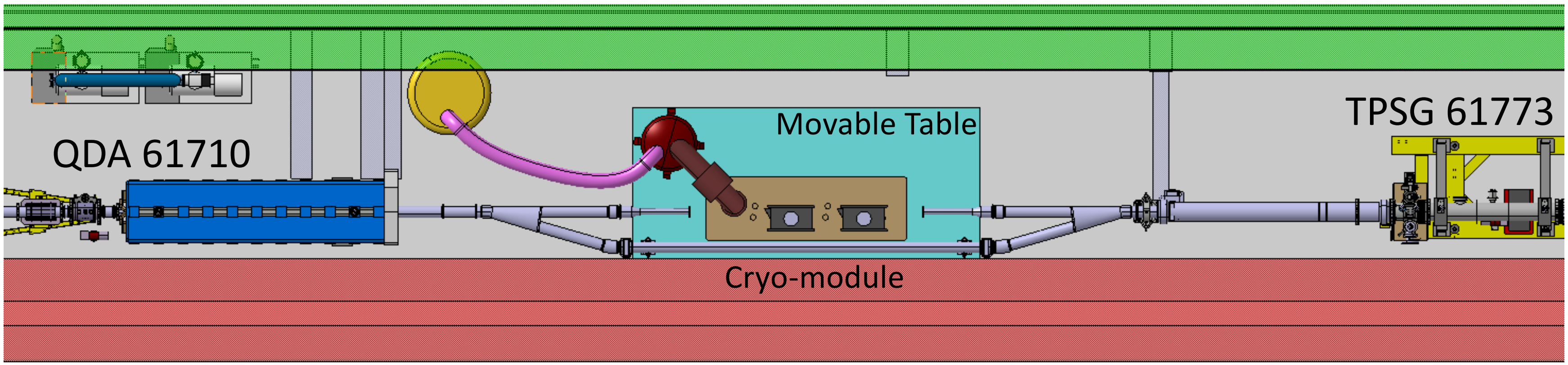


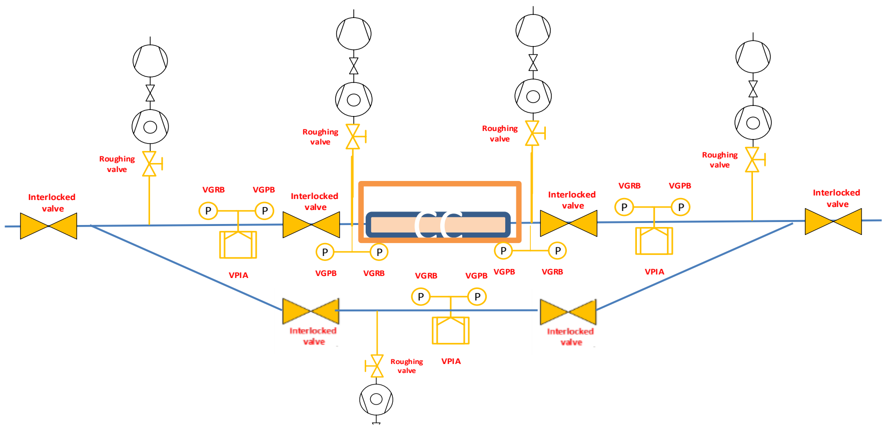
Compatible with other LHC/ISOLDE/SPL/.. Assemblies

Clean room tooling under study

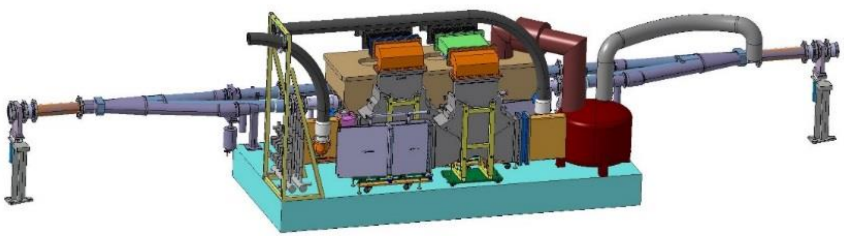
SPS-LSS6 Implantation

11.5m overall space, CM installed in a by-pass & motorized transfer table





Multiple Vacuum sectorization to accommodate bypass & module replacement



RF & Cryo on movable table with liquid Helium