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Vacuum for HL-LHC CC

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International Review of the Crab Cavity system design and production plan for the HL-LHC, 21 June 2019

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TE-VSC scope

Design	Procurement	Assembly at surface	Acceptance tests	Installation in the tunnel
• Integration of vacuum components and instrumentation • Specifications for vacuum components • Cabling request (DIC)	• Vacuum components and instrumentation (e.g. pumping groups, gauges) • Beam screens • PIMs (incl CWT) • Safety valves • PLCs and crates • SCADA • Surface treatment of vacuum components		• Leak tightness test of the assembled module • RGA measurements of the assembled module	• Cabling • Installation of vacuum components and instrumentation/ vacuum sectorization

1. Production of vacuum component drawings is within the WP4 (approval by TE-VSC mandatory)
2. Raw material procured by TE-VSC (quantity to be communicated by WP4)
3. Support for Test in SM18 (TE-VSC and AL4030)

TE-VSC organization and link persons

LHC

Coordination and resources
V. Baglin, G. Riddone, A. Carvalho

Design
C. Garion, J Hansen
J. Perez Espinos
R. Tavares Rego
G. Pigny

Q4/2019

Procurement
J. Hansen
A. Carvalho
L. Ferreira
G. Pigny

Q1/2022

Acceptance tests
G. Bregliozzi

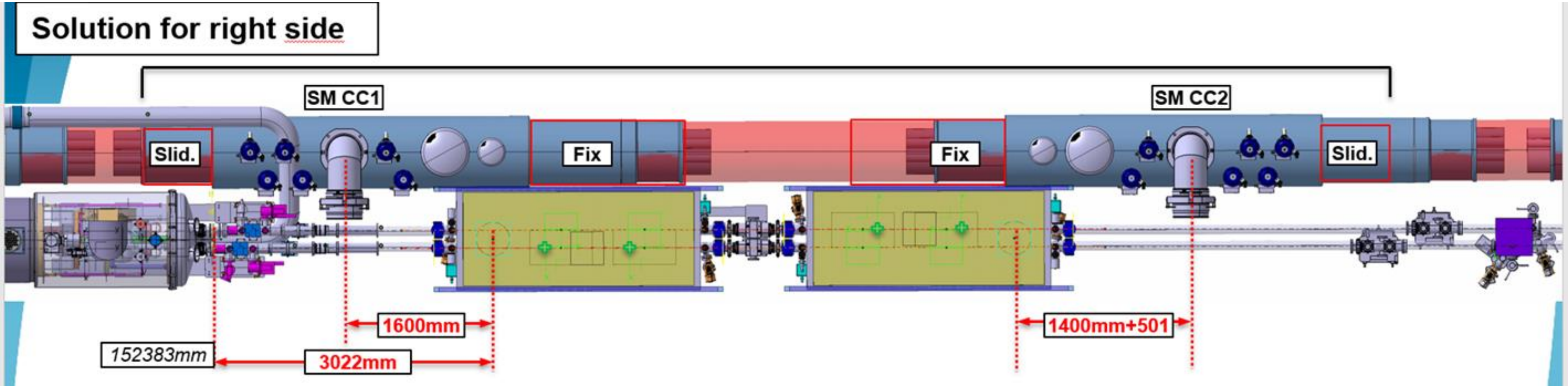
Q1/2025

Installation in the tunnel
G. Bregliozzi
G. Pigny

Q3/2025

Integration layout

- 2 types of crab cavities and, therefore, cryomodules (see also T. Capelli talk):
  - the Double Quarter Wave (DQW) cryomodules (P5);
  - the RF Dipole (RFD) cryomodules (P1).
- The preliminary integration of the vacuum components is based on the RFD cryomodule, since the DQW cryomodule is still in design phase.



RFD cryomodules in IP1R

Vacuum requirements

Vacuum level

- beam vacuum: better than $1\cdot10^{-9}$ mbar @ 2K
- insulation vacuum: better than $1\cdot10^{-6}$ mbar @ 2K

EDMS#2043014

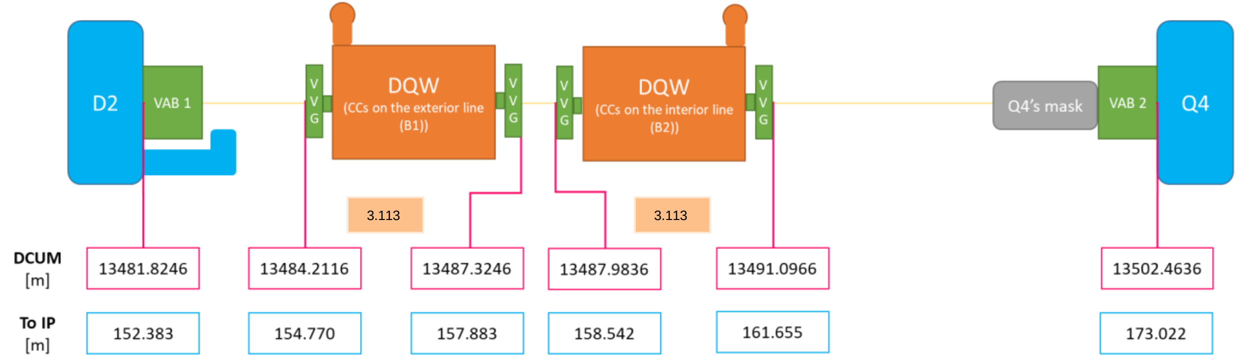
Leak-tightness rate

- for beam vacuum chamber: better than $1\cdot10^{-10}$ mbar·l/s — EDMS#1752123
- for insulation vacuum chamber (He to ins. vacuum @RT): better than 10^{-9} mbar·l/s (single component) — EDMS#353384.

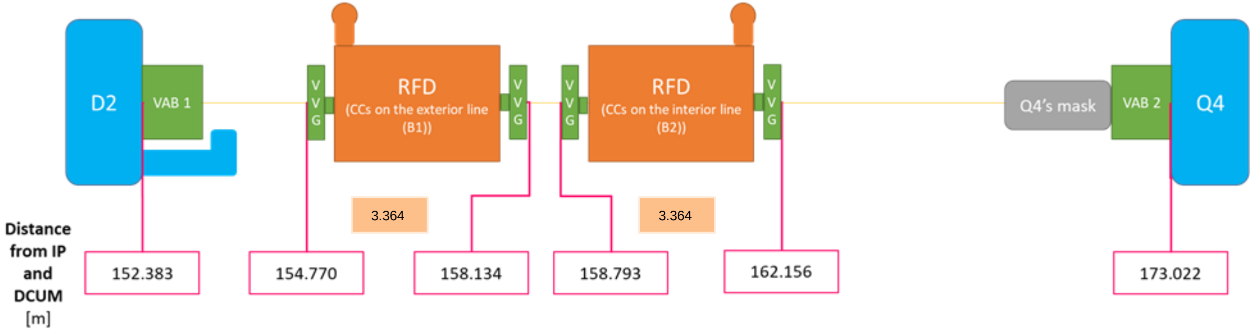
Vacuum input

- Input taken into account to perform the conceptual design of the CC vacuum system:
  - Functional position;
  - Maximum beam aperture along the CC area;
  - Cold bore tolerances and temperature (<2.8 K);
  - Alignment specifications;
  - Vacuum sectorisation and instrumentation.

Vacuum Input - Location and functional position



LSS5R layout between D2 and Q4



LSS1R layout between D2 and Q4

Vacuum Input – max beam aperture and cold bore

Plane	Maximum beam aperture along the non-crabbed cavity line
Horizontal and vertical	55.2 mm*

* Considering all the beam aperture contributions as specified by the WP2

Cold bore

Description	Value [mm]
Operation temperature	2 K
Nominal outer diameter at 300 K	88 mm
Cold bore wall thickness	2 mm
Nominal inner diameter at 300 K	84 mm
Cylindricity (in the inner diameter)	0.5 mm
Material	Titanium grade 2

Vacuum system assumptions

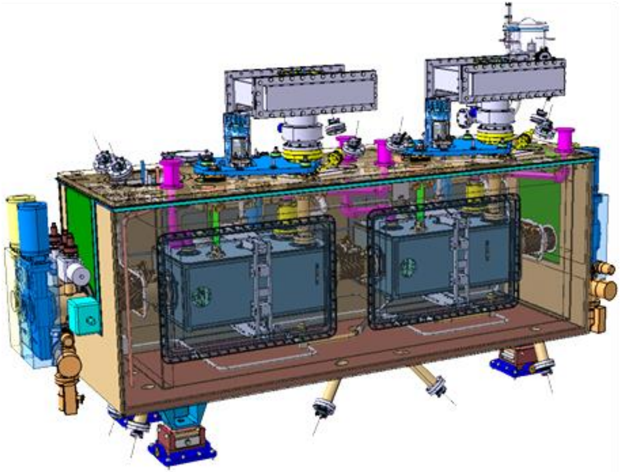
- Assumptions taken into account in order to define the vacuum system:
  - Sectorisation implies two sector valves (VVGs) in each beam line;
  - The four VVGs located in the beam line are supported by the cryomodule;
  - The cryomodule does not shrink during cold down;
  - Beam screens, plug-ins (cavity interconnections and cold-warm transitions (CWT)), vacuum instrumentation and cryomodule interconnection are supported by the cryomodule frame and the cavity modules.

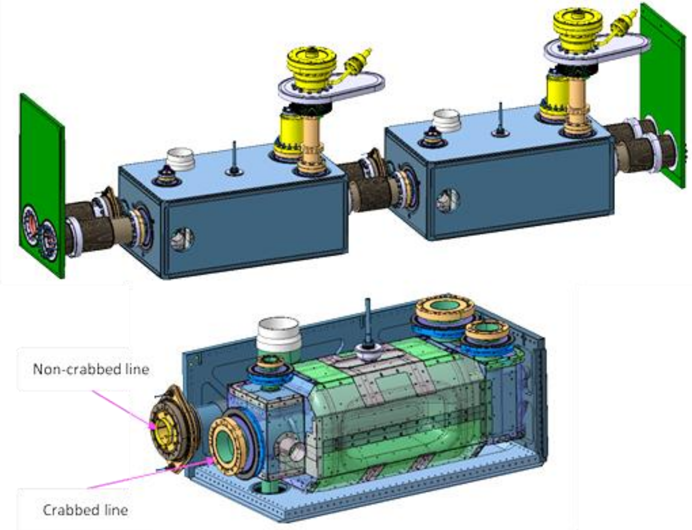
- Vacuum system has been divided according to:
  - Beam vacuum;
  - Interconnections;
  - Insulation vacuum.

Integration of the vacuum components in the cryomodule

Two beam line types can be identified for each crab cavity:

- Crabbed beam line;
- Non-crabbed beam line.





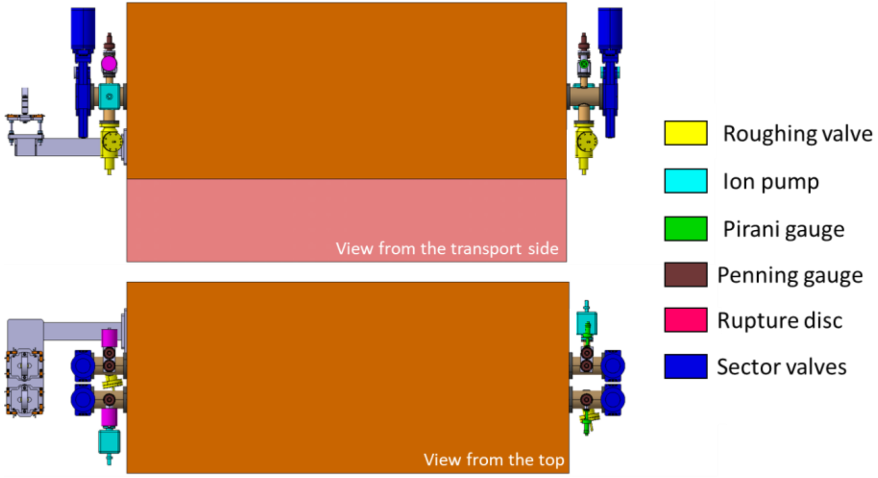
Preliminary **RFD cryomodule** (ST1050008_01)

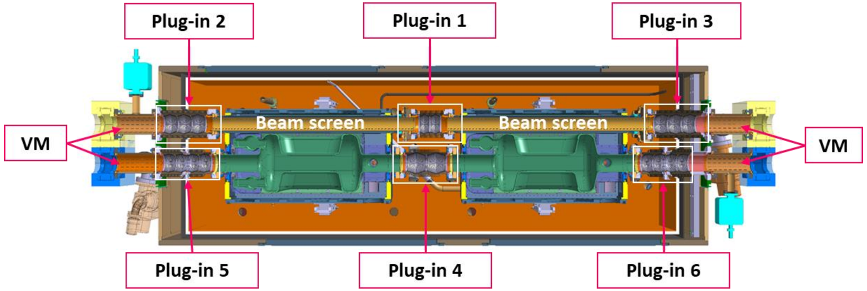
Cryomodule bill of components

			Components	Quantity per cryomodule
Beam vacuum	Cryomodule (Interior)	Crabbed line	Plug-in 1	1
			Plug-in 2	1
			Plug-in 3	1
		Non-crabbed line	Beam screen + cooling tubes + end connections	2
			Plug-in 4	1
			Plug-in 5	1
			Plug-in 6	1
	Cryomodule (Exterior)		Roughing valve	2
			Ion pump	2
			Pirani	2
			Penning	6
			Rupture disc	2
			Sector valves	4
			Extremity vacuum modules (VM)	4
			Vacuum modules supports	4
			Drift chamber support	0.5*

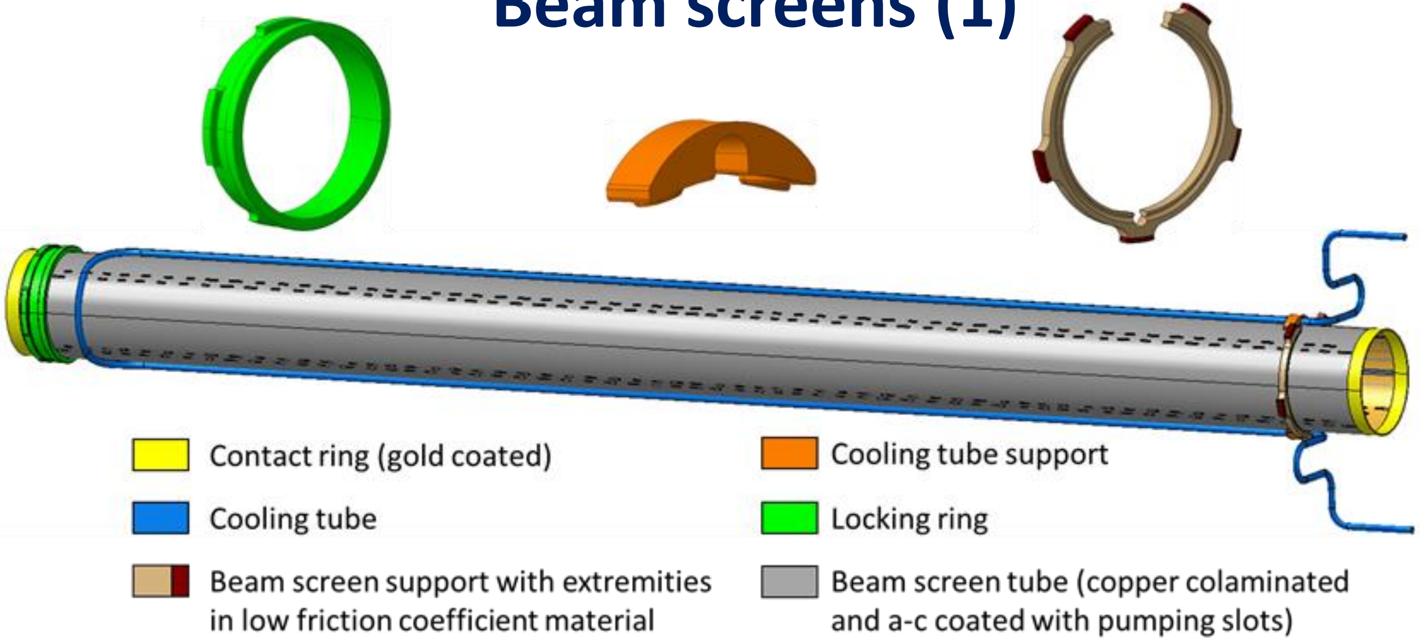
*s1 per 2 cryomodules

We assume the same components for RFD type as for DQW type





Beam screens (1)



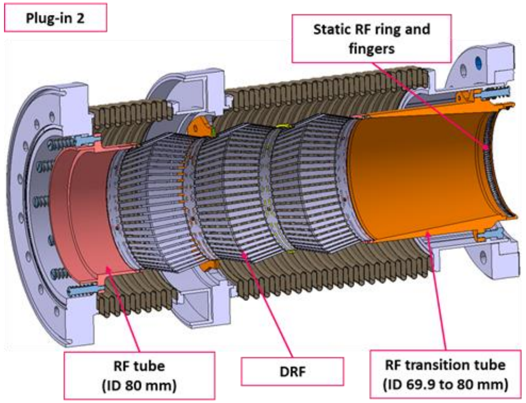
Beam screen tube: made of stainless steel with a colaminated copper layer that is a-C coated (to minimise the gas load on the adjacent cavities);
Extremity contact rings: gold coated;
Cooling pipes: maintain the beam screen temperature (5 to 20 K);
Beam screen support and locking ring: to ensures an easy beam screen insertion inside the cold bore and alignment.

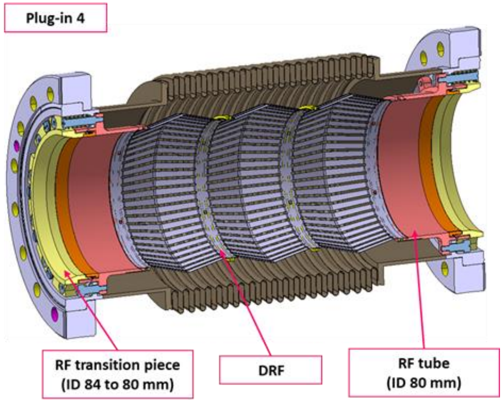
Beam screens (2)

Component	Description	Value	Value in
Beam screen tube	Transparency	2%	
	Slot dimension	With ≈1.5mm, ≈6-10 mm length	
	Coating	a-C coating	
	Temperature	5 to 20K	
	Shape	Circular	
	Material	Stainless steel P506	
	Wall thickness	1 mm	
	Cooper layer thickness	0.075 mm	
	Wall thickness tolerance	0.05 mm	radius
	Cylindricity	0.5 mm	diameter
Cooling pipes	Material	Stainless steel P506	
	External diameter	4.76 mm	
	Inner diameter	3.7 mm	
	External diameter tolerance	0.05 mm	diameter
	Welding tolerance	0.1 mm	diameter
Beam screen support	Thickness	9.85 mm ($\emptyset_i = 72.1\ mm\ and\ \emptyset_o = 91.8\ mm$)	
	Shape of the external surface	0.1 mm	diameter
	Shape of the internal surface	0.2 mm	radius
	Minimum annular gap with bimetallic transition	0.05 mm	radius

CLEARANCE: 1.3 mm (radius) --> considering the beam screen and the bimetallic transition tolerances, the beam aperture given by WP2 and the positioning tolerances

Plug-in modules





6 types of Plug-in modules
No aC-coating on CWT
To be noticed:

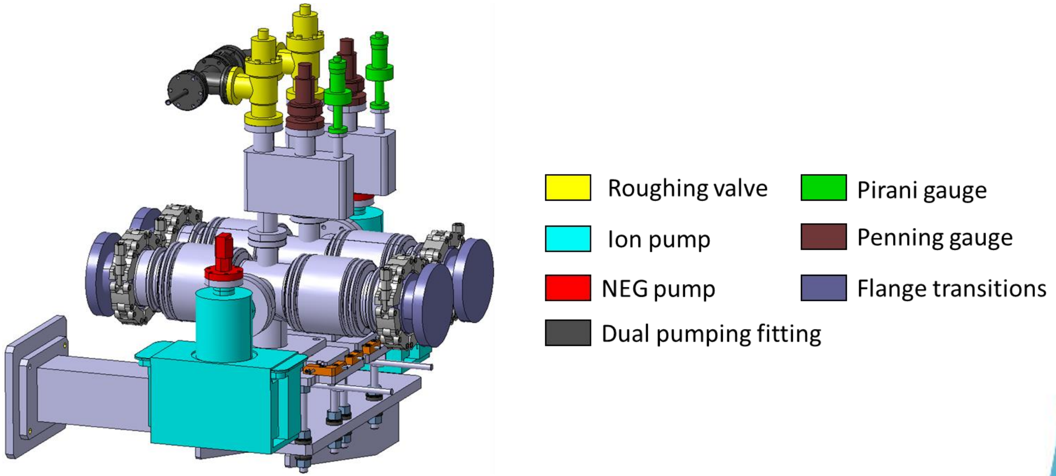
- Deformable RF (DRF) bridges to cope with impedance
- DRF bridges more robust than standard bridges ==> baseline for new Inner Triplet interconnect

Plug-in	Installed length at warm [mm]	ID [mm]	Material		
			Bellow	RF tubes/transitions	DRF
Plug-in 1	187	69.9	Stainless steel (0.15 mm of thickness)	Oxygen free copper (OFE Cu)	Copper beryllium with rhodium coating
Plug-in 2 (CWT)	318	80 – 69.9			
Plug-in 3 (CWT)	282	69.9 - 80			
Plug-in 4	264	84 – 80 – 84			
Plug-in 5 (CWT)	374	80 - 84			
Plug-in 6 (CWT)	302	84 - 80			

EDMS#2012795

Cryomodule Interconnection

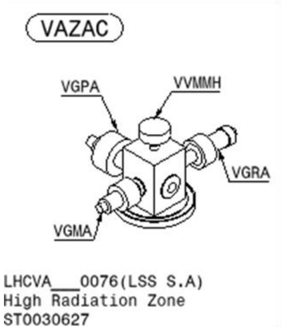
		Components	Quantity per interconnection
Beam vacuum	Interconnection (2 beam lines)	Roughing valve	2
		Ion pump	2
		NEG pump	2
		Dual pumping fitting	1
		Pirani	2
		Penning	2
		Flange transitions + clamps	4
		Gauge fittings	2
		Support for the interconnection modules	1
		Double bellow vacuum module	2



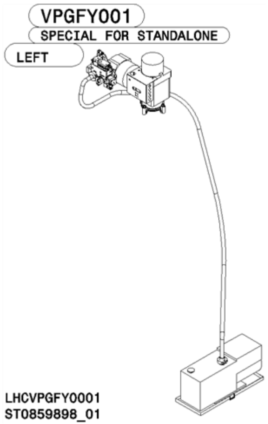
Insulation vacuum

	Components	Total quantity per cryomodule
Insulation vacuum	Pumping fixed groups	1
	Roughing valves	1
	Gauges	1
	Flap valve	1
	Spring relief valve	1

Gauges + Valve



Pumping group



Flap valve DN160

Integration of these components still to be done by WP4

Sizing of the flap valve has to be confirmed (WP4-WP9)

Procurement of the *vacuum components*

Cryomodule	Assembly in	Components needed by	Critical components	Comments
DQW #1	CERN	Sept 2020	Plug-in modules Beam screens	
DQW 2 to 5	UK	June 2021		In kind contribution Sector valves* Possible in-kind contributions Extremity chambers Penning-Pirani gauges* Roughing angle valves Rupture discs Ion pumps*
RFD #1	Canada	Beam screen: June 2020 Others: Sept 2020	Plug-in modules Beam screens	
RFD 2 to 5	Canada	Beam screen: Sept 2021 Others: March 2022		
SPS Test - RFD	UK	Beam screen: April 2020 Others: June 2020	Plug-in modules Beam screens	- Is the beam screen needed on the non-crabbed line? - 3 plug-in modules only?

*these components have to follow TE-VSC standards, in particular for controls and electronics, due to the fact that TE-VSC will ensure maintenance and operation

Timeline for critical items: Plug-in modules

- Two main components: bellows and RF bridges

Raw material (custom made bellows according to CERN material specification - P525 and 3D-forged AISI316 LN)

9 months (incl. supplier qualification)

Production of bellows

3 months

Assembly and acceptance test

2 months

Production of RF bridges*

12 months

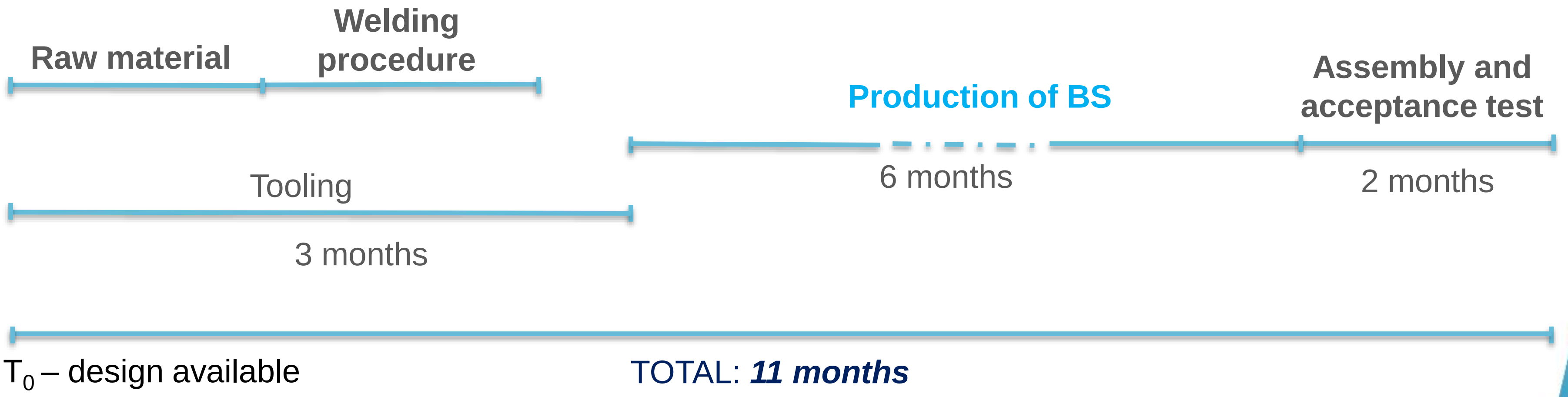
T_0 – design available

TOTAL: *14 months*

**based on Inner Triplet experience*

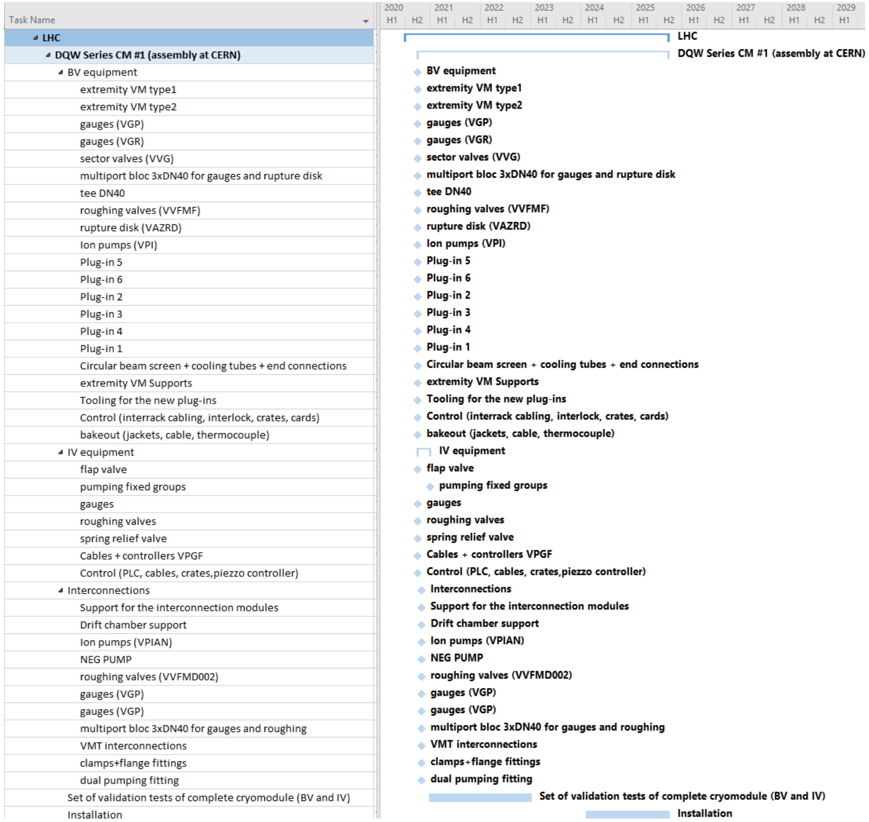
Timeline for critical items: Beam screen

- Beam screens include cooling tubes and extremity components



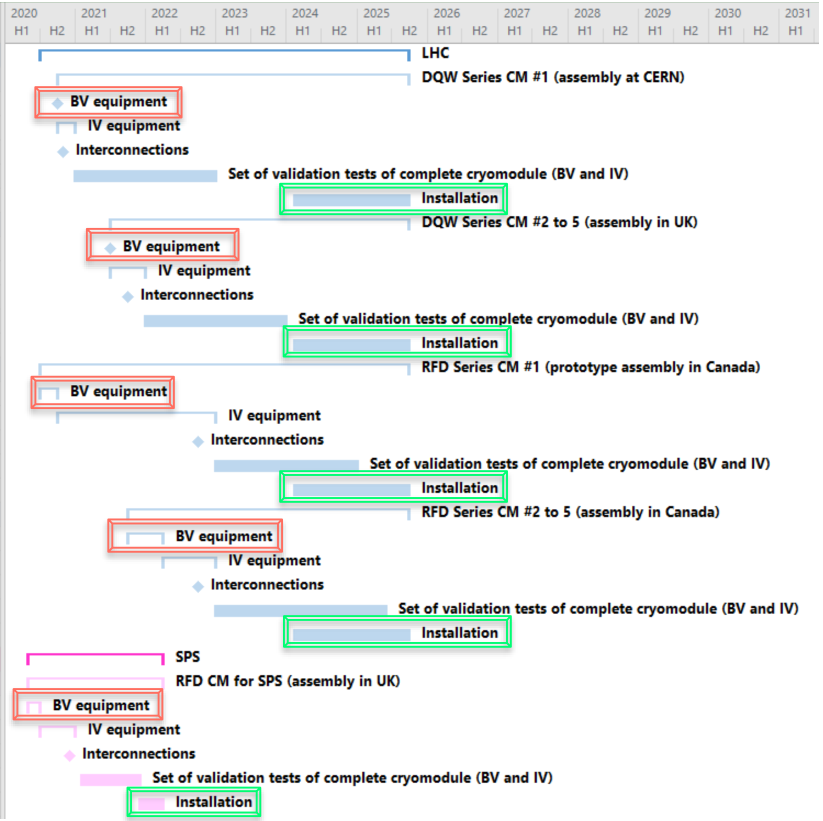
Planning (1)

- EDMS#2155574: 5 categories
  - Beam vacuum components (dates from WP4)
  - Insulation vacuum components (dates from WP4)
  - Interconnections (assumption of 3 months before validation tests)
  - Validation tests: BV and IV (dates from WP4)
  - Installation (dates based on WP4 master schedule)



Planning (2)

Task Name
LHC
DQW Series CM #1 (assembly at CERN)
BV equipment
IV equipment
Interconnections
Set of validation tests of complete cryomodule (BV and IV)
Installation
DQW Series CM #2 to 5 (assembly in UK)
BV equipment
IV equipment
Interconnections
Set of validation tests of complete cryomodule (BV and IV)
Installation
RFD Series CM #1 (prototype assembly in Canada)
BV equipment
IV equipment
Interconnections
Set of validation tests of complete cryomodule (BV and IV)
Installation
RFD Series CM #2 to 5 (assembly in Canada)
BV equipment
IV equipment
Interconnections
Set of validation tests of complete cryomodule (BV and IV)
Installation
SPS
RFD CM for SPS (assembly in UK)
BV equipment
IV equipment
Interconnections
Set of validation tests of complete cryomodule (BV and IV)
Installation



Conclusions

- Design & Integration are not completed yet
- Procurement of plug-in modules and beam screen on the critical path: 14 and 11 months respectively for the production from the availability of the drawings: “*needed by” date* for SPS, for DQW#1 and RFD#1, it seems tight
- TE-VSC resources have been recently re-estimated. They are within the allocated budget

Documentation

- TE-VSC contribution to the HL-LHC WP4: EDMS#1754567
- Conceptual design of the Crab Cavities vacuum system – EDMS#1864637
- TE-VSC mandate for insulation vacuum of RF equipment in the SPS tunnel – EDMS#1953501
- TE-VSC mandate for insulation vacuum of RF equipment in the LHC tunnel - EDMS#2143391
- Planning: vacuum equipment for WP4 – EDMS#2155574
- Criteria for vacuum acceptance tests - EDMS#1752123
- Codification of surface cleanliness levels – EDMS#347564

Thanks for your attention

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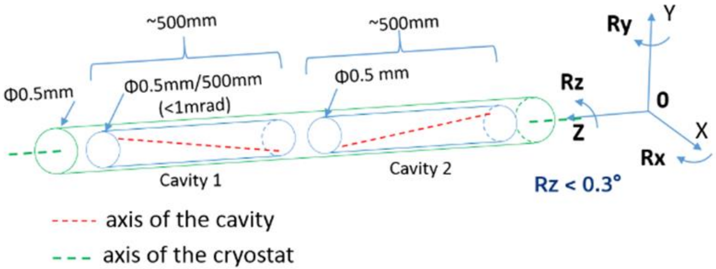
HL-LHC PROJECT

Extra slides

Vacuum input - Alignment specifications

The CCs beam line will be equipped with the Frequency Scanning Interferometry (FSI) alignment system.
The non-crabbed beam line is rigidly attached to the CCs, thus, it will follow the CCs displacements.
The adjustment of the cavities is performed at room temperature.
The position at warm will be known quite accurately (± 0.1 mm at 1σ).
The contributions taken into account in the alignment tolerance budget are:

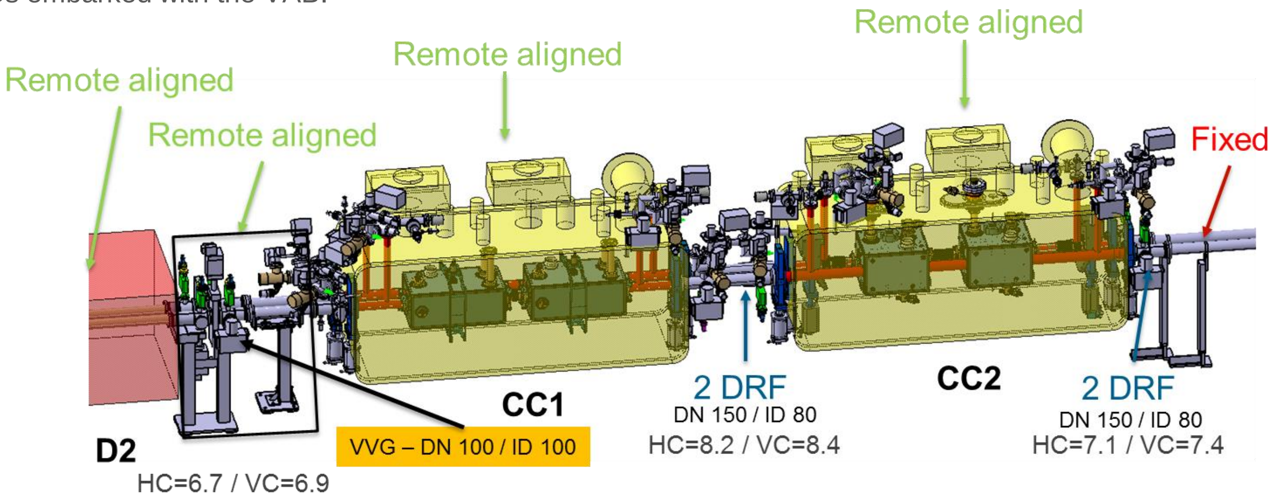
- Fiducialisation of the axis of the cavity with respect to the magnetic centre = 0.5 mm (in diameter);
- The cold bore position with respect to the cavity magnetic centre = 1.75 mm (in radius);
- Internal monitoring of the position of the mechanical axis of the flanges of the dressed cavities:
  - Rx: < 0.057° → Ø0.5 mm/500 mm (neglected);
  - Rz: < 0.3° → ≈Ø1 mm (in radius).



Note that the ground motion is not taken into account since the cavities are remotely aligned.

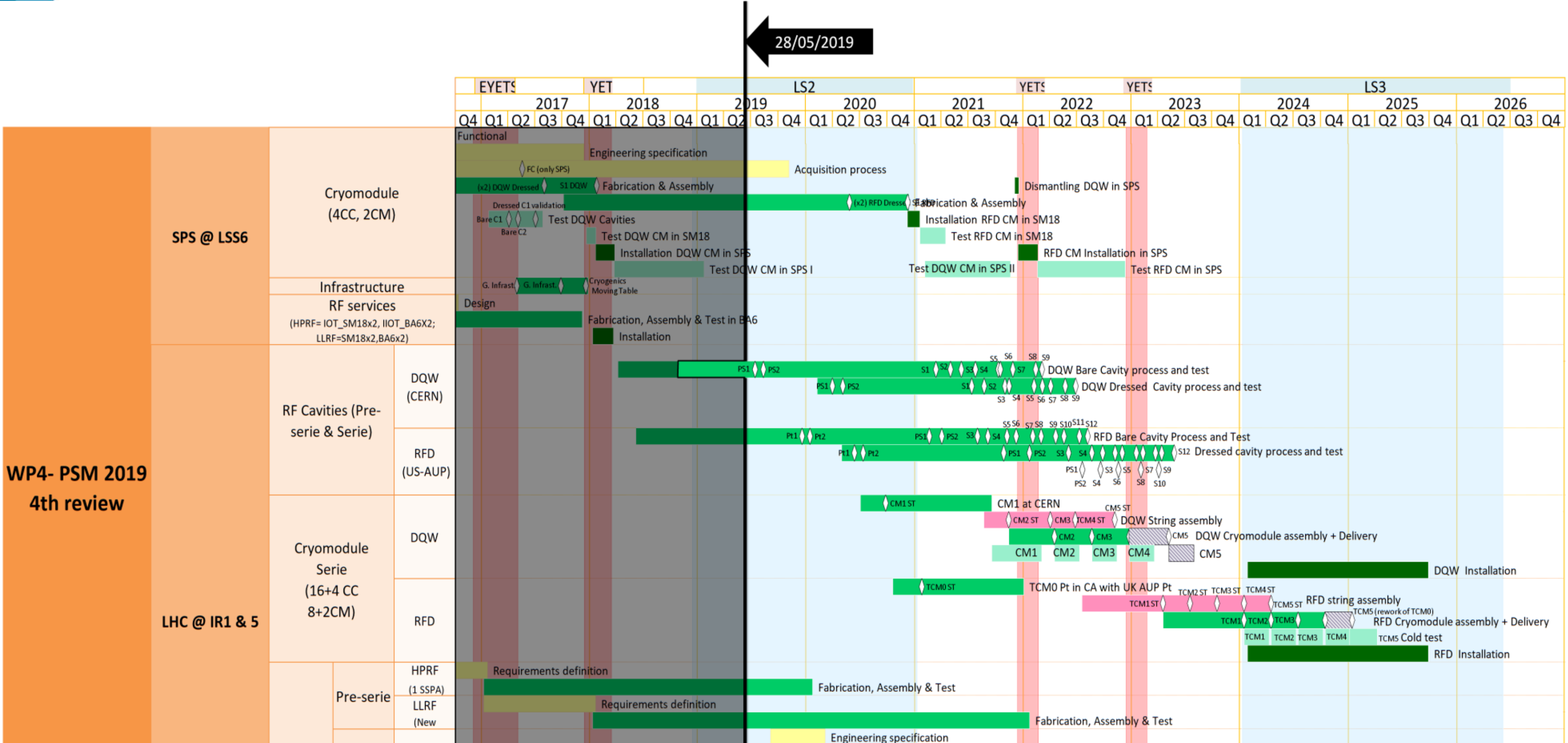
Remotely aligned D2 VABs

- D2 VAB with the new VSC interface platform and with the SU remote alignment platform (type 2).
- Vacuum chambers (VCs), between D2 and the CCs, must be remote aligned (in study).
  - VCs embarked with the VAB.



- Total
  - **2 VVGs already in the WP12 baseline.**
  - **1 Survey platform for type 2 support to be added to WP12 baseline.**
  - **8 VVGs + 4 DRF + 2 new vacuum chambers + 2 flange transition pieces already included in the WP4 baseline.**
  - **Motors + sensors kit by WP15.4.**

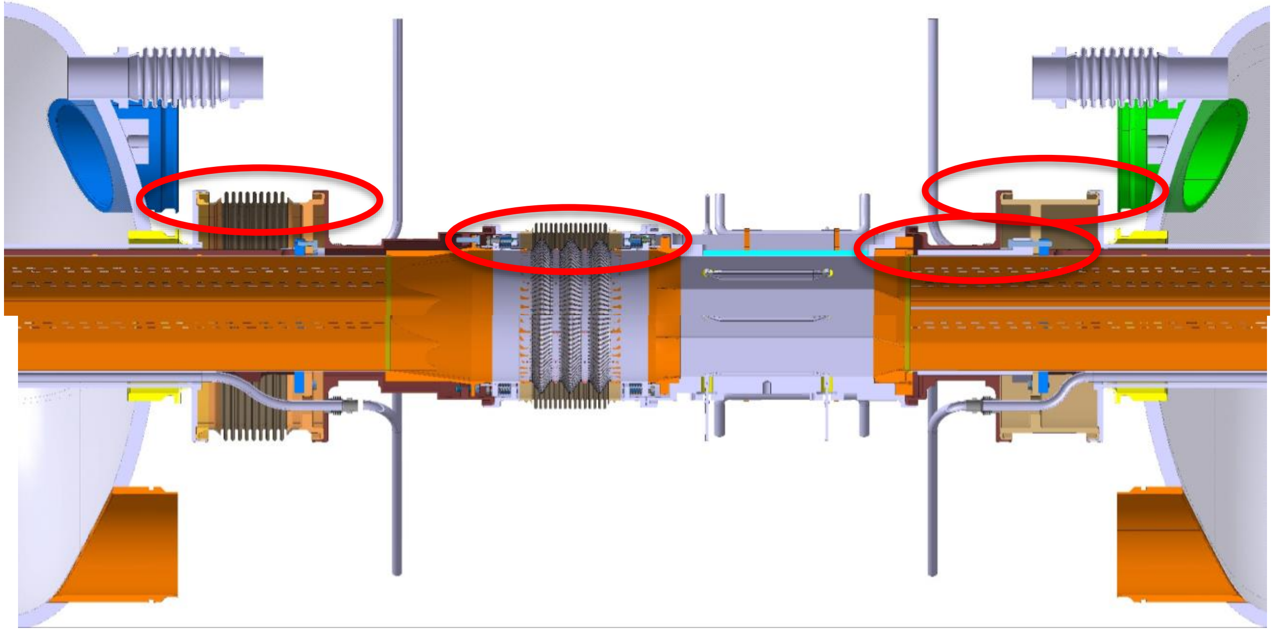
Master schedule WP4



Beam screen extremities and interconnections

Layout

0/90° cut



+/-45° cut

- More compact components (transversally)
- Longer absorber at the beam screen extremities
- Update of the interconnection module design

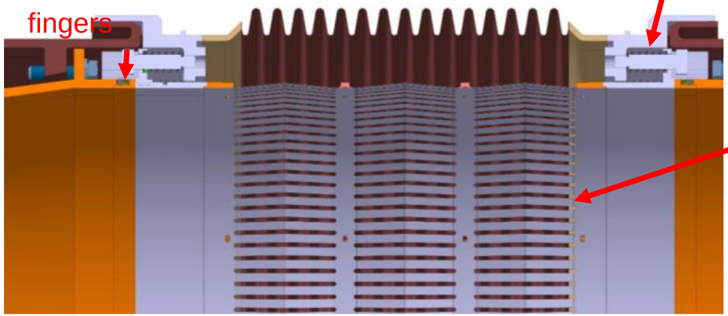
*BPM model provided by WP 13

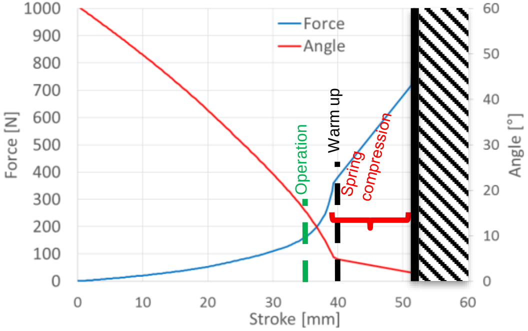
Beam screen extremities and interconnections

Interconnection module

Copper Beryllium deformable RF bridge:
- Circular aperture
- C17410
- 0.1 mm thick, 3 mm width, gap: 1.4 mm
- 3 convolutions

20 titanium G5 springs
(total prestress: ~360 N)

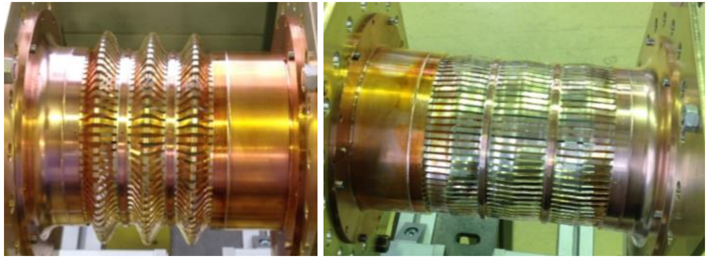




Expected behaviour and working conditions of the RF bridge

Longitudinal constraint, due to the finger extension limitation, is reduced thanks to the static RF fingers and the springs.

Full interconnection module prototype under manufacturing. Mechanical and RF tests will be done, in particular the RF performance with transversal offset will be assessed (early 2018).



as installed

in operation

Deformable RF fingers