



Tolerances, alignment strategies & tooling for LHC IP1 and IP5 vacuum system

J. Hansen on behalf of WP12



HL-LHC CERN 18th of October

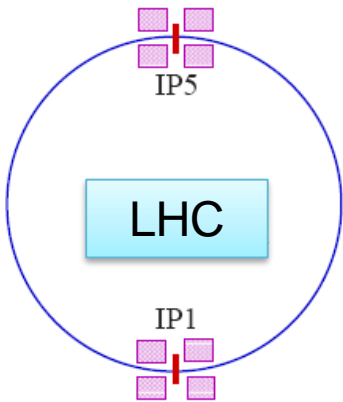
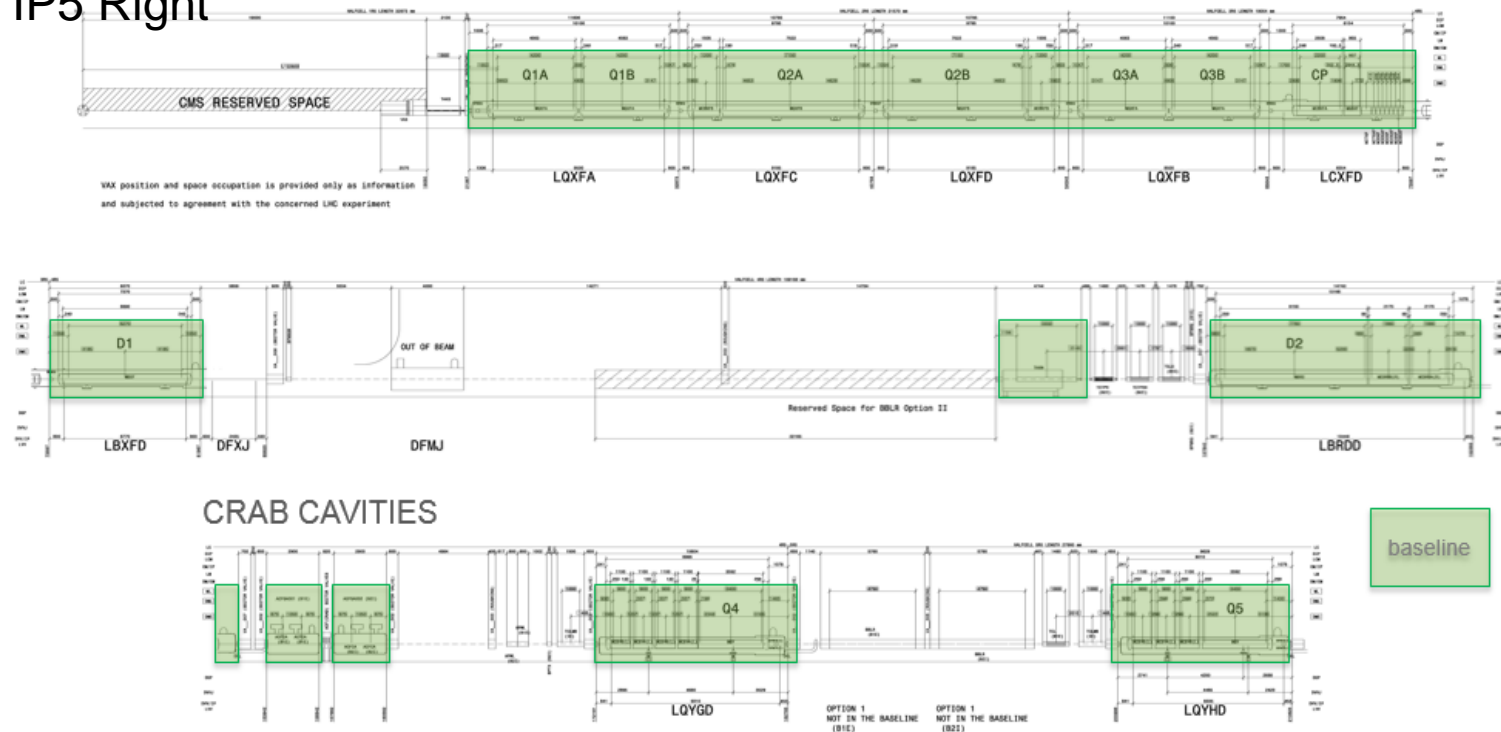
Outline

1. Introduction
2. Vacuum components to be aligned
3. Alignment methods
4. Tolerances for vacuum components
5. Standard and Deformable RF (DRF) bellows
6. Summary
7. Next steps

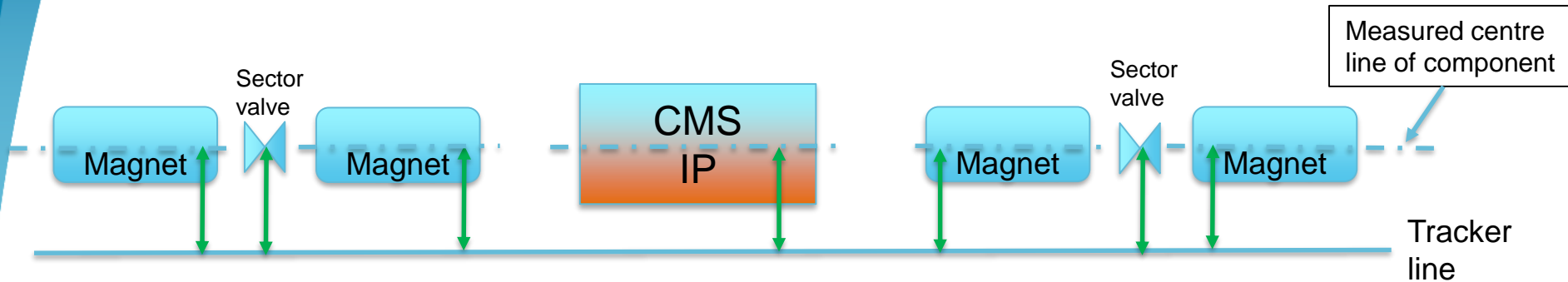
Base line for alignment of IP1 and IP5

- For LS3 all magnets, TAXN, and the CRAB cavities in IP1 and IP5 from Q1 to Q5 will be installed with remote alignment controlled from the CCC.
- Remote alignment will assure the beam is passing through the optimum position in the CMS and ATLAS detector.
- It is still to be decided by HL-LHC if other equipment (VABs, BPMs, collimators) will be manual aligned or remote aligned from CCC or in the tunnel.

IP5 Right

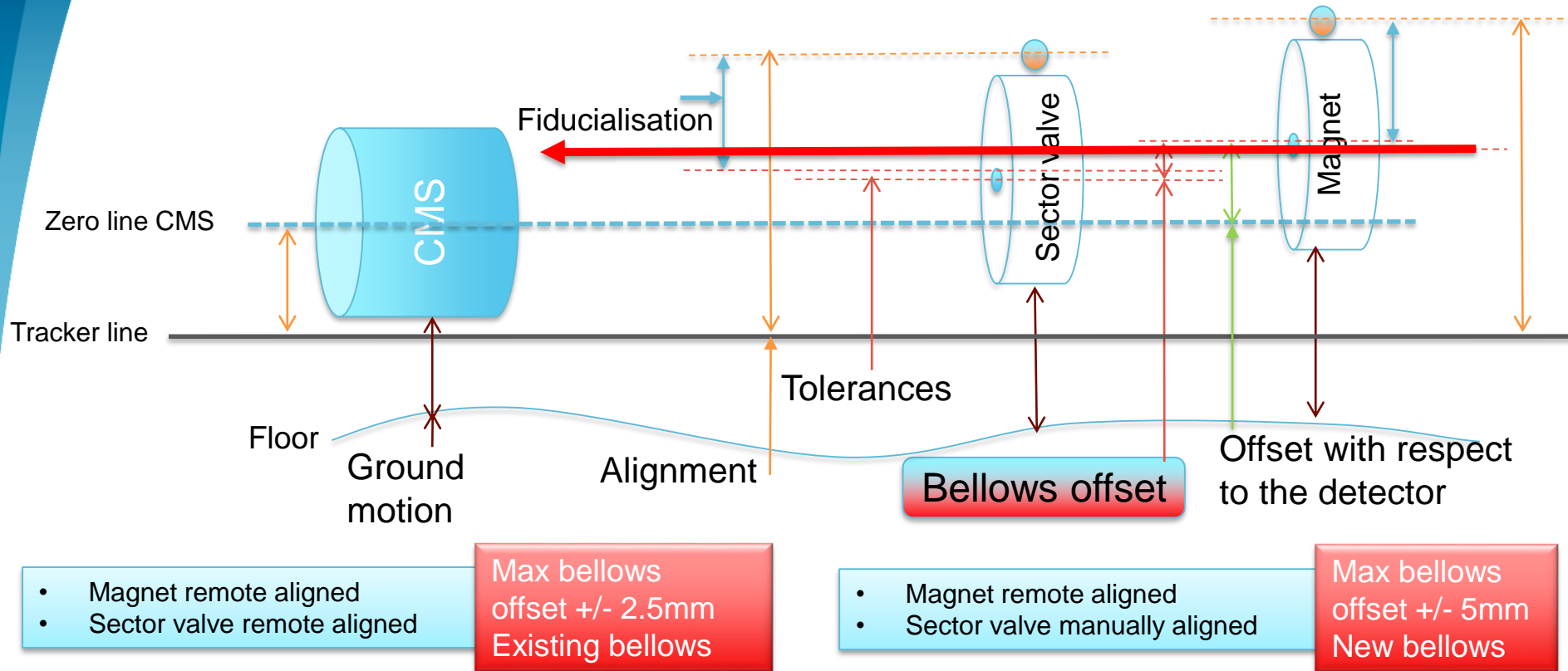


Alignment sequence of all remote aligned components.



- 1. Survey aligns the machine from Q7 to Q7 with a line that passes through the best guess of the inner tracker center
- 2. The vacuum system is connected and the magnets cooled to operation temperature.
- 3. The best orbit is established to allow first collisions during beam commissioning.
- 4. First collisions shows the displacement of the IP with respect to the inner tracker center.
- 5. Orbit is adjusted by remote alignment from Q1 to Q5 and with orbit correctors from Q6 to Q7 with immediate feedback of the beam. (Manual aligned component shall have a free aperture of $\pm 2.5\text{mm}$)
- 6. During the following YETS the machine can be fully realigned to the new reference.

Bellows offset in IP1 and IP5 between D1 and Q6



Maximum expected offset in the bellows after first alignment:

- Alignment tolerance.
- Fiducialisation.
- Tolerance between fiducialisation point and bellows connection.

Approx.: +/-2.5mm

This value is mainly link to mechanical tolerances, not SU alignment accuracy

Bellows offset for the remote alignment: +/- 2.5 mm in horizontal and vertical:

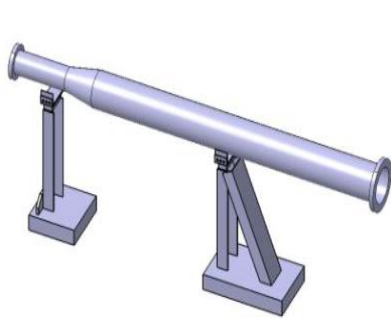
- +/- 2mm for magnet alignment corrections with respect to the detector.
- +/-0,3mm for ground motion (Normally the ground motion for 2 items in series are < 0.1mm)
- +/-0.2mm margin.

Vacuum components to be aligned

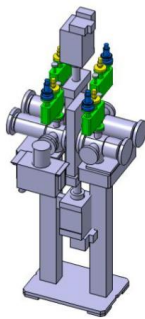
Components to be aligned by Survey

Manually aligned:

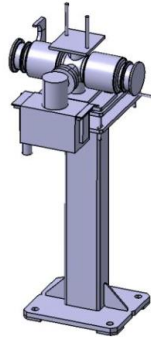
(support only or with vacuum component)



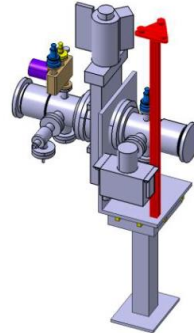
Transition Vacuum Chambers with supports



Double vacuum assembly

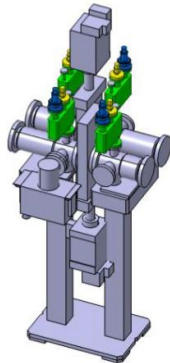


Double vacuum module



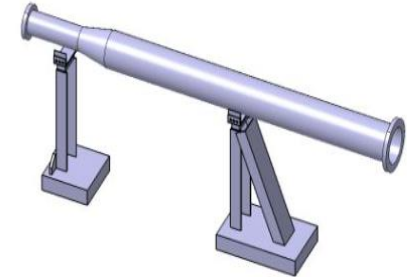
Single vacuum assembly

Remote aligned:

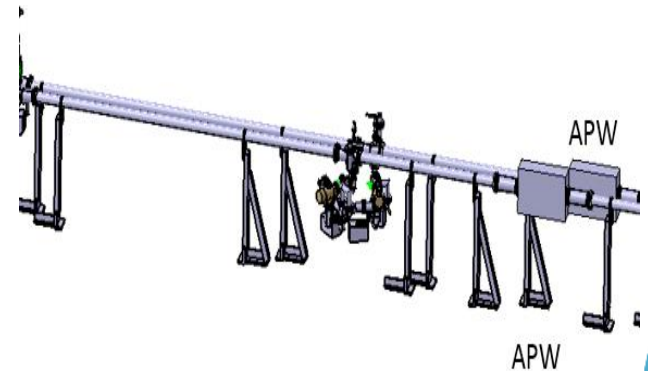


Double vacuum assembly

Components aligned by TE/VSC

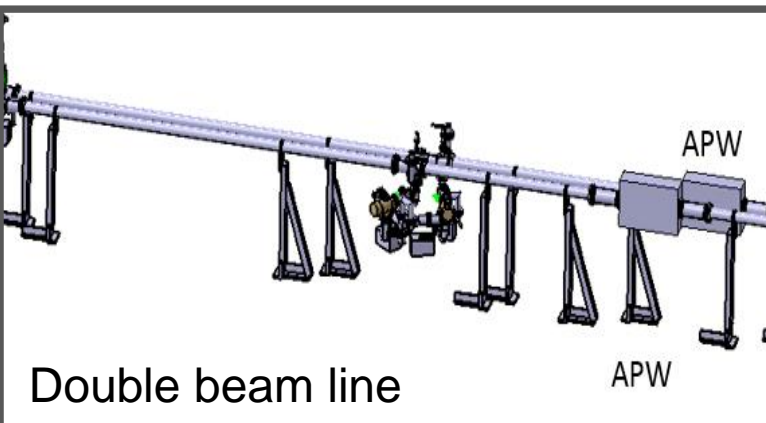
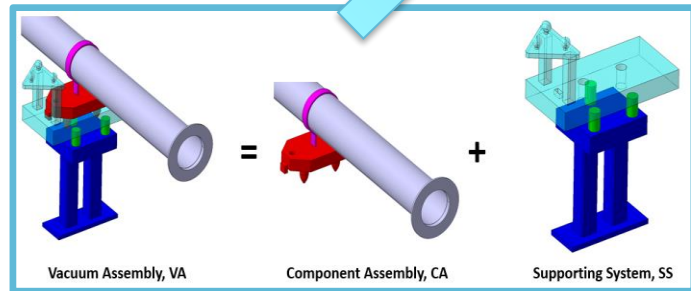
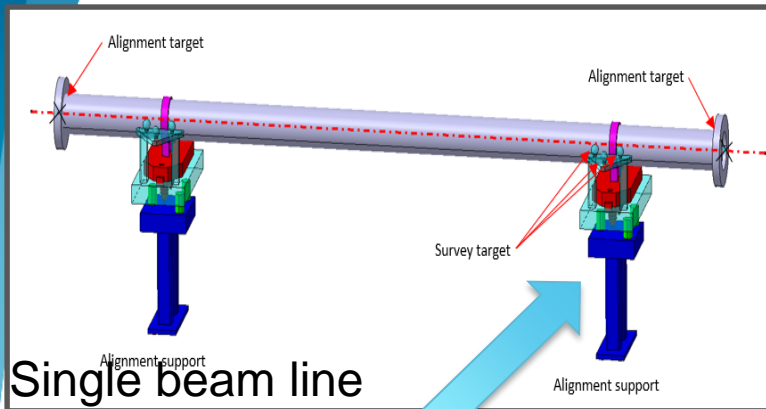


Transition Vacuum Chambers with supports



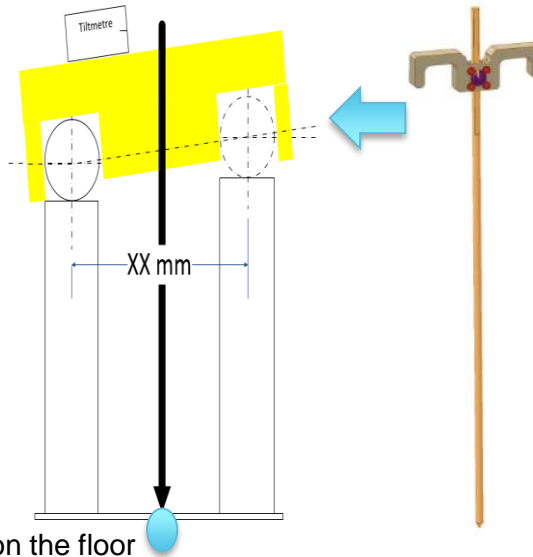
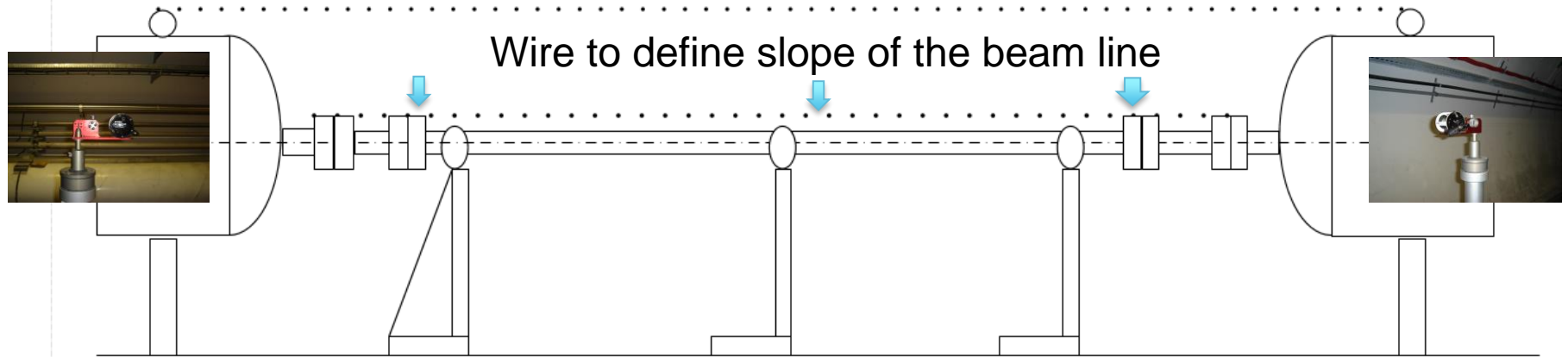
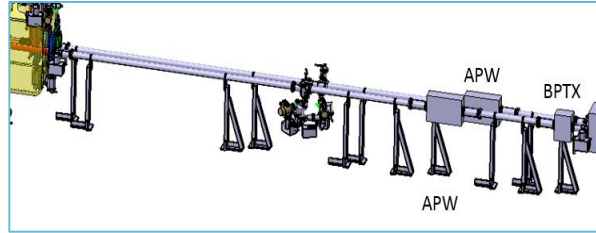
Vacuum Chambers with supports

Pre-aligned vacuum chamber supports



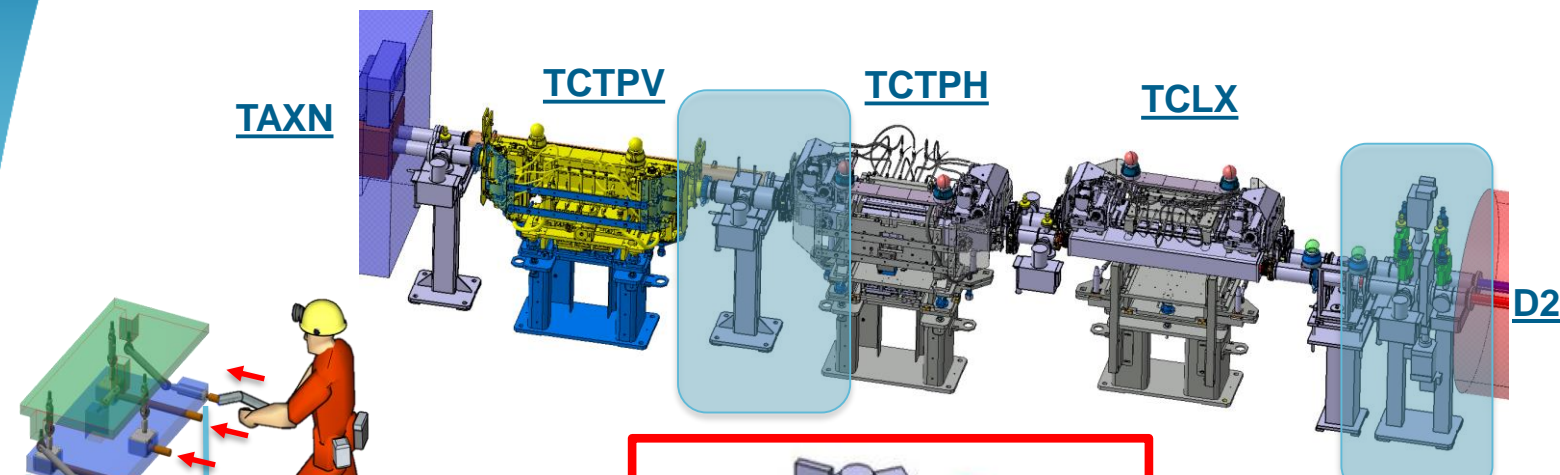
- **Proposal:**
 - Alignment of supports before the installation of vacuum chambers to minimize intervention time in a radioactive zone (ALARA principal)
- **Each installation has to be evaluated:**
 - How often do we dismantle the system?
 - Do we reinstall the same items if dismantled?
 - Do we have enough aperture for ground motion?
 - Extra technical complications.
 - What is the time gained compared to time spent on bakeout, pumping and leak detection?
 - What radiation dose do we gain if pre-aligned?
- **First analyses show:**
 - Combination chambers supports with little beam clearance shall be aligned by SU.
 - Small or no gain to pre-align vacuum supports for standard chambers.

Vacuum chamber alignment by TE/VSC (Installation LHC)



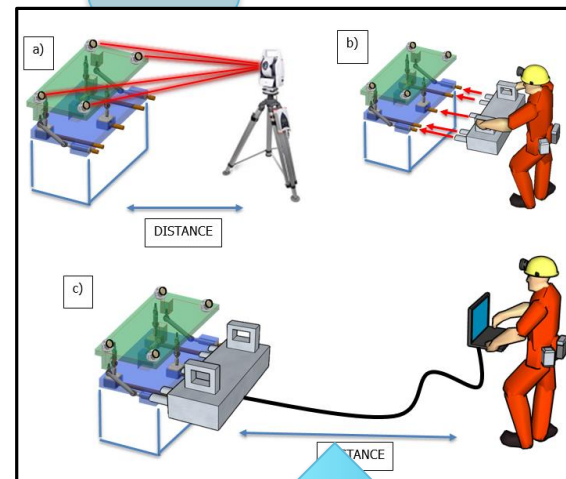
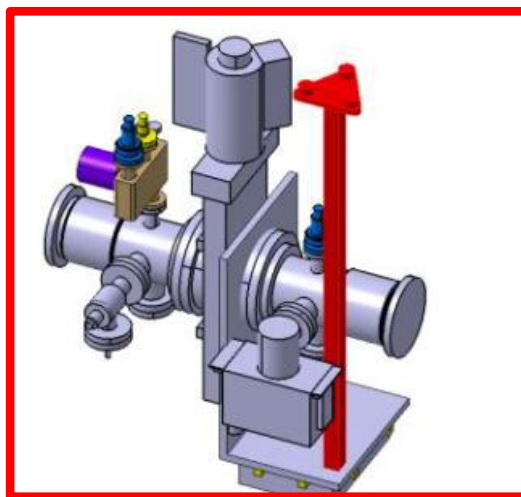
1. Define slope with points aligned by SU.
2. Define tilt and distance beam axis's and beam position with a tilt metre and beam tube tooling.

Alignment of vacuum module and supports



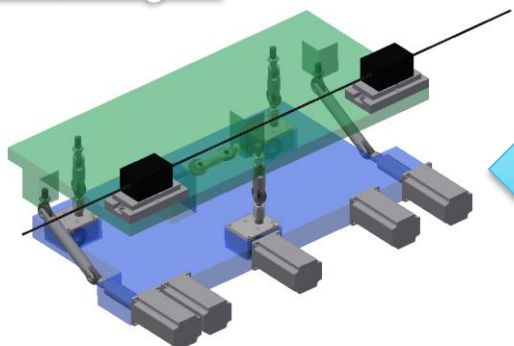
Manual

Without
standardized
platform more
difficult and more
time consuming



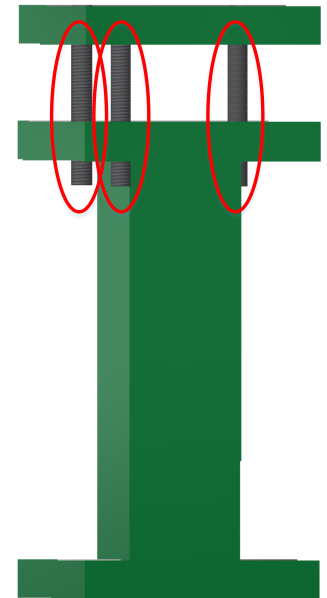
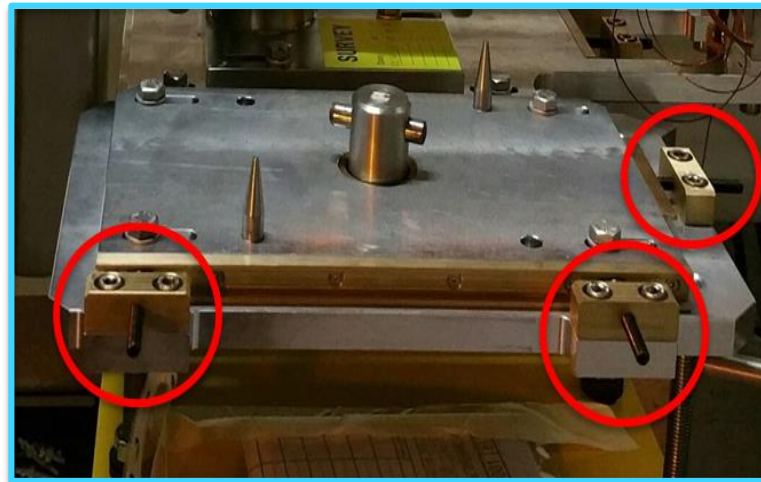
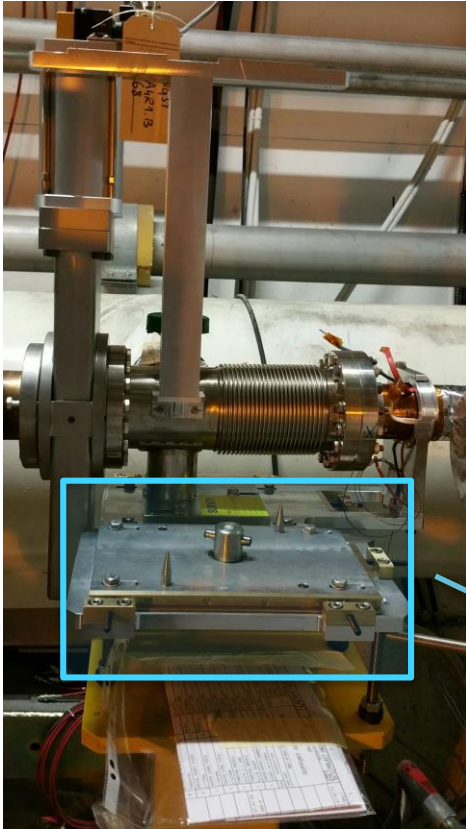
Remote
Resident motors and
sensors

Plug-in
motors
Alignment by
wire

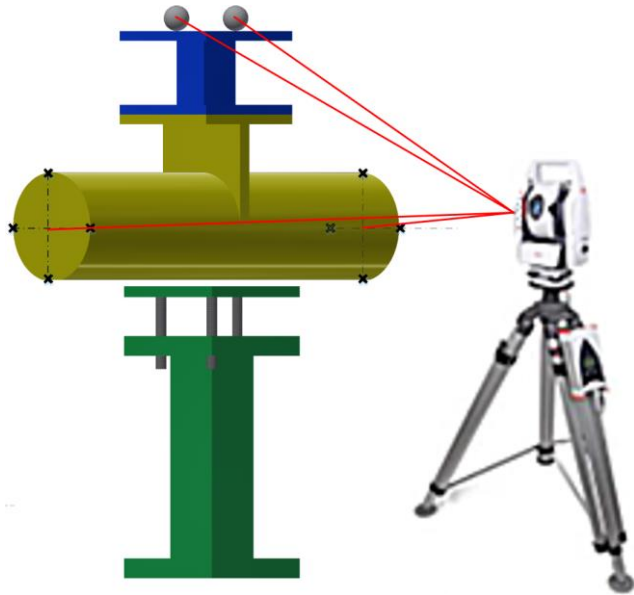


Sector valve and vacuum module support

- The base support for the pumping modules and sector valve modules will have two position pins and a locking mechanism.
- All supports will have two individual manual adjustments platforms in X-Y-Z. One for each beam line.

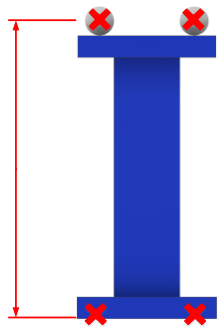


Alignment of module on the surface

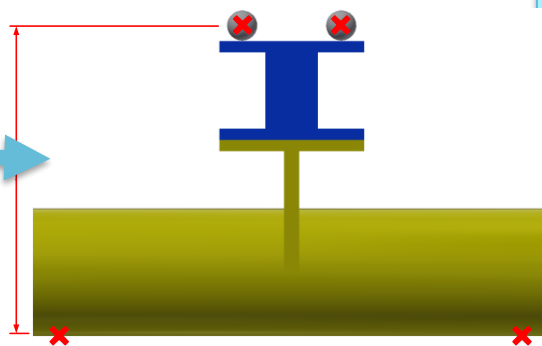


- The vacuum module shall be fiducialised before installation in the tunnel
- This is done in two steps:
 - Step 1. Fiducialisation of module with standard targets .
 - Step 2. Check the module has the same dimensions as the dummy target support.

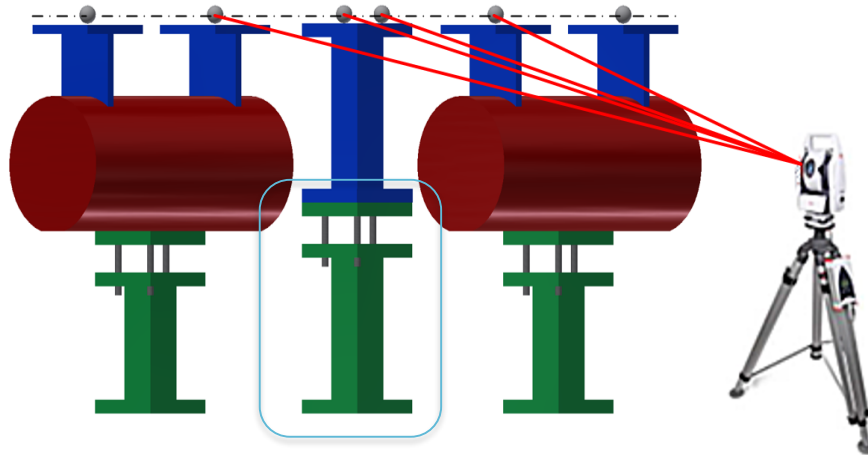
Dummy
target support



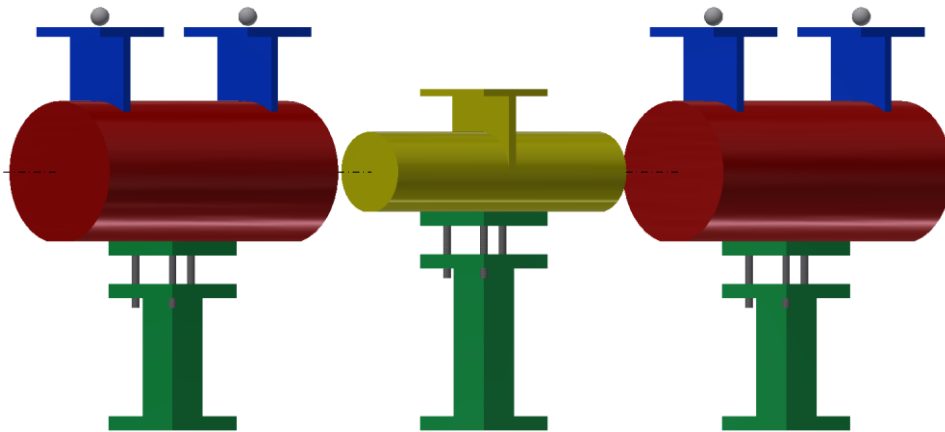
Vacuum module
With target support



Installation of module in tunnel



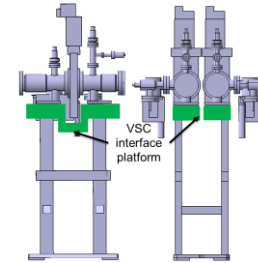
- Adjust the support



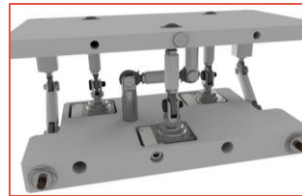
- No further alignment will be required in the tunnel after installation of the module or module exchange.
(Minimum beam clearance: $\pm 2.5\text{mm}$ if aligned)

Principal of alignment table for sector valve modules

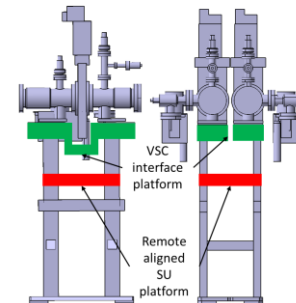
- Type 1 (Manual) is made of a new VSC interface platform between the support and the valves.
 - New interface to align each beam line independently.
 - Fiducialisation and alignment by Survey team.



- Type 2 (Combined Manual and Remote) is made of both the new VSC interface platform together with a SU remote alignment platform
 - Includes resident motors and sensors to allow remote alignment.
 - SU remote alignment platform is required to be assessed for robustness with respect to ΔP applied on the sector valve or any other component. (In case of failure, the remote aligned platform has to be redesigned)



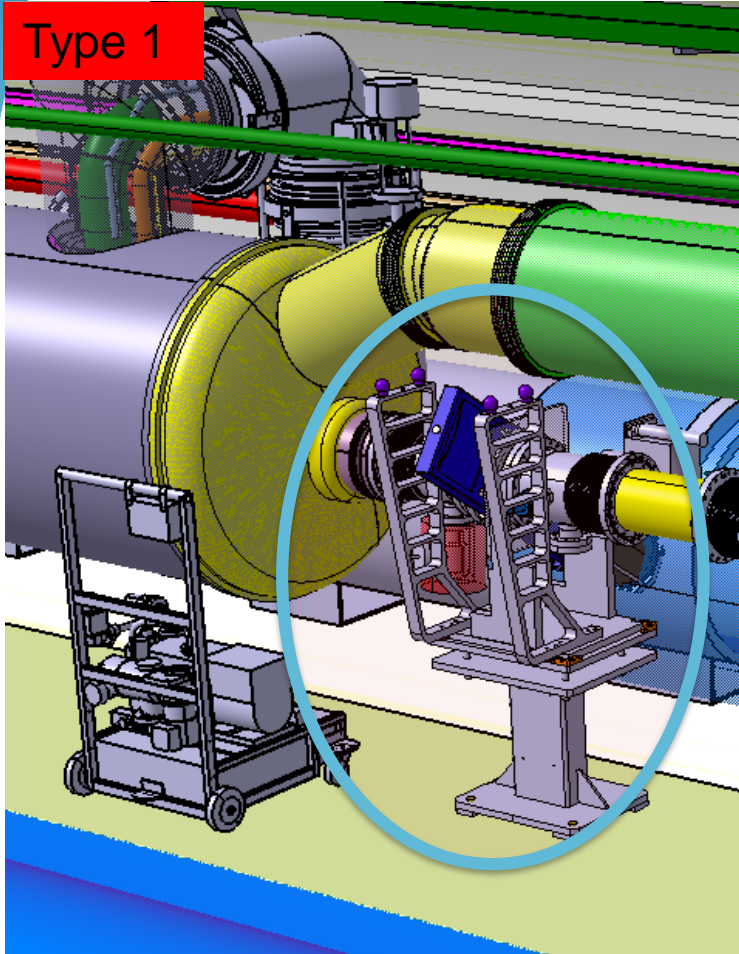
Remote aligned SU platform



- Remote alignment will only be used with limited beam aperture. (Extra cost 100 KCHF per unit).

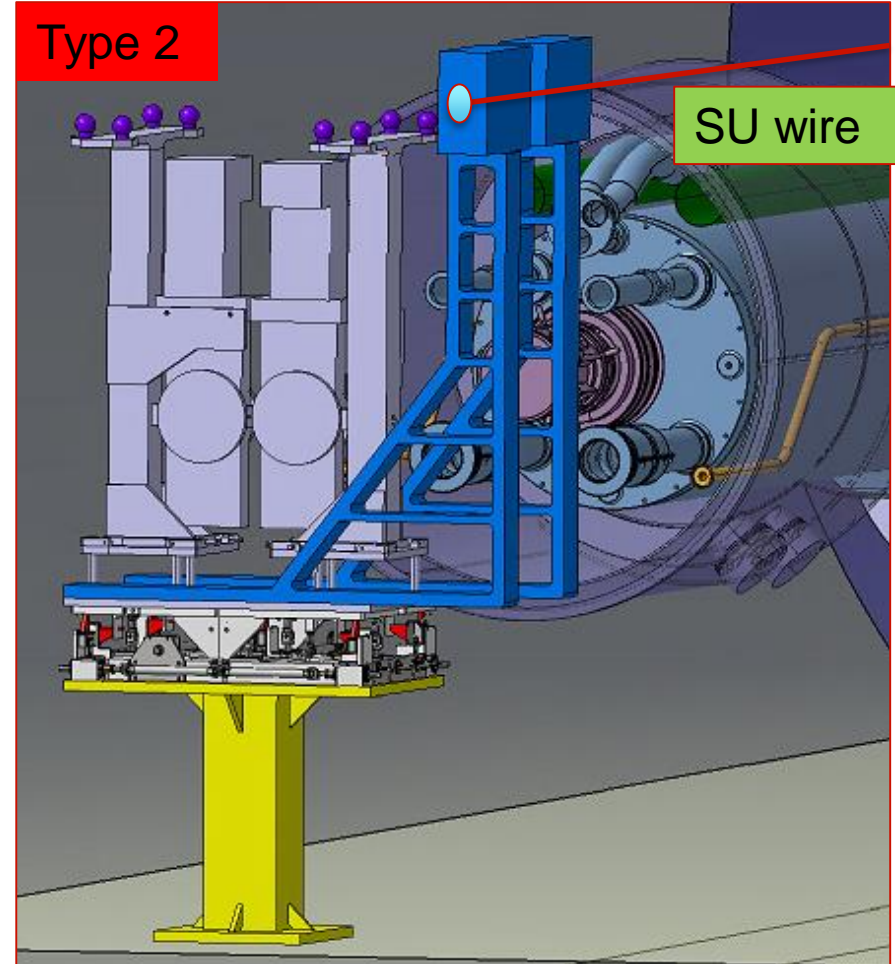
Alignment tables for sector valve modules

Type 1



Manually alignment by SU
of mono-valve (Exit D1)

Type 2



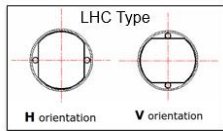
Remote alignment with wire by
SU of double-valves (D2)

Tolerances for cold warm transitions

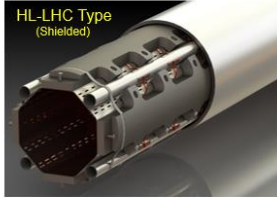
Beam screen

Beam screen:

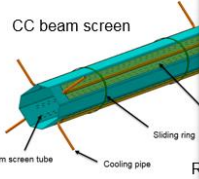
- Three types of beam screens:
 - LHC type:
 - Supported using co-laminated sliding rings - Beam screen sits on the bottom of the cold bore.
 - HL-LHC type:
 - Shielded - Inner triplet (IT) - Using spring supports - Has tungsten shields and the supports center
 - Unshielded - D2 - Using co-laminated sliding rings - Beam screen sits on the bottom of the cold bore type (IN STUDY).
 - Crab Cavities (CC) beam screen:
 - Supported using co-laminated sliding rings - Beam screen seats on the bottom of the cold bore.



Reference [5].



Reference [4]. Ricardo Rego - Vincent Baglin - 07/06/2018



-The alignment tolerances of the beam screens is not discussed in this presentation.

-Assumptions and Request:

-The cold warm transition **flanges** shall be within +/- 0,5mm of nominal position.

-This value is used for the maximum bellows offset calculations.

Beam screen (Continued)

LHC Type beam screen (continued):

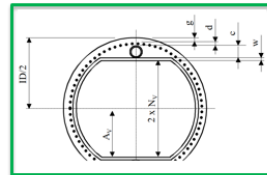
Parameters	Value LHC Type [mm]
$A_{v,r}^*$	First vertical/Radial beam screen half aperture
ID	Nominal cold bore inner ϕ
ΔID	Tolerance on cold bore inner ϕ
g	Minimum gap (continuous support and no support)
Δb	Tolerance on beam screen outer half-dimension
w	Nominal beam screen wall thickness
Δw	Tolerance on beam screen wall thickness
c	Nominal cooling tube outer diameter
Δc	Tolerance on cooling tube outer diameter
d	Nominal sliding ring thickness
Δd	Tolerance on sliding ring thickness
λ	Longitudinal distance between rings

- * Indicated tolerances are +/- tolerance;
- * 1 mm stainless steel + 0.075 mm copper (collimation)

Reference [8].

LHC type beam screen				
	50A	50L	63	69
ID	50	50	62.98	69.08
ΔID	0.35#	0.35#	0.38#	0.74#

Reference [5].



Reference [7].

Beam screen (Continued)

Beam screen:

Supported using co-laminated sliding rings:

Position computation [8]:

$$0.99727 * \left(d + 3\Delta d + \frac{0.4\lambda}{1000} \right).$$

First mechanical half aperture $A_{v,r}^*$, [8]:

$$A_v^* = \frac{ID}{2} - \frac{3\Delta ID}{2} - 2g - 4\Delta b - w - \Delta w - c - 3\Delta c - 0.99727 * \left(d + 3\Delta d + \frac{0.4\lambda}{1000} \right);$$

$$A_r^* = \frac{ID}{2} - \frac{3\Delta ID}{2} - 2g - 4\Delta b - w - \Delta w - 0.99727 * \left(d + 3\Delta d + \frac{0.4\lambda}{1000} \right).$$

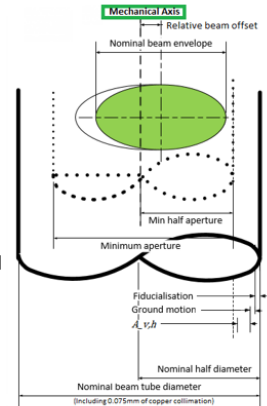
Account the following values from $A_{v,r}^*$ to obtain the final mechanical half aperture $A_{v,r}$:

Thermal expansion/compression = 0.155 mm, [1].

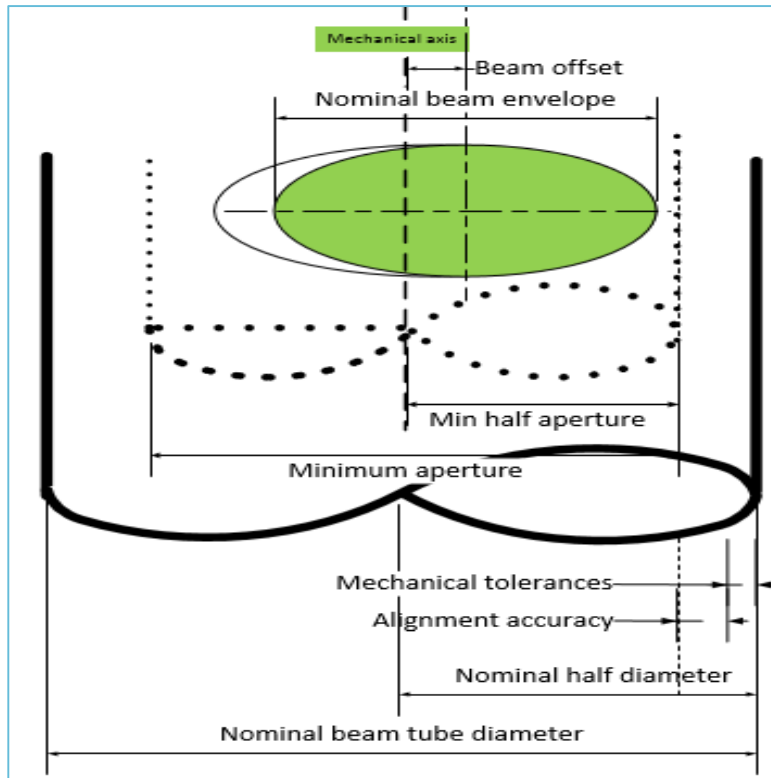
a-C coating \rightarrow neglected.

Minimum half aperture (MHA) available for the:

$$MHA = A_{v,r} - F - GM - RO.$$



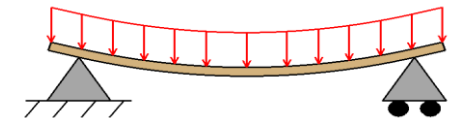
Vacuum chamber tolerances



- Mechanical tolerances:
 - **Circularity + Straightness,**
- Alignment Accuracy:
 - *Accuracy of the alignment tools, systems, techniques or methods .*

NOTE:

- the sag is not considered, since one should position the supports in a way that the maximum effect in the chamber is the chamber straightness

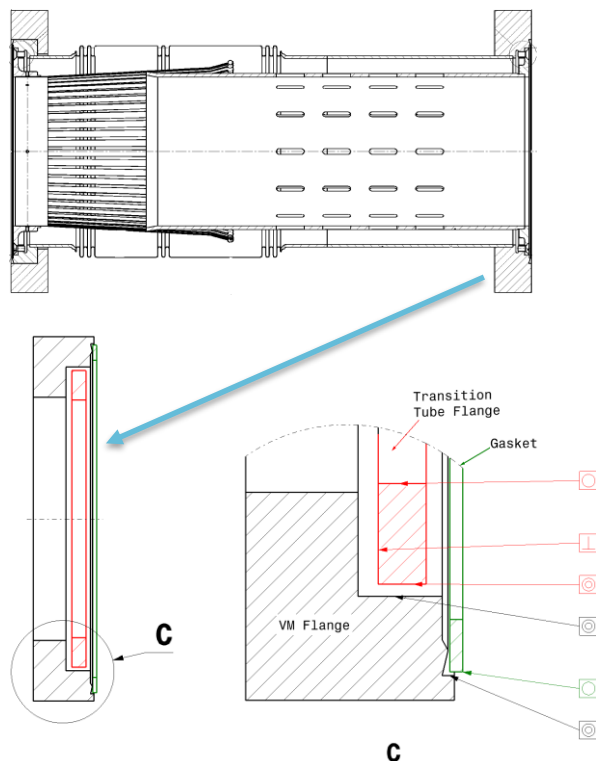


Vacuum chamber									Alignment Accuracy (AA) [mm]
	ID 80		ID 91		ID 212.7		ID 250		
	C [mm]	St [mm]	C [mm]	St [mm]	C [mm]	St [mm]	C [mm]	St [mm]	
Copper	+/-2	+/-4	-	-	-	-	-	-	+/-2
Stainless Steel	+/-1	+/-2	+/-1	+/-2	+/-2	+/-2	+/-2	+/-2	

- C – Circularity.
- St – Straightness.
- Values in diameter (+/-).

Vacuum module (VM) tolerances

- In order to calculate mechanical aperture available for the beam passage, one has to take into account:
 - The tolerances for: RF Fingers, the Transition Tube, Flanges, Copper Gasket.
 - Alignment Accuracy: Depends on the flanges of the supporting components up and downstream.



Parameters			Value [mm]				
			ID 63	ID 80	ID 91	ID 212.7	ID 250
Mechanical tolerances	Position	Perpendicularity of the VM flange	+/- 0.05	+/- 0.05	+/- 0.05	+/- 0.05	+/- 0.05
		Concentricity of the VM flange (where the flange of the RF fingers or of the transition tube sits (worst case))	+/- 0.15	+/- 0.15	+/- 0.15	+/- 0.15	+/- 0.15
		Concentricity of the outer part of the flange of the RF fingers or of the transition tube (worst case)	- 0.15	- 0.15	- 0.15	- 0.2	- 0.2
		Circularity of the inner part of the flange of the transition tube or of the RF finger (worst case)	+/- 0.1	+/- 0.1	+/- 0.1	+/- 0.1	+/- 0.1
		Concentricity of the VM flange (where the gasket sits)	+/- 0.05	+/- 0.05	+/- 0.05	+/- 0.05	+/- 0.05
		Circularity of the outer part of the gasket	+/- 0.05	+/- 0.05	+/- 0.05	+/- 0.05	+/- 0.05
		Gap between flanges and gasket	+/- 0.275	+/- 0.275	+/- 0.275	+/- 0.275	+/- 0.275
	Straightness of the Transition Tube (S)		+/- 0.1	+/- 0.1	+/- 0.1	+/- 0.1	+/- 0.1
Alignment Accuracy (AA)			+/- 2	+/- 2	+/- 2	+/- 2	+/- 2

Vacuum sector valves



- **To compute the mechanical aperture:**
 - We subtract the Mechanical tolerances:
 - Concentricity between flanges CO;
 - Circularity of the flanges CI;
 - Alignment Accuracy AA:
- One has to take into account that the RF passage might be where the mechanical aperture is smallest.
- The minimum aperture in the RF passage is computed as follows (in diameter):
 - $B - 2 * A$.

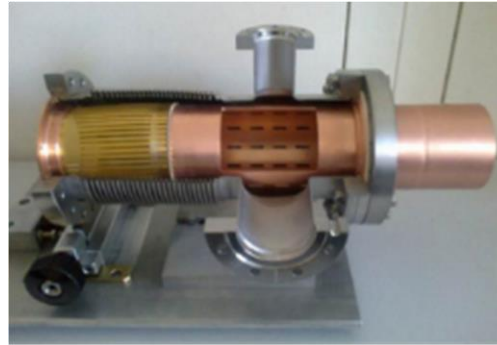
Parameters	Value [mm]				
	ID 63	ID 80	ID 100	ID 150	ID 200
Concentricity between flanges CO *	+/-0.1	+/-0.1	+/-0.1	+/-0.15	+/-0.15
Circularity of the flanges CI *	+/-0.1	+/-0.1	+/-0.1	+/-0.1	+/-0.1
Alignment Accuracy AA *	+/-2	2	+/-2	+/-2	+/-2
Minimum aperture in the RF passage (in diameter)	63	80	96	145.100	197.975

Values in diameter (+/-).

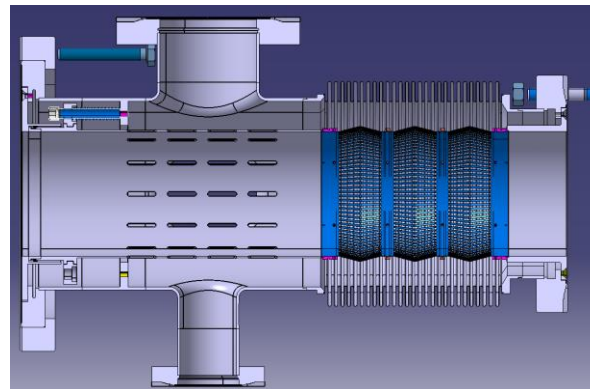
Aperture
94 mm

Standard and DRF bellows

- Standard RF bridge with RF fingers for stroke up to ± 2 mm (RSS*) :
 - Compatible with all fixed components or all remote.

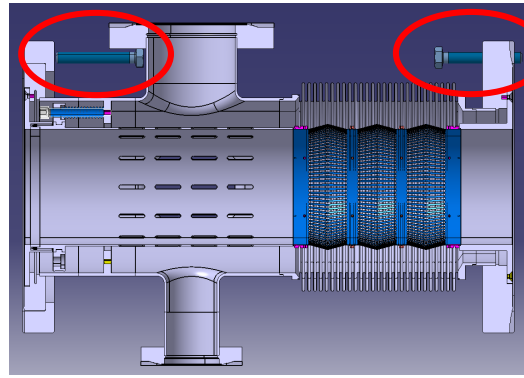
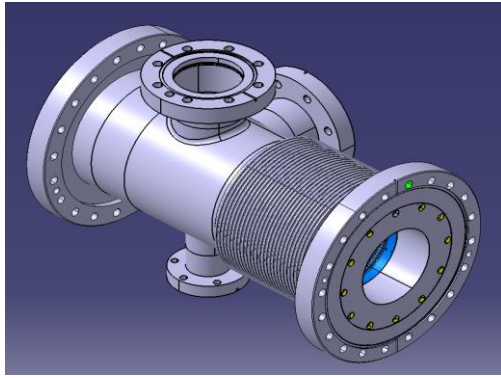


- Deformable RF bridge (DRF) shall be used for displacements larger than ± 2 mm, up to ± 5 mm.



RSS*: Root Sum of Squares

Types of modules (DN63 to DN250)

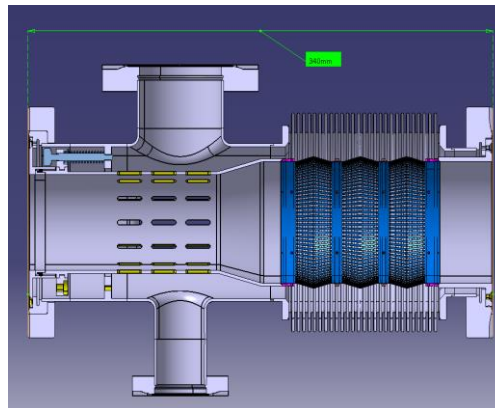
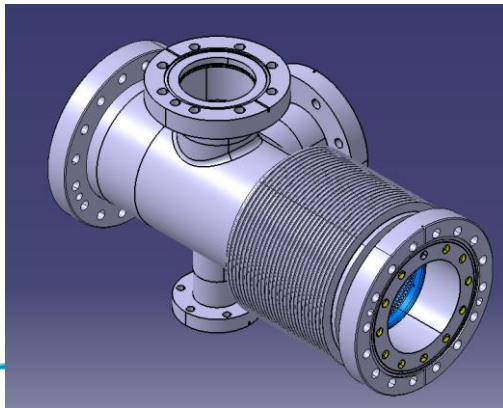
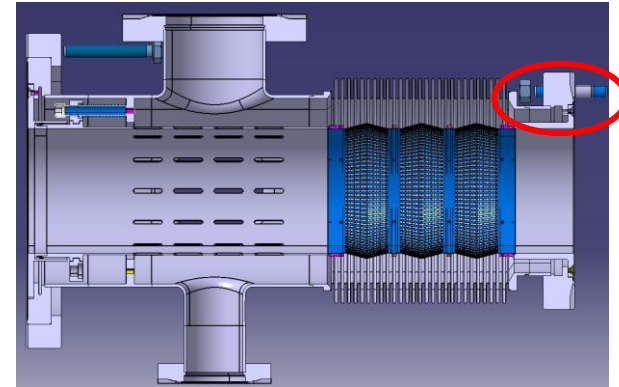
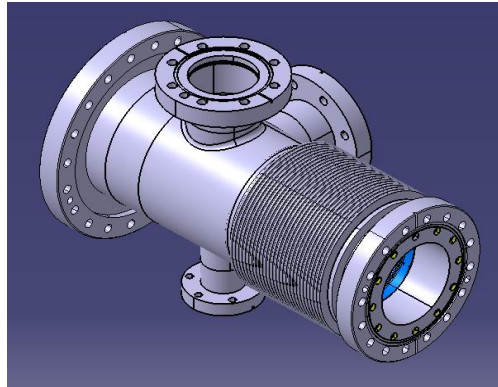


Type 1:
-1 beam aperture

-Same flange size both ends

Type 2:
-1 beam aperture

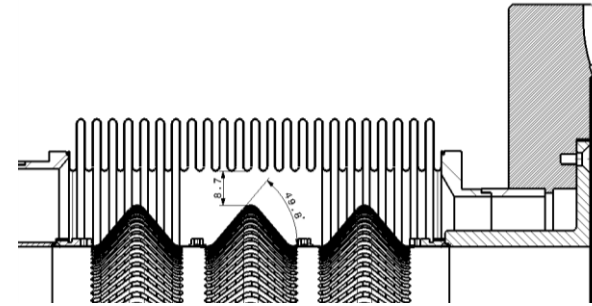
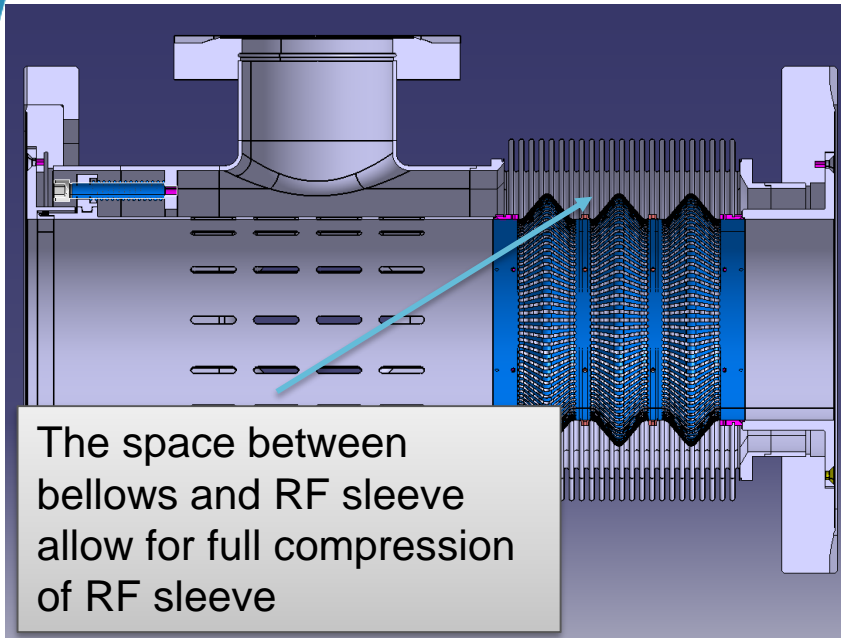
-2 different flange sizes



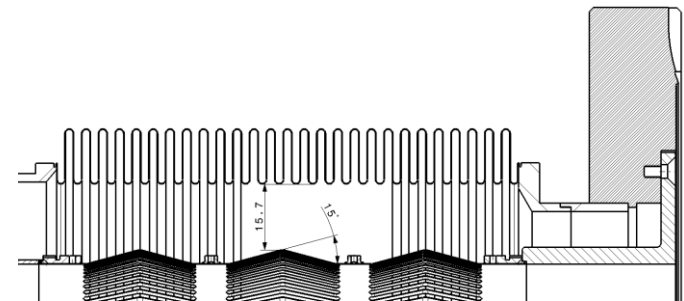
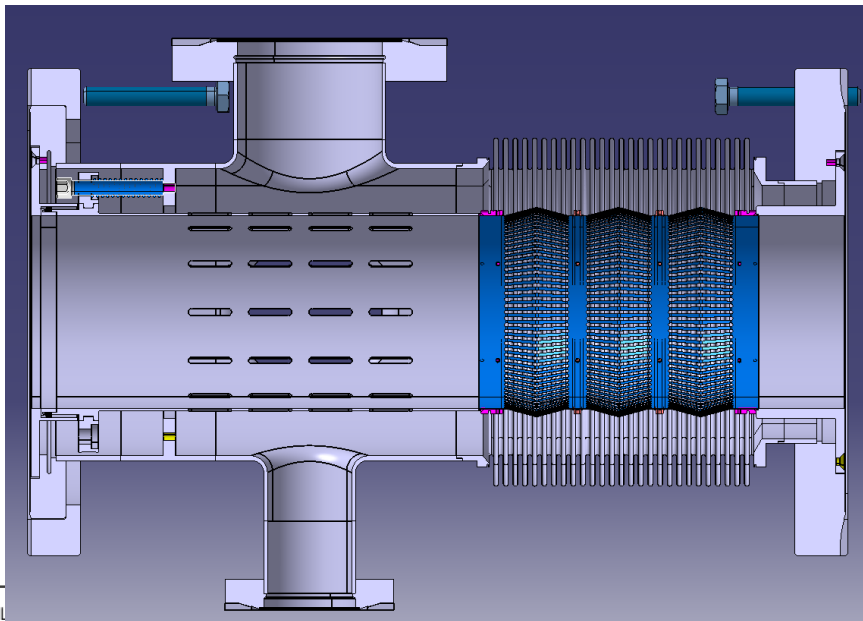
Type 3:
-2 beam apertures

-Same flange size both ends

DRF module

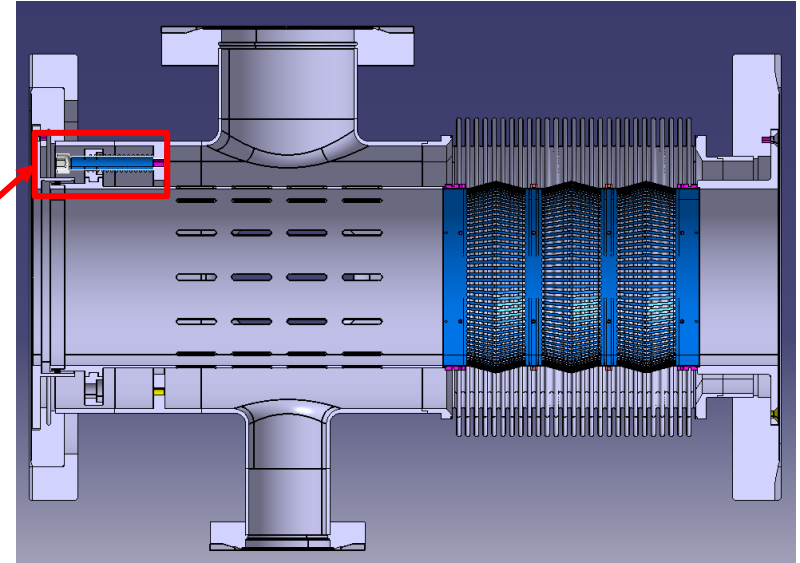
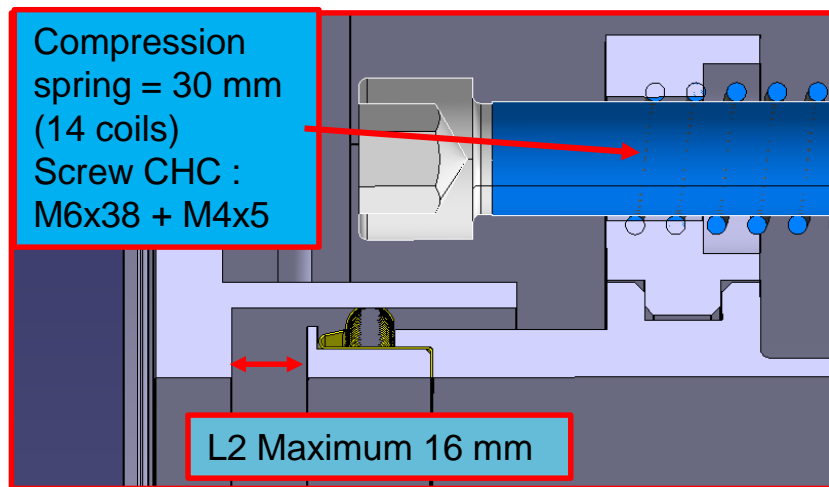


- Inside diameter = 80 mm
- Flange: DN 150 rot. + DN 150 fix)
- Module compressed 16 mm
- Total Length = 324 mm.
- Angle of the RF bridge contact = 49.8°
- Length: Installation length (for coldmass)



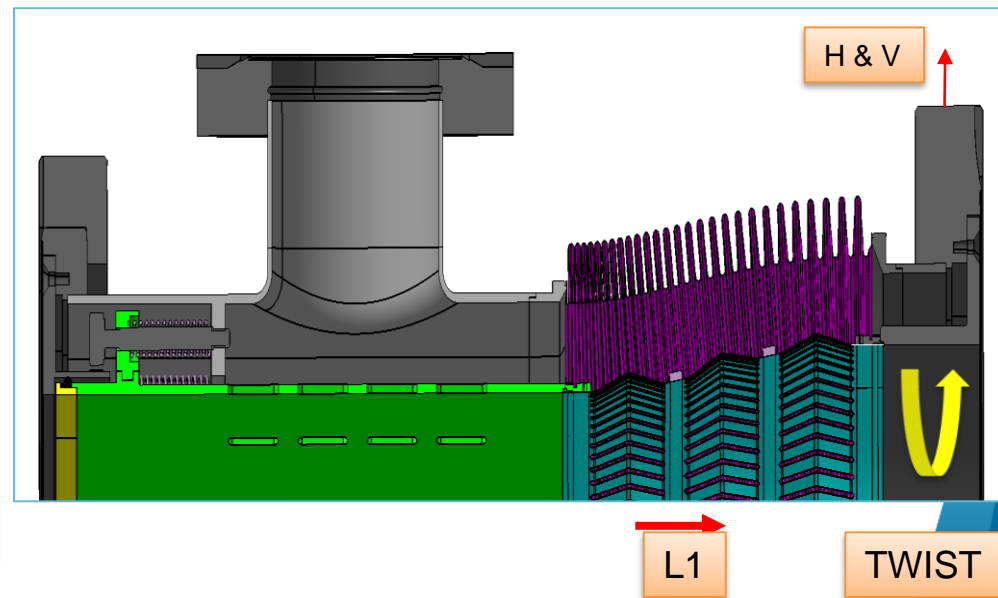
- Bellow is in free length
- Total Length = 340 mm.
- Angle of the RF bridge contact = 15°
- Length: Working length cold and warm
- Extension of sleeve (15°) = +4.1mm

DRF module (Different operation positions)



Working range for RF bridge:

- Horizontal and Vertical (H&V) = ± 5 mm
- Twist (rotation) = 1 mrad
- Extension of RF bridge L1 (15°) = +4.1mm
- Extension of sliding contact L2 = +16 mm (for accidental elongation/extension)



Summary

- New beam optics require bigger beam aperture in the vacuum components and better alignment.
- It is still to be decided by HL-LHC if VABs, BPMs, collimators will be manual aligned or remote aligned (from CCC or in the tunnel).
- Standard bellows/RF bridges have to be replaced with new RF bellows allowing for bigger flange offsets depending on remote alignment or manual alignment.
- Combined sector valve platforms are under study.
- Manual alignment of vacuum chambers in the tunnel is still a correct ALARA solution.

Next Steps

- Complete the study for combined manual and remote aligned platforms for all sizes of sector valves.
- Continue tests of new DRF bellows (RF and mechanical).
- Validate beam aperture clearance to assure manual alignment is sufficient.



Thanks for you attention

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