DESIGN OF A TEST CRYOMODULE FOR THE SUPERCONDUCTING PROTON LINAC OF CERN

Patricia DUCHESNE (IPNO)
Patxi DUTHIL (IPNO)
Sébastien ROUSSELOT (IPNO)

Vittorio PARMA (CERN)
Arnaud VANDE CRAEN (CERN)

Unité mixte de recherche
CNRS-IN2P3
Université Paris-Sud 11

91406 Orsay cedex
Tél. : +33 1 69 15 73 40
Fax : +33 1 69 15 64 70
http://ipnweb.in2p3.fr

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INSTITUT DE PHYSIQUE NUCLÉAIRE
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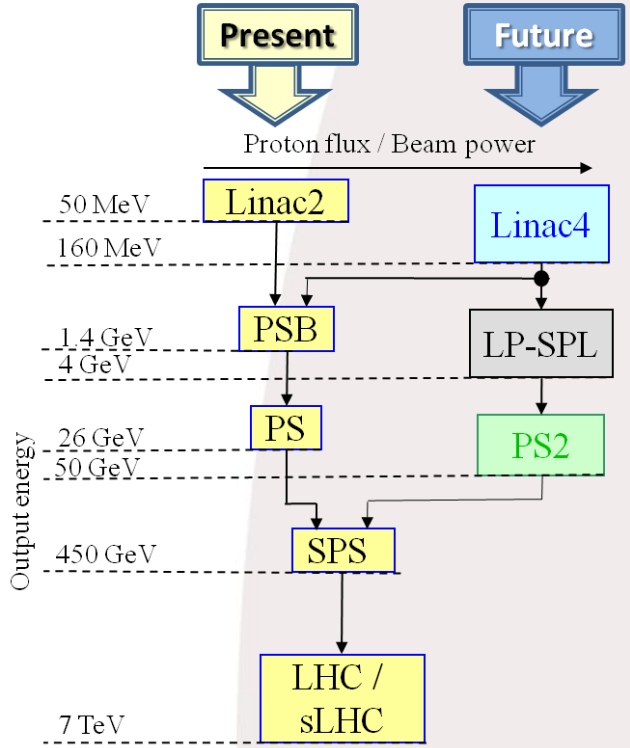
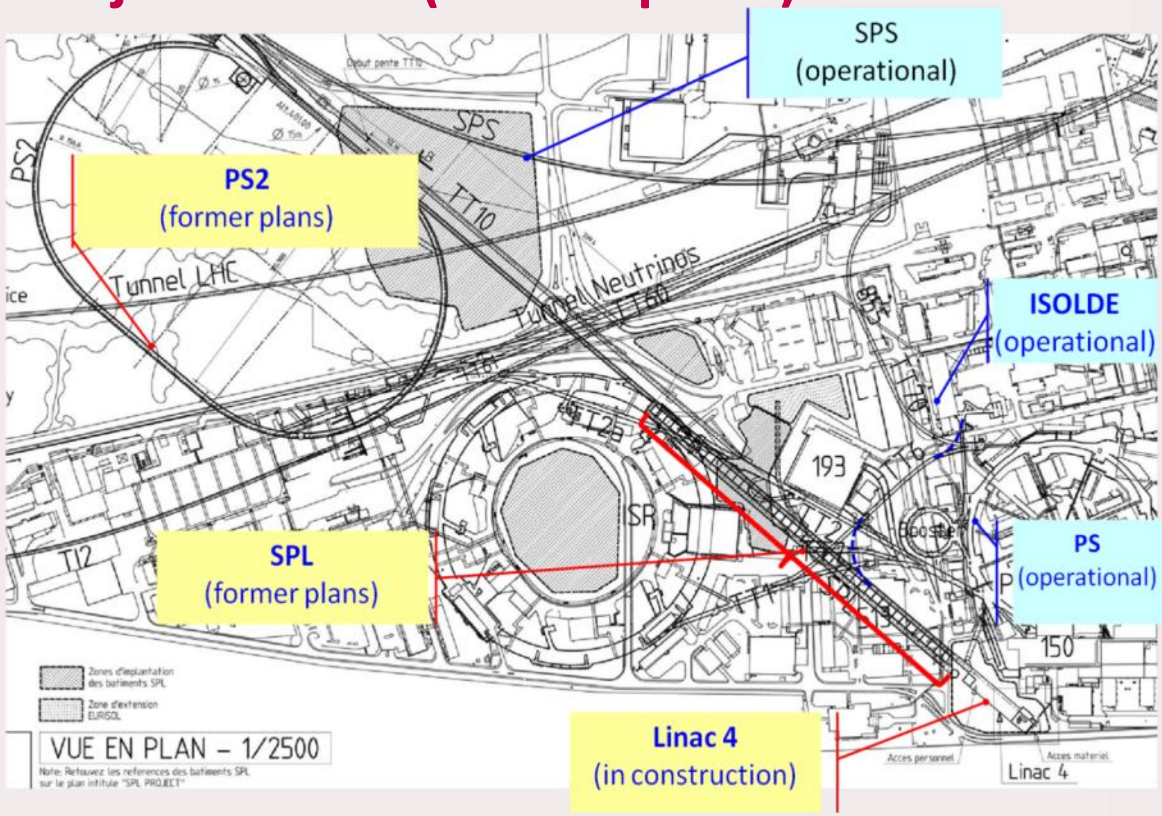
CONTENTS

CERN’s expected new LHC injection line (former plans)





LP-SPL: **Low Power**-Superconducting Proton Linac (4 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
sLHC: “Super-luminosity” LHC (up to 10^{35} $cm^{-2}s^{-1}$)

CERN's new scientific strategy: R&D for a High Power SPL (HP-SPL)

General orientation:

Focus on R&D for key technologies for a high-intensity proton source (HP SPL) for a neutrino facility

In particular, for the cryo-module development:

- Development, construction and test of β=1 elliptical cavities, 704 MHz
- Development, construction and test of RF couplers
- Test of a string of 4 β=1 cavities in a machine-type configuration

→ This program calls for the design and construction of a **short cryo-module** for testing purposes

Goal

Design and construct a ½-lenght cryo-module for 4 $\beta=1$ cavities (as close as possible to a machine-type cryomodule)

Motivations

- Test-bench for RF testing on a multi-cavity assembly driven by a single or multiple RF source(s)
- Enable RF testing of cavities in horizontal position, housed in machine-type configuration (helium tanks with tuners, and powered by machine-type RF couplers)
- Validate the design of critical components like RF couplers, tuners, HOM couplers in their real operating environment

Cryostat specific main objectives

Learning of the critical assembly phases:

- From clean room assembly of cavities to a cryomodule
- Alignment/assembly procedure

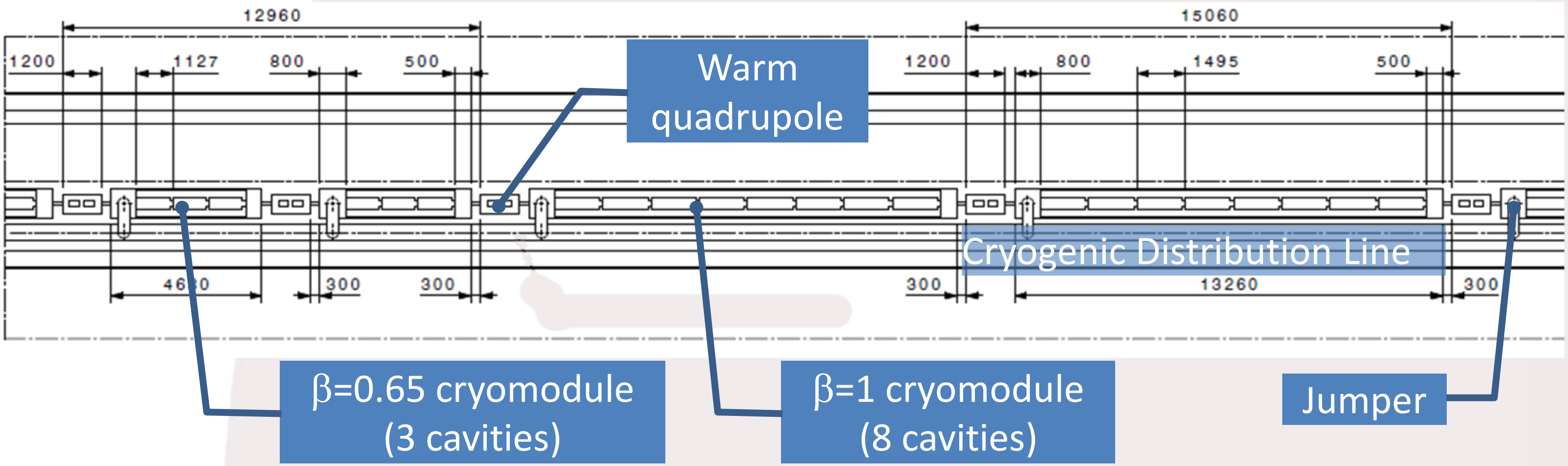
Proof of concept of "2-in-1" RF coupler/cavity supporting:

- Fully integrated RF coupler: assembly constraints
- Active cooling effect on cavity alignment

Operation issues:

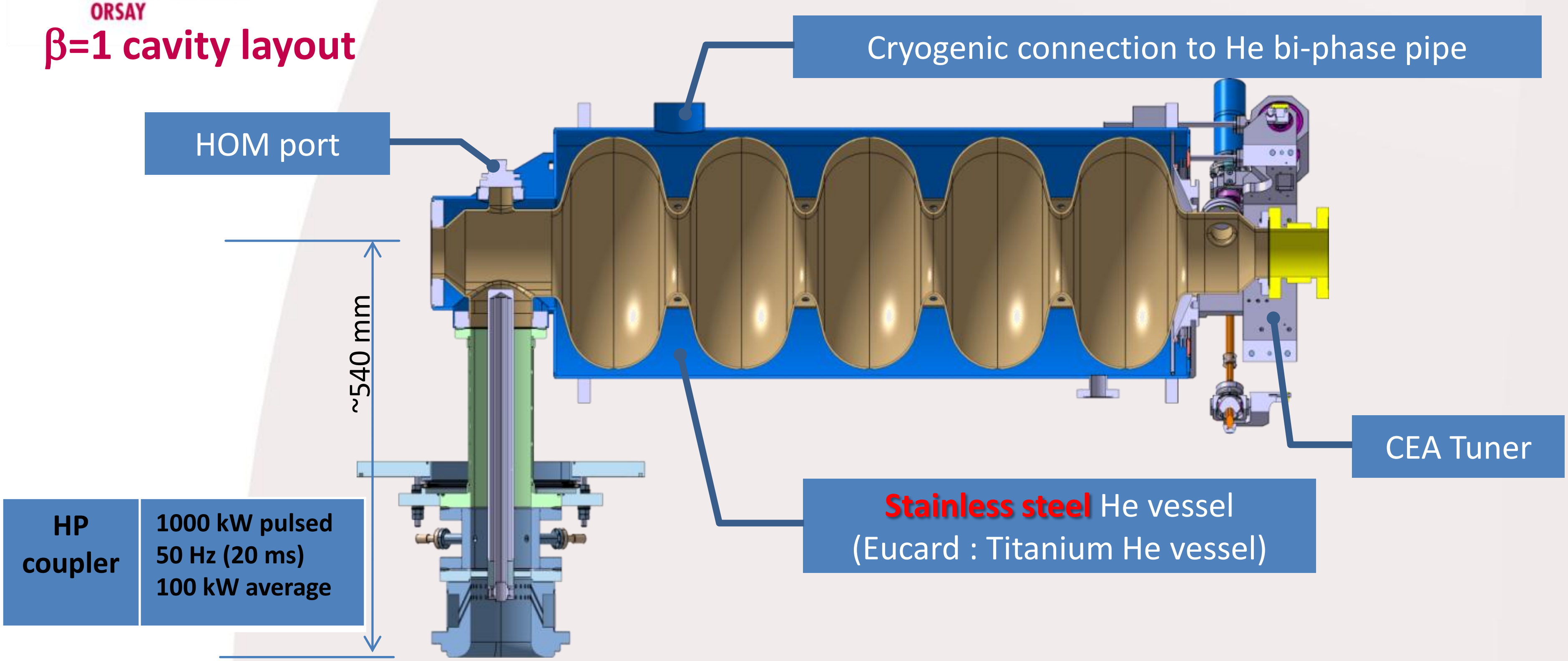
- Cool-down/warm-up transients, thermo-mechanics, heat loads
- Alignment/position stability of cavities
- Cryogenic operations (He filling, level controls, RF coupler support tube cooling)

« Segmented » architecture with warm quads and a cryo distribution line



β=1 CRYO-MODULE IN A POSSIBLE SPL LAYOUT

β=1 cavity layout



The He vessel includes specific interfaces for the cryomodule integration (Eucard cavity interfaces for Cryolab-CEA not compatible with SPL integration):

- Inter-cavity supports
- Cryogenic feeds
- External magnetic shielding via cryoperm™ (not shown)
- Tooling (in/outside the clean room)

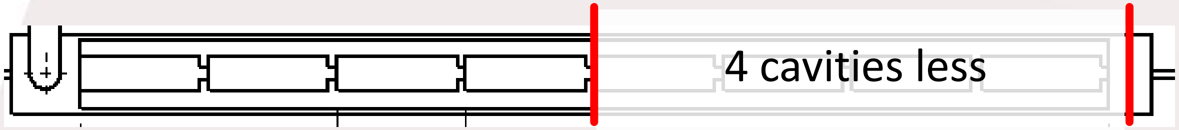
Requirement	Value
β	1
Frequency	704.4 MHz
Qo	10×10^9
Gradient	25 MV/m
Operat. T	2 K

2K Heat Loads (per β=1 cavity)

Operating condition	**Value**	
Beam current/pulse lenght	**40 mA/0.4 ms beam pulse**	**20 mA/0.8 ms beam pulse**
cryo duty cycle	4.11%	8.22%
quality factor	10×10^{9}	5×10^{9}
accelerating field	25 MV/m	25 MV/m

Source of Heat Load	**Heat Load @ 2K (per cavity)**	
Beam current/pulse lenght	**40 mA/0.4 ms beam pulse**	**20 mA/0.8 ms beam pulse**
dynamic heat load per cavity	5.1 W	20.4 W
static losses	<1 W (tbc)	~ 1 W (tbc)
power coupler loss at 2 K	<0.2 W	<0.2 W
HOM loss in cavity at 2 K	<1	<3 W
HOM coupler loss at 2 K (per coupl.)	<0.2 W	<0.2 W
beam loss	1 W	1 W
Total @ 2 K	**8.5 W**	**25.8 W**

The short cryomodule design strategy



Short Cryomodule designed to be compatible with a full-length 8 cavities cryomodule

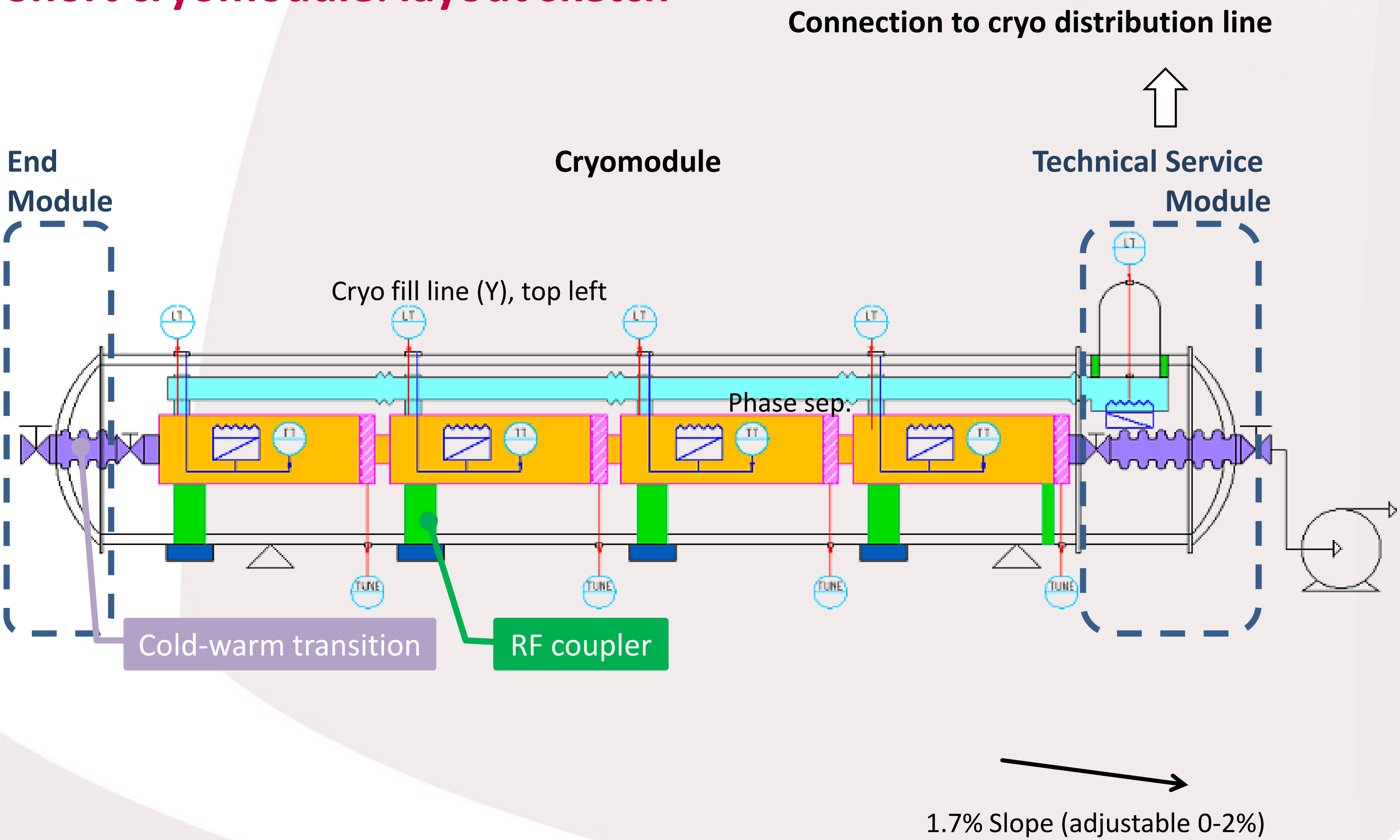
- Mechanical design
- Cryogenics (Heat loads, T and P profiles, segmented machine layout)
- Designed for 0%-2% test (for 1.7% expected tunnel slope)

The short cryomodule development: a collaboration effort

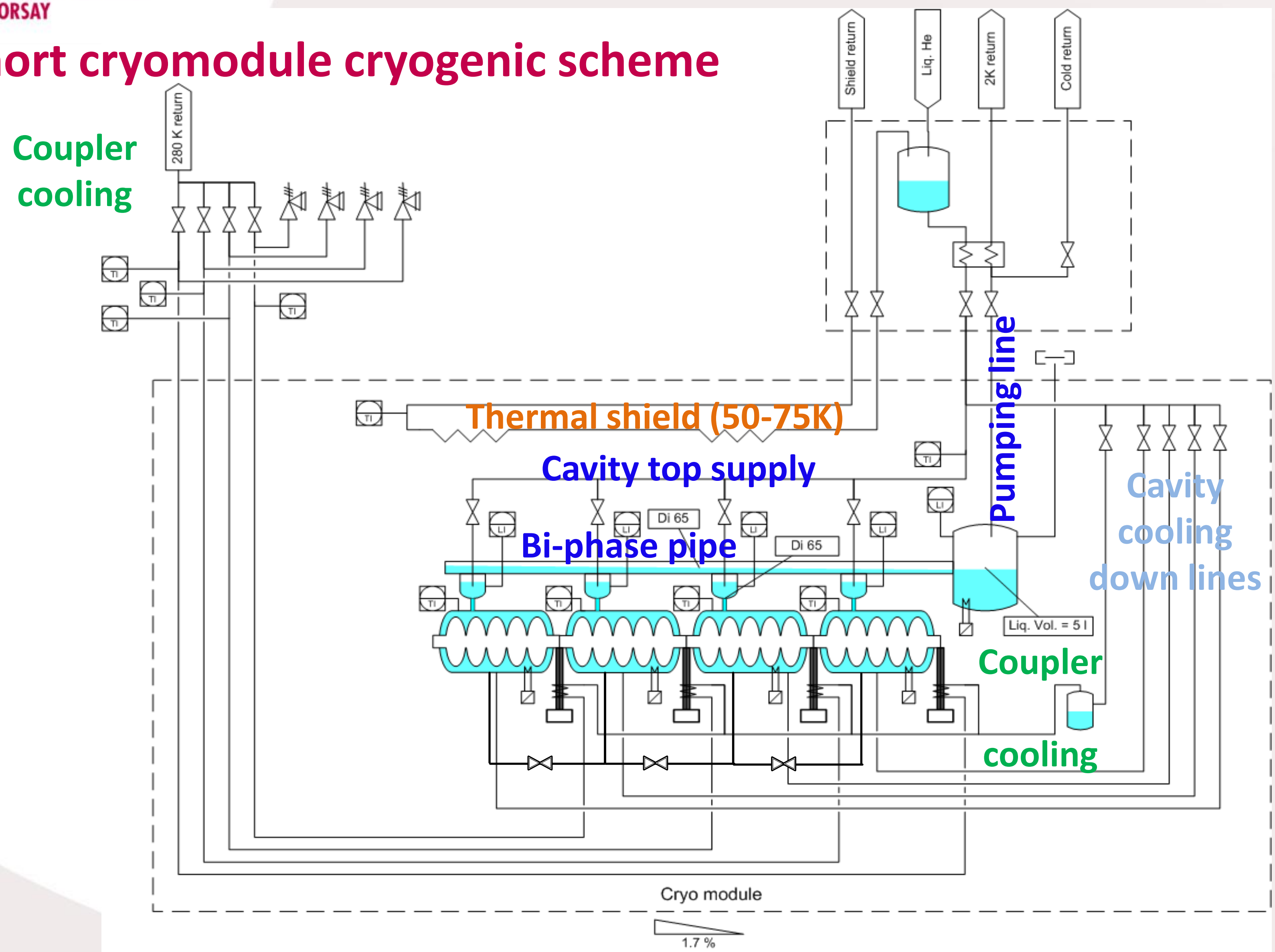
Institute	Supply
CEA – Saclay (F)	1. Design of **β=1 cavities** (EuCARD task 10.2.2) 2. Design & construction of **4 helium vessels for β=1 cavities*** 3. Supply of **4 (+4) tuners*** 4. Testing of RF couplers*
CNRS - IPNO – Orsay (F)	1. Supply of **prototype cryomodule cryostat components*** 2. Design & construction of **cryostat assembly tools***
Stony Brook/BNL/AES team	*(Under DOE grant)* 1. Designing, building and testing of **1 β=1 SPL cavity**.
CERN	**1. 4 (+4) β=1 cavities (supplied from European industry)**
CERN	**1. 4 (+4) RF couplers (2 types)**

* Special French in-kind contribution to CERN

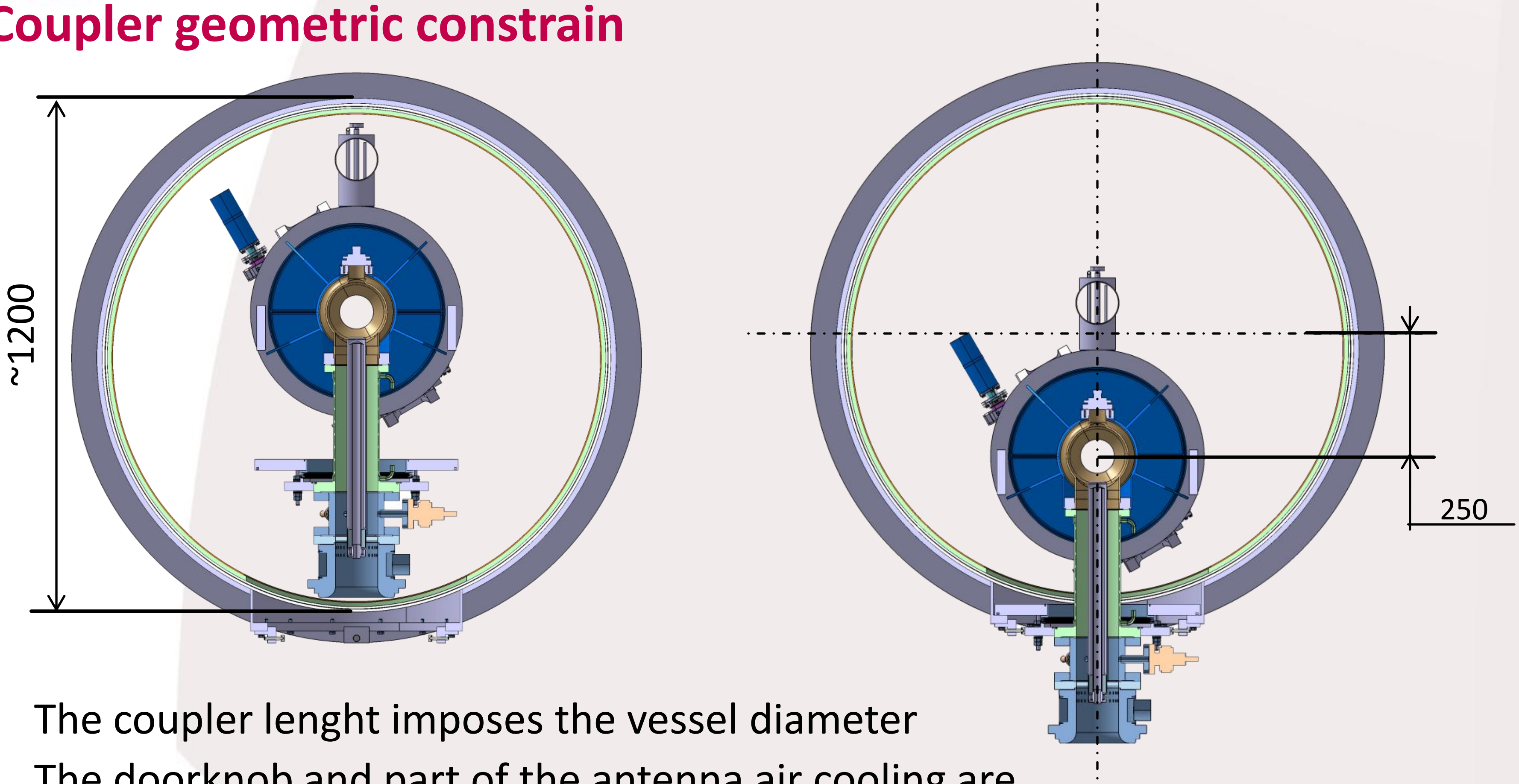
Short cryomodule: layout sketch



Short cryomodule cryogenic scheme



Coupler geometric constrain



- The coupler lenght imposes the vessel diameter
- The doorknob and part of the antenna air cooling are removed for the cryostating in order to reduce this length.

$\Rightarrow$ Vessel diameter is reduced from 1500 mm to 1200 mm.

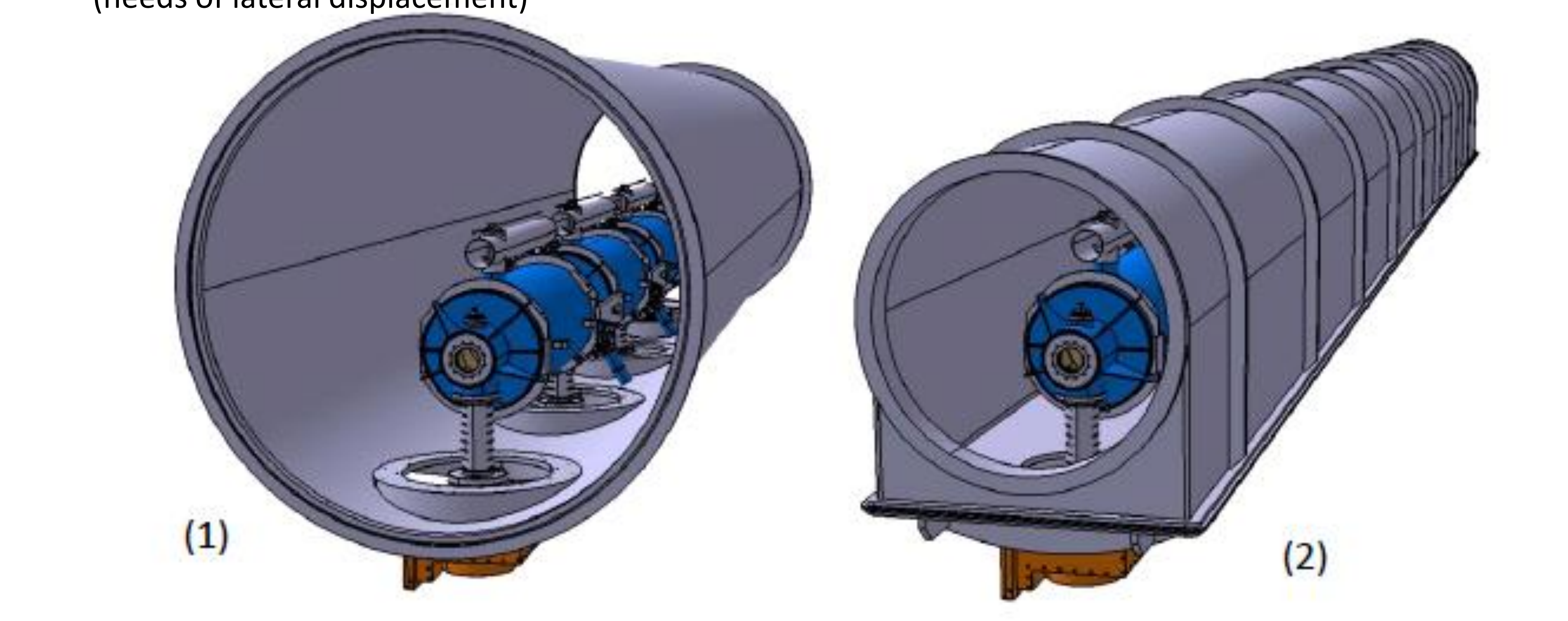
Vacuum vessel alternatives

Tube type (longitudinal cryostating)

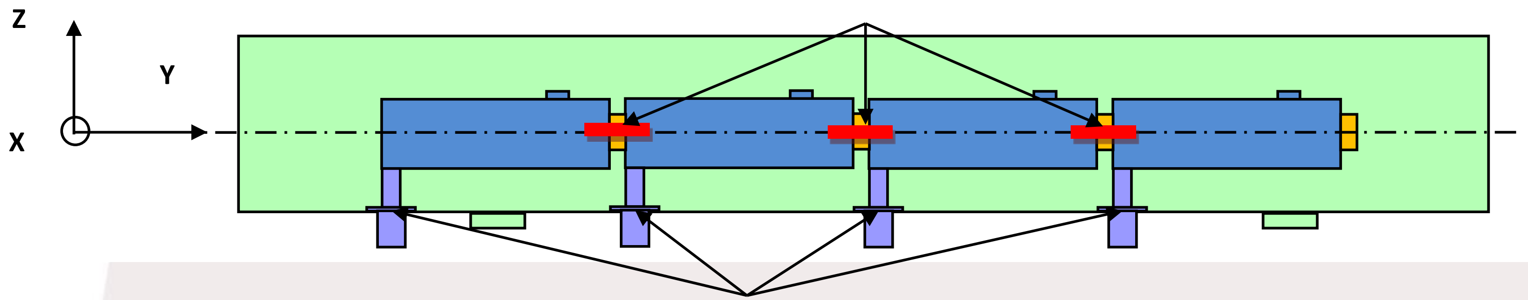
- Intrinsic better mechanical behavior (inertia, vacuum)
- Simpler construction
- Larger diameter of the tank : 1200 mm
- Needs of windows for the accessibility of the cryostat components (corrective, repair actions)
- Involves a more complex set of tooling (needs of lateral displacement)

U type (vertical cryostating)

- More complex vessel design (need of a large opened window)
- Simpler tooling for cryostating (to be discussed)
- Smaller tank diameter : 1020mm



The supporting system concept



RF coupler double-walled tube flange fixed to vacuum vessel

The RF coupler (its double-walled tube) provides:

- fixed point for each cavity (thermal contractions)
- mechanical supporting of each cavity on the vacuum vessel

The intercavity support provides:

- a 2nd vertical support to each cavity (limits vertical self-weight sag)
- relative sliding between adjacent cavities along the beam axis
- enhancement of the transverse stiffness to the string of cavity (increases the eigenfrequencies of first modes)

Alignement requirements

Transversal position specification

BUDGET OF TOLERANCE			
Step	**Sub-step**	**Tolerances (3σ)**	**Total envelopes**
Cryo-module assembly	Cavity and He vessel assembly	*± 0.1 mm*	Positioning of the cavity w.r.t. beam axis **± 0.5 mm**
	Supporting system assembly	*± 0.2 mm*	
	Vacuum vessel construction	*± 0.2 mm*	
Transport and handling (± 0.5 g any direction)	N.A.	*± 0.1 mm*	Stability of the cavity w.r.t. beam axis **± 0.3 mm**
Testing/operation	Vacuum pumping	*± 0.2 mm*	
	Cool-down		
	RF tests		
	Warm-up		
	Thermal cycles		

Construction precision

Long-term stability

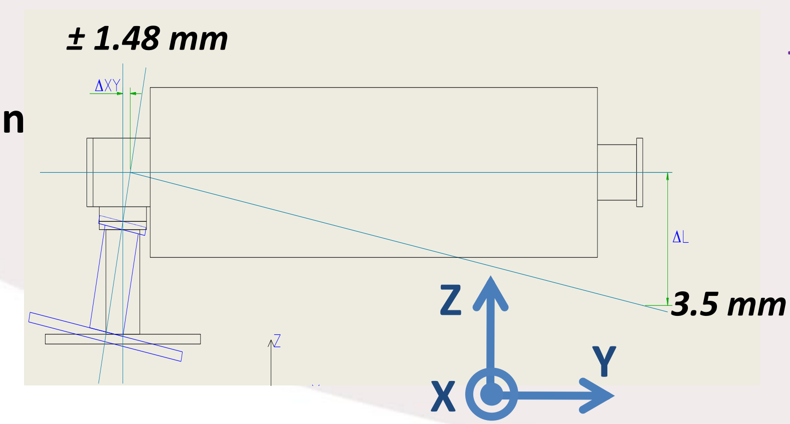
Cavity-to-vacuum vessel tolerances

#	Stack of construction tolerances					
#		Angular tolerance (planarity or perpendicularity)	Radial tolerance induced by angular tolerance	Radial tolerance	Angle	Δz (@ cavity extremity 1100mm)
1	Cavity flangeø152	0.3 mm (cavity design)	± 0.6 mm	± 0.1 mm (Th.Renaglia)	0.122°	3.5 mm / 3.1 mm
2	Double-walled tube top flange ø152	0.02 mm (drwg SPLACSMC0024)	± 0.04 mm			
3	Cu RF gasket ø152	N.A.	N.A.	± 0.05 mm (drwg SPLACSMC0025)		
4	Double-walled tube top flange ø500	0.02 mm (drwg SPLACSMC0024)	± 0.02 mm		0.06° / 0.037°	
5	Vac.vessel flange ø500	0.5 mm / 0.3 mm (experience LHC)	± 0.42 mm / ± 0.25 mm	± 0.25 mm (experience LHC)		
	TOTAL ΔXY		**± 1.48 mm / ± 1.31 mm**			

For each cavity, needs of:

- on the coupler side

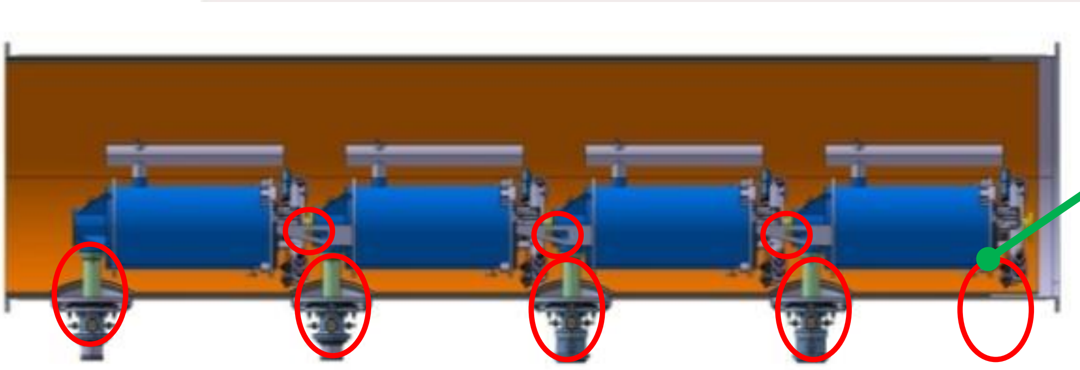
- **Longitudinal compensation**
  ΔX, ΔY, ΔZ
- **Angular compensation**
  θ_X, θ_Y, θ_Z

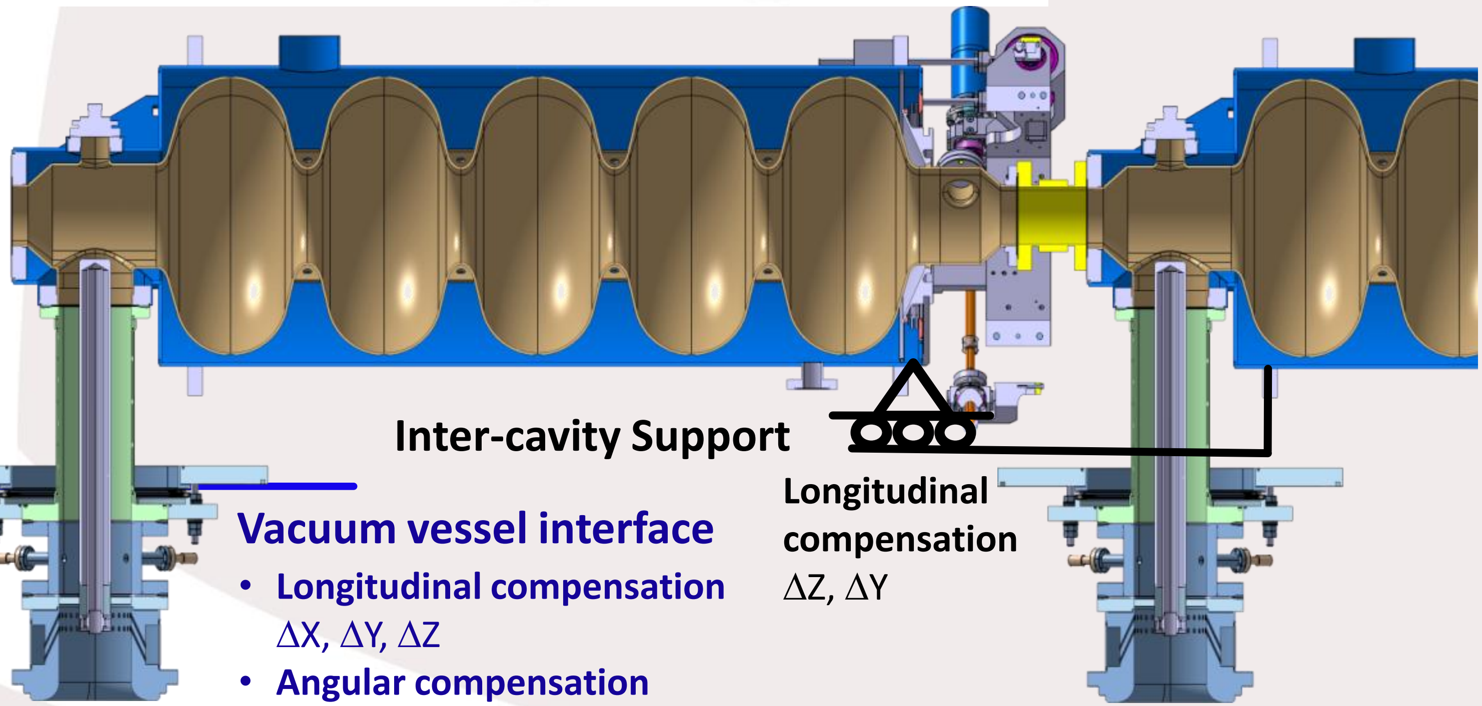


- on the tuner side

Longitudinal compensation
ΔZ (weight) (sag = 2.5 mm)
ΔY (thermal contraction)

The supporting system implementation



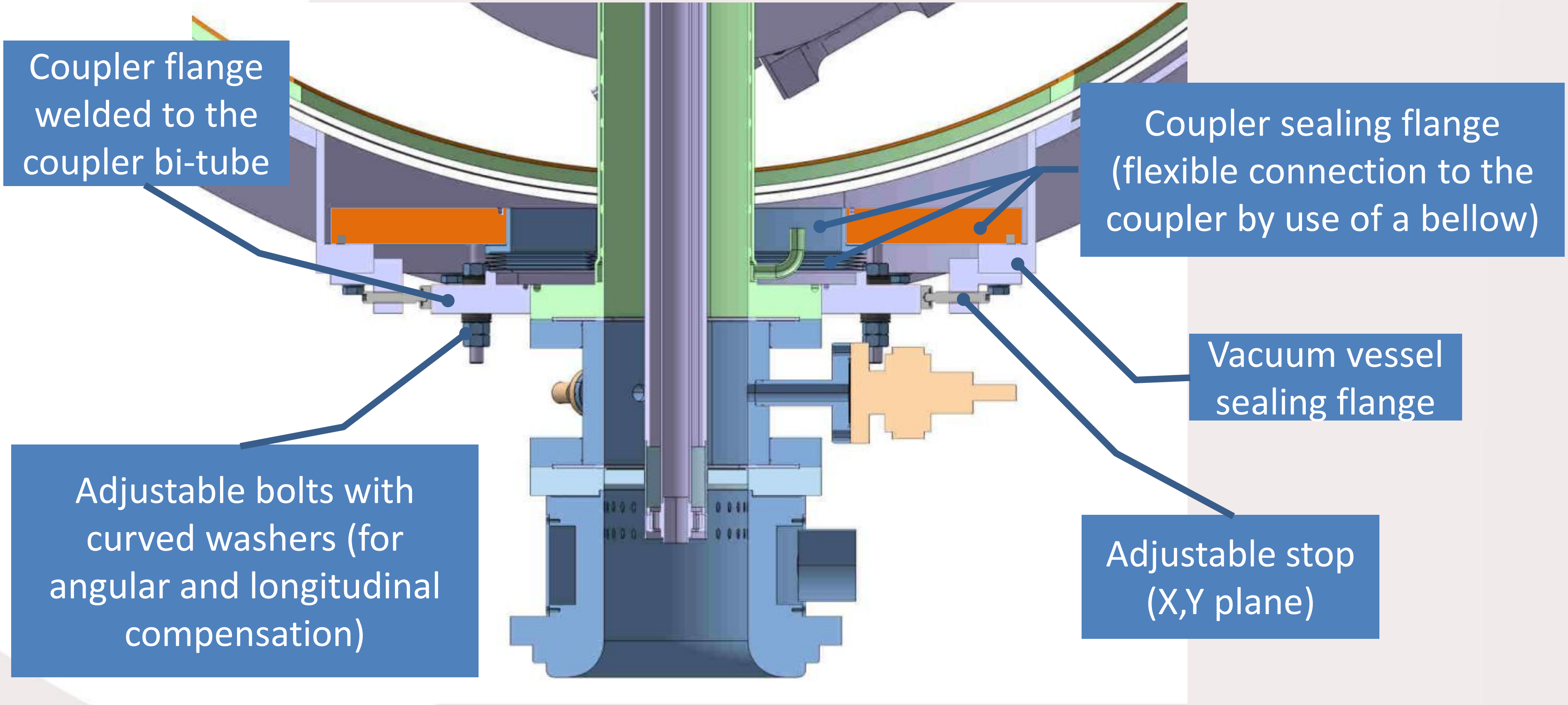


Vacuum vessel interface

- **Longitudinal compensation** ΔX, ΔY, ΔZ
- **Angular compensation** θ_X, θ_Y, θ_Z
- **Fixation (rigid connexion)**

The vacuum vessel/coupler interface (1/3)

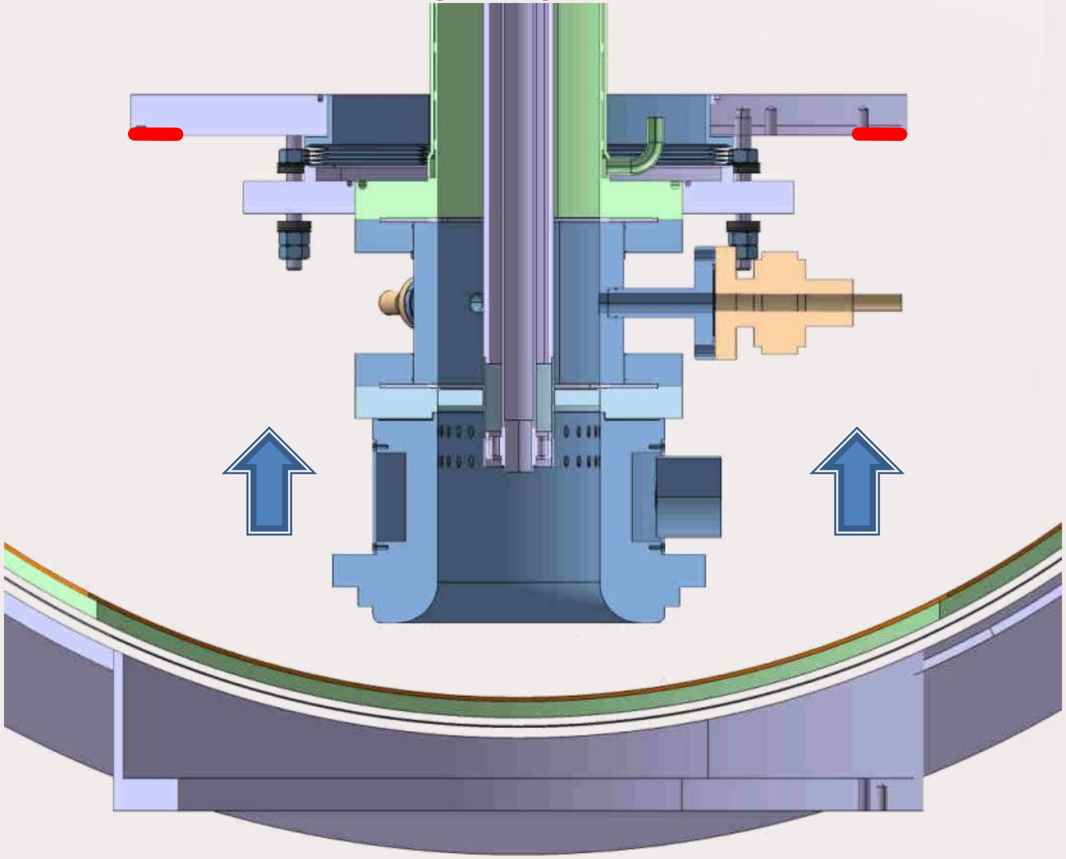
Components



The vacuum vessel/coupler interface (2/3)

Assembly procedure

- **Vacuum vessel lift of**



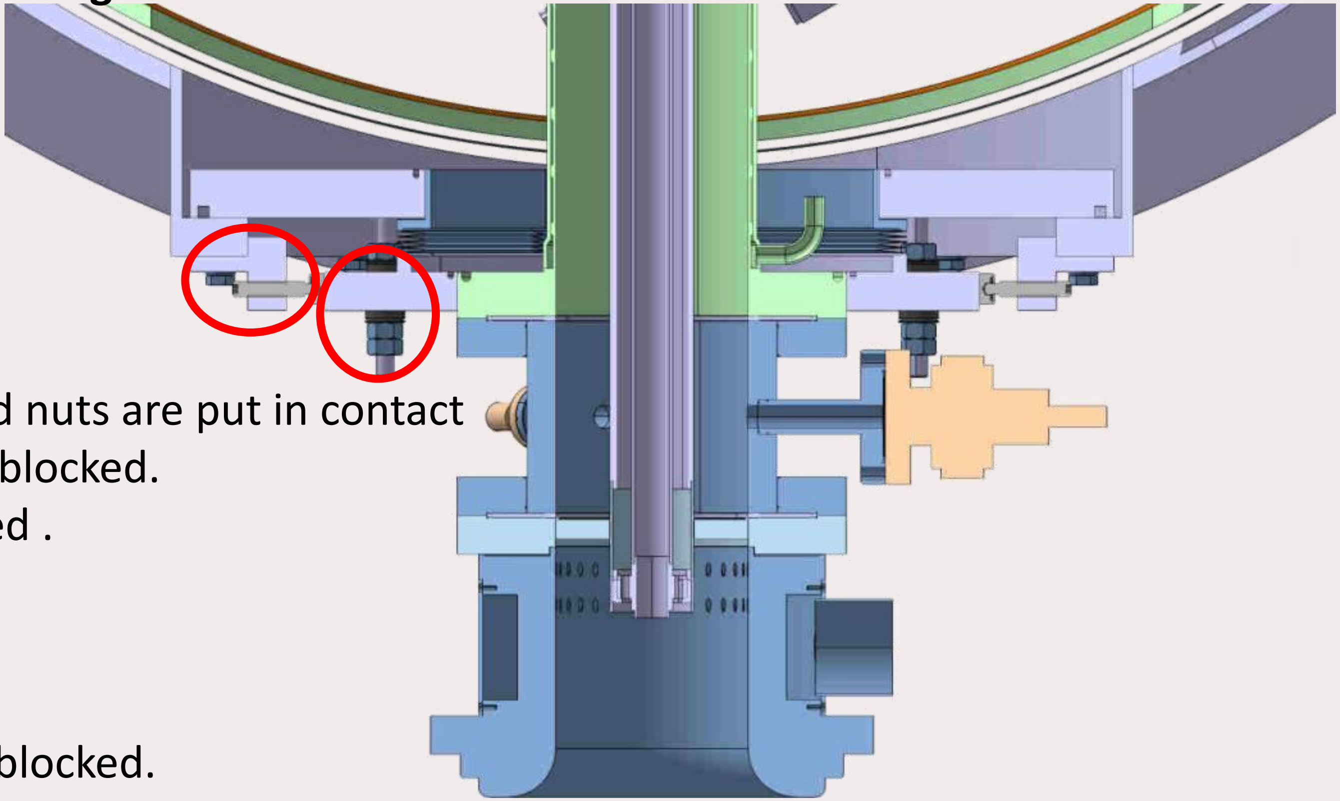
- **Contact of the 4 coupler sealing flanges to the 4 bearings of the vacuum vessel**
- **And fixing**

⇒ defaults located at the level of the 4 bearing plans are compensated by the flexibility of the bellows.

The vacuum vessel/coupler interface (3/3)

Assembly procedure

Fixation of the coupler flange



Lower curved washers and nuts are put in contact to the coupler flange and blocked.
Upper nuts can be clamped .

X,Y adjustable stops are blocked.

→ **No motion is allowed between the coupler flange and the vacuum vessel bearing (translation nor rotation).**

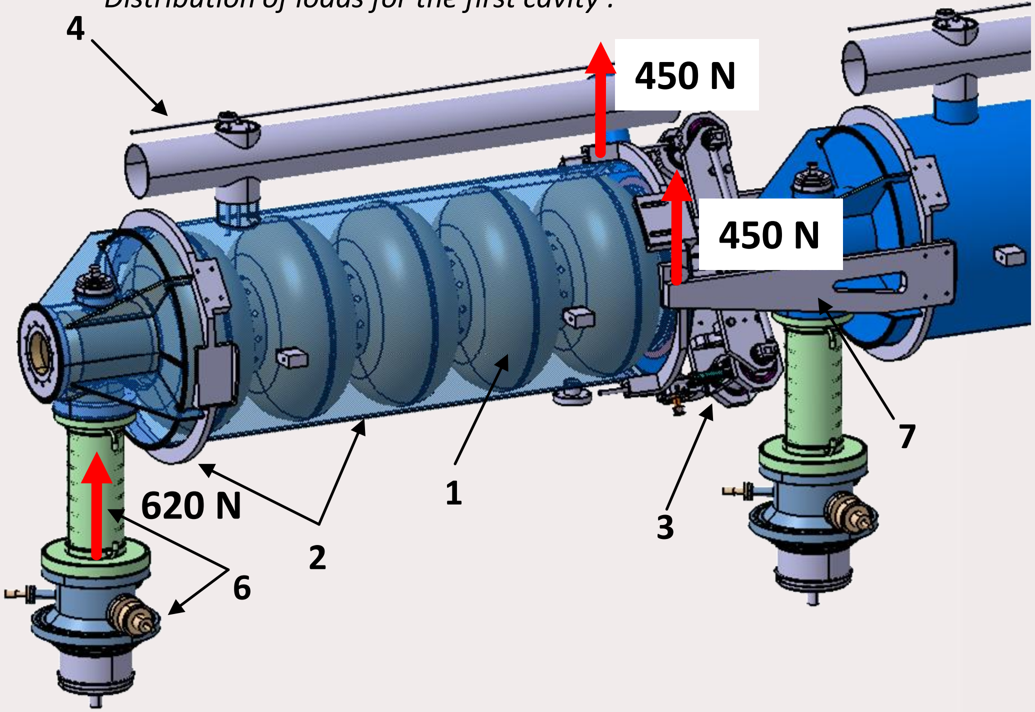
The inter-cavity supporting system (1/3)

Functionalities

- Second vertical support (alignement) ⇒ Stiffness
- Sliding interface along Y axis ⇒ Contact interface

	Components		Weight (Kg)
1	Cavity		55
2	Helium tank	Envelope	36
		Anneaux (2)	15
3	Tuner		18
4	Cryogenic pipes		6
5	Magnetic shield (estimated)		17
6	Coupler	Bi-walled tube	8
		Others	35
7	Inter-cavity connections		15

Distribution of loads for the first cavity :

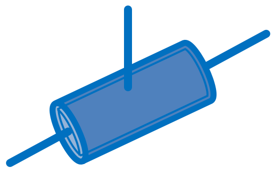


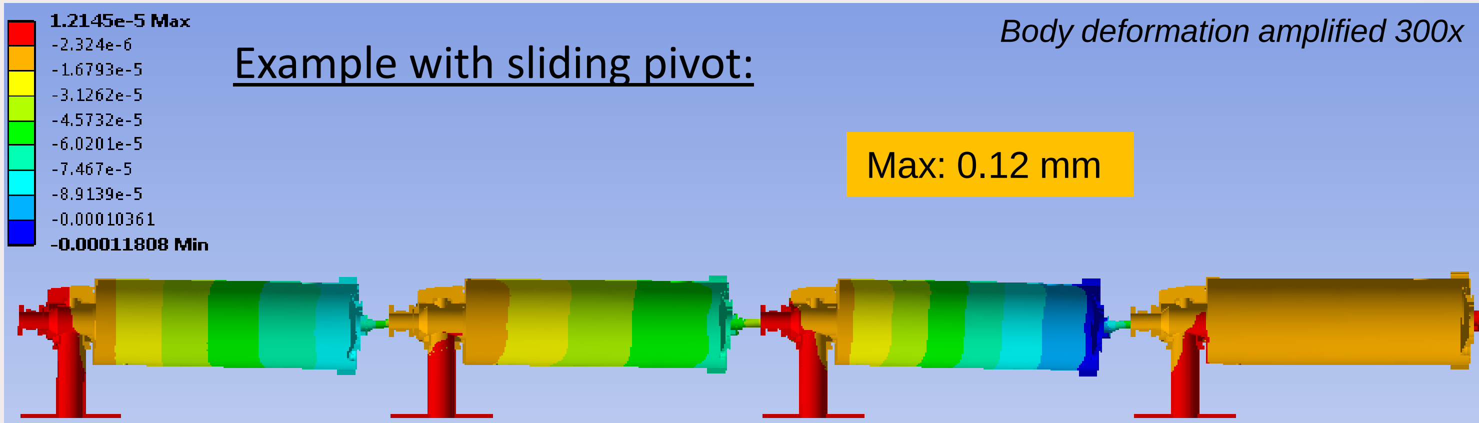
1 set :

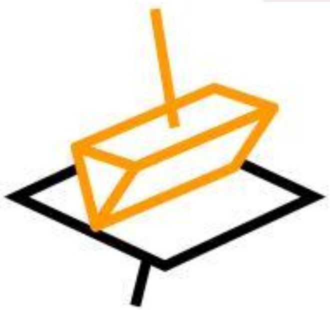
Cavity + He Tank + tuner + Cryo pipes+ magnetic shield + bi-walled tube = **155 Kg**

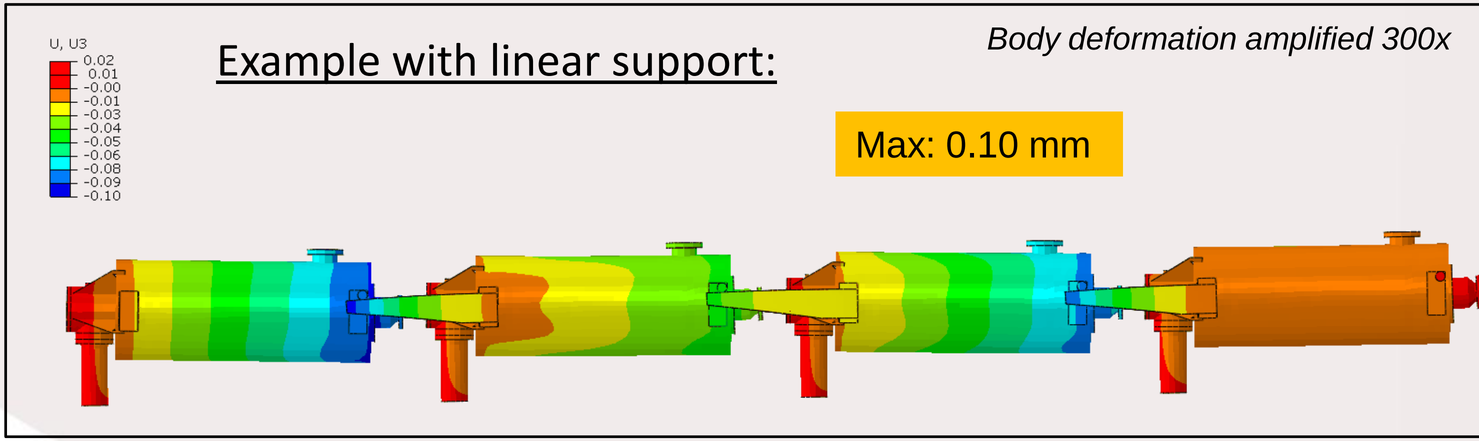
The inter-cavity supporting system (2/3)

Deflection under gravity







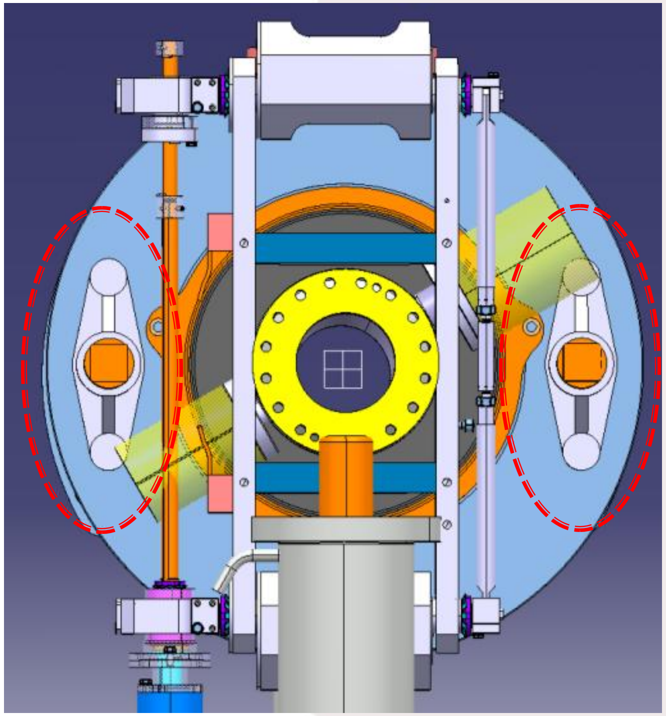


Whatever the principle chosen, finding an acceptable solution is possible in term of deflection

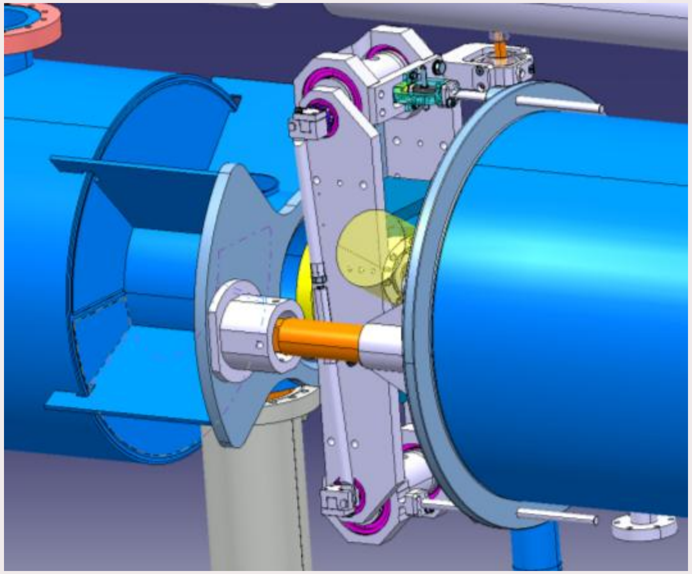
The inter-cavity supporting system (3/3)

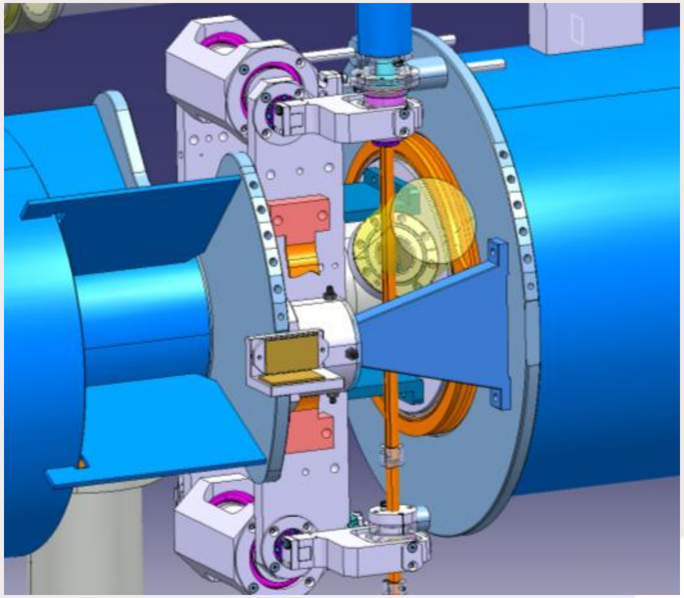
Optimization

➢ Modification of the orientation of the tuner (vertical position)



Examples:
The extremity of the rod is supported by 4 spherical bearings
➔ Sliding in Y axis allowed
➔ Rotations not locked





➢ Modification of the helium tank :
- Ti ➔ Stainless steel
- Fixation of the supports on the face plate of the helium tank

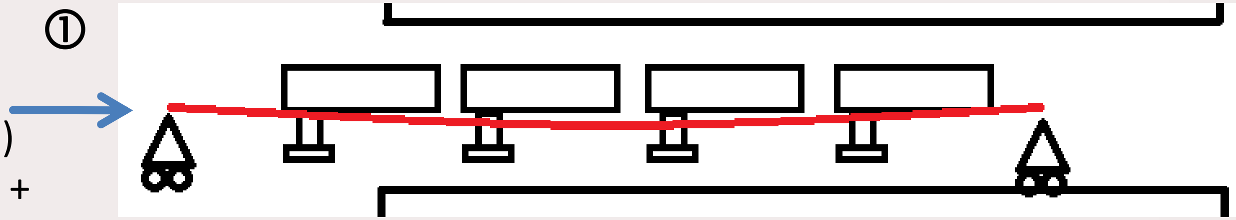
➔ Reduction of the lenght of intercavity supports

Concepts

- Cavities are aligned on the alignment tooling before cryostating.
- Same tooling used for the cryostating ⇒ String alignment should not be altered during the insertion.
- Length of the beam: ~7 m for 4 cavities short cryo-module, ~14 m for 8 cavities cryo-module.

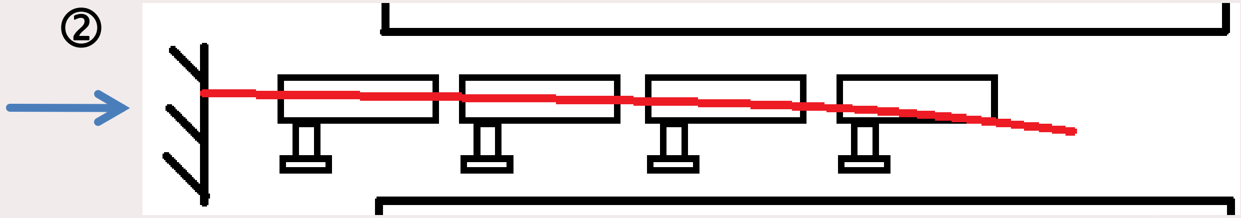
① Critical points:
- Sliding on the wall of the vacuum vessel (in the presence of the shields)
- Overall dimensions (string + tooling + sag) in regards with the vessel diameter

①



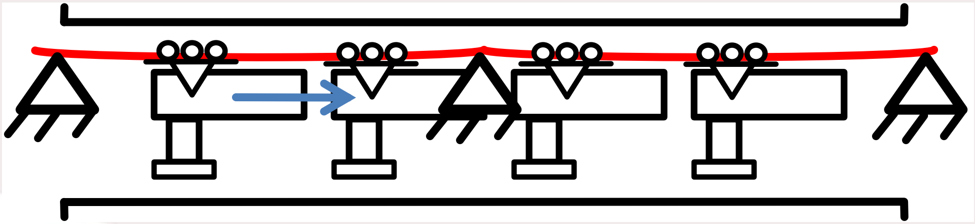
② Critical point:
Overall dimensions (string + tooling + sag) in regards with the vessel diameter

②

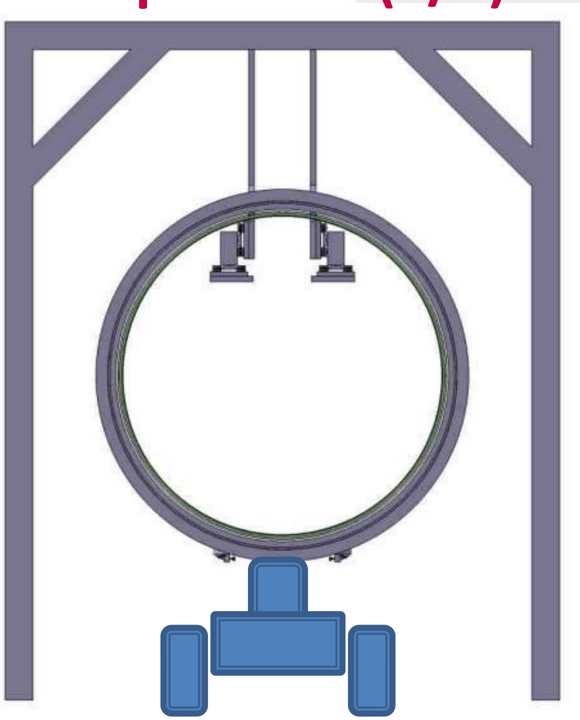


③ Critical point:
- Positioning the tooling within (along) the vacuum vessel (openings)

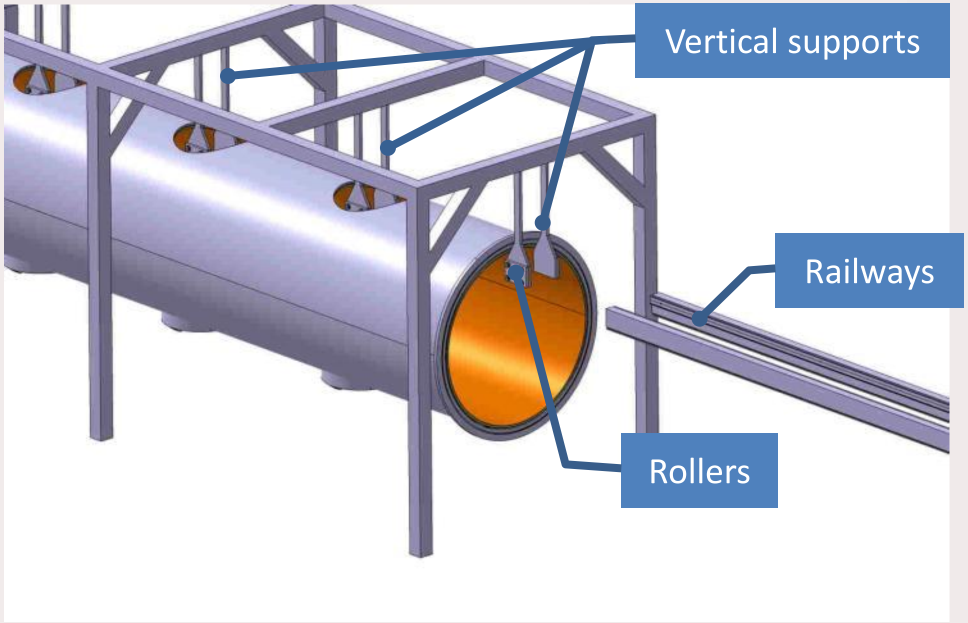
③



Example (1/3)

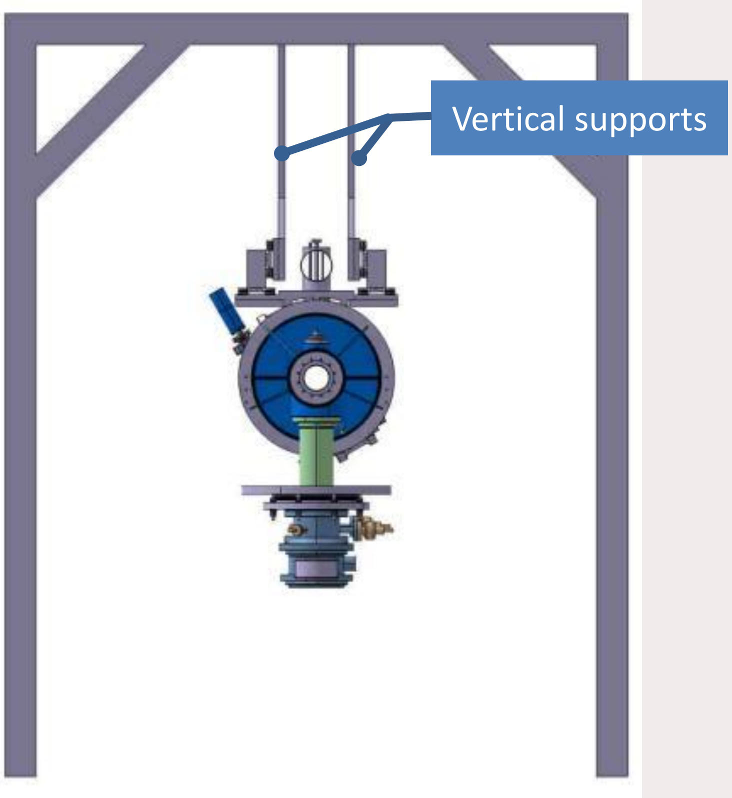


The vacuum vessel is supported by a dedicated tool allowing its displacement and lift of.



Fix tooling (around the vacuum vessel) :
Vertical supports are equipped with rollers allowing the insertion of railways within the vacuum vessel.

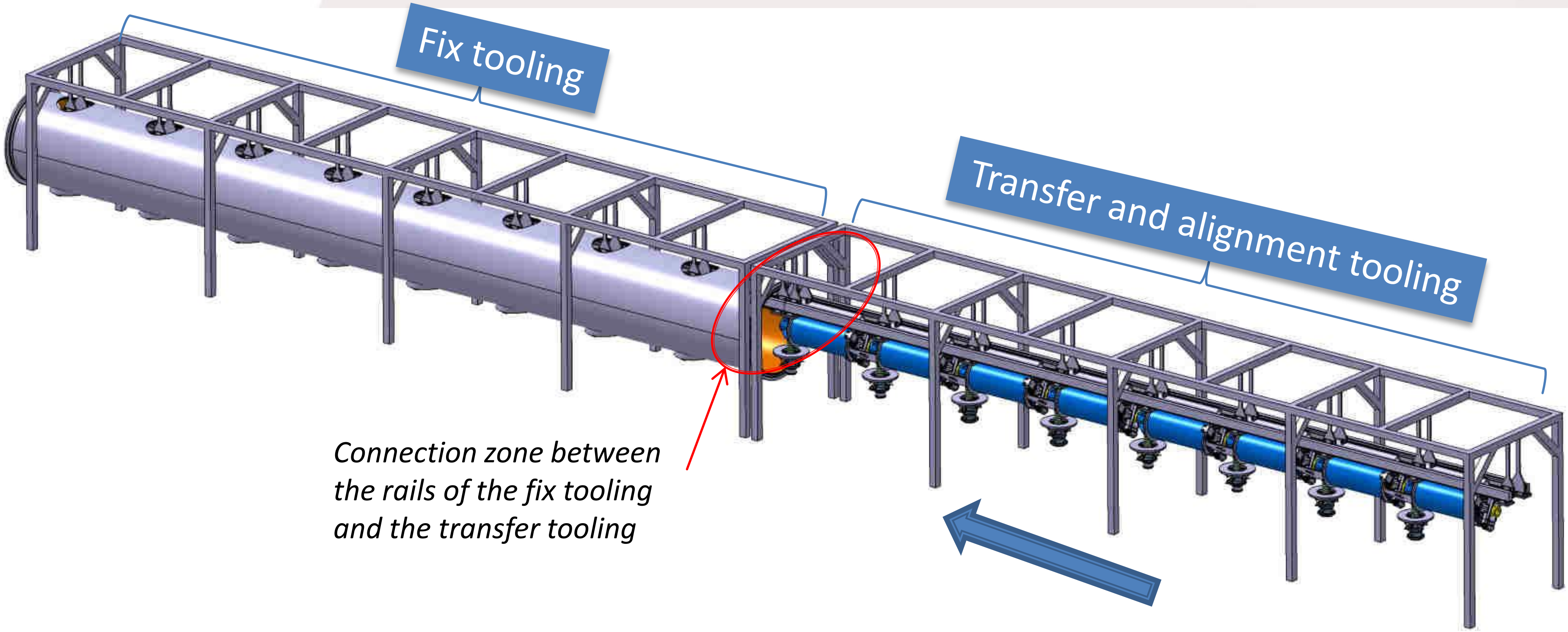
Example (2/3)



Transfer and alignment tooling

The string of cavities is supported by the same type of vertical supports and rails than for the fix tooling. Cavities are guided by the rails and can roll on them.

Example (3/3)



The string of cavities is moved along the rails inside the vacuum vessel

Investigation ⇒ Common tooling for the assembly inside the clean room and alignment outside

SUMMARY

- A ½-lenght cryomodule for the full test of 4 β=1 cavities is being design for the CERN

Issued from a collaboration between different institutes, it will be as similar as possible to a machine-type cryomodule for a future SPL

- **For now:**
  - Most of cryo-module requirements are settled
  - Most of the conceptual choices are made (cavity supporting system, cryogenic scheme…)
  - Still needing conceptual design work: magnetic shielding, thermal shield
  - Vacuum vessel: 2 concepts are being compared
    - Tube-type, large diameter (radial space constraint from cavity/tuner)
    - U type, construction complexity (=cost)
  - Assembly tooling concepts are under progress

- **Calendar:**
  - Preliminary design review will take place in Summer 2011
  - Detailed design review End 2011
  - Procurement of cryostat components starting in 2012
  - Assembly of cryomodule in second half of 2013, followed by testing

THANK YOU FOR YOUR ATTENTION

Unité mixte de recherche
CNRS-IN2P3
Université Paris-Sud 11

91406 Orsay cedex
Tél. : +33 1 69 15 73 40
Fax : +33 1 69 15 64 70
http://ipnweb.in2p3.fr