Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

PIP-II Cryomodules Design Overview

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International workshop on cryomodule design and standardization

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Layout

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2. Strong-back concept
   2.1 SSR Configuration
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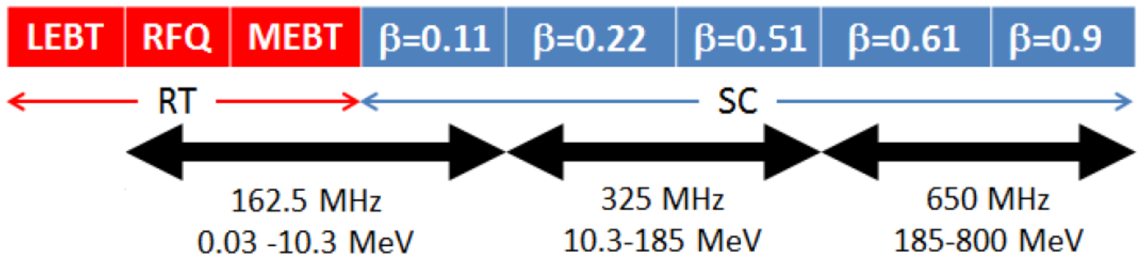
   2.3 Assembly process
3. Cryogenic layout of the cryomodules
4. Interfaces
5. Alignment

Introduction

The PIP II Superconducting Linac is composed of 5 types of cryomodules.
All have been designed for CW operation.



CM type	Cavities per CM	Number of CMs	CM configuration$^{\bullet}$	CM length (m)	Q_0 at 2K (10^{10})	Surface resistance, (nΩ)	Loaded $Q^{\clubsuit}$ (10^6)
HWR	8	1	8 × (sc)	5.93	0.5	9.6 ($2.75^{\spadesuit}$)	2.32
SSR1	8	2	4 × (csc)	5.3	0.6	14 ($10^{\#}$)	3.02
SSR2	5	7	sccsccsc	$6.5^{\blacklozenge}$	0.8	14.4	5.05
LB650	3	11	ccc	$4.32^{\blacklozenge}$	2.15	9.0	10.36
HB650	6	4	cccccc	$9.92^{\blacklozenge}$	3	8.7	9.92

New Functional Requirements Specifications will be out in the next weeks.

1. Design strategy

To decrease the design effort and the cost of the project, our idea was to design all the cryomodules with the same design concept: the strong-back, and then to have one configuration for the single spoke cryomodules, and one for the elliptical cryomodules.

SSR1 & SSR2 Cryomodules

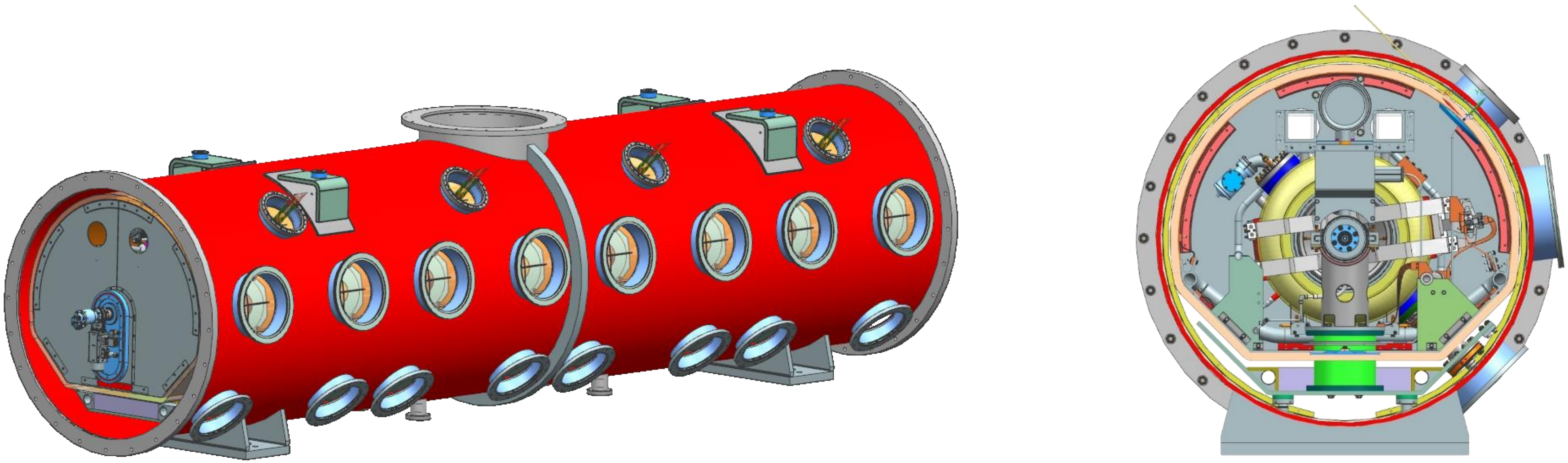
- Similar cavity design
- Similar tuner
- Same coupler
- Similar configuration:
  SSR1: **C**-**S**-**C**-**C**-**S**-**C**-**C**-**S**-**C**-**C**-**S**-**C**
  SSR2: **S**-**C**-**C**-**S**-**C**-**C**-**S**-**C**
- Similar solenoid
- Similar BPM
- Similar current leads
- Same cryogenic layout

LB650 & HB650 Cryomodules

- Similar cavity design
- Similar tuner
- Same coupler
- Similar configuration
  LB650: **C**-**C**-**C**
  HB650: **C**-**C**-**C**-**C**-**C**-**C**
- Same cryogenic layout

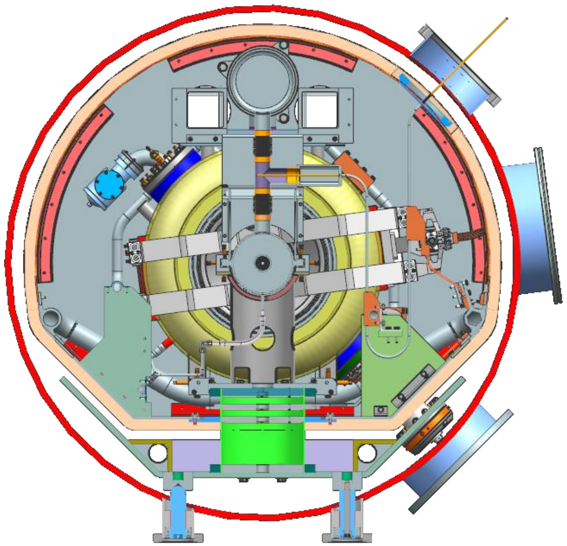
2. Strong-back concept

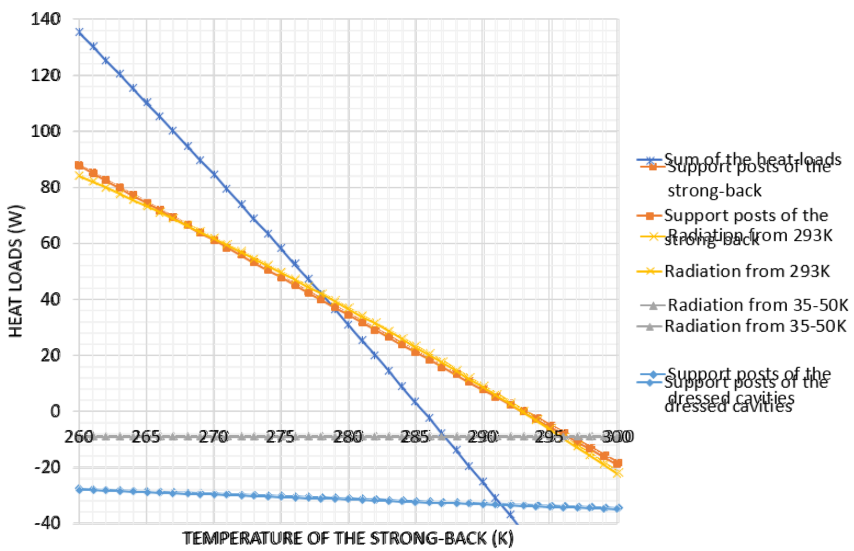
All cryomodules are based on a strong-back at room temperature. Calculations have been done in order to warrant that the strong-back will be still warm after the cool down of the cryomodule.



2. Strong-back concept

All the heat-loads applied on the strong-back can be estimated analytically according to the temperature of the strong-back. Then applying the 1st law of thermodynamics, the equilibrium temperature can be calculated.





T equilibrium : 286 K
Max vertical displacement : 2 µm

This variation of temperature is not an issue for the alignment.

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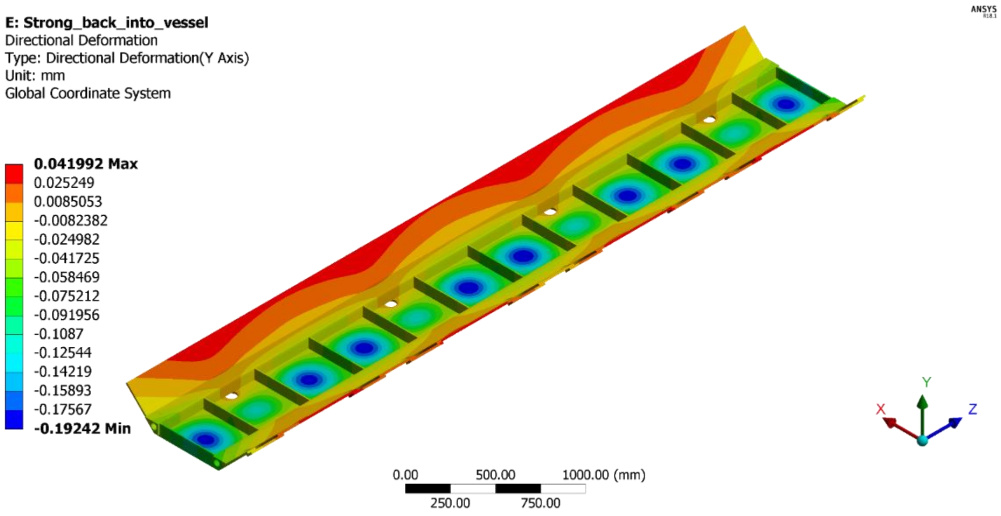
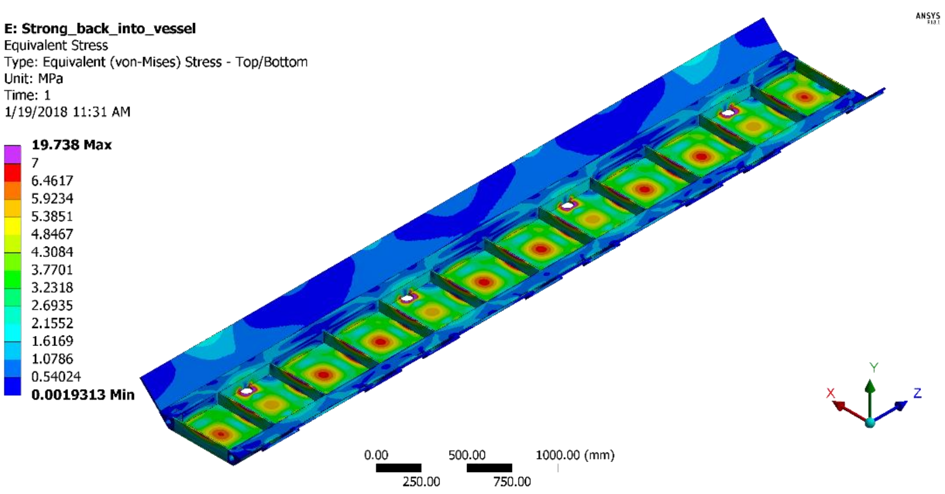
2. Strong-back concept



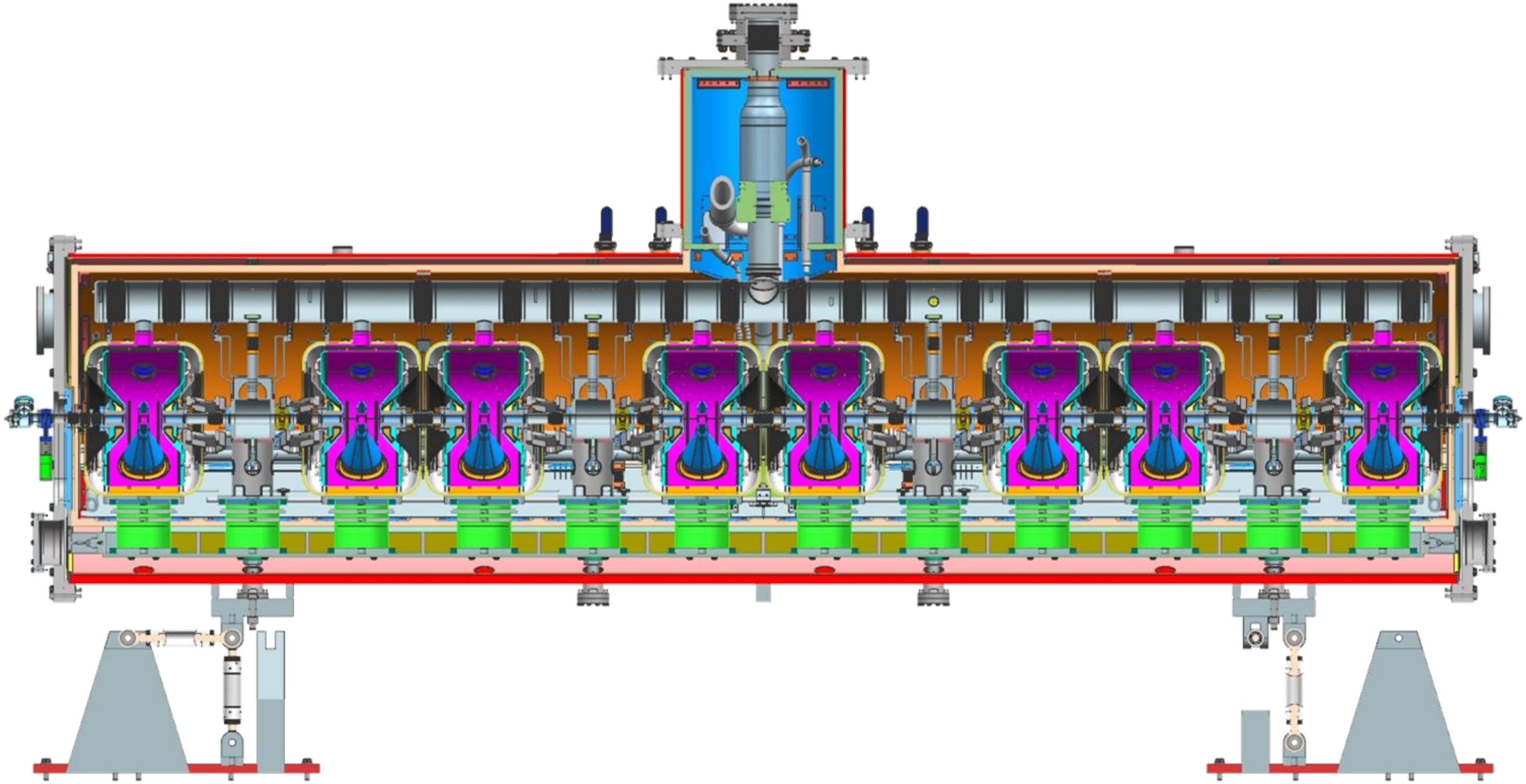
Structural and thermal analysis have been done in order to estimate the stress and the displacement.



The vertical displacement of the strong-back is very low around 0.2 mm and the max Von Mises stress is around 20 MPa compared to 55 MPa the max allowable stress for welded aluminum 6061-T6.

2. Strong-back concept

2.1 SSR configuration

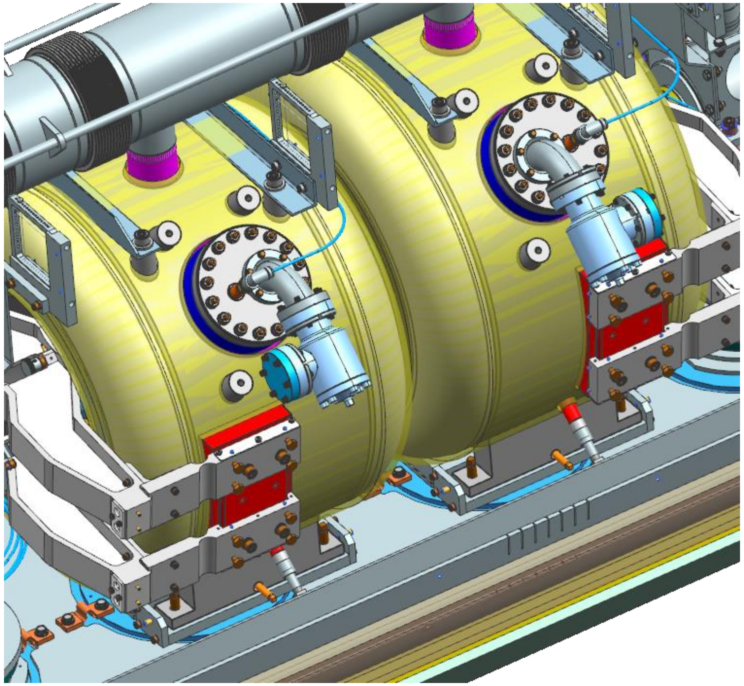


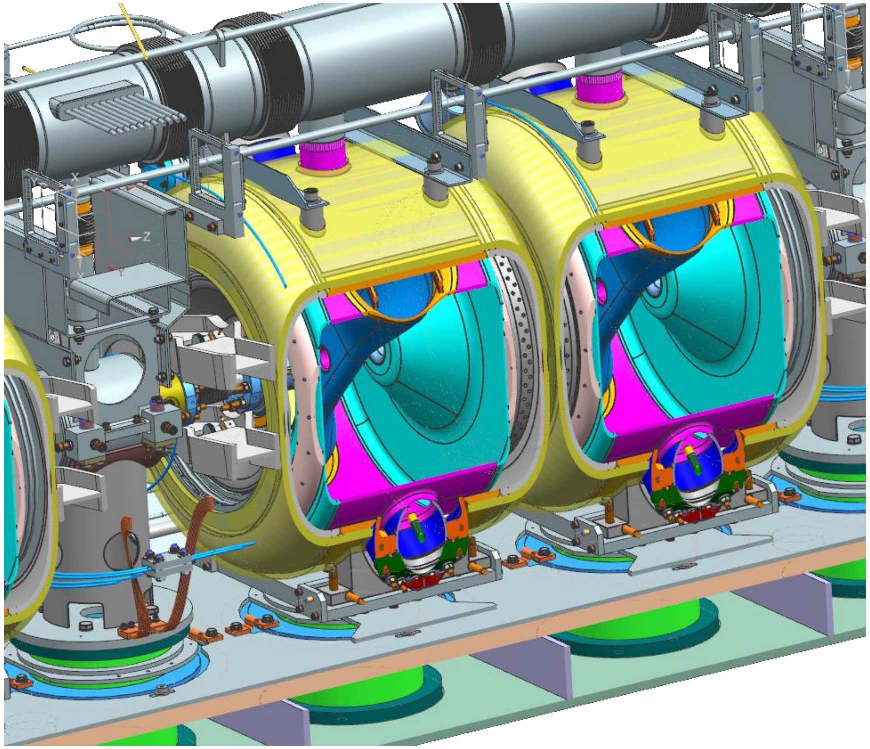
SSR configuration - One support post per cavity and per solenoid

2. Strong-back concept

2.1 SSR configuration

With several sets of screws, we control the location of each cavity. Then each cavity are secured with nuts.





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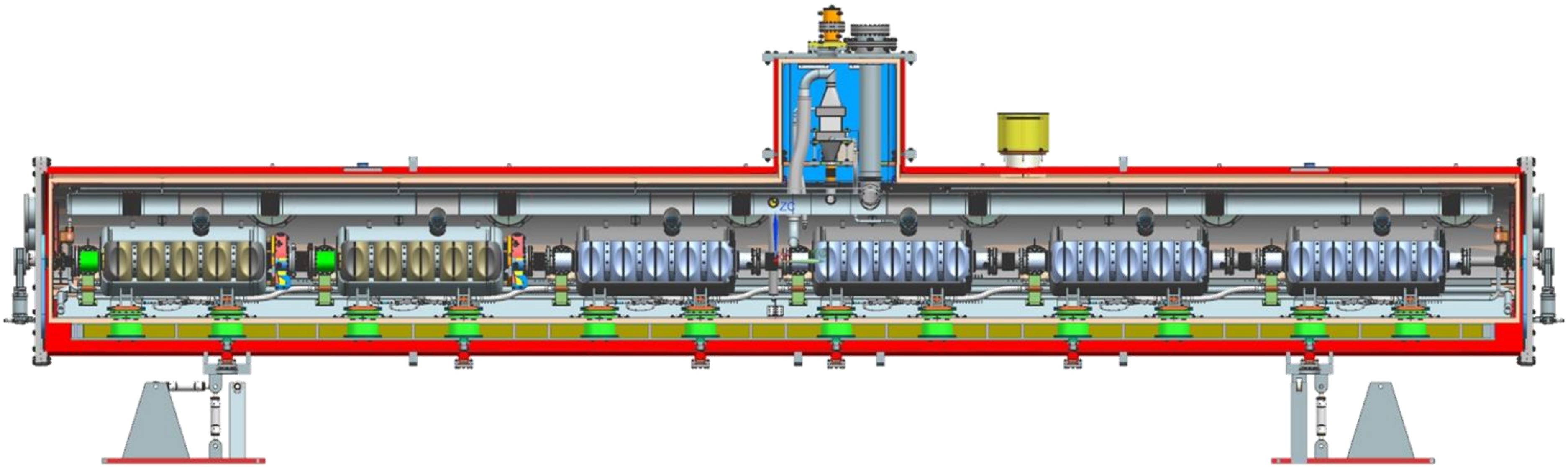
2. Strong-back concept

2.2 650 configuration

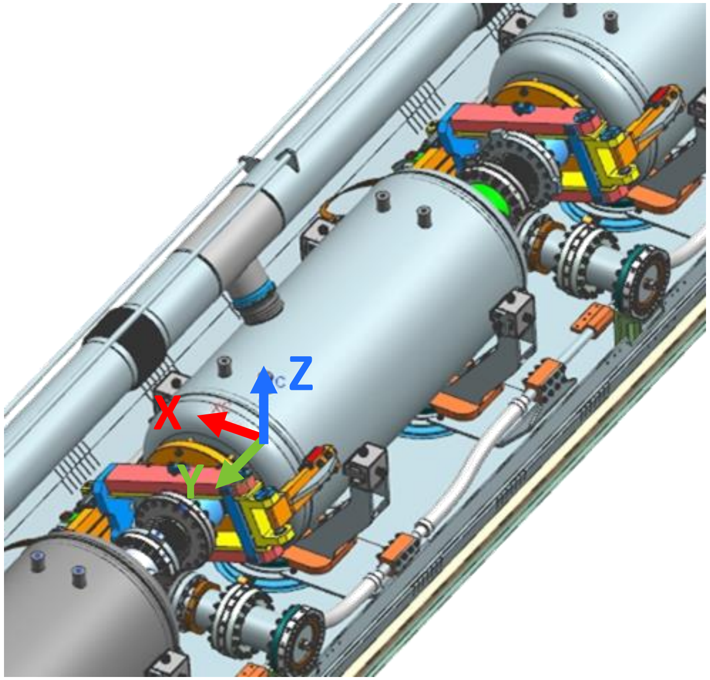


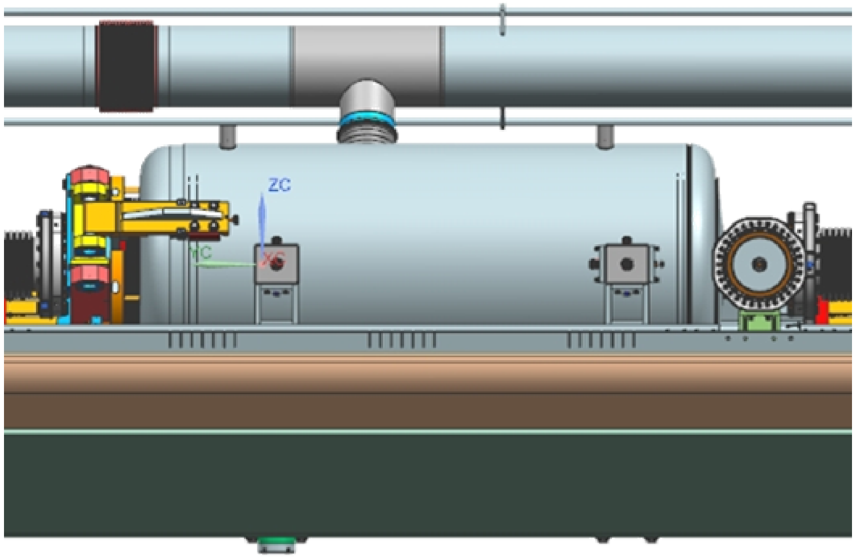
650 configuration - Two support posts per cavity

2. Strong-back concept

2.2 650 configuration

4 Lugs are welded on each cavity as LCLS II cavities. But, there is no invar rod inside the coldmass, the alignment is exclusively done using the C clamps. With several sets of screws and springs, we control the location of each cavity.



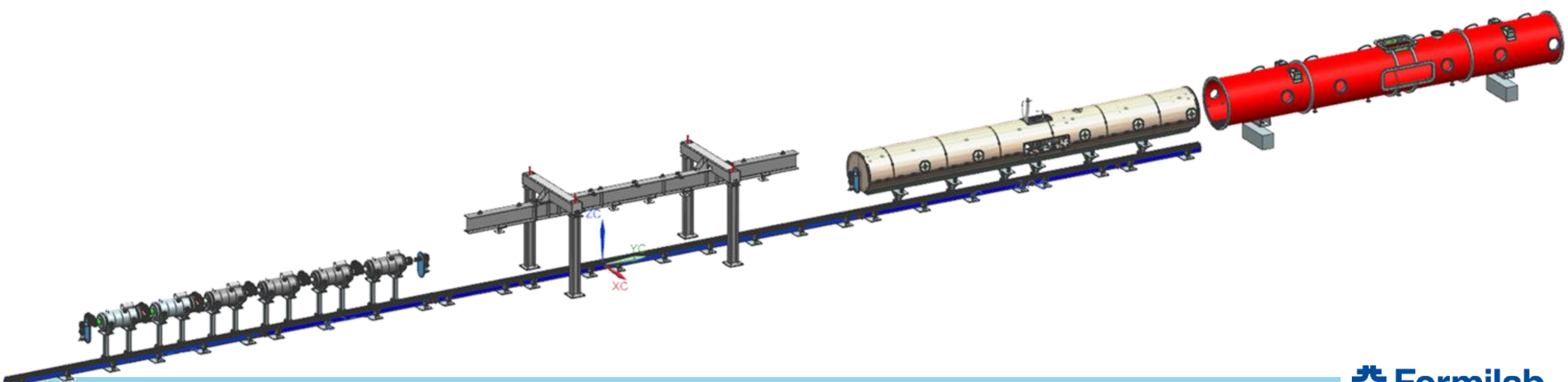


2. Strong-back concept

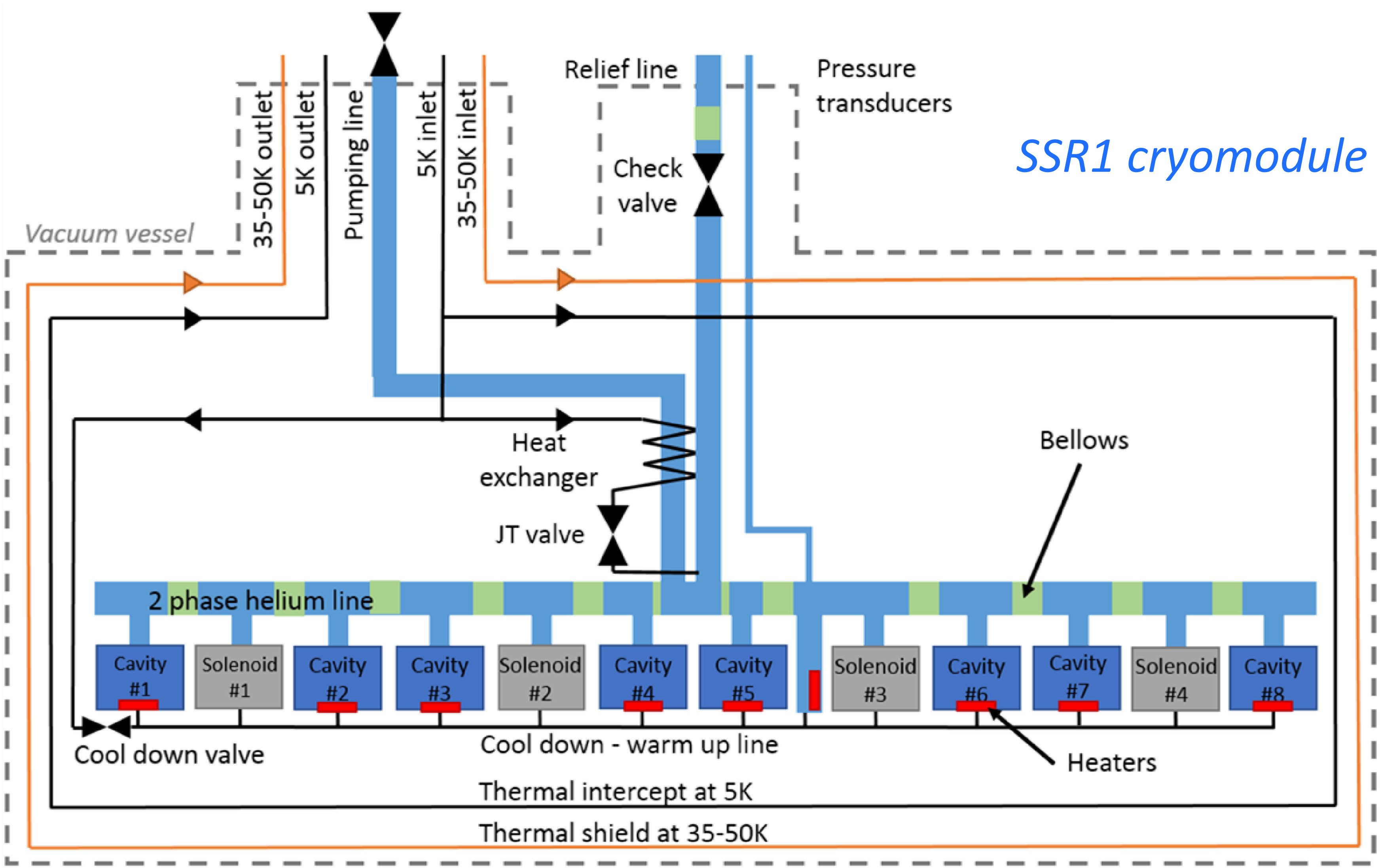
2.3 Assembly process

The assembly process is the same for SRR and 650 configurations:

- Workstation 1: Assembly of the cavity string in the clean room
- Workstation 2: Lifting of the string assembly
  Welding of the cool-down / warm up line
  Moving down the string assembly on the strong-back assembly
- Workstation 3: Assembly of the cold-mass
- Workstation 4: Insertion of the cold-mass in the vacuum vessel
  Completion of the cryomodule



3. Cryogenic layout of the cryomodules

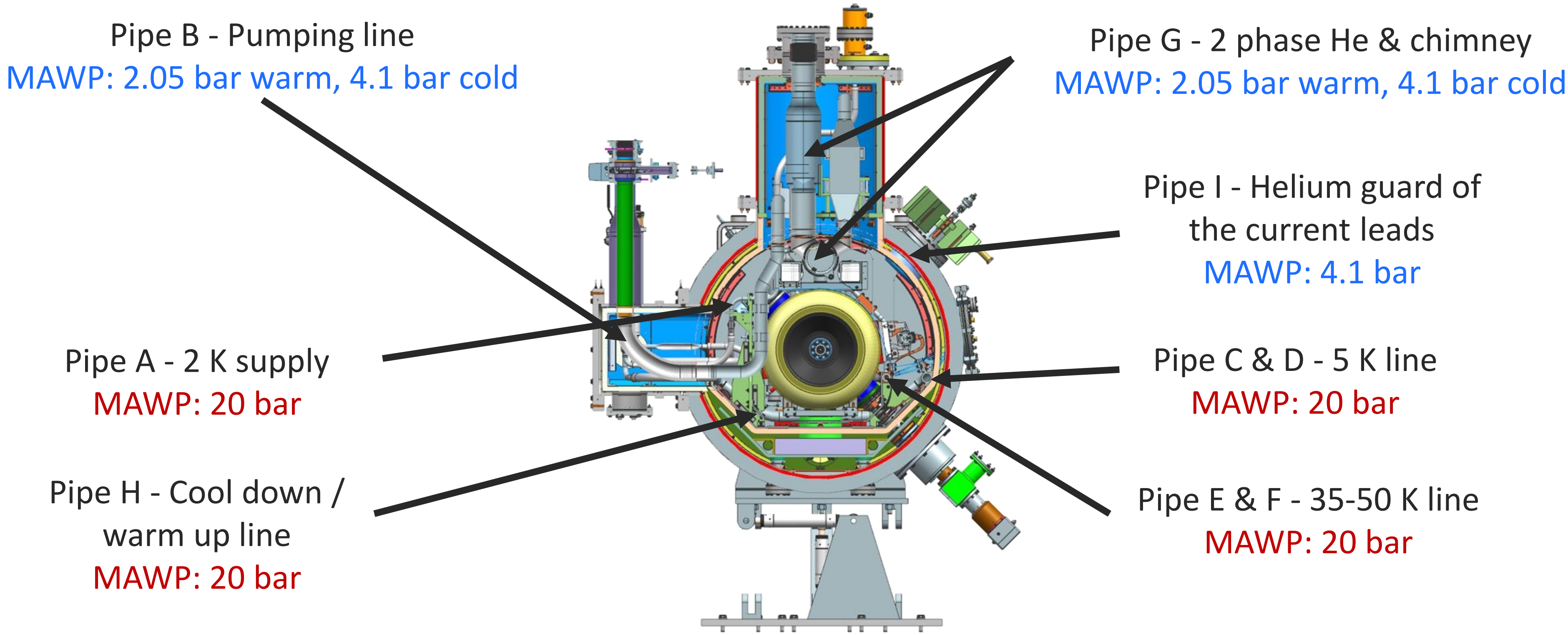


3. Cryogenic layout of the cryomodules

All cryomodules have the same layout and the same pressure design values.

All cryomodules need to be compatible with a fast cool down:

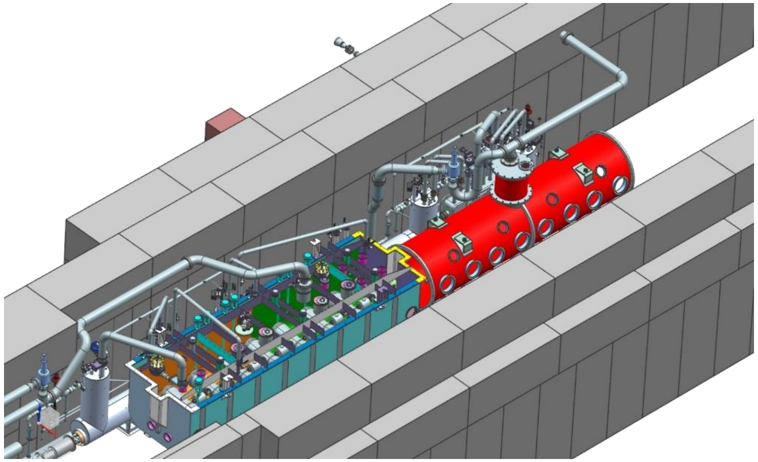
- Above 20 K/hour through the Q-disease regime 90 - 175 K.
- Above 120 K/hour through the superconducting transition at 9.2 K

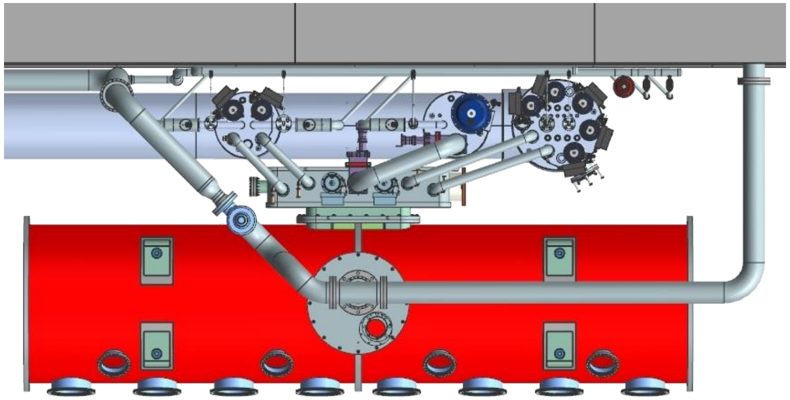


4. Interfaces

Cryomodules will be tested at PIP2IT and then they will be set up in the PIP2 Linac. Therefore it is essential to have a common interface.

- The transverse envelope and the weight of each cryomodule as specified in the Functional Requirements Specification cannot be exceed (max 14 000 kg Cryomodule + lifting fixture)
- Identical cryogenic side port, will simplify a lot the design of PIP2IT and PIP2 Linac.

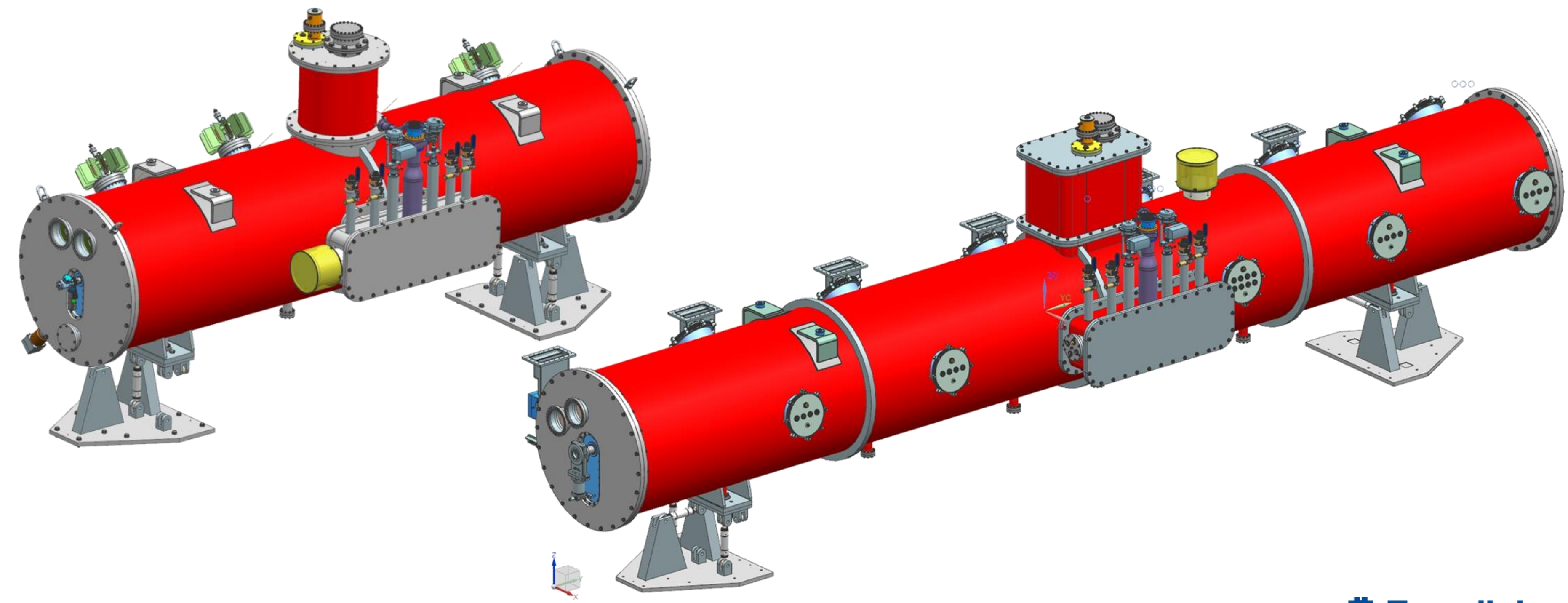




4. Interfaces

Cryomodules will be tested at PIP2IT and then they will be set up in the PIP2 Linac. Therefore it is essential to have a common interface.

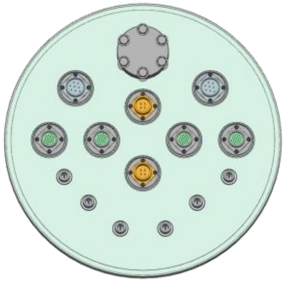
- Cryomodules need to be designed in order to accommodate the same cryomodule stands. These stands allow a movement of +/- 30 mm in all directions



4. Interfaces

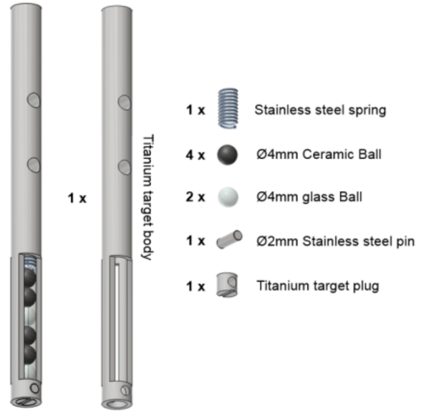
Cryomodules will be tested at PIP2IT and then they will be set up in the PIP2 Linac. Therefore, it is essential to have a common interface.

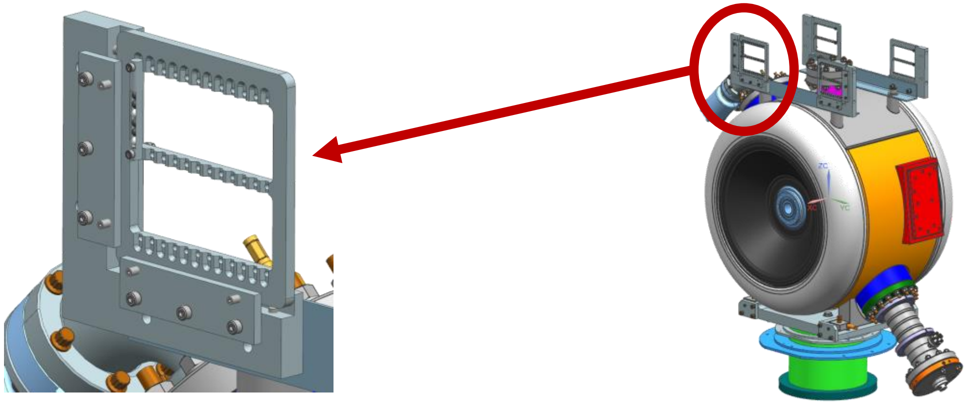
- It will be better to use the same cryomodule movers.



- Instrumentation connector need to be standardized. Detoronics or Ceramtec connectors will be used.

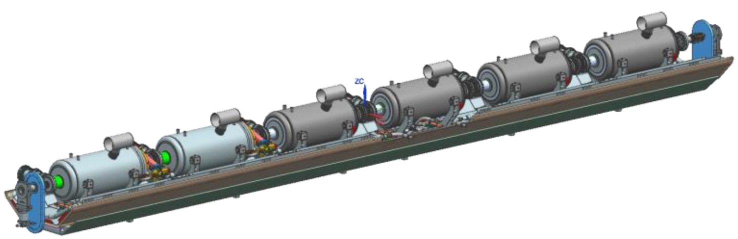
- The same fiducials on each cavity and solenoid will be used

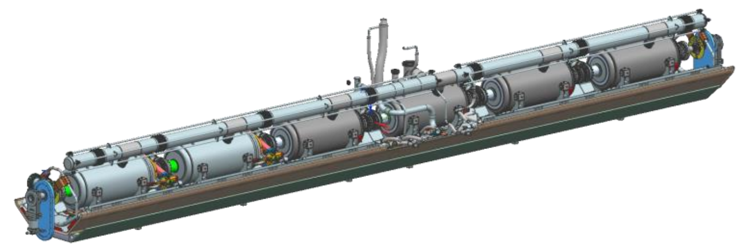




5. Alignment strategy

1. Cavities will be measured in order to record their geometrical, electric and magnetic axis wrt fiducials placed on their top.
2. During the assembly of the beam line, inclinometers will be placed on each cavity to get a rough alignment and avoid stress on the bellows.
3. Once the beam line moved down on the strong-back, a rough alignment of the cavities will be done taking into account the shift due to the thermal contraction during the cool-down. After welding the two-phase helium pipe, 4 fiducials will be set up on each cavity and the final alignment will be done.

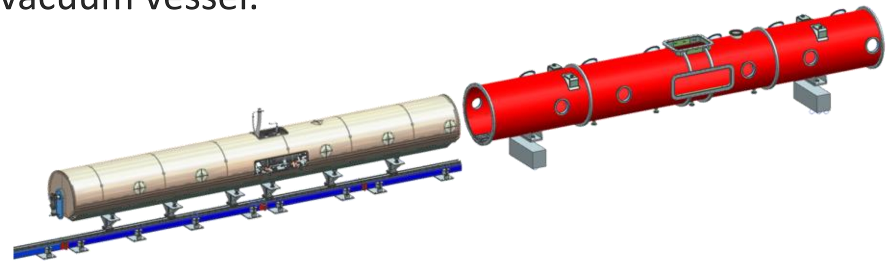




Transverse cavity alignment error, mm RMS	<1
Angular cavity alignment error, mrad RMS	≤10
Transverse solenoid alignment error, mm RMS	<0.5
Angular solenoid alignment error, mrad RMS	<1

5. Alignment strategy

The key of the strong-back strategy is to support the strong-back in the same way on the insertion tooling and inside the vacuum vessel.



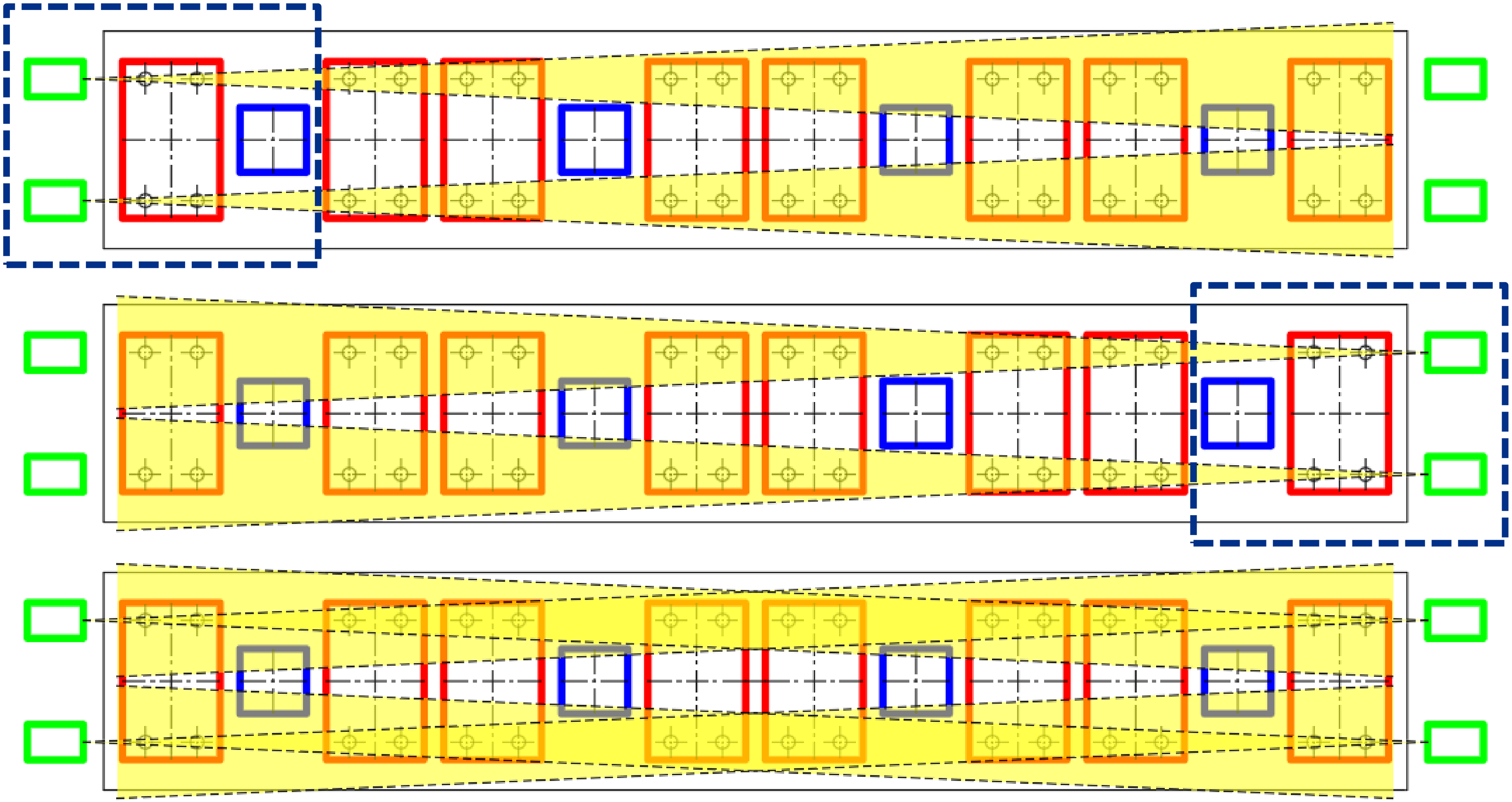
4. The coldmass will be inserted in the vacuum vessel slightly below the nominal position. Rollers located below the strong-back will be used. Then the coldmass will be lift up using several set of screws. Finally the alignment will be transferred to the vacuum vessel. (*The insertion tooling is still under-designed).*

5. After the insertion, the alignment of all the cavities will be checked using HBCAM.

6. Finally the alignment will be transferred to the vacuum vessel.

7. View ports will allow to control the location of the cavities during transport, and cool down.

5. Alignment strategy / SSR1 cryomodule



- BCAM: at least 20m range with active targets
  - Minimum distance: 80cm

Conclusion

SSR1 & SRR2 Cryomodules

- Since all SSR cryomodule will be fabricated at Fermilab, less analysis will be necessary and dedicated to the transport.
- SSR1 prototype cryomodule will validate the strong-back concept.
- If the strong-back concept is validated, the strong-back will be also used for SSR1 & SSR2 cryomodules.

LB650 & HB650 Cryomodules

- Our design strategy was so far to use the feedback of SSR1 cryomodule to design the 650 cryomodules
- However, the 650 configuration is different from SSR configuration especially the way how the cavities are hold and aligned.
- Due to the fact that main of these cryomodules will be assembled in Europe, the transport is an important topic for which no calculations have been done so far.