DESIGN OF A SHORT CRYOMODULE FOR THE SUPER PROTON LINAC

IPNO – CNRS

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Contents

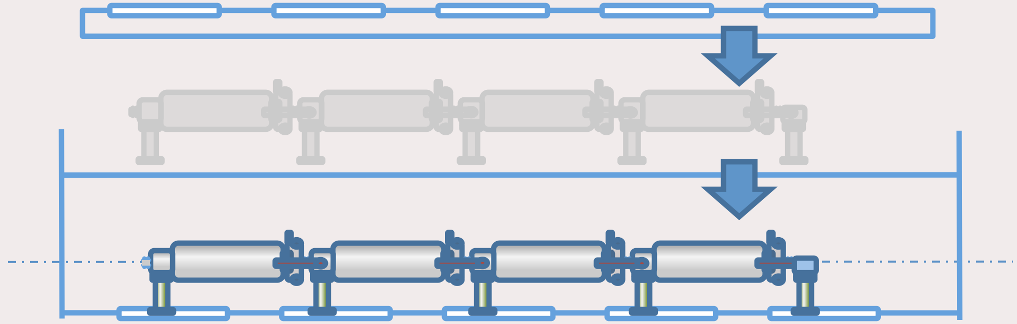
1 – Conceptual design choices

Conceptual design study

Several mechanical studies were achieved to compare different:

- vacuum vessels ;
- thermal shields (70K);
- magnetic shields;
- cavity support systems;
- alignment procedures;
- cryogenic distributions lines integration;
- assembly procedures;
- tooling.

⇒ A vacuum vessel with a removable top cover (lid) was chosen.



It allows:

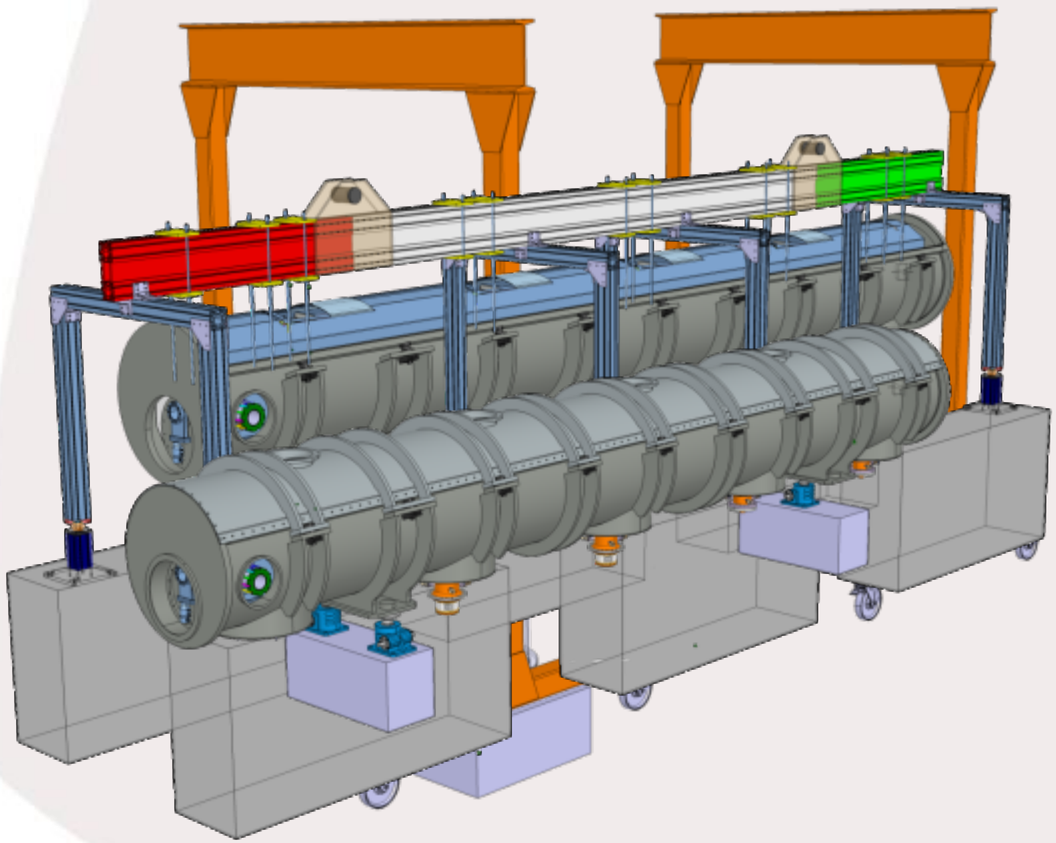
- A simpler vertical cryostating (simpler tooling)
- A better alignment diagnostic of the string of cavities

This choice was validated at the Conceptual Design Review (November 4th 2011)

⇒ Now: detailed design study

1 – Conceptual design choices

Assembly concept



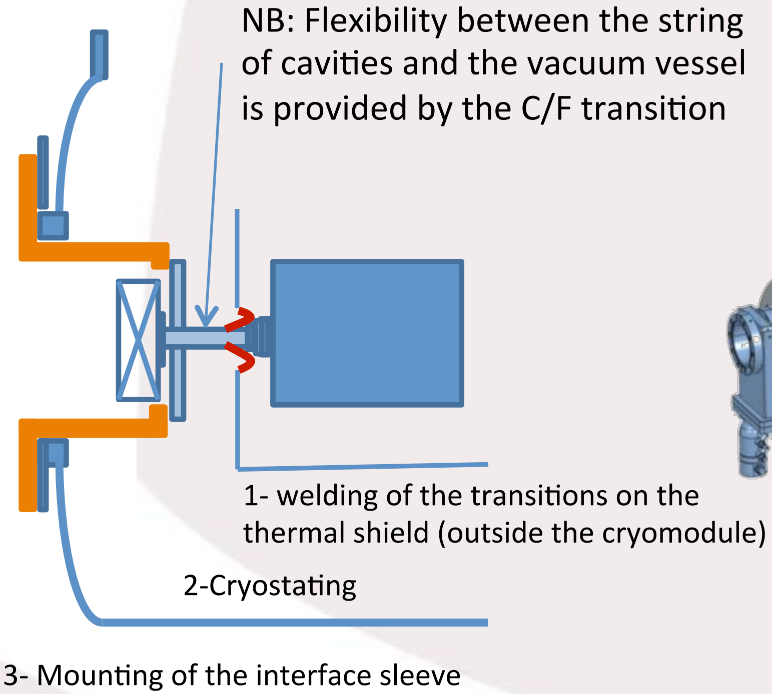
2 – Vacuum vessel design

Vacuum vessel / string of cavities interface

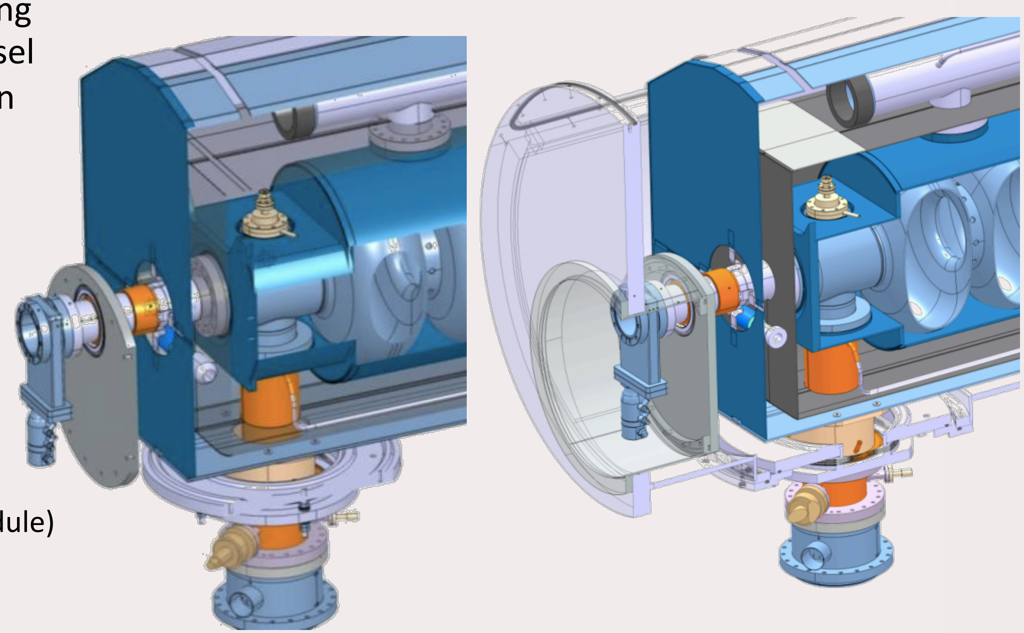
Context:

- Warm valves at the end of the string of cavities;
- Cold /warm transitions should then be assembled before cryostating (i.e. oustide the cryostat);
- The thermal shield is mounted onto the string of cavities before cryostating
- Presence of a top lid on the vacuum vessel ⇒ no need of removable end caps.

Prevailed principle for the interface:



Mechanical integration

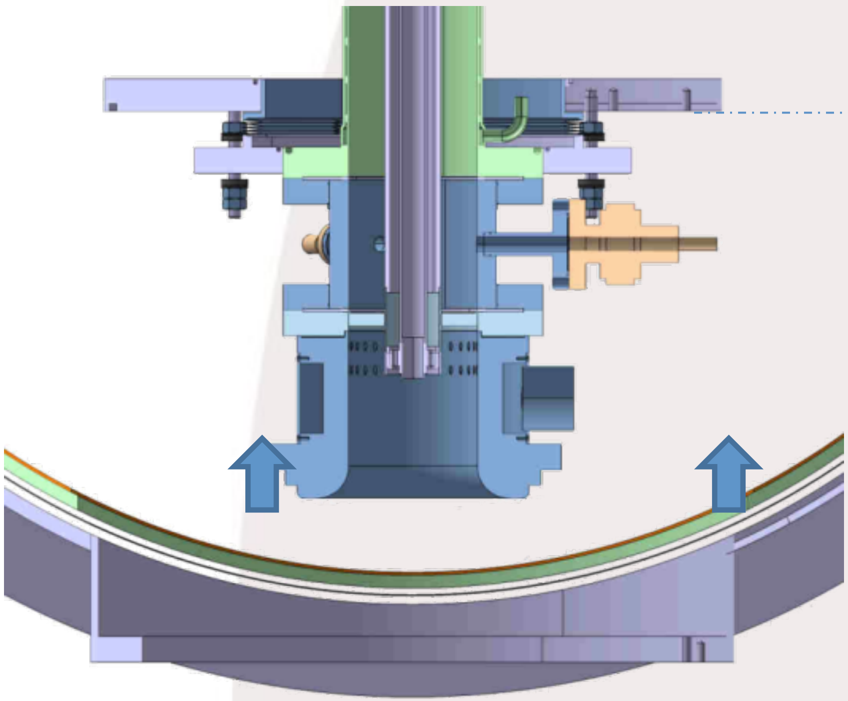


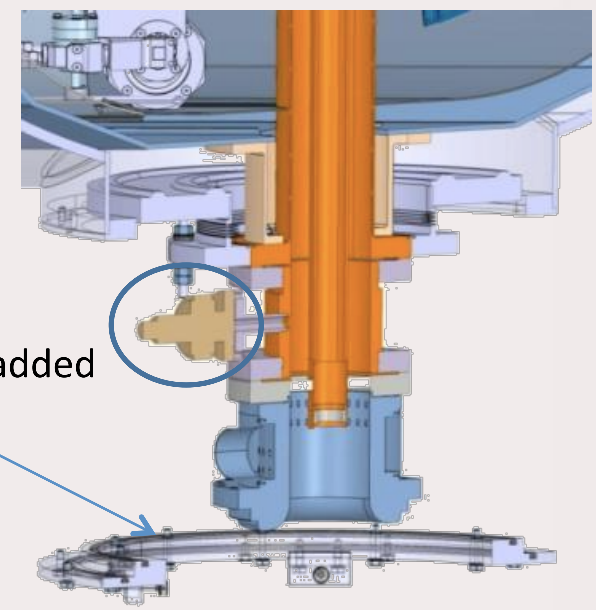
⇒ The cold/warm transition is now thermally optimized (CERN+CNRS)

2 – Vacuum vessel design

Vacuum vessel / Coupler interface

CERN
Cf. Paulo Azevedo's presentation





A closure flange is added

- It allows to:
- enlarge the bearings of the vacuum vessel
- avoid the beam axis translation which was necessary to integrate the vacuum gauge;
- the (small) reduction of the diameter of the coupler sealing flange

2 – Vacuum vessel design

Top closure tightness

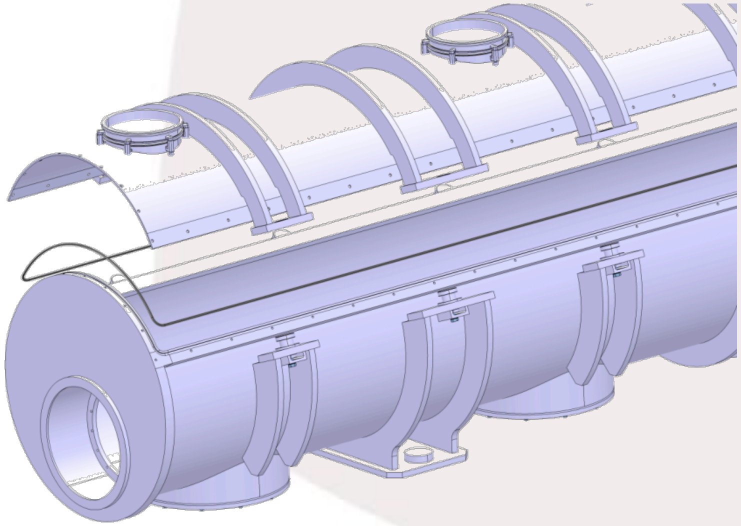
Context:

To learn from the alignment procedure and for an easy maintenance access, the top lid is not welded on the prototype (TBC)

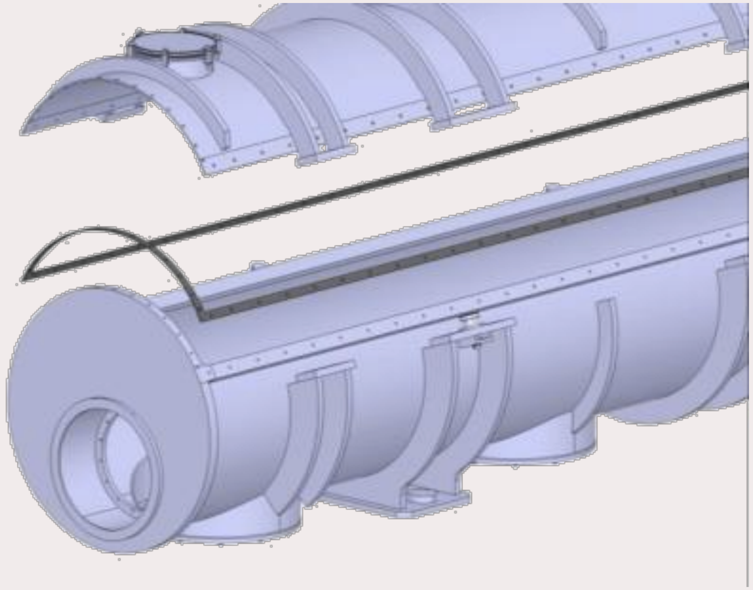
⇒ Tightness is provided by a polymer joint

2 solutions are studied:

- a polymer o-ring inserted in a groove machined in the top flange of the vacuum vessel;



- a polymer flat joint laying on the top flange of the vacuum vessel

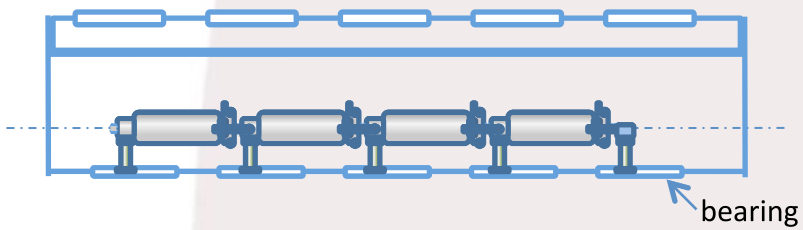


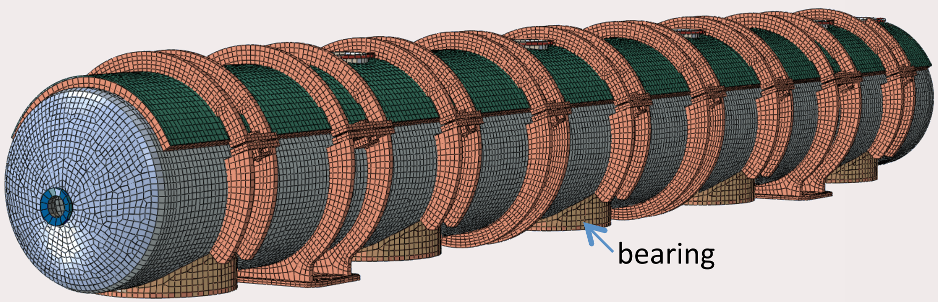
⇒ Discussions are carried out with a possible provider to help for the design

2 – Vacuum vessel design

Mechanical approaches

- Static analysis were carried out during the conceptual design
  - Different loading scenarii were considered (linked to the cryostating procedure)
    - Vacuum Vessel Weight;
    - Vacuum Vessel Weight + loading with the string of cavities;
    - External pressure to simulate vacuum;
    - Transport accelerations;
  - Goals:
    - Verify that the displacement of the bearings vacuum vessel was small (in order to keep the alignment of the string of cavities within the specifications);





Version CNRS (Nov. 2011) with dish ends

    - Verify the mechanical strength of the prevailed concepts;
    - Assess the interaction between the top lid and the vacuum vessel.

- Buckling analysis
  - Linear and non linear analysis were achieved
  - Goals:
    - Assess the buckling behavior of this vacuum vessel;
    - Verify the structural stability of this vacuum vessel.

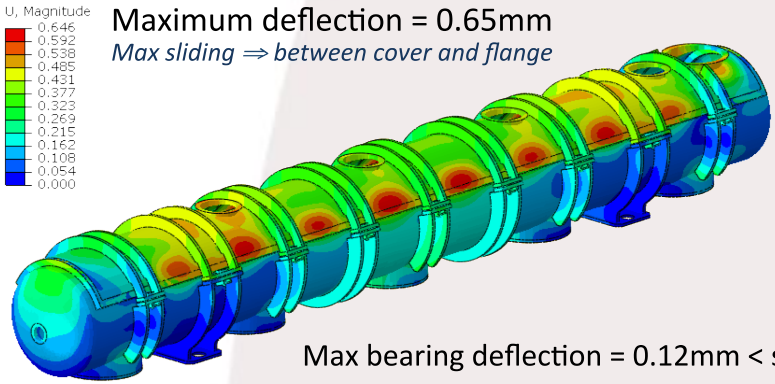
Mechanical approaches

- Static analysis: example of results

• *Displacements*

Maximum deflection = 0.65mm

Max sliding ⇒ between cover and flange

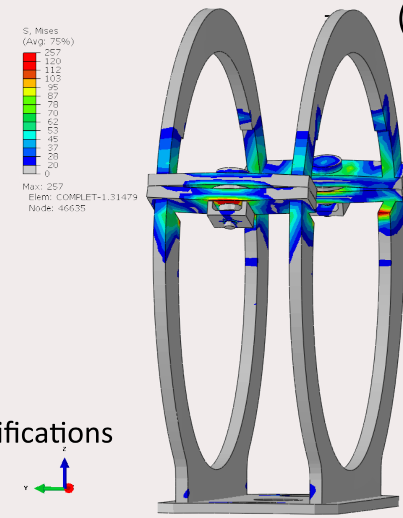


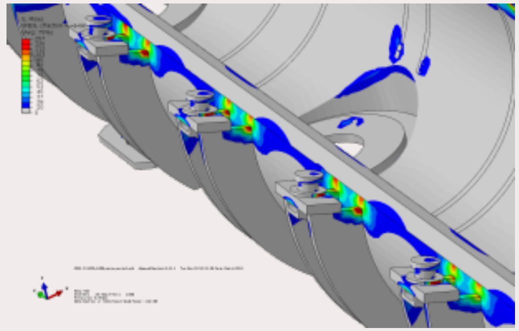
Max bearing deflection = 0.12mm < specifications

Version CNRS (Nov. 2011) with dish ends

• *Stress*

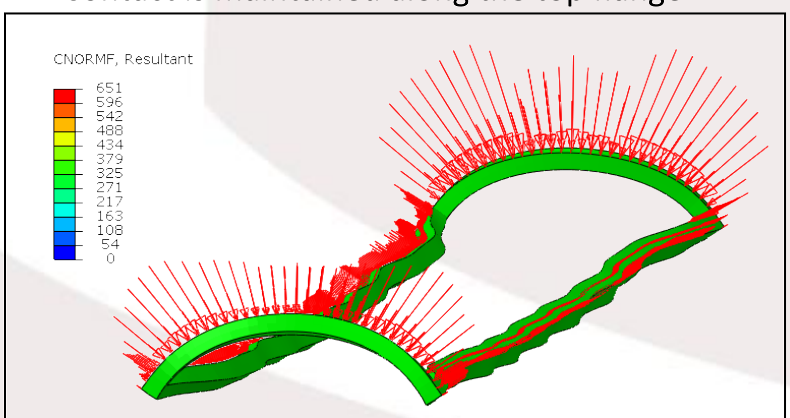
⇒Stress is maximum in the connection zone between top and bottom reinforcement rings (but acceptable)





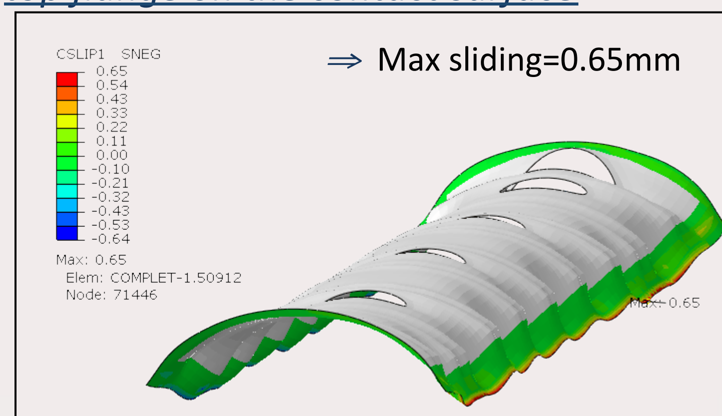
• *Contact force on the top flange*

⇒ Contact is maintained along the top flange



• *Displacement between the lid and the top flange on the contact surface*

⇒ Max sliding=0.65mm



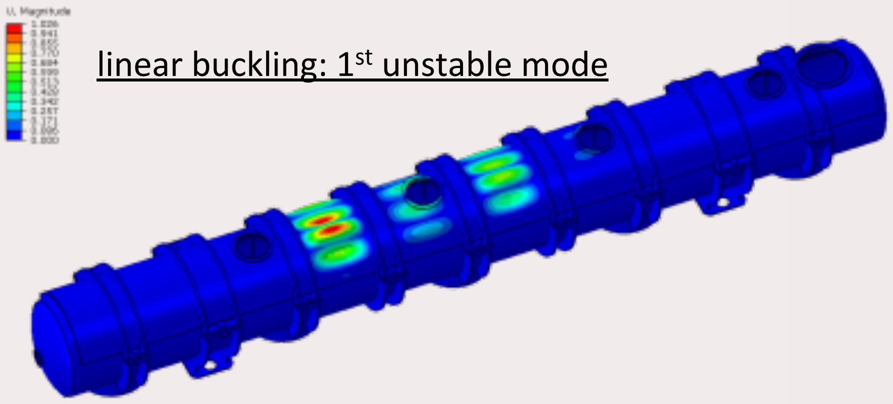
Mechanical approaches

- Buckling analysis
  - NB:
    - Numerical approaches were carried out by CNRS and CERN.
    - Different models and codes were used and compared:
      - CNRS used Abaqus; CERN ANSYS
      - CNRS model was based on a complete CAD model; CERN model was based on a simplified model that allowed to assess a global behavior of the vacuum vessel and might be used for design optimization
    - Our goal was to define a confident approach for the buckling problem of this vacuum vessel
  - Linear Buckling

CNRS Version: **Load factor (Mode1): 42**
CERN Version (Simplified model): **Load factor (mode 1): 45**

⇒ Load factor > 40
⇒ Good agreement

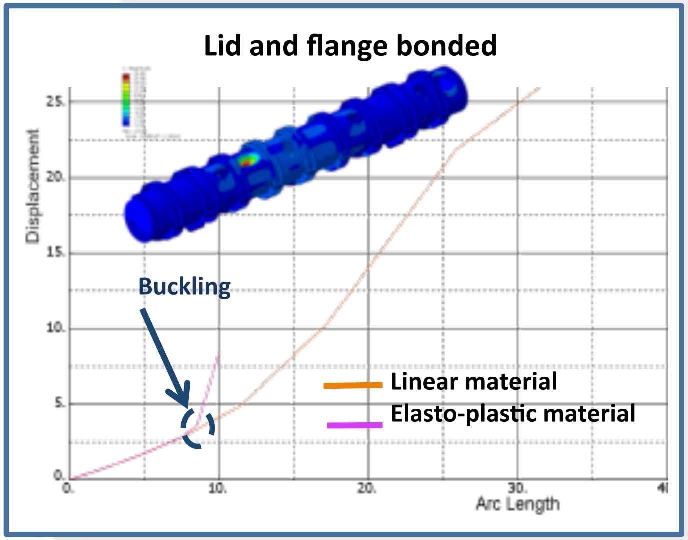
linear buckling: 1st unstable mode

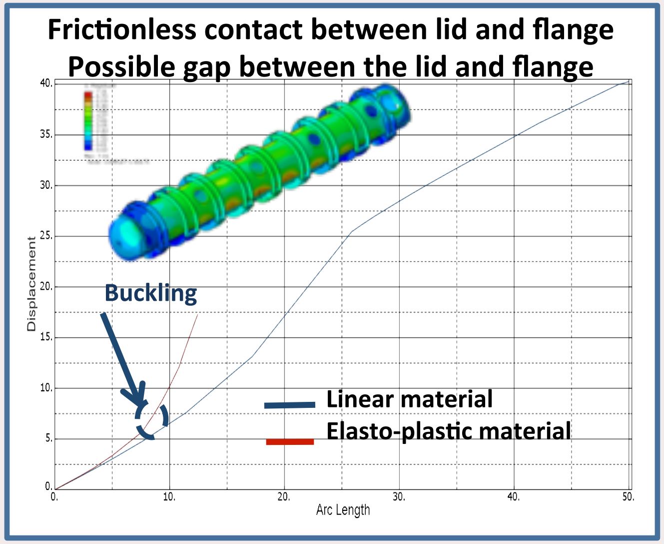


Version CNRS (Nov. 2011) with dish ends, holes & bolts

2 – Vacuum vessel design

- Buckling analysis
  - Non Linear Buckling
    - **Pre-deformation of 5 mm** (applied on the 1st buckling mode issued from the linear buckling analysis achieved with bonded contact)
    - **Bonded** contact or **sliding** contact between lid and flange (Abaqus: possible separation (gap) / ansys: no separation)
    - Linear material or **Nonlinear** material





⇒ Load factor > 7.5

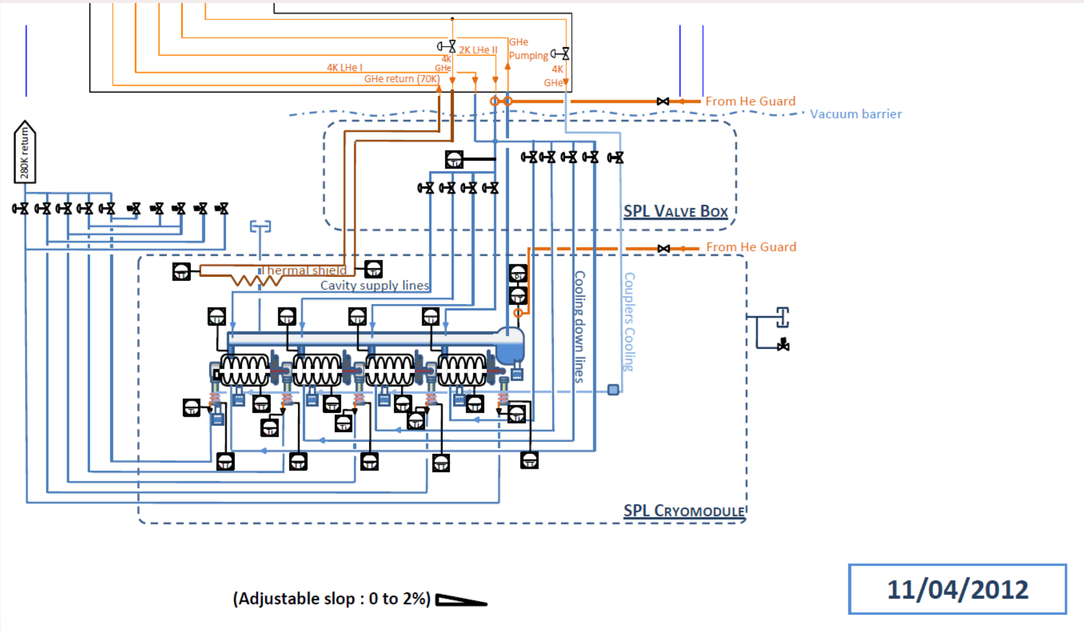
⇒ This action is still under progress: convergence between CNRS and CERN models

- Present work
  - We now focus on the optimization of the design of the vacuum vessel (static + buckling analysis):
    - Lowering the number of reinforcements rings
    - Finding a better design of the connection between top and bottom rings

2 – Cryogenic jumper & cold box

Context:

- The cryomodule includes a top lid for:
• an easy assembly / de-assembly process; alignment procedure;
• a simple access to key components
- The test bunker volume is limited (especially the height of the roof)
- The cryomodule will rotate from an horizontal position to a 2% slop during the tests
- The prototype includes more cryogenic lines than a machine cryomodule



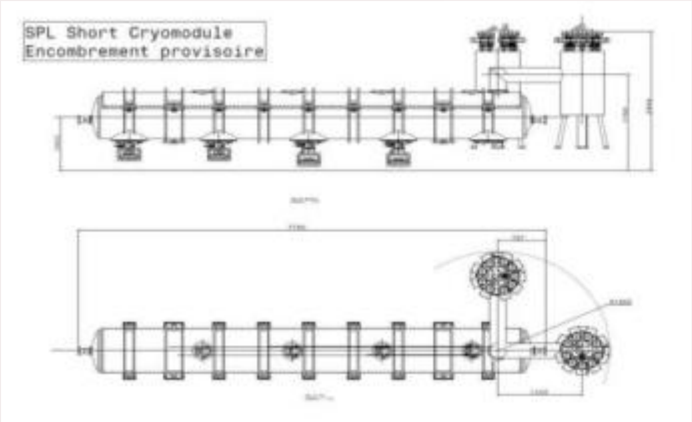
Solutions studied:

• Connection of the jumper to the top lid of the cryomodule;
• Connection of the jumper to the main part of the cryomodule vacuum vessel;

2 – Cryogenic jumper & cold box

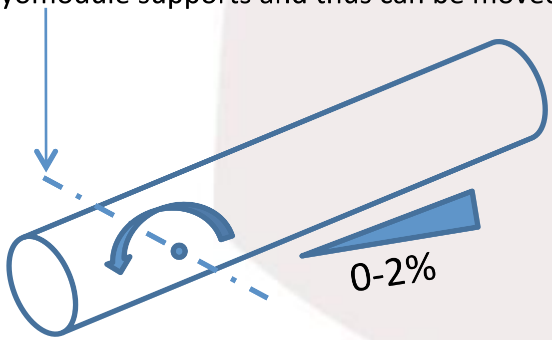
Position of the cold box

2 possible positions:
- aside the cryomodule;
- in the beam axis direction.

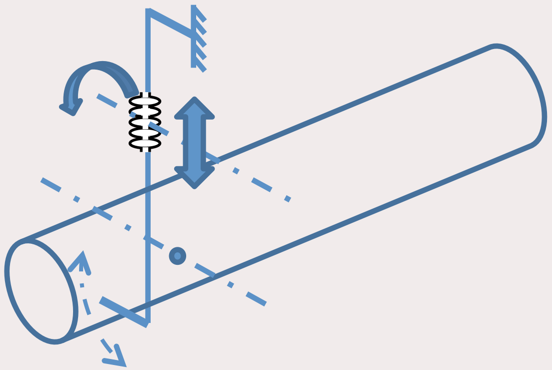


The jumper should compensate the slop by transforming the rotation induced by the inclination of the cryomodule (1.15°) into a {translation + bending} motion
⇒ use of a bellows

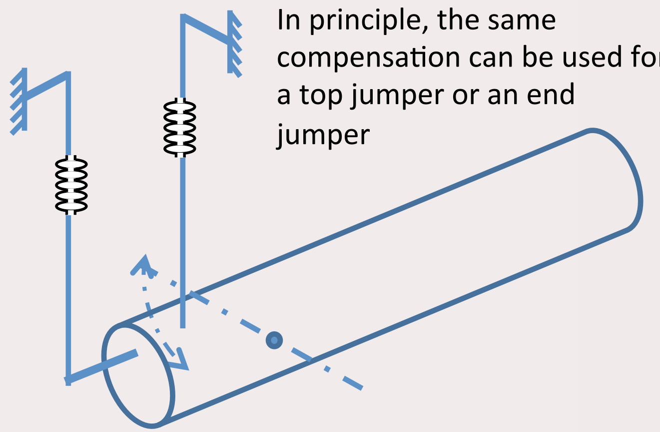
Rotation axis of the cryomodule (NB: the position of this axis depends on the cryomodule supports and thus can be moved)



{Translation + bending} compensation by use of a bellows



In principle, the same compensation can be used for a top jumper or an end jumper



⇒the amplitude of the translation (compression/traction) versus the bending amplitude depends on the position of this bellows from the rotation axis of the cryomodule (we prefer a translation motion)

2 – Cryogenic jumper & cold box

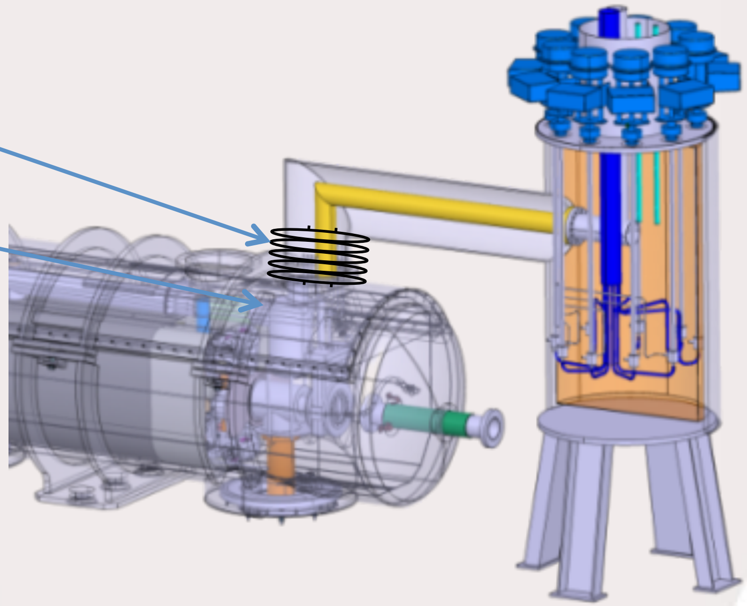
Top lid jumper

Pros:

- Easy connection /disconnection of the jumper and cryogenic lines (large access);

Cons:

- disconnection of the jumper and cryogenic lines is required before lid removal;
- due to the space requirement of the jumper, it is very difficult to get enough space for the LHe level sensor lid interface and connection to the separator;
- due to the space requirement of the jumper and position of the separator (on the end support pod), reinforcements of the vacuum vessel which are located in the vessel bearing plane have to be cut inducing more displacement of this bearing during pumping;



2 – Cryogenic jumper & cold box

Lateral jumper

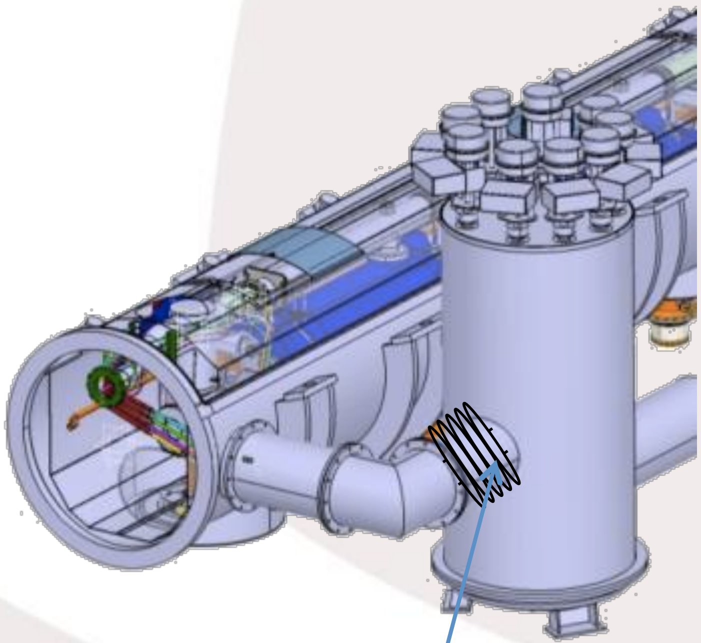
Pros:

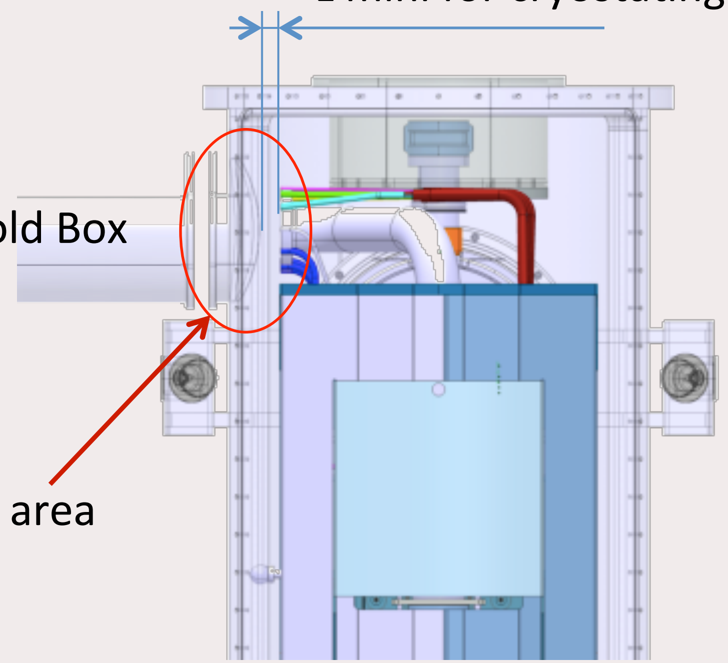
• Disconnection of the jumper and cryogenic lines is NOT required before lid removal;

Cons:

• Connection /disconnection of the cryogenic lines is difficult (due to poor access);

• Connection of the pumping tube to the phase separator is difficult due to the lack of space between the phase separator and the wall of the vacuum vessel (cf. next slide);

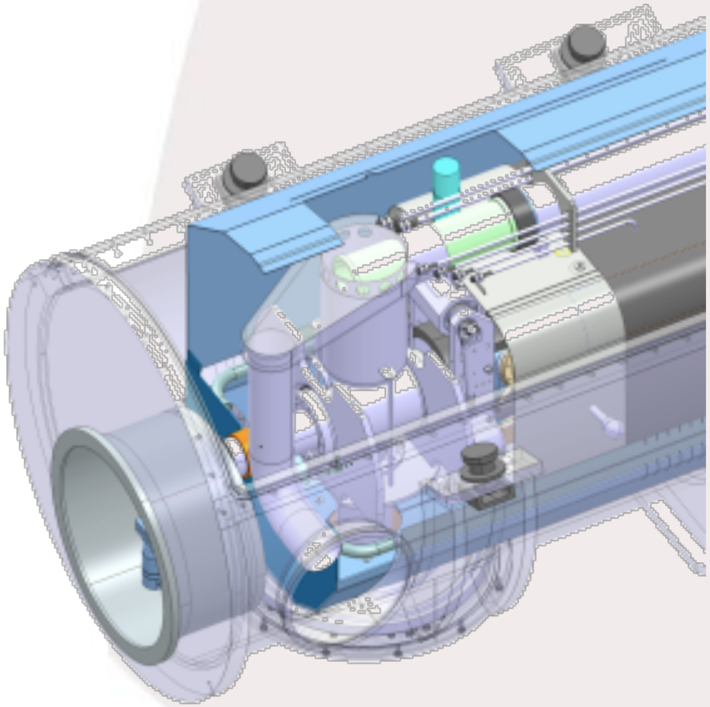


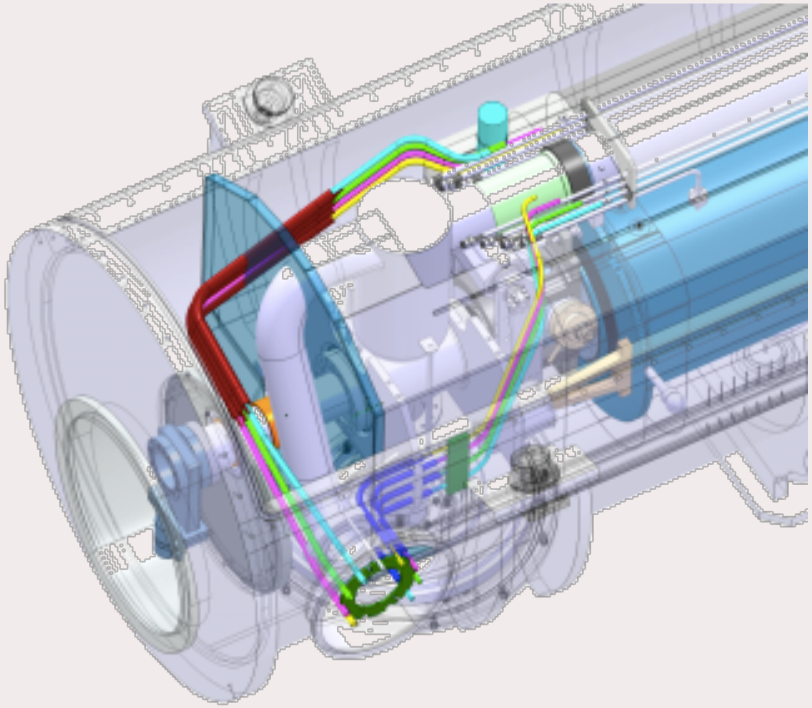


2 – Cryogenic jumper & cold box

Lateral jumper

Connection of the pumping tube onto the phase separator in the case of a lateral jumper





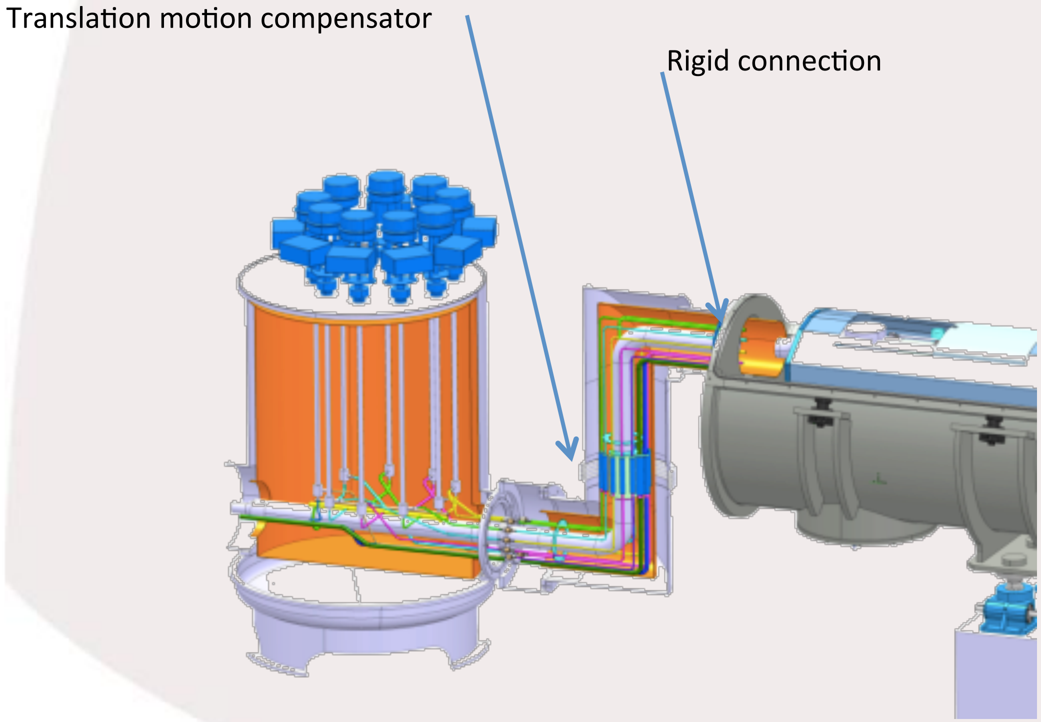
2 – Cryogenic jumper & cold box

Longitudinal jumper

Pros:

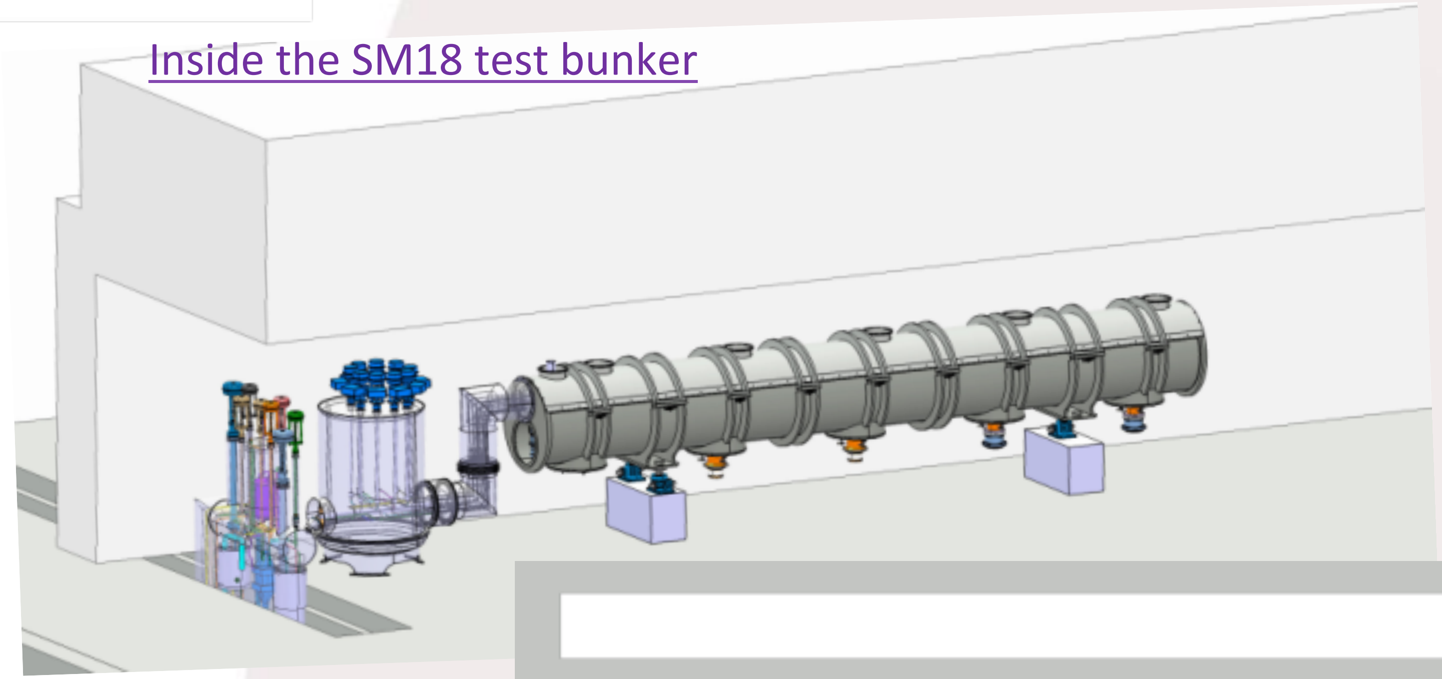
• Disconnection of the jumper and cryogenic lines is NOT required before lid removal;

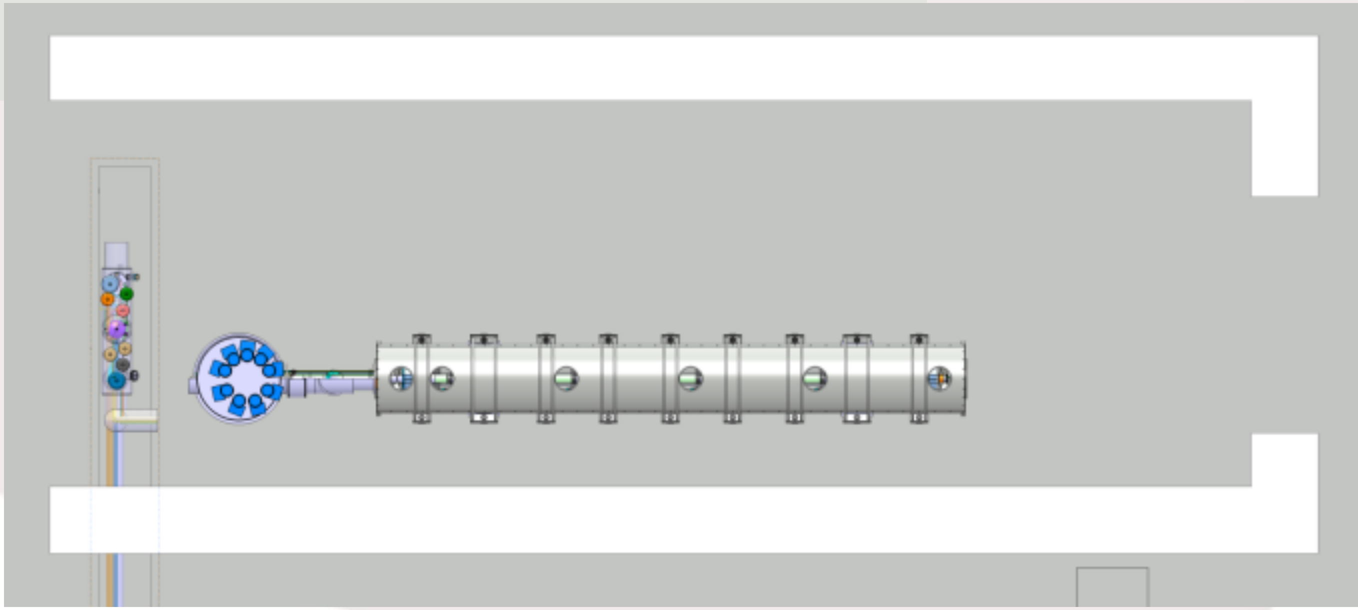
• Connection /disconnection of the cryogenic lines is easy (large access);



2 – Cryogenic jumper & cold box

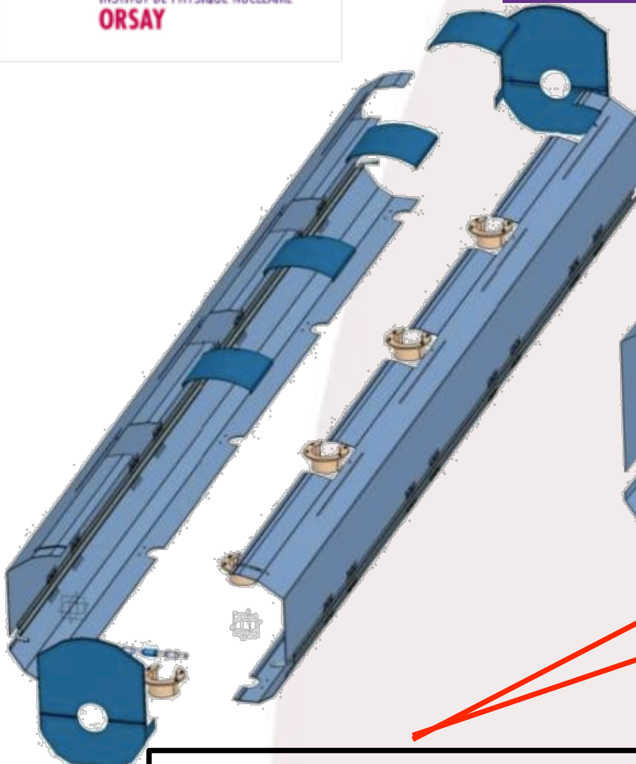
Inside the SM18 test bunker

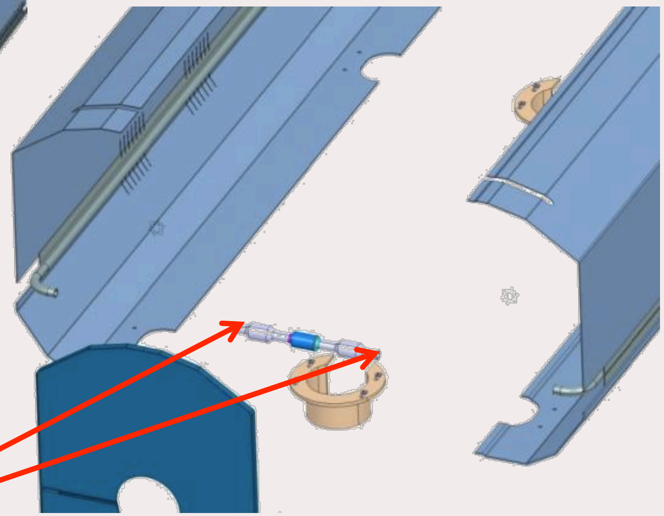




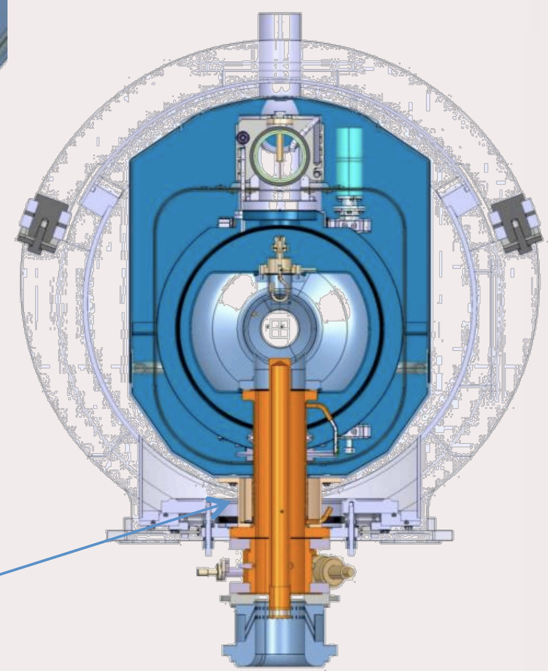
3 – Thermal shield

The thermal shield is mounted on the string of cavities before cryostating





Inox/inox welding
(use of bi-metallic transitions)



Support of the thermal shield on the flange of the coupler (design is under progress)

Conclusion

1 – Conceptual design choice

- A cryostat with a top lid allowing a vertical cryostating was chosen

2 - Vacuum vessel design

- Conceptual choices are effective and justified by mechanical approaches (static and buckling analysis)
- Discussions with companies are carried out concerning construction aspects (vacuum vessel, closure tightness)
- and should be intensified during the present detailed study
- Optimization of the vacuum vessel is under progress

2 – Cryogenic jumper & Cold box

- Position of the cryogenic jumper has been addressed taking into account the cryomodule and the bunker environments
- The cold box design is under progress

3 - Thermal shield

- Conceptual design has been chosen
- Detailed study is under progress

We aim at finishing the detailed study of the vacuum vessel by the end of July.

THANK YOUR FOR YOUR ATTENTION