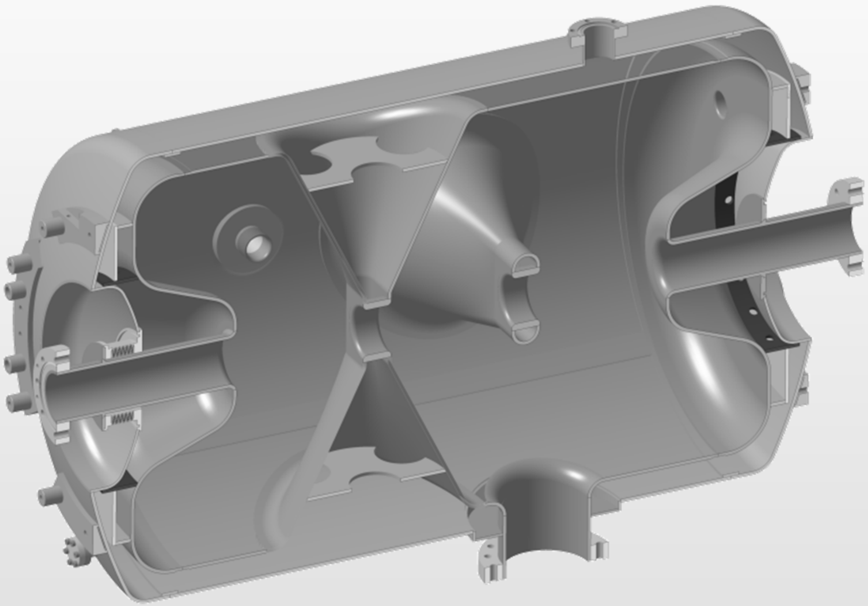
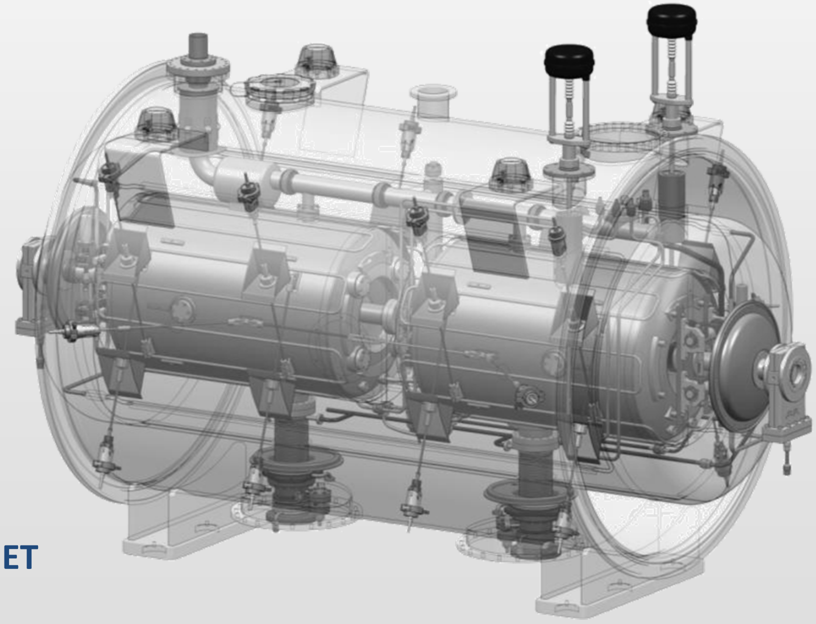
Design of the 352MHz, beta 0.50, Double-Spoke Cavity for ESS





Patricia DUCHESNE, Guillaume OLRY

Sylvain BRAULT, Sébastien BOUSSON, Patxi DUTHIL, Denis REYNET

Institut de Physique Nucléaire d'Orsay

SRF 2013, PARIS, September 27, 2013

INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

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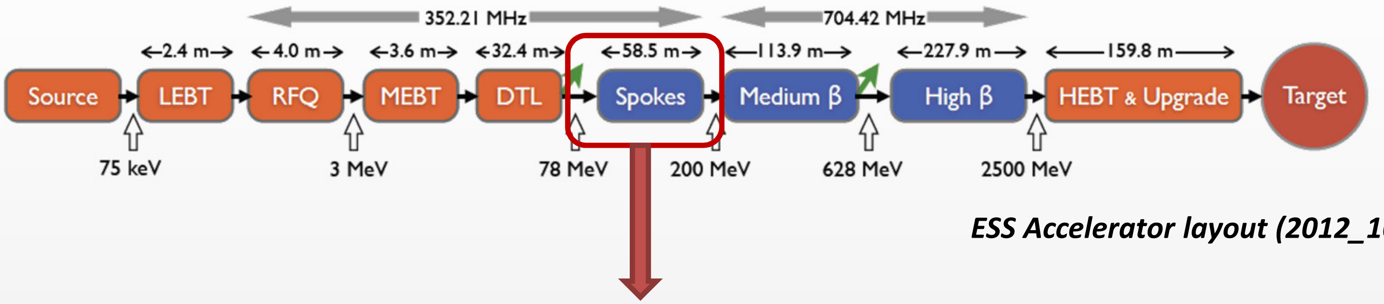
- ❑ **CONTEXT**
- ❑ RF DESIGN OF THE RESONATOR
- ❑ MECHANICAL DESIGN OF THE RESONATOR
- ❑ INTEGRATION IN THE CRYOMODULE
- ❑ STATUS OF THE PROTOTYPES

CONTEXT

❑ ESS Superconducting Spoke section:



ESS Accelerator layout (2012_10_02)

- 28 Double Spoke cavities (3 accelerating gaps)
- beta=0.50
- frequency: 352.2 MHz
- grouped by pair in 14 cryomodules
- operating temperature: 2K
- Accelerating gradient: Eacc = 8 MV/m
- Peak field specifications: Epk < 35 MV/m, Bpk < 70 mT

ESS SPOKE SECTION

CONTEXT

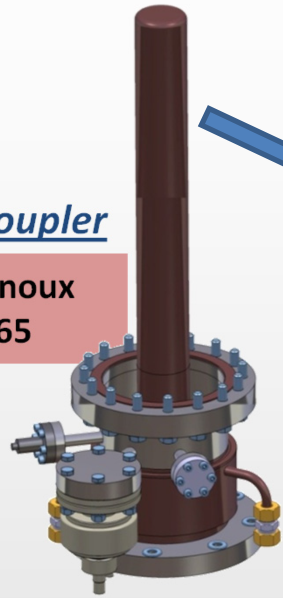
❑ Activities of IPN Orsay Laboratory on ESS Spoke section:

- ❑ **Design**
- ❑ **Fabrication of prototypes**
- ❑ **tests of prototypes**:
  - Vertical tests of cavities
  - Power couplers conditioning (Test bench @CEA/Saclay)
  - Tests of CTS
  - Low power tests of cryomodule

  (High power tests at UPPSALA)

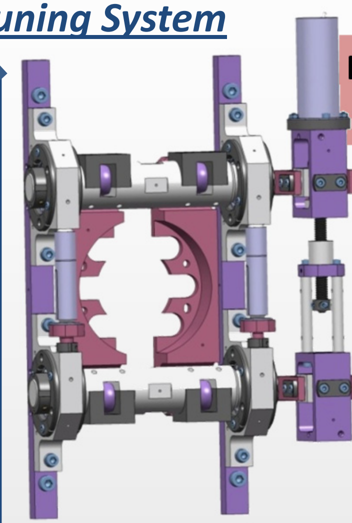
Power coupler

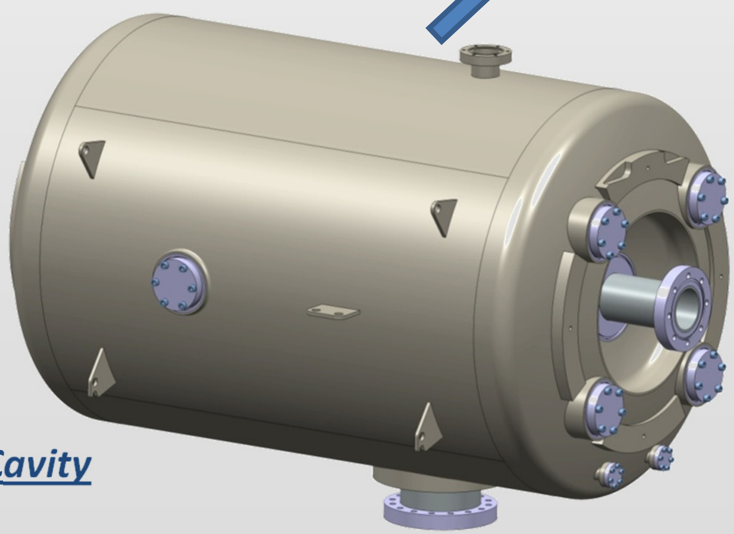
E. Rampnoux
THP065



Cold Tuning System

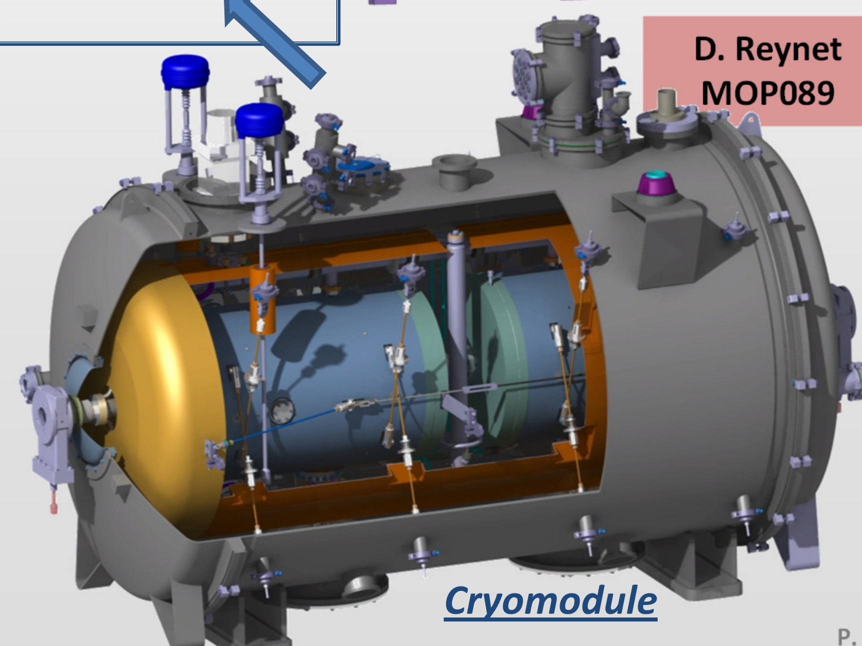
N. Gandolfo
THP078





Cavity

D. Reynet
MOP089



Cryomodule

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SPECIFICATIONS FOR THE DOUBLE SPOKE CAVITY

Parameters established by the beam dynamics simulations:

DOUBLE-SPOKE CAVITY	
Beam mode	**Pulsed (4% duty cycle)**
Frequency [MHz]	**352.2**
Beta_optimal	**0.50**
Temperature (K)	**2**
Bpk [mT]	**70 (max)**
Epk [MV/m]	**35 (max)**
Gradient Eacc [MV/m]	**8**
Lacc (=beta optimal x nb of gaps x λ /2) [m]	**0.639**
Bpk/Eacc [mT/(MV/m)]	**< 8.75**
Epk/Eacc	**< 4.38**
Beam tube diameter [mm]	**50 (min)**
RF peak power [kW]	**300 (max)**

OPTIMIZATION OF THE GEOMETRY

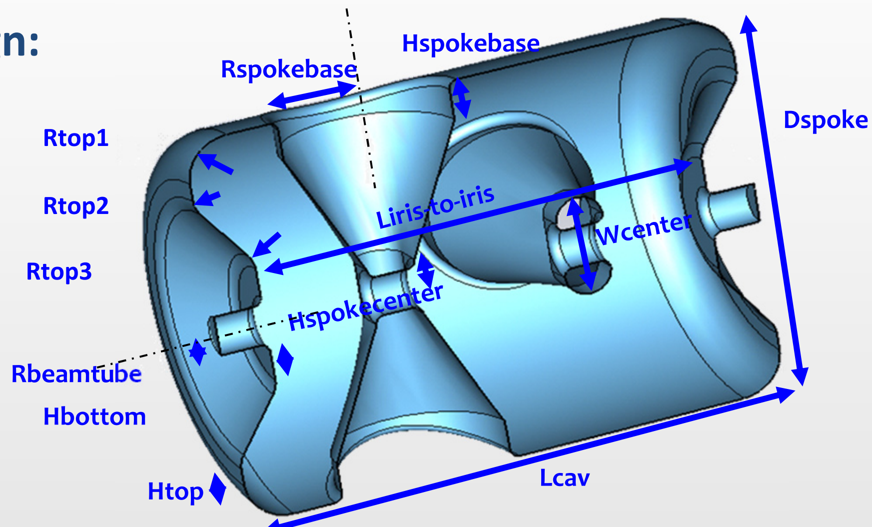
- **Main goal:** fulfil the criteria of the peak surface field to accelerating gradient ratios

$$\frac{E_{pk}}{E_{acc}} < 4.38 \qquad \frac{B_{pk}}{E_{acc}} < 8.75 \text{ [mT/MV/m]}$$

The optimization method of the RF design:

- Parameterization of the geometry
- Sensitivity analysis on the ratios Epk/Eacc & Bpk/Eacc
- CST MicroWave Studio (MWS)
- Results cross-checked with to mesh types:

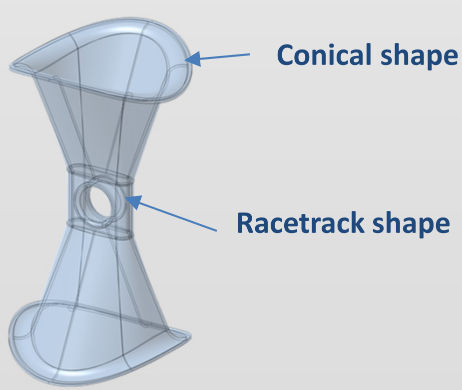
  hexahedral and tetrahedral



Parameters list for Spoke optimization – ***G. Olry***

Geometry of the spoke bars:

Based on our feedback from two Single-Spoke resonators and a Triple-Spoke resonator fabrication (EURISOL)



➔ Achievement of an acceptable solution

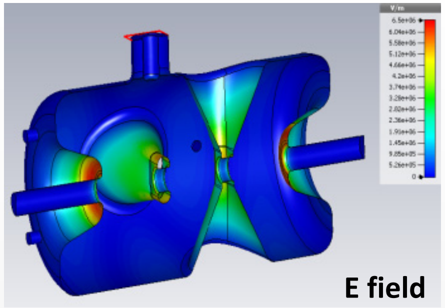
RF RESULTS

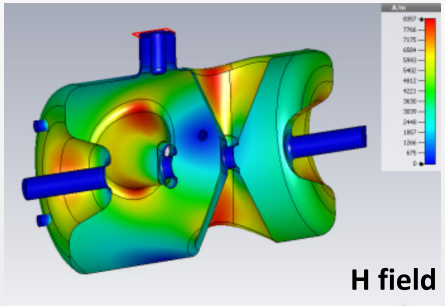
❑ Last modifications (included in the prototypes)

- Technical issues for manufacturing
- New ESS requirements

} Minor parameters changes

Mesh type	Hexahedral (2.2 millions meshcells)	Tetrahedral (600000 tetra.)
Beta optimal	0.50	0.50
Epk/Eacc	4.51	4.33
Bpk/Eacc [mT/MV/m]	6.99	6.89
G [Ohm]	131	130
r/Q [Ohm]	425	426





- Epk/Eacc > 4.38: compromise between the cavity length, end cap shape feasibility and tuning sensitivity.
- Lacc = 3 / 2 x beta optimal x lambda

❑ Coupling calculations: Qext = $1.5 \cdot 10^5$ (with the parameters 50mA and 8MV/m)

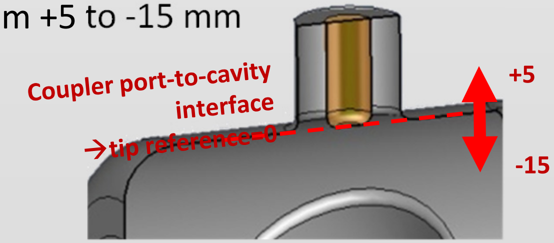
- **Coupler port location (∅=100mm):**
  Variation of the coupler port center from 100 to 170mm (↔ distance to the origin)

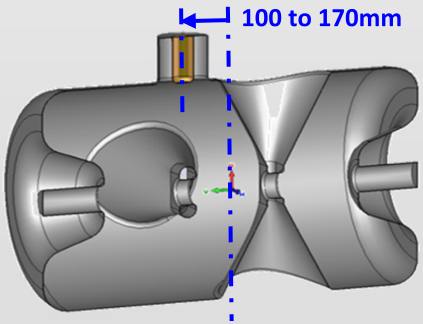
- **Penetration of the antenna:** Variation from +5 to -15 mm

Qext = $1.5 \cdot 10^5$ for:

⇒ 5mm of tip penetration

⇒ coupler port location: 120mm





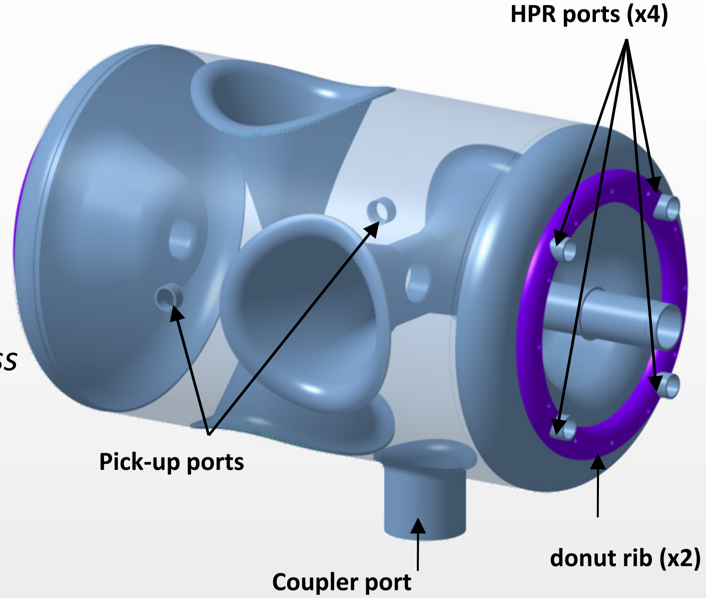
*MWS model of the cavity with antenna – **G. Olry***

CONTENTS

MECHANICAL STUDIES

❑ Criteria taken into account

- **Cavity preparation:** *High Pressure Rinsing (HPR)*
  ➔ easy and efficient
- **Life cycle of the cavity:** *Leak tests & cryomodule tests*
  ➔ No risk of damage (plastic deformation at room T°)
- **Manufacturing constraints:** *Metal forming & Assembly process*
  ➔ Feasible (at a reasonable cost)



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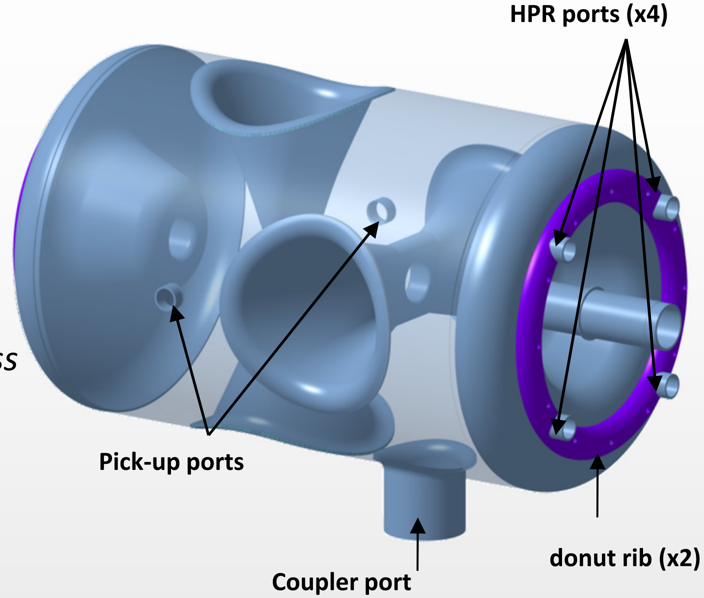

❑ Integration of the Helium vessel

- Connections with the beam tubes: **Flange / bellows** (For the tuning)
- Helium vessel: **Titanium grade 2**
  - ➢ Ease of assembly with niobium
  - ➢ No problem of thermal stresses
  - ➢ May act as a reinforcement of the cavity

*ESS Double Spoke Cavity – **S. Brault***

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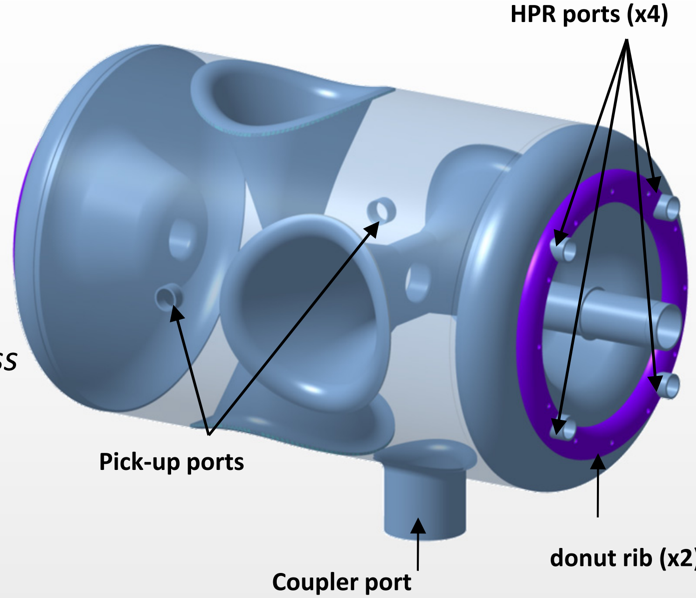

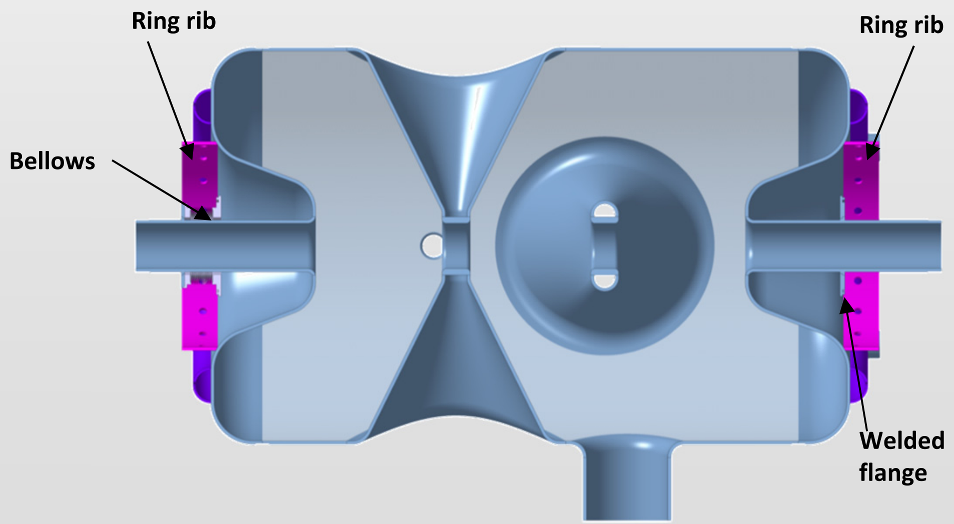

*ESS Double Spoke Cavity – **S. Brault***

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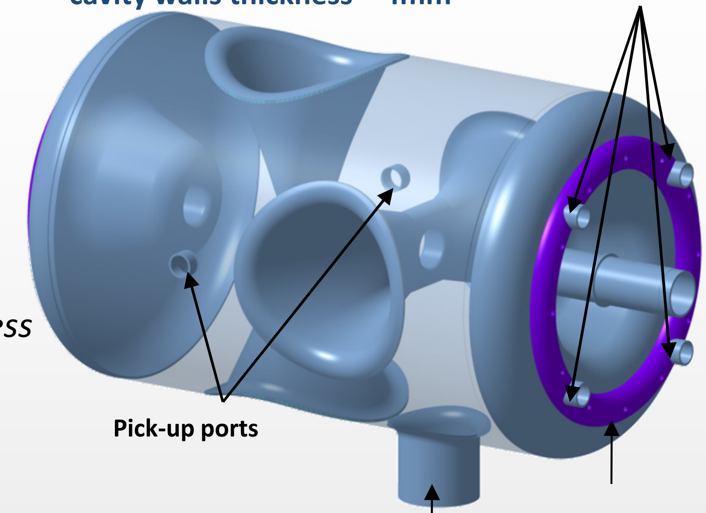

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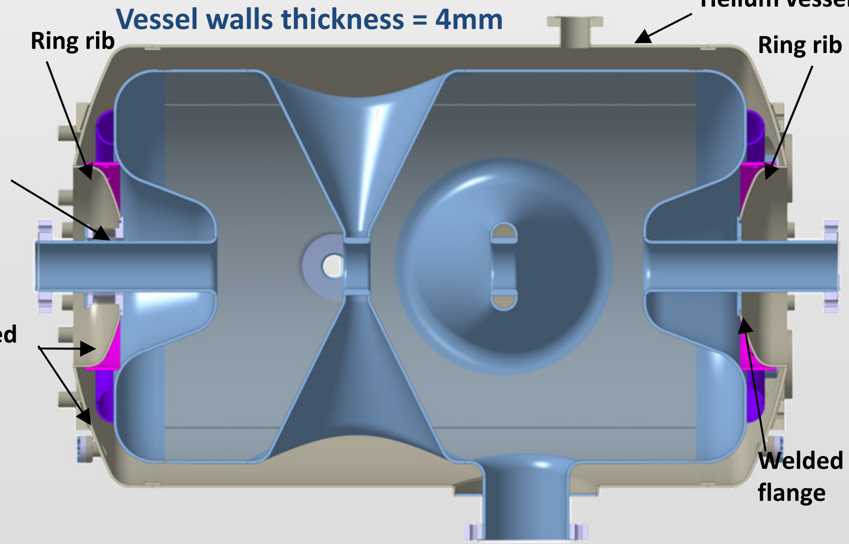
  - No problem of thermal stresses
  - May act as a reinforcement of the cavity
- Standard dished end cups



ESS Double Spoke Cavity – ***S. Brault***

⇒ **Result of the iterative numerical simulations**

MECHANICAL BEHAVIOUR

❑ Mechanical simulations

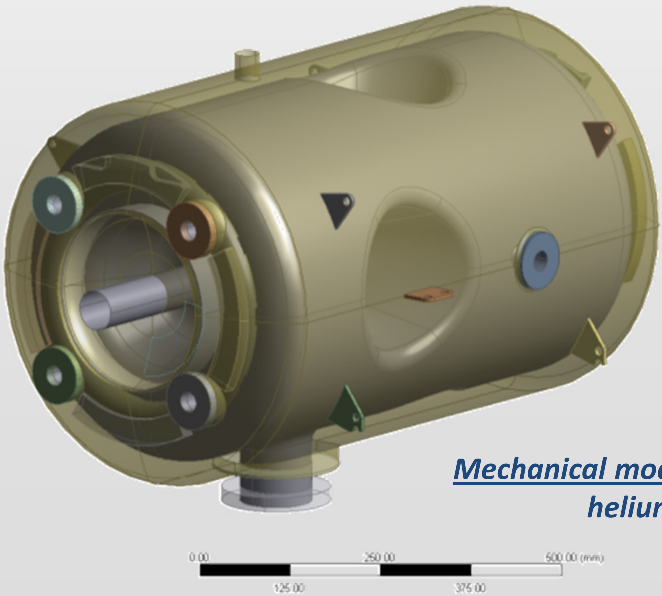
Different load cases studied according to the life cycle of the cavity

Static and modal analysis

(ANSYS Mechanical V14)

- Leak tests during fabrication
- Pressure test (Cool down at 4K)
- Mechanical vibration modes

➔ *Check no plastic strains*
➔ *Define maximum pressure during cool down*
➔ *Check sensitivity to microphonics*



***Mechanical model**: cavity with its helium vessel*

MECHANICAL BEHAVIOUR

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Different load cases studied according to the life cycle of the cavity

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- Mechanical vibration modes

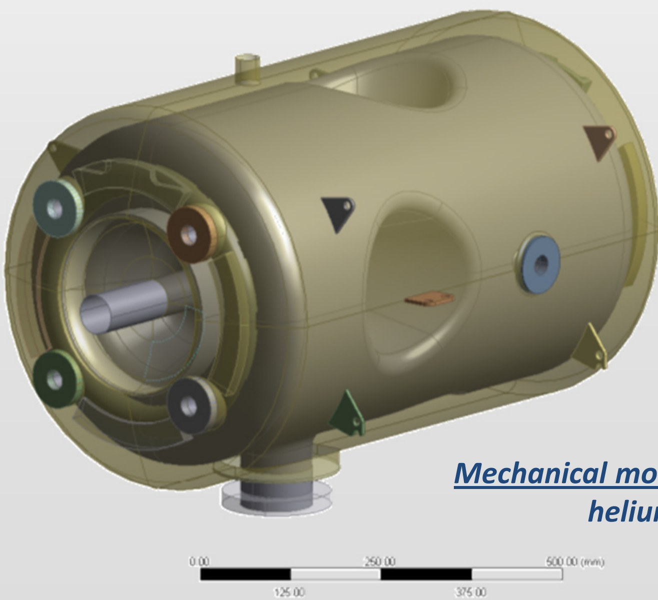
➔ *Check no plastic strains*
➔ *Define maximum pressure during cool down*
➔ *Check sensitivity to microphonics*

RF-Mechanical coupled analysis

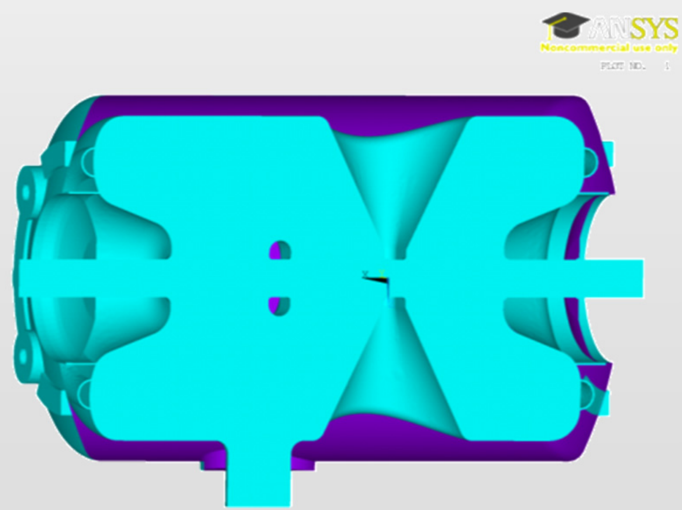
(ANSYS APDL & EMAG V14)

- RF sensitivity by pulling on beam tubes
- RF sensitivity due to the He bath pressure fluctuation
- RF sensitivity due to the Lorentz forces

➔ *Define sensitivity for the cold tuning system*
➔ *Define a range for the pressure and Lorentz detuning factors*



***Mechanical model*: cavity with its helium vessel**

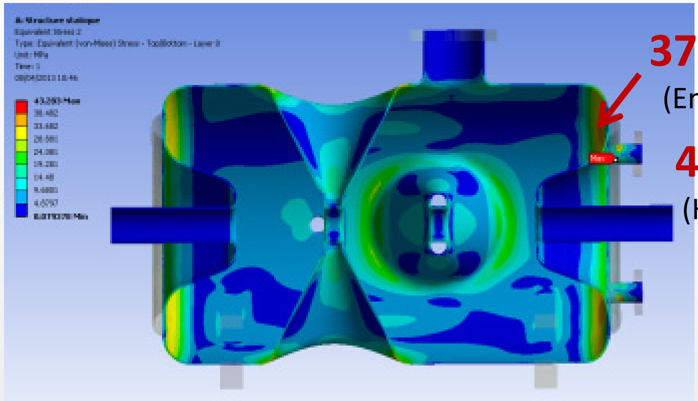


***RF-Mechanical model:* cavity with its helium vessel**

STATIC AND MODAL RESULTS

❑ Static results

- **Leak test on the bare cavity:**

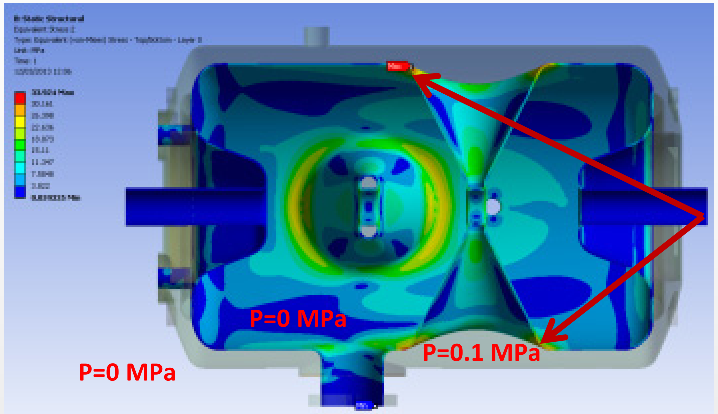


37 MPa (End cup)

43 MPa (HPR port)

⇒ σ_{max} < 50 MPa (Yield stress of Niobium at room T°)
⇒ The donut ribs are necessary

Pressure test with ΔP = +0.1 MPa:



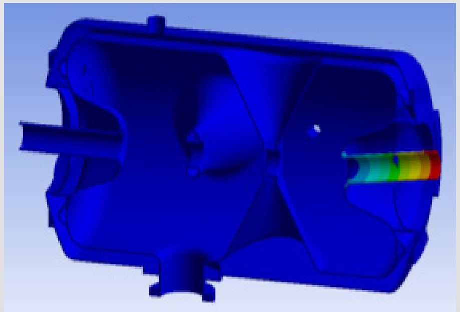
34 Mpa (top of the Spoke bar)

⇒ Max pressure (Cool down) estimated to be 1.47 bar at σ_{max} = 50 Mpa

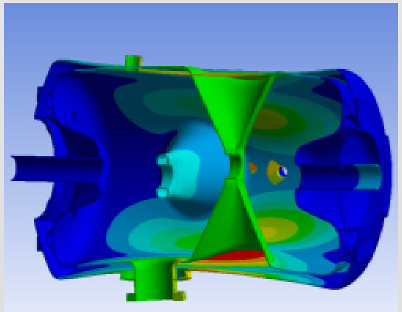
❑ Mechanical modes

N°	Frequency	Mode
1 & 2	212Hz	Beam tube on CTS side
3 & 4	265Hz & 275Hz	Spoke bar/Helium vessel
5 & 6	285Hz	Coupled mode Cavity/Helium vessel
7	313Hz	Helium vessel
8 to 11	315Hz to 365Hz	Coupled mode Cavity/Helium vessel
12	396Hz	beam tubes

⇒ First critical mode (mode 3) >> 50 Hz



Mode 1: 212 Hz



Mode 3: 265 Hz

RESULTS ON THE RF SENSITIVITY

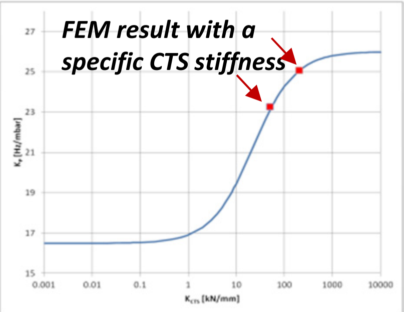
❑ Sensitivity to Helium bath pressure fluctuation

K_P without CTS (free ends)	**+16.5 Hz/mbar**
K_P with greatly stiff CTS*	**+26.0 Hz/mbar**

*The beam tube is connected rigidly to the helium vessel at the level of the 4 CTS supports (along the beam axis)

K_P as a function of the CTS stiffness:

$$K_P = K_P^{\infty} - \frac{\partial f}{\partial z} \frac{\vec{F}^{\infty} \cdot \vec{u}_z}{(K_{cav} + K_{CST})\Delta P}$$



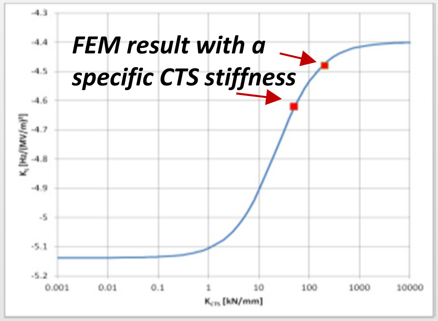
❑ Sensitivity to Lorentz forces detuning

		For 8MV/m
K_L without CTS (free ends)	**-5.13 Hz/(MV/m)²**	Δf = -328 Hz **
K_L with stiff CTS	**-4.4 Hz/(MV/m)²**	Δf = -282 Hz

**bandwidth = 1530 Hz

K_L as a function of the CTS stiffness:

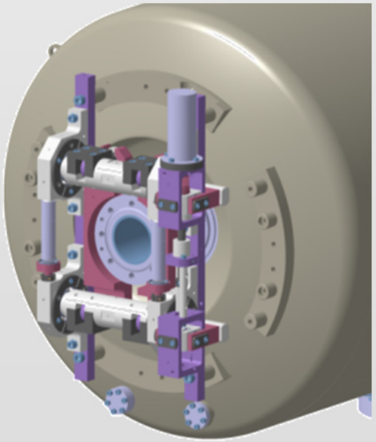
$$K_L = K_L^{\infty} + \frac{\partial f}{\partial z} \frac{\vec{F}^{\infty} \cdot \vec{u}_z}{(K_{cav} + K_{SAF})E_{acc}^2}$$



❑ RF sensitivity for cavity tuning

Stiffness of the cavity	**20 kN/mm**
Tuning sensitivity Δf/Δz	**135 kHz/mm**

⇒ At 2K: the tuning range is +173 kHz (1.28mm of max displacement not to exceed 400 MPa)



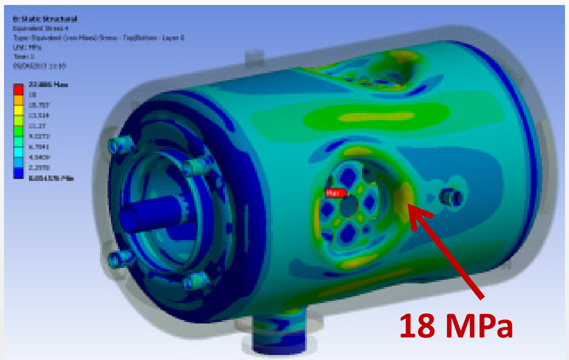
*View of the Cold Tuning System – **N. Gandolfo***

DETAILED MECHANICAL STUDIES

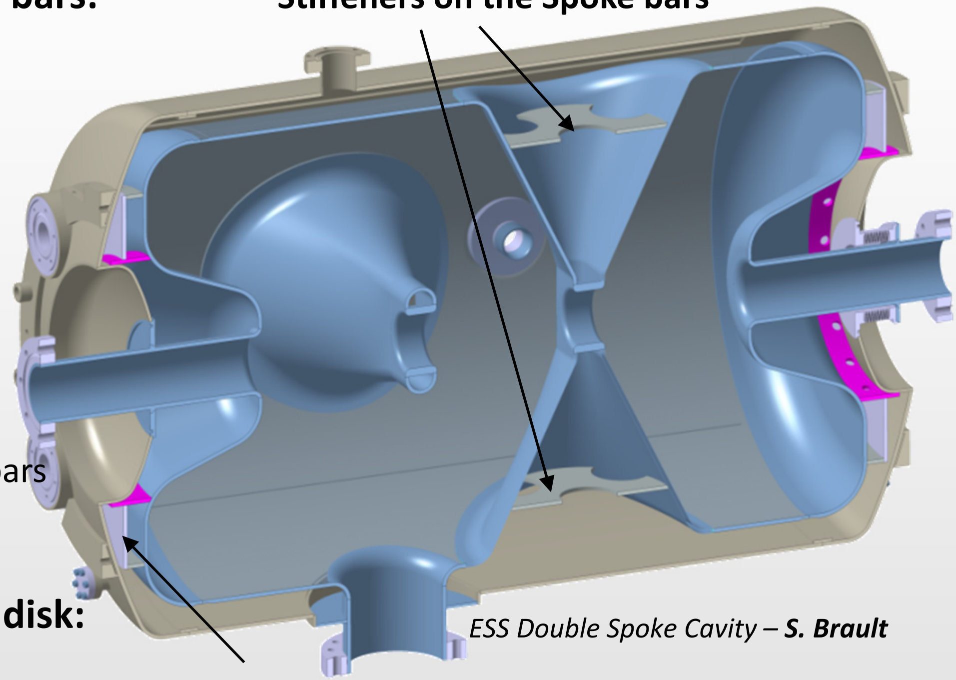
❑ Last modifications (included in the prototypes)

- **Adding of some new stiffeners on the Spoke bars:**

Pressure test with ΔP = 0.1 Mpa:



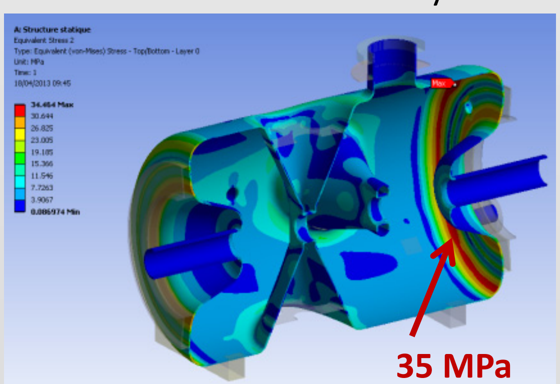
⇒ Maximum pressure (Cool down) estimated to 2.77 bars



*ESS Double Spoke Cavity – **S. Brault***

- **Replacement of the donut rib by a titanium disk:**

Leak test on the bare cavity:

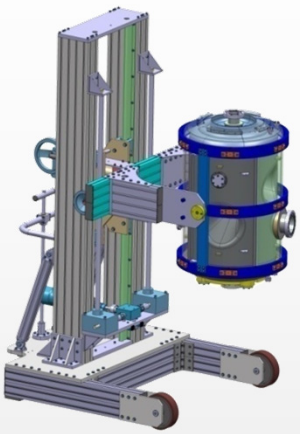


⇒ Manufacturing and assembly easier

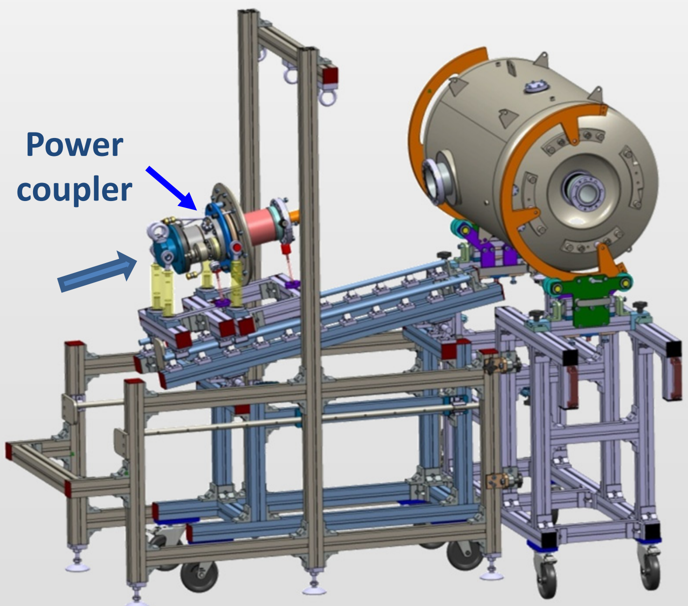
CONTENTS

CAVITY ASSEMBLY INTO THE CLEAN ROOM

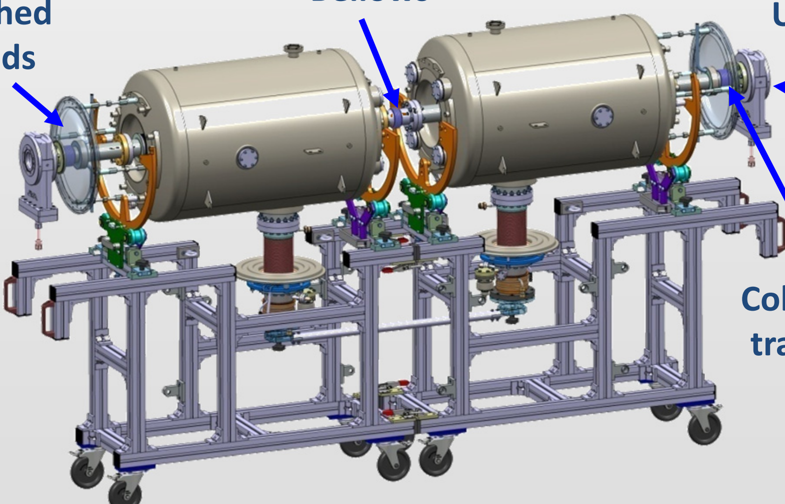
- ❑ **High Pressure Rinsing HPR (100bars) in clean room ISO 4**



- ❑ **Assembly of the cavities with:**
  - ➢ power coupler
  - ➢ cold-warm transitions, dished ends and bellows
  - ➢ warm Ultra High Vacuum gate valves



Work in progress

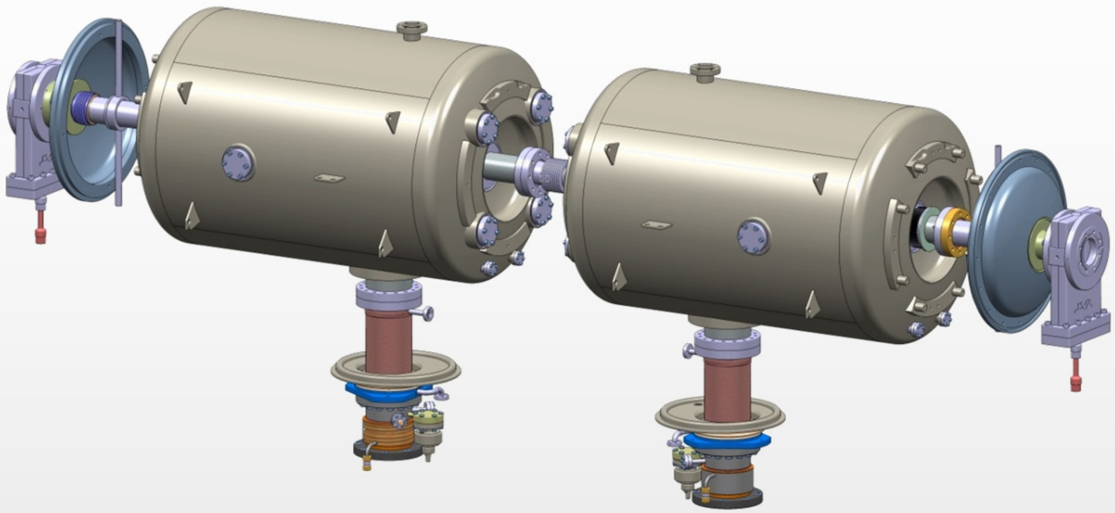


The orientation of each cavity is chosen in order to facilitate the maintenance operations of the cold tuning system after insertion in the vacuum vessel

ASSEMBLY OUTSIDE THE CLEAN ROOM

❑ Assembly outside the clean room

- Magnetic shield
- Cryogenic distribution
- Thermal shield and supporting rods
- Cold tuning system ...



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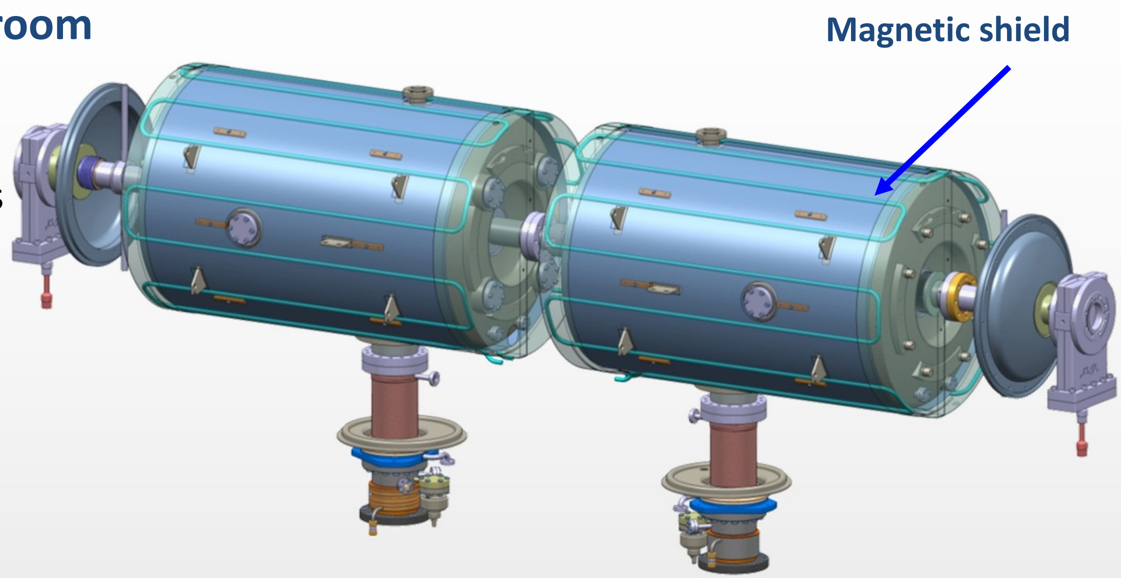

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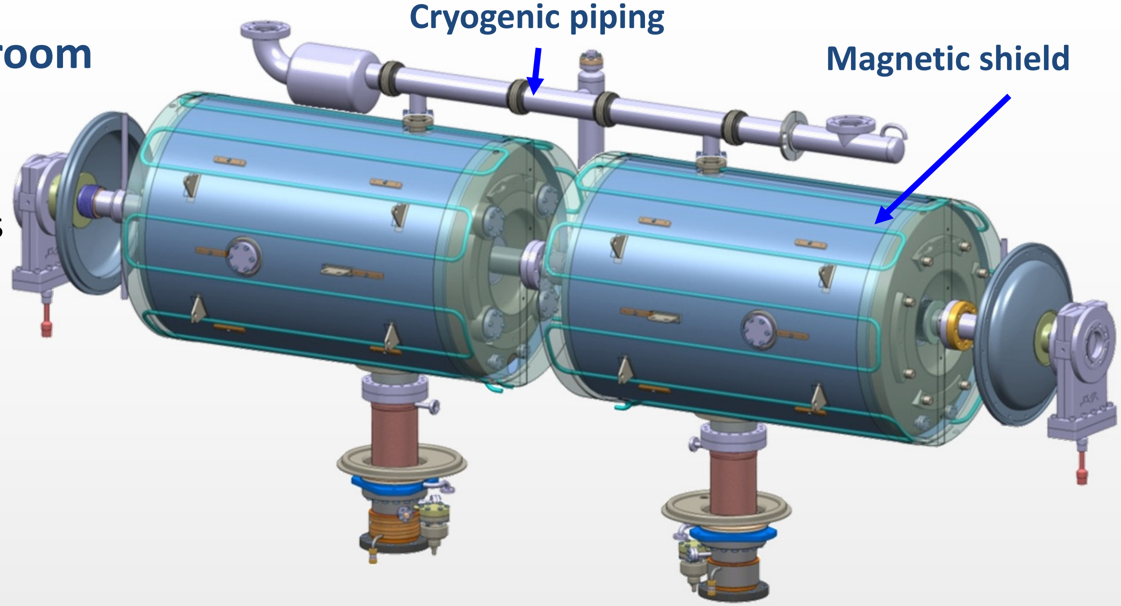

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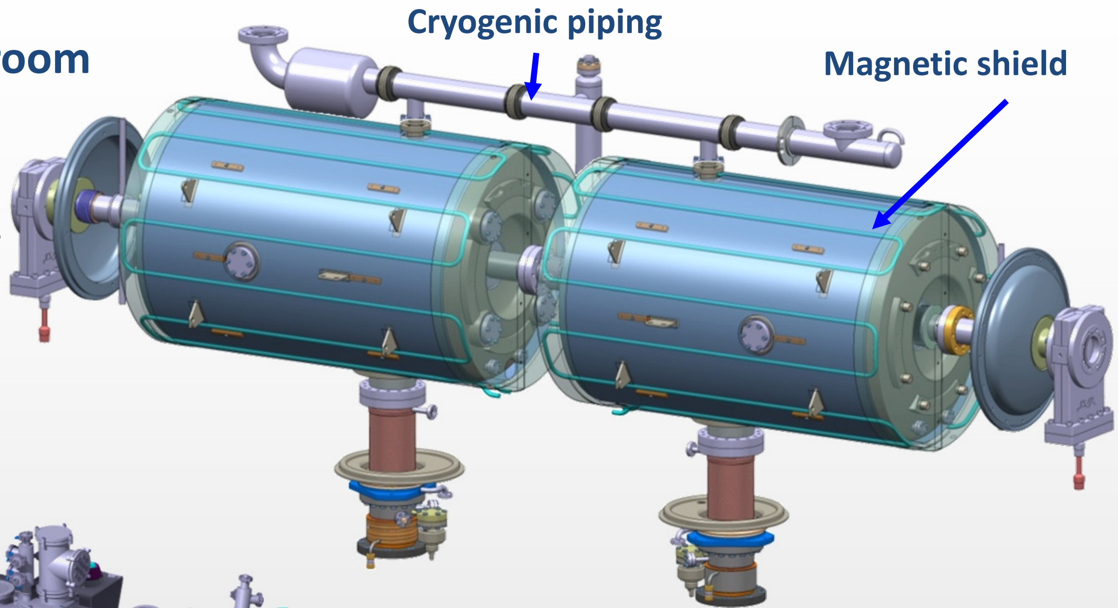
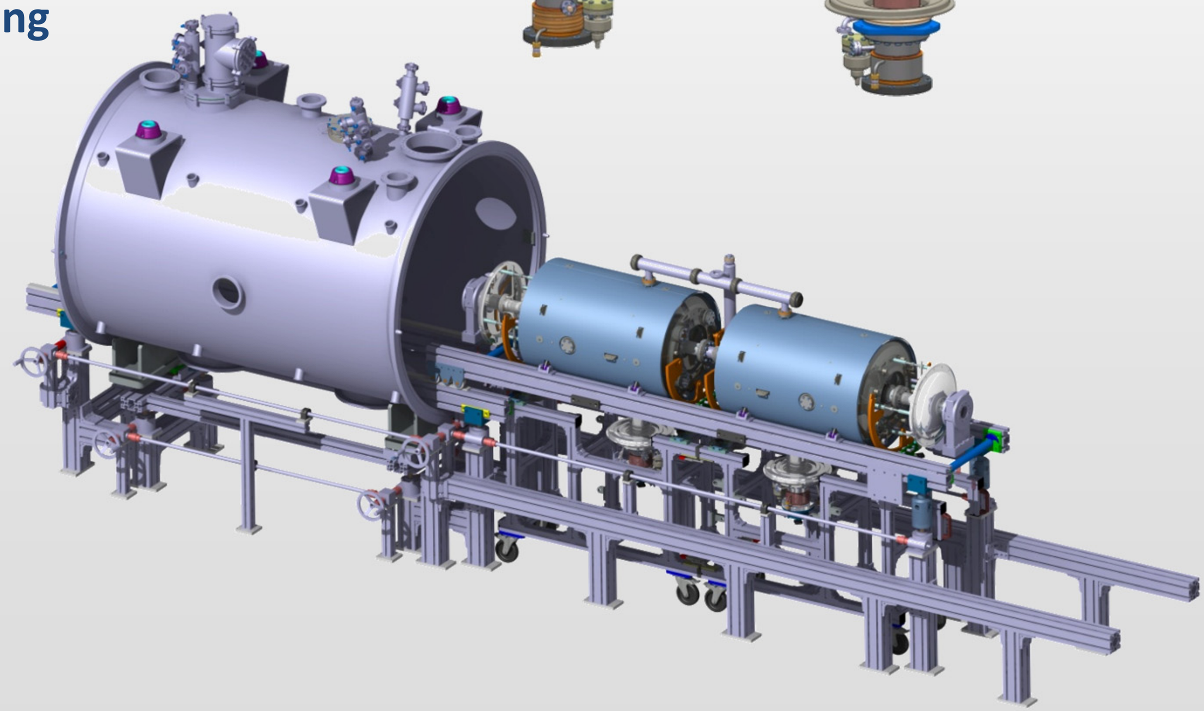


❑ Tooling for cryostating



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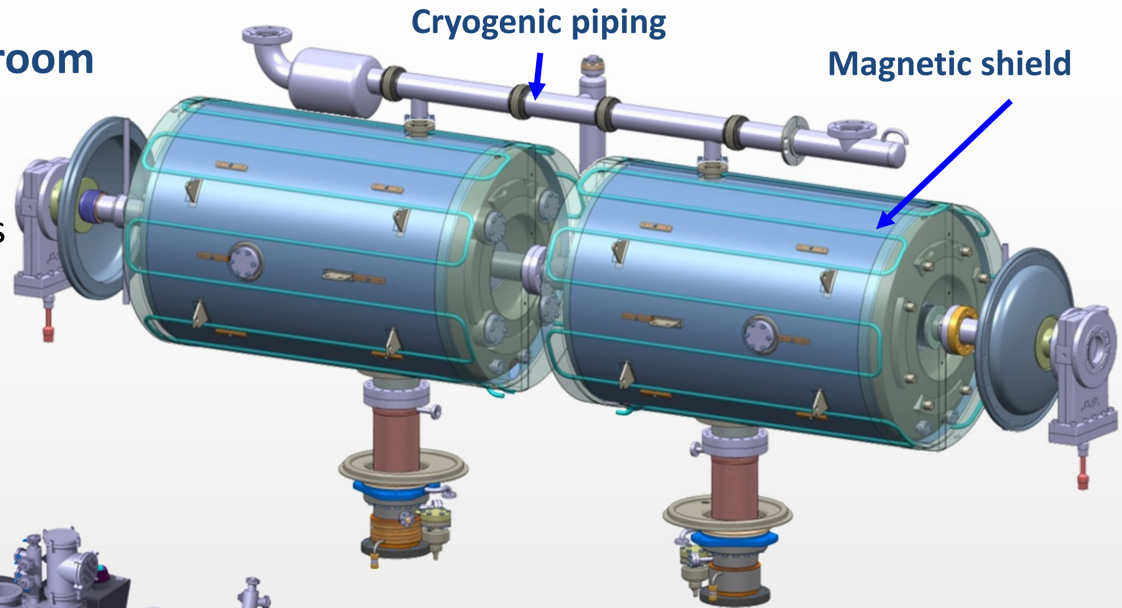

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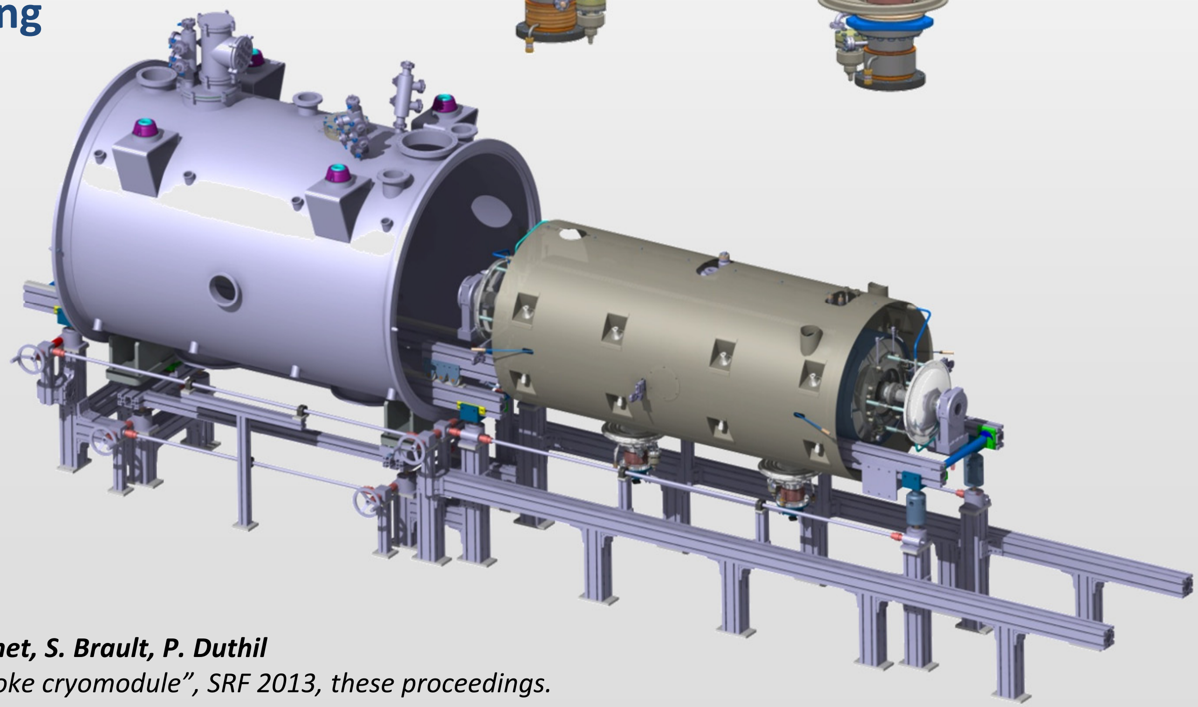

D. Reynet
MOP089

ESS Spoke Cryomodule – ***D. Reynet, S. Brault, P. Duthil***
Details in: "Design of the ESS Spoke cryomodule", SRF 2013, these proceedings.

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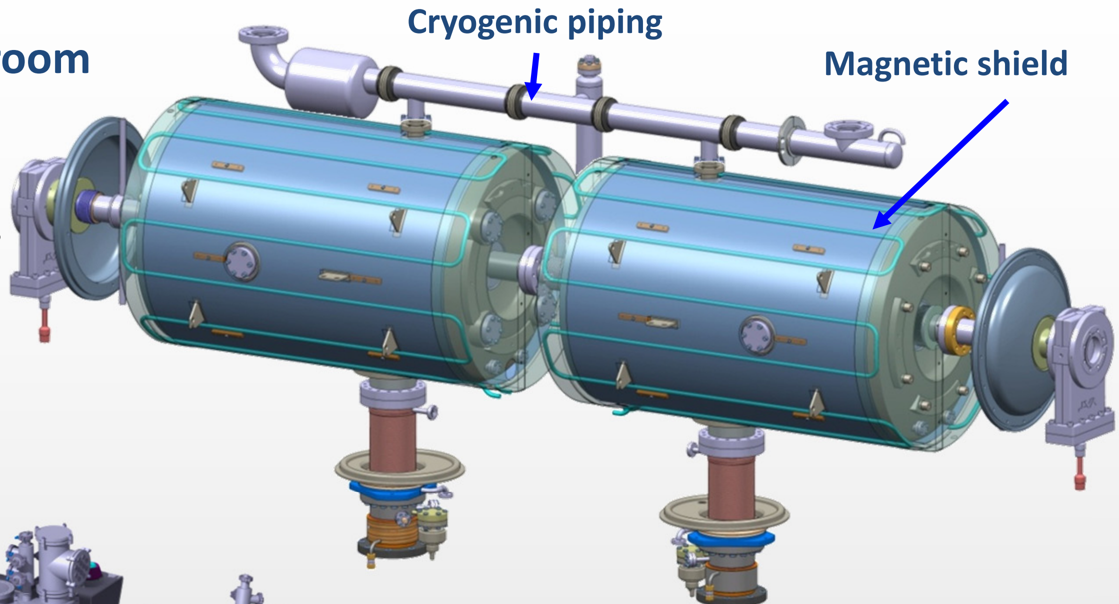
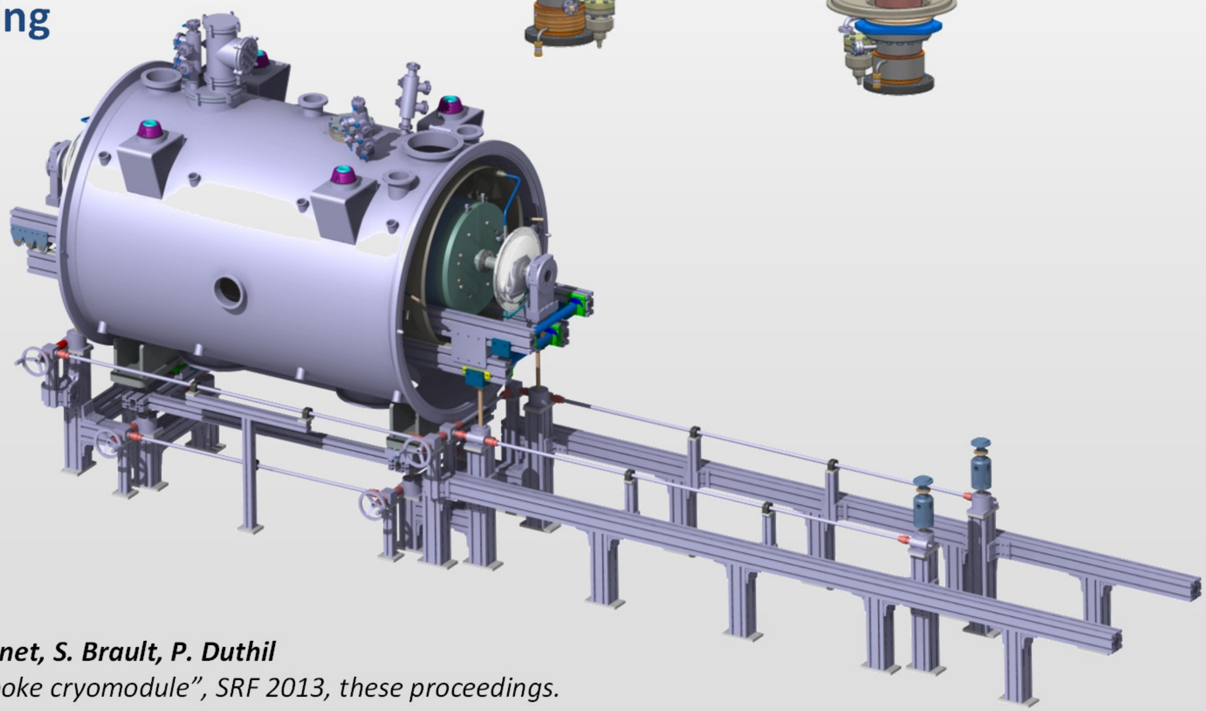


❑ Tooling for cryostating



D. Reynet
MOP089

*ESS Spoke Cryomodule – **D. Reynet, S. Brault, P. Duthil***
Details in: "Design of the ESS Spoke cryomodule", SRF 2013, these proceedings.

SUPPORTING SYSTEM

❑ Principle of supporting system

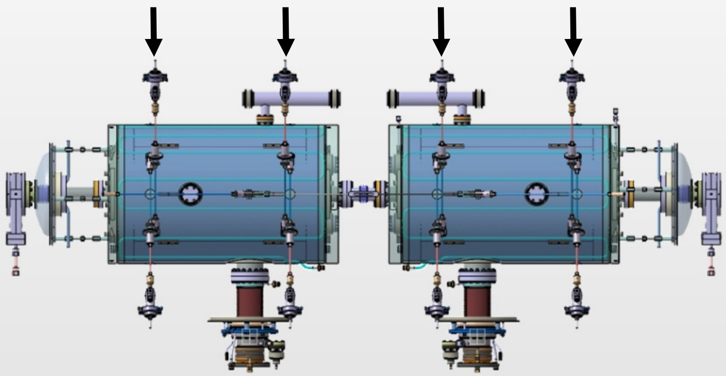
Several considerations:

- 2 cavities: length = 2.86m, weight <500 Kg (with thermal shield)
- Static heat load
- Assembly and alignment methods

➢ **Antagonist tie rods in some vertical planes**

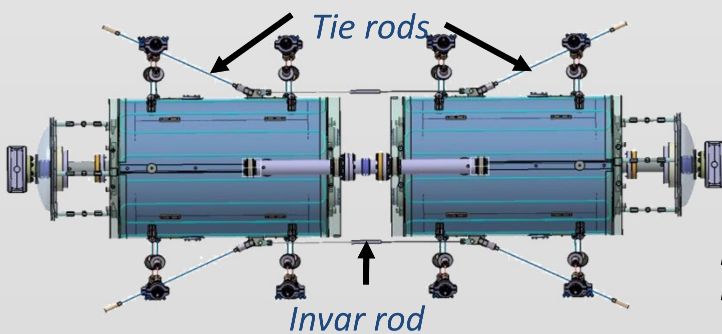
➔ Vertical and lateral positions

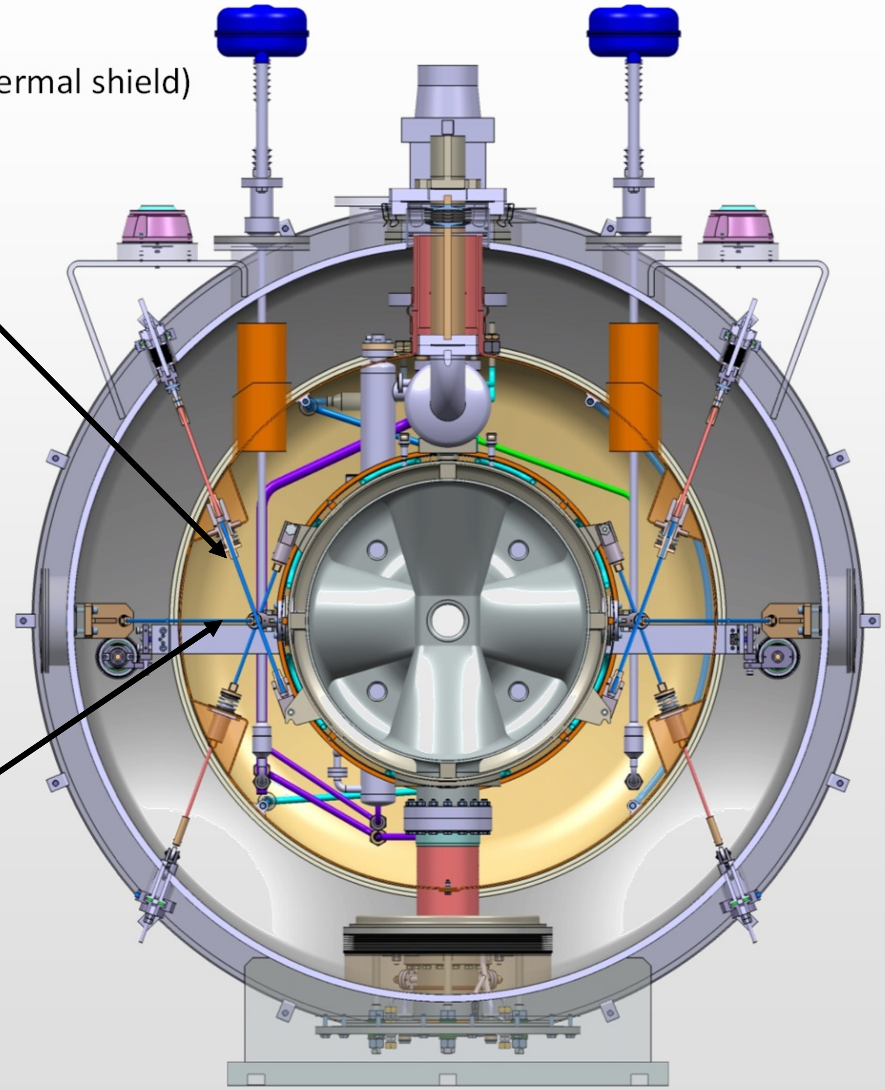
4 identical tie rods by vertical plane



➢ **Tie rods and invar rods in a horizontal plane**

➔ Position along beam axis





*ESS Spoke Cryomodule – **D. Reynet, S. Brault, P. Duthil***
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CONTENTS

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FABRICATION OF PROTOTYPES

STATUS OF THE PROTOTYPES

❑ Cavity: 3 prototypes

- 1 by SDMS (France)
- 2 by ZANON (Italy)

➢ Start of contract: March 2013

➢ Ongoing discussions about the manufacturing of:
- the Spoke bars in several pieces
- the end cups of the cavity

➢ Delivery: April 2014

❑ Power coupler: 4 prototypes

- 2 by SCT (France)
- 2 by PMB (France)

➢ Start of manufacturing: September 2013

➢ Delivery: November 2013

❑ Cold Tuning System: 2 prototypes

ESIM (France): mechanical components
NOLIAC (Denmark) &
PHYSIK INSTRUMENTE (Germany): Piezo actuators

➢ Delivery: done

N. Gandolfo
THP078

Prototype mounted on the triple Spoke cavity (Eucard) at IPNO

THANK YOU FOR YOUR ATTENTION