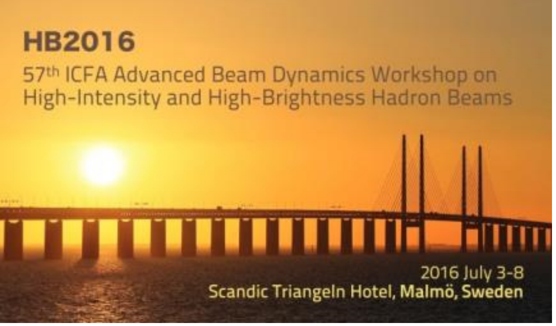
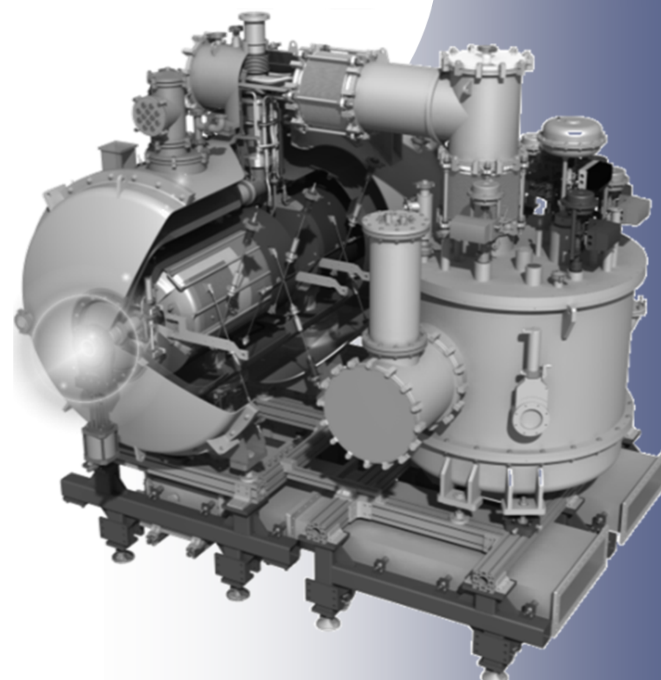


July 6th 2016

Design and prototyping of the Spoke Cyromodule for ESS linac

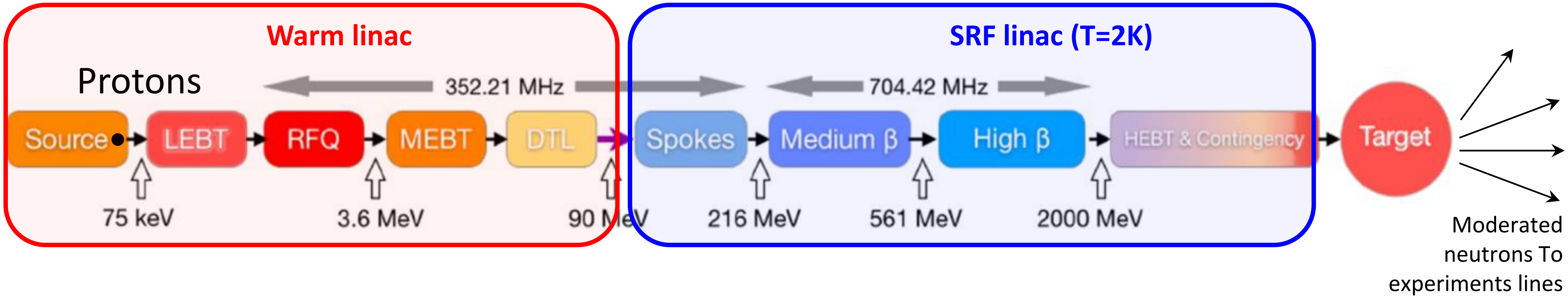
P. DUTHIL (CNRS-IN2P3 IPN Orsay / Division Accélérateurs)

on behalf of the IPNO team and ESS colleagues



IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY
UNIVERSITÉ PARIS SUD
cnrs IN2P3 Les deux infinis
ess EUROPEAN SPALLATION SOURCE

The European Spallation Source (ESS) LINear ACcelerator

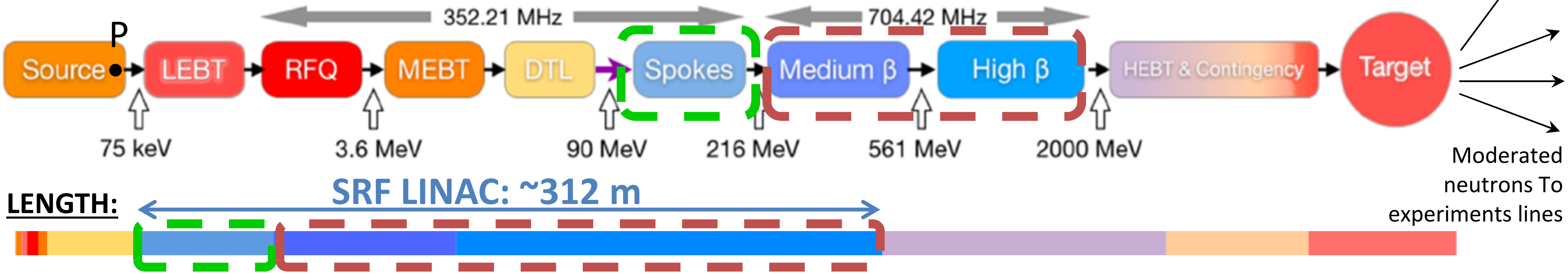


Top-level requirements	
Pulse length (ms)	2.86
Energy (GeV)	2
Peak current (mA)	62.5
Pulse repetition frequency (Hz)	14
Average power (MW)	5
Peak power (MW)	125

ESS Linac is special and innovative:

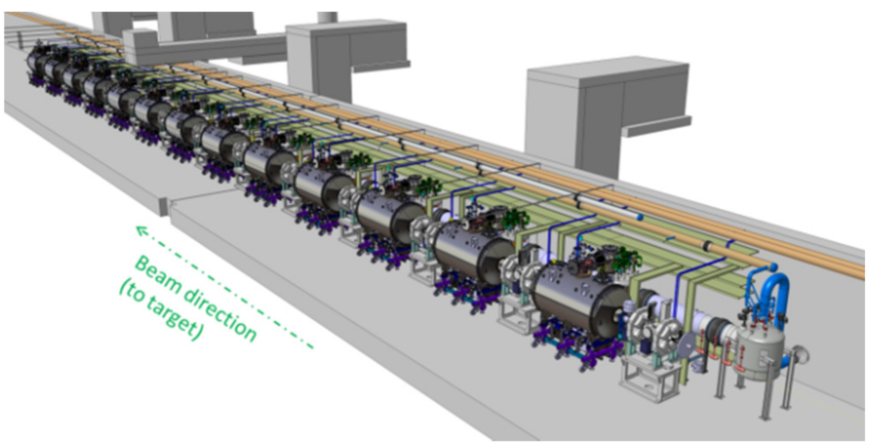
- **Mainly based on SRF (Superconducting Radio Frequency) technology**
- **Very powerful (~4 times higher than SNS)**
- **First accelerator to use (double) Spoke cavities**
- **Challenging accelerating gradients**

The European Spallation Source (ESS) LINAC



SRF cavity cooling: 2 K in saturated He II bath (⇒ simple techno.+ few energy stored + pressure control)

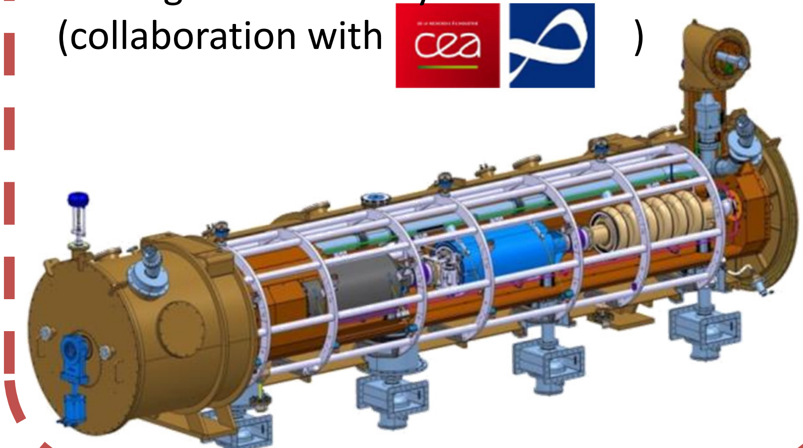
CNRS CONTRIBUTION (CNRS/IN2P3/IPNO)



Design, construction and installation of the main parts of the **Spoke section** (~56 m)

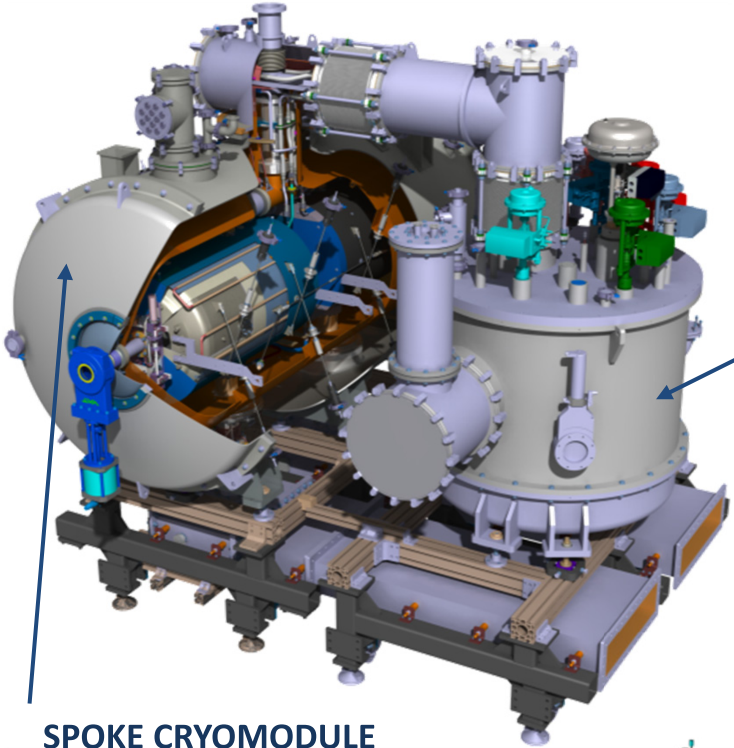
Elliptical section (~256 m):

- design of the 40 cryomodules (collaboration with cea)

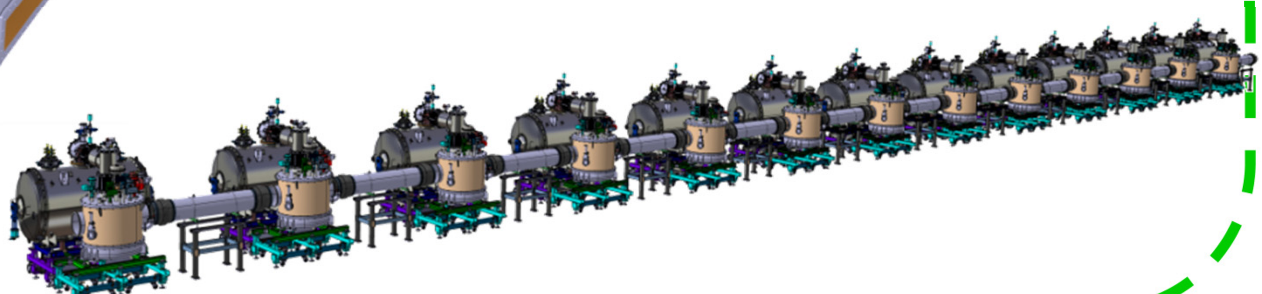


Spoke section

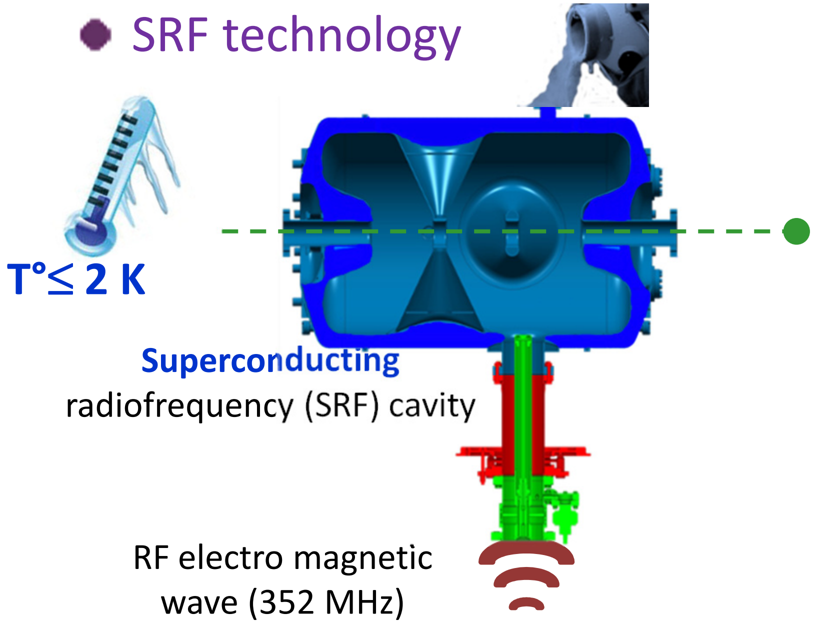
- 13 cryomodules
- Cryogenic Distribution System for the Spoke section (CDS-SL):
    - 13 valve boxes (managing cryofluids distribution and cryogenic process)



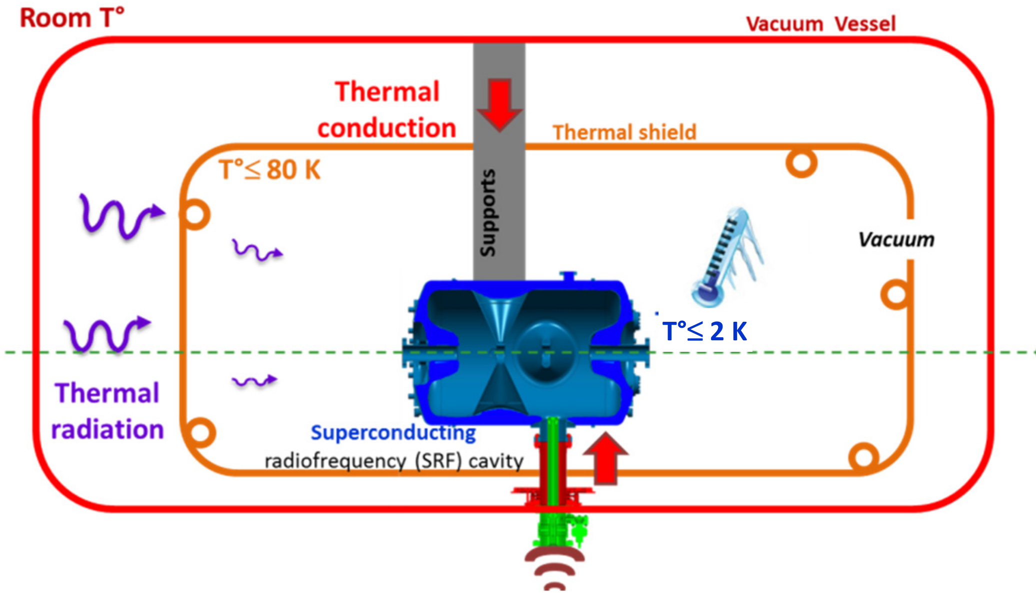
- Cryogenic Distribution Line (CDL)



- **A cryomodule: what is it and what for?**
  - SRF technology



CRYOMODULE



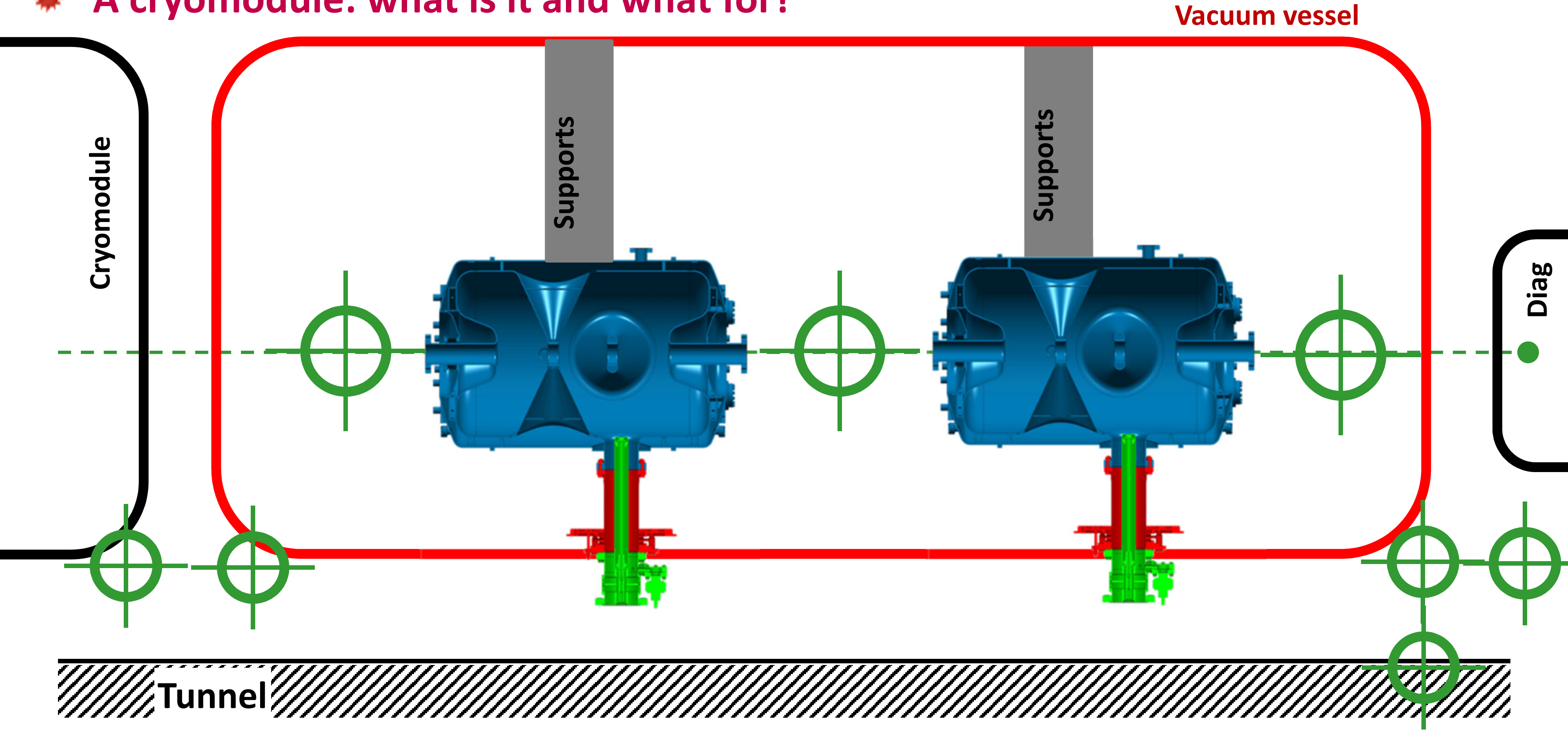
  - Cryomodule functionalities

1/ To provide a cryogenic environment to the cold mass (cavity) = horiz. cryostat:

- distributing the cryofluids to cool-down and maintain at cold T° (LHe, LN_2)

- limiting the heat loads

A cryomodule: what is it and what for?

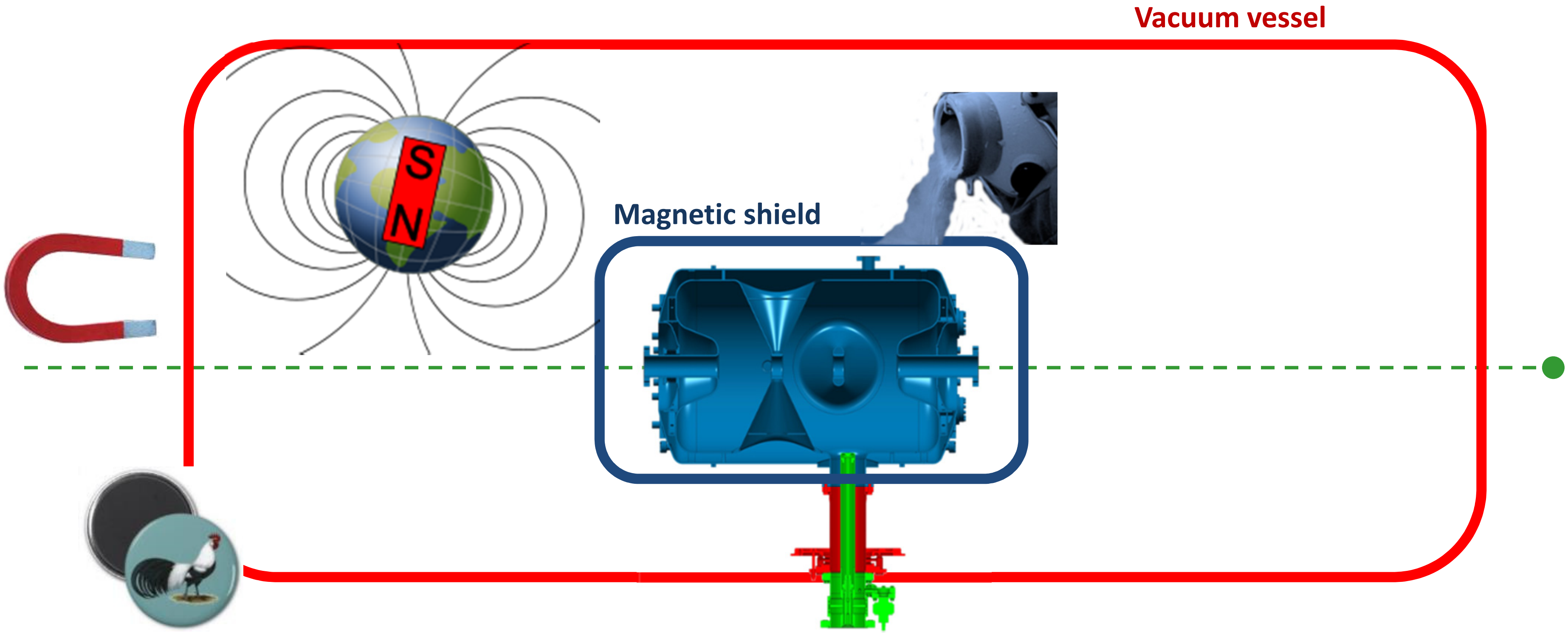


2/ To support the cavities and perform accurate alignment

- **with respect to the beam axis**
- **with respect to other linac components (cryomodules, diagnostics, tunnel)**

NB: alignment must be preserved during thermal and pressure cycles

A cryomodule: what is it and what for?

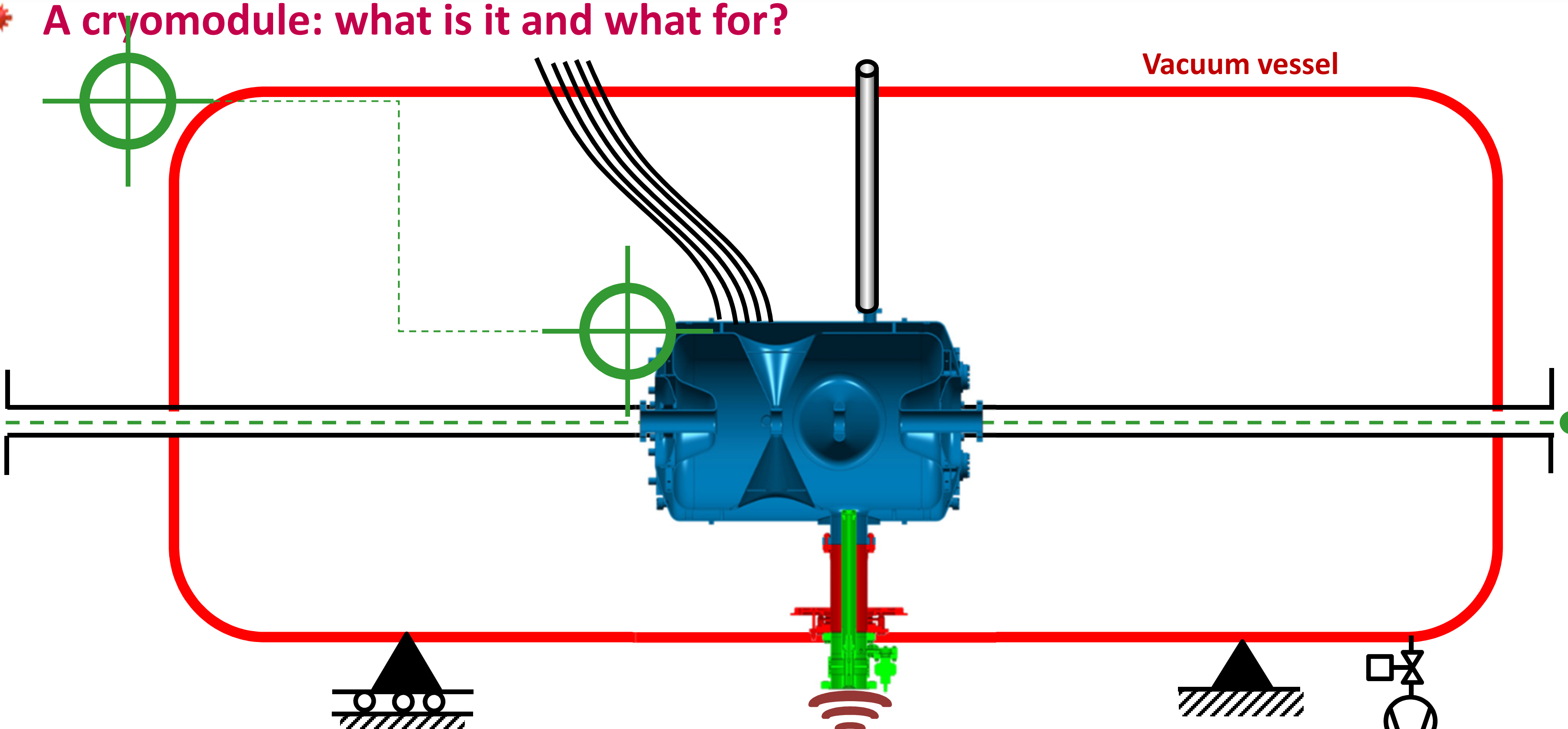


3/ To offer magnetic shielding

- **from the local magnetic sources**
- **from the earth magnetic shield**

NB: the magnetic shield might be cooled (for better performances)

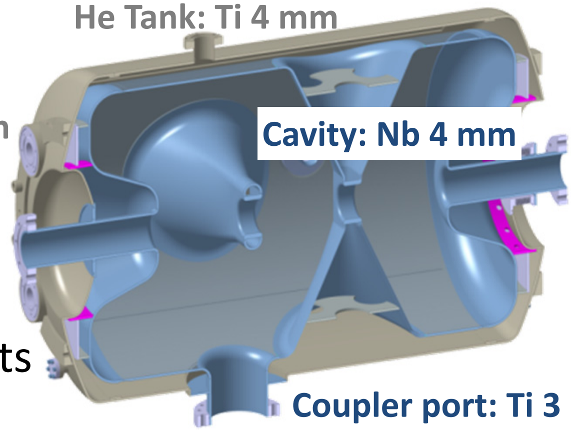
A cryomodule: what is it and what for?



4/ To provide all interfaces between the cavity and the tunnel:

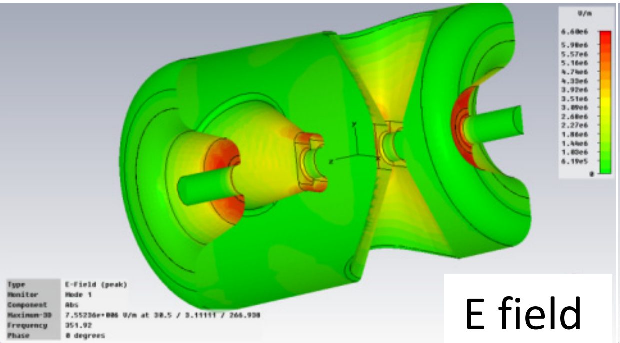
- beam pipe
- RF
- cryogenic
- vacuum
- diagnostic (instrumentation)
- mechanical (support and alignment)

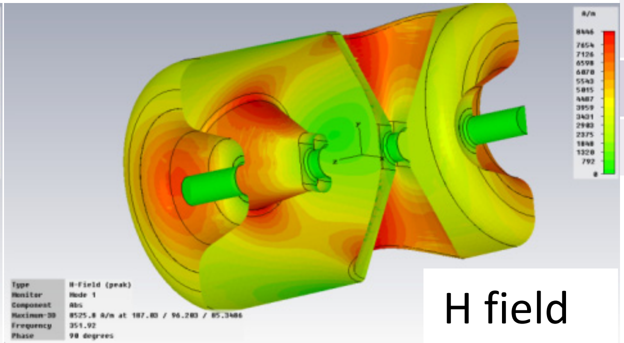
Cavity and liquid helium tank: design



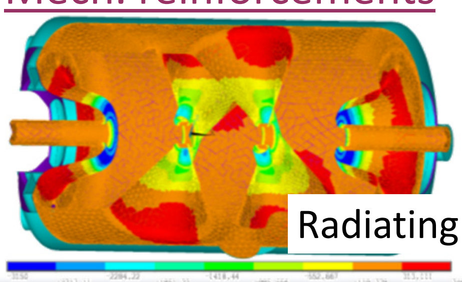
DOUBLE-SPOKE CAVITY	
Frequency [MHz]	352.21
Beta_optimum	0.50
Operating gradient [MV/m]	9.0
Bpk [mT]	62
Epk [MV/m]	39
G [Ohm]	130
r/Q [Ohm]	426
Lacc (=beta optimal x nb of gaps x λ /2) [m]	0.639
Bpk/Eacc [mT/MV/m]	6.88
Epk/Eacc	4.34

- RF shape optimizations





- Mech. reinforcements

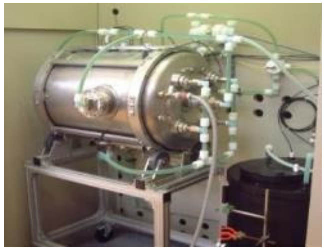
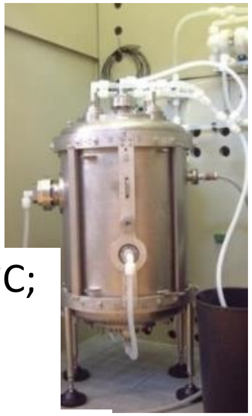


Coupling RF with mechanical models:

- Lorentz detuning coeff. : $K_l = \Delta f/Eacc^2 \sim -5.5$ Hz/(MV/m)^2
- Pressure sensitivity : $Kp = \Delta f/\Delta p \sim 15$ Hz/mbar
- Tuning sentivity : $\Delta f/\Delta z = 130$ kHz/mm

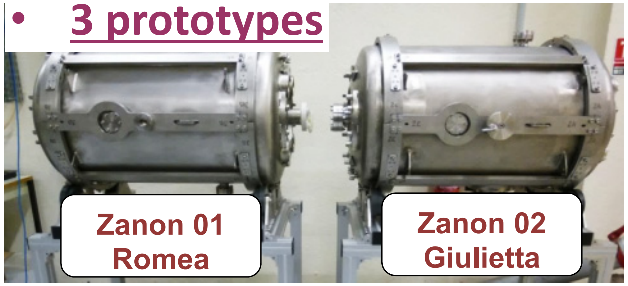
Prototypes, preparations and tests

- **Etching**

3 positions; T < 15°C;
~ 8 hours
⇒ 200 µm

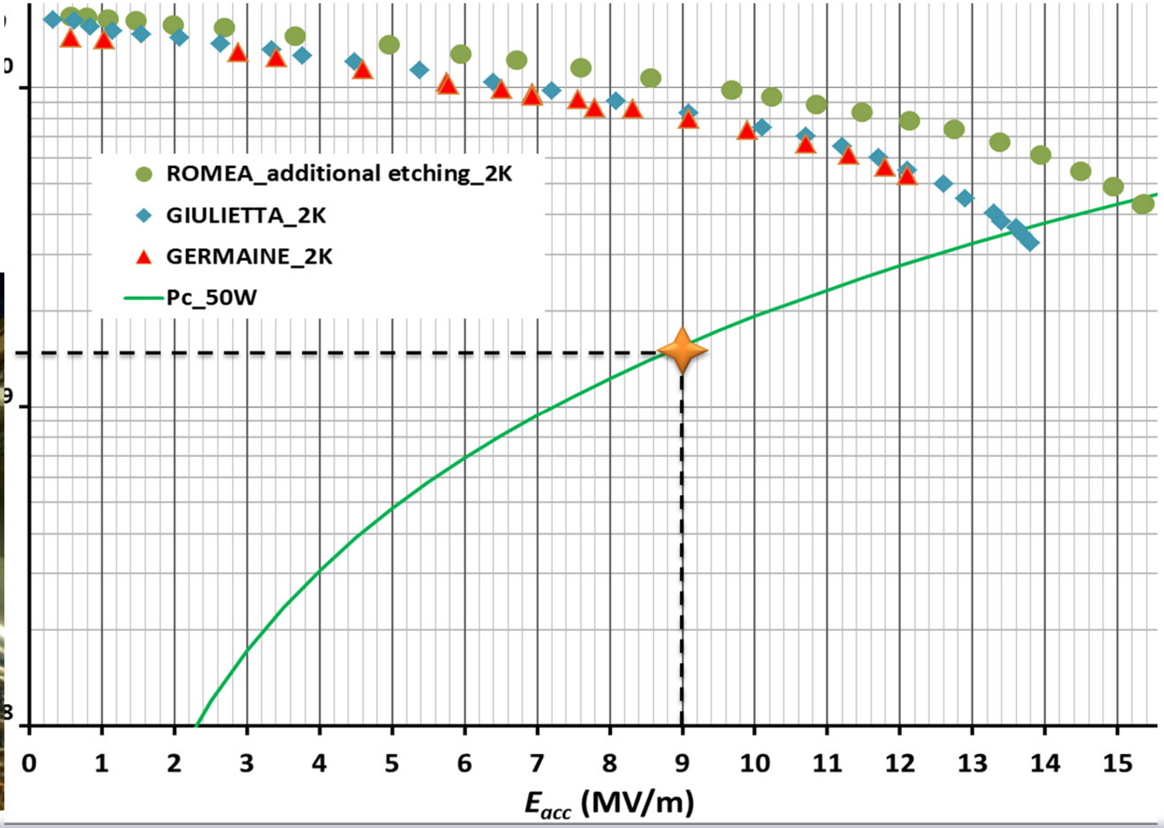
- **3 prototypes**

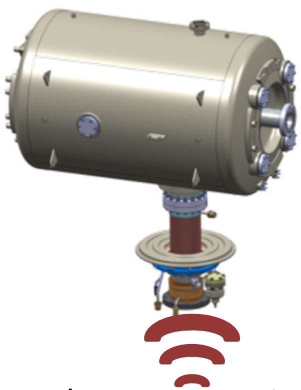


- **High Pressure Rinsing**


100 bars; 6 ports;
~ 12 hours

- **Tests in vertical cryostat**

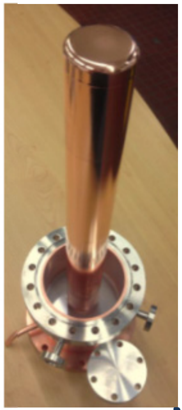


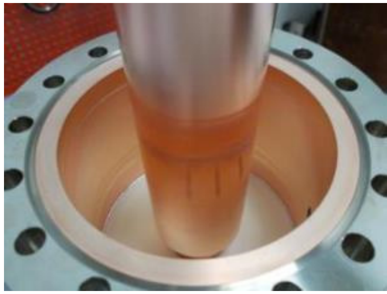


Coupler	
Single ceramic window	
TiN coating (nm)	~ 5 – 10
Frequency [MHz]	352.21
P max [kW]	400

⇒ 4 prototypes manufactured (PMB; CST)

- <u>Inner conductor (antenna)</u>

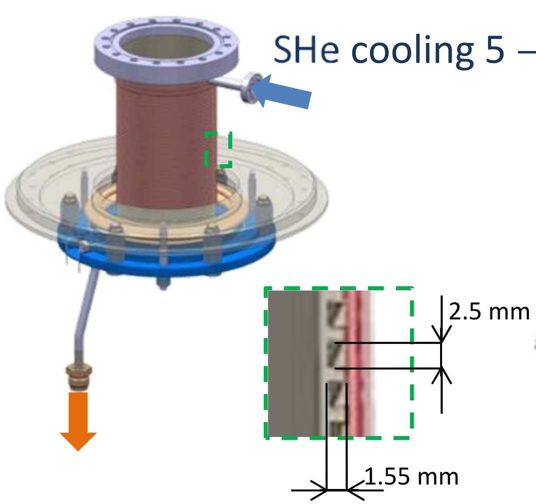


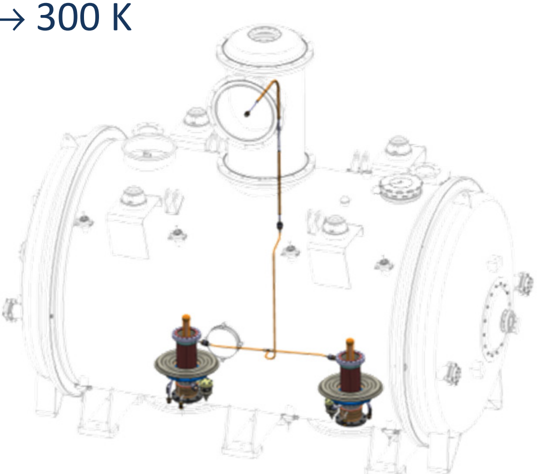


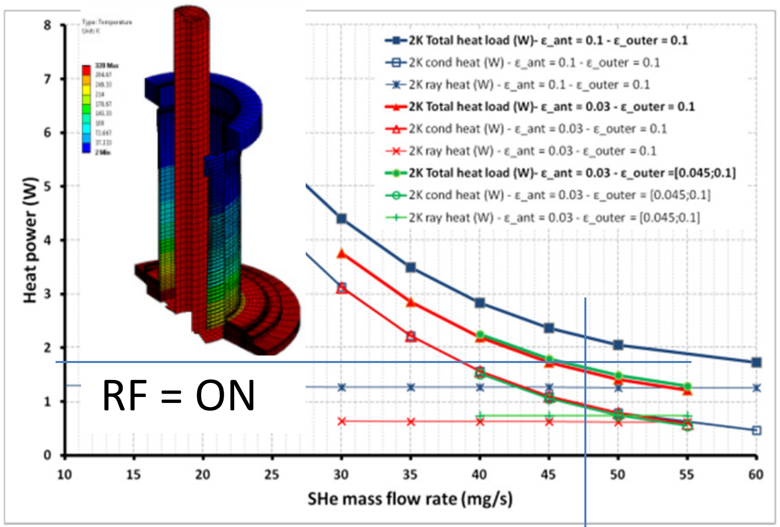
<u>RF power coupler (1 ceramic window)</u>

MUSICC 3D soft.⇒ multipacting simulations

- <u>Outer conductor (antenna)</u>

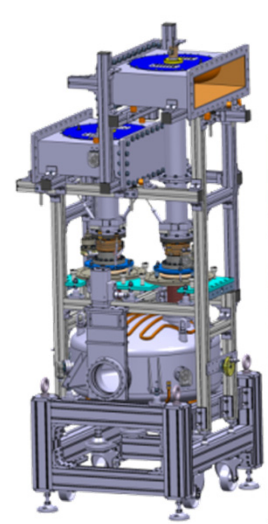
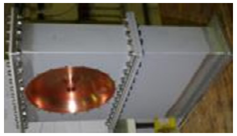


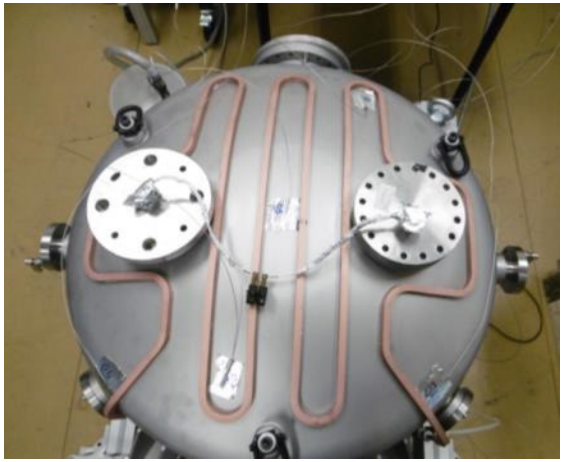




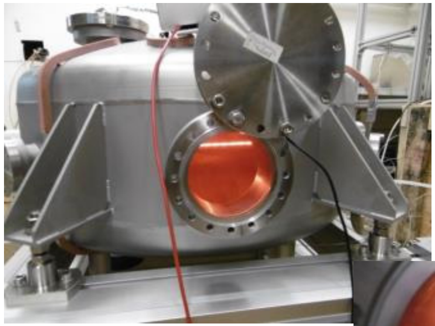
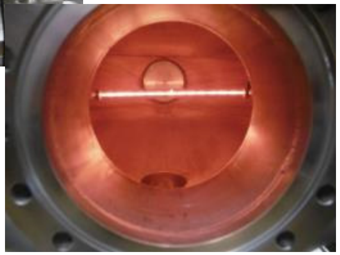
⇒ SHe: 46 mg/s

Conditioning bench for the RF couplers



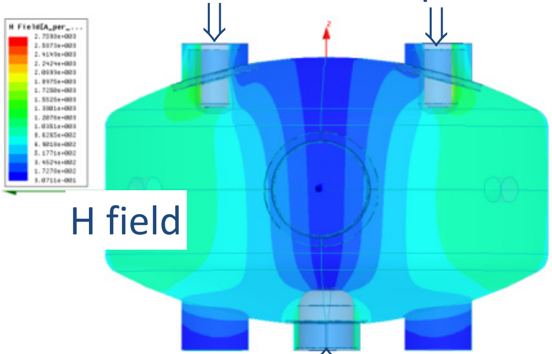
- **Preliminary tests of the cooling system**
  IR heating inside the cavity
  Radiated heat: up to 1 kW

↓

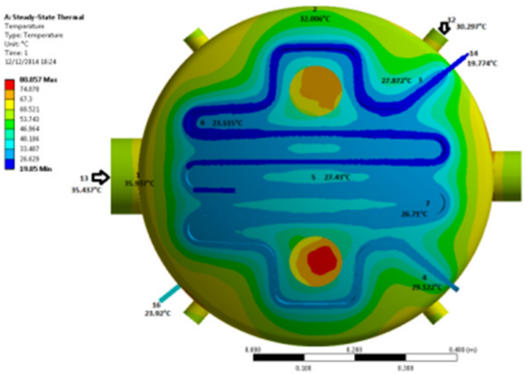
- **Model: RF to thermal, mechanical coupling (ANSYS HFSS ↔ mech.)**

Coupler 1 ⇓ Coupler 2 ⇓



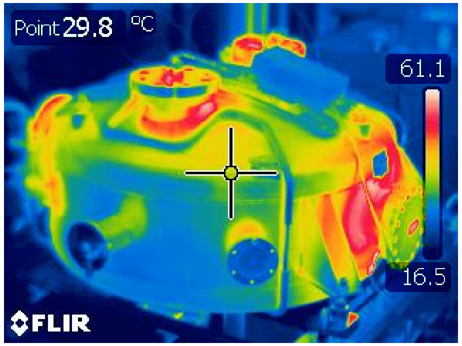
⇑ Plunger

↔



P_{RF} = 400 000 W; DC = 5%
Water mass flow rate: 3.6 g/s

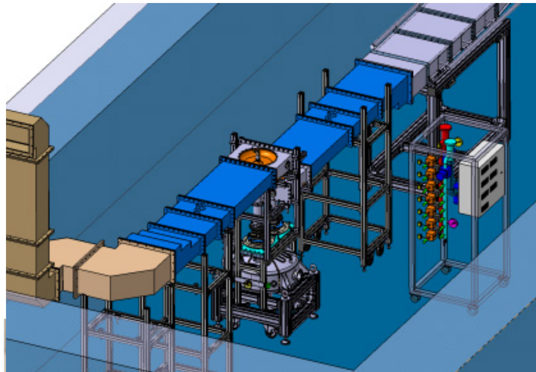
↔



✓ Validation (rough agreement)

RF power couplers 3/4

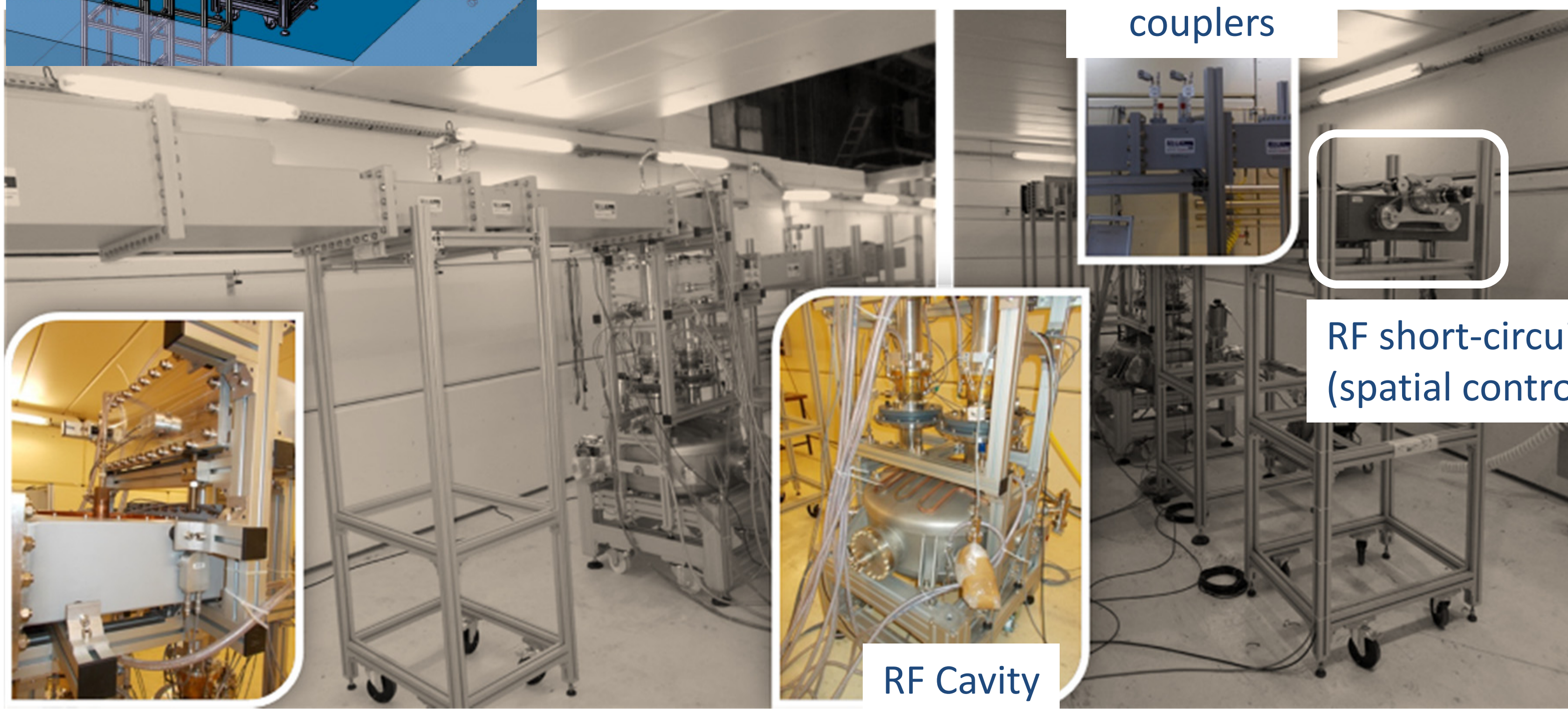
Conditioning bench for the RF couplers



- Installed at CEA Saclay (klystron 352 MHz)
- Integration (RF, mech., electronics…) done by IPNO

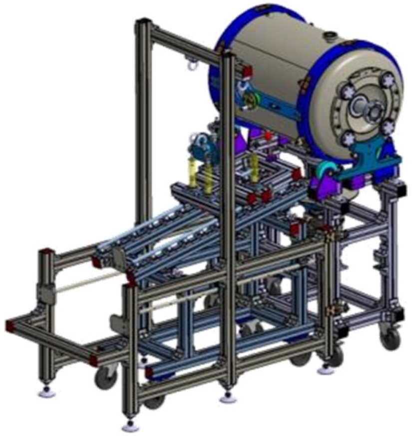
⇒ one coupler failure (break of ceramic window) during RF tests (half of the nominal power)

⇒ one coupler conditioned



Example of qualifying tooling and assembly procedures

- Tooling to assemble the coupler onto the cavity (inside ISO 4 cleanroom)

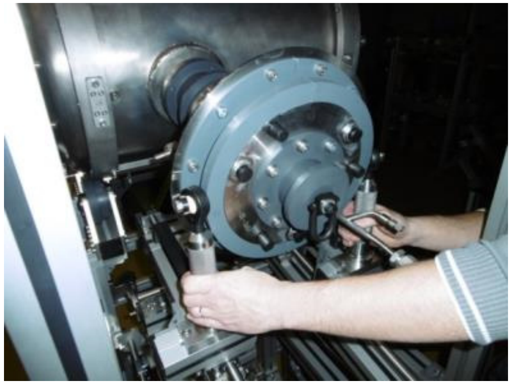


3D printed mock-ups of:

the RF coupler

the double wall tube

✓ Test of the assembly procedure



Cold tuner system

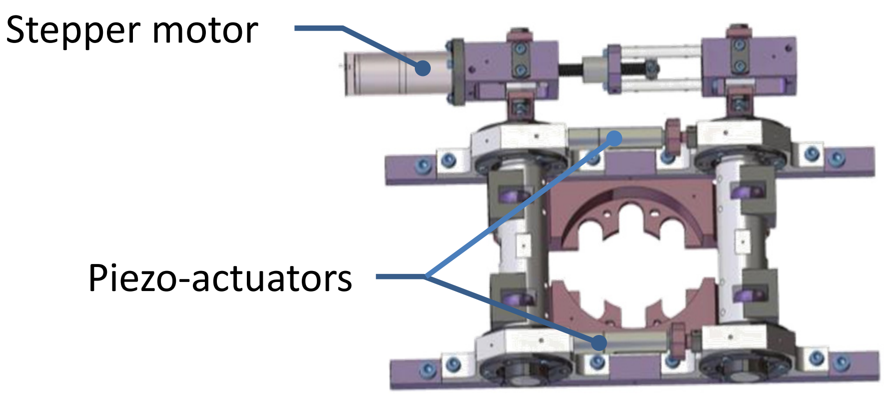
Goals:

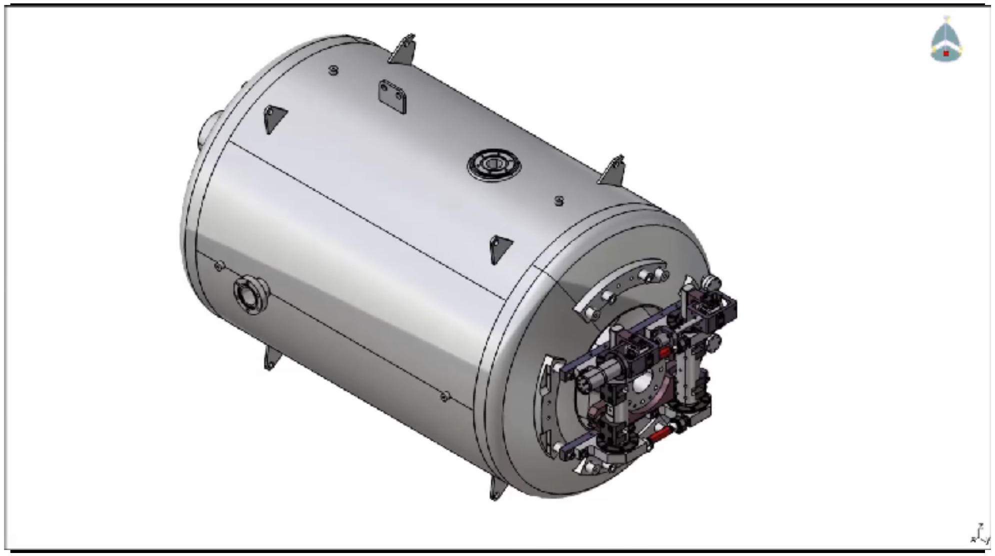
- To tune the resonance frequency of the cavity
  - ✓after cool-down
  - ⇒ Large and slow action
- To balance:
  - ✓ microphonics (pressure waves)
  - ✓Lorentz forces detuning
  - ⇒Small and fast action
- By changing RF volume of the cavity

COLD TUNIG SYSTEM	
Slow tuning (stepper motor)	
Max. stroke (mm)	1.3
Tuning range (kHz)	170
Tuning resolution (kHz)	1.1
Fast tuning (piezo actuators)	
Tuning range (at 2 K) (Hz)	~ 800

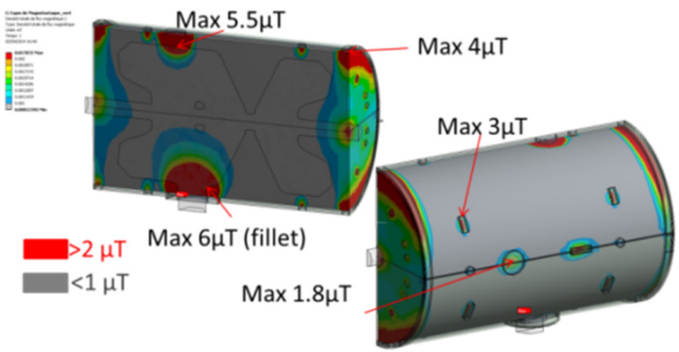
Technology:

- Double lever type CTS

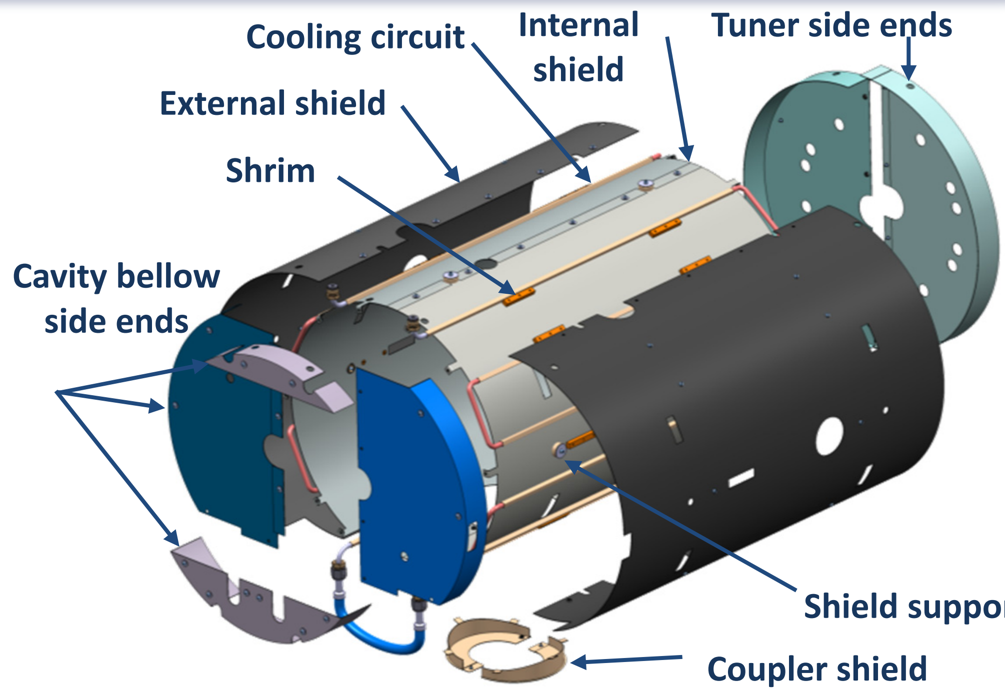


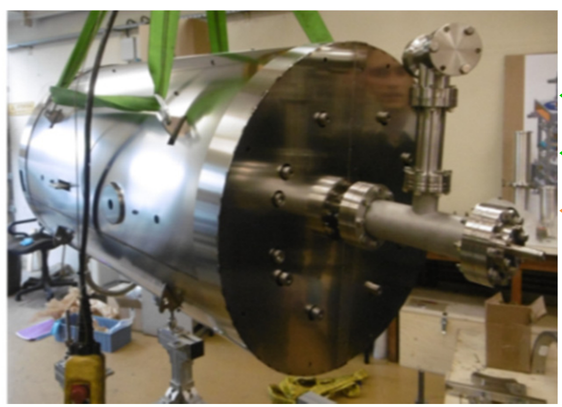


Cavities magnetic shield



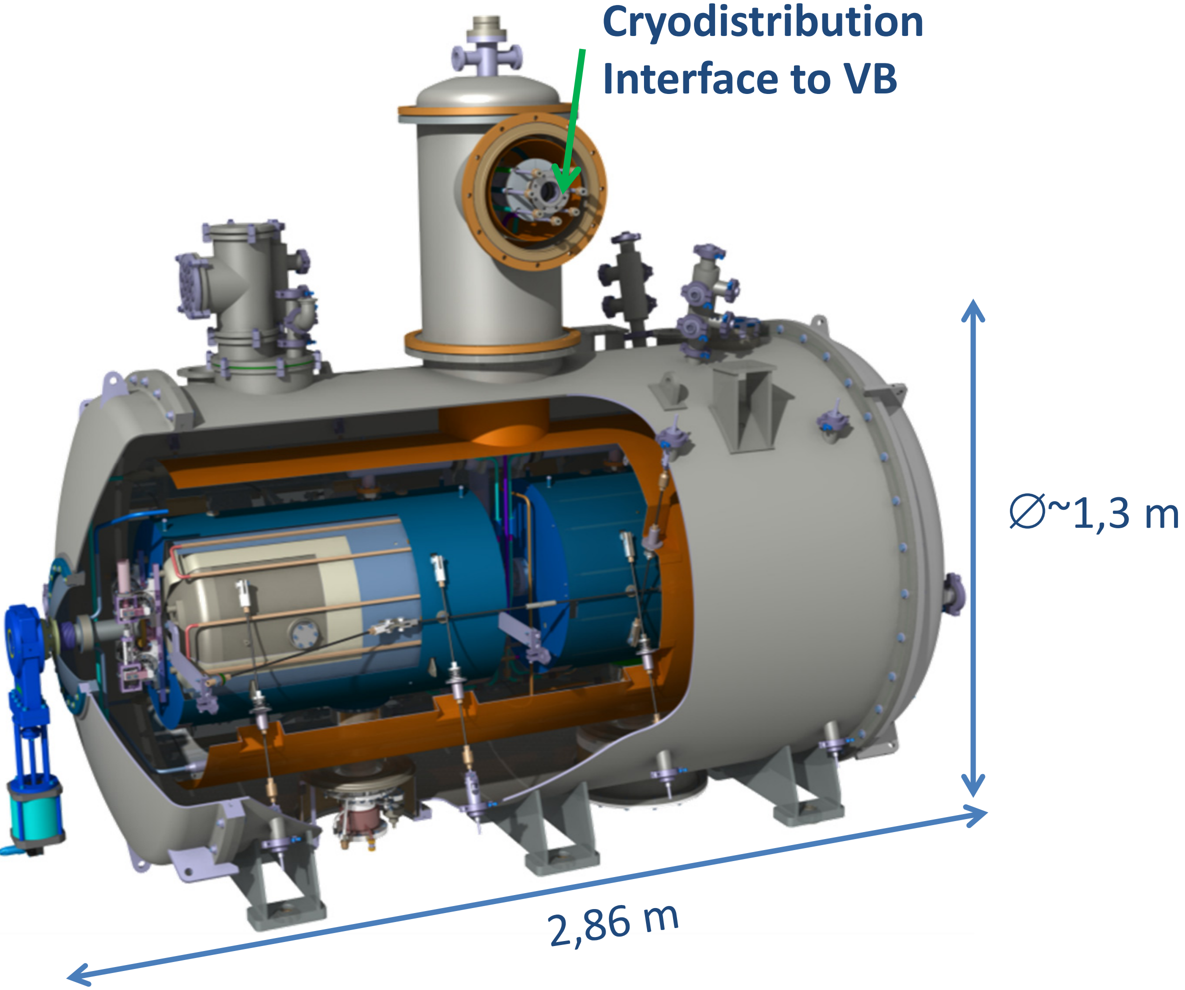
- ✓ Material: Cryophy®
- ✓ Actively cooled (better performances)





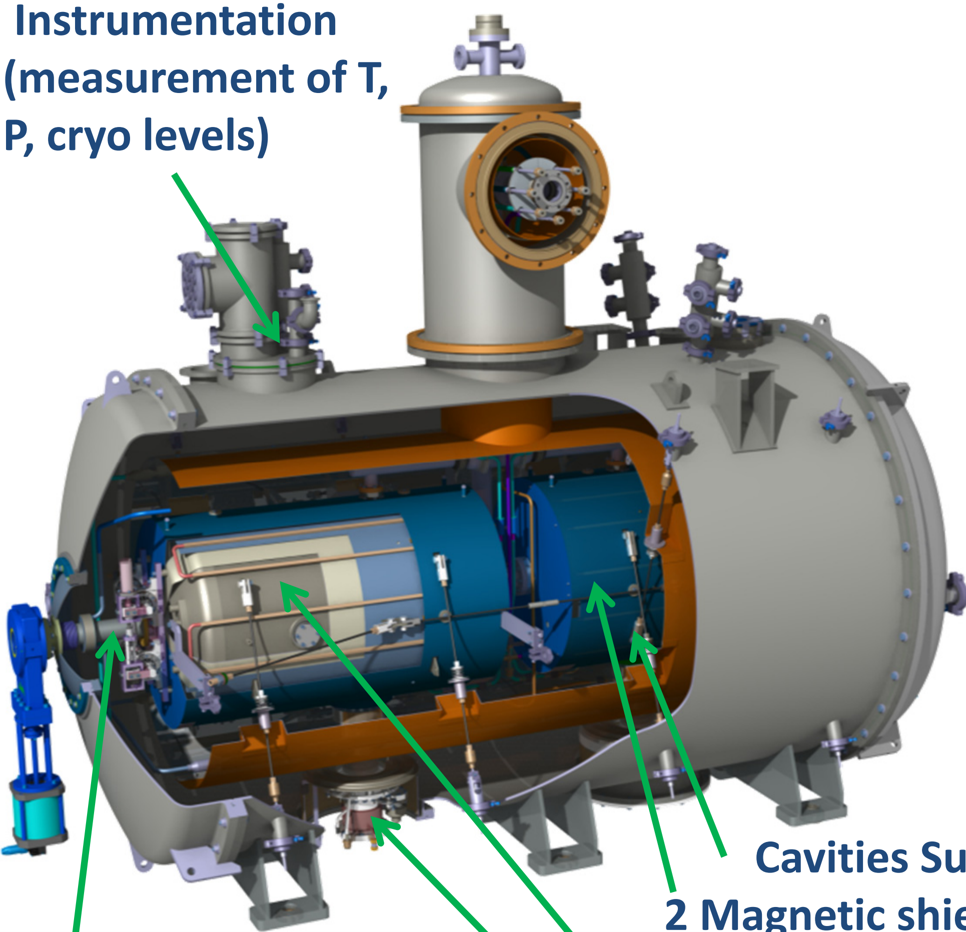
- ✓ Magnetic shields fabricated
- ✓ Assembly test performed
- ✓ To be tested within the cryomodule

The ESS Spoke cryomodule



The Prototype Spoke cryomodule

The ESS Spoke cryomodule



Cryomodule heat load budget

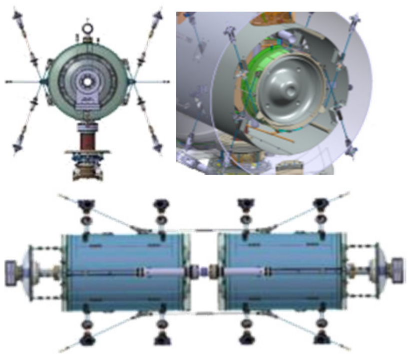
- 2 double Spoke cavities @ 2 K (sat. HeII):
  - ✓ Dynamic heat loads: 2 x 2.5 W
  - ✓ Beam loss: 1.5 W

  2 RF power couplers
  - ✓ 2 x 1,75 W @ 2 K
  - ✓ Heat intercept: SHe 3 bara; 5-300 K
    Liquefaction power: 2 x 0.50 g/s
- Rest of static heat loads @ 2 K: ~ 6,5 W (total~ 10 W)
- Dynamic heat loads ~ 2/3 x Static heat loads

The Prototype Spoke cryomodule

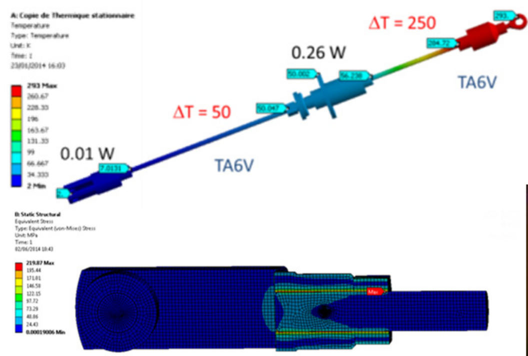
Supporting system for the string of cavities

- ✓ Antagonist rods

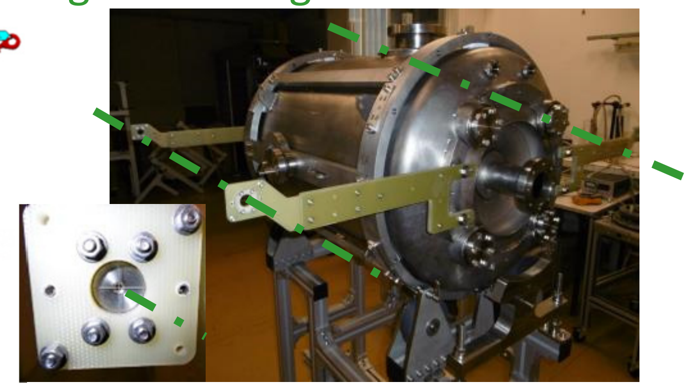


⇨ For vacuum and cryogenics operating conditions: alignment might be possible

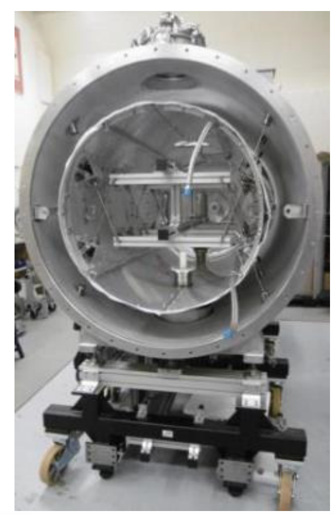
- ✓ Optimization



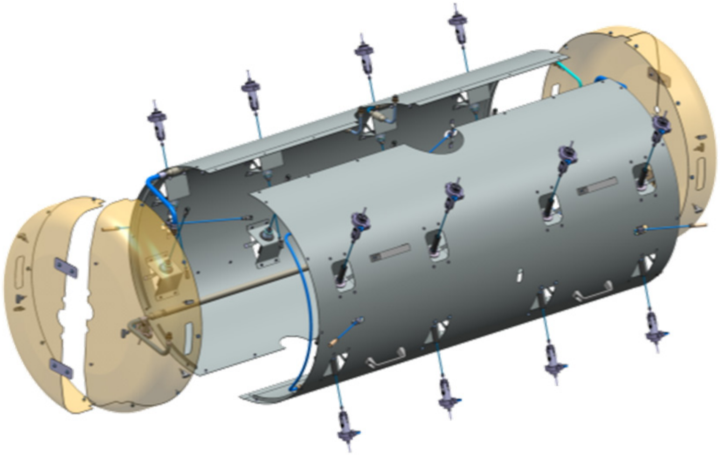
- ✓ Optical fiducials + windows for the alignment diagnostic



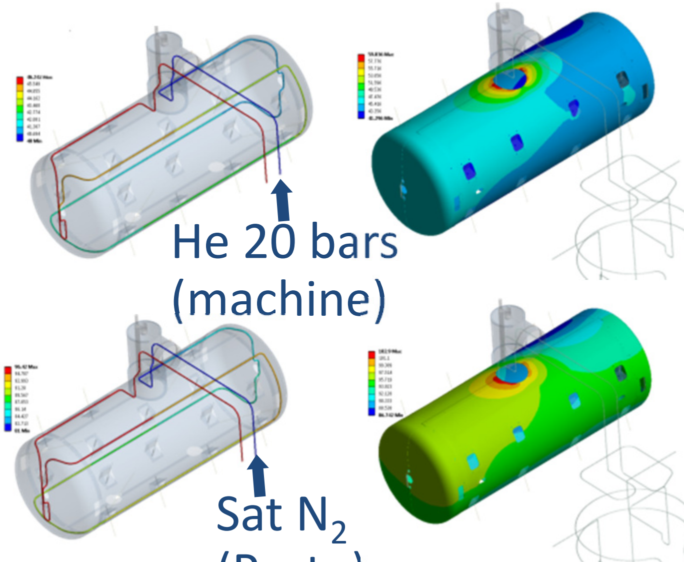
- ✓ Assembly tested (no cold mass)

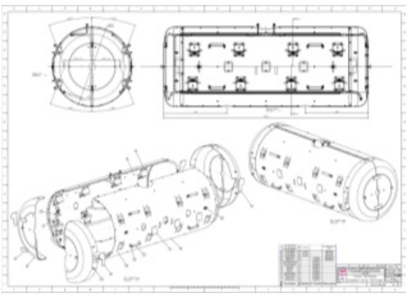


Cryomodule thermal shield

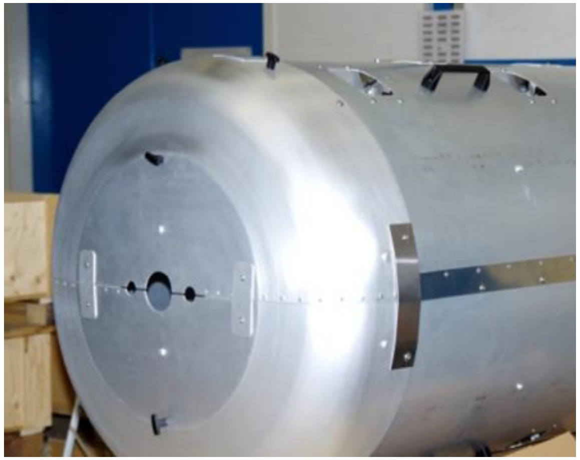


- ✓ Material: Al6062
- ✓ Thickness: 2 mm

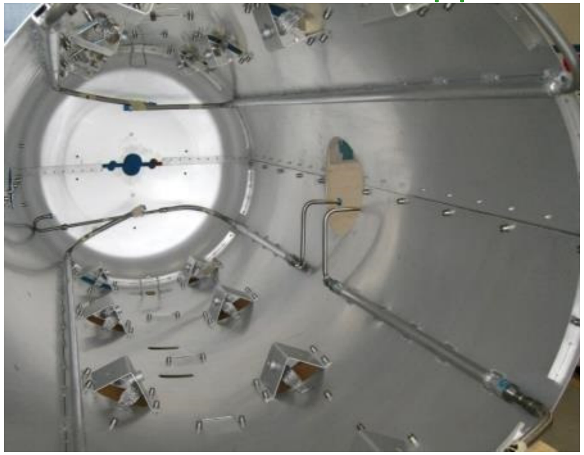




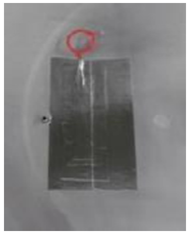
✓ Thermal shield fabricated



✓ Assembled and supported (rods)



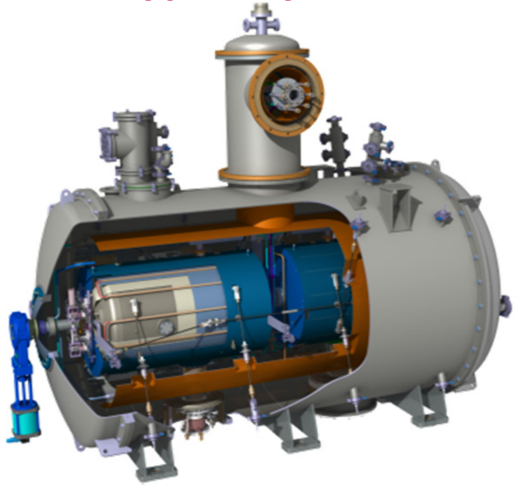
✓Instrum. and cool-down test



⇒ 30 W @ 80 K

Prototyping the Spoke section

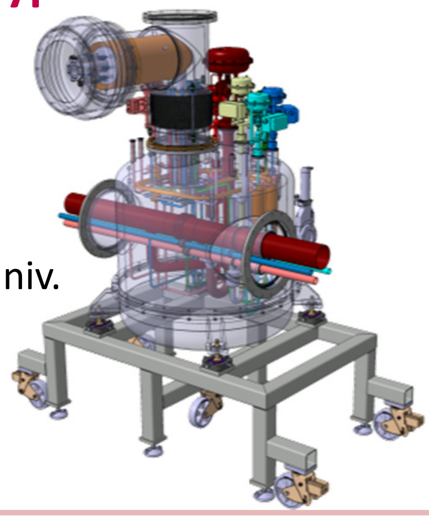
Prototype Cryomodule



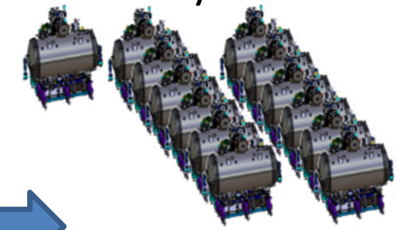
Prototype and test Valve box

IPNO

Uppsala univ.



ESS Series cryomodules



Uppsala univ.

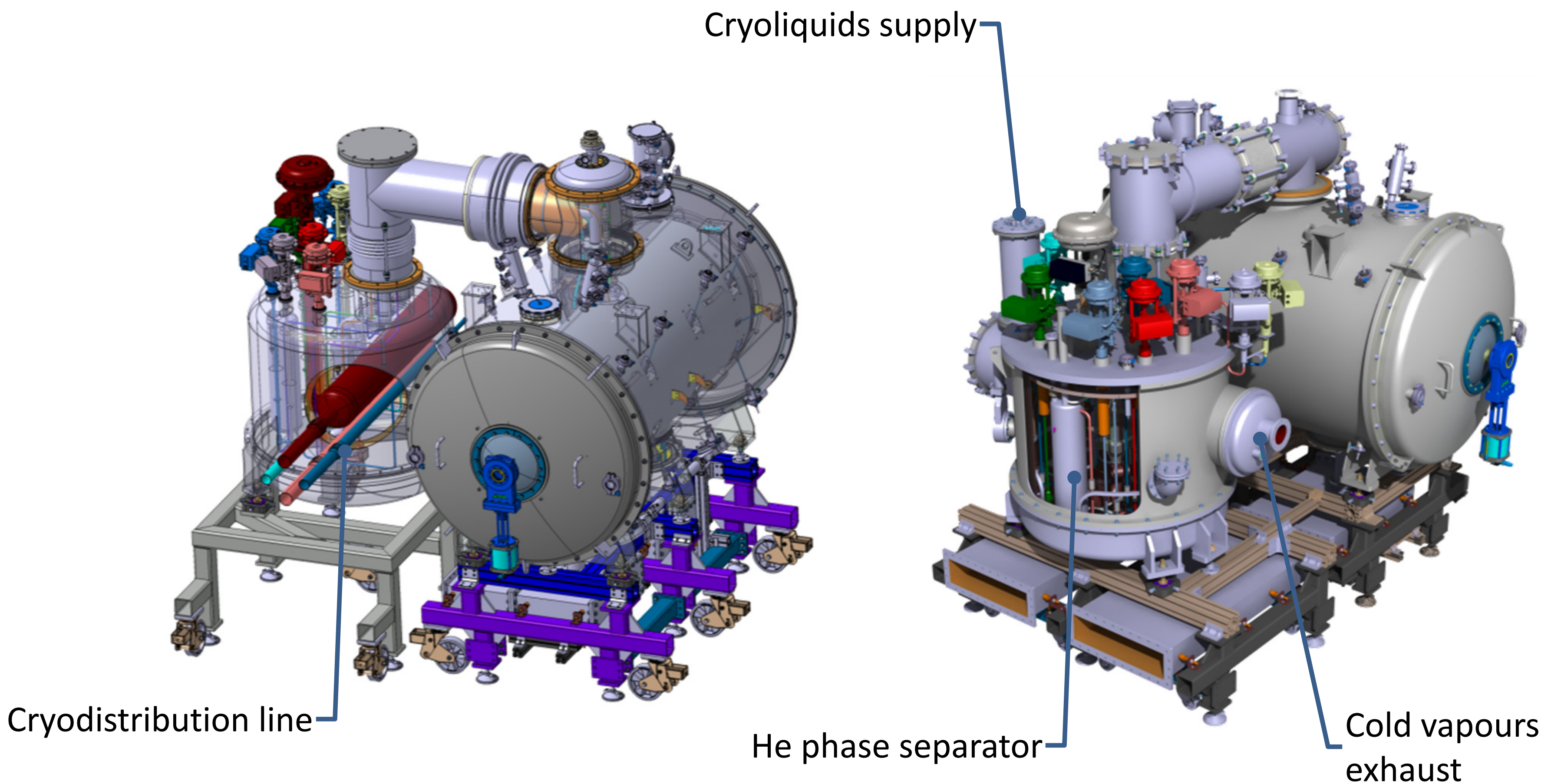
- A prototype and test valve box:
  - ✓Prototype valve box ⇒ to validate the valve box concepts
    ⇒ to validate the prototype Spoke cryomodule
  - ✓Test valve box ⇒ to validate 13 series Spoke cryomodules

⇒ Compromise between an optimized test stand and a demonstrator (cryoprocess, assembly)

- A versatile (flexible) valve box
  - ✓Tests at IPNOrsay (FRANCE)
  - ✓Tests at Uppsala University (SWEDEN)

  ⇒ To manage different cryogenic infrastructures

Prototype valve box



Prototype Spoke valve box status

✓ Vacuum vessel

✓ Cryodistribution piping

✓ Cryodistribution components

He/He Heat exchanger
(Superfluid helium production)

✓ Ready for factory acceptance tests

Crymodule components

- All components received and tested
  - ✓Cavities
    - 3 prototypes manufactured
    - All tested beyond ESS requirements
    - However Q_O decrease observed after several thermal cycles

    ⇒ Hydrides formation on the inner surface of the cavity induce defects that are not recovered at room T°

⇒ UHV furnace installed at Supratech facilities (IPNO)
⇒ Thermally and vacuum qualified up to 1400 °C

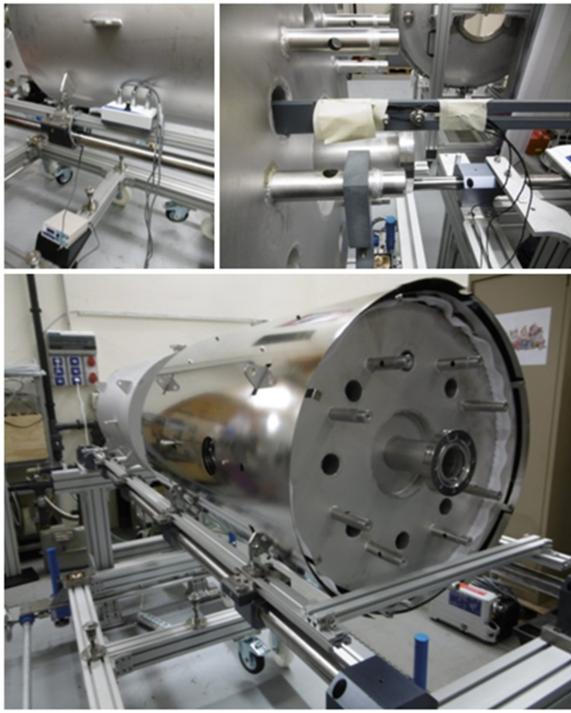
⇒ Heat treatment procedure tested on samples and 1.3 GHz cavity
⇒ 1 Spoke cavity to be annealed (650 °C) by the end of this summer

- **Crymodule components**
  - All components received and tested
    - ✓Couplers
      - 4 prototypes manufactured
      - 1 coupler failure during RF conditioning (analysis)
      - 1 coupler conditioned
      - Conditioning of others couplers to be done
  - Assemblies of subparts tested
- **Assembly of the cryomodule started with a string of 2 mock-up cavities**
  - To test the assembly procedure
  - To validate the magnetic shield

(spatial measurements of the attenuation of the environment magnetic field at room and N_2 T° by this summer)

  - To validate the cryogenic process

(helium tanks of the cavities have the same volume and geometry as the Spoke cavities)



Conclusion

- **Spoke prototype valve box**
  - Factory acceptance tests next week
  - Installation at Orsay to perfom the first cryogenic test of the prototype Spoke cryomodule at IPNO

Thank you for your attention

EUROPEAN SPALLATION SOURCE

IN2P3 Les deux infinis

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