High Gradient cryomodule: status and update (from SPL to HG)

With the contribution of Katarzyna Turaj, Karim Gibran Hernandez Chahin, Alick Macpherson, Sotirios Papadopoulos, Julien Pascal Dequaire

SPL (Superconducting Proton Linac) Short Cryomodule
foreseen as a low power injector into PS2 (that would have replaced PS)

HG (High Gradient) Cryomodule

Goal:

- Design and construct a cryo-module for 4 β=1 cavities

Motivation:

- Test-bench for RF testing on a multi-cavity assembly driven by a single or multiple RF source(s)
- Demonstration of reachable accelerating gradients and Q-values for 704 MHz, multi-cell, β=1 cavities.
- Enable RF testing of cavities in horizontal position, housed in their helium tanks, tuned, and powered by machine-type RF couplers
- Validate by testing critical components like RF couplers, tuners, HOM couplers in their real operating environment

Cryomodule-related goals:

- Validation of design
  - Innovative supporting of cavities via the RF couplers
- Learning of the critical assembly phases:
  - handling of long string of cavities with complete RF coupler
  - alignment/assembly in the cryostat
- Validation through operational experience:
  - Cool-down/warm-up transients and thermal mechanics
  - Gas-cooled RF coupler double-wall tube (active cooling effect on cavity alignment)
  - Alignment/position stability of cavities
  - Cryogenic operation (He filling, level control, etc.)

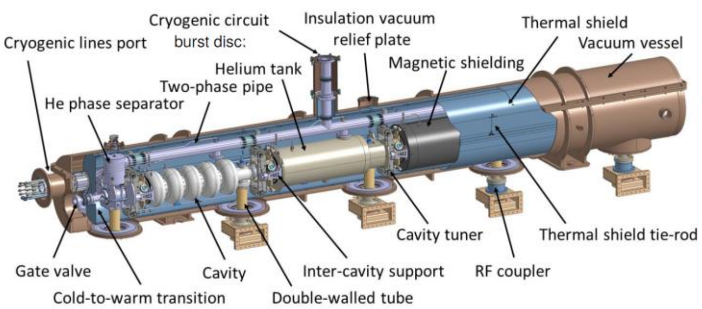
SPL (superconducting Proton Linac) Short Cryomodule

Main contributions for short cryo up to now

CEA – Saclay (F)
Design of **β=1 cavities** (EuCARDtask 10.2.2)
Design & construction of **4 helium vessels for β=1 cavities** (French in-kind contribution)
Supply of **4 tuners** (French in-kind contribution)
Testing of RF couplers

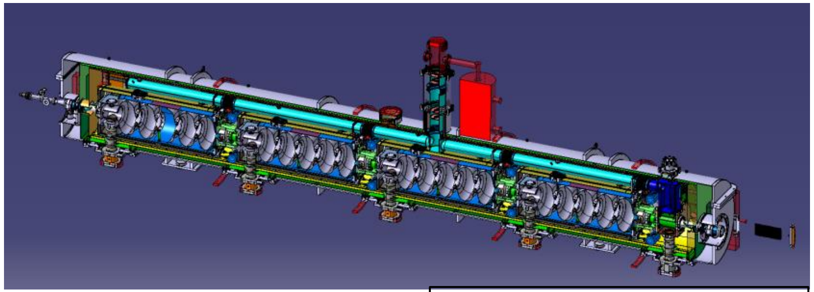
CNRS – IPN – Orsay (F)
Design of **prototype cryo-module cryostat** (French in-kind contribution)
Construction of the vacuum vessel
Design of **cryostat assembly tools** (French in-kind contribution)

CERN
4 β=1 cavities
4 RF couplers

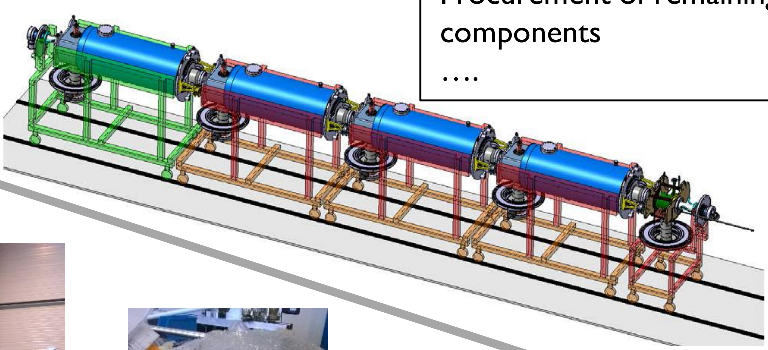


HG (High Gradient) Cryomodule

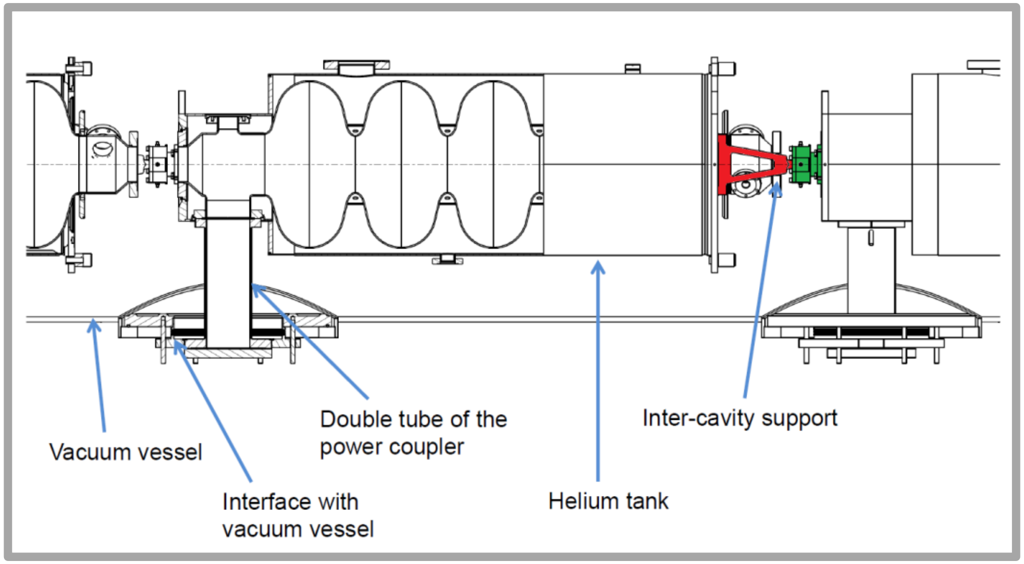
HG cryomodule: goal & motivations



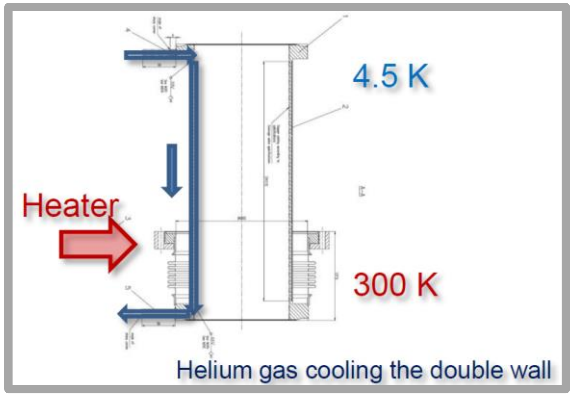
CERN
Finalization of drawings
Clean room tools
Procurement of remaining components
….

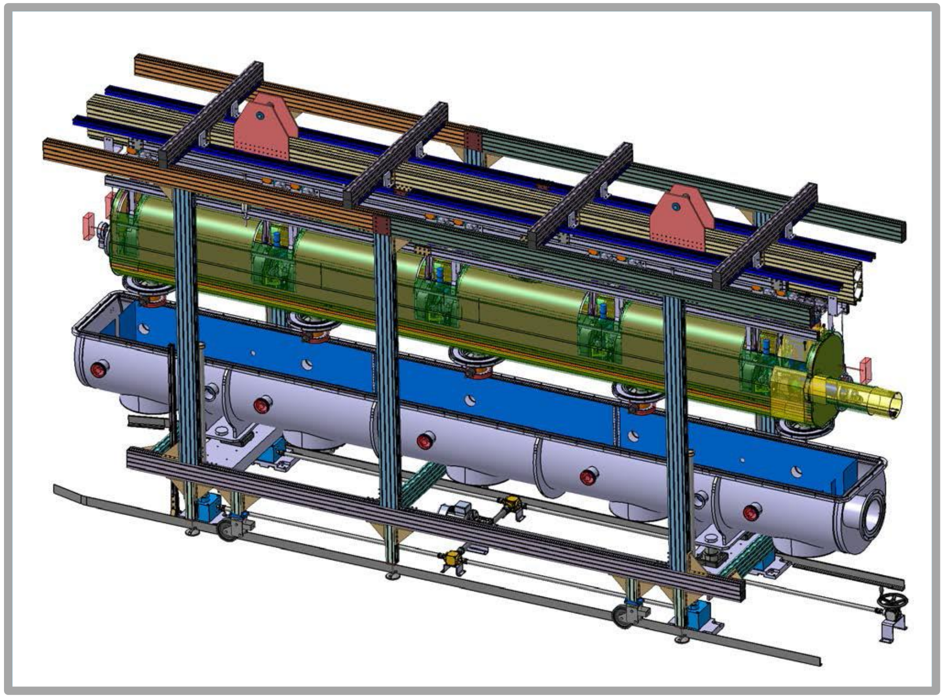


HG cryomodule: few hints



Requirement	Value
β	1
Frequency	704.4 MHz
Qo	>5 x 10^9
Gradient	25 MV/m
Operat. T	2 K

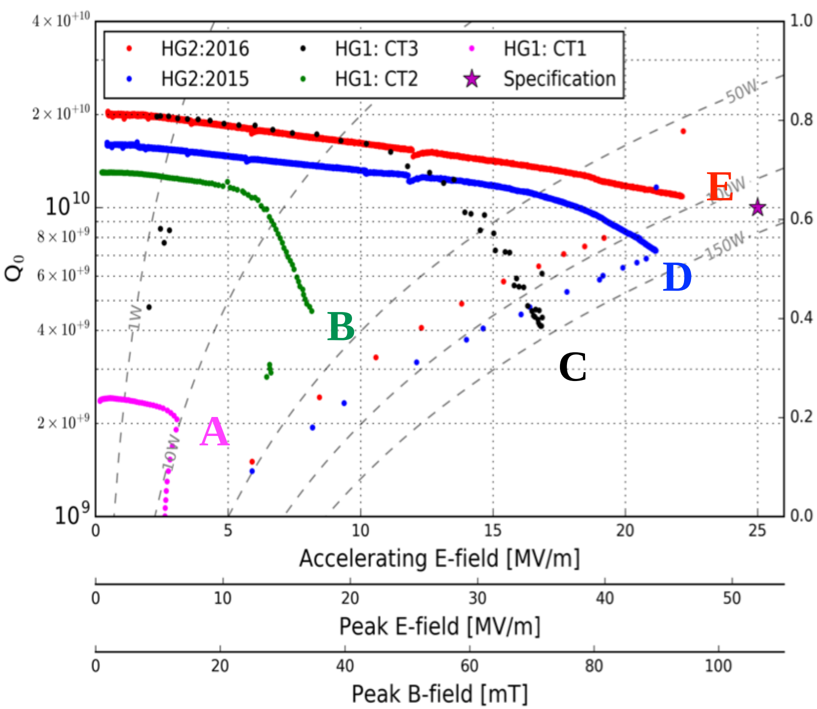




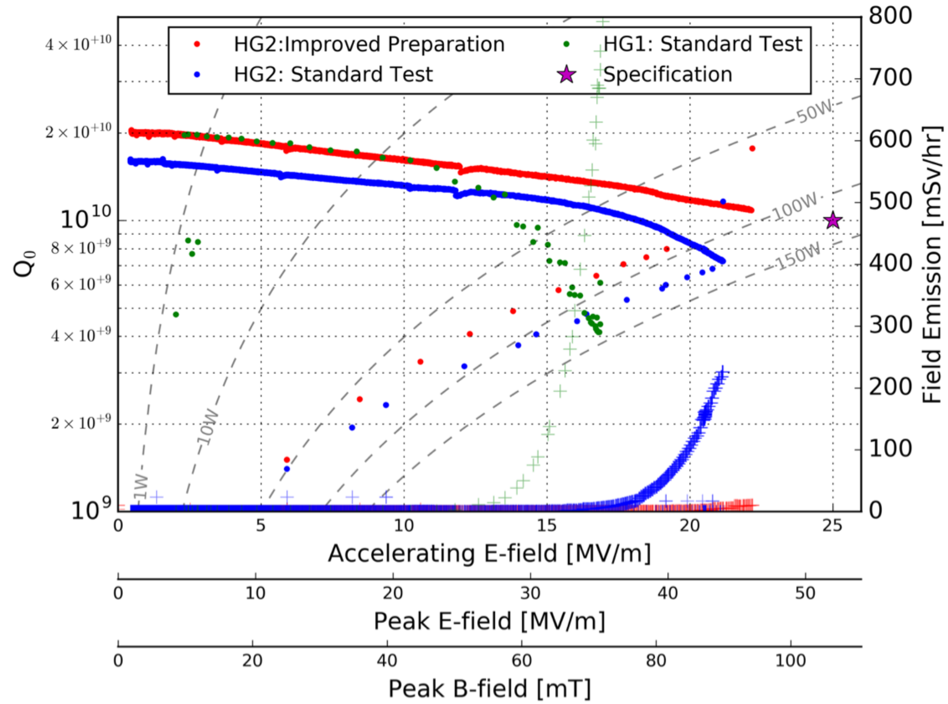
- Innovative supporting condition (coupler)
- Innovative coupler cooling (double walled tube)
- Vertical cryostating

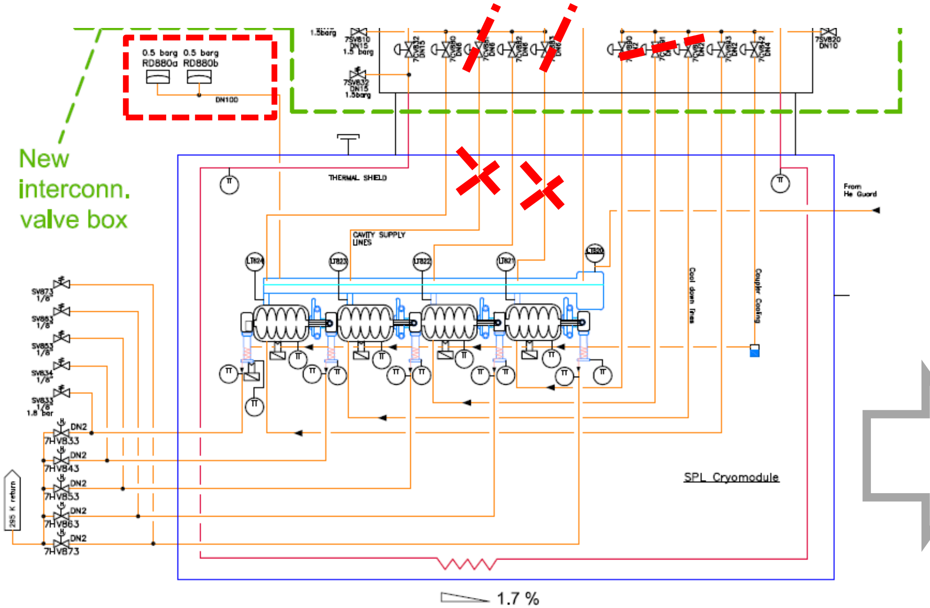
Cold Test	A	B	C	D	E
Cavity	HG1	HG1	HG1	HG2	HG2
Standard HPR	✗	✗	✓	✓	✓
120°C Bakeout	✓	✓	✗	✗	✗
Thermal Gradient Control at T_c	✓	✓	✓	✓	✓
Ambient B-field (<30nT)	✗	✓	✓	✓	✓
Improved Pre-HPR Preparation	✗	✗	✗	✗	✓

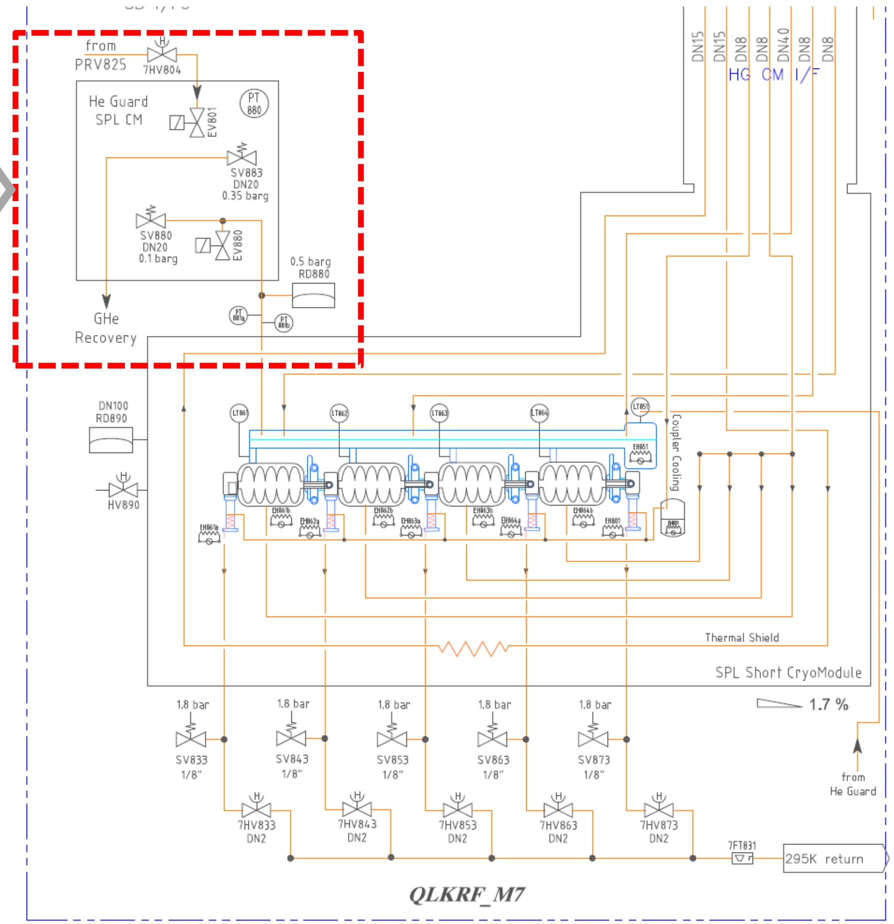
Evolution of Cavity Performance



Comparison of HG 1 & HG2





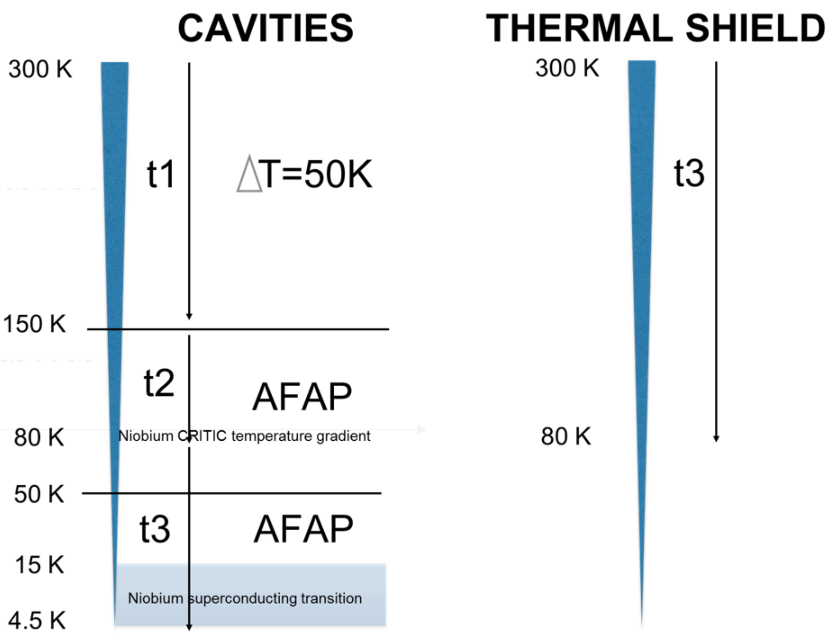


- Operating condition: p<0.5 bar gauge
- Box with valves to reduce peaks during transient
- Redundant cryogenic reduced (but not eliminated)

Circuit	Temp. in K	Pressure in bar	Heat load in W	Flow rate in g/s
Thermal radiation shield	50 – 75	1.4 - 1.15	240	1.85
Liquid supply (two cavity circuits)	2.2	1.2	200 dynamic	10 in total
Helium return	2	0.0031	-	10
Power couplers 4x	4.5 – 300	1.25 – 1.05	-	0.1

Proposal to adopt the same operating procedures for CRAB test cryomodule

CoolDown

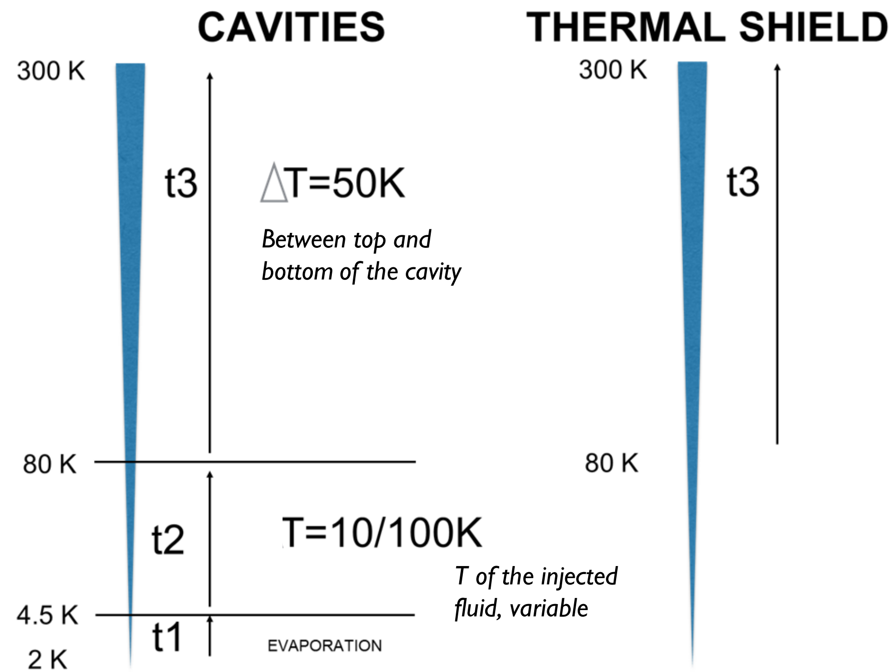


- T1 - Cavities 300 K → 150 K (control of ΔT ~ 50 K)
- T2 - Cavities 150 K → 80 K (AFAP)
- T3 - Cavities 80 K → 4.5 K (AFAP)
- T3 - Thermal Shield 300 K → 80 K
- T4 – Cavities 4.5 K → 2 K

OPTION:

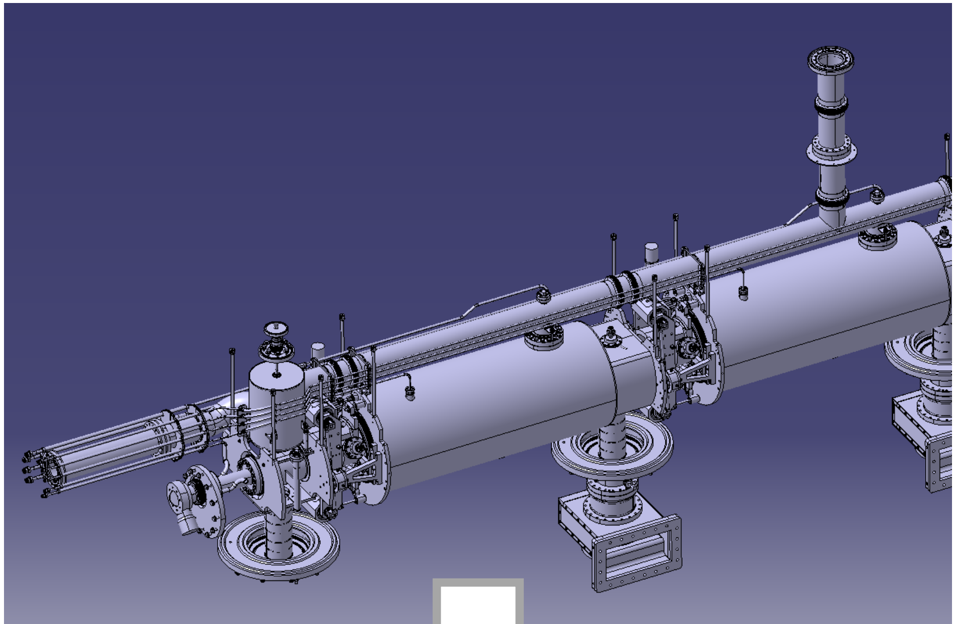
- T3 - Cavities 80 K → 15 K (AFAP)
- + stop at 15 K for thermalization
- + cavities 15 K → 4.5 K

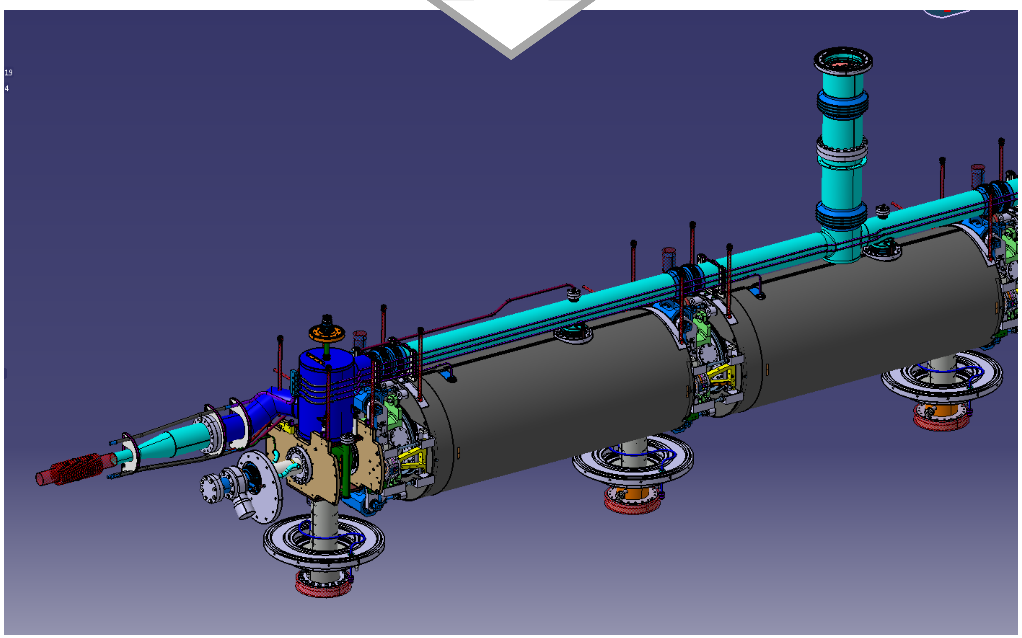
WarmUp



- T1 - Cavities 2 K → 4.5 K (Evaporation by heaters)
- T2 - Cavities 4.5 K → 80 K (control of T ~ 10-100 K)
- T3 - Cavities 80 K → 300 K (control of ΔT ~ 50 K)
- T3 - Thermal Shield 80 K → 300 K

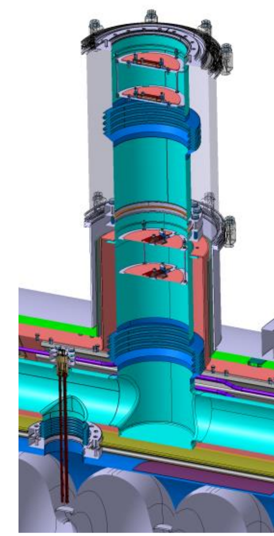
Cryo lines





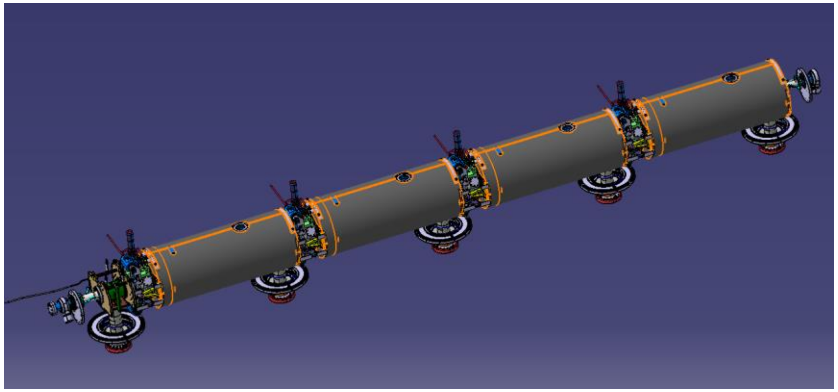
Modifications (cryo lines, vaporizator, separator, CW transitions):

- New chimney with intermediate shields to reduce heat transfer on the biphase tube
- New materials : 1.4429 (316LN) is the best but not always possible
- Safety devices under dimensioning (past calculations are available but not definitive)
- Welded details compliant with European Standards
- Adaptation to new warm magnetic shield

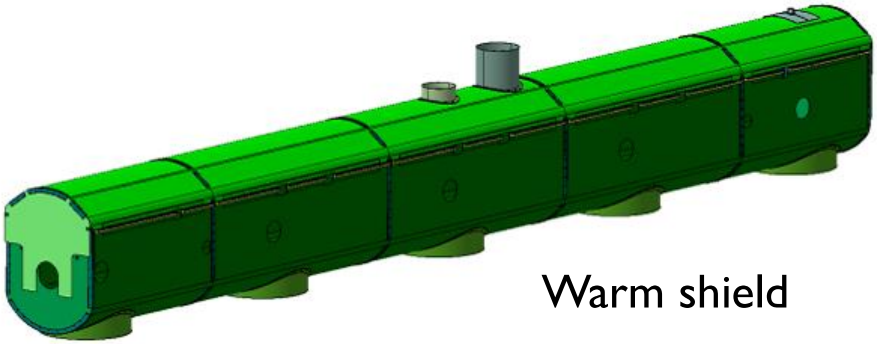


New warm magnetic shield

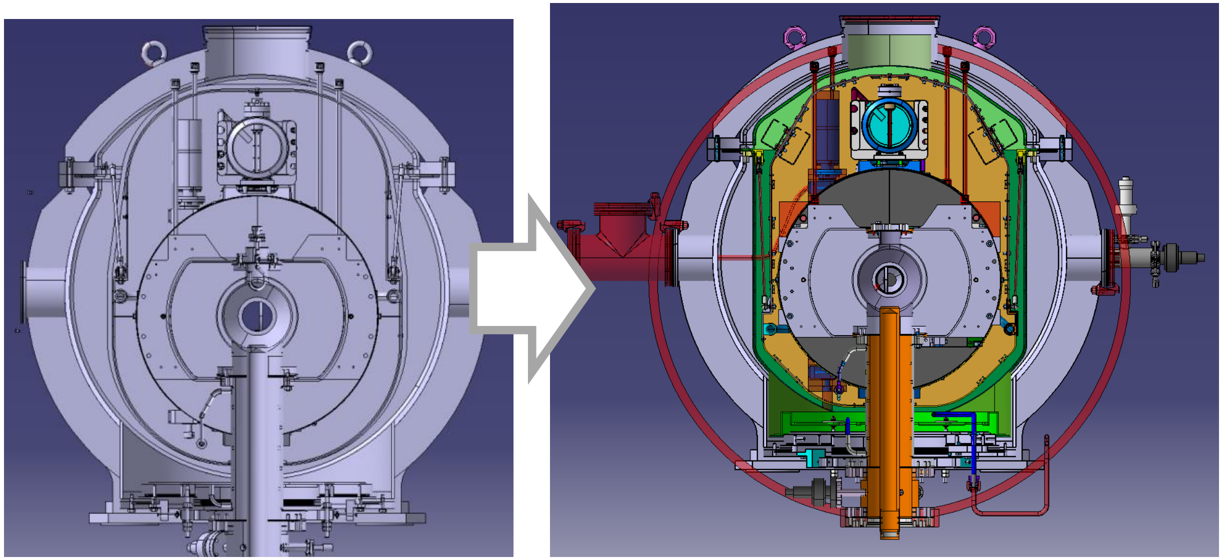
Simulations showed need of warm magnetic shield
Magnetic shielding: 3 levels of shielding strategy resumed -> need to introduce a warm magnetic shield in coupler region

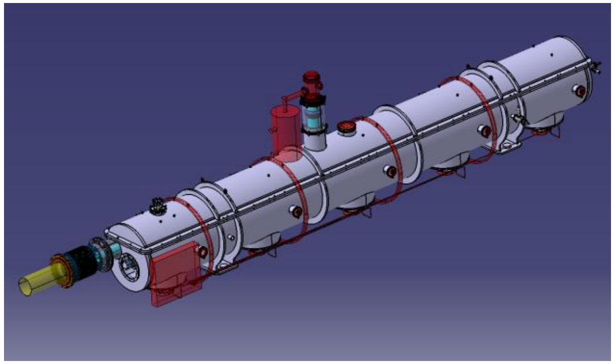


Cold shields



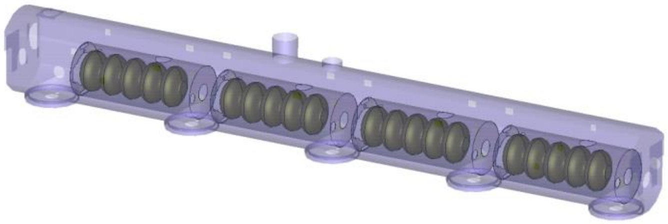
Warm shield

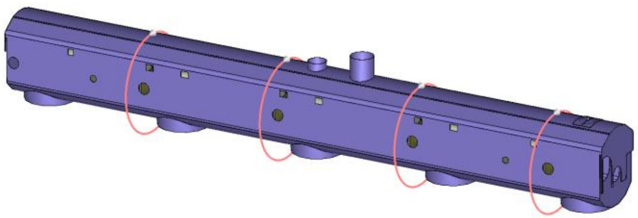




Correction coils

New warm magnetic shield: simulation



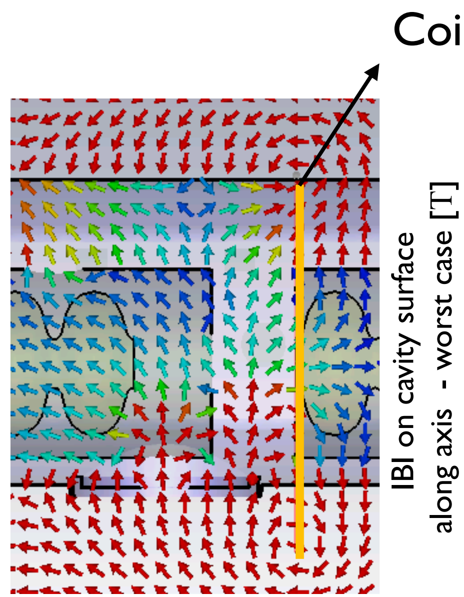


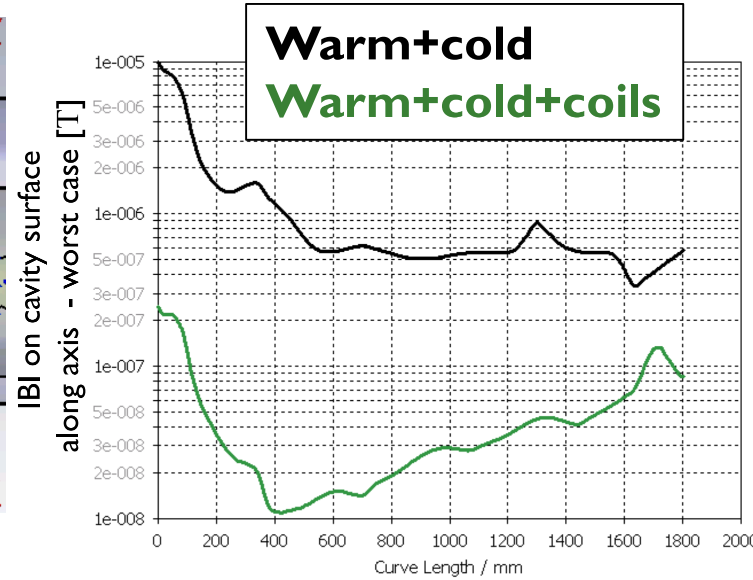
Considering also recent studies on quenching, Q deterioration and recovery: $B_{ext} < 0.1 \mu T$!

Early results further investigation needed.

3D Simulation results (CST)
2D plot – axial side view

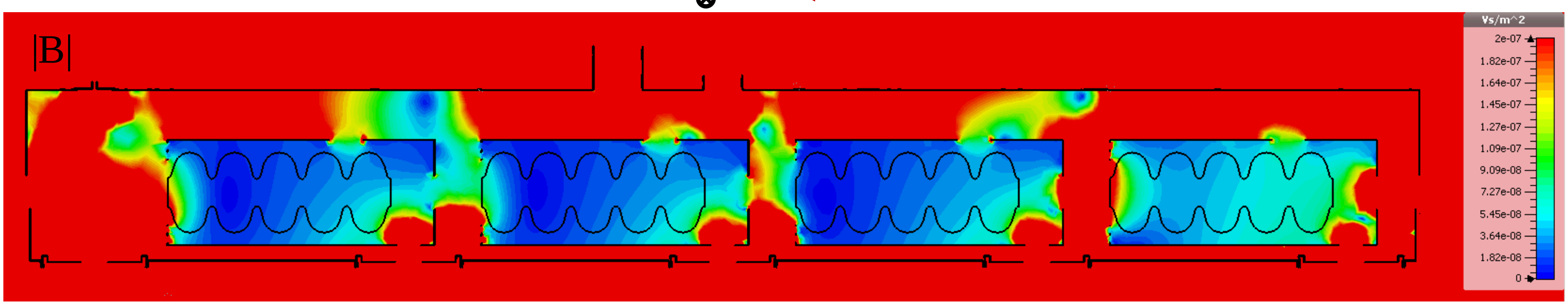
Warm + cold magnetic shield + compensating coils

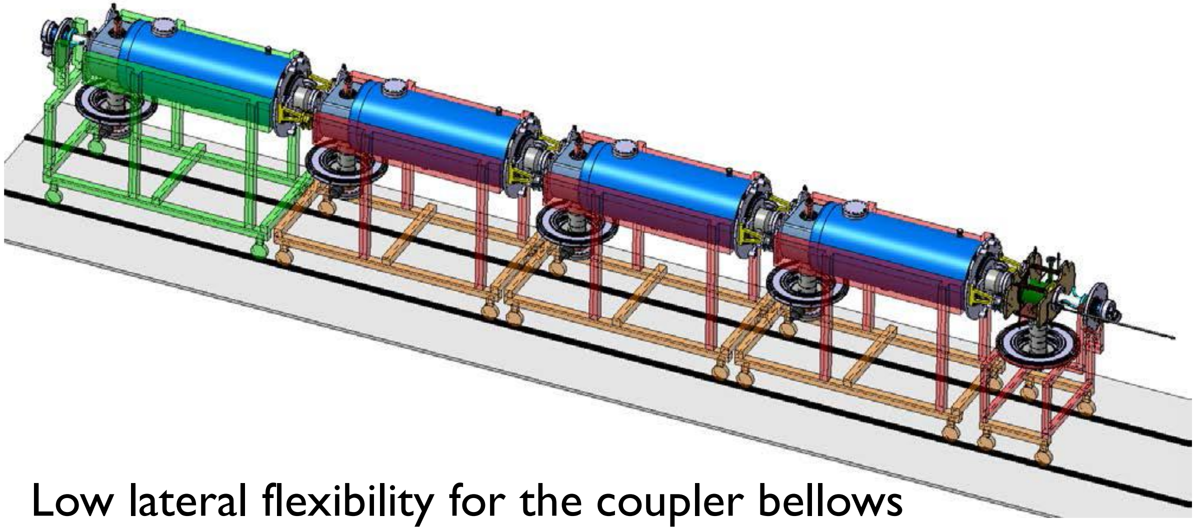




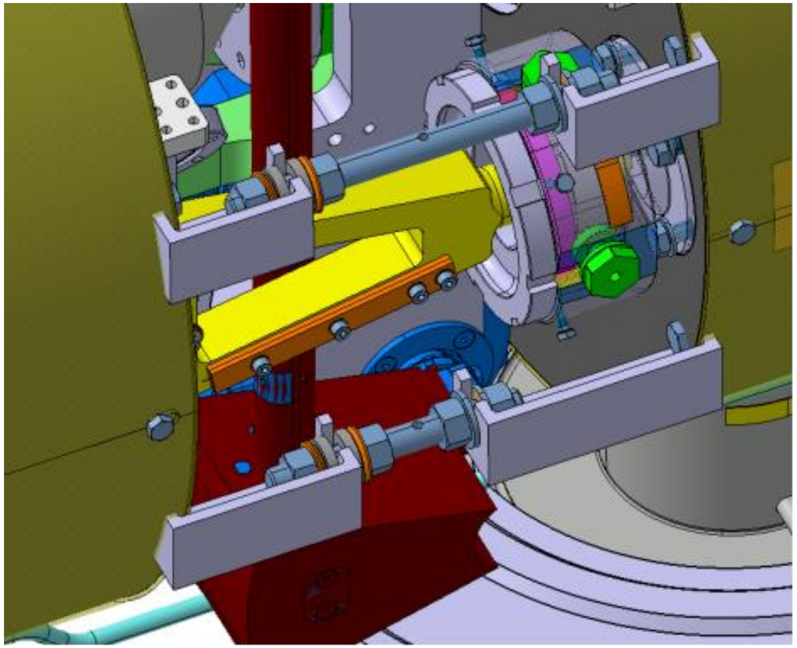
⊙ I ⊗ **B=50μT**

0.2 μT



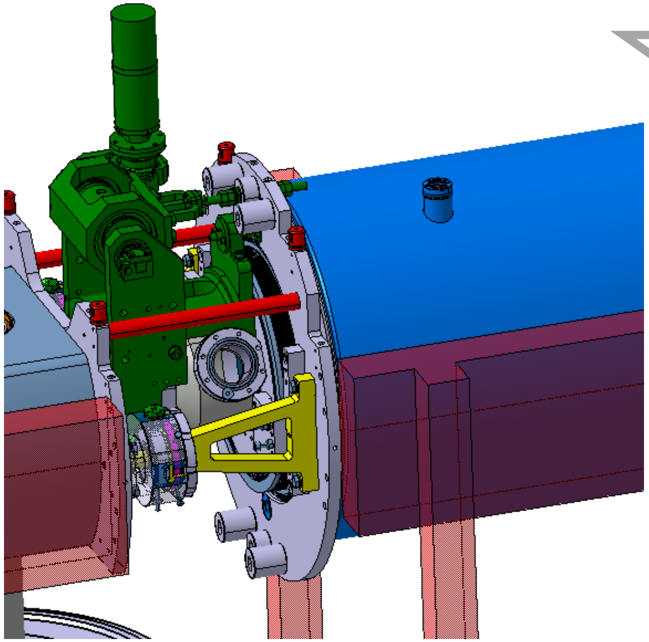


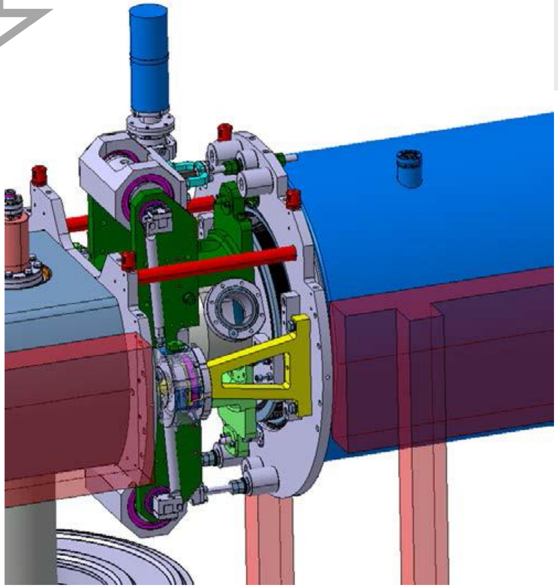
- Low lateral flexibility for the coupler bellows
- Torsion to be avoided on intercavity bellows
- Limited space for assembly in the intercavity region



- Stiffening of the intercavity region
- Modification of the intercavity support to facilitate the adjustment
- **<u>Tuner to cut</u>** (assembly impossible in the intercavity region) -> out of the clean room
- Additional targets for position measurement

Assembly in clean room

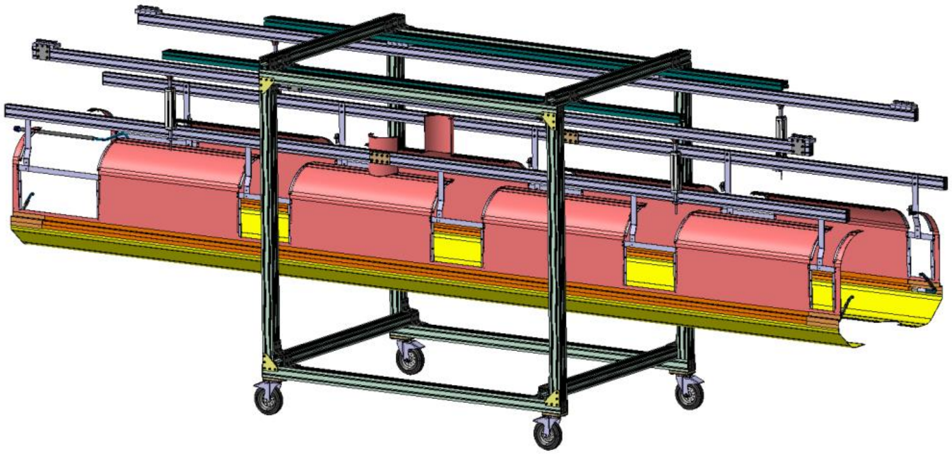


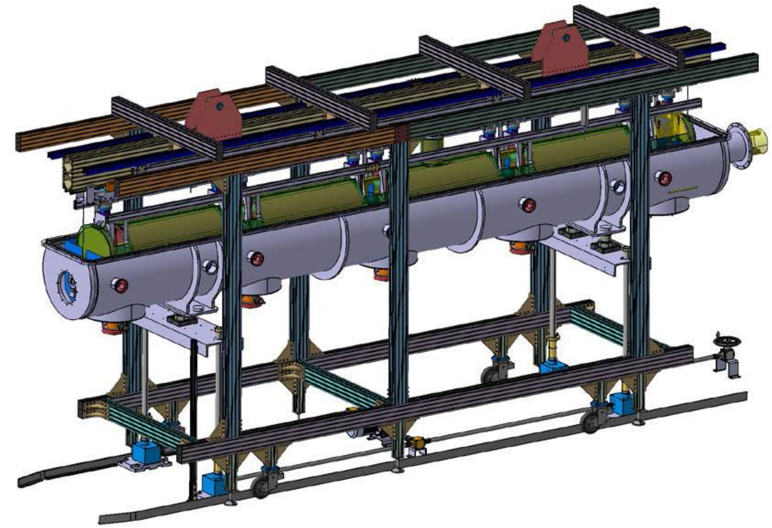


Preliminary procedure available but not validated

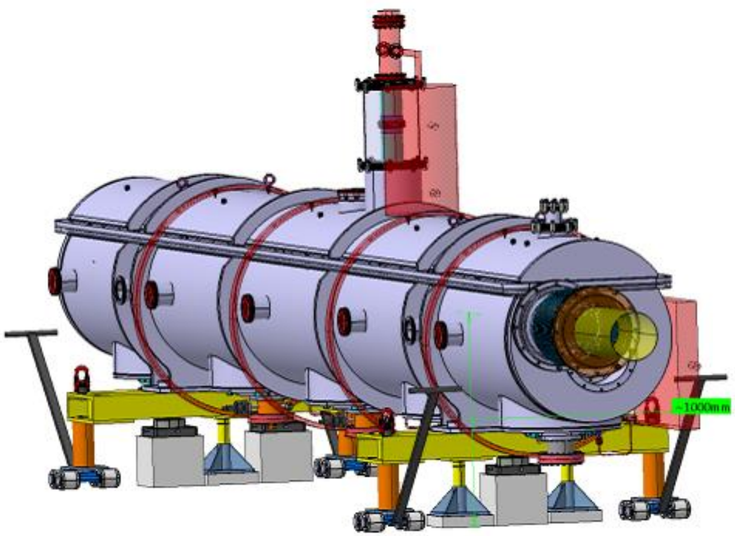
- Procedure to validate
- Coupler assembly direction to validate
- Modification on the tuner frame
- Tools for clean room assembly to design

Design of tools for cryostating is available CNRS - IPN - Orsay



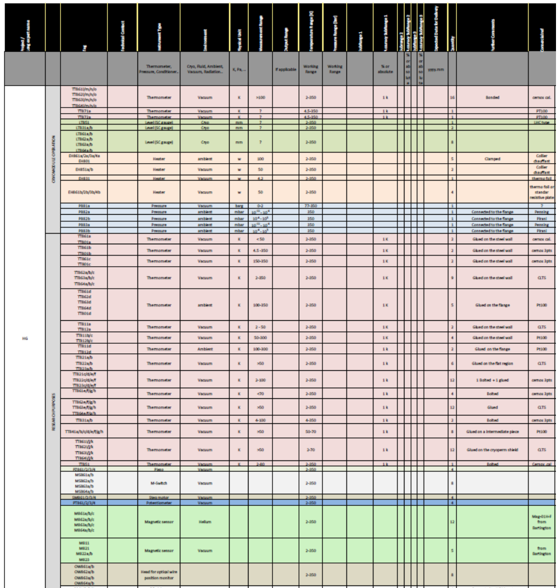


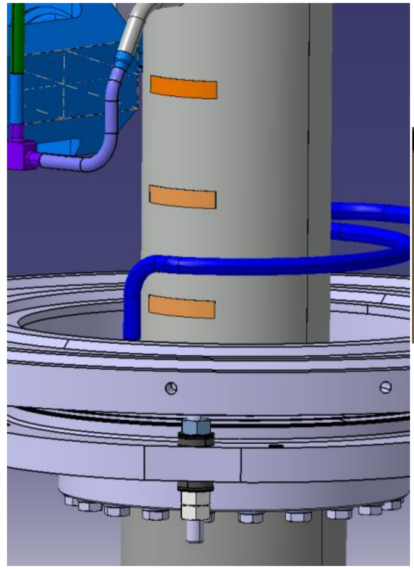
Tools for transport have been designed

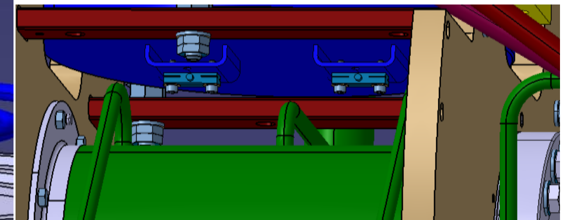


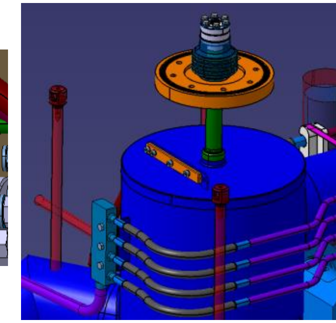
Tools to be modified (modification on cryo lines, on thermal shield, on intercavity supports)

Cryostating procedure to update with the new shielding (and, in addition, door knobs assembly from bottom, as close as possible to the test bunker)



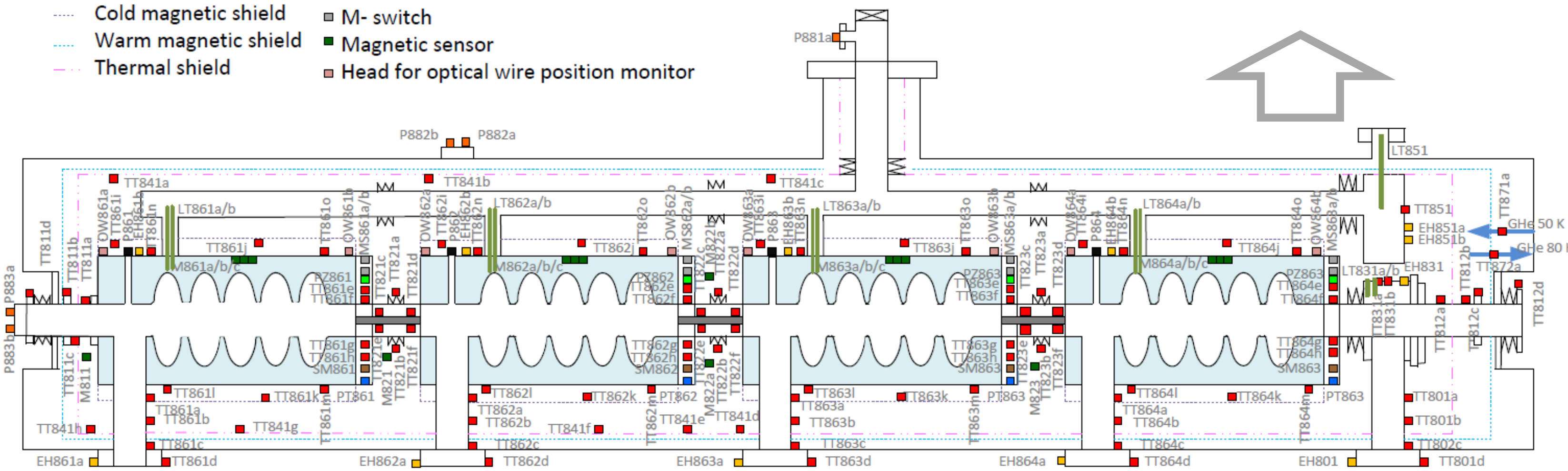


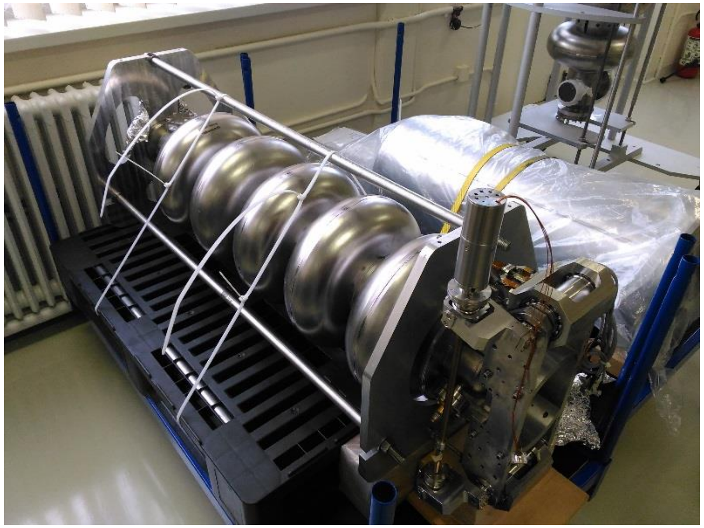




- integration in drawings
- new magnetic sensors in the intercavity region and inside the He vessel (TBC)
- flow meter installed in the valve box

- Thermometer
- Heater
- Level gauge
- Cold magnetic shield
- Warm magnetic shield
- Thermal shield
- Step motor
- Piezo
- Potentiometer
- M- switch
- Magnetic sensor
- Head for optical wire position monitor
- Pressure sensor
- Pick-up





Available components:

- vacuum vessel
- couplers
- tuners
- MLI
- gate valves
- waveguides
- Nb cavities
    - 4 cavities delivered (produced by industry)
    - 1 cavity under manufacturing at CERN
    - all He vessels available

Master schedule :

- Clean room assembly: August, September, October 2017
- Cryostating: November 2017 to May 2018
- Order of main components is expected for the second half of 2016

Next steps

- Finalization of the cryomodule internal components
- Safety dossier to complete
- Tools for clean room
- Launch procurement of: thermal shield, magnetic shields, cryo lines…

Research activities ongoing

- Cavity measurement at cold: optical wire system to be developed -> space reserved
- Pick-up development ongoing
- HOM coupler integration

Questions for discussion

- Cryogenic operation with p<0.5 barg? Related peak smoothing?
- Safety devices and thermal load on bi-phase pipeline?
- Magnetic sensor at cryogenic T?
- Tuner end-switch and displacement sensor?
- Material for cryogenic line inside warm magnetic shield?
- Updates on optical/wire position sensors for cavity displacement measurement?

Thank you…

Back-up slides