Design of a test cryomodule for the high energy section of the Eurotrans linac

HPPA5 workshop
Mol, May, 6-9, 2007
INFN Milano, LASA
Serena Barbanotti

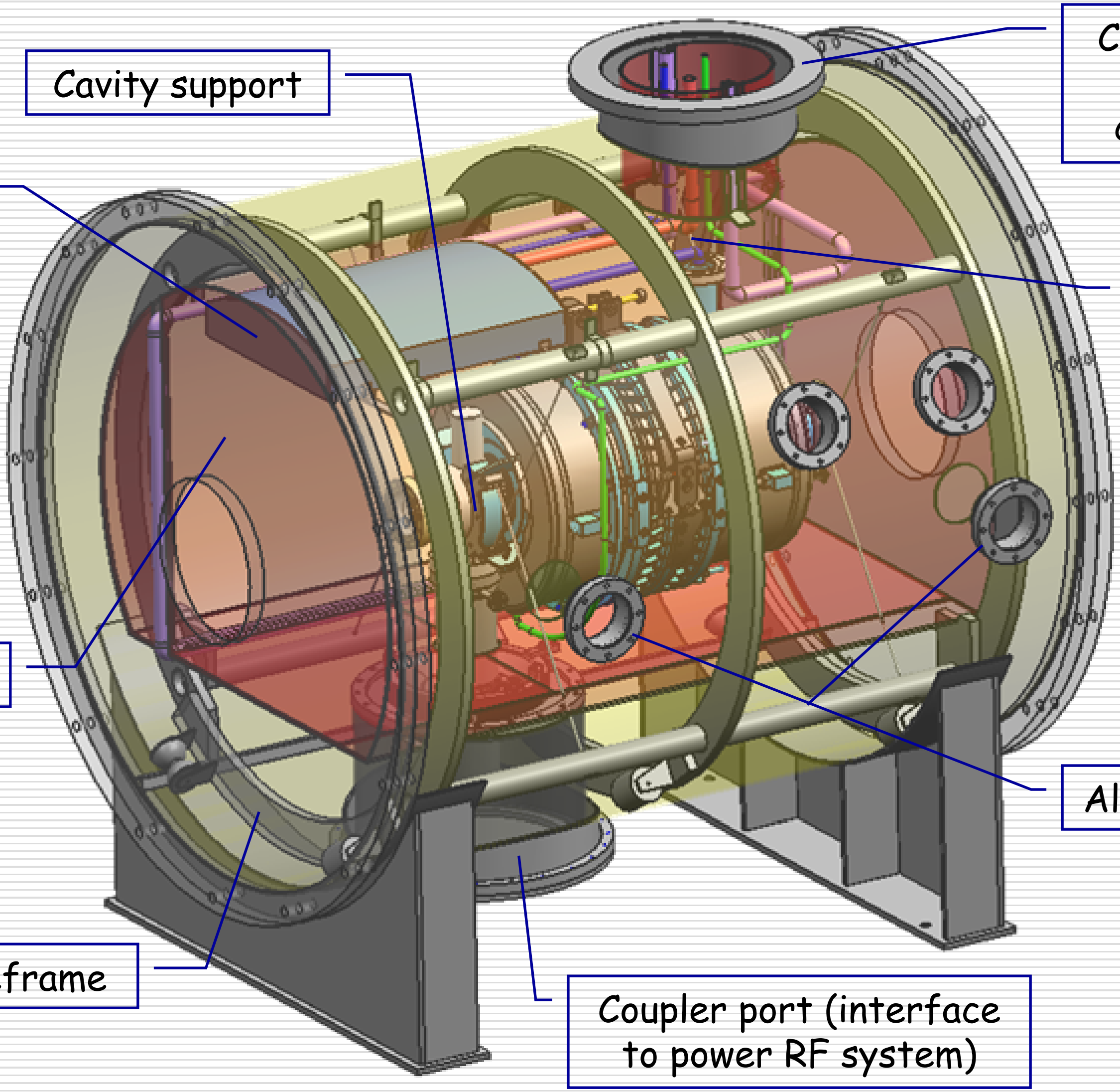
EUROTRANS
- EUROpean Research Programme for the TRANSmutation of High Level -
Nuclear Waste in an Accelerator Driven System

Outline

- Cryomodule task in EUROTRANS
  - Deliver an operational prototype cryomodule to be extensively tested (without beam, but at high RF power levels as in its operating condition)
    - Design by INFN & IPN
    - Assembly and testing at IPN Orsay

- ADS accelerator features
  - High availability and reliability
  - Easy disconnection from beam line and cryogenic plant

Layout of the cryomodule



Cavity support

Phase separator

Cold box connection (interface to cryogenic system)

Piping

70 K shield

Alignment ports

Spaceframe

Coupler port (interface to power RF system)

Function provided by the module

- Guarantees the cryogenic environment for cavity operation
  - subatmospheric LHe operation at 2 K, where superconductor surface resistance is extremely small
- Limits the heat inleak to the He bath from the outer room temperature environment

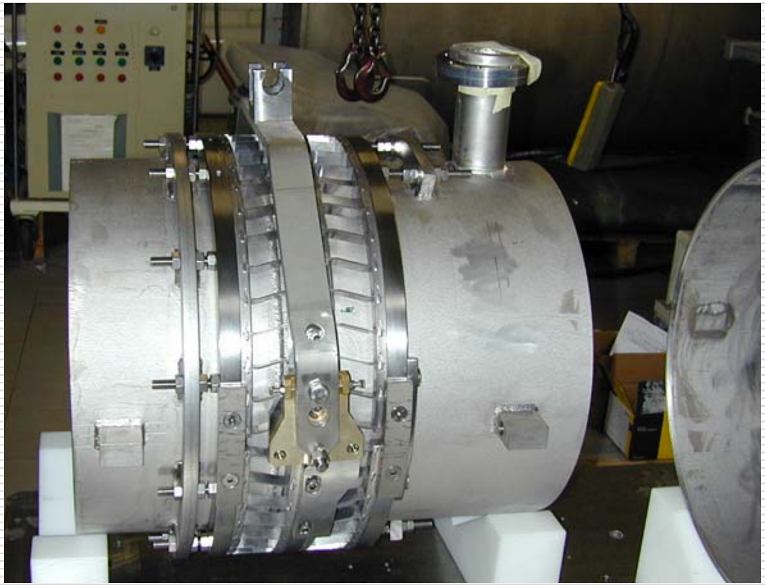
  [thermal cycle 1 W @ 2 K = 750 W r.t.]
  - by conduction (choice of materials and geometries)
  - by convection (vacuum vessel in isolation vacuum)
  - by radiation (r.t. thermal radiation intercepted at higher temperatures with thermal shielding and attenuated with use of multilayer insulation)
- Structural support for the RF cavities
  - controlled and reproducible alignment (from warm to cold)

Main design constraints

- Cavity supporting scheme
  - Simplified handling and assembly (no vertical movement)
- Coupler interface
  - Vertical position (IPN request)
- Minimized long. dimensions for linac footprint
  - Flat heads VS standard PV heads
- Pipe connection to the cryogenic plant (and valve box)
  - Thermal shielding with LN

Module components: cavity

- The two existing cavities are being tuned and equipped with ancillary components
  - He reservoir, tuner, couplers …
- More details on tuner, tanks and cavity will be presented by N. Panzeri



Cavity supporting scheme

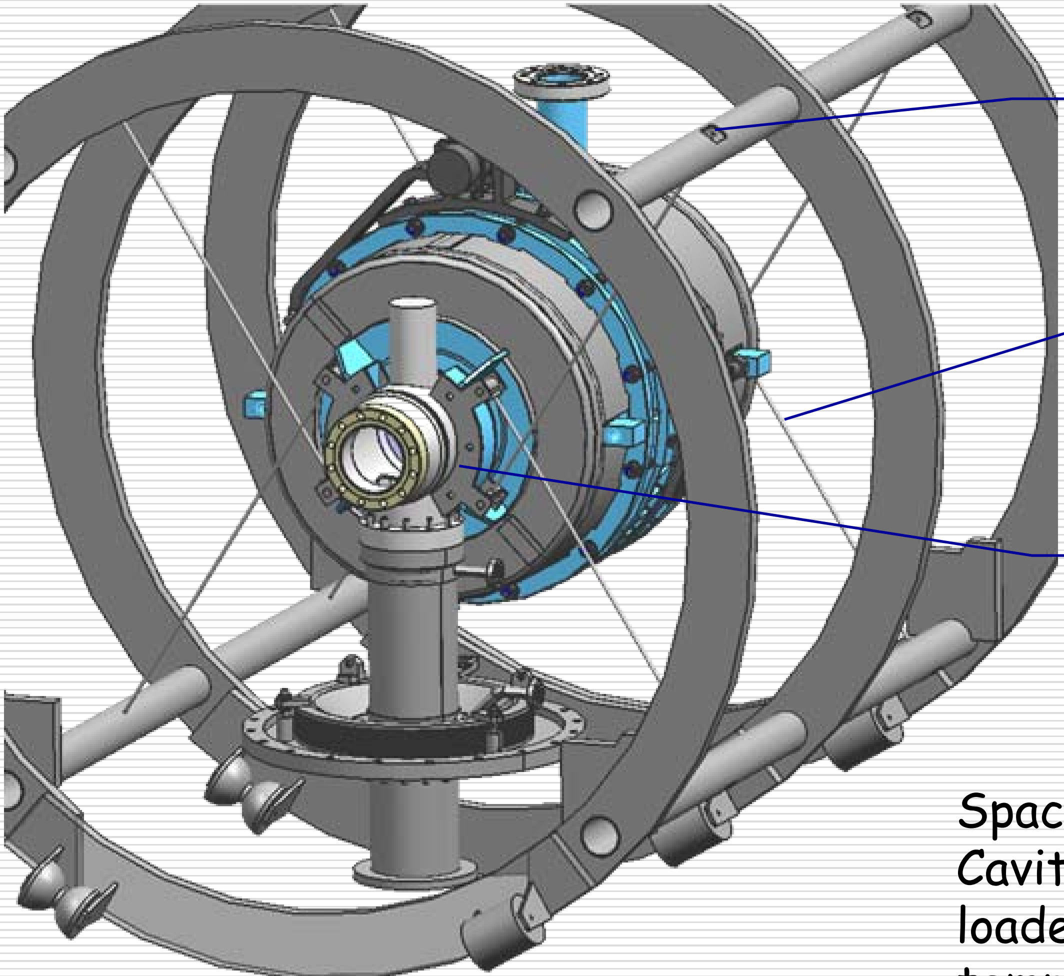
- RF warm window divides the “clean” vacuum volumes (inner cavity surface) from the ambient pressure RF waveguide

- Coupler components up to the RF window need to be assembled in the clean room, to prevent contamination of the cavity surface

- RF window sensitive to transverse stresses
  - Vertical orientation (no dead load)
  - From bottom of vessel (reduced dust contamination)

- To prevent transverse stresses on the coupler window, differential longitudinal termal contractions have to be taken in account

Choice of cavity support scheme



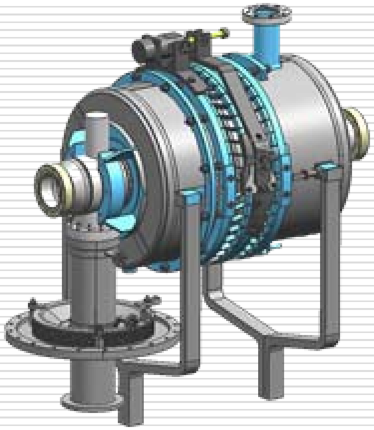
Adjustable rod connection

Support rod

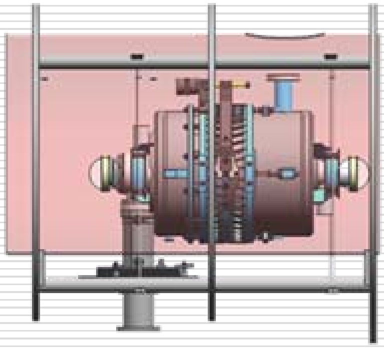
Rod connection to the cavity

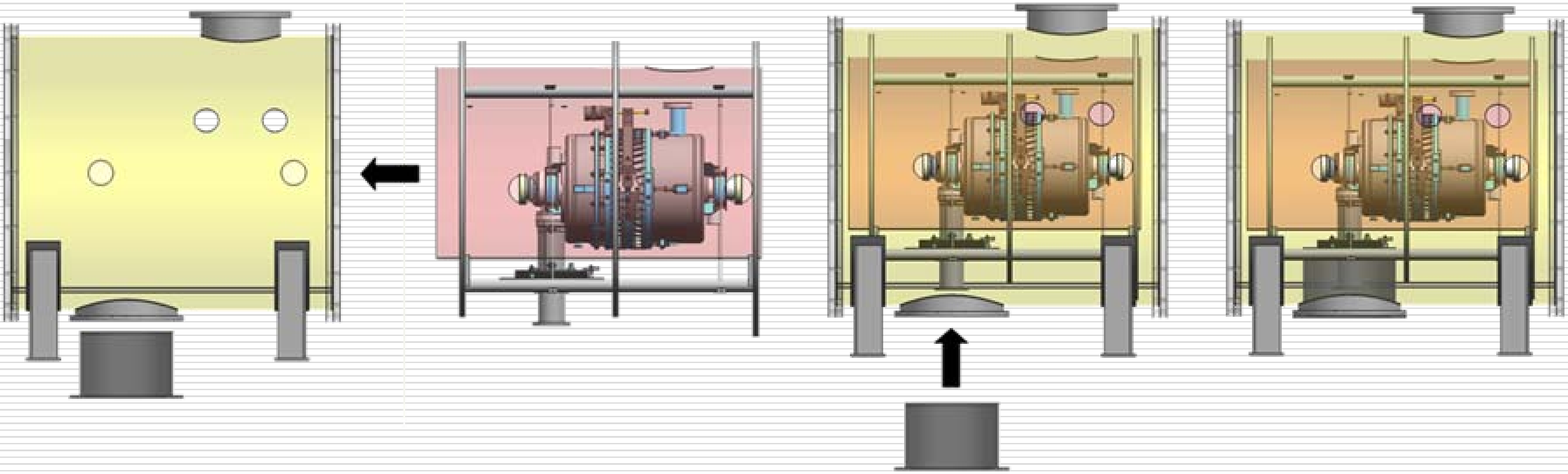
Spaceframe concept (as SNS)
Cavity is attached through tension loaded tie rods to a room temperature frame

Simple coupler assembly



- No vertical translation is needed
- Cavity and coupler mounted on spaceframe
- Spaceframe is then rolled in vessel

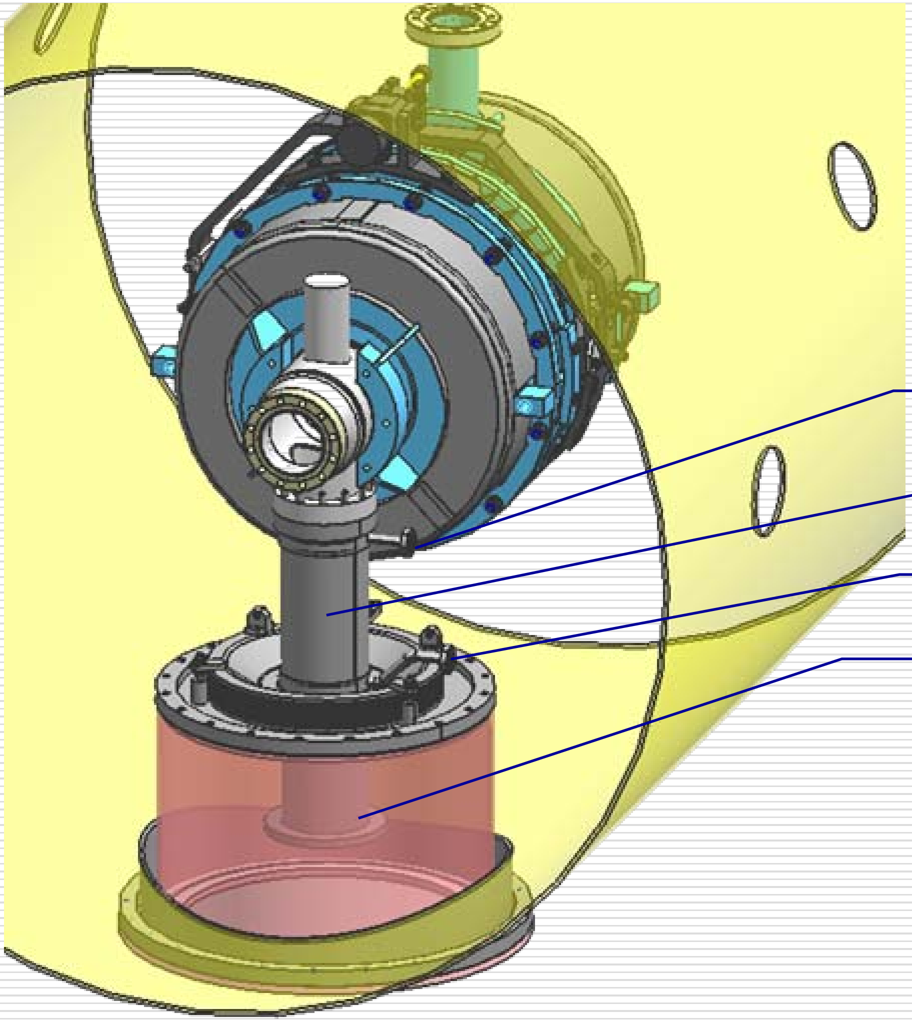




Choice of coupler connection

Vertical orientation (from below) to reduce risks of contamination of cavity surface

Outer conductor cooled with flow of supercritical LHe to prevent heat inleak through conduction



Cold LHe IN

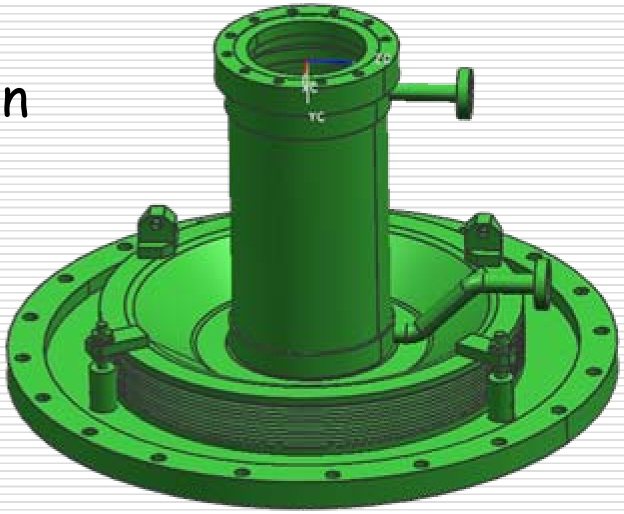
Coupler outer conductor

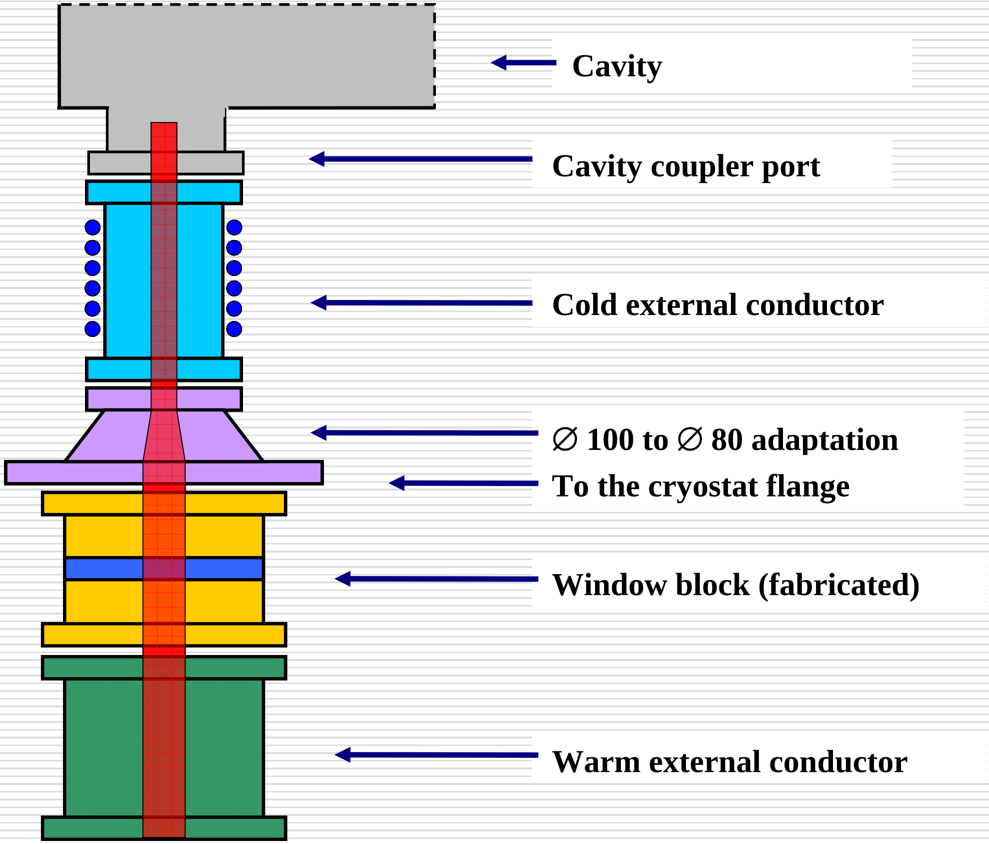
Warm He Vapor OUT

300 K RF Window (simplified model shown here for assessment of clearance needed during assembly)

Coupler-vessel interface

- The coupler constrains the vessel design





Cavity

Cavity coupler port

Cold external conductor

∅ 100 to ∅ 80 adaptation

To the cryostat flange

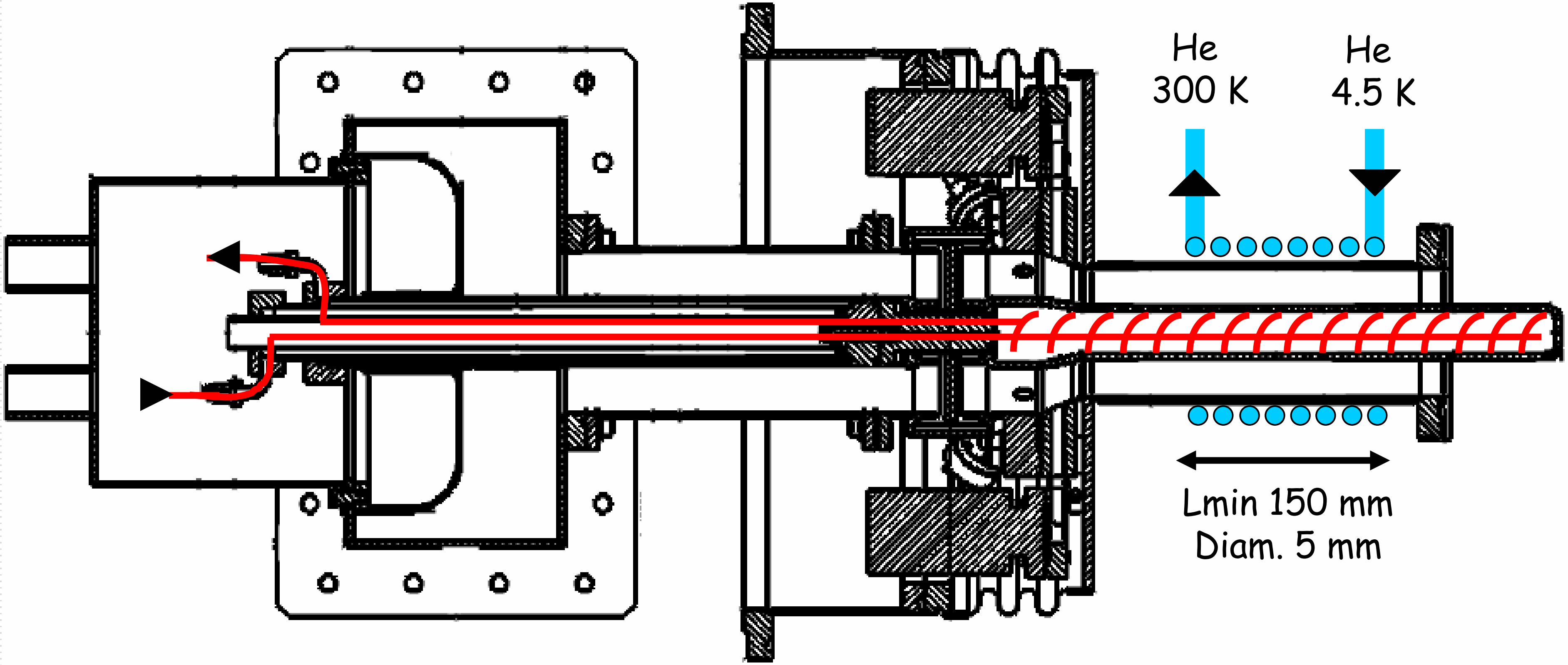
Window block (fabricated)

Warm external conductor

- Final detailed layout still to be defined
- Preliminary design based on coupler geometry under study at CEA/Saclay for the cavity tests in the horizontal module CryHoLab

Coupler cooling scheme (IPN)

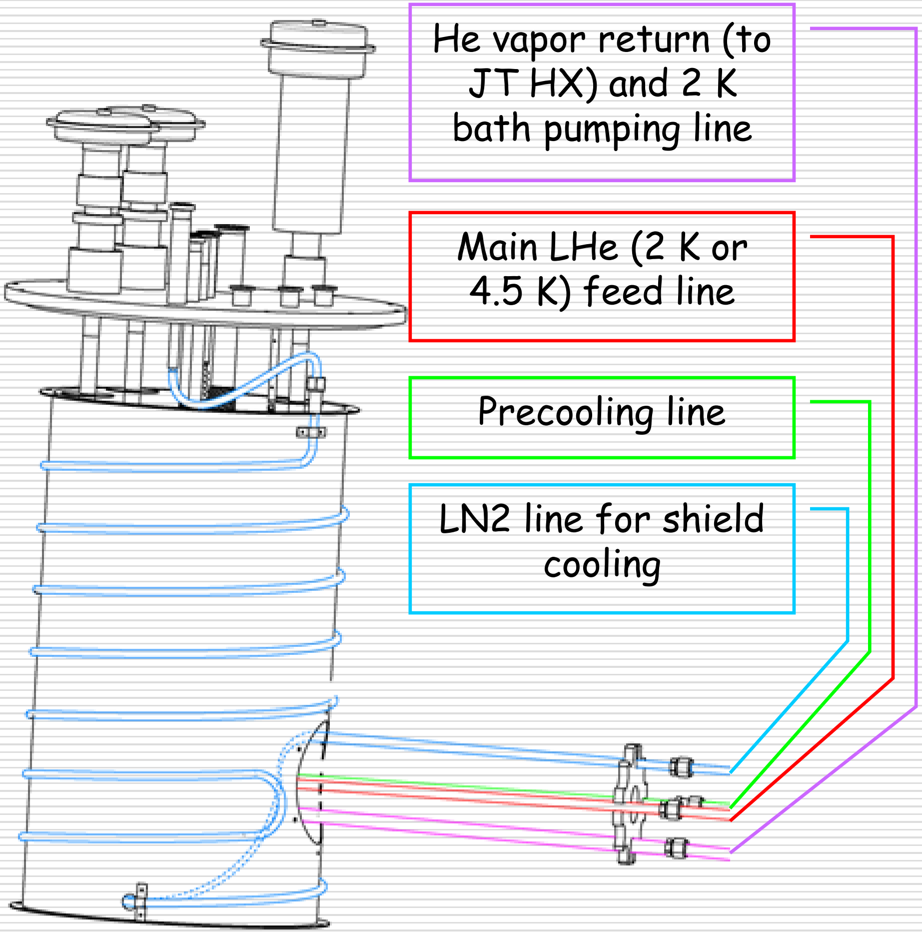
- **Outer conductor:** Helium cooling



- **Inner conductor:** Water cooling

From S. Bousson, IPN

The IPN CM0 valve box



He vapor return (to JT HX) and 2 K bath pumping line

Main LHe (2 K or 4.5 K) feed line

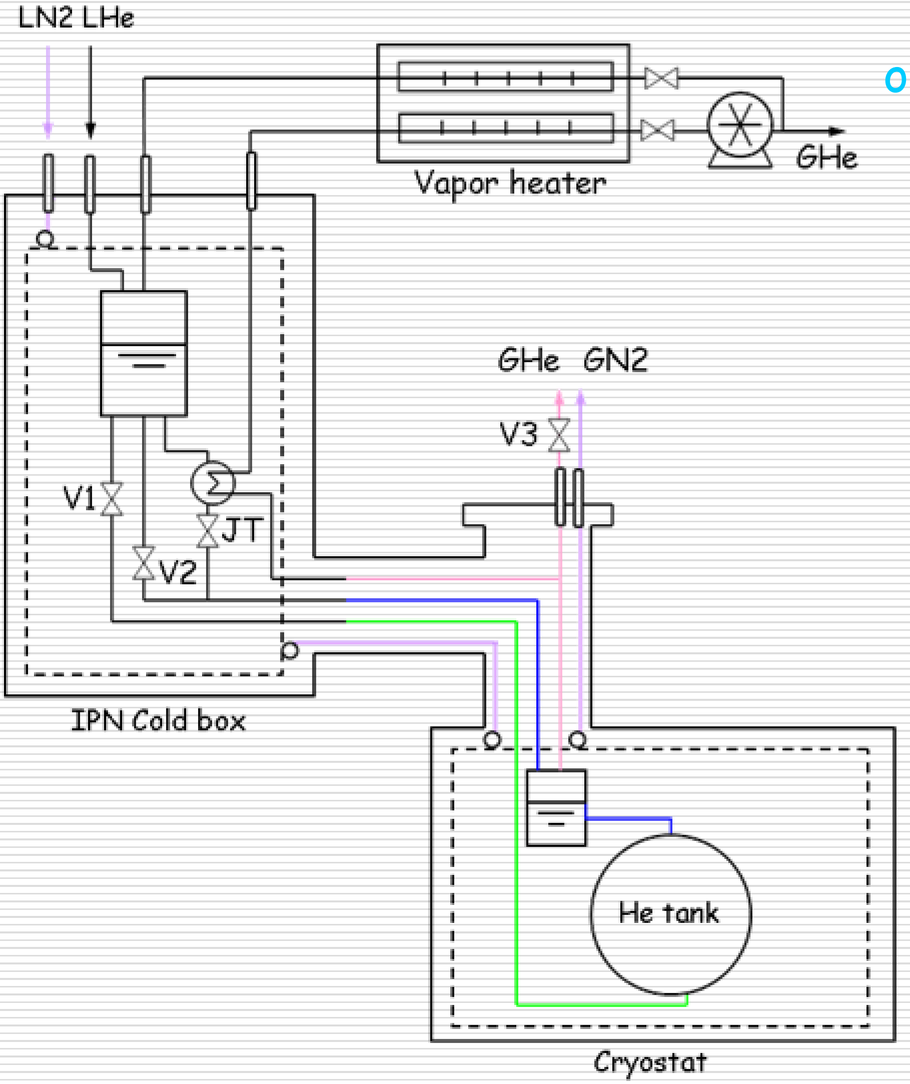
Precooling line

LN2 line for shield cooling

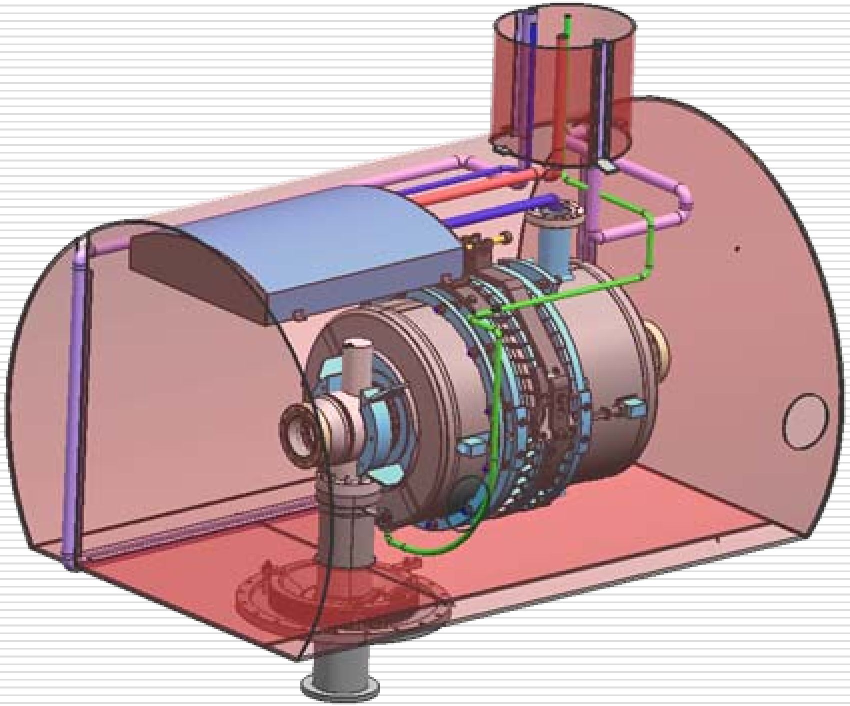
From C. Commeaux & F. Lutton, IPN

- Nominal capacity of 50 W
  - Line for precooling of the cavity with He vapor/LHe (entering from bottom)
  - Stationary 4.5 K mode: red line sends 4.5 K LHe in cryomodule from cold box (2.5 g/s, 50 W)
  - JT valve and counterflow heat exchanger to fill the phase separator with 2.2 g/s LHe at 2 K
- No independent circuit for LHe at 4.5 K (coupler cooling)
- No separate 40 K/50 K He gas circuit for shields

Functional interface and inner cryo piping

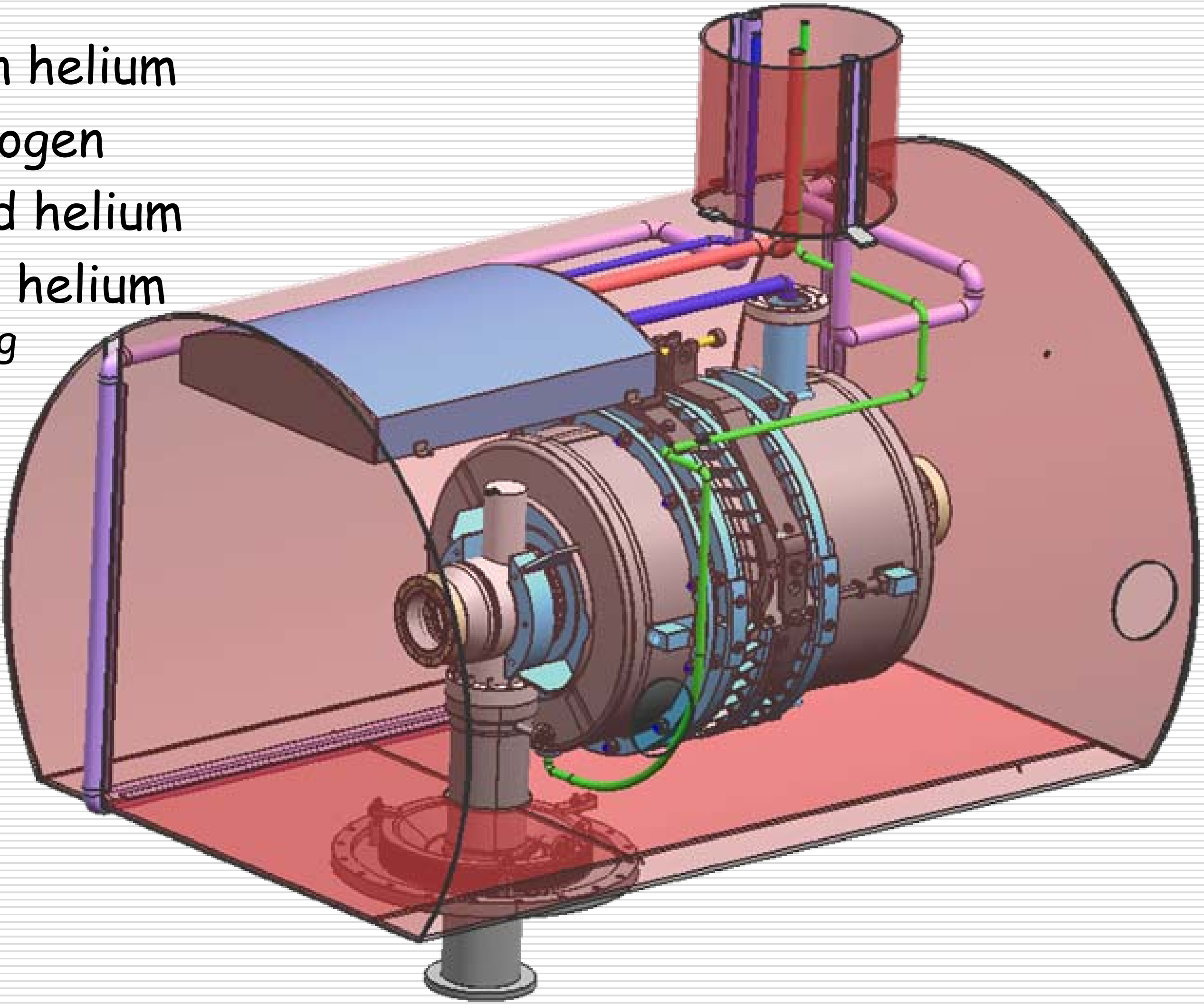


- Routed the main cryo piping in the module
  - No coupler circuit yet (can be separate from CB)



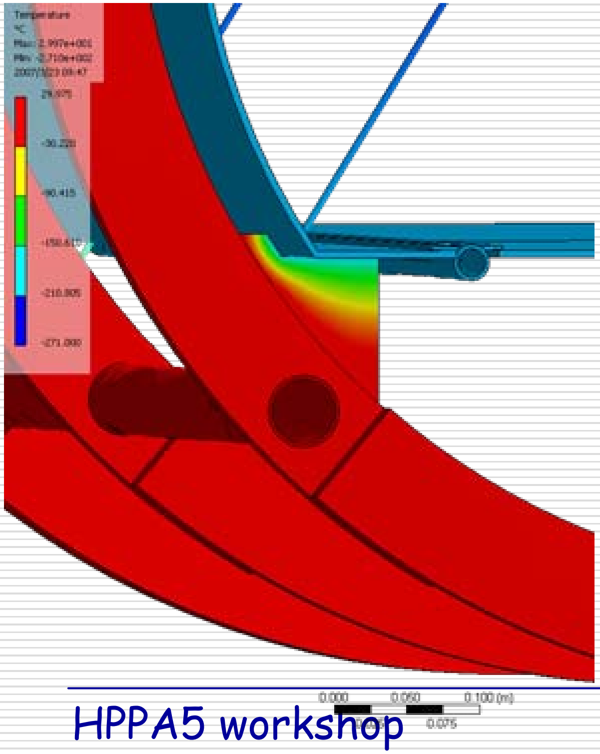
Routing of the cryogenic piping

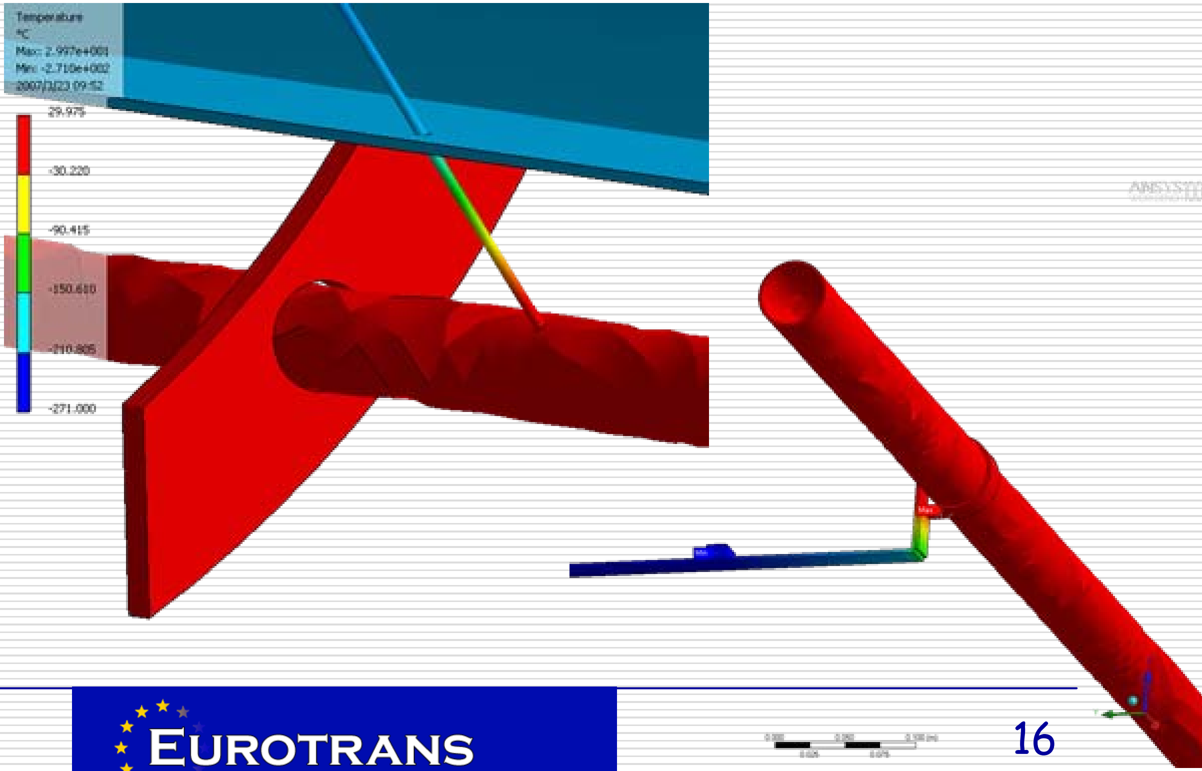
- Green: cool down helium
- Violet: 70 K nitrogen
- Blue: 2 K in liquid helium
- Pink: 2 K out gas helium
  (and 2K bath pumping line, with sufficient pumping speed)



Thermal design: Heat inleak estimation

- Analysis of the direct conduction paths to the low temperature circuits using temperature dependent material properties
- Estimation checked "a posteriori" with FEM models

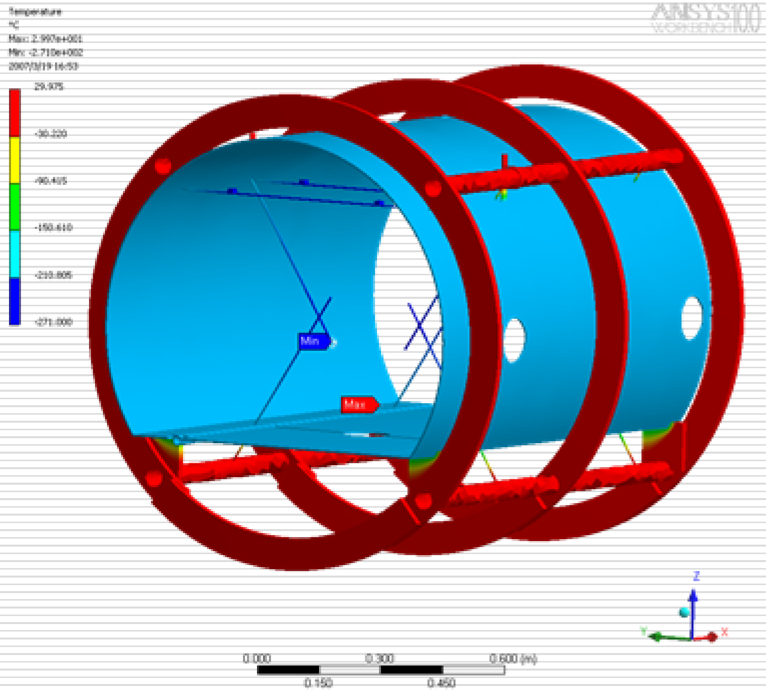




Thermal design: Heat load assessment

	2 K circuit	
	Static	**Dynamic**
RF load @ 8.5 MV/m & 5 10^9		22.58
Tie rods connections from shield	0.12	
Phase separator support frame	0.44	
Thermal radiation[1]	0.40	
Cabling	0.10	
Coupler[2]	1.00	6.77
[1] Based on 0.1 W/m² from 77 K surfaces and 2 W/m² from 300 K. [2] Static from SNS estimates (30% conduction, 70% radiation) Dynamic based on SNS estimate, 30% of RF load		
Total [W]	**2.07**	**29.35**
	70 K circuit	
	Static	**Dynamic**
Tie rods connections to shield	8.14	
G10 shield supports	52.10	
Phase separator support frame	18.33	
Thermal radiation[1]	15.08	
Coupler		
Cabling	1.00	
Total [W]	**94.65**	**0.00**

$$P_{RF} = \frac{(E_{acc} L_{act})^2}{R/Q \;\; Q_0}$$



Cryo spreadsheet: Mass flow assessment 1/2

Coolant		**LN**	**LHe**
Temperature levels		77 K	2 K
		Shield circuit	Cavity circuit
Temp in	(K)	77.00	2.0
Press in	(bar)	1.0	1.0
Enthalpy in	(J/g)	-122.5	1.642
Entropy in	(J/gK)	2.8	0.958
Density in	(kg/m3)	808.2	145.7
Temp out	(K)	78.00	2.0
Press out	(bar)	1.0	SV @ 33
Enthalpy out	(J/g)	78.0	25.04
Entropy out	(J/gK)	5.4	12.58
Density out	(kg/m3)	4.5	0.8
Δ Entalphy	(J/g)	200.5	23.4
Computed static heat load	(W/module)	94.6	2.07
Computed dynamic heat load	(W/module)	0.0	29.35
Number of modules		1.0	1.0
Total static heat	(W)	94.65	2.07
Total dynamic heat	(W)	0.00	29.35
Other heat (valves, boxes)	(W)	0.0	0.0
Total predicted heat	(W)	94.65	31.42
Heat uncertainty factor (on static only)		1.00	1.00
Heat uncertainty factor (on dynamic only)		1.00	1.00
Design heat load	(W)	94.65	31.42
Design mass flow	(g/s)	0.47	1.34

Dynamic RF is based on E_{acc}=8.5 MV/m and a conservative Q=5 10^9

Contributions from cold box to the system

$$\dot{m} = \frac{P_{load}}{\Delta H}$$

(…)

Cryo spreadsheet: Mass flow assessment 2/2

(…)

Coolant		LN	LHe
Design ideal power	(W)	272.9	4650.2
4.5 K equiv design power	(W)	4.2	70.8
Efficiency (fraction Carnot)		0.30	0.20
Efficiency in Watts/Watt	(W/W)	9.6	740.1
Nominal operating power	(kW)	0.9	23.3
Overcapacity factor		1.30	1.30
Maximum mass flow	(g/s)	0.6	1.7
Heat load including all factors	(W)	123.0	40.8
Overall multiplier		1.3	1.3
Installed power	(kW)	1.2	30.2
Installed 4.5 K equiv	(W)	5.4	138.1

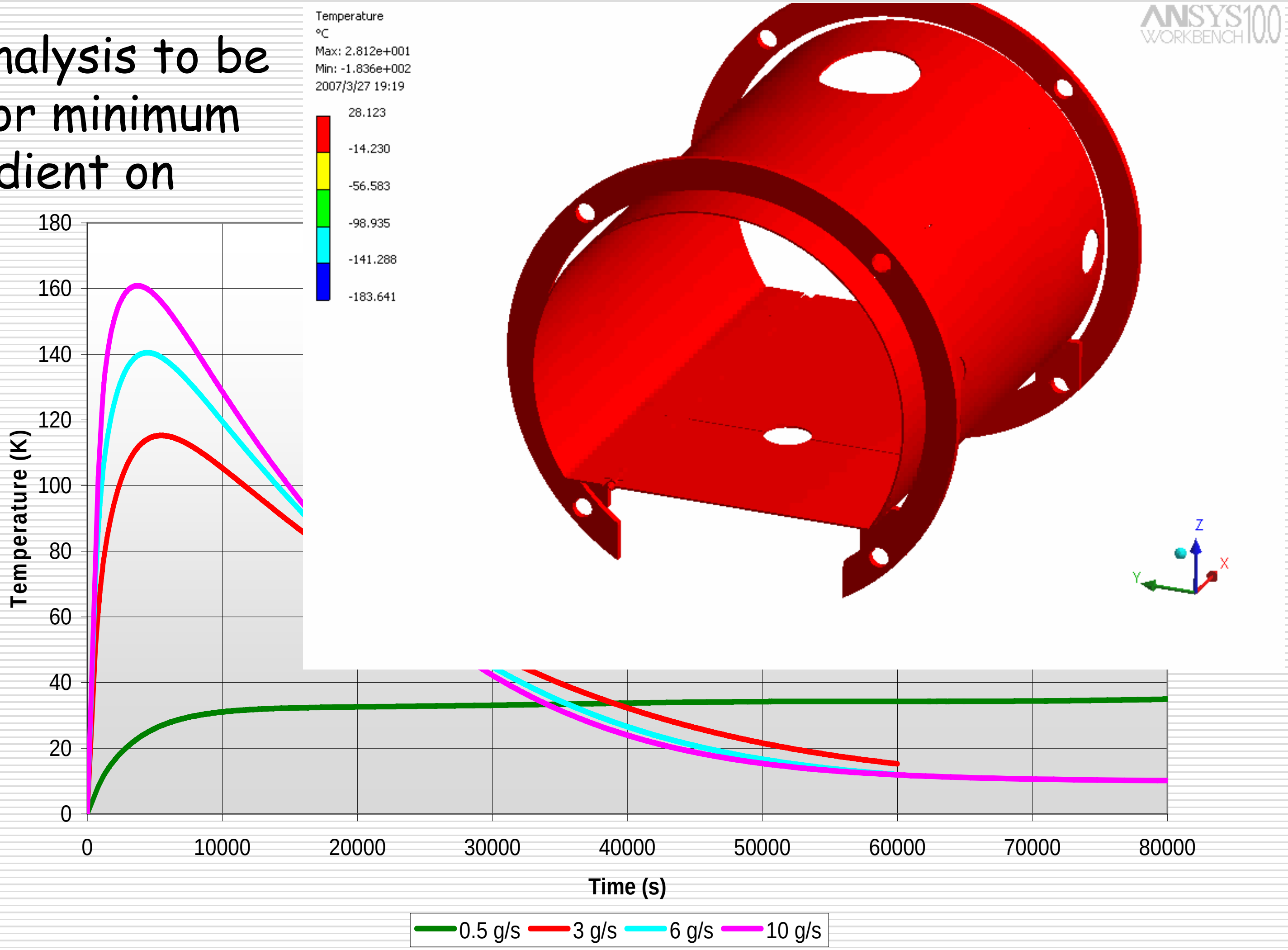
Assume 30% contingency on heat load estimates (and therefore mass flows)

Within CM0 capabilities

- Estimations only for the LN shield circuit and the 2 K subatmospheric cooling
- Coupler cooling and additional 4.5 K thermalizations need to be integrated
  - SNS design: supercritical LHe from 4.5 K to 300 K requiring 0.0375 g/s (2/3 static, 1/3 dynamic)

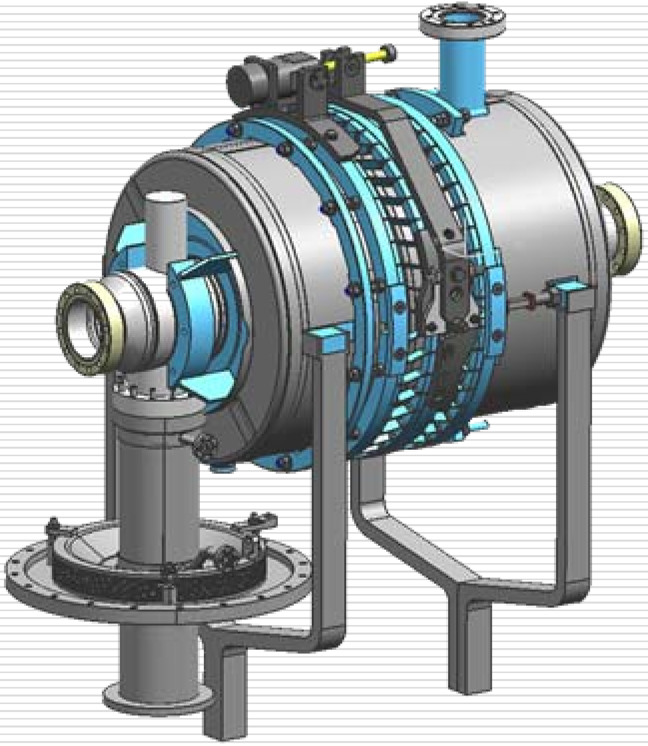
Shield cool down

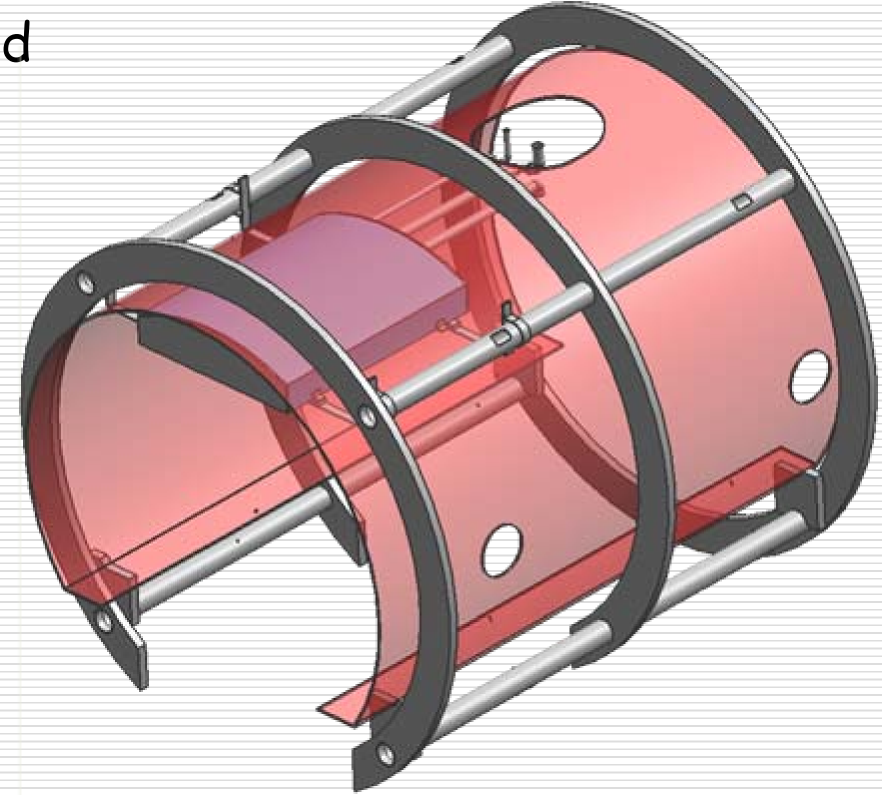
- Cool down analysis to be optimized for minimum thermal gradient on shield



Cryomodule assembly procedure 1/6

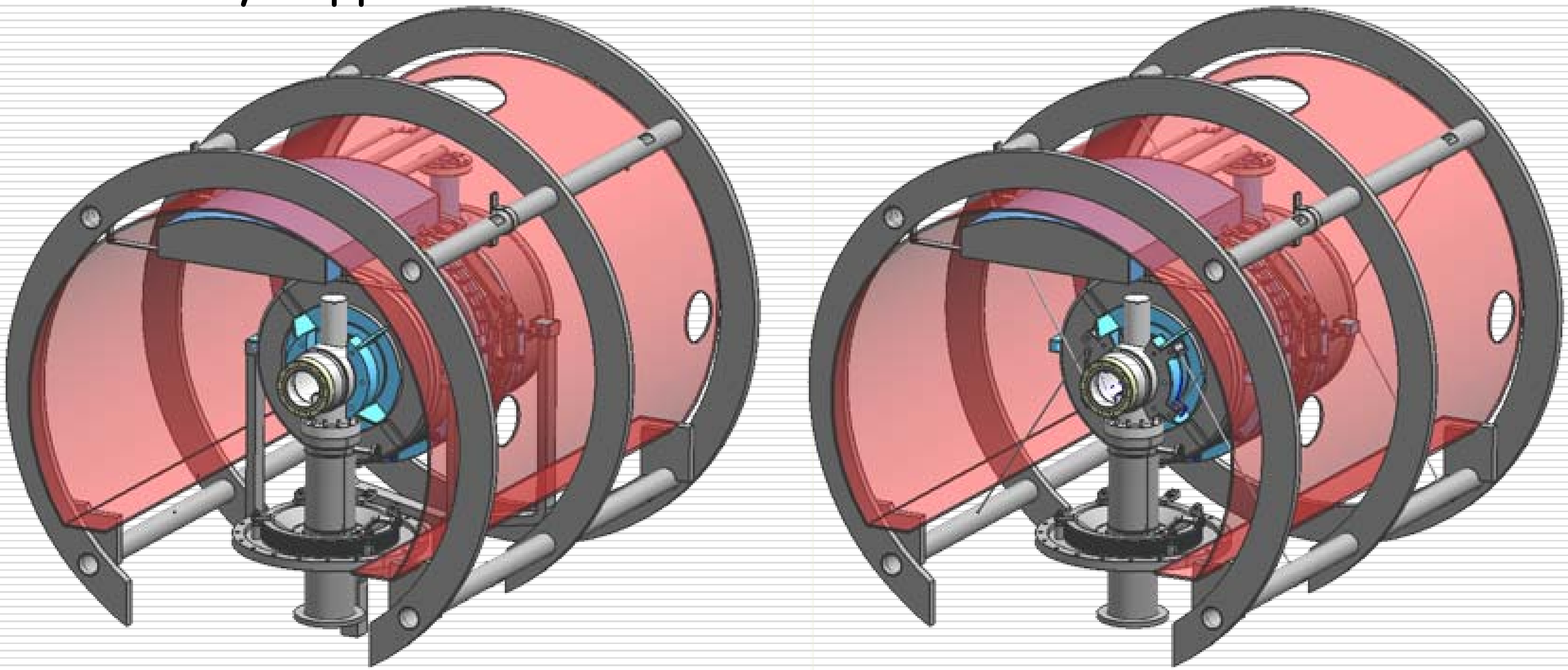
- Cavity, helium tank and cold coupler part to RF window pre-assembled in clean room
- Cavity supported via the support pads, tuner assembled
- Space-frame pre-assembled





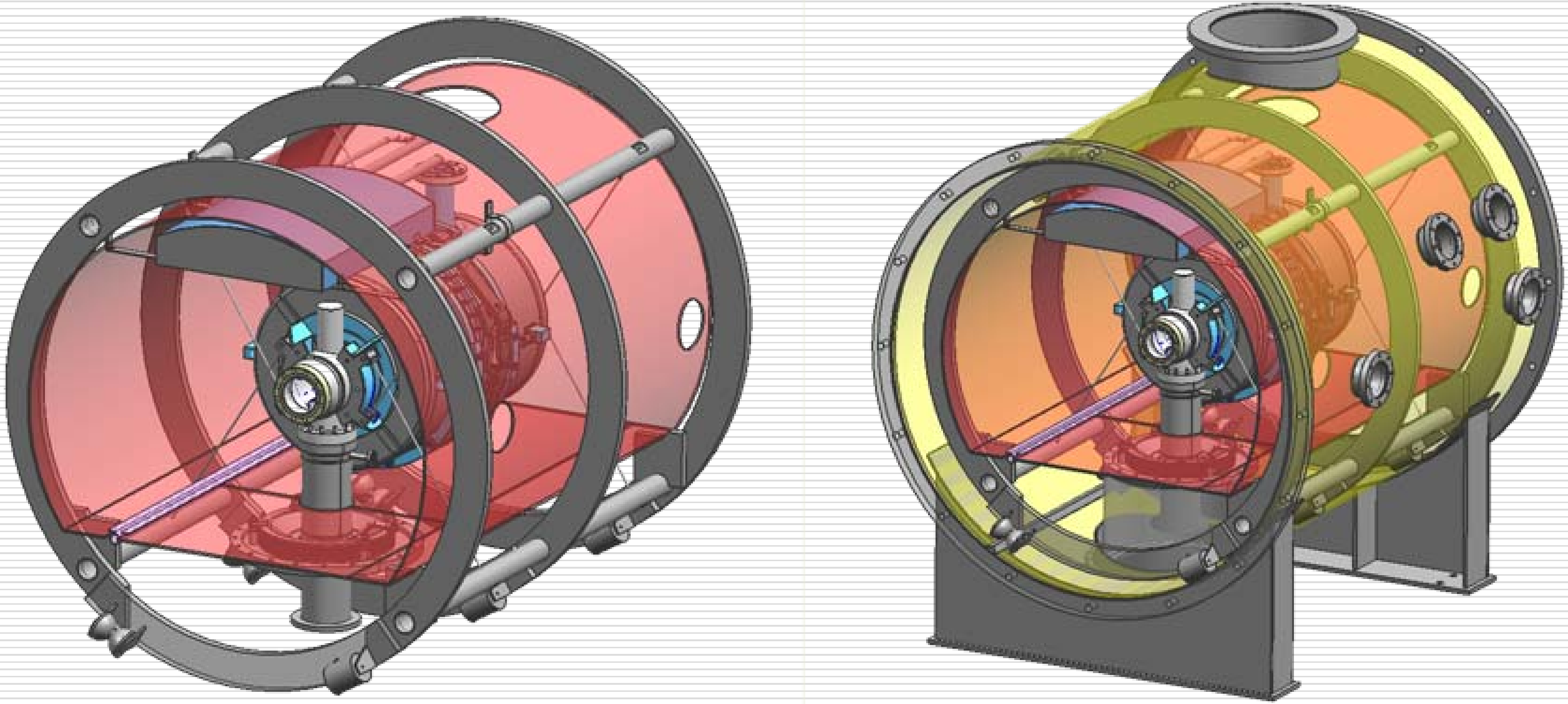
Cryomodule assembly procedure 2/6

- Cavity slid into spaceframe
- Cavity connected to the spaceframe via tension rods and pre-aligned
- Cavity supports removed



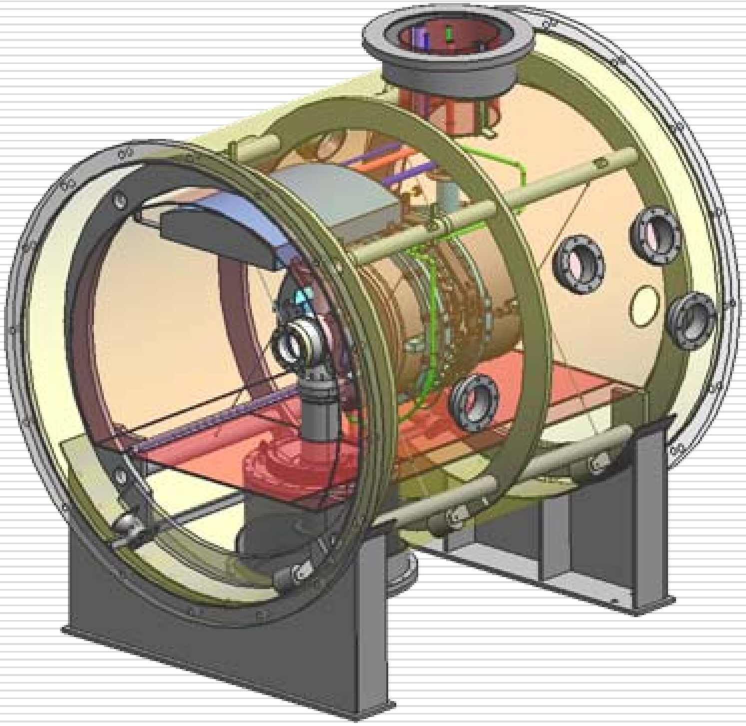
Cryomodule assembly procedure 3/6

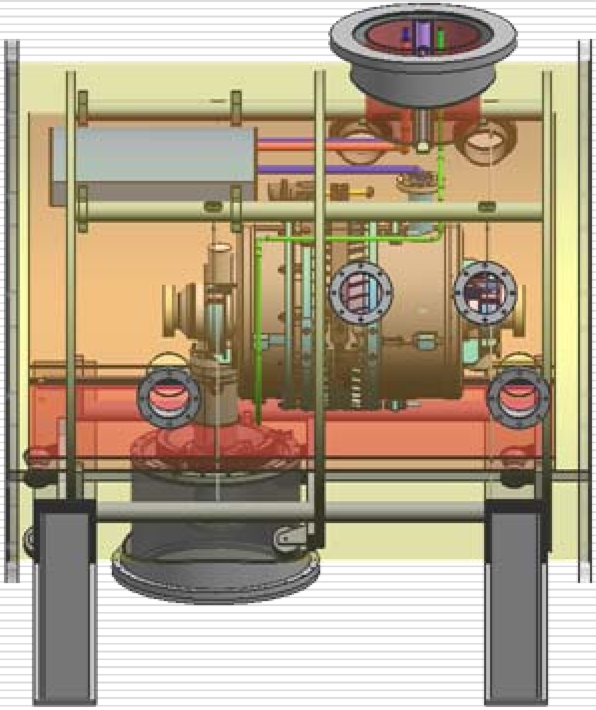
- Inserted bottom parts of the 70 K shield (front and rear)
- Wheels mounted on the spaceframe rings
- Spaceframe slid in the vessel



Cryomodule assembly procedure 4/6

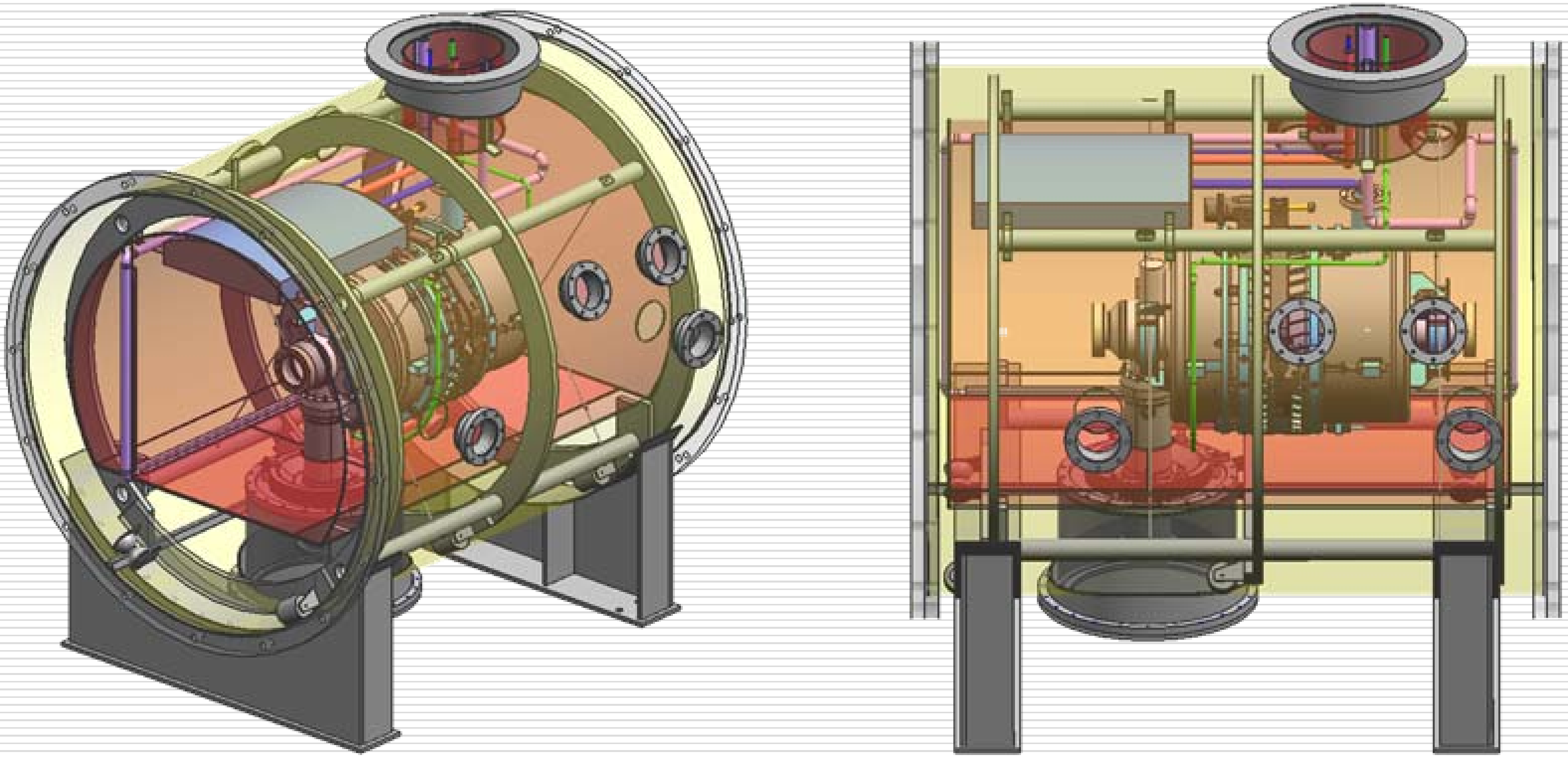
- Cool down pipe (green) assembled
- Connection pipes and shield to the cold box assembled





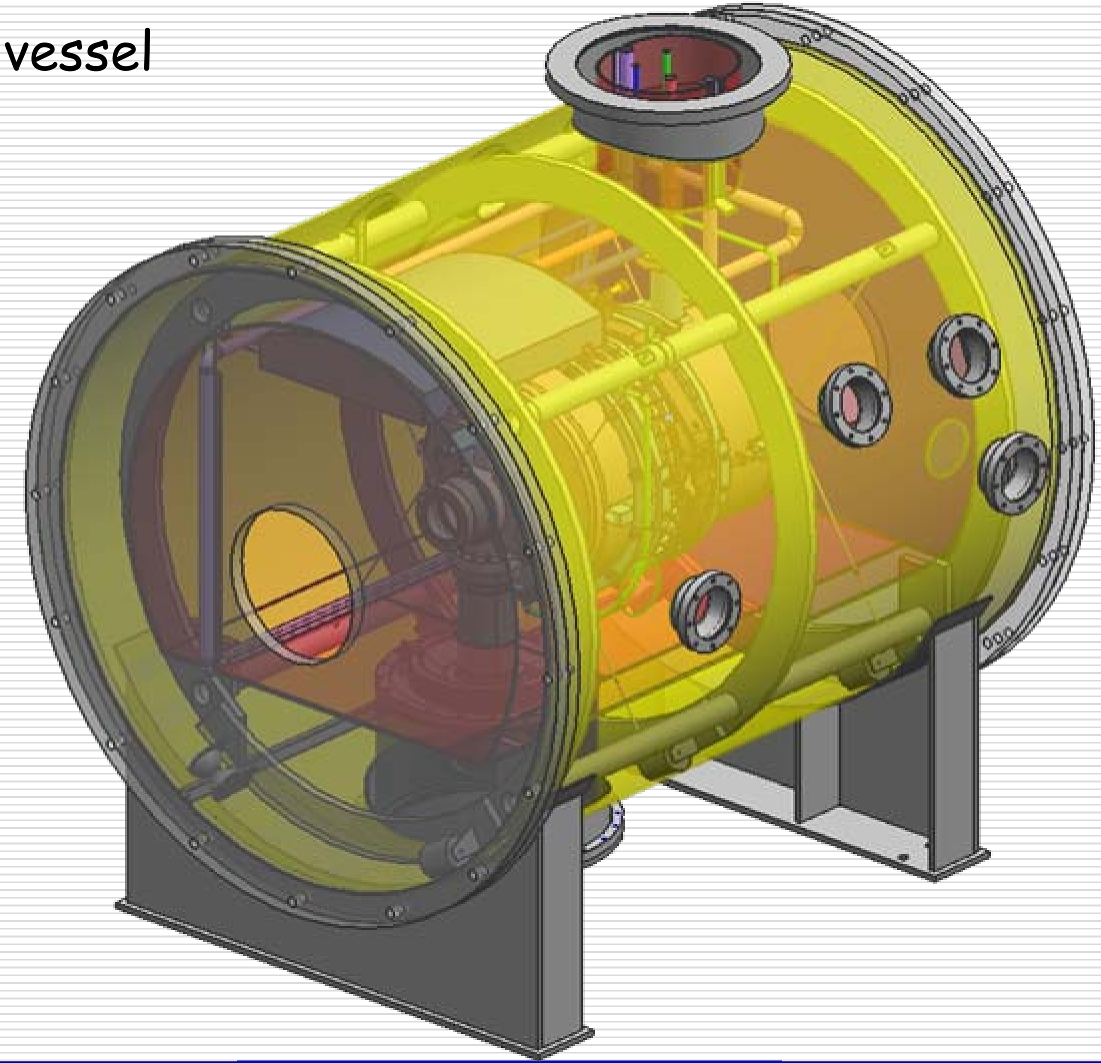
Cryomodule assembly procedure 5/6

- Shield heads and 70 K piping assembled



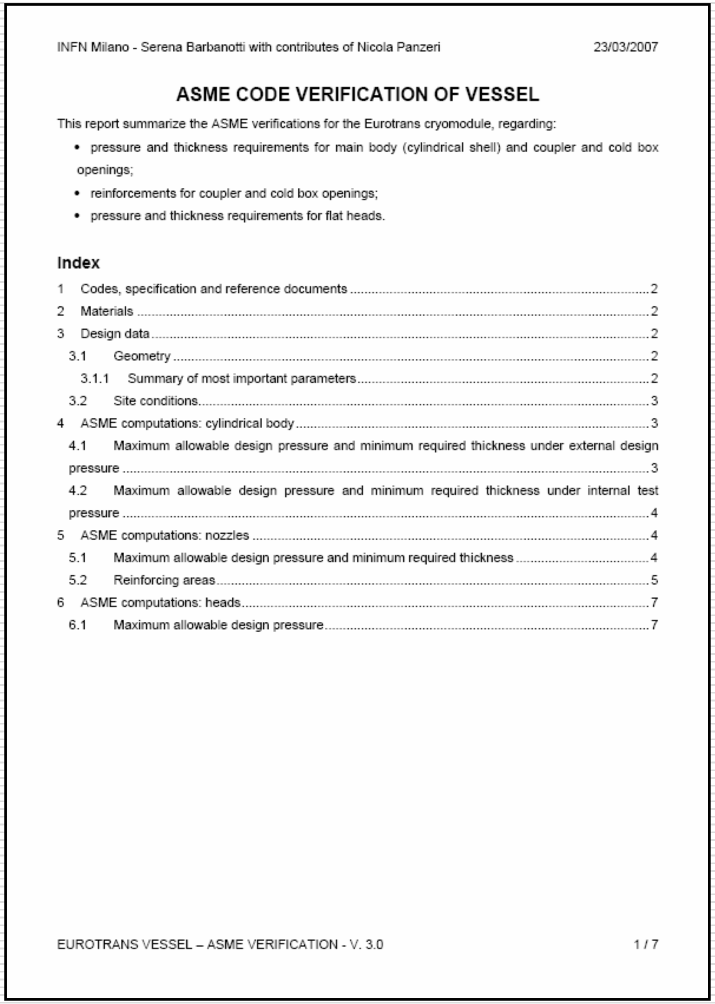
Cryomodule assembly procedure 6/6

- Closure of the vessel



ASME code verification

- Formal ASME procedure followed to verify design data:
  - pressure and thickness requirements for main body (cylindrical shell) and coupler and cold box openings;
  - reinforcements for coupler and cold box openings;
  - pressure and thickness requirements for flat heads.



INFN Milano - Serena Barbanotti with contributes of Nicola Panzeri 23/03/2007

ASME CODE VERIFICATION OF VESSEL

This report summarize the ASME verifications for the Eurotrans cryomodule, regarding:

- pressure and thickness requirements for main body (cylindrical shell) and coupler and cold box openings;
- reinforcements for coupler and cold box openings;
- pressure and thickness requirements for flat heads.

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SUPRATECH on the IPN orsay site

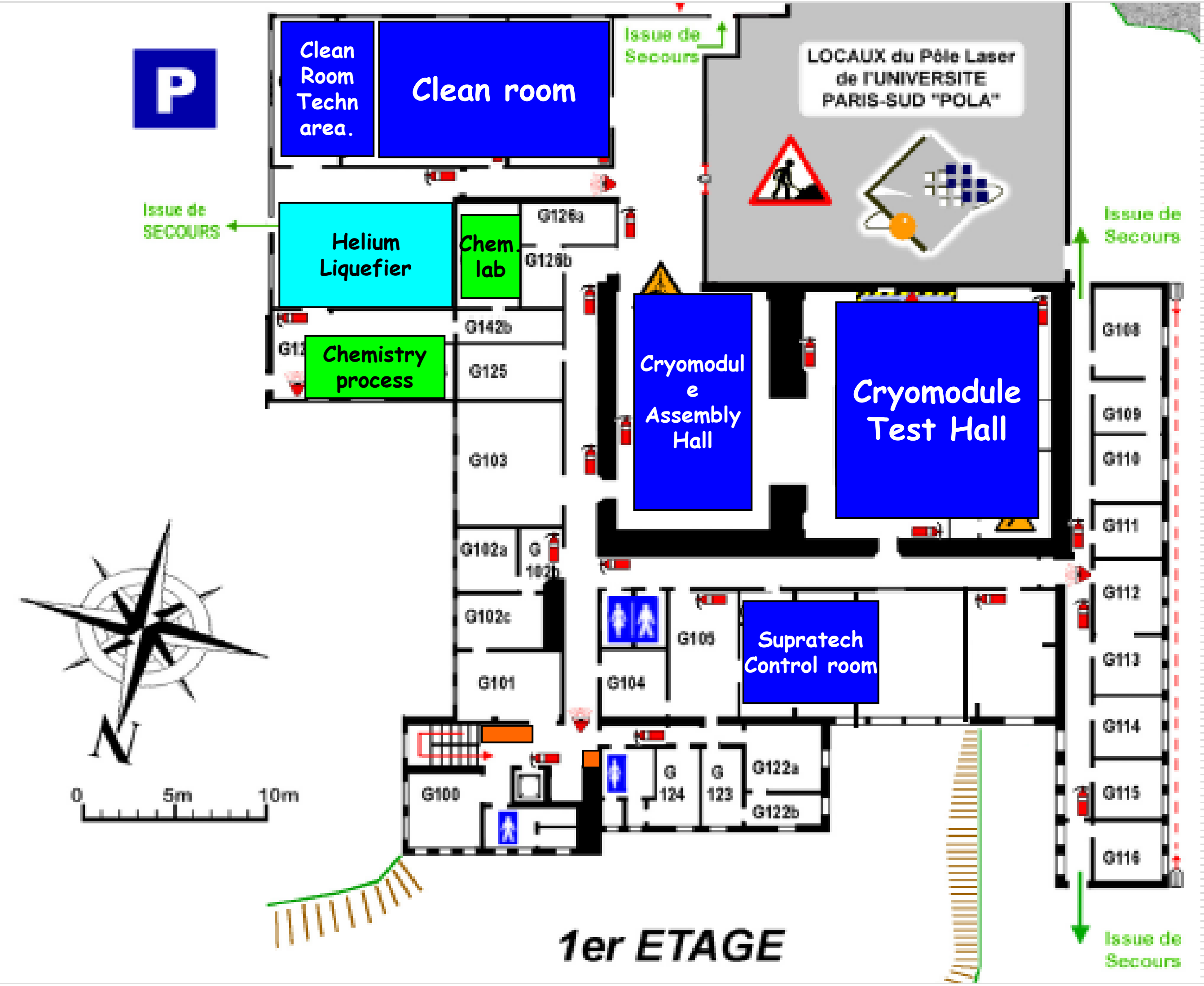
- High power RF sources
  - 350 MHz (for EURISOL and EUROTRANS): 10 kW units
  - 700 MHz sources : 80 kW unit (I.O.T.)

- A clean room for cryomodule assembly
  - a 85 m^2 clean room, with 45 m^2 of class 10/100
  - Include ultra-pure water production and HPR facility

- An Helium liquifier

- A cavity chemistry facility
  - A new addition to Supratech

Orsay site for module installation



Conclusions

- Module Design to be completed soon
  - Beam vacuum
  - Adaptation to final coupler choice
  - Review and finalize cryo piping and interface with Orsay facility
  - Issue drawings for construction bids (fall/end 2007)

- Timeline
  - 12/2007 final engineering and start procurement
  - Fall 2008, assembly in Orsay