The SPL Short Cryo-module:
Status Report
(outcome of the conceptual review)

V.Parma,
CERN, TE-MSC
On bahalf of the
Cryomodule development team

1st Open Collaboration Meeting on Superconduting Linacs for High Power Proton Beams (SLHiPP-1), *CERN, 4th November 2011*

The cryomodule development team

System/Activity	Responsible/members	Lab
Cryo-module coordination	V.Parma	CERN
Cryo-module conceptual design	R.Bonomi, D.Caparros, O.Capatina, P.Coelho, V.Parma,Th.Renaglia, A.Vande Craen, L.R.Williams	CERN
Cryo-module detailed design & Integration & Cryostat assembly tooling	Ph.Dambre, P.Duthil, P.Duchesne, S.Rousselot, D.Reynet	CNRS/IPNO-Orsay
Cavities/He vessel/tuner	O.Brunner, O.Capatina, Th.Renaglia, F.Pillon, N.Valverde, W.Weingarten/S.Chel, G.Devanz	CERN/CEA-Saclay
RF Coupler	E.Montesinos/S.Chel, G.Devanz	CERN/CEA Saclay
Vacuum systems	S.Calatroni (now G.Vandoni)	CERN
Cryogenics	U.Wagner	CERN
Survey and alignment	P.Bestman	CERN
SPL Machine architecture	F.Gerigk	CERN

Goals of the conceptual review

Reviewers: R.Garoby, CERN BE-HDO (Chair); C.Hauviller, CERN EN-HDO; L.Tavian, CERN TE-CRG; P.Bosland, CEA-Saclay; H.Saugnac, IPNO-Orsay.

Charge to the Review Committee:

In general, comments and feedback are encouraged on any subject that you find relevant.

More specifically, the Review Committee is asked to comment upon the design adequacy and make recommendations on the following points:

1) - Cavity helium tank concept and interfaces to cryo-module;
2) - Supporting system concept for the cavities in the cryo-module;
3) - Vacuum vessel concept and choice of the associated assembly tooling; possibility of extending the concepts to a full size 8-cavity cryo-module;
4) - Cryostat thermal design concept;
5) - Cryogenic scheme, control and diagnostic devices.

Agenda of the review

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Report from the review committee

21/11/2011

Report of the Review Committee
of the SPL Cryo-module Conceptual Design

November 4, 2011 - CERN

Committee Members

P. Bosland (CEA-Saclay), R. Garoby (CERN) [Chair], C. Hauviller (CERN), H. Saugnac (IPN-Orsay), L. Tavian (CERN).

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- Cryogenic scheme, control and diagnostic devices.

Report Content

1. Preamble
2. General observations
3. Responses to the charge

Annex 1: Agenda
Annex 2: Participants

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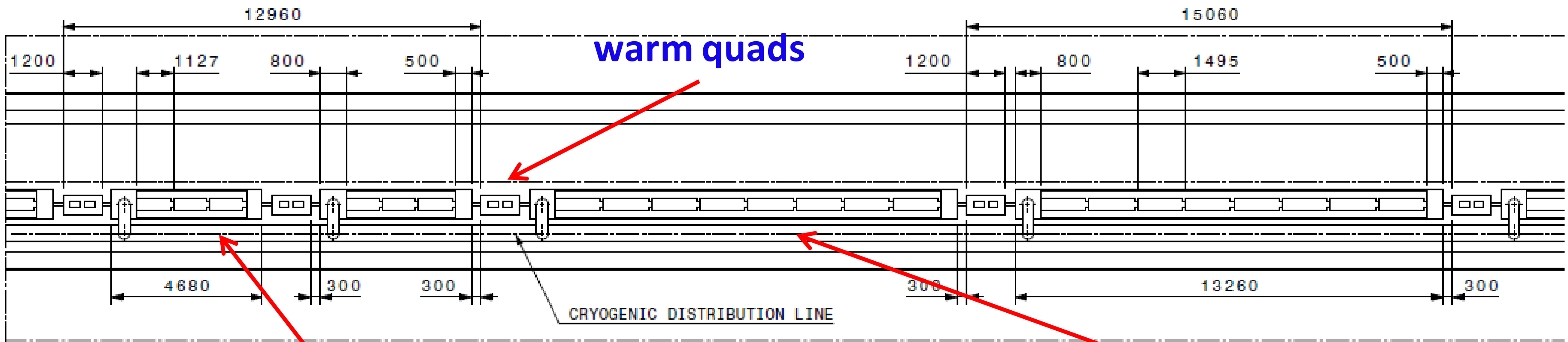
A possible SPL architecture

«segmented» with warm quads and a cryo distribution line:

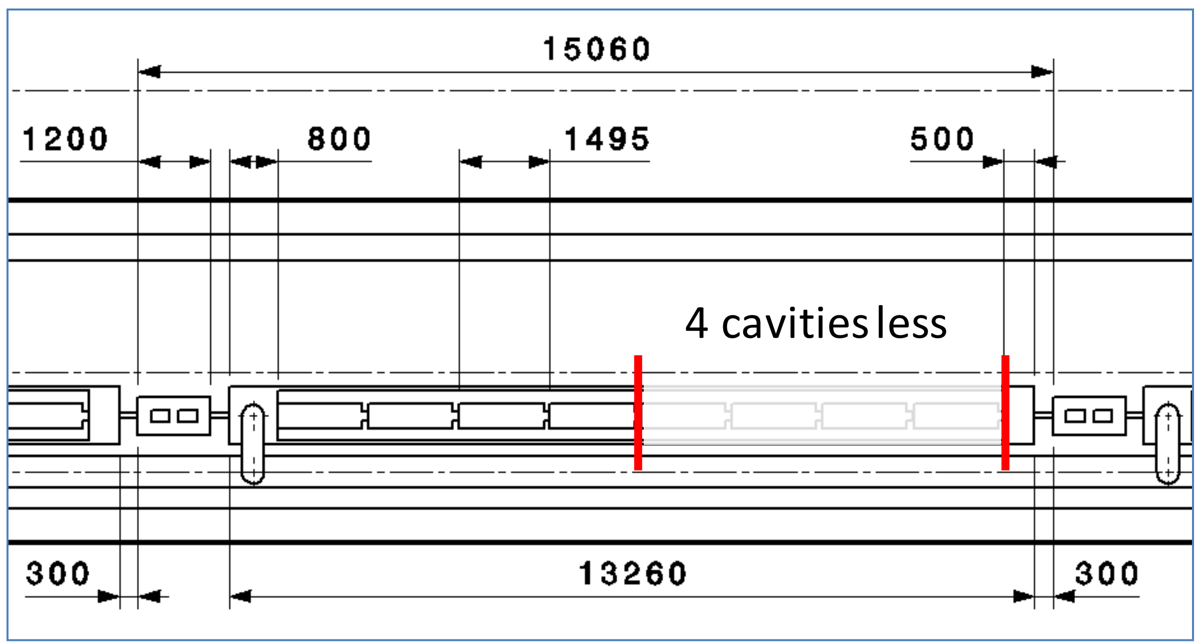


β =0.65 cryomodule (3 cavities)

β =1 cryomodule (8 cavities)

Short Cryomodule designed possibly to be compatible with a full-lenght 8 cavity cryomodule:

- Mechanical design
- Cryogenics (Heat loads, T and p profiles)



(from workshop on SPL vacuum and cryogenic sectorisation http://indico.cern.ch/conferenceDisplay.py?confId=68499)

Short Cryo-module: Goal & Motivation

Goal:

- Design and construct a ½-lenght cryo-module for testing of a string of 4 β=1 cavities

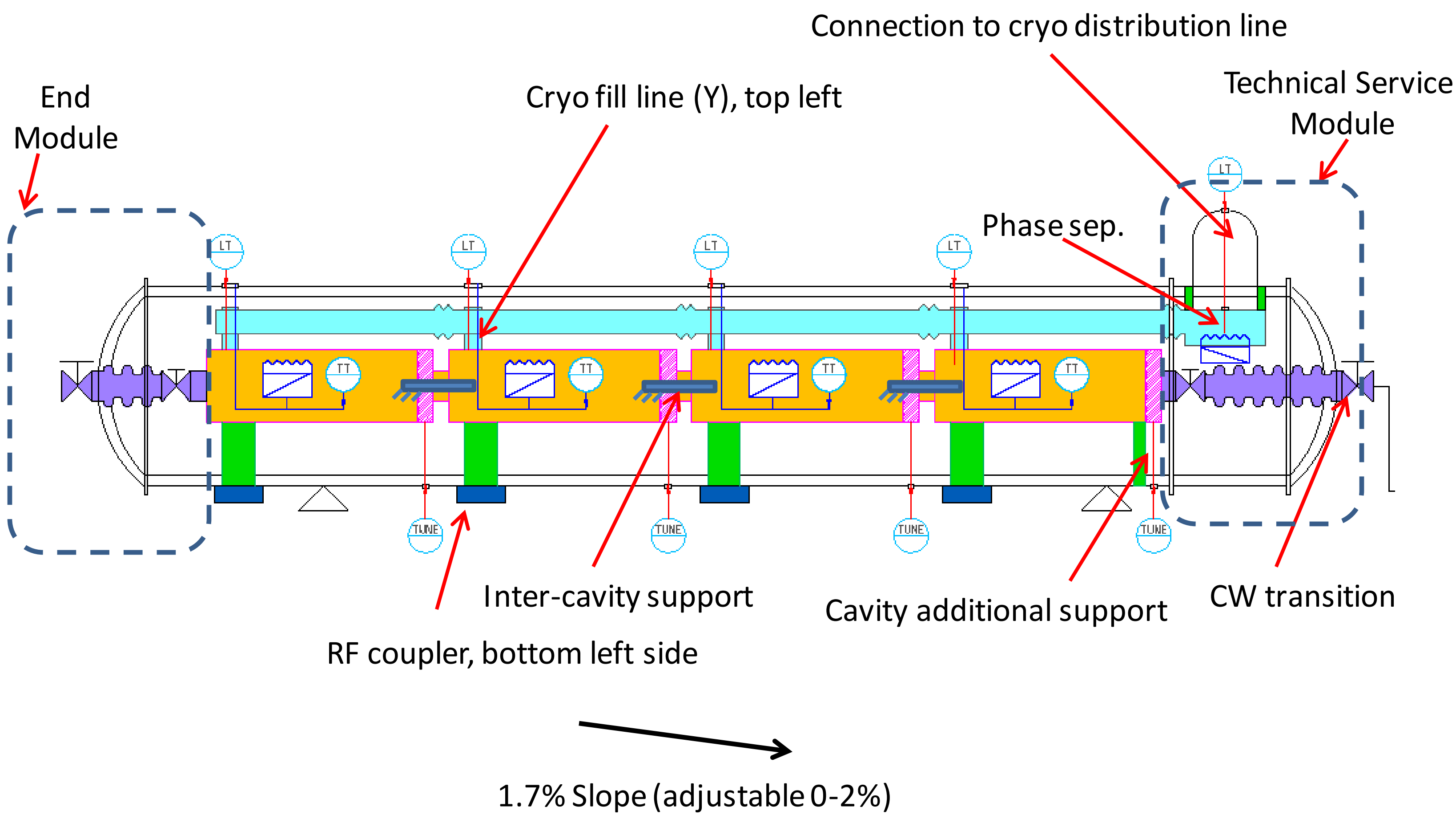
1st Motivation:

- Test-bench for RF testing on a multi-cavity assembly driven by a single or multiple RF source(s)
- Enable testing of critical components like RF couplers, tuners, HOM couplers in their real operating environment

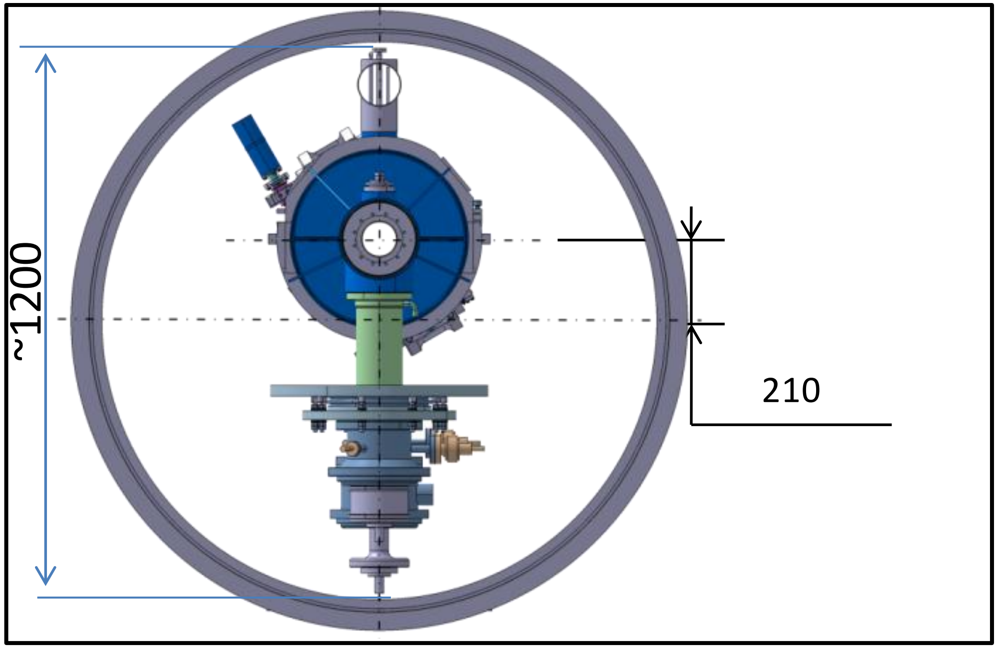
Cryo-module-related goals:

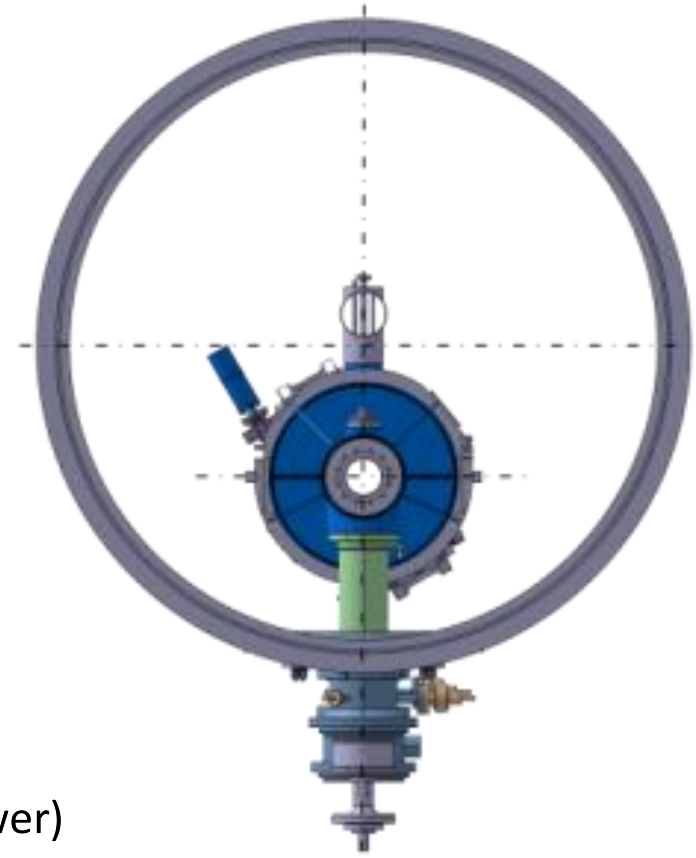
- Validation of design & construction issues
- Learning of the critical assembly phases (from clean-room to cryostat assembly)
- Learning and validation through operational experience:
  - Cool-down/warm-up transients and thermal mechanics
  - Alignment/position stability of cavities
  - Cryogenic operation (He filling, level control, RF coupler support tube cooling …)

Short cryomodule: layout schematic



Cryostat assembly constraint





Constraints:

- ➢ RF coupler in 1 part (single window for high power)
- ➢ Cavity and RF coupler are assembled in clean-room class 10
- ➢ Train of cavities assembled in clean room class 10

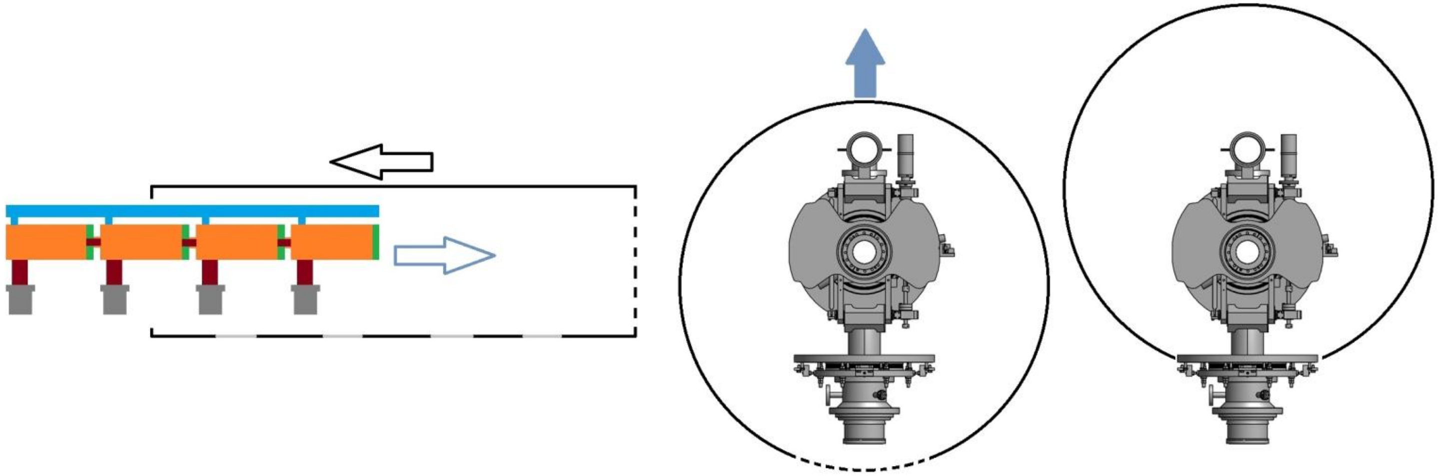
Consequences:

→ No cryostat component allowed in a class 10 clean room

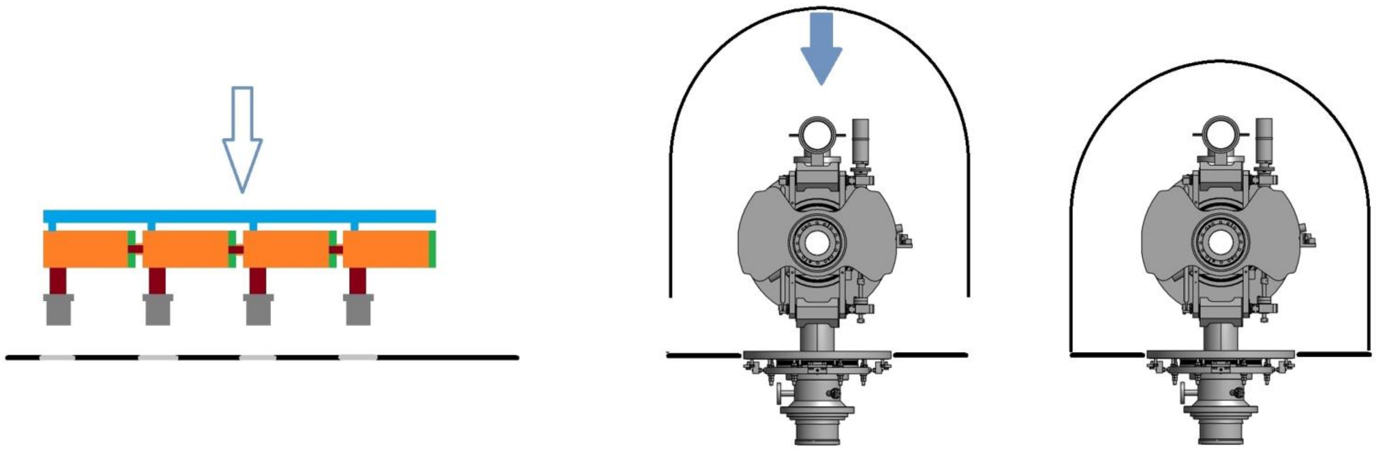
→ An LHC-type cryostat leads to a large diameter (i.e. tunnel space, HL from RT,…)

Vacuum vessel conceptual alternatives

Cylindrical vessel type (LHC like)



2-part vessel type



see talk of Patxi

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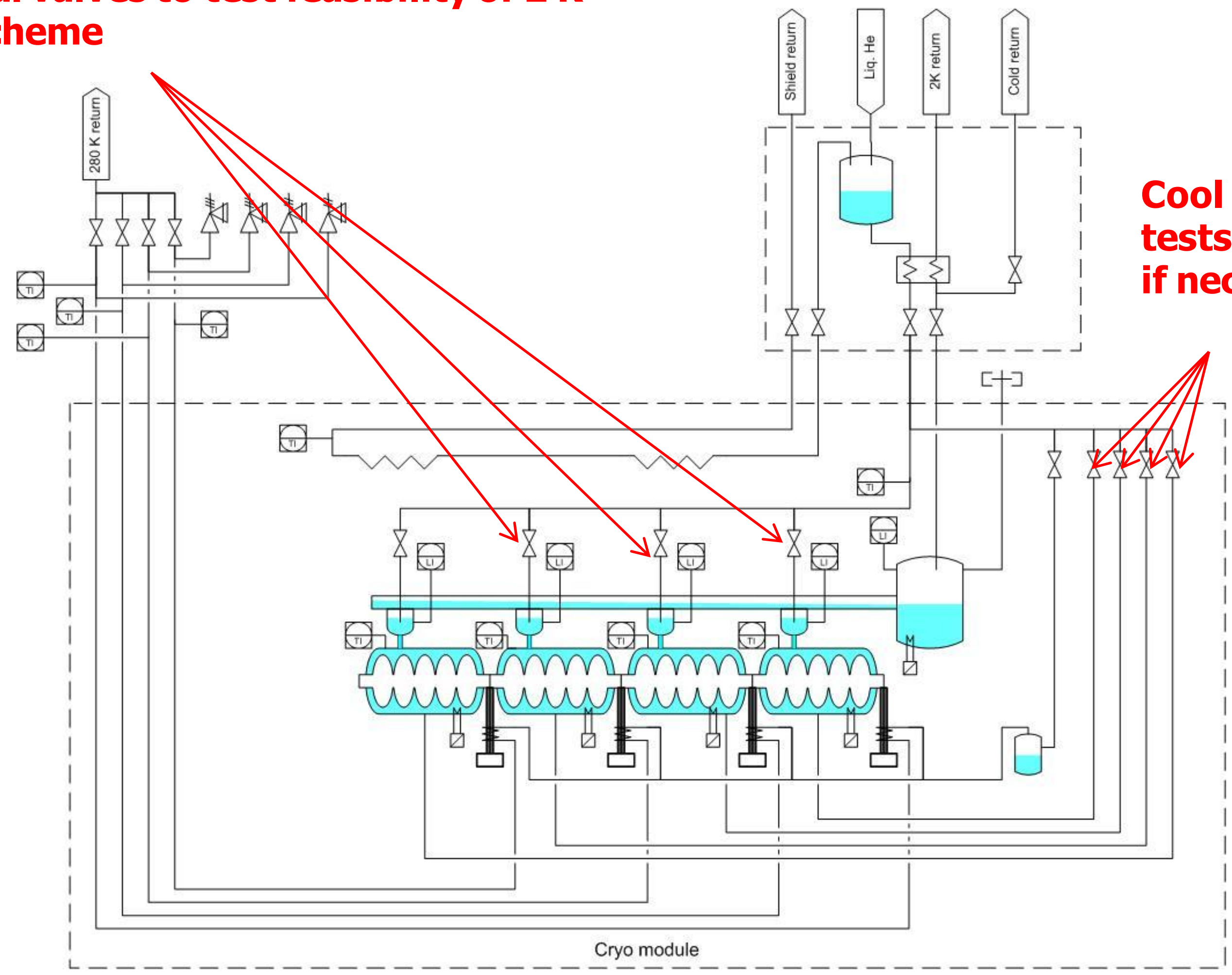
SPL short module

Additional valves to test feasibility of 2 K supply scheme

Cool down valves; tests should show if necessary



U.Wagner's presentation

Piping and valve design

Definition basis

Heat loads for SPL high-β module

	Heat load [W]	Temperature level [K]	Nominal pressure [bar]	Nominal mass flow [g/s]
Thermal shield	240	50 - 75	16 - 18	1.8
Coupler cooling	(1120)	5-280	1.1	0.78
2.0 K static load	5.0	2.0	0.031	0.25
2.0 K total load	200	2.0	0.031	10

Static load estimated to 2.5 % of total load.
Even half or double the static load has no influence on design.

Assessment of static load is of minor importance at this state.

Piping and valve design

Definition basis

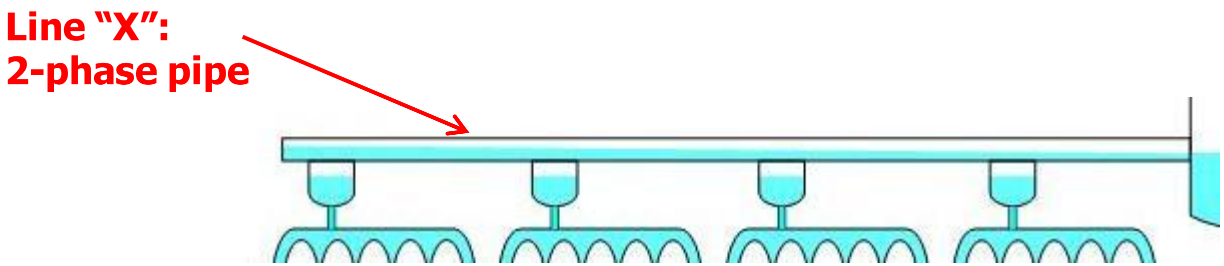
- **Short module cryostat as integration test for full-size high-β module**
- **Piping and valve dimensioning as for full-size high-β module**
  - Where reasonable!
- **General remark:**
  - The design has "reasonable margins".
  - Principally we want to test cavities not piping limits.

U.Wagner's presentation

Piping design

Line X: 2-phase pipe

- **Design basis:**
  - Vapour flow speed < 7 m/s to avoid drag of liquid
  - Low pressure loss for isothermal cavities
- **Value: 80 mm Di**
  - 15 m line; 10 g/s; Δp = 0.07 mbar; $\Delta T(\Delta p)$ = 0.08 mK; vapour speed = 2.7 m/s



U.Wagner’s presentation

Piping design

Updated table

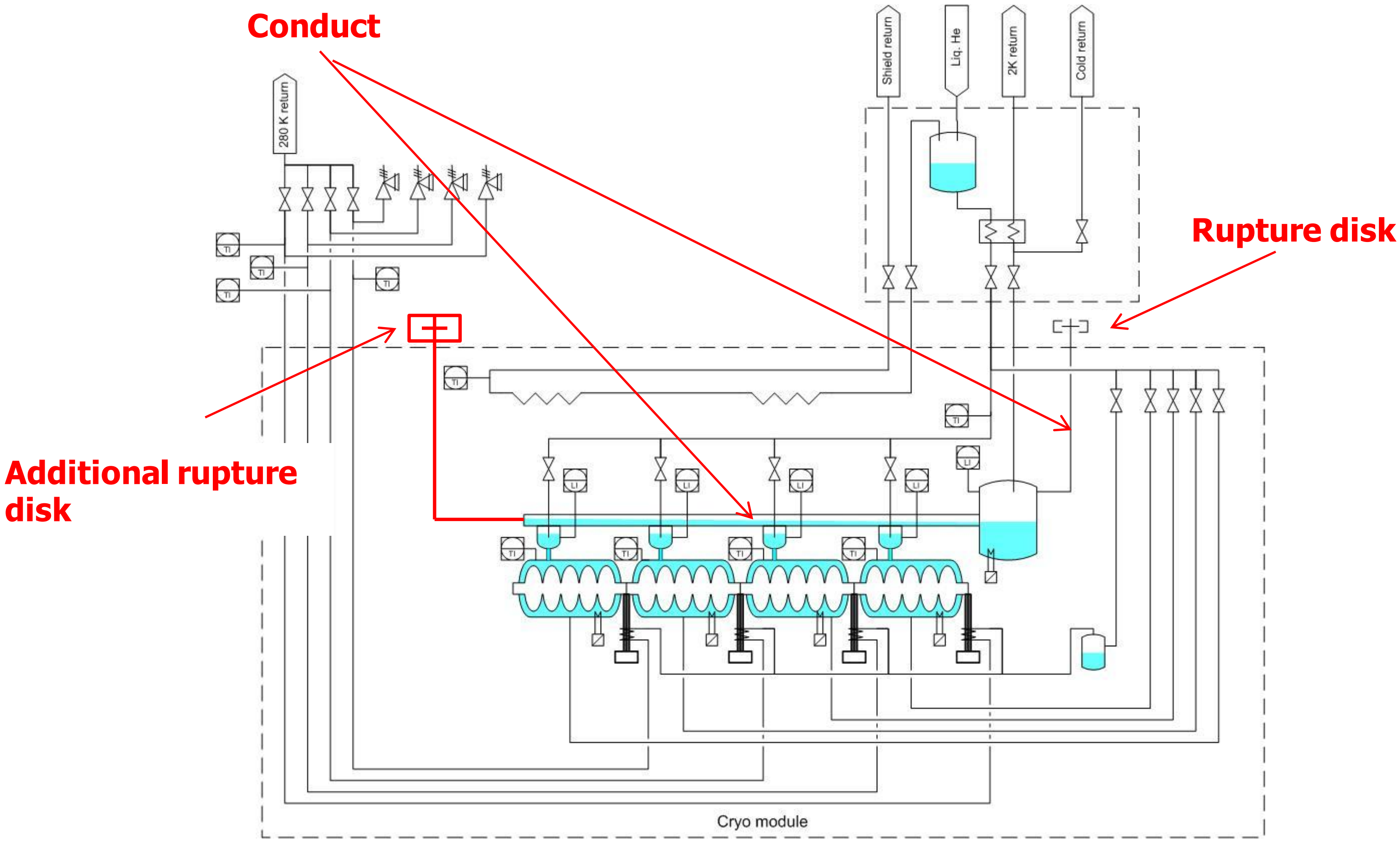
SPL Pressure/Temperature Table

Line	Description	Pipe Size (ID min. value) [mm]	Normal operating pressure [MPa]	Normal operating temperature [T]	Cool-down / warm-up pressure [MPa]	Cool-down / warm-up temperature [K]	T range [K]	Maximum operating pressure [MPa]	Design pressure [MPa]	Test pressure [MPa]	Comment
L	Cavity helium enclosure	cavity OD + 10	0.0031	2	0.13 @ 293K 0.2 @ 2K	293-2	2-293	0.15 @ 293K 0.2 @ 2K	TBD	TBD	
X	Bi-phase pipe	80	0.0031	2	0.13 @ 293K 0.2 @ 2K	293-2	2-293	0.15 @ 293K 0.2 @ 2K	TBD	TBD	
Y	Cavity top connection	80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
XB	Pumping line	80	0.0031	2	[illegible] 0.2 @ 2K	293-2	2-293	[illegible] 0.2 @ 2K	TBD	TBD	
E	Thermal shield supply	15	1.8	~50	2	293-50	50-293	2	2		Heat intercept
E'	Thermal shield return	15	1.8	~50	2	293-50	50-293				Return only
W	Cryostat vacuum vessel	1000 (TBD)	vacuum	293	vacuum	293	237-293	O.P. 0.1	I.P. 0.15	N.A.	
C1	Cavity filling	6	0.1	4.5	0.1	293-4.5	4.5-293				Liquid supply
C2	Coupler cooling	6	0.1	4.5-293	0.1	293-4.5	4.5-293				Gaseous supply
C3	Cavity top supply	10	0.1	2	0.1	293-4.5	2-293				2 phase supply

Minimum values

U.Wagner's presentation

SPL short module



U.Wagner's presentation

Recommandations

3.3 Cryostat thermal design concept / Cryogenic scheme, control and diagnostic devices

Observation

- Incomplete cryogenic risk analysis for the final sizing of safety relief system on the He circuits and on the vacuum vessels.

Comment

- Lack of a unique database for designers (heat loads, pressure, temperature,…).
- Is a phase separator for the coupler supply really needed? Consequence of feeding the couplers directly with 2.2 K, 1.3 bar subcooled liquid?
- The process and instrumentation diagram shows 2 Joule-Thomson valves in series (one in the cryo-module and the second in the SM18 cryogenic infrastructure) which could create hydraulic impedance issue.

Recommendations

- Make available and maintain a complete and up-to date set of parameters.
- Make an exhaustive cryogenic risk analysis prior to deciding upon the size of the safety relief systems.
- Specify cool-down and warm-up requirements and constraints.
- Check deformations (screens, shields,…) during cool-down and warm-up.
- Check compatibility with SM18 cryogenic infrastructure.
- Assess the unbalance of the subcooling heat exchanger.
- Develop a thermo-hydraulic model to analyze the robustness of the 2 K He level controls (RF transients).
- Finalize the list of additional instrumentation for prototype validation and include it on the P&I diagram.
- Study alternative for instrumentation feedthroughs without cold ceramic insulators.
- Elaborate a procedure for cooling down the cold magnetic shield, taking into account the cavity cool down and the impact on the '100K effect'.

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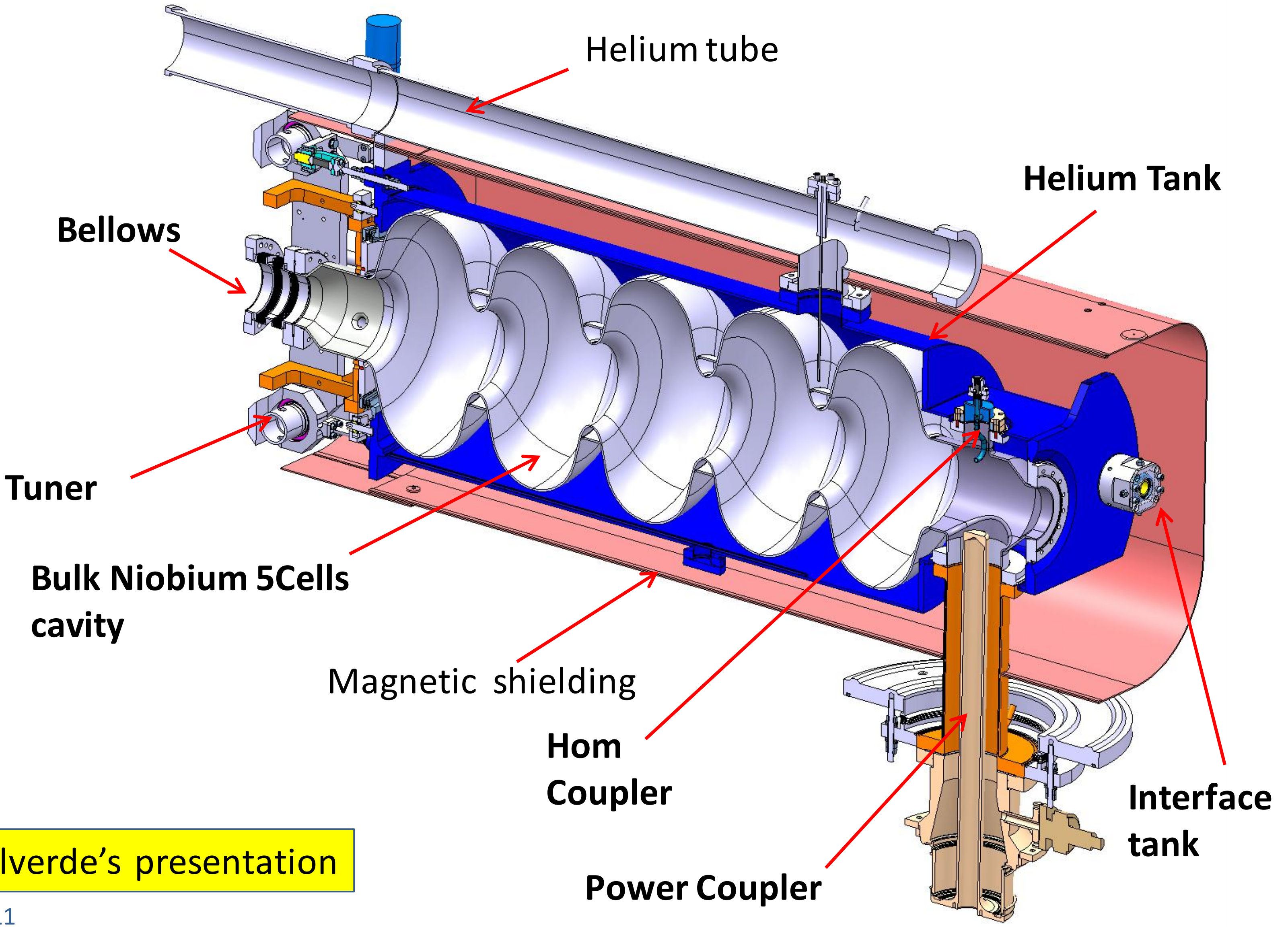
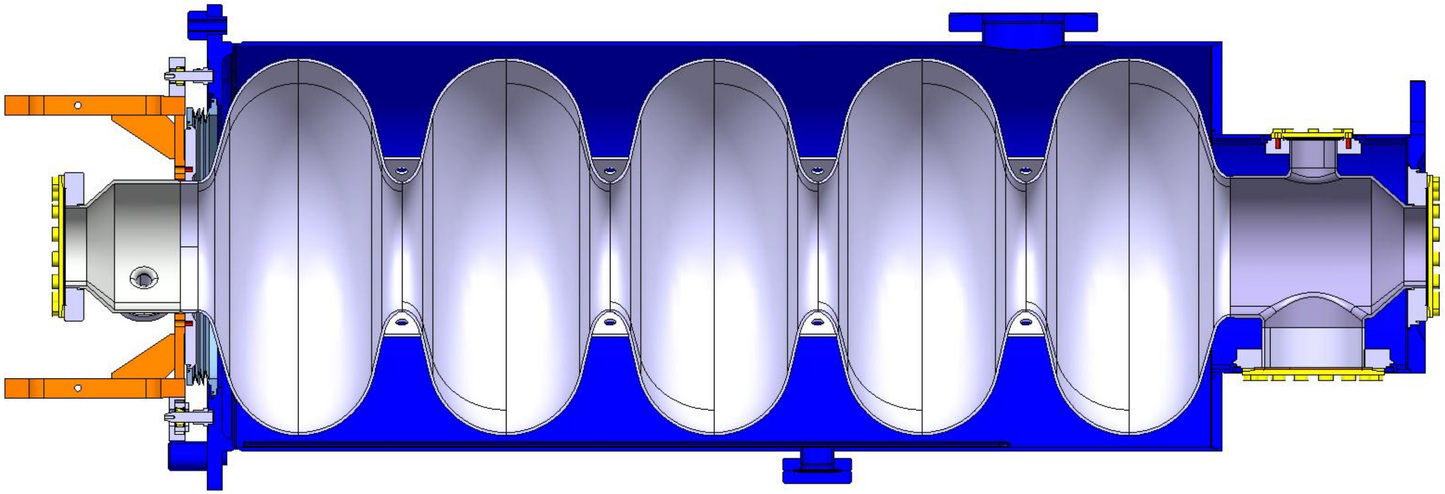
INTRODUCTION- CAVITY SPL



N.Valverde's presentation

HELIUM TANK

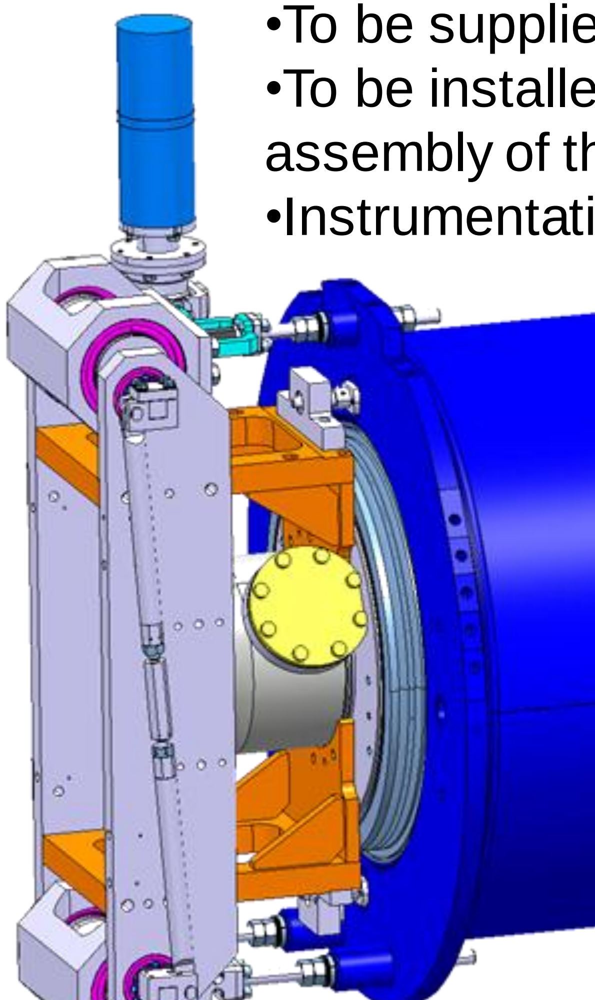
- Designed by CERN (SS material)
- To be manufactured by CEA
- Assembly cavity-tank by CERN

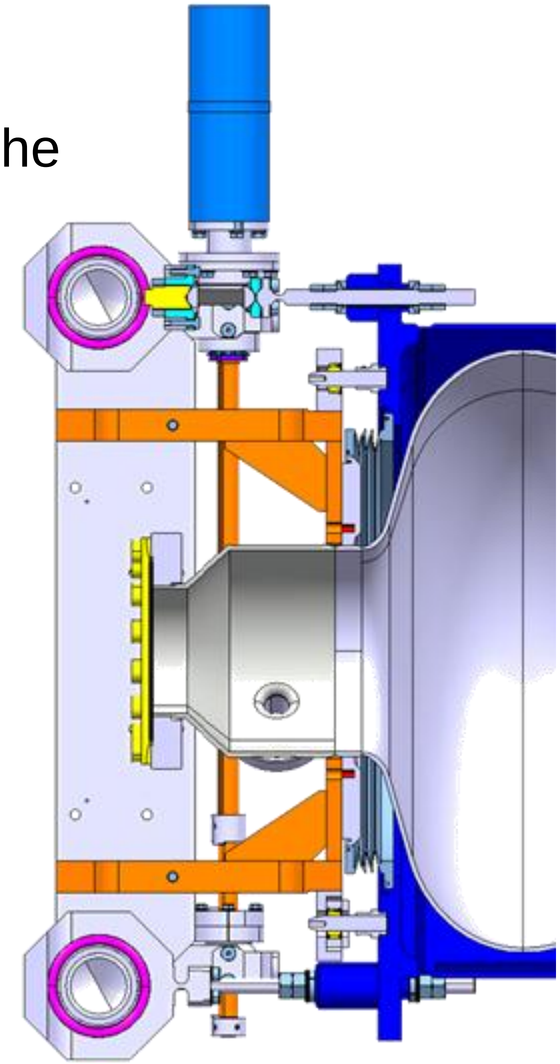


N.Valverde's presentation

TUNER

- To be supplied by CEA
- To be installed by CERN during the assembly of the cryo-module
- Instrumentation / control cables

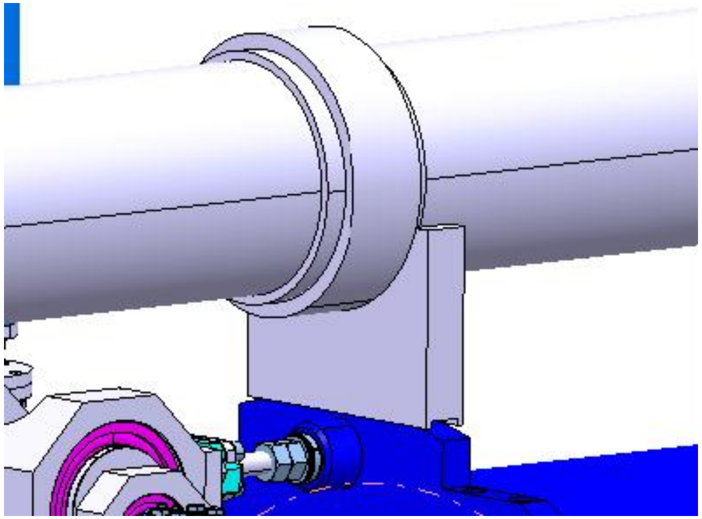


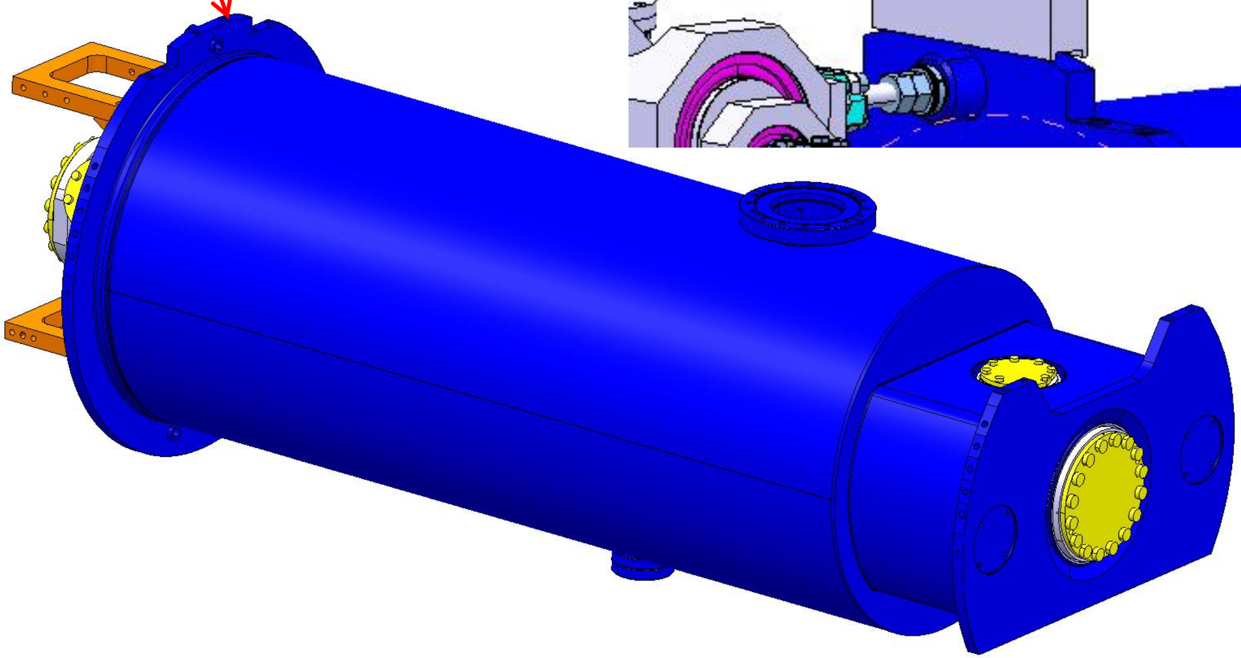


N.Valverde's presentation

HELIUM TANK

Support for helium tube





N.Valverde's presentation

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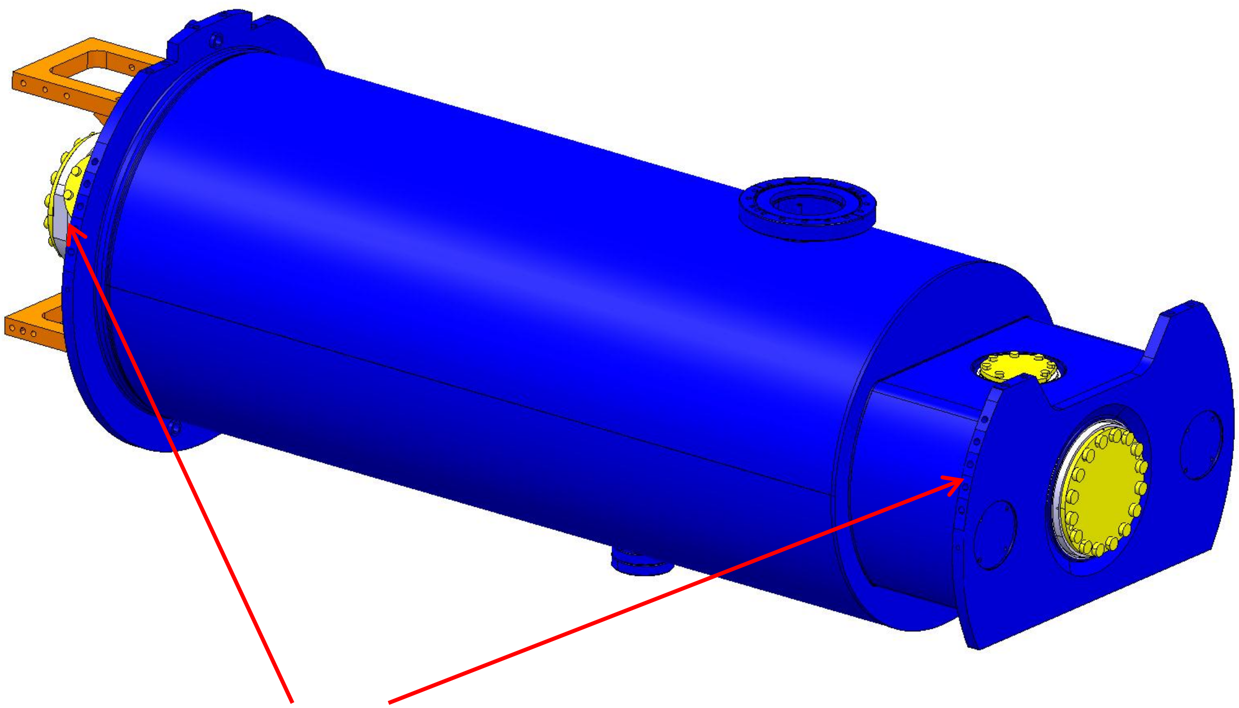
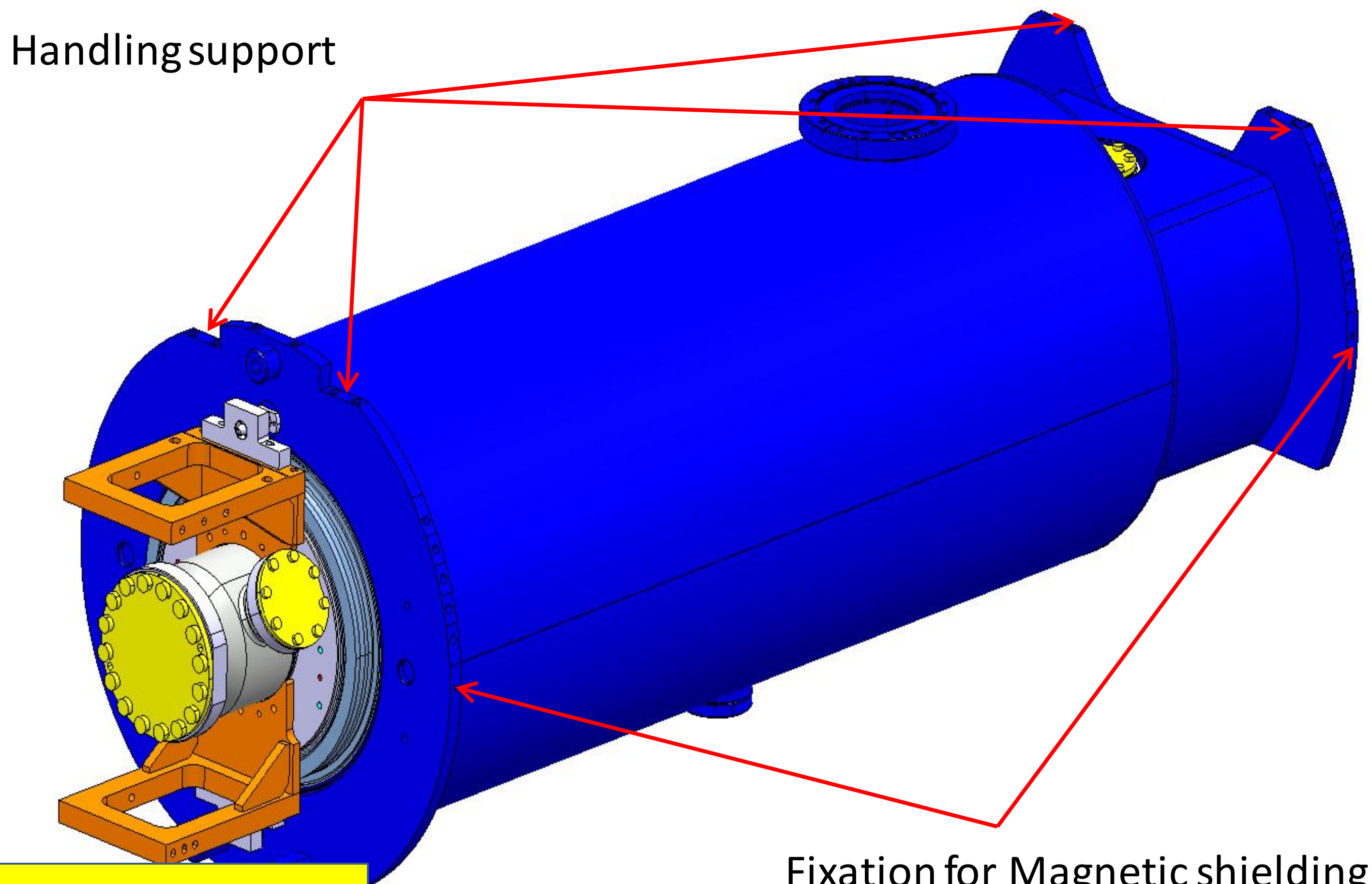


Interface for alignment supports

The alignment system supports are designed by the cryo-module team compatible with all adjacent equipment (magnetic shielding etc…)

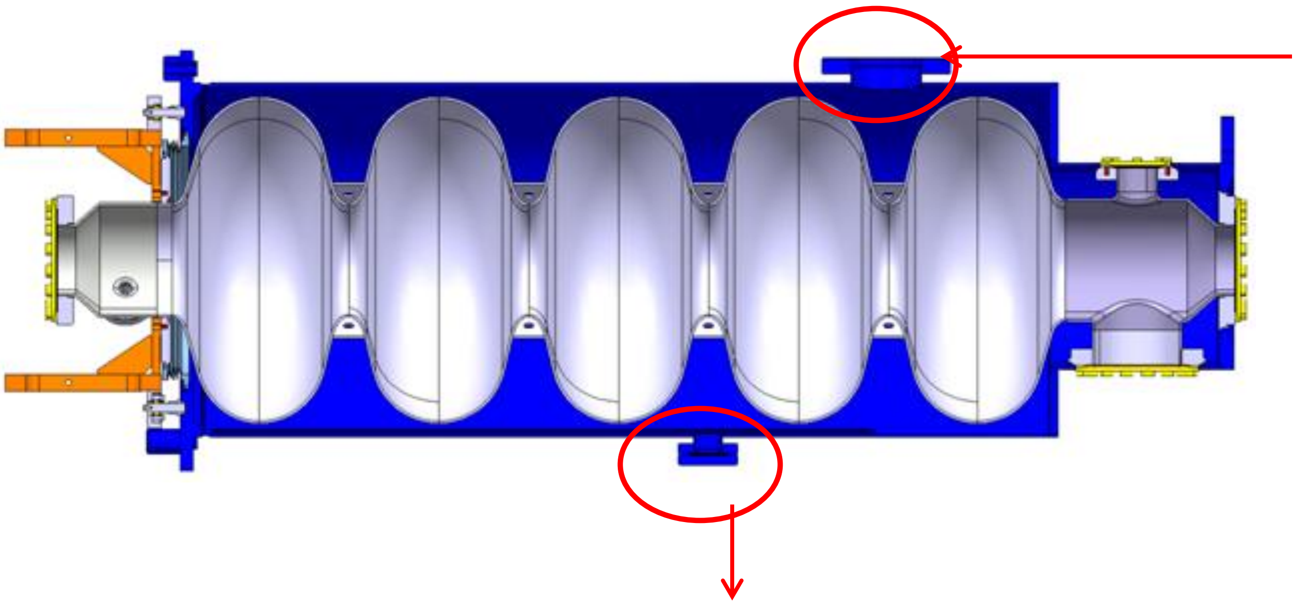
N.Valverde's presentation

HELIUM TANK



N.Valverde's presentation

HELIUM TANK- Interface Cryo



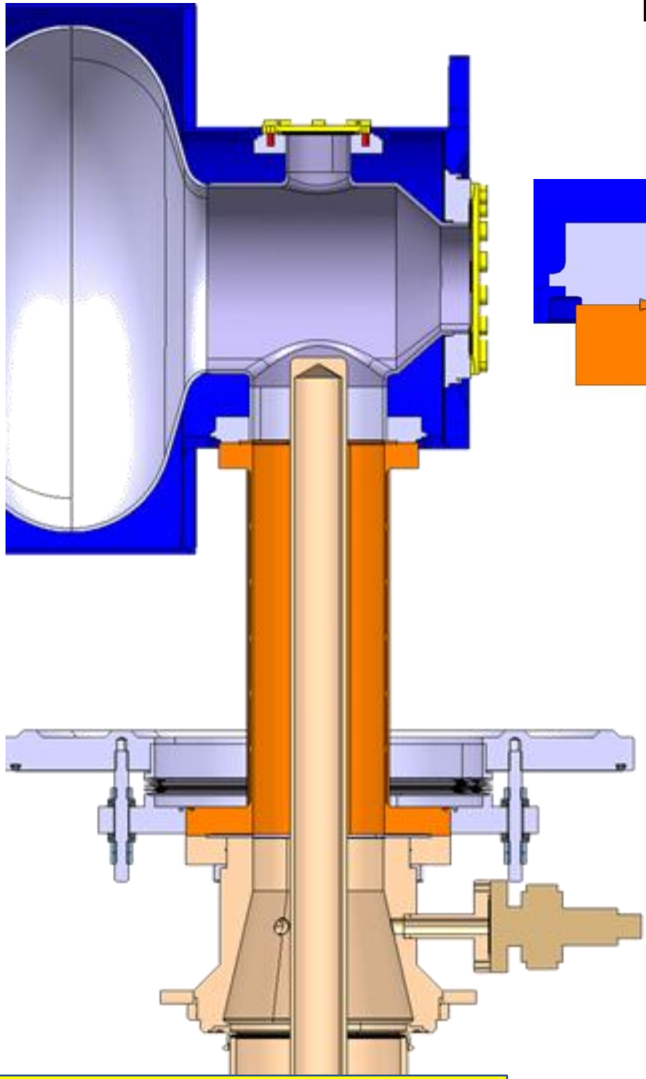
SS CF UHV DN100, tube dia 80 mm -It has been designed to extract the heat in a nominal performance (pulsed).

SS CF UHV DN 40, tube dia 27 mm. In principle not needed in a first phase. Will be closed with a flange.

Needs to be defined by cryo if instrumentation (ex. heaters...) or other equipments (ex. helium supply pipe...) need to be installed before assembly of the helium tank.

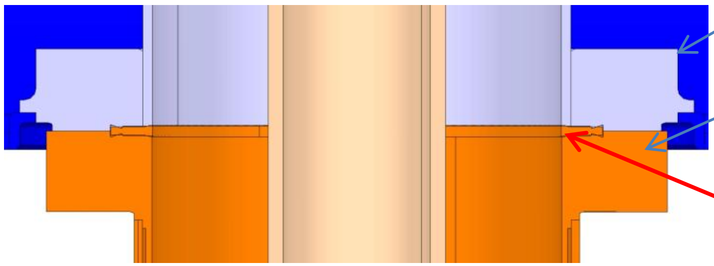
N.Valverde's presentation

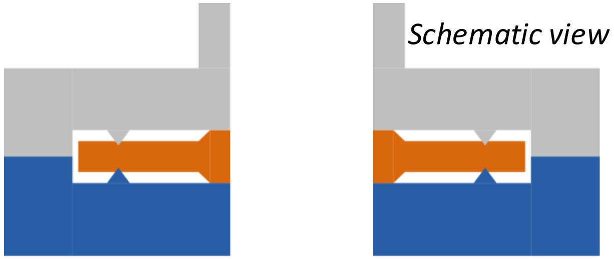
POWER COUPLER



N.Valverde's presentation

Designed and provided by CERN (BE/RF)





Requirements to fulfill:

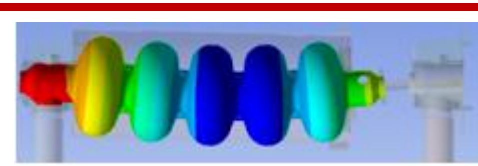
- RF Electric continuity
- Support for the cavity→ <u>(The cavity + tank is not designed for cantilever supporting)</u>

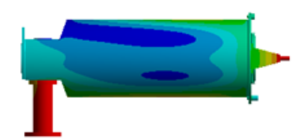
5. Conclusion

BUDGET OF TOLERANCE			
Step	**Sub-step**	**Tolerances (3σ)**	**Total envelopes**
Cryo-module assembly	Cavity and He vessel assembly	*± 0.1 mm (TBD)*	Positioning of the cavity w.r.t. beam axis **± 0.5 mm**
	Supporting system assembly	*± 0.2 mm (TBD)*	
	Vacuum vessel construction	*± 0.2 mm (TBD)*	

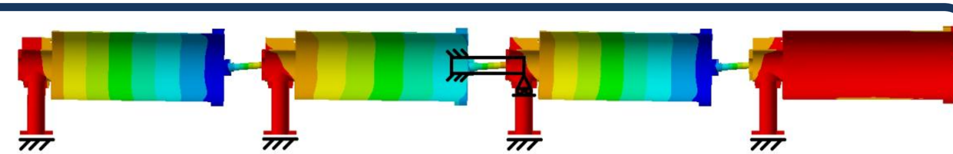
Loads: Self weight and weight of components

Cavity (measured by ends only)
Helium vessel

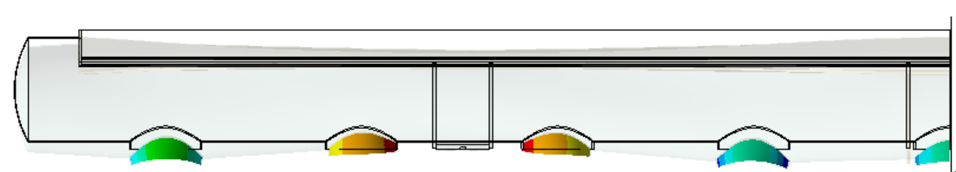




Helium vessel, inter-cavity support, string of cavities



Vacuum vessel, interfaces.



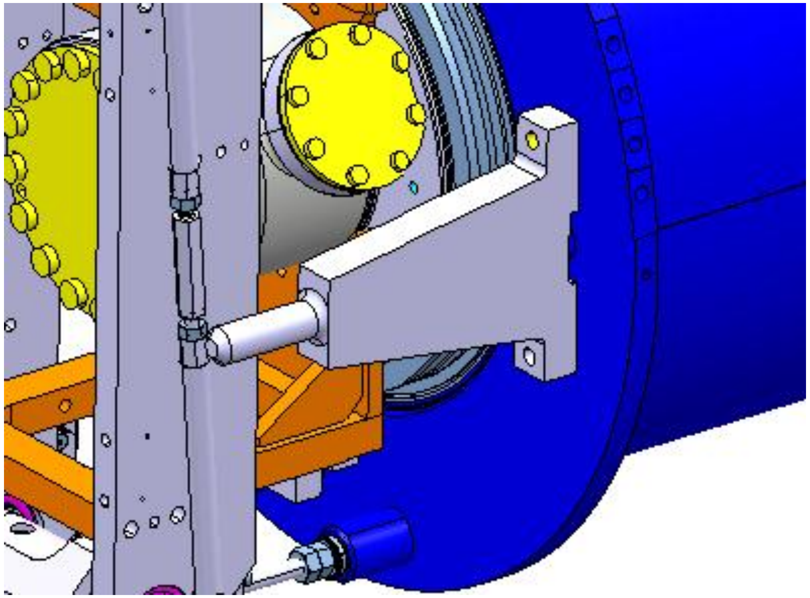
Models above are obsolete or conceptual

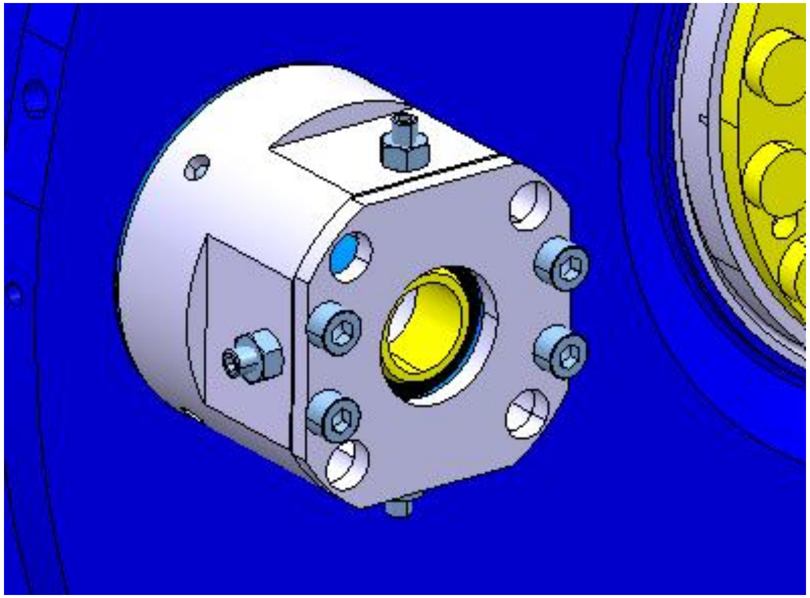
SP P.Azevedo's presentation

A. Vande Craen TE/MSC-CMI 04/11/2011

Proposed design

- Proposed solution



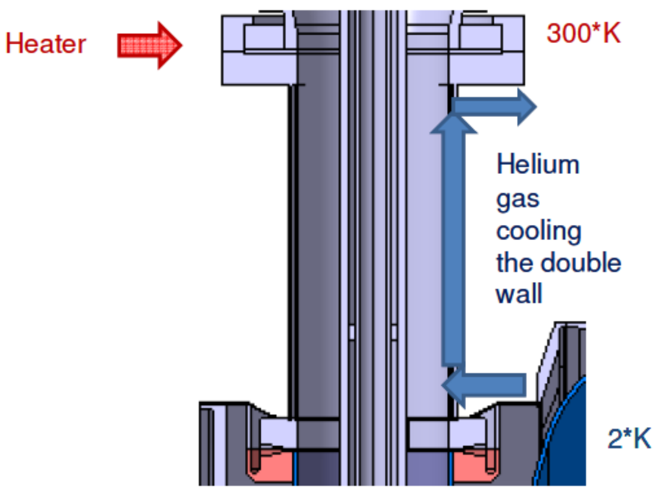


A.Vande Craen's presentation

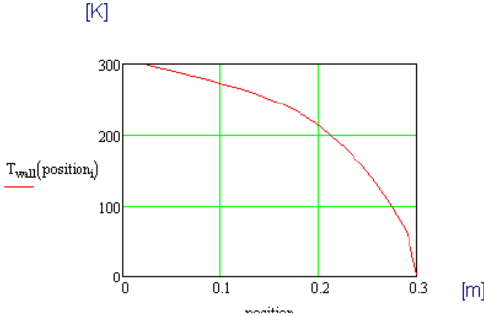
2. Power coupler as support

Active cooling of PC double walled tube

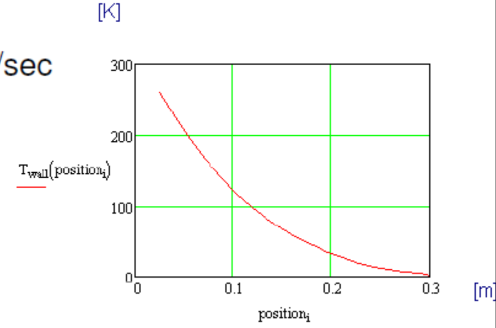
- Cooling gas at 4.5 K input
- Lower part at 2 K and upper part at 300 K
- Heater at upper part to insure 30 ºC of flange temperature
- 1000 kW pulsed (100 kW average), 704.4 MHz, 50 Ω
- H=300 mm; D=100 mm; eint=1.5 mm; eext=2 mm
- Copper on stainless steel; Copper RRR = 30 (Sergio Calatroni)



- Why cooling the wall?
  - No cooling temperature profile => Gives 21W to 2K



  - Cooling with 42 mgram/sec temperature profile => Gives 0.1W to 2K



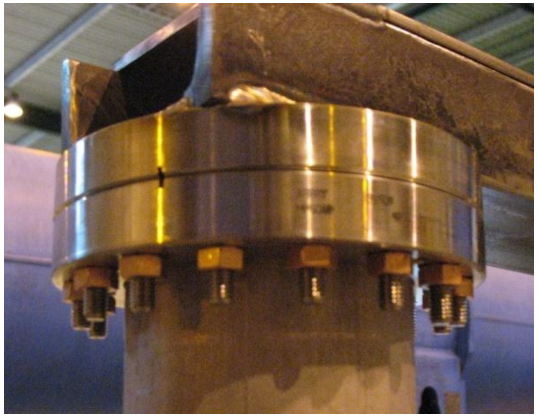
Courtesy of Ofelia Capatina

The active cooling of the double walled tube was not conceived to cope with its support function. However, due to the cavity alignment requirements, the thermal profile of the double tube and its reproducibility become a fundamental issue.

Further work on this subject is being carried out by Rossana Bonomi (TE/MSC).

Power coupler mock-up

- Tube : same inertia as double walled tube
- Real flanges
- Force at end of beam (torque on flange)

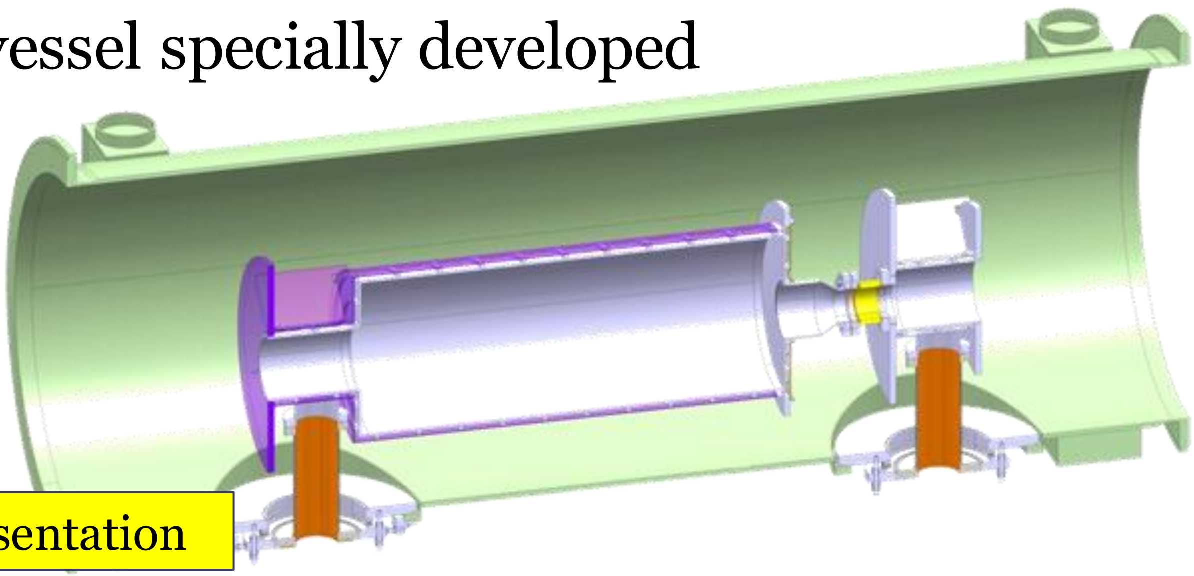


A.Vande Craen's presentation

Supporting scheme mock-up

Still in development

- Cooled with liquid nitrogen
- Same mechanical behaviour as real cavity/Helium Tank
- Real surrounding components
  - Double walled tube
  - Inter-cavity support
- Vacuum vessel specially developed



A.Vande Craen's presentation

Recommendations

3. Response to the Charge

3.1 Cavity helium tank concept and interfaces to cryo-module / Supporting system concept for the cavities in the cryo-module

Observation

A new and innovative concept is being proposed which makes use of the large main RF couplers to support all the equipment inside the cryo-module tank. Clear benefits are expected in terms of static heat loss.

Comment

- Delicate design issues:
  - Transfer of loads through vacuum flanges. Since no data was presented about leak and mechanical robustness at the level of coupler support flange on vacuum vessel, the Committee considers that the design is at initial stage.
  - Complex inter-tank support with numerous constraints.
- The boundary conditions should be clearly expressed to help understand the relevance of the mechanical analysis.
- The foreseen mock-ups are very important for validating crucial concepts (alignment at cold, inter-cavity connection, ...).

Recommendations

- The solutions imagined for the transfer of loads through vacuum flanges deserve extensive testing.
- Demonstrate that the tank rigidity is sufficient for the slow and fast tuning systems to work properly.
- Demonstrate that no plastic deformation of the cavity will occur during thermal cycling because of the difference in the thermal contraction coefficients between the stainless steel of the helium tank and the niobium of the cavity.
- The welded bellows between cavities may be a source of dust contamination. Elaborate a cleaning procedure of these bellows in order to limit the risk of cavity performance degradation.
- More mechanical analyses are required to bridge the gap between the ones using simplified models (e.g. for the inter-tank) and the ones with detailed models (e.g. couplers).
- Need for analysis of loads under thermal transients.
- Need for analysis of the mechanical eigenmodes.

Agenda of the review

Agenda:

8:45-8:50	Welcome (R.Garoby), 5’;
8:50-9:20	The Short Cryomodule: requirements (V.Parma), 30’;
9:20-9:50	Cryogenic scheme, pipes and valves dimensions (U.Wagner, CERN), 30’;
9:50-10:20	The cavity/helium vessel/tuner assembly (O.Capatina, CERN), 30’;
10:20-10:40	Coffee break, 20’;
10:40-11:20	Cavity supporting system (A.Vande Craen, P.Azevedo, CERN), 40’;
11:20-12:00	Vacuum vessel and assembly tooling and procedures (P.Duthil, CNRS), 40’
12:00-12:30	Magnetic shielding and thermal shielding (P.Duthil, CNRS), 30’;
12:30-13:30	Lunch break, 60’
13:30-14:15	Cryogenic line circuits, Technical Service Module (P.Duthil, CNRS), 45’;
14:15-14:45	Questions from the reviewers, 30’;
14:45-15:15	Coffee break, 30’;
14:45-16:00	Reviewers’ closed session, 1h 15’;
16:00-16:30	Recommendations from reviewers and Conclusions
16:30	Adjourn

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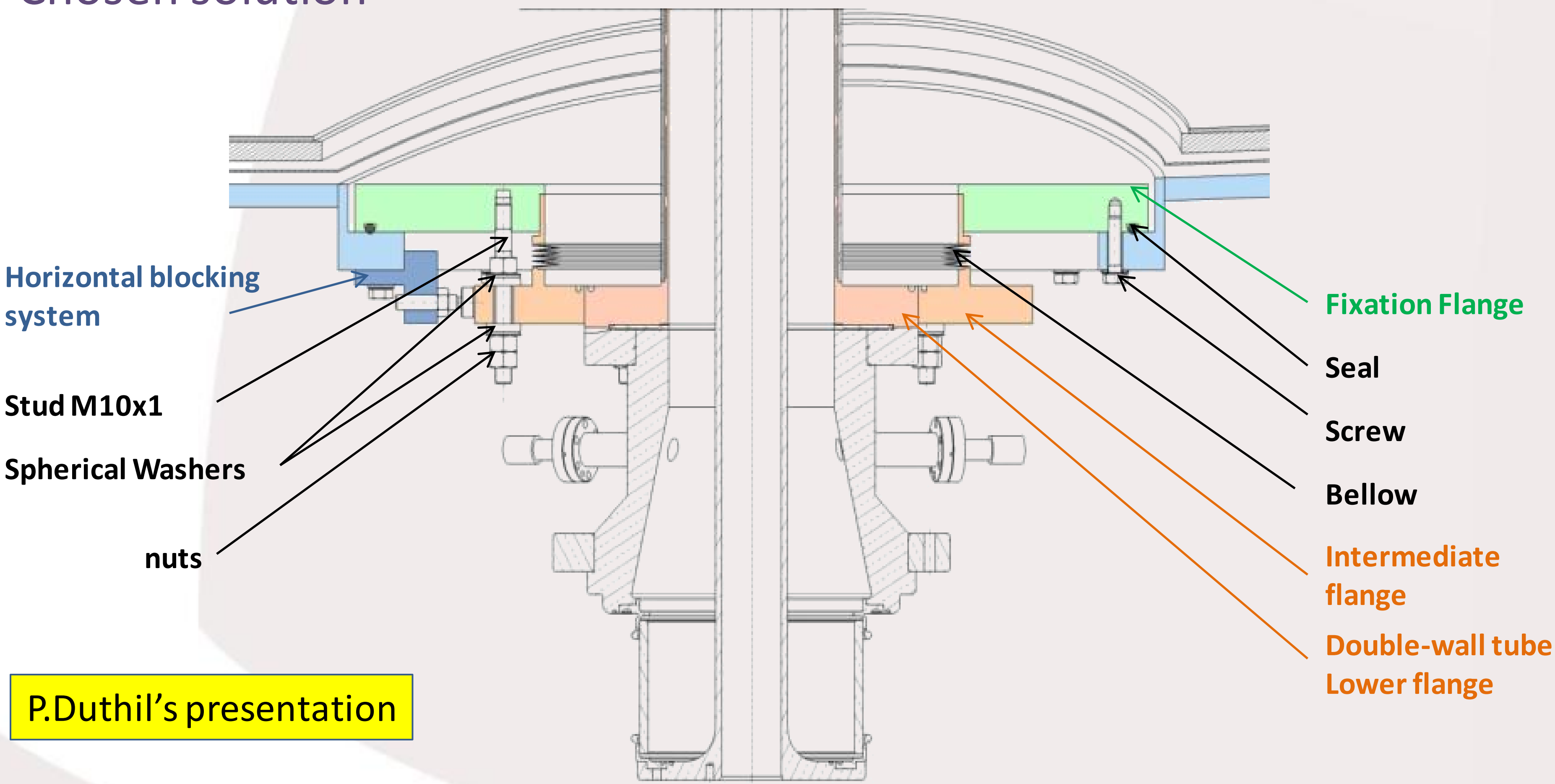
VACUUM VESSEL / COUPLER INTERFACE

Coupler compensation interface with the vacuum vessel

Chosen solution



P.Duthil's presentation

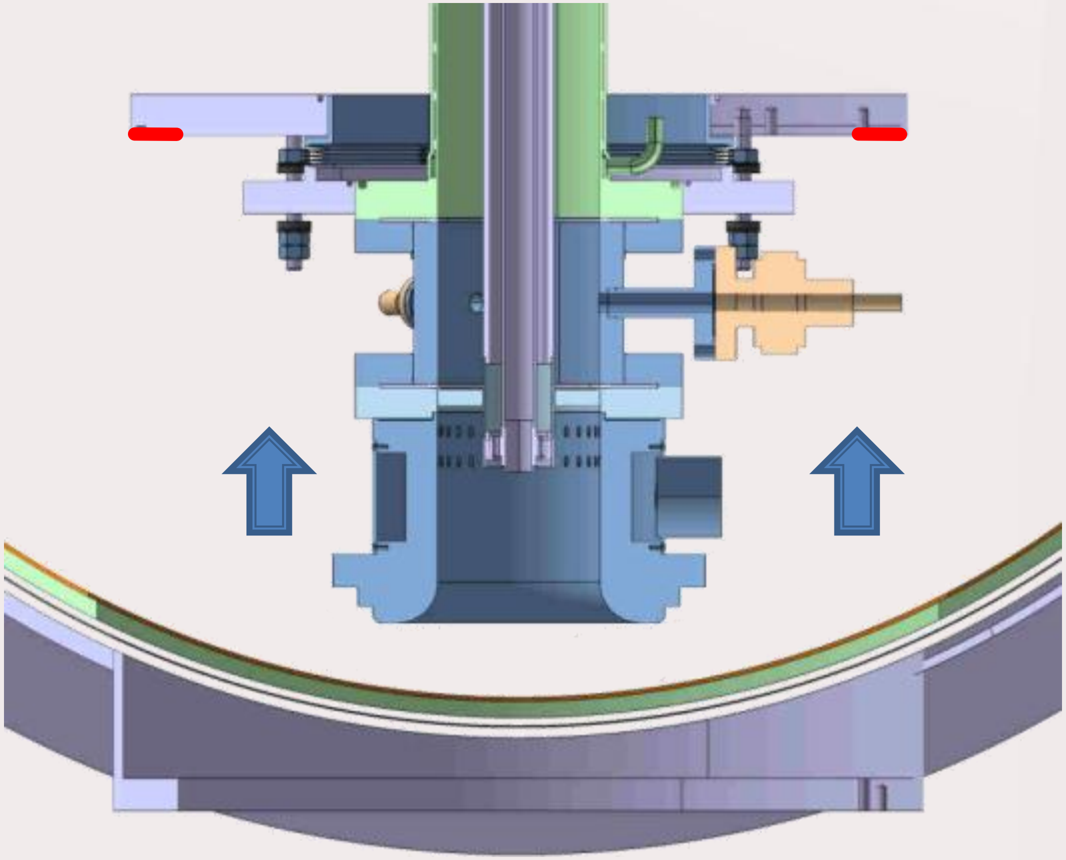
The detailed study of this interface has been done.
It will soon be constructed and tested on a mock-up by CERN.

Note technique : NT-21B-004
CONCEPTION DES PALIERS SUPPORTS

Coupler compensation interface with the vacuum vessel

Assembly procedure

- **Vacuum vessel lift of**



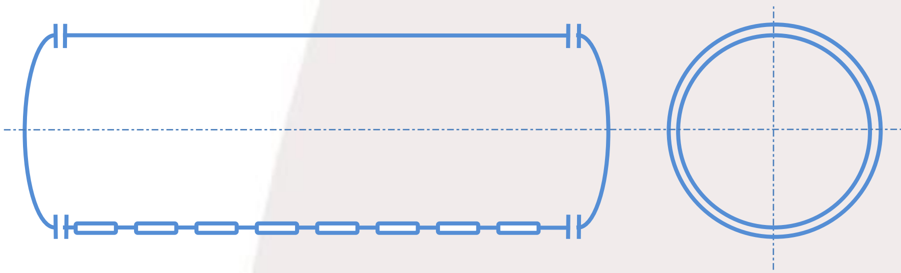
P.Duthil's presentation

- **Contact of the 4 coupler sealing flanges to the 4 bearings of the vacuum vessel**
- **And fixing**

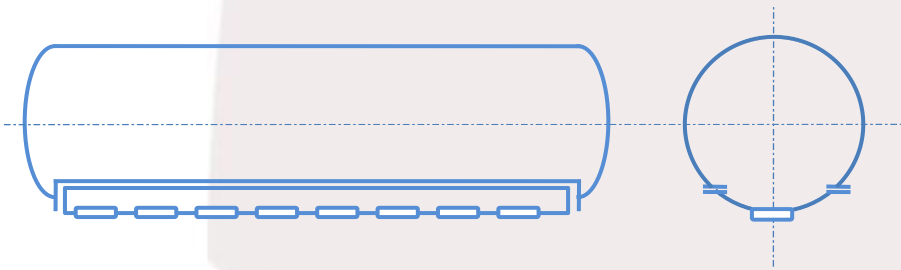
⇒ defaults located at the level of the 4 bearing plans are compensated by the flexibility of the bellows.

VACUUM VESSEL DESIGN

Different concepts



Cylindrical vacuum vessel (LHC type)



Vacuum vessel with longitudinal aperture

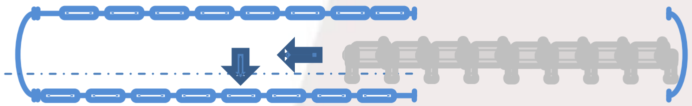
- Bottom cover
- Top cover

P.Duthil's presentation

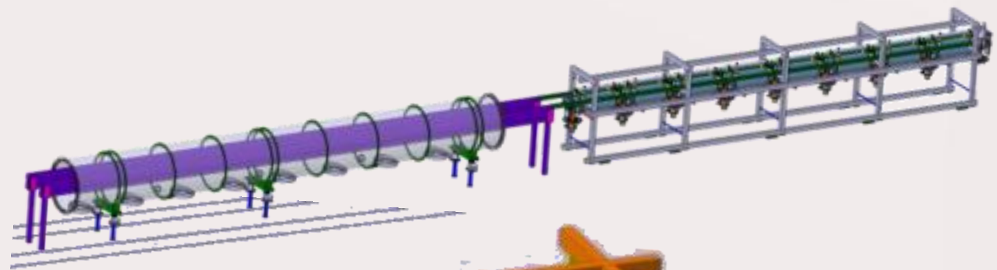
INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY

CONCEPTUAL CRYOSTATING TOOLING

➢ Horizontal cryostating Tooling Studies

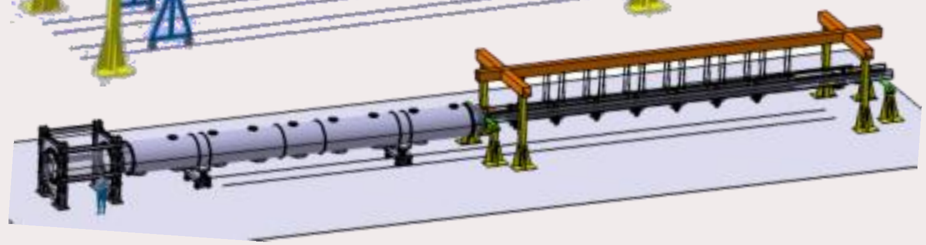


Mobile Frame tooling

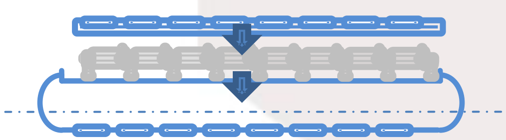


Mobile Trolley Tooling

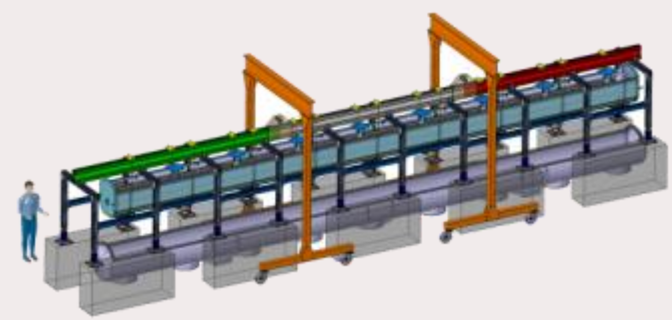
Cantilever Tooling



➢ Vertical Cryostating Tooling Study



Vertical Cryostating Tooling



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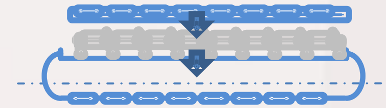
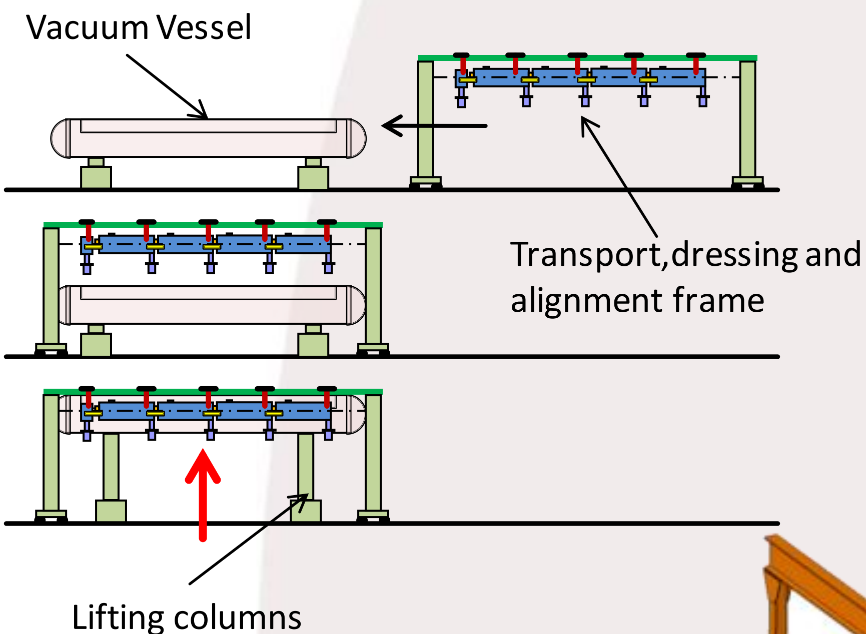
CONCEPTUAL CRYOSTATING TOOLING



Vertical cryostating tooling

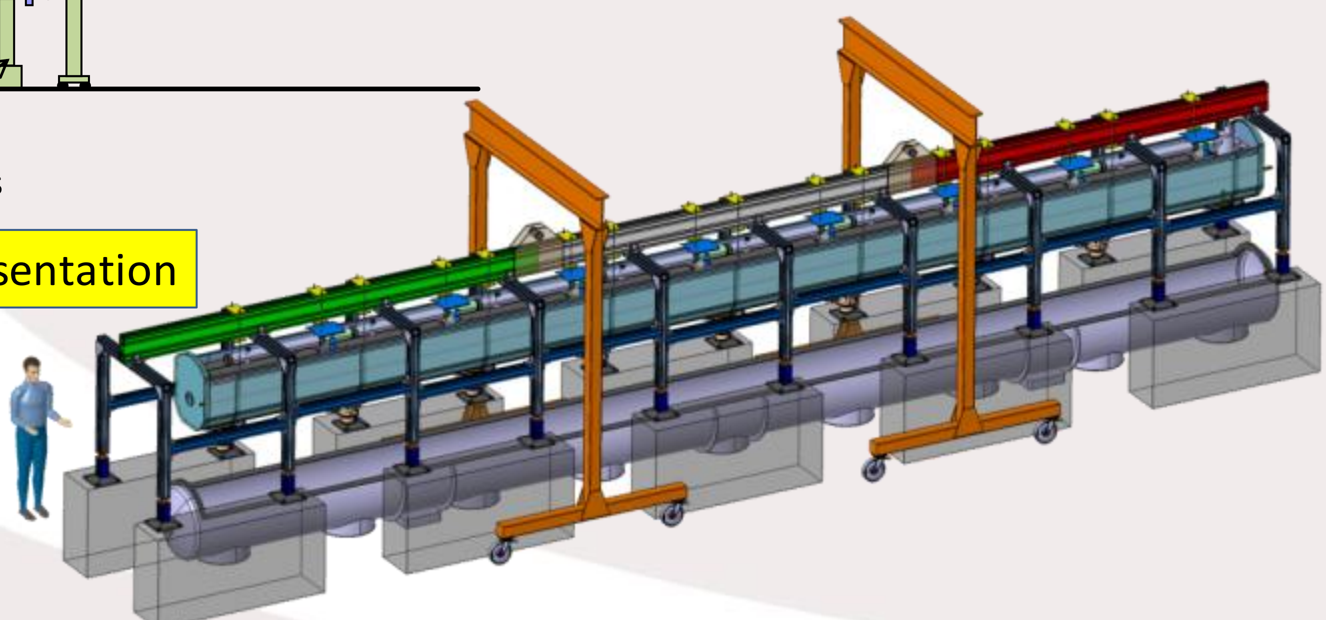


➢ Vertical Translation of the Vacuum Vessel

No Loss of alignment

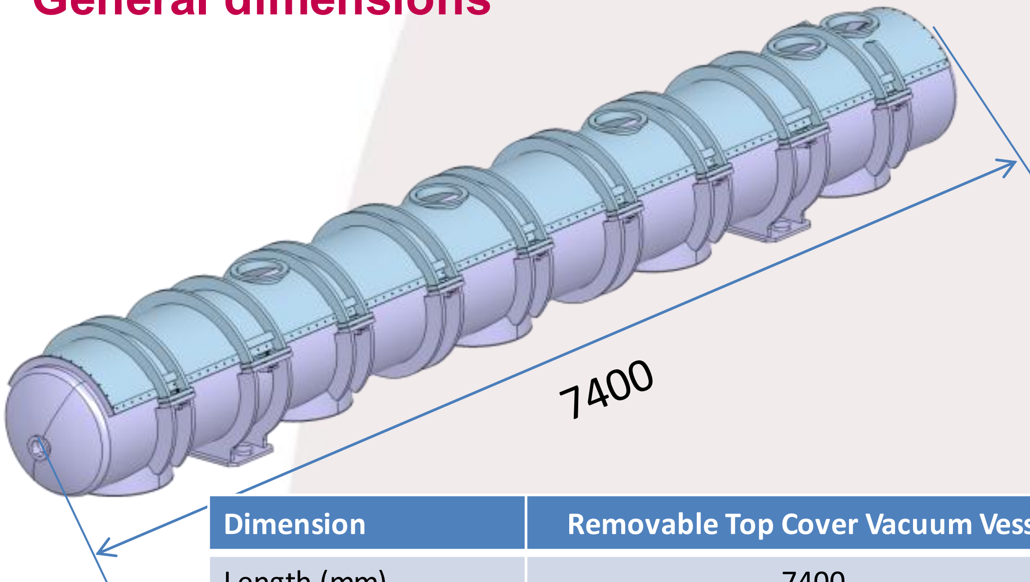
➢ Top Opened Vacuum Vessel

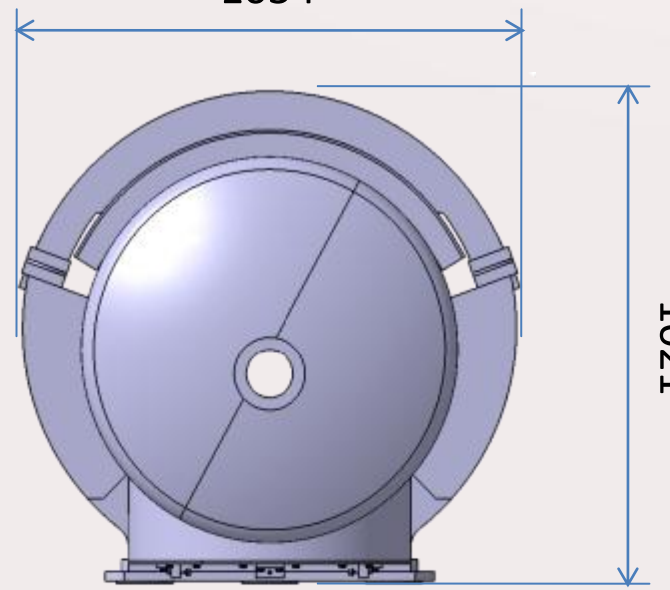
P.Duthil's presentation



REMOVABLE TOP COVER VACUUM VESSEL

General dimensions

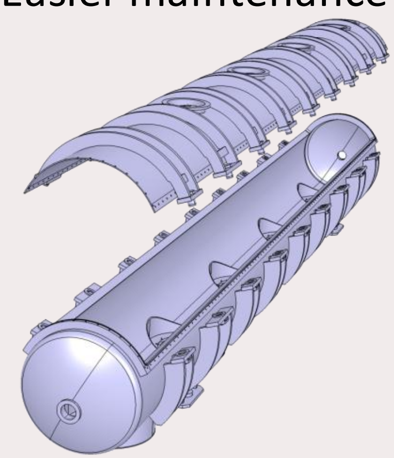




Dimension	Removable Top Cover Vacuum Vessel
Length (mm)	7400
Height (mm)	950
Thikness (mm)	10 (tube) and 6 (Top Cover)
Material	Steel and Stainless steel for flanges
Weight (ton)	2.4
Diametre (mm)	800/900
Number of openings	2 + 5 + 5 (2 beam flanges+ 5 coupler bearings ports + 5 access ports)
Number of Supports	2

Smaller diameter

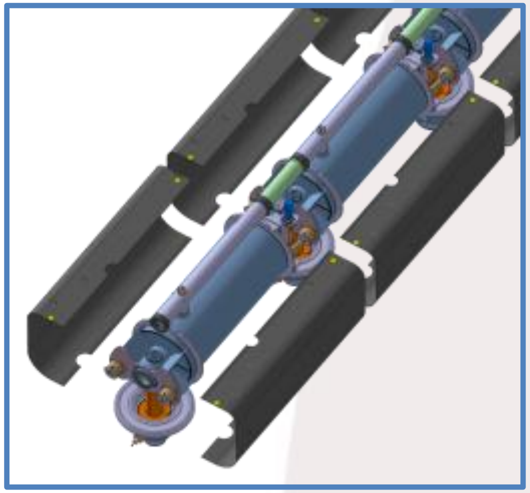
⇒ Easier maintenance access



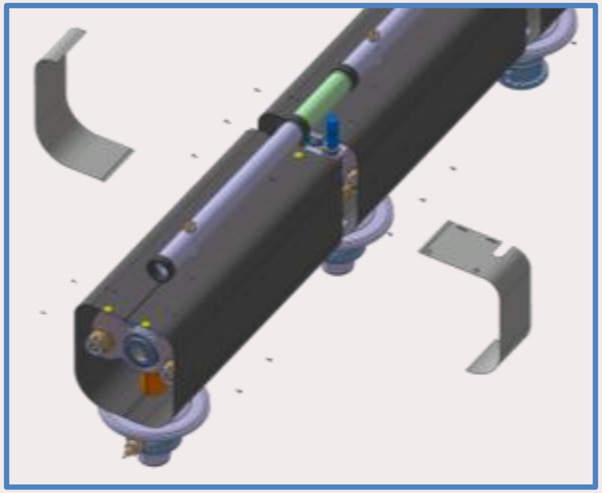
P.Duthil's presentation

Cold magnetic shield

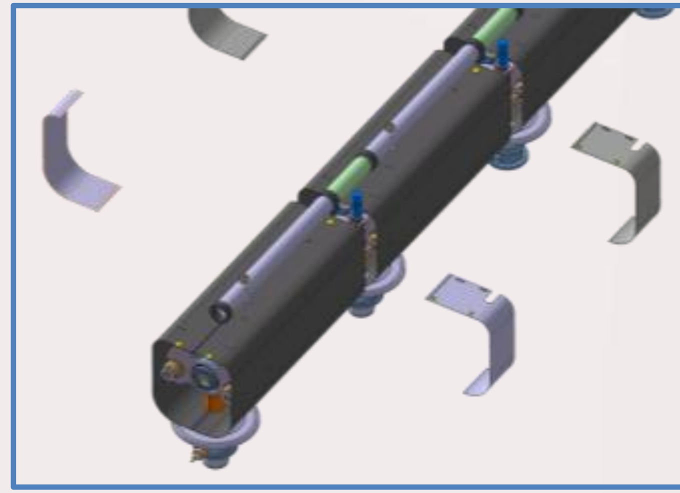
One shield for the string of cavities



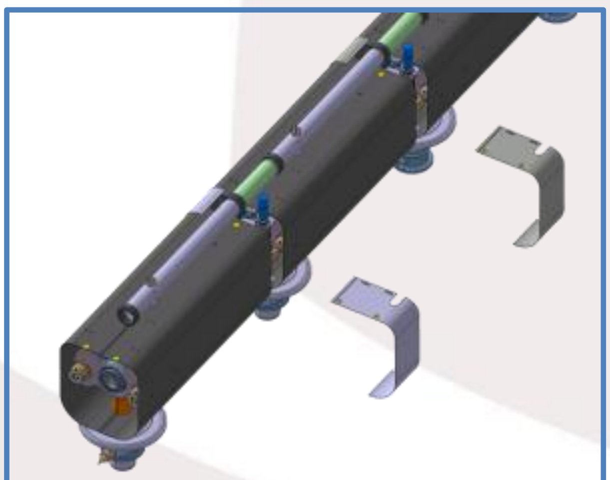
1- Positionning of the half screens

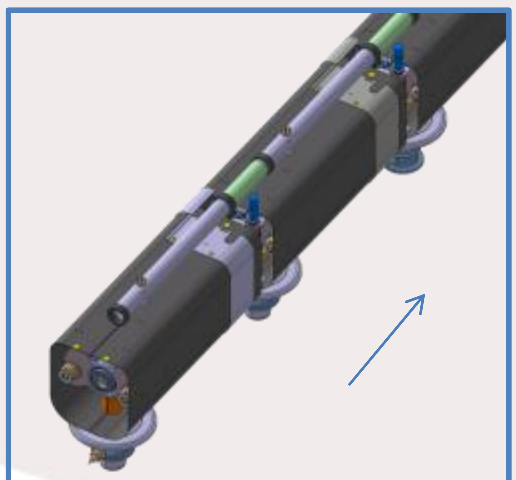


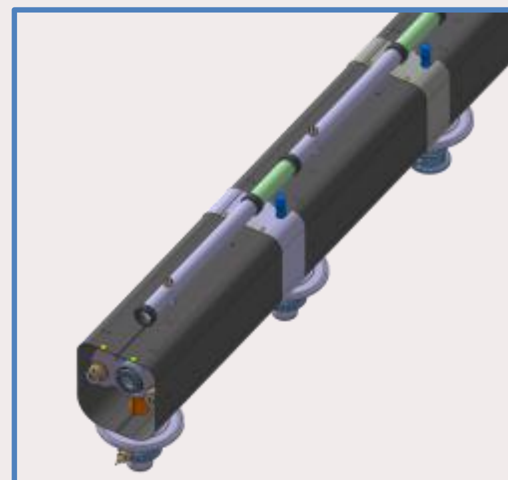
2- Fixation with screws on the tank interface



3- Positionning of the half sleeves



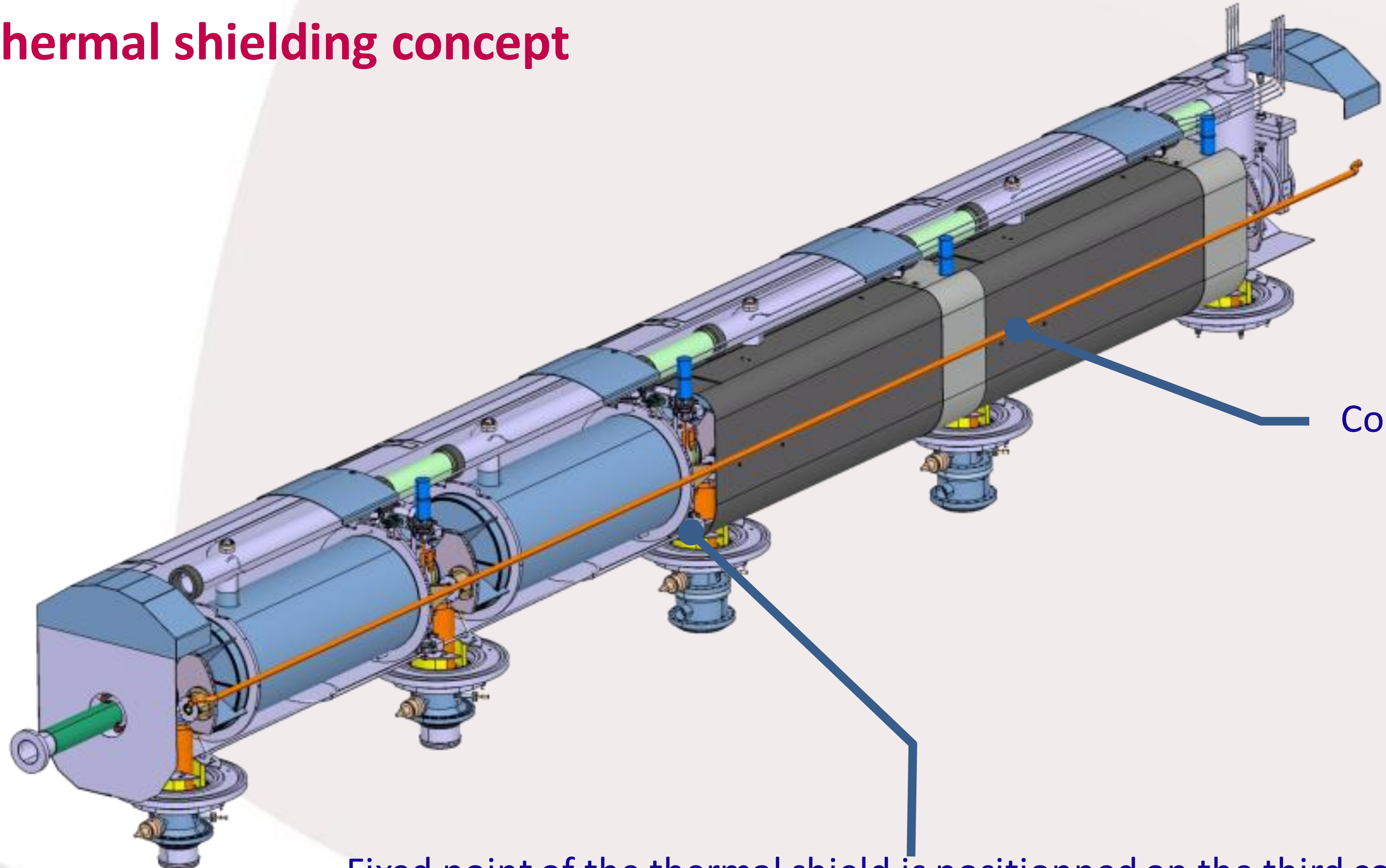




4,5 & 6- Positionning of the half sleeves

P.Duthil's presentation

Thermal shielding concept



Fixed point of the thermal shield is positionned on the third coupler
→ 25mm of max thermal displacement (at extremities)

P.Duthil's presentation

Recommendations

3.2 Vacuum vessel concept and choice of the associated assembly tooling / Possibility of extending the concepts to a full size 8-cavity cryo-module

Observation

- The design team is explicitly giving priority to the quality of positioning when preferring a removable top cover vacuum vessel.

Comment

- The removable top cover solution is an interesting choice, simplifying the integration of the helium vessel inside the vacuum vessel
- The vessel flanges are critical because of their dimensions and flexibility. Extrapolation to 13 meters is a challenge. Cost impact has not been shown.

Recommendations

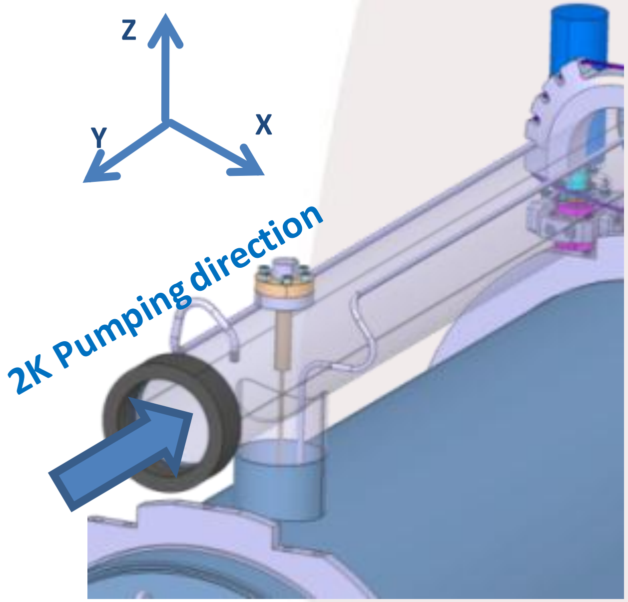
- Concerning vessel flanges: special treatment of the corners should be considered (large radii), machining should better be done after welding, X-rings joint could help.
- Study means to rigidify the cover in the axial direction.
- Proceed with transient FEM analysis.
- Start discussions with manufacturers on the Vacuum Vessel fabrication aspects.
- Prepare back-up solutions for the prototype vacuum vessel in case of tightness problems.
- Study the feasibility of a fully welded top-cover option as an alternative for series production.

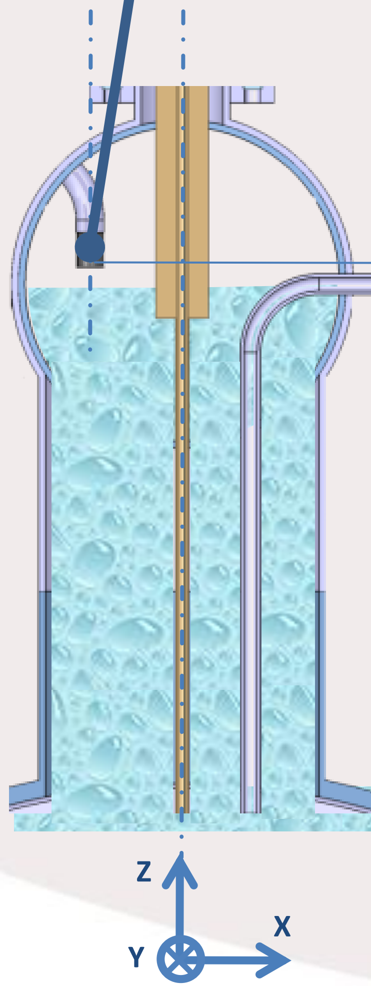
Filling line

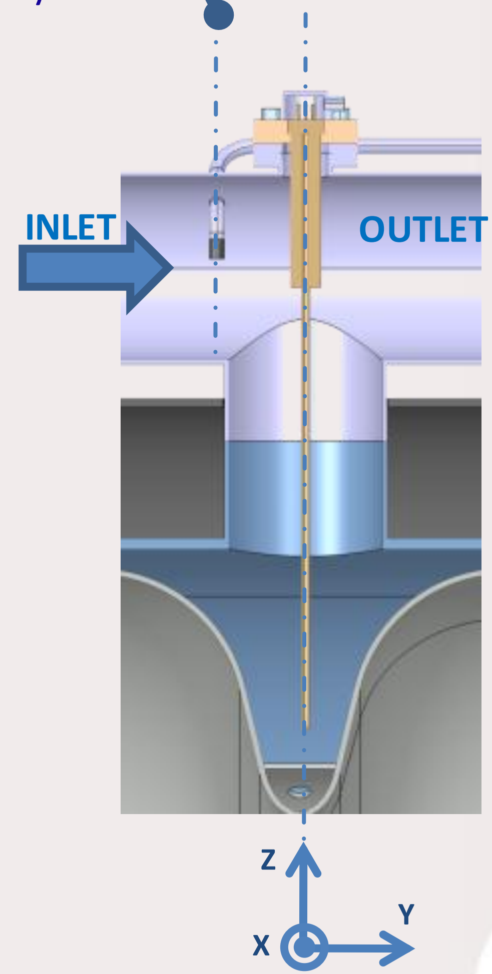
End of the filling line : porous metallic medium (TBC)

Filling line shifted from the cavity bath

End of the filling line above the max. level of LHe (0% slope)







Phase separators

Coupler Phase separator

Volume: 1L; T°=4,5K.

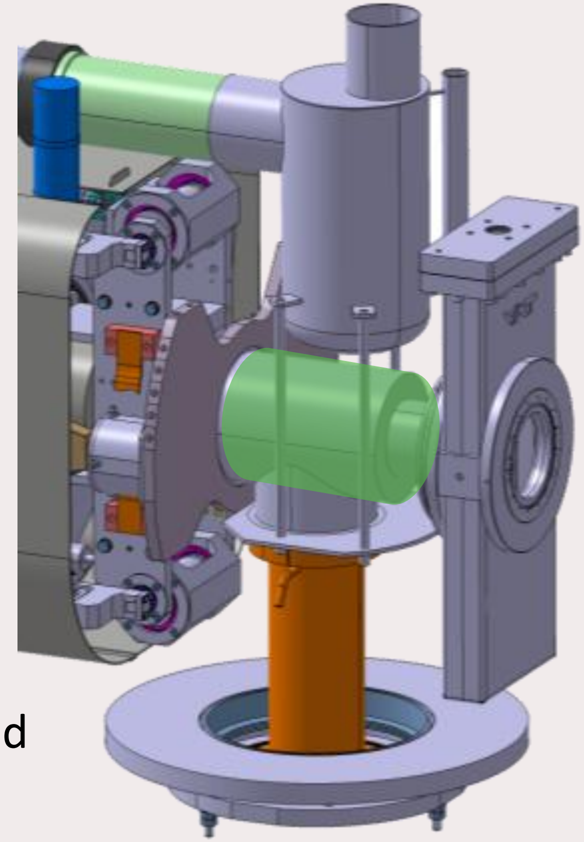
Positioned around the beam pipe

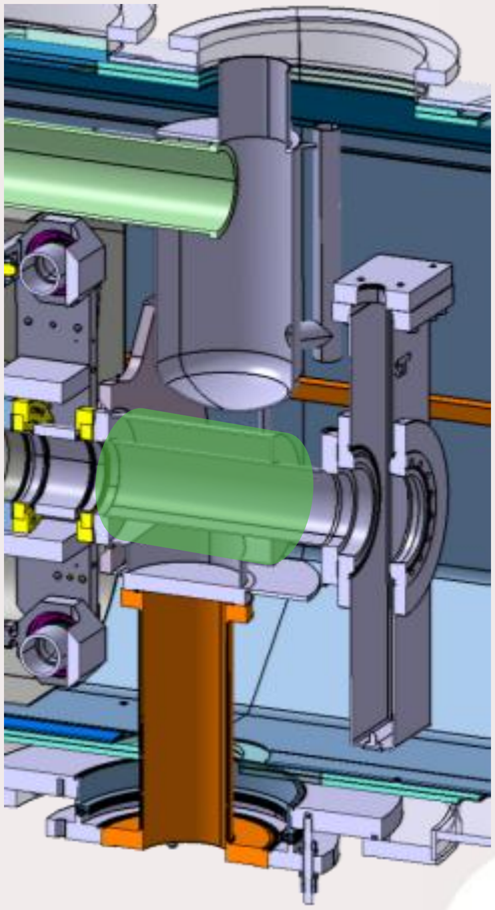
On the complementary support bi-tube.

T°=4,5K > 2K will not affect the alignment (ΔL/L<<1 for the double-walled tube)

NB: The double-walled tube will partially provide heat loss to generate helium vapor for the couplers cooling (0.1W).

(10W are required; heaters would be required for regulation - TBC)

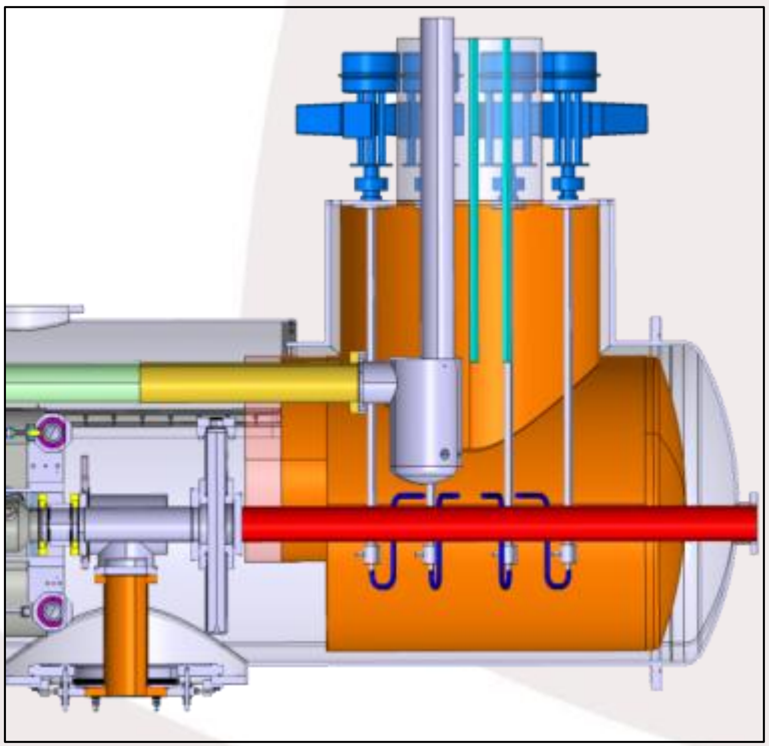


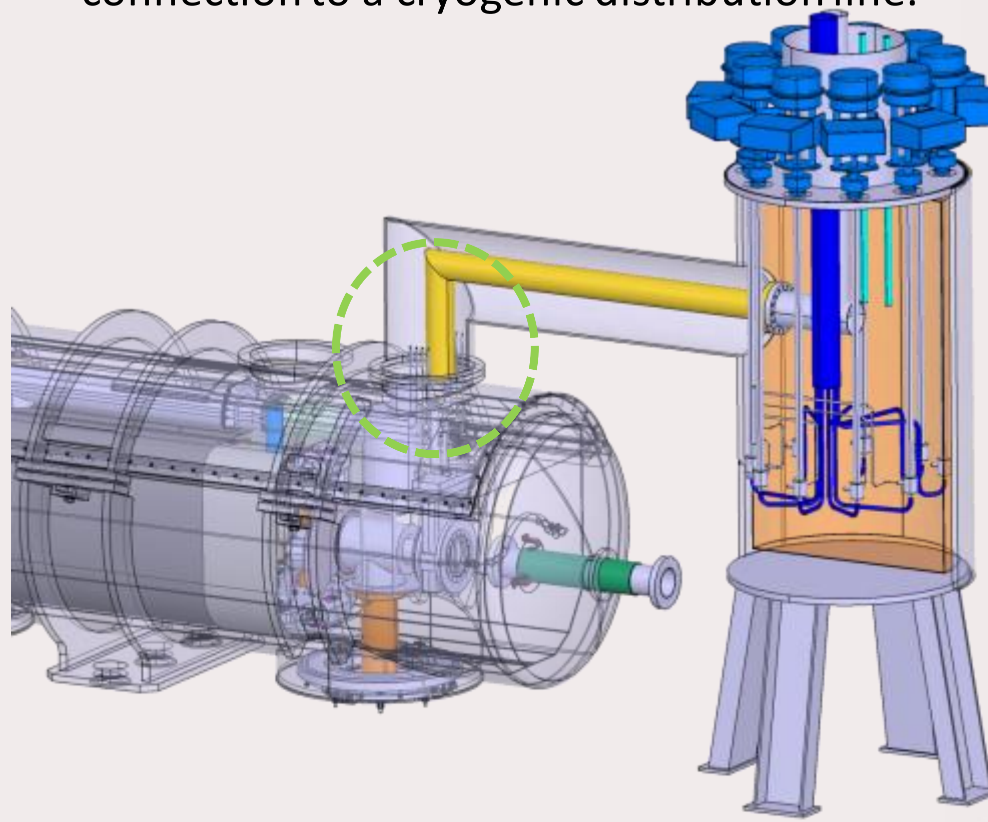


Technical Service Module

Technical Service Module
Including the cryogenic valves

Proposed solution:
cryogenic valves are placed in a separated cold box
Connection via a jumper to simulate the connection to a cryogenic distribution line.





Conclusions from the review

- The review committee did not identify show stoppers in the concepts presented, nor did it recommend major design changes

- The committee recognized the value of the original and innovative proposed concepts (in particular supporting system and cryomodule vessel with top opening);

- and recommended to pursue the work with additional design effort (mechanical, both static and dynamic analysis, thermo-mechanics during transients…) and underlined the importance of the mock-ups for testing

- The committee suggested a number of changes:
  - Instrumentation (T gauges, heaters) moved to insulation vacuum
  - Vapour generation for coupler tube cooling via active heater (not by static heat load)
  - Introduce the possibility of welding vessel top cover in case of need (back-up for leak tightness)
  - …

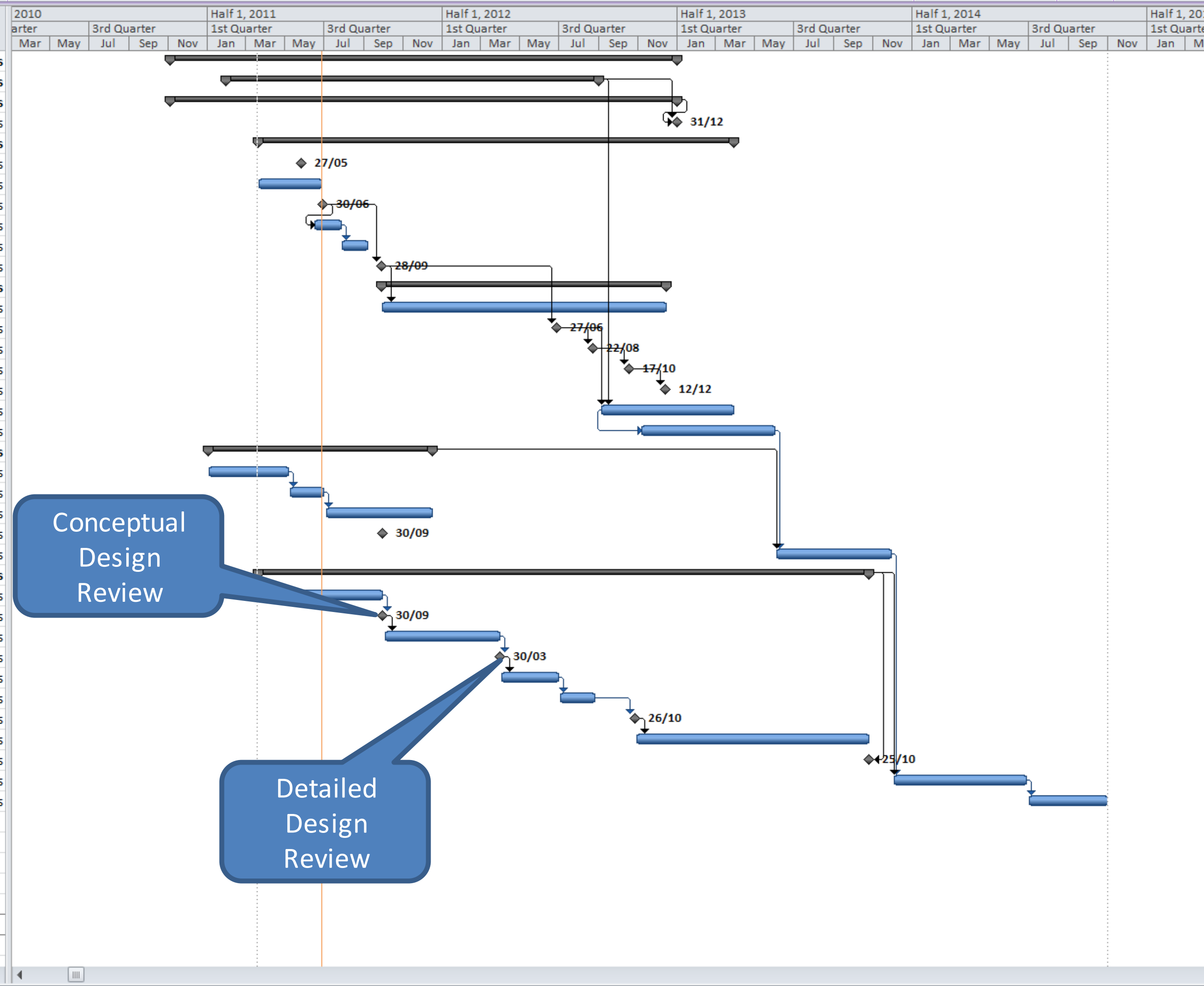
- Additional design effort is recommended (but is part of the detailed design phase!):
  - Cryogenic risk analysis
  - Define cool down and warm up requirements and constraints, and elaborate a procedure for cooling down the cold magnetic shield
  - Check compatibility with SM18 cryogenic infrastructure.
  - Develop a thermo-hydraulic model to analyze the robustness of the 2 K He level controls (RF transients).
  - Finalize the list of additional instrumentation for prototype validation and include it on the P&I diagram.
  - Study alternative for instrumentation feedthroughs without cold ceramic insulators.
  - …

- Improve project management & communication: set-up a complete and up-to-date data-base listing the design parameters.

  → a project oriented working group with regular meetings (typically 1 per month) is probably the most appropriate answer

Schedule

ID	Task Name	Duration
1	**SM18**	**562 days**
2	**Cryogenic**	**415 days**
12	**RF**	**562 days**
138	SM18 ready	0 days
139	**Cavities production**	**530 days**
140	Niobium delivery	0 days
141	Cavities design (incl. detailed design)	71 days
142	Cavities design validation	0 days
143	Tech. spec.	6 wks
144	Call for tender	6 wks
145	Signature of contract	0 days
146	**Cavities production**	**317 days**
147	Production	63.4 wks
148	Cavity 1	0 days
149	Cavity 2	0 days
150	Cavity 3	0 days
151	Cavity 4	0 days
152	Cavities test in vertical cryostat (SM18)	30 wks
153	Insertion of cavities in helium enclosure	30 wks
154	**Couplers**	**250 days**
155	Brazing, EB welding, assembly (coupler,TD, test cavity)	18 wks
156	Clean room assembly (DESY)	8 wks
157	RF power tests (CEA), couplers ready for SPL cavities	24 wks
158	Prototypes validation	0 mons
159	Cavities - coupler assembly	26 wks
160	**Cryostat**	**680 days**
161	Conceptual design	28 wks
162	Conceptual design review	0 days
163	Detailed design	26 wks
164	Detailed design review	0 days
165	Preparation of tender documents	13 wks
166	Tendering	8 wks
167	Signature of contract	0 days
168	cryostat and tooling production	52 wks
169	Tooling ready for crysotating	0 days
170	Cryostating and RT qualification testing	30 wks
171	RF tests	18 wks



« nobody will ever blame you for not being on schedule or for overspending. But you will be judged (and possibly blamed) on the results of your work »

(CERN anonymous)

Thank you for your patience