DESIGN OF A SHORT CRYOMODULE FOR THE SUPERCONDUCTING PROTON LINAC OF CERN

IPNOrsay – CNRS	CERN	CEA
Sébastien ROUSSELOT	Vittorio PARMA	Stéphane CHEL
Patxi DUTHIL	Arnaud VANDE CRAEN	Guillaume DEVANZ
Patricia DUCHESNE	Paulo AZEVEDO	
Philippe DAMBRE	Lloyd R. WILLIAMS	
Denis REYNET	Ofelia CAPATINA	

Unité mixte de recherche
CNRS-IN2P3
Université Paris-Sud 11

91406 Orsay cedex
Tél. : +33 1 69 15 73 40
Fax : +33 1 69 15 64 70
http://ipnweb.in2p3.fr

TTC meeting
December 6th 2011

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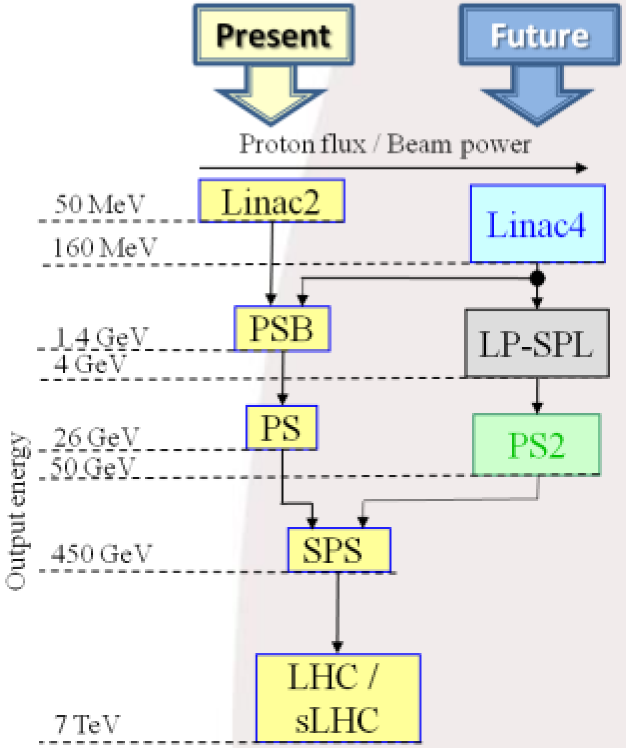
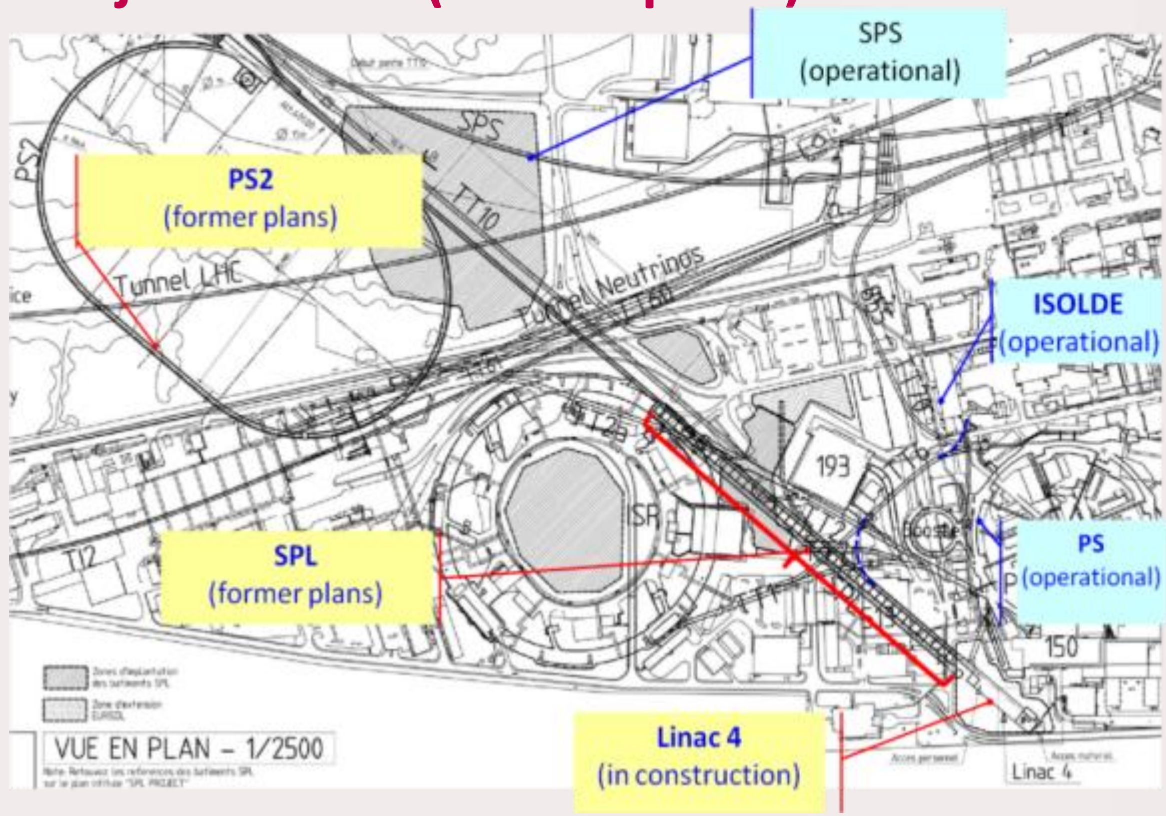
CERN's expected new LHC injection line (former plans)





LP-SPL: **Low Power**-Superconducting Proton Linac (4 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
sLHC: "Super-luminosity" LHC (up to 10^{35} $cm^{-2}s^{-1}$)

CERN's new scientific strategy: R&D for a High Power SPL (HP-SPL)

General orientation:

Focus on R&D for key technologies for a high-intensity proton source (HP SPL) for a neutrino facility

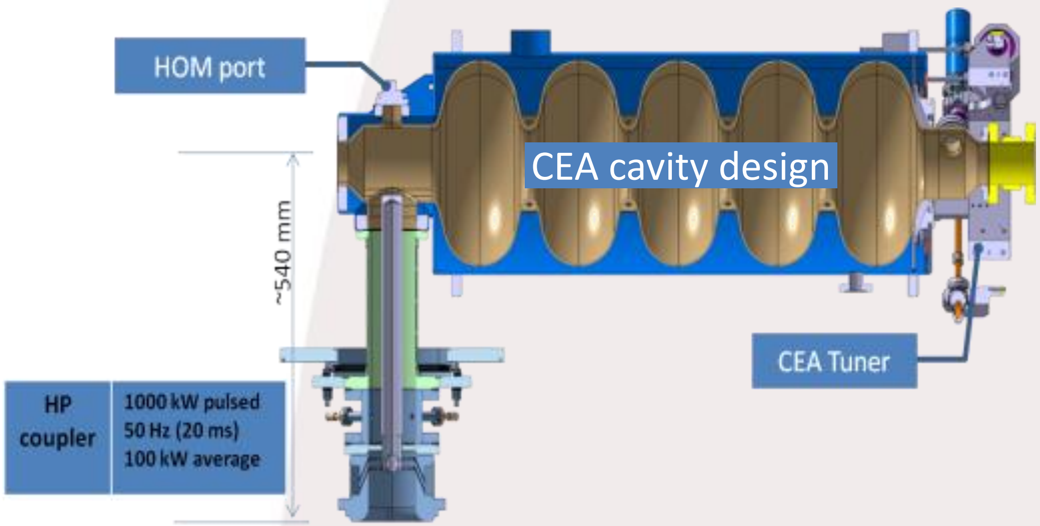
In particular, for the cryo-module development:

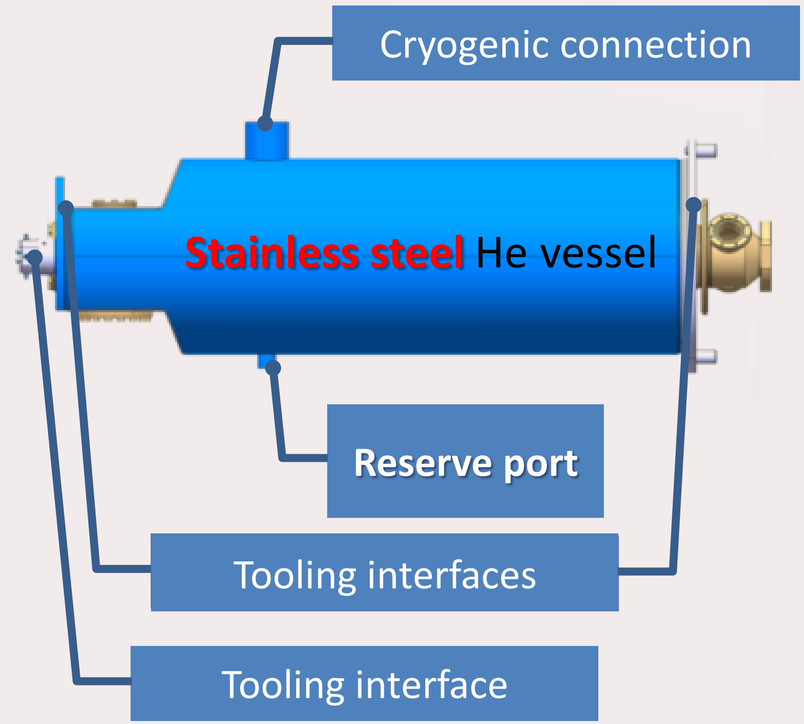
- Development, construction and test of β=1 elliptical cavities, 704 MHz
- Development, construction and test of RF couplers
- Test of a string of 4 β=1 cavities in a machine-type configuration

→ This program calls for the design and construction of a **short cryo-module** for testing purposes

β=1 CRYO-MODULE IN A POSSIBLE SPL LAYOUT

β=1 cavity layout





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

The He vessel includes specific interfaces for the cryomodule integration:

- Inter-cavity supports
- 1 cryogenic feed
- External magnetic shielding via cryoperm™ (not shown)
- Tooling (in/outside the clean room)

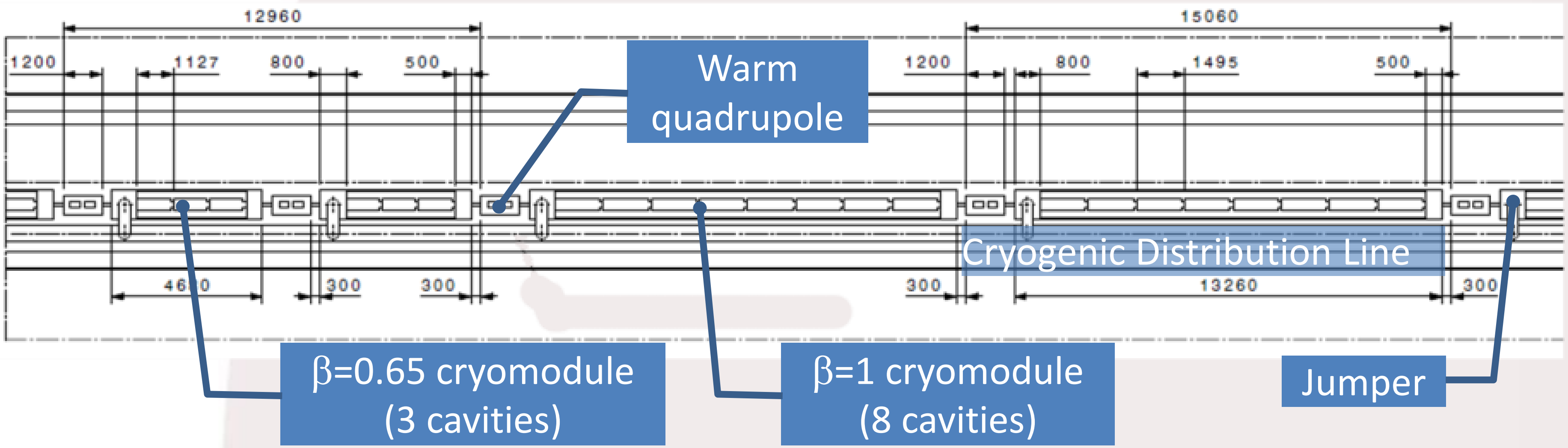
2K Heat Loads (per β=1 cavity)

Operating condition	**Value**	
Beam current/pulse lenght	**40 mA/0.4 ms beam pulse**	**20 mA/0.8 ms beam pulse**
cryo duty cycle	4.11%	8.22%
quality factor	10×10^9	5×10^9
accelerating field	25 MV/m	25 MV/m

Source of Heat Load	**Heat Load @ 2K (per cavity)**	
Beam current/pulse lenght	**40 mA/0.4 ms beam pulse**	**20 mA/0.8 ms beam pulse**
dynamic heat load per cavity	5.1 W	20.4 W
static losses	<1 W (tbc)	~ 1 W (tbc)
power coupler loss at 2 K	<0.2 W	<0.2 W
HOM loss in cavity at 2 K	<1	<3 W
HOM coupler loss at 2 K (per coupl.)	<0.2 W	<0.2 W
beam loss	1 W	1 W
Total @ 2 K	**8.5 W**	**25.8 W**

« Segmented » architecture with warm quads and a cryo distribution line

- 60 β=0.65 cavities in 20 cryomodules
- 184 β=1 cavities in 23 cryomodules
- SRF linac ~ 500 m long



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.

⇒Assessment of static load is of minor importance at this state (end of conceptual design)

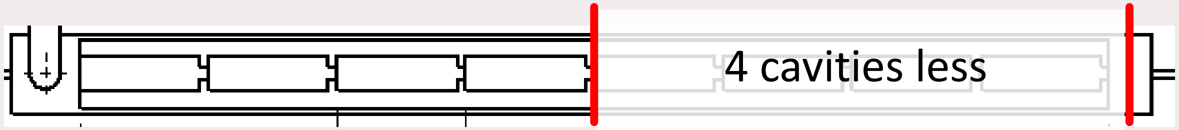
The short cryomodule design strategy

- Test-bench for RF testing on a multi-cavity assembly driven by a single or multiple RF source(s)
- Enable RF testing of cavities in horizontal position, housed in machine-type configuration
- Validate the design of critical components like RF couplers, tuners, HOM couplers in their real operating environment → short cryomodule design

Goal

Design and construct a ½-lenght cryomodule

- for the test of 4 β=1 cavities (instead of 8 in a machine type cryomodule)



- in conditions as close as possible to a machine-type cryomodule
  - → Mechanical design
  - → Cryogenics (Heat loads, T and P profiles, segmented machine layout)
  - → Designed for 0%-2% test (for 1.7% expected tunnel slope)

Cryostat and tooling overview

Cryostat specific main objectives

Learning of the critical assembly phases:

- From the assembly of cavities in the clean room to the a cryomodule test
- Alignment/assembly procedure

Proof of concept of "2-in-1" RF coupler/cavity supporting:

- Fully integrated RF coupler: assembly constraints
- Active cooling effect on cavity alignment

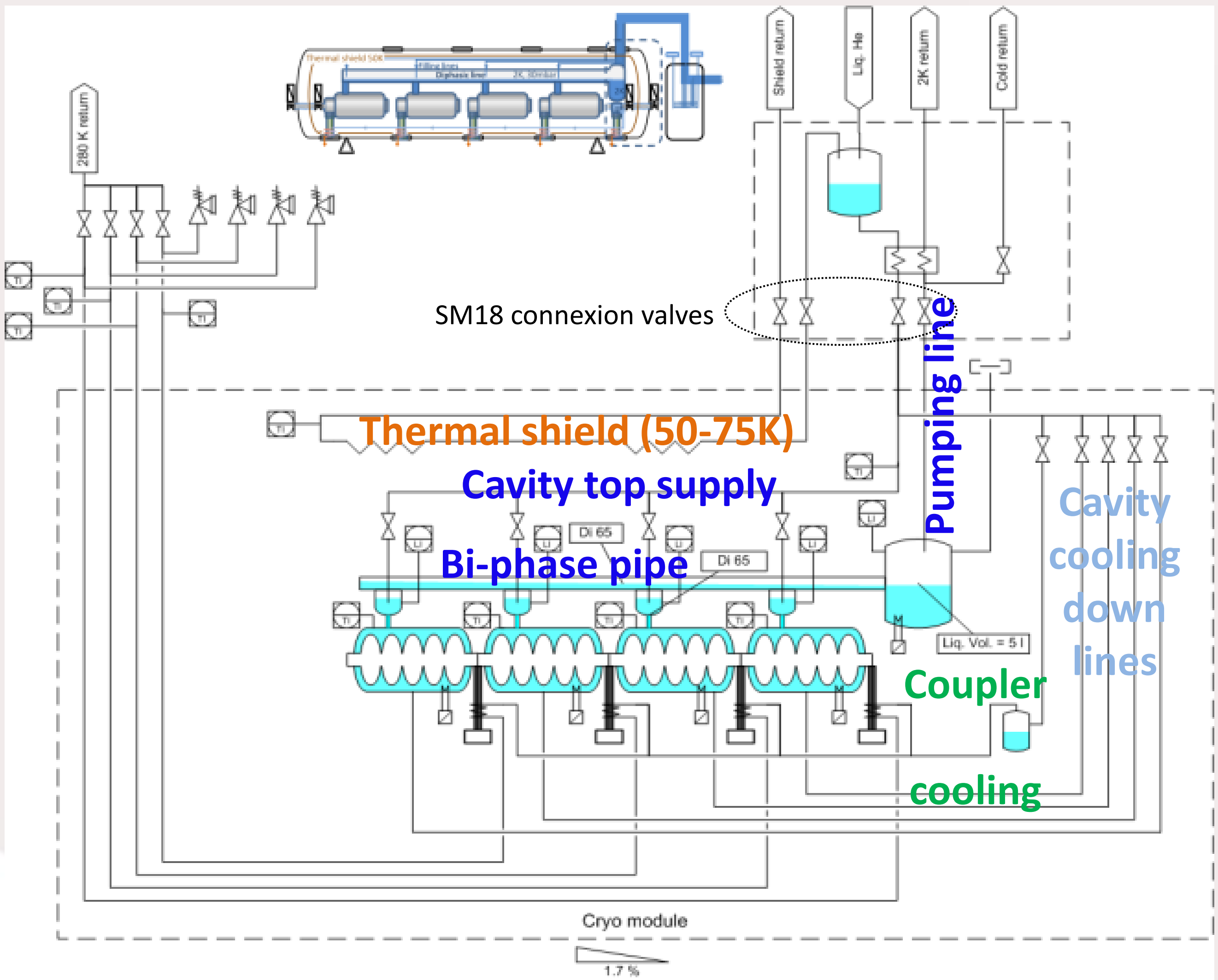
Operation issues:

- Cool-down/warm-up transients, thermo-mechanics, heat loads
- Alignment/position stability of cavities
- Cryogenic operations (He filling, level controls, RF coupler support tube cooling)

Technical solutions focus on the ½-lentgh cryomodule
But technical solutions are developed for the full length cryomodule
(Specifically the tooling for the cryostating)

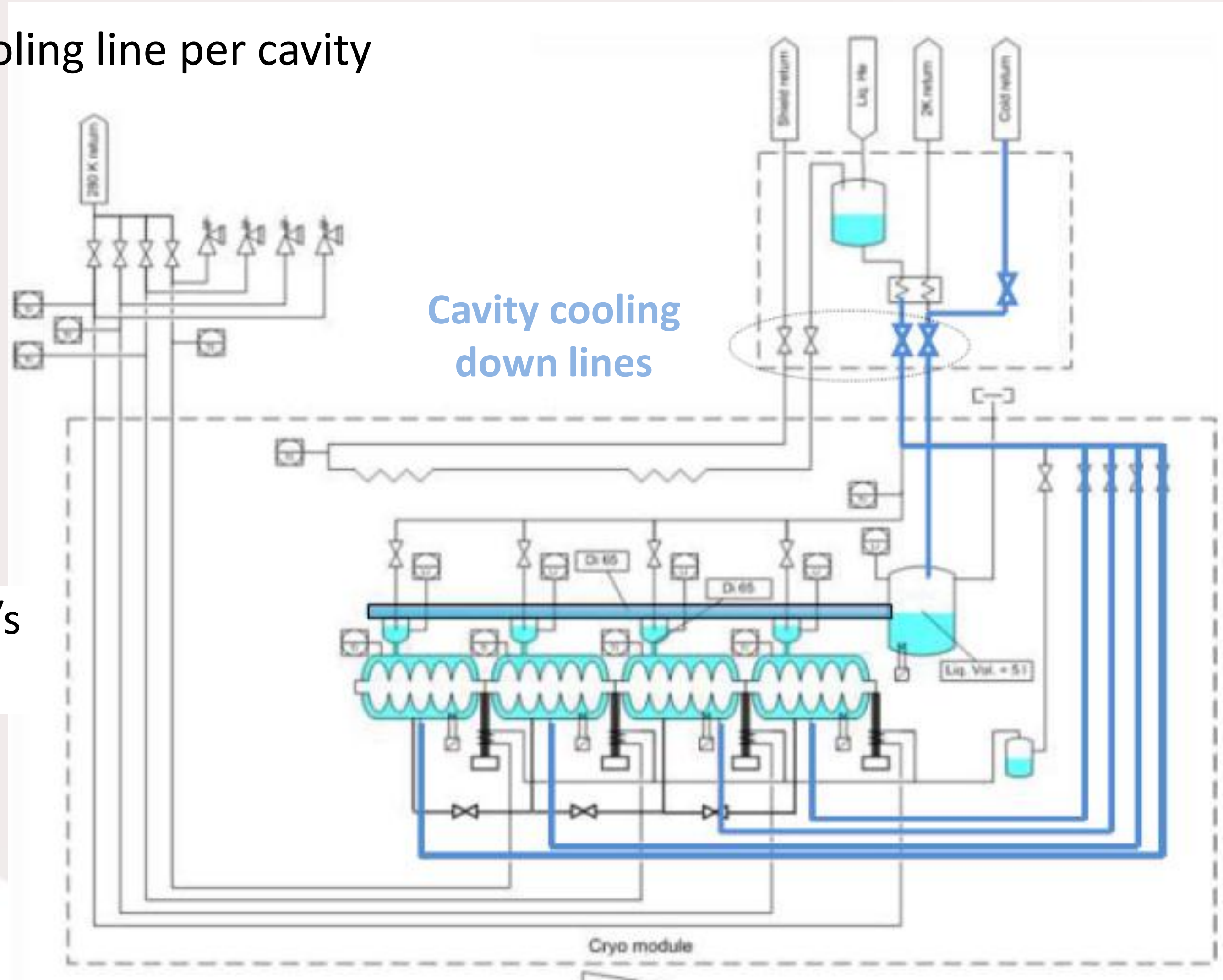
Short cryomodule cryogenic scheme

Coupler cooling



Cooling lines

Requirements: 1 cooling line per cavity



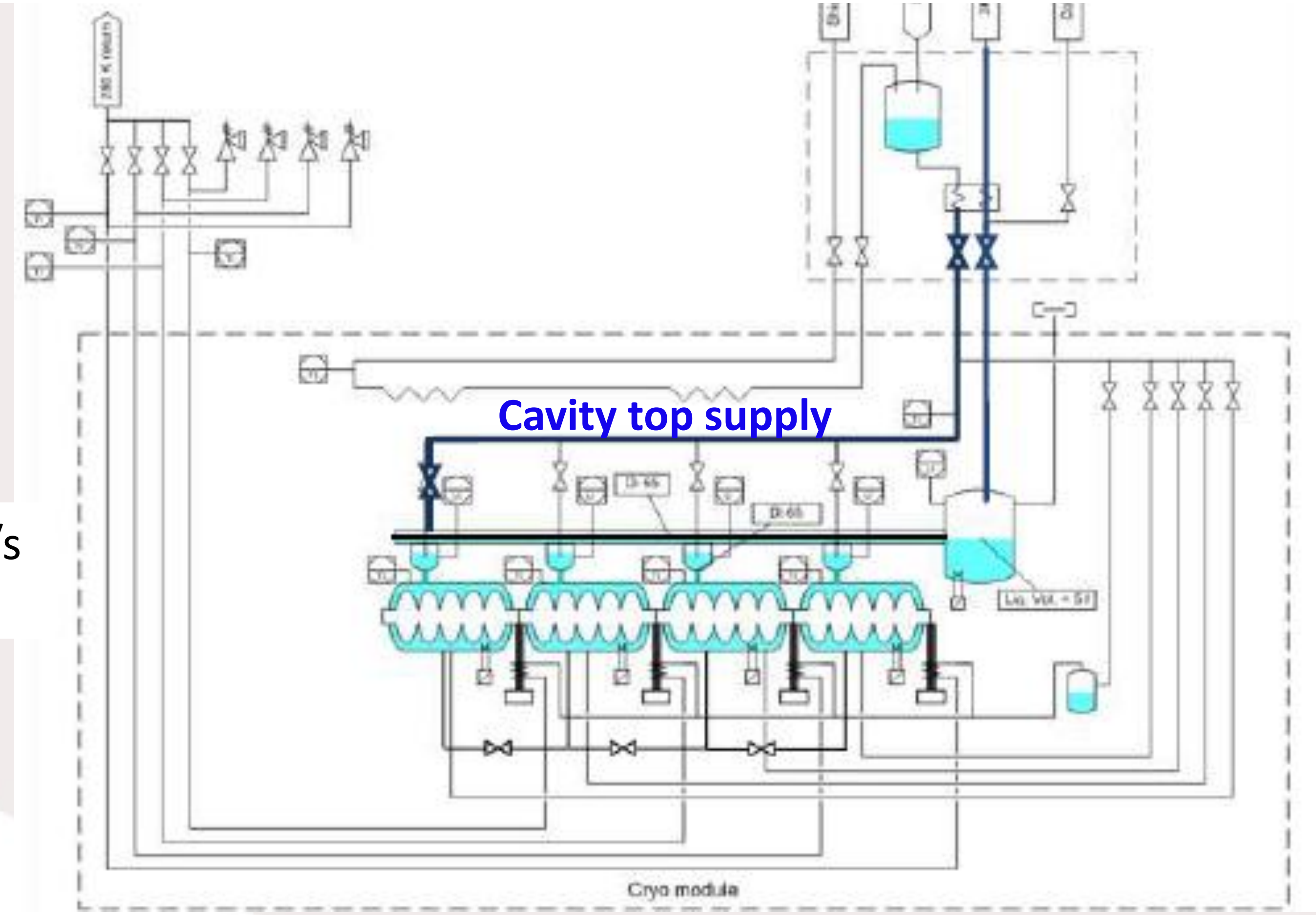
Mass flow rate ~2.5g/s per cavity

Expectation (machine): 1 cooling line for the hole string of cavities ?

Filling lines

Requirements: 1 JT valve may allow for the filling of the first cavity then for the filling of the others via a roman fountain (successive helium fall filling via the diphasic pipe)

Mass flow rate ~10g/s



Slope : 1.7% (ajustable from 0 to 2% for the tests)

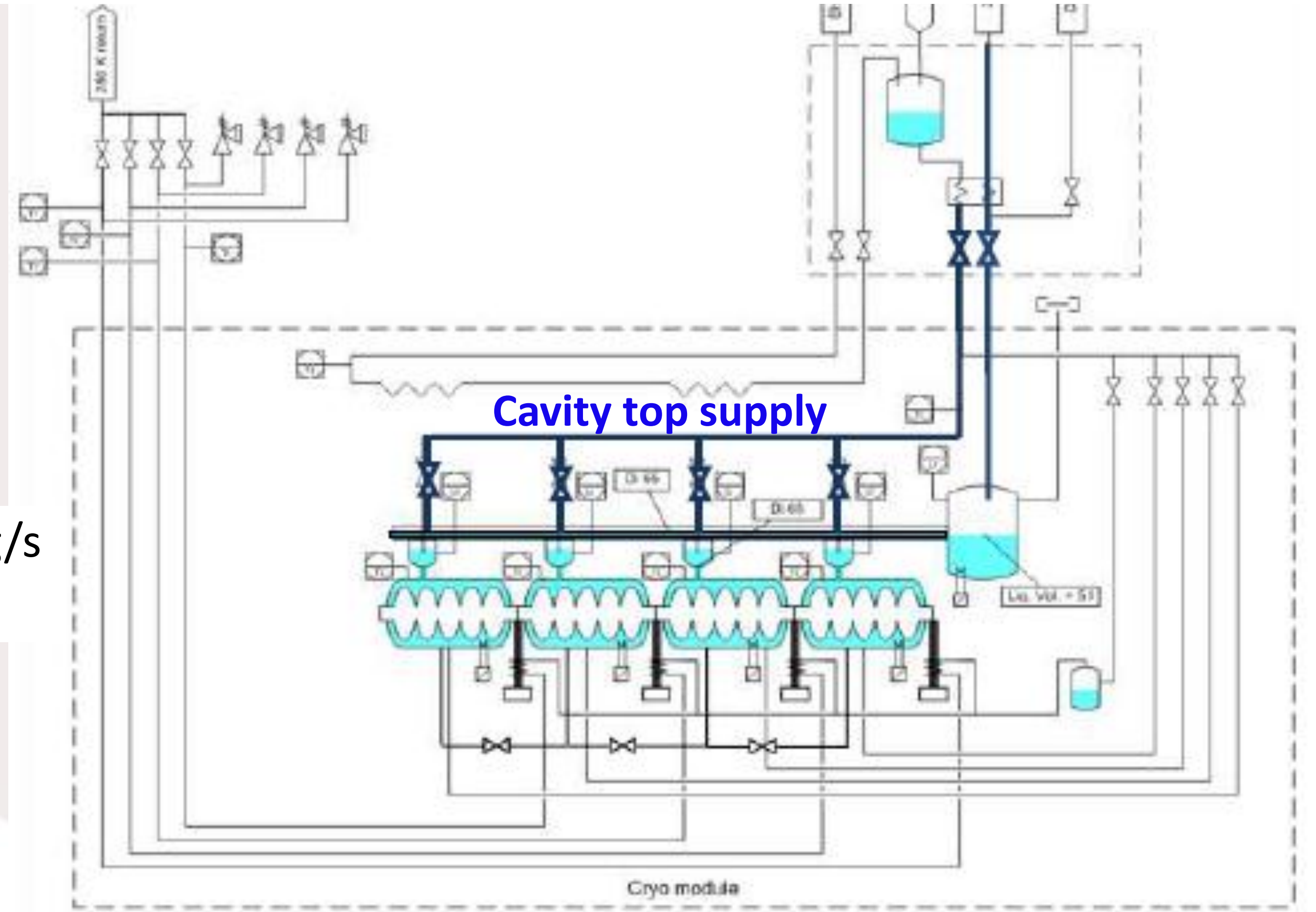
Filling lines

Requirements: If slope = 0% or in case of a problem with the roman fountain (superfluid)
⇒1 filling line per cavity (each being equipped with a JT valve)

(Prototype only:

priority = test bench for a string of 4 cavities)

Mass flow rates ~2.5g/s per cavity



Slope : (0% for the tests)

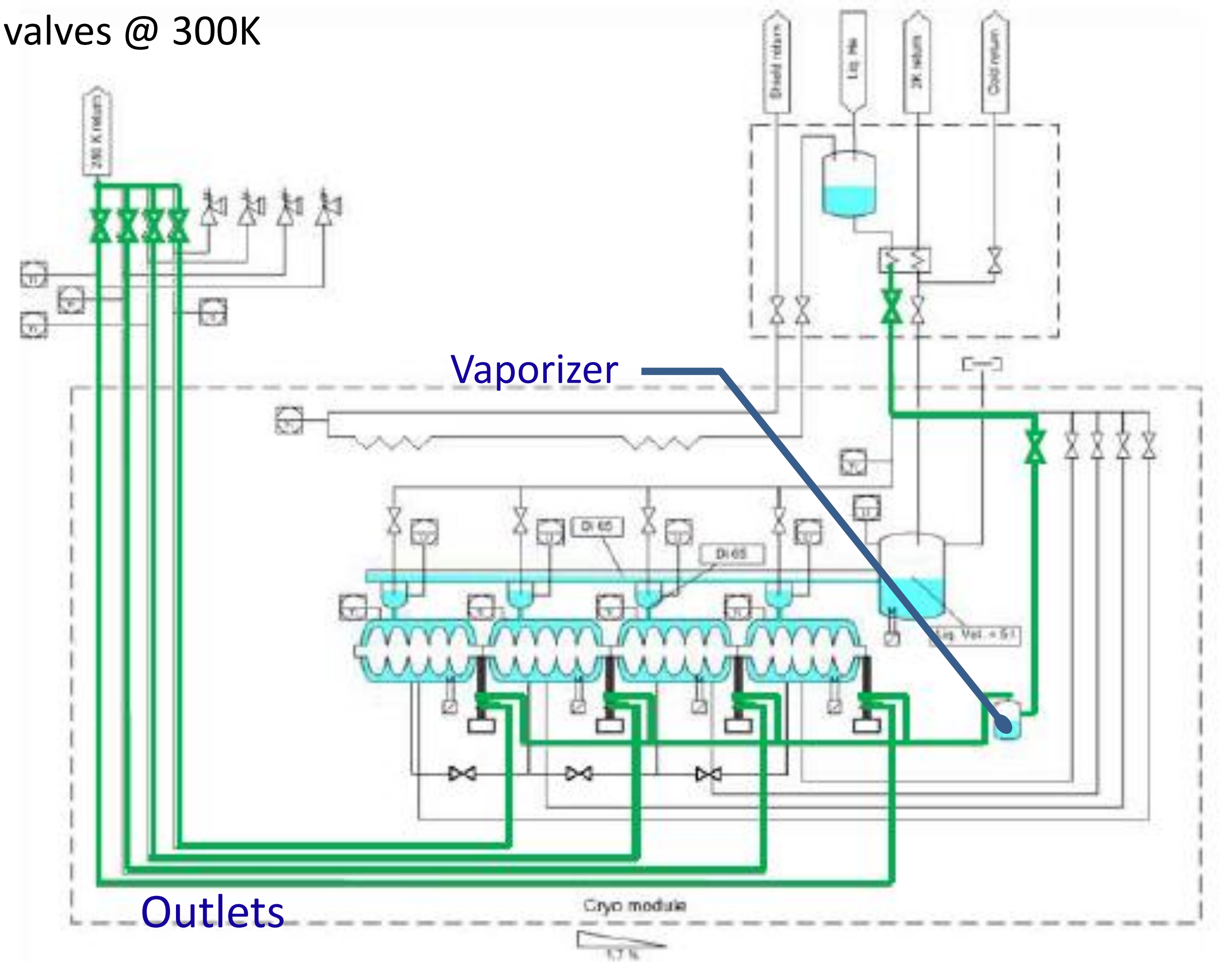
Coupler cooling line

Requirements: One single line for the cooling of the couplers.

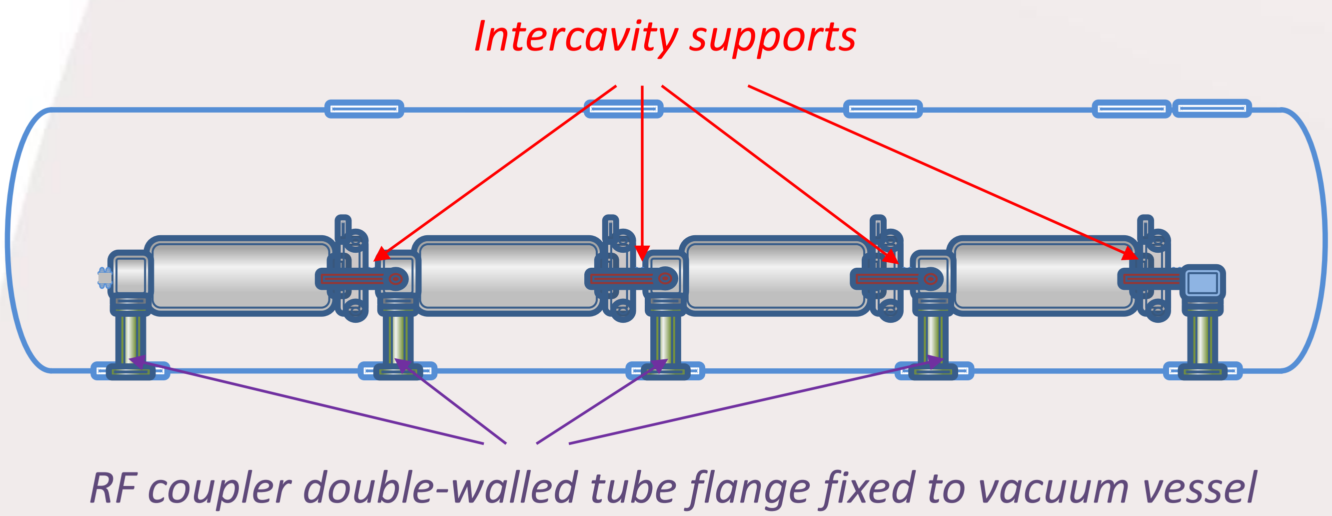
4 outlets with 4 control valves @ 300K

1 vaporizer (boiler)

Mass flow rate ~0.8g/s



The concept



The RF coupler (its double-walled tube) provides:

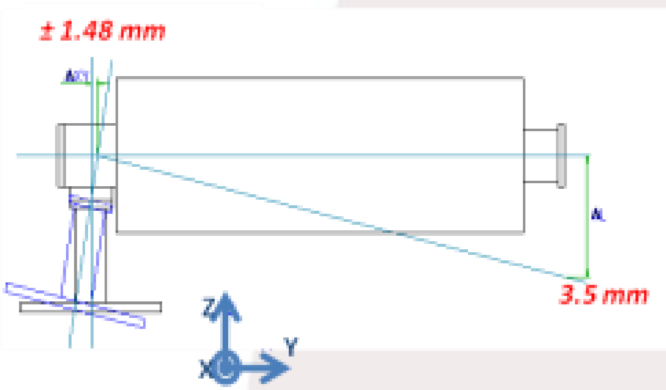
- fixed point for each cavity (thermal contractions)
- mechanical supporting of each cavity on the vacuum vessel

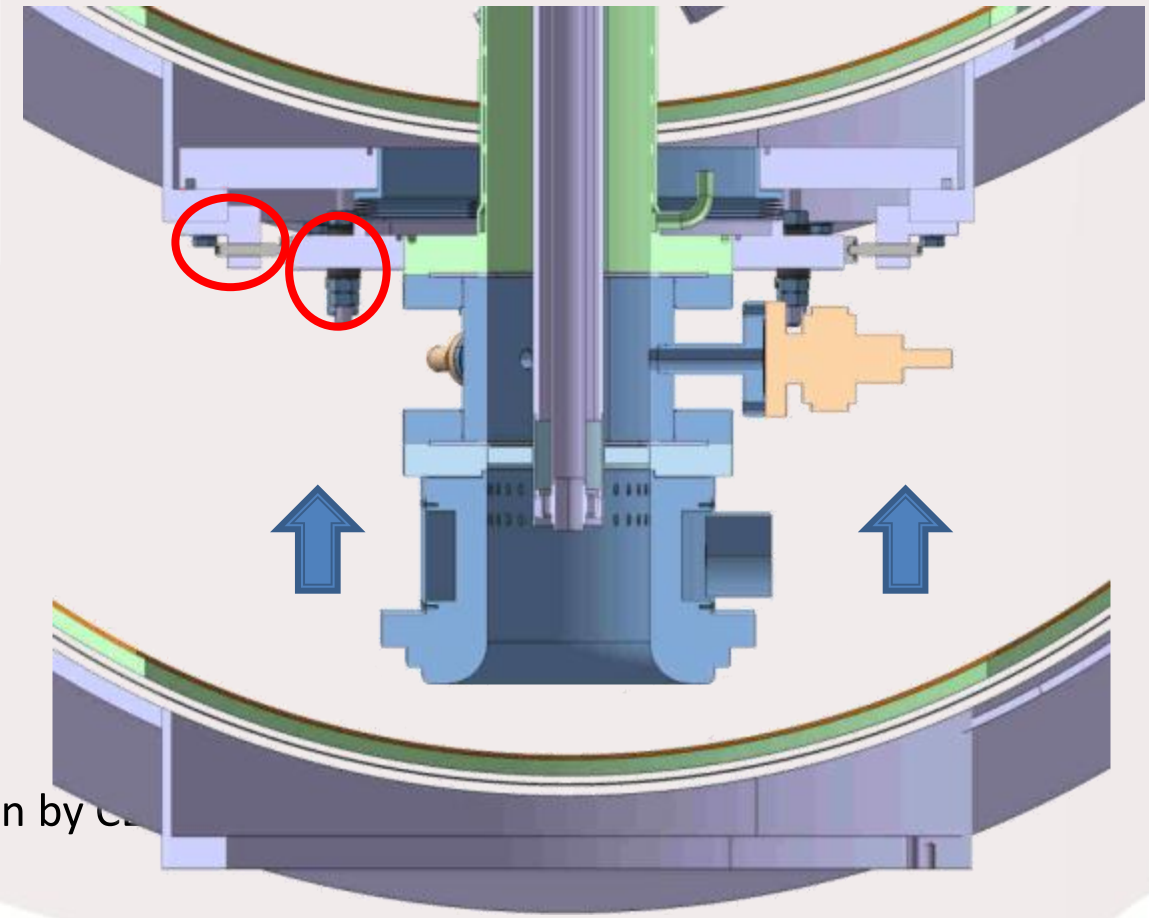
The intercavity supports provide:

- a 2nd vertical support to each cavity (limits vertical self-weight sag)
- relative sliding between adjacent cavities along the beam axis
- enhancement of the transverse stiffness to the string of cavity (increases the eigenfrequencies of first modes)

Coupler / Vacuum vessel interface

Interface → fixed point, compensation of the geometrical defaults {coupler + cavity}





- Status:

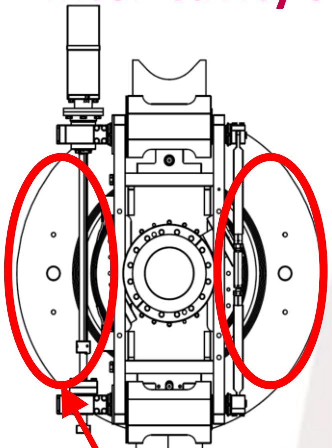
Detail designed done

⇒A mock-up is under construction by C

⇒ To be tested (Q1/2012)

CAVITY SUPPORTING SYSTEM

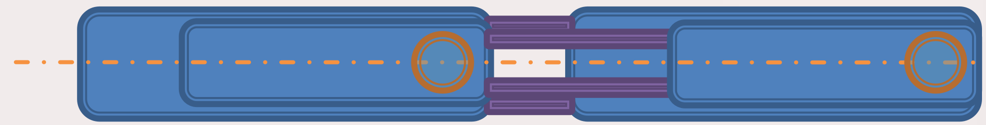
Inter-cavity supports



Free space for supports

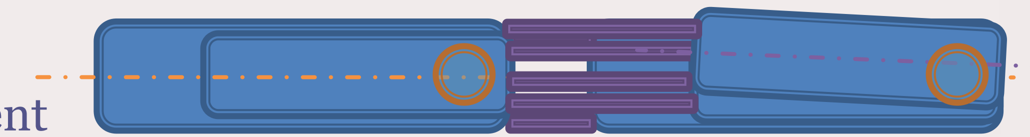
2 supports

- Thermal contraction:
  - Longitudinal
    - 4.5 mm



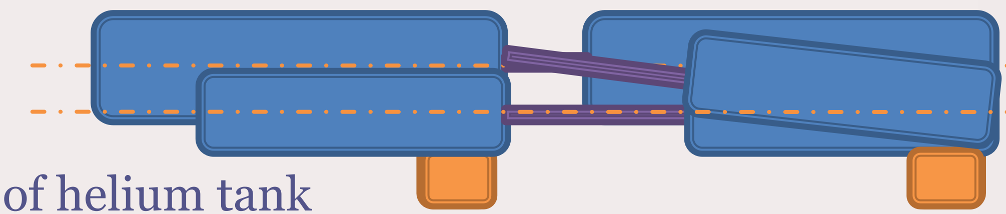
  - Transversal
    - 1.15 mm
    - Max displacement of beam axis = 0.6 mm (transient)

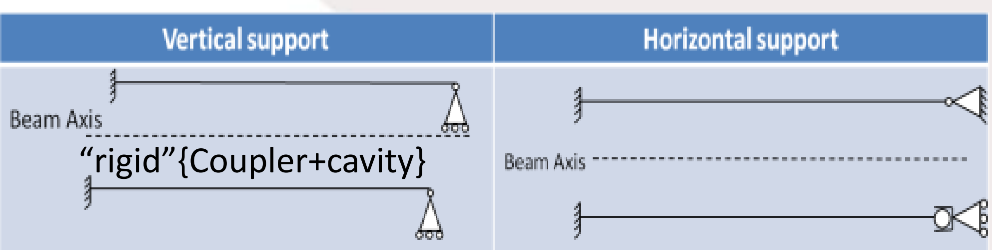
      ⇒ deformation of helium tank



  - Vertical
    - 1.2 mm
    - Blocked

      ⇒ deformation of helium tank





- Status:

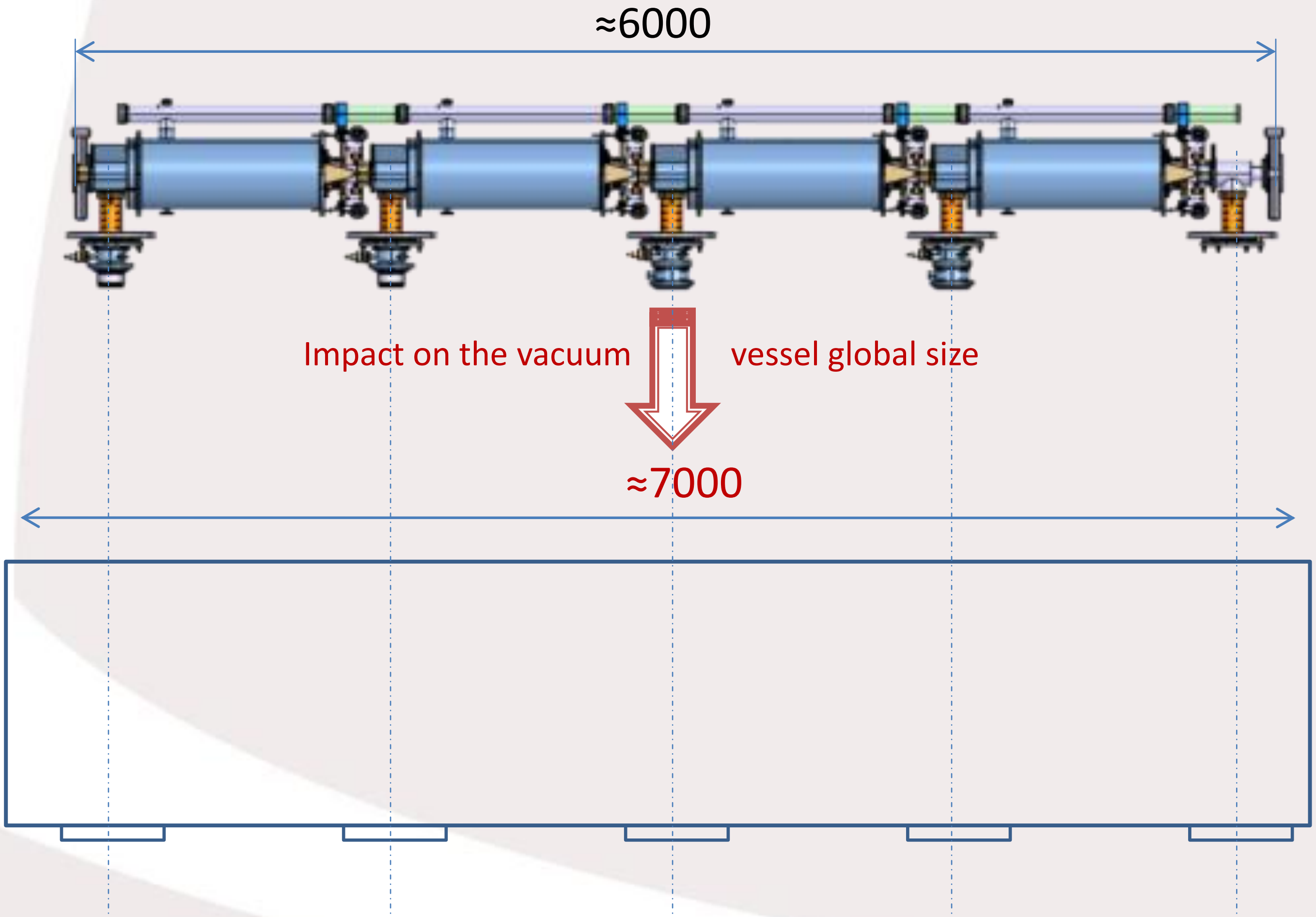
  Detail designed under progress

  ⇒ A mock-up is under construction by CERN

  ⇒ To be tested (Q1/2012)

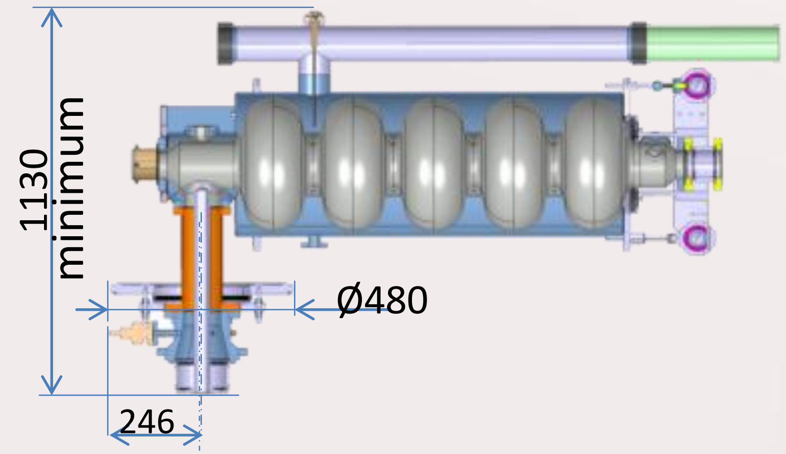
Constraints

- **Constraints due to the assembly method of the string of cavities**
  - Pre-Alignment in the clean room required (interconnection bellows)
  - Cavities cleaned and filled with nitrogen (1020mbar) → 2 x valves minimum



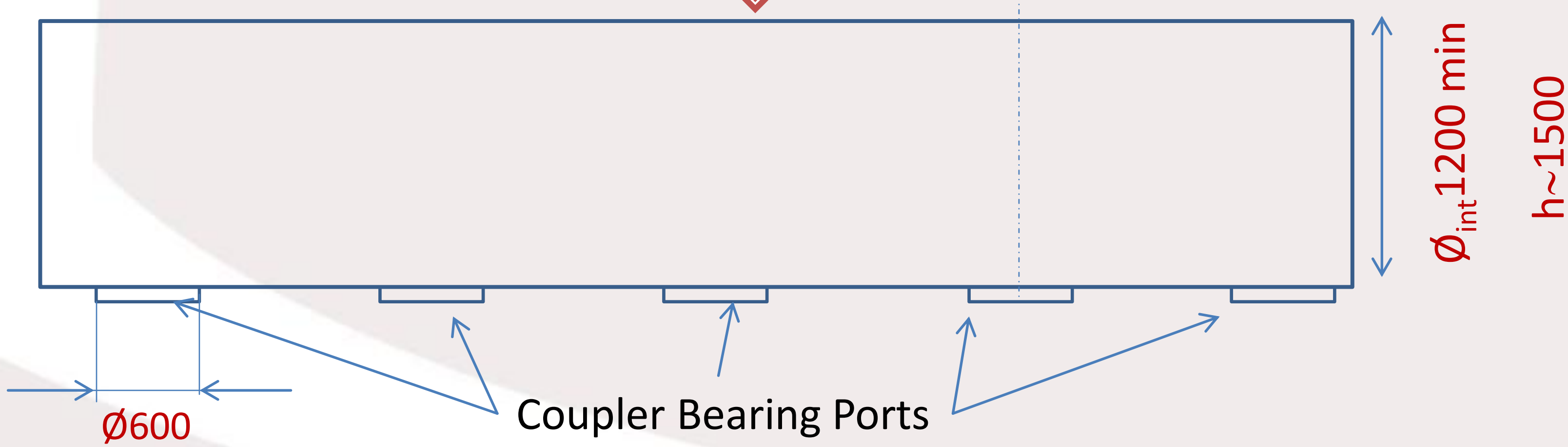
Constraints

- **Constraints due to the supporting System:**
  - Cavities supported and fixed by the lower flange of the double-wall tube of the coupler
  - Size of the power coupler
  - Size of the vacuum gauge



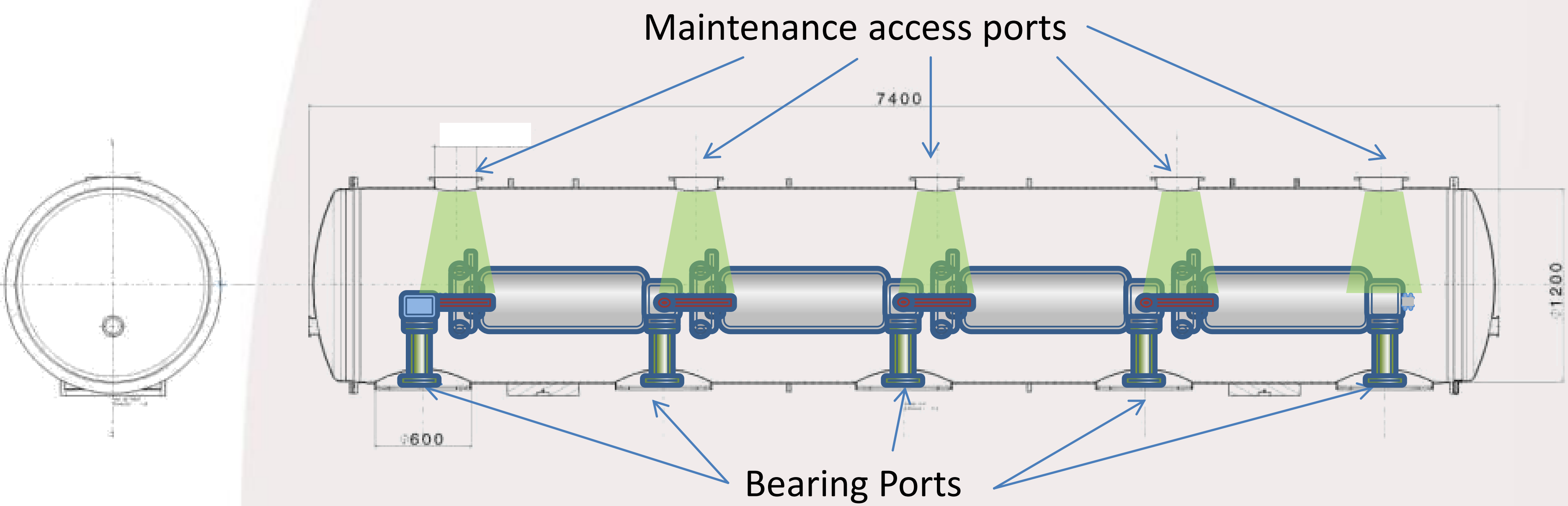
Outer part of the coupler disassembled

Impact on the vacuum vessel global size



Requirements

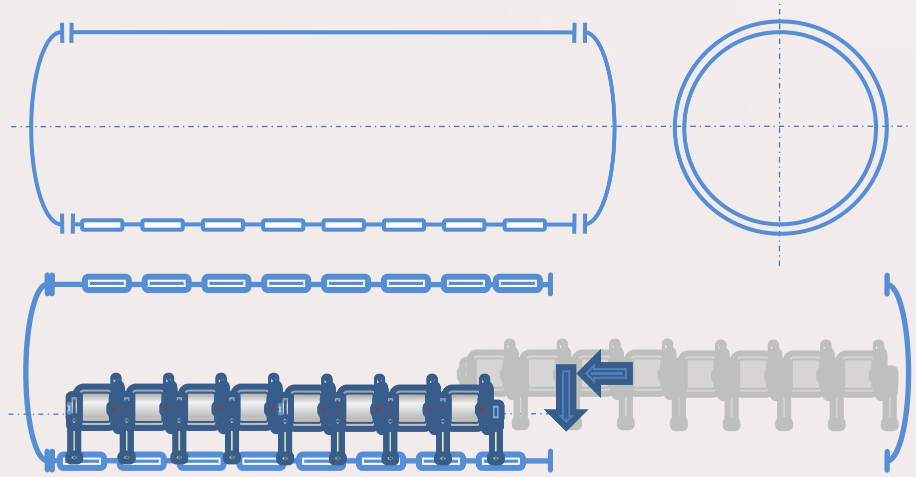
Maintenance aspects : Access to the tuner, the HOM, without decryostating



VACUUM VESSEL DESIGN

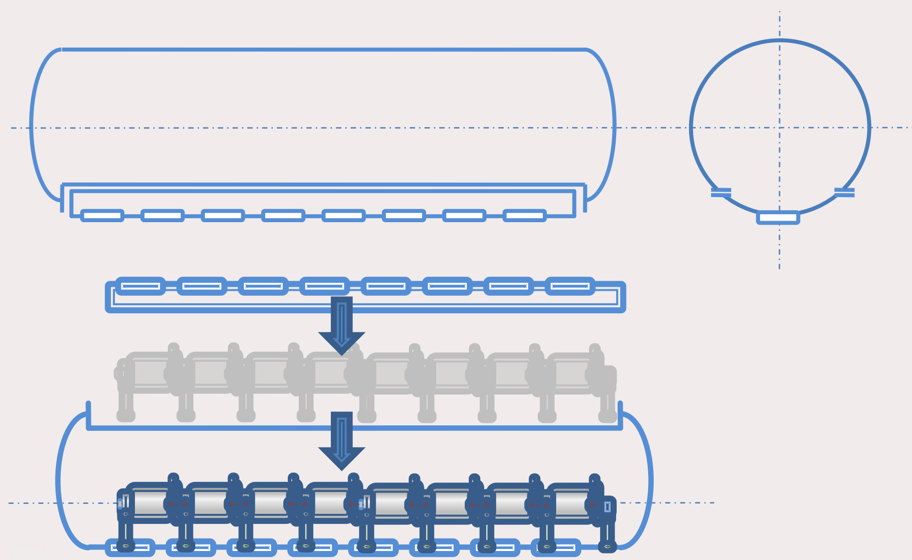
Vacuum vessel concepts

- Cylindrical vacuum vessel (LHC type)



⇒ Horizontal cryostating

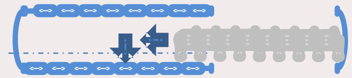
- Vacuum vessel with longitudinal aperture
  - Bottom aperture
  - **Top apperture**



⇒ Vertical cryostating

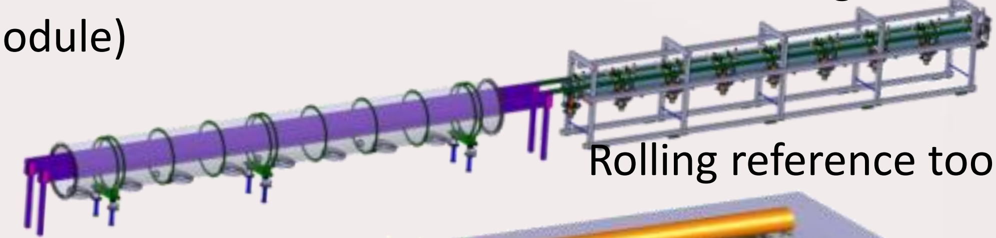
VACUUM VESSEL DESIGN - TOOLING

➢ Horizontal cryostating Tooling Studies

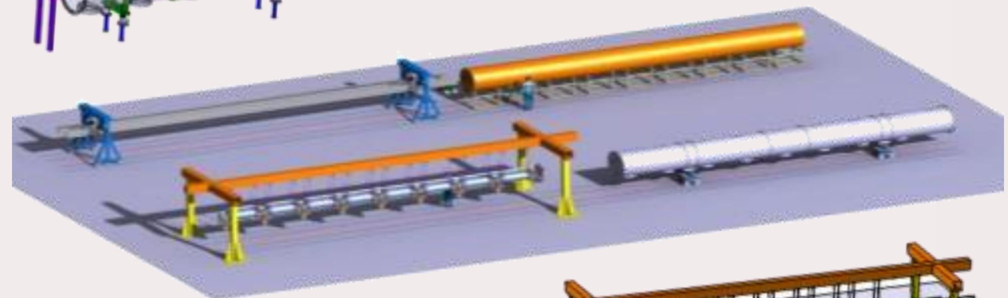


3 concepts were studied (8 cavities cryomodule)

Reference beam path and rolling frame

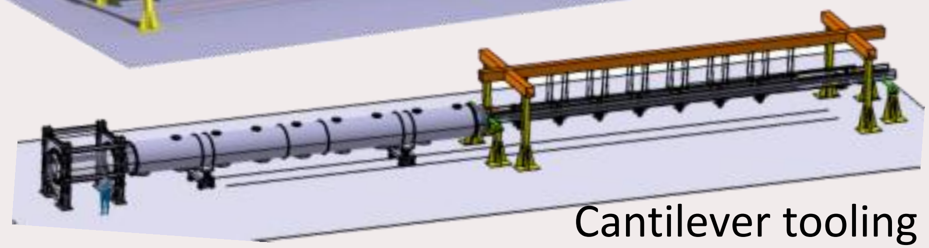


Rolling reference tool



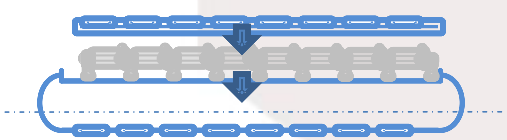
Assembly procedure

- dressing of the string of cavities
- alignment
- cryostating

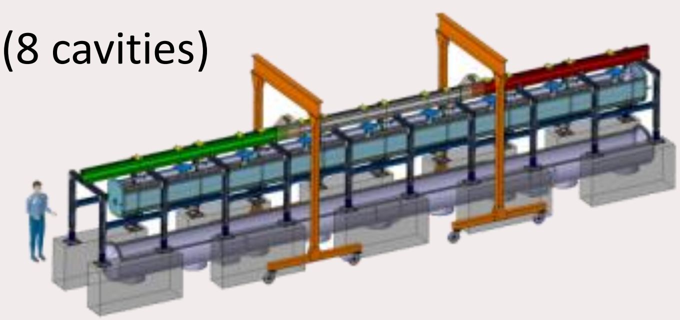


Cantilever tooling

➢ Vertical Cryostating Tooling Study



1 concept was studied (8 cavities)

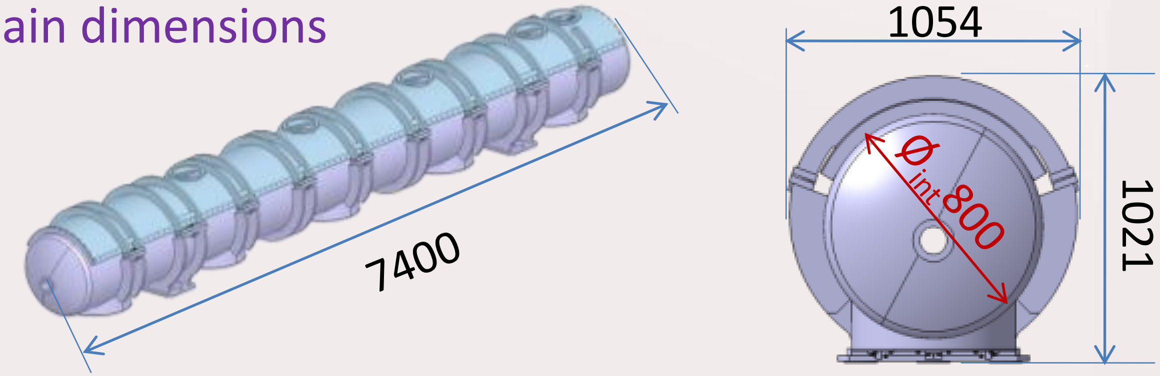


- All tools were compared (for long and short cryomodule)

Retained concept

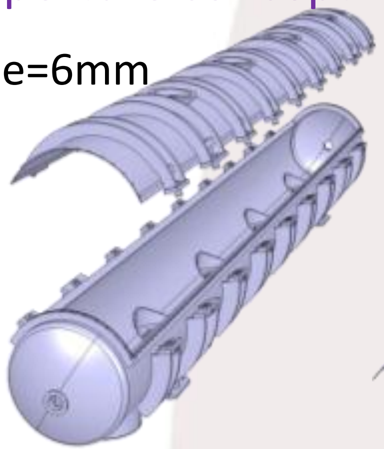
Cylindrical vacuum vessel with long top aperture

- Main dimensions

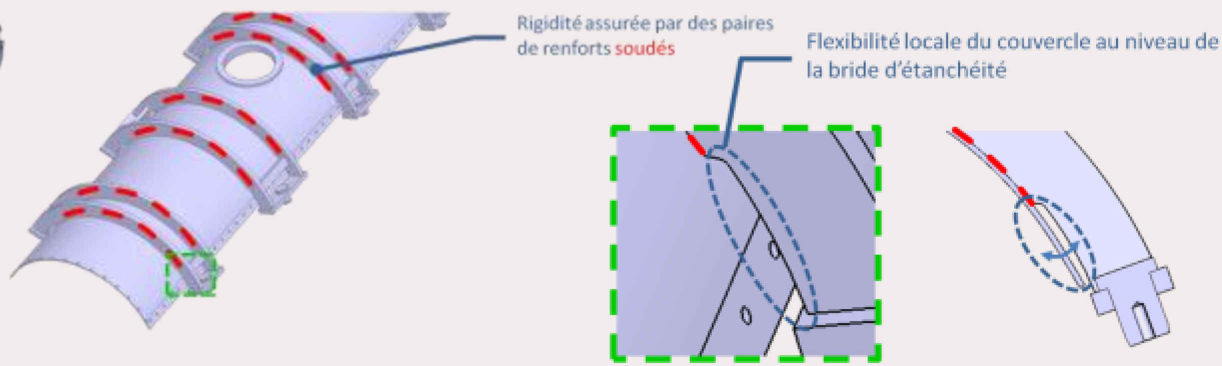


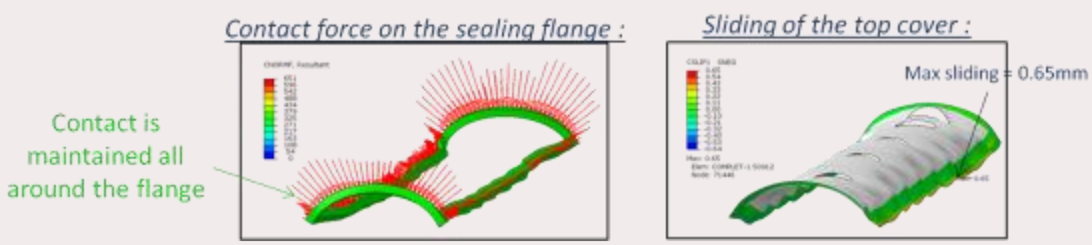
- Aperture concept

e=6mm



e=10mm



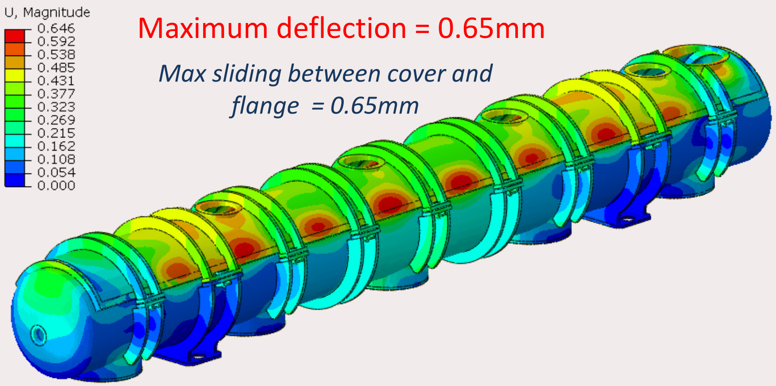


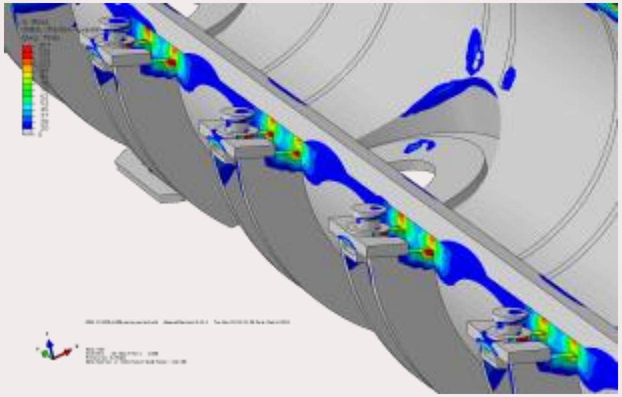
Aperture sealing

- Prototype (short cryomodule) : polymer seal placed in a groove / (soft) welding
- Machine cryomodule (long) : welding

- Mechanical studies
  - Static analysis

    Different loading scenarii (linked to the cryostating procedure)
    - VV Weight
    - VV Weight + loading with the string of cavities
    - Vacuum
    - Transport





  - Buckling (linear) analysis

$\Rightarrow$ The vessel fulfills mechanical requirements (optimization still needed)

- Construction study

A company was consulted to verify the possibility (and cost) of constructing this vacuum vessel.

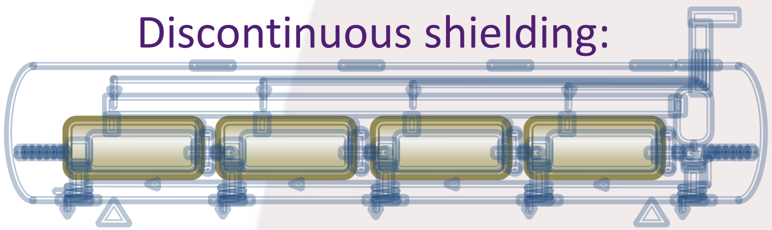
NB: The company (CMI) is currently in charge of 3 vacuum vessels (being 9, 10 and 11m long) for spare connection cryostats for the LHC.

$\Rightarrow$ The vessel seems to be feasible (with a 20% higher cost – 1 unit)

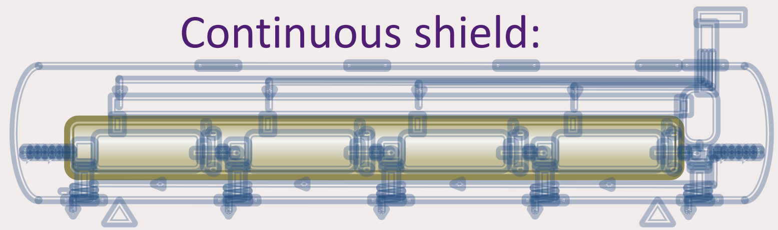
Cold magnetic shielding

2 concepts were studied:

Discontinuous shielding:



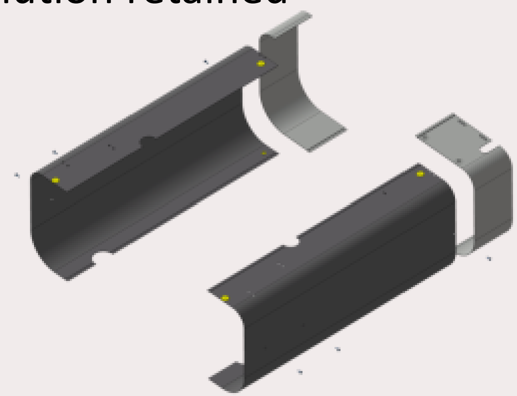
Continuous shield:



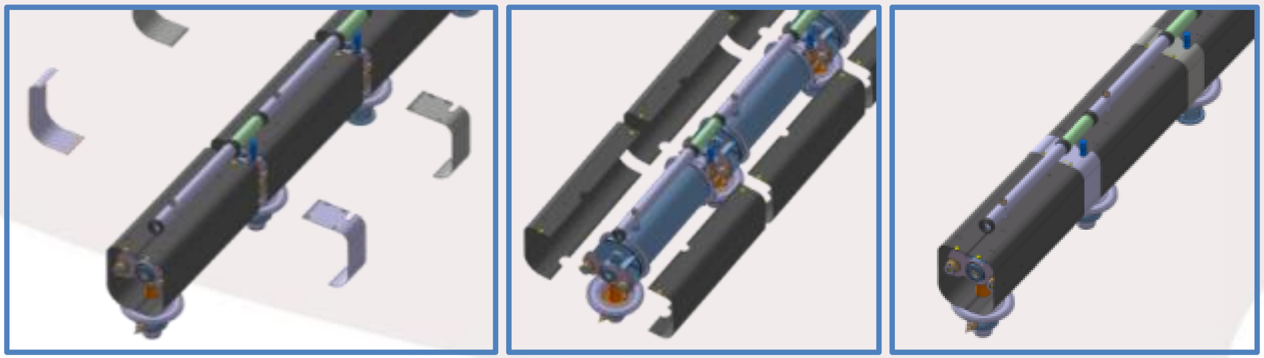
Need to be mounted before the tuner
End cap closures:
- lack of space
- needs of several apertures (tuner supports)

→ solution abandoned

Solution retained

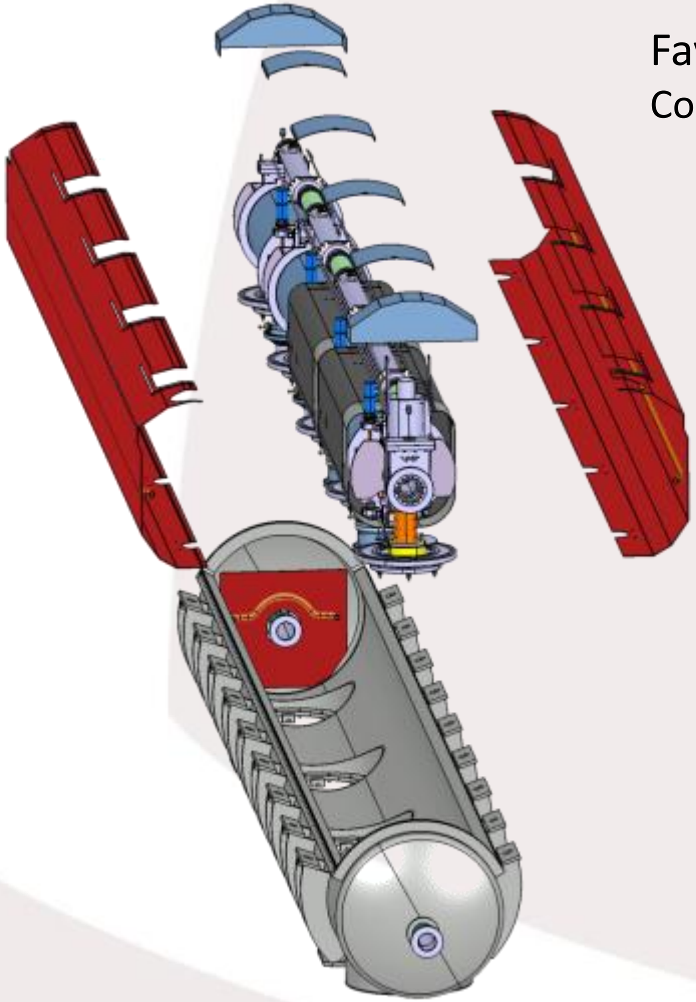


Alternative solution (CERN):
magnetic shield inside the cavity LHe tank
→ difficulty to manufacture the tank
→ solution abandoned
(now for the prototype;
could be studied again
in the future)



Thermal shielding

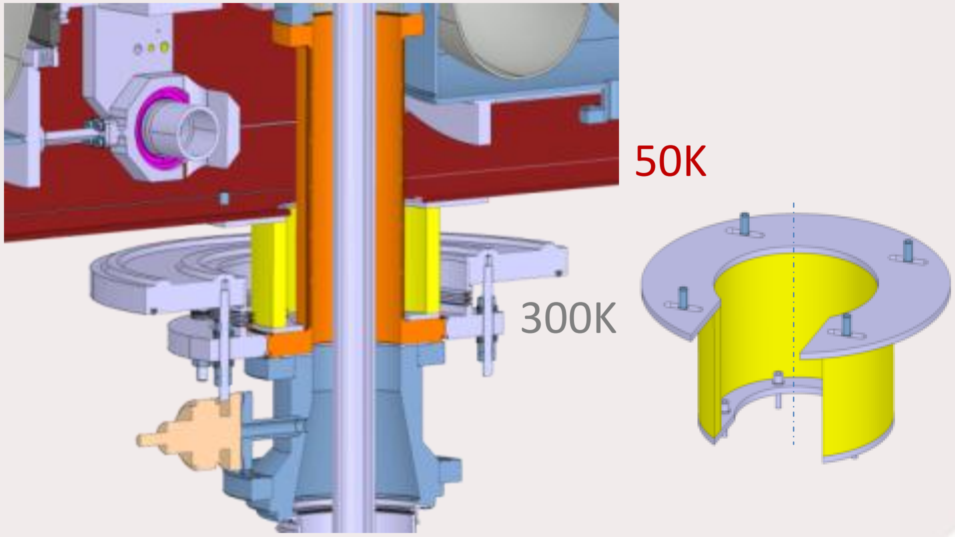
Several concepts were studied (some for a cylindrical vacuum vessel)



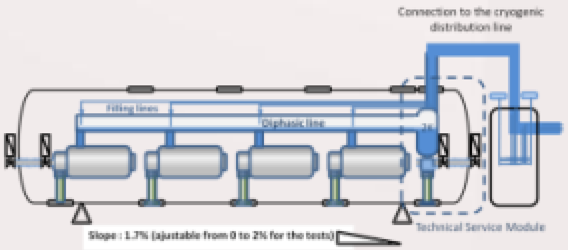
Favored solution:

Continuous shield 2 (or 3) main parts

Interfaced on the coupler flange

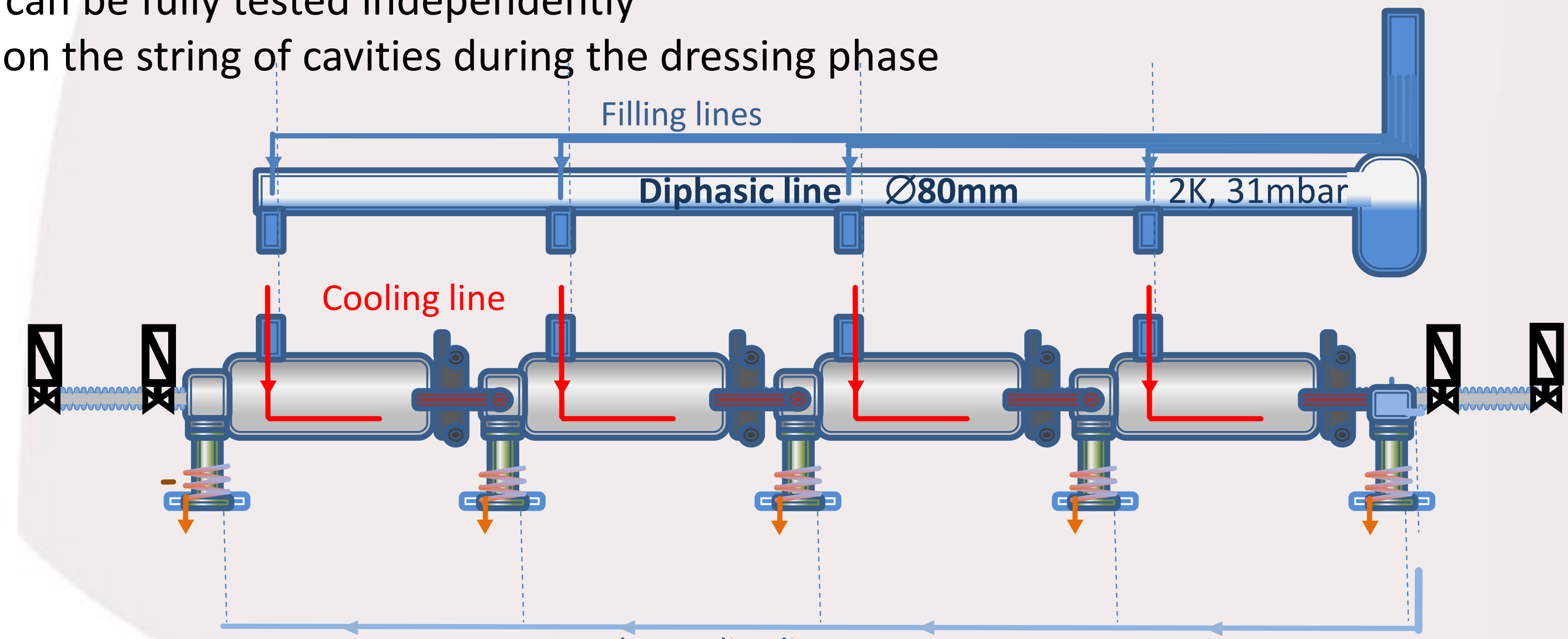


Cryogenic distribution



Diphasic line + filling line + 2K phase separator

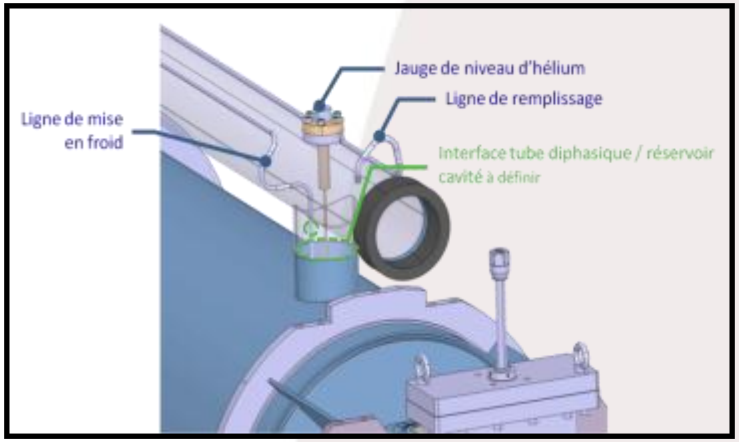
- One component
- Assembled separately **outside** the clean room
- Tightness can be fully tested independently
- Mounted on the string of cavities during the dressing phase

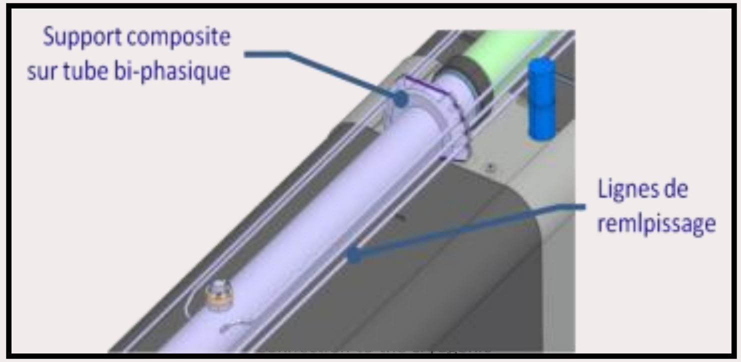


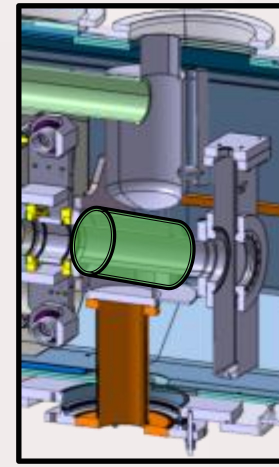
Coupler cooling line (+boiler)

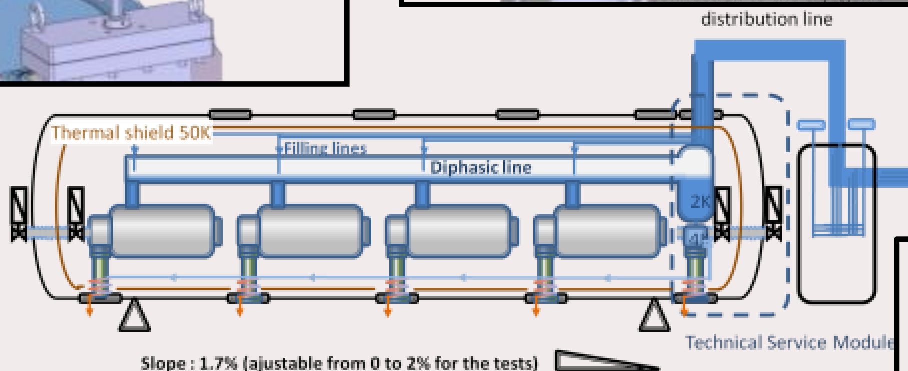
- The line is assembled on the couplers during the dressing phase
- The vapor generator (boiler) is integrated in the string of cavities

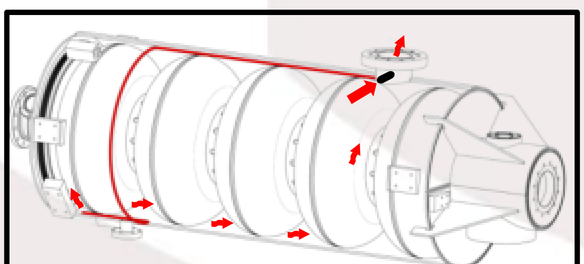
Cryogenic distribution

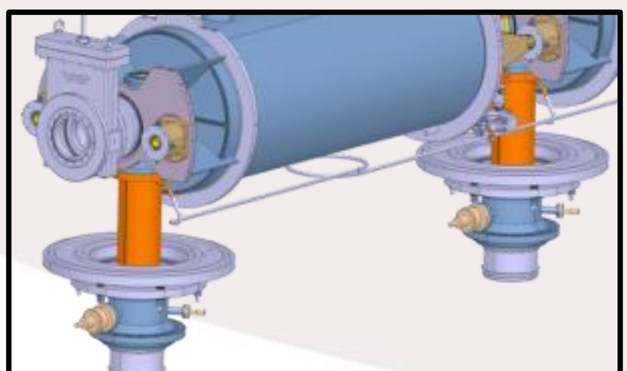


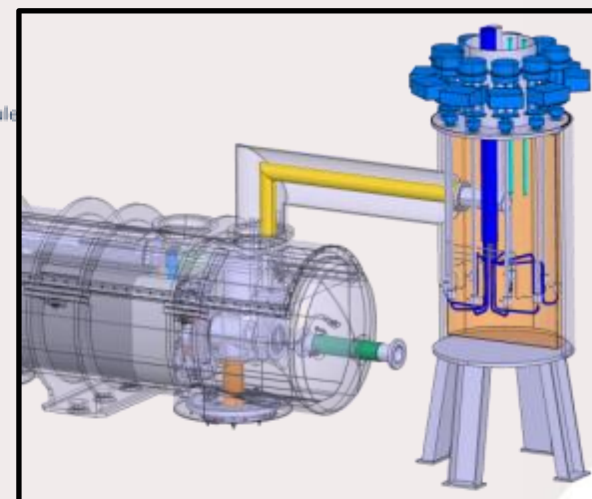












SUMMARY

- A ½-lenght cryomodule for the full test of 4 β=1 cavities is being design for the CERN

Issued from a collaboration between different institutes, it will be as similar as possible to a machine-type cryomodule for a possible SPL machine

- **For now:**
  - Cryo-module requirements are settled
  - Most of the conceptual choices are made (cavity supporting system, cryogenic scheme…)
  - Conceptual design study is (nearly) over → review: November 4th 2011
  - Still needing of some conceptual design work (cryogenic jumper connection, thermal shield)

- **Perspectives:**
  - Detailed design is beginning (→mid 2012)
  - Test of the cryomodule → 2014

SPL on indico: http://indico.cern.ch/categoryDisplay.py?categId=1893]

THANK YOU FOR YOUR ATTENTION

Unité mixte de recherche
CNRS-IN2P3
Université Paris-Sud 11

91406 Orsay cedex
Tél. : +33 1 69 15 73 40
Fax : +33 1 69 15 64 70
http://ipnweb.in2p3.fr