SPL mechanical design and cavities construction

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Overview

- Global context
- Interfaces definition
- Cavity manufacturing
- Conclusion

Global context

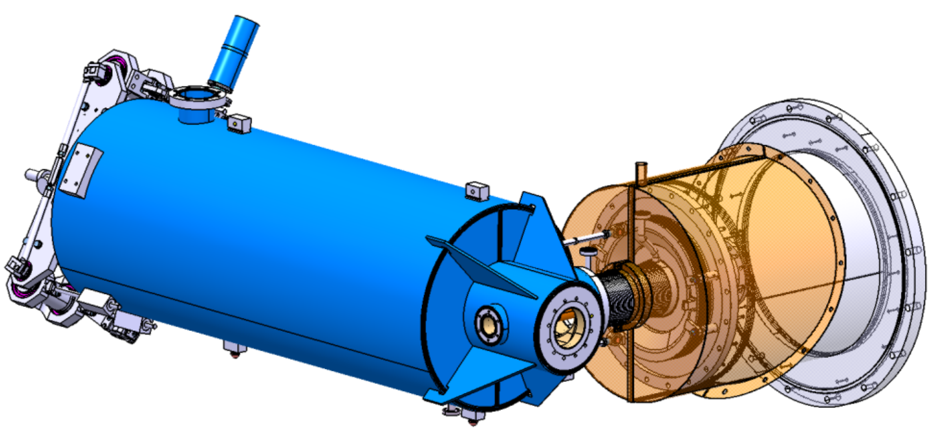
- Global context
    - What are we talking about
    - Who is doing what

=> *Example of fruitful collaboration*

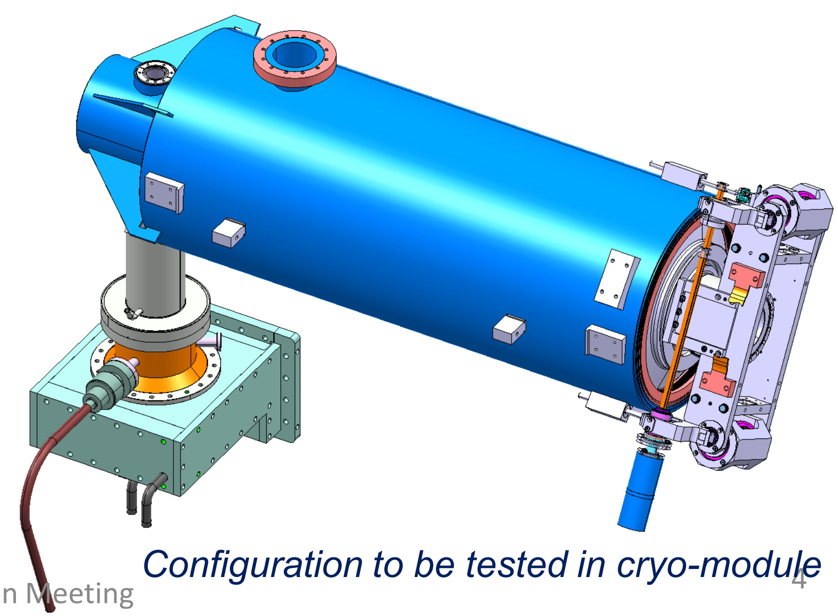
Global context

- "Equipped cavities"
  - 1 beta=1 "equipped cavity" to be manufactured, installed and tested by CEA in the "CRYHOLAB" at Saclay
  - 1 beta=0.65 "equipped cavity" to be manufactured by IPN Orsay, to be installed and tested in the "CRYHOLAB" at CEA Saclay
  - 4 + 4 cavities beta=1 "equipped cavities" to be manufactured, installed and tested by CERN in SPL cryo-module(s)

- Different helium tanks
- Minor differences for cavities b=1



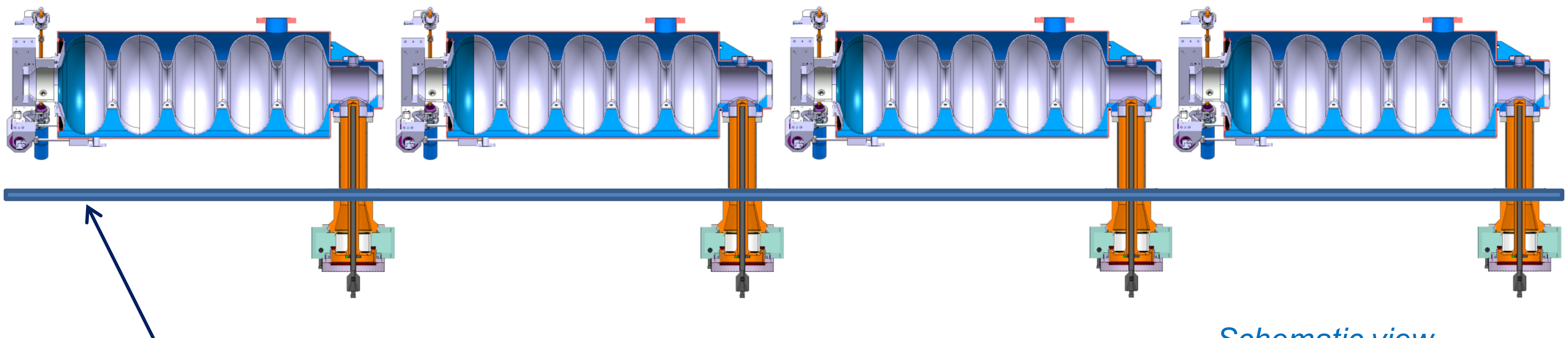
Configuration to be tested in CRYHOLAB



Configuration to be tested in cryo-module

Global context

- A string of 4 “equipped beta=1 cavities” + main coupler to be installed into a short cryo-module by end 2012



Short cryo-module design to be done by IPN Orsay
(see talks on Friday morning WG3 Cryogenics)

Schematic view of string of 4 “equipped cavities” and main coupler

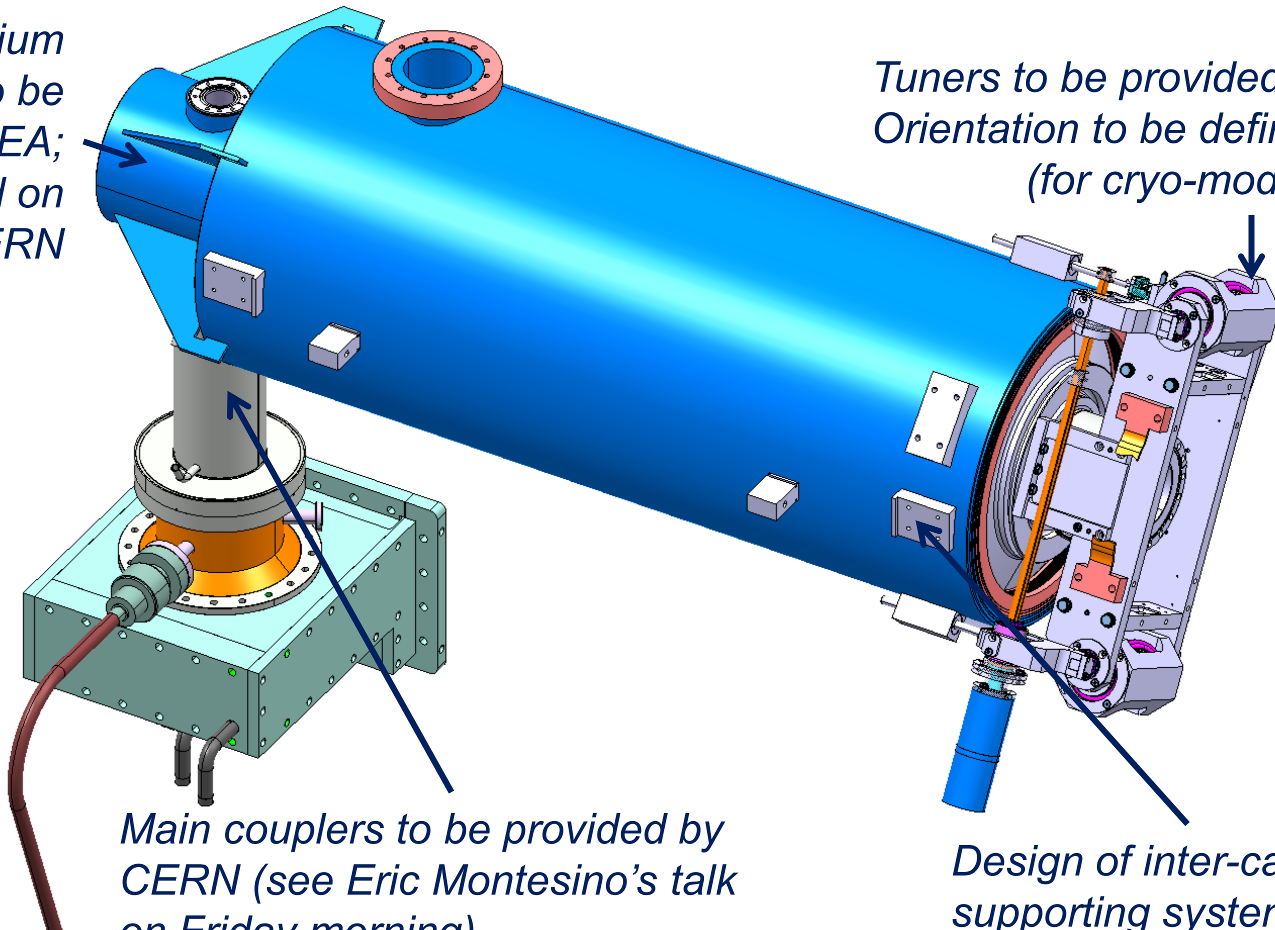
- A string of 8 “equipped beta=1 cavities” + main coupler to be installed into a short cryo-module by end 2014

Global context

- SPL beta = 1 cavity + helium tank + tuner + main coupler to be installed and tested in cryo-module at CERN

4 titanium helium tanks to be provided by CEA; to be welded on cavity by CERN

Tuners to be provided by CEA; Orientation to be defined by IPN Orsay (for cryo-module needs)

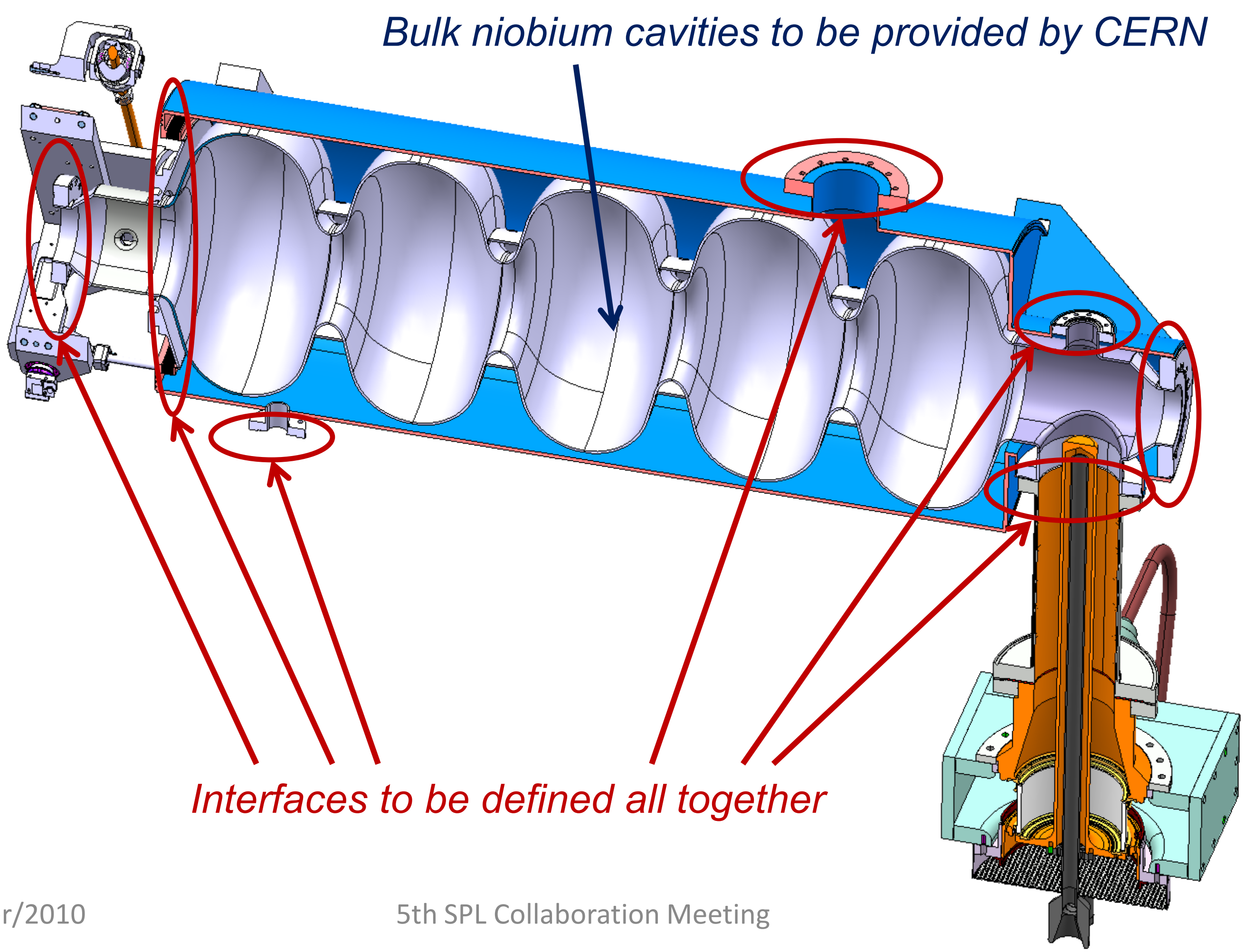


Main couplers to be provided by CERN (see Eric Montesino's talk on Friday morning)

Design of inter-cavity supporting system to be provided IPN Orsay

Global context

- SPL beta = 1 cavity + helium tank + tuner + main coupler to be installed and tested in cryo-module at CERN



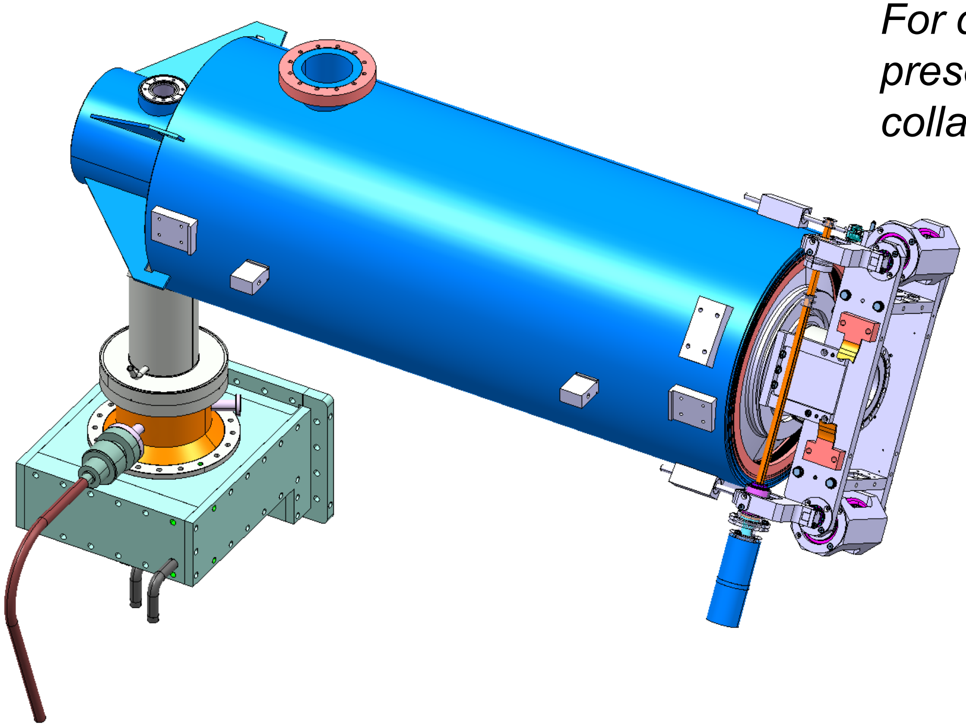
Interfaces

- Interfaces
  - Helium tank – cryomodule piping
  - Cavity – helium tank
  - Cavity – couplers and pickup port
  - Cavity – cavity
  - Helium tank – helium tank
  - Remarks

Interfaces

- Helium tank – cryomodule piping

  - Helium ports dimension:
    - The helium ports dimensions were calculated with respect to maximum heat flow to be evacuated through



For details see Ofelia Capatina's presentation in the frame of the 4th collaboration meeting in Lund

Some theory concerning HeII

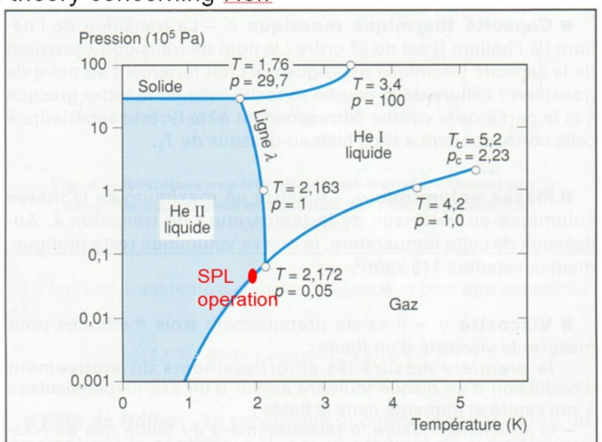


Fig. 1. – Diagramme de phase de ^{4}He.

Interfaces

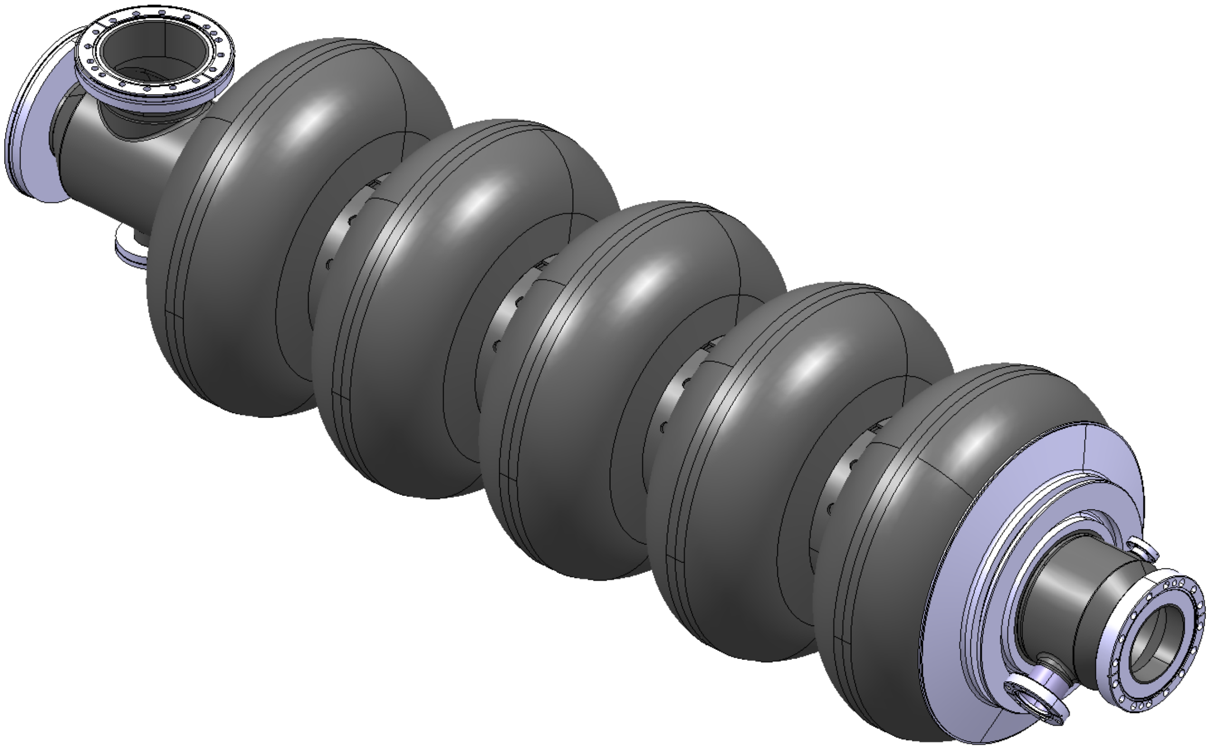
- Helium tank – cryomodule piping
  - Different materials transition
    - Cryo- module piping foreseen in Stainless Steel
    - Helium tank in Titanium
      - *Remark:* Helium tank in Titanium was chosen one year ago motivated by:
        - Same coefficient of thermal contraction as Niobium
        - The international proven technology (in particular mass production at DESY)
        - CEA tuner designed for Titanium tank
          - If Stainless Steel tank – larger tuner stoke needed or
          - Grater thermal stress on the cavity

Interfaces

- Helium tank – cryomodule piping
  - Titanium / Stainless Steel transition could be done by different techniques:
    - Explosion bonding
      - Samples already manufactured in the past by CERN but leak-tightness in superfluid helium still to be proven
    - Brazing
      - Technique still to be proven – tests ongoing at CERN
    - Through flanges and helicoflex sealing
      - The most reliable solution up to now => proposed solution as baseline

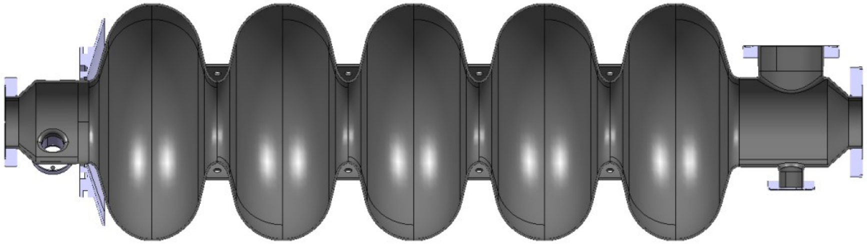
Interfaces

- Cavity – helium tank
  - Niobium – Titanium transition:
    - EB welding Nb to Ti or
    - EB welding Nb to NbTi + EB welding NbTi to Ti



Interfaces

- Cavity – helium tank
  - DESY choice:
    - EB welding Nb to NbTi +
      EB welding NbTi to Ti
    - NbTi flanges

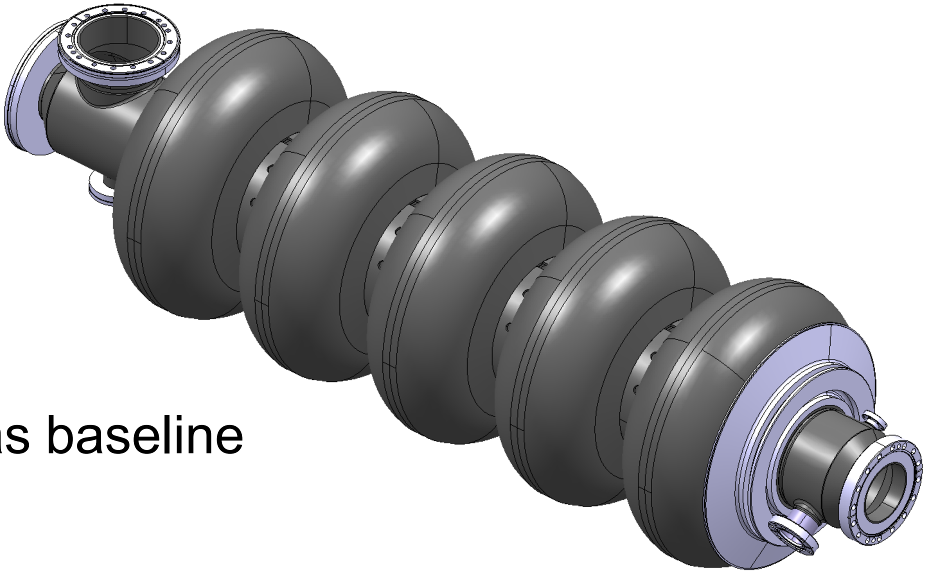


  - Choice motivated by the stability of the mechanical properties after heat treatment at 1400ºC => NbTi
  - Heat treatment no longer at 1400ºC but at 800ºC =>
    A properly selected Titanium (cheaper) could be then a valid option (instead of NbTi)
    - The grade 5 Titanium Ti6Al4V:
      - Has excellent mechanical properties at cryogenic temperature
      - Beta transus temperature: 1000ºC
      - Forging temperature: 950-980ºC
      - Solution annealing temperature: 900-950ºC

        => The mechanical properties of Ti6Al4V should not be degraded after heat treatment at 800ºC
      - However grade 5 is an alloy and not a pure Ti !

Interfaces

- Cavity – helium tank
  - The theory shows that Ti grade 5 is a valid option; However validation tests will be performed soon:
    - Ti to Nb EB weld mechanical properties
    - Stability of mechanical properties of Ti grade 5 after heat treatment at 800 C



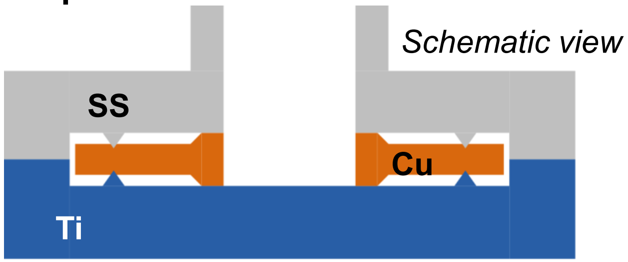
- *Remark:* The choice of flanges material and interface to helium tank should be coherent => Nb to be EB welded directly on Ti:
  Flanges and cone in Ti grade 5 as baseline

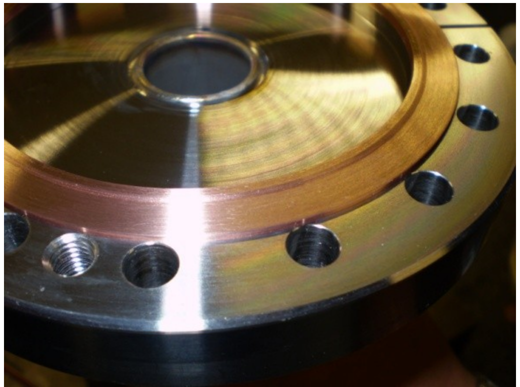
Interfaces

- Cavity – couplers and pickup port
  - The cavity flange in Ti, coupler flanges in Stainless Steel
  - The relative thermal contraction between Ti and SS is 0.15 mm/m
  - The most critical interface is between the cavity and the main coupler

  - The main coupler interface gasket will have to insure:
    - RF continuity – ideally OFE copper
    - Leak tightness at room and cryogenic temperature

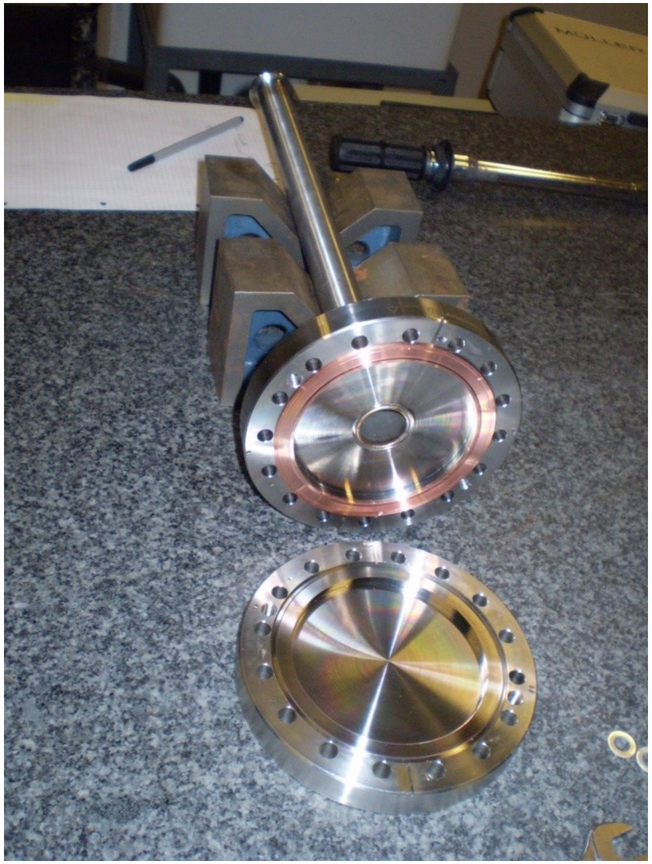
      (During operation it separates the cryostat vacuum from the machine vacuum)
  - The baseline solution is:
    - CF flange in Stainless Steel
    - OFE copper RF gasket "LHC type"
    - CF flange in Titanium grade 5





Interfaces

- Cavity – couplers and pickup port
  - Test of CF flange SS + OFE copper + CF flange Ti grade 5
  - The assembly was tested with 2 gaskets, room temperature – liquid nitrogen thermal cycle more 4 times each



Interfaces

- Cavity – couplers and pickup port
  - CF flange SS + OFE copper + CF flange Ti grade 5; 2 gaskets tested:
    - Different rough material OFE copper
    - Different manufacturing
  - Preliminary results:
    - 1st gasket: No leak detected with sensibility better than 1*10^-10 mbar*l/s at warm and cold after 4 thermal cycle
    - 2nd gasket:
      - Leak of 9*10^-6 mbar*l/s detected at warm after the 4th th. cycle
      - Leak of 2*10^-8 mbar*l/s detected at cold after 5th thermal chock

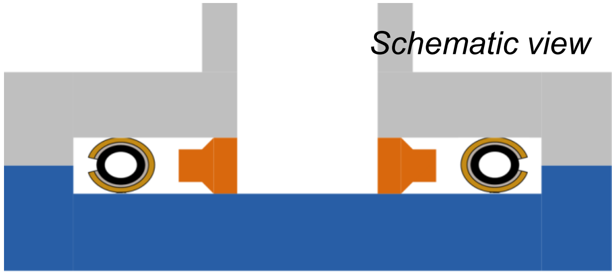
Courtesy of A. Sinturel

  - Next:
    - Used gasket copper mechanical properties will be extensively analyzed => define proper gasket parameters
    - Tests will be continued with additional gaskets
    - Additional tests with the Titanium flange after heat treatment at 800ºC

Interfaces

- Cavity – couplers and pickup port
  - Conclusion
    - Interface material (flanges, cone): Titanium grade 5 as baseline; Validation tests will be performed soon:
      - Ti to Nb EB weld mechanical properties
      - Stability of mechanical properties of Ti grade 5 after heat treatment at 800 C
    - Alternative: All interfaces in NbTi

    - Solution CF flange SS + OFE copper + CF flange Ti as baseline but gasket parameters still to be properly determined and prove reliable performance
    - Alternative:
      - We will decouple the functionalities:
        - Use the internal part for RF continuity
        - Use Helicoflex for leak tightness instead of CF



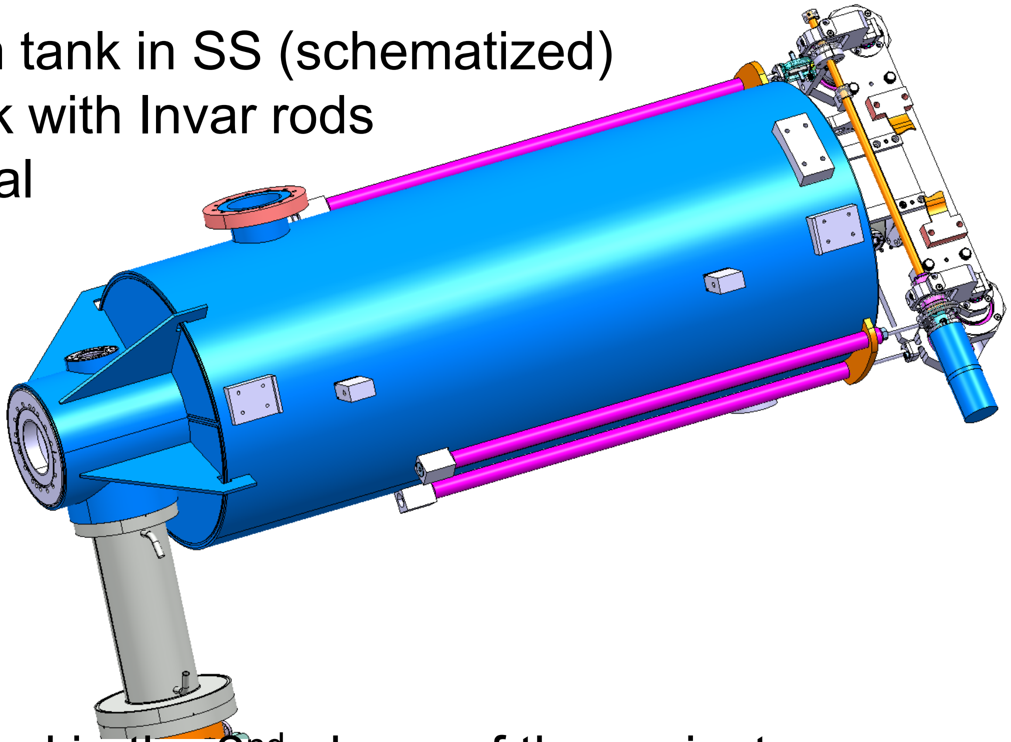
Interfaces

- Cavity – cavity
  - The cavity – cavity connection passes through a Stainless Steel bellow connection => solution similar to the connection cavity – main coupler to be applied

- Helium tank – helium tank connection
  - Design ongoing by IPN Orsay

Interfaces

- Remarks – helium tank choice
  - DESY solutions were not applicable for all our needs => special developments and tests were required
  - The Titanium choice of the helium tank is definitely not the simplest and the cheapest solution
  - A possible solution of helium tank in SS (schematized) – the combination of SS tank with Invar rods could get to the same thermal contraction as Niobium => all the drawbacks of the SS solution would be solved



  - This solution will be developed in the 2nd phase of the project

Cavities manufacturing

- Beta=1 cavities manufacturing
  - Niobium procurement
  - Manufacturing process
  - Planning considerations

Cavities manufacturing

- Niobium procurement
  - Niobium will be provided by Plansee by February 2011
  - A test piece was sent to CERN for qualification; Tests performed:

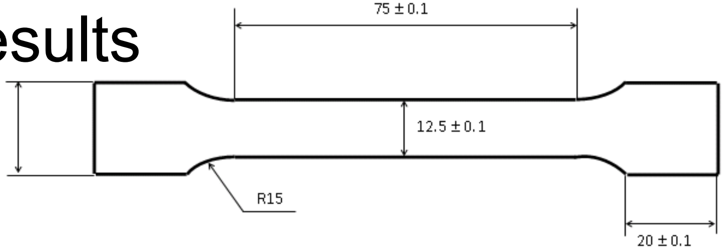
    - Ultrasonic inspection, for continuity faults and for variations of attenuation
    - Surface roughness, Rt
    - Hardness, HV10
    - Tensile properties, longitudinal and transverse to rolling direction
    - Microstructure, for grain size and uniformity
    - Electrical residual resistivity ratio RRR, in bulk material

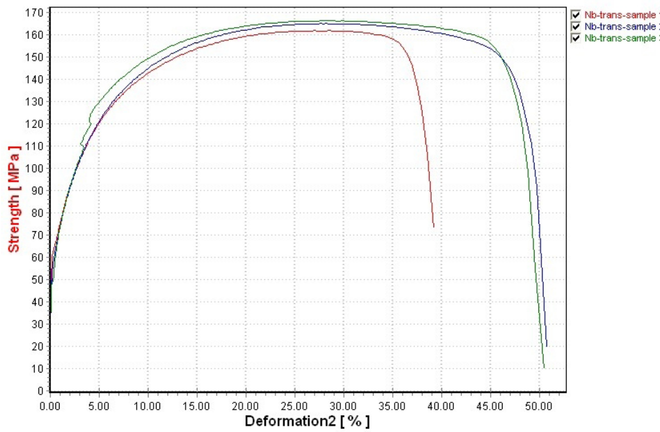
Cavities manufacturing

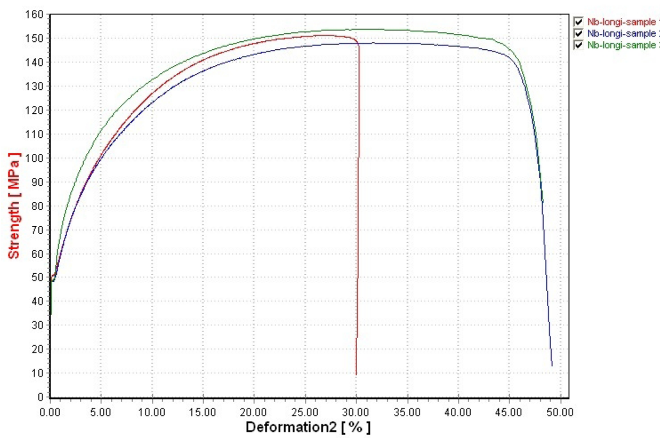
- Niobium procurement - Test piece results
  - Ultrasonic inspection
    - The whole pieces was scanned
    - No discontinuities were detected
    - Attenuation variation was smaller than 20 %
      => results within specifications
  - Surface roughness, Rt≤14.7μm within specification (≤15μm)
  - The average hardness results in 41.3 HV10 => within specification (max. 60 HV10)

Cavities manufacturing

- Niobium procurement - Test piece results
  - Tensile tests on 3 samples from longitudinal and transverse to rolling direction => within spec
    - Average tensile strengths (spec min. 140 MPa)
      - 151 MPa longitudinal
      - 164 MPa transverse
    - Average yield strengths (spec min. 50 Mpa, max 100 MPa)
      - 49 MPa longitudinal
      - 56 MPa transverse
    - Average tensile elongations at break
      - 42 %
      - 46 %





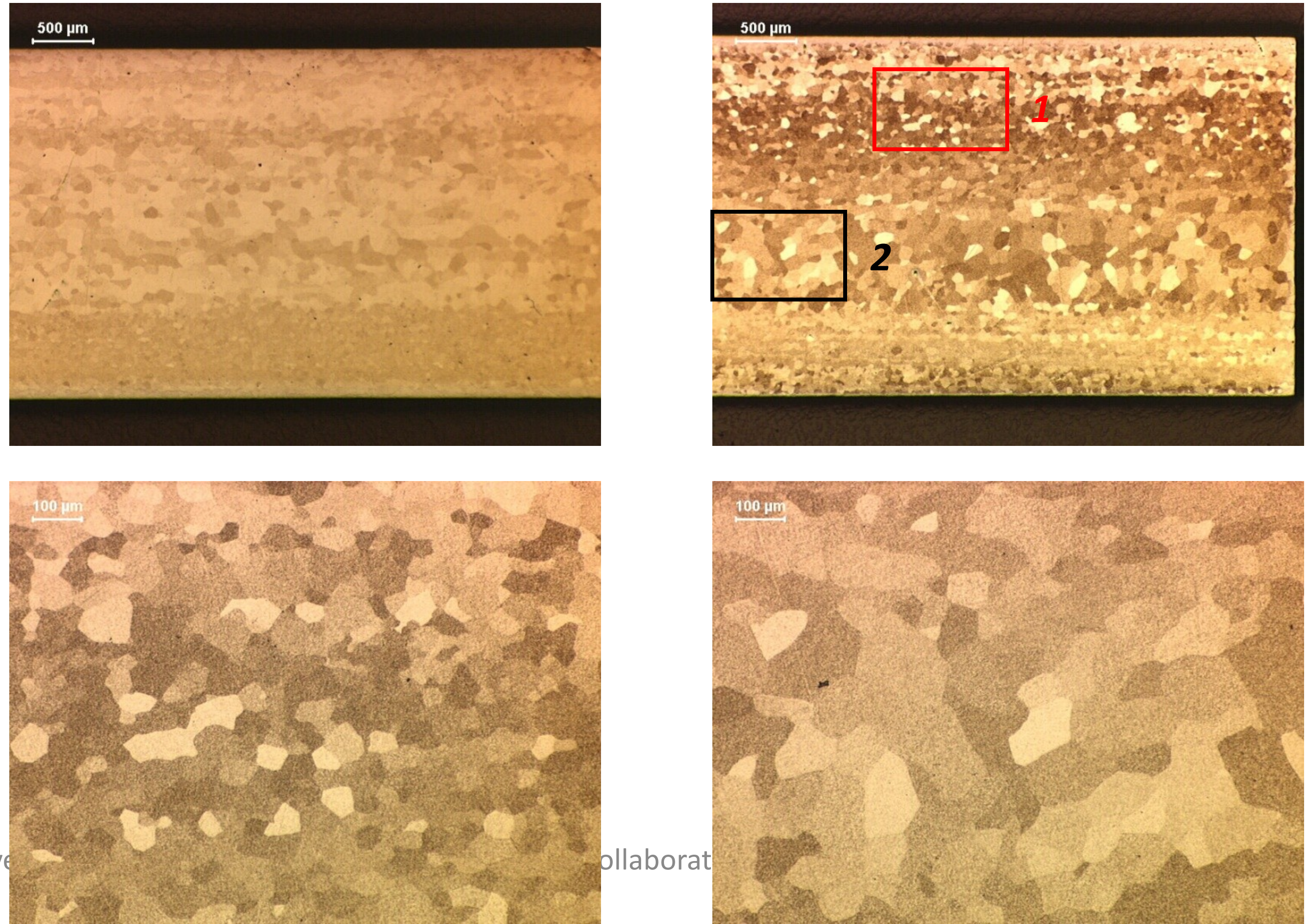


Cavities manufacturing

- Niobium procurement - Test piece results
  - Electrical residual resistivity ratio RRR, in bulk material
    - Three samples 2x2x100 mm tested at room and at 9.5 K
    - RRR > 380 within specification

Cavities manufacturing

- Niobium procurement - Test piece results
  - Microstructure, for grain size and uniformity => out of specification; could induce geometrical irregularities during spinning => corrective actions under discussion



Cavities process

- Cavity manufacturing
  - Niobium procurement – will be extensively tested at CERN
  - Manufacturing by industry up to cavity tuning:

Spinnnig of half-cells (8 middle, 2 end)
Manufacture of 2 end groups
Machining for iris and stiffening rings welding preparation
Manufacture of NbTi flanges (main coupler, HOM, pick-up, extremities)
Manufacture of interface to helium tank
Degreasing
3D control
RF measurement of half-cell frequency
Ultrasonic cleaning; CP (20 µm on each side) inner and outer surface, rinsed in de-ionized filtered hot water of 0.2µm max, dried in laminar airflow in clean room 1000 or better
3 µm CP if storage time > 8h after previous step
EB welding of the irises (8 half cells, 2 end groups, helium tank interfaces, all Nb flanges) and from inside (within 8h from previous)
EB welding of stiffening rings
Inspection and dimensions control of “dumb-bell” + extremities
Frequency measurement of dumb-bell + extremities

Machining of both equator ends determined by evaluation of frequency
Ultrasonic cleaning; CP(20 µm on each side) inner and outer surface, rinsed in de-ionized filtered hot water of 0.2µm max, dried in laminar airflow in clean room 1000 or better
Anodization of dumb-bell and inspection
Grinding if needed + 20 µm CP, rinsed, dried, anodized again
3 µm CP cleaning
EB welding of all equators (4 dumbbells, 2 end groups, $p < 5\cdot10^{-5}$ mbar) from outside in full penetration; protection against Nb vaporization
Leak test
Field flatness measurement and tuning
Transport frame + delivery to CERN

Cavities process

- Cavities process
- 1st Stage
  - Manufacturing of cavity as presented before
    (by Industry, some equipment to be provided by CERN, QA checks with CERN personnel present)
  - Delivery to CERN
  - EP “hard” (thickness 140 μm) – to be done at CERN
  - HPWR to remove residuals from EP (criteria TBD)
  - HV annealing at 800°C (1 – 2 h, 10-5 – 10-6 mbar)
  - Field flatness measurement + re-tuning if needed
  - Short EP 20 μm
  - HPWR in SM18 clean room
  - Closing of cavity, assembly of pickup probes and vacuum valves, drying by pumping, all in SM18 clean room; storage under vacuum

Cavities process

- 2nd Stage
  - Assembly on vertical cryostat
  - Baking at 120°C
  - Cold RF test in vertical cryostat (at CERN)
- 3rd Stage
  - Analysis of RF test; if OK goto 4th stage
  - If not, either (if no quench) goto 2nd stage “HPWR in SM18 clean room”
  - or (if quench) go to optical inspection for identification of problem, mechanical intervention, short CP, etc,
- 4th Stage
  - Disassembling in SM18 clean room the pickup probes and vacuum valves, cavity under protective gas at overpressure
  - Welding of the helium tank (Tank to be provided by CEA, welding by the cavity manufacturer) with cavity under protective gas
  - Leak test of He tank
  - Storage of cavity in SM18 clean room cabinet

Cavities process

- 5th Stage
  - Assembling of the string of the 4 cavities in SM18 clean room with the pickup probes, couplers and gate valves
  - Pumping, leak test and baking in SM18 clean room
  - Assembling full cryo-module outside clean room
  - Horizontal cold test in bunker

Cavities manufacturing

- Planning considerations
  - Niobium procurement: February 2011
  - Cavities manufacturing by Industry
    - Start manufacturing by February 2011
    - Expected delivery by end 2011
    - Then process at CERN as detailed before

Conclusions

- Helium tank and interfaces issues:
  - Titanium choice revealed to be more complicated than expected
  - “Copy – Paste” solutions are an illusion; however it made the work scientifically more interesting
  - Several solutions exist but the simplest still to be validated
  - If we could come back one year ago we would choose Stainless Steel helium tank – this solution will be developed in the 2nd phase of the project
- Cavities manufacturing
  - Niobium furniture has to be followed closely
  - Manufacturing by Industry foreseen to start in February 2011; expected delivery by end 2011

Thank you for your attention !

and

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