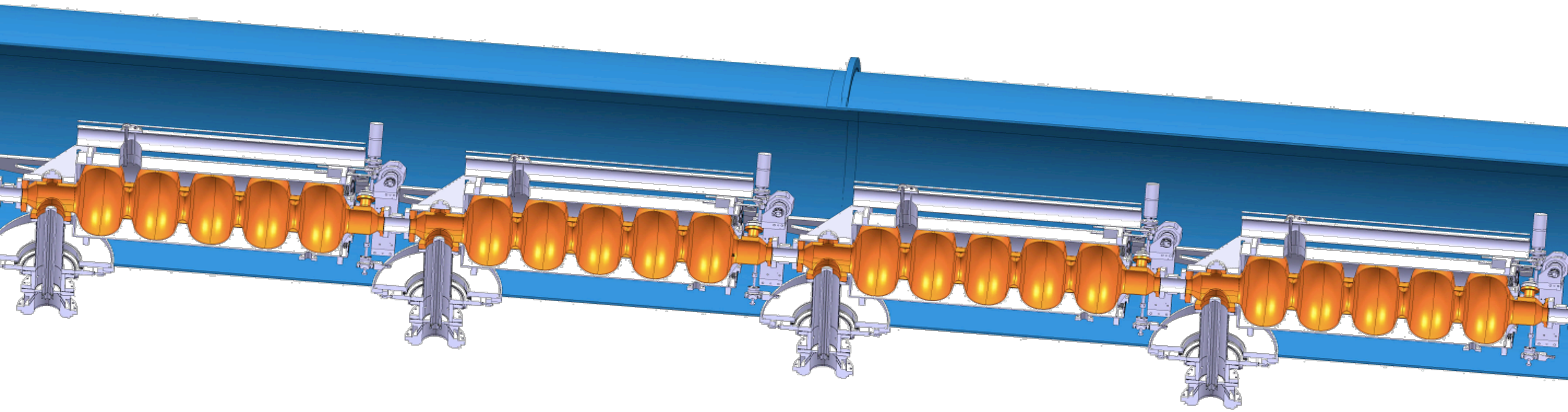
SPL cavity and helium tank

Ofelia Capatina
on behalf of the SPL team

In the frame of the SPL study

- A string of 4 “equipped beta=1 cavities” + main coupler to be tested at CERN into a short cryo-module during 2014



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

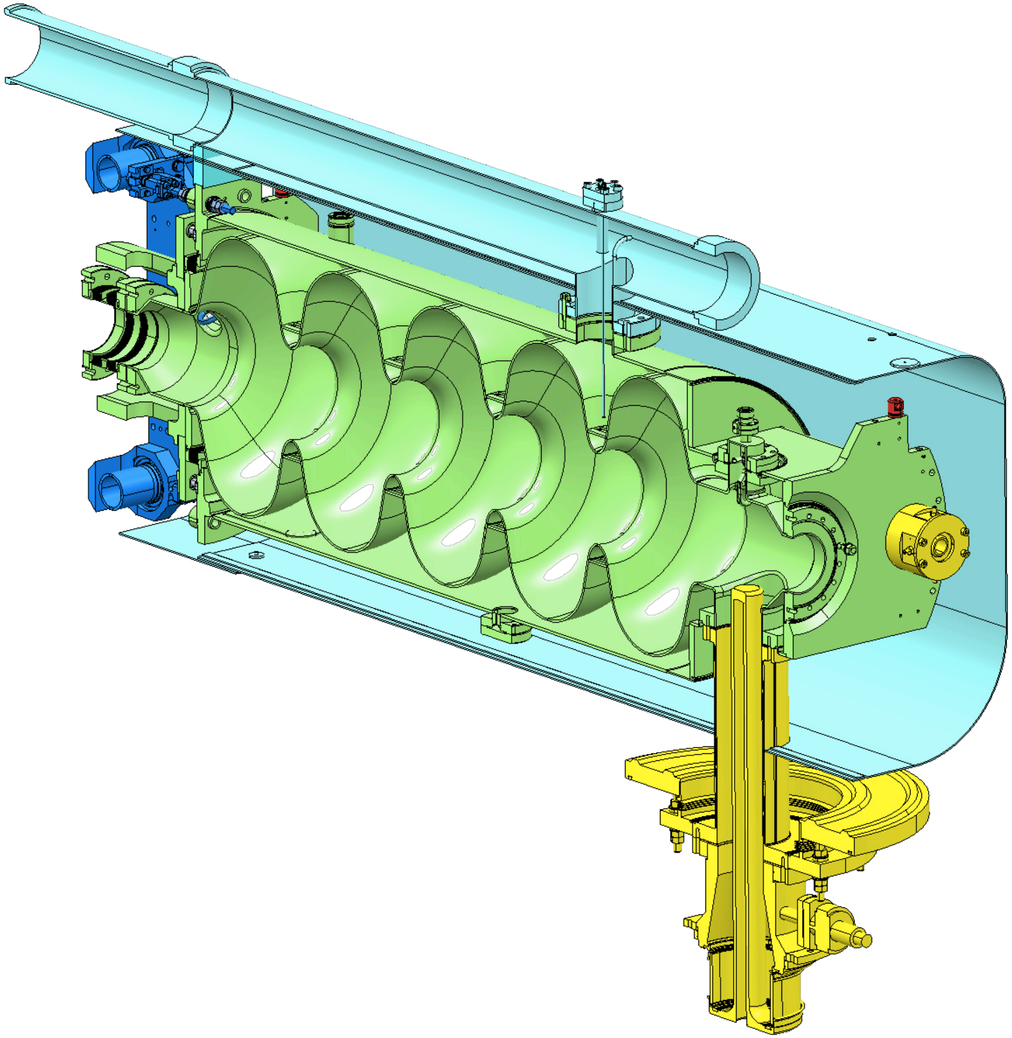
In the frame of the SPL study

- Cavities
  - Ofelia Capatina - General talk
  - Nuria Valverde & Ignacio Aviles - Ongoing prototyping activities at CERN – this afternoon
  - Janic Chambrillon – SM18 clean room and SRF infrastructure refurbishment – this afternoon
  - Kitty Liao – Cavity vertical tests and diagnostics – this afternoon

- Cryo-module
  - Vittorio Parma - General talk – this afternoon
  - Patxi Duthil – Design progress of short cryo-module at IPNO – tomorrow morning
  - Paulo Coelho – Mock-ups of the cavity supporting system – this afternoon
  - Rossana Bonomi – Thermal studies – tomorrow morning

Overview

- Introduction
- Cavity
- Helium tank
- Tuning
- Summary



Introduction

- Cavities under manufacturing
  - 2 copper cavities β=1 at CERN
  - 4 niobium cavities β=1 in Industry (RI)
  - 1 niobium cavity β=1 at CERN

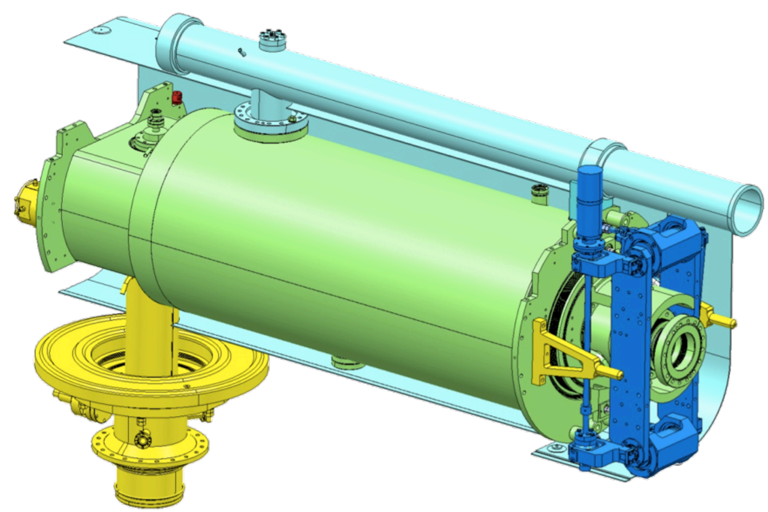
  + SS helium tank to be tested at CERN in cryomodule

  - 1 niobium cavity β=0.65 in Industry by IPNO
  - 1 (2?) niobium cavity β=1 in Industry by CEA

  + Titanium helium tank to be tested at CEA in Cryholab

Introduction

- Beta = 1, CERN cavities
  - RF design done by CEA
  - Mechanical design done by CEA and CERN
  - Stainless steel helium tank design by CERN, manufacturing by CEA
  - 2 copper cavity manufacturing ongoing at CERN
  - 5 niobium cavities to be manufactured by end 2012
    - 4 in industry (Research Instruments)
    - 1 at CERN
  - To be tested in the short cryo-module at CERN
  - CEA tuner
  - CERN main coupler



Configuration to be tested in cryo-module

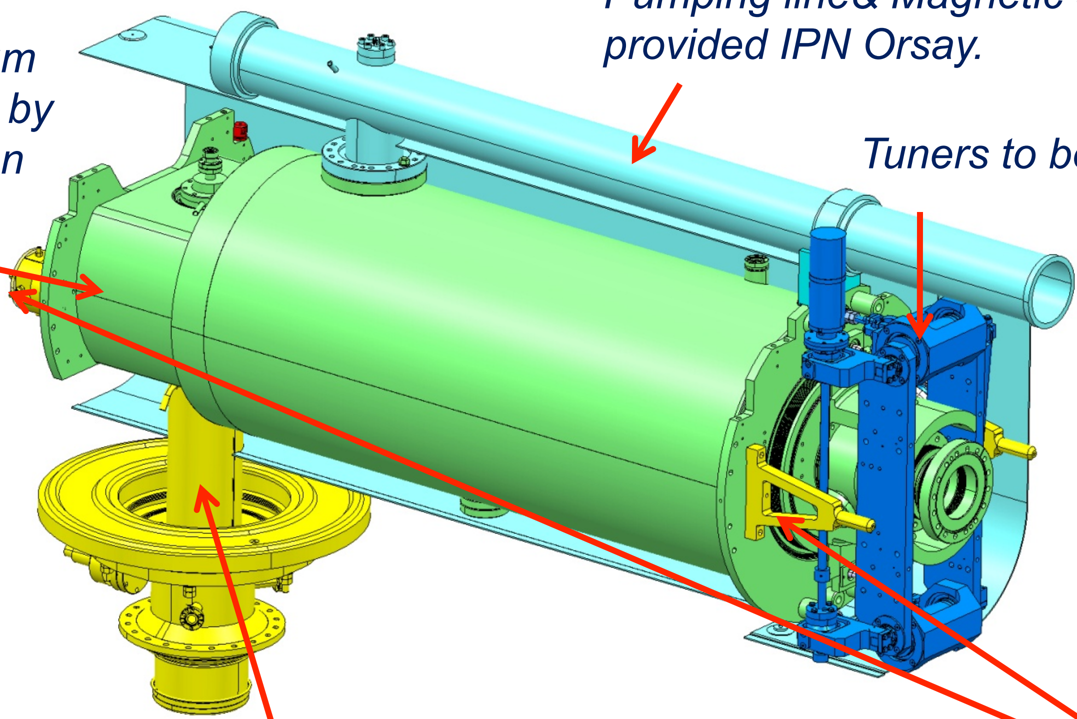
Introduction

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

Stainless steel helium tanks to be provided by CEA; to be welded on cavity by CERN.

Pumping line& Magnetic shield to be provided IPN Orsay.

Tuners to be provided by CEA.

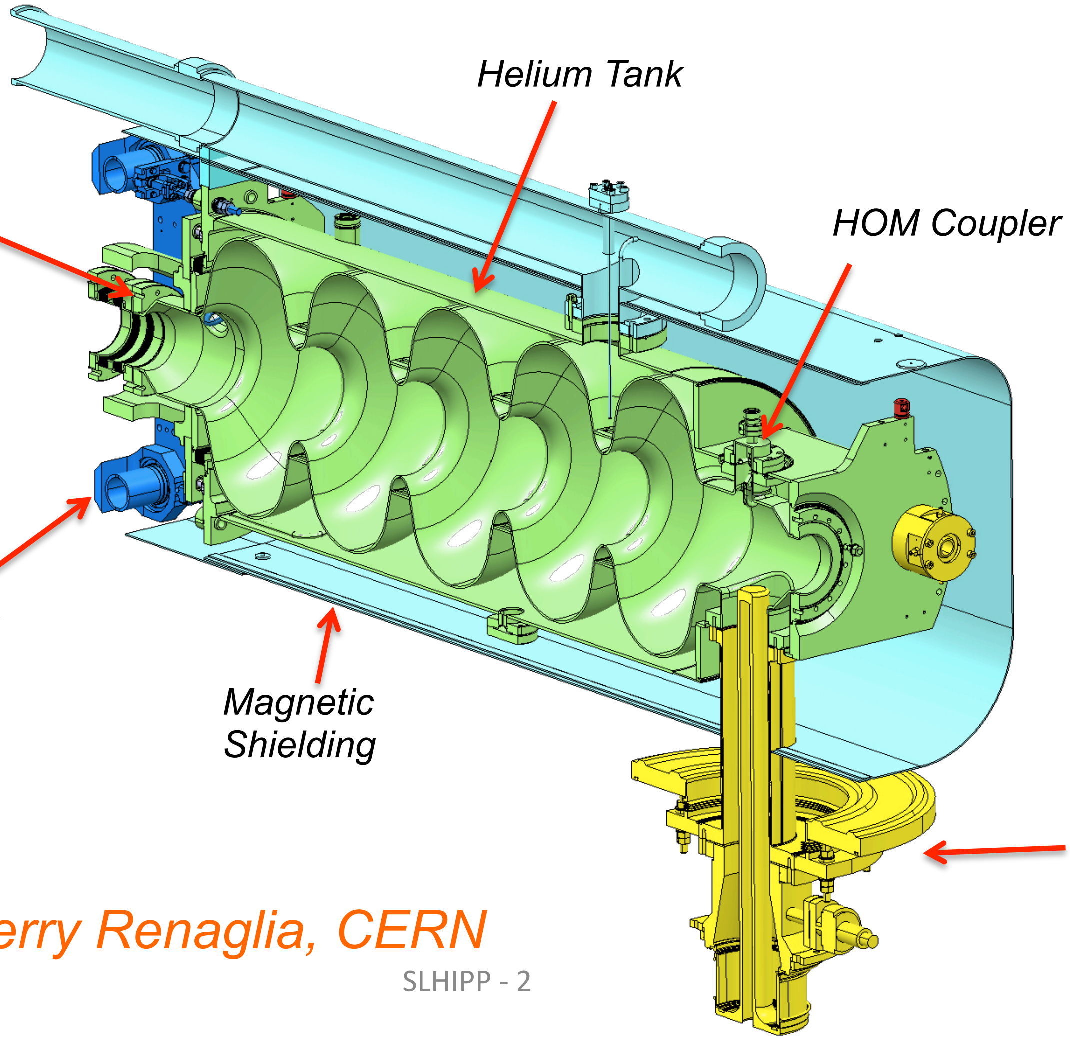


Main couplers to be provided by CERN

Design of inter-cavity supporting system by CERN

Introduction

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



Francois Pillon, Thierry Renaglia, CERN

Cavity

- Design
- Manufacturing
- Process

Cavity – design

- RF design

Juliette Plouin, CEA, 3rd SPL collaboration meeting

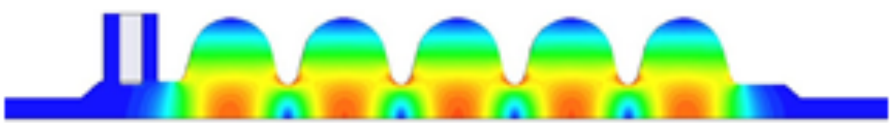
Irfu

cea saclay

RF parameters of the Saclay β = 1 cavity

	SPL	Tesla(a)	HIPPI
Number of gaps (Ngap)	5	9	5
Frequency [MHz]	704.4	1300	704.4
Beta	1	1	0.47
Bpk/Eacc [mT/(MV/m)]	4.20	4.26	5.59
Epk/Eacc	1.99	2	3.36
G [Ohm]	270	270	161
Cell to cell coupling	1.92 %	1.87 %	1.35 %
r/Q [Ohms]	566	1036	173
Beam diameter aperture [mm]	129.2	70	80
Lacc = Ngap.β.λ/2 [m]	1.0647	1.038	0.5
Maximum energy gain @ Bpk = 100 mT (MeV)	25	24	9
Operating Temperature (O.T.)	2 K	2 K	2 K
R_{BCS} @ O.T. (theoretical ♦) (nΩ)	3.2	11	3.2
Q_0 @ O.T. for R_{BCS}	$8.4 \cdot 10^{10}$	$2.5 \cdot 10^{10}$	$5 \cdot 10^{10}$

(a) : Tesla TDR, part II, 2001



♦ $R_{BCS} = 2.10^{-4}\frac{1}{T}\left(\frac{f}{1.5}\right)^2 e^{-17.67/T}$

Field pattern at 704 MHz (HFSS)

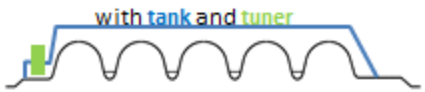
Cavity – design

- Mechanical dimensioning
  - Static (quasi-static)
    - Lorentz detuning
    - Maximum pressure / sensitivity to fluctuation
    - Deformation for tuning
    - Handling configurations
    - Thermo-mechanical
  - Natural vibration modes
  - Bucking

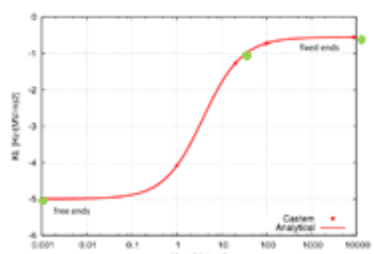
Cavity – design

- Mechanical dimensioning

Mechanical parameters of the cavity



	SPL	HIPPI
Nominal wall thickness [mm]	3	4
Cavity stiffness Kcav [kN/mm]	3.84	2.25
Tuning sensitivity Δf/Δz [kHz/mm]	164	295
K_L with fixed ends [Hz/(MV/m)²]	-0.55	-2.7
K_L with free ends [Hz/(MV/m)²]	-5	-20.3
Pressure sensitivity K_P [Hz/mbar] (fixed ends)	1.2	



The cavity will be equipped with a Saclay 4 tuner. The stiffness of the HIPPI - Saclay 4 tuner has been measured : K_{ext} 35 kN/mm

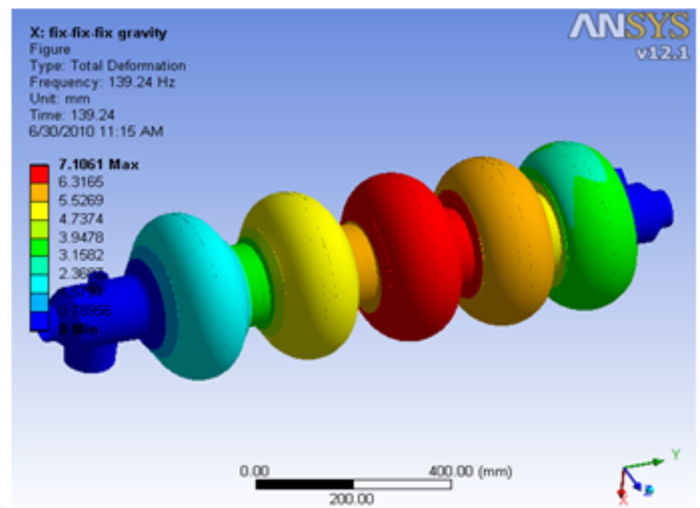
The SPL cavity equipped with this tuner would present a detuning coefficient $|K_L| = 1$ Hz/(MV/m)² ≈ $|K_L|$ estimated for Tesla

02/05/2012 SPL cavity design by CEA-Saclay – Juliette Plouin 7

Juliette Plouin, CEA, 3rd SPL collaboration meeting

Mechanical behaviour for real dimensions

- Dynamic (natural frequencies):
  - 3rd mode at ~140 Hz (longitudinal)



OC, 01/July/2 20

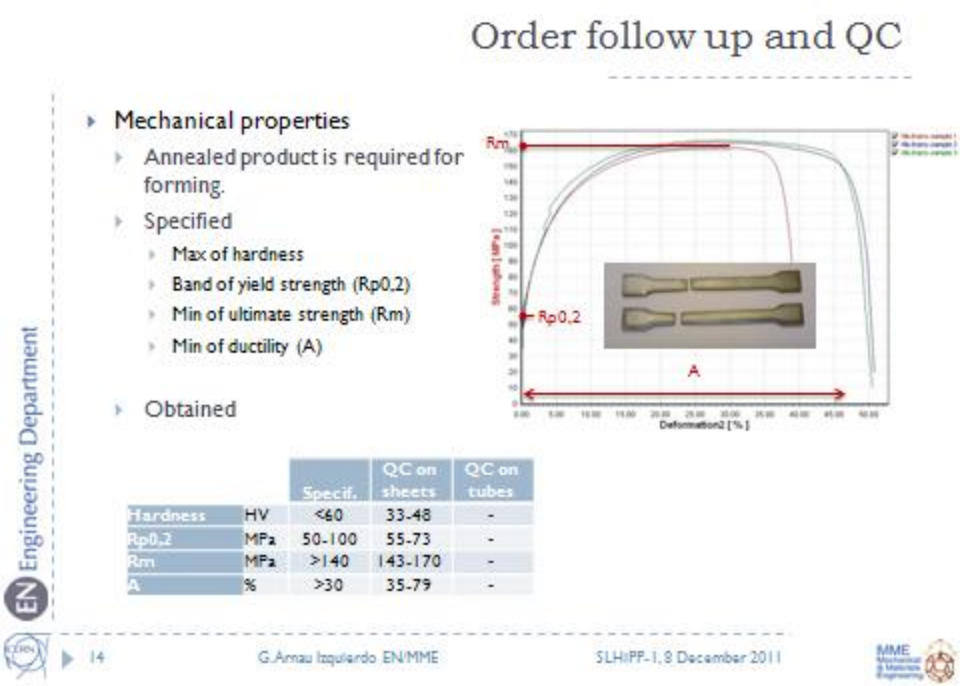
Ofelia Capatina, CERN, 4th SPL collaboration meeting jointly with ESS

Cavity - manufacturing

- Material
- Shaping
- RF tests / trimming
- Welding
- R & D

Cavity - manufacturing

- Material – Niobium supply



Order follow up and QC

- Mechanical properties
  - Annealed product is required for forming.
  - Specified
    - Max of hardness
    - Band of yield strength (Rp0.2)
    - Min of ultimate strength (Rm)
    - Min of ductility (A)
  - Obtained

		Specif.	QC on sheets	QC on tubes
Hardness	HV	<60	33-48	-
Rp0.2	MPa	50-100	55-73	-
Rm	MPa	>140	143-170	-
A	%	>30	35-79	-

Engineering Department EN

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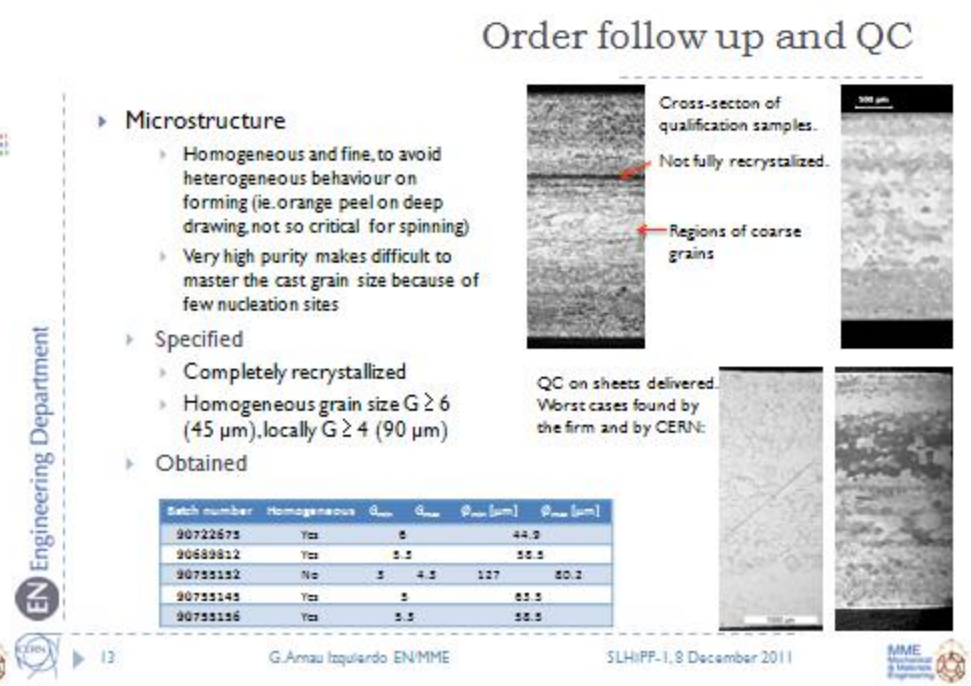

Order follow up and QC

- Microstructure
  - Homogeneous and fine, to avoid heterogeneous behaviour on forming (ie. orange peel on deep drawing, not so critical for spinning)
  - Very high purity makes difficult to master the cast grain size because of few nucleation sites
- Specified
  - Completely recrystallized
  - Homogeneous grain size G ≥ 6 (45 μm), locally G ≥ 4 (90 μm)
- Obtained

Batch number	Homogeneous	G_{min}	G_{max}	φ_{min} [μm]	φ_{max} [μm]
90722675	Yes	6		44.9	
90689812	Yes	5.5		58.5	
90755152	No	5	4.5	127	80.2
90755145	Yes	5		63.5	
90755156	Yes	5.5		58.5	

Engineering Department EN

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Gonzalo Arnau, CERN, SLHIPP – 1

Cavity – manufacturing

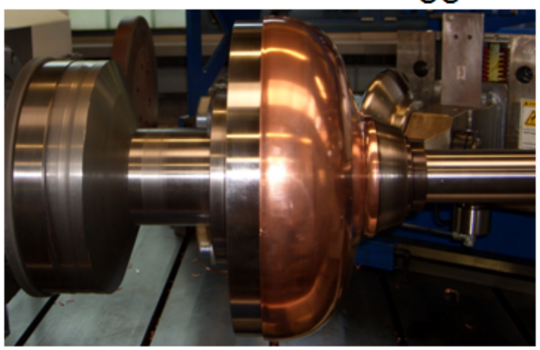
- Shaping

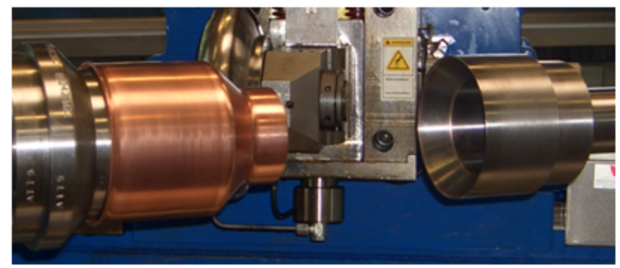
Nuria Valverde, CERN - ESS, SLHIPP – 1

Shaping of half-cells & extremities

Half-cells & extremities

Fabrication of half-cells and extremities by spinning.
Subcontracted to Heggli

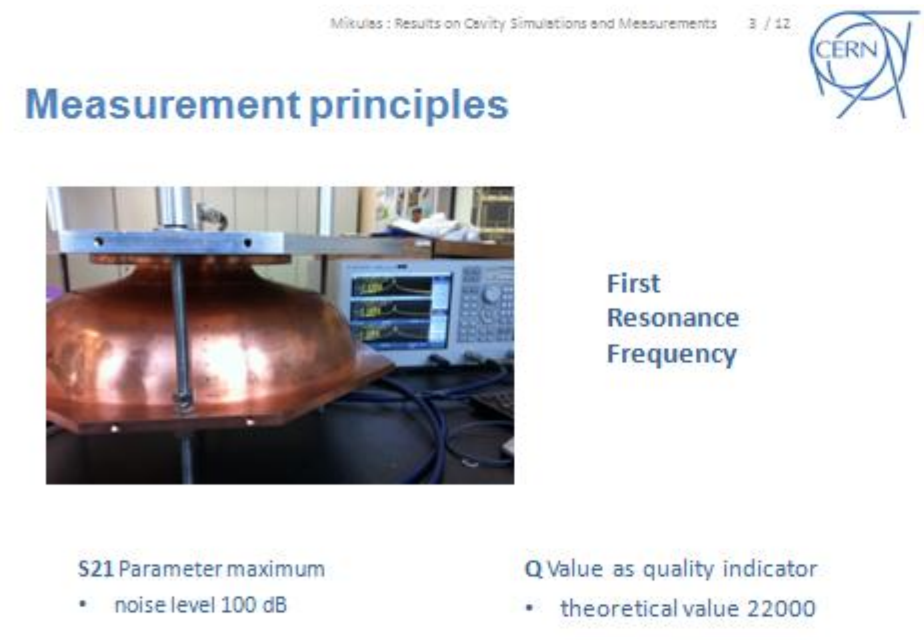


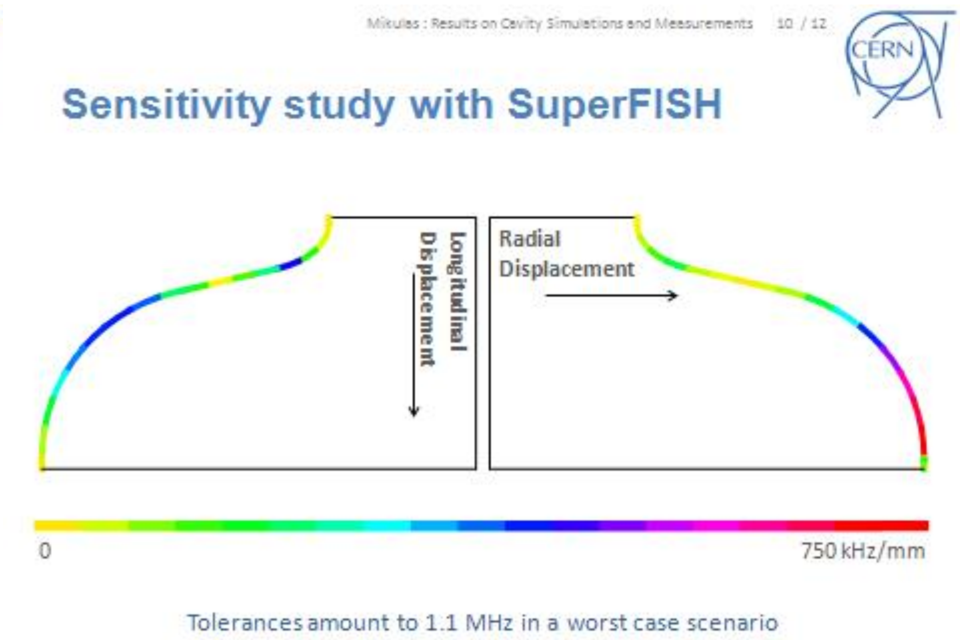


Engineering Department N. Valverde 8

Cavity – manufacturing

- RF measurements / trimming



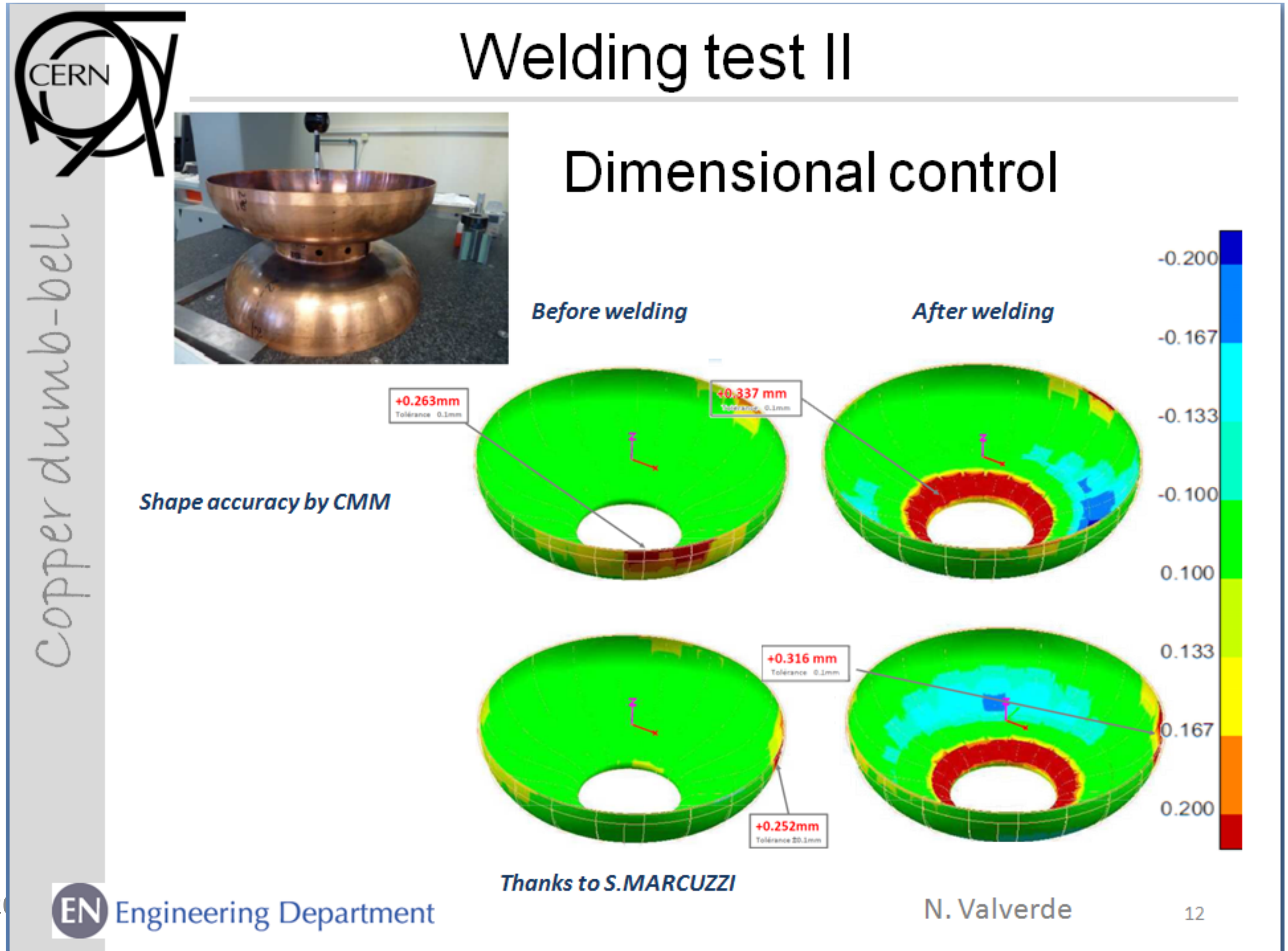


Szabina Mikulas & Nikolai Schwerg, CERN, SLHIPP – 1

Cavity – manufacturing

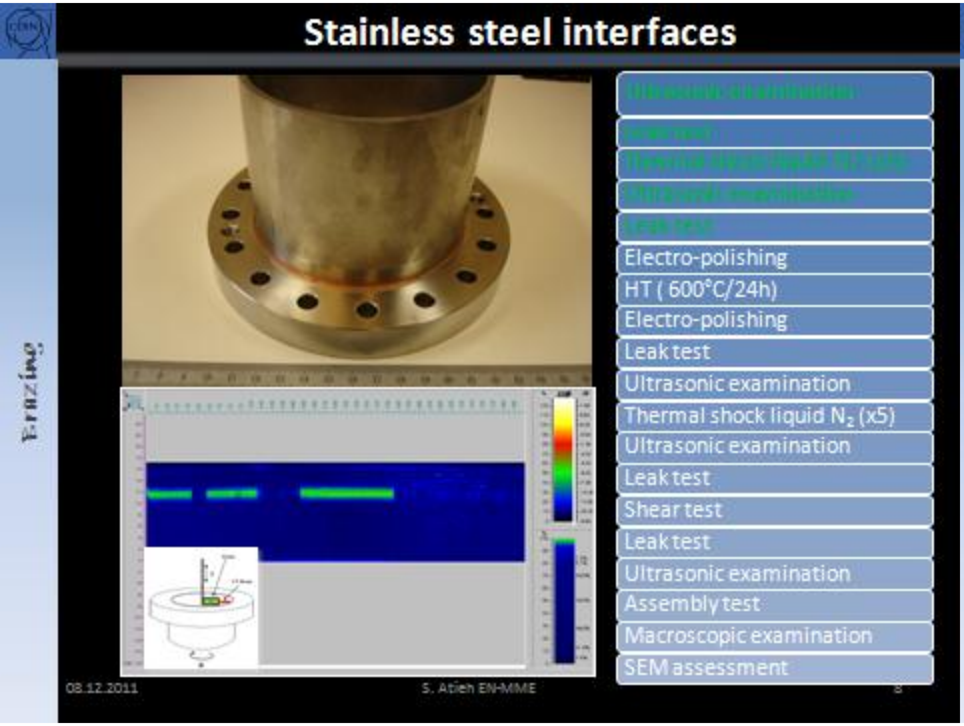
- Welding

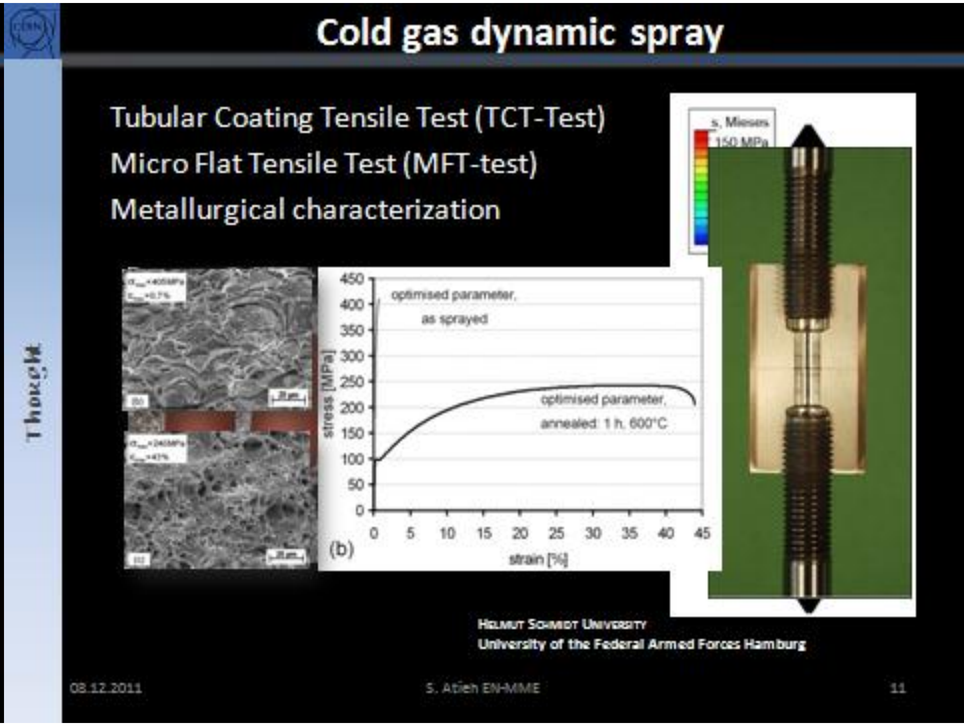
Nuria Valverde, CERN - ESS, SLHIPP – 1



Cavity – manufacturing

- Qualifications and R&D





Said Atieh, CERN, SLHIPP – 1

Cavity – process

- Cavities process: Cavities delivery to CERN.
- 1st Stage
  - 1-1 Check metrology.
  - 1-2 Optical inspection. (weld iris equator).
  - 1-3 Field flatness measurement + tuning.
  - 1-4 Electrolytic polishing “hard” (thickness 140 µm).
  - 1-5 HPWR to remove residuals from EP (criteria TBD).
  - 1-6 Optical inspection. (weld iris equator).
  - 1-7 HV annealing at 600°C (1 – 2 h, 10-5 – 10-6 mbar).
  - 1-8 Optical inspection. (weld iris equator)
  - ***1-9 Front tank welding.***
  - 1-10 Field flatness measurement + re-tuning if needed.
  - 1-11 Electrolytic polishing “Short”(Thickness 20 µm).
  - 1-12 HPWR in SM18 clean room.
  - 1-13 Closing of cavity, assembly of pickup probes and vacuum valves, drying by pumping, all in SM18 clean room; storage under vacuum.

Cavity – process

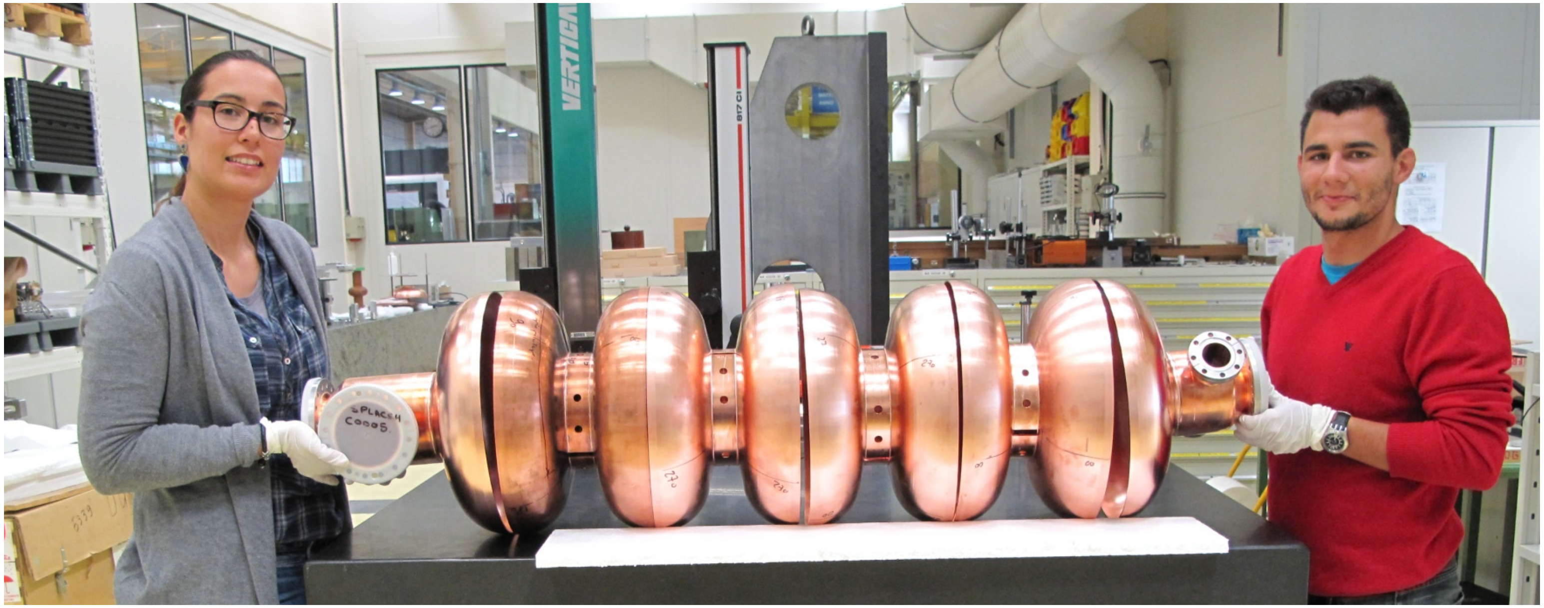
- 2nd Stage
  - 2-1 Assembly on vertical cryostat.
  - 2-2 Baking at 120°C.
  - 2-3 Cold RF test in vertical cryostat (at CERN).
- 3rd Stage
  - 3-1 Analysis of RF test; if OK go to 4th stage.
  - 3-2 If not, either (if no quench) go to 2nd stage "HPWR in SM18 clean room".
  - 3-3 or (if quench) go to optical inspection for identification of problem, mechanical intervention, short CP, etc.
- 4th Stage
  - 4-1 Disassembling in SM18 clean room the pickup probes and vacuum valves, cavity under protective gas at overpressure
  - ***4-2*** ***Welding of the helium tank.*** Tuner assembly test.

    Locator structure socket cavity axis(with cavity under protective gas)
  - 4-3 Leak test of He tank
  - 4-4 Storage of cavity in SM18 clean room cabinet.

Cavity – process

- 5th Stage
  - 5-1 Assembling of the string of the 4 cavities in SM18 clean room with the pickup probes, couplers and gate valves.
  - 5-2 Pumping, leak test and baking in SM18 clean room.
- 6th Stage
  - 6-1 Assembling tuner.
  - 6-2 Assembling full cryo-module outside clean room.
  - 6-3 Horizontal cold test in bunker.

Cavity

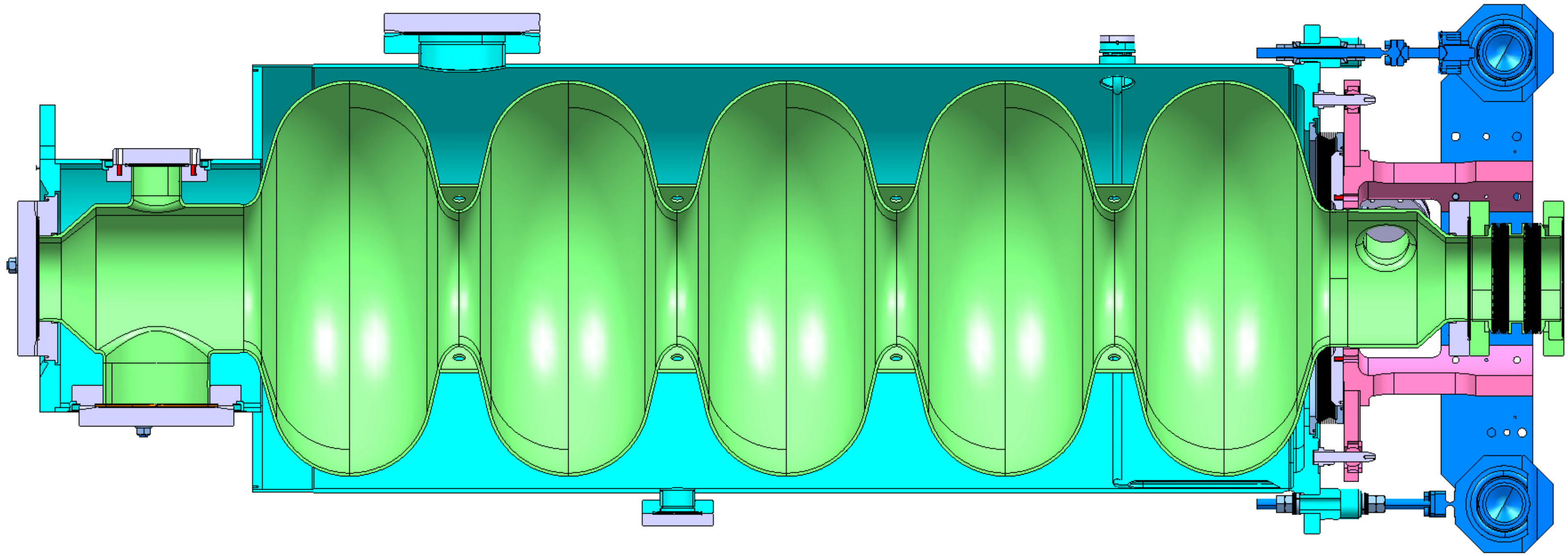


- Designed for ideal shape
- Manufactured at warm (+ processing)
- Has to work at the right frequency at cold (2 K)
- It deforms at cold during functioning (Lorentz forces, helium pressure fluctuation)

Cavity

- It deforms at cold during functioning
  - Deformation limited by the cavity design (wall thickness, reinforcement rings)
  - Also limited by a proper helium tank and tuner design (as boundary conditions for the cavity)

Helium tank



Helium tank

- Heat load to superfluid helium extraction
- Boundary condition to cavity => Stiffness
- Material choice
  - Interfaces
  - Tuning principle + tuner range

Helium tank – heat load extraction

- Operation point: saturated He II at 2 K

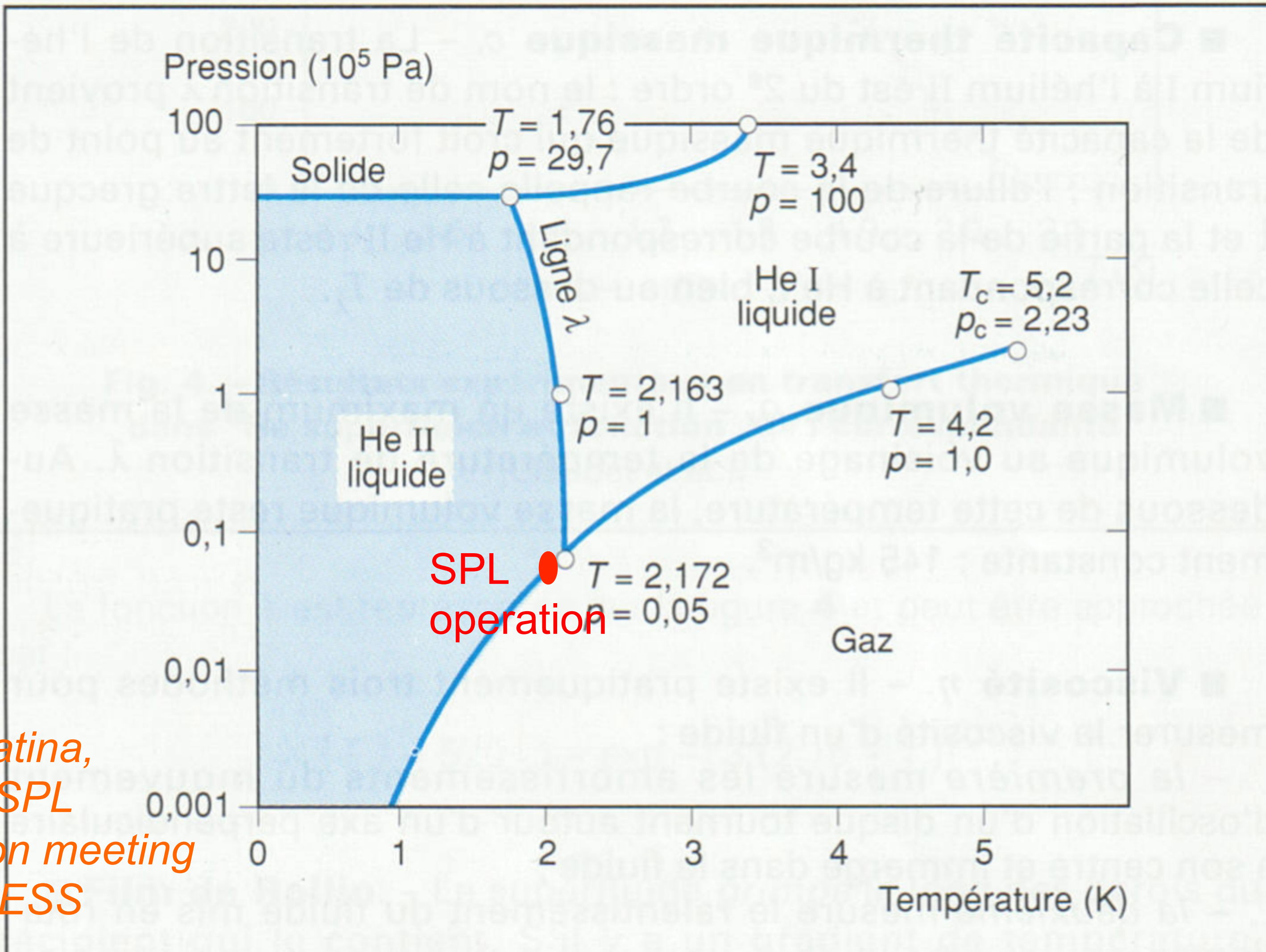


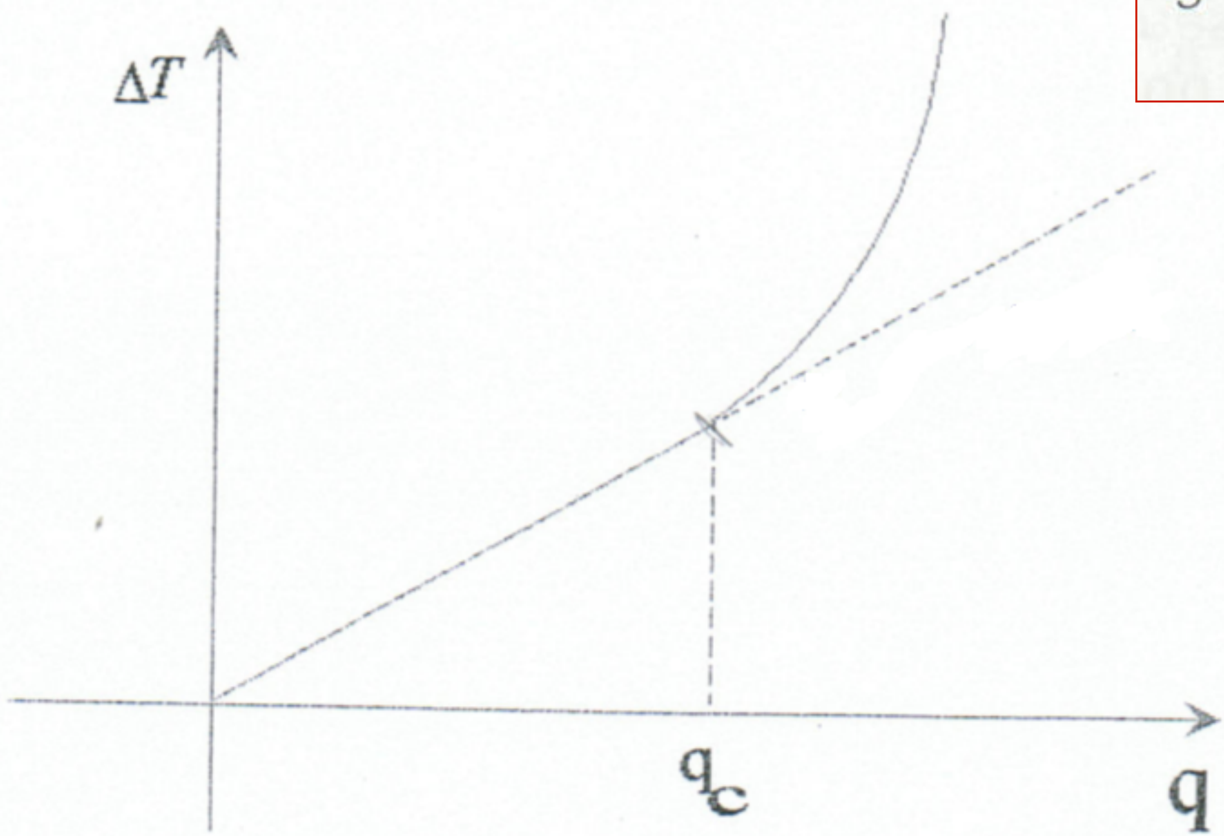
Fig. 1. – Diagramme de phase de ^{4}He.

Ofelia Capatina, CERN, 4th SPL collaboration meeting jointly with ESS

Helium tank – heat load extraction

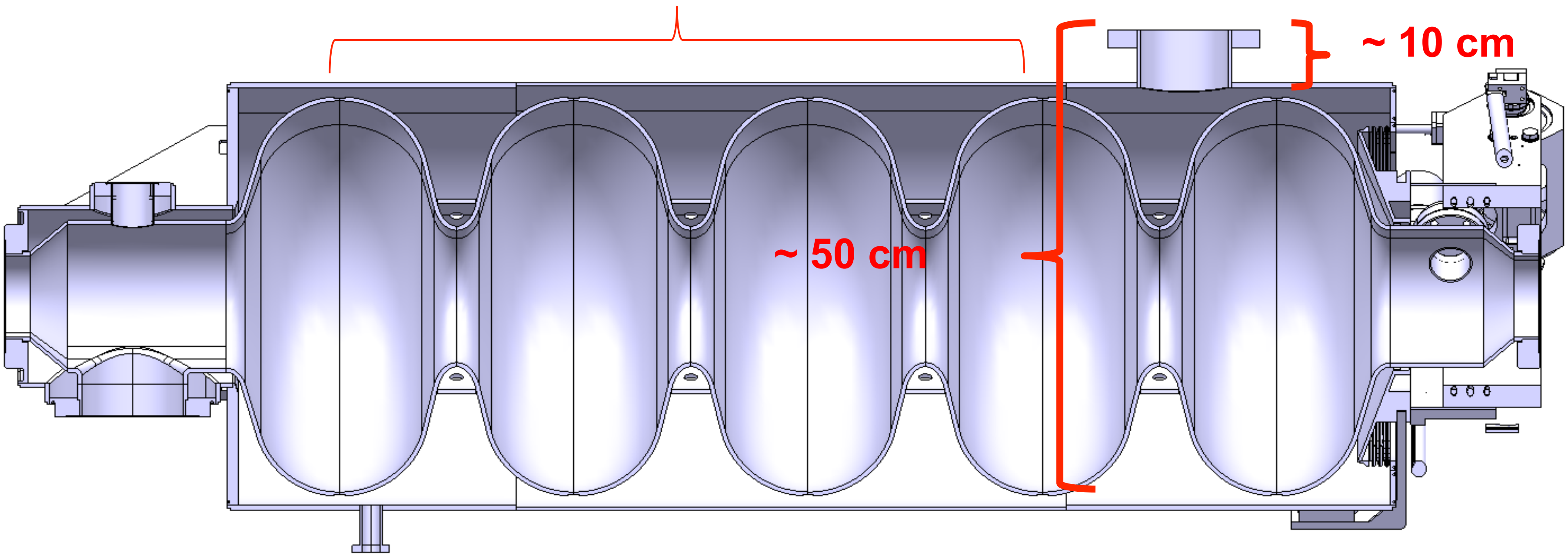
- Heat flux in He II depend on bath temp. and channel dimension

$$\frac{\dot{Q}}{s} = \left[\frac{X(T_f) - X(T_c)}{l}\right]^{0,29}$$



Helium tank – heat load extraction

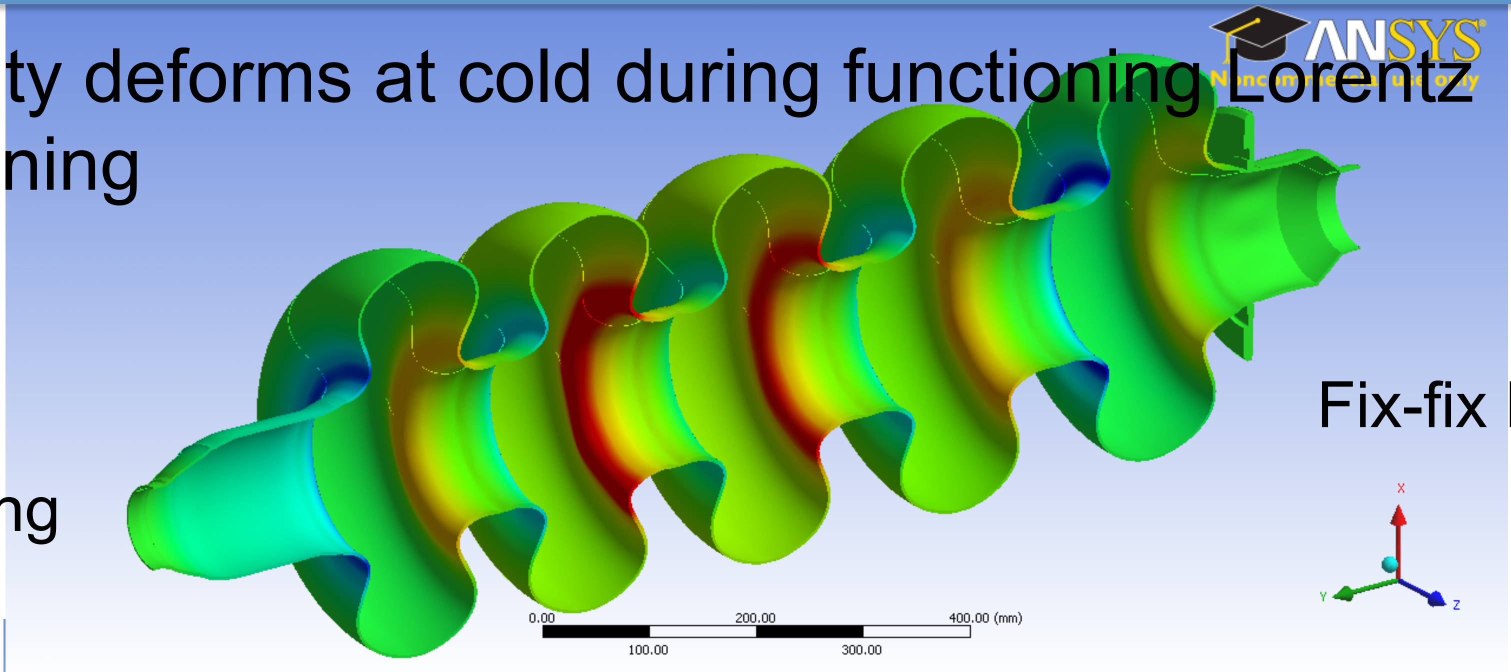
- Heat load from 0.8 – 1.5 W/cm^2 => Tank dimensions accordingly to extract dynamic heat load 20 W



Helium tank – BC to cavity

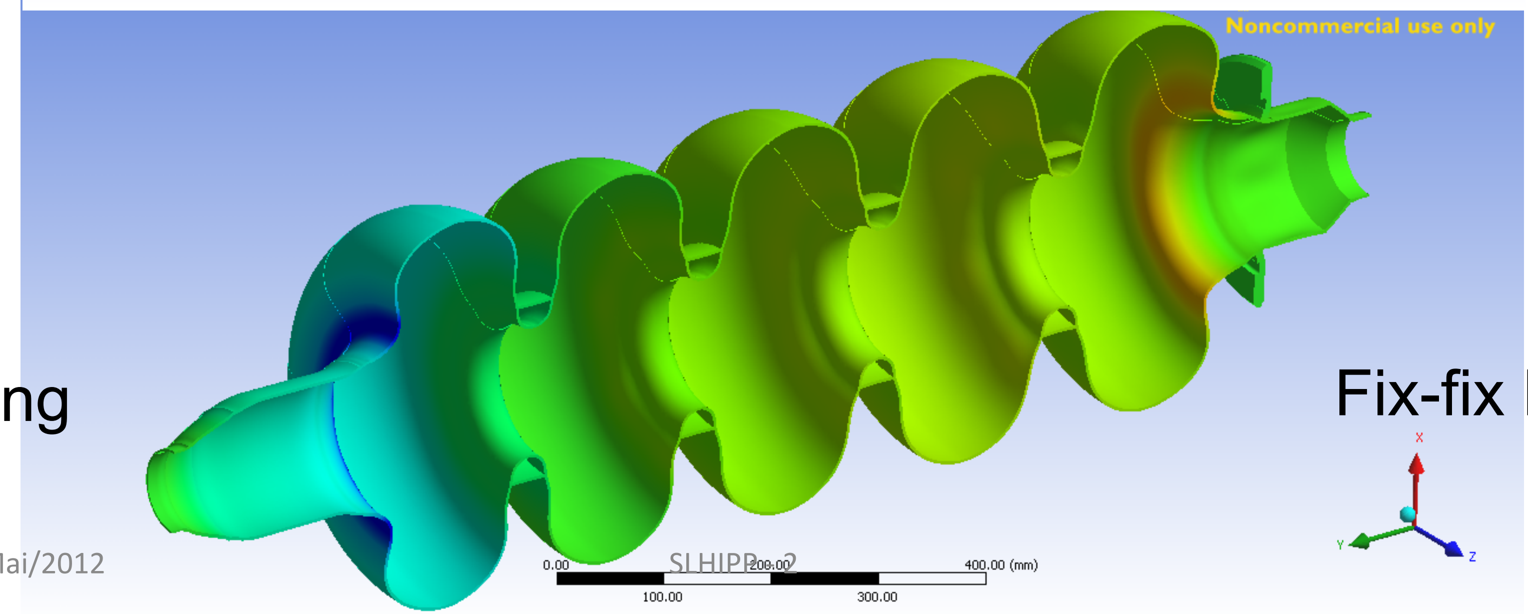
- Cavity deforms at cold during functioning Lorentz detuning

No stiffening rings



Fix-fix BC

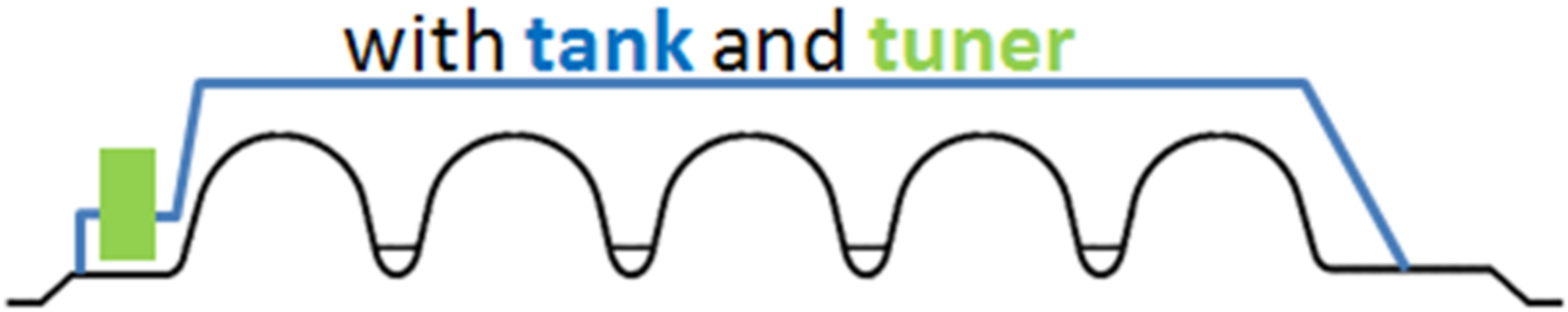
With stiffening rings



Fix-fix BC

Helium tank – BC to cavity

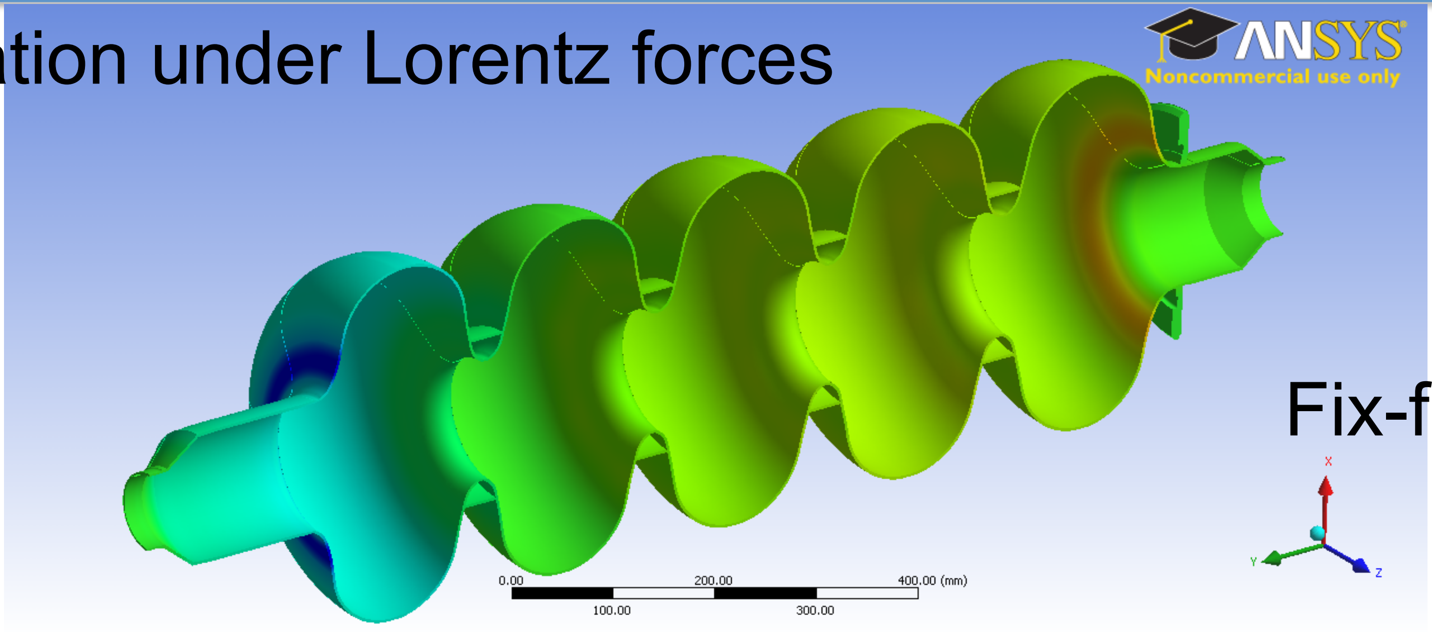
- Helium tank + tuner act as boundary conditions to cavity => different stiffness gives different deformation of cavity due to Lorentz forces



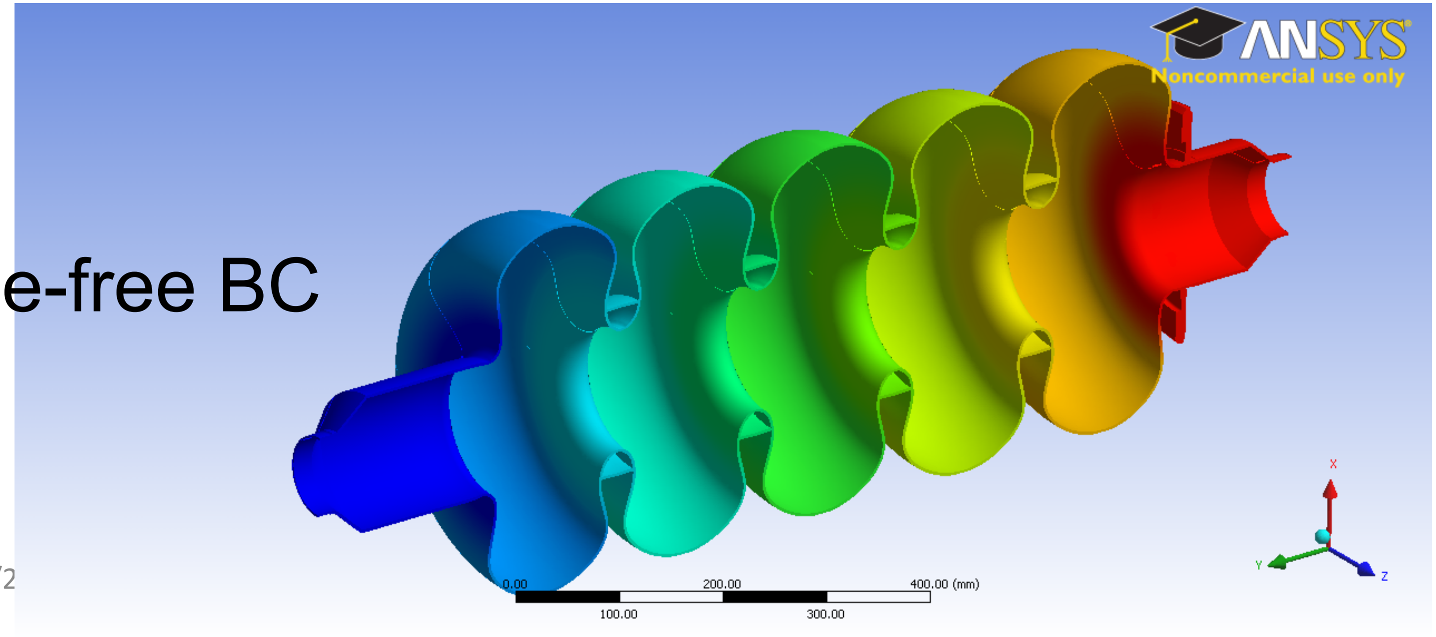
- Zero tank + tuner stiffness equivalent to free-free BC for cavity
- Infinite tank + tuner stiffness equivalent to fix-fix BC for cavity

Helium tank – BC to cavity

deformation under Lorentz forces



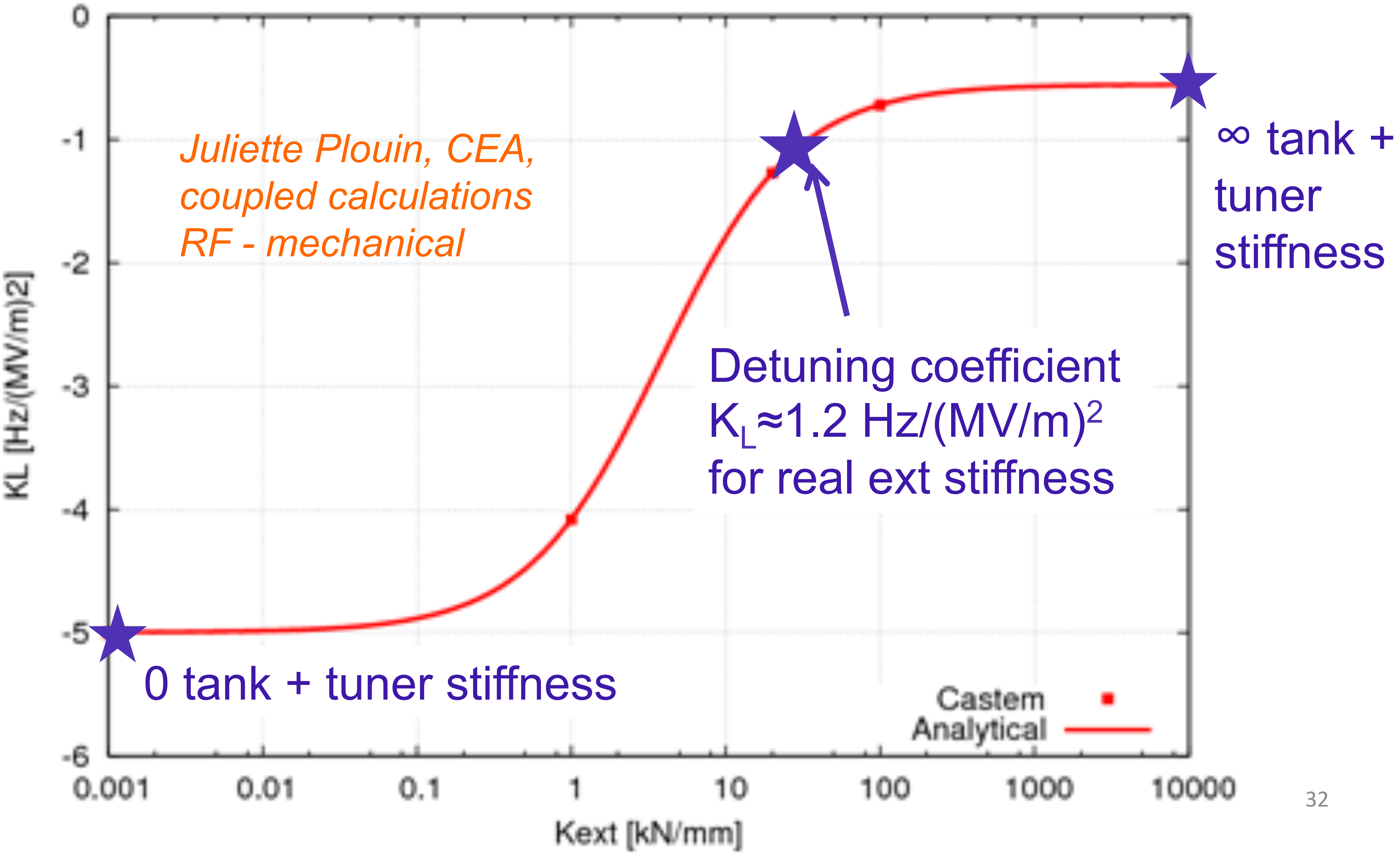
Fix-fix BC



Free-free BC

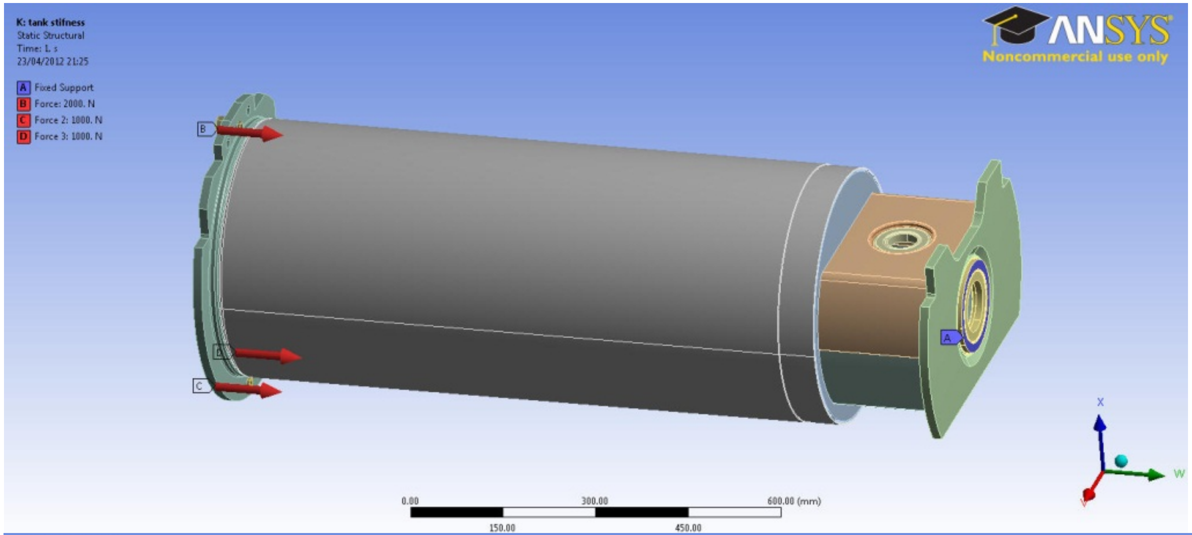
Helium tank – BC to cavity

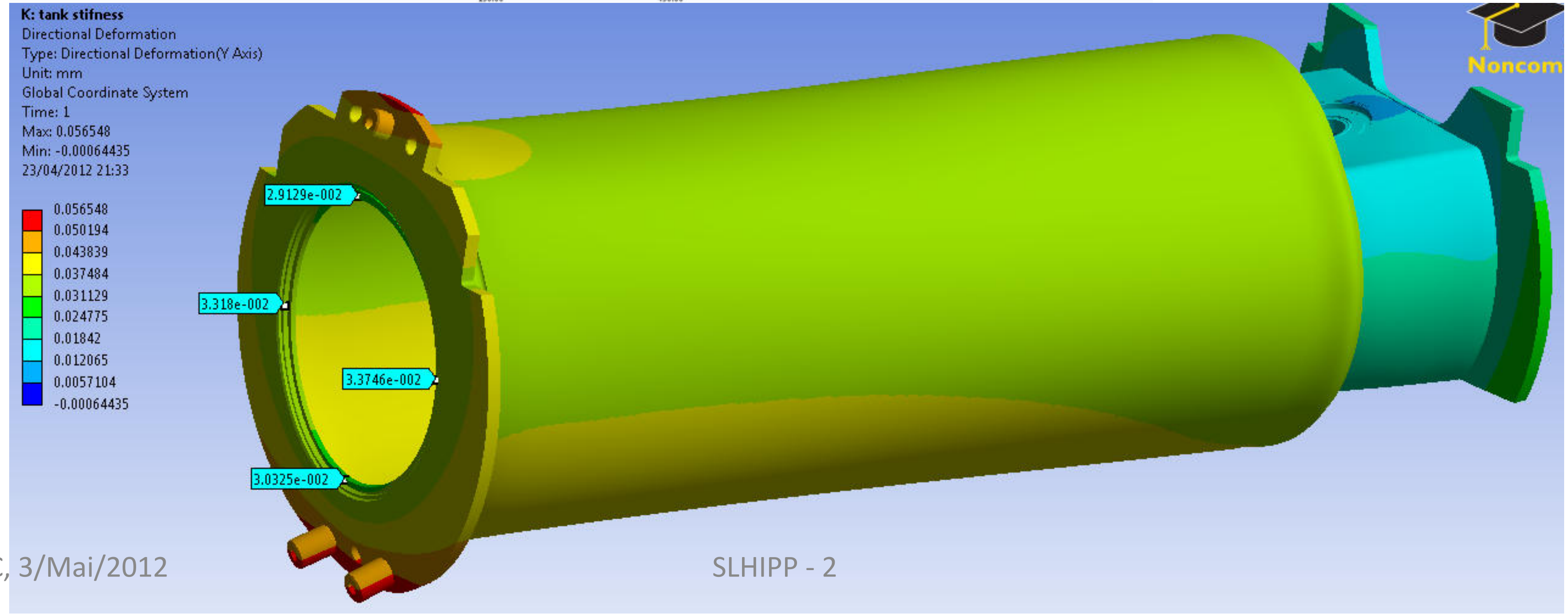
- Lorentz detuning => min helium tank stiffness 100 kN/mm



Helium tank – BC to cavity

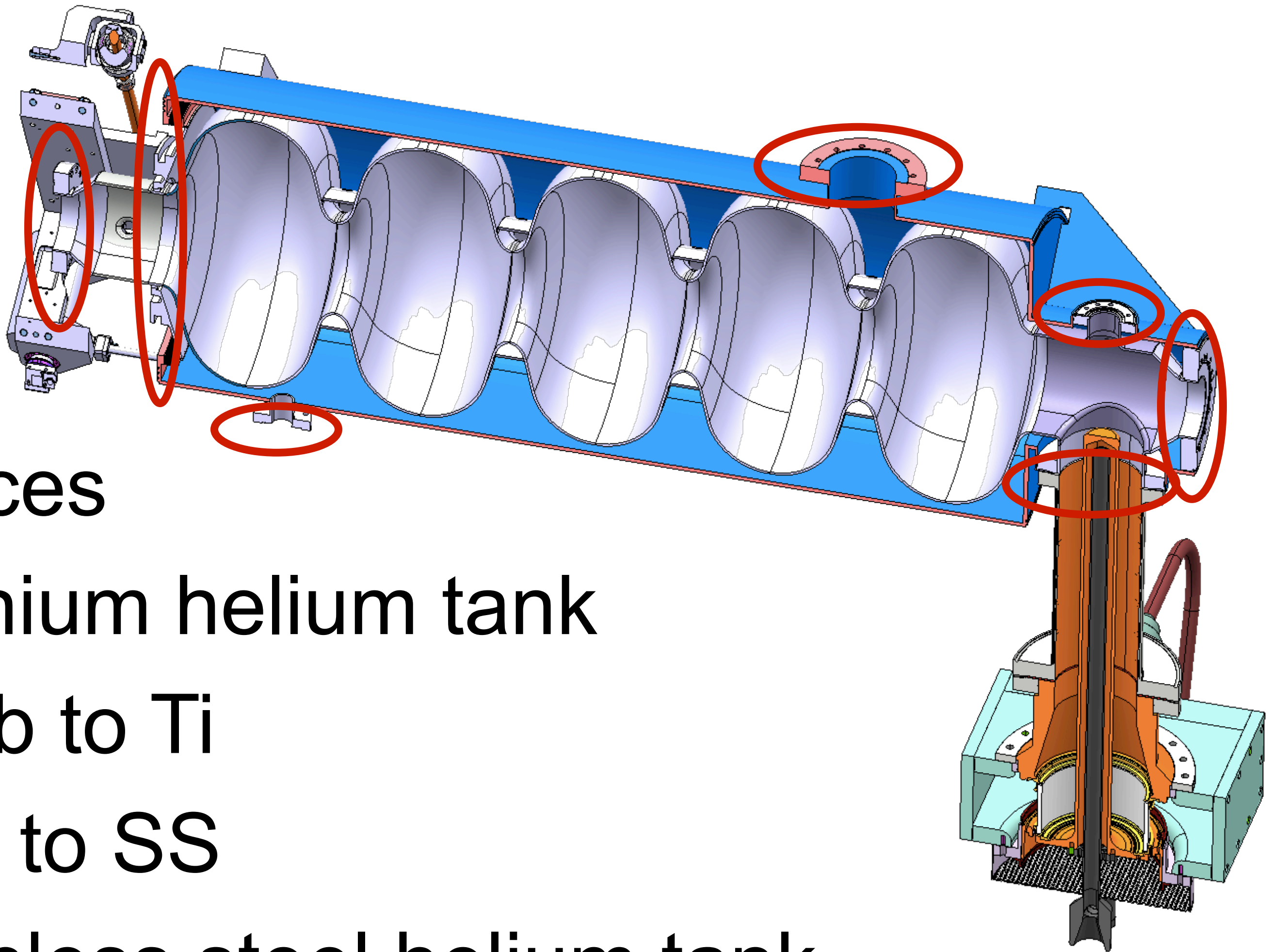
- Calculated SS tank stiffness 130 kN/mm





Marco Esposito, CERN

Helium tank – material choice



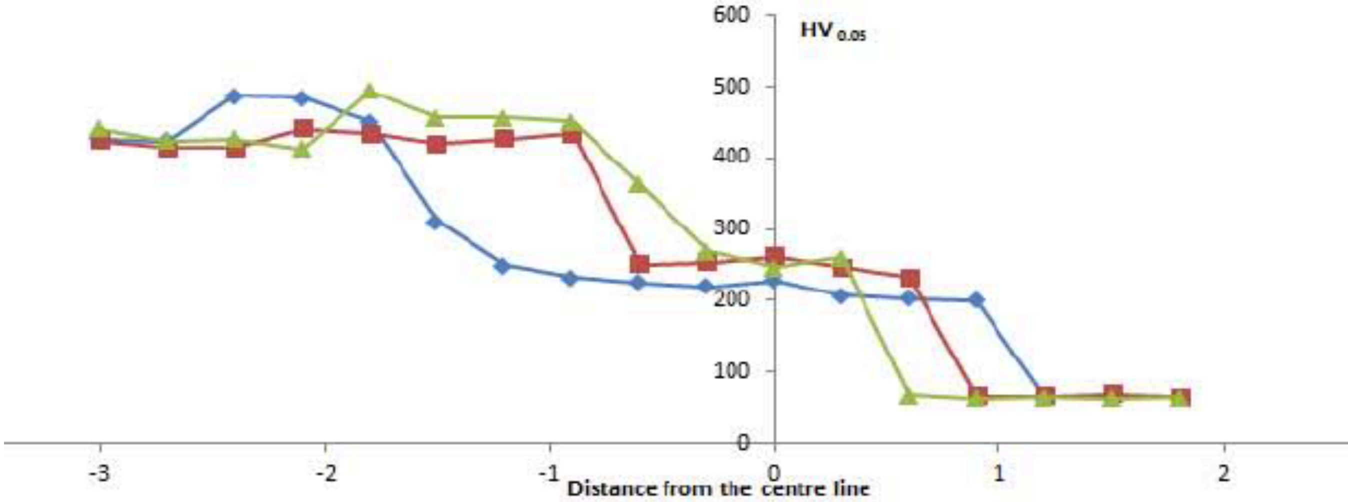
- Interfaces
  - Titanium helium tank
    - Nb to Ti
    - Ti to SS
  - Stainless steel helium tank
    - Nb to SS

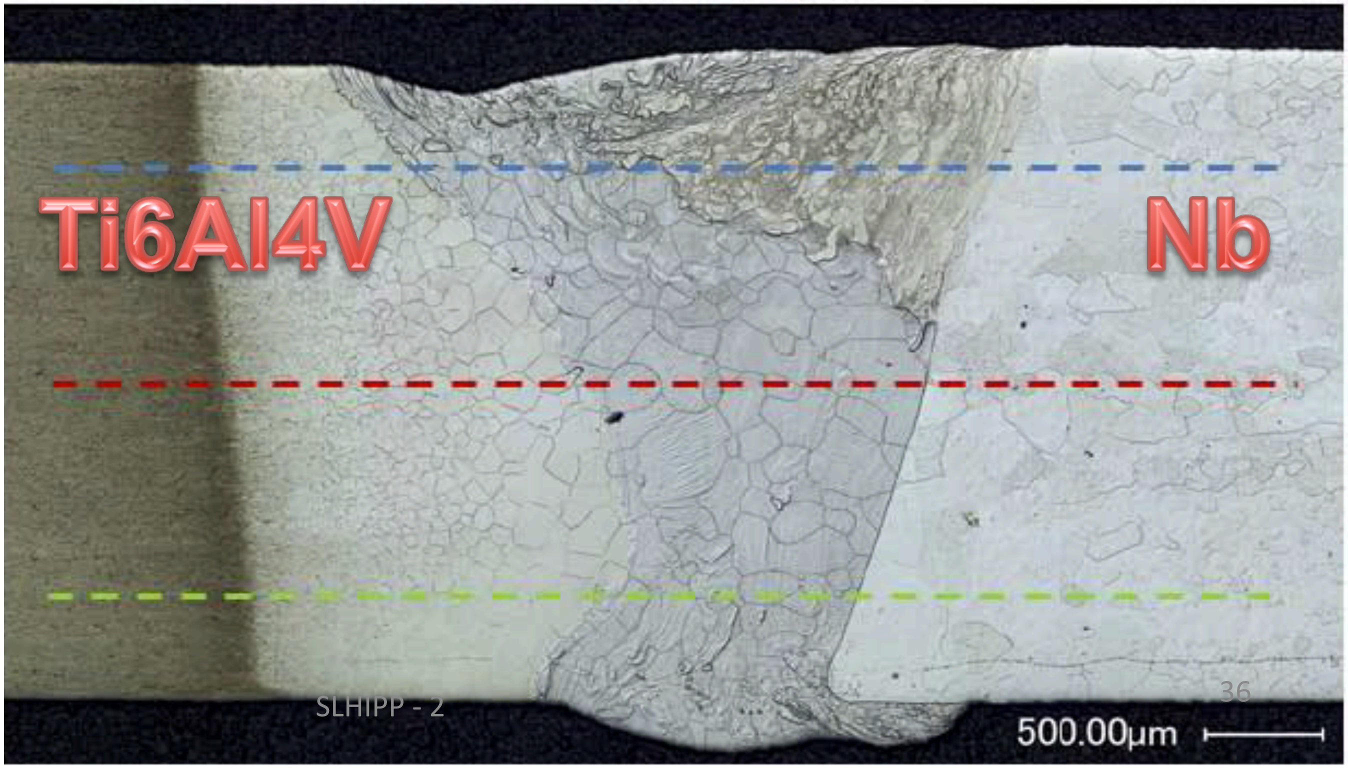
Helium tank – material choice

- Niobium to titanium
  - DESY XFEL choice:
    - EB welding Nb to NbTi and NbTi to Ti grade 2
    - NbTi flanges
  - Choice motivated by the stability of the mechanical properties after HT at 1400ºC
  - 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 (alloy) for flanges and transition to helium tank

Helium tank – material choice

- Niobium to titanium grade 5 (Ti6Al4V) EB welding successfully tested before and after heat treatment at 800 C





Helium tank – material choice

- Titanium to stainless steel
  - By flange connection

CF flange SS 316LN + OFE copper + CF flange Ti6Al4V, liquid nitrogen tests

Helium tank – material choice

- Niobium to stainless steel - vacuum brazing

Brazing test I

Brazing Nb / SS 316 LN is a key technology

Developed at CERN in 1987

Difference in thermal expansion of Nb/SS

Nb tube fitted to SS flange

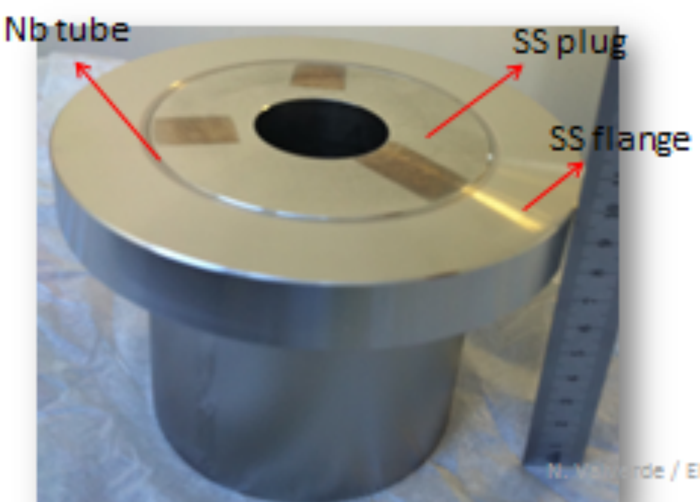
Clearance ≤ 20 µm

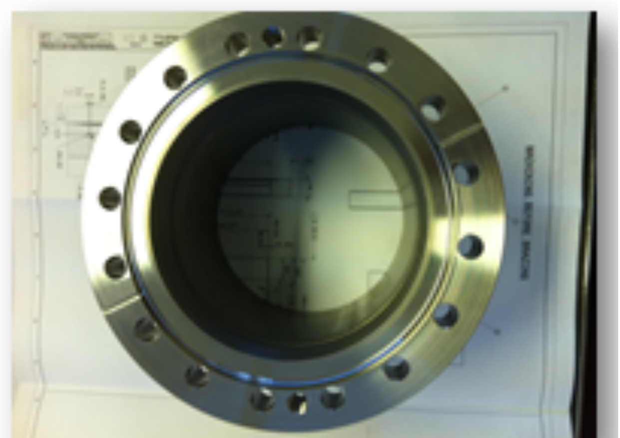
SS plug to expand the Nb

Pure Cu filler metal

Brazing temperature 1100°C, Δ_{time} <<

P< 10^{-5} mbar

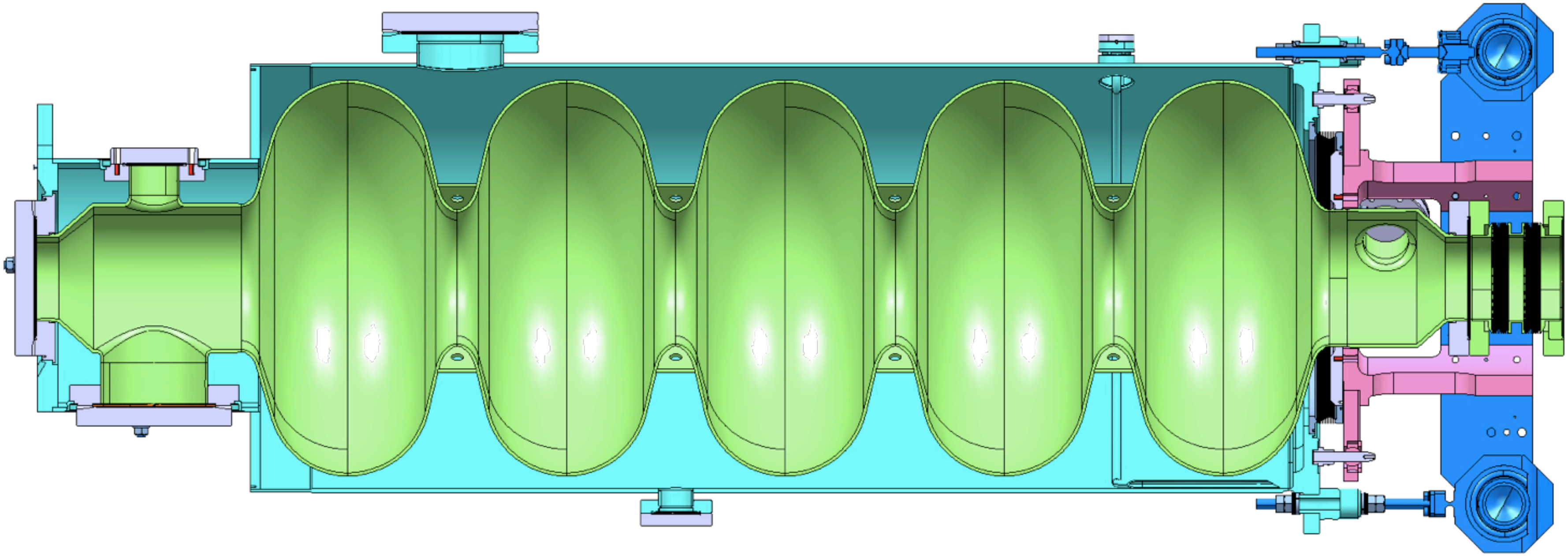




Flange after machining the SS plug

Helium tank – material choice

- Baseline for cavities developed at CERN Stainless steel helium tank
  - Differential thermal contraction between cavity and helium tank during cool-down

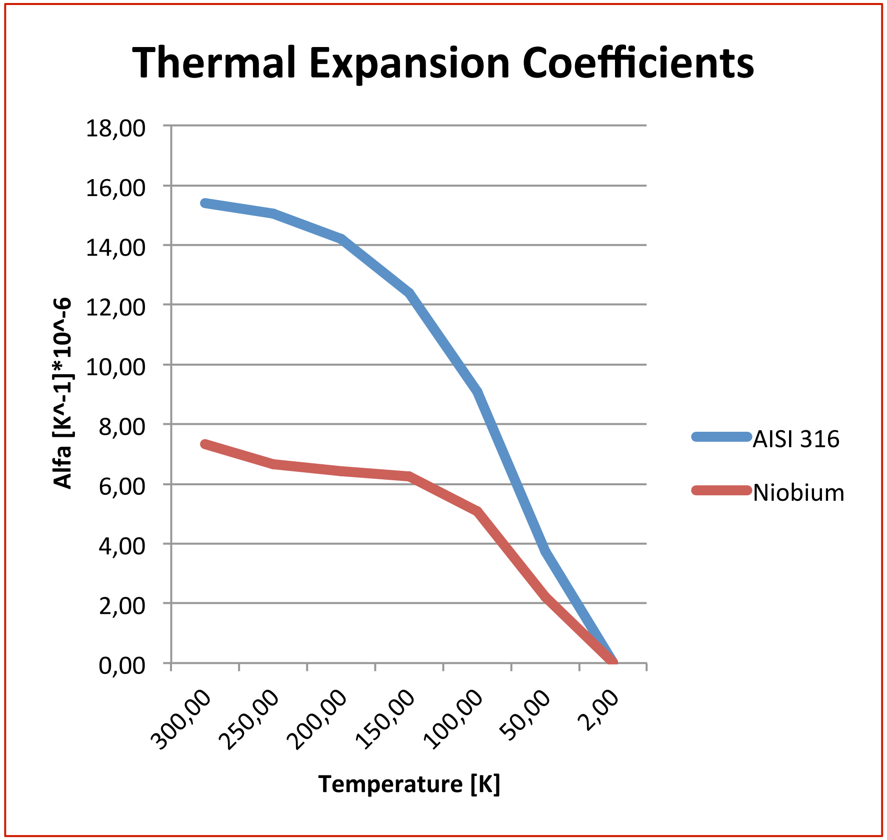


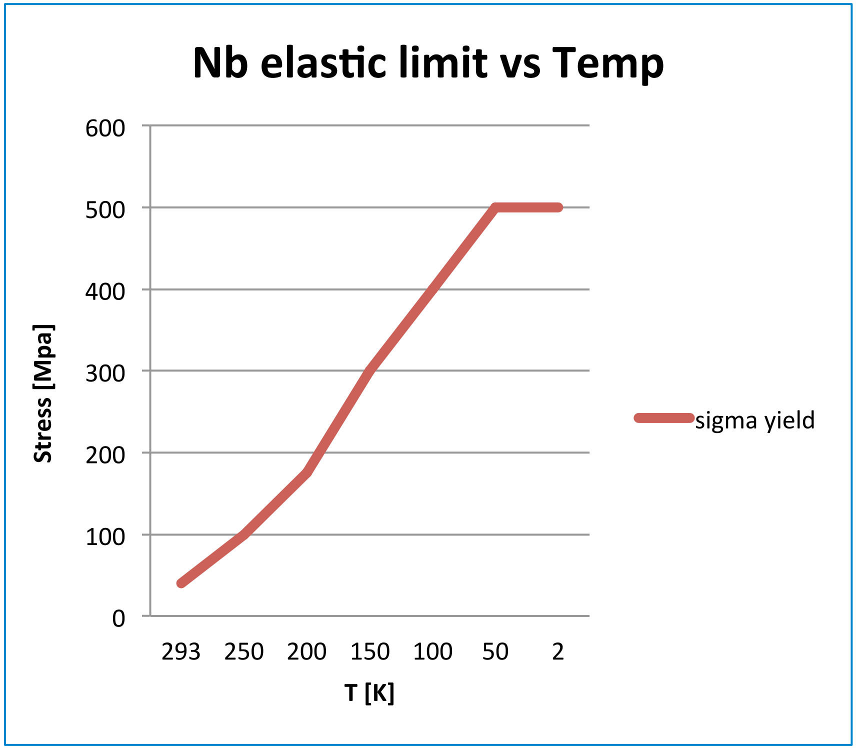
Helium tank – material choice

Material properties

Moduli of elasticity
E_{inox}= 190-210 Gpa
E_{Nb}= 105GPa

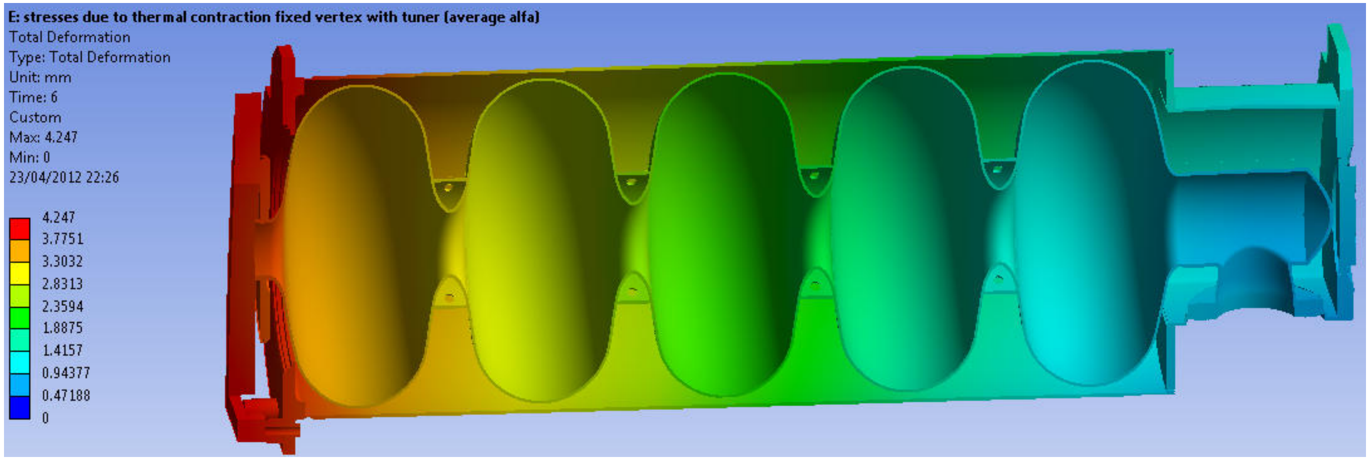
AISI316
resistance:
σ_y>200MPa
σ_r>500MPa



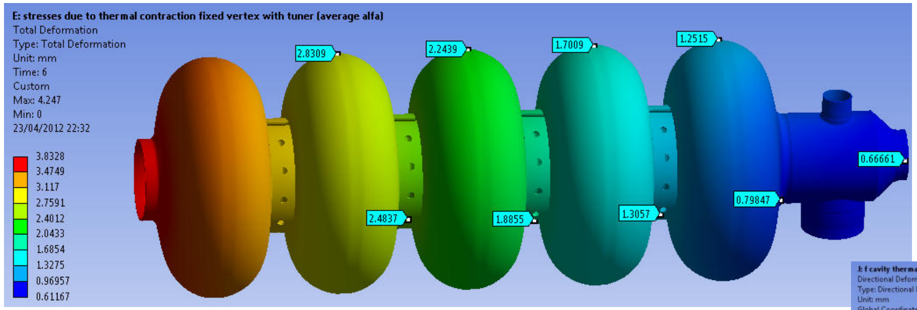


Helium tank – material choice

Thermal contraction deformation during cool-down

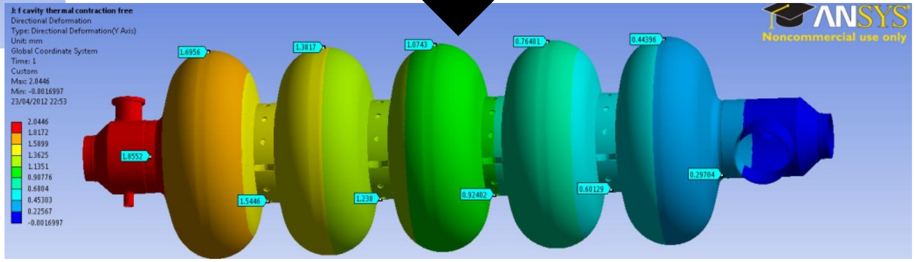


Final deformed shape of the assembly @ 2K



Deformed shape of cavity connected to tank

Deformed shape of cavity free



Max constrained : $\Delta s_c \approx 3mm$

Max free : $\Delta s_f \approx 1.5mm$

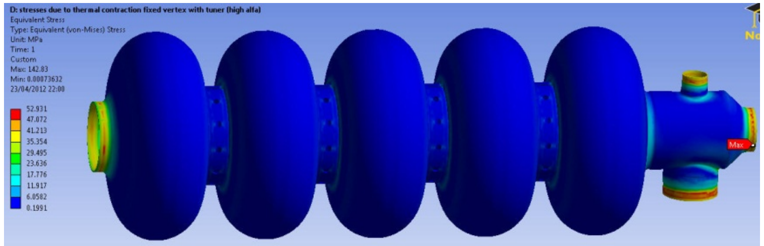
difference: $\Delta s_c - \Delta s_f \approx 1.5mm$

Marco Esposito, CERN

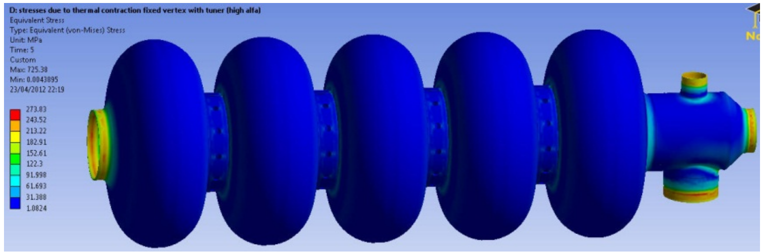
Helium tank – material choice

Thermal stresses during cool-down

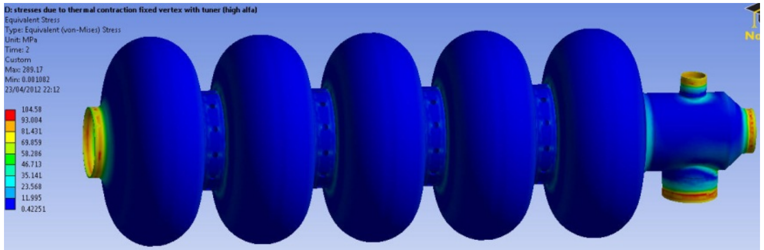
250K
Max
53MPa



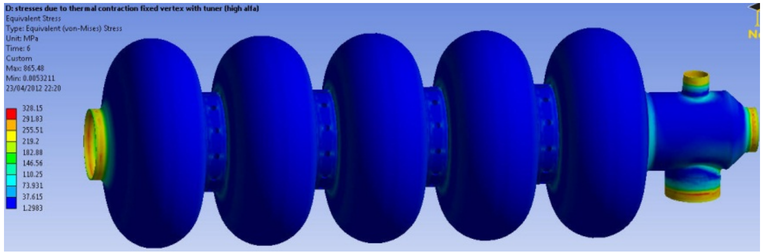
50K
Max
274MPa



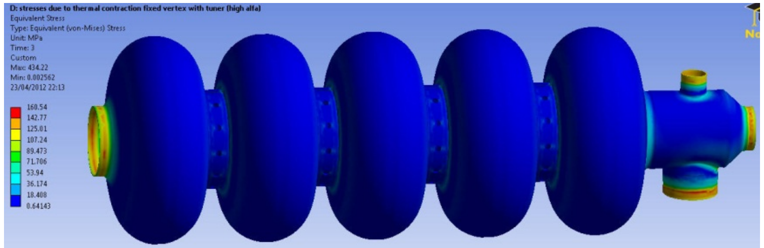
200K
Max
105MPa



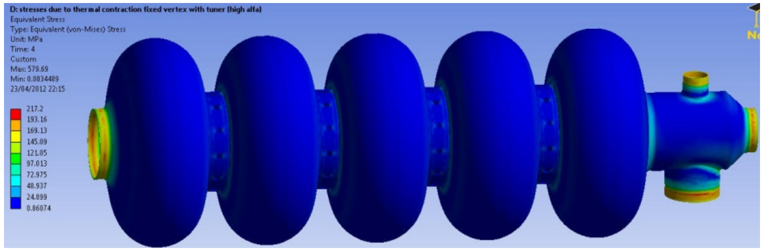
2K
Max
328MPa

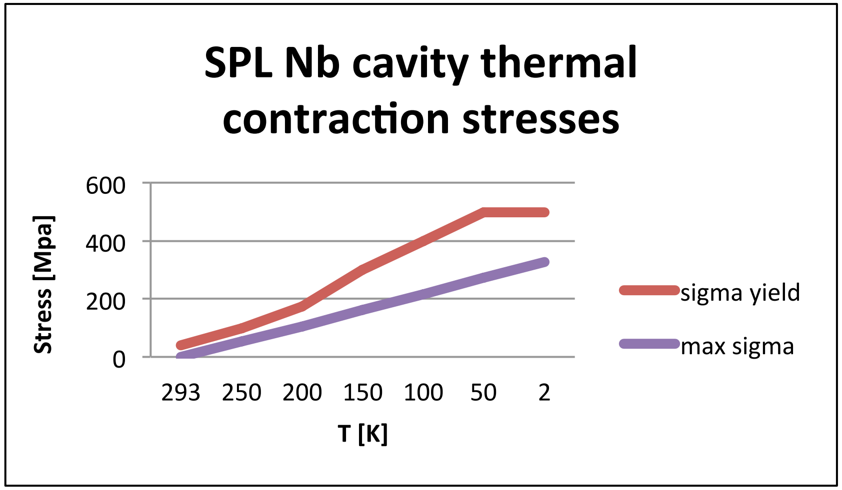


150K
Max
161MPa



100K
Max
217MPa

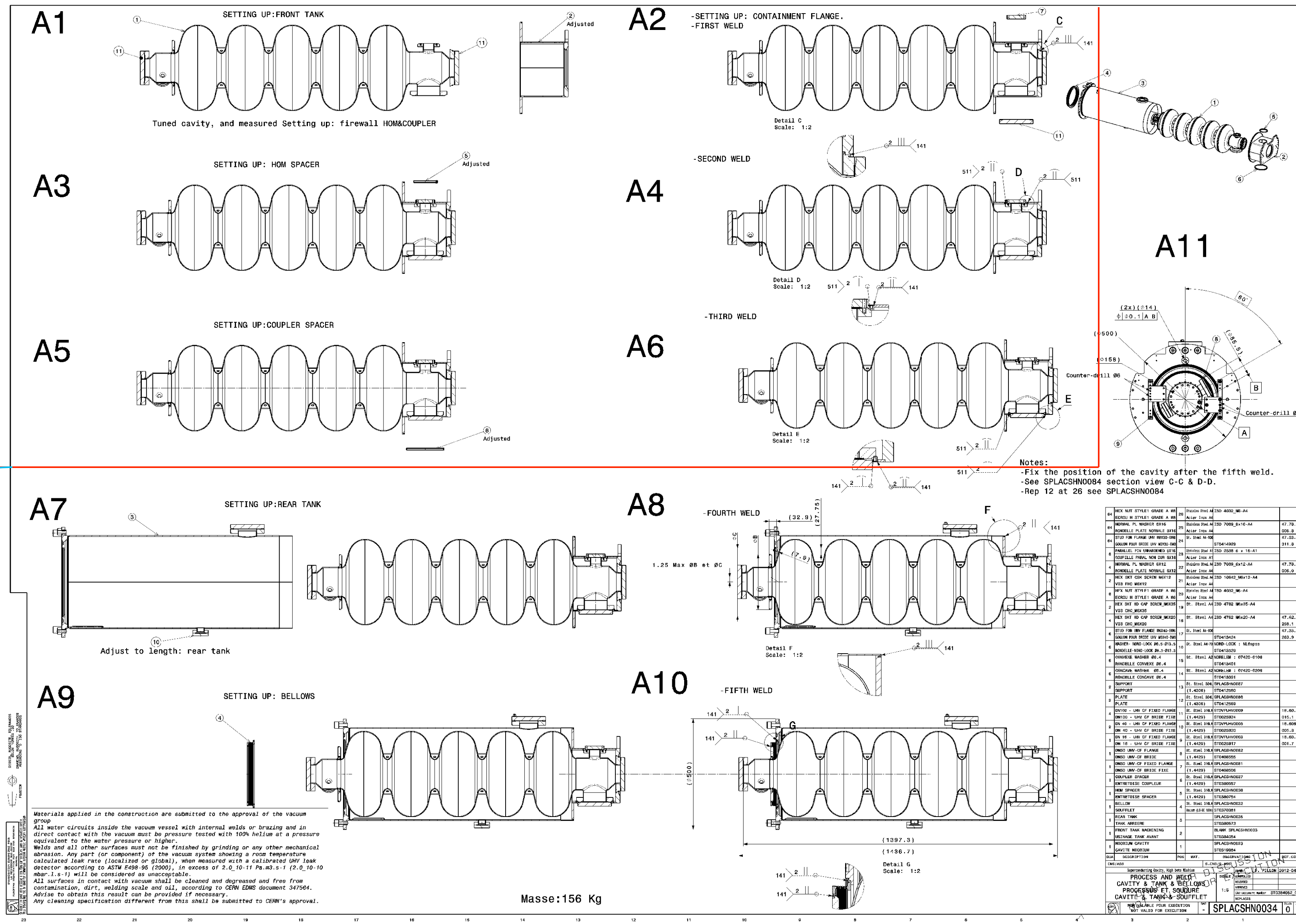




Helium Tank manufacturing

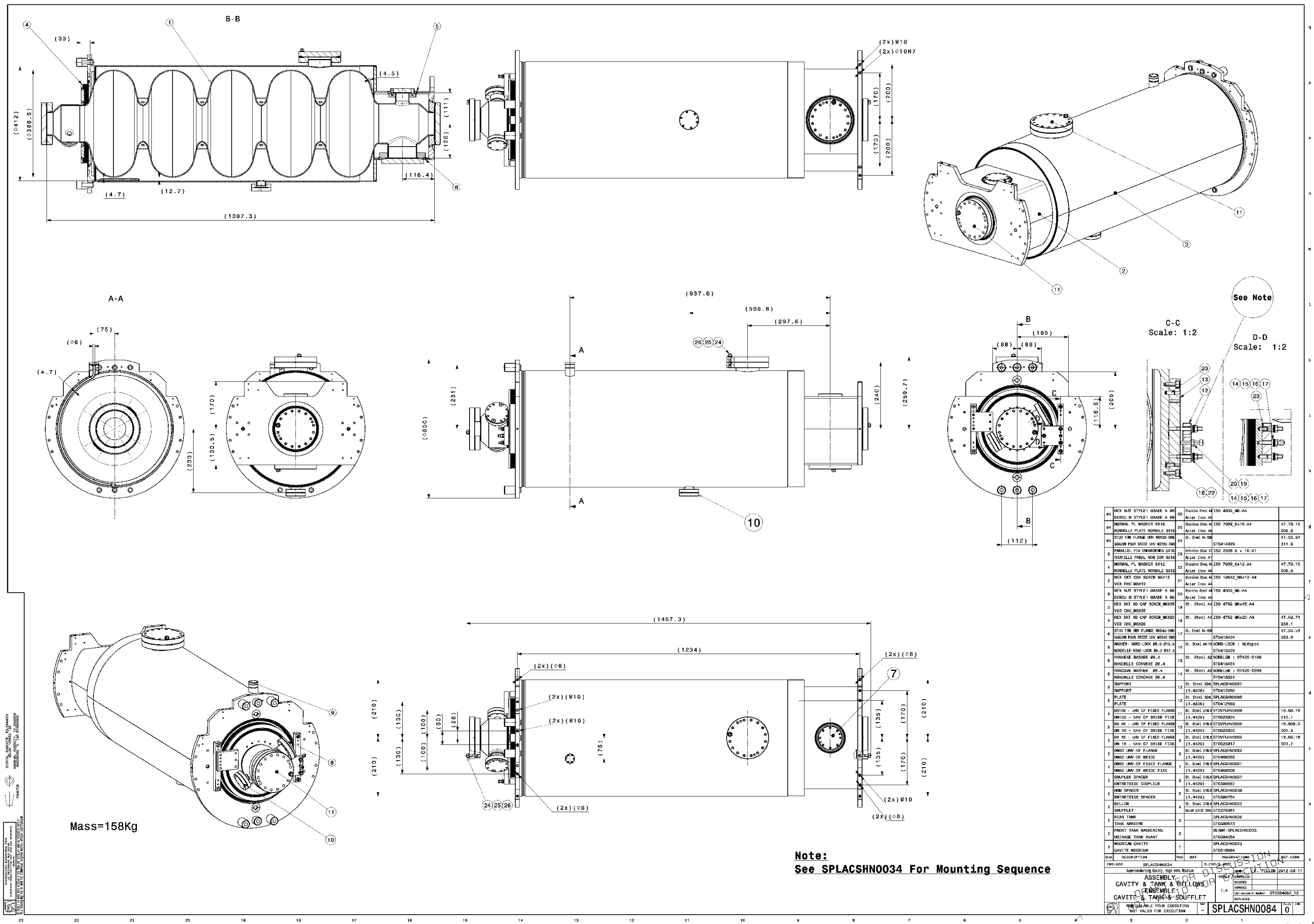
STEP 1-9

STEP 4-2

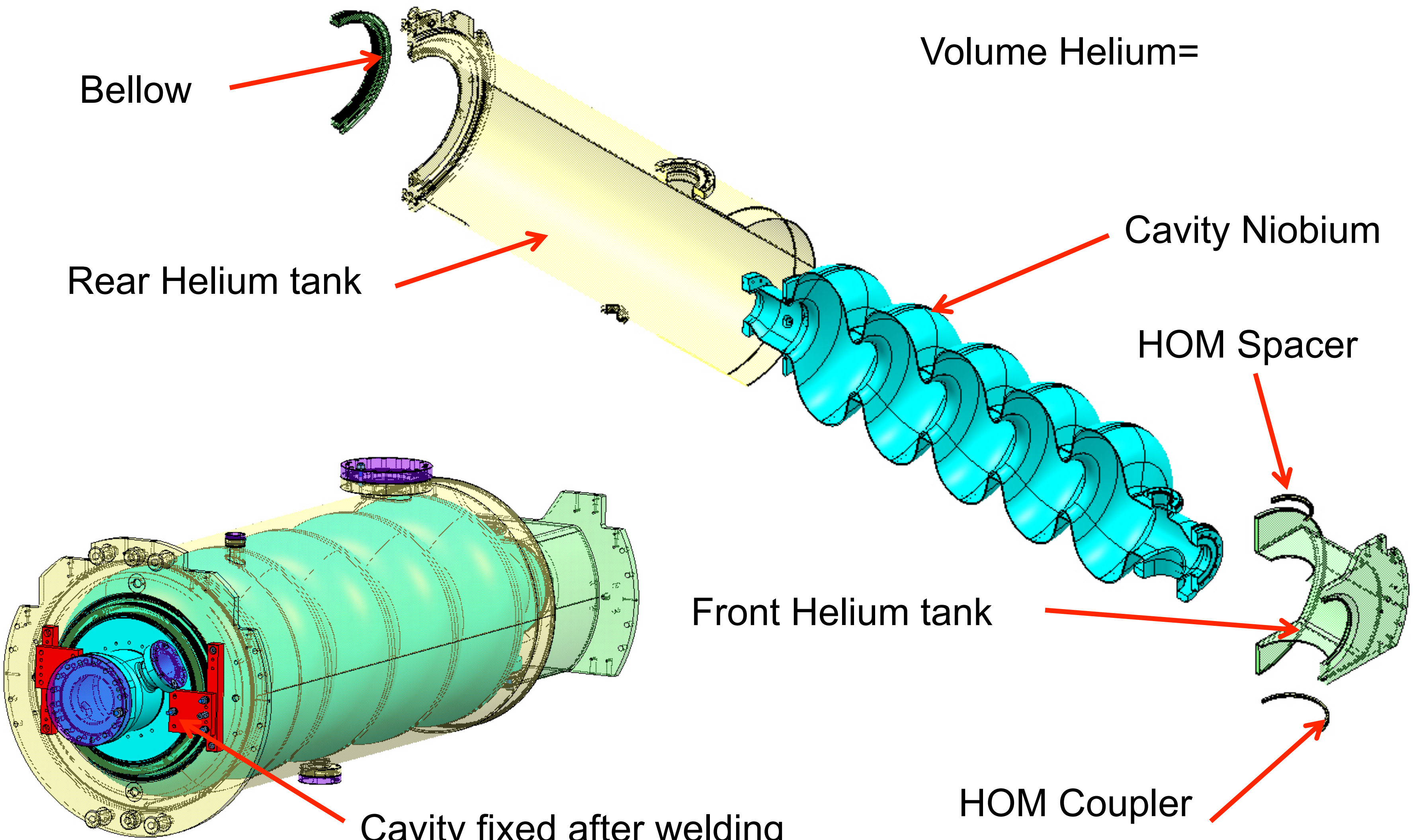


François Pillon, Thierry Renaglia, CERN

Helium Tank manufacturing

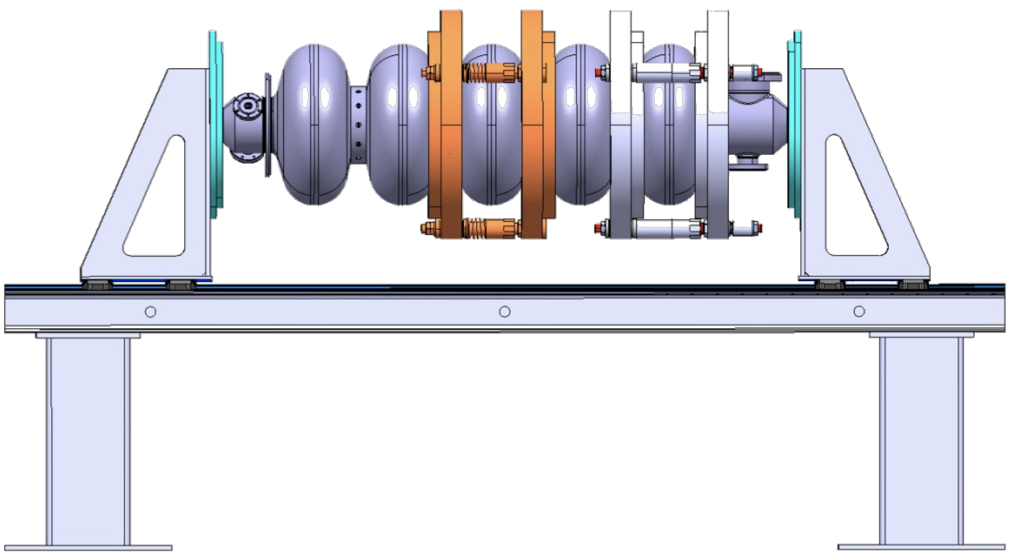


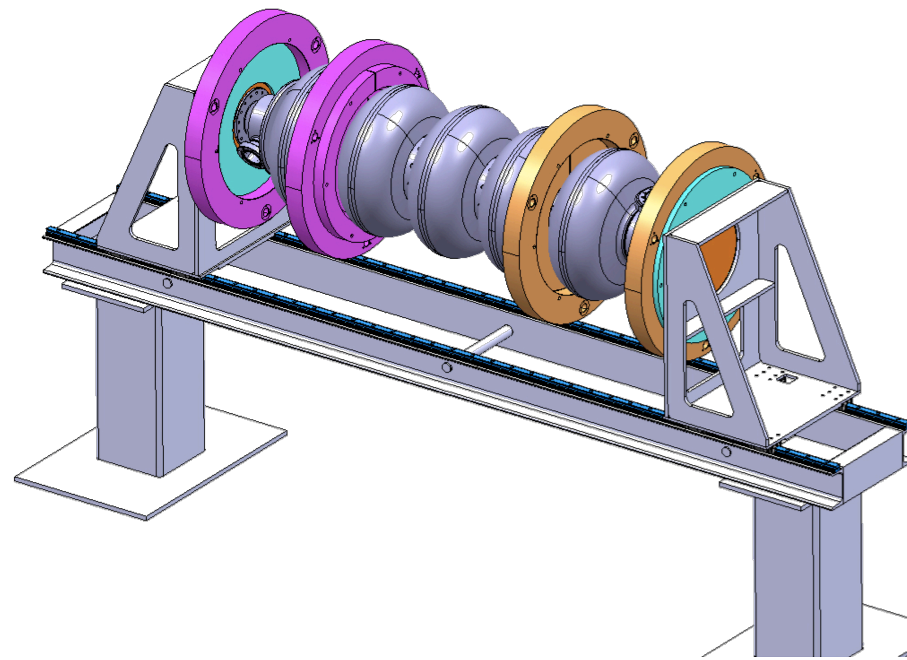
Helium Tank manufacturing



Tuning

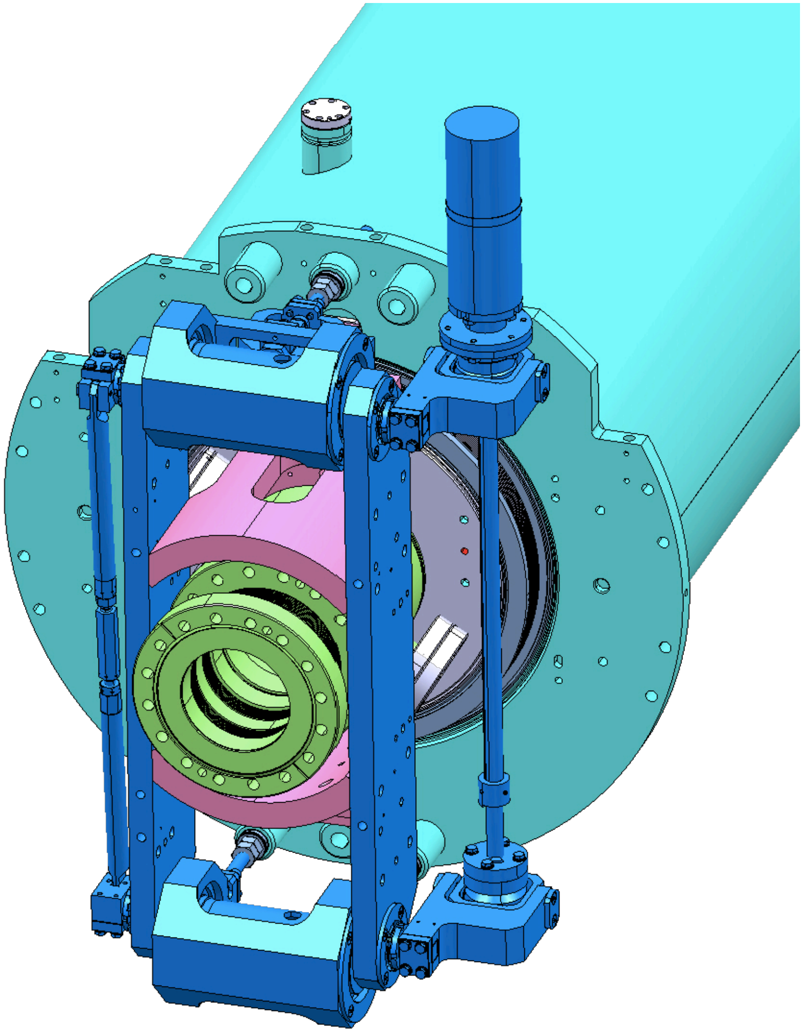
- Cavity manufactured at warm but has to function at required frequency at cold – tuning process:
  - Each dumb-bell trimmed after RF measurement
  - Complete cavity tuned cell by cell at warm

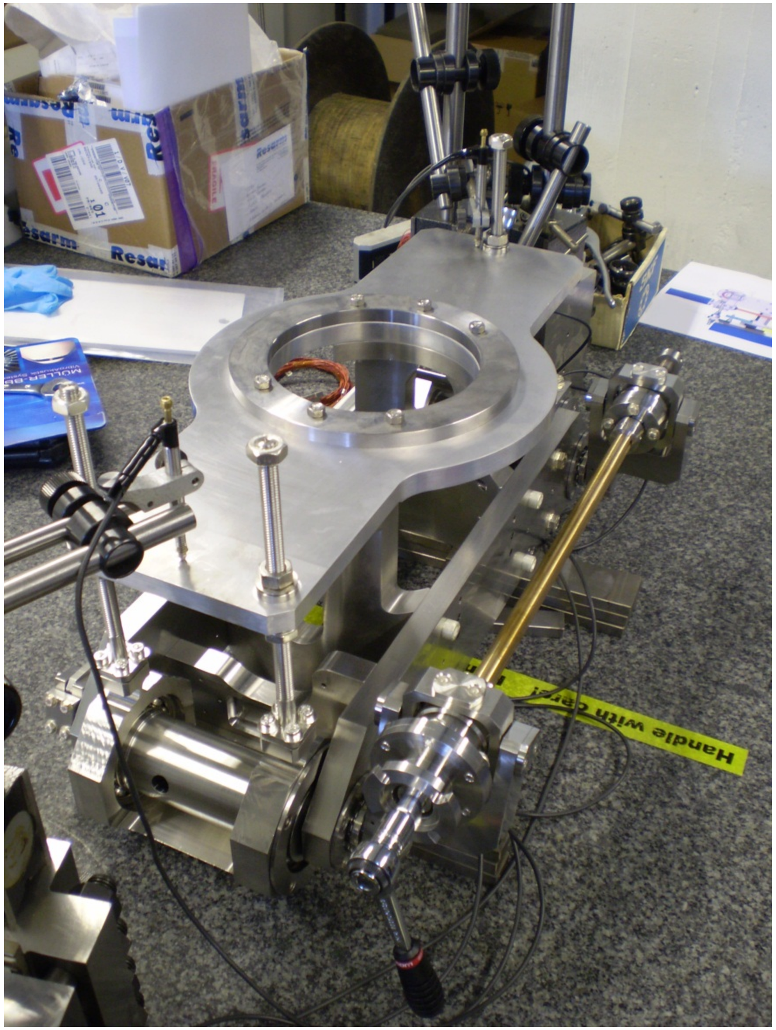




  - Cavity tuned at cold using the tuner

Tuner





Tuner

- Developed and manufactured by CEA
  - 8 tuners in total will be provided by CEA (ready for delivery)
  - 1 set already at CERN

Tuner

- Developed by CEA

Irfu cea saclay

Tuning system requirements

Can be corrected with room temperature tuning using plastic deformation:

- Fabrication tolerances
- Main cavity treatments :
  - 800°C heat treatment against Q desease,
  - First heavy chemical treatment (150 to 200 µm)
- Field inbalance between cells

Has to be corrected with the cold tuner:

- The remaining error of the room temperature tuning
- The effect of the last chemical treatments
- The differential shrinkage of materials of the cavity, He vessel and tuner
- He Pressure, Lorentz detuning,

However:

- Last points (diff. Shrinkage) can be taken into account for series cavities after the full test of the first prototype

RANGE? (also operation/commissioning of the accelerator)

G. Devanz CEA-Saclay, SPL 3rd coll. meeting

Guillaume Devanz, CEA, 3rd SPL collaboration meeting

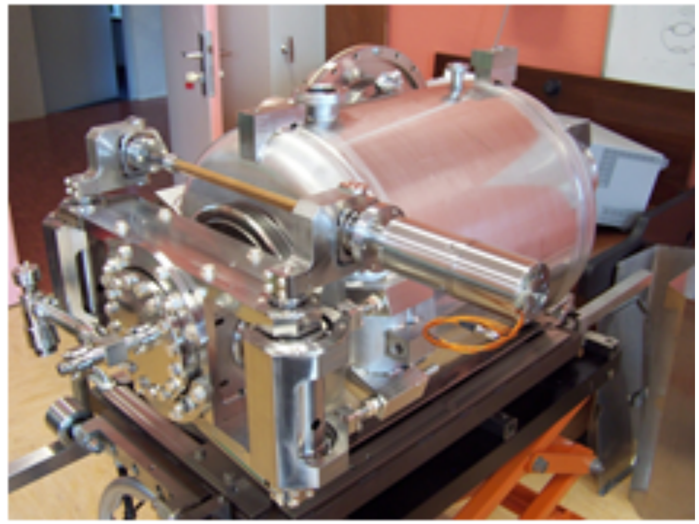
Tuner

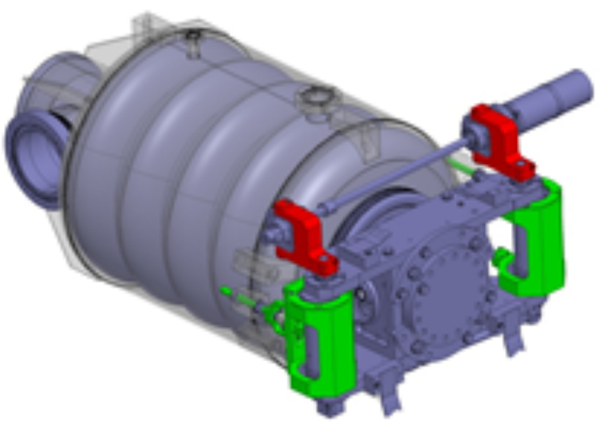
- Developed by CEA

Irfu
cea
saclay

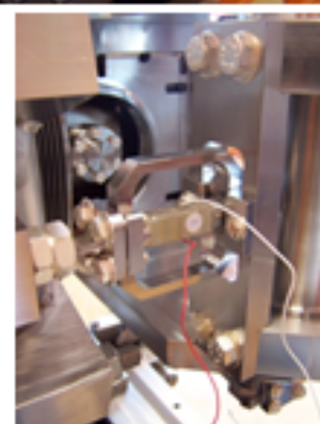
Saclay piezo tuner for 700MHz cavities

- Slow tuner with symmetric action
- Excentric/lever arm provenSaclay design
- Planetary gear box (3 stages)
- Single NOLIAC 30mm piezo actuator
- Stiffness measured on the tuner pneumatic jack = 35 kN/mm
- Initially developed for the beta=0.5 5-cell cavity





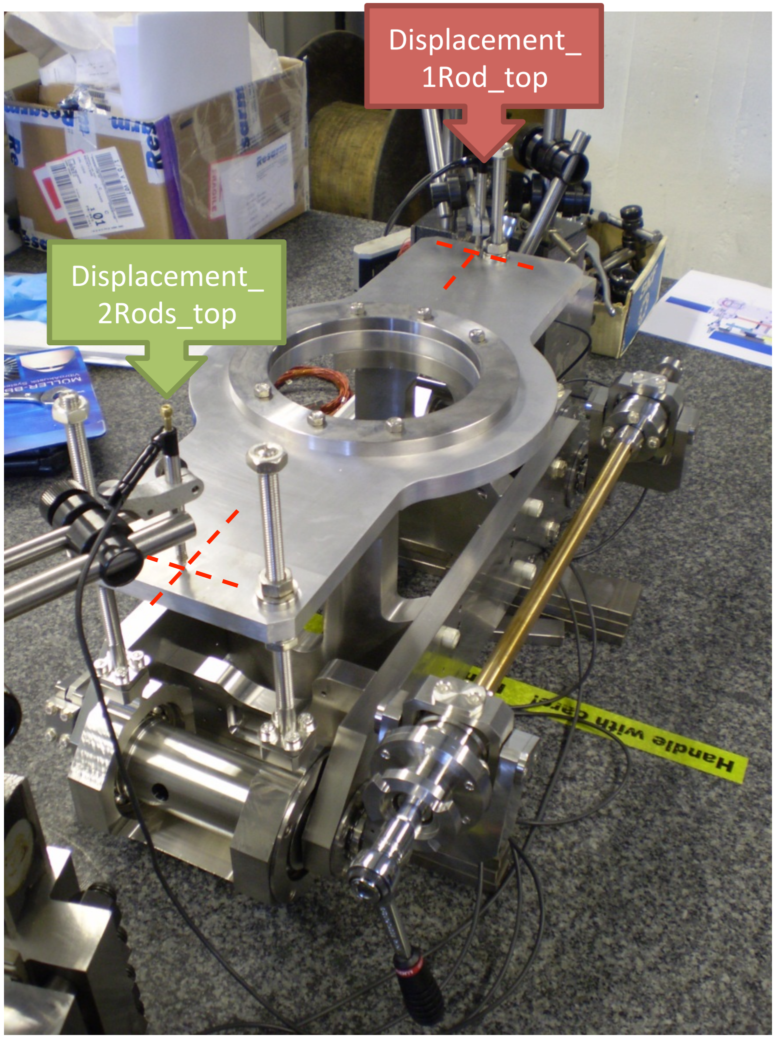
G. Devanz CEA-Saclay, SPL 3rd coll. meeting

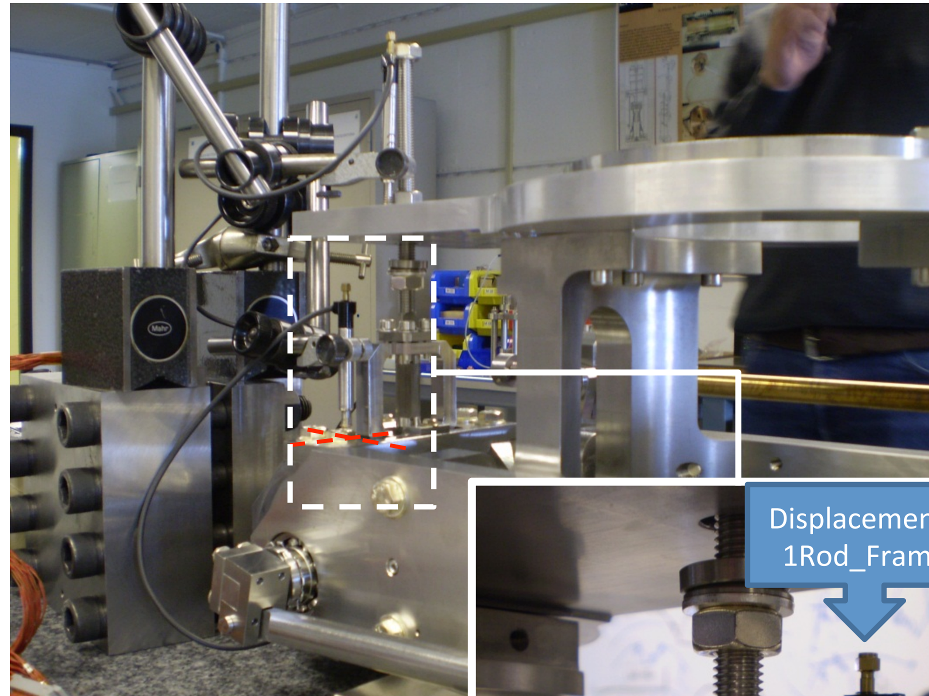


Guillaume Devanz, CEA, 3rd SPL collaboration meeting

Tuner

- The provided set is under test and “familiarization” at CERN



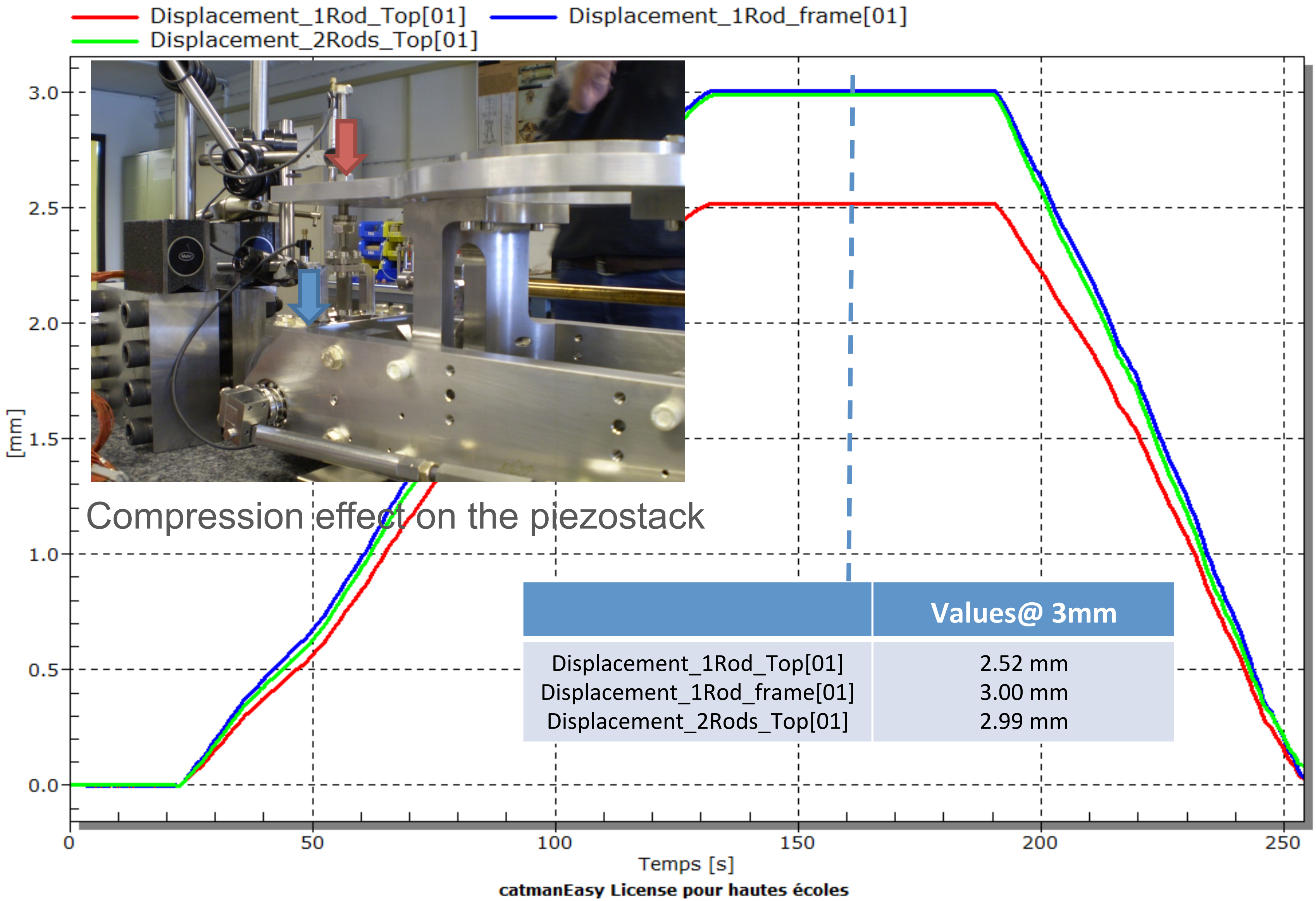


Michael Guinchard, CERN

- 3 LVDT’s HBM® – WI +/- 2.5mm
- DAQ QuantumX from HBM ® – Fs 50 Hz

Tuner

- The provided set is under test and “familiarization” at CERN



	Values@ 3mm
Displacement_1Rod_Top[01]	2.52 mm
Displacement_1Rod_frame[01]	3.00 mm
Displacement_2Rods_Top[01]	2.99 mm

Summary

- Cavities
  - Several cavity developments all over the world, related to the SPL project
  - They will be tested independently by each collaborator in their own testing facilities
  - Cavities to be installed in the SPL cryo-module will be provided by CERN by end of 2012:
    - 4 manufacturing ongoing in industry (RI)
    - 1 (spare) manufacturing ongoing at CERN
  - Copper cavities under manufacturing at CERN for HOM tests and identification of possible difficulties

Summary

- Helium tank
  - Baseline at CERN: Stainless Steel
  - Design finalised
  - Will be passed for manufacturing to CEA
- Tuning
  - Tuning process to be confirmed after manufacturing tolerances and tuning results for copper cavities
  - Familiarization with CEA tuner ongoing at CERN; still several points to be clarified with our colleagues from CEA