SPL cavities design and construction; Design evolution for ESS needs

Ofelia Capatina (CERN), Juliette Plouin (CEA), Guillaume Olry (IPNO)
on behalf of the SPL cavity development team

Overview

- Collaboration: who is doing what
- SPL equipped cavities
- SPL beta=1 CERN cavities
- Cavity design evolution from SPL to ESS
- Summary

COLLABORATION: WHO IS DOING WHAT?

Beta 0.65

IPN Orsay: 1 cavity with Titanium Helium vessel

Beta 1.0

CEA/Saclay: 1 cavity with Titanium Helium vessel
Stainless Steel Helium vessels and tuning systems for the CERN cavities

CERN: 4 cavities with Stainless Steel vessels
2 ≠ RF coupler types

BNL: 1 « Universal » cavity

HOM

Rostock U.: HOM coupler design

Royal Holloway U. of London: Cavity-to-cavity coupling effects

BNL: Cavity-to-cavity coupling effects & HOM coupler design

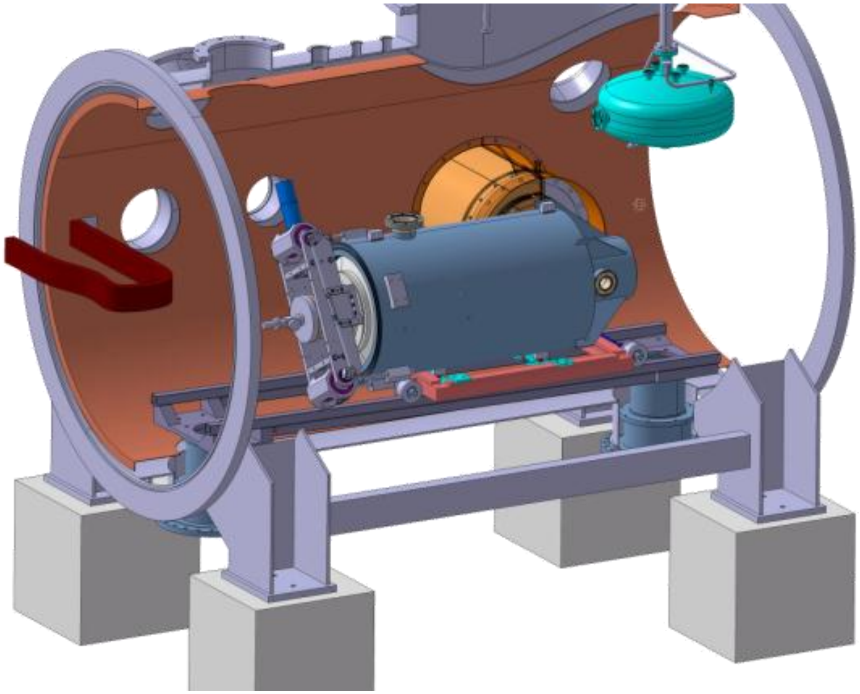
SHORT-CRYOMODULE

CERN & IPN Orsay

Guillaume Olry, IPNO, talk SRF 2011 Chicago

SPL equipped cavities

- Beta = 0.65
  - RF design done by IPNO
  - Mechanical design done by IPNO
  - Titanium helium tank
  - 1 niobium cavity to be manufactured by IPN Orsay
  - To be tested in the “CRYHOLAB” at CEA Saclay
  - CEA tuner
  - CEA main coupler



Configuration to be tested in CRYHOLAB

BETA 0.65

RF design

→ Operating gradient: 19 MV/m

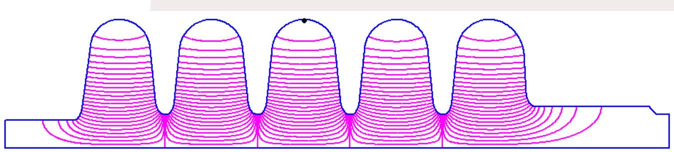
Epk/Eacc<2.6 (<-> Epk=50 MV/m)

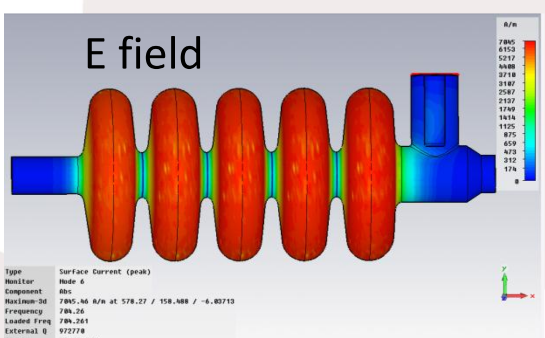
Bpk/Eacc<5.2 mT/(MV/m) (<-> Bpk=100 mT)

EM calculations

1/ in 2D with SUPERFISH

2/ in 3D with CST MWS → RF coupler integration





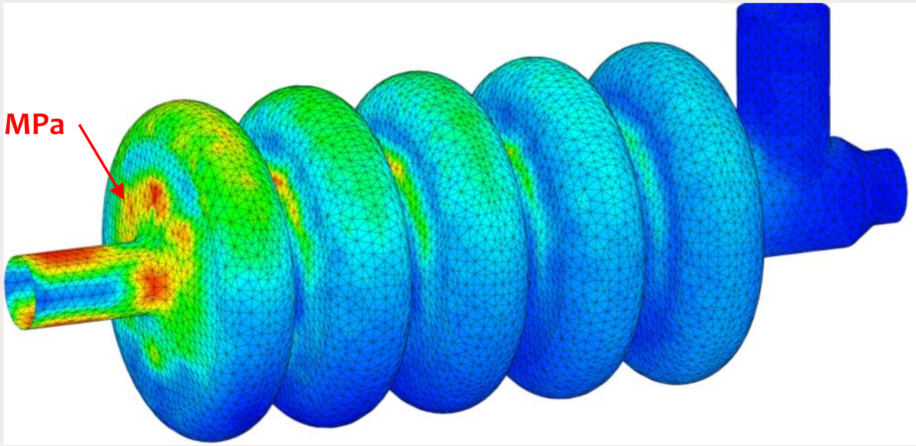
f (MHz)	704.0
Epk/Eacc	2.63
Bpk/Eacc (mT/MV/m)	5.12
K (%)	1.45
r/Q (Ohm)	275
G (Ohm)	197
Vacc @βg & 1 Joule (MV)	1.11
Qo (@2K, Rres=2nΩ)	3.9 10^{10}
Transit Time Factor	0.65

Guillaume Olry, IPNO, talk SRF 2011 Chicago

BETA 0.65

Mechanical design

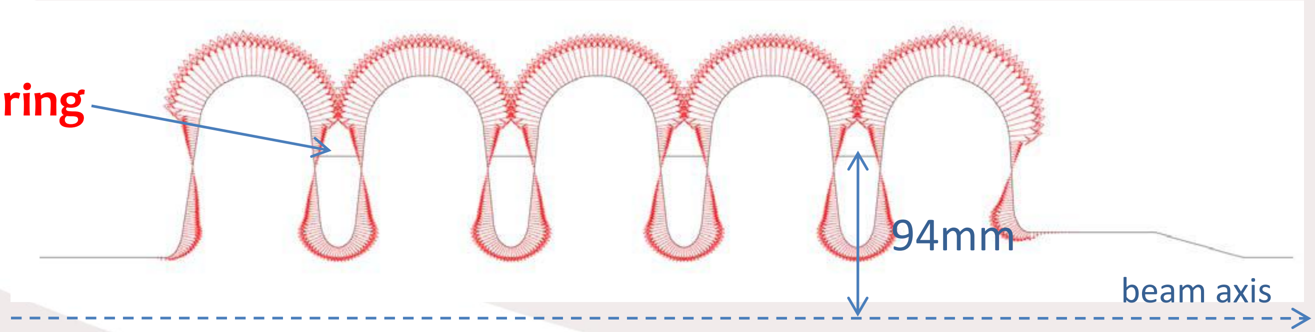
- ❑ Von Mises stresses for 1.5 bar @ 300K **< 50 MPa with 4mm**



Cavity walls = 4mm
→Niobium cost ~70 k€

- ❑ Lorentz forces detuning factor : **K_L~ -1.6 Hz/(MV/m)²**

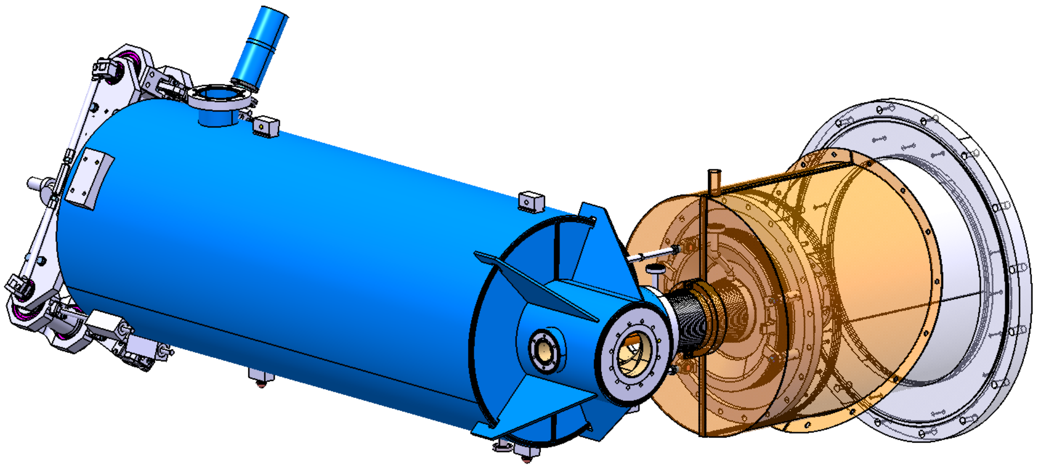
1 stiffening ring



Guillaume Olry, IPNO, talk SRF 2011 Chicago

SPL equipped cavities

- Beta = 1, CEA cavity
  - RF design done by CEA (will be compared later in this talk to ESS design)
  - Mechanical design done by CEA
  - Titanium helium tank
  - 1 niobium cavity to be manufactured by CEA
  - To be tested in the “CRYHOLAB” at CEA Saclay
  - CEA tuner
  - CEA main coupler

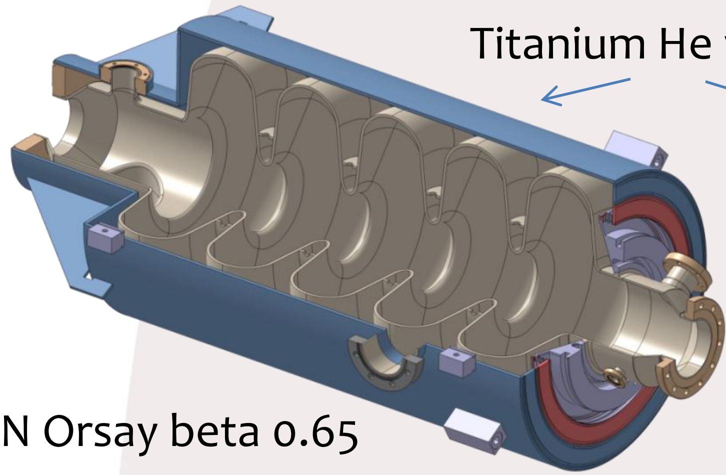


Configuration to be tested in CRYHOLAB

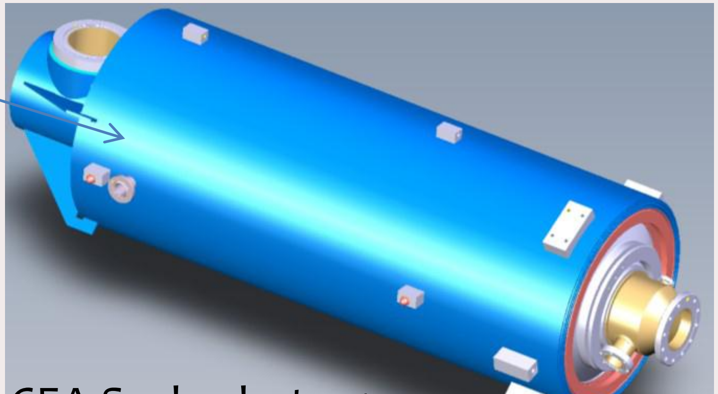
BETA 0.65 & BETA=1 COMMON FEATURES

- **Orders: end of 2011**
- **Same helium vessel design and same end-groups**

Titanium He vessel

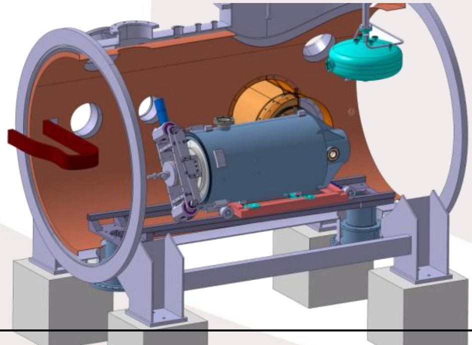


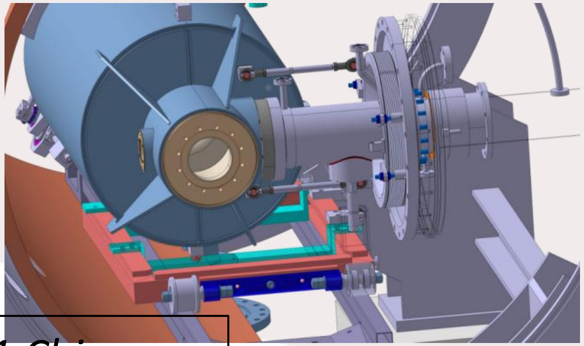
IPN Orsay beta 0.65



CEA Saclay beta=1

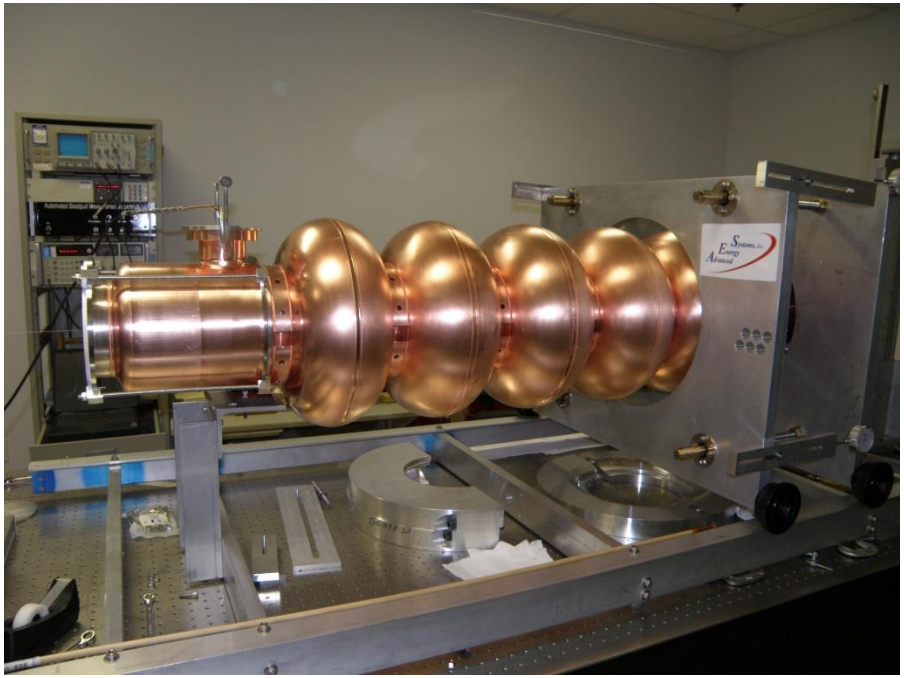
→ **Final test in horizontal cryostat with the same auxiliary components** (tuning system + RF coupler)





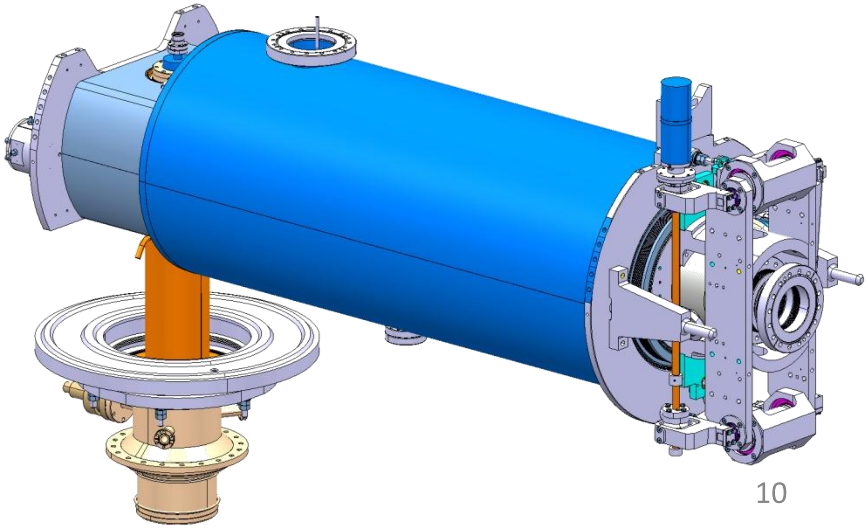
SPL equipped cavities

- Beta = 1, BNL cavities
  - 1 copper cavity and 1 niobium cavity designed and manufactured by BNL
  - Will be presented by Rama Calaga today at 14h00



SPL equipped cavities

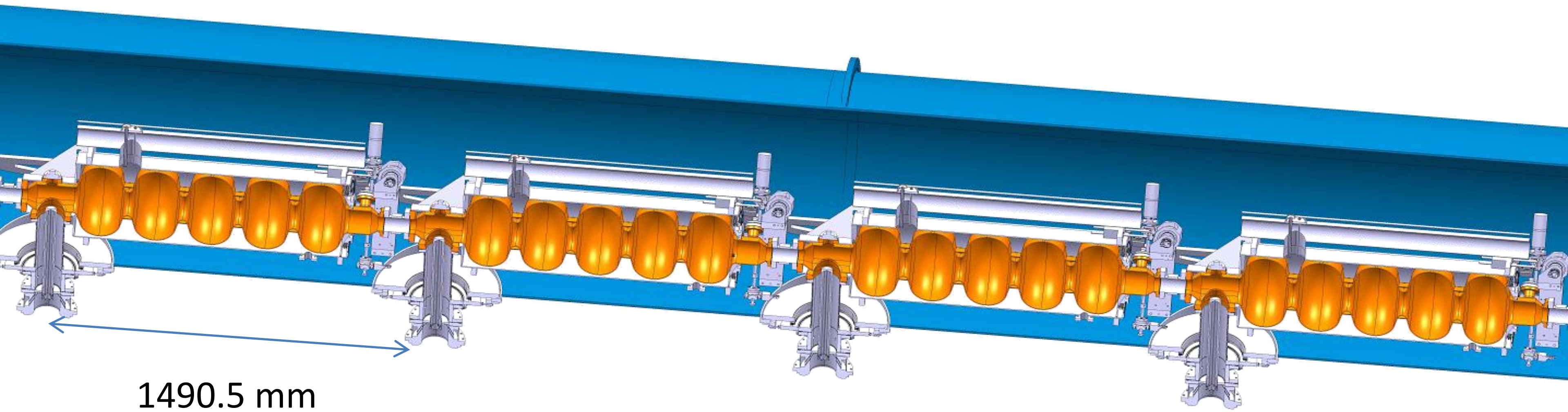
- Beta = 1, CERN cavities
  - RF design done by CEA
  - Mechanical design done by CEA and CERN
  - Stainless steel helium tank
  - 2 copper cavity manufacturing ongoing at CERN
  - 5 niobium cavities to be manufactured by end 2012
    - 4 in industry (Research Instruments)
    - 1 at CERN
  - To be tested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



Configuration to be tested in cryo-module

SPL beta=1 CERN cavities

- A string of 4 “equipped beta=1 cavities” + main coupler to be installed into a short cryo-module by 2013



Short cryo-module design to be done by IPN Orsay (see talk tomorrow by Vittorio Parma)

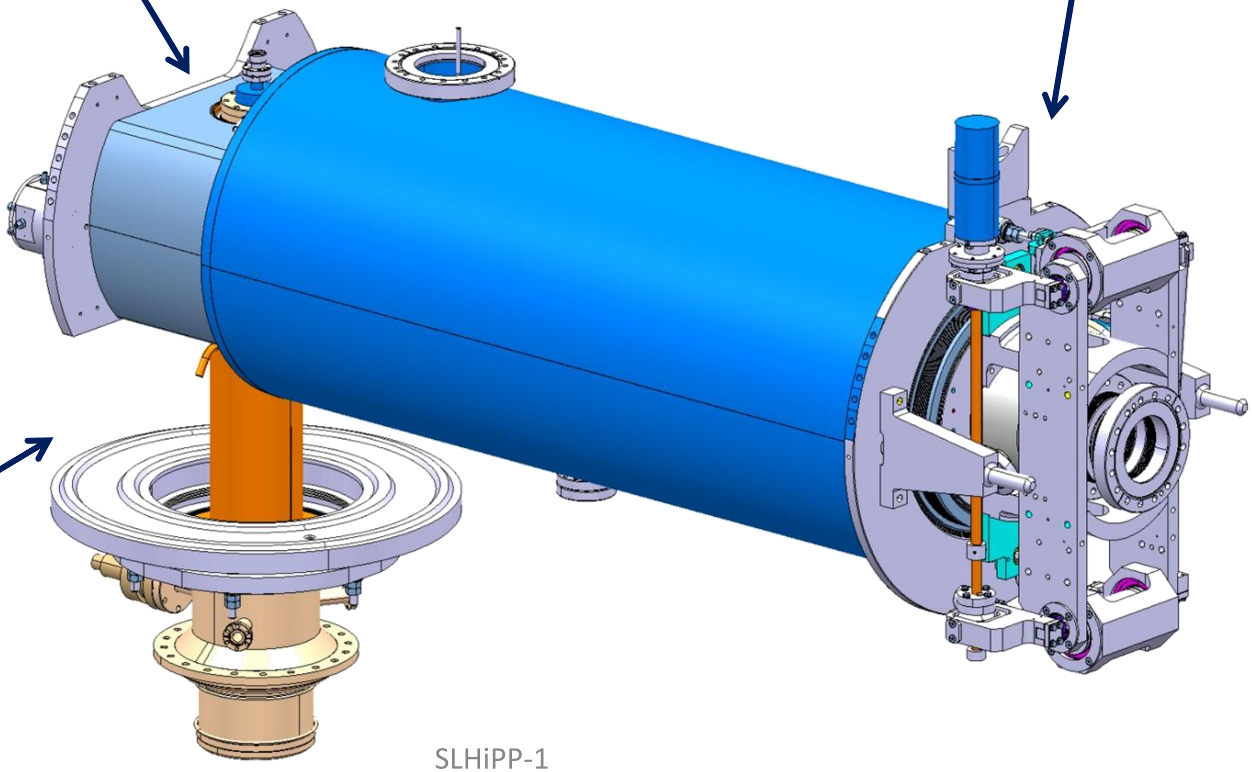
Schematic view of string of 4 “equipped cavities” and main coupler

SPL beta=1 CERN cavities

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

Stainless Steel helium tanks designed by CERN;
4 tanks to be provided by CEA;
to be welded on cavity by CERN

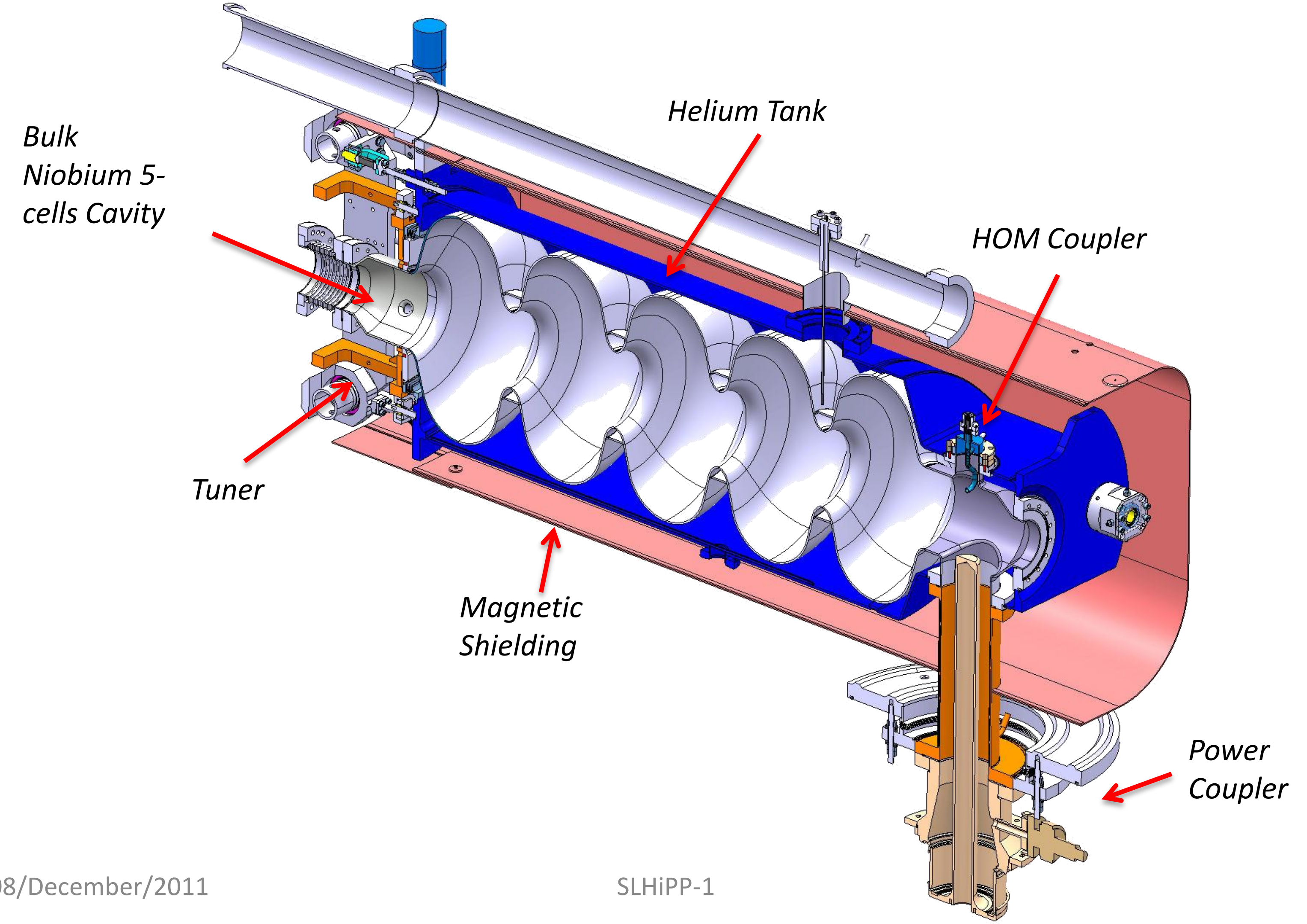
Tuners to be provided by CEA



Main couplers to be provided by CERN (see Eric Montesino's talk tomorrow)

SPL beta=1 CERN cavities

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



SPL beta=1 CERN cavities

- RF design
  - Done by CEA Saclay in 2009
  - Comparison RF design SPL / ESS later in this talk

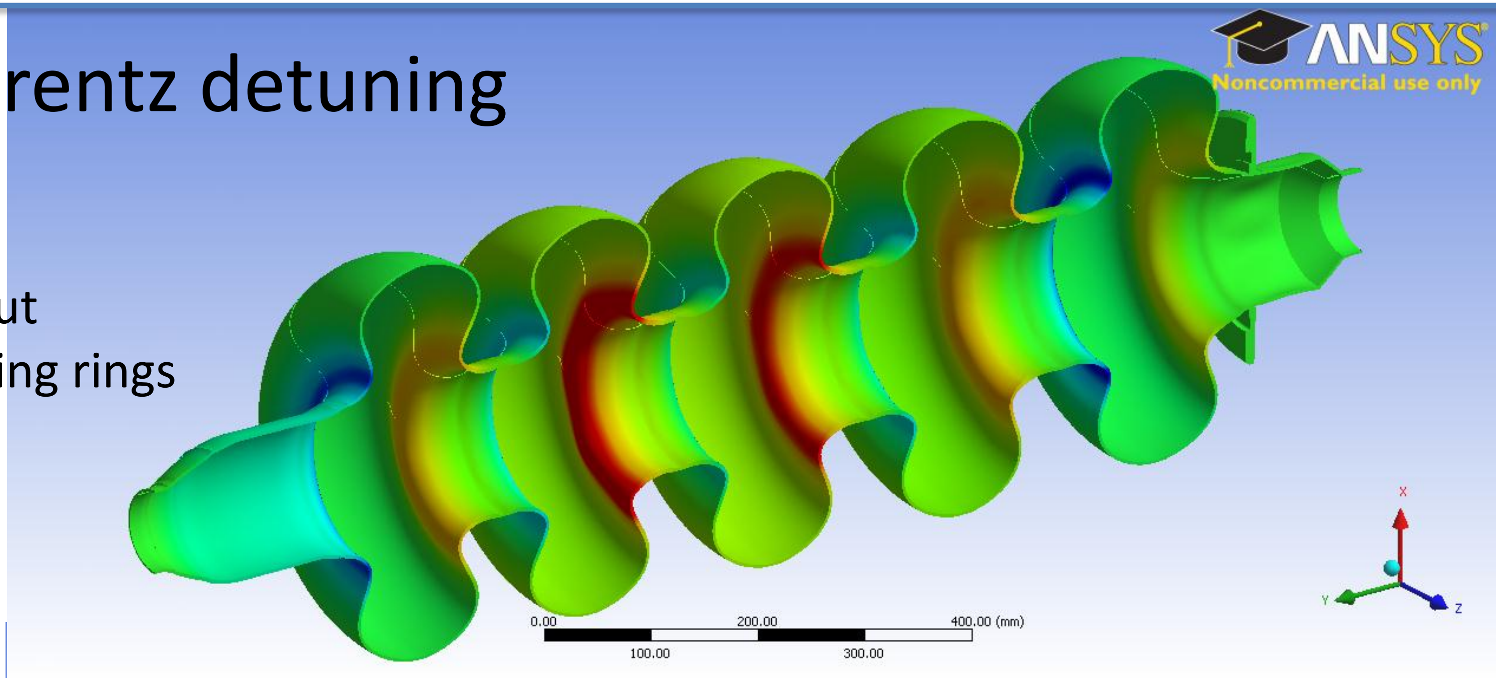
SPL beta=1 CERN cavities

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

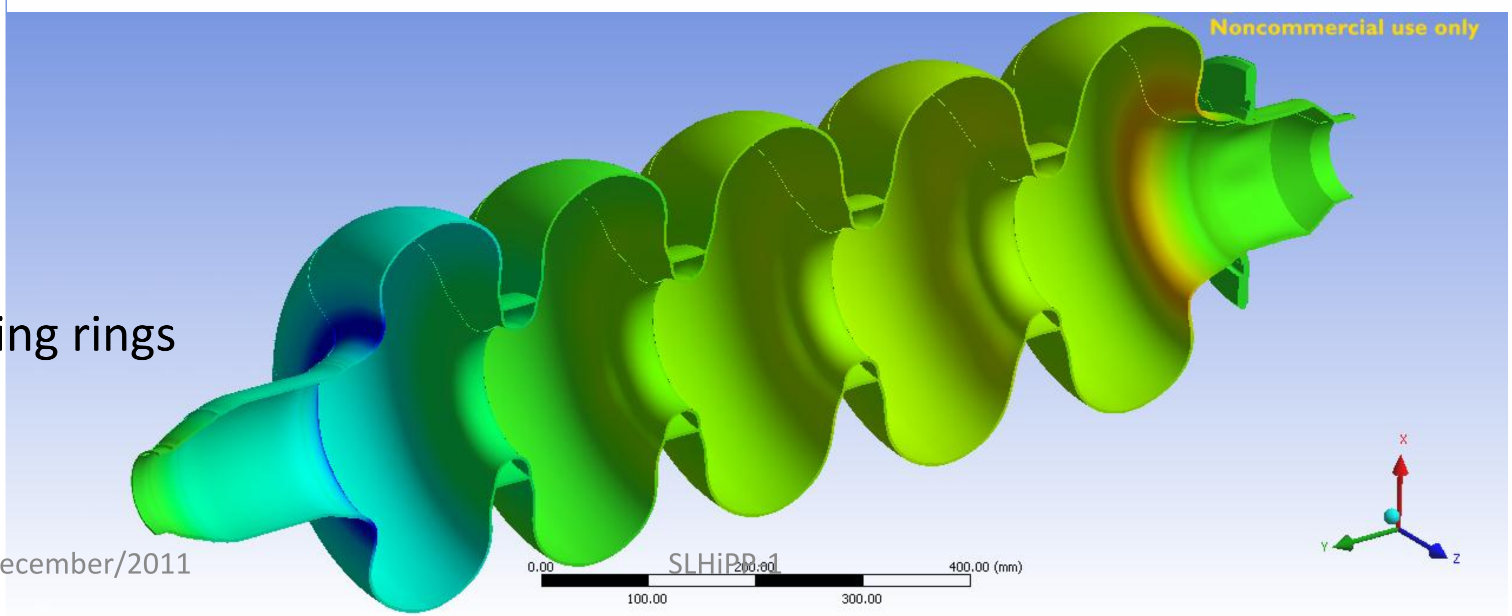
SPL beta=1 CERN cavities

- Lorentz detuning

Without stiffening rings

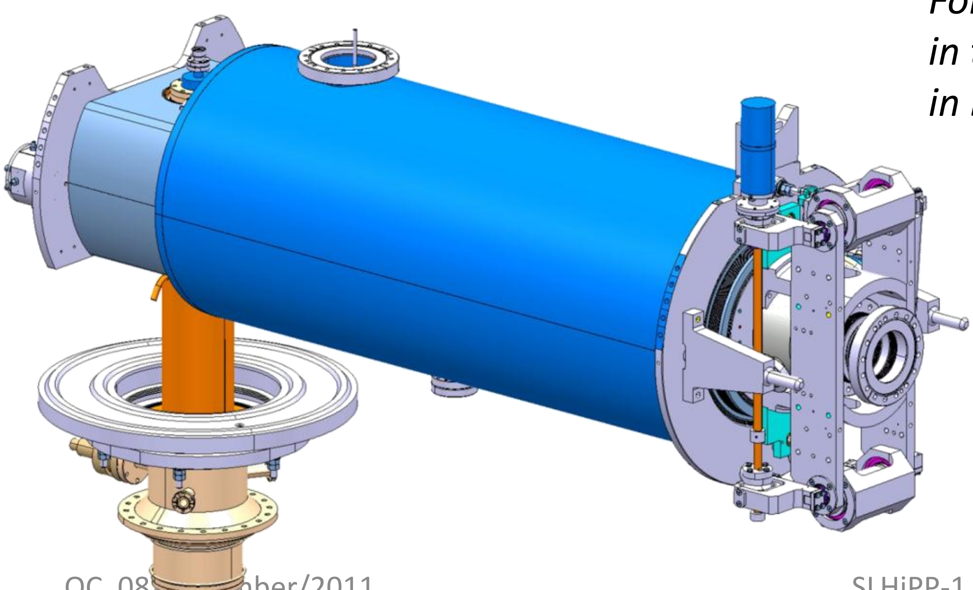


With stiffening rings



SPL beta=1 CERN cavities

- Helium tank
  - Two configurations designed and partially tested / interfaces: Titanium and Stainless steel
  - Stainless steel helium tank chosen as baseline for CERN cavities
  - 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

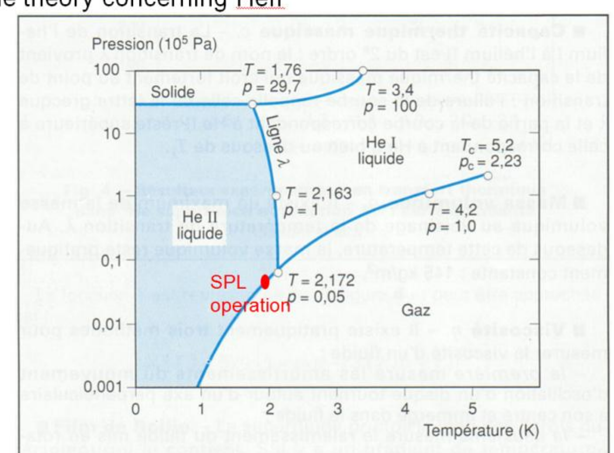
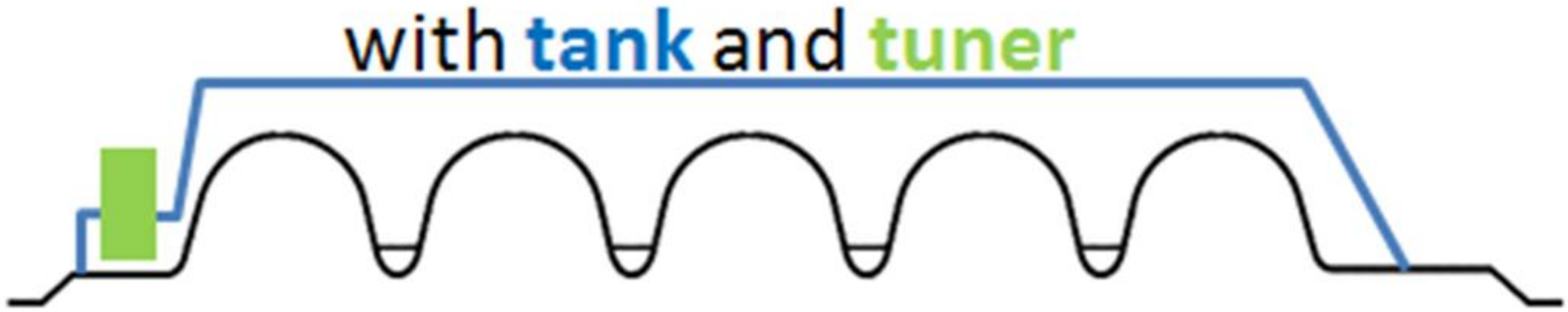


Fig. 1. – Diagramme de phase de ^{4}He.

SPL beta=1 CERN cavities

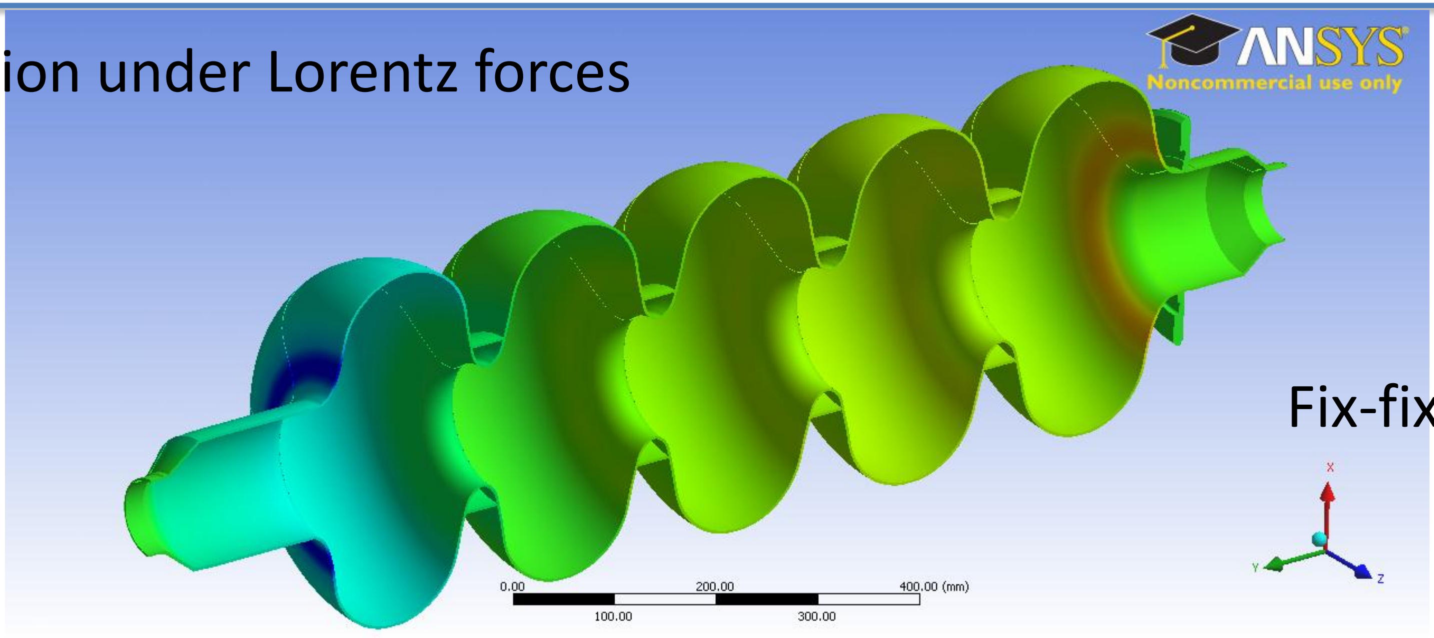
- Helium tank + tuner act as boundary conditions to cavity => different stiffness gives different deformation of cavity due to Lorentz forces



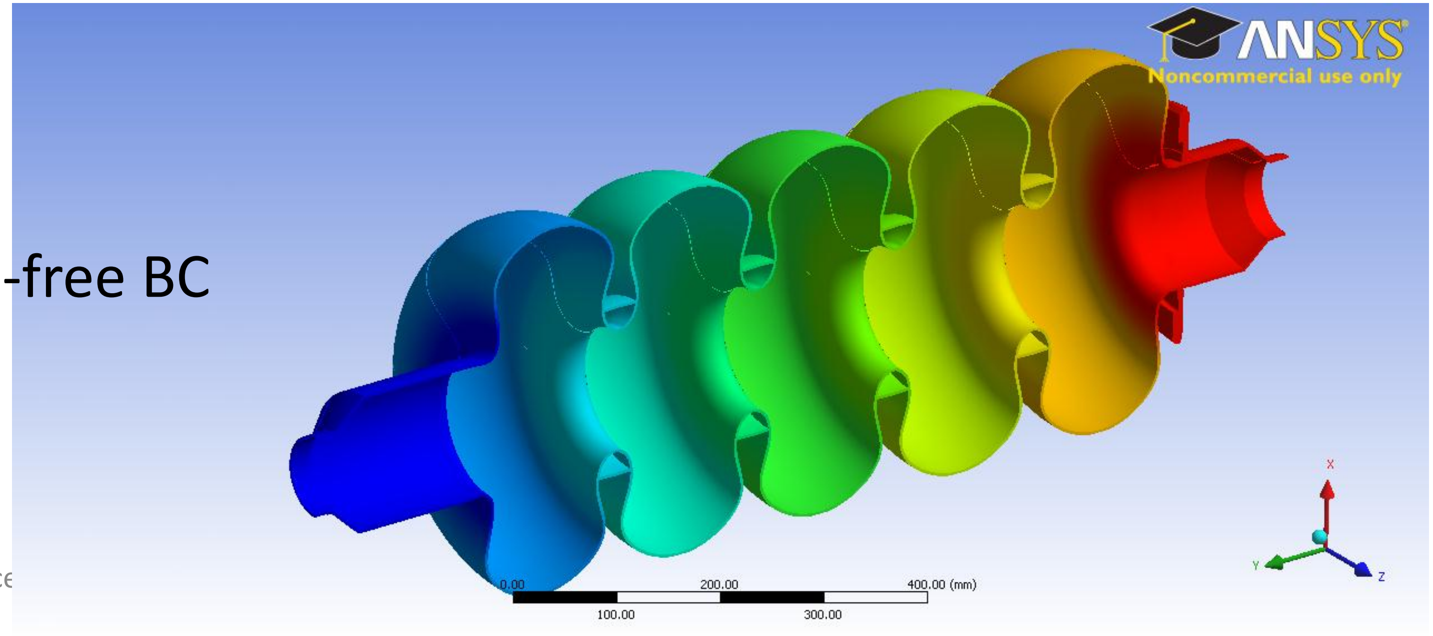
- Zero tank + tuner stiffness equivalent to free-free BC for cavity
- Infinite tank + tuner stiffness equivalent to fix-fix BC for cavity

SPL beta=1 CERN cavities

Deformation under Lorentz forces



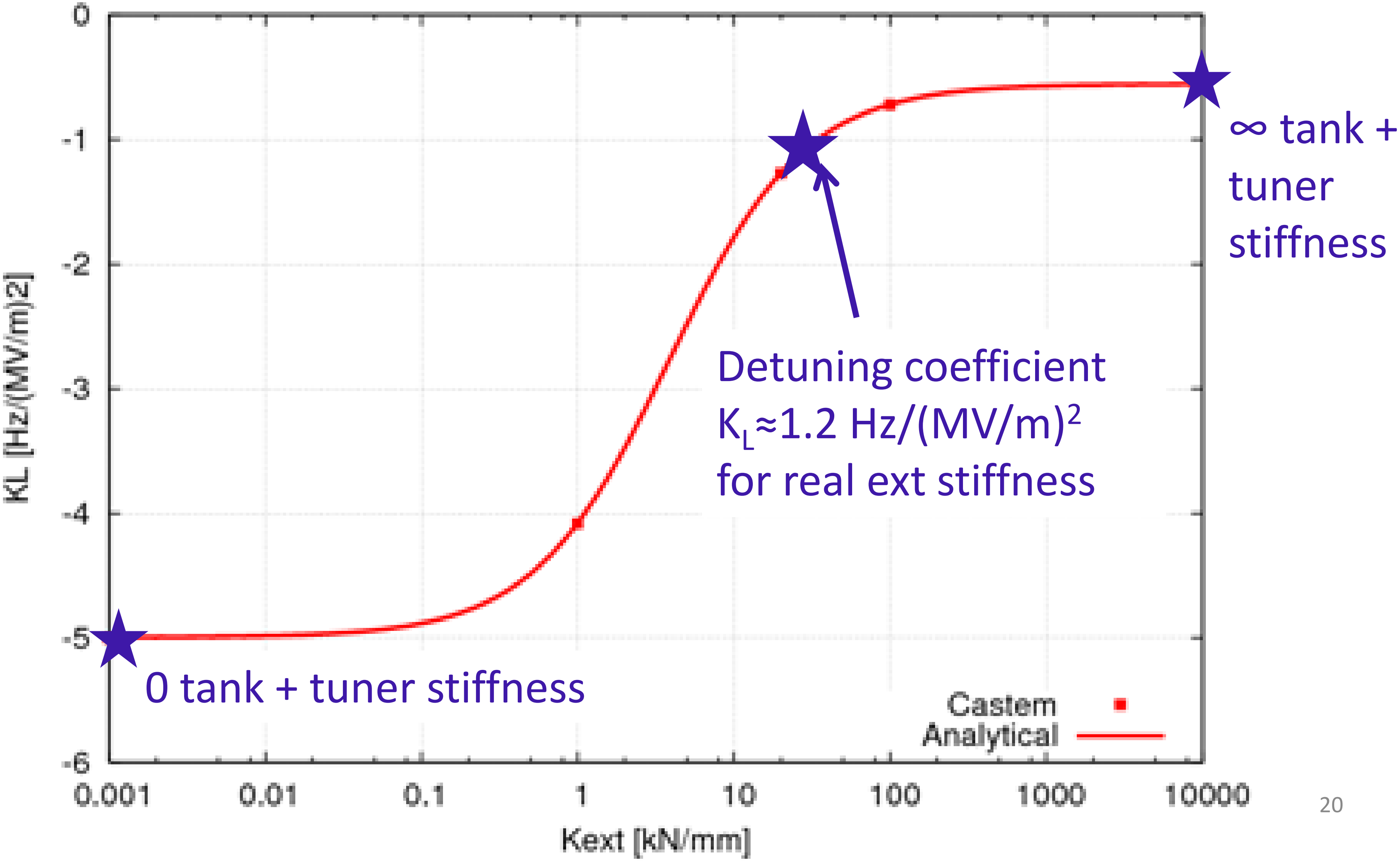
Fix-fix BC



Free-free BC

SPL beta=1 CERN cavities

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



SPL beta=1 CERN cavities

- Manufacturing
  - 4 niobium cavities by industry and 1 niobium cavity by CERN by end of 2012
    - *Talk by Gonzalo Arnau concerning materials*
    - *Talk by Said Atieh concerning manufacturing and R&D*
  - 2 copper cavities manufacturing ongoing
    - Help to adjust manufacturing parameters and identify possible
    - 1 cavity will be used for HOM measurements
    - 1 cavity will be used for sputtering tests
    - *Talk by Nuria Valverde concerning manufacturing*
- Cavity preparation
  - *Talk by Leonel Marques concerning Elecro-Polishing plant at CERN*
  - Field flatness measurement system and tuning system still to be designed

Cavity design evolution from SPL to ESS

Juliette Plouin CEA-Saclay

Cavity RF design : SPL vs ESS

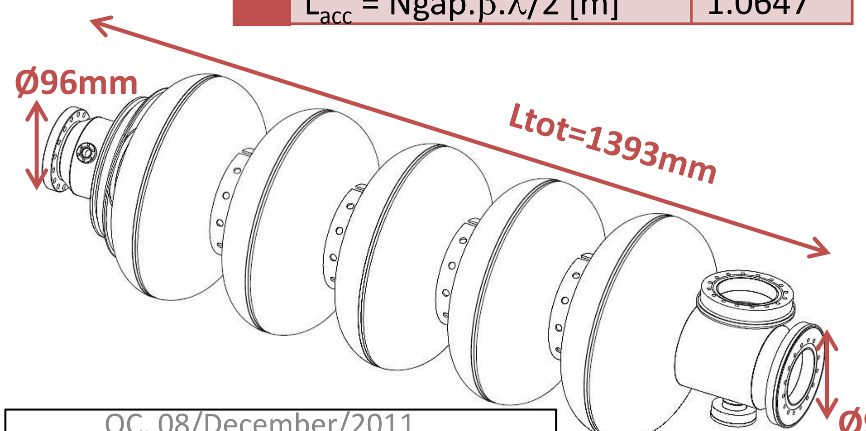
SPL

DESIGN PARAMETERS

RF frequency	704.42 MHz
Cavity geometrical beta	1
Accelerating gradient	25 MV/m
Maximum surface E field	40 MV/m
Average pulse current	40 mA
Peak RF power	1 MW
Repetition frequency	50 Hz
Duty cycle	5%
Operating Temperature	2 K

RF PARAMETERS

Bpk/Eacc [mT/(MV/m)]	4.20
Epk/Eacc	1.99
G [Ohm]	270
Cell to cell coupling	1.92 %
r/Q [Ohms]	566
L_{acc} = Ngap.β.λ/2 [m]	1.0647



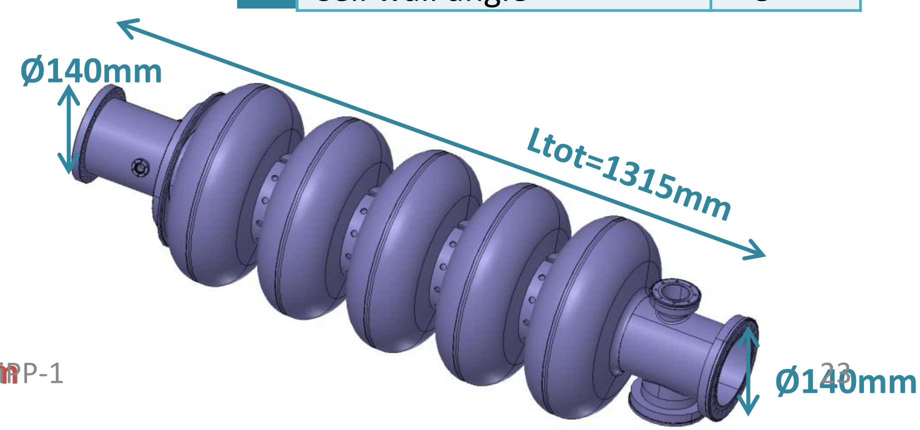
ESS

DESIGN PARAMETERS

RF frequency	704.42 MHz
Cavity geometrical beta	0.86
Accelerating gradient	18 MV/m
Q_0 at nominal field	> 6 10^9
Maximum surface E field	40 MV/m
Average pulse current	50 mA
Peak RF power	900 kW
Repetition frequency	14 Hz
Beam pulse length	2.86 ms
Operating Temperature	2 K

RF PARAMETERS

Bpk/Eacc [mT/(MV/m)]	4.3
Epk/Eacc	2.2
G [Ohm]	241
Cell to cell coupling	1.8 %
r/Q [Ohms]	477
L_{acc} = Ngap.β.λ/2 [m]	0.915
Cell wall angle	> 8°



Juliette Plouin CEA-Saclay

Coupled RF/mechanicals design

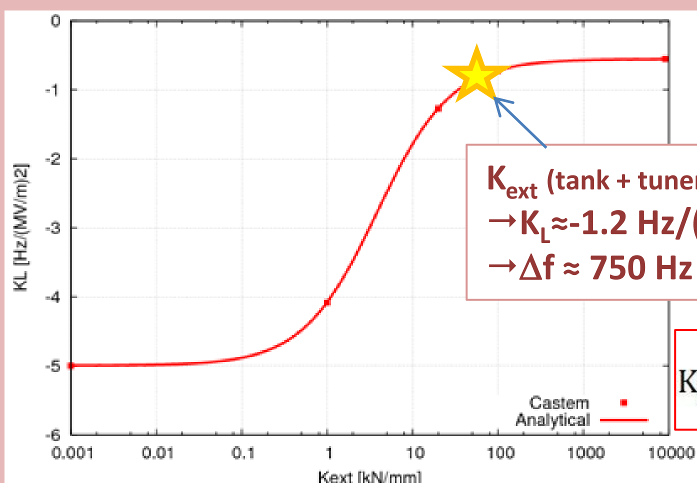
$K_L = \Delta f / E_{acc}^2$

☑ Reduction of K_L with stiffening rings (SPL and ESS)

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

Nominal wall thickness [mm]	3.6
Cavity stiffness Kcav [kN/mm]	2.59
Tuning sensitivity Δf/Δz [kHz/mm]	197
K_L with fixed ends [Hz/(MV/m)²]	-0.36
K_L with free ends [Hz/(MV/m)²]	-8.9
Pressure sensitivity K_P [Hz/mbar] (fixed ends)	4.85

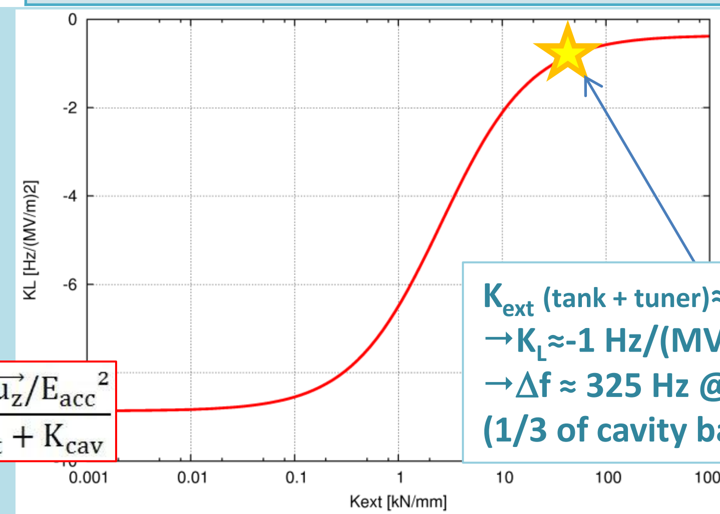
SPL



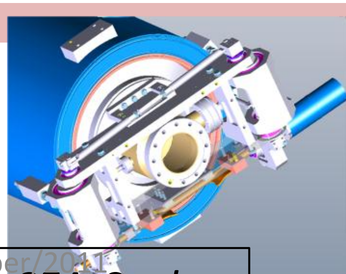
K_{ext} (tank + tuner)≈35kN/mm
→K_L≈-1.2 Hz/(MV/m)²
→Δf ≈ 750 Hz @ 25MV/m

$$K_L = K_{L\infty} + \frac{\Delta f}{\Delta z}\frac{\left(\overrightarrow{F_\infty}\cdot\overrightarrow{u_z}/E_{acc}^2\right)}{K_{ext} + K_{cav}}$$

ESS



K_{ext} (tank + tuner)≈30 kN/mm
→K_L≈-1 Hz/(MV/m)²
→Δf ≈ 325 Hz @ 18 MV/m
(1/3 of cavity bandwidth)



SPL and ESS cavities will be equipped with Saclay V type tuners for slow and fast tuning

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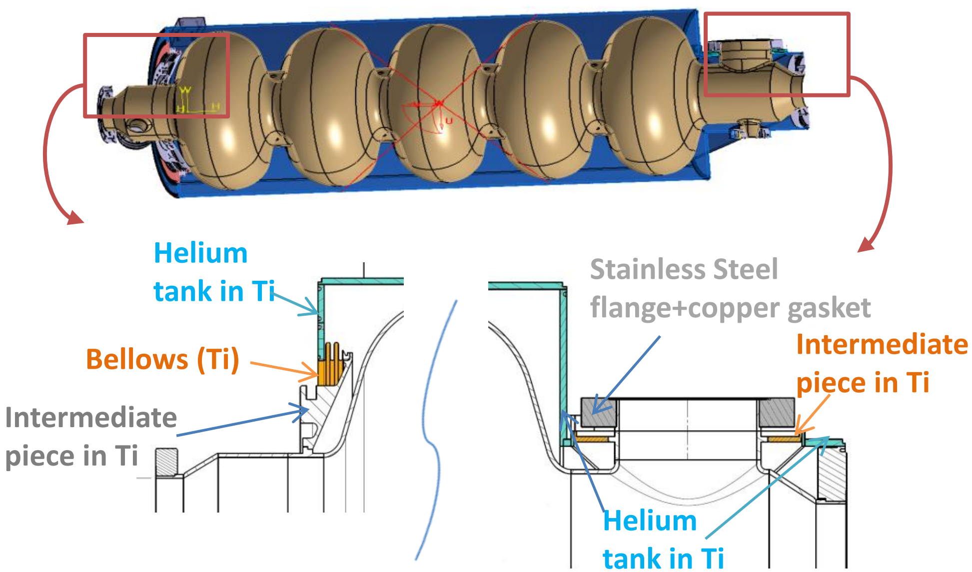
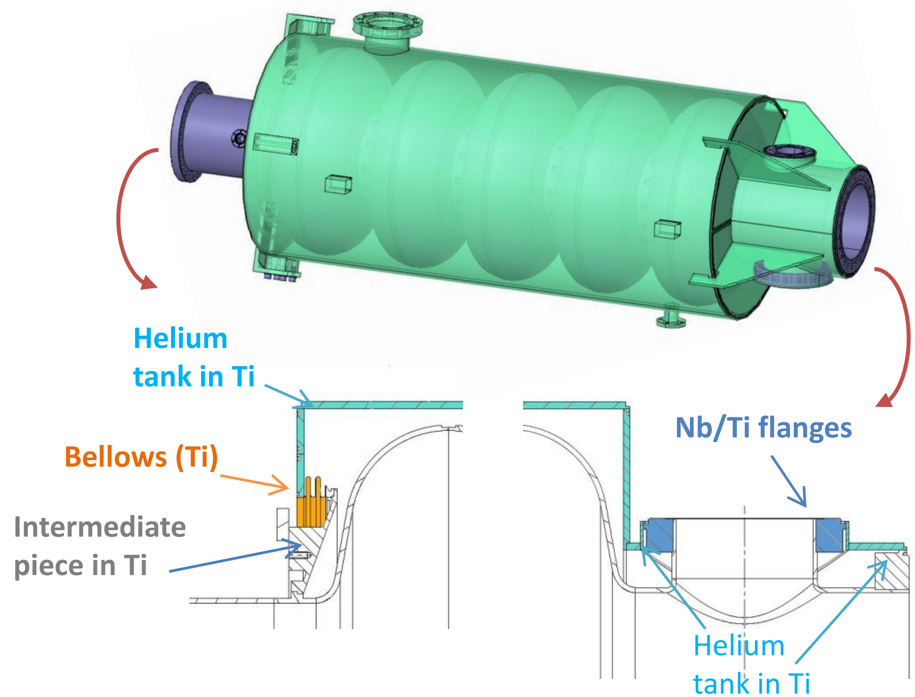
Mechanicals design

☑ **Saclay prototype : possible integration in Cryholab**





- **Helium tank in Titanium** (limits the differential shrinkage with Nb during cooling down)
- All flanges made of Nb or Nb/Ti
- except the FPC flange, in stainless steel with copper gasket, to be compatible with the HIPPI coupler, and for safety reasons
  - ⇨ intermediate piece in Ti needed

- **Helium tank in Titanium** (limits the differential shrinkage with Nb during cooling down)
- All flanges made of Nb or Nb/Ti

The position of the HOM ports could change after the prototypes, in relation with HOM couplers studies (SPL and ESS)

Juliette Plouin CEA-Saclay

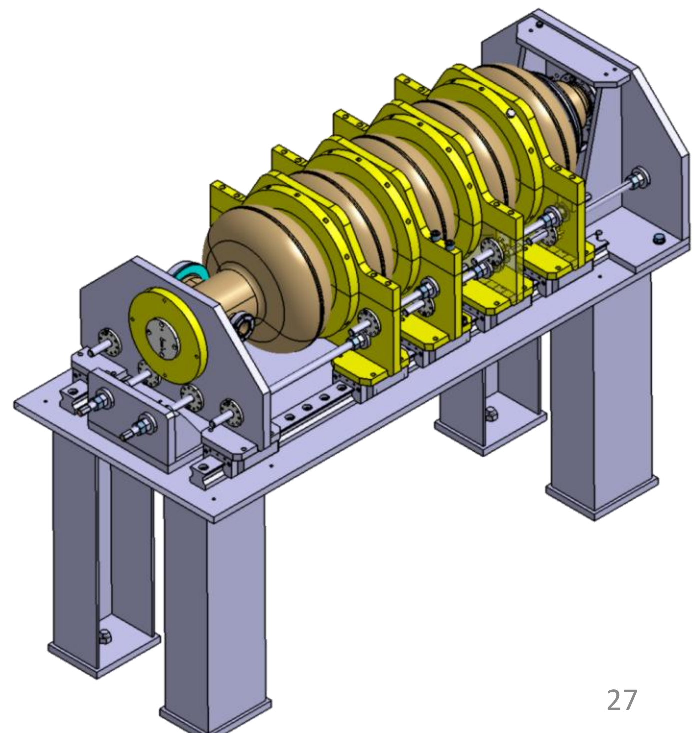
- ESS cavity without extremity “cones”

+ easier to extract the HOM propagating in a larger tube
+ easier for the manufacturing
+ easier for electro polishing and more generally for cavity cleaning
+ more rigid, thus less sensitive to Lorentz forces

- longer cavity (for larger tubes one should increase the length to avoid the fundamental mode to be dissipated on the inter-cavities bellow)
- bigger flanges
- a priori more difficult to mount the tuning system

Equipment for cavity preparation

- Vertical electro-polishing (installed and tested at Saclay)
- Ready to use for both SPL and ESS cavities



- Cavity tuning set-up for field flatness achievement at room temperature (under development)
- Cell by cell tuning between plates
- This set-up is adaptable for both SPL and ESS cavities

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Summary

- 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 next year:
  - 4 to be manufactured in industry
  - 1 (spare) to be manufactured at CERN

- SPL beta=1 cavity design by CEA was used as basis for beta=0.86 cavity design for ESS