Status of 704 MHz developments

at CEA-Saclay

Introduction

CEA-Saclay is involved in programs aiming at designing and prototyping 700 MHz sc cavities and components:

- ➢ for SPL
  - European program FP7 (EuCARD, CNI-PP-SLHC)
  - Contribution Exceptionnelle de la France au CERN
- ➢ for ESS
  - ESS collaboration (MoU to be signed)

Introduction

Tasks we are leading or participating in:

- the design of 704 MHz cavity, He tank, frequency tuner
- the prototyping of 704 MHz high beta and high gradient elliptical cavity
- the fabrication of set of pieces (He tank for high beta cavity, new frequency tuners)
- the processing of 704 MHz power couplers up to 1MW
- the RF tests at cold of components (power couplers, tuners), the optimization of LFD compensation scheme
- the construction or upgrade of equipments needed for preparation and test of components (vertical EP station, HPR station, vertical and horizontal cryostats)

High β cavity: RF design

Reference Parameters (see CDR SPL II)	
RF frequency	704.4 MHz
Gradient	25 MV/m
Number of cells/cavity	5
Average pulse current	40 mA
Synchronous phase	-15°

Optimisation of the cavity design done in 3 steps:

Step 1) Find the best cavity shape with respect to r/Q, Ep/Eacc, Bp/Eacc

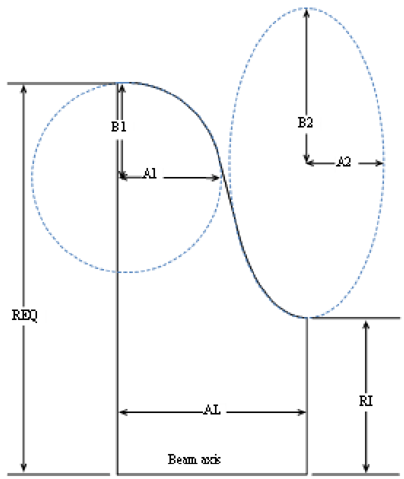
Step 2) Do what is necessary to reach the optimal coupling Qex

Step 3) Add stiffeners to keep the LFD under control

RF design: cavity shape

RF parameters for the TM010

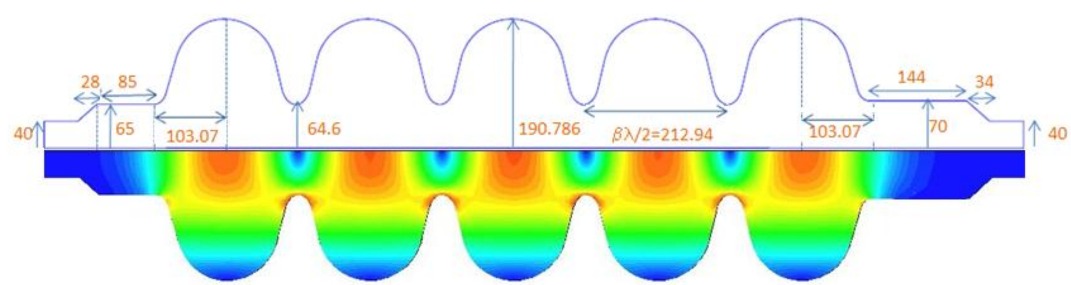
after iterations between step1 & step2 and optimisation



	outer ½ cell pick-up side	Inner ½ cells	outer ½ cell FPC side
Equator REQ	190.786	190.786	190.786
Iris RI	65	64.6	70
Length AL	103.07	106.47	103.07
E_ellipse A1	74.45	77.5	74.45
E_ellipse B1	83.27	77.5	76.89
I_ellipse A2	18.5	22.1	18.5
I_ellipse B2	24.9	35.1	24.9

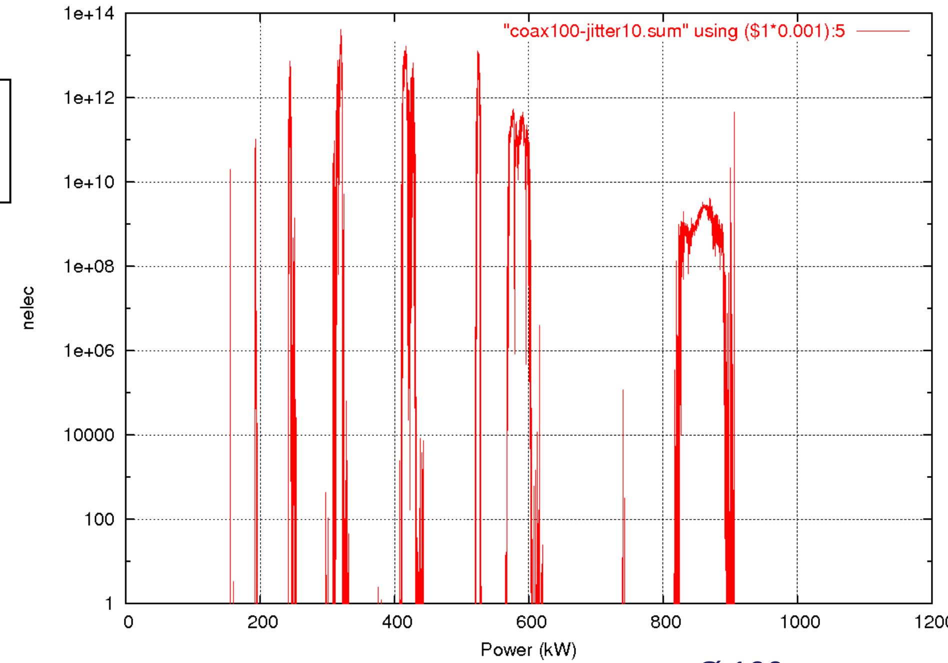
	SPL	Tesla	HIPPI
Number of cells	**5**	9	5
Frequency [MHz]	**704.4**	1300	704.4
Beta	**1**	1	0.47
Bpk/Eacc [mT/(MV/m)]	**4.20**	4.26	5.59
Epk/Eacc	**1.99**	2	3.36
G [Ω]	**270**	270	161
Cell to cell coupling [%]	**1.92**	1.87	1.35
r/Q [Ω]	**566**	1036	173
Lacc = Ngap.β.λ/2 [m]	**1.065**	1.038	0.5
Operating Temp. [K]	**2 K**	2 K	2 K
Theor. R_{BCS} @ O.T. [nΩ]	**3.2**	11	3.2
$Q_0/10^{10}$ @ O.T. for R_{BCS}	**8.4**	2.5	5

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



RF design: coupler location

With our set of cavity and beam parameters:
Qex,opt=**1.2 e6 ; **Pbeam=Pin,max=**1029 kW**



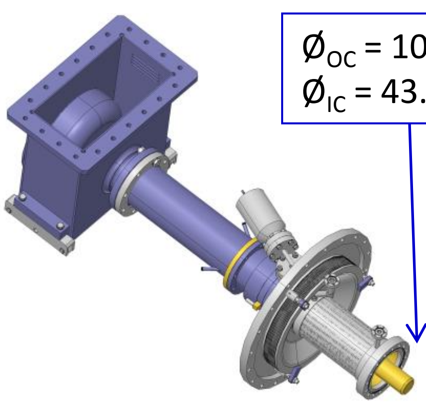
50Ω – Ø100mm coaxial coupler is

free of multipactor levels

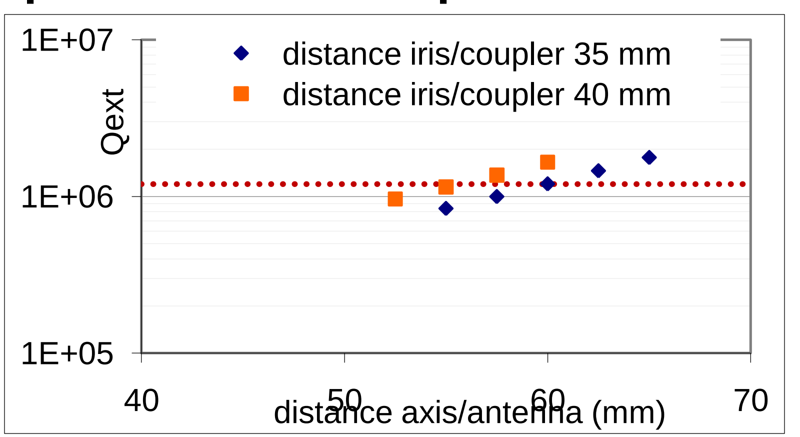
either around 1MW or 500 kW

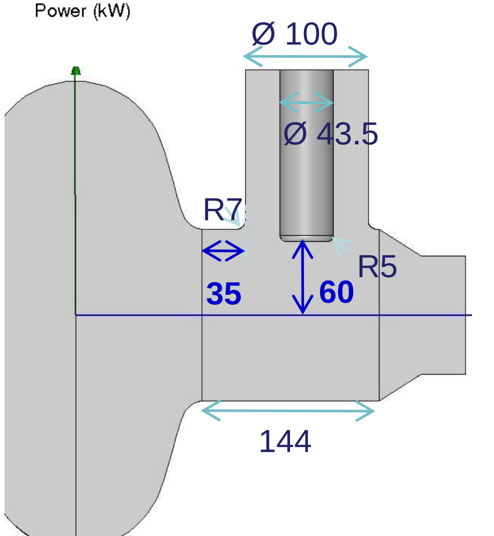
⇨**safe for β=1 and β=0.65 cavities**

Optimisation of coupler location

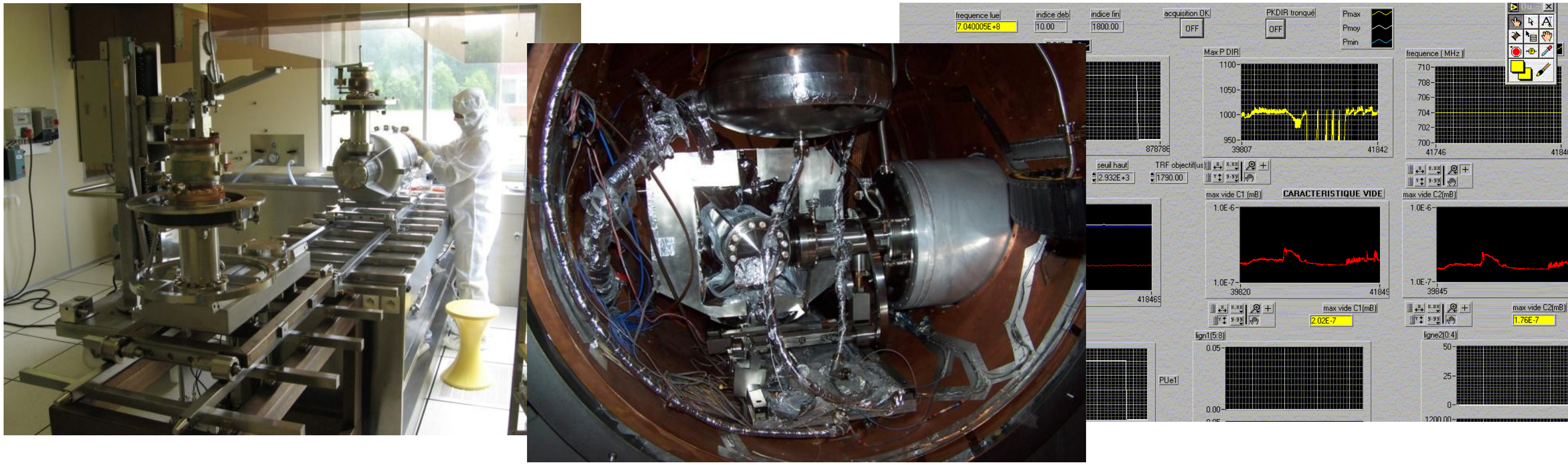


$Ø_{OC}$ = 100mm
$Ø_{IC}$ = 43.5 mm





Qualification of 700MHz - 1MW coupler



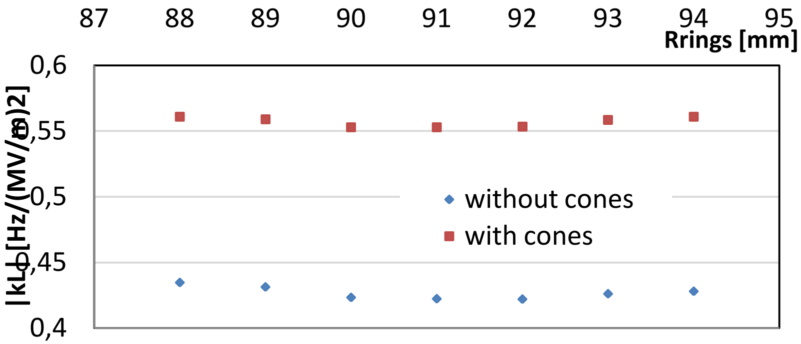
- Two couplers successfully processed last year on a dedicated RF test stand up to 1.2 MW peak @10% DC in TW for 300hrs
- Assembly of one coupler on HIPPI cavity (700 MHz, β=0.5) in ISO4 CR, and installation in test cryostat CryHoLab
- Only short time of RF processing in full reflection was necessary to reach high power levels
- Cavity and coupler operation at 1MW full DC for several hours
- Efficient counter-flow GHe cooling of the coupler leading to limited heat transfer to the LHe bath

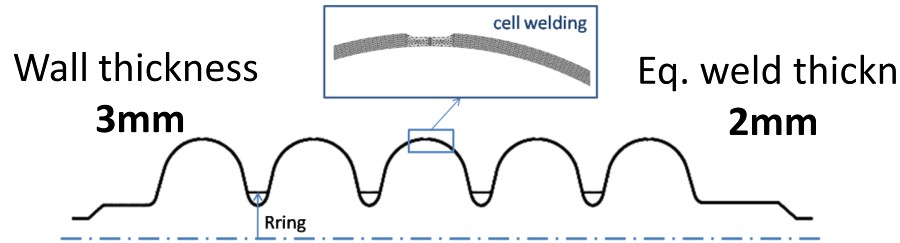
Qualification of 704 MHz power coupler on sc cavity at 2K operated at Ppeak=1.1 MW with tpulse=2 ms and frep=50Hz

LFD studies

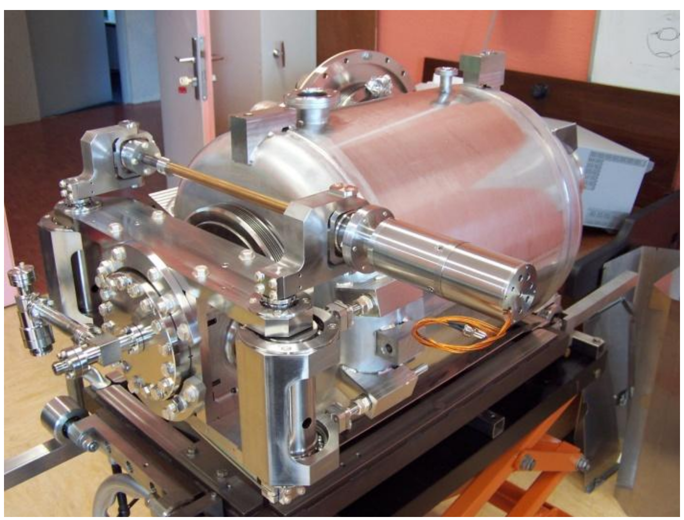
Due to the pulsed mode operation, LFD is of major concern

To limit this effect and partially compensate for it, mechanical stiffeners and piezo actuators are used (correction algorithm is optimised in SLHC-PP)



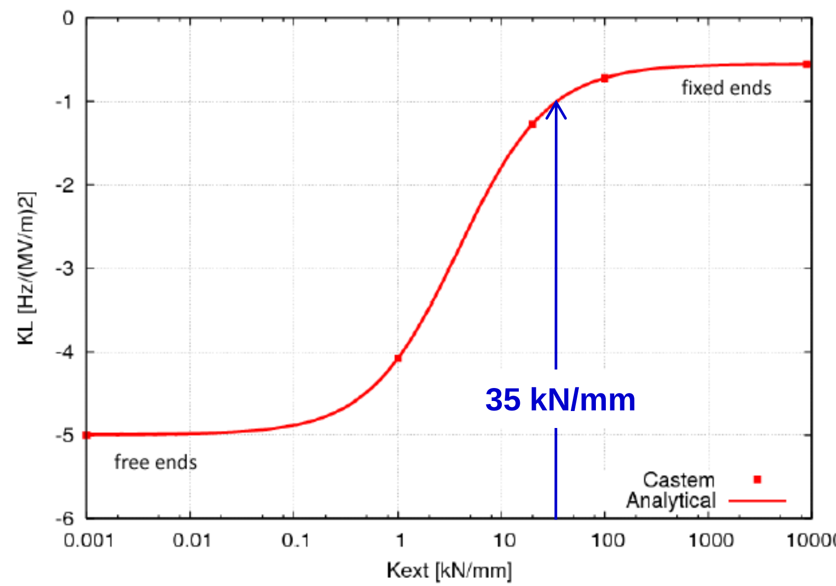


Optimal position of stiffeners: **Rring= 91 mm**



Measured tuner stiffness: **35 kN/mm**

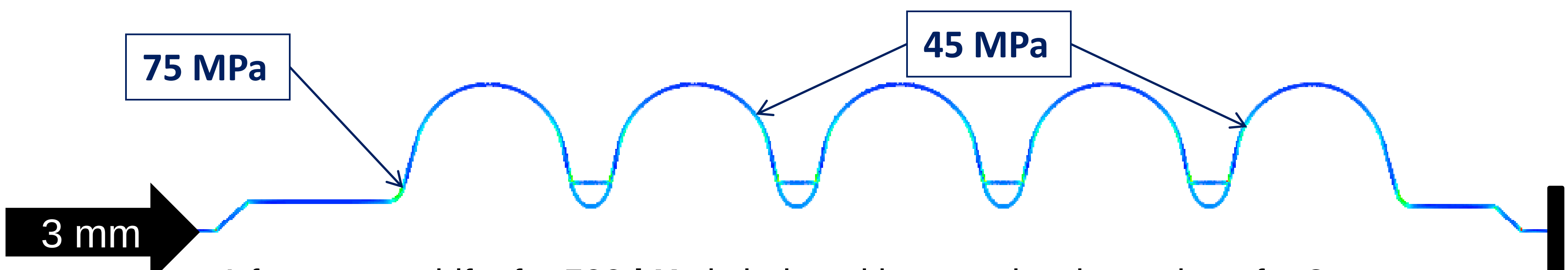
Saclay IV tuner on HIPPI cavity



For the cavity+tuner : $|K_L| \approx$ **1 Hz/(MV/m)²**

Frequency sensitivity

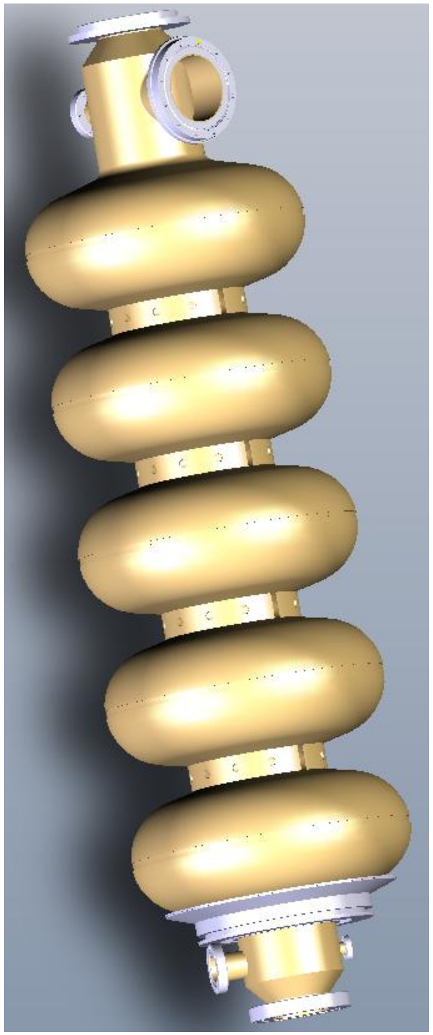
	SPL	
Nominal wall thickness [mm]	3	
Cavity stiffness Kcav [kN/mm]	3.84	
Sensitivity to He pressure [Hz/mbar] (fixed ends)	1.2	→ safe
K_L with fixed ends [Hz/(MV/m)^2]	-0.55	
K_L with free ends [Hz/(MV/m)^2]	-5	
K_L with realistic bound. cond. [Hz/(MV/m)^2]	-1	→ safe
Tuning sensitivity $\Delta f/\Delta z$ [kHz/mm]	164	
Stress per mm of tuning [MPa/mm]	25	



A frequency shift of ~ **500 kHz** is induced by a cavity shortening of ~ **3 mm** (standard value for the Saclay IV tuner)

Max stress **~ 75 MPa** remains far below the yield strength of Nb at 2K → safe

Optimized design of 704 MHz β=1 cavity



With this optimized design, prototypes would fit on our frames for surface preparation (BCP, VEP, HPR) and test in vertical cryostat

☑ assymetric cavity

beam tube Ø140 mm with a Ø100 mm port for power coupler

beam tube Ø130 mm with a Ø10 mm port for pick-up probe

☑ stiffening rings between adjacent cells

☑ inner diameter of the cavity flanges fixed to 80 mm

To perform qualification tests in horizontal cryostat or cryomodule, study of a fully equipped cavity (tuner, coupler, tank, …) is necessary

➲ power coupler port cooled by LHe

➲ lateral frequency tuner (similar to Saclay IV)

➲ each beam tube equipped with one Ø40 mm HOM port

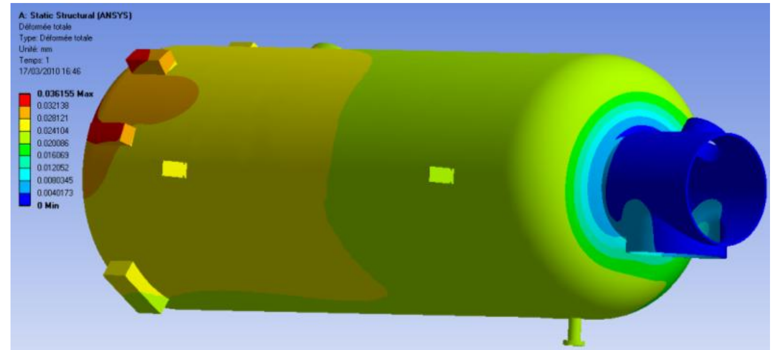
➲ fabrication of cavity and He tank without brazing

Helium tank made of Ti ; flanges made of NbTi

Mechanical optimization: Helium tank

Efficiency of the tuner strongly depends on the tank stiffness

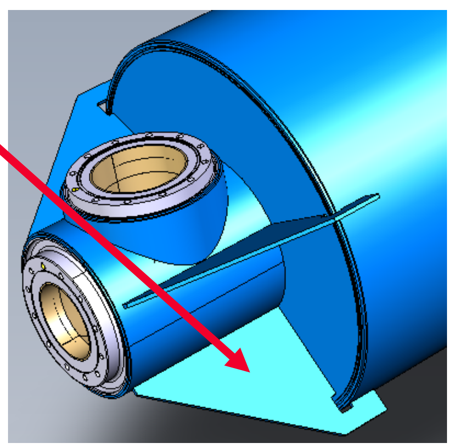
target: stiffness = 80 kN/mm (2x tuner stiffness)

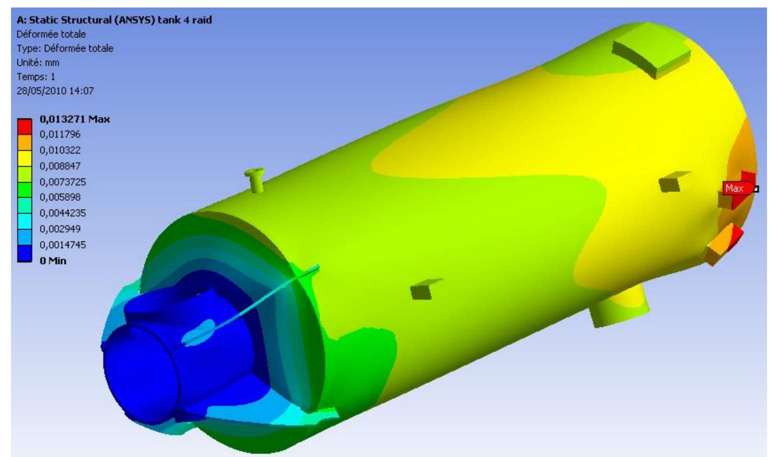


Thickn. = 3 mm Thickn. = 4 mm

Stiffness = 25.7 kN/mm

After optimisation:
- tank and Ti flange (thickness, size)
- wings (location, shape, number)





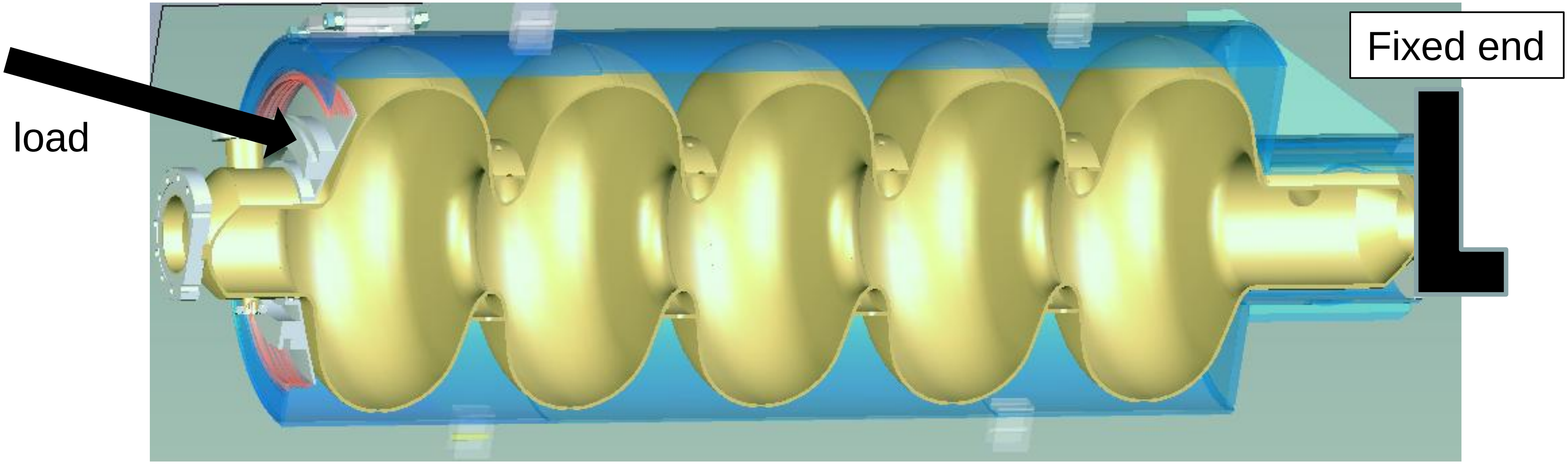
4 wings ; Thickn. = 5 mm

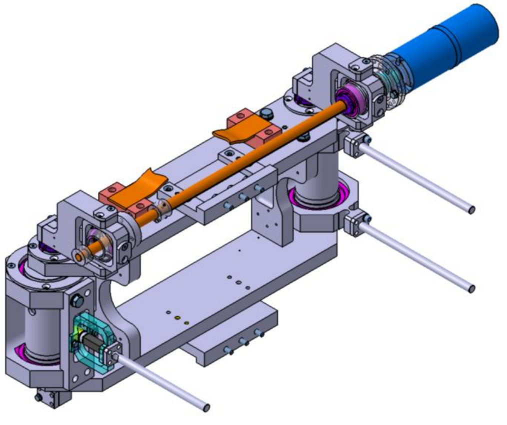
Stiffness = 77 kN/mm

New frequency tuner

Design principle:

The tuner load is applied on the Ti flange while keeping He tank at the same position





New lateral tuner Saclay V

Based on design of tuner developed for 704 MHz β=0.5 cavity and qualified at cold and under vacuum

Changes done from previous design:

- Use of Ti flange to ease assembling on cavity strings
- Compatible with 130 mm beam tube diameters
- More room for HOM coupler
- Piezo frame with optimized stiffness (40 kN/mm)

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Achievements

- Cavity design complies with the requirements of the SPL $\beta = 1$ cavities (peak fields, r/Q, Qex)
- The beam tube cooled by LHeII insures thermal stability at high average power (100kW)
- After mechanical optimization of tank and tuner and considering the results of tests (SLHC-PP), LFD should not be an issue
- New lateral tuner (Saclay V type) adapted from a previous version in order to be ease the assembling on “cavity strings”

Plans for the next months

1) Fabrication of a cavity+Helium tank prototype

Delivery of cavity w/o LHe tank expected in September 2011

- Tuning and field flatness
- Surface preparation (Vertical Electropolishing, HPR in CR-ISO4)
- Low power RF test in our vertical cryostat CV1

Last fabrication sequence and delivery of cavity with tank expected in Dec. 2011

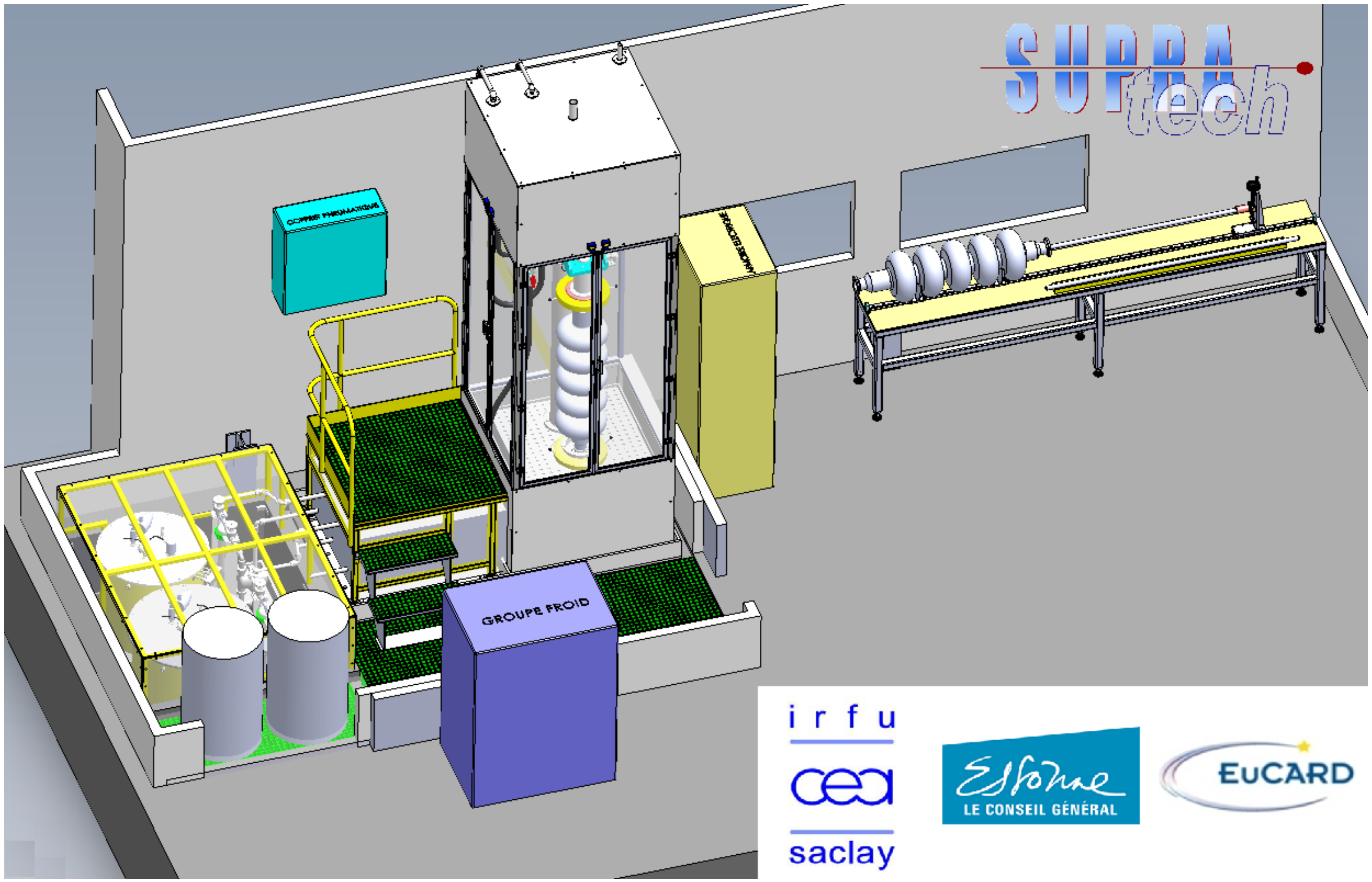
High power couplers and tuners fit on the cavity+tank: this fully equipped cavity could be tested in horizontal cryostat (CryHoLab) or operated in a 4-cavities cryomodule

2) Fabrication of 4 Helium tanks (with same design)

3) Fabrication of 8+1 tuners

Delivery expected in December 2010

Surface preparation: Vertical EP station

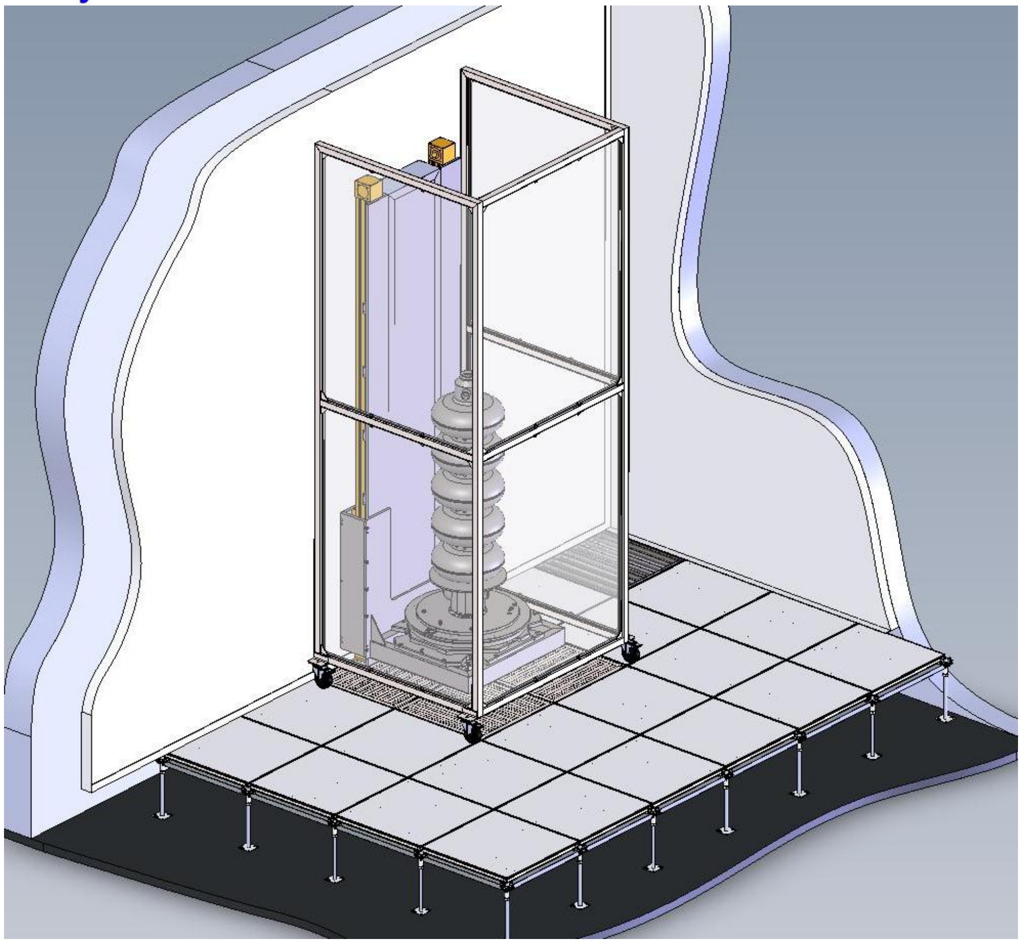


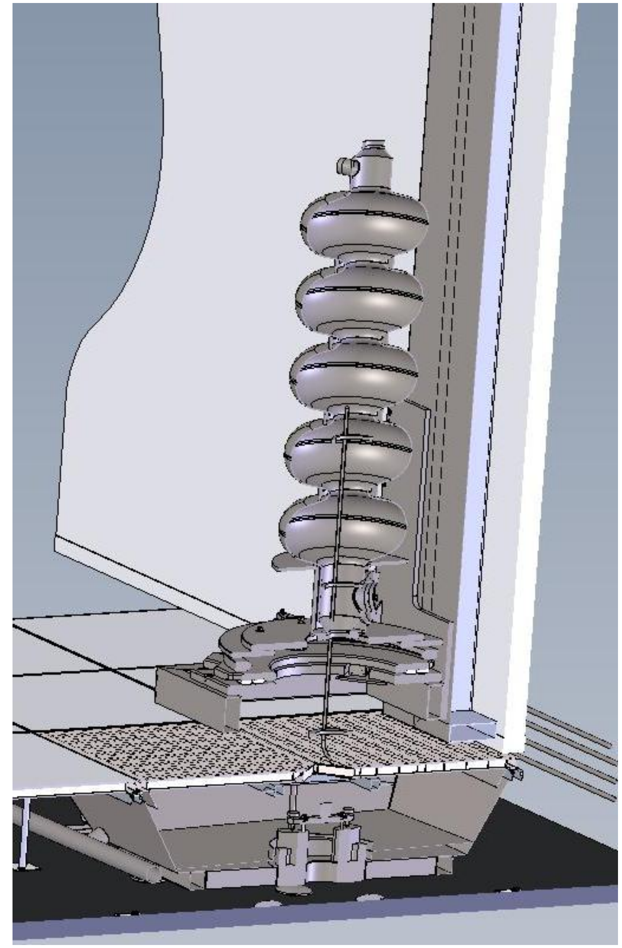
Vertical Electropolishing station to be built in the 2nd semester 2010

Preparation of the area (resin layer, connection to liquid acid effluents storage tanks) started

First tests expected in February 2011

New High Pressure Rinsing station in Clean Room





HPR station to be tested in November 2010

Installation in our new clean room in 2011 (during a shutdown for maintenance)

704 MHz technology for both SPL & ESS projects

- Components can (have to) be designed to satisfy requirements of both SPL and ESS projects:

  - Tuner developed for the 704 MHz - β = 1 elliptical cavity fits on β = 0.65 cavity too (IPN-Orsay studies) and same tuner should fit the β = 0.XX ESS cavities (assuming a beam tube diameter of 130mm)

  - The same LFD compensation scheme (and electronic racks?) could be used for all SPL and ESS cavities providing that the designs of these cavities are optimized wrt LFD coef. (stiffeners, Nb thickness, …)

- We need a multi-MW test stand:

  - The 704 MHz HIPPI coupler is a nice starting design already qualified up to power source capability (1.1 MW at 10% DC): where is the limit (weak part, max power…)?

  - Pin in operation is around 1 MW for both SPL and ESS high β cavities: qualification of couplers up to some MWs seems necessary to insure safety margin and reliable operation

Thank you