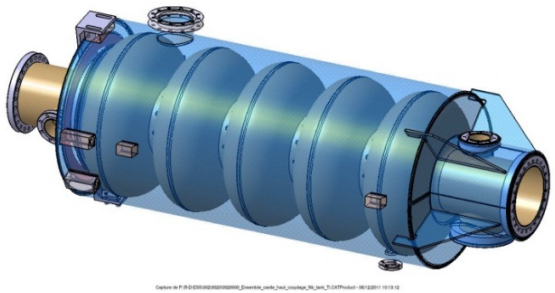
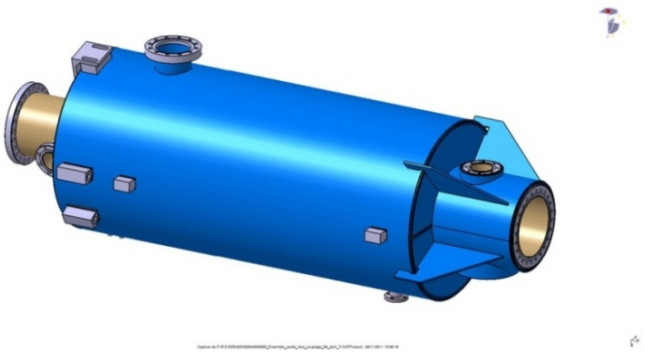
ESS elliptical cavity activities at CEA-Saclay

Juliette Plouin, Guillaume Devanz

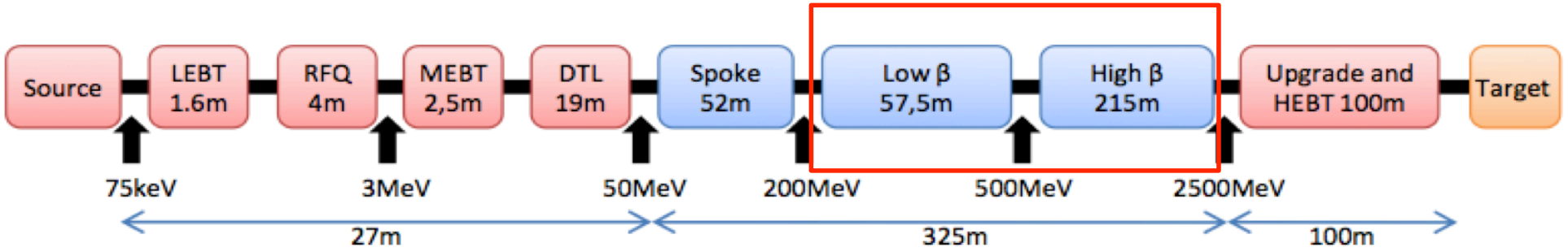




Outline

- Cavity RF/mechanical design
- Helium tank
- High Order Modes/extraction
- Power coupler
- Tooling and equipments
- Milestones

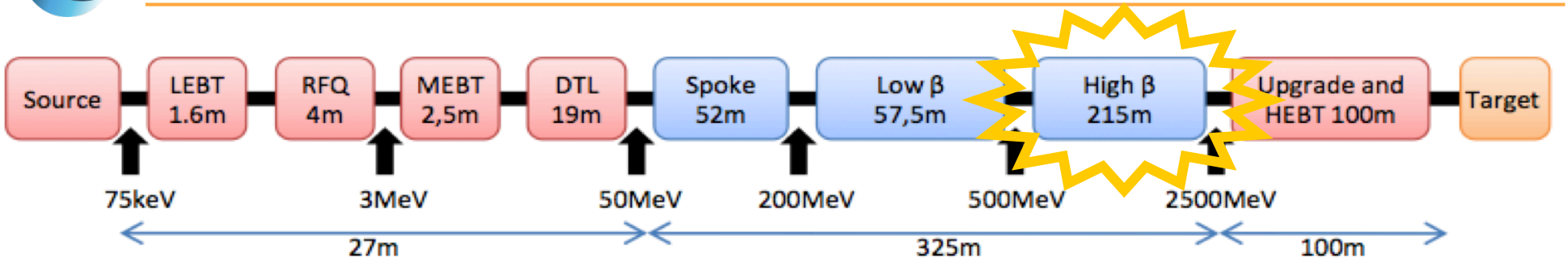
Elliptical cavities in ESS



- 5-cell cavities, bulk niobium
- two beta families
- frequency = 704.42 MHz
- performance specifications (T = 2 K):
- Peak field specifications : Epk < 40 MV/m

beta	Eacc VT (MV/m)	Eacc Linac (MV/m)	Qo @ nominal Eacc
0.70	17	15	5e9
0.90	20	18	6e9

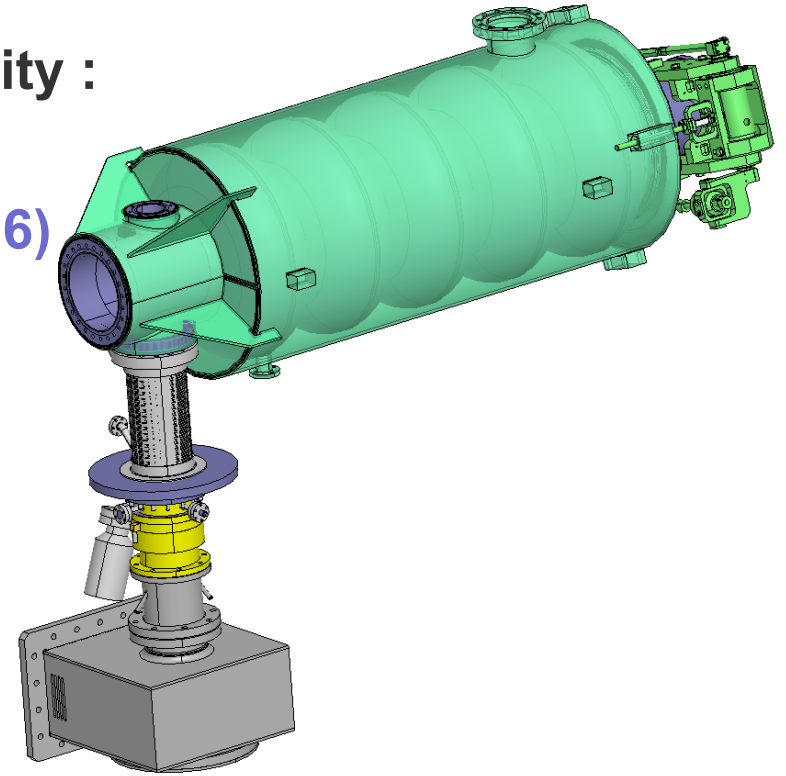
High beta cavities at CEA-Saclay



8 equipped superconducting high beta cavity :

design, fabrication and tests

- Elliptical 5-cells 704.42 MHz cavity **(β = 0,86)**
- Fundamental power couplers
- High Order Modes couplers
- Cold tuning systems
- Magnetic shields



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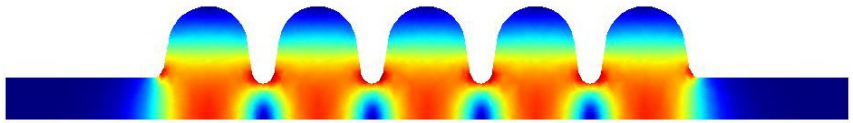
RF design of high beta cavities : cells



Mode fondamental @704,42 MHz

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

Advantages of high cell to cell coupling for TM_{01}:

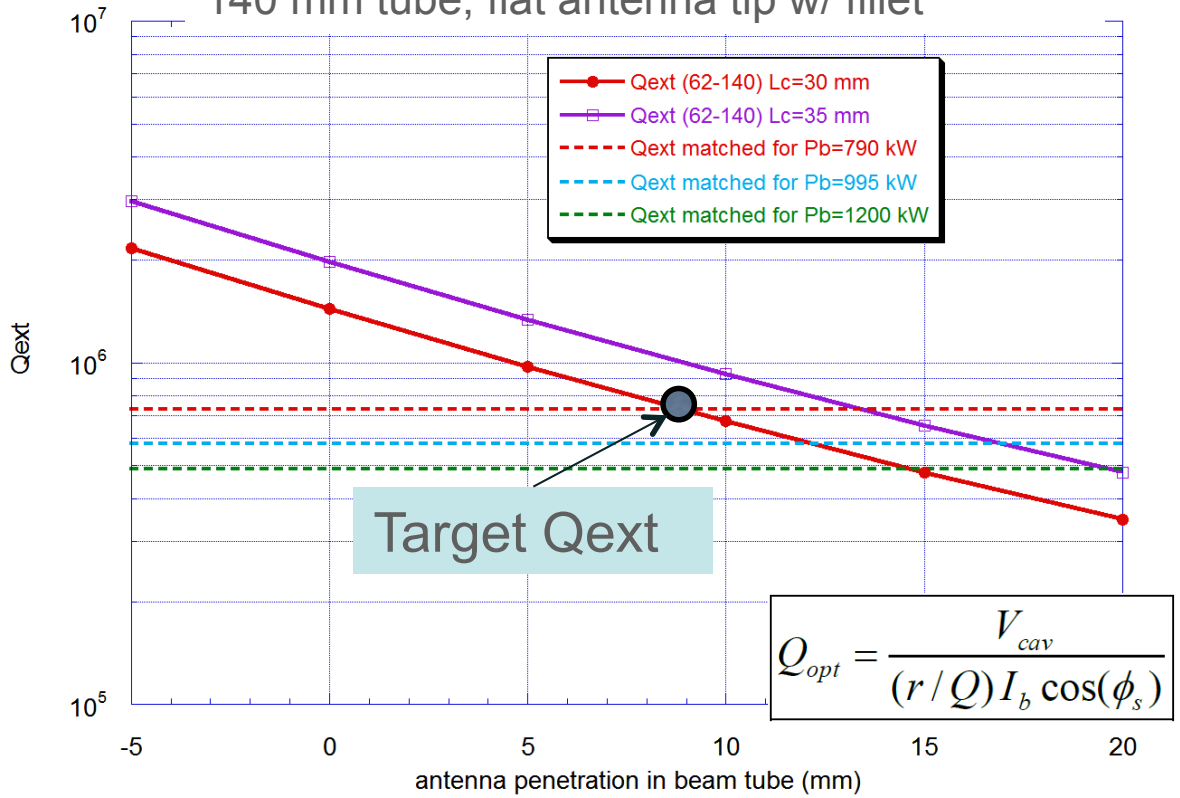
- easier to obtain field flatness, control over peak fields distribution among cells
- more consistent Qext across cavities
- enhanced mode separation between π and $4\pi/5$ modes
- HOM also better coupled to the outer cells (needed for damping)

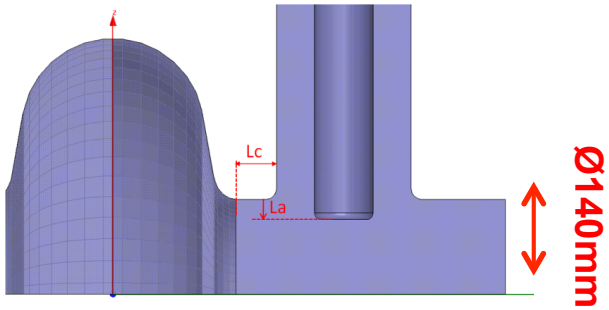
RF PARAMETERS		
	Bpk/Eacc [mT/(MV/m)]	4.3
	Epk/Eacc	2.2
	G [Ohm]	241
	Cell to cell coupling	1.8 %
	r/Q [Ohms]	477
	L_{acc} = Ngap.$\beta.\lambda/2$ [m]	0.915
	Cell wall angle	> 8°

RF design of high beta cavities : beam tubes

✓ External coupling

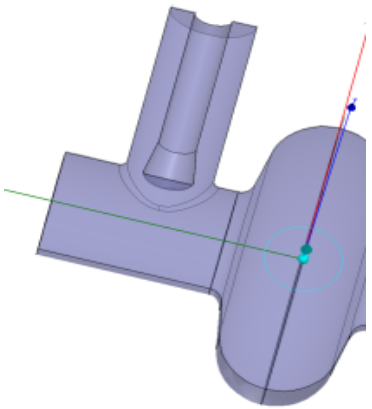
140 mm tube, flat antenna tip w/ fillet





- Lc can be reduced to 30 mm

- Qext could be decreased of 15% with a conical antenna tip

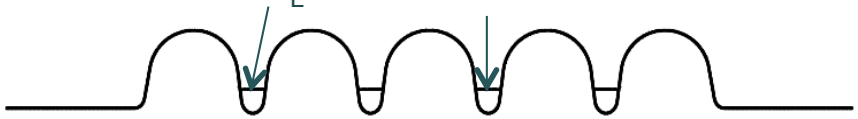


✓ HOM propagation :140 mm diameter is more favourable

	Cutoff frequencies (GHz)						
Diamètre (mm)	TE11	TM01	TE21	TM11	TE01	TE31	TM21
130	**1.3535**	**1.7683**	2.2405	2.8143	2.8143	3.0769	3.7831
140	**1.2568**	**1.6420**	2.0804	2.6132	2.6132	2.8571	3.5129

RF/mechanical design

Réduction de K_L avec des anneaux

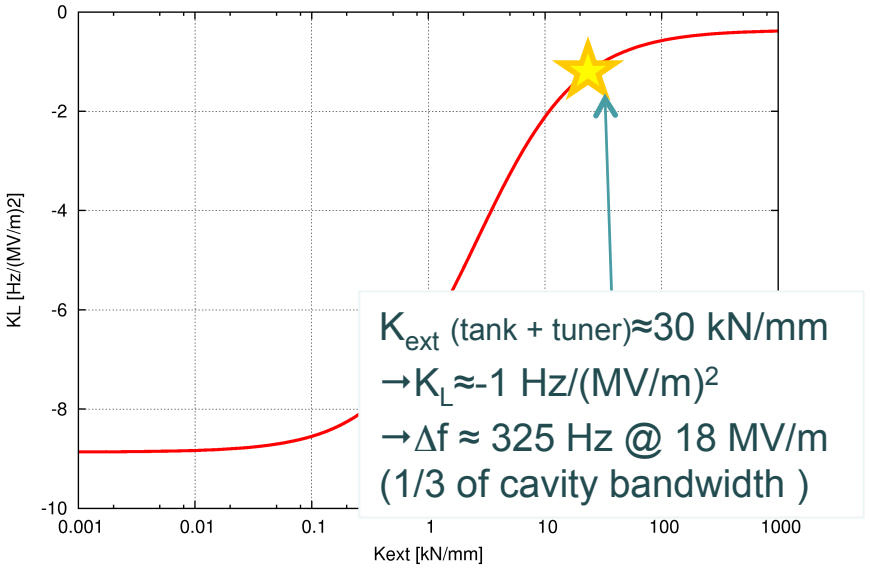


Lorentz detuning

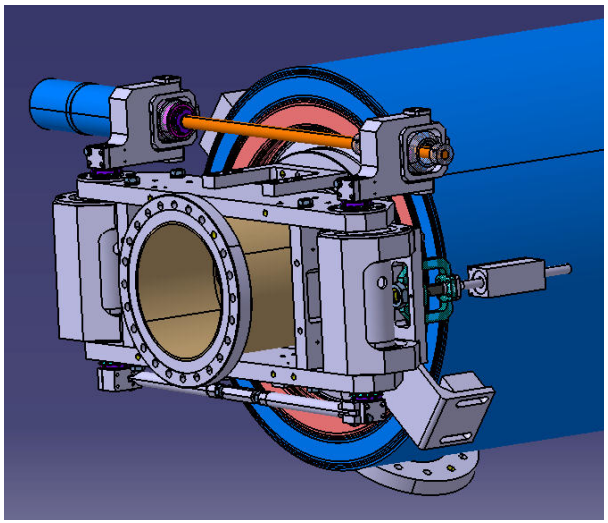
$$K_L = \Delta f / E_{acc}^{\ 2}$$

$$K_L = K_{L\infty} + \frac{\Delta f}{\Delta z} \frac{\vec{F_\infty}.\vec{u_z}/E_{acc}^{\ 2}}{K_{ext} + K_{cav}}$$

Nominal wall thickness [mm]	3.6
Cavity stiffness Kcav [kN/mm]	2.59
Tuning sensitivity $\Delta f/\Delta z$ [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



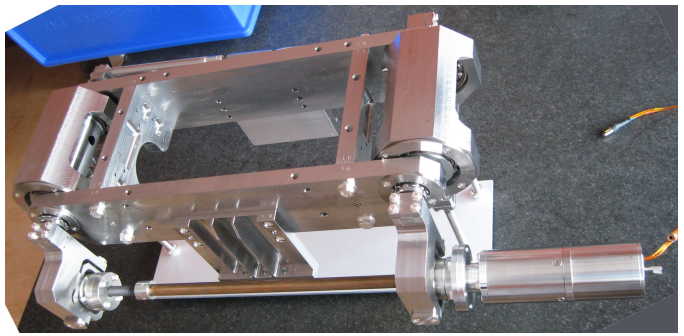
K_{ext} (tank + tuner)≈30 kN/mm
→K_L≈-1 Hz/(MV/m)²
→Δf ≈ 325 Hz @ 18 MV/m
(1/3 of cavity bandwidth)



Saclay-V tuner concept adapted to the ESS cavity

Fast/slow tuner (with piezo)

SPL tuner

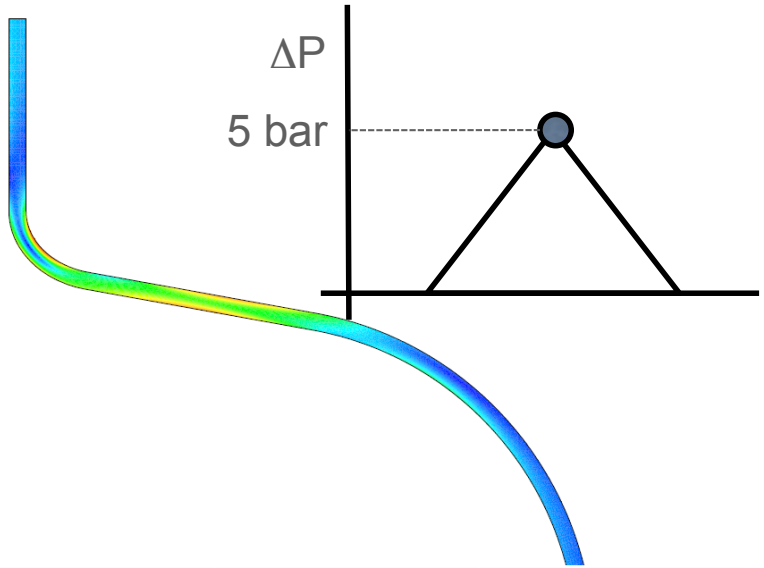


Resistance to pressure tests

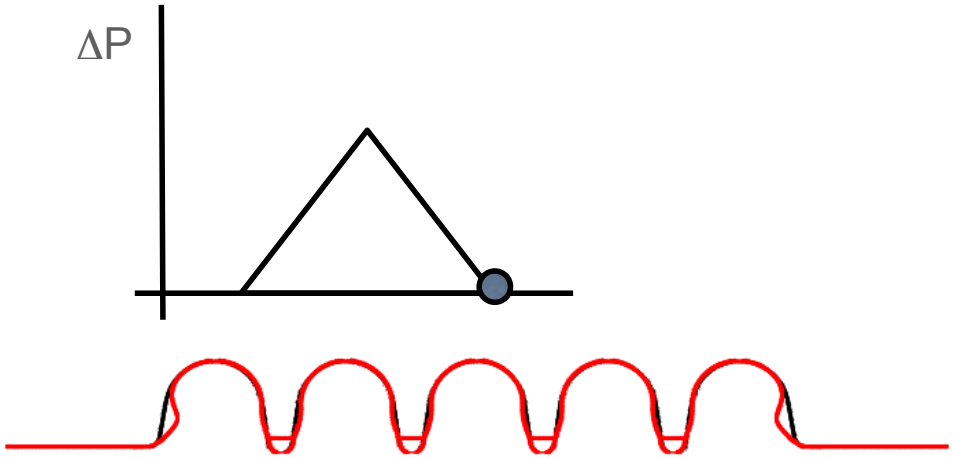
We foresee a pressure test of the He tank/cavity will be carried out for certification (similar to TUV test for X-FEL cavities)

Simulation of cavity deformation with a *plastic* model, 3.6 mm thickness

- The differential pressure is cycled : 0-5-0 bars
- external rig used to maintain cavity length : fixed ends
- max residual deformation after 1 cycle : 7μm for 1 cycle, detuning 560 Hz



Max VM stress	Max deformation	Delta f
54 Mpa	0.235 mm	33.9 kHz



Max. residual deformation	Residual detuning
6.7 μm	-563 Hz

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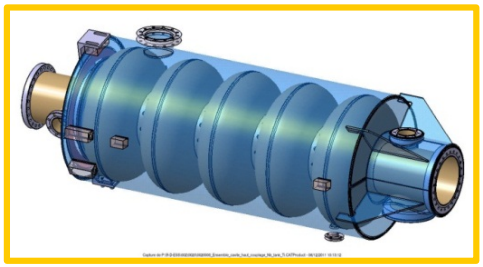
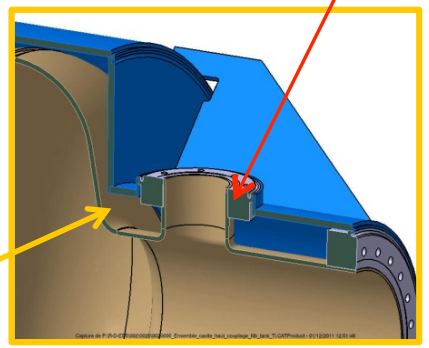
Helium vessel



Helium vessel in Titanium

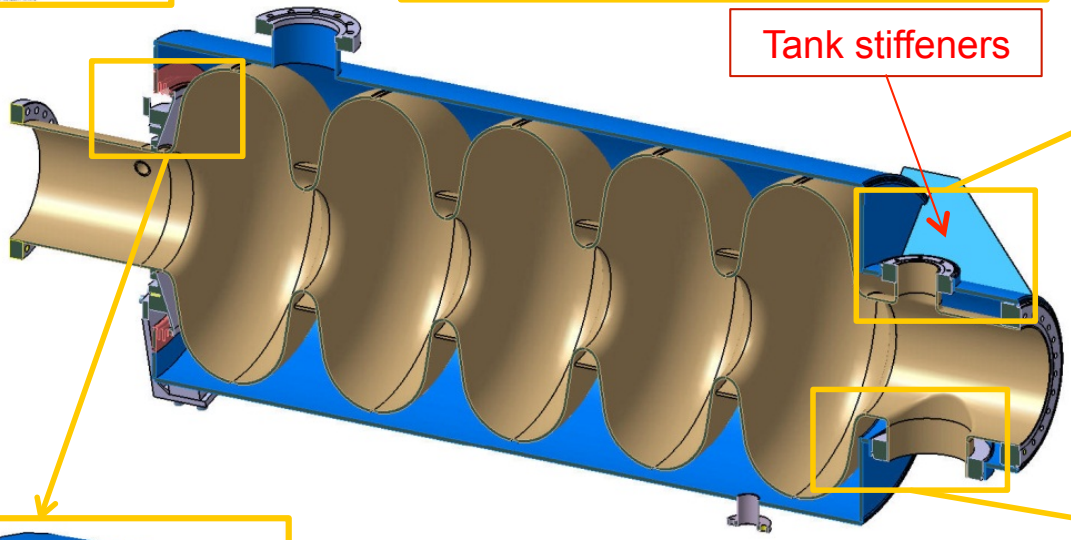
(no brazing, marginal differential shrinkage with Nb, compact FPC port)

HOM port flanges (NbTi)

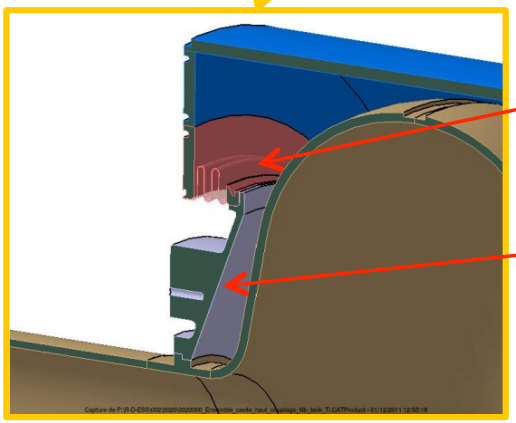


Tank stiffeners

Al Mg Si
Hex seals

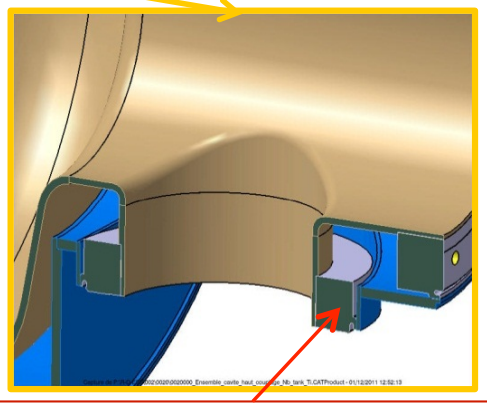


The position of the HOM ports could change after the prototypes, in relation with HOM couplers studies



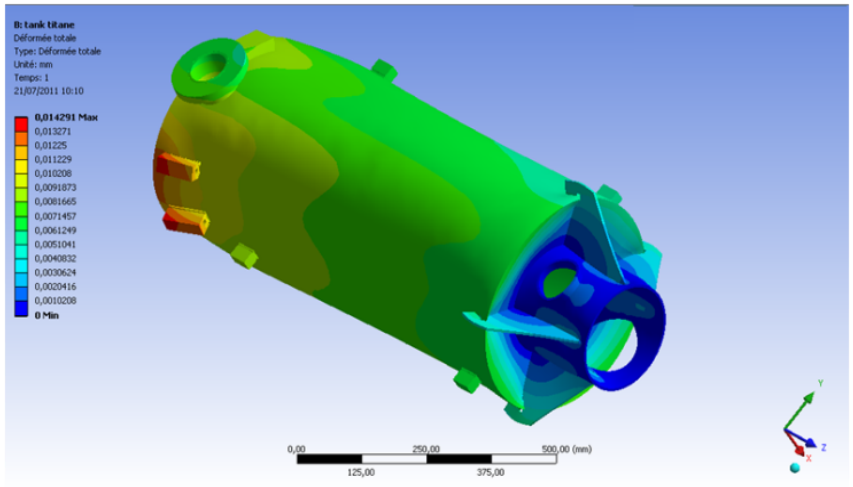
Hydroformed bellows (Ti)

Flange bellows/tuner (Ti)



Power coupler port flanges (NbTi)

Mechanical modes: cavity + vessel

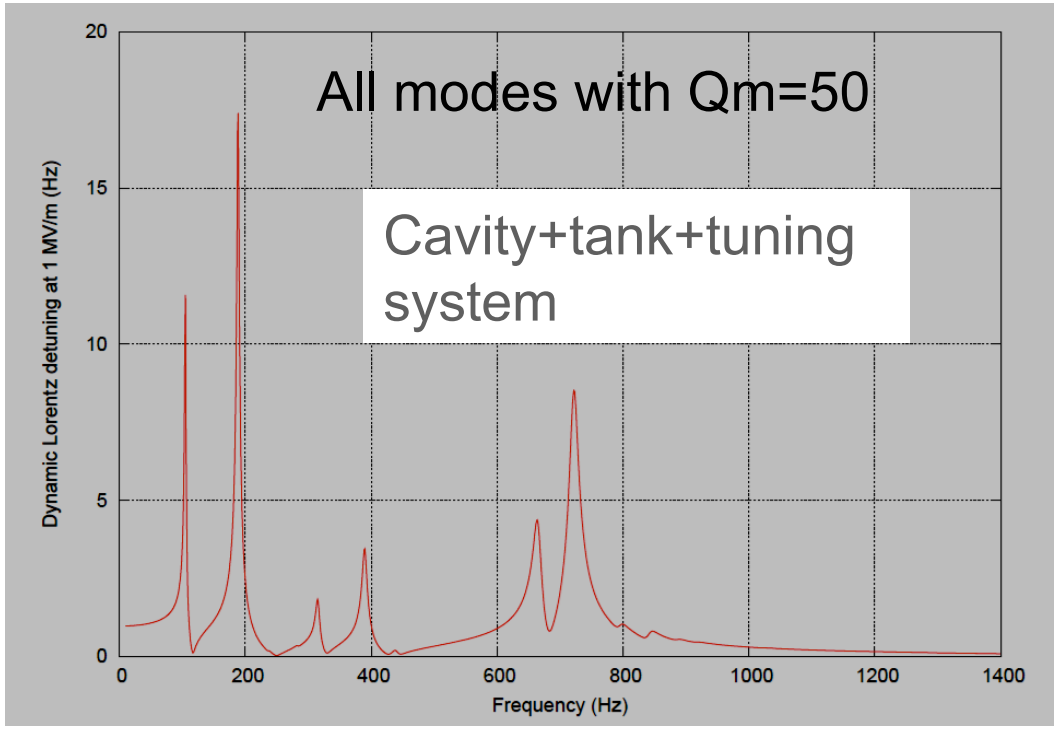


5 mm thick Ti tank

Stiffness = 70 kN/m

Longitudinal mechanical modes with RF frequency deviation:

Simulation of Lorentz detuning transfer function



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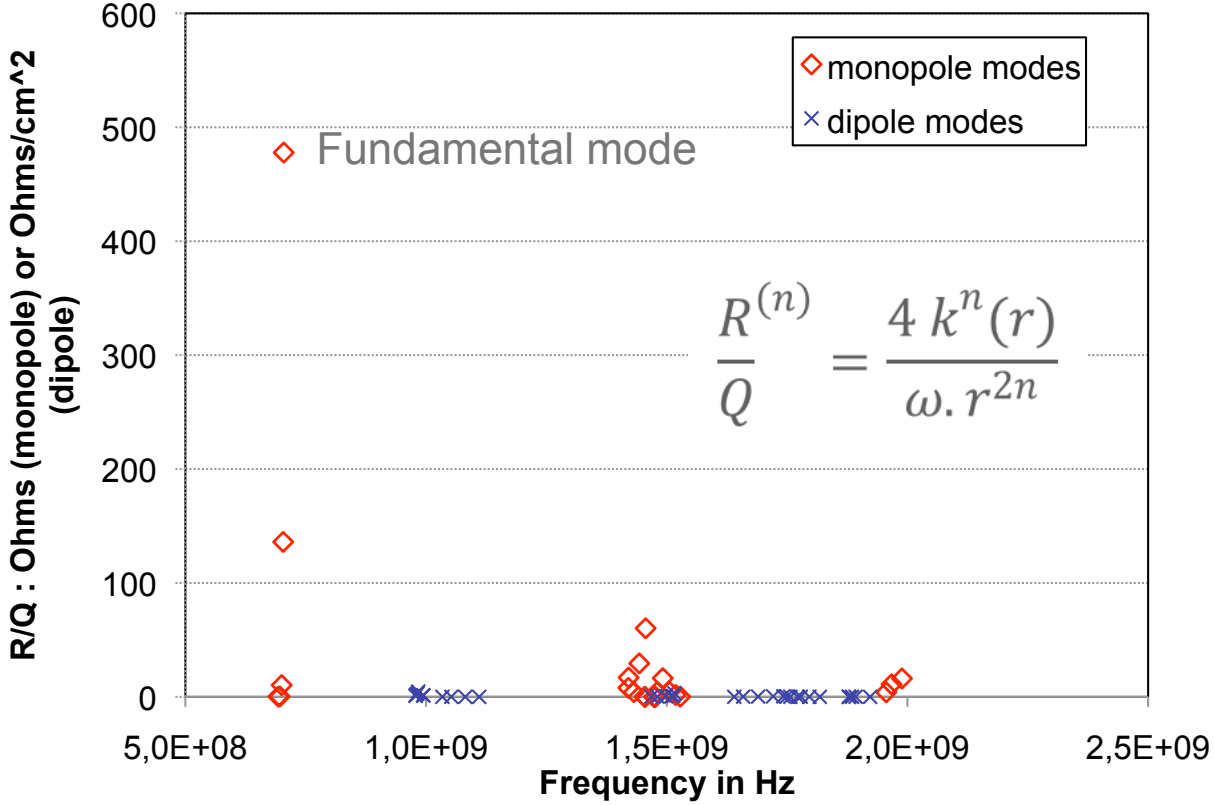
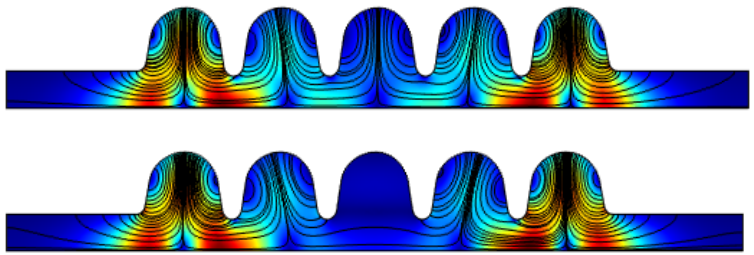
High Order Modes (HOM)



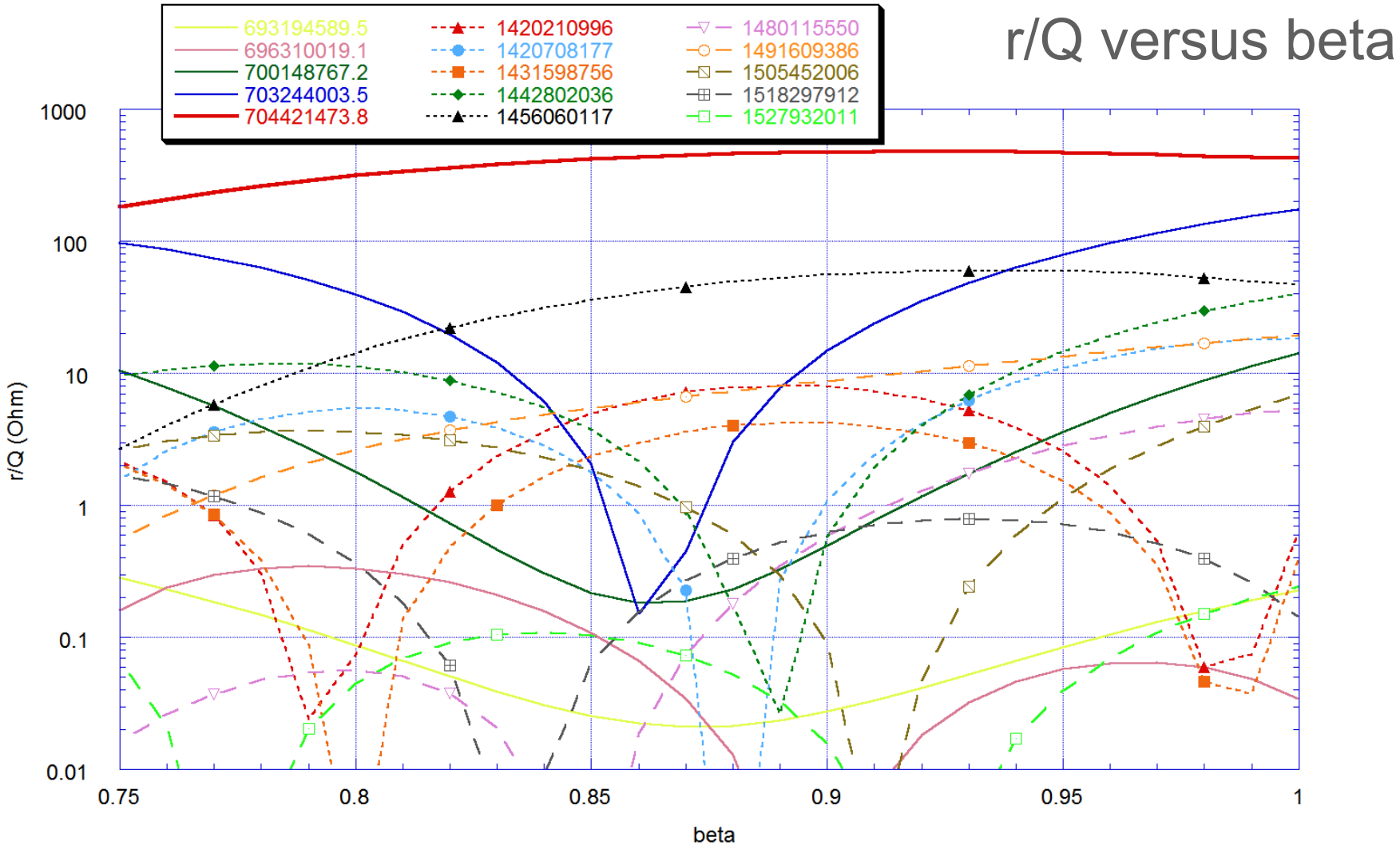
All HOM have been identified up to 2 GHz, with r/Q calculated

2 monopolar modes identified around 1420 MHz. Closest machine line at 1408,8MHz= 2x704.4 MHz, i.e. 11.2 MHz appart. Matching the mode and the machine line would require a cavity elongation of 28 mm

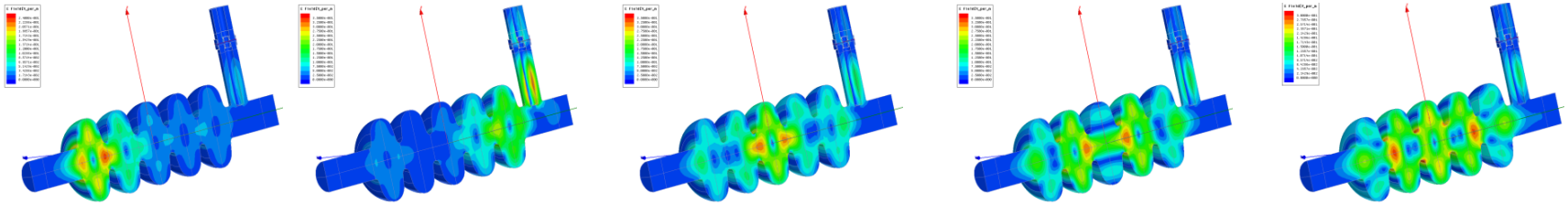


HOM : first monopolar bands

Monopole HOM for the 5-cell below cutoff



HOM damping by power coupler

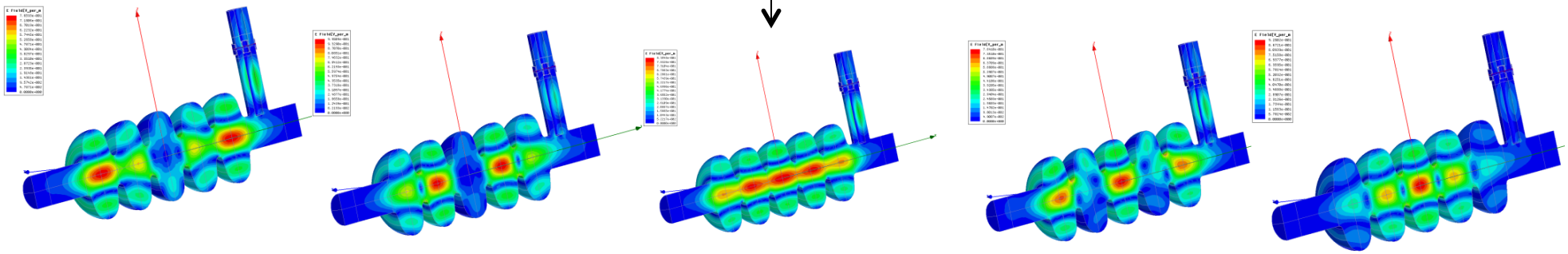


Freq	Q	Max. r/Q
1,420314E+09	1,58E+05	8
1,421856E+09	4,30E+03	17
1,431672E+09	3,22E+04	4
1,442845E+09	3,30E+04	29
1,456038E+09	4,41E+04	60

First monopolar band
Maximum Qext 1.6e5

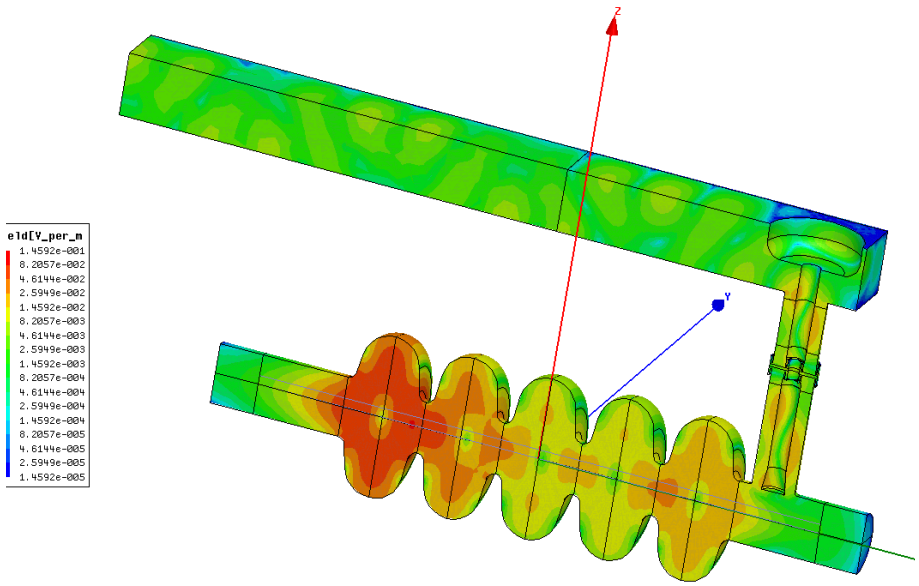
Freq	Q	Max. r/Q
1,480140E+09	1,98E+04	5
1,491491E+09	1,33E+04	17
1,505236E+09	1,40E+04	4
1,518154E+09	1,87E+04	4
1,527895E+09	4,57E+04	0,2

Second monopolar band
Maximum Qext 4.6e4

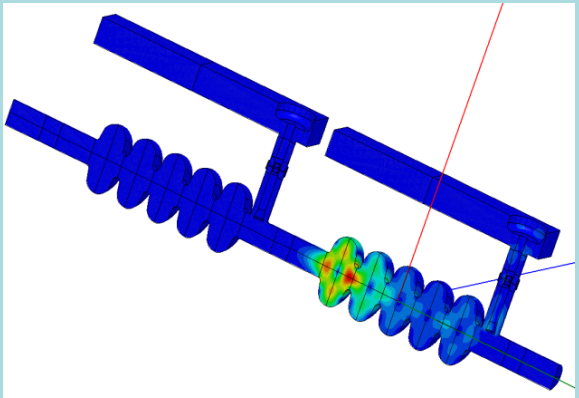


- Mostly damped by the FPC antenna
- But optimistic case because of matched termination

HOM damping - More realistic coupler modeling



Electric field amplitude (logscale) – 1420 MHz



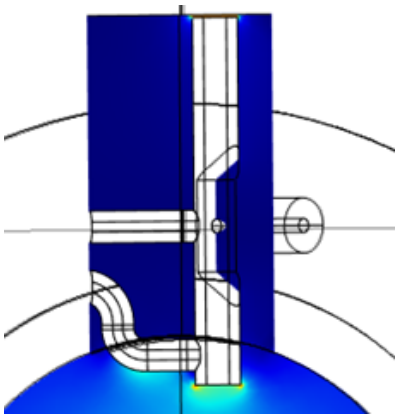
Study of multiple cavity interaction started

F (MHz)	Matched termination	Doorknob + WG
1 420 300	1.58e5	4.06E+05
1 421 018	4.30e3	2.38E+04
1 431 633	3.22e4	6.36E+05
1 442 796	3.30e4	1.27E+06
1 456 101	4.41e4	5.05E+05
1 480 038	1.98e4	1.29E+05
1 491 485	1.33e4	2.03E+05
1 505 199	1.40e4	4.99E+05
1 518 257	1.87e4	1.94E+05
1 527 899	4.57e4	6.08E+05

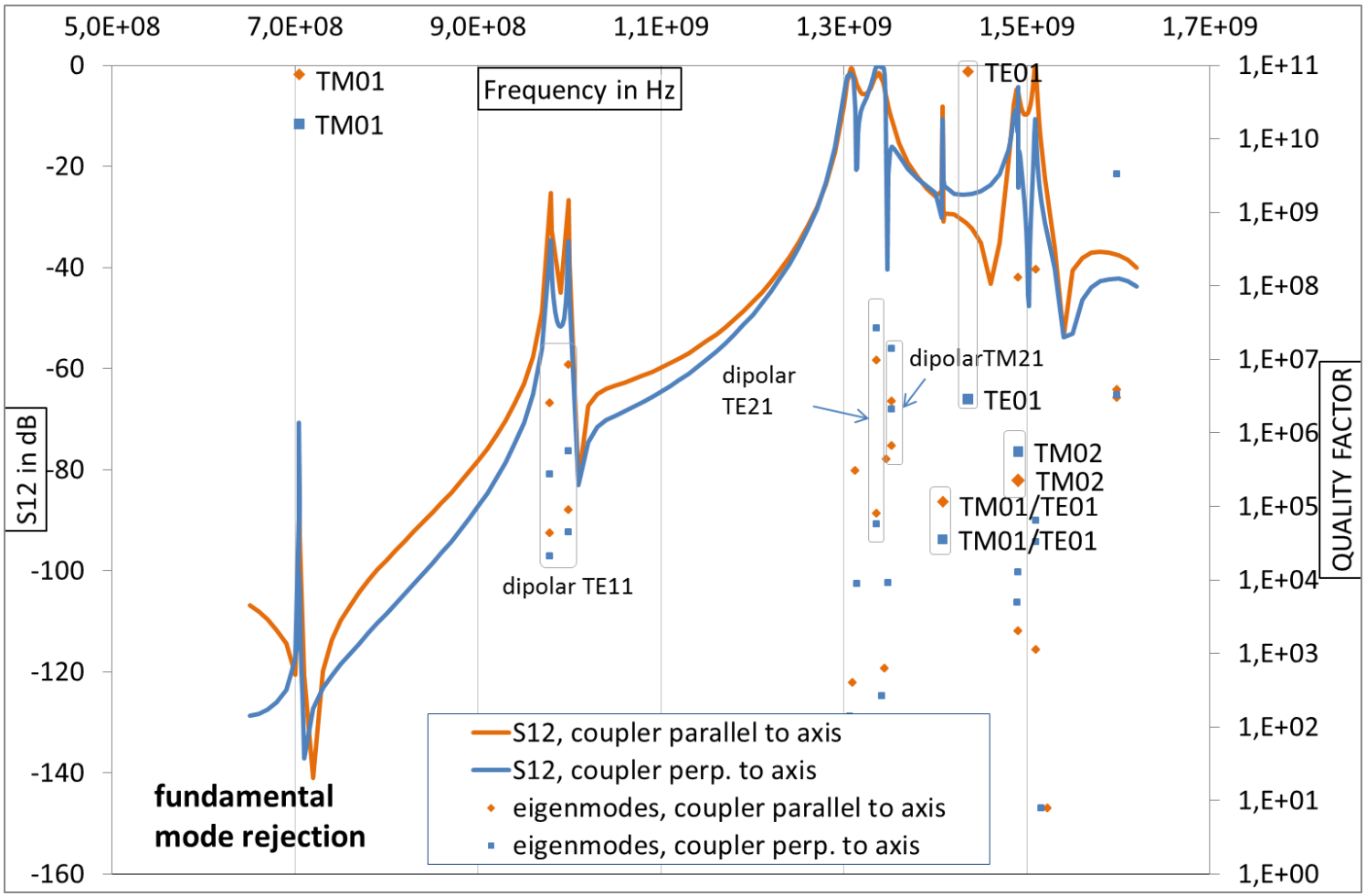
The coupler is fully modeled, but the transmission characteristics of the high power waveguide network are unknown. Here, the rectangular WG is terminated by a lossy short.

HOM couplers conceptual design

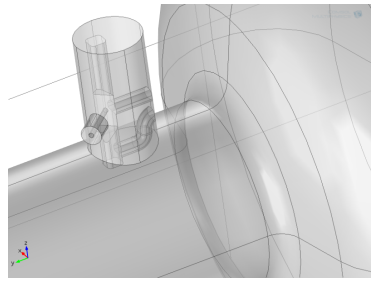
Desy type, *Ø 50 mm for the internal diameter of the port*



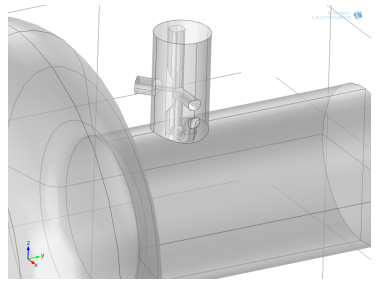
characteristics on a ***single cell***



Coupler parallel to axis

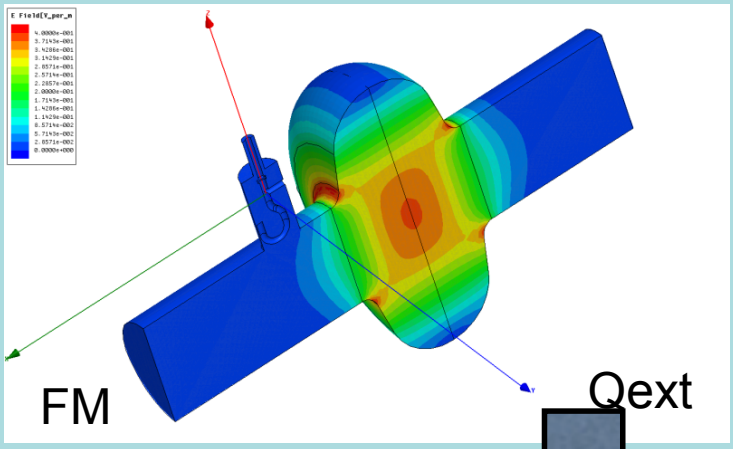


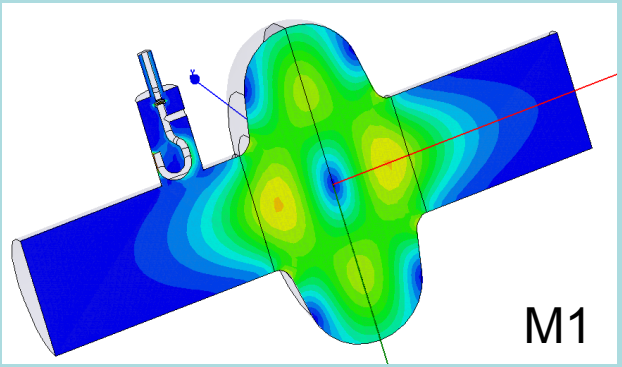
Coupler perp. to axis



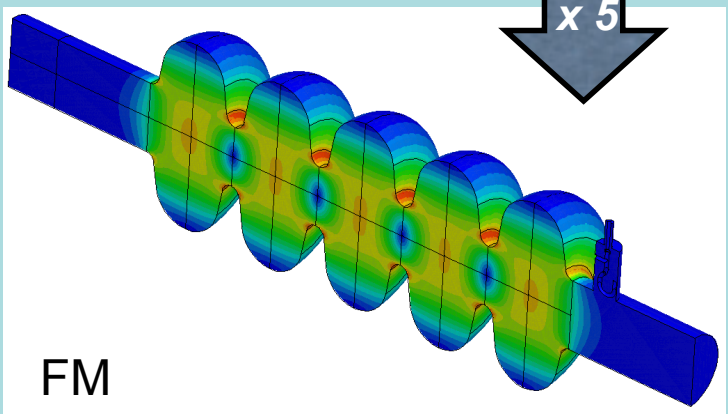
HOM couplers conceptual design

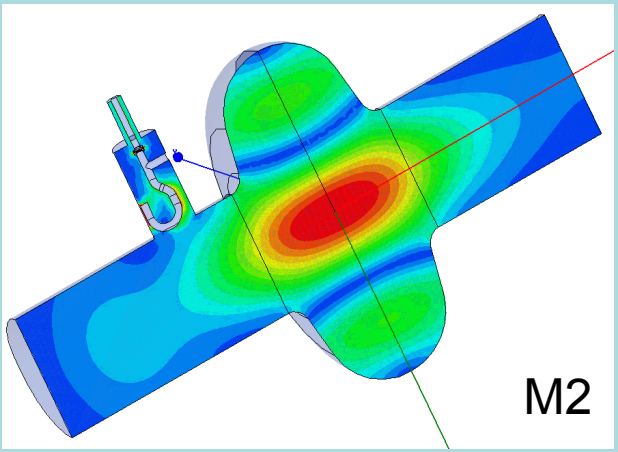
CERN-Saclay type, *Ø 50 mm for the internal diameter of the port*





x 5





Single cell mode	Single cell Qext
FM	4.4e10
M1	3.4e4
M2	6.0e3

Study is on-going, FM Qext aimed at for rejection is 1e12 on the 5-cell cavity (in this example FM Qext = 2e11)

Both types of HOM couplers show the possibility of fundamental mode rejection
Two HOM ports (with relative angle *now* 105°) are included in the prototype cavities

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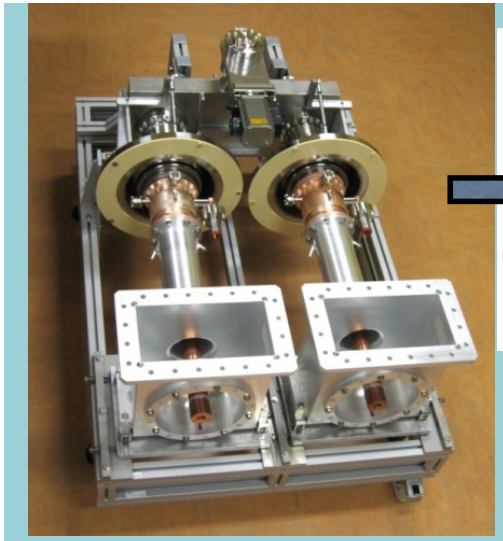
Power coupler

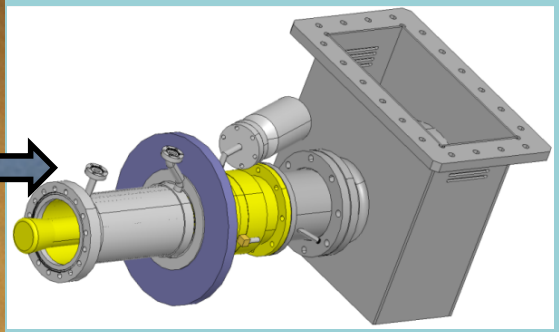
ESS specifications with beam current = 50mA	
Frequency (MHz)	704.42
Repetition rate (Hz)	14
Beam pulse length (ms)	2.86
Nominal peak power transmitted by power couplers (kW)	< 900
Maximum admissible peak power (kW)	1200

✓ Starting from Saclay HIPPI 1MW 10%DC coupler (KEK type window)

✓ HIPPI couplers validated up to 1.2 MW (P_{avg}=120kW) and with 704 MHz cavity in Cryholab (1 MW full reflexion)



CARE-HIPPI Couplers



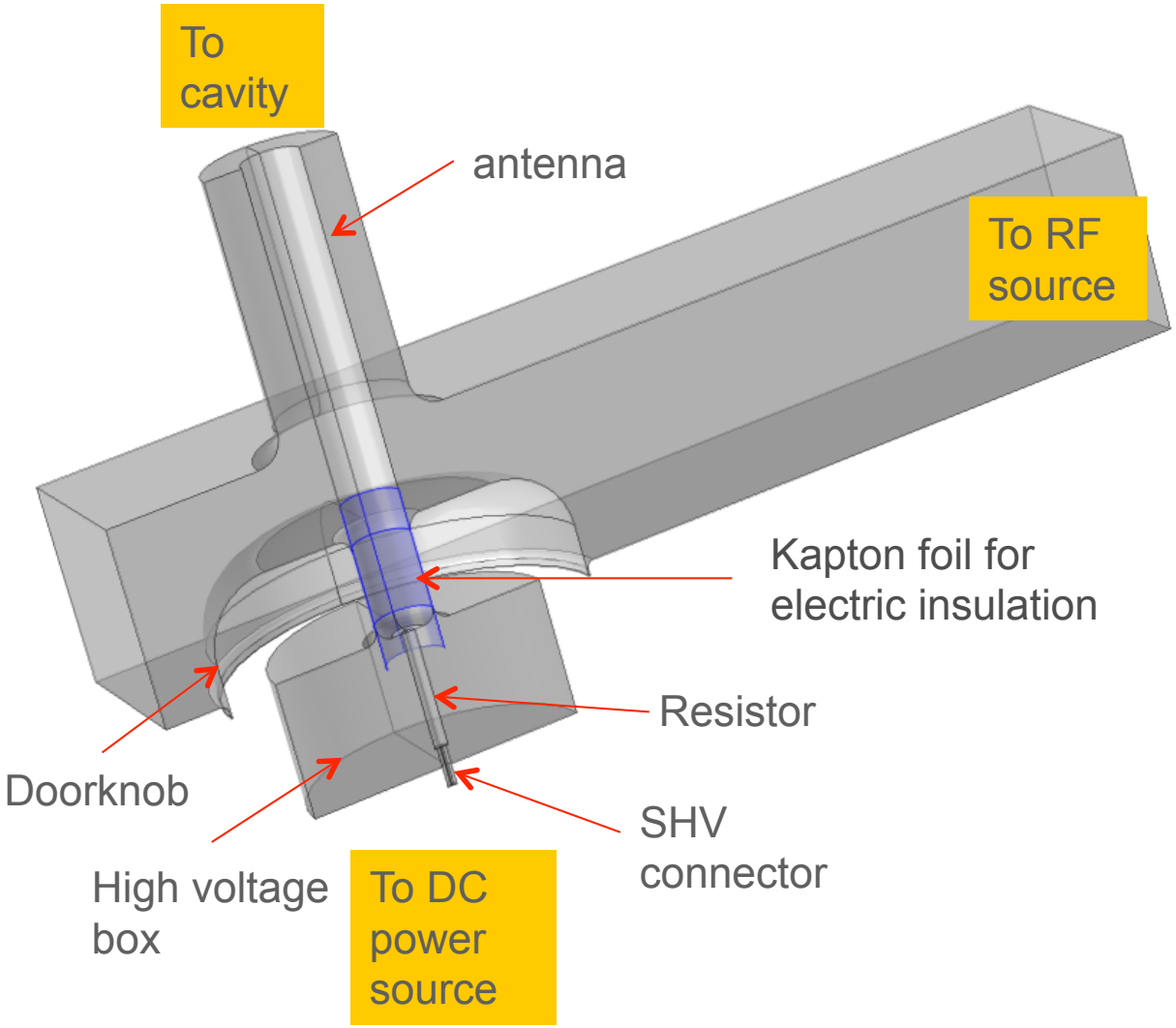
External modification: Integration to ESS cryomodule (instead of Cryholab)

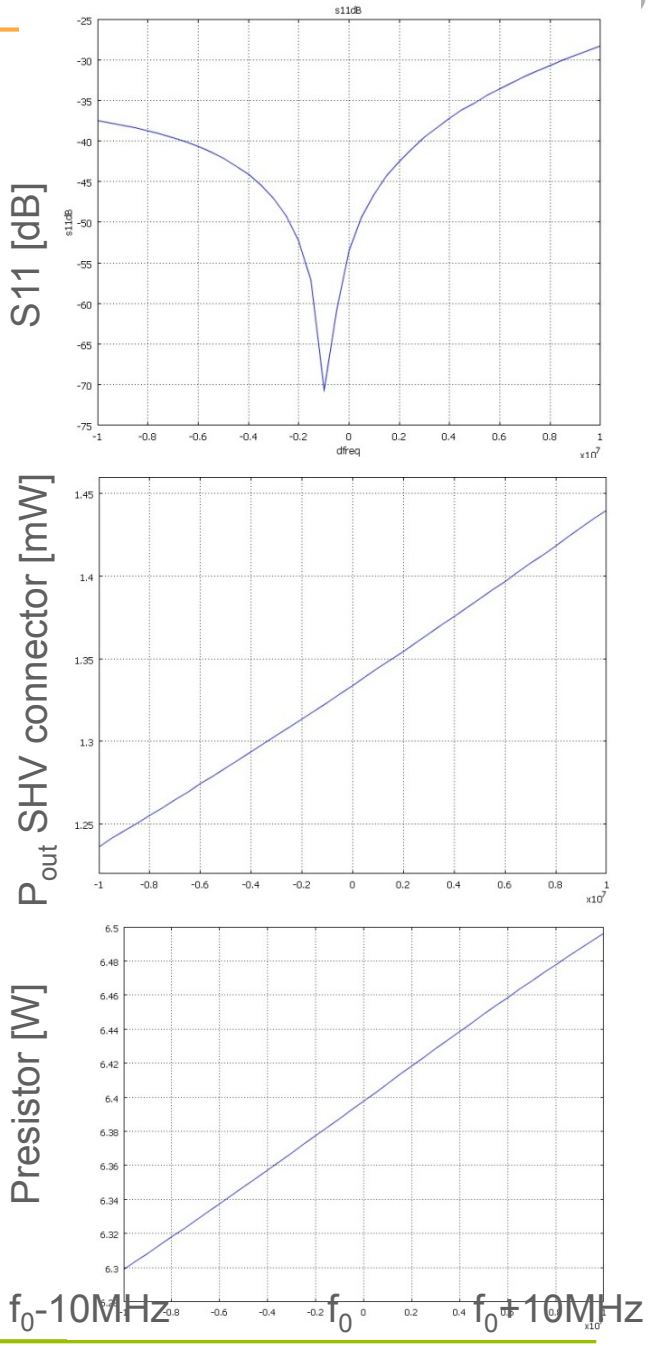
Current activities:

- Evaluation of maximum admissible peak power of Saclay HIPPI power coupler in SW and TW regime
- Starting thermo-mechanical calculations for air cooling assessment (tested up to 25kW average power, full reflection in horizontal cryostat)
- Study of antenna HV biasing started

Antenna high voltage biasing

Preliminary design





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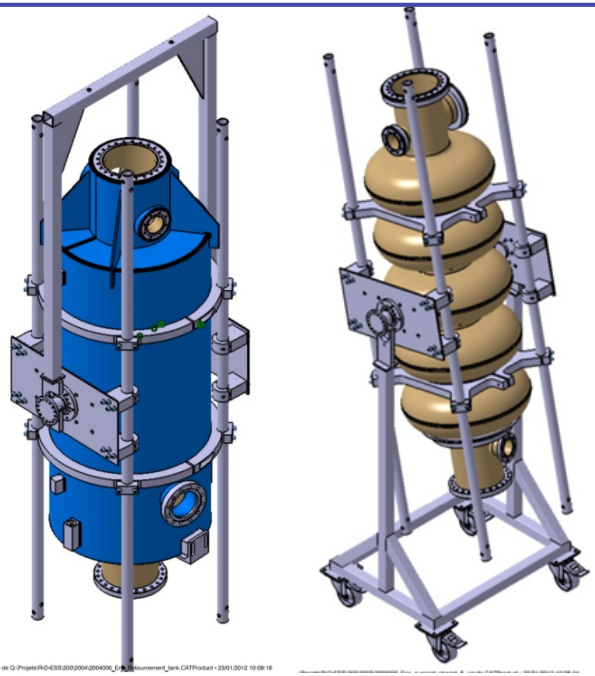
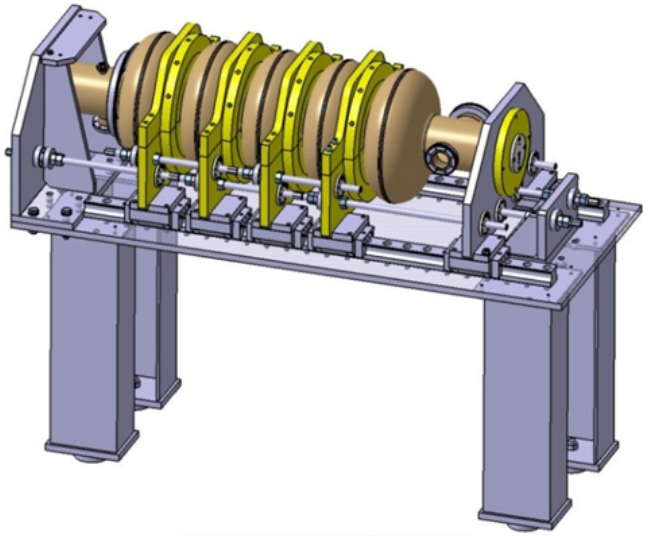
Cavity tooling

New Saclay vertical EP station: commissionned with 1.3 GHz single cell



Design of cavity handling tools

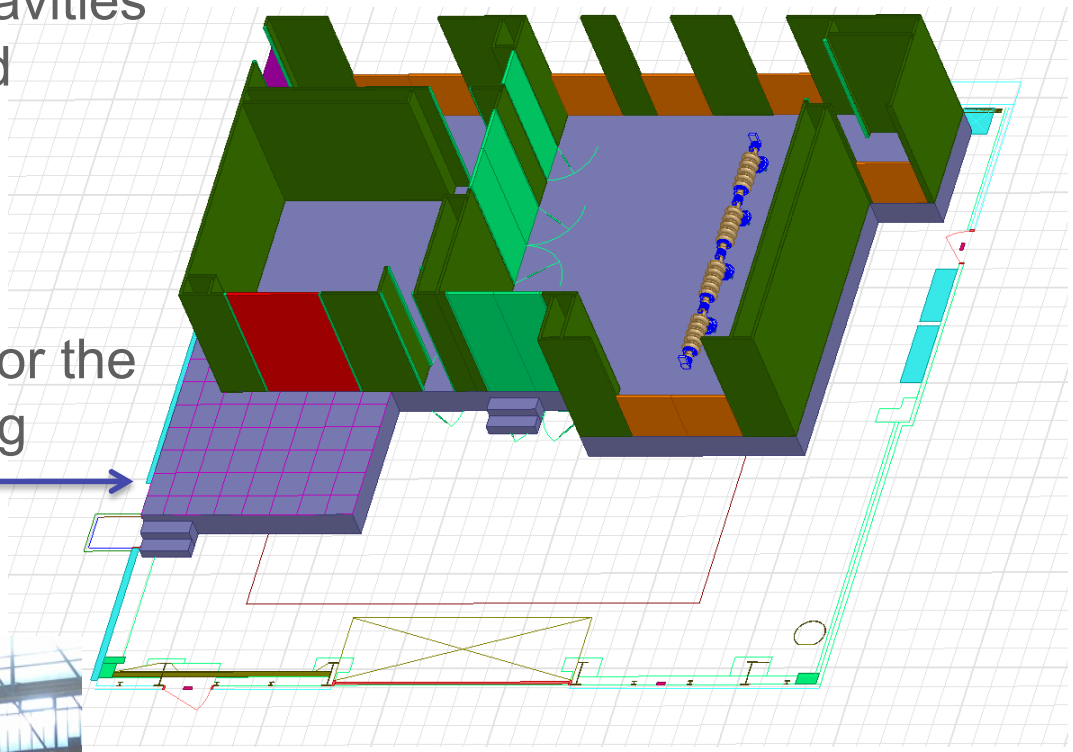
Field flatness tool under fabrication

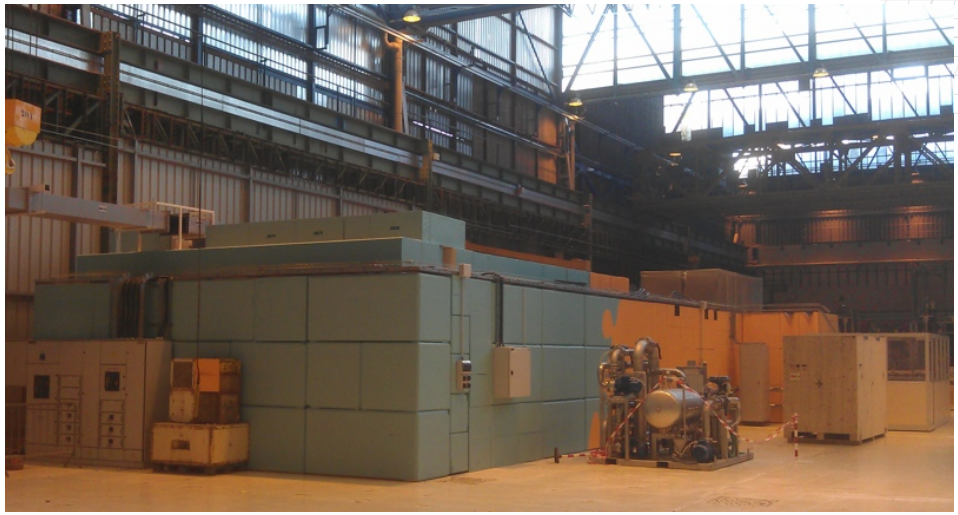


ESS high beta cryomodule technical demonstrator

The design and assembly of a 4 cavities cryomodule is planned at CEA and IPNO

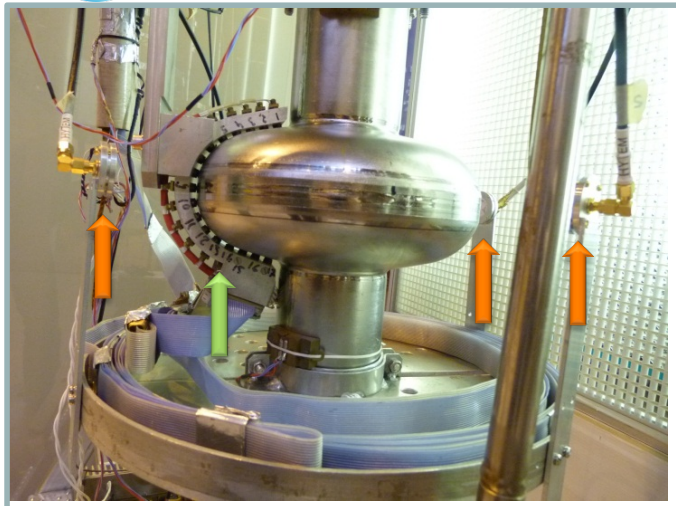
A new clean room will be build at Saclay, with dimensions adapted for the assembly of a 4 ESS cavities string





Saclay cryomodule test bunker

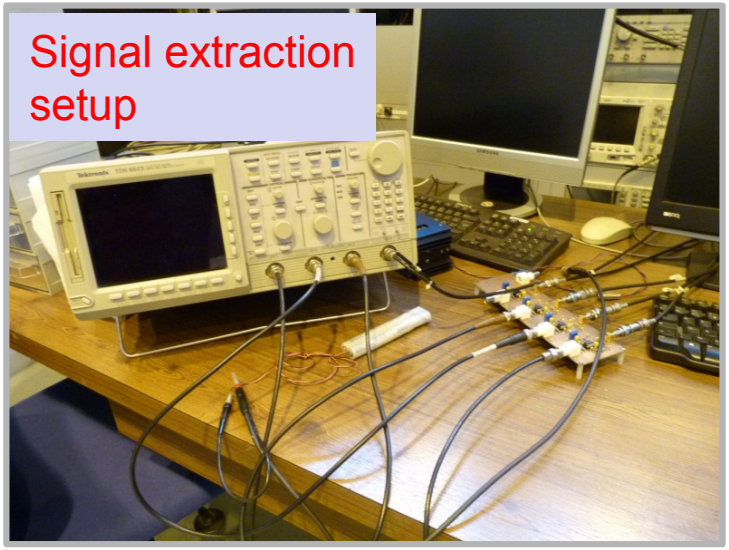
Instrumentation: 2nd sound device



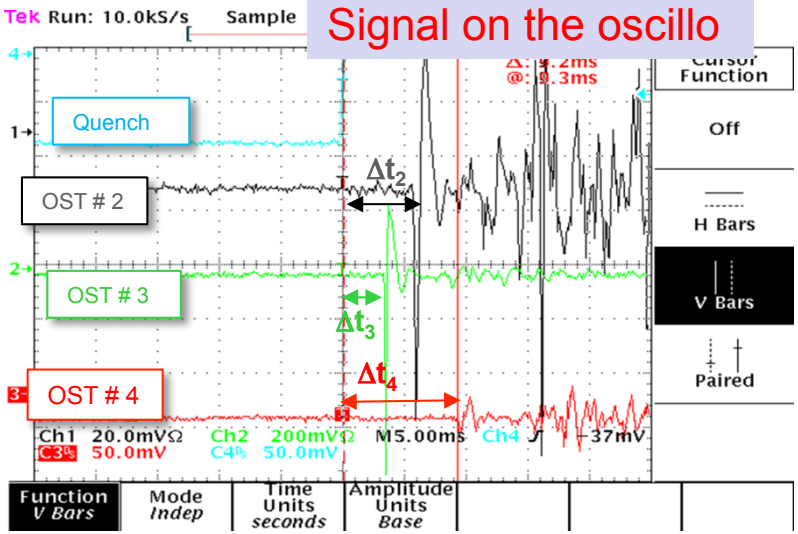
The **4 OSTs** are positionned in the plane of cavity equator

The 1300 MHz monocell cavity is also equipped with a CEA rotative **temperature map system**

Signal extraction setup



Signal on the oscillo

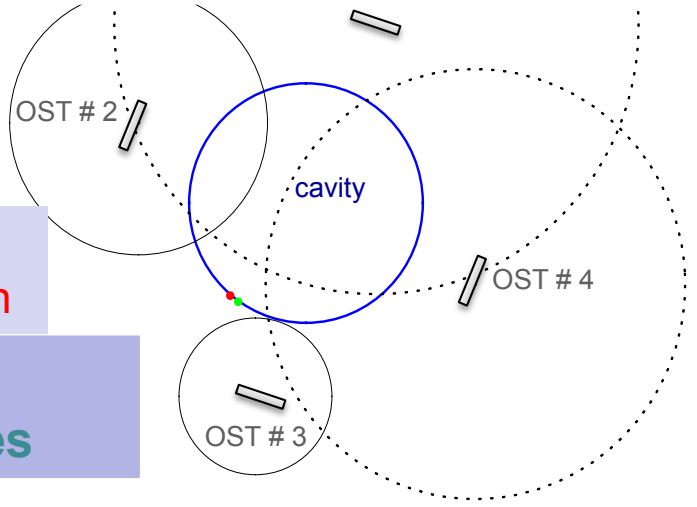


The **red dot** is the quench position measured by temperature mapping

The **green dot** is the quench position from OSTs #2 and #3 **and** optimization calculations

⇨**More details and discussion in Kitty Liao's presentation**

Tentative triangulation



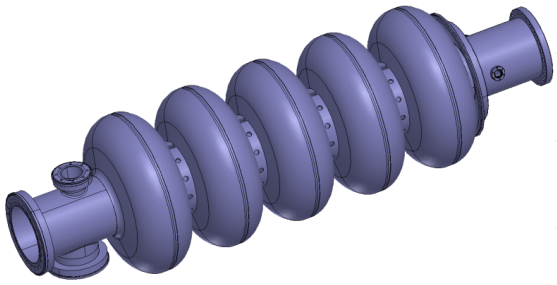
Quench localization by 2nd sound method will be developped in order to be used for multicell cavities

Outline

- Cavity RF/mechanical design
- Helium tank
- High Order Modes/extraction
- Power coupler
- Tooling and equipments
- Milestones

Milestones

	2010	2011				2012				2013				2014				2015				2016			
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Kick Off	◆																								
1st Nb order				◆																					
2 cavities order						◆																			
2 cavities delivery										◆															
2 cavities test											◆														
Power coupler order													◆												
2nd Nb order														◆											
HOM coupler order															◆										
HOM coupler delivery																◆									
6 cavities order																	◆								
Power coupler test																	◆								
6 cavities delivery																				◆					
Last cavity test																					◆				



A new plan is now proposed in order to have 4 fully equiped cavities available in 2014 for the cryomodule technical demonstrator assembly (tested at Saclay in 2015)