SPL cavity design by CEA-Saclay

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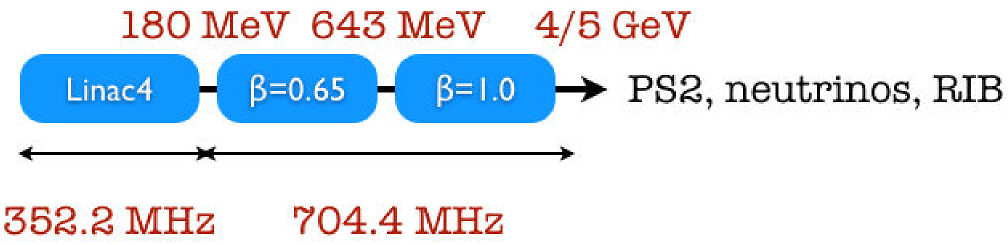
Requirements of the β = 1 SPL cavities

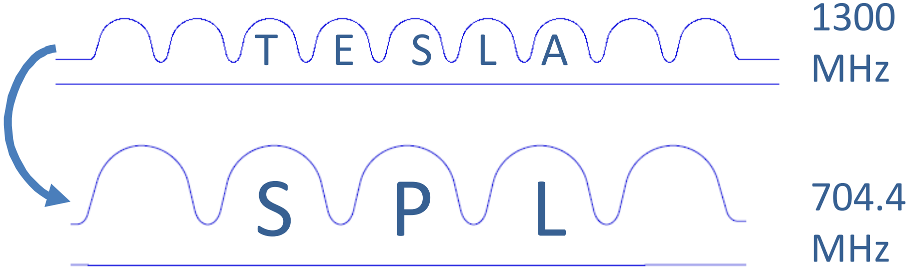


RF frequency	704.4 MHz
Gradient	25 MV/m
Number of cells/cavity	5
Average pulsed current	40 mA
r/Q	570 Ω
Q_0	10^{10}
Synchronous phase	-15°

CDR of the SPL II, 2006

Geometry of the Saclay design

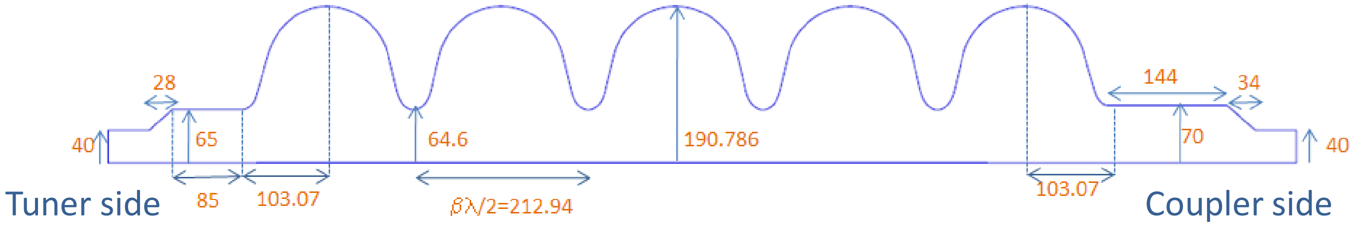
- The inner cells have been directly scaled from the Tesla design

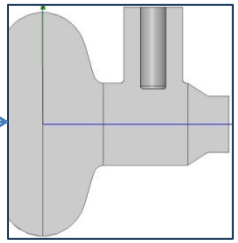


	inner ½ cells	outer ½ cells FPC side	outer ½ cells tuner side
External radius (REQ)	190.786	190.786	190.786
Iris radius (RI)	65	64.6	70
Length (AL)	103.07	106.47	103.07
Equator ellipse a (A1)	74.45	77.5	74.45
Equator ellipse b (B1)	83.27	77.5	76.89
Iris ellipse a (A2)	18.5	22.1	18.5
Iris ellipse b (B2)	24.9	35.1	24.9

- The outer ½ cells have been adapted to match 704.4 MHz with the SPL draft tubes, and to optimize the RF parameters

- The drift tube at the coupler side has 140 mm diameter (coupler has 100 mm diameter)
- The drift tube at the tuner side has 130 mm diameter
- Both tubes end with 80 mm diameter



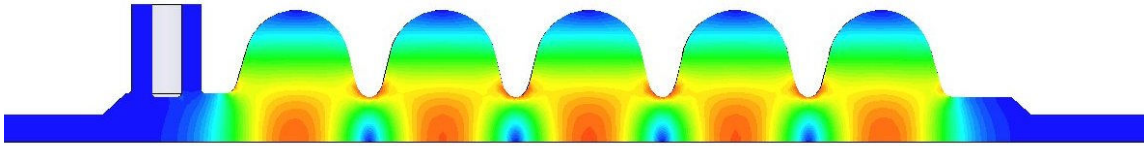


- Overall length of the cavity : 1393 mm, provided that we use NbTi flanges of the TTF-Tesla type.

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}	**$8.4*10^{10}$**	$2.5*10^{10}$	$5*10^{10}$

[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)

Fundamental Power Coupler external Q

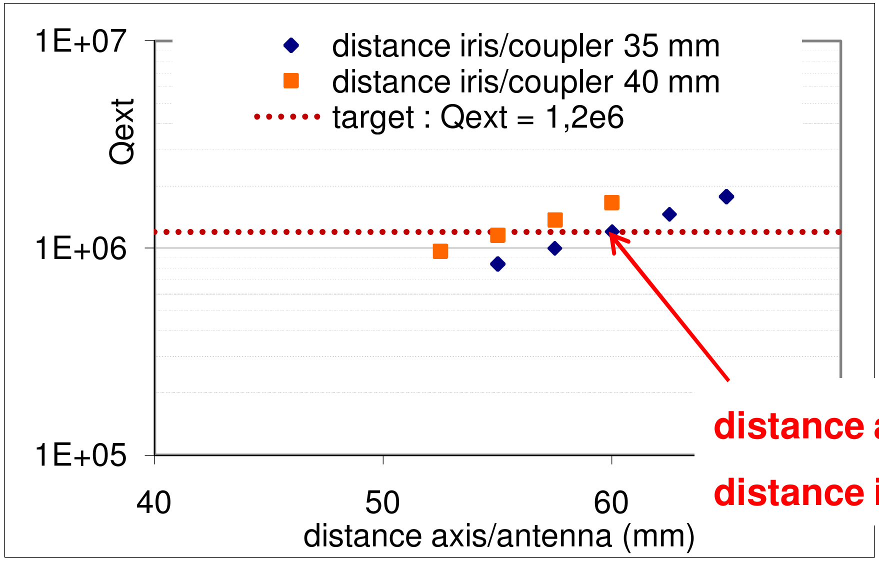
The target value for the external Q is **$Q_{ext} = 1.2*10^6$** calculated with :

$$Q_{ext} = \frac{E_{acc}.L_{acc}}{2.\frac{r}{Q}.I_0.\cos(\varphi_s)}$$

Eacc = 25 MV/m
I_0 = 40 mA
φ_S = 15°
Lacc = 1.0647 m
r/Q = 566 Ω

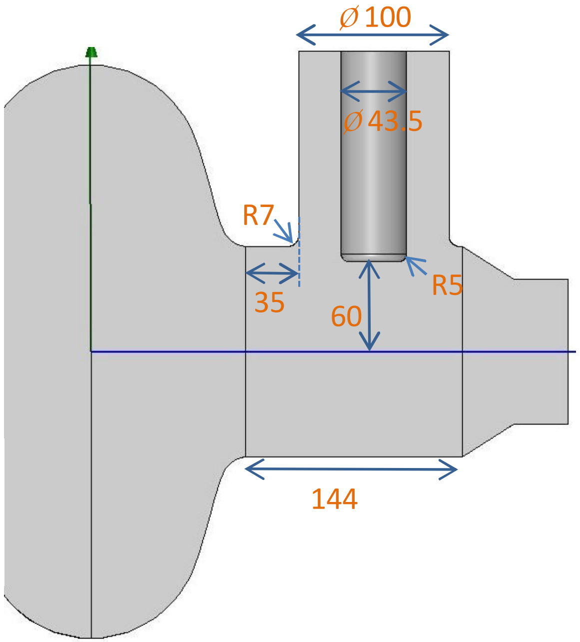
The cavity will be equipped with a HIPPI type FPC, with port 50 Ω, $Ø_{ext}$ = 100mm, $Ø_{ext}$ = 43.5 mm

Achievement of the target Q_{ext} with the **position** and **penetration** of the antenna



distance axis/antenna 60 mm

distance iris/coupler 35 mm

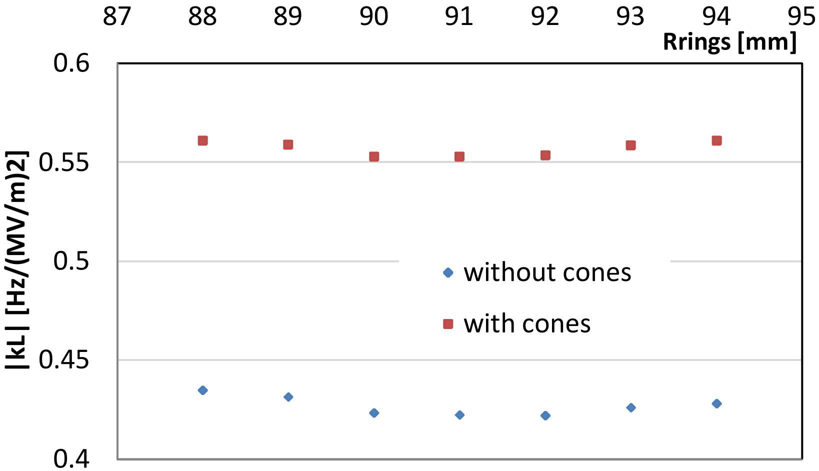


Mechanical stiffening of the cavity

Cavity aimed to work in the **pulsed** mode ⇨ sensitivity to **Lorentz detuning** is critical

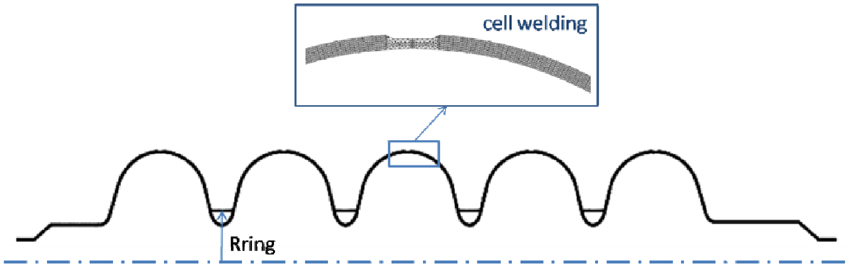
Lorentz detuning coefficient : $K_L = \Delta f / E_{acc}^2$

➲ Insertion of **stiffening rings** to reduce $|K_L|$



around the optimum

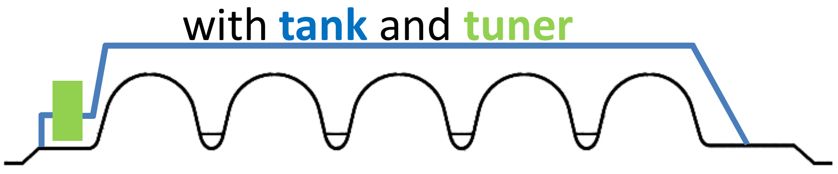
Mechanical model of the cavity (CASTEM)



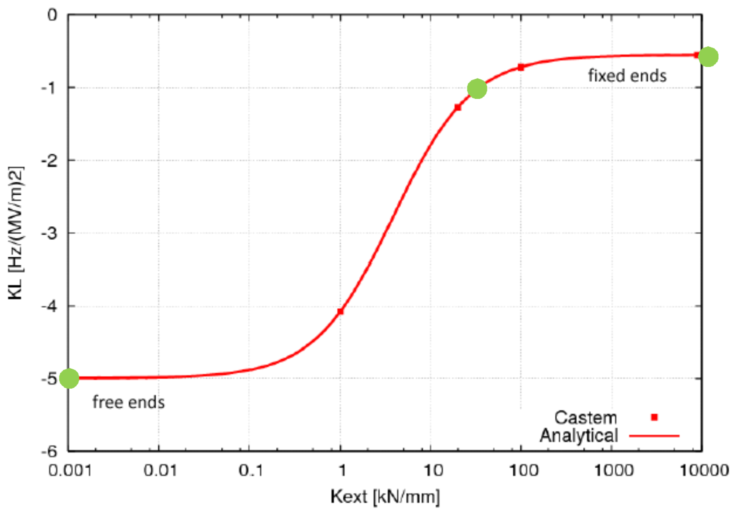
The cones are an element of flexibility in the structure ⇨ they increase $|K_L|$

Optimal position for Rring = 91 mm

Mechanical parameters of the cavity



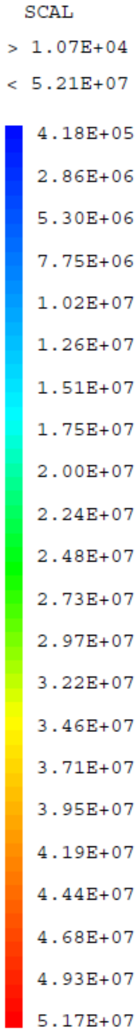
	SPL	HIPPI
Nominal wall thickness [mm]	3	4
Cavity stiffness Kcav [kN/mm]	3.84	2.25
Tuning sensitivity $\Delta f/\Delta z$ [kHz/mm]	164	295
K_L with fixed ends [Hz/(MV/m)^2]	-0.55	-2.7
K_L with free ends [Hz/(MV/m)^2]	-5	-20.3
Pressure sensitivity K_P [Hz/mbar] (fixed ends)	1.2	

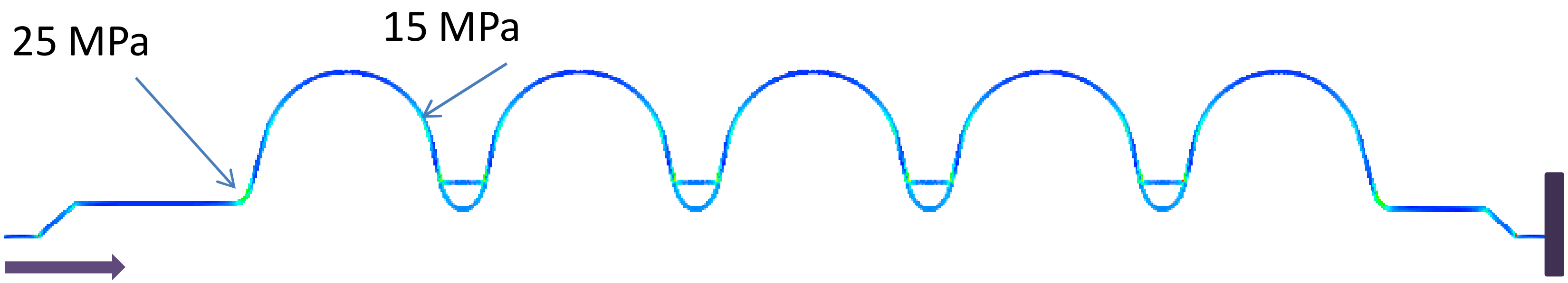


The cavity will be equipped with a Saclay 4 tuner. The stiffness of the HIPPI - Saclay 4 tuner has been measured : K_{ext} 35 kN/mm

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

Mechanical stresses in the cavity





for 1 mm axial deformation

Tuning sensitivity Δf/Δz = 164 kHz/mm

Saclay 4 tuner can provide an axial displacement of ~ 2-3 mm : max stress in the cavity ~ **50-75 MPa**, corresponding to a detuning of ~ **330-500 kHz**

At 2 K, yield stress is 400 MPa for Niobium

HOM (1) : list

Operating frequency mode (π) : f_0 = 704.4 MHz

No monopole HOM at $2f_0$

Mode at 2111.64 MHz very near $3f_0$

Cut-off frequencies for the mode TM010
Ø 80 mm : 2865 MHz
Ø 130 mm : 1763 MHz
Ø 140 mm : 1637 MHz

List of **monopole HOM** calculated with Superfish between 0 and 3000 kHz
Axisymmetric calculations

#freq	r/Q	beta_opt	Qo	Rs_nOhm
692.459406	15.495341	0.55	5.87048e+10	4.58
695.691165	40.295848	0.63	5.85048e+10	4.60
699.762722	86.977902	0.71	5.82537e+10	4.62
703.121236	173.038043	0.81	5.80475e+10	4.64
704.420268	**565.499512**	**1.00**	**5.8134e+10**	**4.65**
1293.187800	3.150182	0.66	4.06538e+10	9.75
1303.568690	7.969888	0.72	4.01921e+10	9.86
1317.445320	17.344152	0.79	3.95608e+10	10.02
1329.742220	59.154893	1.00	3.9004e+10	10.16
1335.734260	107.744313	0.98	3.8525e+10	10.23
1450.724780	0.831396	0.92	5.06898e+10	11.62
1460.366080	1.999197	0.89	5.03429e+10	11.74
1474.206000	2.839266	0.85	5.03023e+10	11.92
1488.535980	2.701775	0.80	5.09436e+10	12.10
1499.066360	2.342662	0.73	5.20134e+10	12.24
1843.272060	0.209069	0.95	3.35164e+10	17.22
1858.324840	0.596186	0.91	3.26306e+10	17.47
1881.326440	1.603429	0.98	3.28434e+10	17.84
1911.484360	1.329645	0.94	3.31308e+10	18.33
1948.248770	1.819111	1.00	3.35394e+10	18.95
2000.236410	2.451434	0.98	3.13642e+10	19.84
2039.865120	1.377179	0.78	3.70143e+10	20.53
2072.798390	3.019703	0.83	3.349e+10	21.12
2086.249930	5.689452	0.88	3.00335e+10	21.36
2089.642160	19.164504	1.00	2.90251e+10	21.42
2111.640680	**10.636820**	**1.00**	**2.94648e+10**	**21.82**
2119.767790	8.476595	1.00	2.65214e+10	21.97
2138.944200	1.075819	0.95	2.94674e+10	22.33
2175.157760	1.744804	0.91	3.24669e+10	23.00
2219.889020	4.482180	0.97	3.46431e+10	23.86
2262.192880	7.529522	1.00	3.6688e+10	24.68
2290.061390	0.330347	0.85	4.00758e+10	25.23
2464.607050	0.764947	0.95	2.5928e+10	28.82
2485.980300	1.514541	1.00	2.63647e+10	29.28
2512.576190	1.303253	0.96	2.84428e+10	29.86
2538.171130	8.505168	1.00	3.13472e+10	30.42
2559.022710	6.760250	0.99	3.40374e+10	30.88
2565.011240	2.855068	0.95	3.43392e+10	31.01
2639.339900	0.070686	0.90	2.41594e+10	32.69
2645.191100	0.071469	1.00	2.48068e+10	32.82
2650.937090	0.150348	1.00	2.47399e+10	32.96
2657.099030	0.275372	1.00	2.44513e+10	33.10
2721.471070	1.230228	0.96	2.23449e+10	34.60
2765.009700	0.249521	0.83	2.99369e+10	35.63
2781.989510	0.411752	0.87	2.61634e+10	36.04
2799.460470	0.229298	0.90	2.30615e+10	36.46
2809.660150	6.941103	1.00	2.09609e+10	36.71

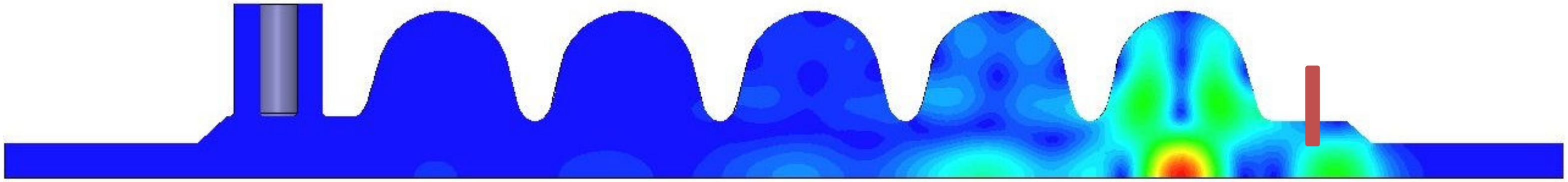
HOM (2) : mode at ~ $3f_0$

#freq	r/Q	beta_opt	Qo	Rs_nOhm
2111.640680	10.6	1.00	2.95e+10	21.82

$Q_{ext\ antenna} = \omega W/P_{ant} = 14.7*10^9$ (short circuit at the ceramic position)

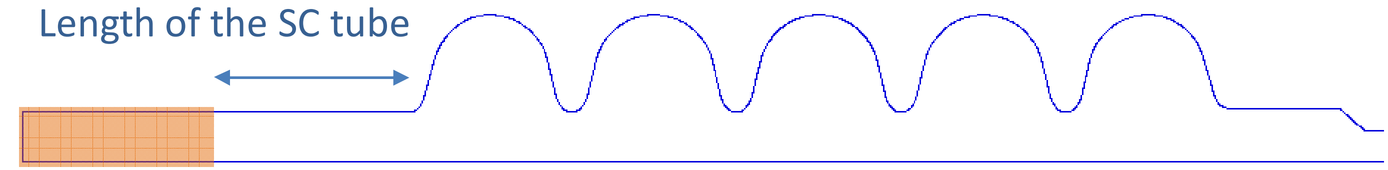
W : energy dissipated in the cavity

P_{ant} : power dissipated on the antenna

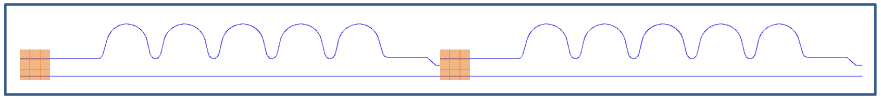


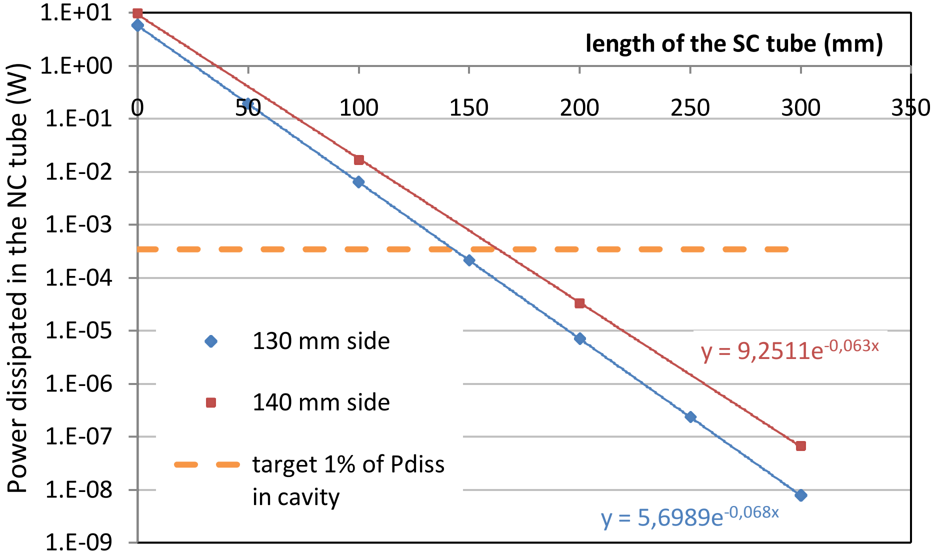
- This mode can be excited by the beam ➲ dangerous
- Rather high r/Q ➲ significant effect on the beam
- High Q_{ext} antenna ➲ not dissipated by the FPC’s antenna
- Mode localized in the tuner side cell ➲ could be extracted by the antenna pick-up

Alternate design : cavities with absorbing tubes



Power dissipated in the cavity : 34.06 mW
(norm. to 1MV/m)





NC tube in stainless steel ($\sigma = 10^6$ S/m)

☑ Absorption of HOM at one side

☑ Tube without cone increases stiffness

☒ Length of the tube :

According to this graph, with NC tube in stainless steel, the SC tube must be longer than 150 mm in order to dissipate less than 1 % of the RF power in the NC tube

Achievements and plans

Achievements

- The Saclay design complies with the requirements of the SPL $\beta = 1$ cavities
- Thanks to the optimization of the mechanical behavior of the cavity, the Lorentz force detuning is not an issue
- The Saclay 4 tuner is able to tune the cavity without extra stress over the whole frequency range

Plans

- At this stage, the reference design remains the Saclay cavity with cones.
- HOM calculations have still to be completed
- If HOM dampers are needed, we propose an alternate cavity , which could be easily coupled to an absorbing tube
- The detailed mechanical design with the Helium tank has to be realized