DAΦNE TECHNICAL NOTE

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Note: **RF-12**

STUDY OF DIFFERENT SHAPES FOR A THIRD HARMONIC CAVITY

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1 - Introduction

The need for controlling the bunch length in DAΦNE has already been stressed elsewhere [1]. The most straightforward solution is to add a higher harmonic cavity, as it has been done in other storage rings. In particular, a third harmonic cavity seems to be the best compromise, for two fundamental reasons:

a) A second harmonic cavity would certainly provide a higher shunt impedance for the same geometrical structure (since R/Q is independent on frequency and Q scales as $1/\sqrt{f}$) but would not allow HOMs to propagate down the beam pipe easily; moreover, what is relevant to bunch length control is the product frequency times voltage, i.e. if the frequency goes down by factor 2/3 the voltage must go up by 3/2, that means, since $P = V^2/2R_s$, the dissipated power roughly increases by a factor $(3/2)^{3/2} = 1.8$, so there's no advantage either from this last point of view.

b) A fourth (or even higher) harmonic cavity would imply too small physical dimensions compared with the pipe radius (4.3 cm), hence almost a null cavity.

In this paper we shall describe several possible designs for such a cavity, which were explored according to different requirements, i. e.:

1) 'Rounded' cavity with long tapers, like the main RF cavity, but of smaller size.

2) 'Single-mode' cavity, to give minimum contribution to the DAΦNE impedance.

3) High shunt impedance cavity, either 'nosecone' or 'rounded', just to keep RF power to a minimum, and so to use a simple and cheap solid state amplifier instead of an expensive klystron.

4) 'Double-cell' or even 'triple-cell' cavity to further increase the shunt impedance.

By this time it is not yet clear whether the cavity may be operated also in the passive mode, with evident saving on RF power at the third harmonic, provided the main cavity power consumption is not too big. We feel it is better to have a fully powered RF system, and high shunt impedance anyway, to ensure more flexibility for the collider operation. A general requirement is to avoid the presence of high Q parasitic modes. We plan either to apply suitable broadband dampers, like in the main RF cavity, or to reduce the shunt impedance (in one case) of the fundamental mode until it remains the only mode trapped inside. The beam pipe aperture is quite large (4.3 cm radius), and doesn't allow us to push the R_s of the fundamental mode to a very big value at the third harmonic frequency.

In this work we used the well-known codes URMEL and TBCI by Weiland and co-workers.

2 - Rounded tapered cavity

The initial design consisted of a rounded (or 'bell-shaped') cell with two tapers from the cavity iris of 6.5 cm to the beam pipe radius of 4.3 cm (Fig. 1). The reasons for this choice are quite the same as for the choice of the main RF cavity, i.e. simplicity and reliability of construction and cooling, low HOM contents, with a low value of the shunt impedance (630 kΩ) as a drawback. Also, it should be mentioned that its contribution to the ring broadband impedance was estimated to be 0.06 Ω (M. Zobov, private communication). This seems acceptable if we take into account the advantage of having practically no parasitic modes in the cavity. The longitudinally available space (1 m), the minimum iris radius (4.3 cm) and the frequency (1104 MHz) dictated the physical dimensions of the structure. The cavity R/Q and R_s are displayed in Figs. 2 and 3 respectively, as functions of the ratio a/h (radius/gap), where every time the cavity size was re-adjusted to keep the cavity resonating at the nominal frequency.

The total and the HOM longitudinal loss factor are shown versus a/h in Fig. 4. It is clearly recognized that the total loss factor is dominated by the fundamental mode, while no dominant mode appears in the HOM loss factor, which exhibits a smoothly decreasing behaviour (like $\sim (a/h)^{-2}$ as predicted by theory).

It is interesting to look at the behaviour of the two first monopole modes TM_{011} and TM_{020}, as shown in Fig. 5. It gives us some hints on how to let them propagate out of the cell in a more detailed design. We see that in the TM_{011} case the frequency becomes insensitive to a large change in a/h above a certain value (a/h ~ 1.5), while in the TM_{020} case the frequency is steeply increasing between 0.5 and 1. and slowly decreasing above. Such a strange behaviour is interpreted as a consequence of the presence of tapers with large apertures, that causes a large distortion of the field profile. Calculations of the transverse loss factor were also performed, as a further check (Fig. 6).

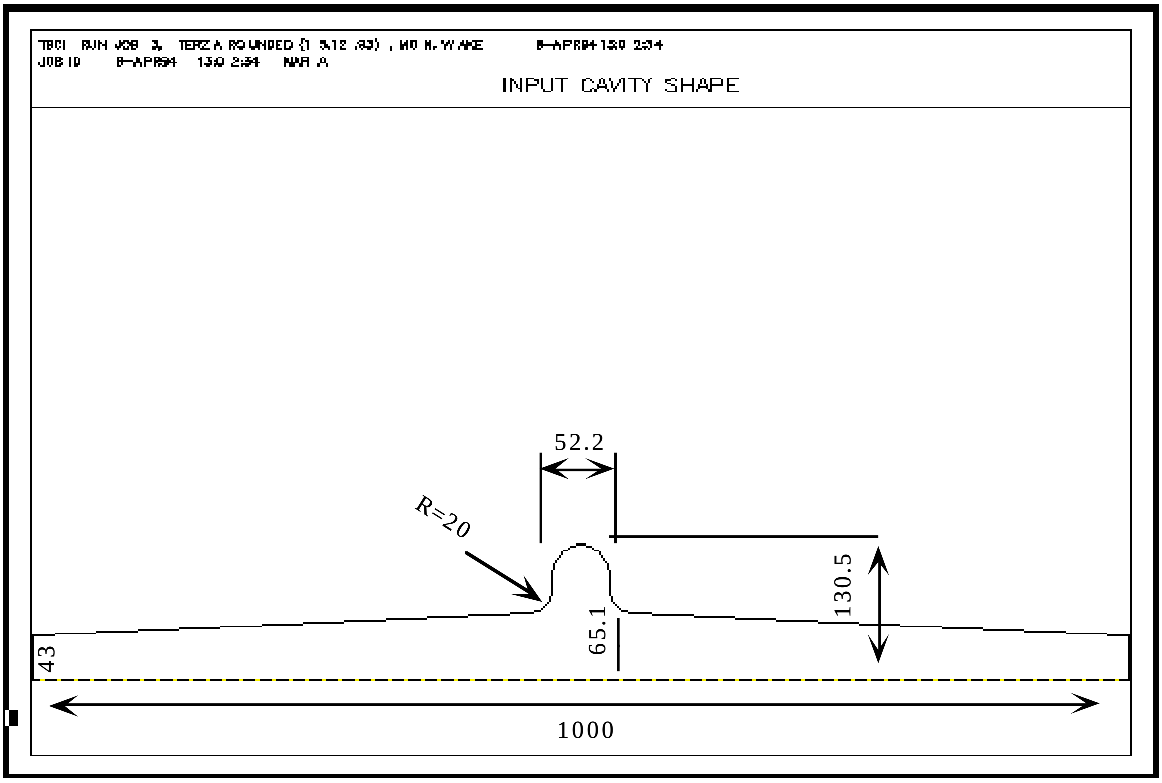

Fig. 1 - The 'rounded' long tapered cell

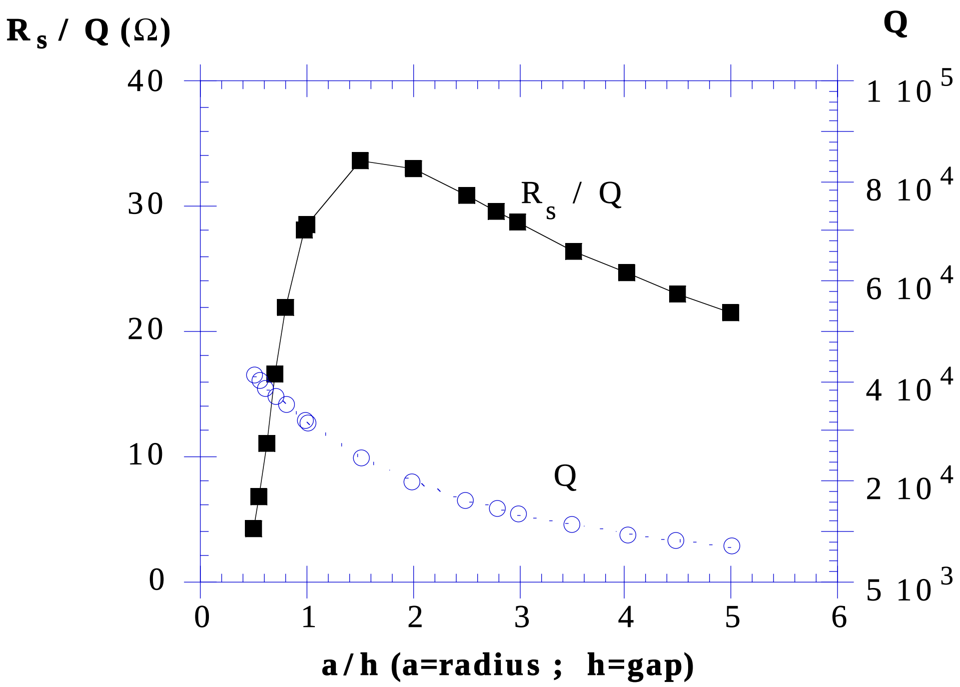

Fig. 2 - R_s/Q and Q of the accelerating mode as functions of the ratio radius/gap of the rounded cavity

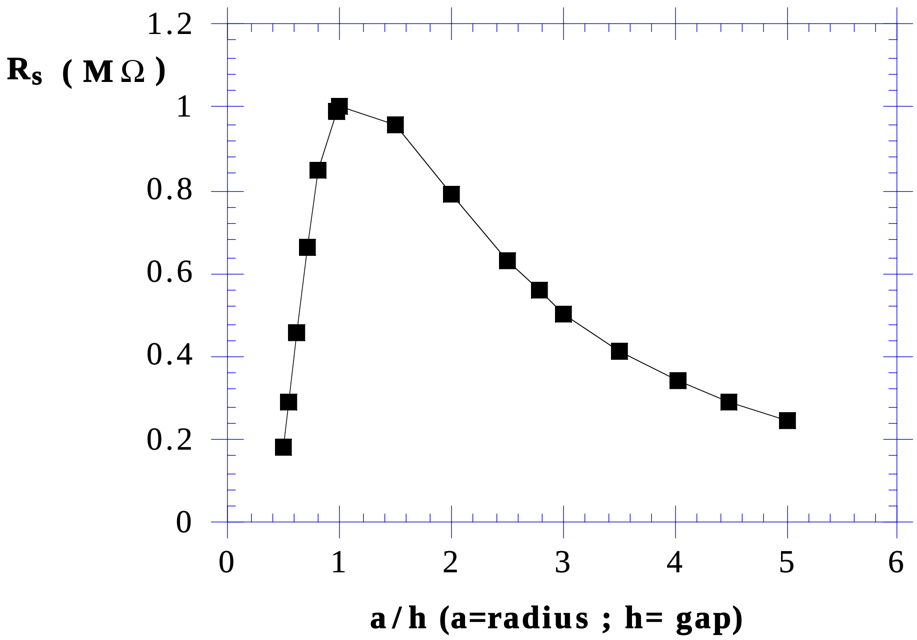

Fig. 3 - R_s of the accelerating mode as function of the ratio radius/gap of the rounded cavity

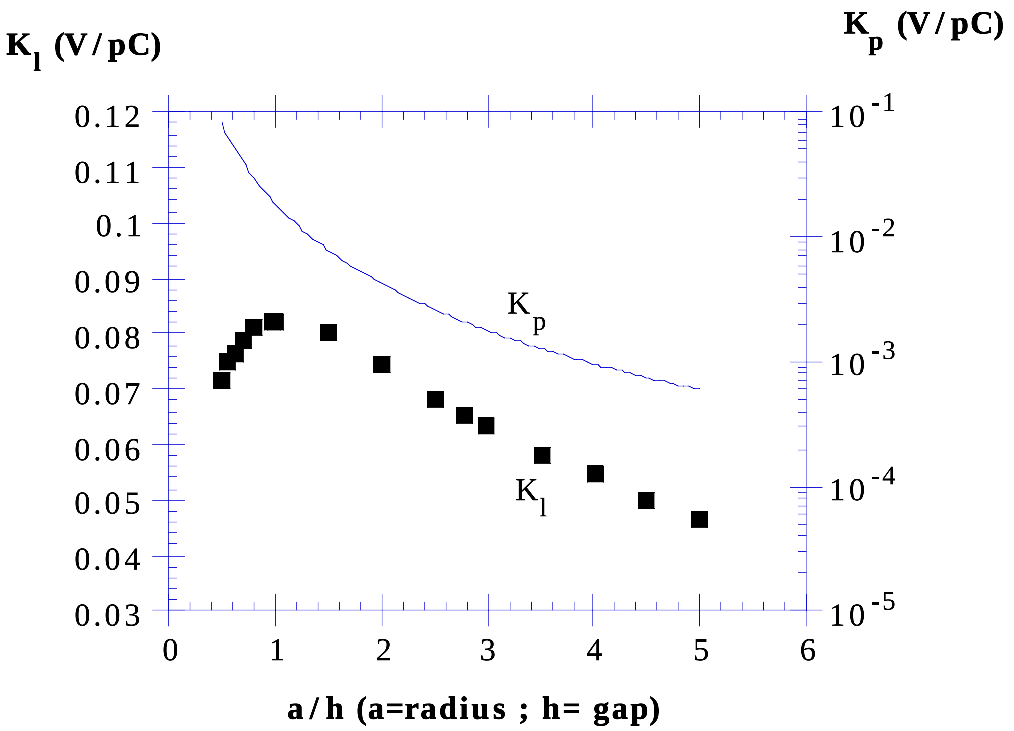

Fig. 4 - Total and parasitic (as fitted to an exponential) monopole loss factor as functions of the ratio radius/gap of the rounded cavity

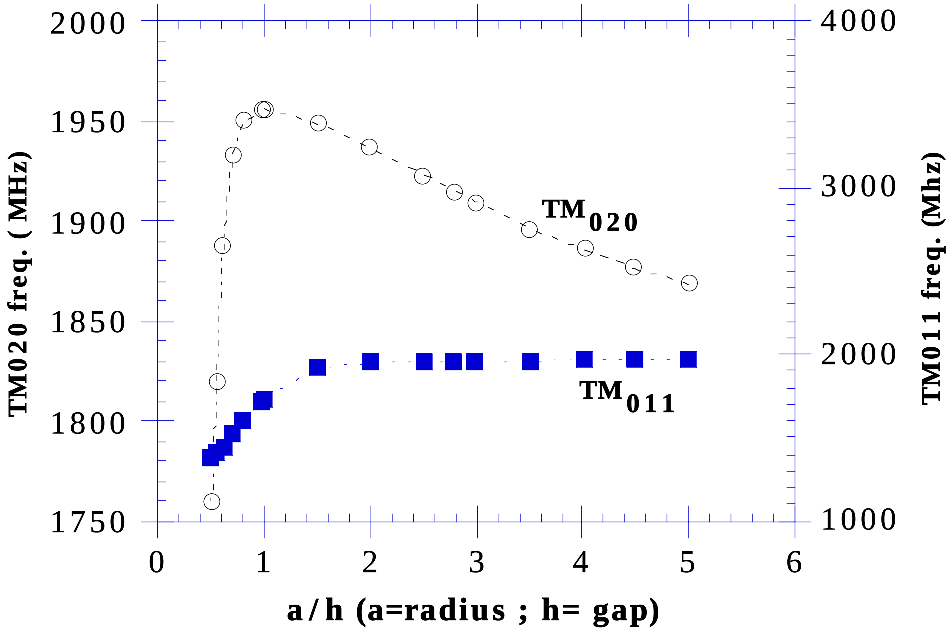

Fig. 5 - Frequency variation of TM_{020} and TM_{011} as functions of the ratio radius/gap of the rounded cavity

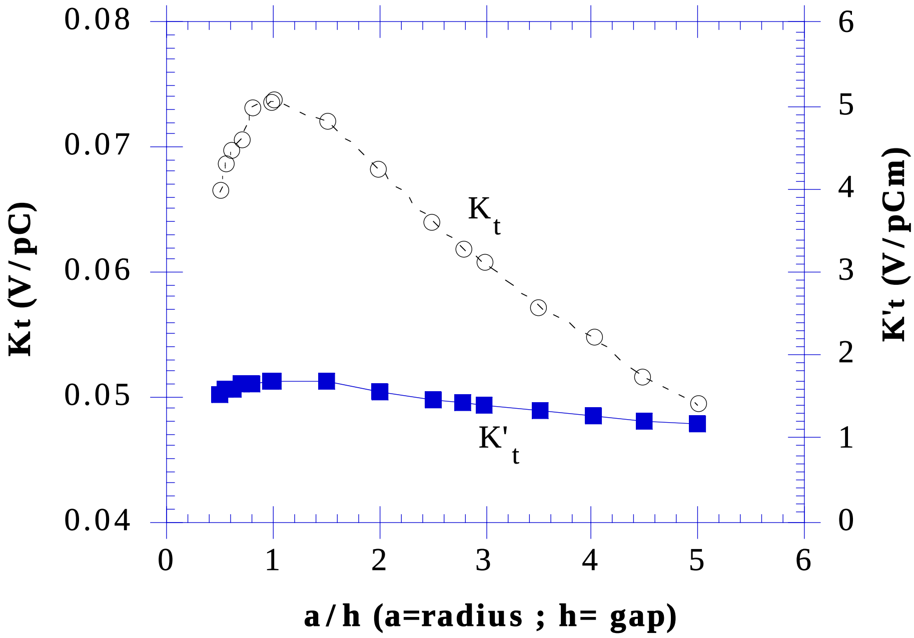

Fig. 6 - Transverse loss parameter and derivative as functions of the ratio radius/gap of the rounded cavity

3 - Nosecone cavity

A 'nosecone' design was considered as a possible way to have a real single mode cavity. In this case a taper is not helpful, since it can prevent some modes from propagating through the beam pipe. Hence the cell looks directly at the pipe and, profiting from the previous work on the rounded cavity, has the radius and the distance between the noses re-adjusted in order to make the TM_{011} and TM_{020} frequencies higher than the beam tube cutoff (2671 MHz). The elliptical profile helps to shift the two first HOMs above cutoff, while the nose radius was chosen large enough to avoid too high surface electric field. In this way something is lost on the R/Q but all the monopole modes look free to propagate down the beam vacuum chamber. This is confirmed by the behaviour of the TM_{011} mode (Fig. 7), where the existence of a threshold is clearly recognized. It can be generally said that only the first dipole mode TM_{110} is left in this cavity so that suitable damping (e.g. through an antenna) must be provided (Fig. 8), according to multibunch transverse instability calculations. Other dipole modes have practically disappeared (see, for instance, Fig. 9 where the behaviour of TE_{111} is displayed).

The surface electric field as function of the gap between the two noses is shown in Fig. 10. The Kilpatrick criterion is satisfied down to a distance of 0.5 cm (pessimistic figure). In this case also the power loss is kept reasonably low (≤ 20 kW). The general conclusion about this special nosecone structure is that, while the shunt impedance can be increased up to 0.8 MΩ by a proper choice of the gap (Fig. 11), the HOM impedance is kept practically to zero. An example is displayed in Fig. 12, where the field lines of the TM_{020} are seen to invade more the beam tube than the cavity body, which is depicted in Fig. 13, with the relevant physical dimensions. To confirm these observations, a run of the wakefield calculator ABCI [2] was made, and the resulting cavity impedance doesn't show any other mode but the fundamental (Fig. 14), where the real part of the cavity impedance is computed by taking into account the wakefield only at a distance of 25 m.

Construction and cooling of these cavities may be difficult, due to their rather complicated geometry and reduced size. Tolerances due to construction errors of ± 0.1 mm (quite big!) have been simulated and are displayed in Fig. 15 for the most critical positions, with the other points kept fixed. The cavity doesn't look too sensitive from this point of view.

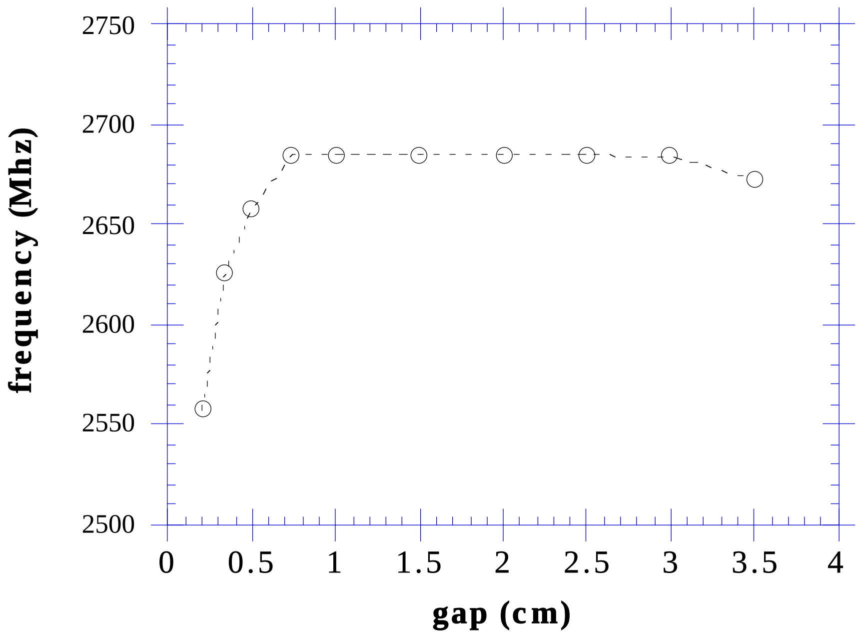

Fig. 7 - Frequency variation of the mode TM_{011} as function of the gap of the nosecone cavity

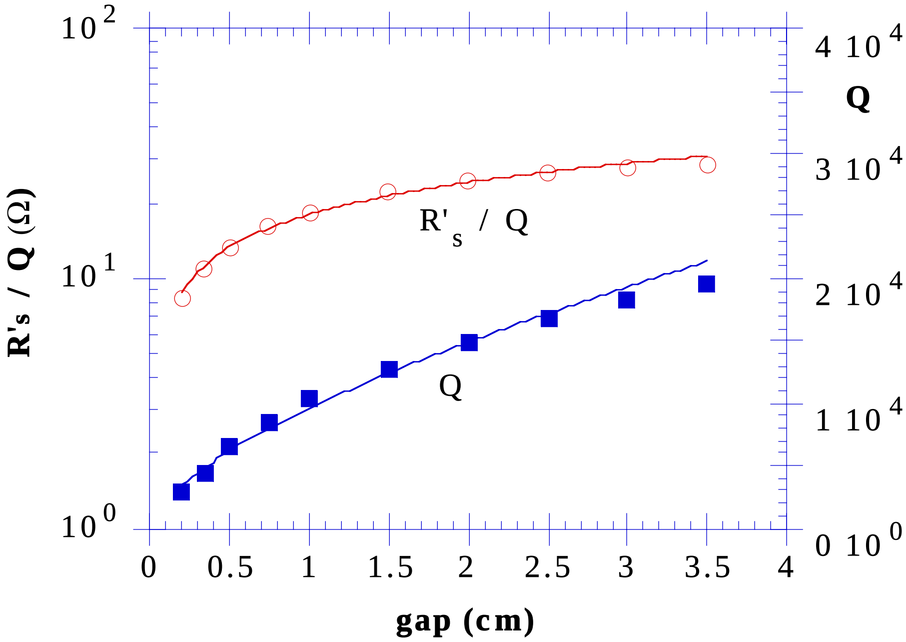

Fig. 8 - R's / Q calculated at 4.3 cm and Q of the dipolar mode TM_{110} as functions of the gap of the nosecone cavity

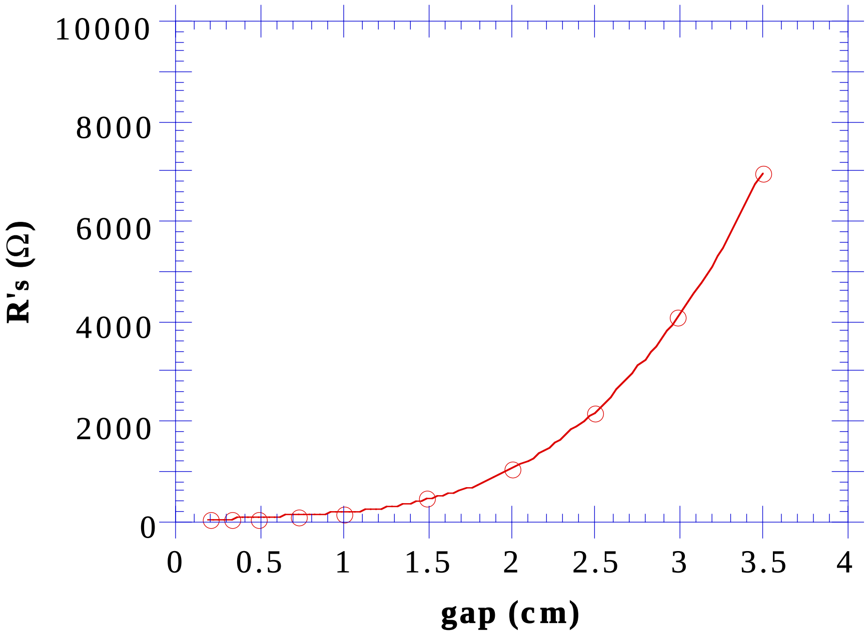

Fig. 9 - Transverse shunt impedance R's of the dipolar mode TE_{111} as function of the gap of the nosecone cavity

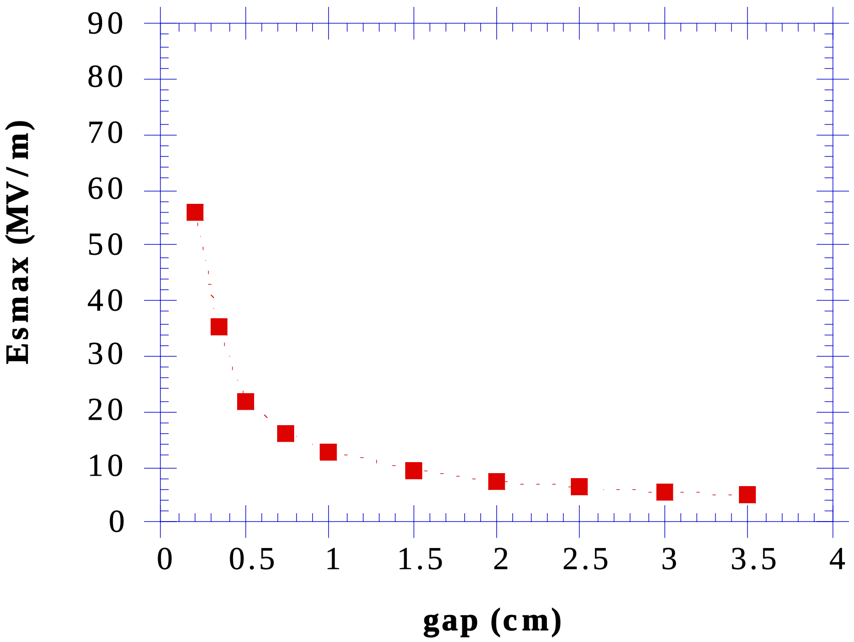

Fig. 10 - Maximum surface electric field as function of the gap of the nosecone cavity for 75 kV effective voltage on axis

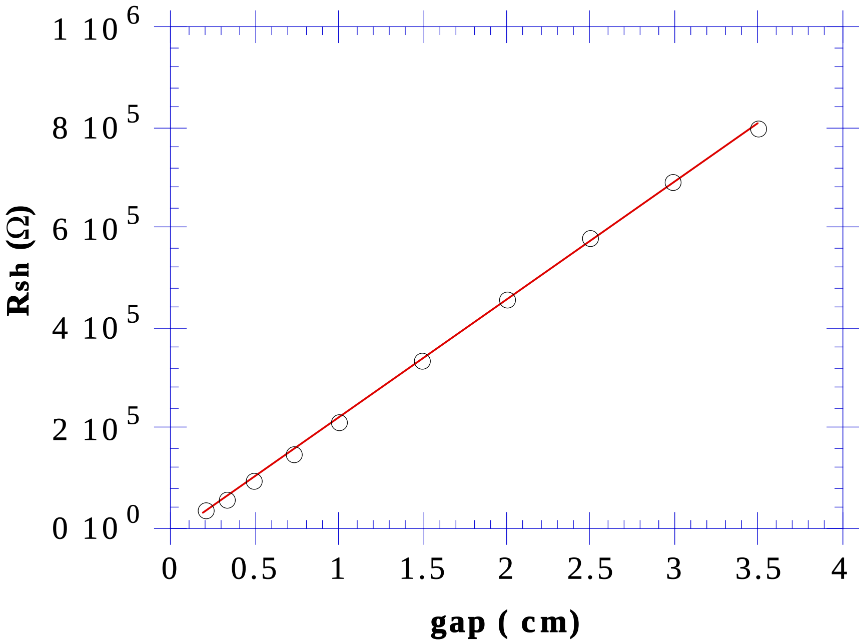

Fig. 11 - R_{sh} of the fundamental mode as function of the gap of the nosecone cavity (with superimposed fit)

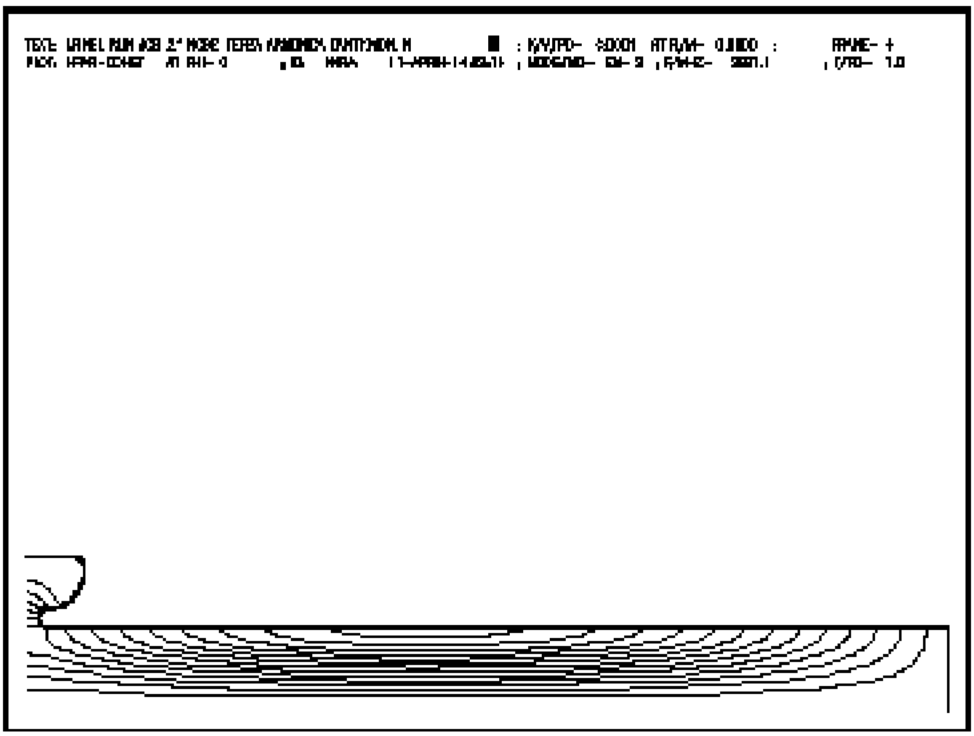

Fig. 12 - Electric field lines of the TM_{020} mode in the 'nosecone' cavity

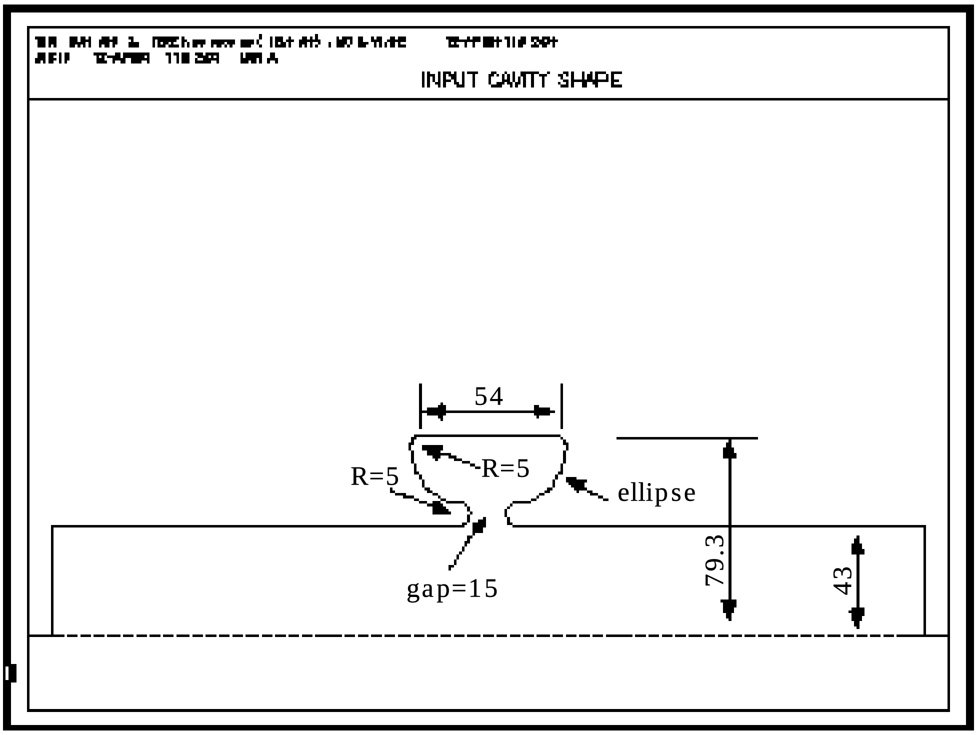

Fig. 13 - The 'nosecone' single mode cavity

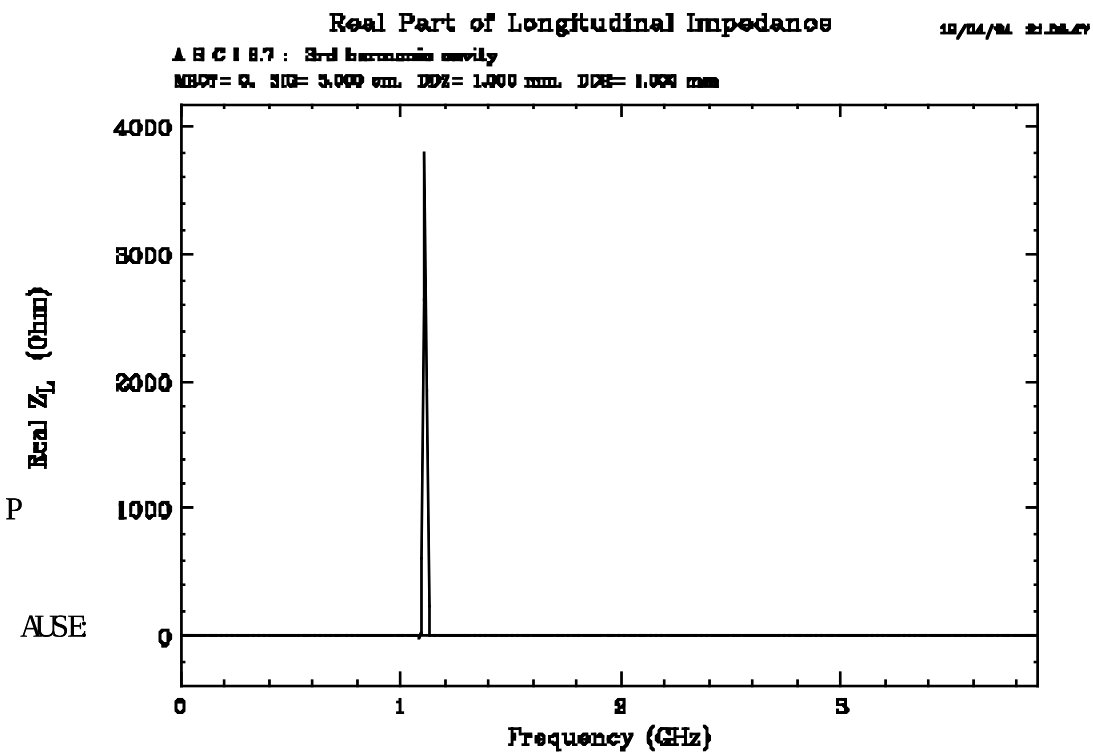

Fig. 14 - The longitudinal impedance of the 'nosecone' single-mode cavity

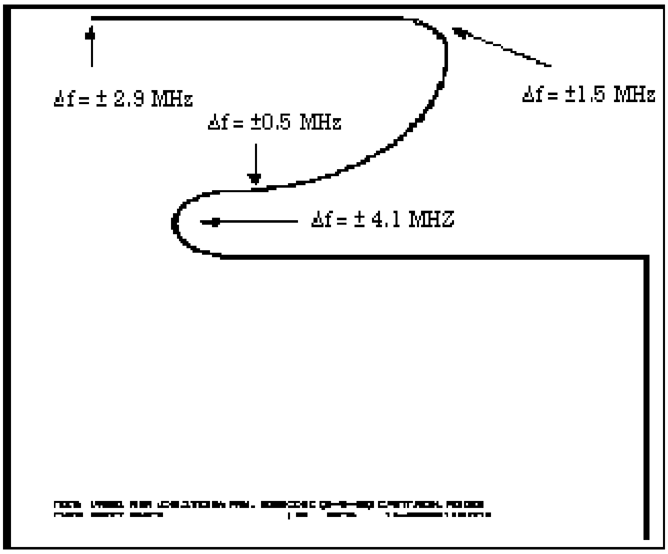

Fig. 15 - Tolerances on some critical points

4 - Rounded and Nosecone High R_S cells

To save money on the RF power amplifier, high R_S structures were considered too. First, a rounded profile (Fig. 16) was chosen with the optimum value a/h ~ 1, obtaining R_S = 1.85 MΩ and 4 (monopole + dipole) trapped modes, which have to be damped anyway. Second, a quite optimized nosecone cell (Fig. 17) was accurately studied by re-adjusting the gap, to get maximum R/Q and simultaneously not to decrease the Q-value. The resulting R_S is 1.96 MΩ at 1104 MHz. Also in this case 4 HOMs are left in the cavity. Tolerances for a ±0.1 mm construction error in some critical points are shown in Figs. 18 and 19 for both cell designs.

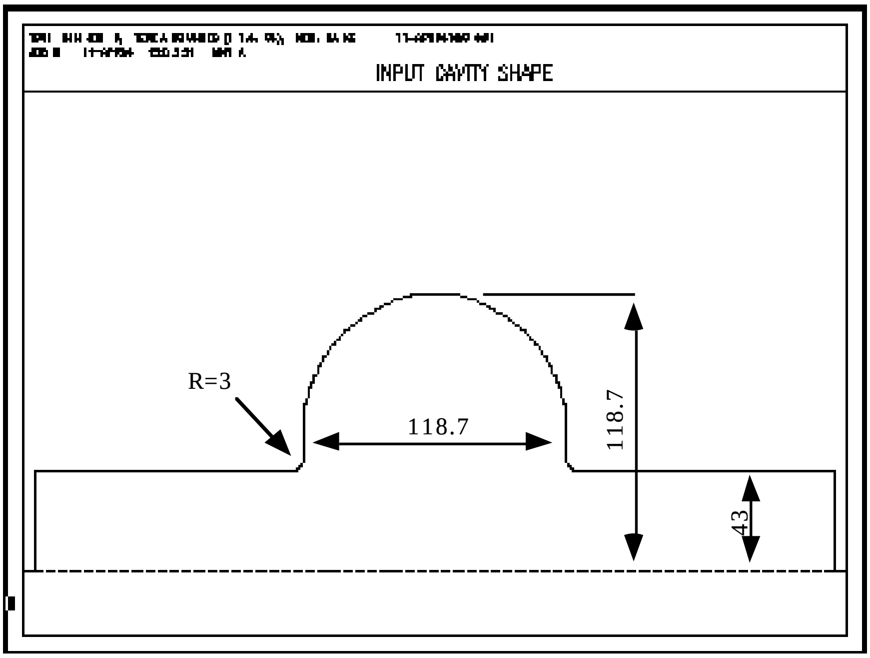

Fig. 16 - Rounded high R_S cell

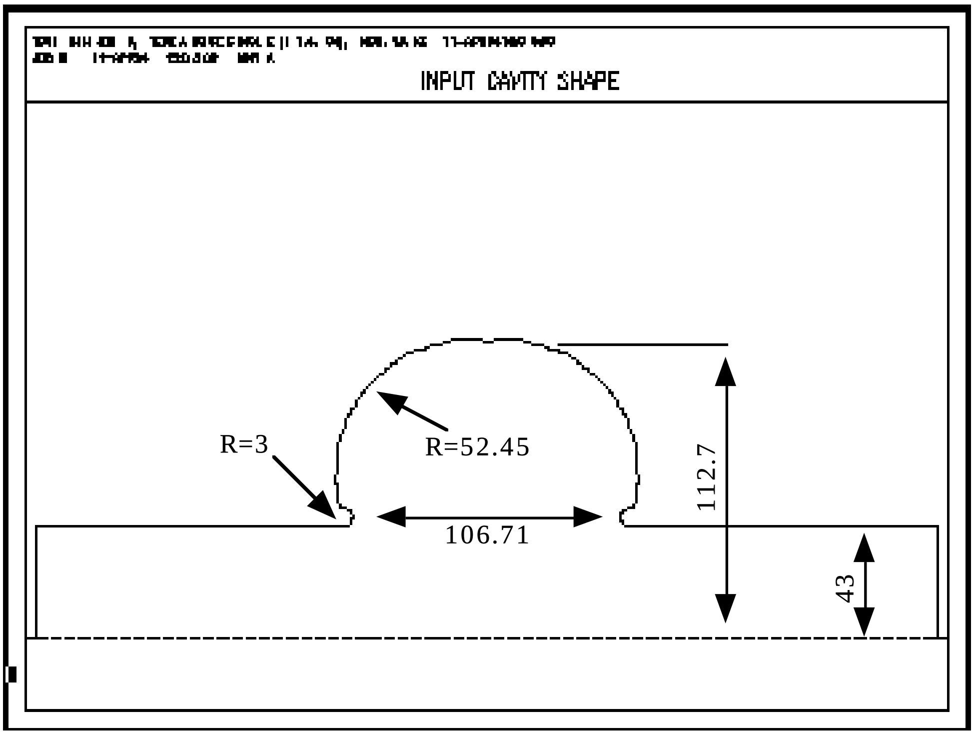

Fig. 17 - Nosecone high R_s cell

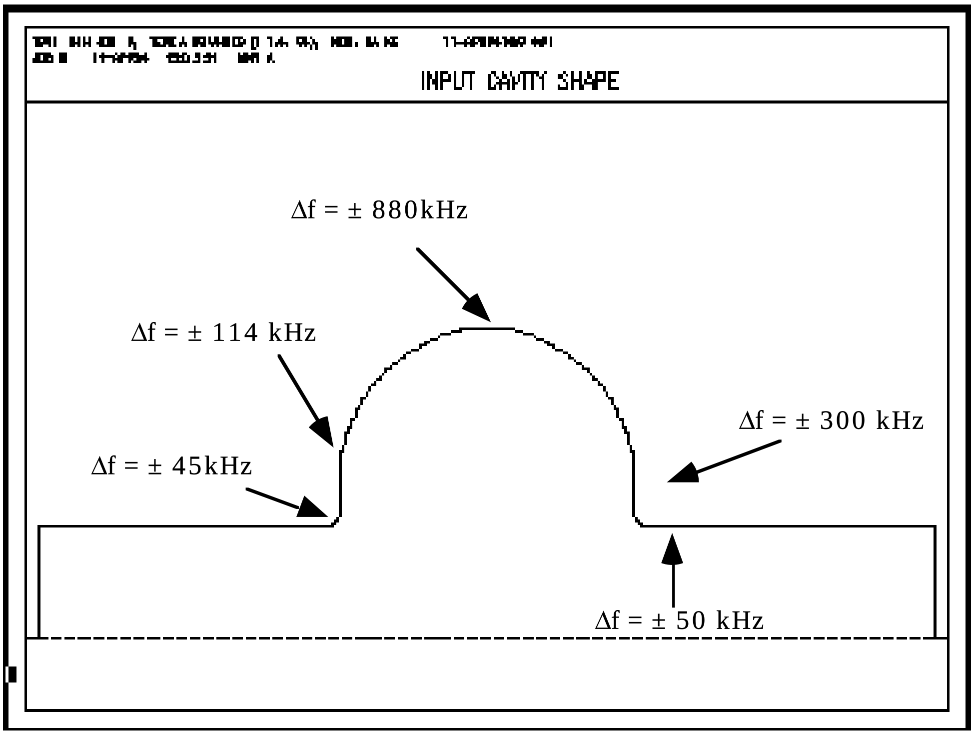

Fig. 18 - Tolerances on the high R_s rounded cell

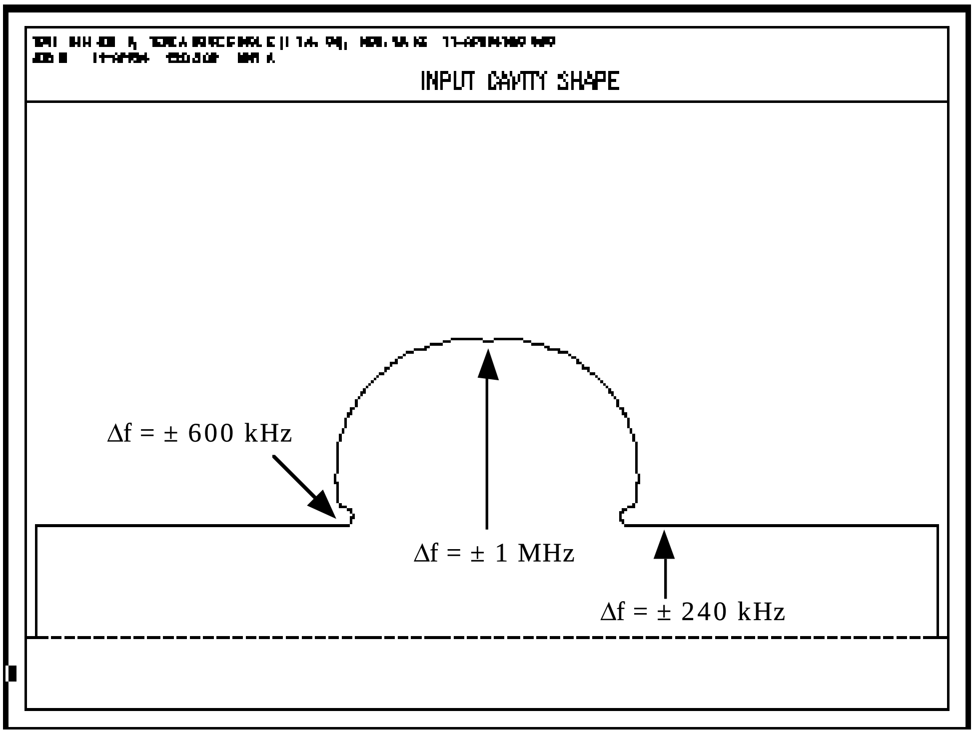

Fig. 19 - Tolerance on the high R_S nosecone cell

5 - Double cell RF cavity

To further increase the shunt resistance, a double cell system was considered (Fig. 20). The cell profile is rounded since the gain in R_S is deemed high enough not to use a nosecone profile. The resulting value is R_S = 3.6 MΩ. Unfortunately, such coupled structures (also more cumbersome) show a variety of HOMs at low frequency, which remain trapped in the cavity and must be damped (see Table I). Moreover, its contribution to the machine broadband impedance was estimated (ABCI) to be 0.23 Ω, while for the single-cell nosecone cavity this value is ~ 0.054 Ω. Particular care has to be taken to damp the 0 - mode at the fundamental frequency, although this problem has already been solved by Boussard et al. [3].

As an exercise, also a 3 - cell structure (Fig. 21) was simulated with R_S = 5.1 MΩ, reproducing the same problems as the double cavity and, of course, requiring even more space in the DAΦNE main rings.

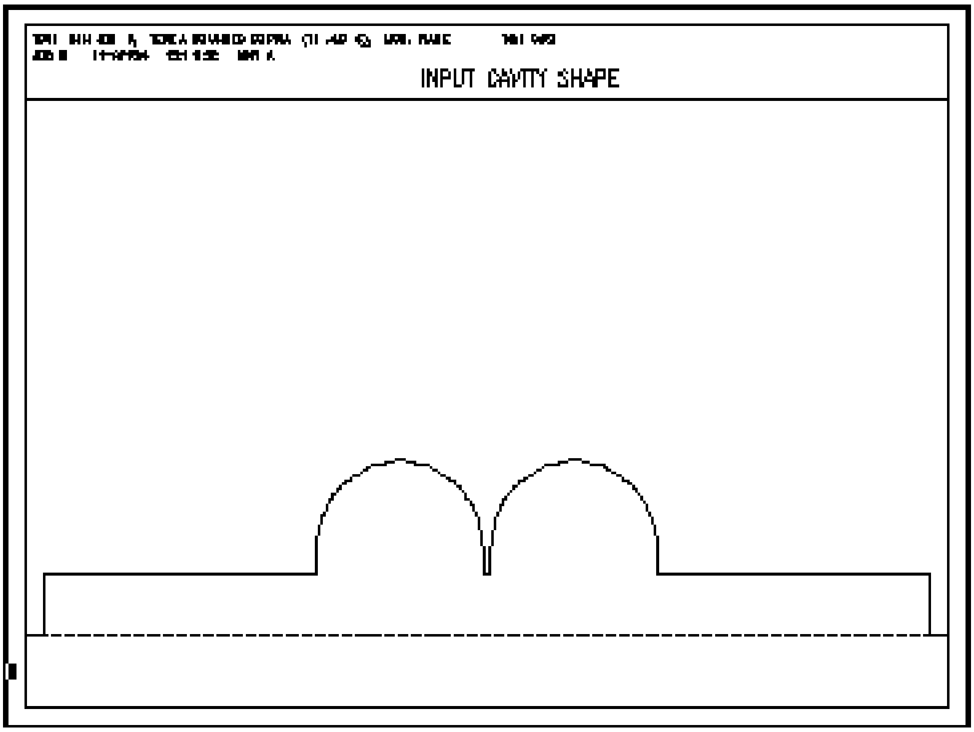

Fig. 20 - Rounded double cell cavity

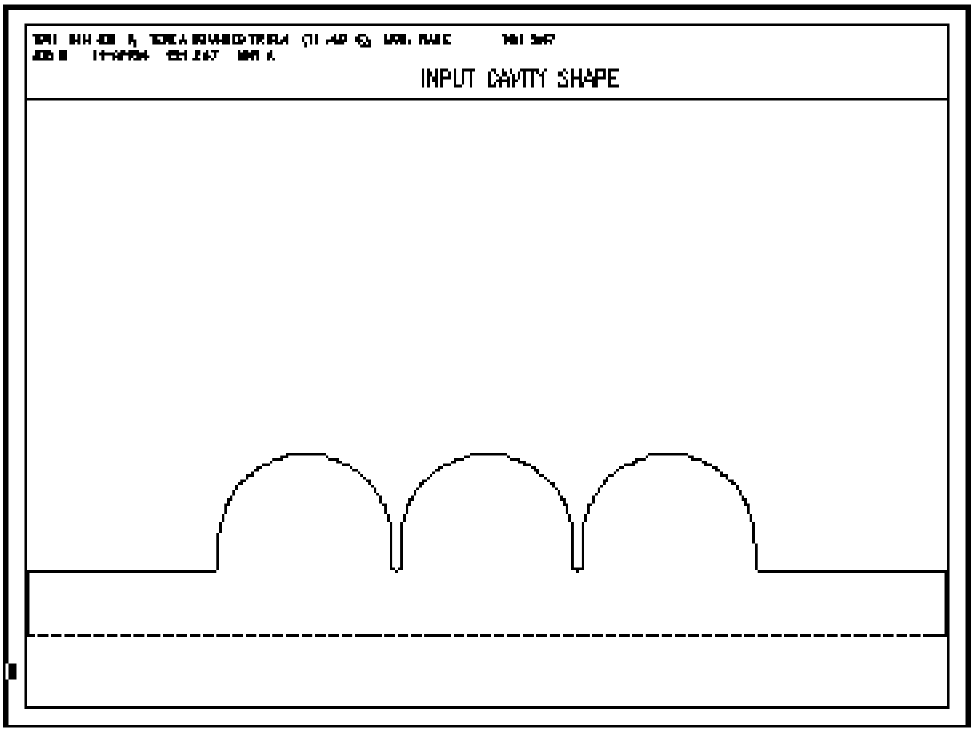

Fig. 21 - Rounded triple cell cavity

Table I - Main parameters of the lowest monopole modes of the rounded double cell cavity

	Freq. (MHz)	R/Q (Ω)	Q
1) TM_{010} "0"	1078.580	2.3	31500
2) TM_{010} "π" (accelerating)	1104.05	114.0	31600
3) TM_{011} "0"	1868.838	16.3	31600
4) TM_{011} "π"	1922.226	30.7	31000
5) TM_{020} "0"	2292.958	0.3	43500
6) TM_{020} "π"	2359.162	0.3	45000
7) "Trapped"	2749.083	1.4	34000
8) "Trapped"	2753.006	0.2	34000
9) TM_{021} "0"	2886.985	0.9	39900
10) TM_{021} "π"	2931.219	2.8	41700
11) TM_{012} "0"	2965.594	5.3	47000
12) TM_{012} "π"	3010.753	2.6	37000

6 - Conclusions

Our main concern is to avoid multibunch instabilities, i.e. the presence of several high R_s modes in the cavity. Thus we exclude the 2-cell or even the 3-cell solution, where the coupling between cells would increase the number of trapped HOMs, but also the long tapered solution, which exhibits several HOMs and furthermore is quite cumbersome. The available space is indeed restricted to ≤ 50 cm, so the alternative is between a low resistance structure (which would not require dampers, but just an antenna) and a high resistance structure (either nosecone or rounded) which would certainly require dampers.

All the described cavities comply (within at least a factor 10) with Kilpatrick's criterion on the maximum surface electric field [4]. A summary of the most important results is given in Table II, where tuning sensitivity is calculated assuming a 1.5 cm radius cylindrical tuner.

Table II - Summary results for the nosecone (single-mode) and nosecone and rounded (High R_S) cavity

	Nosecone (gap=15)	Nosecone High R_s	Rounded High R_s
Frequency (MHz)	1104.57	1104.59	1104.71
R/Q (Ω)	33.38	58.73	65.36
R_S (MΩ)	0.335	1.96	1.85
V_{gap} (kV)	75	75	75
P_d (kW)	8.4	1.43	1.52
W (mJoule)	12.13	6.2	6.9
E_S max (MV/m)	9.5	2.8	1.97
B_S max (Gauss)	114	29	30.6
Tuner sensitivity (mm/MHz)	0.6	4.7	4.8
TM_{011} mode:			
Frequency (MHz)	propagating	1839.61	1916.26
R_S (kΩ)	-	612.0	672.6
TM_{020} mode:			
Frequency (MHz)	propagating	2429.	2342.
R_S (kΩ)	-	4.7	7.6
TM_{110} mode:			
Frequency (MHz)	1601.	1644.	1604.
R'_S (kΩ) (at 4.3 cm)	266.	366.	299.
TE_{111} mode:			
Frequency (MHz)	2020.	1453.7	1412.6
R'_S (kΩ) (at 4.3 cm)	0.416	84.6	150.3

References

1) *M. Migliorati, L. Palumbo and M. Zobov: "Bunch Lengthening in DAΦNE Main Ring", DAΦNE Technical Note G-22, November 1993. and "Bunch Length Control in DAΦNE by a Higher Harmonic Cavity", DAΦNE Technical Note G-24, May 1994.*

2) *Y. Chin: "Users's Guide for new ABCI", CERN SL/92-49 (AP).*

3) *D. Boussard, H.P. Kindermann and V. Rossi: "RF feedback applied to a multicell superconducting cavity", Proc. of the 1st European Particle Accelerator Conference (EPAC), Rome, June 1988, p. 985.*

4) *W. P. Kilpatrick: "Criterion for Vacuum Sparking designed to include both RF and DC", VCRL - 2321, Sept. 1953.*