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Studies for the optimization of the HMPID CsI-RICH detector

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Abstract

The optimization of the HMPID RICH geometrical parameters has been performed with beam tests and Monte Carlo simulations. The results show that with a radiator having 50% larger thickness than the 10 mm so far adopted, the detector can be operated at a gain reduced by the same factor, thus decreasing the photon feedback background and improving the stability of operation in presence of heavily ionizing events. In addition, the use of a low gain has the remarkable advantage of providing a reserve of photoelectrons which could be exploited by increasing the gain, in the case of a degradation of the CsI photocathodes quantum efficiency.

1 Introduction

Before proceeding to the final design of the High Momentum PID RICH detector, we have accomplished a study of all factors that could be optimized. The HMPID RICH has a proximity focusing geometry, with a liquid C_6F_{14} radiator and a pad-segmented CsI photocathode (PC) inside a multiwire chamber. A detailed description is given in the Technical Design Report [1], where the detector parameters, which will be discussed in the present study, were choosen to be: C_6F_{14} radiator thickness of 10 mm, proximity gap of 80 mm, pad size of 8x8.4 mm^2 (wire pitch 4.2 mm), single electron pulse height (PH) A_0 of 40 ADC channels (1 ADC channel = 0.17 fC).

In the proximity focusing configuration three main sources of error have to be considered when optimizing the Cherenkov angle resolution. These are:

1) The *chromatic error*. The energy dependence of the refractive index of the liquid C_6F_{14} radiator within the accepted UV range of photons (established by the convolution of the media transmission and the CsI quantum efficiency (QE)), results in a spread of the Cherenkov angle. On the one hand, one aims at achieving the largest number of photoelectrons optimizing the media tranparency and enlarging the detected UV range towards the higher photon energies, where the CsI QE gets larger. On the other hand, at these energies, the refractive index dispersion, hence the chromatic error, increases rapidly, thus worsening the final resolution.

2) The *geometric error*. It is a twofold effect where both the radiator thickness T_r and the proximity gap T_g are involved. The uncertainty on the photon emission point, along the particle track in the radiator, determines an error on the Cherenkov angle which depends on the ratio T_r/T_g. For the radiator, T_r has to be chosen such that it gives acceptable resolution for a given T_g and a sufficient number of detected photons. For the proximity gap, there are two limiting cases to be studied: a) there is no sense in increasing T_g over the stage where the geometrical contribution starts to be much smaller than the chromatic one; b) the high particle density in which the HMPID is foreseen to operate (about 15$\%$ occupancy) may have an opposite effect on the resolution when increasing T_g, since a larger gap will introduce a greater amount of background originated from ring overlapping in the fiducial area considered by the pattern recognition algorithm [1].

3) The *localization error*. It is determined by some geometrical parameters of the MWPC (pad size and wire pitch) and may be worsened by the photon feedback, which grows with the chamber gain A_0, and by the overlap of pad clusters belonging to different Cherenkov rings in multi-particle events.

The Cherenkov angle resolution per track is a function of the factors enumerated above but also of the number of detected photons, being inversely proportional to the square root of that number. Therefore it was interesting also to examine the possibility to have a design that allows to recuperate a possible deterioration of the CsI PCs QE (aging).

In the following we present the measurements and simulations performed to optimize the various parameters listed above.

2 Variation of the radiator thickness: experimental results

The variation of the radiator thickness T_r acts in two ways on the final resolution of the detector. An increase of T_r will proportionally increase the number of photons produced in the radiator. However, due to the cutoff in the transparency curve, the high energy photons leaving the radiator will be less represented than the lower energy ones, which is desirable from the chromatic error point of view. We have therefore studied the dependence of the main parameters used to evaluate the RICH performance in a dedicated run at fixed gap.

In fig. 1 are shown the event multiplicities (numbers of pad hits, of raw and resolved clusters, of photoelectrons) from PS beam test of the small RICH proto-1, equipped with PC24, as a function of the radiator thickness. The chamber gain was set to 27 ADC, which is lower than the optimal value cited in the introduction, to reduce the pad cluster size and then the fraction of overlapping clusters which resulted rather large at 40 ADC, as a consequence of the smaller proximity gap used in proto-1. Although the number of produced Cherenkov photons is directly proportional to the radiator thickness, the multiplicities of detected photons do not increase linearly because of the worsening of the radiator transparency for higher energy photons and because of the geometrical overlapping of the pad clusters [1].

Fig. 2 shows the Cherenkov angle resolution as a function of the radiator thickness in the same test, for two angle reconstruction algorithms, described in [2]. Due to the dominance of the chromatic error, the deterioration of the *single photon* resolution with the radiator thickness becomes relevant only after 10 mm. However, the *ring* angular resolution reaches a plateau after that value, as a result of the larger number of resolved clusters (fig. 1) compensating the degradation of the *single photon* resolution, since $\sigma_{ring} = \frac{\sigma_{photon}}{\sqrt{N_{clus}}}$.

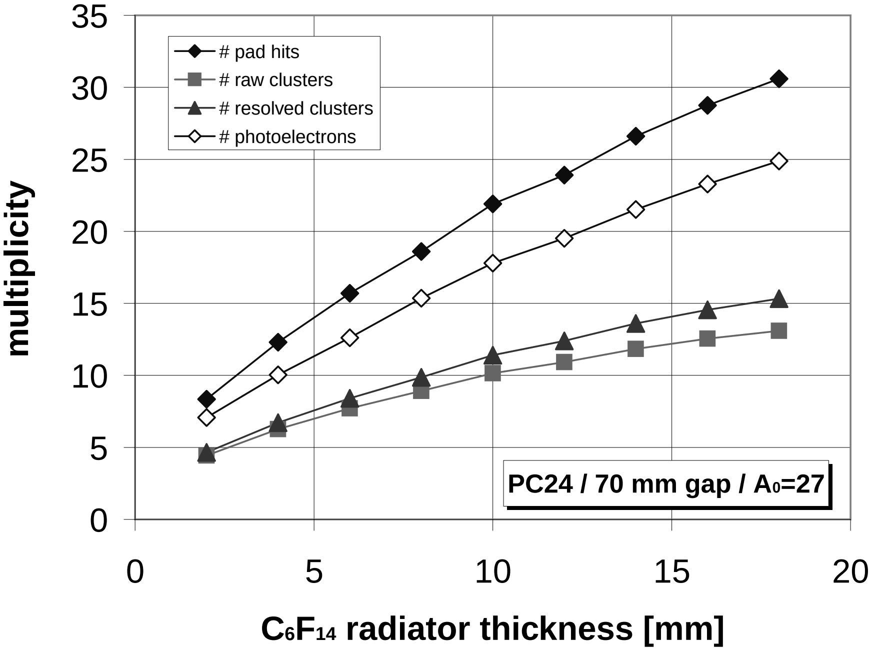

Figure 1: Measured event multiplicities as a function of the radiator thickness; PS beam test, small RICH proto-1, PC24, 3 GeV/c π, 70 mm proximity gap, single electron PH A_0=27 ADC channels (1 ADC channel = 0.17 fC).

3 Optimization of radiator thickness, chamber gain and proximity gap with Monte Carlo simulations

The experimental results have demonstrated the possibility of using a larger radiator thickness, since this has no visible effect on the ring angular resolution, at least when evaluated at level of single particle test beam events. Hence we have studied single- and multi-particle Monte Carlo events to improve the HMPID performance and stability of operation by a combined optimization of radiator thickness, chamber gain and proximity gap.

3.1 Simulation of single-particle events

Using the Monte Carlo simulation program *RICHSIM* described in [1, 3], 350 GeV/c single π events, in different detector configurations, have been generated and analysed.

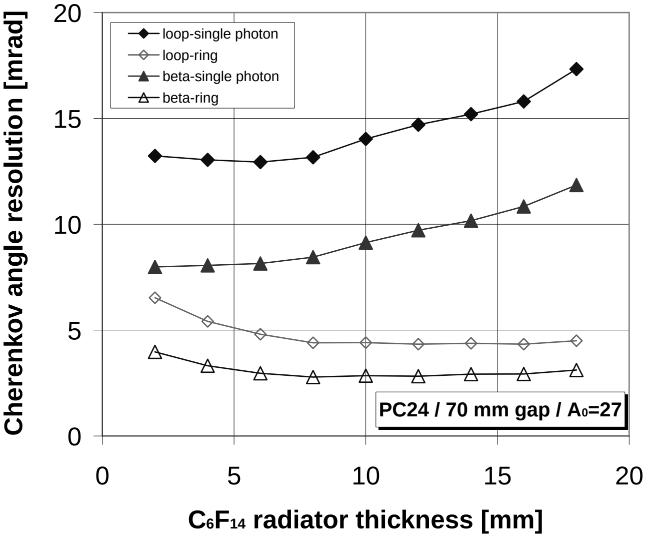

Figure 2: Cherenkov angle resolution as a function of the radiator thickness, obtained with two angle reconstruction algorithms, the *beta* and the *loop* methods ([1, 2]); PS beam test, small RICH proto-1, PC24, 3 GeV/c π, 70 mm proximity gap, single electron PH A_0=27 ADC channels (1 ADC channel = 0.17 fC).

Fig. 3 shows the cluster multiplicities as a function of A_0, the single electron PH. One can clearly deduce that with a 15 mm radiator the detector gain could be lowered by 50% with respect to 40 ADC, the optimal value with 10 mm thickness.

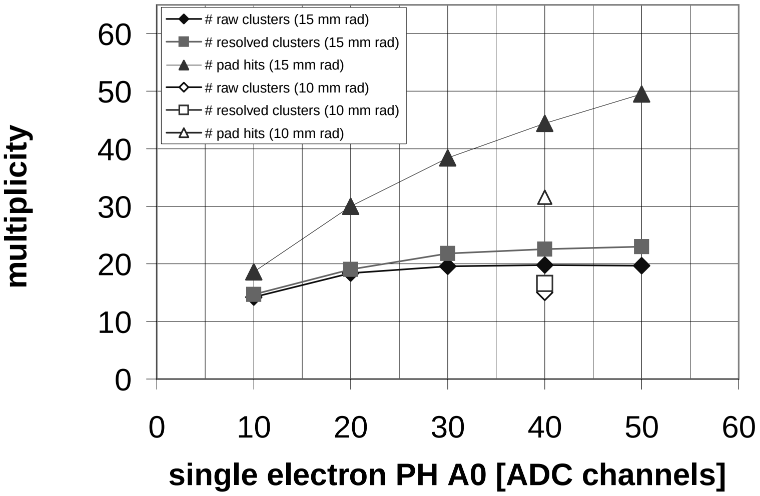

Figure 3: Main quantities from simulated events analysis, as a function of the single electron PH, obtained with 350 GeV/c π and a 103 mm proximity gap. The results for 10 mm radiator are in good agreement with experimental data.

One immediate consequence of operating the chamber at A_0= 20 ADC is the reduction in the number of feedback photons (fig. 4). The chamber stability has been found very satisfactory in PS and SPS test beams [1], as well as in the STAR experiment at BNL, showing no breakdowns at the selected high voltage values. However, operating the chamber at a smaller gain has also the considerable advantage of reducing the total charge released by the Cherenkov photoelectrons and the charged particles (fig. 5), resulting in a safer operation, especially in presence of heavily ionizing events foreseen during the ALICE run time.

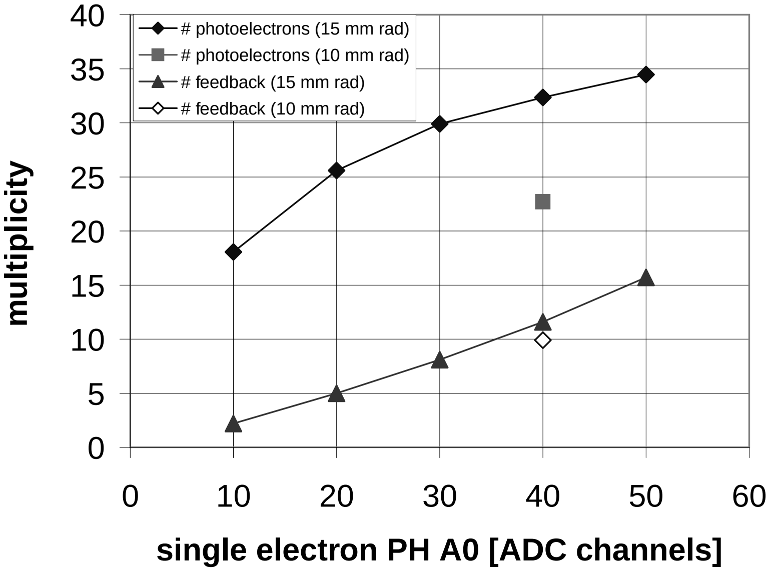

Figure 4: Total number of photoelectrons in the Cherenkov fiducial and number of feedback photoelectrons, from simulated events, as a function of the single electron PH, obtained with 350 GeV/c π and a 103 mm proximity gap.

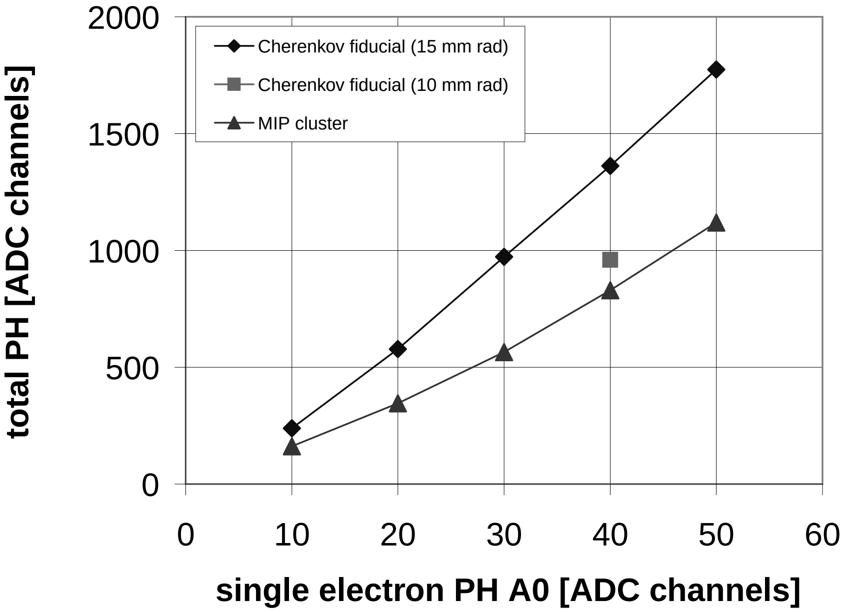

Figure 5: Total pulse height in the Cherenkov fiducial and PH of the MIP cluster as a function of the single electron PH, from simulated events, obtained with 350 GeV/c π and 103 mm proximity gap.

In fig. 6 is shown the Cherenkov angle resolution as a function of A_0, for two proximity gap values. In the considered range, the resolution does not depend on the single electron PH. On the contrary, as expected, the proximity gap has some evident effects on both the single photon and the ring angle resolutions, the larger gap value providing better results, at least in single particle, low background events. As pointed out in the introduction, in a high density event, a smaller gap may be more suitable.

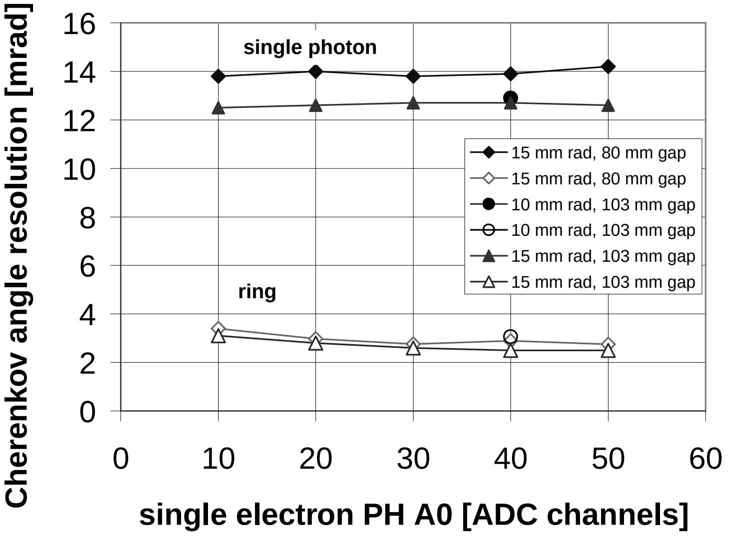

Figure 6: Cherenkov angle resolution, for two values of radiator thickness and proximity gap, in function of the gain, obtained with 350 GeV/c π.

The dependence on the particle incidence angle (counted from normal incidence), shown in fig. 7 is rather weak up to 10^o, when the total internal reflection in the quartz window of the radiator vessel causes a loss of Cherenkov photons.

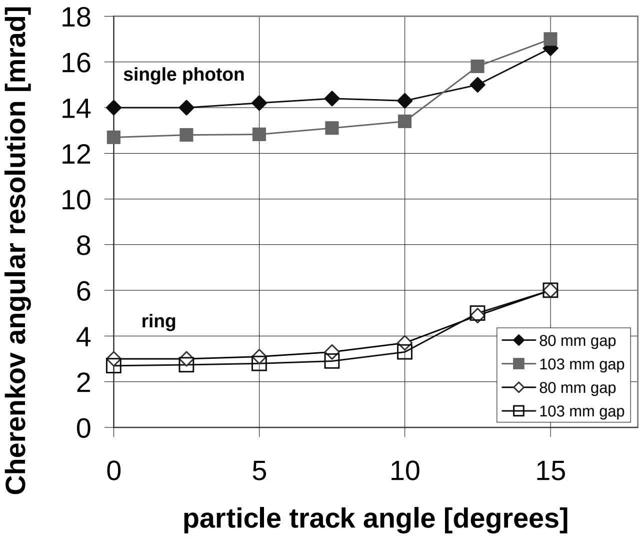

Figure 7: Cherenkov angle resolution, for two proximity gap values, as a function of the particle incidence angle, obtained with 350 GeV/c π and A_0 = 20 ADC.

Although the quoted values refer to single particle events, the angle reconstruction has been achieved applying the same cut, in the azimuthal angle, used for the multi-particle events, to discard pad clusters included in the sector of the Cherenkov fiducial area which gets wider the larger the incidence angle.

3.2 Simulation of multi-particle events

The optimization of the detector parameters has been performed also in multi-particle events generated with the ALIROOT package, where the real size HMPID detector is implemented. Single rings have been merged to background events, corresponding to a charged particle hit density of 100 m^{-2}, and analysed with the Hough transform based pattern recognition algorithm described in [1, 4]. Tab. 1 shows the variation of the angular resolution and of the mean detector occupancy with the chamber gain, the radiator thickness and the proximity gap, at 8000 and 4000 charged particles per unit of rapidity. The Cherenkov angle resolution is obtained from the pattern recognition of single rings, at 5^o particle incidence angle, merged with fully reconstructed ALIROOT background events.

Table 1: Cherenkov angle ring resolution σ and mean detector occupancy, obtained in two charged particles mulitplicity conditions, as a function of three detector parameters: radiator thickness, proximity gap and chamber gain.

dN/dy	**radiator thickness (mm)**	**proximity gap (mm)**	**chamber gain (ADC)**	σ **(mrad)**	**occupancy (%)**
8000	10	80	40	7.5 ± 0.3	14.2
8000	10	104	40	8.6 ± 0.4	14.8
8000	15	80	20	7.7 ± 0.3	10.6
8000	15	104	20	8.7 ± 0.4	11.3
8000	15	80	30	7.4 ± 0.3	12.8
4000	15	80	20	6.0 ± 0.3	5.9
4000	15	80	30	6.0 ± 0.2	7.5
4000	15	104	20	6.1 ± 0.2	5.9
4000	15	104	30	6.6 ± 0.3	7.7

As expected, at the two considered particle densities, the occupancy decreases with the gain, due to the lower single electron detection efficiency, the smaller number of pads per cluster and the reduced photon feedback contribution. On the other hand, the Cherenkov angle resolution is mainly affected by the proximity gap, the smaller value beeing more favourable because of the reduced background contribution in the fiducial area used for the pattern recognition algorithm. We have considered also a reduced dN/dy of 4000 charged particles per unit of rapidity to verify whether the choice of an 80 mm proximity gap was optimal only in a high density particle flux. The results show clearly that such a gap thickness will not deteriorate the angle resolution at a lower detector occupancy, keeping the same pattern recognition algorithm.

4 Pad size optimization

The dominance of the chromatic aberration over all the contributions to the Cherenkov angle resolution renders ineffective any reduction of the localization error [2]. Therefore we have decided to keep the original pad segmentation, also taking into account that operating the RICH at a reduced gain will decrease the photon feedback and improve the localization accuracy, especially for the charged particles, which are accompanied by the larger fraction of the feedabck contribution.

5 Recovery of the performance in case of CsI PCs aging

The detector performance has been evaluated taking into account an overall degradation of the CsI photocathodes quantum efficiency, up to 50%, for three values of gain (20, 30 and 40 ADC). The variation of the main event quantities and of the Cherenkov angle ring resolution with the QE degradation are presented, respectively, in figs. 8 and 9.

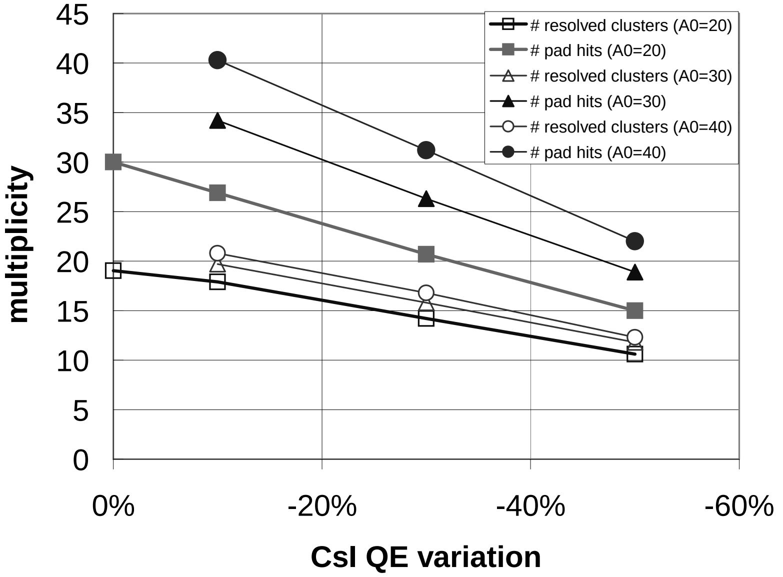

Figure 8: Main event quantities as a function of the CsI QE degradation, for three A_0 values, obtained with 350 GeV/c π and a 103 mm proximity gap.

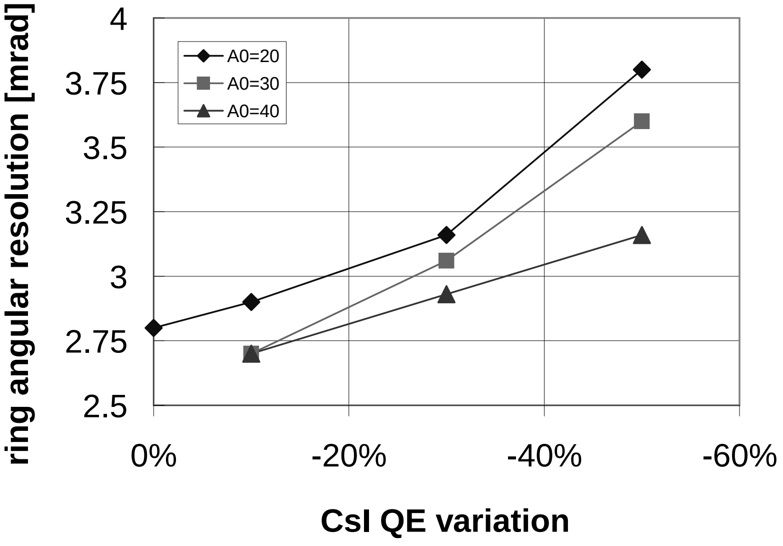

Figure 9: Cherenkov ring angular resolution as a function of the CsI QE degradation, for three A_0 values, obtained with 350 GeV/c π and 103 mm proximity gap.

These plots suggest that, in the configuration with 15 mm radiator thickness, in case of photocathode aging, the particle identification capability could be restored, increasing the detector gain, and kept almost constant up to a QE deterioration of 30%. Indeed, as a results of the improved single electron detection efficiency and the enlarged cluster size, one can fully recover the amount of pad hits but only partially the number of clusters.

6 Conclusions

We have studied the influence of two design parameters, the radiator thickness and the proximity gap, on the HMPID detector performance, with test beams and Monte Carlo simulation. We have decided to use a thickness of 15 mm for the C_6F_{14} radiator, since the presented study has pointed out that:

i) such a radiator thickness allows to operate the detector at a gain of 20 ADC, instead of the 40 ADC necessary with 10 mm thickness, keeping the performance at a satifactory level;

ii) the lower gain will result in a safer operation of the detector due to the reduction of the ionization released by charged particles crossing the chamber and of the photon feedback background;

iii) the photoelectron reserve provided by the larger radiator thickness could be exploited in case of a degradation of the photocathodes quantum efficiency, up to 30%, simply by raising the chamber gain.

About the proximity gap, a thickness of 80 mm seems to be the more suitable for the pattern recognition and the Cherenkov angle resolution, since a larger ring radius (corresponding to a larger gap) will increase the probability of overlapping and then introduce more background in the fiducial area examined by the algorithm.

References

[1] *ALICE collaboration*, **Technical Design Report of the High Momentum Particle Identification Detector, CERN/LHCC 98-19**;

[2] *A. Di Mauro*, **A study of the angular resolution of the ALICE HMPID CsI-RICH detector**, Internal Note ALICE/98-34 .

[3] *A. Di Mauro et al.*, Nucl. Instr. & Meth. A433 (1999),190-200.

[4] *D. Elia et al.*, Nucl. Instr. & Meth. A433 (1999),262-267.