Some further studies on factors affecting the pixel resolution

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1 Introduction

Since our first report, there has been a very constructive discussion between physicists in the BTeV collaboration and the engineering team working on pixel electronics front end design at Fermilab. A preferred solution has emerged, based on a pixel size of 50 μm in the small dimension and analog readout. In this follow-up report, performed with the same algorithm described before [1], we have extended our study to examine a few questions affecting the analog front end design. The task of designing a front end device suitable for BTeV needs is quite challenging. Several conflicting requirements are included in our specification: we are striving for an analog readout, with fast digitization in order to have the analog information extracted from the front end quickly, without excessive penalty either in space or power consumption and a threshold quite low and uniform compared with results achieved so far in large scale pixel system [2]. Finally, we are likely to experience gain loss due to radiation damage in the course of the life of this detector and the effect of this degradation of the signal for a given front end device needs to be considered.

2 Studies on the optimal dynamic range of the analog front end and the ADC

One of the questions that we decided to explore more thoroughly is the interplay between maximum dynamic range and ADC resolution. In our initial study, we have assumed the maximum dynamic range of the analog front end and the ADC to be 48,000 electrons. This has been motivated by the known shape of the Landau distribution, with a long tail above the most probable energy loss for a minimum ionizing particle in silicon (24,000 electrons). However, the goal of measuring the charge collected in the pixel with the maximum pulse height more accurately obviously conflicts with the goal of having enough dynamic range to measure accurately pulse heights corresponding to the high energy tail of the Landau conflicts with the ability to measure the charge in the neighboring pixels accurately at any given bit resolution. It is interesting to see the interplay of these two factors. We have studied this issue at two different angles in the non-bending plane: $\theta_x = 100$ mrad and $\theta_x = 200$ mrad. Fig. 1 shows the study at $\theta = 100$ mrad and Fig. 2 the corresponding results at $\theta = 200$ mrad. In both cases the solid line defines binary readout, quite insensitive to the dynamic range of the front end electronics. However it can be seen that for the quite limited resolution provided by a 2 bit ADC there is actually an optimum in the maximum dynamic range at about 25,000 electrons. For higher resolution, this minimum appears to be a threshold, above which there is not much improvement in resolution achieved by increasing the dynamic range. At a larger angle (200 mrad), where the ratio between the maximum pixel charge signal and the signal in its neighbors becomes progressively lower, the results are consistent, but are even more favorable to the lower dynamic range.

3 Study of threshold, number of bits and lower pulse height effects

In our initial study we adopted some quite optimistic assumptions on the minimum achievable threshold (1,500 electrons). On the other hand, we have shown that a 4 bit dynamic range does not produce significant degradation and is quite adequate for our goals. We have now extended our investigation by examining the consequences of relaxing some of the assumptions adopted in the previous study. In addition, we have decided to focus our investigation on three different choices of digitization resolution: 2 bits, 4 bits and 2 bits with logarithmic response. The last example has been motivated by the recent proposal by A. Mekkaoui of introducing a flash ADC incorporated in the unit cell implemented with a few independent comparators. The logarithmic response is a traditional solution to range compression that we may want to consider. The results reported here assume that the charge carriers collected are electrons. In addition we assume that the ADC is a device that is independent of the discriminator determining when a given cell has a useful signal. If the ADC is linear, the range between the threshold and the maximum linear range assumed is divided in a number of equal intervals consistent with the number of bits (for instance, 3 intervals for 2 bits) and the charge is digitized accordingly. Given the low level of threshold assumed, the results are not very different if the interval being digitized is between 0 and the maximum range of linearity assumed.

Fig. 3 shows a comparison of the performance of different ADC's for a threshold choice of 2000 There is a definite difference between the region within 100 mr of normal incidence and the rest of the solid angle. The angle θ_x is the track angle in the non-bending plane and the angle θ_y is the angle in the bending plane. In the former region the resolution improves smoothly from 10 to about 5 μm as the angle increases. The higher number of bits is helpful at larger angles, where a resolution of about 3 μm is achievable with a 4 bit ADC. Finally, a non linear response flattens the resolution achievable in the region of larger angles. Fig. 4 shows that if we assume that the threshold changes around the nominal value with a rms value of 450 electrons, we will not see a dramatic effect on average.

Fig. 5 shows the comparison between a threshold of 3000 electrons and a threshold of 2000 electrons. This picture shows that the effect of changing the threshold is not very dramatic. Its impact is less significant than the choice to use a coarser digitization. Lastly, Fig. 6 shows the effect of reducing the maximum pulse height of a factor of 60% at two different ADC sensitivity. The biggest effect is again at larger angles. Some improvement in the 2 bit option performance could be achieved if a non linear response was chosen.

4 Conclusions and further studies

We think that a solution with a 4 bit ADC with a dynamic range of 24,000 electrons would be the best one to achieve the optimum resolution within the whole angular region covered by the BTeV experiment. A solution involving a 2 bit ADC with a non linear response offers comparable performance in the forward region and is worse by 2 to 4 μm at larger angles.

Several refinements are necessary to this study. At high pulse heights, the effect of delta rays might be non negligible and we should introduce it in the simulation. In addition, the effects of radiation damage are likely to need a more sophisticated model. Moreover the effects of the time development of the signal and cross talk between neighboring channels need to be refined. These studies should be completed soon. On the other hand, we feel that it would be useful to simulate the impact of this angle dependent resolution on the physics goals of BTeV.

References

[1] Marina Artuso and Janchun Wang, BTeV Internal Report BTeV-Int-97-18

[2] M. Campbell, 7th Pisa Meeting on Advanced Detectors and private communication.

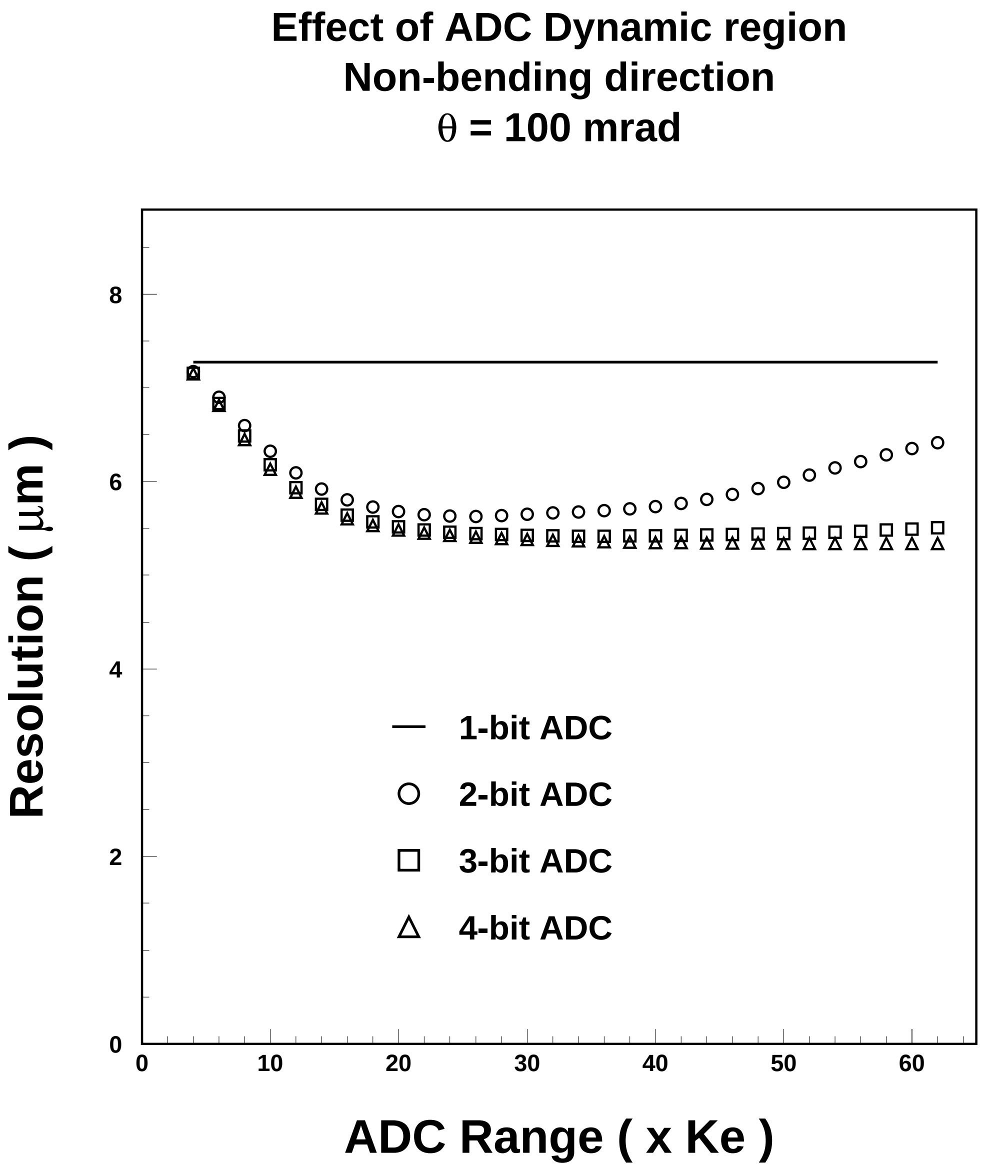

Figure 1: Effect of dynamic range of the ADC for different number of bits, for tracks incident at 100 mrad.

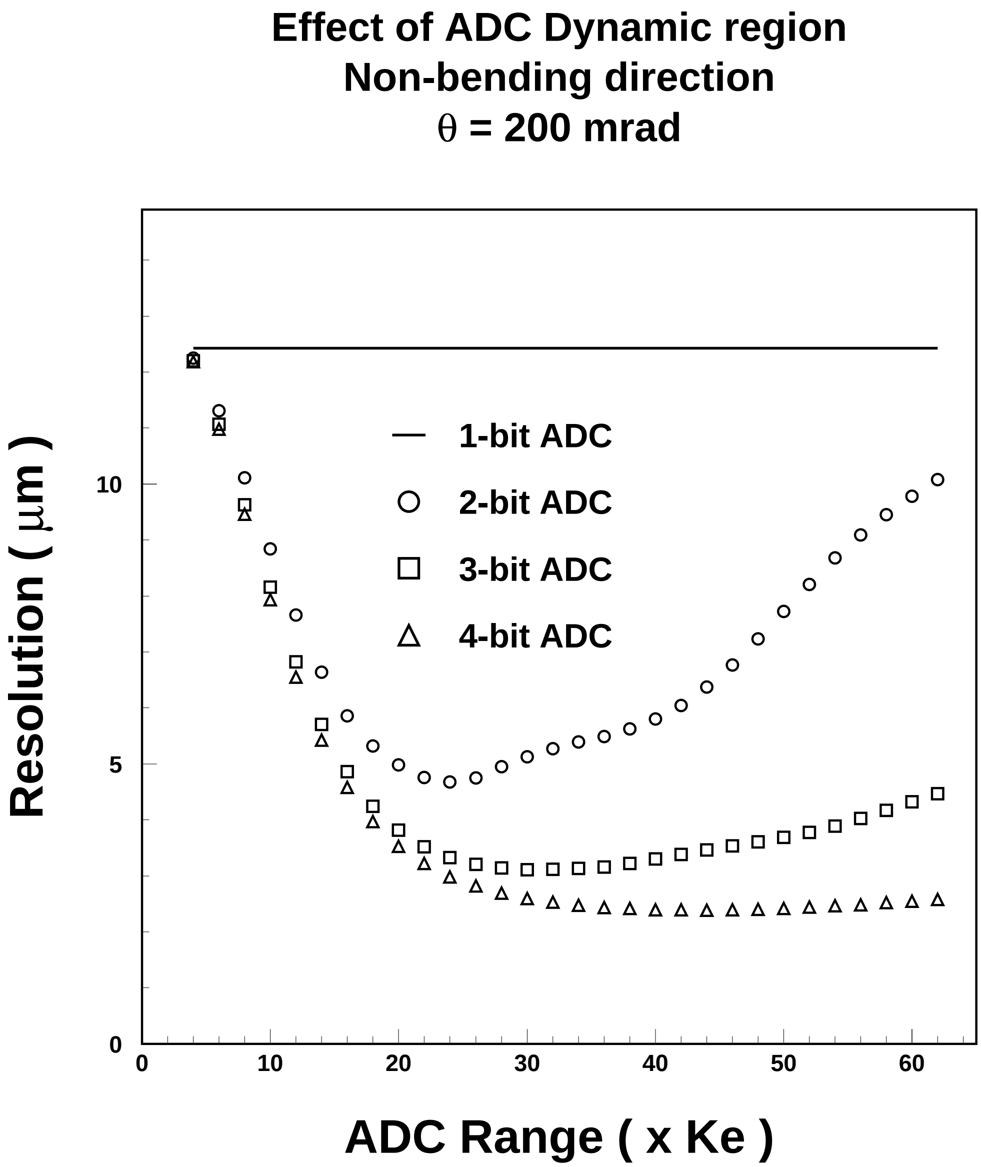

Figure 2: Effect of dynamic range of the ADC for different number of bits, for tracks incident at 200 mrad.

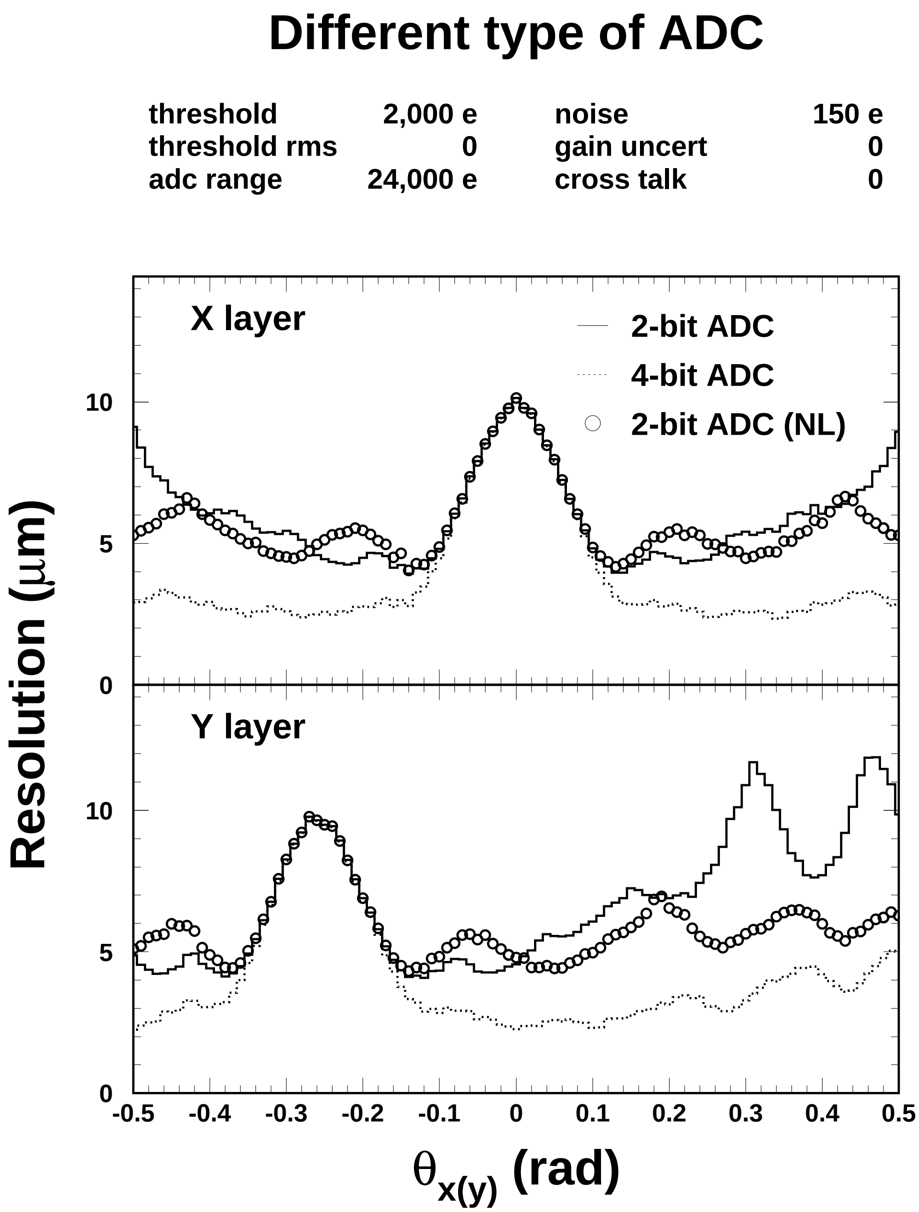

Figure 3: Comparison between different ADC resolution, with a nominal threshold of 2000 electrons and a threshold spread of 450 electrons

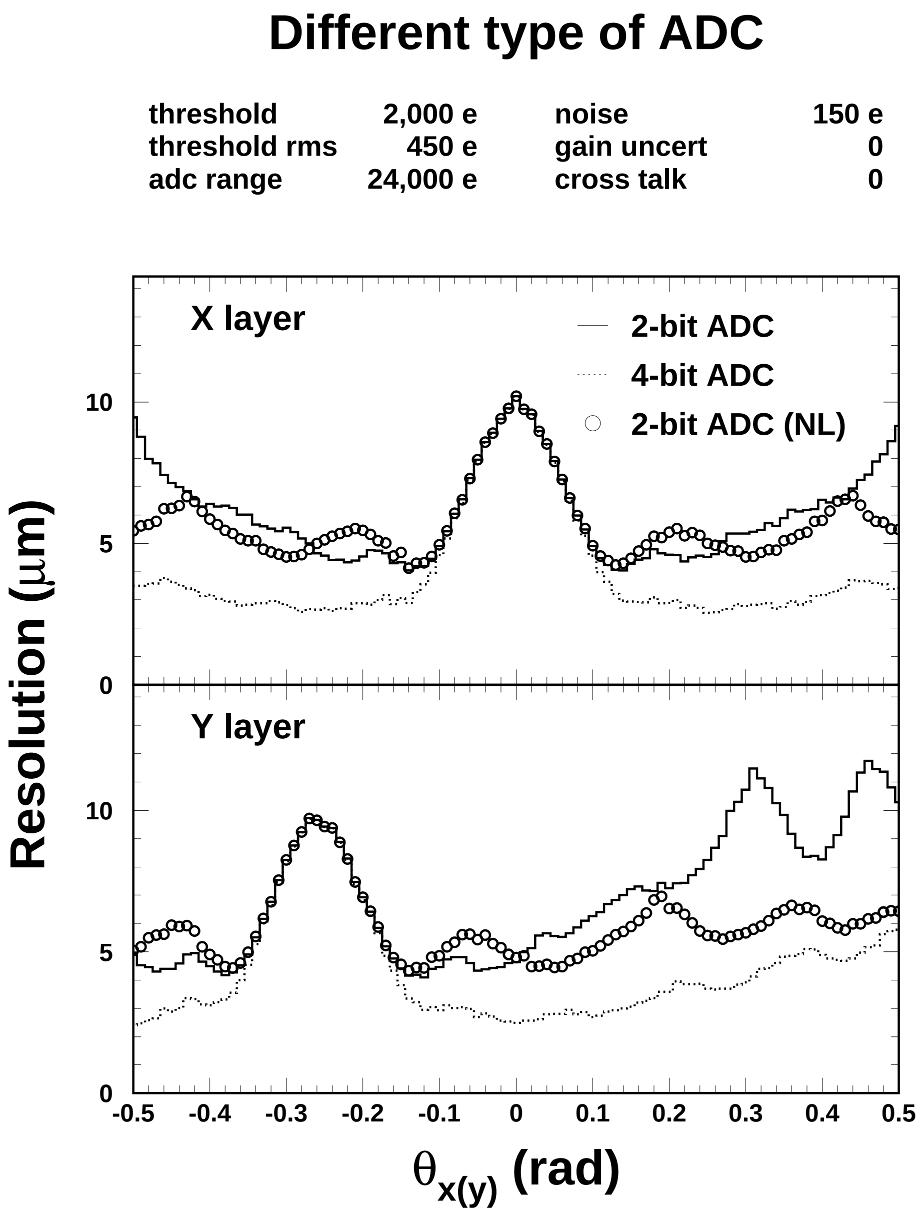

Figure 4: Comparison between different ADC resolution, with a nominal threshold of 2000 electrons and a threshold spread of 450 electrons

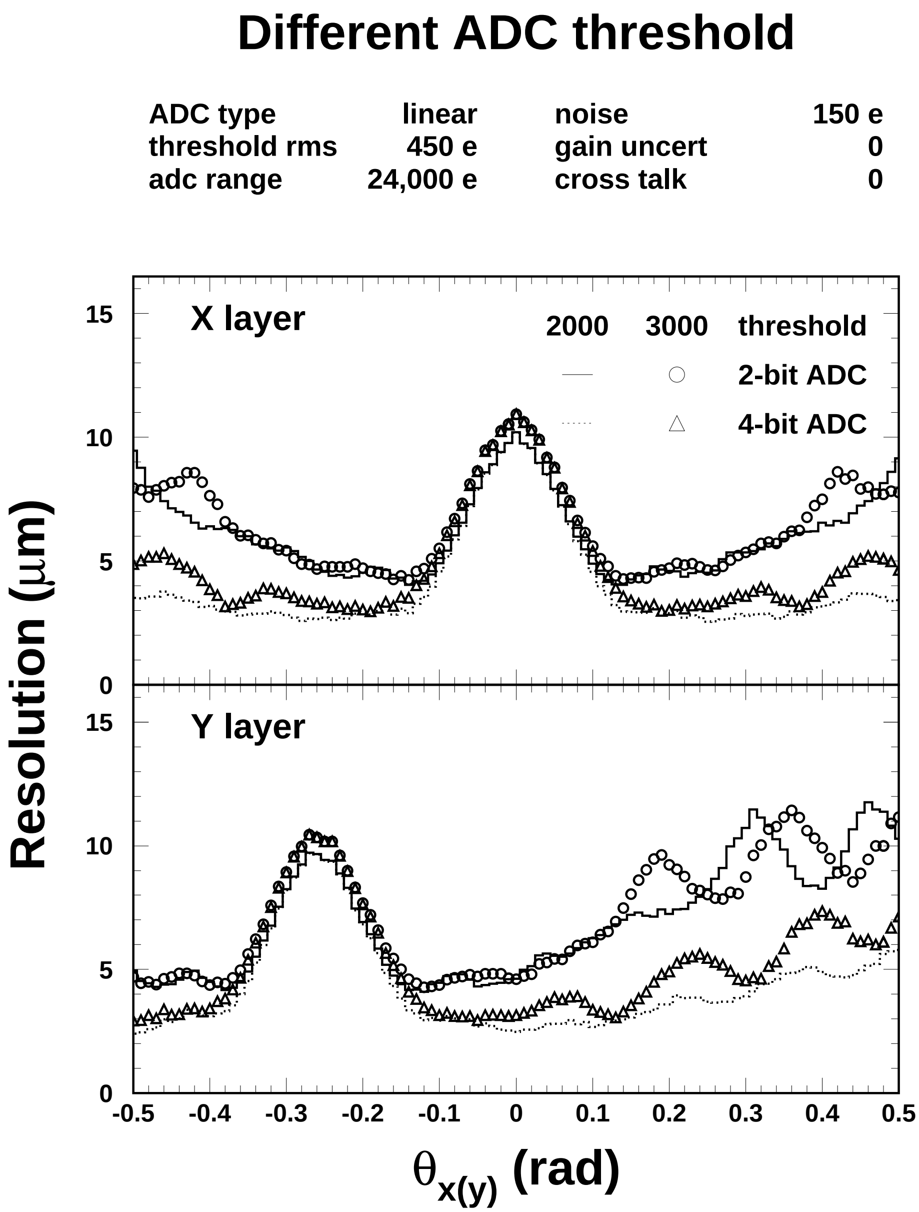

Figure 5: Comparison between different ADC resolution, with a nominal threshold of 3000 electrons and no threshold spread

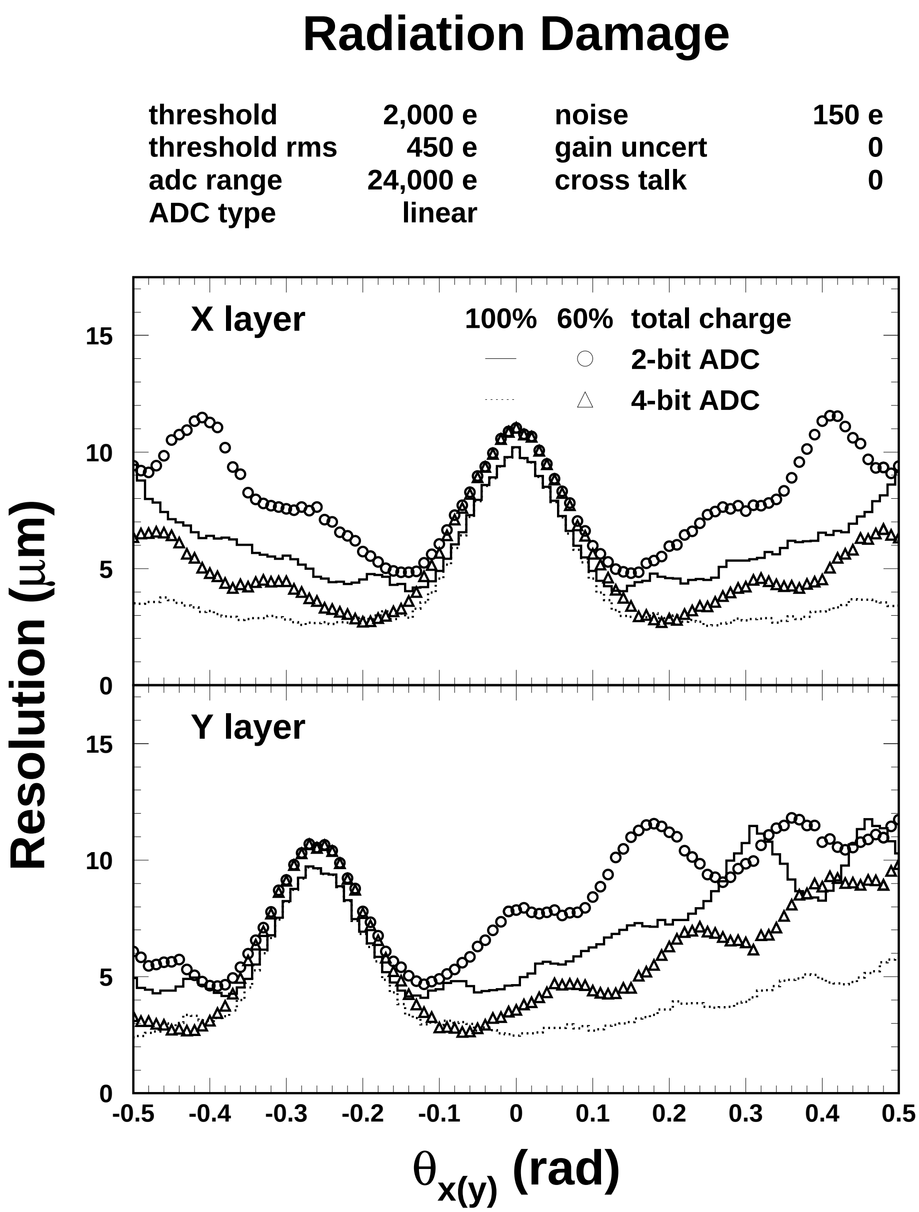

Figure 6: Comparison between different ADC resolution, with a nominal threshold of 2000 electrons and a reduced pulse height (60 %).