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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Space resolution of a silicon pixel detector as a function of the track angle

P. Morettini[a,*], D. Barberis[a], M. Bozzo[a], C. Caso[a], M. Dameri[a], G. Darbo[a], G. Gagliardi[a], B. Osculati[a], C. Pizzorno[a], L. Rossi[a], G. Sette[a], F. Vernocchi[a], J. Ridky[b], P. Sicho[b], V. Vrba[b], R. Leitner[c], J. Jakubek[d], J. Kubasta[d], S. Pospisil[d], B. Sopko[d], M. Campbell[e], E. Cantatore[e], E. Heijne[e], P. Middelkamp[e], L. Scharfetter[e], W. Snoeys[e]

[a] *INFN, Dipartimento di Fisica, Via Dodecaneso 33, 16146 Genova, Italy*
[b] *ASCR, Prague, Czech Republic*
[c] *NC, Prague, Czech Republic*
[d] *Czech Technical University, Czech Republic*
[e] *CERN, Geneva, Italy*

Abstract

We measured the spatial resolution of a 300 μm thick 75 × 500 μm silicon pixel detector as a function of the track angle using a 120 GeV pion beam.

We observed that 13% of tracks perpendicular to the detector give a signal on two neighboring pixels; this fraction increases to 50% at an angle of 15° w.r.t. the normal incidence direction. The average spatial resolution is 28.2 μm at 0° and 14.6 μm at 15°. The detector efficiency is not affected by the charge sharing between pixels.

Our data agree with the predictions of a simple geometrical model describing the charge sharing in the region between pixels. This model can be the basis for a full simulation of the behaviour of a pixel detector.

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1. The experimental setup

We tested an array of 16 × 128 silicon pixels; the detector thickness was 300 μm and the pixel size was 75 × 500 μm. The detector was bump-bonded to an Omega 2 readout chip [1] and read out by a dedicated VME board. The Omega 2 is a binary readout system; it was operated at a typical threshold of 6000 electrons.

For the track reconstruction we used a silicon strip telescope made of 3 planes with 20 μm pitch and 3 planes with 40 μm pitch. We will call Z the direction of the 20 μm strips and Y the direction of the 40 μm ones. The pixel detector had the high resolution direction along the Z axis. The beam direction is X.

The strip readout was performed using Amplex amplifiers [2] and the DRAMS read out system [3]. The DRAMS are camac boards that we read using the same VME system reading the Omega 2 chip. This system was able to read 800 events per burst.

The trigger was provided by a set of 5 scintillators defining an active area of $1 \times 2\,\text{mm}^2$.

The pixel detector was mounted on a motorized table allowing changes of the Y and Z position; the table also allow to rotate the detector around the Y axis. We will call θ the rotation angle of the detector; $\theta = 0$ means that the detector is perpendicular to the beam line.

With this set up we took a total of 600 000 triggers at the CERN H6 beam line (120 GeV pions).

2. Data analysis

The tracks have been reconstructed using the strip informations only. We used only unambiguous events, i.e. we asked for 3 points in the Y direction and 3 in the Z direction.

In case of multiple contiguous hits the strip point was defined as the barycenter of the charge deposition; when calculating the coordinates of the cluster each point has been assigned a weight proportional to the deposited charge.

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[*] Corresponding author.

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A clustering algorithm was also applied to the pixel points. Any group of contiguous hits was considered as a single point, and its position, considering that we only have a binary information, was determined as the digital barycenter of the individual hits, i.e.

$$Z = \frac{1}{N}\sum_{i=0}^{N} z_i,$$

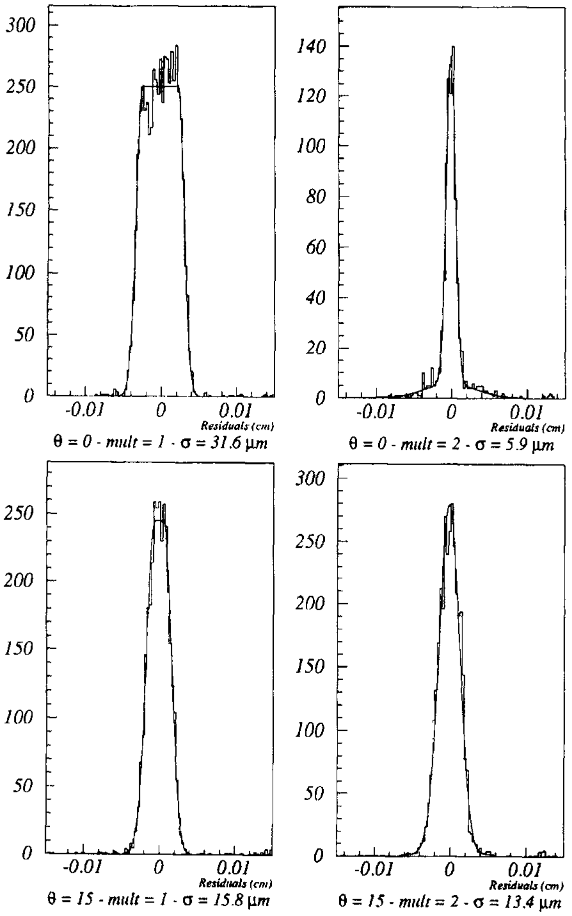
where N is number of pixels showing a signal (we will call this "point multiplicity") and z_i is the coordinate of the center of the pixel.

The distribution of the residuals (i.e. the difference between the pixel point and the extrapolation of the reconstructed track to the pixel plane) was then plotted separately for each class of multiplicity of the pixel point. We used two different functions for the fit: the sum of the gaussian (a) and a rectangular distribution smeared by a gaussian (b). We used in each case the function giving the best chi-square. The resolution we quote is the sigma of the dominant gaussian for the function (a) and half width of the box plus the sigma of the smearing gaussian for the function (b). This resolution is actually the convolution of the resolution of the pixel detector and of the telescope. The latter is however negligible in most cases (it is of the order of 3 μm in the Z direction).

Fig. 1 shows the residual distributions for point multiplicity 1 and 2 and for $\theta = 0°$ and 15°. In the first case we see that points with multiplicity 1 have the expected rectangular distribution (the width of the rectangle is compatible with the size of the pixel in the Z direction). At 15° both the multiplicity 1 and multiplicity 2 distributions have a gaussian shape.

3. Discussion of the results

Fig. 2(a) shows the behaviour of the pixel point multiplicity as a function of the track angle. At 0° only 13% of the tracks give a signal in two neighboring pixels; these are



θ = 0 - mult = 1 - σ = 31.6 μm

θ = 0 - mult = 2 - σ = 5.9 μm

θ = 15 - mult = 1 - σ = 15.8 μm

θ = 15 - mult = 2 - σ = 13.4 μm

Fig. 1. Plots of the residuals at the pixel plain for different values of the pixel point multiplicity and of the track angle θ.

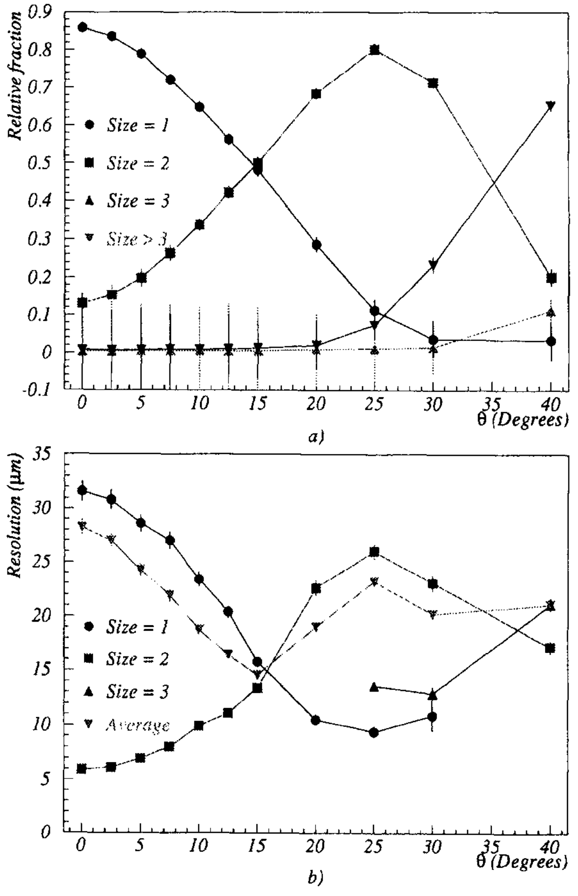


Fig. 2. (a) Relative fractions of pixel points with multiplicity 1, 2, 3 and >3 as a function of the track angle. (b) Detector resolution as a function of the track angle.

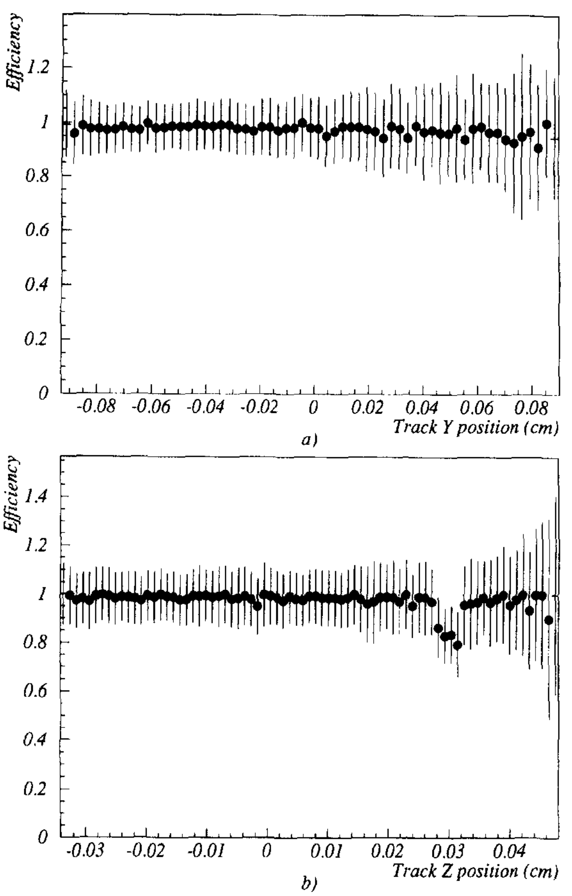


Fig. 3. Pixel detector efficiency as a function of position. No holes at the boundary between pixels are visible.

the tracks hitting the detector in a narrow zone around the pixel boundary. The fraction of points with multiplicity 2 become 50% at 15°. At larger angles the double hits become dominant, while the remaining single hits are coming from tracks centered w.r.t the pixel.

Fig. 2(b) shows the resolution as a function of the track angle. We can see that points having the higher resolution are the rarest ones. In fact the rarest multiplicity classes correspond to the tracks hitting the detector in well defined positions; obviously the spatial resolution for these tracks is higher. It is however interesting to note the trend of the average resolution of the detector; the resolution has a minimum when the size one and size two classes are equally populated. In our case this happens at 15°, and the average resolution is 14.6 μm.

We also studied the efficiency of the pixel detector as a function of the track position (Fig. 3). Since there are no inefficiencies in the regions between two pixels we can conclude that there is no effect of the charge sharing on the pixel detector efficiency, which stays constant at 99%.

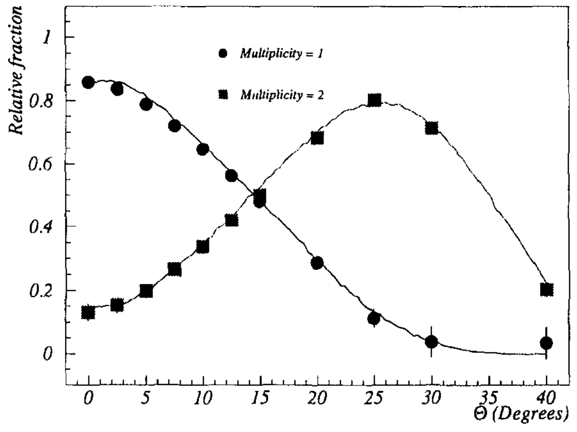


Fig. 4. The measured fractions of pixels point size 1 and 2 compared with the results of the geometrical model.

4. Conclusions

Our measurement of a pixel detector spatial resolution as a function of the track angle seems to agree with the naive expectations related to the charge sharing between neighboring pixels. To verify this agreement we have used a simple montecarlo program, in which the charge deposited in the detector is geometrically assigned to the different pixels. We assumed that each pixel completely collects the charge deposited in its central region; the collection function of a single pixel drops linearly from 1 to 0 in a region of width w centered at the boundary between two pixels (charge sharing region); w is a free parameter of the model. The other parameters of the model are the width of the pixel, the thickness of the detector and the ratio between the threshold and the average charge deposited by a MIP.

Fig. 4 shows the prediction of the model for $w = 9.2$ μm, compared with our data, for the fractions of single and double pixel clusters. The good agreement indicates that a geometrical model is sufficient to describe the observed behaviour, so it can be used as a basis for a full montecarlo description of the detector.

Acknowledgements

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