Resolution of the Layer00 Silicon Detector for Various Configurations

1 Introduction

We have written a realistic simulation of a silicon detector with p-strip readout, in order to calculate the intrinsic resolution as a function of crossing angle, intermediary strip, signal to noise, and strip pitch. This information allows the silicon design to be optimised given a certain modularity of the detector. In section 2, the simulation is described. In section 3, our results are given and discussed. Our conclusions are presented in section 4.

2 Simulation of the silicon detector

The simulation of the silicon detector is performed with 5 variable parameters:

- The pitch of the readout;
- The signal to noise ratio;
- The presence or absence of an intermediary strip;
- The angle of the track, α;
- The position of the track, η, on first entering the silicon.

By integrating over values of η from 0 to the strip pitch, the resolution can be determined as a function of crossing angle for a given pitch, signal-to-noise and presence or absence of intermediary strip.

To simulate the response, the track is stepped through the silicon in 1μm steps, starting at the position η and progressing at an angle α. At each step, the total number of electron-hole pairs created is determined. These are drifted to the collection side of the silicon, taking account of diffusion and of the Lorenz angle. The charge is divided between the readout strips and random noise added. Each of these steps is now detailed followed by a description of the algorithm used to reconstruct the particle position.

2.1 Landau Fluctuations

At each step, the total number of electron-hole pairs created is determined. This is done by calculating the number of collisions in 1μm of silicon: a Poisson distribution of mean 4.

Then for each interaction, the energy losses are calculated according to [1]. In 90% of all collisions, the energy loss is less than 170eV, and the mean energy loss for these collisions is 30eV. However in 2% of cases, it is greater than 1000eV, and in 0.2% of cases, it is greater than 10000eV. It is these high energy fluctuations which lead to the well known quasi-Landau distribution for the sum of all energy losses in the silicon. Since these large fluctuations occur rarely, they cause biases in the position determination on an event-by-event basis. Over many events, this leads to a broadening in the resolution.

2.2 Diffusion

The holes are allowed diffuse to the surface according to the model of Belau et al. [2], which takes account of both the broadening of the cloud of holes and of the Lorenz angle, which for a field of 1.4 Tesla, causes the holes to drift at an angle of 2.7^o. We have assumed a full depletion voltage of 50V for the silicon, and an operating voltage of 60V. We have verified that our simulation gives the same results as presented in this paper for the same operating conditions. This model has in turn been checked against data.

2.3 Charge Division

Having diffused the holes to the surface of the silicon, the charge is divided according to which strip it is nearest to. In the case that we have an intermediary strip, 80% of the charge on this strip is split between its two neighbours.

2.4 Noise

In order to simulate a signal-to-noise ratio of $S : N$, noise is added randomly to each strip assuming it comes from a Gaussian distribution with a sigma of N, where the most probable value of the Landau has a value S.

2.5 Reconstruction

The algorithm used to reconstruct the position of the particle proceeds by scanning for the strip with the highest signal, provided that signal is greater than 3:1. Its highest neighbour is taken, provided its signal is greater than 1.5:1. Then the position is determined by $\eta = R/(L + R)$ where L, R are the left and right most strips.

This algorithm works well for small angles but is quite poor at large angles. Consequently, for crossing angles greater than 15^o, we have used an algorithm as described by the DELPHI collaboration [3]. All strips greater than 2:1 about the highest signal are taken and the position is the midpoint between the first and last channels of the cluster, corrected with

$$\omega = [min(S_{first}, \bar{S}) - min(S_{last}, \bar{S})]/(2\bar{S})$$

where $\bar{S}$ is the average pulse-height of all channels in between.

The effects that each of the ingredients in our simulation has on the calculated resolution is shown in Fig. 1. Turning on diffusion improves the resolution at small angles. The Lorenz angle shifts the distribution, while the Landau distribution degrades the resolution, particularly at large angles.

3 Results

We have calculated the resolution as a function of crossing angle for:

- strip pitches of 50,60,70,80,90,100μm;
- with and without intermediary strips;
- for signal-to-noise ratios of 10:1 and 13:1, which were chosen as worst case and average case scenarios, based on the likely cable lengths and chip parameterisation at our disposal as of 25.11.98.

Fig. 2 shows the resolution for a 50μm pitch detector with S:N of 13:1, with and without an intermediary strip. Four points are noteworthy:

- firstly, for angles $<\approx 7^o$, the intermediary strip plays an important role;
- secondly, for angles $>\approx 7^o$, the intermediary strip would degrade the resolution by 1 to 2μm;
- thirdly, the effect of the Lorenz angle is evident.
- fourthly, for angles greater than about 12^o, the resolution degrades rapidly.

Fig. 3 shows the same plot but repeats it for $50, 60, 70, 80\mu$m detectors as indicated. The behaviour in each case is similar. The angular range, over which an intermediary strip is useful, broadens as the pitch increases. In all cases, the resolution degrades rapidly for angles greater than 15^o.

Fig. 4 shows the same plots for $50, 60, 70, 80, 90, 100\mu$m pitch, with and without intermediary strips, but this time for a signal-to-noise of 10:1. It is noted that for small angles the degradation (with respect to S/N of 13:1) is small, about 1μm, but for larger angles it is much bigger, up to 5μm. This is a consequence of the fact that in spreading itself over more strips, the charge per strip begins to be obscured by the noise. If we are led to mechanical designs which require longer cable lengths, as now seems likely, then the noise will be worse than had been envisaged, and the resolutions at large angles will be particularly affected.

Fig. 5 summarises these plots for each pitch *with* and *without* an intermediary strip. We note an important point:

- Above about 15^o, the resolution is **insensitive** to the strip pitch, and furthermore, it is better **not** to use an intermediary strip here.

3.1 Resolutions for three geometries

With these plots, we can now calculate the response of any mechanical design in terms of the resolution we would expect. We have done this for three cases:

- Firstly, for an 8-fold detector with 50μm read-out pitch with an intermediary strip. This was the favoured design as of 25.11.98.
- Secondly, for a 12-fold detector with 70μm read-out pitch with an intermediary strip. This would be the naive basic design if we were to go to a 12-fold modularity, whether to gain resolution, reduce readout, or for triggering purposes.
- Thirdly, for a 12-fold detector with varying pitches. We have used our results to perform an optimisation for the best average resolution, subject to the constraint that 128 channels span 9432μm, the width of detector required for a 12-fold geometry with 10% overlaps. Our solution requires starting off with 90μm pitch-no-intermediary for the first 3 strips, changing to 80μm pitch-no-intermediary for the next 15, changing to 80μm pitch-with-intermediary for the next 25, changing to 70μm pitch-with-intermediary for the next 6, changing to 60μm pitch-with-intermediary for the next 5, and finally 50μm pitch-with-intermediary until the centre of the detector. The pattern is repeated on the other side.

Fig. 6 shows the result of these configurations. 8-fold modularity with 50μm pitch is clearly the worst. Although having the greatest number of tracks with 5μm resolution it has long tails. 15% of all tracks have resolutions greater than 15μm and 45% have resolutions greater than 10μm. This is due principally to the poor resolution at large crossing angles. 12-fold modularity with 70μm pitch is better. 5% of tracks have resolutions worse than 15μm and 38% of tracks have resolutions worse than 10μm. However, the best solution is obtained with our optimisation technique. Now less than 5% of tracks have resolutions worse than 10μm and in addition the response is more uniform over the detector.

3.2 Efficiencies

A further consideration is the efficiency for reconstucting clusters, especially important if Layer00 might be used in the trigger. For the 8-fold geometry, the efficiency is 99.5% assuming a signal-to-noise of 10:1.

We have also examined the efficiency for a worst-case-scenario of 7:1 corresponding to 3000 e.n.c. For the 8-fold geometry with 50μm pitch and an intermediary strip, the efficiency would deteriorate to 87%, while for our optimised 12-fold geometry described above, it would remain higher than 99%.

If it was necessary to run with a single strip threshold of 4 to 1, (rather than 3 to 1,) in order to suppress noise, then the efficiency for the 8-fold geometry deteriorates to 60%, while for the optimised 12-fold geometry, it would be 94%.

4 Conclusions

We have produced a simulation which allows us to calculate the resolution of detectors of different modularity and strip pitches. In addition, it lets us optimise the strip pitches for a given mechanical design.

A number of important points have been established.

- It is extremely beneficial to use an intermediary readout strip at small angles ($< 7^o$).
- It is better *not* to use an intermediary strip at larger angles, especially if we have poor signal-to-noise
- For large angles ($> 15^o$), the resolution is independent of readout pitch.
- For large angles ($> 15^o$), the resolution is poor ($> 10\mu$m). For this reason, unless there are overwhelming mechanical reasons, we would advise against an 8-fold geometry. This is especially true if the detector is to be used in the trigger.

At the present time, the best design would appear to be of 12-fold modularity with a variable readout pitch from 50μm in the centre to 90μm at the edges. This also ties in well with the number of readout chips, the cable lengths, and the triggering modularity of SVX.

References

[1] H. Bichsel, "Inelastic electronic collision cross sections for Monte Carlo calculations." *Nucl. Inst. and Meth.* **B**52 (1990) 136.

[2] Belau et al., "Charge Collection in Silicon Strip Detectors" *Nucl. Inst. and Meth.* 214 (1983) 253.

[3] V. Chabaud, "The DELPHI Silicon Strip Microvertex Detector with Double Sided Readout" CERN-PPE/95-86.

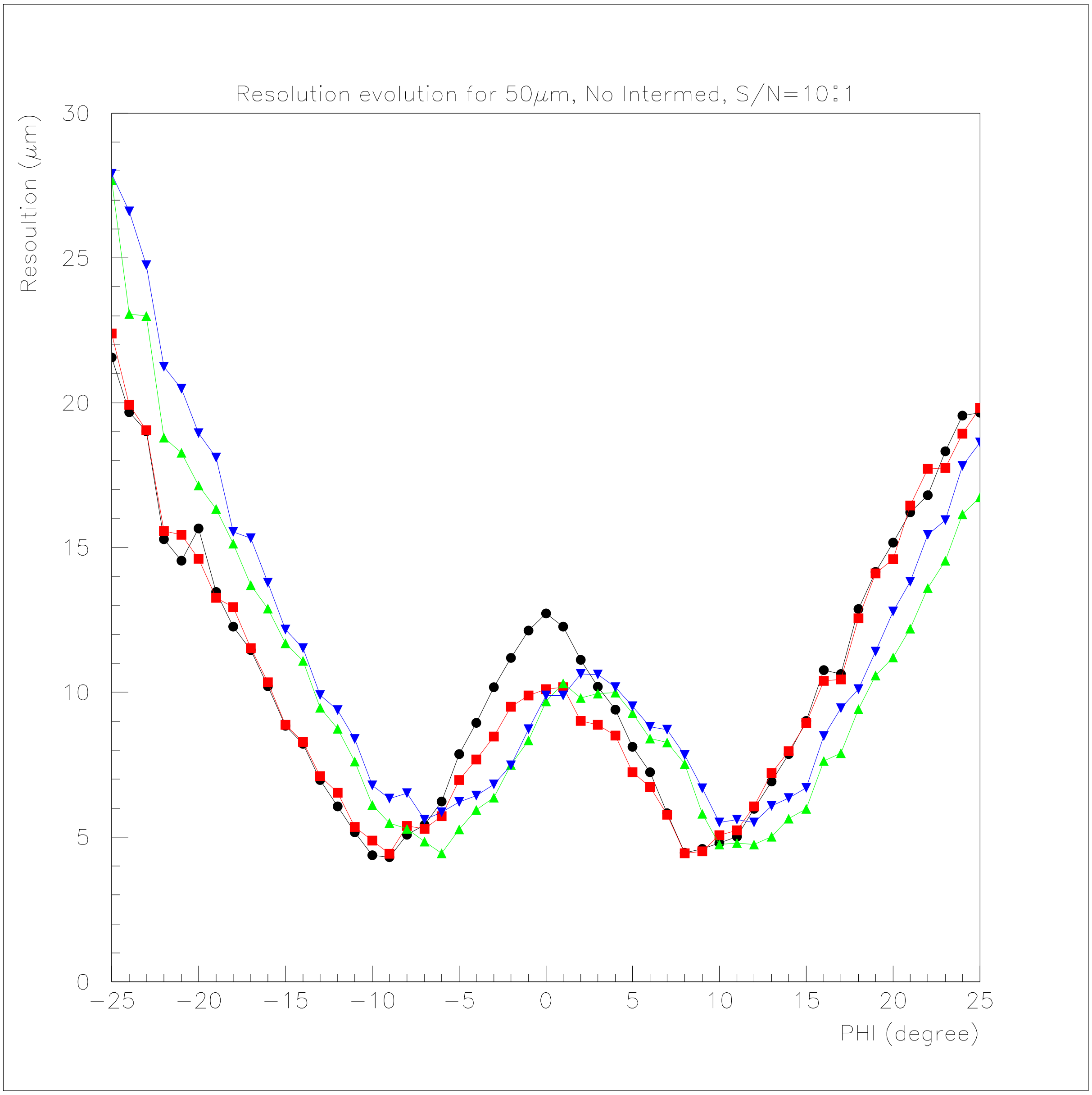

Figure 1: The resolution as a function of crossing angles for 50μm pitch detectors with signal-to-noise of 10:1. The reconstuction algorithm used is the simple $R/(L+R)$ throughout the angular range.
Circles are with no diffusion, no Lorenz angle, and no Landau.
Squares are with diffusion, no Lorenz angle, and no Landau.
Triangles are with diffusion, Lorenz angle, and no Landau.
Inverted triangles are with diffusion, Lorenz angle, and Landau.

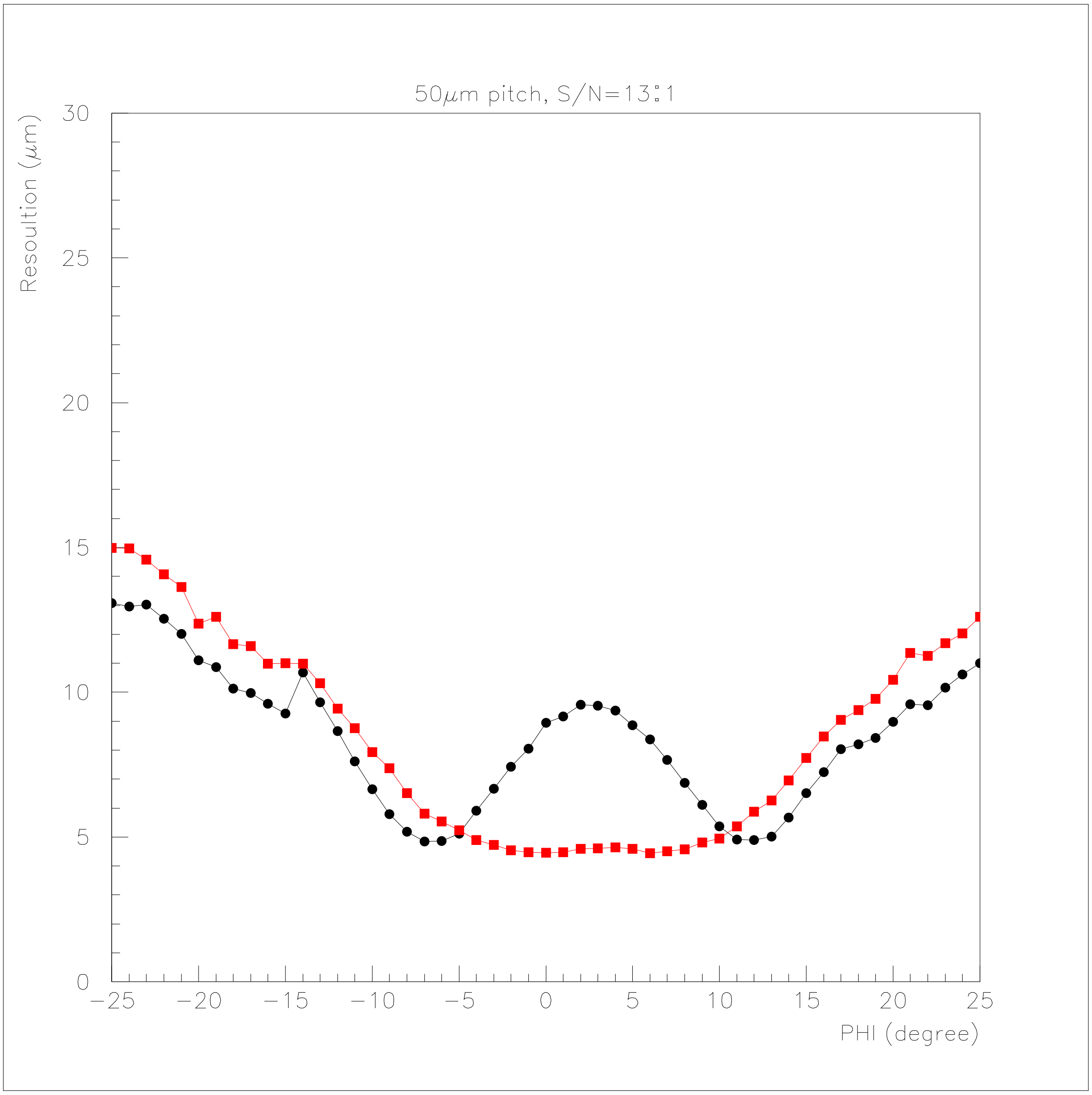

Figure 2: The resolution as a function of crossing angles for 50μm pitch detectors with signal-to-noise of 13:1.
The circles are **without** an intermediary strip.
The squares are **with** an intermediary strip.

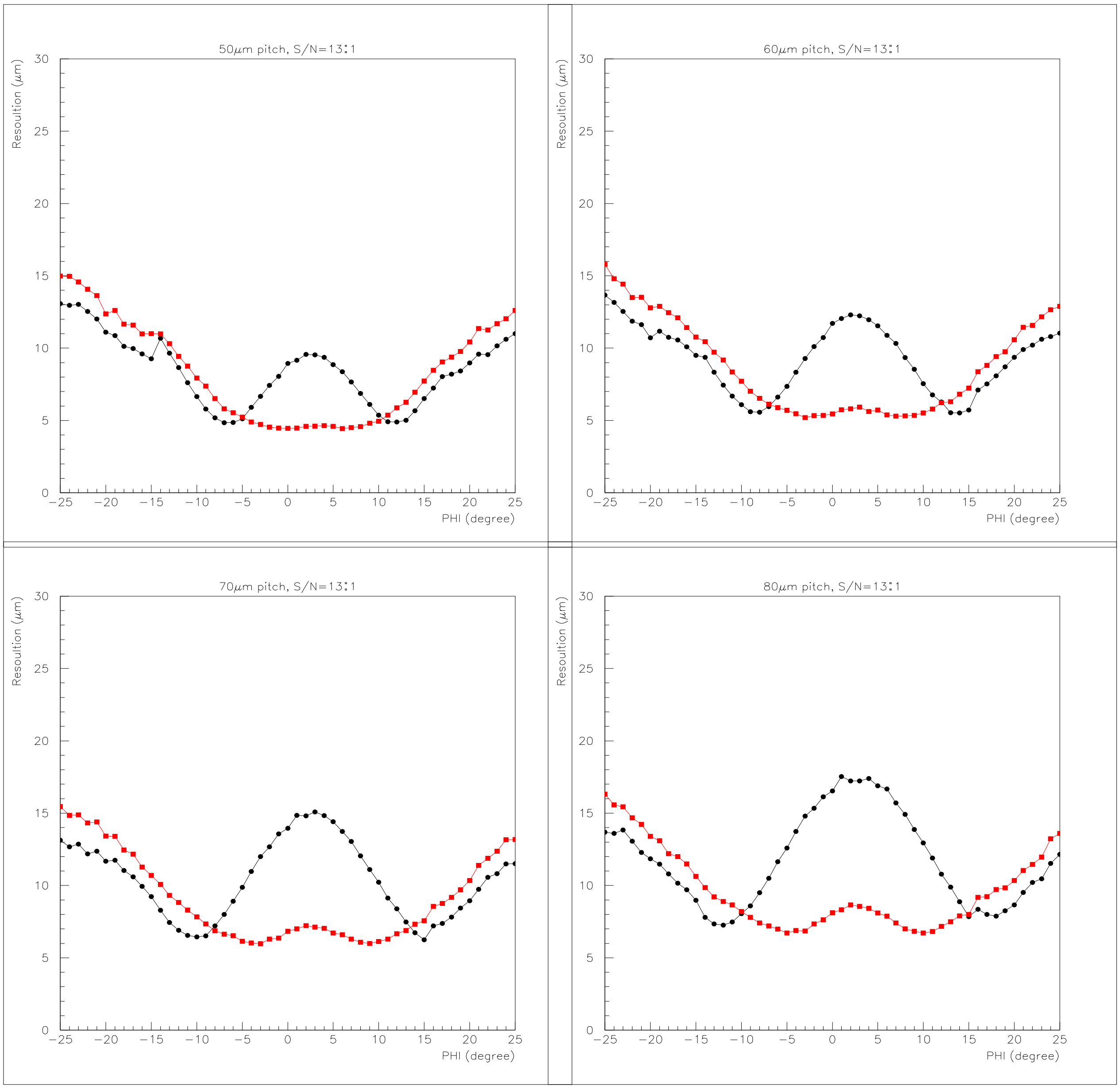

Figure 3: The resolution as a function of crossing angles for pitches as indicated for detectors with signal-to-noise of 13:1.

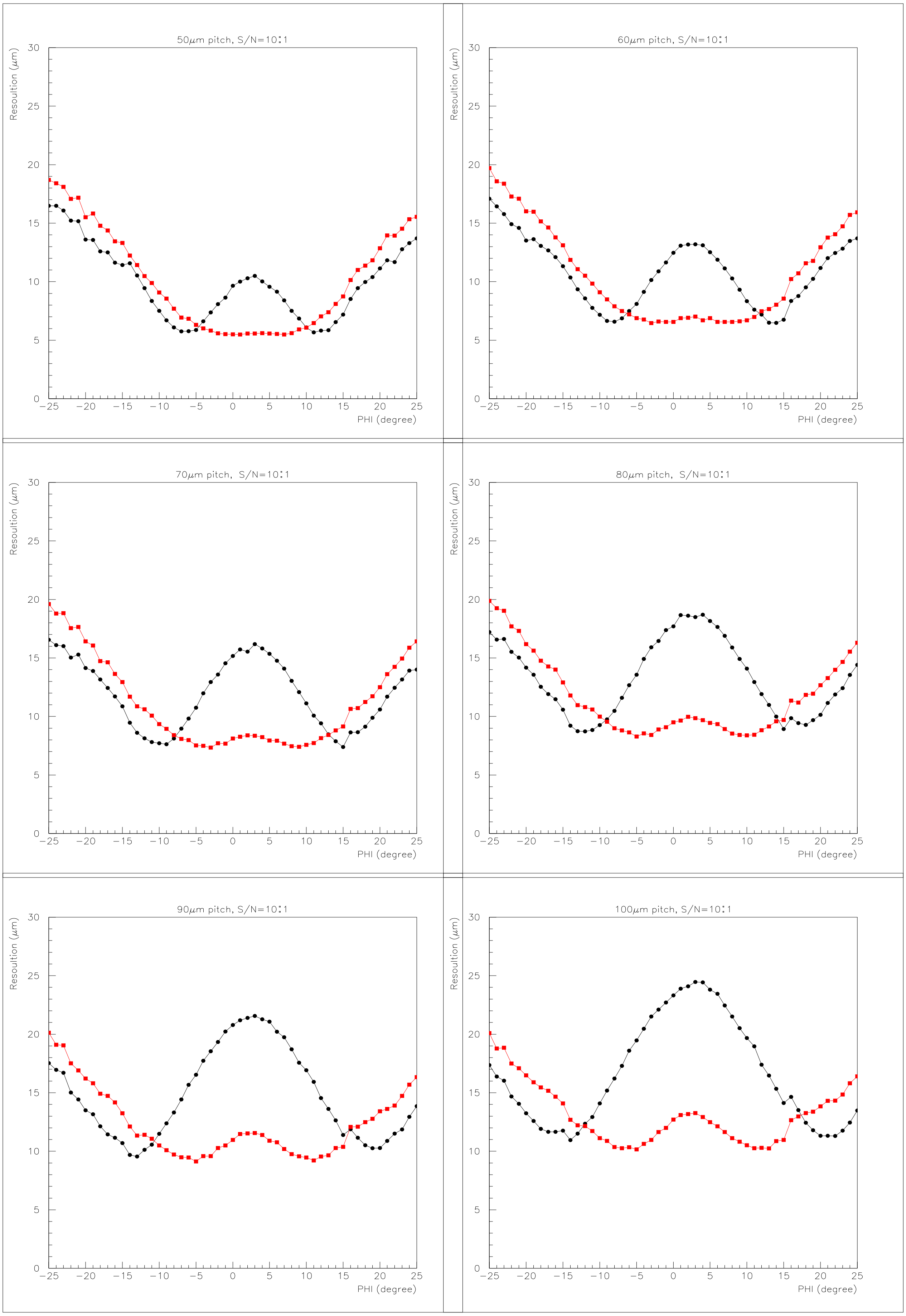

Figure 4: The resolution as a function of crossing angles for pitches as indicated for detectors with signal-to-noise of 10:1.

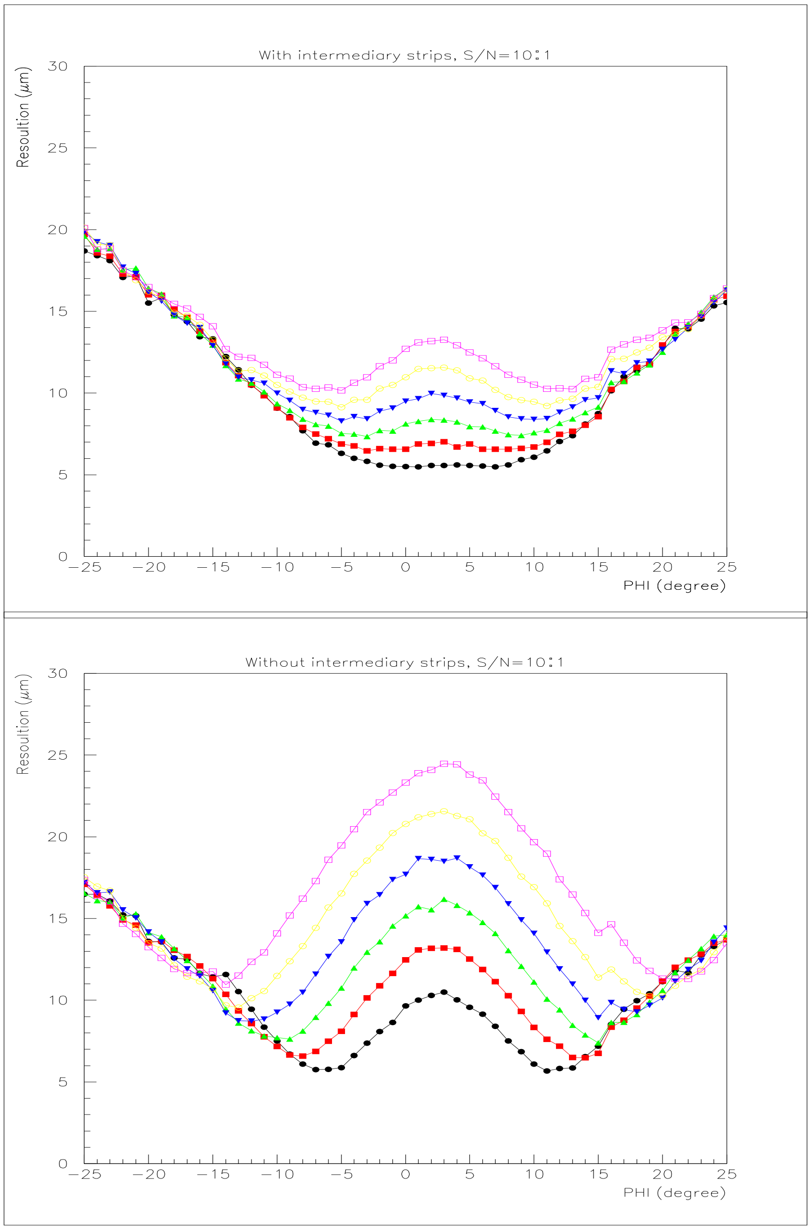

Figure 5: The resolution as a function of crossing angles, with and without intermediary strips for detectors with signal-to-noise of 10:1.
Closed Circles are for 50μm pitch.
Closed Squares are for 60μm pitch.
Triangles are for 70μm pitch.
Inverted triangles are for 80μm pitch.
Open Circles are for 90μm pitch.
Open Squares are for 100μm pitch.

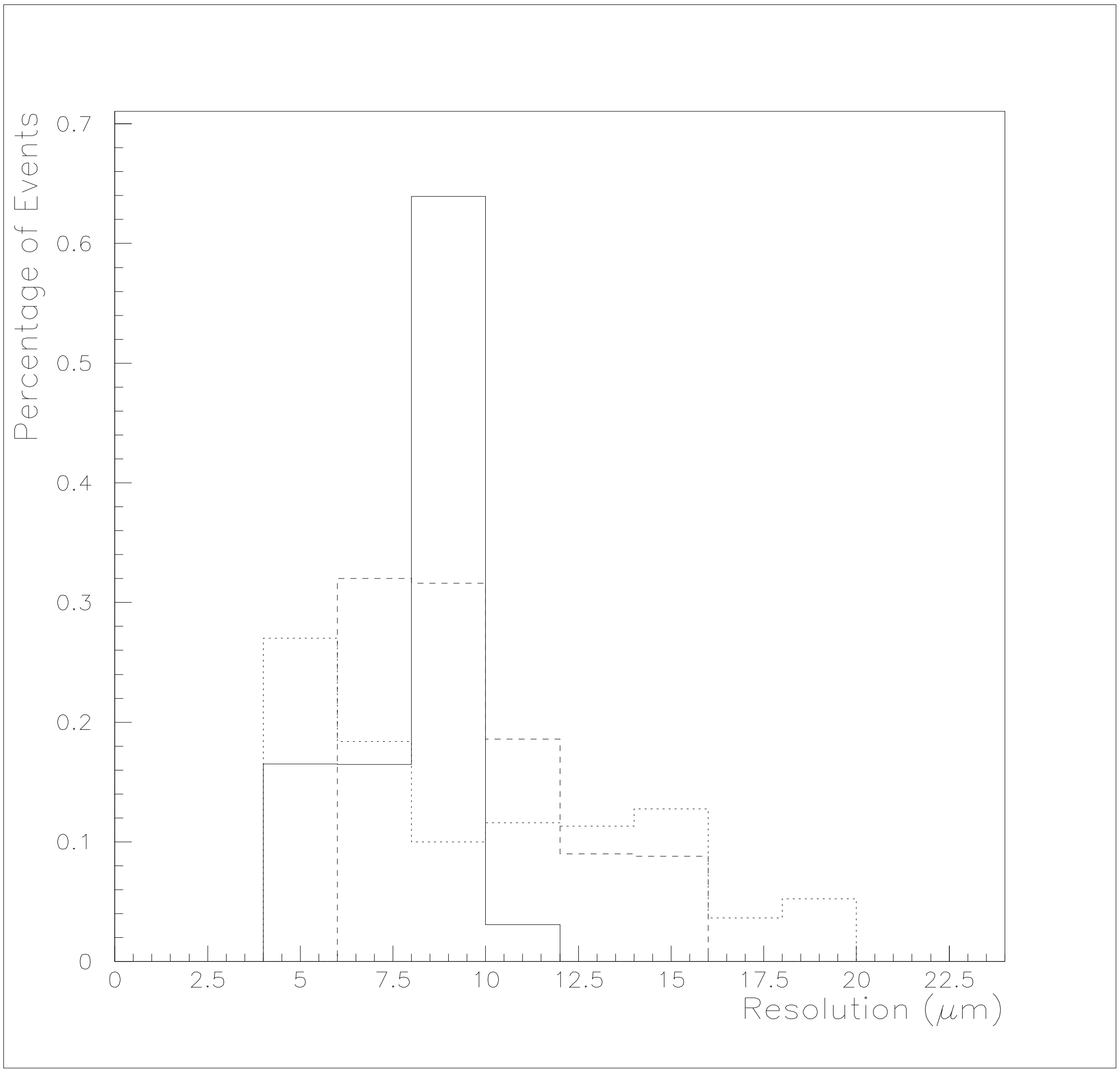

Figure 6: Fraction of tracks at a given resolution.
The dotted line is for 8-fold 50μm pitch.
The dashed line is for 12-fold 70μm pitch.
The solid line is for a 12-fold detector with the optimisation described in the text.