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Oct 22, 1999

Acceptance considerations for outer tracker straw tubes

1 Introduction

In this note we present the results of geometrical acceptance studies for a double layer of LHCb outer tracker straws. The results are obtained by simulating the hit response to tracks traversing the double layer. The goal of these simulations is to determine the geometrical acceptance for tracks causing resp. zero, one or two hits in the detector.

2 Geometry

The simplified geometry used in the program is shown in fig 1. The geometry is described by three parameters:

- *pitch:* the wire-to-wire spacing of cells inside a single layer
- *rcell:* the cell radius
- *dist:* the distance between the adjacent wire planes

Together the *pitch* and *rcell* parameters define the size of the *dead-space* between two neighboring cells, according to the simple formula:

$$rdead = pitch - (2 \times rcell)$$

In this study we vary the value of each of these parameters in order to study the effect on the track detection efficiency.

Figure 1 shows an example of a number of tracks passing through the detection layer. Each track can either cause: 0, 1 or 2 hits. To quantify the track detection efficiency, the percentage of zero, single and double hits will be presented for each choice of the geometry parameters.

To a good approximation tracks passing through a detection layer in LHCb will be straight lines (with the exception of very low momentum tracks - these are not considered here). The track detection efficiency will furthermore depend on the track *angle*. The distribution of track angles depends mainly on the location of the particular detection layer in the LHCb setup.

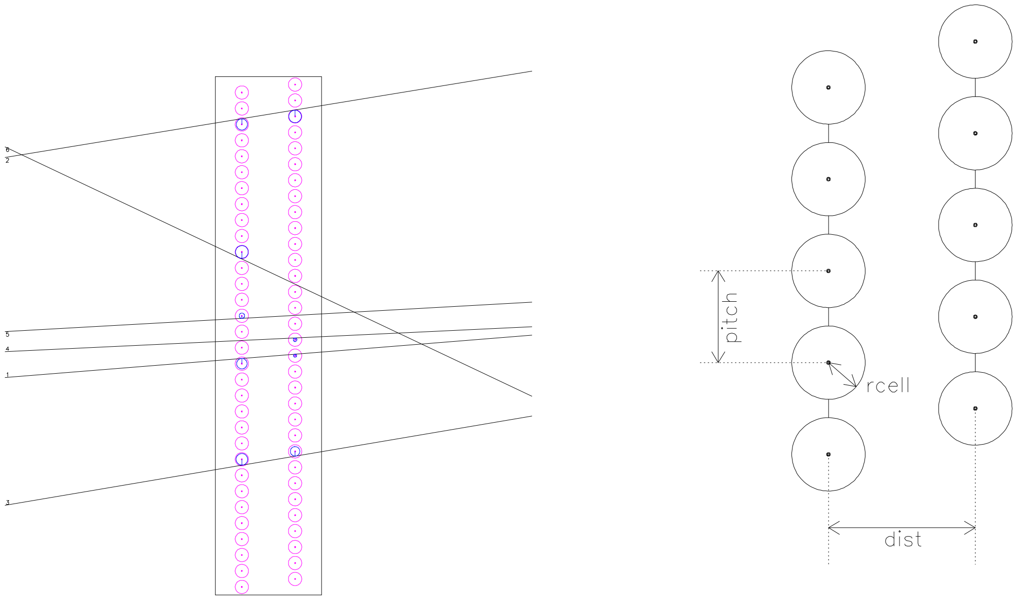

Figure 1: A number of tracks traversing a double detection layer. On the right the simplified geometry of the layer model.

Typically, a chamber positioned near the beam line observes high momentum tracks travelling at small angles, while chambers positioned close to the edge of the fiducial volume will observe lower momentum tracks travelling under relatively large angles.

In these simulations we generate track angles according to a Gaussian distribution. The spread of this distribution is parametrized by the sigma of this Gaussian, denoted as σ in the plots.

Unless specified otherwise, the following geometry is chosen to be a default one in this simulation: rcell = 0.25 cm, pitch 0.6 cm, dist=2.0 cm.

3 Track angle systematics

As an example of how tracks under different angles are effected differently, consider the plots in fig 2.

The plot shows the number of cases where two hits, one hit and zero hits are detected as a function of the angle of the track. The sum of these three distributions is an overall Gaussian distribution, corresponding to the "beam profile" of generated tracks. In this case the beam profile has a width of $\sigma = 0.3$ rad.

In the following we will define three numbers, extracted from plots of this type:

- ε_2 : the total fraction of tracks causing 2 hits
- ε_1 : the total fraction of tracks causing 1 hit

- ε_0 : the total fraction of tracks causing 0 hit

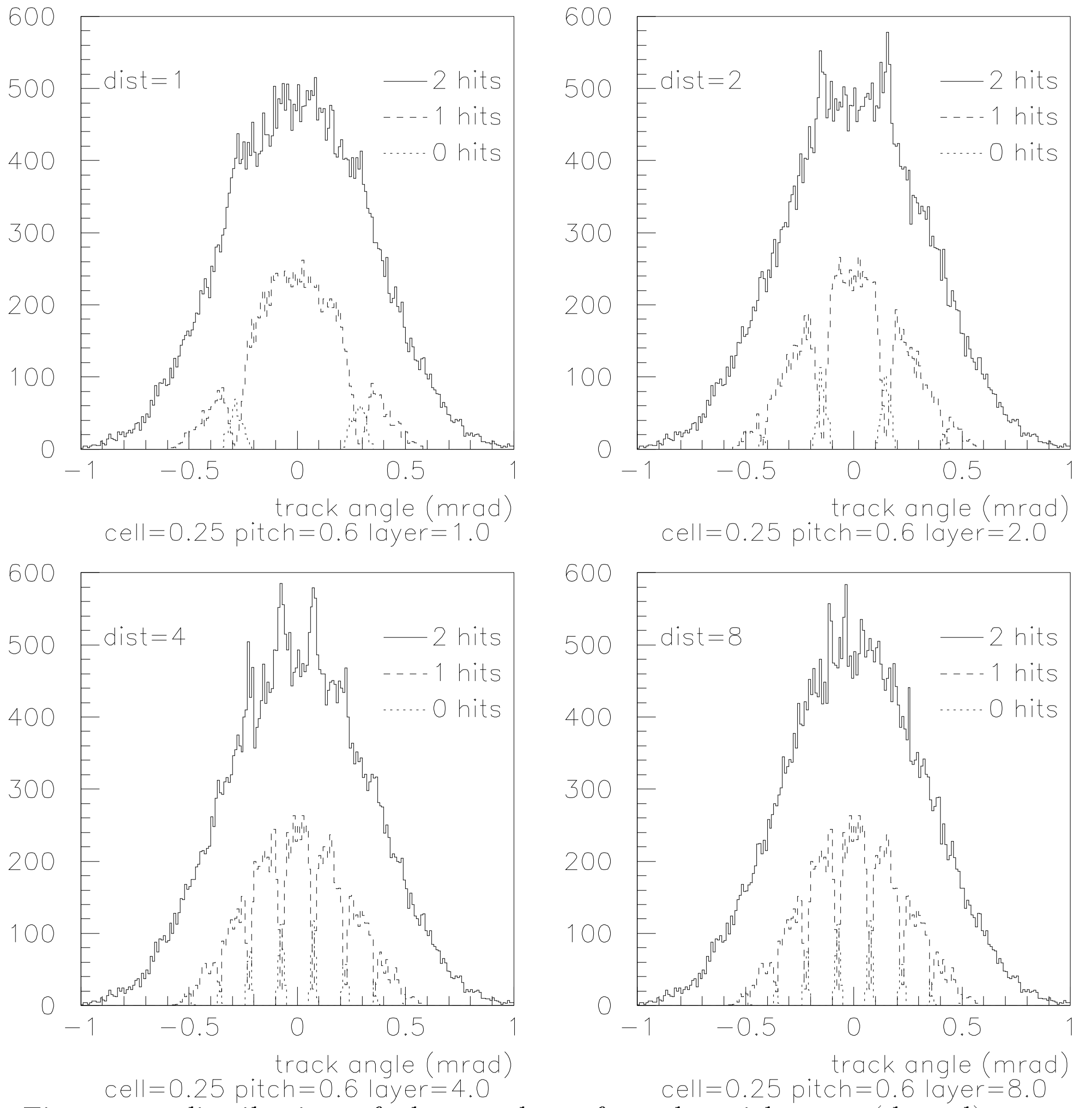

Figure 2: distribution of the number of tracks with zero (dotted), one (dashed) and two (full line) hits versus the track angle.

4 Pitch, cell size and layer spacing

We proceed to calculate the numbers ε_0, ε_1 and ε_2 for varying pitch and cell size. In fig 3 these numbers are plotted as function of the pitch distance. Clearly for pitch sizes close to $2\times$ rcell (i.e. $2\times 0.25 = 0.5$, or no dead space), the efficiency for full detection (2 hits) is almost 100%, the efficiency for one or no hits is almost zero. However, the ε_1 and ε_2 rise stronly when the dead space increases. The plots show, that requiring less that 1% inefficiency requires pitches of certainly less than 0.57 cm. This is only an upper limit, as the study assumes a 100% detection efficiency up to the complete edge of the cell.

To estimate the sensitivity of the "edge-effects" in the cell, we have varied the "radius-of-efficiency" of the straw-tubes. The plots in fig 4 show the same efficiency numbers as before, in this case for a varying "cell-efficiency" radius from 0.20 cm to a full efficient 0.25 cm. The plot shows that e.g. a reduction of the cell efficiency radius from 0.25 cm to 0.23 cm, gives an increase of zero-hit fraction of approximately 2% to 4%.

The sensitivity to the layer distance is studied in fig 5. The plots show that the "staggering" effect of the layers is only effective if the distance between the layers is less than approximately two centimeters. (The exact number depends on the assumed beam angle distribution.) For distances larger than 3 cm the efficiencies do not depend critically on the layer separation.

5 Acceptance effects due to track angles

The above results are obtained from a sample of incident tracks traversing the detection plane under various angles. The event-to-event distribution of these angles will depend on the position of the particular tracking layer under study.

In this section we present the efficiency results as we vary the track-angle distribution to realistic cases valid for the LHCb experiment. The sample of tracks is generated according to a Gaussian distribution characterised by an *average* and a *sigma*.

Fig 5 shows the acceptances for a detector setup with a *pitch*=0.6cm, *rcell*=0.25 cm and *dist*=2.0cm. The jump in efficiency close σ=0.1 shows where staggering of the monolayers becomes effective.

Fig 5 shows the acceptances for two fixed widths of angle distributions, but varying the average angle under which these tracks are generated. There is no strong dependency observed here.

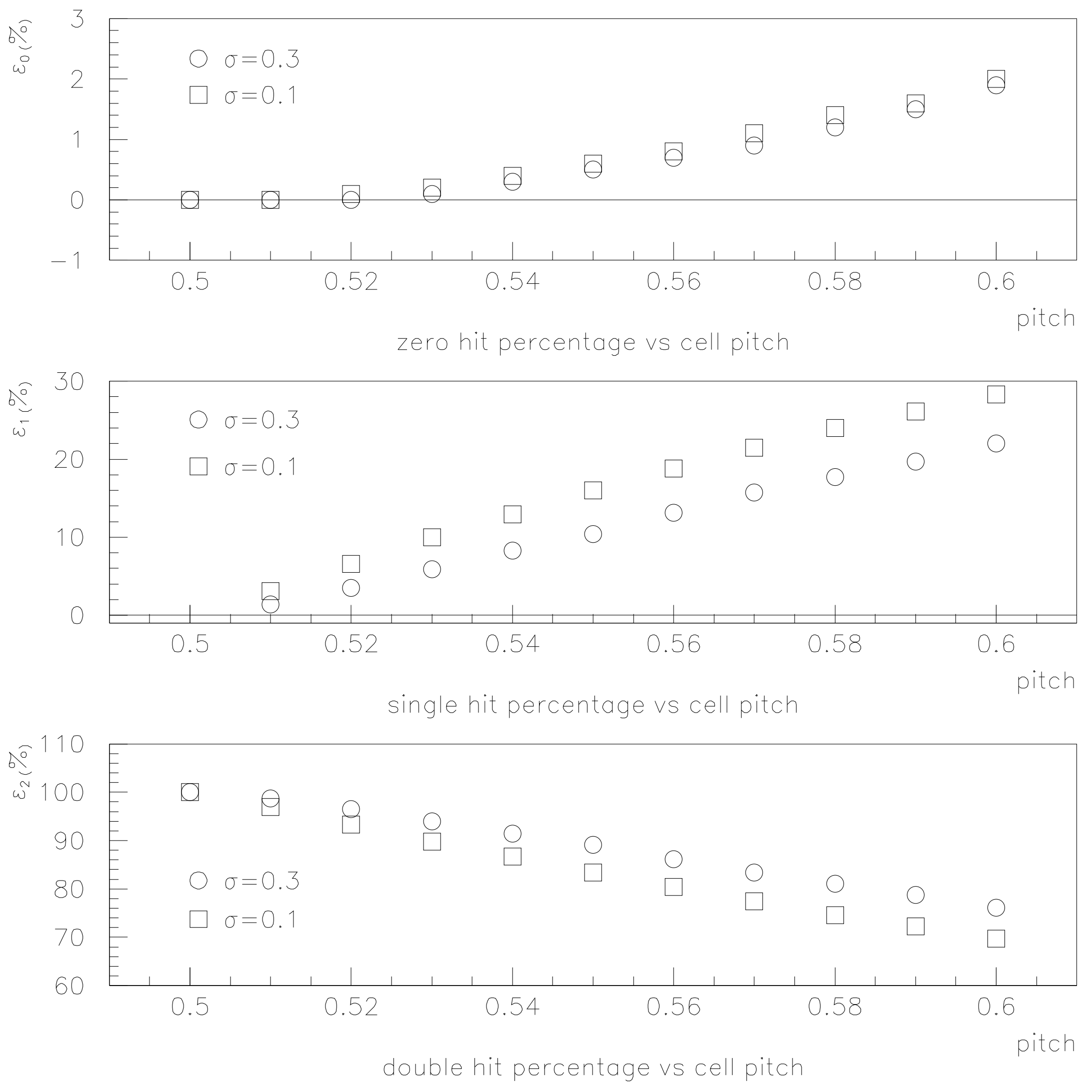

Figure 3: Hit efficiencies as function of the pitch for cell radius = 0.25 cm, layer distance = 2.0 cm. The circles assume a track angle distribution with σ=0.3 rad, the squares σ=0.1 rad

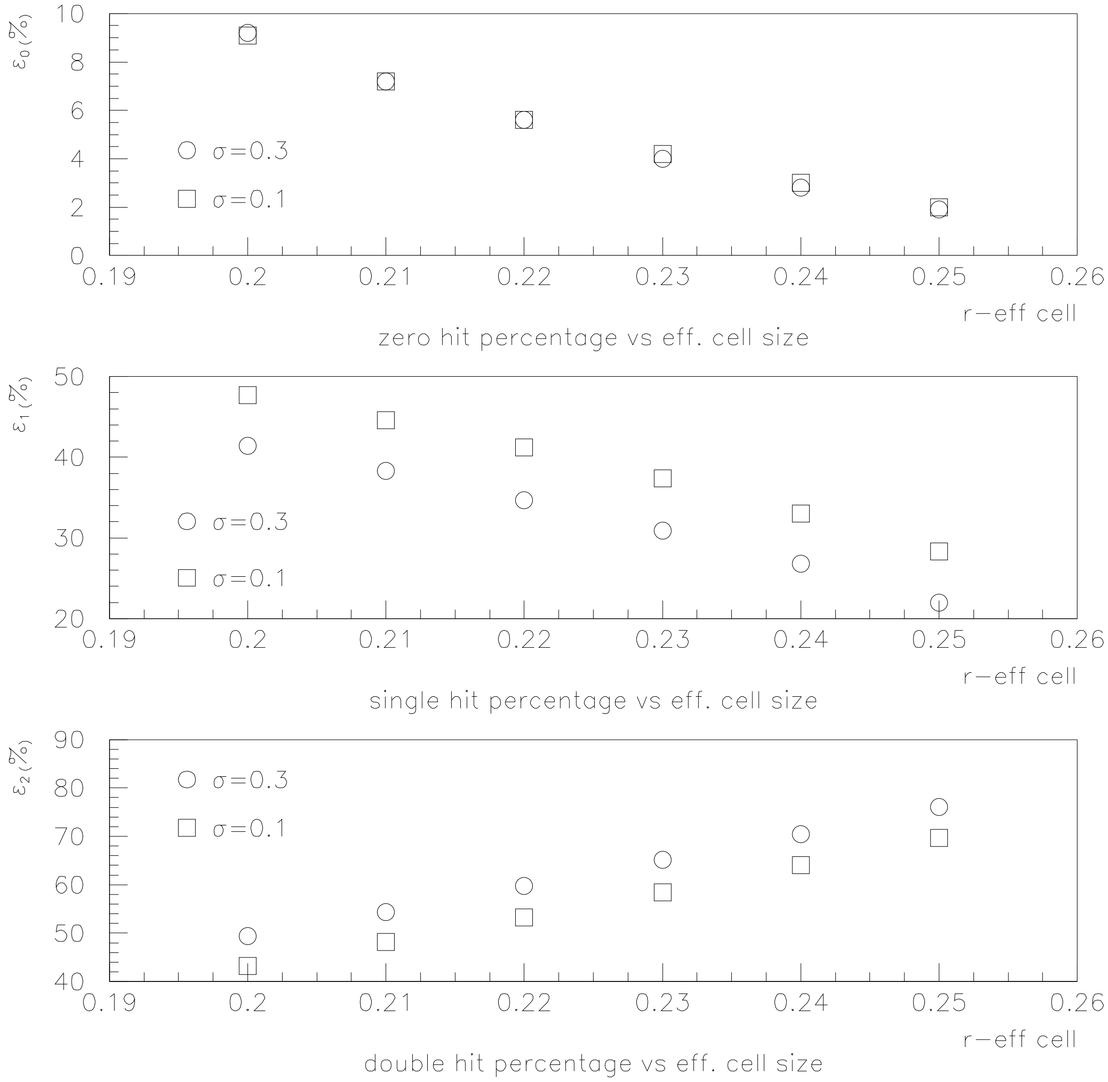

Figure 4: Hit efficiencies as function of the efficiency radius of a straw cell, for pitch = 0.60 cm, layer distance = 2.0 cm. The circles assume a track angle distribution with σ=0.3 rad, the squares σ=0.1 rad

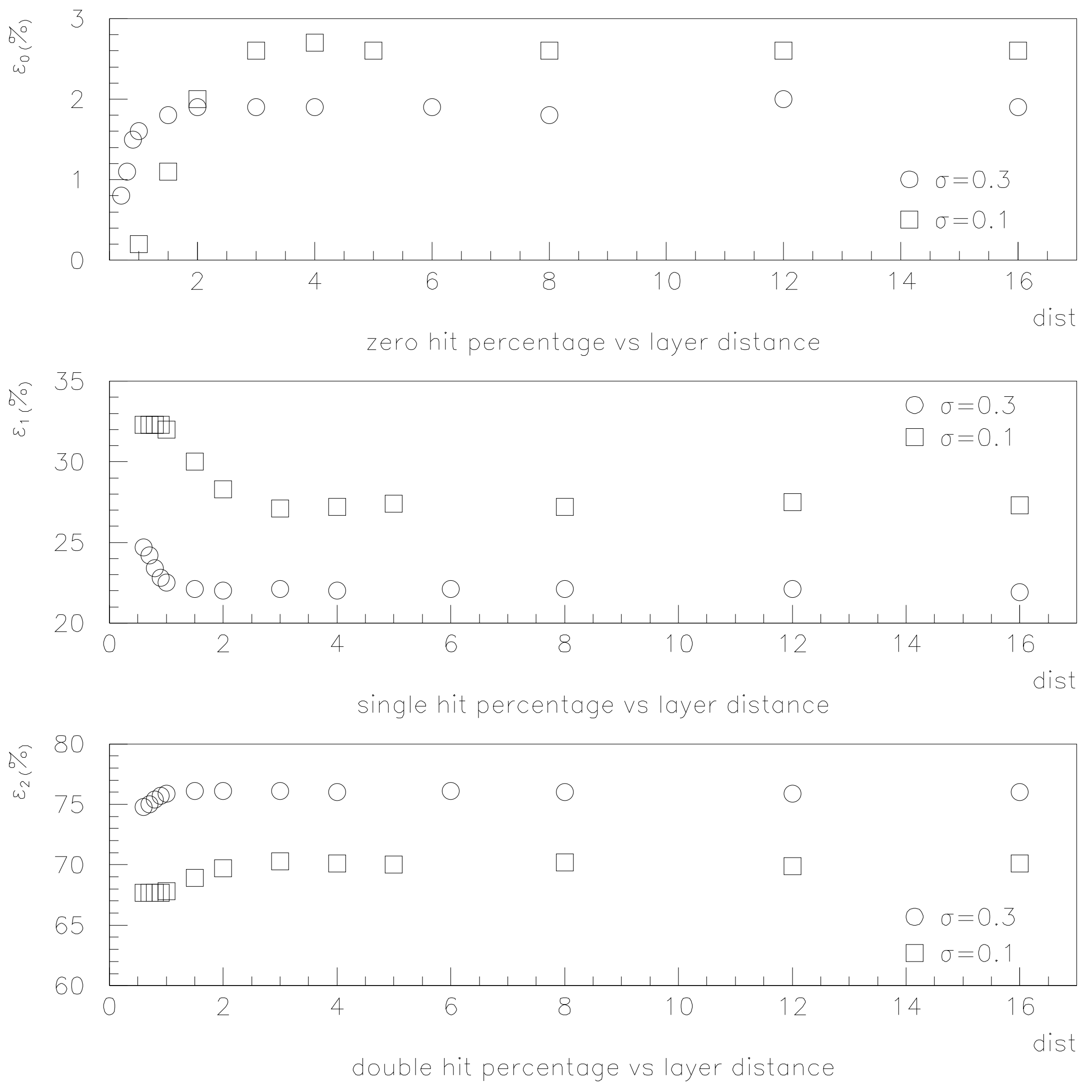

Figure 5: Hit efficiencies as function of the layer spacing, for a pitch of 0.60 cm and a cell efficiency radius of 0.25 cm. The circles assume a track angle distribution with σ=0.3 rad, the squares σ=0.1 rad

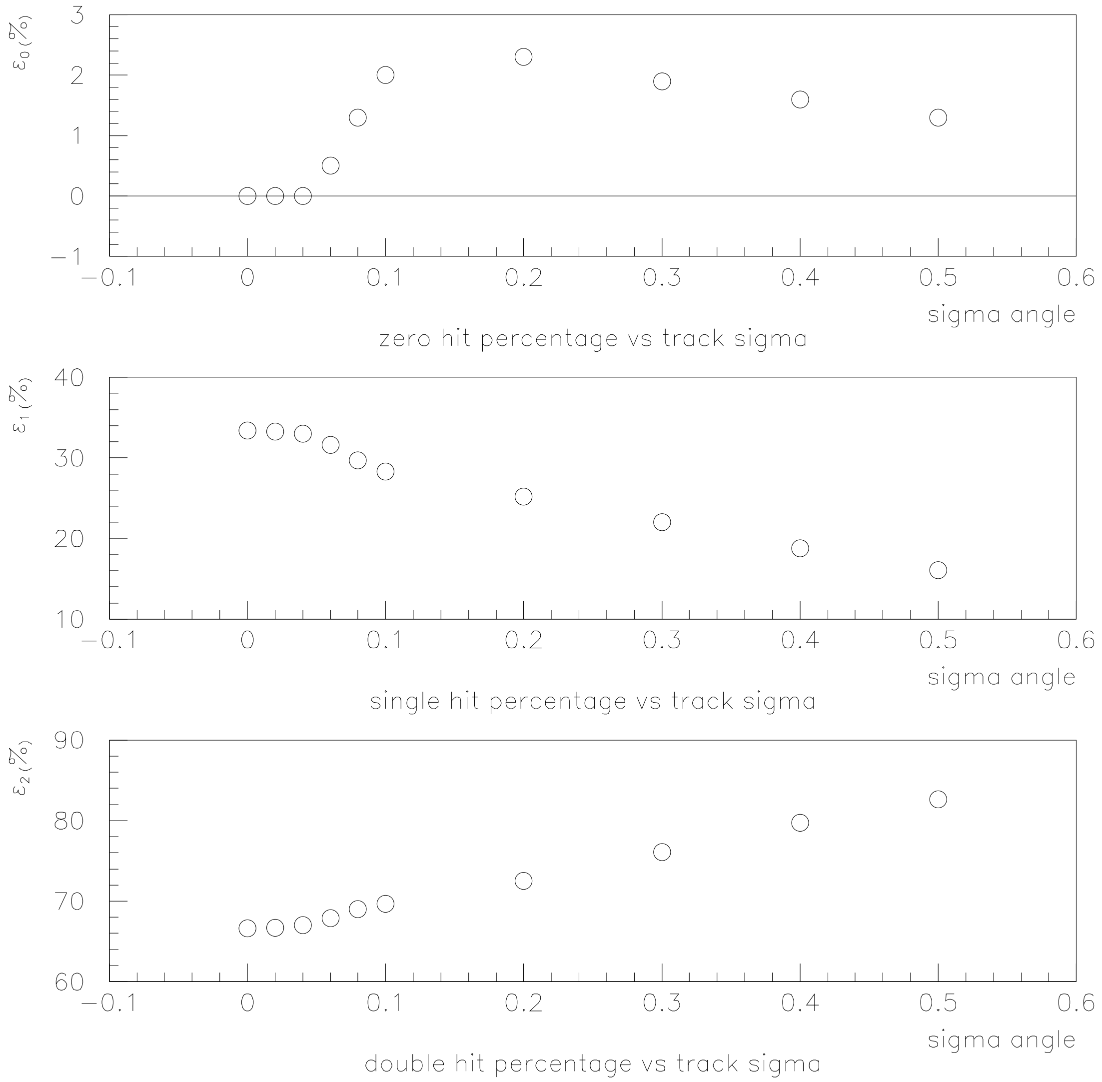

Figure 6: Hit efficiencies as function of the incident particle trajectory angles (see text). The average angle is 0 degrees (perpendicular). Plotted are the efficiencies vs. the rms of the angle distribution. The cell radius=0.25 cm, the pitch = 0.60 cm, the layer distance=2.0cm

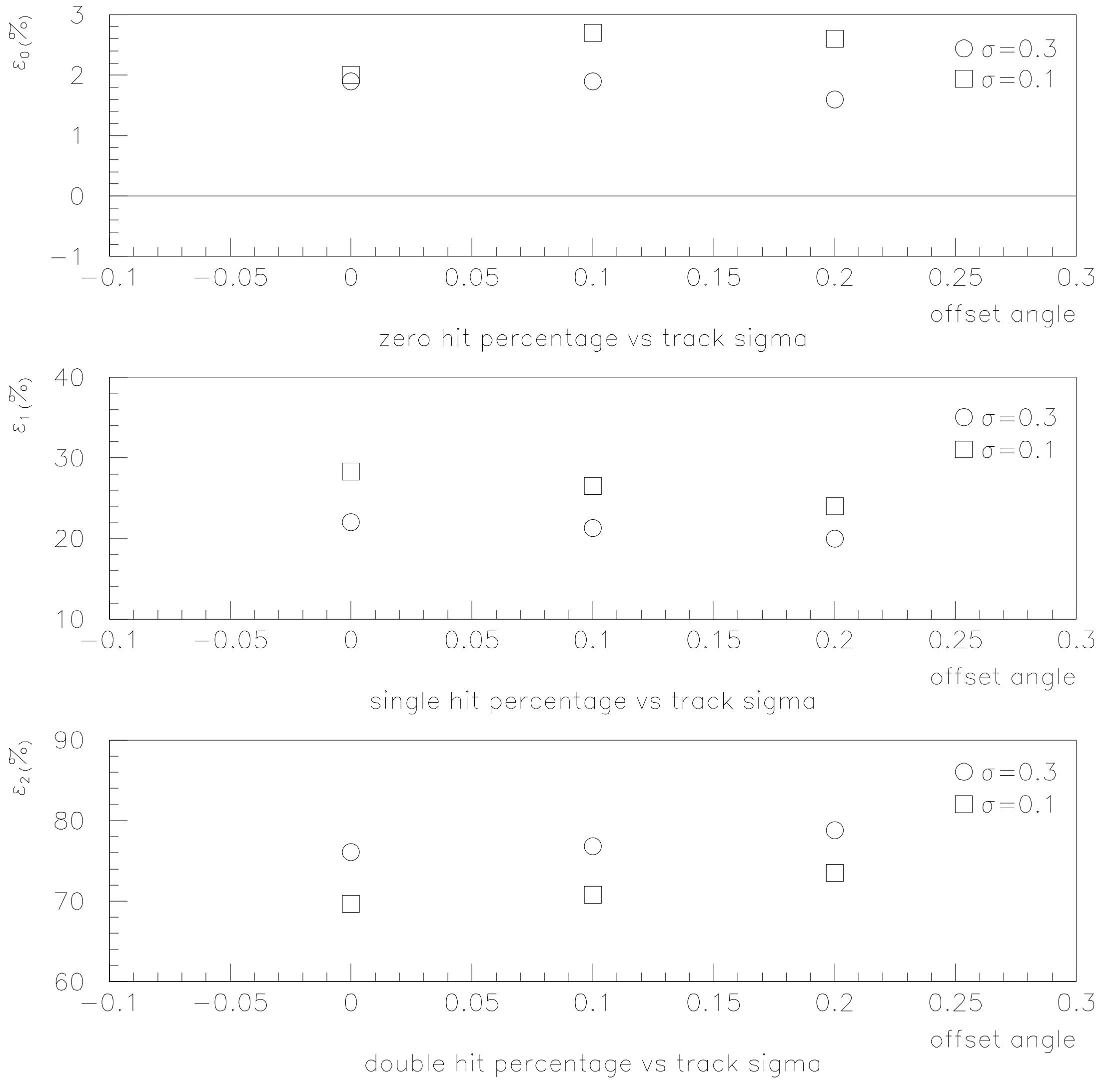

Figure 7: Hit efficiencies as function of the incident particle trajectory angles (see text). The rms of the distribution is 0.3 rad (circles) or 0.1 rad (squares). Plotted are the efficiencies vs. the average angle of the distribution. The cell radius=0.25 cm, the pitch = 0.60 cm, the layer distance=2.0cm

6 Conclusions

In this note the geometric efficiency for detecting two (ε_2), one (ε_1) or zero (ε_0) hits in a double layer is studied, for a wide variety of passing tracks. The exact numbers depend on the distribution of track angles, however some general conclusions can be drawn:

- the size of the dead area between two adjacent cells in a layer must be kept to a minimum, i.e. as close to zero as possible. The loss of efficiency will be strongly worsened if the efficient cell radius is less then the mechanical radius.
- if the layer spacing can be made smaller than one cm, a gain in ε_0 can be made. For spacings larger than two cm the effect is rather marginal.

Clearly the observations presented here are only based on geometrical acceptances. There are other arguments for different layouts, motivated e.g. by geometrical stability of the design, electronic behaviour, or from requirements of drift time relations in adjacent layers. These need to be taken into account in separate studies.