A first look at occupancies in Layer 00

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1 Introduction

This note describes a quick simulation of the Layer 00 detector and likely occupancy levels in the presence of $t\bar{t}$, minimum bias, and pile-up events.

2 Generator and Layer 00 simulation

The PYTHIA generator has been used for this study using standard defaults. $p\bar{p}$ beams were input at a centre of mass energy of 1.8 TeV with default production and decays selected for minimum bias events, and $t\bar{t}$ production selected to study the response in top events. All results described below are for 1000 events, where the event is either minimum bias, $t\bar{t}$, or a superposition of $t\bar{t}$ with 2 or 5 minimum bias events.

All charged tracks were extrapolated outwards from their production point assuming a magnetic field of 1.4 T. The tracks were only extrapolated to their further point on the first spiral of the helix: thus only the first loop of tracks which spiral through the detector was considered. Additionally, no photon conversions or scattering in the beam pipe were considered.

The Layer 00 detector was simulated assuming it described an octagon in the transverse plane. The largest circle which could fit inside this octagon had a radius of 1.6 cm, and the mid-points of the plaquettes were tangential to this circle. Therefore, each plaquette had a length in the transverse plane of 1.325 cm, giving a total active length for the detector of 10.60 cm. The modules were simulated to be 0.03 cm (300μm) thick. The strip pitch was taken to be .005 cm (50μm), giving 265 readout channels per plaquette and 2120 for the whole detector. The detector was assumed to be infinitely long in the z direction.

When a track passed through the Layer 00 detector, it was assumed that charge could be observed on the readout strips on either side of the track. Taking the crossing angle into account, the track could therefore 'hit' between 2 and 5 or more strips. No attempt has been made to implement thresholds based on likely noise levels. It was assumed that if the track passed beside a readout strip, it gave a 'hit' on that strip.

3 Results

3.1 Basic parameters

The total number of charged tracks for single $t\bar{t}$ events and minimum bias events is shown in Fig. 1a. For $t\bar{t}$ a mean of 103 tracks was obtained while for minimum bias events, only 57 tracks were produced on average. Very low momentum tracks or those which were produced from the decay of a long-lived neutral do not cross Layer 00. Fig. 1b shows the number of charged tracks which would cross the Layer 00 detector. For $t\bar{t}$ events a mean of 94 tracks is seen, while for minimum bias events a mean of 51 tracks, The p_T distribution of those tracks which cross Layer 00 is shown in Fig.1c. As expected, the $t\bar{t}$ events have a much harder spectrum. The distance of closest approach at Layer 00 of each track to its nearest neighbour is shown in Fig.1d. Already from this plot, we can make an estimate of the likely double-occupancy in $t\bar{t}$ events. 19700 tracks have neighbours within two strip pitches (100μm). The total number of tracks passing the detector is 103000: 1000 (the number of events generated) times 103 (the average number of events). Thus we obtain 19.1% as a rough estimate for the double-occupancy in $t\bar{t}$ events. We return to a more accurate determination in section 3.3.

3.2 Crossing Angles

It might be expected that the 8-fold geometry gives unacceptably large crossing angles. With the simulation strategy described in section 2, a track which crosses the plaquette at 90^o would be said to distribute its charge over 2 strips (those on either side of it.) With larger crossing angles and low momenta, this number can increase. Tracks which distribute their charge over large numbers of strips are problematic for three reasons: firstly, the S/N for these tracks is worse; secondly, there is a greater likelihood of overlapping clusters; thirdly, the total readout time will be increased.

Fig. 2a shows the number of tracks per event which distribute themselves over 2,3,4 and 5 or more strips for $t\bar{t}$ events. Expressed as percentages, on average 21% of the tracks occupy 2 strips, 42% occupy 3 strips, 32% occupy 4 strips and 5% occupy 5 or more.

Fig. 2b shows a similar distribution for minimum bias events. The percentage of tracks crossing 2,3,4 and 5 or more strips is the same as for $t\bar{t}$ events, though of course the total number of tracks is smaller.

3.3 Double Occupancy

Ideally, each strip should only be hit once per event. Fig. 3a shows the number of strips which were hit once, twice, and three or more times in an event for $t\bar{t}$ events. Fig. 3b shows the same quantities for minimum bias events. Due to the smaller number of tracks in minimum bias events, fewer strips are hit by more than one track.

As we are most interested in the double (and even triple) occupancy cases, Fig. 4a shows the number of strips/event which have a double occupancy for $t\bar{t}$ events. On average, 23 strips have double occupancy (where we recall that 103 tracks on average have crossed the detector.) Expressed as a percentage of all strips which have been hit (Fig. 4b), this corresponds to 8% of all signal strips having been hit by two tracks. Fig. 4c shows the same plot for triple-occupancy strips while Fig. 4d shows that typically 0.7% of all signal strips have been hit by three tracks.

Fig. 5 shows similar plot to Fig. 4, but now for $t\bar{t}$ events superimposed on 2 minimum bias events. The double and triple occupancy rates, as a percentage of all strips, are typically 12 % and 1.4 % respectively.

Finally, Fig. 6 shows similar plots for $t\bar{t}$ events superimposed on 5 minimum bias events, a worst case scenario which the Run2 TDR describes as a 'hypothetical but not unreasonable situation'. Now the double and triple occupancy rates, as a percentage of all strips, are typically 19% and 3.2% respectively.

To evaluate the effect that strip occupancies have on tracks, the assumption is made that if two track clusters overlap, then both tracks are mis-measured. This is a conservative approach as 'clever' deconvolution algorithms could possibly improve the situation. With this hypothesis, Fig. 7a shows the total number of tracks which would be mis-measured due to overlapping clusters in $t\bar{t}$ events, $t\bar{t}$ with 2 minimum bias events, and $t\bar{t}$ with 5 minimum bias events. The average numbers of mis-measured tracks are 19, 62 and 167 respectively.

Fig. 7b shows the number of mis-measured tracks as a percentage of the total number of tracks inside the Layer 00 acceptance. For $t\bar{t}$ events, an average of 20% of tracks are mis-measured; for $t\bar{t}$ with 2 minimum bias events, an average of 32% are mis-measured; while for $t\bar{t}$ with 5 minimum bias events, an average of 49% are mis-measured.

4 Discussion

To summarise the situation, Fig. 8 shows the relationship between the number of tracks in the event and the percentage of strips with double or triple occupancy. As expected, increasing the number of tracks in an event increases the hit occupancy. The **slope** of this plot is determined by the design parameters of the Layer 00 detector. For example, a much smaller slope could be obtained by thinning the detector to be 50μm wide and decreasing the strip pitch to 10μm.

Fig. 9 shows the relationship between the percentage of strips with double or triple occupancy and the percentage of mis-measured tracks. The linear increase is even more obvious in this case and the slope is not very dependent on the design parameters (I believe simple statistics of the 'k balls in n boxes' can predict this slope.) Therefore, all that can be done to reduce the number of mis-measured tracks, is to try and work as far down the plot as possible. In other words, the proportion of double or triple occupancy strips must be minimised.

Unfortunately, the naive idea of simply reducing the strip pitch will not give much reduction in the hit occupancy rate, since already at 50μm pitch, the tracks, on average, produce signals on 3 strips. Decreasing the pitch would simply increase the number of strips which see signals. Possible solutions could involve thinning the detectors or changing from an 8-fold geometry so as to minimise the crossing angles.

5 Conclusions

This study provides a starting point for an optimisation of the design of Layer 00. It is easy to vary certain simple parameters and observe the effect on crossing angle and occupancy rates. Possible variations might include:

- changing the readout pitch;
- changing the modularity from 8-fold;
- changing the z segmentation (at the moment considered infinite);
- changing the detector thickness.

More complex alterations which may become necessary include:

- introducing realistic signal to noise ratios, especially for large-angle tracks;
- implementing 'clever' algorithms which could attempt to separate joined clusters (which would reduce the effective double-occupancy);
- redoing this study with ISAJET rather than PYTHIA;
- Including the effects of scattering and conversions.

My first impressions are that we are going to have sizable double and triple occupancies at the level of 15% of all strips hit, or at the level of a potential mis-measurement in about 30% of all tracks.

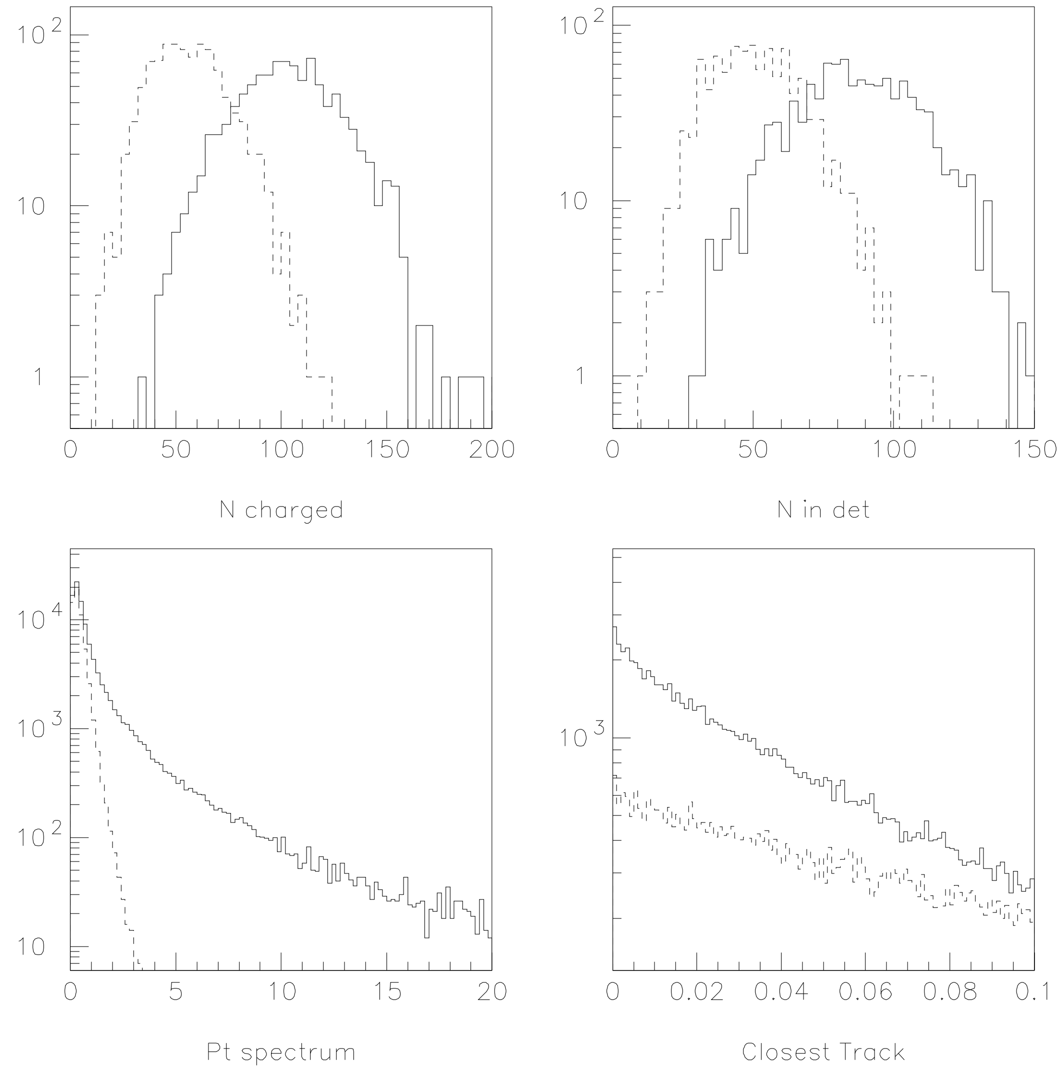

Figure 1: a) Top Left: Distribution of Number of Tracks in $t\bar{t}$ (solid) and minimum bias (dashed) events.
b) Top Right: Distribution of Number of Tracks crossing Layer 00 per event for $t\bar{t}$ (solid) and minimum bias (dashed).
c) Bottom Left: Momentum Spectrum for $t\bar{t}$ (solid) and minimum bias (dashed) events.
d) Bottom Right: Distribution for each track of the distance to the closest neighbouring track for $t\bar{t}$ (solid) and minimum bias (dashed) events.

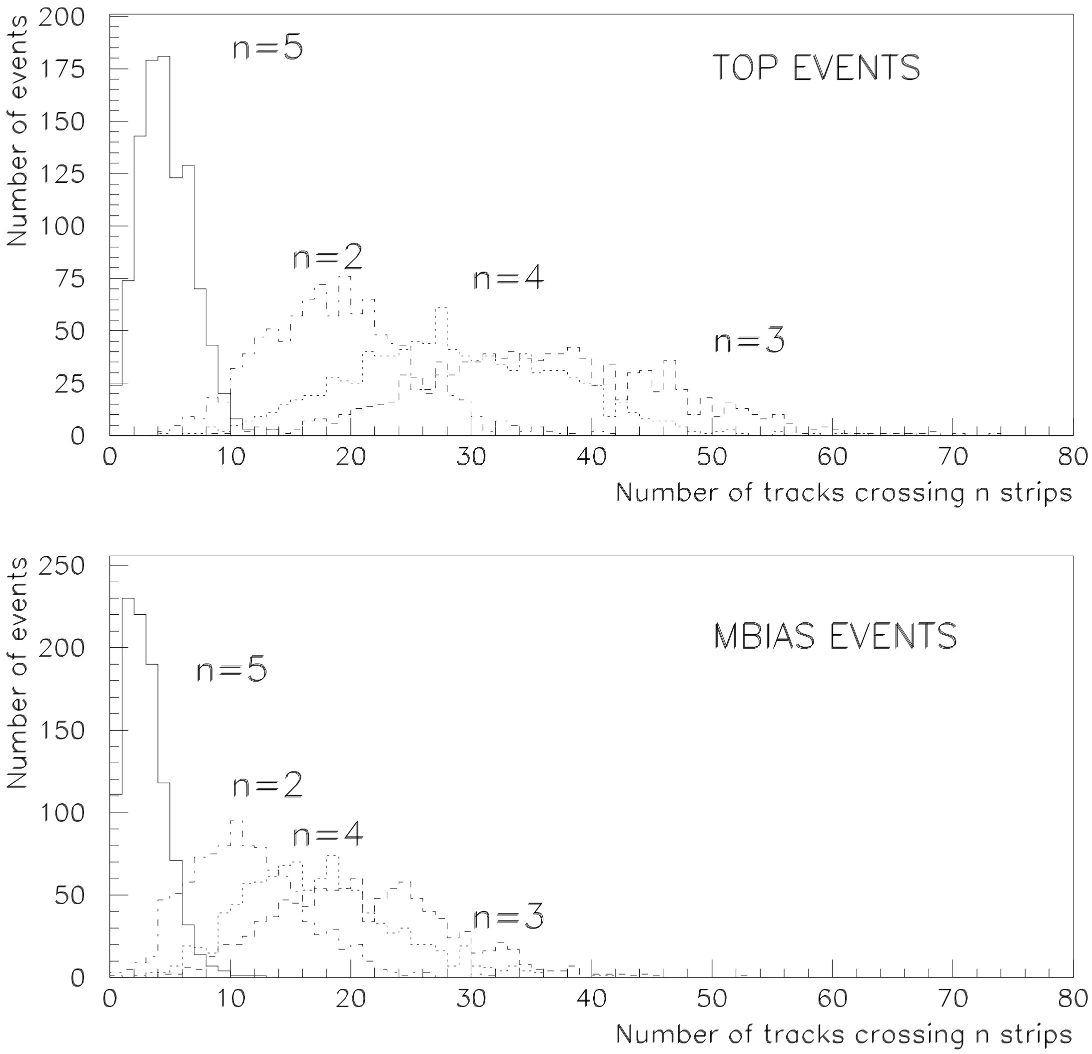

Figure 2: Distribution of Number of Tracks which, on account of their angle, deposit charge on 2,3,4 or >= 5 readout strips for:
a) (Upper Plot) $t\bar{t}$ events; b) (Lower Plot) minimum bias events.

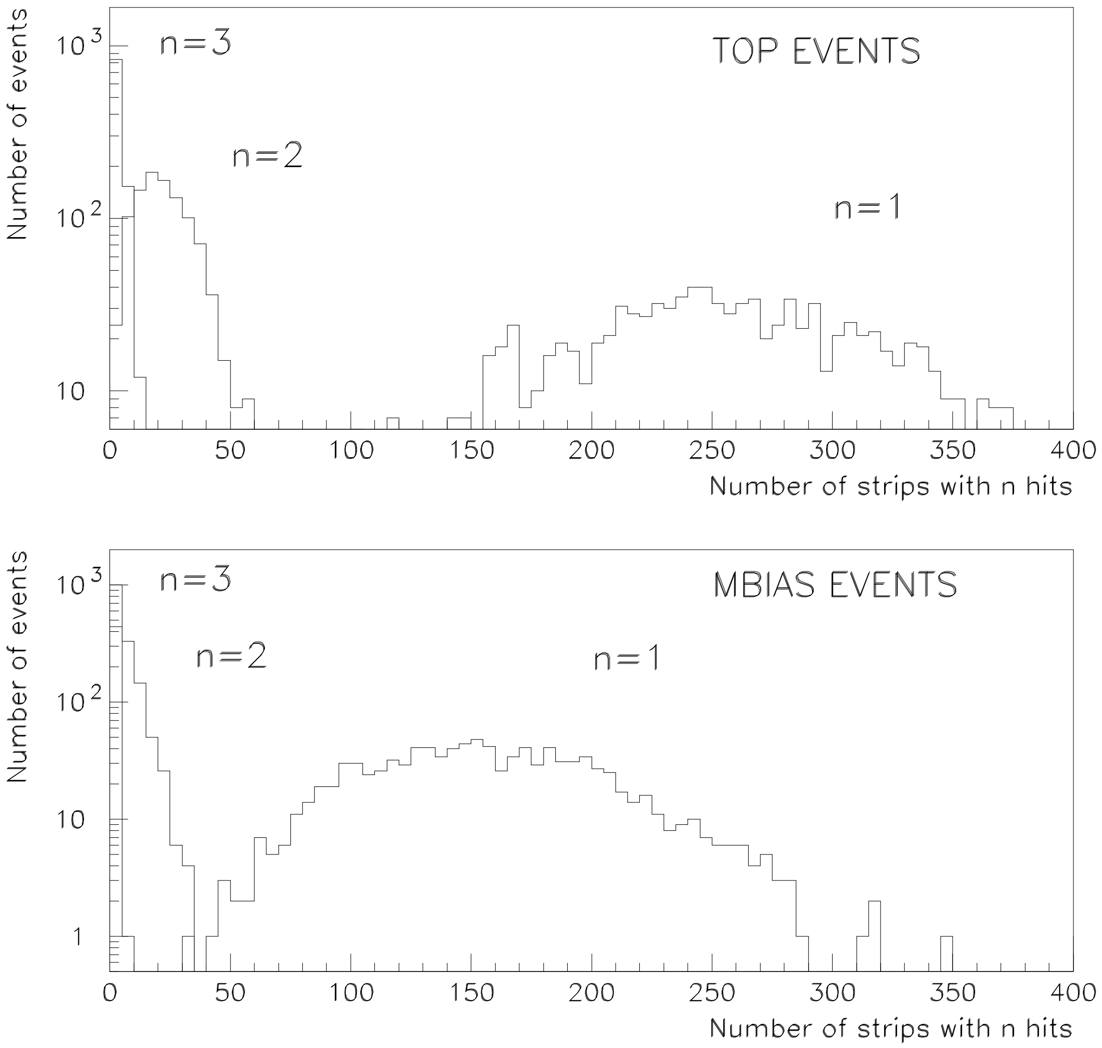

Figure 3: Distribution of Number of Readout Strips which have been hit by 1,2 or 3 tracks for a) (Upper Plot) $t\bar{t}$ events; b) (Lower Plot) minimum bias events.

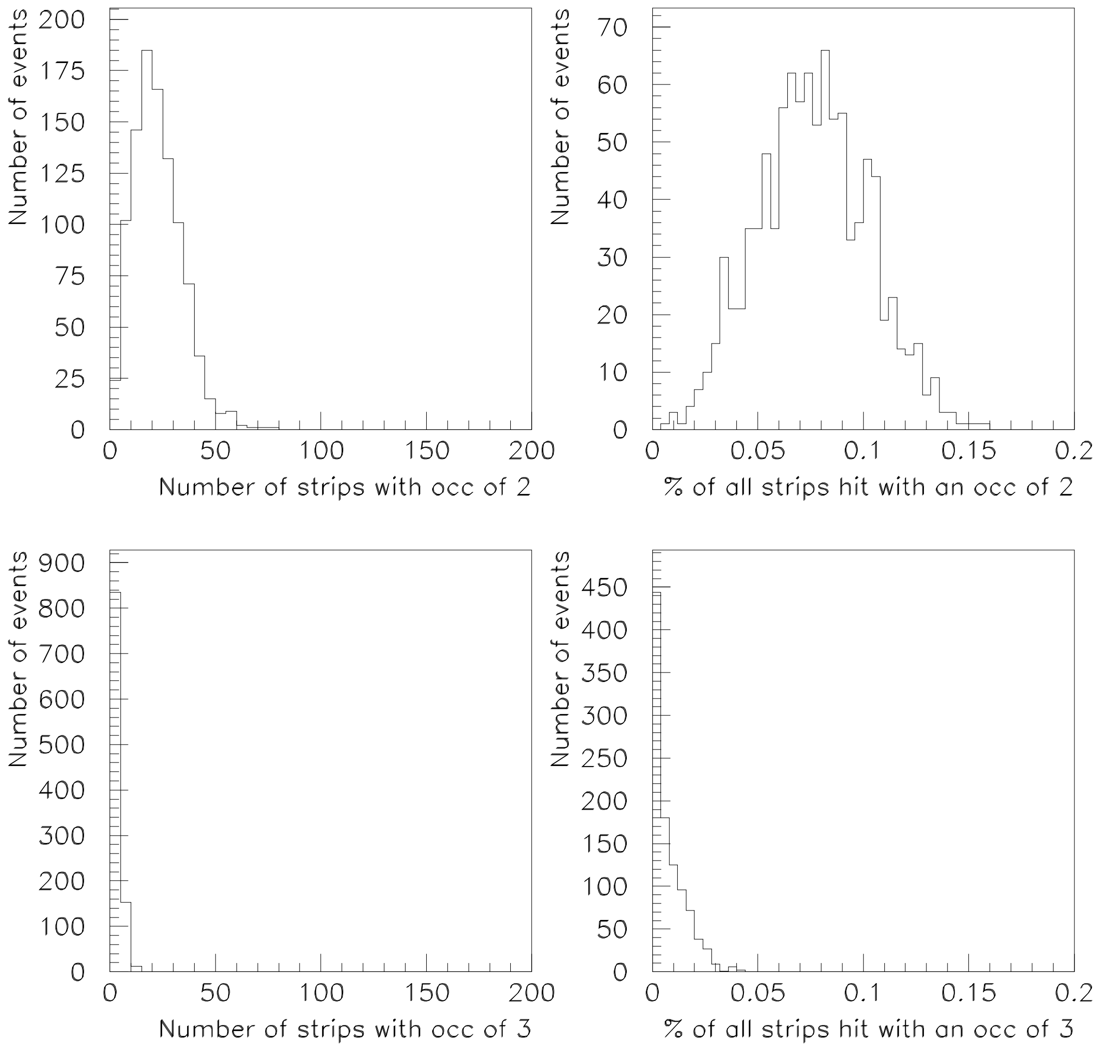

Figure 4: a) Top Left: Number of Readout Strips which have been hit by 2 tracks (double occupancy) in $t\bar{t}$ events.
b) Top Right: Number of double occupancy readout strips as a percentage of the total number of strips hit in an event, for $t\bar{t}$ events.
c) Bottom Left: Number of Readout Strips which have been hit by 3 tracks (triple occupancy) in $t\bar{t}$ events.
d) Bottom Right: Number of triple occupancy readout strips as a percentage of the total number of strips hit in an event, for $t\bar{t}$ events.

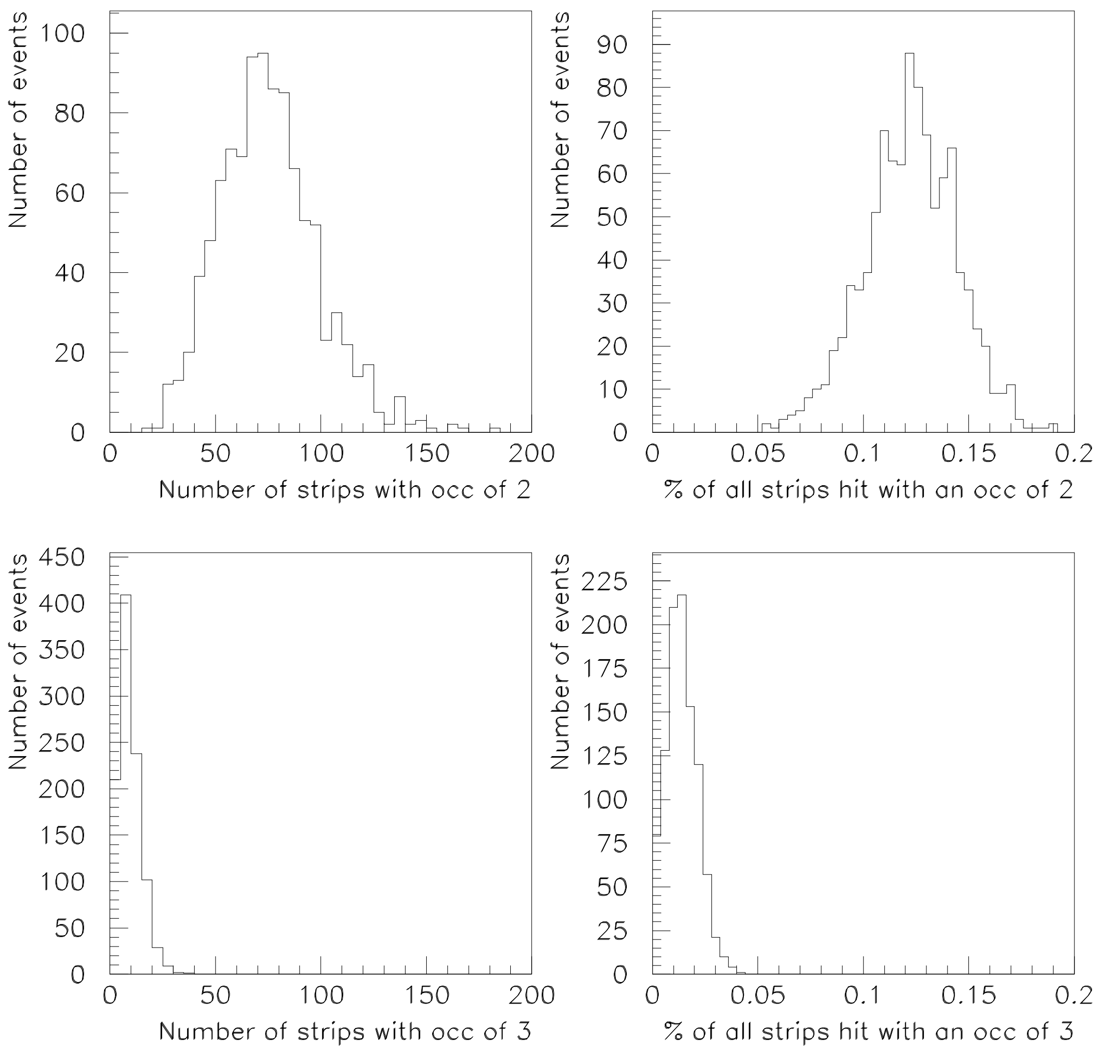

Figure 5: Same scheme as for Fig. 4 but now with two minimum bias interaction superimposed on the $t\bar{t}$ interaction.

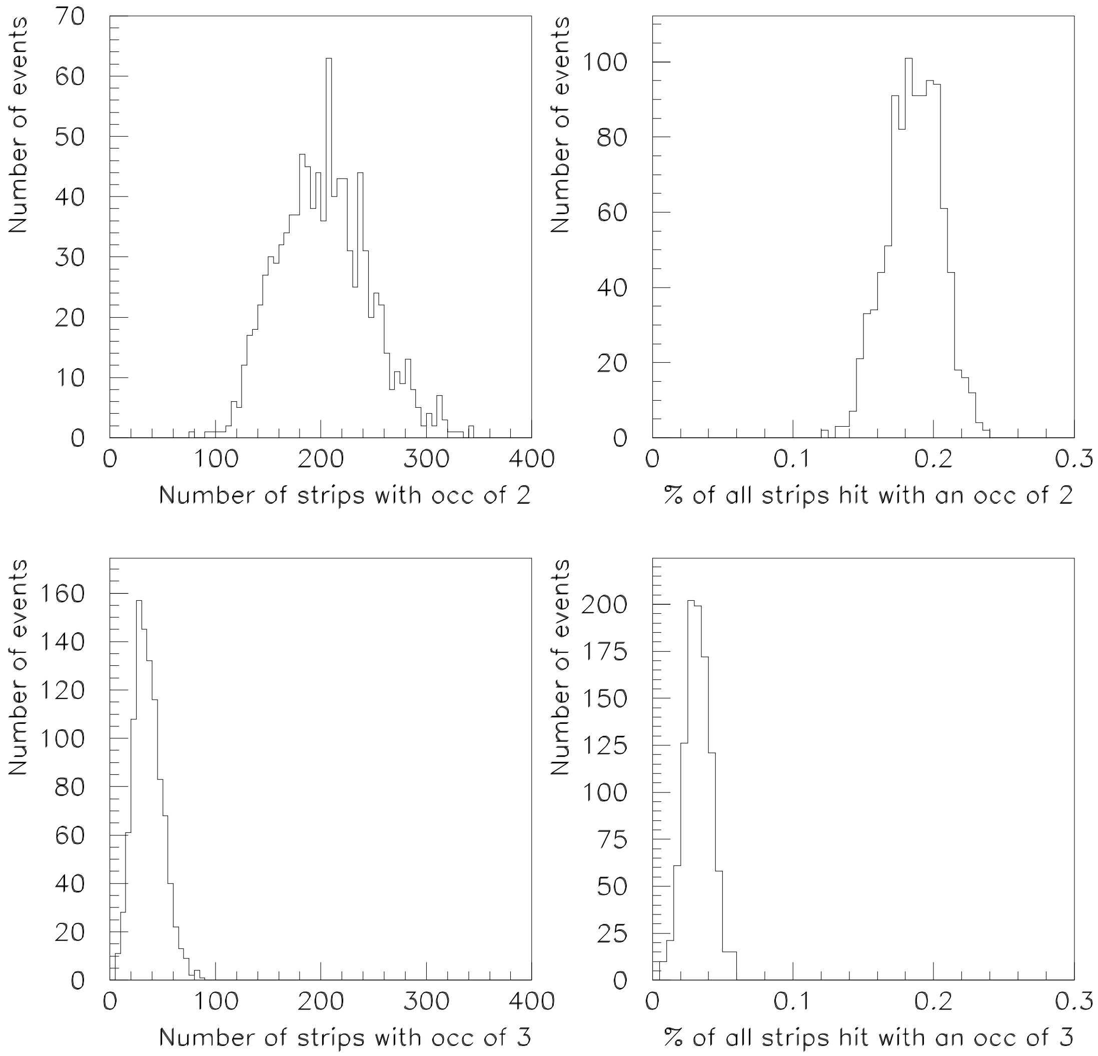

Figure 6: Same scheme as for Fig. 4 but now with five minimum bias interaction superimposed on the $t\bar{t}$ interaction.

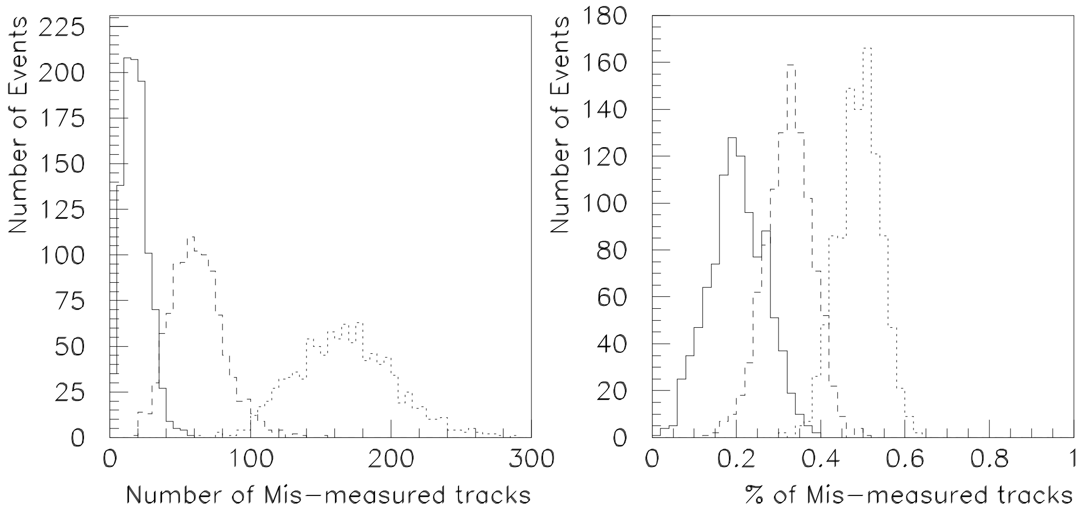

Figure 7: a) Left: Number of mis-measured tracks per event due to overlapping clusters for:
$t\bar{t}$ events (solid line);
$t\bar{t}$ + 2 minimum bias events (dashed line);
$t\bar{t}$ + 5 minimum bias events (dotted line).
b) Right: Mis-measured tracks as a percentage of the total number of tracks inside the Layer 00 acceptance.

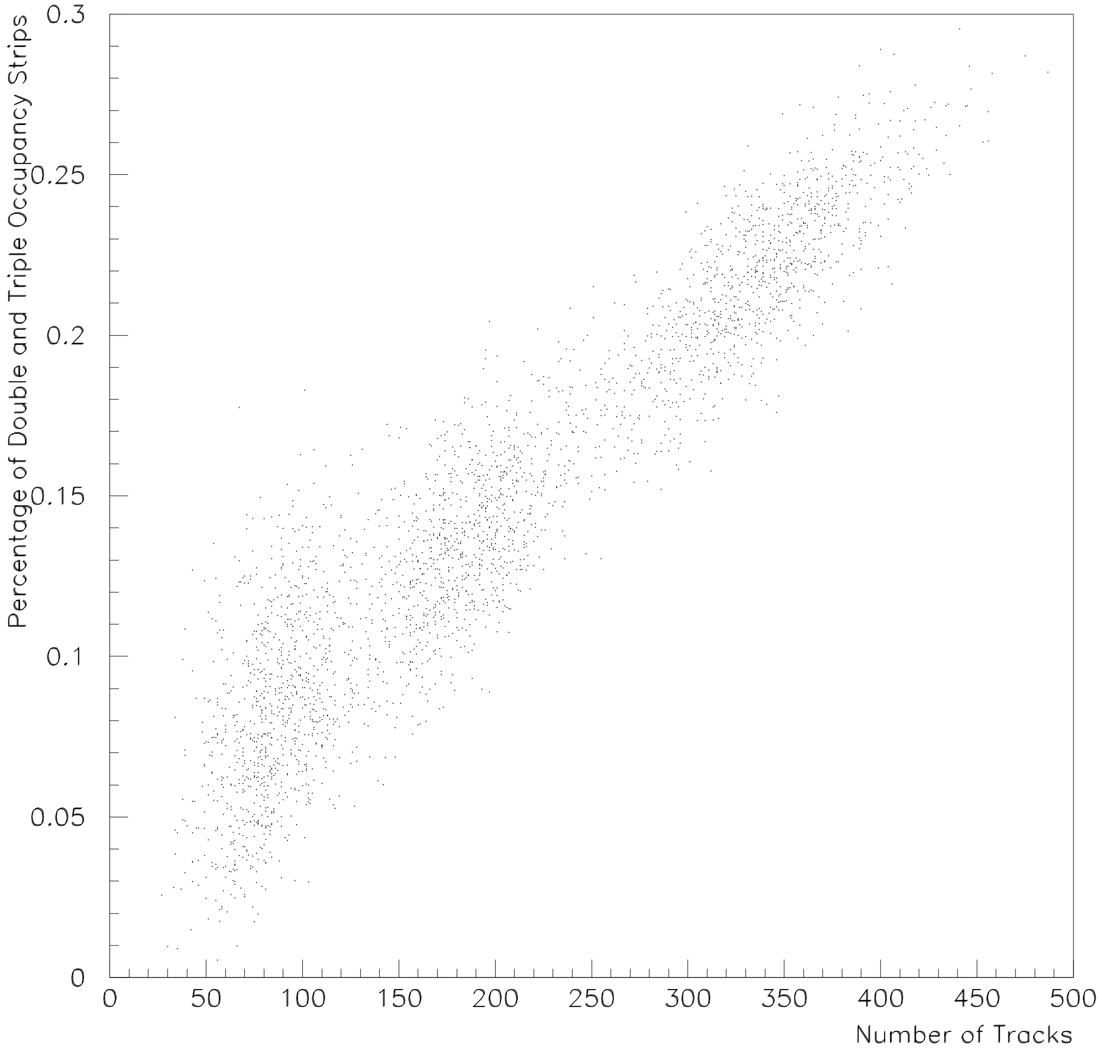

Figure 8: The relationship between the Number of Tracks and the Percentage of Strips having double or triple occupancy. Each point on the plot corresponds to one event from the samples of $t\bar{t}$ events, $t\bar{t}$ + 2 minimum bias events, and $t\bar{t}$ + 5 minimum bias events. The three distinct samples can just about be discerned in the plot.

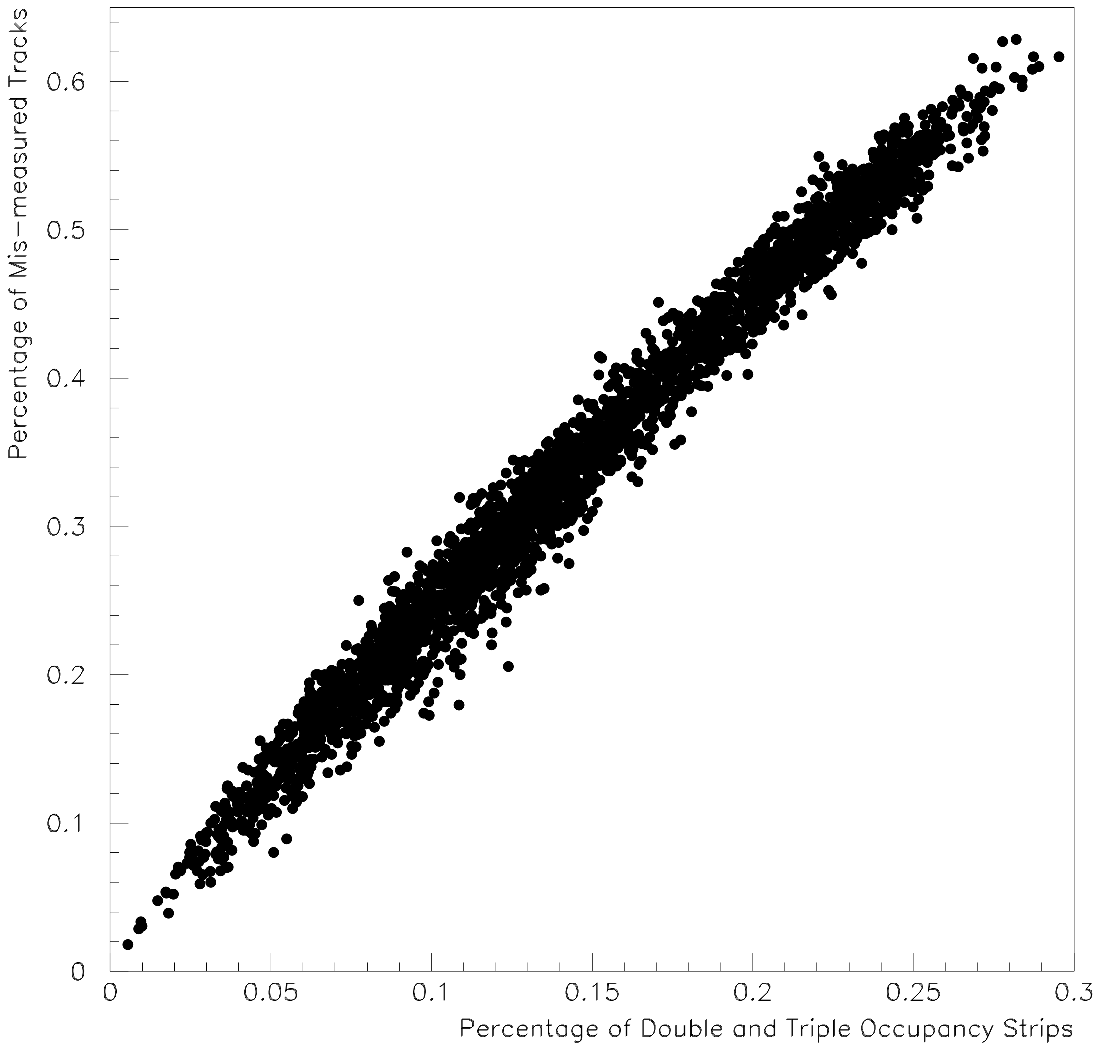

Figure 9: The relationship between the Percentage of Strips having double or triple occupancy and the Percentage of Mis-measured Tracks. Each point on the plot corresponds to one event from the samples of $t\bar{t}$ events, $t\bar{t}$ + 2 minimum bias events, and $t\bar{t}$ + 5 minimum bias events. A strong linear relationship is observed.