GEM TN-92-246

Studies of Multi-Track Resolution in the Interpolating Pad Chambers of the GEM Tracker

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December 7, 1992

Abstract:

The coordinate finding and resolution of the Interpolating Pad Chambers proposed for the GEM tracker have been studied using a simulation program written by V. Cherniatin and A. Chikanian. The program incorporates data collected using Cathode Strip Chambers running in CF_4CO_2. gas. Three methods have been studied for coordinate determination, one using a Gaussian fit approach, one using the center of gravity of the charge deposition and the third using the function from Mathieson[1]. The best results for single coordinate finding are achieved with the Mathieson function and similar results are obtained with the gaussian method. The latter was used to study the two track resolution as a function of distance between tracks which was found to be degraded by at worst a factor 3 at a separation of about 1.5 pad widths and to reach a limit at about 0.2 pad widths separation. When two tracks were closer together than this, they could no longer be resolved. In addition, the case of three tracks was studied, and although it is not possible to reconstruct three tracks on the same pad, the average total charge per layer can be used effectively enough to recognize them, and three tracks on two pads can be resolved.

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1. ABSTRACT.

The coordinate finding and resolution of the Interpolating Pad Chambers proposed for the GEM tracker have been studied using a simulation program written by V.Cherniatin and A. Chikanian. The program incorporates data collected using Cathode Strip Chambers running in CF_4CO_2. gas. Three methods have been studied for coordinate determination, one using a Gaussian fit approach, one using the center of gravity of the charge deposition and the third using the function from Mathieson [1]. The best results for single coordinate finding are acheived with the Mathieson function and similar results are obtained with the gaussian method. The latter was used to study the two track resolution as a function of distance between tracks which was found to be degraded by at worst a factor 3 at a separation of about 1.5 pad widths and to reach a limit at about 0.2 pad widths separation. When two tracks were closer together than this, they could no longer be resolved. In addition, the case of three tracks was studied, and although it is not possible to reconstruct three tracks on the same pad, the average total charge per layer can be used effectively enough to recognise them, and three tracks on two pads can be resolved.

2. INTRODUCTION.

The ability of the GEM tracker to do multi track finding is very important in the study of heavy particles (b and t) for three reasons. One is to measure the charge of the electron in a heavy jet in order to identify the primary quark. The second reason is to measure the momentum of the electron when the jet is collimated and the electron energy in the calorimeter is hard to disentangle from the rest of the jet. The third reason is to identify the 3-prong decay of the τ where three tracks travel through the tracker closely together. Figure 1 shows the distribution of the number of $p_T > 1.0$ GeV neighbours a particle in a t jet (including minimum bias) typically has, where a neighbour is defined as another track within 3 pad widths in the phi direction. Only tracks with $p_T > 1$ GeV were considered, these being the lowest p_T tracks which look straight from the point of view of the Interpolating Pad Chambers (IPCs). Furthermore, the momentum resolution of important signal tracks could in principle be adversly affected by the near presence of another track, either from a minimum bias event or from another track in the signal event itself. The expected frequency of such an occurence is low, however, as shown in Figure 2 where the number of nearest neighbours of a $H^0 \rightarrow Z^0Z^0 \rightarrow l^+l^-l^+l^-$ is plotted for 1000 signal events, but obviously this will depend on the particular signal in question.

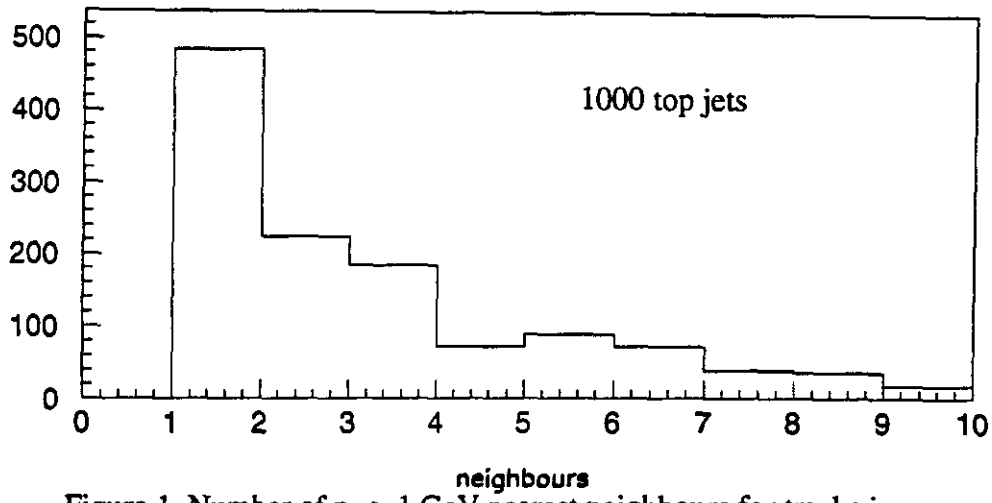

Figure 1. Number of $p_T > 1$ GeV nearest neighbours for tracks in top jets (zero suppressed)

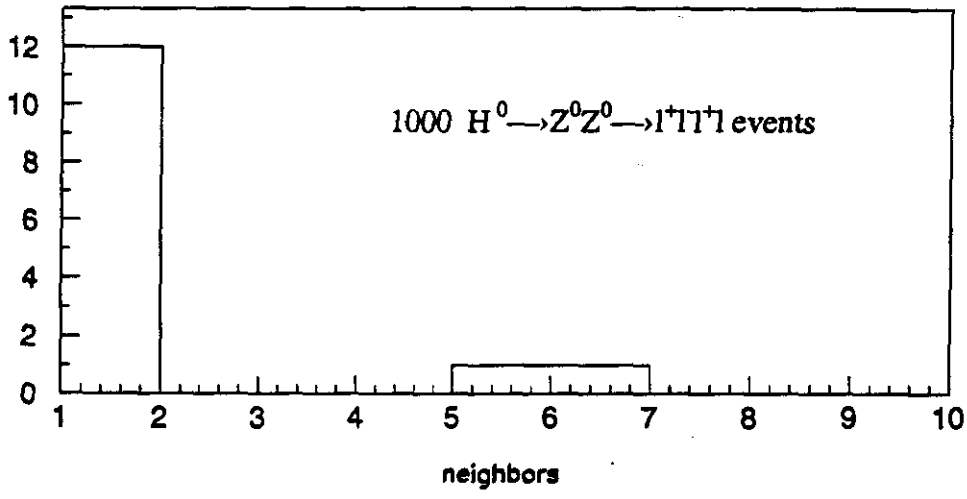

Figure 2. Number of $p_T > 1$ GeV nearest neighbours for signal tracks in $H^0 \rightarrow Z^0Z^0 \rightarrow l^+l^-l^+l^-$

3. THE SIMULATION PROGRAM.

The program used to simulate the IPCs was written by V.Cherniatin and A.Chikanian at BNL. In the program, primary electrons (15/mm) are produced along the incident track according to a measured distribution (measured at Dubna). The energy distribution is shown in Figure 3 for the primary electrons. The effects of high energy delta rays are included, as can be seen by the high energy tail of the distribution. The electrons then step towards the anode wire according to their mean free path (55μm) including the effects of diffusion (51 μm/mm drift) along the field lines. The effect of E x B is not included in this study because the pad chambers in the barrel of the GEM tracker are to be inclined at the Lorentz angle. The anode gain is folded with a Polya distribution and a gain of 2×10^4 is taken as the operating gain of the IPCs. One half of the anode charge signal is induced on the pads according to the recipe from Mathieson and a noise of 1500 electrons rms is added to each pad. Finally, a 1% calibration contribution is added to the noise which should include the effects of different

pad capacitances for each pad. The signal is then reduced to 20% of its original value, assuming a 20ns collection time of the signal.

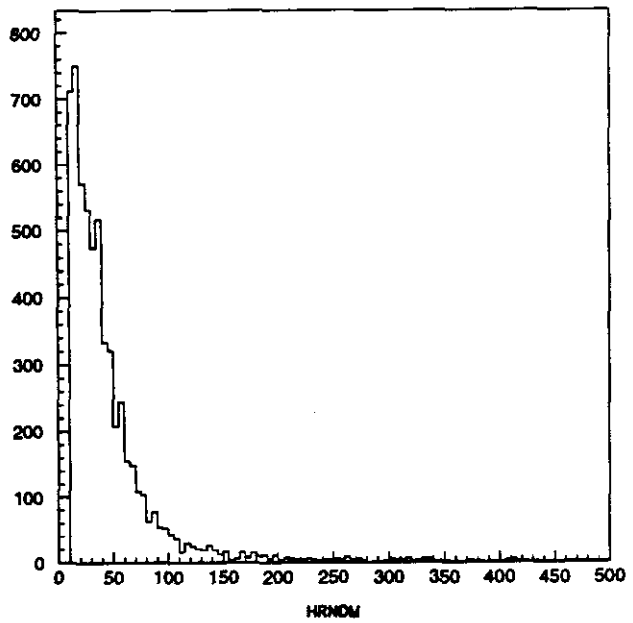

Figure 3. Energy of primary electrons (eV).

4. COORDINATE FINDING FOR SINGLE TRACKS.

4.1 The Gaussian Approach.

For a track incident on the center of a pad, the charge distibution looks like that shown in Figure 4 where each bin corresponds to one pad and the number of entries corresponds to the amount of charge deposited on that pad in pC. It should be kept in mind throughout that the best signal on a pad is a large signal, such that the signal to noise ratio is large. The smaller the absolute size of the signal on a pad, the more the noise will distort the signal on that pad. Because of this, a threshold is imposed on the pad signals of 0.002 pC, corresponding to a signal:noise ratio of about 10:1. This ensures that no pad can singularly distort the Gaussian

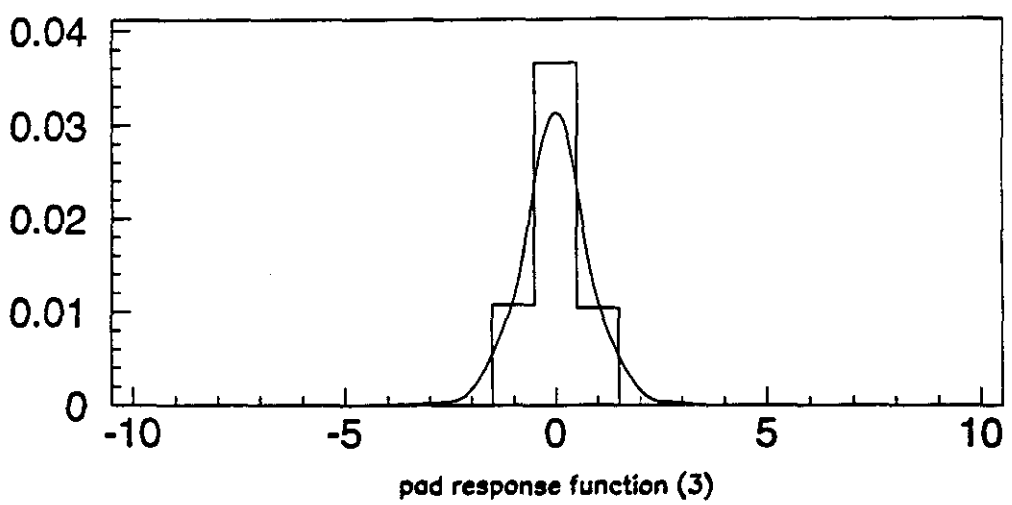

Figure 4. Charge induced on three pads in pC.

fit applied to the charge distribution. The fit uses the total charge on all pads above threshold (3 when the track passes through the centre of the pad) for the normalization and so the two parameters which are determined are the width and the mean. The procedure is followed for many tracks in order to determine the "pad response function"(σ_{PRF}) or the average width of the charge distribution. A similar approach was followed for coordinate reconstruction in the ALEPH TPC [2]. The result of the fits to the width is shown in Figure 5. The mean of the distribution is 0.64 pad widths and this is what is defined as σ_{PRF}. This is expected to be the same, wherever the track crosses the pad, being just a function of

the distance of the pads from the anode wires and their respective pitches. Using the knowledge of σ_{PRF}, the Gaussian for the charge distirbution in Figure 4 can be refit, and the position resolution can be obtained, as shown in Figure 6. With this method, the rms width is found to be 0.012 +/- 0.001 pad widths. This is not the whole story, however, because unfortunately the tracks do not always pass through the centre of the pad. For example, when the track passes at one quarter pad width, the charge distribution looks somewhat different as shown in Figure 7. It is clear that choosing which 3 pads to use in the fit can bias the measured position of the mean. Two possibilities present themselves :

1. Use all pads above some threshold (taken to be 0.002 pC)
2. Use only the two largest pads. (Only pads with large signal to noise)

Figures 8 and 9 show the widths of the two distributions of the measured position obtained from the two scenarios as the track crosses the centre pad at different points. For the two pad case, the resolution

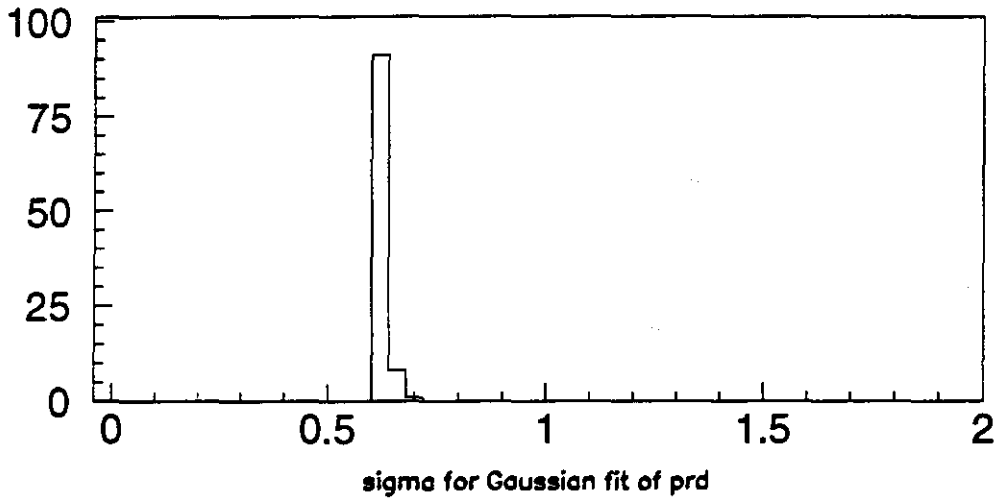

Figure 5. The result of many fits to the width of the charge distribution(in pad widths) made by a track passing through pad center.

is best at the edges but in the centre, it is not possible to measure the position with any certainty, there being two possible solutions which are equally probable. Using all pads above threshold, the best resolution is obtained at pad center. Figure 10 shows the real position - measured position. There is a sinusoidal displacement which is smallest at the pad edges and at the pad center. The slope of the distribution determines how much the displacement will contribute to the position resolution. For example, at the quarter-pad point, where the distribution turns over, the uncertainty of 34μm (0.14 pad widths)from Figure 8 produces only a negligible shift. However, at the edges and center, the displacement is changing rapidly and so a 30μm (0.12 pad widths) uncertainty can change the displacement by as much as much as 5μm. This must be added linearly to the rms width in Figure 8 to produce the resultant position resolution.

4.2 Centre of Gravity Method.

In a similar fashion, the center of gravity can be calculated for

1: all pads above threshold (0.002 pC)

2: the 2 largest pads.

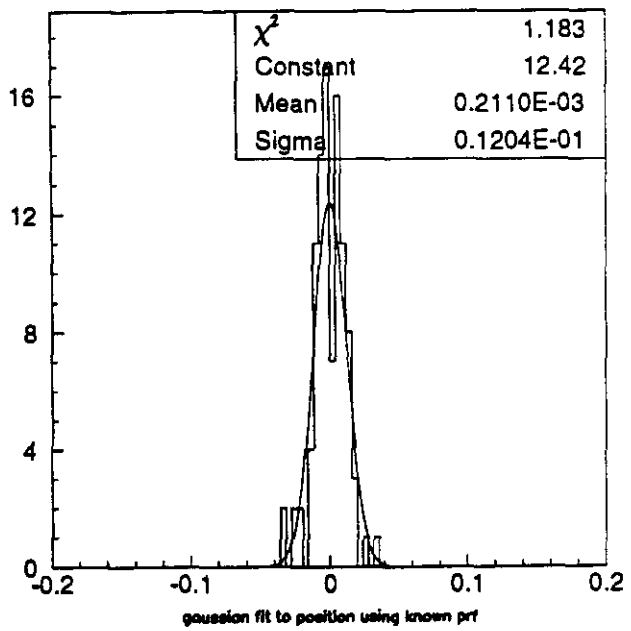

Figure 6. Resolution obtained using σ_{PRF}

The center of gravity is given by the 1st moment divided by the 2nd moment.

$M_0 = m_1/m_0$, where $m_1 = \Sigma\, q_i x_i$ and $m_o = \Sigma\, q_i$. The best results are achieved using a combination of the two categories. In general, two pads give a very narrow position distribution except when the track is at pad center, when all three pads are needed. The results are summarized in Figure 12 for the widths of the position distributions and Figure 13 for the displacements for several track positions across a pad. It can be seen that the displacement is an order of magnitude larger than for the Gaussian.

4.3 Mathieson Function.

The function proposed by Mathieson for fitting to the three largest pads was also studied. This uses t the Newton-Raphson iteration in three variables:

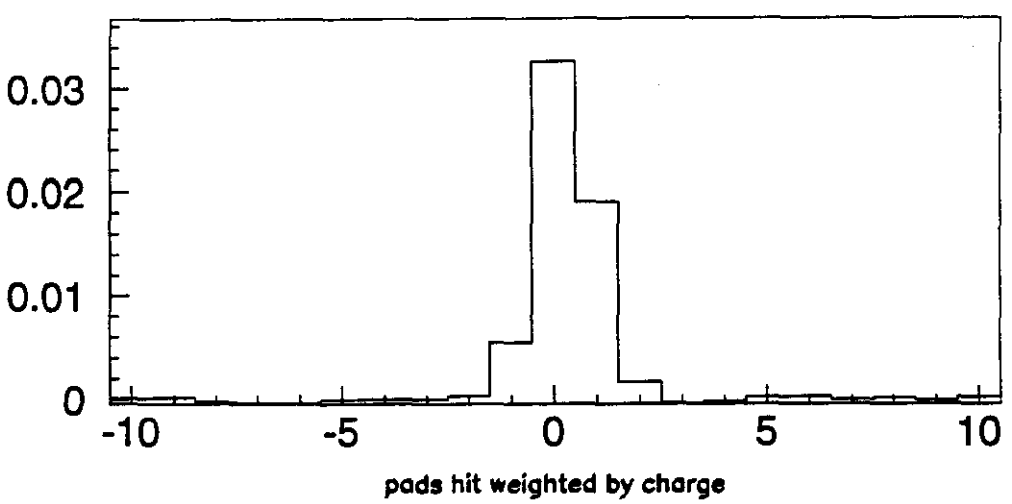

Figure 7. Charge on pads for track at quarter pad width.

position, total charge and avariable which is inversly proportional to the height of the charge distribution. A very good precision was acheived, with very little displacement as shown in Figures 14 and 15. However, the distribution for the track crossing the pad edges is not symmetric, and so the points at 0.5 pad widths are not really a reliable estimate of the resolution. After taking into account the error on the resolution from the displacement, the best resolution is acheived from the Mathieson fit to the 3 largest pads and the Gaussian fit to all pads above threshold. The resultant (corrected) resolutions for these two methods are plotted in Figure 16. A single track resolution of less than 40 μm is acheivable with a gain of 2×10^4.

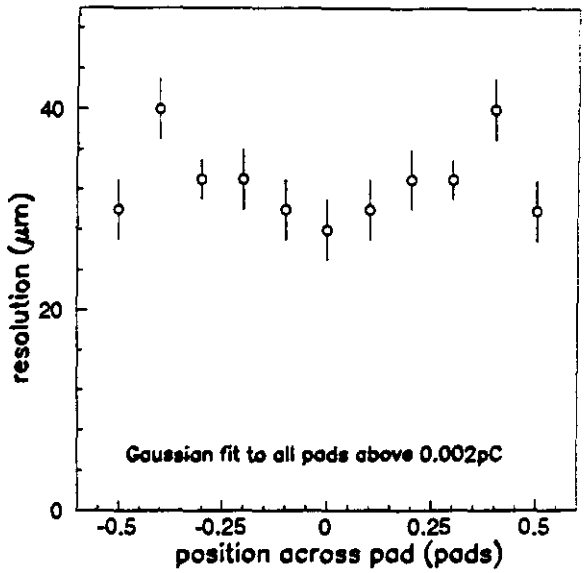

Figure 8. Gaussian fit to all pads above threshold.

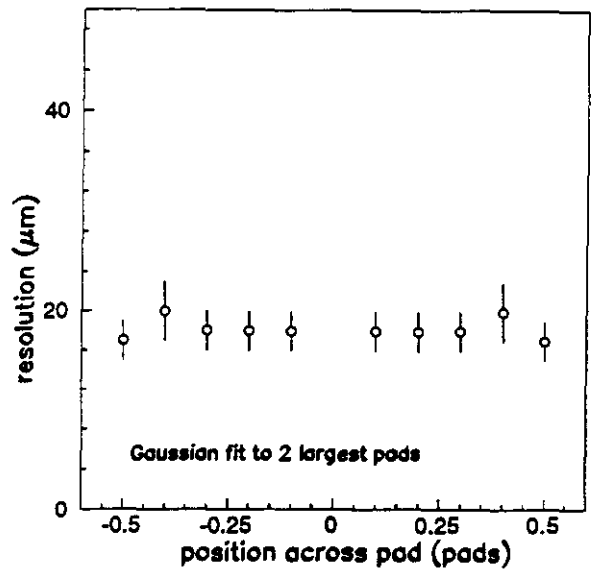

Figure 9. Gaussian fit to two largest pad signals.

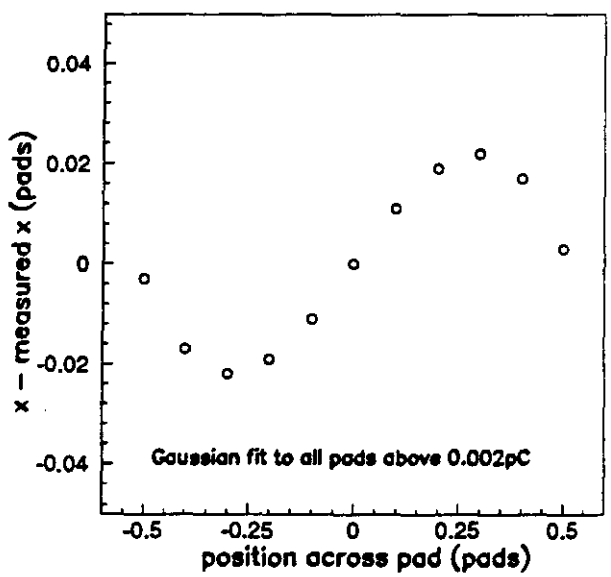

Figure 10. Displacement for Gaussian fit to all pads above threshold (0.002 pC)

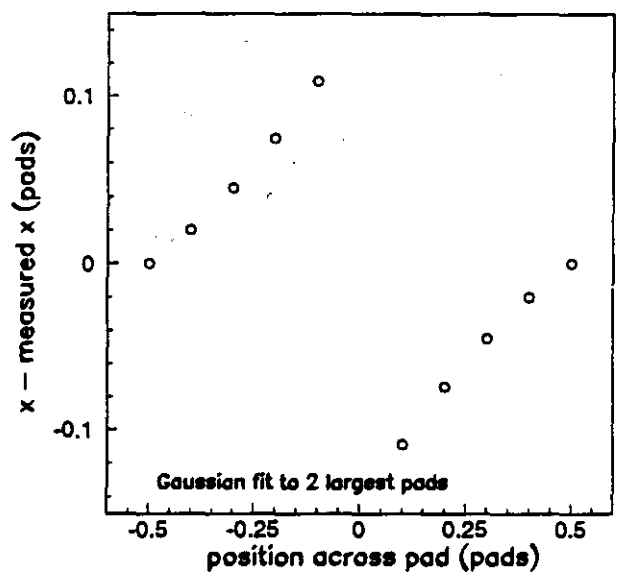

Figure 11. Displacement for Gaussian fit to two largest pad signals.

4.4 The effect of noise on resolution.

The effect of both the calibration noise (pad to pad differences in pad capacitance) and the RMS electronics noise on the resolutionwas studied . Figure 16a shows the resolution as a function of the RMS electronics noise for a calibration noise level of 1% and Figure 16b shows the resolution as a function of calibration noise for a RMS noise level of 1500 electrons.

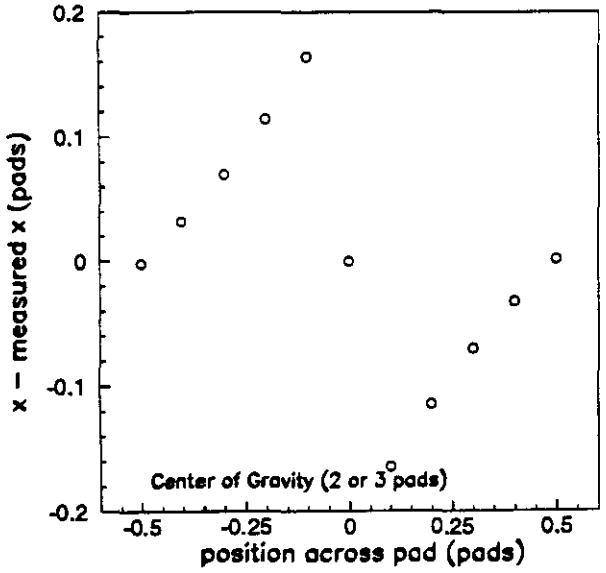

Figure 12. Displacement of mean using the center of gravity of 2 or 3 pads.

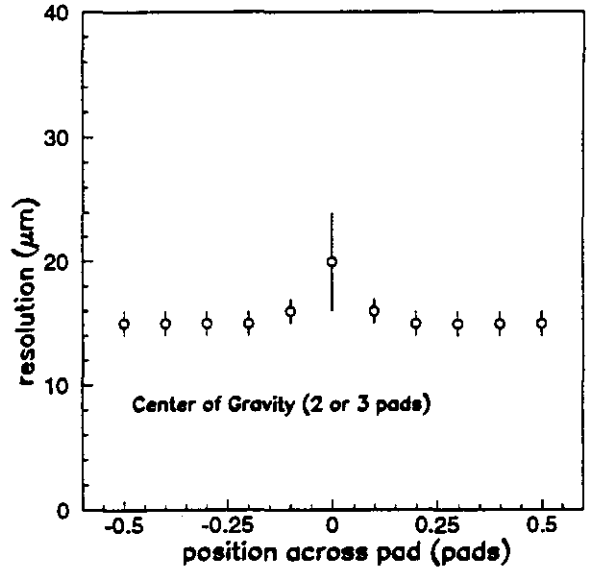

Figure 13. Width of position distribution using the center of gravity of 2 or 3 pads.

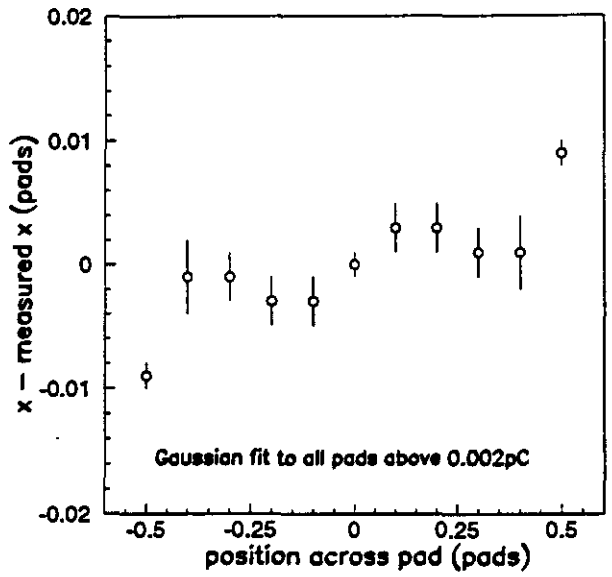

Figure 14. Displacement of mean using the Mathieson fit method.

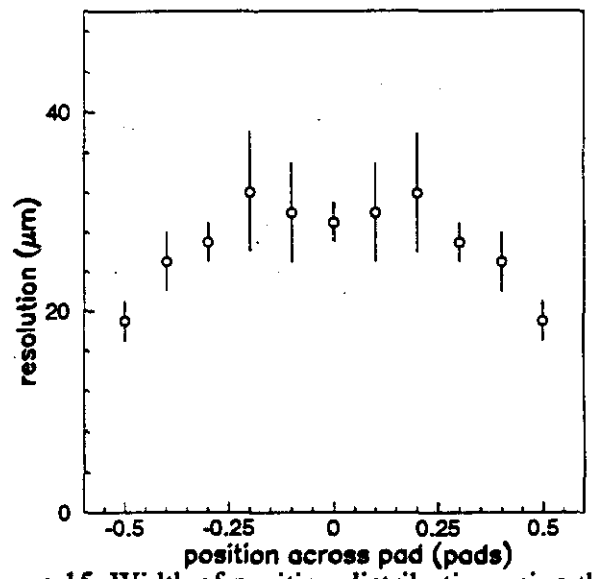

Figure 15. Width of position distribution using the Mathieson fit method.

5. TWO AND THREE TRACK RESOLUTION.

When two tracks are separated by more than one pad, the pattern is easily recognizable. The charge distribution is wider and trying to fit a gaussian with the known σ_{PRF} will yield a large χ^2 as shown in Figure 17. However, when the tracks are nearer than 0.5 pad widths (for example when they cross the same pad), they are more difficult to recognize in this way. The best indicator is the total charge on all pads above threshold. Figure 18 shows this value for 1, 2 and 3 tracks, and a substantal overlap is apparent. However, the GEM tracker has eight layers and so if the charge deposited on each layer is summed and averaged, the separation becomes much more striking as shown in Figure 19. The resulting spill over from one to two tracks is about 2% and from two to three tracks is 4%. This ability of the tracker to positively identify the three prong decay of the τ seems impressive, but it has been

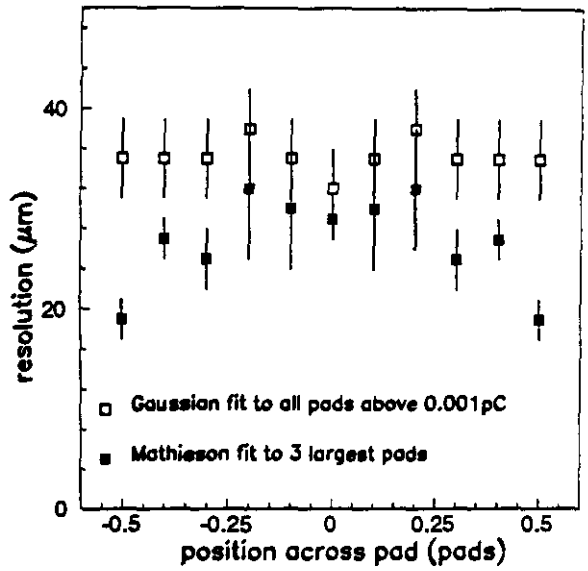

Figure 16. Resolution achieved for the best two methods after displacement corrections.

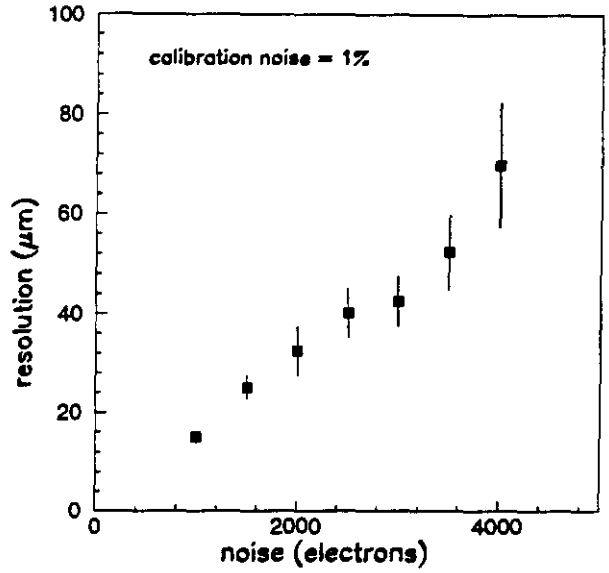

Figure 16a. Width of position distribtuion as a function of RMS electronics noise. (Calibration noise is 1%).

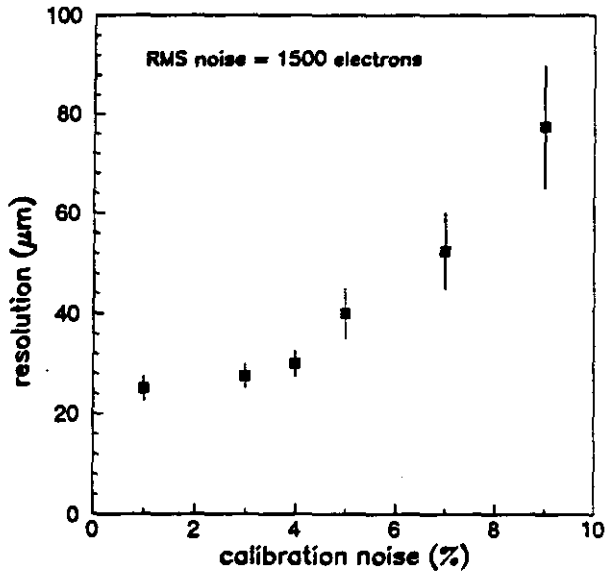

Figure 16b. Width of position distribution as a function of calibration noise. (RMS noise is 1500 electrons).

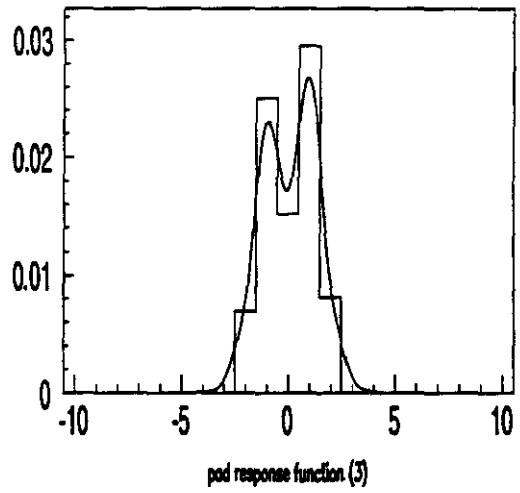

Figure 17. Charge distribution for two tracks separated by 2 pad widths. A fit to a single gaussian of width σ_{RMS} would lead to a very large χ^2

pointed out[3] that the experimental distributions of the total charge on a pad which were measured from Cathode Strip Chambers (CSCs) have larger high energy tails which will degrade the separation. Using the Landau distribution from CSCs collected at the Texas Test Rig (TTR) at SSC Laboratory[4], it was possible to generate the distributions for two and three tracks and to simulate the average over eight layers as before. The results of this test are shown in Figures 18a and 19a. It can be seen that the overlap is very similar to that generated with the simulation program, although the raw Landau distr-

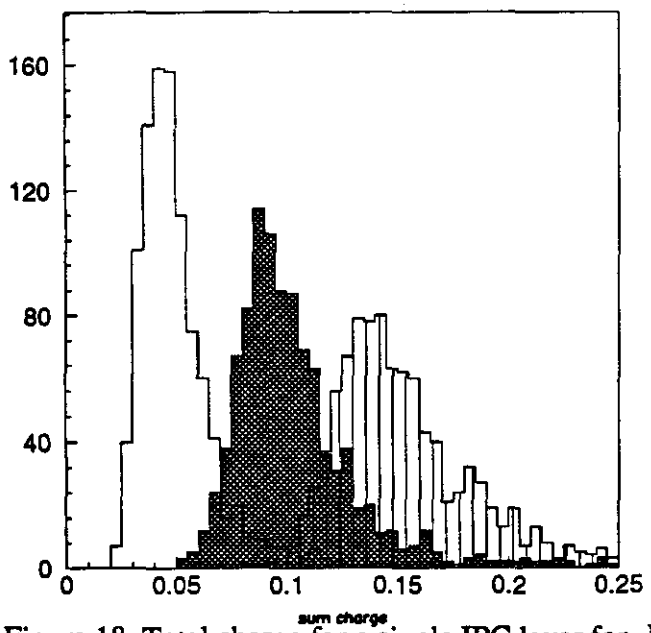

Figure 18. Total charge for a single IPC layer for 1, 2 and 3 tracks (in pC).

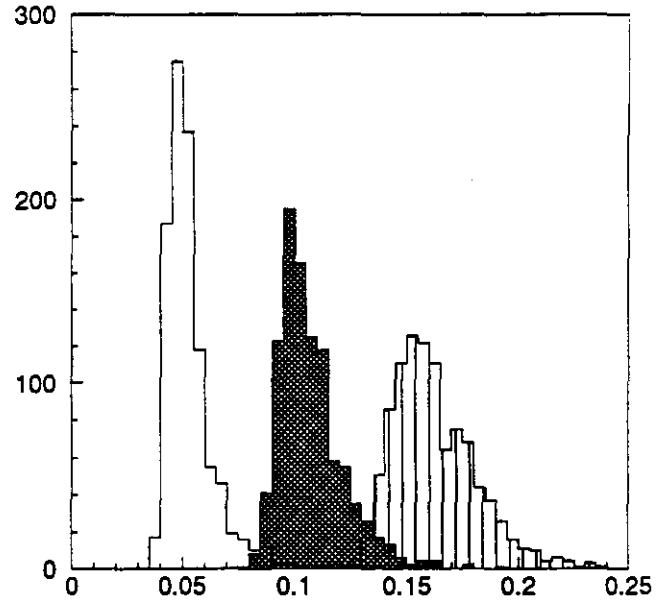

Figure 19. Average charge over 8 layers for 1, 2 and 3 tracks (in pC).

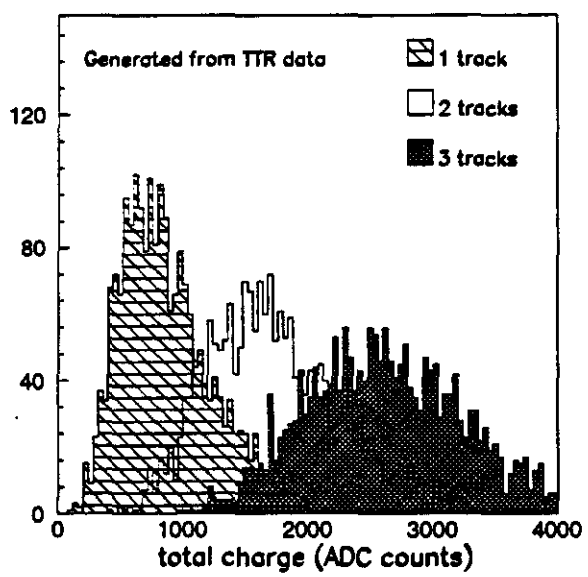

Figure 18a. Total charge for 1, 2 and 3 tracks generated from a Landau distribtuion for 1 track from the TTR.

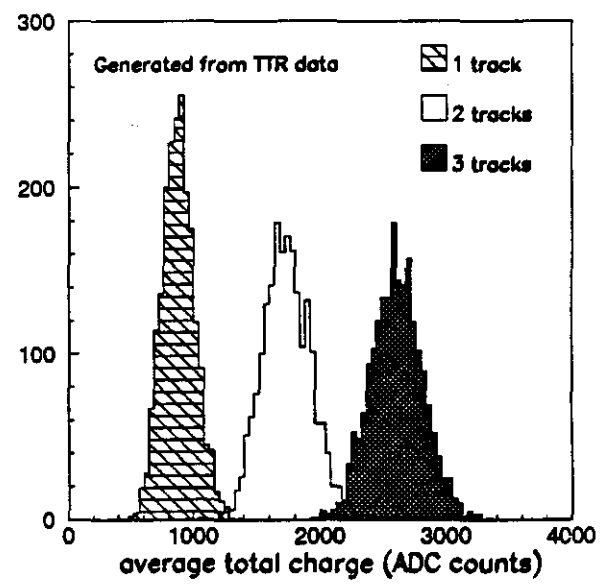

Figure 19a. Average integrated charge for 1, 2 and 3 tracks generated from TTR data.

bution has larger tails. A potential source of degredation is when low momentum tracks cross the tracks of interest. These tracks will be more bendy and will only contribute to one or two layers . This is easy to simulate and with two layers having the charge from two tracks deposited in them for *every* track, the resulting overlap in average charge between one and two tracks changes from 2% to 6%.

When it has been determined that there are indeed two tracks close together, it is necessary to fit to two Gaussians of known width (σ_{PRF}) whose total normalization (total charge) is also known. This results in a three parameter fit of three points and a normalization. The results are shown in Figure 20 for two tracks separated by 0.4 pad widths. The widths and the displacements for several different separations are summarized in Figures 21 and 22. The limit of the two track resolution is reached at

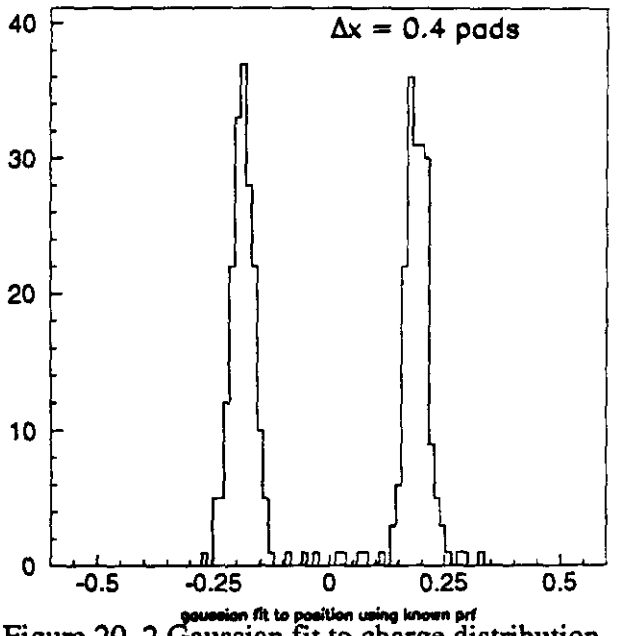

Figure 20. 2 Gaussian fit to charge distribution when the separation of the tracks is 0.4 pad widths.

about 0.2 pad widths (500 μm) beyond which two peaks are no longer resolvable with this method. There is a jump in resolution and in displacement when the fitting procedure moves from three to five pads (the signals on the outer two pads become large enough to be above threshold but are still small enough to sometimes adversly effect the fit). However, five pads are necessary at this point, a fit to only three pads only yields a very large χ^2 and a very large displacement. As was done before in the single track studies, it is necessary to correct the resolution for the effects on it of the displacement. Figure 23 shows the corrected two track resolution.

In all the multi track studies, it has been assumed that all tracks enter at the same azimuthal angle. The issue here is whether a track going through the chamber at an angle will create more primary ionization and thus confuse the fitting procedure by having a greater weight than the other track. However, because the IPCs in GEM are all quite short

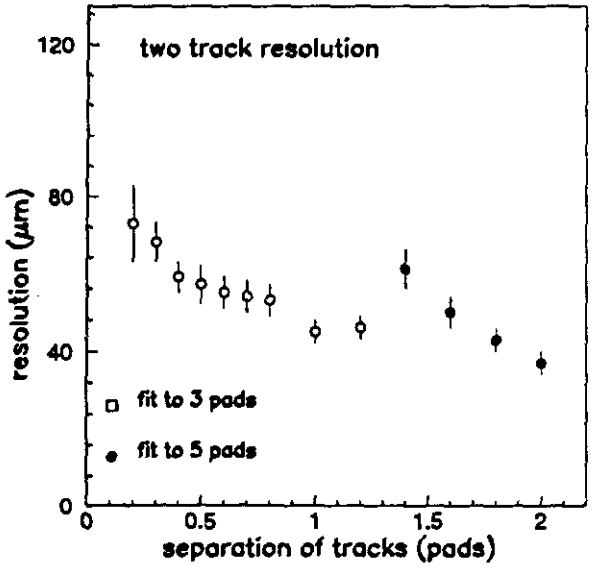

Figure 21. Width of position distributions as a function of separation of two tracks.

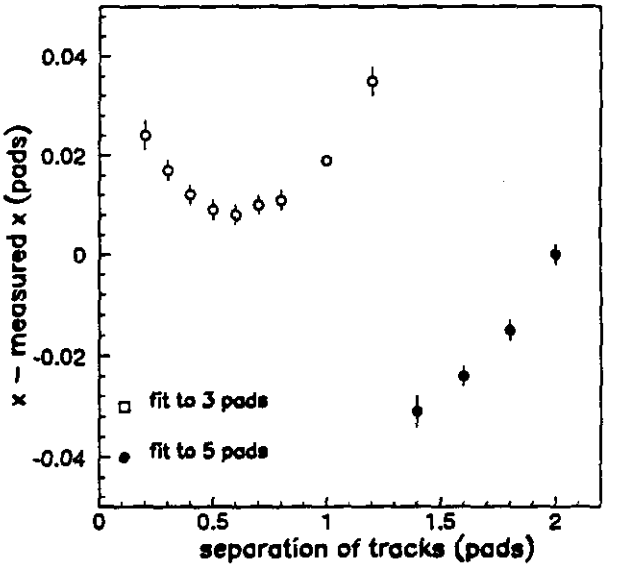

Figure 22. Displacement of measured position from real position as a function of separation of two tracks.

the maximum difference in angle allowed in theta will cause less difference in primary ionization than is induced from the Polya distribution of the gain. For tracks bending in phi, it is possible that one track may contribute as much as two times the other in primary ionization due to its longer path across the chamber. However, this can only happen in one or two layers: the larger the angle across the pad, the less likely the track is to interfere at the next layer.

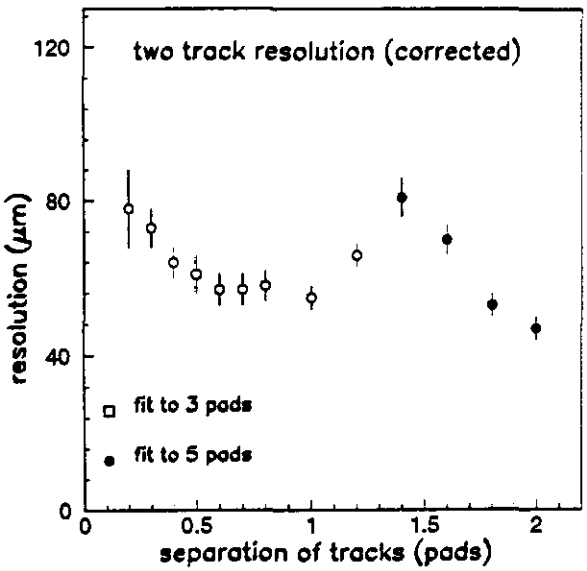

Figure 23. Corrected resolution including effects on the resolution of the displacement as a function of separation of two tracks.

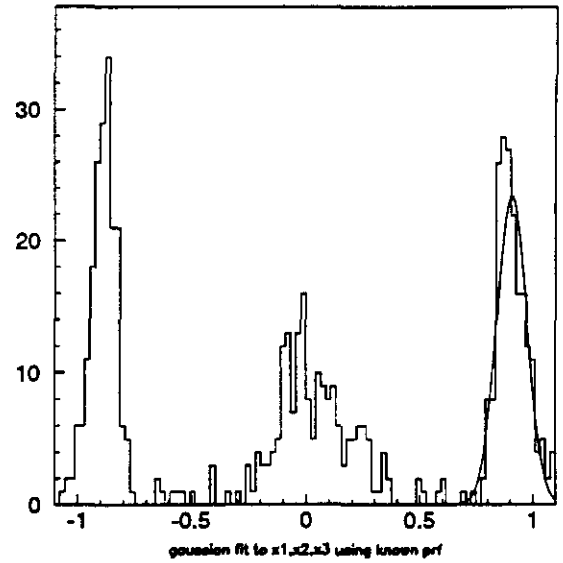

Figure 24. Recomstruction of three tracks crossing two pads at -0.8,0.0 and +0.8 pad widths.

In order to study the three track resolution three tracks were passed through one pad at positions -0.8, 0.0, and 0.8 pad widths. Three peaks could be resolved but three tracks on the same pad (for example at -0.3, 0.0 and 0.3 pad widths) could not. In principle, position information could be recovered from such a charge distribution. In addition, as discussed earlier, the GEM tracker has a formidable ability to recognize three tracks close together from the average charge over eight layers.

6. CONCLUSIONS.

It has been shown, using a program which utilizes the experimental data from CSCs that the single track resolution is very close to that expected from previous studies using Garfield. The two track resolution is impressive, reaching a limit (at least using the Gaussian fitting method) at a separation of about 500 μm (0.2 pad widths) beyond which no further position information can be obtained. However, the average total charge over eight pad layers is a powerful tool when tracks are closer together than this, which is an advantage of the GEM tracker over other trackers where the detection of one track excludes the detection of all others along the whole length of the wire or fibre. To quantify this in terms of the physics goals of the GEM tracker, about 1‰ of Higgs signal events will be unmeasureable due to the signal tracks being confused by many (more than 2) nearby tracks.

7. ACKNOWLEDGEMENTS.

I would like to thank Andrea Ostapchuck for valuable discussions and cite "Moment Method for Analysis of Induced Charge Distribution" (GEM TN-92-225) for a description of triggering possibilities using the moment method for quickly recognizing one or two tracks.

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2.D.Decamp et al. NIM A 294 (1990) 121.
3.Alexi Sumarakov, private communication.
4. G. Mitselmakker, private communication.