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# Study of Pad Chamber Performance

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A simplified pad chamber geometry with a width 2.5 mm along the anode wire direction is used to study the pad chamber performance. From this study, we found that 40 μm hit position resolution and 1.8 c/TeV momentum resolution are achievable when signal/noise ratio is 200 and luminosity is $10^{34}$ $cm^{-2}$ $sec^{-1}$.

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## Abstract

A simplified pad chamber geometry with a width 2.5 mm along the anode wire direction is used to study the pad chamber performance. From this study, we found that 40 $\mu$m hit position resolution and 1.8 c/TeV momentum resolution are achievable when signal/noise ratio is 200 and luminosity is $10^{34} cm^{-2} sec^{-1}$ .

## 1. Introduction

In GEM central tracker[1], silicon detectors and pad chambers are used to find hit positions and then to reconstruct particle trajectories. However, noise from electronics will distort hit positions and make resolution worse. Also, with higher luminosity, there will be more tracks in one bunch crossing. When there are tracks which are too close to each other, we may be not able to identify these two tracks. This will lower down the efficiency. Both of noise and luminosity problems are studied and disccused in this note.

We start our work with describing a simple geometry for pad chambers in section 2. In section 3, we use formula Eq.(2) to generate charge distribution on each pad. Then a reason is given to explain why we use this charge distribution rather than fixed total charge to simulate the total charge induced on cathode planes. Furthermore, we introduce two methods, center of gravity (CG) and non-linear fit (NLF), to analyze hit positions and give a demonstration that the latter is much better than the former. The results of how close two tracks could be so that we can still separate both of them are described in section 4. Also, the calculation for the dependence of hit position resolution on noise and on lumonisity are discussed in section 5 – 6 and the efficiency of survived trajectories are presented in section 7. Finally, a summary is given in section 8.

## 2. Geometry of pad chamber

To study the pad chamber performance, we employ a simple geometry including four cylinders all with the same Z axis, but each with radius 38.988, 48.401, 56.960, and 66.378 cm respectively. Each cylinder represent a superlayer of pad chambers in real geometry. Each pad chamber is constructed with two parallel cathode planes separated by 4 mm and anode wires located at the center between these two cathode planes, thus the distance between anode wires and each cathode plane is 2 mm. For each layer, each cylinder is divided into pads according to the modeled width, $\omega_\phi = 2.5$ mm, in $\phi$ direction. On the basis of $\omega_\phi = 2.5$ mm, $\delta\phi$ is thus calculated for each layer which is equal to $\omega_\phi$ divided by the radius of this layer, and then $\delta\eta$ is obtained from the required relation of $\delta\phi \cdot \delta\eta = 7 \cdot 10^{-4}$.

## 3. Charge distribution and Non-linear fit method

For the charge distribution induced on cathode planes by a charged track passing through pad chambers, we use the formula Eq.(1) to generate the charge density $q(x)^2$ on whole cathode planes with respect to the hit position $x_0$ of this track :

$$q(x) = \frac{q_t}{2L} \frac{1}{\cosh \frac{\pi(x-x_0)}{2L}} \tag{1}$$

where $q_t$, $x$, and $L$ represent the total charge induced on cathode planes for one track, the distance from the original point along the anode wire, and the anode-cathode separation, respectively. The information we want to have is the charge distribution collected on each pad, so we integrate Eq.(1) with respect to $x$ from $x_i - \frac{\omega_\phi}{2}$ to $x_i + \frac{\omega_\phi}{2}$ and then get

$$q_i(x_i) = \frac{2q_t}{\pi} \cdot \tan^{-1} \frac{\sinh \frac{\pi w}{4L}}{\cosh \frac{\pi(x_i - x_0)}{2L}} \tag{2}$$

where $q_i(x_i)$ and $x_i$ are the collected charge on the i'th pad and the center point of the i'th pad.

In our simulation, we collect the distributed charges for one track inside $14 \times 2$ pads. That is, there are 14 pads fired in x direction and 2 pads fired in y direction in one layer for one track passing through pad chambers. As for $q_t$, fixed total charge and charge distribution from energy loss (dE/dX) calculation could be used. The energy loss distribution is shown in Fig.1, while Fig.2 and Fig.3 show the hit position resilutions for both case. One can see that the resolution for the second case is worse than case one. This is because that we use the mean value of the energy loss distribution as the the average signal for signal/noise ratio calculation and from time to time dE/dX from one track can be smaller than the mean value and it may even close to zero, see Fig.1. But the second case is more realistic than the first one in the simulation of pad chamber. So we use the charge distribution from dE/dX calculation in the subsequent work.

When one track passes through pad chambers, we adopt two methods to obtain the hit positions of this track; one is the center of gravity (CG) method with SINe correction and the other one is the nonlinear fit (NLF) method. The first one is very

simple, but there is a systematic error one needs to take care. That is, the hit position calculated by this method is different from the real ones systematically. If the track hits at the edge or at the center of one pad, the difference is close to zero, but if it hits at $\frac{1}{4}$ or $\frac{3}{4}$ of one pad width, the difference is largest. The shape of the difference as a function of real hit positions looks like a SINe wave (Fig.4). Therefore, when using CG, one should calculate SIN correction first and then use these data to modify the hit positions calculated by CG. The second one is the fit of two parameters, the hit position $x_0$ and the total induced charge $q_t$ of one considerd track. When we use this method, the assistance of CG is necessary. In other words, we first use CG to get the conjectural values of $x_0$ and $q_t$ and then take them as the starting points in NLF so as to obtain the more accurate values for $x_0$ and $q_t$.

The resolutions of one track obtained from both CG and CG+NLF are shown in Fig.5 . Form these plots one can see that the hit position resolution is greatly improved from about 100 $\mu$m to about 37 $\mu$m after NLF is applied. Thus we use CG+NLF to calculate the hit position resolution and study the efficiency of track identification.

## 4. The dependence of hit position resolution and momentum resolution on noise

There will be noise from electronic read out, so we will see how it affects the hit position resolution and momentum resolution. To simulate the noise, we use Gaussian distribution. Considering one track passing through the pad chambers, we set $q_i = 0$ if the charge $q_i$ in the fired ith pad is less than 3 $\times$ sigma of noise after noise is added. To see the dependence of hit position resolution and momentum resolution on noise, we plot hit position resolution and momentum resolution as a function of Signal/Noise ratio in Fig.7–8. As a result, we get the higer the Signal/Noise ratio, the better the hit position resolution and momentum resolution, and 40$\mu$m hit position resolution and 1.8 c/TeV momentum resolution can be achieved at a value of Signal/Noise ratio 200. However, the Bremsstrahlung radiation and multiple scattering are not included in this study. These results indicate clearly that the sensibility of noise on hit position resolution and momentum resolution need to be considered.

## 5. The dependence of hit position resolution and momentum resolution on luminosity

For higher luminosity , there will be more tracks in one event thus there will be more chance to have another track hitting nearby. The desired luminosity in SSC is $10^{33} cm^{-2} sec^{-1}$, but it may be up to $10^{34} cm^{-2} sec^{-1}$ as GEM may require so as to increase statistics for heavy Higgs or other heavy particles study.

In our study, we throw background tracks according to the occupancy. The occupancy is about 2% when luminosity is $10^{33} cm^{-2} sec^{-1}$, while for luminosity at $10^{34} cm^{-2} sec^{-1}$ , the occupancy is about 12% . Then we calculate the hit position and momentum of the trigger track under the influence of the background tracks.

We show the dependence of hit position resolution and momentum resolution on luminosity in Fig.9, Fig.10 and Fig. 11. These three graphs show that when luminosity is higher, the hit position resolution and momentum resolution are worse, and 42.5 $\mu$m hit position resolution and 2.0 c/TeV momentum resolution could be achieved when luminosity is $10^{34} cm^{-2} sec^{-1}$.

## 6. Efficiency for hit position identification

We would like to pinpoint the hit position for one track so that we can get the accurate vertex and accurate momentum. However, when two tracks are close to each other, there will be a problem in identifying hit positions. Using NLF, with the output from CG as the conjecture values, we tried to resolve the hit position of the trigger track when there is a background track hitting closer and closer.

The quantities, R.M.S. and FWHM of the hit position resolution, as a function of dx for any one track extracted from the another one are displayed in Fig.6, where star sign(*) and circle sign(o) represent R.M.S. and FWHM, respectively. The so-called "hit position resolution" values denote the difference between real and measured positions for any one concerned track. From Fig.12, when dx is greater than 0.6 cm, the resolution is as good as about 45 $\mu$m. Besides, in Fig.13, the efficiency vs. dx is obtained with nineteen thousands events thrown. We get this result by the definition of efficiency as the number of hit positions identified devided by the number of total number of hit

positions thrown, where we say a hit position is identified if the difference between real and measured hit positions falls between -400 $\mu$m and 400 $\mu$m. Also, Fig.13 indicates that the efficiency is close to 95 % when dx is greater than about 0.6 cm and the efficiency is down to 50 % when dx is about 0.25 cm. This efficiency seems very high. This is due to the cut of hit position difference we used which is 400 $\mu$m , about 9 $\times$ sigma of the resolution. This high efficiency also reflects that the charge cluster analysis for the calculation of center of gravity is good thus when dx is small it still can provide good conjecture values for NFL to calculate the real hit position. However, we would like to point out that if we can't have a good justification to know how many tracks hit together in a same pad then it is meanningless to say that we have good resolution and good efficiency in such small distance. This justification could be done by measuring the width of the charge distribution or the average charge of the 8 hit points in one track. This needs more investigation.

## 7. Efficiency for survived trajectories

Base on the analysis of hit positions, we use a fit equation

$$y = a_1 + a_2 \cdot x + a_3 \cdot x^2 \tag{3}$$

to get the particle trajectory, where x and y are the coordinates in x and y directions for the considered particle, and $a_1$, $a_2$, and $a_3$ are three fit parameters which correspond to vertex position, direction of initial momentum and the curvature respectively. Then along with the usage of

$$P_T = \frac{0.15B}{a_3} \tag{4}$$

we can obtain the momentum of this particle, where B is the applied magnetic filed with a value of 0.8 Tesla.

In view of section 6, when luminosity increases, we determine the real hit position more difficultly and then get the real momentum worse. The efficiency of survived trajectories with respect to luminosity is shown in Fig.10. The efficiency of survived trajectories is denoted by the number of survived trajectories devided by the number

of total trajectories thrown. Here we used several cuts during trajectory fitting: (1) The total $\chi^2$ devided by number of degree of freedom must less then 3. (2) We throw away hit points which are mixed with some other hit(s) from a background tract and then required that there must be at least 6 hit points left for fit in one trajectory. Fig.10 shows that the efficiency is up to 95 % when the luminosity is $10^{34} cm^{-2} sec{-}1$ . However, this is overestimated because the background hits are given independently in each plane while in real case a background track which hit near the trigger track will have all of 8 hit points very close to the trigger track points respectively, therefor there will be more chance to have hit points less than 6 for fitting and thus the efficiency will be lower than what is shown here. Moreover there is no delta electron included and also no multiple scatterring. These should be studied further in full Monte Carlo simulation.

## 8. Summary

In this study, we found that 40 $\mu$m hit position resolution and 1.8 c/Tev momentum resolution are achievable for pad width equal to 2.5 mm with signal/noise ratio at 200 and with luminorsity at $10^{34}$ $cm^{-2}sec^{-1}$. The efficiency of identifying tracks can be as high as 95 % when luminorsity is $10^{34} cm^{-2} sec{-}1$ in ideal case.

## References


1. "The GEM Central Tracker, A progress Report", GEM TN-92-63.
2. I. Endo, T. Kawamoto, Y. Mizuno, T. Ohsugi, T. Taniguchi, and T. Takeshita, Systematic shifts of evaluated charge centroid for the cathode readout proportional chamber, Nuc. Instr. Meth. 188: 51 - 8, 1981.

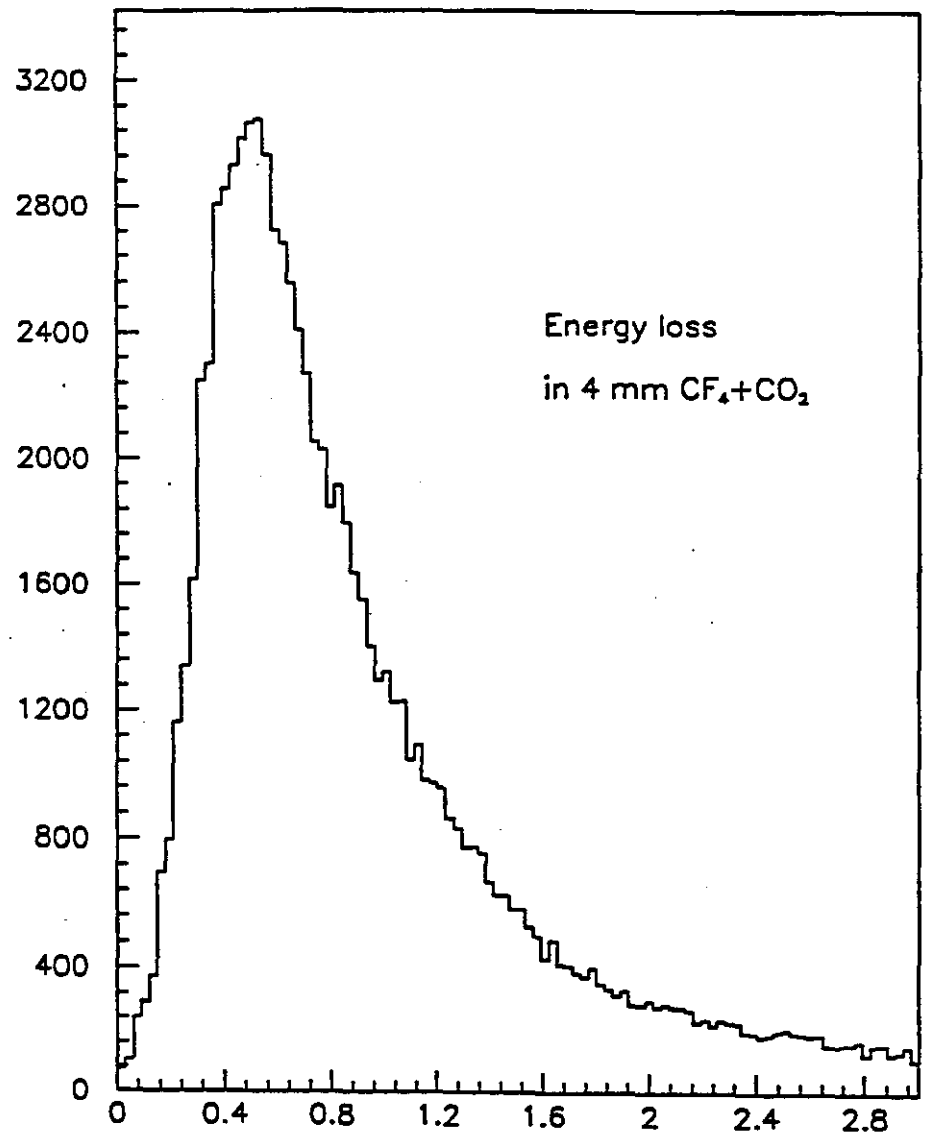


Fig 1. dE/dx ( arb. scale )

## Track and Momentum resolution

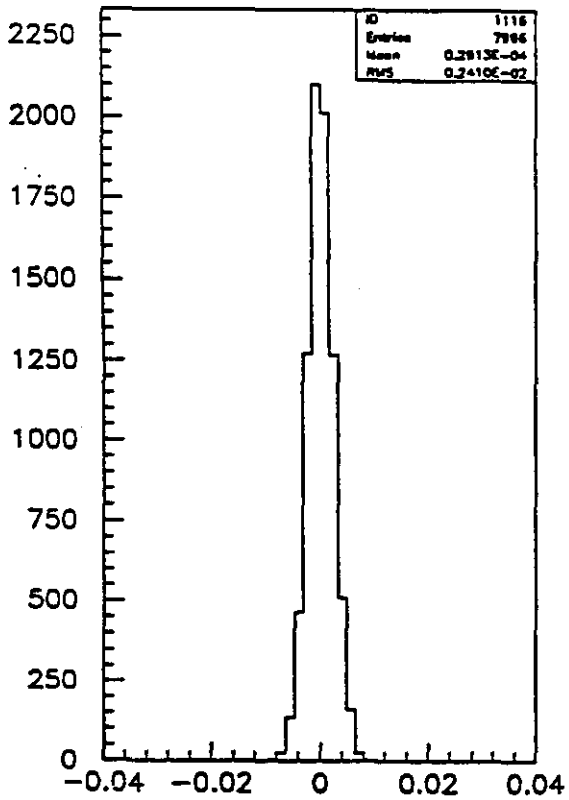


Fig. 2a, delta(x) for fixed energy loss

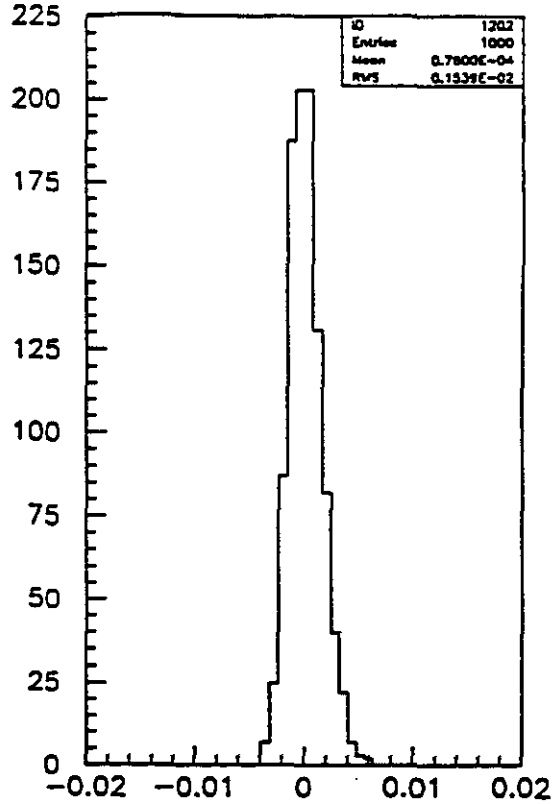


Fig. 2b, $\Delta P_T/P_T^2$ for fixed energy loss

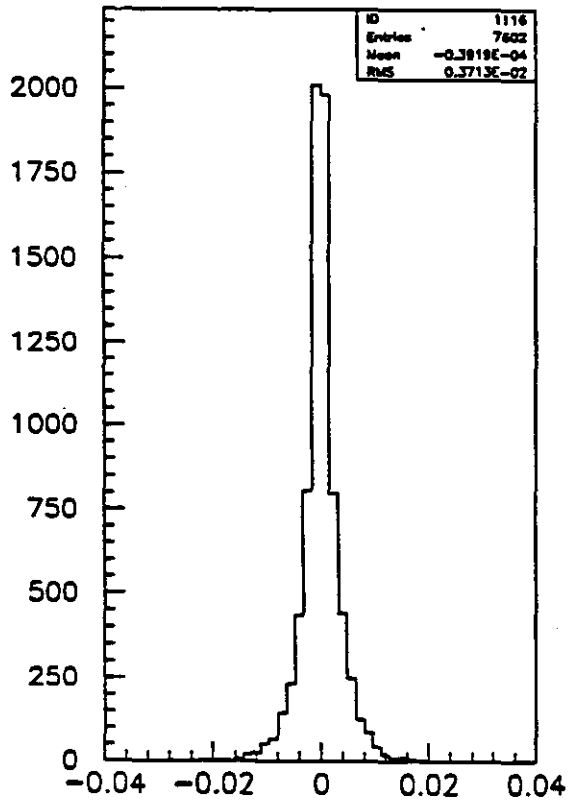


Fig. 3a, delta(x) for dE/dx distribution

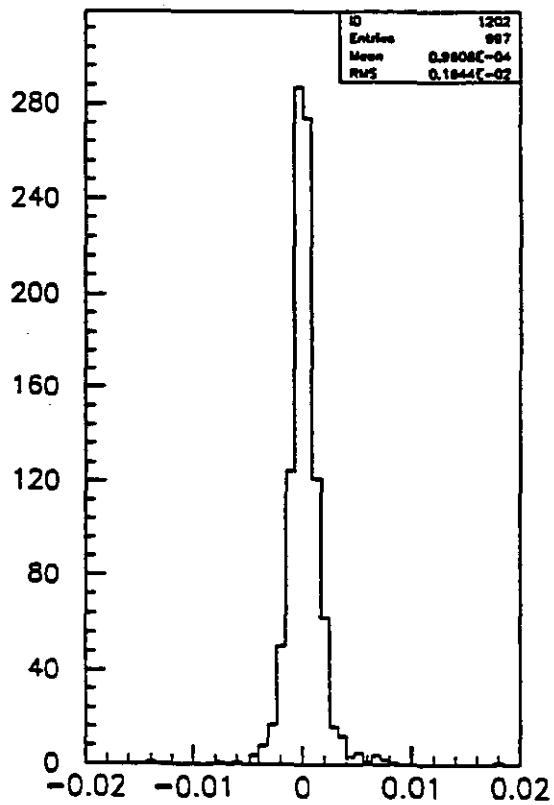


Fig. 3b, $\Delta P_T/P_T^2$ for dE/dx distribution

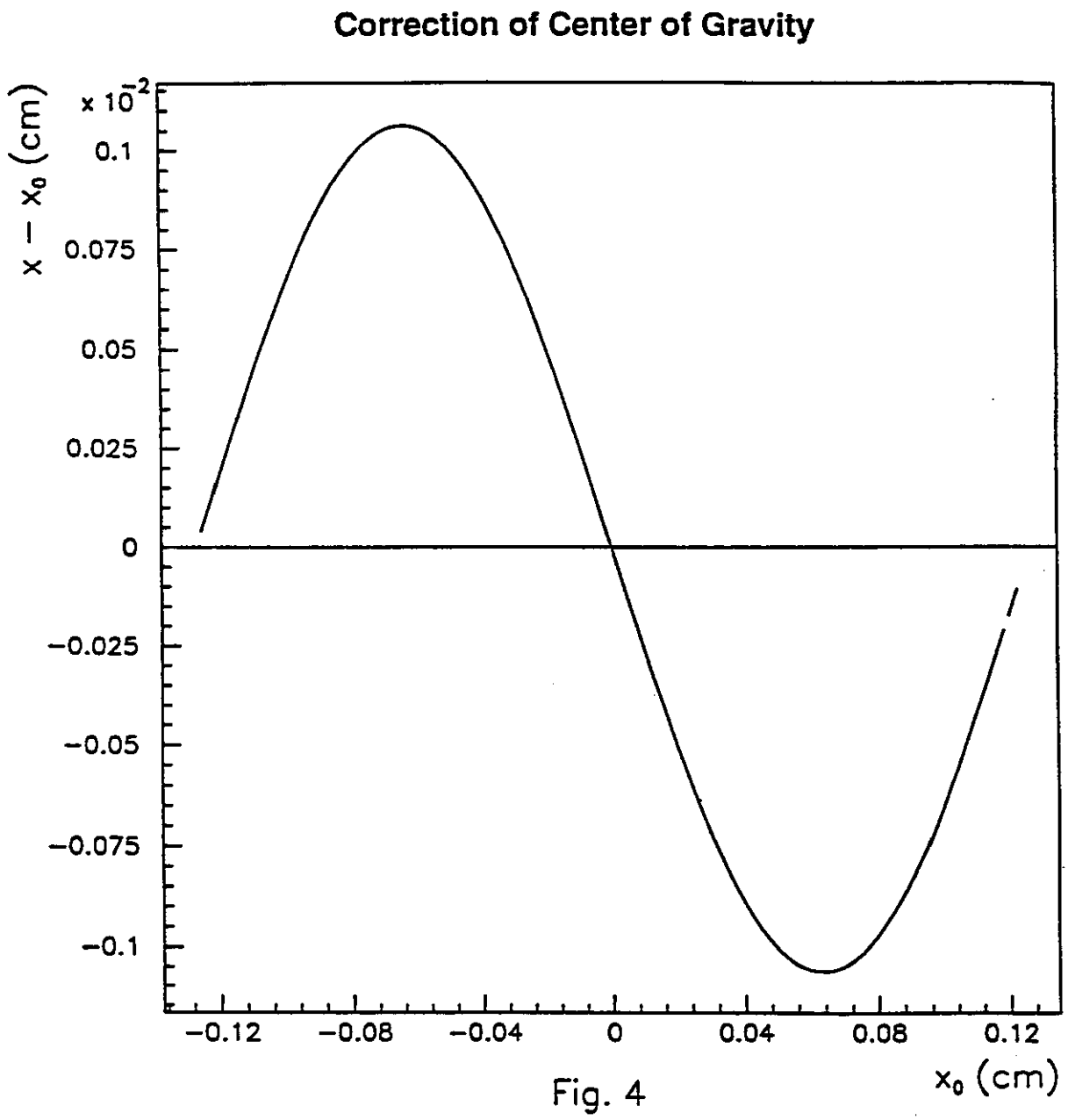
Correction of Center of Gravity
x − x₀ (cm)
x 10⁻²
0.1
0.075
0.05
0.025
0
−0.025
−0.05
−0.075
−0.1
−0.12
−0.08
−0.04
0
0.04
0.08
0.12
x₀ (cm)

Fig. 4

## Track and Momentum resolution

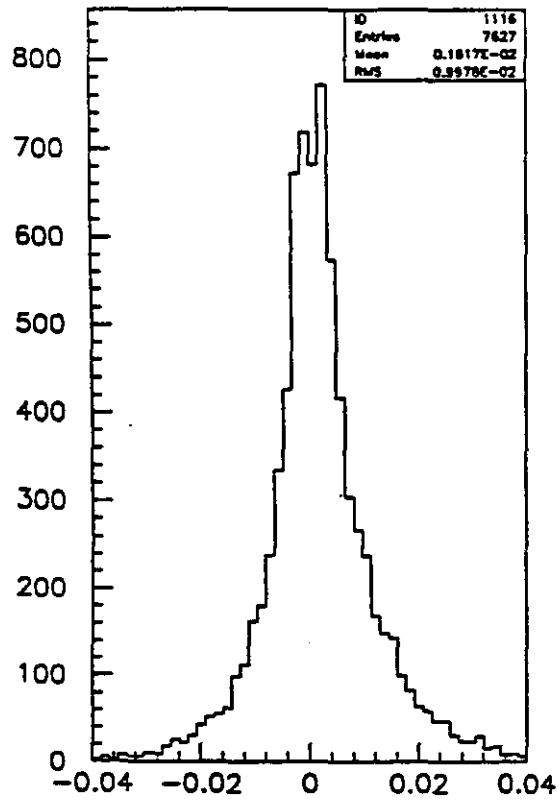


Fig. 5a, delta(x) (cm) Centr−Gravity

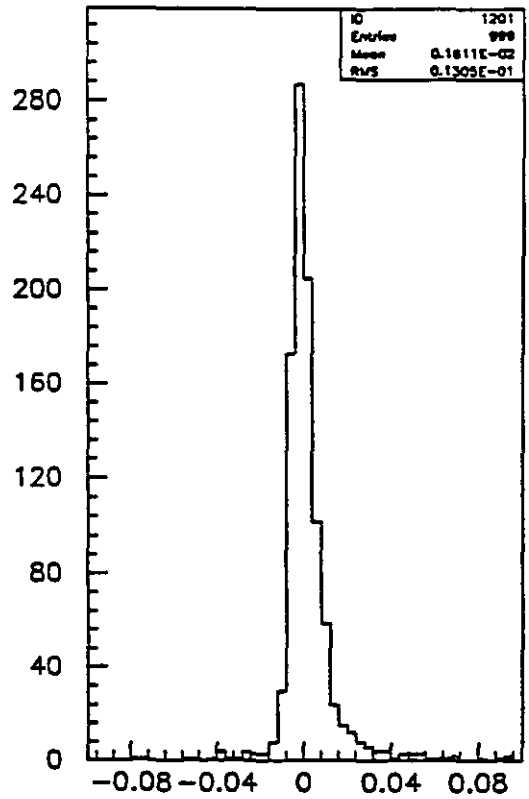


Fig. 5b, $\Delta P_T/P_T^2$ (c/GeV), no vertex

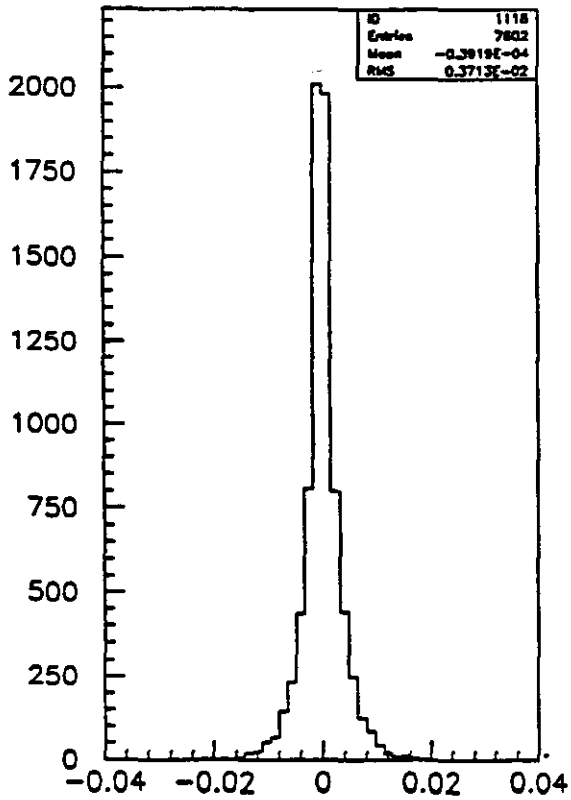


Fig. 6a, delta(x) (cm) non linear fit

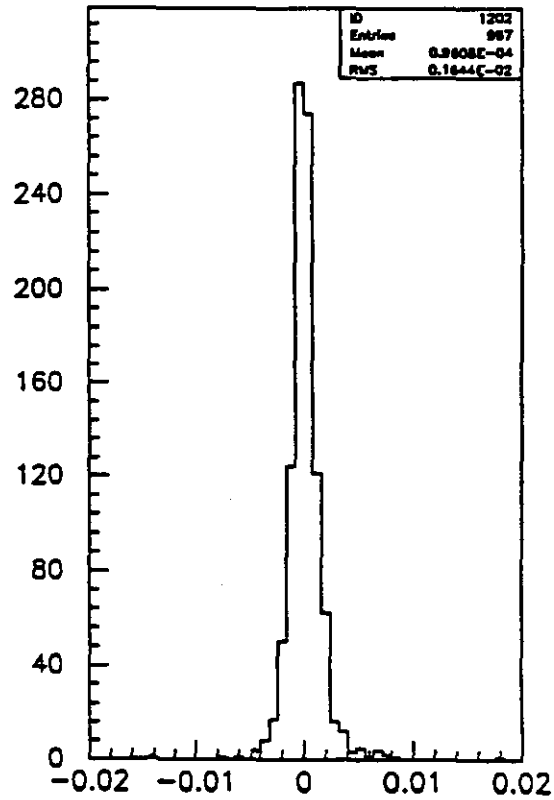


Fig. 6b, $\Delta P_T/P_T^2$ (c/GeV), with vertex

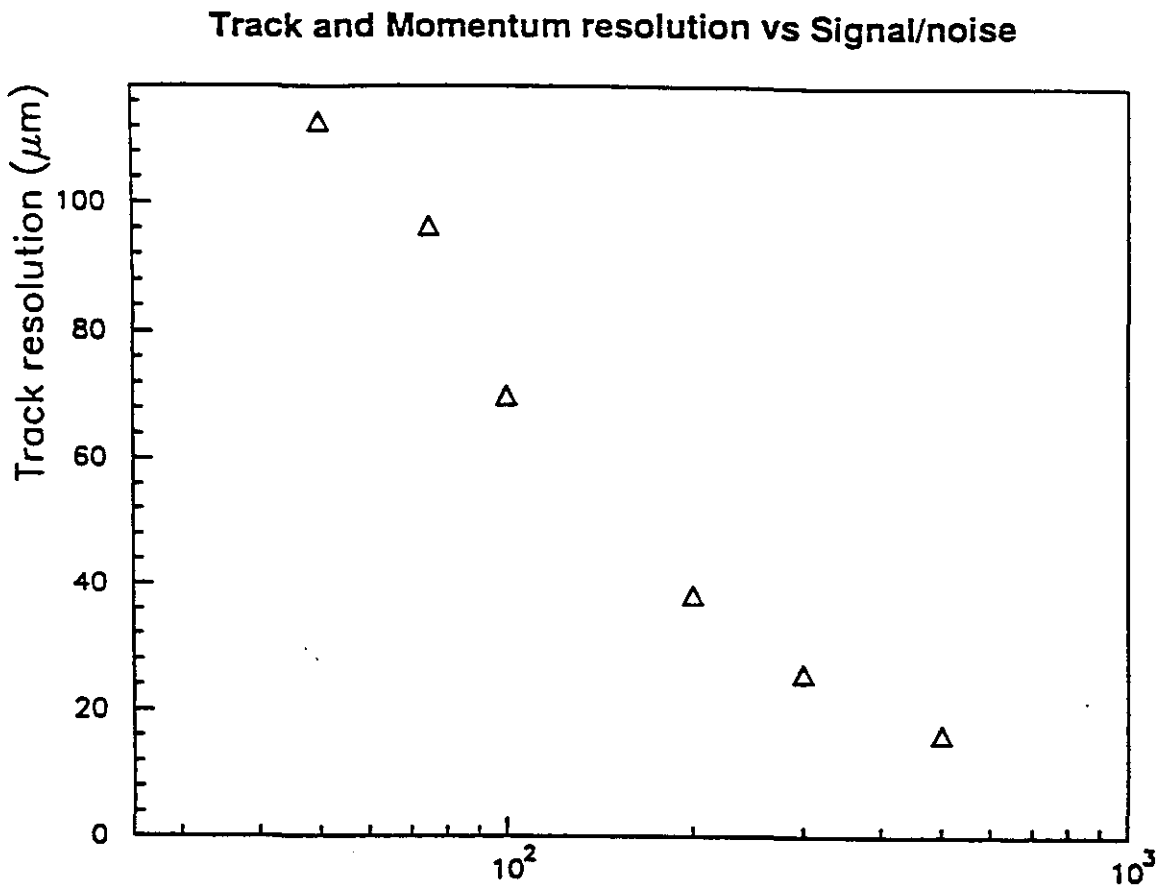


Fig. 7 Signal/noise

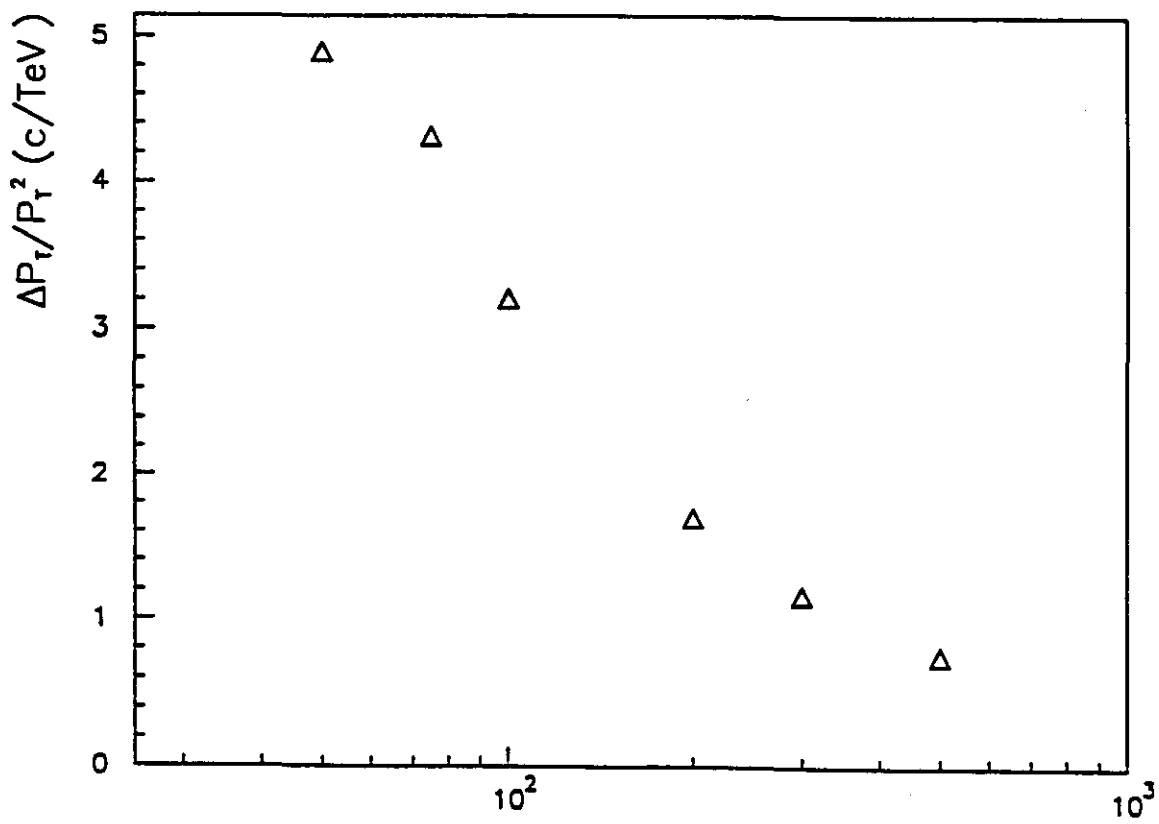


Fig. 8 Signal noise

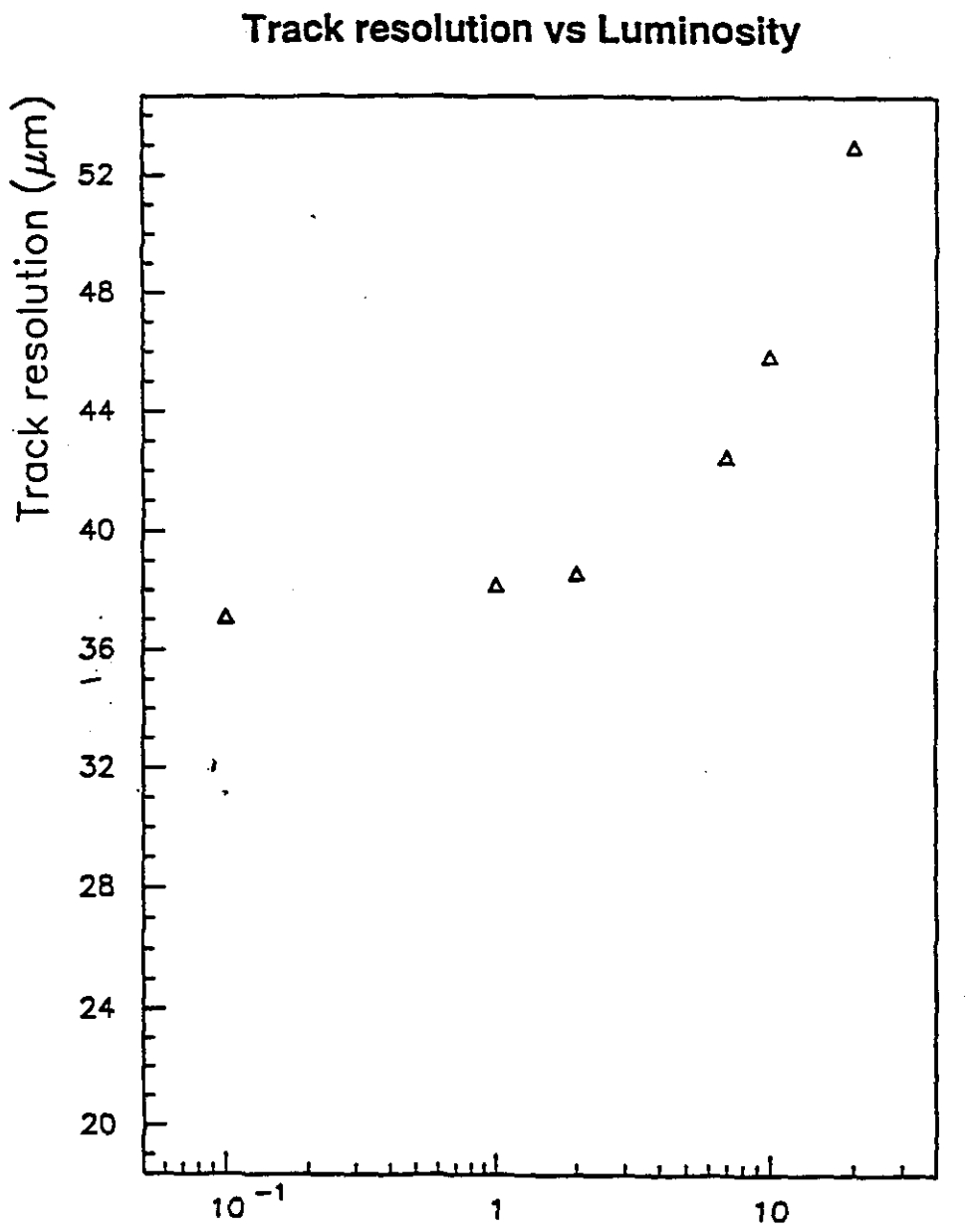


Fig. 9 Luminosity ( $\times 10^{33}$ $cm^{-2}sec^{-1}$)

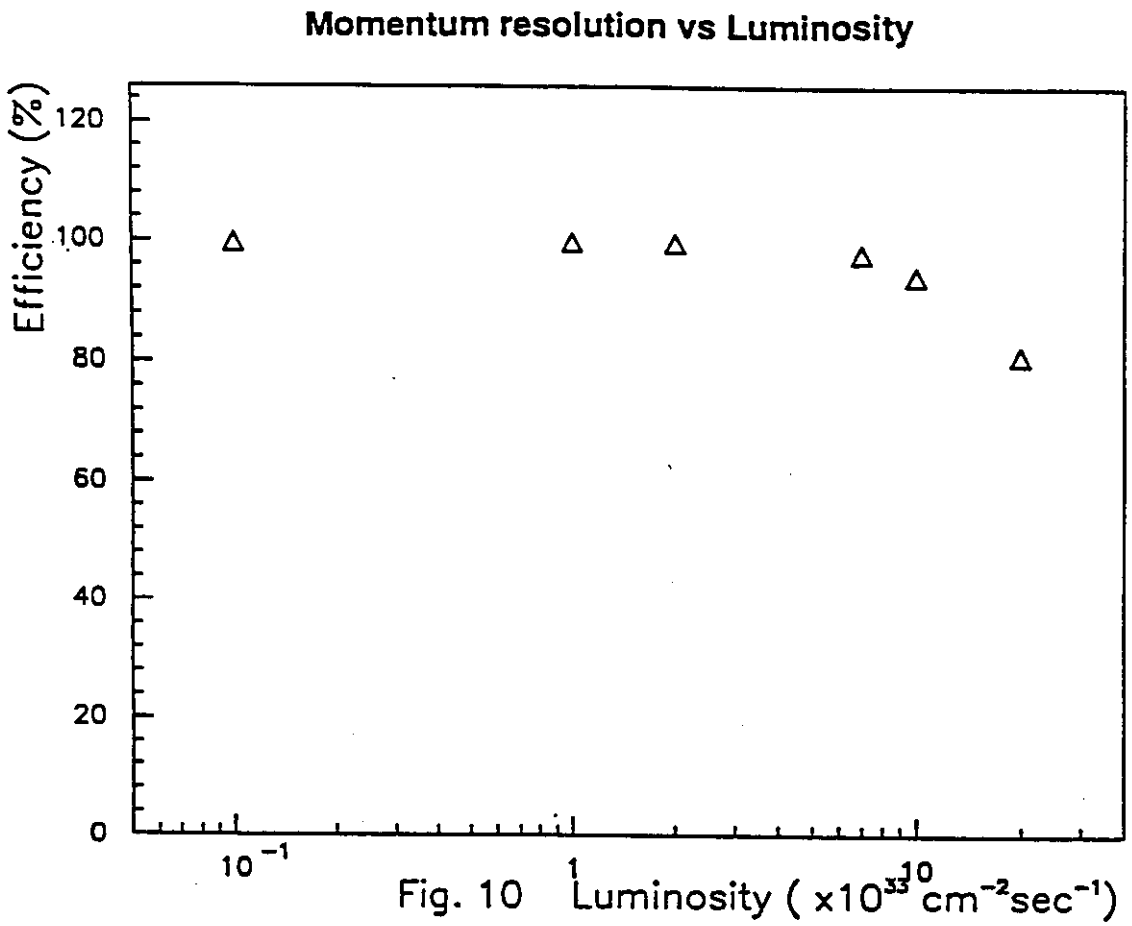
Momentum resolution vs Luminosity
Efficiency (%)
120
100
80
60
40
20
0
$10^{-1}$
1
10
Luminosity ( $\times 10^{33}$ $cm^{-2}sec^{-1}$)

Fig. 10

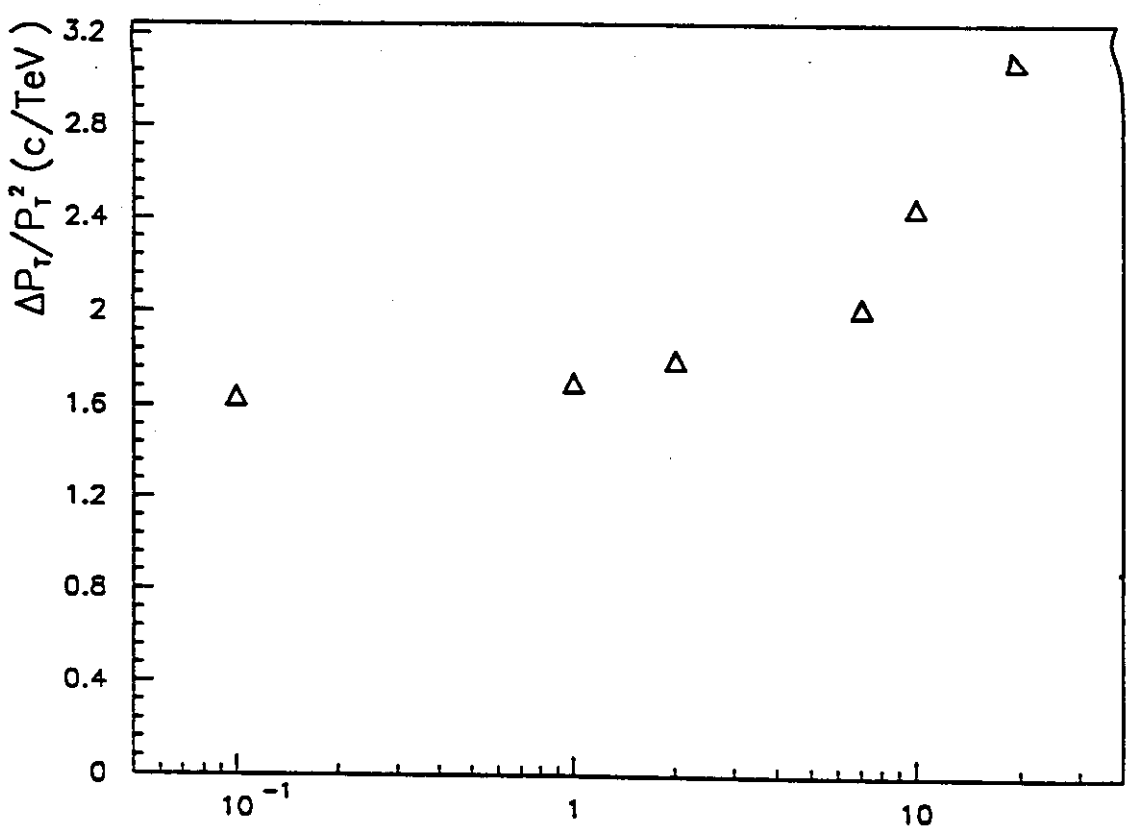
$\Delta P_T/P_T^2$ (c/TeV)
3.2
2.8
2.4
2
1.6
1.2
0.8
0.4
0
$10^{-1}$
1
10
Luminosity ( $\times 10^{33}$ $cm^{-2}sec^{-1}$)

Fig. 11

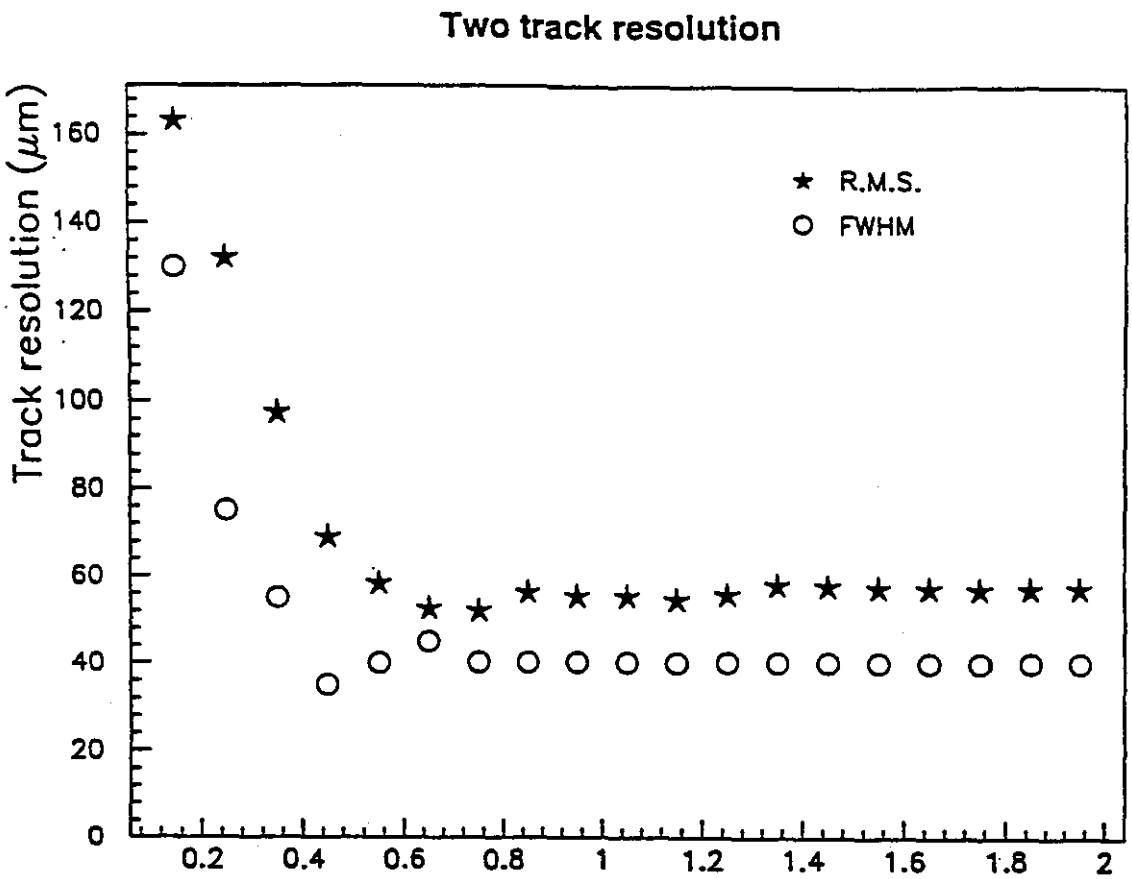


Fig. 12 Two track distance (cm)

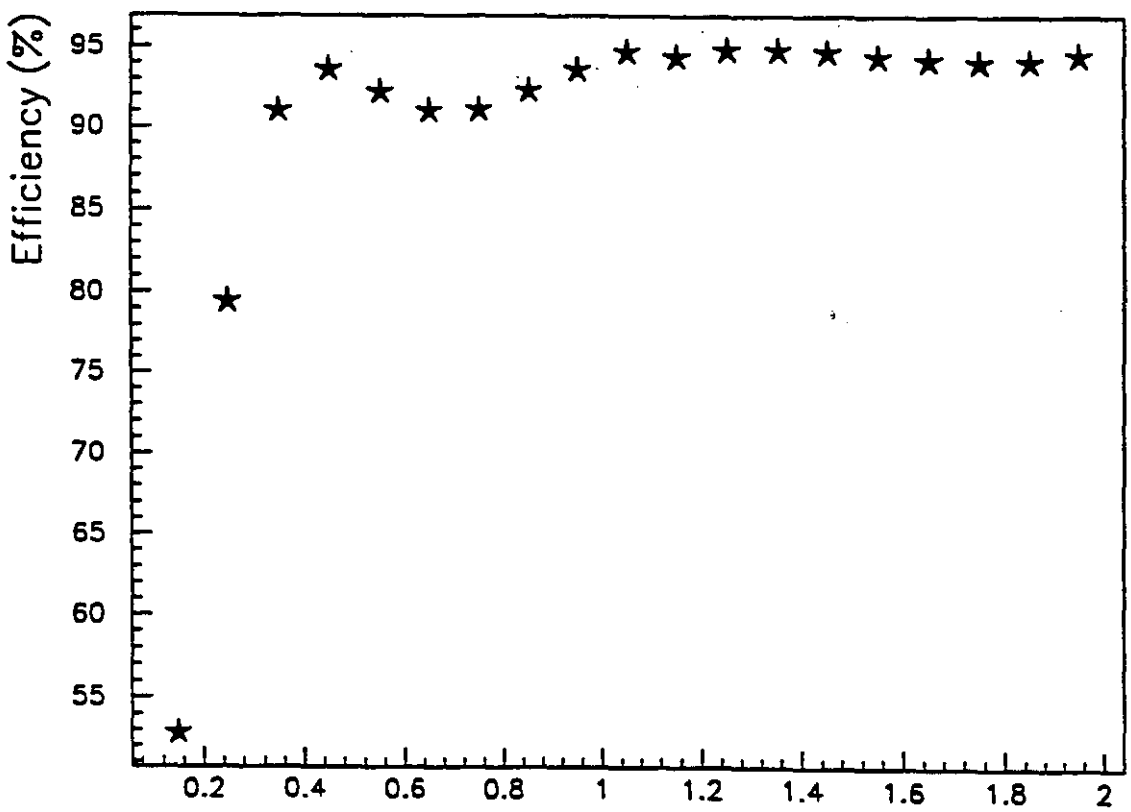


Fig. 13 Two track distance (cm)