Tracking Resolution Requirements in the Meson Spectroscopy Facility at Jefferson Lab

Curtis A. Meyer

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1 Introduction

In order to understand the resolution requirements of the HALL D detector, the *MCFast* program has been used to simulate the tracking elements in the LASS solenoidal field at $B = 2.24T$. The tracks have been generated at 10 distinct total momenta, and then binned in 5° wide bins from 0° to 180°. These tracks have then been tracked through the detector as shown in figure 1.

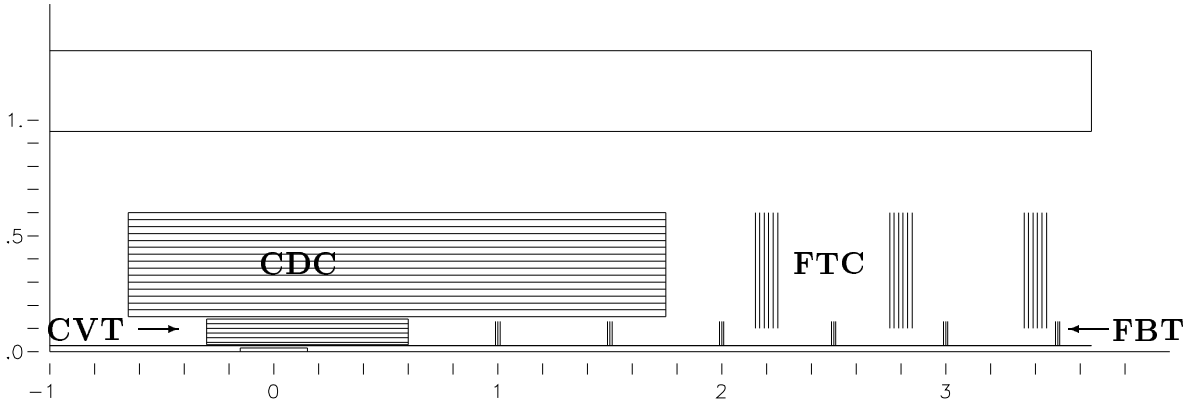

Figure 1: A schematic drawing of the tracking elements in the HALL D detector. All dimensions are in meters. Shown is a side view along the length of the detector system. The large rectangle is the *central drift chamber*, (CDC); the smaller rectangle closer to the target is the *central vertex tracker*, (CVT); the three forward rectangular regions are the *forward tracking chambers*, (FTC); and the six small rectangles close to the beam line are the *forward beam line tracker*, (FBT).

A summary of the geometry and resolutions are given in table 1.

The default detectors has four tracking systems in it. The large rectangular box around the target is the *central drift chamber*, (CDC), a cylindrical chamber with 16 drift layers going out radially. It's nominal $r\phi$ resolution is $200\mu m$. There are also six stereo layers at angles of ± 0.104, and cathode strips on the inner and outer radii. The cathode strips have a nominal $500\mu m$ resolution in z. The innermost layer is at $r = 15cm$, and the outermost is at $r = 60cm$. The chamber extends from $z = -75cm$ to $z = 175cm$.

The smaller rectangle just around the target is a 5–layer vertexing chamber, the *central vertex chamber*, (CVT). This has a nominal $80\mu m$ $r\phi$ resolution, but provides no z information. The innermost layer is at $r = 4cm$ and the outermost is at $r = 12cm$. The chamber extends from $z = -30cm$ to $z = 60cm$.

The three thin boxes in the forward region are 6–layer disk–shaped *forward tracking*

chambers, (FTC). These provide two planes each of u, v and y planes, with a nominal resolution of $200\mu m$ in each plane. These start at $r = 15cm$ and extend out to $r = 60cm$. They are positioned at $z = 220cm$, $z = 280cm$ and $z = 340cm$.

The six small boxes just outside the beam pipe are high resolution, three–plane tracking chambers, the *forward beam line tracker*, (FBT). These provide nominally $20\mu m$ resolution close to the beam pipe. The chambers start at $r = 2.5cm$ and extend to $r = 13cm$. They are placed at $z = 100cm$, $z = 150cm$, $z = 200cm$, $z = 250cm$, $z = 300cm$ and $z = 350cm$. Each plane is nominally $500\mu m$ of silicon.

The conclusions reached in this report are by no means final. The detector sizes and positions are based on Jim Mueller's talk at the June '98 meeting at Jefferson Lab, and have not been significantly varied. The default resolutions have only been educated guesses, and based on this report, it will be seen that several are incorrect. There has also been insufficient time to optimize the size and placement of detector planes, and it is likely that real estate will have to be forfeited outside the $60cm$ radius for other detector systems.

Detector System	Global Geometry				Planes	Resolution
	r_{min}	r_{max}	z_{min}	z_{max}		
CVC	$3.00cm$	$14.00cm$	$-30.0cm$	$45.0cm$	5	$\sigma_{r\phi} = 80\mu m$
CDC	$15.00cm$	$60.00cm$	$-75.0cm$	$175.0cm$	2	$\sigma_z = 500\mu m$
CDC	$15.00cm$	$60.00cm$	$-75.0cm$	$175.0cm$	16	$\sigma_{r\phi} = 200\mu m$
FTC1	$10.00cm$	$60.00cm$	$215.0cm$	$225.0cm$	6	$\sigma_m = 200\mu m$
FTC2	$10.00cm$	$60.00cm$	$275.0cm$	$285.0cm$	6	$\sigma_m = 200\mu m$
FTC3	$10.00cm$	$60.00cm$	$35.0cm$	$345.0cm$	6	$\sigma_m = 200\mu m$
FBT1	$2.50cm$	$13.00cm$	$99.0cm$	$101.0cm$	3	$\sigma_m = 20\mu m$
FBT2	$2.50cm$	$13.00cm$	$149.0cm$	$151.0cm$	3	$\sigma_m = 20\mu m$
FBT3	$2.50cm$	$13.00cm$	$199.0cm$	$201.0cm$	3	$\sigma_m = 20\mu m$
FBT4	$2.50cm$	$13.00cm$	$249.0cm$	$251.0cm$	3	$\sigma_m = 20\mu m$
FBT5	$2.50cm$	$13.00cm$	$299.0cm$	$301.0cm$	3	$\sigma_m = 20\mu m$
FBT6	$2.50cm$	$13.00cm$	$349.0cm$	$351.0cm$	3	$\sigma_m = 20\mu m$

Table 1: The initial geometry and resolution specifications of the detector.

2 The Forward Beam line Tracker

The *Forward Beam line Tracker*, (FBT), is the set of six high-resolution chambers that sit near the beam pipe in the forward region as shown in figure 1. In figure 2 are plotted the total momentum resolution, $\frac{\Delta p}{p}$, as a function of θ as measured from the beam direction. There are ten curves for p ranging from $0.250 GeV/c$ up to $5.000 GeV/c$. The FBT affects only the forward most two bins, $1^\circ < \theta < 5^\circ$ and $5^\circ < \theta < 10^\circ$. The first three plots in figure 2 are for a nominal resolution of $20\mu m$, $100\mu m$ and $200\mu m$ with material (silicon) in the detectors. The fourth plot has $20\mu m$ resolution, but the silicon has been replaced with air. The first three plots show that the resolution in the most forward bin is unaffected by the chamber resolution, and only the removal of material to reduce multiple scattering improves the momentum resolution.

This effect is seen more clearly in figures 3 to 6. These figures show $\frac{\Delta p}{p}$ in each momentum bin in the most forward angular bin. Figure 3 has both the beam-pipe and the mass in the chambers removed, but the chambers retain their $20\mu m$ resolution. Figure 4 puts the beam pipe back in, ($500\mu m$ thick Be pipe at a radius of 2.50 cm and extending the entire length of the solenoid). Finally, figure 5 has the beam-pipe removed, but the material in these chambers put back in.

The effect of the chamber resolution can be seen in figure 6 which has $20\mu m$ resolution, figure 7 which has $100\mu m$ resolution and figure 8 which has $200\mu m$ resolution. The bottom line is that the resolution does not have a significant impact on the momentum resolution. The major role is played by the material — this region is multiple scattering limited. However, the fact that the resolution is degraded does not mean that these chambers are unimportant. These fill an important gap in the solid angle of the detector, and are key to good efficiency.

In fact, as one final test we have set the resolution to $200\mu m$ and replaced the material with gas — essentially gas filled drift or wire chambers. In figure 9 are shown the resolution as a funtion of momentum in the most forward angular bin. One can see that this is in fact better than most of the plots for high resolution silicon detectors. Unless we can develop a zero–mass chamber with extremely high resolution, something much simpler will suffice.

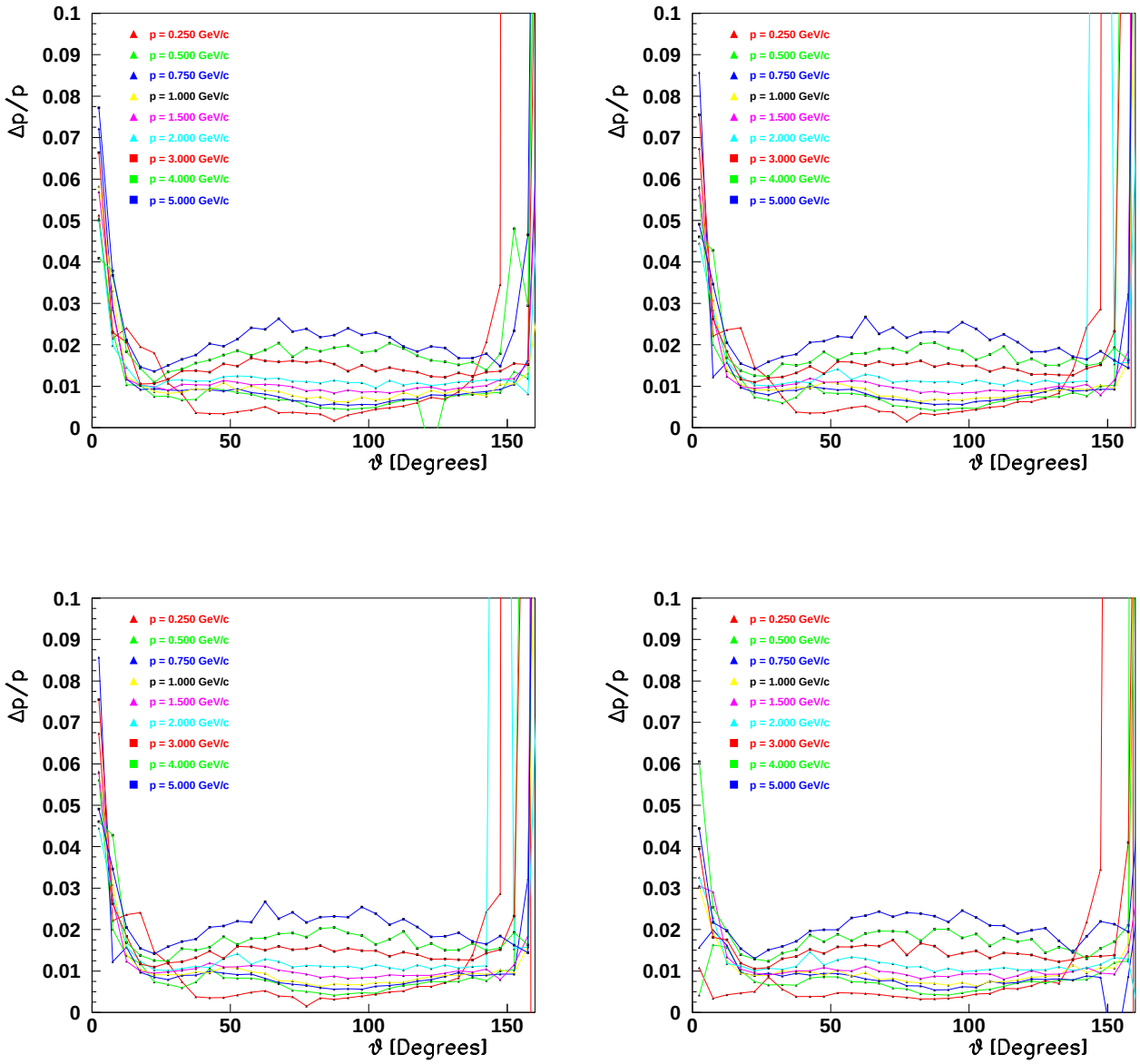

Figure 2: Total momentum resolution , $\sigma(\frac{\Delta p}{p})$,as a function of θ for various momenta. This figure varies the resolution of the FBT system. The upper left figure has all detectors with their nominal resolutions, ($20\mu m$ for the forward), (see Fig. 6). The upper right has $100\mu m$ resolution, (see Fig. 7), and the lower left has $200\mu m$ resolutions, (see Fig. 8). The lower right figure has most of the mass removed from the forward chambers with the $20\mu m$ resolution, (see Fig. 4). Only the lowest two angular bins are affected by this resolution.

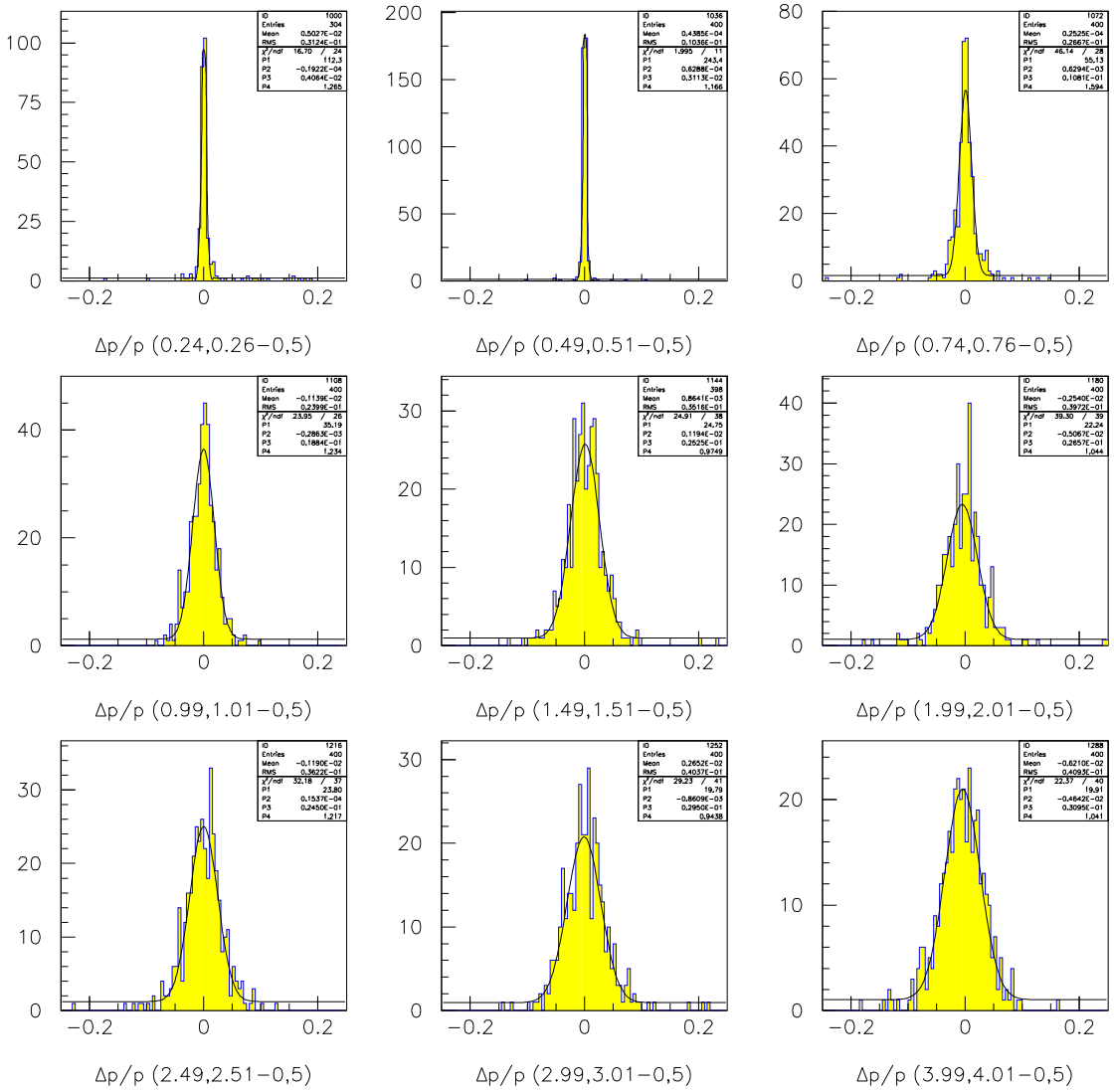

Figure 3: Resolution as a function of momentum in the most forward angular bins. Most of the mass of the chambers and the beam pipe have been removed to minimize multiple scattering. The detectors have a $20\mu m$ resolution.

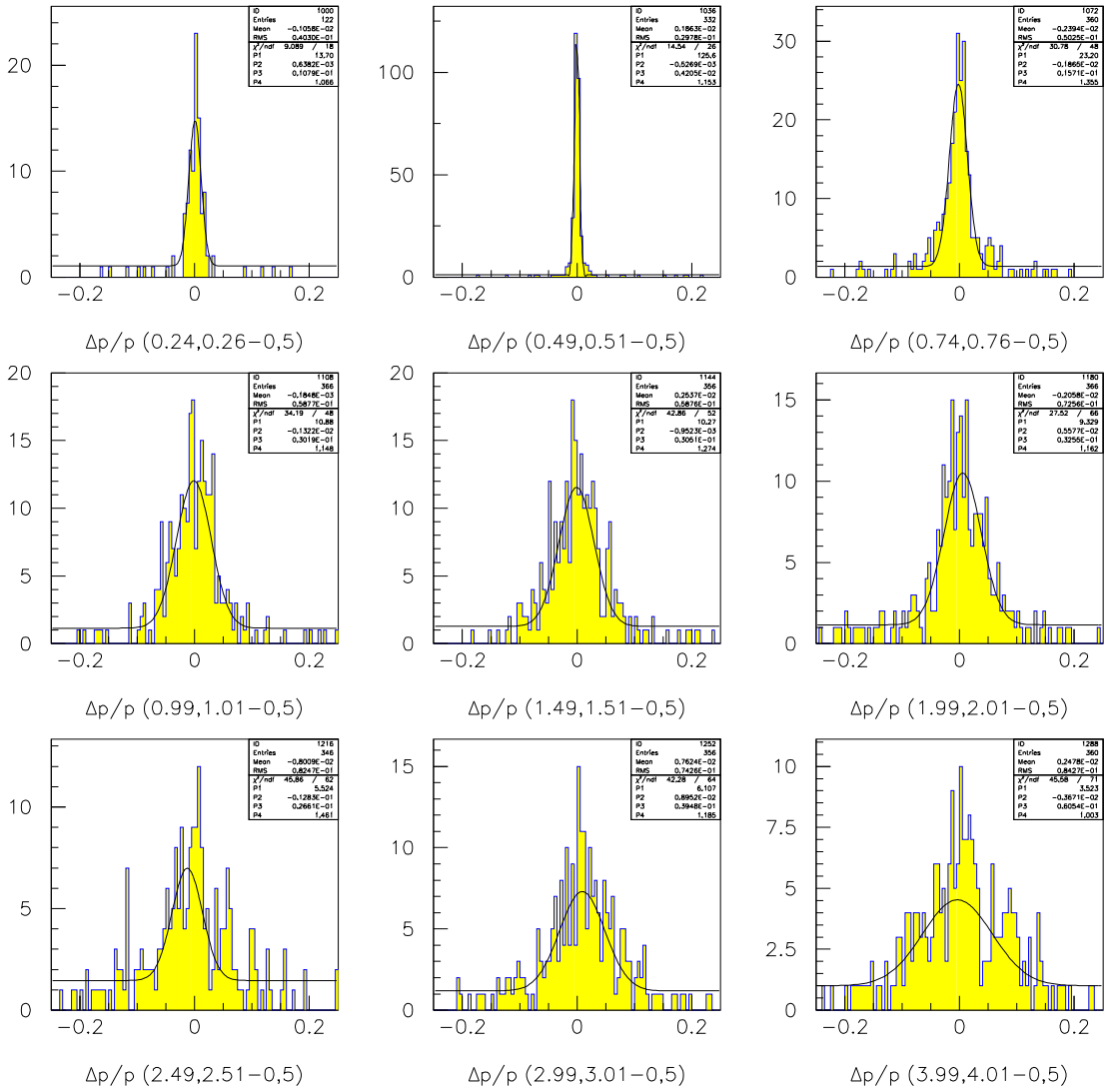

Figure 4: Resolution as a function of momentum in the most forward angular bins. Most of the mass of the chambers has been removed to minimize multiple scattering. The detectors have a $20\mu m$ resolution.

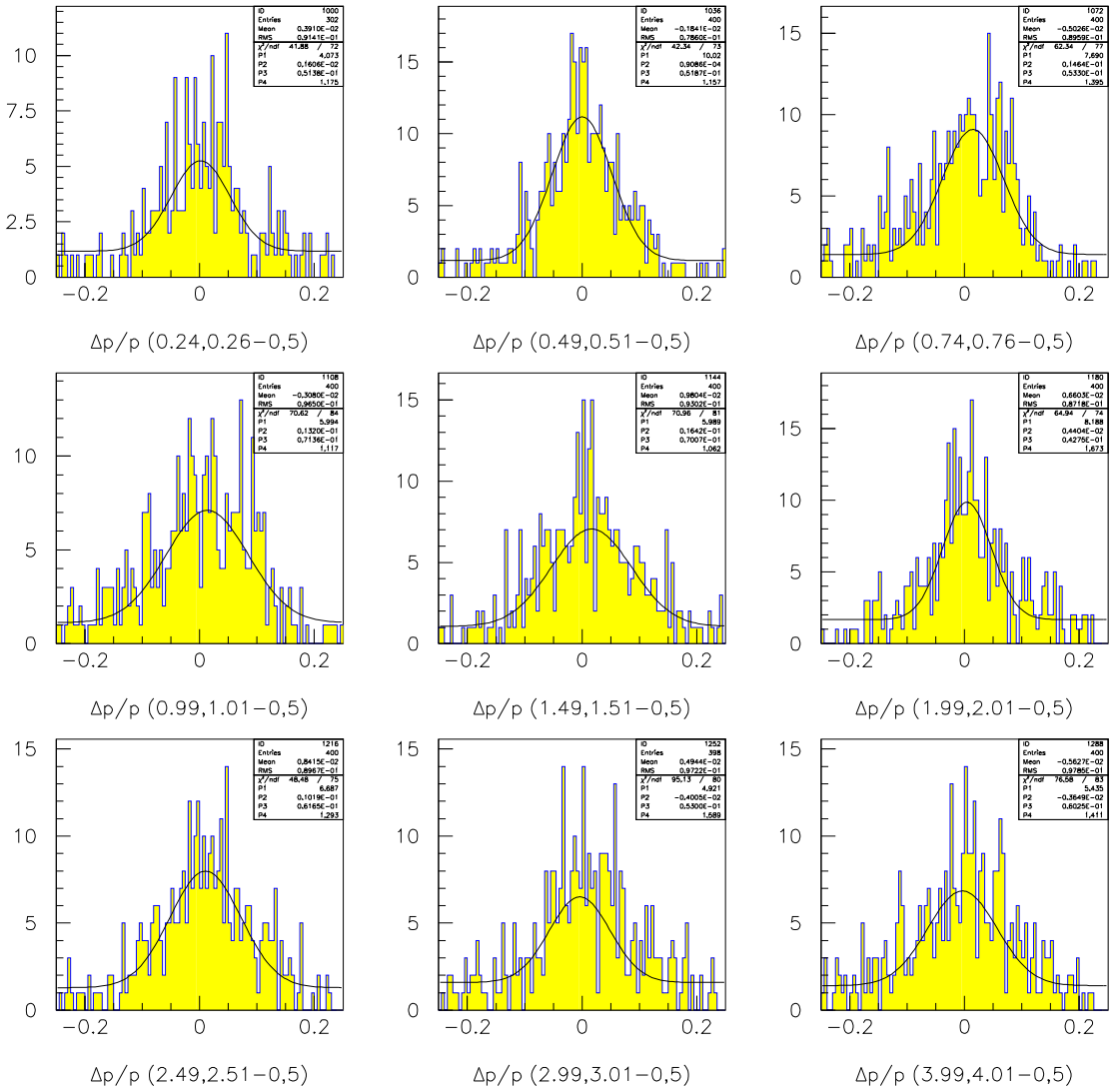

Figure 5: Resolution as a function of momentum in the most forward angular bins. The beam-pipe has been removed, but the chambers still have mass, and the detectors have a $20\mu m$ resolution.

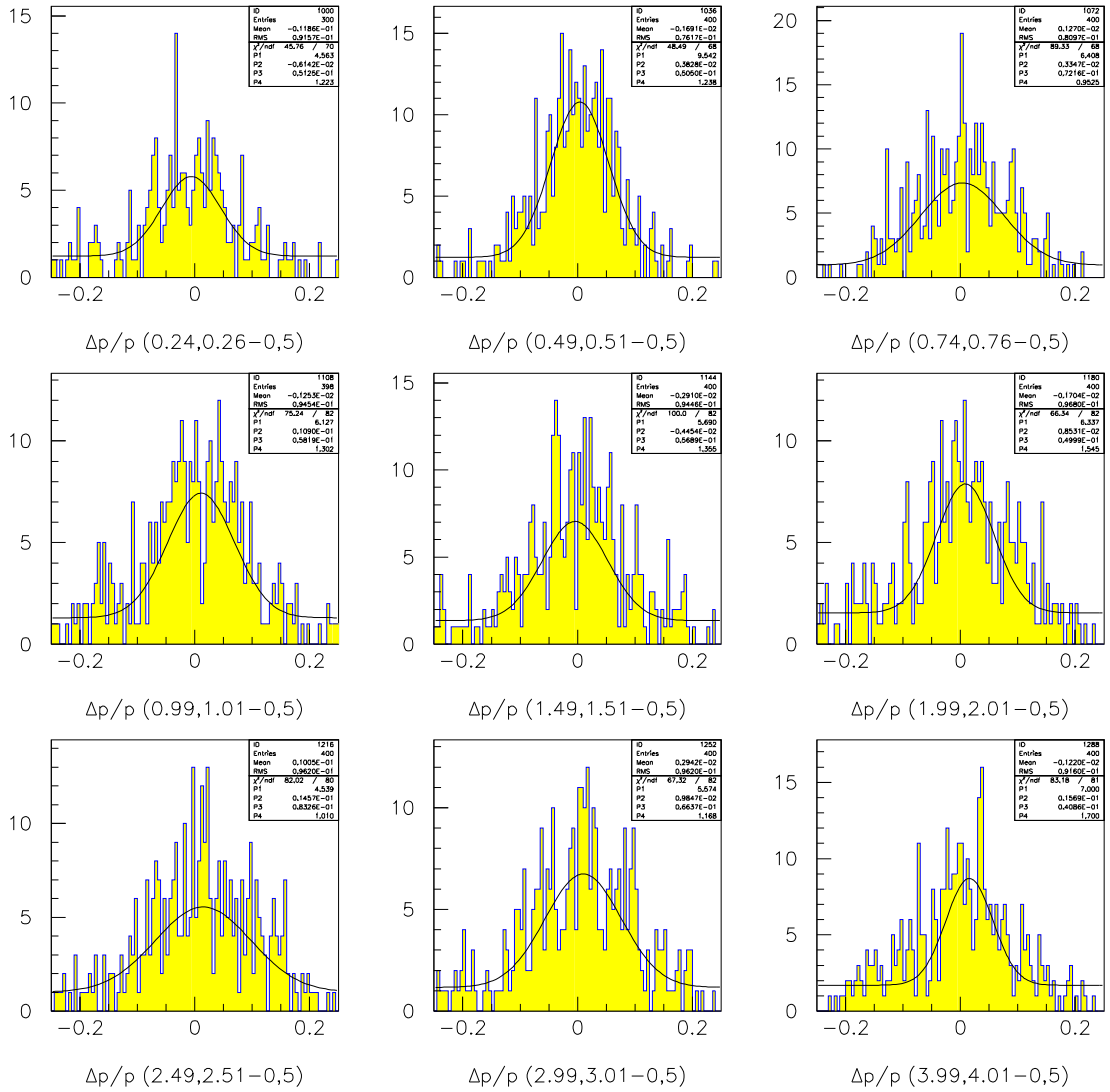

Figure 6: Resolution as a function of momentum in the most forward angular bins. The detectors have $20\mu m$ resolution.

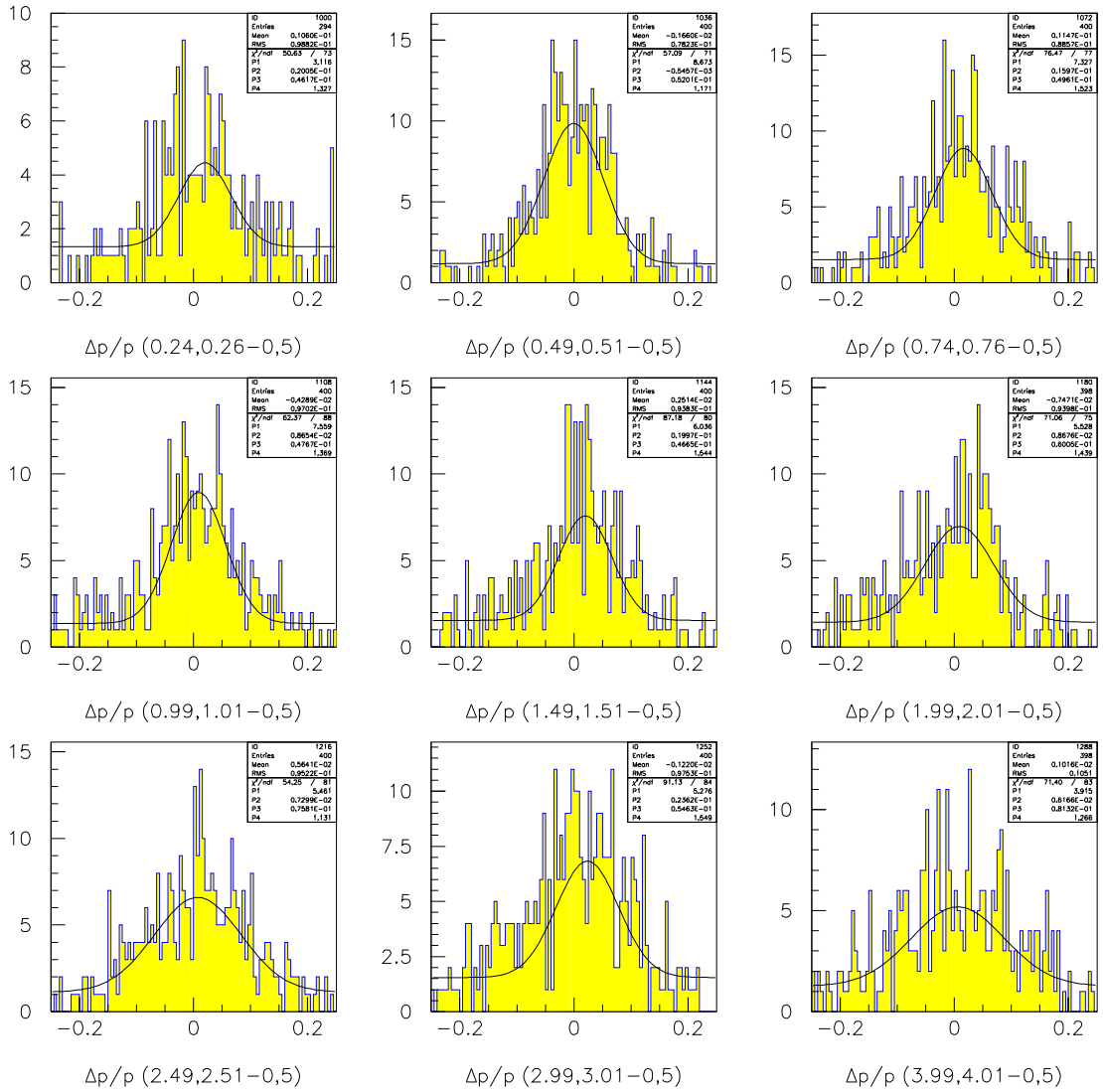

Figure 7: Resolution as a function of momentum in the most forward angular bins. The detector has $100\mu m$ resolution.

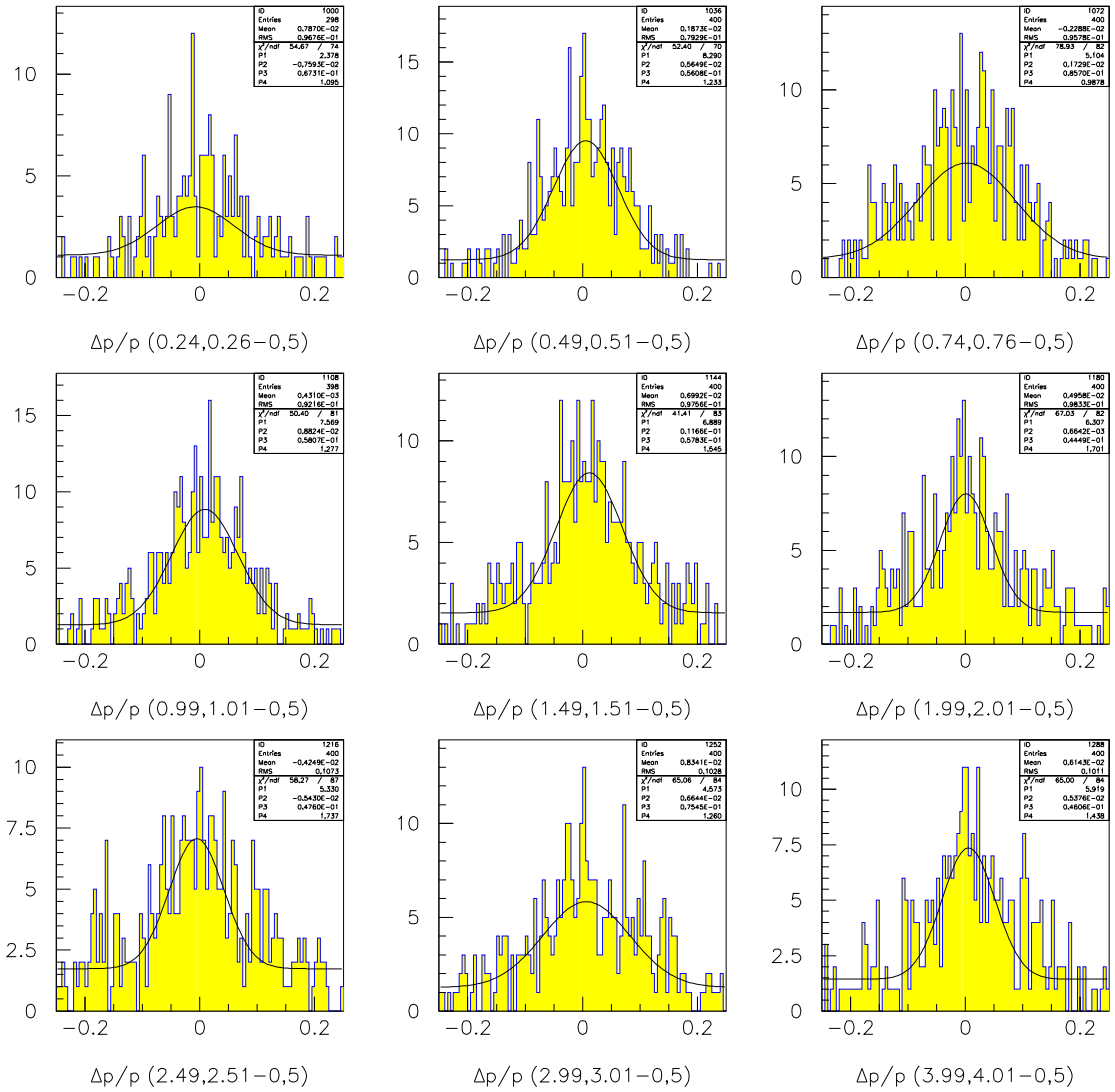

Figure 8: Resolution as a function of momentum in the most forward angular bins. The detector has $200\mu m$ resolution.

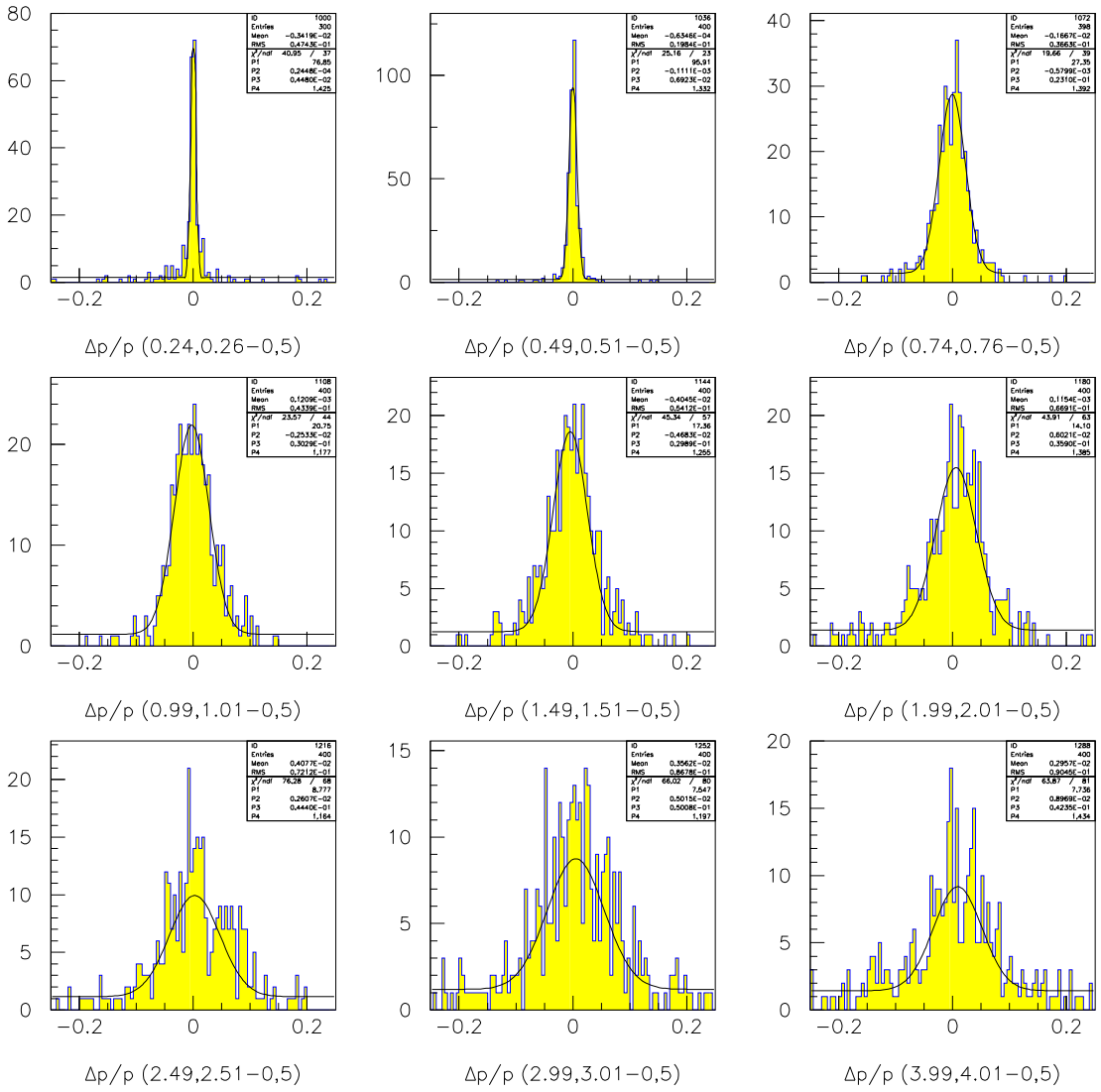

Figure 9: Resolution as a function of momentum in the most forward angular bins. The chambers have been replaced with a $200\mu m$ resolution chamber filled with gas, rather than silicon.

3 The Central Vertex Detector

The *Central Vertex Tracker*, CVT, is a five–layer cylindrical chamber with only $r\phi$ information from an inner radius of 3.00 cm and an outer radius of 14.00 cm. The nominal $r\phi$ resolution is set to $80\mu m$. Figure 10 shows the effect of the resolution on the overall momentum resolution, $\frac{\Delta p}{p}$. The upper left plot is for $20\mu m$, the upper right is for $80\mu m$ and the lower left is for $200\mu m$. This chamber contributes in the 50° to 120° region in θ, and while there is a noticeable improvement in the momentum resolution of $5GeV/c$ tracks in this region, even with $200\mu m$ resolution, most of the tracks will be measured to better than 2%.

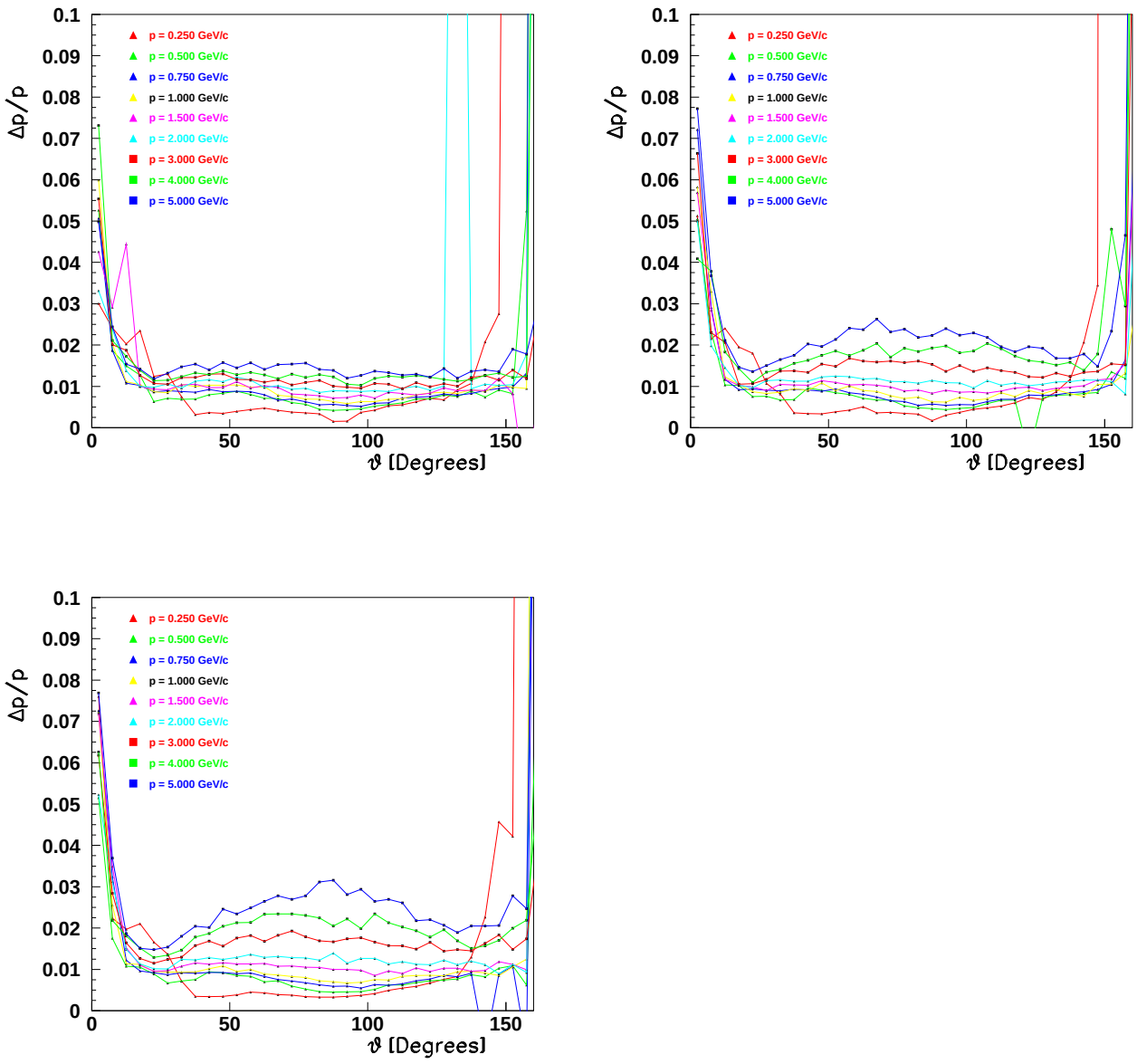

Figure 10: Total momentum resolution, $\sigma(\frac{\Delta p}{p})$, as a function of the resolution of the central vertex tracker. The upper left figure has $20\mu m$ resolution, the upper right has the nominal $80\mu m$ resolution, and the lower left has $200\mu m$ resolution.

4 The Central Drift Chamber

The *Central Drift Chamber*, CDC, is a sixteen–layer cylindrical chamber with cathode strips measuring the z–coordinate at the inner and outer radii. It extends from 15.0 cm to 60.0 cm in radius, and the $r\phi$ resolution is nominally $200\mu m$. There are six stereo layers (5,6,9 and 10 at $+0.104$ radians and 7 and 8 at -0.104 radians). The resolution, $\frac{\Delta p}{p}$ as a function of chamber resolution is shown in figures 11 and 12. Figure 11 shows the effect of varying the $r\phi$ resolution. The upper left plot is for $100\mu m$, the upper right is for $200\mu m$, and the lower left is for $500\mu m$ resolution. Figure 12 shows the effect of varying the z resolution of the cathode strips. The upper left plot is for $100\mu m$, the upper right is for $500\mu m$ and the lower left is for $5000\mu m$ resolutions.

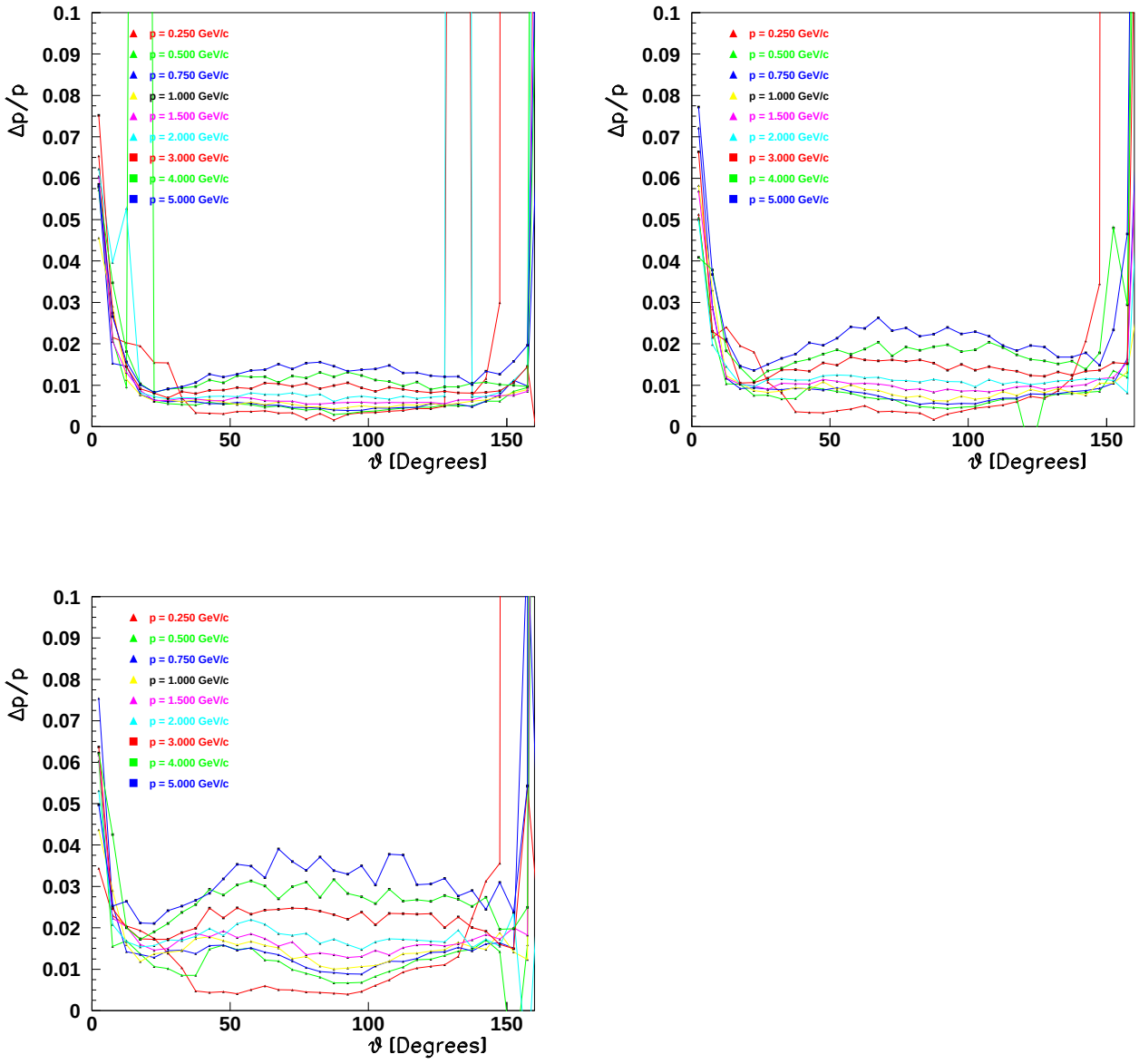

Figure 11: Total momentum resolution, $\sigma(\frac{\Delta p}{p})$, as a function of the resolution of the central drift chamber. The upper left figure has $100\mu m$ resolution, while the upper right has the nominal $200\mu m$. The lower left has $500\mu m$ resolution.

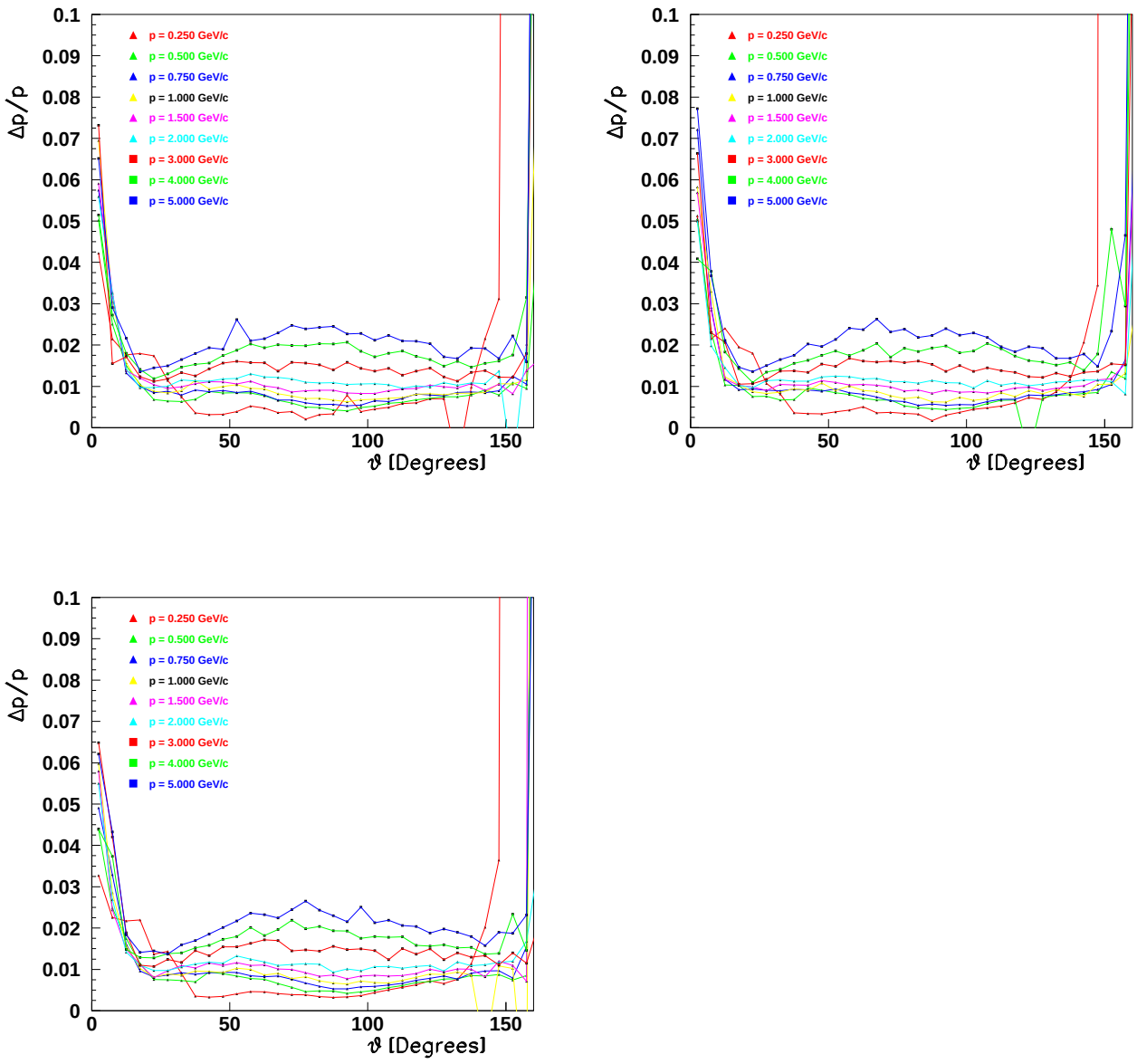

Figure 12: Total momentum resolution, $\sigma(\frac{\Delta p}{p})$, as a function of the z–resolution of the cathode strips. The upper left figure has $100\mu m$ resolution, while the upper right has the nominal $500\mu m$ resolution. The lower left has $5000\mu m$ resolution.

5 The Forward Tracking Chambers

The *Forward Tracking Chambers*, (FTC), consist of three packages of six–plane drift chambers for measuring tracks down–stream of the CTC. The primary purpose of this chamber is to accurately measure the momentum of fast particles that come out of the downstream end of the CTC. In figure 13 are plotted $\frac{\Delta p}{p}$ versus θ for different resolutions in the FTC. The upper left plot has $100\mu m$ resolution, the upper right has the nominal $200\mu m$'s. The lower left has $500\mu m$ and the lower right has $1000\mu m$. The bins that are most affected by these chambers are the 5° to about 30° angles, In figures 14 to 17 are shown the resolution in the 5° to 10° bin for the same resolutions.

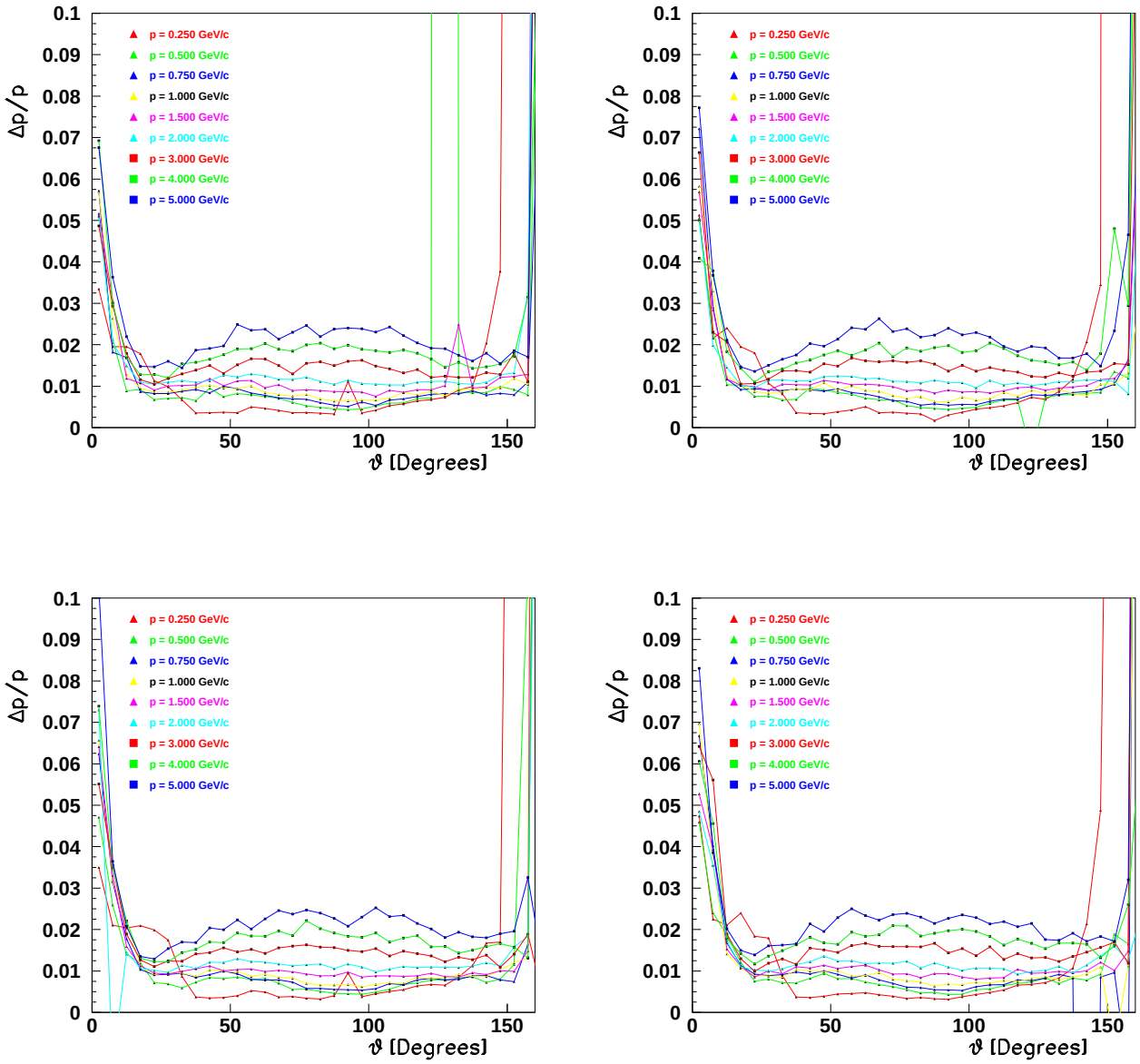

Figure 13: Total momentum resolution, $\sigma(\frac{\Delta p}{p})$, as a function of the resolution of the forward tracking chambers. The upper left figure has $100\mu m$ resolution, while the upper right has the nominal $200\mu m$ resolution. The lower left has $500\mu m$ resolution and the lower right has $1000\mu m$ resolution.

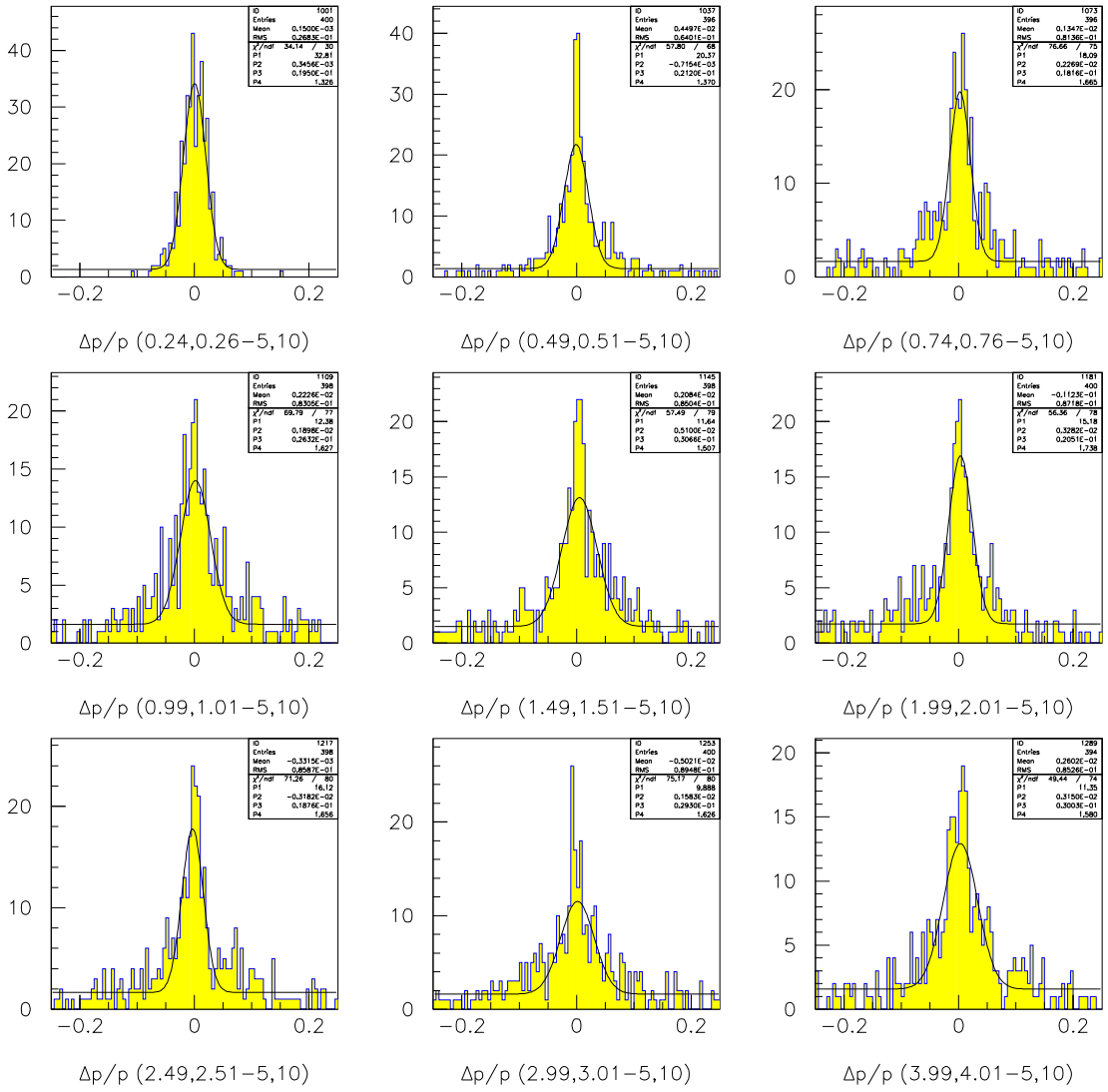

Figure 14: Resolution as a function of momentum in the 5° to 10° angular bin. The forward tracking chamber has a resolution of $100\mu m$.

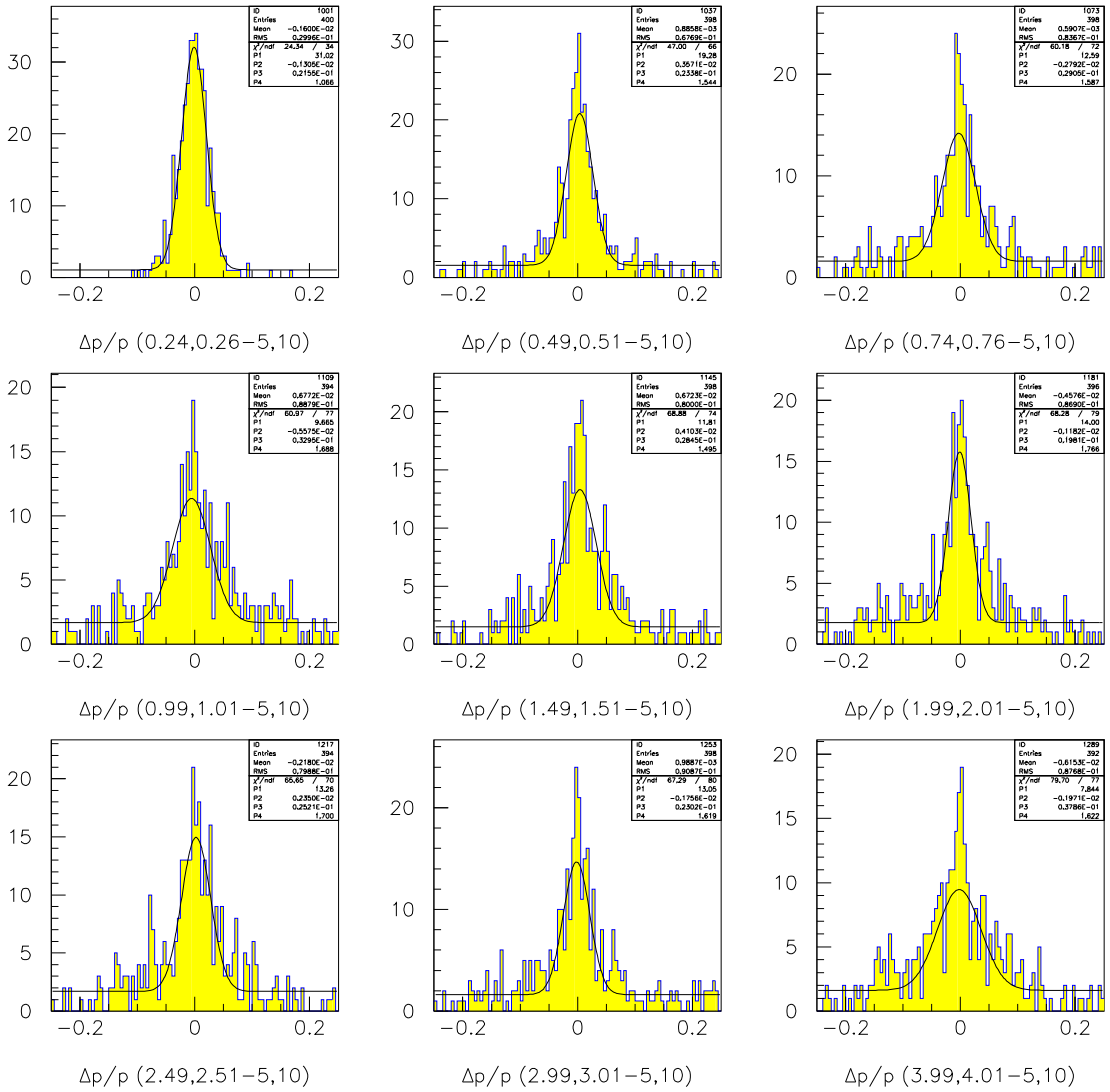

Figure 15: Resolution as a function of momentum in the 5° to 10° angular bin. The forward tracking chamber has a resolution of $200\mu m$.

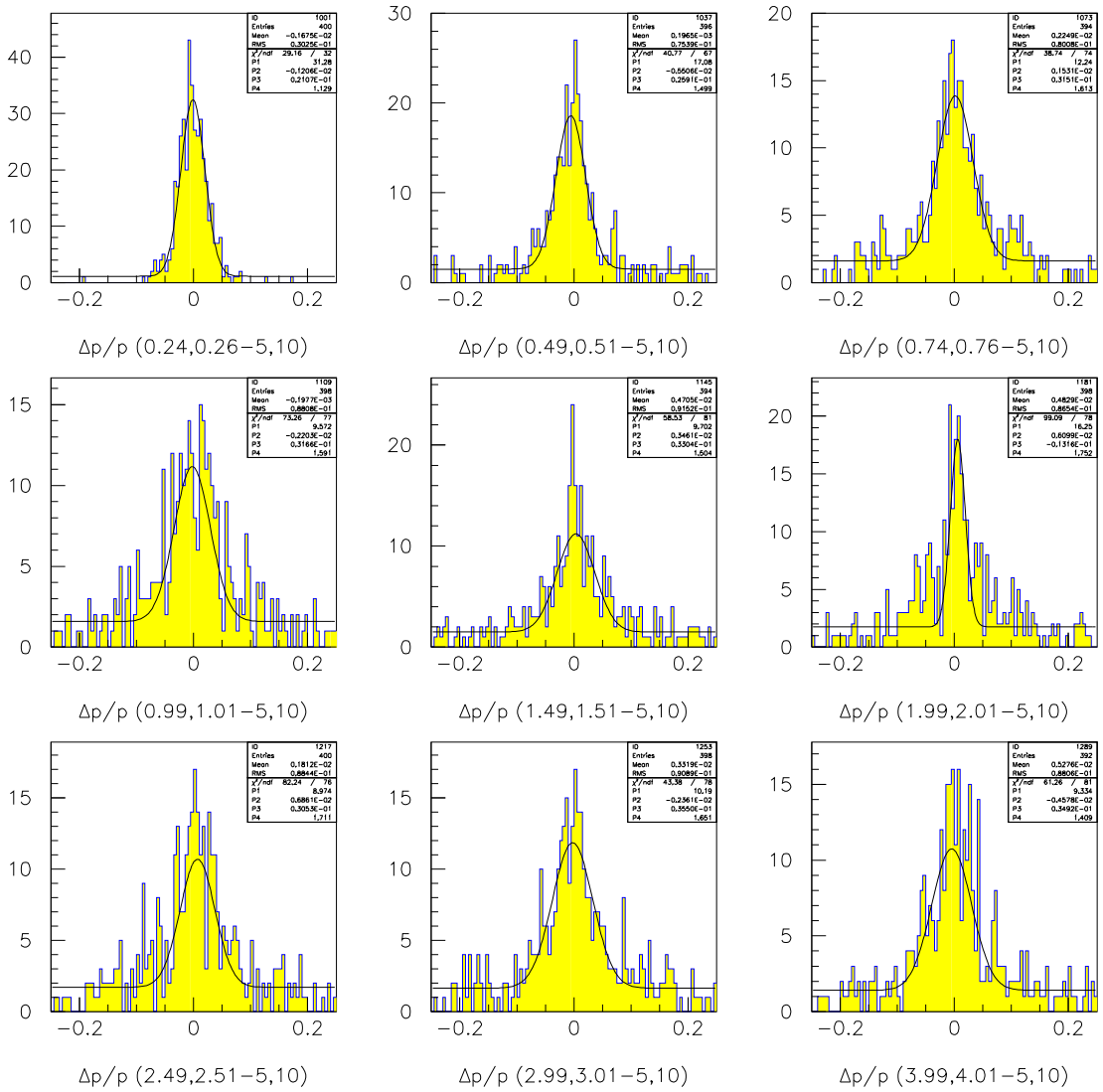

Figure 16: Resolution as a function of momentum in the 5° to 10° angular bin. The forward tracking chamber has a resolution of $500\mu m$.

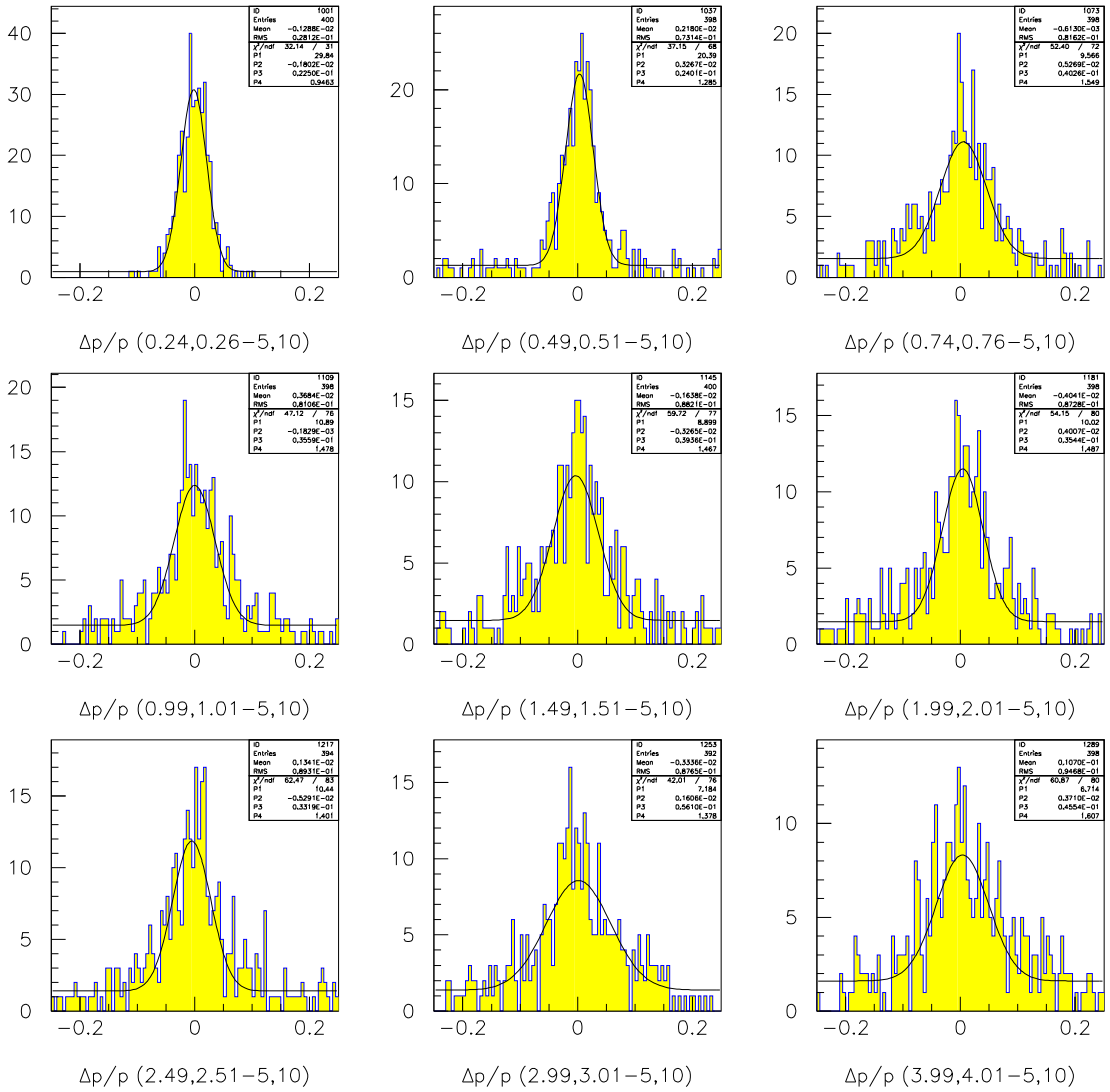

Figure 17: Resolution as a function of momentum in the 5° to 10° angular bin. The forward tracking chamber has a resolution of 1000μm.