Cosmic Ray muon analysis of Magnet off data or why we think errors in the magnetic field didn't cause the charge ratio biases NuMI note 4104

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Abstract

Analysis of the magnet off data suggested that uncertainties in the magnetic field were not related to strange azimuth distributions in the MINOS cosmic ray charge ratio analysis.

1 Introduction

Two ideas for the cause of a number of bias effects seen in the MINOS cosmic ray charge ratio analysis are

- Uncertainties in the magnetic field
- Alignment errors

The minimum information cut (MIC) used in one of the two analyses was motivated by the first idea.[1] There are three arguments that I have used to favor the 2nd idea:

1. Analysis of the Magnet off Data
2. Analysis of Monte Carlo using different field maps to a) generate and b) analyze the data
3. The fact that the charge is a property of the track curvature independent of any details of the magnetic field.

Analysis of the magnet off data has been presented many times, but never documented in a note (other than Erik Beall's thesis)[2]. The purpose of this note is to present that analysis, which was done in 2004 and 2005. Analyses of Monte Carlo data using different magnetic fields to generate and analyze the data were done separately by Brian Rebel, Erik Beall and Gavril Giurgiu. I do not here present any of these results, but it is my clear memory that these were unable to qualitatively account for any of the biased distributions that we saw.

Let me remind the reader of my use of the terms "bias" and "randomization". A bias is something due to the program, alignment, magnetic field, acceptance or anything

*Work referred to in this note was carried out by Erik Beall and Gavril Giurgiu else which will cause an incorrect charge ratio to be measured. The bias can be of either sign and any amount, but when forward and reverse field data are combined appropriately, the bias will cancel. On the other hand, a randomization is a process in which some number of tracks will be randomly assigned a positive or negative charge in equal number. Since the charge ratio +/- is greater than one, this will always lower the charge ratio and this is not canceled by combining forward and reverse field data. This note is mostly about bias, which originally showed up in the azimuth distribution of the charge ratio, but is also present in many other distributions.

2 Magnet On Data

Figures 1-4 show six distributions of the charge ratio as follows:

Upper Left Cosmic Ray Azimuth

Middle Left Cosmic Ray Zenith

Lower Left Momentum

Upper Right Vertex plane

Middle Right Detector Azimuth

Lower Right Detector Zenith

In Figure 1, these plots are shown for the Forward Field; in 2 the Reverse Field; in 3 the Monte Carlo; and in 4 the Combined data. These same distributions were shown in NuMI note 2827[3] to show the effectiveness of combining the data to reduce bias effects from any source. In each plot, the charge ratio is shown before (black) and after (red) a variety of cuts, designed to choose the best muons and get rid of mostly-straight tracks, which cause randomization. Thus the black points have smaller error bars but are lower. Most of the gyrations in Figures 1 and 2 are due to some bias effect. In figure 3, the only distributions which are not flat are the upper left and lower right distributions. These are the result of acceptance effects which have been studied and explained in NuMI note 1049[4]. Bias effects other than acceptance which are seen in MINOS do not show up in the Monte Carlo, which suggests that programming errors along are unlikely to cause the problem. Figure 4 shows the result of combining the forward and reverse data, and all distributions are fairly flat except for the low energy momentum bump, which was the result of hook events. These were later reduced by the application of the BdL cut or the MIC.

For practical purposes, bias effects are those structures in Figures 1 and 2 which do not appear in Figure 3. A noticeable feature of Figures 1 and 2 is that the same bias effects appear whether or not the other cuts are applied. The value of the charge ratio certainly rises with cuts, which is a result of reducing randomization. However, the bias features appear similarly in the black and red points.

3 Magnet Off Data

About two weeks of data was taken with Supermodule one before the magnet was turned on. When Supermodule two was finished, about two weeks of data was taken before its magnet was turned on, although the magnet in Supermodule one was on at the time. For this study, the data was reconstructed as if the magnet was on in the forward field. For Supermodule two, no supermodule one hits were used. The result of the analysis are shown in Figures 5 and 6. All plots are the same as before, except the upper right plot which was done versus impact parameter (or point of closest approach for the track to the coil hole.) When the cuts were applied, almost no events were left, particularly due to the "charged confidence cut" or $\sigma_{1/p}/(q/p)$, so only the no-cuts distributions are shown in 5 and 6.

The qualitative features most associated with the biases, the dependence of the charge ratio on cosmic ray azimuth or detector azimuth, show identical behavior between Figures 1 and 5 & 6. It seems compelling that those features have no dependence on the magnetic field or magnetic field uncertainties, as the data was taken with the magnet off. If they are due to alignment errors, such as a curvature in the coordinate system, they would be the same with the magnetic field on or off, and that is what is seen. It is interesting to note that similar features are seen in both supermodules, while the data is totally independent.

4 An Argument about event topology

All muon tracks which enter the top of MINOS and leave the bottom are bent one way by the magnetic field for the first half of the track in MINOS, and bent the other way after they pass the midpoint. Exceptions are any tracks which enter or leave through the front or back or supermodule gap. About 93/of our tracks are "S" shaped tracks, and the Kalman fitter and swimmer take this into account. Such an S-shaped track is crudely sketched in Figure 7, along with a straight track. An oppositely charged track would correspond to a backward S. The other 7/events are C-shaped or backward C shaped, as shown in Figure 7.

Each track is imagined to be a series of hits along the path of the C or S. Now the main point is that the charge of the track is uniquely determined by whether or not the C and S are forward or backward. The value of the magnetic field is only used to turn that information into a value of the momentum. Therefore the charge ratio, integrated over the momentum distribution, should not depend on the accuracy of the value of the magnetic field. (Actually, this depends on knowing the direction of the magnetic field, so that there should not be unknown curls in the field, but this has never been suggested and is implausible.)

5 Conclusion

A seemingly compelling case has been presented that bias effects seen in charge ratio data are not related to uncertainties in magnetic field, since they identically show up in magnet-off data. This has led us to conclude that small errors in alignment are the cause. This is supported by other studies.

References

[1] The MINOS collaboration Phys. Rev D76, 052003 (2007).

[2] Erik Beall's thesis

[3] NuMI note 2827

[4] NuMI note 1049

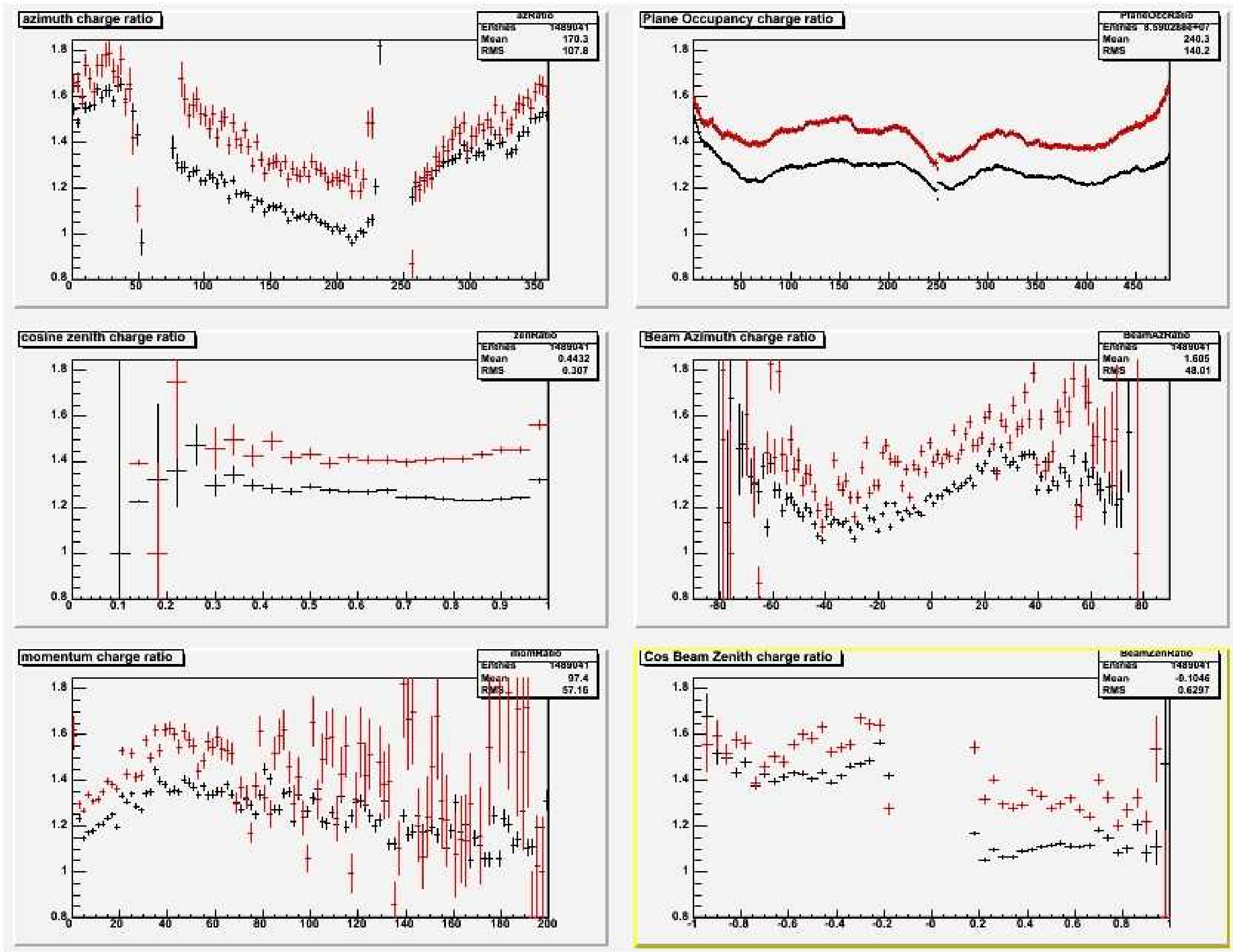

Figure 1: Charged Ratio Distributions for the Forward Field Configuration.

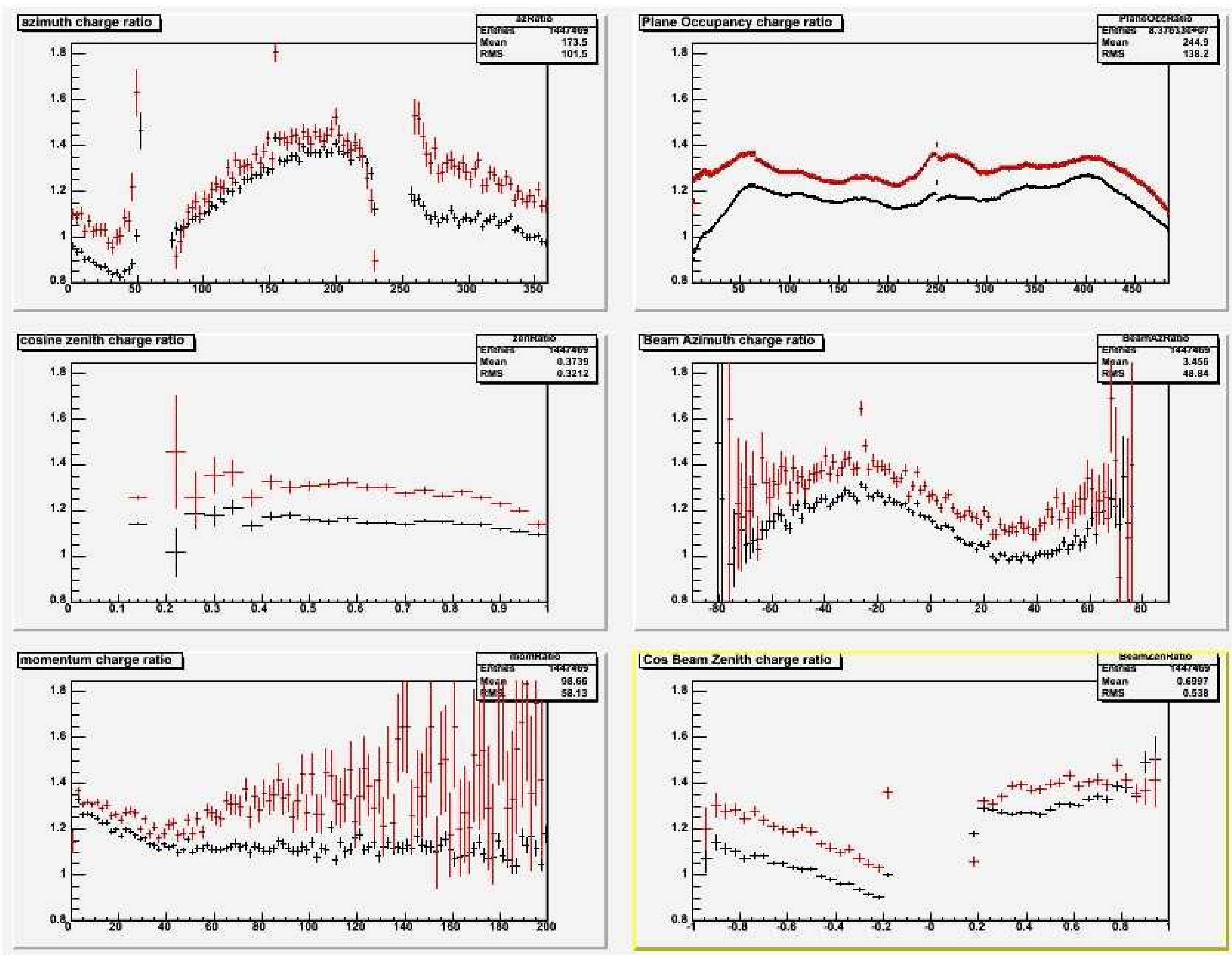

Figure 2: Charged Ratio Distributions for the Reverse Field Configuration.

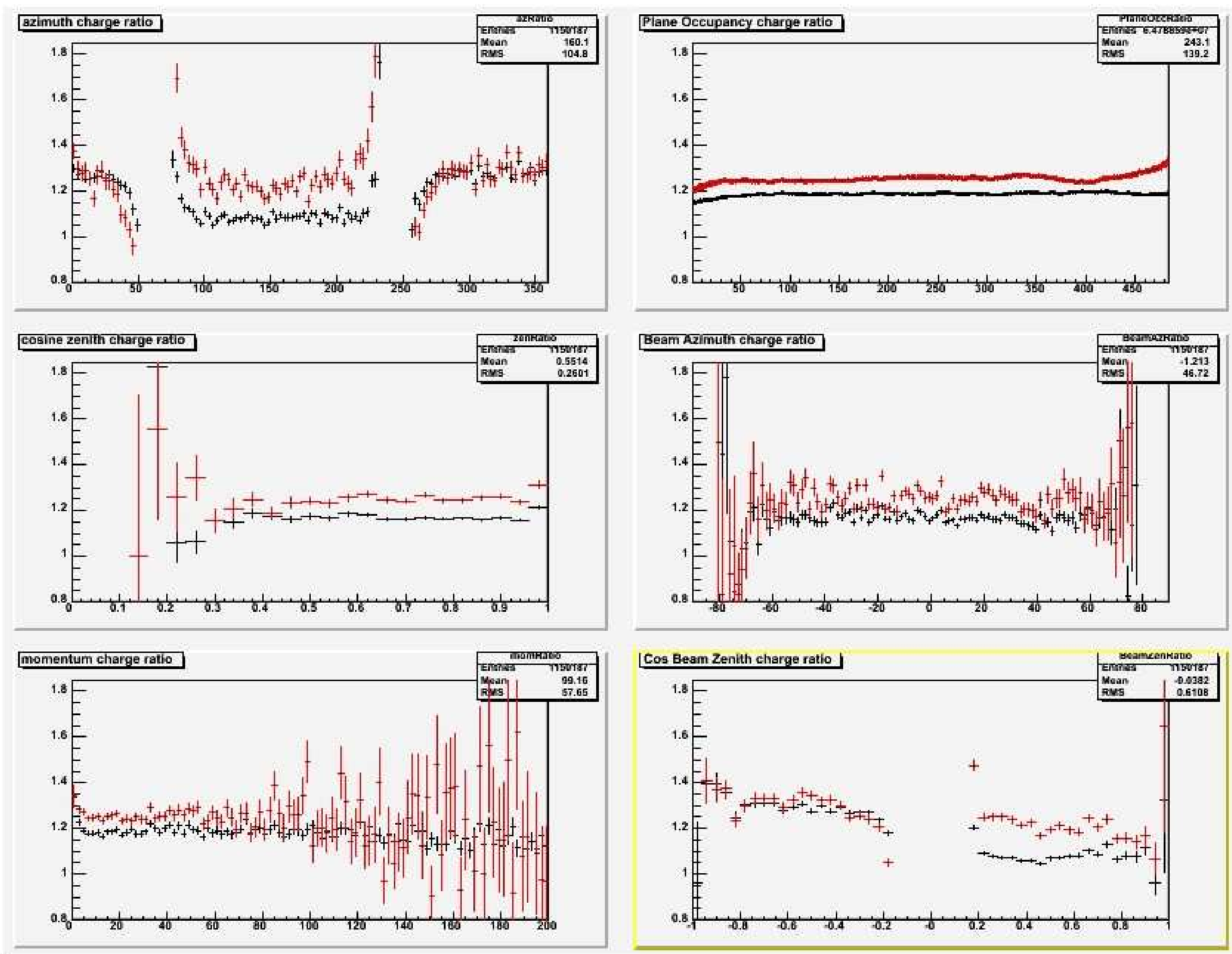

Figure 3: Charged Ratio Distributions for the Monte Carlo.

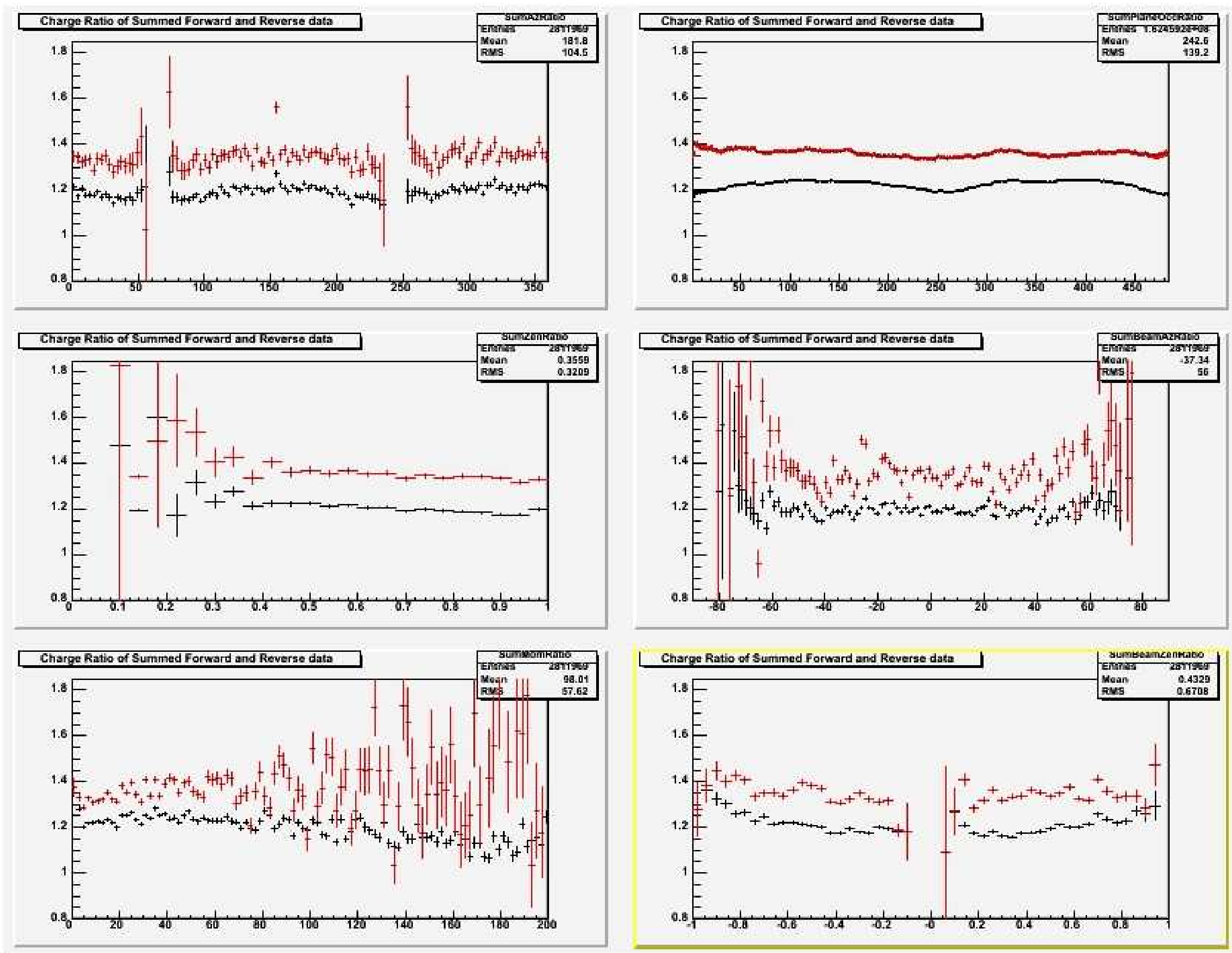

Figure 4: Charged Ratio Distributions when the Forward and Reverse Field Data are Combined

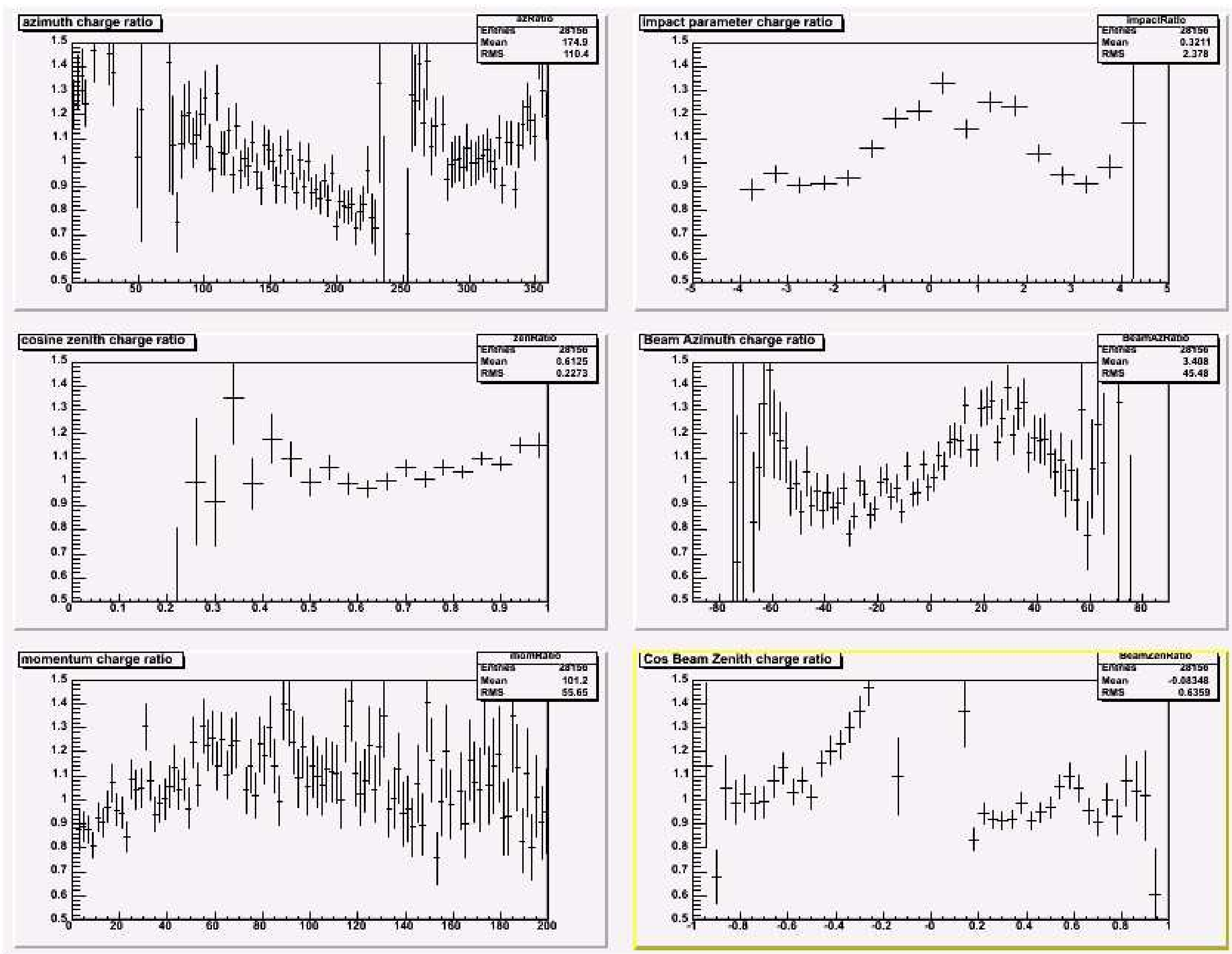

Figure 5: Charged Ratio Distributions for Super Module One when the Magnet was off

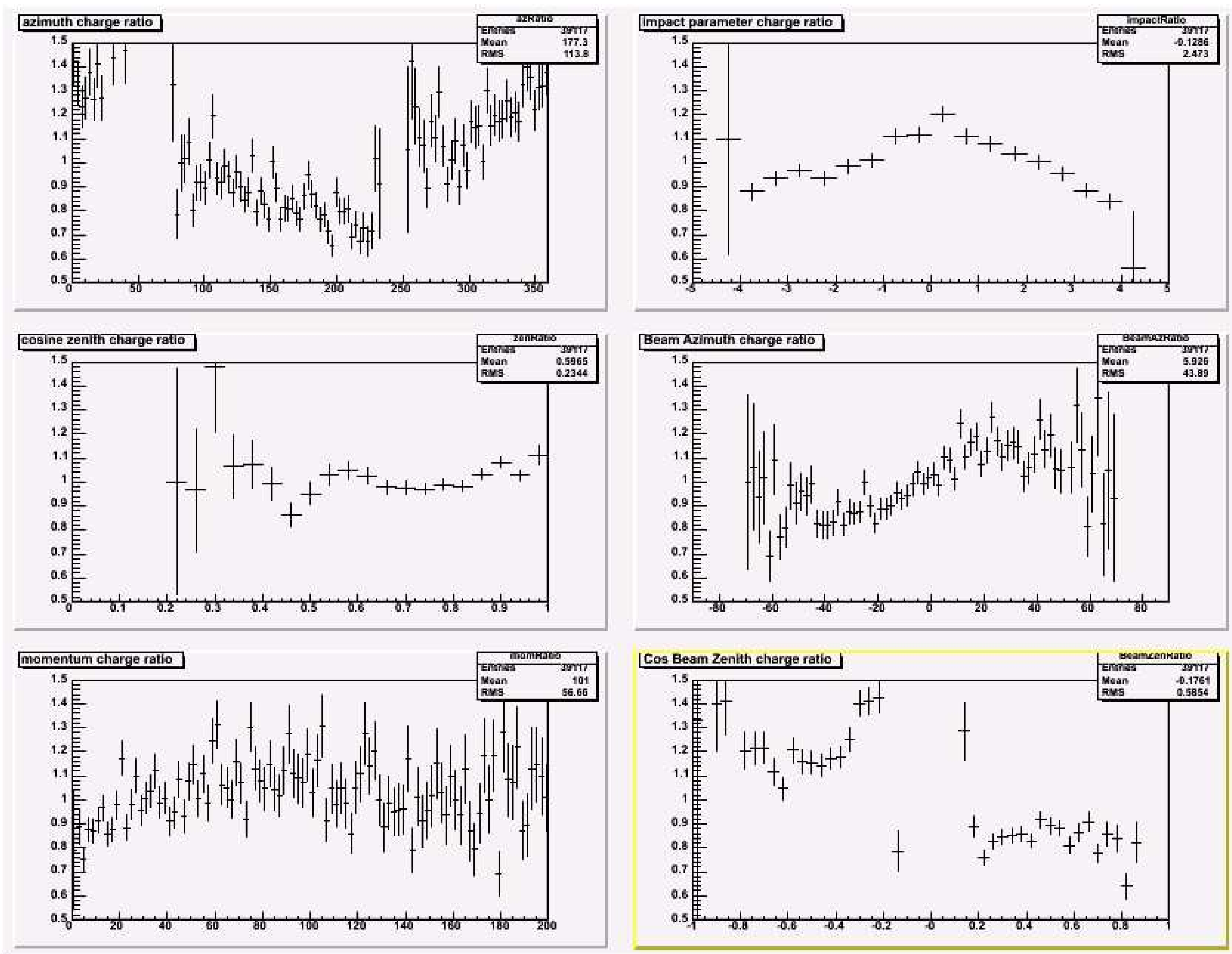

Figure 6: Charged Ratio Distributions for Super Module Two when the Magnet was Off

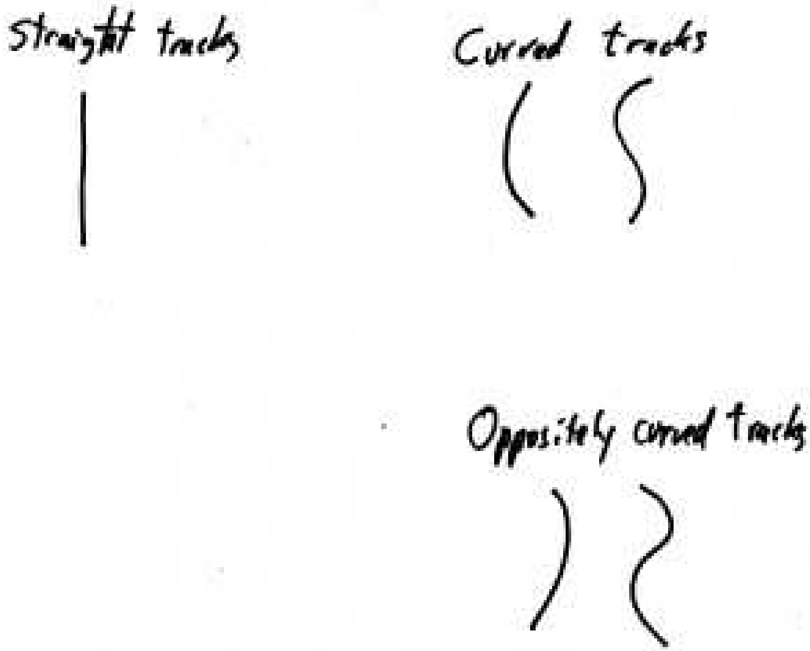

Figure 7: The shape of cosmic ray tracks in MINOS