Charged Particle Tracking in the CLEO II Detector for Neutrino Reconstruction

Michell Morgan

Computer Science Department, Wayne State University, Detroit, Michigan, 48204

Abstract

In neutrino reconstruction analyses, we rely on information from tracks from other particles in the event to determine the neutrino momentum. It is very important to find out as much information as possible about those tracks for neutrino reconstruction. Currently, events with one or more tracks with no z fit are not used, leading to an inefficiency of about 15%. However, such tracks do have hits with z information on charge division wires which are ignored by the tracking program, because charge division hits z information has been observed to be very inaccurate on occasion. We have traced the inaccuracies to the z calibration which was performed only for central tracks and involved fitting with a cubic polynomial. However, for forward tracks, the cubic leads to hits with z positions very far from the actual path of the track. We have investigated solutions to this problem so that we may be able to recover some z information on tracks in events that we currently throw away and use them in neutrino reconstruction.

Introduction

Neutrinos are neutral particles that pass through the detector at the speed of light. Because neutrinos are neutral and weakly interacting, they do not leave tracks in the detector nor hits in the calorimeter. Thus, for neutrino reconstruction, we have to know the energy and momentum of the other particles in the event. The total momentum of the colliding system is zero and thus the final particles in the event must balance. When the momentum and energy are totaled and do not balance, then an assumption that a neutrino went through the detector may be made. In full reconstruction of an event, we want to know about all the particles in the event, including neutrinos. In neutrino reconstruction analyses, we rely on information from tracks from other particles in the event to determine the neutrino momentum. Currently, events with one or more tracks with no z fit are rejected, leading to an inefficiency of about 15%. However, such tracks do have hits with z information on charge division wires which are ignored by the tracking program, because charge division hits z information has been observed to be very inaccurate on occasion. We have traced the inaccuracies to the z calibration which was performed only for central tracks and involved fitting with a cubic polynomial. For forward tracks, the cubic leads to hits with z positions very far from the actual path of the track.

CESR and the CLEO II Detector

To create the collisions between electrons and positrons, the particles are first accelerated in a linear accelerator (electrons to 300 MeV, positrons to 200 MeV) and passed to the synchrotron accelerator which increases the energy to about 5.2 GeV. Then the synchrotron accelerator passes the particles to Cornell Electron Storage Ring (CESR) for collisions in the CLEO II detector. The CLEO II detector is a multipurpose high energy physics detector incorporating charged and neutral particle detection and measurement, used to analyze electron-positron collision events generated by CESR. The electron-positron beams collide and annihilate in the center of the detector producing new particles. Charged particles passing through the drift chambers ionize the gas in the chambers and the resulting ionization is collected by wires in the chambers. The electrical signals from these wires are amplified, digitized, and fed into a computer which reconstructs the path of the original particle from the wire positions and signal delay times.

At CLEO II, the z axis is defined to point along the direction of the positron beam. r is transverse to the beam and ϕ is the azimuthal angle in the plane transverse to the beam. And finally, θ is the polar angle measured from the z axis.

Drift Chambers in CLEO II

There are three drift chambers in the CLEO II detector for a total of 67 wire layers. The common axis of the chambers is aligned along the direction of the storage ring beams. From the drift chambers we can get the momentum, direction and perhaps the identification of the charged particles in the event. The inner drift chamber is the precision tracker (PT) which has six layers. The PT contains axial wires which are parallel to the beam axis and gives no z information but provides the most precise measurements in the $r - \phi$ view determining particle directions near the interaction point. The vertex detector (VD) is the intermediate drift chamber. There are ten wire layers containing axial wires with charge division. The outer drift chamber (DR) has 51 layers and has axial wires (these do not have charge division), stereo wires (at a small angle) and cathodes. There are four total cathode layers in CLEO II. They are perpendicular to the chambers and made up of copper strips. There are cathode layers before the first and after the last layer of the VD and similarly for the DR. The tracking program looks at the hits on the wires and the cathodes and tries to draw a track closest to the hits.

Monte Carlo Program

The Monte Carlo Program is a simulation program tuned to look like real data used with the tracking program. The Monte Carlo Program makes random events of specified types and the tracking program reconstructs the path of the particles from the wire positions. In Monte Carlo events, we can tell what tracks belong to what particles. With Monte Carlo, we produced files of events with only a single track and $B\bar{B}$ events with lots of tracks. In real data, however, there are never good events with only a single track. We look at single tracks for comparison purposes. So we will not have inaccurate information, Monte Carlo knows when part of the detector is dead and knows not to read dead wires. By using the Monte Carlo Program, we can make assumptions about the real data.

Charge Division

The method of charge division[1] relies on the fact that the charge collected at either end of a resistive anode wire is divided in proportion to the length of wire from the point at which the charge is injected. So, charge division wires are read out on both ends to extract a z coordinate. Currently, the z information from the charge division wires is usually ignored by the Tracking Program because it is felt that the z information cannot be trusted. When compared to stereo wire and cathode layers z information, the z information from charge division wires is considered not as precise. So, when stereo and cathode layer hits are found, the Tracking Program uses those hits. However, when there is only charge division wire hits, there may not be a z fit to the track. For neutrino reconstruction, those events are currently thrown away. We would like to retain as many events as possible that have z information for neutrino reconstruction. Therefore, we have done much investigation to see how the z information for charge division wires can be improved.

To find z for charge division, we look at the height of the pulse from both ends of a hit wire. If the hit is closer to one end, we read out more charge at that end because the pulse height is larger. The signals from the wire are amplified because the signals are very small. The equation to get asymmetry (α) is,

$$\alpha = \frac{q'_{\mathrm{west}} - q_{\mathrm{east}}}{q'_{\mathrm{west}} + q_{\mathrm{east}}} \tag{1}$$

q_{east} is the charge read out at the east end of the wire. q'_{west} is the charge read out at the west end of the wire corrected for the difference in gains between the two amplifiers. When asymmetry equals zero the pulse occurred in the middle of the detector.

After we know the asymmetry, We use the following to derive the z information:

$$z = S_0 + S_1\alpha + S_2\alpha^2 + S_3\alpha^3 \tag{2}$$

The S_0 through S_3 constants are determined by the calibration.

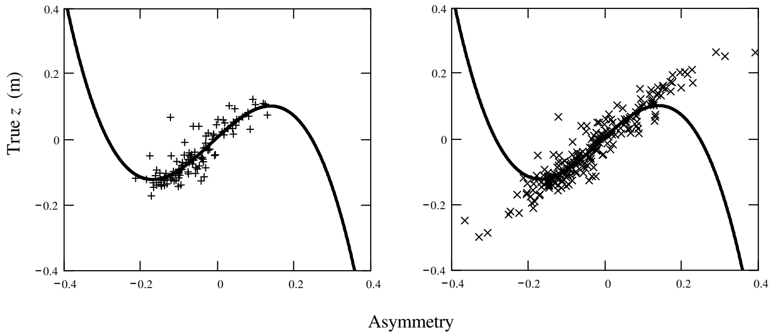

FIGURE 1. Two plots from CLEO II μ–pair data showing true z vs. asymmetry for charge division hits on one wire. The points are the hits and the line is the cubic calibration fit. On the left is only hits in the calibration region. On the right are all the hits on the wire.

Calibration

The current calibration was done wire by wire on Bhabha events which are events with only an electron and a positron going back to back. The calibration is a cubic polynomial fit of the hits for true z (by projecting the track into the VD) vs. asymmetry. Tracks were central in the detector requiring 4 cathode hits and thus $|\cos(\theta)| < 0.71$. This is a small region. Four cathode hits were required, because cathodes gives the best z measurement. Fig. 1 shows two plots made from CLEO II μ–pair data of true z versus asymmetry for charge division hits on one wire. The points represent the hits and the line is the cubic calibration fit. The plot on the left shows the hits on tracks with four cathodes used in the calibration, while the plot on the right shows all the hits on the wire from all tracks. As shown on the plot on the right, the hits outside of the calibration region do not match the cubic fit. When the tracks are outside of this calibrated region, the tracks are forward and the hits are farther away from the track, as shown in Fig. 2. The z information from charge division wires when the tracks are forward is, therefore, observed to be inaccurate. To get a good z measurement, the track should be along the hits on the wires. When there is not good z information, these events are rejected resulting in the aforementioned inefficiencies for neutrino reconstruction.

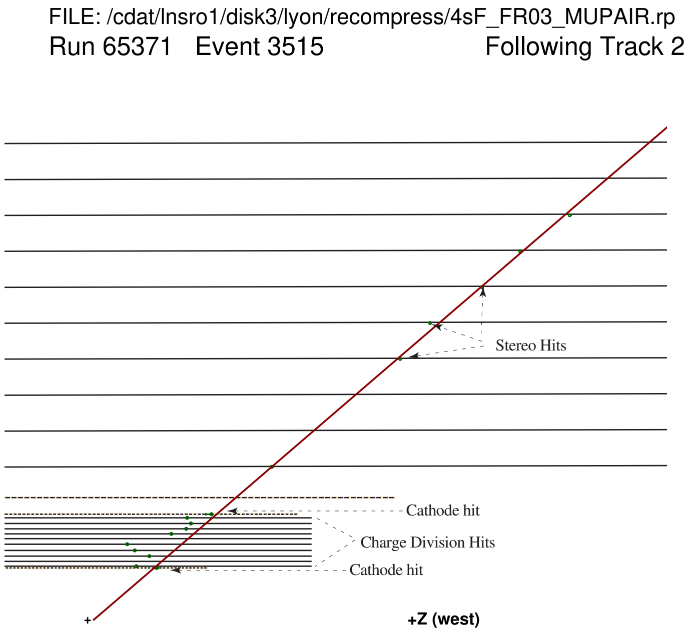

FIGURE 2. $r - z$ View. Charge division wire hits are ignored. Tracking program looks for stereo or cathode hits to make a track. The DR axial wires and the PT detector have been removed for clarity

Currently, the tracking program looks at the path of the particle, and from the $r - z$ view, we can see how a line is drawn to fit closest to the path of the particles. The charge division wire hits in the vertex detector are usually ignored (Fig. 2).

Effects of Calibration on the Data

We looked at Monte Carlo $B\bar{B}$ events with tracks with no z fit and tracks with a good z fit for charge division hits. When looking at charge division vs. $\cos\theta$ as seen in Fig. 3, after doing a distance of closest approach (dca) cut (less than 1 cm) and requiring that

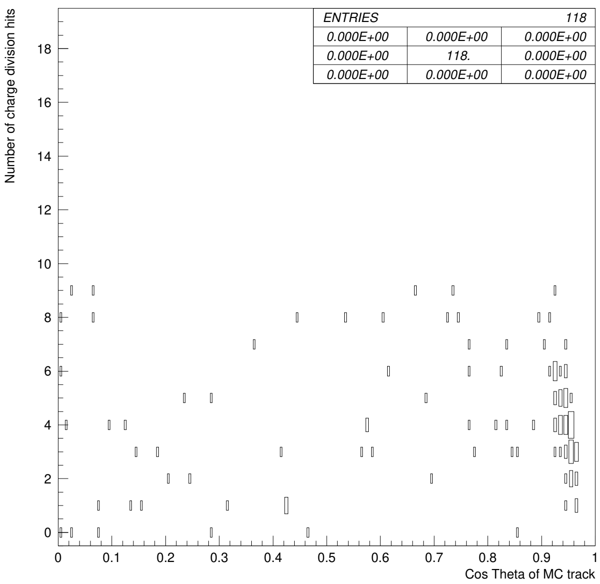

FIGURE 3. From CLEO II μ–pair data shows the number of charge division hits vs. $|\cos(\theta)|$. After doing a distance of closest approach (dca) cut (less than 1 cm) and requiring that the tracks are not curler or ghost tracks, we found the forward tracks the tracking program indicated had no z fit did have charge division hits with z information.

the tracks are not curler or ghost tracks, we found the forward tracks the tracking program indicated had no z fit did have charge division hits with z information. These are events that are currently thrown away. We want to recover these events so that they can be used for neutrino reconstruction which is possible because there are charge division hits. We looked at the difference of the charge division measured z and the true z projected from the Monte Carlo track as shown in the top plots of Fig. 4. For tracks with no z fit (top left), the difference is quite large. However, in the top right histogram of Fig. 4 for tracks with a good z fit the difference is shown to be less. In the difference vs. true z plot at the left bottom for no z fit there is a diagonal which shows the farther away the hits are from the middle of the detector the farther away the hits are from the tracks. When there is a good z fit, however, the charge division hits are nearly flat at zero as shown at the bottom right. The next plot, Fig. 5, we call the Zorro plot because we see a Z figure like the symbol for Zorro. The Z shape reflects the cubic polynomial fit used in the calibration. As seen in these plots, there is a bad z fit for tracks that are forward. Most hits centered at zero as shown in Fig. 4 at the bottom right are on or very near the track which is what we want to see for the forward tracks as well as the tracks used in the calibration.

Improvement of the Calibration

With our findings, we decided something had to be done about the current calibration. We decided that it was not necessary to do a whole new calibration. A great amount of time and work would be needed to do a new calibration. Therefore, we looked at how we could improve what we already have. As mentioned, the calibration was done for tracks

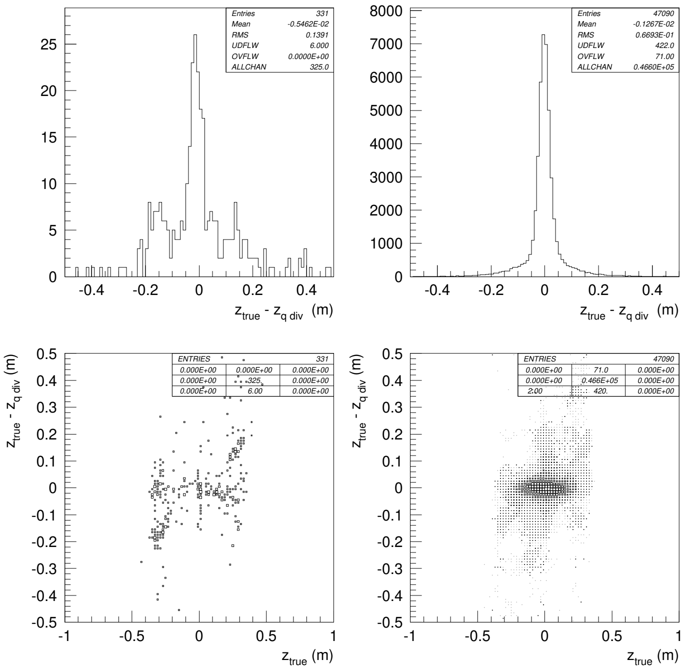

FIGURE 4. In the top plots we looked at the difference of the charge division measured z and the true z projected from the Monte Carlo track. Top left plot shows the difference of the measure charged division z and true z is large with a no z fit and the top right shows it is less with a good z fit. The bottom left shows the difference vs. true z. The diagonal shows that hits farther away from the middle of the detector are father away from the track. The bottom right shows when there is a good z fit, the charge division hits are nearly flat at zero.

that required four cathode hits. Those tracks were fine. We only wanted to improve forward tracks. From the previous section, it is clear that the cubic fit would not work for forward tracks, so we directed our attention to altering the cubic fit. We looked at a linear fit which made the forward tracks look much better. Therefore, we altered the cubic to look linear. We needed a method for converting the coefficients of the cubic (see Eq. (2)) into coefficients of a linear equation.

The linear equation that we used is,

$$z' = S_0' + S_1'\alpha \tag{3}$$

By minimizing the average squared difference between Eq. (2) and Eq. (3) and assuming the asymmetries are evenly distributed in the calibrated region, we can relate new constants to old constants without having to re-calibrate.

$$S_0' = S_0 + \frac{1}{3}\, S_2\, \alpha_{\max}^2 \tag{4}$$

$$S_1' = S_1 + \frac{3}{5}\, S_3\, \alpha_{\max}^2 \tag{5}$$

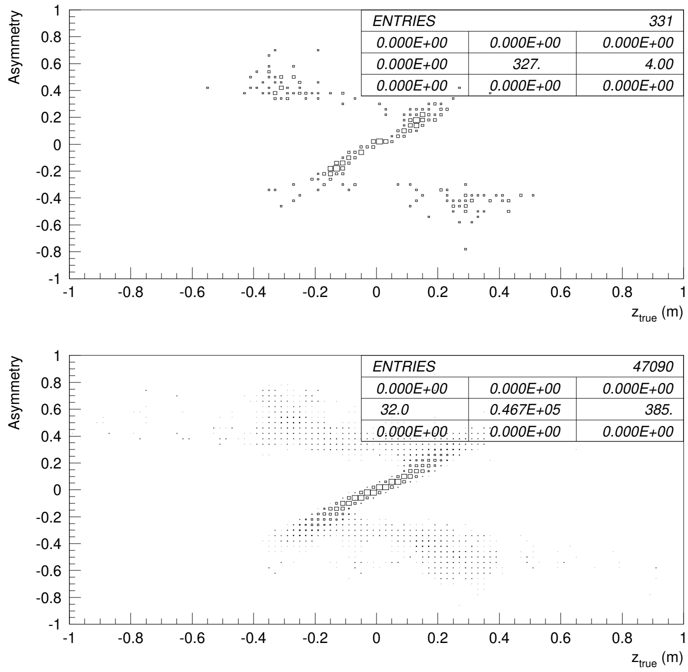

FIGURE 5. We call this plot, the Zorro plot because we see a Z figure like the symbol for Zorro. The Z shape reflects the cubic polynomial fit used in the calibration. As seen in the plot, there is a bad z fit for tracks that are forward

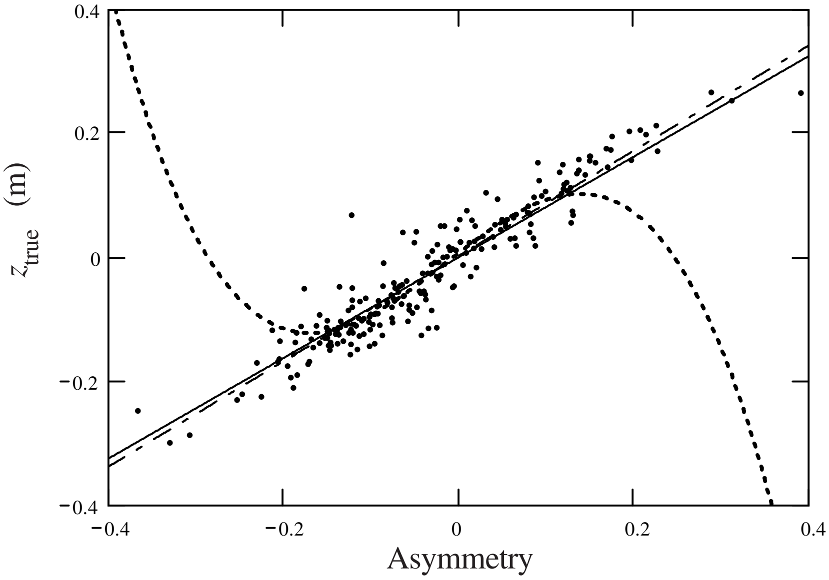

FIGURE 6. This plots shows the comparison of the cubic fit (dotted line), a linear fit (dashed line), and a linearized cubic fit (solid line). The points are the all the hits on the wire instead of just the hits in the calibrated region. The linearized cubic is very close to the linear fit.

$\alpha_{\max}$ is the maximum asymmetry possible for each layer for the cubic calibration. We know the $|\cos(\theta)|$ for the farthest forward tracks in the calibration is 0.71. When we project those tracks to see where they cross the VD layers we can get the maximum z. After we get the maximum z we solve the cubic for the maximum asymmetry for either side of the detector and average the absolute values.

In Fig. 6, we did a comparison of the cubic fit (dotted line), a linear fit (dashed line), and a linearized cubic fit (solid line). We found the linearized cubic is very close to the linear fit. The points are all the hits on the wire instead of just the hits in the calibrated region. By using the linearized cubic it was not necessary to do a new calibration which saved a lot of time.

Fig. 7 shows the charge division z position for one wire (layer 10, wire 50 for μ–pair data for tracks with good z fits) in the VD. The top shows the z position using the cubic fit. There is a sharp cutoff on both sides. The cutoff on the sides is due to the turn of the cubic fit. The bottom shows the z position using the linearized cubic of Eq. (3) removing the cutoffs.

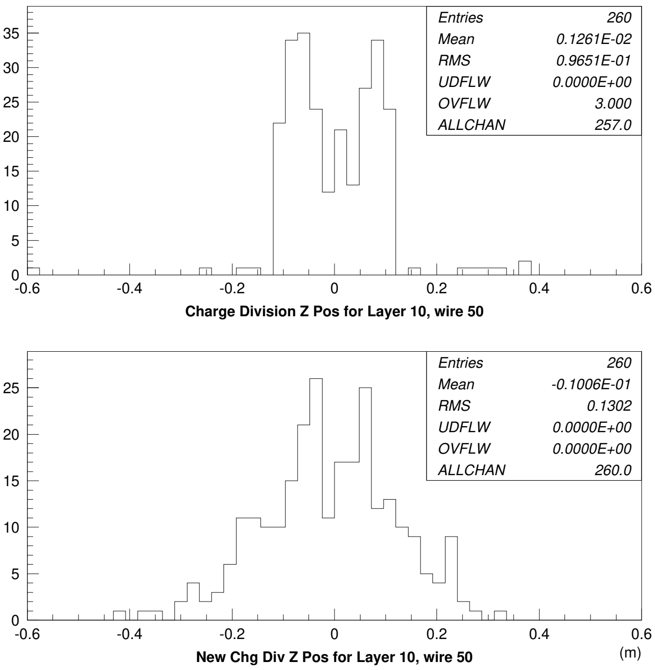

FIGURE 7. The top plot shows the z position using the cubic fit. There is a sharp cutoff on both sides. The cutoff on the sides is due to the turn of the cubic fit. The bottom shows the z position using the linearized cubic of Eq. (3) removing the cutoffs.

Fig. 8 shows the difference of the true z position and the measured charge division z position. The top shows the cubic fit. The bottom shows the linearized cubic which scales down the tails shown in the top plot and shows a better fit to the Gaussian.

At top of Fig. 9 is the true z vs. charge division z of the cubic fit. At the bottom is the same for the linearized cubic. We see a diagonal at the bottom. Here, the charge division z

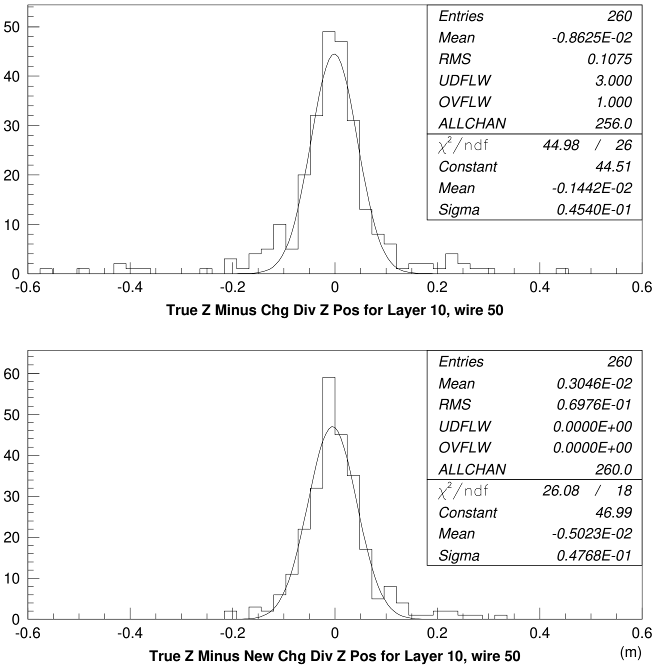

FIGURE 8. This plot shows the difference of the true z position and the measured charge division z position. The top shows the cubic fit. The bottom shows the linearized cubic which scales down the tails shown in the top plot and shows a better fit to the Gaussian.

is nearly the same as the true z. At the top, however, the cubic fit changes the course of the charge division z position; thus, the true z and charge division z do not match.

From the figures, we can see that using the linearized cubic fit makes the measured z position compared to the true z position look much better. They nearly match – which means we can get a good z fit for all tracks.

Summary

We have looked at hundreds of histograms to see how things look now and to try to determine what can be done to improve charge division wires z information. The overall goal is to recover some of the events that the tracking program now throws away because tracks were considered to have no z information. Recovering these tracks means perhaps more events would be available for neutrino reconstruction. As mentioned, the true z vs. asymmetry calibration was done to a cubic polynomial fit for charge division hits in the VD. With this fit, the central tracks looked fine, however for tracks that were forward, the hits were further from the track on the charge division wires. We are not as concerned that central tracks in charge division look good, because we have other ways of measuring z in this region. By using the linearized cubic fit, the charge division measured z and true z line up much better for forward tracks. A z fit for forward tracks will hopefully give us more events that we can use.

We have found a way to improve charge division wires z information, and now we would

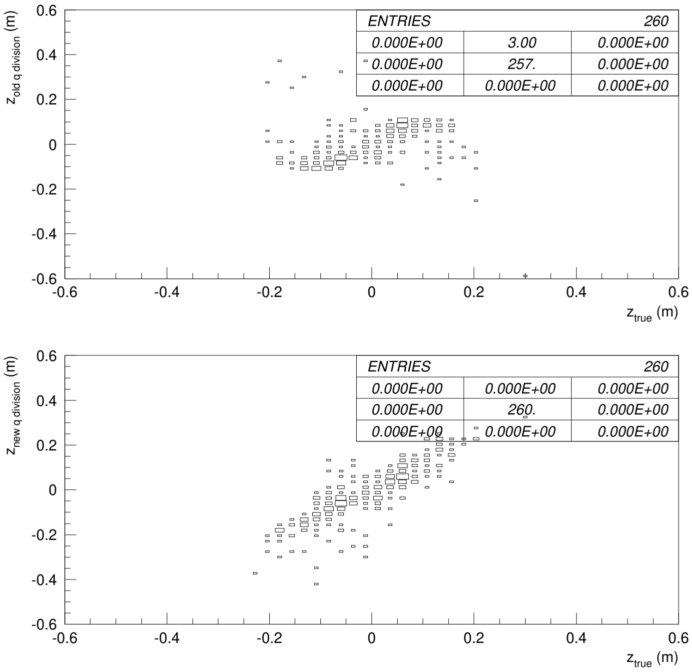

FIGURE 9. At top is the true z vs. charge division z of the cubic fit. At the bottom is the same for the linearized cubic. We see a diagonal at the bottom. Here, the charge division z is nearly the same as the true z. At the top, however, the cubic fit changes the course of the charge division z position; thus, the true z and charge division z do not match.

like to have a package written to implement use of the new linearized cubic fit. Hopefully, in the near future this package will be completed so that it can be distributed to others so that they can use the new linearized cubic fit.

Acknowledgments

We are pleased to acknowledge Prof. Ed Thorndike, and Dr. Adam Lyon, of the University of Rochester, who proposed this Research Experience for Undergraduates project and guided my effort in improving z information for charge division wires so that we have more events for neutrino reconstruction.

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Footnotes and References

1. W.R. Leo, *Techniques for Nuclear and Particle Physics Experiments* revised ed. (Springer-Verlag, New York, 1992).