ENERGY LOSS MEASUREMENTS IN THE PEP TPC*

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Summary

The Time Projection Chamber (TPC) in the PEP-4 experiment has been tested with cosmic ray muons in the past few months. These tests have shown that the TPC is capable of measuring the ionization of single tracks with an accuracy of three percent, and that the results of the small dipole TPC[1] have successfully been scaled to the full device.

Description of the TPC

The PEP TPC[1] is a cylinder two meters long with a radius of one meter filled with argon mixed with 20% methane. The TPC can operate at pressures from one to 10 atmospheres. When a particle traverses the TPC, the electrons liberated by ionization drift parallel to the cylinder axis (z-axis) at about 5 cm per microsecond. The detector plane at each end is divided into six sectors, each of which has 183 detection wires, as shown in Fig. 1. The pulse heights from these wires are used to measure the track ionization. In each sector on the end plane there are 15 rows of pads. The pad spacing is 7.5 mm. The data from these pads provide three dimensional measurements of the track position. For both the pads and the wires a z-position is calculated from the drift time. For the pads an azimuthal position is calculated from the pad pulse heights.

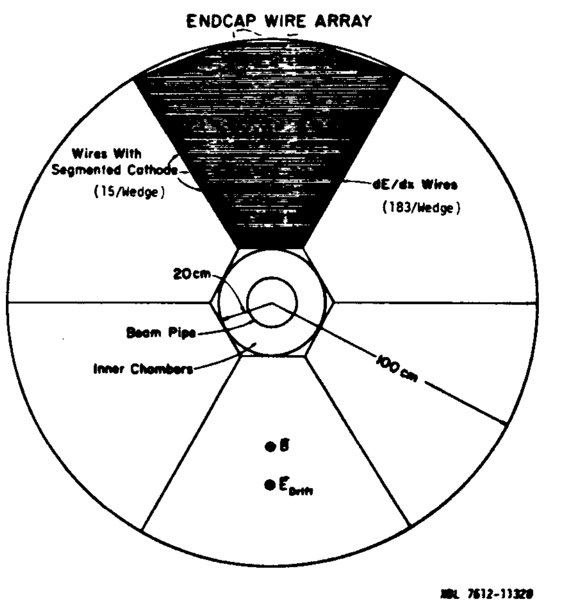

Fig. 1. A schematic drawing of one of the detection end planes of the TPC. All six sectors have the same construction, with 183 wires and 15 pad rows.

Calibration

There are three distinct types of calibrations that are needed for ionization measurements in the TPC, the wire gain maps, the electronics calibration, and the end plane source calibration.

Before the sectors were installed, extensive measurements were made using Iron 55 sources to obtain maps of the variations in wire gain along the wires. As long as the sectors are not changed mechanically, these maps are expected to be permanent properties of the sectors. This assumption of gain map invariance was demonstrated to be a good one for the two sectors that were used in the cosmic ray tests in July and August. Figure 2 shows the gain map made for 4 typical wires in one of these sectors before and after that run. For most sectors the gain variations have an RMS of 3 to 4 percent and are not a serious problem. In fact, for the two sectors used in the August cosmic ray tests the same ionization measurement resolution of 3.3% was obtained whether or not we made these gain map corrections.

Electronics calibrations of all of the approximately 7000 TPC electronics channels in one of the two end caps have been done and used in the analysis. We are still learning how to control the time stability of the calibration and reduce the electronic noise. We expect to improve our resolution by these efforts. However, the ionization measurements are much less sensitive to these things than are the position measurements. Our ionization measurements will gain little from these improvements.

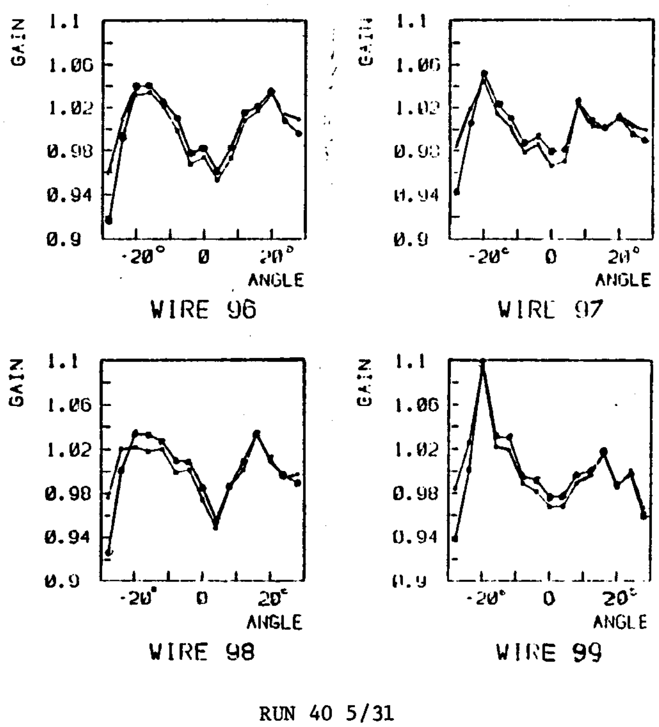

Fig. 2. This figure shows two gain calibrations for 4 wires in a sector that was calibrated in May, taken to IR-2 and used in cosmic ray tests and then recalibrated in October. The gain variations of a few percent reproduced very well except very near to the edge of the sector.

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Each TPC sector is equipped with three rows of Iron 55 sources with a remotely controlable shutter that are used to make end plane source calibrations for each wire. These calibrations will be used for three purposes. They can eliminate the sector to sector and wire to wire gain variations, which are on the order of 15%. They can be used to correct the wire gain map for gain variations due to temperature variations. In the construction of the TPC sectors much care was taken to eliminate these temperature variations and we have no proof from our cosmic ray data that such corrections are needed. The third use of these calibrations is to obtain an absolute energy calibration. This end-plane source calibration system has been operated successfully. As yet these calibrations have not been incorporated into the analysis.

Track Finding in the TPC

The raw data from the TPC arrive in the form of pulse heights in CCD buckets that are 100 nanoseconds, or about 5 mm, apart. A typical track produces a cluster of about five such raw data words on each wire. The first task of the analysis is to find these clusters and determine their peak heights and z-positions. For the pads there is an additional clustering of adjacent pads.

In our present analysis system the pad data only are used to find tracks. After the tracks are found, the wire clusters are associated with the tracks and a selection is made of the wire clusters that are to be used in the ionization measurements. Figure 3 shows an example of a set of wire clusters that have been associated with a track.

To be used in the dE/dx analysis, a wire cluster has to be within one centimeter in z from the track trajectory that was determined from the pad data. A track crosses from 155 to 183 wires if it goes the length of a sector. In our cosmic ray tests in November most sectors have about 10 missing wires, primarily due to calibration problems. Wire clusters are rejected from the sample if there is another cluster or another fitted track within three cm in z on the same wire. This allows us to reduce the interference from other tracks, especially delta-rays. Wire clusters are also rejected from the sample if the clusters on the track on either of the adjacent wires were so large that the electronics were saturated. About 2% of the wire clusters from cosmic ray muons were rejected in this way.

Event Selection for dE/dx Analysis

To study the ionization measurements we selected events that have one and only one track in each of two opposite sectors and we required that they be approximately colinear. This selects a fairly pure sample of cosmic ray muons. In addition, we required that both tracks have at least 120 wires remaining in the sample after all rejections. Figure 4 shows the distribution of the number of wires used in the dE/dx analysis for the track in these events that had the fewest wires used.

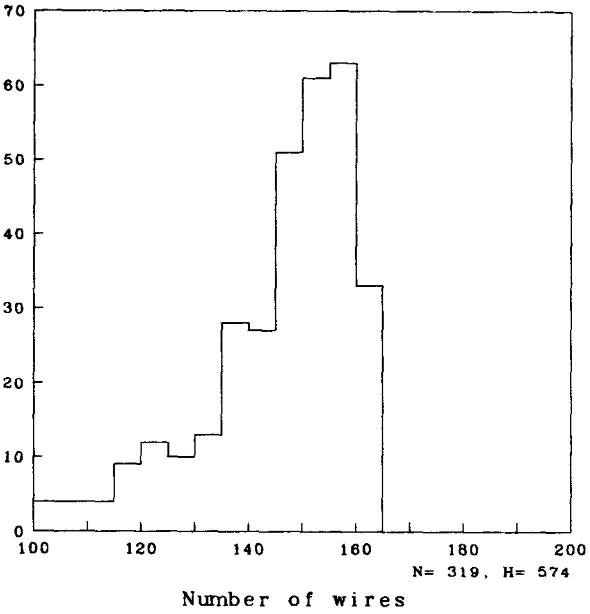

Fig. 4. The dE/dx resolution studies used events with a cosmic ray track found in two sectors. This figure is a distribution of the number of wires used in the dE/dx analysis for the sector that had the fewest number of wires used.

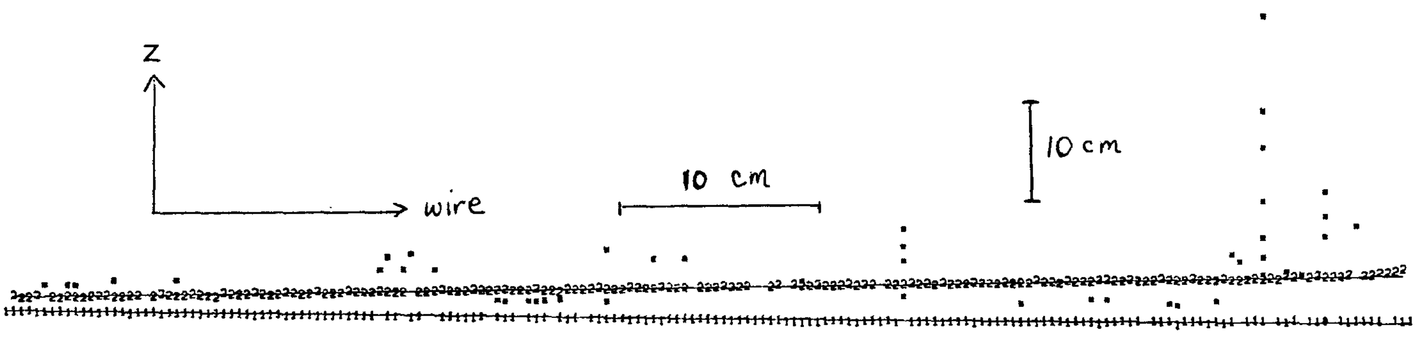

Fig. 3. The wire data for a cosmic ray event in the TPC are plotted in z versus wire number coordinates. The straight lines are the orbits obtained from the fits to the pad data. The numbers are wire clusters that were put onto a track. The asterisks are clusters that were not put on a track. The two tracks seen here are actually one track that is seen in two sectors.

Figure 5 shows for one cosmic ray run at 8.6 atmospheres a dE/dx distribution for all clusters in all tracks in one sector in this sample. The typical threshold for a channel is at about 0.3×10^3. One can see from this plot that we have no large low pulse height contamination and that the threshold does not bias the distribution.

Each track has a dE/dx distribution similar to that of Fig. 5. We choose to use as a measure of the energy loss the mean of the lowest 65% of the pulse heights per unit length. The choice of 65% for the truncated mean was intended as the optimum for 8.5 atmospheres. A larger value for this percentage is probably better at lower pressures. But, the resolution is not very sensitive to this choice.

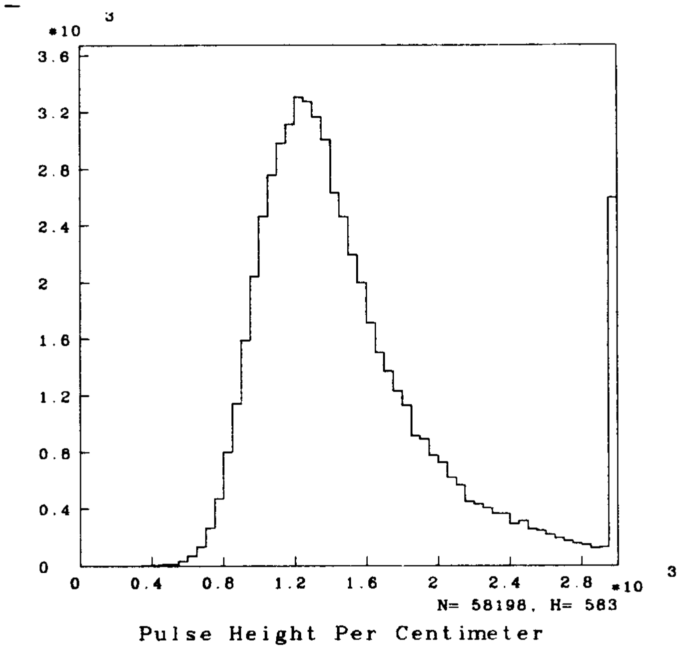

Fig. 5. A distribution of the pulse height (in arbitrary units) per unit length of all cosmic ray muons that were used. The right most bin contains all of the tracks that overflowed the histogram.

The Ionization Measurement Resolution

To measure the resolution for energy loss we compare the two measurements of ionization for a track in the two sectors. Figure 6a shows for one 8.6 atmosphere run a scatter plot of this fractional difference on the x-axis and the tangent of the angle that the track makes with the vertical plane on the y-axis. Figure 6b has the projection onto the x-axis. The σ of the Gaussian that fits this distribution, divided by $\sqrt{2}$ is 3.0 ± 0.2%, which is our resolution. We have done this measurement on many runs and Fig. 6b is typical in that the distribution fits a Gaussian rather well, with very few events out in the tail. Therefore, in contrast to the spatial resolution, which has a non-Gaussian tail, the ionization resolution is fairly straight-forward to measure and interpret.

The fact that we can get this good Gaussian fit in Fig. 6b and that the scatter plot in Fig. 6a has no slope to it shows that we are able to correct well for electron capture. In fact, for the run used for Fig. 6 the electron capture rate was 0.60 per meter, and a track at the center of the TPC has a pulse height of 55% of the pulse height of a track with the same velocity at the end of the TPC. Although we can operate with such high electron capture, we intend to fix the problem, and return to the conditions of our August cosmic ray tests when the capture was consistently less than 10%

We have measured the dE/dx resolution for many runs in our November cosmic ray tests. The dE/dx resolutions measured at the same pressure and magnetic field agree with one another. The results that we obtained at three different pressures, averaged over all runs at 4 kG magnetic field, were[2]

Pressure (Atm)	dE/dx resolution (%)
8.64	(2.80 ± 0.06)
4.02	(3.56 ± 0.09)
1.50	(4.65 ± 0.14)

These errors are statistical only. We estimate that there are systematic errors of about 0.2% also.

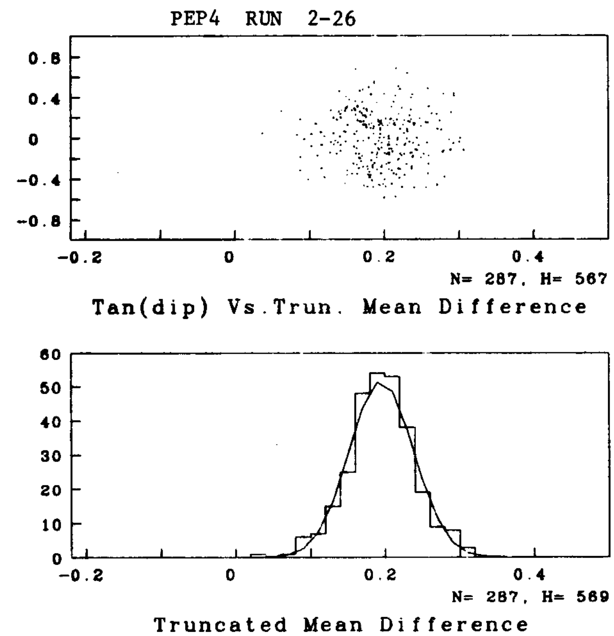

Fig. 6. a) A scatter plot for one 8.6 atmosphere run of the tangent of the angle that the cosmic ray track makes with a vertical plane against the fractional difference in the 65% truncated means measured for the track measured in two sectors, and b) a projection of this truncated mean difference. The width of the Gaussian fit corresponds to a dE/dx resolution of 3.0%.

Comparison with Expectations

The 2.8% resolution that we found at 8.6 atmospheres is better than the 3% that we set for our goal at 10 atmospheres. How much better could we do? We know that we can increase the number of wires that we use and that we can reduce the wire gain fluctuations. With these improvements we should be able to reduce the 2.8% to 2.6%. The Monte Carlo simulations that we made before we built the TPC indicated that 2.5% was the best that we could do. If we use the dE/dx distribution that we observe (one like the one in Fig. 5, but with minimum ionizing tracks only) as the input to a Monte Carlo, we estimate that 2.4% is the best that we can do at 8.6 atmospheres. Therefore, the 2.8% resolution that we see at 8.6 atmospheres seems to be within 20% of the best that we can expect to do.

Relativistic Rise Measurements

We have measured the relativistic rise in the energy loss distribution for our cosmic ray muons. Such a measurement is shown in Fig. 7. Plotted also on this figure, with arbitrary normalization, is a calculation of the most probable value[3] of the ionization. The disagreement between the measurement and the calculation at high momentum is due to a presently poor momentum resolution and a rapidly falling momentum distribution. At present, our momentum resolution is about 50% at 6 GeV.

We characterize the relativistic rise by the ratio of the k⁻π separation at 3.5 GeV to minimum ionizing, which we measure with our muons as

$$k^{-}\pi \text{ separation} = \frac{dE/dx\ (2.65\ \text{GeV}) - dE/dx\ (0.75\ \text{GeV})}{(dE/dx)\text{min}}$$

Our measurements of these values are:

Pressure	$k^-\pi$ separation at 3.5 GeV
1.50	0.176 ± 0.009
4.02	0.151 ± 0.005
8.64	0.121 ± 0.005

These values of $k^-\pi$ separation agree with the calculations that we made, as seen in Fig. 8, though they are somewhat smaller than those predicted by others.[4]

When we combine our measured resolutions with the calculated $k^-\pi$ separation, we can calculate the number of standard deviations of $k^-\pi$ separation that we can expect. These are

Pressure	Expected Standard Deviations of $k^-\pi$ Separation
1.50	3.41 ± 0.16
4.02	3.76 ± 0.13
8.64	3.92 ± 0.15

Thus our findings are that there is little pressure dependence for the $k^-\pi$ separation in the TPC. The separation at 8.6 atmospheres is only 15 ± 6% better than at 1.5 atmospheres.

Actual Resolution

The resolutions that we have quoted so far involve comparing a track with itself. A more severe test of the resolution is to compare many different tracks at the same momentum. The resolutions that we get by this method are worse than the previously quoted resolutions by about 35% at all three pressures. This is true even for minimum ionizing particles for which the momentum resolution does not seriously degrade out dE/dx resolution. We have not yet understood this.

Particle Identification in Multi-Track Events

The TPC has just moved into the beam at PEP and we have, as yet no experience with its ability to do particle identification in multi-track events. Our simulations indicate that for Q-Qbar events at 15+15 GeV we can get reliable dEdx measurements for tracks that are at least 3 cm away from other tracks in z. The effect of this is to get good ionization measurements for about 90% of the tracks and get poor accuracy on the rest.

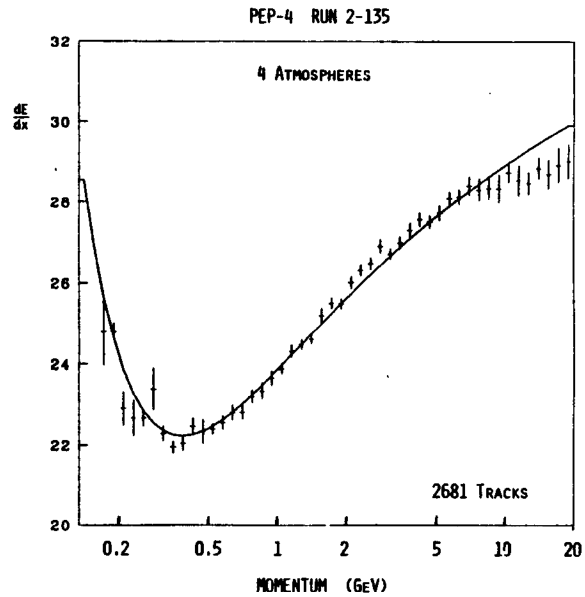

Fig. 7. TPC measurements of the ionization of cosmic ray muons at 4 atmospheres. The data points are averages of 65% truncated means. The dashed curve is a calculation (arbitrarily normalized) of the most probable energy loss.

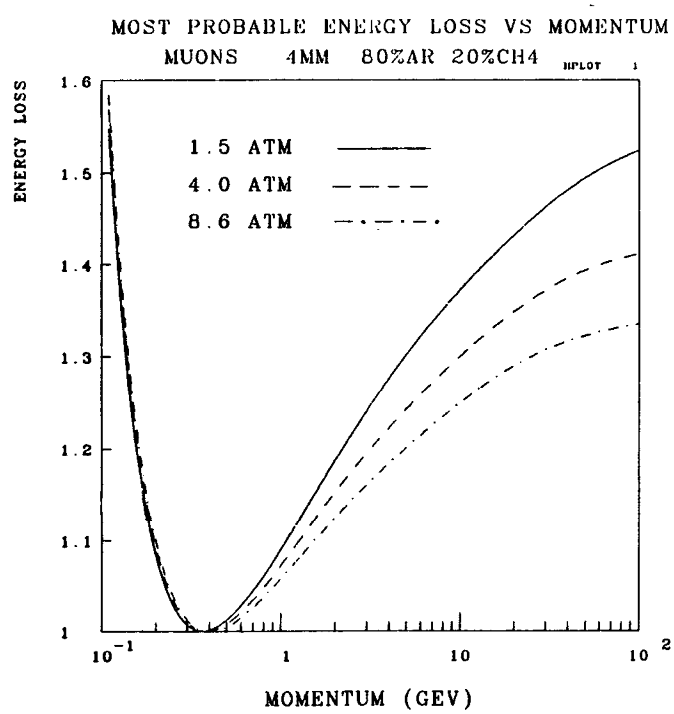

Fig. 8. A calculation of the most probable value for the energy loss in the TPC for three different pressures.

References

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