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An Investigation of Multiple Coulomb Scattering For Particle Identification in the STAR TPC

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Abstract

The STAR TPC identifies particles based on dE/dx versus momentum. In this study, we examine multiple Coulomb scattering as an alternative method of particle identification in the TPC. We examine the angular scattering as a function of particle type and momentum.

1 Introduction

An interesting problem in the TPC is the ability to distinguish between pions and electrons at 200 MeV. The point of this note is to examine whether or not Multiple Coulomb Scattering is useful in making this distinction.

Normal particle identification in the TPC is done with dE/dx versus p, however, at momenta of 200 MeV and greater, this method of identification breaks down. This is due to relativistic effects on the particles as they move faster and faster. Particles lose energy less rapidly as they go faster until becoming relativistic, where energy loss is approximately constant. As particles become "ultra relativistic" the energy loss slowly increases, causing the so called "relativistic rise". This is especially evident in electrons, as they move at much higher speeds than the other particles at the same momenta because of their small mass. When looking at the MCS data, for consistency, we looked at everything in terms of momentum. By doing this we could look at the MCS data and compare it with the dE/dx data.

2 Basic Parameters

In order to examine the effects of MCS we used a rectangular geometry for the TPC with a volume 4 m long, 20 cm by 20 cm square, filled with air, with pad rows every twenty centimeters. This simplified several calculations. When using GEANT to track the particle stream through our fictitious TPC, we turned off many physics processes to better understand how MCS was affecting the particles, and to avoid confusion in the data. The only processes we left on were MCS, continuous energy loss, and δ-ray production. By doing this we didn't have to worry about the particles being affected by any physics processes other than the ones we were interested in so we could concentrate on the effects of MCS. Another factor we had to consider was the 50 and 100 MeV kaons and protons were stopping in the gas, making the measurements and data for those momenta invalid and not useful.

3 Modules Created

In order to examine these effects, the TAS module mcs_eval was written and included in the tev package. This module examines the effects of MCS and produces two tables:

1. mcs_eval containing the values of a_y (average angle scattered per track ($\bar{\alpha}y$), rmsa_y (truncated root mean square of the a_y values), and de (the truncated dE/dx value for the track) and
2. mcs_abar containing the values of ypp (the actual values of the angles scattered at each hit for every track (αy)).

Diagram 1 contains an exaggerated picture of a hypothetical track, showing the angle scattering effects we are looking at. The method by which we examine the angle is simple. Every time the track makes a hit, its x and y and z position are recorded. By measuring the distance from the previous hit in the x and y directions, we can calculate the angle by $y/l = \sin\Theta$ where for small angles $\sin\Theta = \Theta$. Since the tracks leave hits at every pad row, l stays constant. We then just measure the difference in the y values and have the angle measurements α_i. $\bar{\alpha}$ is then calculated by the following equation:

$$\bar{\alpha} = \left(\sum_{I=1}^{n} \mid \alpha_i \mid \right) /n \qquad (1)$$

Each table also contains a primary id, as well as the GEANT id of the track, along with the momentum of the track. Because the physics of MCS is symmetric, we chose in this report to only discuss the scattering in the yz plane. The module however does take data for scattering in the xz plane as well. Analysis of this data should yield results similar to those found in this report.

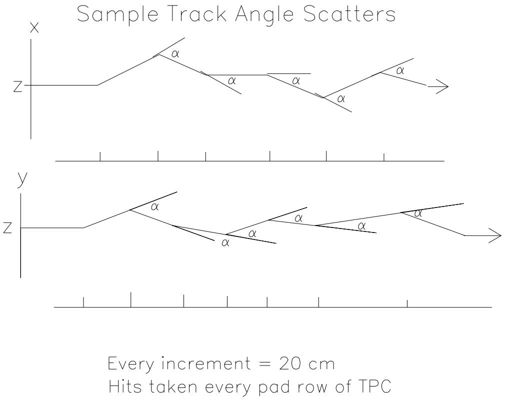

Diagram 1

4 Data Analysis and Results

In order to determine if MCS would prove effective, We examined the mcs_abar table to see the distribution of the quantity ay. This quantity was quite gaussian, and the width of that distribution is known to be approximately equal to $C/\rho\beta$ where C is a constant, ρ is the momentum, and β is the relativistic velocity. By fitting the αy distributions with gaussian curves and finding the mean values, we were able to plot sigma(αy) versus ρ as shown in Figure 1. We then fit these points with the equation:

$$\Theta_0 = .01 \times (\rho^2 + m^2)^{1/2}/\rho^2 \tag{2}$$

where m was the mass of each particle, and ρ was the momentum of the particle. This is a simplified form of the following equation[1]:

$$\Theta_0 = (14.1/\rho\beta) \times Z_{\text{inc}} \times (L/L_R)^{1/2} \times [1 + 1/9 \log_{10}(L/L_R)] \tag{3}$$

which gives the width of the gaussian approximation for the angles at which the particles scattered while moving through the air. Z_{inc} is the charge of the particle, ρ is the momentum of the particle, β is the relativistic velocity of the particle, and L/L_R is the thickness in radiation lengths of the medium being traversed, in this case, air. Equation 2 is only an experimental approximation based on equation 3 which is valid for these studies.

When looking at figure 1, we can see at a momentum of 200 MeV, the plot for the pions

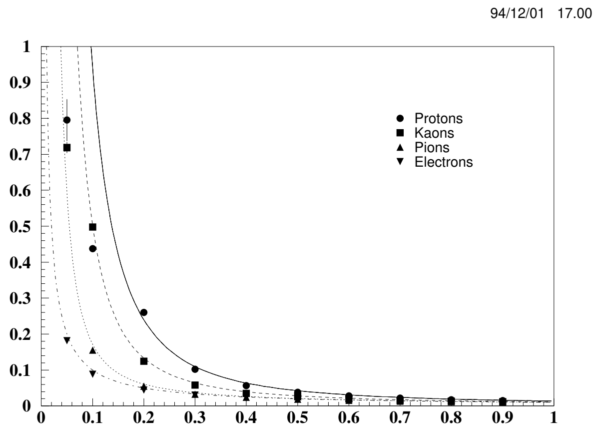

Figure 1: All Particles: Sigma(αy) v. p

and electrons is almost overlapping. The protons and kaons are very distinguishable, but the pions and electrons are right on top of each other. The interesting thing to look in comparing figure 1 to figure 2 is that the dE/dx curve for the electrons does not tail up anywhere near the other particles, yet it does on the Sigma(αy) graph. This is because of the momentum term in equation 2. This means that the separation in the graphs in figure 1 is simply the difference in the value of β for each particle. This is because the value of β for the electrons is almost 1. Because of this, the electrons are "ultra relativistic" and at such velocities their dE/dx values are governed by $Cln\gamma$ whereas the other particles are not "ultra relativistic" and are governed by C/β^2. The width of the angle scattering distribution is not governed by either of these, however. Instead, it is governed by $C/\rho\beta$ which causes the electrons to behave much similar to other particles.

When looking at figure 2, mean de versus ρ, we can see these relativistic effects in the relativistic rise the electrons undergo. Notice that it becomes impossible to distinguish pions from electrons by just dE/dx at roughly 100 MeV. However at 50 MeV the two graphs are widely separated. This is because the pions are not "ultra relativistic" and are still dependent on C/β^2.

After looking at Sigma(αy) and dE/dx, we looked at other quantities that can be calculated from the MCS data to see what would produce the best resolution. We considered rmsay and investigated the width of the rmsαy distribution versus momentum as shown in figure 3. In this figure, one can see that the best fit lines for the rms values do not overlap until 300 MeV. However, this experiment did not conclusively distinguish the pions from the electrons because for some reason to be investigated further, the electron stream produced

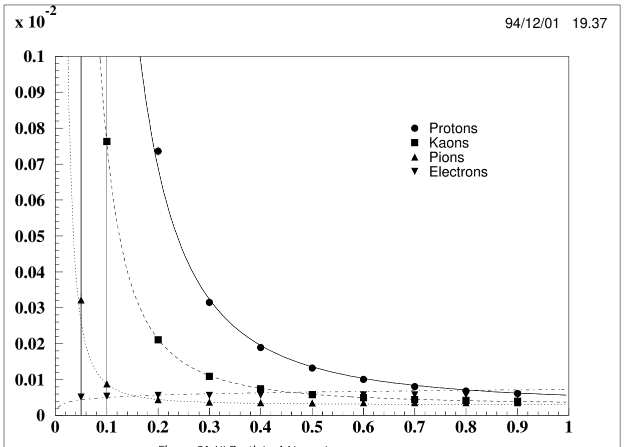

Figure 2: All Particles: Mean de v. p

aberrant points at 200 and 700 MeV. However, we found an excellent fit equation for the Sigma(rmsαy) versus ρ graph:

$$.00125/\rho\beta \tag{4}$$

This comes from the relationship of the sigma(αy) to equation 2, and the distance between the pion graph and the electron graph is wider, although not as significantly as we could have hoped.

We also looked at just distributions of $\bar{\alpha} y$ at specific momenta. As shown in figure 4, at 50 MeV pions and electrons are quite distinguishable. However in figure 5, at 100 MeV, we can see that the pions and electrons are overlapping more and more. In figure 6, the two graphs almost completely overlap at 200 MeV, and in figure 7, at 500 MeV, it is impossible to distinguish the two particles at all.

5 Summary

In this note, we considered many forms of the data available from MCS of particles, including αy, rmsαy and $\bar{\alpha} y$ and compared them to dE/dx. Even though the behavior is somewhat different the MCS data does not provide much additional resolution to the dE/dx measurements.

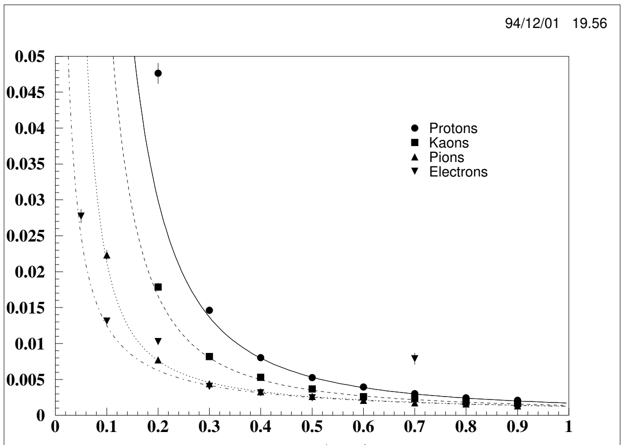

Figure 3: All Particles: Sigma(rmsay) v. p

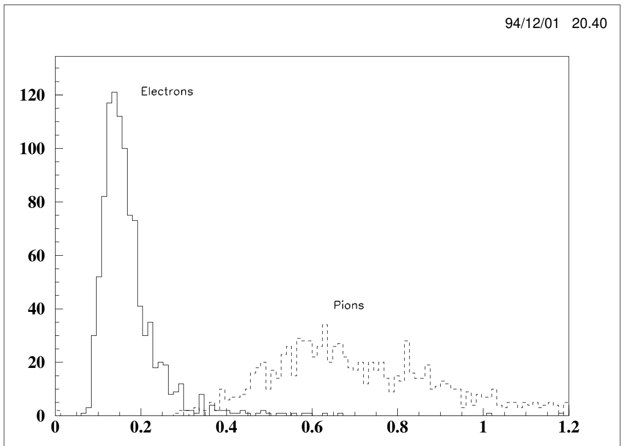

Figure 4: All Particles at 50 MeV

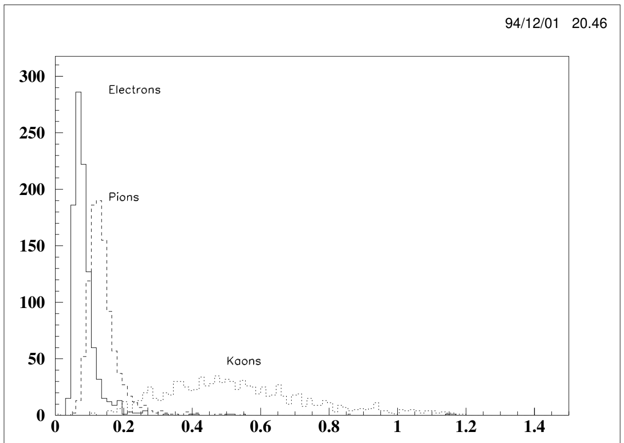

Figure 5: All Particles at 100 MeV

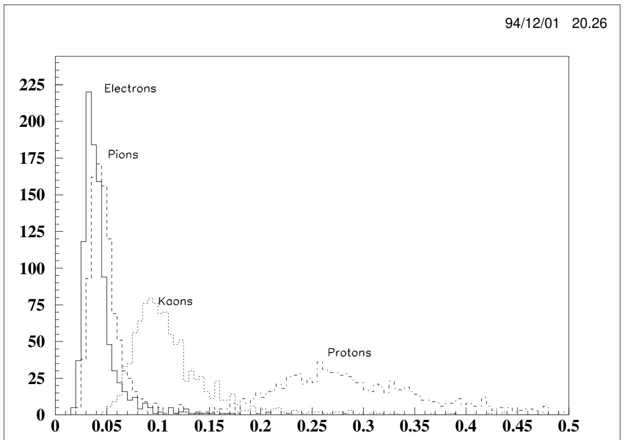

Figure 6: All Partticles at 200 MeV

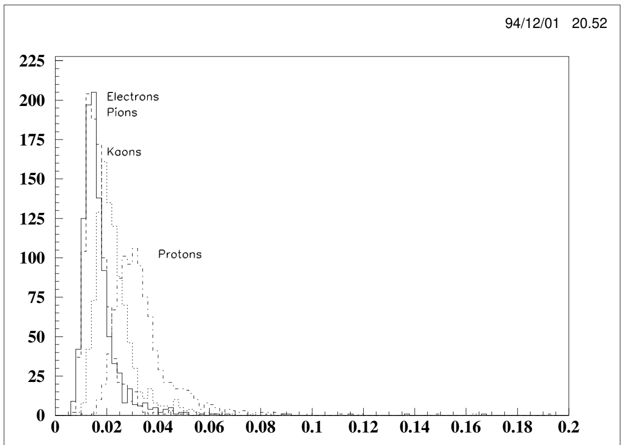

Figure 7: All Particles at 500 MeV

References

[1] Physics Letters B204, (1988) 65.