Electron Identification

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Abstract

During this summer, I was given the project of refining the Rochester electron identification code. To do this, I studied the five primary electron identification variables, analyzing them with the hope of finding errors and their respective limits. I then proceeded to research conversions, which can be used to implement a different method of testing electron-finding algorithms. Overall, I wanted to increase the efficiency of the present Rochester electron identification code, making it more precise and, at the same time, faster.

Introduction

When the first particle accelerators and detectors were built, a problem arose: how can a physicist make sense of the immense quantities of data produced by the collisions of particles? From the beginning, theorists and experimentalists have collaborated in order to establish certain methods of particle identification. These methods have been refined to create a 'fingerprint' for each particle, something that can be used to distinguish one particle from another within a crowded environment of a large collision (Fig. 1). Over the years, thousands of lines of code have been written in order to organize data from events, trying to efficiently label particles. Significant progress has been made in recent years here at CLEO, with an abundance of data from the CLEO II and II.V. The process of identifying particles is far from being totally efficient, but, nonetheless, efficiency is steadily increasing. My project for the summer has been to increase the performance of the University of Rochester identification algorithm, more specifically, the electron algorithm.

Why am I doing this? One of the reasons for this research is to aid in the measurement of V_{cb}. V_{cb}, which is the coupling constant between the charmed and bottom quarks, has a relationship to CP violation. The V_{cb} parameter determines the rate of B^O decay to $D^{*+}\, l^-\, \nu$, with my concern being the lepton (l) element. An electron is a lepton and therefore must be understood in order to measure B meson decay. The efficiency of the electron identification directly affects the efficiency of the identification of the B meson decay. Another reason why I am conducting this research, this pursuit of greater efficiency in electron identification, is to aid in the analysis of CLEO III data. To continually refine our method is an essential goal.

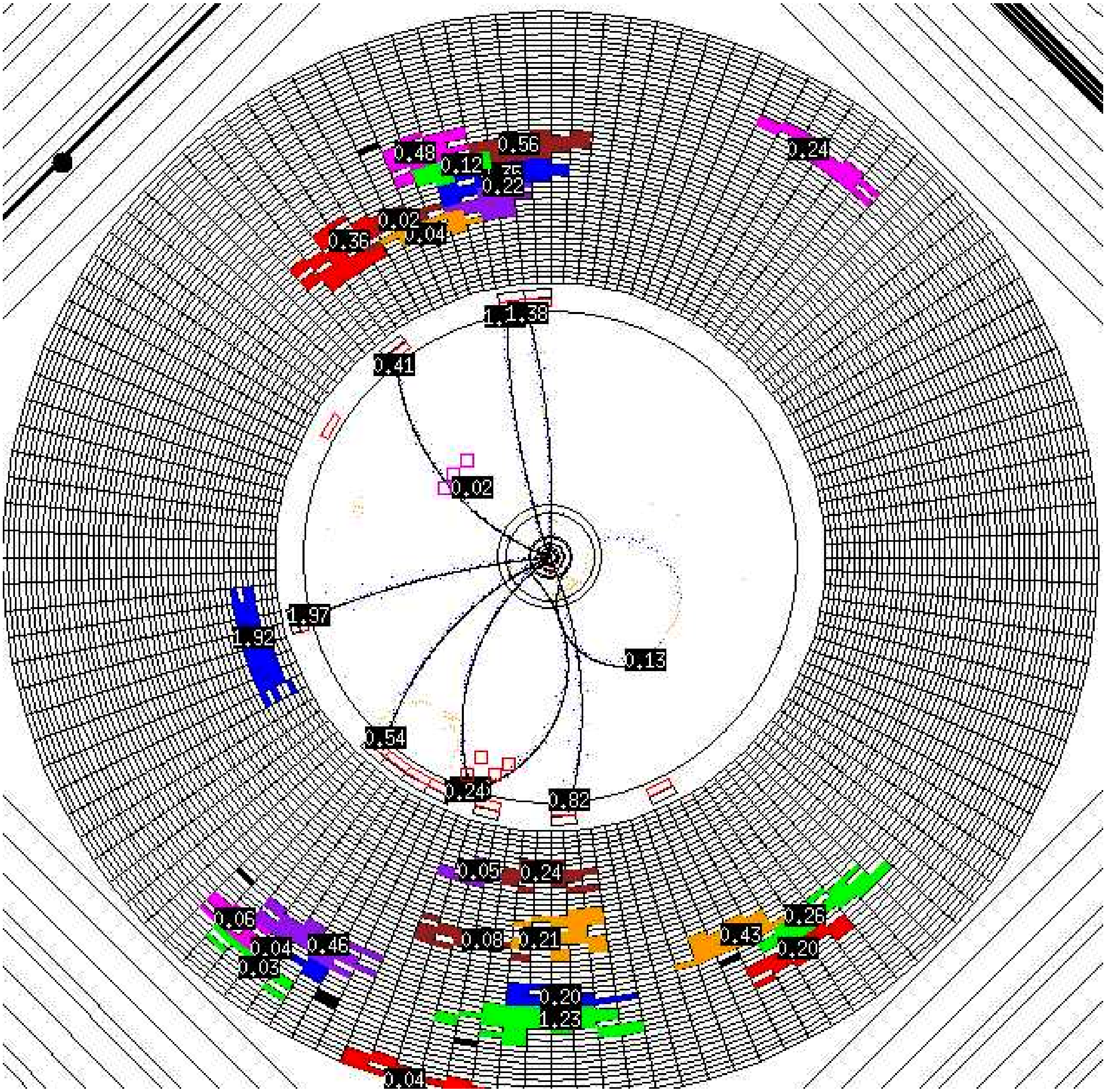


FIGURE 1 A beautiful event display of a 'messy' hadronic event. The problem: where is the electron? (Note: All numbers are in units of GeV.)

Project Synopsis

Enhancing electron I.D. efficiency is a delicate project, requiring precision and consistency. In order to make the identification code more precise, I studied the various components of the code, essentially five variables: E/p, de/dx, E9/E25, width, and chi^2 track matching probability. Using data from the CLEO II detector (Fig. 2), I was able to analyze the five variables, gaining an understanding of each while also finding weaknesses in the present Rochester electron identification code.

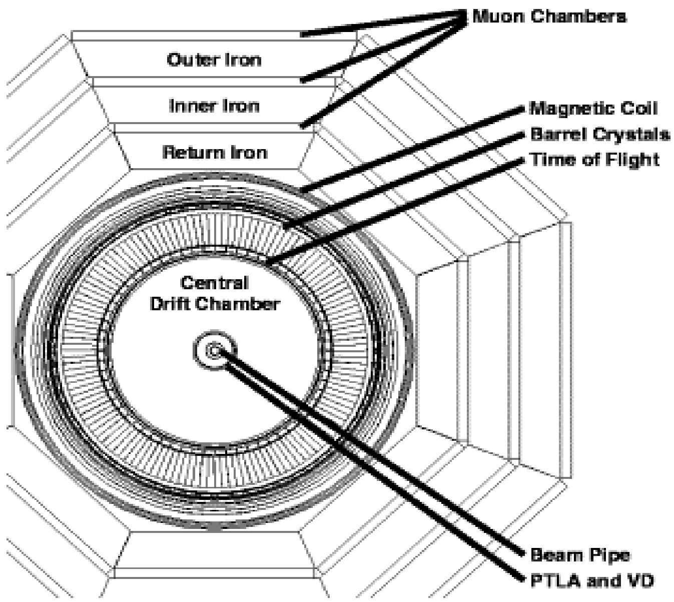


FIGURE 2 CLEO II detector. The elements of primary concern are the drift chamber and the barrel crystals (crystal calorimeter).

In order to study the electron identification variables, I first needed a clean sample of electrons from the CLEO II data set. The events containing clean electrons are radiative bhabhas, an event in which the electron and positron beams of CESR (Cornell Electron Storage Ring) collide, producing an electron, a positron, and one photon (Figs. 3 & 4). These events were skimmed from the data storage tapes, making sure that there were two oppositely charged tracks, two tracks with matching showers, one shower with no track, and other requirements. The purity of our radiative bhabha samples directly effects our ability to accurately measure the efficiency of the variables. Once tested on these clean samples of electrons, the variables would then be used to find electrons in crowded environments, typically called hadronic events (Fig. 1).

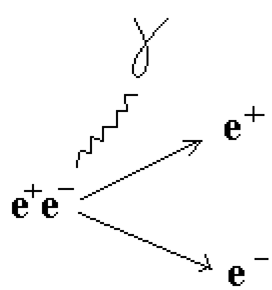


FIGURE 3 A quick schematic of a radiative bhabha event.

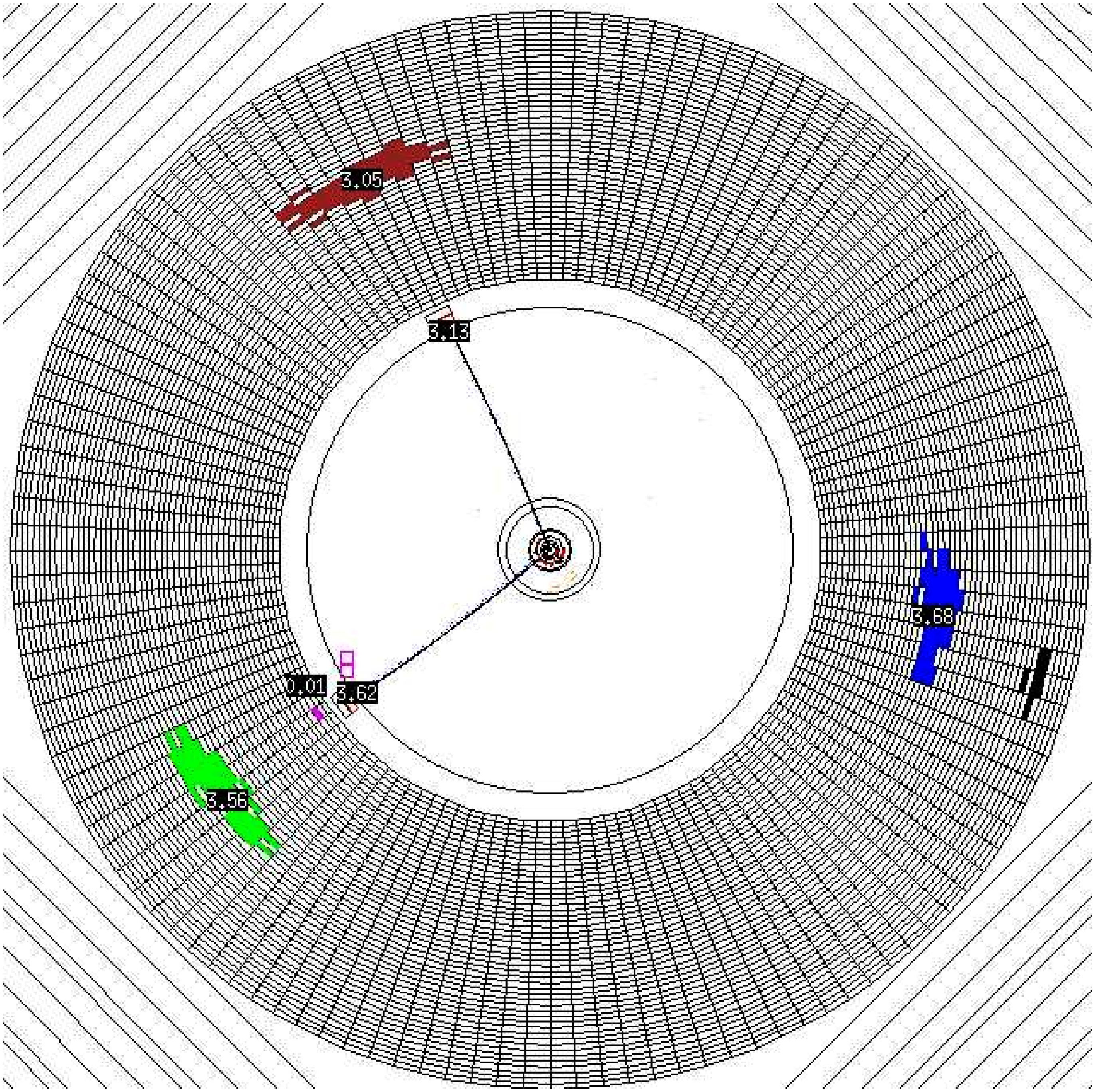


FIGURE 4 An event display of a radiative bhabha. Notice the two distinct tracks with corresponding showers and the third isolated shower.

VARIABLES:

I began my investigation of the identification variables with an extensive study of the shower energy/ track momentum ratio (E/p). As an electron travels through the drift chamber of the detector, it forms a curved path due to the magnetic field within the chamber. Each track has a radius of curvature which depends upon the momentum (p) of the electron (the higher the momentum, the greater the radius of curvature and vice versa). If the electron has enough momentum (more than .25 GeV) it will enter the crystal calorimeter, at which time, it will create an energy shower (E) of photons caused by the electron's interaction with the dense Cesium Iodide (CsI) crystals (Fig. 5).

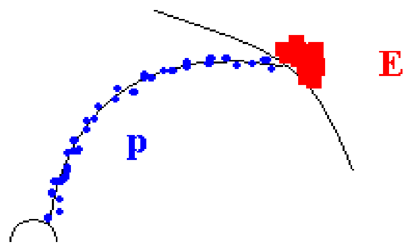


FIGURE 5 A rough sketch of a particle's path and its corresponding energy shower.

The ratio of these two quantities, shower energy and track momentum, forms a unique and powerful variable. By the nature of an electron, it deposits all of its energy into the calorimeter, as opposed to a muon particle, which deposits a small percentage of its energy. Since the mass of an electron is negligible, the momentum is basically a measure of its energy. Therefore, the E/p ratio for an electron should be very close to 1 (Fig. 6).

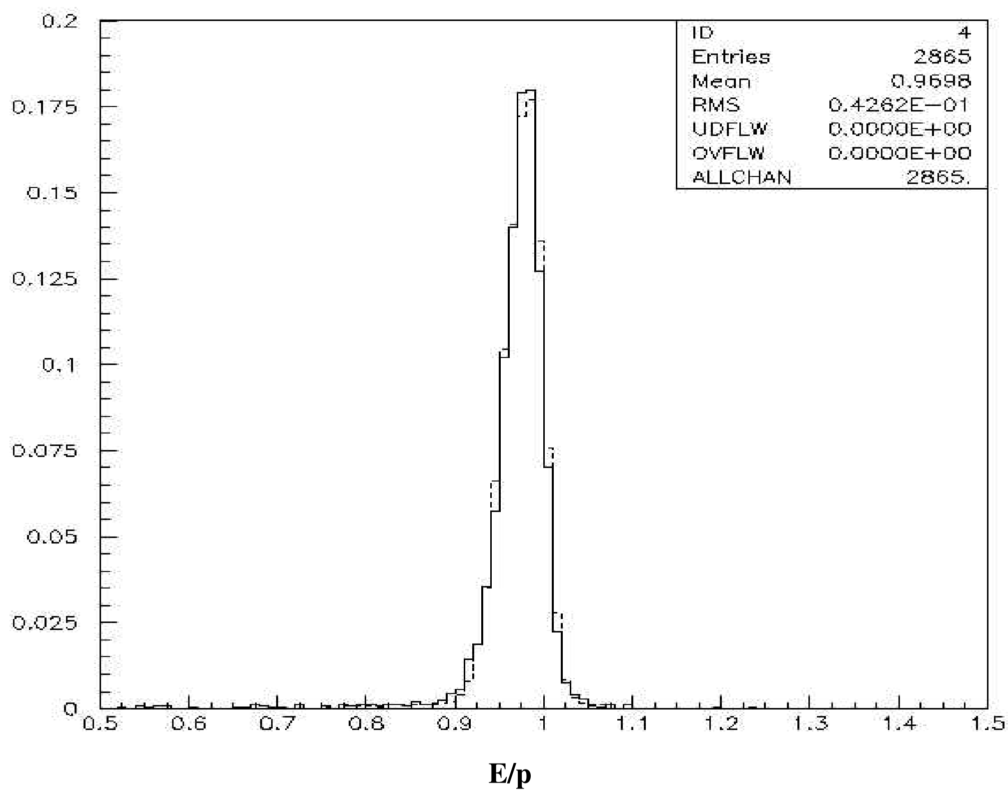
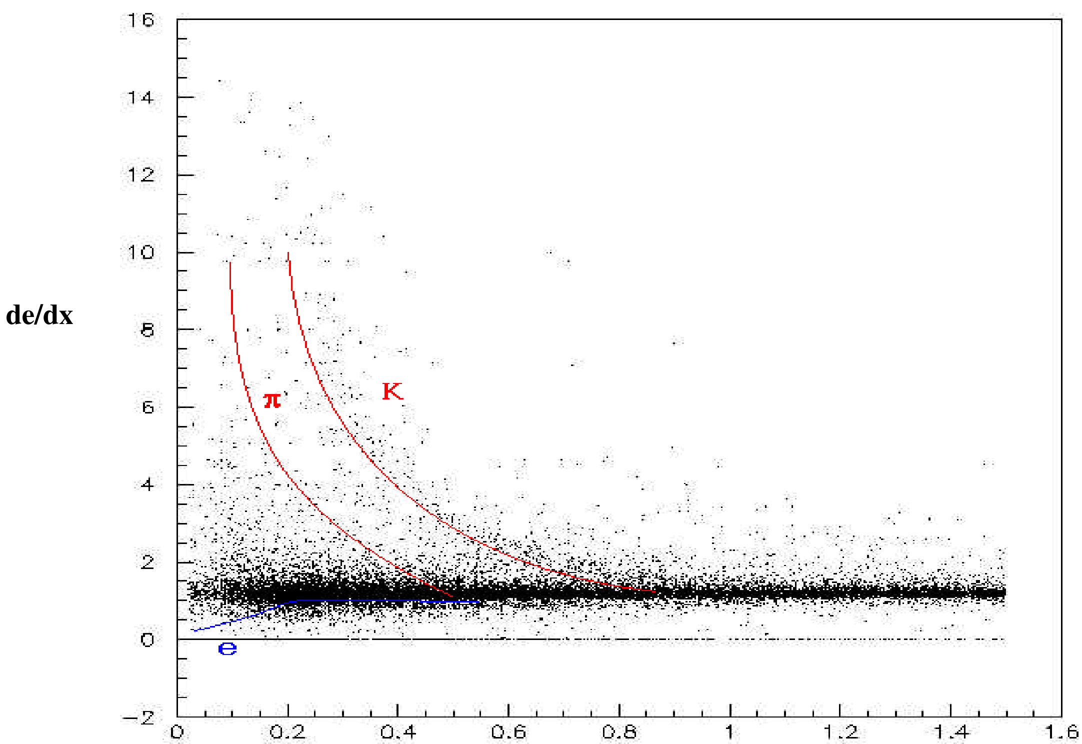


FIGURE 6 A graph of E/p normalized to see the relation of the code's prediction (dashed line) and the experimental results from looking at clean radiative bhabha samples.

As displayed in Figure 6, a clean radiative bhabha sample for the momentum range of 1.0 GeV to 1.2 GeV matches the expectation very well. However, at low momenta, the predictions made by the Rochester electron identification code began to fail.

Why was the code failing at low momenta? I found two primary reasons for skewed results. First, the present Rochester code was not tuned to identify particles of momenta less than .6 GeV. At the time that this algorithm was written, there was not enough high quality data to support research at such low momenta. However, with the immense quantities of data supplied by CLEO II and CLEO II.V, this problem can be corrected. An error in the code has created another problem with low momentum tracks. Sometimes, the present algorithm splits a low momentum track's corresponding shower, causing the E/p measurement to be considerably lower. More research must still be done in order to correct this problem.



p

FIGURE 7 A graph of de/dx versus momentum. As momentum increases, the various de/dx measurement converge. The colored lines have been sketched in to show the approximate location and shape of a particle's de/dx plot.

Following this extensive study of E/p, I proceeded to study the next variable: de/dx, the rate of energy lost per centimeter of distance traveled within the drift chamber. As seen in Figure 4, the particles create paths in the drift chamber. These tracks are reconstructed analyzing hits on thousands of wires running through the ionization chamber. As a particle travels through the chamber, it ionizes the drift chamber gas atoms, causing electrons within the atoms' electron clouds to drift away from the atom, toward the nearest wire, creating a slight current on the charged wire. The ionizing of the gas atoms requires energy. The energy lost in this process of ionization is unique for each particle, giving each particle a unique de/dx plot (Fig. 7). Thus, this variable is useful for determining what particles are in the background of our skimmed samples. Once the background was identified (Fig. 7), I was able to make cuts on energy and momentum conservation and reduce the inclusion of kaons and pions in our samples.

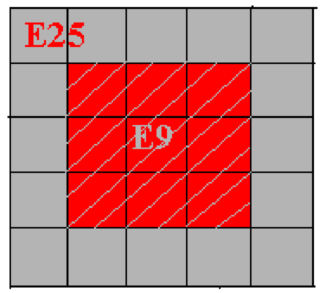
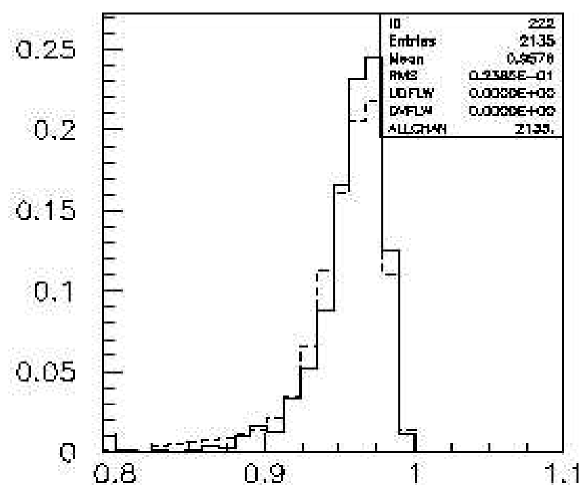


FIGURE 8 A representation of a twenty-five crystal block in the crystal calorimeter.

The third variable I studied was the E9/E25 ratio. As previously stated, most particles create energy showers of varying shapes and sizes when they enter the crystal calorimeter. This third variable compares the amount of energy in the3x3 block of crystals, E9, (the dark section in Fig. 8) to the energy in the 5x5 block, E25, (the dark and gray sections in Fig. 8). Though this variable will never be greater than one, an electron is consistently close to one because, by its nature, an electron has a narrow shower (Fig. 9).

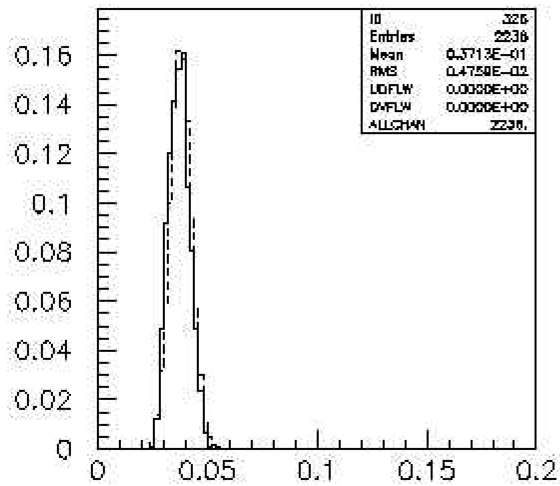


E9/E25

FIGURE 9 A normalized plot of E9/E25. Though its peak is close to one, there remains a large tail. The expected is the dashed line and the experimental, solid.

Even though an electron has a distinct shower pattern, this variable tended to be very weak, being easily corrupted by radiation from nearby showers. This is why Rochester had previously decided to no longer include this variable in its electron identification code.

The fourth variable I studied was the width variable. Closely related to E9/E25, this variable is a measurement of average deviation from the centroid of a shower. Since an electron consistently forms narrow showers, the width measurements are expected to peak close to zero (Fig. 10). Nothing extremely interesting was found concerning this variable. The code provided accurate predictions of electron behavior.



DISTANCE FROM THE CENTROID

FIGURE 10 A typical normalized plot of the width variable.

I finished my study of the variables with the chi^2 track matching probability function. This function computes the probability that a track corresponds to a shower. To find this probability, the chi^2 function considers the x, y, and z coordinates of each track and shower, determining the best possible track/shower match. The benefit of this variable is that it increases the probability that a track will have a corresponding shower, a requirement for an electron.

CONVERSIONS

Following my study of the five variables, I started to study K_S's. A high percentage of K_S's decay to a $\pi^+ \pi^-$ pair. The motivation for this study was to analyze a pure sample of π's. These samples would be used to help characterize background of electron samples, because a majority of background particles are π's. However, this project was quickly abandoned for two reasons: I could not purify the samples enough in order to make any conclusions and another, more promising project was proposed. This new endeavor was the study of conversions. In certain events, a high-energy photon is released from the beam collision. Sometimes this photon interacts with the dense material of the detector and converts into an $e^+ e^-$ pair.

This process naturally produces $e^+ e^-$ pairs within hadronic environments. To date, the primary way of testing electron identification methods outside of bhabha environments yet still in controlled circumstances is to embed pre-selected electrons into a hadronic event. By embedding these electrons, one can see how well an algorithm can find an electron since one is guaranteed to be in that event. However, a conversion does this naturally, saving the time and effort it takes to select and clean electrons and embed these particles into the foreign crowded environment. I was able to select and begin looking at conversion samples within a week as opposed to the months it has taken my mentor and another particle physicist to create embedded samples. Also, using conversions is beneficial because there are different systematics that complement the embbeded study.

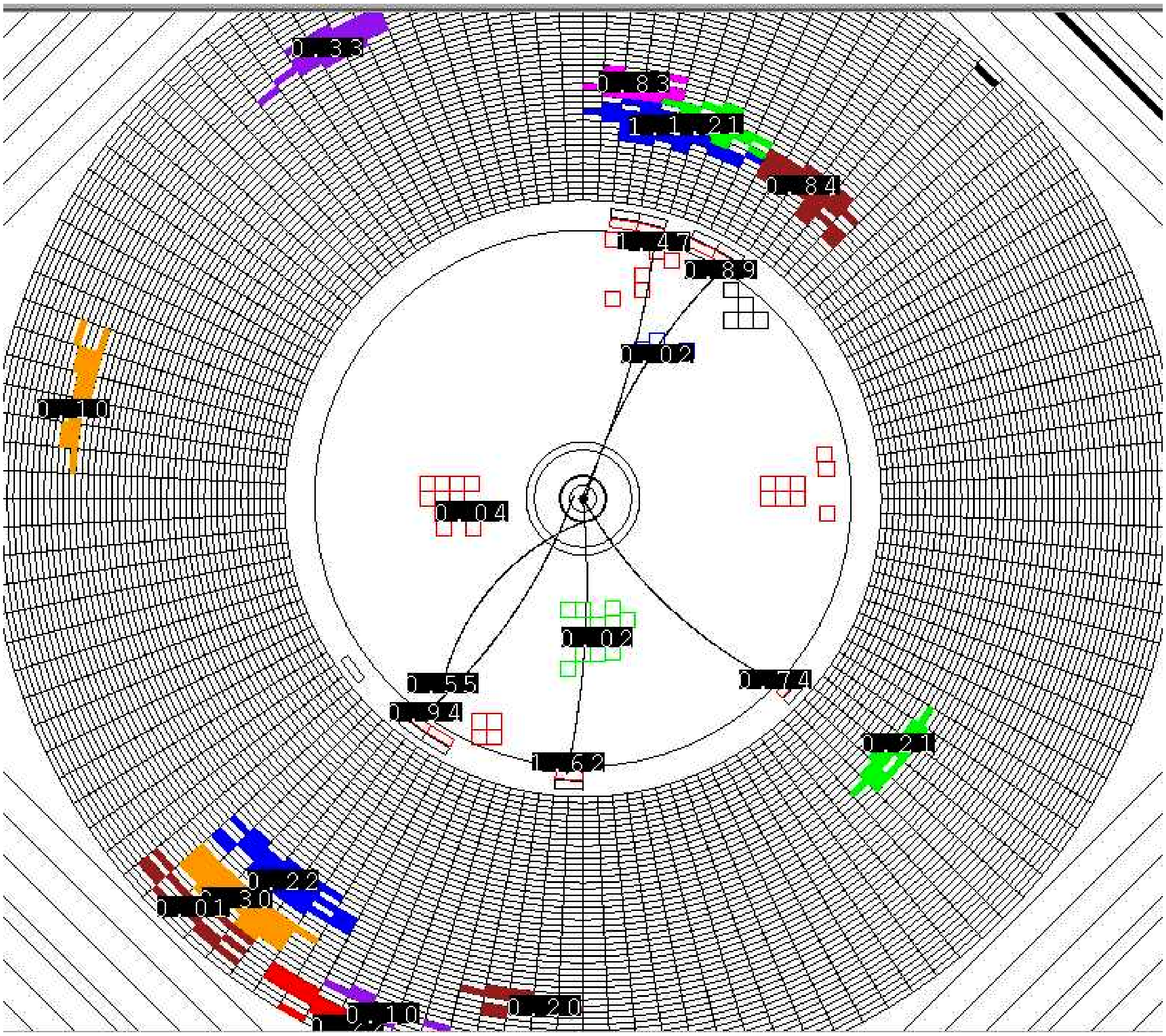


FIGURE 11 An event display of an event with a displaced vertex.

The first step in researching conversions was to select events that contained photons converting to $e^+ e^-$ pairs. To do this I looked for events with secondary vertices, vertices displaced from the beam spot (Figs. 11 & 12).

Aside from requiring a displaced vertex, I also made cuts on the angle between the two tracks at the secondary vertex. Since a photon has no mass, it can not convert into two heavy particles; rather, it converts into two massless particles, or two particles with

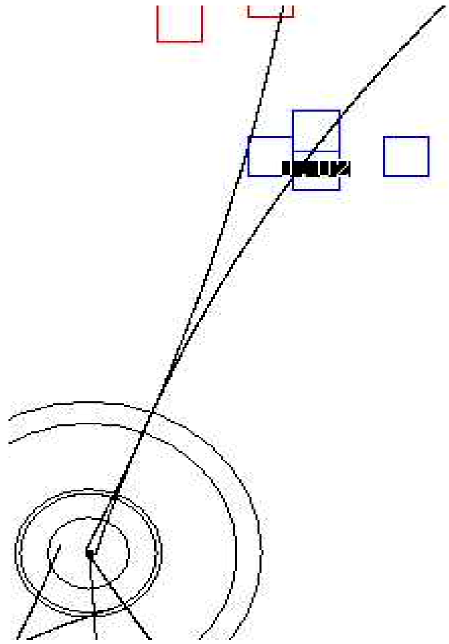


FIGURE 12 Magnifying the vertex reveals that it is displaced from the center, located on the outer VD (vertex detector).

negligible mass, electrons, which have high energy. Only particles with high momenta have tracks with little curvature. If the path has a small radius of curvature, the angle of separation at the secondary vertex must be small. A third cut that I imposed to clean the samples was a requirement that the total charge of the two tracks be zero. Fourthly, one of the two tracks has to satisfy an electron identification code. As a test of my method, I plotted the x and y coordinates of each secondary vertex, seeing if they were located at distances equal to detector materials (Fig. 13). Though the concentric circles lack extreme definition, they still show the presence of detector material.

There are still some issues to be resolved concerning this approach to electron identification. So far, it has confirmed the efficiencies of embedding but has not surpassed them. There is a difference between the Rochester and Cornell between 1.0 GeV and 2.0 GeV momenta that does not show up in the embedding studies. A possible reason for this difference lies in the fact that Cornell still makes a cut on the E9/E25 variable. It appears, when looking at the events that fail Cornell and pass Rochester (Fig. 11) that there is the possibility of shower contamination. Because of this contamination, the E9/E25 ratio is poor and thus a good event is thrown away. There is yet another problem: the samples might be dominated by continuum which would hinder the study of hadronic activity characteristic of B Bbar events.

Conclusions

During this summer, I was able to find the areas of the Rochester electron identification code which need to be refined: low momentum performance and unjustified splitting of showers. Hopefully, these refinements will increase the efficiency of the algorithm. Also, I was able to establish the sensitivity of the E9/E25 variable, justifying its dismissal from the Rochester code. Thirdly, the research I did with the conversions seems promising to be at least a complementary method for electron identification, if not a superior technique.

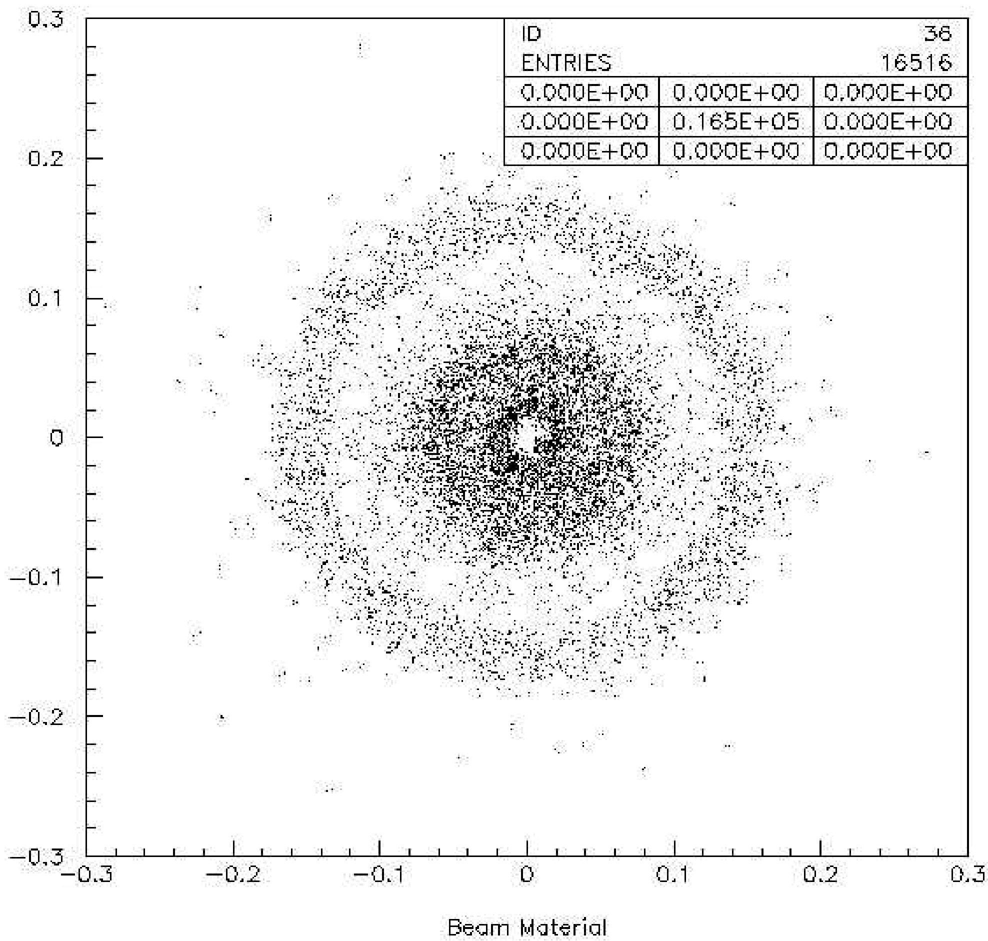


FIGURE 13 A plot of x and y vertex coordinates. Notice the concentric circles at prescribed distances.

Acknowledgments

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