Electron Identification

Brian Winey
Houghton College, Houghton, New York, USA
Physics, Class of 2002
Research performed at Cornell University, Ithaca, New York, USA

Research Supervisor
Daniel Cronin-Hennessy
Department of Physics
University of Rochester, Rochester, New York, USA

SUMMARY
During my summer research experience with the CLEO collaboration of Cornell University, I was given the project of refining the University of Rochester electron identification code. To do this, I studied the five primary electron identification variables, analyzing them, finding errors and limits. I then proceeded to research conversions, a different method of testing electron finding algorithms. Overall, I wanted to increase the efficiency, both in time and selection, of the present Rochester electron identification code.

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 collisions inside the detectors? From the beginning, theorists and experimentalists have collaborated in order to establish certain methods of particle identification. These methods produce a metaphorical signature of various particles, something that can be used to distinguish one particle from the masses within a crowded environment (Figure 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 data sets. 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 efficiency of the University of Rochester particle identification algorithm, more specifically, the electron algorithm.

Why am I doing this? Though there are no pragmatic or existential answers, the primary reason for this research is to aid in the \( V_{cb} \) research. \( V_{cb} \), which is the study of the coupling between the charmed and bottom quarks, has a relationship to CP violation, an essential player in the search for anti-matter. \( V_{cb} \) occurrence is directly related to \( B^0 \) decay to \( D^{* -} \ l^- \ n \), with my concern being the lepton (\( l \)) element. An electron is a lepton and therefore can be studied as part of this B meson decay. To increase 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 analyzing of CLEO III data. To continually refine our method is an essential goal.

METHODS AND MATERIALS
To increase efficiency is a delicate project, requiring precision and consistency. In order to make the identification code more precise, I looked at the various components of the code; essentially five variables: \( E/p \), \( de/dx \), \( E9/E25 \), width, and chi squared track matching probability. Using data from the CLEO II detector (Figure 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 1. A beautiful event display of a 'messy' hadronic event. The problem: where is the electron? (Note: All numbers are in units of GeV.)

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 regiment of electrons from the CLEO II data set. The events most likely to contain 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 storage facilities and analyzed for purity, 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 test the variables. Once tested on the clean samples of electrons, the variables would then be used to find electrons in crowded environments, typically called hadronic events (Figure 1).

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 surrounding the chamber. This curved path varies in curvature, depending upon the momentum (p) of the electron, the higher the momentum, the less curvature of the path. If the electron has enough momentum (more than .3 GeV) it will enter the crystal calorimeter, at which time, it will create an energy shower (E) of photons caused by the electrons interaction with the dense Cesium Iodide (CsI) crystals of the calorimeter (Figure 5).

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 very little 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 (Figure 6).

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 ranges, 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 ranges. However, with the immense quantities of data supplied by CLEO II and CLEO II.V, this exception 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.

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 by processors connected to thousands of wires running through the ionization chamber. As a particle travels through the chamber, it ionizes the gas atoms, causing electrons within the atoms’ clouds to drift toward the nearest wire, creating a slight current on the charged wire. The ionizing of the gas atoms requires energy from the particle. Each particle has a different de/dx shape (Figure 7); thus, this variable is useful for determining what particles are in the background data.

The third variable I studied was the E9/E25 ratio. As previously stated, most particles create energy showers when they enter the crystal calorimeter. These showers have a variety of shapes and concentrations. This third variable compares the amount of energy in the 3x3 block of crystals, E9, (the red section in Figure 8) to the energy in the 5x5 block, E25, (the red and gray sections in Figure 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 (Figure 9).

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 at zero (Figure 10). Nothing extremely interesting was found concerning this variable. The code provided accurate predictions of electron behavior.

I finished my study of the variables with the chi² matching probability function. This function establishes a value for the probability that a track and a shower match. This 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 guarantees that a track will have a corresponding shower, a requirement for an electron.
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.

Figure 5. A quick sketch of a particle’s path and its corresponding energy shower.
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.

Figure 7. A graph of $dE/dx$ versus momentum. As momentum increases, the various $dE/dx$ measurements converge.
Conversions

Following my study of the five variables, I started to research K⁺s. A high percentage of K⁺s decay to a p⁺ p⁻ pair. The motivation for this study was to analyze a pure sample of p⁺s. These samples would be used to help characterize background of electron samples, because a majority of background particles are p⁺s. However, this project was quickly abandoned for two reasons: I could not clean 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 inside 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 embedding 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, studying conversions can eliminate some of the biased conclusions that can result from embedding.

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. 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 negligible mass, electrons, which have high energy. Only particles with high momentum have tracks with little curvature, thus making the angle of separation less. A third cut that I imposed to clean the samples was a requirement that the total charge of the two tracks be zero. One of the two tracks must also pass a hard algorithm electron cut. As a test of my method, I plotted the x and y coordinates of the each vertex, seeing if they were located at distances equal to detector materials (Figure 13). Though the concentric circles lack extreme definition, they still show the presence of detector material, a conformation that I am following the correct leads.
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 discrepancy between the Rochester and Cornell results, particularly between 1.0 GeV and 2.0 GeV. 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 (Figure 11) that there is the possibility of shower smearing. Because of this smearing, the E9/E25 ratio is poor and thus a good event is thrown away. There is yet another problem: DAN, I forget what Dr. Cinabro said!

![Figure 12](image12.png)
Figure 12. Magnifying the vertex reveals that it is displaced from the center, located on the outer VD (vertex detector).

![Figure 13](image13.png)
Figure 13. A plot of x and y vertex coordinates. Notice the concentric circles at prescribed distances.

**CONCLUSIONS**

During this summer, I was able to find the areas of the Rochester electron identification code which need to be refined: the low momentum exception and the 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. Lastly, the research I did with the conversions seems promising to be at least a complementary method for electron identification, if not a better, more time efficient choice.

**ACKNOWLEDGEMENTS**

I am pleased to acknowledge Dr. Daniel Cronin-Hennessy, Postdoc, and Dr. Ed Thorndike, University of Rochester for proposing and encouraging this Research Experience for Undergraduates project and guiding my effort. This work was supported by National Science Foundation REU grants PHYS-9987413 and PHY-9731882 and research grant PHY-9809799.