Search for b Squarks at $\Upsilon(4S)$

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Abstract

We report on the search for a light bottom squark resulting from the decay of $\Upsilon(4S)$. This search was performed on CLEO III data. This is the first search of its kind to look for squarks bound in the form of stable particles. We searched for the formation of a pair of squarks dressed with an up or an anti-up quark to form a pair of charged B mesinos.

Introduction

Supersymmetry (SUSY) is the theory designed to resolve quadratic divergences in the Standard Model[1]. This is done by giving each Standard Model particle a supersymmetric partner which differs in spin by 1/2. These supersymmetric companions may also differ in mass, but are in all other respects are identical. Also, R parity is conserved, which means that if a standard model particle decays into SUSY particles, the SUSY particles must come in pairs; however, if a SUSY particle decays into Standard Model particles, another SUSY particle must occur in the decay products[2]. In the minimal supersymmetric theory, spin 1/2 matter would have spin 0 partners, which yields a simpler theory. However, mass cannot be predicted. No supersymmetric particles have yet been found, possibly because they are too massive to be produced in our current detectors; either way, we do not know what mass range to look for. Recently theorist Edmond Berger has proposed a mass range for the bottom squark and gluino to account for the discrepancy in measured bottom quark cross sections. Bottom quark cross section measured in large hadron colliders ($p\bar{p}$) is larger than the predicted value based on the Standard Model. Berger believes that this can be explained with light bottom squark pair production. The proposed mass range for a bottom squark would be 2GeV< $m_{\tilde{b}}$ <5.5GeV [3].

If the b squark is indeed this light then the decay $\Upsilon \to \tilde{b}\bar{\tilde{b}}$ should occur. A search for b decay $\tilde{b} \to cl\tilde{\nu}$ has already been performed; no results were found, which led them to rule out the existence of a bottom squark with mass range 3.5-4.5 GeV [4]. However, this limit only applies to a bottom squark that can violate R parity: if b squarks cannot violate R parity, this mass range may still be perfectly valid. In this case, the b squarks may each be dressed with an u or $\bar{u}$ to form a $\tilde{B}^+$ or a $\tilde{B}^-$ mesino, with mass range 3-7 GeV [5]. The spin of a $\tilde{B}$ mesino would be 1/2, therefore it would be produced with a $1 + cos^2\theta$ distribution. Decays producing additional pions, such as $\Upsilon \to \tilde{B}^-\tilde{B}^0\pi^+$, might also be possible. The mesinos would be heavy charged particles, and may be mistaken for taus or hadrons. This may be detectable with a combination of dE/dx and RICH or time of flight data What follows are the details of our search for light B mesinos in CLEO III data.

Detector Instruments Used

The primary method of obtaining a particle's mass in this study was to use dE/dx information. When a charged particle travels through the drift chamber it ionizes gas. The magnitude of this ionization is related to the velocity of the particle. The average ionization along a track as measured by the CLEO III drift chamber is called the truncated mean. The ionization loss, or dE/dx is related to the velocity β by the Bethe-Bloch equation. The dE/dx does not, in general, uniquely define β. However, if we restrict ourselves to the range of mesino masses being considered, each dE/dx value corresponds to a single β.

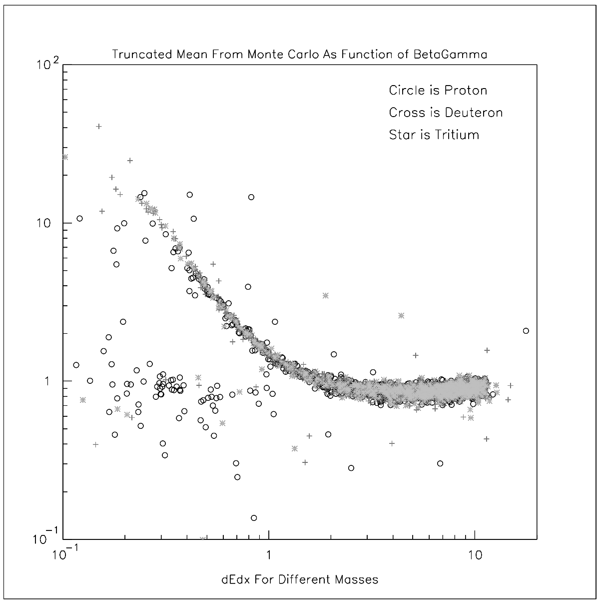

FIGURE 1. Plot of dE/dx versus β, based on data from MC files

The momentum is found in the drift chamber by measuring the radius of curvature of the track in a magnetic field. The radius is proportional to the momentum. Once we know the momentum and find the velocity from dE/dx, we can solve for a particle's mass.

Another way to identify a particle is to use the Ring Imaging Cherenkov detector, or RICH. This is used to find the velocity of a particle through its Cherenkov radiation. This radiation is produced because the particle is moving faster than the velocity of light in the medium used. The angle at which the cone of radiation is emitted is related to the velocity β through the equation $cos\theta = 1/n\beta$, where n is the refractive index of the medium. These measurements are used to calculate log likelihoods for the five known particles. Measurements not consistent with known particles were not accessible for this analysis. Therefore RICH cannot be used to search for a particle with arbitrary mass, but it can be used to check for consistency with known particles.

Monte Carlo Simulations, Data Used

Monte Carlo simulations were used to predict the detector response to a $\Upsilon(4S)$ decay to a pair of b squarks. There are three different possible decay modes, Cases 1, 2, and 3, which are summarized in Table 1. Case 1 events consist of two charged mesinos plus additional pions. Case 2 events consist of a charged mesino, a neutral mesino, and a charged pion. Case 3 events consist of two charge mesinos and two charged pions. Files of 500 events each were created for each decay type and mass hypothesis. Mass was varied between between 4.0 and

5.0 GeV, incremented in steps of 0.2 GeV. There was also a simulation of 3.4 GeV mass.

TABLE 1. Mesino event decay types.

Decay Type	Particles Produced
Case 1	$\gamma \rightarrow \tilde{B}^{+}\tilde{B}^{-}$ + additional π
Case 2	$\gamma \rightarrow \tilde{B}^{+or-}\tilde{B}^{0}$+ charged π
Case 3	$\gamma \rightarrow \tilde{B}^{+}\tilde{B}^{-}\pi^{+}\pi^{-}$

Next, we ran the Monte Carlo files we created through a simple processor to test our ability to reconstruct the input parameters. Included are graphs of mass and momentum of a 4.0 GeV simulated mesino. The mass measured through dE/dx data is in agreement with the mass fed into the simulation, as is the momentum.

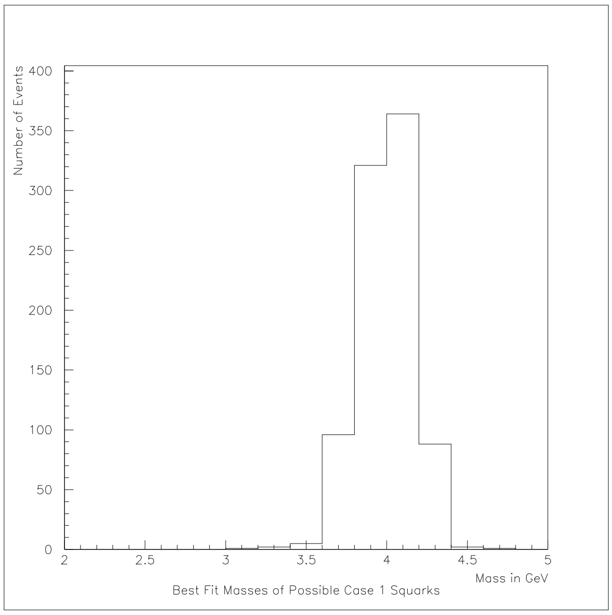

FIGURE 2. Plot of mass for 4.0 GeV mesino mass MC Case 1 event. As you can see, the dE/dx calculation of mass gives us back on average the value we inputted.

Data from Cleo III is classified under skims depending on which trigger lines a given event fired. These skims are then used for placement in a subcollection; however, not every event is classified under the subcollection corresponding to its skim. It was then necessary to determine in which subcollection a mesino may have been stored. We used a processor which extracted data on which trigger lines fired for each Monte Carlo event. We found that the most commonly triggered lines were the Muon Pair line for Case 1 events, Radiative Tau lines for the Case 2 events, and the Hadron line for Case 3 events. However, the Muon Pair subcollection was not available at the time, and the Tau triggered for at least half the events in each file. Also, about 2/3 of events fired both triggers. Based on this information, we decided to search in the dataset 8 Tau subcollection. The average rate at which the Tau line triggered for each type of decay is given in Table 2.

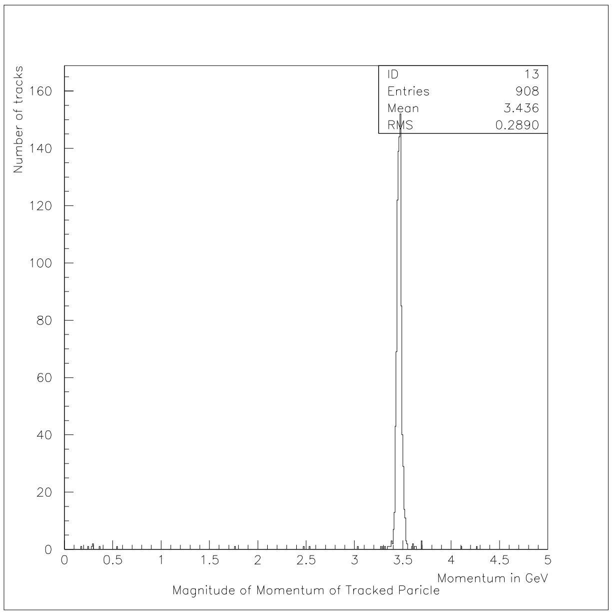

FIGURE 3. Plot of momentum for same MC file. We expected an average momentum of 3.48 GeV for this mass, and the average value we find agrees with expectations.

TABLE 2. Percentage of events of a given decay type triggering Radiative Tau lines.

Decay Type	Percent Triggered
Case 1	0.550
Case 2	0.562
Case 3	0.743

Cuts

Before narrowing it down as to what type of decay an event might be, some general cuts were made. These included:

• **Events come from beam center:** $d_0 < 0.003$
• **Standard quality cuts**
• **Number of tracks $\leq$ 4**
• **Make sure it is not an electron or a proton:** dE/dx sigma for proton and electron hypotheses > 0.5. The dE/dx for a low-mass mesino (3-4 GeV) may be similar to dE/dx for one of these particles. Therefore, we have to use less than a standard 3 sigma cut.
• **Make sure it is not any other known particle:**possible mesinos must be at least three sigma away from muon, kaon, and pion hypotheses.

Next, we did specific cuts to determine if the event is a Case 1 type event, which means there are two charged mesino tracks plus possible neutral pions. These cuts include:

• **Right number of Tracks:** number of tracks = 2 and number of possible mesinos (passed other cuts and are not pions) = 2

• **Both particles have the same mass:** both particles must be within 3 sigma of the average of the two mass measurements.

• **Conservation of energy:** take sum of energy of charged particles plus any neutral pions produced. The difference between this and the center of mass energy must be less than 8% of the center of mass energy

• **Conservation of momentum:** cut if the sum of momenta is greater than 5% of center of mass energy

Cuts were also made for Case 2 and Case 3 events. However, this analysis concentrated on Case 1 events.

Monte Carlo Analysis

The filter was run on signal and background Monte Carlo. The background MC files consisted of 227,000 tau events, along with files from hadron and continuum background collections. Signal Monte Carlo consisted of sets of 500 events each with varying mesino mass, ranging from 3 to 5 GeV. The efficiency of the filter on signal MC depended on the mass used. For a mass range of 4.0 to 5.0 GeV, between 90% and 100% of Case 1 events were passed. For a mass of 3.4 GeV, though, the efficiency dropped to 41%. No events in the mentioned background were passed by the Case 1 filter. However, about 0.5% of tau events were passed by the Case 2 filter. For this reason Case 2 events were not used.

Results from Analysis on Real Data

Next, we ran our processor on the Tau Subcollection files of CLEO III data, in Dataset 8. We found that on average 1 in 40,000 events passed our filter for Case 1 events. Considerably more passed the filter for Case 2 events, but this was obviously background (see Fig. 4).

The average mass of the possible Case 1 mesinos was approximately 3.4 GeV. This mass was calculated from dE/dx measurements (Fig. 5). The average momentum found was 3.98 GeV, which follows conservation of energy(Fig. 6). The angular distribution had a minimum at $\cos\theta = 0$ and a max at $\cos\theta = 1$ see Fig. 8). About 153 possible Case 1 events were found in dataset 8. These events were compared to Monte Carlo Case 1 files of mesinos with mass of 3.4 GeV. Included are plots of the important quantities from possible mesino data and Monte Carlo files with 3.4 GeV mass mesinos.

The number of sigmas by which the real data's dE/dx values differed from the dE/dx hypotheses of standard particles is listed in Table 4. You can see that the particles' dE/dx values most resemble those of an electron. Moreover, the angular distribution might be close to $cos^4\theta$, which is a component of bhabhas' distribution[6]. Because of this we decided to compare the parameters of bhabha events to those of our possible mesinos. We created files of non-radiative bhabhas and radiative bhabhas with one, two, or three photons; a file of 1000 events was created of each type. Next we compared the standard particle RICH log likelihoods in the possible Case 1 data to the bhabha MC values. The results are found in Table 5. Also, we looked at the truncated means of both sets of data, the plots of which are included in Fig. 13 and Fig. 14.

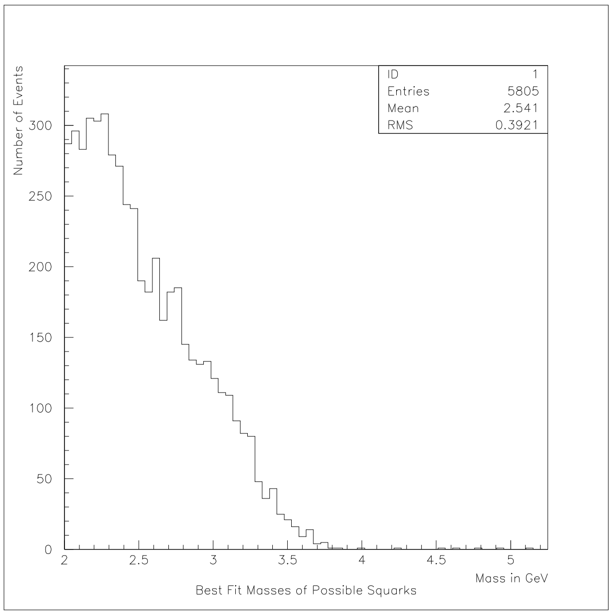

FIGURE 4. This is a plot of the mass calculated from dE/dx measurements of all the possible mesinos found including Case 1, Case 2, and Case 3 events. The distribution overwhelmingly consists of Case 2 background.

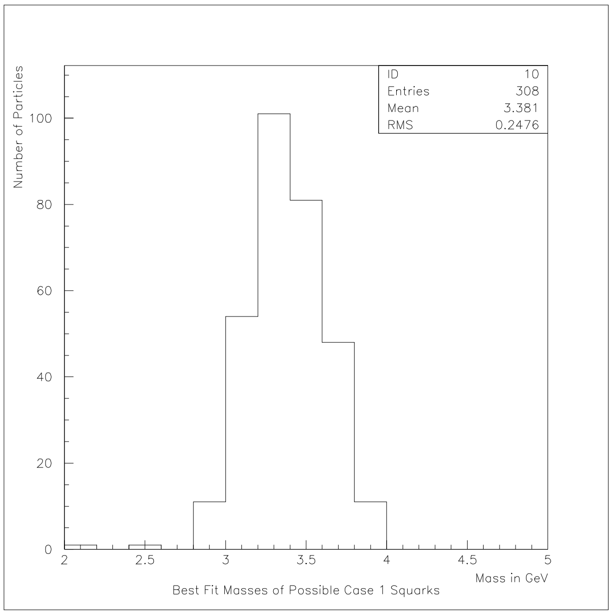

FIGURE 5. Calculated mass for events passing Case 1 filter.

Conclusions

While we have not yet analyzed enough data to come to definite conclusions, it seems

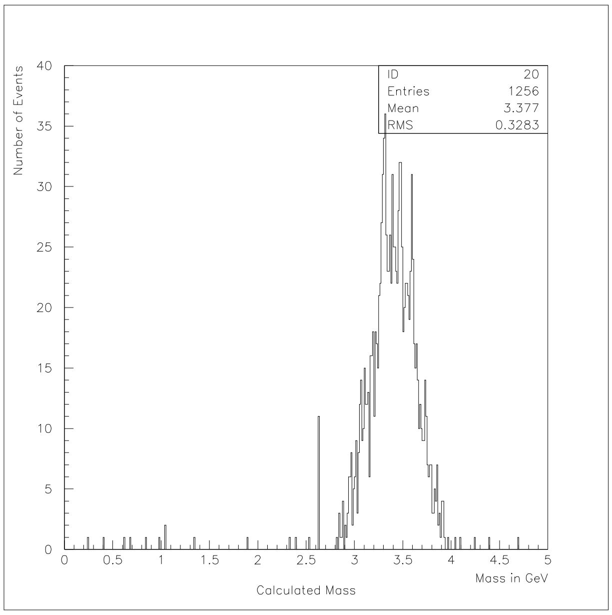

FIGURE 6. Calculated mass for MC 3.4 GeV mass Case 1 events.

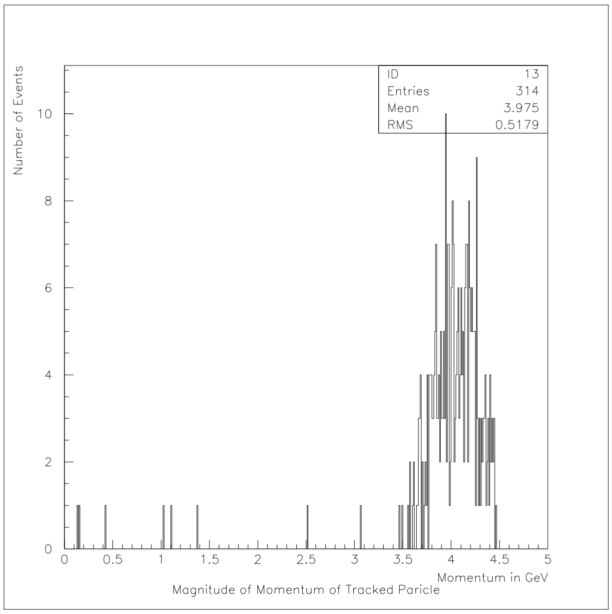

FIGURE 7. Measured momentum for events passing Case 1 filter.

as though the possible Case 1 events we have found are likely to be bhabha events that had poor momentum fits. The angular distribution of our results resembles that of non-radiative bhabhas, as do the RICH log likelihoods and the truncated mean. More work still needs to be done. We are currently creating code to perform the analysis on CLEO II data. CLEO II uses a time of flight device, rather than a Cherenkov detector, to accurately calculate the velocity of the particles. There is much more CLEO II data available for a more thorough

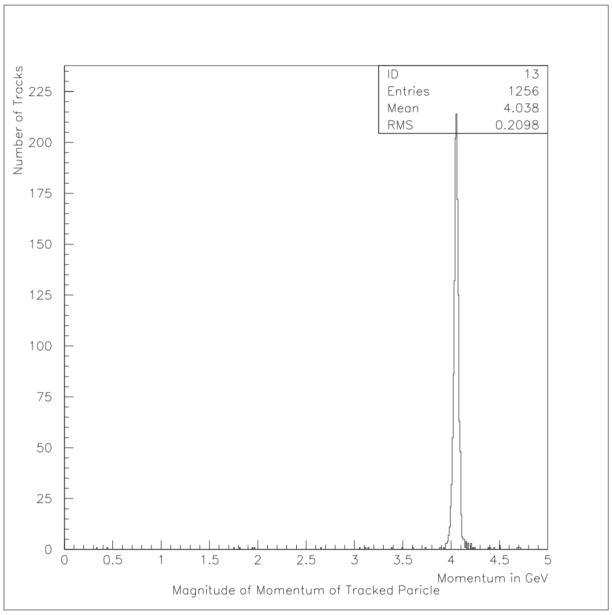

FIGURE 8. Measured momentum for MC 3.4 GeV mass Case 2 events.

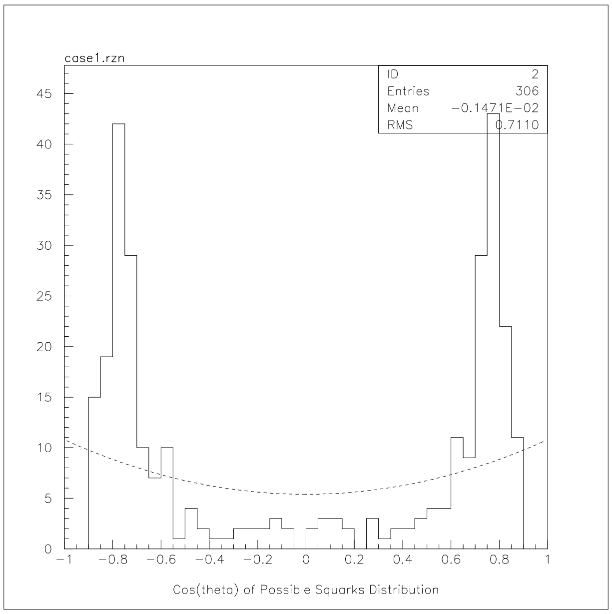

FIGURE 9. Angular distribution for events passing Case 1 filter. The expected angular distribution, the function $1 + cos^2\theta$ is overlayed.

search.

Acknowledgments

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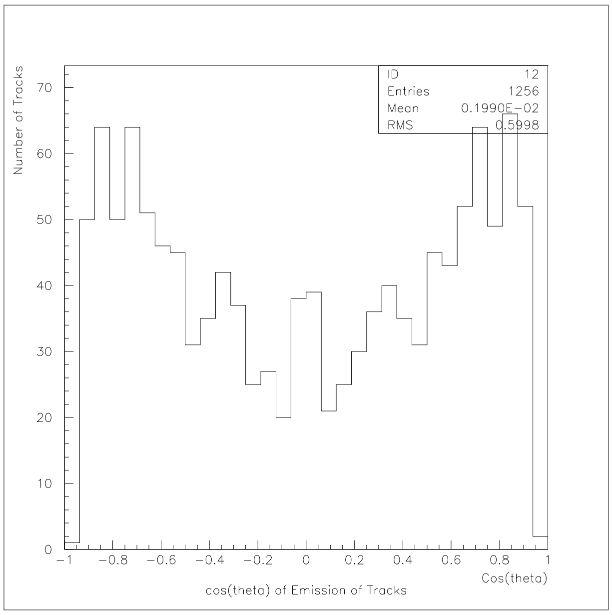

FIGURE 10. Angular distribution of MC 3.4 GeV mass Case 1 events.

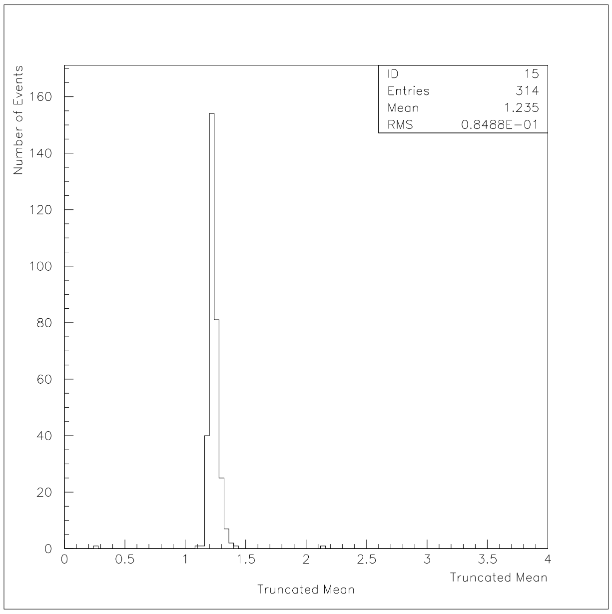

FIGURE 11. Truncated mean for events passing Case 1 filter

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Footnotes and References

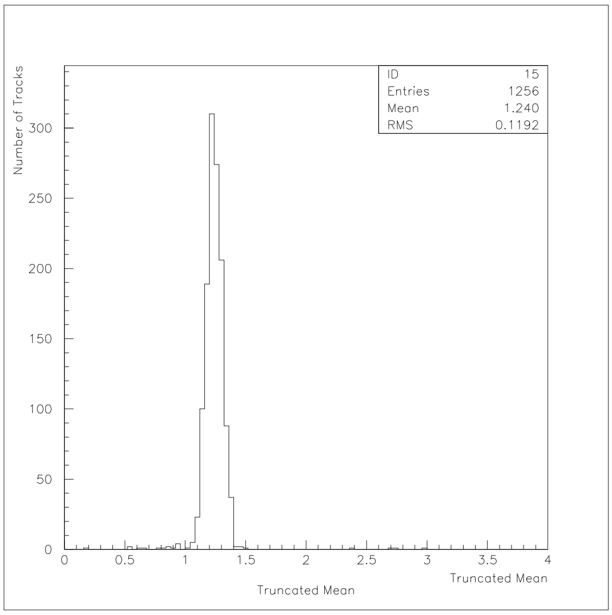

FIGURE 12. Truncated mean for MC 3.4 GeV mass Case 1 events.

TABLE 3. Real Data sigma deviation away from standard dE/dx hypotheses.

Hypothesis	Sigma
electron	1.46
muon	3.64
pion	4.09
kaon	6.00
proton	6.52

1. Drees, Manuel, hep-ph/9611409 v1.
2. Martin, Steven P., hep-ph/97090356 v3.
3. Berger, Edmond L., hep-ph/0103145 v1.
4. CLEO Collaboration, V.Savinov *et al.*, Phys.Rev. D **63**, 051101 (2001).
5. Berger, Edmond L. and L. Clavelli, hep-ph/0105147.
6. Rich Galik, personal communication.

TABLE 4. RICH log likelihoods for both possible mesinos and MC bhabhas

Hypothesis	Possible Case 1	Non-radiative Bhabha
Electron	-130.813	-137.885
Proton	-111.806	-127.205
Pion	-130.76	-137.881

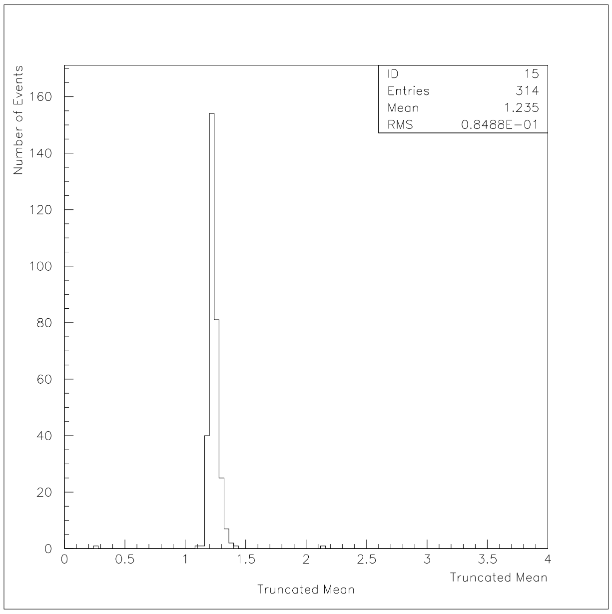

FIGURE 13. Plot of truncated mean for possible Case 1 events

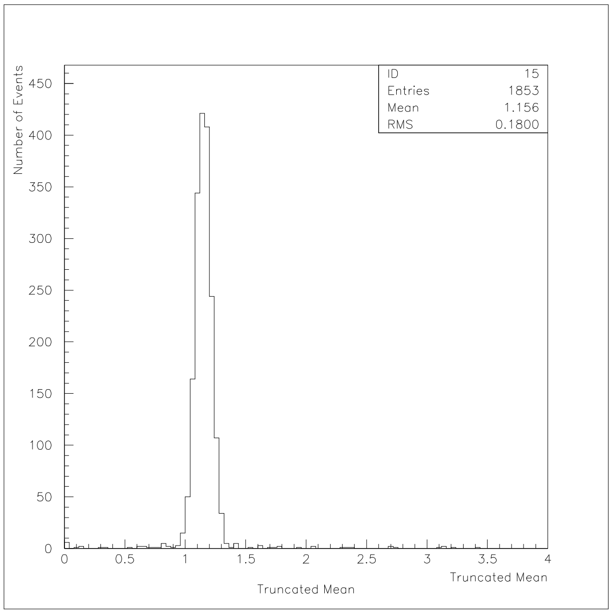

FIGURE 14. Plot of truncated mean for non-radiative bhabha MC simulations