Search for $B \to D_s\eta$

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Abstract

The overall goal of this project is to measure V_{ub}/V_{cb}. This is done by measuring the decay rates of the B meson to the D_s meson and a meson with no charm or strange quark. My particular task was to look at the decay of $B \to D_s\eta$. CLEO II and II.V data and Monte Carlo were used, cuts on kinematic quantities were studied and optimized and an upper limit is placed on the decay.

Introduction

In the domain of particle physics, the Cabibbo-Kobayashi-Maskawa (CKM) Matrix is an important element in understanding what goes on with quarks. The CKM matrix describes the weak transitions of quarks. Likewise, the elements of the CKM matrix describe the mixing between mass states and weak eigenstates. Objects that have a well defined mass are a mixture of the weak eigenstates. Moreover, a greater knowledge of the elements of the CKM matrix may provide greater insight into CP violation. Therefore, we desire to know what the values of the CKM elements are. (See Fig. 1 [1])

This study focuses on the measurement of V_{ub}/V_{cb}. To measure these elements we study the transition of the b quark to a u quark or a c quark. In particular we use the CLEO II and II.V data from CESR. This data is tuned to 10.58 GeV, which corresponds to the $\Upsilon(4s)$ system, which is a $b\bar{b}$ bound state. There is also data taken 55 MeV below resonance to get off resonance data.

There are four possible decay methods for the $\Upsilon(4s)$ system, shown in Fig. 2. The first three provide only minor contributions , however, the fourth decay, which is not found in the $\Upsilon(1s)$ (2s) or (3s) systems, is the decay that we are interested in. In this decay the strong force holding the $b\bar{b}$ bound state together breaks, creating a light quark and its anti-quark, such as a $u\bar{u}$. In this case the $\Upsilon(4s)$ system decays into a B meson and a $\overline{B}$ meson. It is this set of mesons that we are interested in.

We use the decays of the b quark in the B mesons to measure the CKM elements. However, this becomes difficult as there are several modes for the B meson to decay, as shown in Fig. 3. They may prodcue similar or even identical final states, causing confusion as to what decays are contributing to the results. There are many theoretical values for the branching ratios [2]. So, our task is to analyze the multiple channels of B decays in an attempt to measure the CKM elements.

Method and Analysis

We desire to measure the ratio of the CKM elements V_{ub}/V_{cb}. In order to do this we focus on the spectator decay of the B-mesons, as can be seen in Fig. 3. Most b decays are $b \to c$ with the emission of a virtual W. Yet, in this case, the b quark decays through the weak interaction to either a c quark or a u quark. One advantage of dealing with the spectator decay is that the quarks do not mix. Quarks from the weak decay stay together and the quarks from the meson decay stay together.

Besides the possible decays of the b quark, there are several possible decays that the W-boson can undergo, as can be seen in Fig. 3. This study focuses on the W-boson decaying to a c quark and an $\overline{s}$ quark. We restrict ourselves to this for two main reasons. First, the W decaying into a lepton and a neutrino poses many difficulties for the reconstruction of the neutrino. They cannot easily be detected, only inferred, by energy and momentum conservation and there is the possibility of having more than one neutrino in an event. So the reconstruction can get messy and it becomes difficult to get a clean result.

The second decay mode, $W \to \overline{u}d$, is difficult because the quarks could mix, or the products of the W decay and the rest of the B-meson decay could be similar. Therefore, in order to look at a theoretically simple channel, we focus on $W \to \overline{c}s$, which materializes mainly in the form of a D_s or a D_s^* meson. The $D_s^{(*)}$ cannot be confused with the products of the rest of the B meson. Therefore, we study $B \to D_s^{(*)} X_u$, where X_u is some meson composed of a u quark and the other light quark in the B meson, such as η, π^+, π^o, etc. Ken Mclean has already studied many of the possibilities, and my task is to study $B \to D_s\eta$, where $D_s \to \phi\pi$, and $\phi \to K^+K^-$, with $\eta \to \gamma\gamma$.

In order to begin the search, code was written in Kinematic Analysis Language (KAL). This code was then run over the CLEO II and CLEO II.V Monte marlo and data. The Monte Carlo and data that were used was from skims that Ken had done earlier. These skims had the following properties:[3, 4]

1. Class 10 (Hadronic)
2. 4 or more charged tracks
3. R2GL < 0.6
4. at least one $D_s^{(*)-}$ candidate with a momentum greater than 1.5 GeV,
5. at least one B-meson candidate.

At least one B meson candidate must satisfy:

1. $M_{beam} = \sqrt{E_{beam}^2 - p_{B-candidate}^2} > 5.2\ \mathrm{GeV}/c^2$
2. $|\Delta E| = |E_{beam} - E_{B-candidate}| < 0.3\ \mathrm{GeV}$

The first three cuts are to ensure that the event is hadronic and not an event with a well defined jet axis which would likely be a continumm ($q\overline{q}$) event. The last set of cuts is to ensure that the event has what we are looking for.

After the KAL code was run on the Monte Carlo, the results were analyzed in Physics Analysis Workstation (PAW). The different variables were compared between the signal Monte Carlo, the on-resonance ($B\overline{B}$) Monte Carlo, and the continumm ($Q\overline{Q}$) Monte Carlo. By comparing the different Monte Carlos, cuts on the variables were determined so as to maximize the $signal^2$ to "background" ratio which is related to the statistical significance of the signal Ken had a PAW script set up to compare the signal, $B\overline{B}$ Monte Carlo, and the $Q\overline{Q}$ Monte Carlo for variables I chose, and determine the cut which would maximize the signal. Some of the variables that we cut on to suppress the continumm can be seen in Fig. 4. The variables were then compared to find the best increase in significance. After the best variables to cut on were selected, seen in Table 1, they were run through a Fortran routine which optimized the cuts simultaneously to maximize the $signal^2$ to ¡noise¿ ratio.

The variables that were cut on can be seen in Table 1, along with the value associated with the cut.

TABLE 1. Cuts selected for B→ $D_s\eta$

Variable	Cut
δB Mass	$<.0069$
ΔE	$<.138$
Cos θ_b	$<.9575$
$\delta\phi$ mass	$<.013$
δD_s mass	$<.016$
Helicity	$>.312$
Cos θ ($\eta\pi$: D_s)	$>$-0.93
Fisher Discriminant	$<.72$
Shape	<1.25
Cos $\theta_{\gamma\gamma}$	$>.44$
$\delta\eta$ mass	$<.04$
$\gamma 1_{e9/e25}{}^{*}\gamma 2_{e9/e25}$	$>.87$
Photon Veto	$<.89$

The δB Mass is the difference between the mass of a B candidate and the nominal value of a B meson. As defined above, ΔE is the difference between the beam energy and the energy of a B canidate. Cos θ_b is the angle the B meson makes with the beam axis. The $\delta\phi$ mass andδD_s mass are the differences between the selected particle and the nominal values of 1.019 GeV/c^2 and 1.968 GeV/c^2 respectively. The helicity variable is the cosine of the angle between the Kaon from the ϕ decay and the π, from the D_s, in the reference frame of the ϕ. Since the D_s meson is a pseudoscalar, ϕ meson is a vector, and the π is a pseudoscalar, the spin projection of the ϕ along the π's decay path must be zero. This results in a cos^2 distribution for the signal and a flat distribution for the background. The variable cos θ ($\eta\pi$: D_s) is the cosine of the angle between the η and the π in the D_s restframe. The Fisher Discriminant is a linear combination of 12 elements. [1] The Fisher used in this cut was composed of cos θ_B,cos θ_{thrust}, which is the angle between the thrust axis of the event and the the beam line, and the sum of momenta in 9 $10^{/circ}$ double cones about the candidate thrust axis. [1] The shape variable is a combination of the R2GL variable, which describes the jettiness of an event (0 is spherical, 1 is jetty), and the thrust difference. Cos $\theta_{\gamma\gamma}$ is the angle between the two photons from the η in the lab rest frame. The $\delta\eta$ mass is the difference between the η candidate and the nominal value of .5475 GeV/c^2. $\gamma 1_{e9/e25}$*$\gamma 2_{e9/e25}$ is the product of the the e9/e25 values for the two photons from the η; this is the ratio of the energy deposited in a 3x3 set of the calorimeter's crystals, about the photon's impact point, to the energy in a 5x5 set of the calorimeter's crystals, about the photon's impact point. The product of $\gamma 1_{e9/e25}$ and $\gamma 2_{e9/e25}$ was used to reduce the number of variables to cut on, and because it was a stronger cut than either of the variables separately. The final variable that was cut on was the photon veto. This variable vetos photons that make a good π^o with some other photon in the event because π^os are more common, so that the photons in the event reconstruct a "good" η.[3] These cuts are grouped according to the type of variable they are. The first three variables dealt with the B-meson, and suppressed $B\overline{B}$ and $Q\overline{Q}$ backgrounds. The next four, $\delta\phi$ mass, δD_s mass, Helicity, and Cos θ ($\eta\pi$: D_s), dealt with the D_s meson and suppressed bad combinatorics in reconstructing the D_s. The next two, Fisher Discriminant and Shape, dealt with the shape of the event and helped suppress continuum background. The last four variables, Cos $\theta_{\gamma\gamma}$, $\delta\eta$ mass, $\gamma 1_{e9/e25}$*$\gamma 2_{e9/e25}$, and the Photon Veto, suppressed $B\overline{B}$ and $Q\overline{Q}$ backgrounds and dealt with suppressing combinatorics in the η reconstruction.

Conclusions

Analyizing the data, we obtain a possible peak for the η mass as seen in Fig. 5. This peak may be artificially due to the χ^2 cut in the skim which could shape the background. However, after all the above cuts are applied, Fig. 6 is obtained. So there is 1 signal event.

Assuming a linear background, we take 50 MeV/c^2 side bands around the D_s mass, apply the cuts again, and find 4 background events in the sidebands. Since the signal region is between $\pm$ 16 MeV/c^2, this is equivalent to having 1.28 background events in the signal. Therefore, with 1 event signal, and 1.28 events background, this gives an upper limit of 2.1×10^{-4}, at a confidence level of 90%, and 23% efficiency, with branching ratios of $\eta \rightarrow \gamma\gamma = 39.2\%$, $D_s \rightarrow \phi\pi = 3.6\%$, $\phi \rightarrow K^+K^- = 49\%$. This number is comparable with Ken's result of $B \rightarrow D_s\pi$, accounting for the difference in the decay rates of the η and the π to $\gamma\gamma$.[3]

In order to ensure that the Monte Carlo was simulating the data correctly (since we use it to tune the cuts), we normalized the $B\overline{B}$ and $Q\overline{Q}$ summed them and compared the sum to the data. The results can be seen in Fig. 7, and Fig. 8. The shape and height seem to match up well, so the Monte Carlo is correctly simulating the data.

So an upperlimit on the branching ratio of $B \rightarrow D_s\eta$, has been obtained, however, there are still many more decays that need to be looked at before an upperlimit can be obtained for V_{ub}/V_{cb}. The result could be improved by a factor of 3 by including other D_s decays, such as $\phi\rho$ and K_sK, etc. The result could further be improved upon by accounting for the $\eta \rightarrow 3\pi$ decay. Then the result would be competative with theory [2]. However to achieve the precision needed, 20 times more luminosity is necessary, which will be available at the next generation B factories such as Babar and BELLE.

For errors see pg 45 of CBX 00-36

Acknowledgments

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Footnotes and References

1. Kenneth W. Mclean, "A search for B^-, $\overline{B} \to D_s^- X_u$ with CLEO II and II.5" Talk given May 2nd, 2000.
2. LMU-13/94 "Remarks on the Quark Diagram Description of Two-body Nonleptonic B-meson Decays" Zhi-Zhong Xing
3. CBX 00-036 Kenneth W. Mclean, Szabolcs Marka, Steven Csorna, "Upper Vertex D_s production in charmless B decays: Searches for $B \to D_s^{(*)}\pi$"
4. CBX 97-92, Kenneth W. Mclean and Steven Csorna, "Initial Studies of Upper Vertex D_s production in B decays: $B \to D_s n\pi$, with n<3 "

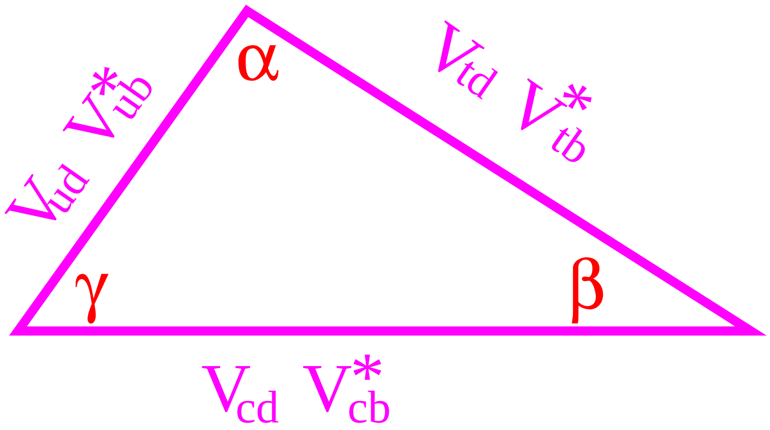


FIGURE 1. CKM Matrix, with the elements as the sides

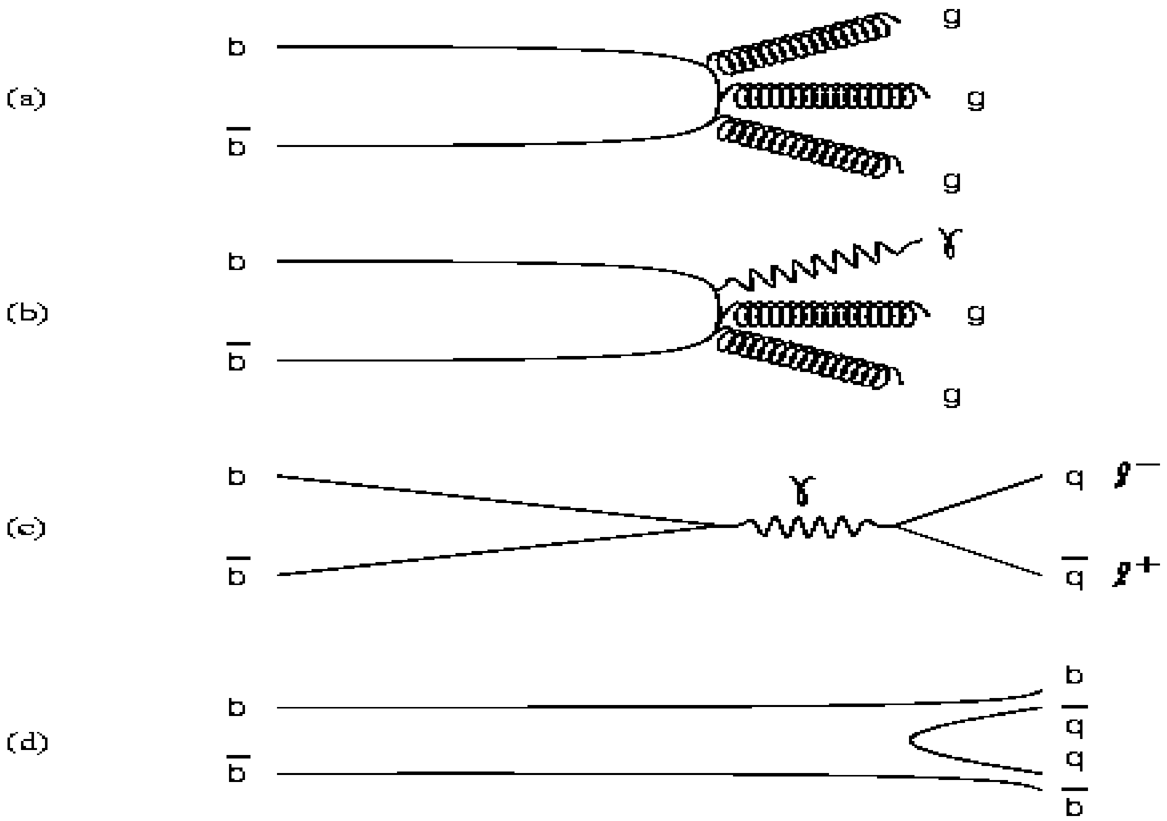
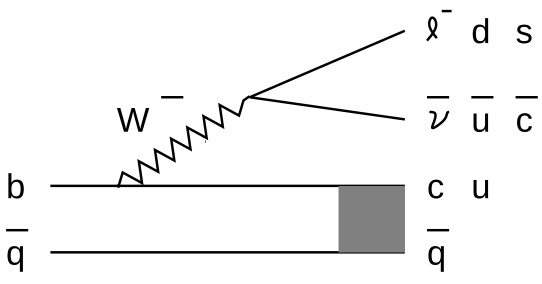
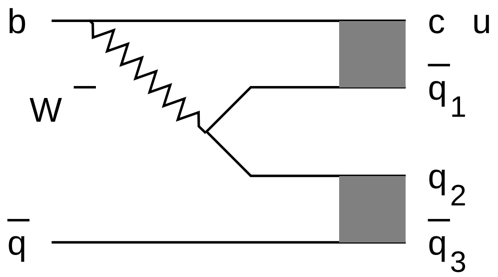


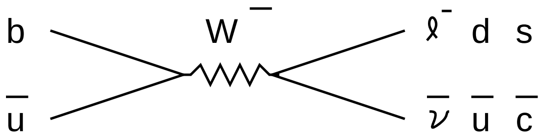
FIGURE 2. 4 possible decay methods of the $\Upsilon(4s)$ system.



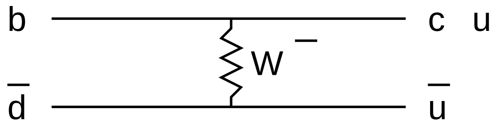
(a) Spectator



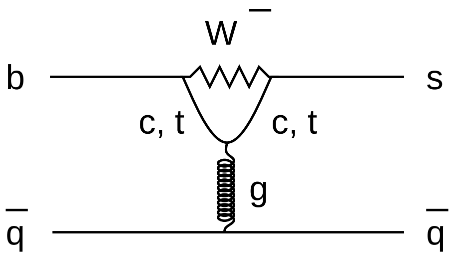
(b) Color Mixed



(c) Annihilation



(d) Exchange



(e) Penguin

FIGURE 3. Methods for a B-meson Decay

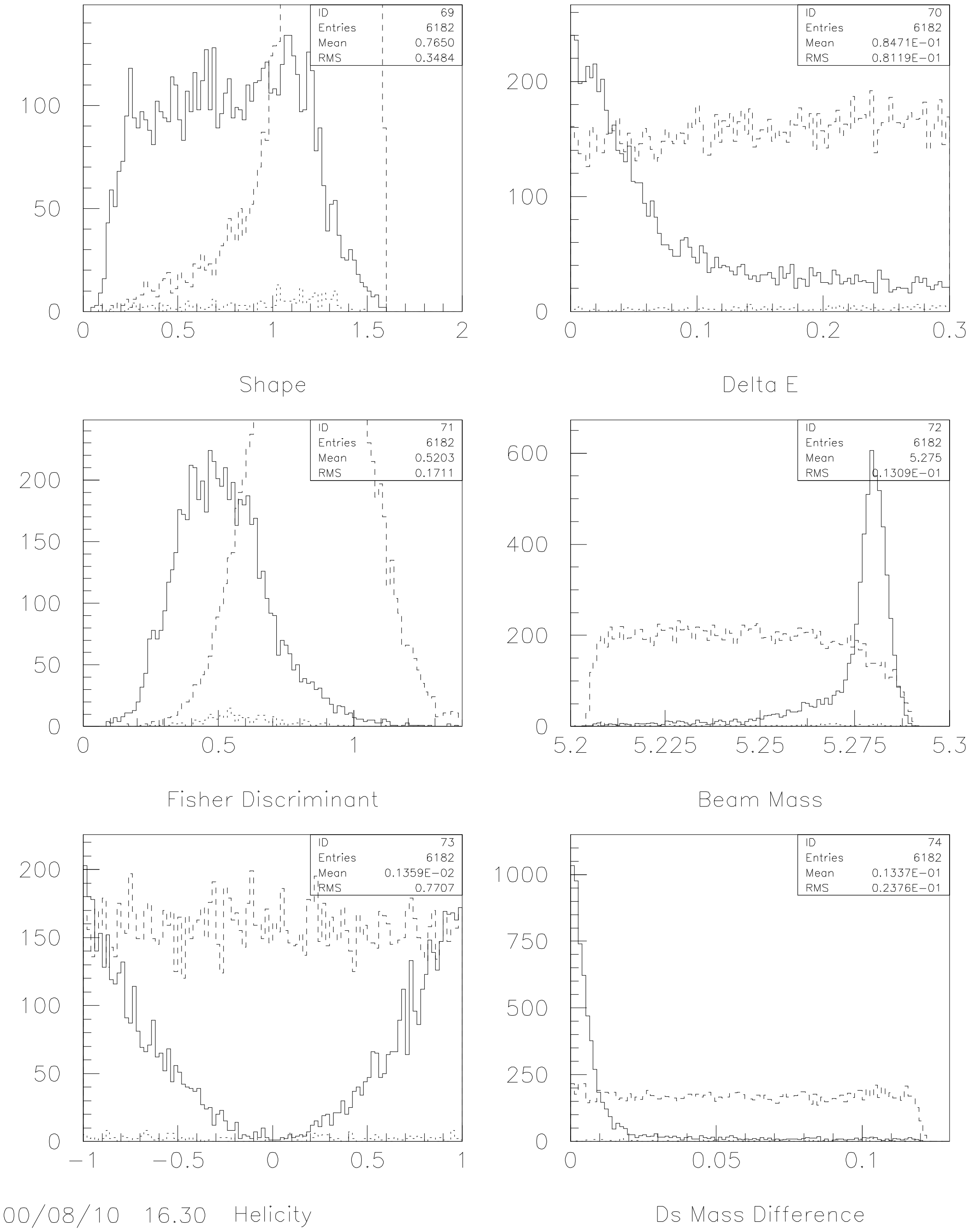


FIGURE 4. Examples of some of the different variables to cut on. Signal is the solid line, continumm is dashed.

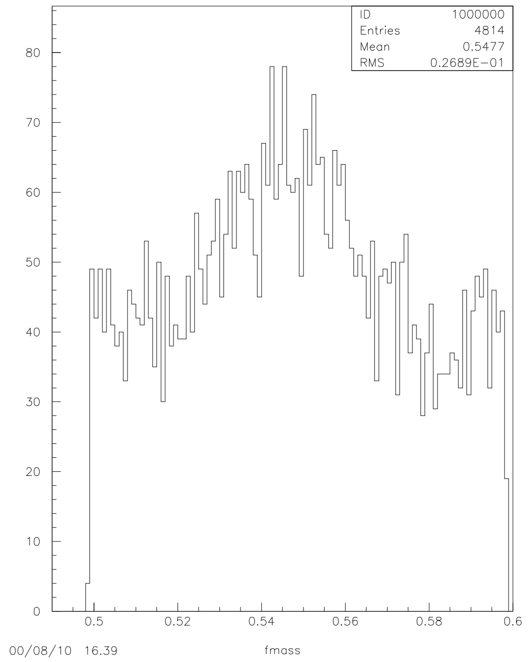


FIGURE 5. Plot of the η mass from CLEO data, no cuts. 4814 events

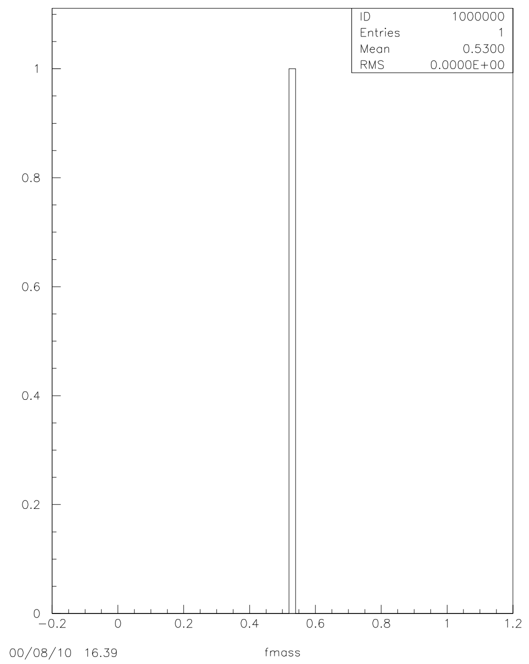


FIGURE 6. Plot of the η mass from CLEO data with all the cuts from Table 1. 1 event.

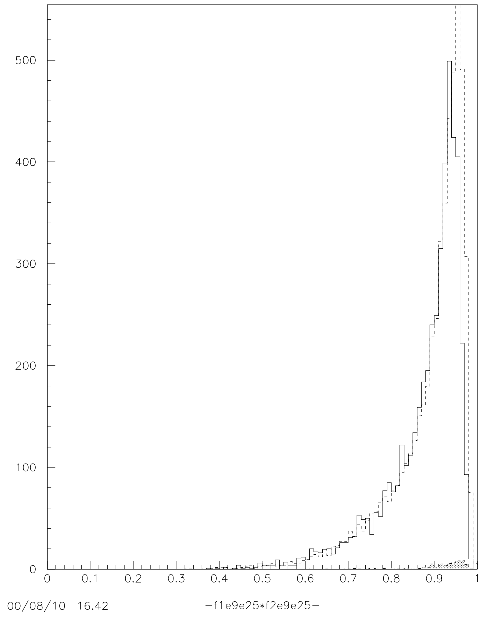


FIGURE 7. Graph of $\gamma 1_{e9/e25} \times \gamma 2_{e9/e25}$ for $B\overline{B}$ and $Q\overline{Q}$ backgrounds (dashed) and CLEO data (solid).

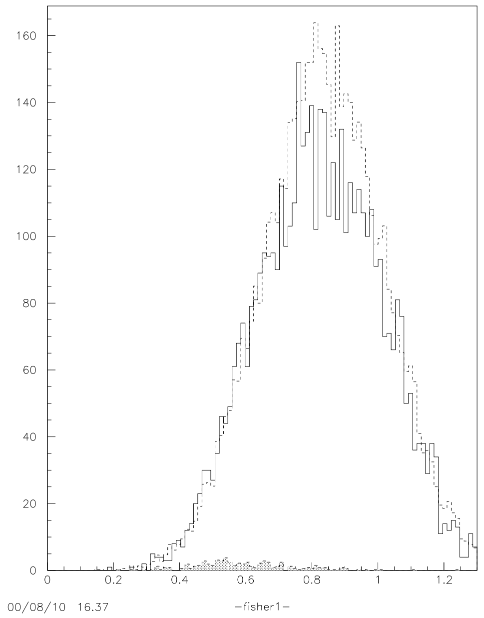


FIGURE 8. Graph of Fisher Discriminant for $B\overline{B}$ and $Q\overline{Q}$ backgrounds (dashed) and CLEO data (solid)