RECENT RESULTS ON B MESON DECAY FROM CLEO

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ABSTRACT

Recent results from the CLEO experiment on the B meson decays are reviewed. It is likely that charmed baryons are produced in B decay. The B to charm rate is consistent with a small $b \rightarrow u$ coupling. We have set the 90 % C.L. limits on V_{ub} and V_{cb} K–M matrix elements using the B meson semileptonic branching fraction.

1. Introduction

In the framework of the standard model a b quark decays into a c quark or a u quark by emitting a virtual W^- meson. This statement is true only if the off-diagonal elements of K–M matrix are non zero.[1] Otherwise the b quark would be stable. The $b \to c$ coupling, V_{cb}, is not zero, since we have seen the B mesons decay into charmed mesons.[2] On the otherhand it is important for the K–M parameterization to have a non-zero $b \to u$ coupling, V_{ub}, in order to allow the CP violation in the K^0 system. We will show what information B meson decay can provide on the elements V_{ub} and V_{cb}.

2. Summary of B decays at CLEO

At CLEO we have been studying various modes of the B meson decays. There are $b \to u$ and $b \to c$. There are the leptonic and hadronic decays of a virtual W^-. These are seen in the inclusive and exclusive decays of the B mesons. We first discuss the exclusive decay modes that have been investigated.

1) The semileptonic exclusive decay modes.

Although we have been trying to measure the branching fractions of B going into $D^*\ell\nu$ and an upper limit on $B^+ \to \rho^0\ell^+\nu$,[3] since neutrinos escape detection these semileptonic modes only supported our results from the inclusive modes. But these modes will be more important as we take more data because we expect that the branching fractions of these modes will be relatively large.

2) The $b \to c$ hadronic exclusive decay modes.

The search for the hadronic exclusive decays, such as $B \to D\pi$, $D\pi\pi$, $D^*\pi$, $D^*\pi\pi$, is called the reconstruction of the B mesons. Reconstruction has not only allowed us to determine the branching fractions but also to make measurements of the masses of the charged and neutral B mesons, their mass difference, and the B meson spin.[4]

Fig. 1 shows the angular distribution of the direction of B mesons with respect to the beam direction in the $\Upsilon(4S)$ rest frame. Since $\Upsilon(4S)$ is polarized in the beam direction, a $\sin^2\theta$ distribution is expected if it decays into two spin zero particles. This data is consistent with the $\sin^2\theta$ distribution.

3) The $b \to u$ hadronic exclusive decay modes.

The exclusive decay modes, such as $B \to \pi^+\pi^-$, $\rho^0\pi^+$, $\rho^0\rho^0$, are the most promising fully hadronic modes where the $b \to u$ transition may show up. Unfortunately since we have not found any positive evidence of the existence of these

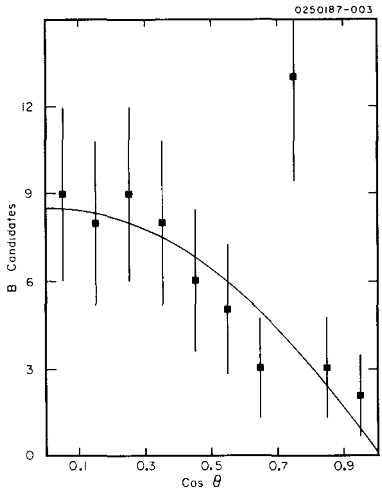


Fig. 1 The angular distribution of the reconstructed B mesons. The functional form of the curve used to fit the data os $sin^2\,\theta$.

decays we can only set upper limits of the order of 10^{-4} on these decay modes, implying upper limits of a few tens of percent for $b \rightarrow u$ over $b \rightarrow c$, depending on the decay mode and models of exclusive hadronic decays used.[4]

3. Semileptonic branching fraction of the B meson

The electron and muon momentum spectra from B decays are shown in Fig. 2. Since the lepton spectrum is acceptance limitted and because some of

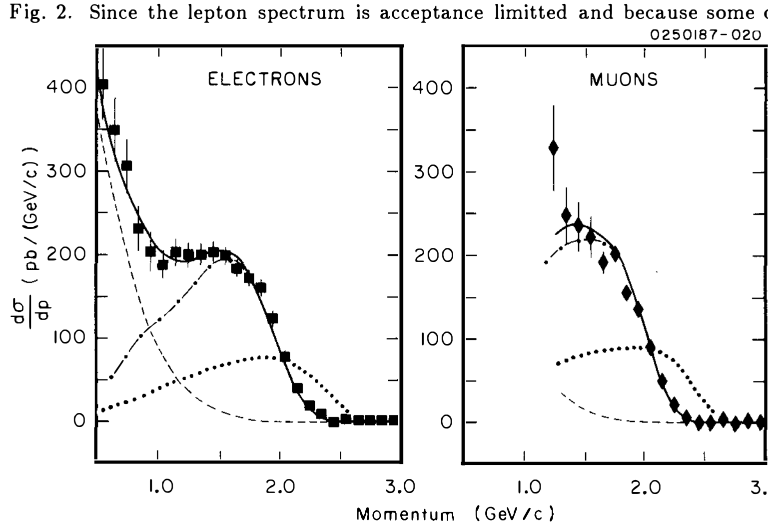


Fig. 2 The electron and muon momentum distribution. The solid lines are the sum of the $b \rightarrow c\ell\nu$ and $b \rightarrow u\ell\nu$ and $b \rightarrow c \rightarrow s\ell\nu$ for the Altarelli model as an example. Dotted lines are the contribution from $b \rightarrow c \rightarrow s\ell\nu$, dashed lines from $b \rightarrow c\ell\nu$, and dot-dashed lines from $b \rightarrow u\ell\nu$ (Notice $b \rightarrow u\ell\nu$ is not from the result of the fit but shows the shape of the spectrum.)

the leptons come from D meson decay, the measured spectra must be fitted to a theoretical spectrum to determine the B meson semileptonic branching fraction. This analysis also determines the relative contribution of $b \to u$, $b \to c$ and the contribution from D meson decays. The function form we have fit is

$$G(p) = A_{cb} \times G_{cb}(p) + A_{ub} \times G_{ub}(p) + A_{sc} \times G_{sc}(p)$$

where G_{ij} are theoretical momentum spectra for leptons coming from $j \to i\ell^-\overline{\nu}_e$ transition and A_{ij} are free parameters used to fit the data. We have fitted our data to six different theoretical models and gotten branching fractions.

1) Semileptonic branching fraction of B mesons is 10.7 % ± 0.3 % ± 0.7 %.[5]

The first error is the statistical error and the second error is the systematic error and is estimated from the uncertainties associated with the model dependence.

2) Although it is sensitive to the model, upper limit on $b \to u\ell\nu$ over $b \to c\ell\nu$ varies from 2 % to 7 % for various $b \to u$ and $b \to c$ models.

V_{ub} and V_{cb} can be calculated from $b \to c\ell\nu$ and $b \to u\ell\nu$ and the lifetime of the B meson since the K–M matrix elements V_{ub} and V_{cb} are related to the semileptonic branching fraction of the B meson and its lifetime through the equation :[6]

$$\begin{aligned}\Gamma_{SL} &= \frac{Br(b \to c\ell^-\overline{\nu}) + Br(b \to u\ell^-\overline{\nu})}{\tau_b}, \\ &= \Gamma_0(m_b) \times (F(m_b, m_c) \times |V_{cb}|^2 + F(m_b, m_u) \times |V_{ub}|^2),\end{aligned}$$

where,

$$\begin{aligned}\tau_b &= 1.17 \pm 0.14(\text{p sec}), \\ \Gamma_0(m_b) &= \frac{G_F{}^2 m_b{}^5}{192\pi^3}, \\ &= 1.0/(0.92 \pm 0.18 \times 10^{-2}\text{psec}), \\ &\text{for } m_b = 5.0 \pm 0.2\ GeV/c^2\ , \\ F(m_b, m_c) &= 0.48, \quad F(m_b, m_u) = 1.0.\end{aligned}$$

Using the world average value of τ_b,[7] and assuming the b mass to be 5.0 GeV/c^2 and theoretically calculated phase space factors for the semileptonic decays,[8] We have set a limit for V_{cb} vs V_{ub} from the semileptonic branching fraction as follows.

$$0.00055 < 0.48 \times |V_{cb}|^2 + |V_{ub}|^2 < 0.00120\ (90\% C.L.)$$

The errȍr in the estimate of the mass of the b quark, dominates because the fifth power of the mass is used. From the above limit on V_{cb} vs V_{ub} we have set a limit on V_{cb},

$$0.034 < |V_{cb}| < 0.050\ (90\% C.L.),$$

assuming V_{ub} is equal to zero. We do not have clear boundary for the ratio of $V_{ub}$to $V_{cb}$from this method since it largely depends on both $b \to c$ and $b \to u$ models.

Futhermore by looking at the end point of the lepton spectra, where the contributions of $b \to c\ell\nu$ are negligible due to the large mass of the c quark, we have found the branching fraction of B to ℓX, where the lepton momentum is between 2.4 and 2.6 GeV/c is less than 2.2×10^{-4}.[5] This number is used to obtain the upper limits of $b \to u$ over $b \to c$ for any theoretical model with negligible $b \to c$ model dependence. The upper limits are 1.7, and 2.4 % for the Altarelli, and Grinstein models. And the upper limits on the ratio of V_{ub} to V_{cb} are 0.10 and 0.17, respectively.

4. The Decay of B to Charm

Another method to get information on V_{cb} and V_{ub} is to find the amount of inclusive charm production per B meson decay. We expect that the number of the c quark per B meson decay is the sum of $b \to c$, which is about 1.0, and 0.15 from the contribution from virtual W^- decays into $\bar{c}s$.

We have seen $B \to D_S$ and ψ. Fig. 3 is the $\mu^+\mu^-$mass distribution and clear ψ peak is seen. The inclusive $B \to \psi$ branching fraction is measured to be $1.17 \pm 0.17 \pm 0.21$ %.[9] Fig. 4 shows the $\phi\pi^+$ mass distribution and clear D_S peak is seen on the data taken at $\Upsilon(4S)$ energy. The inclusive $B \to D_S$ branching fraction is measured to be 9.5 ± 2.5 % assuming the branching fraction B($D_S \to \phi\pi^+$) is equal to 4 %.[10]

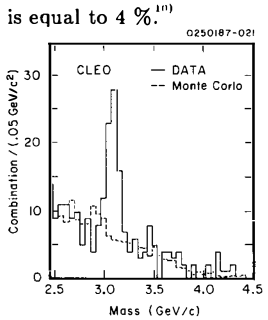


Fig. 3 The $\mu^+\mu^-$ mass distribution showing clear ψ peak from B meson decay.

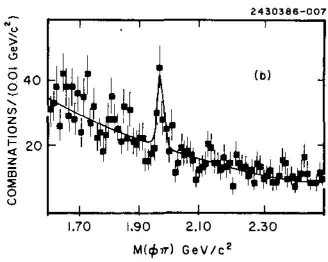
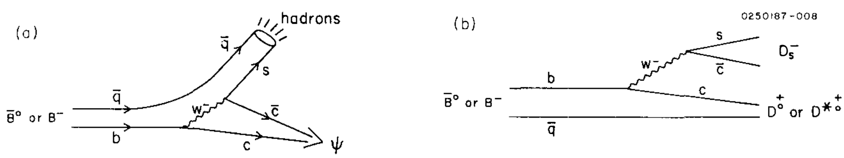


Fig. 4 The $\phi\pi^+$ mass distribution showing clear D_S peak from B meson decay.

From quark diagrams here, it is a reasonable assumption for the first order calculation that D_S's and ψ's arise from the $W^- \to \bar{c}s$ vertex. This is partly confirmed by the fact that the D_S momentum spectrum is consistent with two-body decay modes as $B \to D_S D$. and that we observed $B \to \psi K^+$ and ψK^{*0}. So we assign the charm from the $W^- \to \bar{c}s$ to D_S and ψ.



What's left is $b \to c$ and the c quarks most likely hadronize as D's, D^*'s and charmed baryons. We have found B to D^0X, D^+X and D^{*+}X by observing D^0 going to $K^-\pi^+$ and D^+ to $K^-\pi^+\pi^+$.[2)]

$K^-\pi^+$, $K^-\pi^+\pi^+$ invariant mass distributions are shown in Fig. 5a and b. D^{*+} is found through the decay into $D^0\pi^+$ with D^0 decaying into $K^-\pi^+$. The $K\pi\pi$ - $K\pi$ mass difference is required to be within $\pm$ 1.5 MeV of the known $D^{*+}-D^0$ mass difference of 145.4 MeV. The resulting $K^+\pi^-$ mass distribution is shown in Fig. 5c. We have measured

$$B(B \to D^0 X) \times B(D^0 \to K^-\pi^+) = 0.0210 \pm 0.0015 \pm 0.0021$$

$$B(B \to D^+ X) \times B(D^+ \to K^-\pi^+\pi^+) = 0.0190 \pm 0.0040 \pm 0.0020$$

$$B(B \to D^{*+} X) \times B(D^{*+} \to D^0\pi^+) \times B(D^0 \to K^-\pi^+) = 0.0073 \pm 0.0012 \pm 0.0007.$$

Adding our B meson to D^0 and D^+ meson numbers with the latest Mark III D branching fractions,[11)]

$$B(D^0 \to K^-\pi^+) = 0.042 \pm 0.004$$

$$B(D^+ \to K^-\pi^+\pi^+) = 0.093 \pm 0.014,$$

70 $\pm$ 8 $\pm$ 6 % is the total branching fraction of B meson to D meson since all

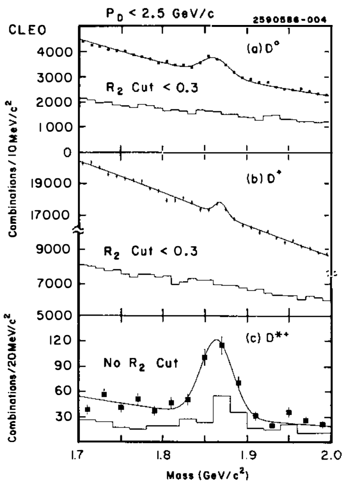


Fig. 5 The mass plots for D^0, D^+ and D^0 from D^{*+}. The data points are from an $\Upsilon(4S)$ run. The histgrams represents data taken on the continuum and scaled up by the ratio of the luminosities and crosssections.

a.) $K^-\pi^+$ mass distribution showing evidence for D^0.

b.) $K^-\pi^+\pi^+$ mass distribution showing evidence for D^+.

c.) $K^-\pi^+$mass distribution requiring the $K\pi\pi$ - $K\pi$ mass difference be within $\pm$ 1.5 MeV of the known D^{*+} $-D^0$ mass difference of 145.4 MeV, showing evidence for D^{*+}.

D^*'s decay to D^0 or D^+. Note that these numbers differ significantly from the results quoted in D. Bortoletto *et. al.*,[2] because of the change in the D branching fractions.

We have measured inclusive Λ and proton production.[12]

$$B(B \to \Lambda X) = 4.2 \pm 0.6 \pm 0.4\%$$

$$B(B \to pX) = 6.1 \pm 0.7 \pm 1.0\%.$$

Notice that the B to proton fraction does not include the protons from Λ decay. Tha fact that the proton fraction is close to the Λ fraction indicates that Λ's are produced from charmed baryon decay because if there isn't charmed baryon production we should see Λ fraction of one or two tenth of proton fraction considering $s\bar{s}$ popping probability. Futhermore we have seen a footprint of B to charmed baryon by tagging a flavour of B meson by the charge of the lepton and looking at Λ's from the other B mesons.[12]

We estimate B to Λ_c fraction of 7 $\pm$ 3 %. Adding $B \to \Lambda_c$ and $B \to D$, the total branching fraction of $b \to c$ is 77 $\pm$ 10 %. Although 77 $\pm$ 10 % is about 2 σ away from 100% $b \to c$, since it depends on the Mark III D meson branching fractions and our assumption of the products of the hadronization of $b \to c$ we would rather believe a small $b \to u$ coupling from the lepton momentum spectra.

5. Conclusions

In summary, we have measured inclusive semileptonic branching fraction of 10.7 $\pm$ 0.3 $\pm$ 0.7 %. We have measured B to D^0,D^+,D^{*+},ψ,D_S inclusive decays. It is likely that charmed baryons are produced in B decay and the rate is 7 $\pm$ 3 % per B meson decay. B to charm rate is not inconsistent with a small $b \to u$coupling any more. We have set the 90 % C.L. limits on $V_{ub}$and V_{cb} using the B meson semileptonic branching fraction.

References and Footnotes

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