Measurements of the Branching Ratio of $B \to X\ell\nu$

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On behalf of the CLEO collaboration

Abstract

We report preliminary measurements of $\mathcal{B}(B \to X\ell\nu)$ that have been made with single and dilepton events from data collected with the CLEO-II detector. In the dilepton events we used charge and kinematic correlations to obtain the electron spectrum of B decays. We also measure the B^+ and B^o semileptonic branching fractions using tagging. Assuming equal semileptonic partial decay widths, their ratio is equivalent to the ratio of lifetimes.

1. Introduction

The semileptonic branching fraction of the B meson has been a persistent puzzle in heavy flavor physics. While experimental measurements have consistently been smaller than 11%, theoretical expectations have remained at 12.5% or higher [1]. The most precise measurements have been based on analyses of the inclusive lepton momentum spectrum at the $\Upsilon(4S)$ resonance. In this paper, we describe a measurement which has achieved a statistical precision of better than 0.5%. The measurement is limited by significant systematic uncertainties. The contribution of primary decays ($B \to X\ell\nu$) must be separated from that of secondary charm decays ($b \to c \to Y\ell\nu$) by fitting the spectrum to the predictions of theoretical models. Results obtained with different models span a range that is greater than the experimental error.

Recently the ARGUS collaboration presented an elegant analysis that reduces the model dependence by using dilepton events [2]. In this paper we describe a similar analysis based on a ten times larger data sample.

The lifetime of B^+ is predicted to be slightly longer than that of B^o. Assuming that the semileptonic partial decay widths are equal the B^+ semileptonic branching fraction should be larger than B^o. We report the separate measurements of charged and neutral B semileptonic branching fractions and their ratio.

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2. $\mathcal{B}(B \to X\ell\nu)$ from Single Lepton Spectrum

Our data sample was collected with the CLEO-II detector at the Cornell Electron Storage Ring (CESR). The CLEO-II detector has previously been described in detail [3]. Figure 1 shows the electron and muon spectra from the B decays observed with 0.94 fb^{-1} of the $\Upsilon(4S)$ resonance data. The inclusive spectra contain contributions from primary B decays and from secondary B decays $B \to DX$ followed by $D \to Y\ell\nu$. By fitting to theoretical models, we extract the average B semileptonic branching fraction. A fit to ISGW model[4] with a floating D^{**} fraction yields $\mathcal{B}(B \to X\ell\nu) = (10.98 \pm 0.10 \pm 0.33)\%$. for a D** fraction of $21 \pm 2\%$. Using the ACCMM model[5], we obtain $\mathcal{B}(B \to X\ell\nu) = (10.65 \pm 0.05 \pm 0.33)\%$. The systematic error in this result includes a 1% uncertainty in our electron identification efficiency, a 2% uncertainty in the tracking efficiency.

3. $\mathcal{B}(B \to X\ell\nu)$ with Lepton Tags

The data sample for this analysis consists of an integrated luminosity of 2.07 fb^{-1} at the $\Upsilon(4S)$

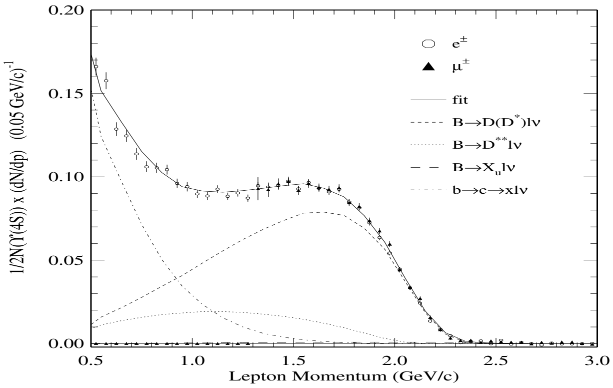

Figure 1. Fit to the lepton spectrum of the ISGW model with a floating D^{**} fraction.

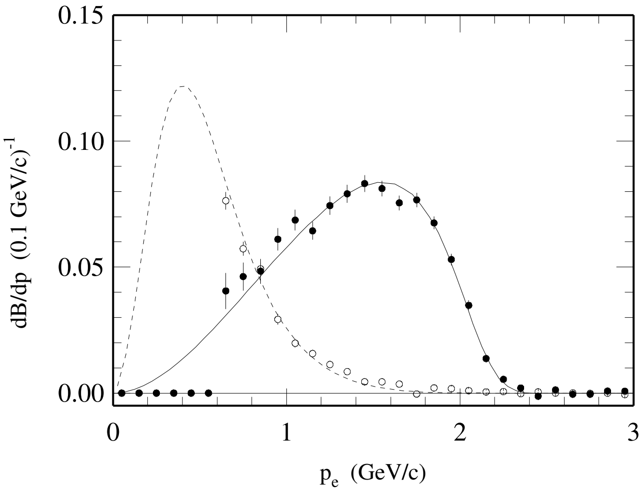

Figure 2. Spectra of electrons from primary decays $B \to Xe\nu$ (filled circles) and secondary decays $b \to c \to y\ell\nu$ (open circles) from the analysis of $B\bar{B}$ events tagged by a high-momentum lepton. The curves show the results of fits to the ACCMM model.

resonance. In each event the presence of a lepton with a momentum above 1.4 GeV/c was required, since high-momentum leptons at the $\Upsilon(4S)$ are predominantly from $b \to c\ell\nu$ transitions. We then looked for an additional electron accompanying this tag, with a minimum momentum requirement of 0.6 GeV/c to allow measurement of most of the B-meson semileptonic decay spectrum. When the other B decays semileptonically, the daughter electron usually has a charge that is opposite to that of the tag. When the second electron is from the semileptonic decay of a charmed particle produced in the decay of the other B, the charge is usually the same as the tag's. Secondary electrons from charm decay on the same side as the tag lepton can also contribute. In this case the charges are opposite, and events of this type complicate the charge-correlation pattern. To suppress electrons from the same B and retain those from the opposite B, we imposed the "diagonal" cut, $p_e + \cos\theta_{\ell e} > 1$, on the unlike-sign sample. This requirement suppresses the same-B background by a factor of 25, while keeping 67% of the signal.

After corrections for fakes, leptons from J/ψ and $\pi^o \to e^+e^-\gamma$ decays, from decays of τ's produced in $B \to X\tau\nu$ and false tags by secondary leptons above 1.4 GeV/c, the unlike- and like-sign electron momentum spectra can be expressed algebraically in terms of the primary and secondary branching fractions as

$$\frac{dN(\ell^\pm e^\mp)}{dp} = N_\ell \eta(p) \left[\frac{d\mathcal{B}(b)}{dp}(1-\chi) + \frac{d\mathcal{B}(c)}{dp}\chi\right] \epsilon(p), \tag{1}$$

$$\frac{dN(\ell^\pm e^\pm)}{dp} = N_\ell \eta(p) \left[\frac{d\mathcal{B}(b)}{dp}\chi + \frac{d\mathcal{B}(c)}{dp}(1-\chi)\right], \tag{2}$$

where $\eta(p)$ is the efficiency of electron identification and $\epsilon(p)$ is the efficiency of the diagonal cut that we applied to the unlike-sign electrons. The number of tag leptons in the $B\bar{B}$ data sample was $N_\ell = 247811 \pm 771$.

The effect of neutral B-meson mixing is parameterized by $\chi = f_0\chi_0$, where χ_0 is the $B^0\bar{B}^0$ mixing parameter and f_0 is the fraction of Υ(4S) decays which produce neutral B mesons, χ has been directly measured to be 0.079 ± 0.012[6]. The error includes both statistical and systematic components, but the measurement is immune to uncertainty in f_0. Eqs. 1 and 2 have been solved to obtain the primary and secondary electron spectra shown in Fig. 2.

By integrating the primary spectrum from 0.6 GeV/c to 2.5 GeV/c we calculate the partial branching ratio $\mathcal{B}(B \to Xe\nu, p_e > 0.6\ \mathrm{GeV/c}) = (9.76 \pm 0.16)\%$, where the error is only statistical. This result is almost completely model-independent. The fraction of undetected electrons below 0.6 GeV/c, determined using models of ACCMM and ISGW is only $(5.8 \pm 0.5)\%$. With this extrapolation, we obtain the semileptonic branching fraction of B mesons $\mathcal{B}(B \to Xe\nu) = (10.36 \pm 0.17 \pm 0.40)\%$. The systematic error in this result includes a 1% uncertainty in our electron identification efficiency, a 2% uncertainty in the tracking efficiency, and the uncertainty in the mixing parameter χ.

Neglecting the contribution from V_{ub}, the B-meson inclusive branching fraction is related to the CKM matrix element V_{cb}:

$$\Gamma(B \to X\ell\nu) = \gamma_c |V_{cb}|^2, \tag{3}$$

where the factor γ_c must be obtained from theory. With both ACCMM and ISGW models ($\gamma_c = 40 \pm 8\ ps^{-1}$ and $41 \pm 8\ ps^{-1}$, respectively) and the average lifetime for charged and neutral B mesons of $1.49 \pm 0.05\ ps$ [7] we obtain $|V_{cb}| = 0.042 \pm 0.001 \pm 0.004$. In this result the first error combines all of the experimental uncertainties, both statistical and systematic. It is much smaller than

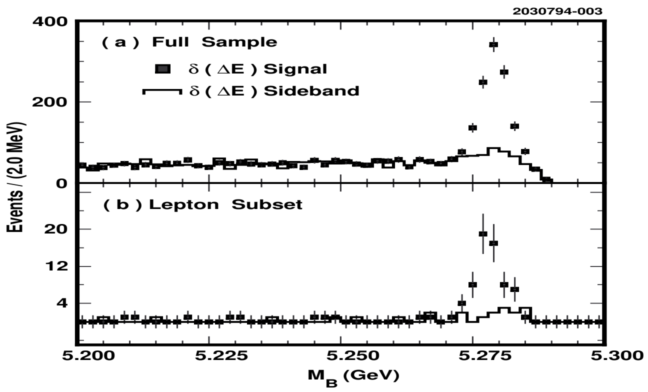

Figure 3. $B^- \to$ hadrons tags

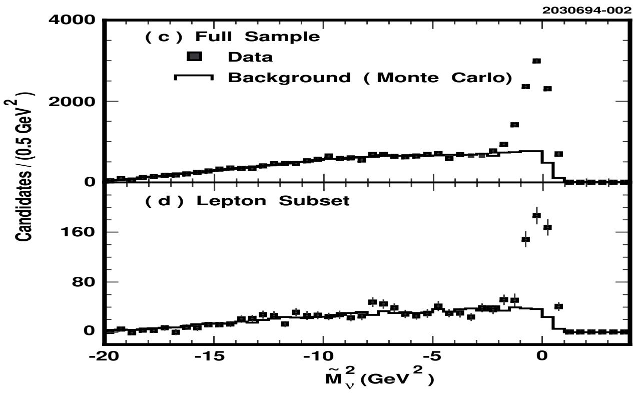

Figure 4. $\overline{B^0} \to D^{*+}\ell^-\overline{\nu}$ tags

the second error, which is an estimated 10% theoretical uncertainty in the computation of γ_c.

4. $\mathcal{B}(B^+ \to X\ell\nu)$ and $\mathcal{B}(B^o \to X\ell\nu)$ from tagging

We measure the B^+ semileptonic branching fraction in a sample of fully reconstructed B^- decays. We reconstruct B^- in eight different modes: $D^{(*)}\pi^-$, $D^{(*)}\rho^-$, $D^{(*)}a_1^-$, and $K^{(*)}J/\psi$. The candidate momenta and energies, $\vec{p}_B$ and E_B, of the measured components are used to calculate the beam-constrained mass $M_B = \sqrt{E_{\rm beam}^2 - |\vec{p}_B|^2}$ and the normalized energy difference between the B and the beam energy $\delta(\Delta E) = (E_{\rm beam} - E_B)/\sigma(\Delta E)$, where $\sigma(\Delta E)$ is the expected resolution on $E_{\rm beam} - E_B$. For signal, M_B peaks at the B mass, and $\delta(\Delta E)$ is a normal Gaussian. Figure 3(a) shows the M_B distribution for the B^- tags in the $\delta(\Delta E)$ signal (points) and sideband (histogram) regions. We find 834 ± 42 tags using 1.35 fb^{-1} of on-resonance data.

Additional leptons are selected in the range 1.4–2.4 GeV/c. The leptons are from the semileptonic decay of the remaining B mesons in the events. After the fake and secondary lepton subtractions and correction for efficiencies, we obtain 97.2 ± 20.8 $e^\pm$ and 73.0 ± 19.8 $\mu^\pm$ candidates and $\mathcal{B}(B^+ \to X\ell\nu) = (10.1 \pm 1.8 \pm 1.4)\%$. This is the first measurement of the B^+ semileptonic branching fraction.

While we find 515 ± 31 fully reconstructed B^o events using the hadronic tagging, we use two more tagging methods for B^o. In the two techniques, B^os are partially reconstructed as $B^o \to D^{*-}\pi^+$ or $B^o \to D^{*-}\ell^+\nu$, $D^{*-} \to D^o\pi^-$, where D^o is unseen. We reconstruct 822 ± 53 tags using partially reconstructed $B^o \to D^{*-}\pi^+$ decays. In the $B^o \to D^{*-}\ell^+\nu$ partial reconstruction we utilizes leptons which have momentum > 1.8 GeV/c to suppress feed-down from $B^o \to \bar{D}^{**}\ell^+\nu$ decays. The squared neutrino mass M_ν^2 is calculated assuming that the B is at rest. Figure 4(a) shows the M_ν^2 distribution, which give 7119 ± 139 tags. We find the lepton subsets for three tags and measure $\mathcal{B}(B^o \to X\ell\nu)$ separately. We then average three measurements weighting each by the statistical and uncorrelated systematic errors to obtain $\mathcal{B}(B^o \to X\ell\nu) = (10.9 \pm 0.7 \pm 1.1)\%$.

Assuming the semileptonic partial widths are equal, we obtain the ratio of lifetimes, $\tau_+/\tau_o = 0.93 \pm 0.18 \pm 0.12$.

5. Conclusions

In conclusion, we have made new measurements of $\mathcal{B}(B \to X\ell\nu)$. Using the inclusive spectum, we obtain a preliminary result of $\mathcal{B}(B \to X\ell\nu) = (10.98 \pm 0.10 \pm 0.33)\%$ for the ISGW model and $(10.65 \pm 0.05 \pm 0.33)\%$ for ACCMM. Using the lepton tag method, our preliminary measurement is $\mathcal{B}(B \to Xe\nu) = (10.36 \pm 0.17 \pm 0.40)\%$. They are in agreement with other recent measurements, and significantly below theoretical expectations. The latter measurement is largely independent of theoretical models, and is insensitive to possible non-$B\bar{B}$ decays of the $\Upsilon(4S)$. Using three tagging techniques, we have also measured $\mathcal{B}(B^+ \to X\ell\nu) = (10.1 \pm 1.8 \pm 1.4)\%$ and $\mathcal{B}(B^o \to X\ell\nu) = (10.9 \pm 0.7 \pm 1.1)\%$ and the ratio of lifetimes, $\tau_+/\tau_o = 0.93 \pm 0.18 \pm 0.12$.

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