RECENT CLEO RESULTS ON B PHYSICS

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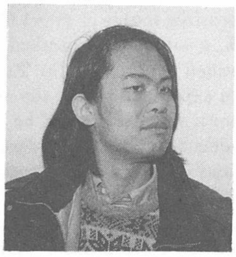

Abstract

Recent highlights of B physics from the CLEO experiment include observation of rare decays. We observe the branching fraction for $B \to K^{*}\gamma$ to be $(4.5 \pm 1.5 \pm 0.9) \times 10^{-5}$. For the individual modes $B \to K^{+}\pi^{-}$ and $B \to \pi^{+}\pi^{-}$, we can only set upper limits of 3×10^{-5} at 90% confidence level. However, when we sum the two decay modes, we see a statistically significant signal with a net branching fraction corresponding to 2.4×10^{-5}. We also confirm non-zero $|V_{ub}/V_{cb}|$ using the endpoint of the B-meson lepton spectrum. The partial branching ratio is smaller than the previous measurements. We measure $\Delta B_{ub}(2.4,2.6) = (0.53 \pm 0.14 \pm 0.13) \times 10^{-4}$, and the corresponding $|V_{ub}/V_{cb}|$ ranges from 0.05 to 0.11.

Introduction

The CESR storage ring delivers a peak luminosity of $2 \times 10^{32} cm^{-2}s^{-1}$, and a daily integrated luminosity often approaches 10 pb^{-1}. The CLEO II detector[1] has collected more than 1.5 fb^{-1} of e^+e^- annihilation data on the $\Upsilon(4S)$ resonance since 1990, 1.4 fb^{-1} of which are available for physics. Also 0.6 fb^{-1} of data taken off the $\Upsilon(4S)$ resonance is used to evaluate $e^+e^- \to q\overline{q}$ background. The sensitivity for detecting some of B-meson rare decays, reaching a few $\times 10^{-5}$ level, has become small enough to be truly interesting, since it is comparable to the branching fractions expected for these decays.

We have found a few of these decays recently: $B \to K^*\gamma$; and $B \to K^+\pi^-$ and/or $\pi^+\pi^-$. The higher precision confirmation of the previously found $b \to u$ signal[2),3)] reveals that its branching fraction is somewhat smaller.

$b \to s\gamma$ and $B \to K^*\gamma$

The importance of one-loop, flavor-changing neutral current diagrams (penguins diagrams) has been reviewed in literature. For example, it might be an explanation for the $\Delta I = 1/2$ rule in K meson decays,[4)] and it is a possible source of direct CP violation in K and B decays.[5)]

The radiative penguin process, $b \to s\gamma$, is of particular interest since it produces a high energy photon which can be identified experimentally. Taking into account substantial QCD corrections,[6)] the rate for $b \to s\gamma$ is expected to be in the range $(2-4) \times 10^{-4}$. Observation of a rate substantially outside this range, therefore, would be an evidence for non-standard-model contributions. Note that some models beyond the Standard Model predict much smaller rates because their additional contributions can interfere destructively with the standard diagrams.[7)]

We have searched for high energy photons between 2.2. and 2.7 GeV. The observed number of photons is consistent with the background from $e^+e^- \to q\overline{q}$ estimated from the off-resonance data. Our preliminary upper limit at 90% confidence level is 5.4×10^{-4}.

Individual exclusive final states arising from $b \to s\gamma$ are much easier to identify. Unfortunately, their rates predicted from the Standard Model are more uncertain than that for the inclusive process $b \to s\gamma$ due to soft QCD effects. Estimates for the fraction of $b \to s\gamma$ which materializes as $B \to K^*\gamma$ range from 5% to 40%.[8)]

We use all K^* decay modes except $K^{*0} \to K^0\pi^0$. For each $B \to K^*\gamma$ decay candidate, we compute the beam constrained mass, $M_{K^*\gamma}= \sqrt{E_{beam}^2 - P_B^2}$, where E_{beam} is the nominal beam energy and P_B is the momentum of the B candidate. It must be consistent with the B mass. The mass resolution, 2.8 MeV, is dominated by the fluctuation in the beam energy. We also compute ΔE, the difference between the total energy of the decay products and that of the B (=E_{beam}), which should be 0. The resolution in ΔE is 40 MeV. Since $\Delta E = 0$ implies that either the photon or the K^* candidates has energy greater than 2.65 GeV almost no $B\overline{B}$ decays other than $b \to s\gamma$ can satisfy these conditions.

In order to reduce the background coming from $e^+e^- \to q\overline{q}$, in particular those events with photons from initial state radiation (ISR), we use various event-shape variables. The signal events should be spherical and the photon direction should be random with respect to the rest of the event. On the other hand, the $e^+e^- \to q\overline{q}$ background is jet-like and tends to have photons along the "jet" direction.

The unisotropic production of the B meson relative to the beam direction, and the helicity polarization of the K^* are also used to further reduce background.

The distributions of ΔE and $M_{K^*\gamma}$ for $B^0 \to K^{*0}\gamma$ decay candidates in the on-resonance data are shown in Fig. 1. We have applied a cut on $M_{K^*\gamma}$ before plotting ΔE and a cut on ΔE before plotting $M_{K^*\gamma}$. There is an excess of events over a smooth background at $\Delta E \approx 0$ GeV

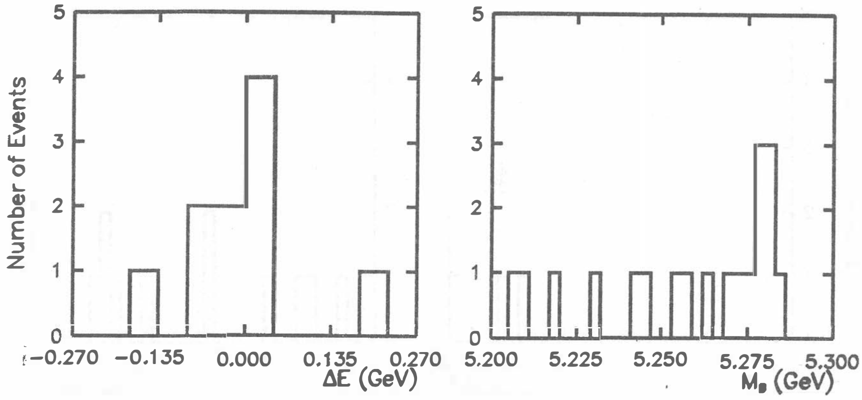

Fig. 1. a) ΔE and b) $M_{K^*\gamma}$ distributions for $B^0 \rightarrow K^{*0}\gamma$ candidates.

and $M_{K^*\gamma} \approx$ 5.28 GeV. The background is falling near $M^{max}_{K^*\gamma} = 5.289\ GeV$ because the phase space as a function of $M_{K^*\gamma}$ near $M^{max}_{K^*\gamma}$ is proportional to $\sqrt{M^{max}_{K^*\gamma} - M_{K^*\gamma}}$. Therefore, the cut on $M_{K^*\gamma}$ made for ΔE plot eliminates many background events, whereas there are still sizable background in $M_{K^*\gamma}$ plot below 5.27 GeV. In order to access the significance of the excess one needs to estimate the level of background under the peak. We characterize the shape of the background by the ratio of the numbers of events in the signal region and in the "sideband". The signal region is defined in the $M_{K^*\gamma}$-ΔE space ($M_{K^*\gamma}$>5.274 GeV and $|\Delta E| < 90\ MeV$). The "sideband" is its surrounding, *i.e.* $M_{K^*\gamma}$>5.2 GeV and $|\Delta E| < 280\ MeV$ excluding the signal region. We estimate that this ratio is 1:38 using a Monte Carlo simulation of $e^+e^- \rightarrow q\overline{q}$ events. For this estimate to be reliable, the Monte Carlo needs to be able to predict the following distributions properly: (1) photon energies; (2) photon transverse momenta with respect to the jet axes; (3) momenta of charged particles; and (4) transverse momenta of charged particles. When the Monte Carlo is modified within limits so that these distributions still agree with data, the ratio 1:38 changes only by a few percent. In the on-resonance data, the ratio is 8/41. There is a probability of 3.5×10^{-5} that the observed ratio would be equal to or greater than 8/41 if the intrinsic ratio were 1:38. When the small background coming from $B\overline{B}$ decays is included, this probability increases to 1.4×10^{-4}. Since the probability that this excess is a fluctuation is very small, we attribute the observed peak to the decay $B^0 \rightarrow K^{*0}\gamma$. The resulting branching fraction is $(4.0 \pm 1.7 \pm 0.8) \times 10^{-5}$.

A similar analysis for the decay $B^- \rightarrow K^{*-}\gamma$ using the two K^{*-} decay modes are performed and resulting $M_{K^*\gamma}$ distributions are shown in Fig. 2. The excesses in the signal region, particularly in $K^{*-} \rightarrow K^0_S\pi^-$, is supporting evidence that $B \rightarrow K^*\gamma$ exists. The probability that the excess in $B^- \rightarrow K^{*-}\gamma$ is a results of fluctuation is 20 times larger than that for $B^0 \rightarrow K^{*0}\gamma$. When interpreted as a signal the branching fraction corresponds to $(5.7 \pm 3.1 \pm 1.1) \times 10^{-5}$. Averaging the two results, we obtain the branching fraction of $B \rightarrow K^*\gamma$ of $(4.5 \pm 1.5 \pm 0.9) \times 10^{-5}$.

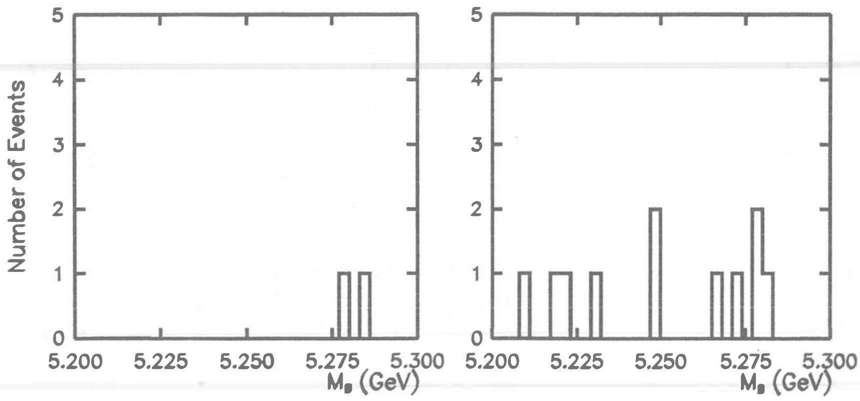

Fig. 2. $M_{K^*\gamma}$ distributions: a) $B^- \to K^{*-}\gamma$, $K^{*-} \to K^0_S\pi^-$; c) $B^- \to K^{*-}\gamma$, $K^{*-} \to K^-\pi^0$.

$B \to K^+\pi^-$ and/or $\pi^+\pi^-$

The decays $B \to K^+\pi^-$ and $B \to \pi^+\pi^-$ would arise from both the hadronic penguin $b \to sg$ and the $b \to u$ transition. Bauer, *et al.*,[9] predict the branching fraction for $B \to \pi^+\pi^-$ to be 1×10^{-5} based on our new measurement, $|V_{ub}/V_{cb}| = 0.07$, which is described below. Predictions for the $B \to K^+\pi^-$ branching fraction are also in the vicinity of 1×10^{-5}.[10]

The method we use to enrich the contribution of these decays in the data is very similar to that for $B \to K^*\gamma$. Since the K and the π from these decays carry about 2.6 GeV/c of momenta, the only information the CLEO II detector provides to distinguish the two decay modes is the dE/dx measurements. The K/π separation is only $1.8 \pm 0.1\ \sigma$. When we calculate ΔE, we always use the π mass for the charged particles. When the decay $B \to K^+\pi^-$ is reconstructed in this way, ΔE will be centered around -42 MeV. There will be no shift in $M_{K\pi}$ since it depends only on momentum measurements. Fig. 3 shows the ΔE and $M_{K\pi}$ distributions from the on-resonance data after cuts similar to $B \to K^*\gamma$ analysis are made.

In order to estimate how many $B \to K^+\pi^-$ and $B \to \pi^+\pi^-$ decays are in the data, we use ΔE, $M_{K^*\gamma}$, dE/dx as well as event shape information and perform a maximum likelihood fit of the data to the sum of what is expected for the signal decays as well as background. The shape of the background is estimated, as in $B \to K^*\gamma$ analysis, by our Monte Carlo program. The fitted background in $M_{K^*\gamma}$ distribution is lower than the data. This apparent discrepancy occurs is because the fit is obtained using events with $|\Delta E|$ up to 0.270 GeV, whereas the plot is made with $|\Delta E| < 0.090$ GeV.

The best fit is obtained when we include a total of 11.5 $B \to K^+\pi^-$ and $B \to \pi^+\pi^-$ decays. The decrease in the likelihood when the signal contribution is forced to be zero implies that this signal is a 5.3σ effect. In order to account for the uncertainty in the expected background shape, we change it in such a way that the difference between the background and the signals is reduced. When we repeat our analysis with this new background shape, the significance of the signal decreases to 4.1σ.

When interpreted as a signal, the sum of the branching fractions for $B \to K^+\pi^-$ and $B \to \pi^+\pi^-$ decays is $(2.4^{+0.9}_{-0.7}) \times 10^{-5}$, and the fraction of the contribution from the $B \to K^+\pi^-$ is loosely constrained to 0.55 ± 0.25. If we look for individual decays, we can only set upper

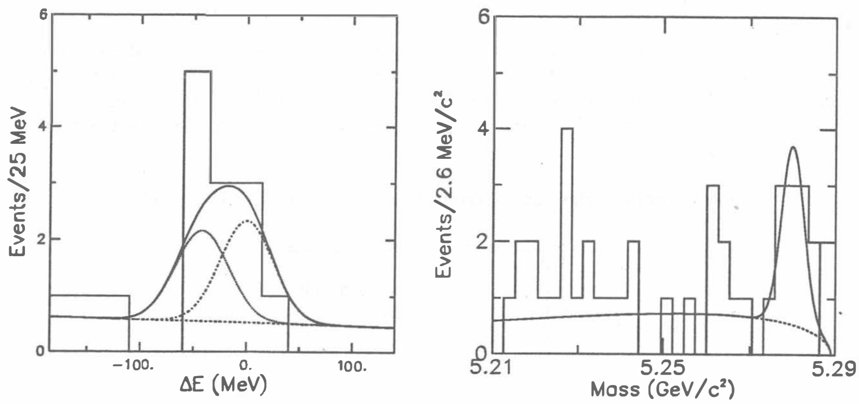

Fig. 3. ΔE and $M_{K\pi}$ distribution for $B \to K^+\pi^-$ and/or $\pi^+\pi^-$.

limits for each of the decay modes. They are both 3×10^{-5} at 90% confidence level.

Charmless B Semileptonic Decays

We have confirmed a non-zero value of $|V_{ub}/V_{cb}|$ by observing leptons beyond the limit for $b \to c\ell\overline{\nu}$. Non-vanishing $|V_{ub}/V_{cb}|$ would be necessary if the Standard Model were to explain CP violation.

We search for leptons in the momentum range between 2.4 and 2.6 GeV, where we expect no $b \to c$ contribution. The background from $e^+e^- \to q\overline{q}$ is subtracted using the off-resonance data after its contribution is reduced using event shape information. Because the CLEO II detector is more hermetic, event shape and the missing momentum are measured substantially better than CLEO I. By requiring very spherical events ($R_2 < 0.2$) and large (> 1 GeV) missing momentum we reduce the $e^+e^- \to q\overline{q}$ background by a factor of 70.

The leptons from $b \to c$ would vanish above 2.3 GeV in the B rest frame. When the effects of the B motion and momentum resolution are taken into account, the limit increases to 2.4 GeV. However, since their total contribution is almost two orders of magnitude larger than the signal, we need to study carefully the effect of momentum mismeasurements beyond what Gaussain resolution function would describe. We do this in two steps. First, we look at μ-pair events and make sure our estimate of the momentum resolution is reasonable and the tail is accounted for by a Gaussian resolution function at least in a clean event environment.

We use data in order to assess the effect of complex multi-hadron environment confusing lepton track reconstruction. We take tracks from clean events such as Bhabha's, and μ- and τ-pair events. They are embedded in multi-hadron events, reconstructed again from individual hits and their momenta are measured. The shifts in the momentum measurements after embedding are often found to be associated with bad "track quality", which is characterized by the r.m.s. hit-track distances, the closest approach of the track to the primary vertex in the $r - \phi$ and $r - z$ projections and the number of hits used in the track fit. From this study, we conclude that stringent track quality requirements reduce momentum-mismeasured tracks to a negligible level. Even if our estimate of the background is off by a factor of two, the final results are not effected.

Table 1 contains the numbers of leptons found in our data as well as the estimates of backgrounds. The momentum distribution of the off-resonance data is fitted to smooth functions before it is used for the subtraction of the $e^+e^- \to q\bar{q}$ background from the on-resonance data. This will minimize the statistical error due to the smaller-statistics of off-resonance data.

Table 1. Lepton yields and backgrounds with strict cuts (2.4 to 2.6 GeV/c).

	$e + \mu$
N_{ON}	77
N_{OFF}	$14.2 \pm 2.9 \pm 2.6$
Excess	$45.9 \pm 10.9 \pm 5.6$
$b \to c$	$3.9 \pm 1.3 \pm 0.8$
$b \to u\ell\bar{\nu}$	$42.0 \pm 11.0 \pm 5.7$

We obtain the partial branching fraction $\Delta B_{ub}(2.4,2.6)$ of $(0.53 \pm 0.14 \pm 0.13) \times 10^{-4}$, and correspondent $|V_{ub}/V_{cb}|$ ranges from 0.05 to 0.11. This is significantly less than the CLEO I result of $(1.8 \pm 0.4 \pm 0.3) \times 10^{-4}$ (2.6σ effect when the common systematic errors are considered properly.)

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