Search for the Lepton Flavor Violating B Decays $B^0 \rightarrow \mu \tau$ and $B^0 \rightarrow e \tau$ at CLEO2

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Using almost 10 million $B\bar{B}$ decays produced at CESR, the CLEO collaboration has set the most stringent limits to date on the lepton flavor violating decays $B^0 \rightarrow \mu (e) \tau$.

1. Introduction

A lepton flavor violating decay such as $B^0 \rightarrow \mu \tau$ and $B^0 \rightarrow e \tau$ could conceivably proceed through a box diagram involving an exchange of a neutrino along with a suitable mixing matrix. In the Standard Model, neutrinos are usually taken to be massless, and this decay route is thus excluded. One expects that with neutrino masses in the eV range, this decay would be heavily suppressed and should not visible at any current facilities. Thus observation of this decay mode would constitute important evidence of physics beyond the Standard Model. The previous best limits on the branching fractions are $B(B^0 \rightarrow \mu \tau) < 8.3 \times 10^{-4}$ and $B(B^0 \rightarrow e \tau) < 5.3 \times 10^{-4}$.

The data used in this analysis were produced at the CESR $e^+e^-$ collider at the $\Upsilon(4S)$ resonance using the CLEO2 detector. The dataset comprises some $9.6 \times 10^6 B\bar{B}$ decays, and also includes some $4.5 fb^{-1}$ of data taken some $60 MeV$ below the resonance to gauge the size of non-$B$ backgrounds, including continuum $q\bar{q}$ production, and 2 photon fusion events. The continuum (and tau) event samples below resonance can be scaled according to the ratio of accepted luminosity to beam energy squared, $L/E_{Beam}^2$, to extrapolate the behavior of these components at the $\Upsilon(4S)$. The scale factor is 1.99 for this data. Backgrounds from 2 photon events are minimized by doing a cut on the missing momentum in the event.

The final state events we look for involve $\mu(e)^+ \tau^-$ or its charge conjugate recoiling against a generic $B^0$ or $B^\dag$ decay. The $\tau$ is identified by its leptonic decays to $e \nu \nu$ and $\mu \nu \nu$ states. As a shorthand for this presentation, we refer to the decay chain $B \rightarrow l \tau, \tau \rightarrow l' \nu \nu$ as $(l, l')$. In the $B$ rest frame, the primary lepton, $l$, is monoenergetic. In the lab frame, the $B$ is slightly boosted, and thus the primary lepton has a momentum between 2.2 and 2.5 GeV, easily within the electron and muon particle identification abilities of the CLEO detector. The secondary lepton has a range of momenta and is required to have momentum greater than 0.6 (1.0) GeV for electron (muon) identification. In this study the missing energy-momentum four vector, determined by reference to the known beam energy, is referred to as $P_{\mu \nu}$.

Two neural networks are used to exclude backgrounds from continuum and $B\bar{B}$ events. For continuum suppression, the neural net $NN_{cont}$ uses as inputs $R2$ (the ratio of the 2nd to 0th Fox Wolfram moments), the event sphericity, the event thrust, the cosine of the angle between the momentum difference of the leptons and the thrust axis of the rest of the event, and the cosine of the angle between the (unobserved) neutrino pair and lepton pair. This network is trained using samples of signal and generic continuum Monte Carlo. The network used to suppress events from $B\bar{B}$
events, $NN_{BB}$, uses three inputs. These are the beam energy constrained $B$ candidate mass, the difference between the candidate $B$ energy and the beam energy, and the cosine of the angle between the primary lepton and the momentum of the other $B$ in the event. This network is trained with signal and $B\bar{B}$ generic Monte Carlo samples. For each of the four possible $(l,l')$ modes, events are rejected by cuts in the $NN_{cont}$ vs $NN_{BB}$ plane.

As a cross check of the analysis method, we compare the data and Monte Carlo agreement in the side bands of the primary lepton - this sample requires that the primary lepton momentum be either in the (2.0,2.2) GeV window or the (2.5,2.7) GeV window. Fig 1 is a plot of the off resonance subtracted Data and generic $B$ Monte Carlo for events in this primary lepton sideband for the $(\mu,e)$ sample. The plots show the output of the continuum neural net, the $B\bar{B}$ neural net, the difference between the measured and true $\tau$ mass using $P_{\nu\nu}$, and the beam energy constrained $\tau$ mass difference, in which the missing neutrino pair energy is taken to be the difference between the beam energy and the sum of the lepton energies.

Another check compares primary lepton sideband data for the off resonance data events to the events in the absolutely normalized continuum generic Monte Carlo. Fig 2 shows the same quantities as above for these samples in the $(\mu,e)$ sample. The agreement is good. It is found however that in the $(e,e)$ mode, the data exceeds the continuum Monte Carlo expectation, due to the presence of unmodelled 2 photon fusion events. We thus scale the Monte Carlo in the signal region by this ratio. The largest single systematic uncertainty is in the estimation of the missing four momentum of the two neutrinos (5.4%), resulting in total systematic uncertainties of 7.4% in $(\mu,e)$ and $(e,\mu)$ modes and 8.9% in $(e,e)$ and $(\mu,\mu)$ modes.

Combining these results we obtain the 90% C.L. upper limits on the branching fractions to be:

$$B(B^0 \to \mu\tau) < 3.8 \times 10^{-5}$$
$$B(B^0 \to e\tau) < 1.1 \times 10^{-4}$$

These results assume that the $\tau$ from these decays are unpolarized. In the limit of a pure $V-A$ ($V+A$) interaction the efficiency increases (decreases) by 11% (8%). These are the most stringent limits to date on these processes, surpassing the previous CLEO results by a factor of 22(5).
Table 1
Summary of the data for each mode: Numbers of observed events on resonance (N(on)), and off resonance (N(off)) for the primary lepton signal region, number of events remaining after on resonance subtraction of off resonance events in the primary lepton signal region (N(obs)), and the expected numbers of events from $B\bar{B}$ and continuum Monte Carlos. The final 90% confidence level upper limits for each mode are also given.

| Mode     | (l, l') | ($\mu$, e) | ($\mu$, $\mu$) | ($e$, e) | ($e$, $\mu$) |
|----------|---------|------------|----------------|----------|--------------|
| N(on)    | 19      | 10         | 28             | 6        |              |
| N(off)   | 2       | 3          | 7              | 0        |              |
| N(obs)   | 15.0 ± 5.2 | 4.0 ± 4.7 | 14.0 ± 7.5 | 6.0 ± 2.4 |              |
| $< N_{BB} >$ | 23.7 ± 2.7 | 9.0 ± 1.4 | 11.6 ± 1.4 | 5.1 ± 0.8 |              |
| $< N_{cont} >$ | 1.8 ± 0.6 | 0.4 ± 0.2 | 3.1 ± 1.0 | 0.5 ± 0.3 |              |
| U.L. ($10^{-4}$) | 0.55 | 0.87 | 1.64 | 1.46 |              |

Figure 2. (a) $NN_{cont}$, (b) $NN_{BB}$, (c) measured $\tau$ mass, (d) beam energy constrained $\tau$ mass distributions for continuum Monte Carlo (histograms) and off resonance data (points) in the primary lepton sideband region for the ($\mu$, e) mode.

for the $\mu(e)$ primary lepton mode. This work has been submitted to Phys. Rev. Lett.

REFERENCES
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