Rare B decays in Collider Experiments

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Abstract. The recent results on the semileptonic and leptonic rare B decays from the collider experiments are reviewed. Additionally, the recent measurements of lepton flavor violation in τ decays are presented.

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INTRODUCTION

Rare B decays play a crucial role in testing the Standard Model (SM) as well as probing physics beyond the SM. The semileptonic decay $B^+ \rightarrow K^+ \nu\overline{\nu}$, and leptonic decays $B^+ \rightarrow \tau^+ \nu$, $B^0 \rightarrow \nu\overline{\nu}(\gamma)$, $B^0 \rightarrow \tau^+\tau^-$ and $B_{s,d} \rightarrow \mu^+\mu^-(\phi)$ from B-factories (BaBar and Belle) and Tevatron (D0 and CDF) are discussed here. These channels have yet to be observed experimentally. In order to measure the branching fractions of the order of $10^{-5} - 10^{-10}$, high luminosity and a good experimental technique are needed. B mesons are produced at the BaBar and Belle detectors situated at the asymmetric e^+e^- PEP-II and KEKB colliders, respectively. Both colliders are operated at the $\sqrt{s} = 10.58$ GeV $\Upsilon(4S)$ resonance at which the $b\overline{b}$ cross section is 1.05 nb. By now, BaBar and Belle have reached the total integrated luminosity of 300 fb^{-1} and 490 fb^{-1}, respectively. Tevatron $p\overline{p}$ collider operated at $\sqrt{s} = 1.96$ TeV produces 10^{10} $b\overline{b}$/year. Currently, D0 and CDF have each collected a total integrated luminosity of ~ 1.4 fb^{-1} data.

RESULTS OF SEMILEPTONIC AND LEPTONIC B DECAYS

Due to the multiple neutrinos in the final state of $B^+ \rightarrow K^+\nu\overline{\nu}$, $B^+ \rightarrow \tau^+\nu$, $B^0 \rightarrow \nu\overline{\nu}(\gamma)$, and $B^0 \rightarrow \tau^+\tau^-$ decays, an analysis technique is developed to search for these channels. The technique is based on the full reconstruction of one B meson from an $\Upsilon(4S) \rightarrow B\overline{B}$ event either semileptonically ($B \rightarrow D^{(*)} l\nu$) or hadronically ($B \rightarrow DX$, $X = K, \pi, \pi^0$ combination). All the remaining charged and neutral particles in that event are then used in reconstructing the decay of the accompanying B referred as to the signal B.

The flavor-changing neutral current (FCNC) inclusive decay $b^+ \rightarrow s^+\nu\overline{\nu}$ is the cleanest mode among the rare B decays. In the SM, the branching fraction of $B^+ \rightarrow K^+\nu\overline{\nu}$ is estimated to be $(3.8^{+1.2}_{-0.6}) \times 10^{-6}$ [1]. Both BaBar and Belle have searched for $B^+ \rightarrow K^+\nu\overline{\nu}$ and a 90% C.L. limits on the branching fraction are set. The BaBar measurement, based on 82 fb^{-1}, gives result of $B(B^+ \rightarrow K^+\nu\overline{\nu}) < 5.2 \times 10^{-5}$ [2] and Belle has subsequently improved the limit to 3.6×10^{-5} [3] using 253 fb^{-1} data. The relevant $b \rightarrow d\nu\overline{\nu}$

decay is suppressed compared to $b \to s\nu\overline{\nu}$ by Cabibbo-Kobayashi-Maskawa (CKM) matrix elements of $|V_{td}|^2/|V_{ts}|^2$ [4]. A 90% C.L. limit on the $B(B^+ \to \pi^+\nu\overline{\nu}) < 1.0 \times 10^{-4}$ is set for the first time by BaBar [2].

The purely leptonic B meson decays can be used to determine the B meson decay constant, f_B, CKM matrix elements, and to probe the physics beyond the SM. The leptonic charged B decay proceeds via the W-boson annihilation while the neutral B decays proceeds via electroweak penguin with Z and box diagrams. The amplitude of $B \to ll^{'}$, $(l = e, \mu, \tau)$ decay contains a helicity suppression factor of m_l^2/m_B^2, where $m_l(m_B)$ represents the lepton(B meson) mass. The channels involving τ will be of interest since the electrons and muons are more suppressed relative to the τ channel.

One of the interesting channels searched for by BaBar and Belle is $B^+ \to \tau^+\nu_\tau$. The SM prediction is $B(B^+ \to \tau^+\nu_\tau) = (9.3^{+3.4}_{-2.3}) \times 10^{-5}$ [5]. Both experiments have obtained a 90% C.L. limit on the branching fraction of τ channel. The results are 2.6×10^{-4} at 211 fb^{-1} [6] and 1.8×10^{-4} at 253 fb^{-1} [3], respectively.

The neutral B^0 decay, $B^0 \to \tau^+\tau^-$, has been sought in BaBar. The SM prediction for $B(B^0 \to \tau^+\tau^-) = 1.2 \times 10^{-7}[f_B/200\ MeV]^2[|V_{td}|/0.007]^2$ [7]. The preliminary limit presented in the talk is now updated: using 211 fb^{-1}, 90% C.L. limit of $B(B^0 \to \tau^+\tau^-) < 3.2 \times 10^{-3}$ is set [8].

The neutral decay of $B_s(B_d) \to \mu^+\mu^-$ was investigated by D0 and CDF (BaBar and Belle). The SM prediction for B_s and B_d decays are $(3.42 \pm 0.54) \times 10^{-9}$ and $(1.00 \pm 0.14) \times 10^{-10}$ [9], respectively. D0 has recently updated the $B_s \to \mu^+\mu^-$ measurement to 300 pb^{-1} and at the 90% C.L. upper limit is found to be $B(B_s \to \mu^+\mu^-) < 3.0 \times 10^{-7}$ [10]. Combining this result with the CDF result at 364 pb^{-1}, $B(B_s \to \mu^+\mu^-) < 1.5 \times 10^{-7}$ [11], the limit is found to be $B(B_s \to \mu^+\mu^-) < 1.2 \times 10^{-7}$ [12]. BaBar and Belle set an 90% C.L. limit on the branching fraction of $B_d \to \mu^+\mu^-$. The results are $< 8.3 \times 10^{-8}$ at 111 fb^{-1} [13] and $< 1.6 \times 10^{-7}$ at 78 fb^{-1} [14], respectively. D0 updated also the limit on branching fraction of exclusive FCNC $B_s \to \mu^+\mu^-\phi$ to 300 pb^{-1}. The preliminary 90% C.L. limit is $B(B_s \to \mu^+\mu^-\phi) < 3.2 \times 10^{-6}$ [15].

The $B^0 \to \nu\overline{\nu}(\gamma)$ decay has been investigated in BaBar. The SM predicts a very small branching fraction for the invisible decay and 10^{-9} for $B^0 \to \nu\overline{\nu}\gamma$ [16]. In the invisible decay, the B^0 decays into particles that are not charged and deposit no energy in the calorimeter. Based on 82 fb^{-1}, BaBar has established a 90% C.L. limit on $B(B^0 \to \nu\overline{\nu}) < 22 \times 10^{-5}$ and $B(B^0 \to \nu\overline{\nu}\gamma) < 4.7 \times 10^{-5}$ [17].

LEPTON FLAVOR VIOLATION IN τ DECAYS

Lepton flavor is exactly conserved in SM, thus any observation of a lepton-flavor violation (LFV) decay is a clear signature of new physics. Some supersymmetric and other models enhance the branching fraction up to $10^{-7} - 10^{-9}$ [18], which can be accessible at the B-factories. The recent results from the neutrino oscillation experiments shows that LFV can occur in SM, however the branching fraction in 3-prong τ decay is not expected to be more than 10^{-14} [19]. Because the τ pair cross section is $\sigma_{\tau\tau} = (0.89 \pm 0.2)$ nb, LFV decays associated with τ leptons can be studied in B-factories. Both BaBar and Belle searched for LFV decay $\tau \to l\gamma$, $(l = e, \mu)$ in data containing 2.07×10^8 and 0.8×10^8 $\tau^+\tau^-$ pair events. None of the experiments have seen any signal events exceeding background expectation in the signal region. A 90% C.L. limit of $B(\tau \rightarrow e(\mu)\gamma) < 1.1(0.7) \times 10^{-7}$ [20]([21]) is obtained by BaBar. The limit by Belle at the 90% C.L. is $B(\tau \rightarrow e(\mu)\gamma) < 3.9(3.1) \times 10^{-7}$ [22]([23]). The constraints imposed by the limit of $B(\tau^+ \rightarrow e^+(\mu^+)\gamma)$ on the mSUGRA models which are characterized by a set of universal parameters at m_{GUT} scale: gaugino mass ($m_{1/2}$) and scalar mass (m_0), is presented in the talk [24]. The constraints by $B(\tau \rightarrow e(\mu)\gamma)$ are significant in the case of inverted (normal) neutrino mass hierarchy $m_{\nu 1} \sim m_{\nu 2} >> m_{\nu 3}$. An analysis for the decay $\tau \rightarrow lhh^{'}$, $(h = \pi, K; l = e, \mu)$ is performed by BaBar [25]. No events are observed in the signal region and upper limits at 90% C.L. have been obtained for all the channels at 221 fb^{-1}. The branching fraction of the eight flavor violation modes are in the range of $(1.2 - 3.2) \times 10^{-7}$. The six flavor and lepton number violation modes have an upper limit of between $(0.7 - 4.8) \times 10^{-7}$.

CONCLUSION

The observation of the rare B decays will provide determination of the some SM parameters and put constraints on the non-SM parameters. Some channels mentioned above are expected to be observed within a few years.

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