Title:	Study of Rare Decays & Exotic States in Quarkonium at belle
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Abstract: The number of leptons belonging to each generation is conserved in any interaction: this rule is known as the lepton flavor number conservation. In 1998, the Super- Kamiokande experiment announced convincing evidence for neutrino oscillations implying that neutrinos have certain mass. This also violates the conservation of lepton flavor. On the other hand, currently lepton flavor universality LFU violation is the most excited anomaly in the flavor physics. Although the SM gauge couplings do not discriminate between different generations of leptons, there are some new physics (NP) models such as: leptoquarks model, Z 0 model, which predict the enhancement of the couplings with increasing lepton mass. Also, it has been pointed out that the violation of lepton flavor universality generically implies the violation of lepton flavor. Thus, one can constrain the parameters for the NP models, describing LFU violation, by studying the charge lepton flavor violation (CLFV). Moreover, flavor changing neutral current (FCNC) interactions serve as a powerful probe of physics beyond the SM. As SM model operators can not generate FCNCs in the tree level diagram, NP operators dominate the SM loop corrections by producing FCNCs in the tree level diagram. CLFV interaction in various bottomonium ($b\bar{b}$) decays can provide the alternative access to study all those NP operators. CLEO and BaBar collaborations have already published some results on the search for CLFV in Υ(nS)[n = 1, 2, 3] decays. For Υ(1S), only Υ(1S) → $\mu^{\pm}\tau^{\mp}$ has been studied so far, and not Υ(1S) → $e^{\pm}\mu^{\mp}$ and Υ(1S) → $e^{\pm}\tau^{\mp}$ transitions. Belle has the largest Υ(2S) data sample corresponding to 158 million Υ(2S) decays and the resulting number of Υ(1S) produced in Υ(2S) → $\pi^{+}\pi^{-}$ Υ(1S) decays is around 28 million. Four particles final state in Υ(2S) → $\pi^{+}\pi^{-}$ Υ(1S)[→ `` 0 ] [`, ` 0 = e, μ, τ ] provides a better control over background with efficient triggering. On the other hand, CLFV decays with an extra photon in the final state (RLFV), Υ(nS) → γ`` 0 could allow one to access the operators which are inaccessible in two-body CLFV decays. But, there are no results available on RLFV decays. In this thesis, we search for the Υ(1S) → ` ± ` 0∓ and Υ(1S) → γ` ± ` 0∓ decays using Υ(1S) with di- pion tagging. We use Υ(1S) → ` ± ` ∓ [` = e, μ] decays as the calibration modes. To validate the signal extraction procedure, we measure the branching fractions for Υ(1S) → $e^{+}e^{-}$ and Υ(1S) → $\mu^{+}\mu^{-}$ modes. The obtained results on the branching fraction measurements, B[Υ(1S) → $e^{+}e^{-}$] = (2.40 ± 0.01(stat) ± 0.12(syst)) × 10^{-2} and B[Υ(1S) → $\mu^{+}\mu^{-}$] = (2.46 ± 0.01(stat) ± 0.11(syst)) × 10^{-2}, agree with the world average values within corresponding uncertai- nties. In the absence of signal, we set upper limit (UL) on the branching fraction of the CLFV decays at the 90% CL. The obtained ULs of branching fractions for Υ(1S) → $e^{\pm}\mu^{\mp}$, Υ(1S) → $\mu^{\pm}\tau^{\mp}$, Υ(1S) → $e^{\pm}\tau^{\mp}$, Υ(1S) → $\gamma e^{\pm}\mu^{\mp}$, Υ(1S) → $\gamma\mu^{\pm}\tau^{\mp}$, and Υ(1S) → $\gamma e^{\pm}\tau^{\mp}$ are3 3.9 × 10^{-7}, 2.7 × 10^{-6}, 2.7 × 10^{-6}, 4.2 × 10^{-7}, 6.1 × 10^{-6}, and 6.5 × 10^{-6}, respectively. The result for the Υ(1S) → $\mu^{\pm}\tau^{\mp}$ decay is 2.3 times more stringent than the previous result from the CLEO collaboration, while the remaining modes are searched for the first time. Couple of studies has already been done on vector quarkonia decays such as: Υ(nS) → `` 0 and J/ψ → `` 0 decays. But, no experimental studies have been performed on scalar quarkonium decays. Corresponding p-wave states of χ_{b0}(1P) and χ_{c0}, those have been efficiently produced in radiative transition of Υ(2S) decays, can be used to search for CLFV scalar quarkonium decays. In this thesis, we search for CLFV in χ_{b0}(1P) → ` ± ` 0∓ decays using Υ(2S) data, where `, ` 0 = e, μ, τ leptons. Along with that, we also search for χ_{b1}(1P) → ` ± ` 0∓ and χ_{b2}(1P) → ` ± ` 0∓ decays, which provide the result for CLFV in axial vector and tensor meson decays, respectively. To study CLFV χ_{bJ}(1P) → ` ± ` 0∓ decays, use χ_{bJ}(1P) → γΥ(1S)[→ ` + ` −] decays as the calibration modes, where ` = e, μ leptons. Due to very less number of charged tracks with one (or two) photons in the final state, QED Bhabha events become dominating background here. We simulate the Bhabha trigger effect to estimate the effect of Bhabha veto that has already been applied on Υ(2S) data collected by the Belle detector. We measure the branching fractions of calibration modes. Measured branching fractions of Υ(2S) → $\gamma\gamma e^{+}e^{-}$ ($\gamma\gamma\mu^{+}\mu^{-}$) decays for J = 0, 1, and 2 are (1.6 ± 0.2) × 10^{-5} ((1.5 ± 0.1) × 10^{-5}), (5.37 ± 0.06) × 10^{-4} ((6.14 ± 0.04) × 10^{-4}), and (2.96 ± 0.05) × 10^{-4} ((3.30 ± 0.03) × 10^{-4}), respectively, which agree with the corresponding world average values within uncertainties. We study the SM backgrounds and estimate the expected ULs of branching fractions using MC simulated events. Expected ULs of branching fractions for $\chi_{b[0,1,2]}$(1P) → $e^{\pm}\mu^{\mp}$, $\chi_{b[0,1,2]}$(1P) → $\mu^{\pm}\tau^{\mp}$, and $\chi_{b[0,1,2]}$(1P) → $e^{\pm}\tau^{\mp}$ are [1.3 × 10^{-6}, 6.9 × 10^{-7}, 7.0×10^{-7}], [1.7×10^{-5}, 1.5×10^{-5}, 1.4×10^{-5}], and [3.1×10^{-5}, 1.3×10^{-5}, 1.3×10^{-5}], respectively. This study is under internal review of the Belle collaboration. Last two decade have been very exciting for the quarkonium sector. Many new states have been found which find no place in the conventional spectroscopy and are strong contenders of the exotic quarkonium states (like tetra-quark, molecular, hybrid). X(3872) has remained the poster boy of these exotic states, from the time it was first observed by the Belle Collaboration in 2003. One of the salient features ∗0 0 of X(3872) is that the mass coincides exactly with the D D 0 (or D D ∗0) threshold: m D 0 + m D ∗0 - m X(3872) = (0.00±0.18) MeV/c^2, which naturally pushes the molecular interpretations. Negative C-odd partner search of X(3872) (X(3872) → J/ψη, X(3872) → $\chi_{c1}\gamma$, X(3872) → $\eta_c\omega$, X(3872) → $\eta_c\pi\pi$) and charged partner search4 in $X(3872)^{+}$ → J/ψ$\pi^{+}\pi^{0}$ suggest that X(3872) is an iso-singlet state. In that scenario, its decay into its discovery mode X(3872) → J/ψ$\pi^{+}\pi^{-}$ is expected to be isospin violating. Further, one expect the decay X(3872) → J/ψω(→ $\pi^{+}\pi^{-}\pi^{0}$) to be an isospin allowed and should have larger branching fraction, something like $R_{3\pi/2\pi}$ ≡ B(X(3872) → J/ψω)/B(X(3872) → J/ψ$\pi^{+}\pi^{-}$) ∼ 30. Isospin violating decays of X(3872) are sensitive to the inner structures and have been investigated in different scenarios. Couple of studies also suggest that the isospin violation comes from the molecular structure of the X(3872). However, the previous measurement by the Belle with 256 fb^{-1} data suggest $R_{3\pi/2\pi}$ to be 1.0 ± 0.4 (stat) ± 0.3 (syst). BaBar Collaboration using their full data set (426 fb^{-1}) measured this ratio to be 0.7 ± 0.3 (1.7±1.3) for B^{+} (B^{0}) events. Recently, BESIII has published the result on $R_{3\pi/2\pi}$ to be 1.6 +0.4

−0.3 (stat)±0.2 (syst), which is on higher side. All the results bring the picture of large isospin violation, which is not truly understood so far. Belle accumulated 711 fb^{-1} data, almost twice of BaBar. More precise measurement with the full Belle data set will help to understand the nature of X(3872). Also, the X(3915) is the another interesting exotic charmonium state. Measurements suggest the quantum numbers for X(3915) can be either 0^{++} or 2^{++}. BaBar measured the branching fraction of X(3915) → J/ψω decay to be ~ 20 times of the branching fraction for X(3872) → J/ψω. BESIII reported the branching fraction of X(3915) → J/ψω to be suppressed as compared to X(3872) → J/ψω decays. In this thesis, we study the branching fractions of X(3872) → J/ψω and X(3915) → J/ψω using the largest Y(4S) data sample collected by the Belle detector. For this study, we describe the analysis strategy, event selection criteria, background suppression using MC simulated samples. This study is under internal review of the Belle collaboration. We hope to finalize this analysis soon.

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