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Search for lepton-flavor-violating τ decays into three leptons with 719 million produced $\tau^+\tau^-$ pairs

Belle Collaboration

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ABSTRACT

We present a search for lepton-flavor-violating τ decays into three leptons (electrons or muons) using 782 fb^{-1} of data collected with the Belle detector at the KEKB asymmetric-energy e^+e^- collider. No evidence for these decays is observed and we set 90% confidence level upper limits on the branching fractions between 1.5×10^{-8} and 2.7×10^{-8}.

1. Introduction

Lepton flavor violation (LFV) appears in various extensions of the Standard Model (SM). In particular, lepton-flavor-violating $\tau^- \to \ell^-\ell^+\ell^-$ (where $\ell = e$ or μ) decays are discussed in various supersymmetric models [1–8], models with little Higgs [9,10], left-right symmetric models [11] as well as models with heavy singlet Dirac neutrinos [12] and very light pseudoscalar bosons [13]. Some of these models with certain combinations of parameters predict that the branching fractions for $\tau^- \to \ell^-\ell^+\ell^-$ decays can be as large as 10^{-7}, which is in the range already accessible in high-statistics B factory experiments.

Searches for lepton flavor violation in $\tau^- \to \ell^-\ell^+\ell^-$ (where $\ell = e$ or μ) decays have been performed since 1982 [14], starting from the pioneering experiment MARKII [15]. In the previous high-statistics analyses, Belle (BaBar) reached 90% confidence level upper limits on the branching fractions of the order of 10^{-8} [16,17], based on samples with about 535 (376) fb^{-1} of data. Here, we update our previous results with a larger data set (782 fb^{-1}), collected with the Belle detector at the KEKB asymmetric-energy e^+e^- collider [18], taken at the $\Upsilon(4S)$ resonance and 60 MeV below it. We apply the same selection criteria as in the previous analysis, but optimized for the new data sample.

The Belle detector is a large-solid-angle magnetic spectrometer that consists of a silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of aerogel threshold Cherenkov counters (ACC), a barrel-like arrangement of time-of-flight scintillation counters (TOF), and an electromagnetic calorimeter comprised of CsI(Tl) crystals (ECL), all located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. An iron flux-return located outside the coil is instrumented to detect K_L^0 mesons and to identify muons (KLM). The detector is described in detail elsewhere [19].

Leptons are identified using likelihood ratios calculated from the response of various subsystems of the detector. For electron identification, the likelihood ratio is defined as $\mathcal{P}(e) = \mathcal{L}_e/(\mathcal{L}_e + \mathcal{L}_x)$, where $\mathcal{L}_e$ and $\mathcal{L}_x$ are the likelihoods for electron and non-electron hypotheses, respectively, determined using the ratio of the energy deposit in the ECL to the momentum measured in the SVD and CDC, the shower shape in the ECL, the matching between the position of charged track trajectory and the cluster position in the ECL, the hit information from the ACC and the dE/dx information in the CDC [20]. For muon identification, the likelihood ratio is defined as $(\mathcal{P}(\mu) = \mathcal{L}_\mu/(\mathcal{L}_\mu + \mathcal{L}_\pi + \mathcal{L}_K))$, where $\mathcal{L}_\mu$, $\mathcal{L}_\pi$ and $\mathcal{L}_K$ are the likelihoods for muon, pion and kaon hypotheses, respectively, based on the matching quality and penetration depth of associated hits in the KLM [21].

In order to optimize the event selection and to estimate the signal efficiency, we use Monte Carlo (MC) samples. The signal and the background (BG) events from generic $\tau^+\tau^-$ decays are generated by KORALB/TAUOLA [22]. In the signal MC, we generate $\tau^+\tau^-$ pairs, where one τ decays into three leptons and the other τ decays generically. All leptons from $\tau^- \to \ell^-\ell^+\ell^-$ decays are assumed to have a phase space distribution in the τ lepton's rest frame [23]. Other backgrounds including $B\bar{B}$ and $e^+e^- \to q\bar{q}$ $(q = u, d, s, c)$ processes, Bhabhas, $e^+e^- \to \mu^+\mu^-$, and two-photon processes are generated by EvtGen [24], BHLUMI [25], KKMC [22], and AAFHB [26], respectively. All kinematic variables are calculated in the laboratory frame unless otherwise specified. In particular, variables calculated in the e^+e^- center-of-mass (CM) system are indicated by the superscript "CM".