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Belle II experiment sensitivity to the LFV decays $\tau^{\pm} \to \ell^{\pm} + \text{invisible}$

The Belle II Collaboration

Abstract

We study the charged lepton flavor violating decay $\tau \to \ell\alpha$, where α is a non-standard invisible boson that leaves the Belle II detector undetected and ℓ is either an electron or a muon. This Note presents plots showing relevant observables, and upper limit estimates using Belle II simulated data, assuming no $\tau \to \ell\alpha$ signal in 62.8 fb^{-1} of integrated luminosity.

Contents

1. INTRODUCTION

We present preliminary Monte Carlo studies on the search for $\tau \to \ell\alpha$ decays, where ℓ is either an electron or a muon, and α is a particle that escapes the Belle II detector undetected. This is a charged Lepton Flavor Violating (LFV) process not present in the Standard Model of particle physics (SM), but appears in various new physics models [1–8]. For a massless α particle, the current limits at 95 % C.L. are $Br(\tau \to e\alpha)/Br(\tau \to e\nu\overline{\nu}) < 1.5\%$ and $Br(\tau \to \mu\alpha)/Br(\tau \to \mu\nu\overline{\nu}) < 2.6\%$, as reported by the ARGUS Collaboration [9].

The search is based on measuring the production of LFV $\tau \to \ell\alpha$ decays with respect to the SM process $\tau \to \ell\nu_l\nu_\tau$.

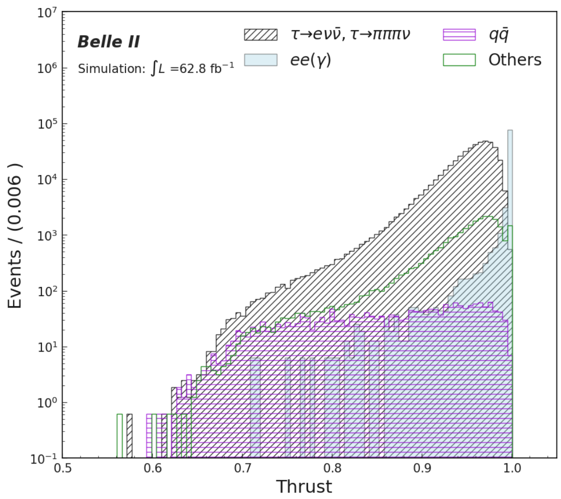
Figure 2.1.1 presents the three distributions used for signal optimization in simulated data, after requiring standard selection criteria on the reconstructed objects.

The measurement is performed in the so called pseudo-rest frame, a technique developed by ARGUS [9]. Section 3 presents the relevant distributions used for this measurement.

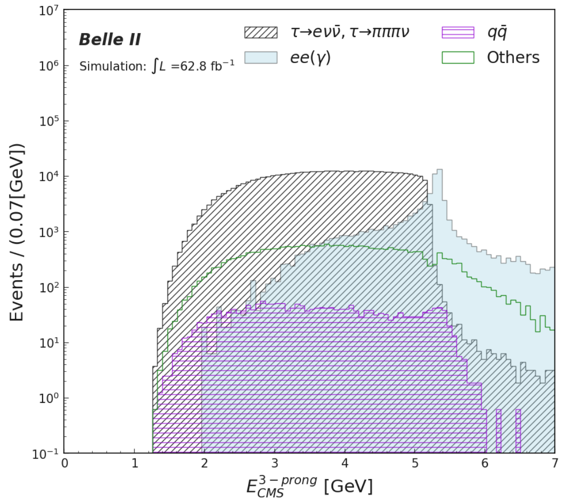
Finally, for 62.8 fb^{-1} of data, Fig. 4.1.1 shows the expected 95 % C.L. upper limits on $Br(\tau \to \ell\alpha)/Br(\tau \to \ell\nu\overline{\nu})$ for different masses of the α particle without systematic uncertainties, and in Fig. 4.2.1 including the dominant systematic effects.

2. BACKGROUND SUPPRESSION

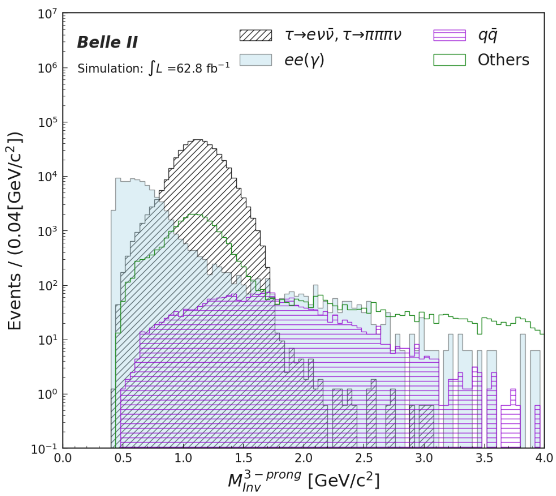
2.1. Distributions used for optimization



(a) Thrust of the event.



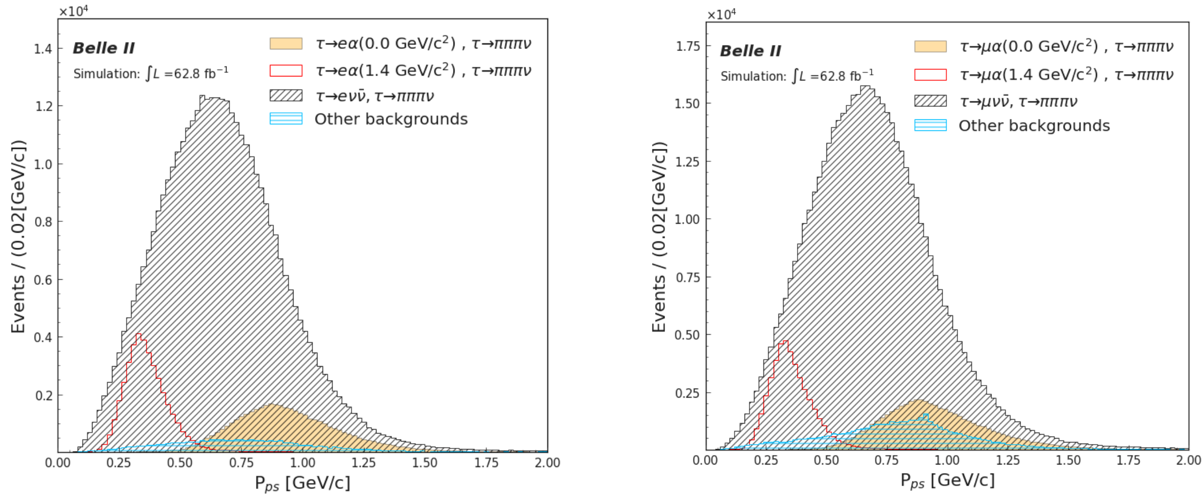
(b) Energy of the 3-prong system.



(c) Invariant mass of the 3-prong system.

FIG. 2.1.1: Event distributions for reconstructed 3x1-prong decays. The 3x1-prong topology is obtained by means of the thrust vector ($\widehat{n}_{thrust}$, defined below), which is used to separate the event into signal (1-prong) and tag (3-prong) hemispheres. Candidate events are identified with the tag side τ decaying into into three charged pion candidates, $\tau \to \pi\pi\pi\nu$, and with the signal side τ decaying into one electron candidate, $\tau \to e\nu\bar{\nu}$. Neutrinos are not reconstructed. Shown are: a) the event thrust distribution, defined as $T = \sum_i \frac{|\overrightarrow{p}_i^{CMS} \cdot \widehat{n}_{thrust}|}{\sum |\overrightarrow{p}_i^{CMS}|}$, where $\overrightarrow{p}_i^{CMS}$ is the momentum in the center-of-mass frame of the i-th reconstructed particle in the event (tracks and photons), and $\widehat{n}_{thrust}$ is the (thrust) direction that maximizes the sum; b) the energy of the 3-prong system calculated from tracks and photons; and c) the invariant mass of the 3-prong system, $M_{Inv}^{3-prong} = \sqrt{E_{3-prong}^2 - p_{3-prong}^2}$.

3. τ PSEUDO-REST FRAME



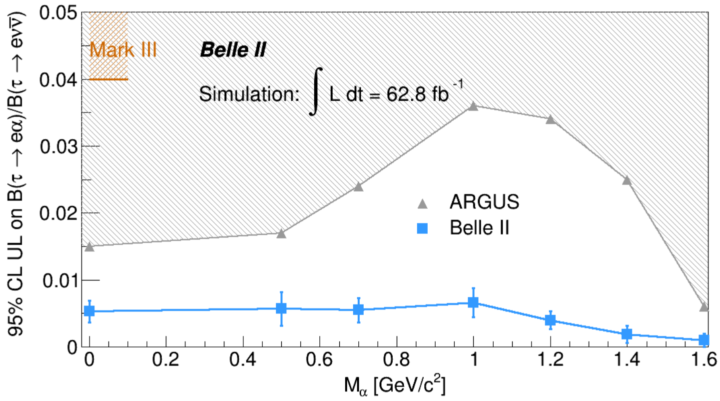
(a) Electron channel.

(b) Muon channel.

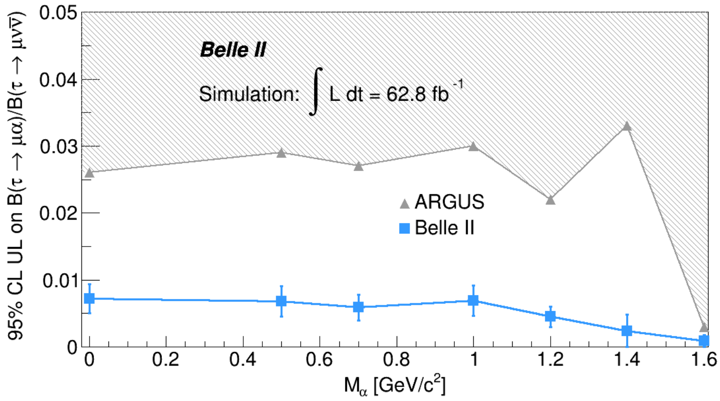
FIG. 3.0.1: Lepton momentum distributions in the τ "pseudo-rest" frame obtained from simulated data. Shown are the contributions from $\tau \to \ell\nu\bar{\nu}$ (signal) decays and the remaining SM background. Distributions of non-standard decays, $\tau \to \ell\alpha$, are also shown for masses $M_\alpha = 0$ and 1.4 GeV$/c^2$, assuming $\mathcal{B}(\tau \to \ell\alpha)/\mathcal{B}(\tau \to \ell\nu\nu) = 0.1$. The Lorentz boost of the lepton to the signal τ rest frame must be approximated, since neither the neutrino (in the tag side) nor the α (in the signal side) can be detected in order to reconstruct completely neither τ: following the ARGUS method, the direction of the signal τ is approximated to the direction of the total momentum of the 3-prong system, $\vec{e}_\tau \approx -\vec{e}_{3h}$, while its energy is fixed to the energy of one electron beam in the center-of-mass frame, $E_\tau = E_{beam}$.

4. UPPER LIMIT ESTIMATION

4.1. Upper limit estimation: no systematic uncertainties included



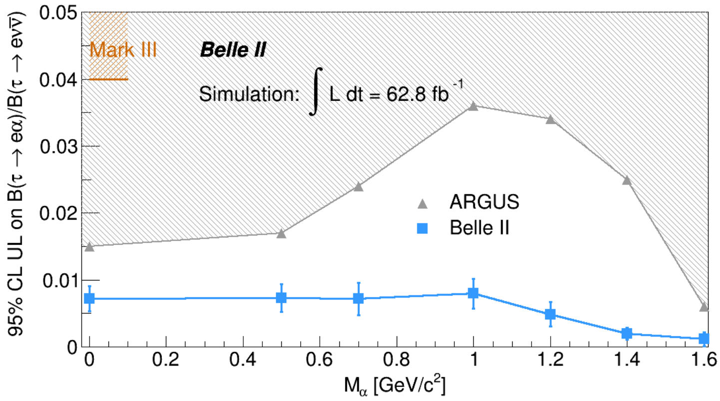
(a) Electron channel.



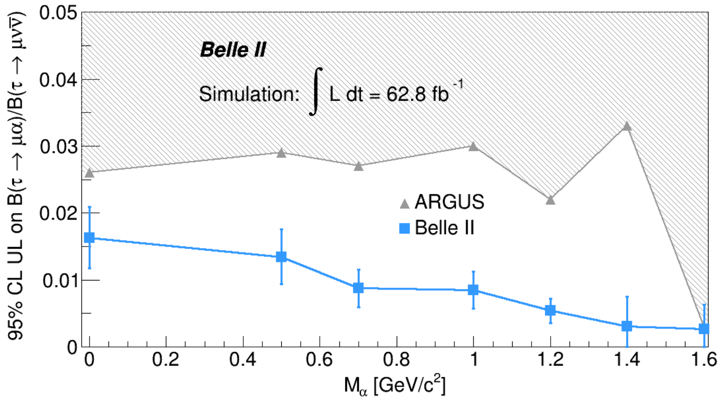
(b) Muon channel.

FIG. 4.1.1: 95% C.L. upper limit estimations for $\mathcal{B}(\tau \to \ell\alpha)/\mathcal{B}(\tau \to \ell\nu\nu)$ using the ARGUS method, assuming 62.8 fb^{-1} of Belle II simulated data. Previous experimental results from the ARGUS [9] and Mark III [10] collaborations are also shown. Belle II estimates are based on an asymptotic implementation of the CL_s technique. No systematic uncertainties are included.

4.2. Upper limit estimation: including dominant systematic uncertainties



(a) Electron channel.



(b) Muon channel.

FIG. 4.2.1: 95% C.L. upper limit estimations for $\mathcal{B}(\tau \to \ell\alpha)/\mathcal{B}(\tau \to \ell\nu\nu)$ using the ARGUS method, assuming 62.8 fb^{-1} of Belle II simulated data. Previous experimental results from the ARGUS [9] and Mark III [10] collaborations are also shown. Belle II estimates are based on an asymptotic implementation of the CL_s technique. Upper limit including dominant systematic uncertainties.

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