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Search for lepton flavor universality violation in leptonic τ decays with 1x1 and 3x1 topologies

The Belle II Collaboration

Abstract

Lepton Flavour Universality (LFU) requires that the three charged lepton couple to the W bosons in the same way. LFU can be tested in τ decays by measuring the following ratios:

$$R_\mu = \frac{\mathcal{B}[\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau]}{\mathcal{B}[\tau^- \to e^- \bar{\nu}_e \nu_\tau]}, \quad R_{h=\pi,K} = \frac{\mathcal{B}[\tau \to h \nu_\tau]}{\mathcal{B}[h \to \mu \nu_\mu]}, \quad R_e = \frac{\mathcal{B}[\tau^- \to e^- \bar{\nu}_e \nu_\tau]}{\mathcal{B}[\mu^- \to e^- \bar{\nu}_e \nu_\mu]} \tag{1}$$

We specifically target the measurement of the ratio R_μ in the 3x1 and 1x1 topologies of τ-pair decays.

For the 3x1 topology a cut-based analysis was developed that outperforms the world-leading BABAR study [1] both in terms of signal efficiency and purity (Fig. 4 and 5). A projection of the statistical uncertainty on R_μ is provided, where we estimate that Belle II can reach the BABAR precision with 108 fb^{-1} of data (Fig. 6). The MC trigger efficiency (Fig.1) and some kinematic distributions (Fig. 2, 3) are also presented.

For the 1x1 topology two different Multivariate (MVA) methods were developed to discriminate between signal and background events: fast Boosted Decision Tree (BDT) and Neural Network (NN). We compare the two MVA methods to the world-leading CLEO study [2] in terms of signal efficiency and purity (Fig. 10, 11). We also investigated the MC trigger efficiency for the 1x1 topology (Fig.7, 8, 9).

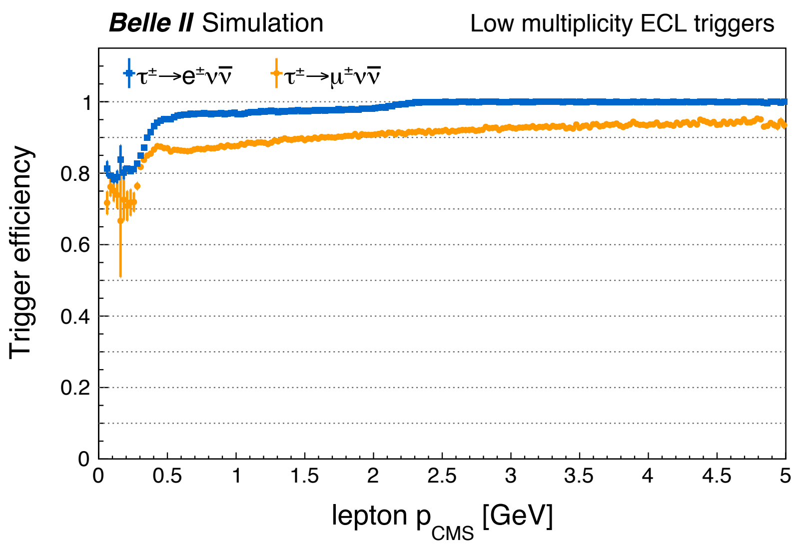

FIG. 1: The trigger efficiency measured in MC for the $\tau^{\pm} \to e^{\pm}\nu\bar{\nu}$ channel (blue) and $\tau^{\pm} \to \mu^{\pm}\nu\bar{\nu}$ channel (orange) as a function of the lepton momentum in the CMS frame. The trigger requirement is the logical OR of low multiplicity ECL bits. Statistical errors are shown.

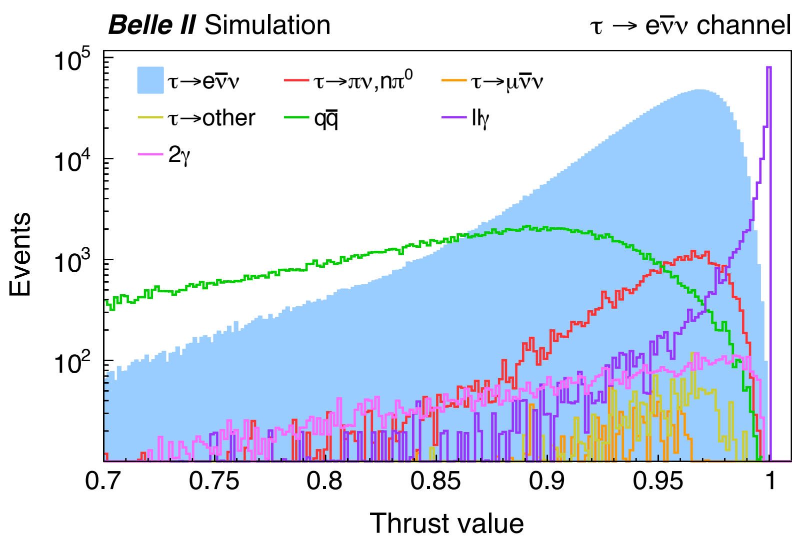

FIG. 2: MC distribution of the thrust value in the $\tau \to e\nu\bar{\nu}$ channel. The signal (filled histogram) is compared to the backgrounds processes (coloured lines). The distribution is shown before the cut on the variable itself.

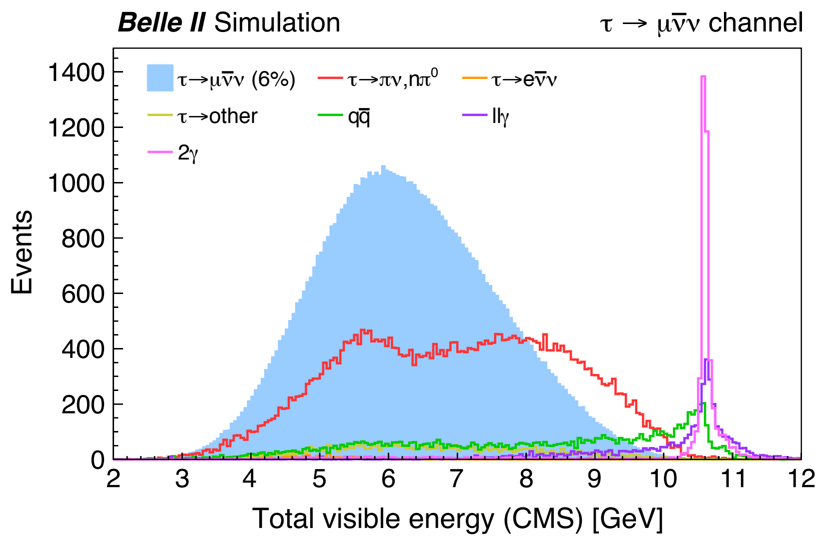

FIG. 3: MC distribution of the total visible energy in the CMS frame in the $\tau \to \mu\nu\bar{\nu}$ channel. The signal (filled histogram) is compared to the backgrounds processes (coloured lines). The signal is scaled by a factor of 0.06 so that the backgrounds are more visible. The distribution is shown before the cut on the variable itself.

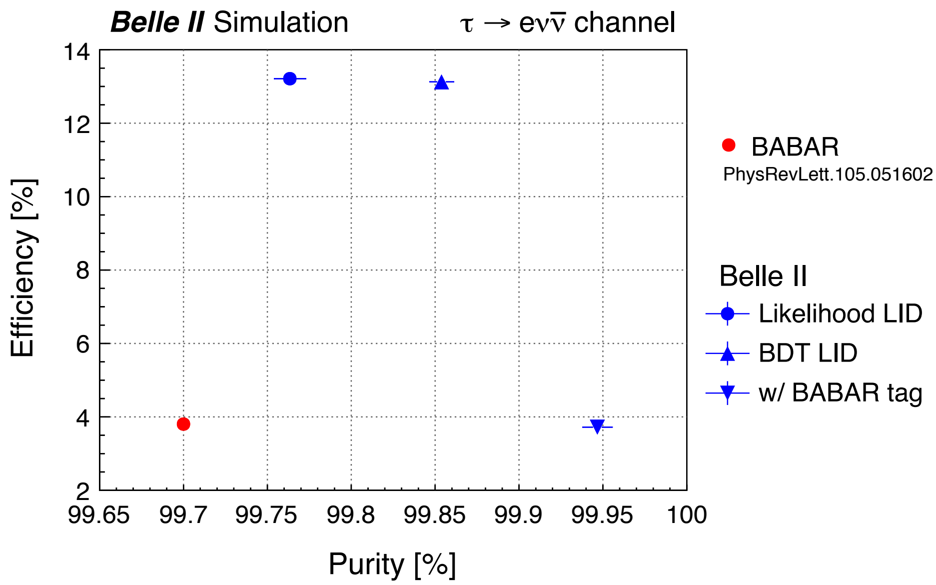

FIG. 4: Efficiency and purity in the $\tau \to e\bar{\nu}\nu$ channel. The red point indicates the achieved performance from the world-leading BABAR measurement [1]. The blue points indicate the expected performance at Belle II with (circle) likelihood electron ID > 0.9, (upward triangle) BDT electron ID > 0.99 and (downward triangle) the BABAR-style tag side selection using pion ID. Statistical uncertainties are shown for the Belle II numbers.

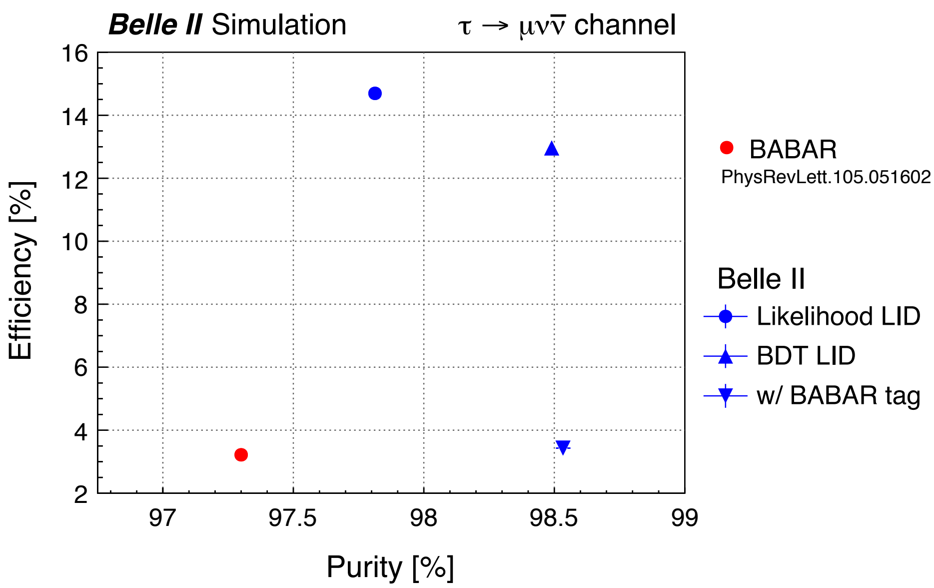

FIG. 5: Efficiency and purity in the $\tau \to \mu\bar{\nu}\nu$ channel. The red point indicates the achieved performance from the world-leading BABAR measurement [1]. The blue points indicate the expected performance at Belle II with (circle) likelihood muon ID > 0.9, (upward triangle) BDT muon ID > 0.9 and (downward triangle) the BABAR-style tag side selection using pion ID. Statistical uncertainties are shown for the Belle II numbers.

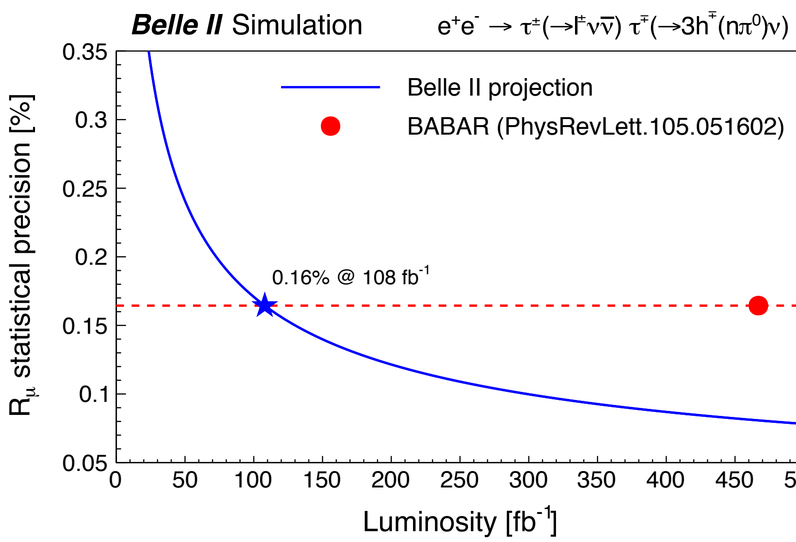

FIG. 6: Projection of the statistical precision on $R_\mu = \mathcal{B}[\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau] \ / \ \mathcal{B}[\tau^- \to e^-\bar{\nu}_e\nu_\tau]$ as a function of recorded luminosity. Belle II (blue curve) is expected to reach the BABAR [1] statistical precision (red circle) with 108 fb^{-1} of data (blue star).

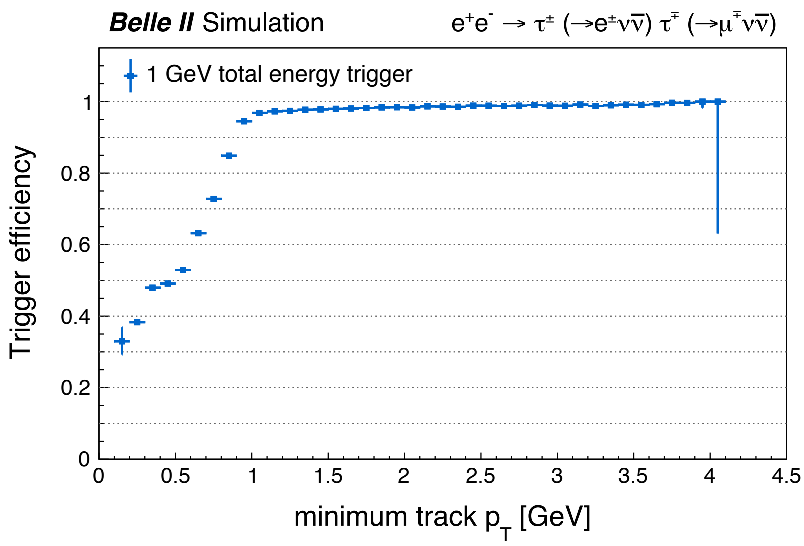

FIG. 7: The trigger efficiency measured in MC for the 1x1 topology in the $e\mu$ channel as a function of the minimum p_T of the two tracks. The 1 GeV total energy threshold ECL trigger is considered. Statistical errors are shown.

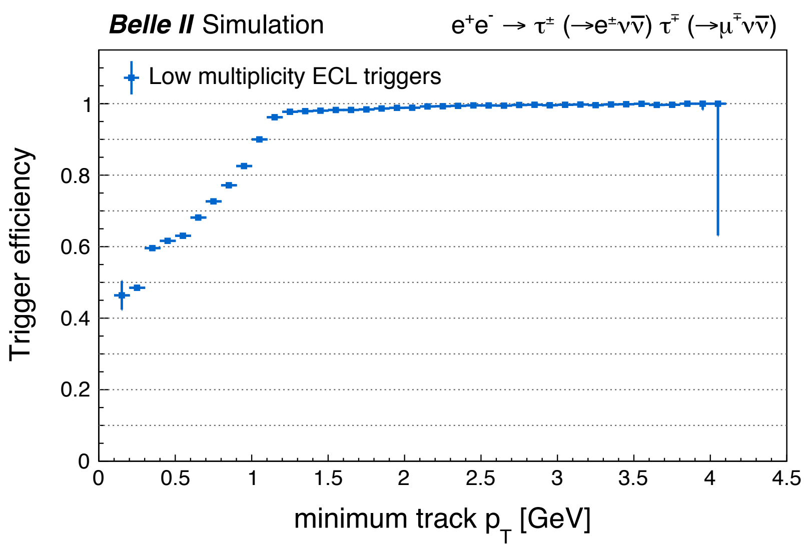

FIG. 8: The trigger efficiency measured in MC for the 1x1 topology in the $e\mu$ channel as a function of the minimum p_T of the two tracks. The trigger requirement is the logical OR of low multiplicity ECL bits. Statistical errors are shown.

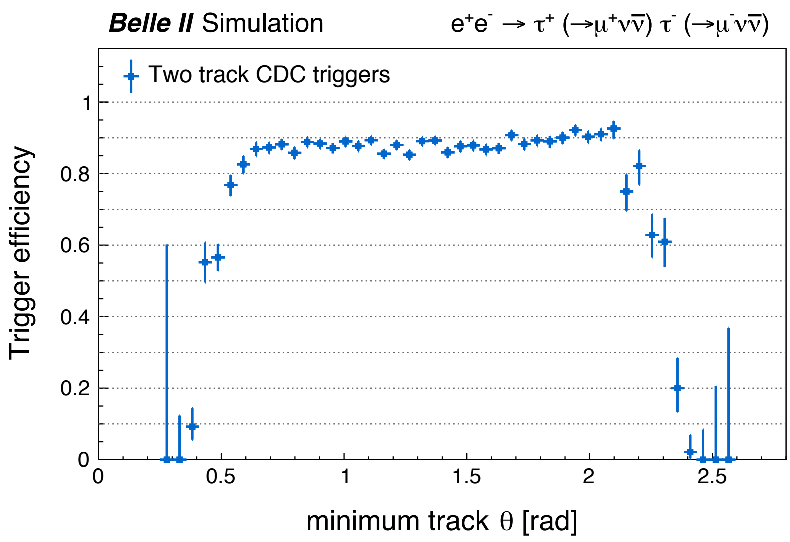

FIG. 9: The trigger efficiency measured in MC for the 1x1 topology in the $\mu\mu$ channel as a function of the polar angle of the track with lowest p_T. The trigger requirement is the logical OR of two track CDC bits. Statistical errors are shown.

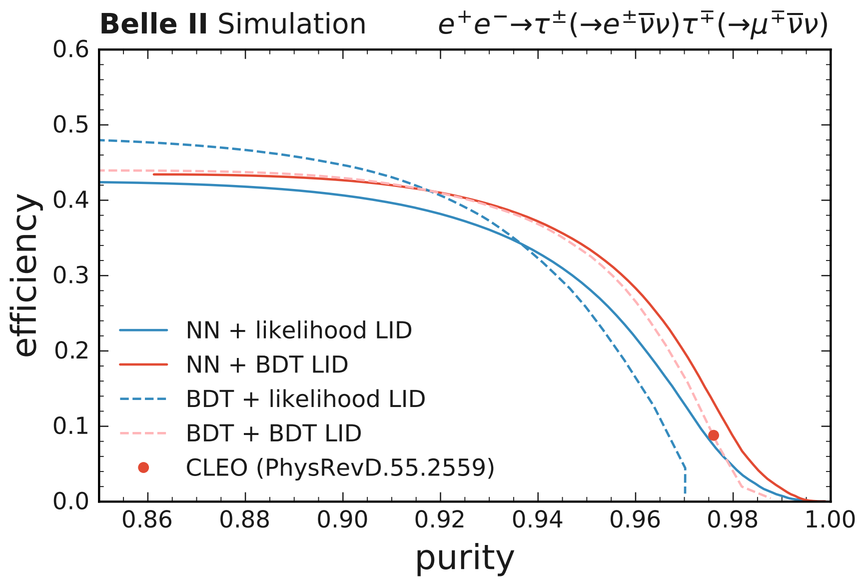

FIG. 10: Efficiency vs purity for the 1x1 τ topology. The NN approach behaves better than fastBDT and the new BDT LID perform better than likelihood LID. Overall, results show that Belle II is capable to almost match CLEO performances in the $e\mu$ case.

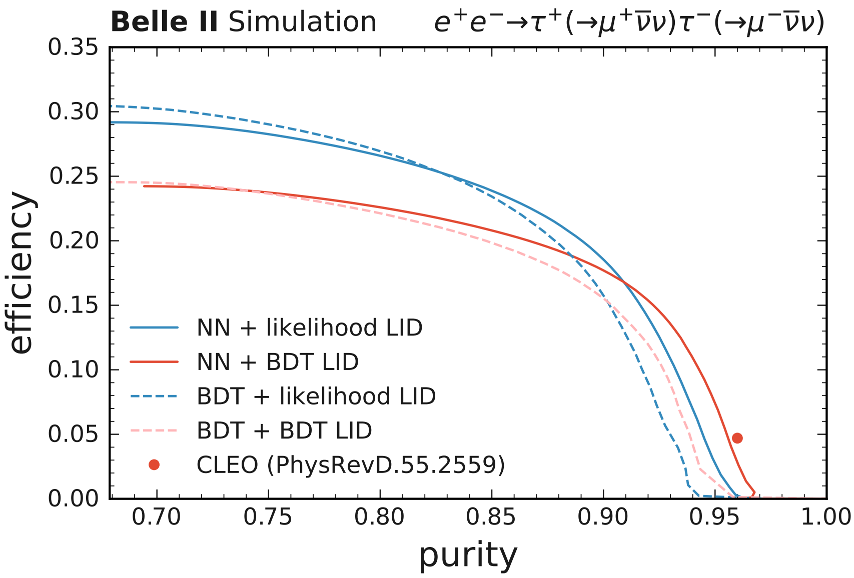

FIG. 11: Efficiency vs purity for the 1x1 τ topology for the $\mu\mu$ case. The NN approach behaves better than fastBDT and the new BDT LID perform better than likelihood LID. Overall, results show that Belle II is capable to almost match CLEO performances in the $\mu\mu$ case.

[1] B. Aubert, Y. Karyotakis, J. P. Lees, V. Poireau, E. Prencipe, X. Prudent, V. Tisserand, J. Garra Tico, E. Grauges, M. Martinelli, and et al., *Measurements of Charged Current Lepton Universality and —Vus— Using Tau Lepton Decays to* $e^-\nu^- e\nu\tau$*,* $\mu^-\nu^-\mu\nu\tau$*,* $\pi^-\nu\tau$*, and* $K^-\nu\tau$, Physical Review Letters **105** (Jul, 2010) . `http://dx.doi.org/10.1103/PhysRevLett.105.051602`.

[2] A. Anastassov et al., CLEO, *Experimental test of lepton universality in tau decay*, Phys. Rev. D **55** (1997) 2559–2576. [Erratum: Phys.Rev.D 58, 119904 (1998)].