# Simulation study for the test of lepton universality in B-decays at Belle


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## Introduction

Recently Belle, BaBar, and LHCb reported on the large deviation of $R(D^{(*)}) = \mathcal{B}(\bar{B} \to D^{(*)}\tau^-\bar{\vartheta}_\tau)/\mathcal{B}(\bar{B} \to D^{(*)}l^-\bar{\vartheta}_l)$, where $l = e$ or $\mu$, from the Standard Model (SM) prediction [1]. In many theoretical attempts to explain this disagreement the new interactions, that can be of different Lorentz structure from $V - A$, are implemented [2].

If the amplitude of the new interaction is proportional to the lepton mass, we can expect that $e$ - $\mu$ lepton non-universality will be also revealed in semileptonic $B$-decays.

In particular, one can expect the difference of $D^{*+}$ polarization in $\bar{B} \to D^{*+}l^-\bar{\vartheta}_l$ ($l = e$ or $\mu$) due to small non-$V - A$ correction to the semimuonic decay. We choose the $D^{*+}$ polarization as a probe for new contribution because the systematic effects of different $\mu$ and $e$ reconstruction and identification efficiencies are cancelled out in each bin of the lepton momentum.

## Methods

We perform the recoil mass method to prove the presence of neutrino. Since lepton efficiency is known with more than 1% uncertainty we have to exclude it from the analysis. Therefore, we compare the $D^{*+}$ polarization in bins of lepton momentum for muons and electrons. To investigate the background and exclude unphysical events we use recoil mass distribution (fig. 1,2):

$$M_{rec}^2 = \left[\frac{E_{beam}}{2} - E_{D^*l}\right]^2 - p_{D^*l}^2$$

Neglecting of the $\bar{B}$-meson momentum results in the smearing of the signal ($\sigma \sim 0.5\ \mathrm{GeV}^2/c^4$).

$D^{*+}$ is reconstructed in the decay chain $D^{*+} \to D^0\pi^+$, followed by $D^0 \to K^-\pi^+$. $\bar{B}$ is partially reconstructed by combining $D^{*+}$ and $l^-$. The cleanest decay channel of $D^0$ is used to reduce background contribution in systematic error. Moreover, to improve the resolution of the invariant mass of $D^0\pi^+_{slow}$ system we use vertex fit and then mass-vertex fit for the $D^0$-meson and refit $\pi^+_{slow}$ in the decay vertex of $D^{*+}$.

## Analysis

Using the Belle sample of generic Monte Carlo (MC) for both charged and neutral $B$-meson production, we studied how to reduce the systematic uncertainty of the measurement and then to estimate its residual.

We studied all possible backgrounds and divided them into three categories: those, obtained from the data, universal backgrounds, and flavour dependent, which can contribute differently to electron and muon samples.

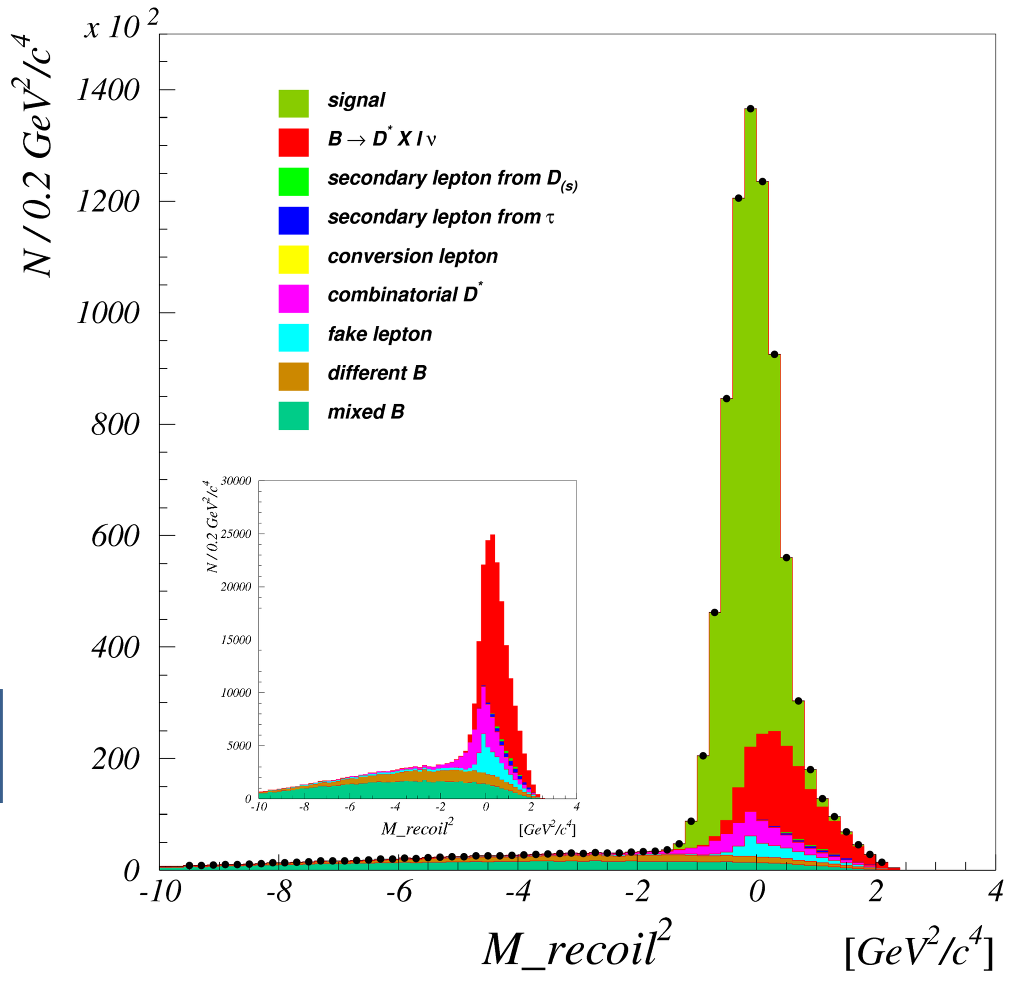


**Figure 1.** Recoil mass distribution for electrons

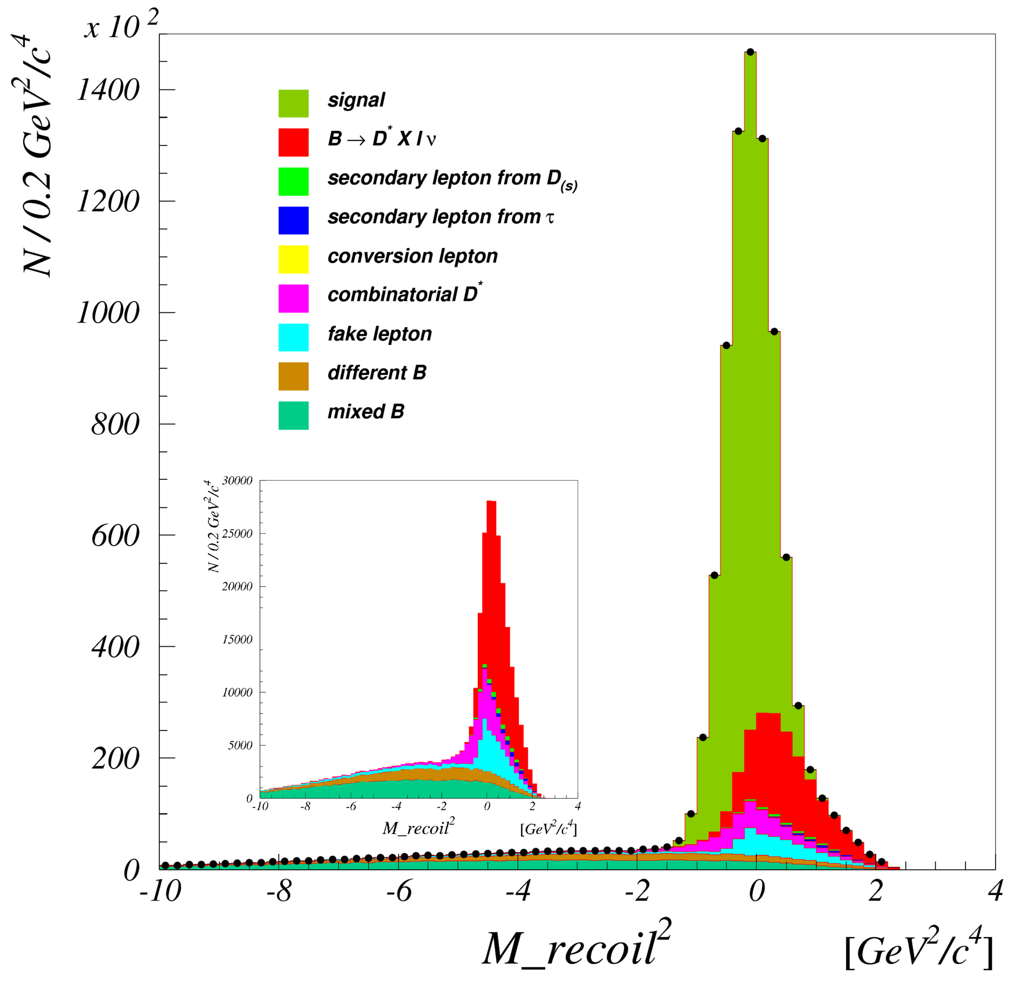


**Figure 2.** Recoil mass distribution for muons

The first type of background includes fake leptons, which could be taken from the data as we know their fake rates respectively to the lepton momentum, continuum, which we obtain from the data, collected under $\Upsilon(4S)$ resonance, and combinatorial $D^{*+}$. To subtract the last one, we fit the $D^0\pi^+$ invariant mass distribution in each bin of the main distributions to obtain the number of the true $D^{*+}$. The shape of the signal is taken from the MC.

The second type consists of uncorrelated background ($D^{*+}$ and $l^-$ come from different $B$-mesons), secondary leptons from $\tau^-$, and $\bar{B}$ semileptonic decays to $D^{**} \to D^*\pi$ or non-resonant $D^*\pi$ final states: $\bar{B} \to D^{*+}Xl^-\bar{\vartheta}_l$. Despite the bad understanding of the last two sources, their contribution is the same for both electrons and muons events.

The last type of backgrounds includes electrons from photon conversion and secondary leptons from $D_{(s)}$. The contribution of both of them is comparatively small.

The slow pion efficiency depends strongly on its momentum, which correlates with the direction of its emission ($\theta_\pi$ angle in the $D^*$ rest frame). This significantly biases the $cos\theta_\pi$ distribution. Therefore, we have to perform the efficiency corrections before $D^{*+}$ polarization fit, as it depends on $cos\theta_\pi$ (fig. 3,4).

## Results and Discussion

The analysis shows us, that lepton non-universal background causes the most systematic errors in the proposed measurement. However, some poorly researched sources of the universal background could also yield to the $D^{*+}$ polarization uncertainty. Especially due to their high contribution at the signal area in recoil mass and lepton momentum distribution.

To reduce systematic errors level we use very stringent selection criteria. Thus, we have a very pure signal at the expense of slightly lower signal efficiency. In the present study the systematics uncertainty dominates over the statistical error, thus our strategy is justified.

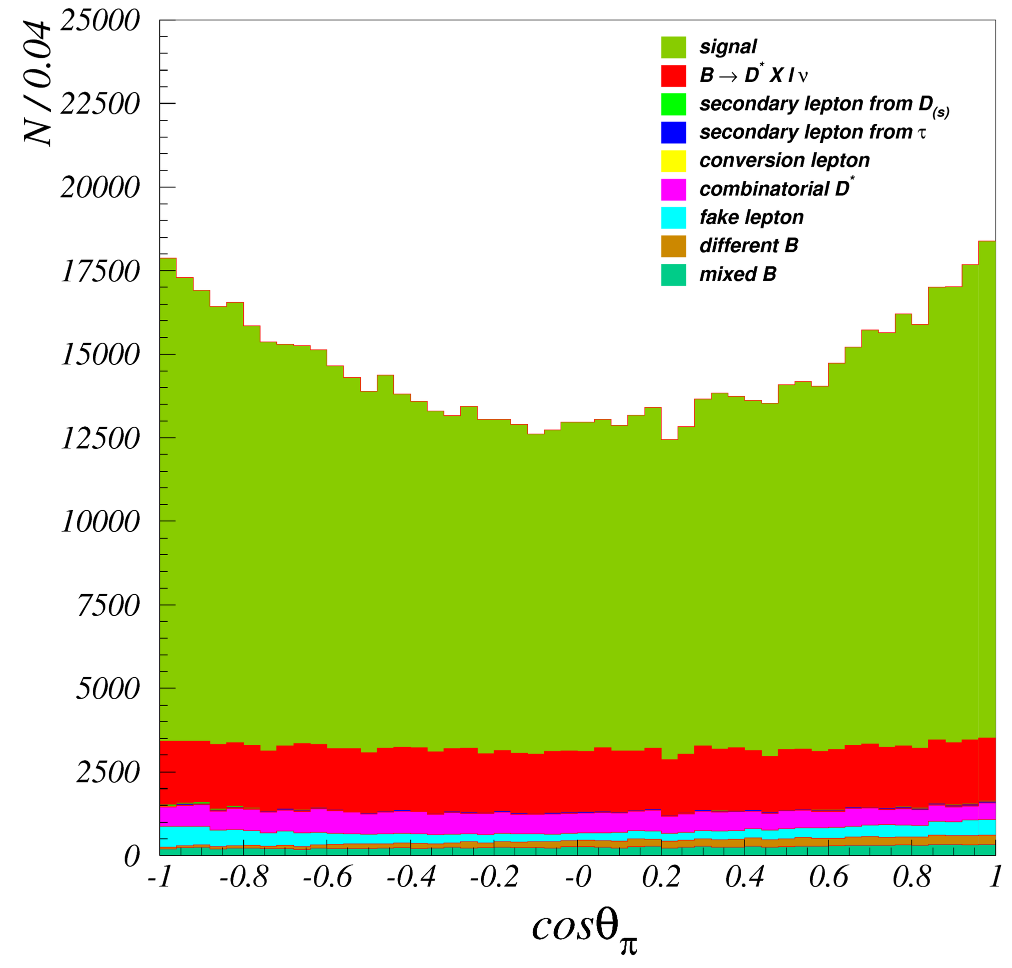


**Figure 3.** $cos\theta_\pi$ distribution for electrons

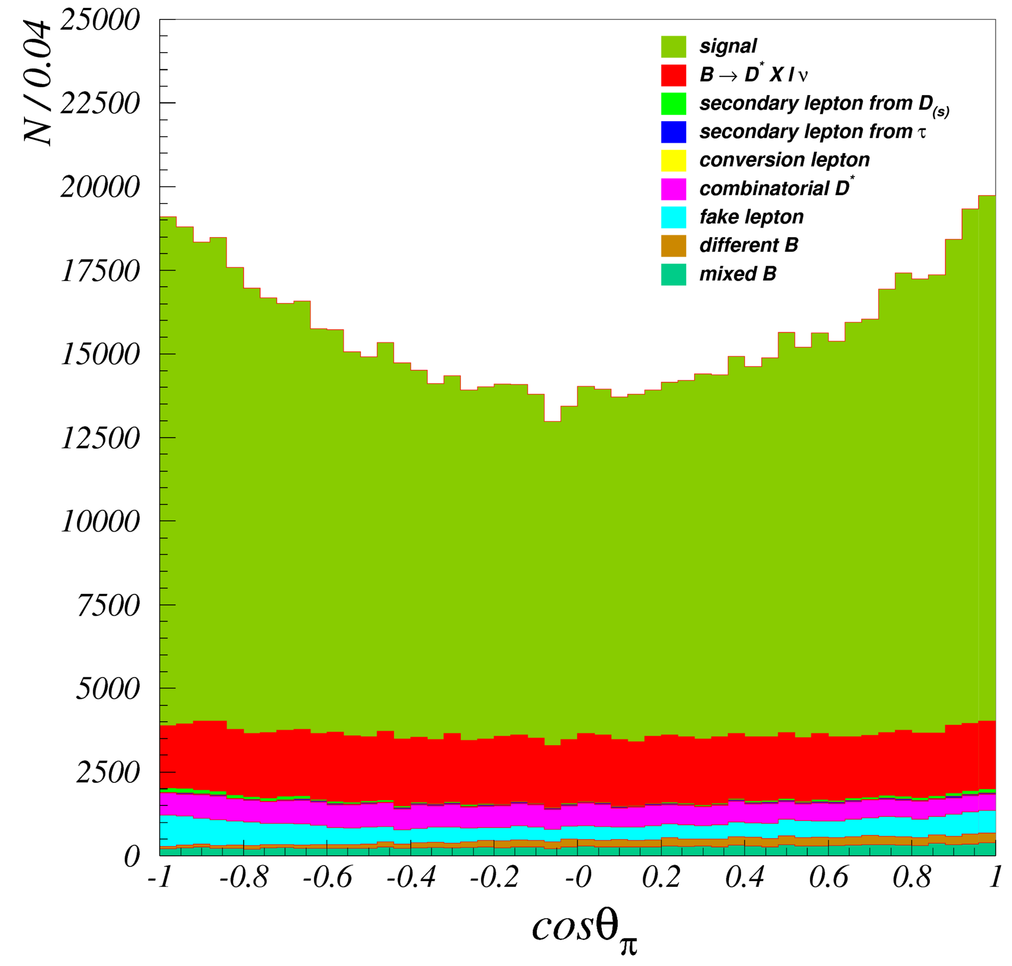


**Figure 4.** $cos\theta_\pi$ distribution for muons

## Conclusions

Based on that MC analysis we conclude that it is possible to perform such measurement using full data sample collected by Belle detector [3] (fig. 5,6).

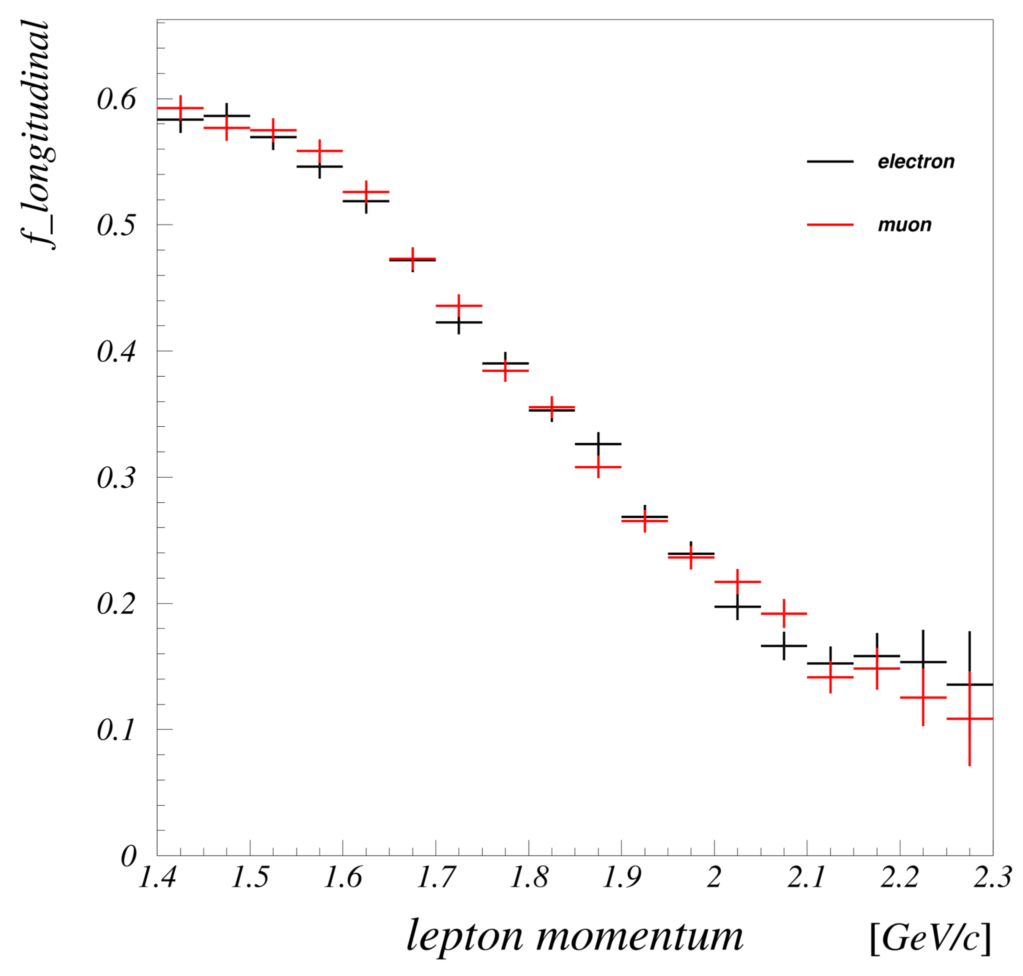


**Figure 5.** Expected longitudinal polarization versus lepton momentum

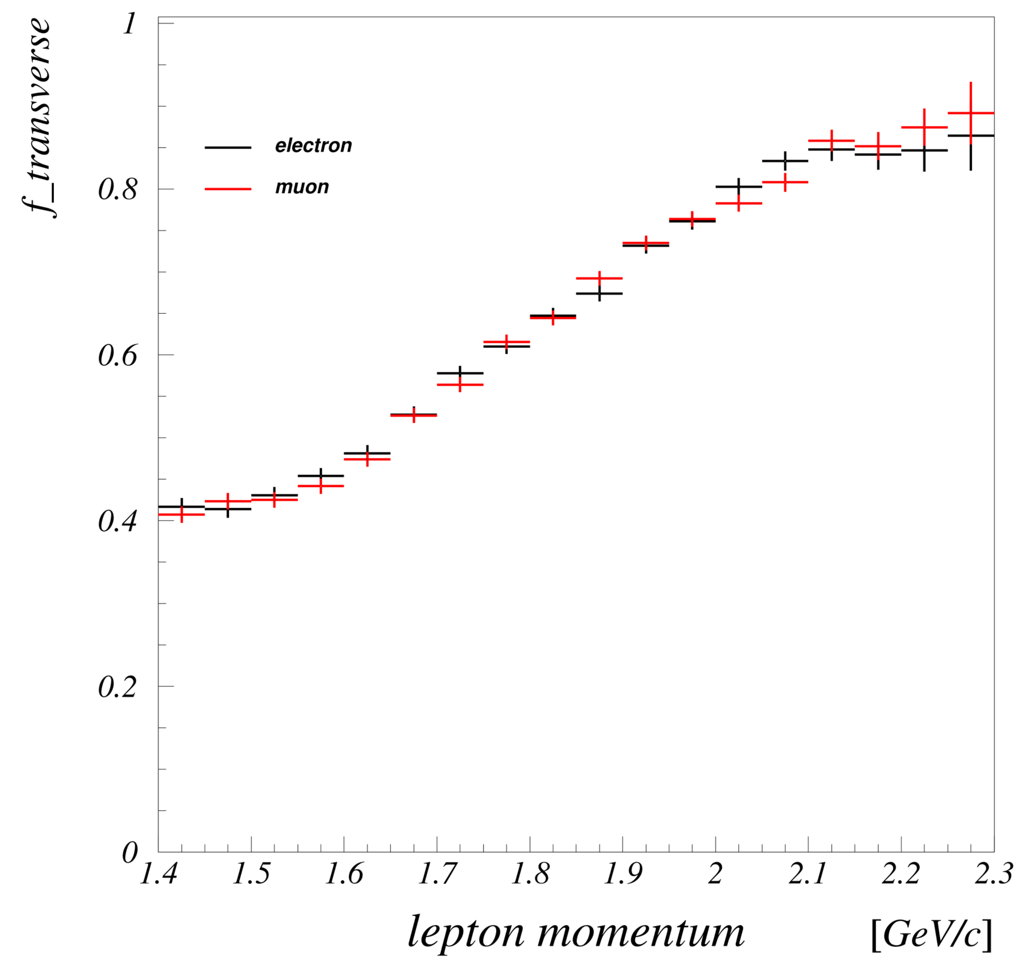


**Figure 6.** Expected transverse polarization versus lepton momentum

Optimization of the selection criteria is still under the study. In the future other $D^0$ decay modes can be used to increase statistics.

After testing the method with Belle data, we plan to continue an even more accurate study on Belle II.

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