Searching for lepton flavour violation at Belle and Belle II

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The search for $\tau \to \ell\gamma$ - a story of magnitudes

Lepton flavour violation (LFV) is predicted to appear in a wide variety of New Physics (NP) models. Of the τ processes, the decays $\tau \to \ell\gamma$ ($\ell = \mu, e$) are predicted to be the dominant decay modes in a range of these models. The decay rates for these processes in the Standard Model (SM) are predicted to be unobservably low despite the existence of neutrino oscillation. Observation of LFV processes of this type would be an unambiguous signature of NP.

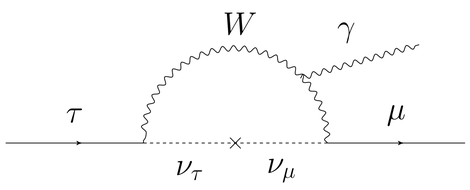


Figure 1: $\tau \to \mu\gamma$ via neutrino mixing

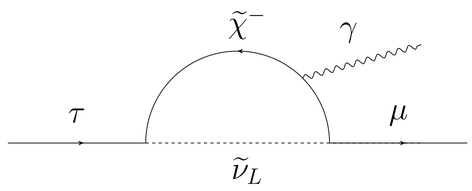


Figure 2: $\tau \to \mu\gamma$ via a SUSY process

No past search for $\tau \to \ell\gamma$ has found an LFV signal; however upper limits on branching fractions have been established. The most recent search by Belle[1] in 2008 over 535 fb^{-1} of data determined

$$\Gamma_{\tau\to e\gamma} < 12.0 \cdot 10^{-8} \quad \text{and} \quad \Gamma_{\tau\to\mu\gamma} < 4.5 \cdot 10^{-8}.$$

A 2010 paper[2] using the entire BaBar data set of 515.5 fb^{-1} improved on these limits:

$$\Gamma_{\tau\to e\gamma} < 3.3 \cdot 10^{-8} \quad \text{and} \quad \Gamma_{\tau\to\mu\gamma} < 4.4 \cdot 10^{-8}.$$

Project outline

Following from previous analyses by the Belle and BaBar collaborations, this work will search for $\tau \to \ell\gamma$ using the complete Belle tau data set, with comprises decays $e^+e^- \to \tau^+\tau^-$, and sets up an environment for performing the search over Belle II data. Unlike most previous Belle analyses, this analysis will be performed using the Belle II analysis software framework (`basf2`). This framework is more powerful and user-friendly than `BASF`, and poses unique problems such as reading Belle data formatted for the Belle analysis software framework (`BASF`), and reducing the remotely stored data set to a manageable amount prior to analysis.

In searching for $\tau \to \mu\gamma$, which constitutes the initial search of the project, we use a range of selection criteria to discriminate signal from background; these initial selection variables have been chosen based on the 2008 Belle search[1] and will be refined through analysis of signal and background Monte Carlo (MC).

Variable	**Value/Range**	**Description**
p_μ^{CM}	< 4.5 GeV/c	Momentum of muon in CM frame
p_{sum}^{CM}	< 9.0 GeV/c	CM momentum of system (tracks + signal γ)
$p_{t,\mu}$	> 0.1 GeV/c	Transverse momentum of muon
p_μ	> 1.0 GeV/c	Momentum of muon
E_γ	> 0.5 GeV	Energy of signal γ
$\cos\theta_\gamma^{\mathrm{CM}}$	$0.4 < \cos\theta < 0.8$	Cosine of polar angle of signal photon
No. of tracks	$= 2$ or 4	-

The dominant backgrounds are $\tau^+\tau^-$ events with the decay $\tau^\pm \to \mu^\pm\nu_\tau\nu_\mu$ or $\tau \to \pi\nu_\tau$ (wherein the pion is misidentified as a muon and combined with a photon from beam background or ISR); radiative $e^+e^- \to \mu^+\mu^-$ also comprise some of the background sources.

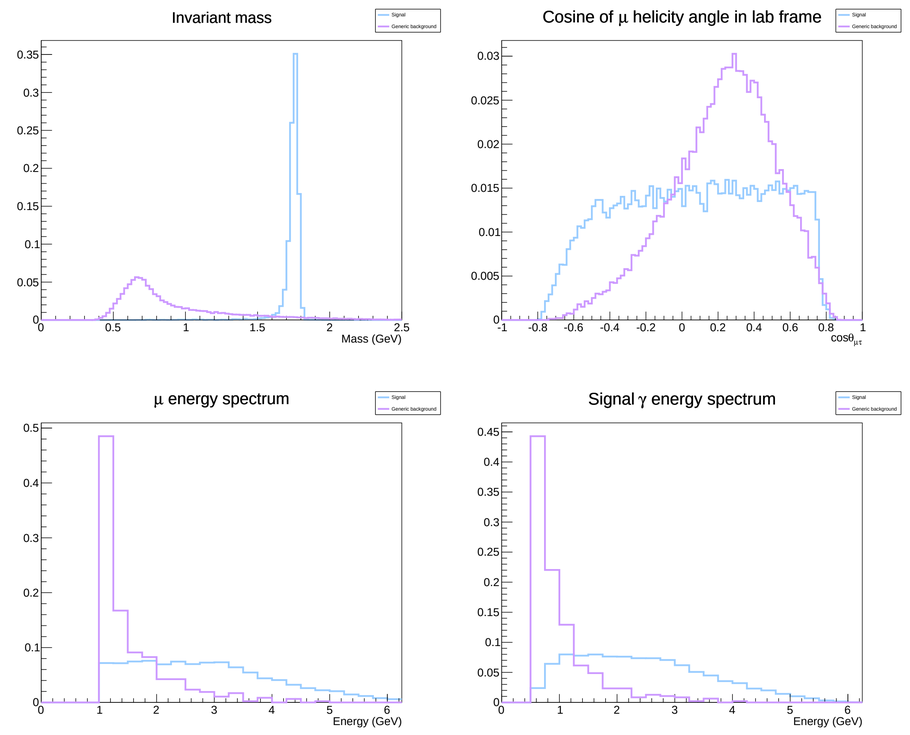
References

[1] K. Hayasaka et al. New search for $\tau \to \mu\gamma$ and $\tau \to e\gamma$ decays at Belle. *Phys. Lett.*, B666:16-22, 2008.

[2] B. Aubert et al. Searches for Lepton Flavor Violation in the Decays $\tau^\pm \to e^\pm\gamma$ and $\tau^\pm \to \mu^\pm\gamma$. *Phys. Rev. Lett.*, 104:021802, 2010.

Signal and background comparisons (MC)

To determine which selection criteria cuts are to be applied to data to best discern signal from background, we perform our analysis over signal and background MC. The current signal MC is produced using the `KK` generator implemented through `basf2`, where we generate $e^+e^- \to \tau^+\tau^-$ with one τ decaying to $\mu\gamma$ and the other (tag side) decaying generically. The background MC is Belle II Monte Carlo comprising generically decaying tau pairs.



Overlayed normalised plots of signal and background MC after cuts are shown above for several variables: the invariant mass of signal side track and photon, the cosine of the muon helicity angle, and the muon and signal photon energy spectra.

Belle and Belle II

The Belle experiment is an international collaboration based in KEK in Japan, which ran from 1999-2010 and collected 1 ab^{-1} of data using the KEKB particle accelerator. The Belle II experiment will use an upgraded accelerator, SuperKEKB, capable of two orders of magnitude more luminosity. More information about the detector and the experiment is available on nearby posters.

Currently only Belle data is available; the analysis is designed to be easily run over Belle II data once it becomes available. The Belle experiment is more suited to the search for LFV in the tau-sector than LHC experiments for several reasons. Chiefly, the number of taus produced at Belle (and in the future Belle II) is far greater than that at comparable LHC experiments. The events are clean, with very little background. Further, Belle can reconstruct neutrals very well, and the trigger is highly efficient for τ decays.

Future progress

Additional variables need to be tracked so that more selection criteria can be applied.
To access the tau data set, we must use the `b2bii` convertor module (Belle to Belle II), a recent addition to `basf2`. Further, we must apply a specialised skim to reduce the data set to a manageable amount prior to analysis. Data mining techniques will be employed to maximise background rejection.

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