Search for the LFV-Decay $\tau \rightarrow \mu \pi^0$

18.03.2021 DPG-spring-conference

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• e-e+-Accelerator at $\Upsilon$ (4S)-resonance (10.6 GeV)

• Pair-Production of B-Mesons

• Also ideal environment for $\tau$-Pair-Production

→ low background, distinct signal from B-events

https://belle2.desy.de/
https://www.cityofirvine.org/multicultural-and-international-affairs/tsukuba-japan
New single-track trigger at Belle2

- Greatly improved triggering on single-tracks
- 1-1-Topologies measurements possible
- Improvement in signal-data

Tau-decay modes:

\[ \tau \rightarrow \ell \nu \ell \nu_T \] 40% \[ \tau \rightarrow q\bar{q}' \nu_T \] 60%

\[ \begin{array}{c}
1-\text{Prong} \\
40% \\
45% \\
15%
\end{array} \]

\[ \begin{array}{c}
3-\text{Prong} \\
40%
\end{array} \]

Petar Rados, Ami Rostomyan (DESY): Analysis of tau events in the runs 1973-1987

Marton Nemeth-Csoka
Current state of LFV tau-decays

Due to Single-Track-Trigger 1-Prongonly $\frac{1}{5}$ of the luminosity needed

<table>
<thead>
<tr>
<th>Observables</th>
<th>Belle (2014)</th>
<th>Belle II</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Br}(\tau \rightarrow \mu \nu)$ [10^{-9}]</td>
<td>$&lt; 45$</td>
<td>$&lt; 15$</td>
</tr>
<tr>
<td>$\text{Br}(\tau \rightarrow e \nu)$ [10^{-9}]</td>
<td>$&lt; 120$</td>
<td>$&lt; 39$</td>
</tr>
<tr>
<td>$\text{Br}(\tau \rightarrow \mu \mu \nu)$ [10^{-9}]</td>
<td>$&lt; 21$</td>
<td>$&lt; 3$</td>
</tr>
<tr>
<td>$\text{Br}(\tau \rightarrow e e e)$ [10^{-9}]</td>
<td>$&lt; 27$</td>
<td>$&lt; 4$</td>
</tr>
<tr>
<td>$\text{Br}(\tau \rightarrow e K K)^{0}$ [10^{-9}]</td>
<td>$&lt; 33$</td>
<td>$&lt; 6$</td>
</tr>
<tr>
<td>$\text{Br}(\tau \rightarrow \mu \pi^{0})$ [10^{-9}]</td>
<td>$&lt; 120$</td>
<td>$&lt; 34$</td>
</tr>
<tr>
<td>$\left</td>
<td>\Im(\eta_{i})(\tau \rightarrow K_{S}^{0} \pi \nu)\right</td>
<td>$</td>
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Integrated Luminosity

<table>
<thead>
<tr>
<th></th>
<th>Belle</th>
<th>Belle2 (8.3.2021)</th>
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<tbody>
<tr>
<td></td>
<td>710 fb^{-1}</td>
<td>94.48 fb^{-1}</td>
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LFV-Decay $\tau \rightarrow \mu \pi^0$

- LFV-decay with no loops at tree-level
- All final state particles are measurable
- 2-body decay
  $\rightarrow$ in tau rest system Pion and Muon have same total momentum
- tau rest system can be estimated directly from decay products (no neutrino)
## Expected challenges

### Analysis of 1-1 and 1-3 topologies:

<table>
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<th>Possible approaches</th>
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<tbody>
<tr>
<td>• First $\pi^0$ has to be reconstructed via $\pi^0 \rightarrow \gamma\gamma$ → Cut on invariant $\pi^0$-mass</td>
</tr>
<tr>
<td>• BB-background → Cut with event shape variables e.g. thrust</td>
</tr>
<tr>
<td>• generic tau and qq background → explicit reconstruction</td>
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</tbody>
</table>
First look, $\pi^0$-reconstruction

generated 10 000 MC-sample with decay:

\[ e^+ e^- \rightarrow [\tau^- \rightarrow \mu \pi^0][\tau^+ \rightarrow \text{generic}] \]

Used recommended eff60 $\pi^0$-cuts:

Fill gammas:

- $[\text{clusterNHits}>1.5]$ and $[0.2967<\text{clusterTheta}<2.6180]$]

and

- $[\text{clusterReg}=1 \text{ and } E>0.0225]$ or $[\text{clusterReg}=2 \text{ and } E>0.020]$ or $[\text{clusterReg}=3 \text{ and } E>0.020]$]

then $\pi^0 \rightarrow \gamma\gamma$ with $0.03<\text{InvM}$
First look, tau-reconstruction

→ Sharp signal peak visible

→ ~60% of signal can be reconstructed

new single-track trigger

on tag-side: 1-prongs and 3-prongs

→ high statistics
Cut on $[\pi^0 \rightarrow \gamma\gamma]$-invariant mass (MC)

$3\sigma$-Cut: $0.1137 \text{ GeV} < \text{invM}(\pi^0) < 0.1503 \text{ GeV}$
Cut on $[\pi^0 \rightarrow \gamma\gamma]$-invariant mass (MC)

3σ-Cut: $0.1137 \text{ GeV} < \text{invM}(\pi^0) < 0.1503 \text{ GeV}$
Cut on $[\tau \rightarrow \mu \pi]$-invariant mass (MC)

$3\sigma$-Cut: $1.7268 \text{ GeV} < \text{invM}(\tau \rightarrow \mu \pi^0) < 1.8448 \text{ GeV}$

→ 50% of signal can be reconstructed

→ almost all data is from signal
Cut on $[\tau \rightarrow \mu\pi]-\text{invM}$ on generic tau-BG

$3\sigma$-Cut: $1.7268 \text{ GeV} < \text{invM}(\tau \rightarrow \mu\pi^0) < 1.8448 \text{ GeV}$

- Background is cut by *%

*MC-Data with background, before and after invM-Cuts*
Cut on Event-Shape: Thrust

- Taus have high momentum
- Thrust ≠ 1 because of neutrinos

→ Low-momentum B-Mesons can be eliminated by Thrust-Cut
Summary: LFV decay $\tau \rightarrow \mu \pi^0$

- Increased data due to single-track-trigger with 1-1-topology
- 2-body-decay with fully reconstructed final state
- BB-, qq-background
- Cuts on invariant Mass, Thrust