Search for lepton-flavor, lepton- and baryon-number violating tau decays at Belle

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Outline

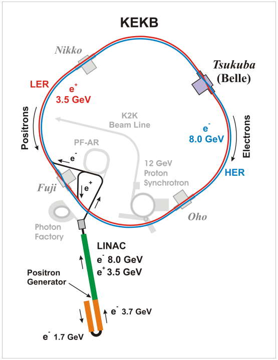
Lepton-flavor, lepton- and baryon-number violating tau decays

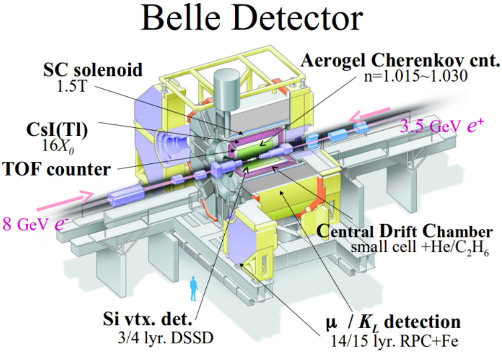
- Search for $\tau \to p\ell\ell'$ ($\ell^{(\prime)} = \mu, e$) decays [NEW] Belle preliminary

- KEKB and Belle detector
- Introduction
- Selection criteria
- Sideband study
- Expected background
- Results in data
- Summary

KEKB and Belle detector

- KEKB: Mostly e^+ (3.5 GeV) and e^- (8 GeV) mostly collide at center-of-mass energy 10.58 GeV.
- $\sigma(bb) \sim 1.1\mathrm{nb}$ and $\sigma(\tau\tau) \sim 0.9\mathrm{nb}$: So a B factory as well as τ factory.

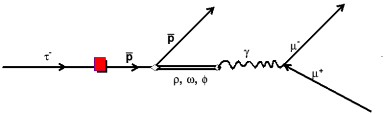




- Collected close to $1\mathrm{ab}^{-1}$ data at different resonances and off-resonances.

Introduction

- Sakharov formulated three conditions to explain matter-antimatter asymmetry in the universe [JETP Lett. 5, 24-27, 1967]
  1. Baryon number violation 2. C-symmetry and CP-symmetry violation 3. Interaction out of thermal equilibrium
- Searching for six decay channels $\tau^- \to p\mu^-\mu^-$, $\bar{p}\mu^+\mu^-$, pe^-e^- , $\bar{p}e^+e^-$, $\bar{p}e^+\mu^-$ and $\bar{p}e^-\mu^+$ using the data recorded by Belle
- Any observation of lepton flavor, lepton and baryon number violation would be a clear sign for new physics
- A diagram for $\tau^- \to \bar{p}\mu^+\mu^-$ possible in a new physics scenario proposed by Fuentes-Martin et al. [JHEP 1501,134 (2015)], shown in right

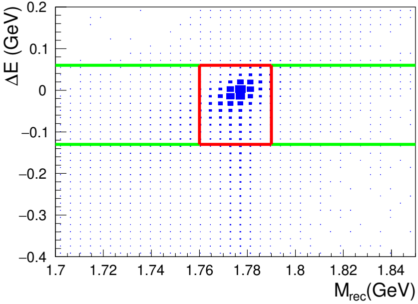


- LHCb set $\mathcal{B}(\tau^- \to p\mu^-\mu^-) < 4.4 \times 10^{-7}$ and $\mathcal{B}(\tau^- \to \bar{p}\mu^+\mu^-) < 3.3 \times 10^{-7}$ at 90% confidence level using 1 fb^{-1} pp collision data [Phys. Lett. B 724 (2013)]

- $711\,\mathrm{fb}^{-1}$ ($89.4\,\mathrm{fb}^{-1}$) data recorded at ($60\,\mathrm{MeV}$ below) the $\Upsilon(4S)$ resonance and a sample of $121\,\mathrm{fb}^{-1}$ collected near the $\Upsilon(5S)$ peak are used in the analysis.

We reconstruct $\tau \to p\ell\ell'$ ($\ell^{(')} = \mu,\, e$)

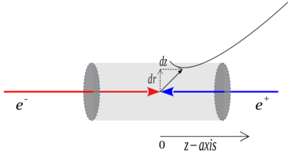
- Variables to identify signal:
  $M_{\rm rec} = \sqrt{E^2_{p\ell\ell'} - \vec{p}^{\,2}_{p\ell\ell'}}$,
  $\Delta E = E^{\rm CM}_{p\ell\ell'} - E^{\rm CM}_{\rm beam}$
- Red box denotes the signal region.
- The sideband is the ΔE–$M_{\rm rec}$ region outside the red box; we use it to check the overall data - MC agreement for different variables.
- The ΔE strip, indicated by the region between two green lines excluding the red box is used to calculate the expected background yield in the signal region.



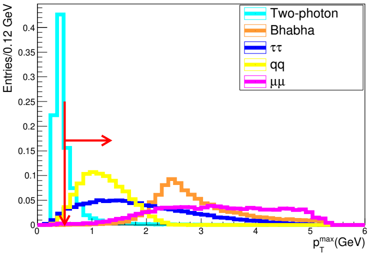
ΔE-$M_{\rm rec}$ distribution for $\tau^- \to \bar{p}e^-e^+$ in signal MC

Preliminary selections

- Select events with $17^\circ < \theta < 150^\circ$, where θ is the polar angle relative to the z axis.
- Impact parameters: $|dr| < 0.5$ cm and $|dz| < 3$ cm
- Transverse momentum $p_{\mathrm{T}} > 0.1$ GeV and energy of γ, $E_\gamma > 0.1$ GeV
- Sum of charge : $|q_{sum}| = 0$
- Maximum p_T of charged track, $p_T^{\max} > 0.5$ GeV
- $E_{\mathrm{rec}} > 3$ GeV or $p_T^{\max} > 1$ GeV where $E_{\mathrm{rec}} =$ sum of momentum of all charged tracks and energy of all photons in CM frame.
- For two-track events: $E_{\mathrm{ECL}} < 11$ GeV & $5^\circ < \theta_{\mathrm{miss}} < 175^\circ$
- For 2-4 track events: $E_{\mathrm{tot}} < 9$ GeV or $\theta^{\max} < 175$ degree or $2 < E_{\mathrm{ECL}} < 10$ GeV
  where $E_{\mathrm{tot}} = E_{\mathrm{rec}} + p_{\mathrm{miss}}^{\mathrm{CM}}$, E_{ECL} is the sum of energy deposited in the ECL



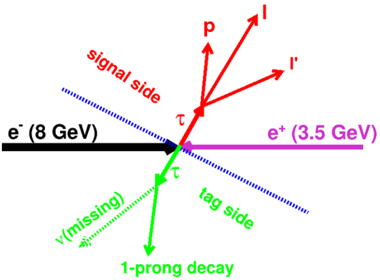
$|dr| < 0.5$ cm and $|dz| < 3.0$ cm



$p_T^{\max} > 0.5$ GeV

Additional selections

- 3-1 event topolgy is used to select the $\tau\tau$ events.
- Protons are identified with P$(p/K) > 0.6$ and P$(p/\pi) > 0.6$.
- We apply eID > 0.9 and μID > 0.9 to select the electron and muon candidates.
- eID$(p) < 0.9$ to suppress electron misidentification.

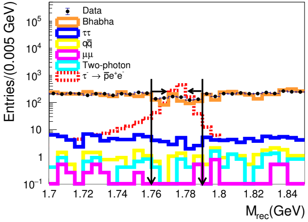


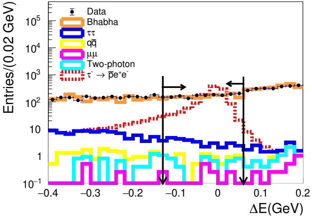
- In addition, thrust>0.9, $\cos\theta^{\mathrm{CM}}_{\mathrm{tag-miss}} > 0$ and $5 < \theta_{\mathrm{miss}} < 175$ degree are applied for all the channels.
- For $\tau^- \to \overline{p}e^-e^+$, $\tau^- \to pe^-e^-$, $\tau^- \to \overline{p}e^+\mu^-$ and $\tau^- \to p\mu^-\mu^-$ channels, gamma conversion veto >0.2 GeV (on oppositely-charged track pairs assuming electron mass hypothesis) applied.
- In addition $E_{\mathrm{ECL}} < 10$ GeV applied for $\tau^- \to \overline{p}e^-e^+$, $\tau^- \to pe^-e^-$ channels to reject the remaining two-photon and radiative Bhabha backgrounds.

Sideband study

- Sideband shape is shown in the case of $\tau^- \to \overline{p}e^+e^-$ channel without conversion veto.

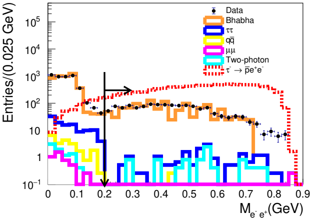
Belle preliminary

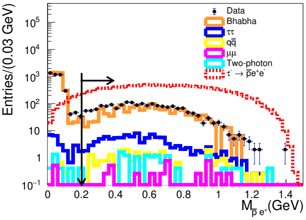




$M_{\rm rec}$ sideband

ΔE sideband



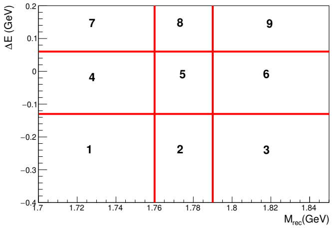


$M_{e^-e^+}$

$M_{\overline{p}e^+}$

- $M_{e^-e^+}$ and $M_{\overline{p}e^+}$ are obtained assuming electron mass hypothesis.

Expected background in signal region



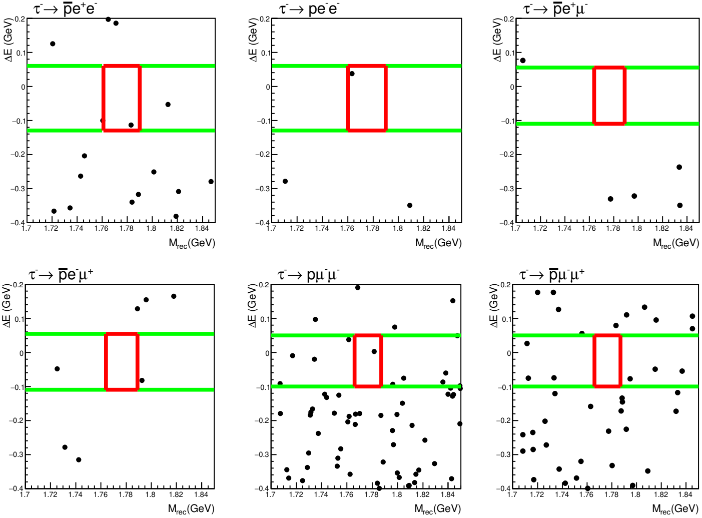
Division of region to predict the expected background

- We estimate the expected number of backgrounds in the signal region from the sideband assuming background events are distributed uniformly in regions 4 and 6 (ΔE strip).
- Background event density $= \dfrac{N_{\text{strip}}}{\text{Area}}$
  where N_{strip} is the number of events observed in regions 4 and 6.
- The event density is then multiplied by the area of signal blind (region 5) to determine the number of events expected in the signal region.
- The method is first verified in MC then applied to data.
- The uniformity in region 4 and 6 is checked without applying proton ID.

Results

- Number of observed events are consistent with the background prediction.

Belle preliminary



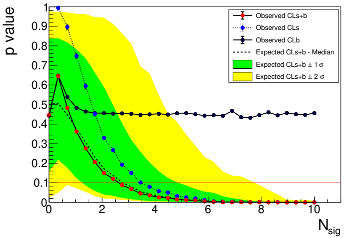
Limits

- Upper limit (UL) on the signal yield is set using the Feldman-Cousins [G. J. Feldman and R. D. Cousins, Phys. Rev. D 57, 3873 (1998)] method.
- For $\tau^- \to p\mu^-\mu^-$:
  No event in the signal region
  Expected background in the signal region $= 1.30 \pm 0.46$
  UL on the signal yield $= 2.6$ at 90% CL.
- Upper limit on

  $$\mathcal{B}(\tau^- \to \overline{p}e^-\mu^+) < \frac{N_{\rm sig}^{\rm UL}}{2N_{\tau\tau}\epsilon},$$

  $N_{\tau\tau} = 841 \times 10^6$ $\tau\tau$ pairs , $\epsilon = 4.6\%$, signal efficiency

  $< 3.4 \times 10^{-8}$ at 90% CL.



Scan result for upperlimit,

$\tau^- \to \overline{p}e^-\mu^+$

All channels	$\epsilon\,(\%)$	$N_{\rm BG}$	$N_{\rm obs}$	$N_{\rm sig}^{\rm UL}$	$\mathcal{B}\,(\times 10^{-8})$
$\tau^- \to \overline{p}e^+e^-$	7.8	0.50 ± 0.35	1	3.2	< 2.4
$\tau^- \to pe^-e^-$	8.0	0.23 ± 0.07	1	3.6	< 2.7
$\tau^- \to \overline{p}e^+\mu^-$	6.5	0.22 ± 0.06	0	1.8	< 1.6
$\tau^- \to \overline{p}e^-\mu^+$	6.9	0.40 ± 0.28	0	2.0	< 1.7
$\tau^- \to p\mu^-\mu^-$	4.6	1.30 ± 0.46	1	2.6	< 3.4
$\tau^- \to \overline{p}\mu^-\mu^+$	5.0	1.14 ± 0.43	0	1.5	< 1.8

Summary

- LHCb set $\mathcal{B}(\tau^- \to p\mu^-\mu^-) < 4.4 \times 10^{-7}$ and $\mathcal{B}(\tau^- \to \overline{p}\mu^+\mu^-) < 3.3 \times 10^{-7}$ at 90% CL using 1 fb^{-1} pp collision data.
- Our limit for $\mathcal{B}(\tau^- \to p\mu^-\mu^-) < 3.4 \times 10^{-8}$ and $\mathcal{B}(\tau^- \to \overline{p}\mu^-\mu^+) < 1.8 \times 10^{-8}$ improve by an order of magnitude using 841×10^6 $\tau^+\tau^-$ events.
- Also set the world's first limit on other four channels.
- More improved results are expected from Belle II.

THANK YOU