Measurement of the $\tau^- \to \pi^- \nu_\tau e^+ e^-$ branching fraction by Belle

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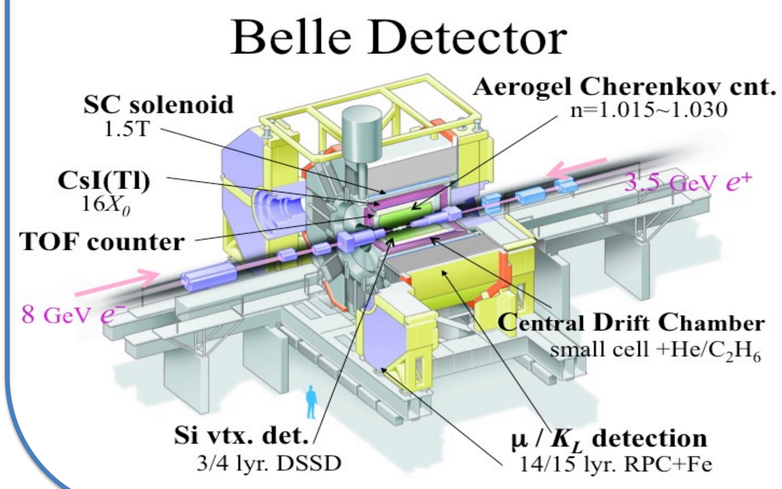
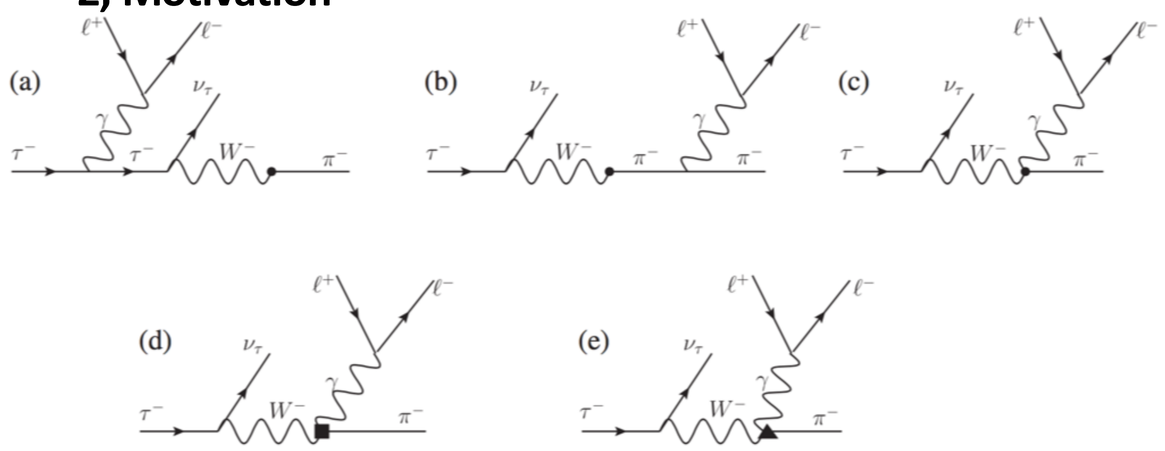
1, Introduction

The Belle detector, located at the interaction point of the electron - positron asymmetric energy collider (KEKB), has been working not only as a B-factory but also as a Tau-factory. The world's largest statistics of tau, 9×10^8 $\tau^+\tau^-$ pair events have been collected at BELLE.



Several searches for NP as well as precision measurements for τ leptons have been carried out at Belle. For SM precision measurements, the mass of τ and the branching fractions of various hadronic decay modes are measured.[1] To probe NP, lepton-flavor violating decays and CPV in the charged lepton sector are searched.

2, Motivation



Feynman Diagrams of the decay modes under consideration[1]. Diagrams (a), (b) and (c) indicate the internal bremsstrahlung due to the radiative γ off the τ, π and vertex. (d) and (e) represent the contribution of γ emitted off the vector and axial-vector current that mediating the hadronization.

Due to the $\gamma^*W^*\pi$ vertex, a measurement of $Br(\tau^\pm \to \pi^\pm \nu_\tau e^+ e^-)$ not only provides information on the relevant form factors that can be extrapolated by Resonance Chiral Theory, but also plays a role in evaluating the hadronic light-by-light contribution to muon g-2 and in computing the radiative corrections to $\pi \to \ell\, \nu$ and $\tau \to \pi\, \nu_\tau$ decays. The Br is predicted[2] as $1.7\ ^{+1.1}_{-0.3} \times 10^{-5}$.

3, Selection criteria

First, standard pre-selection for $\tau^+\tau^-$ pair is applied, followed by additional selections for the mode of concern.

1	$2 <$ Number of charged tracks < 8
2	$\lvert$Sum of charge$\rvert \leq 2$
3	Sum of momenta of charged tracks in the CM frame ($P^{\rm CM}$) < 10 GeV/c
4	Sum of energy deposit in the ECL $E_{ECL} < 10$ GeV
5	Maximum Pt of charged track ($P\mathrm{t}_{\rm max}$) > 0.5 GeV/c
6	Event vertex $\lvert r\rvert < 0.5$ cm, $\lvert z\rvert < 3.0$ cm
7	For 2 track events, 7-1,7-2, and 7-3 must be satisfied:
7-1	Sum of $P^{\rm CM} < 9$ GeV/c
7-2	Sum of $E_{ECL} < 9$ GeV
7-3	$5° < \theta_{\text{missing momentum}} < 175°$
8	$E_{\rm rec}$=[Sum of $P^{\rm CM}$ + Sum of $E_\gamma^{\rm CM}$ (energy of γ in the CM frame)] > 3 GeV .or. $P\mathrm{t}_{\rm max} > 1.0$ GeV/c
9	For 2-4 track events, 9-1 and 9-2 must be satisfied:
9-1	$E_{\rm tot}$=[$E_{\rm rec} + P^{\rm CM}_{\rm miss}$] < 9 GeV .or. maximum opening angle $< 175°$
9-2	[Number of tracks within $30° < \theta < 130°$] ≥ 2 .or. [Sum of E_{ECL} - Sum of $E_\gamma^{\rm CM}$] < 5.3 GeV
10	Maximum opening angle $> 20°$

Descriptions	Relevant cuts
Energy-Momentum	$P_t^{LAB} > 0.1 GeV/c$, $P_\pi^{CMS/LAB} > 0.2 GeV/c$
PID	eID($e^\pm$)>0.5, μID(π)<0.95, eID(π)<0.2, $\pi ID(\pi) > 0.4$
Secondary vertex	$\lvert r_{xy}\rvert < 1.2$ cm, $-1 < z < 1.5$ cm
Angular distribution	$\lvert cos(\tau - 3prong)\rvert \leq 1$
Invariant mass	$1.05 < M_{3prong} < 1.8$ GeV/c^2
Event shape	$0.85 < \frac{\lvert\overrightarrow{P_{e^+}}+\overrightarrow{P_{e^-}}+\overrightarrow{P_\pi}+\overrightarrow{P_{sig\gamma}}-\overrightarrow{P_{tag}}-\overrightarrow{P_{tag\gamma}}\rvert}{\lvert P_{e^+}\rvert+\lvert P_{e^-}\rvert+\lvert P_\pi\rvert+\lvert P_{sig\gamma}\rvert+\lvert P_{tag}\rvert+\lvert P_{tag\gamma}\rvert} < 0.99$ (in CMS)
Gamma Veto	$E_{total\_signalside\_\gamma} < 400$ MeV, $E_{signal\_\gamma\_max} < 300$ MeV, $N_{\gamma\_bothsides} < 8$
π^0 veto	$110 < M_{\gamma\gamma} < 160$ MeV, $110 < M_{e^+e^-\gamma} < 165$ MeV

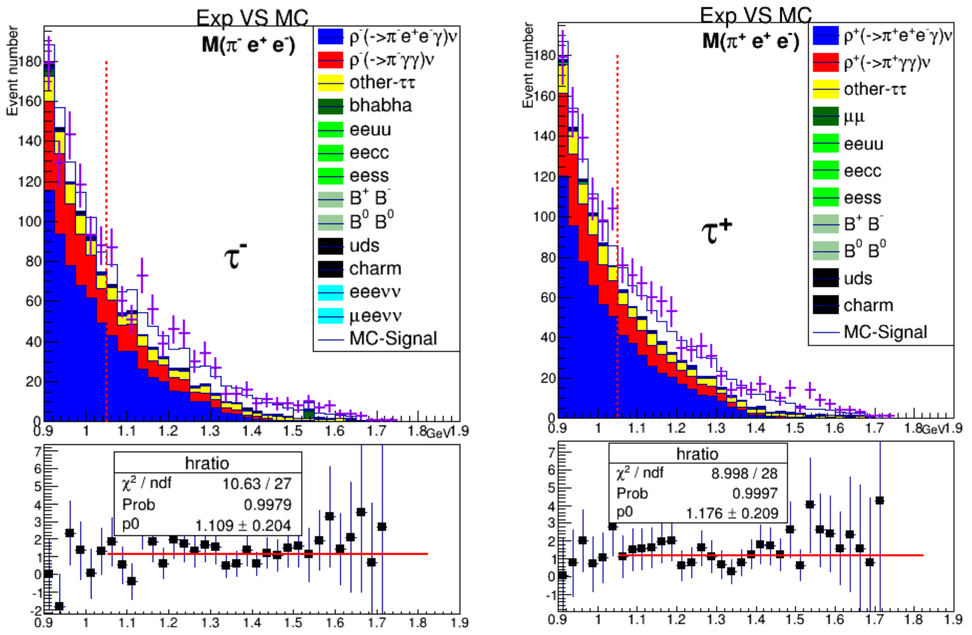
4, Background

MC samples for processes that can occur at Y(4S), such as generic $\tau^+\tau^-$, Bhabha, di-muon, two-photon and $q\bar{q}$ processes are exploited. The amounts of MC samples for all the processes are at least three times larger than the experimental data. Full set of EXP/MC corrections (from the sideband studies) were applied to the signal and background detection efficiencies. The number of BKG events is predicted as 458 ± 22.

Constituents of background events:
(55.2%) $\tau^- \to \rho^- \nu_\tau \to \pi^- \pi^0 \nu_\tau \to \pi^- e^- e^+ \gamma \nu_\tau$
(24.0%) $\tau^- \to \rho^- \nu_\tau \to \pi^- \pi^0 \nu_\tau \to \pi^- \gamma \gamma \nu_\tau$
(14.4%) Other τ^- decays
(2.7%) Continuum processes
(2.7%) Two-photon processes
(0.8%) Bhabha process
(0.04%) B decays

5, Opening the box

After opening the box, we observed 676 events inside the signal box of $\tau^- \to \pi^- e^- e^+ \nu_\tau$, and 689 events in the charge-conjugated mode. While the expected background are 458 ± 22 events for τ^- and 455 ± 21 events for τ^+, so clear signal events are observed. The resultant branching fraction $Br(\tau^\pm \to \pi^\pm e^- e^+ \nu_\tau)$ is measured to be $(2.33 \pm 0.19 \pm 0.19) \times 10^{-5}$, where the first error is statistical and the second is systematic. The result is consistent with theoretical prediction[2].



Systematics that have been taken into account: luminosity, tracking efficiency, trigger correction, PID correction, BRs of BKG modes, BKG/signal detection efficiency, π^0 veto.

6, Conclusion

A first measurement of branching fraction for the rare tau decay $\tau^\pm \to \pi^\pm e^- e^+ \nu_\tau$ is presented, using a 562 fb^{-1} dataset collected at the Y(4S) resonance with Belle detector (SVD2) at the KEKB asymmetric-energy e^+e^- collider. The branching fraction is measured to be $Br(\tau^\pm \to \pi^\pm e^- e^+ \nu_\tau) = (2.33 \pm 0.19 \pm 0.19) \times 10^{-5}$, which is the first measurement on this decay mode.

Reference:
[1], J. Brodzicka, et al., Physics achievements from the Belle experiment [J]. Progress of Theoretical and Experimental Physics, 2012, 2012(1): 04D001.
[2], P. Roig, A. Guevara, G. L. Castro, Weak radiative pion vertex in $\tau^- \to \pi^- \nu_\tau \ell^+ \ell^-$ decays [J]. Physical Review D, 2013, 88(3): 033007.