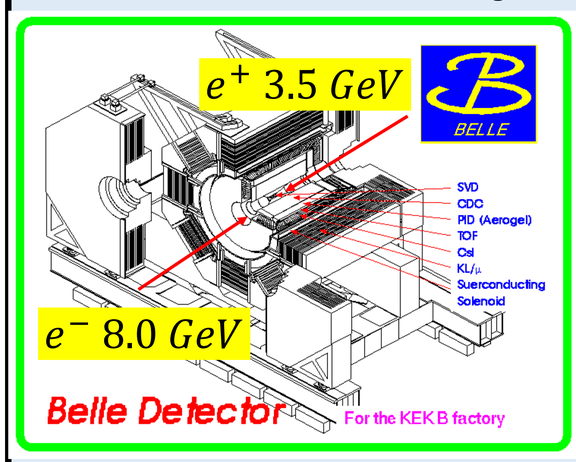
Study of $\tau^{\pm}\to l^{\pm}l'^{+}l'^{-}\nu_{\tau}\nu_{l}$ $(l,l'=e,\mu)$ at Belle

University of Tokyo / Department of Physics, Aihara / Yokoyama lab.[A], Budker Institute of Nuclear Physics.[B]
Junya Sasaki[A], Hiroaki Aihara[A], Denis Epifanov[B], Nobuhiro Shimizu[A], Yifan Jin[A], and Belle Collaboration

1 The Belle experiment (KEK, Japan)



1. e^-e^+ collider
2. $\sqrt{s}=10.58$ GeV
3. Integrated luminosity $\int L\,dt \sim 1\ \mathrm{ab}^{-1}$
4. Products; $B\bar{B}$, $\tau^-\tau^+$, $c\bar{c}$, … etc

Belle is a B-meson factory, and also a ***tau factory***.

$N_{\tau\tau}\sim 9.0\times 10^8$

2 Purpose Check the Standard Model (SM)'s prediction

We measure the **branching ratio of $\tau^{\pm}\to l^{\pm}l'^{+}l'^{-}\nu_{\tau}\nu_{l}$,** and its **Michel-like parameters.**

*The Michel-like parameter is the bilinear combination of the Michel parameters.

For example,

$$Q_{LL} = \beta^- = \frac{1}{4}\left(-3+\frac{16}{3}\rho-\frac{1}{3}\xi+\frac{16}{9}\xi\delta+\xi'+\xi''\right),$$
$$Q_{RR} = \beta^+ = \frac{1}{4}\left(-3+\frac{16}{3}\rho+\frac{1}{3}\xi-\frac{16}{9}\xi\delta-\xi'+\xi''\right),$$
$$Q_{LR} = \alpha^-+\gamma^- = \frac{1}{4}\left(5-\frac{16}{3}\rho+\frac{1}{3}\xi-\frac{16}{9}\xi\delta+\xi'-\xi''\right)$$
$$Q_{RL} = \alpha^++\gamma^+ = \frac{1}{4}\left(5-\frac{16}{3}\rho-\frac{1}{3}\xi+\frac{16}{9}\xi\delta-\xi'-\xi''\right)$$

Reference: P. Roig et al., B2TIP@Pittsburgh 's slide

Only Q_{LL}= 1 is non-zero in the SM

$$\frac{d\Gamma_5}{dx_1 d\Omega_1 dx_2 d\Omega_2 dx_3 d\Omega_3} = \frac{M^2|\vec{\mathbf{p}}_1||\vec{\mathbf{p}}_2||\vec{\mathbf{p}}_3|}{3\cdot 2^{21}\pi^{10}}\mathcal{T}^s_{\alpha\beta}I^{\alpha\beta}(P)$$

$$\mathcal{T}^s_{\alpha\beta}I^{\alpha\beta}(P) = e^4|G_{\ell\ell'}|^2\left[\left(Q_{LL}T^Q_{LL}+Q_{RL}T^Q_{RL}+B_{RL}T^B_{RL}+L\leftrightarrow R\right)+\Re e\left(I_\alpha T^I_\alpha+I_\beta T^I_\beta\right)\right]$$

$Q, B,$ and I : Michel-like parameters (constant value)
T : Kinematic variables

Differential decay width can be written with the form depending on the Michel-like parameters.

Some of Michel-like parameters can be measured by the branching ratio. For example,

$$Q_{LL} = BR^{\text{Measured}}_{\tau^{\pm}\to l^{\pm}l^{+}l^{-}\nu_{\tau}\nu_{l}}/BR^{\text{SM predicted}}_{\tau^{\pm}\to l^{\pm}l^{+}l^{-}\nu_{\tau}\nu_{l}}$$

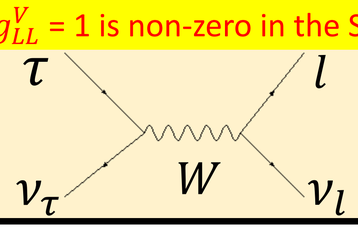
The Michel parameter is a bilinear combination of coupling constant $g^i_{\lambda\rho}$

$$\mathcal{L}\propto\sum_{\substack{i=S,V,T\\ \lambda,\rho=L,R}}\{g^i_{\lambda\rho}[\bar{l}'_\lambda\Gamma^i(\nu_{l'})_\xi][\overline{(\nu_l)_\kappa}\Gamma_i l_\rho]\}$$

$\Gamma^S=I, \Gamma^V=\gamma^\mu, \Gamma^T=\sigma^{\mu\nu}/\sqrt{2}$

Measurement of the Michel-like parameter is useful to check the coupling structure in the weak interaction.

Only g^V_{LL} = 1 is non-zero in the SM



Standard Model's prediction is;
$\rho=3/4, \delta=3/4, \xi=1, \xi'=1, \xi''=1$
$Q_{LL}=1 \quad Q_{RR}=0 \quad Q_{LR}=0 \quad Q_{RL}=0$

3 Previous Experiment of $\tau^{\pm}\to l^{\pm}l'^{+}l'^{-}\nu_{\tau}\nu_{l}$

CLEO II measured branching ratio of $\tau\to ee^+e^-\nu_\tau\nu_e$, $\tau\to\mu e^+e^-\nu_\tau\nu_\mu$

Result of CLEO II (uncertainty: stat. syst. from their knowledge of BG)

Integrated luminosity $3.6\mathrm{fb}^{-1}$
$N_{\tau\tau}=(3.28\pm0.05)\times10^6$

$Br(\tau\to ee^+e^-\nu_\tau\nu_e)=(2.7^{+1.5+0.4+0.1}_{-1.1-0.4-0.3})\times10^{-5}$
$Br(\tau\to\mu e^+e^-\nu_\tau\nu_\mu)<3.2\times10^{-5}$ (at 90% C.L.)

Reference: Phys. Rev. Lett. 76, 2637 (1996)

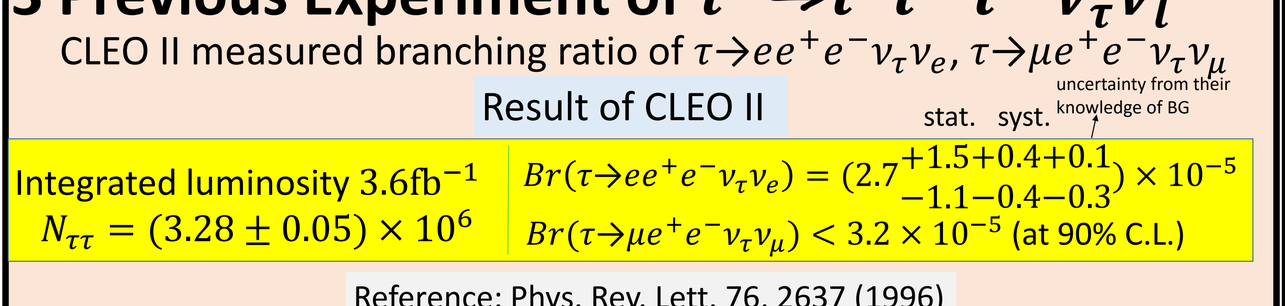
Belle has the huge number of tau-pairs ($N_{\tau\tau}\sim9.0\times10^8$).
More precise measurement is possible at Belle.

4 New Event generator of $\tau^{\pm}\to l^{\pm}l'^{+}l'^{-}\nu_{\tau}\nu_{l}$

To measure the branching ratio of $\tau^{\pm}\to l^{\pm}l'^{+}l'^{-}\nu_{\tau}\nu_{l}$ and the Michel-like parameters, **We developed the event generator of $\tau^{\pm}\to l^{\pm}l'^{+}l'^{-}\nu_{\tau}\nu_{l}$ with considering full matrix elements of two diagrams shown in the bottom right.**

Invariant Mass of $l^{\pm}l'^{+}l'^{-}$ (generated events)

$\tau^{\pm}\to e^{\pm}e^+e^-\nu_\tau\nu_e$ $\tau^{\pm}\to\mu^{\pm}e^+e^-\nu_\tau\nu_\mu$ $\tau^{\pm}\to e^{\pm}\mu^+\mu^-\nu_\tau\nu_e$ $\tau^{\pm}\to\mu^{\pm}\mu^+\mu^-\nu_\tau\nu_\mu$

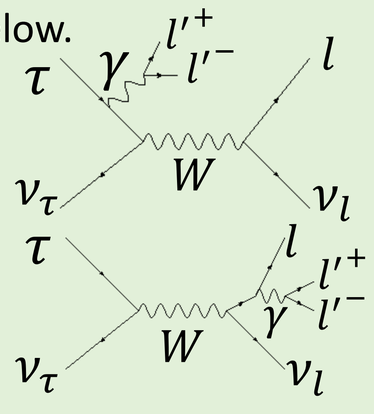


The branching ratio is predicted from the SM as below.

Expected branching ratio from the SM

$\tau^{\pm}\to e^{\pm}e^+e^-\nu_\tau\nu_e$ $(4.21\pm0.01)\times10^{-5}$
$\tau^{\pm}\to\mu^{\pm}e^+e^-\nu_\tau\nu_\mu$ $(1.984\pm0.001)\times10^{-5}$
$\tau^{\pm}\to e^{\pm}\mu^+\mu^-\nu_\tau\nu_e$ $(1.247\pm0.001)\times10^{-7}$
$\tau^{\pm}\to\mu^{\pm}\mu^+\mu^-\nu_\tau\nu_\mu$ $(1.183\pm0.001)\times10^{-7}$

Reference: arXiv:1508.01822v2 [hep-ph]



5. Background(BG) suppression

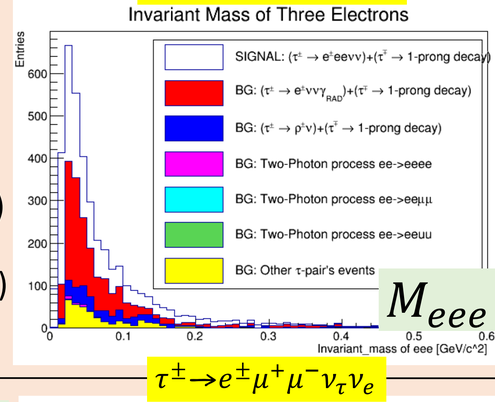
We study selection criteria to suppress backgrounds.

The backgrounds contamination after the selection

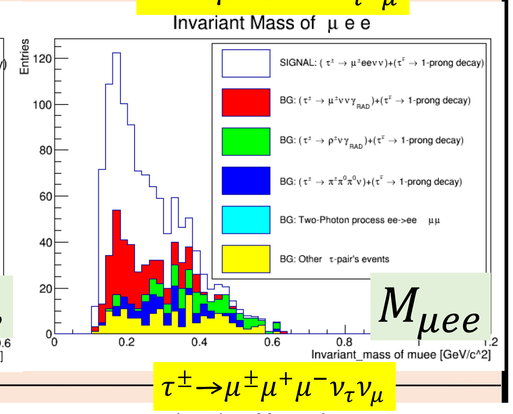
γ-conversion is the source of severe remaining BGs for these two modes

Example;
$\tau\to e\nu_\tau\nu_e\gamma \to e\nu_\tau\nu_e\,(e^+e^-)$
$\tau\to\mu\nu_\tau\nu_\mu\gamma \to \mu\nu_\tau\nu_\mu\,(e^+e^-)$

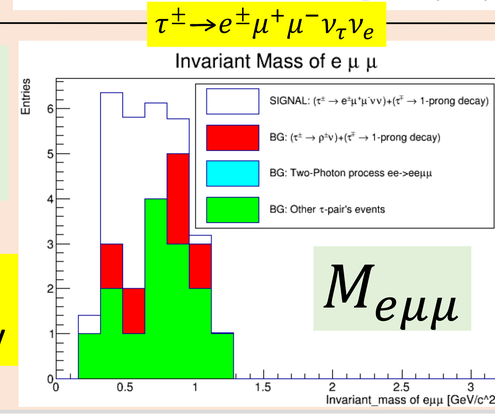
$\tau^{\pm}\to e^{\pm}e^+e^-\nu_\tau\nu_e$



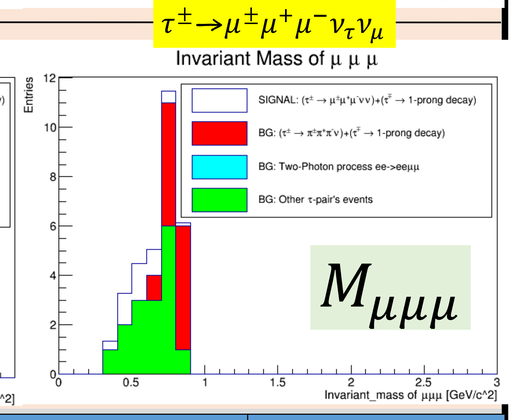
$\tau^{\pm}\to\mu^{\pm}e^+e^-\nu_\tau\nu_\mu$



$\tau^{\pm}\to e^{\pm}\mu^+\mu^-\nu_\tau\nu_e$



$\tau^{\pm}\to\mu^{\pm}\mu^+\mu^-\nu_\tau\nu_\mu$



Mis-identification of pion as muon is the source of remaining severe BGs for these two modes.

Summary of this study

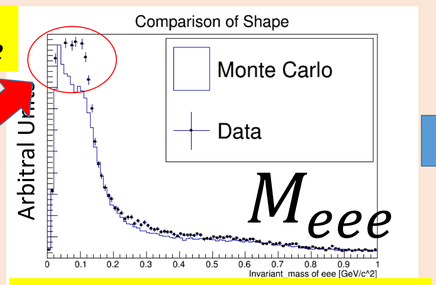
Mode / Contents	$e^{\pm}e^+e^-\nu_\tau\nu_e$	$\mu^{\pm}e^+e^-\nu_\tau\nu_\mu$	$e^{\pm}\mu^+\mu^-\nu_\tau\nu_e$	$\mu^{\pm}\mu^+\mu^-\nu_\tau\nu_\mu$
Detection Efficiency	1.76 %	1.20%	3.56%	1.67%
Main Background(s)	$\tau\to e\nu_\tau\nu_e\gamma$ $\tau\to\pi\pi^0\nu_\tau$	$\tau\to\mu\nu_\tau\nu_\mu\gamma$ $\tau\to\pi\pi^0\gamma\nu_\tau$ $\tau\to\pi\pi^0\pi^0\nu_\tau$	$\tau\to\pi\pi^0\nu_\tau$	$\tau\to\pi\pi^+\pi^-\nu_\tau$
Expected number of signals at Belle	1300	430	8	4
Purity of signal	47%	50%	37%	16%

6 Validation

To validate the MC simulation we have checked the shape of histogram (MC and data) of invariant mass of three electrons

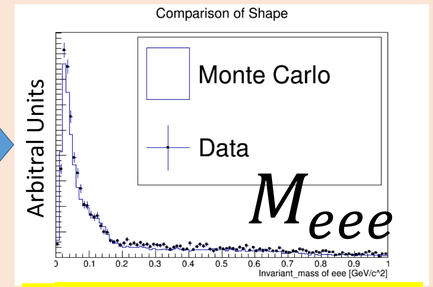
$\tau^{\pm}\to e^{\pm}e^+e^-\nu_\tau\nu_e$

Discrepancy of shape is observed.

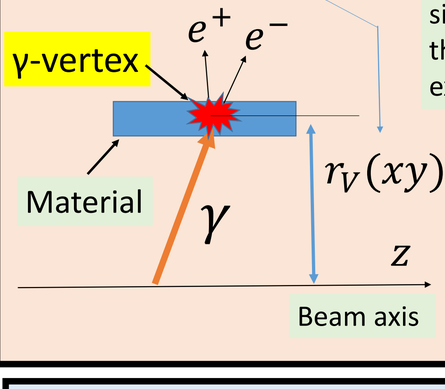


After applying pre-selection (BG dominant ~ 100%)

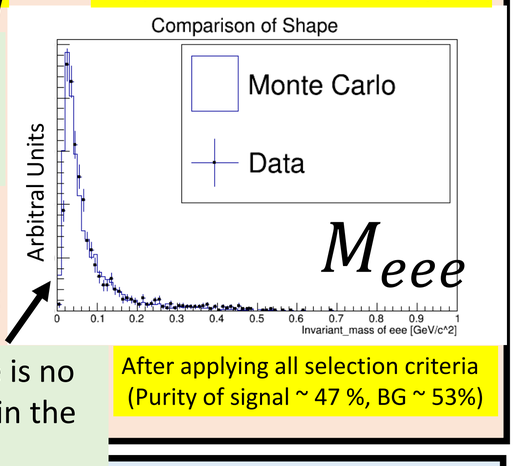
After applying
$r_V(xy)<1.6$cm,
the discrepancy disappears.



After applying γ-vertex cut (BG dominant ~ 90%)



It is expected the MC simulation does not realize the γ-conversion of the real experiment.



After applying all selection criteria (Purity of signal ~ 47 %, BG ~ 53%)

It is considered there is no "critical" problem(s) in the simulation.

7 Conclusion

① Research of $\tau^{\pm}\to l^{\pm}l'^{+}l'^{-}\nu_{\tau}\nu_{l}$ is ongoing.
② New event generator of $\tau^{\pm}\to l^{\pm}l'^{+}l'^{-}\nu_{\tau}\nu_{l}$ has been developed to measure the branching ratio and the Michel-like parameters.
③ Validation of simulation is ongoing by the comparison of behavior of MC and experimental data.

Future Plan

1. First, we measure the branching ratio
   ->Finalize the selection criteria
   ->Evaluate statistical & systematic errors.
2. Measure the Michel-like parameters.

E-Mail: Junya Sasaki <sasaki@hep.phys.s.u-tokyo.ac.jp>