STUDY OF FIVE-BODY LEPTONIC DECAYS OF TAU $\tau^{\pm} \rightarrow l^{\pm} l'^{+} l'^{-} \nu_{\tau} \nu_{l}\ (l, l' = e, \mu)$

22/05/2017 Workshop at Mexico

University of Tokyo / Department of physics

Aihara group

Junya Sasaki

OUTLINE

- Introduction
- Belle Experiment
- Study of Monte Carlo Simulation
- Study of Systematic Uncertainties
- Study of method to measure a Michel parameter
- Future plan

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Introduction : Why tau's 5-leptonic decay?

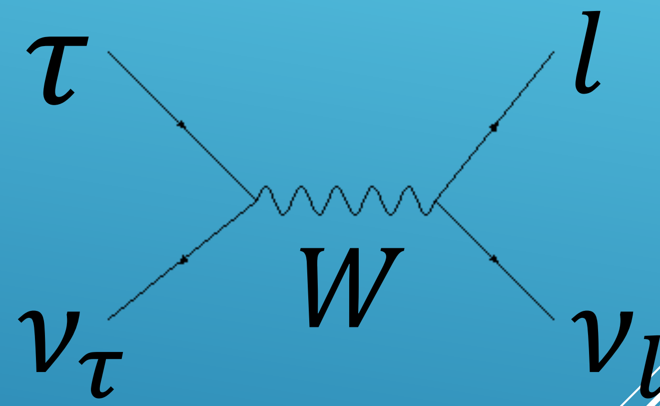
$$\mathcal{L} \propto \sum_{\substack{i=S,V,T \\ \lambda,\rho=L,R}} \{ g^i_{\lambda\rho} [\overline{l'_\lambda} \Gamma^i (\nu_{l'})_\xi][\overline{(\nu_l)_\kappa} \Gamma_i l_\rho] \}$$

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

Purpose :
Constrain a coupling constant $g^i_{\lambda\rho}$.

In the Standard Model, g^V_{LL} = 1, and others are $g^i_{\lambda\rho} = 0$

In the SM, the Lorentz structure of the charged weak current has a V-A coupling. We study the Lorentz structure through the constraints of Michel-like parameters.



RECENT CONSTRAINTS TO $g^i_{\lambda\rho}$

In τ decays only polarization and spectrum of daughters is measured. Possible to measure corresponding **polarizations in radiative decays**

Table 5: 95% CL experimental bounds for the leptonic τ-decay couplings [101]

$\tau^- \to e^- \bar{\nu}_e \nu_\tau$			
$\lvert g^S_{RR}\rvert < 0.70$	$\lvert g^S_{LR}\rvert < 0.99$	$\lvert g^S_{RL}\rvert \le 2$	$\lvert g^S_{LL}\rvert \le 2$
$\lvert g^V_{RR}\rvert < 0.17$	$\lvert g^V_{LR}\rvert < 0.13$	$\lvert g^V_{RL}\rvert < 0.52$	$\lvert g^V_{LL}\rvert \le 1$
$\lvert g^T_{RR}\rvert \equiv 0$	$\lvert g^T_{LR}\rvert < 0.082$	$\lvert g^T_{RL}\rvert < 0.51$	$\lvert g^T_{LL}\rvert \equiv 0$
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$			
$\lvert g^S_{RR}\rvert < 0.72$	$\lvert g^S_{LR}\rvert < 0.95$	$\lvert g^S_{RL}\rvert \le 2$	$\lvert g^S_{LL}\rvert \le 2$
$\lvert g^V_{RR}\rvert < 0.18$	$\lvert g^V_{LR}\rvert < 0.12$	$\lvert g^V_{RL}\rvert < 0.52$	$\lvert g^V_{LL}\rvert \le 1$
$\lvert g^T_{RR}\rvert \equiv 0$	$\lvert g^T_{LR}\rvert < 0.079$	$\lvert g^T_{RL}\rvert < 0.51$	$\lvert g^T_{LL}\rvert \equiv 0$

5 lepton decays in the SM & beyond @ Belle(-II)

Pablo Roig (Cinvestav, Mexico)

Tighter constraints to these coupling constants is possible from Michel-like parameters

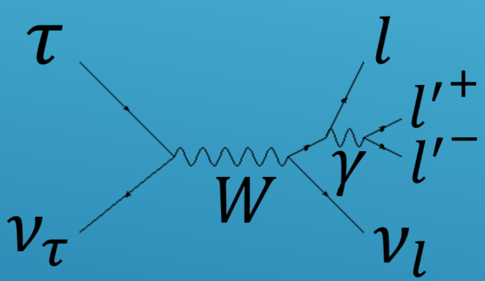
Reference: P. Roig et al., B2TIP@Pittsburgh 's slide

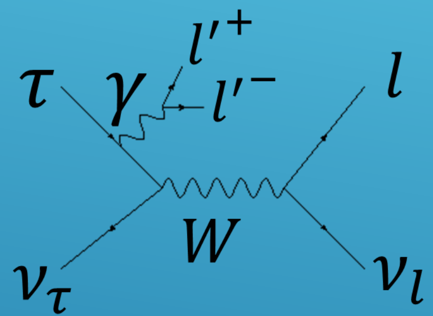
Michel-like parameters appear in a width of five-body leptonic decays of tau

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

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

$$\tau^{\pm} \to l^{\pm} l'^{+} l'^{-} \nu_\tau \nu_l \; (l, l' = e, \mu)$$





Michel parameters

$$Q_{LL} = \frac{1}{4}|g^S_{LL}|^2 + |g^V_{LL}|^2$$

$$Q_{RL} = \frac{1}{4}|g^S_{RL}|^2 + |g^V_{RL}|^2 + |g^T_{RL}|^2$$

$$Q_{RL} = \frac{1}{4}|g^S_{LR}|^2 + |g^V_{LR}|^2 + |g^T_{LR}|^2$$

$$Q_{RR} = \frac{1}{4}|g^S_{RR}|^2 + |g^V_{RR}|^2$$

$$B_{RL} = \frac{1}{16}|g^S_{RL} + 6g^T_{RL}|^2 + |g^V_{RL}|^2$$

$$B_{LR} = \frac{1}{16}|g^S_{LR} + 6g^T_{LR}|^2 + |g^V_{LR}|^2$$

$$I_\alpha = \frac{1}{4}g^V_{LR}(g^S_{RL} + 6g^T_{RL})^* + \frac{1}{4}g^{V*}_{RL}(g^S_{LR} + 6g^T_{LR})$$

$$I_\beta = g^V_{LL}g^{S*}_{RR}/2 + g^{V*}_{RR}g^S_{LL}/2$$

↑From:
W. Fetscher, H. J. Gerber and K. F. Johnson, Phys. Lett. B 173, 102 (1986)

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

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

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

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

Prediction from theory

Channel	
$\mathrm{BR}(\tau^- \to e^- e^+ e^- \bar{\nu}_e \nu_\tau) \times 10^5$	4.21 ± 0.01
$\mathrm{BR}(\tau^- \to e^- \mu^+ \mu^- \bar{\nu}_e \nu_\tau) \times 10^7$	1.247 ± 0.001
$\mathrm{BR}(\tau^- \to \mu^- e^+ e^- \bar{\nu}_\mu \nu_\tau) \times 10^5$	1.984 ± 0.004
$\mathrm{BR}(\tau^- \to \mu^- \mu^+ \mu^- \bar{\nu}_\mu \nu_\tau) \times 10^7$	1.183 ± 0.001

Ref. [JHEP 1604, 185 (2016)]

Michel-like parameters are the combination of coupling constants $g^i_{\lambda\rho}$

We measure the Michel-like parameters through the measurement of branching fraction of five-body leptonic decays of tau

(the detail will be described later)

STRATEGY OF MEASUREMENT

- Use the value of branching fraction will be measured by the data of experiment
- Use the theoretical formula of branching fraction which depends on the Michel parameters

$$BR_{\text{exp}} = BR_{\text{SM}}[Q_{LL} + bQ_{LR} + cB_{LR} + Q_{RR} + dQ_{RL} + eB_{RL} + \Re(fI_\alpha + gI_\beta)] + BR_{\text{NLO}}.$$

Assuming the discrepancy Δ,

$$BR^{\text{Measured}}_{\tau^\pm \to l^\pm l^+ l^- \nu_\tau \nu_l} = BR^{\text{SM predicted}}_{\tau^\pm \to l^\pm l^+ l^- \nu_\tau \nu_l} + \Delta$$

We constrain the Michel-like parameters by,

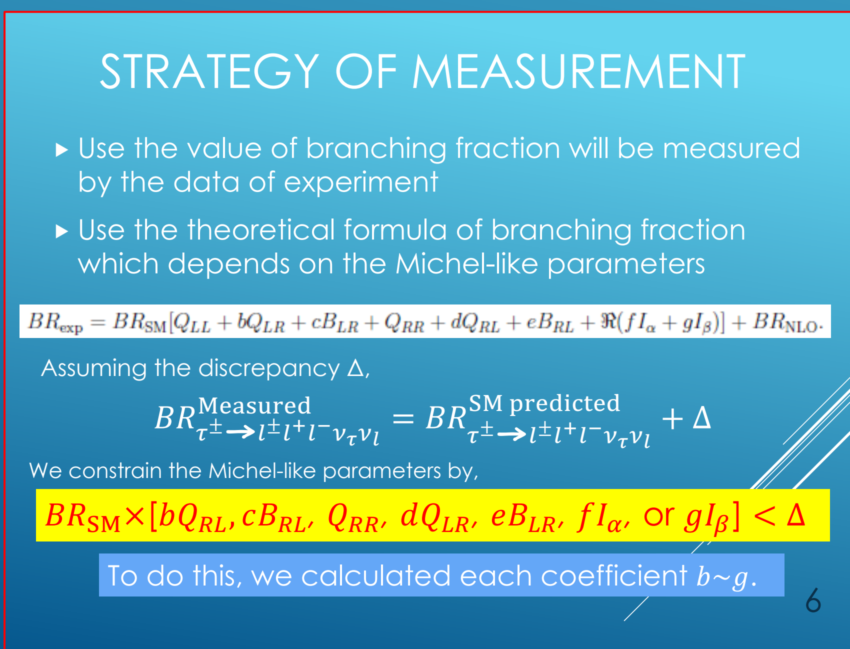
$BR_{\text{SM}} \times [bQ_{RL}, cB_{RL}, Q_{RR}, dQ_{LR}, eB_{LR}, fI_\alpha,$ or $gI_\beta] < \Delta$

To do this, we calculated each coefficient $b \sim g$.

In general, Michel parameters are measured by kinematical fitting to extract it. However in our strategy, we try to constrain the Michel parameters only from the information of branching fraction.
We assume that, the discrepancy of branching fraction between the measured one and that of SMs' prediction is brought by only one term in $BR_{\text{SM}} \times [bQ_{RL}, cB_{RL}, Q_{RR}, dQ_{LR}, eB_{LR}, fI_{\alpha},$ or $gI_{\beta}]$.

We give tighter constraints to Michel parameters by the discrepancy Δ:

$$Q_{RL} < \Delta/(BR_{\text{SM}}b), \quad B_{RL} < \Delta/(BR_{\text{SM}}c), \quad Q_{RR} < \Delta/(BR_{\text{SM}}), \quad Q_{LR} < \Delta/(BR_{\text{SM}}d),$$
$$B_{LR} < \Delta/(BR_{\text{SM}}e), \quad I_{\alpha} < \Delta/(BR_{\text{SM}}f), \quad I_{\beta} < \Delta/(BR_{\text{SM}}g),$$



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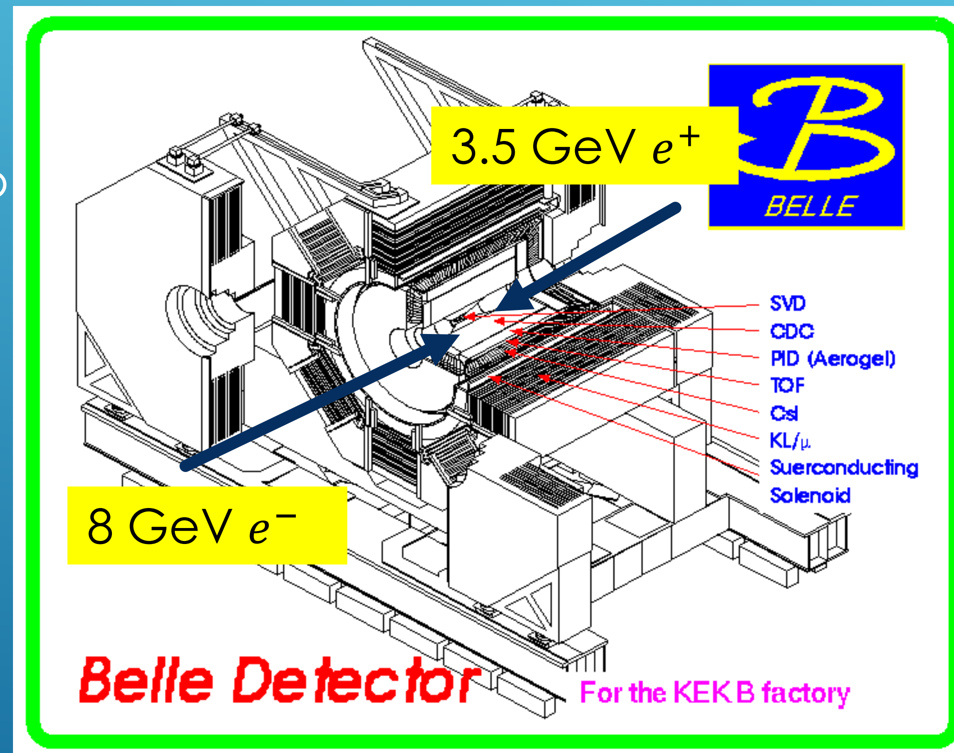
BELLE EXPERIMENT

- Integrated Luminosity 1000 fb^{-1}
- Energy of Collision e^{-} (8 GeV) / e^{+} (3.5 GeV)
- $\sqrt{s} = 10.58\ \mathrm{GeV}$

$e^{+}e^{-} \rightarrow B\bar{B}$ σ_{BB} ~ 1.05 nb (neutral+charged)

$e^{+}e^{-} \rightarrow \tau^{+}\tau^{-}$ $\sigma_{\tau\tau}$ = (0.919±0.003) nb

Belle is B factory,
and also tau-factory.



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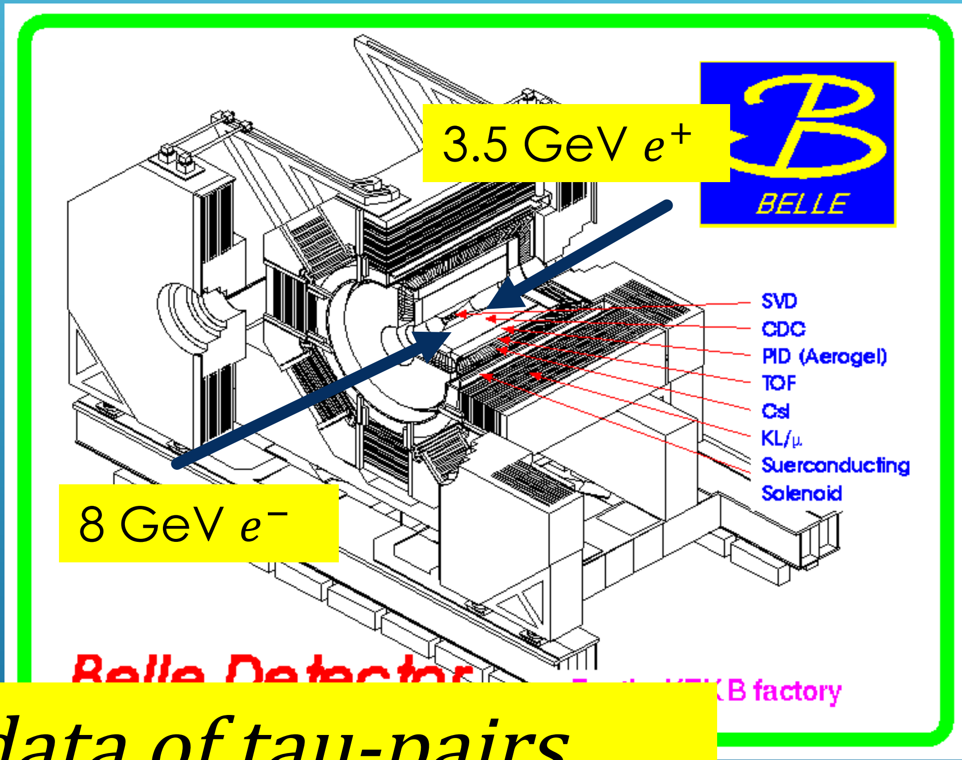

Belle has large data of tau-pairs

$N_{\tau\tau} \sim 9.0\times10^8$

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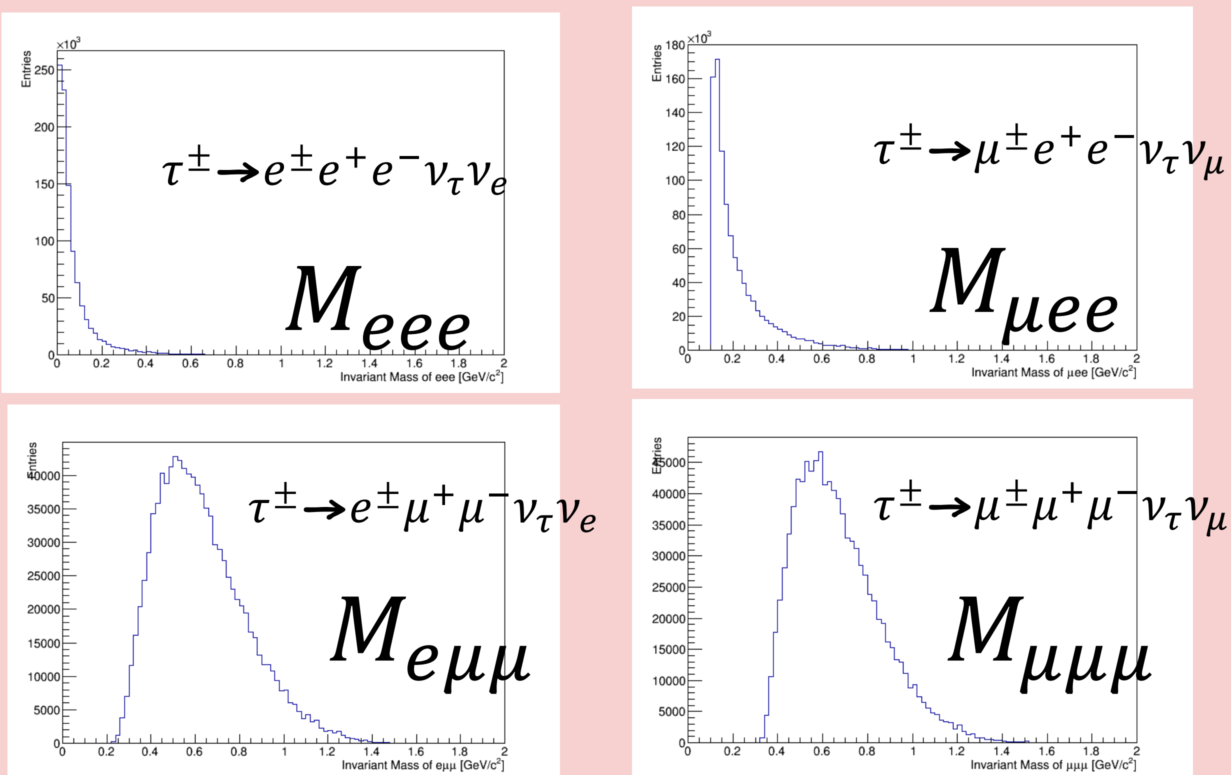
STUDY OF MONTE CARLO SAMPLE

- We developed the event generator of $\boldsymbol{\tau^{\pm} \to l^{\pm} l^{+} l^{-} \nu_{\tau} \nu_{l}}$ by using full matrix elements given in Ref. [JHEP 1604, 185 (2016)]

STUDY OF MONTE CARLO SAMPLE

- We developed the event generator of $\tau^{\pm}\to l^{\pm}l^{+}l^{-}\nu_{\tau}\nu_{l}$ by using full matrix elements given in Ref. [JHEP 1604, 185 (2016)]

Invariant mass of $l^{\pm}l^{+}l^{-}$ [GeV/c^2] (Generated events)



Framework:
KKMC+PHOTOS+TAUOLA

Recent published analytical formalism of $\tau^{\pm}\to l^{\pm}l^{+}l^{-}\nu_{\tau}\nu_{l}$ was embedded

Signal Monte Carlo sample is generated by this developed generator.

SELECTION

Pre-selection of tau-pair and **thrust selection** are applied at the first stage

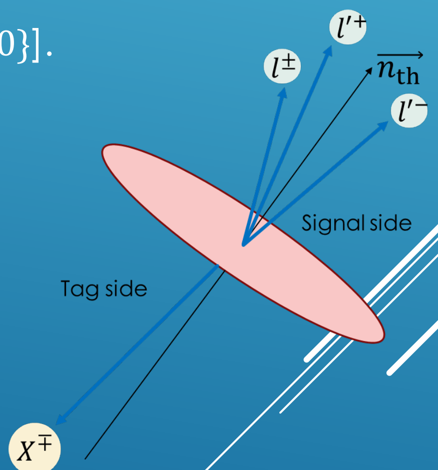
Thrust selection is applied as following method (in the CM-frame).

- Define thrust vector by $\overrightarrow{n_{\rm th}} = \max\{\frac{\sum_{\rm sig,tag}|\overrightarrow{n_{\rm th}}\cdot\overrightarrow{p_i}|}{\sum_{\rm sig,tag}|\overrightarrow{p_i}|}\}$
- Separate signal and tag side by:

  $[\{\overrightarrow{n_{\rm th}}\cdot\overrightarrow{p_{i_{\rm sig}}} < 0\}\&\&\{\overrightarrow{n_{\rm th}}\cdot\overrightarrow{p_{\rm tag}} > 0\}]$ or $[\{\overrightarrow{n_{\rm th}}\cdot\overrightarrow{p_{i_{\rm sig}}} > 0\}\&\&\{\overrightarrow{n_{\rm th}}\cdot\overrightarrow{p_{\rm tag}} < 0\}]$.
- Require the number of charged tracks in signal side to be three and that of tag side to be one
- Require $\sum_{\rm sig} Q = \pm 1$ and $\sum_{\rm tag} Q = \mp 1$

$\overrightarrow{p_{i_{\rm sig}}}$: momentum vector of electrons in signal-side

$\overrightarrow{p_{\rm tag}}$: momentum vector of charged particle in tag-side



※Pre-selection of tau-pair and second stage selection are written in a backup

We use 1-prong decay of tau as tag

SELECTION

Pre-selection of tau-pair and **thrust selection** are applied at the first stage

Thrust selection is applied as following metho... ...).

The Detail of selection is described in backup slide (to save time)

...ectrons in

- Define thrust vector by $\overrightarrow{n_{\mathrm{th}}} = \max\{\frac{\Sigma_{\mathrm{sig}}...$ ...

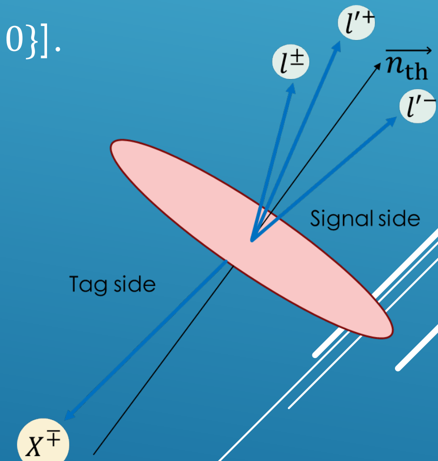
...entum vector of charged particle

...g side

- Separate signal and ta...

  $[\{\overrightarrow{n_{\mathrm{th}}} \cdot \overrightarrow{p_{i_{\mathrm{sig}}}} < 0\}$ ... $\{\overrightarrow{n_{\mathrm{th}}} \cdot \overrightarrow{p_{\mathrm{tag}}} < 0\}]$.

- Requi... ...s in signal side to be th... ...one
- Re... $\Sigma_{\mathrm{tag}} Q = \mp 1$



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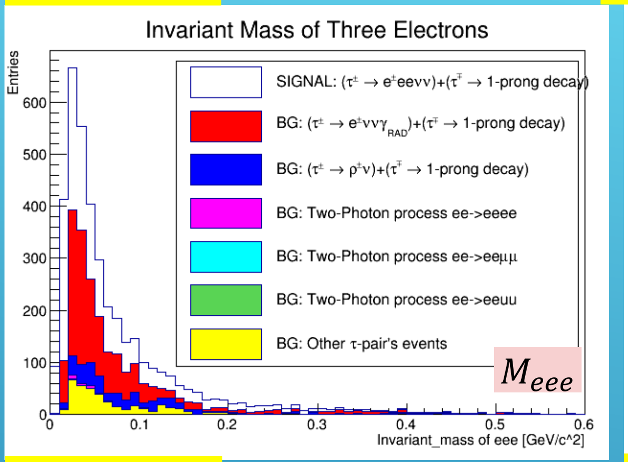
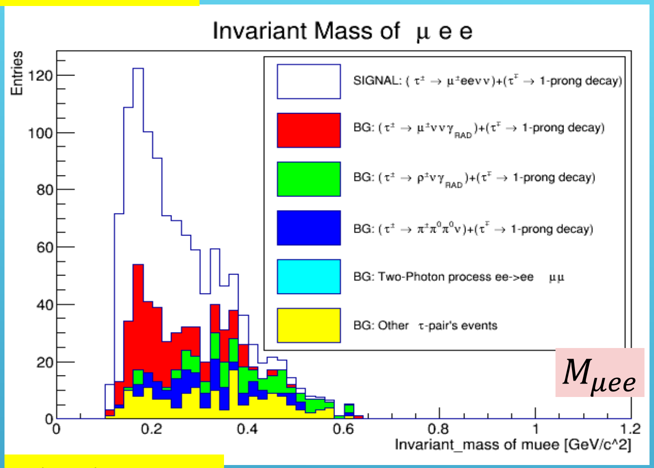
CONTAMINATION OF BACKGROUND

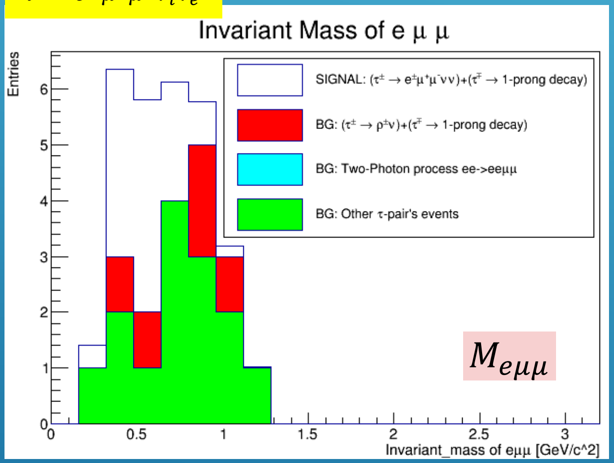
$\tau^{\pm} \to e^{\pm} e^{+} e^{-} \nu_{\tau} \nu_{e}$



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



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



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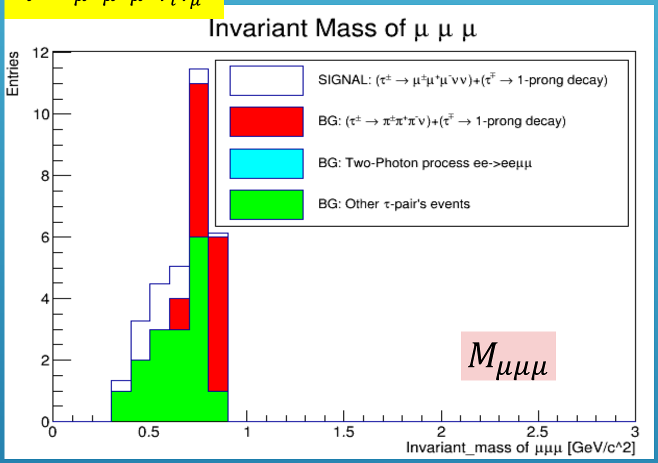
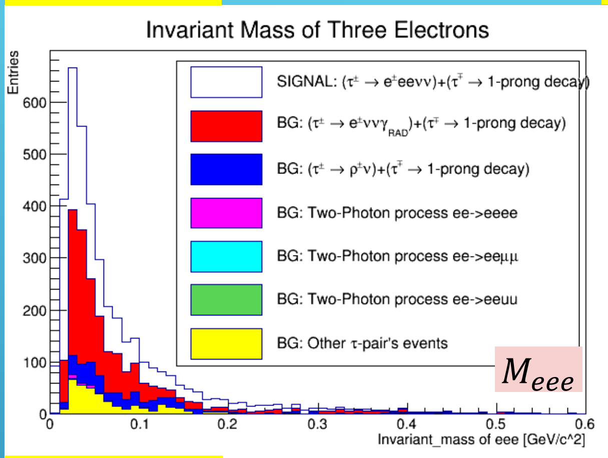


To evaluate the background and calculate efficiencies, a Monte Carlo (MC) sample of 4 million signal decays was used. Histograms shown left are plotted by assuming the SM predicted branching ratio.

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



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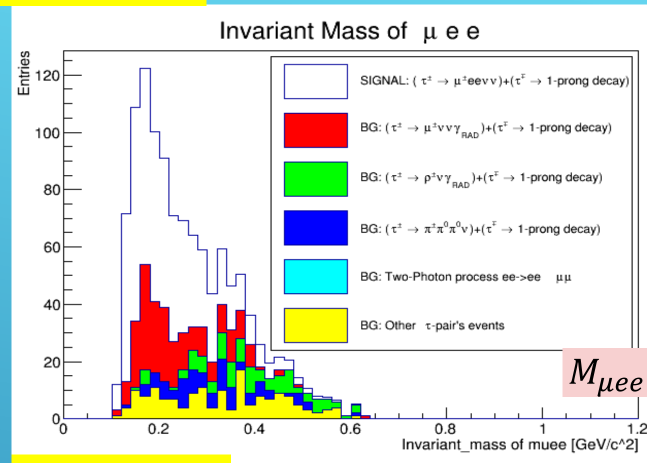

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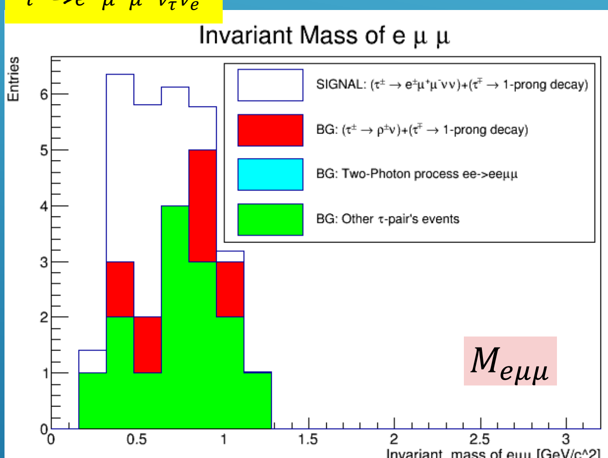

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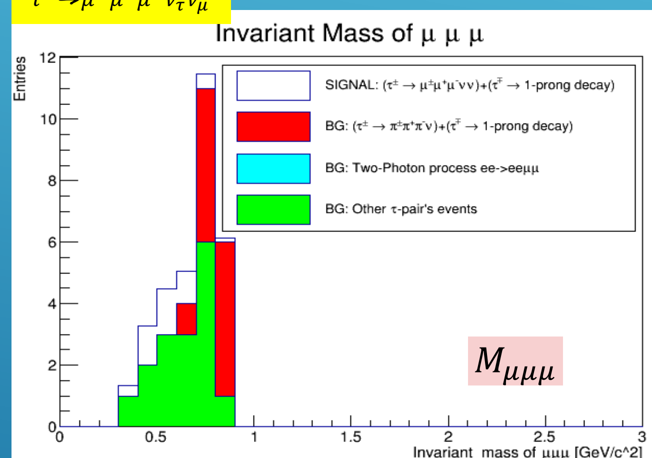

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After the selection

⇒⇒⇒

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

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STUDY OF SYSTEMATIC UNCERTAINTIES

For the measurement of branching fraction, we use this ↓ formula.

$$BR[\tau^{\pm}\to l^{\pm}l'^{+}l'^{-}\nu_{\tau}\nu_{l}]BR[1-\mathrm{prong}] = \frac{N_{\mathrm{total}} - N_{\mathrm{bg}}}{2\sigma_{\tau\tau}L\varepsilon^{\mathrm{sig}}R}$$

Signal-side Tag-side

N_{total}: Number of entries after applying all selections

$\varepsilon^{\mathrm{sig}}$: Detection efficiency of signal

$BR[1-\mathrm{prong}]$=0.8524±0.0006 : Fraction of 1-prong decay of tau (from Particle Data Group (2016))

N_{bg} : Number of backgrounds

L : Integrated Luminosity we use

R: Correction factor of detection efficiency $R = \frac{\varepsilon_{\mathrm{trg}}^{\mathrm{data}}}{\varepsilon_{\mathrm{trg}}^{\mathrm{MC}}} \frac{\varepsilon_{PID}^{\mathrm{data}}(l^{\pm})}{\varepsilon_{PID}^{\mathrm{MC}}(l^{\pm})} \frac{\varepsilon_{PID}^{\mathrm{data}}(l'^{+})}{\varepsilon_{PID}^{\mathrm{MC}}(l'^{+})} \frac{\varepsilon_{PID}^{\mathrm{data}}(l'^{-})}{\varepsilon_{PID}^{\mathrm{MC}}(l'^{-})}$

Contents of systematic uncertainties

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For charged tracks' reconstruction in the signal-side

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Trigger correction
Tag-side
Luminosity
Background
Selection Cut

$$\frac{N_{\text{total}} - N_{\text{bg}}}{2\sigma_{\tau\tau} L \varepsilon^{\text{sig}} R}$$

N_{total}: Number of entries after applying all selections

ε^{sig}: Detection efficiency of signal

$BR[1-\text{prong}]$=0.8524±0.0006 : Fraction of 1-prong decay of tau (from Particle Data Group (2016))

N_{bg} : Number of backgrounds

L : Integrated Luminosity we use

R: Correction factor of detection efficiency $R = \frac{\varepsilon^{\text{data}}_{\text{trg}}}{\varepsilon^{\text{MC}}_{\text{trg}}} \frac{\varepsilon^{\text{data}}_{PID}(l^{\pm})}{\varepsilon^{\text{MC}}_{PID}(l^{\pm})} \frac{\varepsilon^{\text{data}}_{PID}(l\prime^{+})}{\varepsilon^{\text{MC}}_{PID}(l\prime^{+})} \frac{\varepsilon^{\text{data}}_{PID}(l\prime^{-})}{\varepsilon^{\text{MC}}_{PID}(l\prime^{-})}$

Contents of systematic uncertainties

contents
PID correction
Tracking efficiency
Trigger correction
Tag-side
Luminosity
Background
Selection Cut

$$\frac{N_{\mathrm{total}} - N_{\mathrm{bg}}}{2\sigma_{\tau\tau} L \varepsilon^{\mathrm{sig}} R}$$

N_{total}: Number of entries after applying all selections

$\varepsilon^{\mathrm{sig}}$: Detection efficiency of signal

$BR[1-\mathrm{prong}]$=0.8524±0.0006 : Fraction of 1-prong decay of tau (from Particle Data Group (2016))

N_{bg} : Number of backgrounds

L : Integrated Luminosity we use

R: Correction factor of detection efficiency $R = \frac{\varepsilon_{\mathrm{trg}}^{\mathrm{data}}}{\varepsilon_{\mathrm{trg}}^{\mathrm{MC}}} \frac{\varepsilon_{PID}^{\mathrm{data}}(l^{\pm})}{\varepsilon_{PID}^{\mathrm{MC}}(l^{\pm})} \frac{\varepsilon_{PID}^{\mathrm{data}}(l'^{+})}{\varepsilon_{PID}^{\mathrm{MC}}(l'^{+})} \frac{\varepsilon_{PID}^{\mathrm{data}}(l'^{-})}{\varepsilon_{PID}^{\mathrm{MC}}(l'^{-})}$

Contents of systematic uncertainties

contents
PID correction
Tracking efficiency
Trigger correction
Tag-side
Luminosity
Background
Selection Cut

$$\frac{N_{\mathrm{total}} - N_{\mathrm{bg}}}{2\sigma_{\tau\tau} L \varepsilon^{\mathrm{sig}} R}$$

In next page, we show the preliminary results of systematic uncertainties for four modes.

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

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

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

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

Preliminary : estimation of systematic uncertainties

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

Table 11: Systematic uncertainties of the $\tau^- \to e^- e^+ e^- \bar{\nu}_e \nu_\tau$

contents	syst. error (SVD1)	syst. error (SVD2)
PID correction	7.3%	5.0%
Tracking efficiency	1.1%	1.1%
Trigger correction	0.1%	0.1%
Tag-side	0.35%	0.35%
Luminosity	1.4%	1.4%
Background	5.5%	2.8%
Selection Cut	–	–
Total	9.3%	6.0%

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

Table 12: Systematic uncertainties of the $\tau^- \to \mu^- e^+ e^- \bar{\nu}_\mu \nu_\tau$

contents	syst. error (SVD1)	syst. error (SVD2)
PID correction	6.9%	6.4%
Tracking efficiency	1.1%	1.1%
Trigger correction	0.1%	0.1%
Tag-side	0.35%	0.35%
Luminosity	1.4%	1.4%
Background	9.6%	4.8%
Selection Cut	–	–
Total	12.0%	8.2%

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

Table 13: Systematic uncertainties of the $\tau^- \to e^- \mu^+ \mu^- \bar{\nu}_e \nu_\tau$

contents	syst. error (SVD1)	syst. error (SVD2)
PID correction	8.7%	7.4%
Tracking efficiency	1.1%	1.1%
Trigger correction	0.1%	0.1%
Tag-side	0.35%	0.35%
Luminosity	1.4%	1.4%
Background	71%	35%
Selection Cut	–	–
Total	72%	36%

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

Table 14: Systematic uncertainties of the $\tau^- \to \mu^- \mu^+ \mu^- \bar{\nu}_\mu \nu_\tau$

contents	syst. error (SVD1)	syst. error (SVD2)
PID correction	6.2%	8.4%
Tracking efficiency	1.1%	1.1%
Trigger correction	0.1%	0.1%
Tag-side	0.35%	0.35%
Luminosity	1.4%	1.4%
Background	71%	35%
Selection Cut	–	–
Total	72%	36%

Preliminary : estimation of systematic uncertainties

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

Table 11: Systematic uncertainties of the $\tau^{-} \to e^{-} e^{+} e^{-} \bar{\nu}_{e} \nu_{\tau}$

contents	syst. error (SVD1)	syst. error (SVD2)
PID correction	7.3%	5.0%
Tracking efficiency	1.1%	1.1%
Trigger correction	0.1%	0.1%
Tag-side	0.35%	0.35%
Luminosity	1.4%	1.4%
Background	5.5%	2.8%
Selection Cut	–	–
Total	9.3%	6.0%

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

Table 12: Systematic uncertainties of the $\tau^{-} \to \mu^{-} e^{+} e^{-} \bar{\nu}_{\mu} \nu_{\tau}$

contents	syst. error (SVD1)	syst. error (SVD2)
PID correction	6.9%	6.4%
Tracking efficiency	1.1%	1.1%
Trigger correction	0.1%	0.1%
Tag-side	0.35%	0.35%
Luminosity	1.4%	1.4%
Background	9.6%	4.8%
Selection Cut	–	–
Total	12.0%	8.2%

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

Table 13: Systematic uncertainties of the $\tau^{-} \to e^{-} \mu^{+} \mu^{-} \bar{\nu}_{e} \nu_{\tau}$

contents	syst. error (SVD1)	syst. error (SVD2)
PID correction	8.7%	7.4%
Tracking efficiency	1.1%	1.1%
Trigger correction	0.1%	0.1%
Tag-side	0.35%	0.35%
Luminosity	1.4%	1.4%
Background	71%	35%
Selection Cut	–	–
Total	72%	36%

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

Table 14: Systematic uncertainties of the $\tau^{-} \to \mu^{-} \mu^{+} \mu^{-} \bar{\nu}_{\mu} \nu_{\tau}$

contents	syst. error (SVD1)	syst. error (SVD2)
PID correction	6.2%	8.4%
Tracking efficiency	1.1%	1.1%
Trigger correction	0.1%	0.1%
Tag-side	0.35%	0.35%
Luminosity	1.4%	1.4%
Background	71%	35%
Selection Cut	–	–
Total	72%	36%

Preliminary : estimation of systematic uncertainties

$\tau^{\pm} \rightarrow e^{\pm} e^{+} e^{-} \nu_{\tau} \nu_{e}$

Table 11: Systematic uncertainties of the $\tau^- \to e^- e^+ e^- \bar{\nu}_e \nu_\tau$

contents	syst. error (SVD1)	syst. error (SVD2)
PID correction	7.3%	5.0%
Tracking efficiency	1.1%	1.1%
Trigger correction	0.1%	0.1%
Tag-side	0.35%	0.35%
Luminosity	1.4%	1.4%
Background	5.5%	2.8%
Selection Cut	–	–
Total	9.3%	[illegible]

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

Table 12: Systematic uncertainties of the $\tau^- \to \mu^- e^+ e^- \bar{\nu}_\mu \nu_\tau$

contents	syst. error (SVD1)	syst. error (SVD2)
PID correction	6.9%	[illegible]
Tracking efficiency	[illegible]	[illegible]
Trigger correcti[illegible]	[illegible]	[illegible]
Ta[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible].4%
[illegible]	[illegible]	4.8%
[illegible]	[illegible]	–
[illegible]	12.0%	8.2%

Remaining "Selection Cut" will be determined soon

$\tau^{\pm} \rightarrow e^{\pm}$ [illegible]

Table 13: S[illegible]

con[illegible]	[illegible]	[illegible] error (SVD2)
PID co[illegible]	[illegible]	7.4%
Tracking e[illegible]	[illegible]	1.1%
Trigger cor[illegible]	0.1%	0.1%
Tag-sid[illegible]	0.35%	0.35%
Luminosity	1.4%	1.4%
Background	71%	35%
Selection Cut	–	–
Total	72%	36%

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

Table 14: Systematic uncertainties of the $\tau^- \to \mu^- \mu^+ \mu^- \bar{\nu}_\mu \nu_\tau$

contents	syst. error (SVD1)	syst. error (SVD2)
PID correction	6.2%	8.4%
Tracking efficiency	1.1%	1.1%
Trigger correction	0.1%	0.1%
Tag-side	0.35%	0.35%
Luminosity	1.4%	1.4%
Background	71%	35%
Selection Cut	–	–
Total	72%	36%

OUTLINE

- Introduction
- Belle Experiment
- Study of Monte Carlo Simulation
- Study of Systematic Uncertainties
- Study of method to measure a Michel parameter
- Future plan

STRATEGY OF CALCULATION OF $b\sim g$

$$BR_{\text{exp}} = BR_{\text{SM}}[Q_{LL} + bQ_{LR} + cB_{LR} + Q_{RR} + dQ_{RL} + eB_{RL} + \Re(fI_\alpha + gI_\beta)] + BR_{\text{NLO}}.$$

Previous slide →

BACKUP : MICHEL-LIKE PARAMETERS

We show the method of calculation of $b\sim g$ and calculated coefficient $b\sim g$ from next page.

$$BR_{\text{exp}} = BR_{\text{SM}}[Q_{LL} + bQ_{LR} + cB_{LR} + Q_{RR} + dQ_{RL} + eB_{RL} + \Re(fI_\alpha + gI_\beta)] + BR_{\text{NLO}}.$$

Assuming the discrepancy Δ,

$$BR^{\text{Measured}}_{\tau^\pm \to l^\pm l^+ l^- \nu_\tau \nu_l} = BR^{\text{SM predicted}}_{\tau^\pm \to l^\pm l^+ l^- \nu_\tau \nu_l} + \Delta$$

We constrain the Michel-like parameters by,

$BR_{\text{SM}} \times [bQ_{RL}, cB_{RL}, Q_{RR}, dQ_{LR}, eB_{LR}, fI_\alpha$, or $gI_\beta] < \Delta$

- Method of Monte Carlo integral is used
- Take the ratio of BR_{SM} to avoid considering the complicated common factor appears in the theoretical formula

$$b\sim g = \frac{1}{BR_{\text{SM}}} BR_{\text{NP}} = \frac{1}{\Gamma_{\text{SM}}}\int d\Gamma_{\text{NP}} d(PS) = \frac{1}{\Gamma_{\text{SM}}}\int \frac{d\Gamma_{\text{NP}}}{d\Gamma_{\text{SM}}/\Gamma_{\text{SM}}}[(d\Gamma_{\text{SM}}/\Gamma_{\text{SM}})d(PS)]$$
$$= \frac{1}{\Gamma_{\text{SM}}}\int \frac{d\Gamma_{\text{NP}}}{d\tilde{\Gamma}_{\text{SM}}}[(d\tilde{\Gamma}_{\text{SM}})d(PS)] \approx \frac{1}{\Gamma_{\text{SM}}}\frac{1}{N_{\text{gen}}}\sum_{\mathbf{x}\in\Omega}\frac{d\Gamma_{\text{NP}}(\mathbf{x})}{d\tilde{\Gamma}_{\text{SM}}(\mathbf{x})} = \frac{1}{N_{\text{gen}}}\sum_{\mathbf{x}\in\Omega}\frac{d\Gamma_{\text{NP}}(\mathbf{x})}{d\Gamma_{\text{SM}}(\mathbf{x})}, \quad (5.2)$$

where, $d\tilde{\Gamma}_{\text{SM}} = d\Gamma_{\text{SM}}/\Gamma_{\text{SM}}$ is a normalized differential decay width of the SM, Ω is an allowed phase space (PS), $\mathbf{x}$ follows the distribution of $d\Gamma_{\text{SM}}$, and N_{gen} is the number of generated events.

↑ from my note

STRATEGY OF CALCULATION OF $b{\sim}g$

$$BR_{\rm exp} = BR_{\rm SM}[Q_{LL} + bQ_{LR} + cB_{LR} + Q_{RR} + dQ_{RL} + eB_{RL} + \Re(fI_\alpha + gI_\beta)] + BR_{\rm NLO}.$$

Previous slide →

$$Q_{LL} = \frac{1}{4}|g^S_{LL}|^2 + |g^V_{LL}|^2$$
$$Q_{RL} = \frac{1}{4}|g^S_{RL}|^2 + |g^V_{RL}|^2 + |g^T_{RL}|^2$$
$$Q_{RL} = \frac{1}{4}|g^S_{LR}|^2 + |g^V_{LR}|^2 + |g^T_{LR}|^2$$
$$Q_{RR} = \frac{1}{4}|g^S_{RR}|^2 + |g^V_{RR}|^2$$
$$B_{RL} = \frac{1}{16}|g^S_{RL} + 6g^T_{RL}|^2 + |g^V_{RL}|^2$$
$$B_{LR} = \frac{1}{16}|g^S_{LR} + 6g^T_{LR}|^2 + |g^V_{LR}|^2$$
$$I_\alpha = \frac{1}{4}g^V_{LR}(g^S_{RL} + 6g^T_{RL})^* + \frac{1}{4}g^{V*}_{RL}(g^S_{LR} + 6g^T_{LR})$$
$$I_\beta = g^V_{LL}g^{S*}_{RR}/2 + g^{V*}_{RR}g^S_{LL}/2$$

- Method of Monte Carlo integral
- Take the ratio of $BR_{\rm SM}$ to avoid considering the complicated common factor appears in the theoretical formula

$$b \sim g = \frac{1}{BR_{\rm SM}}BR_{\rm NP} = \frac{1}{\Gamma_{\rm SM}}\int d\Gamma_{\rm NP}d(PS) = \frac{1}{\Gamma_{\rm SM}}\int \frac{d\Gamma_{\rm NP}}{d\Gamma_{\rm SM}/\Gamma_{\rm SM}}[(d\Gamma_{\rm SM}/\Gamma_{\rm SM})d(PS)]$$
$$= \frac{1}{\Gamma_{\rm SM}}\int \frac{d\Gamma_{\rm NP}}{d\tilde{\Gamma}_{\rm SM}}[(d\tilde{\Gamma}_{\rm SM})d(PS)] \approx \frac{1}{\Gamma_{\rm SM}}\frac{1}{N_{\rm gen}}\sum_{\mathbf{x}\in\Omega}\frac{d\Gamma_{\rm NP}(\mathbf{x})}{d\tilde{\Gamma}_{\rm SM}(\mathbf{x})} = \frac{1}{N_{\rm gen}}\sum_{\mathbf{x}\in\Omega}\frac{d\Gamma_{\rm NP}(\mathbf{x})}{d\Gamma_{\rm SM}(\mathbf{x})}, \quad (5.2)$$

where, $d\tilde{\Gamma}_{\rm SM} = d\Gamma_{\rm SM}/\Gamma_{\rm SM}$ is a normalized differential decay width of the SM, Ω is an allowed phase space (PS), $\mathbf{x}$ follows the distribution of $d\Gamma_{\rm SM}$, and $N_{\rm gen}$ is the number of generated events.

↑ from my note

- Method of Monte Carlo integral is used
- Take the ratio of BR_{SM} to avoid considering the complicated common factor appears in the theoretical formula

$$b{\sim}g = \frac{1}{N_{\mathrm{gen}}} \sum_{\mathbf{x}\in\Omega} \frac{d\Gamma^{b\sim g}_{\mathrm{NP}}(\mathbf{x})}{d\Gamma_{\mathrm{SM}}(\mathbf{x})}$$

$$b \sim g = \frac{1}{BR_{\mathrm{SM}}} BR_{\mathrm{NP}} = \frac{1}{\Gamma_{\mathrm{SM}}} \int d\Gamma_{\mathrm{NP}} d(PS) = \frac{1}{\Gamma_{\mathrm{SM}}} \int \frac{d\Gamma_{\mathrm{NP}}}{d\Gamma_{\mathrm{SM}}/\Gamma_{\mathrm{SM}}} [(d\Gamma_{\mathrm{SM}}/\Gamma_{\mathrm{SM}}) d(PS)]$$
$$= \frac{1}{\Gamma_{\mathrm{SM}}} \int \frac{d\Gamma_{\mathrm{NP}}}{d\widetilde{\Gamma}_{\mathrm{SM}}} [(d\widetilde{\Gamma}_{\mathrm{SM}}) d(PS)] \approx \frac{1}{\Gamma_{\mathrm{SM}}} \frac{1}{N_{\mathrm{gen}}} \sum_{\mathbf{x}\in\Omega} \frac{d\Gamma_{\mathrm{NP}}(\mathbf{x})}{d\widetilde{\Gamma}_{\mathrm{SM}}(\mathbf{x})} = \frac{1}{N_{\mathrm{gen}}} \sum_{\mathbf{x}\in\Omega} \frac{d\Gamma_{\mathrm{NP}}(\mathbf{x})}{d\Gamma_{\mathrm{SM}}(\mathbf{x})}, \quad (5.2)$$

where, $d\widetilde{\Gamma}_{\mathrm{SM}} = d\Gamma_{\mathrm{SM}}/\Gamma_{\mathrm{SM}}$ is a normalized differential decay width of the SM, Ω is an allowed phase space (PS), $\mathbf{x}$ follows the distribution of $d\Gamma_{\mathrm{SM}}$, and N_{gen} is the number of generated events.

↑ from my note

From next page, we show the result of calculated coefficients for our four target modes.

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

↓ from my note

7.4.1 Case of $\tau^- \to e^- e^+ e^- \bar{\nu}_e \nu_\tau$

The result is,

$$BR_{\rm exp} = BR_{\rm SM}\{Q_{LL} + (1.051 \pm 0.036)Q_{LR} + (-0.2053 \pm 0.1431)B_{LR} + L \leftrightarrow R$$
$$+\Re[(0.2416 \pm 0.0002)I_\alpha + (0.8606 \pm 0.0001)I_\beta]\} + BR_{\rm NLO}. \qquad (7.19)$$

The formulation of coupling constant g^i_{jk} is written by,

$$BR_{\rm exp} = BR_{\rm SM}\{|g^V_{LL}|^2(1 + \frac{|g^S_{LL}|^2}{4|g^V_{LL}|^2}) + (0.2501 \pm 0.0001)|g^S_{RL}|^2 + (0.8465 \pm 0.1073)|g^V_{RL}|^2$$
$$+(2.693 \pm 0.215)|g^T_{RL}|^2 + \Re[-(0.1540 \pm 0.1073)g^S_{RL}g^{T*}_{RL} + (0.4303 \pm 0.0001)g^S_{LL}g^{V*}_{RR}$$
$$+(0.06039 \pm 0.00004)g^S_{LR}g^{V*}_{RL} + (0.3623 \pm 0.0002)g^V_{LR}g^{T*}_{RL}] + L \leftrightarrow R\} + BR_{\rm NLO}. \qquad (7.20)$$

Sensitive   Not Sensitive

Because of pseudo peculiarity which appears in some terms, some result include large error. This pseudo peculiarity is caused mainly by the factor of virtual gamma conversion ($\gamma \to ee$)

$$|1/{q_{ee}}^2|^2 \sim |1/O(1\text{MeV})^2|^2$$

in the matrix element.

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

↓ from my note

7.4.2 Case of $\tau^- \to \mu^- e^+ e^- \bar{\nu}_\mu \nu_\tau$

The result is,

$$BR_{\mathrm{exp}} = BR_{\mathrm{SM}}\{Q_{LL} + \underline{(1.220. \pm 0.049)Q_{LR}} + \underline{(-0.8717 \pm 0.1957)B_{LR}} + L \leftrightarrow R + \Re[\underline{(181.3 \pm 0.1)I_\alpha} + \underline{(104.4 \pm 0.1)I_\beta}]\} + BR_{\mathrm{NLO}}. \quad (7.22)$$

The formulation of coupling constant g^i_{jk} is written by,

$$BR_{\mathrm{exp}} = BR_{\mathrm{SM}}\{|g^V_{LL}|^2(1 + \frac{|g^S_{LL}|^2}{\underline{4|g^V_{LL}|^2}}) + \underline{(0.2506 \pm 0.0001)|g^S_{RL}|^2} + \underline{(0.3484 \pm 0.1468)|g^V_{RL}|^2} + \underline{(1.699 \pm 0.294)|g^T_{RL}|^2} + \Re[\underline{-(0.6538 \pm 0.1468)g^S_{RL}g^{T*}_{RL}} + \underline{(52.20 \pm 0.01)g^S_{LL}g^{V*}_{RR}} + \underline{(45.33 \pm 0.01)g^S_{LR}g^{V*}_{RL}} + \underline{(272.0 \pm 0.1)g^V_{LR}g^{T*}_{RL}}] + L \leftrightarrow R\} + BR_{\mathrm{NLO}}. \quad (7.23)$$

Super Sensitive

Sensitive

Not Sensitive

Because of pseudo peculiarity which appears in some terms, some result include large error. However, there are some parameters which is super sensitive.

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

↓ from my note

7.4.3 Case of $\tau^- \to e^-\mu^+\mu^-\bar{\nu}_e\nu_\tau$

The result is,

$$BR_{\rm exp} = BR_{\rm SM}\{Q_{LL} + (1.226 \pm 0.001)Q_{LR} + (-0.8456 \pm 0.0001)B_{LR} + L \leftrightarrow R + \Re[(0.2253 \pm 0.0001)I_\alpha + (0.5231 \pm 0.0001)I_\beta]\} + BR_{\rm NLO}. \quad (7.24)$$

The formulation of coupling constant g^i_{jk} is written by,

$$BR_{\rm exp} = BR_{\rm SM}\{|g^V_{LL}|^2(1 + \frac{|g^S_{LL}|^2}{4|g^V_{LL}|^2}) + (0.2536 \pm 0.0001)|g^S_{RL}|^2 + (0.3802 \pm 0.0001)|g^V_{RL}|^2 + (1.775 \pm 0.001)|g^T_{RL}|^2 + \Re[-(0.6342 \pm 0.0001)g^S_{RL}g^{T*}_{RL} + (0.2616 \pm 0.0001)g^S_{LL}g^{V*}_{RR} + (0.05633 \pm 0.00001)g^S_{LR}g^{V*}_{RL} + (0.3380 \pm 0.0001)g^V_{LR}g^{T*}_{RL}] + L \leftrightarrow R\} + BR_{\rm NLO}. \quad (7.25)$$

Sensitive (red underline) — Not Sensitive (blue underline)

This case is peculiarity-free and the error of all coefficients are small.

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

↓ from my note

7.4.4 Case of $\tau^- \to \mu^-\mu^+\mu^-\bar{\nu}_\mu\nu_\tau$

The result is,

$$BR_{\text{exp}} = BR_{\text{SM}}\{Q_{LL} + (1.216 \pm 0.005)Q_{LR} + (-0.8459 \pm 0.0005)B_{LR} + L \leftrightarrow R \\ + \Re[-(18.00 \pm 0.01)I_\alpha + (197.3 \pm 0.1)I_\beta]\} + BR_{\text{NLO}}. \quad (7.26)$$

The formulation of coupling constant g^i_{jk} is written by,

$$BR_{\text{exp}} = BR_{\text{SM}}\{|g^V_{LL}|^2(1 + \frac{1}{4}|g^S_{LL}|^2) + (0.2512 \pm 0.0001)|g^S_{RL}|^2 + (0.3704 \pm 0.0001)|g^V_{RL}|^2 \\ + (1.745 \pm 0.015)|g^T_{RL}|^2 + \Re[-(0.6344 \pm 0.0004)g^S_{RL}g^{T*}_{RL} + (98.67 \pm 0.01)g^S_{LL}g^{V*}_{RR} \\ -(4.510 \pm 0.001)g^S_{LR}g^{V*}_{RL} - (27.060 \pm 0.006)g^V_{LR}g^{T*}_{RL}] + L \leftrightarrow R\} + BR_{\text{NLO}}. \quad (7.27)$$

Super Sensitive

Sensitive

Not Sensitive

This case is peculiarity-free and the error of all coefficients are small.
There are some parameters which is super sensitive.

POSSIBLE MEASUREMENT

Because of expected statistics, we concentrate on the measurement through two modes:

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

The statistics of other two modes ($\tau^{\pm}\to e^{\pm}\mu^{+}\mu^{-}\nu_{\tau}\nu_{e}$, $\tau^{\pm}\to \mu^{\pm}\mu^{+}\mu^{-}\nu_{\tau}\nu_{\mu}$) expected to be small because of its expected branching fraction is small. And the measurement of Michel parameters is difficult from these two modes.

Expected BRs from the Standard Model

	Channel	Prediction from theory
$\tau^{\pm}\to e^{\pm}e^{+}e^{-}\nu_{\tau}\nu_{e}$	$\mathrm{BR}(\tau^{-}\to e^{-}e^{+}e^{-}\bar{\nu}_{e}\nu_{\tau})\times 10^{5}$	4.21 ± 0.01
$\tau^{\pm}\to e^{\pm}\mu^{+}\mu^{-}\nu_{\tau}\nu_{e}$	$\mathrm{BR}(\tau^{-}\to e^{-}\mu^{+}\mu^{-}\bar{\nu}_{e}\nu_{\tau})\times 10^{7}$	1.247 ± 0.001
$\tau^{\pm}\to \mu^{\pm}e^{+}e^{-}\nu_{\tau}\nu_{\mu}$	$\mathrm{BR}(\tau^{-}\to \mu^{-}e^{+}e^{-}\bar{\nu}_{\mu}\nu_{\tau})\times 10^{5}$	1.984 ± 0.004
$\tau^{\pm}\to \mu^{\pm}\mu^{+}\mu^{-}\nu_{\tau}\nu_{\mu}$	$\mathrm{BR}(\tau^{-}\to \mu^{-}\mu^{+}\mu^{-}\bar{\nu}_{\mu}\nu_{\tau})\times 10^{7}$	1.183 ± 0.001

Ref. [JHEP 1604, 185 (2016)]

Result of Monte Carlo simulation

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

POSSIBLE MEASUREMENT

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

※Other modes' formula is in backup slides

↓ from my note

7.4.1 Case of $\tau^- \to e^- e^+ e^- \bar{\nu}_e \nu_\tau$

The result is,

$$BR_{\text{exp}} = BR_{\text{SM}}\{Q_{LL} + (1.051 \pm 0.036)Q_{LR} + (-0.2053 \pm 0.1431)B_{LR} + L \leftrightarrow R + \Re[(0.2416 \pm 0.0002)I_\alpha + (0.8606 \pm 0.0001)I_\beta]\} + BR_{\text{NLO}}. \quad (7.19)$$

The formulation of coupling constant g^i_{jk} is written by,

$$BR_{\text{exp}} = BR_{\text{SM}}\{|g^V_{LL}|^2(1 + \frac{|g^S_{LL}|^2}{4|g^V_{LL}|^2}) + (0.2501 \pm 0.0001)|g^S_{RL}|^2 + (0.8465 \pm 0.1073)|g^V_{RL}|^2 + (2.693 \pm 0.215)|g^T_{RL}|^2 + \Re[-(0.1540 \pm 0.1073)g^S_{RL}g^{T*}_{RL} + (0.4303 \pm 0.0001)g^S_{LL}g^{V*}_{RR} + (0.06039 \pm 0.00004)g^S_{LR}g^{V*}_{RL} + (0.3623 \pm 0.0002)g^V_{LR}g^{T*}_{RL}] + L \leftrightarrow R\} + BR_{\text{NLO}}. \quad (7.20)$$

Sensitive — Not Sensitive

Because of pseudo peculiarity which appears in some terms, some result include large error. This pseudo peculiarity is caused mainly by the factor of virtual gamma conversion ($\gamma \to ee$)

$$|1/{q_{ee}}^2|^2 \sim |1/O(1\text{MeV})^2|^2$$

in the matrix element.

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

↓ from my note

7.4.2 Case of $\tau^- \to \mu^- e^+ e^- \bar{\nu}_\mu \nu_\tau$

The result is,

$$BR_{\text{exp}} = BR_{\text{SM}}\{Q_{LL} + (1.220. \pm 0.049)Q_{LR} + (-0.8717 \pm 0.1957)B_{LR} + L \leftrightarrow R + \Re[(181.3 \pm 0.1)I_\alpha + (104.4 \pm 0.1)I_\beta]\} + BR_{\text{NLO}}. \quad (7.22)$$

The formulation of coupling constant g^i_{jk} is written by,

$$BR_{\text{exp}} = BR_{\text{SM}}\{|g^V_{LL}|^2(1 + \frac{|g^S_{LL}|^2}{4|g^V_{LL}|^2}) + (0.2506 \pm 0.0001)|g^S_{RL}|^2 + (0.3484 \pm 0.1468)|g^V_{RL}|^2 + (1.699 \pm 0.294)|g^T_{RL}|^2 + \Re[-(0.6538 \pm 0.1468)g^S_{RL}g^{T*}_{RL} + (52.20 \pm 0.01)g^S_{LL}g^{V*}_{RR} + (45.33 \pm 0.01)g^S_{LR}g^{V*}_{RL} + (272.0 \pm 0.1)g^V_{LR}g^{T*}_{RL}] + L \leftrightarrow R\} + BR_{\text{NLO}}. \quad (7.23)$$

Super Sensitive — Sensiti ve — Not Sensitive

Because of pseudo peculiarity which appears in some terms, some result include large error. However, there are some parameters which is super sensitive.

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Tighter constraints on for example:

$$g^{V*}_{LR} g^{T}_{RL} \quad g^{S}_{LR} g^{V*}_{RL} \quad g^{S}_{LL} g^{V*}_{RR}$$

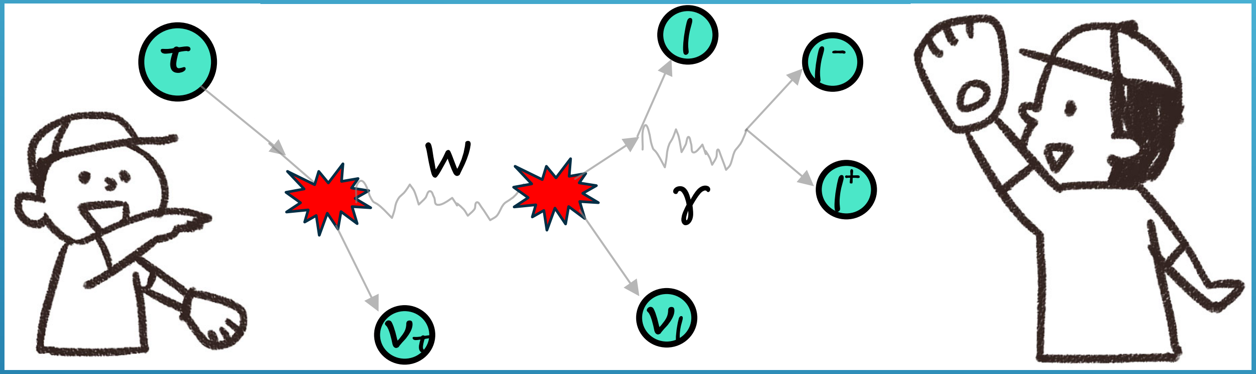
are possible from the measurement of BRs' of $\tau^{\pm} \to e^{\pm} e^{+} e^{-} \nu_{\tau} \nu_{e}$, $\tau^{\pm} \to \mu^{\pm} e^{+} e^{-} \nu_{\tau} \nu_{\mu}$.

OUTLINE

- Introduction
- Belle Experiment
- Study of Monte Carlo Simulation
- Study of Systematic Uncertainties
- Study of method to measure a Michel parameter
- Future plan

FUTURE PLAN

- Finalize the study of systematic uncertainties.
- Measure the branching fraction
- Give the tighter constraints to Michel parameters



THANK YOU!

BACKUP

RESULT OF TRIGGER EFFICIENCY'S CORRECTION FACTOR

- Use GDL trigger bits
- Separate the GDL trigger bits into two groups; one is charged trigger Z, another is neutral trigger N

↓ from my Belle note

$$\bar{R}_{\rm trg} = \frac{\varepsilon_{\rm trg}^{\rm data}}{\varepsilon_{\rm trg}^{\rm MC}} = \frac{(\varepsilon_Z + \varepsilon_N - \varepsilon_Z\varepsilon_N)_{\rm data}}{(\varepsilon_Z + \varepsilon_N - \varepsilon_Z\varepsilon_N)_{\rm MC}}.$$

$$\bar{R}_{\rm trg} + \delta\bar{R}_{\rm trg} = \frac{\varepsilon_{\rm trg}^{\rm data} + \delta\varepsilon_{\rm trg}^{\rm data}}{\varepsilon_{\rm trg}^{\rm MC} + \delta\varepsilon_{\rm trg}^{\rm MC}} \sim \frac{\varepsilon_{\rm trg}^{\rm data}}{\varepsilon_{\rm trg}^{\rm MC}} + \frac{\varepsilon_{\rm trg}^{\rm data}}{\varepsilon_{\rm trg}^{\rm MC}}\left(\frac{\delta\varepsilon_{\rm trg}^{\rm data}}{\varepsilon_{\rm trg}^{\rm data}} - \frac{\delta\varepsilon_{\rm trg}^{\rm MC}}{\varepsilon_{\rm trg}^{\rm MC}}\right)$$

Table 9: $\varepsilon_{\rm trg}^{\rm MC}$, $\varepsilon_{\rm trg}^{\rm data}$, and $\bar{R}_{\rm trg}$ of SVD1 for each channel just after applying pre-selection

Channel	$\varepsilon_{\rm trg}^{\rm MC} \pm \delta\varepsilon_{\rm trg}^{\rm MC}$ [%]	$\varepsilon_{\rm trg}^{\rm data} \pm \delta\varepsilon_{\rm trg}^{\rm data}$ [%]	$\bar{R}_{\rm trg} \pm \delta\bar{R}_{\rm trg}$
$e^-e^+e^-\bar{\nu}_e\nu_\tau$	95.3 ± 0.1	93.5 ± 0.2	0.981 ± 0.0004
$\mu^-e^+e^-\bar{\nu}_\mu\nu_\tau$	97.5 ± 0.03	98.4 ± 0.09	1.01 ± 0.0006
$e^-\mu^+\mu^-\bar{\nu}_e\nu_\tau$	98.7 ± 0.07	97.9 ± 0.5	0.992 ± 0.005
$\mu^-\mu^+\mu^-\bar{\nu}_\mu\nu_\tau$	92.2 ± 0.4	99.3 ± 0.4	1.08 ± 0.0008

Table 10: $\varepsilon_{\rm trg}^{\rm MC}$, $\varepsilon_{\rm trg}^{\rm data}$, and $\bar{R}_{\rm trg}$ of SVD2 for each channel just after applying pre-selection

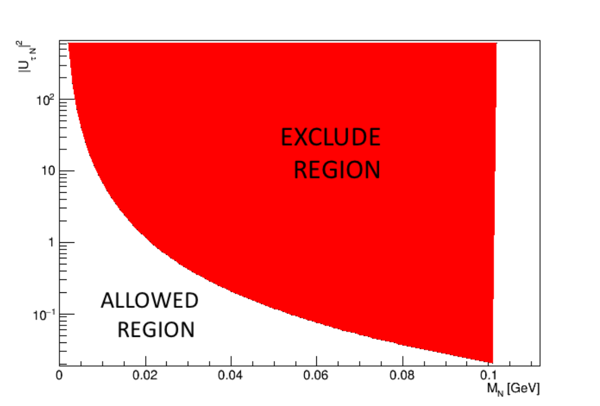
Channel	$\varepsilon_{\rm trg}^{\rm MC} \pm \delta\varepsilon_{\rm trg}^{\rm MC}$ [%]	$\varepsilon_{\rm trg}^{\rm data} \pm \delta\varepsilon_{\rm trg}^{\rm data}$ [%]	$\bar{R}_{\rm trg} \pm \delta\bar{R}_{\rm trg}$
$e^-e^+e^-\bar{\nu}_e\nu_\tau$	94.7 ± 0.2	91.9 ± 0.3	0.970 ± 0.0006
$\mu^-e^+e^-\bar{\nu}_\mu\nu_\tau$	95.3 ± 0.1	97.8 ± 0.06	1.03 ± 0.0009
$e^-\mu^+\mu^-\bar{\nu}_e\nu_\tau$	97.6 ± 0.05	97.7 ± 0.3	1.00 ± 0.002
$\mu^-\mu^+\mu^-\bar{\nu}_\mu\nu_\tau$	94.1 ± 0.1	98.1 ± 0.3	1.04 ± 0.001

POSSIBLE SEARCH: HEAVY NEUTRINO

Measurement of branching fraction allows us to constrain the region of heavy Neutrino Model
(The detail is described in my Belle Note !! Put link here !!)

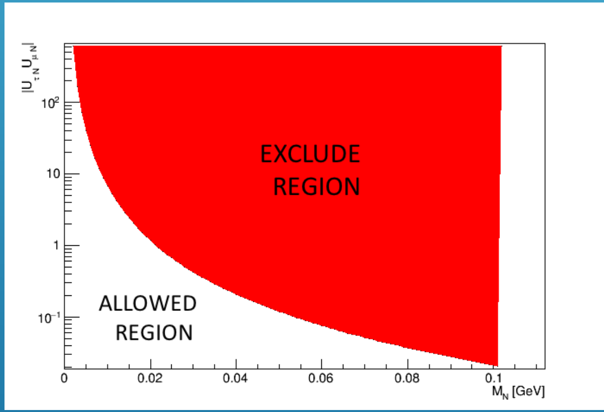
Sensitivities from BR($\tau^{\pm} \rightarrow e^{\pm} e^{+} e^{-} \nu_{\tau} \nu_{e}$) **(assuming the accuracy 5%)**

$|U_{\tau N}|^2$ VS M_N



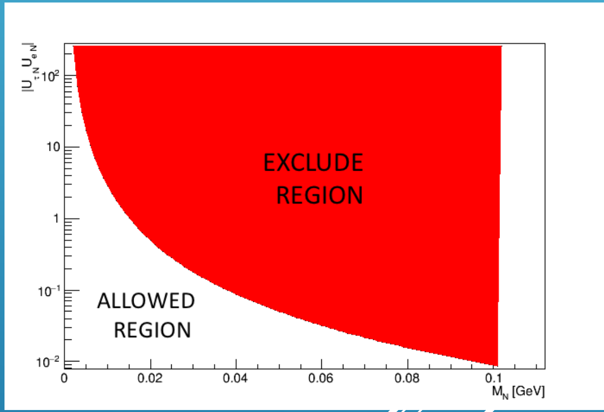
Weak!!

$|U_{\tau N} U_{eN}|$ VS M_N



New information

$|U_{eN}|^2$ VS M_N



Weak!!

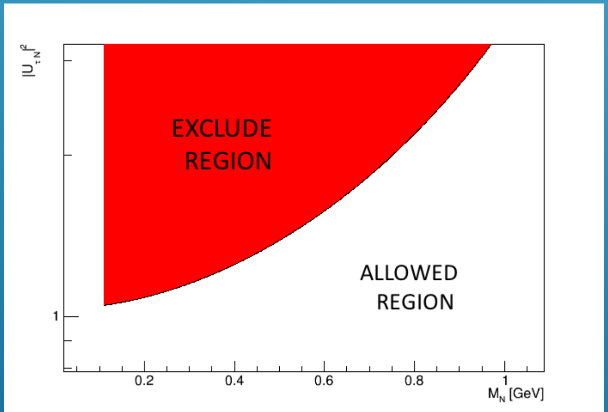
Only < 100 MeV is calculated because of the sensitivity.

POSSIBLE SEARCH: HEAVY NEUTRINO

Measurement of branching fraction allows us to constrain the region of heavy Neutrino Model
(The detail is described in my Belle Note !! Put link here !!)

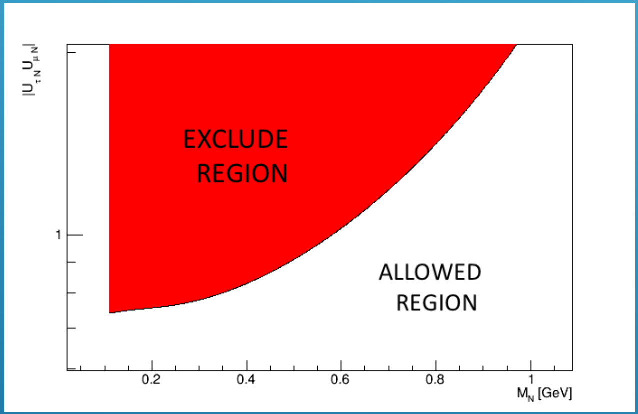
Sensitivities from BR($\tau^{\pm} \to \mu^{\pm} e^{+} e^{-} \nu_{\tau} \nu_{\mu}$) **(assuming the accuracy 5%)**

$|U_{\tau N}|^2$ VS M_N



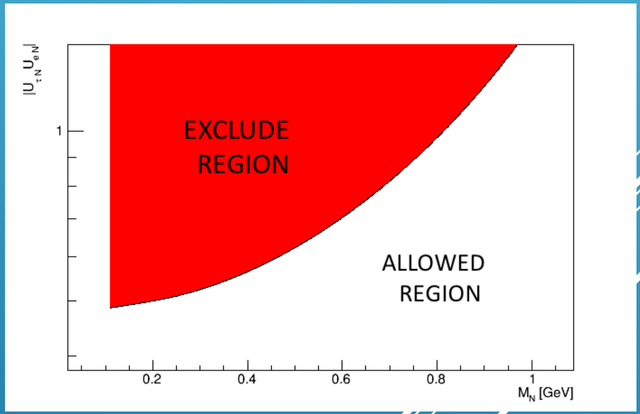
Weak!!

$|U_{\tau N} U_{\mu N}|$ VS M_N



New information

$|U_{\mu N}|^2$ VS M_N



Weak!!

Only > 100 MeV is calculated because of on-shell condition.

BACKUP: DETAIL OF SELECTION CRITERIA

PRE-SELECTION OF TAU-PAIR

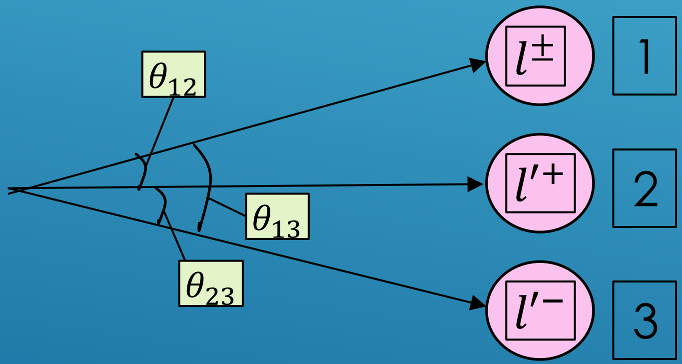
Table 3: Pre-selection criteria of tau-pair

Index	Selection Criteria
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^{CM}) < 10 GeV/c
4	Sum of energy deposit in the ECL E(ECL) < 10 GeV
5	Maximum Pt of charged track (Pt_{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^{CM} < 9 GeV/c
7-2	Sum of E(ECL) < 9 GeV
7-3	5 deg < $\theta_{\mathrm{missing\ momentum}}$ < 175 deg
8	E_{rec}=[Sum of P^{CM} + Sum of E_γ^{CM} (energy of γ in the CM frame)] > 3 GeV .or. Pt_{max} > 1.0 GeV/c
9	For 2-4 track events, 9-1 and 9-2 must be satisfied:
9-1	E_{tot}=[$E_{\mathrm{rec}} + P_{\mathrm{miss}}^{\mathrm{CM}}$] < 9 GeV .or. maximum opening angle < 175 deg
9-2	[Number of tracks within 30 < θ < 130 deg] ≥ 2 .or. [Sum of E(ECL) - Sum of E_γ^{CM}] < 5.3 GeV
10	Maximum opening angle > 20 deg

SECOND STAGE SELECTION

Explanation of defined word

Sum of $\cos\theta_{ij}$: $(\sum_{i<j}\cos\theta_{ij})$



SECOND STAGE SELECTION

$$\tau^{\pm} \rightarrow e^{\pm} e^{+} e^{-} \nu_{\tau} \nu_{e}$$

1. Number of charged track = 4
2. Total charge (sum of Q_{sig} + sum of Q_{tag}) = 0
3. Number of photons (with $E(\gamma)_{CM}$> 0.06 GeV) <= 8
4. Total ECL energy deposition < 9 GeV
5. 1.5 GeV/c^2 < M_{missing} < 7 GeV/ c^2
6. Number of tracks in signal side = 3 && Number of track in tag side = 1
7. Max transverse momentum of electron in signal side $|\overrightarrow{p_{t\_i}}|$ > 0.15 GeV / c (CM-frame)

$\tau^{\pm} \rightarrow e^{\pm} e^{+} e^{-} \nu_{\tau} \nu_{e}$

8. Reconstructed vertex position of $\gamma(\rightarrow e^+e^-)$ should be $r(xy - \mathrm{plane})$ < 1.5cm
9. Reconstructed vertex position of $\gamma(\rightarrow e^+e^-)$ should be $r(xyz - \mathrm{space})$ < 3.0cm
10. The number of γ in signal-side <= 1 && The sum of energy of γ in signal-side < 0.5 GeV
11. Sum of $\cos\theta_{ij}$: $(\sum_{i<j} \cos\theta_{ij})$ >2.90
12. $|dz_i|$ of electrons in signal-side should be $|dz_i|$< 1cm
13. The momentum of virtual gamma in lab frame < 3 GeV/c
14. Polar angle of the missing momentum 30 deg < θ < 150 deg

SECOND STAGE SELECTION

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

1. Number of charged track = 4
2. Total charge (sum of Q_{sig} + sum of Q_{tag}) = 0
3. Number of photons (with $E(\gamma)_{CM}$> 0.06 GeV) <= 8
4. Total number of gamma in sig & tag –side <= 4
5. Total ECL energy deposition < 9 GeV
6. 1.5 GeV/c^2 < M_{missing} < 7 GeV/ c^2
7. Number of charged tracks in signal side = 3 && Number of charged track in tag side = 1
8. Reconstructed vertex position of $\gamma(\rightarrow e^{+}e^{-})$ should be $r(xy - \text{plane})$ < 1.5cm
9. The sum of energy of γ in signal-side < 0.5 GeV
10. Sum of $\cos\theta_{ij}$: $(\sum_{i<j} \cos\theta_{ij})$ >2.93
11. Polar angle of the missing momentum 30 deg < θ < 150 deg

SECOND STAGE SELECTION

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

1. Number of charged track = 4
2. Total charge (sum of $Q_{\rm sig}$ + sum of $Q_{\rm tag}$) = 0
3. Number of photons (with $E(\gamma)_{CM}$> 0.06 GeV) <= 8
4. Total ECL energy deposition < 9 GeV
5. 1.5 GeV/c^2 < $M_{\rm missing}$ < 7 GeV/ c^2
6. Number of tracks in signal side = 3 && Number of track in tag side = 1
8. The number of γ in signal-side <= 1 && The sum of energy of γ in signal-side < 0.5 GeV
9. Sum of $\cos\theta_{ij}$: $(\sum_{i<j}\cos\theta_{ij})$ >2.70
10. $(E_c/p)_{\mu}$ of muons in signal-side should be < 0.5
11. Polar angle of the missing momentum 30 deg < θ < 150 deg
12. Invariant mass of $\mu^{+}\mu^{-}$ should be < 0.5 GeV/c^2

SECOND STAGE SELECTION

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

1. Number of charged track = 4
2. Total charge (sum of Q_{sig} + sum of Q_{tag}) = 0
3. Number of photons (with $E(\gamma)_{CM}$> 0.06 GeV) <= 8
4. Total ECL energy deposition < 9 GeV
5. 1.5 GeV/c^2 < M_{missing} < 7 GeV/ c^2
6. Number of tracks in signal side = 3 && Number of track in tag side = 1
8. The number of γ in signal-side = 0
9. Sum of $\cos\theta_{ij}$: $(\sum_{i<j}\cos\theta_{ij})$ >2.85
10. $(E_c)_\mu$ of muons in signal-side should be < 0.4 GeV/c^2
11. Polar angle of the missing momentum 30 deg < θ < 150 deg
12. $|dz_i|$ of electrons in signal-side should be $|dz_i|$< 0.1cm

PREVIOUS EXPERIMENT

PREVIOUS EXPERIMENT

CLEOII measured the branching fraction of $\tau^{\pm} \to (e/\mu^{\pm}) e^{+} e^{-} \nu_{\tau} \nu_{e/\mu}$

Result of CLEOII

$$Br(\tau \to e e^{+} e^{-} \nu_{\tau} \nu_{e}) = (2.7^{+1.5+0.4+0.1}_{-1.1-0.4-0.3}) \times 10^{-5}$$

$$Br(\tau \to \mu e^{+} e^{-} \nu_{\tau} \nu_{\mu}) < 3.2 \times 10^{-5}$$ (at 90% C.L.)

CLEO-II experiment

Decay mode	Number of events
$\tau^{\pm} \to e^{\pm} e^{+} e^{-} \nu_{\tau} \nu_{e}$	5
$\tau^{\pm} \to \mu^{\pm} e^{+} e^{-} \nu_{\tau} \nu_{\mu}$	1

Integrated luminosity $3.6 fb^{-1}$

$N_{\tau\tau} = (3.28 \pm 0.05) \times 10^{6}$

Detection efficiency:

$\tau \to e e^{+} e^{-} \nu_{\tau} \nu_{e}$ (2.7±0.1)%

$\tau \to \mu e^{+} e^{-} \nu_{\tau} \nu_{\mu}$ (1.9±0.1)%

- Main source of systematic error
  - Uncertainties of lepton identification efficiency
  - Uncertainties of reconstruction efficiency of slow tracks

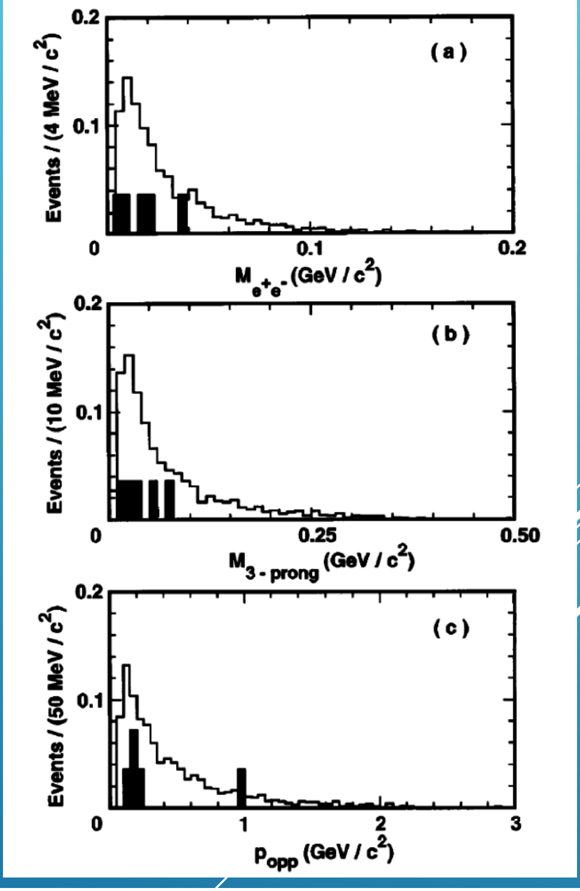


FIG. 3. Comparison of the kinematical distributions of the $\tau \to e e^{+} e^{-} \nu_{\tau} \nu_{e}$ Monte Carlo (solid line) and the data (shaded histogram) for events passing all selection requirements: (a) the $e^{+}e^{-}$ invariant mass averaged over two possible combinations, $M_{e^{+}e^{-}}$, (b) the 3-prong invariant mass, $M_{3\text{-prong}}$, and (c) the momentum of the electron on the 3-prong side with the charge opposite to that of the parent tau, p_{opp}. The normalization of the plots is arbitrary.

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