Measurement of the Michel parameters ($\bar{\eta}$, $\xi\kappa$) in the radiative leptonic decay of τ

19th Sep

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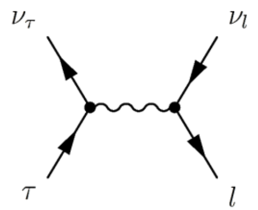
Introduction

☐ Michel parameters

- Assuming QFT and Lorentz invariance, amplitude of τ's leptonic decay is expressed as a sum of S, V and T interactions with g_{ij}^{N} .

$\mathcal{M} =$



$$= \frac{4G_F}{\sqrt{2}} \sum_{\substack{N=S,V,T \\ i,j=L,R}} g_{ij}^{N} \left[\overline{u}_i(l)\Gamma^N v_n(\nu_l)\right] \left[\overline{u}_m(\nu_\tau)\Gamma_N u_j(\tau)\right]$$

S : scalar
V : vector
T : tensor

good unbiased test of the SM, where only $g_{LL}^{V} = 1$ is nonzero

μ $J = \frac{1}{2}$

Mass $m = 0.1134289267 \pm 0.000000$
Mass $m = 105.6583715 \pm 0.0000035$
Mean life $\tau = (2.1969811 \pm 0.00000$
$\tau_{\mu^+}/\tau_{\mu^-} = 1.00002 \pm 0.00008$
$c\tau = 658.6384$ m
Magnetic moment anomaly $(g-2)/2$
$(g_{\mu^+} - g_{\mu^-}) \,/\, g_{\rm average} = (-0.11 \pm$
Electric dipole moment $d = (-0.1 \pm$

Decay parameters [b]

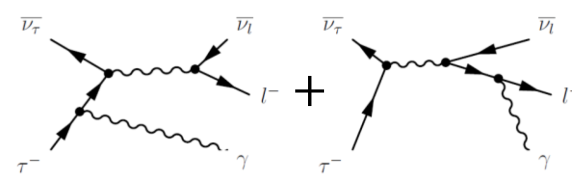
$\rho = 0.74979 \pm 0.00026$
$\eta = 0.057 \pm 0.034$
$\delta = 0.75047 \pm 0.00034$
$\xi P_\mu = 1.0009^{+0.0016}_{-0.0007}$ [c]
$\xi P_\mu \delta/\rho = 1.0018^{+0.0016}_{-0.0007}$ [c]
$\xi' = 1.00 \pm 0.04$
$\xi'' = 0.7 \pm 0.4$
$\alpha/A = (0 \pm 4) \times 10^{-3}$
$\alpha'/A = (-10 \pm 20) \times 10^{-3}$
$\beta/A = (4 \pm 6) \times 10^{-3}$
$\beta'/A = (2 \pm 7) \times 10^{-3}$
$\overline{\eta} = 0.02 \pm 0.08$

PDG summary table

- bilinear combinations of g_{ij}^{N} are experimentally observable $\rightarrow \boldsymbol{\rho, \eta, \xi\delta, \xi, \overline{\eta}, \xi\kappa}$
- Measurement of $\boldsymbol{\rho, \eta, \xi\delta, \xi}$ are already ongoing in ordinary leptonic decay $\boldsymbol{\tau \rightarrow l\nu\overline{\nu}}$.
- Of all MPs, $\boldsymbol{\overline{\eta}}$ and $\boldsymbol{\xi\kappa}$ are measured only by the radiative leptonic decay $\boldsymbol{\tau \rightarrow l\nu\overline{\nu}\gamma}$
  - Small branching ratio : $\mathcal{B}_r(\tau \rightarrow e\overline{\nu}\nu\gamma) \sim 1.75\%$, $\mathcal{B}_r(\tau \rightarrow \mu\overline{\nu}\nu\gamma) \sim 0.36\%$, $E_\gamma > 10$ MeV (CLEO experiment)

$$\overline{\eta} = |g_{RL}^{V}|^2 + |g_{LR}^{V}|^2 + \frac{1}{8}\left(|g_{RL}^{S} + 2g_{RL}^{T}|^2 + |g_{LR}^{S} + 2g_{LR}^{T}|^2\right) + 2\left(|g_{RL}^{T}|^2 + |g_{LR}^{T}|^2\right)$$

$$\xi\kappa = |g_{RL}^{V}|^2 - |g_{LR}^{V}|^2 + \frac{1}{8}\left(|g_{RL}^{S} + 2g_{RL}^{T}|^2 - |g_{LR}^{S} + 2g_{LR}^{T}|^2\right) + 2\left(|g_{RL}^{T}|^2 - |g_{LR}^{T}|^2\right)$$

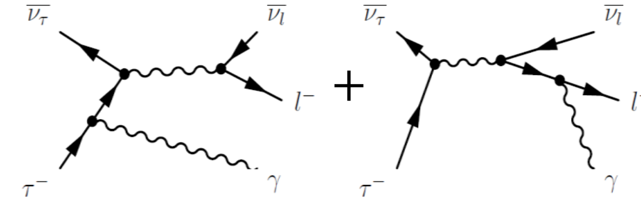


The purpose of this study is to measure the values of $\overline{\eta}, \xi\kappa$

MP	ρ	η	$\xi\delta$	ξ_h	$\overline{\eta}$	$\xi\kappa$
SM	0.75	0	0.75	1	0	0
EX	0.747 ± 0.010	0.013 ± 0.020	0.0746 ± 0.021	0.995 ± 0.007	not measured yet	

PDG Chin. Phys. C38, 090001 (2014).

Physics motivation



- Observation of γ is equivalent to the measurement of polarization of the daughter lepton:
  - coupling of τ with the right handed daughter lepton $\propto 1 - \xi'$
  - $\xi' = -\xi - 4\xi\kappa + 8\xi\delta/3$

Final piece to reveal the $V - A$ structure!

- $\bar{\eta}$ gives a constraint on each term

$$\bar{\eta} = \left|g^V_{RL}\right|^2 + \left|g^V_{LR}\right|^2 + \frac{1}{8}\left(\left|g^S_{RL} + 2g^T_{RL}\right|^2 + \left|g^S_{LR} + 2g^T_{LR}\right|^2\right) + 2\left(\left|g^T_{RL}\right|^2 + \left|g^T_{LR}\right|^2\right)$$

$\tau \to e\nu_e\nu_\tau$		
$\lvert g^S_{RR}\rvert < 0.70$	$\lvert g^V_{RR}\rvert < 0.17$	$\lvert g^T_{RR}\rvert \equiv 0$
$\lvert g^S_{LR}\rvert < 0.99$	$\lvert g^V_{LR}\rvert < 0.13$	$\lvert g^T_{LR}\rvert < 0.082$
$\lvert g^S_{RL}\rvert < 2.01$	$\lvert g^V_{RL}\rvert < 0.52$	$\lvert g^T_{RL}\rvert < 0.51$
$\lvert g^S_{LL}\rvert < 2.01$	$\lvert g^V_{LL}\rvert < 1.005$	$\lvert g^T_{LL}\rvert \equiv 0$
$\tau \to \mu\nu_\mu\nu_\tau$		
$\lvert g^S_{RR}\rvert < 0.72$	$\lvert g^V_{RR}\rvert < 0.18$	$\lvert g^T_{RR}\rvert \equiv 0$
$\lvert g^S_{LR}\rvert < 0.95$	$\lvert g^V_{LR}\rvert < 0.12$	$\lvert g^T_{LR}\rvert < 0.079$
$\lvert g^S_{RL}\rvert < 2.01$	$\lvert g^V_{RL}\rvert < 0.52$	$\lvert g^T_{RL}\rvert < 0.51$
$\lvert g^S_{LL}\rvert < 2.01$	$\lvert g^V_{LL}\rvert < 1.005$	$\lvert g^T_{LL}\rvert \equiv 0$

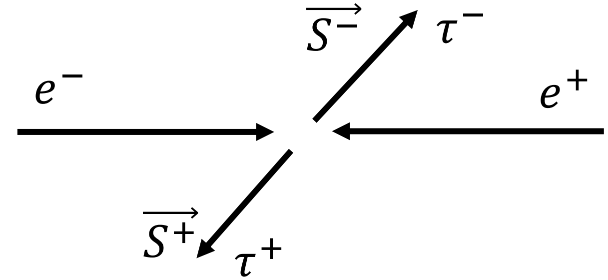
PDG Tau decay parameters

$$\left.\begin{aligned} \left|g^V_{RL}\right| &< 0.52 \\ \left|g^T_{RL}\right| &< 0.51 \\ \left|g^S_{RL}\right| &< 2.01 \\ \left|g^S_{LR}\right| &< 0.95 \end{aligned}\right\}$$

These values are not well known yet

Further constraint on NP models

Method



- $\mathrm{d}\Gamma(\tau^- \to l^- \bar{\nu}\nu\gamma) \propto \boldsymbol{A^-} - \overrightarrow{\boldsymbol{B^-}} \cdot \overrightarrow{S^-}$

$$\boxed{\begin{aligned}\mathrm{d}\Gamma = &\ \underline{n_V + \left(1 - \tfrac{4}{3}\rho\right)(2n_S + n_V - n_T) + \boldsymbol{\bar{\eta}}(2n_S - 2n_V + n_T)}\ \boldsymbol{A^-} \\ &- \overrightarrow{S^-} \cdot \underline{\boldsymbol{\xi} \textstyle\sum_{k=l,\gamma} \overrightarrow{e^k} \left\{n_V^k - \tfrac{1}{3}\left(1 - \tfrac{4}{3}\delta\right)(2n_S^k + 5n_V^k - n_T^k) + \boldsymbol{\kappa}(2n_S^k - 2n_V^k + n_T^k)\right\}}\ \overrightarrow{\boldsymbol{B^-}}\end{aligned}}$$

where $\overrightarrow{e^k}$ is direction of $k = l, \gamma$ and n_*^* are known function, whose arguments are experimentally observable.

- Measurement of $\boldsymbol{\xi\kappa}$ requires information of τ's spin
- We use correlation of the $\tau\tau$ pairs
  - The cross section $\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega_\tau}$ under the definite direction of spin $(\overrightarrow{S^-}, \overrightarrow{S^+})$ is expressed as $\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega_\tau} = D_0 + D_{ij} S_i^- S_j^+$: D_0 spin-independent, D_{ij} spin-dependent coefficients.
- We use $\tau^+ \to \rho^+(\to \pi^+\pi^0)\bar{\nu}$ decay as a spin analyzer.
  - $\mathrm{d}\Gamma(\tau^+ \to \rho^+\nu) = \boldsymbol{A^+} - \overrightarrow{\boldsymbol{B^+}} \cdot \overrightarrow{S^+}$

$$\boldsymbol{\mathrm{d}\sigma(\tau^-\tau^+ \to (l^-\nu\bar{\nu}\gamma)(\rho^+\bar{\nu}))}$$
$$\boldsymbol{\propto D_0 A^- A^+ + D_{ij} B_i^- B_j^+}$$

PDF of signal

$\boldsymbol{\bar{\eta}}$ $\boldsymbol{\xi\kappa}$

Method

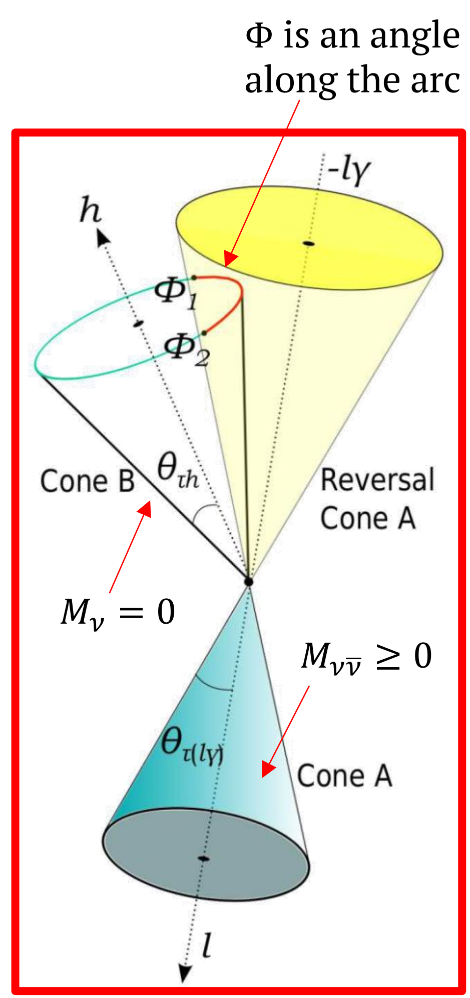
- The Michel Parameters are fitted using the likelihood function: $\mathcal{L}(\bar{\eta}, \xi\kappa) = \sum \log(PDF)$
  - "bare" PDF= $\dfrac{d\sigma}{\underbrace{dE_l^* d\Omega_l^* dE_\gamma^* d\Omega_\gamma^*}_{\tau^- \text{ side}} \underbrace{d\Omega_\rho^* dm_\rho^2 d\widetilde{\Omega}_\pi}_{\tau^+ \text{ side}} d\Omega_\tau}$

$$J = \left|\frac{\partial(E_l^*, \Omega_l^*)}{\partial(P_l, \Omega_l)}\right| \cdot \left|\frac{\partial\left(E_\gamma^*, \Omega_\gamma^*\right)}{\partial\left(P_\gamma, \Omega_\gamma\right)}\right| \cdot \left|\frac{\partial(\Omega_\rho^*, \Omega_\tau)}{\partial(P_\rho, \Omega_\rho, \Phi)}\right|$$

Convert to CMS

$$\frac{d\sigma}{dP_l d\Omega_l dP_\gamma d\Omega_\gamma dP_\rho d\Omega_\rho dm_\rho^2 d\widetilde{\Omega}_\pi \boxed{d\Phi}}$$

integrate out



Final formula

$$S(\vec{x}) = \frac{d\sigma}{dP_l d\Omega_l dP_\gamma d\Omega_\gamma dP_\rho d\Omega_\rho dm_\rho^2 d\widetilde{\Omega}_\pi} = \int_{\Phi_1}^{\Phi_2} d\Phi \frac{d\sigma}{dP_l d\Omega_l dP_\gamma d\Omega_\gamma dP_\rho d\Omega_\rho dm_\rho^2 d\widetilde{\Omega}_\pi d\Phi}$$

- $S(\vec{x})$: the visible PDF for observable $\vec{x}$ ($N_{\text{dim.}} = 12$)
- $S(\vec{x})$ has a form: $\vec{x} = \{P_l, \Omega_l, P_\gamma, \Omega_\gamma, P_\rho, \Omega_\rho, m_{\pi\pi}^2, \tilde{\Omega}_\pi\}$

Method

- Event selection & existence of BG → the visible PDF is formulated as sum of signal and BGs
  - $P_{tot}(\vec{x}) = (1 - \sum \lambda_i) \cdot \frac{S(\vec{x})\varepsilon(\vec{x})}{\int \mathrm{d}\vec{x} S(\vec{x})\varepsilon(\vec{x})} + \sum \lambda_i \frac{B_i(\vec{x})\varepsilon(\vec{x})}{\int \mathrm{d}\vec{x} B_i(\vec{x})\varepsilon(\vec{x})}$

    i: index of background

    $S(\vec{x})$: PDF of signal

    $B_i(\vec{x})$: PDF of i-th background

    λ_i: fraction of i-th background component

    $\varepsilon(\vec{x})$: selection efficiency

- $\varepsilon(\vec{x})$ does not depend on $\bar{\eta}$, $\xi\kappa$ and drops when $\mathcal{L}$ is formulated: ←no necessity of the tabulation of $\varepsilon(\vec{x})$

- Normalization is evaluated by MC
  - $S(\vec{x}) = A_0(\vec{x}) + A_{\bar{\eta}}(\vec{x}) \cdot \bar{\eta} + A_{\xi\kappa}(\vec{x}) \cdot \xi\kappa$
  - $\int \mathrm{d}\vec{x} S(\vec{x})\varepsilon(\vec{x}) = \int \mathrm{d}\vec{x} \varepsilon(\vec{x}) A_0(\vec{x}) \frac{A_0 + A_{\bar{\eta}}\bar{\eta} + A_{\xi\kappa}\xi\kappa}{A_0} = \frac{\sigma_0 \bar{\varepsilon}}{N_{\mathrm{sel}}} \sum_k \frac{A_0 + A_{\bar{\eta}}\bar{\eta} + A_{\xi\kappa}\xi\kappa}{A_0}$

$\sigma_0 = \int \mathrm{d}\vec{x} A_0(\vec{x})$

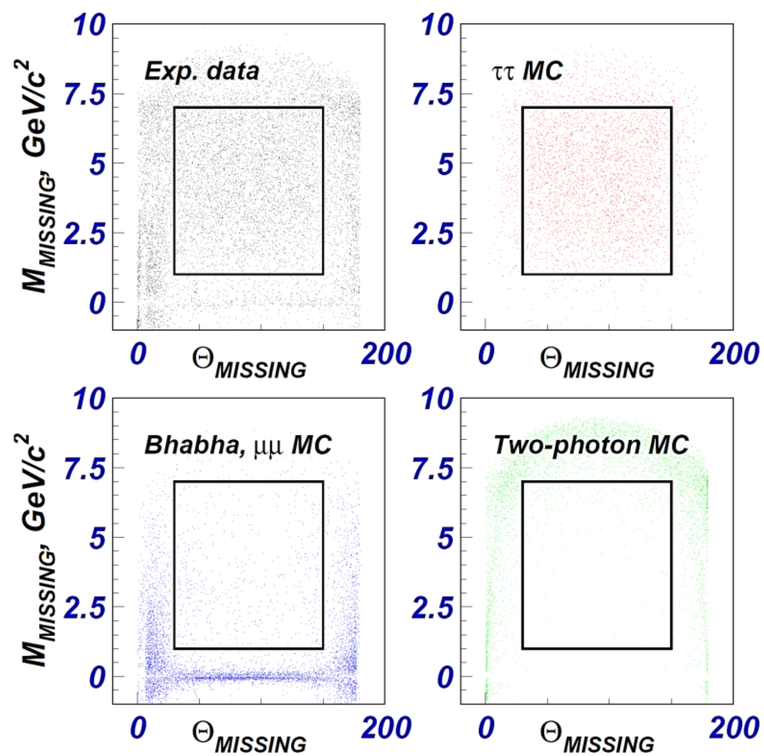
$$= \frac{\sigma_0 \bar{\varepsilon}}{N_{sel}} \left[1 + N_{\bar{\eta}} \cdot \bar{\eta} + N_{\xi\kappa} \cdot \xi\kappa\right]$$

σ_0: absolute normalization
$N_{\bar{\eta}}, N_{\xi\kappa}$: relative normalization

Event selection

- We use all data taken with $\Upsilon(4S)$ energy: $703\ \mathrm{fb}^{-1}$
- Preselection of $\tau\tau$

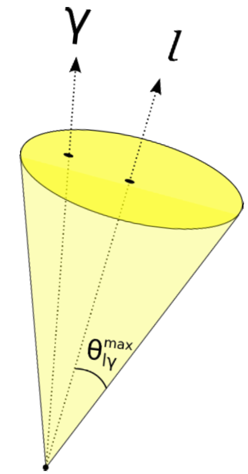
1. exactly two oppositely charged tracks
   - dr < 0.5 cm, $|\mathrm{dz}| < 2.5$ cm, one $P_t > 0.5\ \mathrm{GeV}/c$, the other $P_t > 0.1\ \mathrm{GeV}/c$
2. ECL cluster energy < 9 GeV
3. opening angle of two tracks $20^\circ < \psi < 175^\circ$
4. N_γ<5 for E_γ>80 MeV
5. $1\ \mathrm{GeV}/c^2 < M_{\mathrm{missing}} < 7\ \mathrm{GeV}/c^2$
6. $30^\circ < \theta_{\mathrm{missing}} < 175^\circ$



In particular, the last two requirements well discriminate other physics processes like

- Bhabha $e^+e^- \to e^+e^-$
- $e^+e^- \to \mu^+\mu^-$
- Two photon processes

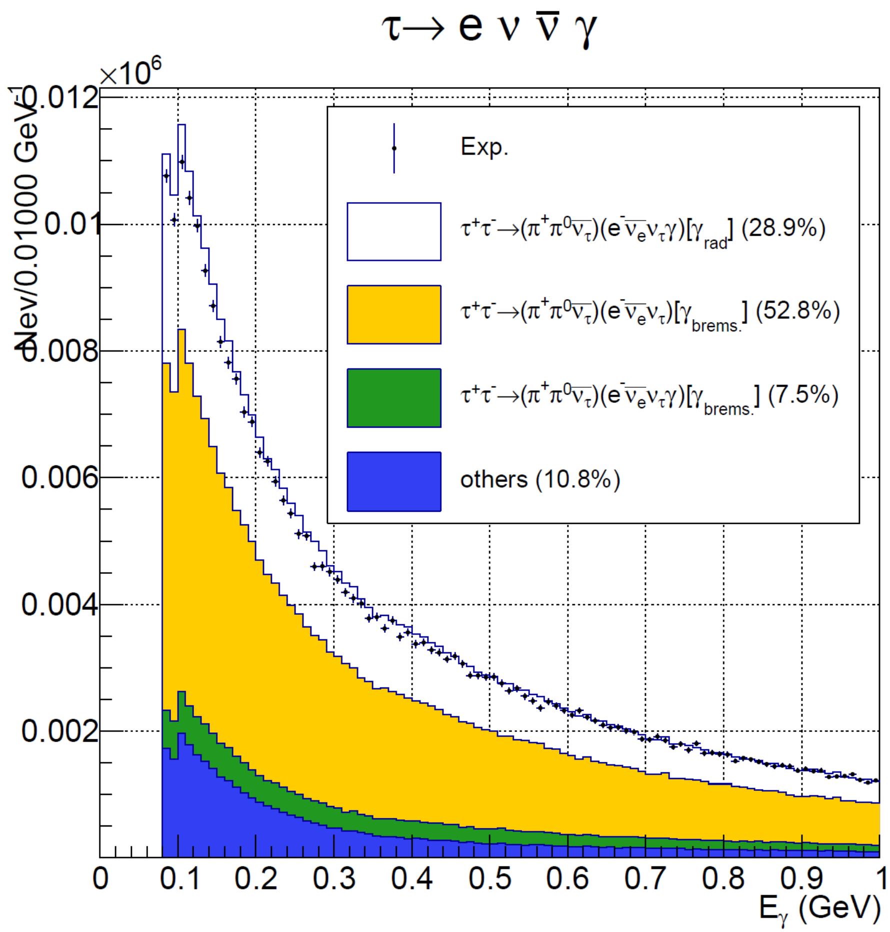
Event selection



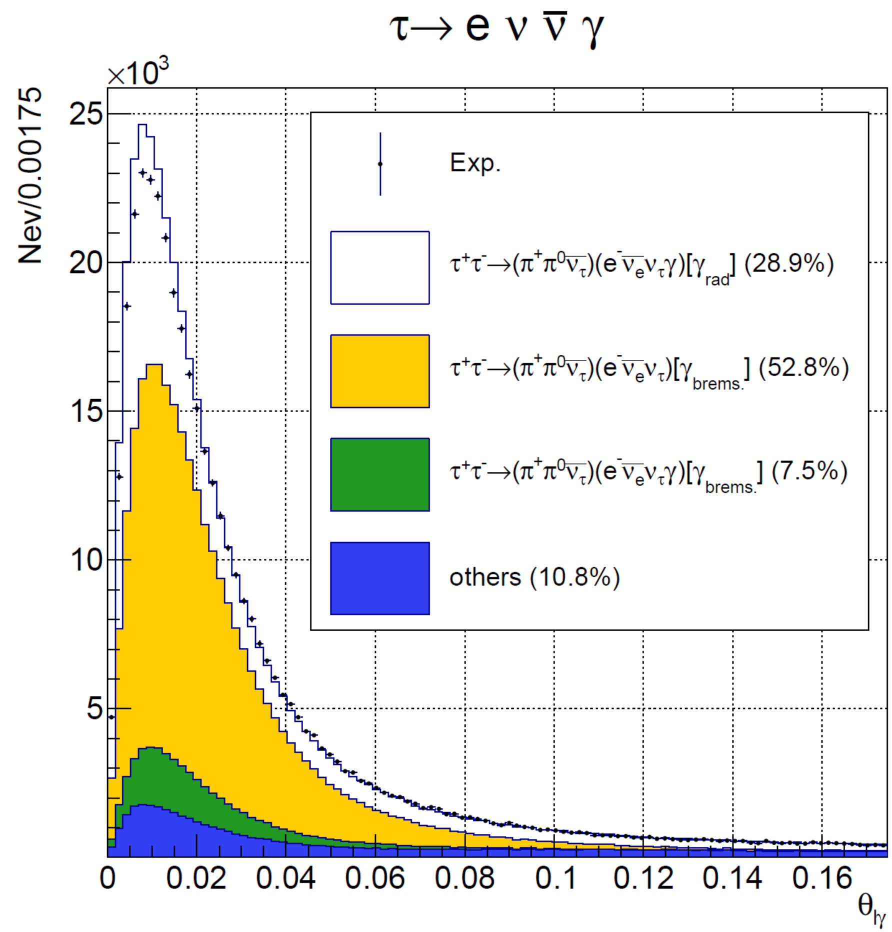
□Final selection

- Electron: $\frac{P_e}{P_e+P_x} > 0.9$, Muon: $\frac{P_\mu}{P_\mu+P_\mu+P_K} > 0.9$
- Pion: $\frac{P_\pi}{P_\pi+P_K} > 0.4$
- π^0 candidate: 115 MeV/c^2<$m_{\gamma\gamma}$<150 MeV/c^2 for E_γ>80 MeV
- ρ candidate: 0.5 GeV/c^2<$m_{\pi\pi}$<1.5 GeV/c^2
- $\theta_{\rho(l\gamma)} > 90°$
- $\cos\theta_{e\gamma} > 0.9848$, $\cos\theta_{\mu\gamma} > 0.9700$
- Energy of photons which are not associated with any tracks
  $E_{\text{extra}\gamma}$<0.2 GeV for $\tau \to e\nu\bar{\nu}\gamma$ and
  $E_{\text{extra}\gamma}$<0.3 GeV for $\tau \to \mu\nu\bar{\nu}\gamma$

$\tau \to e\nu\bar{\nu}\gamma$ candidates



E_γ



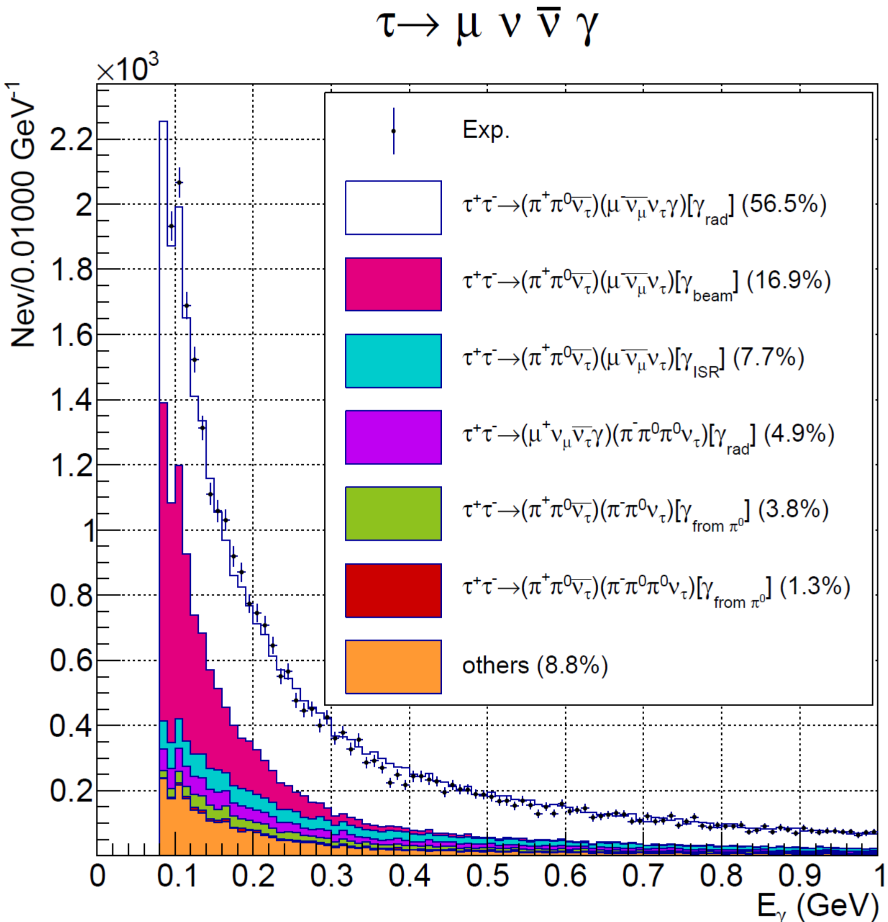
$\theta_{e\gamma}$

$\varepsilon^{\mathrm{EX}} = (4.44 \pm 0.19)\%$

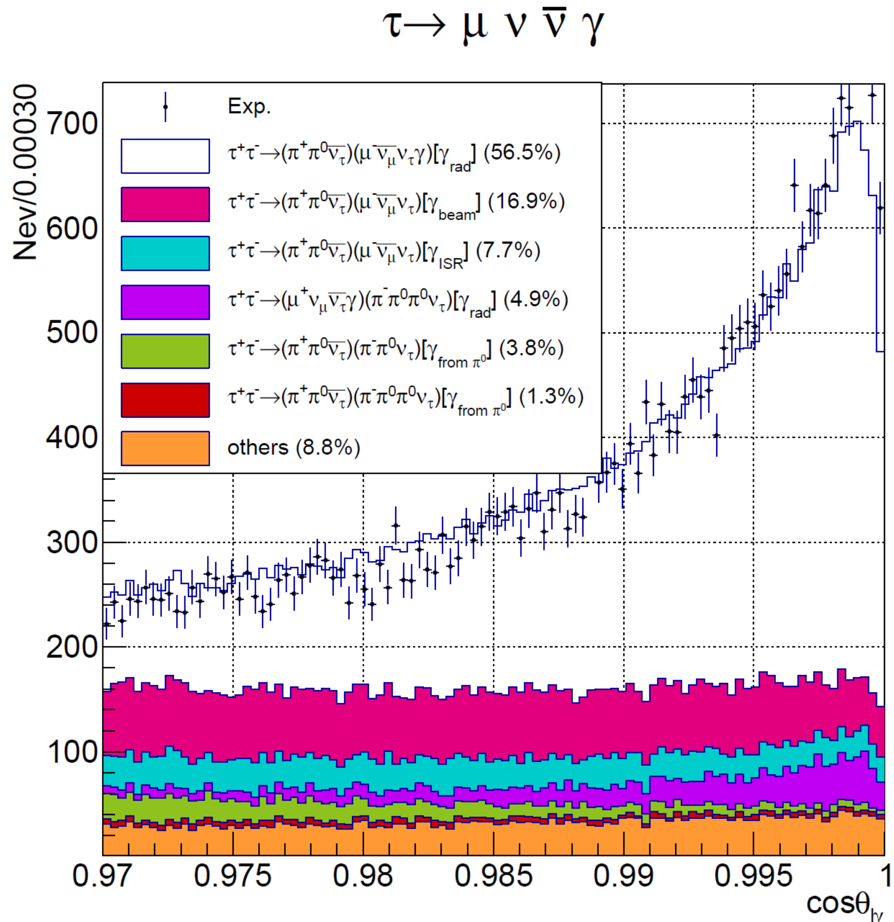
$N_{sel}(\tau^- \to e^-\nu\bar{\nu}\gamma) = 420005$

$N_{sel}(\tau^+ \to e^+\nu\bar{\nu}\gamma) = 412639$

$\tau \to \mu\nu\bar{\nu}\gamma$ candidates



E_γ



$\cos\theta_{\mu\gamma}$

$\varepsilon^{\mathrm{EX}} = (3.40 \pm 0.15)\%$

$N_{sel}(\tau^- \to \mu^-\nu\bar{\nu}\gamma) = 35984$
$N_{sel}(\tau^+ \to \mu^+\nu\bar{\nu}\gamma) = 36784$

Analysis of the experimental data

- $P_{\mathrm{tot}}(\vec{x}) = (1-\sum\lambda_i)\cdot\frac{S(\vec{x})\varepsilon^{\mathrm{MC}}(\vec{x})}{\int \mathrm{d}\vec{x}S(\vec{x})\varepsilon^{\mathrm{MC}}} + \sum\lambda_i\frac{B_i(\vec{x})\varepsilon^{\mathrm{MC}}}{\int \mathrm{d}\vec{x}B_i(\vec{x})\varepsilon^{\mathrm{MC}}}$

$$\varepsilon^{\mathrm{EX}}(\vec{x}) \to \varepsilon^{\mathrm{MC}}(\vec{x})\cdot R(\vec{x}) \quad \text{with } R(\vec{x}) = \frac{\varepsilon^{\mathrm{EX}}(\vec{x})}{\varepsilon^{\mathrm{MC}}(\vec{x})}$$

- $P_{tot}(\vec{x}) = (1-\sum\lambda_i)\cdot\frac{S(\vec{x})\varepsilon^{\mathrm{MC}}(\vec{x})R(\vec{x})}{\int \mathrm{d}\vec{x}S(\vec{x})\varepsilon^{\mathrm{MC}}R(\vec{x})} + \sum\lambda_i\frac{B_i(\vec{x})\varepsilon^{\mathrm{MC}}R(\vec{x})}{\int \mathrm{d}\vec{x}B_i(\vec{x})\varepsilon^{\mathrm{MC}}R(\vec{x})}$
- The difference of the efficiencies b.t.w MC and EX is taken account by the correction factors $R(\vec{x})$.
- $R(\vec{x}) = R_{\mathrm{trg}}$ … trigger efficiency correction

$\times R_l(P_l, \cos\theta_l)$ … lepton efficiency correction

$\times R_\gamma(P_\gamma, \cos\theta_\gamma)$ … photon efficiency correction

$\times R_\pi(P_\pi, \cos\theta_\pi)$ … pion efficiency correction

$\times R_{\pi^0}(P_{\pi^0}, \cos\theta_{\pi^0})$ … neutral pion efficiency correction

Analysis of the experimental data

- $R_l(P_l, \cos\theta_l) \equiv R_{\text{rec}} \cdot R_{LID}$
  - reconstruction efficiency correction is taken using $\tau \to \pi\pi\pi\nu$
  - lepton ID efficiency correction is estimated from two photon events: $e^+e^- \to e^+e^-l^+l^-$
- $R_\pi(P_\pi, \cos\theta_\pi) \equiv R_{\text{rec}} \cdot R_{\pi ID}$
  - pion ID efficiency correction is estimated from $D^{*+} \to D^0\pi^+$ decay
- $R_\gamma\left(P_\gamma, \cos\theta_\gamma\right), R_{\pi^0}(P_{\pi^0}, \cos\theta_{\pi^0})$
  - photon and π^0 efficiency corrections are taken from a comparison between $\tau \to \pi\pi^0\nu$ and $\tau \to \pi\nu$ decays
- R_{trg}
  - trigger reconstruction efficiency correction is extracted based on the independent neutral and charged signal information

Evaluation of systematic uncertainties

	$\tau \to e\nu\bar{\nu}\gamma$		$\tau \to \mu\nu\bar{\nu}\gamma$	
Item	$\sigma^{e}_{\bar{\eta}}$	$\sigma^{e}_{\xi\kappa}$	$\sigma^{\mu}_{\bar{\eta}}$	$\sigma^{\mu}_{\xi\kappa}$
Relative normalizations	4.2	0.94	0.15	0.04
Absolute normalizations	1.0	0.01	0.03	0.001
Description of the background PDF	2.5	0.24	0.67	0.22
Input of branching ratio	3.8	0.05	0.25	0.01
Effect of cluster merge in ECL	2.2	0.46	0.02	0.06
Detector resolution	0.74	0.20	0.22	0.02
Correction factor R	1.9	0.14	0.04	0.04
Beam energy spread	negligible	negligible	negligible	negligible
Total	7.0	1.1	0.76	0.24

Evaluation of systematic uncertainties

- Input of branching ratio
  - Uncertainties from existing Br values
  - the error is taken from the PDG values
  - the selected fractions $\delta\lambda_i/\lambda_i$ are varied and movement of fitted MPs are evaluated
- Normalizations
  - The uncertainty comes from finite number of MC events
  - The errors from the normalizations are estimated based on a central limiting theorem: $\delta N^2 = \mathrm{Var}(A/A_0)/N_{MC}$
- Correction factor tables $R(\vec{x})$
  - The effect of the error of R (δR) is estimated by varying the R values and observing the shift of MPs.

Evaluation of systematic uncertainties

- Effect of the detector resolution is estimated by turning on/off the unfolding with the resolution function.

- The effect of the beam energy spread is evaluated by varying the $\sqrt{s}$ values based on the uncertainties when we calculate PDFs: $S(\vec{x})$ and $B(\vec{x})$.

Result

- Due to the poor sensitivity of $\tau \to e\nu\bar{\nu}\gamma$ events, $\bar{\eta}$ is extracted from only $\tau \to \mu\nu\bar{\nu}\gamma$ events
- $(\xi\kappa)^e$ is fitted by fixing $\bar{\eta} = \bar{\eta}_{\mathrm{SM}} = 0$.
- $\bar{\eta}^\mu$ and $(\xi\kappa)^\mu$ are fitted simultaneously

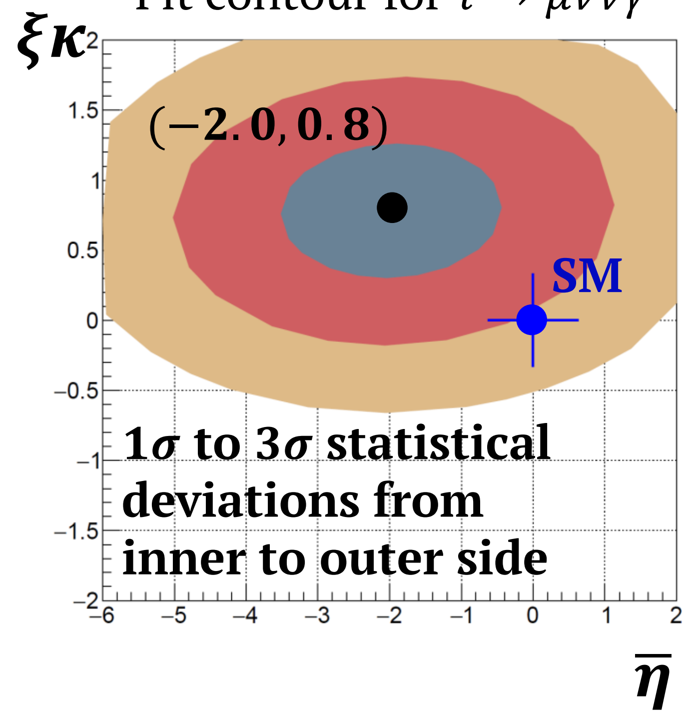
$$
\begin{aligned}
(\xi\kappa)^{(e)} &= -0.5 \pm 0.8 \pm 1.1, \\
\bar{\eta}^{\mu} &= -2.0 \pm 1.5 \pm 0.8, \\
(\xi\kappa)^{(\mu)} &= 0.8 \pm 0.5 \pm 0.2,
\end{aligned}
$$

The first error is statistical and the second is systematic.

$\xi\kappa$ are naively combined:

$$\xi\kappa = 0.6 \pm 0.5$$

Fit contour for $\tau \to \mu\nu\bar{\nu}\gamma$



- Correlation between $\bar{\eta}^\mu$ and $(\xi\kappa)^\mu$ is small (~7%)

Conclusion

- We present the first measurement of the Michel parameter $\bar{\eta}$ and $\xi\kappa$ in radiative leptonic decay $\tau \to l\nu\bar{\nu}\gamma$ using all $703\ \mathrm{fb}^{-1}$ available Belle data.
- Both $\bar{\eta}$ and $\xi\kappa$ are important to constrain general couplings of τ into leptons
- The $\bar{\eta}$ is obtained only from $\tau \to \mu\nu\bar{\nu}\gamma$ mode due to the poor sensitivity of electron mode while the $\xi\kappa$ is obtained using both modes
- The results:

$$
\begin{aligned}
(\xi\kappa)^{(e)} &= -0.5 \pm 0.8 \pm 1.1, \\
\bar{\eta}^{\mu} &= -2.0 \pm 1.5 \pm 0.8, \\
(\xi\kappa)^{(\mu)} &= 0.8 \pm 0.5 \pm 0.2,
\end{aligned}
$$

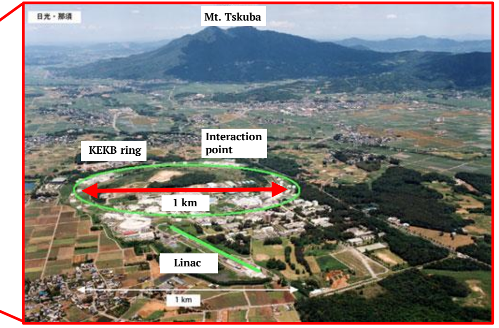
- The statistical uncertainty is larger than the systematic. The Belle II experiment (×50 stat.) allows us to do further precision tests.
- The conference paper (BELLE-CONF#1610) will be submitted on arxiv.


Thank you!

Backup

Canon EOS 6D

Belle experiment



☐KEKB accelerator

- ee collider located at Tsukuba, Ibaraki, Japan
- Energy asymmetry: $(E_{e^-}, E_{e^+}) = (8.0, 3.5)$ GeV, $\sqrt{s} = E_{\Upsilon(4S)} = 10.58$ GeV
- B-factory: collects ee collision data for 12 years.
- Total integrated luminosity: 1ab^{-1}: $\Upsilon(4S) \to o(10^9)$ BB-pairs, $\tau\tau$-pairs

☐Belle detector

- 1.5 T magnetic field
- Vertexing
  - double sided silicon strip detector
- Momentum tracking
  - drift chamber (He + C_2H_5)
- Calorimeter
  - γ: CsI(TI): $16X_0$
- Particle Identifications
  - TOF (time of flight) counter } K/π
  - aerogel Cherenkov counter }
  - $\frac{dE}{dx}$ using drift chamber — e/π
  - K_L, μ: RPC/Fe sandwich — K_L