Study of the Lorentz structure of tau decays and the rare tau decays from Belle

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τ

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2. Tau rare decays
   - ✓ $\tau \to \pi \ell \ell \nu$
   - ✓ $\tau \to \ell \ell \ell \nu\nu$

   Y.Jin gives a poster presentation.
   Please visit #E3 poster.
   (See Program Book Page 71)
3. Michel parameter measurement
   - ✓ $\tau \to \ell \gamma \nu\nu$
   - ✓ $\tau \to \ell \nu\nu$
4. Summary

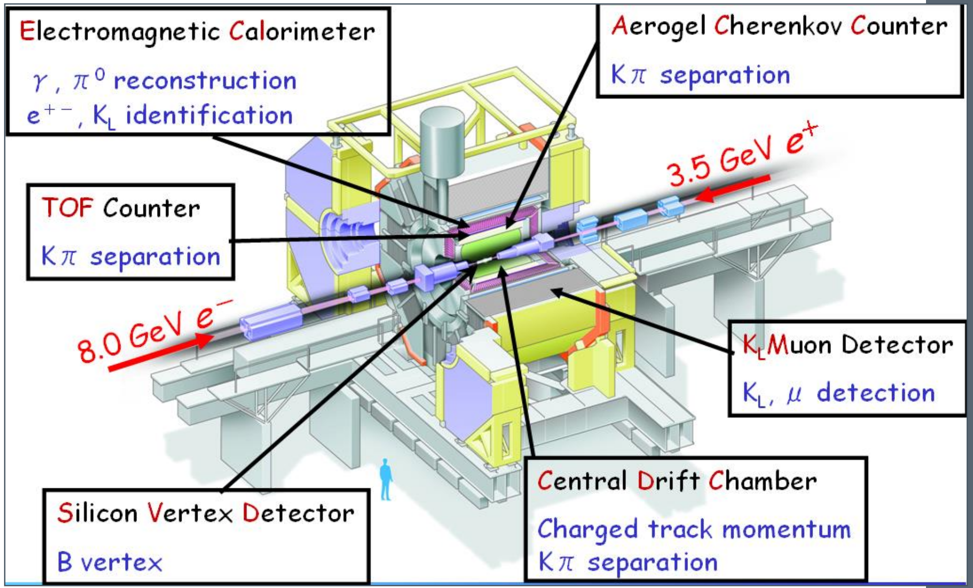
τ KEKB/Belle

B-factory: E at CM = Υ(4S)

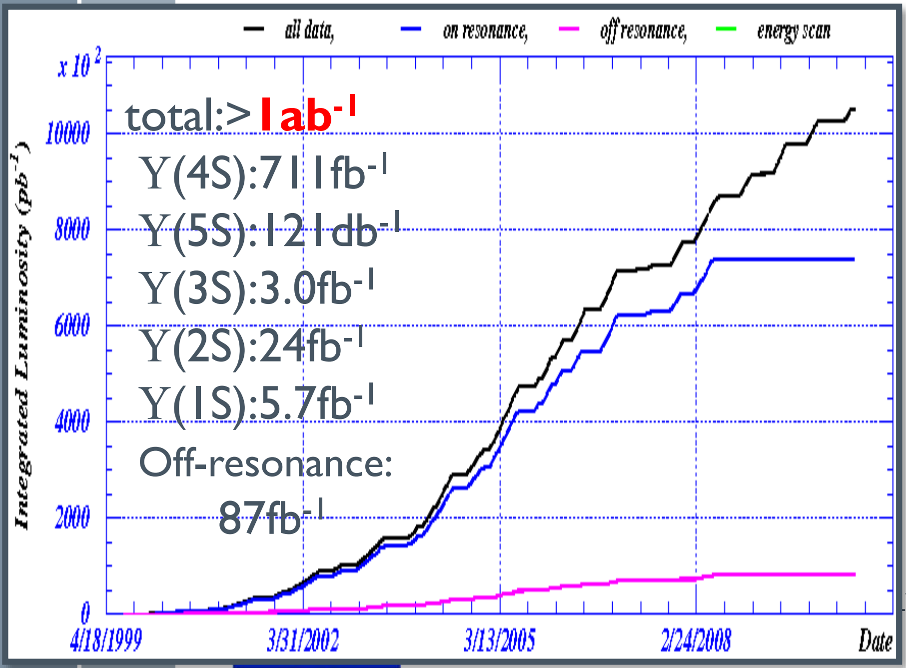
e^+(3.5 GeV) e^-(8 GeV)

$\sigma(\tau\tau):\sigma(b\bar{b})$=0.9:1.1

→B-factory is also a τ-factory!



Belle finished data taking on Jun.30,2010.



Good track reconstruction and particle identification

Lepton ID eff.~ (80-90)%

Fake rate ~ (0.1-3)%

We can analyze ~9x10^8 ττ sample at Belle.

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Tau rare decays

› Some of tau decays allowed by SM are expected to be very small.

→B-factory's sensitivity can reach to observe some of them.

We study

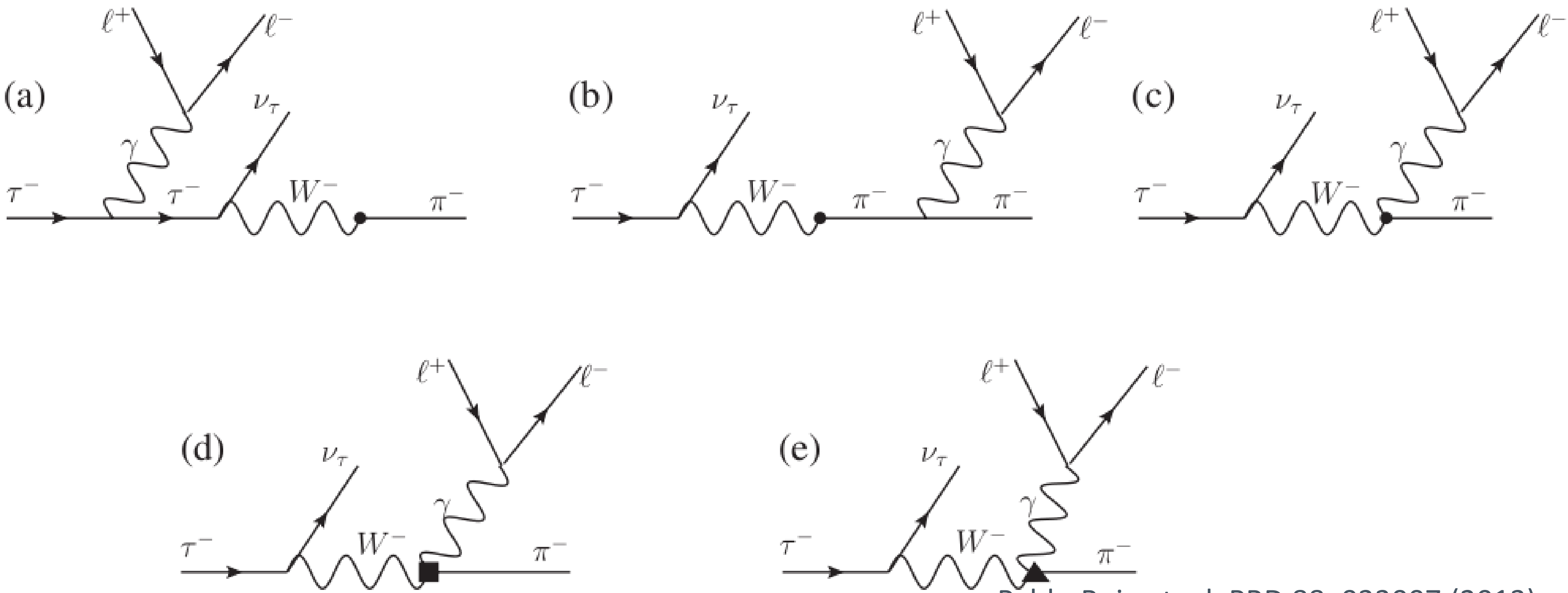
$\tau \to \ell \ \ell'^{+} \ell'^{-} \nu\nu$

$\tau \to \pi \ell^{+} \ell^{-} \nu$

using Belle's full data sample. (ℓ =e, μ)

τ Physics motivation

Intermediate processes of $\tau \to \pi \ell^+ \ell^- \nu$



Pablo.Roig et. al, PRD 88, 033007 (2013)

Recent progress of the hadron physics enables us to calc. the contributions of the detailed processes for this decay. → Good test for hadron physics

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Theoretical prediction

Theoretical prediction of BF for $\tau \to \pi \ell^+ \ell^- \nu$

$$BR(\tau^- \to \pi^- \nu_\tau e^+ e^-) = \left(1.7^{+1.1}_{-0.3}\right) \cdot 10^{-5}$$

$$BR(\tau^- \to \pi^- \nu_\tau \mu^+ \mu^-) \in \left[3 \cdot 10^{-7}, 1 \cdot 10^{-5}\right]$$

Pablo.Roig et. al, PRD 88, 033007 (2013)

These modes have been never searched for and $O(10^{-5})$ is reachable sensitivity at B-factory.

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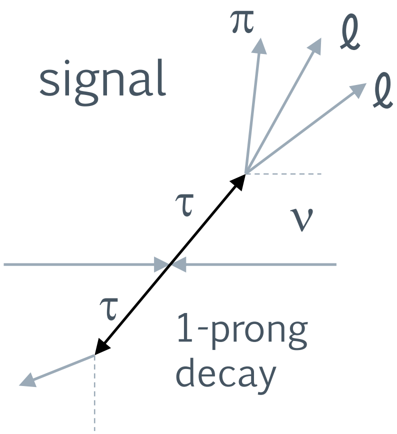
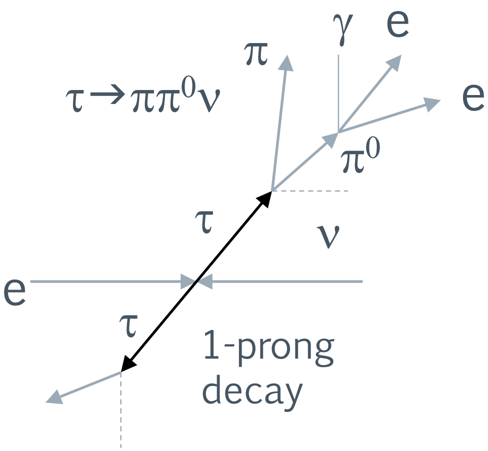
Signal topology/Expected BG

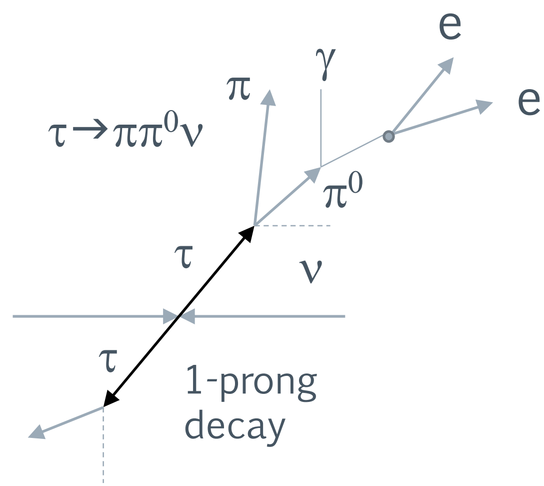
signal



BG for
e mode

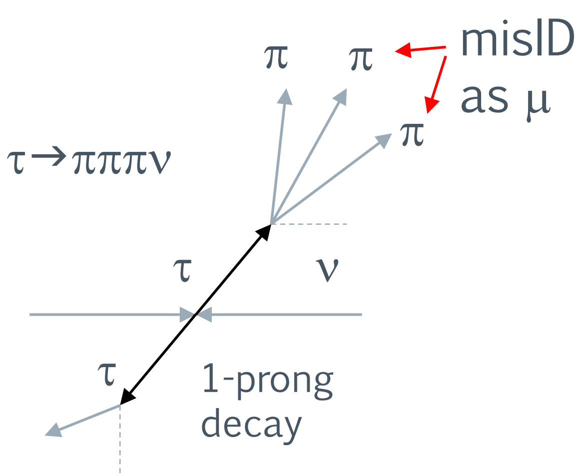


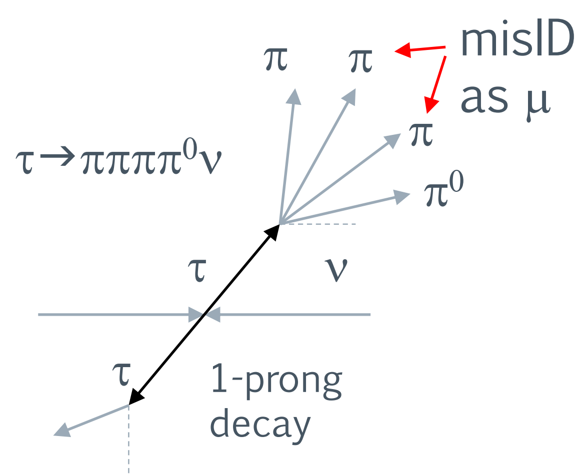
BR($\pi^0 \to \gamma ee$)~1.2%



γ-conversion

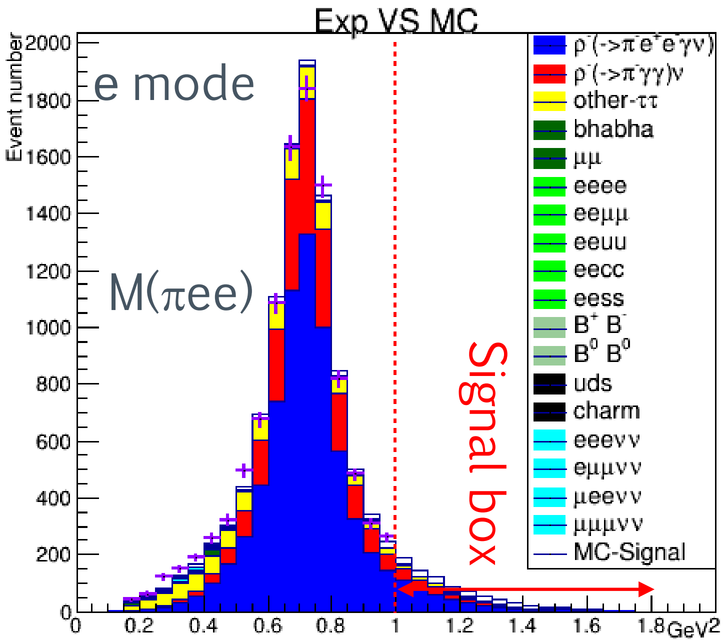
BG for
μ mode





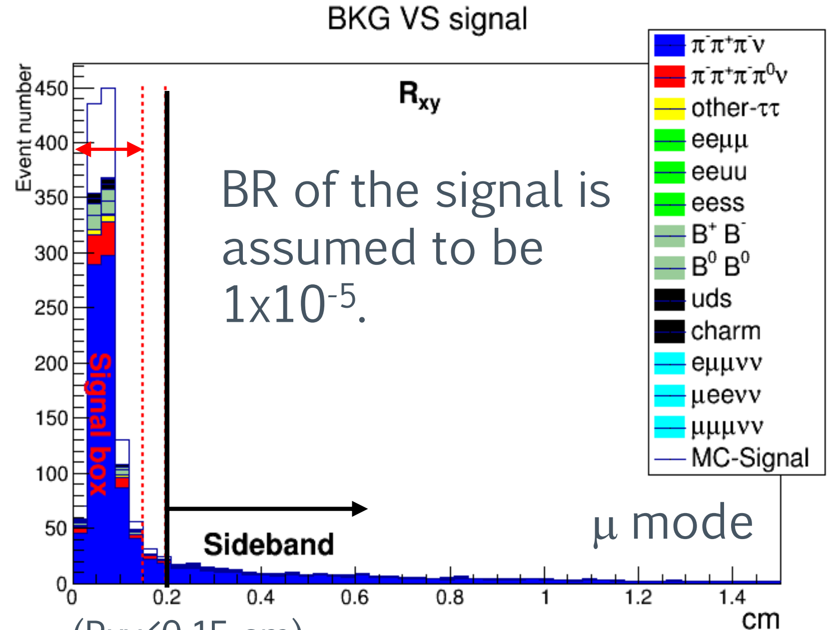
τ Signal extraction

- To avoid any bias, we perform blind analysis.
- We set different signal box for e and μ modes.



(1.05<M<1.8 GeV/c^2)

BR of the signal is assumed to be 1.7x10^{-5}.



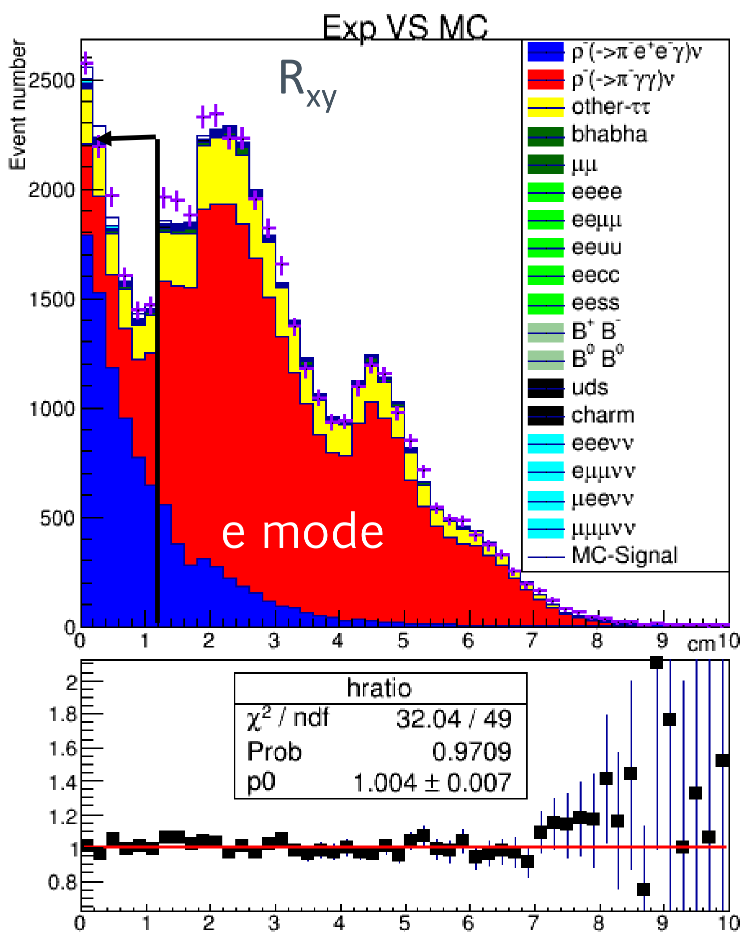
(Rxy<0.15 cm)

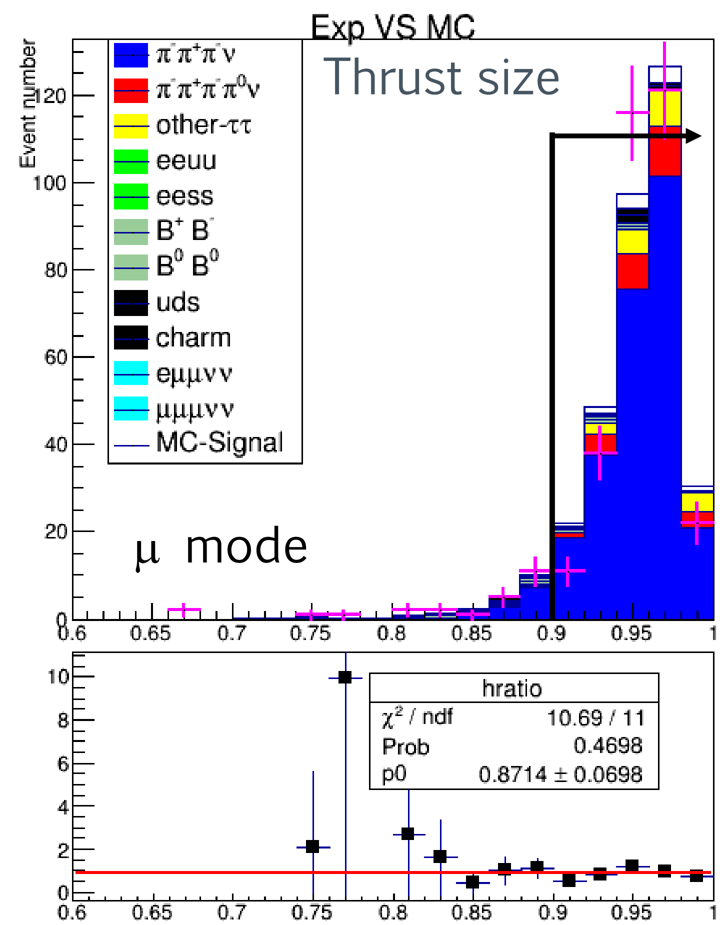
Rxy: the distance of μμ vertex from interaction point.

By subtracting BG MC in the signal box, signal yield will be evaluated.

Distributions in sideband region

› Good agreement is seen between MC and data in sideband region.→ Data well-understood





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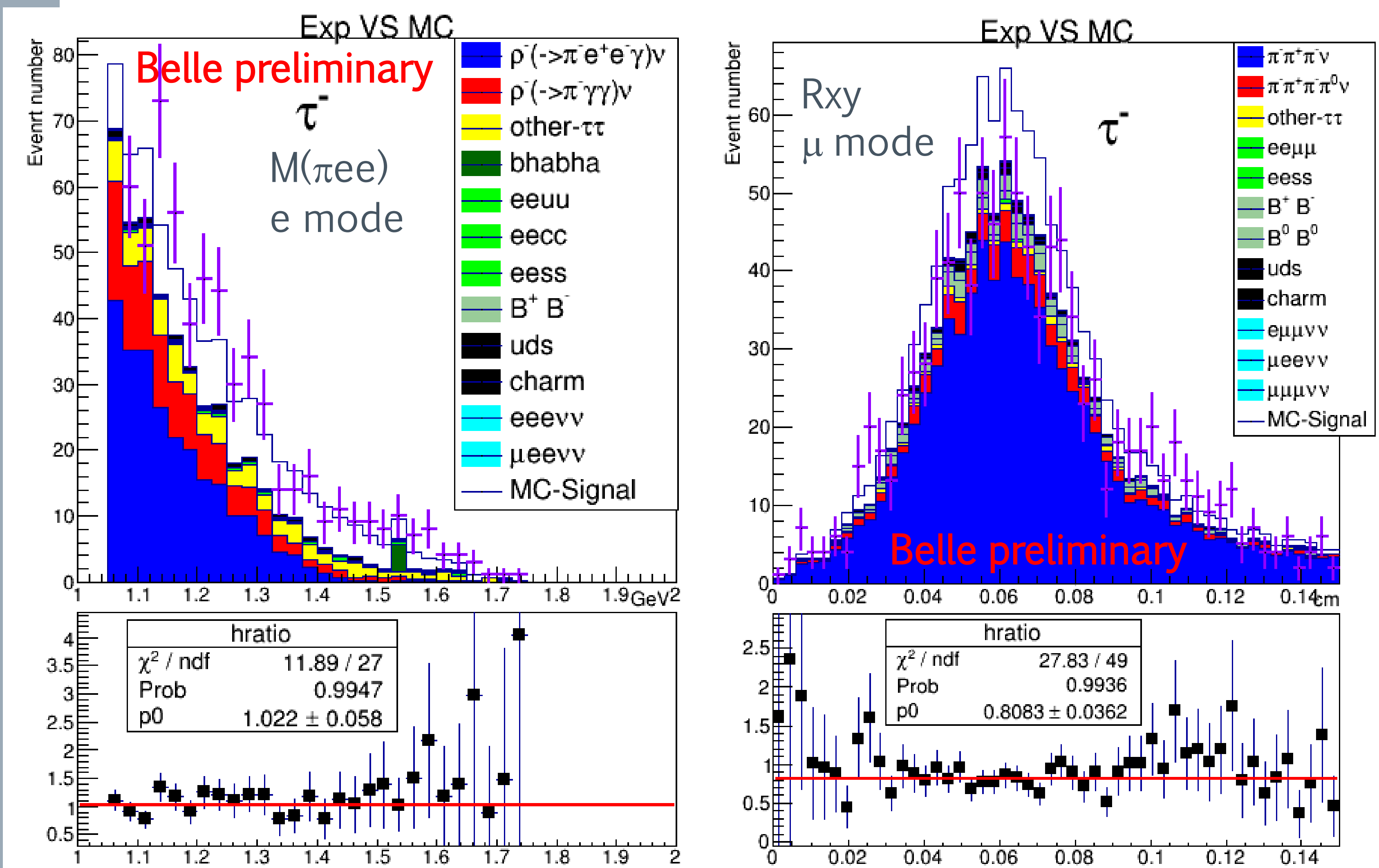
Opening the signal boxes



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Results

	$\tau^- \to \pi^- e^+ e^- \nu$	$\tau^+ \to \pi^+ e^+ e^- \nu$	$\tau^- \to \pi^- \mu^+ \mu^- \nu$	$\tau^+ \to \pi^+ \mu^+ \mu^- \nu$
Signal MC	165 ± 6	166 ± 6	205 ± 8	206 ± 8
BG MC	458 ± 22	455 ± 21	937 ± 44	933 ± 44
Observed	676	689	1001	967

$BR(\tau \to \pi e e \nu) = (2.33 \pm 0.19 \pm 0.19) \times 10^{-5}$

$BR(\tau \to \pi \mu \mu \nu) < 5.5 \times 10^{-6}$ @90%CL   **Belle preliminary**

First observation for $\tau \to \pi e e \nu$

In both case, the biggest contribution for the systematics comes from BG estimation.

Theoretical prediction (Pablo.Roig et. al, PRD 88, 033007 (2013))

$$BR(\tau^- \to \pi^- \nu_\tau e^+ e^-) = (1.7^{+1.1}_{-0.3}) \cdot 10^{-5}$$

$$BR(\tau^- \to \pi^- \nu_\tau \mu^+ \mu^-) \in [3 \cdot 10^{-7}, 1 \cdot 10^{-5}]$$

τ

$\tau \to \ell\ \ell'^{+}\ \ell'^{-} \nu\nu$

- $\tau \to \ell\ \ell'^{+}\ \ell'^{-} \nu\nu$ is also a rare decay which can be established by B-factory measurement.

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

$$Br(\tau \to \mu e^{+} e^{-} \nu_\tau \nu_\mu) < 3.2 \times 10^{-5}$$ @90% CL

CLEO Result with $3.6 fb^{-1}$

Theoretical prediction: JHEP 1604, 185(2016)

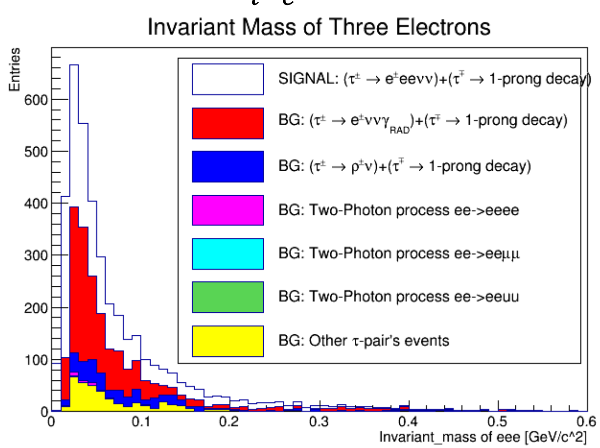
Decay mode	Branching fraction
$\tau^- \to e^- e^+ e^- \bar{\nu}_e \nu_\tau$	$(4.21 \pm 0.01) \times 10^{-5}$
$\tau^- \to e^- \mu^+ \mu^- \bar{\nu}_e \nu_\tau$	$(1.247 \pm 0.001) \times 10^{-7}$
$\tau^- \to \mu^- e^+ e^- \bar{\nu}_\mu \nu_\tau$	$(1.984 \pm 0.004) \times 10^{-5}$
$\tau^- \to \mu^- \mu^+ \mu^- \bar{\nu}_\mu \nu_\tau$	$(1.1831 \pm 0.001) \times 10^{-7}$

Expectation and BG study

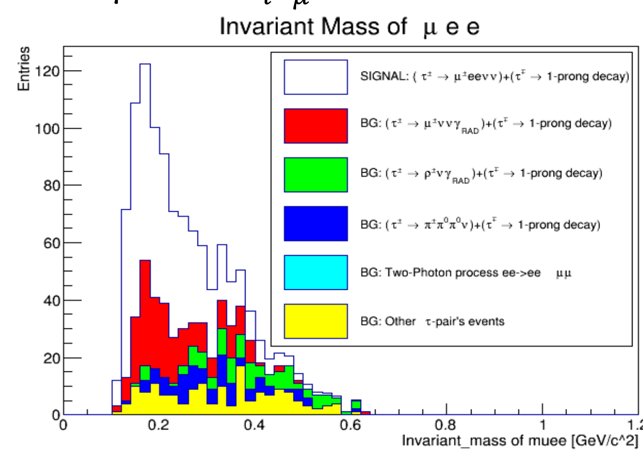
› MC studies almost finished.

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

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



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



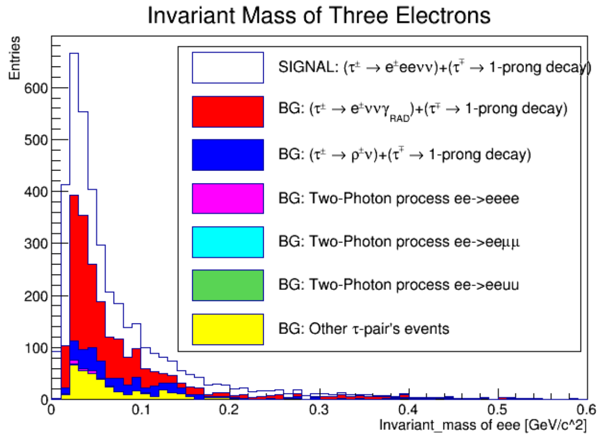
Expectation and BG study

› MC studies almost finished.

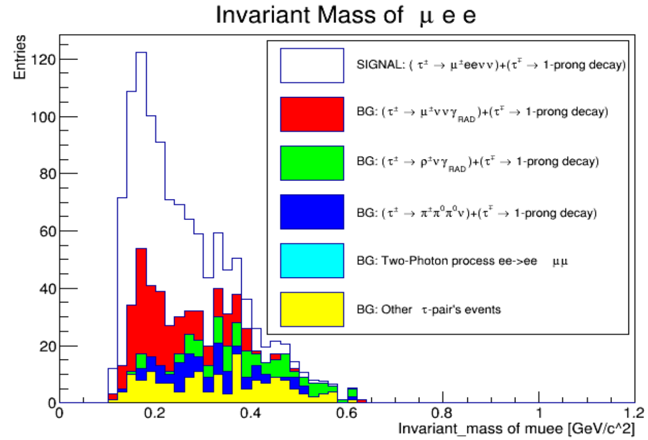
	$e^{\pm}e^{+}e^{-}\nu_{\tau}\nu_{e}$	$\mu^{\pm}e^{+}e^{-}\nu_{\tau}\nu_{\mu}$	$e^{\pm}\mu^{+}\mu^{-}\nu_{\tau}\nu_{e}$	$\mu^{\pm}\mu^{+}\mu^{-}\nu_{\tau}\nu_{\mu}$
Detection Efficiency	1.76 %	1.20%	3.56%	1.67%
Main Background(s)	$e\nu_{\tau}\nu_{e}\gamma, \pi\pi^{0}\nu_{\tau}$	$\mu\nu_{\tau}\nu_{\mu}\gamma,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

We can expect "first observation" for them!

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



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

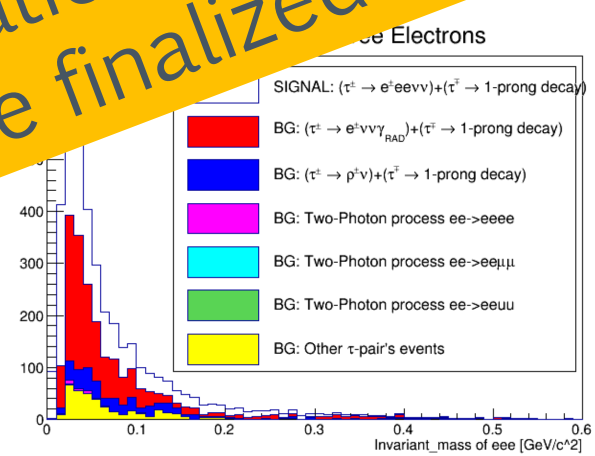


Expectation and BG study

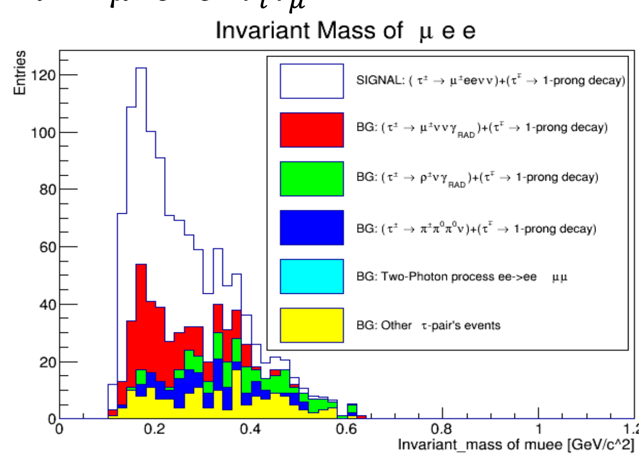
- MC studies almost finished.

	$e^{\pm}e^{+}e^{-}\nu_{\tau}\nu_{e}$	$\mu^{\pm}e^{+}e^{-}\nu_{\tau}\nu_{\mu}$	$e^{\pm}\mu^{+}$ [illegible]	
Detection Efficiency	1.76 %	1.20% [illegible]	[illegible]	[illegible]
Main Background(s)	$e\nu_{\tau}\nu_{e}\gamma, \pi\pi^{0}$ [illegible]	[illegible]	[illegible]	[illegible] τ
Expected number of signals [illegible]	[illegible]	[illegible]	[illegible]	4
[illegible]	[illegible]	[illegible] "...vation" for them!	[illegible]	[illegible] %

Optimization of the selection criteria and evaluation of the systematic uncertainties will be finalized soon.



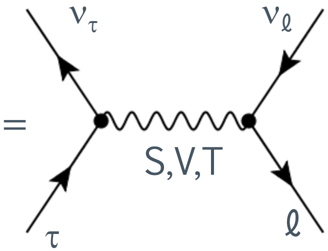
$\tau^{\pm} \to \mu^{\pm}e^{+}e^{-}\nu_{\tau}\nu_{\mu}$



Lorentz structure on τ decay

– In general, an interaction relating to τ leptonic decay can be expressed as:

$\mathcal{M} =$



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

$\ell = e$ or μ

✓In the SM, only g_{LL}^V is non-zero (=1).

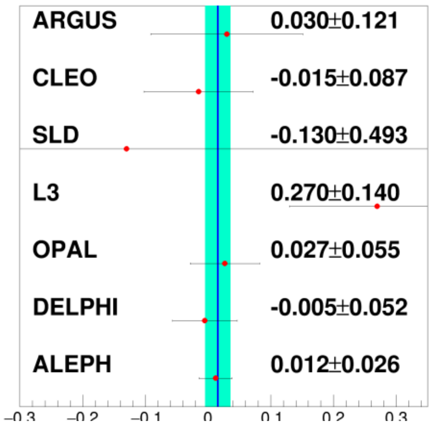
→ Non-zero g_{ij}^N indicates the existence of New Physics, model-independently!

✓Experimentally, only bilinear combinations of g_{ij}^N appear in the observables,

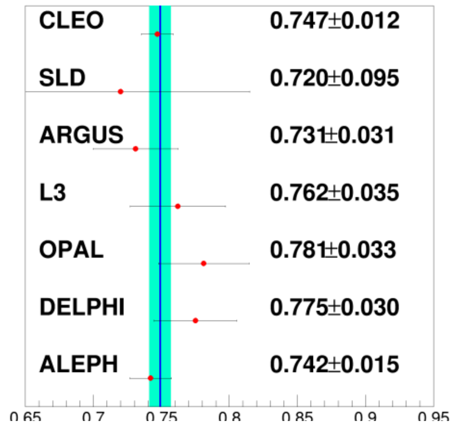
i.e., Michel parameters.

τ Experimental results

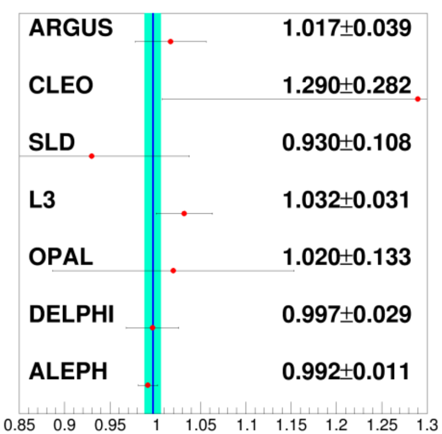
$\eta = 0.013 \pm 0.020$



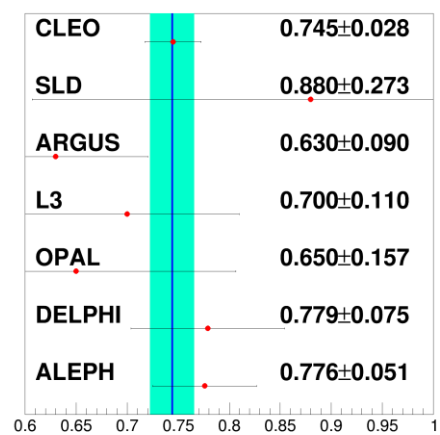
$\rho = 0.745 \pm 0.008$



$\xi_h = 0.985 \pm 0.03$



$\xi\delta = 0.746 \pm 0.021$



- ξ can be extracted from τ hadronic decays: ξ_h
- The accuracy of them in PDG are around a few percent.
- The results have been obtained more than 20 years ago.
- $\bar{\eta}$ and $\xi\kappa$ have not been measured yet.

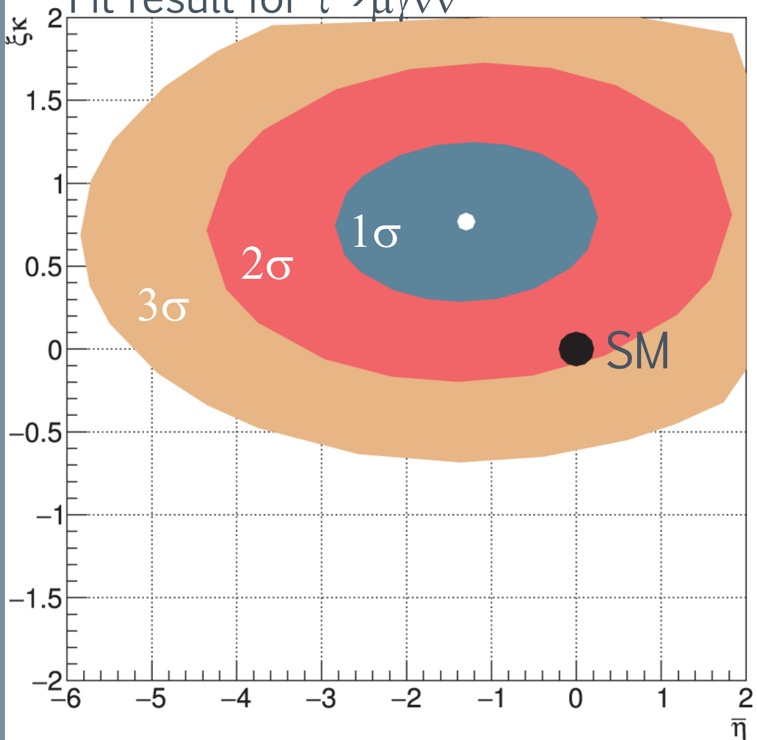
We update/firstly measure them using the world-largest τ data sample.

τ

Result for MP measurement using $\tau \to \ell \gamma \nu \nu$

- Using 711fb^{-1}, Michel parameters $\bar{\eta}, \xi\kappa$ are extracted via radiative tau leptonic decay.

Contour of likelihood



Item	$\sigma^e_{\bar{\eta}}$	$\sigma^e_{\xi\kappa}$	$\sigma^\mu_{\bar{\eta}}$	$\sigma^\mu_{\xi\kappa}$	Evaluated by
Relative normalizations	3.8	0.69	0.13	0.04	MC
Absolute normalizations	1.0	0.01	0.03	0.001	MC
Formulation of PDFs	2.5	0.24	0.67	0.22	MC
Input of branching ratio	3.8	0.05	0.25	0.01	PDG value
Effect of cluster overlap in ECL	2.2	0.46	0.02	0.06	Data
Detector resolution	0.74	0.20	0.22	0.02	MC
Exp/MC corrections	1.9	0.14	0.09	0.10	Data
E_γ selection	0.91	0.22	—	—	Data
Total	**6.8**	**0.93**	**0.77**	**0.25**	

$\tau \to e\gamma\nu\nu$ has no sensitivity for $\bar{\eta}$.
$\bar{\eta}$ is obtained only from $\tau \to \mu\gamma\nu\nu$.
$\xi\kappa$ is averaged from results for $\tau \to \mu\gamma\nu\nu$ and $\tau \to e\gamma\nu\nu$.

PTEP 2018 023C01

First measurement!

$$\bar{\eta} = 1.3 \pm 1.5 \pm 0.8$$
$$\xi\kappa = 0.5 \pm 0.4 \pm 0.2$$

Status for MP measurement using $\tau \to \ell \nu\nu$

› Systematic uncertainties

Source	$\Delta(\rho)$, %	$\Delta(\eta)$, %	$\Delta(\xi_\rho \xi)$, %	$\Delta(\xi_\rho \xi \delta)$, %
Physical corrections				
ISR+$\mathcal{O}(\alpha^3)$	0.10	0.30	0.20	0.15
$\tau \to \ell\nu\nu\gamma$	0.03	0.10	0.09	0.08
$\tau \to \rho\nu\gamma$	0.06	0.16	0.11	0.02
Background	0.20	0.60	0.20	0.20
Apparatus corrections				
Resolution $\oplus$ brems.	0.10	0.33	0.11	0.19
$\sigma(E_{\text{beam}})$	0.07	0.25	0.03	0.15
Normalization				
$\Delta\mathcal{N}$	0.11	0.50	0.17	0.13
without Data/MC corr.	**0.29**	**0.95**	**0.38**	**0.38**
trigger eff. corr.	**$\sim$ 1**	**$\sim$ 2**	**$\sim$ 3**	**$\sim$ 3**

Now, we are working on more-understanding of the trigger efficiency; Aiming to the accuracy of the sub-percent level.

Summary

- Belle studies Lorentz structure of tau decay and rare tau decays:
  - $\tau \to \pi \ell \ell \nu$ firstly has been searched for.
    - *First observation* of $\tau \to \pi ee\nu$ has been *achieved* and the upper limit of BF for $\tau \to \pi\mu\mu\nu$ is set:
    - $BR(\tau \to \pi ee\nu) = (2.33 \pm 0.19 \pm 0.19) \times 10^{-5}$
    - $BR(\tau \to \pi\mu\mu\nu) < 5.5 \times 10^{-6}$ @90CL

Belle preliminary

  - $\tau \to \ell \ell \ell \nu\nu$ analysis is on-going.
    - First observation of $\tau \to \ell ee\nu\nu$ is expected.
  - Michel parameters via $\tau \to \ell \gamma\nu\nu$ have been firstly measured.
    - $\bar{\eta} = 1.3 \pm 1.5 \pm 0.8, \xi\kappa = 0.5 \pm 0.4 \pm 0.2$ PTEP 2018 023C01
  - Michel parameters via $\tau \to \ell \nu\nu$ is on-going.
    - Aiming sub-percent accuracy

τ

Systematic uncertainties for $\tau \to \pi \ell \ell \nu$

	e mode	μ mode
Luminosity	1.4%	1.4%
$\tau\tau$ cross sec.	0.3%	0.3%
Tracking	1.4%	1.4%
PID	3.2%	3.2%
Trigger	0.5%	0.7%
Signal detection eff.	0.4%	0.3%
BG estimation	13.3%	20.5%
Total	14%	21%