Tau physics at Belle

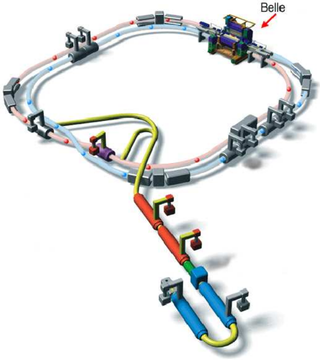
D. Epifanov
The University of Tokyo

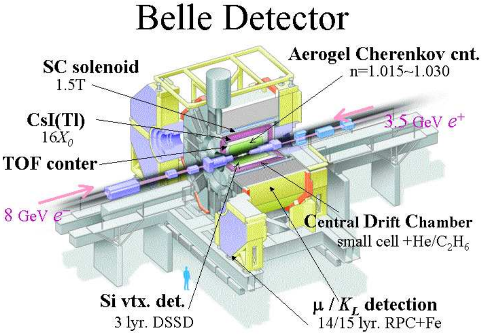
4 July 2013

Outline:

1. Belle experiment
2. Search for LFV decays
3. Measurement of tau lifetime
4. Study of $\tau^- \to K^0_S X^- \nu_\tau$
5. Summary

Belle experiment

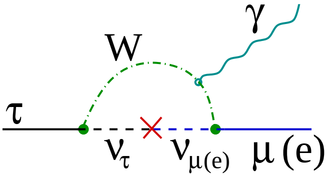




Process	σ, nb
$e^+e^- \to e^+e^-(\gamma)$ $15^o \le \theta \le 165^o$	123.5
$e^+e^- \to \mu^+\mu^-(\gamma)$	1.005
$e^+e^- \to q\bar{q}$ $(q = u, d, s, c)$	3.39
$e^+e^- \to b\bar{b}$	1.05
$e^+e^- \to e^+e^-f\bar{f}$ $(f = u, d, s, c, e, \mu, \tau)$	72.6
$e^+e^- \to \tau^+\tau^-(\gamma)$	0.919

- $E_{e^-} = 8$ GeV, $E_{e^+} = 3.5$ GeV
- Peak luminosity: $L = 2.11 \times 10^{34}$ cm^{-2}s^{-1}
- Integrated luminosity: $\int Ldt \simeq 1$ ab^{-1}, $N_{\tau\tau} \simeq 10^9$
- B-factory is also τ-factory

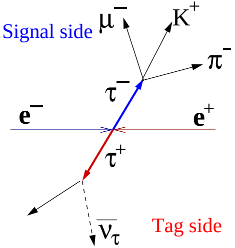
Lepton-flavor-violating (LFV) τ decays

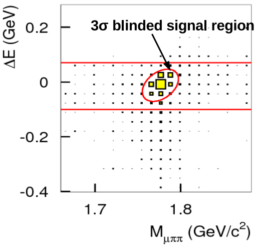


Model	$\mathcal{B}(\tau \to \mu\gamma)$	$\mathcal{B}(\tau \to \ell\ell\ell)$
mSUGRA+seesaw	10^{-8}	10^{-9}
SUSY+SO(10)	10^{-8}	10^{-10}
SM+seesaw	10^{-9}	10^{-10}
Non-universal Z'	10^{-9}	10^{-8}
SUSY+Higgs	10^{-10}	10^{-8}

- Probabililty of LFV decays of charged leptons is extremely small in the Standard Model (SM), $\mathcal{B}(\tau \to \ell\nu) \sim \left(\frac{\Delta m_\nu^2}{m_W^2}\right)^2 < 10^{-54}$
- Many models beyond the SM predict LFV decays with the branching fractions up to $\lesssim 10^{-8}$. As a result observation of LFV is a clear signature of New Physics (NP).
- τ lepton is an excellent laboratory to search for the LFV decays due to the enhanced couplings to the new particles as well as large number of LFV decay modes
- Study of the different τ LFV decay modes allows us to test various NP models.

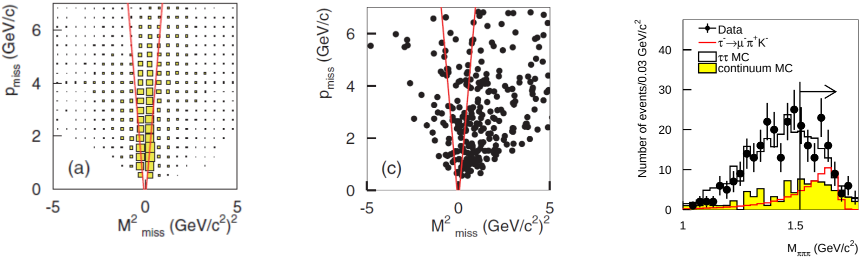
Y. Miyazaki et al. Phys. Lett. B 719 (2013) 346.
In total 14 modes were investigated: 8 LFV $\tau^- \to \ell^- h^+ h'^-$ and 6 lepton-number-violating $\tau^- \to \ell^+ h^- h'^-$ decays.





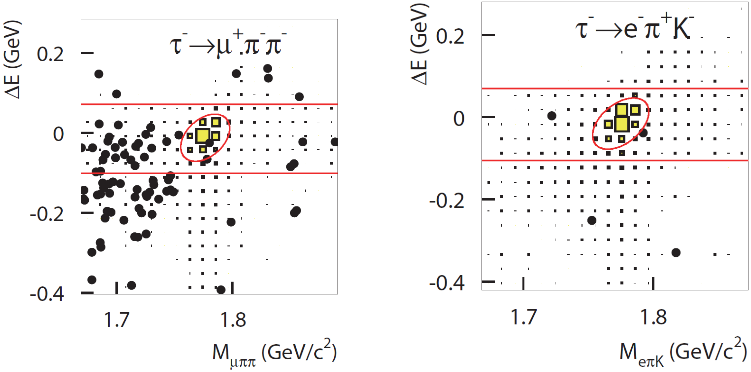
- Tag one τ by its 1-prong decay ($\mathcal{B}_{1-\text{prong}} \simeq 85\%$), the other τ is required to produce the LFV final state
- Suppress background from: $\tau\tau$, continuum $q\bar{q}$ (q=u,d,s,c), $B\bar{B}$, two-photon processes, Bhabha, $\mu\mu(\gamma)$
- Blind Analysis. A search for signal events on the (M_{inv} vs. ΔE) plane: $M_{\text{inv}} \simeq M_\tau$, $\Delta E = E_{\text{LFV}} - E_{\text{beam}} \simeq 0$

- To reject $\tau\tau$, $q\bar{q}$, Bhabha and $\mu\mu(\gamma)$ background:
  - Opening angle between missing momentum $\vec{p}_{\rm missing}$ and the charged track on the tag side is required to be $0 < \cos\theta^{\rm CM}(\vec{p}_{\rm missing}, \vec{p}_{\rm tag}) < 0.85(0.96)$ for the $\tau \to \mu hh'$ $(\tau \to ehh')$.
  - Selection on the thrust (T): $(0.90 \div 0.92) < T < (0.97 \div 0.98)$
- $m^2_{\rm missing}$ ($m^2_{\rm missing}$ vs. $p_{\rm missing}$) selection to reduce $\tau\tau$ and $q\bar{q}$ background for ehh', $\mu\pi\pi$, μKK ($\mu K\pi$) modes
- To suppress background from the $\tau \to 3\pi\nu$ events for the $\tau \to \mu K\pi$ mode we required $M_{3\pi} > 1.52$ GeV/c^2



Results for $\tau \to \ell h h'$

One event in the signal region was found for $\tau^- \to \mu^+\pi^-\pi^-$ and $\tau^- \to \mu^-\pi^+K^-$, no events for the other 12 modes. For all modes the number of observed signal events agrees with the number of expected background events.

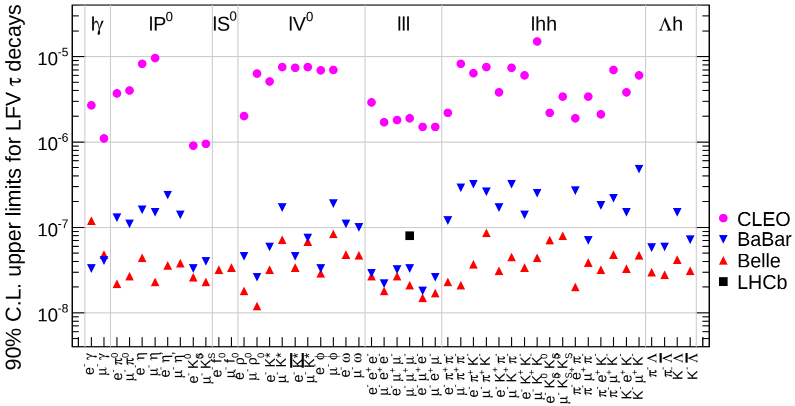


Results for $\tau \to \ell h h'$

Mode	ε (%)	N_{BG}	σ_{syst} (%)	N_{obs}	s_{90}	UL (10^{-8})
$\tau^- \to \mu^-\pi^+\pi^-$	5.83	0.63 ± 0.23	5.7	0	1.87	2.1
$\tau^- \to \mu^+\pi^-\pi^-$	6.55	0.33 ± 0.16	5.6	1	4.01	3.9
$\tau^- \to e^-\pi^+\pi^-$	5.45	0.55 ± 0.23	5.7	0	1.94	2.3
$\tau^- \to e^+\pi^-\pi^-$	6.56	0.37 ± 0.19	5.5	0	2.10	2.0
$\tau^- \to \mu^-K^+K^-$	2.85	0.51 ± 0.19	6.1	0	1.97	4.4
$\tau^- \to \mu^+K^-K^-$	2.98	0.25 ± 0.13	6.2	0	2.21	4.7
$\tau^- \to e^-K^+K^-$	4.29	0.17 ± 0.10	6.7	0	2.29	3.4
$\tau^- \to e^+K^-K^-$	4.64	0.06 ± 0.06	6.5	0	2.39	3.3
$\tau^- \to \mu^-\pi^+K^-$	2.72	0.72 ± 0.28	6.2	1	3.65	8.6
$\tau^- \to e^-\pi^+K^-$	3.97	0.18 ± 0.13	6.4	0	2.27	3.7
$\tau^- \to \mu^-K^+\pi^-$	2.62	0.64 ± 0.23	5.7	0	1.86	4.5
$\tau^- \to e^-K^+\pi^-$	4.07	0.55 ± 0.31	6.2	0	1.97	3.1
$\tau^- \to \mu^+K^-\pi^-$	2.55	0.56 ± 0.21	6.1	0	1.93	4.8
$\tau^- \to e^+K^-\pi^-$	4.00	0.46 ± 0.21	6.2	0	2.03	3.2

Obtained upper limits at 90% CL: $\mathcal{B}(\tau \to \ell h h') < (2.0 \div 8.6) \times 10^{-8}$

Results on LFV decays of τ



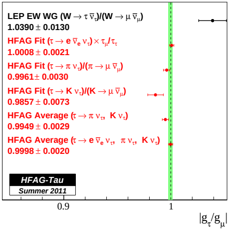
48 different LFV modes were studied at Belle

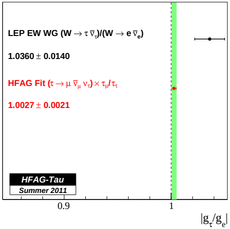
46 modes were analysed with almost full Belle statistics (~ 1 ab^{-1}) and the world best upper limits were obtained. Full statistics study of $\tau \to \mu(e)\gamma$ will be completed soon.

Ongoing studies of the general properties of τ at Belle:

- Lifetime of τ-lepton
- Electric dipole moment
- Michel parameters in leptonic and radiative leptonic τ decays (ρ, η, ξ, δ, $\bar{\eta}$, κ)
- Anomalous magnetic moment of τ in radiative leptonic decays

Precise measurement of the tau lifetime is necessary for the tests of lepton universality.



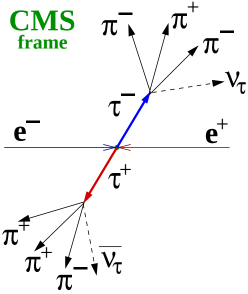


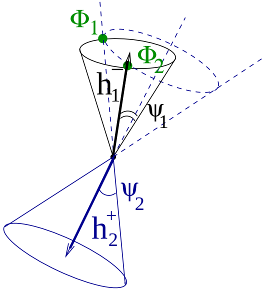
$\frac{2\mathcal{B}(W\to\tau\nu_\tau)}{\mathcal{B}(W\to\mu\nu_\mu)+\mathcal{B}(W\to e\nu_e)} = 1.066 \pm 0.025$: 2.6σ deviation from the SM

S. Schael et al. arXiv:1302.3415 [hep-ex]

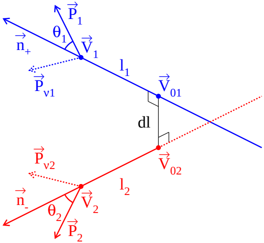
Measurement of τ_τ, method

We analyse $e^+e^- \to \tau^+\tau^- \to (\pi^+\pi^+\pi^-\bar{\nu}_\tau,\ \pi^+\pi^-\pi^-\nu_\tau)$ events.





$$\cos\psi_{1,2} = \frac{2E_\tau E_{h_{1,2}} - M_\tau^2 - m_{h_{1,2}}^2}{2p_\tau p_{h_{1,2}}}$$



$$x = \frac{\ell}{\beta_\tau\gamma_\tau}$$

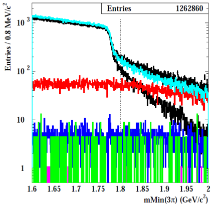
- τ momentum direction is determined with two-fold ambiguity in CMS, for the analysis we use the average axis.
- Asymmetric-energy layout of experiment allows us to determine $\tau^+\tau^-$ production point in LAB independently from the position of beam IP.
- Possibility to test CPT conservation measuring τ^- and τ^+ lifetimes separately.

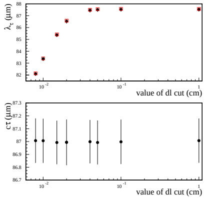
Measurement of τ_τ, selections

Use the data sample of $\int \mathrm{L}dt = 711\ \mathrm{fb}^{-1}$ with $\mathrm{N}_{\tau\tau} = 650 \times 10^6$

Selection criteria:

- Event is separated into two hemispheres in CMS, Thrust>0.9.
- Each hemisphere contains 3 charge pions with the ± 1 net charge.
- There are no additional K^0_S, Λ, π^0 candidates. Number of additional photons $\mathrm{N}_\gamma < 6$ with $\mathrm{E}^{\mathrm{TOT}}_\gamma < 0.7$ GeV.
- $\mathrm{P}_\perp(6\pi) > 0.5$ GeV/c, 4 GeV/c^2 $< \mathrm{M}_{\mathrm{inv}}(6\pi) < 10.25$ GeV/c^2.
- Pseudomass $\sqrt{\mathrm{M}_\mathrm{h}^2 + 2(\mathrm{E}_{\mathrm{beam}} - \mathrm{E}_\mathrm{h})(\mathrm{E}_\mathrm{h} - \mathrm{P}_\mathrm{h})} < 1.8$ GeV/c^2, $\mathrm{h} = (3\pi)^-,\ (3\pi^+)$.
- Cuts on the quality parameters of the vertex fits and tau axis reconstruction.
- Minimal distance between τ^- and τ^+ axes in LAB dl < 0.02 cm.





1148360 events were selected with $\sim$2% background contamination, the main background comes from $\mathrm{e}^+\mathrm{e}^- \to \mathrm{q}\bar{\mathrm{q}}$ (q =u, d, s).

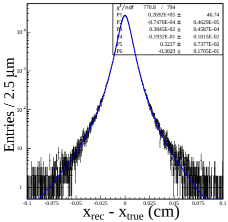
Decay length PDF

$$\mathcal{P}(x) = \mathcal{N}\int e^{-x'/\lambda_\tau} R(x - x'; \vec{P}) dx' + \mathcal{N}_{uds} R(x; \vec{P}) + \mathcal{P}_{cb}(x),$$

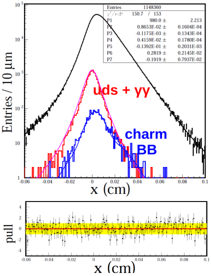
$$R(x; \vec{P}) = (1 - 2.5x) \cdot \exp\left(-\frac{(x - P_1)^2}{2\sigma^2}\right),$$

$$\sigma = P_2 + P_3|x - P_1|^{1/2} + P_4|x - P_1| + P_5|x - P_1|^{3/2}$$

- Free parameters of the fit: λ_τ, $\mathcal{N}$, $\vec{P} = (P_1, \ldots, P_5)$
- λ_τ - estimator of $c\tau_\tau$, $c\tau_\tau = \lambda_\tau + \Delta_{corr}$, Δ_{corr} is determined from MC;
- $R(x; \vec{P})$ - detector resolution function;
- $\mathcal{N}_{uds}$ - contribution of background from $e^+e^- \to q\bar{q}$ $(q = u, d, s)$ (predicted by MC)
- $\mathcal{P}_{cb}(x)$ - PDF for background from $e^+e^- \to q\bar{q}$ $(q = c, b)$ (fixed from MC)



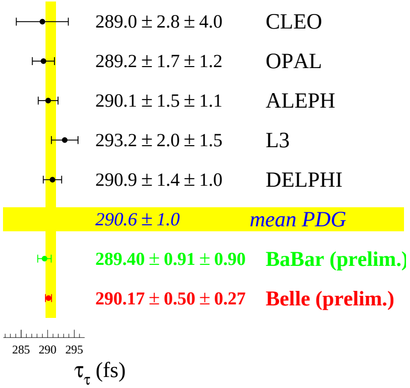
Belle preliminary



From the fit of experimental data $\lambda_\tau = 86.53 \pm 0.16$ μm, after applying $\Delta_{corr} = 0.46$ μm we have:

$$c\tau_\tau = 86.99 \pm 0.16\ \mu m$$

Measurement of τ_τ, preliminary result



Systematic uncertainties

Source	$\Delta c\tau$ (μm)
SVD alignment	0.070
Fit range	0.020
ISR and FSR description	0.018
Beam energy	0.016
Background contribution	0.010
τ-lepton mass accuracy	0.009
Total	0.078

$$c\tau_\tau = (86.99 \pm 0.16(\text{stat.}) \pm 0.08(\text{syst.}))\ \mu\text{m}.$$

$$\tau_\tau = (290.17 \pm 0.50(\text{stat.}) \pm 0.27(\text{syst.})) \times 10^{-15}\ \text{s}.$$

$$|\tau_{\tau^+} - \tau_{\tau^-}|/\tau_{\text{average}} < 7.0 \times 10^{-3}\ \text{at 90\% CL}.$$

Hadronic τ decays

Cabibbo-allowed decays ($\mathcal{B} \sim \cos^2\theta_c$)

$\mathcal{B}(S=0) = (61.85 \pm 0.11)\%$ (PDG)

Cabibbo-suppressed decays ($\mathcal{B} \sim \sin^2\theta_c$)

$\mathcal{B}(S=-1) = (2.88 \pm 0.05)\%$ (PDG)

$$iM_{fi}\left\{\begin{array}{c} S=0 \\ S=-1 \end{array}\right\} = \frac{G_F}{\sqrt{2}}\bar{u}_{\nu_\tau}\gamma^\mu(1-\gamma^5)u_\tau \cdot \left\{\begin{array}{l} \cos\theta_c \cdot \langle \mathrm{hadrons}(q^\mu)|\hat{J}^{S=0}_\mu(q^2)|0\rangle \\ \sin\theta_c \cdot \langle \mathrm{hadrons}(q^\mu)|\hat{J}^{S=-1}_\mu(q^2)|0\rangle \end{array}\right\},\ q^2 \le M_\tau^2$$

The main tasks

- Search for CP violation
- Measurement of branching fractions with highest possible accuracy
- Measurement of low-energy hadronic spectral functions
  - Determination of the decay mechanism (what are intermediate mesons and their contributions)
  - Precise measurement of masses and widths of the intermediate mesons
- Comparison with hadronic formfactors from e^+e^- experiments to check CVC theorem
- Measurement of $\Gamma_{\mathrm{inclusive}}(S=-1)$ to determine s-quark mass and V_{us}:

$$|V_{us}| = \sqrt{\frac{R_{\mathrm{strange}}}{\frac{R_{\mathrm{non-strange}}}{|V_{ud}|^2} - \delta R_{\mathrm{theory}}}}$$

- $R_{\mathrm{strange}} = \mathcal{B}_{\mathrm{strange}}/\mathcal{B}_e$
- $R_{\mathrm{non-strange}} = \mathcal{B}_{\mathrm{non-strange}}/\mathcal{B}_e$
- $\delta R_{\mathrm{theory}}$ - SU(3)-breaking contribution

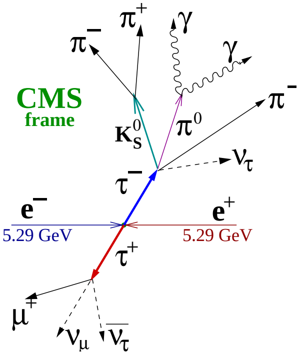
Study of $\tau^- \to K_S^0 X^- \nu_\tau$ decays

Data sample of $\int L dt = 669 \text{ fb}^{-1}$ with $N_{\tau\tau} = 616 \times 10^6$ was used to study inclusive decay $\tau^- \to K_S^0 X^- \nu_\tau$ as well as 6 exclusive modes:

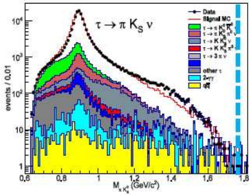
$$\pi^- K_S^0 \nu_\tau \qquad K^- K_S^0 \nu_\tau \qquad \pi^- K_S^0 K_S^0 \nu_\tau$$
$$\pi^- K_S^0 \pi^0 \nu_\tau \qquad K^- K_S^0 \pi^0 \nu_\tau \qquad \pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$$

After the standard $\tau\tau$ preselection criteria we select events with particular configuration.

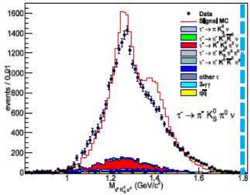
- Event is separated into two hemispheres in CMS, Thrust>0.9
- Tag side: 1-prong (e, μ or $\pi/K(n \geq 0)\pi^0$)
- Signal side:
  - $K_S^0 \to \pi^+\pi^-$: $0.485 \text{ GeV/c}^2 < M_{\pi\pi} < 0.511 \text{ GeV/c}^2$ ($\pm 5\sigma$), 2 cm$< L_{K_S^0} < 20$ cm, $\Delta Z_{1,2} < 2.5$ cm
  - $\pi^0 \to \gamma\gamma$: $-6 < S_{\gamma\gamma}(= \frac{m_{\gamma\gamma} - m_{\pi^0}}{\sigma_{\gamma\gamma}}) < 5$
  - Charged kaon (pion): $\mathcal{P}_{K/\pi} = \frac{\mathcal{L}_K}{\mathcal{L}_\pi + \mathcal{L}_K} > 0.7 (< 0.7)$
- $E_{\gamma \text{extra}}^{\text{LAB}} < 0.2$ GeV



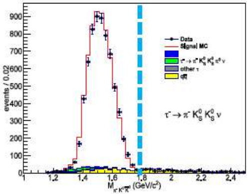
Selected events



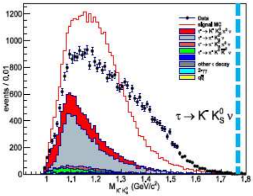
N^{Data} : 157836 ± 397
N^{BG} : 13993 ± 70



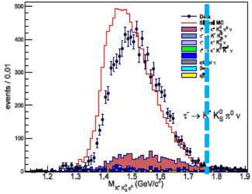
N^{Data} : 26605 ± 211
N^{BG} : 1490 ± 23



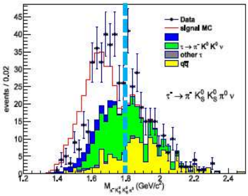
N^{Data} : 6684 ± 82
N^{BG} : 528 ± 14



N^{Data} : 32701 ± 181
N^{BG} : 1162 ± 20



N^{Data} : 8267 ± 114
N^{BG} : 201 ± 8



N^{Data} : 303 ± 17
N^{BG} : 35 ± 3

Calculation of branching fractions

Mode	$K_S^0 X^-$	$\pi^- K_S^0$	$K^- K_S^0$	$\pi^- K_S^0 \pi^0$	$K^- K_S^0 \pi^0$	$\pi^- K_S^0 K_S^0$	$\pi^- K_S^0 K_S^0 \pi^0$
N^{data}	397806 ± 631	157836 ± 541	32701 ± 295	26605 ± 208	8267 ± 109	6684 ± 96	303 ± 33
ε_{det} (%)	9.66	7.09	6.69	2.65	2.19	2.47	0.82
$\frac{N^{bg}}{N^{data}}$ (%)	4.20 ± 0.46	8.86 ± 0.05	3.55 ± 0.07	5.60 ± 0.10	2.43 ± 0.10	7.89 ± 0.24	11.6 ± 1.60
$(\frac{\Delta\mathcal{B}}{\mathcal{B}})_{syst}$(%)	2.4	2.5	4.0	3.9	5.2	4.4	8.1

The main non-$\tau\tau$ background comes from $e^+e^- \to q\bar{q}$ $(q = u,\ d,\ s,\ c)$. To take into account cross-feed background 6 decay modes are analysed simultaneously:

$$N_i^{sig} = \sum_j (\mathcal{E}^{-1})_{ij}(N_j^{data} - N_j^{bg})$$

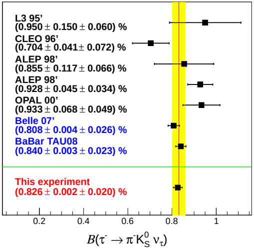
For the $\pi^- K_S^0 \nu$, $K^- K_S^0 \nu$, $\pi^- K_S^0 \pi^0 \nu$ and $K^- K_S^0 \pi^0 \nu$ modes lepton tag is applied and normalisation to the two-lepton events $(\tau^\mp \to e^\mp \nu\nu,\ \tau^\pm \to \mu^\pm \nu\nu)$ method is used to calculate branching fractions:

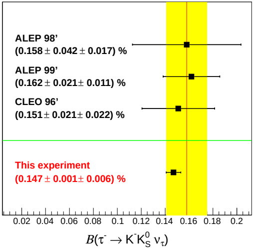
$$\mathcal{B}_i = \frac{N_i^{sig}}{N_{e\text{-}\mu}^{sig}} \frac{\mathcal{B}_e \mathcal{B}_\mu}{\mathcal{B}_e + \mathcal{B}_\mu}$$

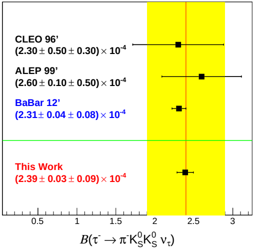
To increase statistics for the remaining $\pi^- K_S^0 K_S^0 \nu$ and $\pi^- K_S^0 K_S^0 \pi^0 \nu$ modes 1-prong tag and luminosity normalisation method are used:

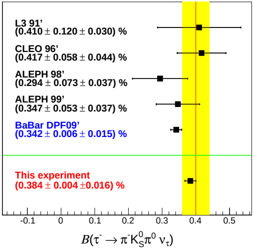
$$\mathcal{B}_i = \frac{N_i^{sig}}{2\mathcal{L}\sigma_{\tau\tau}\mathcal{B}_{1-prong}}$$

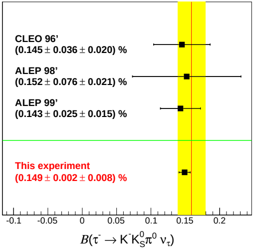
Preliminary result on branching fractions

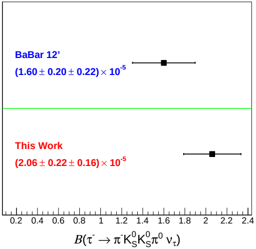






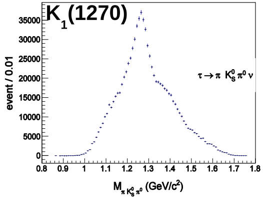


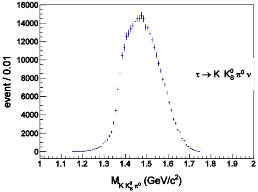




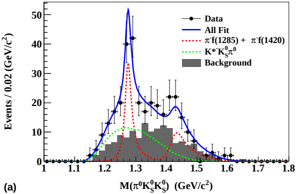
$$\mathcal{B}(\tau^- \to \mathrm{K_S^0} \mathrm{X}^- \nu_\tau) = (9.14 \pm 0.01 \pm 0.22) \times 10^{-3}$$

Unfolded invariant mass distributions (all combinations) were obtained for the $\tau^- \to K_S^0 \pi^- \pi^0 \nu_\tau$ and $\tau^- \to K_S^0 K^- \pi^0 \nu_\tau$ modes.

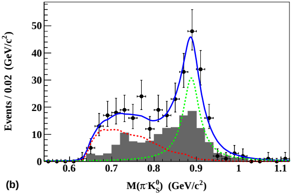




In the study of visible invariant mass spectra for $\tau^- \to \pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$ events



(a)



(b)

$f_1(1285)\pi^-\nu_\tau$ (5.9σ) and $K^{*-}(892)K_S^0\nu_\tau$ intermediate structures are observed, as well as indication of the $f_1(1420)\pi^-\nu_\tau$ (2.7σ) mechanism is seen.

$$\mathcal{B}(\tau^- \to (f_1(1285) \to K_S^0 K_S^0 \pi^0)\pi^-\nu_\tau) = (0.76 \pm 0.12 \pm 0.07) \times 10^{-5}$$
$$\mathcal{B}(\tau^- \to (K^{*-} \to K_S^0 \pi^-)K_S^0 \pi^0 \nu_\tau) = (1.11 \pm 0.15 \pm 0.09) \times 10^{-5}$$

Ongoing studies of hadronic τ decays at Belle

- Spectral function of $\tau^- \to \pi^-\pi^-\pi^+\pi^0\nu_\tau$ decay
- Spectral function of $\tau^- \to \pi^-\pi^0\pi^0\nu_\tau$ decay
- Search for CP violation in $\tau^- \to K^-\pi^-\pi^+\nu_\tau$ decay
- Branching fractions of $\tau^- \to \pi^- \geq 2\pi^0\nu_\tau$
- Branching fractions of $\tau^- \to h_1^- h_2^- h_3^+\nu_\tau$, $h_{1,2,3} = \pi,\ K$

Summary

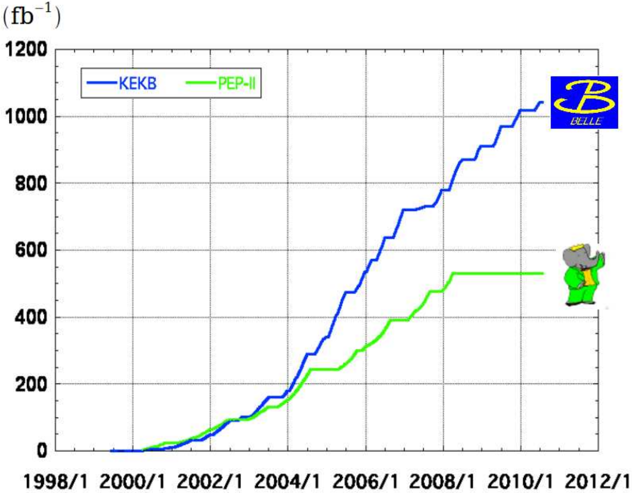
- Belle collected the world largest data sample of ~ 1 ab^{-1} ($\mathrm{N}_{\tau\tau} \simeq 10^9$) in the region of Υ(4S) resonance, which opened a new era in precise studies of τ physics.
- We studied 48 different LFV modes, 46 of them were analysed with almost full data sample and obtained upper limits on the branching fractions are of the order of 10^{-8}. Full statistics study of $\tau \to \mu(\mathrm{e})\gamma$ will be completed soon.
- With statistics of 711 fb^{-1} τ lifetime and upper limit on the relative lifetime difference between τ^+ and τ^- have been measured using new method:

$$\tau_\tau = (290.17 \pm 0.50(\mathrm{stat.}) \pm 0.27(\mathrm{syst.})) \times 10^{-15}\ \mathrm{s.}$$
$$|\tau_{\tau^+} - \tau_{\tau^-}|/\tau_{\mathrm{average}} < 7.0 \times 10^{-3} \text{ at } 90\%\ \mathrm{CL.}$$

  Our preliminary result on τ_τ is almost twice more precise than the current world average value. $|\tau_{\tau^+} - \tau_{\tau^-}|/\tau_{\mathrm{average}}$ has been measured for the first time.
- Using data sample of $\int \mathrm{Ldt} = 669$ fb^{-1} six τ hadronic decay modes with $\mathrm{K^0_S}$ have been investigated. Branching fractions for all modes as well as for the inclusive decay $\tau^- \to \mathrm{K^0_S X^-}\nu_\tau$ have been measured. Unfolded invariant mass spectra have been obtained for the $\tau^- \to \mathrm{K^0_S}\pi^-\pi^0\nu_\tau$ and $\tau^- \to \mathrm{K^0_S K^-}\pi^0\nu_\tau$ modes. For the $\tau^- \to \pi^-\mathrm{K^0_S K^0_S}\pi^0\nu_\tau$ decay $\mathrm{f_1}(1285)\pi^-\nu_\tau$ and $\mathrm{K^{*-}}(892)\mathrm{K^0_S}\nu_\tau$ mechanisms have been observed.
- Lots of ongoing analyses of τ decays at Belle, new results are expected soon.

Backup

Integrated luminosity of B factories



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 25 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

$\sim$ 100 fb^{-1}

$\sim$ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

$\sim$ 54 fb^{-1}

Preselection of $\tau\tau$ events

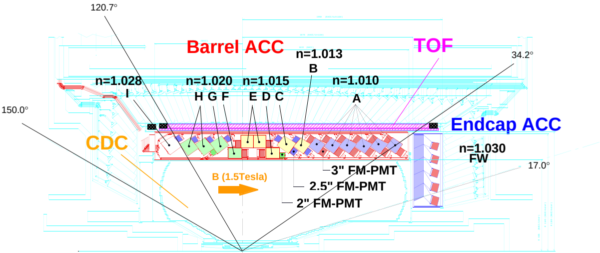
- $2 \leq \mathrm{N_{trk}} \leq 8$
- $|\mathrm{Q_{total}}| \leq 2$
- $\mathrm{P^{LAB}_{\perp\ max}} > 0.5$ GeV/c
- Event vertex $|\mathrm{R}| < 1.0$ cm, $|\mathrm{Z}| < 3.0$ cm
- For $\mathrm{N_{trk}} = 2$:
  - $\sum_{i=1}^{\mathrm{N_{clusters}}} \mathrm{E_i^{LAB}(ECL)} < 11$ GeV
  - $5^o < \theta^{\mathrm{LAB}}_{\mathrm{missing}} < 175^o$
- $\mathrm{E_{rec}} = \sum_{i=1}^{\mathrm{N_{trk}}} |\vec{\mathrm{P_i}}|^{\mathrm{CMS}} + \sum_{j=1}^{\mathrm{N_\gamma}} |\vec{\mathrm{K_j}}|^{\mathrm{CMS}} > 3$ GeV/c OR $\mathrm{P^{LAB}_{\perp\ max}} > 1.0$ GeV/c
- If $2 \leq \mathrm{N_{trk}} \leq 4$:
  - $\mathrm{E_{tot}} = \mathrm{E_{rec}} + |\sum_{i=1}^{\mathrm{N_{trk}}} \vec{\mathrm{P_i}}^{\mathrm{CMS}} + \sum_{j=1}^{\mathrm{N_\gamma}} \vec{\mathrm{K_j}}^{\mathrm{CMS}}| <$ 9 GeV/c OR Maximum opening angle$<175^o$ OR 2 GeV$<$ $\sum_{i=1}^{\mathrm{N_{clusters}}} \mathrm{E_i^{LAB}(ECL)} < 10$ GeV
  - $\mathrm{N_{barrel}} \geq 2$ OR $\sum_{\mathrm{All\ clusters}} \mathrm{E^{CMS}} - \sum_{\mathrm{photons}} \mathrm{E_\gamma^{CMS}} < 5.3$ GeV

Particle identification at Belle

For $e^{\pm}$ a likelihood ratio ID parameter $\mathcal{P}_e = \mathcal{L}_e/(\mathcal{L}_e + \mathcal{L}_x)$ is constructed. $\mathcal{L}_e$ and $\mathcal{L}_x$ include information on the specific ionization (dE/dx) measurement by the CDC, the ratio of the cluster energy in the ECL to the track momentum, the transverse ECL shower shape and the light yield in the ACC. For the $\mathcal{P}_e > 0.8$ requirement electron identification efficiency is 93%.

For $\mu^{\pm}$ a likelihood ratio ID parameter $\mathcal{P}_\mu = \mathcal{L}_\mu/(\mathcal{L}_\mu + \mathcal{L}_\pi + \mathcal{L}_K)$ is introduced. $\mathcal{L}_\mu$, $\mathcal{L}_\pi$ and $\mathcal{L}_K$ are evaluated from the information on the difference between the range calculated from the momentum of the particle and the range measured by KLM, and the χ^2 of the KLM hits with respect to the extrapolated track. For the $\mathcal{P}_\mu > 0.8$ requirement muon identification efficiency is 88%.

To separate pions from kaons we determine the pion $\mathcal{L}'_\pi$ and kaon $\mathcal{L}'_K$ likelihoods from ACC response, the specific ionization (dE/dx) measurement in the CDC and the TOF flight-time measurement for each track, and form a likelihood ratio $\mathcal{P}_{K/\pi} = \mathcal{L}'_K/(\mathcal{L}'_\pi + \mathcal{L}'_K)$ parameter. For the $\mathcal{P}_{\pi/K} > 0.7$ requirement pion identification efficiency is 93%.



Selection of $\tau^- \to K_S^0 X^- \nu_\tau$ decays