Lake Louise Winter Institute 2008

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Study of τ decays at Belle

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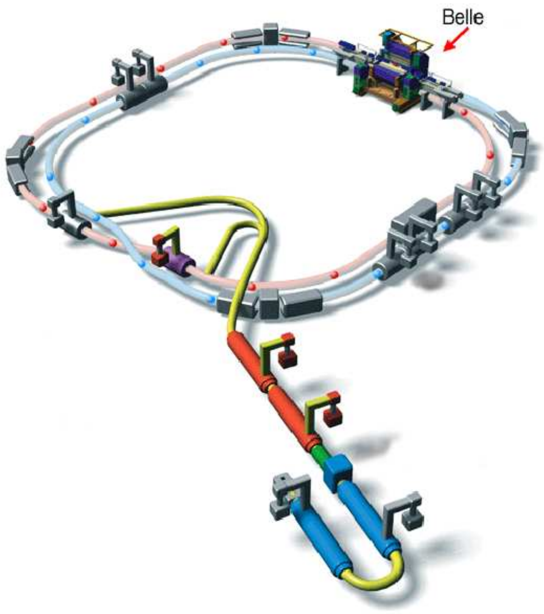
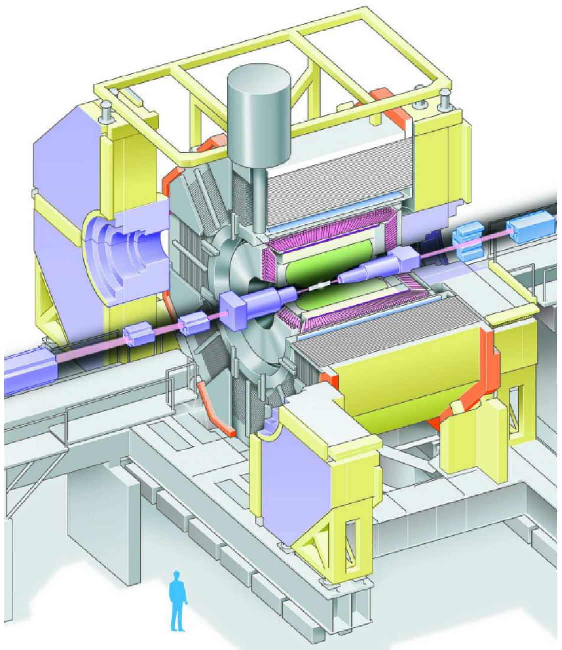
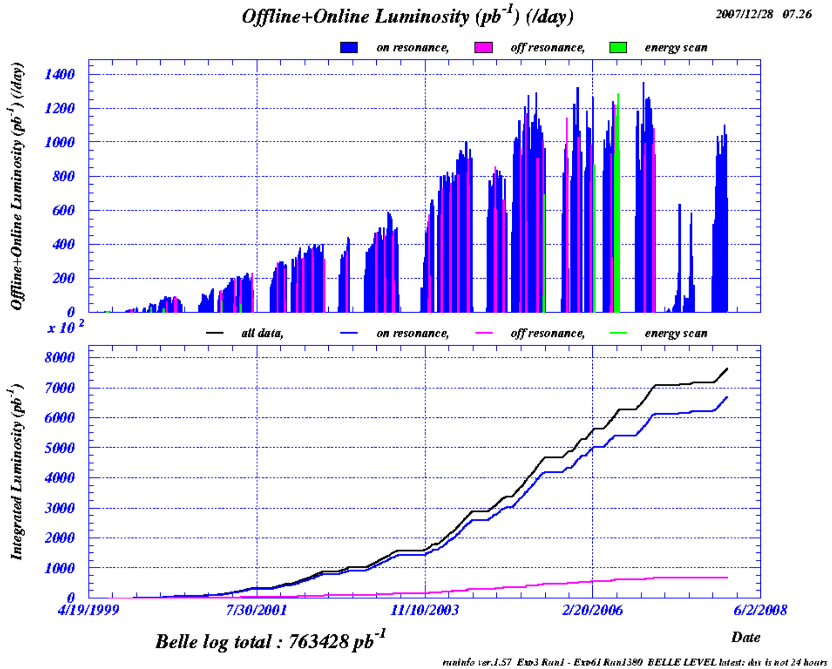
Outline:

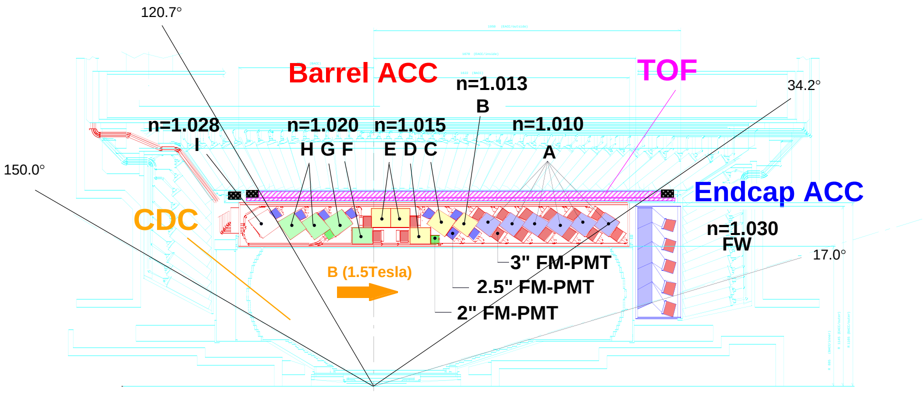
- Introduction
- Study of hadronic τ decays:
  - $\tau^- \to K_S \pi^- \nu_\tau$
  - $\tau^- \to \eta X^- \nu_\tau$
  - $\tau^- \to \phi K^- \nu_\tau$
  - $\tau^- \to \pi^- \pi^0 \nu_\tau$
- Search for lepton-flavor-violating τ decays
- Summary

KEKB B-factory, detector Belle









- $E_{e^-} = 8$ **GeV,** $E_{e^+} = 3.5$ **GeV, beam crossing angle is 0.022 rad.**
- **Peak luminosity** $L = 1.71 \times 10^{34}\ 1/\mathrm{cm}^2/\mathrm{sec}$
- **Integrated luminosity** $\int Ldt = 766\ 1/\mathrm{fb}$
- **B-factory is also** τ**-factory (**$\sigma_{B\bar{B}} = 1.1$ **nb,** $\sigma_{\tau\tau} \simeq 0.9$ **nb):** $N_{\tau\tau} = 704 \times 10^6$

Hadronic τ decays

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

$\mathcal{B}(S=0) = (61.85 \pm 0.10)\%$ (PDG)

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

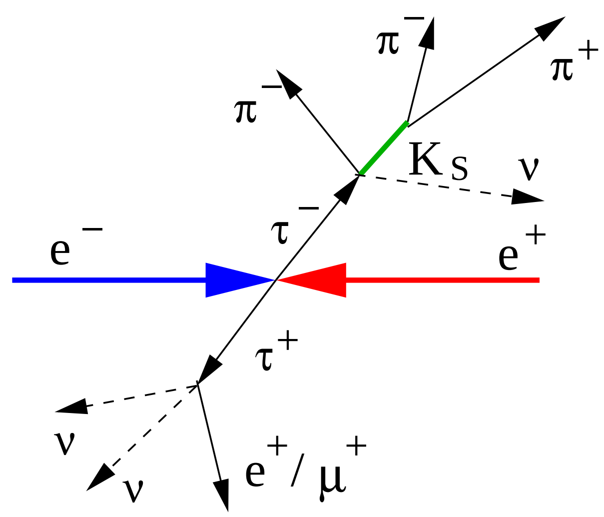
$\mathcal{B}(S=-1) = (2.95 \pm 0.07)\%$ (PDG)

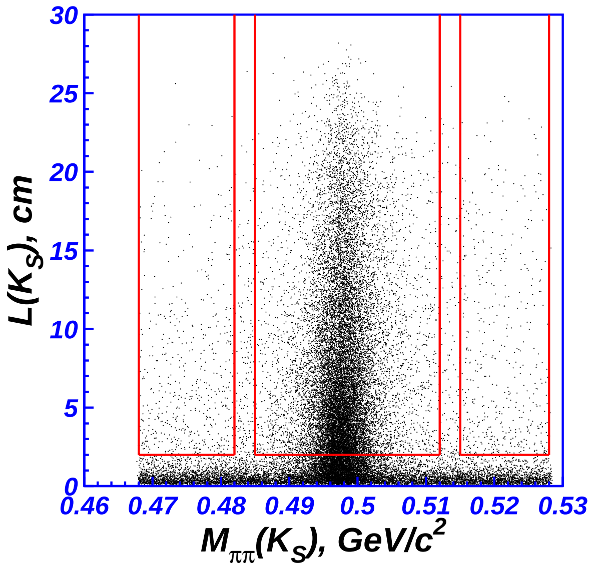
$$iM_{\rm fi}\left\{\begin{array}{c} S=0 \\ S=-1 \end{array}\right\} = \frac{G_F}{\sqrt{2}}\overline{u}_{\nu_\tau}\gamma^\mu(1-\gamma^5)u_\tau \cdot \left\{\begin{array}{c} \cos\theta_c \cdot \langle \mathrm{hadrons}(q^\mu)|\hat{J}_\mu^{S=0}(q^2)|0\rangle \\ \sin\theta_c \cdot \langle \mathrm{hadrons}(q^\mu)|\hat{J}_\mu^{S=-1}(q^2)|0\rangle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

- **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 $\Gamma_{\rm inclusive}(S=-1)$ to determine $V_{\rm us}$ and s-quark mass**

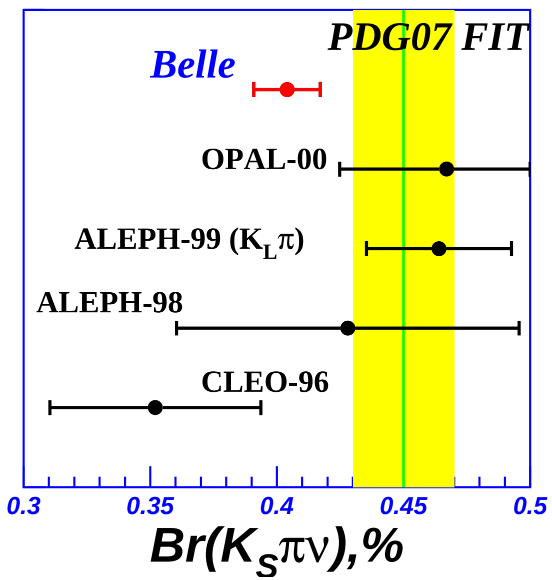
Study of $\tau^- \to K_S \pi^- \nu_\tau$ decay

Statistics: $\int Ldt = 351$ 1/fb $\to 323 \times 10^6$ $\tau\tau$ events (Phys. Lett. B **654**, 65 (2007))





Mode	Contents, %
$K_S\pi\nu$	79
$K_S\pi K_L\nu$	9
$K_S\pi\pi^0\nu$	4
$K_S K\nu$	2
$3\pi\nu$	5
non-$\tau\tau$	1



53110 signal events with efficiency $\varepsilon_{\rm det} \simeq 6\%$

Two-lepton (e, μ) events are used for normalization

$$\mathcal{B}(K_S\pi^\mp\nu_\tau) = \frac{N(l_1^\pm, K_S\pi^\mp)}{N(l_1^\pm, l_2^\mp)} \cdot \frac{\varepsilon(l_1^\pm, l_2^\mp)}{\varepsilon(l_1^\pm, K_S\pi^\mp)} \cdot \mathcal{B}(l_2^\mp \nu_l \nu_\tau), \; l_{1,2} = e, \mu$$

$\mathcal{B}(\tau^- \to K_S\pi^-\nu_\tau) = (0.404 \pm 0.002(\text{stat.}) \pm 0.013(\text{syst.}))\%$

Is in agreement with

$\mathcal{B}(\tau^- \to K^-\pi^0\nu_\tau) = (0.416 \pm 0.003(\text{stat.}) \pm 0.018(\text{syst.}))\%$

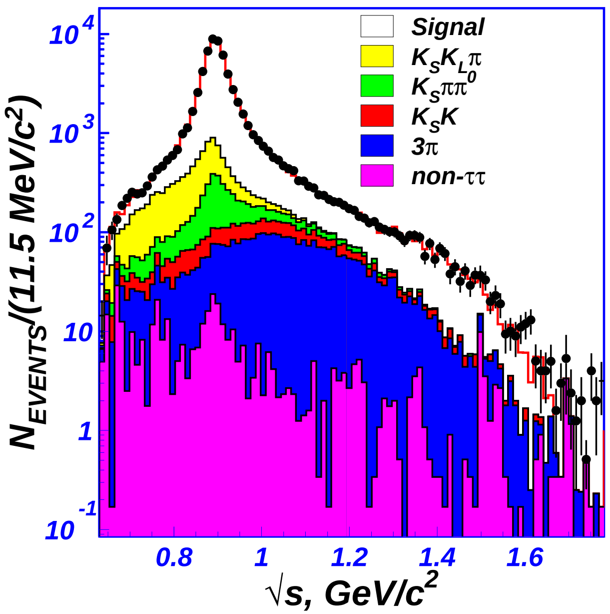
recently measured by BaBar.

$K_S\pi$ mass spectrum

$$\frac{d\Gamma}{d\sqrt{s}} \sim \frac{1}{s}\left(1-\frac{s}{M_\tau^2}\right)^2\left(1+2\frac{s}{M_\tau^2}\right)P\left\{P^2|F_V|^2+\frac{3(M_K^2-M_\pi^2)^2}{4s(1+2\frac{s}{M_\tau^2})}|F_S|^2\right\}$$

$$F_V = \frac{BW_{K^*(892)} + a(K^*(1410))\cdot BW_{K^*(1410)} + a(K^*(1680))\cdot BW_{K^*(1680)}}{1+a(K^*(1410))+a(K^*(1680))}$$

$$F_S = a(K_0^*(800))\cdot BW_{K_0^*(800)} + a(K_0^*(1430))\cdot BW_{K_0^*(1430)}$$

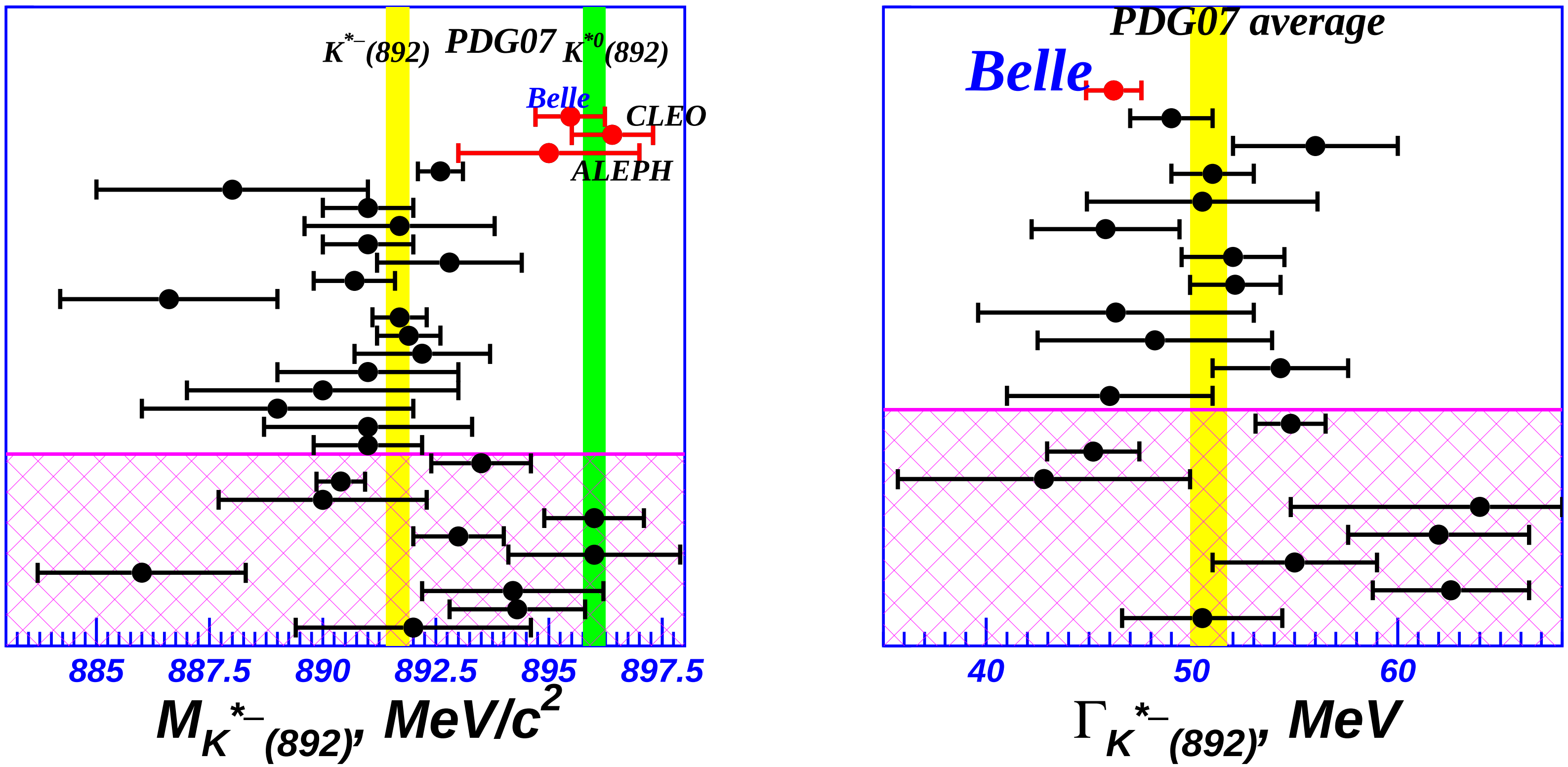


$K_0^*(800) + K^*(892) + K^*(1410)$ model	
$M_{K^*(892)}$	$= 895.47 \pm 0.20$ MeV$/c^2$
$\Gamma_{K^*(892)}$	$= 46.19 \pm 0.57$ MeV
$\lvert a(K^*(1410))\rvert$	$= 0.075 \pm 0.006$
$\arg(a(K^*(1410)))$	$= 1.44 \pm 0.15$
$\lvert a(K_0^*(800))\rvert$	$= 1.57 \pm 0.23$
$\chi^2/\mathrm{Ndf} = 90.2/84$, $P(\chi^2) = 30\%$	

The $K^*(892)$ alone is not sufficient to describe the $K_S\pi$ spectrum

$K_0^*(800) + K^*(892) + K^*(1410)/K_0^*(1430)$ **models provide the best fits**

$K^*(892)^-$ mass and width



$$M(K^*(892)^-) = (895.47 \pm 0.20(\text{stat.}) \pm 0.44(\text{syst.}) \pm 0.59(\text{mod.}))\ \text{MeV}/c^2$$

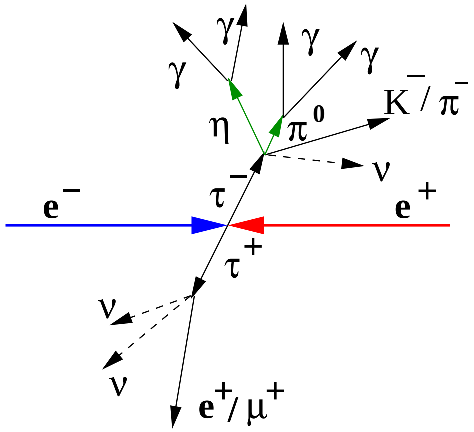
$$\Gamma(K^*(892)^-) = (46.2 \pm 0.6(\text{stat.}) \pm 1.0(\text{syst.}) \pm 0.7(\text{mod.}))\ \text{MeV}$$

	$M(K^*(892)^-)$, MeV/c^2	$\Gamma(K^*(892)^-)$, MeV	Comments
ALEPH	895 ± 2	55 ± 8	$K^-\pi^0$, syst. errors not est.
CLEO	896.4 ± 0.9		$K_S\pi^-$, syst. errors not est.

D. N. Gao and M. L. Yan, "A note on the mass splitting of K*(892)," arXiv:0710.2810 [hep-ph].

Study of $\tau^- \to K^-\eta\nu_\tau$, $K^-\pi^0\eta\nu_\tau(K^{*-}\eta\nu_\tau)$, $\pi^-\pi^0\eta\nu_\tau$ decays

Statistics: $\int L dt = 485$ 1/fb $\to 446 \times 10^6$ $\tau\tau$ events (arXiv:0708.0733 [hep-ex])

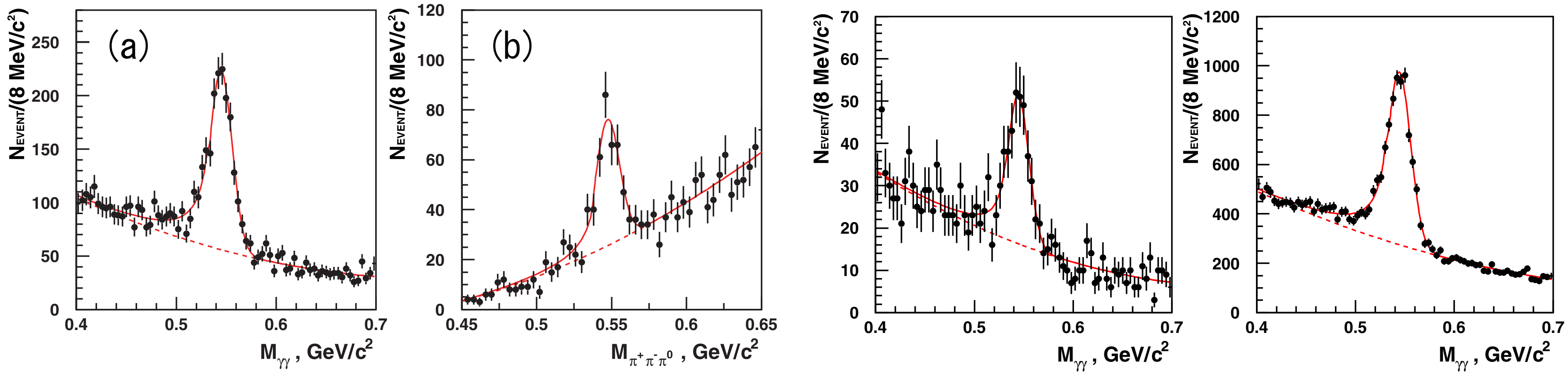


$$N_{K\eta\nu} = 2N_{\tau\tau}\left(\mathcal{B}_{K\eta\nu}\cdot\varepsilon^{K\eta\nu}_{K\eta\nu} + \mathcal{B}_{K\pi^0\eta\nu}\cdot\varepsilon^{K\eta\nu}_{K\pi^0\eta\nu} + \mathcal{B}_{\pi\pi^0\eta\nu}\cdot\varepsilon^{K\eta\nu}_{\pi\pi^0\eta\nu}\right)$$

$$N_{K\pi^0\eta\nu} = 2N_{\tau\tau}\left(\mathcal{B}_{K\eta\nu}\cdot\varepsilon^{K\pi^0\eta\nu}_{K\eta\nu} + \mathcal{B}_{K\pi^0\eta\nu}\cdot\varepsilon^{K\pi^0\eta\nu}_{K\pi^0\eta\nu} + \mathcal{B}_{\pi\pi^0\eta\nu}\cdot\varepsilon^{K\pi^0\eta\nu}_{\pi\pi^0\eta\nu}\right)$$

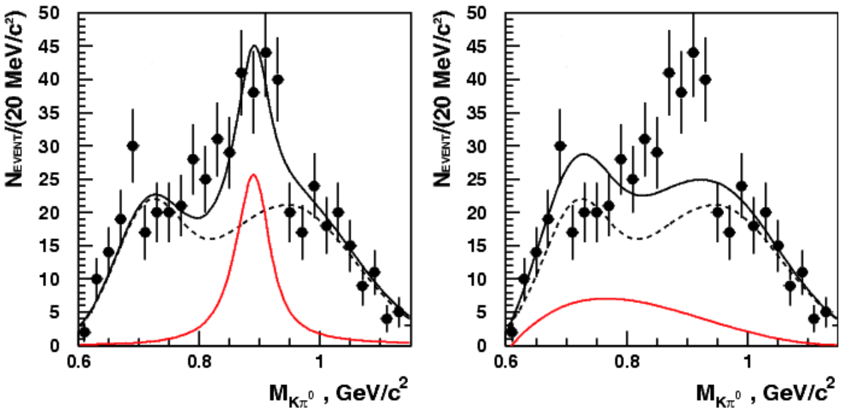
$$N_{\pi\pi^0\eta\nu} = 2N_{\tau\tau}\left(\mathcal{B}_{K\eta\nu}\cdot\varepsilon^{\pi\pi^0\eta\nu}_{K\eta\nu} + \mathcal{B}_{K\pi^0\eta\nu}\cdot\varepsilon^{\pi\pi^0\eta\nu}_{K\pi^0\eta\nu} + \mathcal{B}_{\pi\pi^0\eta\nu}\cdot\varepsilon^{\pi\pi^0\eta\nu}_{\pi\pi^0\eta\nu}\right)$$

$$\varepsilon^{K\eta\nu}_{K\eta\nu} = 0.94\%,\ \varepsilon^{K\pi^0\eta\nu}_{K\pi^0\eta\nu} = 0.35\%,\ \varepsilon^{\pi\pi^0\eta\nu}_{\pi\pi^0\eta\nu} = 0.47\%$$



	η-yield	$q\bar{q}$	other	$K\eta\nu$	$K\pi^0\eta\nu$	$\pi\pi^0\eta\nu$
$K\eta\nu$	1387 ± 43	30.6 ± 15.6	1.1 ± 0.2	–	15.1 ± 3.8	18.0 ± 1.0
$K\pi^0\eta\nu$	270 ± 33	27.0 ± 8.5	1.2 ± 0.4	16.0 ± 0.9	–	85.3 ± 4.6
$\pi\pi^0\eta\nu$	5959 ± 105	212 ± 29	71.6 ± 20	2.4 ± 0.1	9.4 ± 2.4	–
$K\eta\nu$ $(\eta \to 3\pi)$	241 ± 21	9.1 ± 2.2	< 1.18	–	3.3 ± 0.8	5.8 ± 1.3

$\tau^- \to K^*(892)^- \eta\nu_\tau$ study

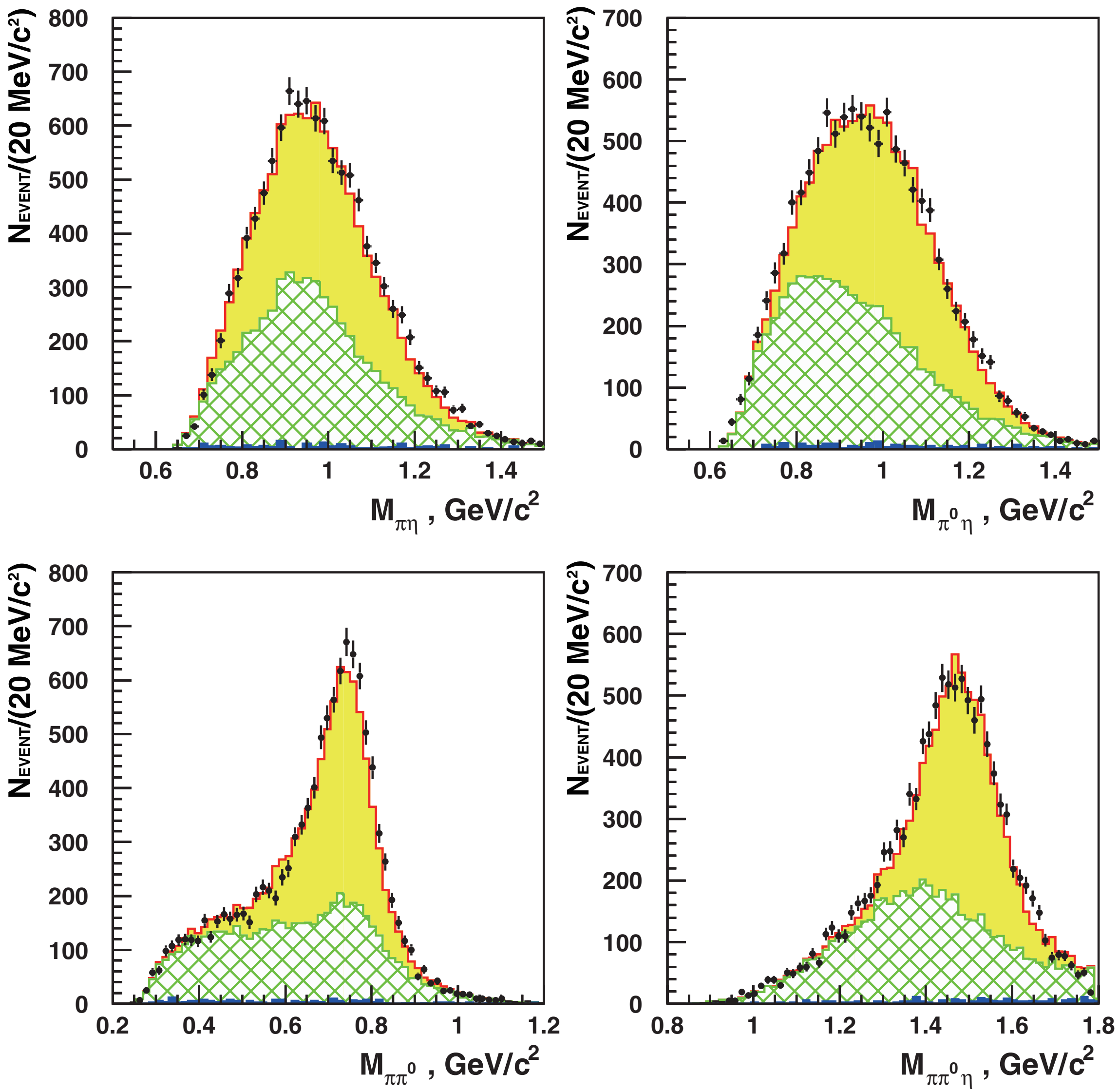


- η signal-band: $(0.50 < M_{\gamma\gamma} < 0.58)$ GeV/c^2
- Continuum BG is evaluated from side-bands: $(0.43 < M_{\gamma\gamma} < 0.48) \cup (0.60 < M_{\gamma\gamma} < 0.65)$ GeV/c^2
- K^*-peaking BG is evaluated from MC: $\tau \to K^*(892)\nu$ (2.3 ± 0.9), $e^+e^- \to q\bar{q}$ (6.5 ± 2.3)
- Fit the data with $K^*(892)$+BG model $\to$ K^* yield is (119 ± 19)
- Detection efficiency $\varepsilon_{\rm det}(K^*\eta\nu) = 0.115\%$

$\mathcal{B}$ results

Mode	Belle preliminary $\mathcal{B}$	Previous $\mathcal{B}$	Experiment
$\tau^- \to K^-\eta\nu_\tau$	$(1.62 \pm 0.05 \pm 0.09) \times 10^{-4}$	$(2.6 \pm 0.5 \pm 0.5) \times 10^{-4}$ $(2.9 \pm 1.3 \pm 0.7) \times 10^{-4}$	CLEO ALEPH
$\tau^- \to K^-\pi^0\eta\nu_\tau$	$(4.7 \pm 1.1 \pm 0.4) \times 10^{-5}$	$(17.7 \pm 5.6 \pm 7.1) \times 10^{-5}$	CLEO
$\tau^- \to \pi^-\pi^0\eta\nu_\tau$	$(1.39 \pm 0.03 \pm 0.07) \times 10^{-3}$	$(1.7 \pm 0.2 \pm 0.2) \times 10^{-3}$ $(1.8 \pm 0.4 \pm 0.2) \times 10^{-3}$	CLEO ALEPH
$\tau^- \to K^{*-}\eta\nu_\tau$	$(1.13 \pm 0.19 \pm 0.07) \times 10^{-4}$	$(2.90 \pm 0.80 \pm 0.42) \times 10^{-4}$	CLEO

Hadronic mass spectra in $\tau^- \to \eta\pi^-\pi^0\nu_\tau$

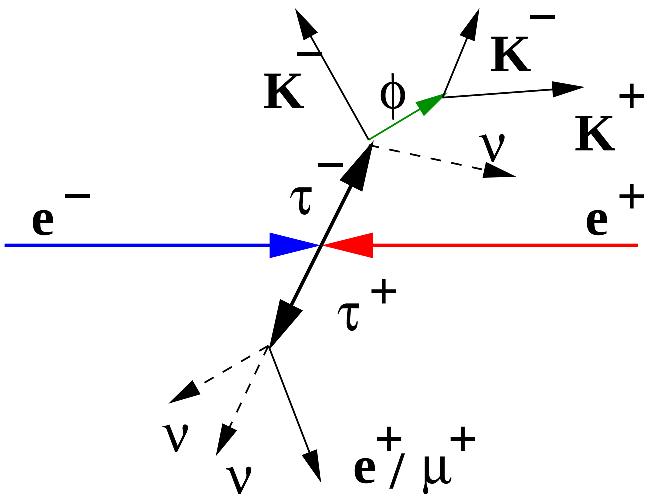


$$\mathcal{B}(\tau^- \to \eta\pi^-\pi^0\nu_\tau) = (1.39 \pm 0.03 \pm 0.07) \cdot 10^{-3}$$

is consistent with $\mathcal{B}^{ee} = (1.3 \pm 0.2) \cdot 10^{-3}$ based on e^+e^- data and CVC

Study of $\tau^- \to \phi K^- \nu_\tau$ decay

Statistics: $\int L dt = 401$ 1/fb $\to 358 \times 10^6$ $\tau\tau$ events (Phys. Lett. B **643**, 5 (2006))

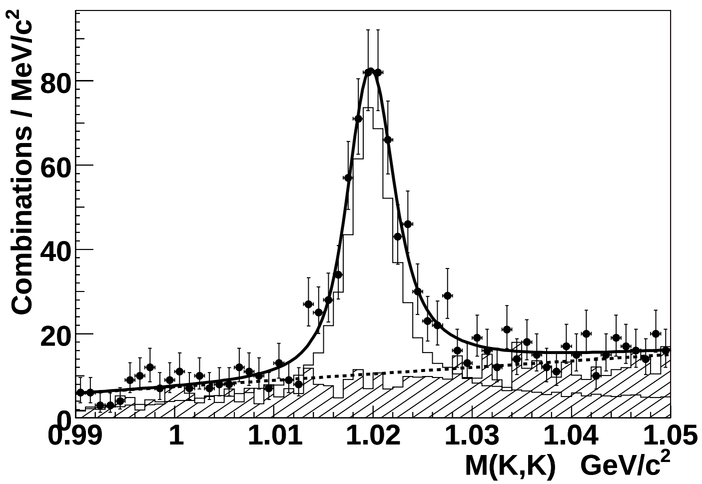


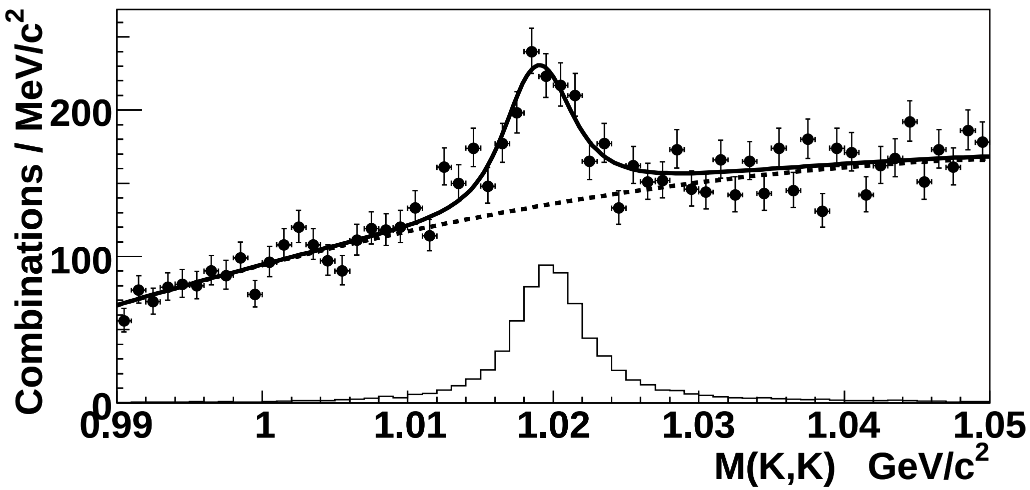
$$N_{\phi K\nu} = 2N_{\tau\tau}\left(\mathcal{B}_{\phi K\nu} \cdot \varepsilon^{\phi K\nu}_{\phi K\nu} + \mathcal{B}_{\phi\pi\nu} \cdot \varepsilon^{\phi K\nu}_{\phi\pi\nu} \right)$$

$$N_{\phi\pi\nu} = 2N_{\tau\tau}\left(\mathcal{B}_{\phi K\nu} \cdot \varepsilon^{\phi\pi\nu}_{\phi K\nu} + \mathcal{B}_{\phi\pi\nu} \cdot \varepsilon^{\phi\pi\nu}_{\phi\pi\nu} \right)$$

MC efficiencies and cross-feed rates (%)

Candidates	$\phi K\nu$	$\phi\pi\nu$	$\phi K\pi^0\nu$
$\tau \to \phi K\nu$	1.826 ± 0.009	0.049 ± 0.002	0.328 ± 0.006
$\tau \to \phi\pi\nu$	0.110 ± 0.002	1.663 ± 0.014	0.009 ± 0.001

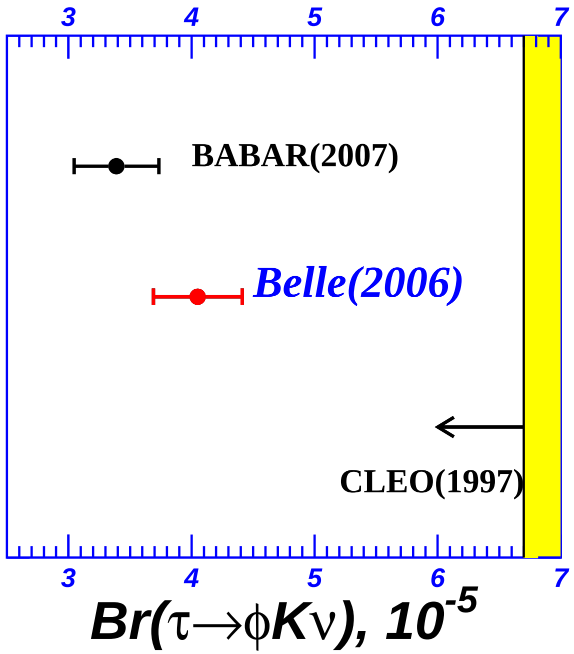




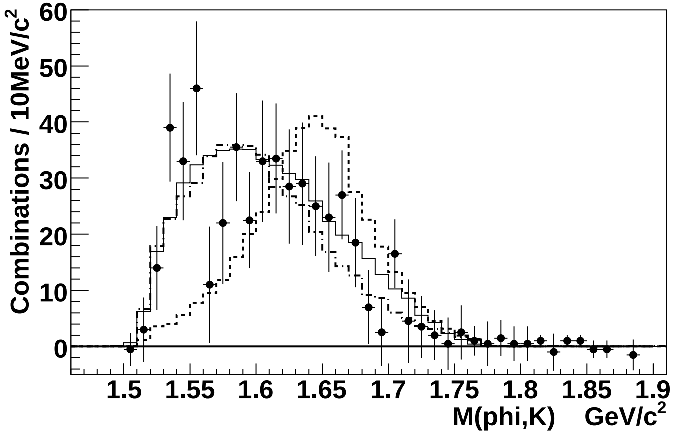
$N_{\phi K\nu} = 573 \pm 32$

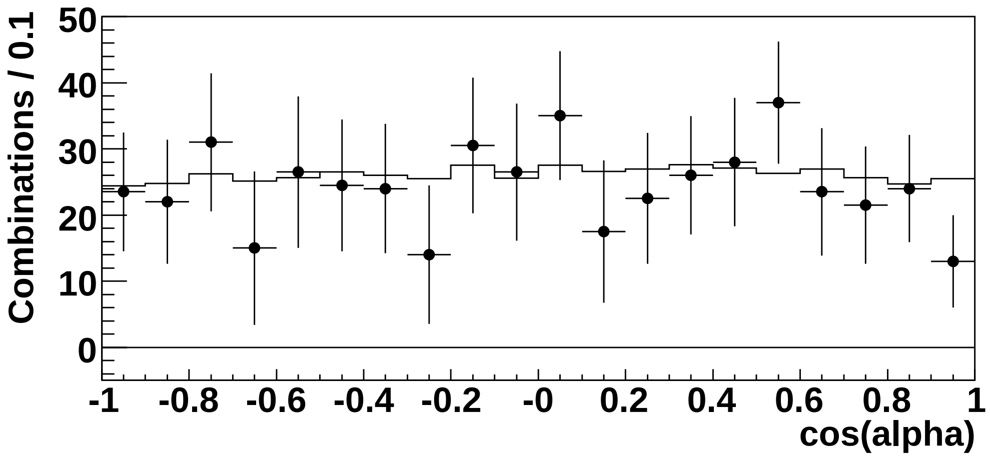
$N_{\phi\pi\nu} = 753 \pm 84$

$$\mathcal{B}(\tau^- \to \phi K^- \nu_\tau) = (4.05 \pm 0.25 \pm 0.26) \times 10^{-5}$$



Source	Value (%)
Track finding	4.0
Particle ID (Lepton)	3.2
Particle ID (K/π)	3.1
Luminosity	1.4
$\tau\tau$ cross section	1.3
Trigger	1.1
Signal MC	0.5
$\mathcal{B}(\phi \to K^+K^-)$	1.2
Γ_ϕ	0.2
Total	6.5

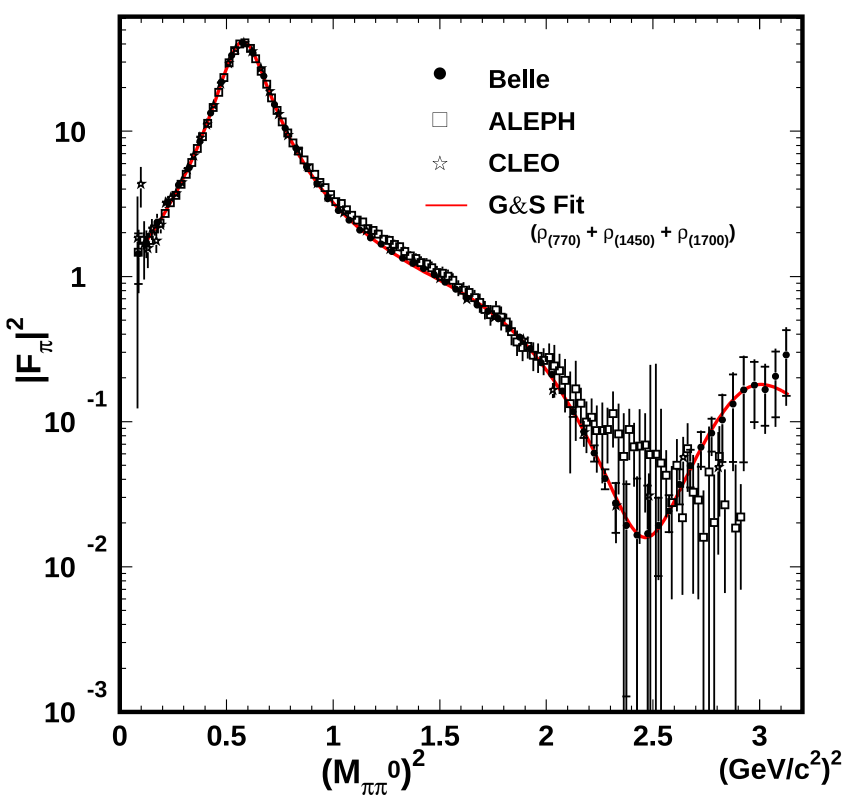


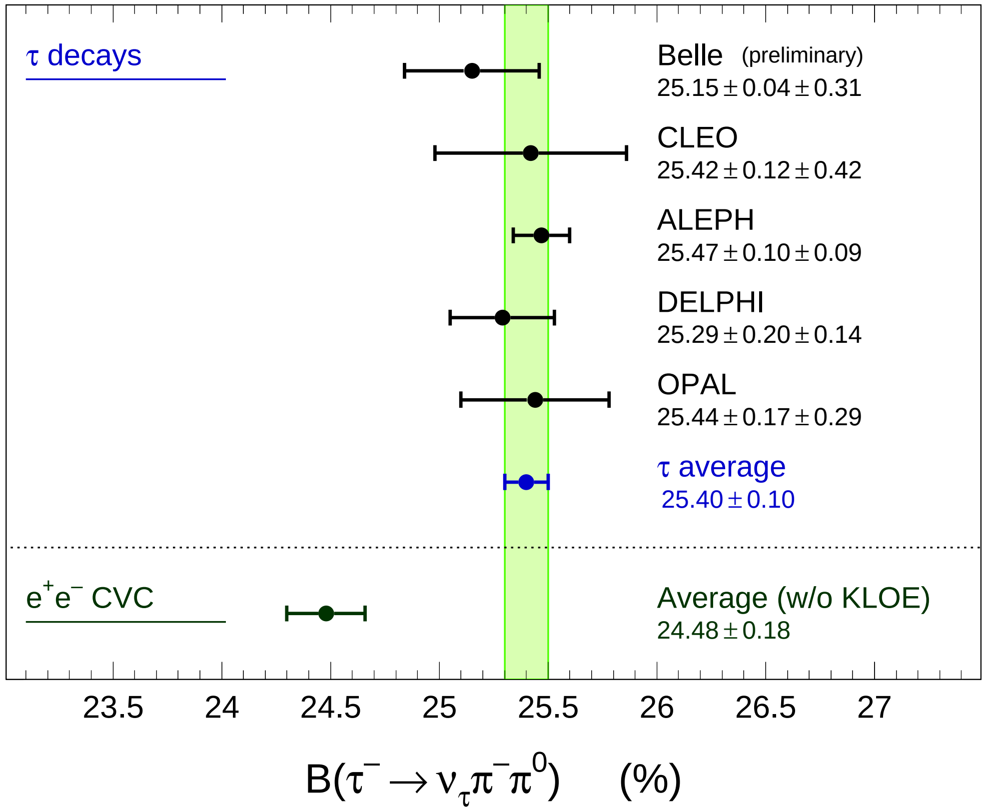


$M(\phi K)$ spectrum agrees well with BW($M_R = 1.57$ GeV/c^2; $\Gamma_R = 0.15$ GeV/c^2) and constant matrix element models.

Study of $\tau^- \to \pi^-\pi^0\nu_\tau$ decay

Statistics: $\int Ldt = 72.2$ 1/fb $\to 66.4 \times 10^6$ $\tau\tau$ events (arXiv:hep-ex/0512071)



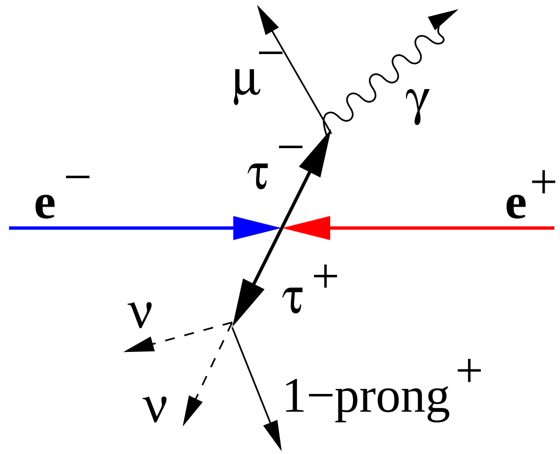


The best $\pi\pi^0$ mass spectrum fit is achieved with the $\rho(770) + \rho(1450) + \rho(1700)$ model.

$\mathcal{B}(\tau^- \to \pi^-\pi^0\nu_\tau)$ from all τ-experiments is systematically higher than the CVC prediction (from e^+e^--experiments): $\mathcal{B}_\tau - \mathcal{B}_{ee} = (0.92 \pm 0.21)\%$. The origin of this discrepancy is still unknown.

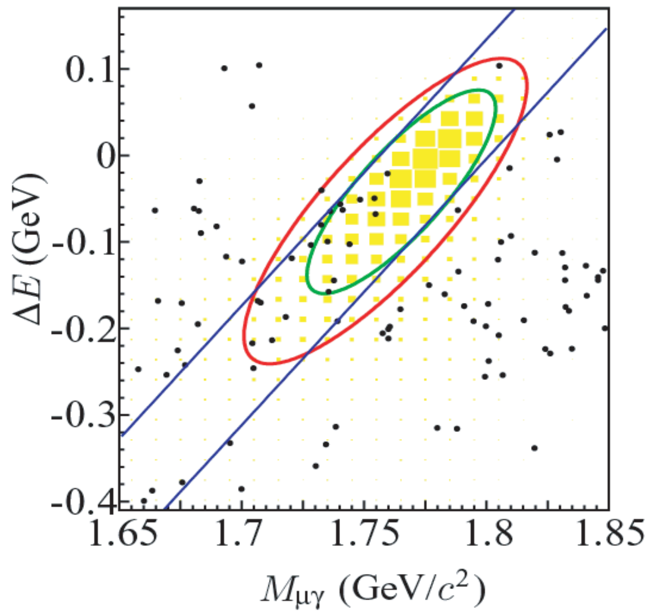
Search for lepton-flavor-violating τ decays

Model	$\mathcal{B}(\tau \to \mu\gamma)$	$\mathcal{B}(\tau \to \ell\ell\ell)$
mSUGRA+seesaw	10^{-7}	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^{-7}



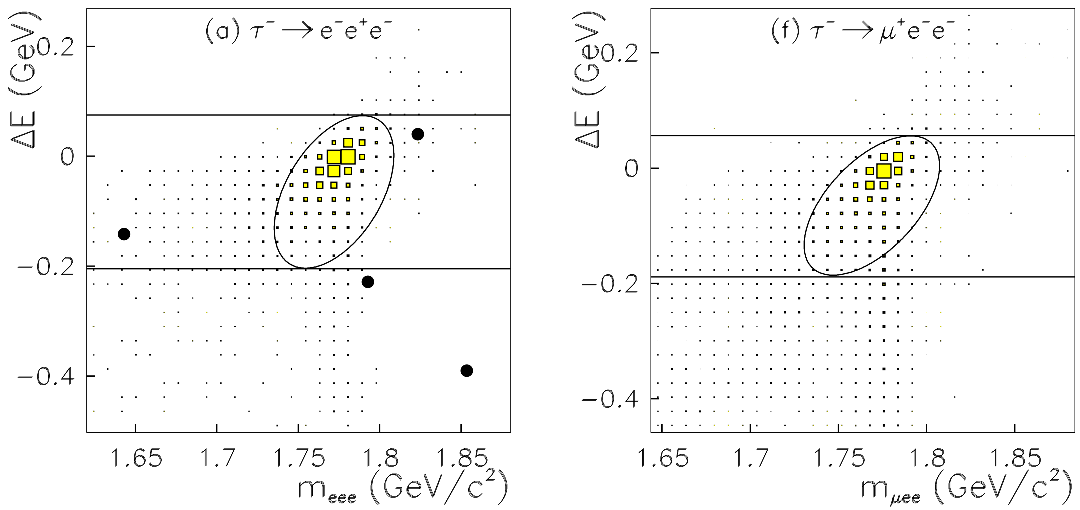
Analysis strategy:

- 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 (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, $M_{\text{inv}} \simeq M_\tau$, $\Delta E = E_{\text{LFV}} - E_{\text{beam}} \simeq 0$
- $\mathcal{B} < \frac{s_{90}}{2N_{\tau\tau}\varepsilon_{\text{mc}}}$



44 different LFV modes are studied at Belle

Search for $\tau^- \to \ell^-\gamma$, $\tau^- \to \ell^-\ell'^-\ell''^+$ $(\ell = e, \mu)$



τ^- mode	Belle		BaBar	
	$\mathcal{B}$, 10^{-8}	$\int L dt$, fb^{-1}	$\mathcal{B}$, 10^{-8}	$\int L dt$, fb^{-1}
$\mu^-\gamma$	4.5	535	6.8	232
$e^-\gamma$	12	535	11	232
$e^-e^-e^+$	3.6	535	4.9	376
$e^-\mu^-\mu^+$	4.1	535	6.6	376
$e^+\mu^-\mu^-$	2.3	535	4.6	376
$\mu^-e^-e^+$	2.7	535	5.0	376
$\mu^-\mu^-\mu^+$	3.2	535	6.7	376
$\mu^+e^-e^-$	2.0	535	2.7	376

Search for $\tau^- \to \ell^- V^0$, $\tau^- \to \ell^- P^0$ ($\ell = e, \mu$; $V^0 = \phi, \omega, \rho^0, K^{*0}, \bar{K}^{*0}$; $P^0 = \pi^0, \eta, \eta'$)

τ^- mode	Belle		BaBar	
	$\mathcal{B}$, 10^{-8}	$\int L dt$, fb^{-1}	$\mathcal{B}$, 10^{-8}	$\int L dt$, fb^{-1}
$e^- \pi^0$	8.0	401	13	339
$e^- \eta$	9.2	401	16	339
$e^- \eta'$	16	401	24	339
$\mu^- \pi^0$	12	401	11	339
$\mu^- \eta$	6.5	401	15	339
$\mu^- \eta'$	13	401	14	339

τ^- mode	Belle		BaBar		CLEO	
	$\mathcal{B}$, 10^{-8}	$\int L dt$, fb^{-1}	$\mathcal{B}$, 10^{-8}	$\int L dt$, fb^{-1}	$\mathcal{B}$, 10^{-8}	$\int L dt$, fb^{-1}
$e^- \rho^0$	6.3	543	–	–	200	4.79
$e^- K^*(892)^0$	7.8	543	–	–	510	4.79
$e^- \bar{K}^*(892)^0$	7.7	543	–	–	740	4.79
$e^- \phi$	7.3	543	–	–	690	4.79
$e^- \omega$	18	543	11	384	–	–
$\mu^- \rho^0$	6.8	543	–	–	630	4.79
$\mu^- K^*(892)^0$	5.9	543	–	–	750	4.79
$\mu^- \bar{K}^*(892)^0$	10	543	–	–	750	4.79
$\mu^- \phi$	13	543	–	–	700	4.79
$\mu^- \omega$	8.9	543	10	384	–	–

Summary

- Huge statistics recorded by Belle allows us to study hadronic τ decays with high accuracy. The branching fractions of several decay modes:

$$\begin{aligned}
\mathcal{B}(\tau^- \to K_S\pi^-\nu_\tau) &= (4.04 \pm 0.02_{\rm stat} \pm 0.13_{\rm syst})\times 10^{-3} \\
\mathcal{B}(\tau^- \to K^-\eta\nu_\tau) &= (1.62 \pm 0.05_{\rm stat} \pm 0.09_{\rm syst})\times 10^{-4} \\
\mathcal{B}(\tau^- \to K^-\pi^0\eta\nu_\tau) &= (4.7 \pm 1.1_{\rm stat} \pm 0.4_{\rm syst})\times 10^{-5} \\
\mathcal{B}(\tau^- \to \pi^-\pi^0\eta\nu_\tau) &= (1.39 \pm 0.03_{\rm stat} \pm 0.07_{\rm syst})\times 10^{-3} \\
\mathcal{B}(\tau^- \to K^{*-}\eta\nu_\tau) &= (1.13 \pm 0.19_{\rm stat} \pm 0.07_{\rm syst})\times 10^{-4} \\
\mathcal{B}(\tau^- \to \phi K^-\nu_\tau) &= (4.05 \pm 0.25_{\rm stat} \pm 0.26_{\rm syst})\times 10^{-5}
\end{aligned}$$

  have better accuracy then the previous measurements. The $\mathcal{B}(\tau^- \to \phi K^-\nu_\tau)$ was measured for the first time.

- We studied the $K_S\pi$ mass spectrum in the $\tau \to K_S\pi\nu$ sample. The $K^*(892)$ alone is not sufficient to describe the $K_S\pi$ invariant mass spectrum. The best description is achieved in the $K_0^*(800) + K^*(892) + K_0^*(1410)$ and $K_0^*(800) + K^*(892) + K_0^*(1430)$ models.

  The values of the $K^*(892)^-$ mass and width we obtained are:

$$M(K^*(892)^-) = (895.47 \pm 0.20_{\rm stat} \pm 0.44_{\rm syst} \pm 0.59_{\rm mod})\ {\rm MeV/c^2}$$
$$\Gamma(K^*(892)^-) = (46.2 \pm 0.6_{\rm stat} \pm 1.0_{\rm syst} \pm 0.7_{\rm mod})\ {\rm MeV}$$

- **In the evaluation of the branching fraction upper limits for the LFV τ decays we are approaching the 10^{-8} level. Parameter space for many models beyond the SM can be restricted.**

Backup slides

Study of the $\tau^- \to K_S \pi^- \nu_\tau$ decay

- **Measurement of $\tau \to K_S\pi\nu_\tau$ branching ratio** $\tau \to \bar{K}^0\pi\nu_\tau$ has the largest $\mathcal{B}$ among decays with one kaon, so provides the dominant contribution to the s-quark mass sensitive total strange hadronic spectral function.
- **$K_S\pi$ mass spectrum (F_V: $K^*(892)$, $K^*(1410)$, $K^*(1680)$; F_S: $K_0^*(800)(\kappa)$, $K_0^*(1430)$)**
  - M. Battle *et al.* [CLEO Collaboration], "Measurement of Cabibbo suppressed decays of the tau lepton," Phys. Rev. Lett. **73**, 1079 (1994) [arXiv:hep-ph/9403329].
  - P. Lichard, Phys.Rev.D **60**, 093012 (1999) (nonzero value of the slope parameter λ_0 of the $K^{\pm}_{\mu 3}$ and $K^0_{\mu 3}$ formfactors implies the existence of the $\tau \to K_0^\star(1430)\nu_\tau$ decay)
  - M. Finkemeier and E. Mirkes, "The scalar contribution to $\tau \to K\pi\nu_\tau$", Z. Phys. C **72**, 619 (1996) [arXiv:hep-ph/9601275].
- **CP violation in $\tau \to K_S\pi\nu_\tau$**
  - J.Kuhn, E.Mirkes,Phys. Lett. **B398**, 407 (1997)
  - G.Bonvicini *et al* (CLEO), Phys.Rev.Lett.**88**, 111803 (2002)
  - I.I.Bigi, A.I.Sanda, Phys. Let. B **625**, 47 (2005)
  - G. Calderon, D. Delepine and G. L. Castro, "Is there a paradox in CP asymmetries of $\tau^\pm \to (K_L, K_S)\pi^\pm\nu_\tau$ decays?" arXiv:hep-ph/0702282.

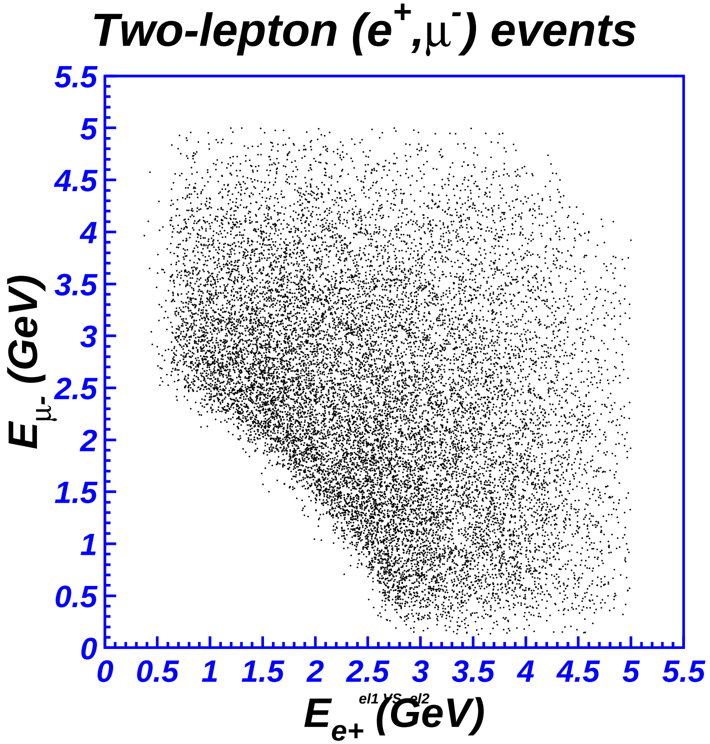
I. Preselection criteria

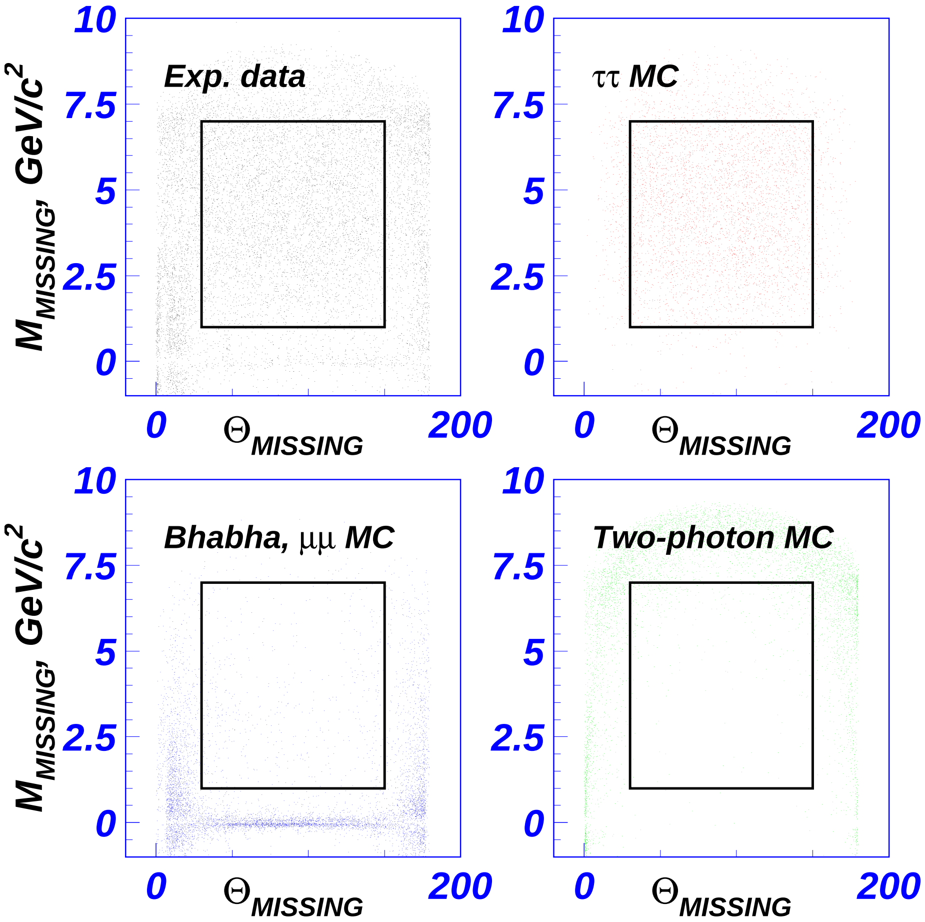
- $2 \leq N_{tracks} \leq 8$
- $|Q_{total}| \leq 2$
- $\sum_{i=1}^{N_{trk}} |\vec{P_i}|^{CMS} < 10$ GeV/c
- $\sum_{i=1}^{N_{clusters}} E_i^{LAB}(ECL) < 10$ GeV
- $P_{\perp\ max}^{LAB} > 0,5$ GeV/c
- Event vertex $|R| < 0,5$ cm, $|Z| < 3$ cm
- For $N_{trk} = 2$:
  - $\sum_{i=1}^{N_{trk}} |\vec{P_i}|^{CMS} < 9$ GeV/c
  - $\sum_{i=1}^{N_{clusters}} E_i^{LAB}(ECL) < 9$ GeV
  - $5^o < \theta_{missing}^{LAB} < 175^o$
- $E_{rec} = \sum_{i=1}^{N_{trk}} |\vec{P_i}|^{CMS} + \sum_{j=1}^{N_\gamma} |\vec{K_j}|^{CMS} > 3$ GeV/c **OR** $P_{\perp\ max}^{LAB} > 1,0$ GeV/c
- If $2 \leq N_{trk} \leq 4$:
  - $E_{tot} = E_{rec} + |\sum_{i=1}^{N_{trk}} \vec{P_i}^{CMS} + \sum_{j=1}^{N_\gamma} \vec{K_j}^{CMS}| < 9$ GeV/c **OR** Maximum opening angle$< 175^o$
  - $N_{barrel} \geq 2$ **OR** $\sum_{All\ clusters} E^{CMS} - \sum_{photons} E_\gamma^{CMS} < 5,3$ GeV
- Maximum opening angle $> 20^o$

II. Additional selection criteria

- $2 \leq N_{\rm tracks} \leq 4$ ($P_{\perp}^{\rm CMS} > 0.1$ GeV/c, $|\triangle r| < 0,5$ cm, $|\triangle z| < 2.5$ cm)
- $|Q_{total}| \leq 1$
- $N_{\gamma} \leq 5$ ($E_{\gamma}^{CMS} > 0.08$ GeV)
- $\sum_{i=1}^{N_{clusters}} E_i^{LAB}(ECL) < 9$ GeV

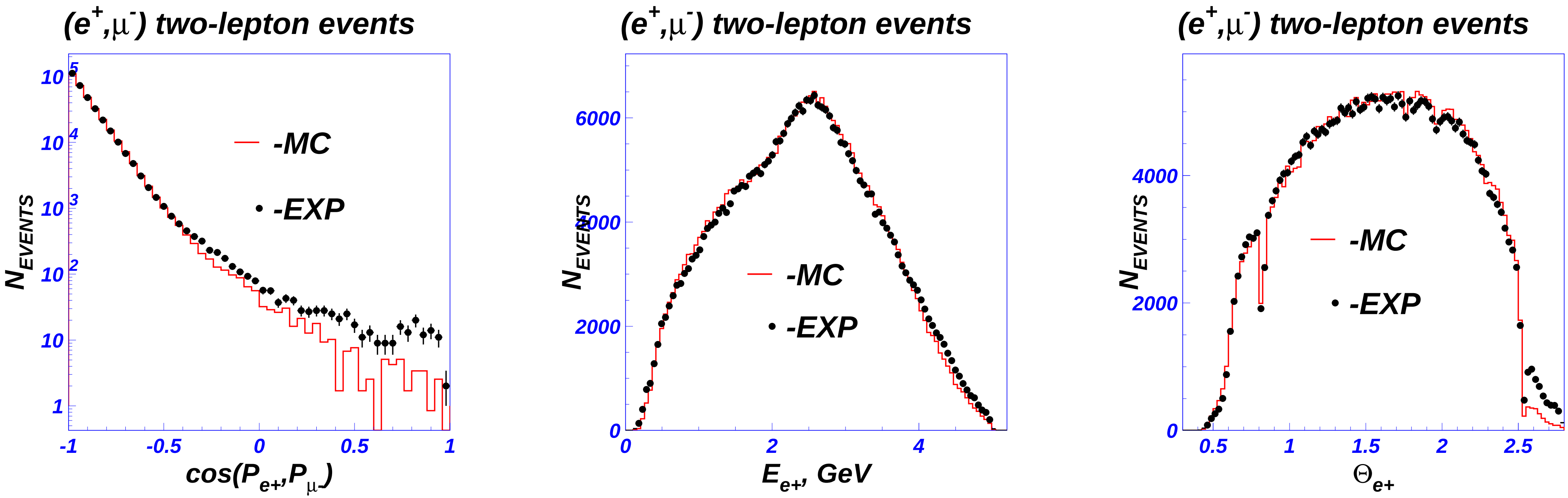
$$1 \text{ GeV/c}^2 \leq M_{\rm missing} \leq 7 \text{ GeV/c}^2$$
$$30^{\rm o} \leq \theta_{\rm missing}^{\rm CMS} \leq 150^{\rm o}$$





Two-lepton (e^+, μ^-) and (e^-, μ^+) events

We select events with two leptons having $cos(\vec{P_e}, \vec{P_\mu}) < 0$

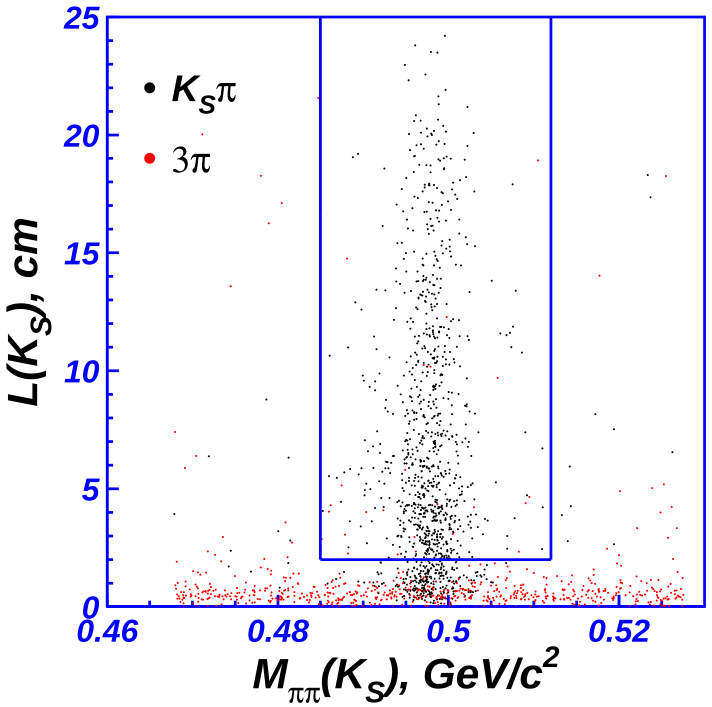


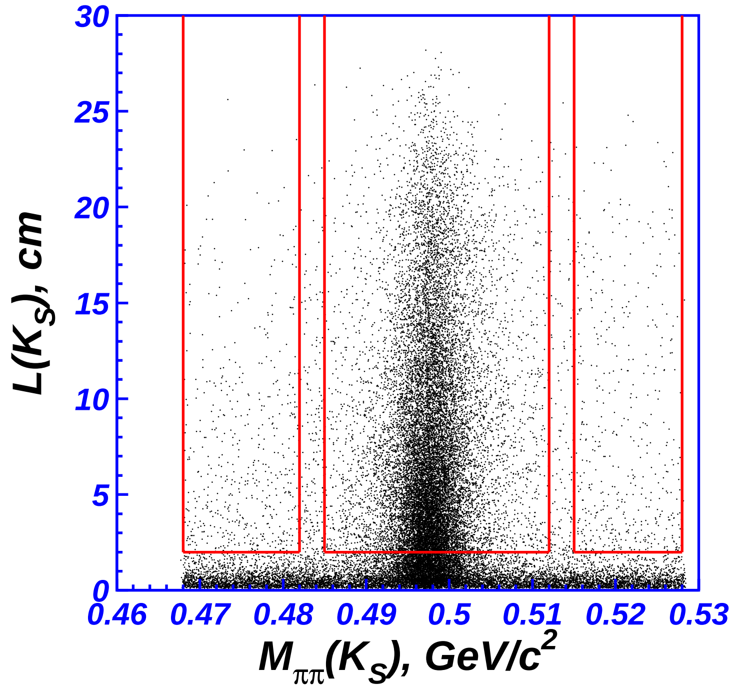
4046048 selected events, detection efficiency $\varepsilon_{\rm det}(e,\mu) = (19.26 \pm 0.01)\%$

The main source of non-$\tau\tau$ background, $e^+e^- \to e^+e^-\mu^+\mu^-$ process, gives about 2% contaminaton. The contribution of the other non-$\tau\tau$ processes is found to be less than 0.1%.

Selection of signal events

- **1 lepton** (e/μ) **with** $\mathcal{P}_e, \mathcal{P}_\mu > 0.8$
- **1 charged pion** π **with** $\mathcal{P}_{K/\pi} < 0.3$
- **1** K_S **candidate reconstructed from** $K_S \to \pi^+\pi^-$
  - $\Delta Z_{1,2} < 1.5cm$
  - $0.1 < l_{\rho-\phi}(K_S) < 20cm$
  - $cos(\vec{P}_\perp, \vec{r}_\perp) \geq 0.95$
  - $L_{K_S} > 2\ cm,\ 485 < M_{\pi\pi}(K_S) < 512\ MeV/c^2\ (\pm 5\sigma)$





$\mathcal{B}(\tau^- \to K_S \pi^- \nu_\tau)$ systematic uncertainty

Source	Contribution,%
K_S detection efficiency	2.5
$\tau^+\tau^-$ background subtraction	1.6
$\sum E_\gamma^{\text{LAB}}$	1.0
Lepton identification efficiency	0.8
Pion momentum	0.5
Non-$\tau^+\tau^-$ background subtraction	0.3
$\mathcal{B}(l\nu_l\nu_\tau)$	0.3
$\frac{\varepsilon(l_1,l_2)}{\varepsilon(l_1,K_S\pi)}$	0.2
K_S momentum	0.2
Pion identification efficiency	0.1
Total	3.3

$$\mathcal{B}(\tau \to K_S \pi \nu_\tau) = (0.404 \pm 0.002_{\text{stat}} \pm 0.013_{\text{syst}})\%$$

$K_S\pi$ mass spectrum fit results

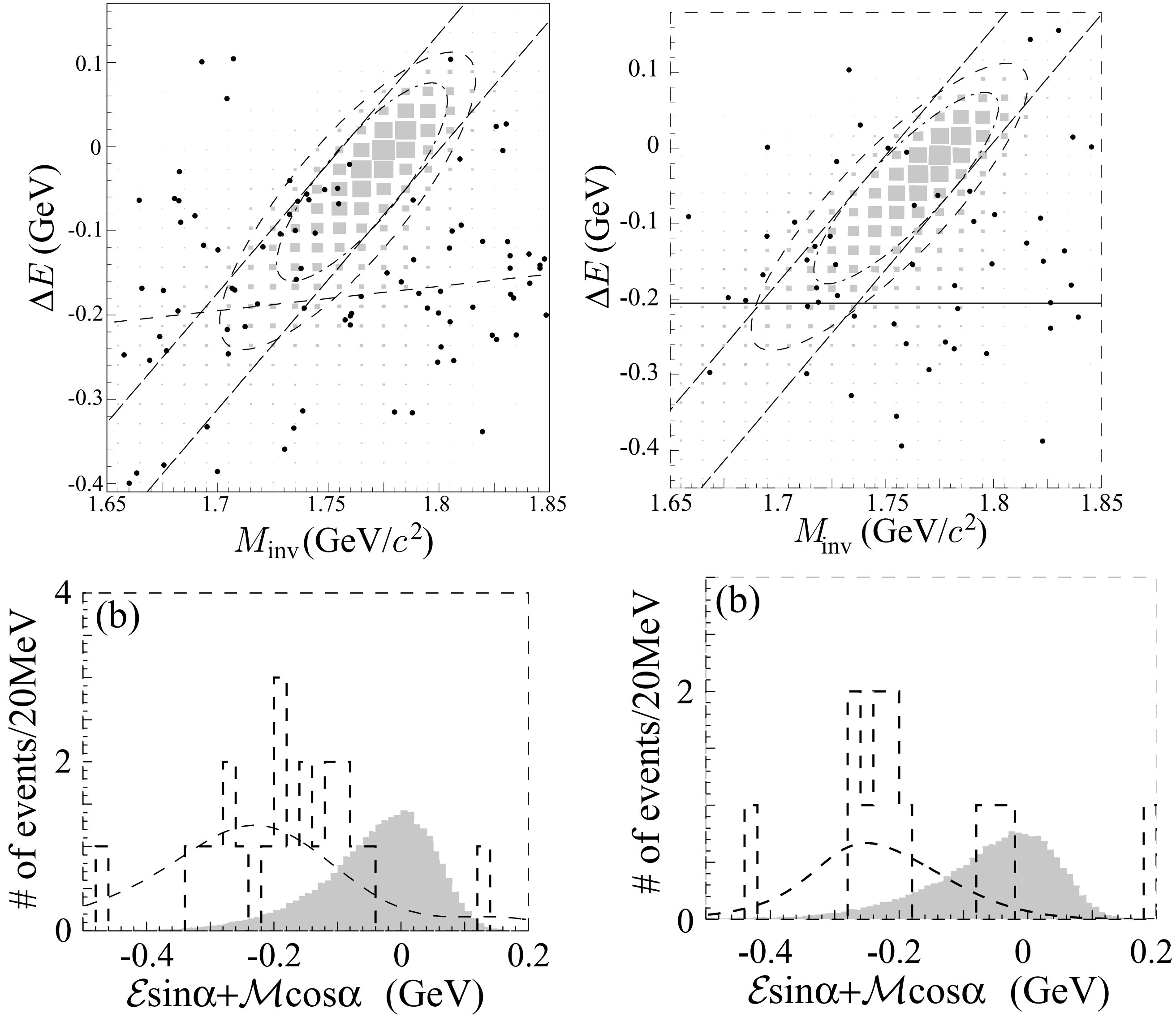
	$K^*(892)$	$K_0^*(800) + K^*(892)+$ $+K^*(1410)$	$K_0^*(800) + K^*(892)+$ $+K^*(1680)$
$M_{K^*(892)^-}$, MeV/c^2	895.53 ± 0.19	895.47 ± 0.20	894.88 ± 0.20
$\Gamma_{K^*(892)^-}$, MeV	49.29 ± 0.46	46.19 ± 0.57	45.52 ± 0.51
$\|\beta\|$		0.075 ± 0.006	
$\arg(\beta)$		1.44 ± 0.15	
$\|\chi\|$			$0.117 \pm$ 0.017 0.033
$\arg(\chi)$			3.17 ± 0.47
$\varkappa$		1.57 ± 0.23	1.53 ± 0.24
χ^2/n.d.f.	448.4/87	90.2/84	106.8/84
$P(\chi^2)$, %	0	30	5

	$K_0^*(800) + K^*(892) + K_0^*(1430)$	
	solution 1	solution 2
$M_{K^*(892)^-}$, MeV/c^2	895.42 ± 0.19	895.50 ± 0.22
$\Gamma_{K^*(892)^-}$, MeV	46.14 ± 0.55	46.20 ± 0.69
$\lvert\gamma\rvert$	0.954 ± 0.081	1.92 ± 0.20
$\arg(\gamma)$	0.62 ± 0.34	4.03 ± 0.09
$\varkappa$	1.27 ± 0.22	2.28 ± 0.47
χ^2/n.d.f.	86.5/84	95.1/84
$P(\chi^2)$, %	41	19

$\mathcal{B}(\tau^- \to \eta X^- \nu_\tau)$ systematic uncertainties (%)

Mode η detection	$K^-\eta\nu_\tau$ $\eta \to \gamma\gamma$	$K^-\pi^0\eta\nu_\tau$ $\eta \to \gamma\gamma$	$\pi^-\pi^0\eta\nu_\tau$ $\eta \to \gamma\gamma$	$K^-\eta\nu_\tau$ $\eta \to 3\pi$	$K^{*-}\eta\nu_\tau$ $\eta \to \gamma\gamma$
Estimation of $K^-\eta\nu_\tau$	–	0.6	1.8×10^{-3}	–	–
Estimation of $K^-\pi^0\eta\nu_\tau$	0.3	–	4.2×10^{-2}	0.4	–
Estimation of $\pi^-\pi^0\eta\nu_\tau$	7.5×10^{-2}	3.3	–	0.1	–
Estimation of $\pi^-\pi^0\pi^0\eta\nu_\tau$	–	–	0.4	–	–
Estimation of $q\bar{q}$	1.5	6.0	0.5	1.5	2.4
Particle ID (K/π)	3.3	2.2	1.0	2.8	2.2
Particle ID (Lepton)	2.3	2.8	2.6	2.6	2.6
Track finding	1.3	1.3	1.3	3.3	1.3
Luminosity measurement	1.6	1.6	1.6	1.6	1.6
π^0 detection	–	2.0	2.0	2.0	2.0
π^0 veto	2.8	2.8	2.8	–	2.8
Signal MC	0.5	1.7	0.7	1.3	1.7
$\mathcal{B}(\eta \to \pi^+\pi^-\pi^0)$	–	–	–	1.6	–
Total	5.6	8.9	5.0	6.3	6.0

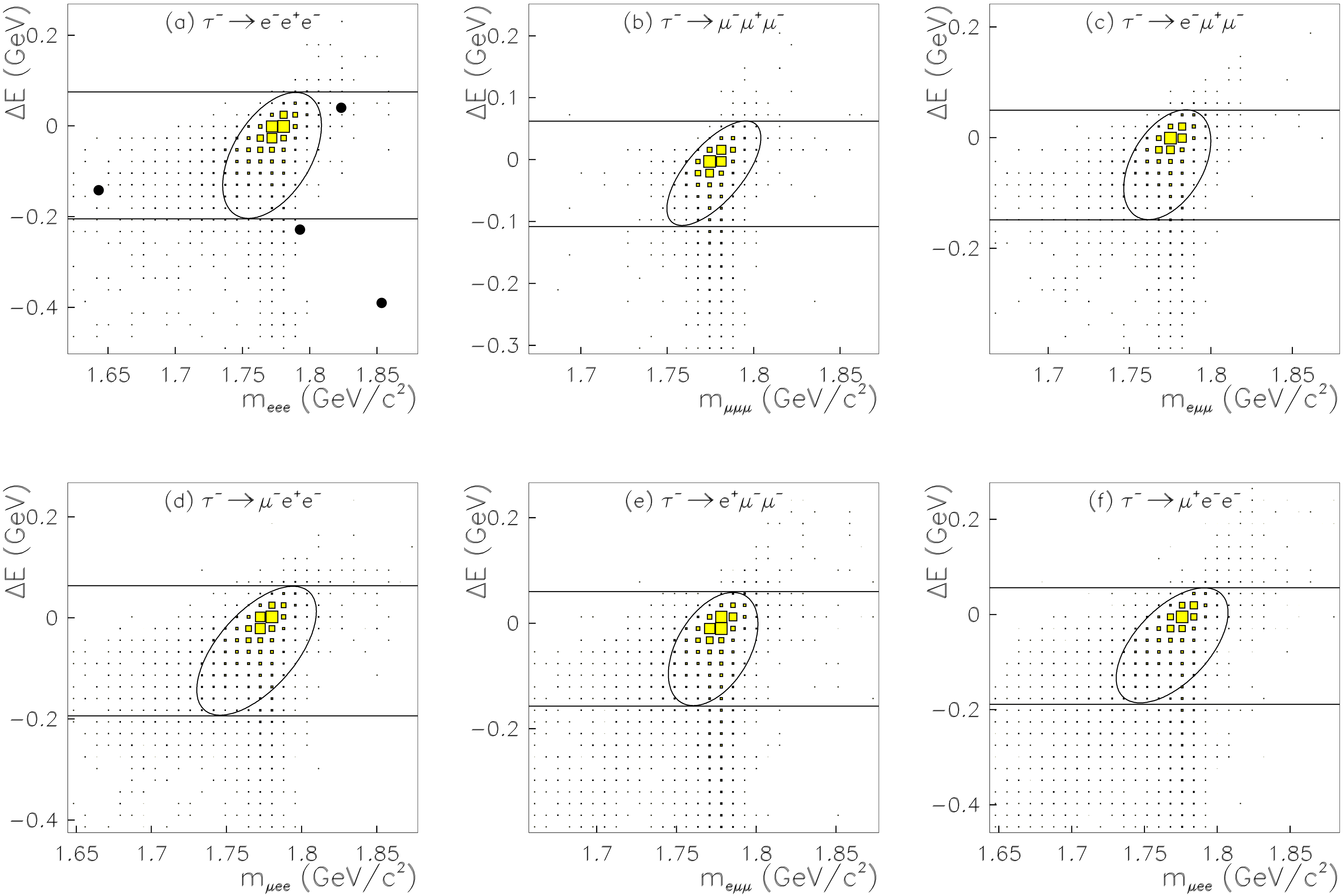
$\tau^- \to \ell^- \gamma$ ($\ell = e, \mu$)



$\mathcal{B}(\tau^- \to \mu^- \gamma) < 4.5 \times 10^{-8}$ $\mathcal{B}(\tau^- \to e^- \gamma) < 12.0 \times 10^{-8}$

$\tau^- \to \ell^- \ell'^- \ell''^+ \ (\ell = e, \mu)$

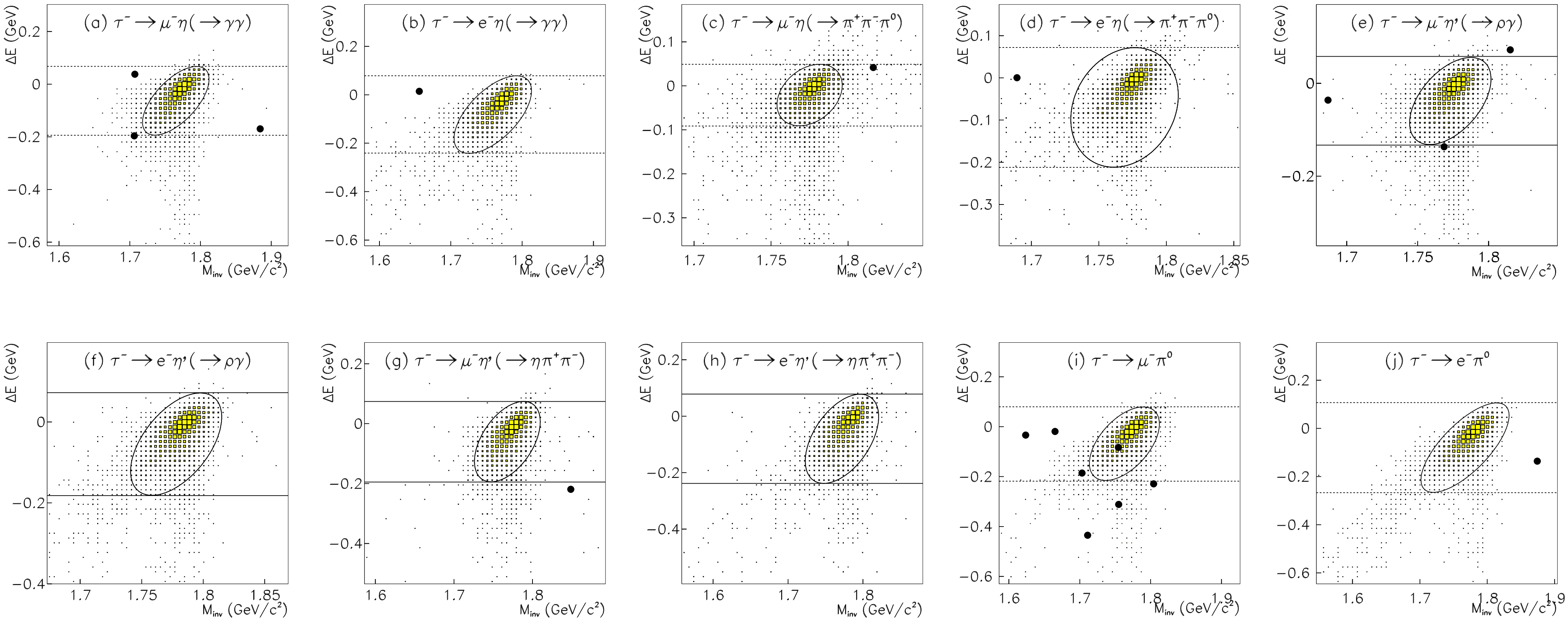
Mode	ε (%)	N_{BG}	σ_{syst} (%)	N_{obs}	s_{90}	$\mathcal{B}(\times 10^{-8})$
$\tau^- \to e^- e^+ e^-$	6.00	0.40±0.30	9.8	0	2.10	3.6
$\tau^- \to \mu^- \mu^+ \mu^-$	7.64	0.07±0.05	7.4	0	2.41	3.2
$\tau^- \to e^- \mu^+ \mu^-$	6.08	0.05±0.03	9.5	0	2.44	4.1
$\tau^- \to \mu^- e^+ e^-$	9.29	0.04±0.04	7.8	0	2.43	2.7
$\tau^- \to e^+ \mu^- \mu^-$	10.8	0.02±0.02	7.6	0	2.44	2.3
$\tau^- \to \mu^+ e^- e^-$	12.5	0.01±0.01	7.7	0	2.46	2.0



(a) $\tau^- \to e^- e^+ e^-$
(b) $\tau^- \to \mu^- \mu^+ \mu^-$
(c) $\tau^- \to e^- \mu^+ \mu^-$
(d) $\tau^- \to \mu^- e^+ e^-$
(e) $\tau^- \to e^+ \mu^- \mu^-$
(f) $\tau^- \to \mu^+ e^- e^-$
ΔE (GeV)
m_{eee} (GeV/c^2)
$m_{\mu\mu\mu}$ (GeV/c^2)
$m_{e\mu\mu}$ (GeV/c^2)
$m_{\mu ee}$ (GeV/c^2)

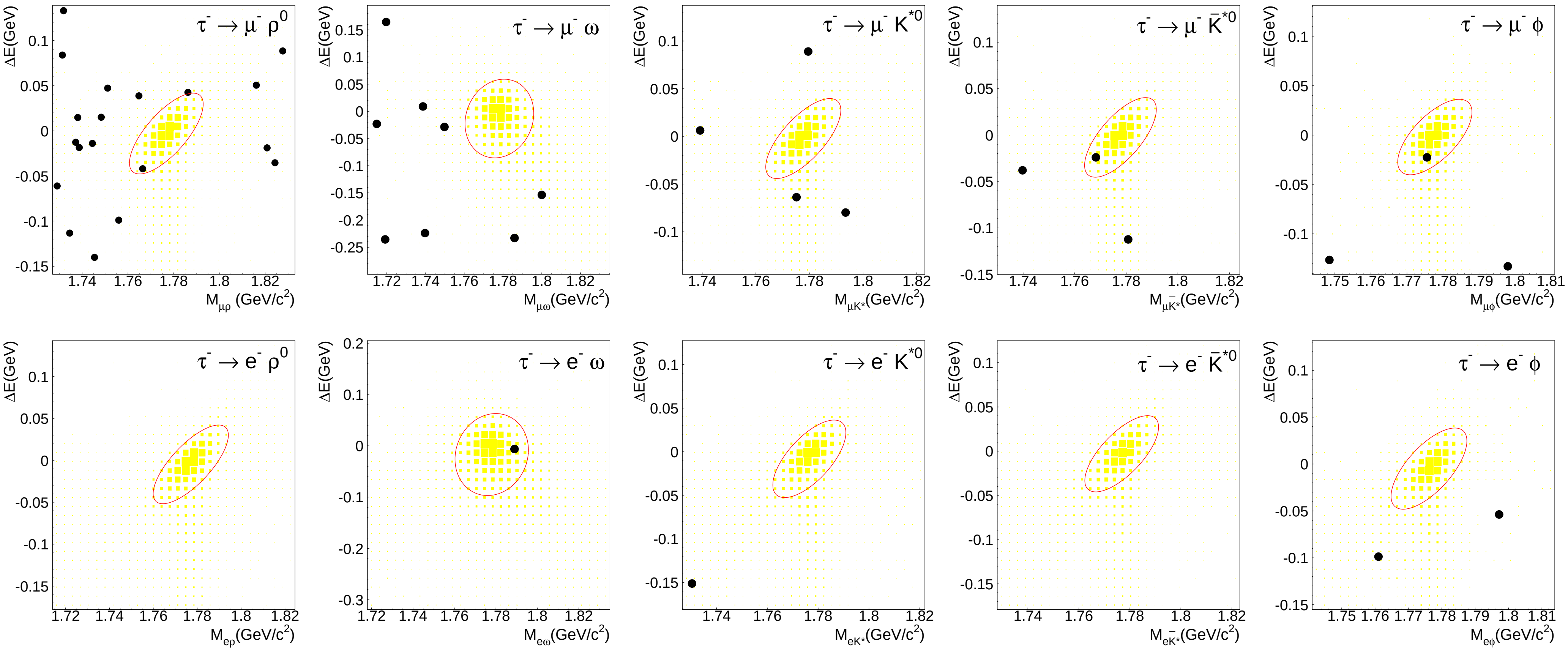
$\tau^- \to \ell^- P^0$ ($\ell = e, \mu$; $P^0 = \pi^0, \eta, \eta'$)

mode	$\mu\eta$		$e\eta$		$\mu\eta'$		$e\eta'$		$\mu\pi^0$	$e\pi^0$
$\eta/\eta'/\pi^0 \to$	3π	$\gamma\gamma$	3π	$\gamma\gamma$	$\pi\pi\eta$	$\rho\gamma$	$\pi\pi\eta$	$\rho\gamma$	$\gamma\gamma$	$\gamma\gamma$
ϵ (%)	6.8	6.4	4.7	4.6	4.9	5.4	4.3	4.8	4.5	3.9
n(exp)	0.2	0.4	0.53	0.25	0	0.23	0	0	0.58	0.20
n(obs)	0	0	0	0	0	0	0	0	1	0
UL @90%CL	2.2	2.1	2.0	2.2	2.5	2.2	2.5	2.5	3.8	2.2
$Br(\times 10^{-8})$			26	17	41	19	47	25	**12**	**8**
combined $Br(\times 10^{-8})$	**6.5**		**9.2**		**13**		**16**			


(a) $\tau^- \to \mu^-\eta(\to\gamma\gamma)$
(b) $\tau^- \to e^-\eta(\to\gamma\gamma)$
(c) $\tau^- \to \mu^-\eta(\to\pi^+\pi^-\pi^0)$
(d) $\tau^- \to e^-\eta(\to\pi^+\pi^-\pi^0)$
(e) $\tau^- \to \mu^-\eta'(\to\rho\gamma)$
(f) $\tau^- \to e^-\eta'(\to\rho\gamma)$
(g) $\tau^- \to \mu^-\eta'(\to\eta\pi^+\pi^-)$
(h) $\tau^- \to e^-\eta'(\to\eta\pi^+\pi^-)$
(i) $\tau^- \to \mu^-\pi^0$
(j) $\tau^- \to e^-\pi^0$
ΔE (GeV)
M_{inv} (GeV/c^2)

$\tau^- \to \ell^- V^0$ ($\ell = e, \mu$; $V^0 = \phi, \omega, \rho^0, K^{*0}, \bar{K}^{*0}$)

Mode $\tau^- \to$	N_{obs}	N_{exp}	ϵ (%)	$\Delta\epsilon/\epsilon$ (%)	s_{90}	UL on $\mathcal{B}$ (90% CL)
$\mu^-\phi$	1	0.17 ± 0.12	3.14	5.2	4.17	1.3×10^{-7}
$e^-\phi$	0	0.18 ± 0.12	3.10	5.3	2.27	7.3×10^{-8}
$\mu^-\omega$	0	0.19 ± 0.20	2.51	6.3	2.22	8.9×10^{-8}
$e^-\omega$	1	< 0.24	2.46	6.3	4.34	1.8×10^{-7}
μ^-K^{*0}	0	0.26 ± 0.15	3.71	4.8	2.20	5.9×10^{-8}
e^-K^{*0}	0	0.08 ± 0.08	3.04	4.9	2.35	7.8×10^{-8}
$\mu^-\bar{K}^{*0}$	1	0.17 ± 0.12	4.02	4.8	4.14	1.0×10^{-7}
$e^-\bar{K}^{*0}$	0	< 0.17	3.21	4.9	2.45	7.7×10^{-8}
$\mu^-\rho^0$	1	1.04 ± 0.28	4.89	4.9	3.34	6.8×10^{-8}
$e^-\rho^0$	0	< 0.17	3.94	5.1	2.46	6.3×10^{-8}


τ⁻ → μ⁻ ρ⁰
τ⁻ → μ⁻ ω
τ⁻ → μ⁻ K*⁰
τ⁻ → μ⁻ K̄*⁰
τ⁻ → μ⁻ φ
τ⁻ → e⁻ ρ⁰
τ⁻ → e⁻ ω
τ⁻ → e⁻ K*⁰
τ⁻ → e⁻ K̄*⁰
τ⁻ → e⁻ φ
ΔE(GeV)
M_μρ (GeV/c²)
M_μω(GeV/c²)
M_μK*(GeV/c²)
M_μK̄*(GeV/c²)
M_μφ(GeV/c²)
M_eρ(GeV/c²)
M_eω(GeV/c²)
M_eK*(GeV/c²)
M_eK̄*(GeV/c²)
M_eφ(GeV/c²)