Recent results on τ decays from Belle

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Contents

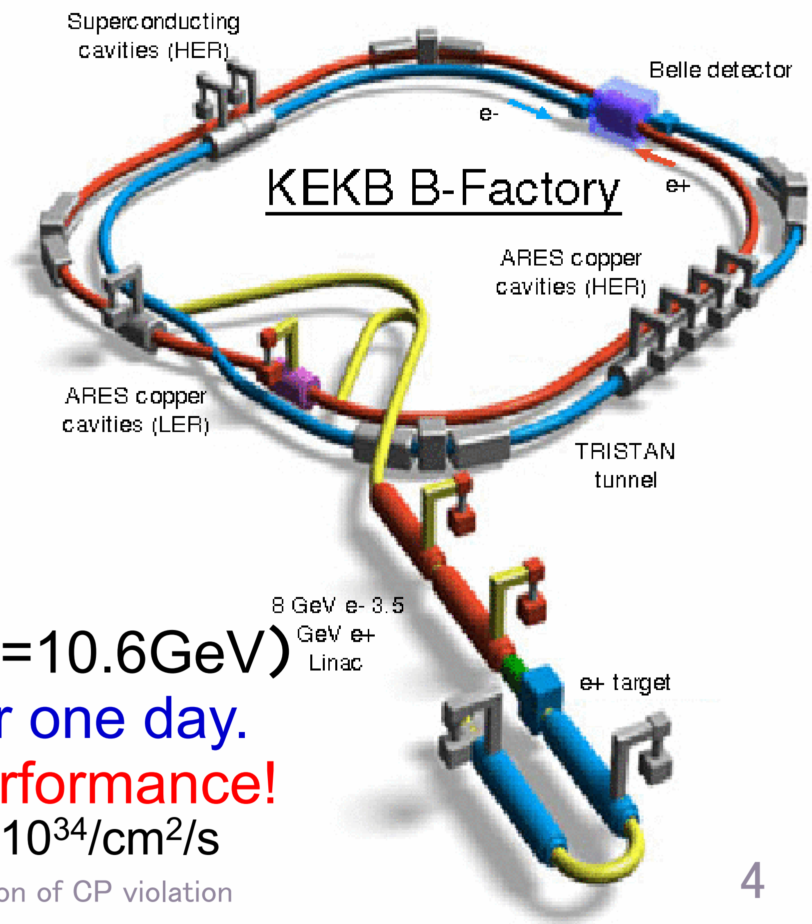
Introduction

Motivation for τ physics

- Precise measurement hadronic τ decay
  - τ is an unique lepton that can decay into hadrons.
  - τ decay provides a good test for low energy QCD.
  - ✓ Chiral theory with vector meson dominance
  - ✓ CVC
- LFV search on τ decay
  - Observation of LFV is a clear signature of New Physics!
  - It is expected that t is most strongly connected to NP because τ has the heaviest mass among leptons.

KEKB accelerator

$e^+e^- \rightarrow \Upsilon(4s) \rightarrow BB$

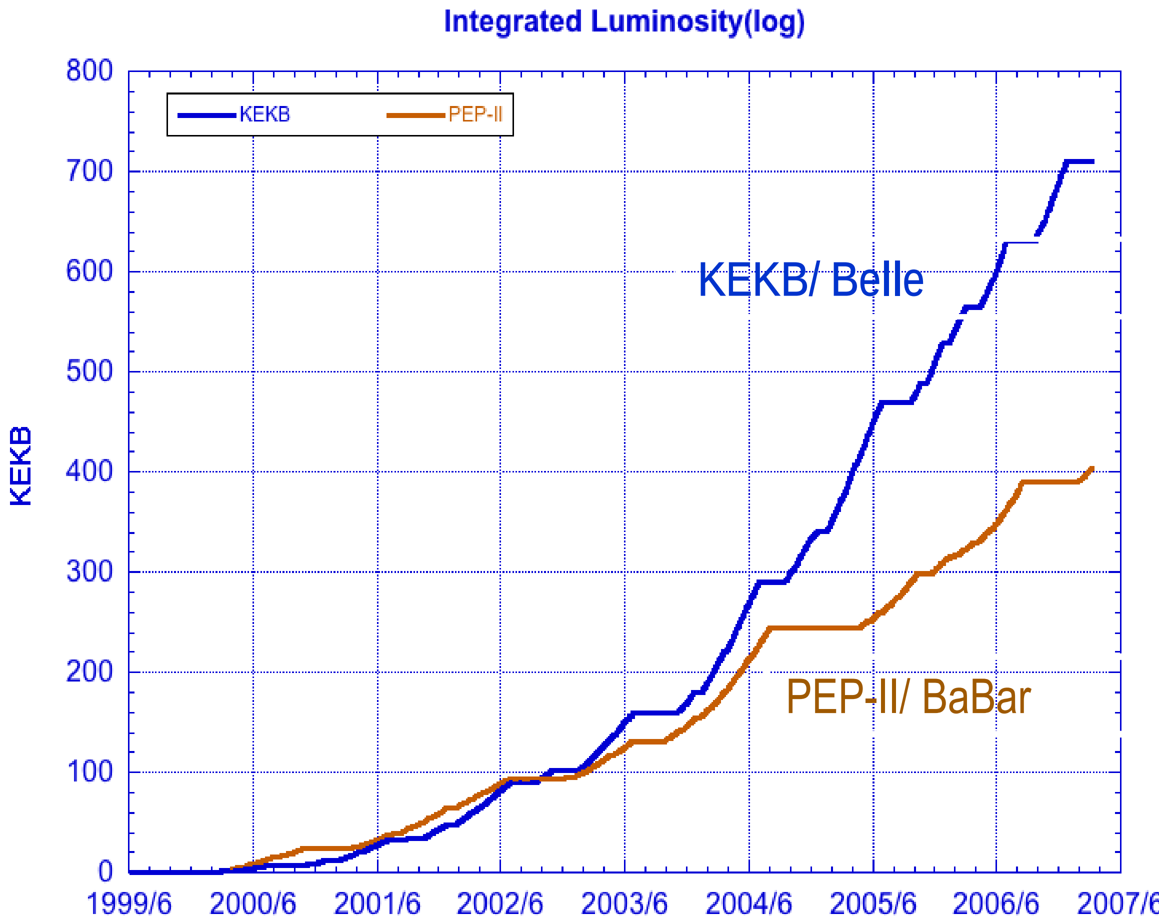


- asymmetric collider/entire length 3km (electron:8GeV,positron:3.5GeV, $s^{1/2}$=10.6GeV)
- one million $B\bar{B}$ pairs are produced per one day.

world's highest performance!

Peak luminosity~$1.7\times10^{34}/cm^2/s$

Integrated Luminosity of KEKB

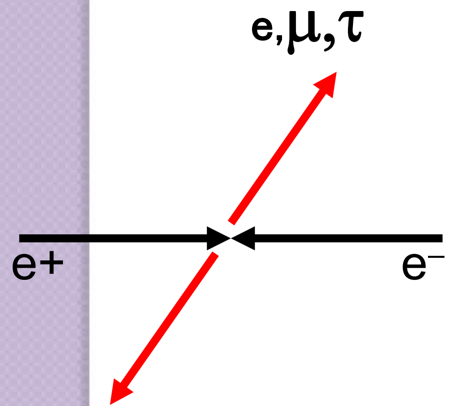


Recently, KEKB delivered more than 720fb^{-1} (world record!) while PEP-II reached around 500fb^{-1}

1fb^{-1} corresponds to 1.1million $b\bar{b}$ pairs.

Events produced at KEKB

lepton pair

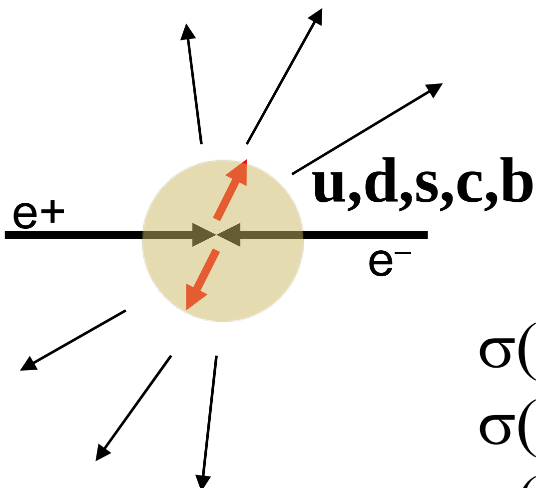


$\sigma(\mu\mu)\sim 1.0\text{nb}$

$\sigma(\tau\tau)\sim 0.9\text{nb}$

$\sigma(\text{bhabha})\sim 124\text{nb}$

quark pair



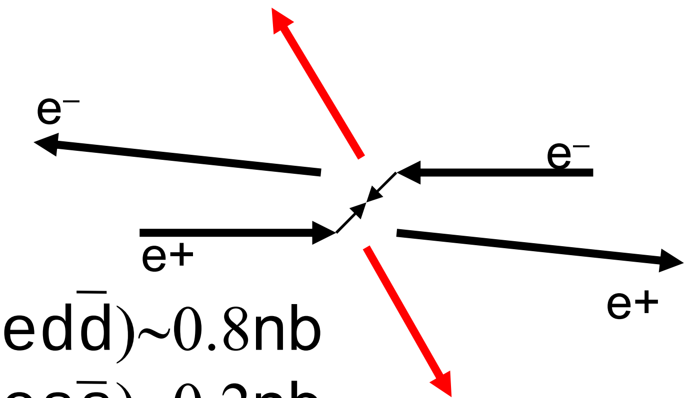
$\sigma(q\bar{q})\sim 1.9\text{nb}$

q=u, d, s

$\sigma(c\bar{c})\sim 1.2\text{nb}$

$\sigma(b\bar{b})\sim 1.1\text{nb}$

2photon process



$\sigma(ee d\bar{d})\sim 0.8\text{nb}$

$\sigma(ee s\bar{s})\sim 0.2\text{nb}$

$\sigma(ee c\bar{c})\sim 0.03\text{nb}$

$\sigma(eeee)\sim 41\text{nb}$

$\sigma(ee\mu\mu)\sim 19\text{nb}$

$\sigma(ee u\bar{u})\sim 12\text{nb}$

B-factory and τ physics

- A B-factory is also a τ-factory!
  - $\sigma(\tau\tau)$~0.9nb/$\sigma(b\bar{b})$~1.1nb at 10.6GeV
  - Almost same number of $\tau^+\tau^-$-pairs is produced as that of $b\bar{b}$-pairs!

Almost all of the recent results related to τ decay are reported from B-factories!

PDG2006

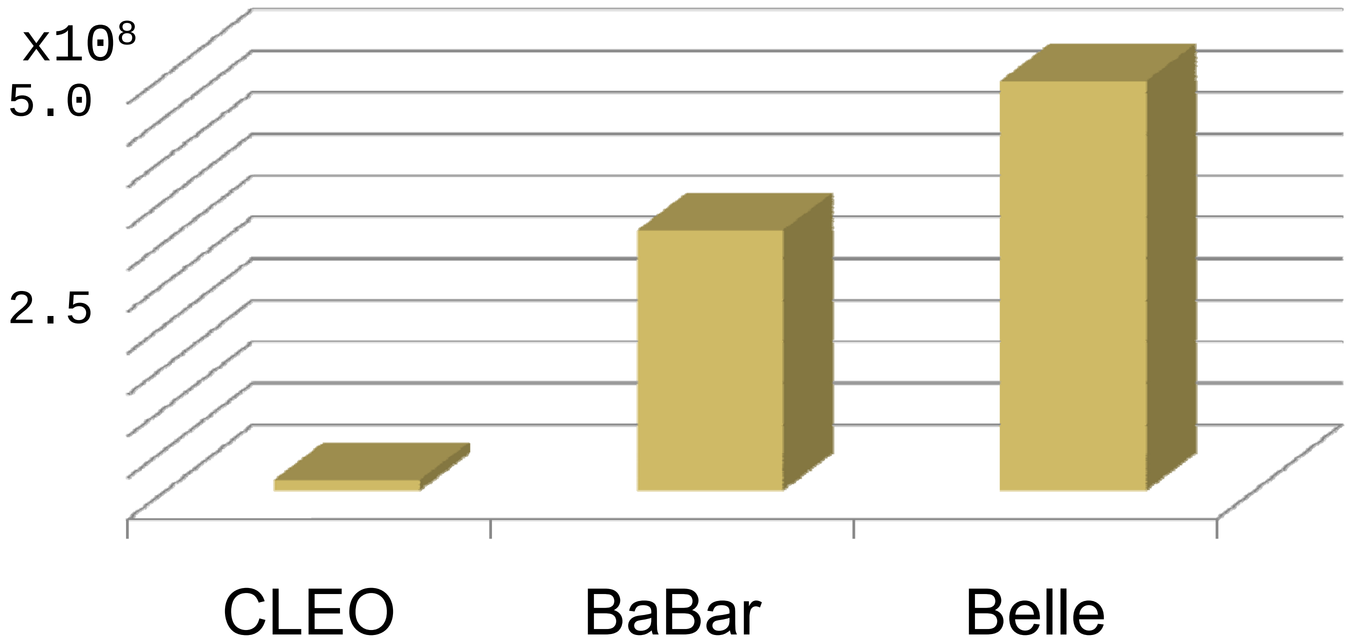
$\Gamma(e^-\gamma)/\Gamma_{total}$ **Γ_{149}/Γ**

Test of lepton family number conservation.

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<1.1 \times 10^{-7}$	90	AUBERT	06C	BABR	232 fb^{-1}, E^{ee}_{cm} = 10.6 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<3.9 \times 10^{-7}$	90	HAYASAKA	05	BELL	86.7 fb^{-1}, E^{ee}_{cm}=10.6 GeV
$<2.7 \times 10^{-6}$	90	EDWARDS	97	CLEO	
$<1.1 \times 10^{-4}$	90	ABREU	95U	DLPH	1990–1993 LEP runs
$<1.2 \times 10^{-4}$	90	ALBRECHT	92K	ARG	E^{ee}_{cm} = 10 GeV
$<2.0 \times 10^{-4}$	90	KEH	88	CBAL	E^{ee}_{cm} = 10 GeV
$<6.4 \times 10^{-4}$	90	HAYES	82	MRK2	E^{ee}_{cm} = 3.8–6.8 GeV

Number of τ pairs

Numbers of τ pairs used for recent analysis

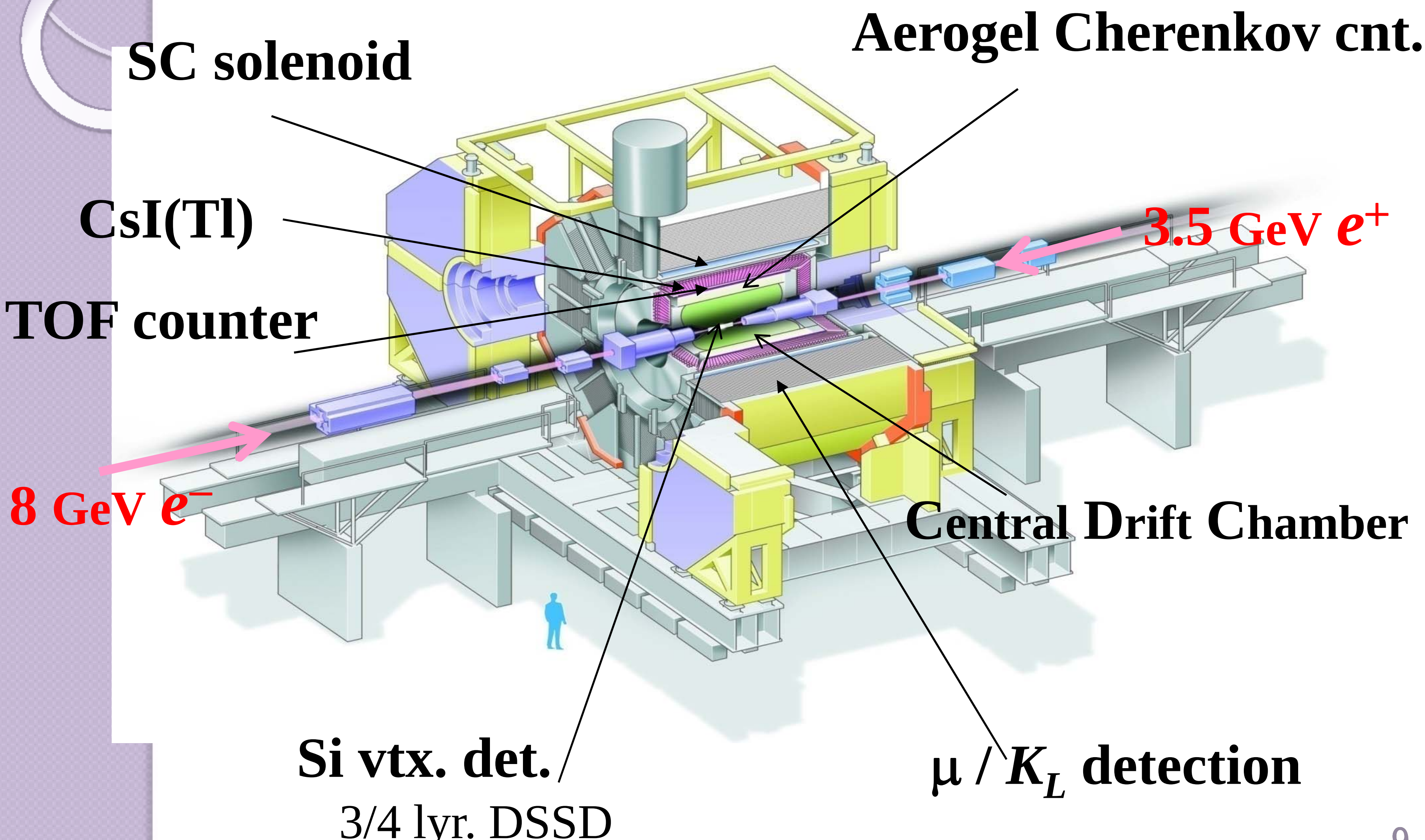


10^8 data sample makes us to analyze Br~10^{-5} precisely and search the new physics up to Br~10^{-8}

Belle has the largest τ pair sample in the world!

→ Belle is a good place to study τ physics.

Belle detector



hadronic τ decays

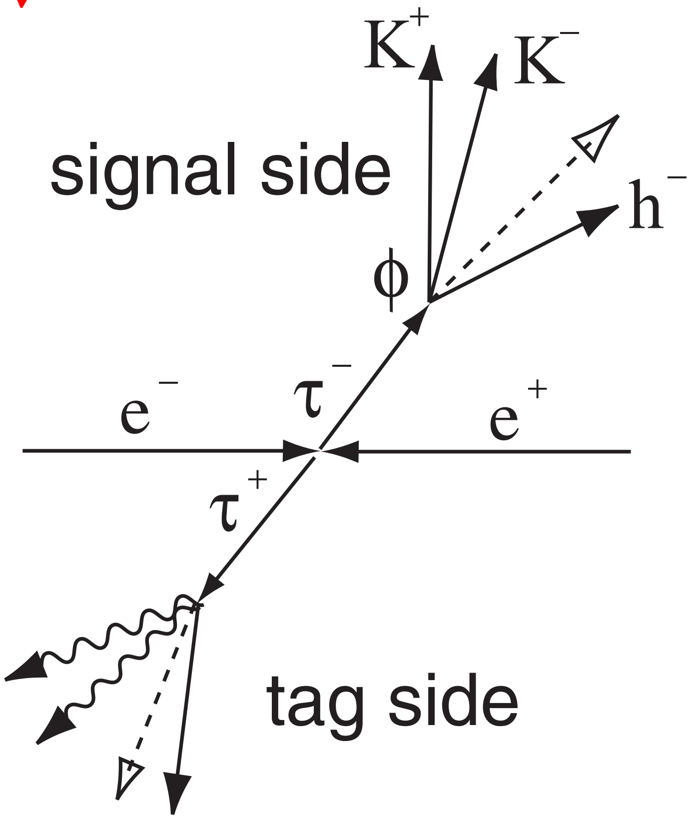
$\tau^- \to \phi K^- \nu_\tau$ study

This mode has not been observed before our analysis.
This analysis is performed with 401fb^{-1} data sample.
B-factory makes us to measure this mode!

Events selections

$\tau^\pm \to \phi\,(K/\pi)^\pm \nu\ (\phi \to K^+K^-)$ & $\tau^\pm \to l^\pm \nu\nu$

- 1-3 topology $(KK(K/\pi)+\ell)$
- $N_\gamma=0$ @signal side
- $N_\gamma<2$ @tag side
- lepton @tag
- K-ID : $\phi \to K^+K^-$



- Extract signal yield from $KK \to \phi$ mass distribution

Signal yield is evaluated by counting the # of phi-mesons in KK mass distribution.

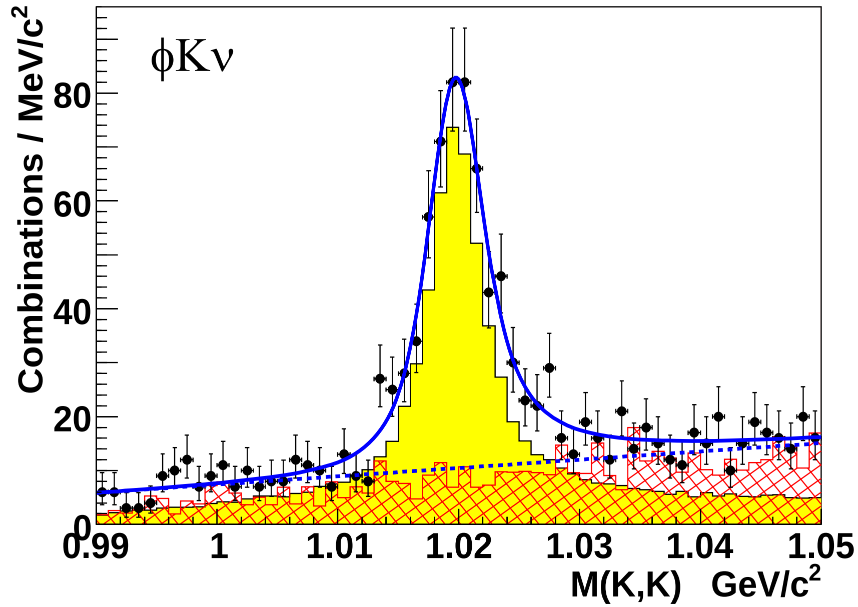
Signal extraction

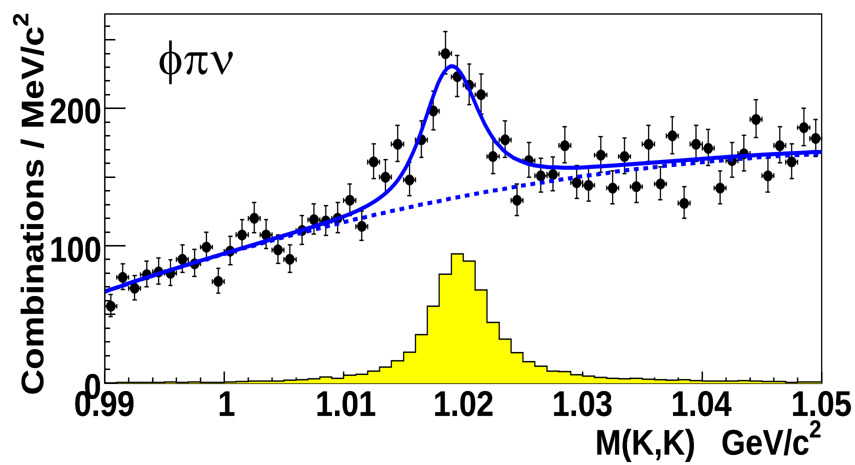
- Fitting with BW x Gauss + BG
  ($\Gamma\phi$=4.26±0.05MeV)
  M_ϕ = 1.019 GeV/c^2
  σ = 1.1 MeV/c^2
  ⇒ agree with MC

- BG: linear function for $\phi K\nu$
  (polynomial function for $\phi\pi\nu$)

- Efficiency: 1.82±0.03 % for $\phi K\nu$

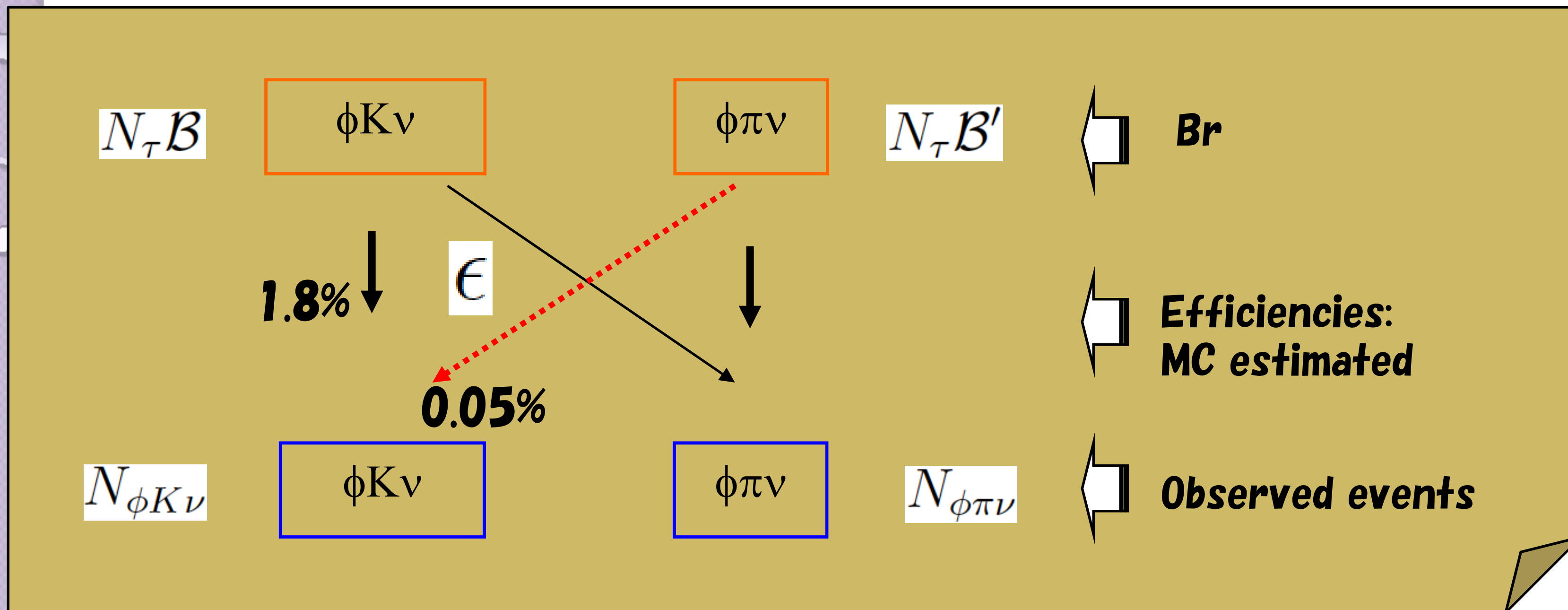
- Signal yield
  $N_{\phi K\nu}$=573±32
  $N_{\phi\pi\nu}$=753±84
  → <u>cross-feed</u>
  through wrong pid





Evaluation of Br.

Solved the equations to obtain Br's.



$$\begin{aligned} N_{\phi K\nu} &= N_\tau \mathcal{B}\,\epsilon_1 + N_\tau \mathcal{B}'\epsilon_1' \\ N_{\phi\pi\nu} &= N_\tau \mathcal{B}\,\epsilon_2 + N_\tau \mathcal{B}'\epsilon_2' \end{aligned}$$

$$\mathcal{B} = \frac{\epsilon_2' N_{\phi K\nu} - \epsilon_1' N_{\phi\pi\nu}}{N_\tau(\epsilon_1\epsilon_2' - \epsilon_1'\epsilon_2)}$$

Br$(\tau \to \phi K \nu)$ = $(4.05 \pm 0.25) \times 10^{-5}$

Br$(\tau \to \phi \pi \nu)$ = $(6.05 \pm 0.71) \times 10^{-5}$

Other contributions not considered yet.
It is rather a maximum value of Br.

Systematic uncertainties

Luminosity	1.4%
τ-pair cross-section	1.3%
Trigger efficiency	1.1%
Track finding efficiency	4.0%
Lepton-ID	3.2%
Kaon-ID/fake	3.1%
Fitting parameter (Γ)	0.2%
MC statistics	0.5%
$B(\phi \to K^- K^+)$	1.2%
Total	6.5%

➡ **Branching fraction**

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

$\tau^- \to K_S \pi^- \nu_\tau$ study

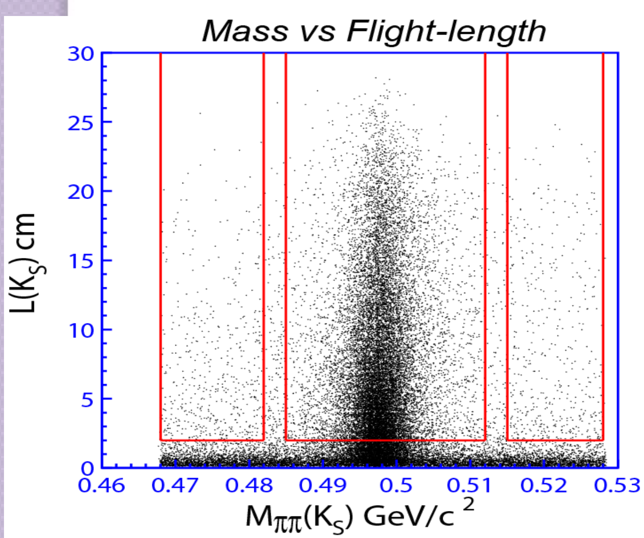
Largest Br among decays with 1 K, so it makes dominant contribution to the s-quark mass sensitive total strange hadronic spectrum function.

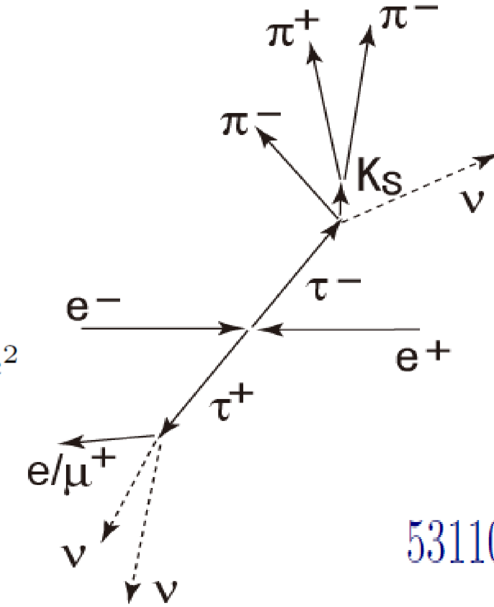
Mode	Contents, %
$\tau \to K_S \pi \nu$	79
$\tau \to K_S \pi K_L \nu$	9
$\tau \to K_S \pi \pi^0 \nu$	4
$\tau \to K_S K \nu$	2
$\tau \to 3\pi\nu$	5
non-$\tau\tau$	1

Events selections

For the K_S candidate:

- $\Delta Z_{1,2} < 1.5$ cm
- $cos(\vec{P}_\perp, \vec{r}_\perp) \geq 0.95$
- $L_{K_S} > 2$ cm
- $485 < M_{\pi\pi}(K_S) < 512$ MeV$/c^2$





351fb^{-1}, 310 M $\tau\tau$–pairs

53110 signal events ($\varepsilon_{det} \simeq 6\%$)

	$(e^+, K_S\pi^-)$	$(e^-, K_S\pi^+)$	$(\mu^+, K_S\pi^-)$	$(\mu^-, K_S\pi^+)$
N_{exp}	13336 ± 137	13308 ± 137	13230 ± 134	13236 ± 134
$\varepsilon(l, K_S\pi)$, %	5.70 ± 0.02	5.58 ± 0.02	5.95 ± 0.02	5.89 ± 0.02

Branching fraction $\mathcal{B}(\tau \to K_S \pi^- \nu_\tau)$

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

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

To cancel systematic errors relating evaluations of luminosity and $\sigma(\tau\tau)$, and track reconstruction eff.

→ Uncertainty of 3.4% is reduced.

Source of the syst. error	Contribution,%
K_S detection efficiency	2.5
$\tau^+\tau^-$ background subtraction	1.6
$\sum E_\gamma^{\mathrm{LAB}}$	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

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

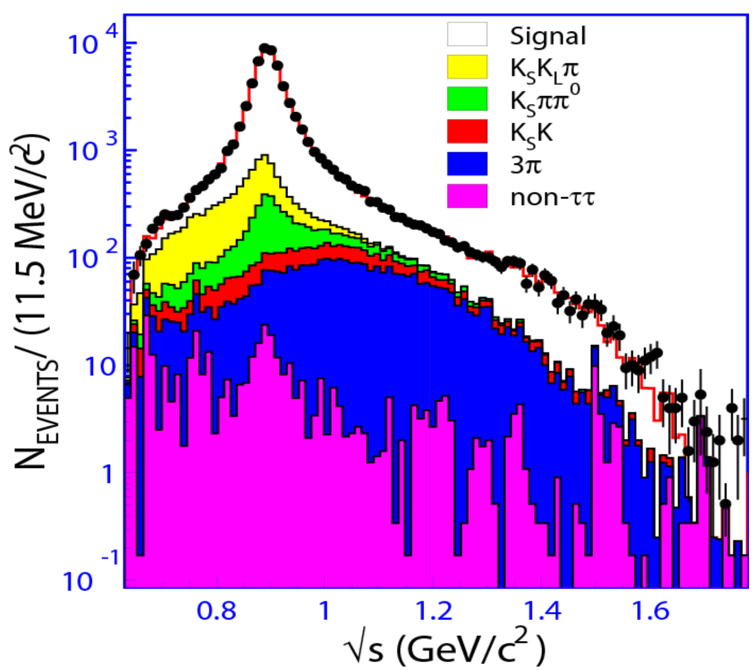
$$B(\tau^- \to K^0\pi^-\nu) = 2.0 \mathrm{x} B(\tau^- \to K_S^0\pi^-\nu)$$
$$= 0.808 \pm 0.004(\mathrm{stat.}) \pm 0.026(\mathrm{syst.})\ \%$$

$K_S\pi^-$ mass spectrum

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

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

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



$K_0^*(800)+K^*(892)+K^*(1410)$ model	
$M_{K^*(892)}$	$= 895.47 \pm 0.20\ MeV/c^2$
$\Gamma_{K^*(892)}$	$= 46.19 \pm 0.57\ MeV$
$\lvert a(K^*(1410))\rvert$	$= (75 \pm 6)\times 10^{-3}$
$\arg(a(K^*(1410)))$	$= 1.44 \pm 0.15$
$\lvert a(K_0^*(800))\rvert$	$= 1.57 \pm 0.23$
$\chi^2/n.d.f. = 90.2/84,\ P(\chi^2) = 30\%$	

Best fit is achieved in $K^*_0(800)+K^*(892)+K^*(1410)/K^*_0(1430)$ but not $K^*(892)$ alone.

K* (892) mass & width

$M(K^*(892)^-) = 895.47 \pm 0.20(\text{stat.}) \pm 0.44(\text{syst.}) \pm 0.59(\text{mod.})$ MeV/c²
$\Gamma(K^*(892)^-) = 42.2 \pm 0.6(\text{stat.}) \pm 1.0(\text{syst.}) \pm 0.7(\text{mod.})$ 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.
PDG $K^{*\pm}$ (K^{*0})	891.66 ± 0.26 (896.00 ± 0.25)	50.8 ± 0.9 (50.3 ± 0.6)	

$\tau \to K\eta\nu$, $K\pi^0\eta\nu$ ($K^*\eta\nu$), and $\pi\pi^0\eta\nu$ study

Analyze τ-decay modes, involving an η,
- Because of poor statistics, previous measurements have large uncertainty.
- Data used are 485/fb (433M τ pairs), x ~100 larger than previously.

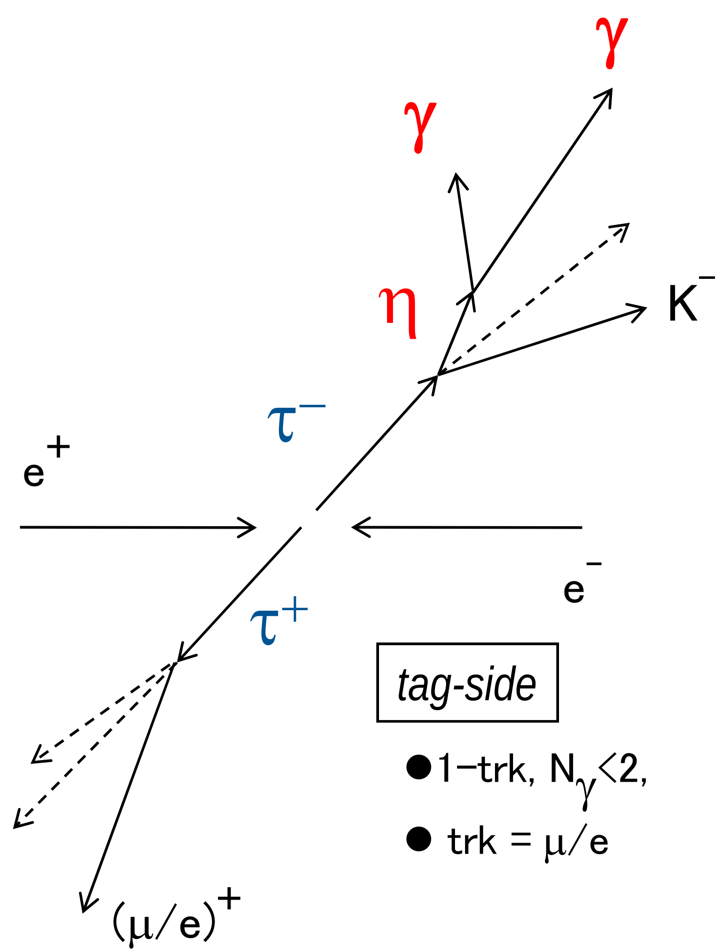
Physics motivations
- CVC hypothesis,
- chiral Lagrangian approach with WZW anomaly,
- High mass resonance.

Event selection with $\eta \to \gamma\gamma$

sig-side

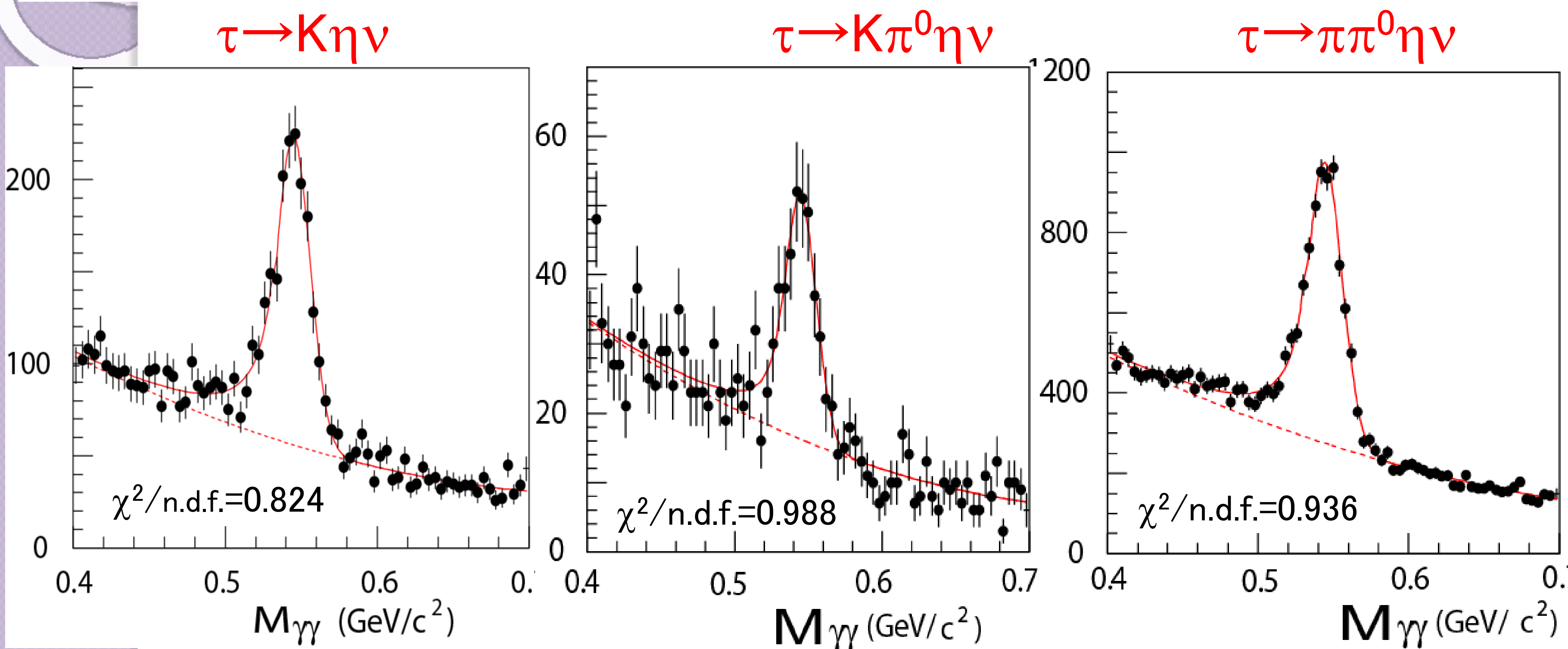
	$K\eta\nu$	$K\pi^0\eta\nu$	$\pi\pi^0\eta\nu$
●1−trk	K		π
●N_γ	2	4	
●2γ	η	η & π^0	

- $|V_{thrust}|>0.8$;
- $M_{sig}<M_\tau$; $M_{tag}<M_\tau$



$\eta \to \gamma\gamma$ yield measurement

Fit data with (signal=Crystal Ball function + BG=second-order polynomial function)



	$K\eta\nu$	$K\pi^0\eta\nu$	$\pi\pi^0\eta\nu$
yields	1387 ± 44	270 ± 33	5959 ± 105
mass (MeV/c^2)	544.9 ± 0.6	544.4 ± 1.0	544.3 ± 0.4
resolution (MeV/c^2)	11.0 ± 0.6	10.7 ± 1.5	11.6 ± 0.3

Extract Branching fractions

Consider cross-feed among the decays,

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

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

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

↑ (η-yield)-($q\bar{q}$+others)

Cross-feed rates

Detection efficiencies

Efficiencies (ε's) include B($\eta \rightarrow \gamma\gamma$).

Selection	$K\eta\nu$	$K\pi 0\eta\nu$	$\pi\pi^0\eta\nu$
$K\eta\nu$	9.41×10^{-3}	3.71×10^{-4}	1.50×10^{-5}
$K\pi^0\eta\nu$	1.14×10^{-4}	3.46×10^{-3}	7.09×10^{-5}
$\pi\pi^0\eta\nu$	1.74×10^{-5}	2.32×10^{-4}	4.71×10^{-3}

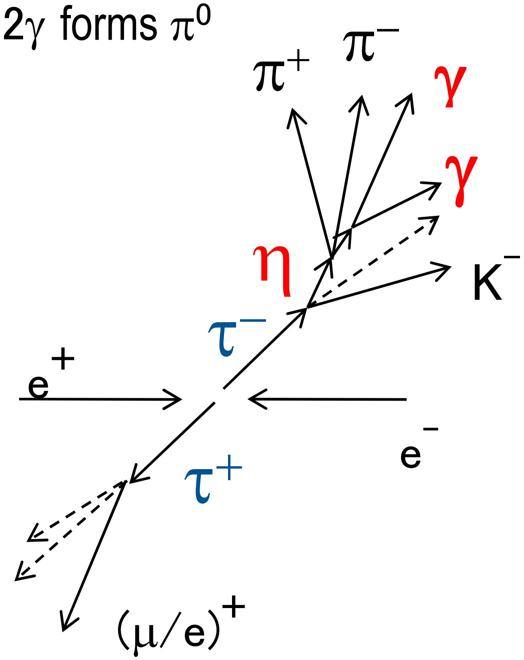
	η-yield	$q\bar{q}$	others	$K\eta\nu$	$K\pi^0\eta\nu$	$\pi\pi^0\eta\nu$
$K\eta\nu$	1387±43 (ev)	30.6±15.6	1.1±0.2		15.1±3.8	18.0±1.0
$K\pi^0\eta\nu$	270±33	27.0±8.5	1.2±0.4	16.0±0.9		85.3±4.6
$\pi\pi^0\eta\nu$	5959±105	212±29	71.6±20	2.4±0.1	9.4±2.4	

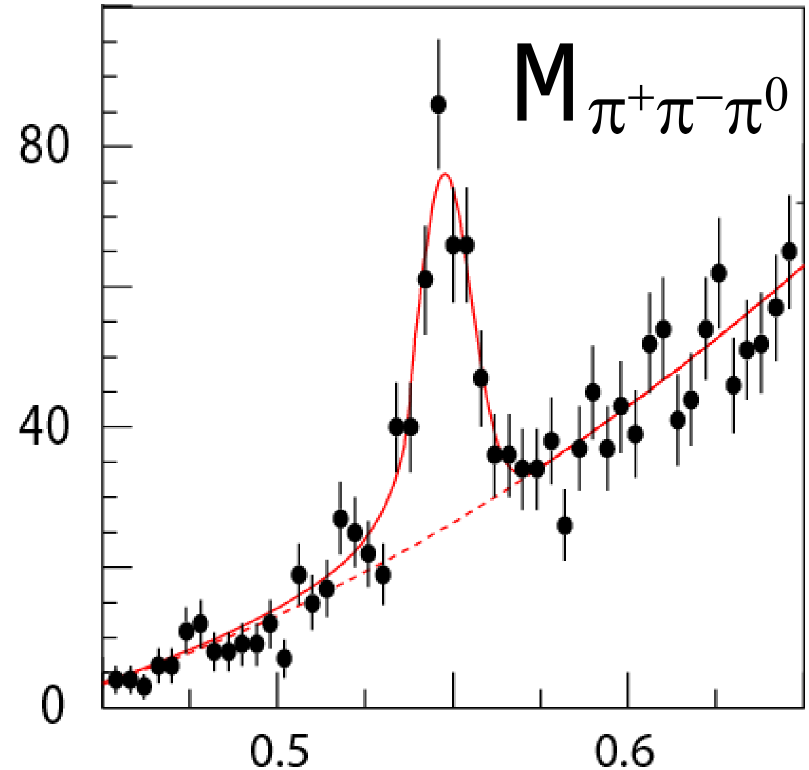
↑ $\pi^-\pi^0\pi^0\eta\nu$, $\pi^-\pi^+\pi^-\eta\nu$

$\mathcal{B}(\tau \to K\eta\nu)$ with $\eta \to \pi^+\pi^-\pi^0$

- 3-trk & $N\gamma$=2
- 1-trk = K
- 2γ forms π^0

sig-side





	result of fitting
yield	241±21
mass (MeV/c^2)	547.4±0.7
resolution(MeV/c^2)	7.5±0.4

Efficiencies (ε's) include $B(\eta \to \pi\pi\pi)$.

	η-yield	$q\bar{q}$	others	$K\eta\nu$	$K\pi^0\eta\nu$	$\pi\pi^0\eta\nu$
ε's				1.56×10^{-3}	8.18×10^{-5}	4.82×10^{-6}
$K\eta\nu$	241±21 (ev)	9.1±2.2	<1.18		3.3±0.8	5.8±1.3

Systematic uncertainties

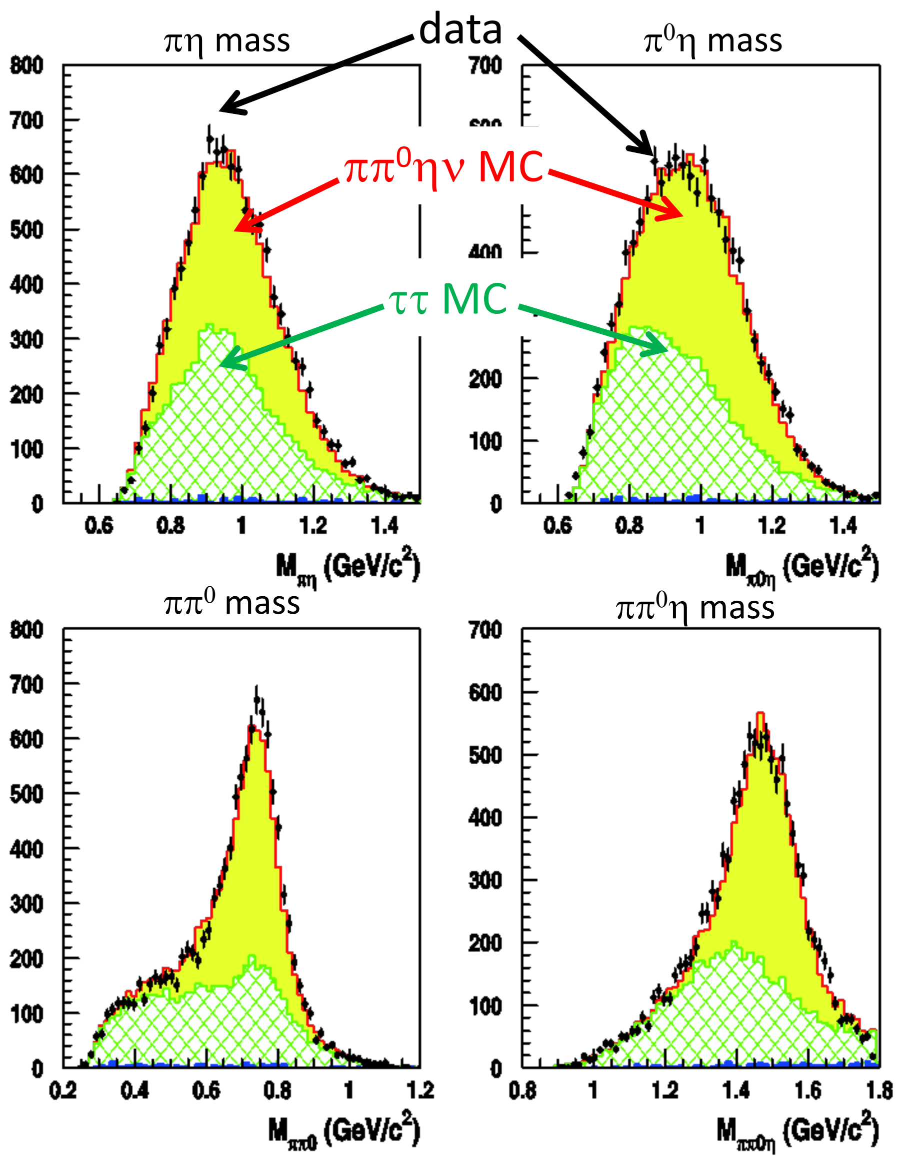
	$K\eta\nu$ $(\eta\to\gamma\gamma)$	$K\eta\nu$ $(\eta\to\pi\pi\pi)$	$K\pi^0\eta\nu$	$\pi\pi^0\eta\nu$
contaminations of $K\eta\nu$	–	–	0.6	0.0018
contaminations of $K\pi^0\eta\nu$	0.3	0.4	–	0.042
contaminations of $\pi\pi^0\eta\nu$	0.075	0.1	3.3	–
contaminations of $\pi\pi^0\pi^0\eta\nu$	–	–	–	0.4
contaminations of qq	1.5	1.5	6.0	0.5
K/p ID	3.3	2.8	2.2	1.0
lepton ID	2.3	2.6	2.8	2.6
tracking	1.3	3.3	1.3	1.3
luminosity	1.6	1.6	1.6	1.6
π^0 detection	–	2.0	2.0	2.0
π^0 veto	2.8	–	2.8	2.8
signal MC	0.5	1.3	1.7	0.7
$B(\eta\to\pi^-\pi^+\pi^0)$	–	1.8	–	–
Total	5.6	6.1	8.9	5.0

Branching fractions

preliminary

	Our results
$K\eta\nu$ $(\eta\to\gamma\gamma)$	$(1.61\pm0.05\pm0.09)\times10^{-4}$
$K\eta\nu$ $(\eta\to\pi^-\pi^+\pi^0)$	$(1.65\pm0.16\pm0.10)\times10^{-4}$
$K\eta\nu$ combined	$(1.62\pm0.10)\times10^{-4}$
$K\pi^0\eta\nu$	$(4.7\pm1.1\pm0.4)\times10^{-5}$
$\pi\pi^0\eta\nu$	$(1.39\pm0.03\pm0.07)\times10^{-3}$

Various mass distributions for $\tau \to \pi\pi^0\eta\nu$



$\tau^- \to \pi^-\pi^0\eta\nu$ MC is generated based on measured $\sigma(e^+e^- \to \pi^+\pi^-\eta)$ and CVC theory.

Good agreements are found in each distribution.

$\tau \to K^{*-}(892)\ \eta\nu$ analysis

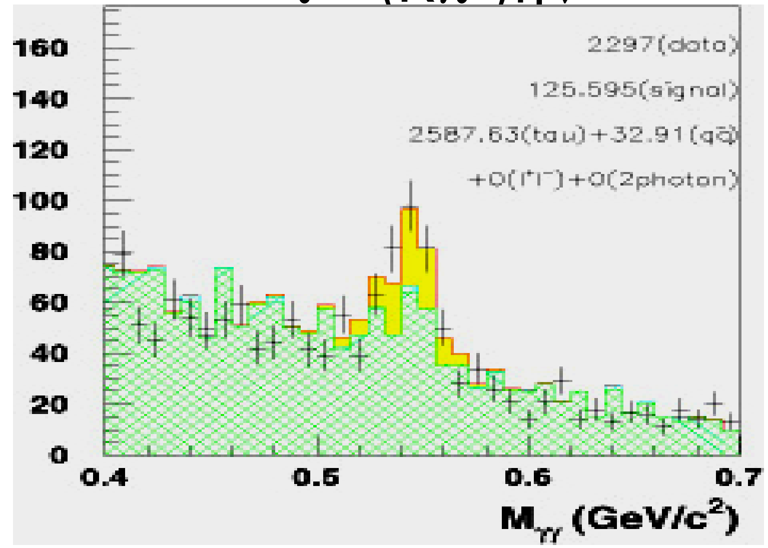
With use of $\tau \to K\pi^0\eta\nu$ samples,

- Signal-band: $0.50 < M_{\gamma\gamma} < 0.58$ (GeV/c^2)
- Side-bands: $0.43 < M_{\gamma\gamma} < 0.48$, $0.60 < M_{\gamma\gamma} < 0.65$

(lower and higher sides show a same $M_{K\pi^0}$ dist.)

- Continuum BG estimated from side-bands.
- $K(892)^{*-}$ peaking BG estimated by MC: $\tau \to \pi\pi^0\eta\nu$, $\tau \to K(892)^{*-}\nu$ and $q\bar{q}$

$\tau \to (K\pi^0)\eta\nu$



$K^{*-}(892)$ yields

- Fit data with

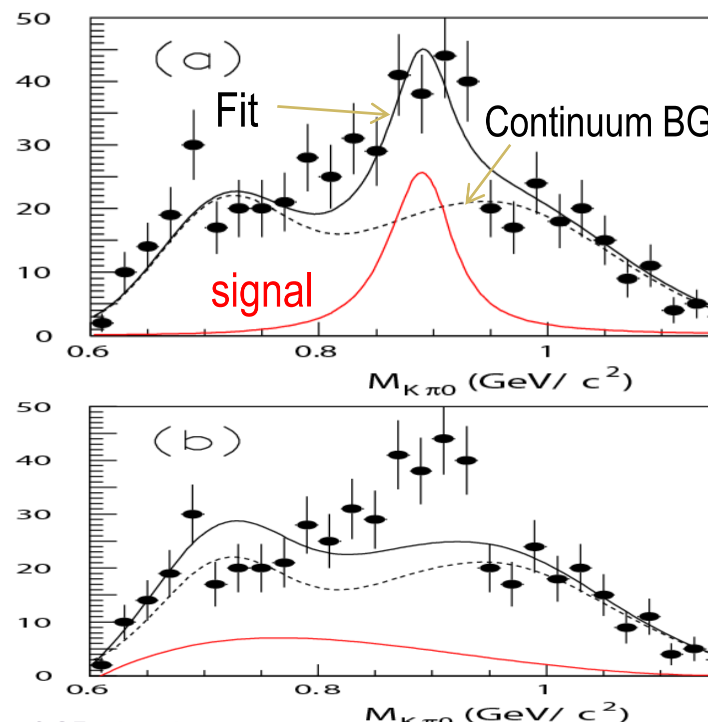
(a) K^{*-} resonance (BW) + BG

(b) V-A phase-space dist. + BG,

- Continuum (dashed curve): χ^2/n.d.f.=1.061, N_{BG}=427±21 events
- No significant contribution from non-resonant comp.

Therefore, we take (a).

	N_{K*}	N_{phase}	χ^2/dof.	prob.
(a)	119±19	—	1.154	0.265
(b)	—	102±21	2.088	0.0008



Systematic uncertainties

	error (%)
peaking BG ($\tau\tau$)	0.94
peaking BG (qq)	2.4
K/π ID	2.2
lepton ID	2.5
tracking	1.3
luminosity	1.6
π^0 detection	2.0
π^0 veto	2.8
Signal MC	1.7
Total	6.1

Branching fractions

$B(K^{*-}\eta\nu)=(1.10\pm0.19\pm0.07)\times10^{-4}$ **preliminary**

Efficiency (ε) include $B(K^{*-}\rightarrow K^-\pi^0)=0.333$, $B(\eta\rightarrow\gamma\gamma)=0.394$, and $B(\tau\rightarrow l\nu\nu)=0.352$.

Efficiency (%)	K^{*-} yields	$K^{*-}\nu$ BG	qq BG
0.115	119 ± 19	2.3 ± 0.9	6.5 ± 2.3

Summary for $\tau^- \to \phi K^- \nu_\tau$

- CLEO has reported that the upper limit on Br is (5.4-6.7)x10^{-5} at 90% C.L. with 3.1fb^{-1} data sample at PRD55,R1119.
- First measurement is achieved owing to a high statistical 401fb^{-1} data sample. KEKB factory makes us to have a huge data sample.
- Branching fraction is $(4.05 \pm 0.25 \pm 0.26)\times10^{-5}$

PLB 643, 5(2006)

Summary for $\tau^- \to K_S \pi^- \nu_\tau$

- $K_S\pi^0$ mass spectrum is very well represented, including $K_0^*(800)^-$ and $K^*(1410)^-$ resonances along $K^*(892)^-$.
- Highly precise $B(\tau^- \to K^0\pi^-\nu)$ measurement is performed.
- High statistical measurement results in different values on Br, M and Γ, compared to PDG07. Need more study.

	Our results	PDG-2007
$B(\tau^- \to K^0\pi^-\nu)$	$(0.808 \pm 0.004 \pm 0.026)$ %	(0.90 ± 0.04) %
$M(K^*(892)^-)$	$(895.47 \pm 0.20 \pm 0.44 \pm 0.59)$ MeV	(891.66 ± 0.26) MeV
$\Gamma(K^*(892)^-)$	$(46.2 \pm 0.6 \pm 1.0 \pm 0.7)$ MeV	(50.8 ± 0.9) 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.
PDG $K^{*\pm}$ (K^{*0})	891.66 ± 0.26 (896.00 ± 0.25)	50.8 ± 0.9 (50.3 ± 0.6)	

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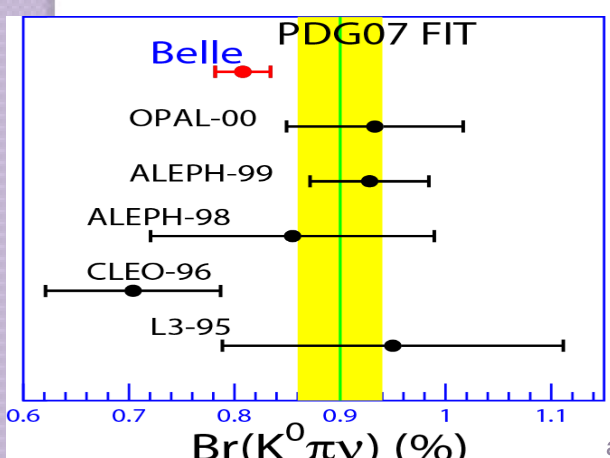

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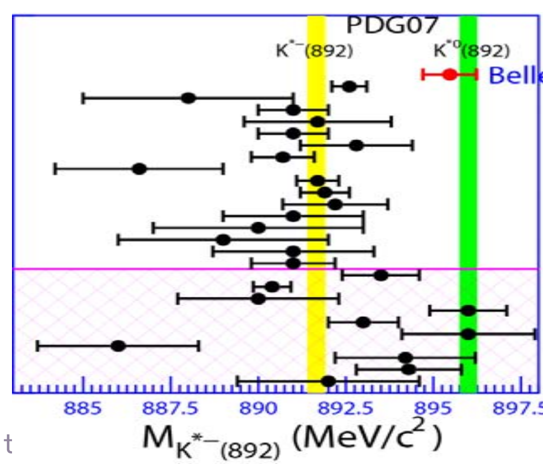
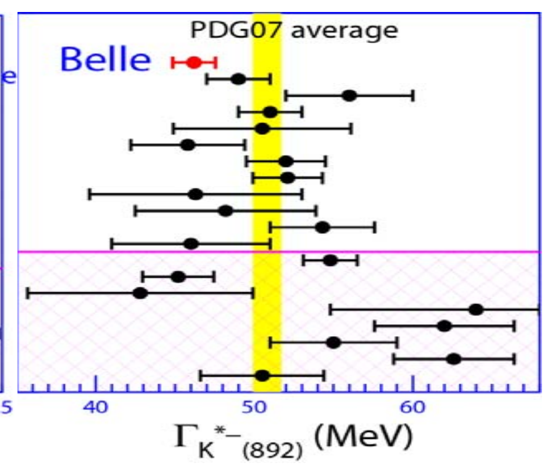


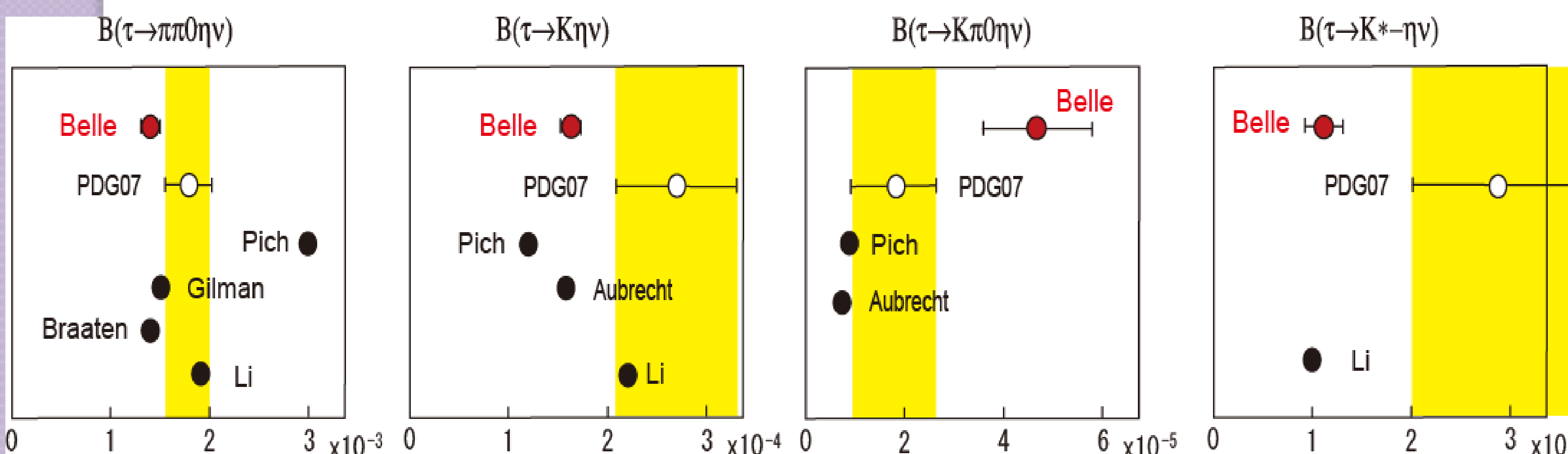


Summary for $\tau \to K\eta\nu$, $K\pi^0\eta\nu$ and $\pi\pi^0\eta\nu$

- Precise $B(\tau^- \to K^-\eta\nu;\ K^-\pi^0\eta\nu;\ K^{*-}\eta\nu;\ \pi^-\pi^0\eta\nu)$ measurements largely improve PDG07 data.
- $B(\tau^- \to \pi^-\pi^0\eta\nu)$ agrees with a CVC calculation, 1.5×10^{-3} by Gilman. Also, mass distributions.

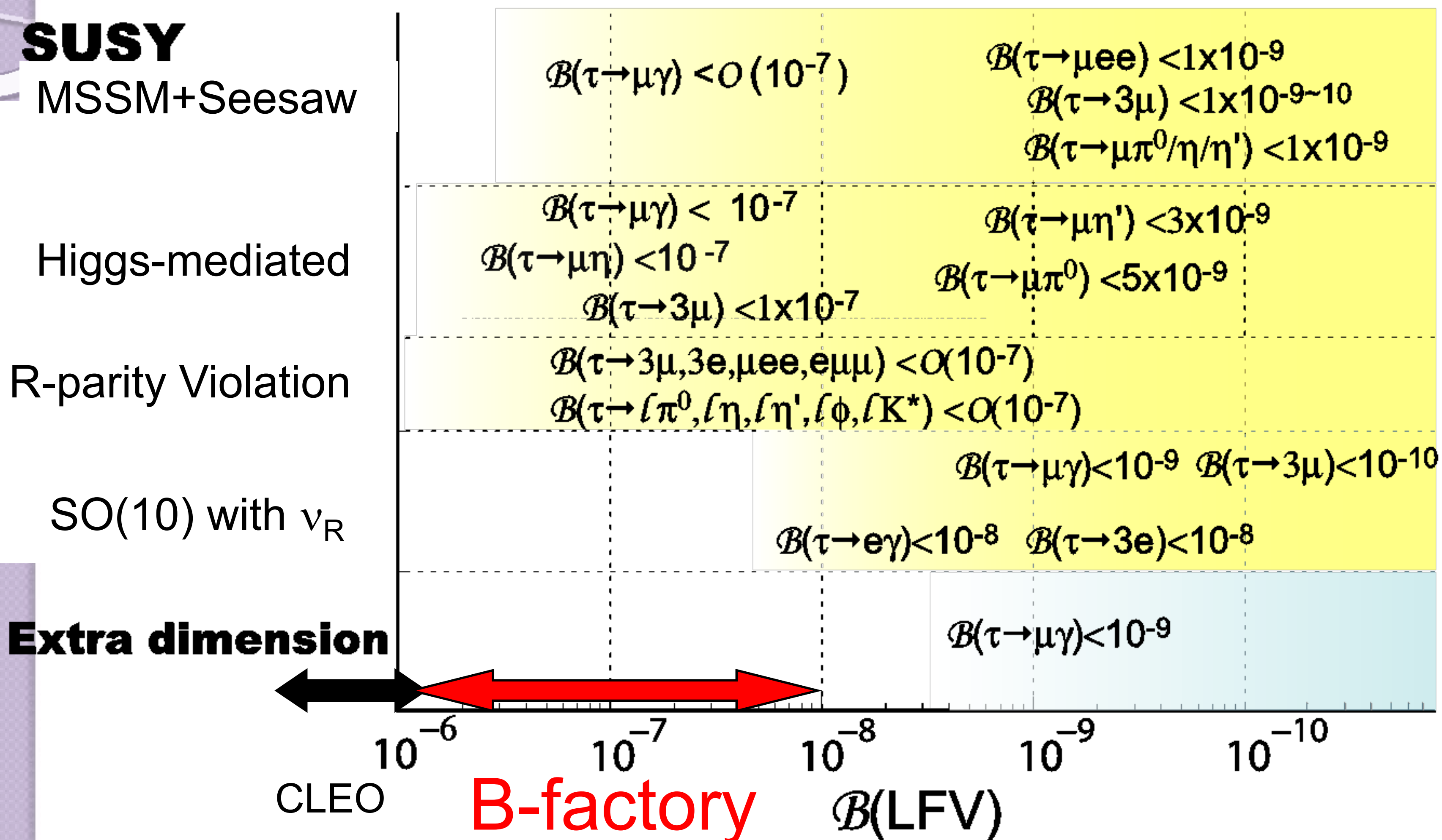
preliminary

	Our results	PDG-2007
$B(\tau^- \to K^-\eta\nu)$	$(1.62\pm0.10)\times10^{-4}$	$(2.7\pm0.6)\times10^{-4}$
$B(\tau^- \to K^-\pi^0\eta\nu)$	$(4.7\pm1.1\pm0.4)\times10^{-5}$	$(1.8\pm0.9)\times10^{-5}$
$B(\tau^- \to K^*(892)^-\eta\nu)$	$(1.10\pm0.19\pm0.07)\times10^{-4}$	$(2.9\pm0.9)\times10^{-4}$
$B(\tau^- \to \pi^-\pi^0\eta\nu)$	$(1.39\pm0.03\pm0.07)\times10^{-3}$	$(1.77\pm0.24)\times10^{-3}$



τ LFV decays

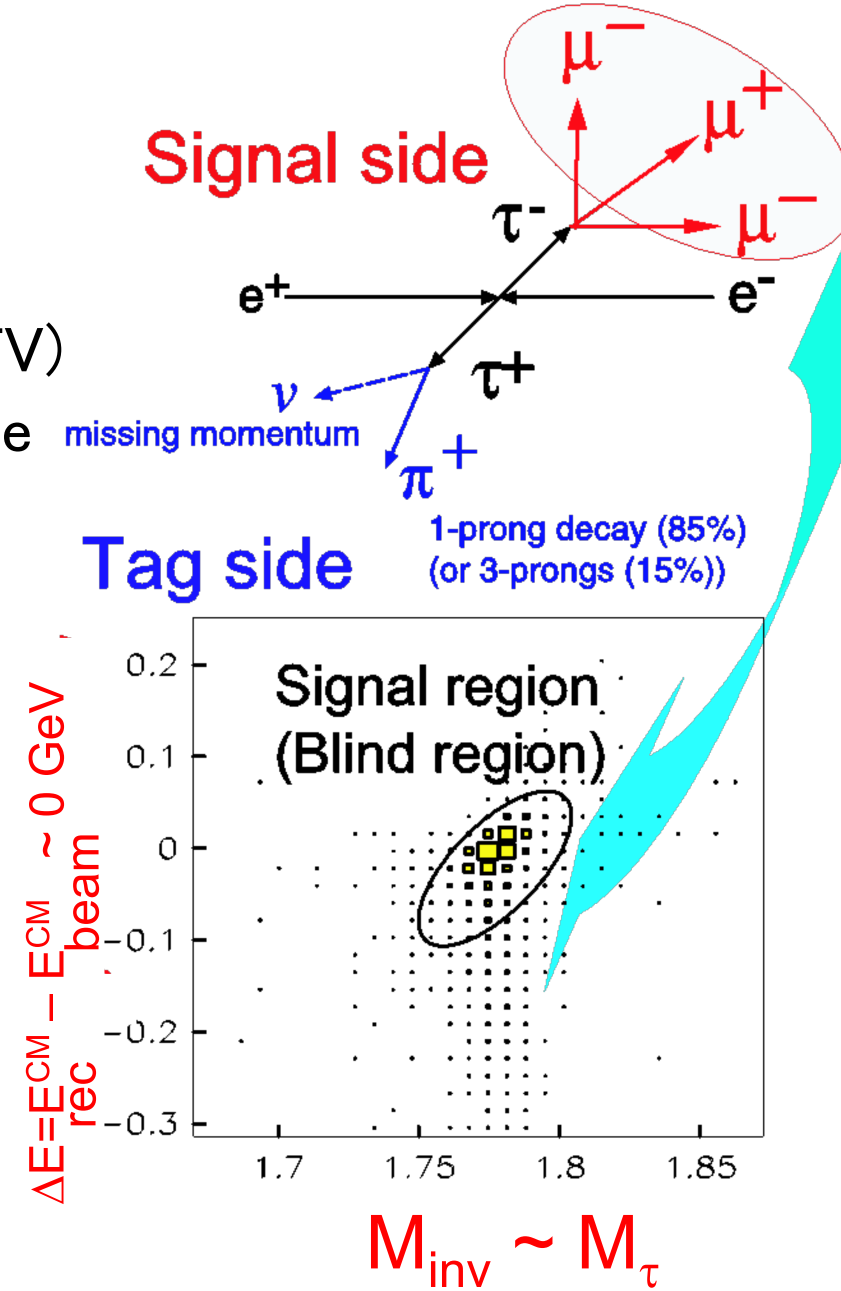
NP models and τ LFV decays



Analysis method

Procedure for a LFV τ decay analysis

1.Select events with low multiplicity
⇒Signal (charged tracks and γ from LFV)
and **Tag** (generic 1−prong decay) side
2. Reduce background events
using PID, kinematical information
3.Calculate M_{inv} and ΔE
⇒We perform blind analysis
4. Estimate signal efficiency and
# of backgrounds in signal region
from sidebands and MC
5.Open the blind region
⇒Observe LFV or set upper limits



Results for $\tau \to l\gamma, l\eta, l\eta', l\pi^0$

$\tau \to \mu\gamma, e\gamma$

Data: 535fb^{-1}

Br($\tau \to \mu\gamma$)<4.5x10^{-8} at 90%C.L.

Br($\tau \to e\gamma$)<1.2x10^{-7} at 90%C.L.

(hep-ex/0705.0650 submitted to PLB)

$\tau \to e/\mu$+pseudoscalar meson (η, η', π^0)

Data:401fb^{-1}

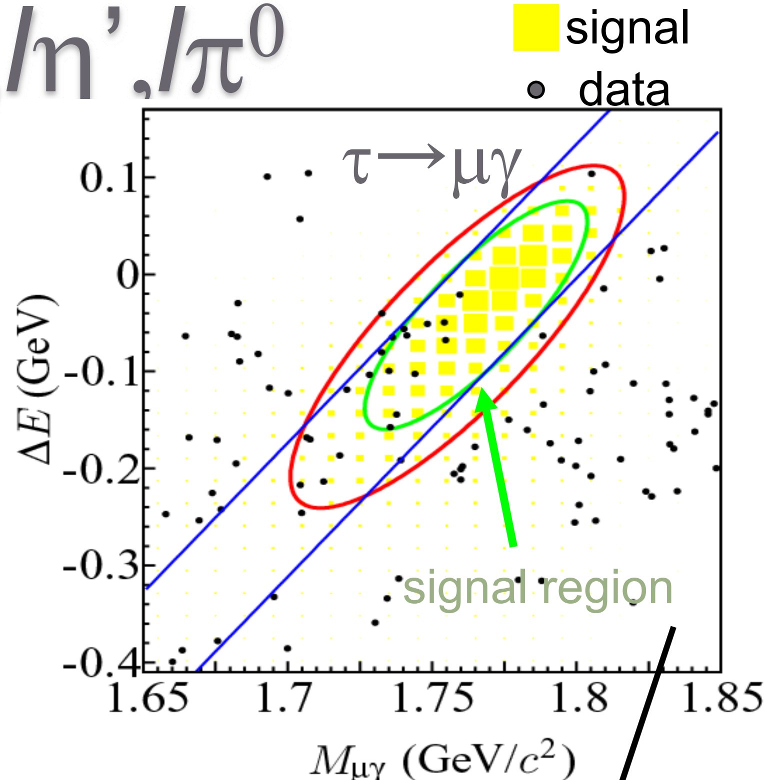
Br($\tau \to l\eta, l\eta', l\pi^0$)<(6.5−16)x10^{-8} at 90%C.L.

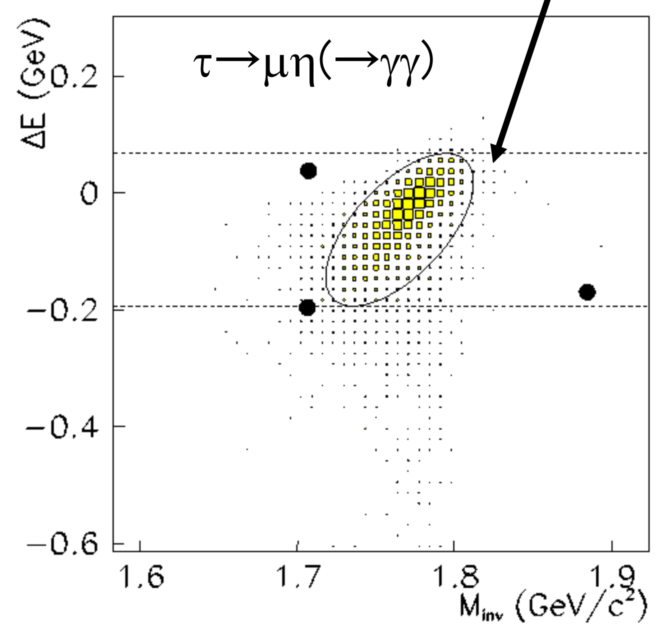
(PLB648, 341 (2007))

⇒Upper limits for LFV τ decays are approaching the O(10^{-8}) level

We proceed now to the updated searches of

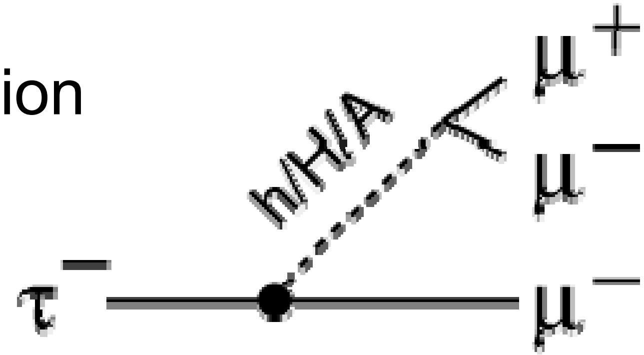
$\tau \to 3$ leptons and $\tau \to lV^0$($V^0=\phi, \omega$)





$\tau \rightarrow 3$ leptons (1)

Predicted to have large branching fraction in Higgs mediated LFV models



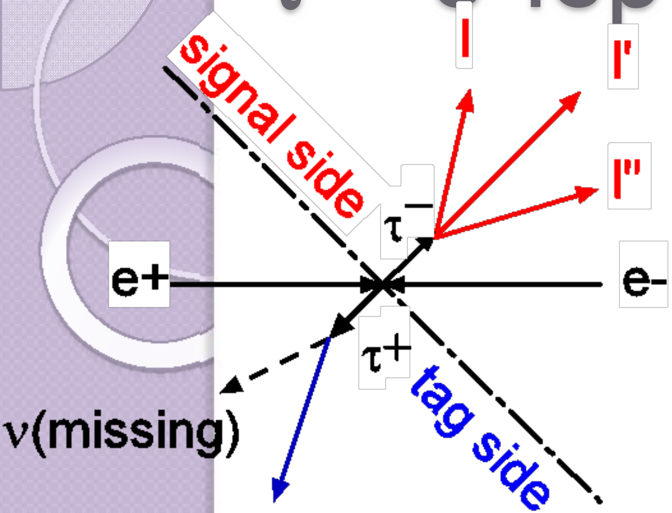
We consider 6 modes: $\tau^- \rightarrow e^-e^+e^-$, $\mu^-\mu^+\mu^-$, $e^-\mu^+\mu^-$, $\mu^-e^+e^-$, $e^+\mu^-\mu^-$ and $\mu^+e^-e^-$

Previous results at Belle (PLB 598, 103 (2004))
Br<(1.9-3.5)x10^{-7} at 90%C.L. (87.1fb^{-1})
(Br<(1.1-3.3)x10^{-7} at 90%C.L. (BaBar 91.5fb^{-1}))

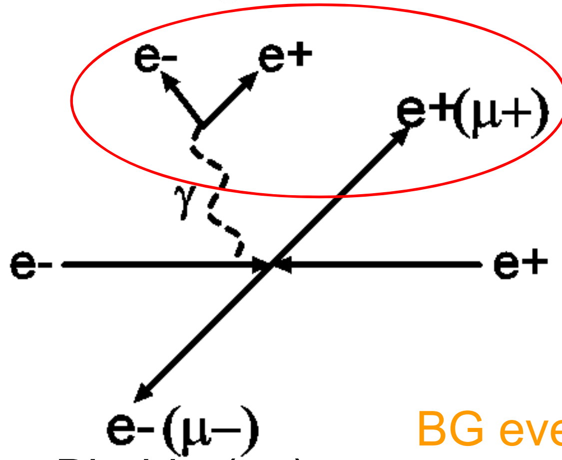
We update the analysis of $\tau \rightarrow 3$ leptons modes using 535fb^{-1} of data

- luminosity is increased by a factor of 6.1 from previous analysis
- optimize event selections for each mode separately taking account of different background compositions

$\tau \rightarrow 3$ leptons (2)

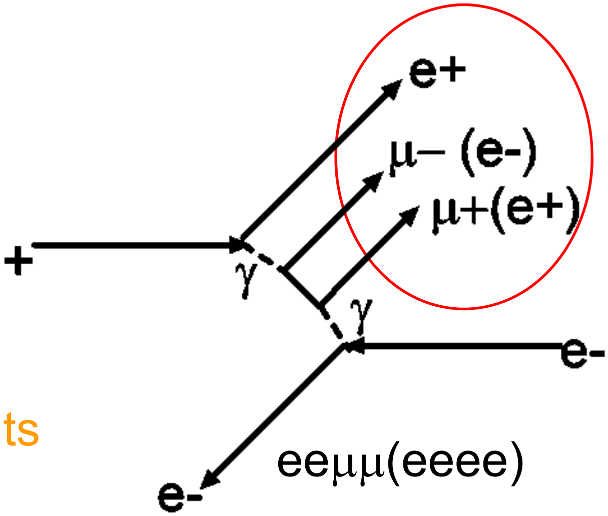


1-prong decay
Signal topology



Bhabha($\mu\mu$)

BG events



ee$\mu\mu$(eeee)

$\tau^- \rightarrow$ Mode	$\mu^-\mu^+\mu^-$	$e^-e^+e^-$	$\mu^-e^+e^-$ $e^-\mu^+\mu^-$	$\mu^+e^-e^-$ $e^+\mu^-\mu^-$
Dominant Background	$\tau\tau$ continuum $\mu\mu\mu\mu$	Bhabha $eeee$ $\tau\tau$	$ee\mu\mu$ $\tau\tau$ $\mu\mu$	$\tau\tau$ continuum

Event selection

For all modes
- $5.29 < E_{total}^{CM} < 9.5$ GeV
- $0.90 < |V_{Thrust}| < 0.97$
- $M_{tag} < M_{\tau}$
- $0.0 < \cos\theta_{tag\text{-}miss}^{CM} < 0.98$

For each mode
- electron-veto on the tag-side
  (e-e+e- and e-μ+μ-)
- γ-conversion veto
  (e-e+e- and μ-e+e-)
- m^2_{miss} and p_{miss}
  (e-e+e-, μ–μ+μ-, e-μ+μ-, μ-e+e-)

τ→3 leptons (3)

Efficiency : 6.0 – 12.5%
→the same or better than
in the previous analysis
Expected BG : 0.0–0.4 events

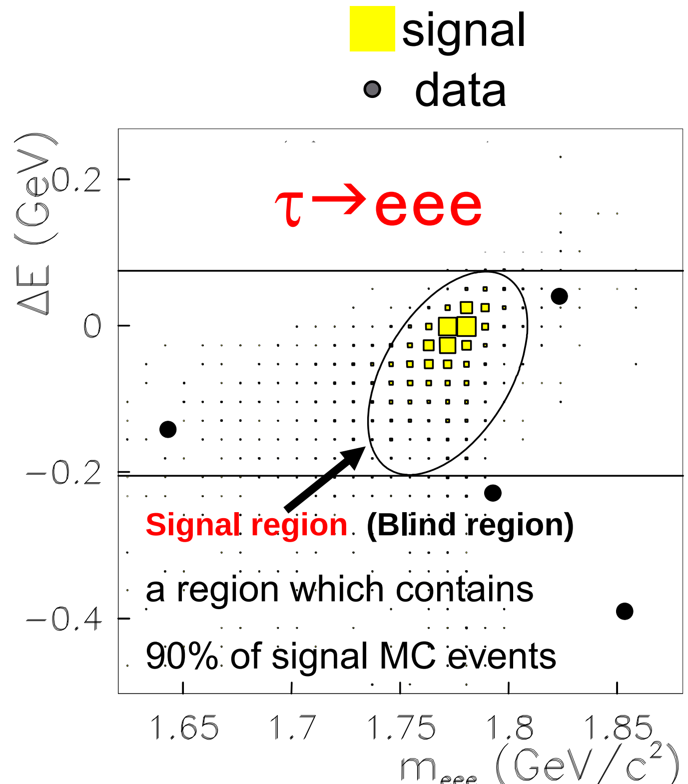
We observe no events in the signal region

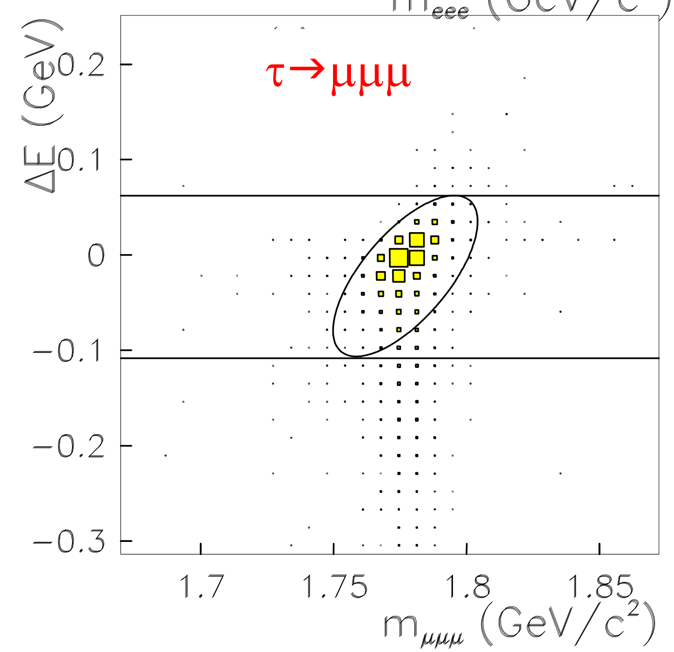
Mode	Upper limits
$\tau^- \to \mu^-\mu^+\mu^-$	$< 3.4 \times 10^{-8}$
$\tau^- \to e^-e^+e^-$	$< 3.6 \times 10^{-8}$
$\tau^- \to \mu^-e^+e^-$	$< 2.8 \times 10^{-8}$
$\tau^- \to e^-\mu^+\mu^-$	$< 4.3 \times 10^{-8}$
$\tau^- \to \mu^+e^-e^-$	$< 2.1 \times 10^{-8}$
$\tau^- \to e^+\mu^-\mu^-$	$< 2.4 \times 10^{-8}$

(Preliminary)

These results are improved by a factor of 4.7-6.8 the best previous values

⇒The most stringent upper limits among LFV τ decays



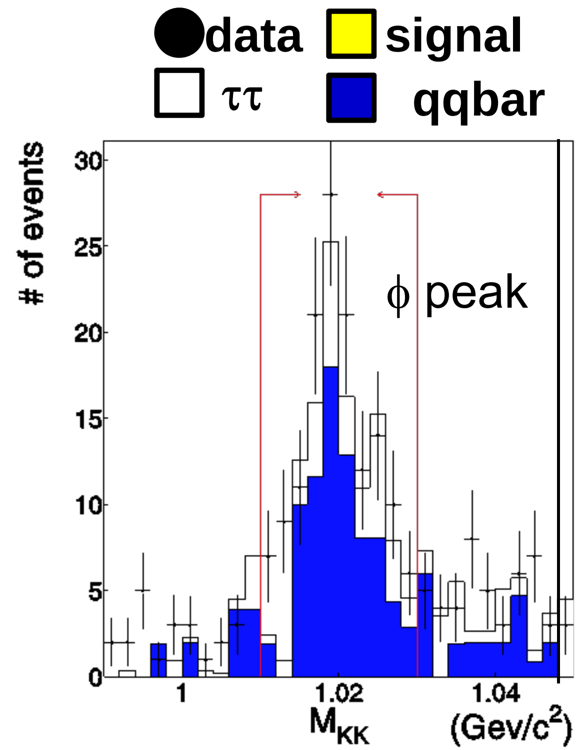


$\tau \rightarrow l\phi,\ l\omega$

Belle Previously (PLB 640, 138 (2006))
Br ($\tau \rightarrow l\phi$) <(7.3-7.7)x10^{-7} @ 154 fb^{-1}

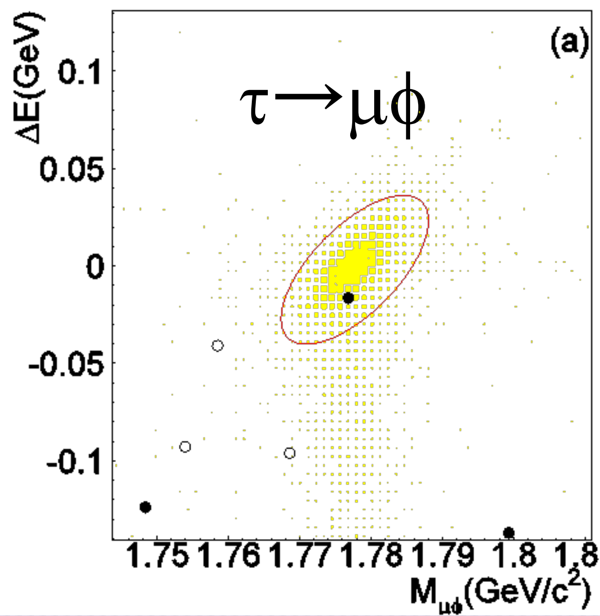
⇒Update using 543 fb^{-1}

- $\phi(\rightarrow K^+K^-)$ mode (Eff. 3.1%)
  Improve by a factor of 4.9 for $\mu\phi$ and 9.6 for $e\phi$ modes
- $\omega(\rightarrow \pi^+\pi^-\pi^0)$ mode (Eff. 2.5%)
  First search!!

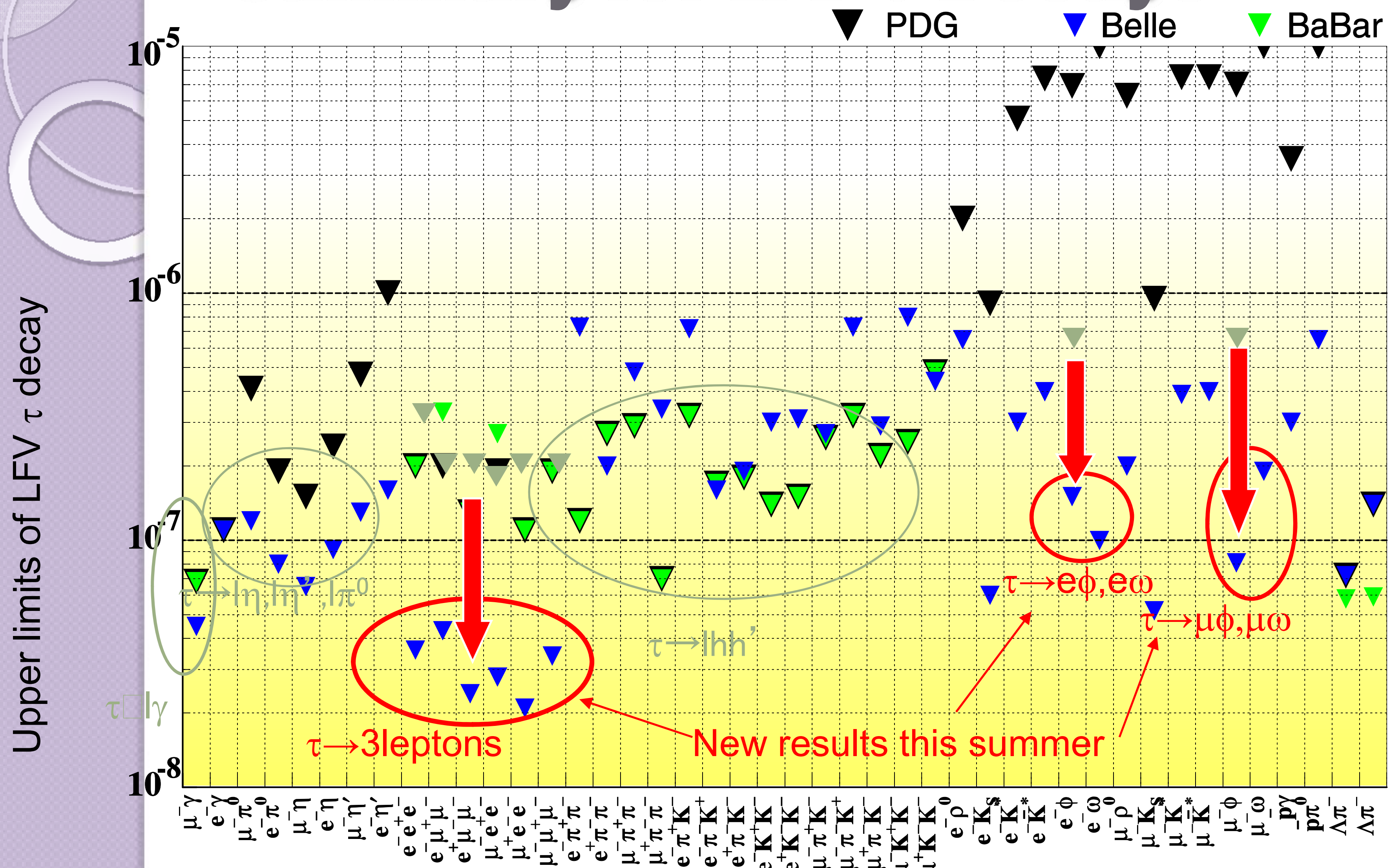


Mode	Expected BG	N_{obs}	Upper limit @90%C.L.
$\tau \rightarrow \mu\phi$	0.11±0.08	1	1.5x10^{-7}
$\tau \rightarrow e\phi$	0.11±0.08	0	0.8x10^{-7}
$\tau \rightarrow \mu\omega$	0.20±0.28	0	1.0x10^{-7}
$\tau \rightarrow e\omega$	0.00±0.07	1	1.9x10^{-7}

(Preliminary)



Summary for LFV τ Decays



ULs for all LFV τ decays are approaching the 10^{-8} level

Summary for LFV search

We update searches for lepton flavor violating τ decays using > 500 fb^{-1} of data at Belle.

⇒ Improved analysis

⇒ Increased luminosity

Br($\tau \to$3 leptons)<(2.1-4.3)x10^{-8}@90%C.L.

→improved by factors of 5-7 the best previous values

→the most stringent upper limits among LFV τ decays

Br($\tau \to l\phi$, $l\omega$) < (0.8-1.9)x10^{-7} @90%C.L.

→$l\phi$: improved by factors of 4.9 and 9.6

→$l\omega$: first search

We provide the highest sensitivities to New Physics via lepton flavor violating τ decays

Summary for this talk

- B-factory is also a τ-factory.
- Belle collaboration has the largest data sample of τ decays in the world:

  more than $5x10^8$ τ-pairs.
- 2~8 times more precise branching fractions are obtained than those measured before.
- Also, detailed mass distributions can be evaluated.
- Most stringent UL on Br of τ decay is obtained.
- We are reaching to $O(10^{-8})$ for all of τ LFV decays.

Belle experiment is the best place to study τ physics!

If you have some good idea for τ physics, please contact us!!