Precise measurement of hadronic tau-decays with eta mesons at Belle

2008.9.23

Tau08

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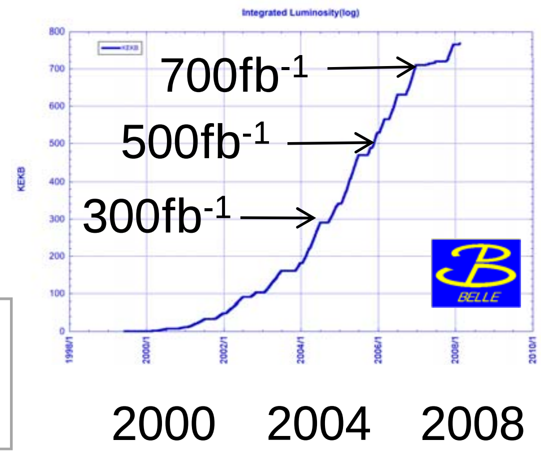
K. Inami and Belle collaboration

Introduction



- Belle detector has collected the τ-pair data with the highest statistics in the world.

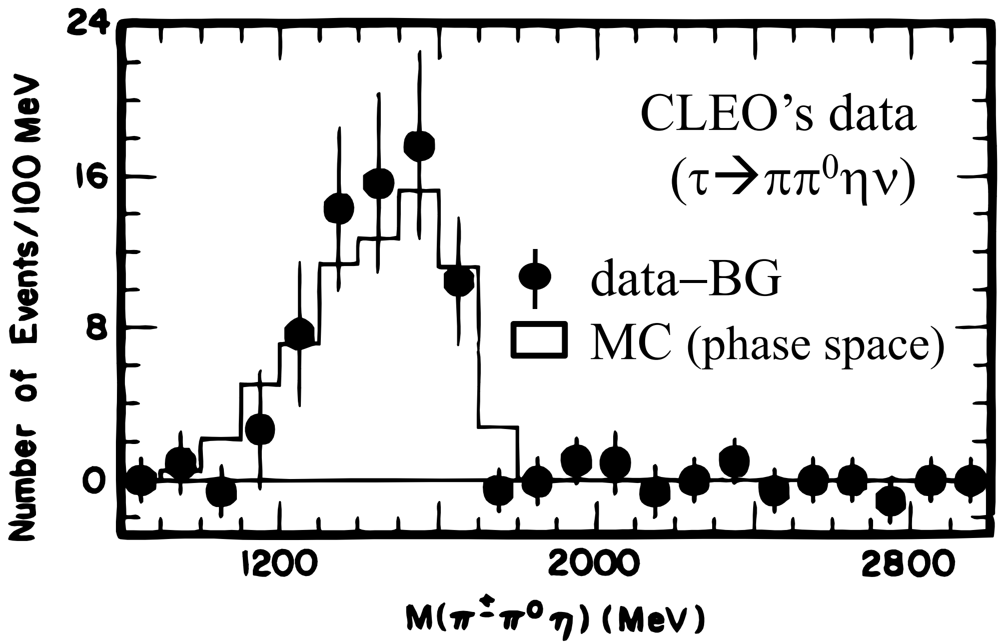
> At the present, about 850fb^{-1} of data have been collected.
> It corresponds to 7.0×10^{8} τ-pairs!

- τ hadronic decay from $e^+e^-\rightarrow\tau^+\tau^-$ process is very clean.
- τ hadronic decay is good for studying low energy QCD phenomena.
  - Test of the Vector dominance model (VDM)
  - Test of the conserved vector current (CVC)

through BR and mass spectra in $\tau\rightarrow\pi\,\pi^0\eta\nu$ decay.

Motivation

We can test CVC through $\tau \rightarrow \pi\pi^0\eta\nu$ decay.



CLEO collaboration has already studied $\tau \rightarrow \pi\pi^0\eta\nu$ decay, but experimental statistics was very limited.

$M_{\pi\pi 0\eta}$ is not distinguishable from phase space alone.

By using a 100 times larger data sample than that of CLEO, we can test CVC from not only BR($\tau \rightarrow \pi\pi^0\eta\nu$) but also $M_{\pi\pi 0\eta}$.

M.Artuso et.al, CLEO collaboration, PRL 69 (1992) 23

Contents

- Event selection
- η with 1 charged track
  - $\tau^- \to K^- \eta \nu$, $K^- \pi^0 \eta \nu$, $\pi^- \pi^0 \eta \nu$ with $\eta \to \gamma\gamma$
  - Cross check for $\tau^- \to K^- \eta (\to \gamma\gamma) \nu$
    - $\tau^- \to K^- \eta (\to \pi\pi\pi^0) \nu$
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- η with K_S
  - $\tau^- \to \pi^- K_S \eta \nu$, $K^- K_S \eta \nu$
  - Result
- $\tau^- \to K^{*-} \eta \nu$ study
  - $\tau^- \to K^- \pi^0 \eta \nu$, $\pi^- K_S \eta \nu$
- Discussion
  - Compare with the previous result
  - Compare with the theoretical predictions
  - Check for CVC

Event selection

Data set : $490 fb^{-1}$

tag side

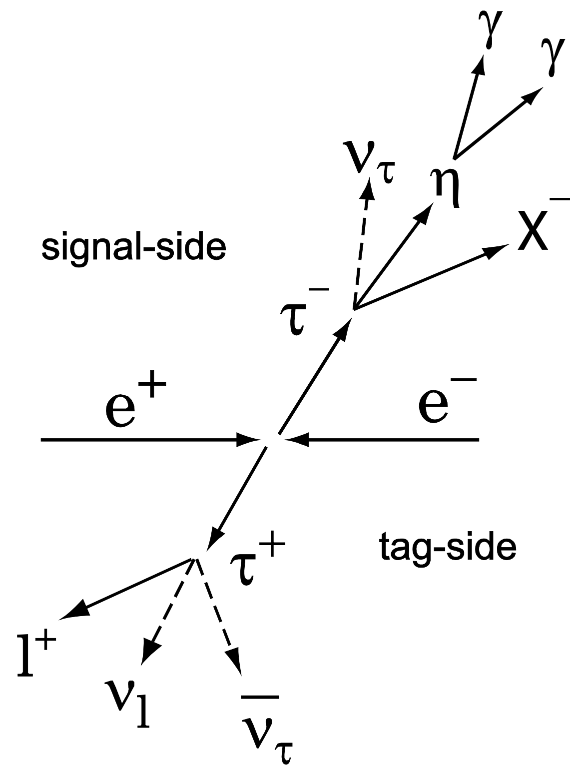
- $\tau^+ \rightarrow l^+ \nu\nu$; 1 charged track
- Require lepton (to suppress $q\bar{q}$ events)

signal side

- $\tau^- \rightarrow X^- \eta \nu$; 1 or 3 charged tracks
  - X^- : K^-, $K^-\pi^0$, $\pi^-\pi^0$, $\pi^- K_S$, $K^{*-}(892)$ systems
  - $\eta \rightarrow \pi^+\pi^-\pi^0$ is used for $\tau^- \rightarrow K^-\eta\nu$ decay only
    - $\pi^0 \rightarrow \gamma\gamma$: $105 < M_{\gamma\gamma} < 165 MeV/c^2$

other requirements

- π^0 veto
- missing momentum



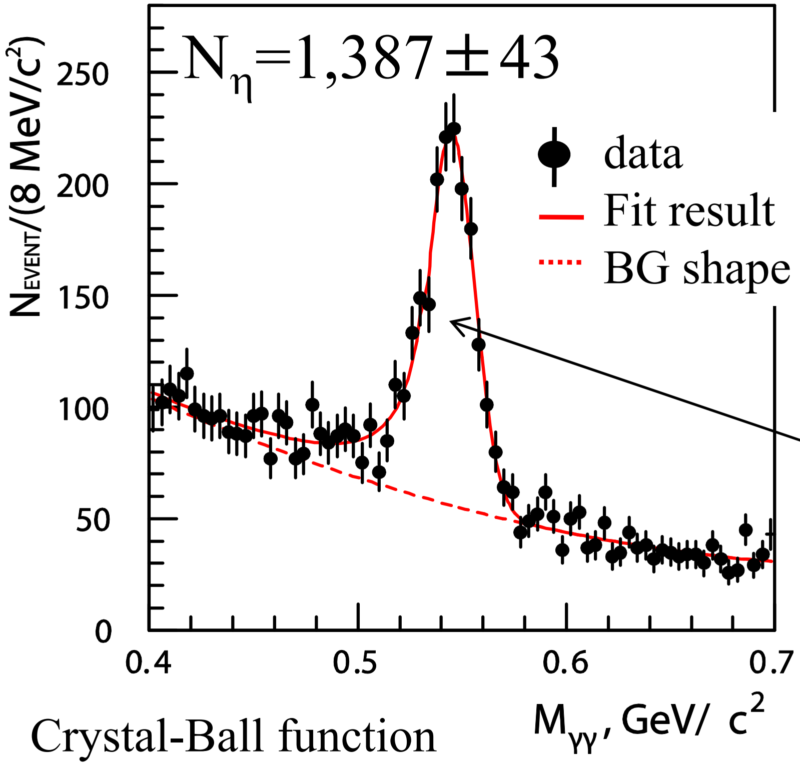
(X^- denotes K^-, $K^-\pi^0$, $\pi^-\pi^0$, $\pi^- K_S$, $K^{*-}(892)$ systems)
$\pi^0 \rightarrow \gamma\gamma$
$K_S \rightarrow \pi^+\pi^-$
$K^{*-}(892) \rightarrow K_S \pi^-$

The number of signal events is evaluated from η mass or K^* mass distribution.

η with 1 charged track

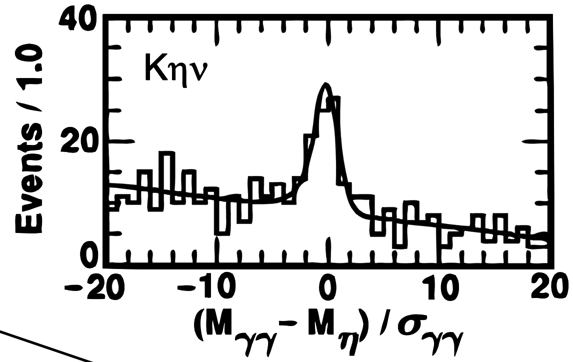
$\tau^- \rightarrow K^- \eta \nu$ ($\eta \rightarrow \gamma\gamma$)

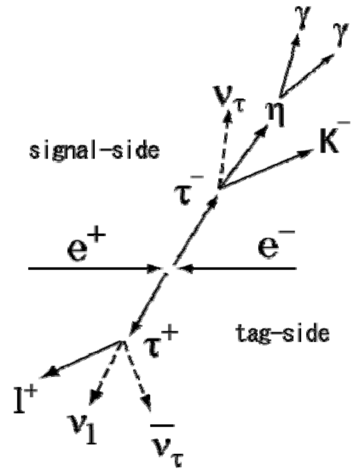
Kην

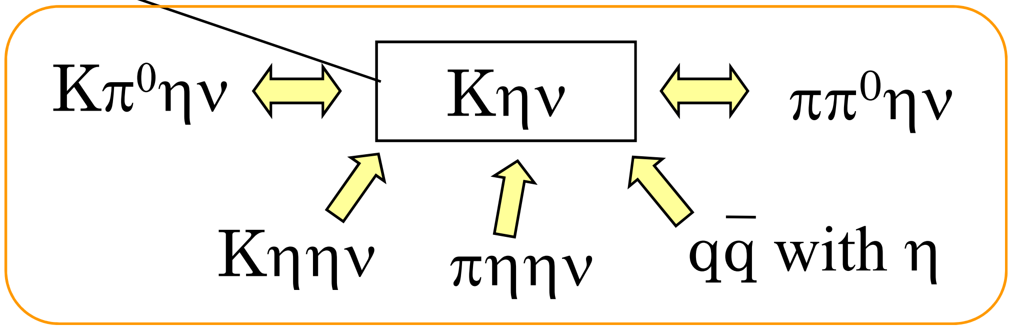


Crystal-Ball function
+ second-order polynomial function

CLEO's result in
τ→Kη(→γγ)ν mode





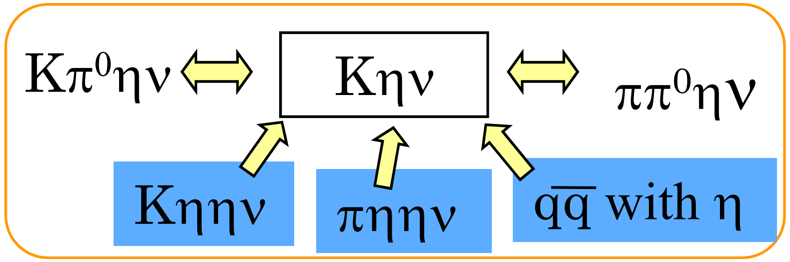


Main η-peaking BG components for τ→Kην are τ→$K\pi^0\eta\nu$, $\pi\pi^0\eta\nu$, ee→$q\bar{q}$.

By evaluating the number of η, Br(τ→Kην) is measured.

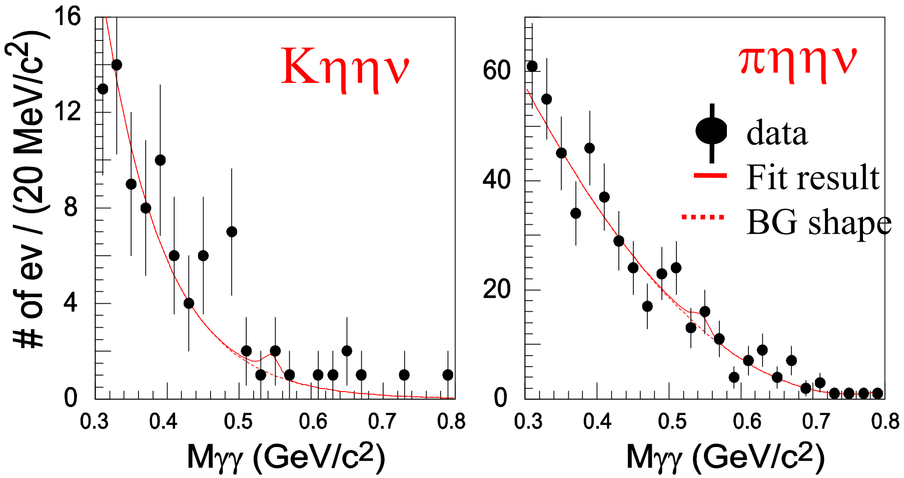
But the signal η peak is contaminated by $K\pi^0\eta\nu$, $\pi\pi^0\eta\nu$ etc.

Peaking BG : $K\eta\eta\nu$,$\pi\eta\eta\nu$,qq ($\eta \rightarrow \gamma\gamma$)



We estimate the contamination of $K\eta\eta$, $\pi\eta\eta$ and $q\bar{q}$ to the signal from data.

$\tau^- \rightarrow K^-\eta\eta\nu$, $\pi^-\eta\eta\nu$ (Special selection of $K/\pi\ \eta\eta$ candidates)



Crystal-Ball function + second-order polynomial function

$BR(\tau \rightarrow K\eta\eta\nu) < 3.0 \times 10^{-6}$ @90%C.L.
$BR(\tau \rightarrow \pi\eta\eta\nu) < 7.4 \times 10^{-6}$ @90%C.L.

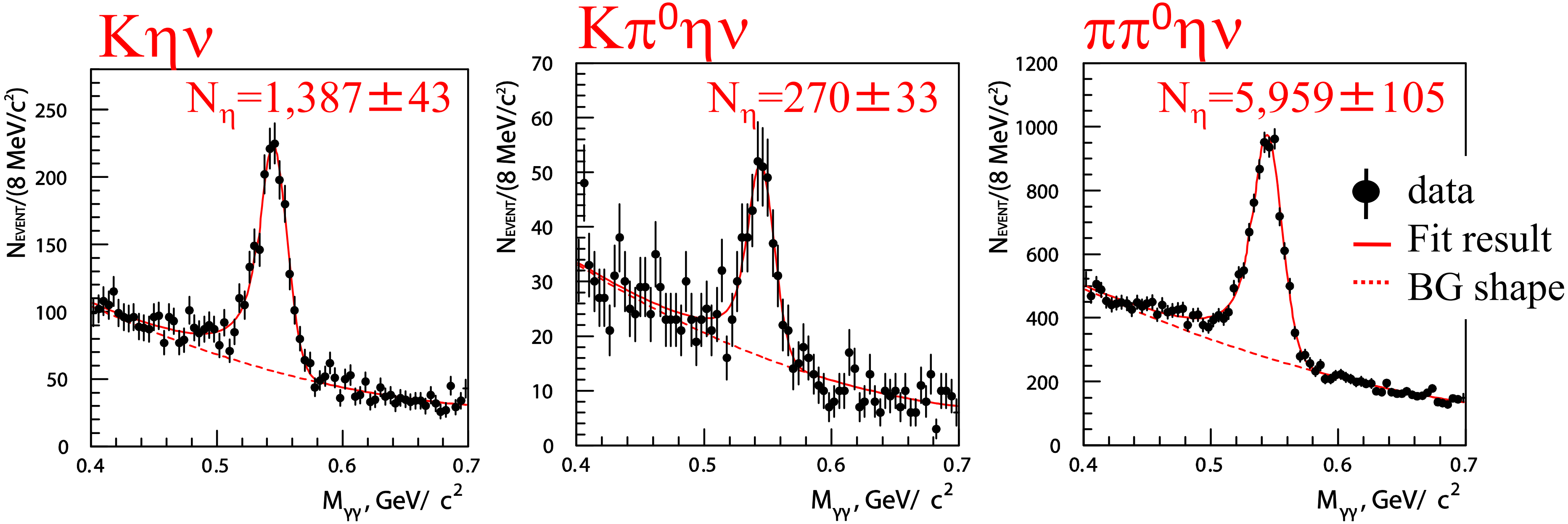
The contamination to the signal mode can be ignored.

$q\bar{q}$ with η

evaluate $q\bar{q}$ events by comparing data and $q\bar{q}$MC with $q\bar{q}$ enriched selection
($M_{tag} > M_\tau$, no $M_{sig} < M_\tau$, $P_{e/\mu} < 0.8$)

$q\bar{q}$ contamination is evaluated to 2.8%, 10% and 3.6% of the signal candidates, N_η, in the $\tau \rightarrow K\eta\nu$, $\tau \rightarrow K\pi^0\eta\nu$ and $\tau \rightarrow \pi\pi^0\eta\nu$ decay, respectively.

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

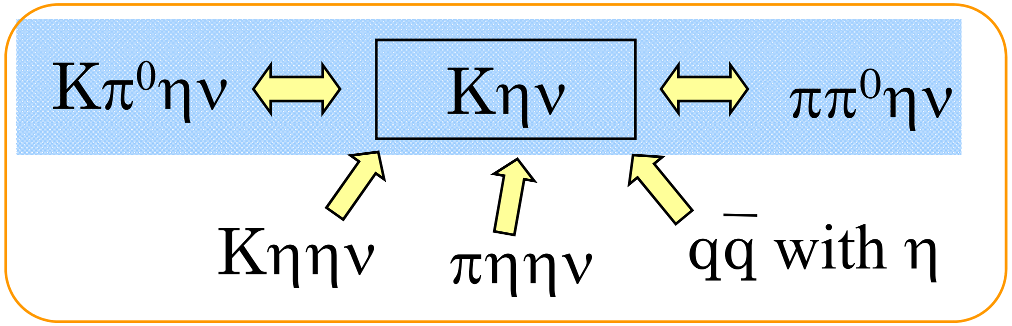


efficiency

$$N_j = 2N_{\tau\tau}\sum_i \varepsilon_j^i B_i$$

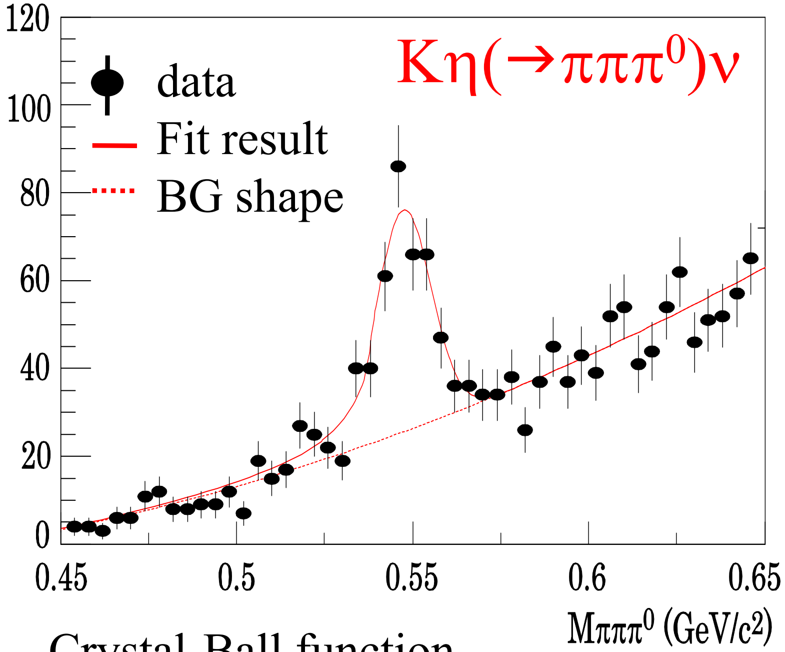
$(i, j = K^-\eta\nu, K^-\pi^0\eta\nu, \pi^-\pi^0\eta\nu)$

Branching ratio



- estimate η yield ⇒ fit Crystal Ball function for γγ mass distributions
- Simultaneously, their BR are evaluated.
- We can suppress systematic errors for each modes

Cross check for $\tau^-\rightarrow K^-\eta\nu$ $(\eta\rightarrow\gamma\gamma)$



Crystal-Ball function
+ second-order polynomial function

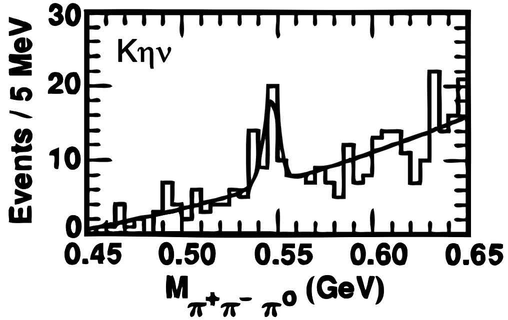
As a cross check for $\tau\rightarrow K\eta(\rightarrow\gamma\gamma)\nu$ mode, we measure the BR of $\tau\rightarrow K\eta(\rightarrow\pi\pi\pi^0)\nu$ mode.

$BR(\tau\rightarrow K\eta\nu)$

$=(1.60\pm0.15\pm0.10)\text{x}10^{-4}$ @$\eta\rightarrow\pi^+\pi^-\pi^0$

$=(1.57\pm0.05\pm0.09)\text{x}10^{-4}$ @$\eta\rightarrow\gamma\gamma$

CLEO's result in
$\tau\rightarrow K\eta(\rightarrow\pi\pi\pi^0)\nu$ mode



We find a good agreement between these two results.

Our measurements have self consistency!

Systematic study

Signal modes		$K\eta\nu$	$K\pi^0\eta\nu$	$\pi\pi^0\eta\nu$	$K\eta\nu$
Items		$\eta\to\gamma\gamma$			$\eta\to\pi\pi\pi^0$
BG subtraction	$K\eta\nu$	--	0.6	1.8×10^{-3}	--
	$K\pi^0\eta\nu$	0.3	--	4.2×10^{-2}	0.4
	$\pi\pi^0\eta\nu$	7.5×10^{-2}	3.3	--	0.1
	$\pi\pi^0\pi^0\eta\nu$	--	--	0.4	--
	$q\bar{q}$	1.5	6.0	0.5	1.5
Detection efficiency	K/π / lepton-ID	3.3/2.3	2.2/2.8	1.0/2.6	2.8/2.6
	Tracking	1.3	1.3	1.3	3.3
	π^0 / $\eta\to\gamma\gamma$	--/2.0	2.0/2.0	2.0/2.0	2.0/--
	π^0 veto	2.8	2.8	2.8	--
stat. error of signal MC		0.5	1.7	0.5	1.3
$BR(\tau\to\pi\pi\pi^0)$		--	--	--	1.6
Luminosity		1.4			
$\sigma(e^+e^-\to\tau^+\tau^-)$		0.3			
total		5.9%	9.1%	5.3%	6.2%

By evaluating cross-feed BG simultaneously, we can suppress systematic errors.

Results (η with 1 charged track)

Belle preliminary

Modes	Our Br or upper limit
$\tau \to K\eta\nu$ (combined)	$(1.58 \pm 0.05 \pm 0.09) \times 10^{-4}$
$\tau \to K\eta\nu$ (@$\eta \to \gamma\gamma$) $\tau \to K\eta\nu$ (@$\eta \to \pi\pi\pi^0$)	$(1.57 \pm 0.05 \pm 0.09) \times 10^{-4}$ $(1.60 \pm 0.15 \pm 0.10) \times 10^{-4}$
$\tau \to K\pi^0\eta\nu$	$(4.6 \pm 1.1 \pm 0.4) \times 10^{-5}$
$\tau \to \pi\pi^0\eta\nu$	$(1.35 \pm 0.03 \pm 0.07) \times 10^{-3}$
$\tau \to K\eta\eta\nu$	$< 3.0 \times 10^{-6}$ @90% C.L.
$\tau \to \pi\eta\eta\nu$	$< 7.4 \times 10^{-6}$ @90% C.L.

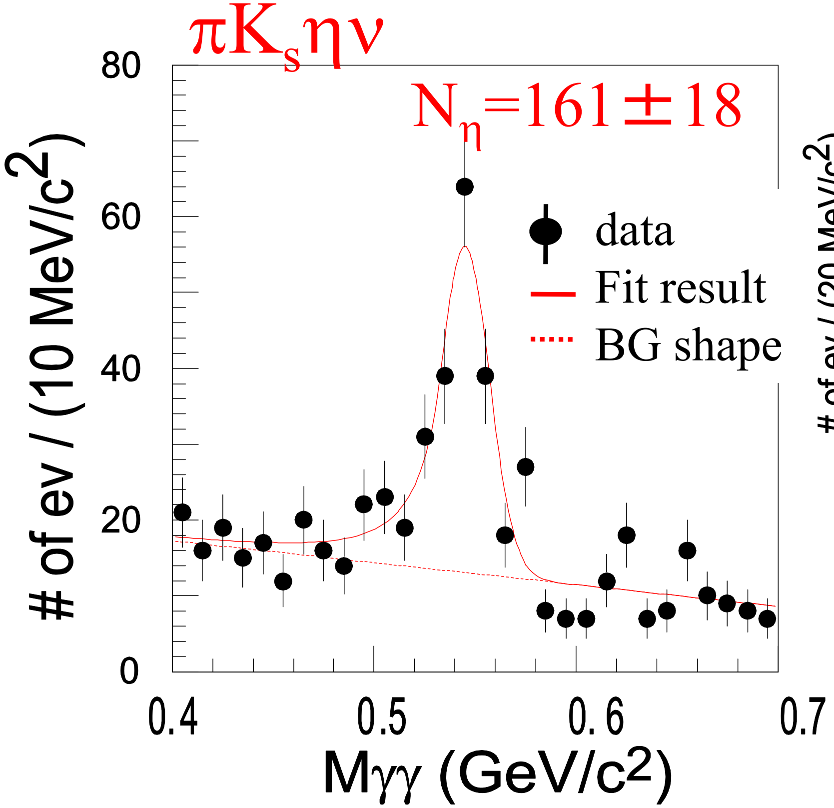
combined

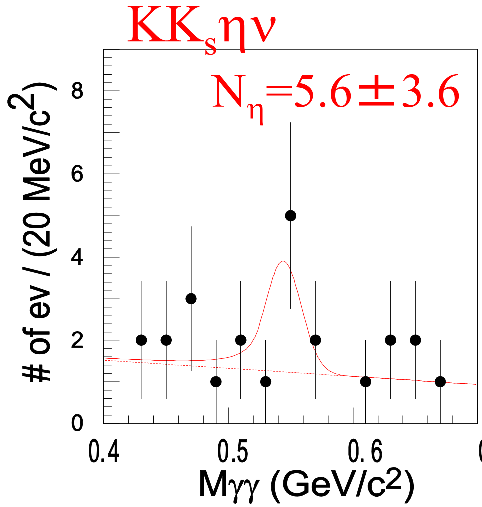
consistent

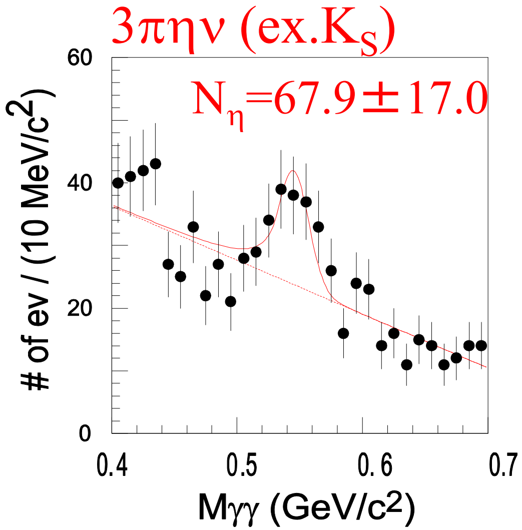
The self consistency shows that our results are reliable.

η with K_S

$\tau^- \rightarrow \pi^- K_s \eta \nu$







efficiency

$$N_j = 2N_{\tau\tau}\sum_i \varepsilon^i_j B_i$$

$(i, j = \pi^- K_S \eta\nu, K^- K_S \eta\nu, 3\pi^\pm \eta\nu)$

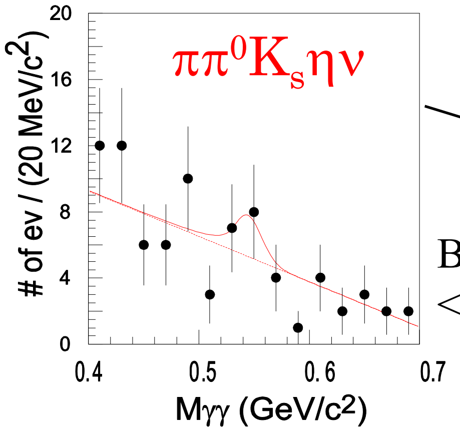
Branching ratio

Simultaneously, these BR are evaluated.

$3\pi\eta\nu$ (K_s sideband) ⟺ $\pi K_s \eta\nu$ ⟺ $KK_s \eta\nu$

$\pi\pi^0 K_s \eta\nu$ — Crossfeed:1%

$q\bar{q}$ with η — Crossfeed:13%



BR($\tau \rightarrow \pi\pi^0 K_s \eta\nu$) $<2.5\times10^{-5}$ @90%C.L.

Crystal-Ball function + second-order polynomial function

Results (η with K_S)

Belle preliminary

Modes	Our Br or upper limit
$\tau \to \pi K_s \eta \nu$	$(4.4 \pm 0.7 \pm 0.3) \times 10^{-5}$
$\tau \to K K_s \eta \nu$	$< 4.5 \times 10^{-6}$ @90% C.L.
$\tau \to \pi \pi^0 K_s \eta \nu$	$< 2.5 \times 10^{-5}$ @90% C.L.

The systematic error for $\tau \to \pi K_s \eta \nu$

- Total : 6.4%
- Fitting function : 4.1%

The uncertainty from the fitting function is dominant one

$\tau^- \rightarrow K^{*-} \eta \nu$ study

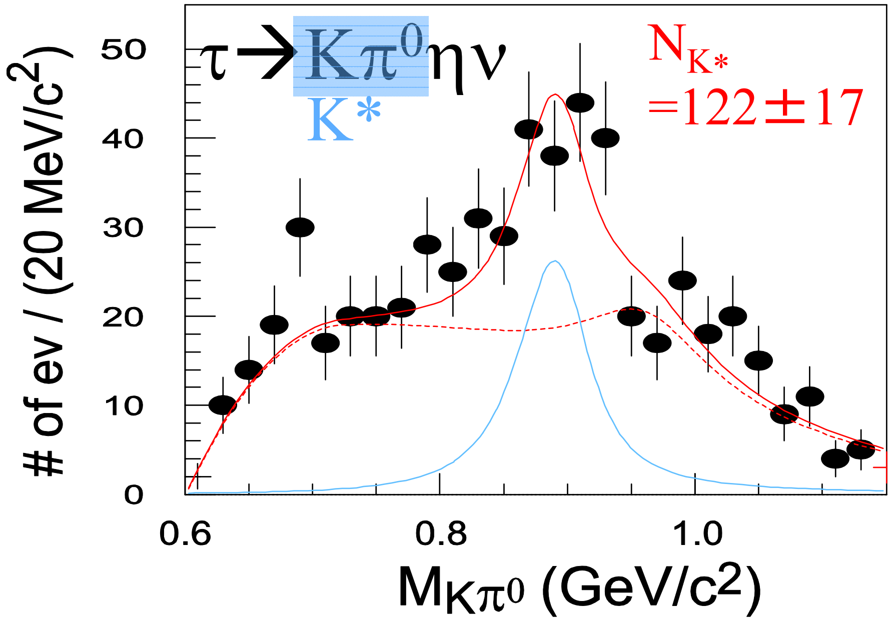
$\tau^- \rightarrow K^{*-} \eta \nu$

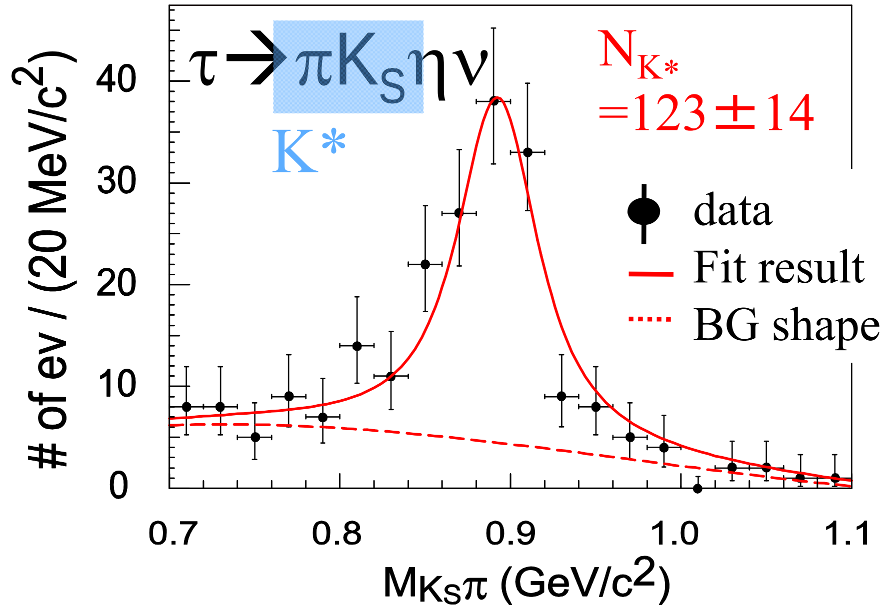
Charged K*(892) decays into $K\pi^0$ or πK_S with same rate because iso-spin relation.

$BR(\tau \rightarrow K\pi^0\eta\nu) = (4.6 \pm 1.1 \pm 0.4) \times 10^{-5}$
$BR(\tau \rightarrow \pi K_s\eta\nu) = (4.4 \pm 0.7 \pm 0.3) \times 10^{-5}$

This agreement suggests that K* is dominant in both modes.

Convoluted Breit-Wigner function + bg function





Main BGs in these modes are evaluated from $M_{\gamma\gamma}$ side bands, respectively.

These fitting results show that K*(892) is almost 100% in the final state in both $\tau \rightarrow K\pi^0\eta\nu$ and $\tau \rightarrow \pi K_S\eta\nu$ decays.

Results ($\tau^- \to K*^- \eta\nu$)

Belle preliminary

Modes	**Our Br**
$\tau \to K^* \eta\nu$ (combined)	$(1.34 \pm 0.12 \pm 0.09)\mathrm{x}10^{-4}$
$\tau \to K^* \eta\nu$ ($@K* \to K\pi^0$)	$(1.13 \pm 0.17 \pm 0.18)\mathrm{x}10^{-4}$
$\tau \to K^* \eta\nu$ ($@K* \to \pi K_S$)	$(1.46 \pm 0.16 \pm 0.09)\mathrm{x}10^{-4}$

combined

consistent

$\tau \to \pi K_S \eta\nu$ mode plays a role as a cross check for $\tau \to K\pi^0\eta\nu$.
The self consistency shows that our results are reliable.

The systematic error for $\tau \to K^* \eta\nu$ ($@K* \to K\pi^0$)

- Total : 16.2% / Fitting function : 15.0%

The systematic error for $\tau \to K^* \eta\nu$ ($@K* \to \pi K_S$)

- Total : 6.4% / Fitting function : 4.1%

The uncertainty from the fitting function is dominant one

DISCUSSION

Comparison with previous CLEO results

We obtain precise results in each τ decay mode including η.

Belle preliminary

Modes	Our Br(x10^{-3})	CLEO's Br(x10^{-3})	Error ratio δ(CLEO)/δ(Belle)
$\tau \to K\eta\nu$	$0.158 \pm 0.005 \pm 0.009$	$0.26 \pm 0.05 \pm 0.05$	7.0
$\tau \to K\pi^0\eta\nu$	$0.046 \pm 0.011 \pm 0.004$	$0.177 \pm 0.056 \pm 0.071$	7.5
$\tau \to \pi\pi^0\eta\nu$	$1.35 \pm 0.03 \pm 0.07$	$1.7 \pm 0.2 \pm 0.2$	3.8
$\tau \to K_S\pi\eta\nu$	$0.044 \pm 0.007 \pm 0.002$	$0.100 \pm 0.035 \pm 0.011$	5.3
$\tau \to K^*\eta\nu$	$0.134 \pm 0.012 \pm 0.009$	$0.290 \pm 0.080 \pm 0.042$	6.0

Modes	Our Upper limit
$\tau \to K_s K\eta\nu$	$<4.5 \times 10^{-6}$ @90% C.L.
$\tau \to K_s\pi\pi^0\eta\nu$	$<2.5 \times 10^{-5}$ @90% C.L.
$\tau \to K\eta\eta\nu$	$<3.0 \times 10^{-6}$ @90% C.L.
$\tau \to \pi\eta\eta\nu$	$<7.4 \times 10^{-6}$ @90% C.L.

The central values of our BRs in all modes are lower than those of the CLEO's results.

- Underestimate BG contributions in CLEO
  - Cross feed BG contribution
  - $q\bar{q}$

- High statistics enable us to reliably estimate BG contributions for each mode using data.
- We check the self consistency of BR in several modes.

Comparison with theoretical predictions

Belle preliminary

Modes	Our Br	Theoretical predictions of Br	
		CVC	Chiral perturbation theory
$\tau \to K\eta\nu$	$(1.58 \pm 0.05 \pm 0.09)\times10^{-4}$	----------	1.2×10^{-4}[3], 2.2×10^{-4}[5], 1.6×10^{-4}[6]
$\tau \to K\pi^0\eta\nu$	$(4.6 \pm 1.1 \pm 0.4)\times10^{-5}$	----------	8.8×10^{-6}[3], 7.7×10^{-6}[6]
$\tau \to \pi\pi^0\eta\nu$	$(1.35 \pm 0.03 \pm 0.07)\times10^{-3}$	$(1.3 \pm 0.2)\times10^{-3}$[1], 1.5×10^{-3}[2]	3×10^{-3}[3], 1.4×10^{-3}[4], 1.9×10^{-3}[5]
$\tau \to K_s\pi\eta\nu$	$(4.4 \pm 0.7 \pm 0.2)\times10^{-5}$	----------	1.1×10^{-5}[3], 0.9×10^{-5}[6]
$\tau \to K^*\eta\nu$	$(1.34 \pm 0.12 \pm 0.09)\times10^{-4}$	----------	1.0×10^{-4}[5]

Modes	Our Upper limit	Theoretical predictions of Br	
		CVC	Chiral perturbation theory
$\tau \to K_sK\eta\nu$	$<4.5\times10^{-6}$ @90% C.L.	----------	1.6×10^{-7}[3], 1.4×10^{-7}[6]
$\tau \to K_s\pi\pi^0\eta\nu$	$<2.5\times10^{-5}$ @90% C.L.	----------	----------
$\tau \to K\eta\eta\nu$	$<3.0\times10^{-6}$ @90% C.L.	----------	1.6×10^{-9}[3], 7.0×10^{-9}[6]
$\tau \to \pi\eta\eta\nu$	$<7.4\times10^{-6}$ @90% C.L.	----------	1.1×10^{-9}[3]

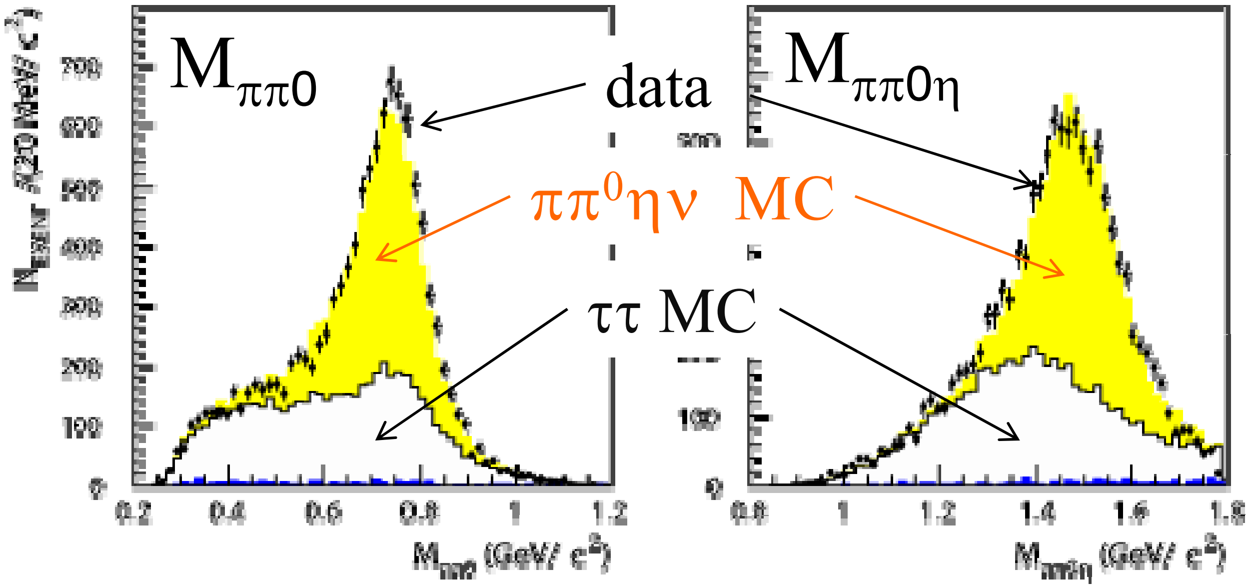
[1]S.I.Eidelman, PLB 257 (1991) 437
[2]F.J.Gilman, PRD 35 (1987) 3541
[3]A.Pich, PLB 196 (1987) 561
[4]E.Braaten, PRD 36 (1987) 2188
[5]B.A.Li, PRD 55 (1997) 1436
[6]G.J.Aubrecht, PRD 24 (1981) 1318

- The CVC prediction of BR($\tau \to \pi\pi^0\eta\nu$) **agrees well** with our result. (our result is more precise)
- High precision of our experiment will allow to discriminate between different theoretical models.

Check for CVC

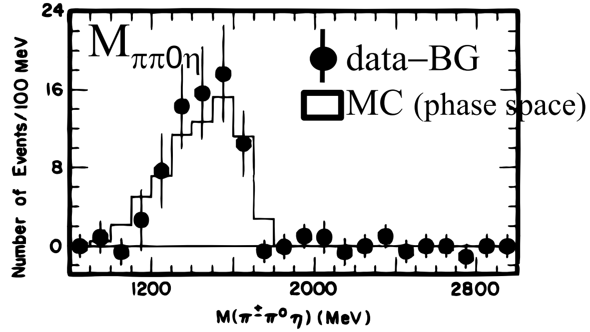
Belle preliminary

$\tau \to \pi\pi^0\eta\nu$ MC generator is designed based on $\sigma(e^+e^- \to \pi^+\pi^-\eta)$ measured more than 10 years ago, assuming CVC.



The distributions for the observed data and MC agree well.

CLEO's data



CVC

$e^+ + e^- \to$ hadrons $\longrightarrow$ $\tau^- \to$ hadrons + ν

TAUOLA MC program : S.Jadach, B.F.L.Ward, Z.Was, Comp.Phys.Commun. 130 (2000) 260

Check for CVC

Belle preliminary

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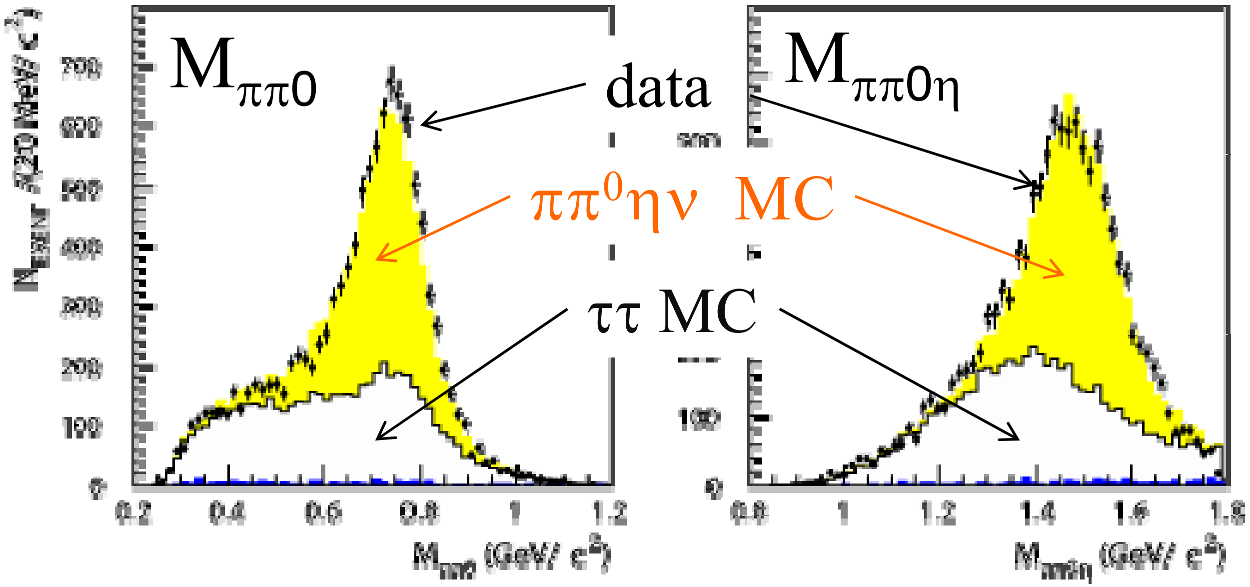

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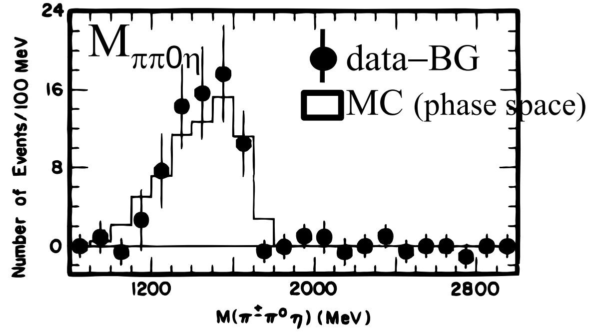
CLEO's data



$e^+ + e^- \to$ hadrons $\xrightarrow{\text{CVC}}$ $\tau^- \to$ hadrons + ν

Check in high accuracy

Now, we can compare $\tau \to$ hadrons+ν and $e^+e^- \to$ hadrons with high accuracy to check CVC.

TAUOLA MC program : S.Jadach, B.F.L.Ward, Z.Was, Comp.Phys.Commun. 130 (2000) 260

Summary

We perform a high-precision study of $\tau\to X+\eta\nu$ based on 4.5×10^{8} τ-pairs.

Improve the uncertainty of BR($\tau\to X+\eta\nu$) by a factor of **3.8~7.5** times

- $BR(\tau\to K\eta\nu)=(1.58\pm0.05\pm0.09)\times10^{-4}$
- $BR(\tau\to K\pi^0\eta\nu)= (4.6\pm1.1\pm0.4)\times10^{-5}$
- $BR(\tau\to \pi\pi^0\eta\nu)= (1.35\pm0.03\pm0.07)\times10^{-3}$
- $BR(\tau\to K_s\pi\eta\nu)= (4.4\pm0.7\pm0.2)\times10^{-5}$
- $BR(\tau\to K^*\eta\nu)= (1.34\pm0.12\pm0.09)\times10^{-4}$

- $BR(\tau\to K_sK\eta\nu) < 4.5\times10^{-6}$ @90% C.L.
- $BR(\tau\to K_s\pi\pi^0\eta\nu) < 2.5\times10^{-5}$ @90% C.L.
- $BR(\tau\to K\eta\eta\nu) < 3.0\times10^{-6}$ @90% C.L.
- $BR(\tau\to \pi\eta\eta\nu) < 7.4\times10^{-6}$ @90% C.L.

Belle preliminary

Our results are reliable

- BG estimation
  - All $\tau\tau$ BGs are evaluated ourselves.
  - $q\bar{q}$ BG are estimated by data.
- The self consistency in $\tau\to K\eta\nu$ and $\tau\to K^*\eta\nu$ branching ratios

Check CVC with high accuracy

- The precise measurement of $\tau\to\pi\pi^0\eta\nu$ decay
- High statistical data

➡ The CVC prediction of BR($\tau\to\pi\pi^0\eta\nu$) **agrees well** with our result.
$M_{\pi\pi0}$ and $M_{\pi\pi0\eta}$ distributions show that CVC model **works well** at this level.

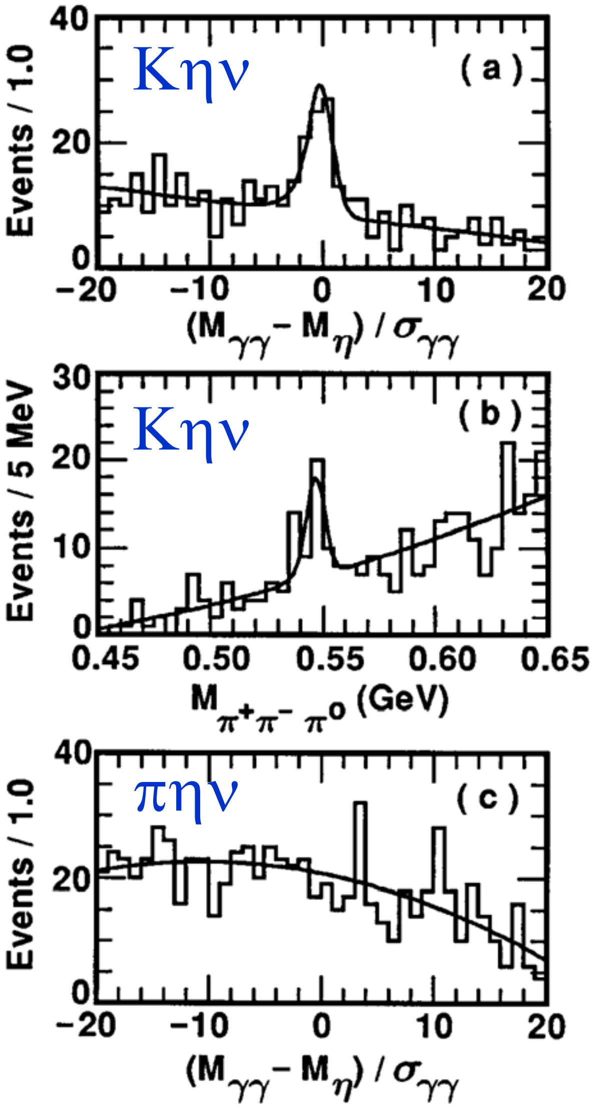
BACK UP

MC generation

For these modes, the efficiency is determined assuming V-A interaction and the phase space decay for the hadronic system.

$\tau \to K\eta\nu$	$\tau \to K_s\pi\eta\nu$
$\tau \to K\pi^0\eta\nu$	$\tau \to K_s K\eta\nu$
$\tau \to K\eta\eta\nu$	$\tau \to K_s\pi\pi^0\eta\nu$
$\tau \to \pi\eta\eta\nu$	$\tau \to K^*\eta\nu$

CLEO's results



Phys. Rev. Lett. 76, 4119–4123 (1996)

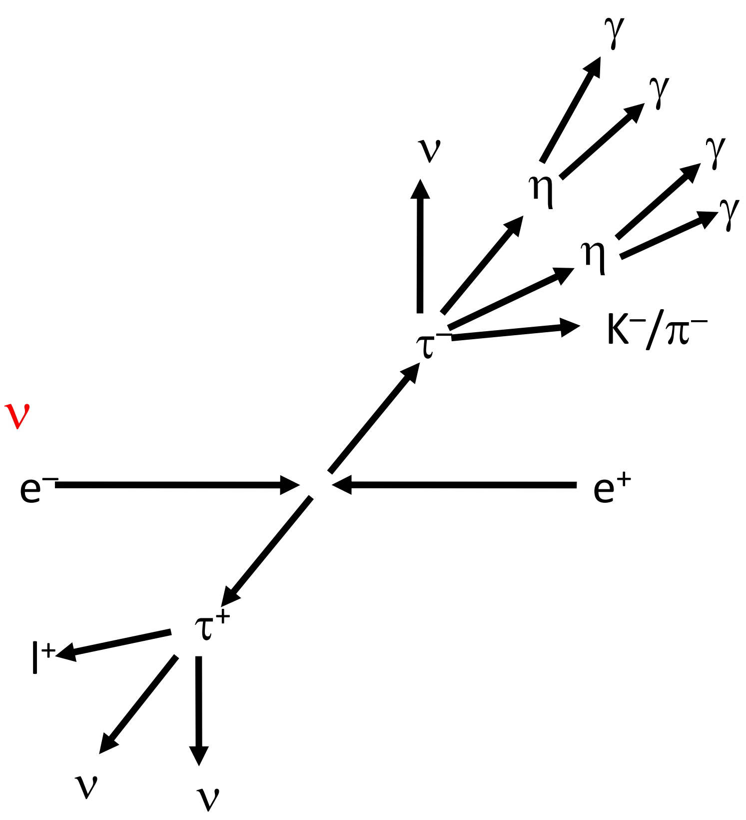
TABLE I. Summary of signals, backgrounds, detection efficiencies, and branching fractions. All errors are statistical.

	$K^-\gamma\gamma$	$K^-\pi^+\pi^-\pi^0$	$\pi^-\gamma\gamma$
η signal	61 ± 11	24 ± 7	$0^{+5.3}_{-0}$
$q\bar{q}$	8.2 ± 3.8	5.9 ± 3.1	2.7 ± 1.9
$\pi^-\pi^0\eta$	3.2 ± 0.8	3.8 ± 1.0	3.9 ± 0.9
Cross-feed eff (%)	1.3 ± 0.1	0.8 ± 0.1	0.8 ± 0.1
Eff (%)	7.6 ± 0.1	3.9 ± 0.1	3.5 ± 0.1
B (10^{-4})	2.6 ± 0.6	2.5 ± 1.3	$0^{+0.62}_{-0}$

- Integrated luminosity of 3.5 fb^{-1} was analyzed.
- Totally, 50 events were observed.
- They assume branching ratio of $K\pi^0\eta\nu$, ~ 10^{-6} from theory
- $Br(K\eta\nu) = (2.6 \pm 0.5 \pm 0.4) \times 10^{-4}$
  $Br(\pi\eta\nu) < 1.4 \times 10^{-4}$

Event selection for $K\eta\eta\nu$ and $\pi\eta\eta\nu$

- 1-1 topology, $\eta\to\gamma\gamma$
- Signal-side
  - $N_\gamma=4$
  - K/π ID for track
  - π^0 veto for γ_η
  - P_η^τ selection in "τ rest frame" for $K\eta\eta\nu$
  - $E_\gamma>0.1$ (0.3) GeV for $K\eta\eta\nu$ ($\pi\eta\eta\nu$)
- Lepton tag



Event selection for $K_S\pi\eta\nu$

- $\tau^- \rightarrow K_s(\rightarrow \pi^-\pi^+)\pi^-\eta\nu$

- 3-1 topology
- Signal side
  - $N\gamma=2$
  - $0.45<M_{\pi\pi}<0.55$
    - Vertex const. fit
  - $0.5<r<30$ cm for K_s vertex
  - Electron veto for hadrons
    - Remove Bhabha BG with shower
  - $E\gamma>0.3$ for eta daughters
- Tag side
  - Lepton tag
  - $N\gamma<3$