Second class current in $\tau \to \pi\eta\nu$ analysis and measurement of $\tau \to hh'h''\nu$ from Belle

~Electroweak physics from Belle (hadronic τ decays)~

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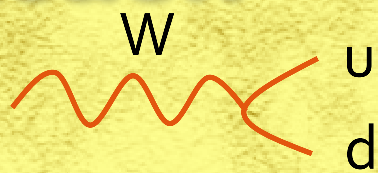
for the Belle collaboration

1. Introduction

- Weak current:



classified into 2 types by $PG(-1)^J$

1st class current

$$PG(-1)^J = +1 \quad J^{PG} = 0^{--}(\pi), 1^{-+}(\rho), 1^{+-}(a_1), \cdots$$

2nd class current

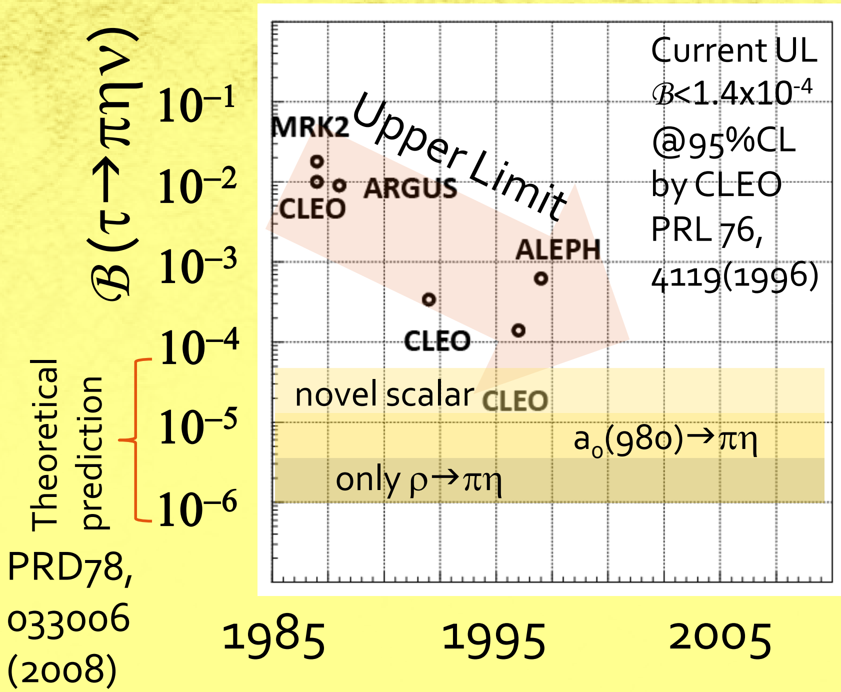
$$PG(-1)^J = -1 \quad J^{PG} = 0^{+-}(a_0), 1^{++}(b_1), \cdots$$

Suppressed by isospin symmetry

No Second class current (SCC) has been observed in any weak interaction yet.

$\tau \to \pi\eta\nu$: typical SCC

$$PG(-1)^J = -1$$

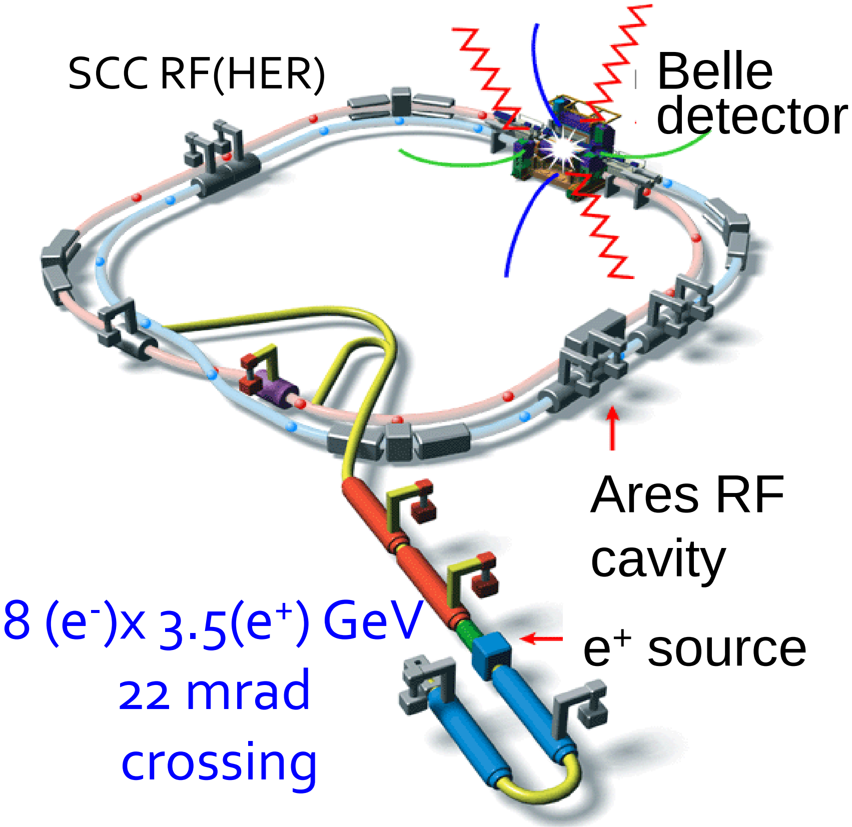


Predicted BF: depend on $\pi\eta$ dynamics

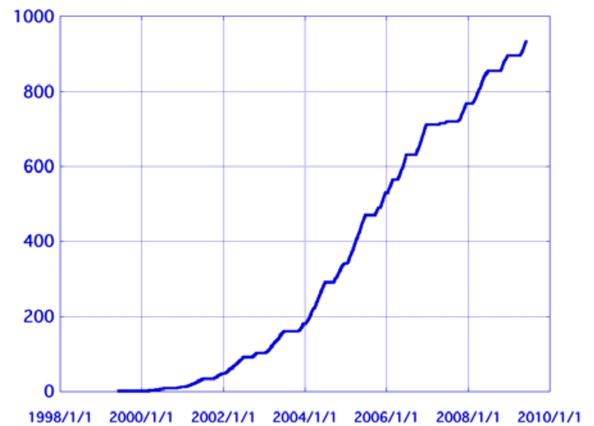
typical~$\mathcal{O}(10^{-5})$

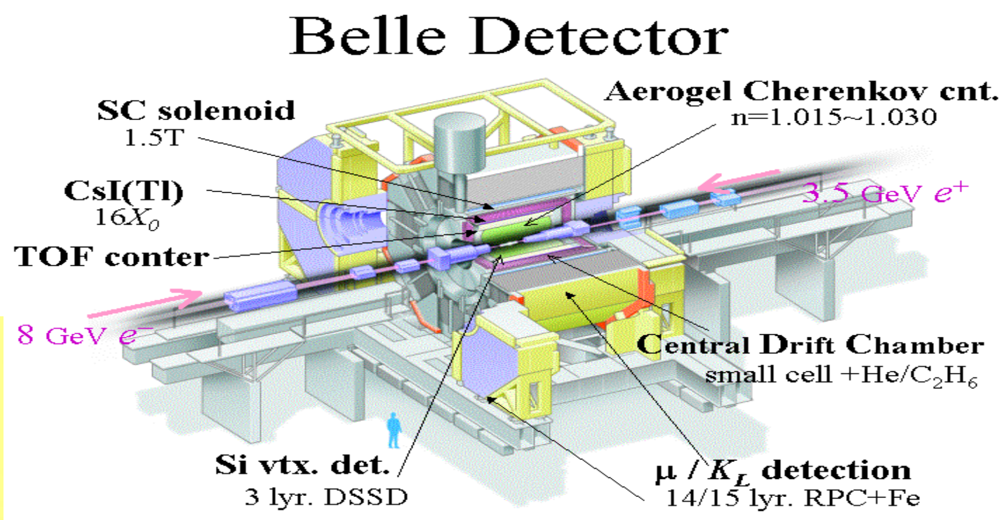
With a 6.2×10^8 τ-pair data sample, $\tau\to\pi\eta\nu$ is searched for.

2. KEKB/Belle



Peak Luminosity
$2.1 \times 10^{34} cm^{-2}s^{-1}$
Integrated Lum.
>950fb^{-1}
17/Jun/2009
World record!





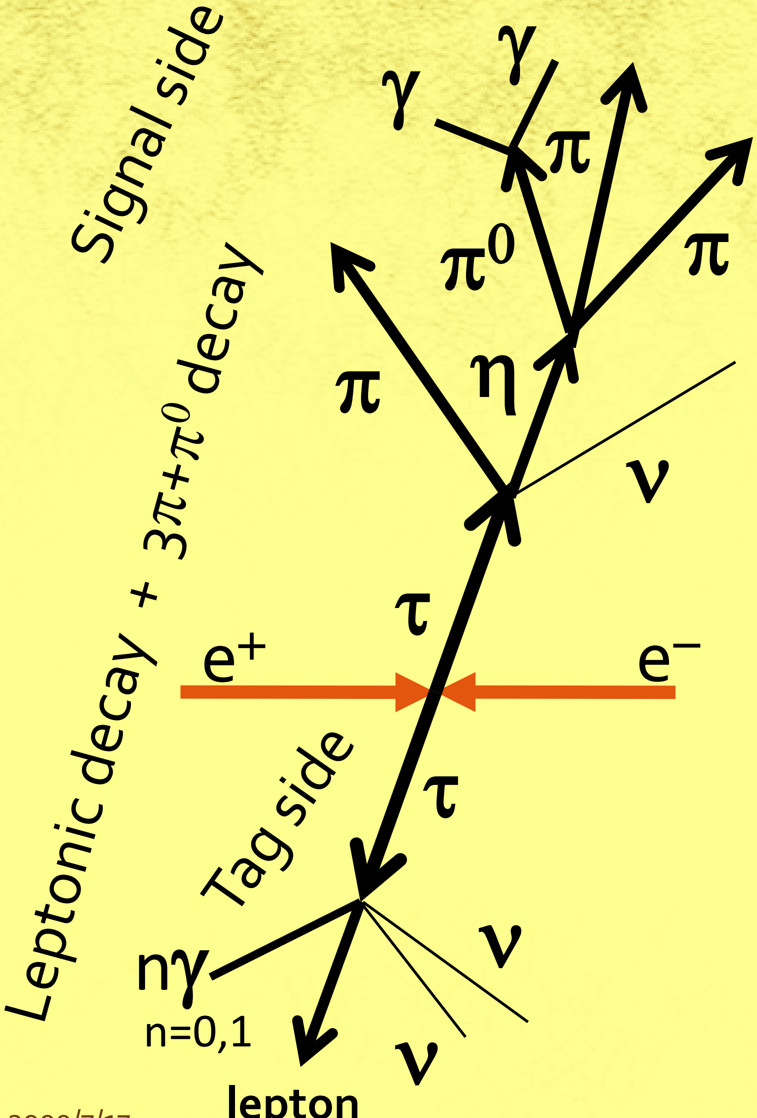
$\sigma(\tau\tau):\sigma(bb)$=1.1:0.9 (nb) at Υ(4S)

A B-factory is also a τ-factory!

Good tracking and particle identification

3. Event Selection

η is reconstructed from $\pi\pi\pi^0$.   # of ηs → # of the signal



Very simple selection criteria:

$3\pi+\pi^0$ --- lepton

π/K–ID, π^0:105<$M_{\gamma\gamma}$<165 MeV/c², lepton-ID

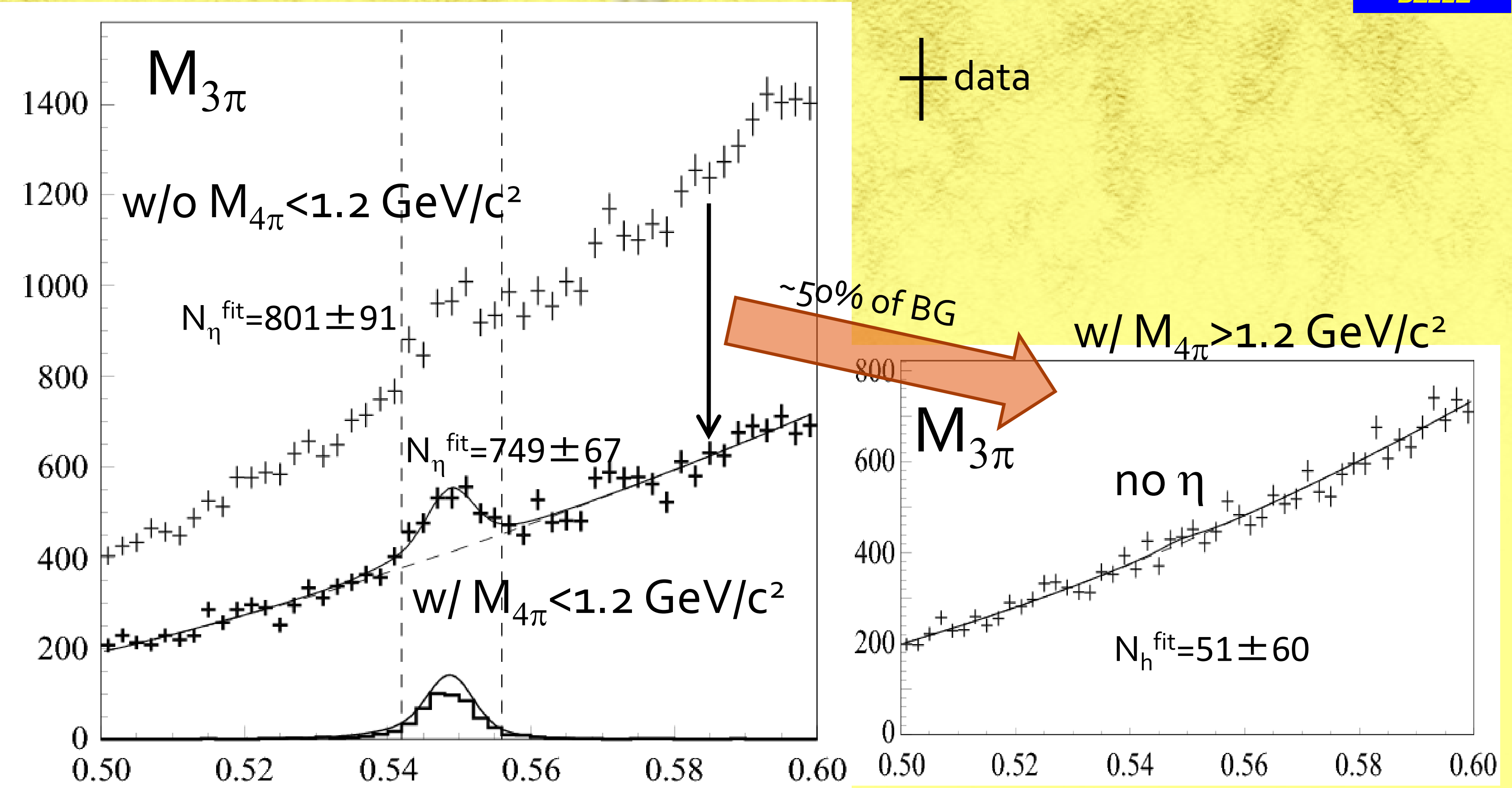
missing: detector acceptance

$M_{sig}<m_\tau$ / $M_{tag}<m_\tau$

In addition,

$M_{4\pi}$<1.2 GeV/c² is required.

4. Effect of $M_{4\pi}$<1.2 GeV/c^2

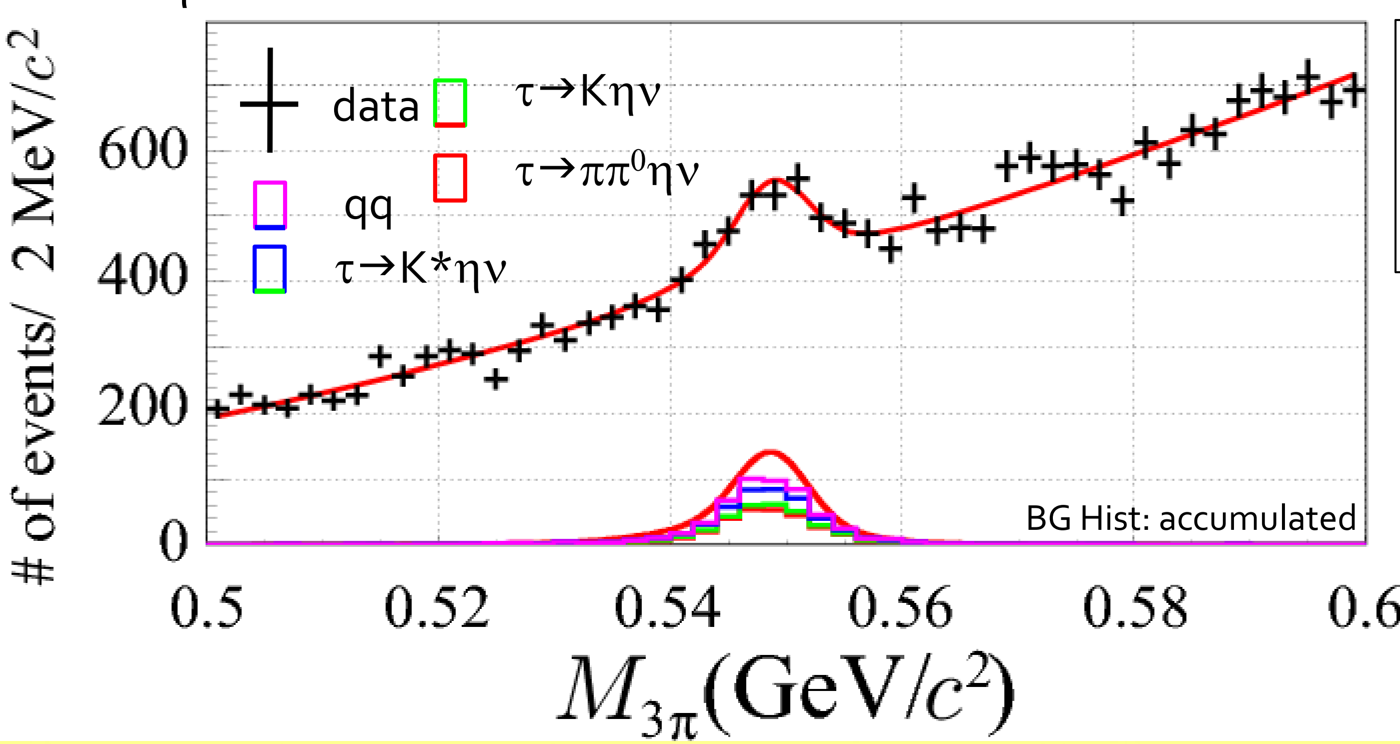


1bin=2 MeV/c^2

succeed in reducing combinatorial BG (mainly $\tau\to\pi\pi\pi\pi^0\nu$, $\tau\to\pi\pi\pi\nu$)

5. Eta signal extraction

In this analysis, BF is evaluated from # of η and η is reconstructed from $\pi^+\pi^-\pi^0$.



Fit result

N_η^{fit} =749.2±67.3

M_η^{fit} =548.9±0.5 (MeV)

χ^2/N_{dof}=62.6/48

BG curve fixed (2^{nd} polynomial) with sideband data

Signal shape (triple gaussian) decided by MC dist.

Our measurement

mode	BF(PLB672,209(2009))
$\tau\to\pi\pi^0\eta\nu$	$(1.35\pm0.03\pm0.07)\times10^{-3}$
$\tau\to K\eta\nu$	$(1.58\pm0.05\pm0.09)\times10^{-4}$
$\tau\to K^*\eta\nu$	$(1.34\pm0.12\pm0.09)\times10^{-4}$

N_η^{fit} =749.2±67.3

$N_{\pi\pi\eta\nu}$ =313.2±7.2

$N_{K\eta\nu}$ =42.4±2.3

$N_{K^*\eta\nu}$ =127.0±3.6

N_{qq} =75.7±11.7

N_η^{sig} =190.9±68.6 (2.8σ w/o systematics)

6. Systematic uncertainties and BF

BELLE

Total systematic uncertainty: 17.6%

n_η=190.9±68.6, ε=4.4%,
$N_{\tau\tau}$=6.2x10^8

$$\mathcal{B} = \frac{n_\eta}{2\varepsilon' N_{\tau\tau}}$$

$$\varepsilon' = \varepsilon \mathcal{B}_{\tau\to\ell\nu\nu} \mathcal{B}_{\eta\to3\pi} \mathcal{B}_{\pi^0\to2\gamma}$$

Source	Error (%)
ηBG($\pi\pi^0\eta\nu$)	10.3
ηBG($K\eta\nu$)	1.4
ηBG($K^*\eta\nu$)	7.4
ηBG(qq)	1.7
Signal shape	1.0
BG shape	10.8
Luminosity	1.4
Cross section	0.3

source	Error(%)
Track finding	3.4
leptonID	2.3
π/KID	0.9
π^0 recon	1.3
Br($\eta\to\pi\pi\pi^0$)	1.3
trigger	0.28
MC stat.	0.32
$\pi\eta$ dynamics	1.3
Total	17.6

Large contribution: error of measurement for $\mathcal{B}(\tau\to\pi\pi^0\eta\nu)$
BG shape determination in the fit

significance (incl. syst.)=2.4σ

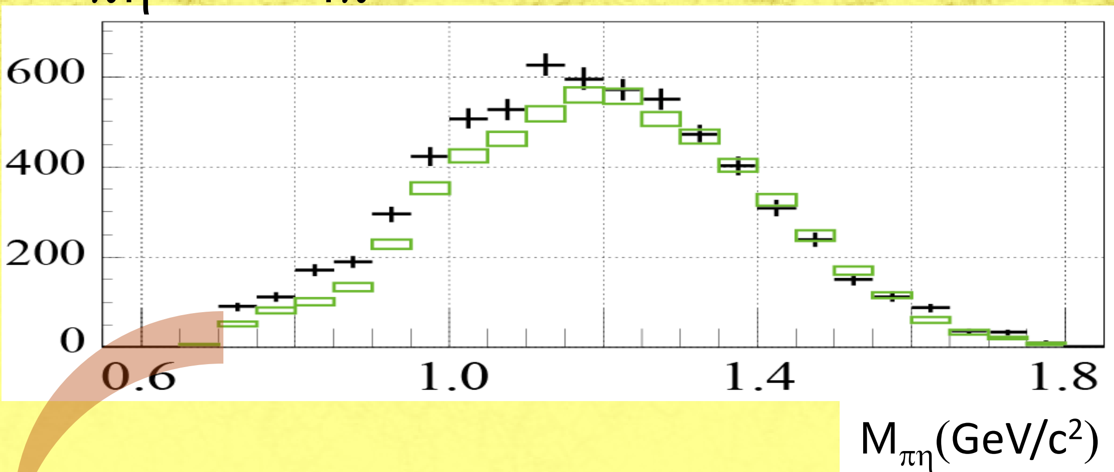
$\mathcal{B}(\tau\to\pi\eta\nu)$=(4.4±1.6±0.8)x$10^{-5}$ hint?

$\mathcal{B}$<7.3x10^{-5} @90%CL **preliminary**

Ours: $\mathcal{B}$<7.9x10^{-5} @95%CL
CLEO: $\mathcal{B}$<1.4x10^{-4}@95%CL
PRL 76, 4119(1996)

7. πη mass distribution

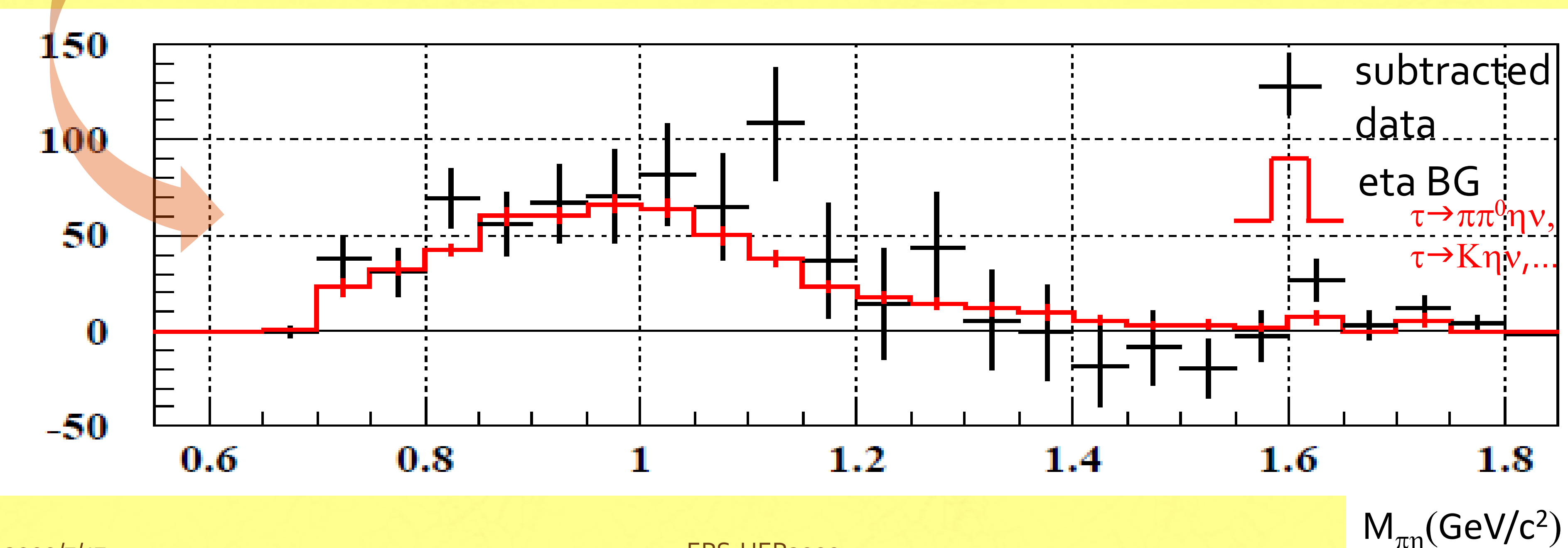
$M_{\pi\eta}(= M_{4\pi})$ distribution of signal region$(542<M_{3\pi}< 556\text{MeV})$



data

non-eta BG determined by eta-side band

$\tau\rightarrow\pi\pi\pi\pi^0\nu$, $\tau\rightarrow\pi\pi\pi\nu$,...

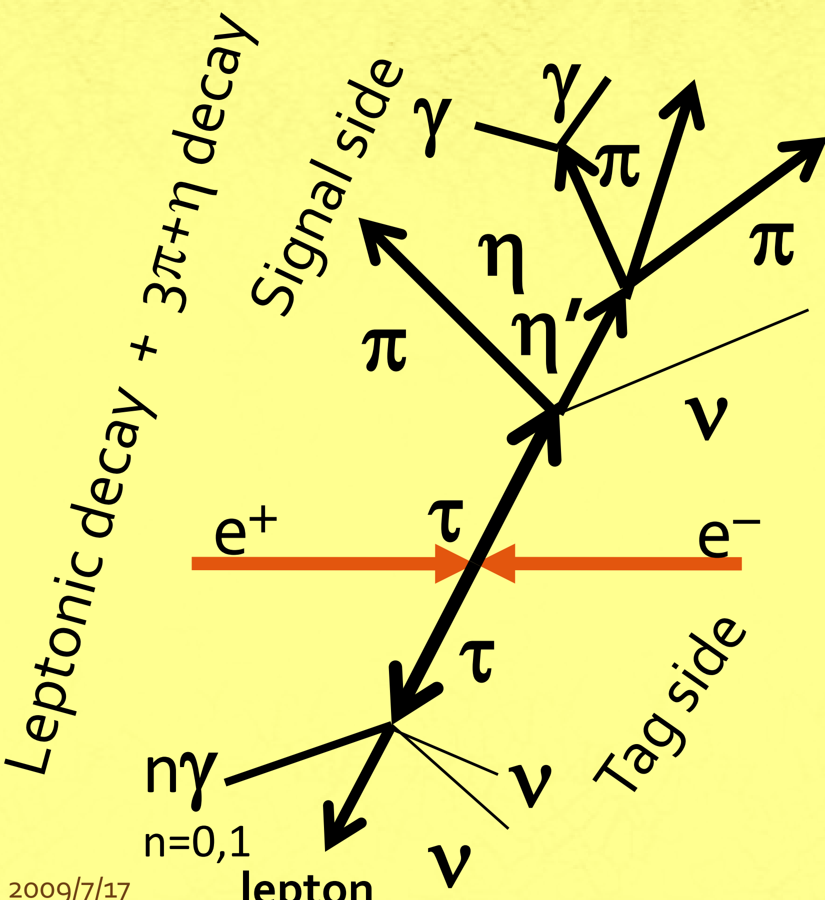


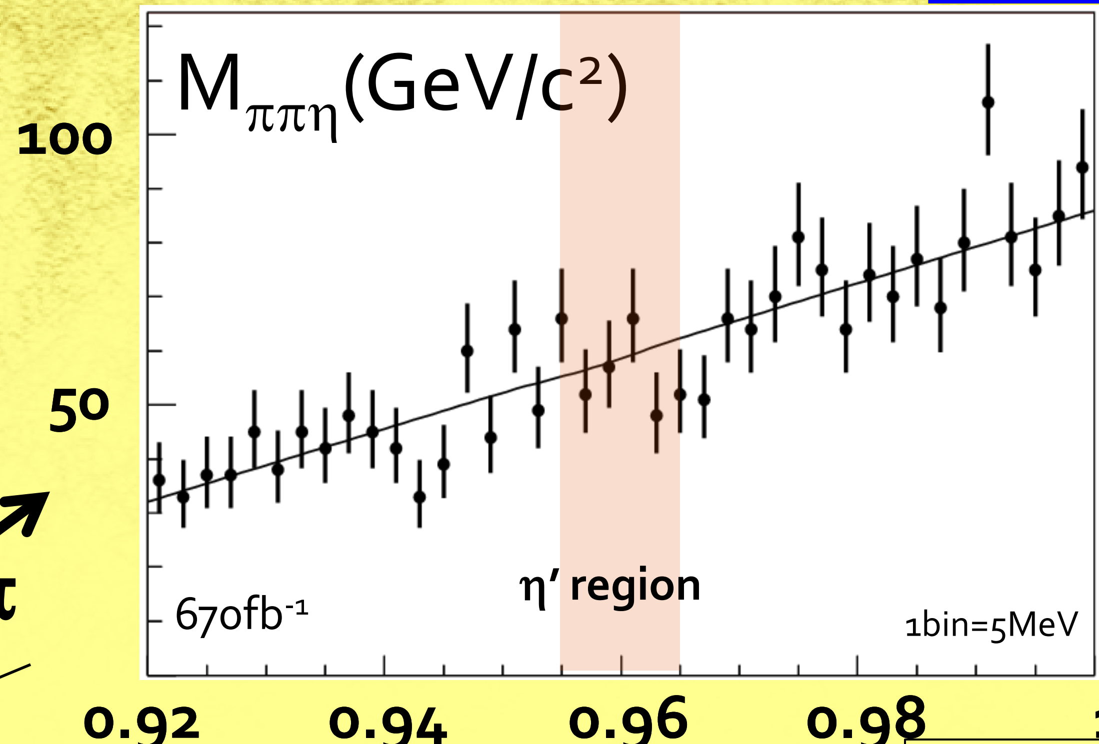
8. $\tau \to \pi \eta'(958) \nu$ search

$\tau \to \pi \eta' \nu$ is also a SCC decay.

$$J^{PG}(\eta) = J^{PG}(\eta') = 0^{-+}$$

η' is reconstructed from $\pi\pi\eta$ and η is from $\gamma\gamma$.





Fit result: $N_{\eta'} = -2.87^{+24.46}_{-23.71}$

double Gaussian +linear

ε=2.9%, $N_{\tau\tau}=6.2\times10^{8}$

$\mathcal{B}=(-0.47^{+3.97}_{-3.85} \pm 0.26)\times10^{-6}$

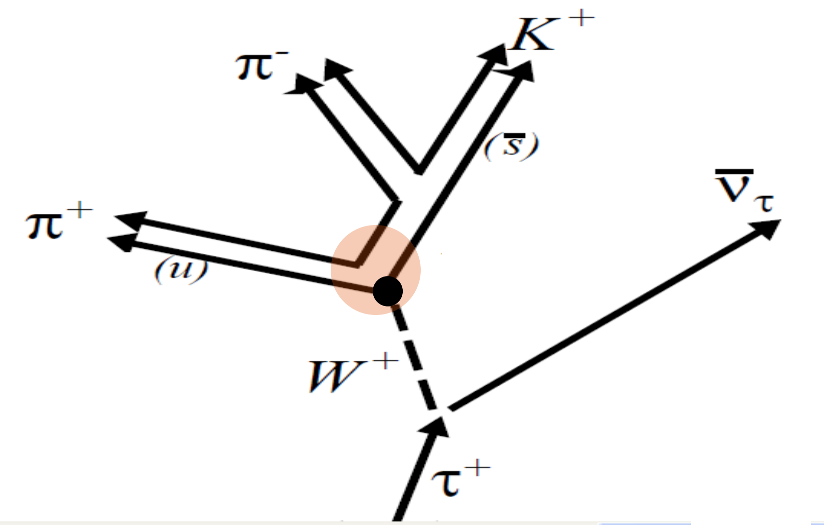
$\mathcal{B}<6.1\times10^{-6}$@90%CL **preliminary**

BaBar: $\mathcal{B}<7.2\times10^{-6}$

PRD77, 112002 (2008)

9. $\tau \rightarrow hh'h''\nu$ analysis ($h=\pi,K$)

Good stage to study CKM |Vus|, m_s, hadron form factors



Especially, $M_{hh'h''}$ brings us some important information for these topics.

With a 666fb^{-1} data sample, $\tau \rightarrow hh'h''\nu$ mode are analyzed:

Selection:
3hadrons – lepton
Rejection: Ks^0, hard γ. π^0 in signal side
$\tau\tau$-like: missing, total P, Total E
π/K-ID: optimized for FOM

$N_{\tau\tau}$: evaluated from efficiency of letponic tag

$\tau \rightarrow hh'h''\nu$ process becomes BG for each other due to mis-PID.
→Simultaneous evaluation is the best way.

10. BF's for $\tau \to hh'h''\nu$ ($h=\pi,K$)

Simultaneous BF evaluation:

$$N_i^{true} = \varepsilon^{-1}_{ij} (N_j^{rec} - N_j^{OtherBG})$$

N_i^{true} : Number of true signal event for i-th mode
N_i^{rec} : Number of reconstructed event for i-th mode
$N_i^{OtherBG}$: Number of estimated background for i-th mode from non-3prong decay

Efficiency migration matrix ε (%)

rec\true	τ→πππν	τ→Kππν	τ→KKπν	τ→KKKν
τ→πππν	23	7.6	2.3	0.73
τ→Kππν	1.3	17	4.8	2.3
τ→KKπν	4.1×10^{-2}	0.47	13	6.0
τ→KKKν	5.0×10^{-4}	1.4×10^{-2}	0.28	9.4

	N^{rec}	N^{other}/N^{rec} (%)
$\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$	8.86×10^6	10.6
$\tau^- \to K^-\pi^+\pi^-\nu_\tau$	7.94×10^5	12.1
$\tau^- \to K^-K^+\pi^-\nu_\tau$	1.08×10^5	6.66
$\tau^- \to K^-K^+K^-\nu_\tau$	3.16×10^3	5.41

	Belle(preliminary)	BaBar	PDG06
$\mathcal{B}(\tau\to\pi\pi\pi\nu)$ (x10^{-2})	**8.42±0.00±0.24**	**8.83±0.01±0.13**	**9.02±0.08**
$\mathcal{B}(\tau\to K\pi\pi\nu)$ (x10^{-3})	**3.28±0.02±0.12**	**2.73±0.02±0.09**	**3.33±0.35**
$\mathcal{B}(\tau\to KK\pi\nu)$ (x10^{-3})	**1.53±0.01±0.05**	**1.35±0.01±0.04**	**1.53±0.10**
$\mathcal{B}(\tau\to KKK\nu)$ (x10^{-5})	**2.62±0.23±0.22**	**1.58±0.13±0.12**	**<3.7**

PDG08 includes BaBar's result.

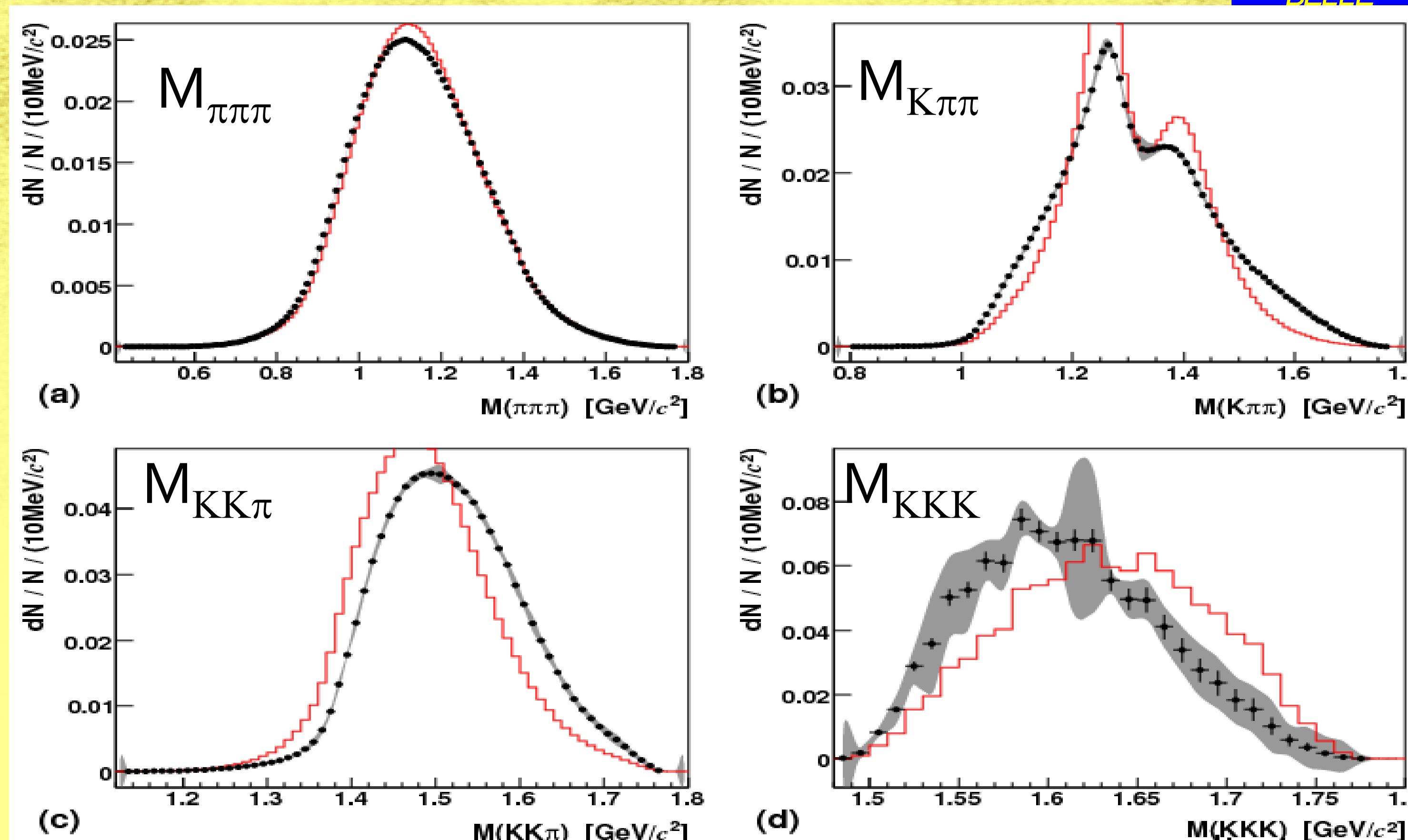
PRL100,011801(2008)

11. Unfolded mass dist. for hh'h"

Unfolded data

Systematic error

TAUOLA



preliminary

unfolding

Response matrix

$$\hat{A}x = b$$

unfolded spectrum

Observed spectrum

$\hat{A}^{-1}$ Obtained by Singular Value Decomposition technique

- First result for the unfolded distributions.
- Different from TAUOLA
- Useful for the determination of |Vus|, ms
- And the discussion of the hadron form factors.

12. Summary

With a 6.2×10^8 τ-pair data sample accumulated by Belle

1. $\tau\to\pi\eta\nu$

Succeed in reducing BG effectively

★ $\mathcal{B}<7.3\times10^{-5}$ @90%CL

- Possible indication of a signal for SCC (2.4σ)
  $\mathcal{B}=(4.4\pm1.6\pm0.8)\times10^{-5}$ preliminary

2. $\tau\to\pi\eta'(958)\nu$

Also SCC decay.

★ $\mathcal{B}<6.1\times10^{-6}$@90%CL

- Zero-consistent
  $\mathcal{B}=(-0.47^{+3.97}_{-3.85}\pm0.26)\times10^{-6}$
  preliminary

BaBar: $\mathcal{B}<7.2\times10^{-6}$

3. $\tau\to hh'h''\nu$ preliminary

Simultaneously measured:

$\mathcal{B}(\tau\to\pi\pi\pi\nu)=(8.42\pm0.00\pm0.24)\times10^{-2}$

$\mathcal{B}(\tau\to K\pi\pi\nu)=(3.28\pm0.02\pm0.12)\times10^{-3}$

$\mathcal{B}(\tau\to KK\pi\nu)=(1.58\pm0.01\pm0.05)\times10^{-3}$

$\mathcal{B}(\tau\to KKK\nu)=(2.62\pm0.23\pm0.23)\times10^{-5}$

Unfolded distributions for M_{hhh}

- first report of the unfolded mass distributions
- different from the models implemented in TAUOLA
- important for a precise determination of |Vus|, m_s, and the discussion of the hadron form factors.

backup

$\eta\pi^-\nu_\tau$		$< 1.4 \times 10^{-4}$	CL=95%
$\eta\pi^-\pi^0\nu_\tau$	[g]	$(1.77\pm0.24)\times 10^{-3}$	
$\eta\pi^-\pi^0\pi^0\nu_\tau$		$(1.5\pm0.5)\times 10^{-4}$	
$\eta K^-\nu_\tau$	[g]	$(2.7\pm0.6)\times 10^{-4}$	
$\eta K^*(892)^-\nu_\tau$		$(2.9\pm0.9)\times 10^{-4}$	
$\eta K^-\pi^0\nu_\tau$		$(1.8\pm0.9)\times 10^{-4}$	
$\eta \overline{K}^0\pi^-\nu_\tau$		$(2.2\pm0.7)\times 10^{-4}$	
$\eta\pi^+\pi^-\pi^- \geq 0$ neutrals ν_τ		$< 3 \times 10^{-3}$	CL=90%
$\eta\pi^-\pi^+\pi^-\nu_\tau$		$(2.3\pm0.5)\times 10^{-4}$	
$\eta a_1(1260)^-\nu_\tau \to \eta\pi^-\rho^0\nu_\tau$		$< 3.9 \times 10^{-4}$	CL=90%
$\eta\eta\pi^-\nu_\tau$		$< 1.1 \times 10^{-4}$	CL=95%
$\eta\eta\pi^-\pi^0\nu_\tau$		$< 2.0 \times 10^{-4}$	CL=95%

mode	BF(PLB672,209(2009))
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$\tau\to\pi\eta\eta\nu$	$<7.4\mathrm{x}10^{-6}$
$\tau\to K\eta\eta\nu$	$<3.0\mathrm{x}10^{-6}$

$\tau\to\pi\pi^0\eta\nu$	313.2 ± 7.2
$\tau\to K\eta\nu$	42.4 ± 2.3
$\tau\to K^*\eta\nu$	127.0 ± 3.6