Hadronic Decay studies of τ lepton at B-factories

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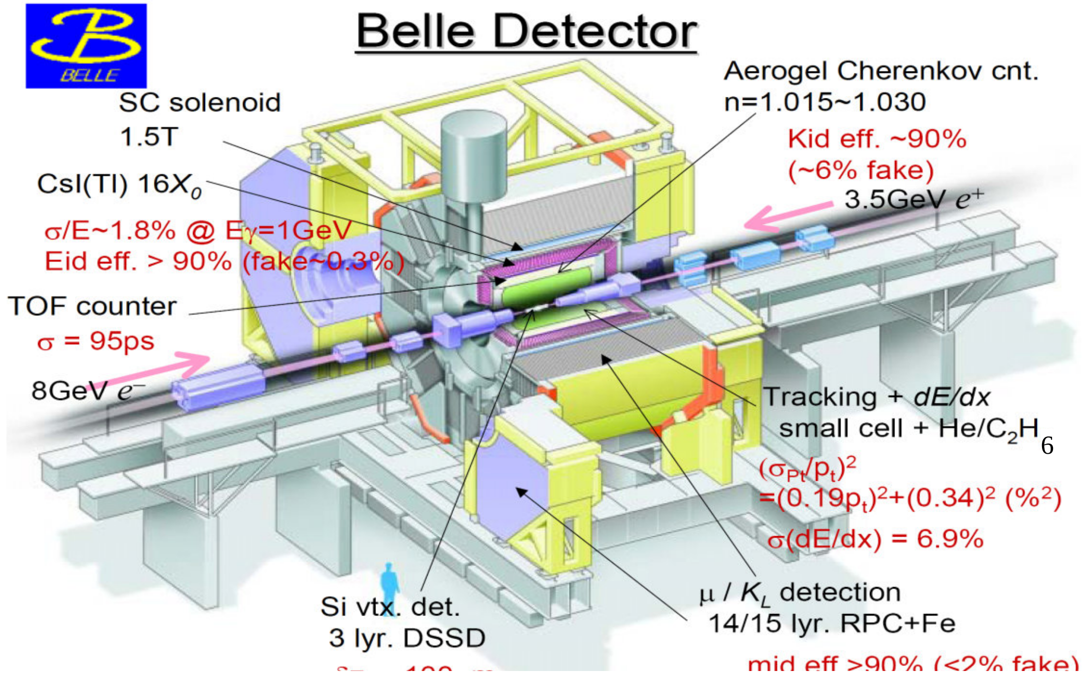
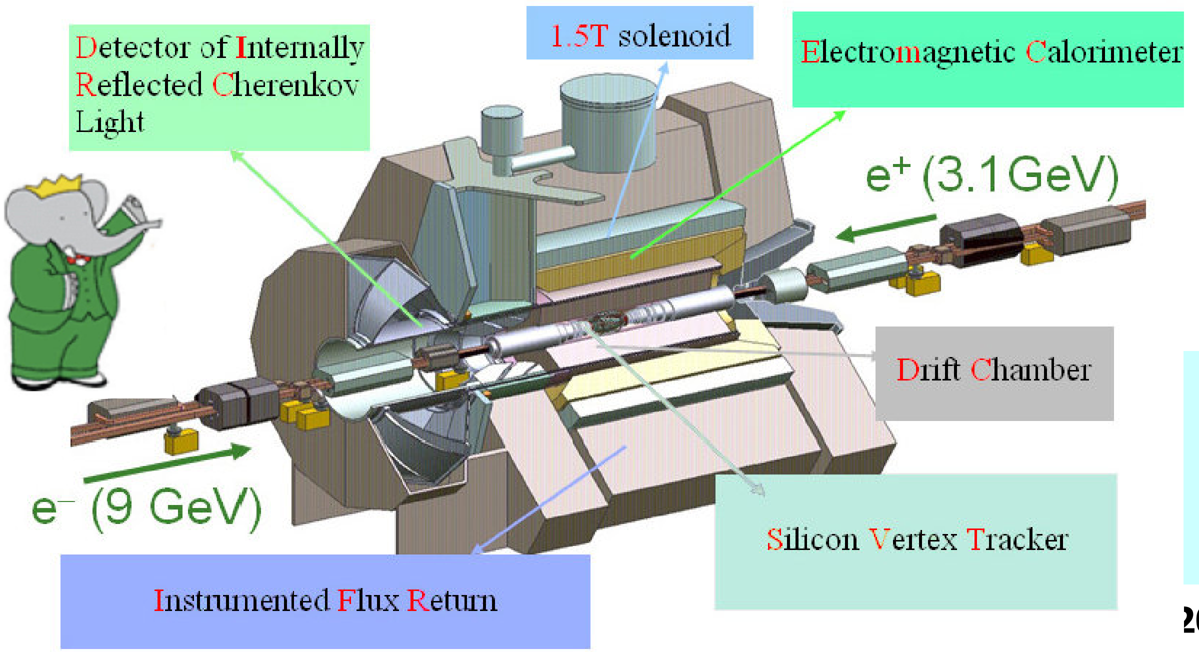
International workshop on Weak Interactions and Neutrinos, Sep.15, 2009

Belle & BaBar experiments



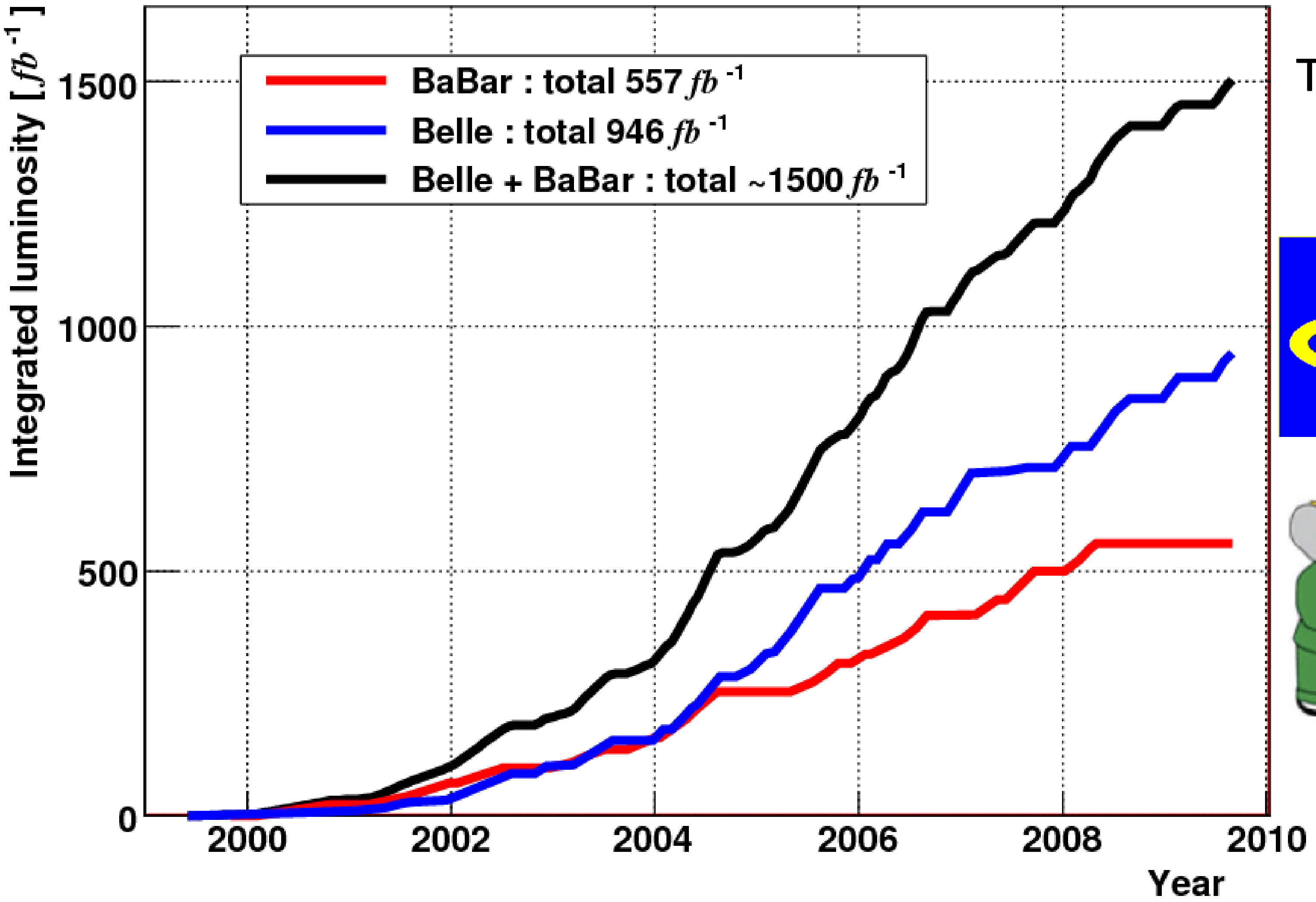


- Good vertexing
- Good PID
- Good photon detection, Eγ resolution
- Energy asymmetry
- High luminosity .....

Decay mode	σ(nb)
$\Psi(4S) \to BB$	1.15
$e^+e^- \to \tau\tau$	0.919
$e^+e^- \to ff$ (f=udsc)	2.8
$e^+e^- \to \mu\mu$	1.15
Bhabha (Barrel)	44
γγ(Barrel)	2.4
2γ(Barrel, P_t>0.1GeV)	~15

- σ(BB) ≈ σ(ττ) : Not just a B-factory but a τ-factory

10 years of B-factories



Total : ~ 1500 fb^{-1}

946 fb^{-1}
(Jul, 2009)

557 fb^{-1}
(Apr, 2008)

1500fb^{-1} ~ 1.4X10^{9} τ pair events!

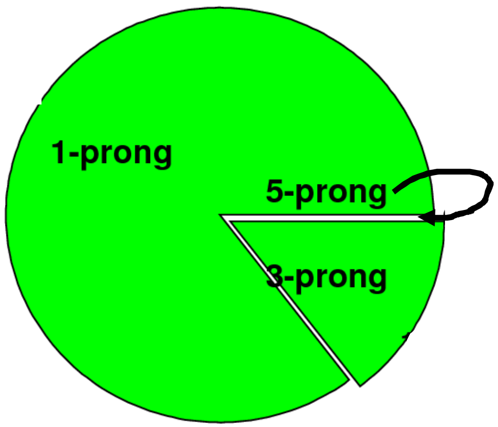
Really many measurements are done and on-going in B- (τ-) factory

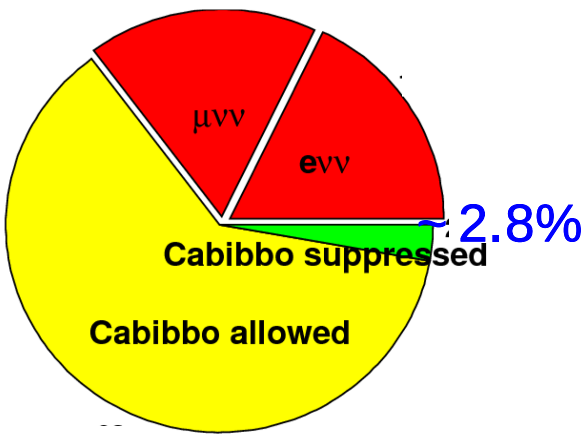
Decay Mode	Experiment	Reference	Result
$(\tau^- \to K^- \nu)/(\tau^- \to e^- \bar{\nu} \nu)$	BaBar	arXiv:0811.1429 [hep-ex]	(0.03882 ± 0.00032 ± 0.00056)
			$\lvert g_\tau / g_\mu \rvert$ = (0.9836 ± 0.0087)
$\tau^- \to K^- \pi^0 \nu$	BaBar	Phys.Rev.D76:051104,2007	$(0.416 \pm 0.003 \pm 0.018) \times 10^{-2}$
$\tau^- \to \bar{K}^0 \pi^- \nu$	BaBar	arXiv:0808.1121 [hep-ex]	$(0.840 \pm 0.004 \pm 0.023) \times 10^{-2}$
	Belle	Phys.Lett.B654:65-73,2007	$(0.808 \pm 0.004 \pm 0.026) \times 10^{-2}$
$\tau^- \to K^- \pi^- \pi^+ \nu$ (excl. K_S^0)	BaBar	Phys.Rev.Lett.100:011801,2008	$(0.273 \pm 0.002 \pm 0.009) \times 10^{-2}$
	Belle	EPS2009	$(0.328 \pm 0.002 \pm 0.012) \times 10^{-2}$
$\tau^- \to K^- \pi^- K^+ \nu$	BaBar	Phys.Rev.Lett.100:011801,2008	$(1.346 \pm 0.010 \pm 0.036) \times 10^{-3}$
	Belle	EPS2009	$(1.53 \pm 0.01 \pm 0.05) \times 10^{-3}$
$\tau^- \to K^- K^- K^+ \nu$	BaBar	Phys.Rev.Lett.100:011801,2008	$(1.58 \pm 0.13 \pm 0.12) \times 10^{-5}$
	Belle	EPS2009	$(2.62 \pm 0.23 \pm 0.22) \times 10^{-5}$
$\tau^- \to K^- \varphi \nu$	BaBar	Phys.Rev.Lett.100:011801,2008	$(3.39 \pm 0.20 \pm 0.28) \times 10^{-5}$
	Belle	Phys.Lett.B643:5-10,2006	$(4.05 \pm 0.25 \pm 0.26) \times 10^{-5}$
$\tau^- \to K^* K^- \nu$	Belle	arXiv:0808.1059 [hep-ex]	$(1.56 \pm 0.02 \pm 0.09) \times 10^{-3}$
$\tau^- \to K^* K^- \pi^0 \nu$	Belle	arXiv:0808.1059 [hep-ex]	$(2.39 \pm 0.46 \pm 0.26) \times 10^{-5}$
$\tau^- \to K^- \eta \nu$	Belle	Phys.Lett.B672:209-218,2009	$(1.58 \pm 0.05 \pm 0.09) \times 10^{-4}$
$\tau^- \to K^- \pi^0$ [illegible] ν	Belle	Phys.Lett.B672:209-218,2009	[illegible] $\times 10^{-5}$
$\tau^- \to K_S^0 \pi^-$ [illegible] ν	Belle	Phys.Lett.B672:209-218,2009	[illegible] $\times 10^{-5}$
$\tau^- \to K^{*-} \eta \nu$	Belle	Phys.Lett.B672:209-218,2009	$(1.34 \pm 0.12 \pm 0.09) \times 10^{-4}$
			(Top of the Page)

Decay Mode	Experiment	Reference	Result
$(\tau^- \to \pi^- \nu)/(\tau^- \to e^- \bar{\nu} \nu)$	BaBar	arXiv:0811.1429 [hep-ex]	(0.594[illegible])
			$\lvert g_\tau / g_\mu \rvert$ = (0.9859 ± 0.0057)
$\tau^- \to \pi^- \pi^0 \nu$	Belle	Phys.Rev.D78:07[illegible]2008	([illegible] ± 0.39) X 10^{-2}
			$a_\mu^{\pi\pi}$ = 52[illegible] ± 1.5 (exp) ± 2.6 (BR) ± 2.5 (isospin
$\tau^- \to \pi^- \pi^- \pi^+ \nu$ (excl. K_S^0)	BaBar	Phys.Rev.Lett.1[illegible]:011801,2008	$(8.83 \pm 0.0$[illegible] $\pm 0.13) \times 10^{-2}$
	Belle	EPS2009	$(8.42 \pm 0.00 \pm 0.24) \times 10^{-2}$
$\tau^- \to \pi^- \pi^0 \eta \nu$	Belle	Phys.Lett.B672:209-,2009	$(1.35 \pm 0.03 \pm 0.07) \times 10^{-3}$
$\tau^- \to \pi^- \eta \nu$ **(Second Class Current)**	Belle	EPS2009	$(4.4 \pm 1.6 \pm 0.8) \times 10^{-5}$
			$< 7.3 \times 10^{-5}$ @ 90% C.L.
$\tau^- \to f_1(1285) \pi^-$ &nu	BaBar	Phys.Rev.D77:112002,2008	$(3.19 \pm 0.18 \pm 0.16 \pm 0.99) \times 10^{-4}$
$\tau^- \to f_1(1285) \pi^- \nu \to 2\pi^- \pi^+ \eta \nu$	BaBar	Phys.Rev.D77:112002,2008	$(1.11 \pm 0.06 \pm 0.05) \times 10^{-4}$
$\tau^- \to 2\pi^- \pi^+ \eta \nu$	BaBar	Phys.Rev.D77:112002,2008	$(1.60 \pm 0.05 \pm 0.11) \times 10^{-4}$
$\tau^- \to \pi^- \eta' \nu$ **(Second Class Current)**	Belle	EPS2009	$(-0.47\ ^{+3.97}_{-3.85} \pm 0.26) \times 10^{-6}$
			$< 6.1 \times 10^{-6}$ @ 90% C.L.
$\tau^- \to \pi^- \eta' \nu$ **(Second Class Current)**	BaBar	Phys.Rev.D77:112002,2008	$< 7.2 \times 10^{-6}$ @ 90% C.L.
$\tau^- \to \pi^- \omega \nu$ **(Second Class Current)**	BaBar	Ph[illegible]	[illegible]69
$\tau^- \to \pi^- \varphi \nu$	BaBar	Phys.Rev.Lett.100:011801,2008	$(3.42 \pm 0.55 \pm 0.25) \times 10^{-5}$

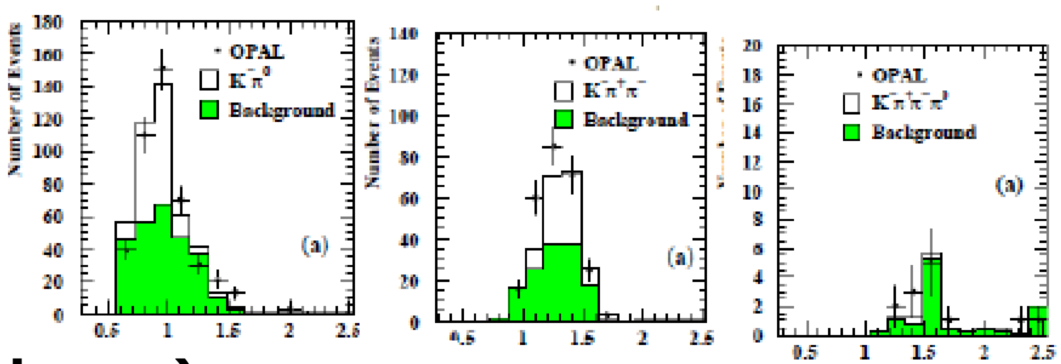
http://www.slac.stanford.edu/xorg/hfag/tau/index.html

Hadronic decays of tau lepton





- The only lepton which can decay to hadrons
  - Rather large mass (1.78GeV)
  - Clean initial state - single τ pair decays decide the kinematics
- Test of CVC and evaluation of a_μ from spectral function.
- Measurements of important physics quantities : V_{us}, m_s, α_s
- Look for leptonic CP violation (NP)



Have been waiting for enough statistics from B-factories (especially, to measure strangeness decays)

Hadronic τ decay programs

- Non-strange final state
  - $\tau \to \eta\pi\nu_\tau$, $\tau \to \eta'\pi\nu_\tau$: Second Class Current
  - $\tau \to \pi\pi^0\nu_\tau$: Test of CVC and $(g-2)_\mu$ (PRD78:0701006,2008)
  - $\tau \to \eta\pi\pi^0\nu_\tau$: Wess-Zumino anomaly
- Strange final state
  - $\tau \to K\pi\nu_\tau$, $\tau \to K\eta X\nu_\tau$
  - 3-prong : $\tau \to h^\pm h^+ h^- \nu_\tau$ ($h = \pi, K$)
  - V_{us} measurement
  - V_{us} using $\Gamma(\tau \to K\nu_\tau)/\Gamma(\tau \to \pi\nu_\tau)$
  - Strange spectral function and V_{us}, m_s measurements
- Other researches
  - 5-prongs, 7-prongs....
  - τ mass measurements (via $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$)
  - Search for CP violation in the charged lepton....

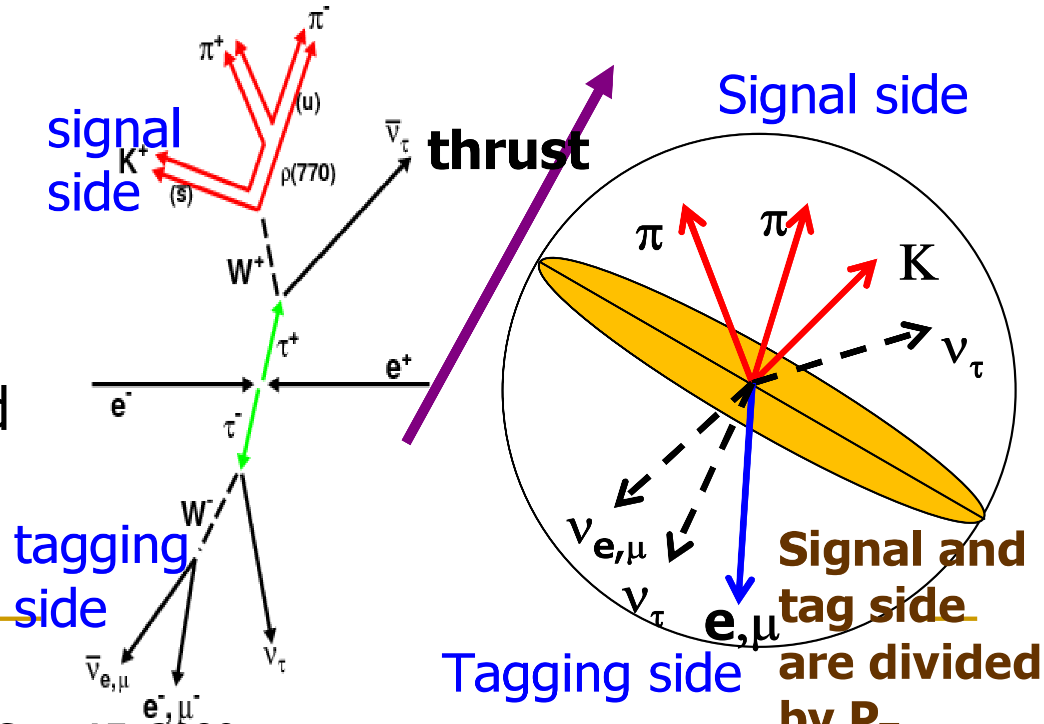
* "Blue" will be presented In this talk

Analysis of hadronic τ decay event

Features of τ pair decays : Low mult., Large P_T, missing E_{tot} and P_{tot}

Main backgrounds	Discrimination
Bhabha, dimuon ($e^+e^- \to e^+e^-$, $\mu^+\mu^-$)	Reconstructed total energy, momentum, **multiplicity**
Continuum ($e^+e^- \to qq$, q=udscb)	**Event topology, thrust**, invariant mass, **multiplicity**
Two-photon	Small transverse momentum, **M_{miss}, P_{miss} recon.**
Beam background	Quality of decay vertex
Other tau decays	**Efficient reconstruction of signal mode**

- Typically, require pure leptonic decay in the tagging side
- In many cases, π/K separation is very important
- Estimate the tau decay background from the MC, or the sideband of resonances



MyeongJae Lee (SNU), "Hadronic tau decays", WIN09, Sep. 15, 2009.

$\tau \to \eta\pi\nu_\tau$: Second Class Current

- 1st Class Current : $PG(-1)^J = +1$
  - $J^{PG} = 0^{--}(\pi), 1^{-+}(\rho), 1^{+-}(a_1),...$
- 2nd Class Current : $PG(-1)^J = -1$
  - $J^{PG} = 0^{+-}(a_0), 1^{++}(b_1),...$
  - S.Weinberg (PR112:1375 (1958))
  - Should be suppressed by isospin symmetry in SM $\propto (m_d - m_u)$
  - $J^{PG}(\tau \to \eta\pi\nu_\tau) = 0^{+-}$, $B(\tau \to \eta\pi\nu_\tau) = 10^{-6} \sim 10^{-5}$
  - Main background : All τ decays containing η

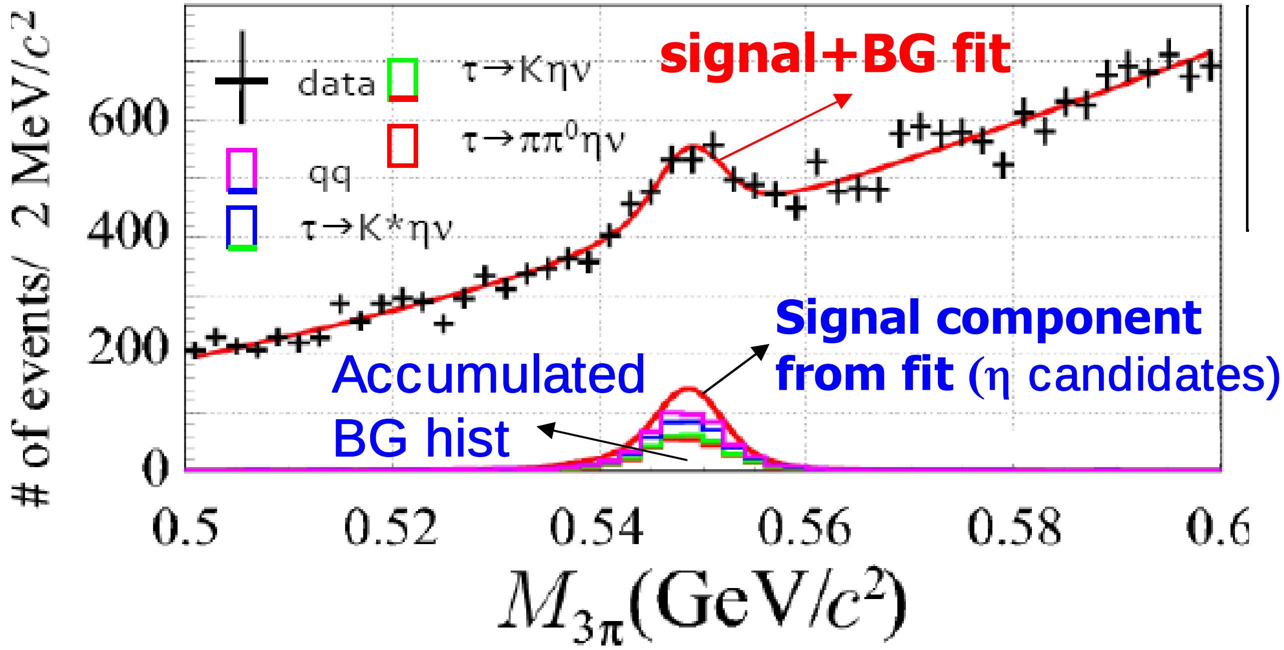
Experiments	$B(\tau \to \eta\pi\nu_\tau)$, 10^{-4} @95% C.L.
MARK3	<250 (@90%)
CLEO, 1987	<180
ARGUS, 1988	<90
CLEO, 1992	<3.4
ALEPH, 1997	<6.2
CLEO, 1996	<1.4 (PDG avg.)

All measurements by Belle Collab. (PLB672,209(2009))

Mode	BF ($\times 10^{-4}$)	Mode	BF (x10-5, @90%)
$\pi^-\pi^0\eta\nu$	$13.5 \pm 0.3 \pm 0.7$	$K^-K^0\eta\nu$	<0.45
$K^-\eta\nu$	$1.58 \pm 0.05 \pm 0.09$	$\pi^-K^0_s\eta\nu$	<2.5
$K^-\pi^0\eta\nu$	$0.46 \pm 0.11 \pm 0.04$	$K^-\eta\eta\nu$	<0.3
$\pi^-K^0_s\eta\nu$	$0.44 \pm 0.07 \pm 0.03$	$\pi^-\eta\eta\nu$	<0.74

Analysis of $\tau\to\eta\pi\nu_\tau$ ($\eta\to3\pi$)

- With standard event selection + $M(4\pi)<1.2$GeV ...



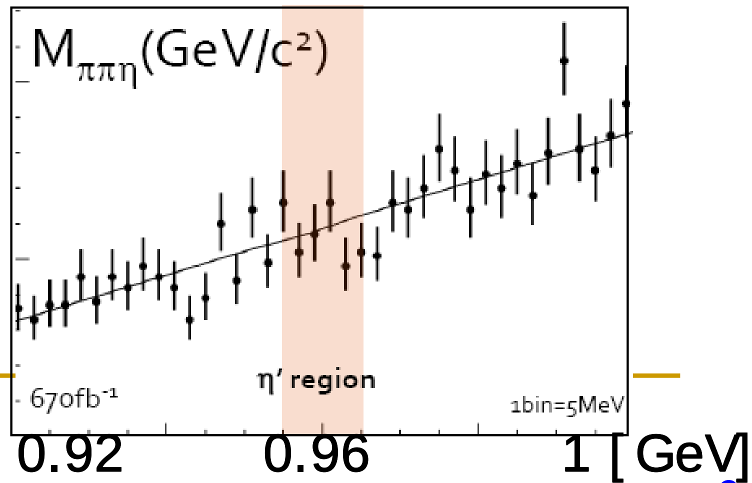
Belle Preliminary (EPS09)

$N_{\tau\tau}$	~620M (670 fb^{-1})
N^{fit}	749± 62
N^{sig}	191± 69
BF	(4.4± 1.6± 0.8)x10^{-5} (2.4σ) or 7.3x10^{-5} @90% C.L.

- Other SCC study : $\tau\to\eta'(958)\pi\nu_\tau$
  - BF < 6.1x10^{-6} @90% C.L. (Belle)
  - BF < 7.2x10^{-6} @90% C.L. (BaBar)

(Phys.Rev.D77:112002,2008)

Belle Preliminary (EPS09)

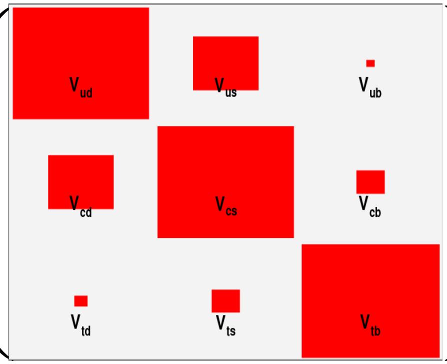


Strange final state decay of τ

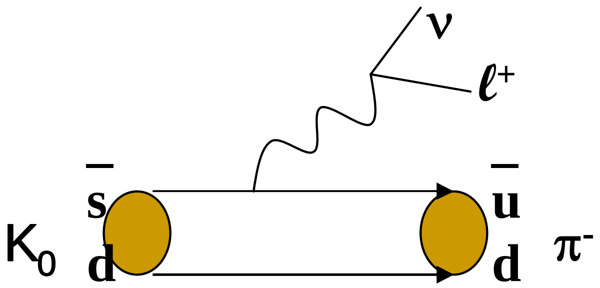
- B-factory detectors have a good π/K separation
  - Useful to discriminate Cabibbo-suppressed decay
- Rather small BR for strangeness decays
  - Need large statistics for studying suppressed decays
- For V_{us} measurement
  - Inclusive measurements of $\tau \rightarrow s$ decays
  - Strange spectral function and simultaneous fit on V_{us} and m_s : need enough statistics and measurements
  - τ decays are the most clean environment to measure V_{us}.
    - Uncertainties are dominated by experimental error.

V_{us} measurement

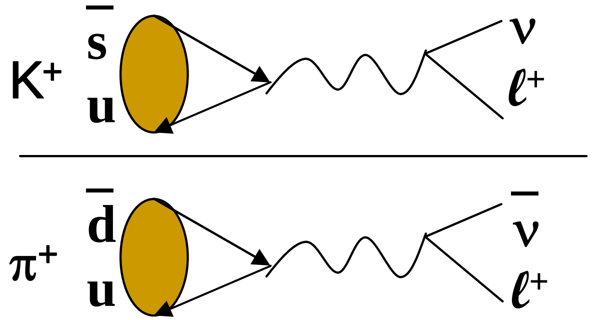
$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \sim$$



- Estimate from the unitarity condition :
  $|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2 = 1 \Rightarrow |V_{us}| = 0.2255 \pm 0.0010$
- From $K_{\ell 3}$ decays or From $K_{\ell 2}$ decays



$\propto f^2 |V_{us}|^2$



$$\propto \left|\frac{V_{us}}{V_{ud}}\right|^2 \frac{f_K^2}{f_\pi^2}$$

$|V_{us}| = 0.2247 \pm 0.0012$

$|V_{us}| = 0.2261 \pm 0.0015$

Good agreements with Unitarity !

V_{us} measurement from τ decay

$$R_\tau = \frac{\Gamma(\tau^- \to (hadrons)^- \nu_\tau)}{\Gamma(\tau^- \to e^- \overline{\nu}_e \nu_\tau)} = R_{\tau,non\text{-}strange} + R_{\tau,strange}$$

Measured from the branching fraction and invariant mass spectra

$$|V_{us}|^2 = \frac{R^W_{\tau,\,strange}}{R^W_{\tau,\,non\text{-}strange} / |V_{ud}|^2 - \delta R^W_\tau}$$

- $|V_{ud}|$ is well measured from super allowed $0^+ \to 0^+$ beta decay
- δR^W_τ is determined from Finite Energy Sum Rule, and is relatively small ($\delta R^W_\tau \sim 0.06 \times R^W_{\tau,\text{ non-strange}} / |V_{ud}|^2 \pm 10\%$)
- $$R_\tau = \frac{1 - BF(\tau \to e\nu\nu_\tau) - BF(\tau \to \mu\nu\nu_\tau)}{BF(\tau \to e\nu\nu_\tau)} = R_{\tau,\text{non-strange}} + R_{\tau,\text{strange}}$$

: **inclusive measurement of strange decays is required.**

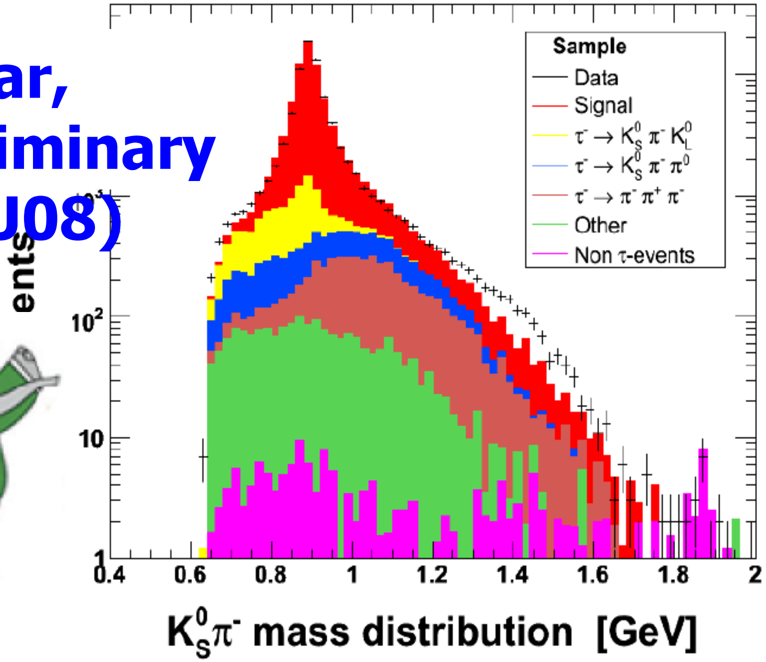
Listing the strange decays : $\tau^- \to K_s \pi^- \nu_\tau$

$M(K^{*0}(892))$ = 895.47± **0.20(stat)**± 0.44(sys)± **0.59(mod) MeV/c²**

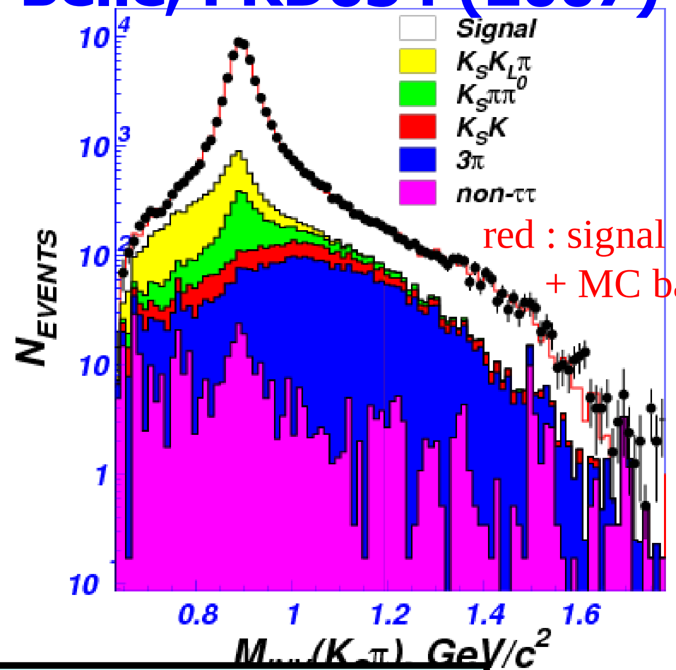
$\Gamma(K^{*0}(892))$ = 42.2± 0.6(stat)± 1.0(sys)± 0.7(mod) MeV

(PDG07 : 896.00± 0.25, 50.3± 0.6)

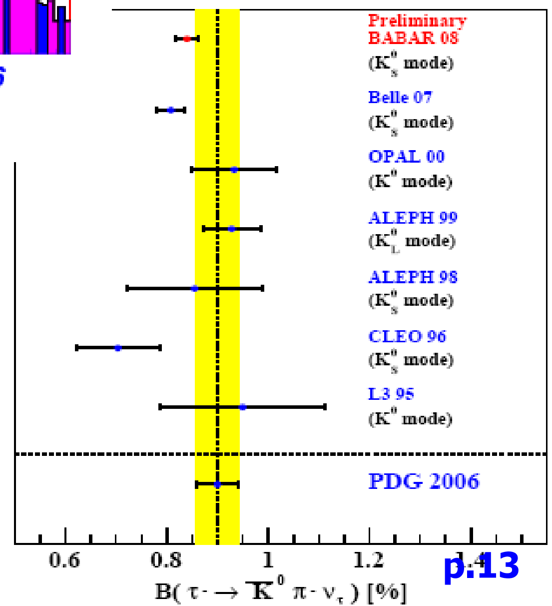
BaBar, Preliminary (TAU08)



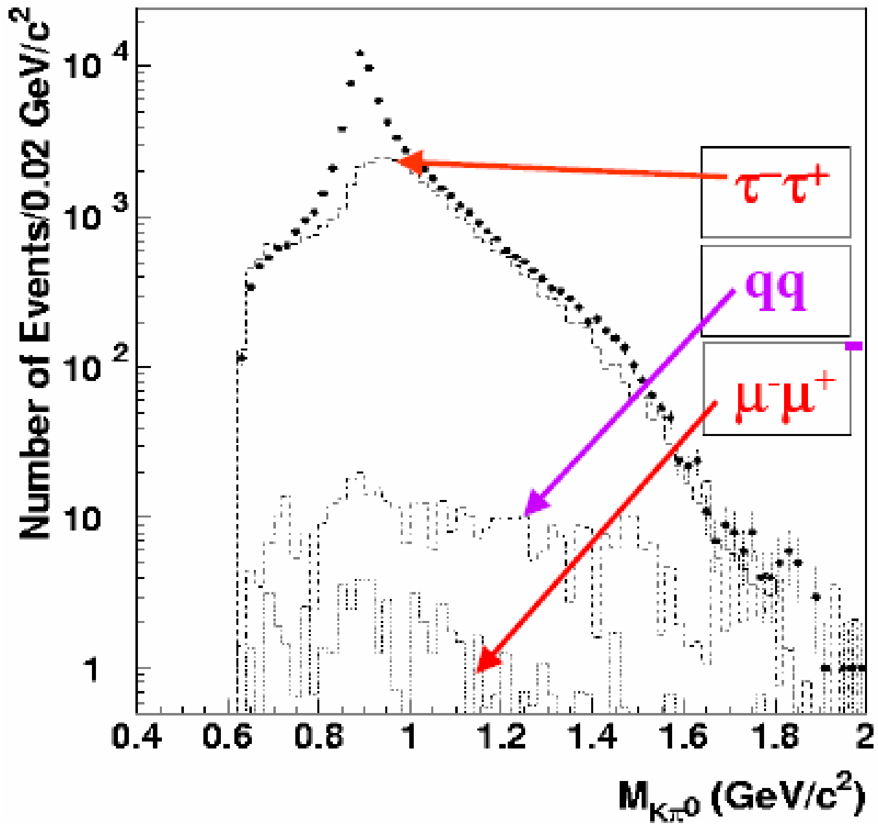
Belle, PRD654 (2007)

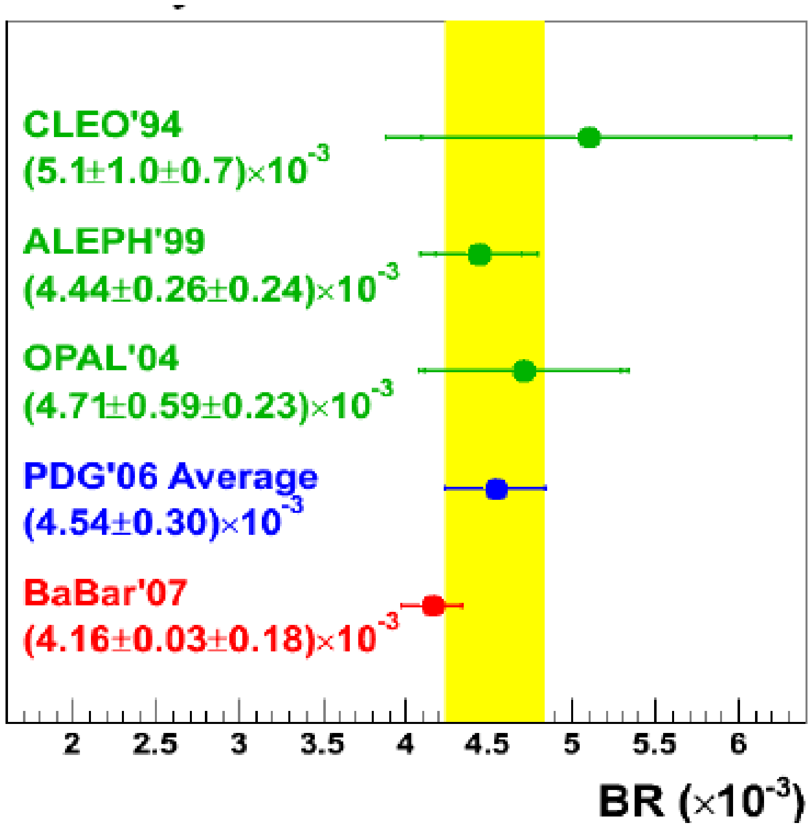


	$N_{\tau\tau}$	ε	N^{signal}	BF (%), $B(\tau^- \to K^0\pi^-\nu_\tau)$ = 2x $B(\tau^- \to K_s\pi^-\nu_\tau)$
Belle	310M	~5.8%	~53k	0.808± 0.004± 0.026
BaBar	350M	~1.1%	~33k	0.840± 0.004± 0.023
PDG07				0.90± 0.04



$\tau^- \to K^- \pi^0 \nu_\tau$

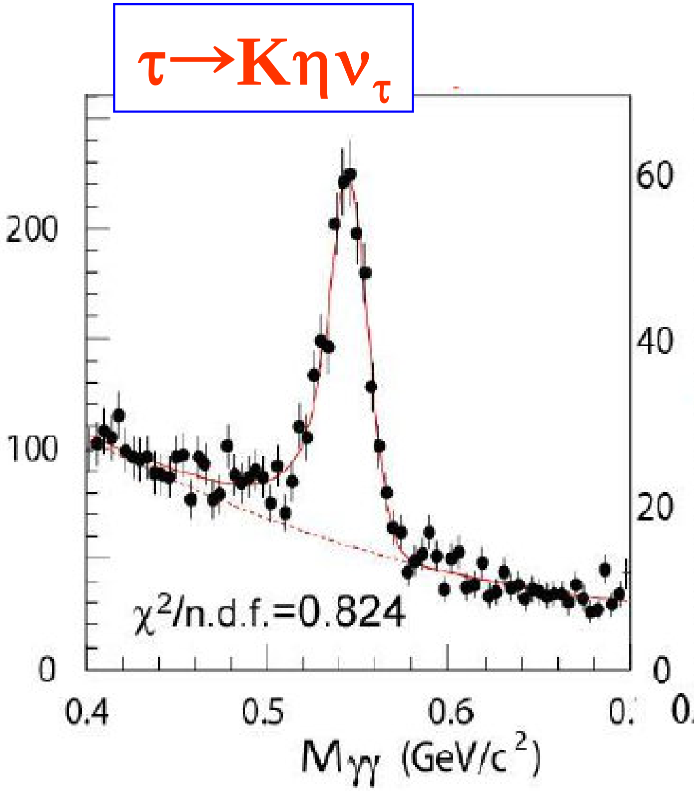


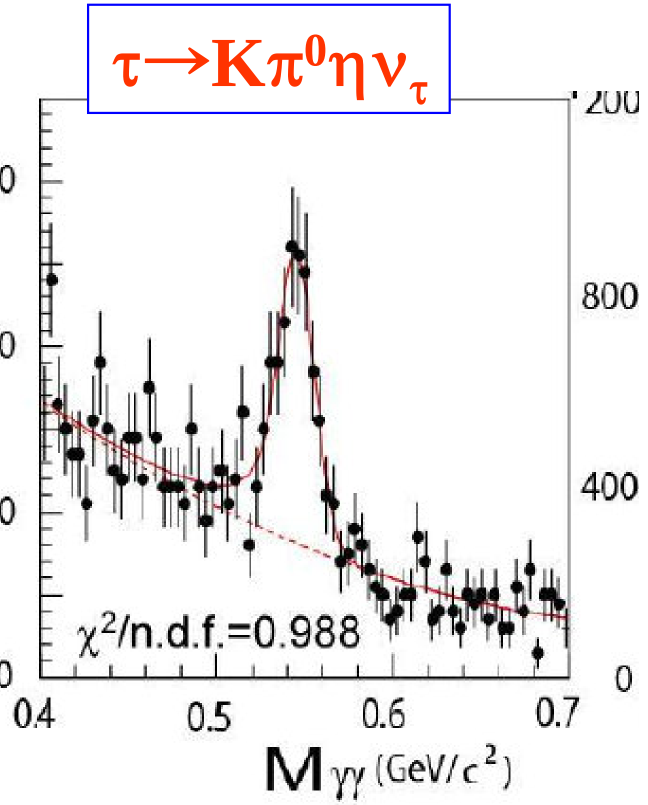


$N_{\tau\tau}$	211M (230 fb^{-1})
ε	~2.3%
N^{signal}/N^{BG}	78k / 38k
BF(%)	0.416± 0.003± 0.018
PRD 76:051104, 2007 (BaBar)	

Large BG from $\tau \to \pi\pi^0\nu_\tau$ (BF~25%) cross-feed,
due to particle mis-identification

τ decays with η : $\tau \to K\eta\nu_\tau$, $\tau \to K\pi^0\eta\nu_\tau$





Belle,
PLB 672:209 (2009)

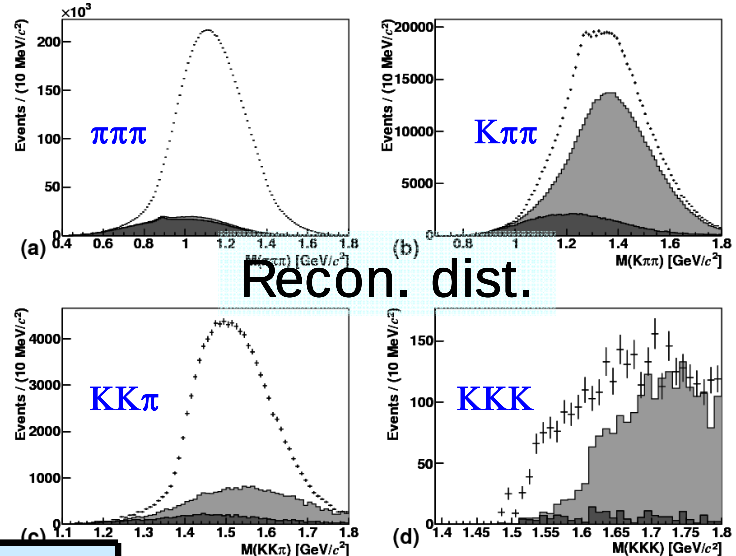
	$\tau \to K\eta\nu_\tau$ ($\eta \to \gamma\gamma$, $\eta \to 3\pi$)	$\tau \to K\pi^0\eta\nu_\tau$ ($\eta \to \gamma\gamma$, $\eta \to 3\pi$)
$N_{\tau\tau}$	450M (490 fb^{-1})	
BF	$(1.58 \pm 0.05 \pm 0.09) \times 10^{-4}$	$(0.46 \pm 0.11 \pm 0.04) \times 10^{-4}$
BF (CLEO,1996)	$(2.6 \pm 0.5 \pm 0.5) \times 10^{-4}$	$(1.77 \pm 0.56 \pm 0.71) \times 10^{-4}$

$\tau^- \to h^- h^+ h^- \nu_\tau$ (h = π, K)

- Four decay modes are correlated due to the particle mis-identification, that one decay mode contributes to the BG of the other decay mode
- Large differences btw BFs make this cross-feed effect significant.

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

N_i^{true} : Number of true signal events for i-th mode
N_i^{rec} : Number of reconstructed events for i-th mode
$N_i^{OtherBG}$: Number of estimated backgrounds for i-th mode from non-3prong decay
ε : efficiency migration matrix



Efficiency migration matrix ε (%)

rec \ true	τ→πππν	τ→Kππν	τ→KKπν	τ→KKKν
τ→πππν	**23.0**	7.6	2.3	0.73
τ→Kππν	1.3	**17.2**	4.8	2.3
τ→KKπν	4.1×10^{-2}	0.47	**12.9**	6.0
τ→KKKν	5.0×10^{-4}	1.4×10^{-2}	0.28	**9.4**

- Efficiency : 10 ~ 20%
- Fake rate from πππ to Kππ is sufficiently small

Branching fraction of $\tau^- \to h^- h^+ h^- \nu_\tau$

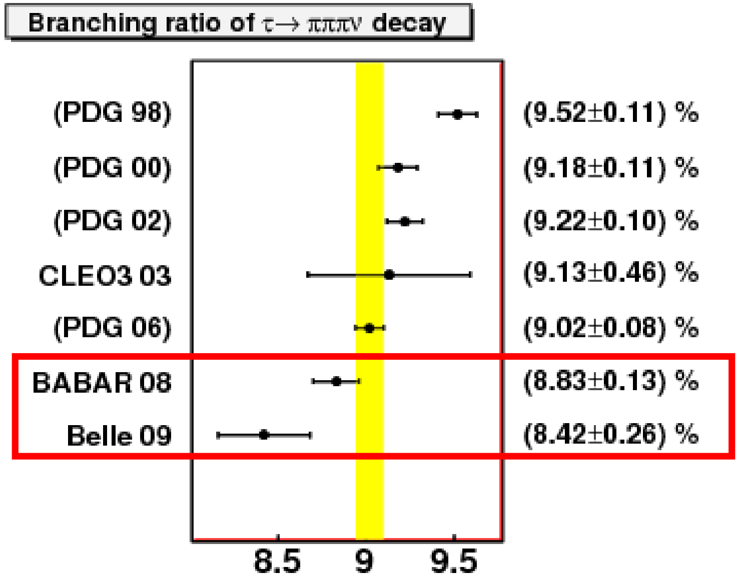
	Branching ratio	N^{rec}	N^{other}/N^{rec}
$\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau$	$(8.42 \pm 0.01(st.)^{+0.26}_{-0.25}(sy.)) \times 10^{-2}$	8.86×10^6	10.6%
$\tau^- \to K^- \pi^+ \pi^- \nu_\tau$	$(3.28 \pm 0.01(st.)^{+0.16}_{-0.16}(sy.)) \times 10^{-3}$	7.94×10^5	12.2%
$\tau^- \to K^- K^+ \pi^- \nu_\tau$	$(1.53 \pm 0.01(st.)^{+0.05}_{-0.05}(sy.)) \times 10^{-3}$	1.08×10^5	6.70%
$\tau^- \to K^- K^+ K^- \nu_\tau$	$(2.62 \pm 0.15(st.)^{+0.17}_{-0.17}(sy.)) \times 10^{-5}$	3.16×10^3	5.45%

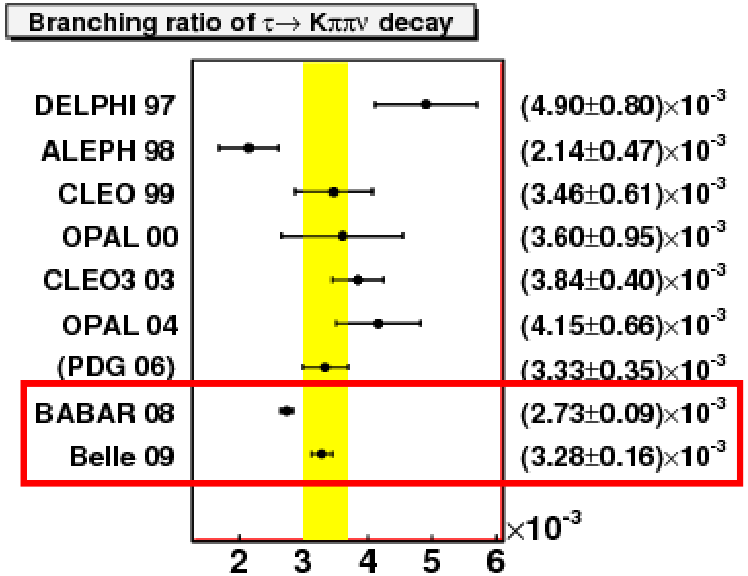
$N_{\tau\tau}$ = 613M, Belle, Preliminary (TAU08 and EPS09)

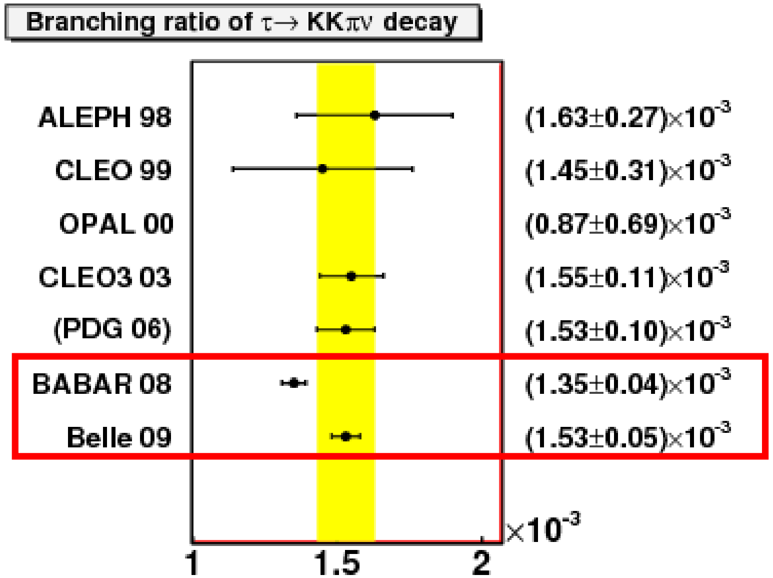
	Branching ratio	N^{rec}
$\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau$	$(8.83 \pm 0.01 \pm 0.13) \times 10^{-2}$	1.60×10^6
$\tau^- \to K^- \pi^+ \pi^- \nu_\tau$	$(2.73 \pm 0.02 \pm 0.09) \times 10^{-3}$	6.96×10^4
$\tau^- \to K^- K^+ \pi^- \nu_\tau$	$(1.35 \pm 0.01 \pm 0.04) \times 10^{-3}$	1.82×10^4
$\tau^- \to K^- K^+ K^- \nu_\tau$	$(1.58 \pm 0.13 \pm 0.12) \times 10^{-5}$	2.75×10^2

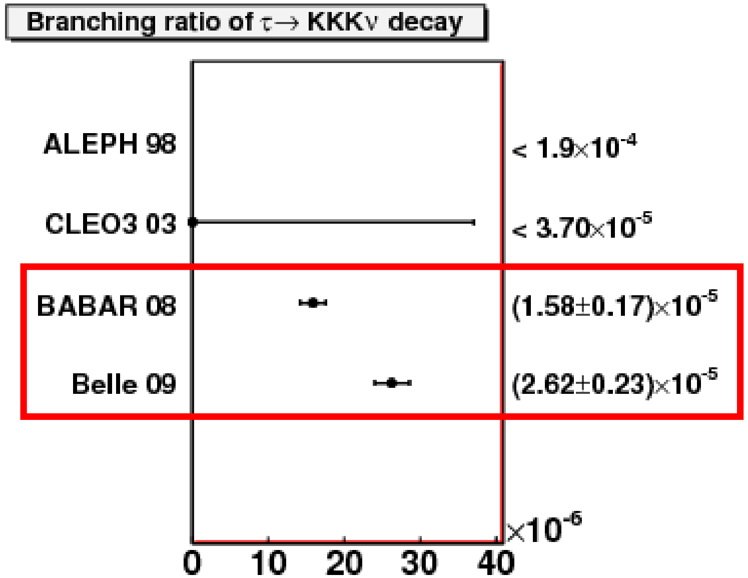
$N_{\tau\tau}$ = 314M, **BaBar, PRL100:011801, 2008**

Branching fraction of $\tau^- \to h^- h^+ h^- \nu_\tau$









Mass spectra of $\tau^- \to h^- h^+ h^- \nu_\tau$

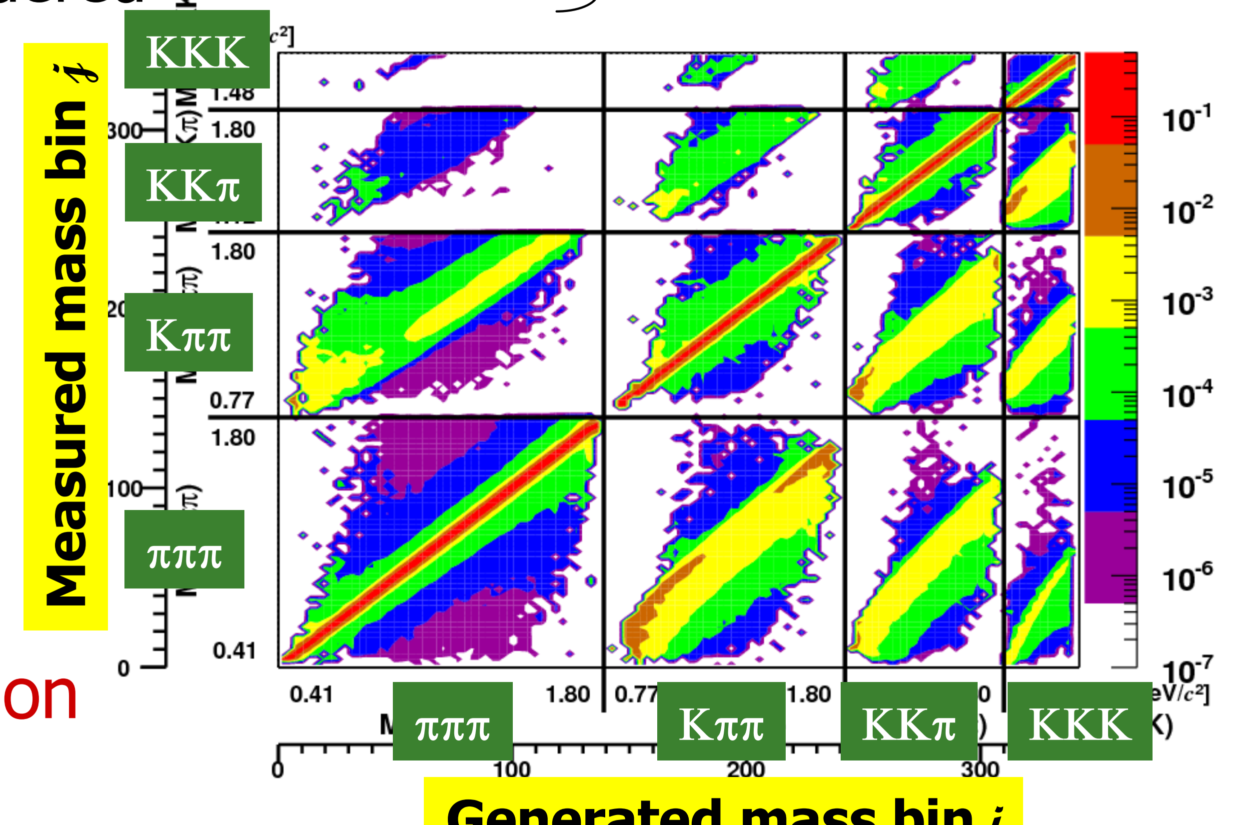
- Motivation
  : to contribute to the evaluation of strange spectral function
- From the unfolding analysis
  - Taking into account the smearing effect
  - Also the feed-down from other modes simultaneously considered

Removing detector effects and get "real" spectrum

Unfolding is a inverse-problem for $A_{ij}x_j=b_i$

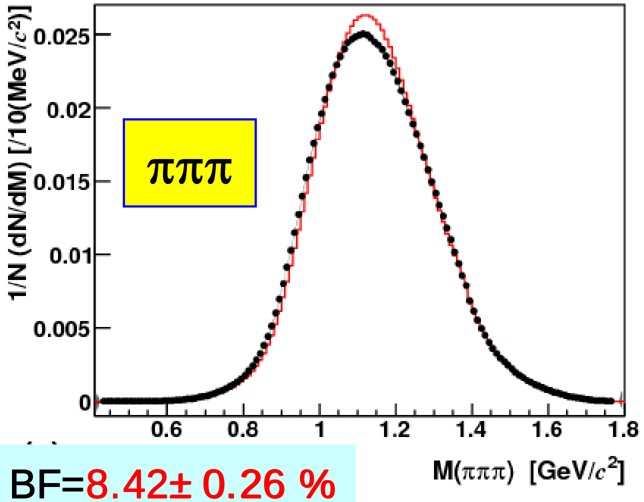
A : Response matrix
x : unfolded spectrum
b : observed spectrum
(with other τ decay BG subtracted)

A^{-1} is obtained from Singular Value Decomposition techniques

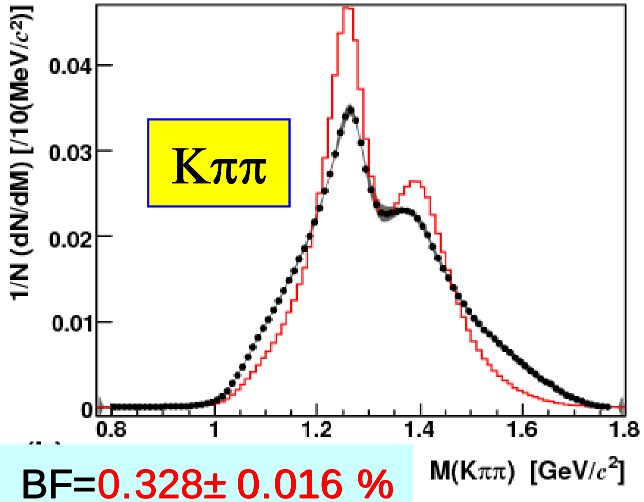


Mass spectra of $\tau^- \to h^- h^+ h^- \nu_\tau$

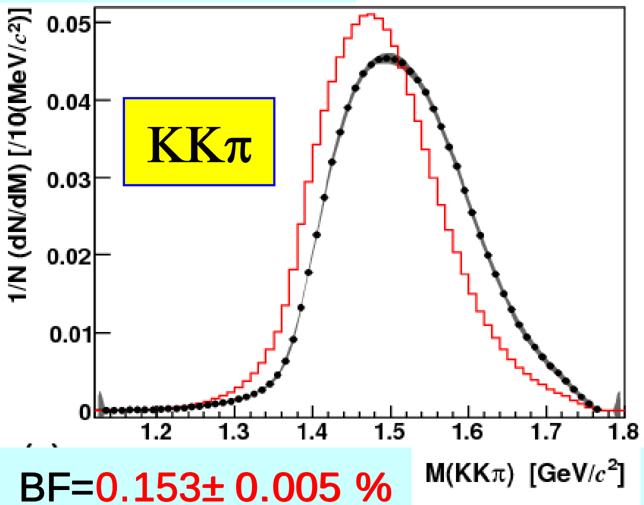
dN/NdM (Normalized distribution)



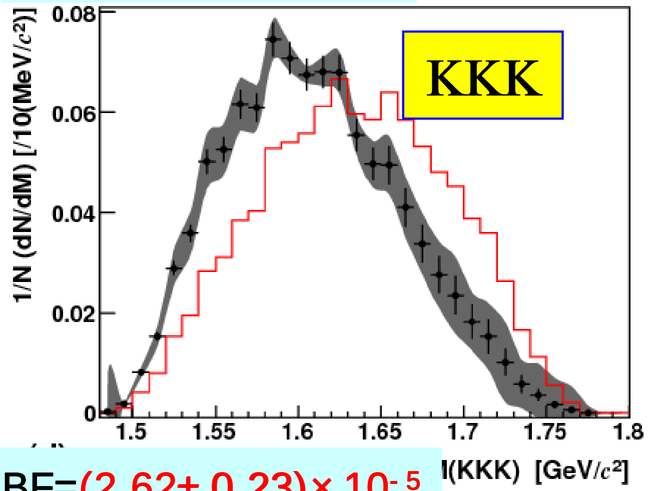
BF=8.42± 0.26 %



BF=0.328± 0.016 %



BF=0.153± 0.005 %



BF=$(2.62\pm 0.23)\times 10^{-5}$

Black point : unfolded spectra + stat. uncert.

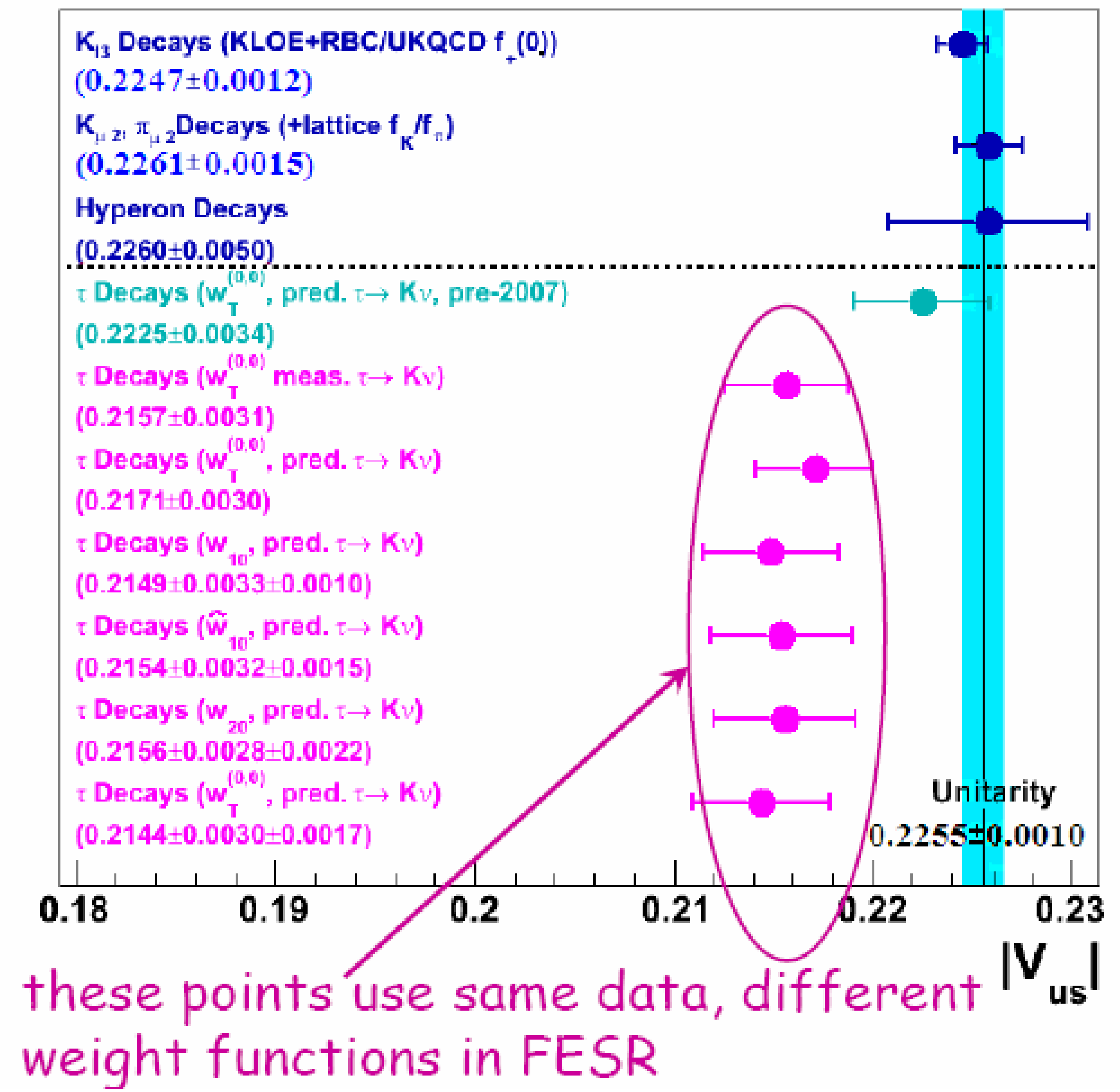
Gray band : syst. uncert.

Red line : MC (TAUOLA) expectations

(normalized to the unfolded dist.)

- First unfolded spectrum for Kππ, KKπ, KKK decays
- Clear differences with theoretical models.
  - Incorrect resonance properties?
  - Incorrect mixing parameter
  - New resonances?
  - Non-resonant decays?

(Semi-)Final V_{us} estimation (BaBar)



(J.Roney, HINT09 (2009, KEK))

Mode	$\mathcal{B}(10^{-3})$
K^-	6.81 ± 0.23
$K^-\pi^0$	4.54 ± 0.30
$\bar{K}^0\pi^-$	8.78 ± 0.38
$K^-\pi^0\pi^0$	0.58 ± 0.24
$\bar{K}^0\pi^-\pi^0$	3.60 ± 0.40
$K^-\pi^+\pi^-$	3.30 ± 0.28
$K^-\eta$	0.27 ± 0.06
$(\bar{K}3\pi)^-$ (estimated)	0.74 ± 0.30
$K_1(1270)^- \to K^-\omega$	0.67 ± 0.21
$(\bar{K}4\pi)^-$ (estimated) and $K^{*-}\eta$	0.40 ± 0.12
Sum	29.69 ± 0.86

- Using the updated BF measurements and PDG avg.
  - Mass spectra are not used
- ~3σ differences with unitarity!

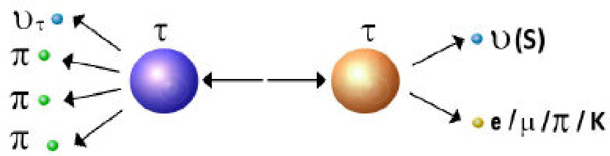
Independent measurement on Vus

$$\frac{\mathcal{B}(\tau \to K\nu)}{\mathcal{B}(\tau \to \pi\nu)} = \frac{f_K^2}{f_\pi^2} \frac{|V_{us}|^2}{|V_{ud}|^2} \frac{(1 - m_K^2/m_\tau^2)^2}{(1 - m_\pi^2/m_\tau^2)^2}$$

- f_K/f_π = 1.189± 0.007 (Lattice QCD)
- Small (~0.03%) theoretical uncertainty can be ignored.
- Use $|V_{ud}|$ = 0.97408± 0.00026 from super-allowed $0^+ \to 0^+$ beta decay

- An independent study has been done by BaBar

$\tau \rightarrow K\nu_\tau$, $\tau \rightarrow \pi\nu_\tau$

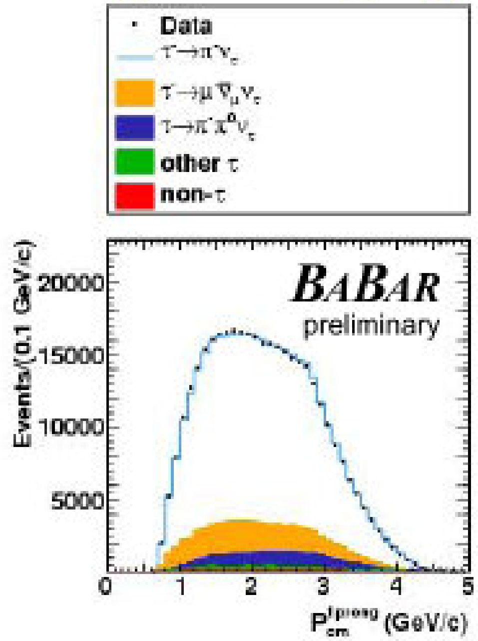


Tagging side
: 3π **(3prong)**

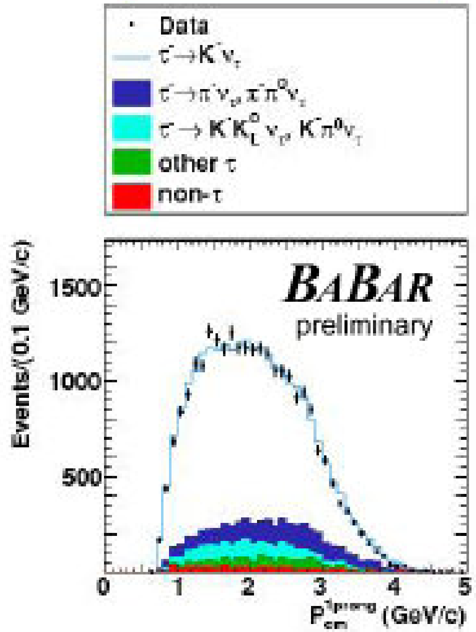
Signal side
: 1- prong

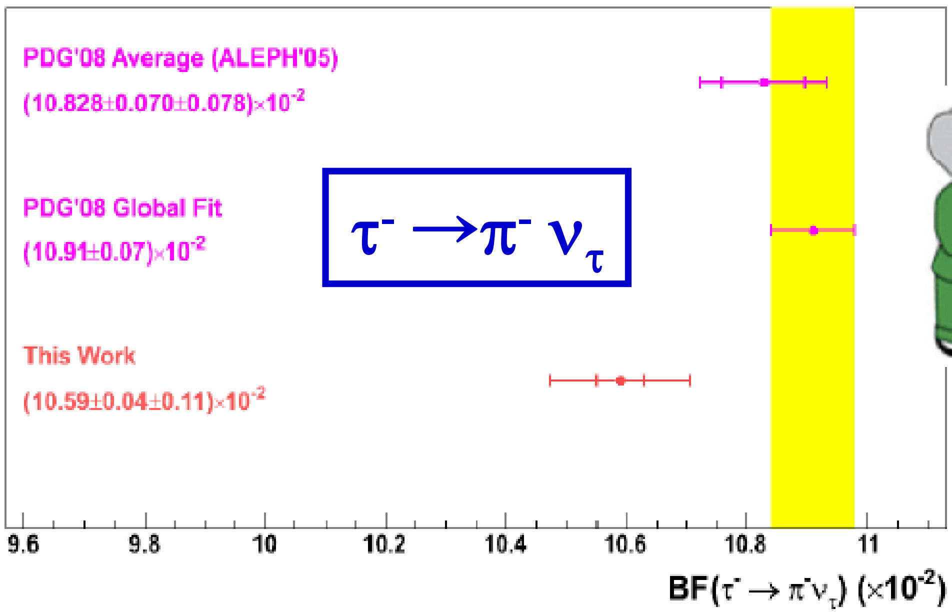
Branching ratios (BaBar, preliminary)	
$B(\tau\rightarrow\pi\nu_\tau)$ / $B(\tau\rightarrow e\nu_\tau\nu_e)$	**(5.945± 0.014± 0.061)x10^{-1}**
$B(\tau\rightarrow K\nu_\tau)$ / $B(\tau\rightarrow e\nu_\tau\nu_e)$	**(3.882± 0.032± 0.056)x10^{-2}**
$B(\tau\rightarrow K\nu_\tau)$ / $B(\tau\rightarrow\pi\nu_\tau)$	**(6.531± 0.056± 0.093)x10^{-2}**

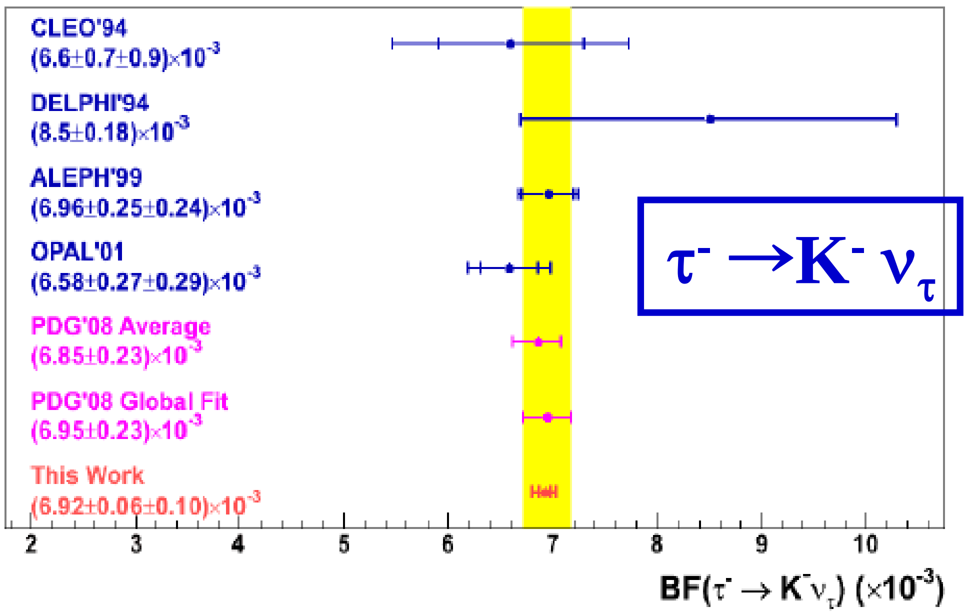
$\tau^- \rightarrow \pi^- \nu_\tau$



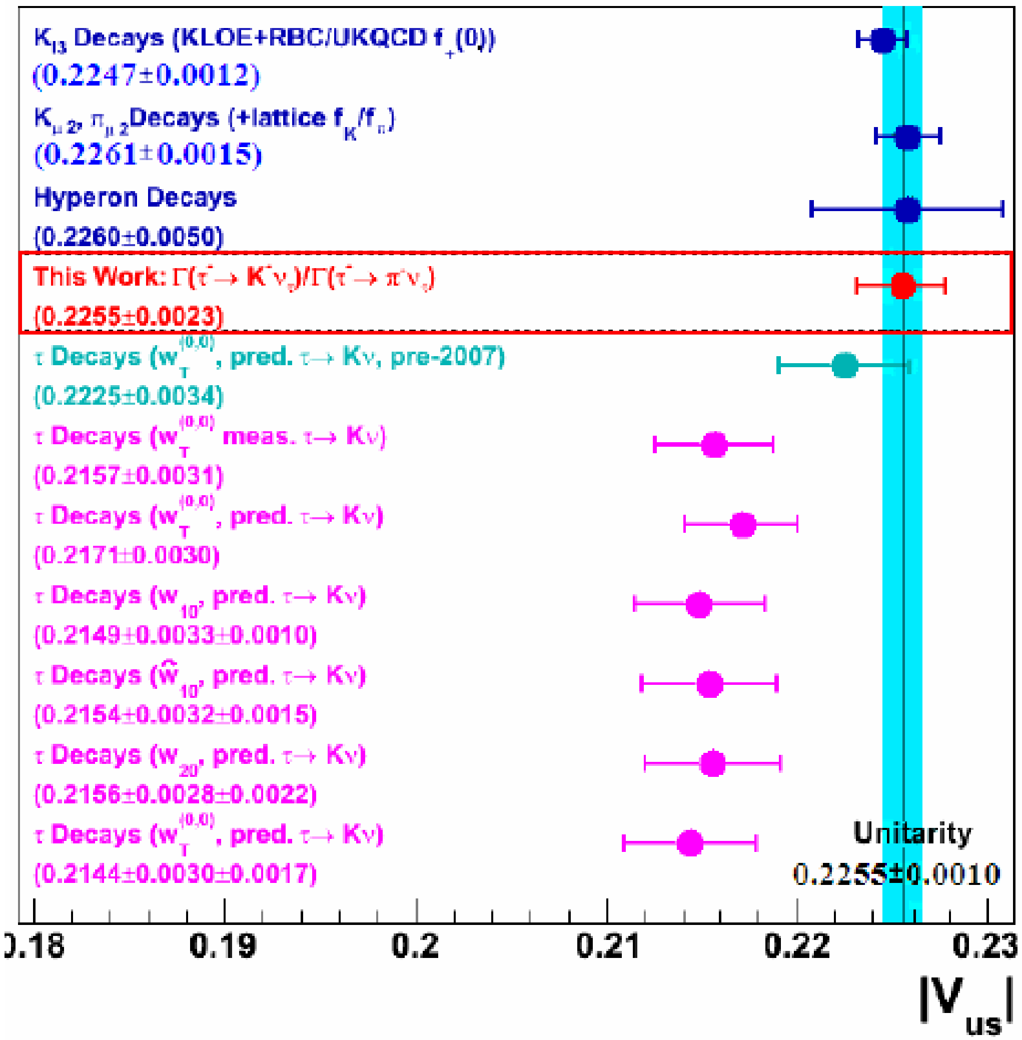
$\tau^- \rightarrow K^- \nu_\tau$







Updated result on V_{us}



M.Roney, HINT09 (2009, KEK)

$|V_{us}|=0.2255\pm 0.0023$

BaBar preliminary

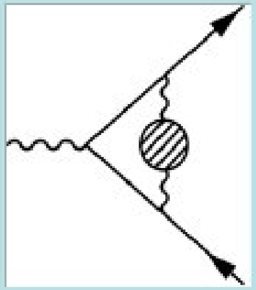
consistent with unitarity.

Summary and conclusion

- B-factory = τ-factory
- Many measurements have been done and are ongoing, specially in hadronic decays of τ
- Recent progress :
  - Second Class Current
    - Can not find any positive signal – SM is still very healthy
  - V_{us} measurement through inclusive measurements on the strange decay of τ
    - Had been an important issue for a few years recently.
    - May be due to the lack of measurements on the strange decay of tau – need more measurements
    - We need simultaneous measurement with m_s – need more studies and (if possible) more statistics.

backups

Hadronic contribution a_{had}



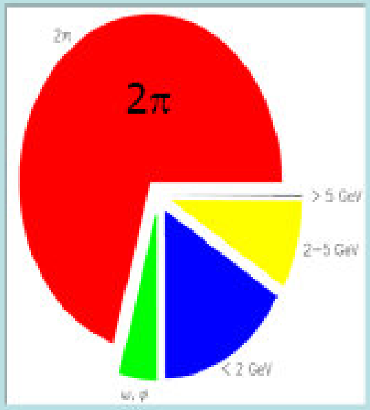
$$a_\mu^{had,LO} = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{4m_\pi^2}^{\infty} ds \frac{R(s)\hat{K}(s)}{s^2}$$

$$R(s) = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}, \quad \sigma_{\mu^+\mu^-} = \frac{85.86nb}{s\left[GeV^2\right]}$$

$\hat{K}$ grows from 0.63 at $s = 4m_\pi^2$ to 1 at $s \to \infty$, $1/s^2$ emphasizes the role of low energies, particularly important is the reaction $e^+e^- \to \pi^+\pi^-$ with a large cross section below 1 GeV.

Central values

Uncertainties

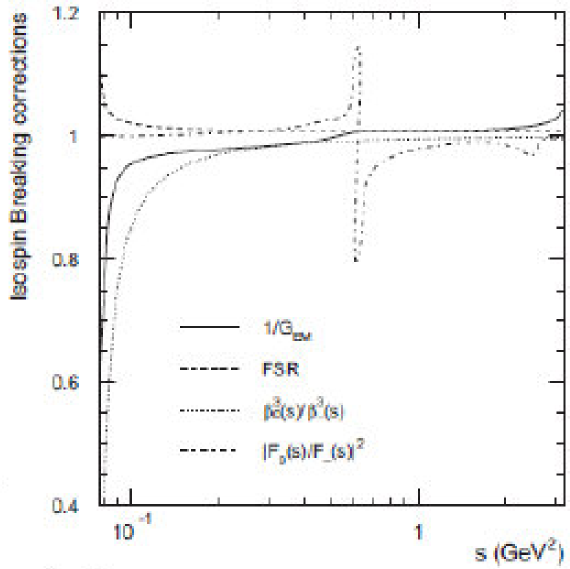


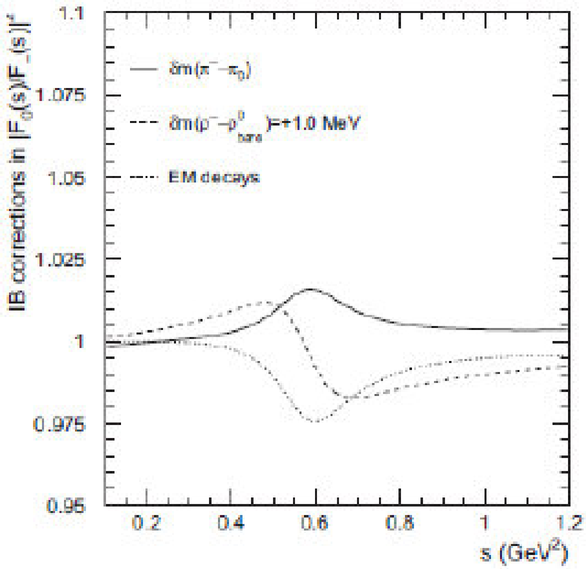
Isospin-breaking corrections

arxiv:0906.5442v2

G.L. Castro,
M. Davier, etc

Other references:
- V. Cirigliano et al., J. High Energy Phys. 08, 002(2002)
- A.Flores-Tlalpa et al., Phys. Rev. D 74, 071301 (2006)





S_{EW}: short distance rad. Cor.

G_{EM}:long distance rad. Cor.

FSR:final state radiation in ee->ππ

π^0 and π- mass difference in the phase sp.

ρ-ω interference

ρ- - ρ^0mass diference

EM decays

Source	$\Delta a_\mu^{\mathrm{had,LO}}[\pi\pi,\tau]$ (10^{-10}) GS model	KS model
S_{EW}	-12.21 ± 0.15	
G_{EM}	-1.92 ± 0.90	
FSR	$+4.67 \pm 0.47$	
ρ–ω interference	$+2.80 \pm 0.19$	$+2.80 \pm 0.15$
$m_{\pi^\pm} - m_{\pi^0}$ effect on σ	-7.88	
$m_{\pi^\pm} - m_{\pi^0}$ effect on Γ_ρ	$+4.09$	$+4.02$
$m_{\rho^\pm} - m_{\rho^0_{\mathrm{bare}}}$	$0.20^{+0.27}_{-0.19}$	$0.11^{+0.19}_{-0.11}$
$\pi\pi\gamma$, electrom. decays	-5.91 ± 0.59	-6.39 ± 0.64
Total	-16.07 ± 1.22	-17.00 ± 1.23
	-16.07 ± 1.53	

$a_\mu^{2\pi}$: 2π contribution to a_μ

Experiment	$a_\mu^{\mathrm{had,LO}}[\pi\pi,\tau]$ (10^{-10})	
	$2m_{\pi^\pm} - 0.36$ GeV	$0.36 - 1.8$ GeV
ALEPH	$9.46 \pm 0.33_{\mathrm{exp}} \pm 0.05_{\mathcal{B}} \pm 0.07_{\mathrm{IB}}$	$499.19 \pm 5.20_{\mathrm{exp}} \pm 2.70_{\mathcal{B}} \pm 1.54_{\mathrm{IB}}$
CLEO	$9.65 \pm 0.42_{\mathrm{exp}} \pm 0.17_{\mathcal{B}} \pm 0.07_{\mathrm{IB}}$	$504.51 \pm 5.36_{\mathrm{exp}} \pm 8.77_{\mathcal{B}} \pm 1.54_{\mathrm{IB}}$
OPAL	$11.31 \pm 0.76_{\mathrm{exp}} \pm 0.15_{\mathcal{B}} \pm 0.07_{\mathrm{IB}}$	$515.56 \pm 9.98_{\mathrm{exp}} \pm 6.95_{\mathcal{B}} \pm 1.54_{\mathrm{IB}}$
Belle	$9.74 \pm 0.28_{\mathrm{exp}} \pm 0.15_{\mathcal{B}} \pm 0.07_{\mathrm{IB}}$	$503.95 \pm 1.90_{\mathrm{exp}} \pm 7.84_{\mathcal{B}} \pm 1.54_{\mathrm{IB}}$
Combined	$9.76 \pm 0.14_{\mathrm{exp}} \pm 0.04_{\mathcal{B}} \pm 0.07_{\mathrm{IB}}$	$505.46 \pm 1.97_{\mathrm{exp}} \pm 2.19_{\mathcal{B}} \pm 1.54_{\mathrm{IB}}$

Integrated from 2π threshold to 1.8GeV

Smallest experimental error for Belle !

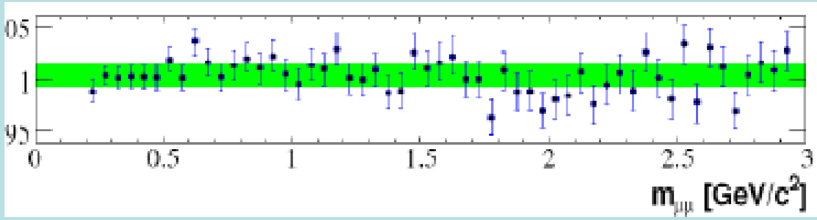
τ : $a_\mu^{\pi\pi} = (514.1 \pm 3.2)\mathrm{x}10^{-10}$

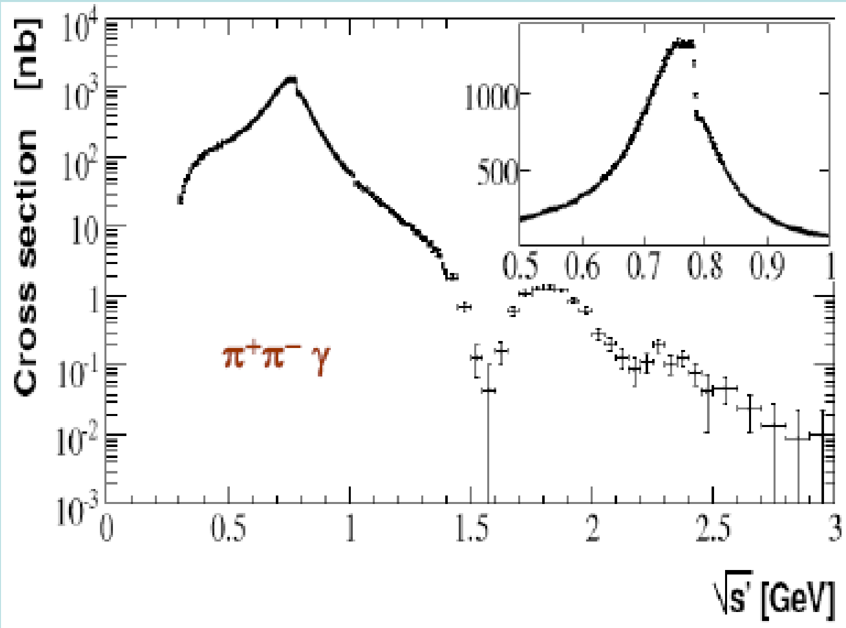
e^+e^- (CMD,SND,KLOE) $a_\mu^{\pi\pi} = (503.5 \pm 3.5)\mathrm{x}10^{-10}$

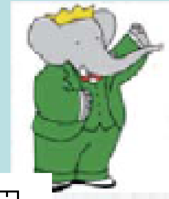
There is a difference btw τ and e^+e^-

$e^+e^- \rightarrow \pi^+\pi^- \gamma$ (first presented at LP09)

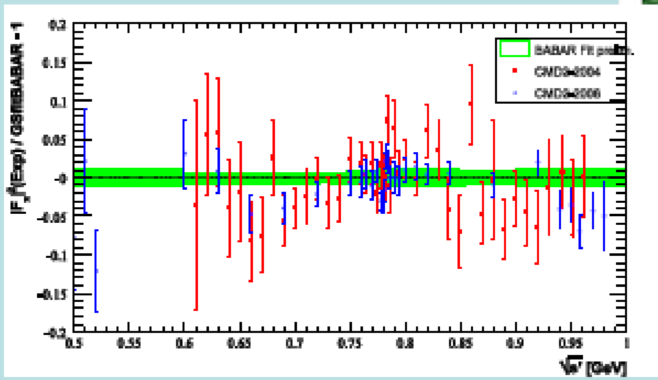
$\mu^+\mu^-\gamma$ - exp/QED



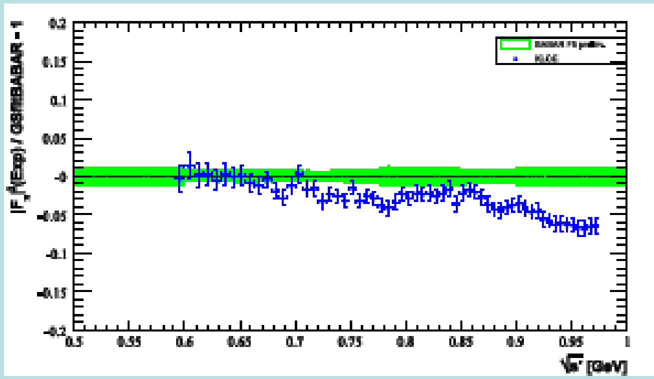




CMD2 vs Babar



KLOE vs Babar



Babar collab.arxiv:0908.3589

Computing $a_\mu^{\pi\pi}$

$$\frac{\sigma_{\mu\mu\gamma}^{data}}{\sigma_{\mu\mu\gamma}^{NLO\ QED}} = 1 + (4.0 \pm 2.0 \pm 5.5 \pm 9.4) \times 10^{-3}$$

From $\pi^+\pi^-$ threshold to 1.8 GeV

$$a_\mu^{\pi\pi(\gamma)} = (514.1 \pm 2.2 \pm 3.1) \times 10^{-10}$$

Previous e^+e^- data: $(502.8 \pm 3.2) \times 10^{-10}$

updated value from $\tau^- \to \pi^-\pi^0\nu_\tau$: $(514.3 \pm 3.0) \times 10^{-10}$

M.Davier et al., arXiv:0906.5443v1 (hep-ph)

According to these results $\Delta a_{\mu,hadr}$ reduces to $\sim 2\sigma$