$|V_{us}|$ and Charge Lepton Universality from τ Decays

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On behalf of BaBar & Belle Collaborations

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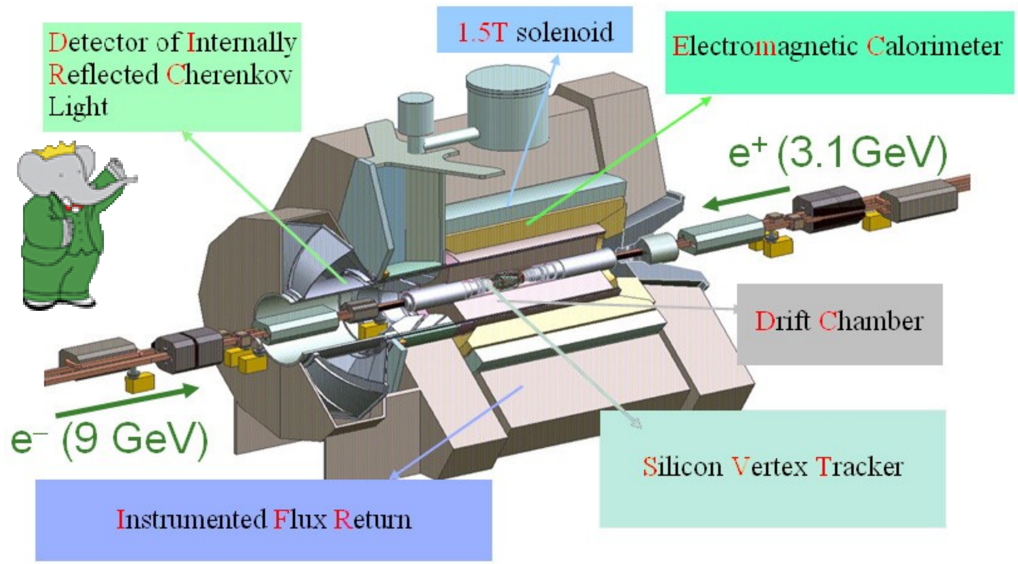
BELLE

University of Victoria | British Columbia Canada

BABAR

BaBar & BELLE Experiments



Asymmetric Detectors

-Good Vertexing

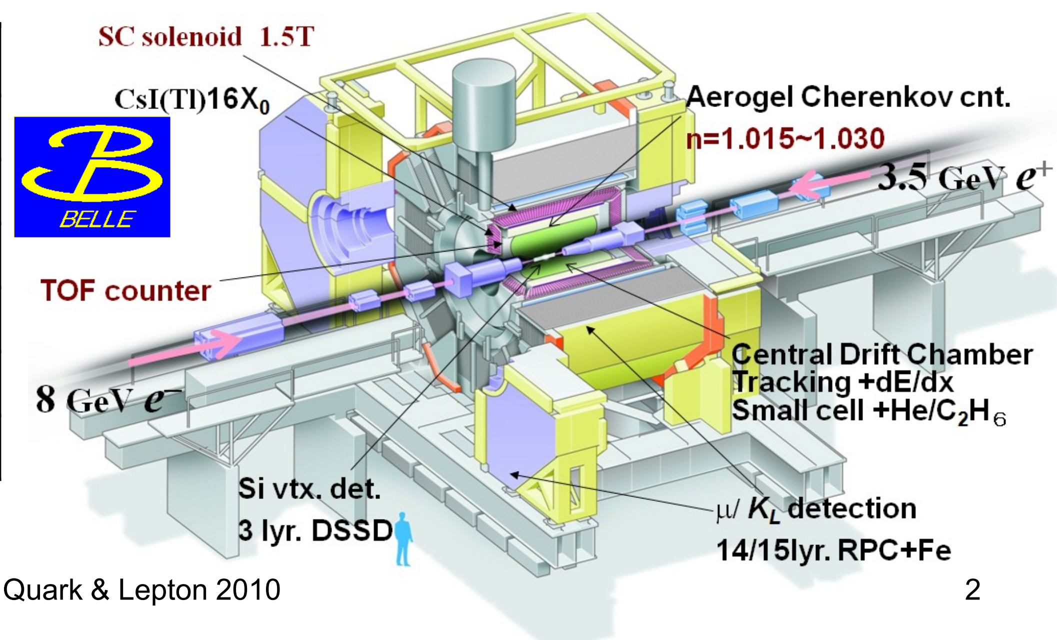
-Good K/π Separation

-Good e,μ Identification

-Good γ Detection/Resolution

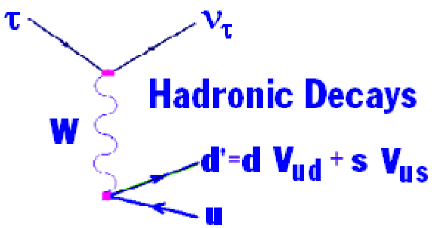
High Luminosity.....

Decay Mode	Cross-Section (nb)
$\Upsilon(4s)\rightarrow B\overline{B}$	1.1
τ Pair	0.919±0.003
$q\overline{q}$ q=u,d,s,c	3.4
μ Pair	1.147±0.005
Two-Photon (Barrel)	2.4
Bhabha (Barrel)	25.52

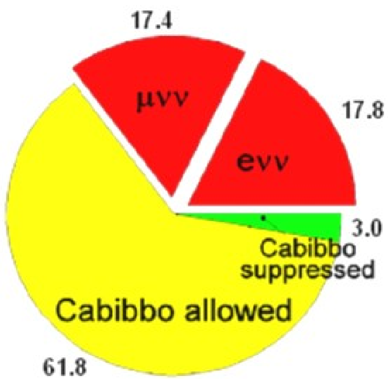


Strange τ Decays

$$B_{had} = 1 - B_e - B_\mu$$



$$R_{\tau,Strange} = R_\tau - R_{\tau,non-Strange}$$



Decay Mode	BF (%)	Belle	BaBar
K^-	0.697±0.010		PRL 105, 051602 (2010)
$K^-\pi^0$	0.431±0.015		PRD-RC 76, 051104 (2007)
$K^-\pi^0\pi^0$ (ex. K^0)	0.060±0.022		
$K^-\pi^0\pi^0\pi^0$ (ex. K^0,η)	0.039±0.022		
$K^0\pi^-$	0.831±0.018	PLB 654, 65 (2007)	Prelim Nucl.Phys.Proc.Suppl.189 (2009)
$K^0\pi^-\pi^0$	0.350±0.015		Prelim arXiv:0910.2884 [hep-ex]
$K^0\pi^-\pi^0\pi^0$	0.031±0.023		
$K^0h^-h^+h^-$	0.029±0.020		
$K^-\pi^-\pi^+$ (ex. K^0)	0.294±0.007	PLB 672, 209 (2009)	PRL 100, 011801 (2008)
$K^-\pi^-\pi^+\pi^0$ (ex. K^0,η)	0.078±0.012		
$K^-\eta$	0.016±0.001	PLB 672, 209 (2009)	
$K^-\eta\ \pi^0$	0.005±0.001	PLB 672, 209 (2009)	
$K^0\eta\ \pi^-$	0.009±0.001	PLB 672, 209 (2009)	
$K^-K^+K^-$	0.0024±0.0008	PLB 643, 5-10 (2006)	PRL 100, 011801 (2008)
$K^-K^0K^0$	0.0015±0.0001	estimated from $K^-K^+K^-$ ($\tau^-\to K^-\phi\nu$ saturates $\tau^-\to K^-K^+K^-\nu$)	
Total	**2.9155±0.0510**	**Error depends on correlations**	

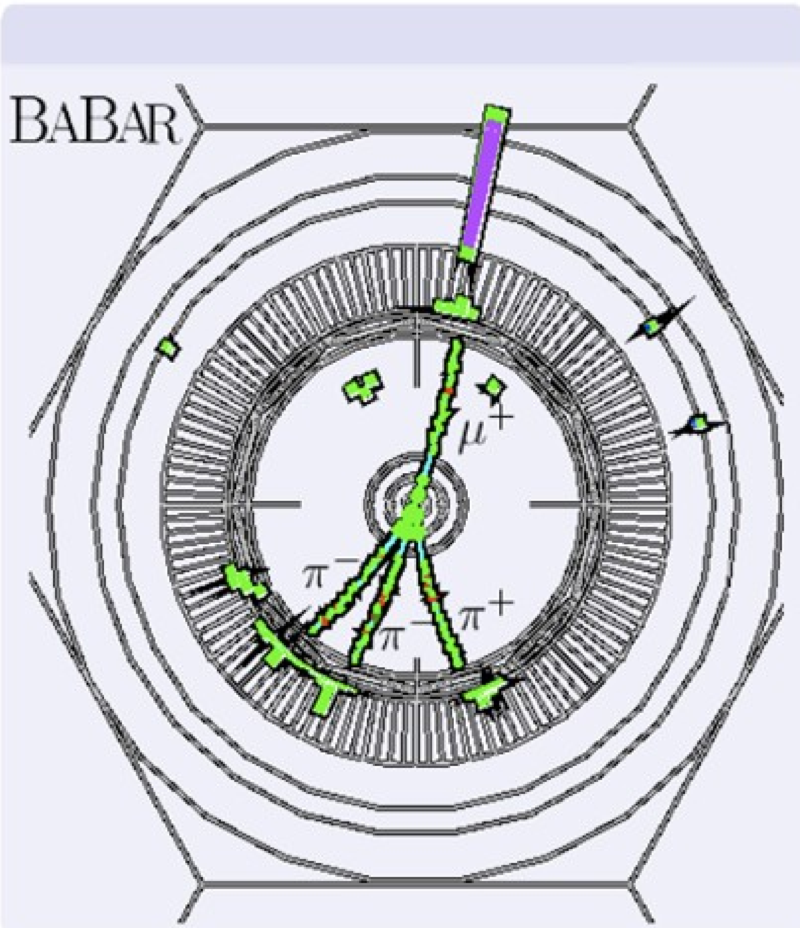
BF from HFAG constrained fit χ^2/d.o.f=135.2/115 CL=9.6% **HFAG: arXiv:1010.1589**

Cross Section at $\Upsilon(4s)$
$\sigma(\tau^+\tau^-)$=(0.919±0.003)nb
Phys. Rev. D 77, 054012 (2008)

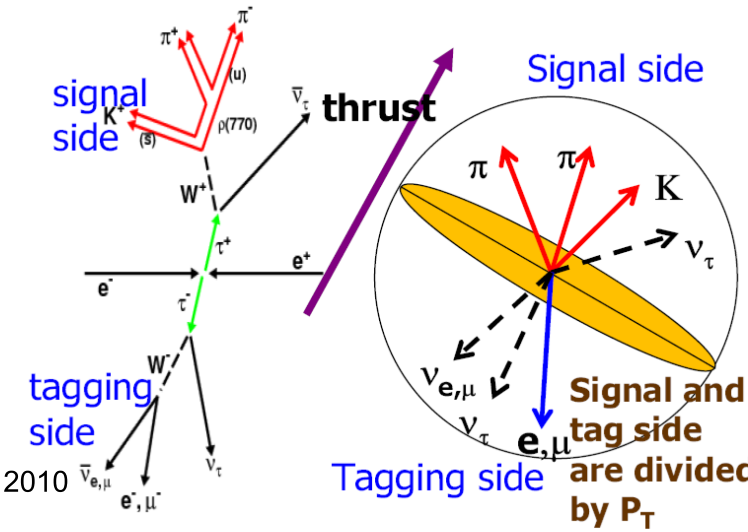
Belle	**$\mathcal{L}$=1ab^{-1}**	**⇒~10x10^8 τ Pairs**
BaBar	**$\mathcal{L}$=531fb^{-1}**	**⇒~5x10^8 τ Pairs**

Hadronic τ Decays at B-Factories

τ-Pair Signature:
Leptonic+Hadronic Decay

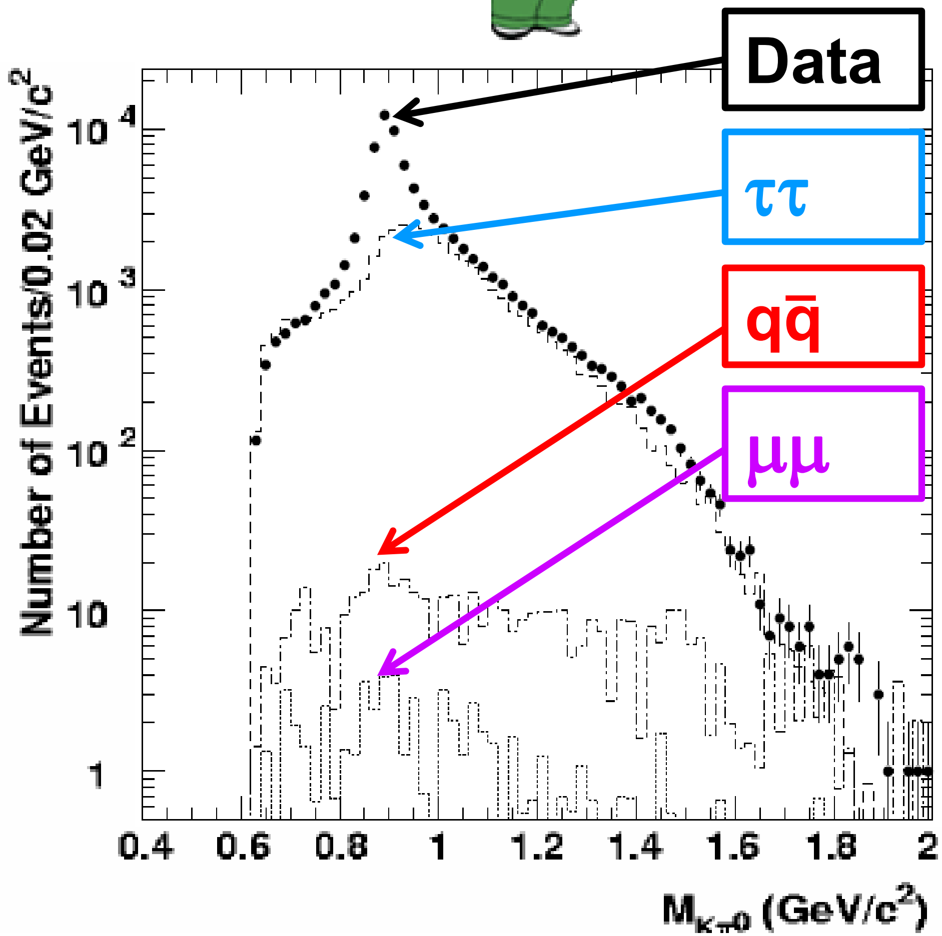


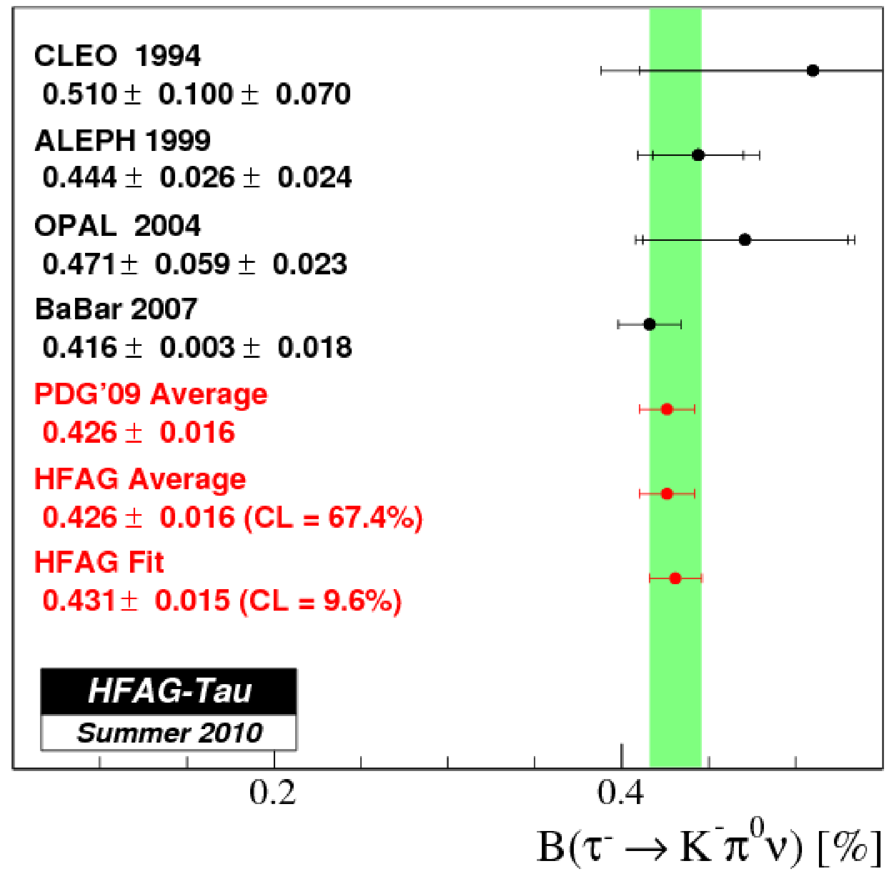
Backgrounds	Discriminates
Bhabha, di-muons	Lepton Momentum Multiplicity Conversion veto $\cos(\theta)$
Two-Photon	Missing Transverse Momentum Missing Mass $\cos(\theta^{Miss})$ Thrust Total Reconstructed Energy
$e^+e^- \to qq$ q=u,d,s,c,b	Thrust Invariant mass Multiplicity
Other τ decays	K/π separation Neutral Identification: π^0,η,γ



$\tau \rightarrow K^- \pi^0 \nu$

BaBar-PRD 76:051104 (2007)

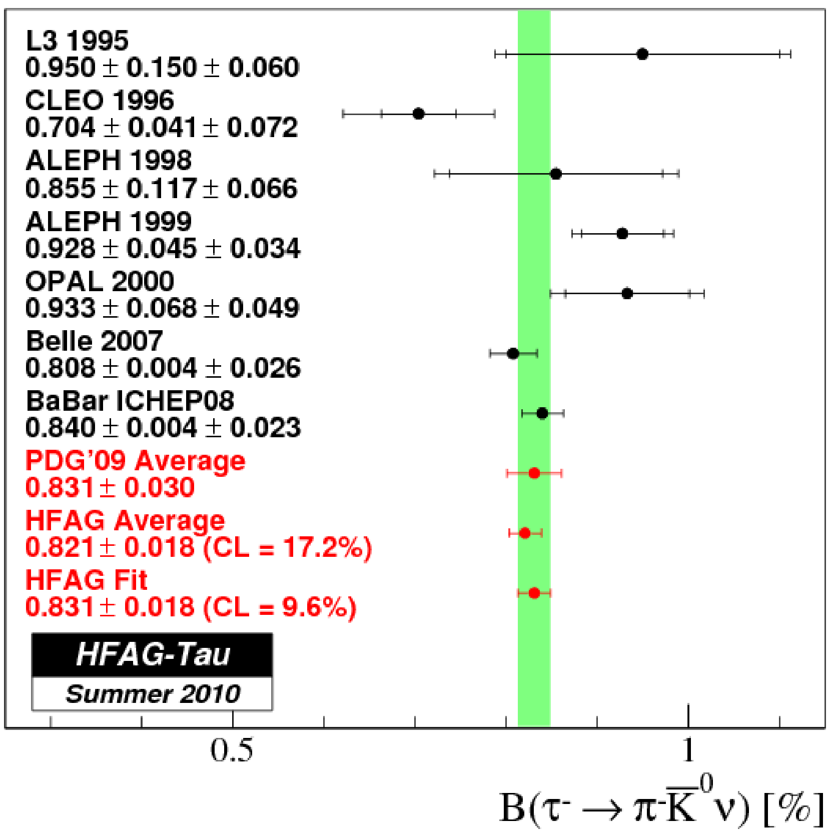


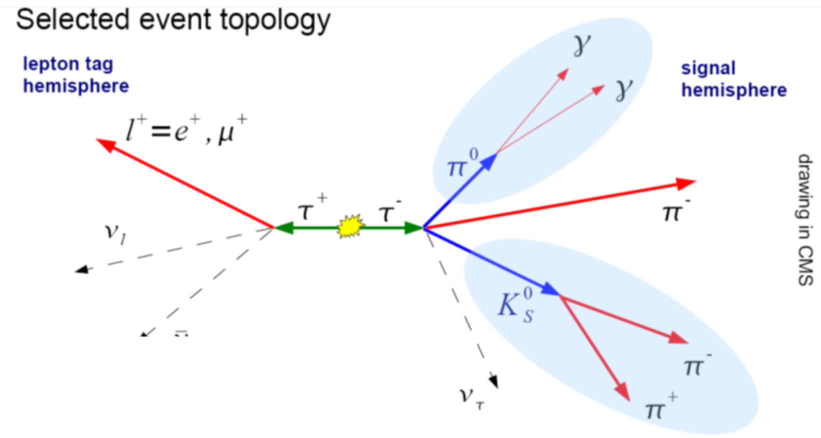


$\tau \to K_S^0 \pi^- \nu$ and $\tau \to K_S^0 \pi^- \pi^0 \nu$

Belle-PLB 654, 65 (2007)

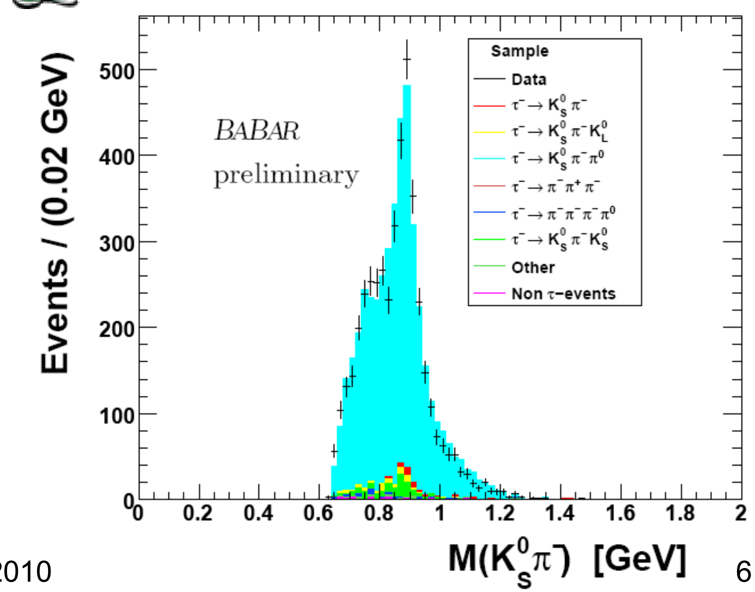
BaBar-prelim
Nucl.Phys.Proc.Suppl.189 (2009)



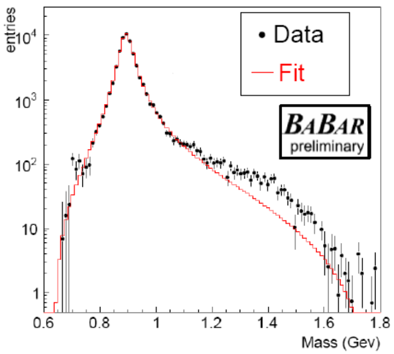


$B(\tau \to K_S^0 \pi^- \pi^0 \nu) = [0.342 \pm 0.006 \pm 0.015]\%$

BaBar-prelim arXiv:0910.2884 [hep-ex]



$\tau \rightarrow K_S^0 \pi^- \nu$



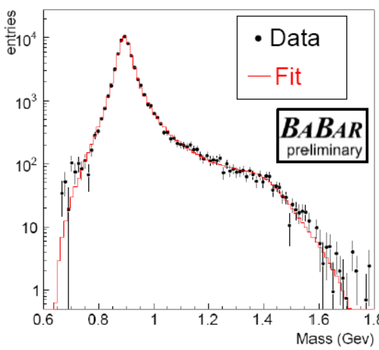
Fit model:

K*(892)

Mass(K*(892))=894.54±0.17±0.19MeV
Width(K*(892))=47.67±0.44±0.57MeV

$\chi^2/ndf = 399.8/97$

$Prob. < 0.0001$



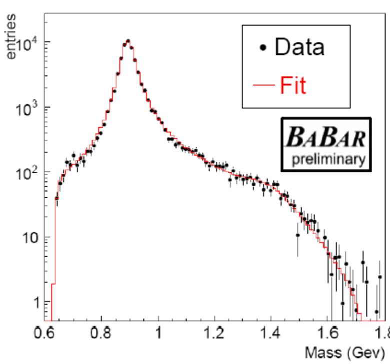
Fit model:

K*(892) + K*(1410)

Mass(K*(892))=894.41±0.19±0.19MeV
Width(K*(892))=46.21±0.46±0.57MeV

$\chi^2/ndf = 130.0/95$

$Prob. = 0.0098$



K*(800) mass and width from BES collaboration (Phys.Lett.B633:681-690,2006)

Fit model:

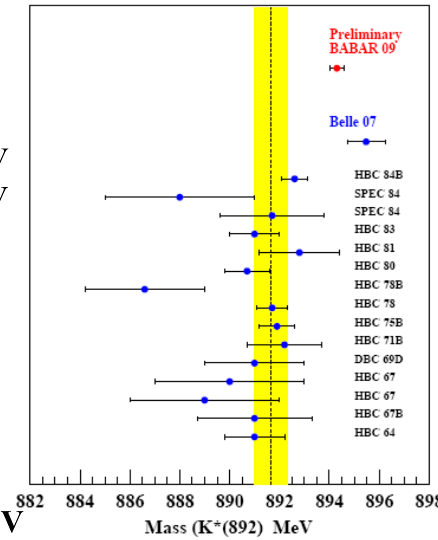
K*(892) + K*(1410) + K*(800)

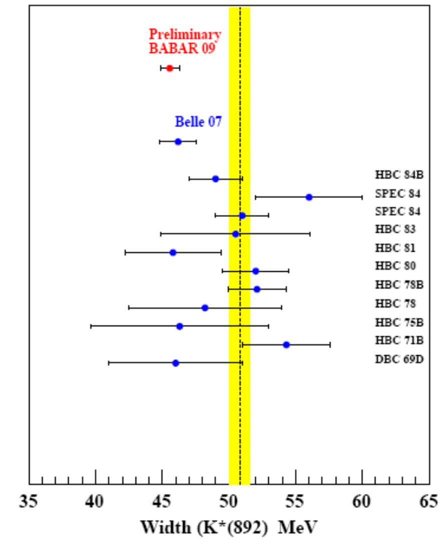
Mass(K*(892))=894.57±0.19±0.19MeV
Width(K*(892))=45.89±0.43±0.57MeV

$\chi^2/ndf = 113.0/94$

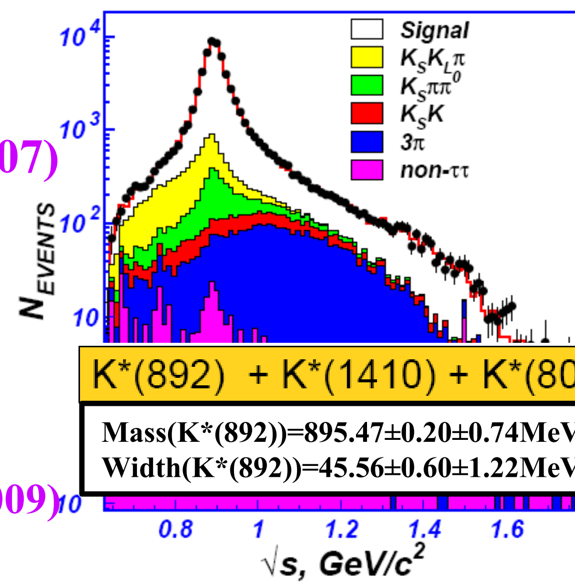
$Prob. = 0.0880$

Best fit





Belle-PLB 654, 65 (2007)



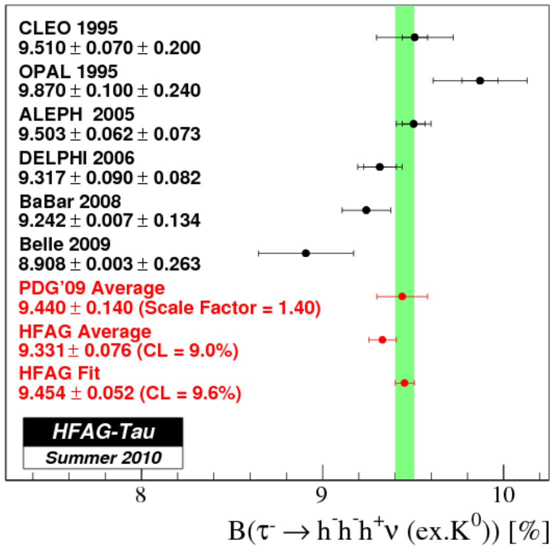
K*(892) + K*(1410) + K*(800)

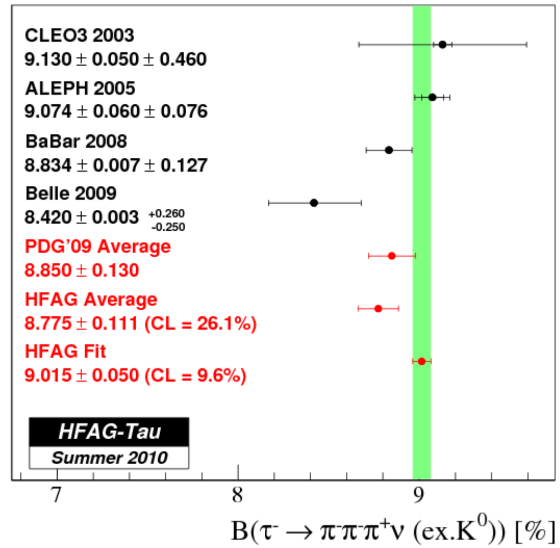
Mass(K*(892))=895.47±0.20±0.74MeV
Width(K*(892))=45.56±0.60±1.22MeV

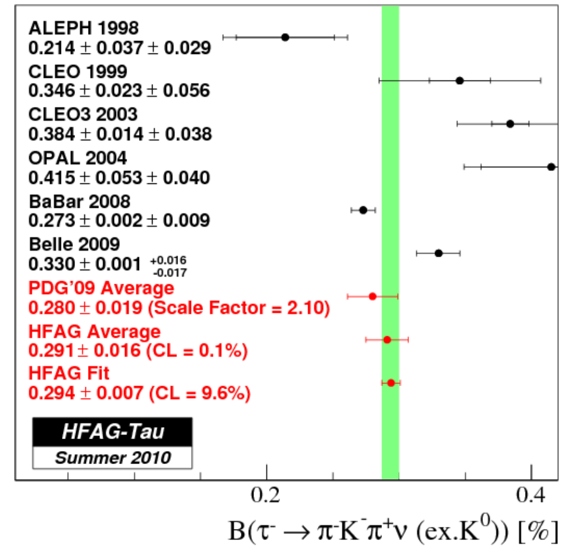
BaBar-prelim

Nucl.Phys.Proc.Suppl.189 (2009)

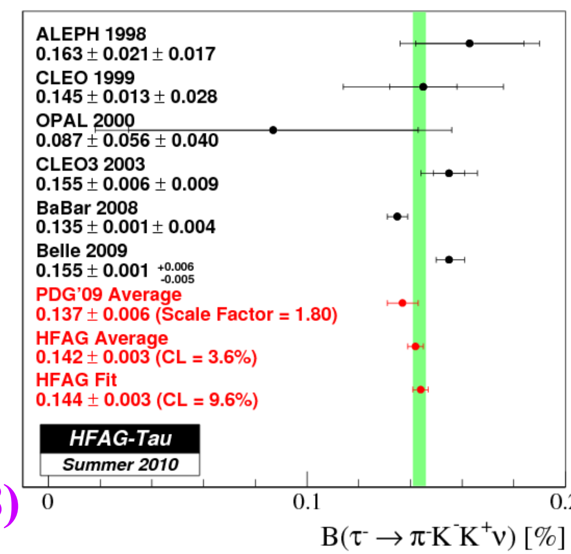
$\tau \to K^- \pi^- \pi^+ \nu$ and $\tau \to K^- K^- K^+ \nu$

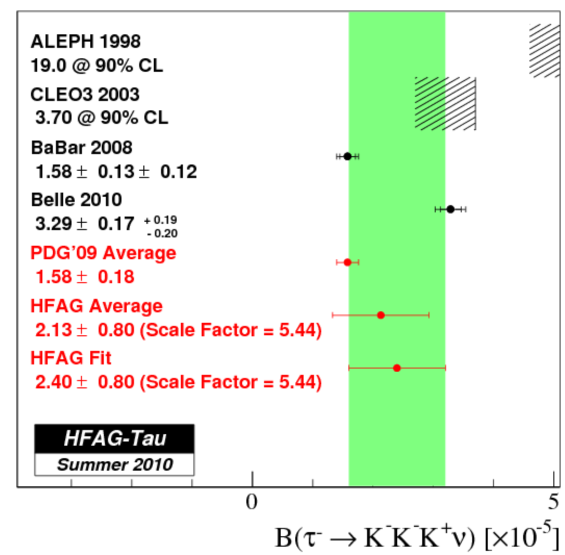






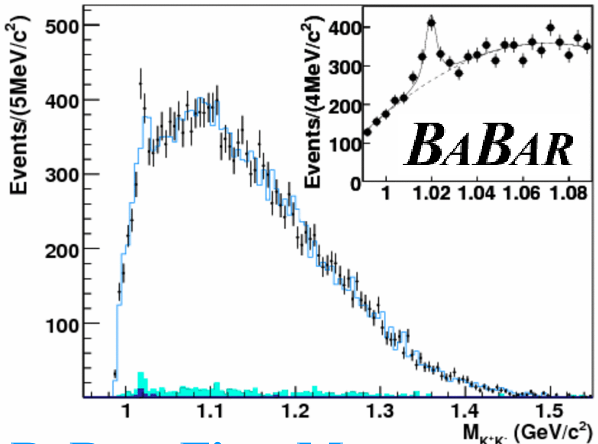
Belle-PLB 672, 209 (2009)





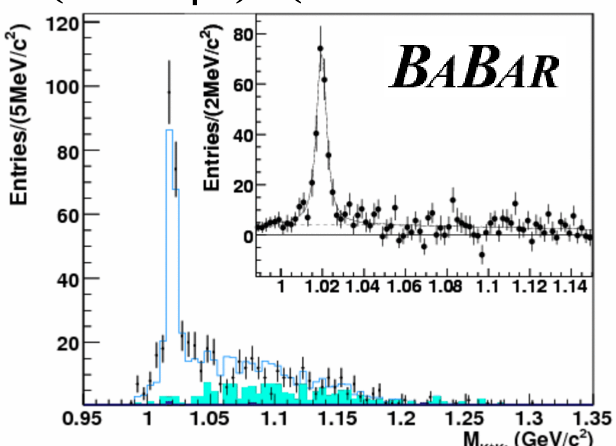
BaBar-PRL100, 011801 (2008)

$\tau \to K^- K^- K^+ \nu$ and $\tau \to K^- \phi \nu$



BaBar: First Measurement

$B(\tau \to \pi^- \phi \nu) = (3.42 \pm 0.55 \pm 0.25) \times 10^{-5}$

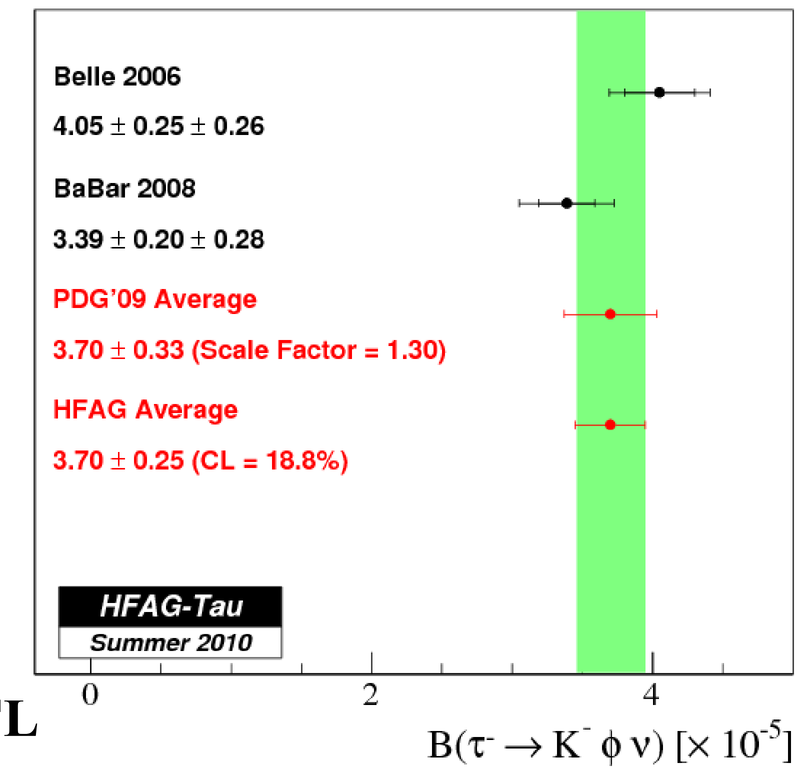


BaBar: Upper Limit

$B(\tau \to K^- K^- K^+ \nu[\text{ex. } \phi]) < 0.25 \times 10^{-5}$ @ 90% CL

Belle-Phys.Lett.B643:5-10,2006

BaBar-PRL100, 011801 (2008)



$\tau \rightarrow K^- \pi^- \pi^+ \nu$ and $\tau \rightarrow K^- K^- K^+ \nu$

$$\sum_i A_{ij} x_i = b_j$$

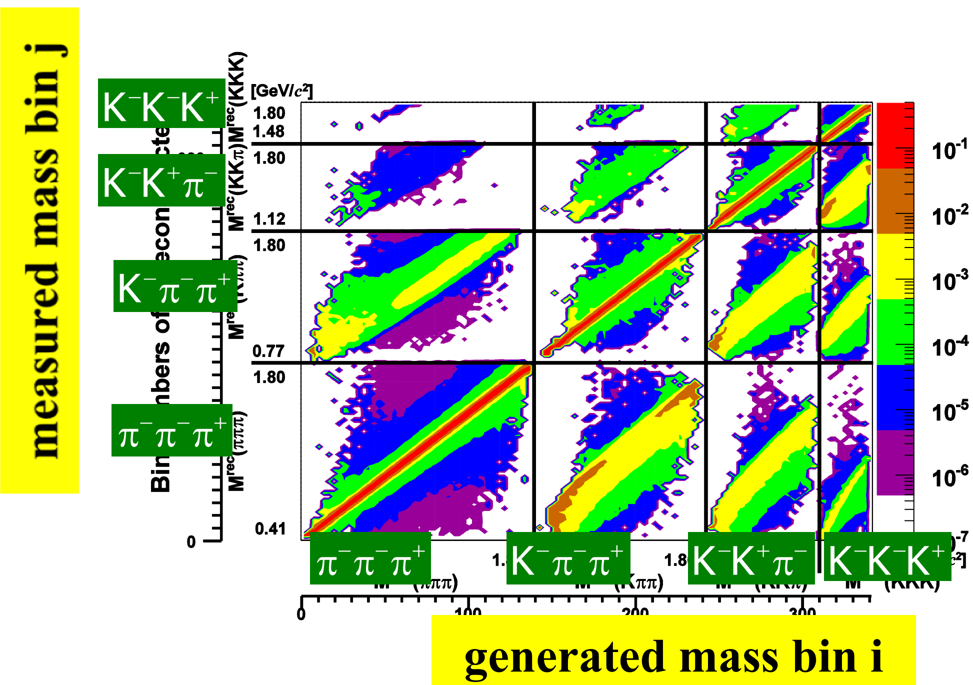
Belle-PLB 672, 209 (2009)

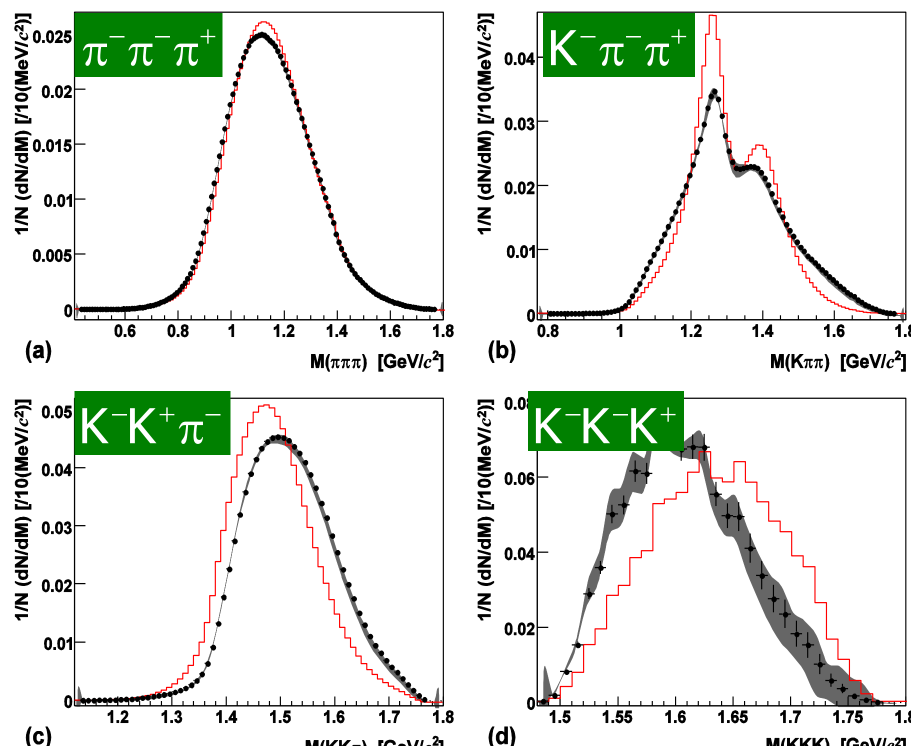
Grey line: Unfolded spectrum

Histogram: Tauola

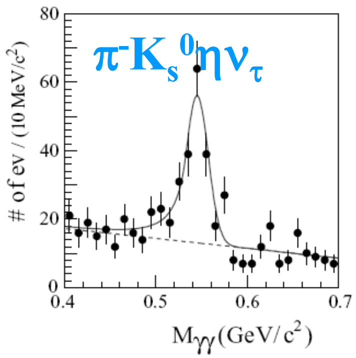
The inverse of A is obtained by **Singular Value Decomposition** Technique.

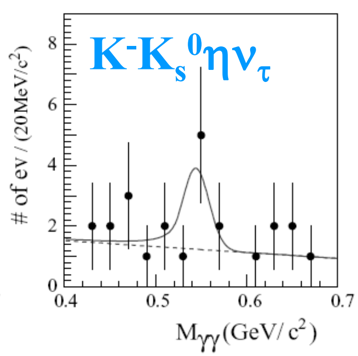
A_{ij} : Response matrix
X_i : Unfolded spectrum
b_j : Observed spectrum

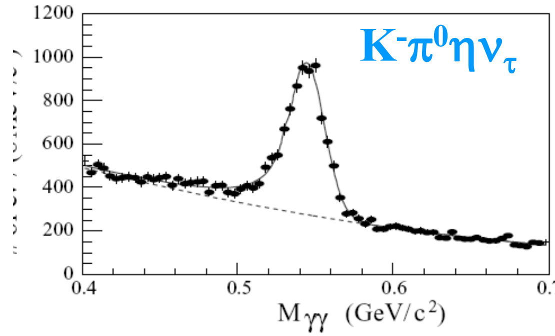


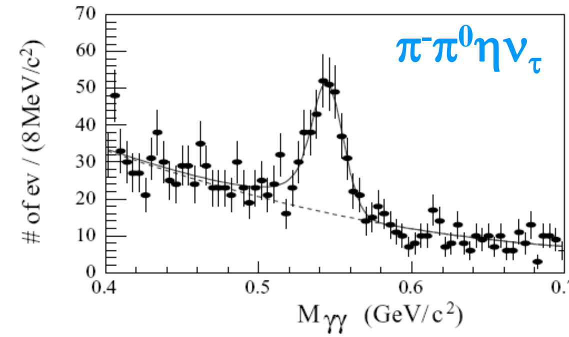


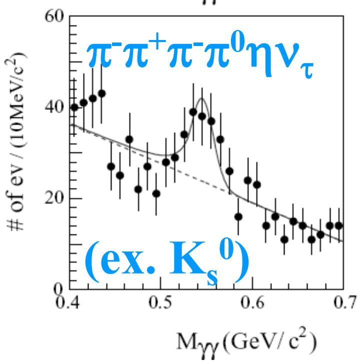
Strange τ Decays with a η

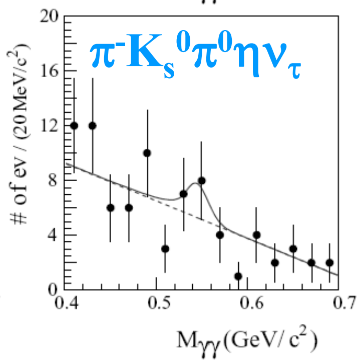


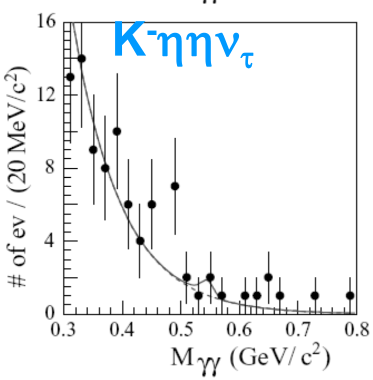


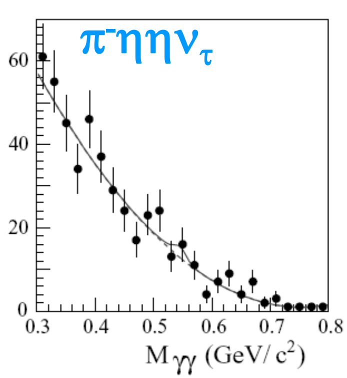








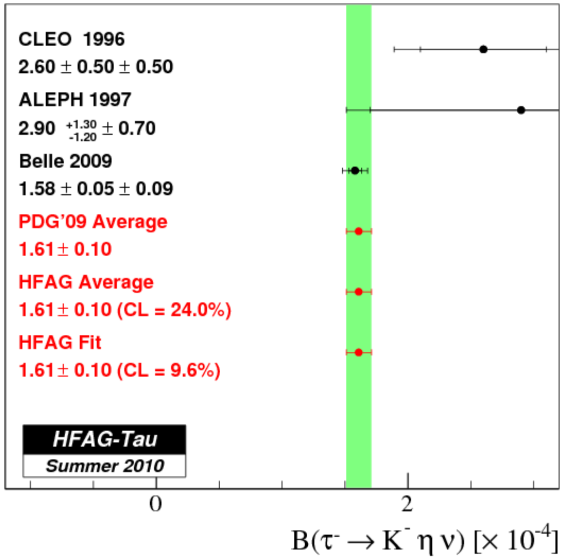


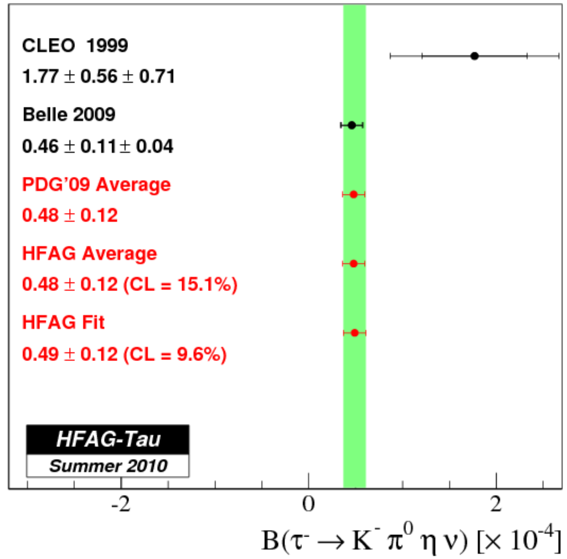


Belle-Phys. Lett. B672, 209 (2009)

Decay Mode	BF (10^{-4})
$\pi^- \pi^0 \eta \nu_\tau$	13.5±0.3 ±0.7
$K^- \eta \nu_\tau$	1.58 ±0.05 ±0.09
$K^- \pi^0 \eta \nu_\tau$	0.46 ±0.11 ±0.04
$\pi^- K_s^0 \eta \nu_\tau$	0.44 ±0.07 ±0.03
$K^{*-} \eta \nu_\tau$	1.34 ±0.12 ±0.09
$\pi^- K_s^0 \pi^0 \eta \nu_\tau$	<0.25 @90%CL
$\pi^- \eta\eta \nu_\tau$	<0.074 @90%CL
$K^- K_s^0 \pi^0 \eta \nu_\tau$	<0.045 @90%CL
$K^- \eta\eta \nu_\tau$	<0.03 @90%CL

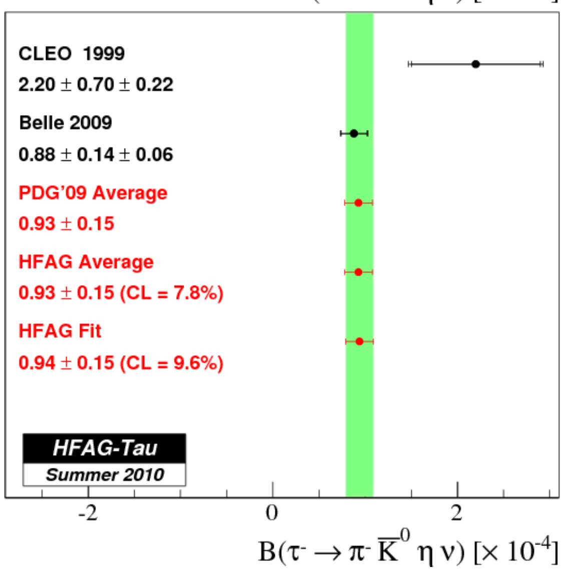
Strange τ Decays with a η

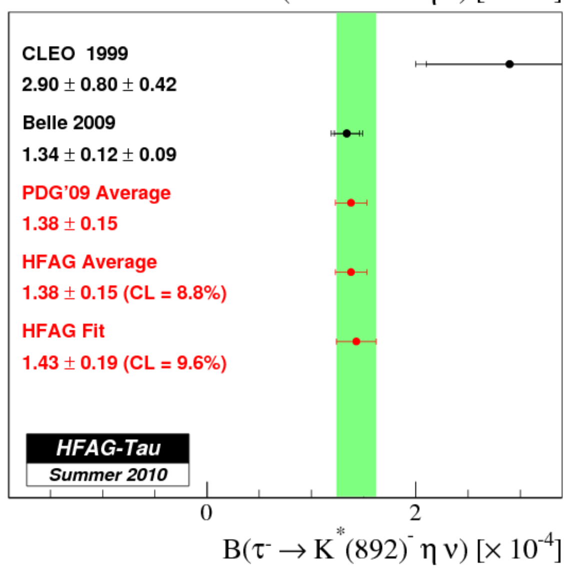




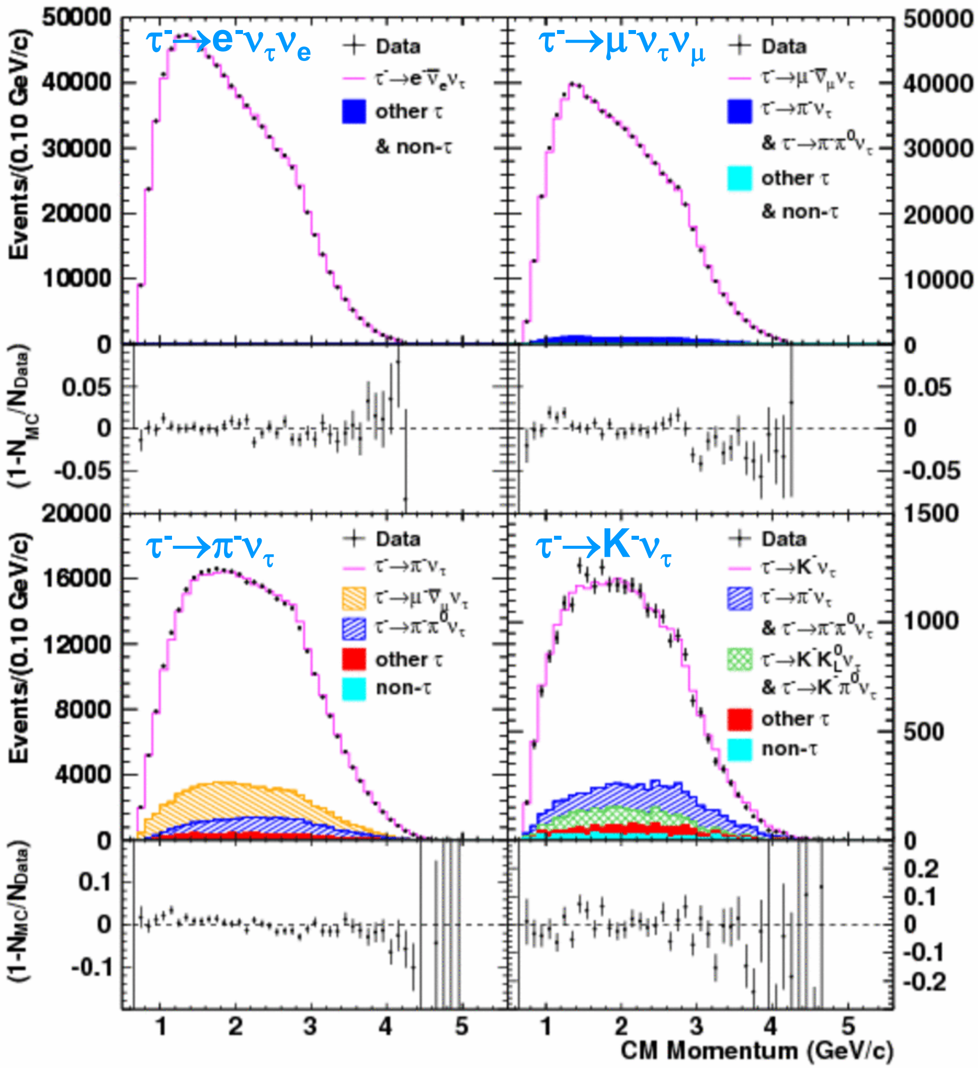
Belle

Phys. Lett. B672, 209 (2009)





1 Prong τ Decays

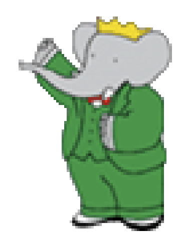


BaBar-Phys. Rev. Lett. 105:051602, 2010

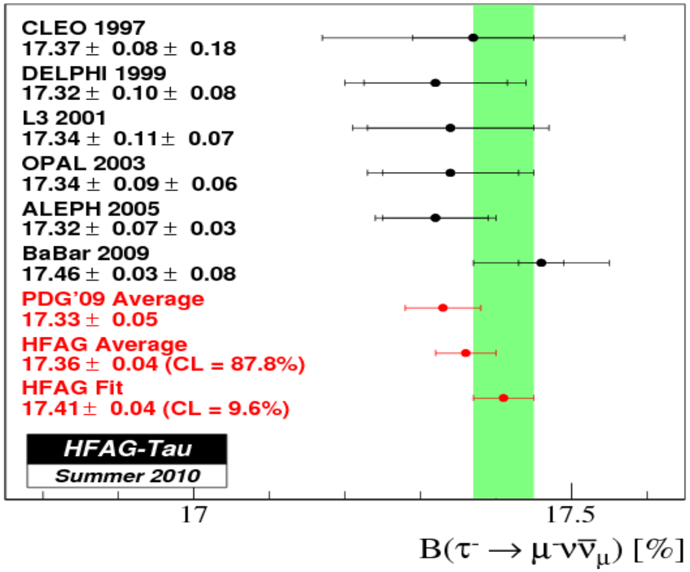
$$R_X = \frac{B(\tau^- \to X^- \upsilon_\tau)}{B(\tau^- \to e^- \overline{\upsilon_e} \upsilon_\tau)}$$

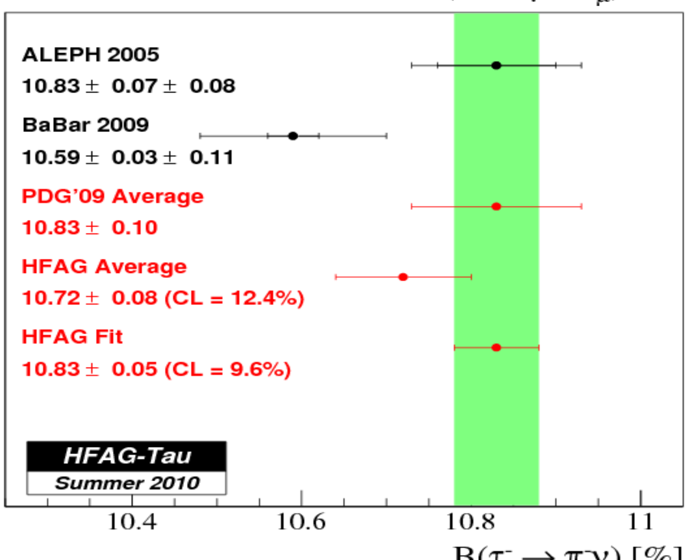
R_μ = 0.9796 ± 0.0016 ± 0.0036
R_π = 0.5945 ± 0.0014 ± 0.0061
R_K = 0.03882 ± 0.00032 ± 0.00057

<u>Major Systematic Uncertainties:</u>
Particle ID
Detector Response
Backgrounds



1 Prong τ Decay

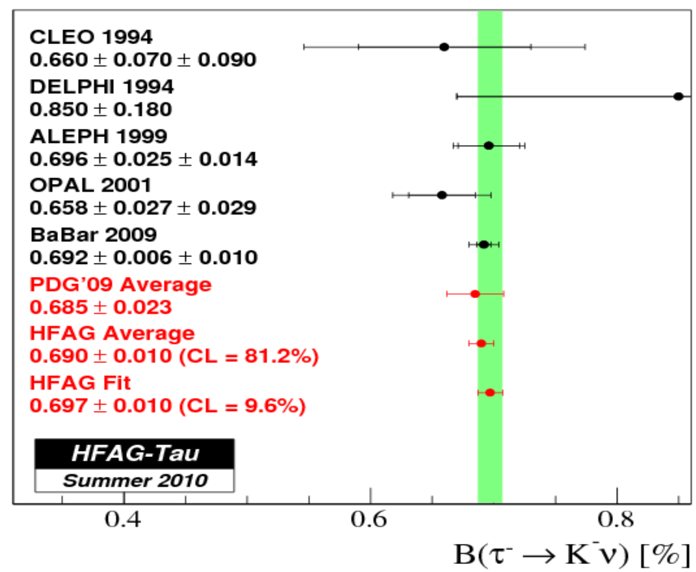




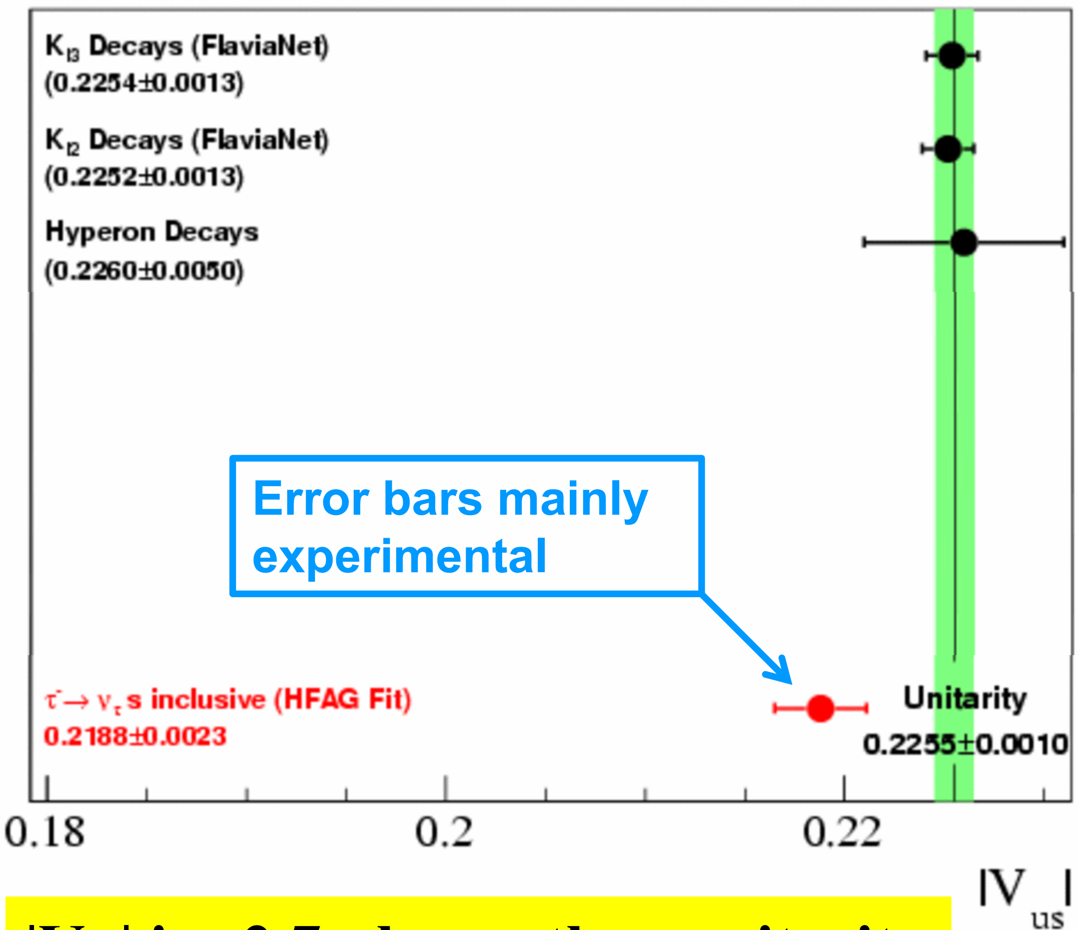
BaBar

Phys. Rev. Lett. 105:051602, 2010

Branching fraction based on:
$B(\tau^- \rightarrow e^- \nu_\tau \nu_e) = (17.82 \pm 0.05)\%$
PDG2008



$|V_{us}|$ from τ's using FESR



$|V_{us}|$ is ~2.7σ lower than unitarity

$$R_\tau = \frac{\Gamma\left(\tau^- \to hadrons^- \nu_\tau(\gamma)\right)}{\Gamma\left(\tau^- \to e^- \bar{\nu}_e \nu_\tau(\gamma)\right)} = R_{\tau,non-strange} + R_{\tau,strange}$$

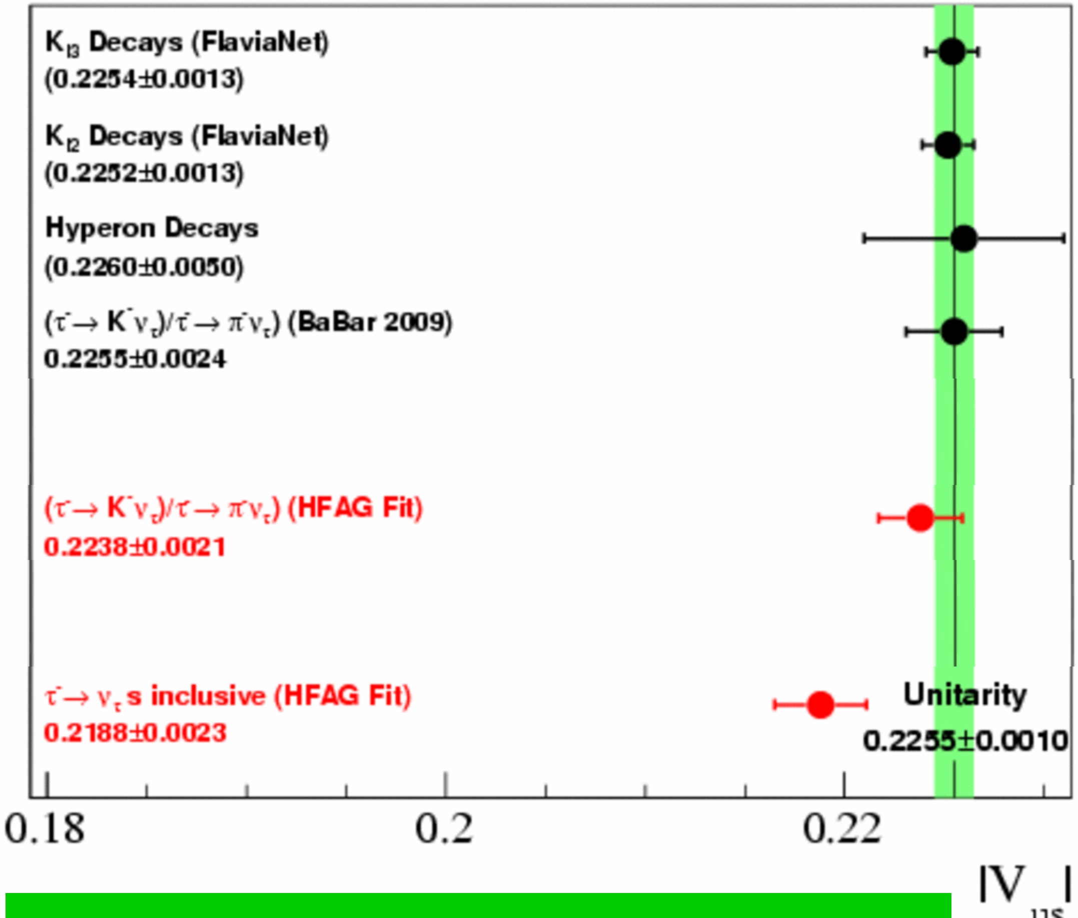
The branching fractions and invariant mass distributions are the experimental input to determine

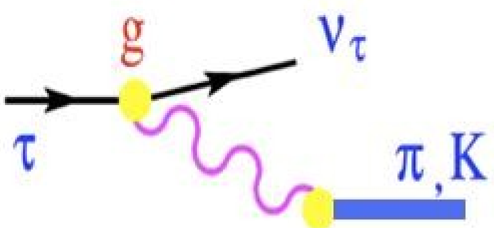
$$|V_{us}|^2 = \frac{R^w_{\tau,strange}}{R^w_{\tau,non-strange} / |V_{ud}|^2 - \delta R^w_\tau}$$

$|V_{ud}|$ is well measured from measured from superallowed beta decays

The δR_τ^W is determined from theory (using the Operator Product Expansion [OPE] and compared to experiment with the Finite Energy Sum Rule [FESR]).

$|V_{us}|$ from $\tau^- \to K^-\nu_\tau / \tau^- \to \pi^-\nu_\tau$





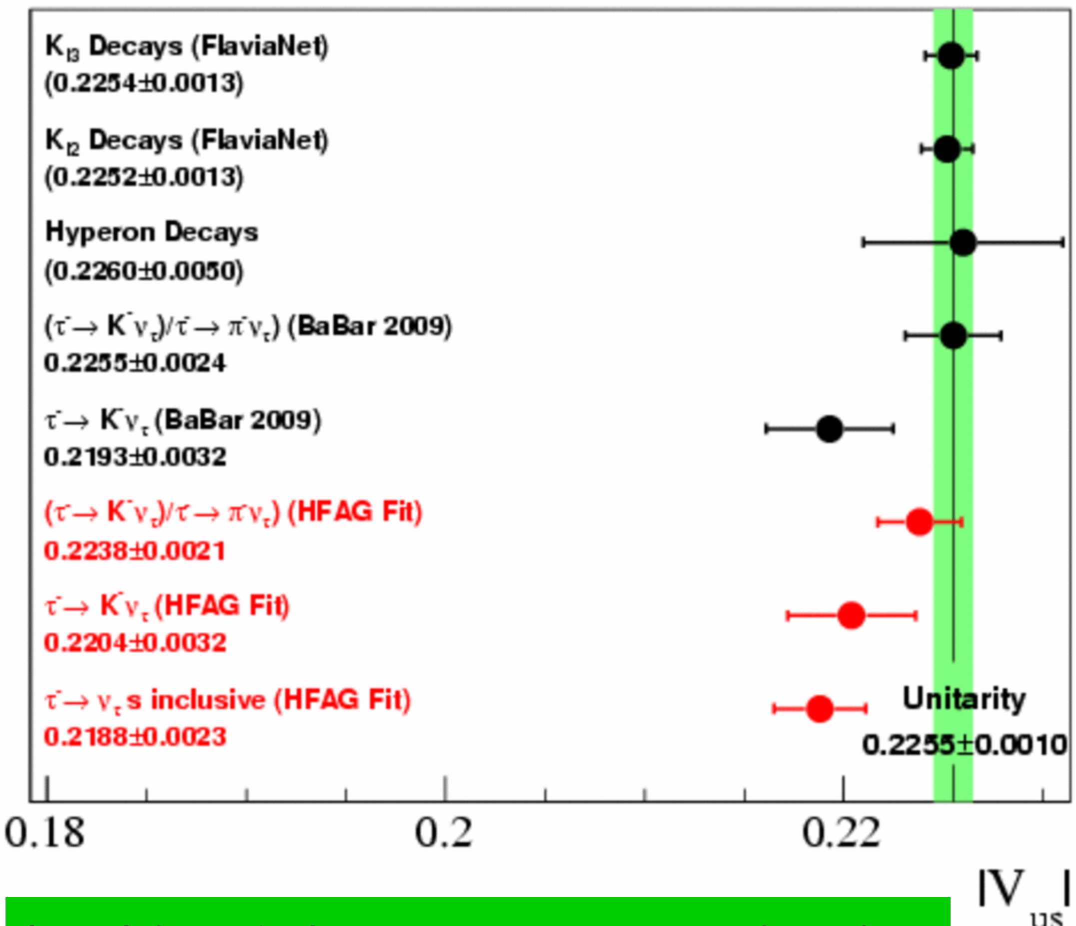
$$\frac{B(\tau^- \to K^-\nu_\tau)}{B(\tau^- \to \pi^-\nu_\tau)} = \frac{f_K^2 |V_{us}|^2}{f_\pi^2 |V_{ud}|^2} \frac{(1 - m_K^2/m_\tau^2)^2}{(1 - m_\pi^2/m_\tau^2)^2}$$

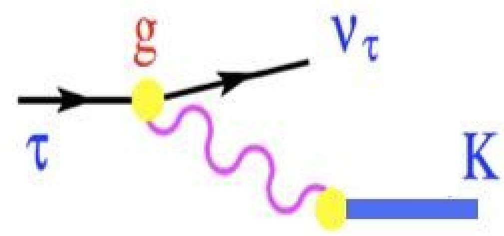
f_K/f_π taken from Lattice QCD.
$f_K/f_\pi = 1.189 \pm 0.007$
E. Follana, et al. PRL 100, 062002 (2008)

$|V_{ud}|$ measured from super allowed beta decays .
$|V_{ud}| = 0.97408 \pm 0.00026$
T. Eronen, et al. PRL 100, 132502 (2008)
J. C Hardy, I. S. Towner, Nucl. Phys. News 16N4, 11 (2006).

$|V_{us}|$ is ~0.6σ lower than unitarity

$|V_{us}|$ from $\tau^- \to K^- \nu_\tau$





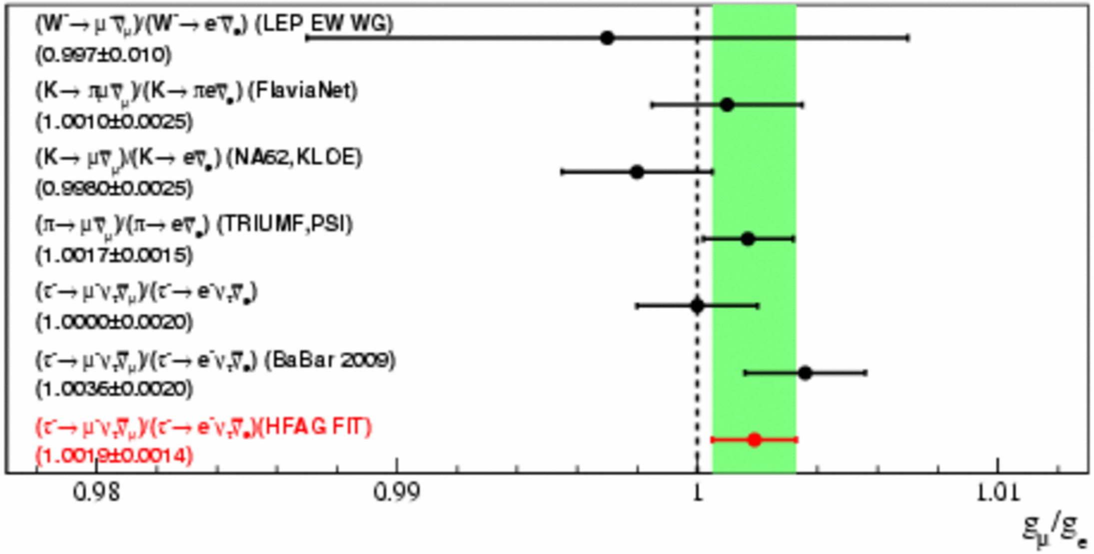
$$B(\tau \to K\upsilon) = \frac{G^2 \tau_\tau m_\tau^3 f_K^2 S_{EW} |V_{us}|^2}{16\pi\hbar} \left(1 - m_K^2 / m_\tau^2\right)^2$$

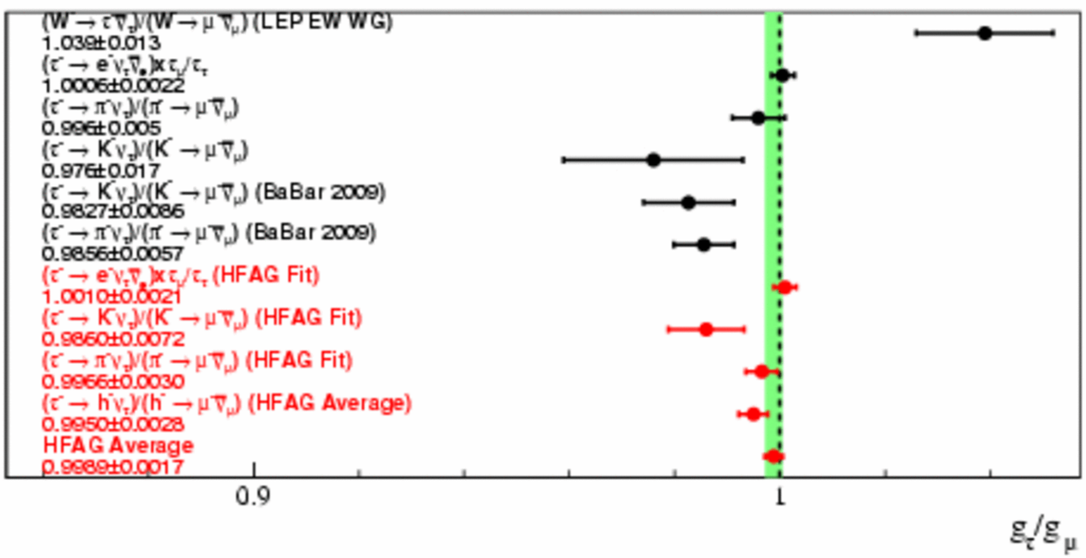
f_K taken from .
f_K=157±2 MeV from Lattice QCD
E. Follana, et al. PRL 100, 062002 (2008)

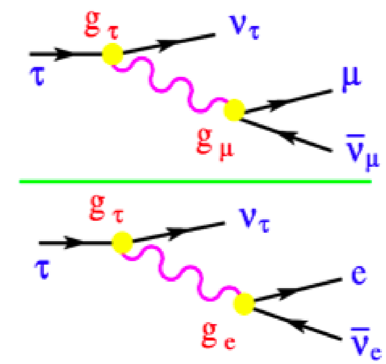
S_{EW}=1.0201±0.0003
J. Erler, Rev. Mex. Fis. 50, 200 (2004).

$|V_{us}|$ is ~1.4σ lower than unitarity

Charged Lepton Universality

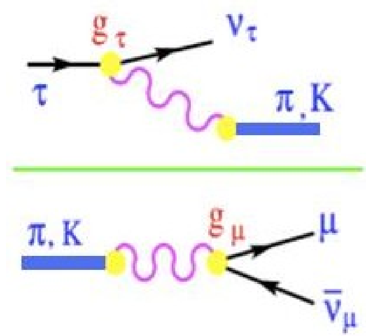






$$\left(\frac{g_\mu}{g_e}\right)^2 = \frac{B(\tau^-\to\mu^-\bar\nu_\mu\nu_\tau)}{B(\tau^-\to e^-\bar\nu_e\nu_\tau)}\frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)}$$

$$f(x) = 1-8x+8x^3-x^4+12x^2\log x$$



$$\left(\frac{g_\tau}{g_\mu}\right)^2 = \frac{B(\tau^-\to h^-\nu_\tau)}{B(h^-\to\mu^-\nu_\tau)}\frac{2m_h m_\mu^2\tau_h}{(1+\delta_h)m_\tau^3\tau_\tau}\frac{(1-m_\mu^2/m_h^2)}{(1-m_h^2/m_\tau^2)}$$

Radiative corrections:

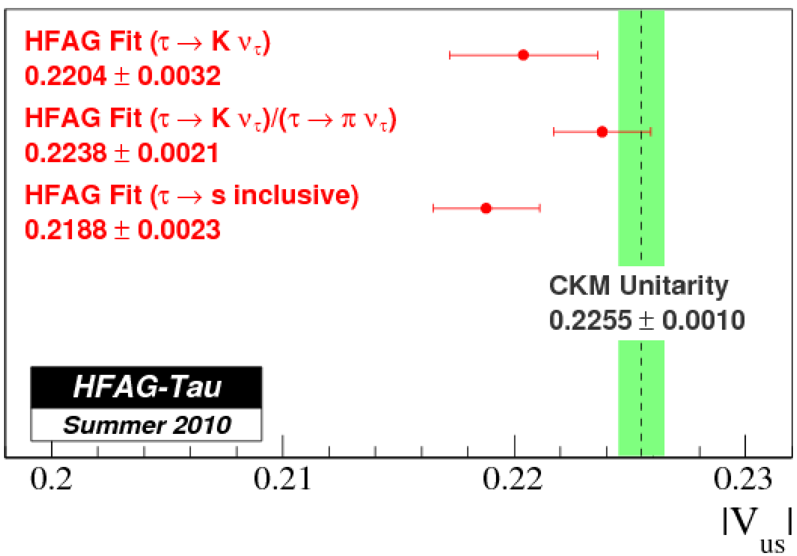
$\delta_\pi = (0.16\pm0.14)\%$ $\delta_K = (0.90\pm0.22)\%$

Summary

In summary BaBar & Belle have measured 9 of the main τ strange branching fractions.

The results have been combined with previous τ measurements to extract:

$|V_{us}|$ extracted from τ's



HFAG: arXiv:1010.1589

Charged Lepton Universality from τ's