$|V_{us}|$ from Tau decay

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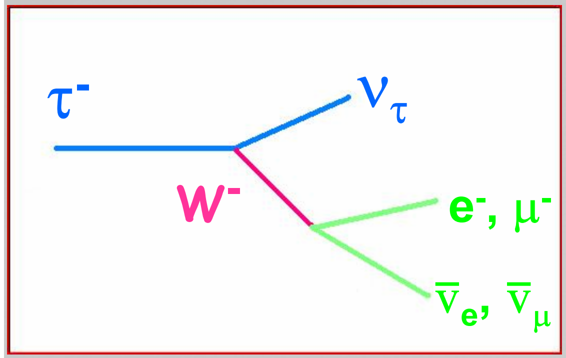
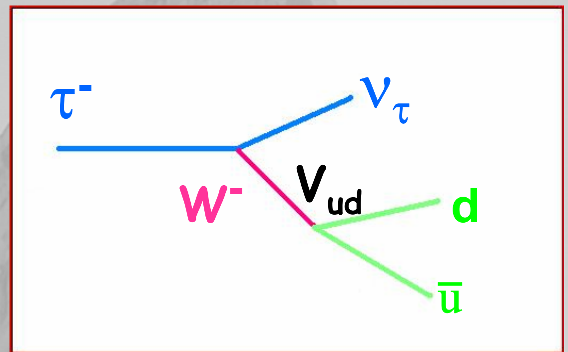
OUTLINE

Introduction
Recent measurements of branching fractions
Determination of $|V_{us}|$
Summary

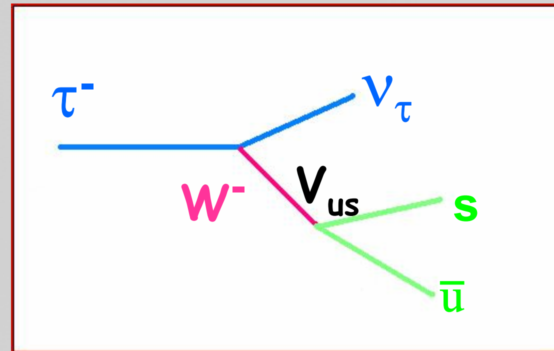
How to determine $|V_{us}|$



leptonic decays



non-strange hadronic decays:
π^-, $\pi^-\pi^0$, $(3\pi)^-$, $(3\pi)^-\pi^0$, etc.



strange hadronic decays:
K^-, $K^-\pi^0$, $\bar{K}^0\pi^-$, $\bar{K}^0\pi^-\pi^0$, etc.

$$R_\tau = \frac{\Gamma(\tau^- \to \text{hadrons } \nu_\tau (\gamma))}{\Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau (\gamma))} = R_{\tau,ns} + R_{\tau,s}$$

Measure the R's

We can related the R's to the CKM elements by:

$$\delta R_\tau = \frac{R_{\tau,ns}}{|V_{ud}|^2} - \frac{R_{\tau,s}}{|V_{us}|^2}$$

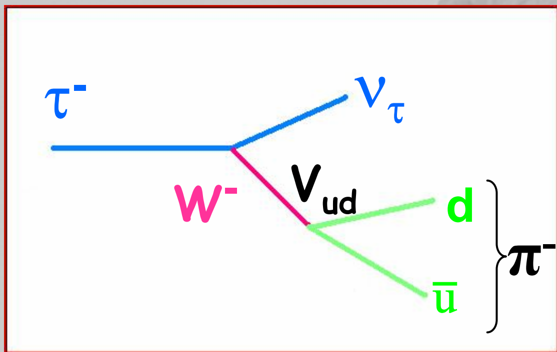
Pich, Tau06, hep-ph0702074,
Gamiz, et al.
PoS KAON 008/0709.0282

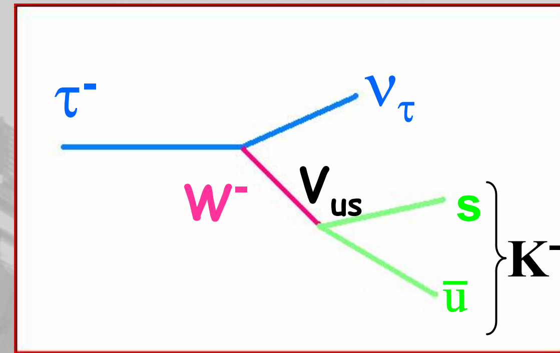
$|V_{ud}|$=0.97418±0.00027 PDG08
$|V_{ud}|$=0.97408±0.00026,
T. Eronen, et al. PRL 100, 132502 (2008)

$$|V_{us}|^2 = \frac{R_{\tau,s}}{R_{\tau,ns}/|V_{ud}|^2 - \delta R_\tau}$$

δR is a SU(3) symmetry breaking correction.
It is small, < $0.1 \bullet R_{\tau,ns}/|V_{ud}|^2$

Another way to determine $|V_{us}|$





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

Assume universality of couplings
EW corrections cancel
Take f_K/f_π from Lattice QCD
$|V_{ud}|$ known
Measure $B(\tau^- \to K^- \nu)/B(\tau^- \to \pi^- \nu)$

The easiest way determine $|V_{us}|$

Unitarity of CKM matrix: $|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2=1$

$|V_{ub}|$ is really small so forget about it.

$|V_{ub}|=(3.93\pm0.36)\times10^{-3}$

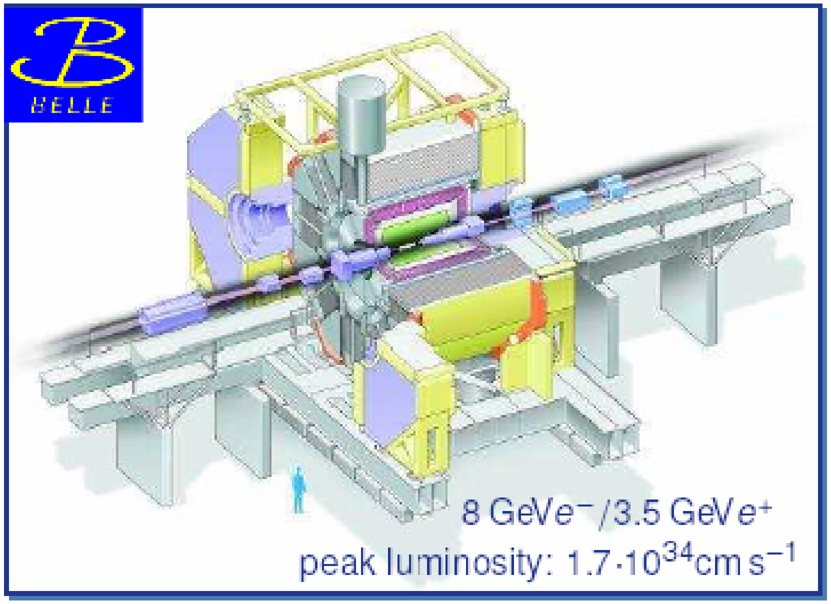
$|V_{ud}|$ is measured really well.

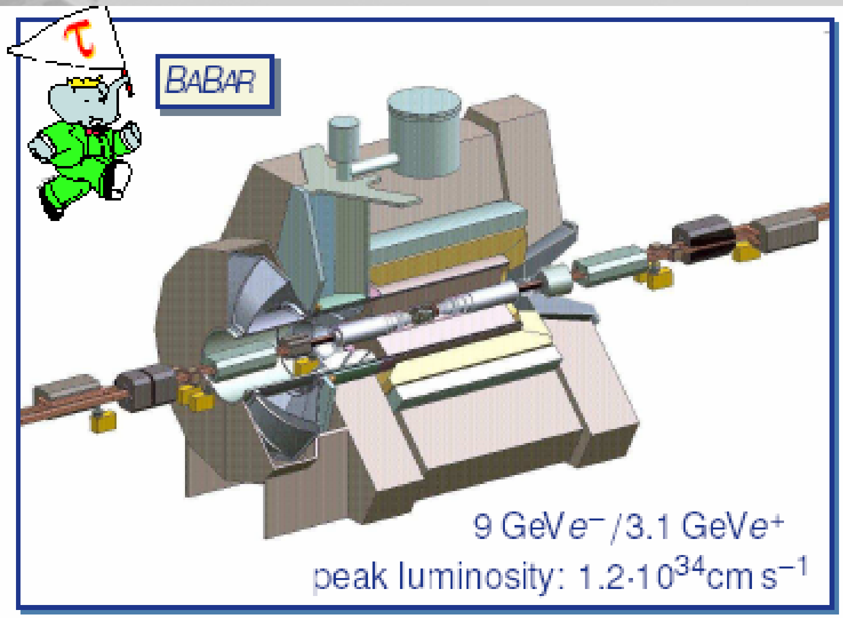
$|V_{ud}|=0.97408\pm0.00026$

$$|V_{us}|=\sqrt{1-|V_{ud}|^2}=0.2262\pm0.0011$$

Some Experimental Details

Since the cross section for $e^+e^- \to \Upsilon(4S) \to B\overline{B}$ is about the same as $e^+e^- \to \tau^+\tau^-$ a B factory is also a τ factory.





Both experiments have a very large (~10^9) sample of tau events

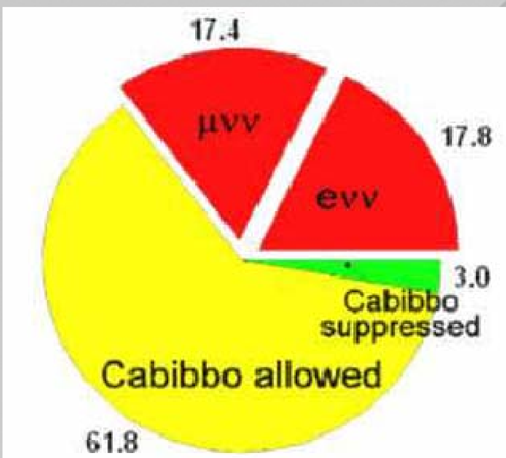
Detectors are well matched to do tau physics:

- k/π particle ID, γ/π^0 reconstruction, charged particle tracking, etc.

Can reduce most non-tau backgrounds to ≤ 1%:

- bhabhas, μ-pairs, $e^+e^- \to q\bar{q}$

A Bit of Recent History

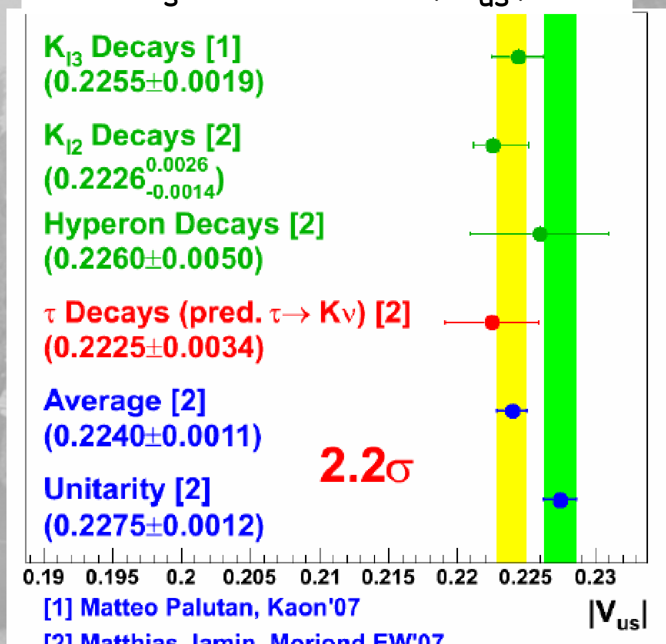


Strange τ Decays:	
Mode	$\mathcal{B}(10^{-3})$
K^-	6.81 ± 0.23
$K^-\pi^0$	4.54 ± 0.30
$\bar{K}^0\pi^-$	8.78 ± 0.38
$K^-\pi^0\pi^0$	0.58 ± 0.24
$\bar{K}^0\pi^-\pi^0$	3.60 ± 0.40
$K^-\pi^+\pi^-$	3.30 ± 0.28
$K^-\eta$	0.27 ± 0.06
$(\bar{K}3\pi)^-$ (estimated)	0.74 ± 0.30
$K_1(1270)^- \to K^-\omega$	0.67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

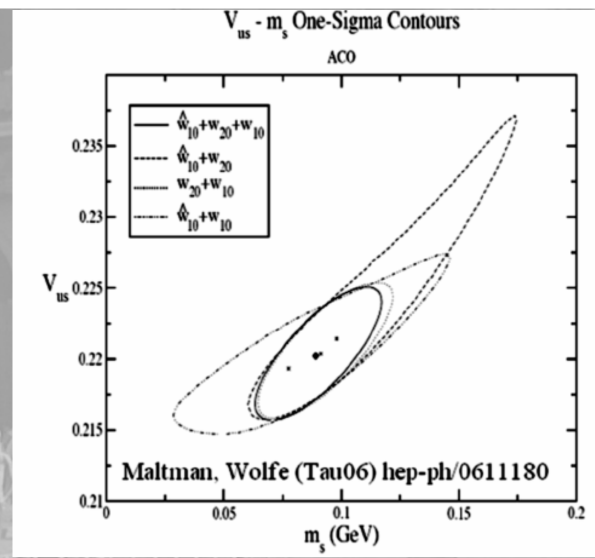
Davier, Hocker, Zhang(RMP 78, 1043, 2006)

BFs dominated by CLEO & LEP

Fix m_s & extract $|V_{us}|$



Simultaneous fit to extract $|V_{us}|$ & m_s



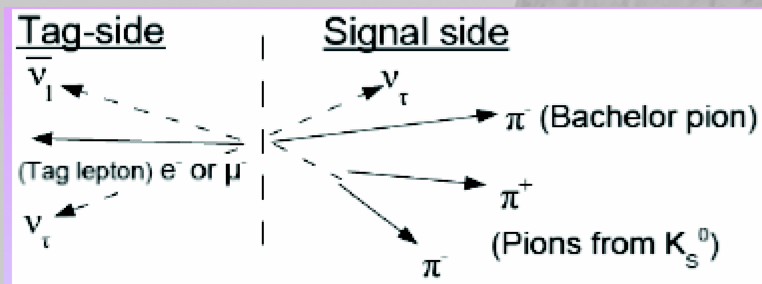
Recent Tau Results relevant to this talk

mode	BaBar	Belle
$\tau^- \to \pi^- \nu$	ICHEP08 (S. Banerjee)	
$\tau^- \to K^- \nu$	ICHEP08 (S. Banerjee)	
$\tau^- \to \overline{K}^0 \pi^- \nu$	ICHEP08 (S. Banerjee)	PL B654; 65, 2007
$\tau^- \to K^- \pi^0 \nu$	PRD 76:051104, 2007	
$\tau^- \to \pi^- \pi^- \pi^+ \nu$	PRL 100 011801 , 2008	
$\tau^- \to K^- \pi^- \pi^+ \nu$	PRL 100 011801 , 2008	ICHEP08 (K. Inami)
$\tau^- \to K^- \pi^- K^+ \nu$	PRL 100 011801 , 2008	ICHEP08 (K. Inami)
$\tau^- \to K^- K^- K^+ \nu$	PRL 100 011801 , 2008	ICHP08 (K. Inami) $\tau^- \to K^- \phi \nu$, PL B643 (2006) 5
$\tau^- \to K^-/K^{*-} \eta \nu$		arXiv:0708.0733

$\tau \to \bar{K}^0 \pi^- \nu$

Preliminary BaBar result presented at ICHEP 08 arXiv:0808.1121v2

Reconstruct $\bar{K}^0$ using $K_s \to \pi^+\pi^-$ mode

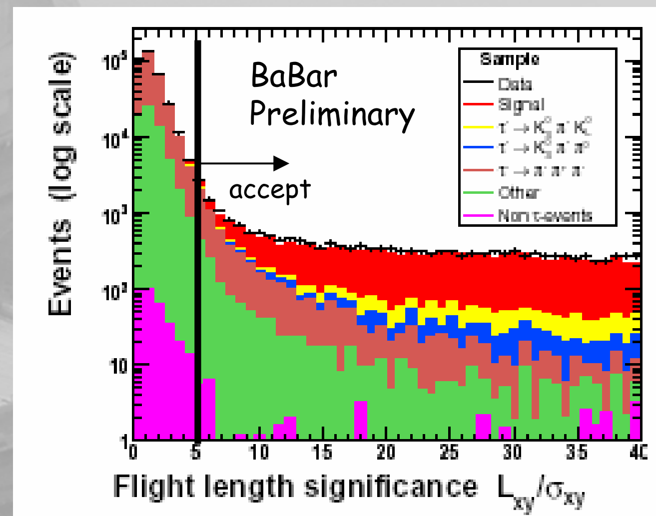


tag side requires e or μ

Total efficiency = 1.1%

Backgrounds are primarily due to other tau decays:

~20% background

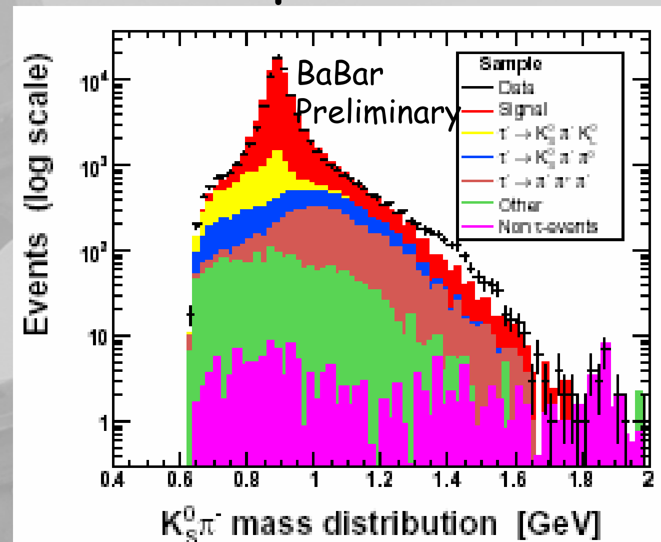


Decay Channel	$w[\%]$	$\frac{\sigma}{\mathcal{B}}[\%]$
$\tau^- \to \pi^- K_S^0 \pi^0 \nu_\tau$	24.24	10.53
$\tau^- \to K^- K_S^0 \pi^0 \nu_\tau$	0.57	17.54
$\tau^- \to \pi^- \bar{K}^0 K_L^0 \nu_\tau$	41.16	10.38
$\tau^- \to \pi^- \bar{K}^0 K_S^0 \nu_\tau$	0.18	20.83
$\tau^- \to K^- \bar{K}^0 \nu_\tau$	2.64	10.46
$\tau^- \to \pi^- \pi^0 \nu_\tau$	0.75	0.39
$\tau^- \to 2\pi^+ \pi^- \nu_\tau$	23.65	0.89
$\tau^- \to 2\pi^- \pi^+ \pi^0 \nu_\tau$	3.41	1.35
$\tau^- \to K^- K^+ \pi^- \nu_\tau$	0.61	2.78
$\tau^- \to K^- \pi^+ \pi^- \nu_\tau$	0.78	10.26

$\tau \to \overline{K}^0 \pi^- \nu$

Data sample contains ~350x10^6 tau-pairs

Structure the data but not the MC in the Kπ mass spectrum



BF($\tau \to \overline{K}^0 \pi^- \nu$)=(0.840±0.004±0.023)%

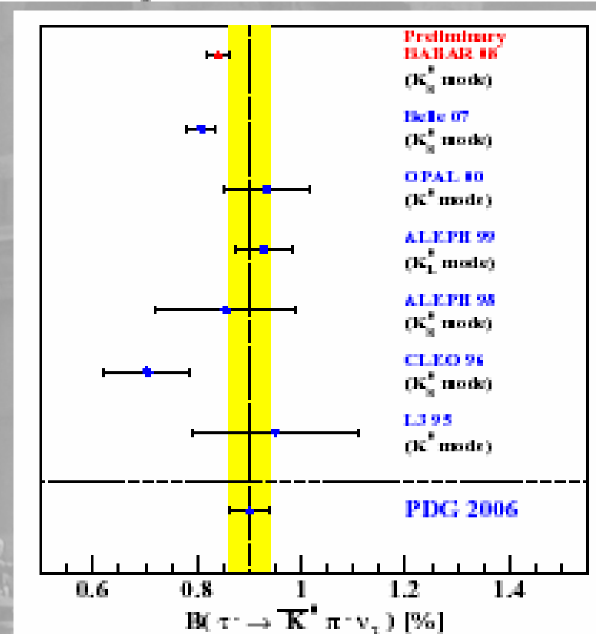
Consistent with recent Belle result:

BF($\tau \to \overline{K}^0 \pi^- \nu$)=(0.808±0.004±0.026)%

(PL B654; 65, 2007)

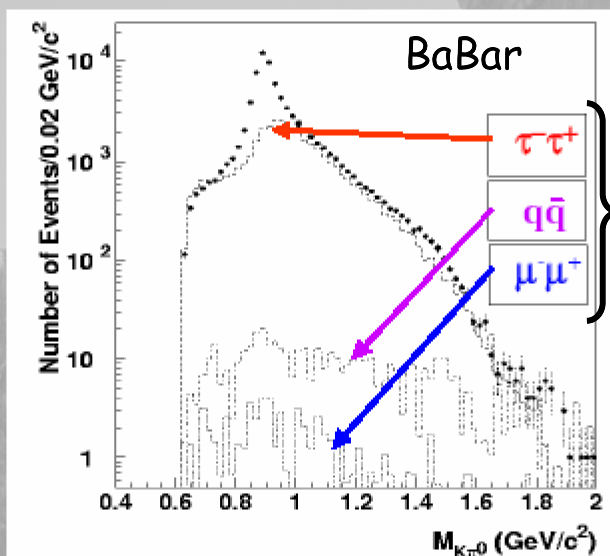
New World Average:

BF($\tau \to \overline{K}^0 \pi^- \nu$)=(0.835±0.022)% (S=1.4)

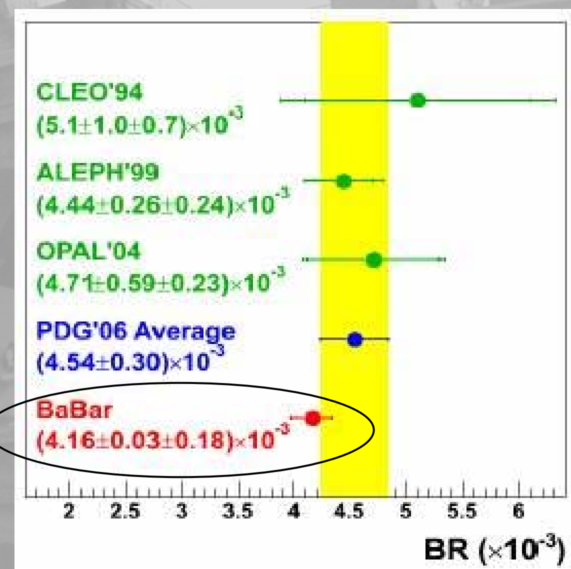


$\tau \to K^- \pi^0 \nu$

High statistics ~211×10^6 τ-pairs $\to 3\times10^4$ signal events
BF measurement limited by systematics
Again structure in the $K\pi$ invariant mass spectrum not in MC



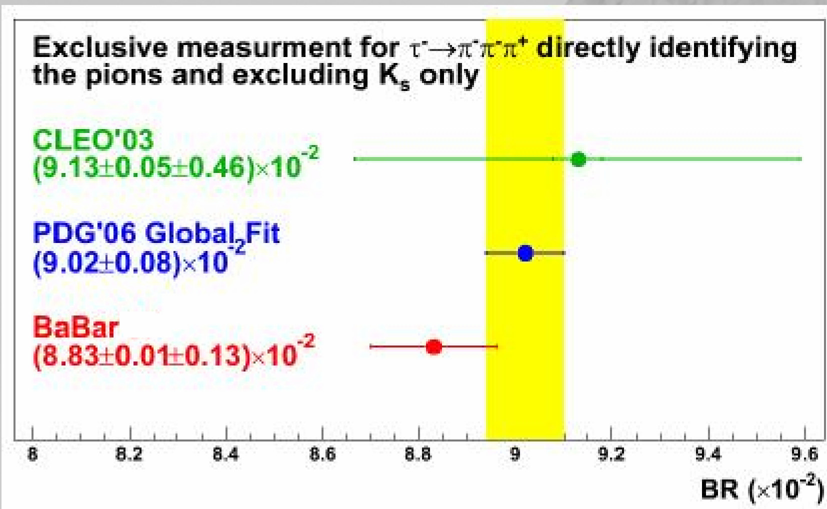
backgrounds

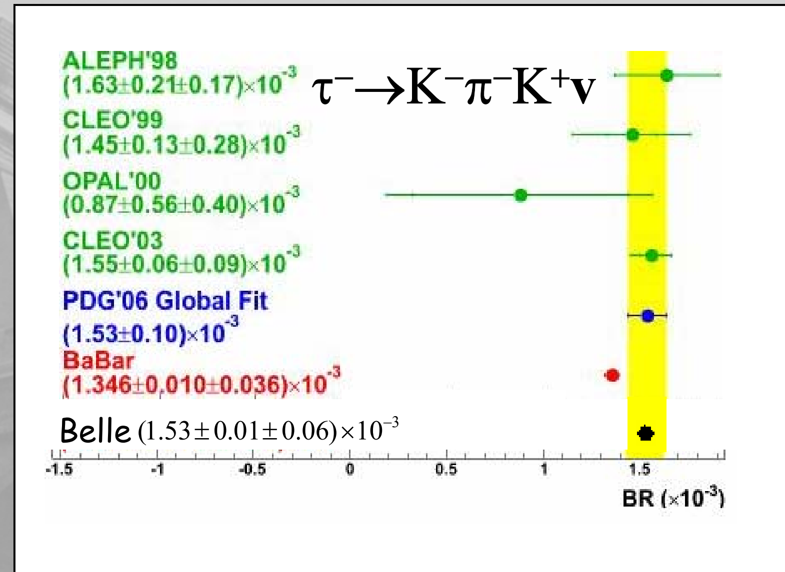


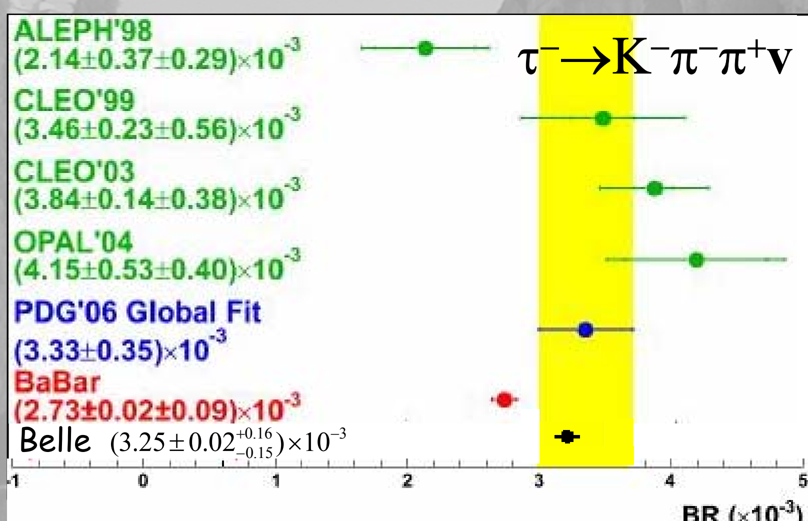
Published: PRD 76:051104, 2007

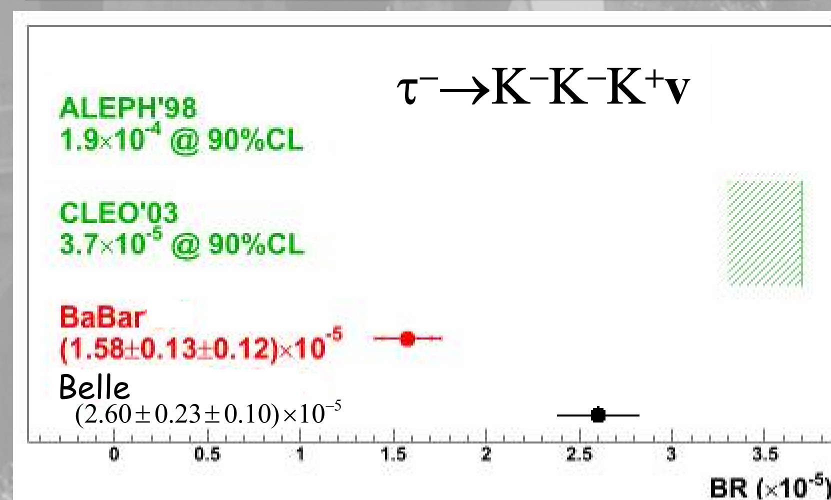
$\tau \to (3h)^- \nu$

BaBar: PRL 100 011801, 2008
Belle: presented at ICHEP 2008









$|V_{us}|$ from τ branching fractions

mode	B_{WA2007} (%)
$\tau^- \to K^- \nu$	0.691±0.023 (measured) *0.715±0.003 ($K_{\mu 2}$)*
$\tau^- \to K^- \pi^0 \nu$	0.426±0.016
$\tau^- \to \bar{K}^0 \pi^- \nu$	0.831±0.028 (S=1.3) → 0.835±0.022
$\tau^- \to K^- \pi^0 \pi^0 \nu$	0.058±0.024
$\tau^- \to \bar{K}^0 \pi^- \pi^0 \nu$	0.360±0.040
$\tau^- \to K^- \pi^- \pi^+ \nu$	0.280±0.016 (S=1.9)
$\tau^- \to K^- \eta \nu$	0.0160±0.002
$\tau^- \to (\bar{K}^0 3\pi)^- \nu$	0.074±0.030 estimated
$\tau^- \to K_1(1270)\nu \to K^- \omega \nu$	0.067±0.021
$\tau^- \to (\bar{K}^0 4\pi)^- \nu$	0.011±0.007 estimated
$\tau^- \to K^{*-} \eta \nu$	0.12±0.004 (S=2)
$\tau^- \to K^- \phi \nu$	0.00370±0.00025
TOTAL	2.830±0.074 → 2.834±0.074 *2.854±0.071($K_{\mu 2}$)* → 2.858±0.071

$$|V_{us}|^2 = \frac{R_{\tau,s}}{R_{\tau,ns}/|V_{ud}|^2 - \delta R_\tau}$$

δR_τ = 0.240±0.032

Gamiz, et al. PoS KAON 008/arXiv:0709.0282

$|V_{us}|$=0.2154±0.0031

$|V_{us}|$=0.2163±0.0031 using $K_{\mu 2}$

$|V_{us}|$ from BFs ~3σ lower than unitarity calculation

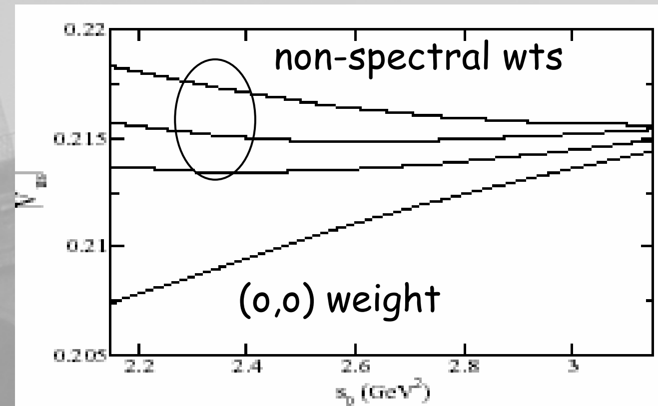
$|V_{us}|$=0.2262±0.0011 using unitarity

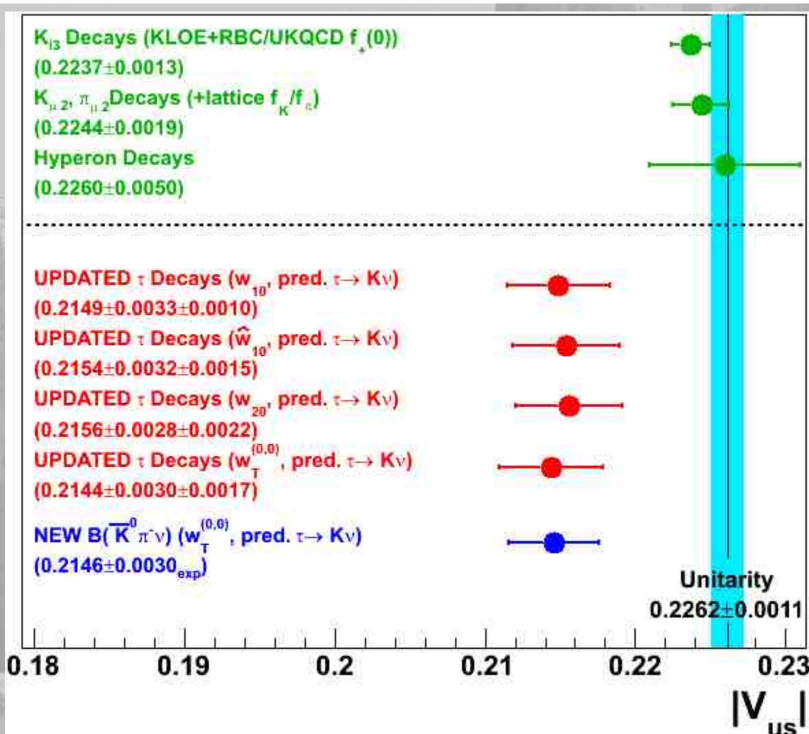
$|V_{us}|$ from τ spectral functions & branching fractions

K. Maltman et al., arXiv:0807.3195 + S. Banerjee ICHEP08

$$|V_{us}|^2 = \frac{R^w_{us}(s_0)}{R^w_{ud}(s_0)/|V_{ud}|^2 - \delta R^w_{OPE}(s_0)}$$

Use various weight factors including non-spectral weights based on ALEPH data + updated τ BFs.





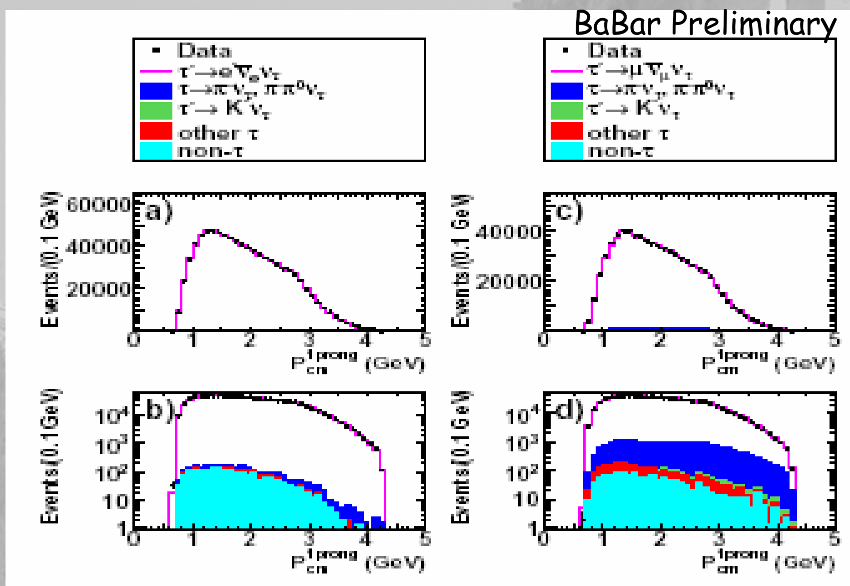
$|V_{us}|$~3σ lower than unitarity calculation.

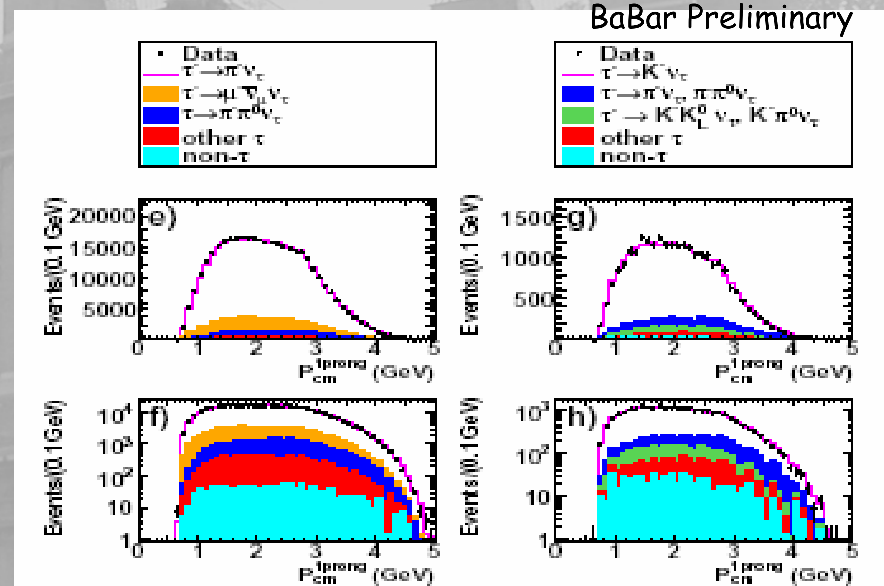
$|V_{us}|$ from $\tau^-\to\pi^-\nu$ & $\tau^-\to K^-\nu$

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

New BaBar results from ICHEP08

measure $B(\tau^-\to\pi^-\nu)$, $B(\tau^-\to K^-\nu)$, $B(\tau^-\to\mu^-\nu\bar{\nu})$ relative to $B(\tau^-\to e^-\nu\bar{\nu})$





$$B(\tau^-\to\pi^-\nu_\tau)/B(\tau^-\to e^-\bar{\nu}_e\nu_\tau)=(59.45\pm0.14\pm0.61)\times10^{-2}$$ PDG06: $(60.76\pm0.61)\times10^{-2}$

$$B(\tau^-\to K^-\nu_\tau)/B(\tau^-\to e^-\bar{\nu}_e\nu_\tau)=(3.882\pm0.032\pm0.056)\times10^{-2}$$ PDG06: $(3.84\pm0.13)\times10^{-2}$

$|V_{us}|$ from $\tau^- \to \pi^- \nu$ & $\tau^- \to K^- \nu$

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

Assume universality of couplings

EW corrections cancel

Take f_K/f_π from Lattice QCD

f_K/f_π= 1.189±0.007, E. Follana, et al. PRL 100, 062002 (2008)

$|V_{ud}|$ known

$|V_{ud}|$ = 0.97408±0.00026,

Use BaBar preliminary measurement of $B(\tau \to K^- \nu)/B(\tau \to \pi^- \nu)$

$B(\tau \to K^- \nu)/B(\tau \to \pi^- \nu)$=0.06531±0.00056±0.00093

$|V_{us}|$=0.2255±0.0023

Agrees with unitarity calculation!

$|V_{us}|$=0.2262±0.0011

Summary

$|V_{us}|$ using R_s is lower than other measurement (~3σ)

Theory/calculation issues?

Experiments still need to measure missing modes

Are correlations properly taken into account when averaging results?

New physics?

$|V_{us}|$ using $B(\tau^- \to K^-\nu)/B(\tau^- \to \pi^-\nu)$ agrees with unitarity

BUT both $B(\tau^- \to K^-\nu)$ & $B(\tau^- \to \pi^-\nu)$ are slightly lower than expected from universality:

$\tau^- \to \mu\nu\bar{\nu}$: $g_\mu/g_e = 1.0036 \pm 0.0020$ BaBar ICHEP08

$\tau^- \to K^-\nu$: $g_\mu/g_e = 0.9859 \pm 0.0057$

$\tau^- \to \pi^-\nu$: $g_\mu/g_e = 0.9636 \pm 0.0087$

New physics?

More results expected from the B factories soon!

spectral functions from BaBar/Belle

expect measurements to be limited by systematics..

Extra Slides