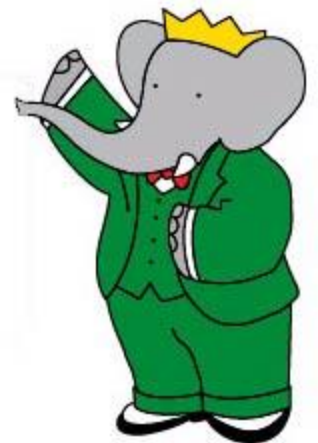


$|V_{us}|$ from strange τ decays

Flavour Physics and CP Violation 2010 : Turin, Italy

Sudarshan Paramesvaran

Royal Holloway, University of London



Outline

- Introduction to τ physics at B factories
- BaBar and Belle detectors
- Theoretical overview for determining $|V_{us}|$ from τ decays
- Experimental determinations of $|V_{us}|$
 - From inclusive $\tau \rightarrow s$ decays
 - Also
$$\frac{B(\tau^- \rightarrow K^- \nu_\tau)}{B(\tau^- \rightarrow \pi^- \nu_\tau)} \propto \frac{|V_{us}|^2}{|V_{ud}|^2}$$
- Experimental Results
- Conclusions

Introduction

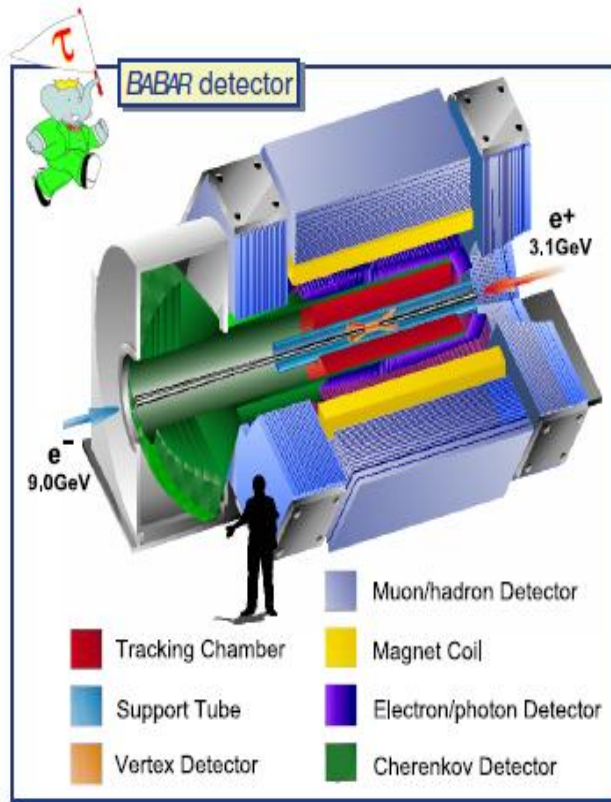
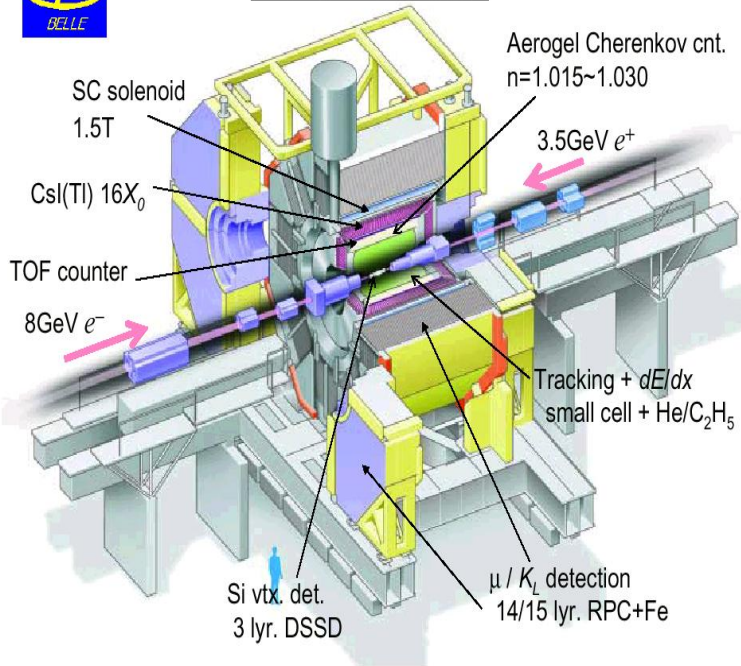
- B factories are also τ factories
 $\sigma_{\tau\tau} = 0.9 \text{ nb}$, $\sigma_{BB} = 1.1 \text{ nb}$
- Belle has recorded over 1000 fb^{-1} of data, while BaBar has 531 fb^{-1} .
- Have produced a wealth of τ physics results:
Much improved constraints on Lepton Flavour Violation
Precise measurements e.g Branching fractions, τ mass
 $|V_{us}|$ from strange hadronic τ decays

Belle & BaBar

e^+e^- colliding at centre-of-mass energy of 10.58 GeV



Belle Detector



For this analysis: SVT+DCH important for secondary vertex (K_s^0)
 Cerenkov detector important for π/K separation
 Calorimeter important for π^0 identification/ electron tagging
 Outermost muon detectors needed for 'tagging'

CKM Matrix element $|V_{us}|$

- $|V_{us}|$ is one of the largest off-diagonal elements of the CKM matrix

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

- Can use unitarity constraint of CKM to determine $|V_{us}|$

$$\therefore |V_{ud}|^2 + |V_{ub}|^2 + |V_{us}|^2 = 1$$

$$V_{ud} = 0.97425 \pm 0.00022$$

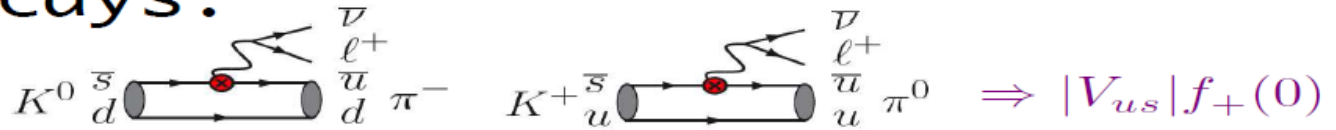
(Towner Hardy 2009)

$$V_{ub} = (3.93 \pm 0.36) \times 10^{-3}$$

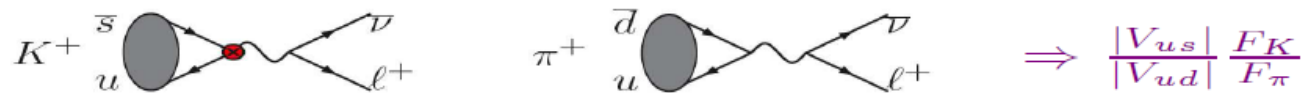
- Leads to $|V_{us}| = 0.2255 \pm 0.0010$

Other methods to determine $|V_{us}|$

K13 decays:



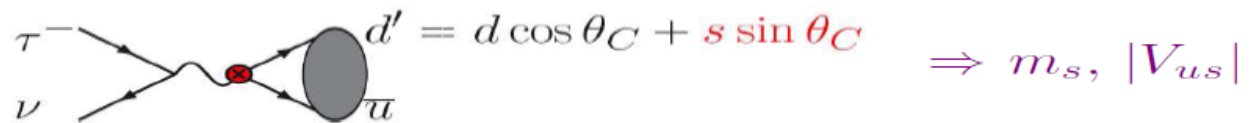
K12 decays:



Hyperon decays:

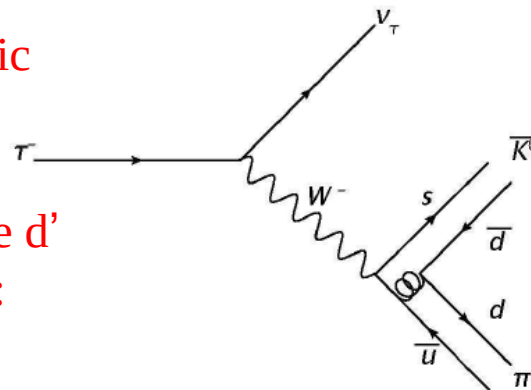


τ decays:



Example of a τ decay to a hadronic strange final state

s quark is a representation of the d' state which has V_{us} dependence:



$$d' = d.V_{ud} + s.V_{us}$$

$|V_{us}|$ determination from inclusive decays of $\tau \rightarrow X_s \nu$

Indices refer to spectral moments
-00 is unweighted difference of
decays widths between strange
and non-strange

Obtained from Operator
Product Expansion, & Finite
Energy Sum Rules

$$|V_{us}|^2 = \frac{R_{\tau, \text{strange}}^{00}}{R_{\tau, \text{non-strange}}^{00} / |V_{ud}|^2 + \delta R_{\tau, \text{theory}}^{00}}$$

SU(3) flavour breaking
term - $< 0.1 \times R_{\tau} / |V_{ud}|^2$

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

Inclusive BR have generally
smaller QCD theory
uncertainties

Can use measured branching
fractions directly as input

Strange branching fractions

(S.Banerjee, ICHEP 2008)

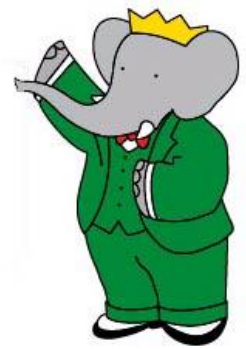
hadronic system in $\tau \rightarrow X_S \nu$	ICHEP08 averages (%)	References
K^- [from τ decay] [indirect, from $K_{\mu 2}$]	0.690 ± 0.010 (0.715 ± 0.004)	PDG 2006 + <i>BaBar</i> 2008 prelim. Gamiz <i>et al.</i> , PoSKAON:008,2008
$K^- \pi^0$	0.426 ± 0.016	<i>BaBar</i> 2007
$\bar{K}^0 \pi^-$	0.835 ± 0.022 ($S = 1.4$)	<i>Belle</i> 2008, <i>BaBar</i> 2008
$K^- \pi^0 \pi^0$	0.058 ± 0.024	PDG 2006
$\bar{K}^0 \pi^0 \pi^-$	0.360 ± 0.040	PDG 2006
$K^- \pi^- \pi^+$	$0.273 \pm 0.002 \pm 0.009$	Phys.Rev.Lett.100:011801,2008
$(\bar{K}^* 3\pi)^-$ (est'd)	0.074 ± 0.030	ALEPH 2005
$K_1(1270) \rightarrow K^- \omega$	0.067 ± 0.021	ALEPH 2005
$(\bar{K}^* 4\pi)^-$ (est'd)	0.011 ± 0.007	ALEPH 2005
$K^- \eta$	$0.016 \pm 0.05 \pm 0.09$	Phys.Lett.B672:209-218,2009
$K^{*-} \eta$	$0.013 \pm 0.12 \pm 0.09$	
$K^- \phi$	0.0037 ± 0.0003 ($S = 1.3$)	<i>Belle</i> 2006, <i>BaBar</i> 2007
TOTAL	2.8447 ± 0.0688 (2.8697 ± 0.0680)	

Improved BaBar $\tau^- \rightarrow K_s \pi^- \pi^0$ presented in the following

Measuring $\tau^- \rightarrow K_S^0 \pi^- \pi^0 \nu_\tau$

(S.Paramesvaran, DPF 2009)

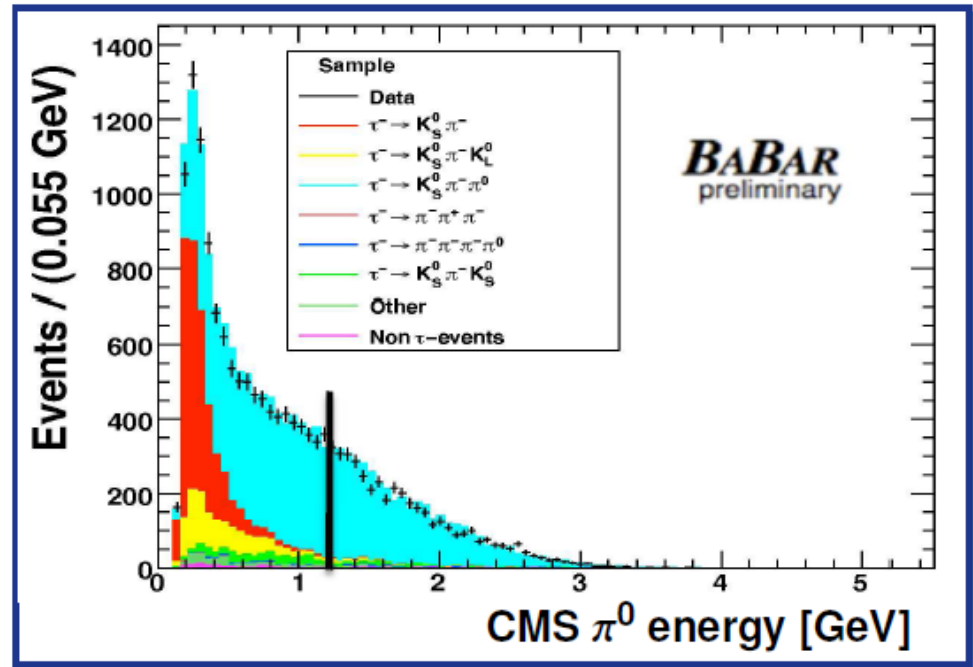
384 fb⁻¹



Lepton tag used to identify one hemisphere – other hemisphere contains signal particles

Momentum of π^0 is within 90 degrees in CM frame of $K_S^0 \pi^-$

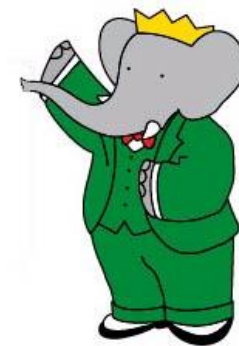
Requirement of π^0 energy to be greater than 1.2 GeV – signal purity = 93%.



$$B(\tau^- \rightarrow \overline{K}^0 \pi^- \pi^0 \nu_\tau) = 0.342 \pm 0.006(stat.) \pm 0.015(syst.)$$

Measuring $\tau^- \rightarrow K_S^0 \pi^- \pi^0 \nu_\tau$

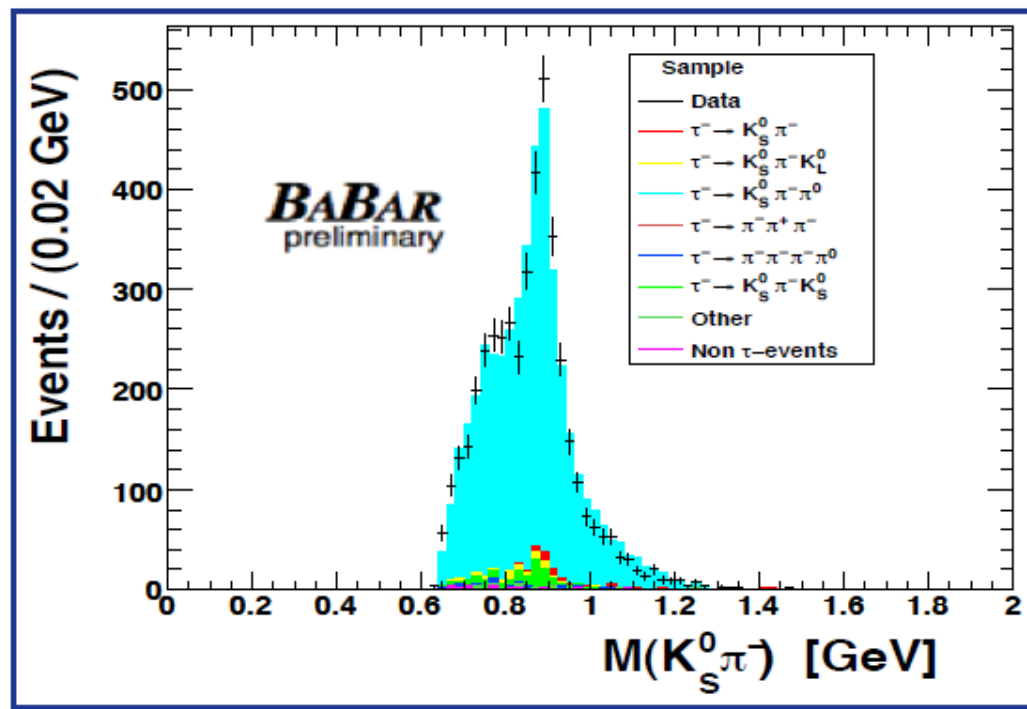
(S.Paramesvaran, DPF 2009)



384 fb⁻¹

Tau Monte Carlo

hadronic invariant mass distributions tuned with data; this also reduces the systematic uncertainty associated with the hard requirement on the π^0 energy.



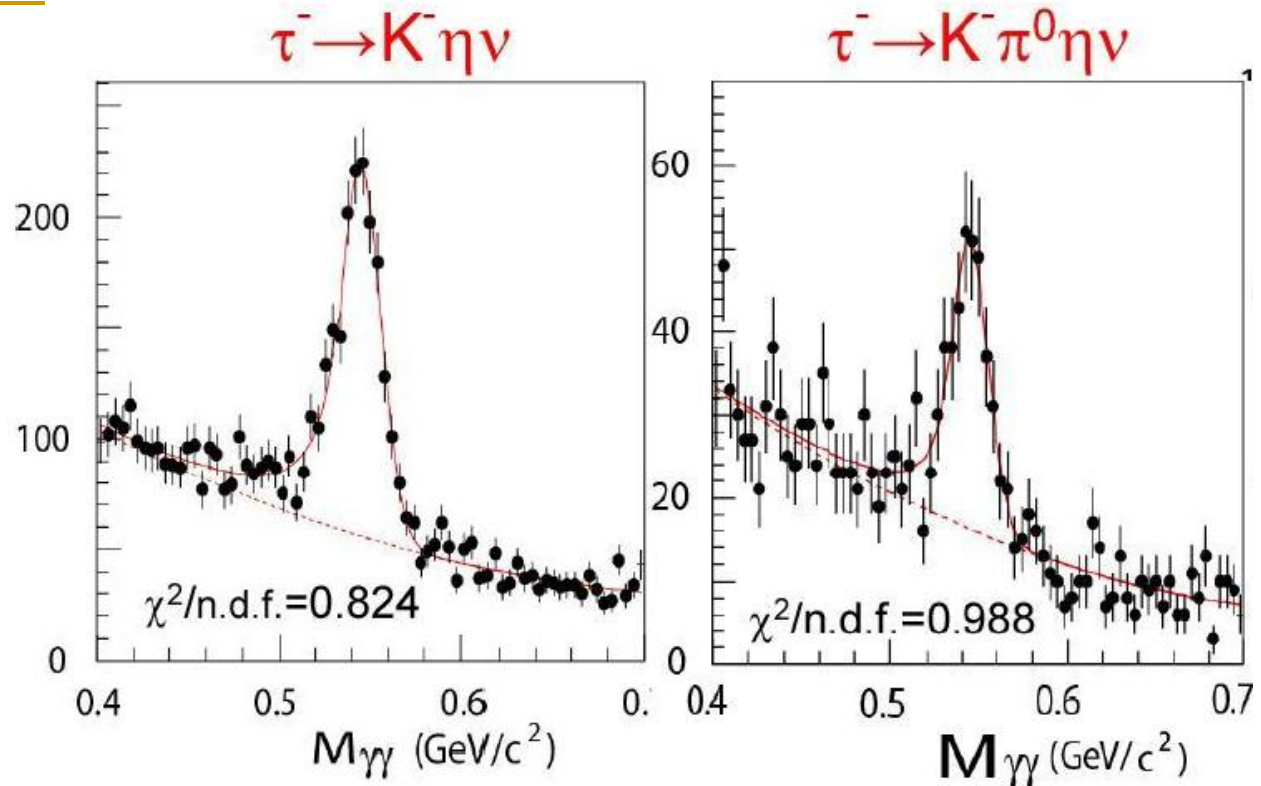
Measuring strange τ decays with η

Phys.Lett.B672:209-
218,2009

490 fb⁻¹

For $\tau^- \rightarrow K^- \eta \nu$
 $\eta \rightarrow \gamma\gamma; \eta \rightarrow 3\pi$

For $\tau^- \rightarrow K^- \pi^0 \eta \nu$
 $\eta \rightarrow \gamma\gamma$

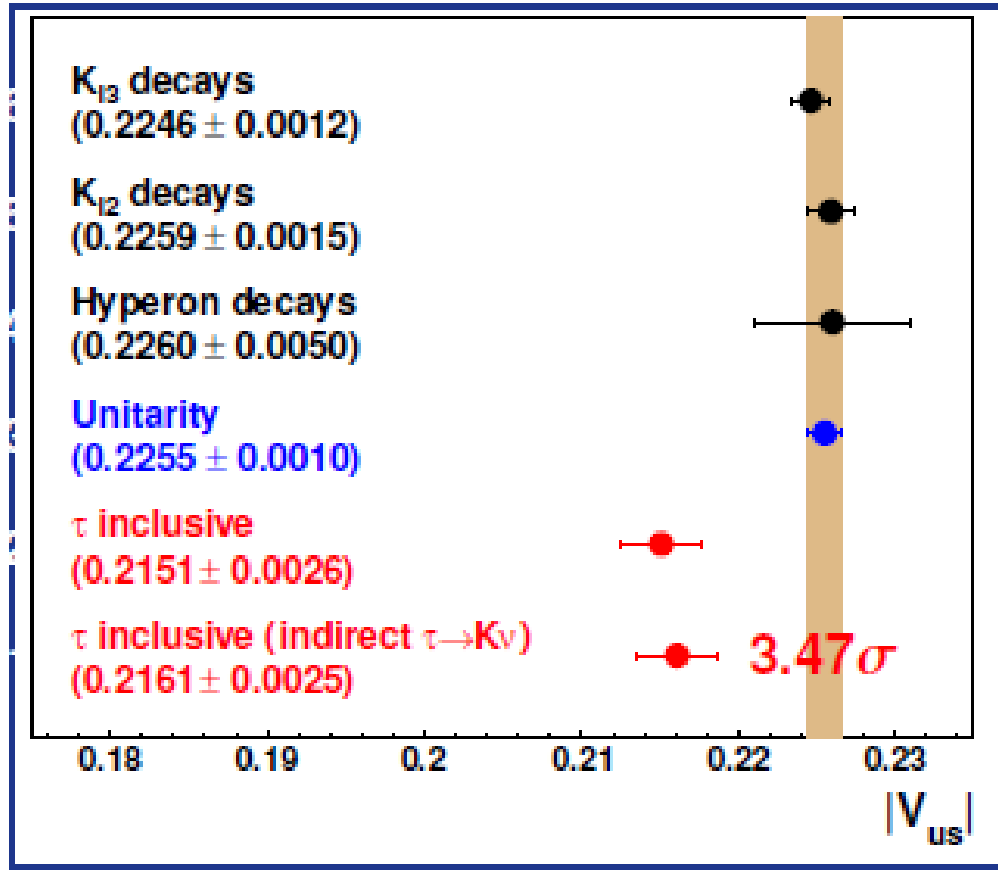


$$B(\tau^- \rightarrow K^- \eta \nu_\tau) = (1.58 \pm 0.05 \pm 0.09) \times 10^{-4}$$

$$B(\tau^- \rightarrow K^- \pi^0 \eta \nu_\tau) = (4.6 \pm 1.1 \pm 0.4) \times 10^{-5}$$



$|V_{us}|$ update (A.Lusiani ICFP 2009)



Using the following information:

$$V_{ud} - \text{Towner Hardy 2009}$$

$$m_s(2\text{GeV}) = 94 \pm 6 \text{ GeV}$$

(M Jamin et al 2006)

$$\delta R_{\tau, \text{theory}}^{00} = 0.240 \pm 0.032$$

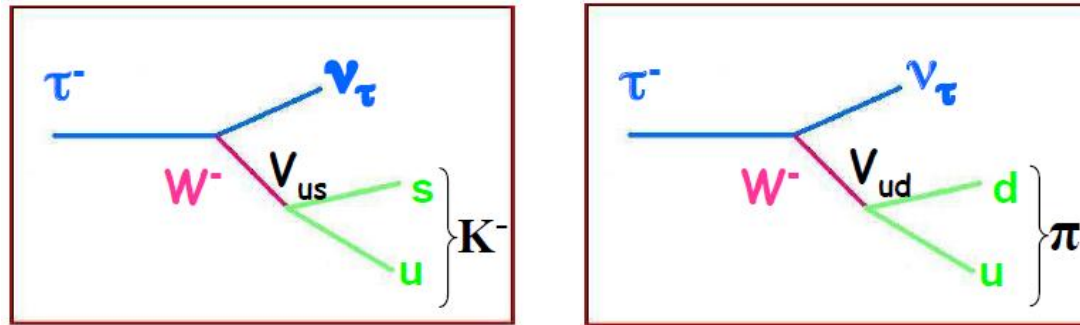
(Gamiz et al. 2007)

Branching fractions from ICHEP 2008, but includes update on $\tau^- \rightarrow K_S^0 \pi^- \pi^0 \nu_\tau$

Alternative $|V_{us}|$ determination

[arXiv:0912.0242](https://arxiv.org/abs/0912.0242)

- Can also obtain $|V_{us}|$ through the Branching fraction ratio between :

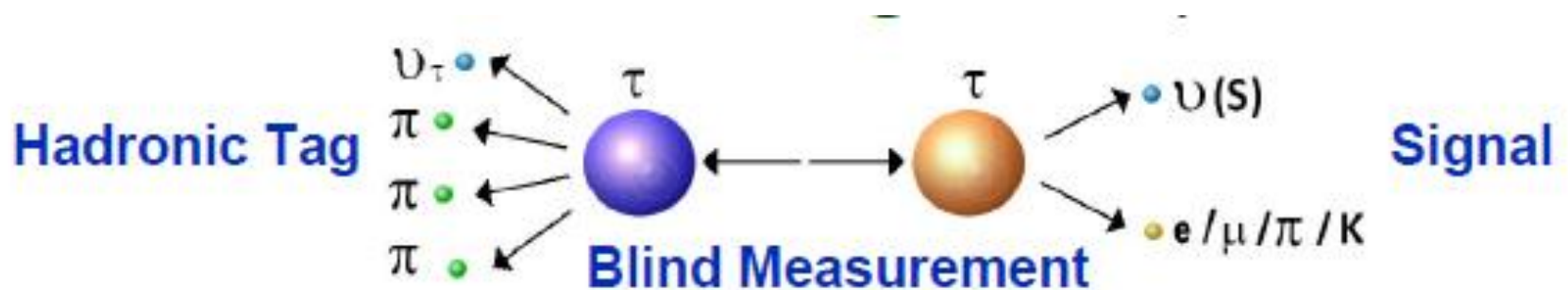


$$\frac{B(\tau^- \rightarrow K^- \nu_\tau)}{B(\tau^- \rightarrow \pi^- \nu_\tau)} = \frac{f_K^2 |V_{us}|^2 (1 - m_K^2 / m_\tau^2)^2}{f_\pi^2 |V_{ud}|^2 (1 - m_\pi^2 / m_\tau^2)^2} (1 + \delta_{LD})$$

Short-distance electroweak corrections cancel

Measuring branching fraction ratios in 1-prong vs 3-prong events

Select events with 3-prongs on the tag side, and 1-prong on the signal side



$$\frac{B(\tau^- \rightarrow \mu^- \nu_\tau \bar{\nu}_\mu)}{B(\tau^- \rightarrow e^- \nu_\tau \bar{\nu}_\mu)} \quad \frac{B(\tau^- \rightarrow \pi^- \nu_\tau)}{B(\tau^- \rightarrow e^- \nu_\tau \bar{\nu}_\mu)} \quad \frac{B(\tau^- \rightarrow K^- \nu_\tau)}{B(\tau^- \rightarrow e^- \nu_\tau \bar{\nu}_\mu)} \quad \boxed{\frac{B(\tau^- \rightarrow K^- \nu_\tau)}{B(\tau^- \rightarrow \pi^- \nu_\tau)}}$$

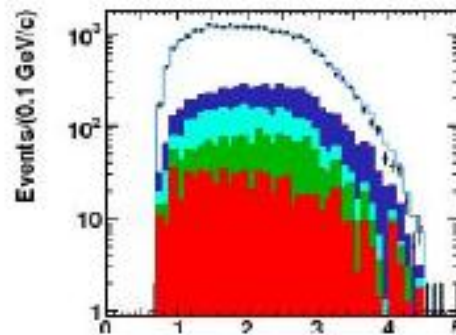
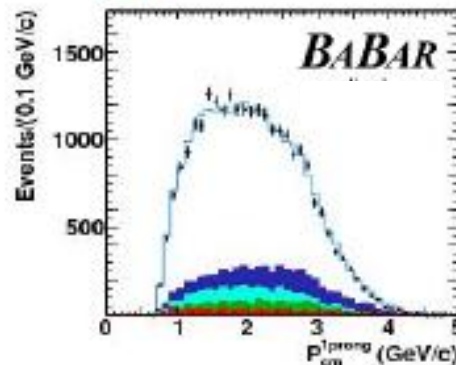
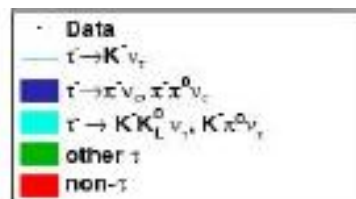
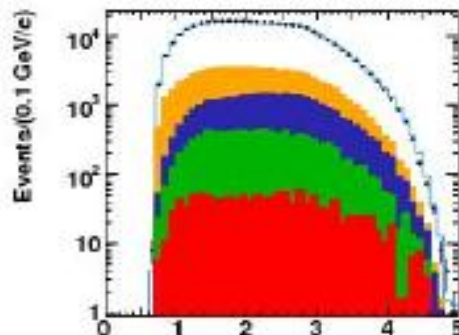
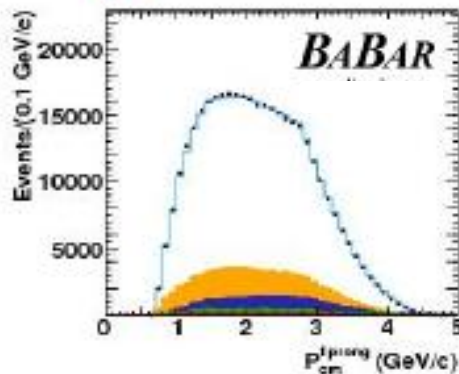
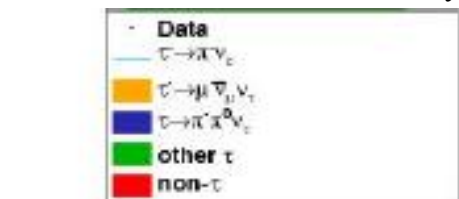
By measuring ratios, benefit from systematic uncertainty cancellation

Branching fraction results (M.Roney CIPANP 2009)

467 fb⁻¹

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

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



Branching Ratios (Preliminary)

$$B(\tau^- \rightarrow \pi^- \nu_\tau) / B(\tau^- \rightarrow e^- \nu_\tau \bar{\nu}_e)$$

$$(5.945 \pm 0.014 \pm 0.061) \times 10^{-1}$$

$$B(\tau^- \rightarrow K^- \nu_\tau) / B(\tau^- \rightarrow e^- \nu_\tau \bar{\nu}_e)$$

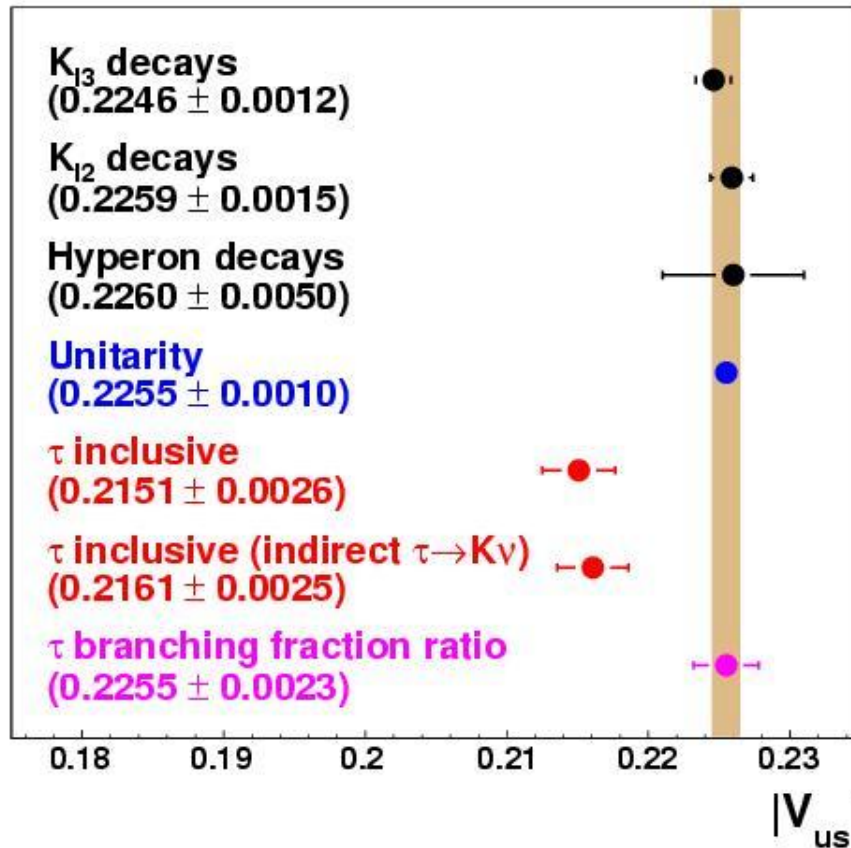
$$(3.882 \pm 0.032 \pm 0.056) \times 10^{-2}$$

$$B(\tau^- \rightarrow K^- \nu_\tau) / B(\tau^- \rightarrow \pi^- \nu_\tau)$$

$$(6.531 \pm 0.056 \pm 0.093) \times 10^{-2}$$

	$\mu^- \bar{\nu}_\mu$	π^-	K^-
Particle ID	0.32	0.51	0.94
EMC & DCH response	0.08	0.64	0.54
Backgrounds	0.08	0.44	0.85
Trigger	0.10	0.10	0.10
$\pi^- \pi^- \pi^+$ modelling	0.01	0.07	0.27
Radiation	0.04	0.10	0.04
$B(\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu_\tau)$	0.05	0.15	0.40
$\mathcal{L} \sigma_{e^+ e^- \rightarrow \tau^+ \tau^-}$	0.02	0.39	0.20
Total [%]	0.36	1.0	1.5

$|V_{us}|$ update from $\frac{B(\tau^- \rightarrow K^- \nu_\tau)}{B(\tau^- \rightarrow \pi^- \nu_\tau)}$



Compatible with unitarity

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

f_K/f_π is obtained from
lattice QCD

(E.Follana et al. PRL 100,
062002(2008))

V_{ud} from super-allowed
beta decays

Conclusion

$$\frac{B(\tau^- \rightarrow K^- \nu_\tau)}{B(\tau^- \rightarrow \pi^- \nu_\tau)} \longrightarrow V_{us} = 0.2255 \pm 0.0023$$

$$\tau \rightarrow s(\text{inclusive}) \longrightarrow V_{us} = 0.2151 \pm 0.0026$$

- $|V_{us}|$ from strange τ decays results in 3σ discrepancy from unitarity – however modes still to be measured by BaBar and Belle so discrepancy could go away – next dominant mode $(\bar{K}3\pi)^-$
- If discrepancy doesn't go away then may have to consider FESR $|V_{us}|$ which deviates from unitarity, and other methods of measuring $|V_{us}|$