$|V_{us}|$ from strange τ decays

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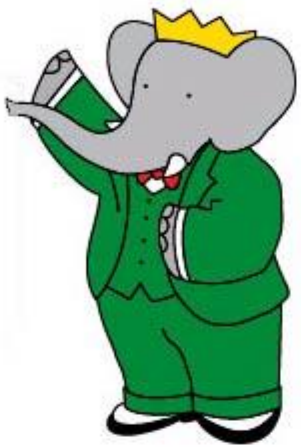
(On behalf of the BaBar Collaboration)



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 $\tau \longrightarrow s$ decays
  - Also $\dfrac{B(\tau^- \to K^- \nu_\tau)}{B(\tau^- \to \pi^- \nu_\tau)} \propto \dfrac{|V_{us}|^2}{|V_{ud}|^2}$
- Experimental Results
- Conclusions

Introduction

- *B* factories are also τ factories

  $\sigma_{\tau\tau}$=0.9nb, σ_{BB}=1.1nb
- Belle has recorded over 1000 fb^{-1} of data, while BaBar has 531 fb^{-1}.
- Have produced a wealth of τ physics results:

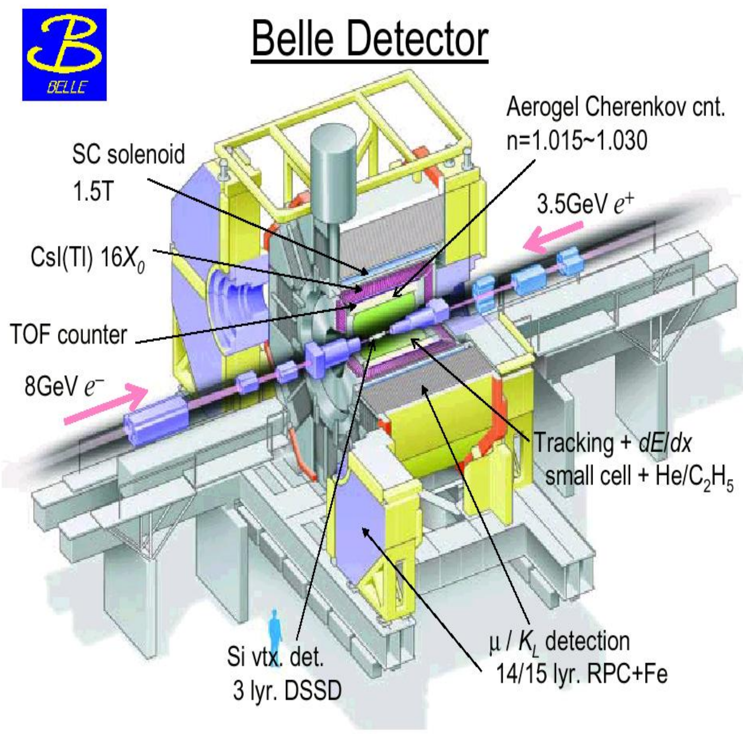
  Much improved constraints on Lepton Flavour Violation

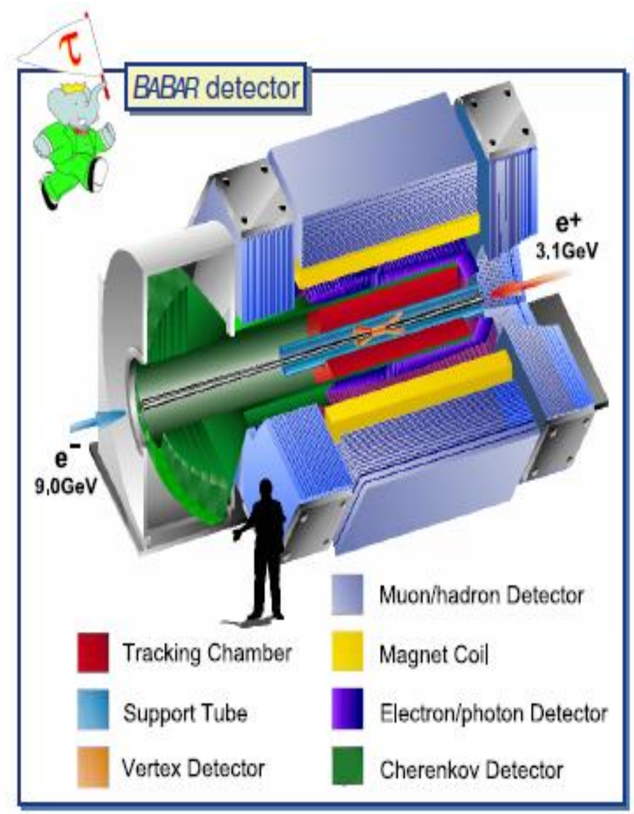
  Precise measurements e.g Branching fractions, τ mass

  $|V_{us}|$ from strange hadronic τ decays

Belle & BaBar

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





For this analysis: SVT+DCH important for secondary vertex (K^0_S)
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 $|V_{us}|$:

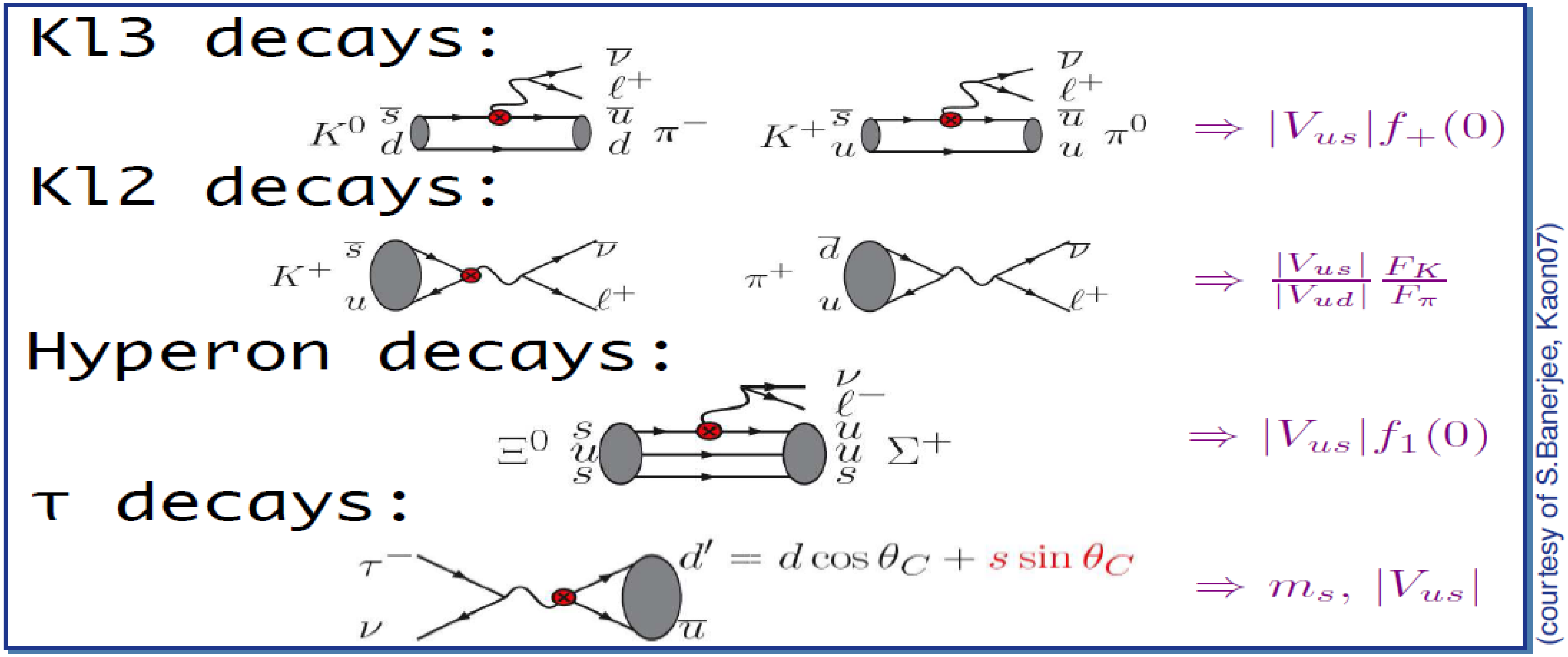
$$|V_{ud}|^2 + |V_{ub}|^2 + |V_{us}|^2 = 1$$

Vud = 0.97425±0.00022 (Towner Hardy 2009)

Vub = $(3.93\pm0.36)\times10^{-3}$

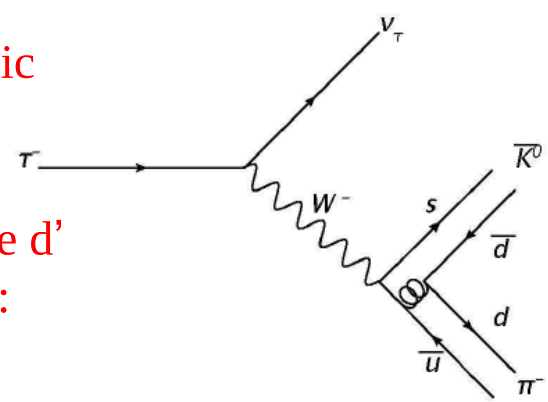
- Leads to $|V_{us}| = 0.2255 \pm 0.0010$

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



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 $\tau \to X_s \nu$

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

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

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

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

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 $\tau \to X_s \nu$	ICHEP08 averages (%)	References
K^- [from τ decay]	0.690 ± 0.010	PDG 2006 + BaBar 2008 prelim.
[indirect, from $K_{\mu 2}$]	(0.715 ± 0.004)	Gamiz *et al.*, PoSKAON:008,2008
$K^-\pi^0$	0.426 ± 0.016	BaBar 2007
$\overline{K}^0\pi^-$	0.835 ± 0.022 ($S = 1.4$)	Belle 2008, BaBar 2008
$K^-\pi^0\pi^0$	0.058 ± 0.024	PDG 2006
$\overline{K}^0\pi^0\pi^-$	0.360 ± 0.040	PDG 2006
$K^-\pi^-\pi^+$	$0.273 \pm 0.002 \pm 0.009$	Phys.Rev.Lett.100:011801,2008
$(\overline{K}3\pi)^-$ (est'd)	0.074 ± 0.030	ALEPH 2005
$K_1(1270) \to K^-\omega$	0.067 ± 0.021	ALEPH 2005
$(\overline{K}4\pi)^-$ (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 ($S = 1.3$)	Belle 2006, BaBar 2007
TOTAL	2.8447 ± 0.0688	
	(2.8697 ± 0.0680)	

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

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

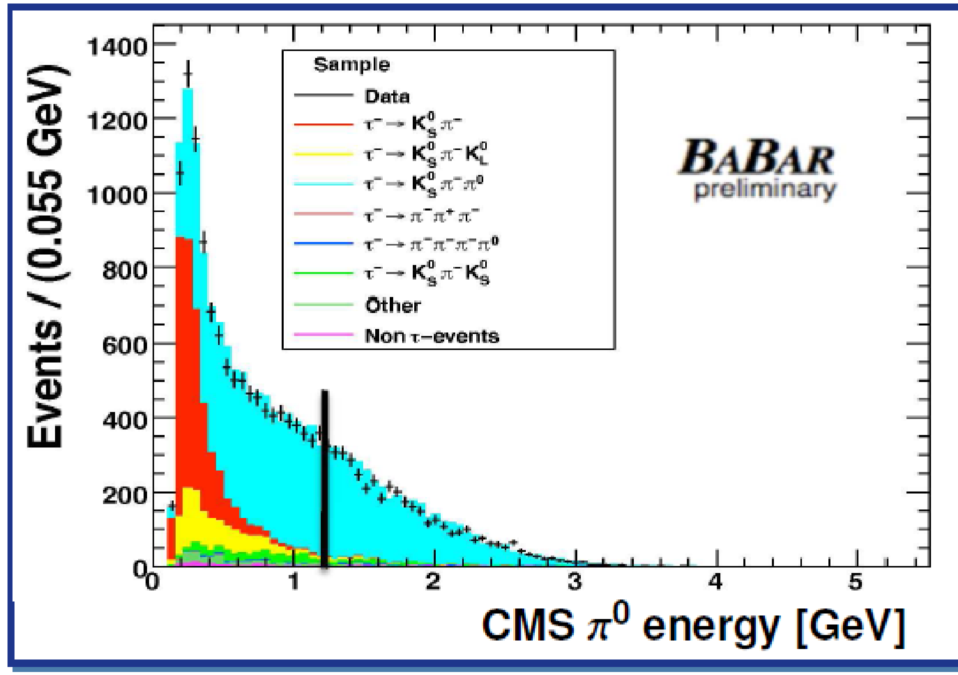
(S.Paramesvaran, DPF 2009)

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 $K_s^0 \pi^-$

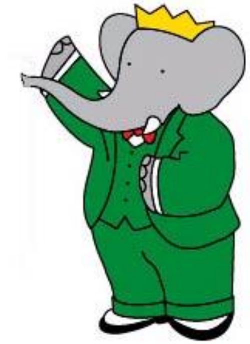
Requirement of π^0 energy to be greater than 1.2 GeV – signal purity = 93%.



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

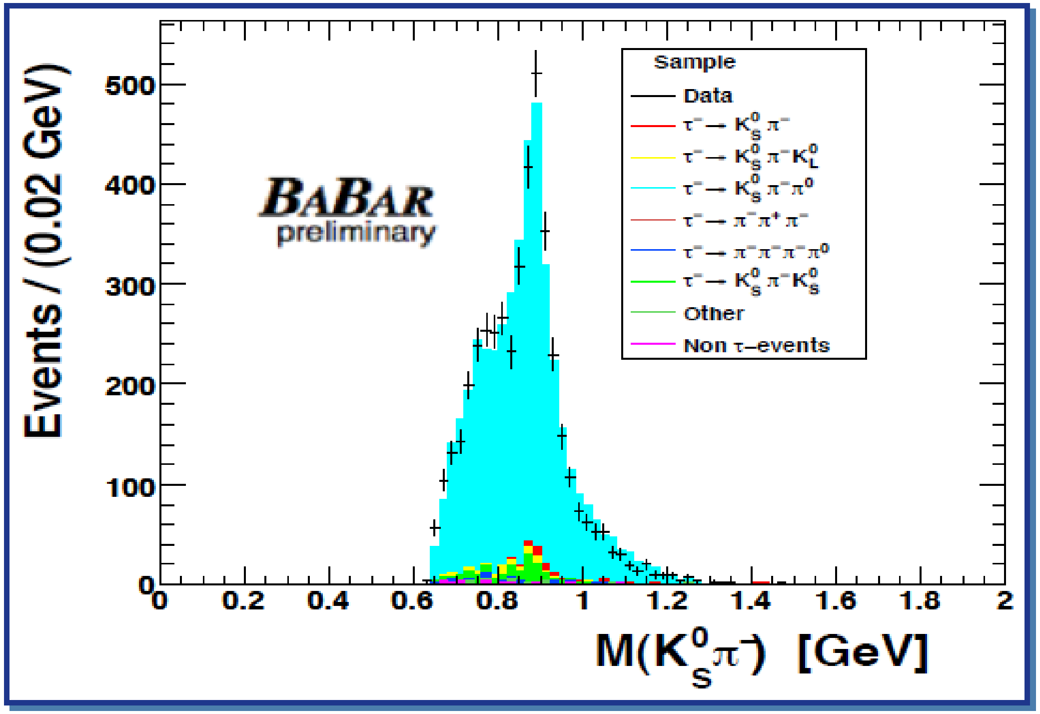
Measuring $\tau^- \to K_S^0 \pi^- \pi^0 \nu_\tau$

(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

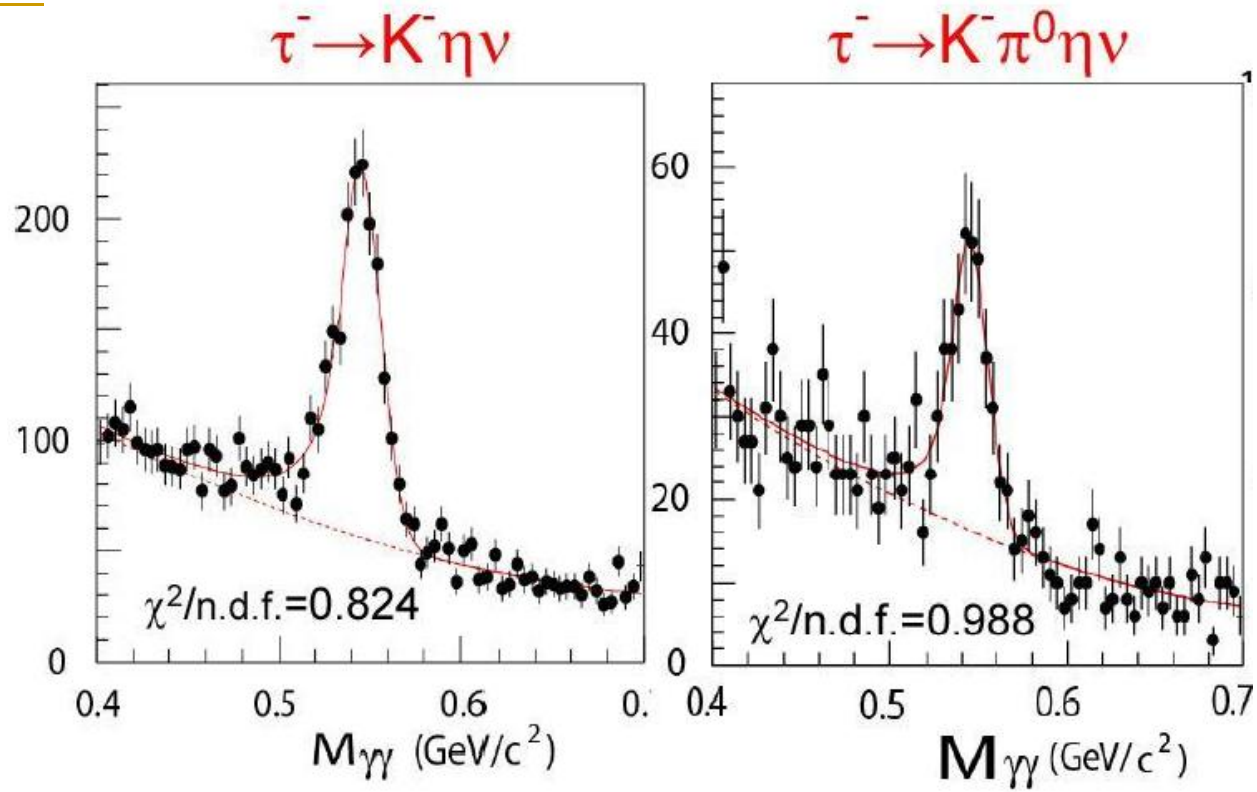
490 fb^{-1}

For $\tau^- \to K^- \eta \nu$

$\eta \to \gamma\gamma; \eta \to 3\pi$

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

$\eta \to \gamma\gamma$

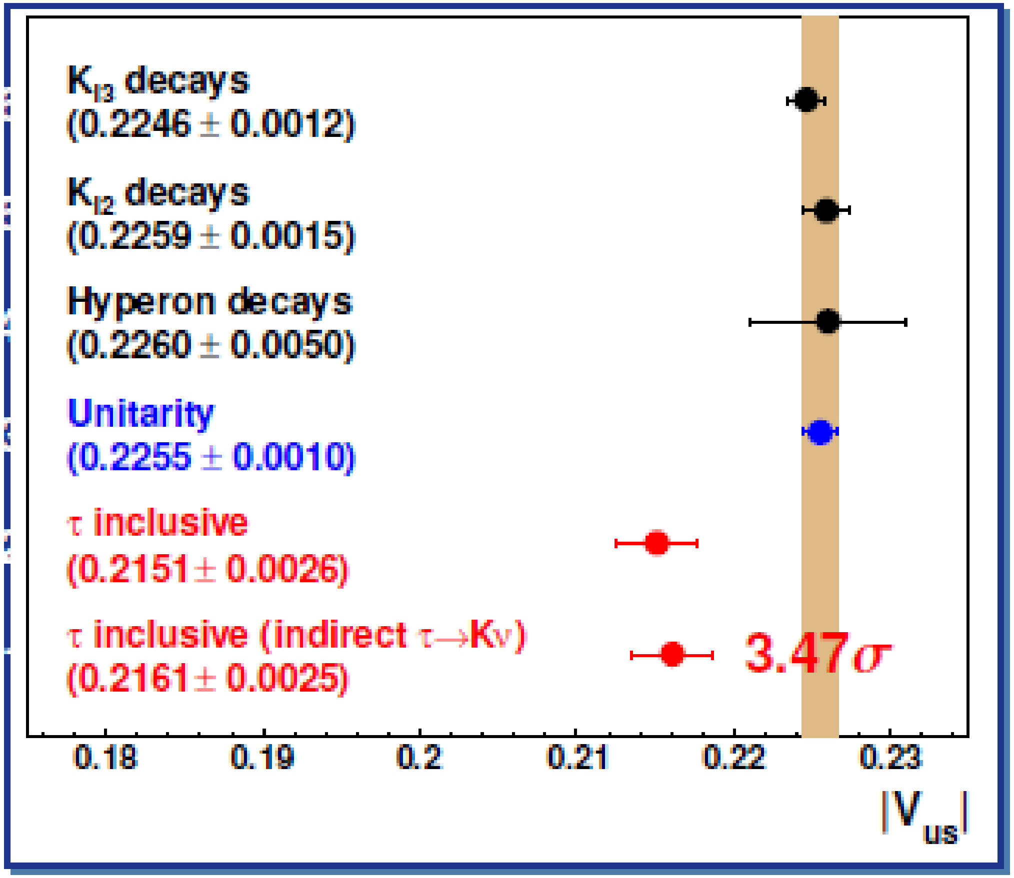


$$B(\tau^- \to K^- \eta \nu_\tau) = (1.58 \pm 0.05 \pm 0.09) \times 10^{-4}$$

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

BELLE

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



Using the following information:

V_{ud} – Towner Hardy 2009

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

(M Jamin et al 2006)

$\delta R^{00}_{\tau,theory} = 0.240 \pm 0.032$

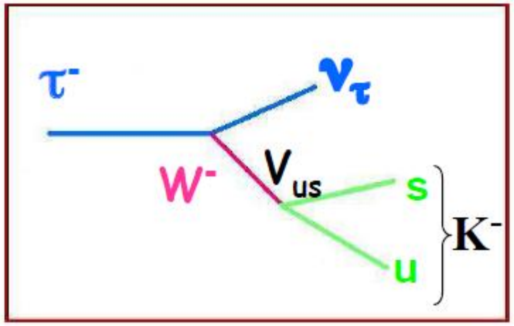
(Gamiz et al. 2007)

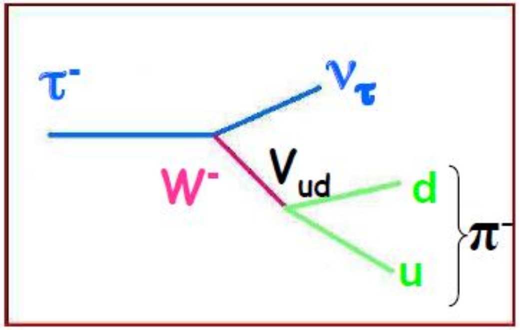
Branching fractions from ICHEP 2008, but includes update on $\tau^- \rightarrow K^0_S \pi^- \pi^0 \nu_\tau$

Alternative $|V_{us}|$ determination

arXiv:0912.0242

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



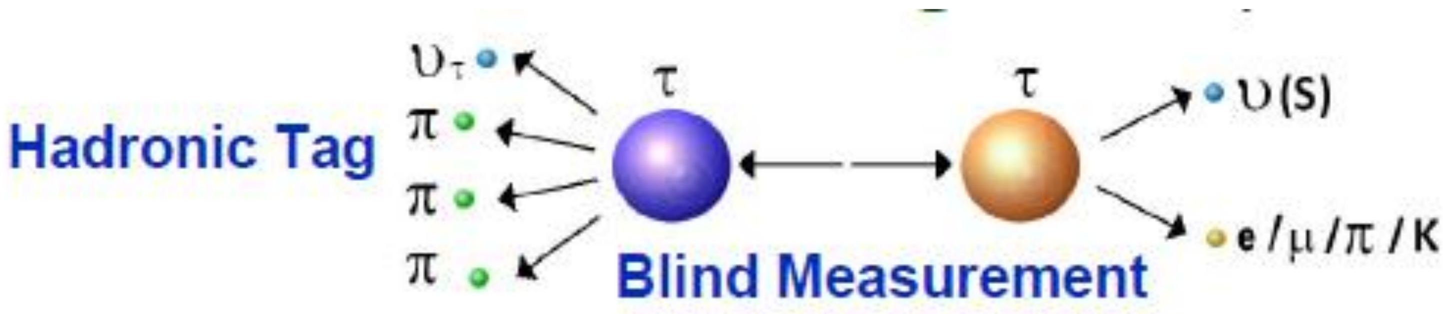


$$\frac{B(\tau^- \to K^- \nu_\tau)}{B(\tau^- \to \pi^- \nu_\tau)} = \frac{f_K^2}{f_\pi^2}\frac{|V_{us}|^2}{|V_{ud}|^2}\frac{(1-m_K^2/m_\tau^2)^2}{(1-m_\pi^2/m_\tau^2)^2}(1+\delta_{LD})$$

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



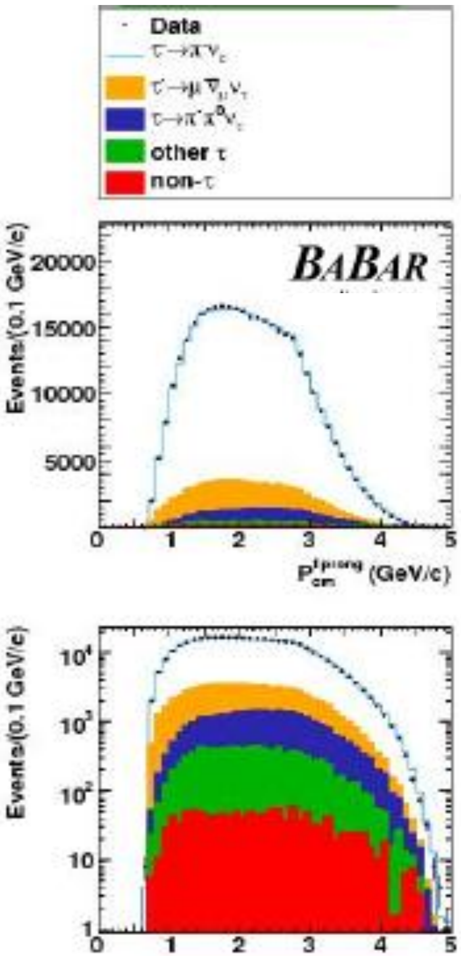
$$\frac{B(\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu)}{B(\tau^- \to e^- \nu_\tau \bar{\nu}_\mu)} \quad \frac{B(\tau^- \to \pi^- \nu_\tau)}{B(\tau^- \to e^- \nu_\tau \bar{\nu}_\mu)} \quad \frac{B(\tau^- \to K^- \nu_\tau)}{B(\tau^- \to e^- \nu_\tau \bar{\nu}_\mu)} \quad \boxed{\frac{B(\tau^- \to K^- \nu_\tau)}{B(\tau^-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

By measuring ratios, benefit from systematic uncertainty cancellation

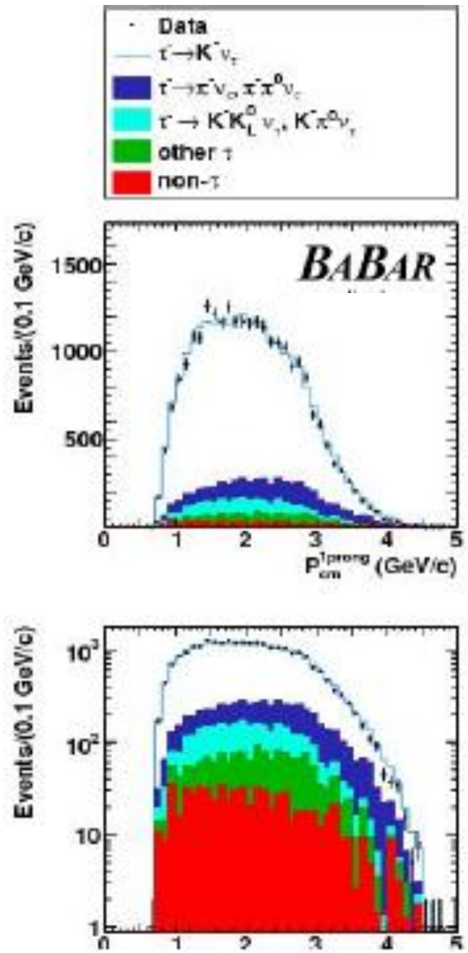
Branching fraction results (M.Roney CIPANP 2009)

467 fb^{-1}

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



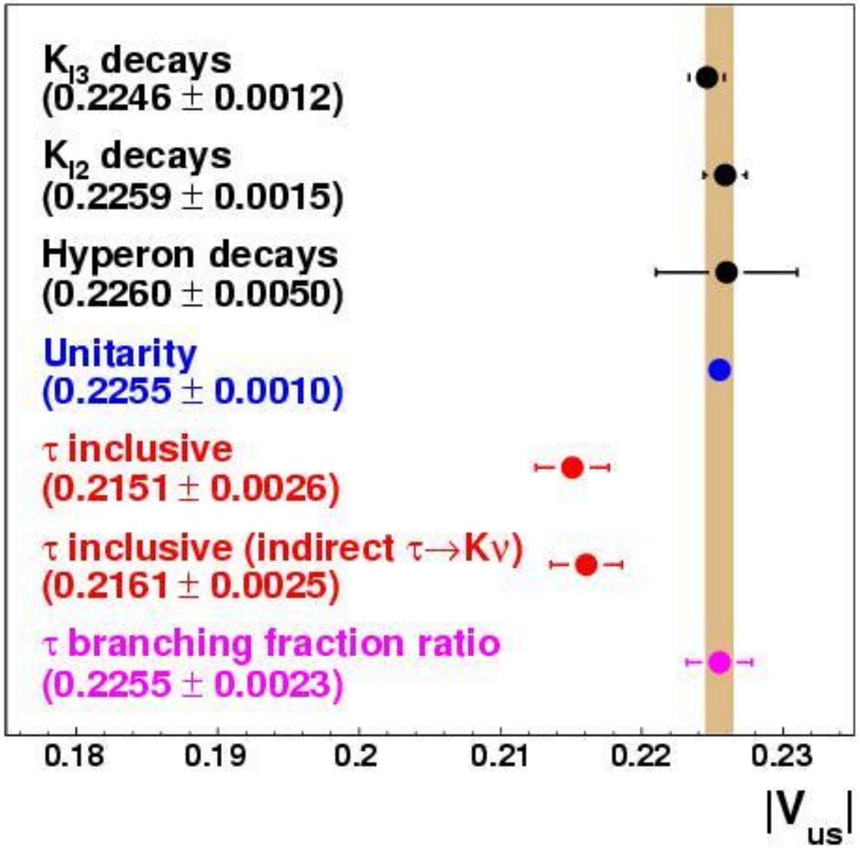
$\tau^- \to K^- \nu_\tau$



Branching Ratios (Preliminary)
$B(\tau^- \to \pi^- \nu_\tau)/B(\tau^- \to e^- \nu_\tau \bar{\nu}_e)$
$(5.945 \pm 0.014 \pm 0.061) \times 10^{-1}$
$B(\tau^- \to K^- \nu_\tau)/B(\tau^- \to e^- \nu_\tau \bar{\nu}_e)$
$(3.882 \pm 0.032 \pm 0.056) \times 10^{-2}$
$B(\tau^- \to K^- \nu_\tau)/B(\tau^- \to \pi^- \nu_\tau)$
$(6.531 \pm 0.056 \pm 0.093) \times 10^{-2}$

	$\mu^- \bar{\nu}_\mu$	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
$\mathcal{B}(\tau^- \to \pi^-\pi^-\pi^+\nu_\tau)$	0.05	0.15	0.40
$\mathcal{L}\sigma_{e^+e^- \to \tau^+\tau^-}$	0.02	0.39	0.20
Total [%]	0.36	1.0	1.5

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



Compatible with unitarity

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

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

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

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

- $|V_{us}|$ 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 $|V_{us}|$