Measurements of τ Decays into Kaons at BaBar and Determination of $|V_{us}|$

Aleksandra Adametz
Heidelberg University

Outline

- τ Physics at BaBar
- Theoretical overview
- Experimental determination of $|V_{us}|$

  $\rightarrow$ from inclusive $\tau \rightarrow s$ decays

  $\rightarrow$ from the ratio $\dfrac{BF(\tau \rightarrow K\nu)}{BF(\tau \rightarrow \pi\nu)}$
- Conclusion

τ Physics at BaBar

BaBar is a τ factory:

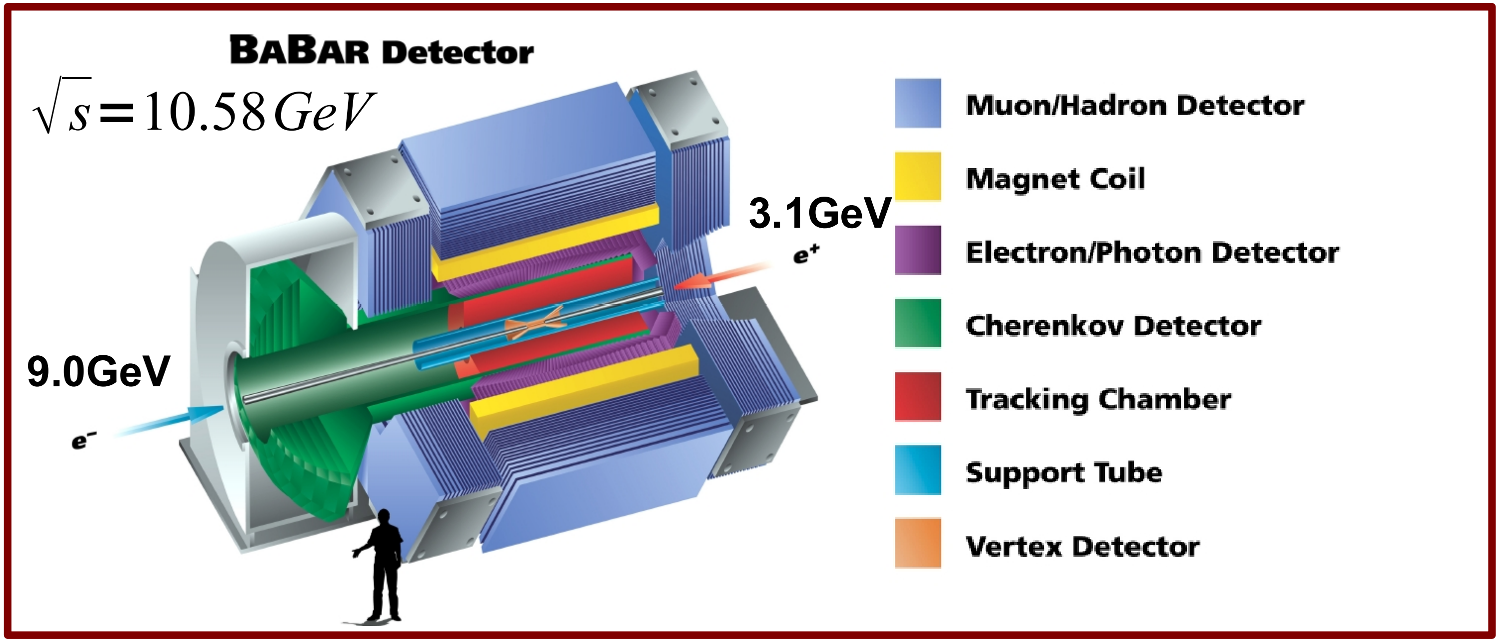
$\sigma_{\tau\tau}$ = 0.9 nb, (σ_{BB} = 1.1 nb)

$\mathcal{L}$ = 531 fb^{-1}

$\rightarrow$ 488 million $\tau\tau$ pairs

Areas of τ Physics with recent results:

- precise τ branching fractions
- τ mass
- constraints on Lepton Flavor Violation
- $|V_{us}|$ from strange τ decays



CKM Matrix element $|V_{us}|$

- Cabibbo-Kobayashi-Maskawa Matrix

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

- Unitarity condition:

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

negligibly small

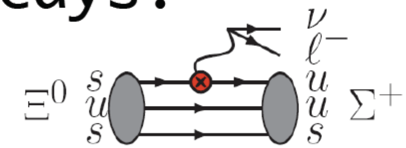
$|V_{ud}| = 0.97425 \pm 0.00022$
(Towner,Hardy 2009)
$|V_{ub}| = (3.93 \pm 0.36) \times 10^{-3}$

$$\boxed{|V_{us}| = 0.2255 \pm 0.0010}$$

Methods of |V$_{us}$| determination

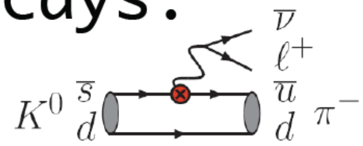
courtesy of S. Banerjee, Kaon07

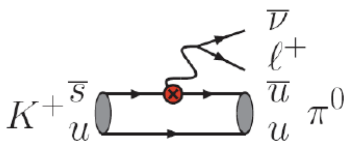
Hyperon decays:



$\Rightarrow |V_{us}| f_1(0)$

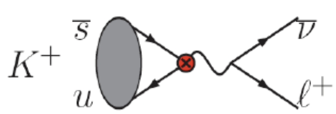
Kl3 decays:

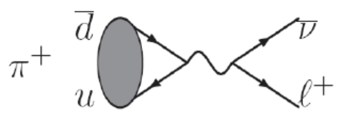




$\Rightarrow |V_{us}| f_+(0)$

Kl2 decays:



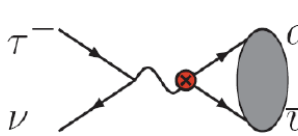


$\Rightarrow \frac{|V_{us}|}{|V_{ud}|} \frac{F_K}{F_\pi}$

τ decays, kl2-like method:

$$\frac{BR(\tau \to K\nu)}{BR(\tau \to \pi\nu)} \propto \frac{|V_{us}|^2}{|V_{ud}|^2} \frac{F_K^2}{F_\pi^2}$$

τ decays:



$d' = d\cos\theta_C + s\sin\theta_C$

$\Rightarrow m_s,\ |V_{us}|$

limited by theory uncertainty:

σ[f+(0)] = 0.51%
(PRL 100:141601,2008)

σ[F_K/F_π] = 0.59%
(PRL 100:062002,2008)

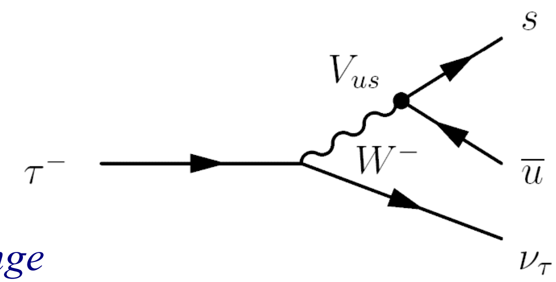
limited by statistical uncertainty

|V$_{us}$| theory uncertainty estimate: 0.23%
(PoSKAON:008, 2008)

$|V_{us}|$ from inclusive $\tau \to s$ decays

τ decay rate into hadrons

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



Branching fractions are experimental input for $|V_{us}|$ determination:

$$|V_{us}|^2 = \frac{R_{\tau, strange}}{\dfrac{R_{\tau, non\,strange}}{|V_{ud}|^2} + \delta R_{OPE}}$$

δR is a SU(3) symmetry breaking correction, obtained from OPE/FESR, small; <0.1* $R_{\tau,ns}/|V_{ud}|^2$

OPE = Operator Product Expansion
FESR = Finite Energy Sum Rules

(Gamiz et al., 2007)

Strange τ Decays

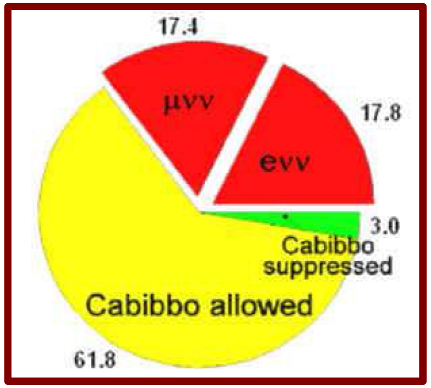
Decay	$\mathcal{B}_{PDG2009}[\%]$			$\frac{\Delta\mathcal{B}}{\mathcal{B}}[\%]$
$\tau^- \to K^-\nu_\tau$	0.685	$\pm$	0.023	3.4
$(\tau^- \to K^-\nu_\tau$ [indirect]	0.715	$\pm$	0.004	0.6)
$\tau^- \to K^-\pi^0\nu_\tau$	0.426	$\pm$	0.016	3.8
$\tau^- \to K^-\pi^0\pi^0\nu_\tau$	0.058	$\pm$	0.024	30
$\tau^- \to \overline{K}^0\nu_\tau$	0.831	$\pm$	0.030	5.7
$\tau^- \to \overline{K}^0\pi^0\nu_\tau$	0.360	$\pm$	0.040	11
$\tau^- \to K^-\pi^-\pi^+\nu_\tau$	0.280	$\pm$	0.002	0.7
$\tau^- \to (\overline{K}\pi\pi\pi)^-\nu_\tau$ (est'd)	0.074	$\pm$	0.030	40
$\tau^- \to (\overline{K}\pi\pi\pi\pi)^-\nu_\tau$ (est'd)	0.011	$\pm$	0.007	64
$\tau^- \to K_1(1270)\nu_\tau \to K^-\omega$	0.067	$\pm$	0.021	31
$\tau^- \to K^-\eta\nu_\tau$	0.016	$\pm$	0.001	6.2
$\tau^- \to K^{*-}\eta\nu_\tau$	0.013	$\pm$	0.002	15
$\tau^- \to K^-\phi\nu_\tau$	0.0037	$\pm$	0.0003	8.1
Total	2.8247	$\pm$	0.0725	2.6
	(2.8547	$\pm$	0.0689	2.4)

(*) indirect $\tau \to K\nu$

use precise measurement of BF[$K \to \mu\nu(\gamma)$]

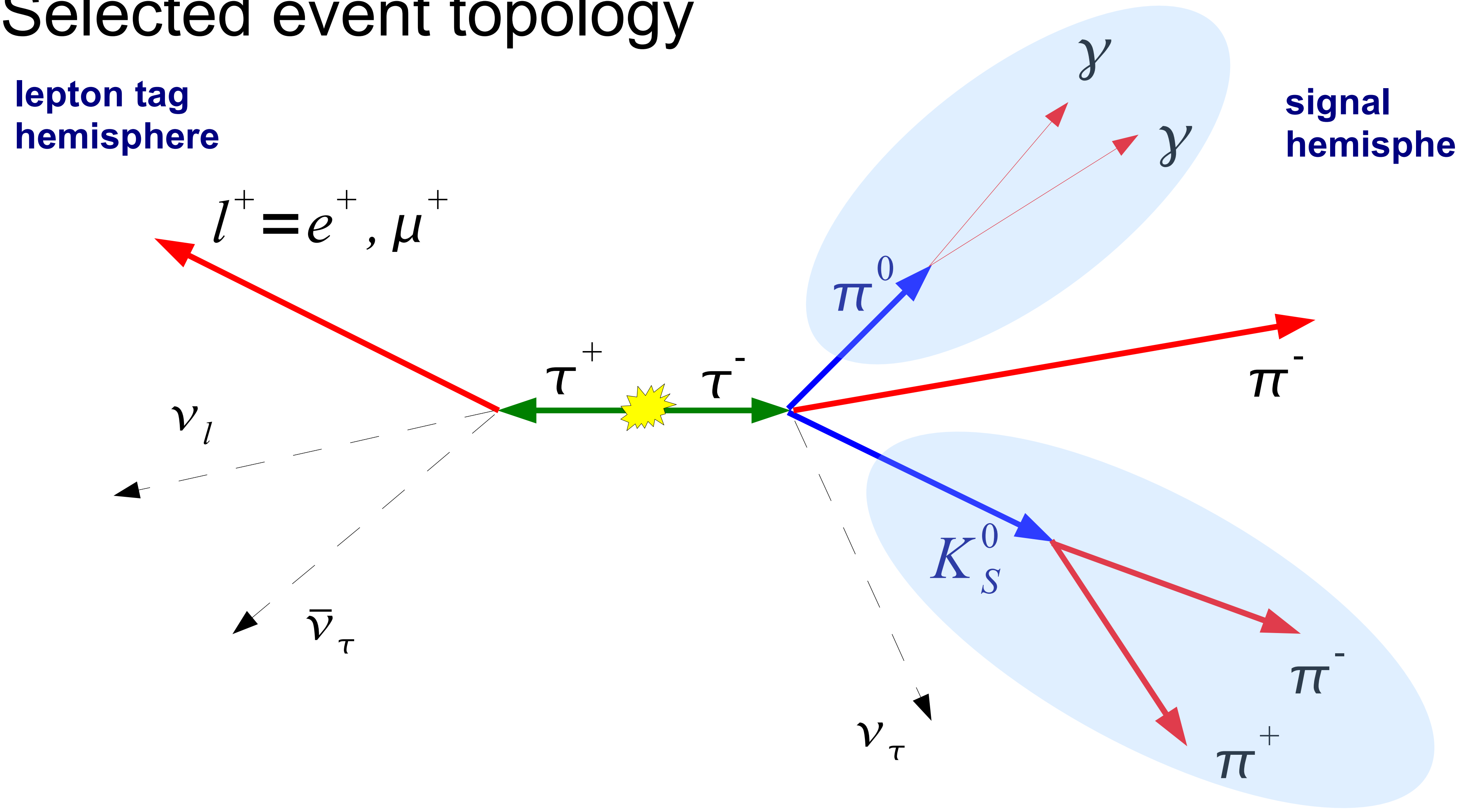
to get indirect measurement of BF[$\tau \to K\nu(\gamma)$]

Rev.Mod.Phys. 78 1043 (2006)



Measurement of $\tau \rightarrow K^0_s \pi \pi^0 \nu_\tau$

Selected event topology

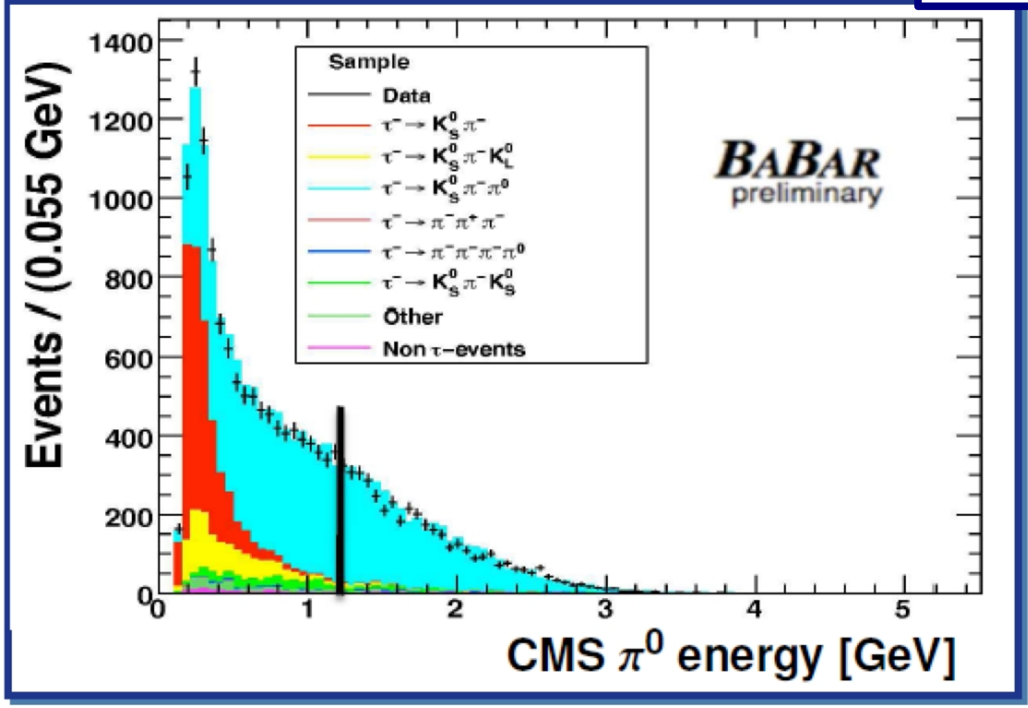


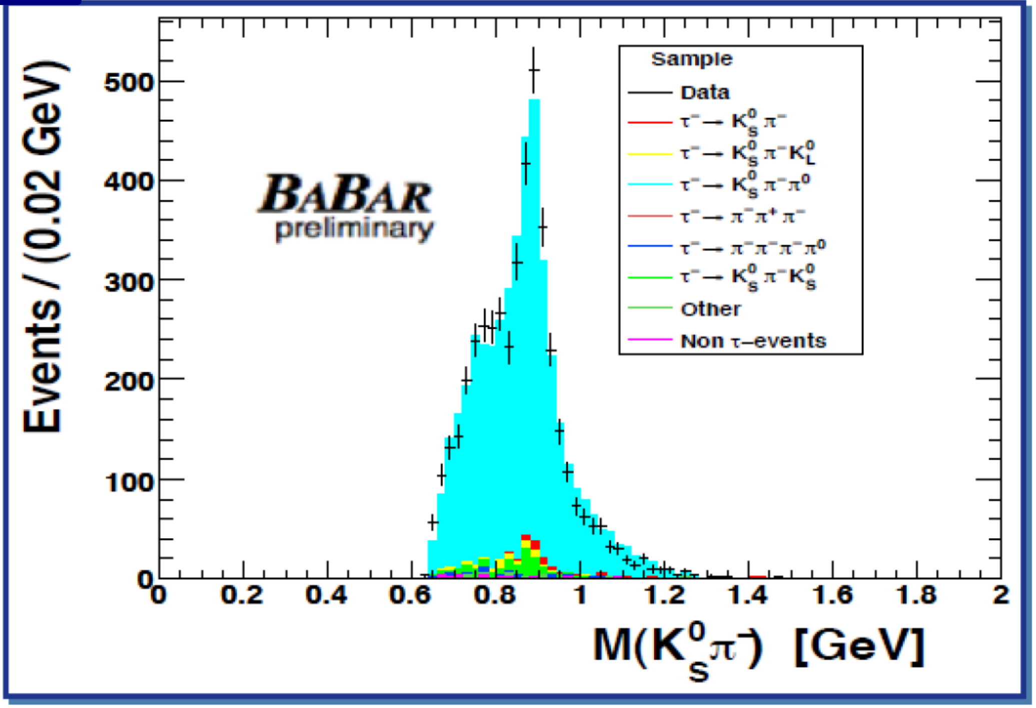
red arrows: particles reconstructed with the BaBar detector

(S.Paramesvaran, DPF2009)

Measurement of $\tau \to K_s^0 \pi \pi^0 \nu_\tau$

384 fb^{-1}





- lepton tag on signal side
- high π^0 energy required in CMS
  - $\to$ high purity (93%)
- π^0 trajectory within 90° of $K_S^0\pi$ momentum

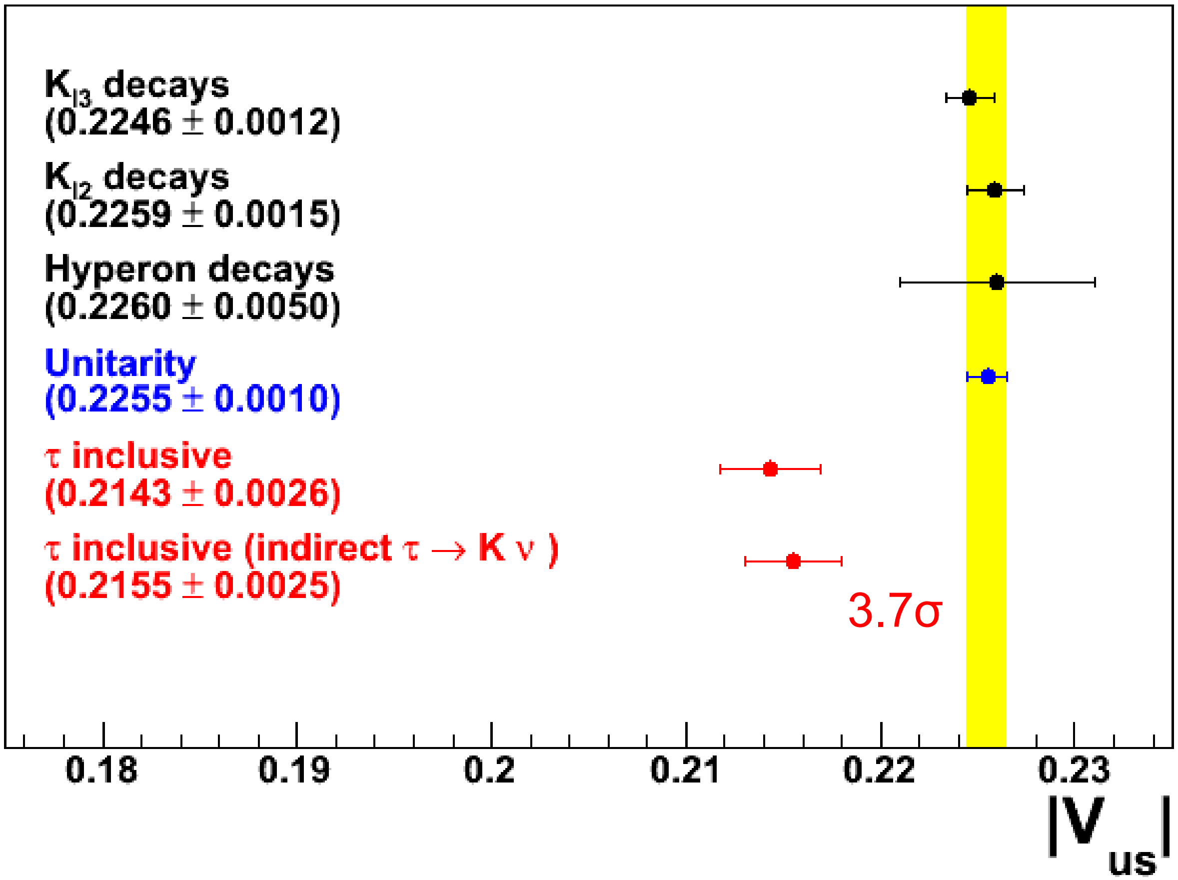
- τ Monte Carlo hadronic mass distribution tuned with data
- Dominant systematic uncertainty:
  - $\to$ π^0 reconstruction efficiency (0.011%, rel. 3.2%)

BABAR preliminary

$$BF(\tau \to K_s^0 \pi \pi^0 \nu_\tau) = [0.342 \pm 0.006(stat.) \pm 0.015(syst.)]\%$$

$\sigma_{rel.}$ 4.7%

|Vus| from inclusive $\tau \rightarrow s$



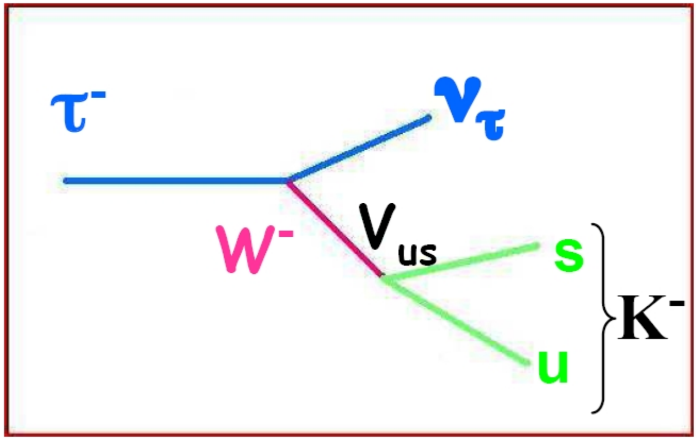
- |Vus| from K,Hyp,Uni. (A.Denig Chiral2009)
- m_s(2GeV) = 94 ± 6 MeV (M.Jamin et al., 2006)
- δR_{OPE} = 0.240 ± 0.032 (Gamiz et al., 2007)
- Vud (Towner, Hardy 2009)
- BF($\tau \rightarrow$ s) from PDG2009

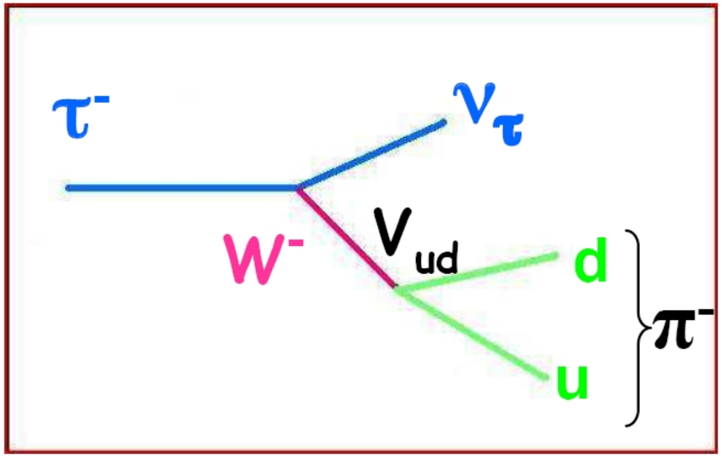
→ update with new

$$BF\left(\tau \rightarrow K_s^0 \pi \pi^0 \nu_\tau\right)$$

|Vus| precision:
→ before update: 1.31%
→ Now: 1.15%

$|V_{us}|$ from ratio $\frac{BF(\tau \to K\nu)}{BF(\tau \to \pi\nu)}$





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

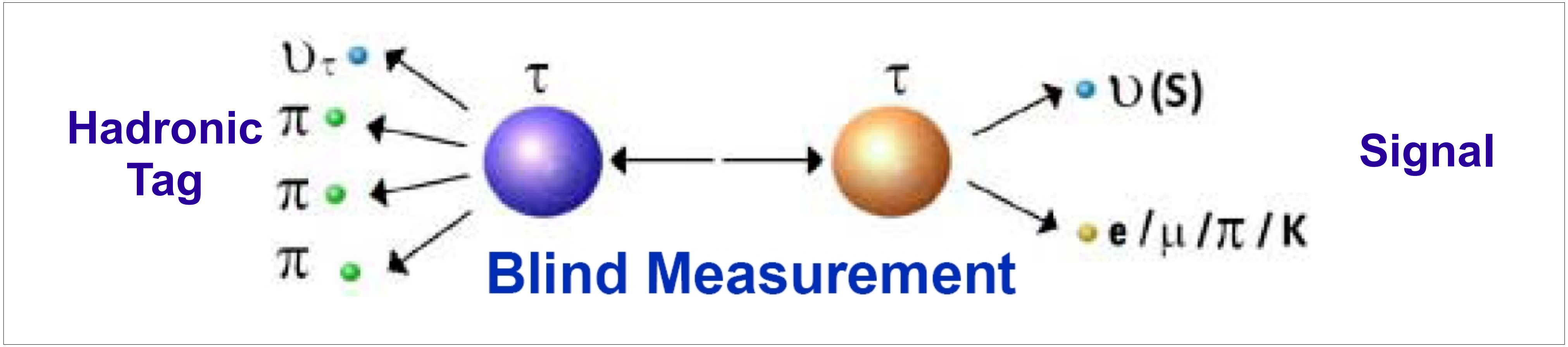
- δ_{LD} long distance electroweak correction

  (short distance correction cancel) (arXiv:0402299)
- $|V_{ud}|$ from super allowed beta decays (Towner, Hardy 2009)
- ratio f_K^2 / f_π^2 from lattice QCD (E. Follana et al. PRL 100)

Measurement of $\frac{BF(\tau \to K \nu)}{BF(\tau \to \pi \nu)}$

Select $\tau\tau$ events with

- one τ decaying into 3 charged pions and neutrino (hadronic tag)
- the other τ into the signal decay



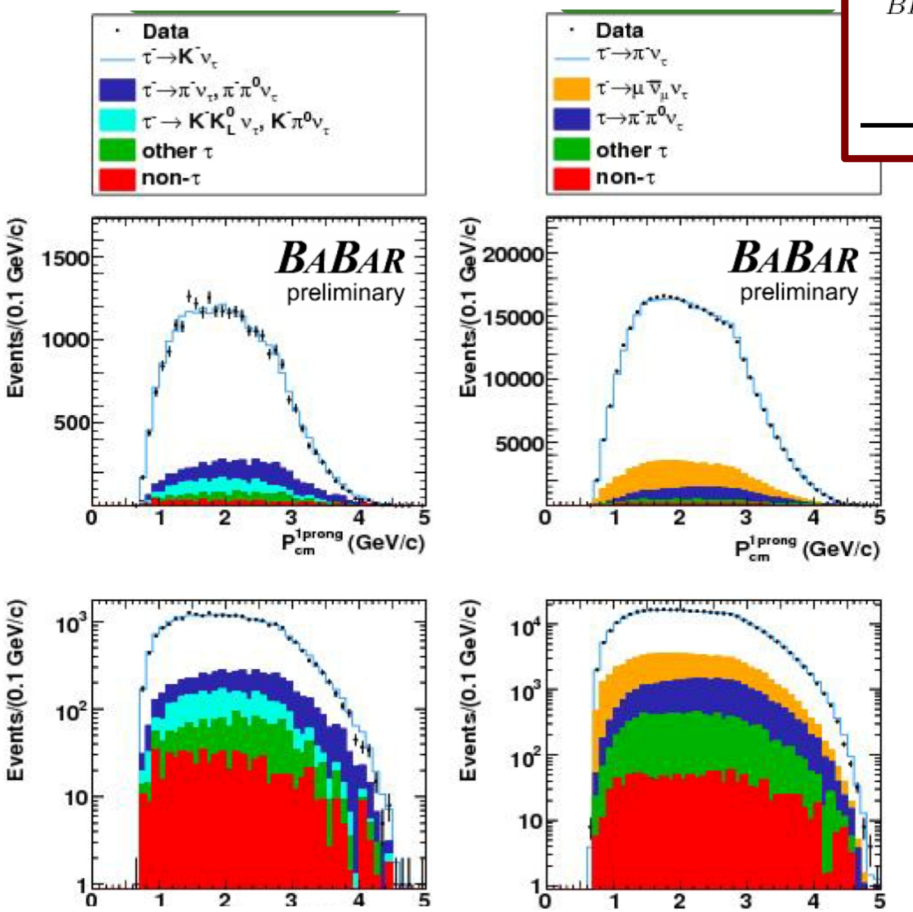
Measure: $\frac{BF(\tau^- \to \pi^- \nu_\tau)}{BF(\tau^- \to e^- \nu_\tau \bar{\nu}_e)}$ $\frac{BF(\tau^- \to K^- \nu_\tau)}{BF(\tau^- \to e^- \nu_\tau \bar{\nu}_e)}$ $\boxed{\frac{BF(\tau^- \to K^- \nu_\tau)}{BF(\tau^- \to \pi^- \nu_\tau)}}$

- Systematic effects cancel in the ratios
  (e.g. uncertainties of efficiencies, luminosity)

$\frac{BF(\tau \to K\nu)}{BF(\tau \to \pi\nu)}$ results

467 fb^{-1}

$\tau \to K\nu$ $\tau \to \pi\nu$



p_K [GeV/c] in CMS p_π [GeV/c] in CMS

Decay	$\tau \to K\nu_\tau$	$\tau \to \pi\nu_\tau$
$\frac{BF}{BF(\tau \to e\nu_\tau\bar{\nu}_e)}$	0.03883 ±0.00032 ±0.00057	0.5945 ±0.0014 ±0.0061
BF	$(0.692 \pm 0.006 \pm 0.010)\%$	$(10.59 \pm 0.03 \pm 0.11)\%$
BF_{PDG}	$(0.685 \pm 0.023)\%$	$(10.828 \pm 0.105)\%$

$B(\tau^- \to K^-\nu_\tau)/B(\tau^- \to \pi^-\nu_\tau)$
$(6.531 \pm 0.056 \pm 0.093) \times 10^{-2}$

Systematic uncertainties:	B(π)/B(e)	B(K)/B(e)
Particle ID	0.51	0.94
Detector response	0.64	0.54
Backgrounds	0.44	0.85
Trigger	0.10	0.10
$\pi^-\pi^-\pi^+$ modelling	0.07	0.27
Radiation	0.10	0.04
$\mathcal{B}(\tau^- \to \pi^-\pi^-\pi^+\nu_\tau)$	0.15	0.40
$\mathcal{L}\sigma_{e^+e^- \to \tau^+\tau^-}$	0.39	0.20
Total [%]	1.0	1.5

next slide

PID uncertainty in $\frac{BF(\tau \to K\nu)}{BF(\tau \to \pi\nu)}$ analysis

One of the dominant systematic effects: charged particle identification

- PID algorithm performance is studied using control samples
- PID algorithm is applied to unbiased track of known type to determine the efficiency in data and simulation: differences are corrected

Kaon and pion identification

- Studied using two independent control samples

A control pion and a control kaon is kinematically selected in the decay chain:

$$D^{*+} \to \pi^{+}_{soft} D^0$$
$$D^0(\to \pi^+ K^-)$$

- control pion has same charge as soft π
- control kaon has opposite charge as soft π

Additional cross check:

τ decays in 3 charged tracks

- determine particle ID of two tracks
- 3rd track is control pion/kaon

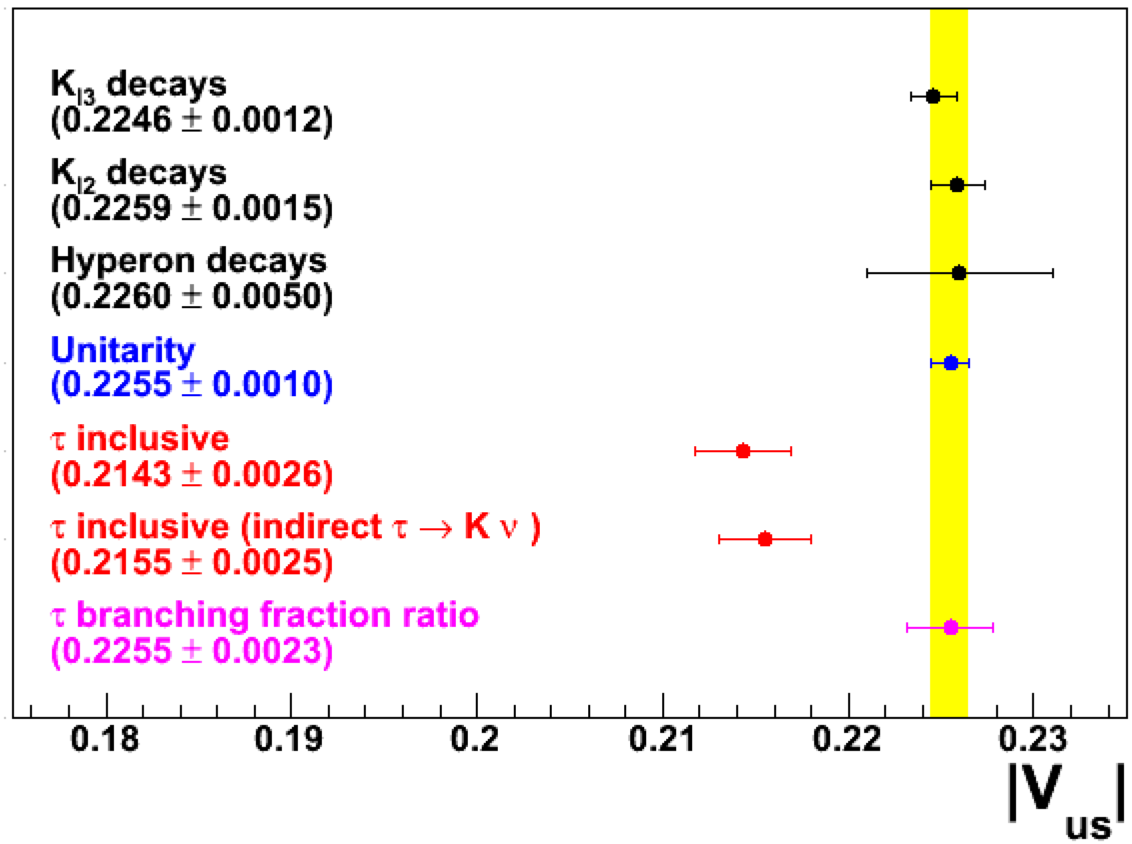
Pion control sample: $\tau^- \to \pi^- \pi^- \pi^+ \nu_\tau$

Kaon control sample: $\tau^- \to K^- \pi^- K^+ \nu_\tau$

Electron and Muon identification: Bhabha and radiative μ-pair control samples

→ e/μ/π/K PID efficiency uncertainties are combined to a total PID uncertainty (previous slide)

$|V_{us}|$ from $\frac{BF(\tau \to K\nu)}{BF(\tau \to \pi\nu)}$



- δ_{LD} = (0.03 ± 0.44)% (arXiv:0811.1429)
- $|V_{ud}|$= 0.97425 ± 0.00022 (Towner, Hardy 2009)
- f_K/f_π = 1.189 ± 0.007 (E. Follana et al. PRL 100)

$|V_{us}|$ consistent with unitarity

Conclusion

Unitarity	0.2255 ± 0.0010
inclusive $\tau \to s$	0.2155 ± 0.0025
$\frac{BF(\tau \to K\nu)}{BF(\tau \to \pi\nu)}$	0.2255 ± 0.0023

- $|V_{us}|$ from BF ratio consistent with unitarity.
- $|V_{us}|$ from inclusive $\tau \to s$ decays: ~3σ discrepancy from unitarity.

However:

- Program of $\tau \to s$ measurements not yet completed. (Only estimates for $\tau^- \to (\overline{K}\pi\pi\pi)^-\nu_\tau$, $\tau^- \to (\overline{K}\pi\pi\pi\pi)^-\nu_\tau$).
- Neglected correlations between BF measurements.
  → The recently formed HFAG-tau group is addressing that.
- Theorists are re-examining the FESR calculation of δR.