HADRONIC TAU DECAYS FROM BABAR & BELLE: MEASUREMENT OF $|V_{us}|$

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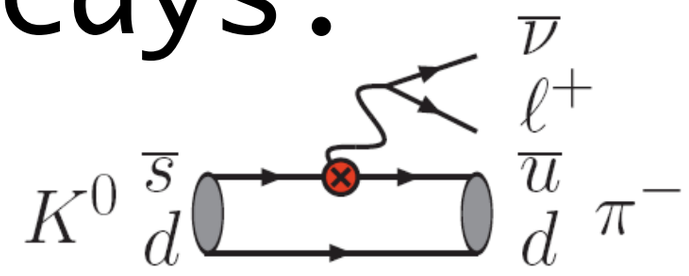
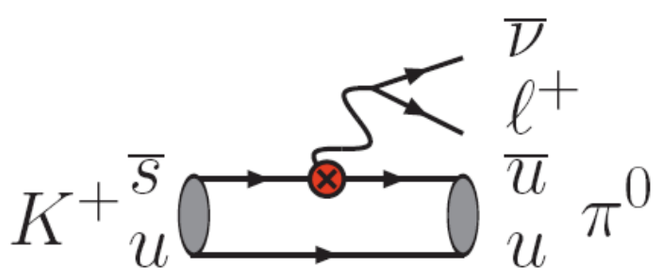
APPROACHES TO $|V_{us}|$

See A.Pich's talk for details

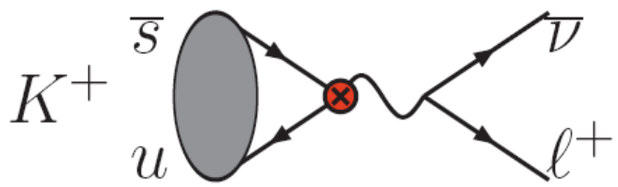
Kl3 decays:

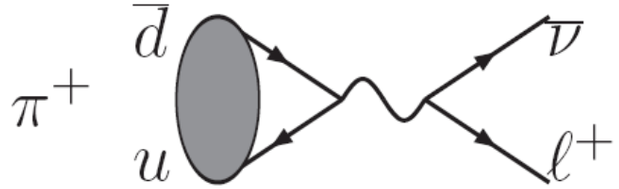




$\Rightarrow |V_{us}| f_+(0)$

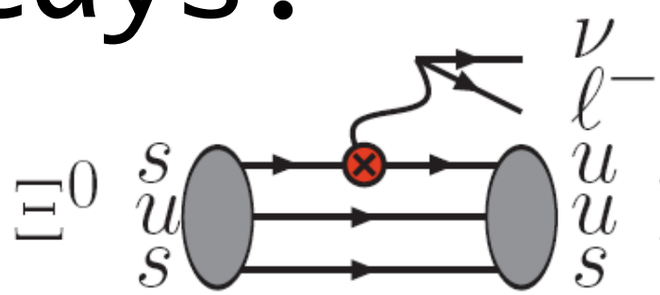
Kl2 decays:





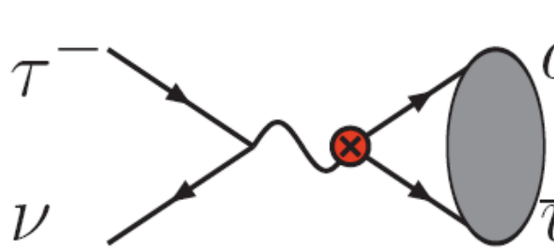
$\Rightarrow \dfrac{|V_{us}|}{|V_{ud}|}\dfrac{F_K}{F_\pi}$

Hyperon decays:



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

τ decays:



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

τ-SPECTRAL DENSITY

Hadronic Width: $$R_\tau = \frac{\Gamma(\tau^- \to \nu_\tau \text{hadrons}^-)}{\Gamma(\tau^- \to \nu_\tau e^- \overline{\nu}_e)}$$

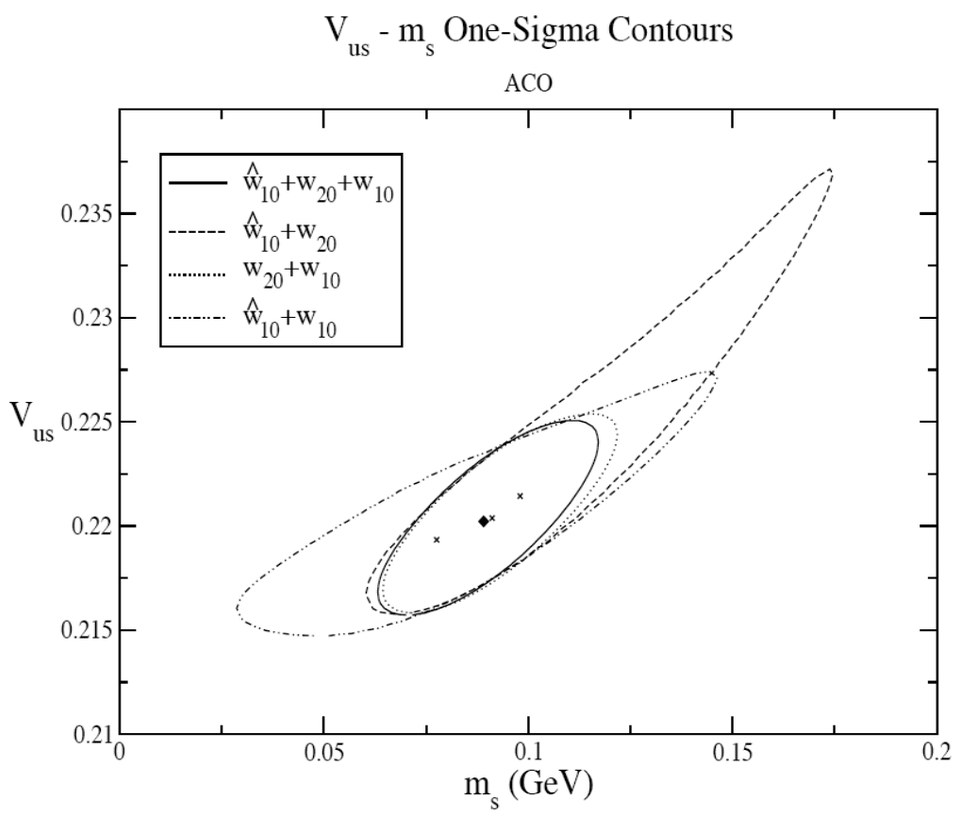
Spectral Moments: $$R_\tau^{kl} = \int_0^1 dz (1-z)^k z^l \frac{dR_\tau}{dz}, \; z = \frac{q^2}{m_\tau^2}$$

Flavor-SU(3) breaking sensitive to m_s : $$\delta R_\tau^{kl} = \frac{R_{\tau,non-strange}^{kl}}{|V_{ud}|^2} - \frac{R_{\tau,strange}^{kl}}{|V_{us}|^2}$$

Possible to simultaneously extract m_s, $|V_{us}|$

Non-spectral weight joint fit contours

Maltman, Wolfe (Tau06)
hep-ph/0611180



$|V_{us}|$ WITH FIXED M_s

$$|V_{us}| = \sqrt{R^{00}_{\tau,strange} \Big/ \left[\frac{R^{00}_{\tau,non-strange}}{|V_{ud}|^2} - \delta R^{00}_{\tau,th}\right]}$$

QCD Sum rules, Lattice:

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

Jamin, Oller, Pich (PRD74, 074009, 2006)

Smallest uncertainity on (0,0) moment

$$\begin{aligned}\delta R^{00}_{\tau,\text{th}} &= 0.1544\,(37) + 9.3\,(3.4)\,m_s^2 \\ &+ 0.0034\,(28) = 0.240\,(32)\end{aligned}$$

Jamin, Tau06 (hep-ph/0612154)

$$\delta R_{\tau,theory} << R_\tau$$

$\Rightarrow$ modest $\Delta(\delta R_{\tau,\text{theory}}) \equiv 13\%$ gives small error on $|V_{us}|$

$$|V_{ud}| = 0.97377 \pm 0.00027$$
(PDG '06)

$R_{strange}$, $R_{non\text{-}strange}$

- Direct measurement averaged with $\mathcal{B}_e$ from $\mathcal{B}_\mu$ & τ_τ:
  $\mathcal{B}_e^{uni} = (17.818 \pm 0.032)\%$

- $$\mathcal{B}_{\rm had} = 1 - \mathcal{B}_e - \mathcal{B}_\mu$$
  $$= 1 - 1.97257\,\mathcal{B}_e^{\rm uni}$$
  $$= (64.853 \pm 0.063)\%$$

- $$R_\tau = (3.640 \pm 0.010)$$

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

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

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

Rstrange, Rnon-strange

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- $\mathcal{B}_{\rm had} = 1 - \mathcal{B}_e - \mathcal{B}_\mu$
  $= 1 - 1.97257\,\mathcal{B}_e^{\rm uni}$
  $= (64.853 \pm 0.063)\%$

- $R_\tau = (3.640 \pm 0.010)$

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

Updates:
- $\tau^- \to K^-\pi^0\nu$ from BaBar
- $\tau^- \to K^0_S\pi^-\nu$ from Belle
- $\tau^- \to K^-\pi^+\pi^-\nu$ from BaBar

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

Strange τ decays:

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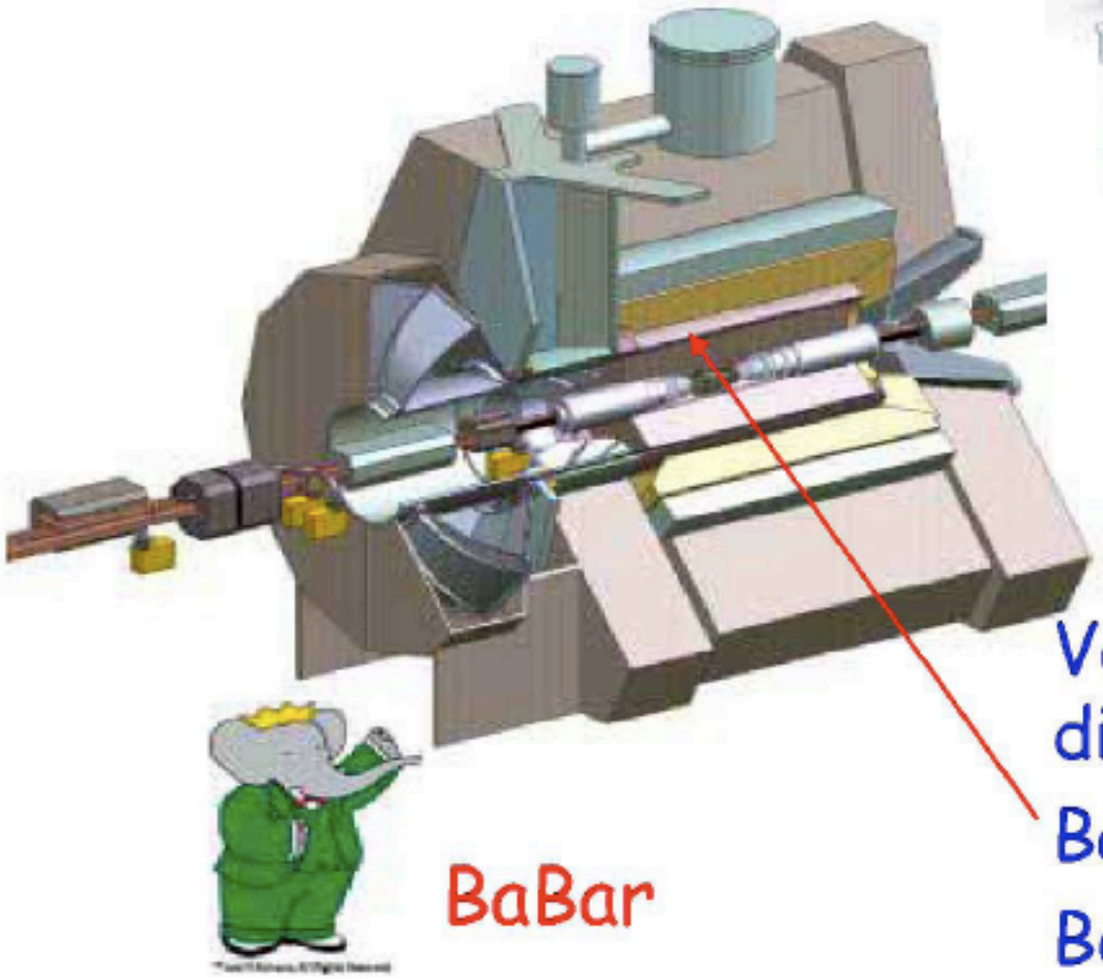
B-FACTORY DETECTORS

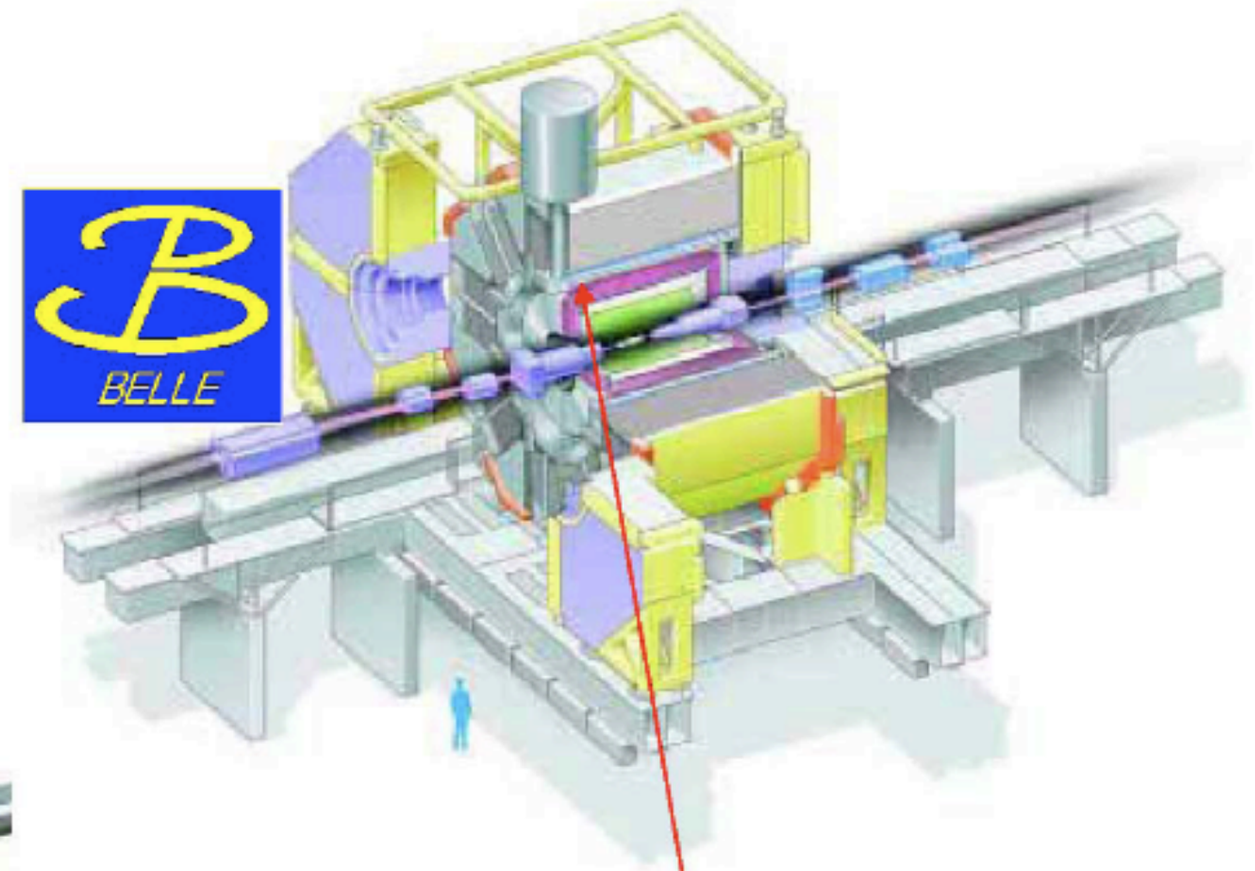
Both operating at $\Upsilon(4S)$

Belle: 8 GeV e^-/3.5 GeV e^+

BaBar: 9 GeV e^-/3.1 GeV e^+



BaBar



Very similar detectors; main difference is in PID:

BaBar: Ring-imaging Cherenkov

Belle: Threshold Cherenkov and TOF

τ-FACTORY STRENGTHS

- B-Factories are also τ-factories

$\sqrt{s}$ = 10.58 GeV ($\Upsilon(4S)$):

$\sigma(e^+e^- \to B\overline{B})$ = 1.1 nb

$\sigma(e^+e^- \to \tau^+\tau^-)$ = 0.9 nb

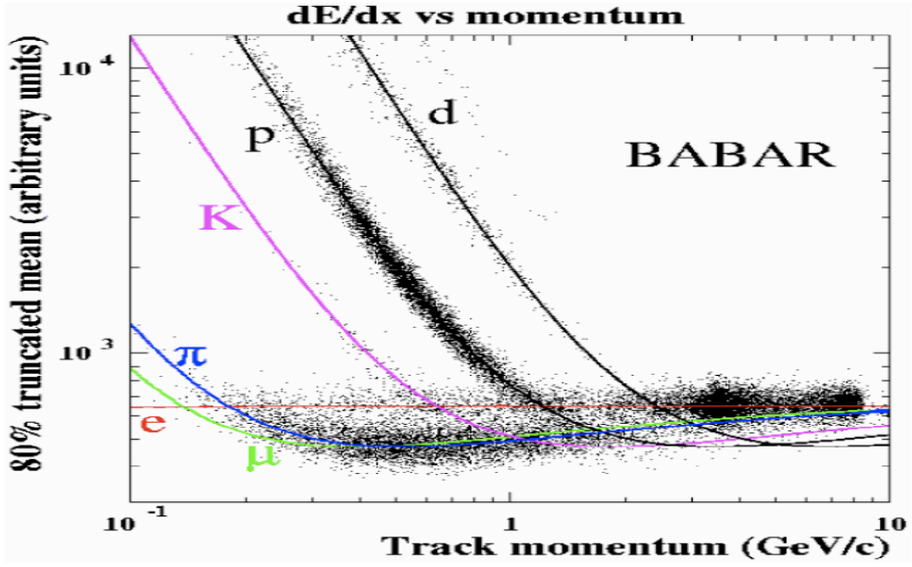
- 2007: $\mathcal{L}$(BaBar) ≈ 400 fb^{-1}
  $\mathcal{L}$(Belle) ≈ 700 fb^{-1}
- Goal by end of 2008:
  $\mathcal{L}$(BaBar+Belle) ≈ 2 ab^{-1}

Experiment	# of τ-pairs
LEP	3×10^5
CLEO	1×10^7
BaBar, Belle	2×10^9

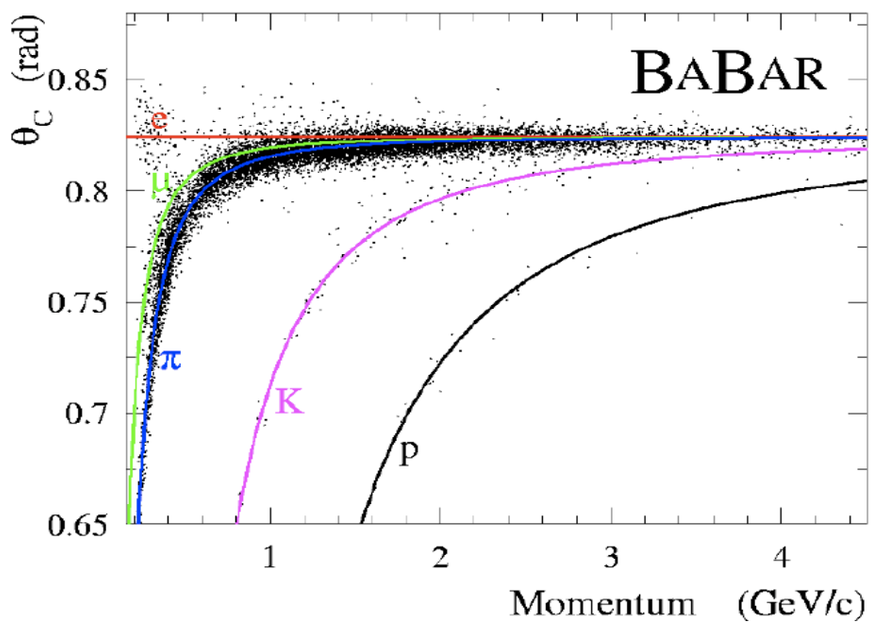
- ***Results reported here results typically use a fraction of the collected luminosity***

Excellent K/π separation

- dEdx

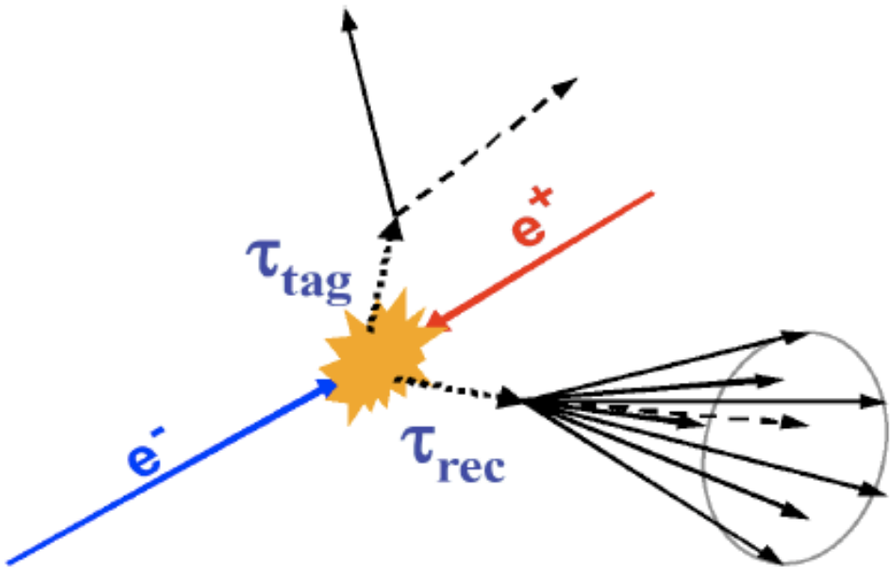


- Cherenkov angle

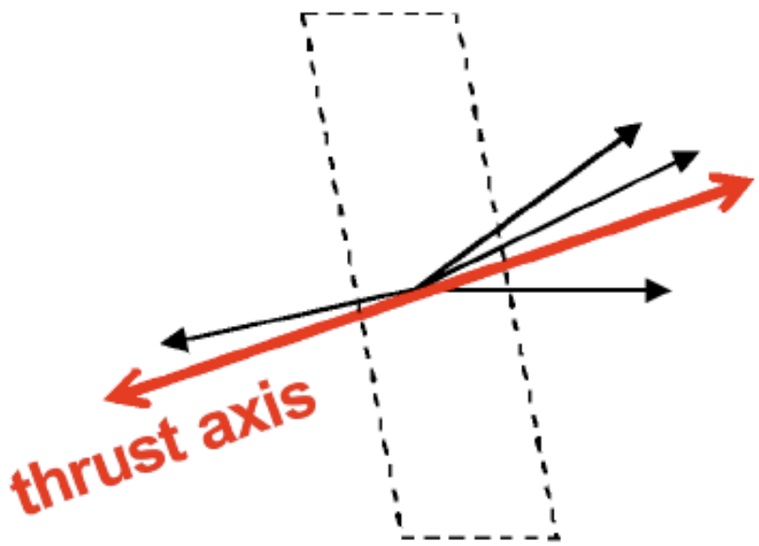


τ-PAIR EVENTS

- Well separated in space

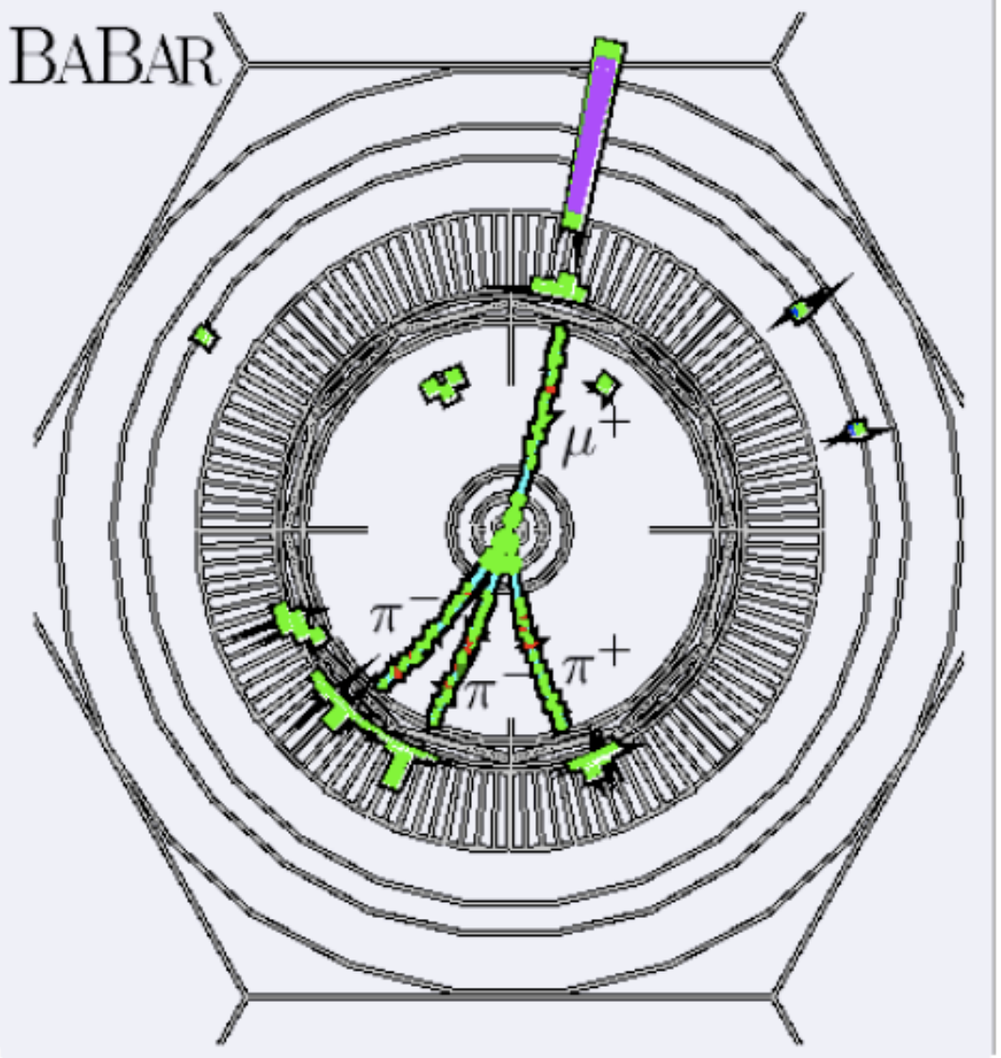


- Divide event into 2 hemispheres in CM frame ⊥ to thrust axis



☛ unique signature:
Leptonic + Hadronic decay

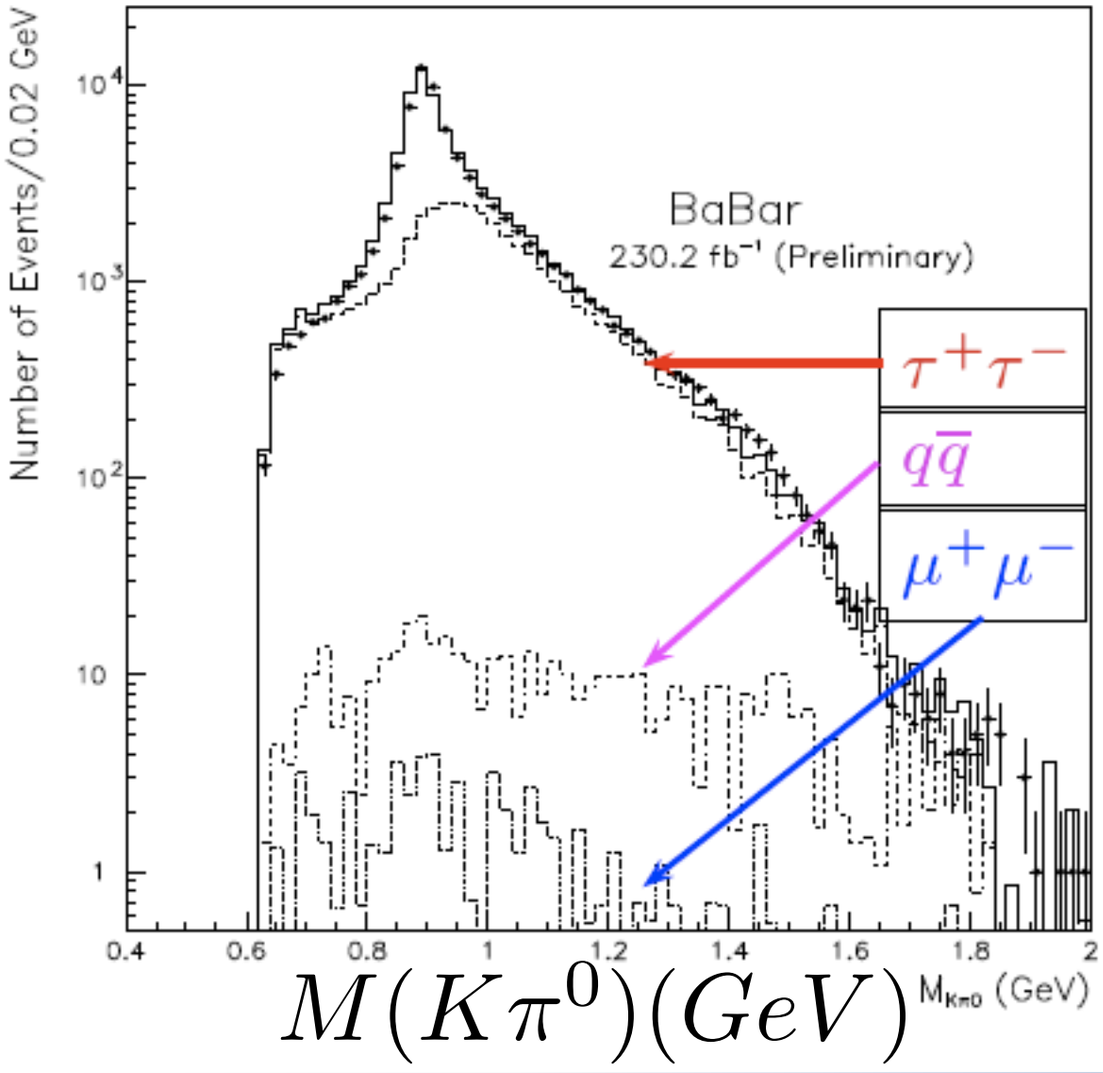
$e^+e^- \to \tau^+ (\mu^+\nu_\mu\bar{\nu}_\tau)\tau^- (3\text{ "prongs" }\nu_\tau)$

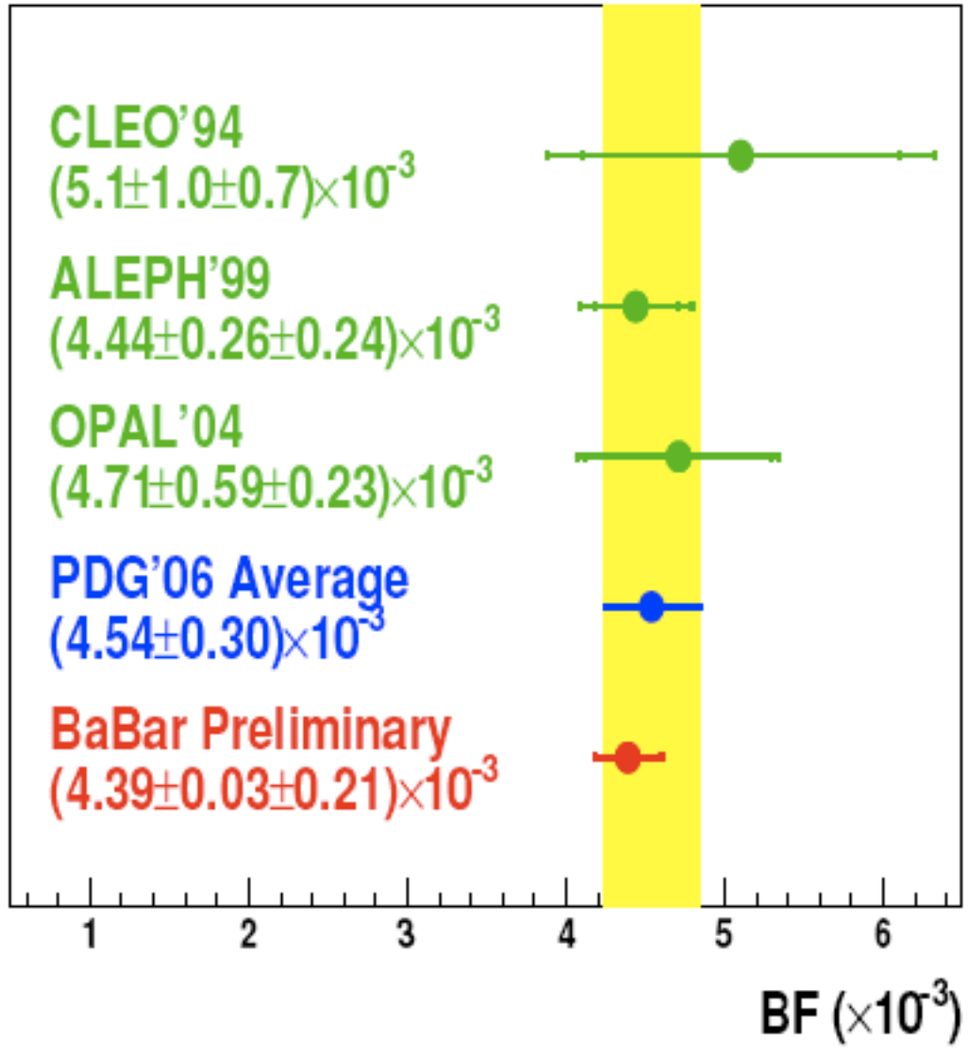


☞ most analyses use leptonic tags

$\tau^- \to K^-\pi^0\nu$ ($\mathcal{L} = 230.2$ fb^{-1}, Tau06)

- 78K e/μ-tagged events: $\tau^+\tau^-$ mostly; $q\bar{q}$, $\mu^+\mu^-$ small
- Efficiency: 2.3%, Purity: 51.9%
- Backgrounds come from K/π mis-ID & additional $\pi^0(s)$ in event
- Dominant systematics come from π^0 reconstruction in-efficiency

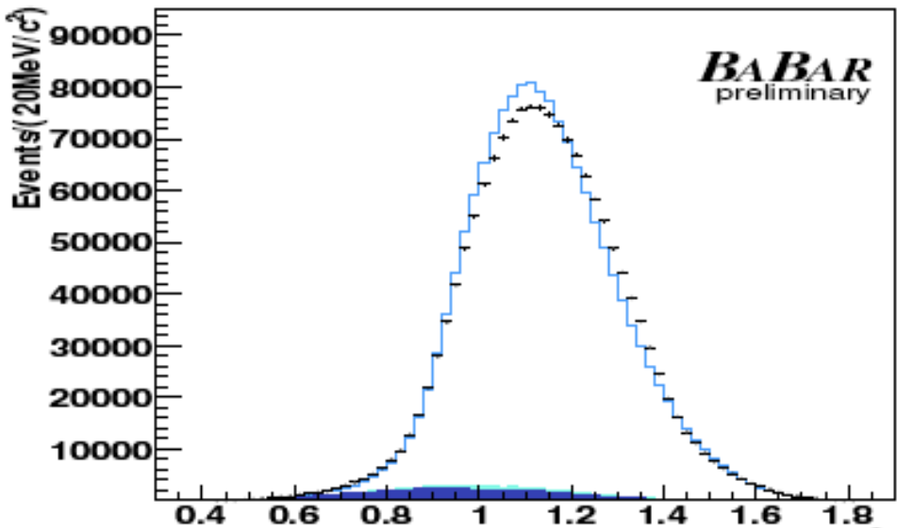




$\tau^- \to h^- h^- h^+ \nu$ ($\mathcal{L} = 344.0$ fb^{-1}, Tau06)

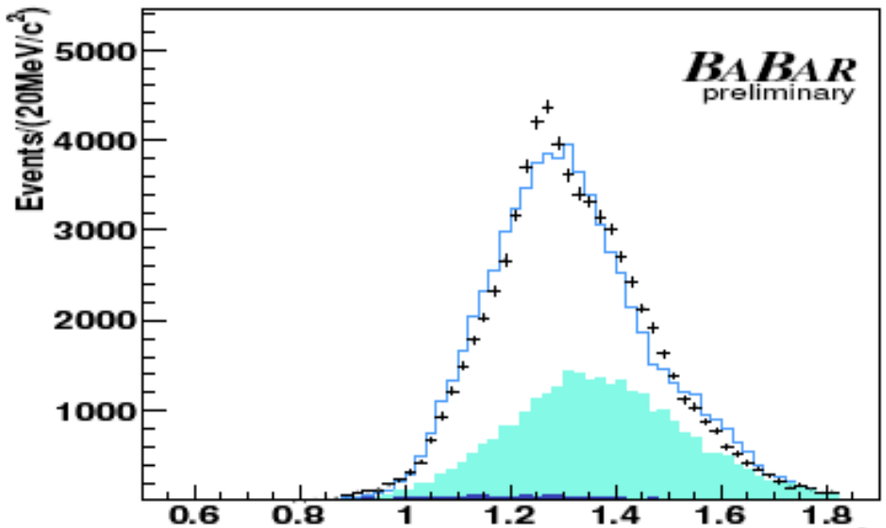
$\pi^-\pi^-\pi^+$

- 1.6M e/μ-tagged events



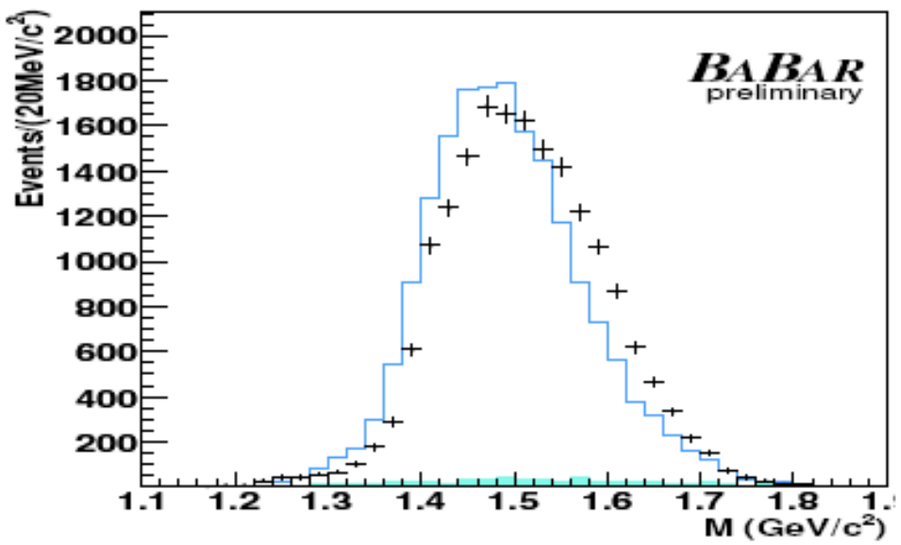
$K^-\pi^-\pi^+$

- 69K e/μ-tagged events



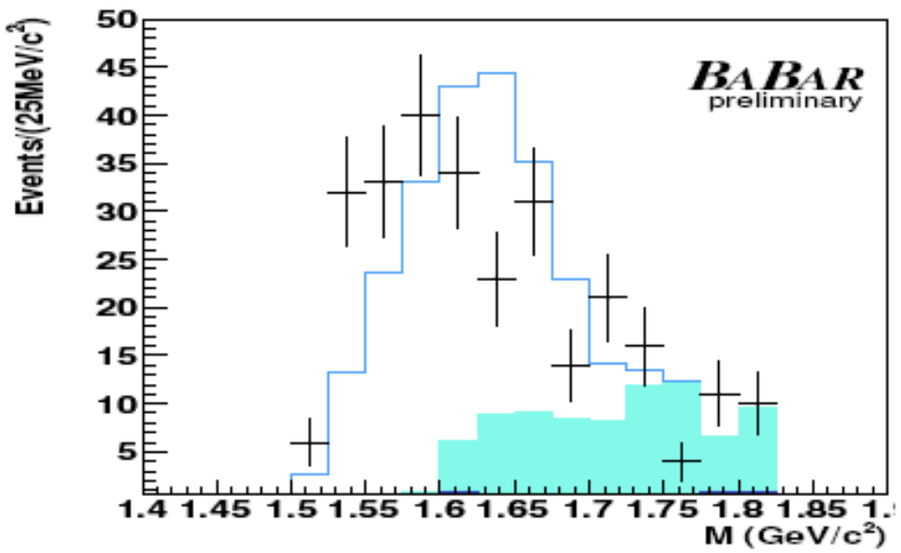
$K^-\pi^-K^+$

- 18K e/μ-tagged events



$K^-K^-K^+$

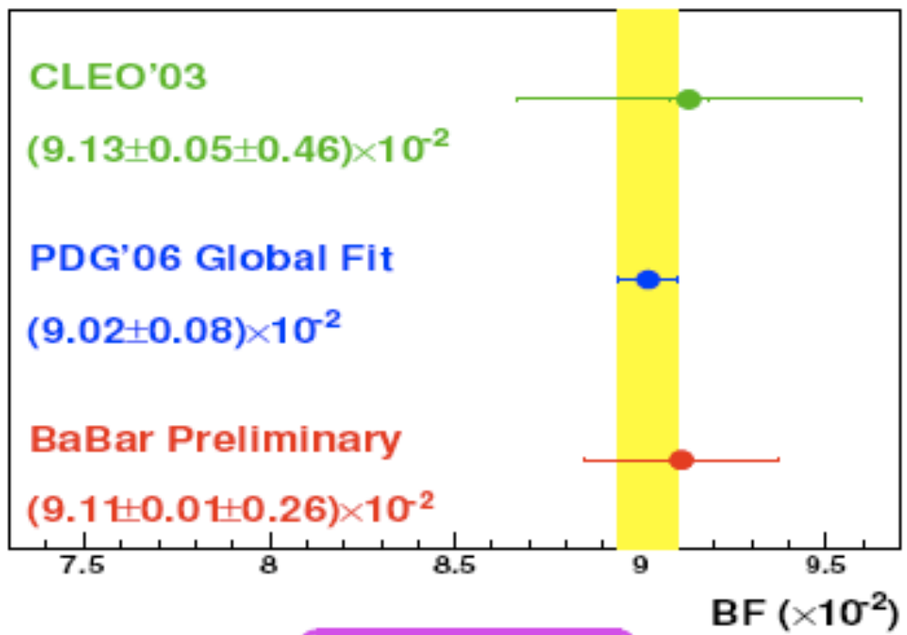
- (275 ± 17) e/μ-tagged events



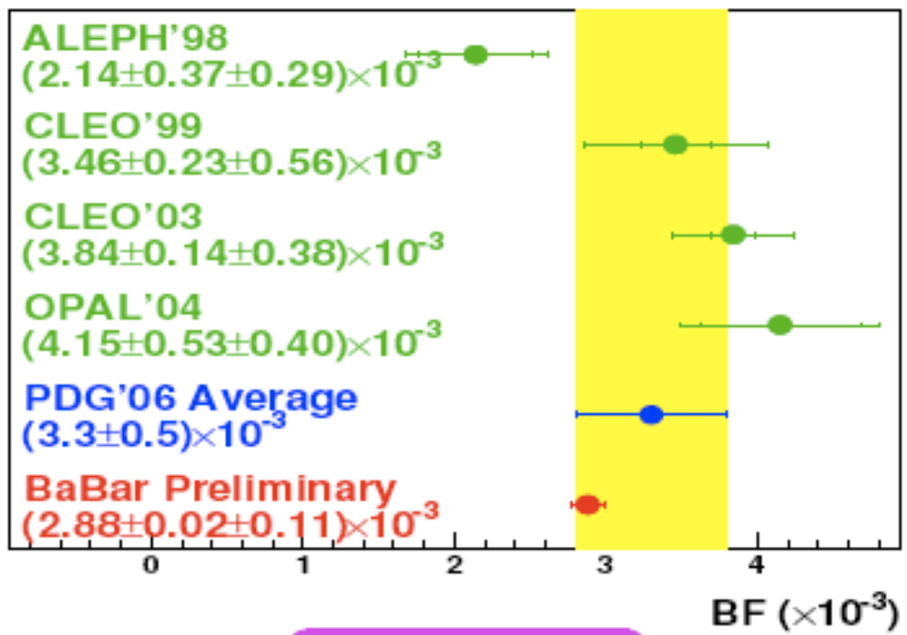
MC: Signal Cross Feed Bkg

$\tau^- \to h^- h^- h^+ \nu$ ($\mathcal{L} = 344.0$ fb^{-1}, Tau06)

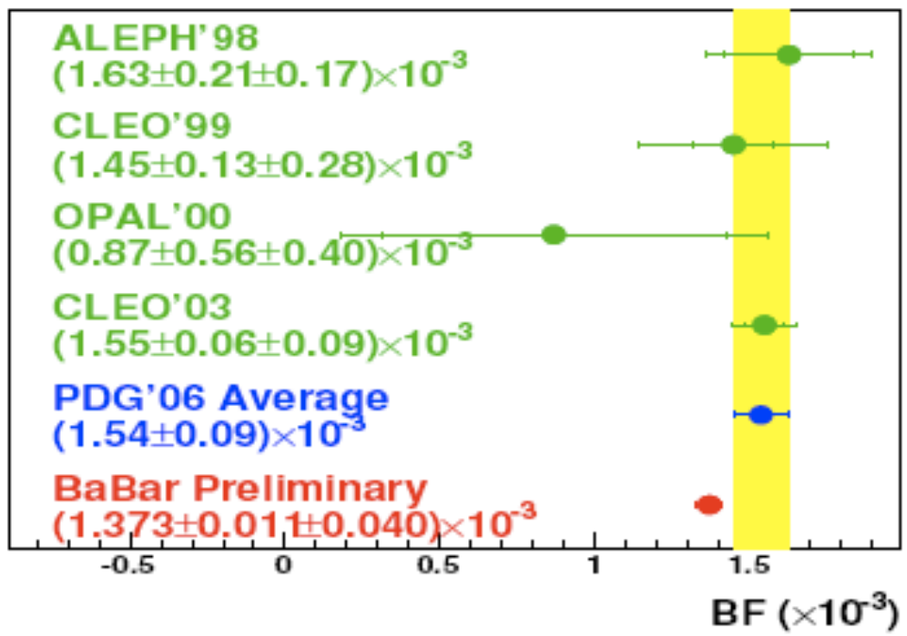
$\pi^-\pi^-\pi^+$



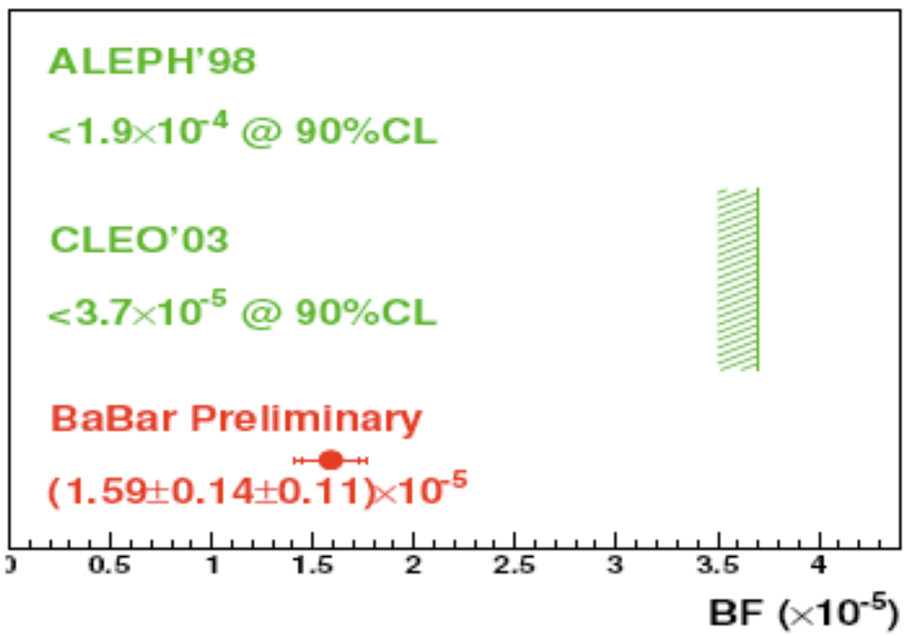
$K^-\pi^-\pi^+$



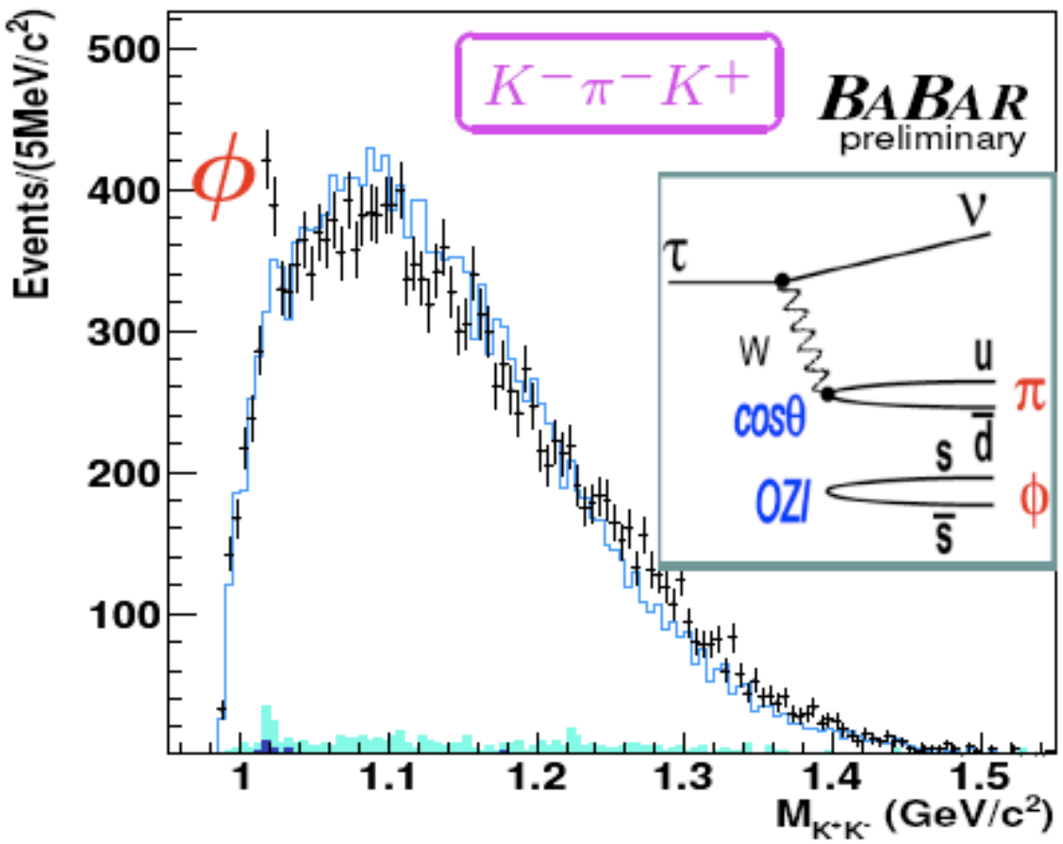
$K^-\pi^-K^+$

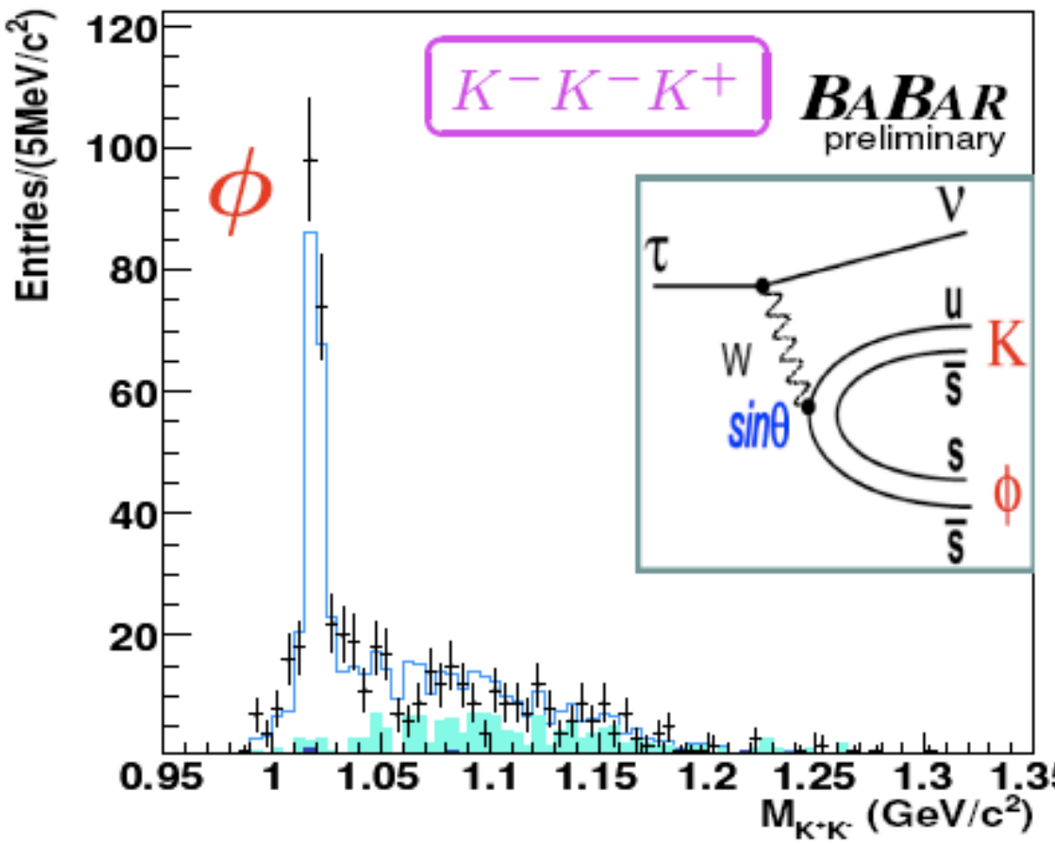


$K^-K^-K^+$



NEW MODES VIA ϕ (TAU06)





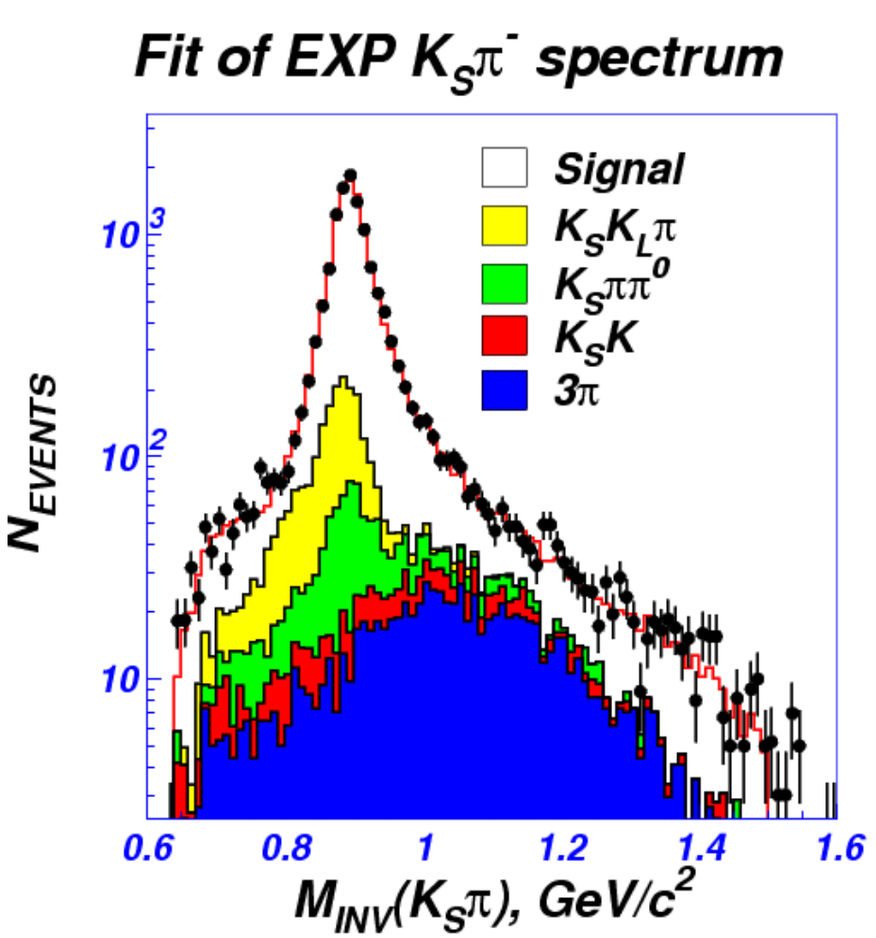
MC: Signal Cross Feed Bkg

- FIRST MEASUREMENTS of $\pi^-\phi$ and inclusive $K^-K^-K^+$ states:
  $\mathcal{B}(\tau^- \to \pi^-\phi\nu_\tau) = (3.49 \pm 0.55 \pm 0.32) \times 10^{-5}$ (Significance: 5.5σ)
  $\mathcal{B}(\tau^- \to K^-\phi\nu_\tau) = (3.48 \pm 0.20 \pm 0.26) \times 10^{-5}$ (Significance: 10.6σ)
- $\tau^- \to K^-\phi\nu_\tau$ consistent with saturating $\tau^- \to K^-K^-K^+\nu_\tau$ channel
- Consistent with Belle: $\mathcal{B}(\tau^- \to K^-\phi\nu_\tau) = (4.06 \pm 0.25 \pm 0.26) \times 10^{-5}$

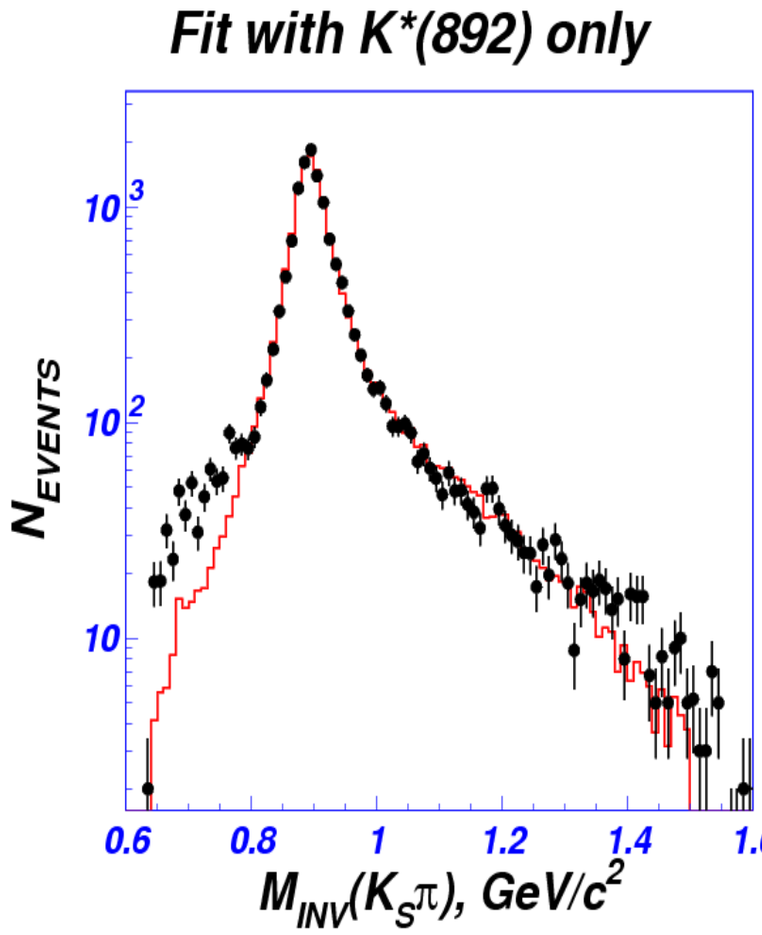
PLB643, 5, 2006

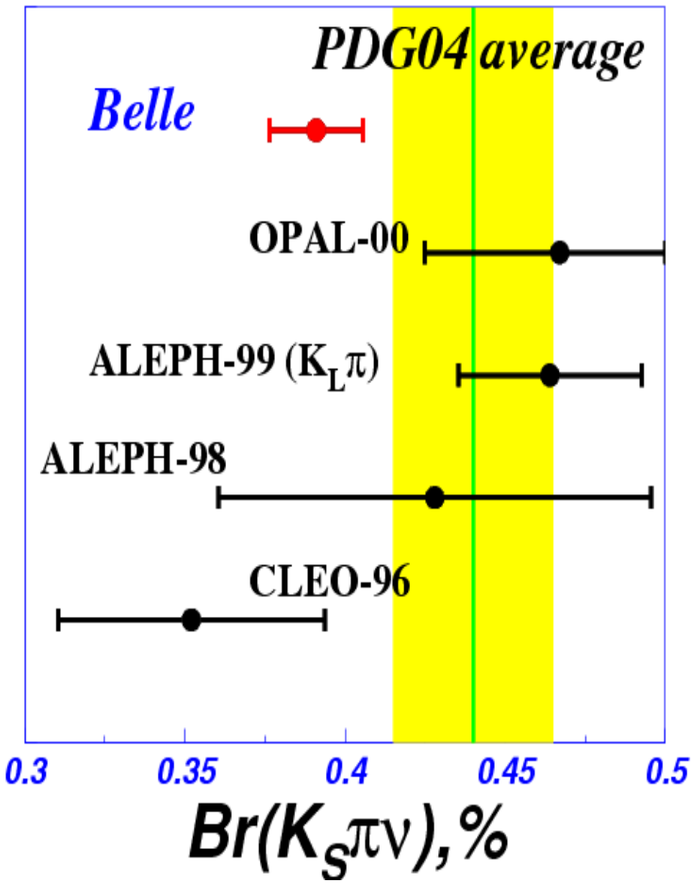
$\tau^- \to K^0_S \pi^- \nu$ ($\mathcal{L} = 351$ fb^{-1}, Tau06)

Evidence of $(K\pi)_{S\text{-wave}}$ contribution



$K^*(892) + K_0^*(800) + K^*(1410)$





$$\mathcal{B}(\tau \to K_S \pi \nu_\tau) = (0.391 \pm 0.004_{\rm stat} \pm 0.014_{\rm syst})\%$$

$|V_{us}|$ FROM τ-DECAYS

Mode	$\mathcal{B}(10^{-3})$	$\mathcal{B}(10^{-3})$
K^-	6.81 ± 0.23	
$K^-\pi^0$	4.54 ± 0.30	Average with $4.39 \pm 0.21 \Rightarrow 4.44 \pm 0.17$
$\overline{K}^0\pi^-$	8.78 ± 0.38	Average with $2(3.91 \pm 0.146) \Rightarrow 8.18 \pm 0.23$
$K^-\pi^0\pi^0$	0.58 ± 0.24	
$\overline{K}^0\pi^-\pi^0$	3.60 ± 0.40	
$K^-\pi^+\pi^-$	3.30 ± 0.28	Average with $2.88 \pm 0.11 \Rightarrow 2.94 \pm 0.10$
$K^-\eta$	0.27 ± 0.06	
$(\overline{K}3\pi)^-$ (estimated)	0.74 ± 0.30	
$K_1(1270)^- \to K^-\omega$	0.67 ± 0.21	
$(\overline{K}4\pi)^-$ (estimated) and $K^{*-}\eta$	0.40 ± 0.12	
Sum	29.69 ± 0.86	Updated Estimate: 28.63 ± 0.72 (Preliminary)

$$R_{strange} = (0.1607 \pm 0.0041), R_{non-strange} = (3.4793 \pm 0.0108)$$

$$\Rightarrow \boxed{|V_{us}| = (0.2165 \pm 0.0031)} \text{ (Br. Fr. error dominates)}$$

$$\frac{\Delta B}{B} = \frac{0.72}{28.63} \approx 2.5\% \longrightarrow 1\% \Rightarrow \Delta(|V_{us}|) = 0.0016 \equiv 0.7\%$$

$\mathcal{B}(\tau^- \to K^-\nu)$ FROM $K_{\mu 2}$ DECAYS

Mode	$\mathcal{B}(10^{-3})$	$\mathcal{B}(10^{-3})$
K^-	6.81 ± 0.23	Replace with 7.15 ± 0.03 $[\mathcal{B}(K^- \to \mu^- \overline{\nu}_\mu), \tau_K, \tau_\tau]$
$K^-\pi^0$	4.54 ± 0.30	Average with $4.39 \pm 0.21 \Rightarrow 4.44 \pm 0.17$
$\overline{K}^0\pi^-$	8.78 ± 0.38	Average with $2(3.91 \pm 0.146) \Rightarrow 8.18 \pm 0.23$
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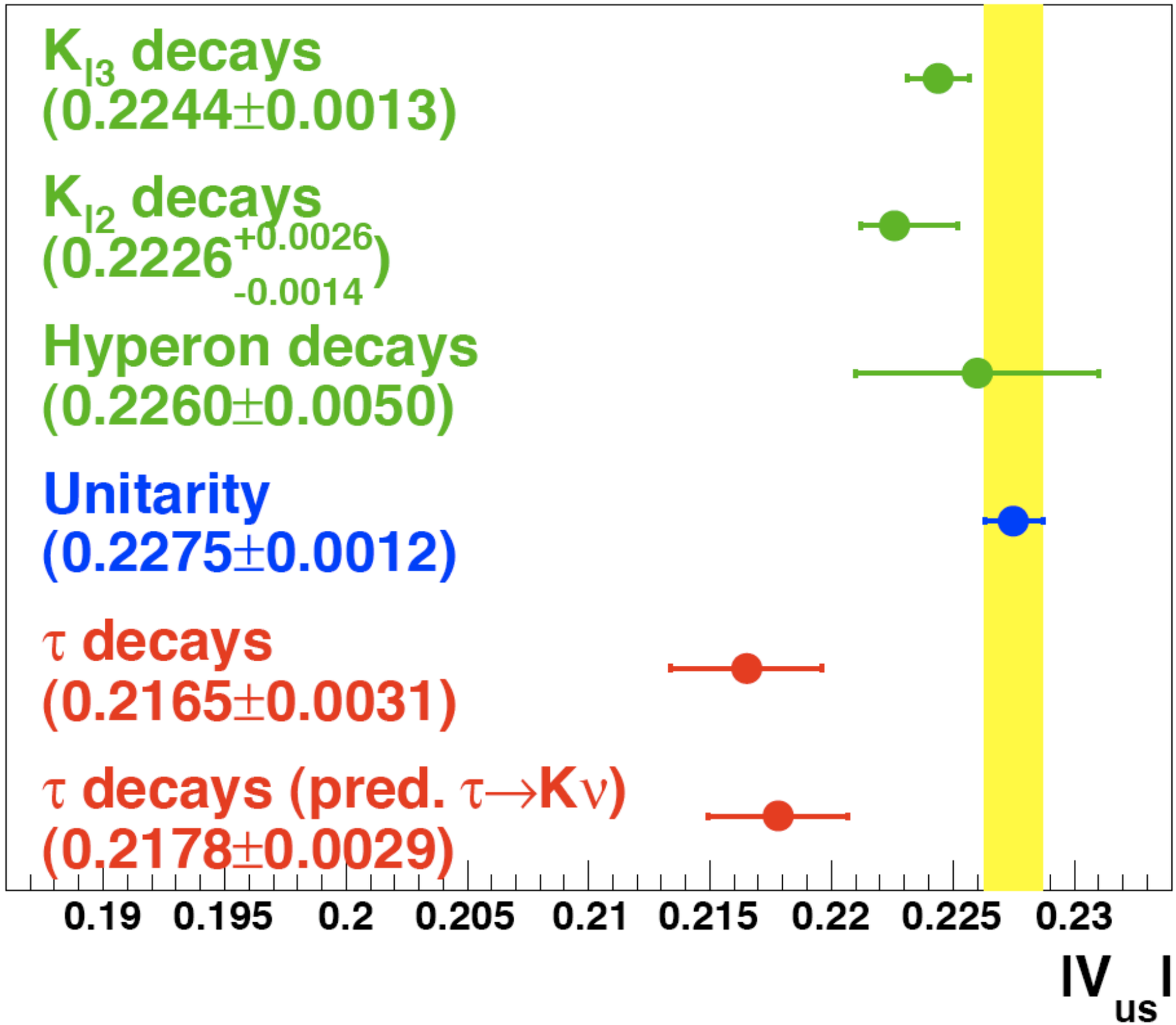
$(\overline{K}4\pi)^-$ (estimated) and $K^{*-}\eta$	0.40 ± 0.12	
Sum	29.69 ± 0.86	Updated Estimate: 28.97 ± 0.68 (Preliminary)

$$R_{strange} = (0.1626 \pm 0.0038), R_{non-strange} = (3.4774 \pm 0.0107)$$

$$\Rightarrow \boxed{|V_{us}| = (0.2178 \pm 0.0029)} \text{ (Br. Fr. error dominates)}$$

$$\frac{\Delta B}{B} = \frac{0.68}{28.97} \approx 2.3\% \longrightarrow 1\% \Rightarrow \Delta(|V_{us}|) = 0.0016 \equiv 0.7\%$$

$|V_{us}|$ MEASUREMENTS



Other measurements from Jamin's talk at Moriond EW 2007

SUMMARY

Preliminary results from BaBar:

- $\mathcal{B}(\tau^- \to K^- \pi^0 \nu) = (4.39 \pm 0.03 \pm 0.21) \times 10^{-3}$
- $\mathcal{B}(\tau^- \to \pi^- \pi^+ \pi^- \nu) = (9.11 \pm 0.01 \pm 0.26) \times 10^{-2}$
- $\mathcal{B}(\tau^- \to K^- \pi^+ \pi^- \nu) = (2.88 \pm 0.02 \pm 0.11) \times 10^{-3}$
- $\mathcal{B}(\tau^- \to K^- K^+ \pi^- \nu) = (13.73 \pm 0.11 \pm 0.40) \times 10^{-4}$
- $\mathcal{B}(\tau^- \to K^- K^+ K^- \nu) = (1.59 \pm 0.14 \pm 0.11) \times 10^{-5}$
- $\mathcal{B}(\tau^- \to \pi^- \phi \nu) = (3.49 \pm 0.55 \pm 0.32) \times 10^{-5}$
- $\mathcal{B}(\tau^- \to K^- \phi \nu) = (3.48 \pm 0.20 \pm 0.26) \times 10^{-5}$

Preliminary results from Belle:

- $\mathcal{B}(\tau^- \to K^0_S \pi^- \nu) = (3.91 \pm 0.04 \pm 0.14) \times 10^{-3}$
- $\mathcal{B}(\tau^- \to K^- \phi \nu) = (4.06 \pm 0.25 \pm 0.26) \times 10^{-5}$

First measurement using data from B-Factories:

- $|V_{us}| = 0.2165 \pm 0.0030$ (from measured τ-decays only)
- $|V_{us}| = 0.2178 \pm 0.0028$ (with predicted $\mathcal{B}(\tau^- \to K^- \nu)$)