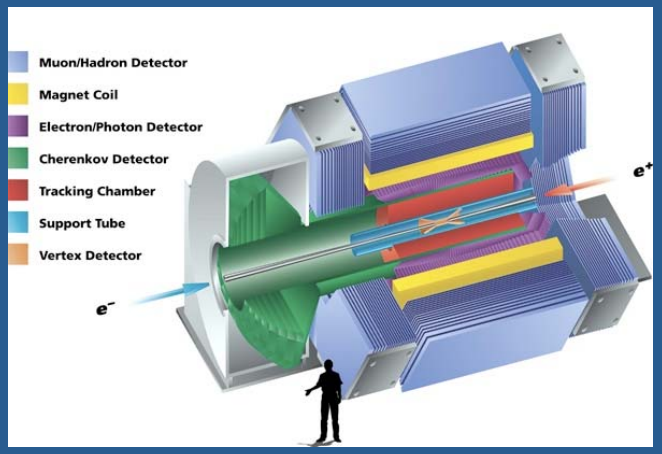
A measurement of $|V_{us}|$ with 1-prong decays and testing lepton universality

BaBar Collaboration

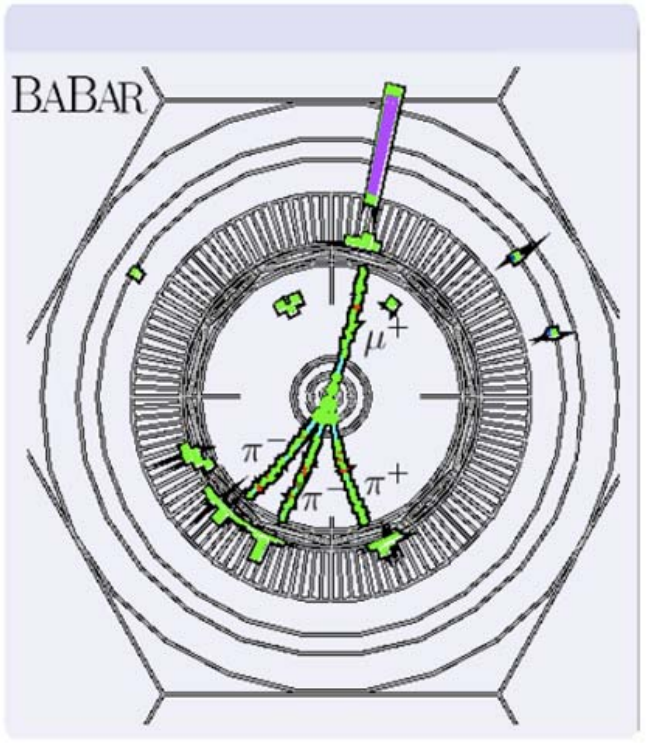
Randall Sobie

Institute of Particle Physics and University of Victoria



Outline

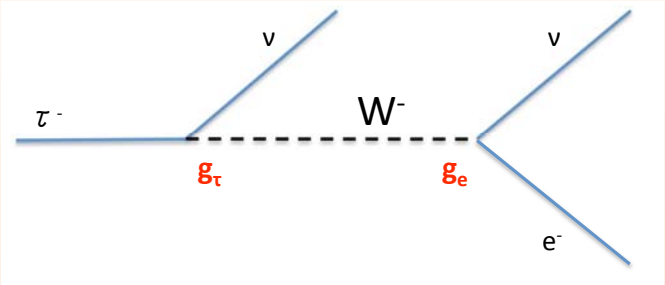
- Motivation
- BaBar detector and data set
- Selection and results
- Discussion
- Summary

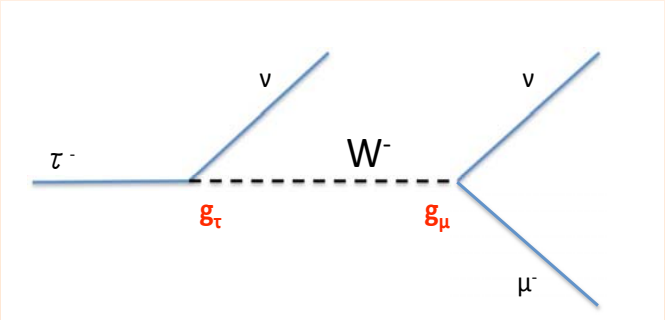


The results in this work have been published in Phys.Rev.Lett.105:051602,2010.

Lepton Universality

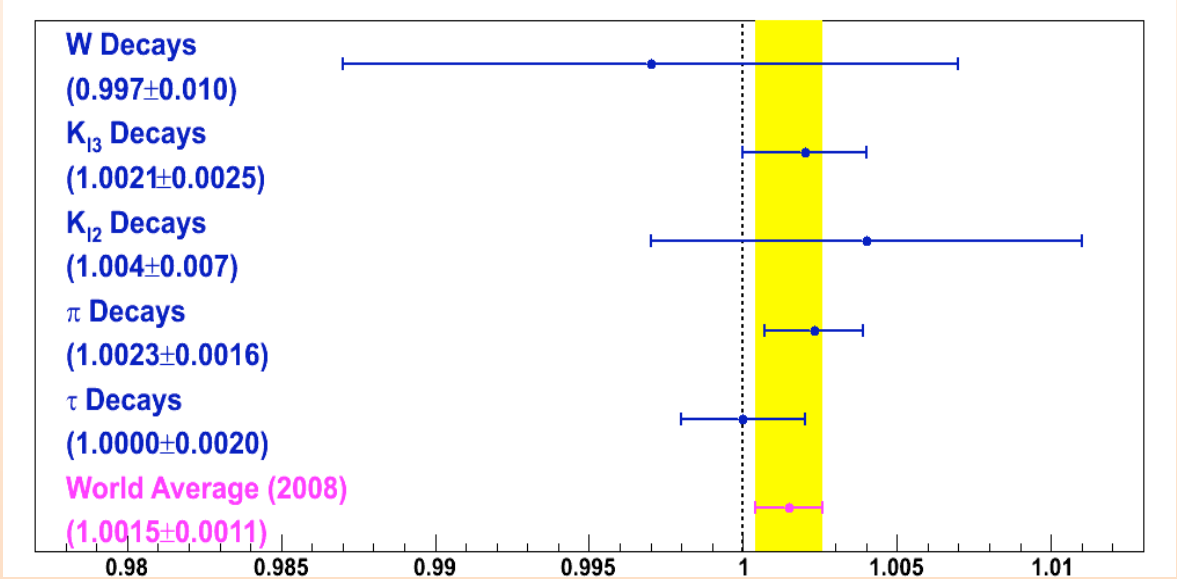
The SM assumes that the coupling of the W to the leptons is identical



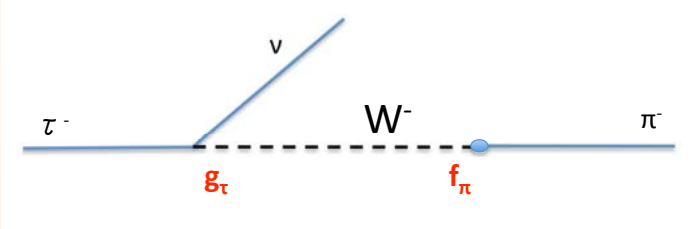


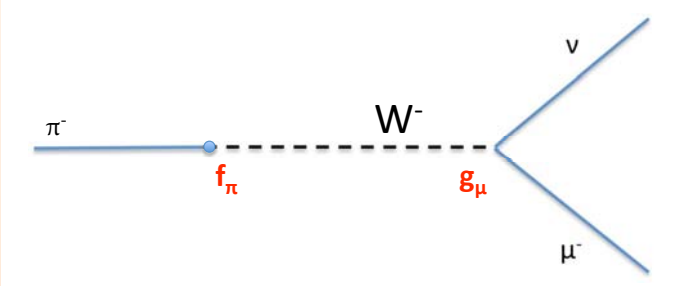
$$g_e = g_\mu = g_\tau$$

$$\left(\frac{g_\mu}{g_e}\right) = \frac{B(\tau^- \to \mu^- \nu\nu)}{B(\tau^- \to e^- \nu\nu)} \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)}$$



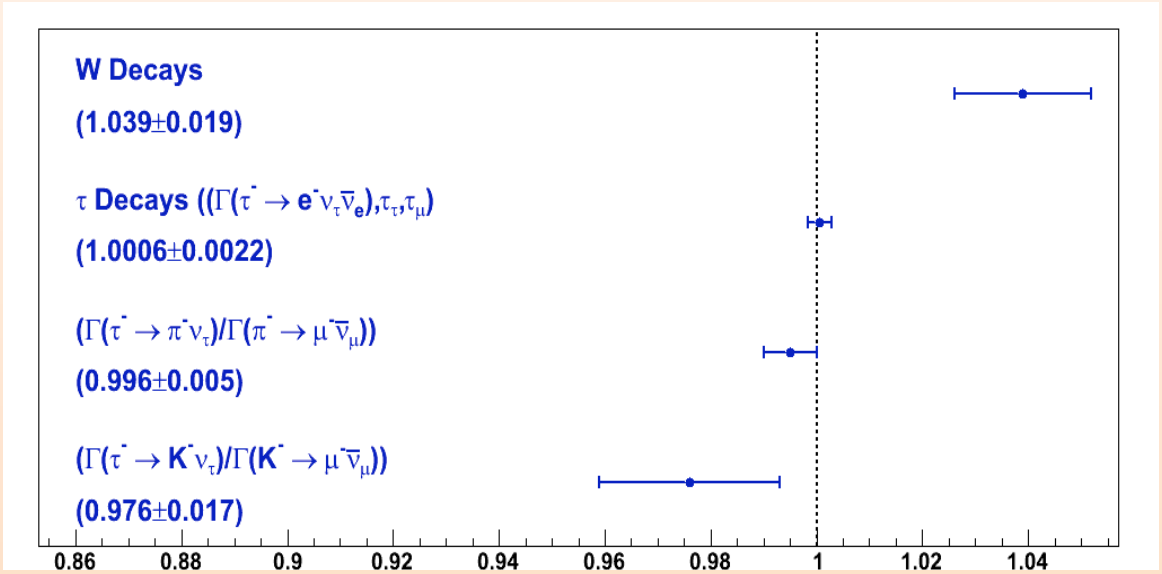
Lepton Universality





$$g_e = g_\mu = g_\tau$$

$$\left(\frac{g_\tau}{g_\mu}\right) = \frac{B(\tau^- \to h^- \nu)}{B(h^- \to \mu^- \nu)} \frac{2 m_h m_\mu^2 \tau_h}{(1+\delta_h) m_\tau^3 \tau_\tau} \left(\frac{1 - m_\mu^2 / m_h^2}{1 - m_h^2 / m_\tau^2}\right)$$



Status of $|V_{us}|$

One can use the unitarity constraint from the CKM matrix
V_{ud} is well measured in super-allowed beta decays
V_{ub} is negligible

$$|V_{ud}|^2 = 1 - |V_{ud}|^2 - |V_{ub}|^2$$

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

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

$$|V_{us}| = 0.2262 \pm 0.0011$$

V_{ud} from Towner and Hardy PR C79 055502 (2009)
V_{ub} from PDG 2008

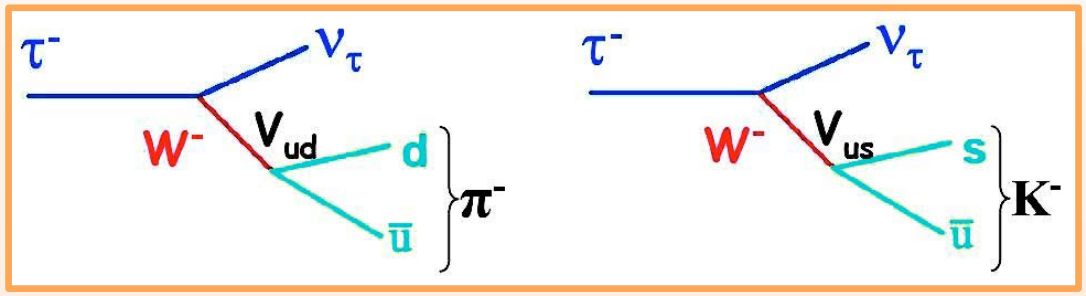
One can also use the inclusive measurement of all the strange hadronic decays to determine V_{us}

$$|V_{us}| = 0.2192 \pm 0.0035$$

ICHEP 2010

Measurement of V_{us}

BaBar has measured V_{us} in two ways:



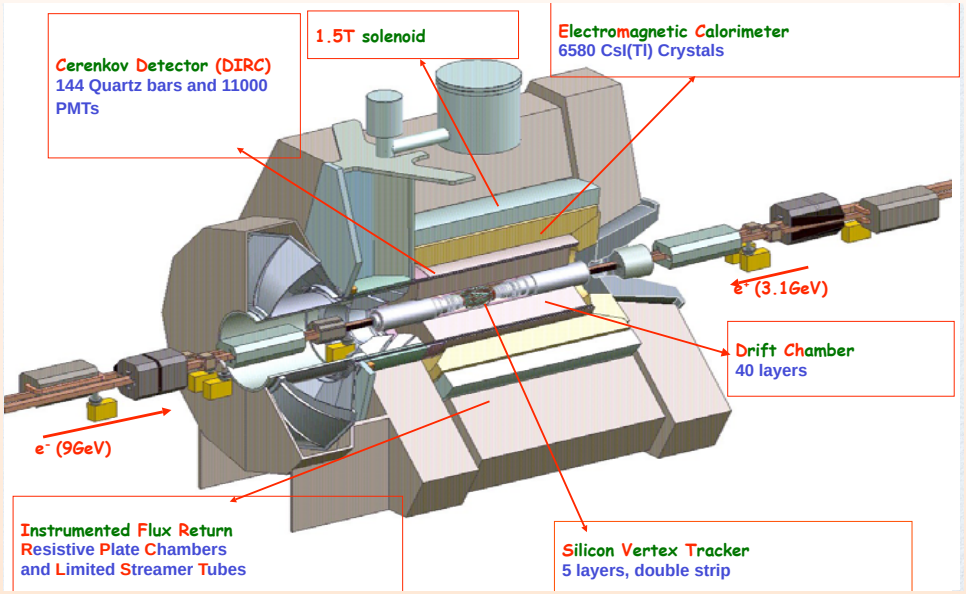
Use the kaon branching fraction

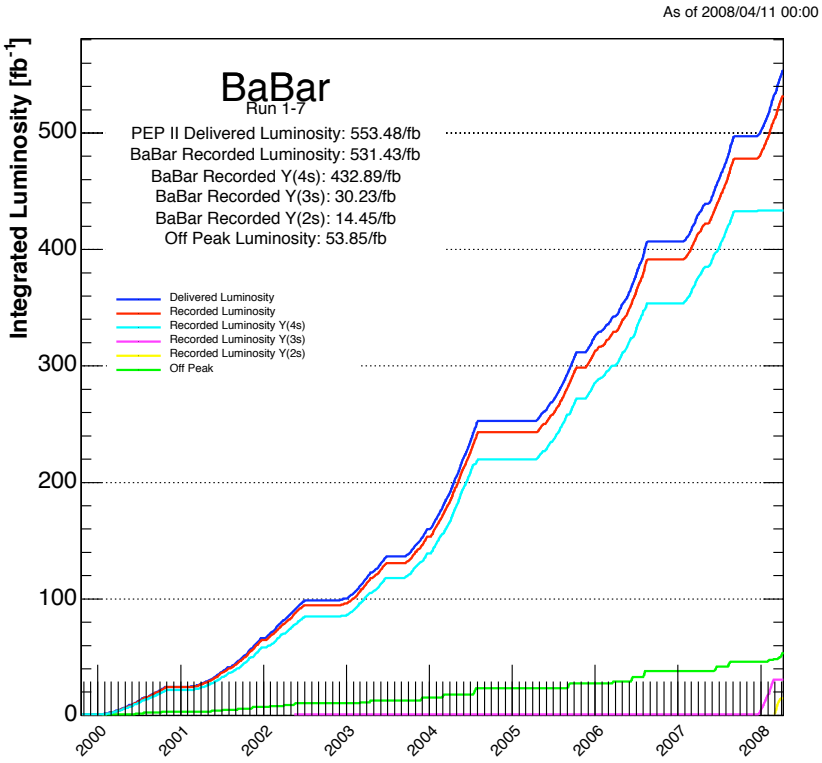
$$B(\tau^- \to K^- \nu_\tau)$$

Use the ratio of kaon to pion branching fractions

$$\frac{B(\tau^- \to K^- \nu_\tau)}{B(\tau^- \to \pi^- \nu_\tau)}$$

Detector and data sample

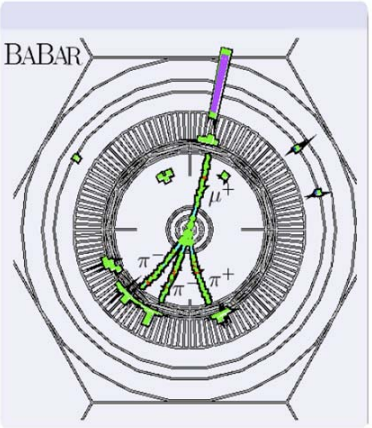




Using a data set based on a luminosity of 467 fb^{-1}

Approximately 900 million tau leptons

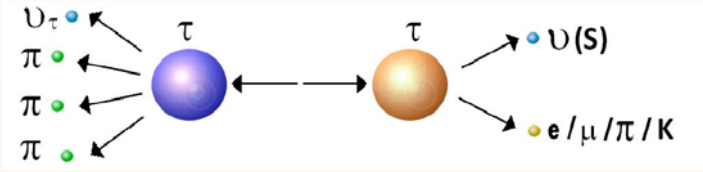
Tau selection



Select tau pair events

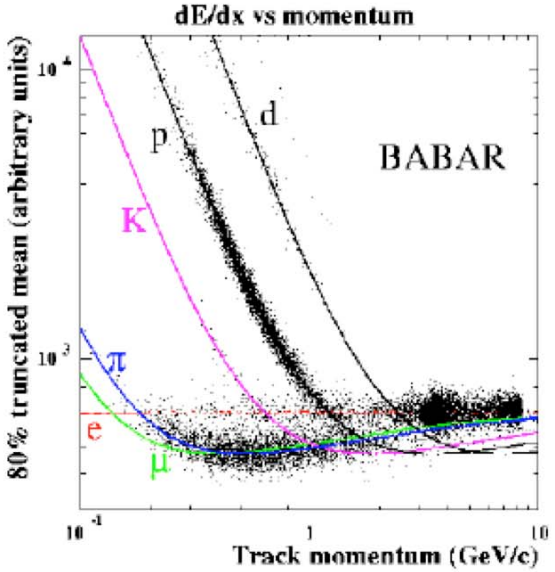
Use one tau decay as a "tag" to reduce background from hadronic events

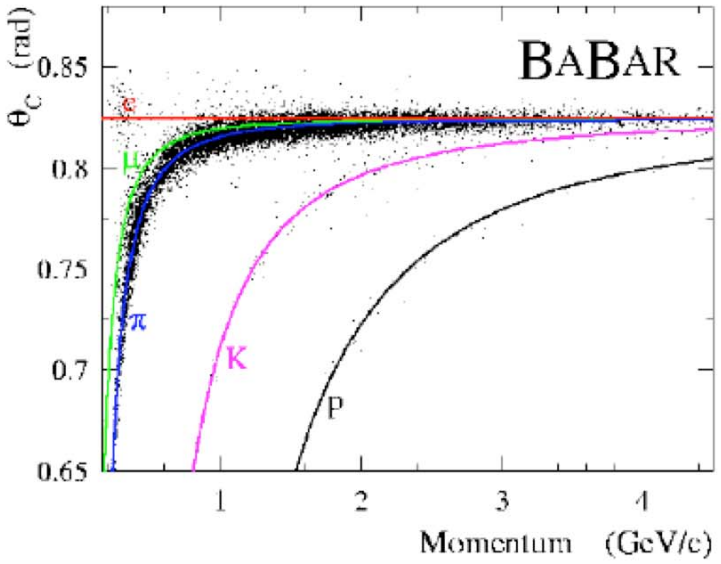
Use tau 3-prong decays as "tag decay" for the study of 1-prong decay modes



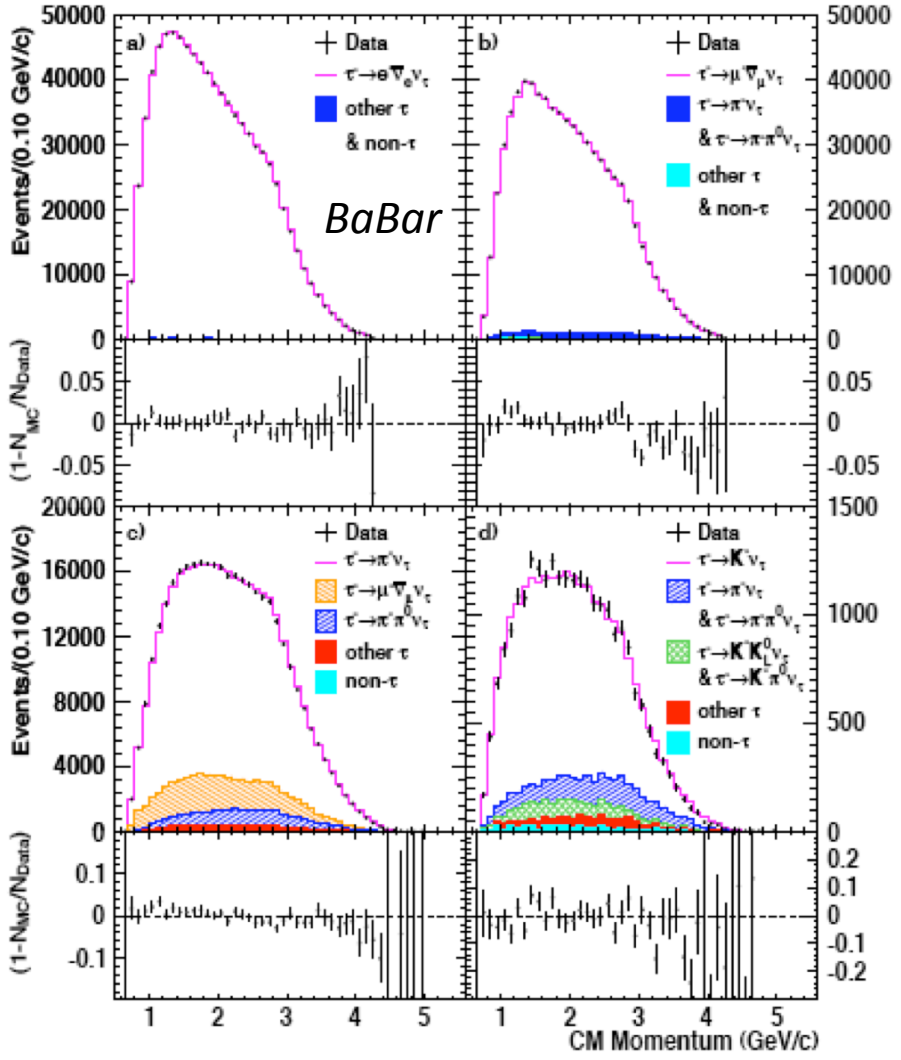
Measure muon, pion and kaon branching fractions relative to the electron mode to reduce systematic errors.

Excellent K/π Separation





Results



$\tau^- \to e^- \bar{\nu}_e \nu_\tau$ $\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$

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

	μ	π	K
N^D	731102	369091	25123
Purity	97.3%	78.7%	76.6%
Total Efficiency	0.485%	0.324%	0.330%
Particle ID Efficiency	74.5%	74.6%	84.6%
Systematic uncertainties:			
Particle ID	0.32	0.51	0.94
Detector 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

Branching fractions

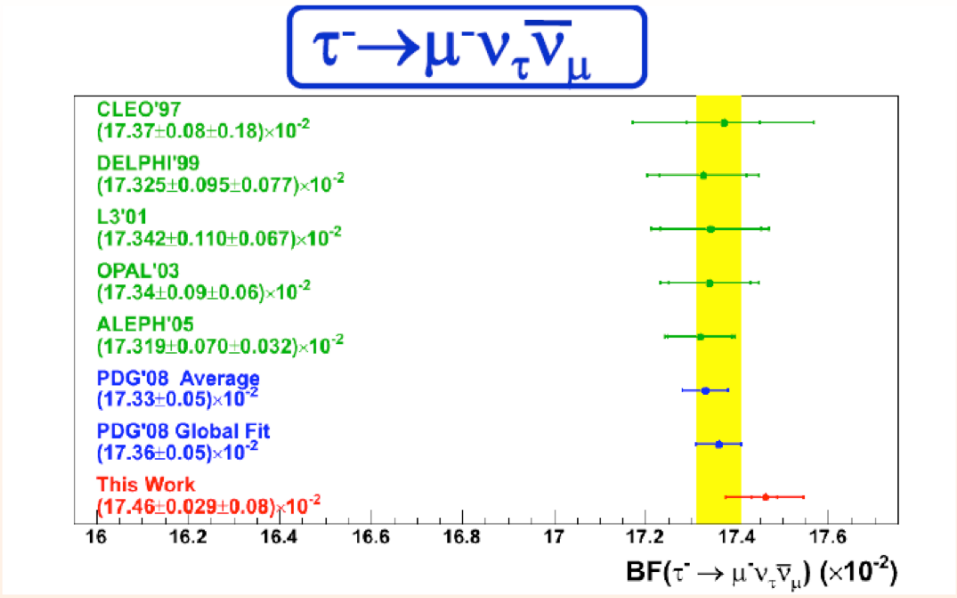
Measure branching fractions relative to electron mode

$$R_\mu = 0.9796 \pm 0.0016 \pm 0.0036$$
$$R_\pi = 0.5945 \pm 0.0014 \pm 0.0061$$
$$R_K = 0.03882 \pm 0.00032 \pm 0.00057$$

$$R_X = \frac{B(\tau^- \to X^- \nu_\tau)}{B(\tau^- \to e^- \bar{\nu}_e \nu_\tau)}$$

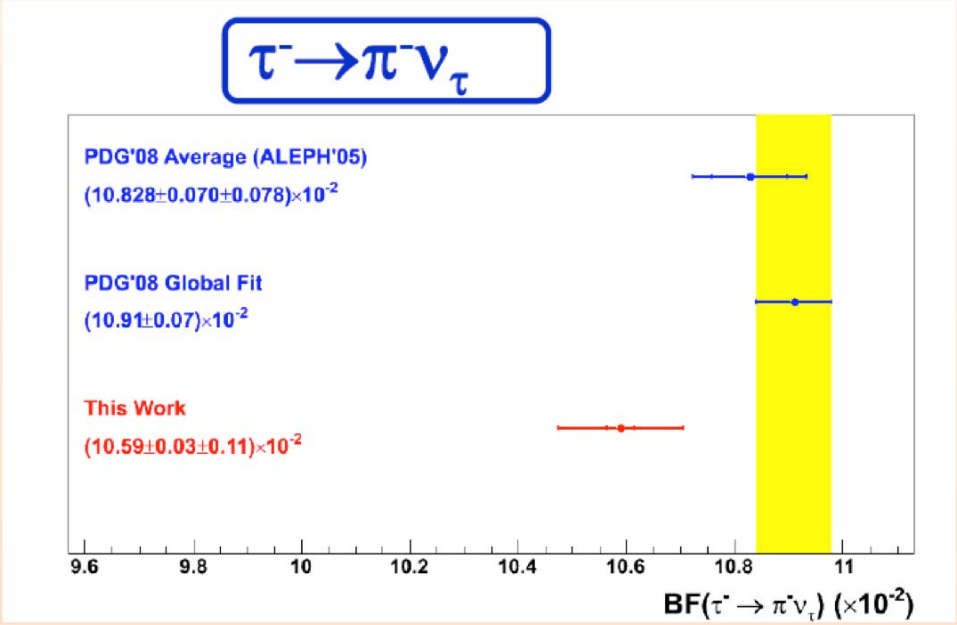
Branching fractions based on $B(\tau^- \to e^- \nu\nu) = (17.82 \pm 0.05)\%$ PDG2008

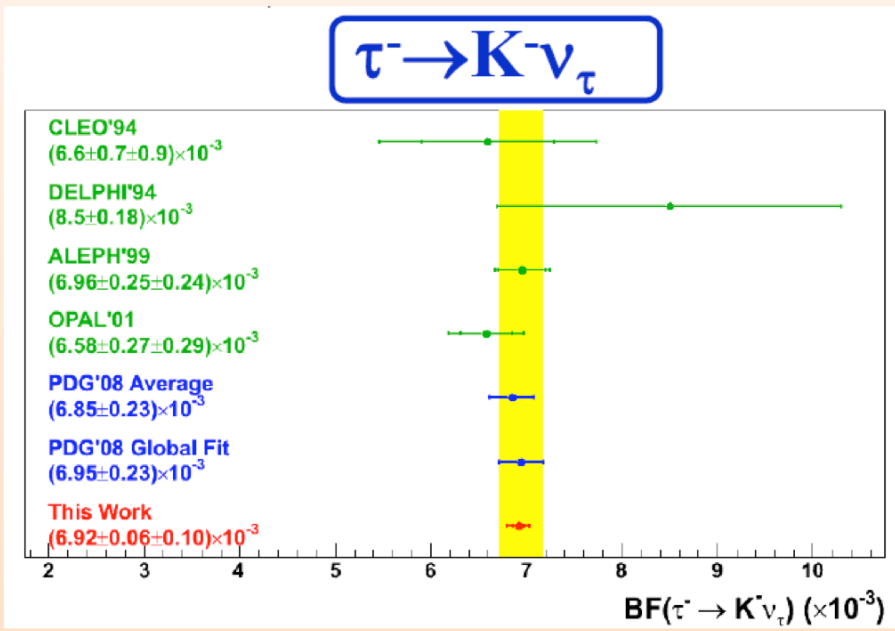
$$B(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau) = (17.46 \pm 0.03 \pm 0.08)\%$$
$$B(\tau^- \to \pi^- \nu_\tau) = (10.59 \pm 0.03 \pm 0.11)\%$$
$$B(\tau^- \to K^- \nu_\tau) = (0.692 \pm 0.006 \pm 0.010)\%$$



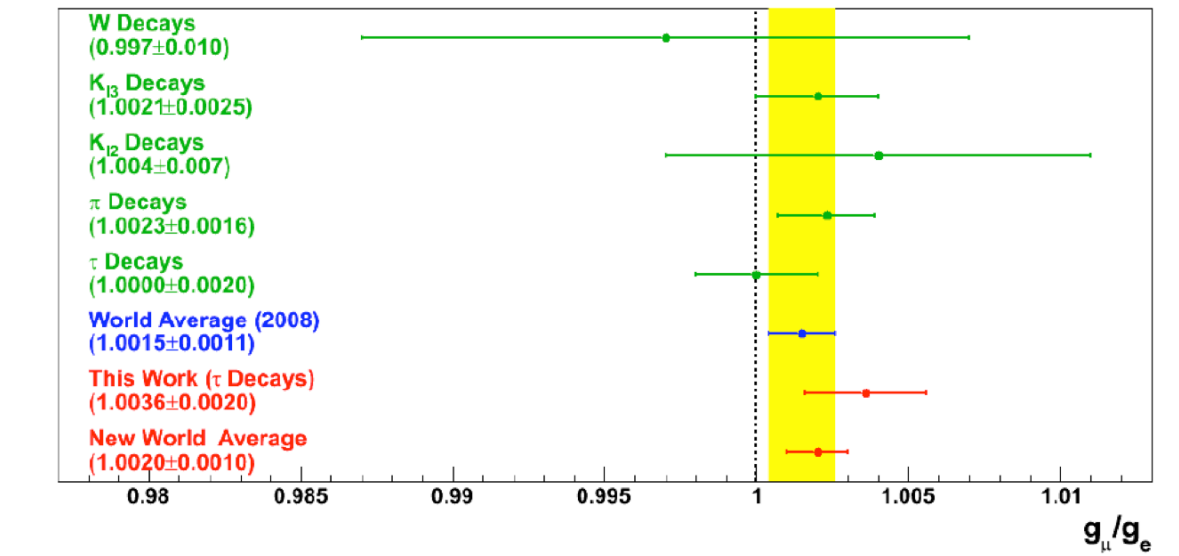
Comparison with previous measurements

$$B(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau) = (17.46 \pm 0.03 \pm 0.08)\%$$
$$B(\tau^- \to \pi^- \nu_\tau) = (10.59 \pm 0.03 \pm 0.11)\%$$
$$B(\tau^- \to K^- \nu_\tau) = (0.692 \pm 0.006 \pm 0.010)\%$$





Lepton universality results



Ratio of the muon and electron coupling using the measured branching fractions

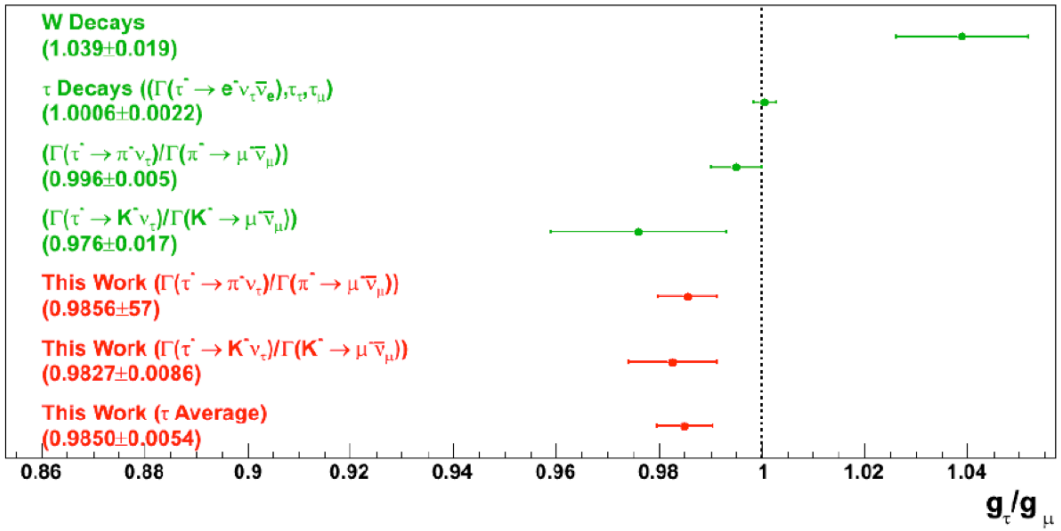
$$\left(\frac{g_\mu}{g_e}\right) = 1.0036 \pm 0.0020$$

Consistent the lepton universality

$$\left(\frac{g_\mu}{g_e}\right)^2 = \frac{B(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{B(\tau^- \to e^- \bar{\nu}_e \nu_\tau)} \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)}$$

$$f(x) = 1 - 8x + 8x^3 - x^4 + 12x^2 \log x$$

More lepton universality results



Ratio of the muon and tau coupling using the measured branching fractions

$$\left(\frac{g_\tau}{g_\mu}\right)_\pi = 0.9856 \pm 0.0057$$

$$\left(\frac{g_\tau}{g_\mu}\right)_K = 0.9827 \pm 0.0086$$

$$\left(\frac{g_\tau}{g_\mu}\right)^2 = \frac{B(\tau^- \to h^- \nu_\tau)}{B(h^- \to \mu^- \nu_\tau)} \frac{2 m_h m_\mu^2 \tau_h}{(1+\delta_h) m_\tau^3 \tau_\tau} \frac{(1 - m_\mu^2 / m_h^2)}{(1 - m_h^2 / m_\tau^2)}$$

Radiative corrections:

$$\delta_\pi = (0.16 \pm 0.14)\% \qquad \delta_K = (0.90 \pm 0.22)\%$$

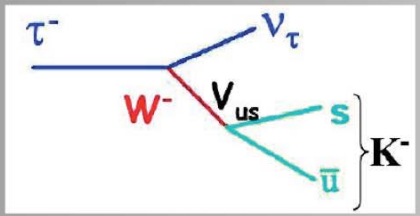
Consistent the lepton universality

V_{US} results

One can extract V_{us} from the kaon branching fraction

$$B(\tau^- \to K^- \nu_\tau) = \frac{G_F^2 f_K^2 |V_{us}|^2 m_\tau^3 \tau_\tau}{16\pi\hbar}\left(1 - \frac{m_K^2}{m_\tau^2}\right)^2 S_{EW}$$

$$S_{EW} = 1.0201 \pm 0.0003$$



$$|V_{us}| = 0.2193 \pm 0.0032$$

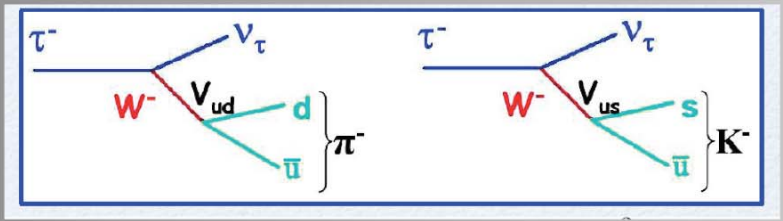
More results on V_{us}

One can determine Vus by the ratio of kaon/pion BFs

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

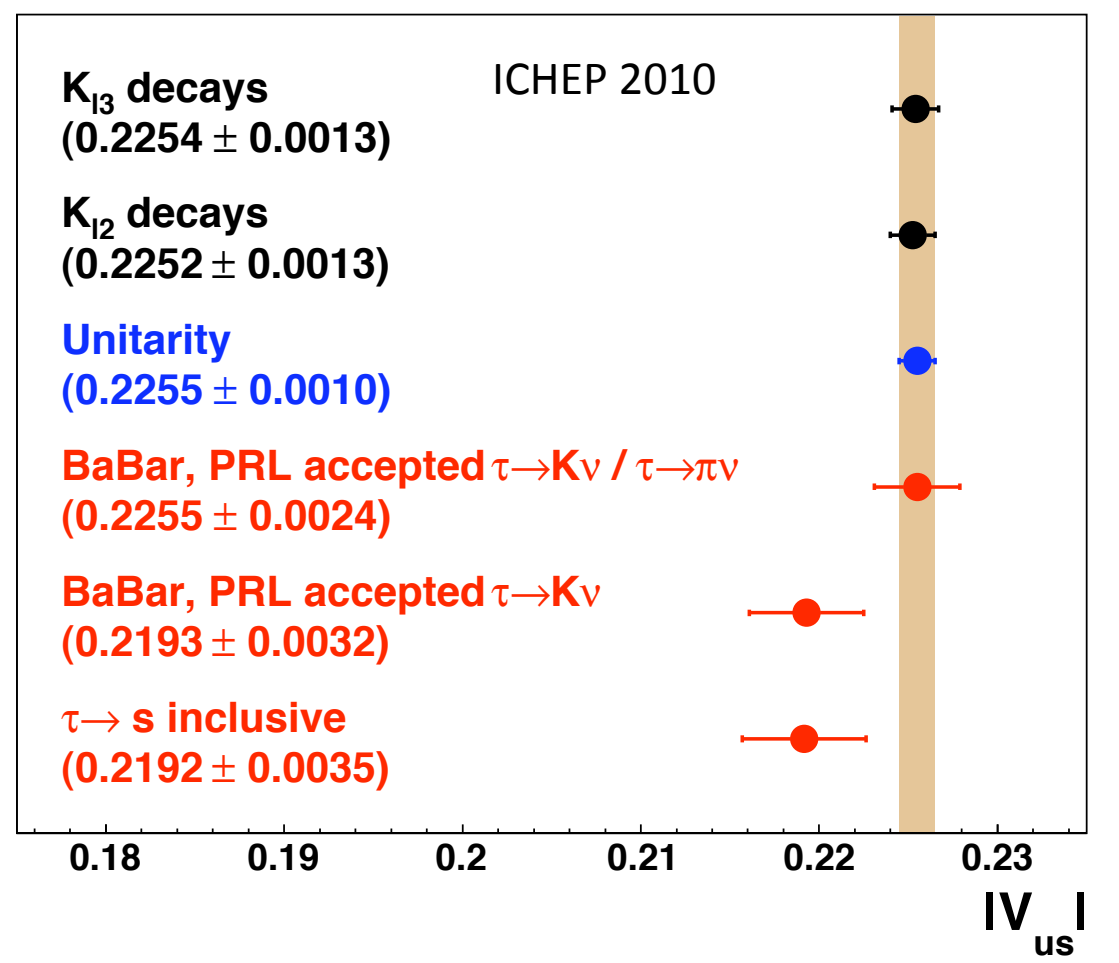
$$f_K / f_\pi = 1.189 \pm 0.007$$

$$\delta_{LD} = (0.03 \pm 0.44)\%$$



$$|V_{us}| = 0.2255 \pm 0.0024$$

V_{us} summary



Results are in good agreement between CKM unitarity constraint, kaon decays and tau decays

Summary

BaBar has made measurements of the one-prong tau decay modes

The results are used to test lepton universality and found to be consistent with unity.

The pion and kaon BFs are also used to measure V_{us}

The results are consistent with value obtained from CKM Unitarity but above the value obtained from the inclusive strange BFs

$$B(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau) = (17.46 \pm 0.03 \pm 0.08)\%$$
$$B(\tau^- \to \pi^- \nu_\tau) = (10.59 \pm 0.03 \pm 0.11)\%$$
$$B(\tau^- \to K^- \nu_\tau) = (0.692 \pm 0.006 \pm 0.010)\%$$

$$\text{Kaon BF} : |V_{us}| = 0.2193 \pm 0.0032$$
$$\text{Kaon:Pion BF} : |V_{ud}| = 0.2255 \pm 0.0024$$

The results in this work have been published in Phys.Rev.Lett.105:051602,2010.