$|V_{us}|$ from τ decays

Alberto Lusiani
INFN and Scuola Normale Superiore
Pisa

(on behalf of the **HFAG-Tau group**)

Introduction

- most precise $|V_{us}|$ experimental determinations from **Kaon decays**
  - uncertainty dominated by uncertainties on lattice QCD estimates of $f_+^{K\pi}(0)$ and f_K/f_π
- $|V_{us}|$ can be determined from $\boldsymbol{B(\tau \rightarrow X_{\text{strange}})}$ **inclusive**, this is **free of lattice QCD uncertainties**
  - $B(\tau \rightarrow X_{\text{strange}})$ from the **sum of exclusive BRs**
  - precision becoming competitive (but lattice QCD uncertainties are also decreasing)
  - theory uncertainty from low energy QCD (**Finite Energy Sum Rules**) and **strange quark mass**
  - by fitting both tau decay rates and spectra both $|V_{us}|$ and m_s can be simultaneously extracted
- $|V_{us}|$ can be determined from τ decays also in a similar way as with Kaons
  - affected by same lattice QCD uncertainties

Outline

- newly included experimental results since 2012 HFAG report
- HFAG-tau fit improvements
- $|V_{us}|$ determinations with τ decays using premilinary 2014 HFAG-tau BR fit

Experimental direct determinations of $|V_{us}|$

- from kaon decays
  - $\Gamma(K \to \pi \ell \nu) = |V_{us}|^2 f_+^{K\pi}(0)^2 \times$ <well known constants, rad. corrections>
  - $\dfrac{\Gamma(K^\pm \to \ell^\pm \nu)}{\Gamma(\pi^\pm \to \ell^\pm \nu)} = \dfrac{|V_{us}|^2}{|V_{ud}|^2} \dfrac{f_K^2}{f_\pi^2} \times$ <well known constants, rad. corrections>
- from tau decays
  - $\dfrac{R(\tau \to X_{\text{strange}})}{V_{us}{}^2} - \dfrac{R(\tau \to X_{\text{non-strange}})}{V_{ud}^2} = \delta R_{\tau,\text{SU3 breaking}}, \quad R(\tau \to X) = \dfrac{\Gamma(\tau \to X)}{\Gamma(\tau \to e \nu \overline{\nu})},$ **inclusive**
  - $\dfrac{B(\tau^- \to K^- \nu_\tau)}{B(\tau^- \to \pi^- \nu_\tau)} = \dfrac{f_K^2 |V_{us}|^2}{f_\pi^2 \, |V_{ud}|^2} \dfrac{\left(1 - m_K^2/m_\tau^2\right)^2}{\left(1 - m_\pi^2/m_\tau^2\right)^2} \dfrac{r_{\text{LD}}(\tau^- \to K^- \nu_\tau)}{r_{\text{LD}}(\tau^- \to \pi^- \nu_\tau)}$
  - $B(\tau^- \to K^- \nu_\tau) = \dfrac{G_F^2 f_K^2 |V_{us}|^2 m_\tau^3 \tau_\tau}{16\pi\hbar} \left(1 - \dfrac{m_K^2}{m_\tau^2}\right)^2 S_{EW}$

$|V_{us}|$ from CKM unitarity

- $|V_{us}| = \sqrt{1 - |V_{ud}|^2}$ ($|V_{ub}|$ negligible)

HFAG-Tau BR fit

- global fit of experimental data on tau branching fractions
  - lepton universality tests
  - determine universality improved $B(\tau \to e\nu\overline{\nu})$
  - determine $|V_{us}|$ with τ decays
- HFAG report 2010, arXiv:1010.1589
- HFAG report 2012, arXiv:1207.1158
- **HFAG report 2014: here first preliminary results**

HFAG Averaging procedures

- use available published and recent preliminary results
- report on arXiv every $\sim$ 2 years, intermediate undates on the web
- goal: avoid PDG-style error scale factors taking better account of
  - statistical and systematic correlations between different results
  - dependencies on common external parameters (e.g. tau pair cross-section)
- quote a confidence level rather than an error scale factor

What is new since 2012

- added *BABAR* PRD 86, 092010 (2012), Study of high-multiplicity 3-prong and 5-prong tau decays at BABAR
- added *BABAR* PRD 86, 092013 (2012), The branching fraction of $\tau \to \pi^- K^0_S K^0_S (\pi^0) \nu$ decays
- added Belle PRD 89, 072009 (2014), Measurements of Branching Fractions of τ decays with one or more K^0_S
- superseeded
  - one Belle 2007 result on $B(\tau^- \to \pi^- \overline{K}^0 \nu_\tau)$, from the 2014 paper
  - one *BABAR* 2008 result on $B(\tau^- \to \pi^- \pi^- \pi^+ \eta \nu_\tau$ (ex.K^0)), from the 2012 high multiplicity paper
  - preliminary *BABAR* and Belle results now in the above papers
- replaced ALEPH inclusive $B(\tau^- \to \pi^- K^0 \overline{K}^0 \pi^0 \nu_\tau)$ result with exclusive $B(\tau^- \to \pi^- \pi^0 K^0_S K^0_L \nu_\tau)$
  - better combine with new results
- removed wrong constraint on τ decay with η (negligible effect on $|V_{us}|$)
- added several new constraints for the new modes in the above papers
- revised the unitarity constraint and $B(\tau^- \to X_s^- \nu_\tau)$ definition

What is new since 2012, BABAR high multiplicity paper

$\Gamma_{811} = B(\tau^- \to \pi^- 2\pi^0 \omega \nu_\tau \text{ (ex. } K^0))$ $(7.3 \pm 1.2 \pm 1.2) \cdot 10^{-5}$
$\Gamma_{812} = B(\tau^- \to 2\pi^- \pi^+ 3\pi^0 \nu_\tau \text{ (ex. } K^0, \eta, \omega, f_1))$ $(0.1 \pm 0.08 \pm 0.30) \cdot 10^{-4}$
$\Gamma_{821} = B(\tau^- \to 3\pi^- 2\pi^+ \nu_\tau \text{ (ex. } K^0, \omega, f_1))$ $(7.68 \pm 0.04 \pm 0.40) \cdot 10^{-4}$
$\Gamma_{822} = B(\tau^- \to K^- 2\pi^- 2\pi^+ \nu_\tau \text{ (ex. } K^0))$ $(0.6 \pm 0.5 \pm 1.1) \cdot 10^{-6}$
$\Gamma_{831} = B(\tau^- \to 2\pi^- \pi^+ \omega \nu_\tau \text{ (ex. } K^0))$ $(8.4 \pm 0.4 \pm 0.6) \cdot 10^{-5}$
$\Gamma_{832} = B(\tau^- \to 3\pi^- 2\pi^+ \pi^0 \nu_\tau \text{ (ex. } K^0, \eta, \omega, f_1))$ $(0.36 \pm 0.03 \pm 0.09) \cdot 10^{-4}$
$\Gamma_{833} = B(\tau^- \to K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau \text{ (ex. } K^0))$ $(1.1 \pm 0.4 \pm 0.4) \cdot 10^{-6}$
$\Gamma_{910} = B(\tau^- \to 2\pi^- \pi^+ \eta \nu_\tau (\eta \to 3\pi^0) \text{ (ex. } K^0))$ $(8.27 \pm 0.88 \pm 0.81) \cdot 10^{-5}$
$\Gamma_{911} = B(\tau^- \to \pi^- 2\pi^0 \eta \nu_\tau (\eta \to \pi^+ \pi^- \pi^0) \text{ (ex. } K^0))$ $(4.57 \pm 0.77 \pm 0.50) \cdot 10^{-5}$
$\Gamma_{920} = B(\tau^- \to \pi^- f_1 \nu_\tau (f_1 \to 2\pi^- 2\pi^+))$ $(5.20 \pm 0.31 \pm 0.37) \cdot 10^{-5}$
$\Gamma_{930} = B(\tau^- \to 2\pi^- \pi^+ \eta \nu_\tau (\eta \to \pi^+ \pi^- \pi^0) \text{ (ex. } K^0))$ $(5.39 \pm 0.27 \pm 0.41) \cdot 10^{-5}$
$\Gamma_{944} = B(\tau^- \to 2\pi^- \pi^+ \eta \nu_\tau (\eta \to \gamma\gamma) \text{ (ex. } K^0))$ $(8.26 \pm 0.35 \pm 0.51) \cdot 10^{-5}$

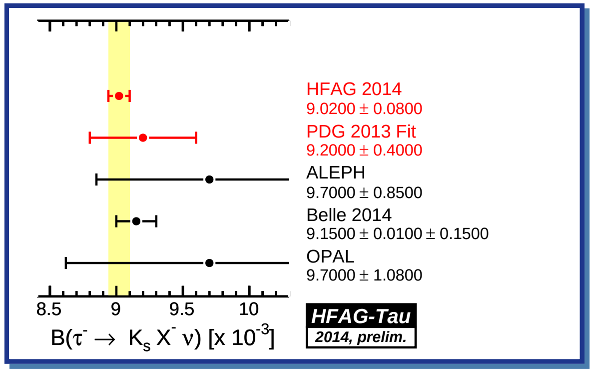
What is new since 2012, BABAR $\tau \to \pi^- K^0_S K^0_S (\pi^0) \nu$

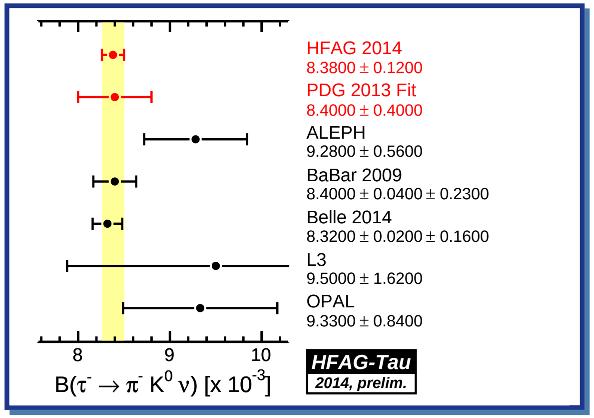
$\Gamma_{47} = B(\tau^- \to \pi^- K^0_S K^0_S \nu_\tau)$ $(2.31 \pm 0.04 \pm 0.08) \cdot 10^{-4}$
$\Gamma_{50} = B(\tau^- \to \pi^- \pi^0 K^0_S K^0_S \nu_\tau)$ $(1.60 \pm 0.20 \pm 0.22) \cdot 10^{-5}$

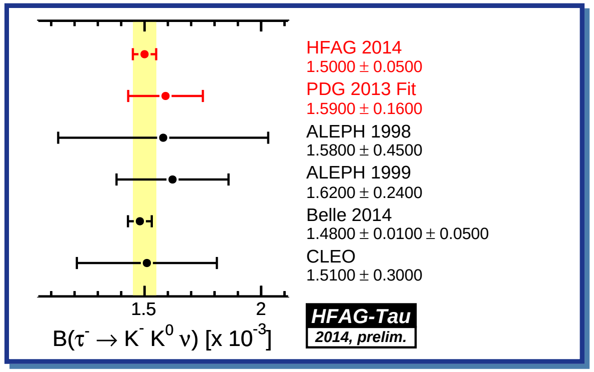
What is new since 2012, Belle $\tau \to$ one or more K^0_S

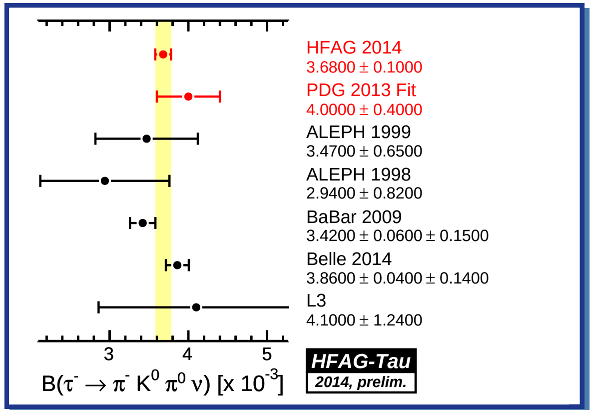
$\Gamma_{33} = B(\tau^- \to K^0_S(\text{particles})^- \nu_\tau)$	$(9.15 \pm 0.01 \pm 0.15) \cdot 10^{-3}$
$\Gamma_{35} = B(\tau^- \to \pi^- \overline{K}^0 \nu_\tau)$	$(8.32 \pm 0.02 \pm 0.16) \cdot 10^{-3}$
$\Gamma_{37} = B(\tau^- \to K^- K^0 \nu_\tau)$	$(14.8 \pm 0.14 \pm 0.54) \cdot 10^{-4}$
$\Gamma_{40} = B(\tau^- \to \pi^- \overline{K}^0 \pi^0 \nu_\tau)$	$(3.86 \pm 0.04 \pm 0.14) \cdot 10^{-3}$
$\Gamma_{42} = B(\tau^- \to K^- \pi^0 K^0 \nu_\tau)$	$(14.96 \pm 0.20 \pm 0.74) \cdot 10^{-4}$
$\Gamma_{47} = B(\tau^- \to \pi^- K^0_S K^0_S \nu_\tau)$	$(2.33 \pm 0.03 \pm 0.09) \cdot 10^{-4}$
$\Gamma_{50} = B(\tau^- \to \pi^- \pi^0 K^0_S K^0_S \nu_\tau)$	$(2.00 \pm 0.22 \pm 0.20) \cdot 10^{-5}$

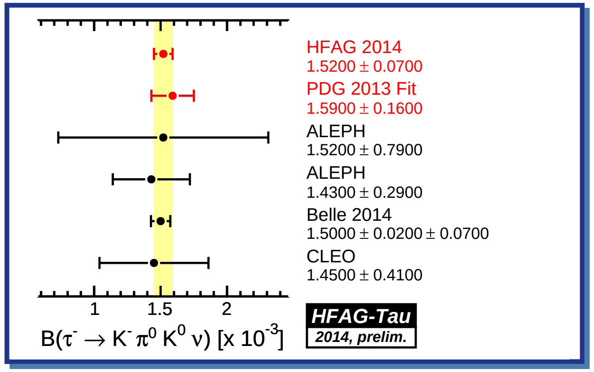
New K^0_S BRs

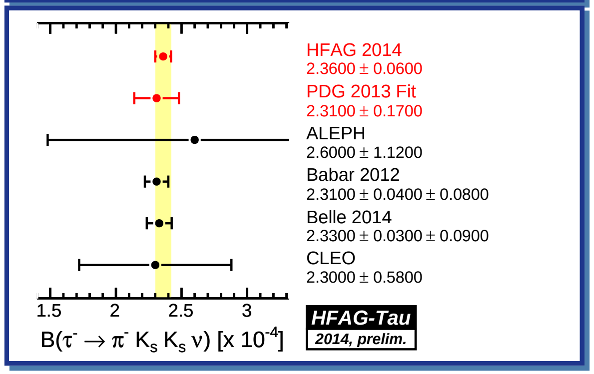

HFAG 2014
9.0200 ± 0.0800
PDG 2013 Fit
9.2000 ± 0.4000
ALEPH
9.7000 ± 0.8500
Belle 2014
9.1500 ± 0.0100 ± 0.1500
OPAL
9.7000 ± 1.0800
8.5 9 9.5 10
B(τ⁻ → K_S X⁻ ν) [x 10⁻³]
HFAG-Tau
2014, prelim.

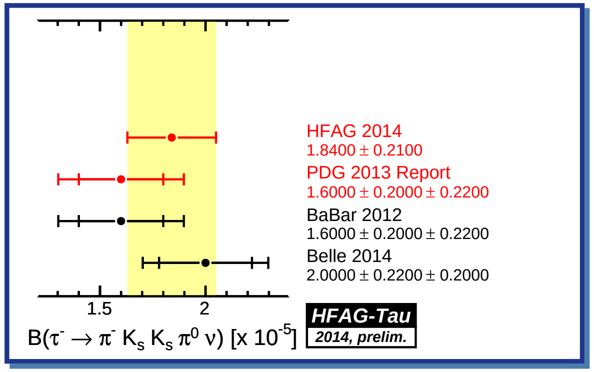

HFAG 2014
8.3800 ± 0.1200
PDG 2013 Fit
8.4000 ± 0.4000
ALEPH
9.2800 ± 0.5600
BaBar 2009
8.4000 ± 0.0400 ± 0.2300
Belle 2014
8.3200 ± 0.0200 ± 0.1600
L3
9.5000 ± 1.6200
OPAL
9.3300 ± 0.8400
8 9 10
B(τ⁻ → π⁻ K⁰ ν) [x 10⁻³]
HFAG-Tau
2014, prelim.


HFAG 2014
1.5000 ± 0.0500
PDG 2013 Fit
1.5900 ± 0.1600
ALEPH 1998
1.5800 ± 0.4500
ALEPH 1999
1.6200 ± 0.2400
Belle 2014
1.4800 ± 0.0100 ± 0.0500
CLEO
1.5100 ± 0.3000
1.5 2
B(τ⁻ → K⁻ K⁰ ν) [x 10⁻³]
HFAG-Tau
2014, prelim.


HFAG 2014
3.6800 ± 0.1000
PDG 2013 Fit
4.0000 ± 0.4000
ALEPH 1999
3.4700 ± 0.6500
ALEPH 1998
2.9400 ± 0.8200
BaBar 2009
3.4200 ± 0.0600 ± 0.1500
Belle 2014
3.8600 ± 0.0400 ± 0.1400
L3
4.1000 ± 1.2400
3 4 5
B(τ⁻ → π⁻ K⁰ π⁰ ν) [x 10⁻³]
HFAG-Tau
2014, prelim.


HFAG 2014
1.5200 ± 0.0700
PDG 2013 Fit
1.5900 ± 0.1600
ALEPH
1.5200 ± 0.7900
ALEPH
1.4300 ± 0.2900
Belle 2014
1.5000 ± 0.0200 ± 0.0700
CLEO
1.4500 ± 0.4100
1 1.5 2
B(τ⁻ → K⁻ π⁰ K⁰ ν) [x 10⁻³]
HFAG-Tau
2014, prelim.


HFAG 2014
2.3600 ± 0.0600
PDG 2013 Fit
2.3100 ± 0.1700
ALEPH
2.6000 ± 1.1200
Babar 2012
2.3100 ± 0.0400 ± 0.0800
Belle 2014
2.3300 ± 0.0300 ± 0.0900
CLEO
2.3000 ± 0.5800
1.5 2 2.5 3
B(τ⁻ → π⁻ K_S K_S ν) [x 10⁻⁴]
HFAG-Tau
2014, prelim.


HFAG 2014
1.8400 ± 0.2100
PDG 2013 Report
1.6000 ± 0.2000 ± 0.2200
BaBar 2012
1.6000 ± 0.2000 ± 0.2200
Belle 2014
2.0000 ± 0.2200 ± 0.2000
1.5 2
B(τ⁻ → π⁻ K_S K_S π⁰ ν) [x 10⁻⁵]
HFAG-Tau
2014, prelim.

What is new since 2012, constraints

removed

$\Gamma_{136} = \Gamma_{104} \cdot \Gamma_{\eta\to\pi^+\pi^-\pi^0} + \Gamma_{78} \cdot \Gamma_{\eta\to 3\pi^0}$

new

$\Gamma_{13} = \Gamma_{14} + \Gamma_{16}$

$\Gamma_{33} = \Gamma_{35} \cdot \Gamma_{<\overline{K}^0|K_S>} + \Gamma_{40} \cdot \Gamma_{<\overline{K}^0|K_S>} + \Gamma_{42} \cdot \Gamma_{<K^0|K_S>} + \Gamma_{47} + \Gamma_{48} + \Gamma_{50} + \Gamma_{51} + \Gamma_{37} \cdot \Gamma_{<K^0|K_S>} + \Gamma_{132} \cdot (\Gamma_{<\overline{K}^0|K_S>} \cdot \Gamma_{\eta\to\text{neutral}}) + \Gamma_{44} \cdot \Gamma_{<\overline{K}^0|K_S>} + \Gamma_{801} \cdot \Gamma_{\phi\to K_S K_L} / (\Gamma_{\phi\to K^+K^-} + \Gamma_{\phi\to K_S K_L})$

$\Gamma_{49} = \Gamma_{50} + \Gamma_{51} + \Gamma_{806}$

$\Gamma_{78} = \Gamma_{810} + \Gamma_{50} \cdot 2 \cdot \Gamma_{K_S\to\pi^+\pi^-} \cdot \Gamma_{K_S\to\pi^0\pi^0} + \Gamma_{132} \cdot (\Gamma_{<\overline{K}^0|K_S>} \cdot \Gamma_{K_S\to\pi^+\pi^-} \cdot \Gamma_{\eta\to 3\pi^0})$

$\Gamma_{103} = \Gamma_{820} + \Gamma_{822} + \Gamma_{831} \cdot \Gamma_{\omega\to\pi^+\pi^-}$

$\Gamma_{104} = \Gamma_{930} + \Gamma_{833} + \Gamma_{831} \cdot \Gamma_{\omega\to\pi^+\pi^-\pi^0}$

$\Gamma_{806} = \Gamma_{50}$

$\Gamma_{810} = \Gamma_{910} + \Gamma_{911} + \Gamma_{811} + \Gamma_{812}$

$\Gamma_{820} = \Gamma_{920} + \Gamma_{821}$

$\Gamma_{830} = \Gamma_{930} + \Gamma_{831} \cdot \Gamma_{\omega\to\pi^+\pi^-\pi^0} + \Gamma_{832}$

$\Gamma_{910} = \Gamma_{136} \cdot \Gamma_{\eta\to 3\pi^0}$

$\Gamma_{930} = \Gamma_{136} \cdot \Gamma_{\eta\to\pi^+\pi^-\pi^0}$

$\Gamma_{944} = \Gamma_{136} \cdot \Gamma_{\eta\to\gamma\gamma}$

$\Gamma_{911} = \Gamma_{945} \cdot \Gamma_{\eta\to\pi^+\pi^-\pi^0}$

revised

$\Gamma_{110} = \Gamma_{10} + \Gamma_{16} + \Gamma_{23} + \Gamma_{28} + \Gamma_{35} + \Gamma_{40} + \Gamma_{128} + \Gamma_{802} + \Gamma_{803} + \Gamma_{151} + \Gamma_{130} + \Gamma_{132} + \Gamma_{44} + \Gamma_{53} + \Gamma_{801} + \Gamma_{822} + \Gamma_{833}$

$\Gamma_{All} = \Gamma_3 + \Gamma_5 + \Gamma_9 + \Gamma_{10} + \Gamma_{14} + \Gamma_{16} + \Gamma_{20} + \Gamma_{23} + \Gamma_{27} + \Gamma_{28} + \Gamma_{30} + \Gamma_{35} + \Gamma_{37} + \Gamma_{40} + \Gamma_{42} + \Gamma_{46} + \Gamma_{62} + \Gamma_{70} + \Gamma_{77} + \Gamma_{78} + \Gamma_{93} + \Gamma_{94} + \Gamma_{104} + \Gamma_{126} + \Gamma_{128} + \Gamma_{802} + \Gamma_{803} + \Gamma_{800} + \Gamma_{151} + \Gamma_{130} + \Gamma_{132} + \Gamma_{44} + \Gamma_{53} + \Gamma_{50} \cdot (1 - 2 \cdot \Gamma_{K_S\to\pi^+\pi^-} \cdot \Gamma_{K_S\to\pi^0\pi^0}) + \Gamma_{51} + \Gamma_{806} + \Gamma_{805} + \Gamma_{801} + \Gamma_{152} + \Gamma_{103}$

What is new since 2012, misc

- **Summer 2010** HFAG, arXiv:1010.1589v3 [hep-ex],
  D. Asner et al., “Averages of b-hadron, c-hadron, and tau-lepton Properties”
  - 12 *BABAR* and 10 Belle measurement added to 124 former measurements in PDG
  - 3 $|V_{us}|$ fits, lepton universality tests
- **Early 2012** HFAG, arXiv:1207.1158 [hep-ex],
  Y. Amhis et al., “Averages of b-hadron, c-hadron, and tau-lepton properties as of early 2012”
  - updated external parameters to PDG 2011 and CODATA 2006
  - drop old ALEPH and CLEO $B(\tau^- \to K^- \eta \nu_\tau)$ measurements
  - added ALEPH: $B(\tau^- \to \pi^- K^0 \overline{K}^0 \nu_\tau)$ and $B(\tau^- \to \pi^- K^0 \overline{K}^0 \pi^0 \nu_\tau)$
  - total of 157 measurements and 47 constraint equations to fit 86 quantities
- HFAG 2014 prelim. fit
- updated external parameters to PDG 2013 and CODATA 2010
  - added 14 new *BABAR* results, 7 new Belle results, related constraints
  - total of 175 measurements and 57 constraint equations to fit 104 quantities

results by collaboration

collaboration	measurements	collaboration	measurements	collaboration	measurements
ALEPH	39	ARGUS	2	BaBar	26
Belle	16	CELLO	1	CLEO	36
CLEO3	6	DELPHI	14	HRS	2
L3	11	OPAL	19	TPC	3

Tau Branching Fractions Fit

- 175 measurements, 57 constraint equations
- fit 104 quantities: 47 BRs, 57 derived quantities, ratios of linear combinations of BR
- χ^2/d.o.f. = 143.8/128, CL = 16.10% (was 5.5% in 2012)
- no unitarity constraint (reduce “pollution” from hadronic to leptonic modes)
- 5.44 error scale factor for inconsistent *BABAR* and Belle $B(\tau^- \to K^- K^- K^+ \nu_\tau)$ as in 2012
- consistent with unitarity, per mill precision, residual = $(9.937 \pm 9.849) \cdot 10^{-4}$

BR fit, leptonic branching fractions

$\Gamma_5 = B(\tau^- \to e^- \overline{\nu}_e \nu_\tau)$	0.17817 ± 0.00041	HFAG 2014 prelim. fit
0.17837 ± 0.00080 ± 0.00000	ALEPH	Schael:2005am
0.17760 ± 0.00180 ± 0.00000	CLEO	Anastassov:1996tc
0.17877 ± 0.00155 ± 0.00000	DELPHI	Abreu:1999rb
0.17806 ± 0.00129 ± 0.00000	L3	Acciarri:2001sg
0.17810 ± 0.00108 ± 0.00000	OPAL	Abbiendi:1998cx
$\Gamma_3 = B(\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau)$	0.17392 ± 0.00040	HFAG 2014 prelim. fit
0.17319 ± 0.00077 ± 0.00000	ALEPH	Schael:2005am
0.17325 ± 0.00122 ± 0.00000	DELPHI	Abreu:1999rb
0.17342 ± 0.00129 ± 0.00000	L3	Acciarri:2001sg
0.17340 ± 0.00108 ± 0.00000	OPAL	Abbiendi:2002jw
$\frac{\Gamma_3}{\Gamma_5} = \frac{B(\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau)}{B(\tau^- \to e^- \overline{\nu}_e \nu_\tau)}$	0.97611 ± 0.00278	HFAG 2014 prelim. fit
0.99700 ± 0.05315 ± 0.00000	ARGUS	Albrecht:1991rh
0.97960 ± 0.00390 ± 0.00053	BaBar	Aubert:2009qj
0.97770 ± 0.01074 ± 0.00000	CLEO	Anastassov:1996tc

Lepton Universality tests

Standard Model (Marciano 1988):

$$\Gamma(L \to \nu_L \ell \overline{\nu}_\ell(\gamma)) = \frac{B(L \to \nu_L \ell \overline{\nu}_\ell)}{\tau_L} = \frac{G_L G_\ell m_L^5}{192\pi^3} f\left(\frac{m_\ell^2}{m_L^2}\right) r_W^L r_\gamma^L ,$$

where

$$G_\ell = \frac{g_\ell^2}{4\sqrt{2}M_W^2} \qquad f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln x$$

$$r_W^L = 1 + \frac{3}{5}\frac{m_L^2}{M_W^2} \qquad r_\gamma^L = 1 + \frac{\alpha(m_L)}{2\pi}\left(\frac{25}{4} - \pi^2\right)$$

Using: $r_\gamma^\tau = 1 - 43.2 \cdot 10^{-4}$ and $r_\gamma^\mu = 1 - 42.4 \cdot 10^{-4}$ (Marciano 1988), M_W from PDG 2013

Proper ratios of the above partial widths:

$$\left(\frac{g_\tau}{g_\mu}\right) = 1.0006 \pm 0.0021 , \qquad \left(\frac{g_\tau}{g_e}\right) = 1.0024 \pm 0.0021 , \qquad \left(\frac{g_\mu}{g_e}\right) = 1.0018 \pm 0.0014 .$$

- no significant change with respect to the Early 2012 HFAG report (no significant new measurement)

Lepton Universality tests (2)

Standard Model:

$$\left(\frac{g_\tau}{g_\mu}\right)^2 = \frac{B(\tau \to h\nu_\tau)}{B(h \to \mu\bar{\nu}_\mu)} \frac{2m_h m_\mu^2 \tau_h}{(1+\delta_h) m_\tau^3 \tau_\tau} \left(\frac{1 - m_\mu^2/m_h^2}{1 - m_h^2/m_\tau^2}\right)^2 \qquad (h = \pi \text{ or } K)$$

rad. corr. $\delta_\pi = (0.16 \pm 0.14)\%$, $\delta_K = (0.90 \pm 0.22)\%$ (Decker 1994)

$$\left(\frac{g_\tau}{g_\mu}\right)_\pi = 0.9958 \pm 0.0031\,, \qquad \left(\frac{g_\tau}{g_\mu}\right)_K = 0.9853 \pm 0.0072\,.$$

electron tests less precise because hadron two body decays to electrons are helicity-suppressed

Averaging the three g_τ/g_μ ratios:

$$\left(\frac{g_\tau}{g_\mu}\right)_{\tau+\pi+K} = 0.9995 \pm 0.0020\,,$$

accounting for statistical correlations.

- no significant change with respect to the Early 2012 HFAG report (no significant new measurement)

Universality improved $B(\tau \to e\nu\bar{\nu})$ and R_{had}

- (Davier 2005): assume lepton universality to improve $B_e = B(\tau \to e\bar{\nu}_e\nu_\tau)$
  - $B_e = B_\mu \cdot f(m_e^2/m_\tau^2)/f(m_\mu^2/m_\tau^2)$
  - $B_e = B(\mu \to e\bar{\nu}_e\nu_\mu) \cdot (\tau_\tau/\tau_\mu) \cdot (m_\tau/m_\mu)^5 \cdot f(m_e^2/m_\tau^2)/f(m_e^2/m_\mu^2) \cdot (\delta_\gamma^\tau\delta_W^\tau)/(\delta_\gamma^\mu\delta_W^\mu)$
    $(B(\mu \to e\bar{\nu}_e\nu_\mu) = 1)$
- HFAG 2014 prelim. fit:
  - $B_e^{\text{univ}} = (17.839 \pm 0.028)\%$
  - $R_{\text{had}} = \dfrac{\Gamma(\tau \to \text{hadrons})}{\Gamma(\tau \to e\nu\bar{\nu})} = 3.6265 \pm 0.0091$

$|V_{us}|$ from inclusive tau partial width to strange

$$|V_{us}| = \sqrt{R_s / \left[\frac{R_{VA}}{|V_{ud}|^2} - \delta R_{\text{theory}}\right]}; \quad R_i = \frac{\Gamma_i}{\Gamma_e^{\text{univ}}} = \frac{B_i}{B_e^{\text{univ}}}; \quad R_{\text{had}} = R_s + R_{VA};$$

- $\delta R_{\text{theory}} = 0.239 \pm 0.030$ (Gamiz et al 2006) QCD sum rules & scattering data
  - uncertainty between two more recent estimates (Gamiz 2007, Maltman 2010)
- $|V_{ud}| = 0.97425 \pm 0.00022$ (Hardy & Towner 2008)
- often $\boldsymbol{B_{\text{had}} = 1 - B_e - B_\mu}$ (or similar expressions based on B_e^{univ})
- since HGAG-Tau 2012: B_{had}, B_{VA} directly from hadronic tau BRs
  - no statistical loss (other expr. more correlated to B_e^{univ})
  - R_{VA} will not absorb effect of unobserved hadronic decay modes
- $|V_{us}|_{\tau s} = 0.2176 \pm 0.0021$ (3.4σ lower than $|V_{us}|_{\text{uni}} = \sqrt{1 - |V_{ud}|^2} = 0.22547 \pm 0.00095$)
  - $B_s = (2.882 \pm 0.047)\%$; $B_{VA} = (61.81 \pm 0.10)\%$)

Tau branching fractions to strange final states

Branching fraction	HFAG 2014 prelim. fit
$\Gamma_{10} = K^- \nu_\tau$	$(0.6955 \pm 0.0096) \cdot 10^{-2}$
$\Gamma_{16} = K^- \pi^0 \nu_\tau$	$(0.4331 \pm 0.0149) \cdot 10^{-2}$
$\Gamma_{23} = K^- 2\pi^0 \nu_\tau$ (ex. K^0)	$(0.0630 \pm 0.0220) \cdot 10^{-2}$
$\Gamma_{28} = K^- 3\pi^0 \nu_\tau$ (ex. K^0, η)	$(0.0419 \pm 0.0216) \cdot 10^{-2}$
$\Gamma_{35} = \pi^- \overline{K}^0 \nu_\tau$	$(0.8378 \pm 0.0123) \cdot 10^{-2}$
$\Gamma_{40} = \pi^- \overline{K}^0 \pi^0 \nu_\tau$	$(0.3680 \pm 0.0103) \cdot 10^{-2}$
$\Gamma_{44} = \pi^- \overline{K}^0 \pi^0 \pi^0 \nu_\tau$	$(0.0124 \pm 0.0204) \cdot 10^{-2}$
$\Gamma_{53} = \overline{K}^0 h^- h^- h^+ \nu_\tau$	$(0.0222 \pm 0.0202) \cdot 10^{-2}$
$\Gamma_{128} = K^- \eta \nu_\tau$	$(0.0153 \pm 0.0008) \cdot 10^{-2}$
$\Gamma_{130} = K^- \pi^0 \eta \nu_\tau$	$(0.0048 \pm 0.0012) \cdot 10^{-2}$
$\Gamma_{132} = \pi^- \overline{K}^0 \eta \nu_\tau$	$(0.0093 \pm 0.0015) \cdot 10^{-2}$
$\Gamma_{151} = K^- \omega \nu_\tau$	$(0.0410 \pm 0.0092) \cdot 10^{-2}$
$\Gamma_{801} = K^- \phi \nu_\tau (\phi \to KK)$	$(0.0037 \pm 0.0014) \cdot 10^{-2}$
$\Gamma_{802} = K^- \pi^- \pi^+ \nu_\tau$ (ex. K^0, ω)	$(0.2923 \pm 0.0068) \cdot 10^{-2}$
$\Gamma_{803} = K^- \pi^- \pi^+ \pi^0 \nu_\tau$ (ex. K^0, ω, η)	$(0.0411 \pm 0.0143) \cdot 10^{-2}$
$\Gamma_{822} = K^- 2\pi^- 2\pi^+ \nu_\tau$ (ex. K^0)	$(0.0001 \pm 0.0001) \cdot 10^{-2}$
$\Gamma_{833} = K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. K^0)	$(0.0001 \pm 0.0001) \cdot 10^{-2}$
$\Gamma_{110} = X_s^- \nu_\tau$	$(2.8816 \pm 0.0470) \cdot 10^{-2}$

$|V_{us}|$ from $B(\tau \to K\nu)/B(\tau \to \pi\nu)$

$$\frac{B(\tau^- \to K^-\nu_\tau)}{B(\tau^- \to \pi^-\nu_\tau)} = \frac{f_K^2\,|V_{us}|^2}{f_\pi^2\,|V_{ud}|^2}\frac{\left(1 - m_K^2/m_\tau^2\right)^2}{\left(1 - m_\pi^2/m_\tau^2\right)^2}\frac{r_{\mathrm{LD}}(\tau^- \to K^-\nu_\tau)}{r_{\mathrm{LD}}(\tau^- \to \pi^-\nu_\tau)}\,.$$

- $|V_{us}|_{\tau K/\pi} = 0.2228 \pm 0.0019$ 1.2σ below CKM unitarity prediction
- details on rad. corrections in the report
- $f_K/f_\pi = 1.1940 \pm 0.0050$ FLAG 2013 2+1
  - lattice uncertainty similar to 2012

$|V_{us}|$ from $B(\tau \to K\nu)$

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

- $|V_{us}|_{\tau K} = 0.2211 \pm 0.0020$ 1.9σ below CKM unitarity prediction
- details on rad. corrections in the report
- $f_K = 156.3 \pm 0.9$ MeV FLAG 2013 2+1
  - lattice uncertainty similar to 2012
- using CODATA 2010

$|V_{us}|$ summary

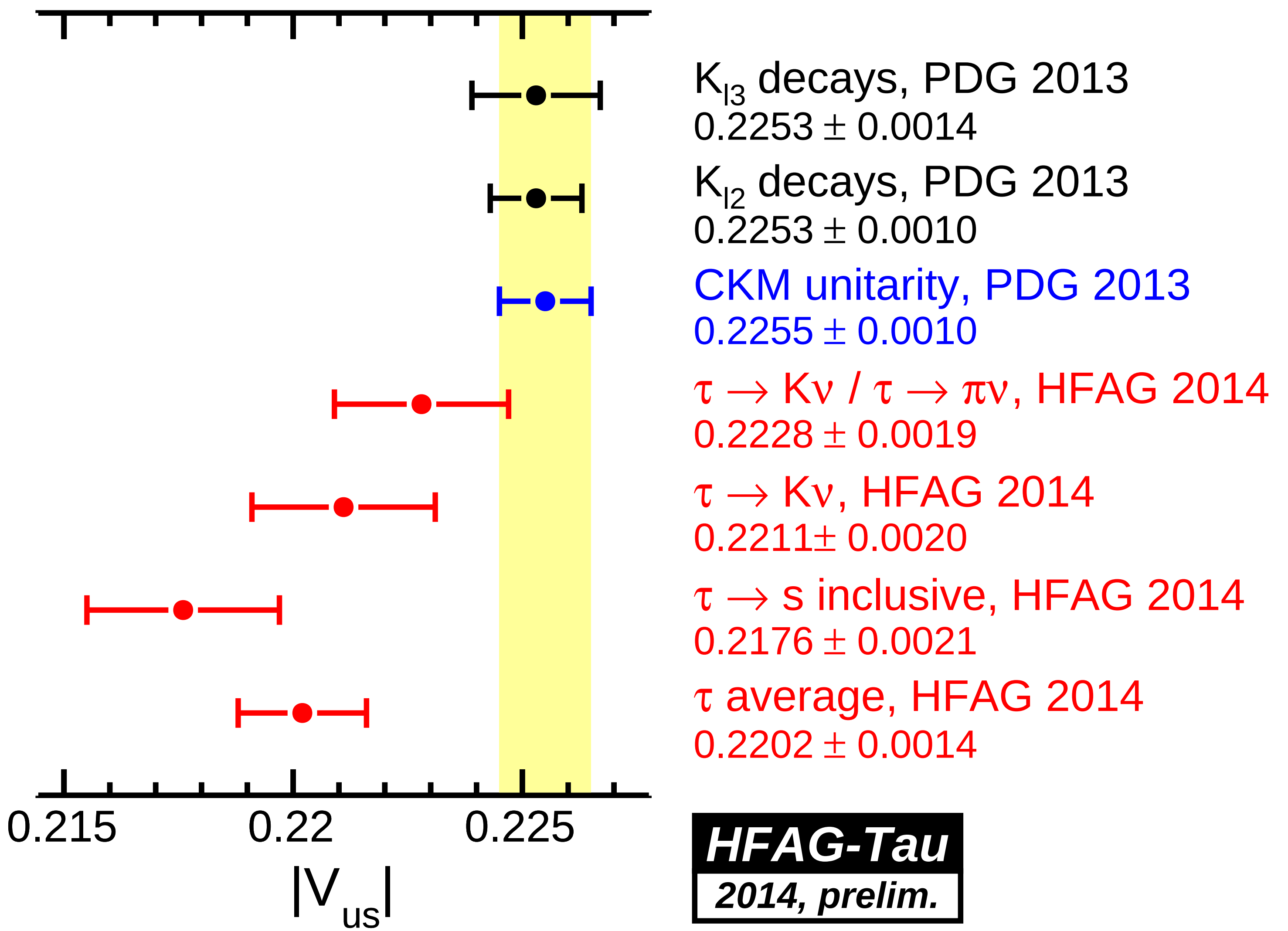
Summary of $|V_{us}|$ measurements, with discrepancies w.r.t. CKM unitarity

$$
\begin{aligned}
|V_{us}|_{\rm uni} &= 0.22547 \pm 0.00095 & & \text{from } \sqrt{1-|V_{ud}|^2} \text{ (CKM unitarity)}\,, \\
|V_{us}|_{\tau s} &= 0.2176 \pm 0.0021 & -3.4\sigma & \text{ from } \Gamma(\tau^- \to X_s^- \nu_\tau)\,, \\
|V_{us}|_{\tau K/\pi} &= 0.2228 \pm 0.0019 & -1.2\sigma & \text{ from } \Gamma(\tau^- \to K^- \nu_\tau)/\Gamma(\tau^- \to \pi^- \nu_\tau)\,, \\
|V_{us}|_{\tau K} &= 0.2211 \pm 0.0020 & -1.9\sigma & \text{ from } \Gamma(\tau^- \to K^- \nu_\tau)\,.
\end{aligned}
$$

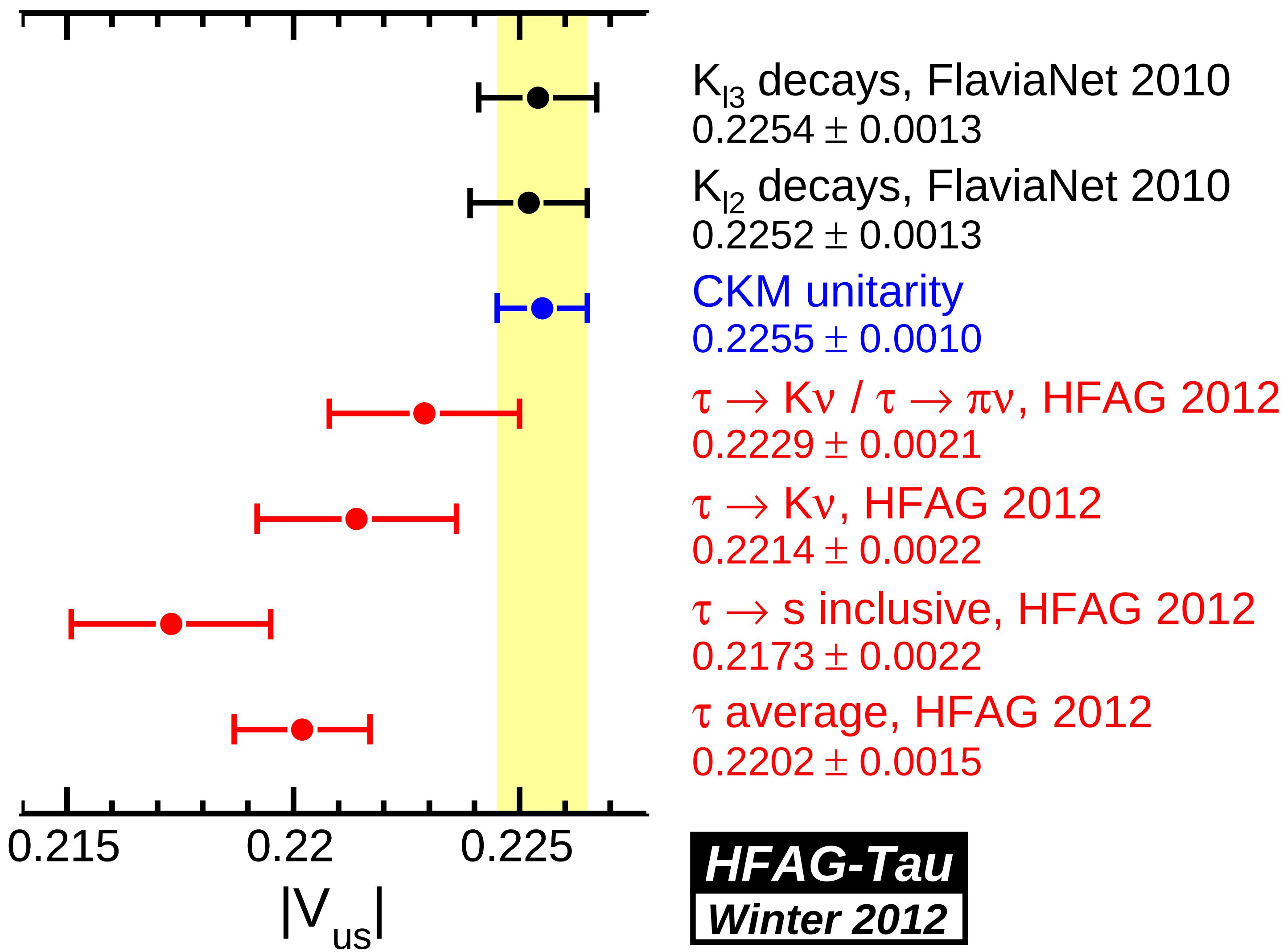
averaging the three $|V_{us}|$ tau determinations

- $|V_{us}|_\tau = 0.2202 \pm 0.0014$ -3.0σ below CKM unitarity
- all significant correlations included
- there is some uncertainty on the correlations of the lattice results (see report for details)
- **no significant change with respect to previous HFAG reports**

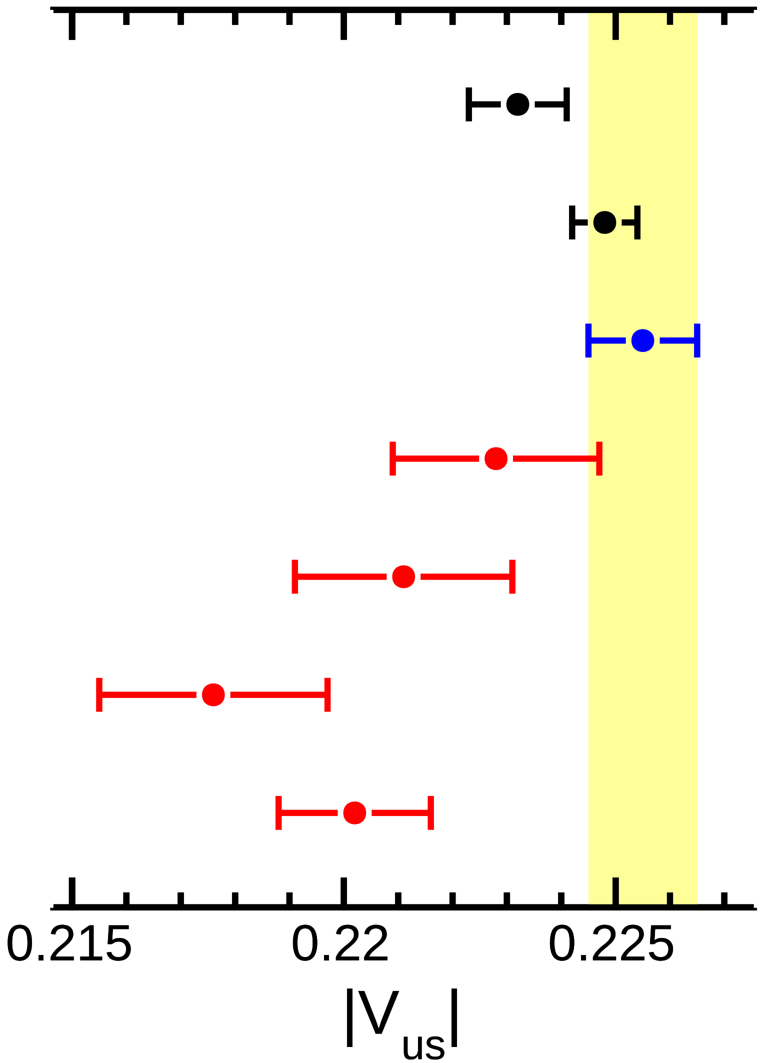
$|V_{us}|$ summary, comparison HFAG 2014 prelim. with PDG 2013



$|V_{us}|$ summary, comparison HFAG 2012 with FlaviaNet 2010



$|V_{us}|$ summary, comparison HFAG 2014 prelim. with Moulson CKM 2014



K_{l3} decays, Moulson CKM 2014
0.2232 ± 0.0009

K_{l2} decays, Moulson CKM 2014
0.2248 ± 0.0006

CKM unitarity, PDG 2013
0.2255 ± 0.0010

$\tau \to K\nu$ / $\tau \to \pi\nu$, HFAG 2014
0.2228 ± 0.0019

$\tau \to K\nu$, HFAG 2014
0.2211± 0.0020

$\tau \to$ s inclusive, HFAG 2014
0.2176 ± 0.0021

τ average, HFAG 2014
0.2202 ± 0.0014

HFAG-Tau
2014, prelim.

Conclusions and prospects

- $|V_{us}|$ from τ still lower than other determinations
- somewhat reduced discrepancy w.r.t. Kaons
- discrepancy would be quite less if $|V_{ud}|$ would also use neutron lifetime data
- may get additional precision results from B-factories
  - *B*A*B*AR will eventually release complex study of $\tau \to K n\pi^0 \nu$, $n = 0$–3