HFAG and PDG tau branching fractions averages and $|V_{us}|$ determination from tau data

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Outline


Tau Branching Fractions Fits

The PDG Tau Branching Fraction Fit

- PDG reports a fit of tau branching fractions since 1994
  - more appropriate treatment of correlations between measurements
  - better use of related experimental inputs, e.g. measurements of $\mathcal{B}(\tau \to \pi\nu)$, $\mathcal{B}(\tau \to K\nu)$, $\mathcal{B}(\tau \to h\nu)$
- since 1996, the "Tau Branching Fractions" PDG mini-review describes the fit
- the fit hinges on the "**basis modes**", a set of non-overlapping and complete tau branching fractions, which are supposed to include all possible decays non-negligible w.r.t. the statistical precision on the unitarity test $\sum \mathcal{B}_i = 1$, now about 0.1%
  - 12 in 1994 to 31 in the 2002 until 2015
- the fit is performed under the **unitarity constraint**
- all fitted measurements are expressed as ratios of linear combinations of basis BRs
- like the PDG averages (which are published together with the fit results) the PDG fit does not scale the uncertainties during the fit procedure that determines the results, but scales them when the fit χ^2 is larger than one, in order to compute the fit results uncertainties
  - the **fit scale factors** are determined with a complex procedure, and are different from scale factors computed for the averages

The HFAG Tau sub-group

- since 2008, the Heavy Flavor Averaging Group (HFAG) has a Tau sub-group
- *BABAR*
  - **Swagato Banerjee** (Victoria $\rightarrow$ Louisville)
  - **A. L.** (convener)
  - **J. Michael Roney** (Victoria)
- Belle
  - **Kiyoshi Hayasaka** (Nagoya $\rightarrow$ Niigata)
  - **Hisaki Hayashii** (Nara)
  - **Boris Shwartz** (Budker)
- LHCb (since ∼2014)
  - **Marcin Chrząszcz** (Zürich / Cracow)
- aim: apply HFAG techniques to best exploit B-factories tau results
  - part of results from B factories, as well as from other experiments, were not used

HFAG Tau Branching Fraction Fit Features

- use published statistical and systematic correlations
- **add correlations from dependencies on common external parameters**
- **use updates of external parameters** from which published measurements depend
  - shift the published values
  - update the respective systematic contribution
- **no unitarity constraint**
  - leptonic tau decays can be considered "cleaner" than hadronic decays for precision measurements
  - the unitarity constraints "pollutes" the leptonic results in an unrecoverable way
- **no scale factors**
  - ad-hoc scale factors may be decided by the authors, there is no automation
  - since 2010, just one $\sim$5.4 scale factor on *BABAR* and Belle $\mathcal{B}(\tau \to KKK\nu)$
- technical implementation of HFAG fit code does not hinge on basis modes and can easily handle any constraint expressed in analytical form

HFAG Tau Branching Fraction Fit Features (2)

ALEPH $\mathcal{B}(\tau \to hn\pi^0\nu)$ vs. $\mathcal{B}(\tau \to \pi n\pi^0\nu)$ modes

- ALEPH still provides the most precise and complete set of tau BR data overall
- ALEPH $\mathcal{B}(\tau \to \pi n\pi^0\nu)$ results are actually coming from measurements of $\mathcal{B}(\tau \to hn\pi^0\nu)$ by subctracting measured $\mathcal{B}(\tau \to Kn\pi^0\nu)$ at the time of the publications
- there is some advantage in using the ALEPH $\mathcal{B}(\tau \to hn\pi^0\nu)$ in combination with the presently available $\mathcal{B}(\tau \to Kn\pi^0\nu)$, and some improvement in accounting for all experimental correlations
- $\Rightarrow$ the HFAG fit uses the ALEPH $\mathcal{B}(\tau \to hn\pi^0\nu)$ instead of the ALEPH $\mathcal{B}(\tau \to \pi n\pi^0\nu)$ results

Inclusion of more especially recent results

- over the time the HFAG fit has included an ever increasing amount of modes and constraints than the PDG

Since 2016 edition, HFAG-Tau group invited to provide the Tau BR fit

- all HFAG fit features except the use of ALEPH $\mathcal{B}(\tau \to hn\pi^0\nu)$ have been ported
  - using $\mathcal{B}(\tau \to hn\pi^0\nu)$ requires improved documentation and ALEPH agreement, it could not be done for 2016 but is planned for 2017
- there are few other negligible differences not worth reporting here
- **PDG fit still uses unitarity constraint, HFAG fit still does not**
- Swagato Banerjee and A.L. authored with Ken Hayes (former author) the tau BR mini-review for PDG 2016
- PDG 2016 will be published in October 2016
- HFAG 2016 may be published since September 2016
- both PDG and HFAG tau fits include several improvements and fixes (see later)

Main Changes from 2014 to 2016

- no new experimental input (there were several in the 2014 report)
- removed two old preliminary results
  - $\Gamma_{35} = \mathcal{B}(\tau \to \pi K^0_S \nu)$, BABAR, ICHEP 2008
  - $\Gamma_{40} = \mathcal{B}(\tau \to \pi K^0_S \pi^0 \nu)$, BABAR, DPF 2009
- removed result $\mathcal{B}[\tau \to K^0_S(\text{particles})^-]$, Belle, 2014
  - information in the paper does not allow computing consistent correlations with the other esclusive results in the same paper; the 2014 report included some inconsistent estimate, which made the results covariance matrix negative-definite
- ALEPH 1998 Γ_{46} $(\tau^- \to \pi^- K^0 \bar{K}^0 \nu_\tau)$ has bee removed because 100% correlated with other esclusive results
- several minor fixes applied to the constraints, thanks to the PDG thorough review
  - (we discovered minor problems also in the PDG constraints. . .)
- added 32 constraint equation to define several inclusive BRs for PDG
- all fixes found to have negligible effects on the main derived results in 2014, like $|V_{us}|$, lepton-universality tests, etc.

Changes from 2014 to 2016 (2)

HFAG 2014

- 174 measurements, 56 constraint equations
- fit 103 quantities: 47 BRs, 56 derived quantities, ratios of linear combinations of BR
- χ^2/d.o.f. = 142.5/127, CL = 16.45% (was 5.5% in 2012)
- no unitarity constraint enforced (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 = $(9.902 \pm 9.850) \cdot 10^{-4}$

HFAG 2016

- 170 measurements, 88 constraint equations
- fit 135 quantities: 47 BRs, 88 derived quantities, ratios of linear combinations of BR
- χ^2/d.o.f. $= 137.3/123$, CL $= 17.84\%$ (was 16.45% in 2012)
- 5.44 error scale factor for inconsistent *BABAR* and Belle $K^-K^-K^+\nu_\tau$ as in 2014
- consistent with unitarity, per mill precision, residual $= (0.0355 \pm 0.1031)\%$

2016 fit inputs results by experiment

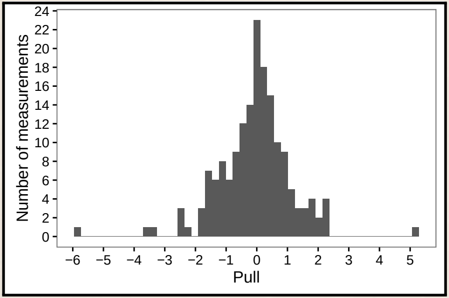
experiment	number of results
ALEPH	39
CLEO	35
BaBar	23
OPAL	19
Belle	15
DELPHI	14
L3	11
CLEO3	6
TPC	3
ARGUS	2
HRS	2
CELLO	1

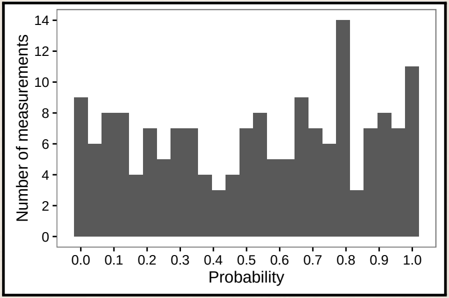
HFAG 2016 basis modes (preliminary)

B ($\tau \to \ldots$)	HFAG 2016 prelim.
$\mu^- \bar{\nu}_\mu \nu_\tau$	17.3917 ± 0.0396
$e^- \bar{\nu}_e \nu_\tau$	17.8162 ± 0.0410
$\pi^- \nu_\tau$	10.8103 ± 0.0526
$K^- \nu_\tau$	0.6960 ± 0.0096
$\pi^- \pi^0 \nu_\tau$	25.5023 ± 0.0918
$K^- \pi^0 \nu_\tau$	0.4327 ± 0.0149
$\pi^- 2\pi^0 \nu_\tau$ (ex. K^0)	9.2424 ± 0.0997
$K^- 2\pi^0 \nu_\tau$ (ex. K^0)	0.0640 ± 0.0220
$\pi^- 3\pi^0 \nu_\tau$ (ex. K^0)	1.0287 ± 0.0749
$K^- 3\pi^0 \nu_\tau$ (ex. K^0, η)	0.0428 ± 0.0216
$h^- 4\pi^0 \nu_\tau$ (ex. K^0, η)	0.1099 ± 0.0391
$\pi^- \bar{K}^0 \nu_\tau$	0.8386 ± 0.0141
$K^- K^0 \nu_\tau$	0.1479 ± 0.0053
$\pi^- \bar{K}^0 \pi^0 \nu_\tau$	0.3812 ± 0.0129
$K^- \pi^0 K^0 \nu_\tau$	0.1502 ± 0.0071
$\pi^- \bar{K}^0 \pi^0 \pi^0 \nu_\tau$ (ex. K^0)	0.0234 ± 0.0231
$\pi^- K_S^0 K_S^0 \nu_\tau$	0.0233 ± 0.0007
$\pi^- K_S^0 K_L^0 \nu_\tau$	0.1047 ± 0.0247
$\pi^- \pi^0 K_S^0 K_S^0 \nu_\tau$	0.0018 ± 0.0002
$\pi^- \pi^0 K_S^0 K_L^0 \nu_\tau$	0.0318 ± 0.0119
$\bar{K}^0 h^- h^- h^+ \nu_\tau$	0.0222 ± 0.0202
$\pi^- \pi^- \pi^+ \nu_\tau$ (ex. K^0, ω)	8.9704 ± 0.0515
$\pi^- \pi^- \pi^+ \pi^0 \nu_\tau$ (ex. K^0, ω)	2.7694 ± 0.0711
$h^- h^- h^+ 2\pi^0 \nu_\tau$ (ex. K^0, ω, η)	0.0976 ± 0.0355
$\pi^- K^- K^+ \nu_\tau$	0.1434 ± 0.0027
$\pi^- K^- K^+ \pi^0 \nu_\tau$	0.0061 ± 0.0018
$\pi^- \pi^0 \eta \nu_\tau$	0.1386 ± 0.0072
$K^- \eta \nu_\tau$	0.0155 ± 0.0008
$K^- \pi^0 \eta \nu_\tau$	0.0048 ± 0.0012
$\pi^- \bar{K}^0 \eta \nu_\tau$	0.0094 ± 0.0015
$\pi^- \pi^+ \pi^- \eta \nu_\tau$ (ex. K^0)	0.0218 ± 0.0013
$K^- \omega \nu_\tau$	0.0410 ± 0.0092
$h^- \pi^0 \omega \nu_\tau$	0.4058 ± 0.0419
$K^- \phi \nu_\tau$	0.0044 ± 0.0016
$\pi^- \omega \nu_\tau$	1.9544 ± 0.0647
$K^- \pi^- \pi^+ \nu_\tau$ (ex. K^0, ω)	0.2923 ± 0.0067
$K^- \pi^- \pi^+ \pi^0 \nu_\tau$ (ex. K^0, ω, η)	0.0410 ± 0.0143
$a_1^- (\to \pi^- \gamma) \nu_\tau$	0.0400 ± 0.0200
$\pi^- 2\pi^0 \omega \nu_\tau$ (ex. K^0)	0.0071 ± 0.0016
$2\pi^- \pi^+ 3\pi^0 \nu_\tau$ (ex. K^0, η, ω, f_1)	0.0013 ± 0.0027
$3\pi^- 2\pi^+ \nu_\tau$ (ex. K^0, ω, f_1)	0.0768 ± 0.0030
$K^- 2\pi^- 2\pi^+ \nu_\tau$ (ex. K^0)	0.0001 ± 0.0001
$2\pi^- \pi^+ \omega \nu_\tau$ (ex. K^0)	0.0084 ± 0.0006
$3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. K^0, η, ω, f_1)	0.0038 ± 0.0009
$K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. K^0)	0.0001 ± 0.0001
$\pi^- f_1 \nu_\tau$ ($f_1 \to 2\pi^- 2\pi^+$)	0.0052 ± 0.0004
$\pi^- 2\pi^0 \eta \nu_\tau$	0.0193 ± 0.0038
$1 - \Gamma_{\mathrm{All}}$	0.0355 ± 0.1031

note: a linear combination sums up to 1

Measurement pulls, pulls probability - HFAG 2016 prelim., no scaling

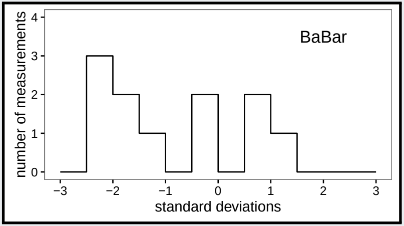




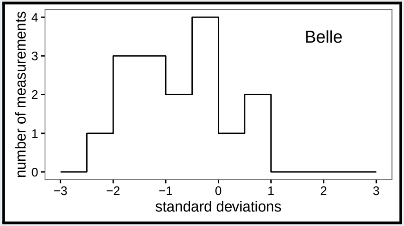
- two outliers: *BABAR* and Belle $\mathcal{B}(\tau \to K^- K^- K^+ \nu_\tau)$ results
- (probabilities expressed as n. of Gaussian sigma's)

B-factories tend to measure lower BFs

BaBar results vs. non-BF fit results



Belle results vs. non-BF fit results



- compared fit results in the same fit with and without B-factories results


Lepton Universality

Lepton universality - HFAG 2016 prelim.

Standard Model for leptons λ, $\rho = e, \mu, \tau$ (Marciano 1988)

$$\Gamma[\lambda \to \nu_\lambda \rho \overline{\nu}_\rho(\gamma)] = \Gamma_{\lambda\rho} = \Gamma_\lambda \mathcal{B}_{\lambda\rho} = \frac{\mathcal{B}_{\lambda\rho}}{\tau_\lambda} = \frac{G_\lambda G_\rho m_\lambda^5}{192\pi^3} f\left(\frac{m_\rho^2}{m_\lambda^2}\right) r_W^\lambda r_\gamma^\lambda ,$$

where

$$G_\lambda = \frac{g_\lambda^2}{4\sqrt{2}M_W^2} \qquad f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln x \qquad f_{\lambda\rho} = f\left(\frac{m_\rho^2}{m_\lambda^2}\right)$$

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

Tests of lepton universality from ratios of above partial widths:

$$\left(\frac{g_\tau}{g_\mu}\right) = \sqrt{\frac{\mathcal{B}_{\tau e}}{\mathcal{B}_{\mu e}} \frac{\tau_\mu m_\mu^5 f_{\mu e} r_W^\mu r_\gamma^\mu}{\tau_\tau m_\tau^5 f_{\tau e} r_W^\tau r_\gamma^\tau}} = 1.0010 \pm 0.0015 = \sqrt{\frac{\mathcal{B}_{\tau e}}{\mathcal{B}_{\tau e}^{\text{SM}}}}$$

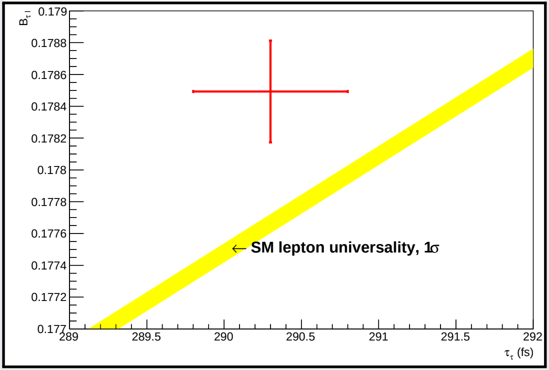
$$\left(\frac{g_\tau}{g_e}\right) = \sqrt{\frac{\mathcal{B}_{\tau\mu}}{\mathcal{B}_{\mu e}} \frac{\tau_\mu m_\mu^5 f_{\mu e} r_W^\mu r_\gamma^\mu}{\tau_\tau m_\tau^5 f_{\tau\mu} r_W^\tau r_\gamma^\tau}} = 1.0029 \pm 0.0015 = \sqrt{\frac{\mathcal{B}_{\tau\mu}}{\mathcal{B}_{\tau\mu}^{\text{SM}}}}$$

$$\left(\frac{g_\mu}{g_e}\right) = \sqrt{\frac{\mathcal{B}_{\tau\mu}}{\mathcal{B}_{\tau e}} \frac{f_{\tau e}}{f_{\tau\mu}}} = 1.0019 \pm 0.0014$$

- precision: **0.20—0.23%** pre-B-Factories ⇒ **0.14—0.15%** today
  thanks essentially to the Belle tau lifetime measurement, PRL 112 (2014) 031801

Lepton universality - HFAG 2016 prelim. (2)

Canonical tau lepton universality test plot



- y axis leptonic BR is proper average of B_e and B_μ

Universality test precision now limited by leptonic BRs

quantity	prec.	contrib.
τ_τ	0.18%	0.090%
$\mathcal{B}_{\tau\to\mu,e}$	0.23%	0.115%
m_τ	0.009%	0.022%

Universality improved $\mathcal{B}(\tau \to e\nu\bar{\nu})$ and R_{had} - HFAG 2016 prelim.

Universality improved $\mathcal{B}(\tau \to e\nu\bar{\nu})$

- (M. Davier, 2005): assume SM lepton universality to improve $\mathcal{B}_e = \mathcal{B}(\tau \to e\bar{\nu}_e\nu_\tau)$ fit $\mathcal{B}_e$ using three determinations:
  - $\mathcal{B}_e = \mathcal{B}_e$
  - $\mathcal{B}_e = \mathcal{B}_\mu \cdot f(m_e^2/m_\tau^2)/f(m_\mu^2/m_\tau^2)$
  - $\mathcal{B}_e = \mathcal{B}(\mu \to e\bar{\nu}_e\nu_\mu) \cdot (\tau_\tau/\tau_\mu) \cdot (m_\tau/m_\mu)^5 \cdot f(m_e^2/m_\tau^2)/f(m_e^2/m_\mu^2) \cdot (\delta_\gamma^\tau \delta_W^\tau)/(\delta_\gamma^\mu \delta_W^\mu)$ [above we have: $\mathcal{B}(\mu \to e\bar{\nu}_e\nu_\mu) = 1$]
- $\boldsymbol{\mathcal{B}_e^{\text{univ}} = (17.815 \pm 0.023)\%}$ HFAG-PDG 2016 prelim. fit

$R_{\text{had}} = \Gamma(\tau \to \text{hadrons})/\Gamma_{\text{univ}}(\tau \to e\nu\bar{\nu})$

- $$R_{\text{had}} = \frac{\Gamma(\tau \to \text{hadrons})}{\Gamma_{\text{univ}}(\tau \to e\nu\bar{\nu})} = \frac{\mathcal{B}_{\text{hadrons}}}{\mathcal{B}_e^{\text{univ}}} = \frac{1 - \mathcal{B}_e^{\text{univ}} - f(m_\mu^2/m_\tau^2)/f(m_e^2/m_\tau^2) \cdot \mathcal{B}_e^{\text{univ}}}{\mathcal{B}_e^{\text{univ}}}$$
  - two different determinations, second one not "contaminated" by hadronic BFs
- $\boldsymbol{R_{\text{had}} = 3.6349 \pm 0.0082}$ HFAG-PDG 2016 prelim. fit
- $\boldsymbol{R_{\text{had}}\text{(leptonic BFs only)} = 3.6397 \pm 0.0070}$ HFAG-PDG 2016 prelim. fit

Lepton Universality tests with hadron decays - HFAG 2016 prelim.

Standard Model:

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

rad. corr. $\delta_\pi = (0.16 \pm 0.12)\%$, $\delta_K = (0.90 \pm 0.22)\%$ (Decker 1994)

$$\boldsymbol{\left(\frac{g_\tau}{g_\mu}\right)_\pi = 0.9961 \pm 0.0027}\ , \qquad \boldsymbol{\left(\frac{g_\tau}{g_\mu}\right)_K = 0.9860 \pm 0.0070}\ .$$

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

Averaging the three g_τ/g_μ ratios:

$$\boldsymbol{\left(\frac{g_\tau}{g_\mu}\right)_{\tau+\pi+K} = 1.0000 \pm 0.0014}\ , \quad \text{(accounting for statistical correlations)}$$

Determination of $|V_{us}|$ from Tau Decays

Determination of $|V_{us}|$ from experimental data

from kaon decays

- $\Gamma(K \to \pi\ell\bar{\nu}_\ell[\gamma]) = \frac{G_F^2 m_K^5}{192\pi^3} C_K^2 S_{\rm EW}^K \left(|V_{us}| f_+^{K\pi}(0)\right)^2 I_K^\ell \left(1 + \delta_{\rm EM}^{K\ell} + \delta_{\rm SU(2)}^{K\pi}\right)^2$
- $\frac{\Gamma(K^\pm \to \ell^\pm\nu)}{\Gamma(\pi^\pm \to \ell^\pm\nu)} = \frac{|V_{us}|^2}{|V_{ud}|^2} \frac{f_K^2}{f_\pi^2} \frac{m_K(1 - m_\ell^2/m_K^2)^2}{m_\pi(1 - m_\ell^2/m_\pi^2)^2} (1 + \delta_{\rm EM})$

from tau decays

- $\frac{R(\tau \to X_{\textbf{strange}})}{|V_{us}|^2} - \frac{R(\tau \to X_{\textbf{non-strange}})}{|V_{ud}|^2} = \delta R_{\tau,\textbf{SU3 breaking}}$, **"tau inclusive"**
  $[R(\tau \to X) = \Gamma(\tau \to X)/\Gamma(\tau \to e\nu\overline{\nu})]$
- $\frac{\mathcal{B}(\tau^- \to K^-\nu_\tau)}{\mathcal{B}(\tau^- \to \pi^-\nu_\tau)} = \frac{f_K^2 |V_{us}|^2}{f_\pi^2 |V_{ud}|^2} \frac{\left(1 - m_K^2/m_\tau^2\right)^2}{\left(1 - m_\pi^2/m_\tau^2\right)^2} \frac{r_{\textbf{LD}}(\tau^- \to K^-\nu_\tau)}{r_{\textbf{LD}}(\tau^- \to \pi^-\nu_\tau)}$
- $\mathcal{B}(\tau^- \to K^-\nu_\tau) = \frac{G_F^2 f_K^2 |V_{us}|^2 m_\tau^3 \tau_\tau}{16\pi\hbar} \left(1 - \frac{m_K^2}{m_\tau^2}\right)^2 S_{EW}^{\tau K}$
  (here one should add long-range rad. correction)
- $\Gamma(\tau \to \bar{K}\pi\nu_\tau[\gamma]) = \frac{G_F^2 m_\tau^5}{96\pi^3} C_K^2 S_{\textbf{EW}}^{\tau K\pi} \left(|V_{us}| f_+^{K\pi}(0)\right)^2 I_K^\tau \left(1 + \delta_{\rm EM}^{K\tau} + \tilde{\delta}_{\rm SU(2)}^{K\pi}\right)^2$

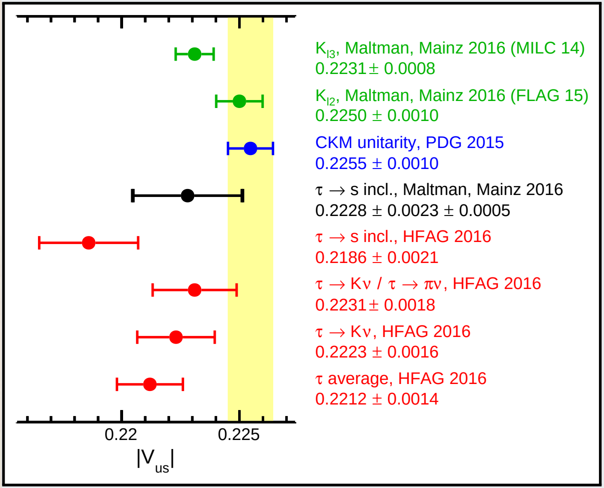
"tau inclusive" $|V_{us}|$ determination

- $$\frac{R(\tau \to X_{\text{strange}})}{|V_{us}|^2} - \frac{R(\tau \to X_{\text{non-strange}})}{|V_{ud}|^2} = \delta R_{\tau,\text{SU3 breaking}}$$
- $\delta R_{\tau,\text{SU3 breaking}}$ can be computed with OPE
  - finite-energy sum rules (FESR) with either fixed-order (FOPT) or contour-improved (CIPT) prescriptions
  - strong dependence from m_s
  - problematic convergence requires special treatment
  - non-pert. terms fitted / estimated using tau spectral functions moments
  - assumptions on $D>4$ OPE contributions
- input $|V_{us}|$ and compute m_s, **Pich & Prades, hep-ph/9909244**
- input m_s and compute $|V_{us}|$
  - **Gamiz, Jamin, Pich, Prades, Schwab, hep-ph/0212230, hep-ph/0408044,**
  - **Maltman, 1011.6391 [hep-ph]**
  - **Maltman (Lattice 2015, 1510.06954 [hep-ph], Mainz QCD Workshop in March 2016**
    - fit of $|V_{us}|$ and $D>4$ condensates on moments of tau spectral functions
    - use QCD lattice to quantify OPE truncation error
    - indicates that $|V_{us}|$ determination with BRs only and without using the spectral functions appears to be plagued by higher than previously estimated uncertainties

Tau branching fractions to strange final states, HFAG 2016 prelim.

Branching fraction	HFAG-PDG 2016 prelim. fit
$K^- \nu_\tau$	0.6960 ± 0.0096
$K^- \pi^0 \nu_\tau$	0.4327 ± 0.0149
$K^- 2\pi^0 \nu_\tau$ (ex. K^0)	0.0640 ± 0.0220
$K^- 3\pi^0 \nu_\tau$ (ex. K^0, η)	0.0428 ± 0.0216
$\pi^- \bar{K}^0 \nu_\tau$	0.8386 ± 0.0141
$\pi^- \bar{K}^0 \pi^0 \nu_\tau$	0.3812 ± 0.0129
$\pi^- \bar{K}^0 \pi^0 \pi^0 \nu_\tau$ (ex. K^0)	0.0234 ± 0.0231
$\bar{K}^0 h^- h^- h^+ \nu_\tau$	0.0222 ± 0.0202
$K^- \eta \nu_\tau$	0.0155 ± 0.0008
$K^- \pi^0 \eta \nu_\tau$	0.0048 ± 0.0012
$\pi^- \bar{K}^0 \eta \nu_\tau$	0.0094 ± 0.0015
$K^- \omega \nu_\tau$	0.0410 ± 0.0092
$K^- \phi \nu_\tau$ ($\phi \to K^+ K^-$)	0.0022 ± 0.0008
$K^- \phi \nu_\tau$ ($\phi \to K^0_S K^0_L$)	0.0015 ± 0.0006
$K^- \pi^- \pi^+ \nu_\tau$ (ex. K^0, ω)	0.2923 ± 0.0067
$K^- \pi^- \pi^+ \pi^0 \nu_\tau$ (ex. K^0, ω, η)	0.0410 ± 0.0143
$K^- 2\pi^- 2\pi^+ \nu_\tau$ (ex. K^0)	0.0001 ± 0.0001
$K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. K^0)	0.0001 ± 0.0001
$X_s^- \nu_\tau$	2.9087 ± 0.0482

$|V_{us}|$ results



- Maltman, Mainz 2016 uses
  - HFAG 2014 fit data
  - available spectral functions
  - Adametz thesis on $B(\tau \to K n \pi^0 \nu)$
  - Moulson CKM 2014 for kaon experimental inputs
  - lattice QCD $N_f = 2+1+1$ form factors
    - K_{l3}: FNAL-MILC 2014
    - $K_{\mu 2}$: FLAG 2015
- CKM unitarity uses $|V_{ud}|$

Conclusions

- HFAG Tau Branching Fraction fit ported to PDG 2016
  - some features planned to be completed in 2017
- HFAG 2016 report ready, will be published soon
- several small improvements and fixes
- updated lepton universality tests and $|V_{us}|$: no change