$|V_{us}|$ from taus (Experiment)

Alberto Lusiani

Scuola Normale Superiore and INFN, sezione di Pisa

SCUOLA NORMALE SUPERIORE

INFN

Outline

Main ways to measure $|V_{us}|$

from kaon decays

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

from tau decays

- $\frac{R(\tau \to X_{\textbf{strange}})}{|V_{us}|^2} = \frac{R(\tau \to X_{\textbf{non-strange}})}{|V_{ud}|^2} - \delta R_{\tau,\textbf{SU3 breaking}},$ — $\tau \to s$ inclusive method

  $[R(\tau \to X) = \Gamma(\tau \to X)/\Gamma(\tau \to e\nu\bar{\nu})]$
- $\frac{\Gamma(\tau^- \to K^- \nu_\tau)}{\Gamma(\tau^- \to \pi^- \nu_\tau)} = \frac{|V_{us}|^2}{|V_{ud}|^2} \frac{f_K^2}{f_\pi^2} \frac{\left(1 - m_K^2/m_\tau^2\right)^2}{\left(1 - m_\pi^2/m_\tau^2\right)^2} \frac{r_{\textbf{LD}}(\tau^- \to K^- \nu_\tau)}{r_{\textbf{LD}}(\tau^- \to \pi^- \nu_\tau)}$ — $\tau \to K/\tau \to \pi$ method

- $\tau \to s$ inclusive method does not require form factors from lattice QCD (and therefore has theory systematics uncorrelated to lattice QCD form factors)

"$\tau \to s$ inclusive" $|V_{us}|$ determination

Determine $|V_{us}|$ and/or m_s from $\mathcal{B}(\tau \to s)$ inclusive

Gamiz, Jamin, Pich, Prades, Schwab, JHEP 01 (2003) 06, PRL 94 (2005) 011803

$$\frac{R(\tau \to X_{\text{strange}})}{|V_{us}|^2} = \frac{R(\tau \to X_{\text{non-strange}})}{|V_{ud}|^2} - \delta R_{\tau,\text{SU3 breaking}}$$

- $\delta R_{\tau,\text{SU3 breaking}}$ computed with OPE techniques using also
  - finite-energy sum rules (FESR)
  - either fixed-order (FOPT) or contour-improved (CIPT) perturbation theory

Determine $|V_{us}|$ relying on the world average for m_s

- E. Gamiz *et al.*, JHEP 01 (2003) 060, PRL 94 (2005) 011803, Nucl. Phys .Proc. Suppl. 169 (2007) 85, PoS KAON (2008) 008

Tau BRs best estimated with global fit of all relevant measurements

HFLAV Tau Spring 2017 fit, in HFLAV Summer 2016 report, Eur.Phys.J. C77 (2017)

Tau BRs Measurements

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
total	170

- 170 measurements, 88 constraint equations
- fit 135 quantities: 47 BRs, 88 derived quantities (ratios of linear combinations of BRs)
- χ^2/d.o.f. $= 137/123$, CL $= 17.79\%$
- consistent with unitarity within 0.1% uncertainty, residual $= (0.03 \pm 0.10)\%$

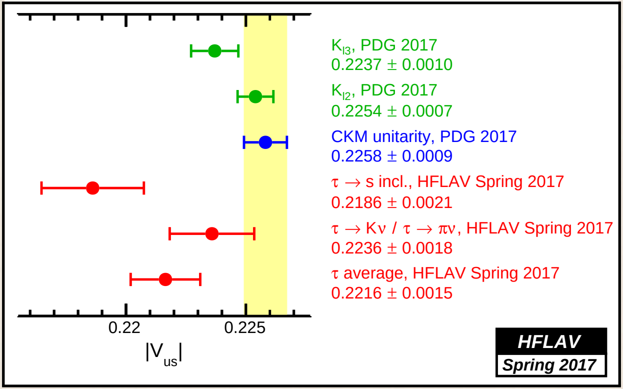
- since 2016, adopted also for PDG

- most measurements systematically limited
  - better experimental conditions at Z^0 peak
  - moderate progress since $\sim$2000
- *B*-factories improved many smaller BRs
- Belle II may contribute in near future

$\mathcal{B}(\tau \to X_s \nu)$ from HFLAV Spring 2017 fit

Tau decay mode	Branching fraction (%)
$K^- \nu_\tau$	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

$|V_{us}|$ from tau BRs using the HFLAV Spring 2017 fit



- $\tau \to s$ inclusive vs. CKM unitarity discrepancy: $-3.1\,\sigma$
  - no significant change since the first HFLAV fit in 2010
- $m_s = 95.00 \pm 5.00\,\text{MeV}$ (PDG 2015), form factors from FLAG 2016
- $\delta R_\tau = 0.242 \pm 0.032$ (E. Gamiz *et al.*, arXiv:hep-ph/0612154v1)
- details in HFLAV Spring 2017 report, Eur. Phys. J. C77 (2017) 895 , arXiv:1612.07233

ICHEP 2018 *BaBar* tau BRs measurements

BaBar preliminary tau BRs measurements, T. Lueck, ICHEP 2018

- simultaneous measurement of 6 modes:

  $\tau \to K\ n\pi^0\ \nu \quad (\text{ex. } K^0 \to 2\pi^0, \text{ ex. } \eta \to 3\pi^0) \quad n = 0, 1, 2, 3$

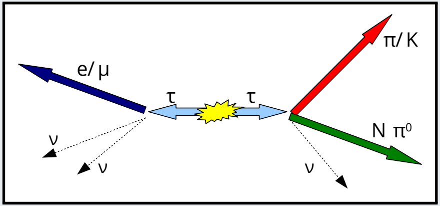
  $\tau \to \pi\ n\pi^0\ \nu \quad (\text{ex. } K^0 \to 2\pi^0, \text{ ex. } \eta \to 3\pi^0) \quad n = 3, 4$

  to best account for cross-feeds between signal modes

Dataset

$\sim$full *BaBar* data sample, $\sim$430fb^{-1}

1–1 prongs tau pairs, e or μ tag



signal side selection

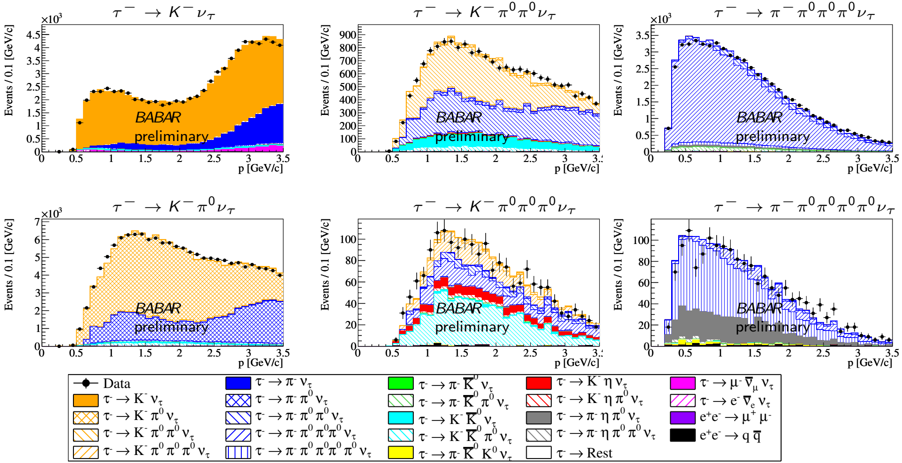
- 1 identified pion or kaon
- from 0 to 4 $\pi^0 \to 2\gamma$ candidates
- no extra unpaired photon

dedicated data control samples studies

- π^0 efficiency
- PID $\pi \to \pi$, $K \to K$, $\pi \to K$
- split-offs (secondary energy deposits due to neutrons produced in hadronic interactions of charged particles in the electro-magnetic calorimeter)

Reconstructed hadron momentum of measured modes (from T.Lueck, ICHEP 2018)

- data - MC comparison after event selection
- all corrections to MC applied



Results, statistical and systematic uncertaintites, *BaBar* preliminary, ICHEP 2018

τ - Decay mode	$K^-\nu_\tau$ ($\times10^{-3}$)	$K^-\pi^0\nu_\tau$ ($\times10^{-3}$)	$K^-2\pi^0\nu_\tau$ ($\times10^{-4}$)	$K^-3\pi^0\nu_\tau$ ($\times10^{-4}$)	$\pi^-3\pi^0\nu_\tau$ ($\times10^{-2}$)	$\pi^-4\pi^0\nu_\tau$ ($\times10^{-4}$)
Branching fraction	7.174	5.054	6.151	1.246	1.168	9.020
Stat. uncertainty	0.033	0.021	0.117	0.164	0.006	0.400
Syst. uncertainty	0.213	0.148	0.338	0.238	0.038	0.652
Total uncertainty	0.216	0.149	0.357	0.289	0.038	0.765
Stat. uncertainty [%]	0.46	0.41	1.91	13.13	0.52	4.44
Syst. uncertainty [%]	2.97	2.93	5.49	19.12	3.23	7.23
Total uncertainty [%]	3.00	2.95	5.81	23.19	3.27	8.48
ϵ_{signal} [%]	0.27	0.27	0.87	3.99	0.27	1.50
ϵ_{bkg} [%]	0.15	0.15	0.87	6.32	0.11	1.67
Background B's[%]	0.18	0.30	1.44	11.52	0.21	3.49
BaBar PID [%]	0.15	0.11	0.18	0.71	0.08	0.20
Custom PID [%]	1.83	1.55	1.78	2.56	0.20	0.26
Muon mis-id [%]	1.48	0.01	0.00	0.00	0.00	0.00
# $\tau^+\tau^-$ pairs [%]	0.79	0.93	1.40	2.61	0.71	0.98
Track efficiency [%]	0.43	0.50	0.76	1.42	0.38	0.53
Split-off correction [%]	1.52	1.84	2.77	5.17	1.40	1.94
π^0 correction [%]	0.03	1.20	3.63	10.56	2.76	5.36
$\pi 5\pi^0 \to \pi 4\pi^0$ migr. [%]	0.00	0.00	0.00	0.02	0.04	1.08
$K4\pi^0 \to K3\pi^0$ migr. [%]	0.00	0.00	0.13	4.78	0.00	0.00

Statistical correlation, *BABAR* preliminary, ICHEP 2018

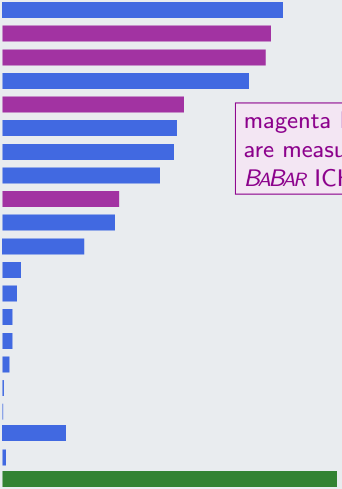
	K	$K\pi^0$	$K2\pi^0$	$K3\pi^0$	$\pi3\pi^0$	$\pi4\pi^0$
K	1.000	-0.029	0.001	-0.000	-0.000	0.000
$K\pi^0$	-0.029	1.000	-0.086	0.004	-0.000	-0.000
$K2\pi^0$	0.001	-0.086	1.000	-0.208	-0.002	0.002
$K3\pi^0$	-0.000	0.004	-0.208	1.000	-0.038	-0.005
$\pi3\pi^0$	-0.000	-0.000	-0.002	-0.038	1.000	-0.312
$\pi4\pi^0$	0.000	-0.000	0.002	-0.005	-0.312	1.000

Systematic correlation, *BABAR* preliminary, ICHEP 2018

	K	$K\pi^0$	$K2\pi^0$	$K3\pi^0$	$\pi3\pi^0$	$\pi4\pi^0$
K	1.000	0.743	0.506	0.251	0.299	0.190
$K\pi^0$	0.743	1.000	0.859	0.554	0.720	0.542
$K2\pi^0$	0.506	0.859	1.000	0.624	0.875	0.684
$K3\pi^0$	0.251	0.554	0.624	1.000	0.636	0.529
$\pi3\pi^0$	0.299	0.720	0.875	0.636	1.000	0.805
$\pi4\pi^0$	0.190	0.542	0.684	0.529	0.805	1.000

HFLAV $|V_{us}|$ from $\tau \to s$ inclusive uncertainties budget (%) for the HFLAV Spring 2017 determination

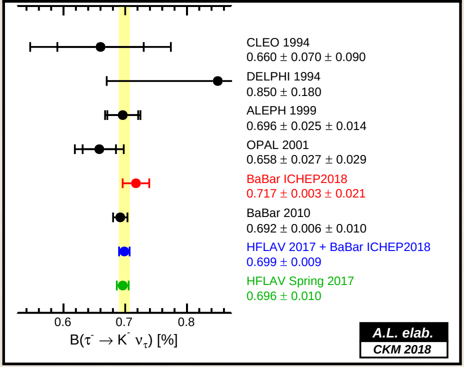
$\pi^- \bar{K}^0 \pi^0 \pi^0 \nu_\tau$ (ex. K^0)	0.3963
$K^- 2\pi^0 \nu_\tau$ (ex. K^0)	0.3789
$K^- 3\pi^0 \nu_\tau$ (ex. K^0, η)	0.3715
$\bar{K}^0 h^- h^- h^+ \nu_\tau$	0.3478
$K^- \pi^0 \nu_\tau$	0.2561
$K^- \pi^- \pi^+ \pi^0 \nu_\tau$ (ex. K^0, ω, η)	0.2456
$\pi^- \bar{K}^0 \nu_\tau$	0.2424
$\pi^- \bar{K}^0 \pi^0 \nu_\tau$	0.2219
$K^- \nu_\tau$	0.1646
$K^- \omega \nu_\tau$	0.1585
$K^- \pi^- \pi^+ \nu_\tau$ (ex. K^0, ω)	0.1157
$\pi^- \bar{K}^0 \eta \nu_\tau$	0.0256
$K^- \pi^0 \eta \nu_\tau$	0.0200
$K^- \eta \nu_\tau$	0.0138
$K^- \phi \nu_\tau$ ($\phi \to K^+ K^-$)	0.0138
$K^- \phi \nu_\tau$ ($\phi \to K^0_S K^0_L$)	0.0096
$K^- 2\pi^- 2\pi^+ \nu_\tau$ (ex. K^0)	0.0021
$K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. K^0)	0.0010
$\tau \to$ non-strange	0.0896
$\mathcal{B}_e^{\text{univ}}$	0.0045
theory	0.4722



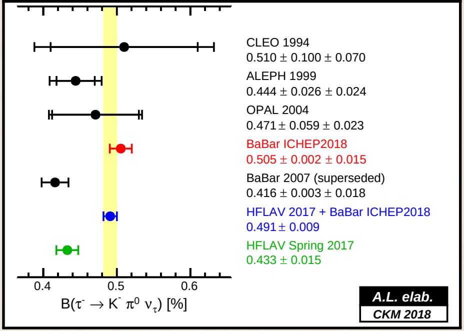
magenta BRs are measured in BABAR ICHEP 2018

Preliminary global HFLAV fit with BABAR ICHEP 2018 results

$\mathcal{B}(\tau \to K\nu)$ measurements and fits



$\mathcal{B}(\tau \to K\pi^0\nu)$ measurements and fits



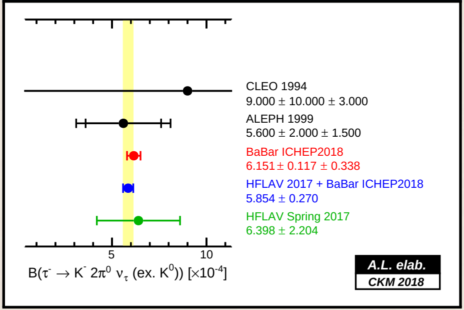
- BABAR 2010 $\mathcal{B}(\tau^- \to K^- \nu_\tau)$ (more precise) statistically independent because measured on 3–1 prongs tau pairs

- new result supersedes BABAR 2007 $\mathcal{B}(\tau^- \to K^- \pi^0 \nu_\tau)$

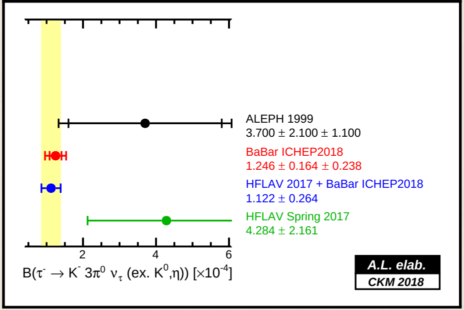
- the plots report a branching fraction and its existing measurements, but note that in the HFLAV global fit also other indirect measurements (ratios of branching fractions, or more inclusive branching fractions) can contribute in a significant way to determine the fit result for the plotted quantities.

Preliminary global HFLAV fit with BABAR ICHEP 2018 results

$\mathcal{B}(\tau \to K 2\pi^0 \nu)$ measurements and fits



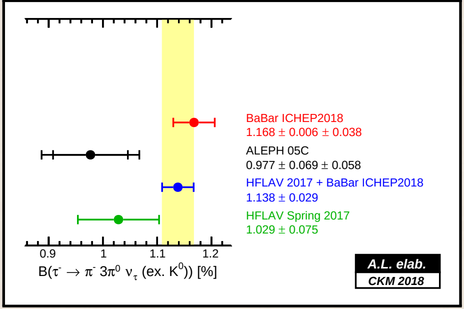
$\mathcal{B}(\tau \to K 3\pi^0 \nu)$ measurements and fits



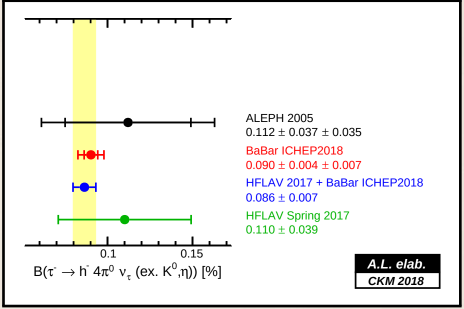
- the plots report a branching fraction and its existing measurements, but note that in the HFLAV global fit also other indirect measurements (ratios of branching fractions, or more inclusive branching fractions) can contribute in a significant way to determine the fit result for the plotted quantities.

Preliminary global HFLAV fit with BABAR ICHEP 2018 results

$\mathcal{B}(\tau\to\pi 3\pi^0\nu)$ measurements and fits



$\mathcal{B}(\tau\to\pi 4\pi^0\nu)$ measurements and fits



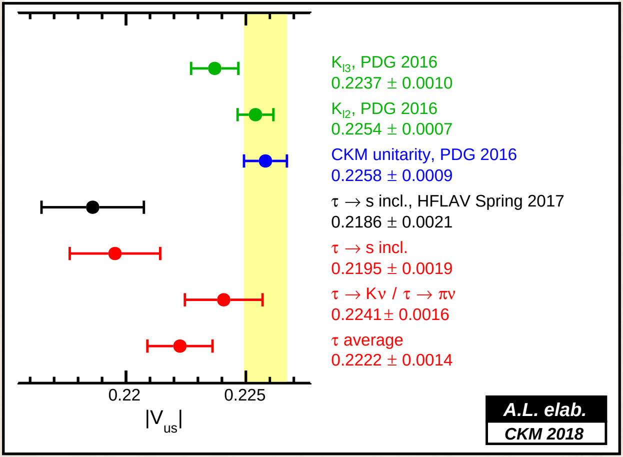
- $\mathcal{B}(\tau^-\to\pi^- 4\pi^0\nu_\tau) = \mathcal{B}(\tau^-\to h^- 4\pi^0\nu_\tau)$, where $h=\pi, K$, since $\mathcal{B}(\tau^-\to K^- 4\pi^0\nu_\tau)$ has not yet been measured and is considered to be negligible

- the plots report a branching fraction and its existing measurements, but note that in the HFLAV global fit also other indirect measurements (ratios of branching fractions, or more inclusive branching fractions) can contribute in a significant way to determine the fit result for the plotted quantities.

HFLAV Spring 2017 + *BaBar* ICHEP 2018 fit

Tau decay mode	Branching fraction (%)
$K^- \nu_\tau$	0.6986 ± 0.0086
$K^- \pi^0 \nu_\tau$	0.4910 ± 0.0091
$K^- 2\pi^0 \nu_\tau$ (ex. K^0)	0.0585 ± 0.0027
$K^- 3\pi^0 \nu_\tau$ (ex. K^0, η)	0.0112 ± 0.0026
$\pi^- \bar{K}^0 \nu_\tau$	0.8388 ± 0.0141
$\pi^- \bar{K}^0 \pi^0 \nu_\tau$	0.3811 ± 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
$K^- \eta \nu_\tau$	0.0154 ± 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
$X_s^- \nu_\tau$	2.9327 ± 0.0413

$|V_{us}|$ from tau, HFLAV 2017 + BABAR ICHEP 2018



- $\tau \to s$ inclusive vs. CKM unitarity discrepancy: $-3.0\,\sigma$
  - no significant change, $|V_{us}|$ increased a bit, uncertainty reduced

Using kaon BRs to predict tau BRs

Use precisely measured kaon BRs to predict tau BRs

M. Antonelli *et al.*, JHEP 10 (2013) 76

$$\mathcal{B}(\tau \to K\nu_\tau) = \frac{m_\tau^3}{2 m_K m_\mu^2} \frac{S_{\textbf{EW}}^\tau}{S_{\textbf{EW}}^K} \left(\frac{1 - m_K^2/m_\tau^2}{1 - m_\mu^2/m_K^2} \right)^2 \frac{\tau_\tau}{\tau_K} R_{\textbf{EM}}^{\tau/K} \mathcal{B}(K_{\mu 2})$$

new:

$$\mathcal{B}(\tau \to \bar{K}\pi\nu_\tau) = \frac{2 m_\tau^5}{m_K^5} \frac{S_{\textbf{EW}}^\tau}{S_{\textbf{EW}}^K} \frac{I_K^\tau}{I_K^\ell} \frac{\left(1 + \delta_{\text{EM}}^{K\tau} + \tilde{\delta}_{\text{SU(2)}}^{K\pi}\right)^2}{\left(1 + \delta_{\text{EM}}^{K\ell} + \delta_{\text{SU(2)}}^{K\pi}\right)^2} \frac{\tau_\tau}{\tau_K} \mathcal{B}(K \to \pi e \bar{\nu}_e)$$

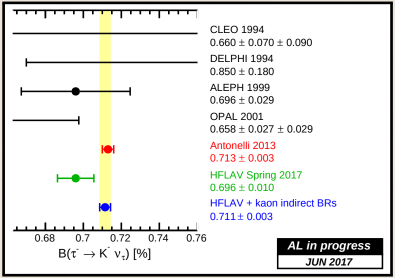
[and similar formula for $\mathcal{B}(\tau \to K\pi^0\nu)$]

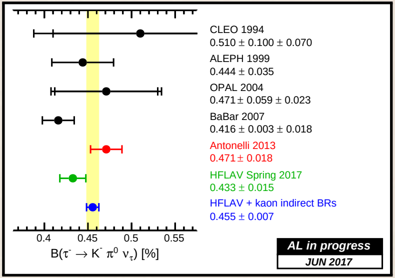
phase space integrals I_K^τ require tau spectral functions

$$I_K^\tau = \frac{1}{m_\tau^2} \int_{s_{K\pi}}^{m_\tau^2} \frac{ds}{s\sqrt{s}} \left(1 - \frac{s}{m_\tau^2}\right)^2 \left[\left(1 + \frac{2s}{m_\tau^2}\right) q_{K\pi}^3(s) |\bar{f}_+(s)|^2 + \frac{3\Delta_{K\pi}^2}{4s} q_{K\pi}(s) |\bar{f}_0(s)|^2\right]$$

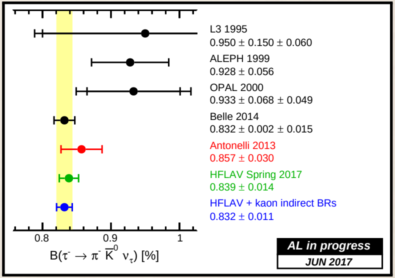
- results:
  - $\mathcal{B}(\tau \to K\nu) = (0.713 \pm 0.003)\%$
  - $\mathcal{B}(\tau \to K\pi^0\nu) = (0.471 \pm 0.018)\%$
  - $\mathcal{B}(\tau \to K^0\pi\nu) = (0.857 \pm 0.030)\%$
- note: the latter two uncertainties are 100% correlated

Tau BRs from kaon BRs, compared to measurements of tau BRs

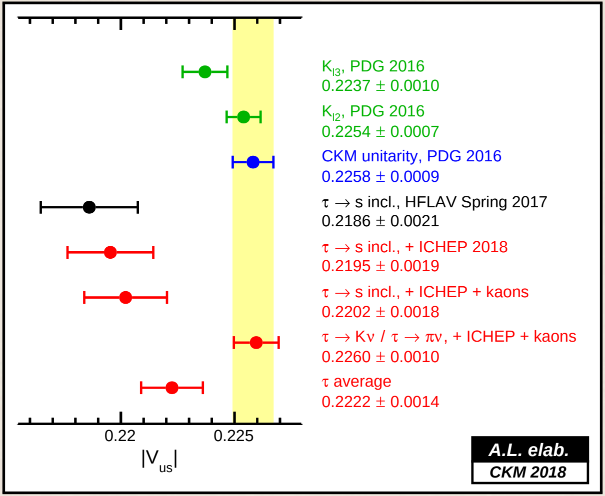




- red: tau BR predicted using kaon BR
- green: HFLAV average using only tau BRs inputs
- blue: HFLAV average combining tau BRs inputs and predictions from kaon BRs



$|V_{us}|$ from tau using HFLAV, BABAR ICHEP 2018, kaon predictions



- $\tau \to s$ inclusive vs. CKM unitarity discrepancy: $-2.7\,\sigma$
- most complete unbiased usage of exp. data for $|V_{us}|$ with $\tau \to s$ inclusive

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

Other $|V_{us}|$ from $\tau \to s$ inclusive determinations (non exhaustive)

- M. Antonelli *et al.*, JHEP 10 (2013) 76
  predict K, $K\pi^0$, $K^0_s\pi$ tau BRs from kaon decays to replace tau results and compute $|V_{us}|$
- J. Hudspith *et al.*, PLB 781 (2018) 206
  - compute $|V_{us}|$ from tau inclusive using also the tau spectral functions
- P. Boyle *et al.*, arXiv:1803.07228 [hep-lat]
  compute $|V_{us}|$ from tau inclusive using lattice QCD
  - Boyle 2018a: uses HFLAV tau BRs + tau spectral functions
  - Boyle 2018b: like 2018a but replaces $\mathcal{B}(\tau \to K\nu)$ with prediction from kaon BRs

Other $|V_{us}|$ from $\tau \to s$ inclusive determinations (non exhaustive)

M. Antonelli *et al.*, JHEP 10 (2013) 76

- predict $K, K\pi^0, K_s^0\pi$ tau BRs from kaon decays to replace tau results
- compute $|V_{us}|$ with the standard technique

Other $|V_{us}|$ from $\tau \to s$ inclusive determinations (non exhaustive)

J. Hudspith *et al.*, PLB 781 (2018) 206

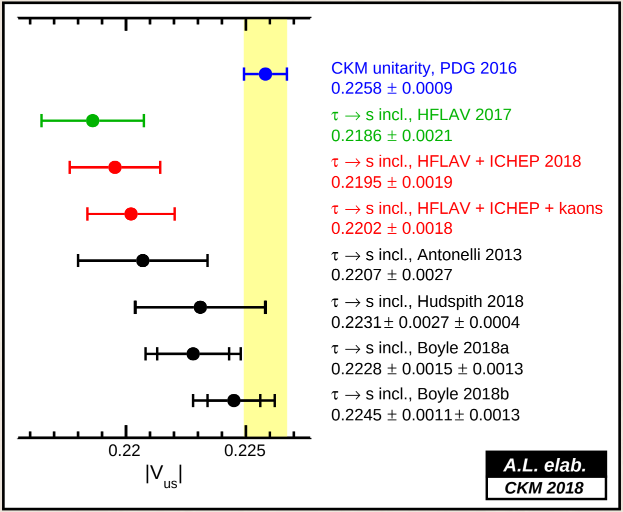
- compute $|V_{us}|$ from tau inclusive using also the tau spectral functions:
  "a combination of continuum and lattice results is shown to suggest a new implementation of the flavor-breaking sum rule approach in which not only |Vus|, but also D>4 effective condensates, are fit to data."
- experimental inputs:
  - HFLAV 2016
  - 2 $\mathcal{B}(\tau \to Kpi)$ branching fractions replaced with kaon-derived values in M. Antonelli *et al.*, JHEP 10 (2013) 7

Other $|V_{us}|$ from $\tau \to s$ inclusive determinations (non exhaustive)

P. Boyle *et al.*, arXiv:1803.07228 [hep-lat]

- compute $|V_{us}|$ from tau inclusive using tau spectral functions and lattice QCD
  - Boyle 2018a: uses HFLAV 2016 tau BRs
  - Boyle 2018b: like 2018a but replaces 2 $\mathcal{B}(\tau \to K\pi\nu)$ branching fractions with kaon-derived values in M. Antonelli *et al.*, JHEP 10 (2013) 7

This work $|V_{us}|$ from tau inclusive determinations compared with several existing ones



Conclusions

$|V_{us}|$ inclusive uncertainties budget (%)
after adding both *BABAR* ICHEP 2018 and kaon indirect results

$\pi^- \bar{K}^0 \pi^0 \pi^0 \nu_\tau$ (ex. K^0)	0.3908
$\bar{K}^0 h^- h^- h^+ \nu_\tau$	0.3430
$K^- \pi^- \pi^+ \pi^0 \nu_\tau$ (ex. K^0, ω, η)	0.2422
$\pi^- \bar{K}^0 \pi^0 \nu_\tau$	0.2178
$K^- \omega \nu_\tau$	0.1563
$\pi^- \bar{K}^0 \nu_\tau$	0.1501
$K^- \pi^- \pi^+ \nu_\tau$ (ex. K^0, ω)	0.1140
$K^- \pi^0 \nu_\tau$	0.0881
$K^- 3\pi^0 \nu_\tau$ (ex. K^0, η)	0.0703
$K^- \nu_\tau$	0.0473
$K^- 2\pi^0 \nu_\tau$ (ex. K^0)	0.0414
$\pi^- \bar{K}^0 \eta \nu_\tau$	0.0253
$K^- \pi^0 \eta \nu_\tau$	0.0197
$K^- \eta \nu_\tau$	0.0136
$K^- \phi \nu_\tau$ ($\phi \to K^+ K^-$)	0.0136
$K^- \phi \nu_\tau$ ($\phi \to K^0_S K^0_L$)	0.0095
$K^- 2\pi^- 2\pi^+ \nu_\tau$ (ex. K^0)	0.0020
$K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. K^0)	0.0010
$\tau \to$ non-strange	0.0853
$\mathcal{B}_e^{\mathbf{univ}}$	0.0045
theory	0.4724

Conclusions

- some progress on the experimental measurements that determine $|V_{us}|$ using tau data a discrepancy w.r.t. CKM unitarity persists, $\geq 2.7\sigma$
- new $|V_{us}|$ from tau inclusive determinations using tau spectral function and lattice QCD, yield $|V_{us}|$ values compatible with kaon results and CKM unitarity

towards new $|V_{us}|$ tau adventures