Updated preliminary determinations of $|V_{us}|$ with tau decays using the HFLAV fit

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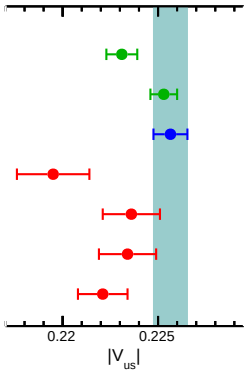
CKM matrix first row unitarity test in $|V_{us}|$ perspective, PDG 2018

- PDG 2018 $|V_{ud}|$- $|V_{us}|$ review
  - $|V_{us}|$ from kaons ∼consistent with unitarity
- HFLAV 2018 report, PRL 93 (2004) 231803
  - $|V_{us}|$ from tau inclusive $>3\sigma$ discrepancy
  - $|V_{us}|$ from tau exclusive ∼consistent

note

- alternative $|V_{us}|$ determinations from $\tau \to X_s \nu$ exist, which are more consistent with kaons and CKM unitarity
  - Hudspith, Lewis, Maltman & Zanotti 2018
  - Boyle *et al.* 2018



- $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2$ ∼consistent with unitarity except when using $|V_{us}|$ from tau inclusive

PDG 2020 $|V_{ud}|$ - $|V_{us}|$ review, HFLAV 2021 preliminary

$|V_{ud}|$

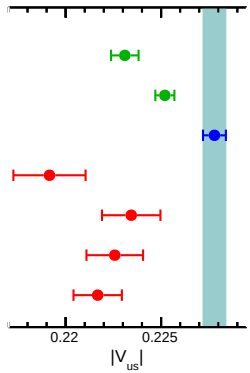
- new dispersive calculation of Δ_R^V inner or universal electroweak radiative corrections (RC) to superallowed nuclear beta decays
  Seng, Gorchtein & Ramsey-Musolf,
  Phys. Rev. D 100, 013001 (2019)
  - $\sim 2\times$ more precise
  - significant shift

$|V_{us}|$ from kaons

- updated more precise lattice QCD constants

$|V_{us}|$ from tau

- updated lattice QCD constants (minor)
- numerical typo fixed on $|V_{us}|$ from $\tau \to K\nu$



- $|V_{ud}|$ - $|V_{us}|_K$ anomaly $\sim 3\,\sigma$

  (scale factor = 2 on $|V_{us}|_K$ because of difference on $|V_{us}|_K$ from $K_{\ell 3}$ and $K_{\mu 2}$)

2021 update on $|V_{ud}|$ - $|V_{us}|$ anomaly, HFLAV 2021 preliminary

$|V_{ud}|$

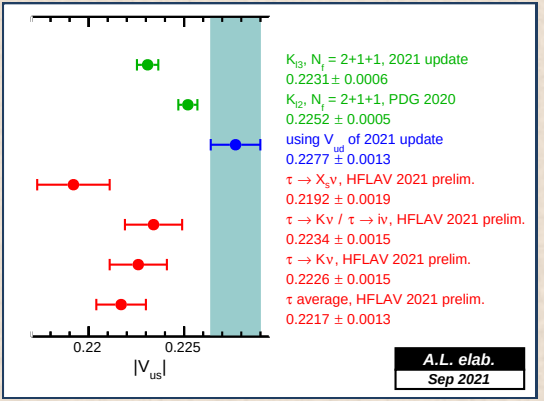
- J.C.Hardy & Ii.S.Towner, PRC 102, 045501 (2020)
  - revised experimental inputs
Marciano and Sirlin 2006	2.361 ± 0.038
Seng et al. 2018/2019	2.467 ± 0.022
Czarnecki, Marciano and Sirlin 2019	2.426 ± 0.032
Adopted value for Δ_R^V	2.454 ± 0.019
  - increased systematic uncertainty (new nuclear corrections)

$|V_{us}|$ from kaons

- improved K_{e3} radiative corrections, Seng, Gorchtein & Ramsey-Musolf, arXiv:2103.04843 [hep-ph]
- new calculation of $|V_{us}|_{K\ell 3}$ Seng, Galviz, Marciano, Meißner, arXiv:2107.14708 [hep-ph]

$|V_{us}|$ from tau

- using 2021 update $|V_{ud}|$ (minor)



- $|V_{ud}|$ - $|V_{us}|_K$ anomaly $\sim 3\,\sigma$
  - no scale factor on $|V_{us}|_K$
  - $\sim 5\,\sigma$ without increased $|V_{ud}|$ systematics

$|V_{us}|$ from tau radiative corrections $R_{\pi\mu 2}$ & $R_{K\mu 2}$ updated in 2019

$|V_{us}|$ from tau inclusive

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

$\tau \to X_s \nu$

$|V_{us}|$ from tau exclusive

- $$\frac{\Gamma(\tau^- \to K^- \nu_\tau)}{\Gamma(\tau^- \to \pi^- \nu_\tau)} = \frac{|V_{us}|^2}{|V_{ud}|^2} \left(\frac{f_{K\pm}}{f_{\pi\pm}}\right)^2 \frac{R_{K\mu 2}}{R_{\pi\mu 2}} \frac{R_{\tau/K}}{R_{\tau/\pi}} \frac{\left(1 - m_K^2/m_\tau^2\right)^2}{\left(1 - m_\pi^2/m_\tau^2\right)^2}$$

$\tau \to K/\tau \to \pi$

- $$\Gamma(\tau^- \to K^- \nu_\tau) = \frac{G_F^2}{16\pi\hbar} |V_{us}|^2 f_{K\pm}^2 R_{K\mu 2} R_{\tau/K} m_\tau^3 \left(1 - \frac{m_K^2}{m_\tau^2}\right)^2$$

$\tau \to K$

New radiative corrections $R_{\pi\mu 2}$ & $R_{K\mu 2}$

- M.Di Carlo *et al.*, "Light-meson leptonic decay rates in lattice QCD+QED", PRD 100, 034514 (2019)
- lattice QCD calculation including QED
-

	$\delta R^{\text{Phys}}_{\pi\mu 2}$ [%]	$\delta R^{\text{Phys}}_{K\mu 2}$ [%]	$\delta R^{\text{IB}}_{K\mu 2}$[%]	$\delta R_{K\mu 2}$ [%]
Cirigliano & Neufeld 2011 (ChPT)	1.76 ± 0.21	0.64 ± 0.24	-0.43 ± 0.12	1.07 ± 0.21
Di Carlo *et al.* 2019 (lattice QCD)	1.53 ± 0.19	0.24 ± 0.10	-0.64 ± 0.07	0.88 ± 0.09

("Phys" = corrections including isospin-breaking term)
Cirigliano & Neufeld 2011 values from Rosner, Stone & Van de Water, arXiv:1509.02220 [hep-ph]

New radiative corrections, usage details

strong isospin-breaking correction

- note: Di Carlo *et al.* 2019 corrections require isospin-symmetric lattice QCD decay constants
  - isospin-breaking correction attribution to either decay constants or radiative correlctions depends on prescription to separate QED from QCD effects
  - physical observables are $f_\pi^2(1+\delta R_{\pi\mu 2})$ and $f_K^2(1+\delta R_{K\mu 2})$
- recent FLAG lattice QCD averages include isospin-breaking terms in $f_{\pi\pm}$, $f_{K\pm}$
- two consistent sets of decay constants and radiative corrections used for $|V_{us}|$ from tau:

	$\delta R_{\pi(\pm)\mu 2}$ [%]	$\delta R_{K(\pm)\mu 2}$ [%]	$f_{K(\pm)}/f_{\pi(\pm)}$	$f_{K(\pm)}[MeV]$
C. & N. 2011 + FLAG Dec 2020	1.76 ± 0.21	1.07 ± 0.21	1.1932 ± 0.0021	155.7 ± 0.3
Di Carlo *et al.* 2019	1.53 ± 0.19	0.24 ± 0.10	1.1966 ± 0.0018	156.1 ± 0.2

correlations

- no correlation is assumed between f_K/f_π and f_K (not quoted in FLAG reports)
  - no significant effects varying correlation in its full range
- correlation Cirigliano & Neufeld 2011 $\delta R_{\pi\pm\mu 2}$ - $\delta R_{K\pm\mu 2} = 0.67$,
  computed for consistency with the quoted uncertainties on the two quantities and their ratio
- correlation Di Carlo *et al.* 2019 $\delta R_{\pi\mu 2}$ - $\delta R_{K\mu 2} = 0.63$,
  using information from S.Simula private communication

2021 update on $|V_{ud}|$ - $|V_{us}|$, HFLAV 2021 prelim., Di Carlo *et al.* 2019 RC

$|V_{ud}|$

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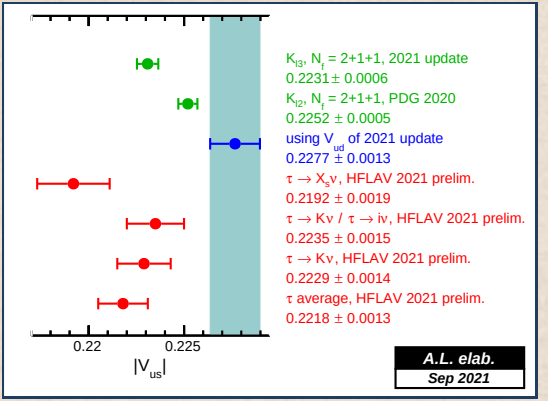
$|V_{us}|$ from tau

- using 2021 update $|V_{ud}|$ (minor)
- Di Carlo *et al.* 2019 radiative corrections



- $|V_{ud}|$ - $|V_{us}|_K$ anomaly $\sim 3\,\sigma$
- no scale factor on $|V_{us}|_K$
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2021 update on $|V_{ud}|$ - $|V_{us}|$, HFLAV 2021 prelim., C. & N. 2011 RC

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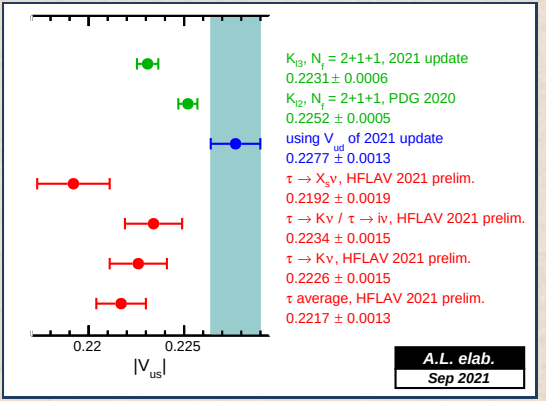
$|V_{us}|$ from tau

- using 2021 update $|V_{ud}|$ (minor)
- Cirigliano & Neufeld 2011 radiative corrections



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Conclusions

- 2021 updates on $|V_{ud}|$, $|V_{us}|_{K\ell 3}$
- recent improvements on radiative corrections used for $|V_{us}|$ from tau
- $|V_{us}|$ from tau precision is limited by tau branching fractions precision, which limits the impact of progresses on radiative corrections
- preliminary HFLAV 2021 results for $|V_{us}|$ from tau

	$\|V_{us}\|$	
$\|V_{us}\|_{\text{uni}}$	0.2277 ± 0.0013	$0.0\,\sigma$
$\|V_{us}\|_{\tau s}$	0.2192 ± 0.0019	$-3.6\,\sigma$

	Cirigliano & Neufeld 2011		Di Carlo *et al.* 2019	
$\|V_{us}\|_{\tau K/\pi}$	0.2234 ± 0.0015	$-2.0\,\sigma$	0.2235 ± 0.0015	$-2.1\,\sigma$
$\|V_{us}\|_{\tau K}$	0.2226 ± 0.0015	$-2.6\,\sigma$	0.2229 ± 0.0014	$-2.6\,\sigma$
$\|V_{us}\|_{\tau}$	0.2217 ± 0.0013	$-3.2\,\sigma$	0.2218 ± 0.0013	$-3.2\,\sigma$

Thanks for your attention!

Backup Slides

$|V_{us}|$ determinations fron kaons

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