Flavor Physics Summary

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Why precision flavor physics?

We know there is physics beyond the Standard Model from cosmology.

We don't know its scale, but intensity frontier experiments could help us pin this down if a discrepancy with the Standard Model is seen.

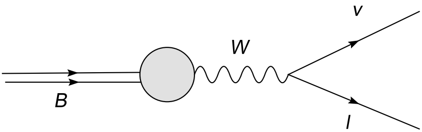
A number of tensions exist, including those within quark flavor physics and with the muon $g-2$. They might go away, or they might become 5σ observations of new physics, as new data (and improved theory) pours in.

Lattice QCD is essential to make use of existing and planned experimental results at the intensity frontier. We are (relatively) cheap compared to these experiments. It would be bad for future funding of our field if we didn't come through for the experiments.

CKM matrix

$$\begin{pmatrix} \mathbf{V_{ud}} & \mathbf{V_{us}} & \mathbf{V_{ub}} \\ \pi \to l\nu & K \to l\nu & B \to l\nu \\ & K \to \pi l\nu & B \to \pi l\nu \\ \mathbf{V_{cd}} & \mathbf{V_{cs}} & \mathbf{V_{cb}} \\ D \to \pi l\nu & D \to K l\nu & B \to D^{(*)} l\nu \\ D \to l\nu & D_s \to l\nu & \Lambda_b \to \Lambda_c l\nu \\ \mathbf{V_{td}} & \mathbf{V_{ts}} & \mathbf{V_{tb}} \\ \langle B_d | \overline{B}_d \rangle & \langle B_s | \overline{B}_s \rangle & \end{pmatrix}$$

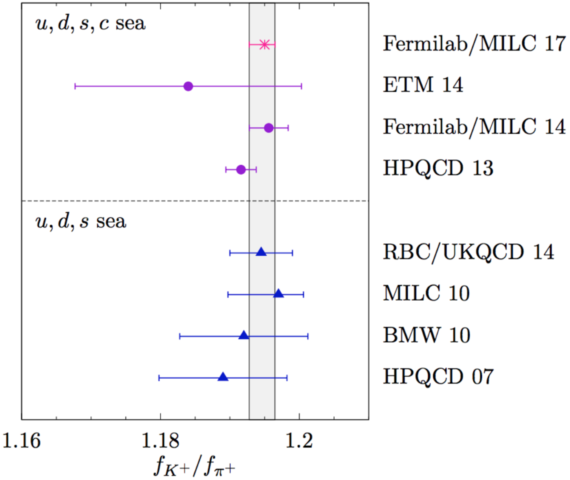
Nonperturbative input needed



$$\Gamma = (\text{known factor})\,(\text{CKM factor})(\text{QCD factor}) \tag{1}$$

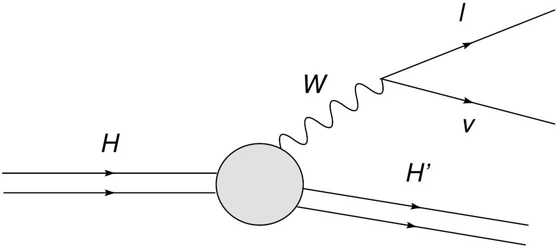
$$\mathcal{B}(B \to \tau \overline{\nu}_\tau) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B \tag{2}$$

Kaon and pion decay constant ratio



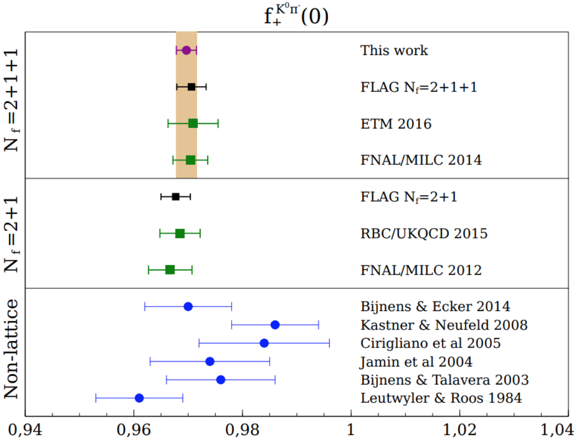
This and other plots courtesy of Steve Gottlieb (arXiv:1812.11211).

Semileptonic decays



Vertex proportional to $|V_{qq'}|$. In order to extract it, a nonperturbative determination of the form factors is needed.

$K \to \pi \ell \nu$ Decay



First Row Unitarity

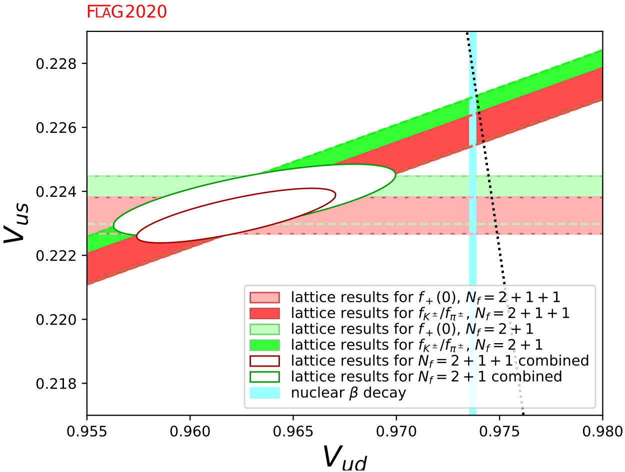
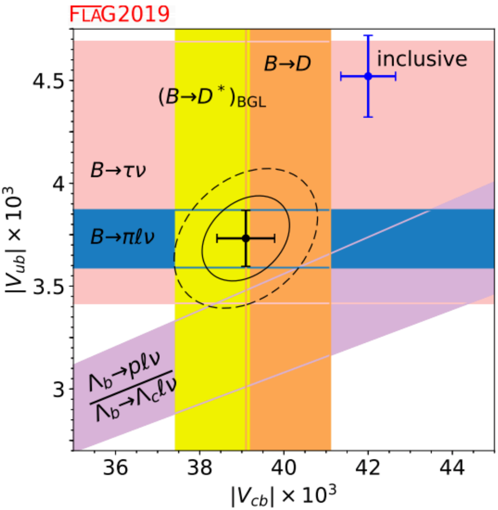


Figure from FLAG.

V_{cb} and V_{ub} Summary



B semileptonic decays

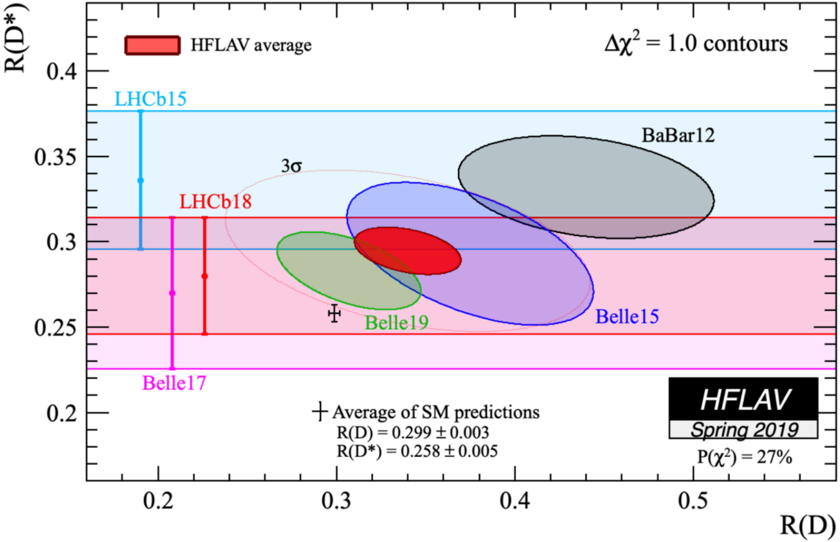
Longstanding tension between exclusive and inclusive determinations of $|V_{cb}|$ and $|V_{ub}|$. A number of proposals looking to address this

W. Jay (Fermilab/MILC)
$B \to \pi$, $B_s \to K$, $B \to K$, $B_{(s)} \to D_{(s)}$, $D \to K$, $D \to \pi$, $D_s \to K$

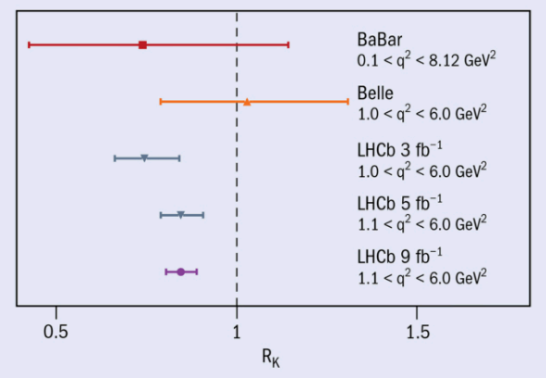
A. Soni (RBC/UKQCD)
$B_c \to J/\psi \ell \nu$, $B_c \to \psi(2s) \ell \nu$

Y. Jang, et al.
$B \to D \ell \nu$, $B \to D^* \ell \nu$ (zero-recoil)

$R(D)$ and $R(D^*)$ Summary



R_K



$$R_K = \text{BR}(B^+ \to K^+\mu^+\mu^-)/\text{BR}(B^+ \to K^+e^+e^-)$$

$K \to \pi\pi$

$$\Re(\varepsilon'_K/\varepsilon) \sim \frac{\omega}{\sqrt{2}|\varepsilon_K|}\left(\frac{\Im(A_2)}{\Re(A_2)} - \frac{\Im(A_0)}{\Re(A_0)}\right) \tag{3}$$

where $\omega = \Re(A_2)/\Re(A_0)$, $A(K^0 \to \pi\pi(I)) = A_I e^{i\delta_I}$.

ε'/ε requires the $\Delta I = 1/2$ channel.

$$\mathrm{Re}(\varepsilon'_K/\epsilon_K) = (16.6 \pm 2.3) \times 10^{-4} \tag{4}$$

RBC/UKQCD result is

$$\mathrm{Re}(\varepsilon'_K/\epsilon_K) = 21.7(2.6)(6.2)(5.0) \times 10^{-4}. \tag{5}$$

RBC/UKQCD $K \to \pi\pi$ calculation

Direct finite-volume approach of Lellouch-Lüscher.

New calculation proposed that would directly obtain the relevant physical matrix element for the $\Delta I = 1/2$ channel from the first excited state. In this case can use existing DWF ensembles without having to make ensembles with special (G-parity) boundary conditions.

Conclusion

Lattice QCD is crucial to make use of planned and existing experiments doing precision tests of the Standard Model.

A number of interesting tensions currently exist. Further work will provide important constraints on new physics scenarios and if we are lucky, a discovery...