The importance of $|V_{ub}|$ and $|V_{cb}|$ in flavor physics

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UCSD

Somehere in the Ethernet, 11 January 2021

The importance of V_{ub} and V_{cb} in physics

Removed *flavor* from *in flavor physics*

Removed the modulus

V_{ub} and V_{cb} are 3 of the 18 parameters of the Standard Model

6 quark and 3 lepton masses, 3 gauge couplings, a VEV, a higgs mass, 4 CKM

19 if $\bar{\theta}$)

26 if neutrinos, 3 masses plus 4 (or 5) PMNS

Isn't that important enough? These are *fundamental* parameters of nature

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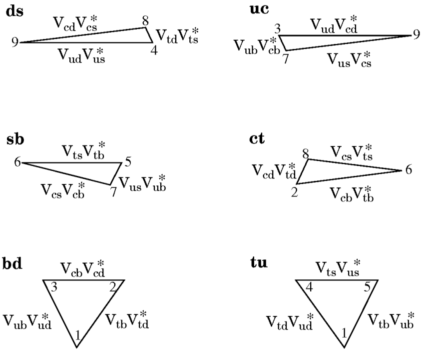
The importance of V_{ub} and V_{cb} in flavor physics

A potpurri

Start with the obvious:

- Lifetimes: B (and B_s, B_c) and Λ_b (and Ξ_b, Ω_b, …)
- Br (u/c)
- Shape of unitarity triangles

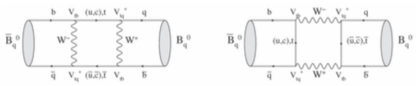


- Squashed triangles ⇒ reduced CPV
- Null tests of CPV can sensitively test for NP

$$B_s \to J/\psi\,\phi$$

- Smallness of $|V_{ub}|$, $|V_{td}|$, then $|V_{cb}|$, $|V_{ts}|$ controls shapes
- $|V_{td}| \sim |V_{ub}|$, $|V_{ts}| \sim |V_{cb}|$

$$\begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$



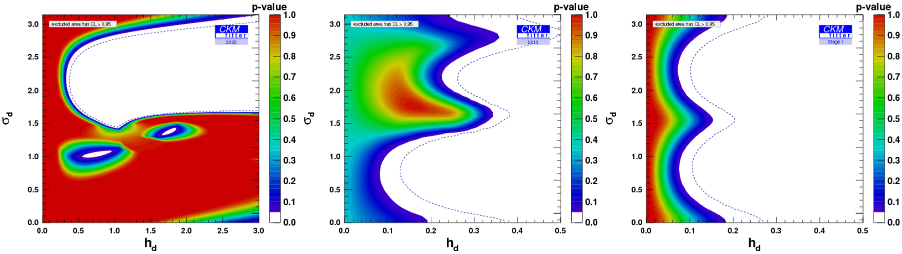
"A precise determination of $|V_{ub}|$ is crucial for improving tests of the standard model (SM) and the sensitivity to new physics in B^0-$\overline{B}^0$ mixing"

-BLT PRD 90, 094003 (2014)

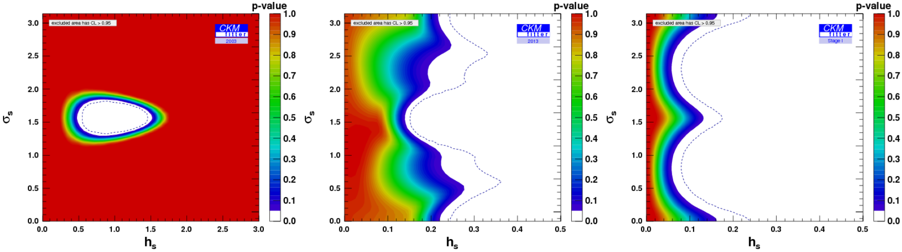
h-σ parametrization of new physics contributions to neutral meson mixing amplitudes

$$M_{12} = (M_{12})_{\mathrm{SM}} \times (1 + h\, e^{2i\sigma})$$

B_d:


excluded area has CL > 0.95
CKM fitter 2003
CKM fitter 2013
CKM fitter Stage I
p-value
σd
hd

B_s: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CKM fitter 2003
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p-value
σs
hs

- Ultimate goal: a theory of flavor: Why are there 3 generations? Why hierarchies of masses? Why texture of mixing matrices?
- SM does not explain, it parametrizes; EFT and simplified mediators are no better

What would a theory of flavor do?

One of these:

- Differentiate among generations by their very short distance interactions, eg, different representations of gauge group (or charges under Froggatt-Nielsen?)
- Explain generations as excitations of composites (meaning: made of more fundamental stuff, surely tightly bound, rather than the modern meaning made of mixed fields)
- ??

Texture of CKM, *i.e.* smallness of $|V_{ub}|$, $|V_{cb}|$ is an important guiding principle.

Froggatt-Nielsen-like models tie this hierarchy of CKMs to hierarchy of masses

Can be within-reach physics, if required by B-anomalies;

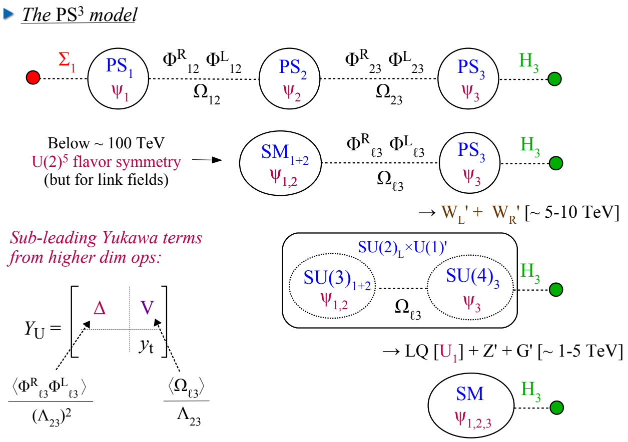
a loop mediator FG model proposed — **BG, Pokorski, Ross, JHEP 1812 (2018) 079**

To put it backwards: CKM hierarchies suggest FG

Theories with flavor → $SU(2) \times U(1)$ eg, PS^3 model

Slide from: **Bordone et al, Phys.Lett. B779 (2018) 317-323**

G. Isidori – New prospects for BSM physics *HC2NP 2019, Tenerife*



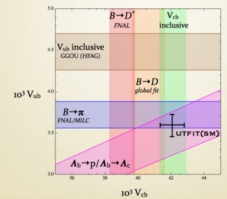
I note that Gauged flavor models also display inverted hierarchy *and* explain the number of generation, but flavor is parametrized. There should be a way to marry these.

Exclusive vs Inclusive determination of $|V_{cb}|$

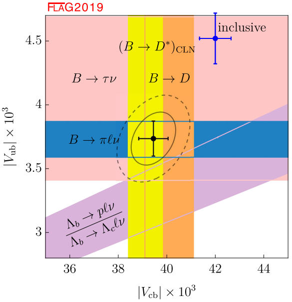
New Physics?

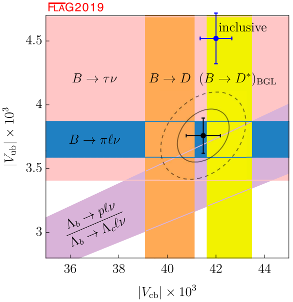
I suppose we will be discussing this for two days!

- extrapolation matters
- must keep in mind CLN makes assumptions beyond BGL
- IMHO: V_{ub} from inclusive: underestimated systematic uncertainties (not in -pink-picture below



But if persists: New Physics?





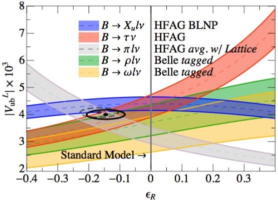
- RH currents won't do

$$|V_{cb}|_{\rm incl} = |V_{cb}|(1+\tfrac{1}{2}\epsilon^2)$$
$$|V_{cb}|_{D^*} = |V_{cb}|(1+\epsilon)$$
$$|V_{cb}|_{D} = |V_{cb}|(1-\epsilon)$$

- SV limit, for *any* SM-EFT dim-6 operators VS, SJNP47('88)511; BGM, PRD54('96)2081; BG unpub
- More general NP dim-6 ops can't either

  Crivellin, Pokorski 1407.1320

  However, disagreement Colangelo-De Fazio, PRD95(2017)011701
- Tension decreased on $|V_{ub}|$ Bernlochner, Ligeti, Turczyk, PRD90(2014)094003



Crivellin & Pokorski:

- If New Physics likely a short distance effect
- Describe by EFT
- Dimension-6 operators can't explain Exc vs Inc:
  - Scalar and tensor operators

$$\mathcal{H}_{\rm eff} = \frac{4G_F V_{qb}}{\sqrt{2}} \Big[(1+c_L)\bar{\ell}_L\gamma^\mu\nu_L\bar{q}_L\gamma_\mu b_L + c_R\bar{\ell}_L\gamma^\mu\nu_L\bar{q}_R\gamma_\mu b_R$$
$$+C_R^S\bar{\ell}_R\nu_L\bar{q}_L\gamma_\mu b_R + C_L^S\bar{\ell}_R\nu_L\bar{q}_R\gamma_\mu b_L + C_L^T\bar{\ell}_R\sigma_{\mu\lambda}\nu_L\bar{q}_R\sigma^{\mu\lambda}b_L + \cdots\Big]$$

don't interfere with SM at $q^2_{\rm max}$ (ie, $v\cdot v'=1$, ie, zero recoil),

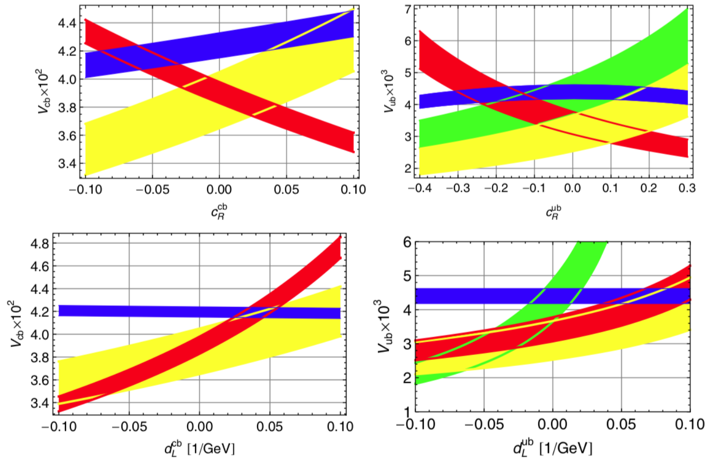
$$\Delta\Gamma(B\to D\ell\nu) \propto |C_L^T|^2 + |C_R^S + C_L^S|^2 +$$
$$\Delta\Gamma(B\to D^*\ell\nu) \propto |C_L^T|^2 + |C_R^S - C_L^S|^2$$
$$\Delta\Gamma(B\to X_c\ell\nu) \propto |C_L^T|^2 + |C_R^S|^2 + |C_L^S|^2$$

idem for $b\to u$, with "+" roughly understood

  - Right handed currents as in previous page (CP argue from W_R FCNC pheno)

- Turn to dim-7: lepton current coupled to dim 4 hadronic vector

$$\mathcal{H}_{\text{eff}} = \frac{4G_F V_{qb}}{\sqrt{2}} \bar{\ell}_L \gamma^\mu \nu_L \left[(1 + c_L)\bar{q}_L \gamma_\mu b_L + g_L \bar{q}_R i \overleftrightarrow{D}_\mu b_L + d_L i \partial^\lambda (\bar{q}_R \sigma_{\mu\lambda} b_R) + L \leftrightarrow R \right]$$



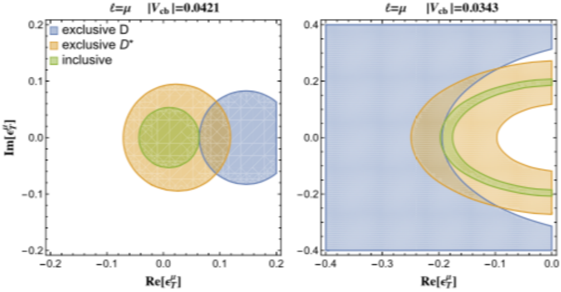
Inclusive: blue; D/π:yellow; D^*/ρ:red; ($B \to \tau\nu$:green)

Colangelo % De Fazio

- EFT, again, but
- Dimension-6 operators can explain Exc vs Inc:
- Only tensor operator:

$$\mathcal{H}_{\text{eff}} = \frac{4G_F V_{qb}}{\sqrt{2}} \left[\bar{\ell}_L \gamma^\mu \nu_L \bar{q}_L \gamma_\mu b_L + \epsilon_T \bar{\ell}_R \sigma_{\mu\lambda} \nu_L \bar{q}_R \sigma^{\mu\lambda} b_L + \cdots \right]$$

- Fit to Branching Fractions



Conclusion

- Shouldn't NP models fit to slope too? (See, eg, Iguro& Watanable JHEP08(2020)006)
- Let's have a good workshop!

The End