LEPTON (NON)-UNIVERSALITY IN (FC) NEUTRAL CURRENT B DECAYS

IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

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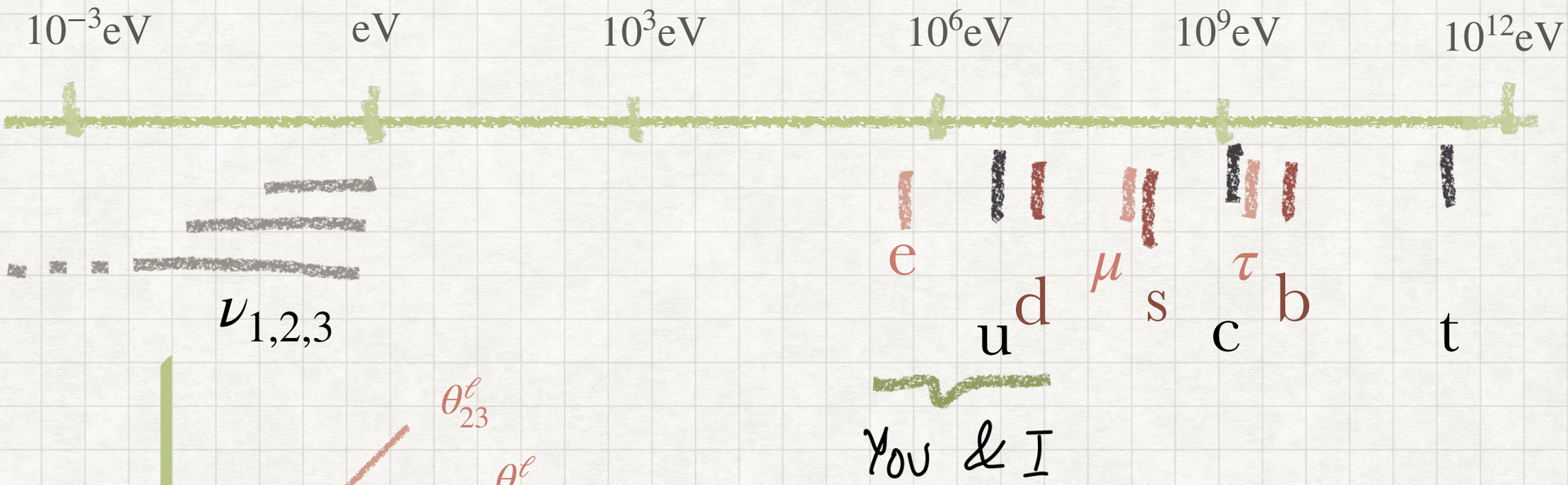
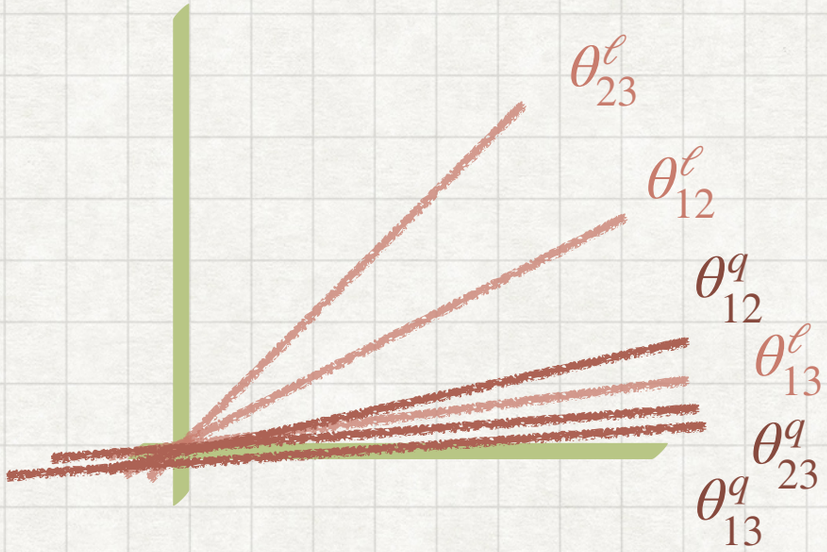
FPCP 2019 U. VICTORIA

The flavor puzzle





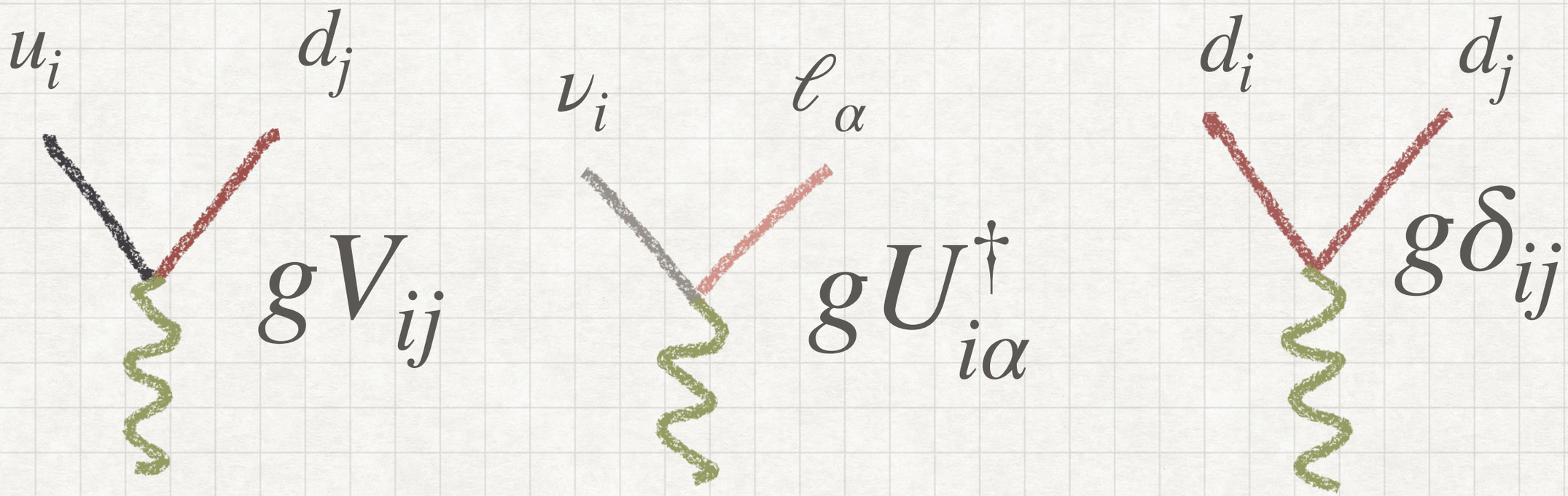
★ 3 copies for each charge

★ Where is all this structure coming from?

* Yet MASS is all we need for the whole of flavor data

Flavor phenomenology

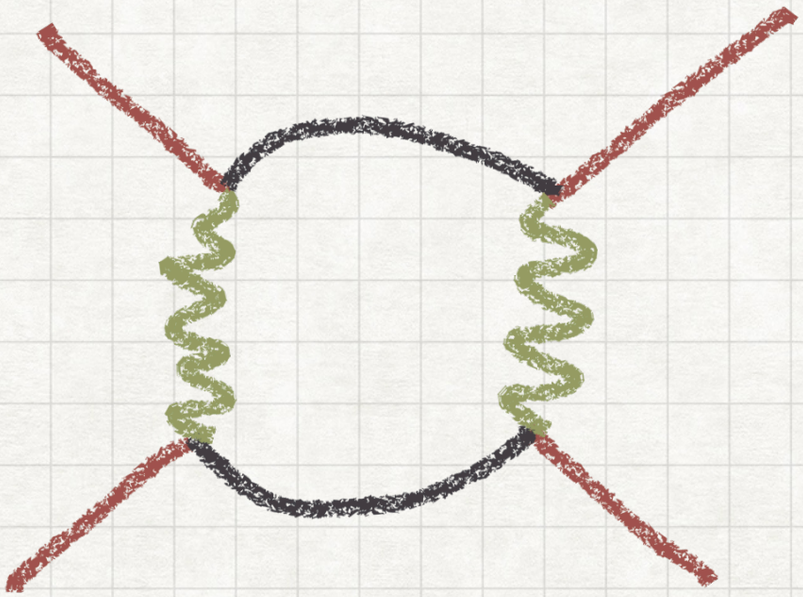
$SU(2)_L$



All flavor is in W couplings and in propagation/ phase space

$(\gamma^\mu p_\mu - m)^{-1}$

The flavor in neutral currents



$$\frac{g^2}{16\pi^2}\left(\frac{V_{ik}^{\dagger} m_{u_k}^2 V_{kj}}{M_W^2}\bar{d}_i\gamma_\mu d_{L,j}\right)^2$$

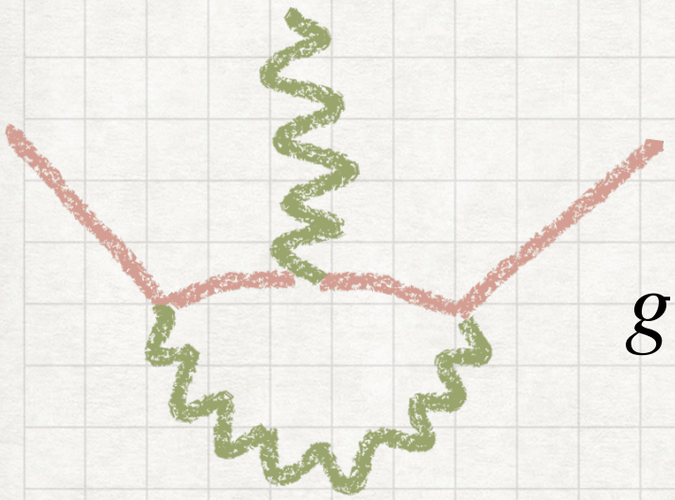
[Glashow, Iliopoulos & Maiani '70]

* And so we can probe NP to scales very very high up

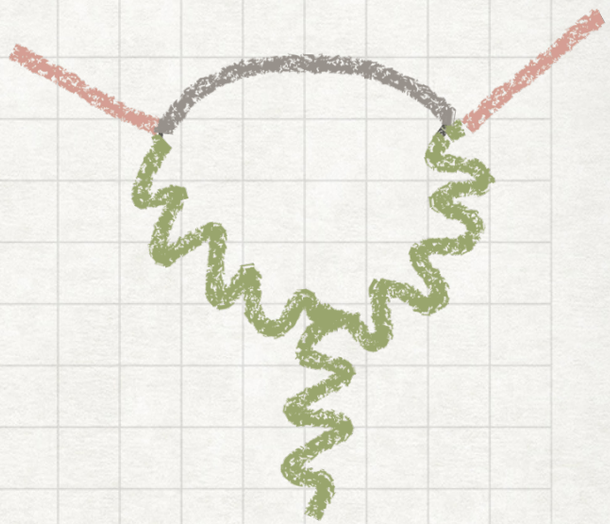
$$E_{NP} \sim 10^3 \text{TeV}$$

Lepton Universality (LU)

LUV **LFV & LUV**



$$g^3\left(\frac{m_\alpha \delta_{\alpha\beta}[q,\gamma]}{16\pi^2 M_W^2}+\frac{U_{\alpha i} m_{\nu_i}^2 U_{i\beta}^\dagger \gamma}{16\pi^2 M_W^2}\right)$$



$$\frac{Z\to \ell\ell}{Z\to \ell'\ell'} = 1 \pm 0.1\,\%\ \ \text{(LEP)}$$

$$\frac{Z\to \ell'\ell}{Z\to \ell\ell} < 10^{-6}\ \ \text{(LEP)}$$

LUV in B meson FCNC

How about, we look for lepton universality on top of quark flavor violation?

We can factor out hadron uncertainties

$$\langle B | \bar{s}\gamma_\mu b_L | K \rangle = f_+(q^2)\,(p+k)_\mu + O(m_\ell/m_B)$$

$$\langle B_s | \bar{s}\gamma_\mu b_L | 0 \rangle = f_{B_s}\, p_\mu + O(m_\ell/m_B)$$

Fully leptonic decays already come with chiral suppression

semileptonic are best

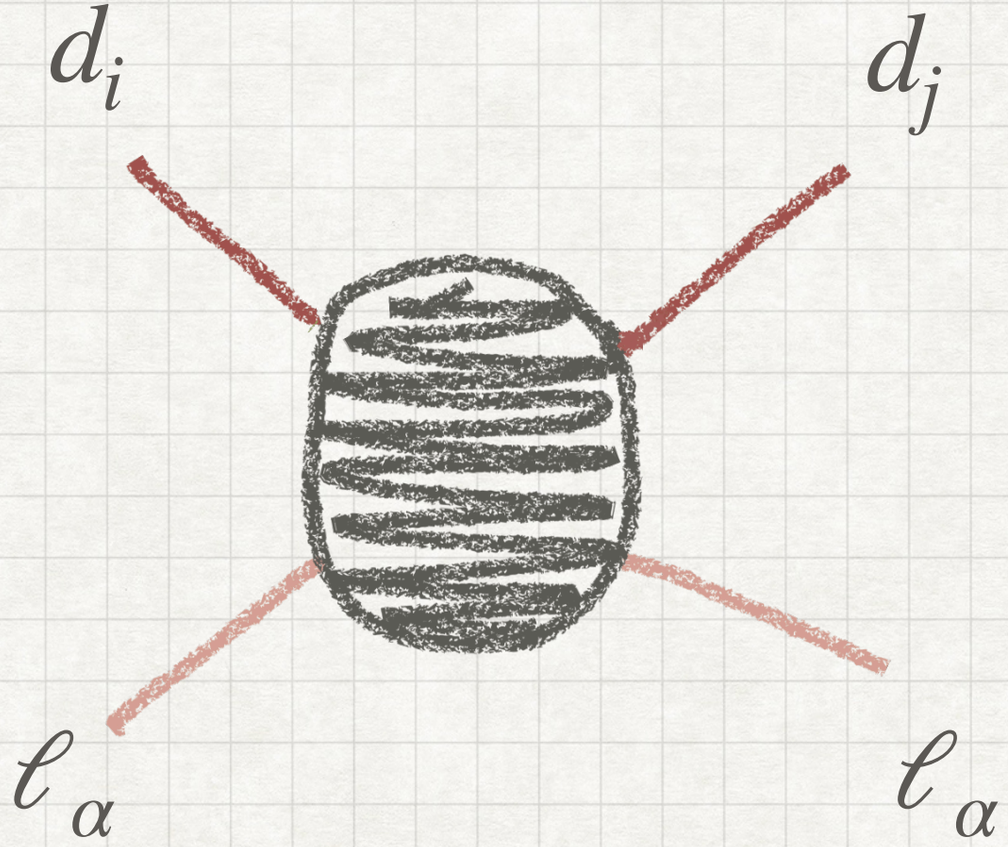
$$\frac{B \to K\ell\ell}{B \to K\ell'\ell'}$$

LUV in B meson FCNC

From the theory-BSM point of view, we have

I) the low background in (q) flavour violating processes

II) a probe into physics that also has lepton flavor



What the data is telling us

$$\frac{B \to K\mu\mu}{B \to Kee} = 0.846 \pm 0.06 \qquad 2.5\sigma$$

[LHCb]

[1 – 6 GeV^2 q^2]

$$\frac{B \to K^*\mu\mu}{B \to K^*ee} = 0.69^{+0.12}_{-0.082} \qquad 2.5\sigma$$

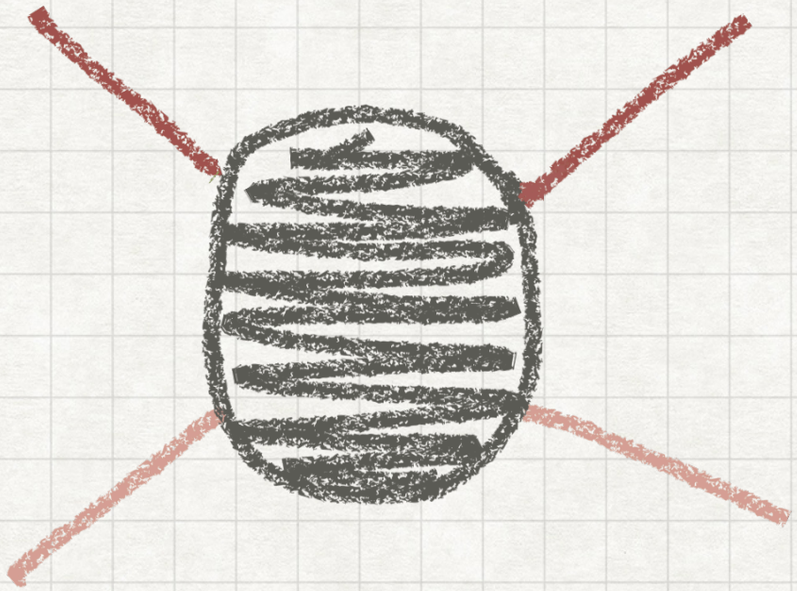
[LHCb]

Also angular observables in muon mode show deviations

Both decays are of the SM o.o.m. but there is a sizeable deficit

Effective Field Theory

Whatever the black box, we can build the effect with gauge and Lorentz invariants



$$\mathcal{O}_9 \quad \bar{s}\gamma_\rho b_L \,\bar{\ell}\gamma^\rho \ell \qquad + b_R$$

$$\mathcal{O}_{10} \quad \bar{s}\gamma_\rho b_L \,\bar{\ell}\gamma^\rho\gamma_5 \ell \qquad + b_R$$

$$\mathcal{O}_S \quad \bar{s} b_R \,\bar{\ell}\ell \qquad + b_L$$

$$\mathcal{O}_P \quad \bar{s} b_R \,\bar{\ell}\gamma_5 \ell \qquad + b_L$$

$$\mathcal{O}_T \quad \bar{s}\sigma_{\rho\kappa} b_L \,\bar{\ell}\sigma^{\rho\kappa}\ell_L + b_R \ell_R$$

[Bobeth, Hiller & Piranishvili, '07]

Effective Field Theory

Whatever the black box, we can build the effect with gauge and Lorentz invariants

ψ	q_L	u_R	d_R	ℓ	e_R
$SU(3)_c$	3	3	3	1	1
$SU(2)_L$	2	1	1	2	1
$U(1)_Y$	1/6	2/3	−1/3	−1/2	−1

Effective Field Theory

Whatever the black box, we can build the effect with gauge and Lorentz invariants

$SU(2)_L \times U(1)_Y$

$-\frac{1}{6}$ $-\frac{1}{3}$ 1 $-\frac{1}{2}$

$\bar{q}_L$ d_R $\bar{\ell}_R$ L_L

$$\mathcal{O}_9 \quad \bar{s}\gamma_\rho b_L \bar{\ell}\gamma^\rho \ell \quad + b_R$$

$$\mathcal{O}_{10} \quad \bar{s}\gamma_\rho b_L \bar{\ell}\gamma^\rho\gamma_5 \ell \quad + b_R$$

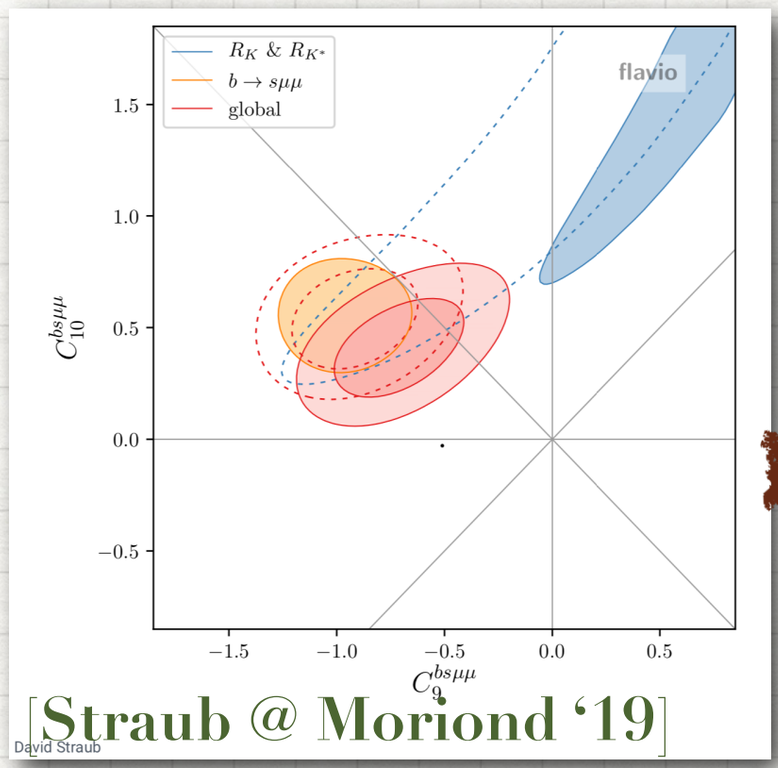
$$\mathcal{O}_S \quad \bar{s} b_R \bar{\ell}\ell \quad + b_L$$

$$-\mathcal{O}_{PS} \quad \bar{s} b_R \bar{\ell}\gamma_5 \ell \quad + b_L$$

$$\mathcal{O}_T \quad \bar{s}\sigma_{\rho\kappa} b_L \bar{\ell}\sigma^{\rho\kappa}\ell_L + b_R \ell_R$$

[RA Camalich & Grinstein , '14]

Effective Field Theory



[Straub @ Moriond '19]

Latest fits point @ LHxLH

$$\mathcal{O}_9 \quad \bar{s}\gamma_\rho b_L \bar{\ell}\gamma^\rho \ell \qquad \pm b_R$$

$$-\mathcal{O}_{10} \quad \bar{s}\gamma_\rho b_L \bar{\ell}\gamma^\rho\gamma_5 \ell \qquad \pm b_R$$

$$\mathcal{O}_S \quad \bar{s} b_R \bar{\ell}\ell$$

$$-\mathcal{O}_P \quad \bar{s} b_R \bar{\ell}\gamma_5 \ell$$

$$\mathcal{O}_T \quad \bar{s}\sigma_{\rho\kappa} b_L \bar{\ell}\sigma^{\rho\kappa}\ell_L + b_R \ell_R$$

$B_s \to \mu\mu$

m_μ / m_B

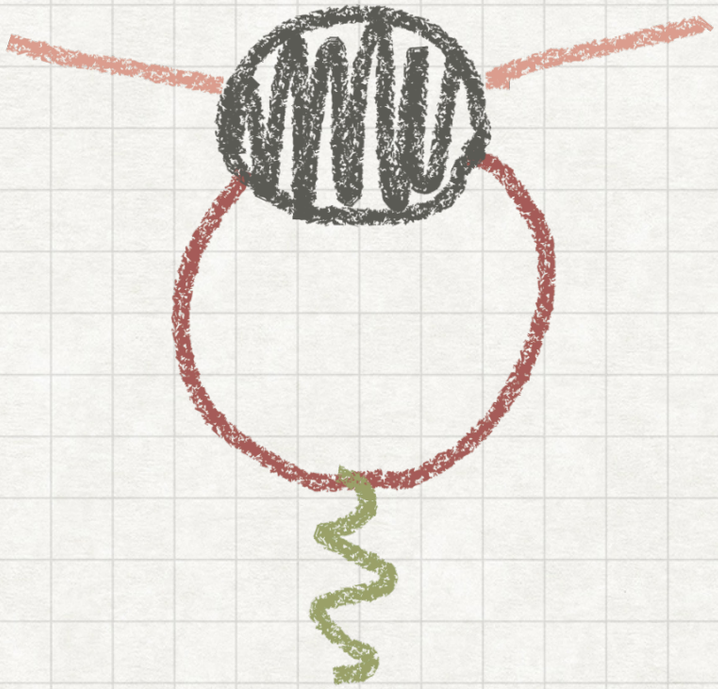
R_{K^*}

Consistency with other data (EFT)

The effect requires $\Lambda \sim 30\text{TeV}$ is such a 'low' scale allowed?

Check for RGE effects

[Feruglio, Paradisi & Patori, '17]

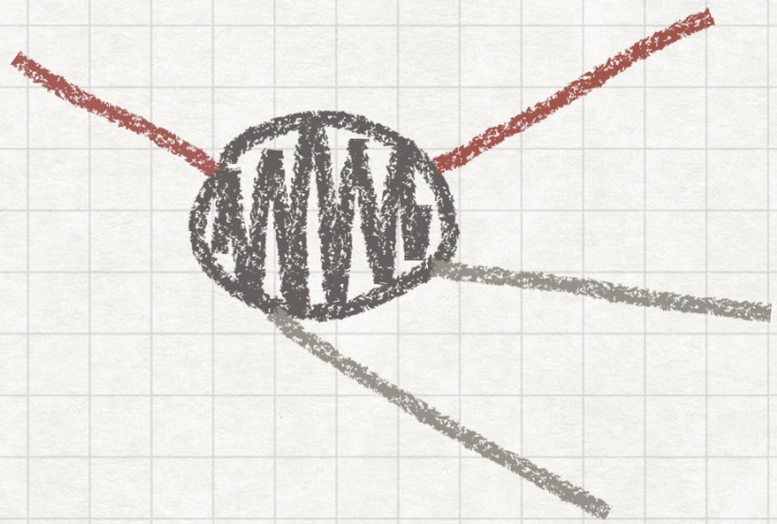


$Z \to \ell\ell$

LH currents bring along friends

[Buras, Girrbach-Noe, Niehoff & Straub, '14]

$$\begin{pmatrix} \nu_L \\ \ell_L \end{pmatrix}$$



$B \to K\nu\nu$

It passes all challenges!

It is not only what it is but what it's not

- ★ No effect on FCNC in s - d transitions
- ★ No effect on purely hadronic physics e.g. $B_s - \bar{B}_s$
- ★ No lepton flavor violation — $\mu \to eee$

$(B \to Ke\mu \lesssim 10^{-1} \times B \to K\mu\mu)$

This can be supported by symmetry
[RA, Camalich & Grinstein, '15]

$$U(1)_e \times U(1)_\mu \times U(1)_\tau$$

$$\begin{pmatrix} c_e & & \\ & c_\mu & \\ & & c_\tau \end{pmatrix}$$

These phases are defined in the mass basis...
which means the new physics aligns with masses.....

Is this effect like all else dictated by mass?

New Physics

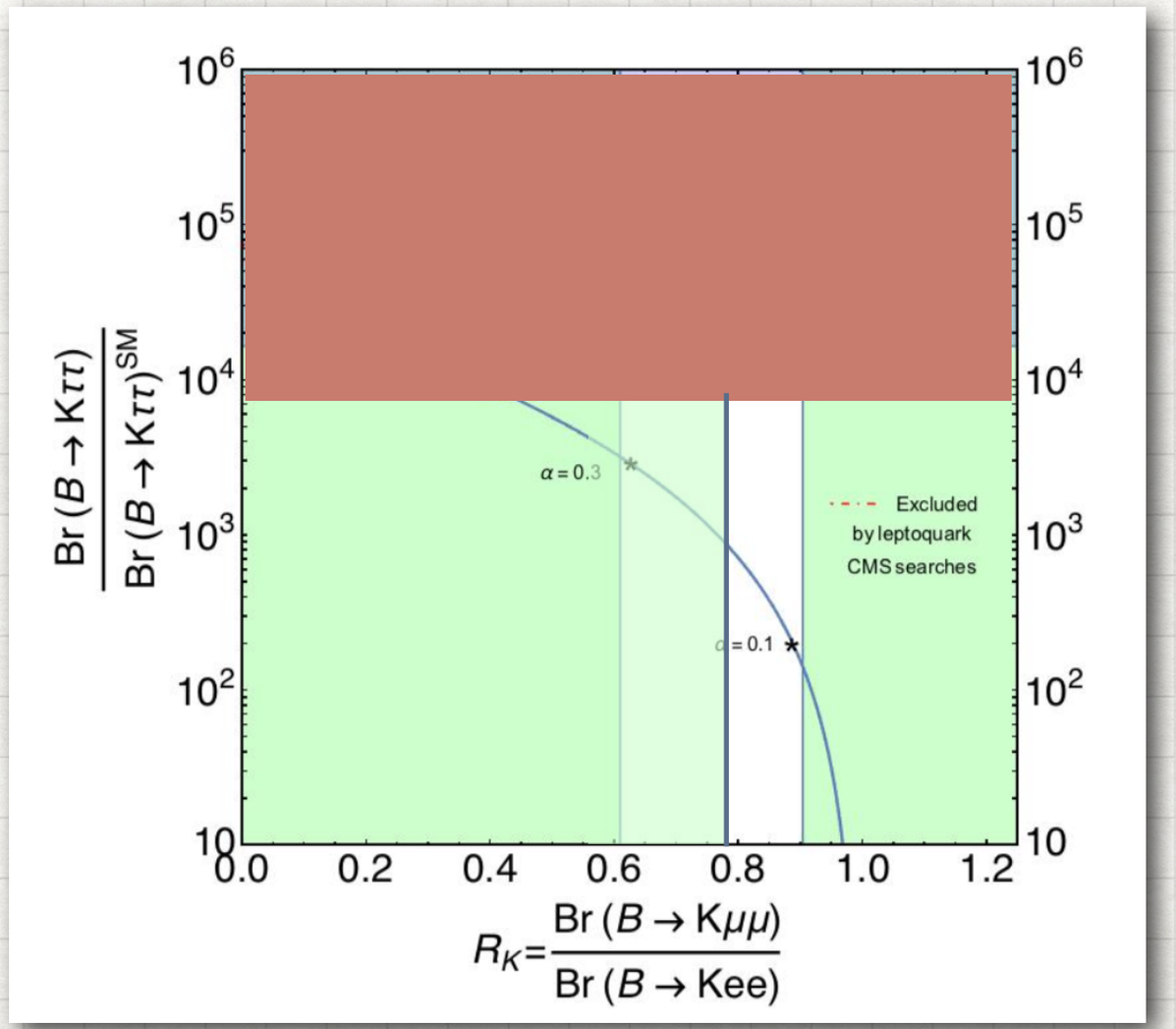
$$c m_\alpha^2 \, \bar{s} \gamma_\rho b_L \, \bar{\ell}_\alpha \gamma^\rho \ell_{L,\alpha}$$

$$\frac{B \to K\tau\tau}{B \to K\mu\mu} \simeq \frac{m_\tau^4}{m_\mu^4}$$

current bound on τ mode

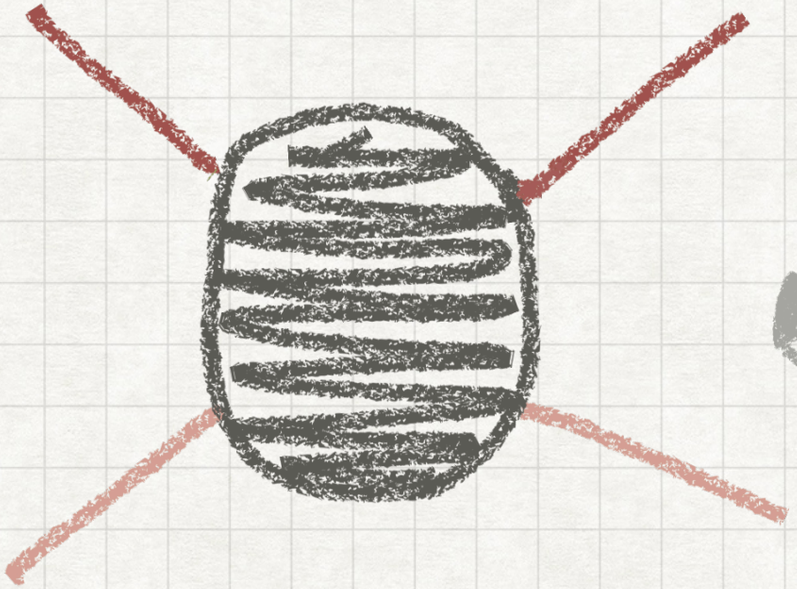
10^4 above μ mode

[Babar, '16]



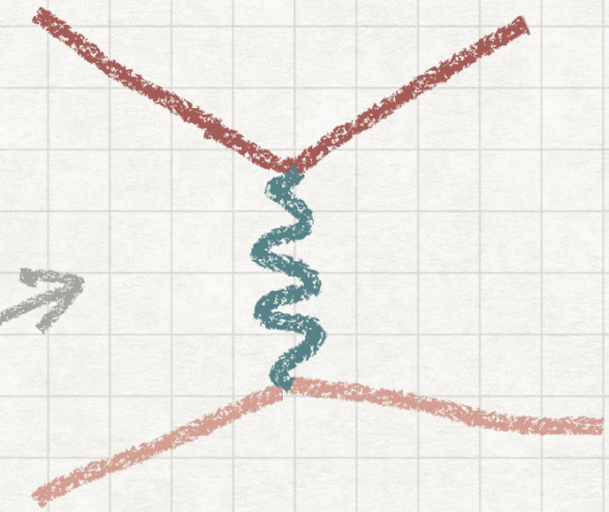
[RA, Camalich & Grinstein, '15]

Opening up the black box



These are then subject to Resonance searches

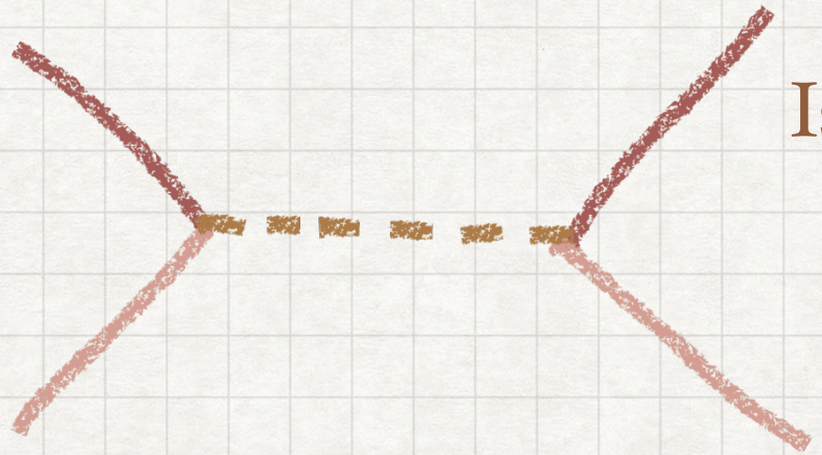
[Talk by You, Wong]



Gauged flavor Symmetry?

Z'

[Refs in this Talk]



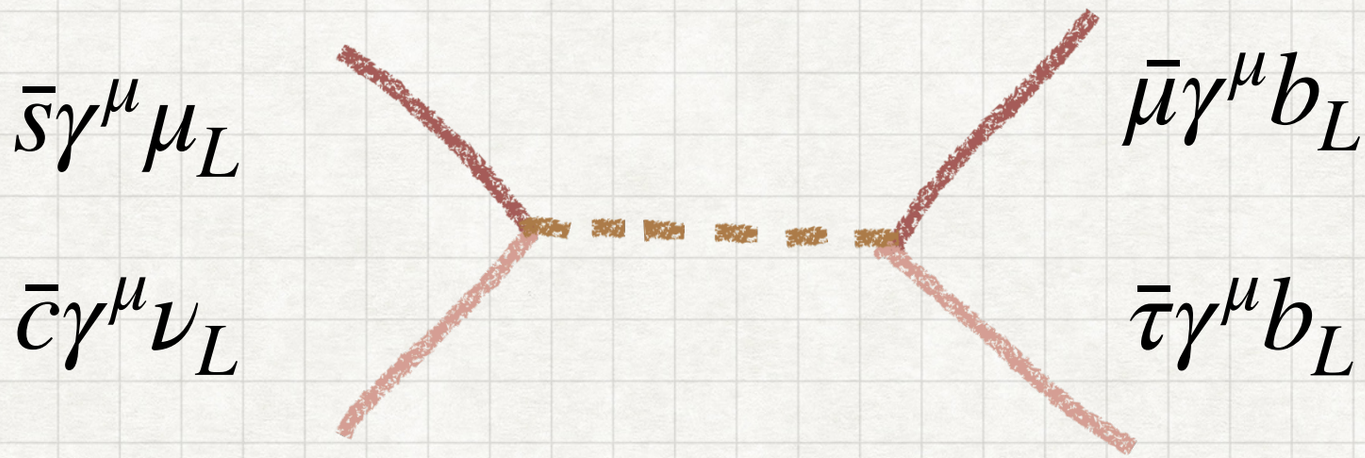
Is this why L+Q?

Leptoquark

[Talk by Malinsky]

A vector LQ (3, 1, 2/3)

$$\bar{q}\gamma^{\mu}L_L V_{\mu}$$



It can also account for the charged anomaly!

With the mass hypothesis has the right size!

$$\text{NC/CC} \quad \text{vs} \quad m_{\mu}^2/m_{\tau}^2$$

Summary

- Could this bring light to the flavor puzzle?
- Is this effect also governed by mass?
- Lepton Unversality & Quark flavor?
- V-A structure & SM in size?