Clues for Flavor from rare lepton and quark decays

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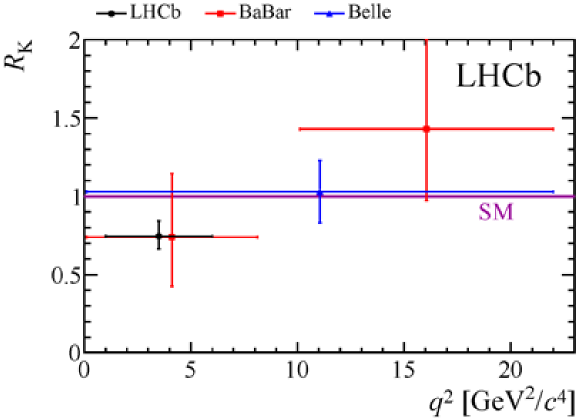
WIN 2015, MPI-K, Heidelberg, 2015/06/10

Based on

IdMV, Hiller (JHEP) `http://arxiv.org/abs/1503.01084`

Clues...

$$R_K \equiv \mathcal{B}\left(B \to K\mu\mu\right)/\mathcal{B}\left(B \to Kee\right)$$



An interesting 2.6σ hint

$$R_K^{\mathrm{LHCb}} = 0.745 \pm^{0.090}_{0.074} \pm 0.036 \tag{1}$$

$$1\,\mathrm{GeV}^2 \leq q^2 < 6\,\mathrm{GeV}^2$$

2.6 σ from universality (SM)
Ratio cancels out theoretical uncertainties

If verified, BSM in quark FCNC linked with lepton sector

New physics BSM interpretation

Hiller, Schmaltz (PRD)
`http://arxiv.org/abs/1408.1627`
Nice slides by Hiller:
`https://indico.cern.ch/event/345526/session/1/contribution/3/material/slides/0.pdf`
Model independent analysis: constrains Wilson coeffs.
can be realized by Leptoquark models (this talk)

See also talks by Fuentes and several talks on Friday:
Descotes-Genon, Heeck, Hernando Morata, Vicente
Other works referenced in the paper
`http://arxiv.org/abs/1503.01084`

New physics and flavor

In SM, flavor only in Yukawa couplings:

$$\mathcal{L}_H = -Y^u H(Qu_R) - Y^d H(Qd_R) - Y^e H(Le_R) + h.c. \tag{2}$$

Probe only masses and CKM: $Y_u Y_u^\dagger$ and $Y_d Y_d^\dagger$
(u_R, d_R are $SU(2)$ singlets)

New physics can help us learn about flavor
Leptoquarks are great examples of this:

$$\mathcal{L}_\Delta = -\lambda \Delta(QL) + h.c. \tag{3}$$

Different processes probe columns and rows of λ matrix

LL and RL leptoquarks

We consider $SU(2)$ triplet leptoquark $\Delta \sim (3,3)$:

$$\mathcal{L}_{LL} = -\lambda \Delta (QL) + h.c. \tag{4}$$

Or $SU(2)$ doublet leptoquark $\Delta \sim (3,2)$:

$$\mathcal{L}_{RL} = -\lambda \Delta \left(d_R L\right) + h.c. \tag{5}$$

λ and R_K

$$\lambda \equiv \begin{pmatrix} \lambda_{de} & \lambda_{d\mu} & \lambda_{d\tau} \\ \lambda_{se} & \lambda_{s\mu} & \lambda_{s\tau} \\ \lambda_{be} & \lambda_{b\mu} & \lambda_{b\tau} \end{pmatrix} \tag{6}$$

R_K probes e, μ columns, s, b rows:

$$0.7 \lesssim \mathrm{Re}[\lambda_{se}\lambda_{be}^* - \lambda_{s\mu}\lambda_{b\mu}^*]\frac{(24\mathrm{TeV})^2}{M^2} \lesssim 1.5 \tag{7}$$

λ and other constraints

Conservative with direct collider detection:
$M > 1$ TeV

B_s mixing from box diagram probes different combination:

$$(\lambda_{se}\lambda_{be}^* + \lambda_{s\mu}\lambda_{b\mu}^* + \lambda_{s\tau}\lambda_{b\tau}^*)^2 \lesssim \frac{M^2}{(12\,\text{TeV})^2} \tag{8}$$

$R_K \sim \lambda^2/M^2$ vs. $\sim \lambda^4/M^2$
Combined: $M < \mathcal{O}(50)$ TeV, in reach of future colliders

Selected flavor data

observable	current 90 % CL limit	constraint	future sensitivity
$\mathcal{B}(\mu \to e\gamma)$	$5.7 \cdot 10^{-13}$ [22]	$\lvert\lambda_{qe}\lambda^*_{q\mu}\rvert \lesssim \frac{M^2}{(34\text{TeV})^2}$	$6 \cdot 10^{-14}$ [23]
$\mathcal{B}(\tau \to e\gamma)$	$1.2 \cdot 10^{-8}$ [24]	$\lvert\lambda_{qe}\lambda^*_{q\tau}\rvert \lesssim \frac{M^2}{(1\text{TeV})^2}$	
$\mathcal{B}(\tau \to \mu\gamma)$	$4.4 \cdot 10^{-8}$ [25]	$\lvert\lambda_{q\mu}\lambda^*_{q\tau}\rvert \lesssim \frac{M^2}{(0.7\text{ TeV})^2}$	$5 \cdot 10^{-9}$ [26]
$\mathcal{B}(\tau \to \mu\eta)$	$6.5 \cdot 10^{-8}$ [27]	$\lvert\lambda_{s\mu}\lambda^*_{s\tau}\rvert \lesssim \frac{M^2}{(3.7\text{ TeV})^2}$	$2 \cdot 10^{-9}$ [26]
$\mathcal{B}(B \to K\mu^\pm e^\mp)$	$3.8 \cdot 10^{-8}$ [28]	$\sqrt{\lvert\lambda_{s\mu}\lambda^*_{be}\rvert^2 + \lvert\lambda_{b\mu}\lambda^*_{se}\rvert^2} \lesssim \frac{M^2}{(19.4\text{ TeV})^2}$	
$\mathcal{B}(B \to K\tau^\pm e^\mp)$	$3.0 \cdot 10^{-5}$ [14]	$\sqrt{\lvert\lambda_{s\tau}\lambda^*_{be}\rvert^2 + \lvert\lambda_{b\tau}\lambda^*_{se}\rvert^2} \lesssim \frac{M^2}{(3.3\text{ TeV})^2}$	
$\mathcal{B}(B \to K\mu^\pm\tau^\mp)$	$4.8 \cdot 10^{-5}$ [14]	$\sqrt{\lvert\lambda_{s\mu}\lambda^*_{b\tau}\rvert^2 + \lvert\lambda_{b\mu}\lambda^*_{s\tau}\rvert^2} \lesssim \frac{M^2}{(2.9\text{ TeV})^2}$	
$\mathcal{B}(B \to \pi\mu^\pm e^\mp)$	$9.2 \cdot 10^{-8}$ [29]	$\sqrt{\lvert\lambda_{d\mu}\lambda^*_{be}\rvert^2 + \lvert\lambda_{b\mu}\lambda^*_{de}\rvert^2} \lesssim \frac{M^2}{(15.6\text{ TeV})^2}$	

COMET, MEG, Mu2e, Mu3e

Future LFV sensitivity probes the Leptoquark parameter space

COMET and Mu2e to 10^{-16} sensitivity
See talks by Litchfield, Papa

Data-Driven

The funniest thing is I didn't even do the caption myself:
`http://www.setheliot.com/blog/wp-content/uploads/2015/02/image2.png`

Simplest data-driven patterns

R_K probes e, μ columns:

$$0.7 \lesssim \mathrm{Re}[\lambda_{se}\lambda^*_{be} - \lambda_{s\mu}\lambda^*_{b\mu}]\frac{(24\mathrm{TeV})^2}{M^2} \lesssim 1.5 \qquad (9)$$

Lepton flavor isolation patterns:

$$\lambda^{[e]} \equiv \begin{pmatrix} \lambda_{de} & 0 & 0 \\ \lambda_{se} & 0 & 0 \\ \lambda_{be} & 0 & 0 \end{pmatrix}, \quad \lambda^{[\mu]} \equiv \begin{pmatrix} 0 & \lambda_{d\mu} & 0 \\ 0 & \lambda_{s\mu} & 0 \\ 0 & \lambda_{b\mu} & 0 \end{pmatrix} \qquad (10)$$

Hierarchical data-driven pattern

Given that fermion-Higgs Yukawa are hierarchical natural to expect a hierarchical λ pattern:

$$\lambda^{[\rho\kappa]} \sim \lambda_0 \begin{pmatrix} \rho_d\kappa & \rho_d & \rho_d \\ \rho\kappa & \rho & \rho \\ \kappa & 1 & 1 \end{pmatrix} \tag{11}$$

LFV arises naturally

Driving $\lambda^{[\rho\kappa]}$ with data

$$\lambda^{[\rho\kappa]} \sim \lambda_0 \begin{pmatrix} \rho_d \kappa & \rho_d & \rho_d \\ \rho\kappa & \rho & \rho \\ \kappa & 1 & 1 \end{pmatrix} \tag{12}$$

current flavor data implies:

$$\rho_d \lesssim 0.02\,, \quad \kappa \lesssim 0.5\,, \quad 10^{-4} \lesssim \rho \lesssim 1\,, \tag{13}$$

$$\rho_d/\rho \lesssim 1.6\,, \quad \kappa/\rho \lesssim 0.5 \tag{14}$$

κ from $\mu \to e\gamma$, ρ_d from rare K decays
$\rho_d\kappa$ from $\mu \to e$ conversion in near future

Correlating *b*-decays and LFV

$$\mathcal{B}(B \to K\mu^\pm e^\mp) \simeq 3 \cdot 10^{-8}\, \kappa^2 \left(\frac{1 - R_K}{0.23}\right)^2 , \tag{15}$$

$$\mathcal{B}(B \to K e^\pm \tau^\mp) \simeq 2 \cdot 10^{-8}\, \kappa^2 \left(\frac{1 - R_K}{0.23}\right)^2 , \tag{16}$$

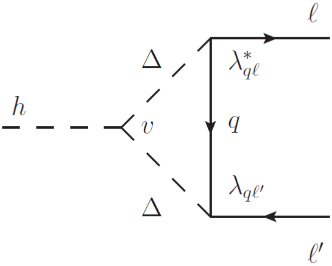
$$\mathcal{B}(B \to K\mu^\pm \tau^\mp) \simeq 2 \cdot 10^{-8} \left(\frac{1 - R_K}{0.23}\right)^2 , \tag{17}$$

$$\mathcal{B}(\mu \to e\gamma) \simeq 2 \cdot 10^{-12}\, \frac{\kappa^2}{\rho^2} \left(\frac{1 - R_K}{0.23}\right)^2 , \tag{18}$$

$$\mathcal{B}(\tau \to e\gamma) \simeq 4 \cdot 10^{-14}\, \frac{\kappa^2}{\rho^2} \left(\frac{1 - R_K}{0.23}\right)^2 , \tag{19}$$

$$\mathcal{B}(\tau \to \mu\gamma) \simeq 3 \cdot 10^{-14}\, \frac{1}{\rho^2} \left(\frac{1 - R_K}{0.23}\right)^2 . \tag{20}$$

Leptoquarks and rare Higgs decays



So e.g. for $\lambda^{[\rho\kappa]}$ we have:

$$\frac{y_{e\tau}}{y_{\mu\tau}} \sim \kappa\,, \qquad \frac{y_{e\mu}}{y_{\mu\tau}} \sim \kappa\,. \tag{22}$$

$\mathcal{B}\left(h \to \mu\tau\right)$ hinted by CMS: too large to be from leptoquark loop

See also talks by Dery, Heeck, and Schumacher

Fermion masses and mixing from flavor symmetries

Flavor symmetries explain fermion masses and mixing

Take subgroup of $U(3)^n$ (accidental in SM)
Charge SM fermions under it e.g.
$L_e, L_\mu, L_\tau \to L_i \sim 3$ of $SU(3)_F$
Then flavon $\phi \sim \bar{3}$ gets VEV $\langle \phi \rangle$ breaking $SU(3)_F$

$$\mathcal{L}_H = -H(\phi^i L_i)(\phi^j e_{R_j}) + h.c. \tag{23}$$

$$Y^{ij} \sim \langle \phi^i \rangle \langle \phi^j \rangle$$

Linking flavor structures of Higgs and Leptoquark

$Y \sim Y(\langle\phi\rangle)$ implies $\lambda \sim \lambda(\langle\phi\rangle)$
Flavor symmetries that explain Y patterns lead to
theory-driven λ patterns
that link Higgs and Leptoquarks

Several theory-driven patterns match the data-driven patterns

$SU(3)_F$ example

Based on:
IdMV, Ross (NPB)
IdMV (JHEP) `http://arxiv.org/abs/1111.3952`
IdMV, Ross (JHEP) `http://arxiv.org/abs/1203.6636`

Flavon with VEV $\langle \phi_{23} \rangle = (0, b, -b)$
Coupling as $\Delta(\phi^i_{23} Q_i)(\phi^j_{23} L_j)$

$$\lambda^{[-2]} = \lambda_0 b^2 \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & -1 \\ 0 & -1 & 1 \end{pmatrix} \qquad (24)$$

A very predictive special limit of $\lambda^{[\rho\kappa]}$

A_4 example

Based on:
Altarelli, Feruglio (NPB)
Altarelli, Meloni (JPG) `http://arxiv.org/abs/0905.0620`
IdMV, Merlo (JHEP) `http://arxiv.org/abs/1011.6662`
IdMV, Pidt (JHEP) `http://arxiv.org/abs/1211.5370`

Flavon with VEV $\langle \phi \rangle = (u, 0, 0)$
Coupling as $\Delta Q(\phi^j L_j)$ (quarks trivial under A_4)

$$\lambda^{[e]} \equiv \begin{pmatrix} \lambda_{de} & 0 & 0 \\ \lambda_{se} & 0 & 0 \\ \lambda_{be} & 0 & 0 \end{pmatrix} \tag{25}$$

Leptoquark lepton flavor isolation

Summary

Clues for Flavor from rare lepton and quark decays

- Clues from rare decays may be first glimpse of BSM
- Leptoquarks are appealing new physics scenario
- Assuming R_K obtain data-driven patterns for λ
- Matched by flavor symmetries theory-driven patterns

Acknowledgments

This project has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement no PIEF-GA-2012-327195 SIFT