New Observables for LHCb's Run 2

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$b \to s$ anomalies

Less than perfect agreement with the SM in a number of $b \to s$ measurements:

1. $$R_K \equiv \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+e^+e^-)} = 0.745^{+0.090}_{-0.074}\,(\mathrm{stat}) \pm 0.036\,(\mathrm{syst})$$

- SM predicts 1 within small corrections
- disagreement rather in muons

[LHCb]

$b \to s$ anomalies

Less than perfect agreement with the SM in a number of $b \to s$ measurements:

2. $\mathcal{B}(B_s \to \phi\mu\mu)$ more than 3σ below SM

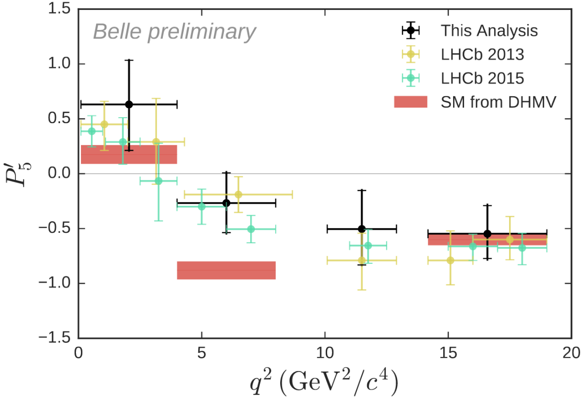
- Same kinematical region $m^2_{\mu\mu} \in [1, 6]$ GeV^2
- Seen with 1/fb, confirmed with full Run-I (3/fb)

[LHCb]

$b \to s$ anomalies

Less than perfect agreement with the SM in a number of $b \to s$ measurements:

3. $B \to K^* \mu\mu$ angular analysis



[LHCb, Belle]

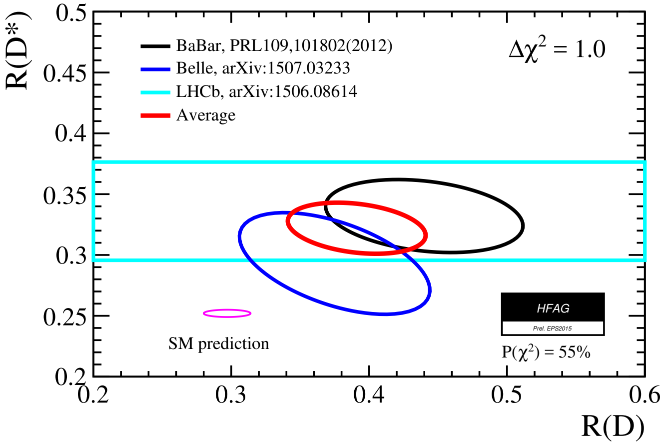
$b \to s$ anomalies

Less than perfect agreement with the SM in a number of $b \to s$ measurements:

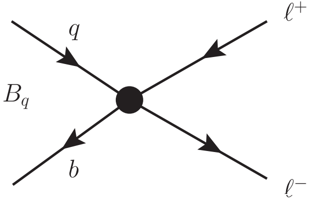
- These results have to be confirmed by LHCb run-II
- They suggest Lepton Flavor Non-Universality with a effect on $\mu\mu$ and not on ee.

$b \to c$ anomalies

$$R(D^{(*)}) \equiv \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}$$



Effective Hamiltonians



$$\mathcal{H}_{\text{eff}} \;=\; -\frac{4G_F}{\sqrt{2}} V_{tb}^* V_{tq} \sum_i C_i(\mu)\mathcal{O}_i(\mu)$$

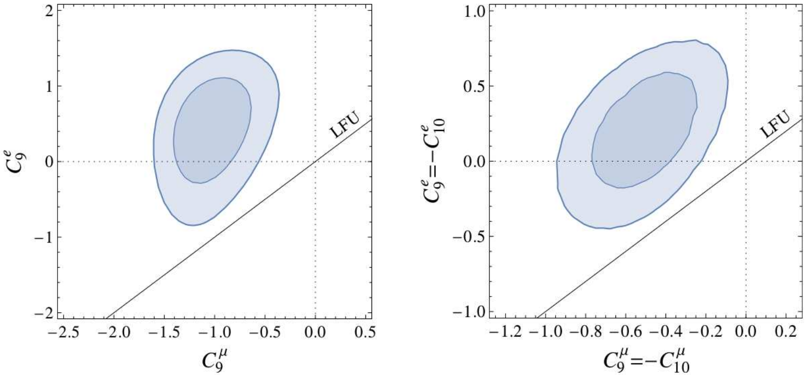
with

$$\begin{aligned} \mathcal{O}_9 &= \frac{\alpha}{4\pi}\,(\bar{b}_L\gamma^\lambda q_L)\,(\bar{\ell}\gamma_\lambda \ell)\ , \\ \mathcal{O}_{10} &= \frac{\alpha}{4\pi}\,(\bar{b}_L\gamma^\lambda q_L)\,(\bar{\ell}\gamma_\lambda\gamma_5 \ell) \\ &\vdots \end{aligned}$$

Wilson coefficients:

$$C_i = C_i^{SM} + \underbrace{\delta C_i}_{\text{new physics}}$$

Lepton Flavor Non-Universality



Global fit on C_9 and C_{10} based on LHCb run 1 data set

[Altmannshofer, Straub]

A Simple Model

- Simple model: Effective coupling to the third generation,

$$\mathscr{H}_{\rm NP} \;=\; G\, \bar{b}'_L \gamma^\lambda b'_L \bar{\tau}'_L \gamma_\lambda \tau'_L$$

- Fields are in the "gauge" basis (primed) $\Longrightarrow$ rotation to the mass eigenbasis

$$\begin{aligned} b'_L &\equiv (d'_L)_3 = (U^d_L)_{3i}\,(d_L)_i \\ \tau'_L &\equiv (\ell'_L)_3 = (U^\ell_L)_{3i}\,(\ell_L)_i \end{aligned}$$

- This generates LFNU and LFV

[Glashow, Guadagnoli, Lane]

Lepton Flavor Violation

- LFNU and LFV measurments put bounds on the U^d and U^ℓ matrices.

- Non-zero Wilson coefficients for $\bar{b} \to \bar{s}\ell_1^+\ell_2^-$

$$\delta C_9 = -\delta C_{10} = \frac{G}{2} \frac{U_4}{-\frac{4G_F}{\sqrt{2}} V_{tb}^* V_{tq} \frac{\alpha_{\rm em}(m_b)}{4\pi}}$$

$\mathcal{B}(B_{(s)} \to \mu^\pm e^\mp)$

LHCb measurement:

- $B_s \to e^\pm \mu^\pm < 1.1(1.4) \times 10^{-8}$ @ 90 (95) % CL
  $B_d \to e^\pm \mu^\pm < 2.8(3.7) \times 10^{-9}$ @ 90 (95) % CL

$\Longrightarrow$ Upper bounds on $G \times U^4$

$\Longrightarrow$ $|U^\ell_{L31}/U^\ell_{L32}| \lesssim 35$

[LHCb]

Naive estimation of the branching ratio R_γ^ℓ

$$R_\gamma^\ell = \frac{\mathcal{B}(B_s \to \ell^+\ell^-\gamma)}{\mathcal{B}(B_s \to \ell^+\ell^-)}$$

1. $\frac{m_\ell^2}{M_{B_s}^2}$: helicity suppression of $B_s \to \ell^+\ell^-$
2. α_{em}: additional γ-emission
3. 4π: phase space

[Melikhov, Nikitin]

Naive estimation of the branching ratio R_γ^ℓ

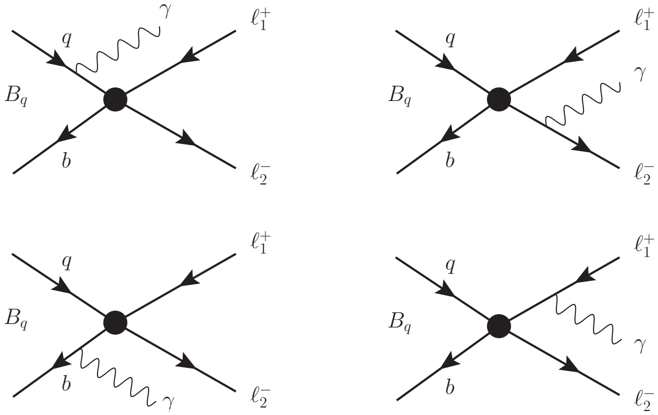
$$R_\gamma^\ell = \frac{\mathcal{B}(B_s \to \ell^+\ell^-\gamma)}{\mathcal{B}(B_s \to \ell^+\ell^-)} \sim \frac{M_{B_s}^2}{m_\ell^2}\frac{\alpha_{\text{em}}}{4\pi}$$

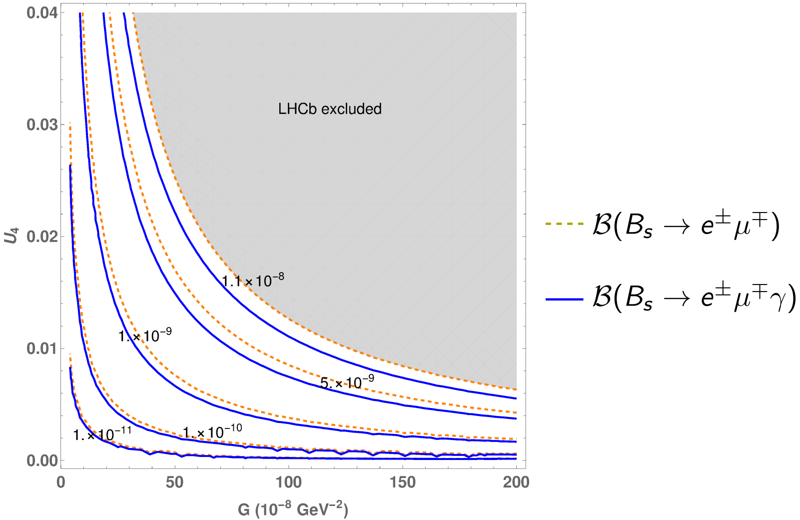
1. $\frac{m_\ell^2}{M_{B_s}^2}$: helicity suppression of $B_s \to \ell^+\ell^-$
2. α_{em}: additional γ-emission
3. 4π: phase space

	R_γ^e	R_γ^μ	R_γ^τ
Naive estimation	10^5	1	α_{em}
Melikhov-Nikitin	10^5	5	10^{-2}

[Melikhov, Nikitin]

$\mathcal{B}(B_s \to \mu^\pm e^\mp \gamma)$





[Guadagnoli, Melikhov, Reboud]

Conclusion

- Radiative enhancement of leptonic decays
- Simple model for LFNU/LFV, but...
- ... $\mathscr{H}_{\mathrm{NP}}$ must be made $SU(3) \times SU(2) \times U(1)$ invariant
  - + This can explain deviation $R(D^{(*)})$
  - − This leads to LFNU in $\tau \to \ell\nu\nu$ (not seen)