Strategies for LFV detection in B decays

Diego Guadagnoli
LAPTh Annecy (France)

Recap of flavor anomalies: $b \to s$

LHCb and B factories measured several key $b \to s$ and $b \to c$ modes.
Agreement with the SM is less than perfect.

❶ $$R_K = \frac{BR(B^+ \to K^+ \mu\mu)_{[1,6]}}{BR(B^+ \to K^+ ee)_{[1,6]}} = 0.745 \cdot (1 \pm 13\%)$$

Recap of flavor anomalies: b → s

LHCb and B factories measured several key $b \to s$ and $b \to c$ modes.
Agreement with the SM is less than perfect.

❶ $$R_K = \frac{BR(B^+ \to K^+ \mu\mu)_{[1,6]}}{BR(B^+ \to K^+ ee)_{[1,6]}} = 0.745 \cdot (1 \pm 13\%)$$

- *the electron channel would be an obvious culprit (brems + low stats).*

  But disagreement is rather in muons

Recap of flavor anomalies: b → s

LHCb and B factories measured several key $b \to s$ and $b \to c$ modes.
Agreement with the SM is less than perfect.

❶ $$R_K = \frac{BR(B^+ \to K^+ \mu\mu)_{[1,6]}}{BR(B^+ \to K^+ ee)_{[1,6]}} = 0.745 \cdot (1 \pm 13\,\%)$$

- *the electron channel would be an obvious culprit (brems + low stats).*
  But disagreement is rather in muons
- *muons are among the most reliable objects within LHCb*

Recap of flavor anomalies: $b \to s$

LHCb and B factories measured several key $b \to s$ and $b \to c$ modes.
Agreement with the SM is less than perfect.

❶ $$R_K = \frac{BR\left(B^+ \to K^+ \mu\mu\right)_{[1,6]}}{BR\left(B^+ \to K^+ e e\right)_{[1,6]}} = 0.745 \cdot \left(1 \pm 13\%\right)$$

- *the electron channel would be an obvious culprit (brems + low stats).*
  But disagreement is rather in muons
- *muons are among the most reliable objects within LHCb*

❷ ***BR($B_s \to \varphi\, \mu\mu$):*** *>3σ below SM prediction.* *Same kinematical region $m^2_{\mu\mu} \in [1, 6]$ GeV^2*

Initially found in 1/fb of LHCb data, then confirmed by a full Run-I analysis (3/fb)

Recap of flavor anomalies: b → s

LHCb and B factories measured several key $b \to s$ and $b \to c$ modes.
Agreement with the SM is less than perfect.

❶ $$R_K = \frac{BR(B^+ \to K^+ \mu\mu)_{[1,6]}}{BR(B^+ \to K^+ ee)_{[1,6]}} = 0.745 \cdot (1 \pm 13\%)$$

- *the electron channel would be an obvious culprit (brems + low stats).*
  But disagreement is rather in muons
- *muons are among the most reliable objects within LHCb*

❷ ***BR($B_s \to \varphi\, \mu\mu$):*** *>3σ below SM prediction.* *Same kinematical region $m^2_{\mu\mu} \in [1, 6]$ GeV^2*

Initially found in 1/fb of LHCb data, then confirmed by a full Run-I analysis (3/fb)

❸ ***$B \to K^* \mu\mu$ angular analysis:*** *discrepancy in P'_5* *Again same region $m^2_{\mu\mu} \in [1, 6]$ GeV^2*

Compatibility between 1/fb and 3/fb LHCb analyses. *Supported also by recent Belle analysis.*

Recap of flavor anomalies: b → s

LHCb and B factories measured several key $b \to s$ and $b \to c$ modes.
Agreement with the SM is less than perfect.

❶ $$R_K = \frac{BR(B^+ \to K^+ \mu\mu)_{[1,6]}}{BR(B^+ \to K^+ ee)_{[1,6]}} = 0.745 \cdot (1 \pm 13\%)$$

- *the electron channel would be an obvious culprit (brems + low stats).*
  But disagreement is rather in muons
- *muons are among the most reliable objects within LHCb*

❷ ***BR($B_s \to \varphi\, \mu\mu$):*** *>3σ below SM prediction. Same kinematical region $m^2_{\mu\mu} \in [1, 6]$ GeV^2*

Initially found in 1/fb of LHCb data, then confirmed by a full Run-I analysis (3/fb)

❸ ***$B \to K^* \mu\mu$ angular analysis:*** *discrepancy in P'_5 Again same region $m^2_{\mu\mu} \in [1, 6]$ GeV^2*

Compatibility between 1/fb and 3/fb LHCb analyses. Supported also by recent Belle analysis.

Significance of the effect is debated.

Recap of flavor anomalies: b → s

LHCb and B factories measured several key $b \to s$ and $b \to c$ modes.
Agreement with the SM is less than perfect.

❶
$$R_K = \frac{BR(B^+ \to K^+ \mu\mu)_{[1,6]}}{BR(B^+ \to K^+ ee)_{[1,6]}} = 0.745 \cdot (1 \pm 13\%)$$

- *the electron channel would be an obvious culprit (brems + low stats).*
  But disagreement is rather in muons
- *muons are among the most reliable objects within LHCb*

❷ ***BR($B_s \to \varphi\, \mu\mu$):*** *>3σ below SM prediction. Same kinematical region $m^2_{\mu\mu} \in [1, 6]$ GeV^2*

Initially found in 1/fb of LHCb data, then confirmed by a full Run-I analysis (3/fb)

❸ ***B → K* μμ angular analysis:*** *discrepancy in P'_5 Again same region $m^2_{\mu\mu} \in [1, 6]$ GeV^2*

Compatibility between 1/fb and 3/fb LHCb analyses. Supported also by recent Belle analysis.

Significance of the effect is debated.

❶ (+ ❷ + ❸) $\Rightarrow$ *There seems to be BSM LFNU and the effect is in μμ, not ee*

Recap of flavor anomalies: b → c

There are long-standing discrepancies in b → c transitions as well.

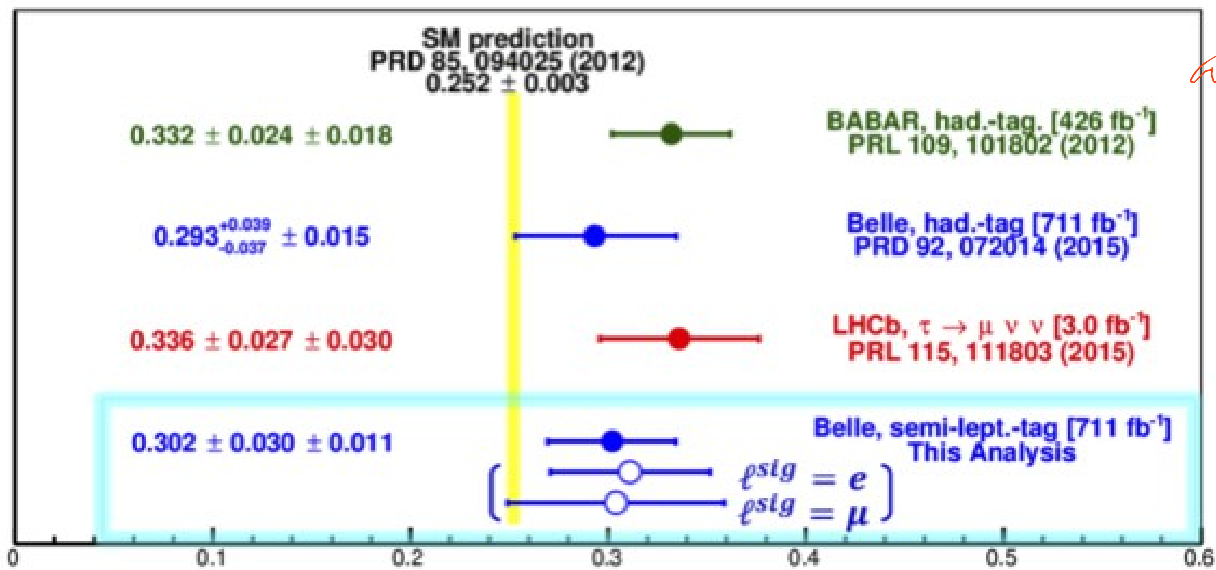
$$R\left(D^{(*)}\right) = \frac{BR\left(B \to D^{(*)} \tau \nu\right)}{BR\left(B \to D^{(*)} \ell \nu\right)} \left(\text{with } \ell = e, \mu\right)$$

Recap of flavor anomalies: b → c

There are long-standing discrepancies in b → c transitions as well.

$$R(D^{(*)}) = \frac{BR(B \to D^{(*)} \tau \nu)}{BR(B \to D^{(*)} \ell \nu)} \; (\text{with } \ell = e, \mu)$$

First discrepancy found by BaBar in 2012 in both R(D) and R(D*)

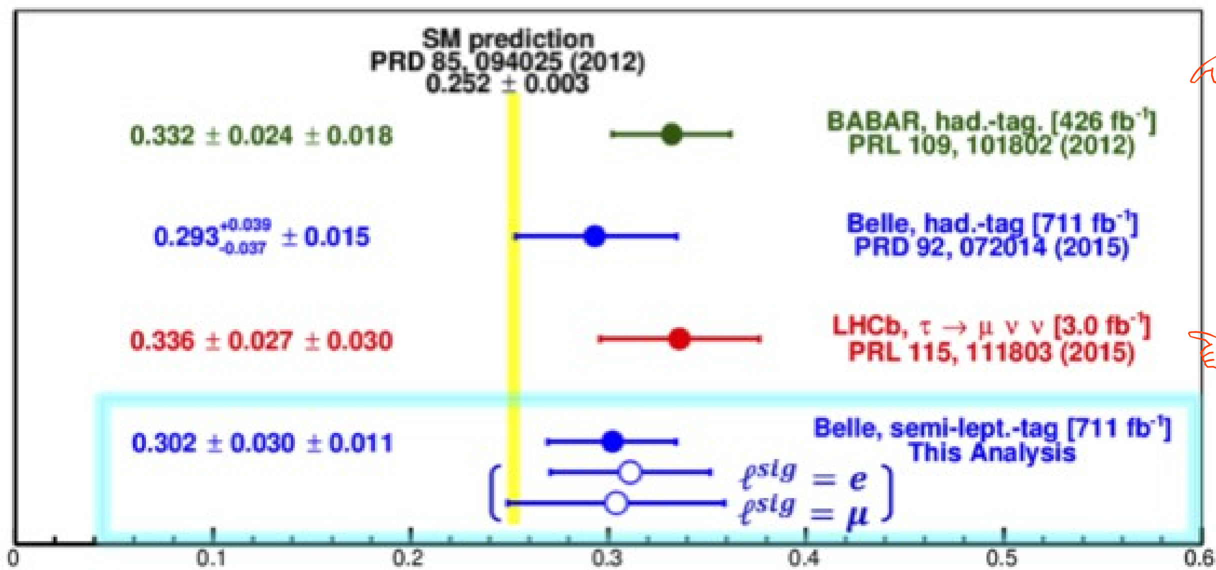


R(D*) state-of-the-art, as of Moriond 2016 (Goldenzweig, Belle)

Recap of flavor anomalies: b → c

There are long-standing discrepancies in b → c transitions as well.

$$R(D^{(*)}) = \frac{BR(B \to D^{(*)} \tau \nu)}{BR(B \to D^{(*)} \ell \nu)} \; (\text{with } \ell = e, \mu)$$



R(D*) state-of-the-art, as of Moriond 2016 (Goldenzweig, Belle)

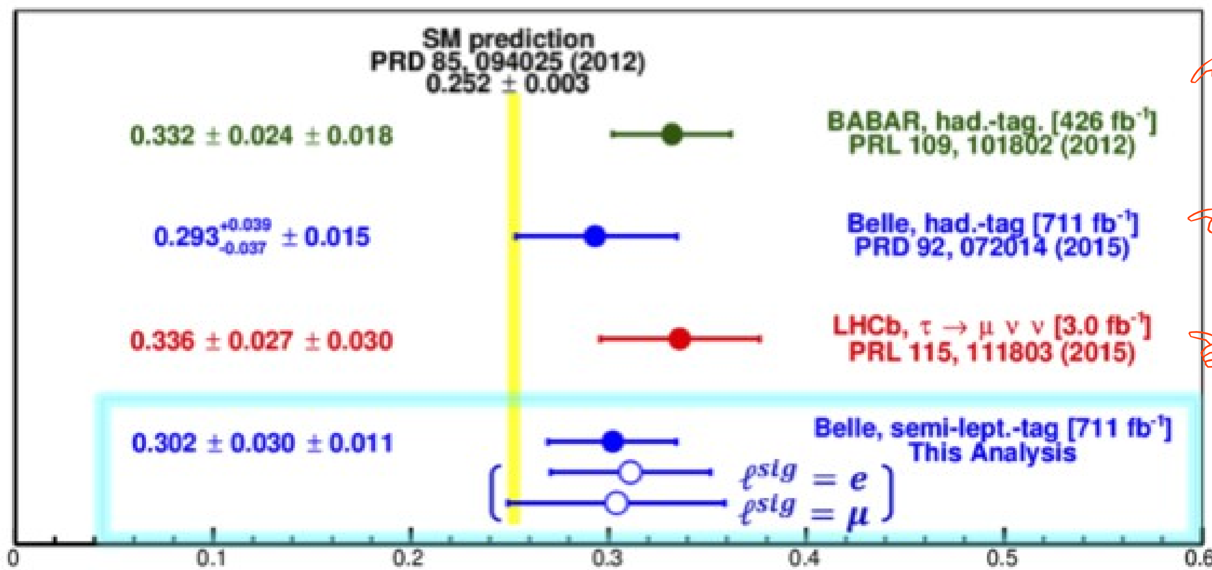
First discrepancy found by BaBar in 2012 in both R(D) and R(D*)

2015: BaBar's R(D*) confirmed by LHCb

Recap of flavor anomalies: b → c

There are long-standing discrepancies in b → c transitions as well.

$$R(D^{(*)}) = \frac{BR(B \to D^{(*)} \tau \nu)}{BR(B \to D^{(*)} \ell \nu)} \, (\text{with } \ell = e, \mu)$$



R(D*) state-of-the-art, as of Moriond 2016 (Goldenzweig, Belle)

First discrepancy found by BaBar in 2012 in both R(D) and R(D*)

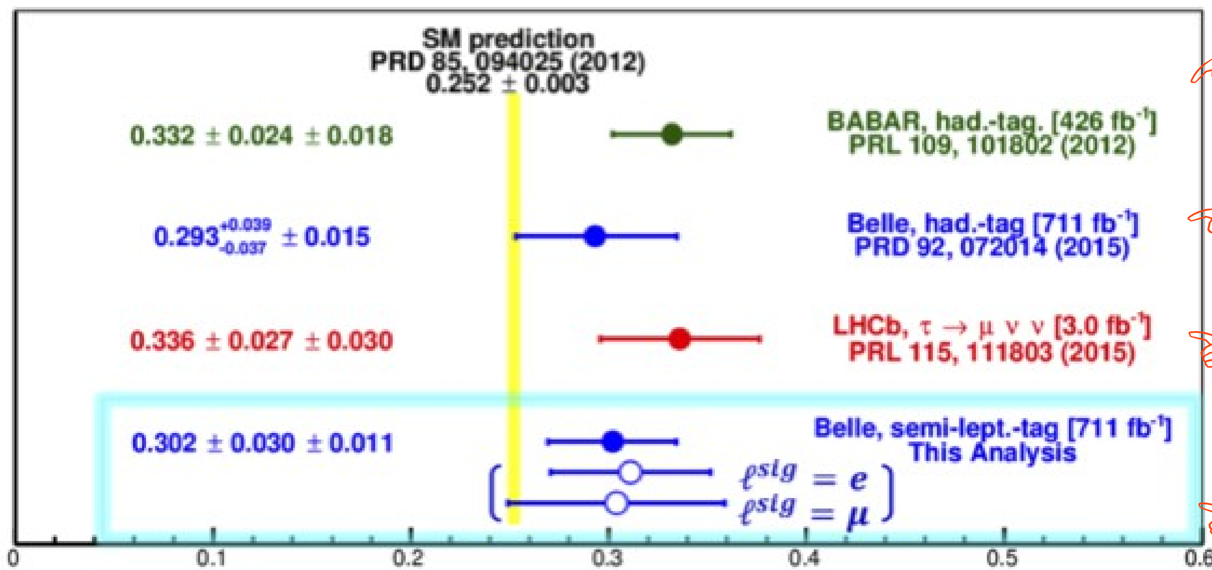
2015: Belle finds a more SM-like R(D*) (hadronic tau's)

2015: BaBar's R(D*) confirmed by LHCb

Recap of flavor anomalies: b → c

There are long-standing discrepancies in b → c transitions as well.

$$R(D^{(*)}) = \frac{BR(B \to D^{(*)} \tau \nu)}{BR(B \to D^{(*)} \ell \nu)} \; (\text{with } \ell = e, \mu)$$



R(D*) state-of-the-art, as of Moriond 2016 (Goldenzweig, Belle)

First discrepancy found by BaBar in 2012 in both R(D) and R(D*)

2015: Belle finds a more SM-like R(D*) (hadronic tau's)

2015: BaBar's R(D*) confirmed by LHCb

2016: Belle also starts to see an R(D*) excess (semi-lep. tau's)

- *Each of the mentioned effect needs confirmation from Run II to be taken seriously*

- *Each of the mentioned effect needs confirmation from Run II to be taken seriously*

- *Yet, focusing (for the moment) on the $b \to s$ discrepancies*

  - ***Q1:*** *Can we (easily) make theoretical sense of data?*
  - ***Q2:*** *What are the most immediate signatures to expect ?*

Concerning Q2: most immediate signatures to expect

Basic observation:

- *If R_K is signaling LFNU at a non-SM level, we may also expect LFV at a non-SM level.*

Concerning Q2: most immediate signatures to expect

Basic observation:

- *If R_K is signaling LFNU at a non-SM level, we may also expect LFV at a non-SM level.*

In fact:

- *Consider a new, LFNU interaction above the EWSB scale, e.g. with*

  new vector bosons: $\bar{\ell} Z' \ell$ *or* *leptoquarks:* $\bar{\ell} \varphi q$

Concerning Q2: most immediate signatures to expect

Basic observation:

- *If R_K is signaling LFNU at a non-SM level, we may also expect LFV at a non-SM level.*

In fact:

- *Consider a new, LFNU interaction above the EWSB scale, e.g. with*

  new vector bosons: $\bar{\ell} Z' \ell$ *or* *leptoquarks:* $\bar{\ell} \varphi q$

- *In what basis are quarks and leptons in the above interaction?*

  Generically, it's not the mass eigenbasis.
  (This basis doesn't yet even exist. We are above the EWSB scale.)

Concerning Q2: most immediate signatures to expect

Basic observation:

- *If R_K is signaling LFNU at a non-SM level, we may also expect LFV at a non-SM level.*

In fact:

- *Consider a new, LFNU interaction above the EWSB scale, e.g. with*

  new vector bosons: $\bar{\ell} Z' \ell$ *or* *leptoquarks:* $\bar{\ell}\, \varphi\, q$

- *In what basis are quarks and leptons in the above interaction?*

  Generically, it's not the mass eigenbasis.
  (This basis doesn't yet even exist. We are above the EWSB scale.)

- *Rotating q and ℓ to the mass eigenbasis generates LFV interactions.*

Concerning Q1: can we easily make theoretical sense of these data?

- *Yes we can. Consider the following Hamiltonian*

$$H_{\mathrm{SM+NP}}(\bar{b} \to \bar{s}\mu\mu) = -\frac{4G_F}{\sqrt{2}} V_{tb}^{*} V_{ts} \frac{\alpha_{\mathrm{em}}}{4\pi} \left[\bar{b}_L \gamma^{\lambda} s_L \cdot \left(C_9^{(\mu)} \bar{\mu} \gamma_{\lambda} \mu \;+\; C_{10}^{(\mu)} \bar{\mu} \gamma_{\lambda} \gamma_5 \mu \right) \right]$$

Concerning Q1: can we easily make theoretical sense of these data?

- *Yes we can. Consider the following Hamiltonian*

About equal size & opposite sign in the SM (at the m_b scale)

$$H_{\mathrm{SM+NP}}(\bar{b} \to \bar{s}\mu\mu) = -\frac{4G_F}{\sqrt{2}} V_{tb}^* V_{ts} \frac{\alpha_{\mathrm{em}}}{4\pi} \left[\bar{b}_L \gamma^\lambda s_L \cdot \left(\boxed{C_9^{(\mu)}} \bar{\mu}\gamma_\lambda \mu + \boxed{C_{10}^{(\mu)}} \bar{\mu}\gamma_\lambda \gamma_5 \mu \right) \right]$$

Concerning Q1: can we easily make theoretical sense of these data?

- *Yes we can. Consider the following Hamiltonian*

About equal size & opposite sign in the SM (at the m_b scale)

$$H_{\mathrm{SM+NP}}(\bar{b} \to \bar{s}\mu\mu) = -\frac{4G_F}{\sqrt{2}} V_{tb}^* V_{ts} \frac{\alpha_{\mathrm{em}}}{4\pi} \left[\bar{b}_L \gamma^\lambda s_L \cdot \left(\boxed{C_9^{(\mu)}} \bar{\mu} \gamma_\lambda \mu + \boxed{C_{10}^{(\mu)}} \bar{\mu} \gamma_\lambda \gamma_5 \mu \right) \right]$$

- *Advocating the same (V – A) x (V – A) structure also for the corrections to $C_{9,10}^{SM}$ (in the μμ-channel only!) would account for:*
  - *R_K lower than 1*
  - *$B \to K\,\mu\mu$ & $B_s \to \mu\mu$ BR data below predictions*
  - *the P_5' anomaly in $B \to K^*\,\mu\mu$*

Concerning Q1: can we easily make theoretical sense of these data?

About equal size & opposite sign in the SM (at the m_b scale)

- *Yes we can. Consider the following Hamiltonian*

$$H_{\mathrm{SM+NP}}(\bar{b}\to\bar{s}\mu\mu) = -\frac{4G_F}{\sqrt{2}} V_{tb}^{*} V_{ts} \frac{\alpha_{\mathrm{em}}}{4\pi} \left[\bar{b}_L \gamma^{\lambda} s_L \cdot \left(\boxed{C_9^{(\mu)}} \bar{\mu}\gamma_{\lambda}\mu + \boxed{C_{10}^{(\mu)}} \bar{\mu}\gamma_{\lambda}\gamma_5\mu\right)\right]$$

- *Advocating the same (V – A) x (V – A) structure also for the corrections to $C_{9,10}^{SM}$ (in the μμ-channel only!) would account for:*
  - *R_K lower than 1*
  - *$B \to K\,\mu\mu$ & $B_s \to \mu\mu$ BR data below predictions*
  - *the P_5' anomaly in $B \to K^*\,\mu\mu$*

- *A fully quantitative test requires a global fit.*

new physics contributions to the Wilson coefficients. We find that the by far largest decrease in the χ^2 can be obtained either by a negative new physics contribution to C_9 (with $C_9^{\mathrm{NP}} \sim -30\% \times C_9^{\mathrm{SM}}$), or by new physics in the $SU(2)_L$ invariant direction $C_9^{\mathrm{NP}} = -C_{10}^{\mathrm{NP}}$, (with $C_9^{\mathrm{NP}} \sim -12\% \times C_9^{\mathrm{SM}}$). A positive NP contribution to C_{10} alone would also improve the fit, although to a lesser extent. [Altmannshofer, Straub, EPJC '15]

For analogous conclusions, see also [Ghosh, Nardecchia, Renner, JHEP '14]

Model example:
Glashow, DG, Lane, PRL 2015

- *As we saw before, all $b \to s$ data are explained at one stroke if:*
  - $C_9^{(\ell)} \approx -C_{10}^{(\ell)}$ *(V – A structure)*
  - $|C_{9,\mathrm{NP}}^{(\mu)}| \gg |C_{9,\mathrm{NP}}^{(e)}|$ *(LFNU)*

Model example:
Glashow, DG, Lane, PRL 2015

- *As we saw before, all $b \to s$ data are explained at one stroke if:*
  - $C_9^{(\ell)} \approx -C_{10}^{(\ell)}$ *(V – A structure)*
  - $|C_{9,\mathrm{NP}}^{(\mu)}| \gg |C_{9,\mathrm{NP}}^{(e)}|$ *(LFNU)*

- *This pattern can be generated from a purely 3rd-generation interaction of the kind*

$$H_{\mathrm{NP}} = G\, \bar{b}'_L \gamma^\lambda b'_L\, \bar{\tau}'_L \gamma_\lambda \tau'_L$$

with $G = 1/\Lambda_{\mathrm{NP}}^2 \ll G_F$

expected e.g. in partial-compositeness frameworks

Model example:
Glashow, DG, Lane, PRL 2015

- *As we saw before, all $b \to s$ data are explained at one stroke if:*
  - $C_9^{(\ell)} \approx -C_{10}^{(\ell)}$ *(V – A structure)*
  - $|C_{9,\mathrm{NP}}^{(\mu)}| \gg |C_{9,\mathrm{NP}}^{(e)}|$ *(LFNU)*

- *This pattern can be generated from a purely 3rd-generation interaction of the kind*

$$H_{\mathrm{NP}} = G\, \bar{b}'_L \gamma^\lambda b'_L\, \bar{\tau}'_L \gamma_\lambda \tau'_L$$

with $G = 1/\Lambda_{\mathrm{NP}}^2 \ll G_F$

expected e.g. in partial-compositeness frameworks

- ***Note:** primed fields*
  - *Fields are in the "gauge" basis (= primed)*

Model example:
Glashow, DG, Lane, PRL 2015

- *As we saw before, all $b \to s$ data are explained at one stroke if:*
  - $C_9^{(\ell)} \approx -C_{10}^{(\ell)}$ *(V – A structure)*
  - $|C_{9,\mathrm{NP}}^{(\mu)}| \gg |C_{9,\mathrm{NP}}^{(e)}|$ *(LFNU)*

- *This pattern can be generated from a purely 3rd-generation interaction of the kind*

$$H_{\mathrm{NP}} = G\, \bar{b}'_L \gamma^\lambda b'_L\, \bar{\tau}'_L \gamma_\lambda \tau'_L$$

with $G = 1/\Lambda_{\mathrm{NP}}^2 \ll G_F$

expected e.g. in partial-compositeness frameworks

- ***Note:** primed fields*
  - *Fields are in the "gauge" basis (= primed)*
  - *They need to be rotated to the mass eigenbasis* ☞

mass basis

$$b'_L \equiv (d'_L)_3 = (U_L^d)_{3i}\boxed{(d_L)_i}$$

$$\tau'_L \equiv (\ell'_L)_3 = (U_L^\ell)_{3i}\boxed{(\ell_L)_i}$$

Model example:
Glashow, DG, Lane, PRL 2015

- *As we saw before, all $b \to s$ data are explained at one stroke if:*
  - $C_9^{(\ell)} \approx -C_{10}^{(\ell)}$ *(V – A structure)*
  - $\left|C_{9,\mathrm{NP}}^{(\mu)}\right| \gg \left|C_{9,\mathrm{NP}}^{(e)}\right|$ *(LFNU)*

- *This pattern can be generated from a purely 3rd-generation interaction of the kind*

$$H_{\mathrm{NP}} = G\, \bar{b}'_L \gamma^\lambda b'_L\, \bar{\tau}'_L \gamma_\lambda \tau'_L$$

with $G = 1/\Lambda_{\mathrm{NP}}^2 \ll G_F$

expected e.g. in partial-compositeness frameworks

- ***Note:*** *primed fields*
  - *Fields are in the "gauge" basis (= primed)*
  - *They need to be rotated to the mass eigenbasis* ☞
  - *This rotation induces* *LFNU and LFV* *effects*

mass basis

$$b'_L \equiv (d'_L)_3 = (U_L^d)_{3i} \boxed{(d_L)_i}$$

$$\tau'_L \equiv (\ell'_L)_3 = (U_L^\ell)_{3i} \boxed{(\ell_L)_i}$$

Explaining b → s data

- *Recalling our full Hamiltonian*

k_{SM} (SM norm. factor)

$$H_{\mathrm{SM+NP}}(\bar{b} \to \bar{s}\mu\mu) = \boxed{-\frac{4G_F}{\sqrt{2}} V_{tb}^{*} V_{ts} \frac{\alpha_{\mathrm{em}}}{4\pi}} \left[\bar{b}_L \gamma^{\lambda} s_L \cdot \left(C_9^{(\mu)}\, \bar{\mu} \gamma_{\lambda} \mu \; + \; C_{10}^{(\mu)}\, \bar{\mu} \gamma_{\lambda} \gamma_5 \mu \right)\right]$$

Explaining b → s data

- *Recalling our full Hamiltonian*

k_{SM} *(SM norm. factor)*

$$H_{\mathrm{SM+NP}}(\bar{b} \to \bar{s}\,\mu\,\mu) = \boxed{-\frac{4\,G_F}{\sqrt{2}}\,V_{tb}^{*}V_{ts}\,\frac{\alpha_{\mathrm{em}}}{4\pi}}\left[\bar{b}_L\,\gamma^{\lambda}s_L \cdot \left(C_9^{(\mu)}\,\bar{\mu}\,\gamma_{\lambda}\,\mu \;+\; C_{10}^{(\mu)}\,\bar{\mu}\,\gamma_{\lambda}\,\gamma_5\,\mu\right)\right]$$

the shift to the C_9 *Wilson coeff. in the μμ-channel becomes*

$$k_{\mathrm{SM}}\,C_9^{(\mu)} = k_{\mathrm{SM}}\,C_{9,\mathrm{SM}} + \frac{G}{2}\,(U_L^d)_{33}^{*}(U_L^d)_{32}\left|(U_L^{\ell})_{32}\right|^2$$

Explaining b → s data

- *Recalling our full Hamiltonian*

k_{SM} (SM norm. factor)

$$H_{\mathrm{SM+NP}}(\bar{b} \to \bar{s}\mu\mu) = \boxed{-\frac{4G_F}{\sqrt{2}} V_{tb}^{*} V_{ts} \frac{\alpha_{\mathrm{em}}}{4\pi}} \left[\bar{b}_L \gamma^{\lambda} s_L \cdot \left(C_9^{(\mu)}\, \bar{\mu}\gamma_{\lambda}\mu + C_{10}^{(\mu)}\, \bar{\mu}\gamma_{\lambda}\gamma_5\mu\right)\right]$$

the shift to the C_9 Wilson coeff. in the μμ-channel becomes

$$k_{\mathrm{SM}}\, C_9^{(\mu)} = k_{\mathrm{SM}}\, C_{9,\mathrm{SM}} + \frac{G}{2} (U_L^d)_{33}^{*} (U_L^d)_{32} |(U_L^{\ell})_{32}|^2$$

The NP contribution has opposite sign than the SM one if

$$G\,(U_L^d)_{32} < 0$$

Explaining b → s data

- *Recalling our full Hamiltonian*

k_{SM} (SM norm. factor)

$$H_{\mathrm{SM+NP}}(\bar{b} \to \bar{s}\mu\mu) = \boxed{-\frac{4G_F}{\sqrt{2}} V_{tb}^* V_{ts} \frac{\alpha_{\mathrm{em}}}{4\pi}} \left[\bar{b}_L \gamma^\lambda s_L \cdot \left(C_9^{(\mu)} \bar{\mu}\gamma_\lambda\mu + C_{10}^{(\mu)} \bar{\mu}\gamma_\lambda\gamma_5\mu\right)\right]$$

the shift to the C_9 Wilson coeff. in the μμ-channel becomes

$$k_{\mathrm{SM}} C_9^{(\mu)} = k_{\mathrm{SM}} C_{9,\mathrm{SM}} + \frac{G}{2} (U_L^d)_{33}^* (U_L^d)_{32} |(U_L^\ell)_{32}|^2$$

The NP contribution has opposite sign than the SM one if

$$G\,(U_L^d)_{32} < 0$$

- *On the other hand, in the ee-channel*

$$k_{\mathrm{SM}} C_9^{(e)} = k_{\mathrm{SM}} C_{9,\mathrm{SM}} + \frac{G}{2} (U_L^d)_{33}^* (U_L^d)_{32} |(U_L^\ell)_{31}|^2$$

Explaining b → s data

- *Recalling our full Hamiltonian*

k_{SM} (SM norm. factor)

$$H_{\mathrm{SM+NP}}(\bar{b} \to \bar{s} \mu \mu) = \boxed{-\frac{4 G_F}{\sqrt{2}} V_{tb}^* V_{ts} \frac{\alpha_{\mathrm{em}}}{4\pi}} \left[\bar{b}_L \gamma^\lambda s_L \cdot \left(C_9^{(\mu)} \bar{\mu} \gamma_\lambda \mu + C_{10}^{(\mu)} \bar{\mu} \gamma_\lambda \gamma_5 \mu \right) \right]$$

the shift to the C_9 Wilson coeff. in the μμ-channel becomes

$$k_{\mathrm{SM}}\, C_9^{(\mu)} = k_{\mathrm{SM}}\, C_{9,\mathrm{SM}} + \frac{G}{2} (U_L^d)_{33}^* (U_L^d)_{32} |(U_L^\ell)_{32}|^2$$

The NP contribution has opposite sign than the SM one if

$$G\, (U_L^d)_{32} < 0$$

- *On the other hand, in the ee-channel*

$$k_{\mathrm{SM}}\, C_9^{(e)} = k_{\mathrm{SM}}\, C_{9,\mathrm{SM}} + \cancel{\frac{G}{2} (U_L^d)_{33}^* (U_L^d)_{32} |(U_L^\ell)_{31}|^2}$$

The NP contrib. in the ee-channel is negligible, as

$$|(U_L^\ell)_{31}|^2 \ll |(U_L^\ell)_{32}|^2$$

Explaining b → s data

- *So, in the above setup*

$$R_K \approx \frac{|C_9^{(\mu)}|^2 + |C_{10}^{(\mu)}|^2}{|C_9^{(e)}|^2 + |C_{10}^{(e)}|^2} \simeq \frac{2|C_{10}^{\mathrm{SM}} + \delta C_{10}|^2}{2|C_{10}^{\mathrm{SM}}|^2}$$

Explaining b → s data

- *So, in the above setup*

$$R_K \approx \frac{|C_9^{(\mu)}|^2 + |C_{10}^{(\mu)}|^2}{|C_9^{(e)}|^2 + |C_{10}^{(e)}|^2} \simeq \frac{2|C_{10}^{\rm SM} + \delta C_{10}|^2}{2|C_{10}^{\rm SM}|^2}$$

factors of 2:
equal contributions from $|C_9|^2$ and $|C_{10}|^2$

Explaining b → s data

- *So, in the above setup*

$$R_K \approx \frac{|C_9^{(\mu)}|^2 + |C_{10}^{(\mu)}|^2}{|C_9^{(e)}|^2 + |C_{10}^{(e)}|^2} \simeq \frac{2|C_{10}^{\rm SM} + \delta C_{10}|^2}{2|C_{10}^{\rm SM}|^2}$$

factors of 2:

equal contributions from $|C_9|^2$ and $|C_{10}|^2$

- *Note as well*

$$0.77 \pm 0.20 = \frac{BR(B_s \to \mu\mu)_{\rm exp}}{BR(B_s \to \mu\mu)_{\rm SM}} = \frac{BR(B_s \to \mu\mu)_{\rm SM+NP}}{BR(B_s \to \mu\mu)_{\rm SM}} = \frac{|C_{10}^{\rm SM} + \delta C_{10}|^2}{|C_{10}^{\rm SM}|^2}$$

Explaining b → s data

- *So, in the above setup*

$$R_K \approx \frac{|C_9^{(\mu)}|^2 + |C_{10}^{(\mu)}|^2}{|C_9^{(e)}|^2 + |C_{10}^{(e)}|^2} \simeq \frac{2|C_{10}^{\rm SM} + \delta C_{10}|^2}{2|C_{10}^{\rm SM}|^2}$$

factors of 2:
equal contributions from $|C_9|^2$ and $|C_{10}|^2$

- *Note as well*

$$0.77 \pm 0.20 = \frac{BR(B_s \to \mu\mu)_{\rm exp}}{BR(B_s \to \mu\mu)_{\rm SM}} = \frac{BR(B_s \to \mu\mu)_{\rm SM+NP}}{BR(B_s \to \mu\mu)_{\rm SM}} = \frac{|C_{10}^{\rm SM} + \delta C_{10}|^2}{|C_{10}^{\rm SM}|^2}$$

implying (within our model) the correlations

$$\frac{BR(B_s \to \mu\mu)_{\rm exp}}{BR(B_s \to \mu\mu)_{\rm SM}} \simeq R_K \simeq \frac{BR(B^+ \to K^+\mu\mu)_{\rm exp}}{BR(B^+ \to K^+\mu\mu)_{\rm SM}}$$

Another good reason to pursue accuracy in the $B_s \to \mu\mu$ measurement

See also
Hiller, Schmaltz, PRD 14

LFV model signatures

As mentioned: if R_K is signaling BSM LFNU, then expect BSM LFV as well

☑ $$\frac{BR(B^+ \to K^+ \mu e)}{BR(B^+ \to K^+ \mu \mu)} = \frac{|\delta C_{10}|^2}{|C_{10}^{\mathrm{SM}} + \delta C_{10}|^2} \cdot \frac{|(U_L^\ell)_{31}|^2}{|(U_L^\ell)_{32}|^2} \cdot 2$$

LFV model signatures

As mentioned: if R_K is signaling BSM LFNU, then expect BSM LFV as well

☑ $$\frac{BR(B^+ \to K^+ \mu e)}{BR(B^+ \to K^+ \mu \mu)} = \boxed{\frac{|\delta C_{10}|^2}{|C_{10}^{\rm SM} + \delta C_{10}|^2}} \cdot \frac{|(U_L^\ell)_{31}|^2}{|(U_L^\ell)_{32}|^2} \cdot 2$$

$= 0.159^2$ according to R_K

LFV model signatures

As mentioned: if R_K is signaling BSM LFNU, then expect BSM LFV as well

☑ $$\frac{BR(B^+ \to K^+ \mu e)}{BR(B^+ \to K^+ \mu \mu)} = \boxed{\frac{|\delta C_{10}|^2}{|C_{10}^{\mathrm{SM}} + \delta C_{10}|^2}} \cdot \frac{|(U_L^\ell)_{31}|^2}{|(U_L^\ell)_{32}|^2} \boxed{\cdot\ 2}$$

$= 0.159^2$ according to R_K

$\mu^+ e^-$ & $\mu^- e^+$ modes

LFV model signatures

As mentioned: if R_K is signaling BSM LFNU, then expect BSM LFV as well

☑ $$\frac{BR(B^+ \to K^+ \mu e)}{BR(B^+ \to K^+ \mu \mu)} = \boxed{\frac{|\delta C_{10}|^2}{|C_{10}^{\mathrm{SM}} + \delta C_{10}|^2}} \cdot \frac{|(U_L^\ell)_{31}|^2}{|(U_L^\ell)_{32}|^2} \cdot \boxed{2}$$

$= 0.159^2$ according to R_K

$\mu^+ e^-$ & $\mu^- e^+$ modes

$$BR(B^+ \to K^+ \mu e) < 2.2 \times 10^{-8} \cdot \frac{|(U_L^\ell)_{31}|^2}{|(U_L^\ell)_{32}|^2}$$

The current BR(B+ → K+ μe) limit yields the weak bound

$$|(U_L^\ell)_{31} / (U_L^\ell)_{32}| < 3.7$$

LFV model signatures

As mentioned: if R_K is signaling BSM LFNU, then expect BSM LFV as well

☑ $$\frac{BR(B^+ \to K^+ \mu e)}{BR(B^+ \to K^+ \mu \mu)} = \boxed{\frac{|\delta C_{10}|^2}{|C_{10}^{\mathrm{SM}} + \delta C_{10}|^2}} \cdot \frac{|(U_L^\ell)_{31}|^2}{|(U_L^\ell)_{32}|^2} \cdot 2$$

= 0.159² according to R_K

$\mu^+ e^-$ & $\mu^- e^+$ modes

$$BR(B^+ \to K^+ \mu e) < 2.2 \times 10^{-8} \cdot \frac{|(U_L^\ell)_{31}|^2}{|(U_L^\ell)_{32}|^2}$$

The current BR(B+ → K+ μe) limit yields the weak bound

$$|(U_L^\ell)_{31} / (U_L^\ell)_{32}| < 3.7$$

☑ $BR(B^+ \to K^+ \mu \tau)$ *would be even more promising, as it scales with* $|(U_L^\ell)_{33} / (U_L^\ell)_{32}|^2$

LFV model signatures

As mentioned: if R_K is signaling BSM LFNU, then expect BSM LFV as well

☑ $$\frac{BR(B^+ \to K^+ \mu e)}{BR(B^+ \to K^+ \mu \mu)} = \boxed{\frac{|\delta C_{10}|^2}{|C_{10}^{\rm SM} + \delta C_{10}|^2}} \cdot \frac{|(U_L^\ell)_{31}|^2}{|(U_L^\ell)_{32}|^2} \boxed{\cdot\ 2}$$

= 0.159^2 according to R_K

$\mu^+ e^-$ & $\mu^- e^+$ modes

$$BR(B^+ \to K^+ \mu e) < 2.2 \times 10^{-8} \cdot \frac{|(U_L^\ell)_{31}|^2}{|(U_L^\ell)_{32}|^2}$$

The current BR(B+ → K+ μe) limit yields the weak bound

$$|(U_L^\ell)_{31} / (U_L^\ell)_{32}| < 3.7$$

☑ $BR(B^+ \to K^+ \mu \tau)$ *would be even more promising, as it scales with* $|(U_L^\ell)_{33} / (U_L^\ell)_{32}|^2$

☑ *An analogous argument holds for purely leptonic modes*

Parenthesis: More quantitative LFV predictions

- *More quantitative LFV predictions require knowledge of the* U_L^ℓ

Reminder:

$$\left(U_L^\ell\right)^\dagger Y_\ell \, U_R^\ell = \hat{Y}_\ell$$

Parenthesis: More quantitative LFV predictions

Reminder:

$$\left(U_L^\ell\right)^\dagger Y_\ell \, U_R^\ell = \hat{Y}_\ell$$

- *More quantitative LFV predictions require knowledge of the* U_L^ℓ
- *One approach:* *DG, Lane, PLB 2015*
  - *Appelquist-Bai-Piai ansatz:*
    the flavor-SU(3) rotations are not all independent. Choosing 3 to be the independent ones allows to predict one SM Yukawa in terms of the other two.

Parenthesis: More quantitative LFV predictions

Reminder:

$$\left(U_L^\ell\right)^\dagger Y_\ell \, U_R^\ell = \hat{Y}_\ell$$

- *More quantitative LFV predictions require knowledge of the* U_L^ℓ
- *One approach:* *DG, Lane, PLB 2015*
  - *Appelquist-Bai-Piai ansatz:*
    the flavor-SU(3) rotations are not all independent. Choosing 3 to be the independent ones allows to predict one SM Yukawa in terms of the other two.
  - *One can thereby determine* Y_ℓ *in terms of* Y_u *and* Y_d
  - *But we don't know* Y_u *and* Y_d *entirely, so we take an (independently motivated) model for them, reproducing quark masses and the CKM matrix [Martin-Lane, PRD 2005].*

Parenthesis: More quantitative LFV predictions

Reminder:

$$(U_L^\ell)^\dagger \, Y_\ell \, U_R^\ell = \hat{Y}_\ell$$

- *More quantitative LFV predictions require knowledge of the U_L^ℓ*
- *One approach:* *DG, Lane, PLB 2015*
  - *Appelquist-Bai-Piai ansatz:*
    the flavor-SU(3) rotations are not all independent. Choosing 3 to be the independent ones allows to predict one SM Yukawa in terms of the other two.
  - *One can thereby determine Y_ℓ in terms of Y_u and Y_d*
  - *But we don't know Y_u and Y_d entirely, so we take an (independently motivated) model for them, reproducing quark masses and the CKM matrix [Martin-Lane, PRD 2005].*
- *Another approach:* *Boucenna, Valle, Vicente, PLB 2015*
  - *One has $(U_L^\ell)^\dagger U_L^\nu$ = PMNS matrix*

Parenthesis: More quantitative LFV predictions

Reminder:

$$(U_L^\ell)^\dagger \, Y_\ell \, U_R^\ell = \hat{Y}_\ell$$

- *More quantitative LFV predictions require knowledge of the* U_L^ℓ
- *One approach:* *DG, Lane, PLB 2015*
  - *Appelquist-Bai-Piai ansatz:*
    the flavor-SU(3) rotations are not all independent. Choosing 3 to be the independent ones allows to predict one SM Yukawa in terms of the other two.
  - *One can thereby determine* Y_ℓ *in terms of* Y_u *and* Y_d
  - *But we don't know* Y_u *and* Y_d *entirely, so we take an (independently motivated) model for them, reproducing quark masses and the CKM matrix [Martin-Lane, PRD 2005].*
- *Another approach:* *Boucenna, Valle, Vicente, PLB 2015*
  - *One has* $(U_L^\ell)^\dagger \, U_L^\nu =$ *PMNS matrix*
  - *Taking* $U_L^\nu = 1$, U_L^ℓ *can be univocally predicted*

More on LFV model signatures

DG, Melikhov, Reboud, 2016

- *Bottom line: we can reasonably expect one of the $B \to K \ell \ell'$ decays in the 10^{-8} ballpark and one of the $B \to \ell \ell'$ decays in the 10^{-10} one, namely ~ 5% of $BR(B_s \to \mu\mu)$*

More on LFV model signatures

DG, Melikhov, Reboud, 2016

- *Bottom line: we can reasonably expect one of the $B \to K \ell \ell'$ decays in the 10^{-8} ballpark and one of the $B \to \ell \ell'$ decays in the 10^{-10} one, namely ~ 5% of $BR(B_s \to \mu\mu)$*

- *The most suppressed of the above modes is most likely $B_s \to \mu e$.*
  (The lepton combination is the farthest from the 3rd generation, and it's chirally suppressed.)

More on LFV model signatures

DG, Melikhov, Reboud, 2016

- *Bottom line: we can reasonably expect one of the $B \to K\ell\ell'$ decays in the 10^{-8} ballpark and one of the $B \to \ell\ell'$ decays in the 10^{-10} one, namely ~ 5% of $BR(B_s \to \mu\mu)$*
- *The most suppressed of the above modes is most likely $B_s \to \mu\, e$.* *(The lepton combination is the farthest from the 3rd generation, and it's chirally suppressed.)*
- *What about $B_s \to \mu\, e\, \gamma$?*
  - *γ = "hard" photon*

    (hard = outside of the di-lepton Invariant-mass signal window)

More on LFV model signatures

DG, Melikhov, Reboud, 2016

- *Bottom line: we can reasonably expect one of the $B \to K \ell \ell'$ decays in the 10^{-8} ballpark and one of the $B \to \ell \ell'$ decays in the 10^{-10} one, namely ~ 5% of $BR(B_s \to \mu\mu)$*

- *The most suppressed of the above modes is most likely $B_s \to \mu\, e$.*
  (The lepton combination is the farthest from the 3rd generation, and it's chirally suppressed.)

- *What about $B_s \to \mu\, e\, \gamma$?*
  - *γ = "hard" photon*

    (hard = outside of the di-lepton Invariant-mass signal window)

☞ *Chiral-suppression factor, of $O(m_\mu / m_{Bs})^2$ replaced by α_{em} / π suppression*

More on LFV model signatures

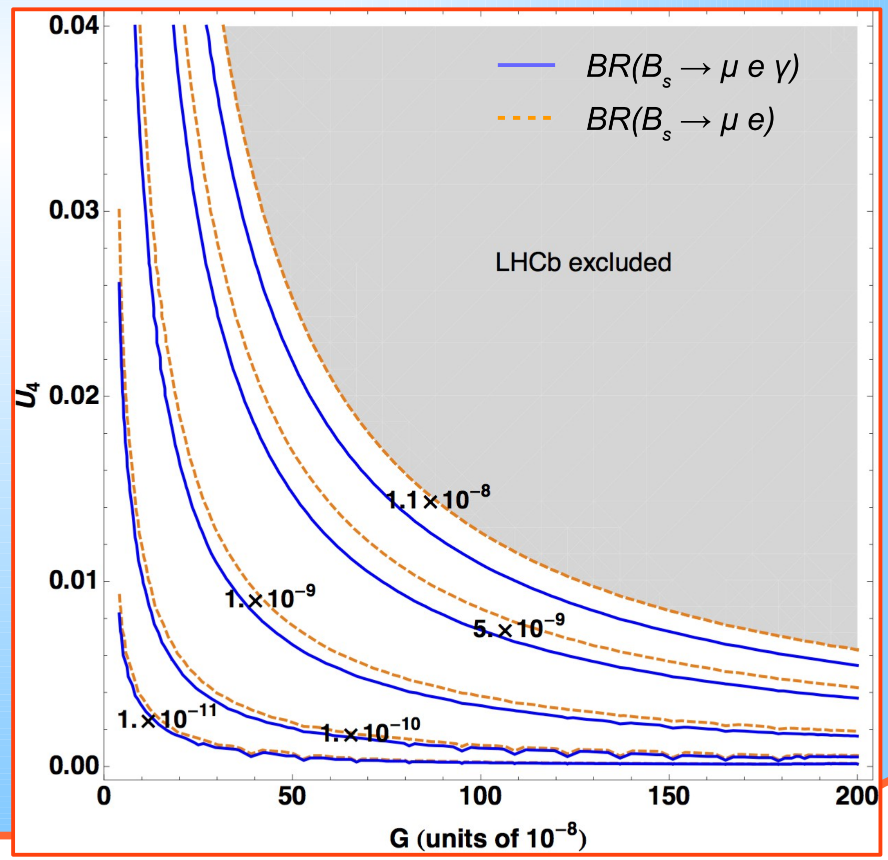
DG, Melikhov, Reboud, 2016

- *Bottom line: we can reasonably expect one of the $B \to K \ell \ell'$ decays in the 10^{-8} ballpark and one of the $B \to \ell \ell'$ decays in the 10^{-10} one, namely ~ 5% of $BR(B_s \to \mu\mu)$*
- *The most suppressed of the above modes is most likely $B_s \to \mu\, e$.*
  (The lepton combination is the farthest from the 3rd generation, and it's chirally suppressed.)
- *What about $B_s \to \mu\, e\, \gamma$?*
  - *γ = "hard" photon*
    (hard = outside of the di-lepton Invariant-mass signal window)

Chiral-suppression factor, of $O(m_\mu / m_{Bs})^2$ replaced by α_{em} / π suppression

Enhancement by ~ 30%

Inclusion of the radiative mode more-than-doubles statistics of the non-radiative



LFV in K decays

- *The interaction advocated in Glashow et al.*

$$H_{\mathrm{NP}} = G\, \bar{b}'_L \gamma^{\lambda} b'_L\, \bar{\tau}'_L \gamma_{\lambda} \tau'_L$$

can also manifest itself in $K \to (\pi)\, \ell\, \ell'$, for example

- $K_L^0 \to e^{\pm}\mu^{\mp}$
- $K^+ \to \pi^+ e^{\pm}\mu^{\mp}$

LFV in K decays

- *The interaction advocated in Glashow et al.*

$$H_{\mathrm{NP}} = G\, \bar{b}'_L \gamma^\lambda b'_L\, \bar{\tau}'_L \gamma_\lambda \tau'_L$$

can also manifest itself in $K \to (\pi)\, \ell\, \ell'$, for example

  - $K_L^0 \to e^\pm \mu^\mp$
  - $K^+ \to \pi^+ e^\pm \mu^\mp$

- *Exp limits*

$$\frac{\Gamma\left(K_L^0 \to e^\pm \mu^\mp\right)}{\Gamma\left(K^+ \to \mu^+ \nu_\mu\right)} < 1.7 \times 10^{-12}$$

BNL E871 Collab., PRL 1998

$$\frac{\Gamma\left(K^+ \to \pi^+ \mu^+ e^-\right)}{\Gamma\left(K^+ \to \pi^0 \mu^+ \nu_\mu\right)} < 3.9 \times 10^{-10}$$

BNL E865 Collab., PRD 2005

LFV in K decays

- *Defining the basic quantity*

$$\beta^{(K)} = \frac{G (U_L^d)^*_{32} (U_L^d)_{31} (U_L^\ell)^*_{31} (U_L^\ell)_{32}}{\frac{4 G_F}{\sqrt{2}} V^*_{us}} \quad \Rightarrow \quad \left|\beta^{(K)}\right|^2 = 2.15 \times 10^{-14}$$

(*within "model A" of DG, Lane, PLB 2015*)

LFV in K decays

- *Defining the basic quantity*

$$\beta^{(K)} = \frac{G\,(U_L^d)^*_{32}(U_L^d)_{31}(U_L^\ell)^*_{31}(U_L^\ell)_{32}}{\frac{4\,G_F}{\sqrt{2}}V^*_{us}}$$

$$\Rightarrow \quad \left|\beta^{(K)}\right|^2 = 2.15\times 10^{-14}$$

within "model A" of DG, Lane, PLB 2015

I obtain

$$\frac{\Gamma\left(K_L^0 \to e^\pm \mu^\mp\right)}{\Gamma\left(K^+ \to \mu^+ \nu_\mu\right)} = \left|\beta^{(K)}\right|^2$$

LFV in K decays

- *Defining the basic quantity*

$$\beta^{(K)} = \frac{G (U_L^d)^*_{32} (U_L^d)_{31} (U_L^\ell)^*_{31} (U_L^\ell)_{32}}{\frac{4 G_F}{\sqrt{2}} V^*_{us}}$$

$$|\beta^{(K)}|^2 = 2.15 \times 10^{-14}$$

within "model A" of DG, Lane, PLB 2015

I obtain

$$\frac{\Gamma(K_L^0 \to e^\pm \mu^\mp)}{\Gamma(K^+ \to \mu^+ \nu_\mu)} = |\beta^{(K)}|^2$$

$$\mathrm{BR}(K_L^0 \to e^\pm \mu^\mp) \approx 6 \times 10^{-14}$$

with

$$\mathrm{BR}(K^+ \to \mu^+ \nu_\mu) \approx 64\,\%$$

$$\Gamma(K^+)/\Gamma(K_L^0) \approx 4.2$$

LFV in K decays

- *Defining the basic quantity*

$$\beta^{(K)} = \frac{G (U_L^d)^*_{32} (U_L^d)_{31} (U_L^\ell)^*_{31} (U_L^\ell)_{32}}{\frac{4 G_F}{\sqrt{2}} V^*_{us}} \quad \Rightarrow \quad |\beta^{(K)}|^2 = 2.15 \times 10^{-14}$$

(*within "model A" of DG, Lane, PLB 2015*)

I obtain

$$\frac{\Gamma(K_L^0 \to e^\pm \mu^\mp)}{\Gamma(K^+ \to \mu^+ \nu_\mu)} = |\beta^{(K)}|^2$$

$$\Downarrow$$

$$\mathrm{BR}(K_L^0 \to e^\pm \mu^\mp) \approx 6 \times 10^{-14}$$

with

$\mathrm{BR}(K^+ \to \mu^+ \nu_\mu) \approx 64\,\%$

$\Gamma(K^+)/\Gamma(K_L^0) \approx 4.2$

$$\frac{\Gamma(K^+ \to \pi^+ \mu^\pm e^\mp)}{\Gamma(K^+ \to \pi^0 \mu^+ \nu_\mu)} = 4\,|\beta^{(K)}|^2$$

$$\Downarrow$$

$$\mathrm{BR}(K^+ \to \pi^+ \mu^\pm e^\mp) \approx 3 \times 10^{-15}$$

with

$\mathrm{BR}(K^+ \to \pi^0 \mu^+ \nu_\mu) \approx 3\,\%$

More signatures

For a recent discussion:
Alonso, Grinstein, Martin-Camalich,
PRL 14

- *Being defined above the EWSB scale, our assumed operator* $G\,\bar{b}'_L \gamma^\lambda b'_L\, \bar{\tau}'_L \gamma_\lambda \tau'_L$ *must actually be made invariant under* $SU(3)_c \times SU(2)_L \times U(1)_Y$

More signatures

For a recent discussion:
Alonso, Grinstein, Martin-Camalich, PRL 14

- *Being defined above the EWSB scale, our assumed operator* $G\, \bar{b}'_L \gamma^\lambda b'_L\, \bar{\tau}'_L \gamma_\lambda \tau'_L$ *must actually be made invariant under* $SU(3)_c \times SU(2)_L \times U(1)_Y$

See:
Bhattacharya, Datta, London, Shivashankara, PLB 15

$$\bar{b}'_L \gamma^\lambda b'_L\, \bar{\tau}'_L \gamma_\lambda \tau'_L \quad \xrightarrow[\text{inv.}]{SU(2)_L} \quad \begin{cases} \bar{Q}'_L \gamma^\lambda Q'_L\, \bar{L}'_L \gamma_\lambda L'_L & \text{[neutral-current int's only]} \\ \bar{Q}'^i_L \gamma^\lambda Q'^j_L\, \bar{L}'^j_L \gamma_\lambda L'^i_L & \text{[also charged-current int's]} \end{cases}$$

More signatures

For a recent discussion:
Alonso, Grinstein, Martin-Camalich, PRL 14

- *Being defined above the EWSB scale, our assumed operator* $G\, \bar{b}'_L \gamma^\lambda b'_L\, \bar{\tau}'_L \gamma_\lambda \tau'_L$ *must actually be made invariant under* $SU(3)_c \times SU(2)_L \times U(1)_Y$

See:
Bhattacharya, Datta, London, Shivashankara, PLB 15

$$\bar{b}'_L \gamma^\lambda b'_L\, \bar{\tau}'_L \gamma_\lambda \tau'_L \quad \xrightarrow[\text{inv.}]{SU(2)_L} \quad \begin{cases} \bar{Q}'_L \gamma^\lambda Q'_L\, \bar{L}'_L \gamma_\lambda L'_L & \text{[neutral-current int's only]} \\ \bar{Q}'^i_L \gamma^\lambda Q'^j_L\, \bar{L}'^j_L \gamma_\lambda L'^i_L & \text{[also charged-current int's]} \end{cases}$$

- *Thus, the generated structures are all of:*

$$t' t' \nu'_\tau \nu'_\tau\,, \qquad t' t' \tau' \tau'\,, \qquad b' b' \nu'_\tau \nu'_\tau\,, \qquad b' b' \tau' \tau'\,, \qquad t' b' \tau' \nu'_\tau$$

More signatures

For a recent discussion:
Alonso, Grinstein, Martin-Camalich, PRL 14

- *Being defined above the EWSB scale, our assumed operator* $G\, \bar{b}'_L \gamma^\lambda b'_L\, \bar{\tau}'_L \gamma_\lambda \tau'_L$ *must actually be made invariant under* $SU(3)_c \times SU(2)_L \times U(1)_Y$

See:
Bhattacharya, Datta, London, Shivashankara, PLB 15

$$\bar{b}'_L \gamma^\lambda b'_L\, \bar{\tau}'_L \gamma_\lambda \tau'_L \xrightarrow[\text{inv.}]{SU(2)_L} \begin{cases} \bar{Q}'_L \gamma^\lambda Q'_L\, \bar{L}'_L \gamma_\lambda L'_L & \text{[neutral-current int's only]} \\ \bar{Q}'^i_L \gamma^\lambda Q'^j_L\, \bar{L}'^j_L \gamma_\lambda L'^i_L & \text{[also charged-current int's]} \end{cases}$$

- *Thus, the generated structures are all of:*

$$t' t' \nu'_\tau \nu'_\tau\,, \quad t' t' \tau' \tau'\,, \quad b' b' \nu'_\tau \nu'_\tau\,, \quad b' b' \tau' \tau'\,, \quad \boxed{t' b' \tau' \nu'_\tau}$$

More signatures

For a recent discussion:
Alonso, Grinstein, Martin-Camalich, PRL 14

- *Being defined above the EWSB scale, our assumed operator* $G\,\bar{b}'_L \gamma^\lambda b'_L\, \bar{\tau}'_L \gamma_\lambda \tau'_L$ *must actually be made invariant under* $SU(3)_c \times SU(2)_L \times U(1)_Y$

See:
Bhattacharya, Datta, London, Shivashankara, PLB 15

$$\bar{b}'_L \gamma^\lambda b'_L\, \bar{\tau}'_L \gamma_\lambda \tau'_L \;\xrightarrow[\text{inv.}]{SU(2)_L}\; \begin{cases} \bar{Q}'_L \gamma^\lambda Q'_L\, \bar{L}'_L \gamma_\lambda L'_L & \text{[neutral-current int's only]} \\ \bar{Q}'^i_L \gamma^\lambda Q'^j_L\, \bar{L}'^j_L \gamma_\lambda L'^i_L & \text{[also charged-current int's]} \end{cases}$$

- *Thus, the generated structures are all of:*

$$t't'\nu'_\tau\nu'_\tau\,, \quad t't'\tau'\tau'\,, \quad b'b'\nu'_\tau\nu'_\tau\,, \quad b'b'\tau'\tau'\,, \quad \boxed{t'b'\tau'\nu'_\tau}$$

- *After rotation to the mass basis (unprimed), the last structure contributes to* $\Gamma(b \to c\,\tau\,\bar{\nu}_i)$

Can explain BaBar + Belle + LHCb deviations on $R(D^{(*)}) = \dfrac{BR(\bar{B} \to D^{(*)+} \tau^- \bar{\nu}_\tau)}{BR(\bar{B} \to D^{(*)+} \ell^- \bar{\nu}_\ell)}$

But this coin has a flip side

Feruglio, Paradisi, Pattori, 2016

- *Properly taking into account RGE running from the NP scale to the scale(s) of the low-energy processes, one finds non-trivial constraints from:*

  - $B \to K \nu\nu$

    See also:
    Calibbi, Crivellin, Ota, PRL 2015

  - *Modifications to LEP-measured* $Z \to \ell\ell$ *couplings*

  - *LFU-breaking effects in* $\tau \to \ell \nu \nu$ *(tested at per mil accuracy)*

But this coin has a flip side

Feruglio, Paradisi, Pattori, 2016

- *Properly taking into account RGE running from the NP scale to the scale(s) of the low-energy processes, one finds non-trivial constraints from:*

  - $B \to K \nu\nu$

    See also:
    Calibbi, Crivellin, Ota, PRL 2015

  - *Modifications to LEP-measured* $Z \to \ell\ell$ *couplings*

  - *LFU-breaking effects in* $\tau \to \ell \nu \nu$ *(tested at per mil accuracy)*

The latter are the most dangerous.
They "strongly disfavour an explanation of the R(D(*)) anomaly model-independently"

But this coin has a flip side

Feruglio, Paradisi, Pattori, 2016

- *Properly taking into account RGE running from the NP scale to the scale(s) of the low-energy processes, one finds non-trivial constraints from:*

  - $B \to K \nu\nu$

    See also: Calibbi, Crivellin, Ota, PRL 2015

  - *Modifications to LEP-measured* $Z \to \ell\ell$ *couplings*

  - *LFU-breaking effects in* $\tau \to \ell \nu \nu$ *(tested at per mil accuracy)*

    The latter are the most dangerous.
    They "strongly disfavour an explanation of the R(D(*)) anomaly model-independently"

- *Also LFV decays of leptons are generated, and they provide sensitive probes.*

  E.g.:

$$\mathrm{BR}(\tau \to \mu\mu) \;\&\; \mathrm{BR}(\tau \to \mu\rho) \sim 5\times 10^{-8}$$

Conclusions

- *In flavor physics there are by now several persistent discrepancies with respect to the SM.*

  Their most convincing aspects are the following:

  - ***Experiments:*** *Results are consistent between LHCb and B factories.*

Conclusions

- *In flavor physics there are by now several persistent discrepancies with respect to the SM.*

  Their most convincing aspects are the following:

  - ***Experiments:*** *Results are consistent between LHCb and B factories.*

  - ***Data:*** *Deviations concern two independent sets of data:* $b \to s$ *and* $b \to c$ *decays.*

    (Yet beware: LFU breaking effects in $\tau \to l \bar{\nu}\nu$ *disfavor model-independently the R(D(*)) anomaly [Feruglio, Paradisi, Pattori, '16])*

Conclusions

- *In flavor physics there are by now several persistent discrepancies with respect to the SM.*

  Their most convincing aspects are the following:

  - ***Experiments:*** *Results are consistent between LHCb and B factories.*

  - ***Data:*** *Deviations concern two independent sets of data:* $b \to s$ *and* $b \to c$ *decays.*

    (Yet beware: LFU breaking effects in $\tau \to l \bar{\nu} \nu$ *disfavor model-independently the R(D(*)) anomaly [Feruglio, Paradisi, Pattori, '16])*

  - ***Data vs. theory:*** *Discrepancies go in a consistent direction.*
    A BSM explanation is already possible within an EFT approach.

Conclusions

- *In flavor physics there are by now several persistent discrepancies with respect to the SM.*

  Their most convincing aspects are the following:

  - ***Experiments:*** *Results are consistent between LHCb and B factories.*

  - ***Data:*** *Deviations concern two independent sets of data: $b \to s$ and $b \to c$ decays.*

    (Yet beware: LFU breaking effects in $\tau \to l \bar{\nu} \nu$ disfavor model-independently the R(D(*)) anomaly [Feruglio, Paradisi, Pattori, '16])

  - ***Data vs. theory:*** *Discrepancies go in a consistent direction.*
    A BSM explanation is already possible within an EFT approach.

- *Early to draw conclusions. But Run II will provide a definite answer*

Conclusions

- *In flavor physics there are by now several persistent discrepancies with respect to the SM.*

  Their most convincing aspects are the following:

  - ***Experiments:*** *Results are consistent between LHCb and B factories.*

  - ***Data:*** *Deviations concern two independent sets of data: $b \to s$ and $b \to c$ decays.*

    (Yet beware: LFU breaking effects in $\tau \to l \bar{\nu}\nu$ disfavor model-independently the R(D(*)) anomaly [Feruglio, Paradisi, Pattori, '16])

  - ***Data vs. theory:*** *Discrepancies go in a consistent direction.*
    A BSM explanation is already possible within an EFT approach.

- *Early to draw conclusions. But Run II will provide a definite answer*

- *Timely to propose further tests. One promising direction is that of LFV.*
  Plenty of channels, many of which largely untested.