Lepton Universality (Violation, and its consequences)

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

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

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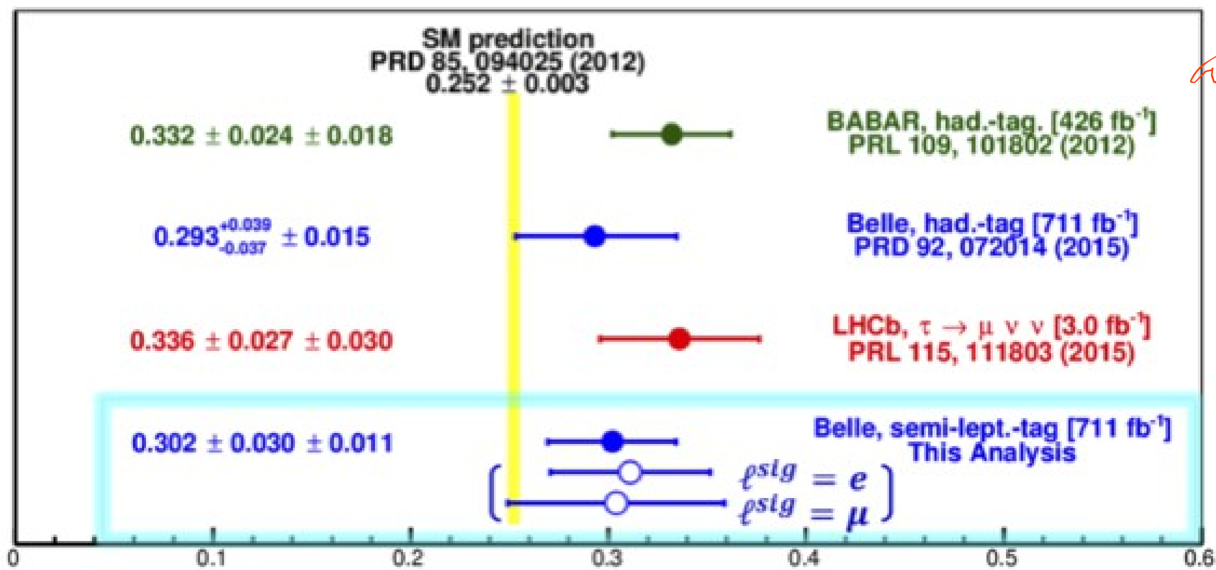

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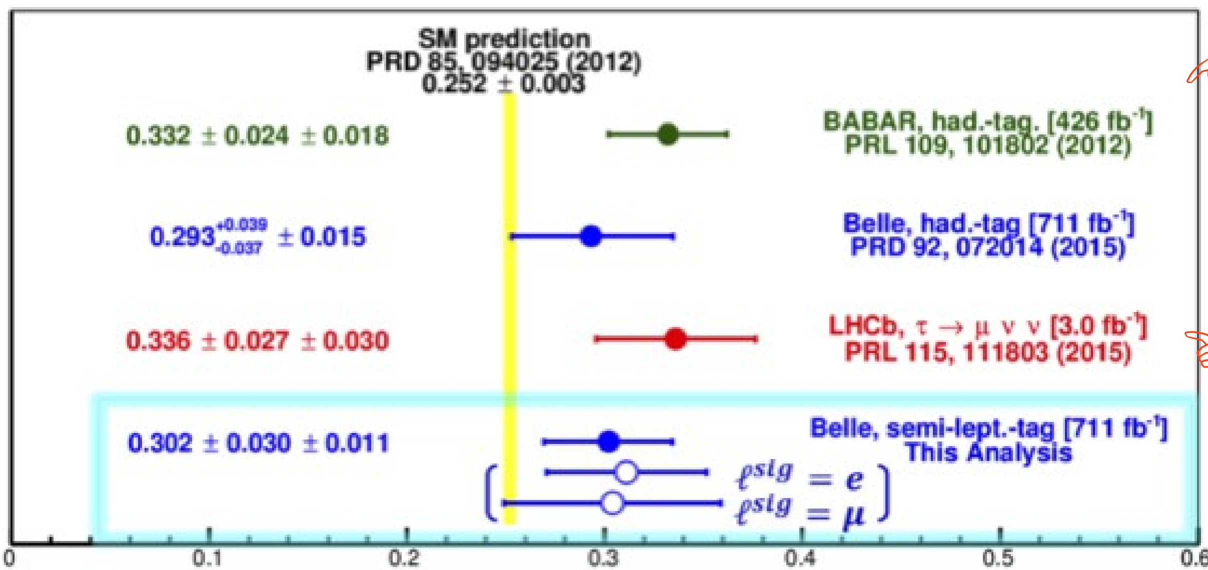

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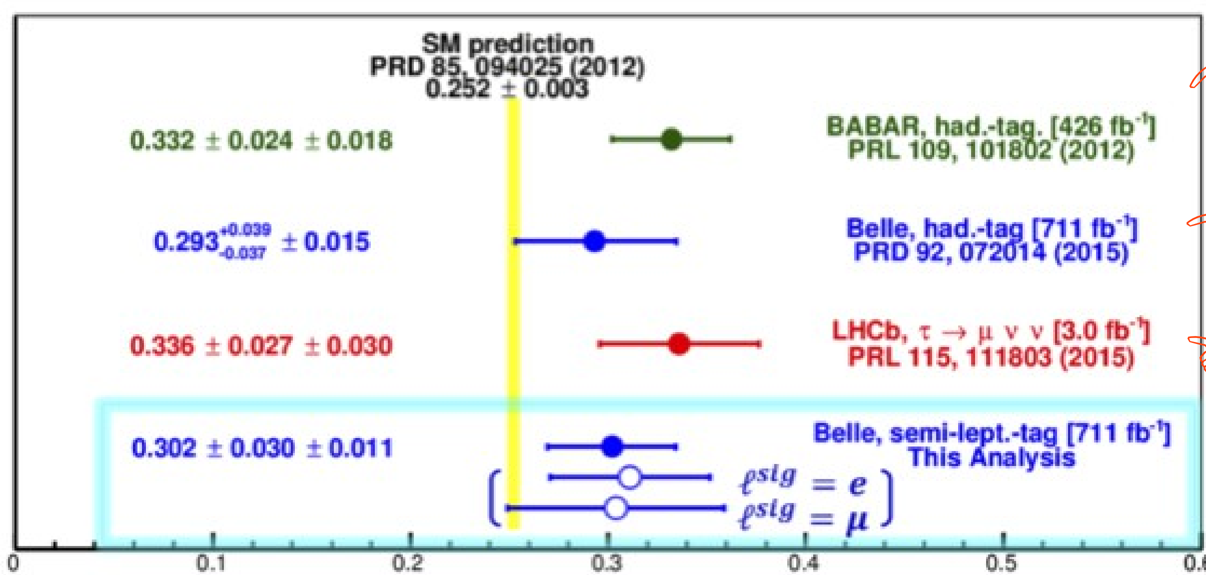

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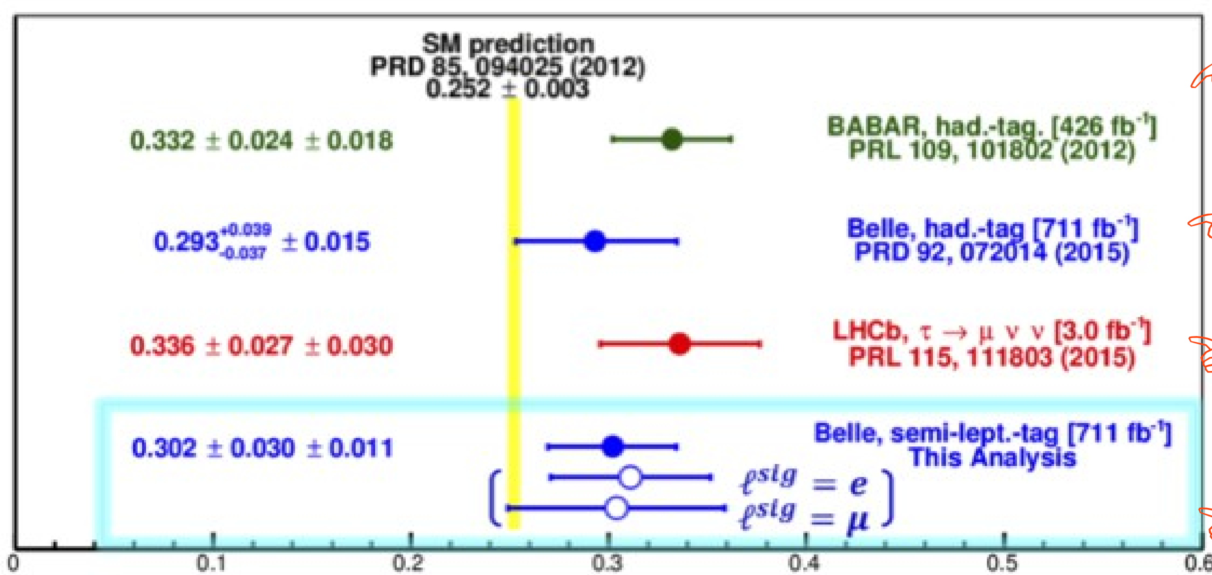

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- 2016: Belle also starts to see an R(D*) excess (semi-lep. tau's)

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- *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:

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

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So, BSM LFNU $\Rightarrow$ BSM LFV (i.e. not suppressed by m_ν)

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- *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*
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- *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 $C_9^{\rm NP} \sim -30\% \times C_9^{\rm SM}$), or by new physics in the $SU(2)_L$ invariant direction $C_9^{\rm NP} = -C_{10}^{\rm NP}$, (with $C_9^{\rm NP} \sim -12\% \times C_9^{\rm SM}$). 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]

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Glashow, DG, Lane, PRL 2015

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

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

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implying (within our model) the correlations

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

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

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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 $BR(B_s \to \mu\mu)$*

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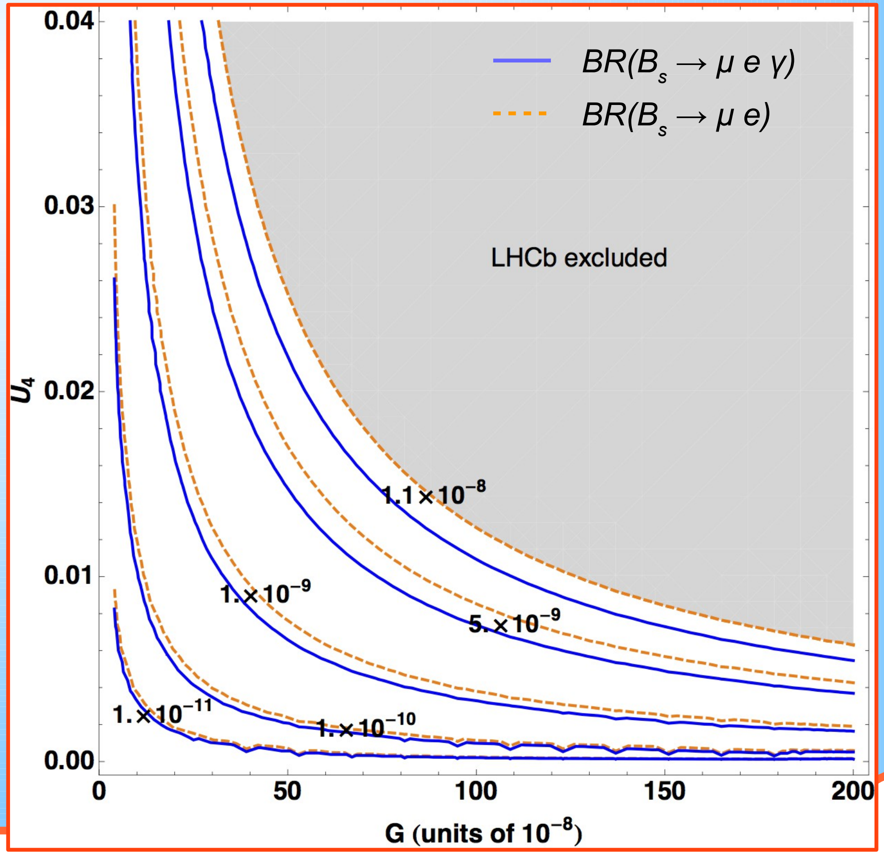
Enhancement by ~ 30%

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



LFV in K decays

- *The interaction advocated in Glashow et al.*

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

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

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- *Exp limits*

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

BNL E871 Collab., PRL 1998

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

BNL E865 Collab., PRD 2005

LFV in K decays

- *Defining the basic quantity*

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

⇒

$$\left|\beta^{(K)}\right|^2 = 2.15\times10^{-14}$$

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

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with

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

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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* $SU(3)_c \times SU(2)_L \times U(1)_Y$

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See:
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- *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

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

  E.g.:

$$\mathrm{BR}(\tau \to 3\mu) \ \& \ \mathrm{BR}(\tau \to \mu\rho) \sim 5 \times 10^{-8}$$

Some models explaining R_K and $R(D^*)$

Bauer-Neubert, PRL 2016

- *Introduce one single leptoquark scalar, transforming as (**3**, **1**, –1/3) under $SU(3)_c \times SU(2)_L \times U(1)_Y$*

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Picks up an up-type quark with a down-type lepton or viceversa

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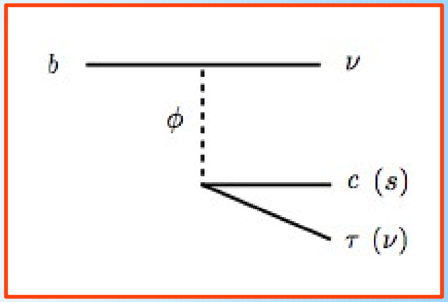
- *Introduce one single leptoquark scalar, transforming as (**3**, **1**, –1/3) under $SU(3)_c \times SU(2)_L \times U(1)_Y$*

Picks up an up-type quark with a down-type lepton or viceversa

- *One coupling does all the job:* $\bar{Q}^c_{Li}\, \lambda_{ij}\, i\tau_2\, L_{Lj}\, \phi$

  - *Two insertions (making a tree diag.) contribute to* $B \to D\, \tau\nu$



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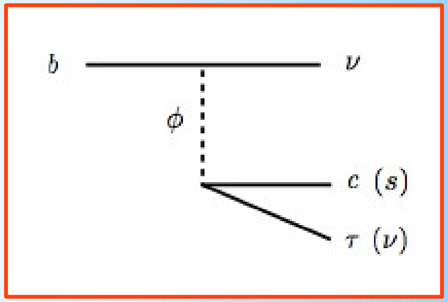

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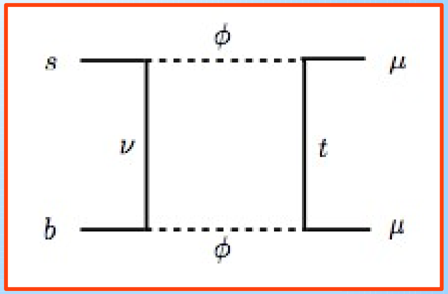

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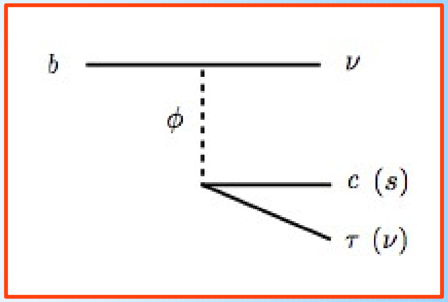

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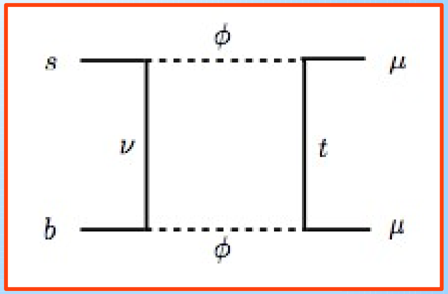

- *With M_ϕ ~ 1 TeV and O(1) generation-diagonal couplings, contributions are just the right size*

One model explaining all flavor anomalies and the diphoton resonance

Buttazzo, Greljo, Isidori, Marzocca 1604.03940

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⇨ *One of the pNGB is the 750-GeV state seen by Atlas & CMS*
It couples to 2 gluons and decays to 2γ via the anomaly

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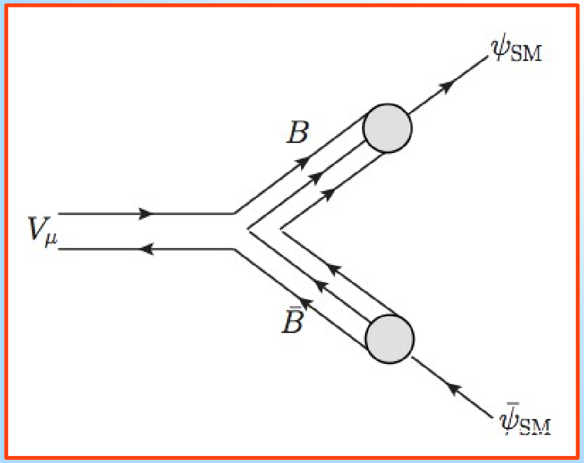

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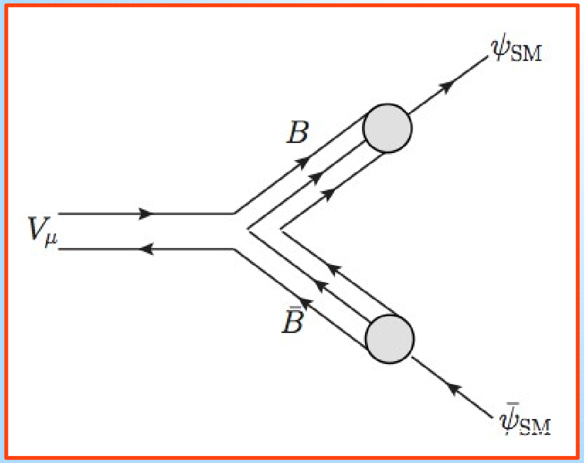

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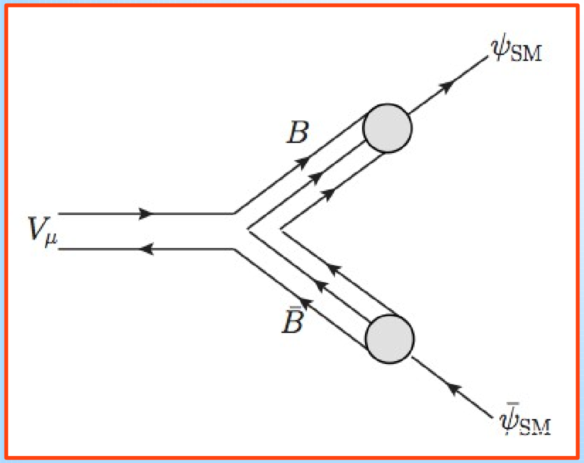

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- *Integrating out the vector mesons then yields automatically (among the others) the effective operator*

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

proposed in [*Glashow, DG, Lane, PRL 15*]

Conclusions

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