B-Physics Anomalies, Lepton Universality Violation and… Cosmology

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Outline

- *Review of the data for the not-necessarily B-physics enthusiast*
  Aim: Show why the picture looks coherent
- *Theory interpretation, and its challenges*
- *Possible signatures in the cosmos*
  (Challenging question. Literature accordingly very sparse)

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A whole range of $b \to s$ measurements with a final-state $\mu\mu$ display a consistent pattern:
Exp < SM

Flavour anomalies

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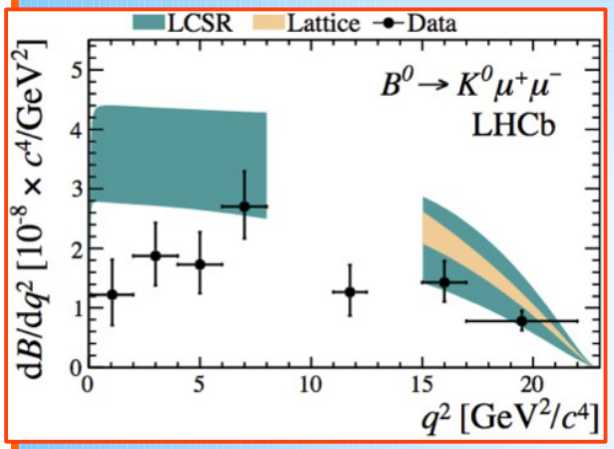
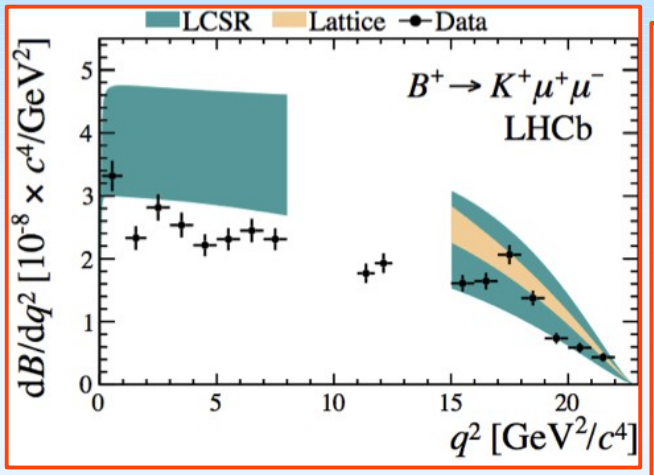
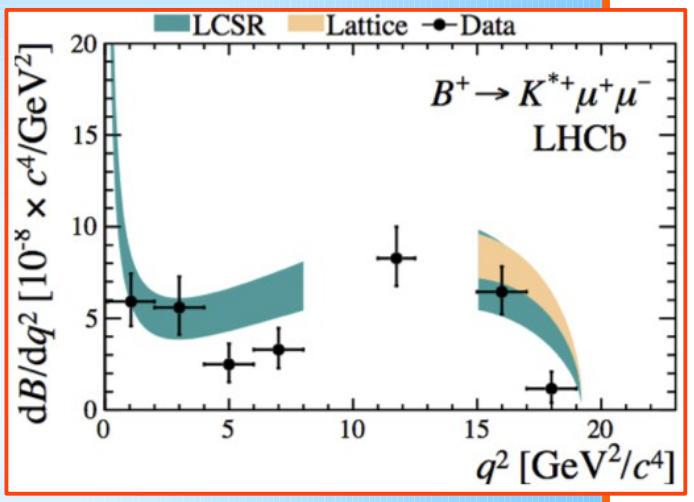
LHCb 2014







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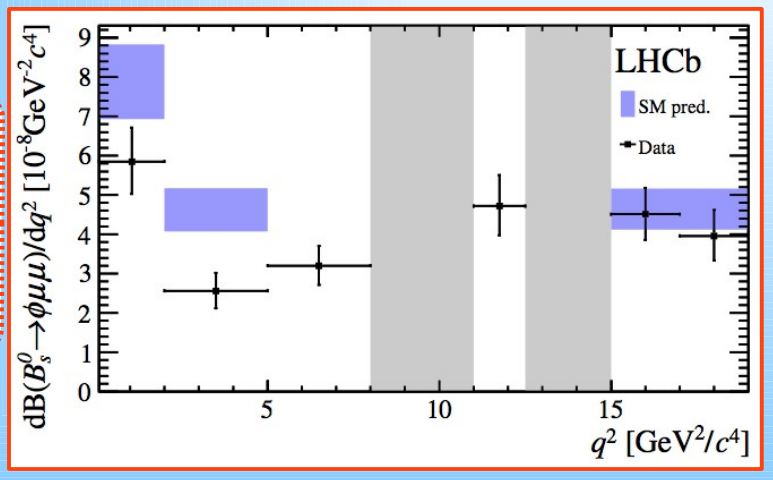

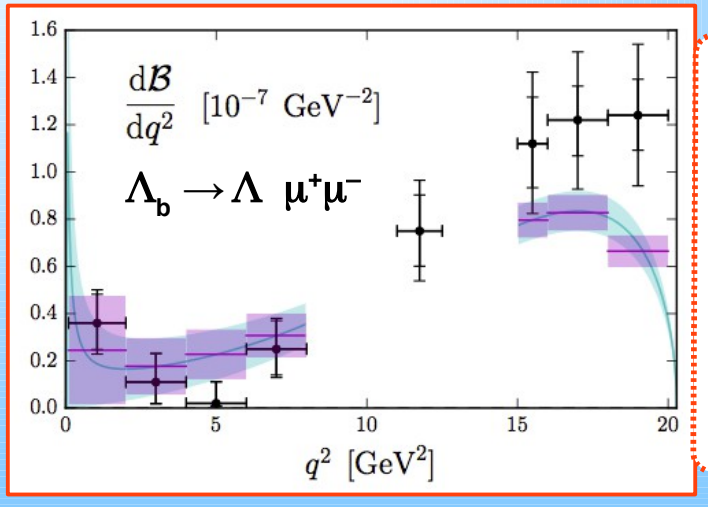

LHCb 2015
& Detmold+Meinel '16

b → s data: apples vs. oranges

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Meson decay widths depend upon the form factors for the transition, e.g. B → K f.f.'s

These f.f's are the bulk of the TH uncertainty

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- ***However, here are clean quantities:***
  ratios of widths to different final-state leptons

$$R_K\left(q^2_{\min}, q^2_{\max}\right) \equiv \left.\frac{\Gamma\left(B^+ \to K^+ \mu\mu\right)}{\Gamma\left(B^+ \to K^+ e e\right)}\right|_{[q^2_{\min}, q^2_{\max}]}$$

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1. $R_K\left(1\,\mathrm{GeV}^2, 6\,\mathrm{GeV}^2\right) = 0.745 \cdot \left(1 \pm 13\%\right)$

   (2.6σ effect)

2. $R_{K^{*0}}\left(1.1\,\mathrm{GeV}^2, 6.0\,\mathrm{GeV}^2\right) = 0.685^{+0.113}_{-0.069} \pm 0.047$

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$$R_{K^{*0}}\left(0.045\,\mathrm{GeV}^2, 1.1\,\mathrm{GeV}^2\right) = 0.660^{+0.110}_{-0.070} \pm 0.024$$

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- *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*

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❸ ***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)

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4. ***B → K* μμ angular analysis:*** *discrepancy in one combination of the angular expansion coefficients, known as P'_5*

b → c data

There are long-standing discrepancies in b → c transitions as well (and coming from 3 exp's)

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

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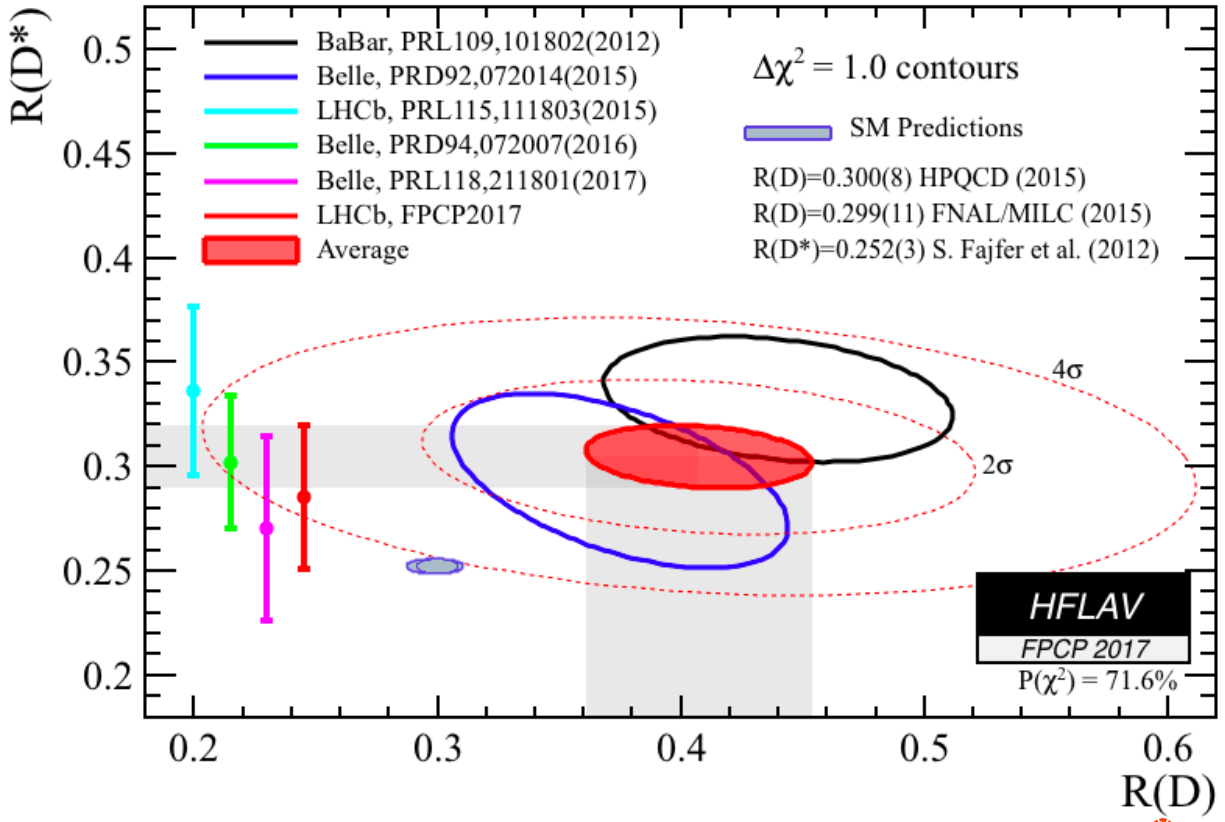

Simultaneous fit to R(D) & R(D*) about 4σ away from SM

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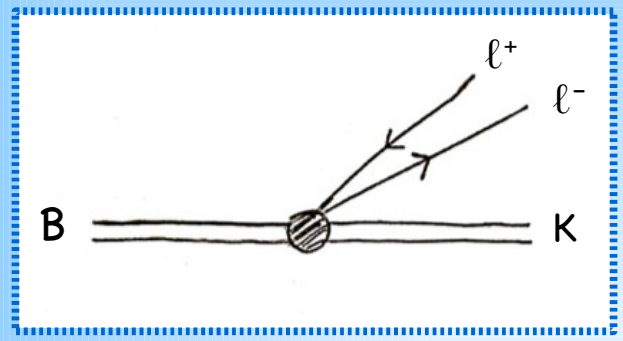
  - *Either dataset conveys the same message: LUV*
  - *Effective interactions for $b \to s$ and $b \to c$ decays are related by SU(2) symmetry.*

    That's what one expects of new interactions above the electroweak scale

b → s transitions:

why interesting

B → K(*) $\ell\ell$ decays: basic theory considerations



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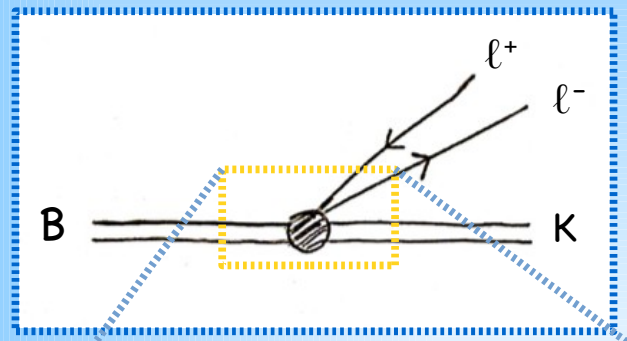

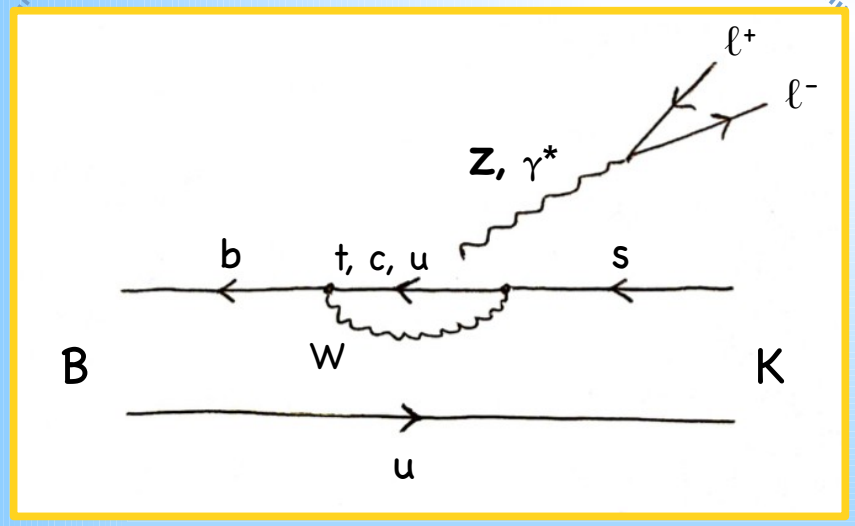

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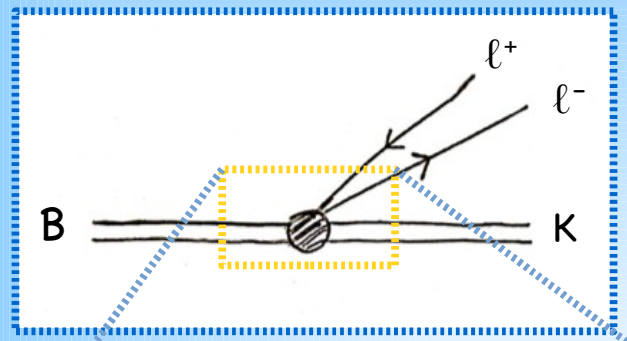

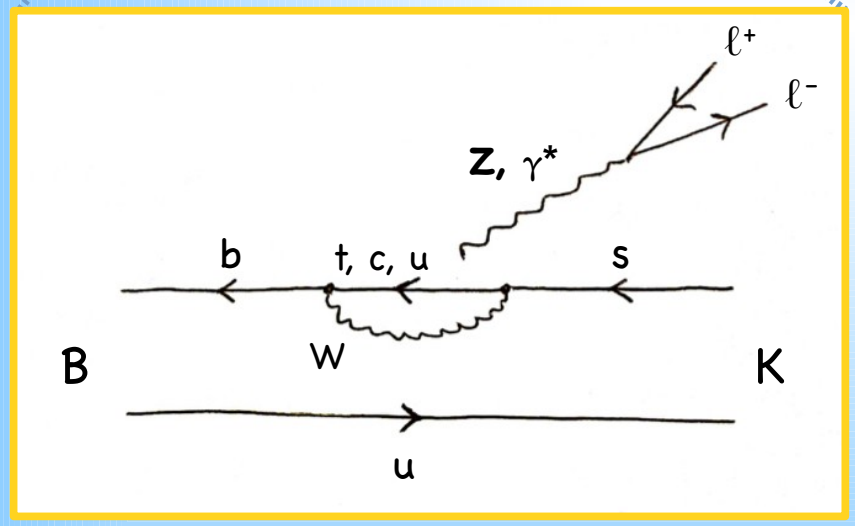

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  ⇨ Loop suppression

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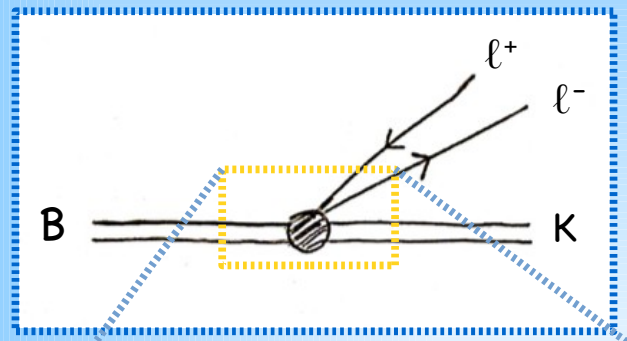

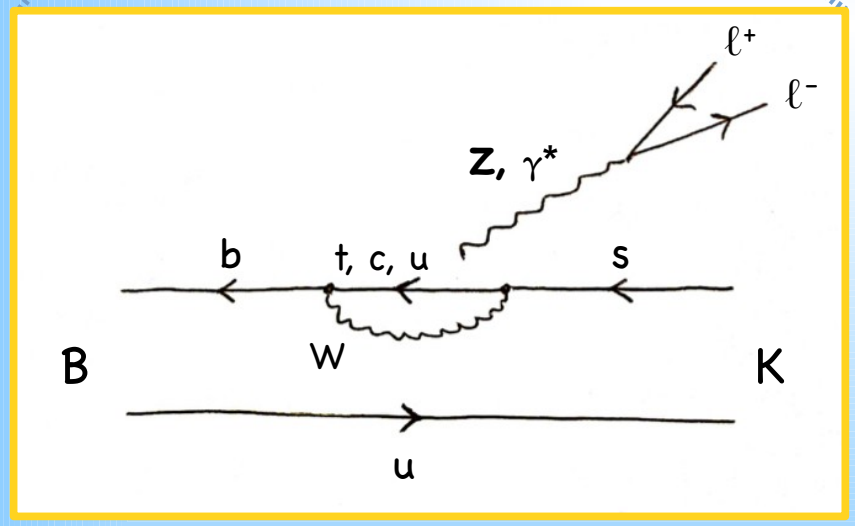

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- the contribution from each up-type quark goes as: $\left(V^{\dagger}\right)_{b\,q_u} \cdot V_{q_u\,s} \cdot f\left(m_{q_u}\right)$

  So, if the up-type quark masses were equal, the corresponding 3 diagrams would sum to 0

  ⇨ "GIM" suppression

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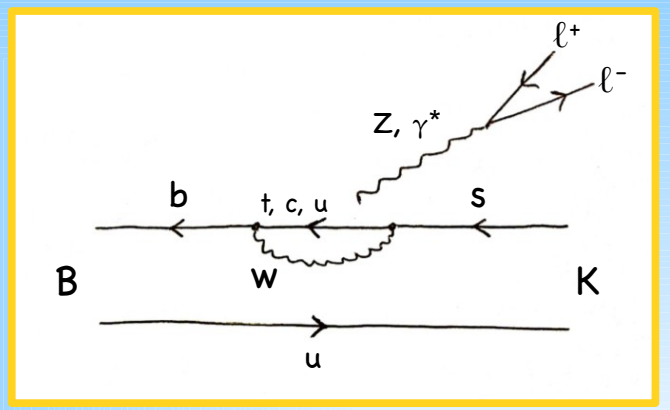

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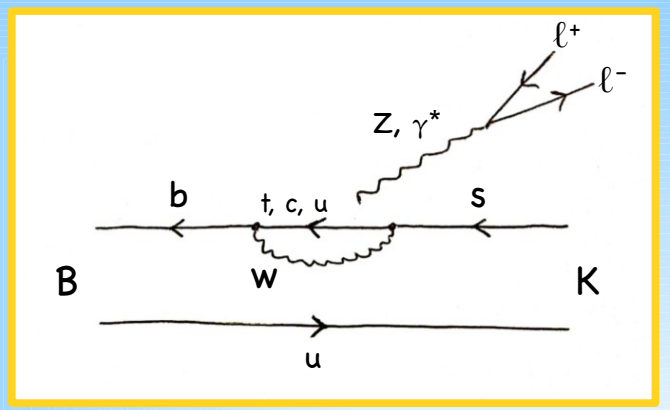

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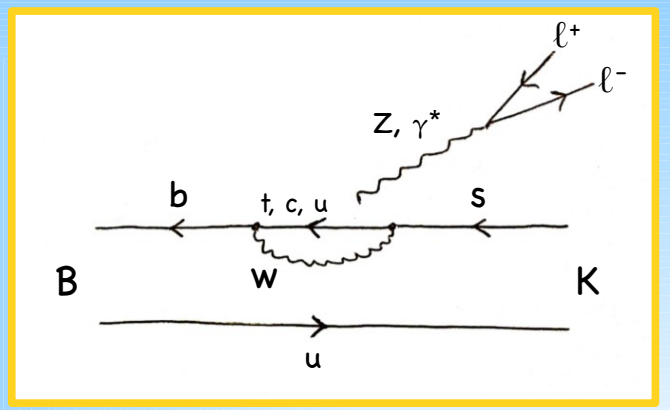

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Two consequences

☑ One can shrink the above diagram to a point, and describe the decay as an effective interaction of the kind

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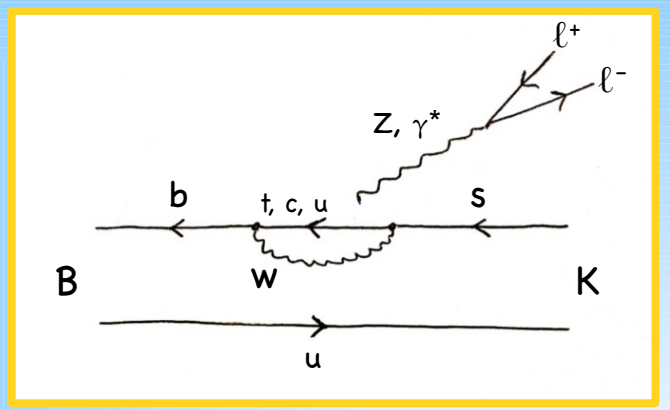

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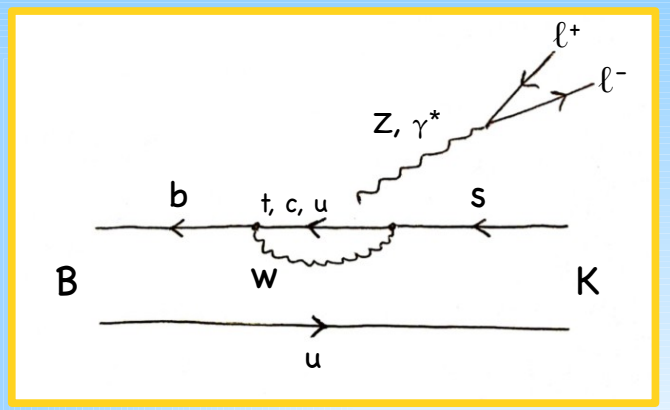

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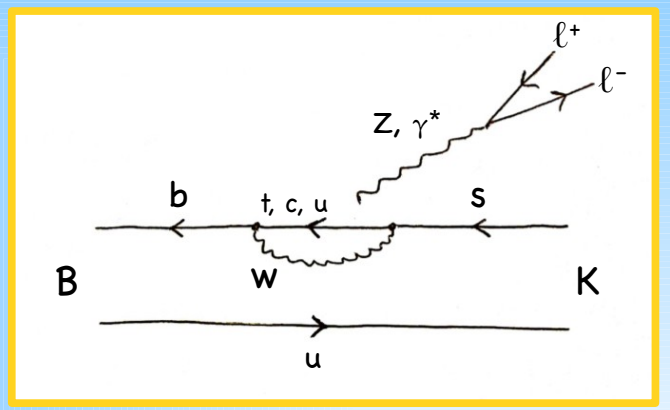

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- b → s decays then provide an indirect probe of any such physics

Flavour anomalies:

Effective-Theory picture

This is regarded as the “level-0” understanding.

In its absence:

- *either the new physics is very light (unlikely)*
- *or something is wrong*

b → s anomalies: EFT understanding

- *Consider the following Hamiltonian*

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

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  - *Effects larger in muons than electrons is suggestive of new physics hierarchically coupled to generations*

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  - *Effects larger in muons than electrons is suggestive of <u>new physics hierarchically coupled to generations</u>*

- *This pattern can be generated from a purely 3rd-generation interaction* [*Glashow, DG, Lane, 2015*]

From EFT

to UV models

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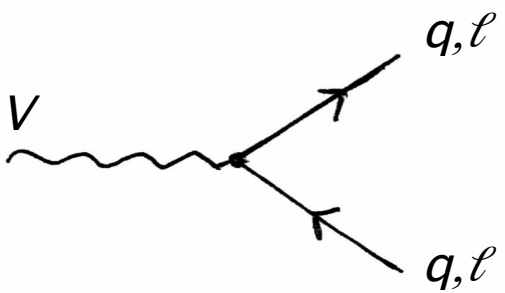

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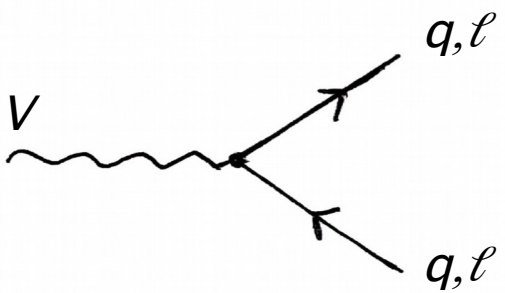

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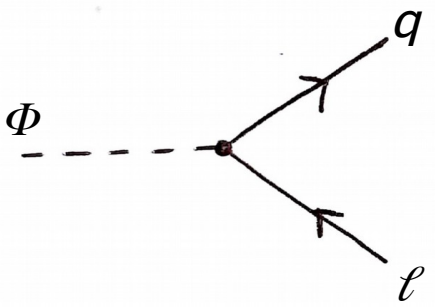

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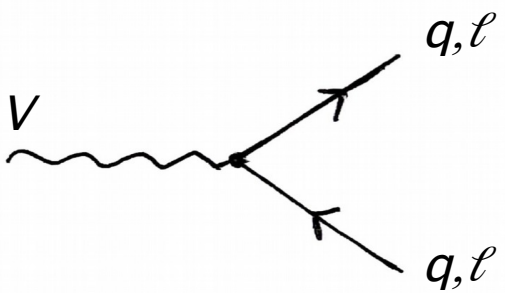

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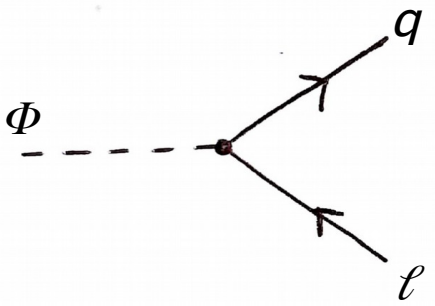

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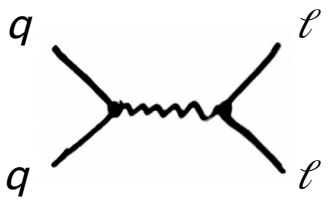

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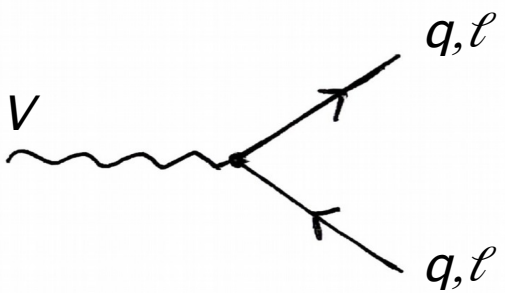

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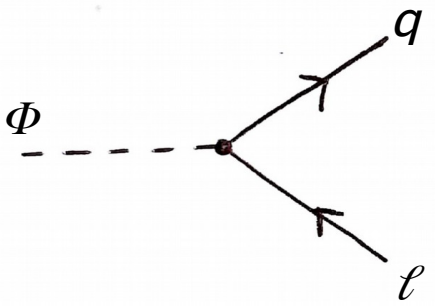

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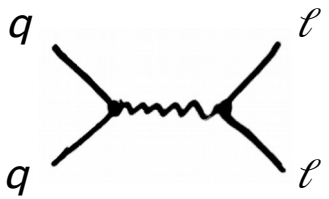

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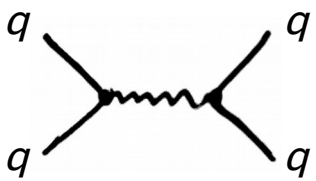

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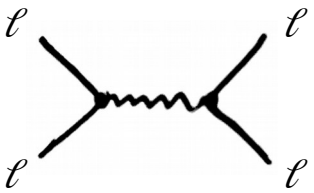

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Constraints from direct searches (e.g. $\to \tau\tau$) potentially strong

And yes they are!

See: [Greljo-Isidori-Marzocca]

[Faroughy-Greljo-Kamenik]

Footprints in the cosmos?

Flavour anomalies and Cosmology: connections?

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Ambitious but not unreasonable:

- *b → s anomalies require TeV-ballpark new particles*
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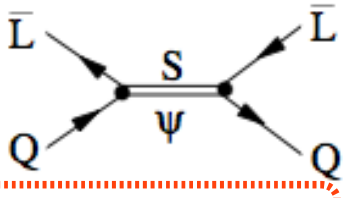


explains b → s anomalies

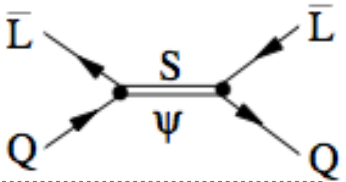
An example with Lepto-Quarks:

"B anomalies and Composite DM", Cline, 2017

- *Suppose LQs are bound states of constituents charged under a new SU(N_{HC})*
  - *The model naturally predicts composite DM*
- ***How the model works:*** *Introduce 3 new particles, charged under SU(N_{HC}). Among them*
  - *A quark partner Ψ ("vectorlike", prevents gauge anomalies)*
  - *A neutrino partner S (right-handed)*

has the quantum numbers of a lepto-quark

- *Because SU(N_{HC}) is confined, one gets meson-like bound states : $\Psi\Psi$, SS and ΨS*
- And S is SM-neutral, so $S^{N_{HC}}$ can be a (composite) DM candidate
- One generates the following interactions



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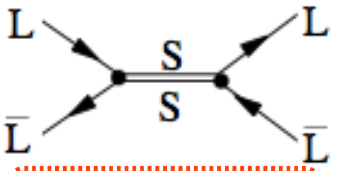

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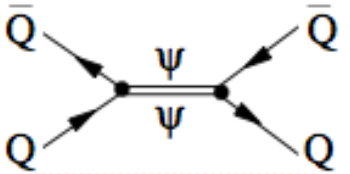

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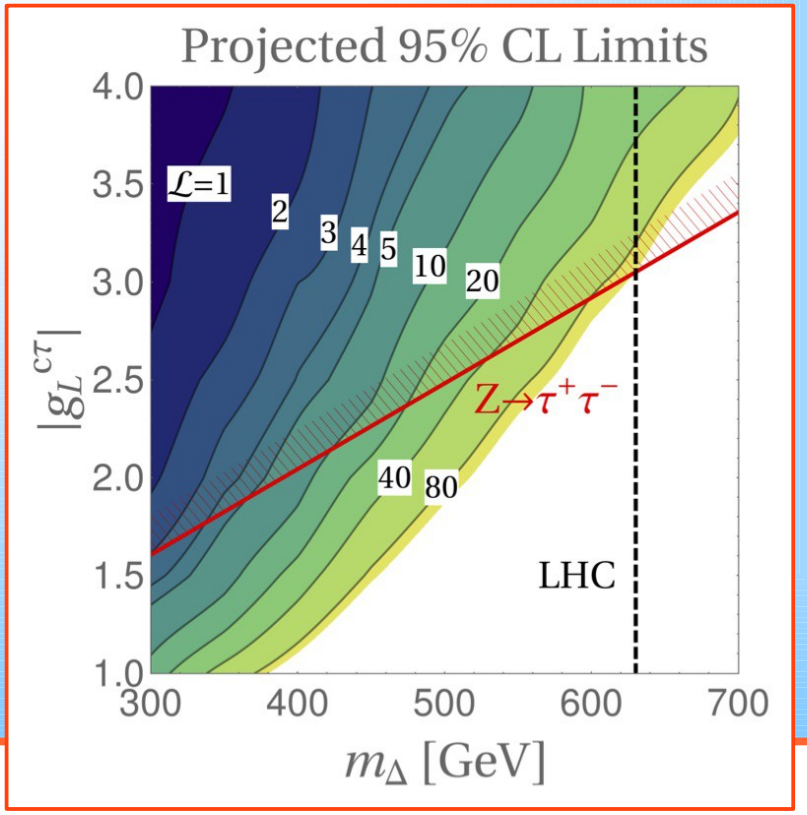

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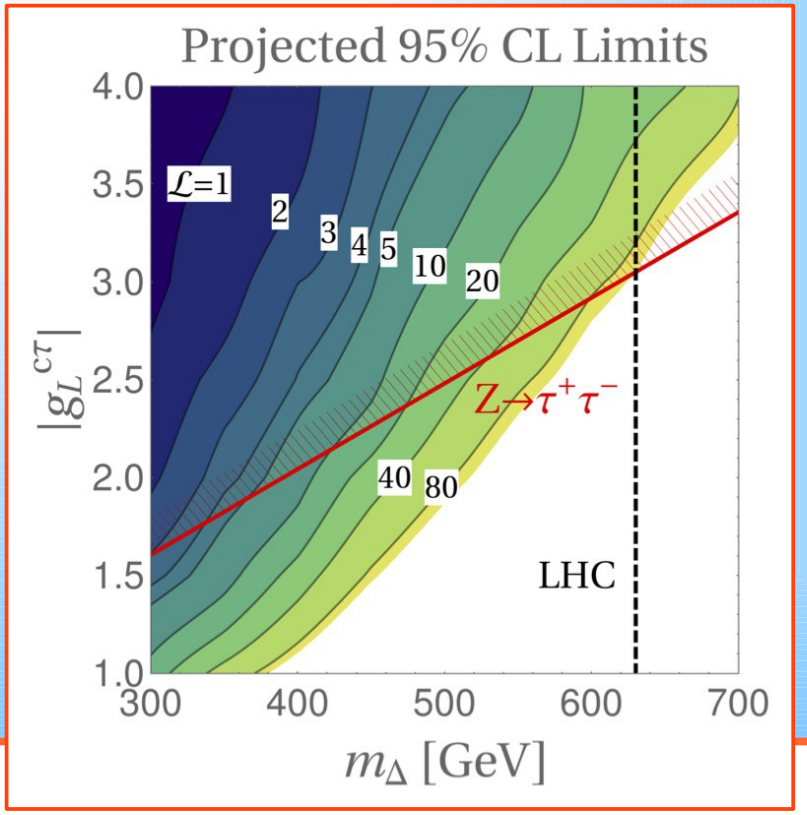
- ***Interesting nonetheless:***

  Could such indirect neutrino strong force be probed elsewhere?



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- *Astro/cosmo quantities may be precious to discern among models being proposed.*
  E.g. via:

  - *Distortions in neutrino fluxes*
  - *DD / ID signatures of the DM candidate(s) of these models*
  - *Any other implications not yet thought of*