Recent progress &
Puzzles in Flavor Physics

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Flavor anomalies

- ***A first qualitative observation***

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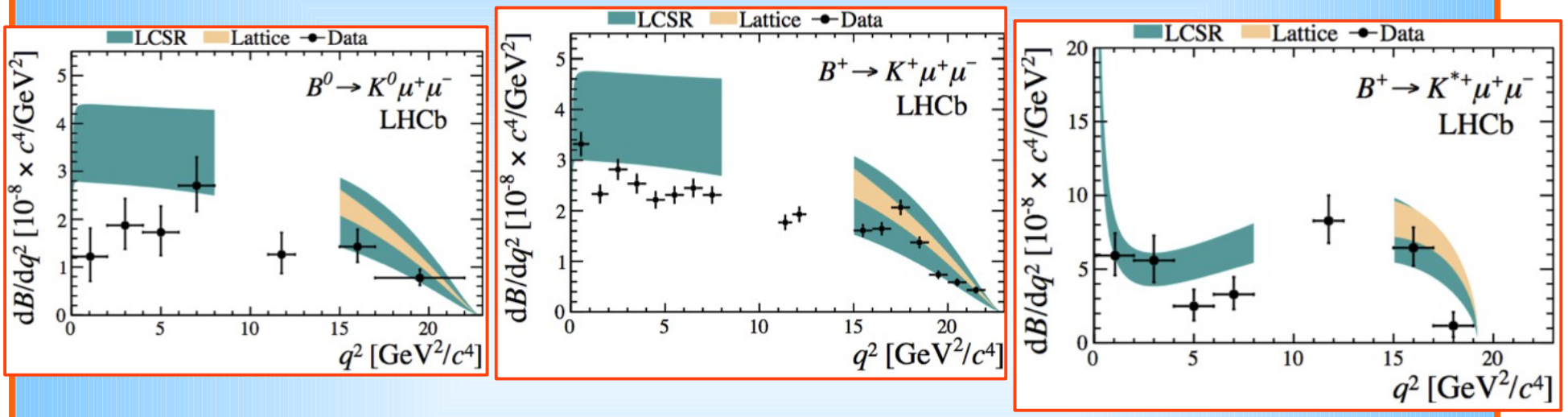

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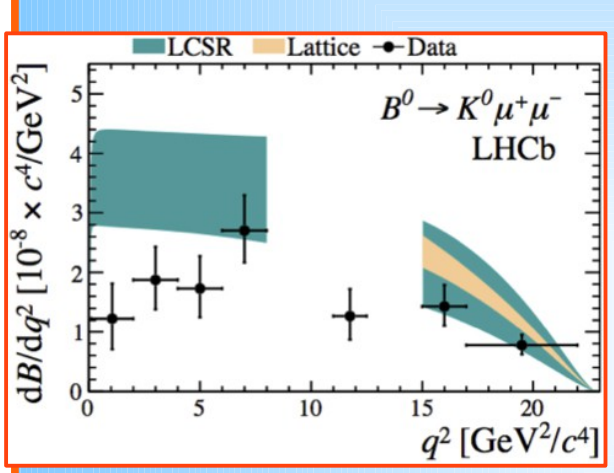

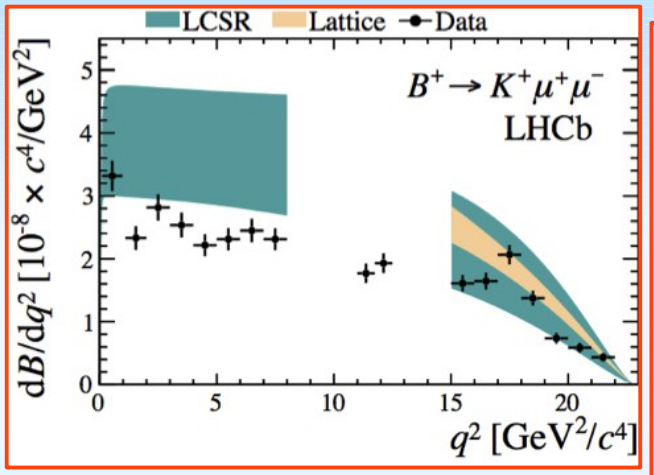

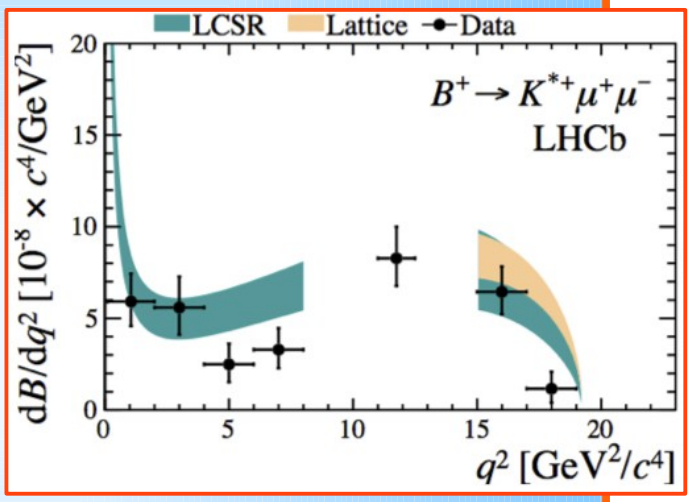

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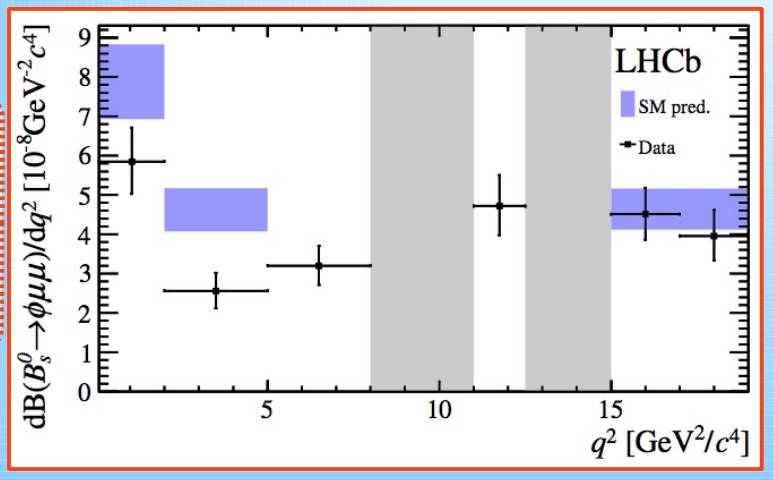

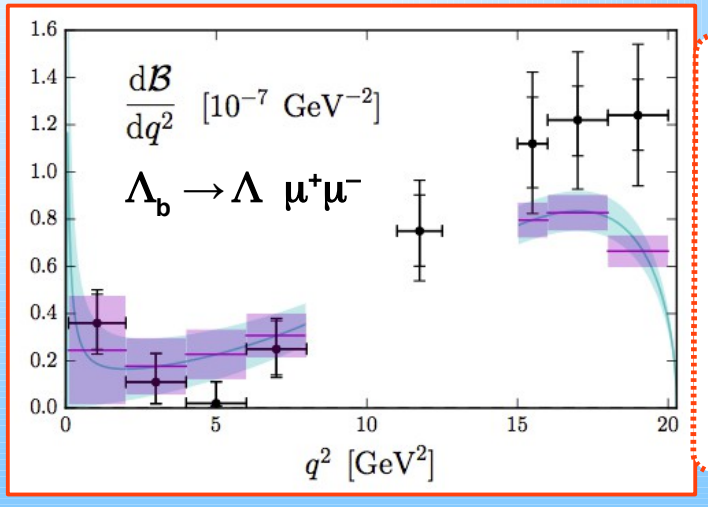

LHCb 2015 & Detmold+Meinel '16

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However, here's a clean quantity:

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

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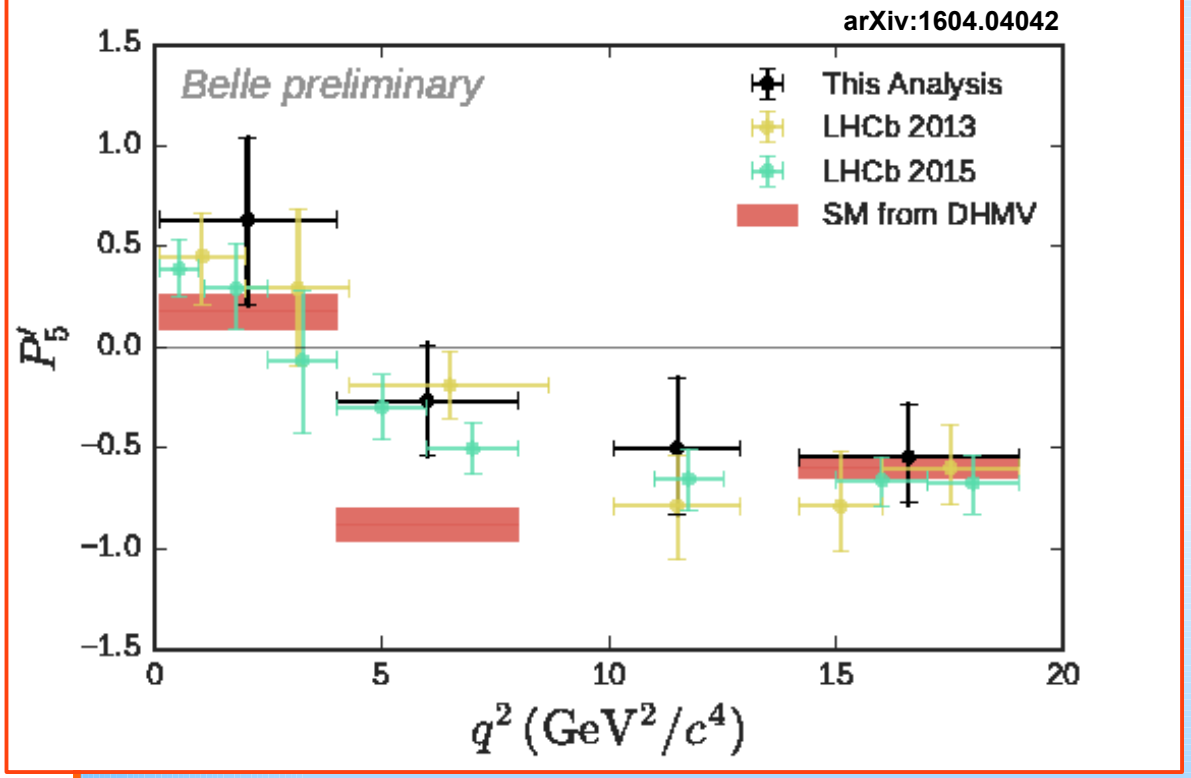

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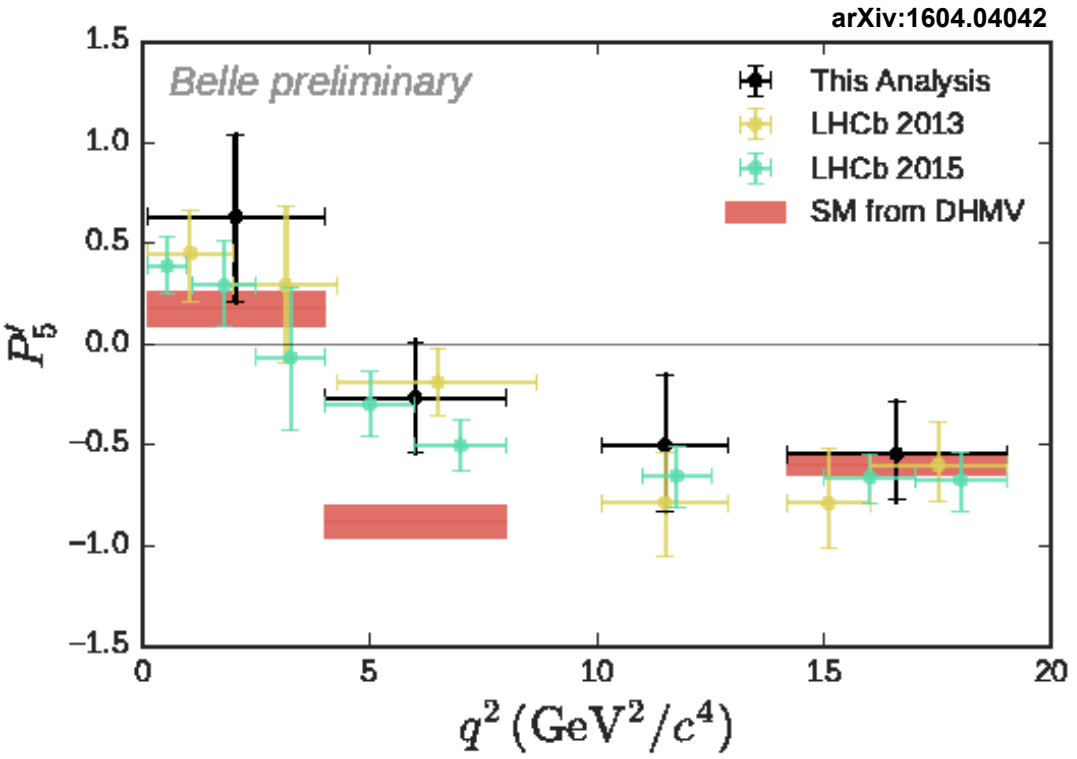

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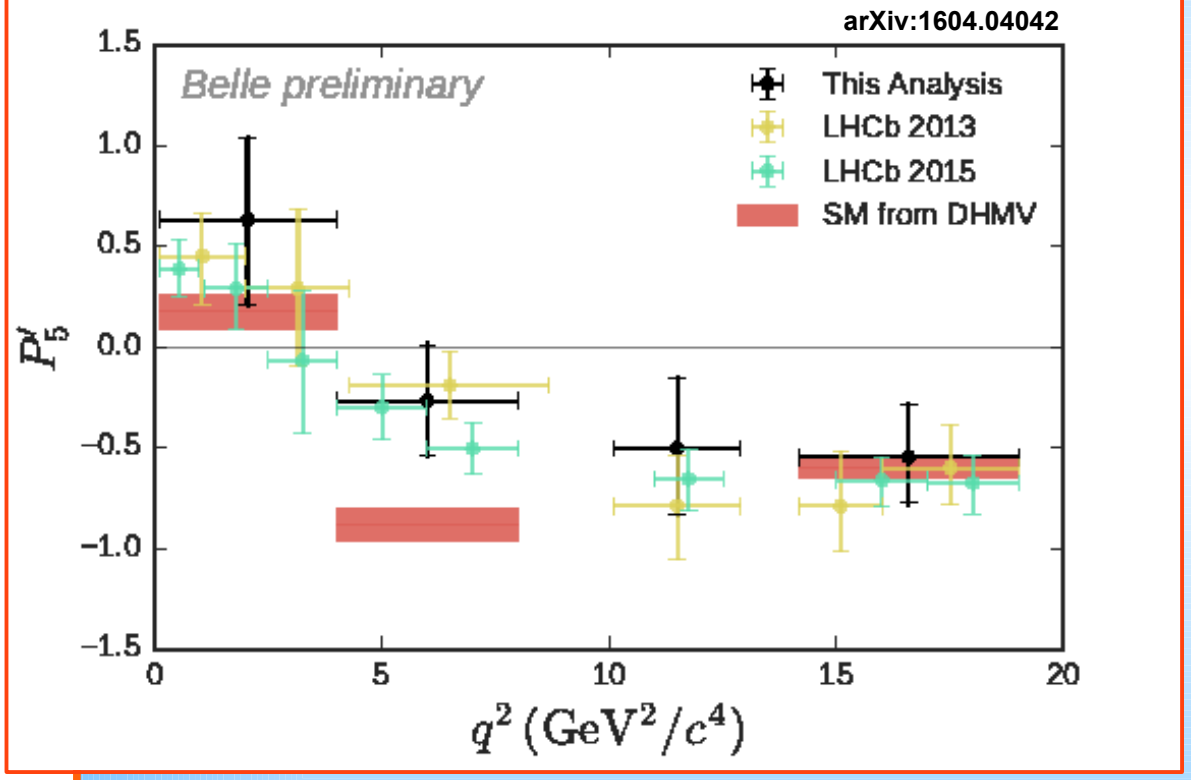

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- What cancels is the dependence on the large-m_b form factors.
- Crucial issue:

  How important departures from the infinite-m_b limit are, for q^2 approaching $4\,m_c^2$.

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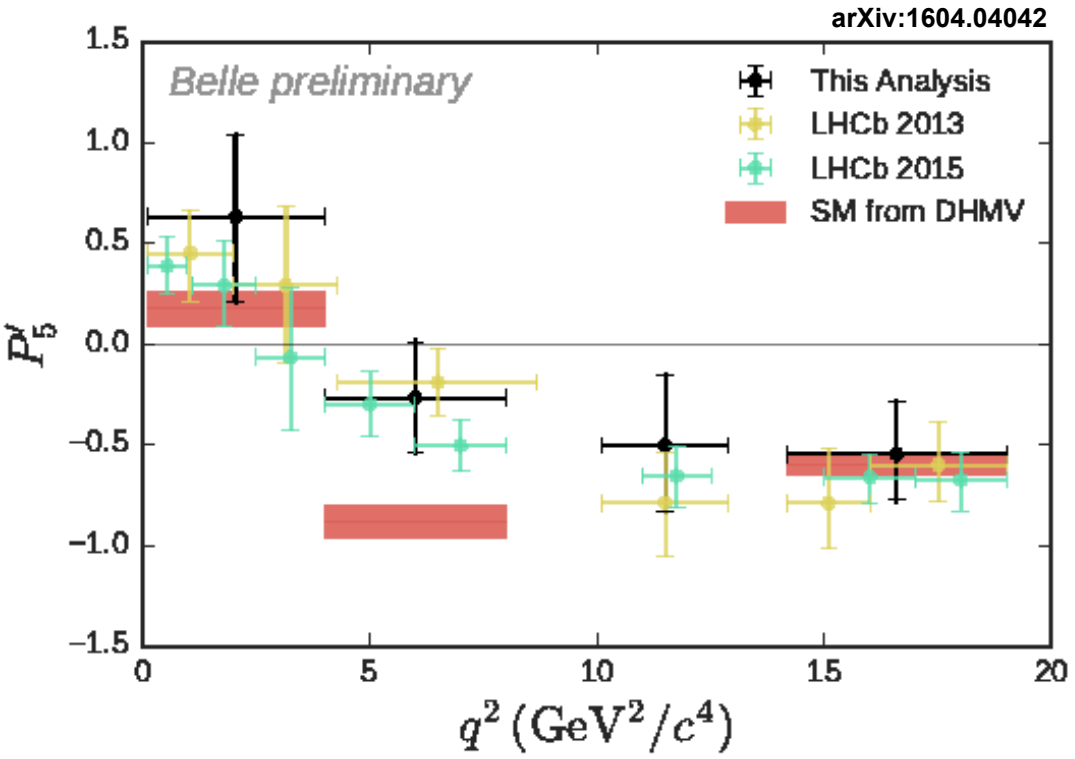

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But interesting nonetheless, because:

- *Effect is again in the same region: $m^2_{\mu\mu} \in [1, 6]\ \mathrm{GeV}^2$*
- *Compatibility between 1/fb and 3/fb LHCb analyses and a recent Belle analysis*

b → c data

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

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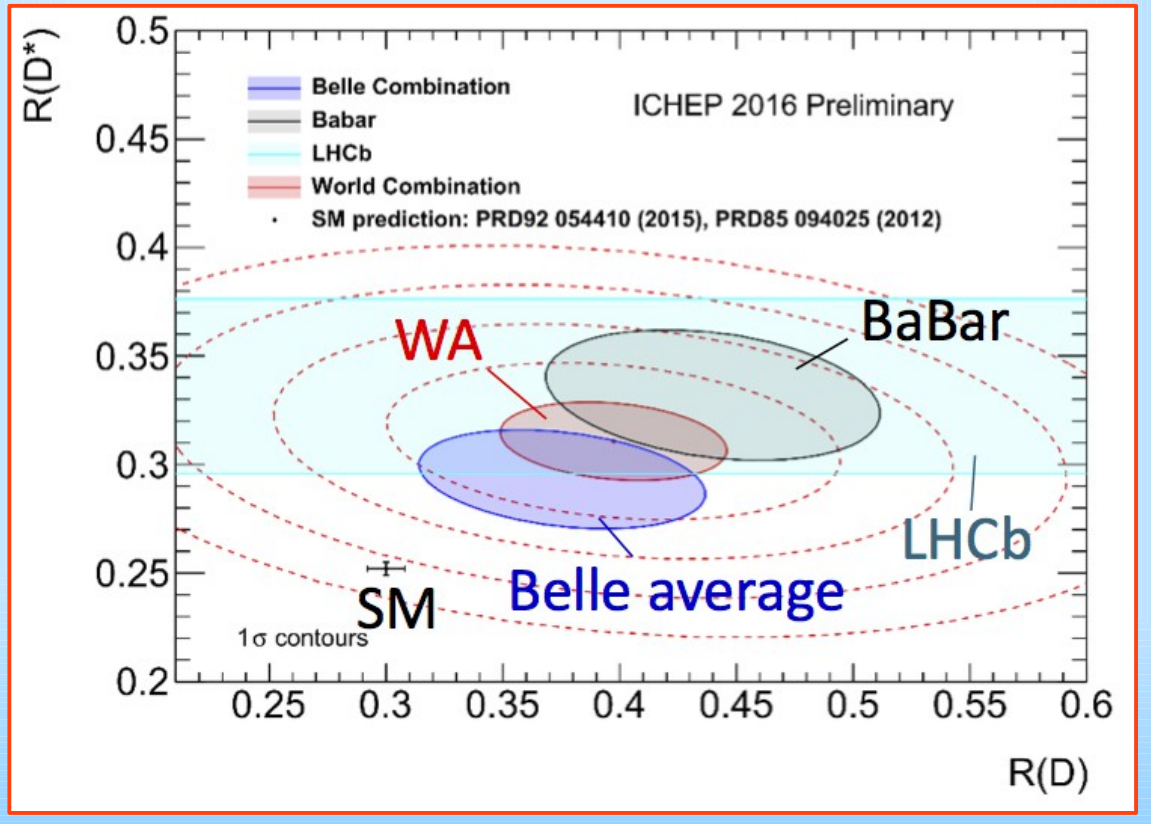

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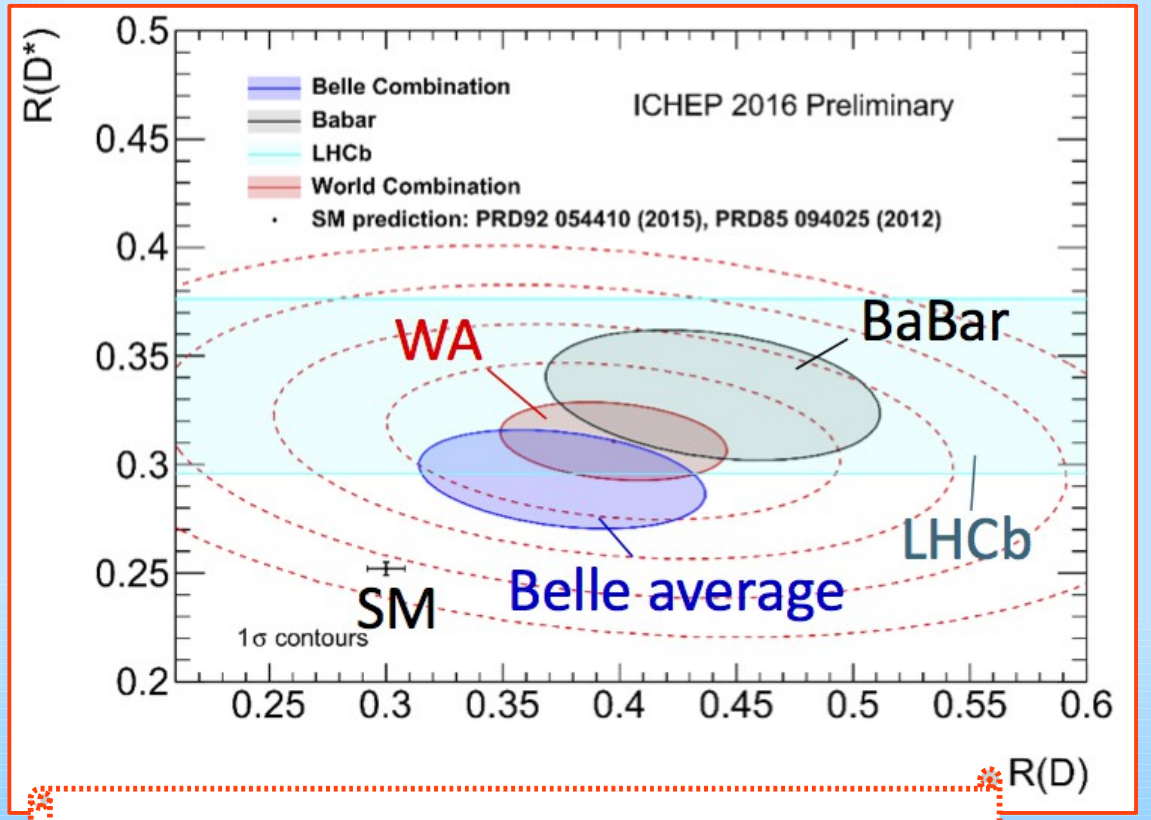

Simultaneous fit to R(D) & R(D*) about 4σ away from SM

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

- *Yes we can. 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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- *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 $C_9^{\text{NP}} \sim -30\% \times C_9^{\text{SM}}$), or by new physics in the $SU(2)_L$ invariant direction $C_9^{\text{NP}} = -C_{10}^{\text{NP}}$, (with $C_9^{\text{NP}} \sim -12\% \times C_9^{\text{SM}}$). 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 *et al.*, 2015

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  - *This rotation induces <u>LUV and LFV</u> effects*

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

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☑ *An analogous argument holds for purely leptonic modes*

More signatures

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

- *Being defined above the EWSB scale, our assumed operator*

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Such effects "strongly disfavour an explanation of the R(D(*)) anomaly model-independently"

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And yes they are!
See: [Greljo-Isidori-Marzocca]
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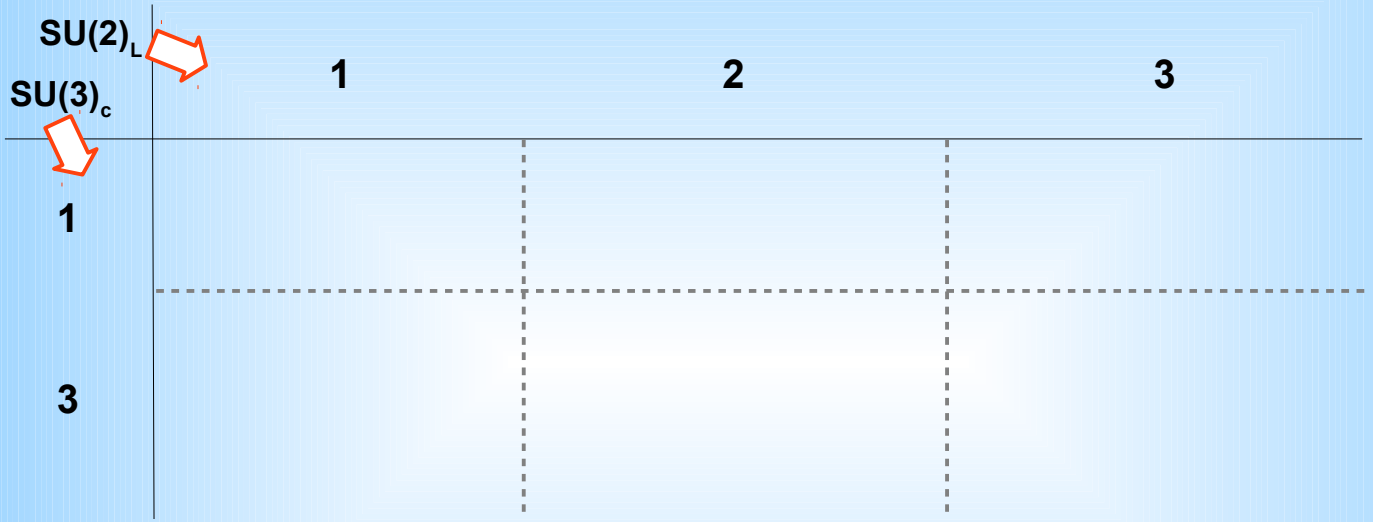
Recap of model-building attempts

focused on models accounting for R_K & R(D(*))



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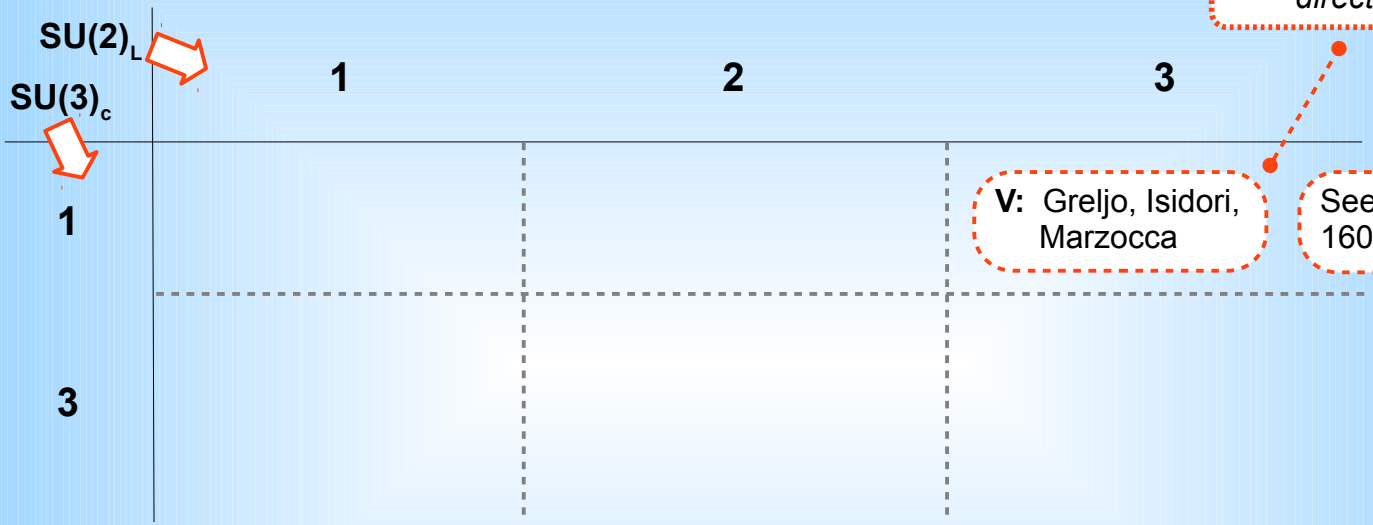

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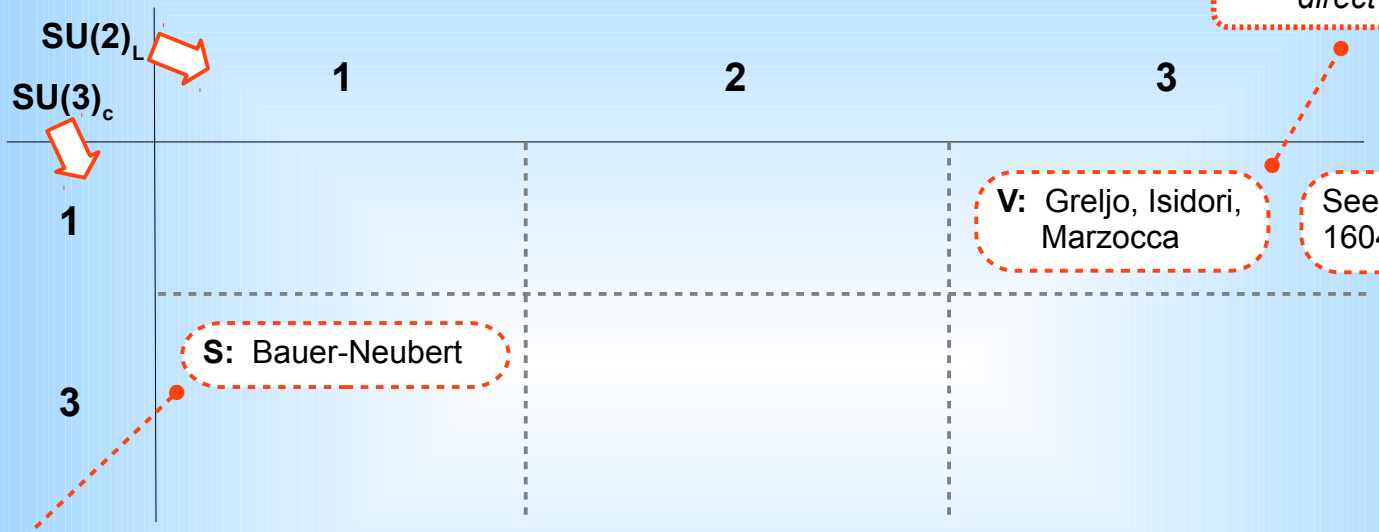

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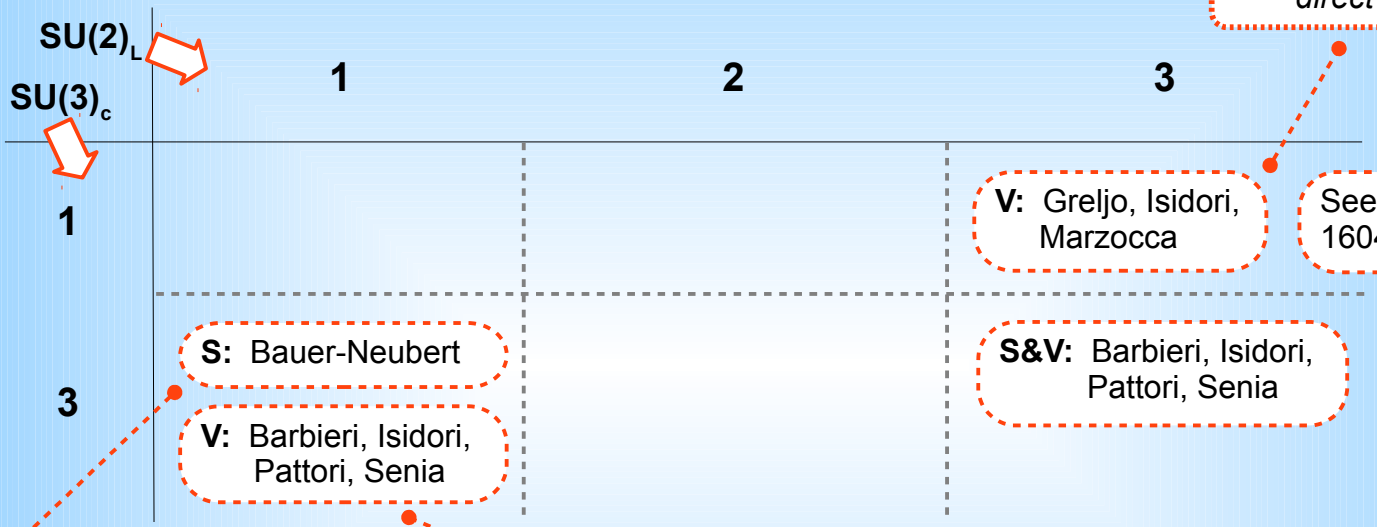

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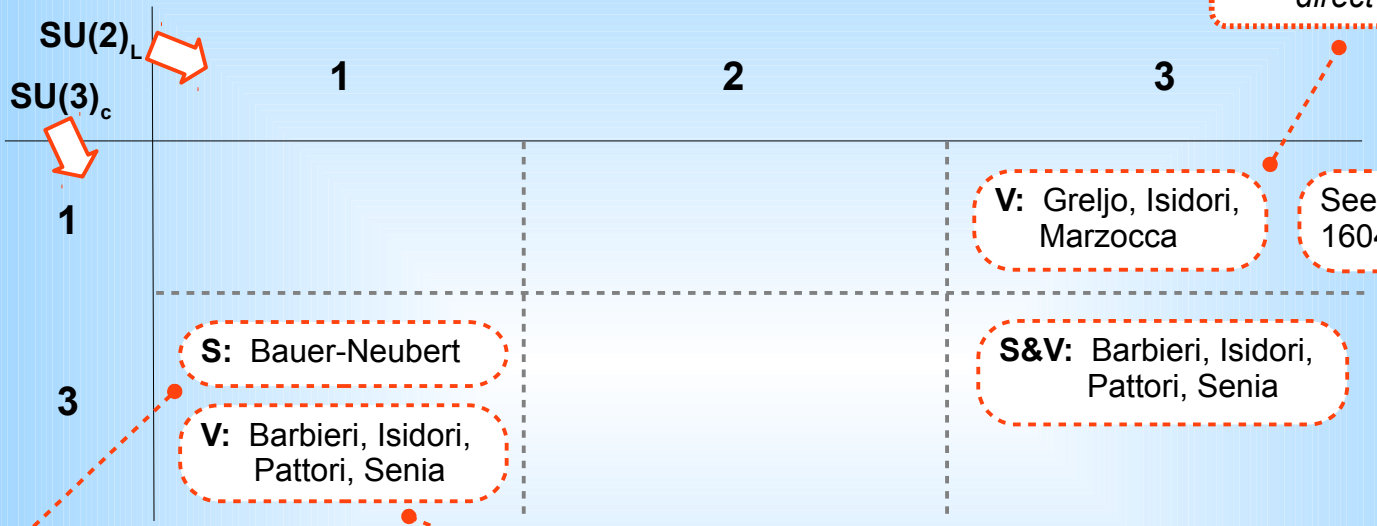

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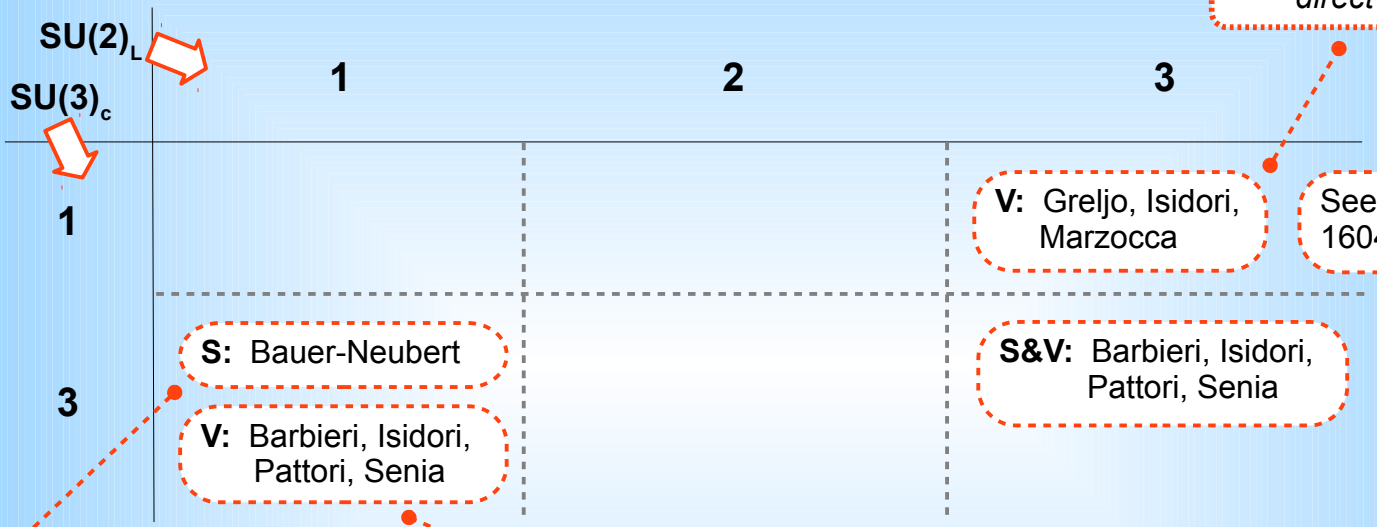

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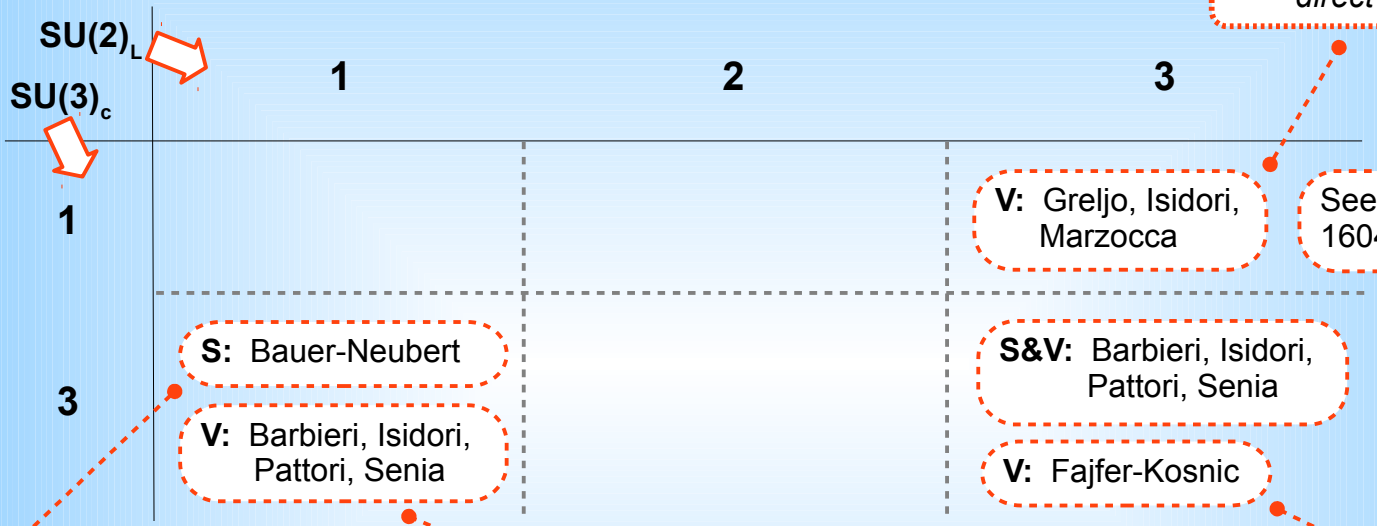

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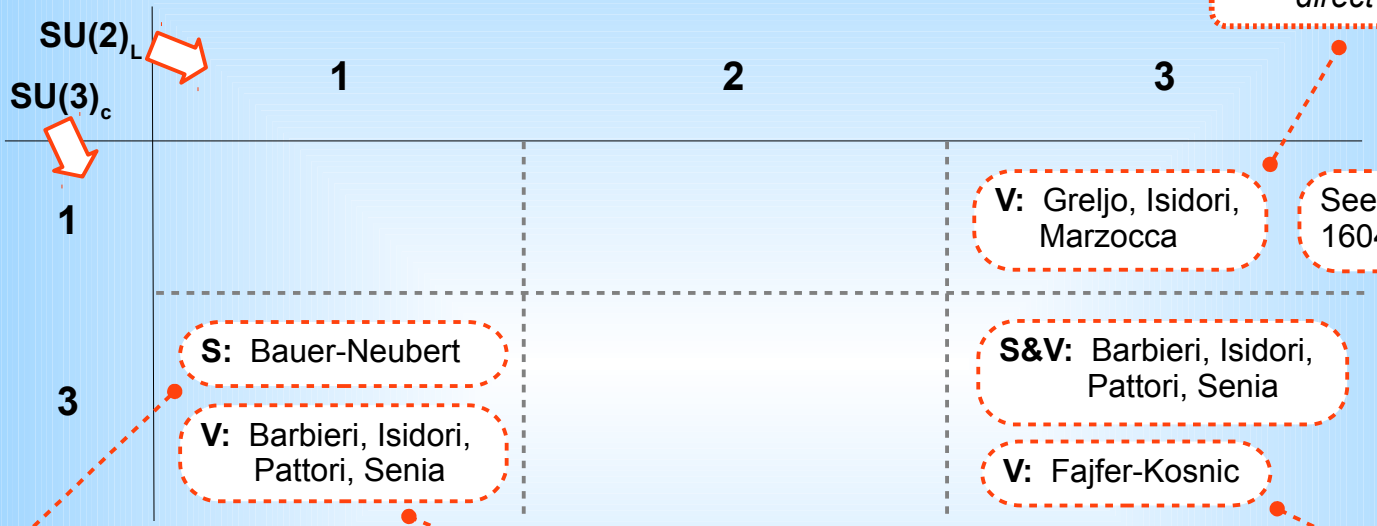

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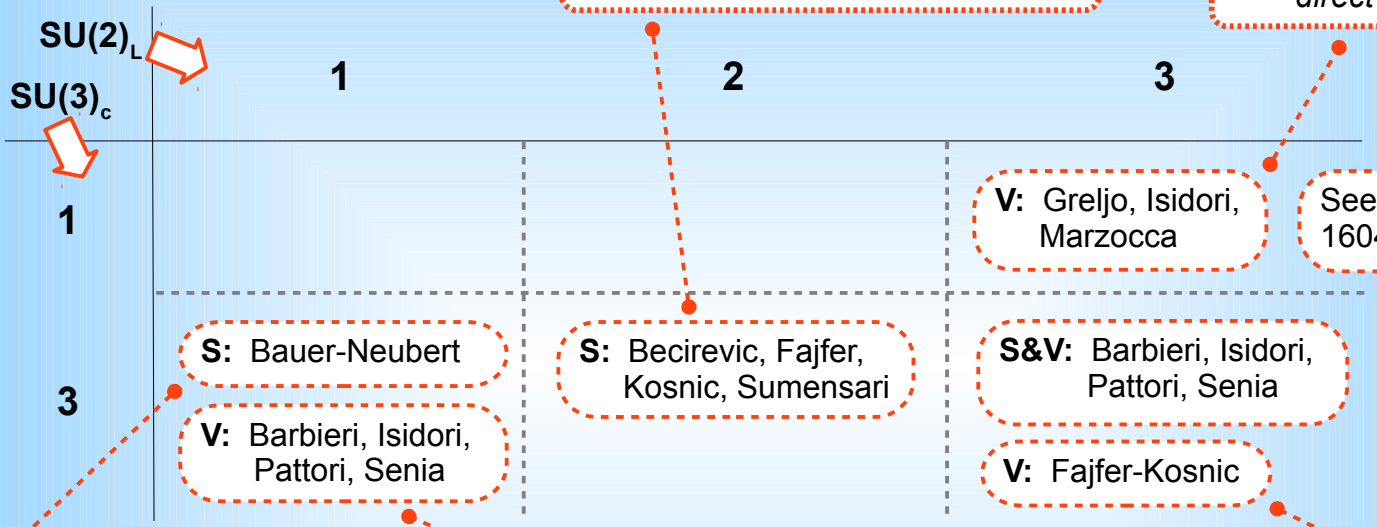

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  (V+A) x (V–A) current invoked

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Hiller, Schmaltz, JHEP 2015

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- ***Extract LD effects from <u>data</u>***

LHCb, 1612.06764

Similar approach as Lyon, Zwicky, '14

Recently, LHCb measured BR($B^+ \to K^+ \mu\mu$) including an accurate parameterization of the LD component in the $c\bar{c}$ region

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Result: *BR compatible with previous measurements, and (again) smaller than SM*

What's the BR result for q^2 in [1, 6] GeV^2 ?

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  - *The FSR component can be systematically subtracted from data*
    (the same way it is in $B_s \to \mu\mu$)
  - *So this measurement gives access to the ISR spectrum, to be compared with theory*
    [Melikhov-Nikitin, '04]

But LQCD calculation of $B \to \gamma$ f.f.'s required

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- *Timely to pursue further tests.*

  Examples:
  - *more measurements of R_K*
  - *more LUV quantities*
  - *other observables sensitive to C_9 & C_{10}*