University of Zurich[UZH]

Flavor physics

[*old problems, recent hopes and new challenges*]

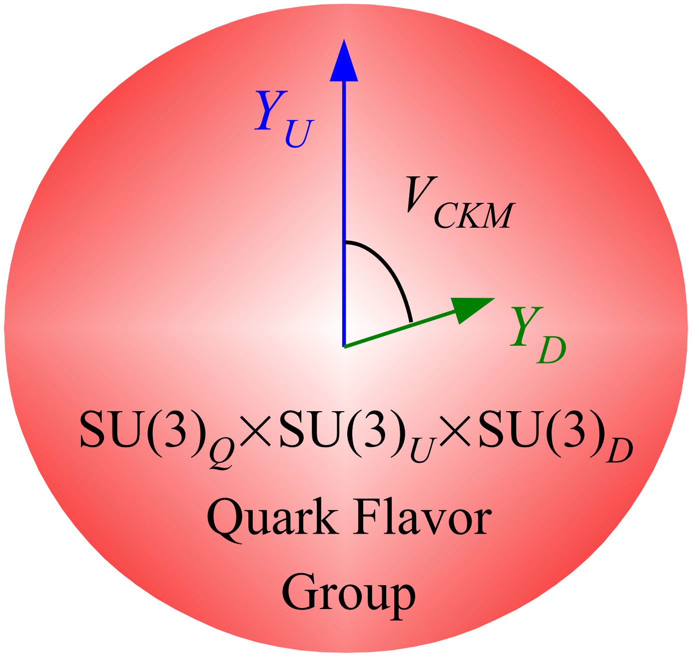
Gino Isidori
[*University of Zürich*]

- An introduction to flavor physics
- Lepton Flavor Universality
- Model building and future prospects

Plan of the lectures:

- An introduction to flavor physics
  - Preface
  - The flavor sector of the Standard Model
  - Properties of the CKM matrix and CKM fits
  - The two flavor puzzles
  - The SM as an effective theory
  - The NP flavor problem
  - MFV and beyond
- Lepton Flavor Universality
- Model building and future prospects

MFV and beyond



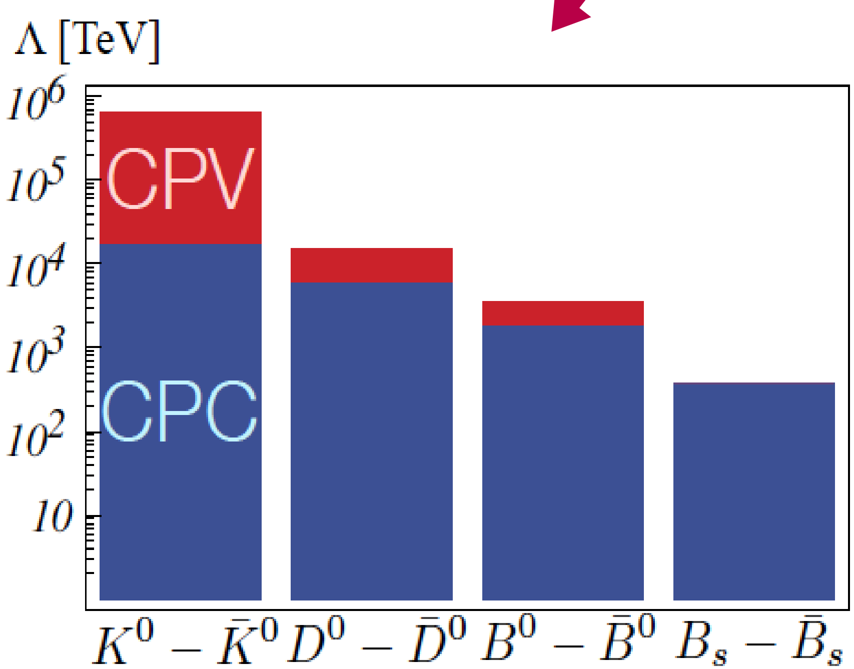
MFV and beyond

Current data show no significant deviations from the SM (at the 5%-30% level, depending on the specific amplitude) on $\Delta F = 2$ observables (mass differences and CP-violating phases) $\rightarrow$ strong bounds on possible BSM contributions:

$$M(B_d - \bar{B}_d) \sim \frac{(y_t^2 V_{tb}^* V_{td})^2}{16\pi^2 m_t^2} + c_{NP} \frac{1}{\Lambda^2}$$

$$c_{NP} \begin{cases} \sim 1 \xrightarrow{\text{tree/strong + generic flavor}} \Lambda \gtrsim 2\times 10^4 \text{ TeV [K]} \\ \sim 1/(16\pi^2) \xrightarrow{\text{loop + generic flavor}} \Lambda \gtrsim 2\times 10^3 \text{ TeV [K]} \\ \sim (y_t V_{ti}^* V_{tj})^2 \xrightarrow{\text{tree/strong + ``alignment''}} \Lambda \gtrsim 5 \text{ TeV [K \& B]} \\ \sim (y_t V_{ti}^* V_{tj})^2/(16\pi^2) \xrightarrow{\text{loop + ``alignment''}} \Lambda \gtrsim 0.5 \text{ TeV [K \& B]} \end{cases}$$

Operator	Bounds on Λ (TeV)		Bounds on c_{ij} ($\Lambda = 1$ TeV)		Observables
	Re	Im	Re	Im	
$(\bar{s}_L \gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	Δm_K; ε_K
$(\bar{s}_R d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	Δm_K; ε_K
$(\bar{c}_L \gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\lvert q/p \rvert, \phi_D$
$(\bar{c}_R u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	Δm_D; $\lvert q/p \rvert, \phi_D$
$(\bar{b}_L \gamma^\mu d_L)^2$	5.1×10^2	9.3×10^2	3.3×10^{-6}	1.0×10^{-6}	Δm_{B_d}; $S_{B_d \to \psi K}$
$(\bar{b}_R d_L)(\bar{b}_L d_R)$	1.9×10^3	3.6×10^3	5.6×10^{-7}	1.7×10^{-7}	Δm_{B_d}; $S_{B_d \to \psi K}$
$(\bar{b}_L \gamma^\mu s_L)^2$	1.1×10^2	1.1×10^2	7.6×10^{-5}	7.6×10^{-5}	Δm_{B_s}
$(\bar{b}_R s_L)(\bar{b}_L s_R)$	3.7×10^2	3.7×10^2	1.3×10^{-5}	1.3×10^{-5}	Δm_{B_s}



highly non trivial flavor structure

MFV hypothesis

MFV and beyond

The MFV hypothesis is the strongest assumption we can make to impose hierarchical structures also on physics beyond the SM:

- Flavor symmetry:

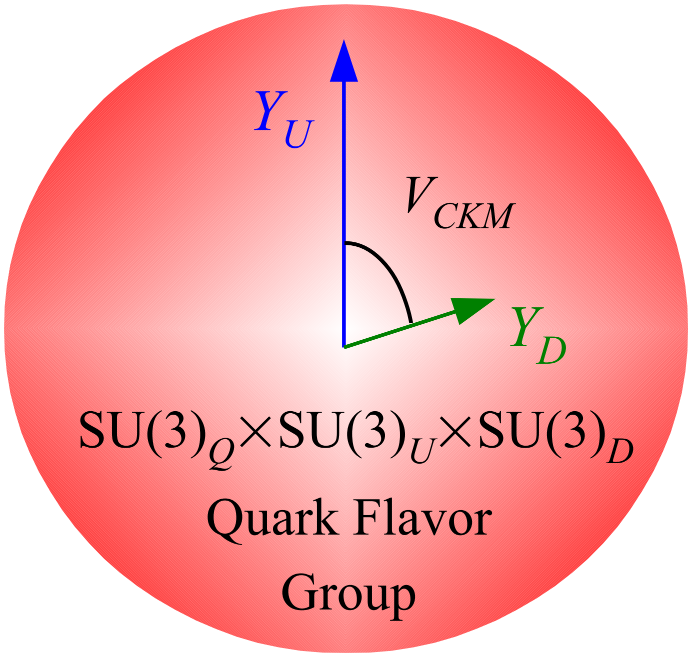
  $U(3)^5 = SU(3)_Q \times SU(3)_U \times SU(3)_D \times \ldots$

  (accidental) global symm. of the SM gauge sector
  $\rightarrow$ promoted to basic symm. of the eff. theory

- Symmetry-breaking terms:

  $Y_D \sim 3_Q \times \bar{3}_D \qquad Y_U \sim 3_Q \times \bar{3}_U$

  SM Yukawa couplings $\rightarrow$ promoted to unique breaking terms of the flavor symmetry



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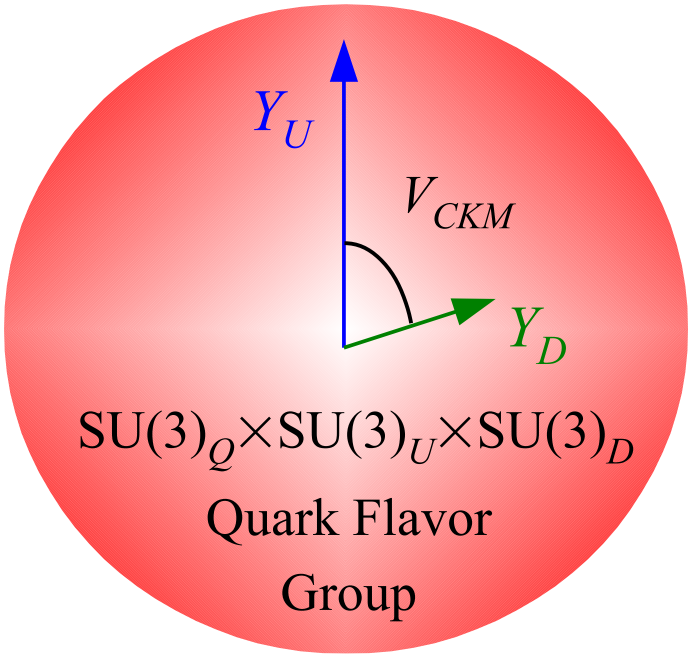

MFV hypothesis: *Yukawa couplings = unique sources of flavor symmetry breaking*

⬇

Automatic GIM & CKM suppression as in the SM
[bounds on NP effective scale of effective operators lowered to ~ TeV]

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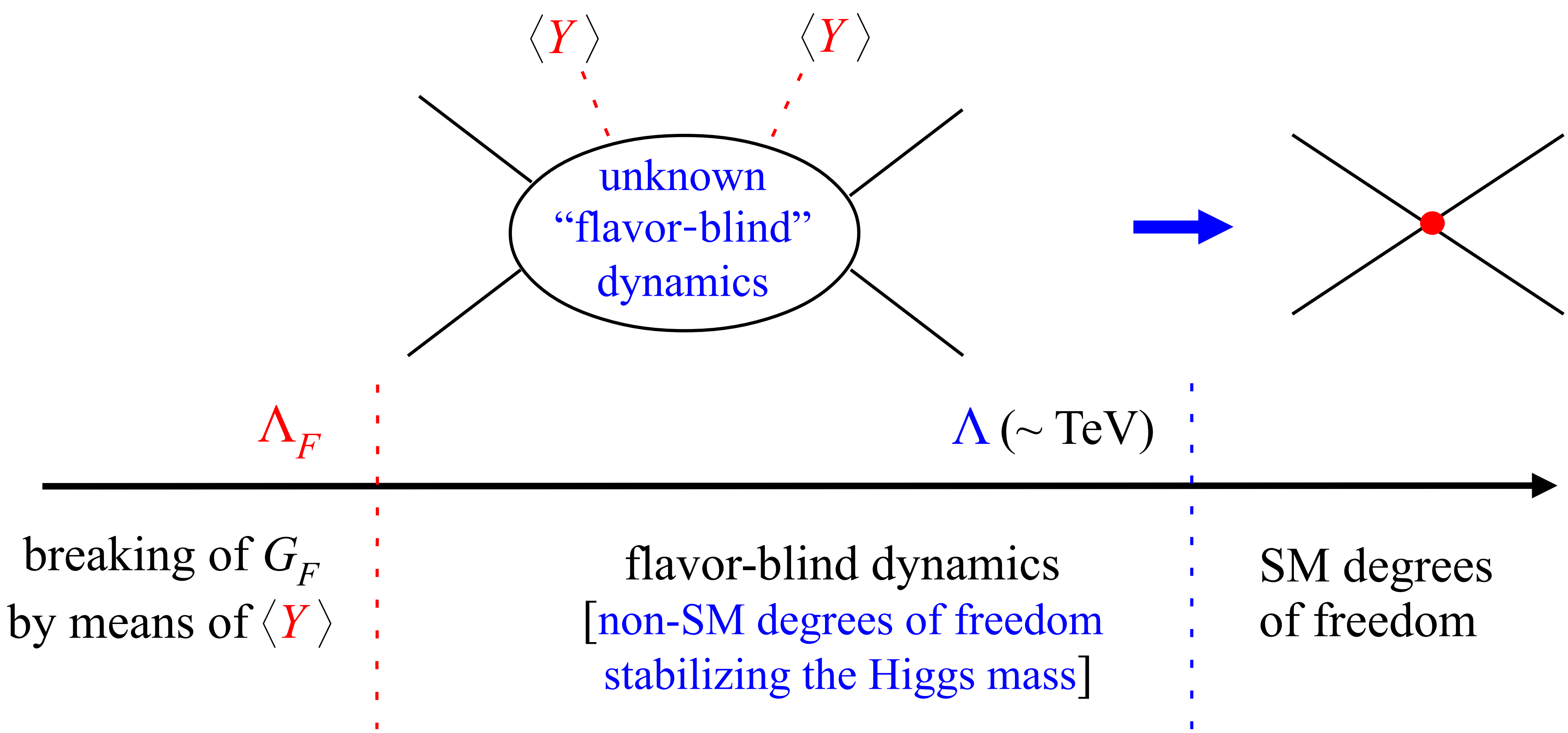
Underlying idea: the Yukawa couplings are generated at some very heavy (unaccessible) energy scale, and they are the only sources of flavor symmetry breaking accessible at low energies



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While this idea can be implemented in explicit NP models (*i.e. gauge-mediated SUSY breaking*) is far from being general...

Flavor anarchy $\longleftrightarrow$ MFV

and it does not address the SM flavor problem (→ no justification for the observed hierarchies of the SM Yukawa couplings): it is only a (consistent) way to postpone the issue...

MFV and beyond

So far, the vast majority of BSM model-building attempts has been based on the following two hypotheses:

- Concentrate only on the Higgs hierarchy problem
- Postpone (ignore) the flavor problem, implicitly assuming the 3 families are "identical" copies (but for Yukawa-type interactions) [*MFV paradigm*]

⬇

Under these hypotheses flavor physics is not very exciting (minor role in the search for physics beyond the SM).

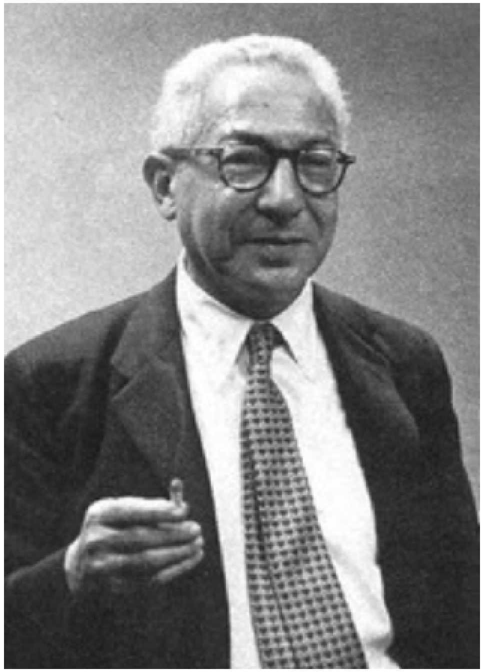
Interesting enough, the recent anomalies seem to suggest to abandon these hypotheses, and in particular the MFV paradigm.

As we shall see next, these data seem to point toward non-trivial flavor dynamics not far from the TeV scale, not obviously related to a stabilization of the Higgs sector, but possibly linked to a solution of the SM flavor problem.

Plan of the lectures:

- An introduction to flavor physics
- Lepton Flavor Universality
  - General considerations on LFU
  - LFU tests in $b \to c$ transitions
  - Rare $b \to s$ decays: generalities
  - The $b \to s\, \ell\ell$ anomalies
  - EFT approaches to the anomalies
- Model building and future prospects

General considerations on LFU



Isidor Issac Rabi

(1898—1988)

General considerations on LFU

In the last few years LHCb, Babar and (to some extent) also Belle reported some "anomalies" (= *deviations from SM predictions*) in B-meson decays.

Data seem to indicate a different (*non-universal*) behavior of different lepton species in specific b (3rd gen.) $\rightarrow$ c,s (2nd) semi-leptonic processes:

- $b \rightarrow c$ charged currents: τ vs. light leptons (μ, e)
- $b \rightarrow s$ neutral currents: μ vs. e

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What is particularly interesting, is that

- These anomalies unambiguously point to relatively low NP scales
- They are sizable (~10-20% compared to SM), and they appear in a consistent correlated way in various observables, most of which can be compute with high accuracy (~1%) within the SM
- They are challenging an assumption (Lepton Flavor Universality), that we gave for granted for many years (*without many good theoretical reasons…*).

Before discussing the precise structure (and the reliability) of these anomalies, it is worth clarifying what we mean by LFU and why it is interesting to test it.

General considerations on LFU

LFU [= *identical behavior of the 3 charged leptons in the limit where we neglect their masses*] is a consequence of the accidental flavor symmetry of the SM Lagrangian in the limit where we neglect the (small) lepton Yukawa couplings:

$$\mathscr{L}_{\rm SM} = \mathscr{L}_{\rm gauge}(A_a, \psi_i) + \mathscr{L}_{\rm Higgs}(H, A_a, \psi_i)$$

3 identical replica of the basic fermion family [$\psi = Q_L, u_R, d_R, L_L, e_R$] in the gauge sector $\Rightarrow$ huge flavor-degeneracy [$U(3)_L \times U(3)_E \times \ldots$]

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$$\downarrow \text{SM Yukawa}$$

$$U(1)_e \times U(1)_\mu \times U(1)_\tau$$

No reason to assume it holds beyond the SM...

[*it is not even an exact symmetry of the SM* !]

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No reason to assume it holds beyond the SM...

However, it has been verified with extremely high accuracy in several systems:

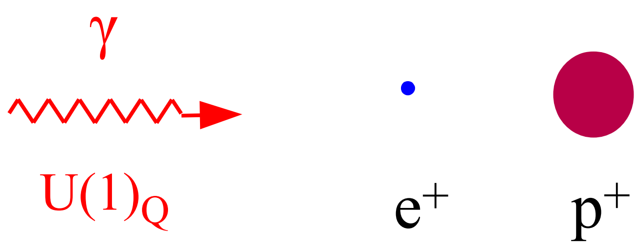
- $Z \to ll$ decays [~ 0.1%]
- $\tau \to l\nu\nu$ decays [~ 0.1%]
- $K \to (\pi)l\nu$ decays [~ 0.1%] & $\pi \to l\nu$ decays [~ 0.01%]

This is why is often assumed as a "sacred principle"....

Still, no deep reason, and no strong experimental tests in semileptonic processes involving 3rd generation quarks, before these recent measurements

General considerations on LFU

Suppose we could test matter only with long wave-length photons...



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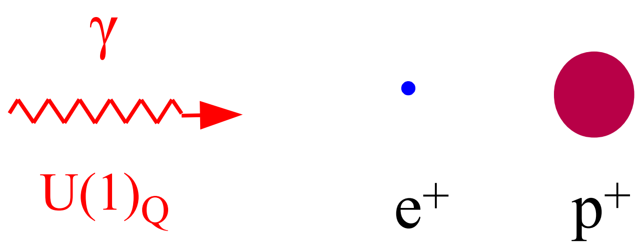

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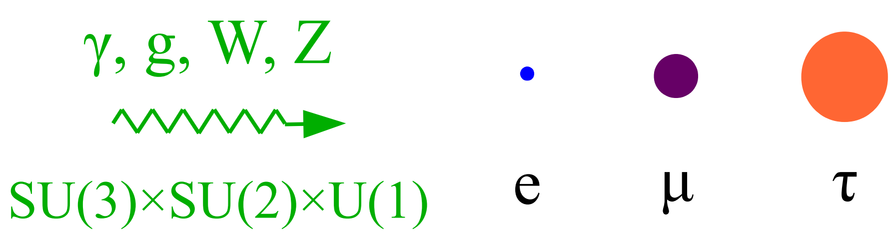
That's exactly the same (misleading) argument we use to infer LFU...



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The SM quantum numbers of the three families could be an "accidental" low-energy property: the different families may well have a very different behavior at high energies, as signaled by their different mass

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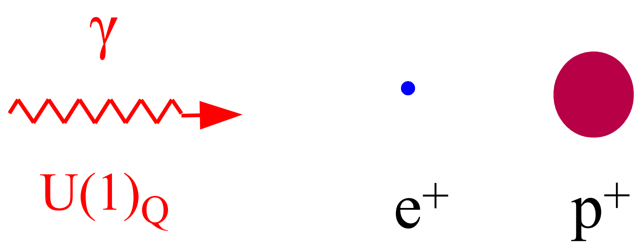

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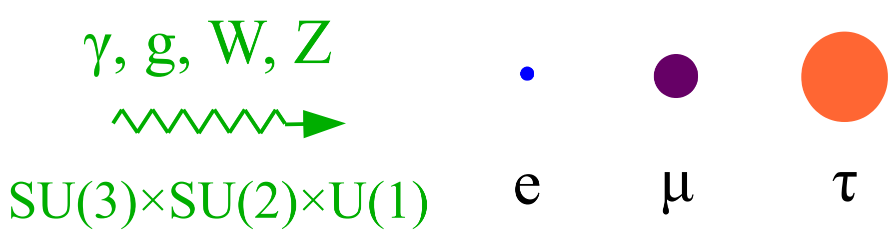

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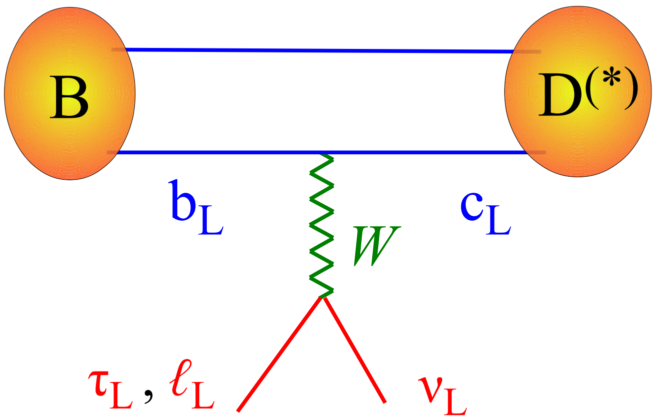
All flavor symmetries could well be only accidental low-energy properties [such as isospin or SU(3) in QCD].

LFU tests in $b \to c$ transitions

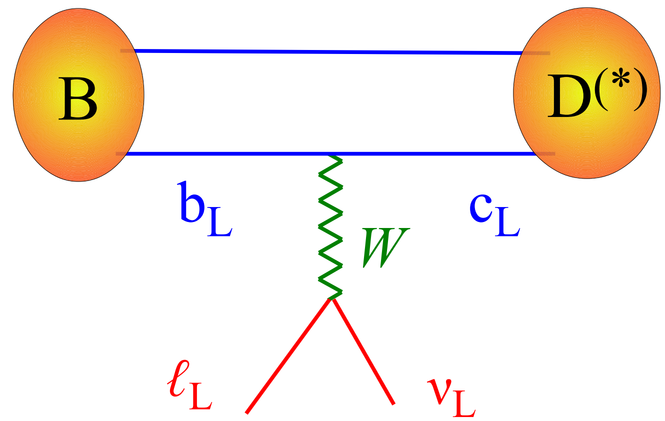


LFU tests in $b \to c$ transitions

The way we test LFU in charged-current $b \to c$ transitions is via the ratios

$$R_{12}(H_c) = \frac{\Gamma(B \to H_c\, \ell_1 \nu_1)}{\Gamma(B \to H_c\, \ell_2 \nu_2)}$$

$$H_c = D \text{ or } D^*$$



We are not able to compute very precisely, separately, numerators and denominators in these ratios because of hadronic uncertainties...

E.g.: $A(B \to D\ell\nu)_{SM} = G_{eff}\, V_{cb}\, \langle D \,|\, \underline{b}_L\, \gamma_\mu\, c_L \,|\, B \rangle\, \underline{\ell}\gamma^\mu\nu$

$$\langle D \,|\, \underline{b}_L\, \gamma_\mu\, c_L \,|\, B \rangle \longrightarrow f_+(q^2)\, (p_B+p_D)_\mu + f_-(q^2)\, (p_B-p_D)_\mu$$

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LFU tests in $b \to c$ transitions

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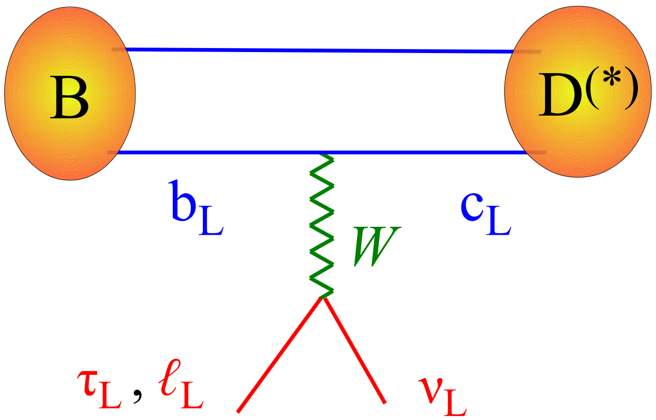

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$\to f_+(q^2)\,(p_B+p_D)_\mu + f_-(q^2)\,(p_B-p_D)_\mu$

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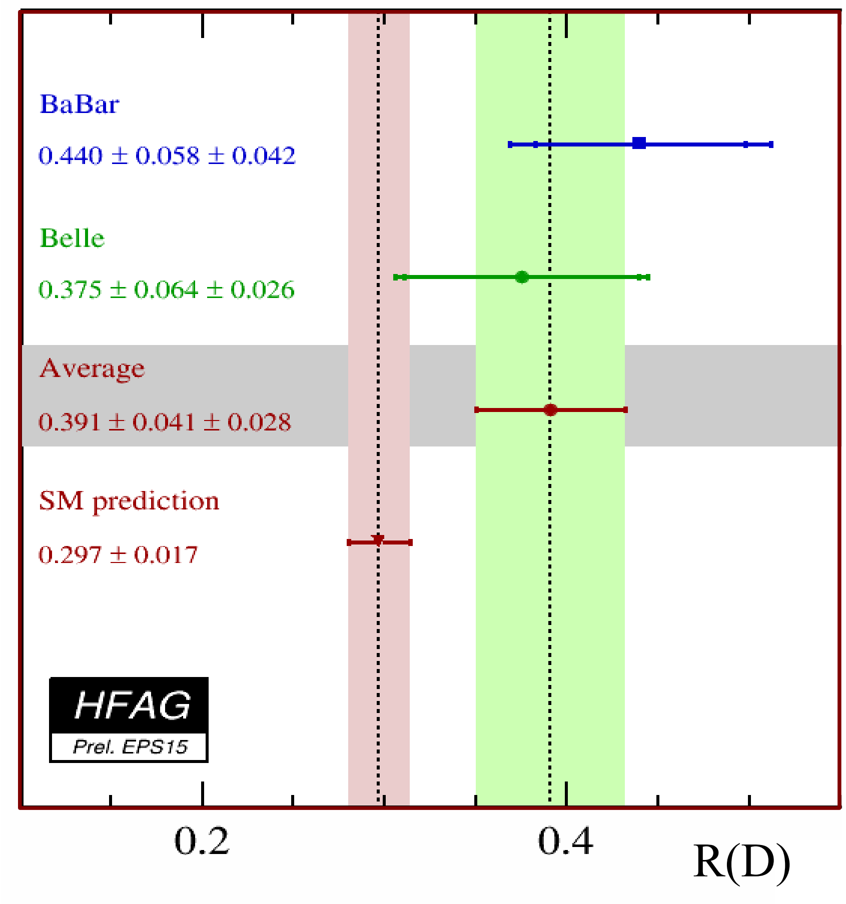
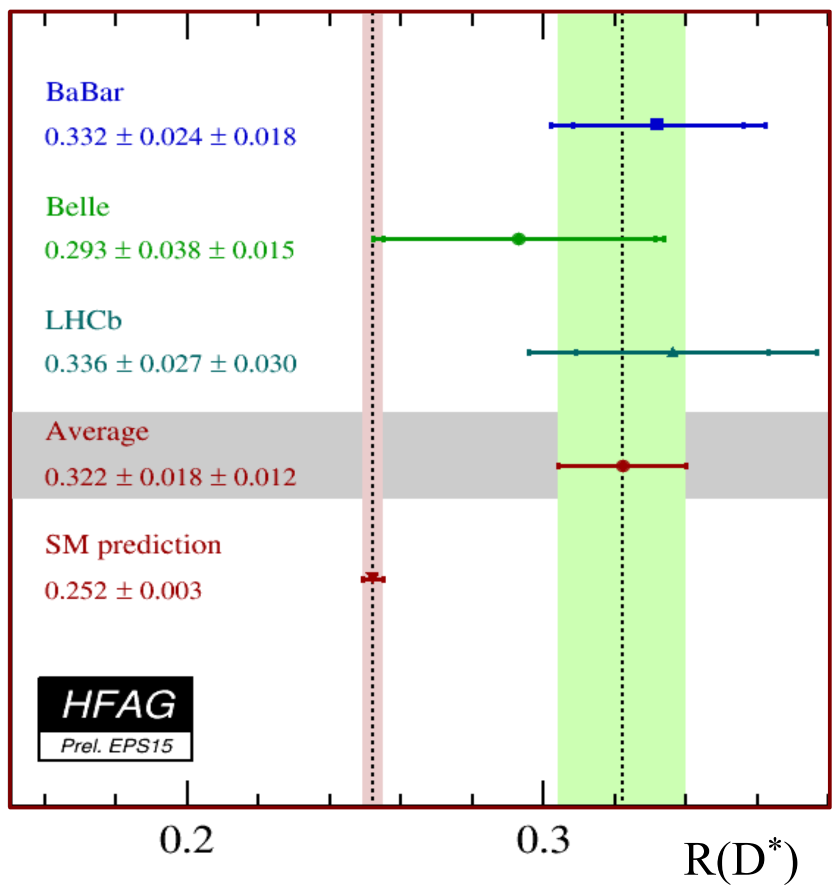
Anomalies appeared when comparing τ vs. light leptons (μ, e)

LFU tests in $b \to c$ transitions

Test of Lepton Flavor Universality in (charged current) $b \to c$ transitions
[τ vs. light leptons (μ, e)]:



2015



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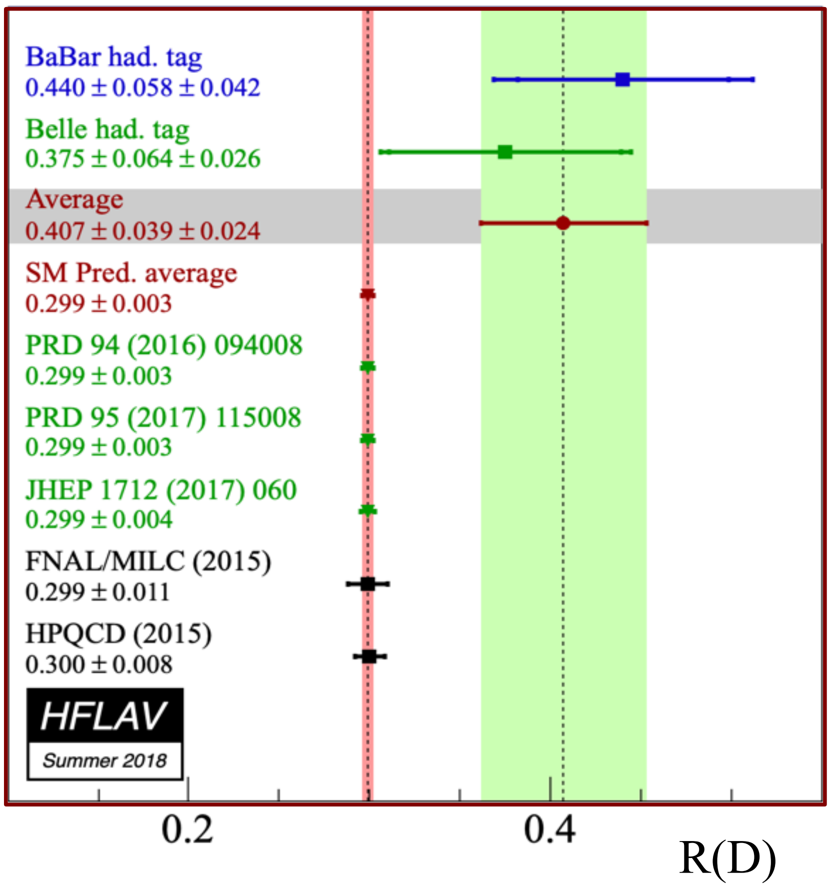
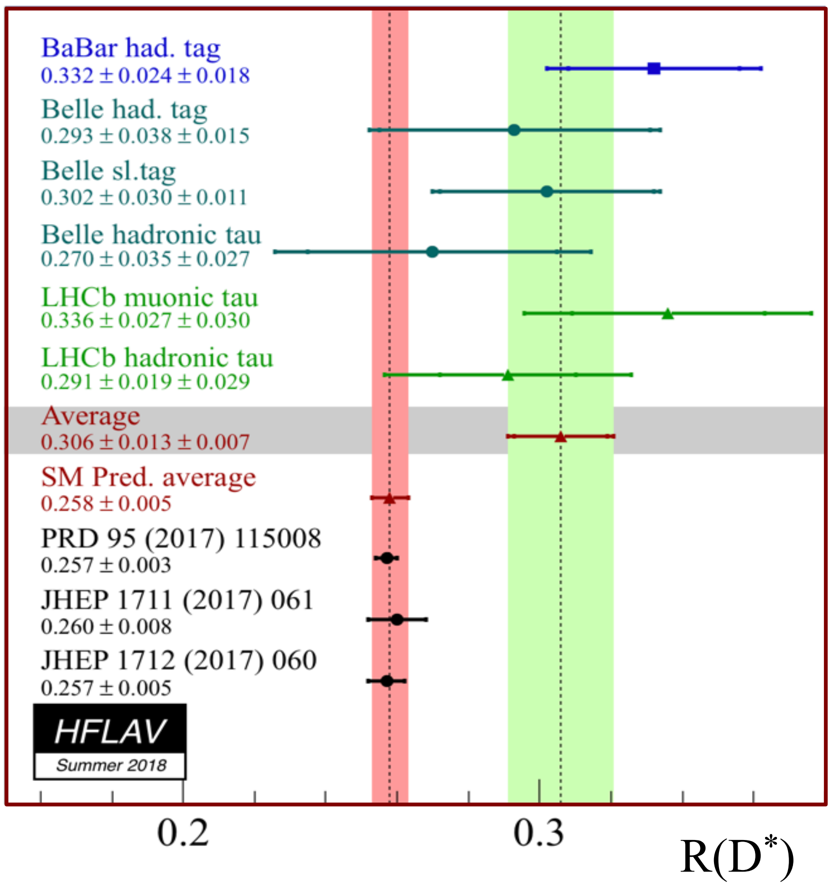
Test of Lepton Flavor Universality in (charged current) $b \to c$ transitions [τ vs. light leptons (μ, e)]:



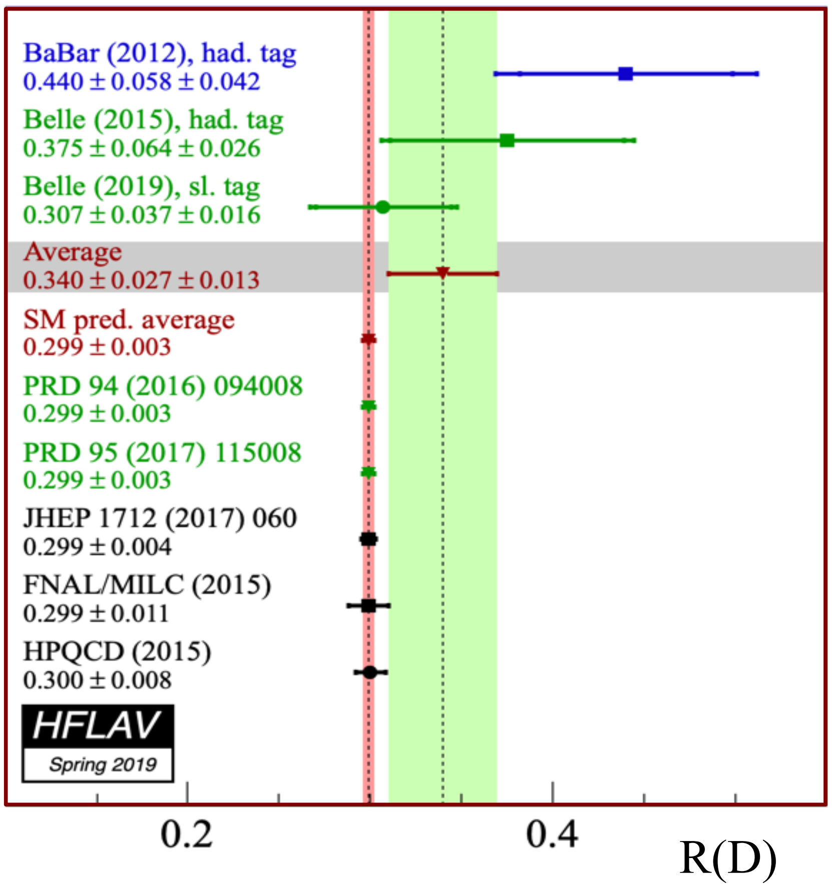
2018

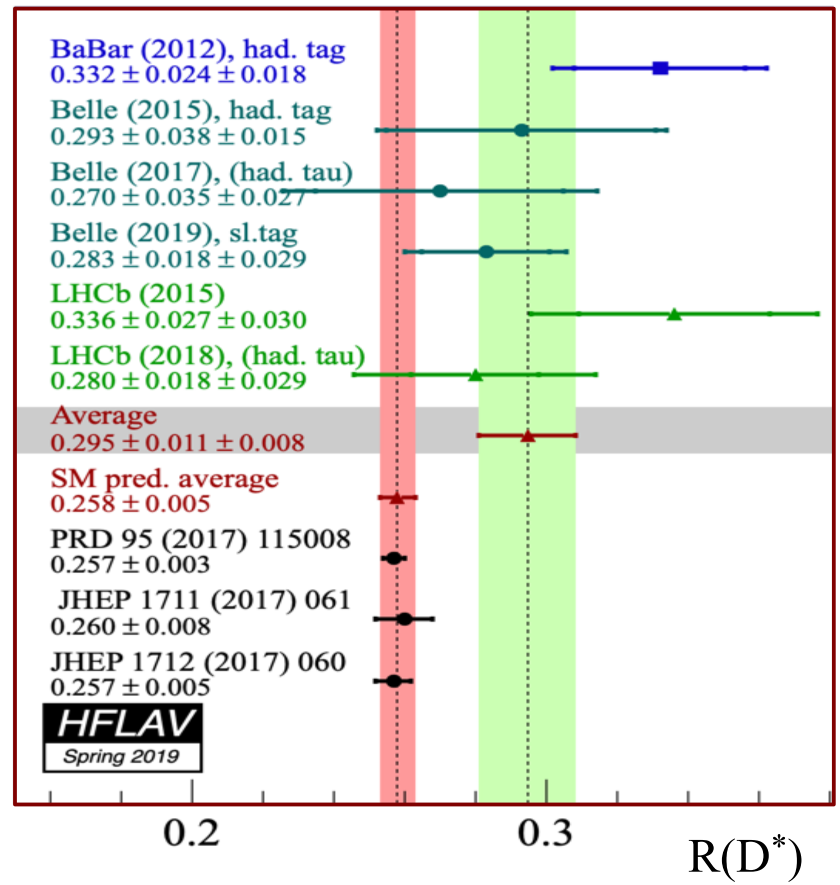


LFU tests in b → c transitions

Test of Lepton Flavor Universality in (charged current) b → c transitions
[τ vs. light leptons (μ, e)]:

2019





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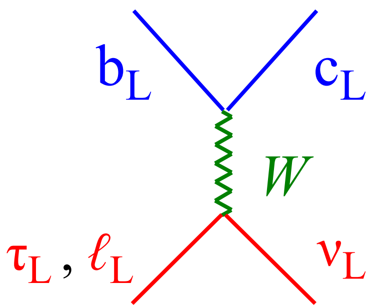

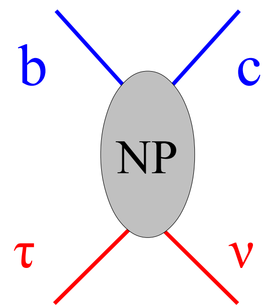

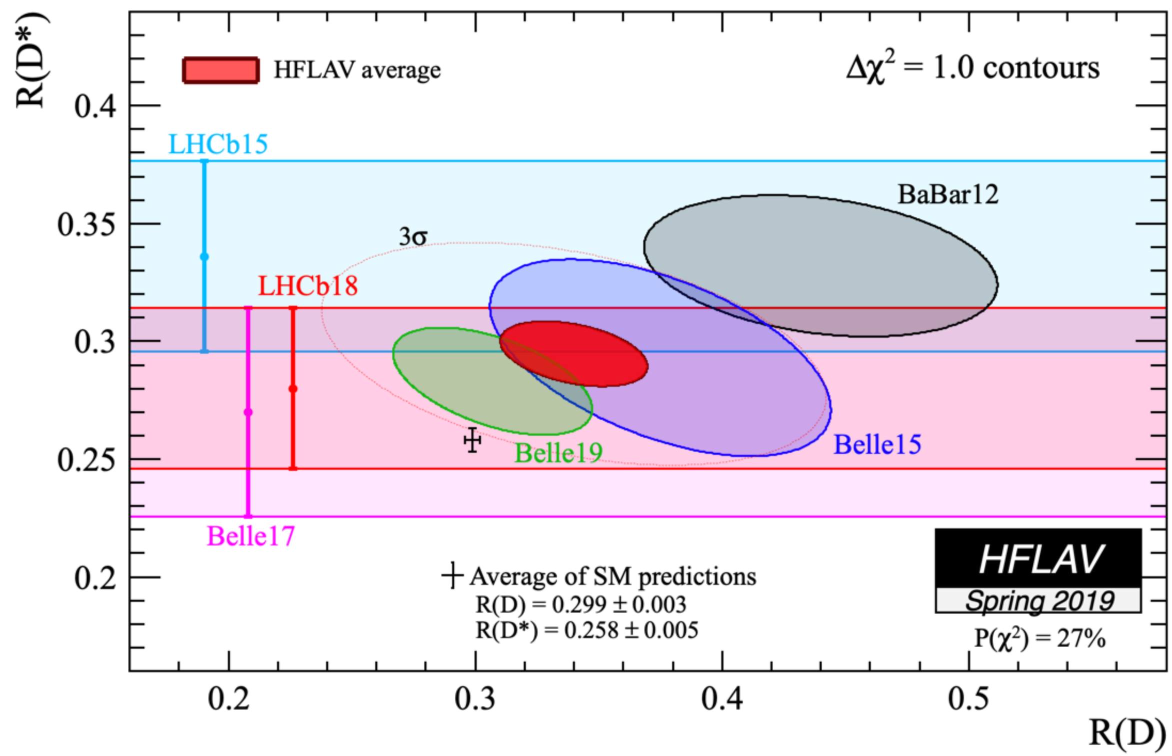

- SM prediction quite solid: hadronic uncertainties cancel (*to large extent*) in the ratio and deviations from 1 in R(X) expected only from phase-space differences
- Consistent results by 3 different exps. → 3.1σ excess over SM ($D + D^*$)

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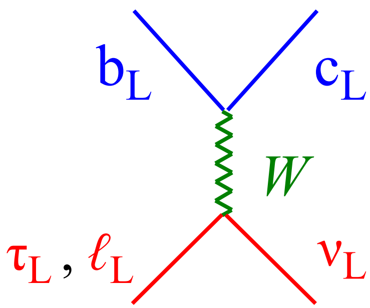
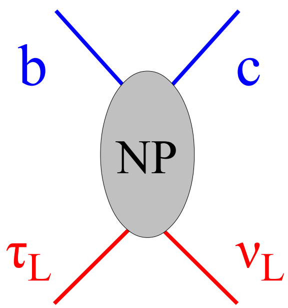
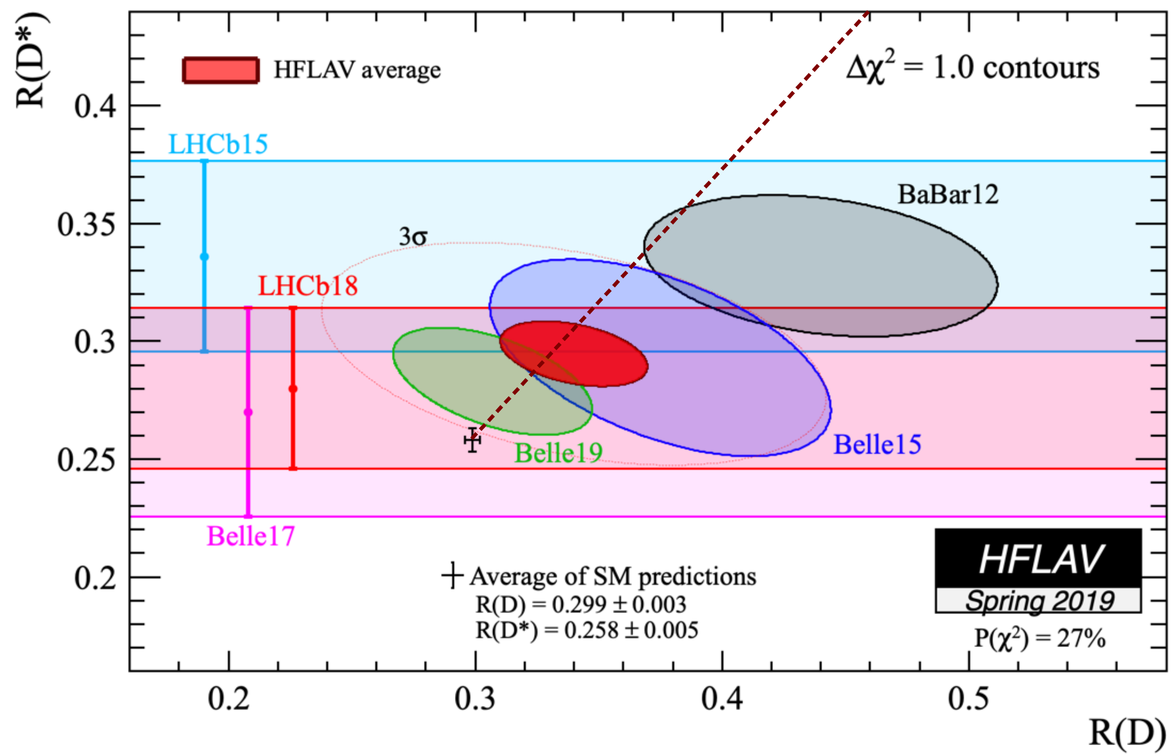
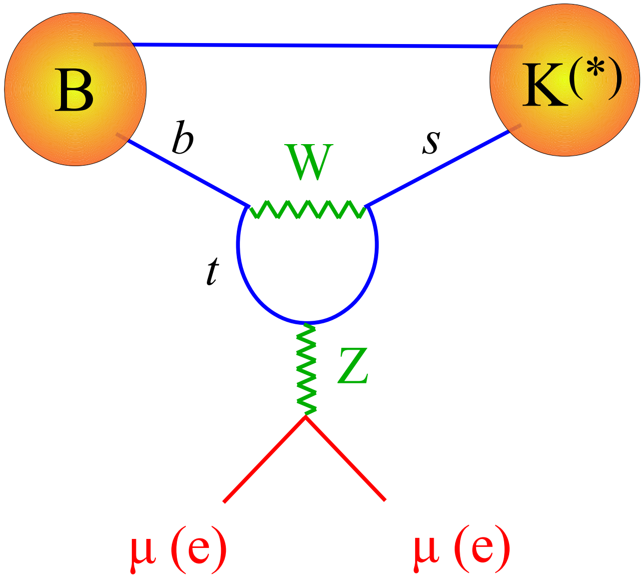






- SM prediction quite solid: hadronic uncertainties cancel (*to large extent*) in the ratio and deviations from 1 in $R(X)$ expected only from phase-space differences
- Consistent results by 3 different exps. $\to$ 3.1σ excess over SM ($D + D^*$)
- The two channels are well consistent with a universal enhancement (~30%) of the SM $b_L \to c_L\, \tau_L\, \nu_L$ amplitude

Rare $b \to s$ decays: generalities



Rare $b \to s$ decays: generalities

The largest (and statistically more significant) set of anomalies is the one extracted from rare decays mediated by $b \to s\, \ell^+\ell^-$ amplitudes [$\ell = \mu, e$]:

- P'_5 anomaly [$B \to K^*\mu\mu$ angular distribution]
- Smallness of all $B \to H_s\, \mu\mu$ rates [H_s=K, K^*, ϕ (from B_s)]
- LFU ratios (μ vs. e) in $B \to K^*\ell\ell$ & $B \to K\, \ell\ell$
- Smallness of BR($B_s \to \mu\mu$)

chronological order

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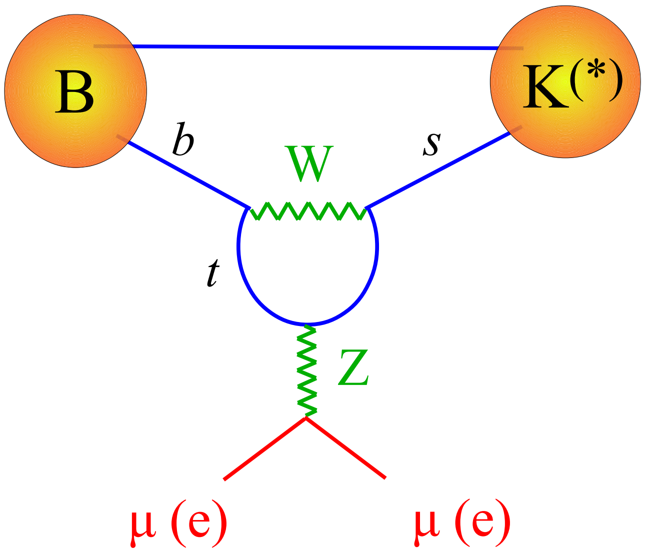
- LFU ratios (μ vs. e) in $B \to K^*\ell\ell$ & $B \to K\, \ell\ell$
- Smallness of BR($B_s \to \mu\mu$)

$b \to s\, ll$ transitions are Flavor Channing Neutral Current amplitudes

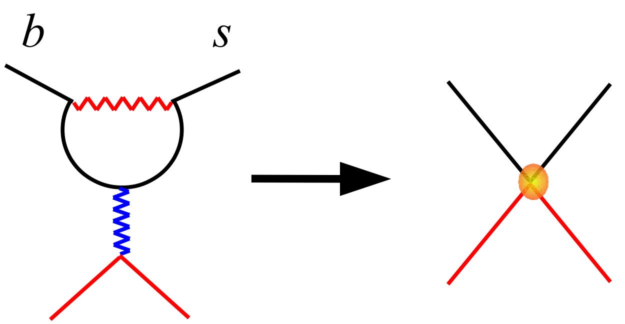
- No SM tree-level contribution
- Strong suppression within the SM because of CKM hierarchy
- Sizable hadronic uncertainties in the rates

→ detailed discussion needed

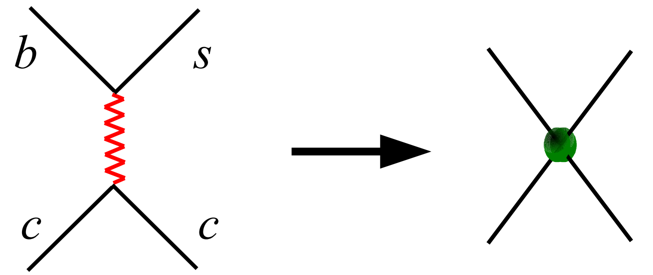


Three-step procedure to deal with the various scales of the problem:

1st step: Construction of a local eff. Hamiltonian at the electroweak scale integrating out all the heavy fields around m_W (including the heavy SM fields)



$$H_{\text{eff}} = \Sigma_i\, C_i(M_W)\, Q_i$$



FCNC operators:

$$Q_6 = \sum_q (\bar{b}_L \gamma_\mu s_L)\bar{q}\gamma^\mu q \quad \text{[Gluon penguin]}$$

$\vdots$

$$Q_9 = (\bar{b}_L \gamma_\mu s_L)\bar{l}\gamma^\mu l \quad [\gamma\ \&\ Z\ \text{penguin}]$$

$$Q_{10} = (\bar{b}_L \gamma_\mu s_L)\bar{l}\gamma^\mu \gamma_5 l \quad \text{[Z penguin]}$$

Four-quark (tree-level) ops.:

$$Q_1 = (\bar{b}_L \gamma_\mu s_L)(\bar{c}_L \gamma^\mu c_L)$$

$$Q_2 = (\bar{b}_L \gamma_\mu c_L)(\bar{c}_L \gamma^\mu s_L)$$

$\vdots$

The interesting short-distance info is encoded in the $C_i(M_W)$ (*initial conditions*) of the Wilson coefficients of the FCNC operators

2nd step: Evolution of H_{eff} down to low scales using RGE

$$H_{\mathrm{eff}} = \Sigma_i\, C_i(M_W)\, Q_i$$

$$\downarrow$$

$$H_{\mathrm{eff}} = \Sigma_i\, C_i(\mu \sim m_b)\, Q_i$$

Penguin operators:

$$Q_6 = \sum_q (\bar{b}_L \gamma_\mu s_L)\, \bar{q}\, \gamma^\mu q$$
$$\vdots$$
$$Q_9 = (\bar{b}_L \gamma_\mu s_L)\, \bar{l}\, \gamma^\mu l$$
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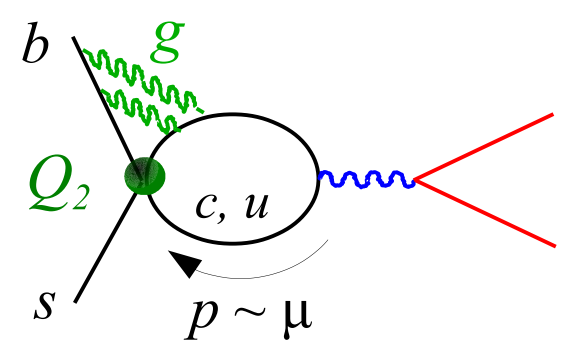
$$Q_2 = (\bar{b}_L \gamma_\mu c_L)(\bar{c}_L \gamma^\mu s_L)$$
$$\vdots$$

Potential dilution of the interesting short-distance information:

Mixing of the four-quark Q_i into the FCNC Q_i [perturbative long-distance contribution]

e.g.:

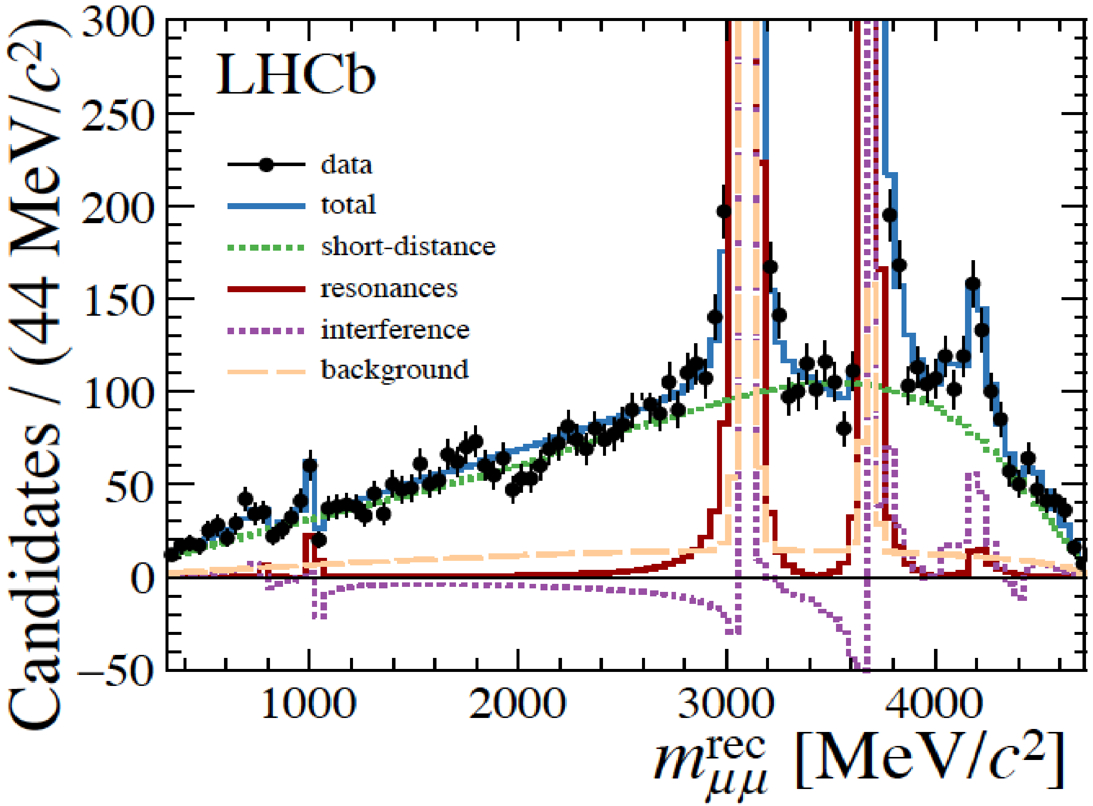


- Small in the case of the Z penguin (Q_{10}) because of the power-like GIM mechanism [mixing parametrically suppressed by $O(m_c^2/m_t^2)$]
- Large for gluon & photon penguins

3rd step: Evaluation of the hadronic matrix elements

$$A(B \to f) = \Sigma_i\, C_i(\mu)\ \langle f \,|\, Q_i \,|\mathrm{B}\, \rangle\, (\mu) \qquad\qquad [\ \mu \sim m_b\ ]$$

- Hadronic uncertainty due to form factors (as in charged-currents)
- Irreducible th. error due to long-distance effects not included in f.f. (*charm* threshold $\to$ particularly large close to $\underline{cc}$ resonances)



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- Hadronic uncertainty due to form factors (as in charged-currents)
- Irreducible th. error due to long-distance effects not included in f.f. (*charm* threshold $\to$ particularly large close to $c\bar{c}$ resonances)

Still, we can make precise prediction in appropriate ratios and/or constructing observables insensitive to long-distance effects.

As far as current anomalies are concerned:

P'_5 anomaly [$B \to K^* \mu\mu$ angular distribution]

Smallness of all $B \to H_s\, \mu\mu$ rates [H_s=K, K^*, ϕ (from B_s)]

LFU ratios (μ vs. e) in $B \to K^* \ell\ell$ & $B \to K\, \ell\ell$

Smallness of BR($B_s \to \mu\mu$)

= th. error very small ($\lesssim$1%)

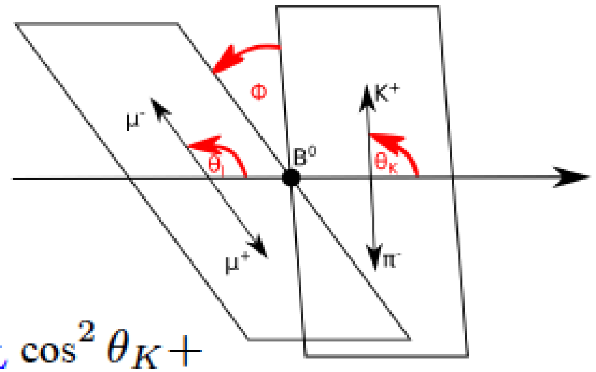
= th. error few %

The $b \rightarrow s\ \ell\ell$ *anomalies*

The $b \to s\ell\ell$ anomalies

I. The P'_5 anomaly

The $B \to K^{*}\mu\mu$ differential distribution:



$$\frac{d^4(\Gamma+\bar{\Gamma})}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi\, dq^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K +$$
$$\frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell +$$
$$S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi +$$
$$S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_\ell +$$
$$S_7\sin 2\theta_K\sin\theta_\ell\sin\phi +$$
$$S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

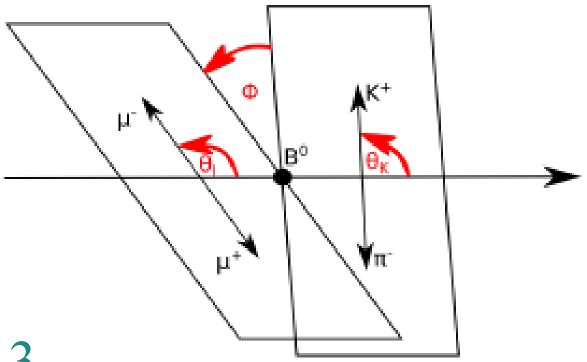
$$P'_{4,5} = \frac{S_{4,5}}{\sqrt{F_L(1-F_L)}}$$

observables designed to cancel f.f. dependence in the heavy-quark limit

Descotes-Genon, Matias, Ramon, Virto '12

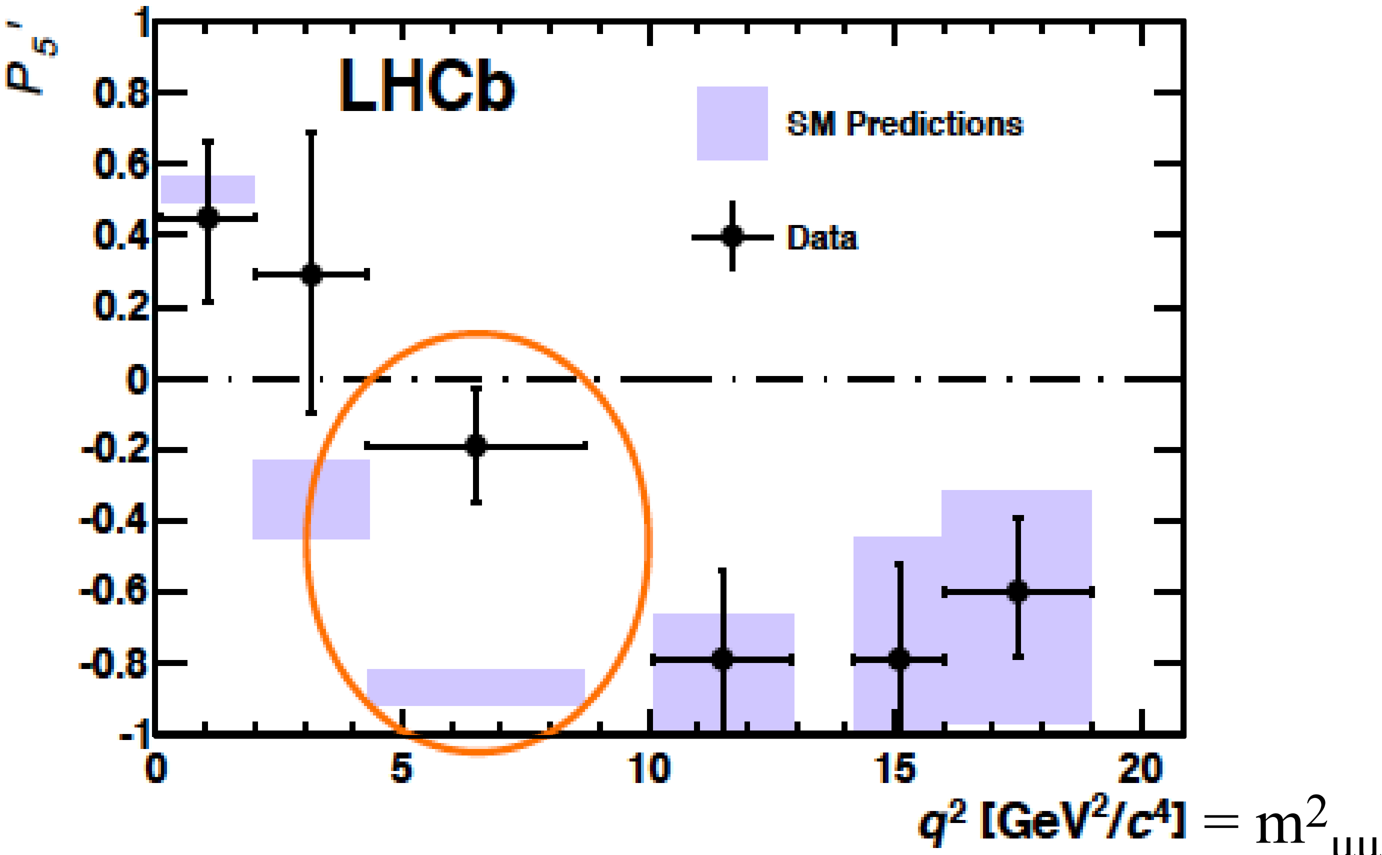
The $b \to s\ell\ell$ anomalies

I. The P'_5 anomaly



The $B \to K^* \mu\mu$ differential distribution:

2013



▶ *The $b \to s\ell\ell$ anomalies*

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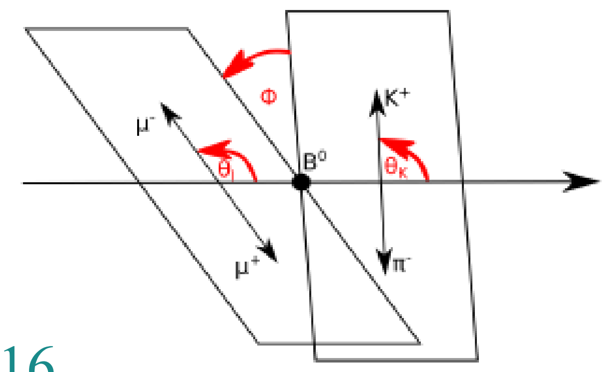
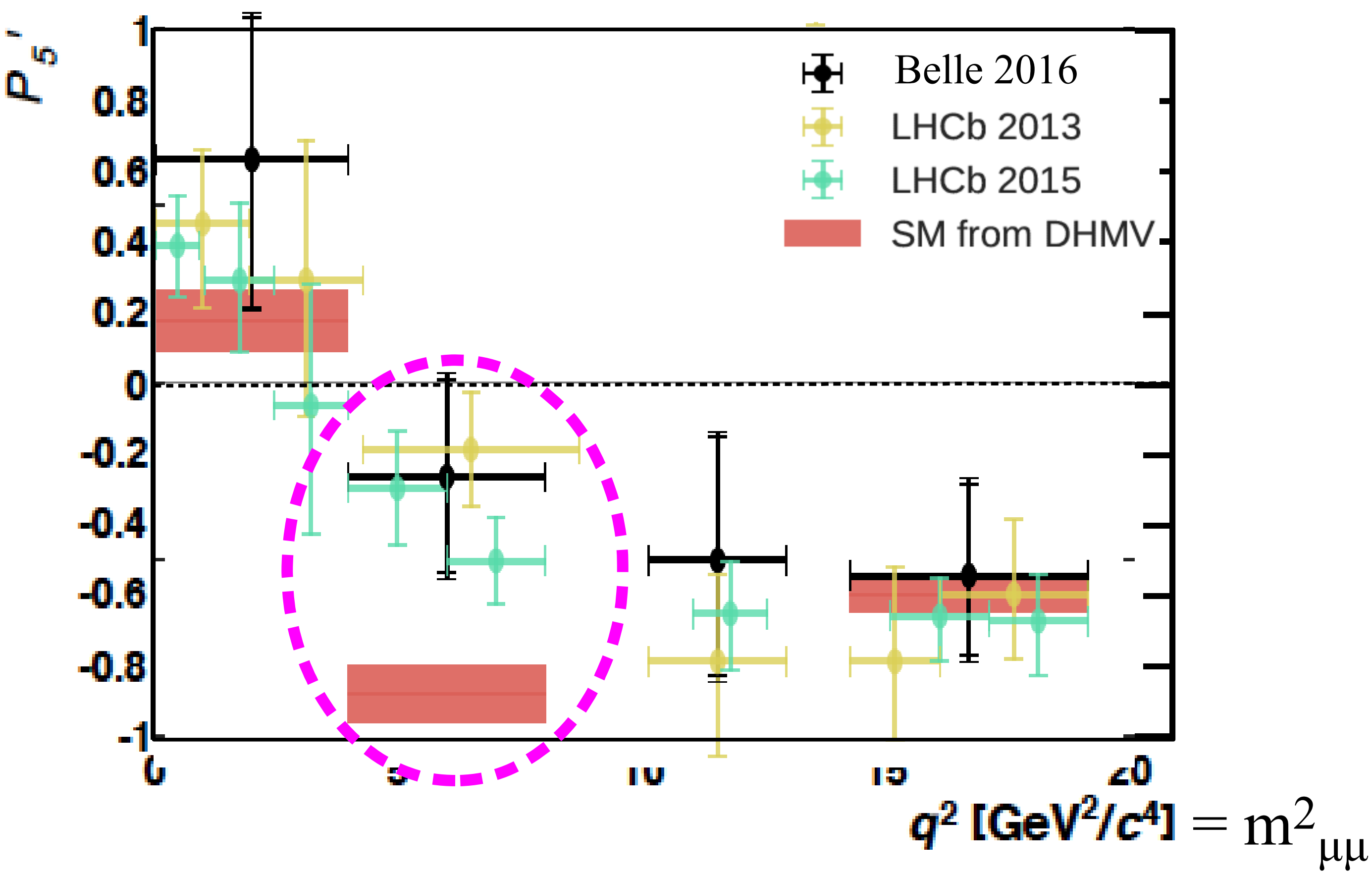


2016



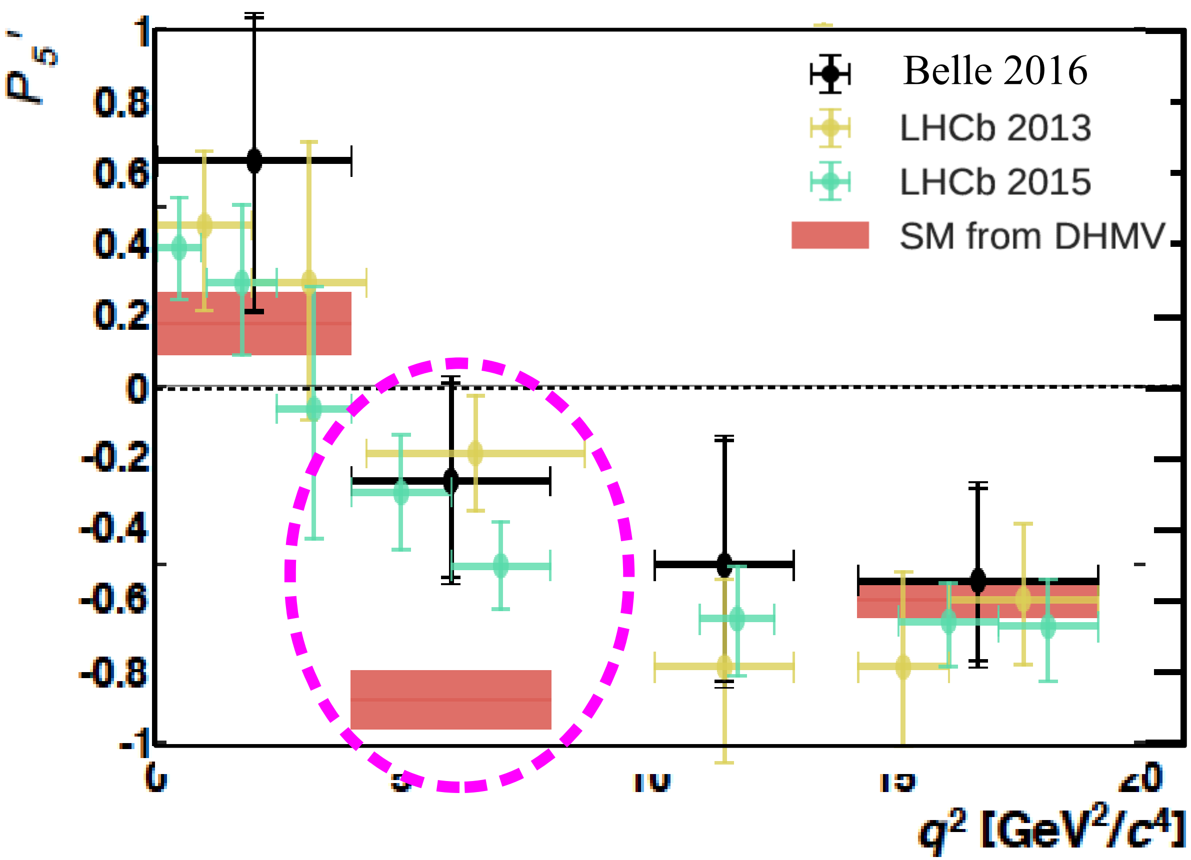
The $b \to s\ell\ell$ anomalies

I. The P'_5 anomaly [$B \to K^* \mu\mu$ differential distribution]

+

II. The smallness of $d\Gamma(B \to H_s\, \mu\mu)$ in several modes [H_s = K, K*, ϕ (from Bs)]

2016



Pro NP:

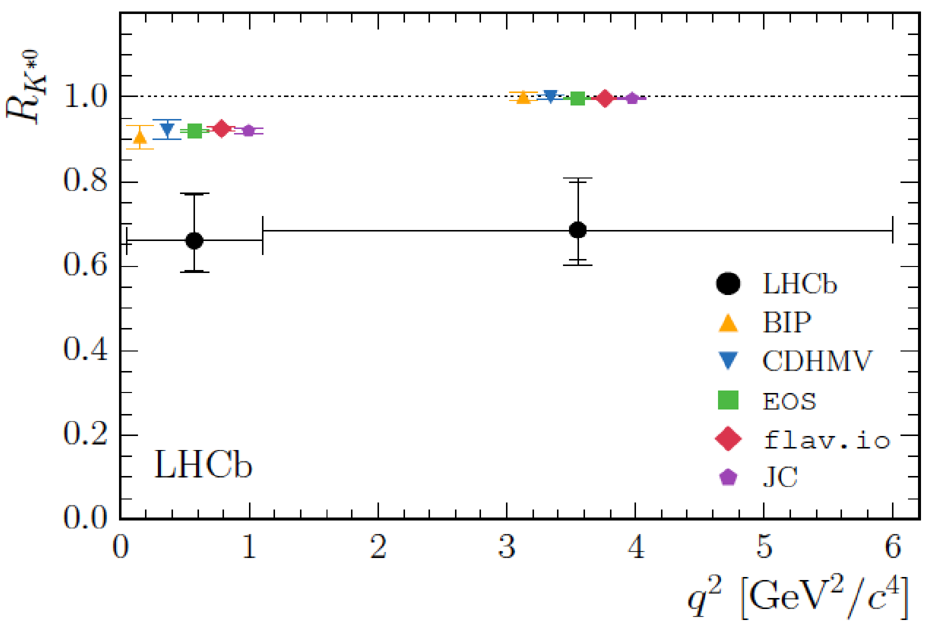
Reduced tension in all the observable *-in all bins-* with a unique fit of non-standard $C_i(M_W) \to$ compatible with effect of short-distance origin [*non-trivial:* O(100) *observ. few Wilson coeff.*]

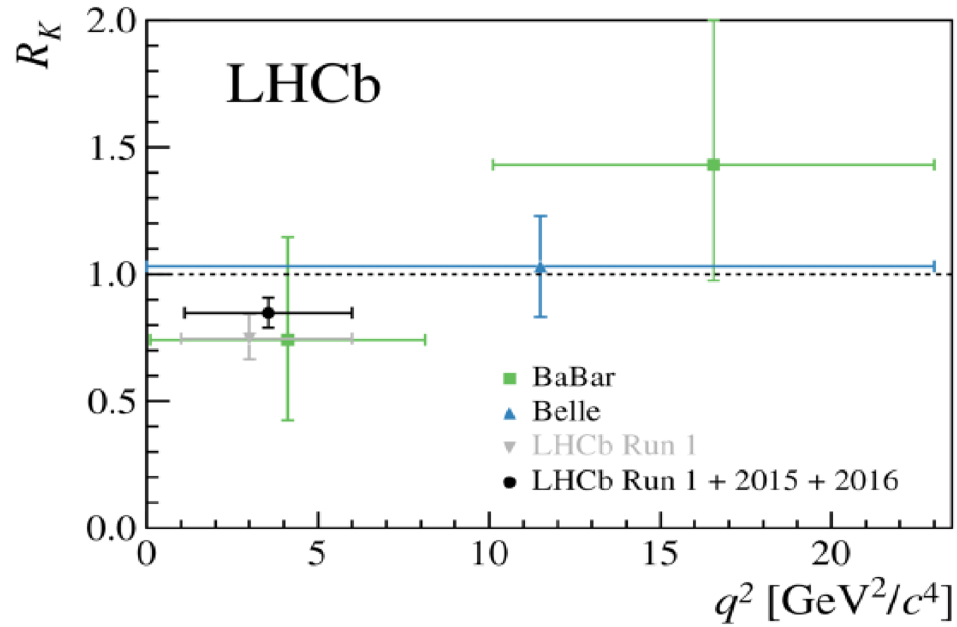
Against NP:

Non-standard effect mainly driven by C_9 ($\leftrightarrow$ *charm loops*) $\to$ significance reduced with conservative estimates of long-distance corrections

The $b \to s\ell\ell$ anomalies

III. The "clean" LFU ratios: $$R_H = \frac{\int d\Gamma(B \to H\,\mu\mu)}{\int d\Gamma(B \to H\,ee)}$$





Deviations from the (*precise & reliable*) SM predictions ranging from 2.2σ to 2.5σ in each of the 3 bins measured by LHCb

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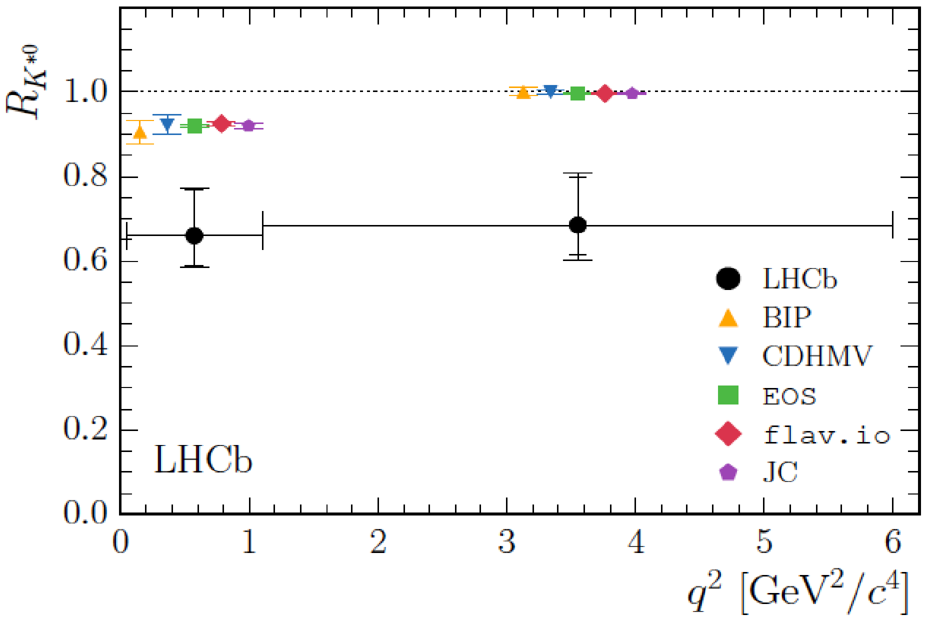
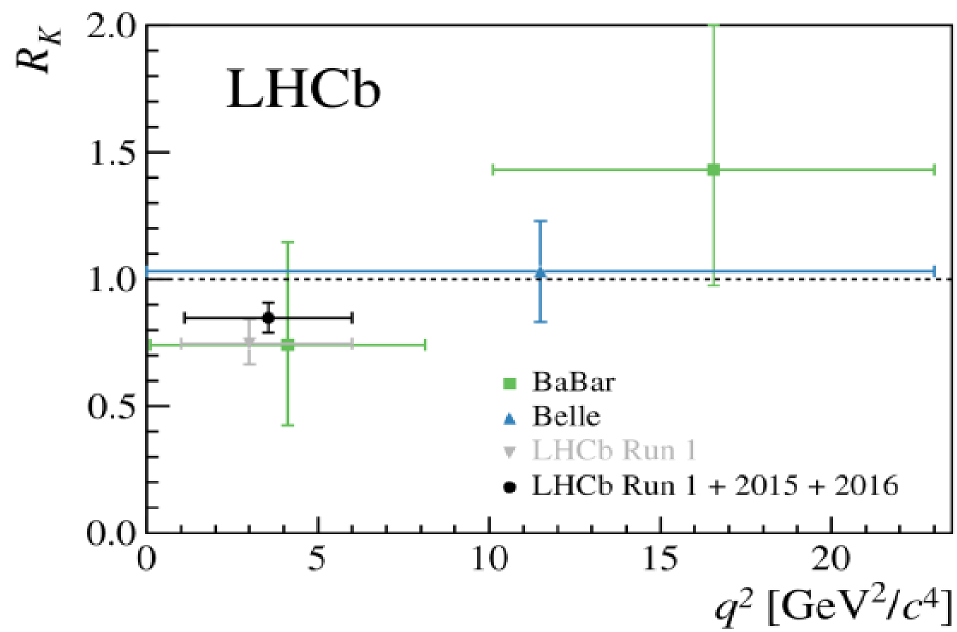
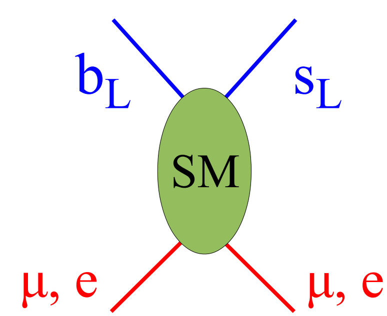
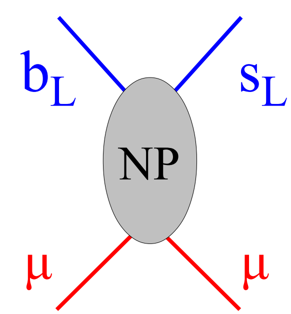




Deviations from the (*precise & reliable*) SM predictions ranging from 2.2σ to 2.5σ in each of the 3 bins measured by LHCb

What is particularly remarkable is that both these LFU breaking effects & the anomalies (I.+II.) are well described by the same set of Wilson coeff. assuming NP only in $b \to s\mu\mu$ and (& not in ee)





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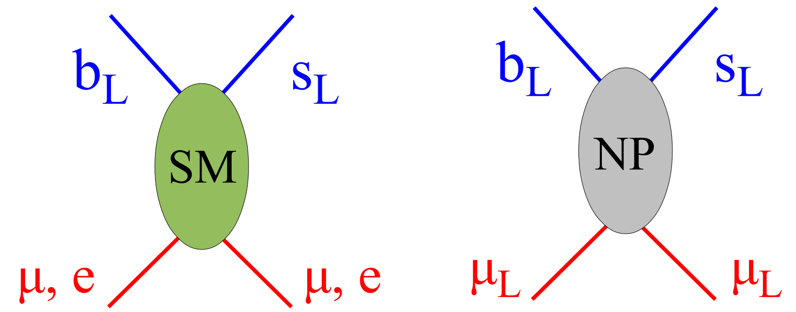

Despite the significance has not increased with the release of new data in 2019, the overall consistency has further increased, as well as the evidence that the putative NP effects come from a pure left-handed operator → expected suppression of BR($B_s \to \mu\mu$) by ~ 20% compared to its SM expectation:

IV.

$$BR(B_s \to \mu\mu)_{SM} = (\,3.57 \pm 0.17\,) \times 10^{-9}$$
$$BR(B_s \to \mu\mu)_{exp} = (\,2.65 \pm 0.43\,) \times 10^{-9}$$

[LHCb+CMS+ATLAS '19]

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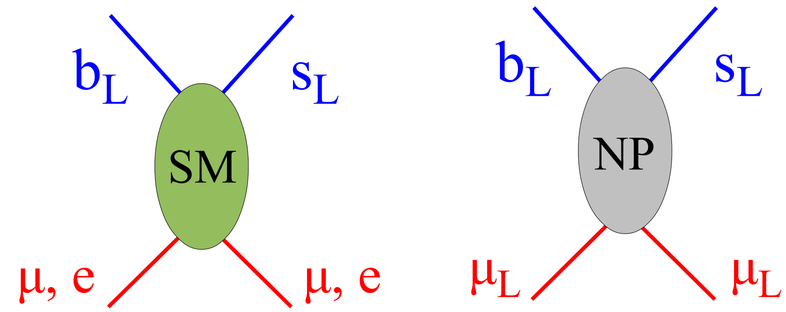

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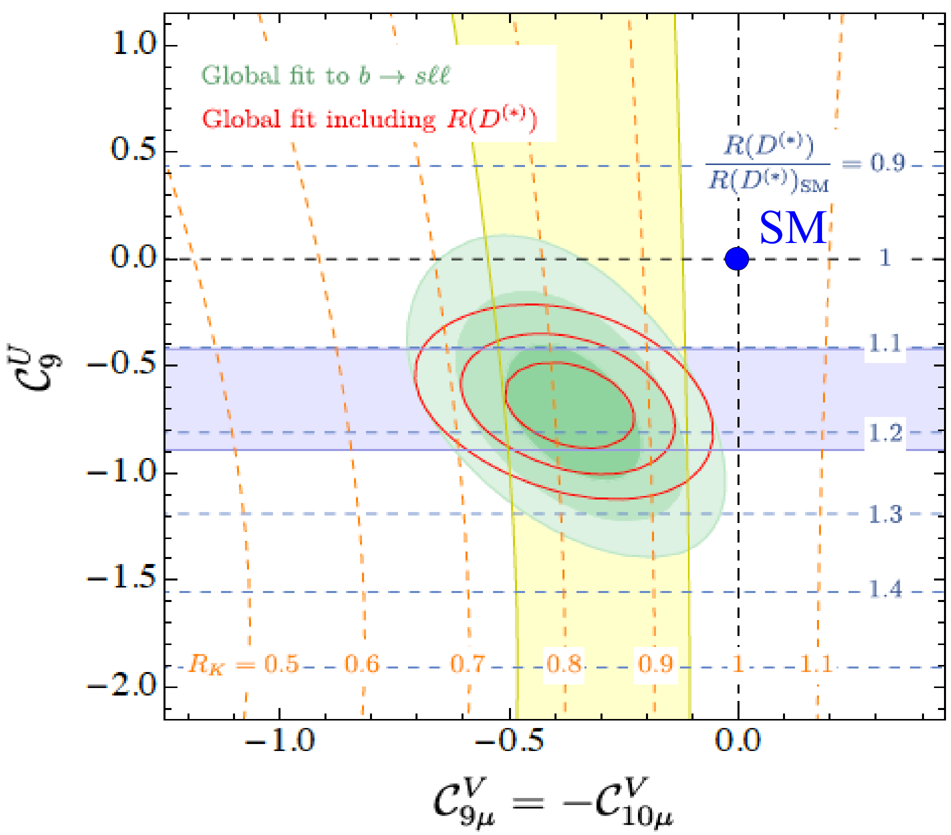
A super-conservative analysis, taking into account only the observables III. & IV, with a single NP operator, leads to a pull of 3.2σ compared to the SM.

The $b \to s\ell\ell$ anomalies

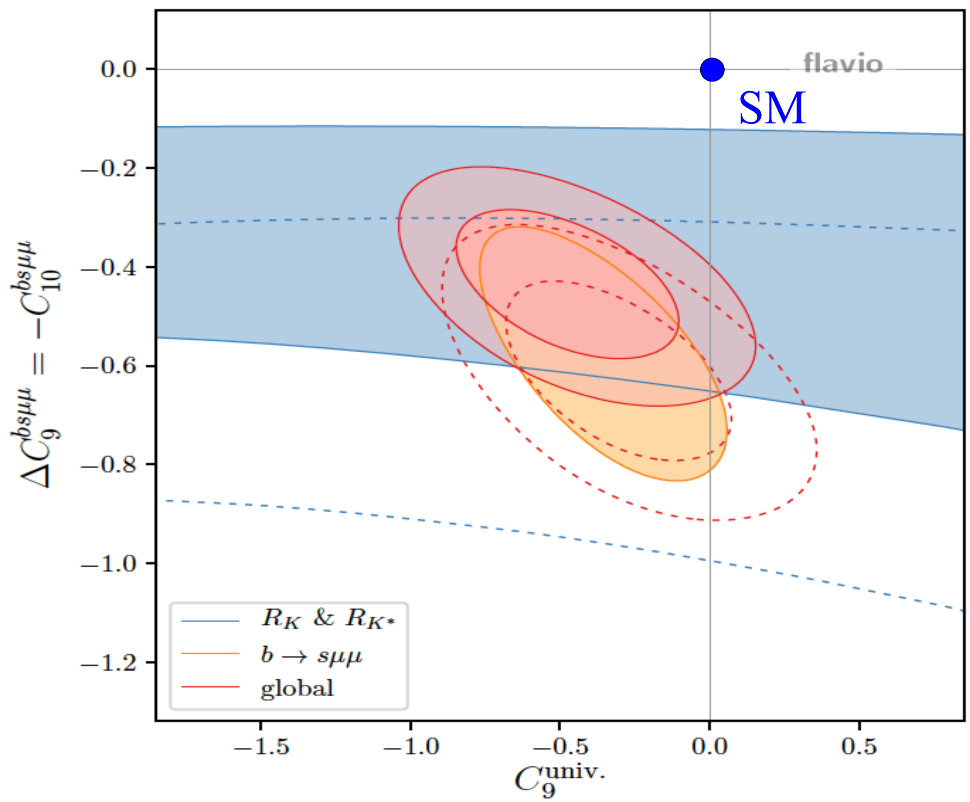
A super-conservative analysis, taking into account only the observables III. & IV, with a single NP operator, leads to a pull of 3.2σ compared to the SM.

More sophisticated analyses, taking into account all observables, with state-of-the-art estimates of hadronic form factors + realistic (*but somehow model-dependent*) estimates of long-distance effects → pulls exceeding 5σ:

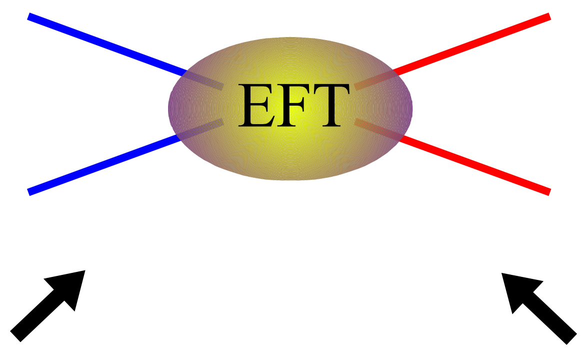
Alguero *et al.* '19

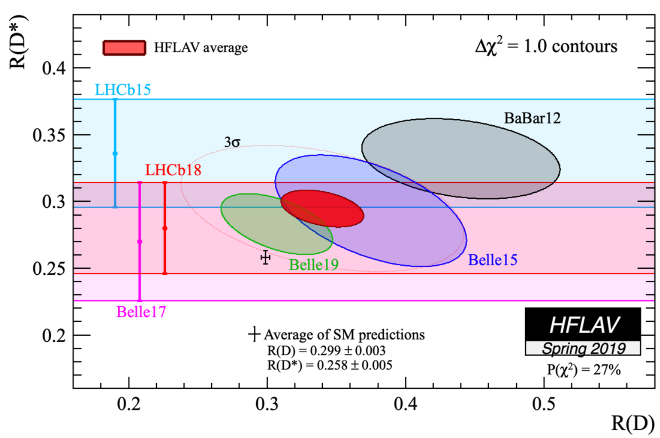


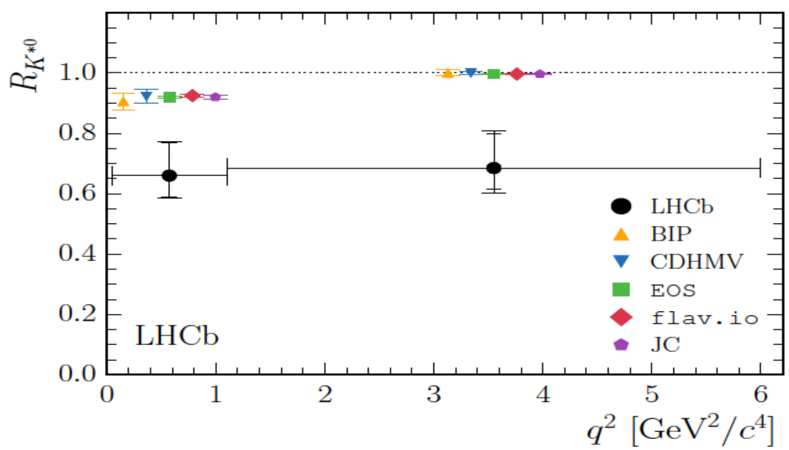
Aebischer *et al.* '19



EFT approaches to the anomalies







EFT approaches to the anomalies

These recent results have stimulated a lot of theoretical activity
(*not particularly instructive to discuss all NP proposals put forward so far...*)

What I will discuss next is a bottom-up approach made of three main steps:

Generic EFT approach – with flavor symmetries

↓

Simplified Dynamical Models & high-energy signatures

↓

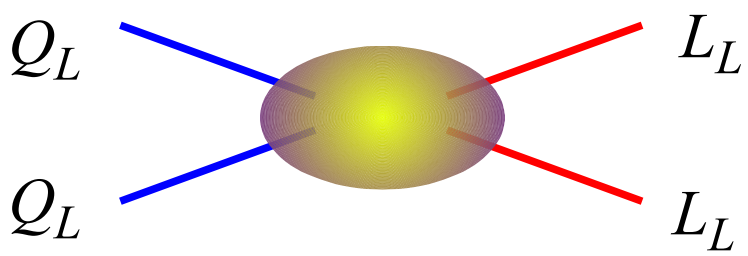
Possible UV completions

The main guide will be the attempt to describe both LFU effects within the same framework [*possibly linking them to the observed pattern of Yukawa couplings*] and, while "going up" in energies (and assumptions)

Check the consistency & derive predictions for
- other low-energy observables
- high-pT physics

EFT approaches to the anomalies

- Anomalies are seen (*so far...*) only in semi-leptonic (quark×lepton) operators
- Data largely favor non-vanishing left-handed current-current operators, although other contributions are also possible



Bhattacharya *et al.* '14
Alonso, Grinstein, Camalich '15
Greljo, GI, Marzocca '15
(+many others...)

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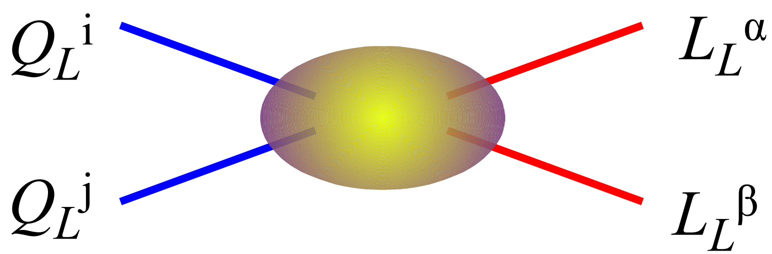

$$\frac{F_{ij\alpha\beta}}{\Lambda^2}\ \bar{Q}_L{}^i\,\Gamma\, Q_L{}^j\ \bar{L}_L{}^\alpha\,\Gamma\, L_L{}^\beta$$

- Large coupling (competing with SM tree-level) in $bc \to l_3\, \nu_3$
- Small non-vanishing coupling (competing with SM FCNC) in $bs \to l_2\, l_2$

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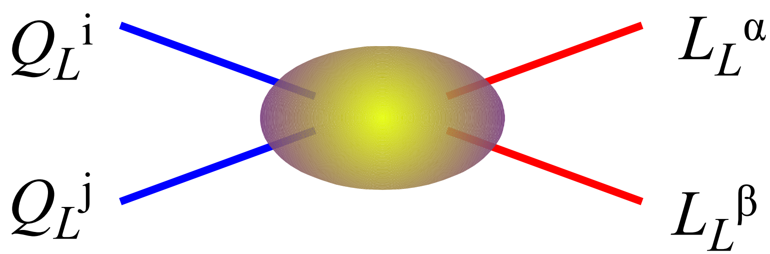

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- Large coupling (competing with SM tree-level) in bc $\to$ $l_3\,\nu_3$
- Small non-vanishing coupling (competing with SM FCNC) in bs $\to$ $l_2\,l_2$

$$F_{ij\alpha\beta} = (\delta_{i3}\times\delta_{3j})\times(\delta_{\alpha 3}\times\delta_{3\beta})\ +$$ small terms for 2^{nd} (& 1^{st}) generations

Link to pattern of the Yukawa couplings !

EFT approaches to the anomalies

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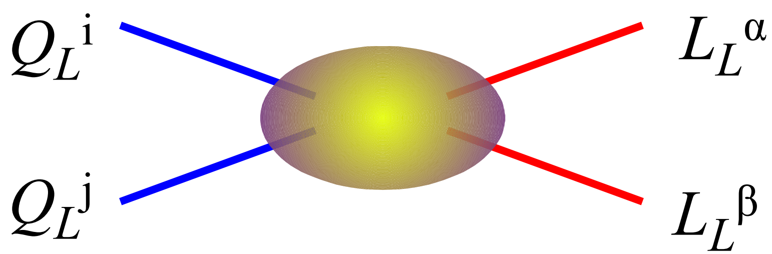
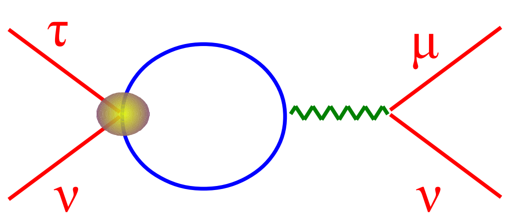


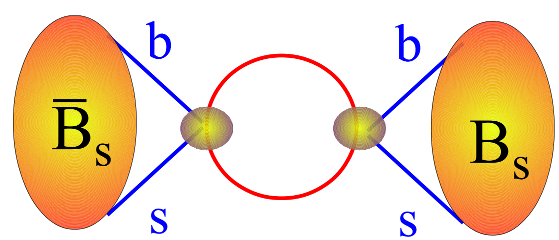
$$\frac{F_{ij\alpha\beta}}{\Lambda^2}\;\bar{Q}_L^{\,i}\,\Gamma\,Q_L^{\,j}\;\bar{L}_L^{\,\alpha}\,\Gamma\,L_L^{\,\beta}$$

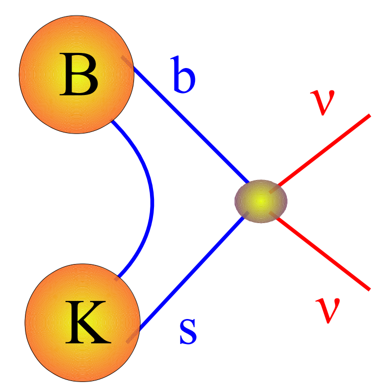
Long list of constraints [FCNCs + semi-leptonic b decays + π, K, τ decays + EWPO]

E.g:



Feruglio, Paradisi, Pattori '16





Calibbi, Crivellin, Ota, '15
(+many others...)

+ *many more...*

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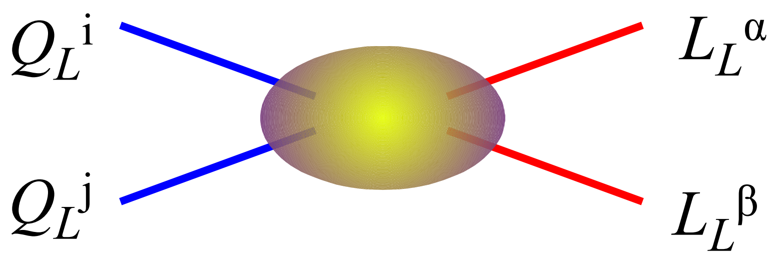

$$\frac{F_{ij\alpha\beta}}{\Lambda^2}\, \bar{Q}_L^i\, \Gamma\, Q_L^j\, \bar{L}_L^\alpha\, \Gamma\, L_L^\beta$$

Long list of constraints [FCNCs + semi-leptonic b decays + π, K, τ decays + EWPO]

↓

Essential role of *flavor symmetries*, not only to explain the pattern of the anomalies, but also to "protect" against too large effects in other low-energy Observables.

We need to go *beyond MFV*, but we must somehow retain many of its good phenomenological features...

EFT-type considerations

The attempt to link the anomalies to the structure of the Yukawa couplings reinforce the idea of a connection among the two, and points toward NP at the TeV scale → "hint" of a possible connection (*still to be understood...*) to the hierarchy problem

N.B.: such link is lost in high-scale NP models addressing only R_K

$b \to c\, \tau\nu$ → $\Lambda|_{R_D} < 9$ TeV

$b \to s\, \mu\mu$ → $\Lambda|_{R_K} < 84$ TeV

Di Luzio, Nardecchia '17

Hierarchy problem ?

Yukawa structure ?

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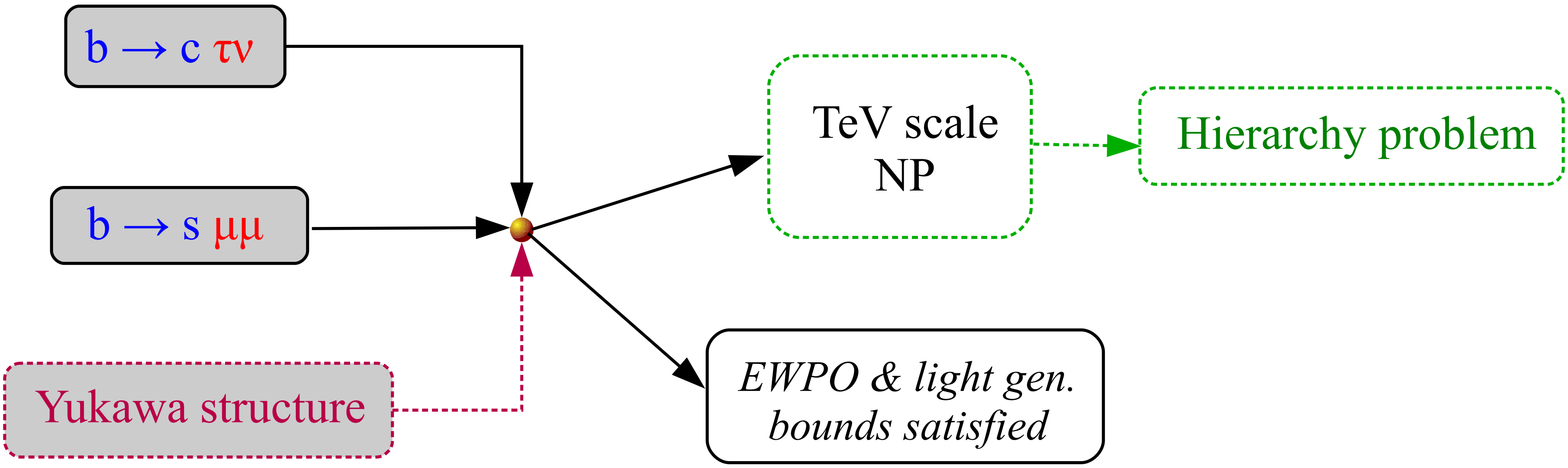

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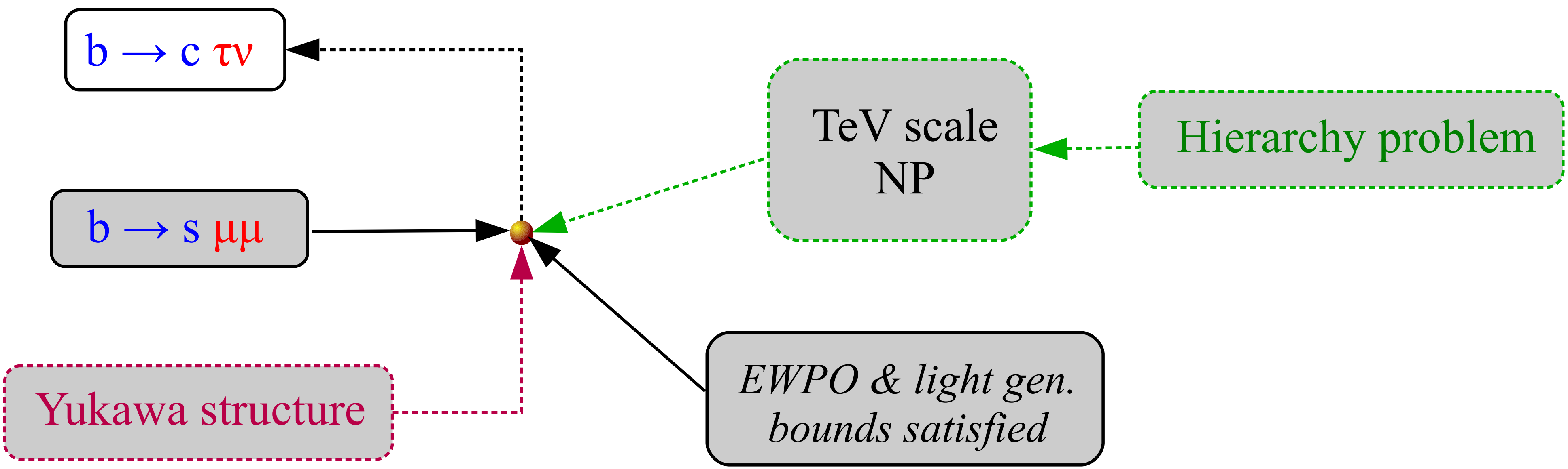
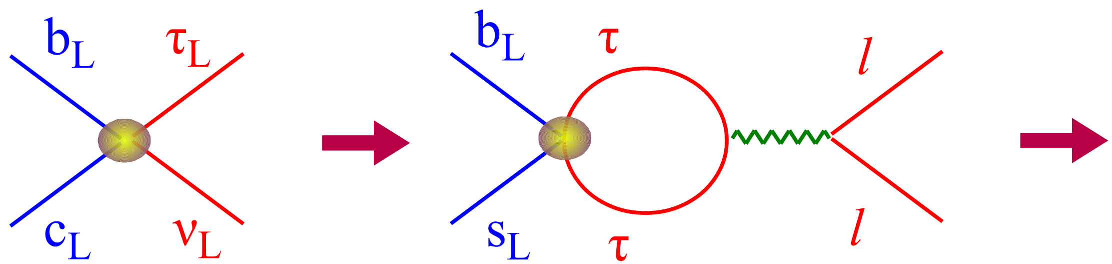
[$\Delta R_D \sim (3\% - 50\%)$ depending on the flavor-breaking structure]



EFT-type considerations

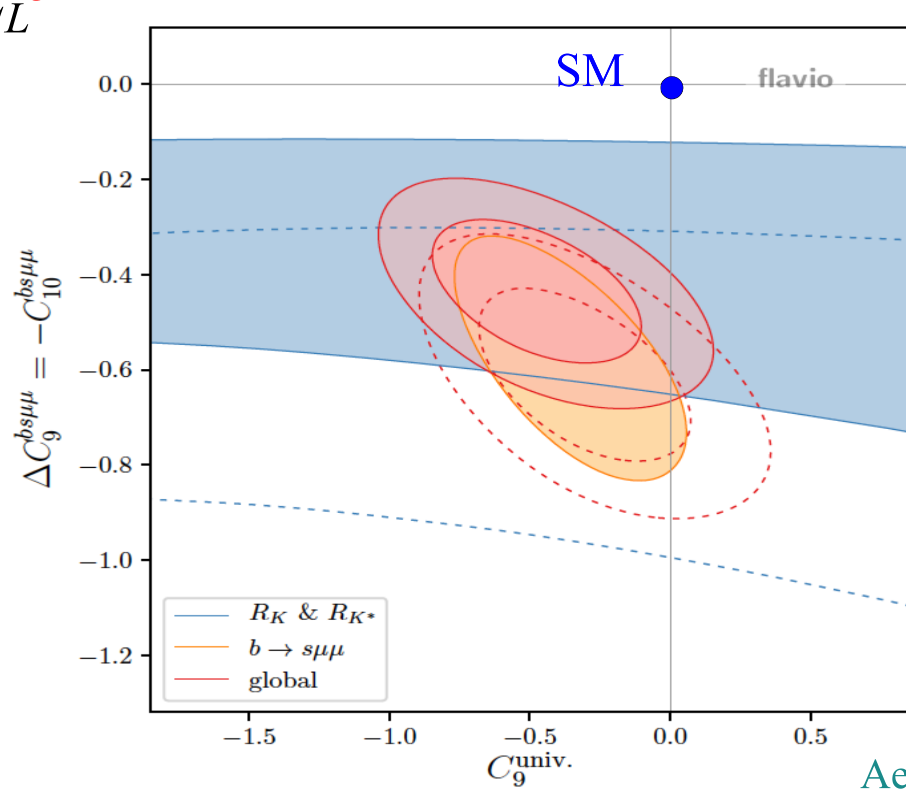
Interestingly, present data already provide a (weak) indication of the connection among the two anomalies within a rather general EFT hypothesis



non-standard but
LF universal
contribution to C_9

Crivellin, Greub, Muller, Saturnino '19

$$\bar{Q}_L^{\,2}\,\Gamma\, Q_L^{\,2}\, \bar{L}_L^{\,3}\,\Gamma\, L_L^{\,3}$$



Aebischer *et al.* '19