$b \to sll$ decays as probe of New Physics

[*what we learned & what we still hope to learn*]

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- Introduction
- A brief look to the data
- *What have we learned?* [3 general BSM lessons]
- An explicit model to address the anomalies
- *What do we still hope to learn?*
- Conclusions

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Introduction

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I would have answered: "*very little*" (*as I guess many theory colleagues…*)

Motivating the answer with

- No evidence of New Physics at high-pT
- SM-like Higgs particle

→ "heavy" NP

- No evidence of New Physics in a series of "clean" flavor-changing observables, such as $\Delta F=2$, but also $b \to s\gamma$ & $B_s \to \mu\mu$

→ MFV-like NP

- Difficulty of making precise ("clean") SM tests in $B \to K^{(*)}ll$ decays

→ LFU tests no so interesting...

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3^{rd} gen. special
$MFV \to U(2)^n$

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→ ~~LFU tests no so interesting…~~

LFU tests are very interesting !

Already since 2015 I give a completely different answer…!

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3rd gen. special
MFV → $U(2)^n$

flavor non-universal interactions

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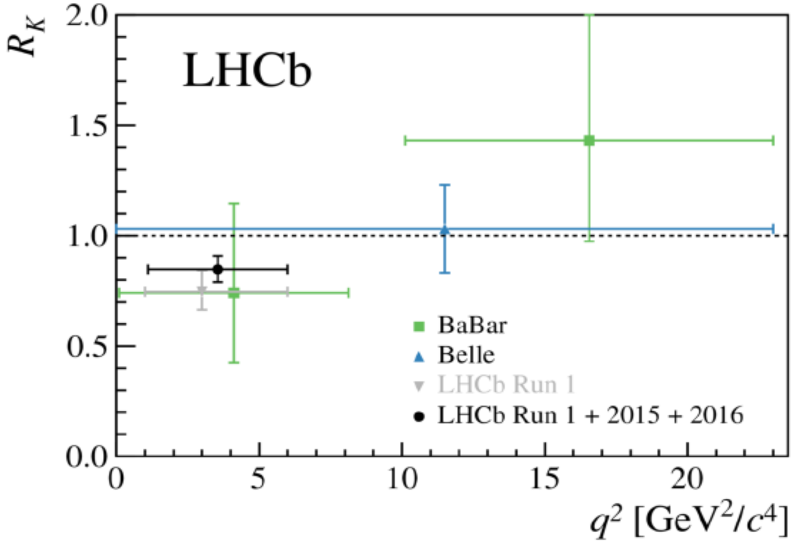
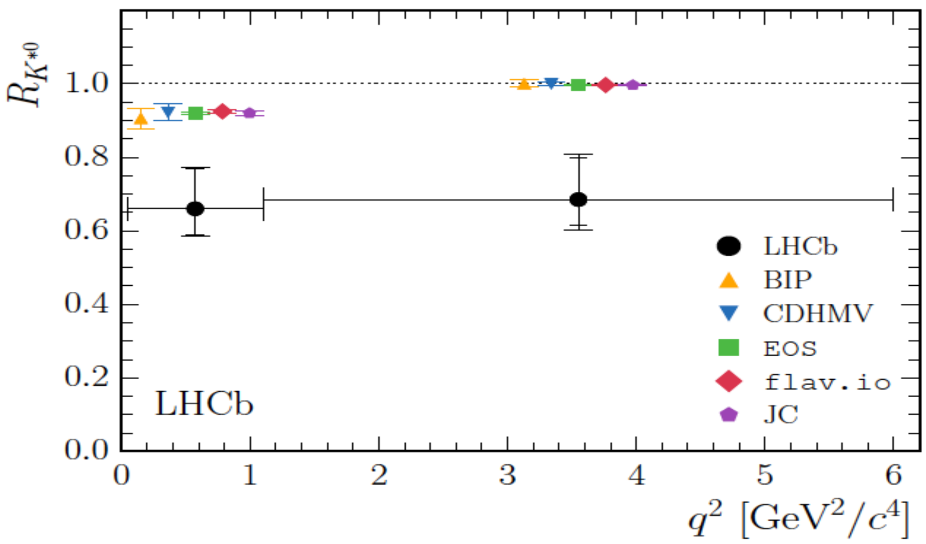
Thanks to the recent $B \to K^{(*)}ll$ data, we have abandoned a few theory prejudices & identified (*partially rediscovered*) *very interesting directions in model building*

A brief look to the data



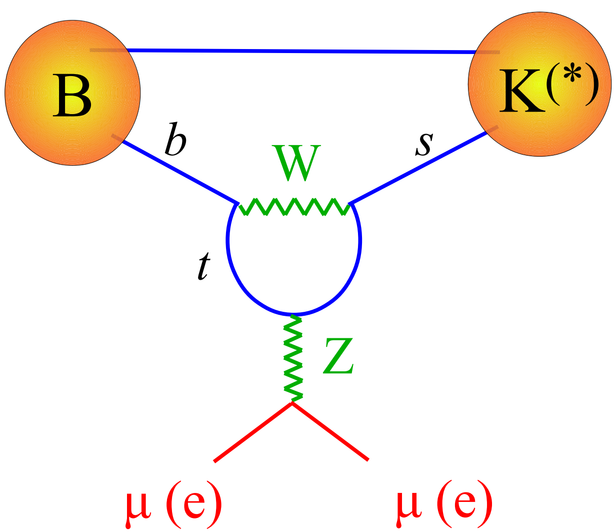


A brief look to the $b \to sll$ anomalies

Starting from 2013, a series of "anomalies" started to appear in exclusive B meson decays of the type $b \to s\,\ell^+\ell^-$ [$\ell = \mu$, 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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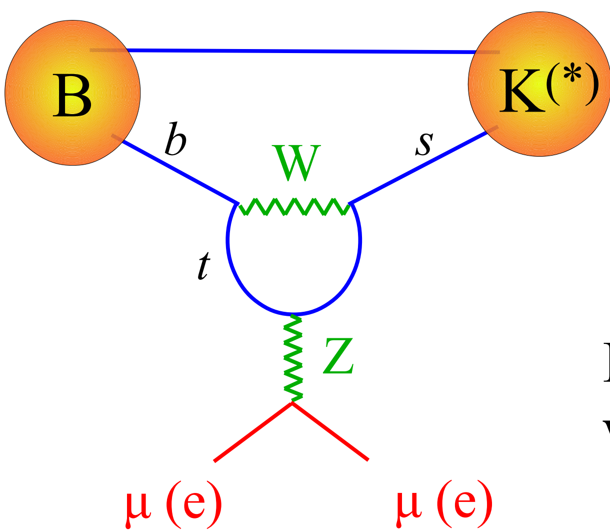
th. error <1%

th. error few %



Dealing with exclusive modes, some of these observables are affected by irreducible theory errors (*form factors*, *long-distance contributions*).

In the following I will briefly highlight only those with small errors

But the striking observation is that the picture of all the data is extremely coherent, pointing to well-defined non-SM effects (of short-distance origin).

A brief look to the $b \to sll$ anomalies

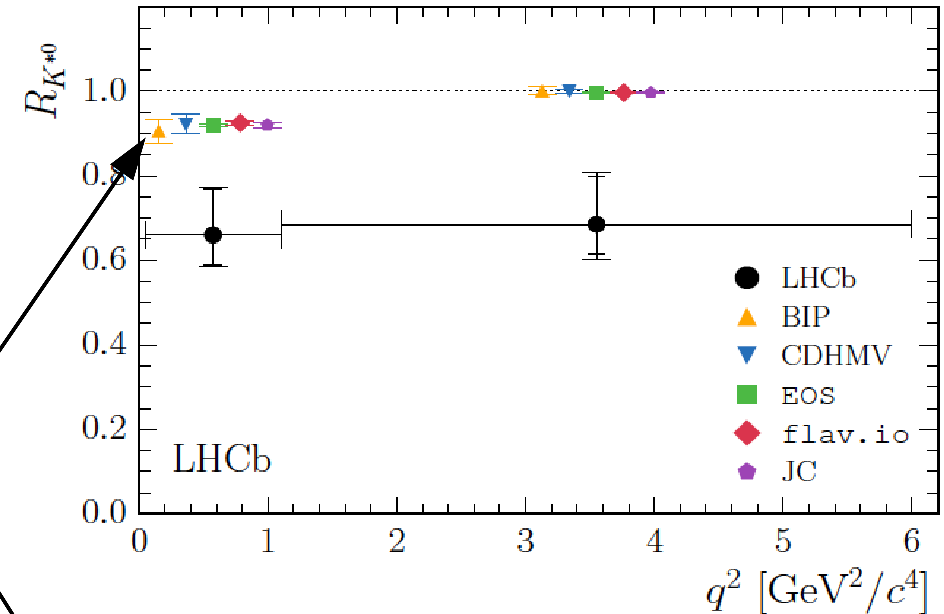
- The "clean" Lepton Flavor Universality ratios:

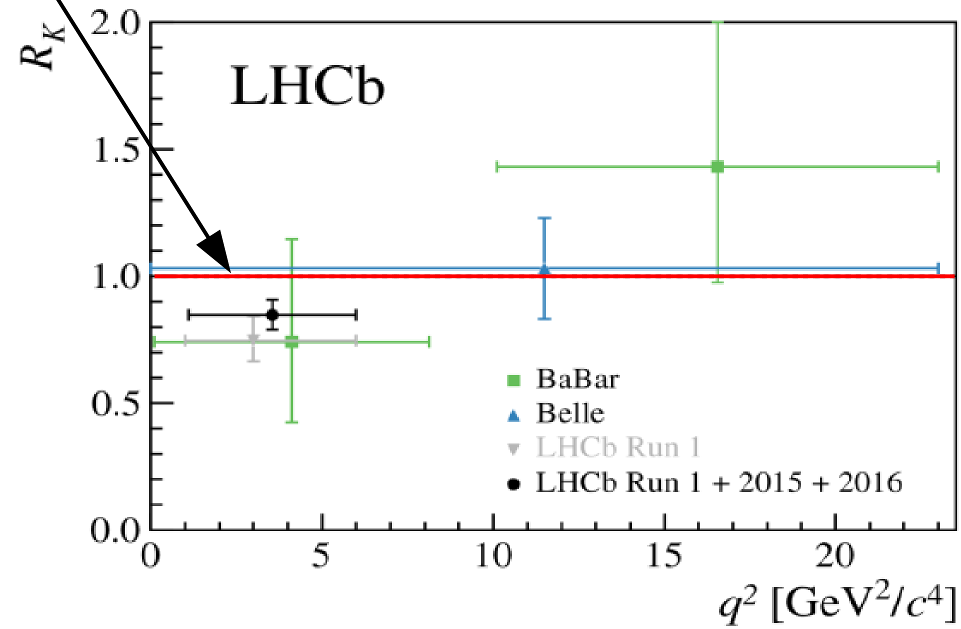
$$R_H = \frac{\int d\Gamma(B \to H\,\mu\mu)}{\int d\Gamma(B \to H\,ee)} \qquad (H = K, K^*)$$

SM prediction very robust: $(R_H) = 1$
[*up tiny QED and lepton mass effects*]

Bordone, GI, Pattori '16

Deviations from the SM predictions ranging from 2.2σ to 2.5σ in each of the 3 bins measured by LHCb

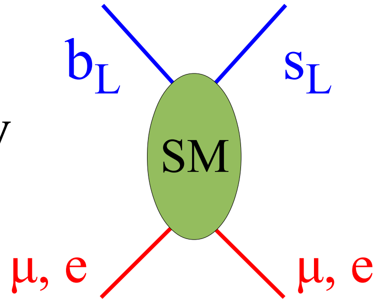


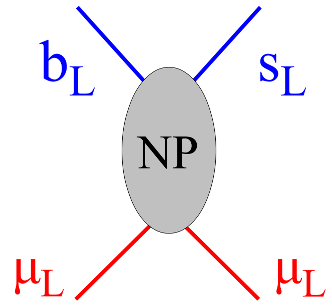


A brief look to the $b \to sll$ anomalies

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

To a large extent, these LFU breaking effects are described by the same set of Wilson coeff. necessary to describe the BR and angular anomalies if we assume NP only in $b \to s\mu\mu$ and (& not in ee)





The significance of the LFU observables alone has not increased in 2019, but the overall consistency with other data has further increased in 2019-2020, as well as the evidence that the putative NP effects come from a pure left-handed operator

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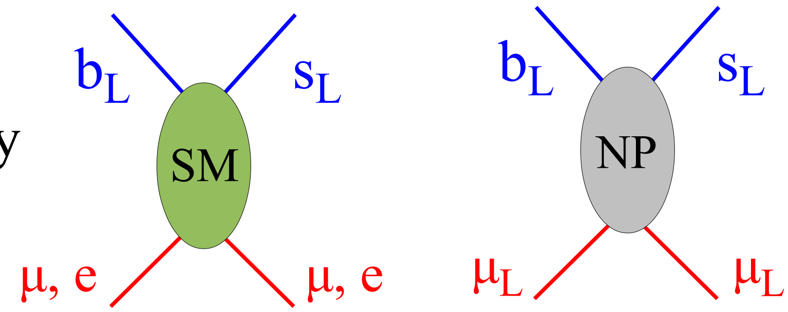

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- Expected suppression of $BR(B_s \to \mu\mu)$ of ~20% compared to its SM value:

$$BR(B_s \to \mu\mu)_{SM} = (3.66 \pm 0.14) \times 10^{-9}$$ Beneke *et al.* '19

$$BR(B_s \to \mu\mu)_{exp} = (2.72 \pm 0.34) \times 10^{-9}$$ ATLAS+CMS+LHCb '19

2.6σ

A super-conservative analysis, taking into account only the observables III. & IV, with a single NP operator, leads to a pull of $\boxed{4.2\sigma}$ compared to the SM.

→ More later today...

What have we learned?

What have we learned?

- The $b \to s\ell\ell$ data show a convincing evidence of LFU violation (μ vs. e) in a rare (FCNC) process
- An independent (slightly less significant, $\sim 3\sigma$) evidence of LFU violation (τ vs. μ) occurs in charged-current semi-leptonic decays $b \to c\ell\nu$

→ More tomorrow...

IF taken together, this is probably the largest "coherent" set of deviations from the SM we have ever seen...

↓ *Three main messages for BSM physics*

(that remains valid/interesting even if (some of) the anomalies will go away)

LFU violation & flavor-non-universal interactions

The role of flavor symmetries

The Return of the Leptoquark

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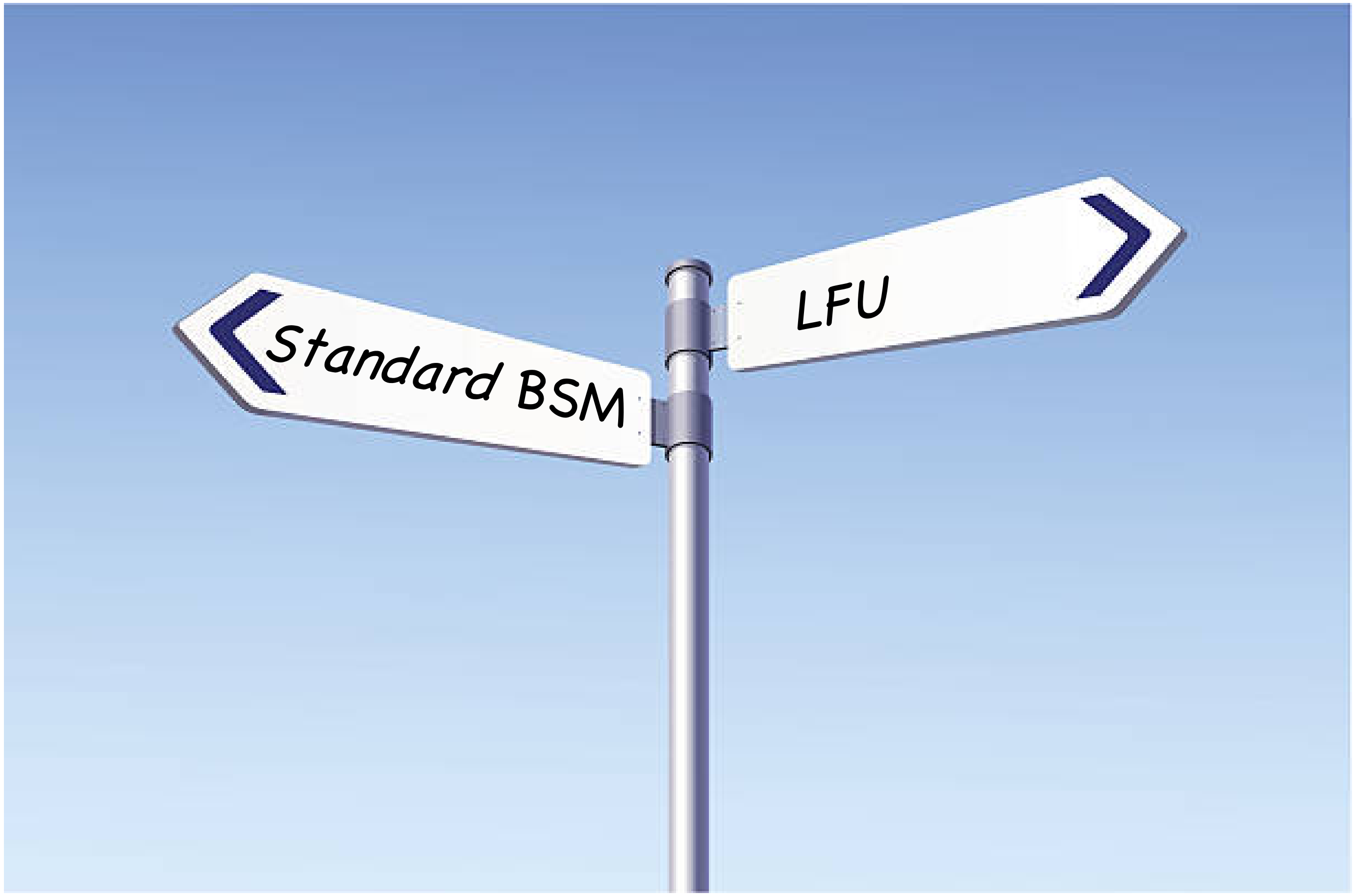

I. *LFU violation and flavor non-universal interactions*

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:

$$\mathscr{L}_{\rm SM} = \mathscr{L}_{\rm gauge}(A_{\rm a}, \psi_{\rm i}) + \mathscr{L}_{\rm Higgs}({\rm H}, A_{\rm a}, \psi_{\rm i})$$

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

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

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%]

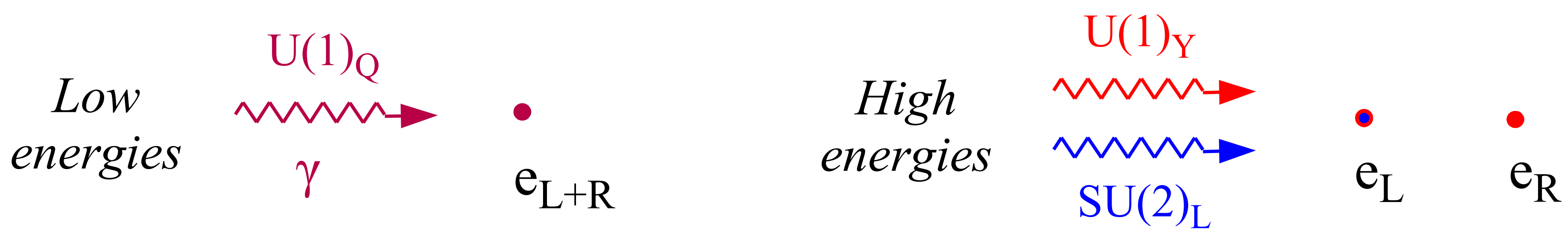
This is why is often assumed as a "sacred principle"....

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

I. *LFU violation and flavor non-universal interactions*

LFU becomes a natural possibility when we consider the flavor universality of the SM gauge sector as pure low-energy property, conceiving underlying interactions which are genuinely flavor non-universal at high energies

We are well aware that the "elementary fields" of QED, namely the Dirac-type elector and the photon are not the elementary constituents of the SM Lagrangian



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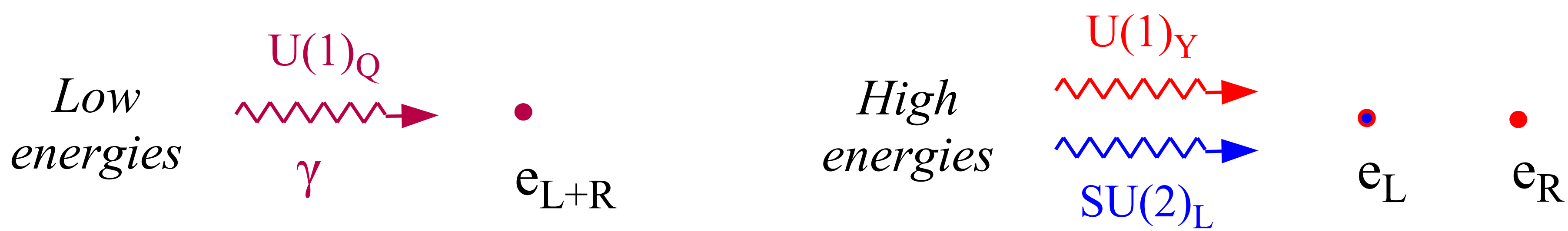
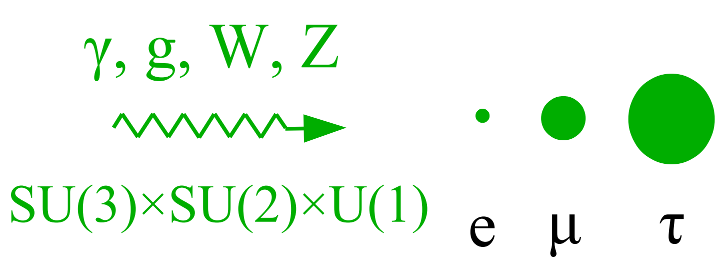


An analog phenomenon could occur for both the SM fermions and the SM gauge interactions, in flavor space



Flavour universality as the low-energy limit of a UV theory where fundamental interactions acts differently on the different generations [*as signaled by their different masses…*]

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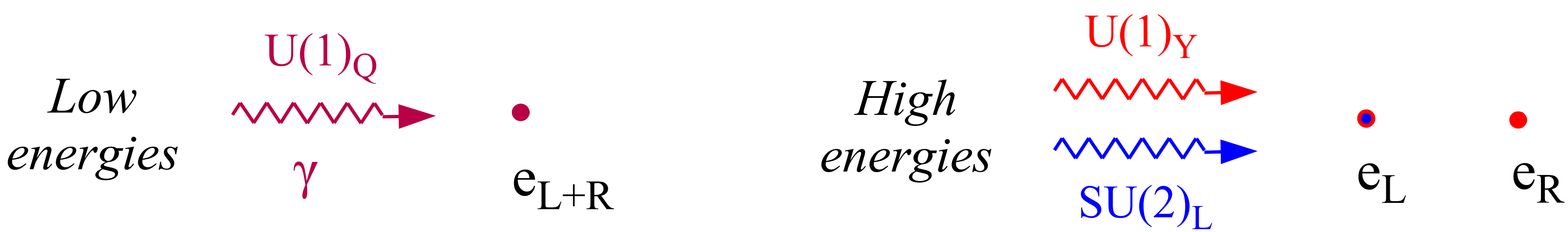

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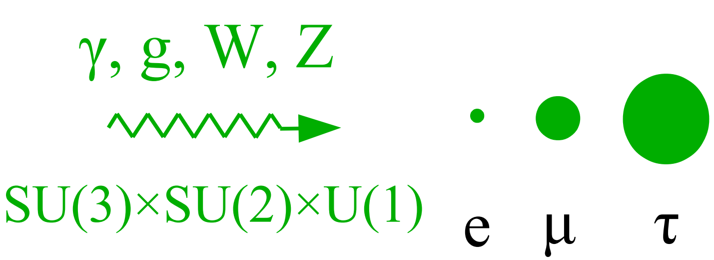


SM fermions = mixture of different UV states is a well explored BSM option [*partial compositeness* → non-universality related to mass]

> The same is not true for the SM gauge bosons [*flavor non-universal gauge interactions*]

▶ What have we learned?

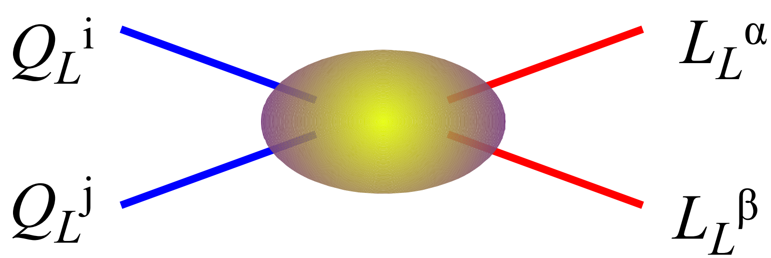
LFU violation & flavor-non-universal interactions

The role of flavor symmetries

The Return of the Leptoquark

II. *The role of flavor symmetries*

- Anomalies are seen only in semi-leptonic (quark×lepton) operators
- We definitely need 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...)

- Large coupling [*competing with SM tree-level*] in $bc \to l_3\,\nu_3$ [R_D, R_{D*}]
- Small coupling [*competing with SM loop-level*] in $bs \to l_2\; l_2$ [R_K, R_{K*}, ...]

$$T_{ij\alpha\beta} = (\delta_{i3}\times\delta_{3j})\times(\delta_{\alpha3}\times\delta_{3\beta}) \; + $$ small terms for 2nd (& 1st) generations → *Link to pattern of the Yukawa couplings !*

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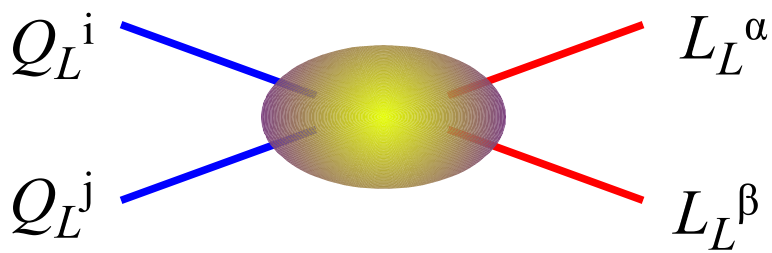

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Long list of constraints [FCNCs + semi-leptonic b decays + π, K, τ decays + EWPO]

↓

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

II. *The role of flavor symmetries*

A very good candidate to address both these issues (link with the origin of the Yukawa couplings + compatibility with other low-energy data) is a chiral flavor symmetry of the type $U(2)^n$

$$\psi = \left[\begin{array}{c} \begin{pmatrix} \psi_1 \\ \psi_2 \end{pmatrix} \\ \hline \psi_3 \end{array} \right]$$

light generations (*flavor doublet*)

3^{rd} generation (*flavor singlet*)

SM fermion (e.g. q_L)

….with suitable (small) symmetry-breaking terms, related to the structures observed in the SM Yukawa couplings

Barbieri, G.I., Jones-Perez, Lodone, Straub, '11

NB: This flavor symmetry does not need to be a "fundamental" symmetry, it could well be an "accidental" symmetry, resulting from non-universal interactions that distinguish the 3^{rd} family

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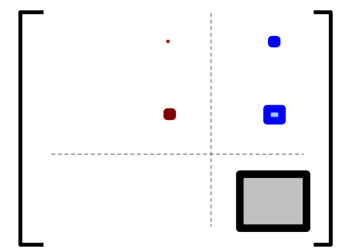
E.g. up-sector: $U(2)_q \times U(2)_u$

$$Y_U = y_t \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \leftarrow U(2)_q \quad \longrightarrow \quad \begin{bmatrix} \Delta & V \\ & 1 \end{bmatrix} \equiv$$



$\uparrow$ $U(2)_u$

unbroken symmetry

after symmetry symmetry

Barbieri, G.I., Jones-Perez, Lodone, Straub, '11

Main idea: the same symmetry-breaking pattern control the mixing $3^{rd} \rightarrow 1^{st}, 2^{nd}$ gen. for the NP responsible for the anomalies

$$|V| \approx |V_{ts}| = 0.04$$
$$|\Delta| \approx y_c = 0.006$$

N.B.: this symmetry & symmetry-breaking pattern was proposed well-before the anomalies appeared [*it is not ambulance chasing...!*]

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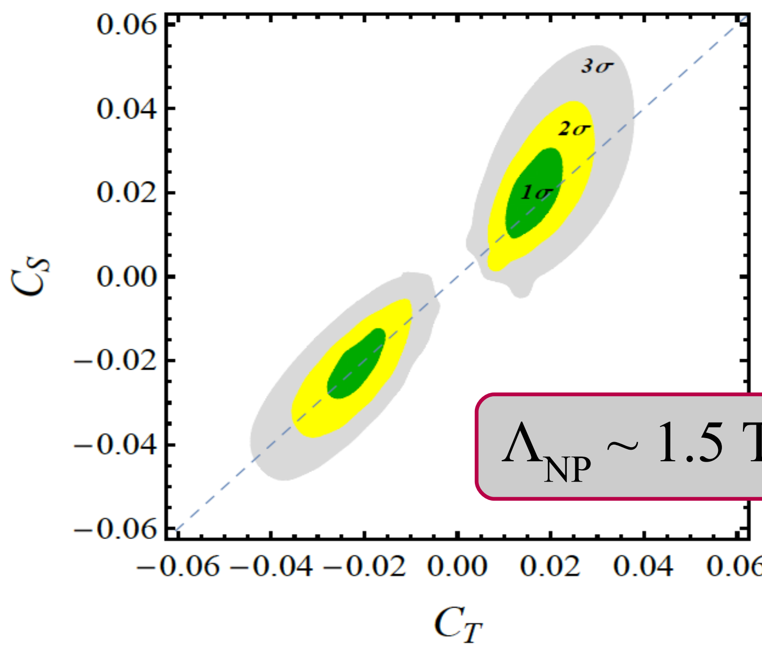
An EFT based on the following two hypothesis:

- $U(2)_q \times U(2)_l$ chiral flavor symmetry
- NP in left-handed semi-leptonic operators only [*at the high-scale*]

provides an excellent fit to the data

Buttazzo, Greljo, GI, Marzocca, '17



$\Lambda_{NP} \sim 1.5$ TeV

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⬇

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N.B.: This set-up was proposed in 2015 and refined in 2017.

Data from 2019 and 2020 have made this picture more consistent:

I. Higher NP scale given smaller central value of the $b \to c$ anomaly

II. Rising "evidence" of LFU contribution to C_9 from $\tau\tau$ loops — Crivellin *et al.* '19, Alguero *et al.* '19, Aebischer *et al.* '19

III. Evidence of a ~20% suppression of $BR(B_s \to \mu\mu)$ [as predicted in 2015...]

IV. First hint of μ/e LFU violation in $\Lambda_b \to pKll$, with $R_{pK} \approx R_K$ — Fuentes-Martin *et al.* 19, LHCb '19

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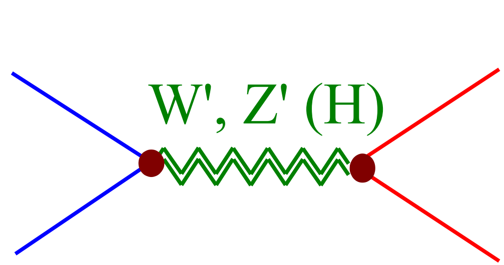
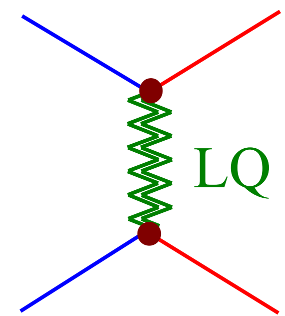
The Return of the Leptoquark

III. *The return of the Leptoquark*

Which mediators can generate the effective operators required for by the EFT fit?
If we restrict the attention to tree-level mediators, not many possibilities...





N.B.: The choice of a tree-level mediator is compelling only if we are interested into a combined fit of the anomalies (→ low scale) effective low-scale of NP.

$\Lambda_{\rm eff} < 9$ TeV ← $b \to c\,\tau\nu$ → few TeV ⇠⇢ Hierarchy problem

$\Lambda_{\rm eff} < 84$ TeV ← $b \to s\,\mu\mu$ → few TeV

Di Luzio, Nardecchia '17

No additional assumptions

Yukawa structure $\xrightarrow{U(2)^n}$ few TeV

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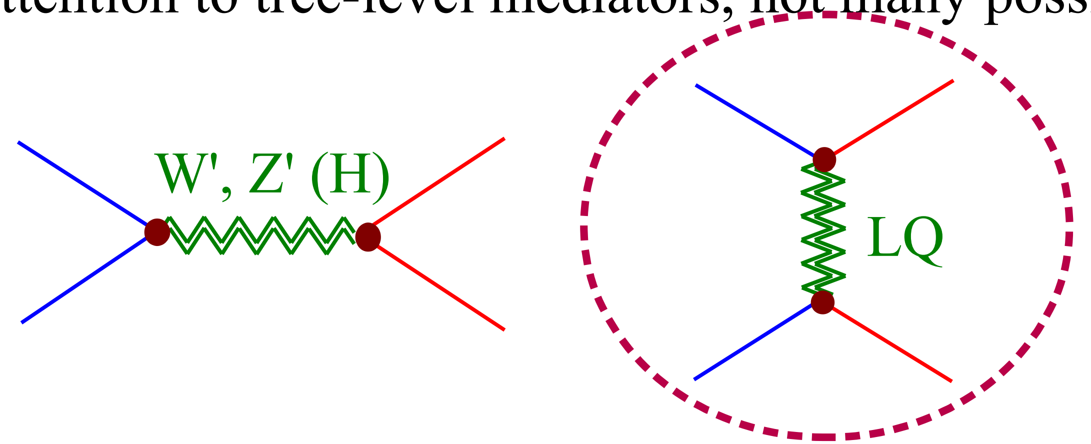
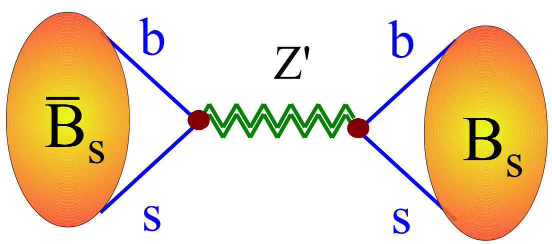
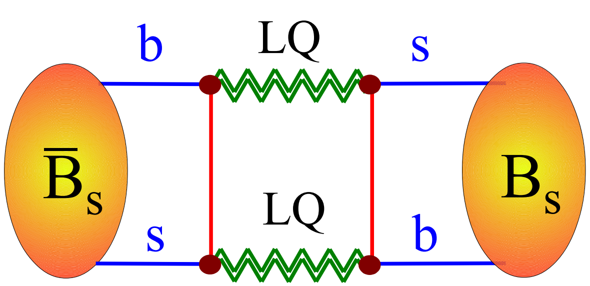


LQ (both scalar and vectors) have two general strong advantages with respect to the other mediators:

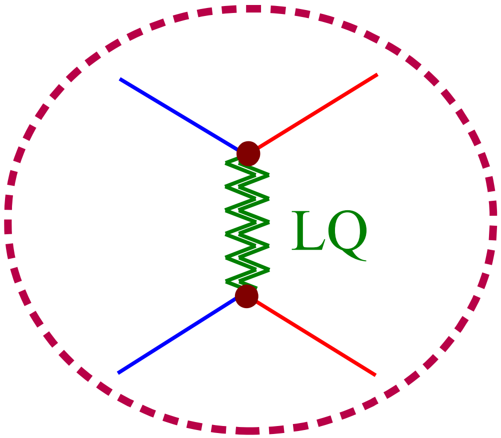
I. $\Delta F=2$ & $\tau \to l\nu\nu$





II. Direct searches: 3rd gen. LQ are also in better shape as far as direct searches are concerned (*contrary to Z'...*).

III. *The return of the Leptoquark*

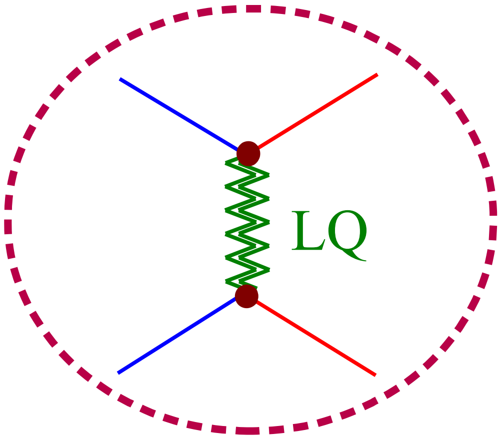


Leptoquarks suffered of an (*undeserved*) "bad reputation" for two main reasons:

- Could mediate proton decay → not a general feature of the LQ: it depends on the model...! [*e.g. not the case in the Pati-Salam model*]

- Severe bounds from processes involving μ & e (such as $K_L \to \mu e$) → avoided with non-trivial flavor structure [*e.g. non-univ. interactions*]

III. The return of the Leptoquark



Leptoquarks suffered of an (*undeserved*) "bad reputation" for two main reasons:

- Could mediate proton decay → not a general feature of the LQ: it depends on the model...! [*e.g. not the case in the Pati-Salam model*]

- Severe bounds from processes involving μ & e (such as $K_L \to \mu e$) → avoided with non-trivial flavor structure [*e.g. non-univ. interactions*]

On the other hand, they are a "natural" feature in many SM extensions → "Renaissance" of LQ models (*to explain the anomalies, but not only...*):

- Scalar LQ as PNG
  Gripaios, '10
  Gripaios, Nardecchia, Renner, '14
  Marzocca '18

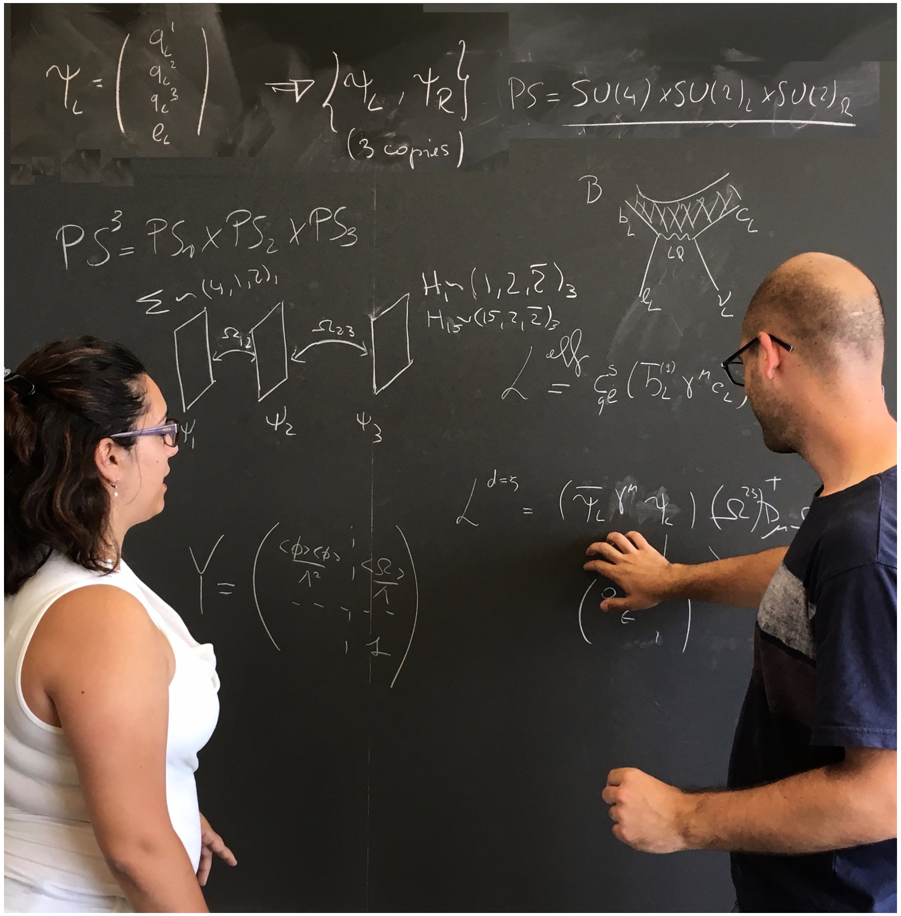
- Scalar LQ from GUTs & ~~R~~ SUSY
  Hiller & Schmaltz, '14; Becirevic *et al.* '16, Fajfer *et al.* '15-'17; Dorsner *et al.* '17; Crivellin *et al.* '17; Altmannshofer *et al.* '17 Trifinopoulos '18, Becirevic *et al.* '18 + ...

- Vector LQ in GUT gauge models
  Assad *et al.* '17
  Di Luzio *et al.* '17
  Bordone et *al.* '17
  + ...

- Vector LQ as techni-fermion resonances
  Barbieri *et al.* '15; Buttazzo *et al.* '16, Barbieri, Murphy, Senia, '17

- LQ as Kaluza-Klein excit.
  Megias, Quiros, Salas '17
  Megias, Panico, Pujolas, Quiros '17
  Blanke, Crivellin, '18

An explicit model to address the anomalies



An explicit (class of) model(s) to address the anomalies

Starting observation: the gauge theory proposed in the 70's to unify quarks and leptons by Pati & Salam predicts a massive vector LQ with the correct quantum numbers to fit both the anomalies:

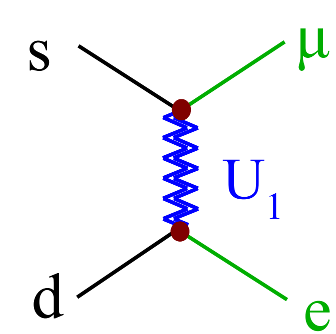
Pati-Salam group: $SU(4)\times SU(2)_L\times SU(2)_R$

Fermions in SU(4): $\begin{bmatrix} Q_L^{\alpha} \\ Q_L^{\beta} \\ Q_L^{\gamma} \\ L_L \end{bmatrix}$ $\begin{bmatrix} Q_R^{\alpha} \\ Q_R^{\beta} \\ Q_R^{\gamma} \\ L_R \end{bmatrix}$

Main Pati-Salam idea:
Lepton number as "the 4th color"

The massive LQ [U_1] arise from the breaking $SU(4) \to SU(3)_C\times U(1)_{B-L}$

The problem of the "original PS model" are the strong bounds on the LQ couplings to 1st & 2nd generations [e.g. $M > 200$ TeV from $K_L \to \mu e$]



Interesting attempts to solve this problem adding extra fermions and/or modifying the gauge group

Calibbi, Crivellin, Li, '17;
Di Luzio, Greljo, Nardecchia, '17
Fornal, Gadam, Grinstein, '18

The PS^3 *model*

$$[\,\mathrm{PS}\,]^3 = [\,SU(4)\times SU(2)_L\times SU(2)_R\,]^3$$

Bordone, Cornella, Fuentes-Martin, GI, '17

Main idea: at high energies the 3 families are charged under 3 independent gauge groups (*gauge bosons carry a flavor index !*)

UV

PS_1 $\psi_1^{L,R}$ $\quad$ PS_2 $\psi_2^{L,R}$ $\quad$ PS_3 $\psi_3^{L,R}$

Unification of quarks and leptons
[natural explanation for $U(1)_Y$ charges]

"De-unification" (= *flavor deconstruction*) of the gauge symmetry

SM

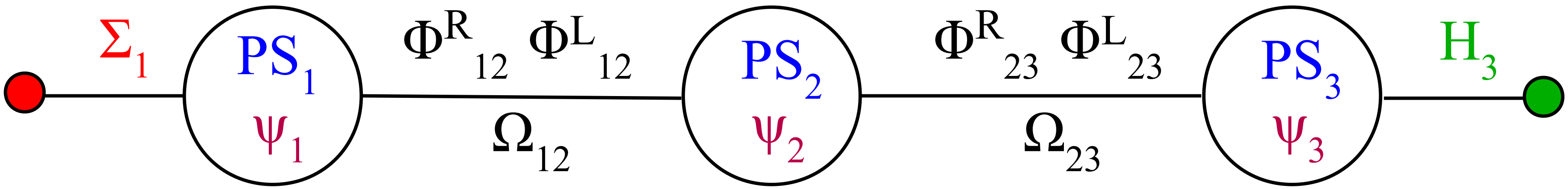
IR

Q_i, u_i, d_i, L_i, e_i

Key advantages:

- Light LQ coupled mainly to 3rd gen.
- Accidental $U(2)^5$ flavor symmetry
- Natural structure of SM Yukawa couplings
- Justification of the whole construction in terms of extra dim.

▶ *The* PS^3 *model*



High-scale breaking

$PS_1 \to SM_1$

link fields

$PS_i \times PS_j \to PS_{i+j}$

Low-scale breaking

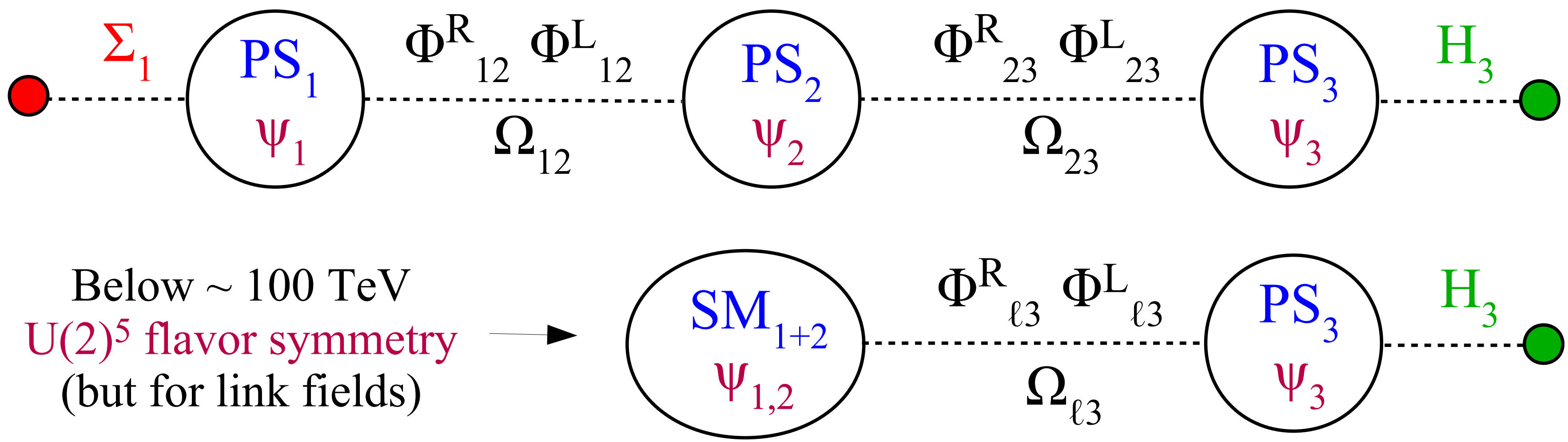
$[SU(2)\times U(1)]_3 \to QED_3$

SM ($\to$ QCD×QED)

- The breaking to the diagonal SM group occurs via appropriate "link" fields, responsible also for the generation of the hierarchy in the Yukawa couplings.

- The 2-3 breaking gives a TeV-scale LQ [+ Z' & G'] coupled mainly to 3rd gen., as in the flavor-universal "4321" model [Di Luzio, Greljo, Nardecchia, '17]

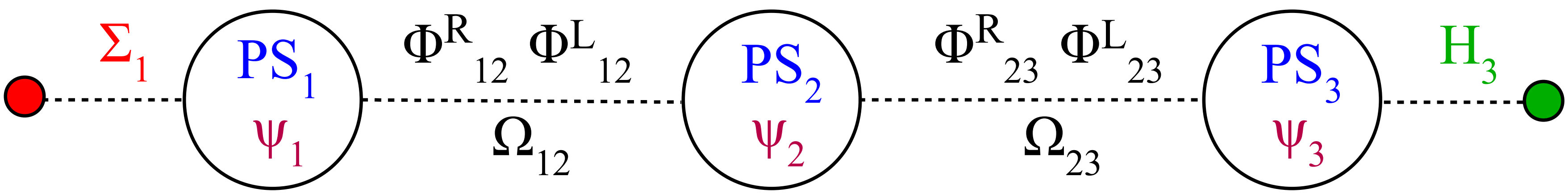
▶ *The* PS^3 *model*



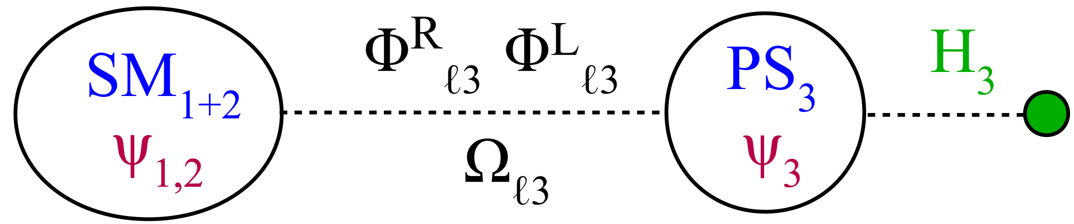
Leading flavor structure:

- Yukawa coupling for 3rd gen. only
- "Light" LQ field (from PS$_3$) coupled only to 3rd gen.
- U(2)^5 symmetry protects flavor-violating effects on light gen.

▸ *The* PS^3 *model*



Below ~ 100 TeV
U(2)^5 flavor symmetry
(but for link fields) →

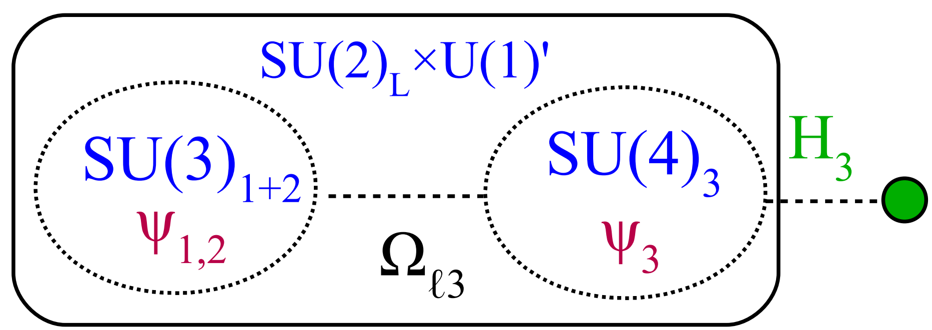


→ $W_L' + W_R'$ [~ 5-10 TeV]

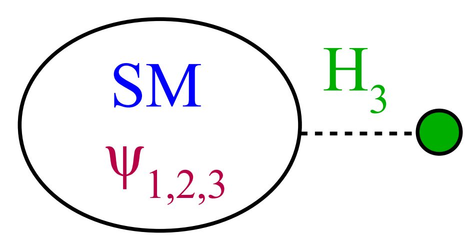
Sub-leading Yukawa terms from higher dim ops:

$$Y_U = \begin{bmatrix} \Delta & V \\ & y_t \end{bmatrix}$$

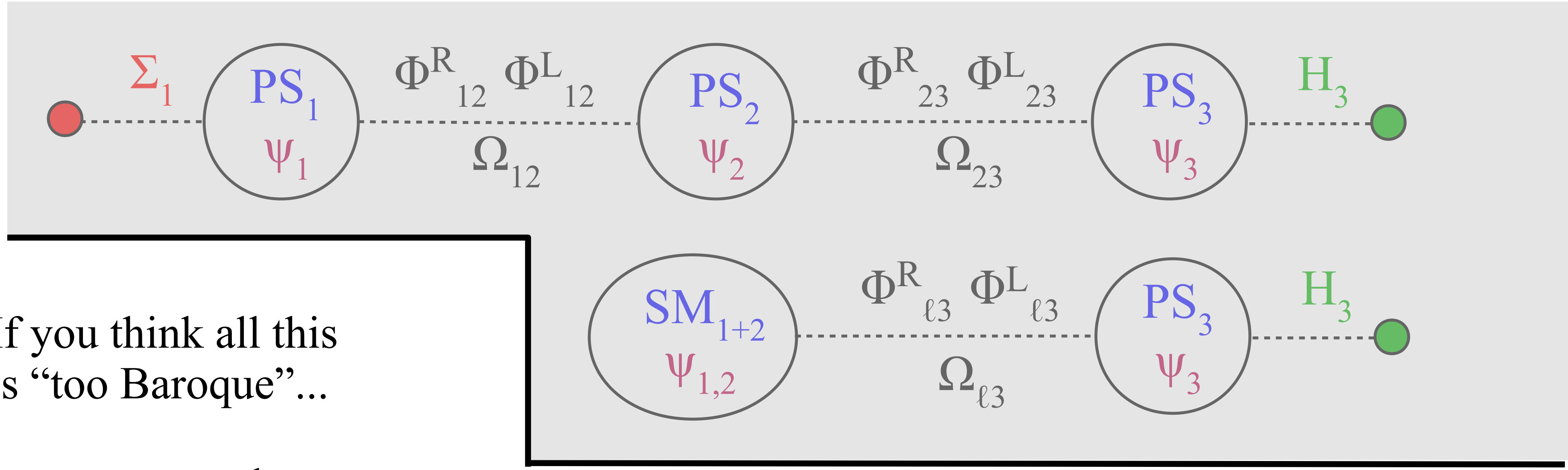
$$\frac{\langle \Phi^R_{\ell 3} \Phi^L_{\ell 3} \rangle}{(\Lambda_{23})^2} \qquad \frac{\langle \Omega_{\ell 3} \rangle}{\Lambda_{23}}$$



→ LQ [U_1] + Z' + G' [~ 1-5 TeV]

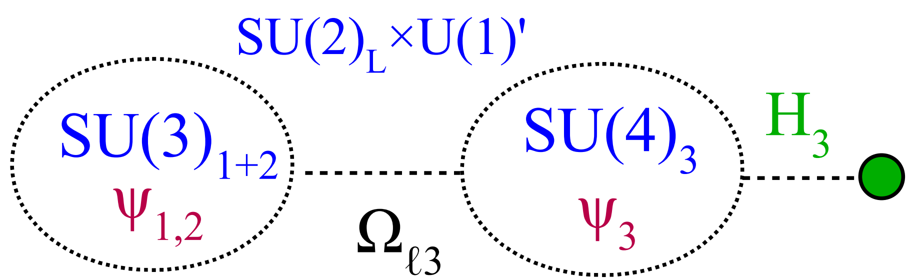


▸ *The* PS^3 *model*



If you think all this is “too Baroque”...

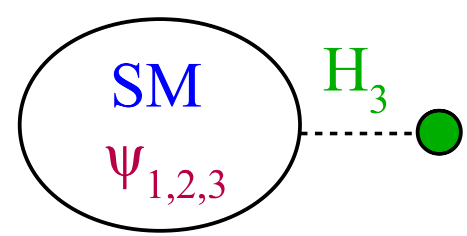
...we can start here:
4321 (*flavor non-universal*) model:



Interesting recent construction leading to the same “low-energy” structure based on new strong dynamics @ few TeV

→ LQ [U_1] + Z' + G' [~ 1-5 TeV]

→ *key feature*: Higgs as a pseudo-Goldstone



Fuentes-Martin & Stangl '20

The PS^3 model

Present collider and low-energy pheno are all controlled by the last-step in the breaking chain [4321 → SM]

Despite the apparent complexity, the construction is highly constrained

Renormalizable structure (no d>5 ops) achieved with vector-like fermions

Field	$SU(4)$	$SU(3)'$	$SU(2)_L$	$U(1)'$
$q_L'^i$	**1**	**3**	**2**	$1/6$
$u_R'^i$	**1**	**3**	**1**	$2/3$
$d_R'^i$	**1**	**3**	**1**	$-1/3$
$\ell_L'^i$	**1**	**1**	**2**	$-1/2$
$e_R'^i$	**1**	**1**	**1**	-1
ψ_L'	**4**	**1**	**2**	0
ψ_u'	**4**	**1**	**1**	$1/2$
ψ_d'	**4**	**1**	**1**	$-1/2$
χ_L^i	**4**	**1**	**2**	0
χ_R^i	**4**	**1**	**2**	0
H_1	**1**	**1**	**2**	$1/2$
H_{15}	**15**	**1**	**2**	$1/2$
Ω_1	$\bar{\mathbf{4}}$	**1**	**1**	$-1/2$
Ω_3	$\bar{\mathbf{4}}$	**3**	**1**	$1/6$
Ω_{15}	**15**	**1**	**1**	0

$SU(4)_3 \times SU(3)_{1+2} \times [\, SU(2)_L \times U(1)' \,]$

ψ_3 $\psi_{1,2}$

$\langle \Omega\text{'s} \rangle$ $\to$ LQ [U_1] + Z' + G' [~ 1-5 TeV]

SM

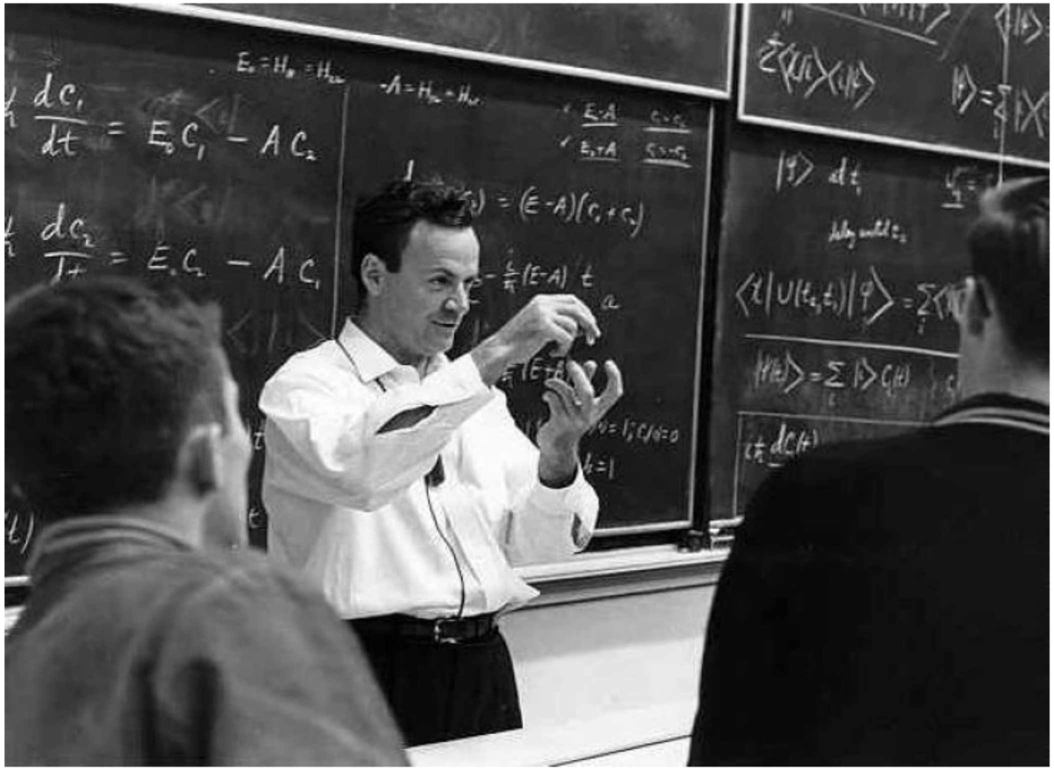
$\psi_{1,2,3}$

- Positive features the EFT reproduced
- Calculability of $\Delta F=2$ processes
- Precise predictions for high-pT data

consistent with present data

Greljo, Stefanek, '18; Di Luzio *et al.* '18
Cornella, Fuentes-Martin, GI, '19
Baker, Fuentes-Martin, GI, König, '19

What do we still hope to learn?



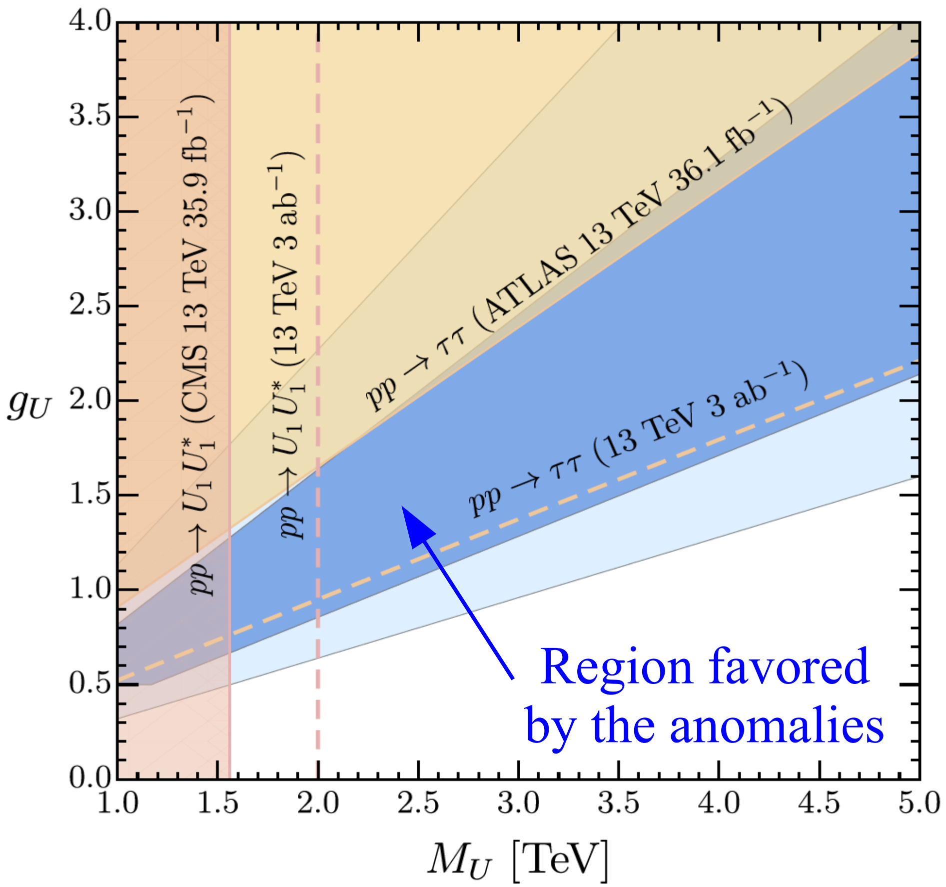
"It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong." [Feynman]

What do we still hope to learn from $b \to s(d)ll$ decays

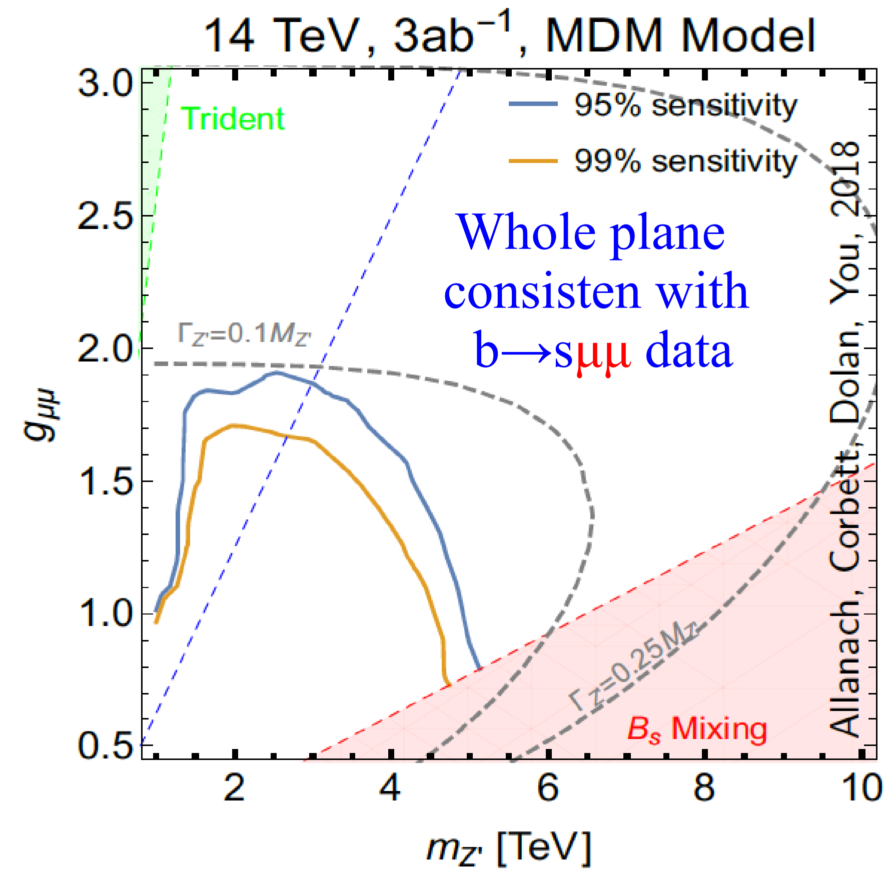
Ideally, to confirm all this... we would like to see a direct signal of the new mediators at high-pT.

But a high-energy discovery is not guaranteed in the short term [*even in the optimistic case of a combined explanation of the anomalies*]

E.g.: U_1 in non-univ. 4321 [Baker *et al.* '19]



E.g.: Z' for $b \to s\mu\mu$ only [Allanach *et al.* '19]



What do we still hope to learn from $b \to s(d)ll$ decays

Since a high-energy discovery is not guaranteed in the short term → key role still played by low-energy observables [*with prominent role of* $b \to s(d)ll'$]:

E.g.: correlations among $b \to s(d)ll'$ within the U(2)-based EFT

	$\mu\mu$ (ee)	$\tau\tau$	$\nu\nu$
$b \to s$	R_K, R_{K^*} *present anomalies*	$B \to K^{(*)} \tau\tau$ ⋮	$B \to K^{(*)} \nu\nu$ ⋮
$b \to d$	$B_d \to \mu\mu$ $B \to \pi\, \mu\mu$ $B_s \to K^{(*)} \mu\mu$ ⋮	$B \to \pi\, \tau\tau$ ⋮	$B \to \pi\, \nu\nu$ ⋮
$s \to d$	*long-distance pollution*	*NA*	$K \to \pi\, \nu\nu$

What do we still hope to learn from $b \to s(d)ll$ decays

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E.g.: correlations among $b \to s(d)ll'$ within the U(2)-based EFT

	$\mu\mu$ (ee)	$\tau\tau$	$\nu\nu$
$b \to s$	R_K, R_{K^*} O(20%) $\quad R_D$	$B \to K^{(*)} \tau\tau$ $\to 100\times$SM	$B \to K^{(*)} \nu\nu$ O(1)
$b \to d$ R_K	$B_d \to \mu\mu$ $B \to \pi\, \mu\mu$ $B_s \to K^{(*)} \mu\mu$ O(20%) $[R_K = R_\pi]$	$B \to \pi\, \tau\tau$ $\to 100\times$SM	$B \to \pi\, \nu\nu$
$s \to d$	*long-distance pollution*	*NA*	$K \to \pi\, \nu\nu$ O(1)

$$\frac{A(b \to d\,ll)_{SM+NP}}{A(b \to s\,ll)_{SM+NP}} = \frac{A(b \to d\; ll)_{SM}}{A(b \to s\; ll)_{SM}}$$

▶ *What do we still hope to learn from $b \to s(d)ll$ decays*

Since a high-energy discovery is not guaranteed in the short term → key role still played by low-energy observables [*with prominent role of* $b \to s(d)ll'$]:

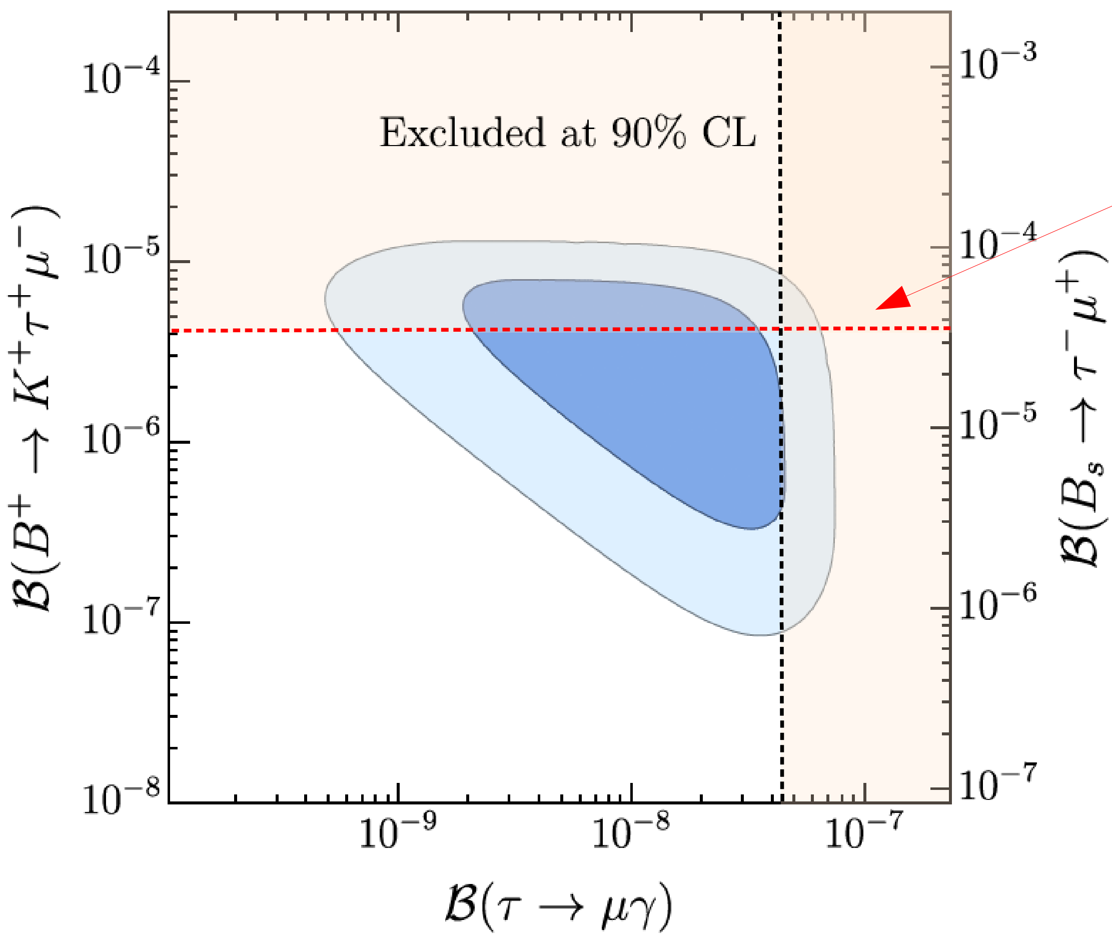
E.g.: correlations among $b \to s(d)ll'$ within the U(2)-based EFT

	μμ (ee)	ττ	νν	τμ	μe
$b \to s$	R_K, R_{K^*} O(20%)	$B \to K^{(*)}\tau\tau$ → 100×SM	$B \to K^{(*)}\nu\nu$ O(1)	$B \to K\tau\mu$ → 10^{-6}	$B \to K\mu e$???
$b \to d$	$B_d \to \mu\mu$ $B \to \pi\mu\mu$ $B_s \to K^{(*)}\mu\mu$ O(20%) $[R_K=R_\pi]$	$B \to \pi\tau\tau$ → 100×SM	$B \to \pi\nu\nu$ O(1)	$B \to \pi\tau\mu$ → 10^{-7}	$B \to \pi\mu e$???
$s \to d$	*long-distance pollution*	*NA*	$K \to \pi\nu\nu$ O(1)	*NA*	$K \to \mu e$???

What do we still hope to learn from $b \to s(d)ll$ decays

Since a high-energy discovery is not guaranteed in the short term → key role still played by low-energy observables [*with prominent role of* $b \to s(d)ll'$]:

E.g.: LFV rates in the PS[3] model



Recent bound by LHCb entering the interesting region of parameter space

More difficult to make precise predictions for $\mu \to e$ transitions.

But both $\mu \to 3e$ and $K_L \to \mu e$ could be quite close to their present exp. bounds:

$BR(\mu \to 3e) \quad \to$ few 10^{-14}

$BR(K_L \to \mu e) \quad \to$ few 10^{-12}

Conclusions

- The "B-physics anomalies" provide a concrete demonstration of the high discovery potential of flavor physics. Even if they will go away, they have been very beneficial in shaking some prejudices in model building and in (re-)opening new interesting directions.

  - If interpreted as NP signals, both set of anomalies are not in contradiction among themselves & with existing low- & high-energy data.
    Taken together, they point to NP coupled mainly to 3rd generation, with a flavor structure connected to that appearing in the SM Yukawa couplings.

  - Simplified models with LQ states seem to be favored. Among them, the U_1 case stands for simplicity & phenomenological success.
    The PS^3 model is an interesting example of (a class of) UV framework(s) which could host it, and could help to shed light on "old" SM problems.

- To understand if any of the two statements above is correct...

… we desperately need more data !!!!!