

Anomalies in B-meson decays

An informal update

Part II: the Disney movies

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Making sense of the anomalies

SMEFT operator	Definition	Matching	Order
$[Q_{lq}^{(1)}]_{aa23}$	$(\bar{l}_a \gamma_\mu l_a) (\bar{q}_2 \gamma^\mu q_3)$	$\mathcal{O}_{9,10}$	Tree
$[Q_{lq}^{(3)}]_{aa23}$	$(\bar{l}_a \gamma_\mu \tau^I l_a) (\bar{q}_2 \gamma^\mu \tau^I q_3)$	$\mathcal{O}_{9,10}$	Tree
$[Q_{qe}]_{23aa}$	$(\bar{q}_2 \gamma_\mu q_3) (\bar{e}_a \gamma^\mu e_a)$	$\mathcal{O}_{9,10}$	Tree
$[Q_{ld}]_{aa23}$	$(\bar{l}_a \gamma_\mu l_a) (\bar{d}_2 \gamma^\mu d_3)$	$\mathcal{O}'_{9,10}$	Tree
$[Q_{ed}]_{aa23}$	$(\bar{e}_a \gamma_\mu e_a) (\bar{d}_2 \gamma^\mu d_3)$	$\mathcal{O}'_{9,10}$	Tree
$[Q_{\varphi l}^{(1)}]_{aa}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi) (\bar{l}_a \gamma^\mu l_a)$	$\mathcal{O}_{9,10}$	1-loop
$[Q_{\varphi l}^{(3)}]_{aa}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu^I \varphi) (\bar{l}_a \gamma^\mu \tau^I l_a)$	$\mathcal{O}_{9,10}$	1-loop
$[Q_{lu}]_{aa33}$	$(\bar{l}_a \gamma_\mu l_a) (\bar{u}_3 \gamma^\mu u_3)$	$\mathcal{O}_{9,10}$	1-loop
$[Q_{\varphi e}]_{aa}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi) (\bar{e}_a \gamma^\mu e_a)$	$\mathcal{O}_{9,10}$	1-loop
$[Q_{eu}]_{aa33}$	$(\bar{e}_a \gamma_\mu e_a) (\bar{u}_3 \gamma^\mu u_3)$	$\mathcal{O}_{9,10}$	1-loop

[Celis, JF, Vicente, Virto, 1704.05672]

WC ($\mu = \Lambda$)	R_K and R_{K^*}	Constraints
$[C_{lq}^{(1)}]_{2223}$	✓	No relevant constraints
$[C_{lq}^{(3)}]_{2223}$	✓	No relevant constraints
$[C_{\varphi l}^{(1)}]_{22}$	✗	Excluded due to EWPD
$[C_{\varphi l}^{(3)}]_{22}$	✗	Excluded due to EWPD
$[C_{lu}]_{2233}$	✓	No relevant constraints

$Q_{lq}^{(1,3)}$ must be present in any solution of the anomalies (either at tree level or at one loop)

$$\Lambda_{\text{tree}} \sim 50 \text{ TeV}$$

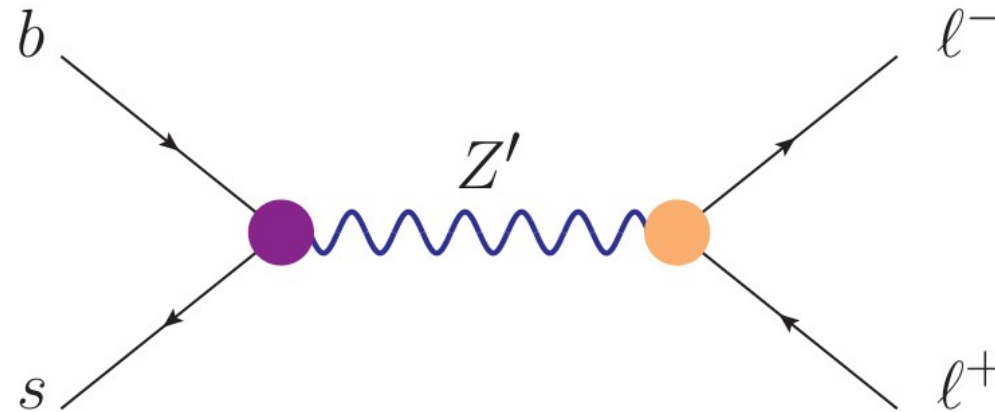
$$\Lambda_{1\text{-loop}} \sim 1 \text{ TeV}$$

A black rectangular area filled with numerous small white dots of varying sizes, resembling a starfield or a night sky.

STANDARD
THE Z' FORCE AWAKENS
MODEL

Z' models for the anomalies

$$G \equiv SU(3)_c \times SU(2)_L \times U(1)_Y \times \mathbf{G}_E$$



Flavor violating couplings to quarks

Lepton-flavor universality violation

What can G_e be?



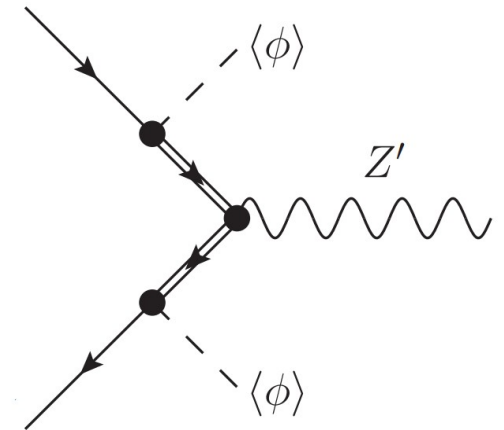
Z' models for the anomalies

Episode VII: The Z' force awakens

The extra gauge group should be **anomaly free**:

- $U(1)_{\mu-\tau}$ + VL fermions
- $U(1)' \subset U(1)_{\mu-\tau} \times U(1)_q$ (arise naturally from the hyp. of Dyn. Yuk)

$$U(1)_q : X_q = X_u = X_d = \text{diag} \left(-\frac{1}{2}, -\frac{1}{2}, 1 \right)$$



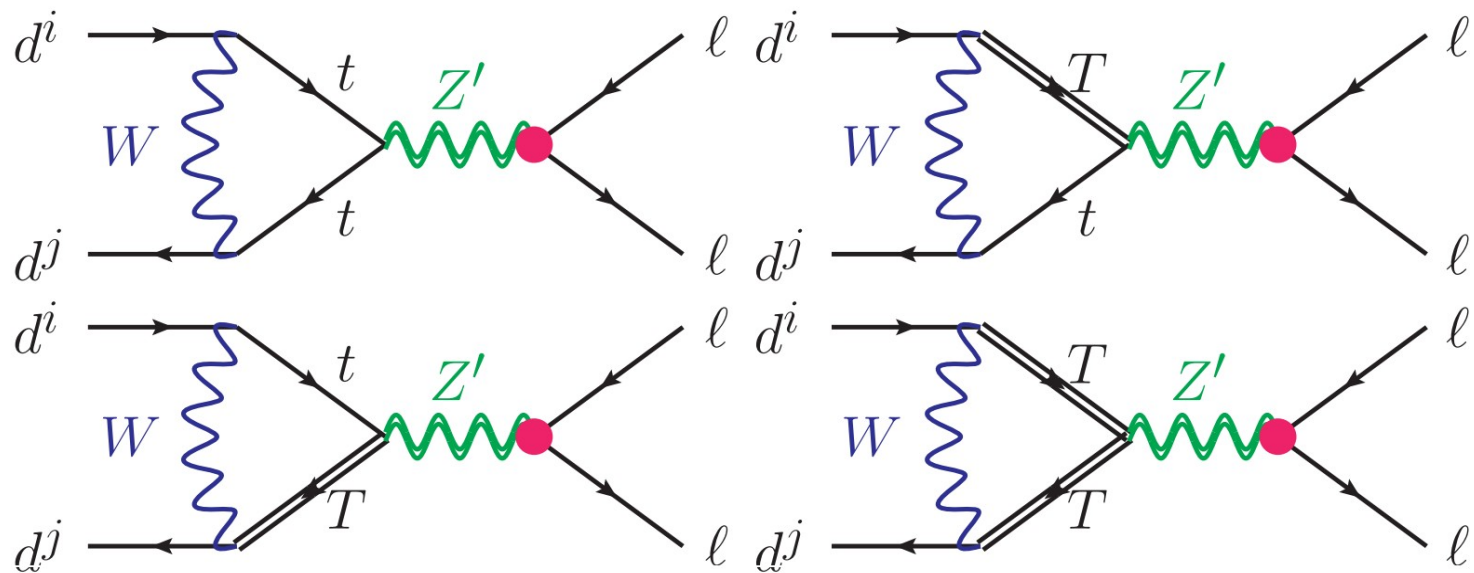
- Completely dark sector, connexion with DM
- Other anomaly free symmetries with extra scalars: $U(1)_{\text{BGL}}$
- $SU(2)_1 \times SU(2)_2 \times U(1)_Y$



Z' models for the anomalies

Episode VII: The Z' force awakens

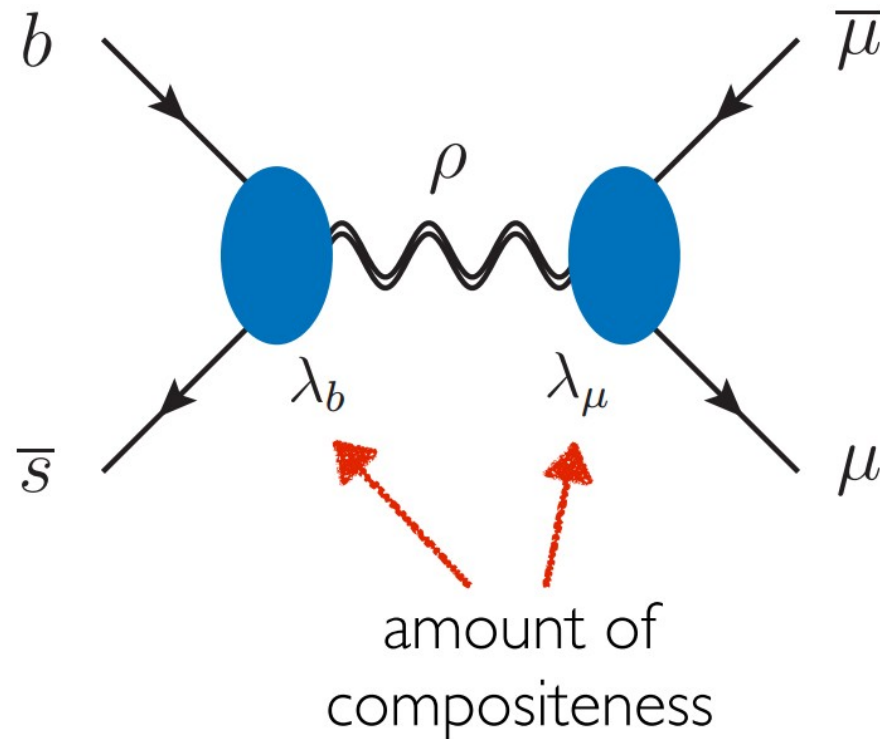
Bringing the game to the **one-loop** order



[Kamenik, Soreq, Zupan, 1704.06005]



Massive resonance from Composite scenarios

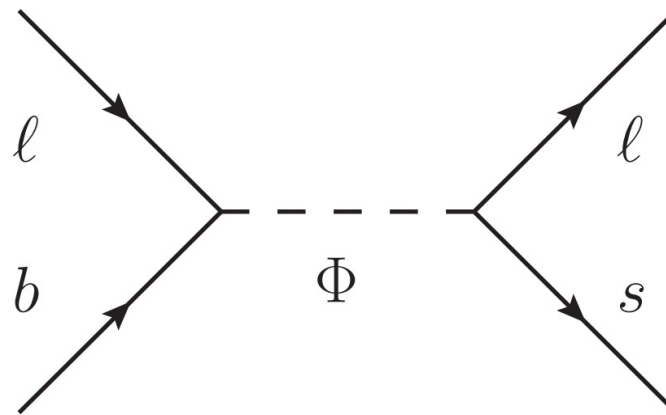


[From Panico at Moriond '17]

See also [Niehoff, Strangl, Straub '15]

Leptoquarks for the anomalies

Rogue one: a leptoquark story



Viable models:

$$S : (\bar{3}, 3)_{1/3} \longrightarrow \mathcal{C}_{lq}^{(1)} = 3\mathcal{C}_{lq}^{(3)}$$

$$U_\mu : (3, 1)_{2/3} \longrightarrow \mathcal{C}_{lq}^{(1)} = \mathcal{C}_{lq}^{(3)}$$

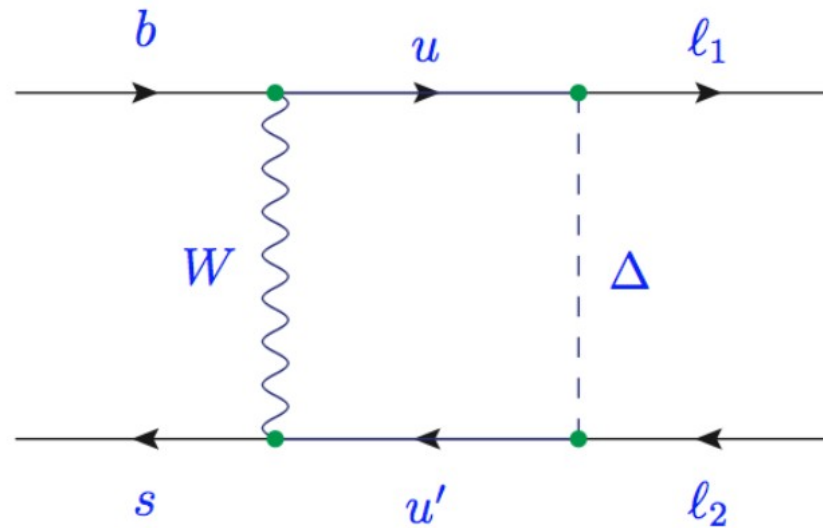
$$U_\mu : (3, 3)_{2/3} \longrightarrow \mathcal{C}_{lq}^{(1)} = -3\mathcal{C}_{lq}^{(3)}$$



Leptoquarks for the anomalies

Rogue one: a leptoquark story

Also bringing the game to the **one-loop** order

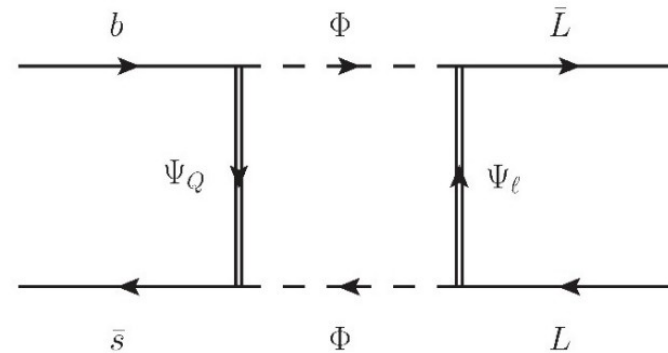
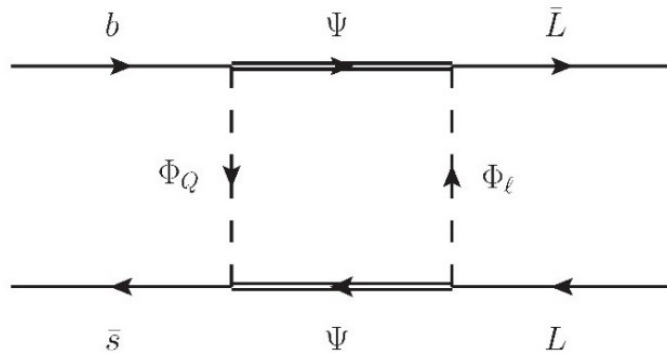


$$S : (3, 2)_{7/6} \longrightarrow \mathcal{C}_{lu}$$

[Bečirević, Sumensari, 1704.05835]



New Scalars and Fermions



■ Possible representations

$SU(2)$	Φ_Q, Ψ_Q	Φ_ℓ, Ψ_ℓ	Ψ, Φ
<i>I</i>	2	2	1
<i>II</i>	1	1	2
<i>III</i>	3	3	2
<i>IV</i>	2	2	3
<i>V</i>	3	1	2
<i>VI</i>	1	3	2

$SU(3)$	Φ_Q, Ψ_Q	Φ_ℓ, Ψ_ℓ	Ψ, Φ
<i>A</i>	3	1	1
<i>B</i>	1	$\bar{3}$	3
<i>C</i>	3	8	8
<i>D</i>	8	$\bar{3}$	3

[Slide from Crivellin at Moriond '17]

Bounds on these models

These models receive bounds essentially from:

- $\Delta F = 2$ transitions (neutral meson mixing)
- Neutrino Trident Production
- Mixing with the SM Z
- Direct searches (with direct production either through light or heavy quarks)
- $B \rightarrow K \bar{\nu} \nu$