Loop effects of heavy new scalars and fermions in $b \to s\mu\mu$

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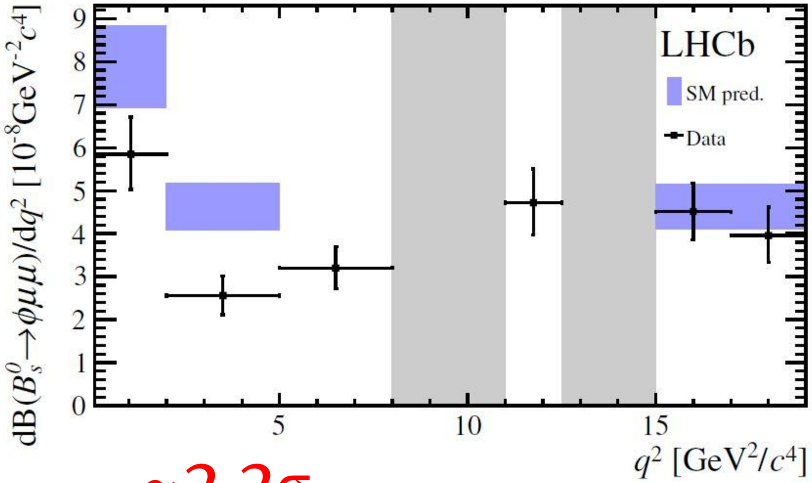
GENT 2019

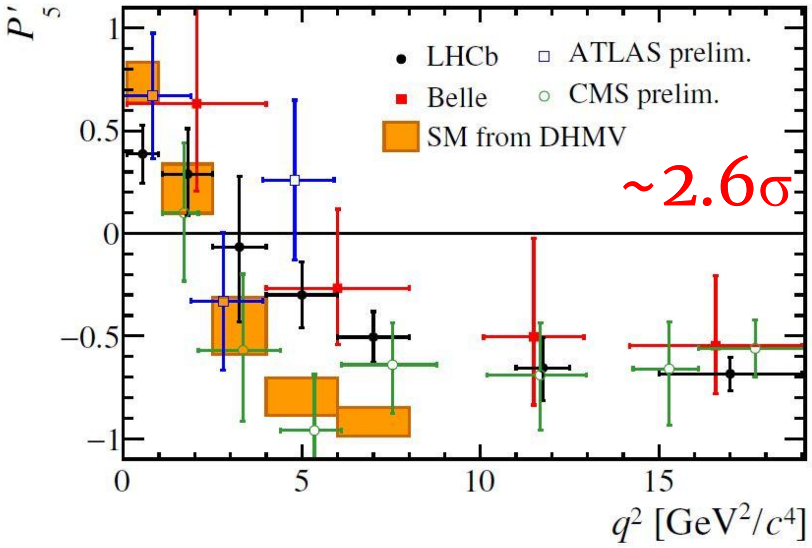
UNIVERSITAT DE BARCELONA

ICCUB

b ⟶ s anomalies



~2.2σ



~2.6σ

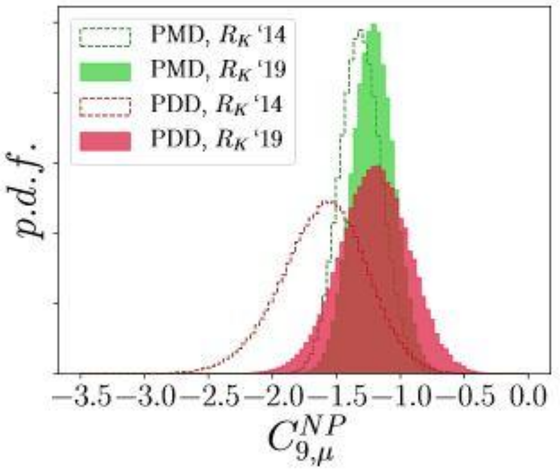
$$R_K^{[1.1,6]} = \frac{\mathcal{B}(B \to K\mu^+\mu^-)}{\mathcal{B}(B \to Ke^+e^-)} = 0.846^{+0.060}_{-0.054}{}^{+0.016}_{-0.014}$$

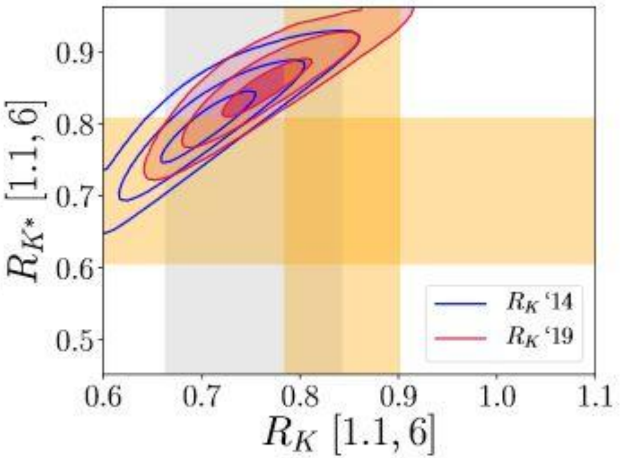
$$R_{K^*}^{[0.045,1.1]} = 0.52^{+0.36}_{-0.26} \pm 0.05$$

$$R_{K^*}^{[1.1,6]} = 0.96^{+0.45}_{-0.29} \pm 0.11$$

$$R_{K^*}^{[15,19]} = 1.18^{+0.52}_{-0.32} \pm 0.10$$

$b \rightarrow s$ anomalies: Global fits

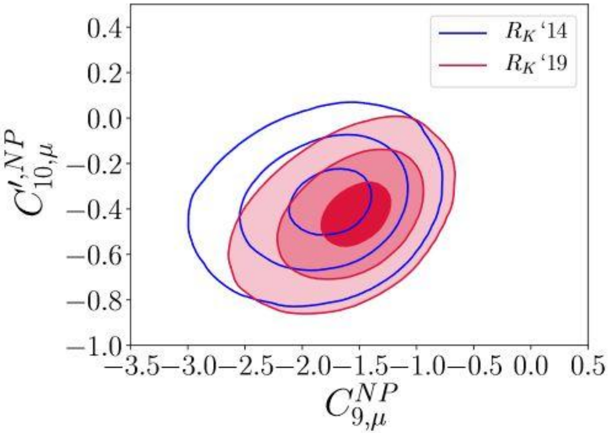


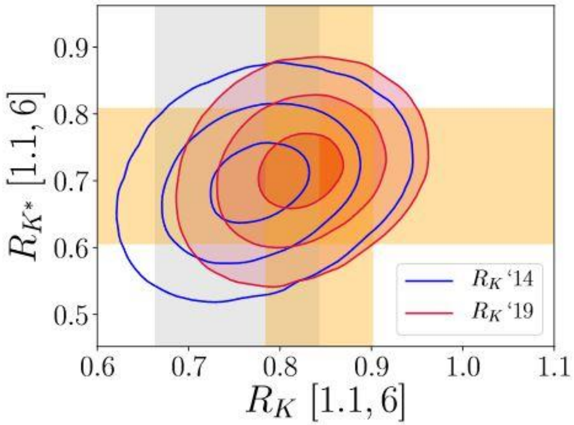


Left-Handed Scenario

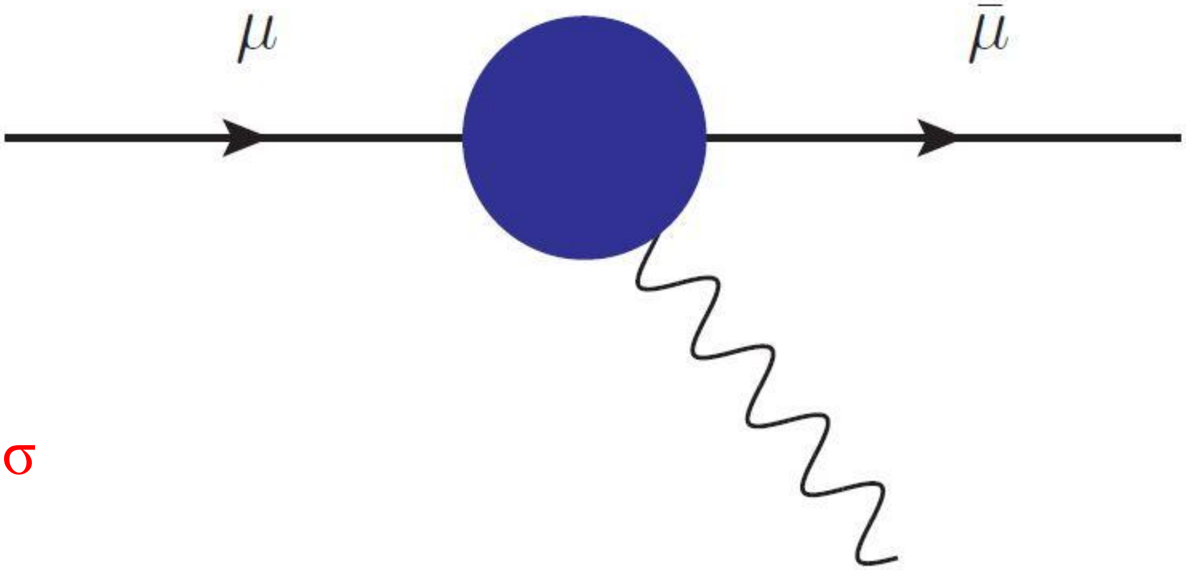
Fedele et al.

Left-Handed & Right-Handed Scenario





Muon anomalous magnetic moment

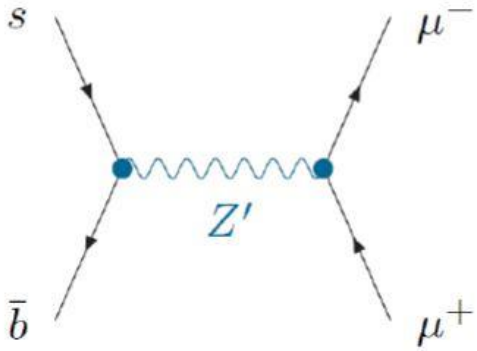


~2.7σ

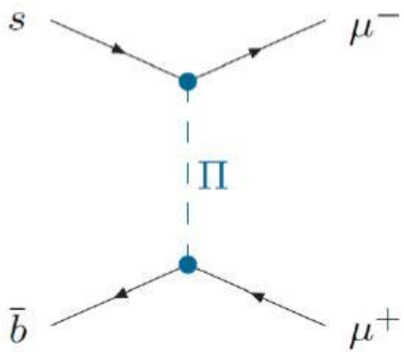
$$\Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (236 \pm 87)10^{-11}$$

Approach to anomalies

tree-level new-physics contributions:



Z' models



Lepto-Quarks

Altmannshofer,Crivellin, Gori, Buras, Heek, Fuentes-Martin, Di Luzio ...

Cornella, Fajfer, Greljo, Kamenik, Crivellin, Bordone, Isidori, Dorsner,Fuentes-Martin, Marzocca, Nardecchia, Renner, Sumensari, Becirevic...

Boxes: Minimal Scenario

Three new particles

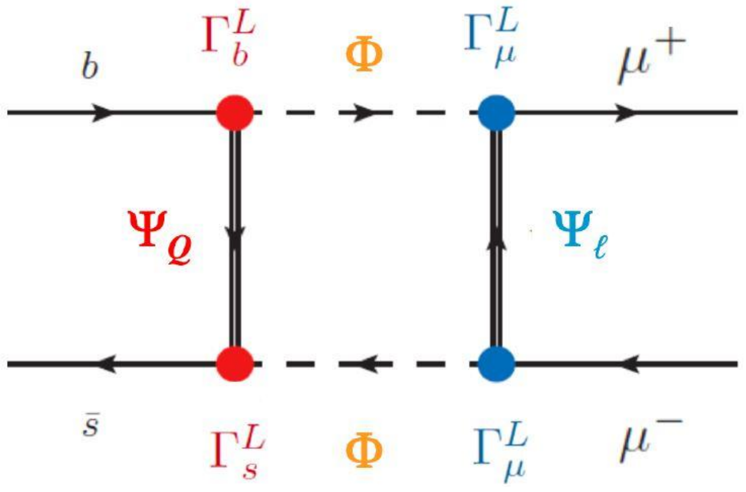
- one scalar Φ
- two vector-like fermions $\Psi^Q \Psi^L$

  (or viceversa)

LH couplings

Generates $C_9 = -C_{10}$

OK with global fits.



Gripaios,Nardecchia,Renner
PA, Crivellin, Hofer, Mescia

Minimal Scenario

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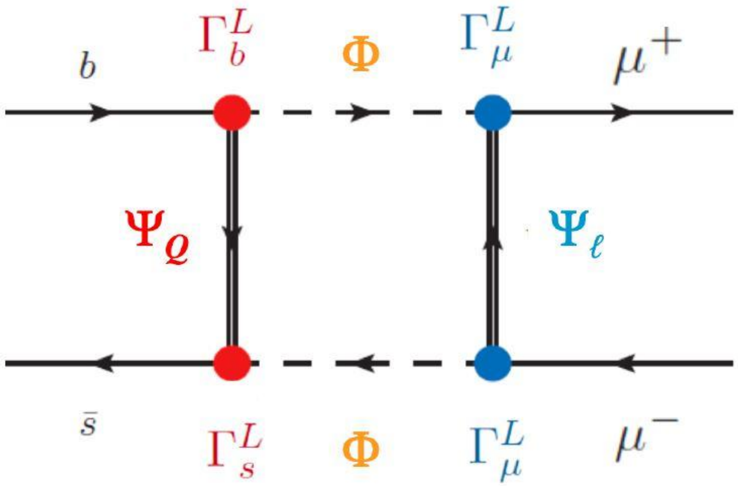
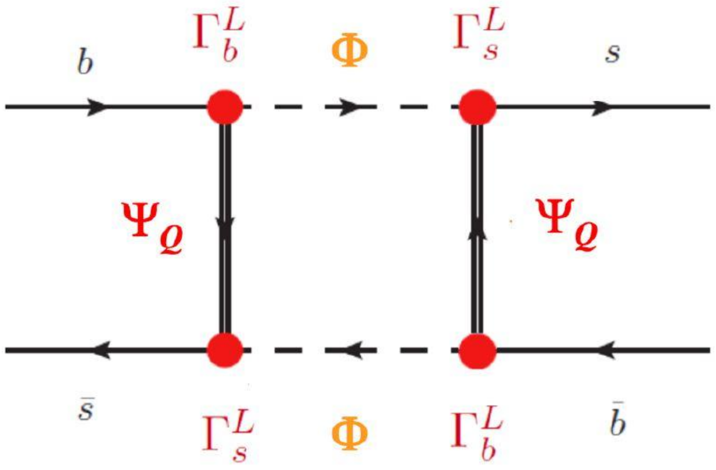


- Z-penguin contribution to $b \to s\ell^+\ell^-$ irrelevant (m_b^2/m_Z^2 suppression compared to box contributions)
- corrections to $Z \to \mu^+\mu^-$ proportional to $m_Z^2/m_{\rm NP}^2$: 1-2 orders of magn. below the sensitivity of LEP for $m_{\rm NP} \gtrsim 1$ TeV

Minimal Scenario

B-Bbar mixing

Very stringent bound



- with Fermilab,MILC'16 lattice results:

$$R_{\Delta B_s} = \frac{\Delta M_{B_s}^{\text{exp}}}{\Delta M_{B_s}^{\text{SM}}} - 1 = -0.09 \pm 0.08$$

$\rightarrow$ experiment slightly below SM prediction

Minimal Scenario

$B_s - \bar{B}_s$ mixing	$b \to s\mu^+\mu^-$
box: $(\Gamma_b^* \Gamma_s)^2$	box: $(\Gamma_b^* \Gamma_s)|\Gamma_\mu|^2$

$$|\Gamma_s^* \Gamma_b| \leq 0.15 \frac{1}{\sqrt{\xi_{B\bar{B}}}} \frac{m_\Psi}{1\,\text{TeV}}$$

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- consequence for $b \to s\mu^+\mu^-$:

$$|C_9^{\text{box}}| = |C_{10}^{\text{box}}| = \frac{1}{3}\,\xi_9^{\text{box}}\,|\Gamma_s^*\Gamma_b|\,|\Gamma_\mu|^2 \times (1\,\text{TeV}/m_\Psi)$$

$$\leq 0.05\,\frac{\xi_9^{\text{box}}}{\sqrt{\xi_{B\bar{B}}}}\,|\Gamma_\mu|^2 \times (1\,\text{TeV}/m_\Psi)$$

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$$\leq 0.05\,\frac{\xi_9^{\text{box}}}{\sqrt{\xi_{B\bar{B}}}}\,|\Gamma_\mu|^2 \times (1\,\text{TeV}/m_\Psi)$$

$$|\Gamma_\mu| \geq 2.1\,\frac{m_\Psi}{\text{TeV}} \quad (2\sigma)$$

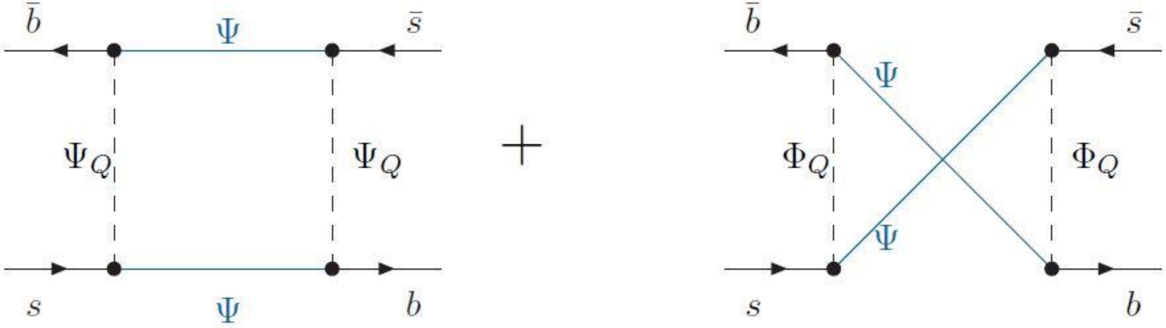
Minimal Scenario: Majorana Fermions

quantum numbers
new particles

$SU(2)$	Φ_Q	Φ_ℓ	Ψ
I	2	2	1
IV	2	2	3

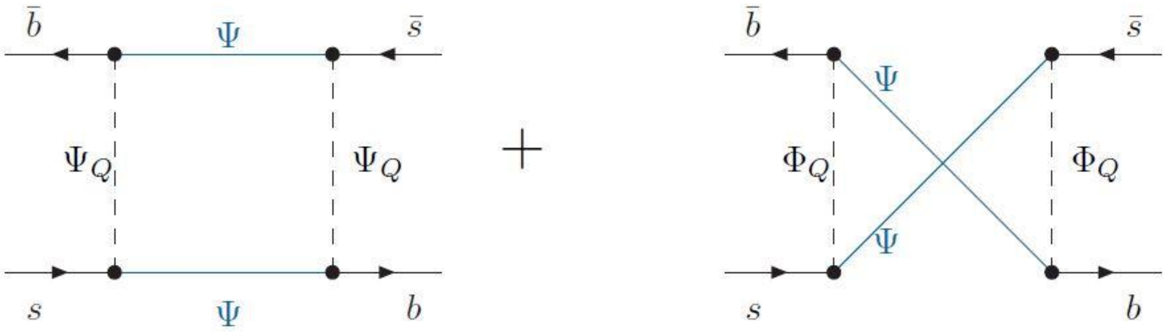
$SU(3)$	Φ_Q	Φ_ℓ	Ψ
A	3	1	1
C	3	8	8

consider Majorana fermions in box:



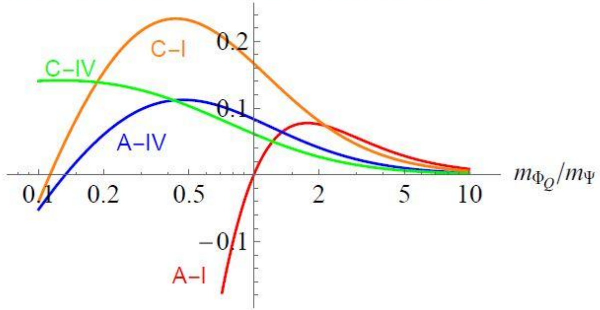
$$= H\left(\frac{m_{\Phi_Q}}{m_\Psi}\right)$$

Minimal Scenario: Majorana Fermions



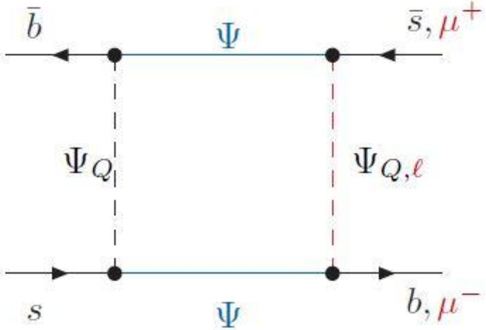
$$= H\left(\frac{m_{\Phi_Q}}{m_\Psi}\right)$$

destructive interference:

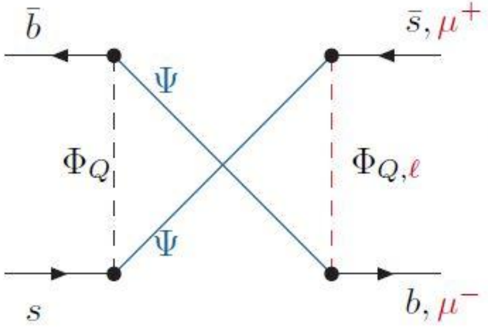


A-I: Majorana singlets
cancellation for $m_{\Phi_Q} \approx m_\Psi \equiv m$
$\rightarrow$ avoids $B_s - \overline{B}_s$ mixing bound

Minimal Scenario: Majorana Fermions

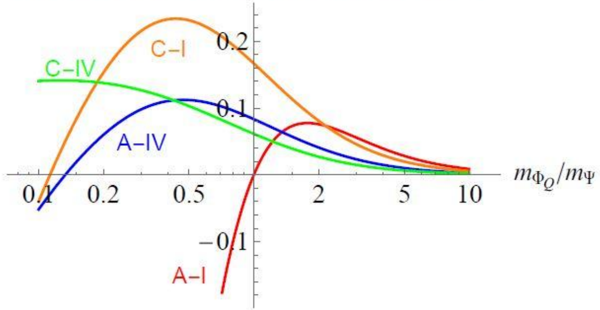


$+$



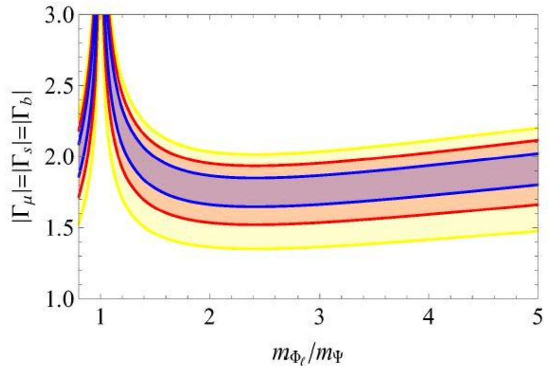
$$= H\left(\frac{m_{\Phi_Q}}{m_\Psi}, \frac{m_{\Phi_\ell}}{m_\Psi}\right)$$

destructive interference:

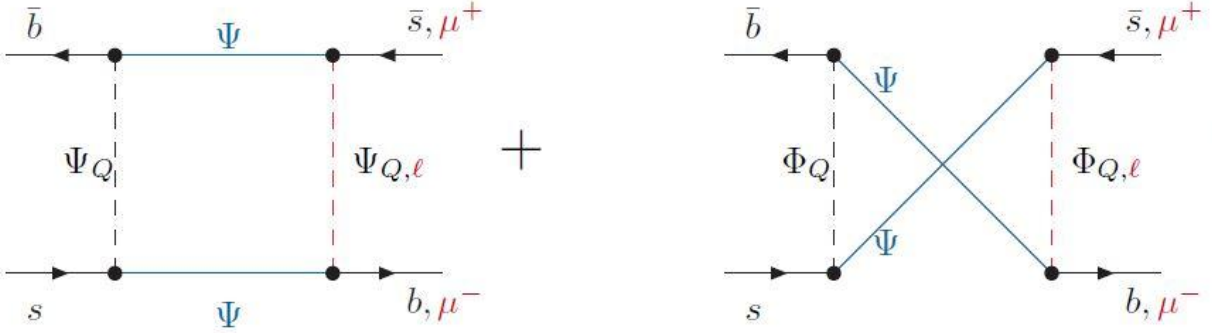


A-I: Majorana singlets
cancellation for $m_{\Phi_Q} \approx m_\Psi \equiv m$
$\rightarrow$ avoids $B_s - \overline{B}_s$ mixing bound

$b \rightarrow s\mu^+\mu^-$: avoid cancellation
$\rightarrow$ assume $m_{\Phi_\ell} \gtrsim 1.5m$



Minimal Scenario



$$= H\left(\frac{m_{\Phi_Q}}{m_\Psi}, \frac{m_{\Phi_\ell}}{m_\Psi}\right)$$

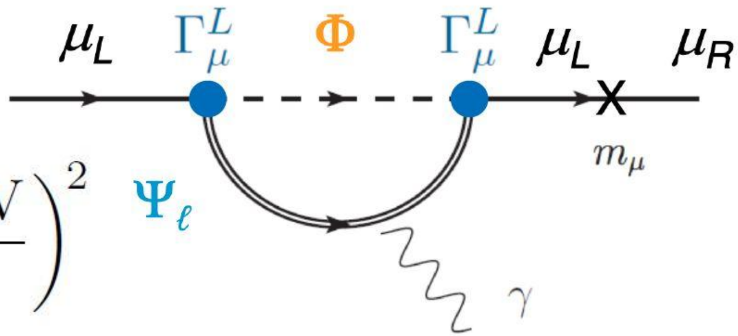
$$\Psi = (1,1), \;\; \Phi_Q = (3,2), \;\; \Phi_\ell = (1,2); \;\; m_\Psi \sim m_{\Phi_Q}, \;\; m_{\Phi_\ell} \sim 2m_\Psi$$

- absence of bound from $B_s - \bar{B}_s$ mixing for $m_\Psi = m_{\Phi_Q}$ allows solution of $b \to s\ell^+\ell^-$ anomalies at 2σ-level for

$$|\Gamma_b| = |\Gamma_s| = |\Gamma_\mu| \gtrsim 1.6$$

Minimal Scenario: g-2

$$\Delta a_\mu = (5.8\times10^{-12})\, \xi_{a_\mu}\, |\Gamma_\mu|^2 \left(\frac{1\,\text{TeV}}{m_\Psi}\right)^2$$



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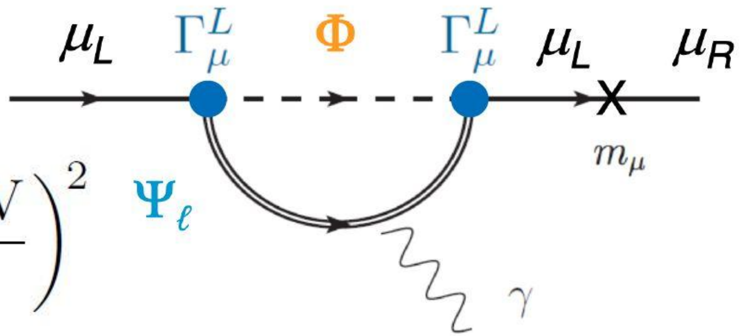


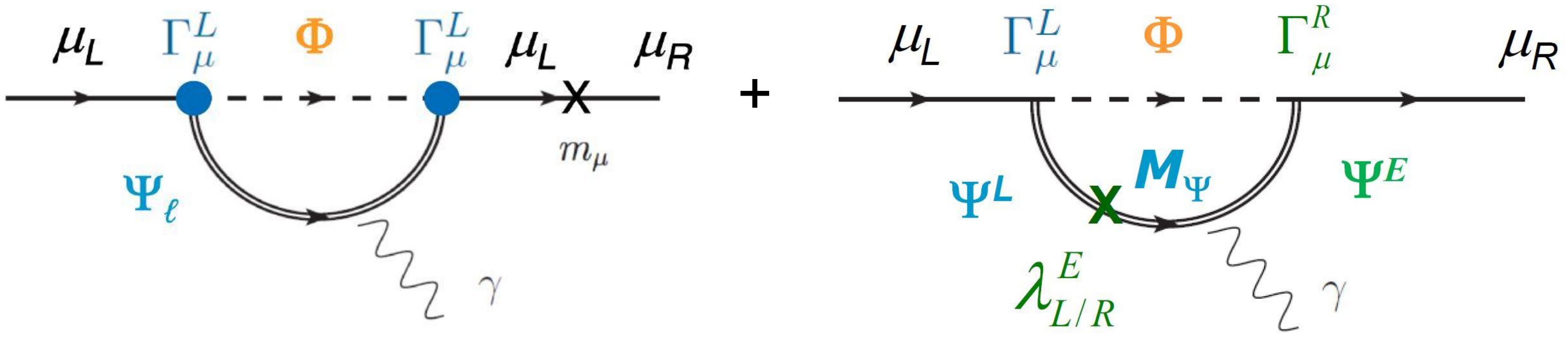
$$\Delta a_\mu = (5.8 \times 10^{-12})\, \xi_{a_\mu}\, |\Gamma_\mu|^2 \left(\frac{1\,\text{TeV}}{m_\Psi}\right)^2$$

- maximum enhancement: $\xi_{a_\mu}^{\max} = 24$

  for $\Psi = (8,2)$, $\Phi_\ell = (8,1)$, hypercharges $|X| \leq 1$

  $\Rightarrow |\Gamma_\mu| \geq 2.1 \, \frac{m_\Psi}{\text{TeV}} \quad (2\sigma)$

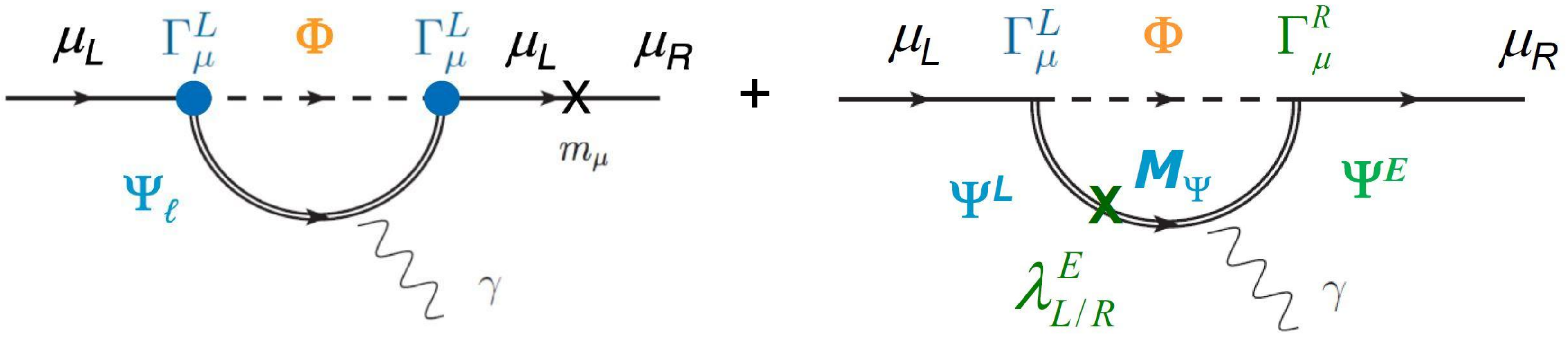
Beyond Minimal Scenario



$$\lambda^E_L \overline{\Psi}^L P_L \Psi^E h + \lambda^E_R \overline{\Psi}^L P_R \Psi^E h$$

SU(2) breaking

Beyond Minimal Scenario

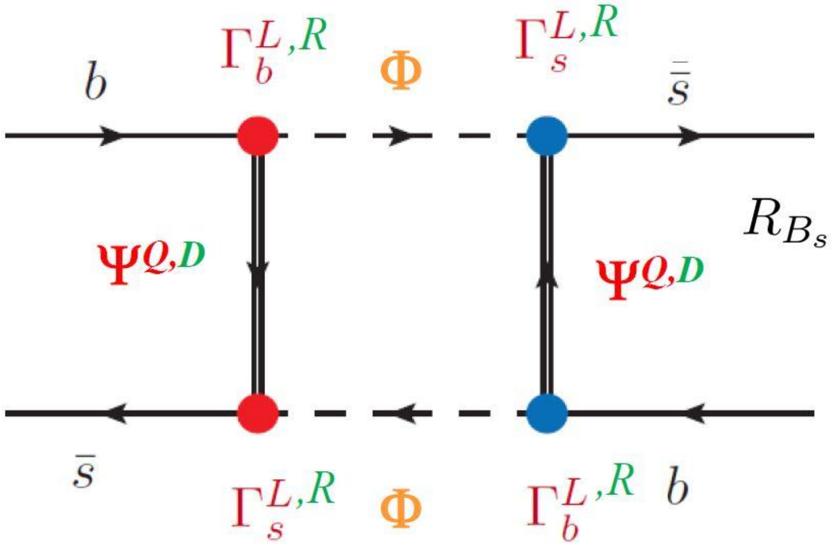


$$\lambda_L^E \overline{\Psi}^L P_L \Psi^E h + \lambda_R^E \overline{\Psi}^L P_R \Psi^E h$$

- one scalar Φ
- two LH vector-like fermions $\Psi^Q \Psi^L$
- one RH vector-like fermion Ψ^E

SU(2) breaking

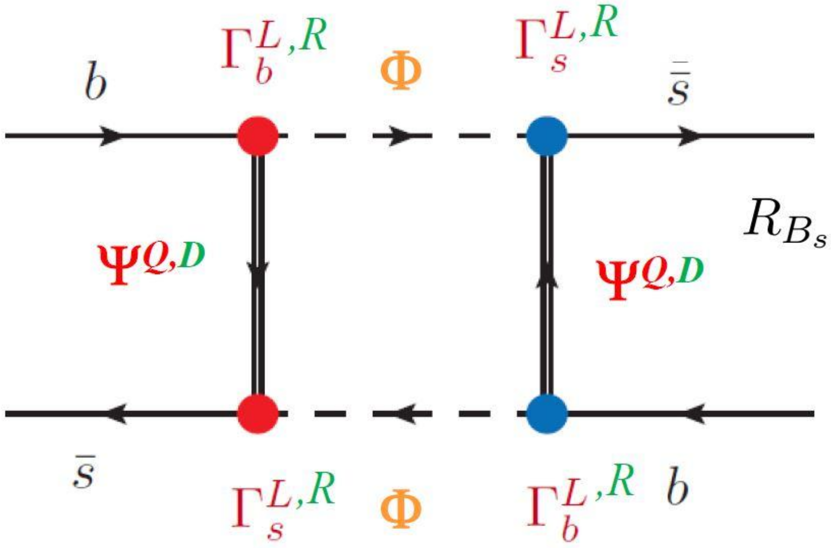
Beyond Minimal Scenario



$$R_{B_s} = 3\frac{(\Gamma_b^L\Gamma_s^L)^2 - 9(\Gamma_b^L\Gamma_s^L)(\Gamma_b^R\Gamma_s^R) + (\Gamma_b^R\Gamma_s^R)^2}{m_\Phi^2/1\,\mathrm{TeV}^2}$$

C_5 and C_1 have opposite sign

Beyond Minimal Scenario



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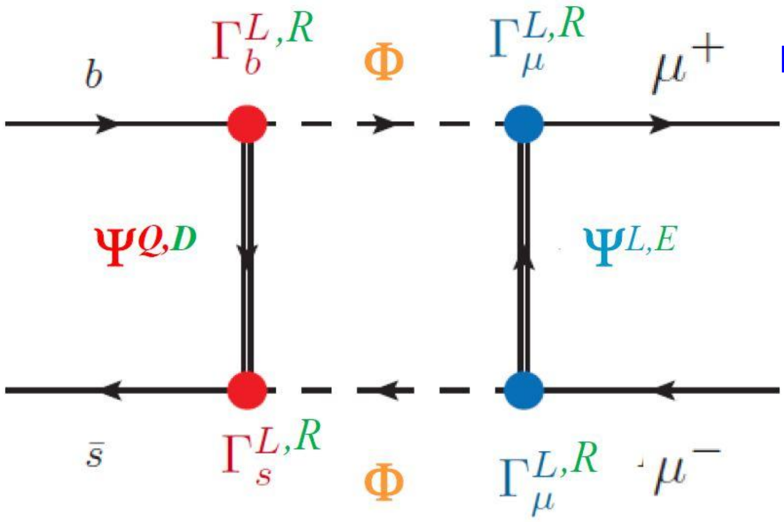

PA, Crivellin, Fedele, Mescia

No scalar or tensor operators.

$$-1.48 \leq C_9 \leq -0.71\,, \qquad -0.12 \leq C_{10} \leq 0.61$$
$$-0.56 \leq C_9' \leq 1.14\,, \qquad -0.57 \leq C_{10}' \leq 0.34$$

Algueró et al

- one scalar Φ
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4th Generation model

$$L^{4\text{th}} = \sum_i \left(\Gamma^L_{q_i}\bar{\Psi}_q P_L q_i + \Gamma^L_{\ell_i}\bar{\Psi}_\ell P_L \ell_i + \Gamma^R_{u_i}\bar{\Psi}_u P_R u_i + \Gamma^R_{d_i}\bar{\Psi}_d P_R d_i + \Gamma^R_{e_i}\bar{\Psi}_e P_R e_i\right)\Phi + \text{h.c.}$$

$$+ \sum_{C=L,R}\left(\lambda^U_C\bar{\Psi}_q P_C\tilde{h}\Psi_u + \lambda^D_C\bar{\Psi}_q P_C h\Psi_d + \lambda^E_C\bar{\Psi}_\ell P_C h\Psi_e\right) + \text{h.c.}$$

$$+ \sum M_F\bar{\Psi}_F\Psi_F + \kappa\, h^\dagger h\,\Phi^\dagger\Phi + m^2_\Phi\Phi^\dagger\Phi\,,$$

	$SU(3)$	$SU(2)$	$U(1)$	$U'(1)$
Ψ_q	3	2	1/6	Z
Ψ_u	3	1	2/3	Z
Ψ_d	3	1	$-1/3$	Z
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We do not couple the up-quark

NO SU(2) breaking in quark sector
CS,CP,CT

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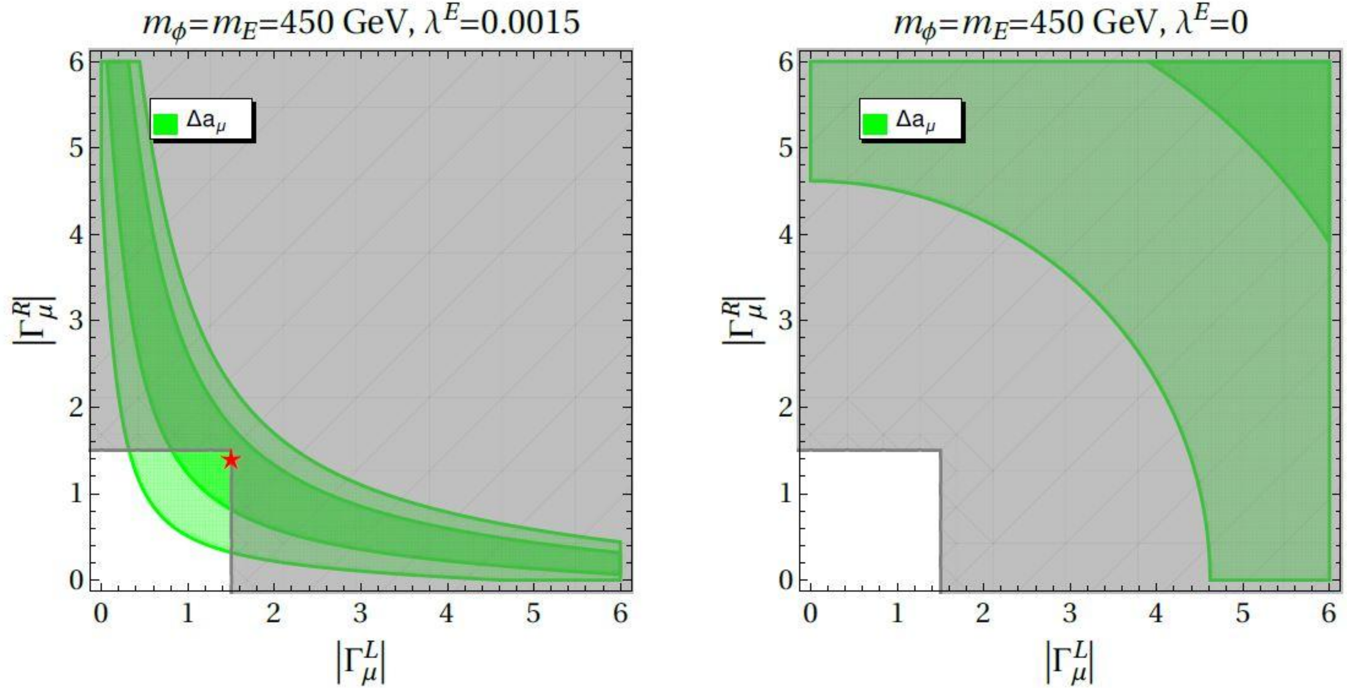
4th Generation model

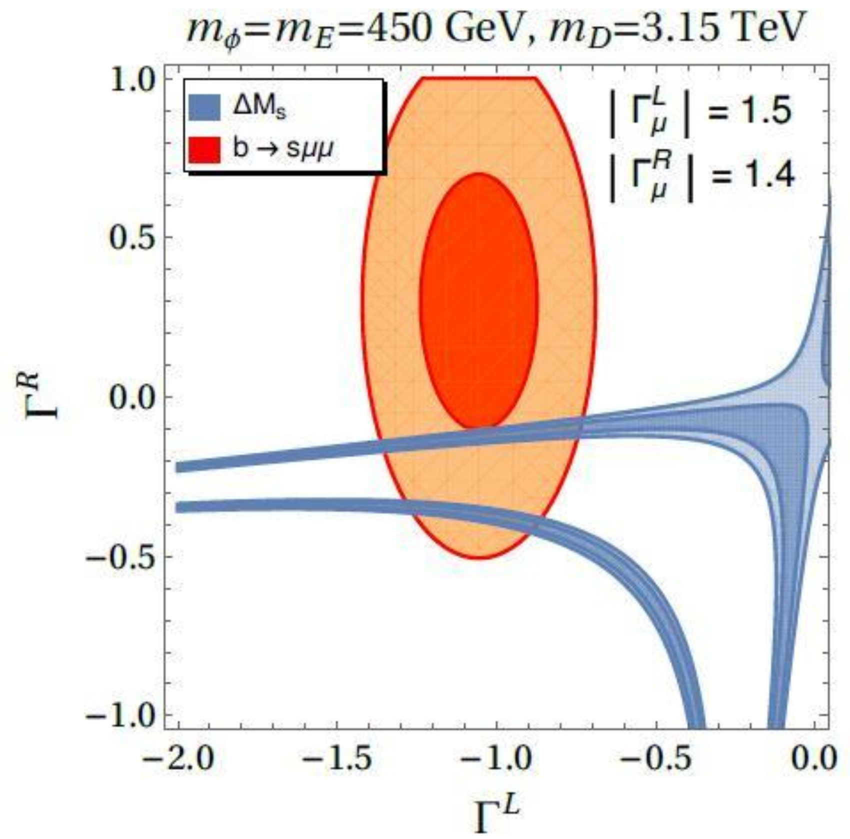
$$\Gamma^L \equiv \Gamma_b^L \Gamma_s^{L*} \qquad \Gamma_\mu^L$$

$$\Gamma^R \equiv \Gamma_b^R \Gamma_s^{R*} \qquad \Gamma_\mu^R$$

$$\lambda_R^E = -\lambda_L^E = \lambda$$



4th Generation model



Summary

- In the LH case, Bs mixing kills the model unless Majorana.
- g-2 impossible in the minimal case

- Introduce RH couplings solves Bs mixing bound and can increase g-2
- General formulae

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Moltes gràcies!

Collider signatures:
similar to sbottom and neutralino searches
$\rightarrow$ masses $\gtrsim 1$ TeV still viable with current Atlas/CMS data

D mixing

$$\Gamma_u = V_{us}\Gamma_s + V_{ub}\Gamma_b \approx V_{us}\Gamma_s$$
$$\Gamma_c = V_{cs}\Gamma_s + V_{cb}\Gamma_b \approx \Gamma_s$$