$(g-2)_\mu$, B-anomalies and DM: A loop model tale

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based on arXiv:1904.05890, 2103.09835, 2104.03228 in collaboration with:

G. Arcadi, P. Arnan, L. Calibbi, A. Crivellin & F. Mescia

Summary

- *Introduction*
- *g-2 and B-anomalies*
- *B-anomalies and DM*
- *All together now!*

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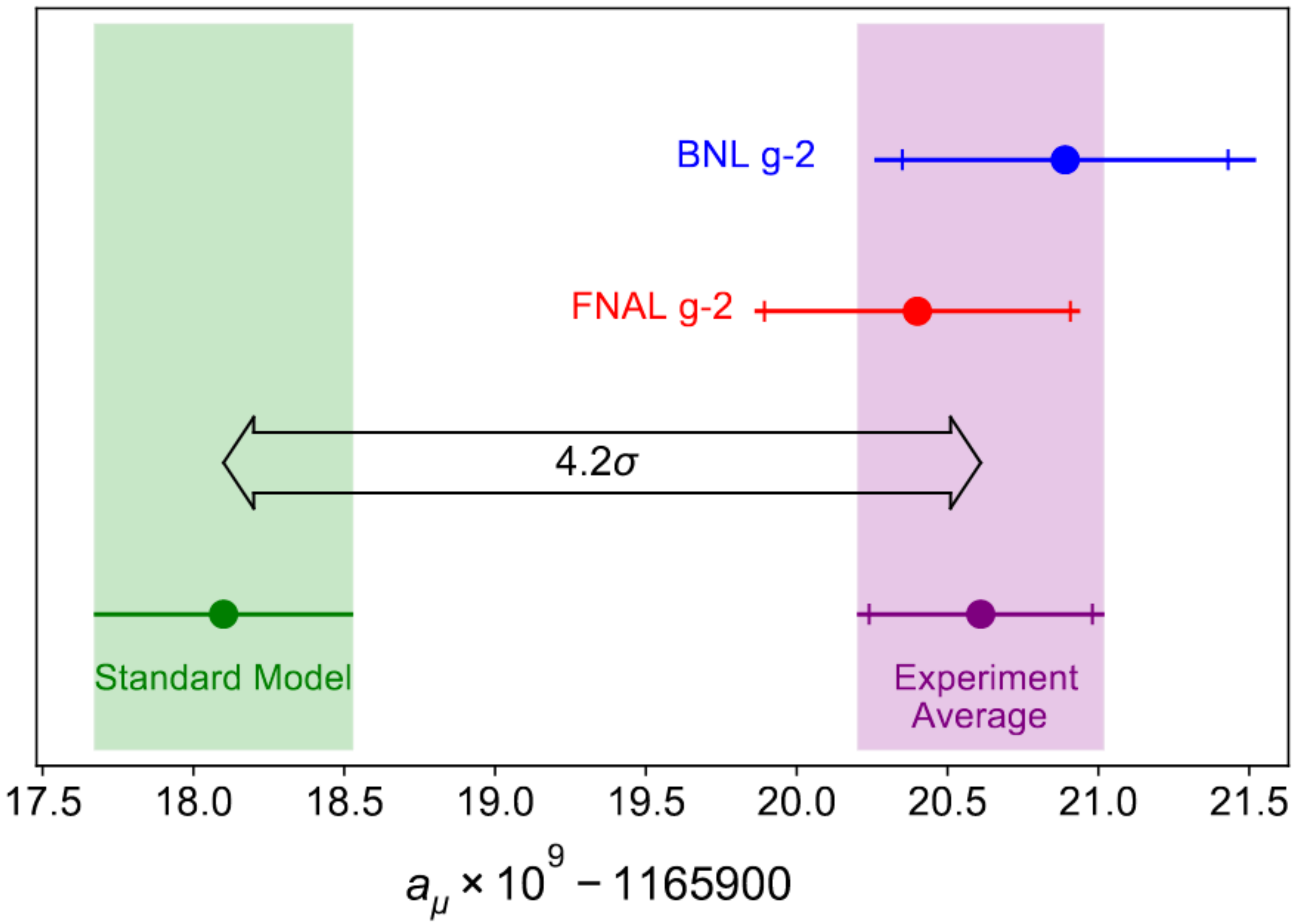
The anomalous muon (g-2)

Striking discrepancy among Theory recommended value and exp. measurements



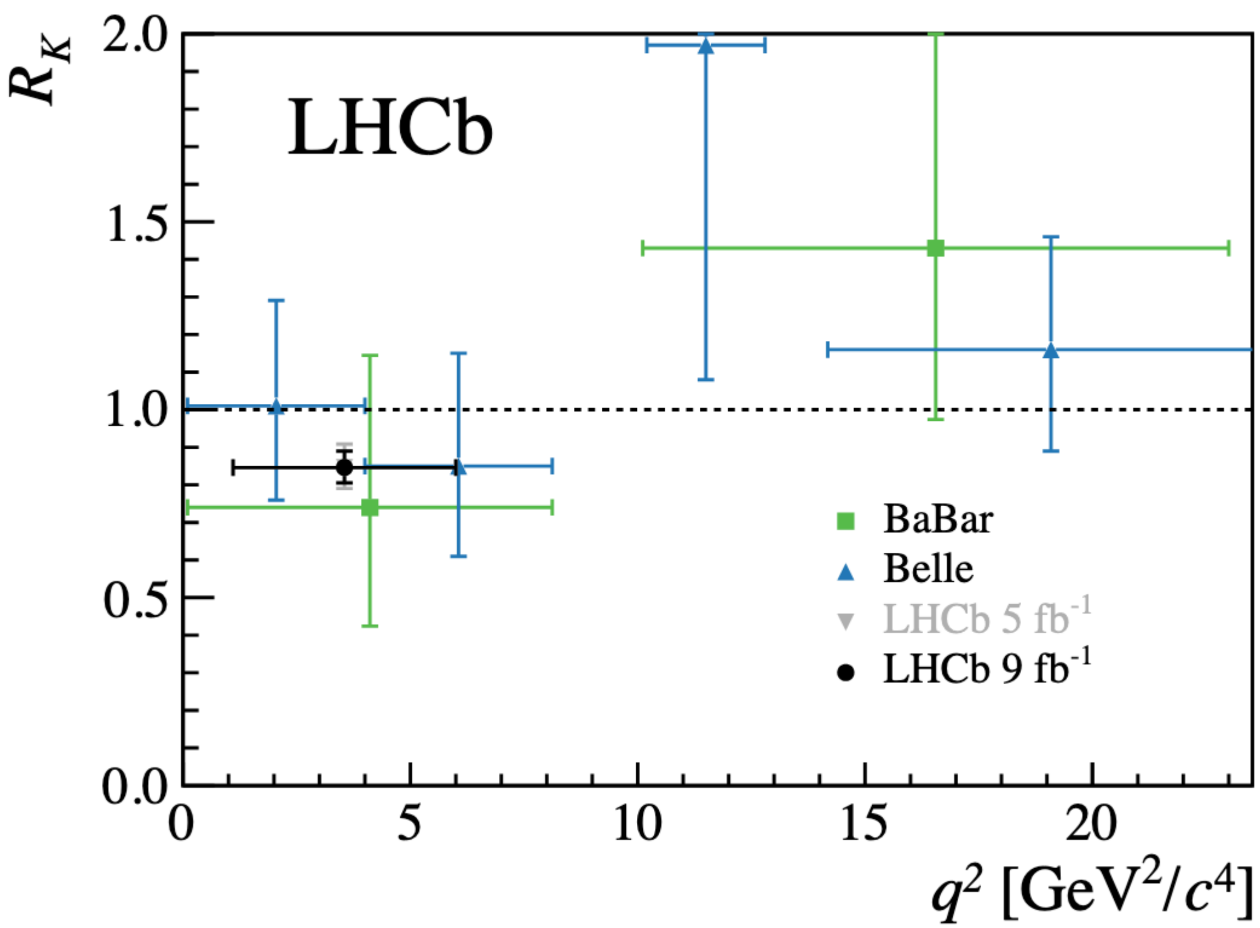
Potentially the single most striking cry for NP observed so far!

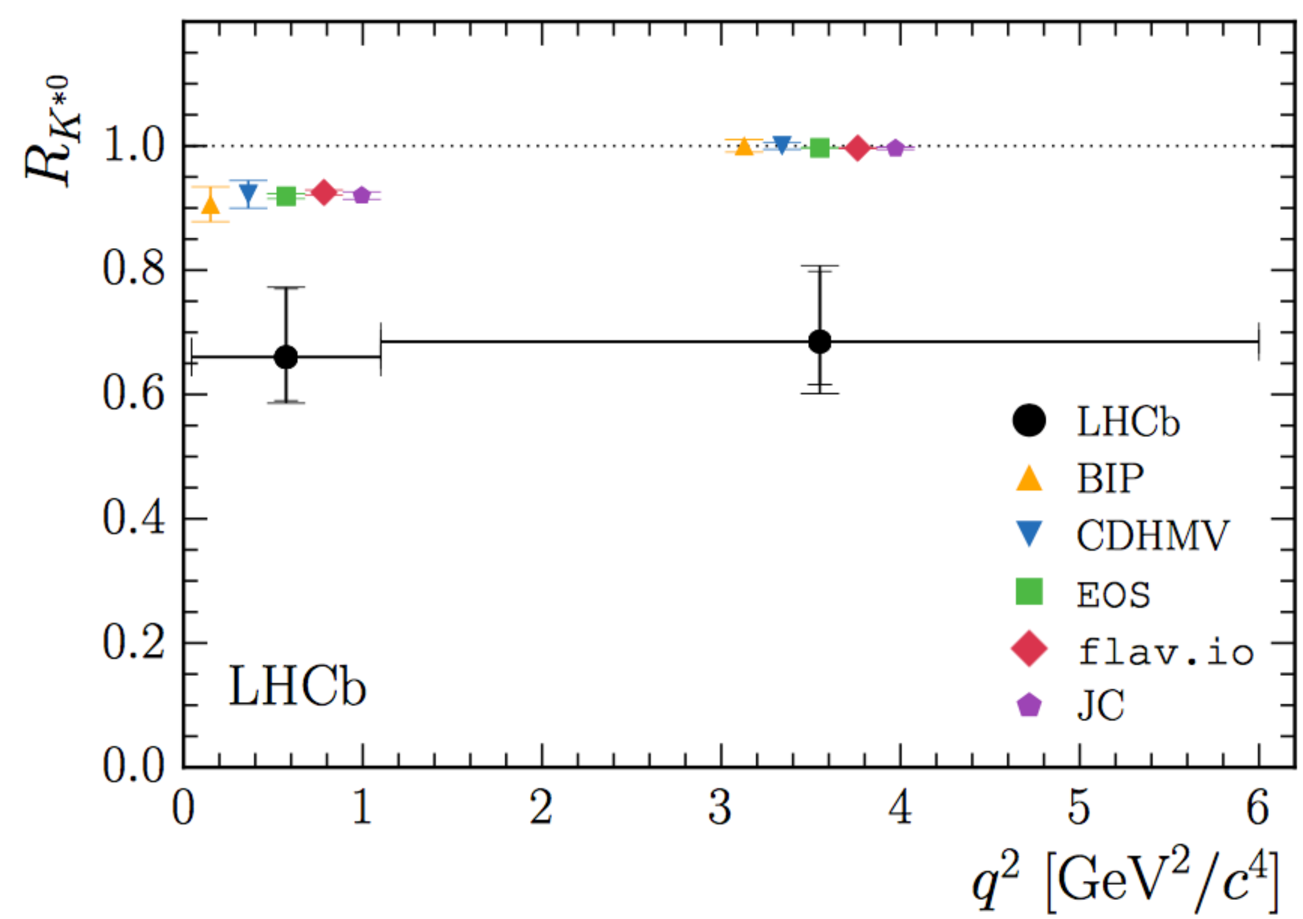
Opportunities with Semi-Leptonic B Decays

No tree-level flavour changing neutral currents (FCNC) in the SM

&

Intriguing set of “Anomalies” in data of exclusive B rare Decays





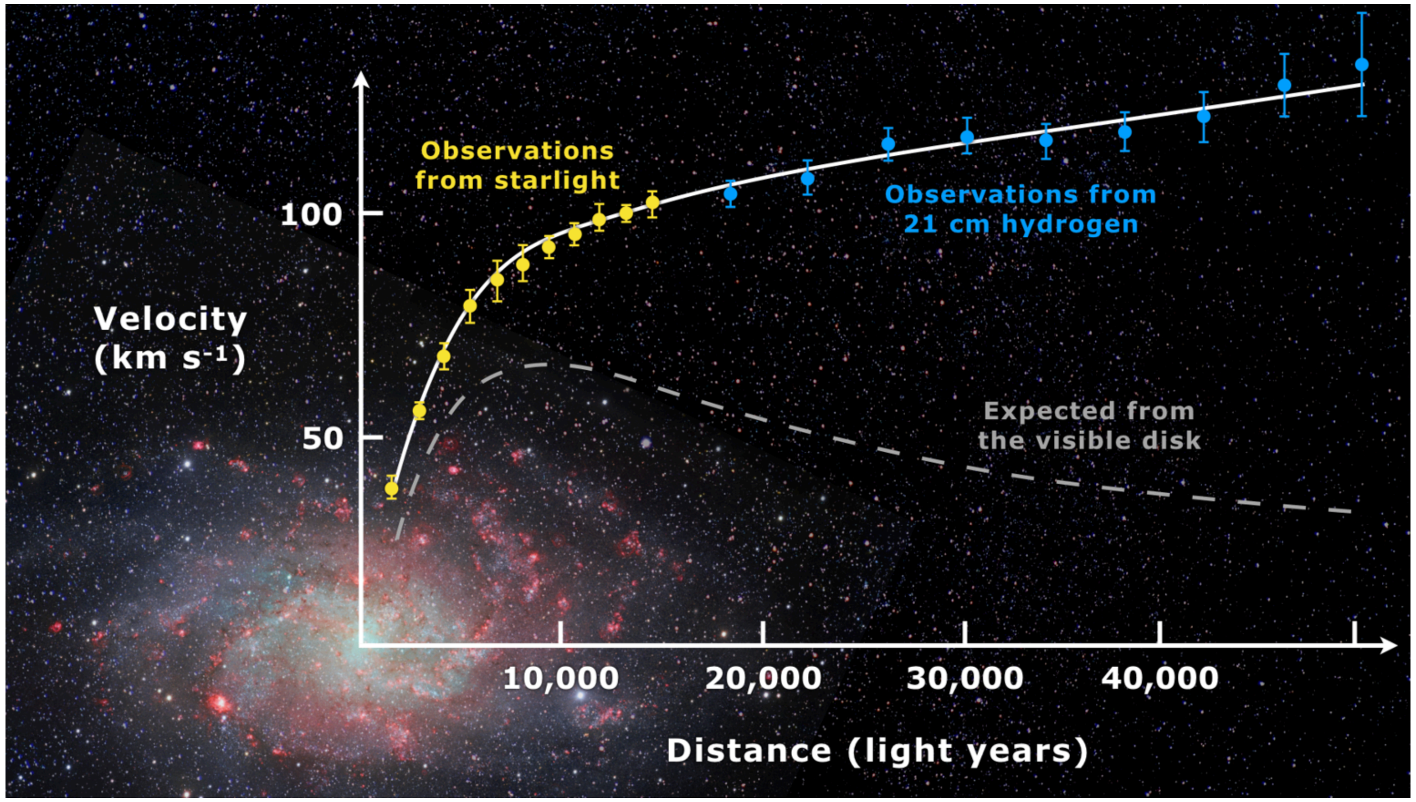
~ 3.1 σ

~ 2.5 σ

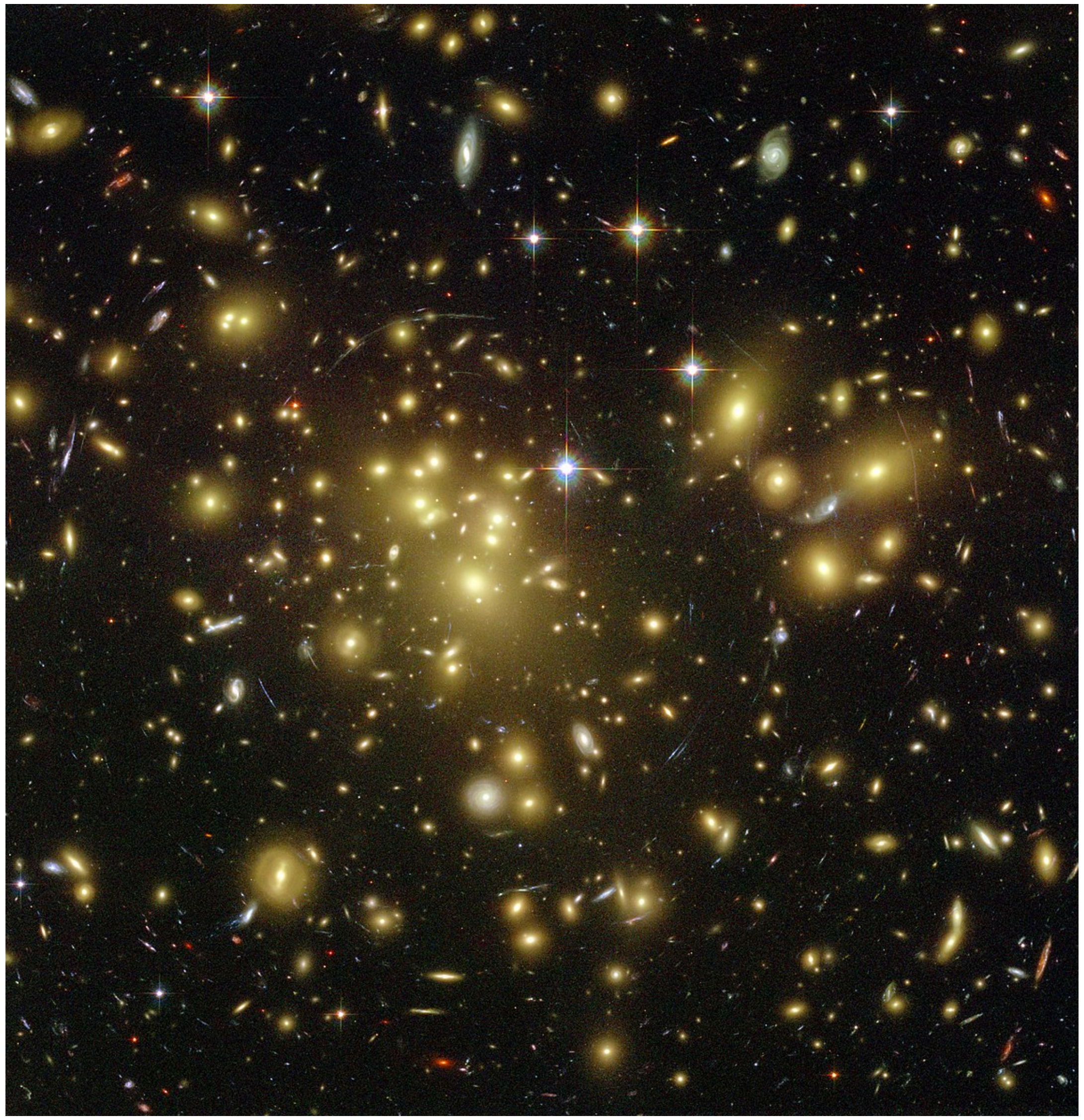
$R_{K^{(*)}} = Br(B \longrightarrow K^{(*)}\mu\mu) / Br(B \longrightarrow K^{(*)}ee)$

Evidence of DM in the Universe

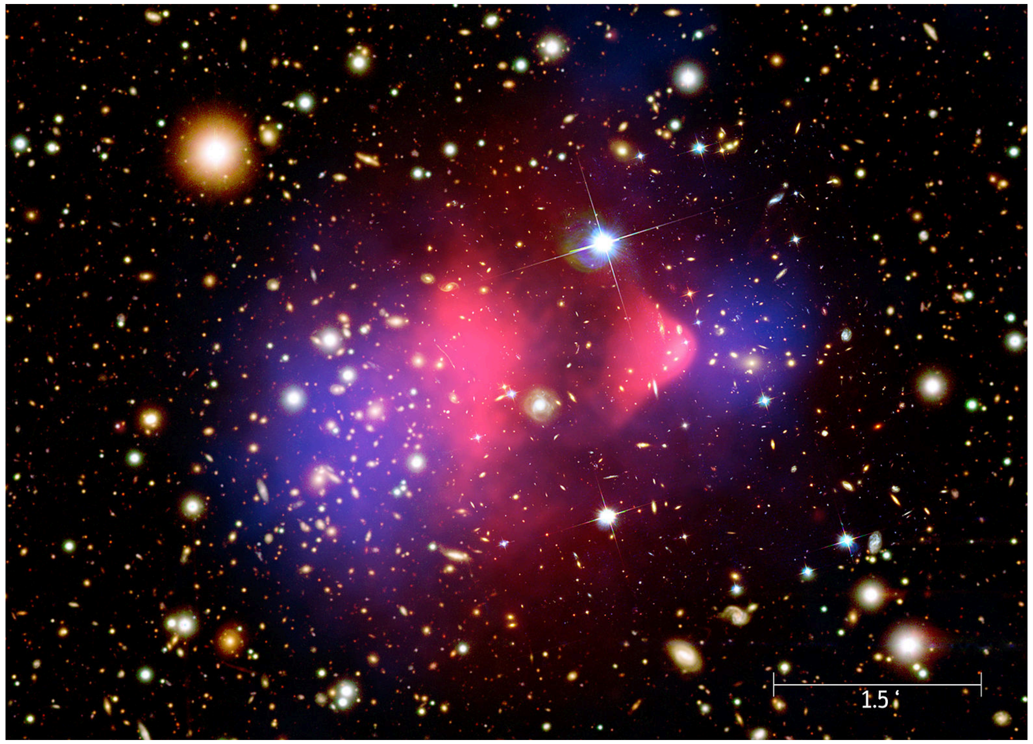
Multiple evidences of presence of DM from Astrophysical observations



Galaxy rotation curves



Gravitational lensing



Bullet Cluster

Summary

- *Introduction*
- *g-2 and B-anomalies (1904.05890)*
- *B-anomalies and DM*
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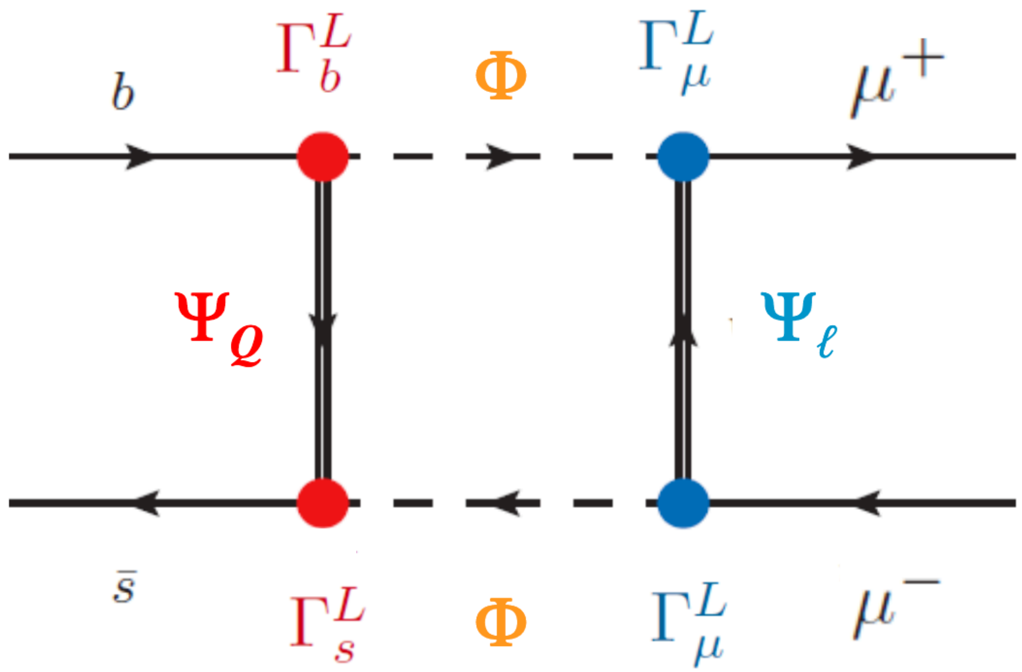
Loop Models

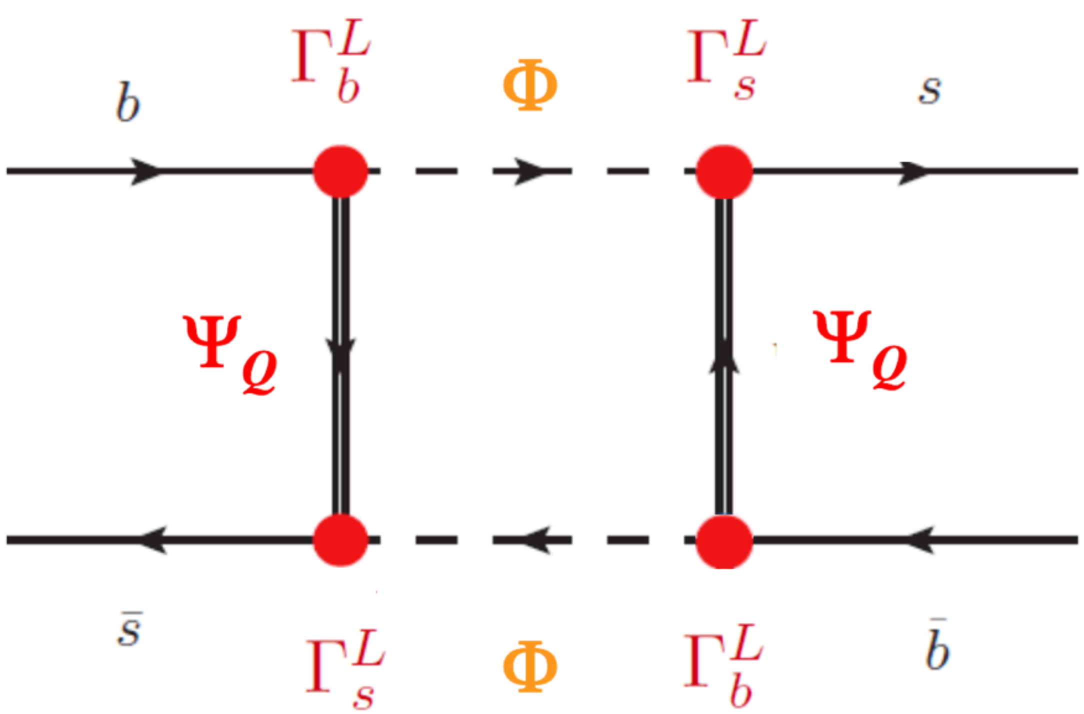


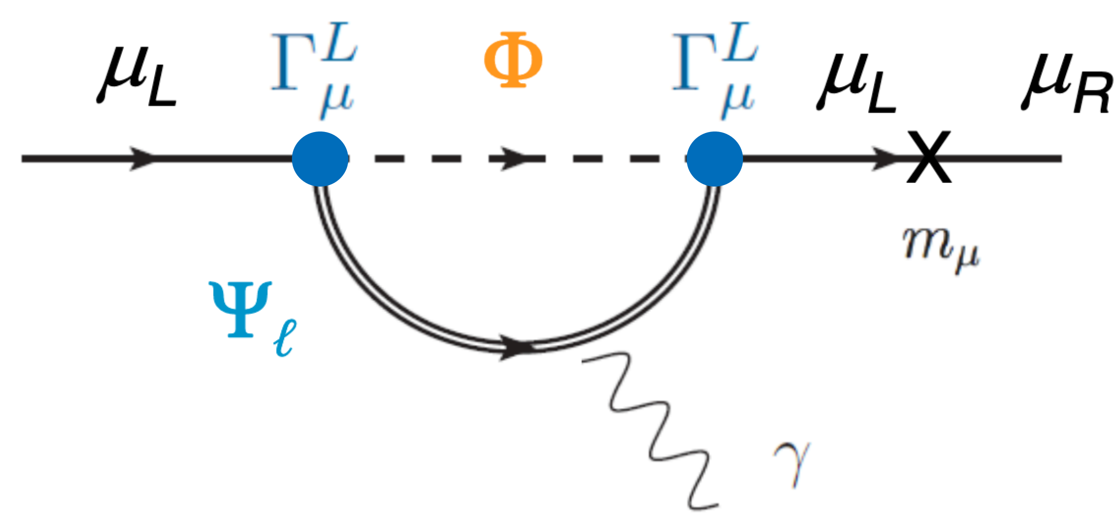
One scalar and 2 vector-like fermions (or vice versa)

$\Longrightarrow$ $\boxed{\text{C9 = -C10}}$

Gripaios, Nardecchia, Renner ’15
Arnan, Crivellin, Hofer, Mescia ’16

Induces contributions to ΔMs and muon g-2





It is not possible to address everything with O(1) couplings and viable masses

A Generic Loop Model including RH couplings

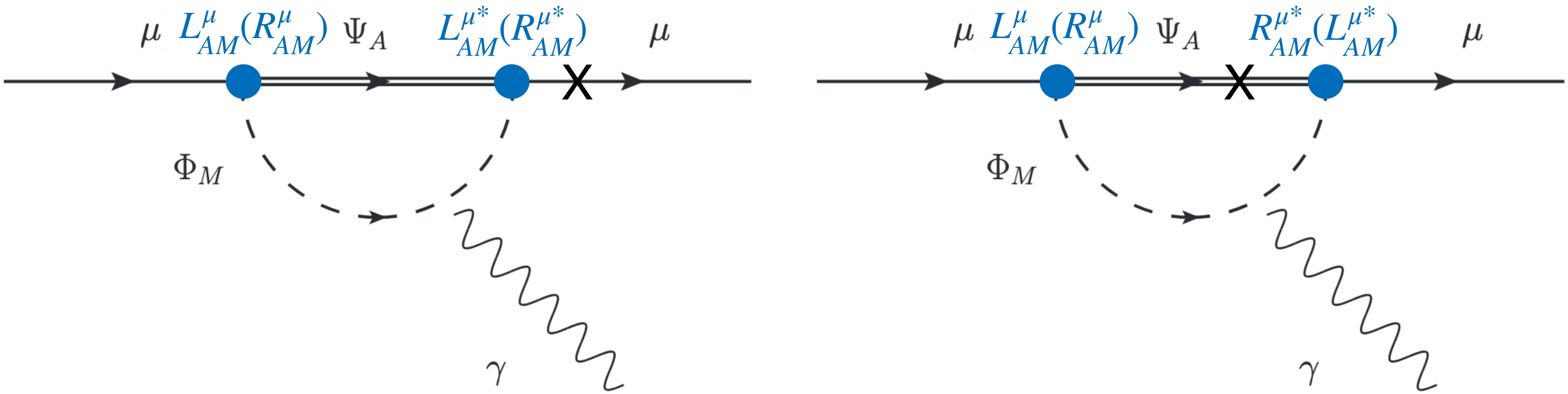
$$\boxed{\begin{aligned}\mathcal{L}_{\rm int} = \Big[& \bar\Psi_A \left(L^b_{AM} P_L b + L^s_{AM} P_L s + L^\mu_{AM} P_L \mu\right) \Phi_M \\ & + \bar\Psi_A \left(R^b_{AM} P_R b + R^s_{AM} P_R s + R^\mu_{AM} P_R \mu\right) \Phi_M \Big] + \text{h.c.}\end{aligned}}$$

Ψ_A, Φ_M : Generic lists containing an arbitrary number of fields

$L^{b,s,\mu}_{AM}, R^{b,s,\mu}_{AM}$: Generic matrices in (A-M) space

- A and M also include implicitly SU(3) indices
- Non-vanishing entries of the coupling matrices ensure the preservation of colour and electric charge

g-2



$$\Delta a_\mu = \frac{\chi_{a_\mu} m_\mu^2}{8\pi^2 m_{\Phi_M}^2} \Big[\left(L^{\mu *}_{AM} L^{\mu}_{AM} + R^{\mu *}_{AM} R^{\mu}_{AM} \right) \left(Q_{\Phi_M} \widetilde{F}_7 (x_{AM}) - Q_{\Psi_A} F_7 (x_{AM}) \right)$$
$$+ \left(L^{\mu *}_{AM} R^{\mu}_{AM} + R^{\mu *}_{AM} L^{\mu}_{AM} \right) \frac{2 m_{\Psi_A}}{m_\mu} \left(Q_{\Phi_M} \widetilde{G}_7 (x_{AM}) - Q_{\Psi_A} G_7 (x_{AM}) \right) \Big]$$

Additional term induced by SU(2) breaking, and chirally enhanced

4th Generation Model

$$L^{4\mathrm{th}} = \sum_i \left(\Gamma^L_{q_i}\bar\Psi_q P_L q_i + \Gamma^L_{\ell_i}\bar\Psi_\ell P_L \ell_i + \Gamma^R_{u_i}\bar\Psi_u P_R u_i + \Gamma^R_{d_i}\bar\Psi_d P_R d_i + \Gamma^R_{e_i}\bar\Psi_e P_R e_i\right)\Phi + \mathrm{h.c.}$$
$$+ \sum_{C=L,R}\left(\lambda^U_C\bar\Psi_q P_C\tilde h\Psi_u + \lambda^D_C\bar\Psi_q P_C h\Psi_d + \lambda^E_C\bar\Psi_\ell P_C h\Psi_e\right) + \mathrm{h.c.}$$
$$+ \sum_{F=q,\ell,u,d,e} M_F\bar\Psi_F\Psi_F + \kappa\, h^\dagger h\,\Phi^\dagger\Phi + m^2_\Phi\Phi^\dagger\Phi$$

We start writing down the most general Lagrangian before EWSB including a 4th vector-like generation and a neutral scalar

	$SU(3)$	$SU(2)$	$U(1)$	$U'(1)$
Ψ_q	3	2	$1/6$	Z
Ψ_u	3	1	$2/3$	Z
Ψ_d	3	1	$-1/3$	Z
Ψ_ℓ	1	2	$-1/2$	Z
Ψ_e	1	1	-1	Z
Φ	1	1	0	$-Z$

NB. We work in the basis with diagonal down-type quarks

4th Generation Model

$$L^{\rm 4th} = \sum_i \left(\Gamma^L_{q_i}\bar\Psi_q P_L q_i + \Gamma^L_{\ell_i}\bar\Psi_\ell P_L \ell_i + \cancel{\Gamma^R_{u_i}\bar\Psi_u P_R u_i} + \Gamma^R_{d_i}\bar\Psi_d P_R d_i + \Gamma^R_{e_i}\bar\Psi_e P_R e_i\right)\Phi + \text{h.c.}$$

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

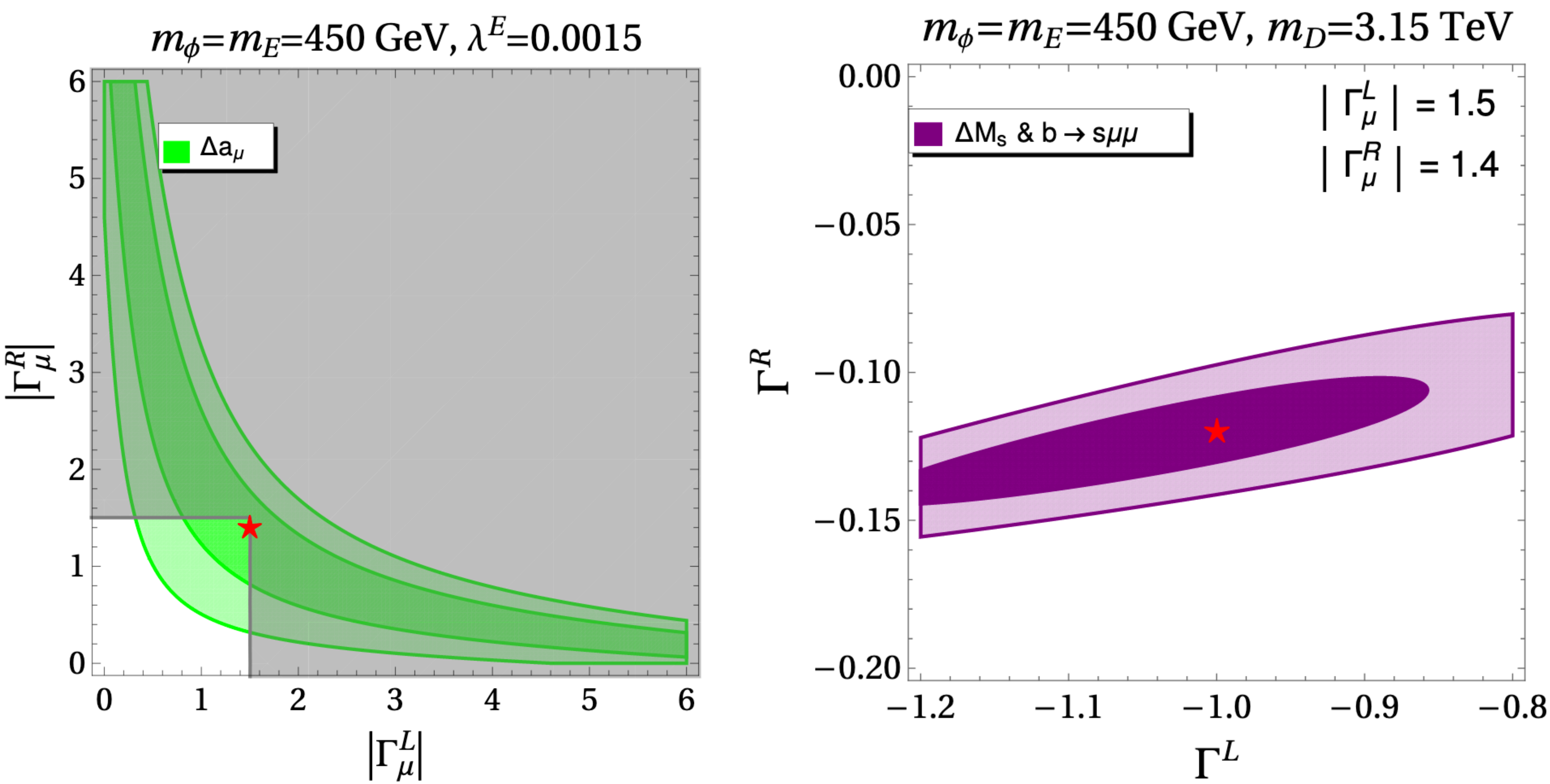
$$+ \sum_{F=q,\ell,u,d,e} \boxed{M_F \bar\Psi_F \Psi_F} + \kappa\, h^\dagger h\, \Phi^\dagger\Phi + m^2_\Phi \Phi^\dagger \Phi$$

We're interested only in couplings to bottom, strange, muon

We neglect SU(2) breaking for down-type quarks
(responsible for phenomenological un-relevant scalar/tensor operators)

We need to diagonalize the lepton sector!

Fit to the Observables



Right-handed coupling (in both sectors) and SU(2) breaking (in the muon sector) both fundamental!

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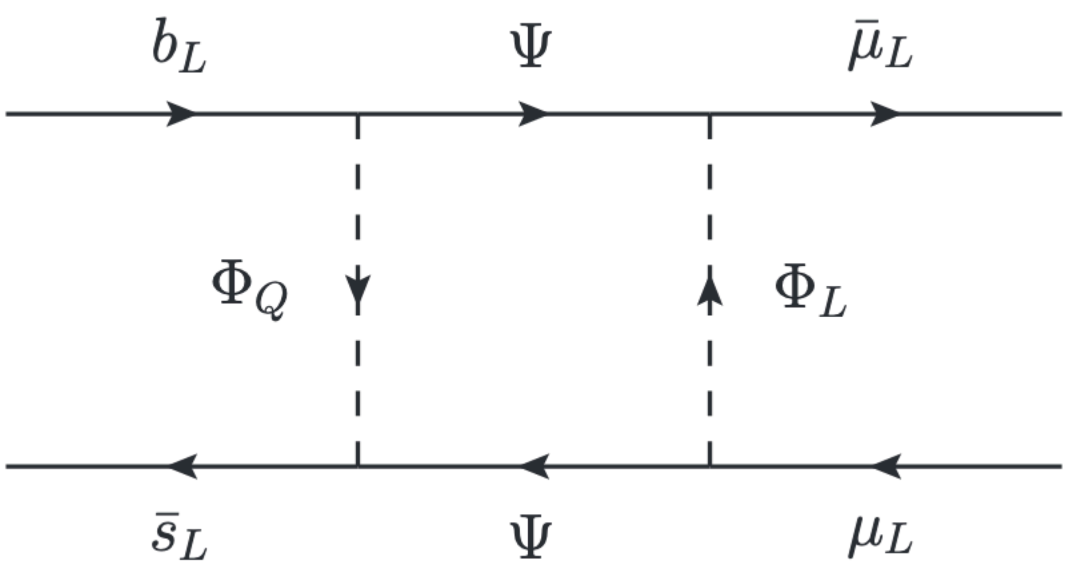
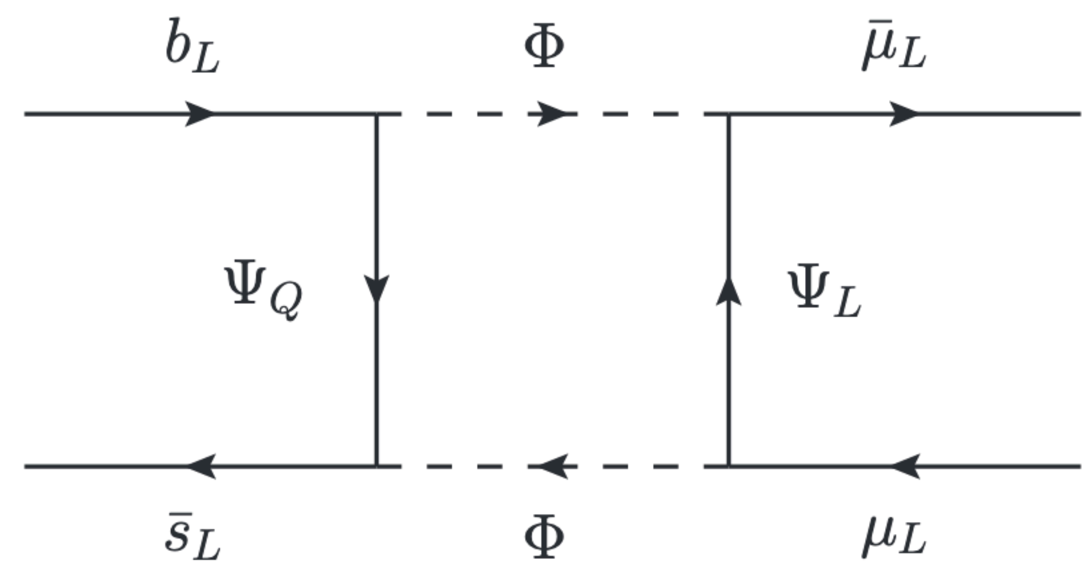
Systematic Studies of All Possible Loop Models

We're not addressing the muon (g-2), so we focus here on LH couplings (only 3 fields)



Class $\mathcal{F}$ – Fermion mediator

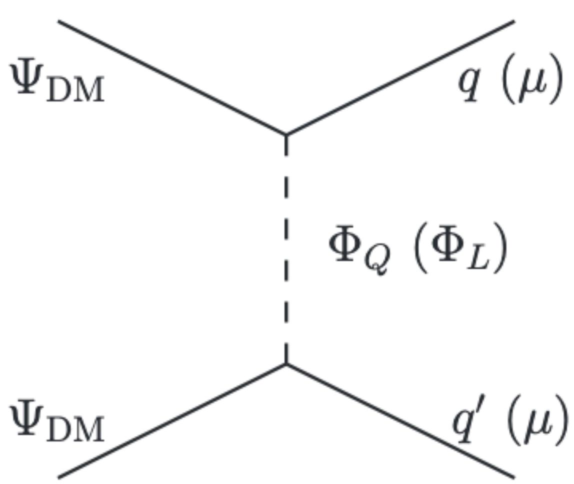
$$\boxed{\mathcal{L}_{\mathcal{F}} \supset \Gamma_i^Q \, \bar{Q}_i \, P_R \Psi \, \Phi_Q + \Gamma_i^L \, \bar{L}_i \, P_R \Psi \, \Phi_L + \text{h.c.}}$$

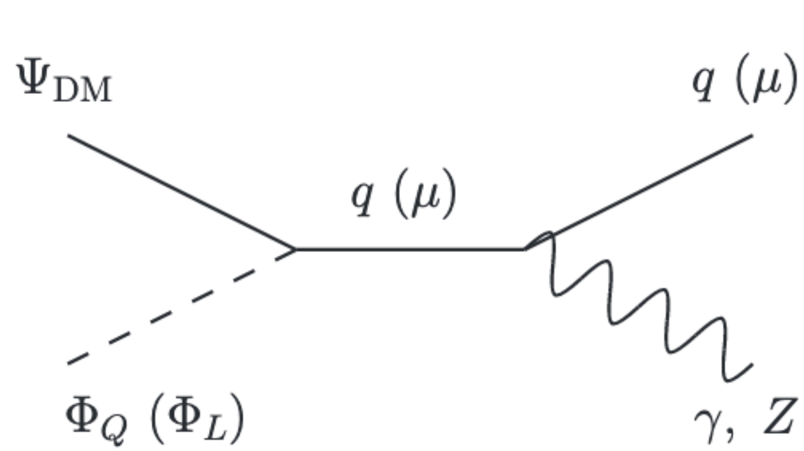


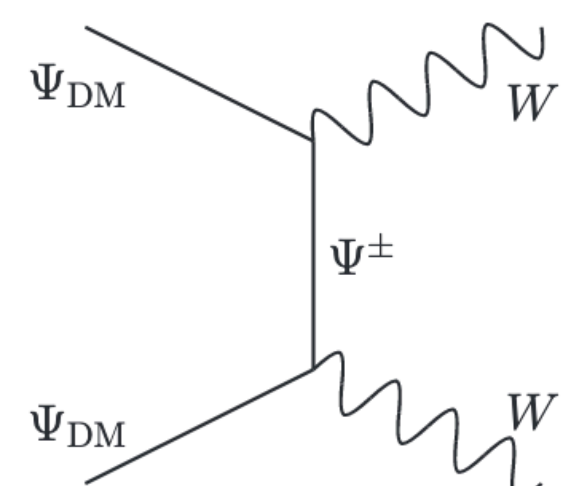
Class $\mathcal{S}$ – Scalar mediator

$$\boxed{\mathcal{L}_{\mathcal{S}} \supset \Gamma_i^Q \, \bar{Q}_i \, P_R \Psi_Q \, \Phi + \Gamma_i^L \, \bar{L}_i \, P_R \Psi_L \, \Phi + \text{h.c.}}$$

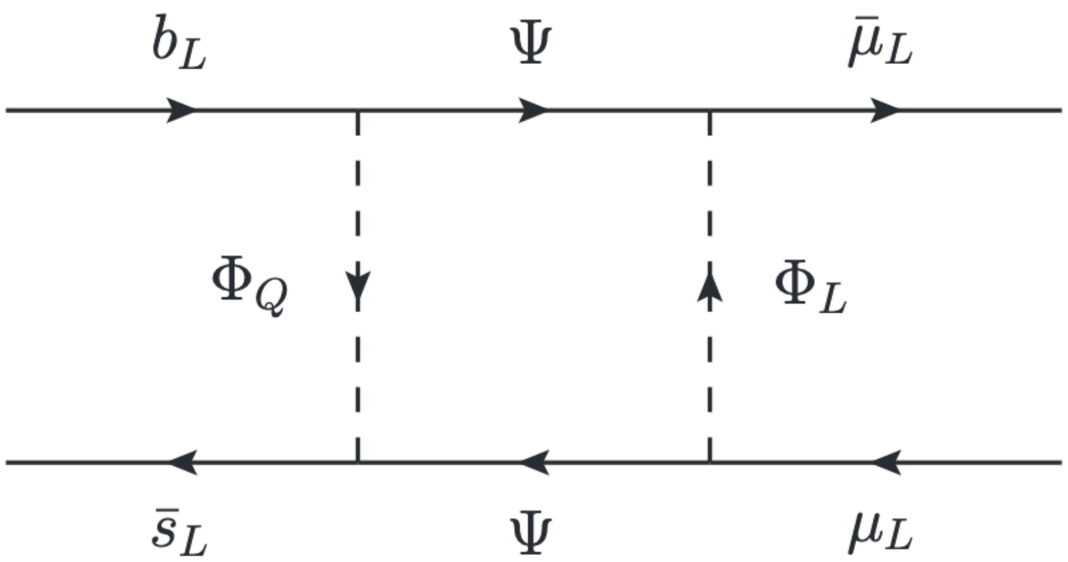
However we're looking for a DM candidate now, which has to be stable and must not be over abundant (ideally reproducing the relic density)



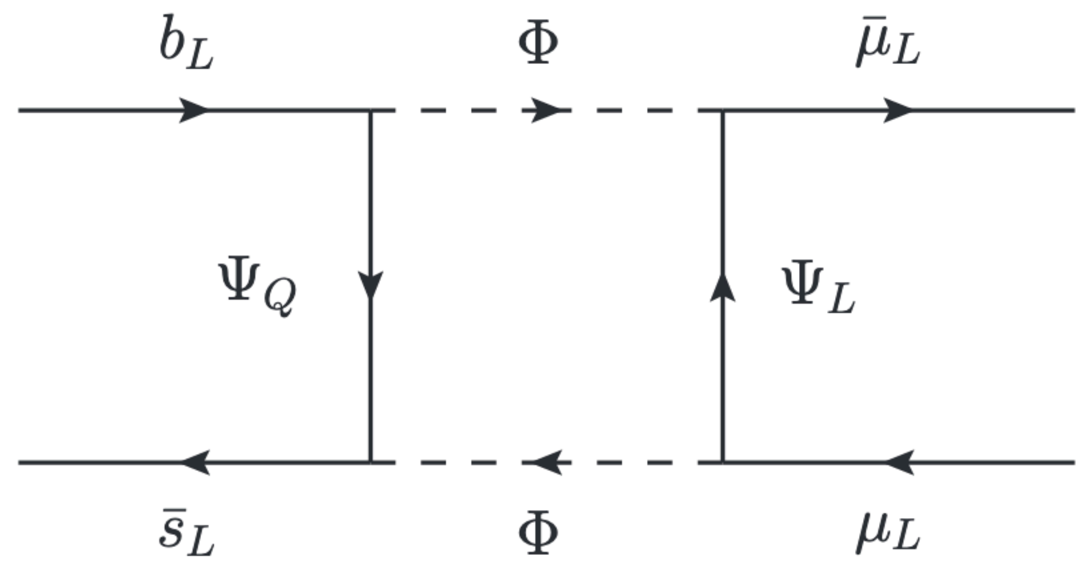




Allowed representations



$Class\ \mathcal{F}$ – Fermion mediator



$Class\ \mathcal{S}$ – Scalar mediator

$SU(3)_c$	Φ_Q, Ψ_Q	Φ_L, Ψ_L	Ψ, Φ
A	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{1}$
B	$\mathbf{1}$	$\bar{\mathbf{3}}$	$\mathbf{3}$

$SU(2)_L$	Φ_Q, Ψ_Q	Φ_L, Ψ_L	Ψ, Φ
I	$\mathbf{2}$	$\mathbf{2}$	$\mathbf{1}$
II	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$
III	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{2}$
IV	$\mathbf{2}$	$\mathbf{2}$	$\mathbf{3}$
V	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{2}$
VI	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{2}$

$U(1)_Y$	Φ_Q, Ψ_Q	Φ_L, Ψ_L	Ψ, Φ
	$1/6 - X$	$-1/2 - X$	X

- X chosen so that there is a neutral state (DM candidate)
- Fermionic DM only allowed for SU(2) singlet or triplet (doublet would require the presence of a additional Majorana fermions)
- Scalar DM allowed for any SU(2) rep. (doublet allowed by suitable mass splitting between CP-even and CP-odd, i.e. Inert Doublet)

Allowed representations

Label	Φ_Q	Φ_L	Ψ
$\mathcal{F}_{\mathrm{IA};\,\text{-}1}$	$(\mathbf{3},\mathbf{2},7/6)$	$(\mathbf{1},\mathbf{2},1/2)^\star$	$(\mathbf{1},\mathbf{1},-1)$
$\mathcal{F}_{\mathrm{IA};\,0}$	$(\mathbf{3},\mathbf{2},1/6)$	$(\mathbf{1},\mathbf{2},-1/2)^\star$	$(\mathbf{1},\mathbf{1},0)^\star$
$\mathcal{F}_{\mathrm{IB};\,\text{-}1/3}$	$(\mathbf{1},\mathbf{2},1/2)^\star$	$(\bar{\mathbf{3}},\mathbf{2},-1/6)$	$(\mathbf{3},\mathbf{1},-1/3)$
$\mathcal{F}_{\mathrm{IB};\,2/3}$	$(\mathbf{1},\mathbf{2},-1/2)^\star$	$(\bar{\mathbf{3}},\mathbf{2},-7/6)$	$(\mathbf{3},\mathbf{1},2/3)$
$\mathcal{F}_{\mathrm{IIA}}$	$(\mathbf{3},\mathbf{1},2/3)$	$(\mathbf{1},\mathbf{1},0)^\star$	$(\mathbf{1},\mathbf{2},-1/2)$
$\mathcal{F}_{\mathrm{IIB}}$	$(\mathbf{1},\mathbf{1},0)^\star$	$(\bar{\mathbf{3}},\mathbf{1},-2/3)$	$(\mathbf{3},\mathbf{2},1/6)$
$\mathcal{F}_{\mathrm{IIIA};\,\text{-}3/2}$	$(\mathbf{3},\mathbf{3},5/3)$	$(\mathbf{1},\mathbf{3},1)^\star$	$(\mathbf{1},\mathbf{2},-3/2)$
$\mathcal{F}_{\mathrm{IIIA};\,\text{-}1/2}$	$(\mathbf{3},\mathbf{3},2/3)$	$(\mathbf{1},\mathbf{3},0)^\star$	$(\mathbf{1},\mathbf{2},-1/2)$
$\mathcal{F}_{\mathrm{IIIA};\,1/2}$	$(\mathbf{3},\mathbf{3},-1/3)$	$(\mathbf{1},\mathbf{3},-1)^\star$	$(\mathbf{1},\mathbf{2},1/2)$
$\mathcal{F}_{\mathrm{IIIB};\,\text{-}5/6}$	$(\mathbf{1},\mathbf{3},1)^\star$	$(\bar{\mathbf{3}},\mathbf{3},1/3)$	$(\mathbf{3},\mathbf{2},-5/6)$
$\mathcal{F}_{\mathrm{IIIB};\,1/6}$	$(\mathbf{1},\mathbf{3},0)^\star$	$(\bar{\mathbf{3}},\mathbf{3},-2/3)$	$(\mathbf{3},\mathbf{2},1/6)$
$\mathcal{F}_{\mathrm{IIIB};\,7/6}$	$(\mathbf{1},\mathbf{3},-1)^\star$	$(\bar{\mathbf{3}},\mathbf{3},-5/3)$	$(\mathbf{3},\mathbf{2},7/6)$
$\mathcal{F}_{\mathrm{IVA};\,\text{-}1}$	$(\mathbf{3},\mathbf{2},7/6)$	$(\mathbf{1},\mathbf{2},1/2)^\star$	$(\mathbf{1},\mathbf{3},-1)$
$\mathcal{F}_{\mathrm{IVA};\,0}$	$(\mathbf{3},\mathbf{2},1/6)$	$(\mathbf{1},\mathbf{2},-1/2)^\star$	$(\mathbf{1},\mathbf{3},0)^\star$
$\mathcal{F}_{\mathrm{IVB};\,\text{-}1/3}$	$(\mathbf{1},\mathbf{2},1/2)^\star$	$(\bar{\mathbf{3}},\mathbf{2},-1/6)$	$(\mathbf{3},\mathbf{3},-1/3)$
$\mathcal{F}_{\mathrm{IVB};\,2/3}$	$(\mathbf{1},\mathbf{2},-1/2)^\star$	$(\bar{\mathbf{3}},\mathbf{2},-7/6)$	$(\mathbf{3},\mathbf{3},2/3)$
$\mathcal{F}_{\mathrm{VA}}$	$(\mathbf{3},\mathbf{3},2/3)$	$(\mathbf{1},\mathbf{1},0)^\star$	$(\mathbf{1},\mathbf{2},-1/2)$
$\mathcal{F}_{\mathrm{VB};\,\text{-}5/6}$	$(\mathbf{1},\mathbf{3},1)^\star$	$(\bar{\mathbf{3}},\mathbf{1},1/3)$	$(\mathbf{3},\mathbf{2},-5/6)$
$\mathcal{F}_{\mathrm{VB};\,1/6}$	$(\mathbf{1},\mathbf{3},0)^\star$	$(\bar{\mathbf{3}},\mathbf{1},-2/3)$	$(\mathbf{3},\mathbf{2},1/6)$
$\mathcal{F}_{\mathrm{VB};\,7/6}$	$(\mathbf{1},\mathbf{3},-1)^\star$	$(\bar{\mathbf{3}},\mathbf{1},-5/3)$	$(\mathbf{3},\mathbf{2},7/6)$
$\mathcal{F}_{\mathrm{VIA};\,\text{-}3/2}$	$(\mathbf{3},\mathbf{1},5/3)$	$(\mathbf{1},\mathbf{3},1)^\star$	$(\mathbf{1},\mathbf{2},-3/2)$
$\mathcal{F}_{\mathrm{VIA};\,\text{-}1/2}$	$(\mathbf{3},\mathbf{1},2/3)$	$(\mathbf{1},\mathbf{3},0)^\star$	$(\mathbf{1},\mathbf{2},-1/2)$
$\mathcal{F}_{\mathrm{VIA};\,1/2}$	$(\mathbf{3},\mathbf{1},-1/3)$	$(\mathbf{1},\mathbf{3},-1)^\star$	$(\mathbf{1},\mathbf{2},1/2)$
$\mathcal{F}_{\mathrm{VIB}}$	$(\mathbf{1},\mathbf{1},0)^\star$	$(\bar{\mathbf{3}},\mathbf{3},-2/3)$	$(\mathbf{3},\mathbf{2},1/6)$

Label	Ψ_Q	Ψ_L	Φ
$\mathcal{S}_{\mathrm{IA}}$	$(\mathbf{3},\mathbf{2},1/6)$	$(\mathbf{1},\mathbf{2},-1/2)$	$(\mathbf{1},\mathbf{1},0)^\star$
$\mathcal{S}_{\mathrm{IIA};\,\text{-}1/2}$	$(\mathbf{3},\mathbf{1},2/3)$	$(\mathbf{1},\mathbf{1},0)^\star$	$(\mathbf{1},\mathbf{2},-1/2)^\star$
$\mathcal{S}_{\mathrm{IIA};\,1/2}$	$(\mathbf{3},\mathbf{1},-1/3)$	$(\mathbf{1},\mathbf{1},-1)$	$(\mathbf{1},\mathbf{2},1/2)^\star$
$\mathcal{S}_{\mathrm{IIB}}$	$(\mathbf{1},\mathbf{1},0)^\star$	$(\bar{\mathbf{3}},\mathbf{1},-2/3)$	$(\mathbf{3},\mathbf{2},1/6)$
$\mathcal{S}_{\mathrm{IIIA};\,\text{-}1/2}$	$(\mathbf{3},\mathbf{3},2/3)$	$(\mathbf{1},\mathbf{3},0)^\star$	$(\mathbf{1},\mathbf{2},-1/2)^\star$
$\mathcal{S}_{\mathrm{IIIA};\,1/2}$	$(\mathbf{3},\mathbf{3},-1/3)$	$(\mathbf{1},\mathbf{3},-1)$	$(\mathbf{1},\mathbf{2},1/2)^\star$
$\mathcal{S}_{\mathrm{IIIB}}$	$(\mathbf{1},\mathbf{3},0)^\star$	$(\bar{\mathbf{3}},\mathbf{3},-2/3)$	$(\mathbf{3},\mathbf{2},1/6)$
$\mathcal{S}_{\mathrm{IVA};\,\text{-}1}$	$(\mathbf{3},\mathbf{2},7/6)$	$(\mathbf{1},\mathbf{2},1/2)$	$(\mathbf{1},\mathbf{3},-1)^\star$
$\mathcal{S}_{\mathrm{IVA};\,0}$	$(\mathbf{3},\mathbf{2},1/6)$	$(\mathbf{1},\mathbf{2},-1/2)$	$(\mathbf{1},\mathbf{3},0)^\star$
$\mathcal{S}_{\mathrm{IVA};\,1}$	$(\mathbf{3},\mathbf{2},-5/6)$	$(\mathbf{1},\mathbf{2},-3/2)$	$(\mathbf{1},\mathbf{3},1)^\star$
$\mathcal{S}_{\mathrm{VA};\,\text{-}1/2}$	$(\mathbf{3},\mathbf{3},2/3)$	$(\mathbf{1},\mathbf{1},0)^\star$	$(\mathbf{1},\mathbf{2},-1/2)^\star$
$\mathcal{S}_{\mathrm{VA};\,1/2}$	$(\mathbf{3},\mathbf{3},-1/3)$	$(\mathbf{1},\mathbf{1},-1)$	$(\mathbf{1},\mathbf{2},1/2)^\star$
$\mathcal{S}_{\mathrm{VB}}$	$(\mathbf{1},\mathbf{3},0)^\star$	$(\bar{\mathbf{3}},\mathbf{1},-2/3)$	$(\mathbf{3},\mathbf{2},1/6)$
$\mathcal{S}_{\mathrm{VIA};\,\text{-}1/2}$	$(\mathbf{3},\mathbf{1},2/3)$	$(\mathbf{1},\mathbf{3},0)^\star$	$(\mathbf{1},\mathbf{2},-1/2)^\star$
$\mathcal{S}_{\mathrm{VIA};\,1/2}$	$(\mathbf{3},\mathbf{1},-1/3)$	$(\mathbf{1},\mathbf{3},-1)$	$(\mathbf{1},\mathbf{2},1/2)^\star$
$\mathcal{S}_{\mathrm{VIB}}$	$(\mathbf{1},\mathbf{1},0)^\star$	$(\bar{\mathbf{3}},\mathbf{3},-2/3)$	$(\mathbf{3},\mathbf{2},1/6)$

DM multiplets marked by *, highlighted models studied in detail in the paper

Flavour bounds

Again not only B-anomalies, but also B_s-$B_s$bar mixing!

$$\left(\delta C_\mu^9\right)_{\mathcal{F}} = -\left(\delta C_\mu^{10}\right)_{\mathcal{F}} = \frac{\sqrt{2}}{4 G_F V_{tb} V_{ts}^*} \frac{\Gamma_Q |\Gamma_\mu^L|^2}{32\pi\alpha_{\rm EM} M_\Psi^2} \left(\eta F\left(x_Q, x_L\right) + 2\chi^M \eta^M G\left(x_Q, x_L\right)\right),$$

$$\left(\delta C^{B\bar{B}}\right)_{\mathcal{F}} = \frac{\Gamma_Q^2}{128\pi^2 M_\Psi^2} \left(\eta_{BB} F\left(x_Q, x_L\right) + 2\chi^M \eta^M G\left(x_Q, x_L\right)\right),$$

$$\left(\delta C_\mu^9\right)_{\mathcal{S}} = -\left(\delta C_\mu^{10}\right)_{\mathcal{S}} = -\frac{\sqrt{2}}{4 G_F V_{tb} V_{ts}^*} \frac{\Gamma_Q |\Gamma_\mu^L|^2}{32\pi\alpha_{\rm EM} M_\Phi^2} \left(\eta - \chi^M \eta^M\right) F\left(y_Q, y_L\right),$$

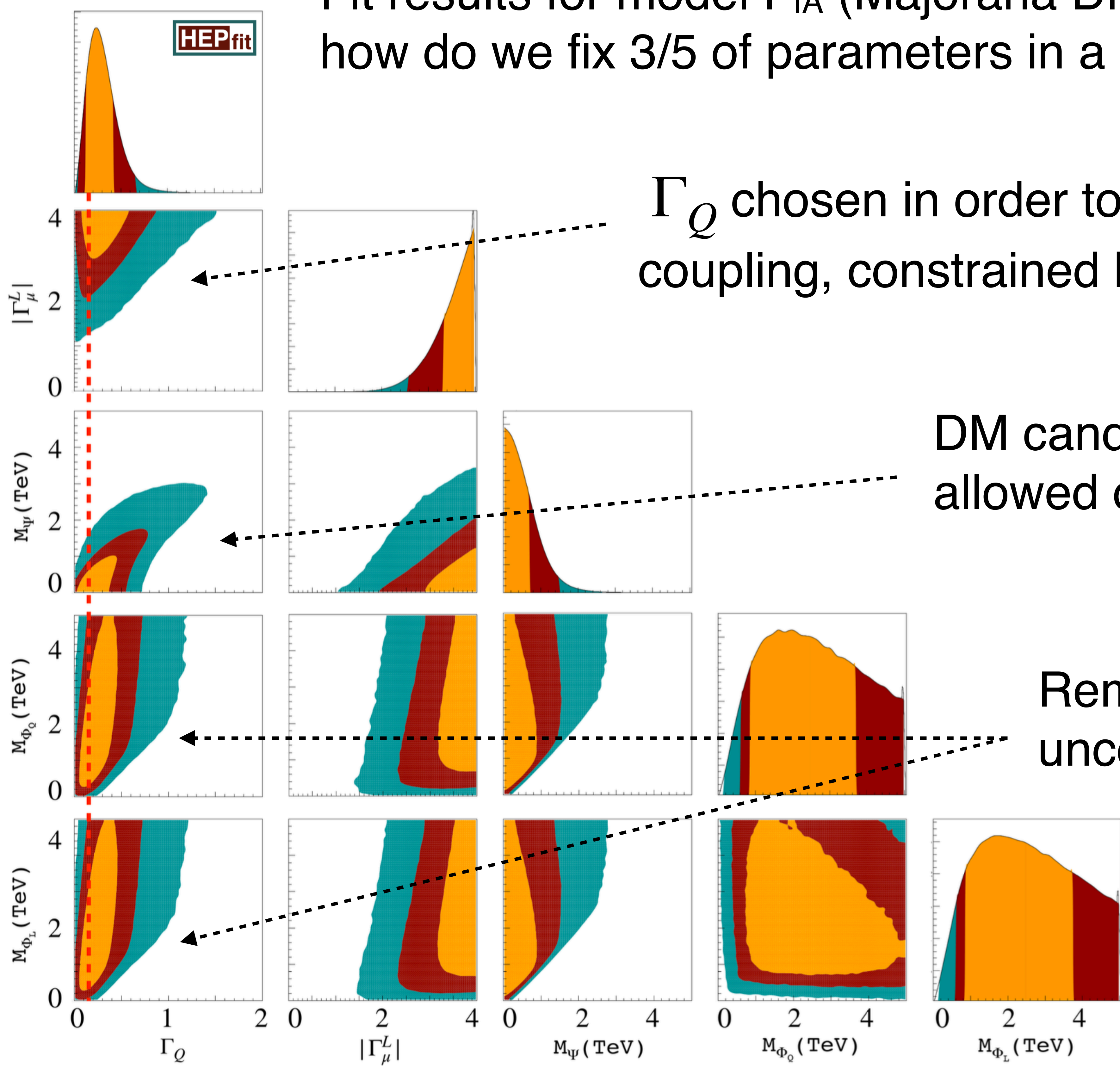
$$\left(\delta C^{B\bar{B}}\right)_{\mathcal{S}} = \frac{\Gamma_Q^2}{128\pi^2 M_\Phi^2} \left(\eta_{BB} - \chi^M \eta^M\right) F\left(y_Q, y_L\right),$$

We start by making a combined fit to Flavour anomalies and B_s-$B_s$bar mixing, in order to extract allowed ranges for 3 masses and 2 couplings

- We require that the DM candidate has to be the lightest NP state
- We allow the remaining masses to be as heavy as 5 TeV
- We allow the lepton coupling in the range [0, 4], while for the quark coupling [0, 2] in models of class F and [-2, 0] in models of class S, in order to reproduce the desired sign in C9 (no effect on B_s-$B_s$bar mixing)

Flavour bounds

Fit results for model F_{IA} (Majorana DM) to extract benchmarks: how do we fix 3/5 of parameters in a 2D plot?



Γ_Q chosen in order to minimise the lepton coupling, constrained by B_s-$B_s$bar mixing

DM candidate mass allowed only up to ~ 1 TeV

Remaining masses largely unconstrained at the 2σ level

Main LHC constraints

A pair of heavy NP candidates can be produced ad LHC by QCD / EW Drell-Yann mediated processes, sequently decaying in jets/leptons + DM

- DM coupling to both heavy states (e.g. scalar DM in class S)

$$\boxed{pp \to \Psi_Q \Psi_Q \to q q' + \not{E}_T}$$

$$\boxed{pp \to \Psi_L \Psi_L \to \mu^+ \mu^- + \not{E}_T}$$

- DM coupling to only 1 heavy state (e.g. fermion DM in class S)

$$\boxed{pp \to \Phi\Phi \to q q' + \not{E}_T}$$

$$\boxed{pp \to \Psi_L \Psi_L \to \mu^+ \mu^- + \Phi\Phi \to \mu^+ \mu^- + q q' + \not{E}_T}$$

or

$$\boxed{pp \to \Phi\Phi \to \mu^+ \mu^- + \not{E}_T}$$

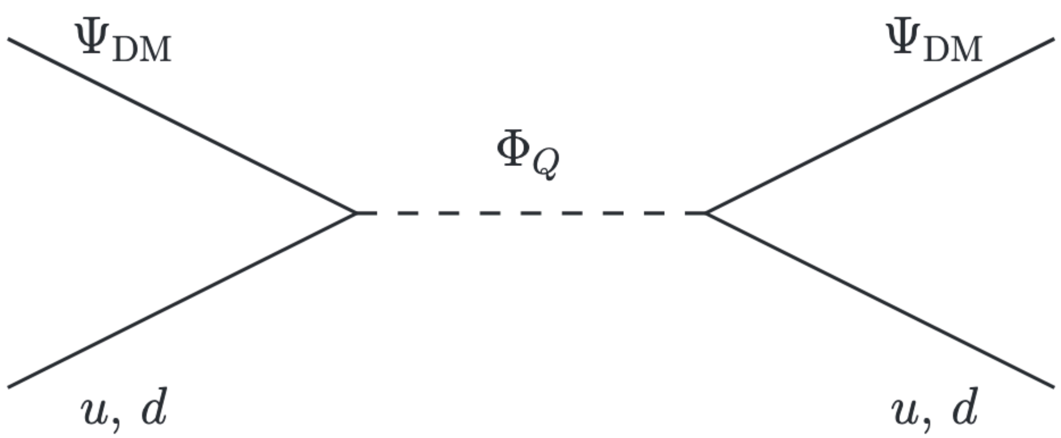
$$\boxed{pp \to \Psi_Q \Psi_Q \to q q' + \Phi\Phi \to q q' + \mu^+ \mu^- + \not{E}_T}$$

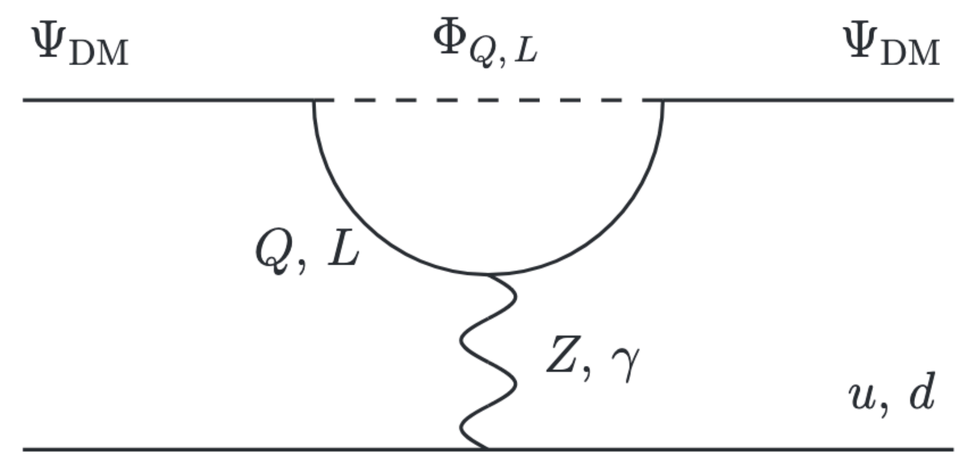
We will recast LHC SUSY searches of jets and/or leptons + ME

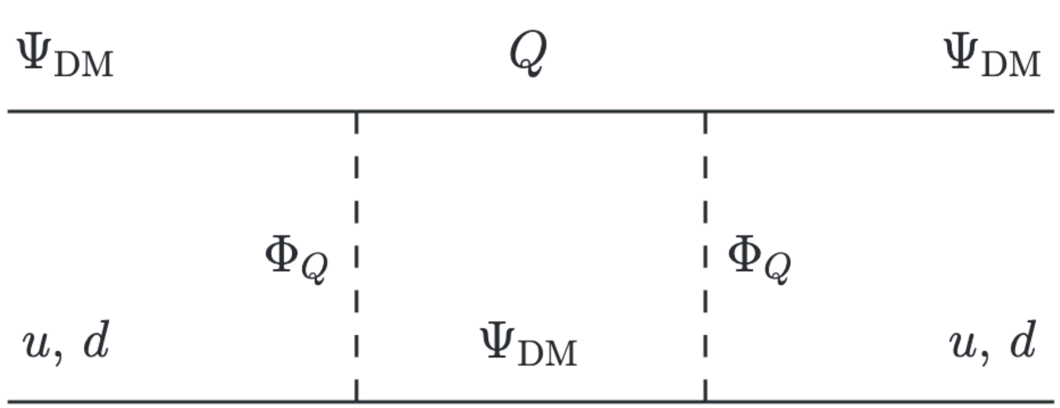
Main DM constraints

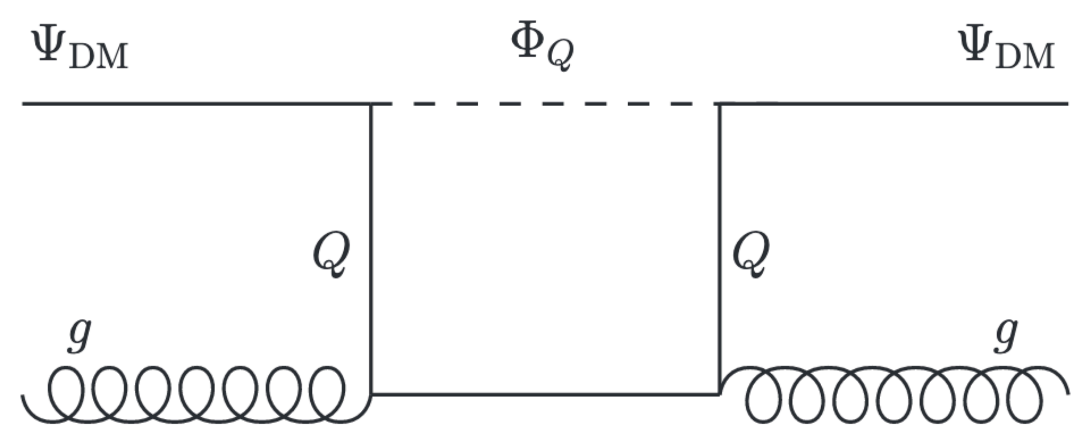
- DM should reproduced the measured relic density $\Omega_{\rm DM}h^2 = 0.1199 \pm 0.0022$ (or at most be under-abundant)

- DM should evade DD constraints, where non-relativistic DM scatters with nucleons in an atom. Principal constrains come from Xenon1T experiment



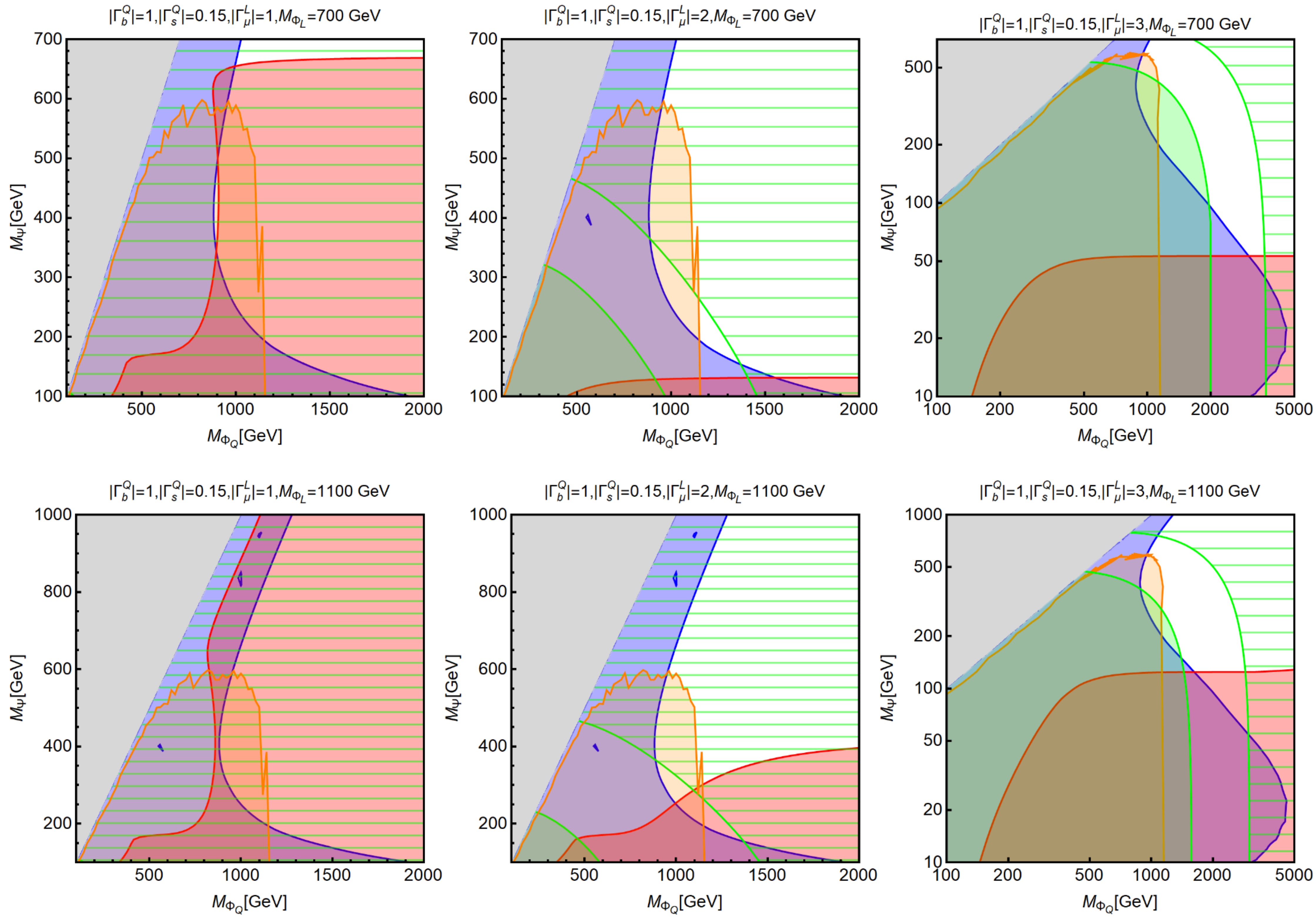






F_{IA} with Majorana DM

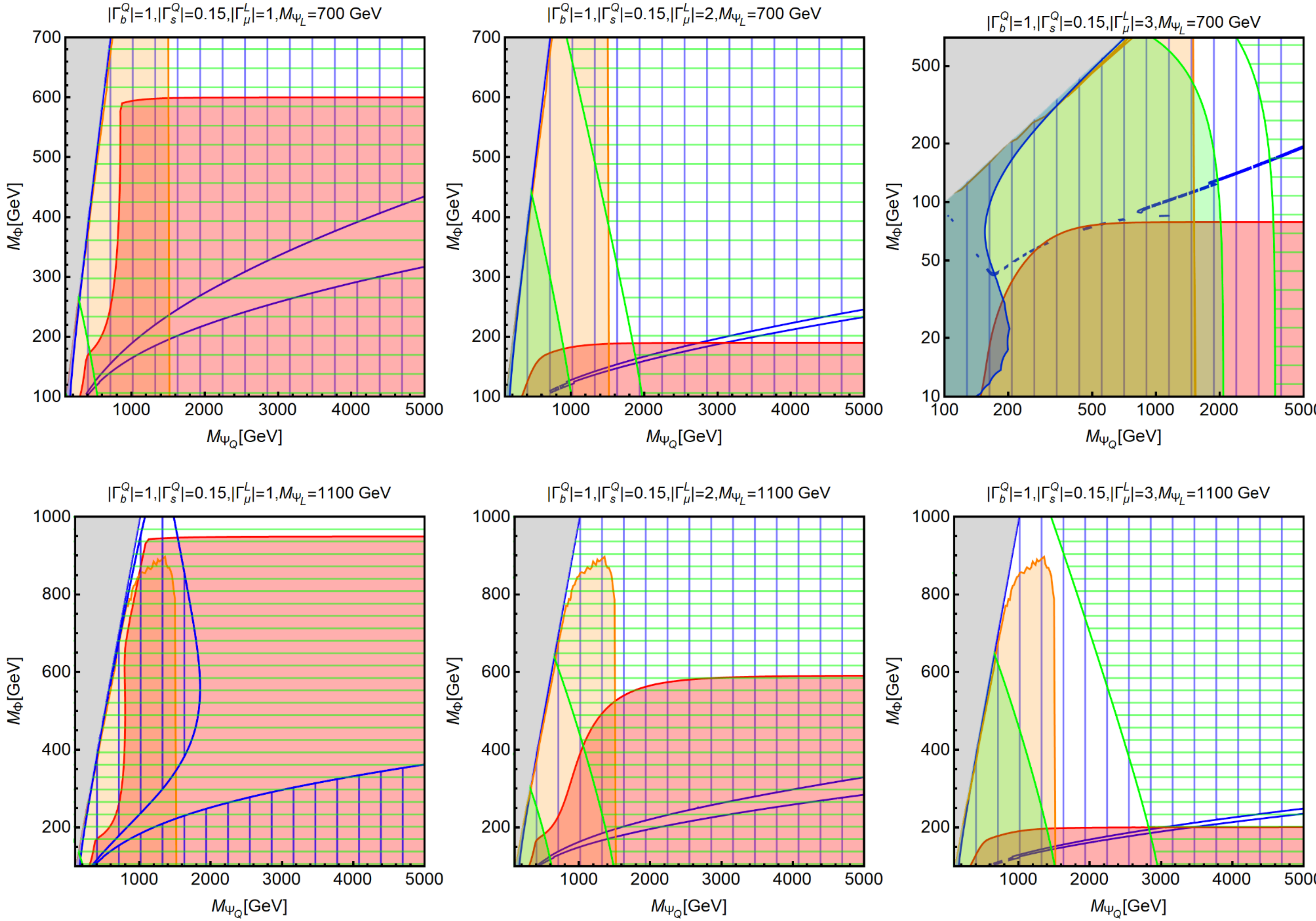
Φ_Q	Φ_L	Ψ
$(\mathbf{3},\mathbf{2},1/6)$	$(\mathbf{1},\mathbf{2},-1/2)$	$(\mathbf{1},\mathbf{1},0)^\star$



Viable model to address everything simultaneously! Allowed only with Majorana, since Dirac interactions with Z/γ induces strong constraints from DD

S_{IA} with complex DM

Ψ_Q	Ψ_L	Φ
$(\mathbf{3},\mathbf{2},1/6)$	$(\mathbf{1},\mathbf{2},-1/2)$	$(\mathbf{1},\mathbf{1},0)^\star$



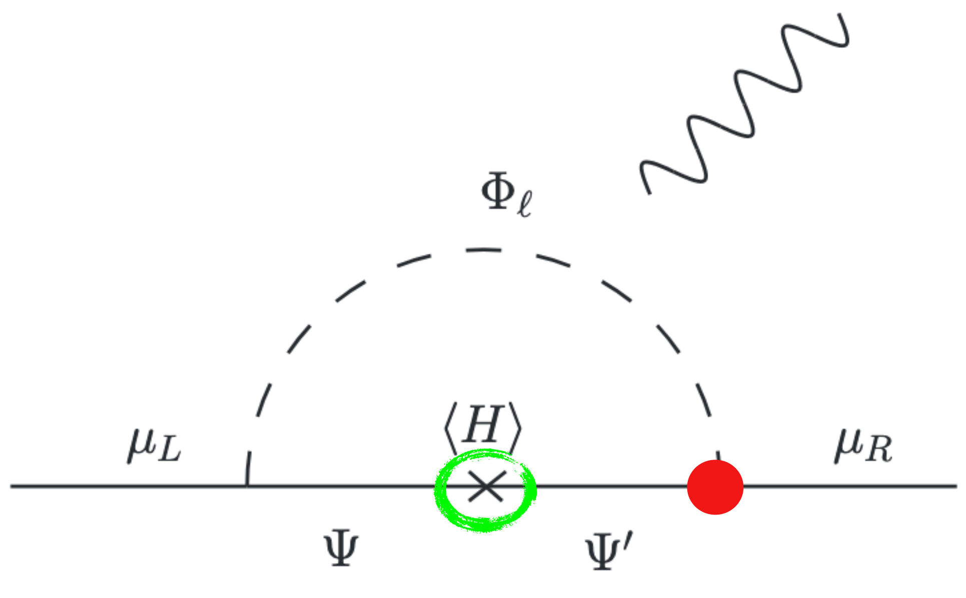
Viable model only if O(100KeV) mass splitting is assumed between CP-even and CP-odd DM comp. (avoiding DD constr. due to non-relativistic scattering)

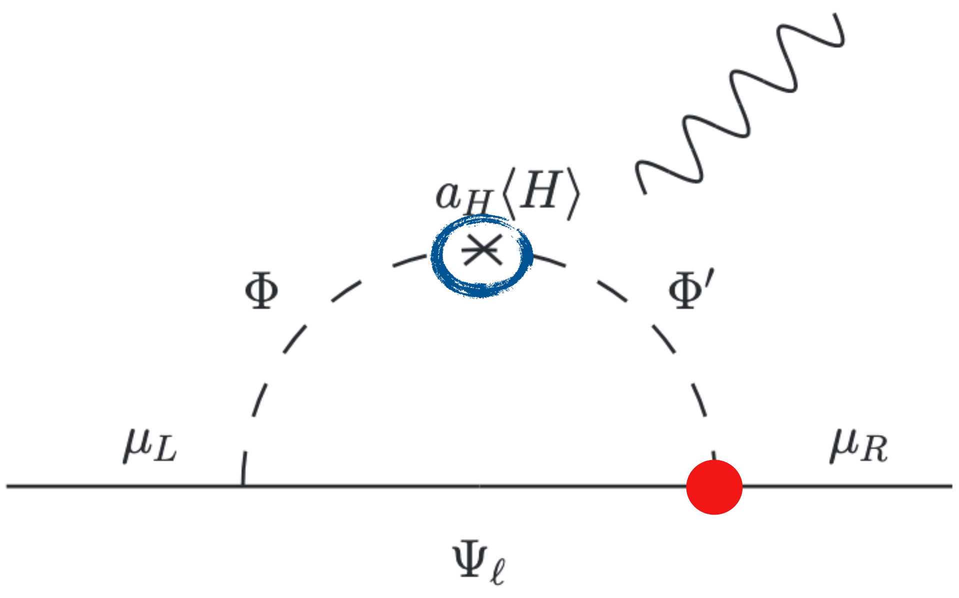
Summary

- *Introduction*
- *g-2 and B-anomalies*
- *B-anomalies and DM*
- *All together now! (2104.03228)*

Systematic Studies of All Possible Loop Models

We're adding back the muon (g-2), so we allow also muon RH couplings (only 4 fields)





- Fermion flavour mediator

$$\mathcal{L}_{\mathcal{F}}^{\Phi_\ell\Phi'_\ell} \supset \Gamma_i^Q\,\bar{Q}_i\,P_R\Psi\,\Phi_q + \Gamma_i^L\,\bar{L}_i\,P_R\Psi\,\Phi_\ell + \Gamma_i^E\,\bar{E}_i\,P_L\Psi\,\Phi'_\ell + a_H\Phi_\ell^\dagger\Phi'_\ell\,H + \mathrm{h.c.}$$

$$\mathcal{L}_{\mathcal{F}}^{\Psi\Psi'} \supset \Gamma_i^Q\,\bar{Q}_i\,P_R\Psi\,\Phi_q + \Gamma_i^L\,\bar{L}_i\,P_R\Psi\,\Phi_\ell + \Gamma_i^E\,\bar{E}_i\,P_L\Psi'\,\Phi_\ell + \lambda_{HL}\bar{\Psi}\,P_L\Psi'\,H + \lambda_{HR}\bar{\Psi}P_R\Psi'H + \mathrm{h.c.}$$

- Scalar flavour mediator

$$\mathcal{L}_{\mathcal{S}}^{\Phi\Phi'} \supset \Gamma_i^Q\,\bar{Q}_i\,P_R\Psi_q\,\Phi + \Gamma_i^L\,\bar{L}_i\,P_R\Psi_\ell\,\Phi + \Gamma_i^E\,\bar{E}_i\,P_L\Psi_\ell\,\Phi' + a_H\Phi^\dagger\Phi'\,H + \mathrm{h.c.}$$

$$\mathcal{L}_{\mathcal{S}}^{\Psi_\ell\Psi'_\ell} \supset \Gamma_i^Q\,\bar{Q}_i\,P_R\Psi_q\,\Phi + \Gamma_i^L\,\bar{L}_i\,P_R\Psi_\ell\,\Phi + \Gamma_i^E\,\bar{E}_i\,P_L\Psi'_\ell\,\Phi + \lambda_{H1}\bar{\Psi}_\ell\,P_R\Psi'_\ell\,H + \lambda_{H2}\bar{\Psi}_\ell\,P_L\Psi'_\ell\,H + \mathrm{h.c.}$$

Allowed representations

We start from the models that we know fit B-anomalies and DM, and add a fourth field inducing RH muon couplings

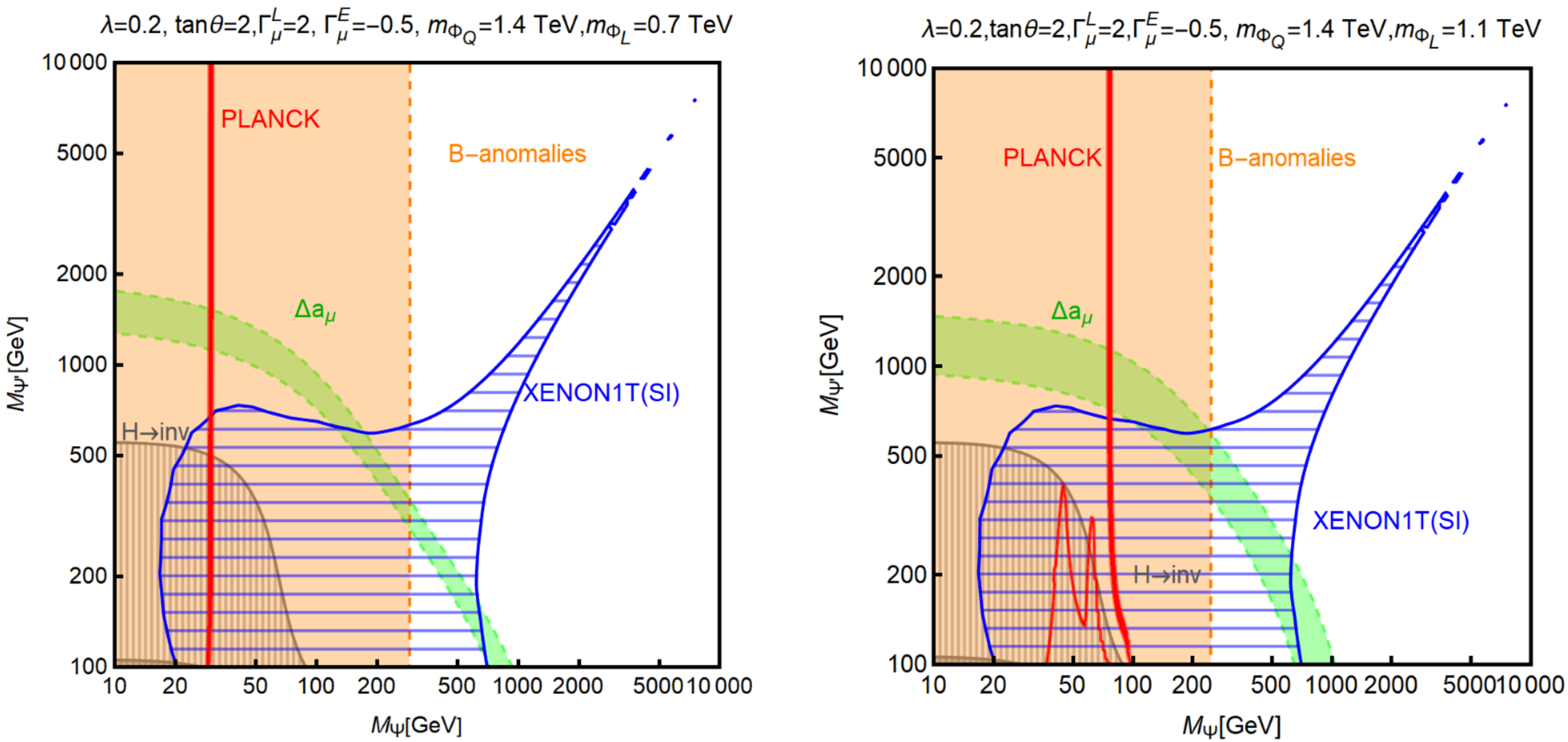
Label	Φ_q/Ψ_q	Φ_ℓ/Ψ_ℓ	Ψ/Φ	Φ'_ℓ/Ψ'_ℓ	Ψ'/Φ'
$\mathcal{F}_{\rm Ia}/\mathcal{S}_{\rm Ia}$	$(\mathbf{3},\mathbf{2},1/6)$	$(\mathbf{1},\mathbf{2},-1/2)$	$(\mathbf{1},\mathbf{1},0)$	$(\mathbf{1},\mathbf{1},-1)$	–
$\mathcal{F}_{\rm Ib}/\mathcal{S}_{\rm Ib}$	$(\mathbf{3},\mathbf{2},1/6)$	$(\mathbf{1},\mathbf{2},-1/2)$	$(\mathbf{1},\mathbf{1},0)$	–	$(\mathbf{1},\mathbf{2},-1/2)$
$\mathcal{F}_{\rm Ic}/\mathcal{S}_{\rm Ic}$	$(\mathbf{3},\mathbf{2},7/6)$	$(\mathbf{1},\mathbf{2},1/2)$	$(\mathbf{1},\mathbf{1},-1)$	$(\mathbf{1},\mathbf{1},0)$	–
$\mathcal{F}_{\rm IIa}/\mathcal{S}_{\rm IIa}$	$(\mathbf{3},\mathbf{1},2/3)$	$(\mathbf{1},\mathbf{1},0)$	$(\mathbf{1},\mathbf{2},-1/2)$	$(\mathbf{1},\mathbf{2},-1/2)$	–
$\mathcal{F}_{\rm IIb}/\mathcal{S}_{\rm IIb}$	$(\mathbf{3},\mathbf{1},2/3)$	$(\mathbf{1},\mathbf{1},0)$	$(\mathbf{1},\mathbf{2},-1/2)$	–	$(\mathbf{1},\mathbf{1},-1)$
$\mathcal{F}_{\rm IIc}/\mathcal{S}_{\rm IIc}$	$(\mathbf{3},\mathbf{1},-1/3)$	$(\mathbf{1},\mathbf{1},-1)$	$(\mathbf{1},\mathbf{2},1/2)$	–	$(\mathbf{1},\mathbf{1},0)$
$\mathcal{F}_{\rm Va}/\mathcal{S}_{\rm Va}$	$(\mathbf{3},\mathbf{3},2/3)$	$(\mathbf{1},\mathbf{1},0)$	$(\mathbf{1},\mathbf{2},-1/2)$	$(\mathbf{1},\mathbf{2},-1/2)$	–
$\mathcal{F}_{\rm Vb}/\mathcal{S}_{\rm Vb}$	$(\mathbf{3},\mathbf{3},2/3)$	$(\mathbf{1},\mathbf{1},0)$	$(\mathbf{1},\mathbf{2},-1/2)$	–	$(\mathbf{1},\mathbf{1},-1)$
$\mathcal{F}_{\rm Vc}/\mathcal{S}_{\rm Vc}$	$(\mathbf{3},\mathbf{3},-1/3)$	$(\mathbf{1},\mathbf{1},-1)$	$(\mathbf{1},\mathbf{2},1/2)$	–	$(\mathbf{1},\mathbf{1},0)$

Singlet DM

Singlet-Doublet mixed DM

F_{IB} with singlet-doublet DM

Φ_Q	Φ_L	Ψ	Ψ'
$(\mathbf{3},\mathbf{2},1/6)$	$(\mathbf{1},\mathbf{2},-1/2)$	$(\mathbf{1},\mathbf{1},0)^\star$	$(\mathbf{1},\mathbf{2},-1/2)^\star$



Viable model to address everything simultaneously!

Conclusions

- To address g-2 and B-anomalies via loop models, we need at least 4 fields, with 2 of them coupling to RH muons

- To address B-anomalies and DM via loop models, we need at least 3 fields, with the DM either being a SU(2) singlet or doublet

- Combining the above, to address everything together via loop models, we need at least 4 fields, with 2 of them coupling to RH muons and the DM either being a SU(2) singlet or doublet

- This is actually doable! Constraints from LHC and DM searches are complementary, and allowed models can be further test with the advent of new data in both fields!

Back-up Slides

What kind of NP could be cut for the job?

- g-2

  NP coupling to Muons; couplings with both Muon chirality is preferred, inducing also coupling to the SM Higgs to exploit chiral enhancement

  $\Longrightarrow$ Leptoquark, or fermion(s) and scalar(s) (allowing for chirality flip)

- $b \to s\mu\mu$

  NP coupling to Muons;

  $\Longrightarrow$ Leptoquark and/or Zprime, or 2 fermions (1 fermion) and 1 scalar (2 scalars) with the single particle acting as mediator between the sectors

- DM

  Stable candidate, neutral and colour singlet; possibly connected to the SM by means of a Dark Sector

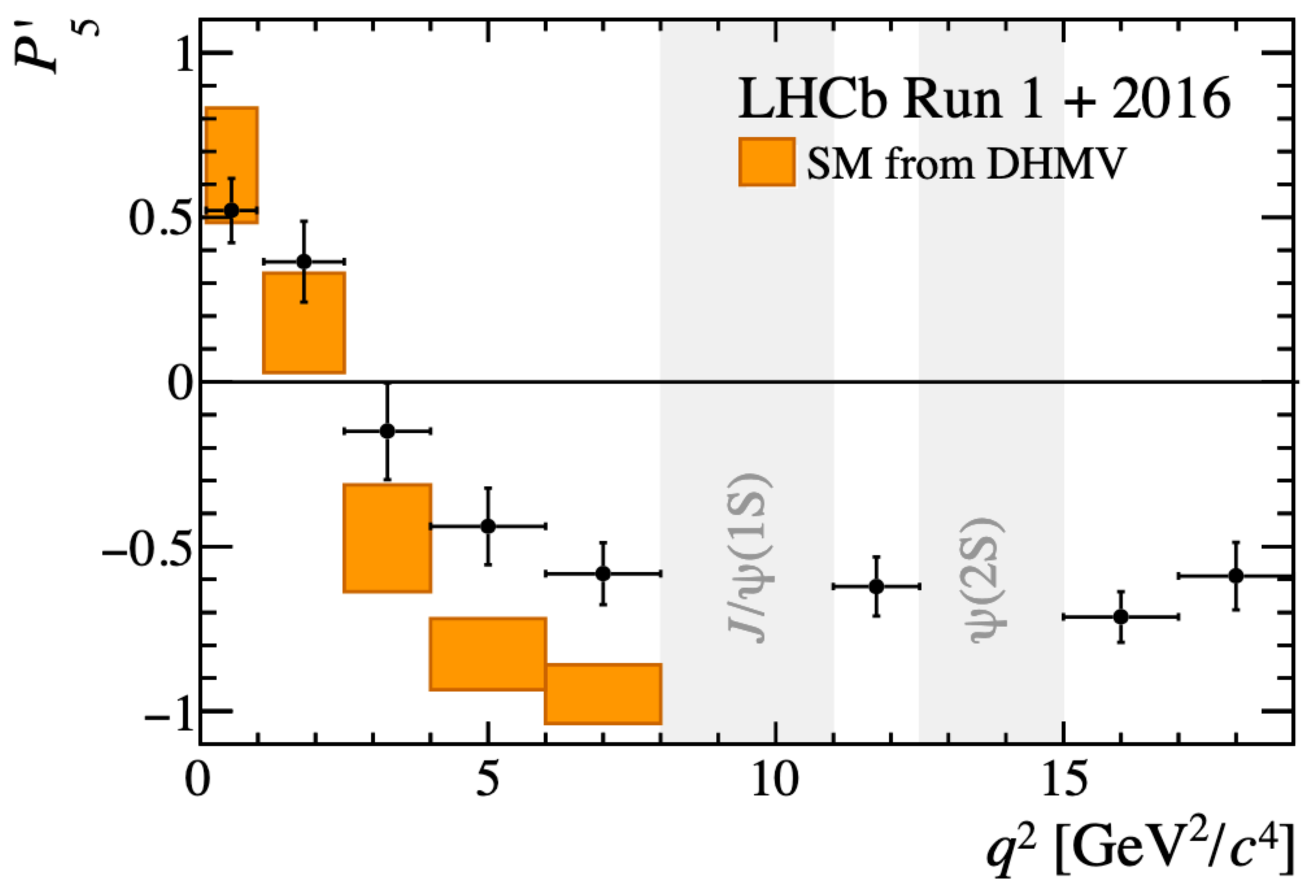
  $\Longrightarrow$ Axions, ALPs, fermions, scalars…

Opportunities with Semi-Leptonic B Decays

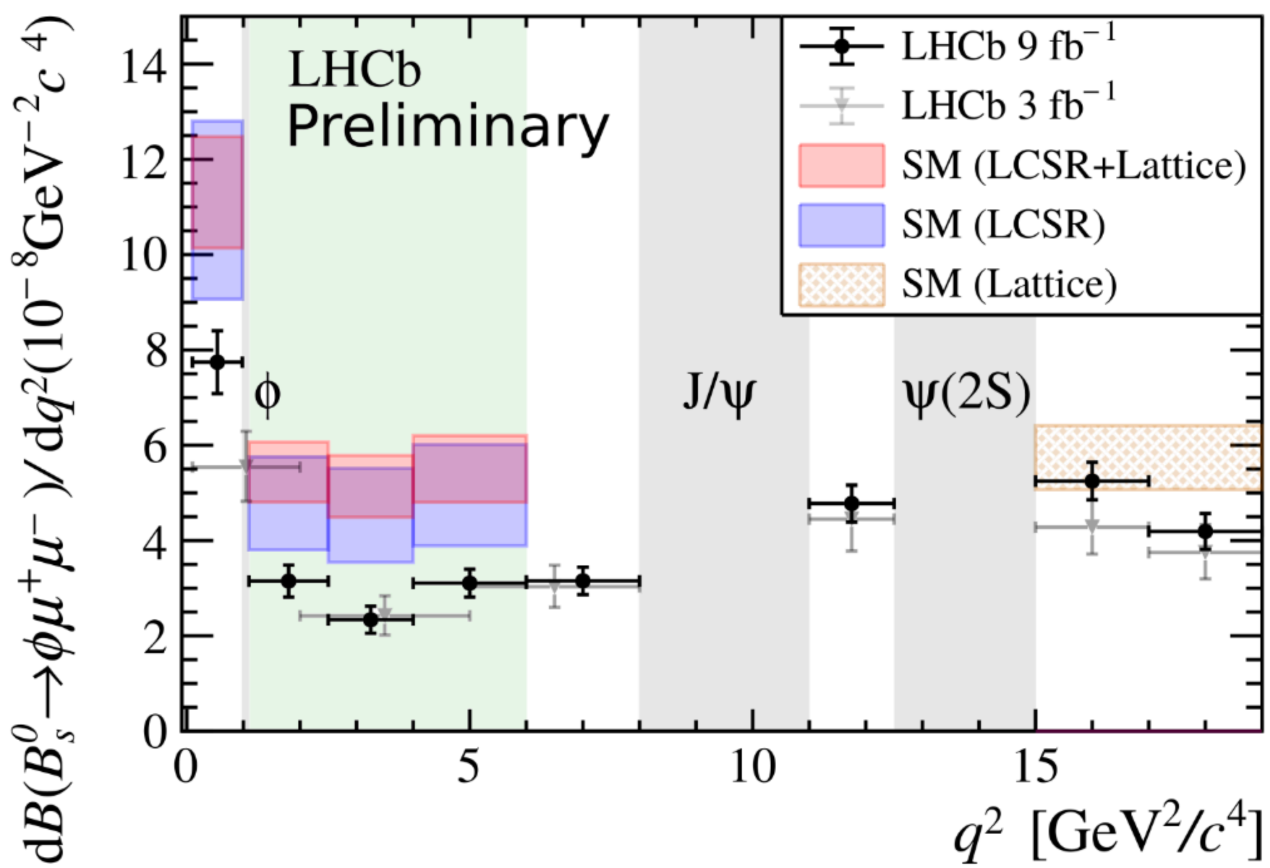
No tree-level flavour changing neutral currents (FCNC) in the SM

&

Intriguing set of “Anomalies” in data of exclusive B rare Decays



[LHCB-PAPER-2021-014, in preparation]



~ 3 σ

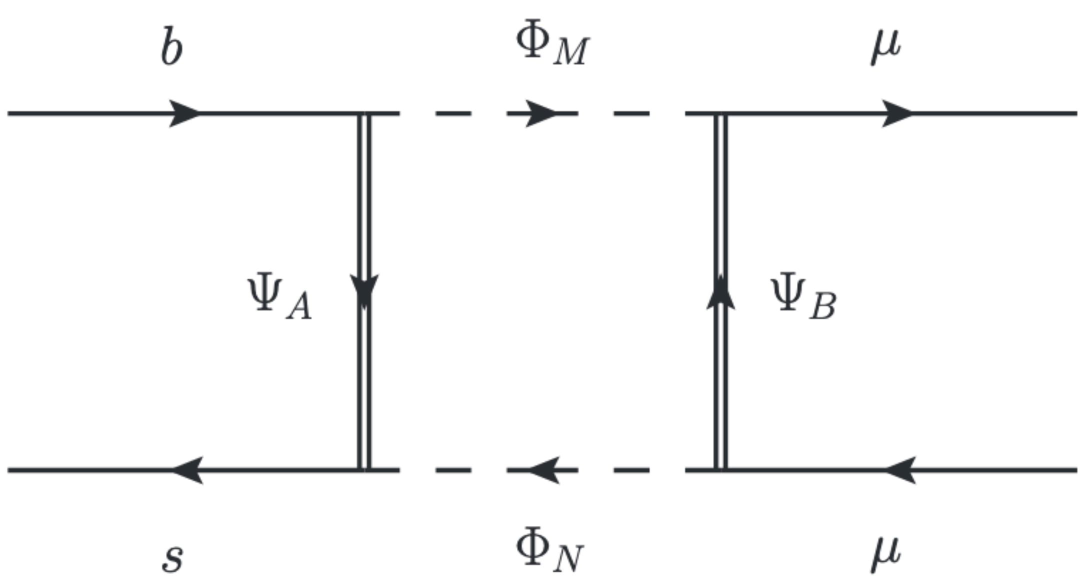
Angular analysis of $B \longrightarrow K^*\mu\mu$ for small dilepton mass, $4 < q^2 / \mathrm{GeV}^2 < 8$.

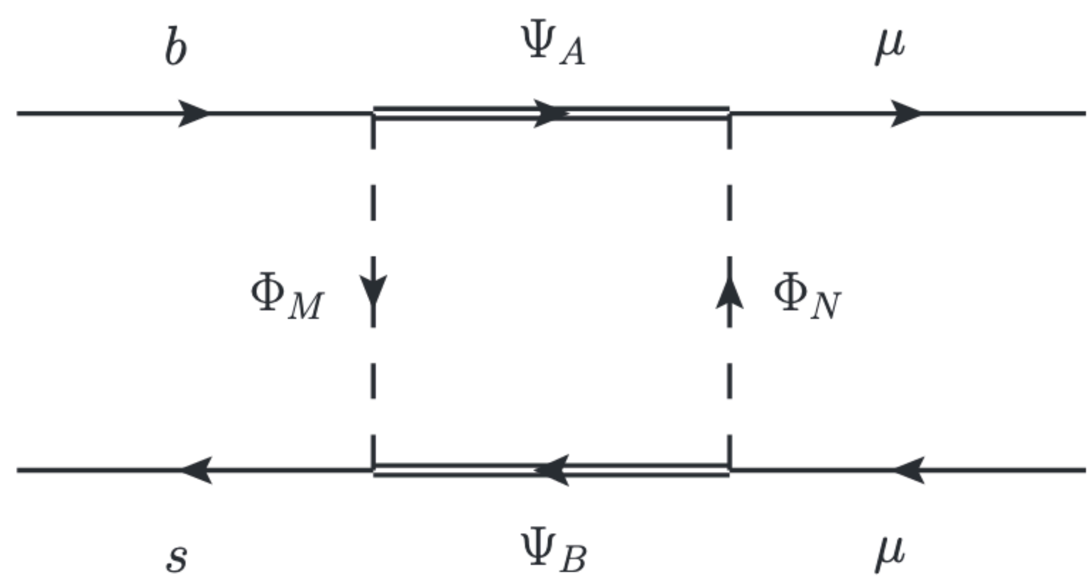
~ 1.8/3.6 σ

Br of $B_s \longrightarrow \phi\mu\mu$

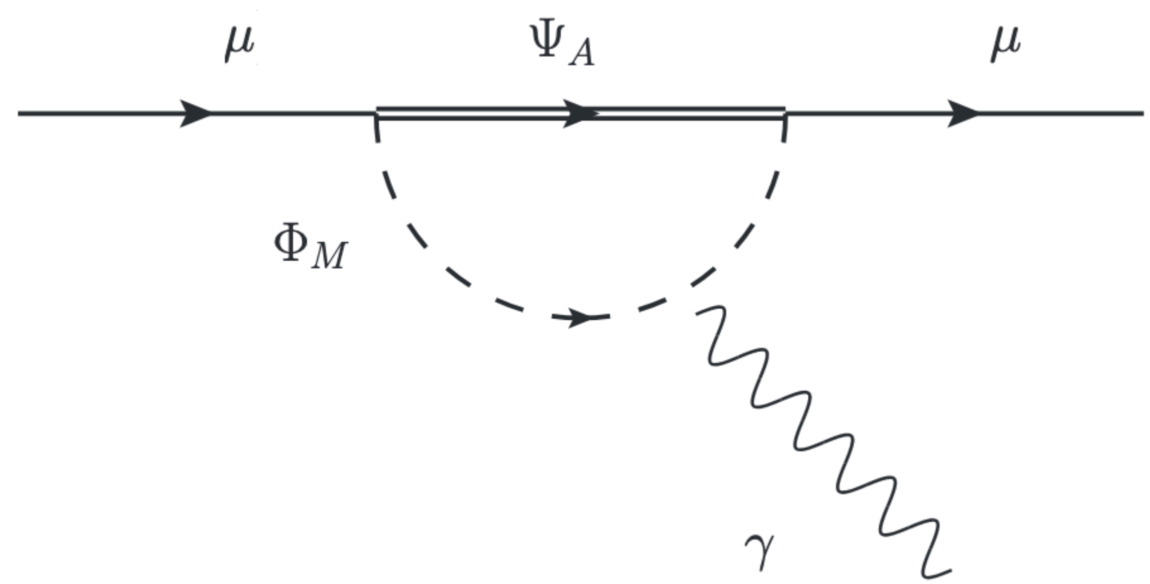
A Generic Loop Model including RH couplings

$$\mathcal{L}_{\text{int}} = \Big[\bar{\Psi}_A \left(L^b_{AM} P_L b + L^s_{AM} P_L s + L^\mu_{AM} P_L \mu \right) \Phi_M$$
$$+ \bar{\Psi}_A \left(R^b_{AM} P_R b + R^s_{AM} P_R s + R^\mu_{AM} P_R \mu \right) \Phi_M \Big] + \text{h.c.}$$

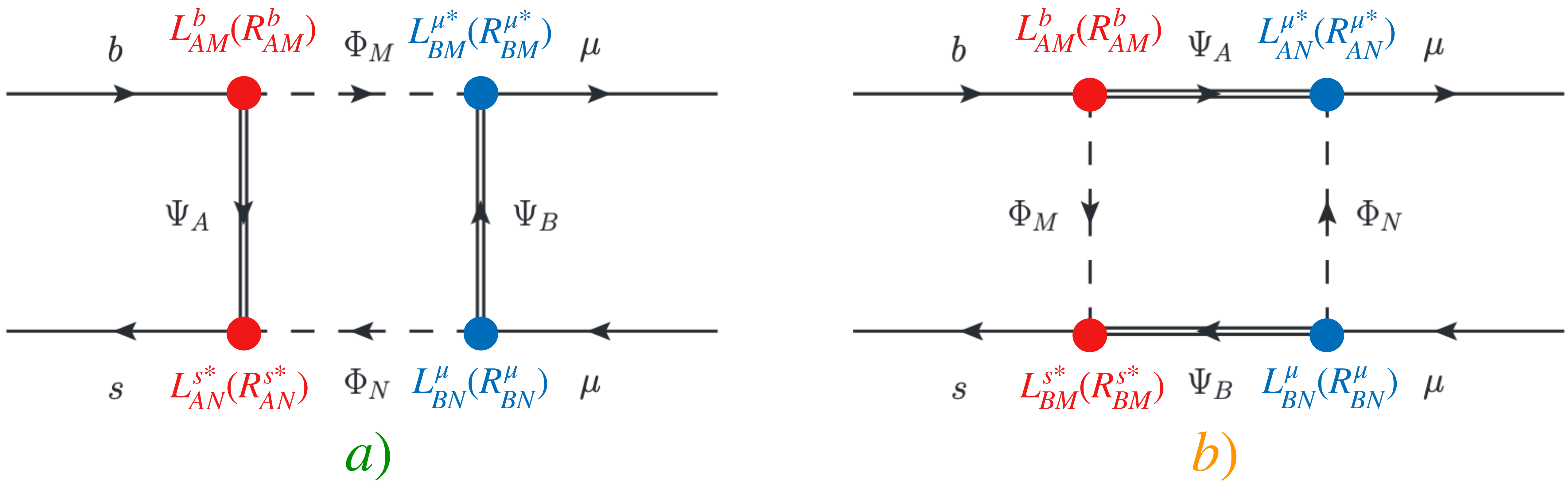




$SU(3)$	$b \to s\ell\bar{\ell}$ type $a)$				$b \to s\ell\bar{\ell}$ type $b)$			
	Ψ_A	Ψ_B	Φ_M	Φ_N	Ψ_A	Ψ_B	Φ_M	Φ_N
I	3	1	1	1	1	1	$\bar{3}$	1
II	1	$\bar{3}$	$\bar{3}$	$\bar{3}$	3	3	1	3
III	3	8	8	8	8	8	$\bar{3}$	8
IV	8	$\bar{3}$	$\bar{3}$	$\bar{3}$	3	3	8	3
V	$\bar{3}$	3	3	3	$\bar{3}$	$\bar{3}$	3	$\bar{3}$



$b \to s\mu\mu$



Two distinct solution, whether the fermion or the scalar is the NP field that couples to both quarks and leptons

$$x_{AM} \equiv (m_{\Psi_A}/m_{\Phi_M})^2$$

$$C_9^{\text{box},\,a)} = -\mathcal{N}\frac{\chi L^{s*}_{AN}L^b_{AM}}{32\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[L^{\mu*}_{BM}L^{\mu}_{BN} + R^{\mu*}_{BM}R^{\mu}_{BN}\right]F(x_{AM},x_{BM},x_{NM})$$

$$C_{10}^{\text{box},\,a)} = \mathcal{N}\frac{\chi L^{s*}_{AN}L^b_{AM}}{32\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[L^{\mu*}_{BM}L^{\mu}_{BN} - R^{\mu*}_{BM}R^{\mu}_{BN}\right]F(x_{AM},x_{BM},x_{NM})$$

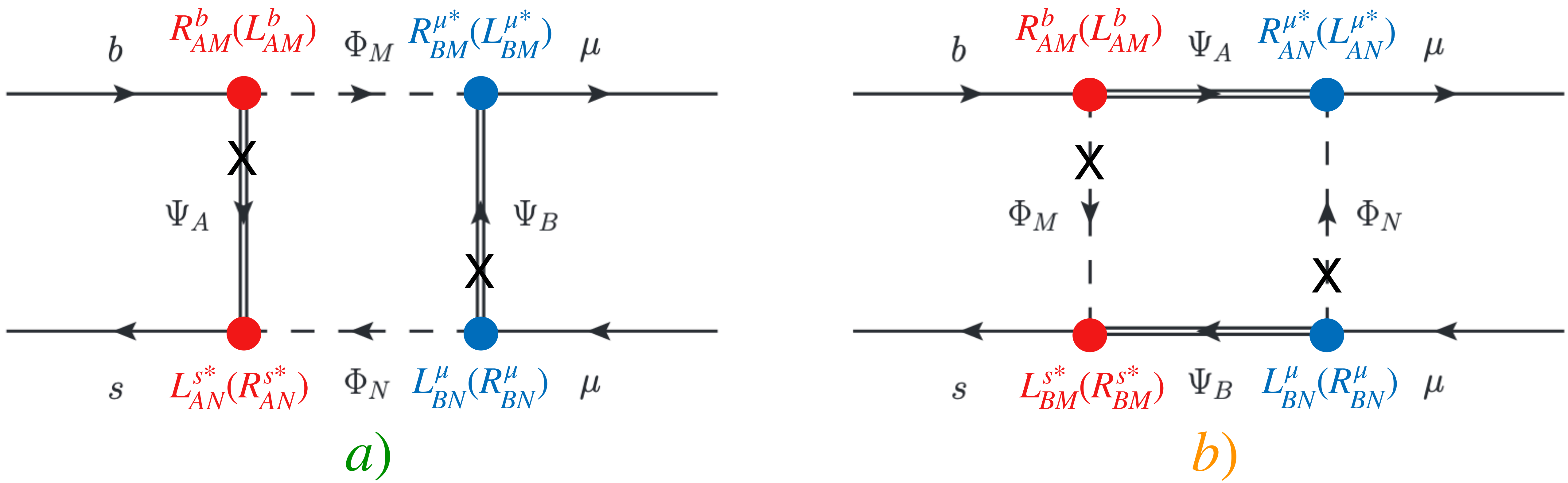
$$C'^{\text{box}}_{9(10)} = \pm\, C^{\text{box}}_{9(10)}(L \leftrightarrow R)$$

$$x_{NM} \equiv (m_{\Phi_N}/m_{\Phi_M})^2$$

$$C_9^{\text{box},\,b)} = -\mathcal{N}\frac{\chi L^{s*}_{BM}L^b_{AM}}{32\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[L^{\mu*}_{AN}L^{\mu}_{BN}F(x_{AM},x_{BM},x_{NM}) - R^{\mu*}_{AN}R^{\mu}_{BN}\frac{m_{\Psi_A}m_{\Psi_B}}{m^2_{\Phi_M}}G(x_{AM},x_{BM},x_{NM})\right]$$

$$C_{10}^{\text{box},\,b)} = \mathcal{N}\frac{\chi L^{s*}_{BM}L^b_{AM}}{32\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[L^{\mu*}_{AN}L^{\mu}_{BN}F(x_{AM},x_{BM},x_{NM}) + R^{\mu*}_{AN}R^{\mu}_{BN}\frac{m_{\Psi_A}m_{\Psi_B}}{m^2_{\Phi_M}}G(x_{AM},x_{BM},x_{NM})\right]$$

b→sμμ



$$C_S^{\text{box},a)} = -\mathcal{N}\frac{\chi L^{s*}_{AN}R^b_{AM}}{16\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[R^{\mu*}_{BM}L^{\mu}_{BN} + L^{\mu*}_{BM}R^{\mu}_{BN}\right]\frac{m_{\Psi_A}m_{\Psi_B}}{m^2_{\Phi_M}}G(x_{AM},x_{BM},x_{NM})$$

$$C_P^{\text{box},a)} = \mathcal{N}\frac{\chi L^{s*}_{AN}R^b_{AM}}{16\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[R^{\mu*}_{BM}L^{\mu}_{BN} - L^{\mu*}_{BM}R^{\mu}_{BN}\right]\frac{m_{\Psi_A}m_{\Psi_B}}{m^2_{\Phi_M}}G(x_{AM},x_{BM},x_{NM})$$

$$C'^{\text{box}}_{S,T(P)} = \pm\, C^{\text{box}}_{S,T(P)}(L \leftrightarrow R)$$

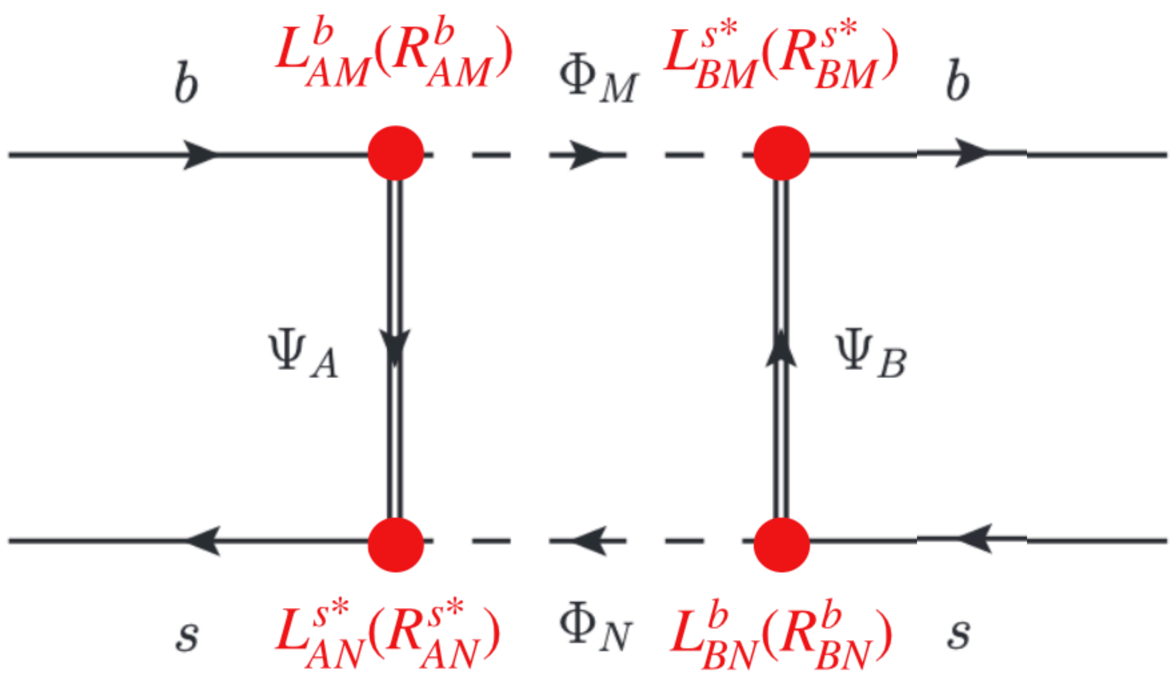
$$C_S^{\text{box},b)} = \mathcal{N}\frac{\chi L^{s*}_{BM}R^b_{AM}}{16\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[R^{\mu*}_{AN}L^{\mu}_{BN}F(x_{AM},x_{BM},x_{NM}) + L^{\mu*}_{AN}R^{\mu}_{BN}\frac{m_{\Psi_A}m_{\Psi_B}}{2m^2_{\Phi_M}}G(x_{AM},x_{BM},x_{NM})\right]$$

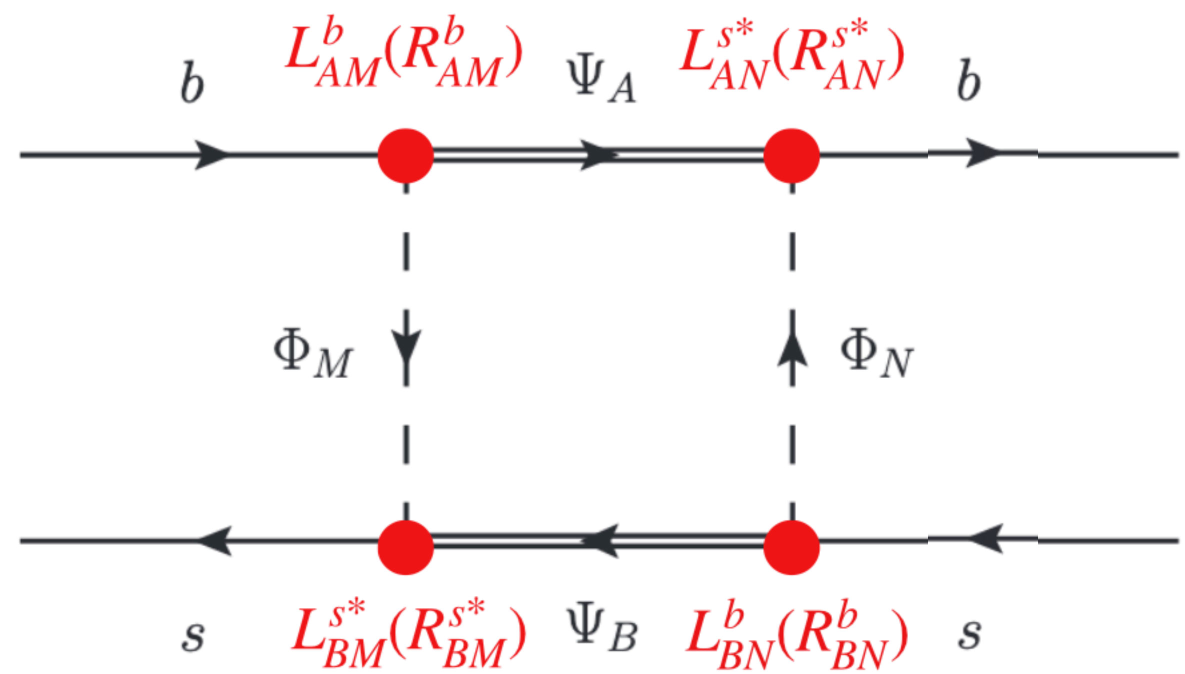
$$C_P^{\text{box},b)} = -\mathcal{N}\frac{\chi L^{s*}_{BM}R^b_{AM}}{16\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\left[R^{\mu*}_{AN}L^{\mu}_{BN}F(x_{AM},x_{BM},x_{NM}) - L^{\mu*}_{AN}R^{\mu}_{BN}\frac{m_{\Psi_A}m_{\Psi_B}}{2m^2_{\Phi_M}}G(x_{AM},x_{BM},x_{NM})\right]$$

$$C_T^{\text{box},b)} = -\mathcal{N}\frac{\chi L^{s*}_{BM}R^b_{AM}L^{\mu*}_{AN}R^{\mu}_{BN}}{16\pi\alpha_{\text{EM}}m^2_{\Phi_M}}\frac{m_{\Psi_A}m_{\Psi_B}}{m^2_{\Phi_M}}G(x_{AM},x_{BM},x_{NM})$$

Additional WC present <u>only</u> in the presence of additional SU(2) breaking effects

ΔMs





Both diagrams appear, independently on b→s$\mu\mu$, since no leptons are involved in this channel

$$C_1 = (\chi_{BB} + \tilde{\chi}_{BB}) \frac{L^{s*}_{AN} L^b_{AM} L^{s*}_{BM} L^b_{BN}}{128\pi^2 m^2_{\Phi_M}} F(x_{AM}, x_{BM}, x_{NM}) \, ,$$

$$C_2 = \chi_{BB} \frac{R^{s*}_{AN} L^b_{AM} R^{s*}_{BM} L^b_{BN}}{64\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) \, ,$$

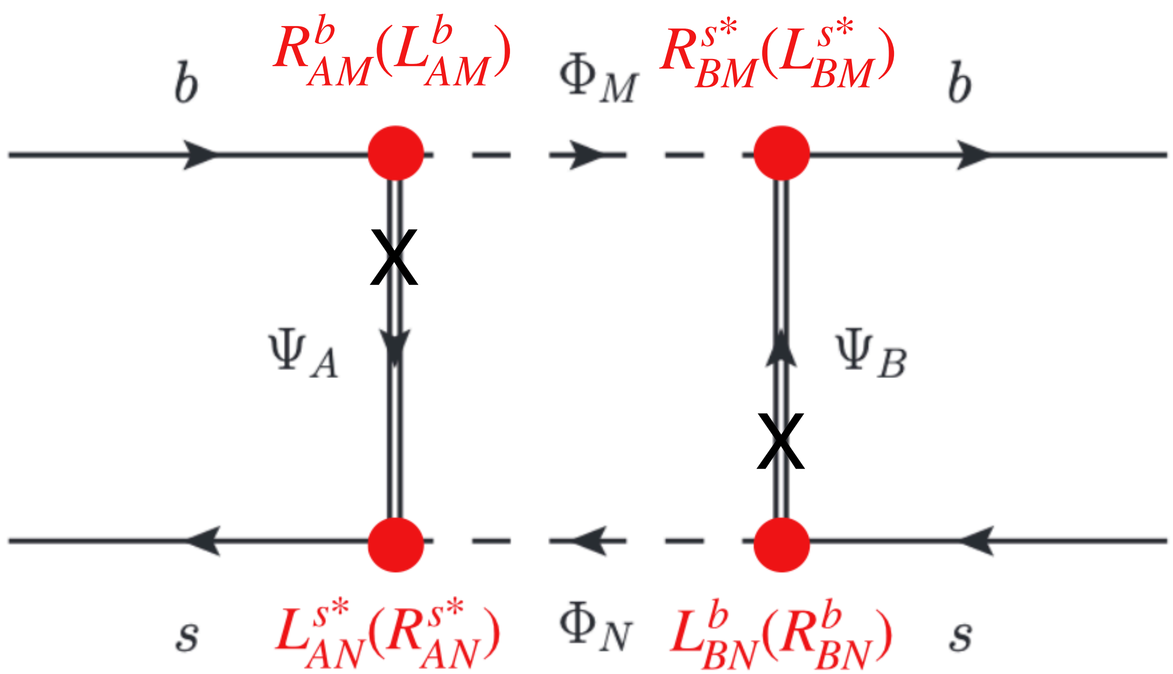
$$C_3 = \tilde{\chi}_{BB} \frac{R^{s*}_{AN} L^b_{AM} R^{s*}_{BM} L^b_{BN}}{64\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) \, ,$$

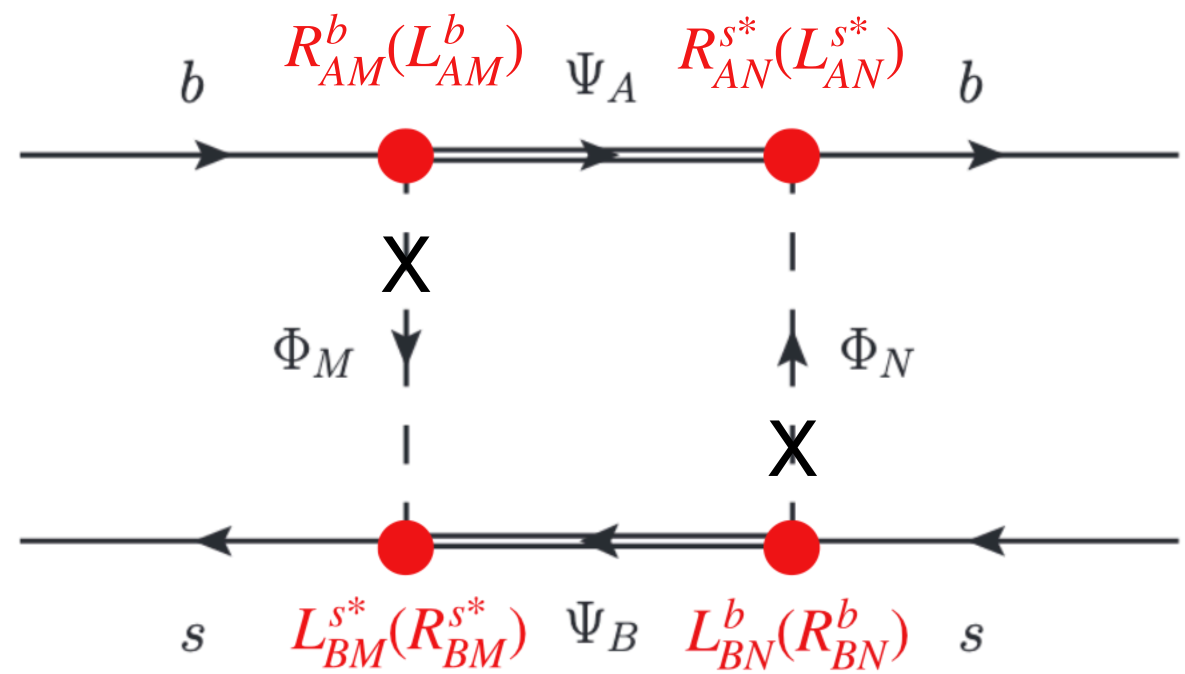
$$\tilde{C}_{1,2,3} = C_{1,2,3} \, (L \leftrightarrow R)$$

$$C_4 = \chi_{BB} \frac{R^{s*}_{AN} L^b_{AM} L^{s*}_{BM} R^b_{BN}}{32\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) - \tilde{\chi}_{BB} \frac{R^{s*}_{AN} R^b_{AM} L^{s*}_{BM} L^b_{BN}}{32\pi^2 m^2_{\Phi_M}} F(x_{AM}, x_{BM}, x_{NM}) \, ,$$

$$C_5 = \tilde{\chi}_{BB} \frac{R^{s*}_{AN} L^b_{AM} L^{s*}_{BM} R^b_{BN}}{32\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) - \chi_{BB} \frac{R^{s*}_{AN} R^b_{AM} L^{s*}_{BM} L^b_{BN}}{32\pi^2 m^2_{\Phi_M}} F(x_{AM}, x_{BM}, x_{NM}) \, ,$$

ΔMs





Both diagrams appear, independently on b→$s\mu\mu$, since no leptons are involved in this channel

$$C_1 = (\chi_{BB} + \tilde{\chi}_{BB}) \frac{L^{s*}_{AN} L^b_{AM} L^{s*}_{BM} L^b_{BN}}{128\pi^2 m^2_{\Phi_M}} F(x_{AM}, x_{BM}, x_{NM}) \,,$$

$$C_2 = \chi_{BB} \frac{R^{s*}_{AN} L^b_{AM} R^{s*}_{BM} L^b_{BN}}{64\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) \,,$$

$$C_3 = \tilde{\chi}_{BB} \frac{R^{s*}_{AN} L^b_{AM} R^{s*}_{BM} L^b_{BN}}{64\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) \,,$$

$$\widetilde{C}_{1,2,3} = C_{1,2,3} \, (L \leftrightarrow R)$$

$$C_4 = \chi_{BB} \frac{R^{s*}_{AN} L^b_{AM} L^{s*}_{BM} R^b_{BN}}{32\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) - \tilde{\chi}_{BB} \frac{R^{s*}_{AN} R^b_{AM} L^{s*}_{BM} L^b_{BN}}{32\pi^2 m^2_{\Phi_M}} F(x_{AM}, x_{BM}, x_{NM}) \,,$$

$$C_5 = \tilde{\chi}_{BB} \frac{R^{s*}_{AN} L^b_{AM} L^{s*}_{BM} R^b_{BN}}{32\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) - \chi_{BB} \frac{R^{s*}_{AN} R^b_{AM} L^{s*}_{BM} L^b_{BN}}{32\pi^2 m^2_{\Phi_M}} F(x_{AM}, x_{BM}, x_{NM}) \,,$$

Additional contributions to WC present in the presence of additional SU(2) breaking effects

ΔMs

Additional contributions to WC present in the presence of additional SU(2) breaking effects

$$C_1 = (\chi_{BB} + \tilde{\chi}_{BB}) \frac{L^{s*}_{AN} L^{b}_{AM} L^{s*}_{BM} L^{b}_{BN}}{128\pi^2 m^2_{\Phi_M}} F(x_{AM}, x_{BM}, x_{NM}) \,,$$

$$C_2 = \chi_{BB} \frac{R^{s*}_{AN} L^{b}_{AM} R^{s*}_{BM} L^{b}_{BN}}{64\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) \,,$$

$$C_3 = \tilde{\chi}_{BB} \frac{R^{s*}_{AN} L^{b}_{AM} R^{s*}_{BM} L^{b}_{BN}}{64\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) \,,$$

$$\widetilde{C}_{1,2,3} = C_{1,2,3} \, (L \leftrightarrow R)$$

$$C_4 = \chi_{BB} \frac{R^{s*}_{AN} L^{b}_{AM} L^{s*}_{BM} R^{b}_{BN}}{32\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) - \tilde{\chi}_{BB} \frac{R^{s*}_{AN} R^{b}_{AM} L^{s*}_{BM} L^{b}_{BN}}{32\pi^2 m^2_{\Phi_M}} F(x_{AM}, x_{BM}, x_{NM}) \,,$$

$$C_5 = \tilde{\chi}_{BB} \frac{R^{s*}_{AN} L^{b}_{AM} L^{s*}_{BM} R^{b}_{BN}}{32\pi^2 m^2_{\Phi_M}} \frac{m_{\Psi_A} m_{\Psi_B}}{m^2_{\Phi_M}} G(x_{AM}, x_{BM}, x_{NM}) - \chi_{BB} \frac{R^{s*}_{AN} R^{b}_{AM} L^{s*}_{BM} L^{b}_{BN}}{32\pi^2 m^2_{\Phi_M}} F(x_{AM}, x_{BM}, x_{NM}) \,,$$

$$\frac{\Delta M_s^{\rm exp}}{\Delta M_s^{\rm SM}} = \left| 1 + \sum_{i,j=1}^{3} R_i(\mu_b) \frac{\eta_{ij}(\mu_b, \mu_H)}{C_1^{\rm SM}(\mu_b)} \left(C_j + \widetilde{C}_j \right) + \sum_{i,j=4}^{5} R_i(\mu_b) \frac{\eta_{ij}(\mu_b, \mu_H)}{C_1^{\rm SM}(\mu_b)} C_j \right|$$
$$= \left| 1 + \frac{0.8\,(C_1 + \widetilde{C}_1) - 1.9\,(C_2 + \widetilde{C}_2) + 0.5\,(C_3 + \widetilde{C}_3) + 5.2\,C_4 + 1.9\,C_5}{C_1^{\rm SM}(\mu_b)} \right|$$

$R_i(\mu_b)$: ratios of matrix elements

μ_H: heavy scale, set at 1 TeV

Arnan, Crivellin, MF, Mescia (1904.05890)

4th Generation Model

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

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

$$+ \sum_{F=q,\ell,u,d,e} M_F\bar{\Psi}_F\Psi_F + \kappa\, h^\dagger h\,\Phi^\dagger\Phi + m^2_\Phi\Phi^\dagger\Phi$$

We’re interested only in couplings to bottom, strange, muon

4th Generation Model

$$
\begin{aligned}
L^{4\mathrm{th}} = & \sum_i \left(\Gamma^L_{q_i} \bar{\Psi}_q P_L q_i + \Gamma^L_{\ell_i} \bar{\Psi}_\ell P_L \ell_i + \cancel{\Gamma^R_{u_i} \bar{\Psi}_u P_R u_i} + \Gamma^R_{d_i} \bar{\Psi}_d P_R d_i + \Gamma^R_{e_i} \bar{\Psi}_e P_R e_i \right) \Phi + \mathrm{h.c.} \\
& + \sum_{C=L,R} \left(\cancel{\lambda^U_C \bar{\Psi}_q P_C \tilde{h} \Psi_u} + \cancel{\lambda^D_C \bar{\Psi}_q P_C h \Psi_d} + \lambda^E_C \bar{\Psi}_\ell P_C h \Psi_e \right) + \mathrm{h.c.} \\
& + \sum_{F=q,\ell,u,d,e} M_F \bar{\Psi}_F \Psi_F + \kappa\, h^\dagger h\, \Phi^\dagger \Phi + m^2_\Phi \Phi^\dagger \Phi
\end{aligned}
$$

We're interested only in couplings to bottom, strange, muon

We neglect SU(2) breaking for down-type quarks
(responsible for phenomenological un-relevant scalar/tensor operators)

4th Generation Model

$$
\begin{aligned}
L^{4\text{th}} = & \sum_i \left(\Gamma^L_{q_i}\bar{\Psi}_q P_L q_i + \Gamma^L_{\ell_i}\bar{\Psi}_\ell P_L \ell_i + \cancel{\Gamma^R_{u_i}\bar{\Psi}_u P_R} u_i + \Gamma^R_{d_i}\bar{\Psi}_d P_R d_i + \Gamma^R_{e_i}\bar{\Psi}_e P_R e_i\right)\Phi + \text{h.c.} \\
& + \sum_{C=L,R}\left(\cancel{\lambda^U_C \bar{\Psi}_q P_C \tilde{h} \Psi_u} + \cancel{\lambda^D_C \bar{\Psi}_q P_C h \Psi_d} + \lambda^E_C \bar{\Psi}_\ell P_C h \Psi_e\right) + \text{h.c.} \\
& + \sum_{F=q,\ell,u,d,e} M_F \bar{\Psi}_F \Psi_F + \kappa\, h^\dagger h\, \Phi^\dagger \Phi + m^2_\Phi \Phi^\dagger \Phi
\end{aligned}
$$

Below EWSB:

$$
L^{4\text{th}}_{\text{mass}} = \begin{pmatrix} \bar{\Psi}_{\ell,2} \\ \bar{\Psi}_e \end{pmatrix}^T \begin{pmatrix} M_\ell & \sqrt{2}v\lambda^E_R \\ \sqrt{2}v\lambda^{E*}_L & M_e \end{pmatrix} P_L \begin{pmatrix} \Psi_{\ell,2} \\ \Psi_e \end{pmatrix} \Rightarrow \boxed{\begin{aligned} & P_L \begin{pmatrix} \Psi_{\ell,2} \\ \Psi_e \end{pmatrix}_I \to W^{E_L}_{IJ}\Psi^{E_L}_J \\ & \begin{pmatrix} \bar{\Psi}_{\ell,2} \\ \bar{\Psi}_e \end{pmatrix}^T_I P_L \to \bar{\Psi}^{E_R}_J W^{E_R}_{IJ} \end{aligned}}
$$

4th Generation Model

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

$$\boxed{\begin{array}{l} P_L\begin{pmatrix}\Psi_{\ell,2}\\ \Psi_e\end{pmatrix}_I \to W^{E_L}_{IJ}\Psi^{E_L}_J \\[2ex] \begin{pmatrix}\bar{\Psi}_{\ell,2}\\ \bar{\Psi}_e\end{pmatrix}^T_I P_L \to \bar{\Psi}^{E_R}_J W^{E_R}_{IJ}\end{array}}$$

$$\boxed{\begin{array}{l} P_L\begin{pmatrix}\Psi_{q,2}\\ \Psi_d\end{pmatrix}_I \to \delta_{IJ}\Psi^{D_L}_J \\[2ex] \begin{pmatrix}\bar{\Psi}_{q,2}\\ \bar{\Psi}_d\end{pmatrix}^T_I P_L \to \bar{\Psi}^{D_R}_J \delta_{IJ}\end{array}}$$

$$\begin{aligned} L^{4\text{th}}_{\text{int}} &= \left(L^b_1\bar{\Psi}^D_1 P_L b + L^s_1\bar{\Psi}^D_1 P_L s + L^\mu_I\bar{\Psi}^E_I P_L\mu\right)\Phi \\ &\quad + \left(R^b_2\bar{\Psi}^D_1 P_R b + R^s_2\bar{\Psi}^D_1 P_R s + R^\mu_I\bar{\Psi}^E_I P_R\mu\right)\Phi \end{aligned}$$

$$L^s_1 = \Gamma^L_s\,, \qquad L^b_1 = \Gamma^L_b\,, \qquad R^s_2 = \Gamma^R_s\,, \qquad R^b_2 = \Gamma^R_b\,,$$

$$L^\mu_1 = \Gamma^L_\mu\cos\theta_L\,, \qquad L^\mu_2 = -\Gamma^L_\mu\sin\theta_L\,, \qquad R^\mu_1 = \Gamma^R_\mu\sin\theta_R\,, \qquad R^\mu_2 = \Gamma^R_\mu\cos\theta_R$$

4th Generation Model - WC

$$\boxed{\Gamma^L \equiv L_1^b L_1^{s*}\,, \qquad \Gamma^R \equiv R_2^b R_2^{s*}}$$

- b→sμμ

$$C_9^{\rm box} = -\mathcal{N}\frac{\Gamma^L}{32\pi\alpha_{\rm EM} m_\Phi^2}\left(|\Gamma_\mu^L|^2 + |\Gamma_\mu^R|^2\right) F(x_D, x_E)$$

$$C_{10}^{\rm box} = \mathcal{N}\frac{\Gamma^L}{32\pi\alpha_{\rm EM} m_\Phi^2}\left(|\Gamma_\mu^L|^2 - |\Gamma_\mu^R|^2\right) F(x_D, x_E)$$

$$C_{9(10)}^{\prime\rm box} = \pm\, C_{9(10)}^{\rm box}(L \leftrightarrow R)$$

- ΔM_S

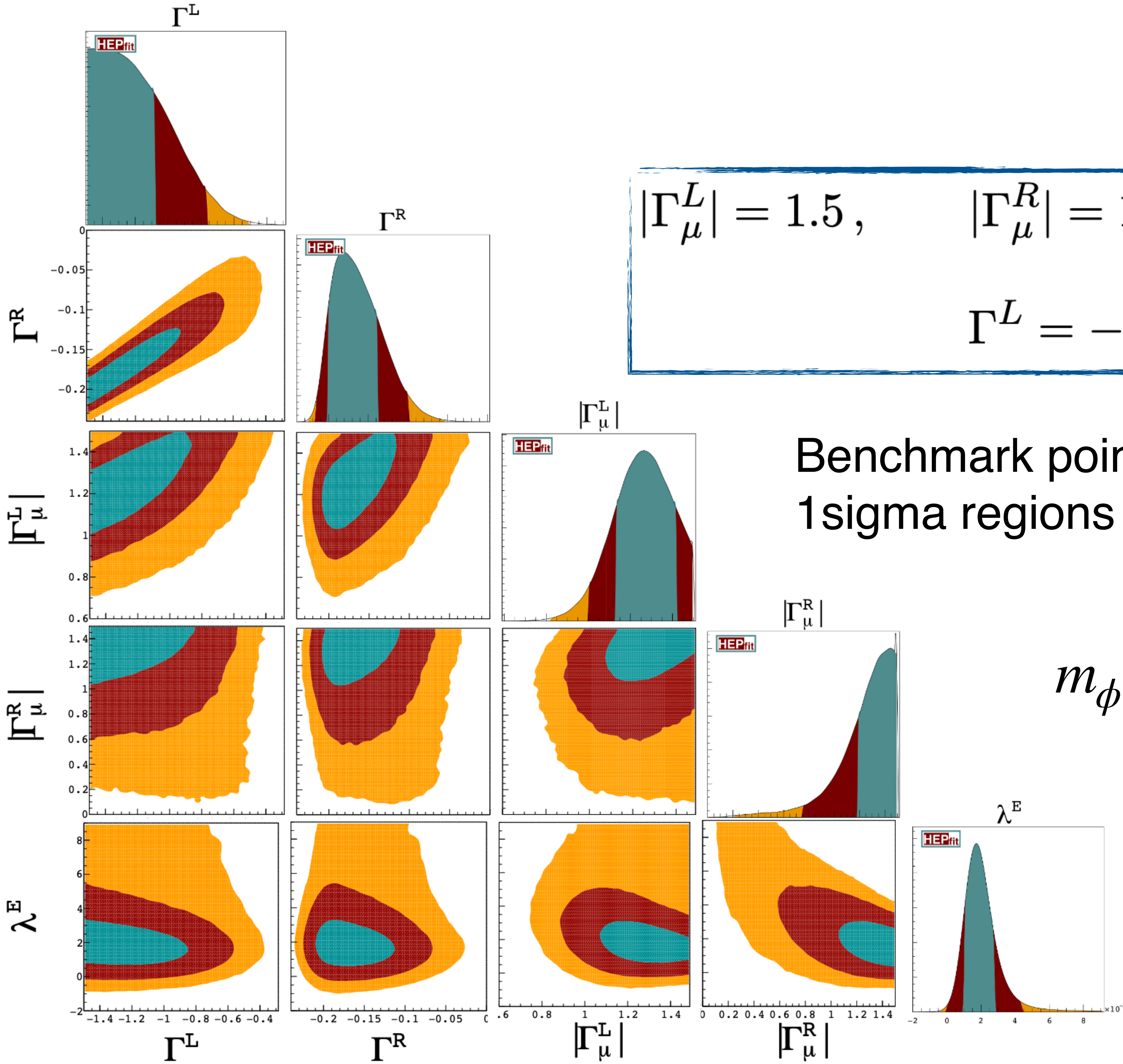
$$C_1 = \frac{|\Gamma^L|^2}{128\pi^2 m_\Phi^2} F(x_D)\,, \quad C_5 = -\frac{\Gamma^L\Gamma^R}{32\pi^2 m_\Phi^2} F(x_D)\,, \quad \tilde{C}_1 = \frac{|\Gamma^R|^2}{128\pi^2 m_\Phi^2} F(x_D)$$

- g-2

$$\boxed{\lambda_R^E = -\lambda_L^E \equiv \lambda^E}$$

$$\Delta a_\mu = \frac{m_\mu^2}{8\pi^2 m_\Phi^2}\left[\left(|\Gamma_\mu^L|^2 + |\Gamma_\mu^R|^2\right) F_7\left(x_E\right) + \frac{8}{\sqrt{2}}\frac{v\,\lambda^E}{m_\mu}\Gamma_\mu^L\Gamma_\mu^R G_7\left(x_E\right)\right]$$

Global Fit



$$|\Gamma^L_\mu| = 1.5\,, \qquad |\Gamma^R_\mu| = 1.4\,, \qquad \lambda^E = 0.0015$$

$$\Gamma^L = -1.0\,, \qquad \Gamma^R = -0.12$$

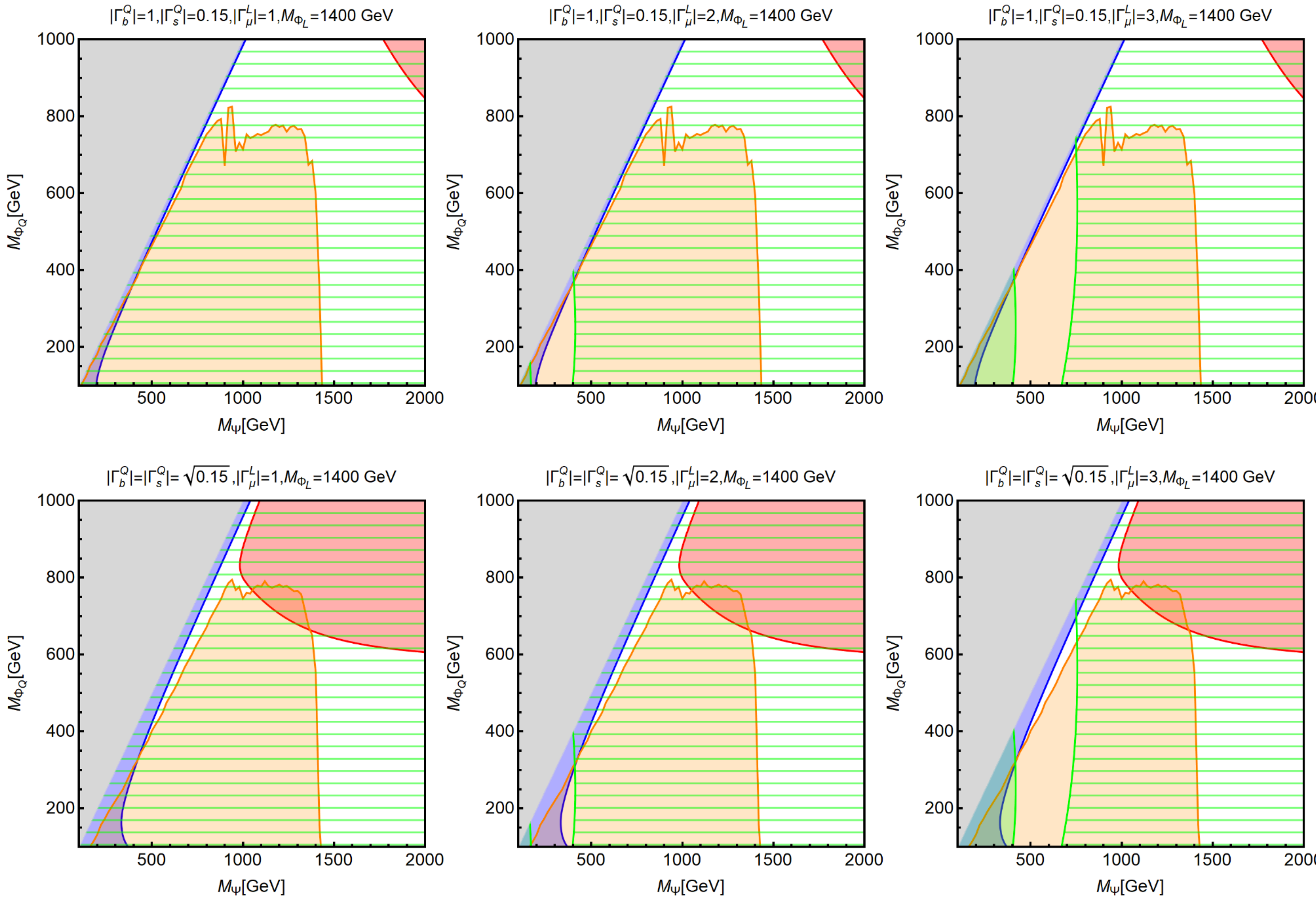
Benchmark point, compatible with all 1sigma regions of combined pdf

$$m_\phi = m_E = 450\,\mathrm{GeV}$$

$$m_D = 3150\,\mathrm{GeV}$$

F_{IB} with real DM

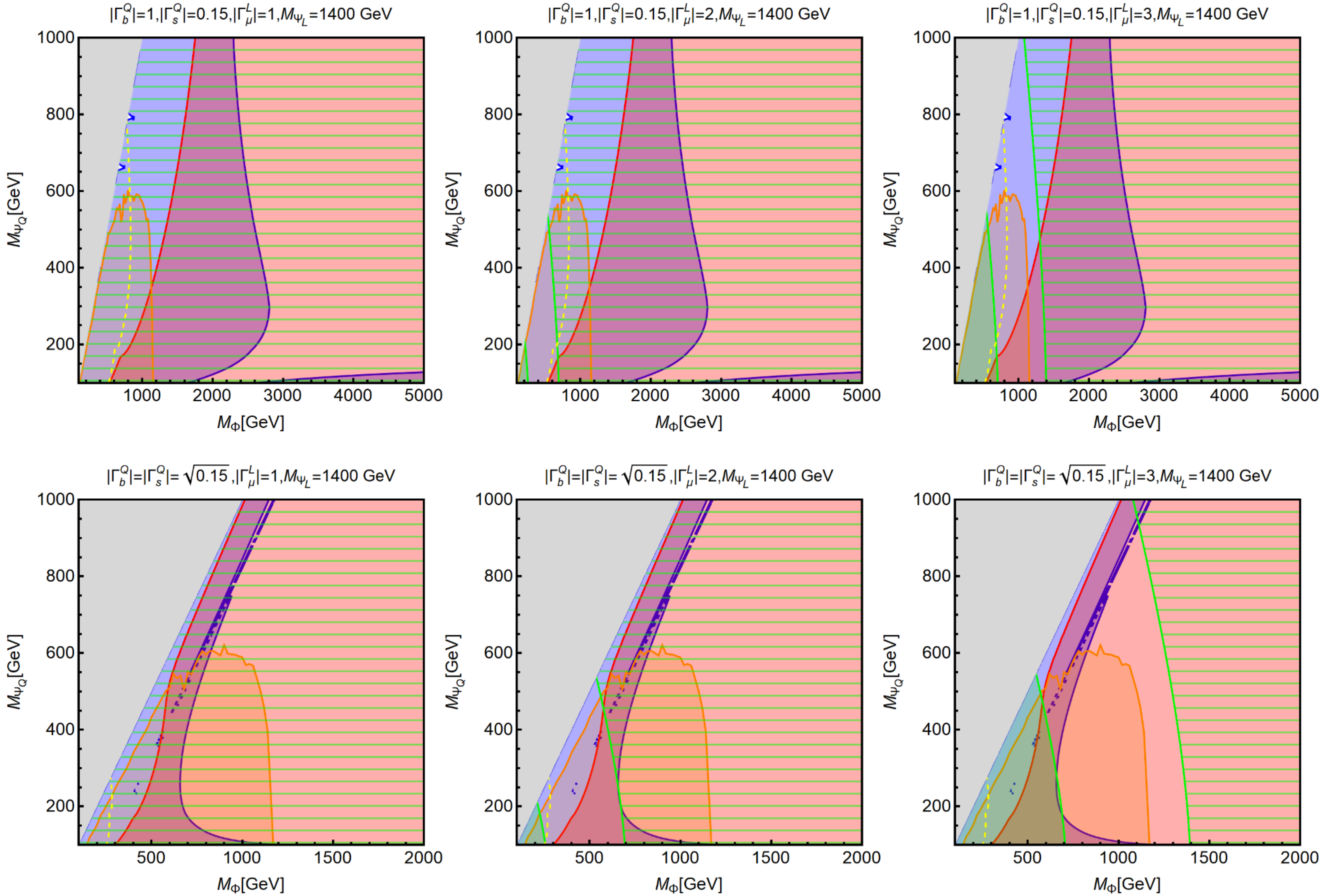
Φ_Q	Φ_L	Ψ
$(\mathbf{1},\mathbf{2},1/2)^\star$	$(\bar{\mathbf{3}},\mathbf{2},-1/6)$	$(\mathbf{3},\mathbf{1},-1/3)$



Requires mass splitting between CP-even and CP-odd DM comp. Either an under-abundant DM is produced, or a not-good-enough contribution to B-anomalies

S_{IIB} with Dirac DM

Ψ_Q	Ψ_L	Φ
$(\mathbf{1},\mathbf{1},0)^\star$	$(\bar{\mathbf{3}},\mathbf{1},-2/3)$	$(\mathbf{3},\mathbf{2},1/6)$

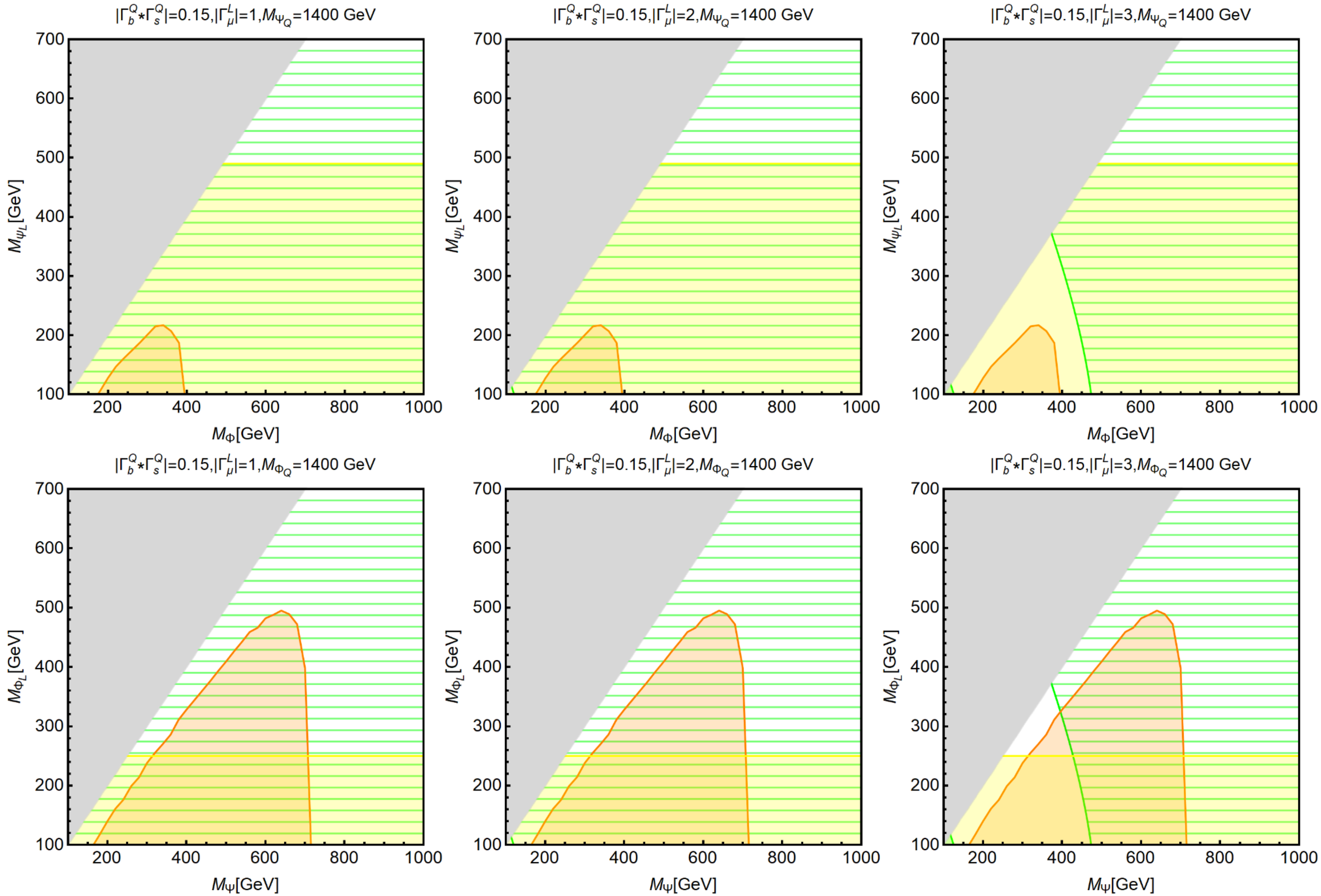


Model excluded by DM bounds!

Ψ_Q	Ψ_L	Φ
$(\mathbf{3},\mathbf{3},2/3)$	$(\mathbf{1},\mathbf{3},0)^\star$	$(\mathbf{1},\mathbf{2},-1/2)^\star$

S_{IIIA} and F_{IIIA}: triplet DM

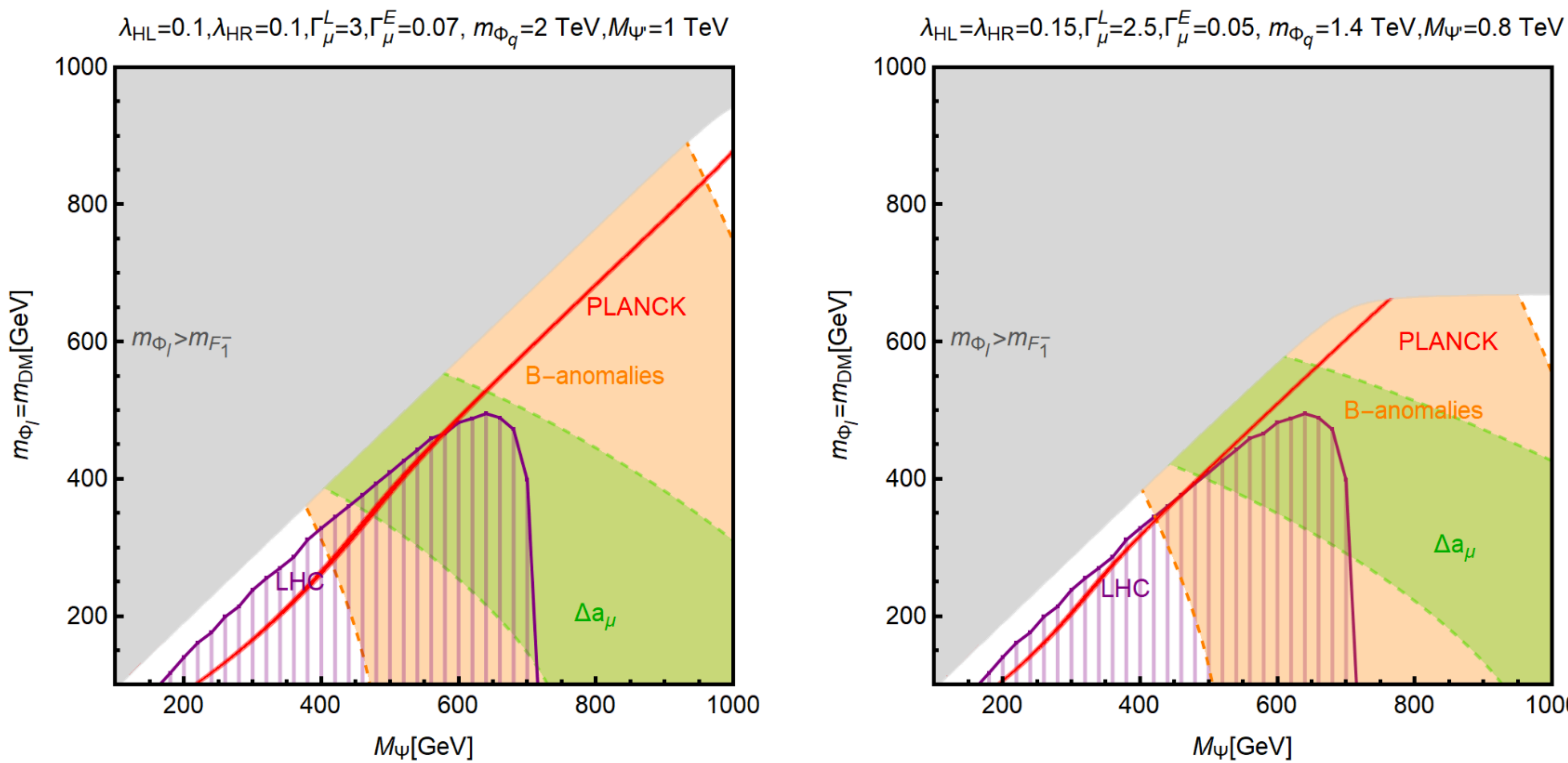
Φ_Q	Φ_L	Ψ
$(\mathbf{3},\mathbf{3},2/3)$	$(\mathbf{1},\mathbf{3},0)^\star$	$(\mathbf{1},\mathbf{2},-1/2)$



Models strongly constraint by LHC disappearing tracks,
DM strongly under-abundant!

F_{IIB} with singlet DM

Φ_Q	Φ_L	Ψ	Ψ'
$(\mathbf{3}, \mathbf{1}, 2/3)$	$(\mathbf{1}, \mathbf{1}, 0)^\star$	$(\mathbf{1}, \mathbf{2}, -1/2)$	$(\mathbf{1}, \mathbf{1}, -1)$



Viable model to address everything simultaneously!