B-physics anomalies and t-channel dark matter

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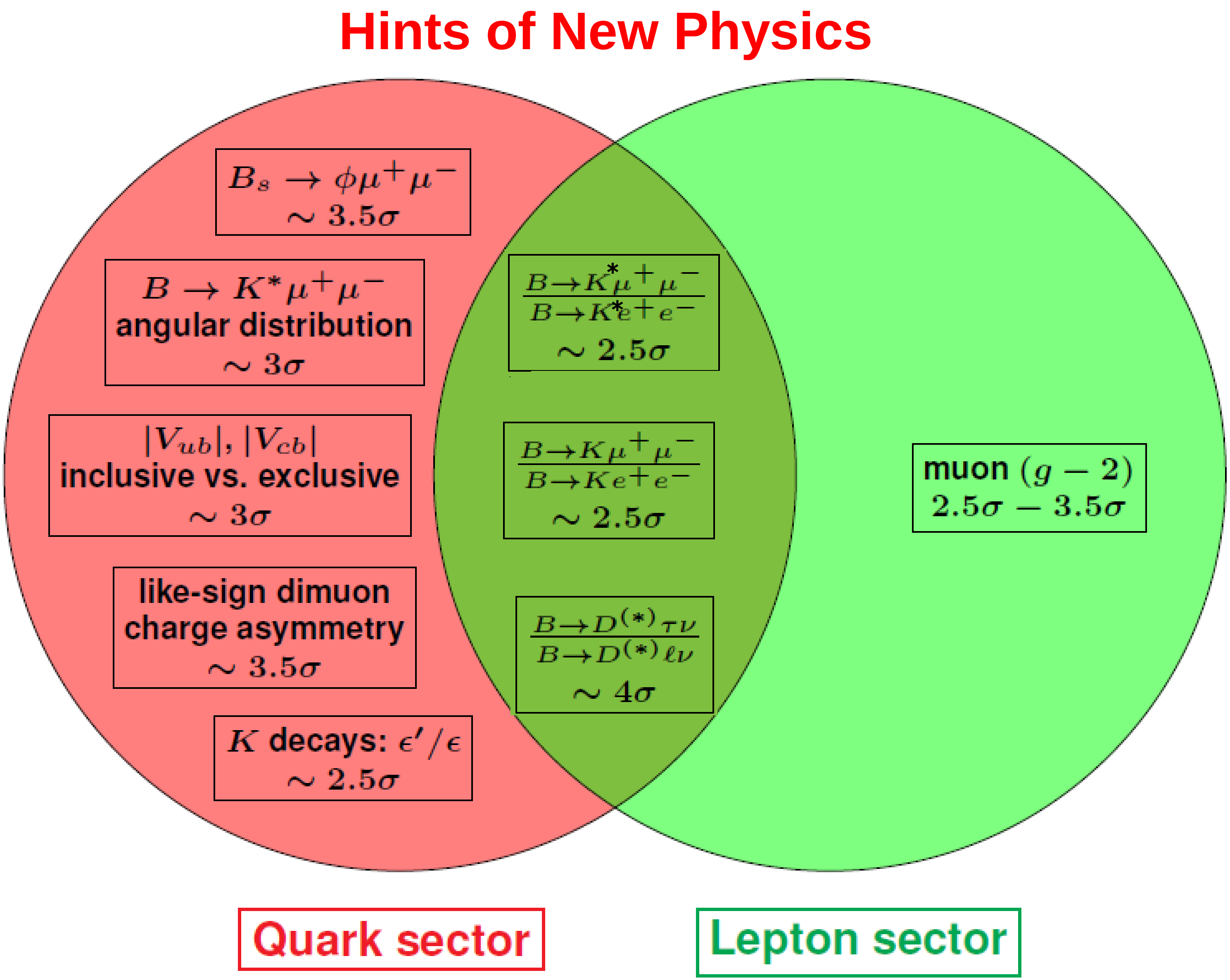
Outline:

- ❖ *B*-Anomalies by loops of scalars and fermions:
  - ☺ Minimal NP field content: *only left-handed couplings*
  - ☺ Stable DM candidate: relic density by thermal freeze-out
  - ☺ Signatures for Direct Searches at Atlas/CMS

5th Red LHC Workshop, May 10-12, 2021

Flavour Anomalies up to now



☺ *B-Anomalies: theoretically clean!*

- *Breaking of Lepton Flavour Universality* (LFU)

  - LFU from $b \to s$ neutral currents: μ vs e

NEW 2021

$$R_{K^{(*)}} = \frac{Br\left(B \to K^{(*)}\mu\mu\right)}{Br\left(B \to K^{(*)}ee\right)}$$

See next talk from Alessandra Gioventu

- New Physics effects are about 15% of the SM

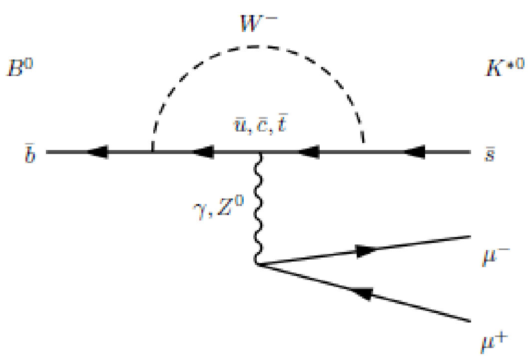
$\sim 3.1\sigma$?!

☺ B-Anomalies: theoretically clean!

❖ *Breaking of Lepton Flavour Universality* (LFU)

➢ LFU from $b \to s$ neutral currents: μ vs e

$b \to s\ \mu\mu$



Suppressed SM processes

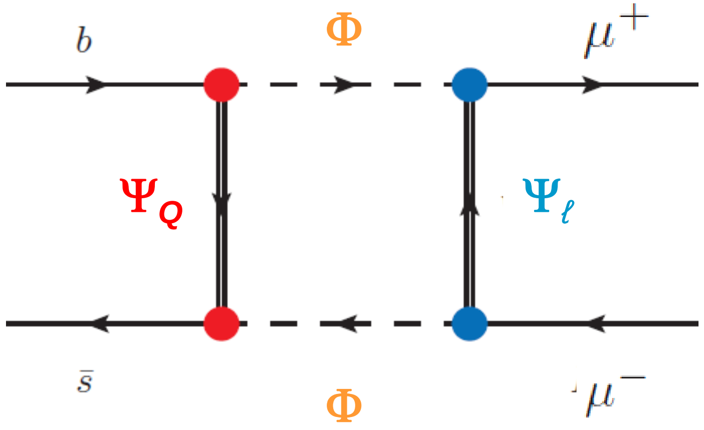
☺ *FCNC processes*

☺ NP at one-loop

Not impossible!
Where we expect

$b \to s\, \mu^+\mu^-$: New Physics Models

☺ Loop-level solutions to *B*-anomalies



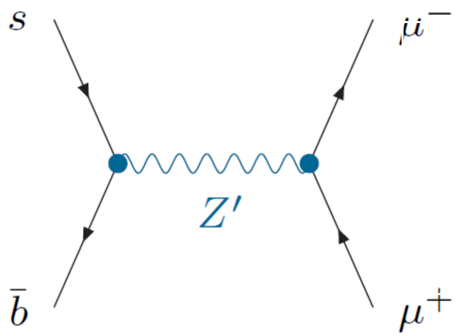
THIS TALK

SM at one-loop

NP at one-loop

It sounds good

☹ tree-level solutions to *B*-anomalies

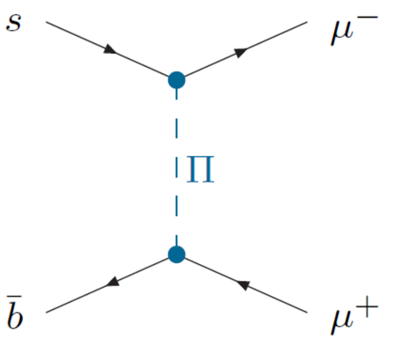


Z' models

SM at one-loop

NP at tree-loop

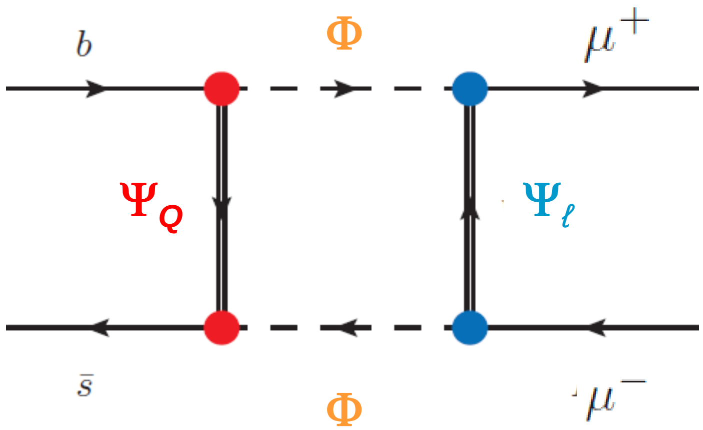
It sounds crazy



Leptoquarks

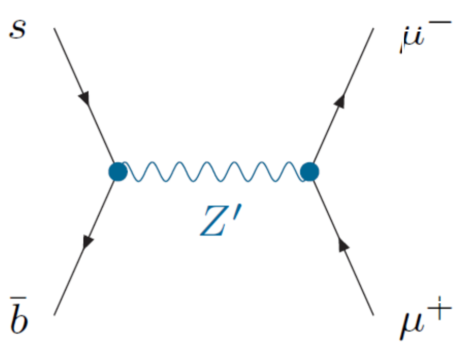
Linking b → s $\mu\mu$ anomalies to DM in loop models

☺ Loop-level solutions to *B*-anomalies



DM candidate from one of the particles in the loops

☹ tree-level solutions to *B*-anomalies

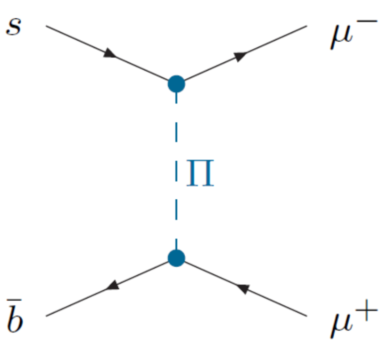


Z' models

No DM candidates

NP at tree-loop

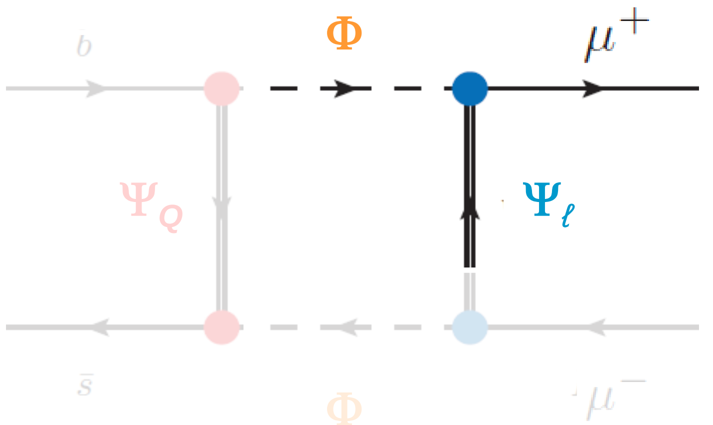
It sounds crazy



Leptoquarks

Linking b → s μμ anomalies to DM in loop models

☺ Loop-level solutions to *B*-anomalies



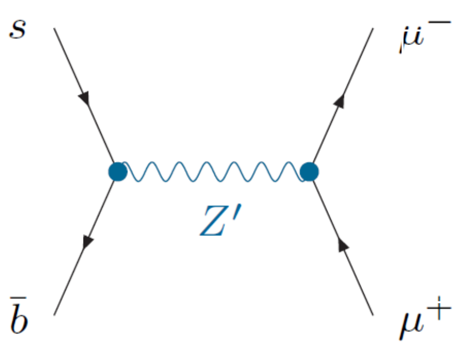
☺ ***for M_Ψ > M_Φ***

Φ is LSP

Lightest Stable particle

→ DM candidate

☹ tree-level solutions to *B*-anomalies



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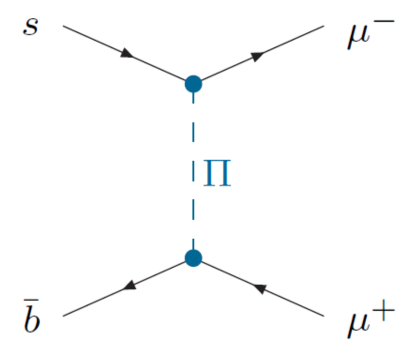
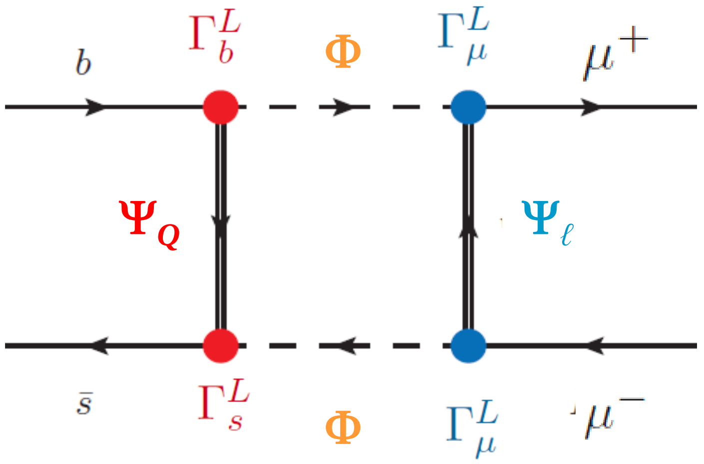


Leptoquarks

Explaining $b \to s\, \mu^+\mu^-$ by loop-models

❖ **Minimal Setup:**

- Three new fields:
  - One scalar , Φ
  - LH vector-like Quark Ψ_Q
  - LH vector-like Lepton Ψ_ℓ



Gripaios, Nardecccha, Renner '15

Arnan, Crivellin, Hofer, F.M '16

Cedeño, Cheek, Martin-Ramiro, Moreno '19

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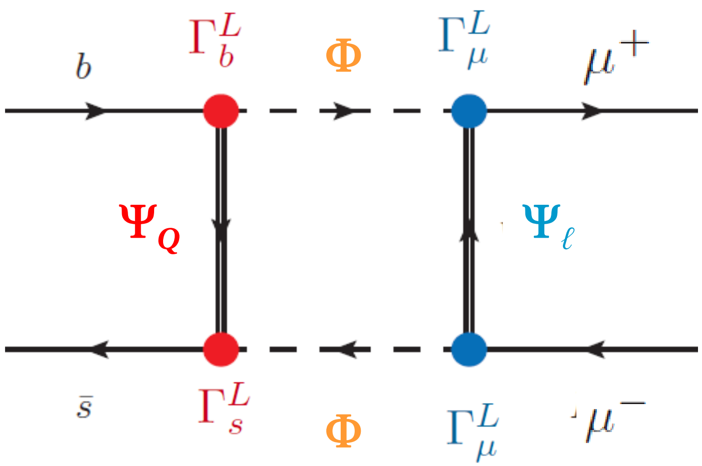
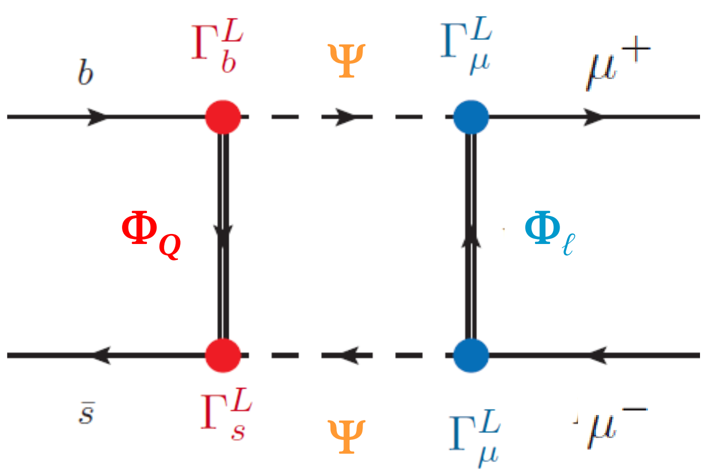


(or vice versa)



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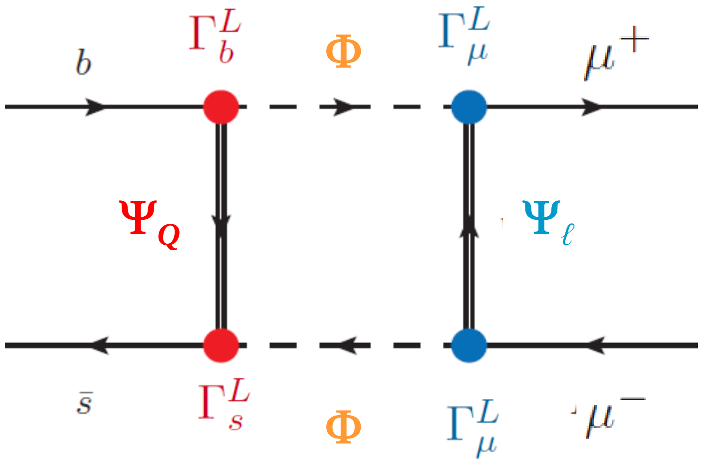

☺ **GOOD Characteristics:**

$\boxed{\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{10}^{\rm NP}}$

➢ scenario with left-handed couplings Γ_b^L, Γ_s^L, Γ_μ^L allows for good description of $b \to s\ell^+\ell^-$ data:

	μ_L	μ_R
q_L	$\mathcal{C}_9^{\rm NP} = -\mathcal{C}_{10}^{\rm NP}$ (4.6σ)	$\mathcal{C}_9^{\rm NP} = \mathcal{C}_{10}^{\rm NP}$ (1.0σ)
q_R	$\mathcal{C}_{9'}^{\rm NP} = -\mathcal{C}_{10'}^{\rm NP}$ (0.6σ)	$\mathcal{C}_{9'}^{\rm NP} = \mathcal{C}_{10'}^{\rm NP}$ (0.1σ)

Explaining b → s μ⁺μ⁻ by loop-models

❖ **Minimal Setup:**

➢ Three new fields:

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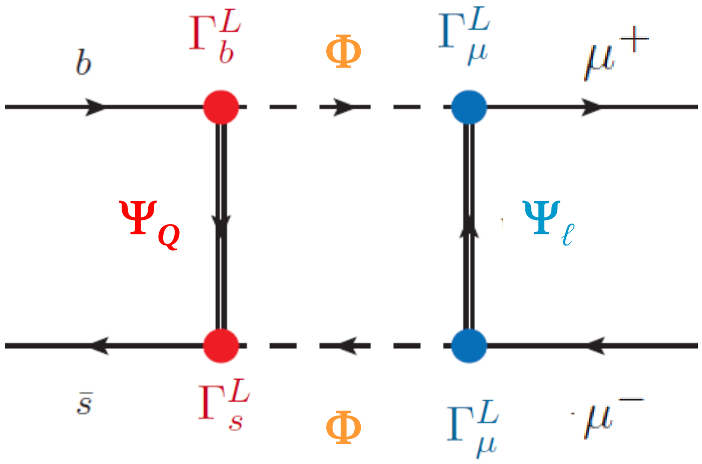
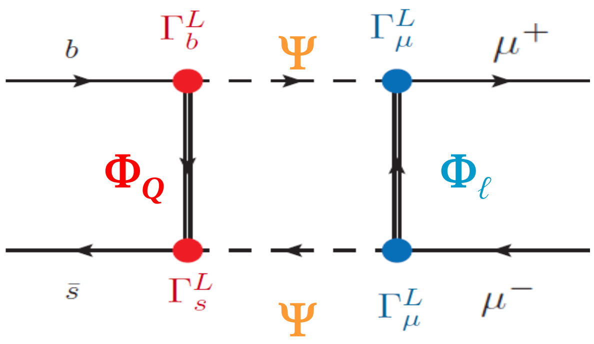


☺ **GOOD Characteristics:** ➡ $\boxed{C_9^{\rm NP} = -C_{10}^{\rm NP}}$

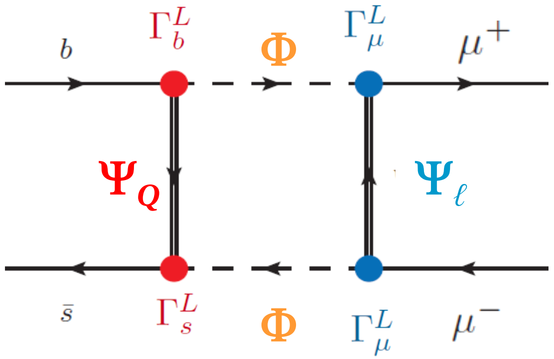
no additional sources of $SU(2)_L$-breaking:

- 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

Systematic study to $b \to s\, \mu^+\mu^-$ by Dark loops



Arcadi, Calibbi, Fedele. FM '21:
Dirac/Scalar DM
up to triplet



❑ *F-model (fermion mediator)*

Φ_Q	Φ_L	Ψ
$(\mathbf{3},\mathbf{2},7/6)$	$(\mathbf{1},\mathbf{2},1/2)^\star$	$(\mathbf{1},\mathbf{1},-1)$
$(\mathbf{3},\mathbf{2},1/6)$	$(\mathbf{1},\mathbf{2},-1/2)^\star$	$(\mathbf{1},\mathbf{1},0)^\star$
$(\mathbf{1},\mathbf{2},1/2)^\star$	$(\bar{\mathbf{3}},\mathbf{2},-1/6)$	$(\mathbf{3},\mathbf{1},-1/3)$
$(\mathbf{1},\mathbf{2},-1/2)^\star$	$(\bar{\mathbf{3}},\mathbf{2},-7/6)$	$(\mathbf{3},\mathbf{1},2/3)$
$(\mathbf{3},\mathbf{1},2/3)$	$(\mathbf{1},\mathbf{1},0)^\star$	$(\mathbf{1},\mathbf{2},-1/2)$
$(\mathbf{1},\mathbf{1},0)^\star$	$(\bar{\mathbf{3}},\mathbf{1},-2/3)$	$(\mathbf{3},\mathbf{2},1/6)$
$(\mathbf{3},\mathbf{3},5/3)$	$(\mathbf{1},\mathbf{3},1)^\star$	$(\mathbf{1},\mathbf{2},-3/2)$
$(\mathbf{3},\mathbf{3},2/3)$	$(\mathbf{1},\mathbf{3},0)^\star$	$(\mathbf{1},\mathbf{2},-1/2)$
$(\mathbf{3},\mathbf{3},-1/3)$	$(\mathbf{1},\mathbf{3},-1)^\star$	$(\mathbf{1},\mathbf{2},1/2)$
$(\mathbf{1},\mathbf{3},1)^\star$	$(\bar{\mathbf{3}},\mathbf{3},1/3)$	$(\mathbf{3},\mathbf{2},-5/6)$
$(\mathbf{1},\mathbf{3},0)^\star$	$(\bar{\mathbf{3}},\mathbf{3},-2/3)$	$(\mathbf{3},\mathbf{2},1/6)$
$(\mathbf{1},\mathbf{3},-1)^\star$	$(\bar{\mathbf{3}},\mathbf{3},-5/3)$	$(\mathbf{3},\mathbf{2},7/6)$

❑ *S-model (scalar mediator)*

Ψ_Q	Ψ_L	Φ
$(\mathbf{3},\mathbf{2},1/6)$	$(\mathbf{1},\mathbf{2},-1/2)$	$(\mathbf{1},\mathbf{1},0)^\star$
$(\mathbf{3},\mathbf{1},2/3)$	$(\mathbf{1},\mathbf{1},0)^\star$	$(\mathbf{1},\mathbf{2},-1/2)^\star$
$(\mathbf{3},\mathbf{1},-1/3)$	$(\mathbf{1},\mathbf{1},-1)$	$(\mathbf{1},\mathbf{2},1/2)^\star$
$(\mathbf{1},\mathbf{1},0)^\star$	$(\bar{\mathbf{3}},\mathbf{1},-2/3)$	$(\mathbf{3},\mathbf{2},1/6)$
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$(\mathbf{3},\mathbf{2},7/6)$	$(\mathbf{1},\mathbf{2},1/2)$	$(\mathbf{1},\mathbf{3},-1)^\star$
$(\mathbf{3},\mathbf{2},1/6)$	$(\mathbf{1},\mathbf{2},-1/2)$	$(\mathbf{1},\mathbf{3},0)^\star$
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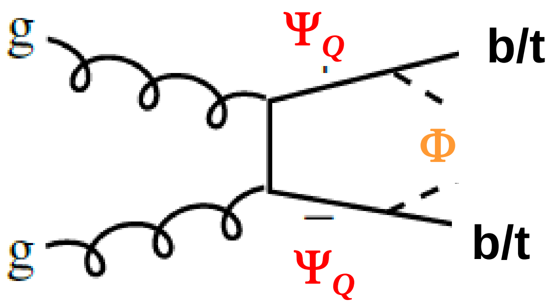
Linking b → s μμ anomalies to DM in loop models

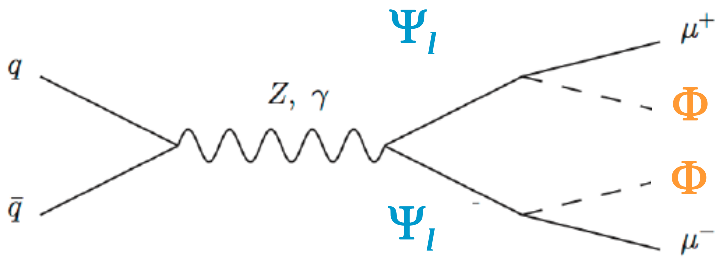
❖ Collider Signatures

For $M_\Phi < M_\Psi$



“Sbottom-like” production

bb/(tt) + MET



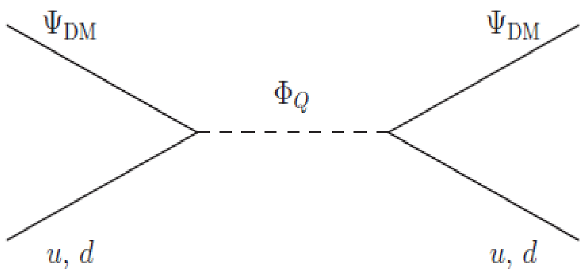
“Slepton-like” production

$\mu\,\mu$ **+ MET**

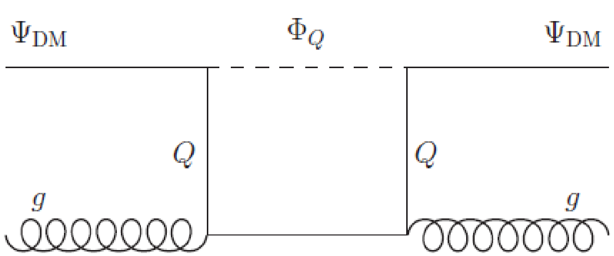
Bounds from direct searches at LHC of sbottoms/sleptons, neutralinos & charginos.

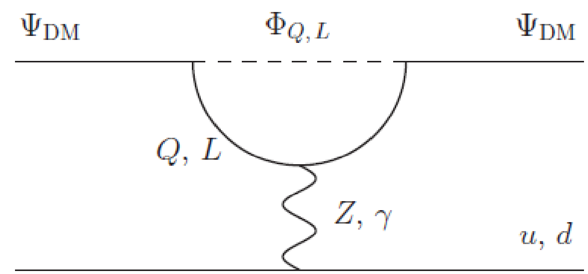
Linking b → s μμ anomalies to DM in loop models

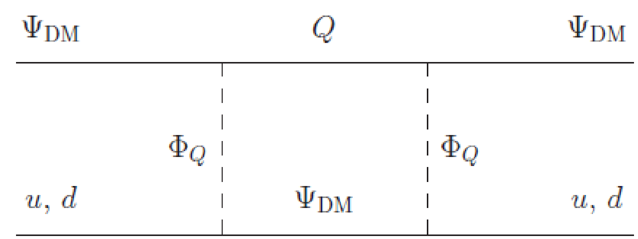
❖ DM Direct Detection



CKM suppressed
(coupling with 1rt generation absent)







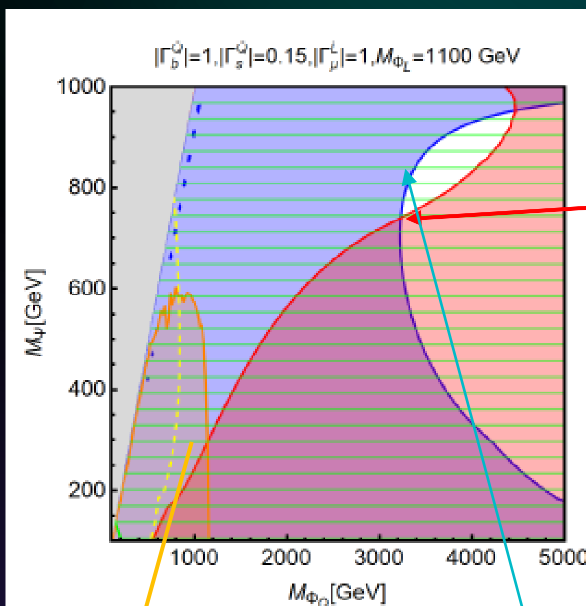
Absent for Real and Majorana DM

Bounds from direct detection of WIMPs at the Xenon

Arcadi, Calibbi, Fedele, FM ’21: systematic study from Dirac/Scalar DM up to SU(2) triplet

Dirac DM

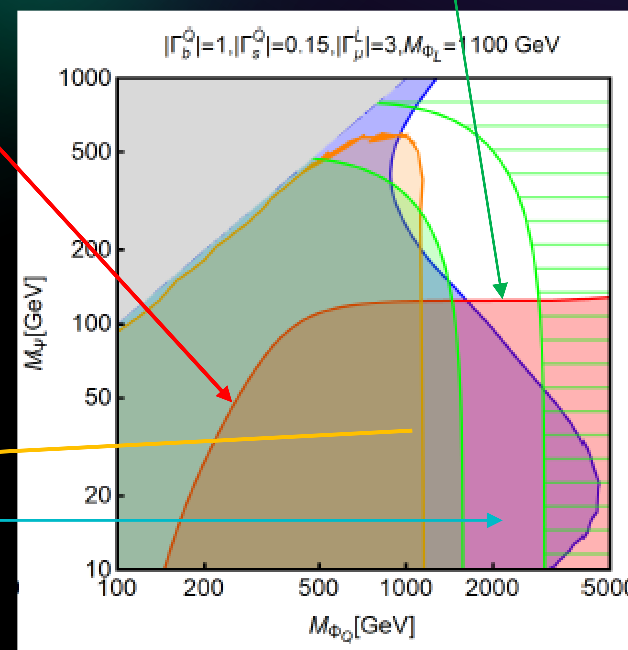
substantially ruled out by Direct Detection



Majorana DM

☺ Viable fit of flavor anomalies

$\Omega h^2 > 0.12$



LHC excluded

XENON1T Excluded

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

Summary

❖ Very interesting pattern of *B*-anomalies in the muon sectors

$b \to s\, \mu^+ \mu^-$

Solutions by dark loops link between DM and B-anomalies

❖ Viable explanation of *B*-anomalies and thermal WIMP DM possible but:

1. Real scalar and Majorana fermion DM favored to avoid DM Direct Detection.

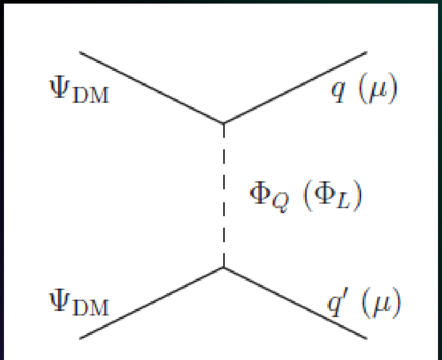
2. Singlet DM preferred to higher EW multiplet, since *B*-anomalies compatible to DM sensitively below the TeV.

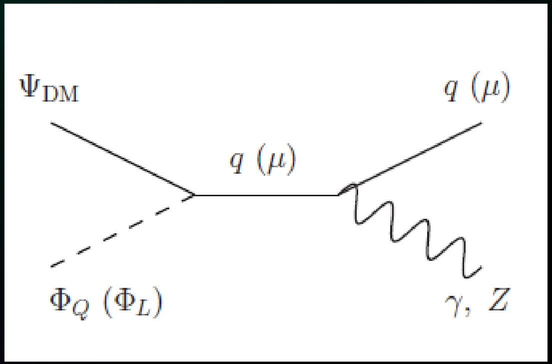
3. Sizable coupling with muon favored to have efficient enough annihilation.

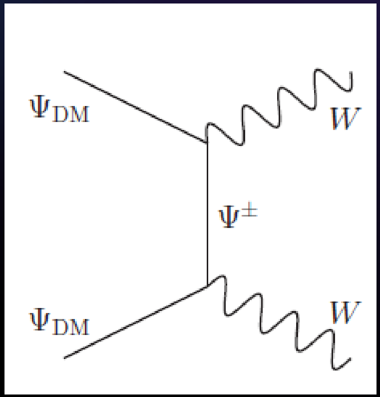
Thanks

Relic Density

$$\Omega_{\rm DM}h^2 \approx 8.76\times 10^{-11}\,{\rm GeV}^{-2}\left[\int_{T_{\rm f.o.}}^{T_0} g_*^{1/2}\langle\sigma v\rangle_{\rm eff}\frac{dT}{M_{\rm DM}}\right]^{-1}$$







Present only if DM is part of SU(2) multiplet

Explaining $b \to s\, \mu^+\mu^-$ by box effects: $B_s - \overline{B}_s$ mixing

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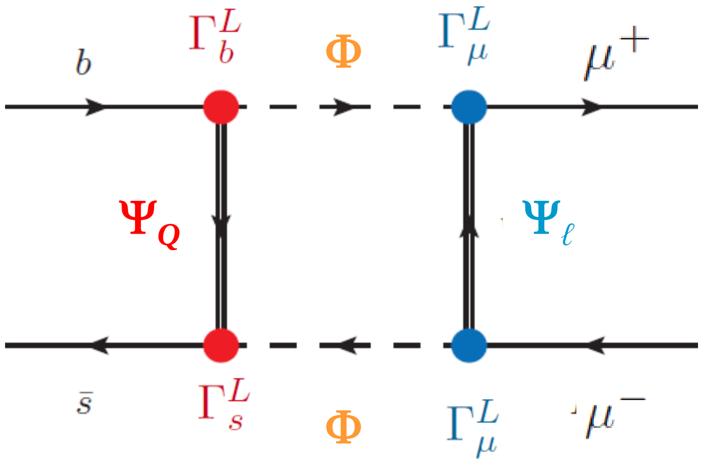
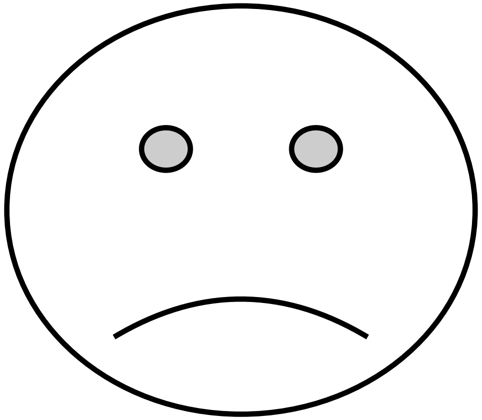
(or vice versa)



☹ **Strongest constraint $B_s - \overline{B}_s$ *mixing***



Di Luzio, Kirk and Lenz '18