

# *B-physics anomalies and t-channel dark matter*

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Outline: 

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❖ *B*-Anomalies by loops of scalars and fermions:

☺ Minimal NP field content: *only left-handed couplings*

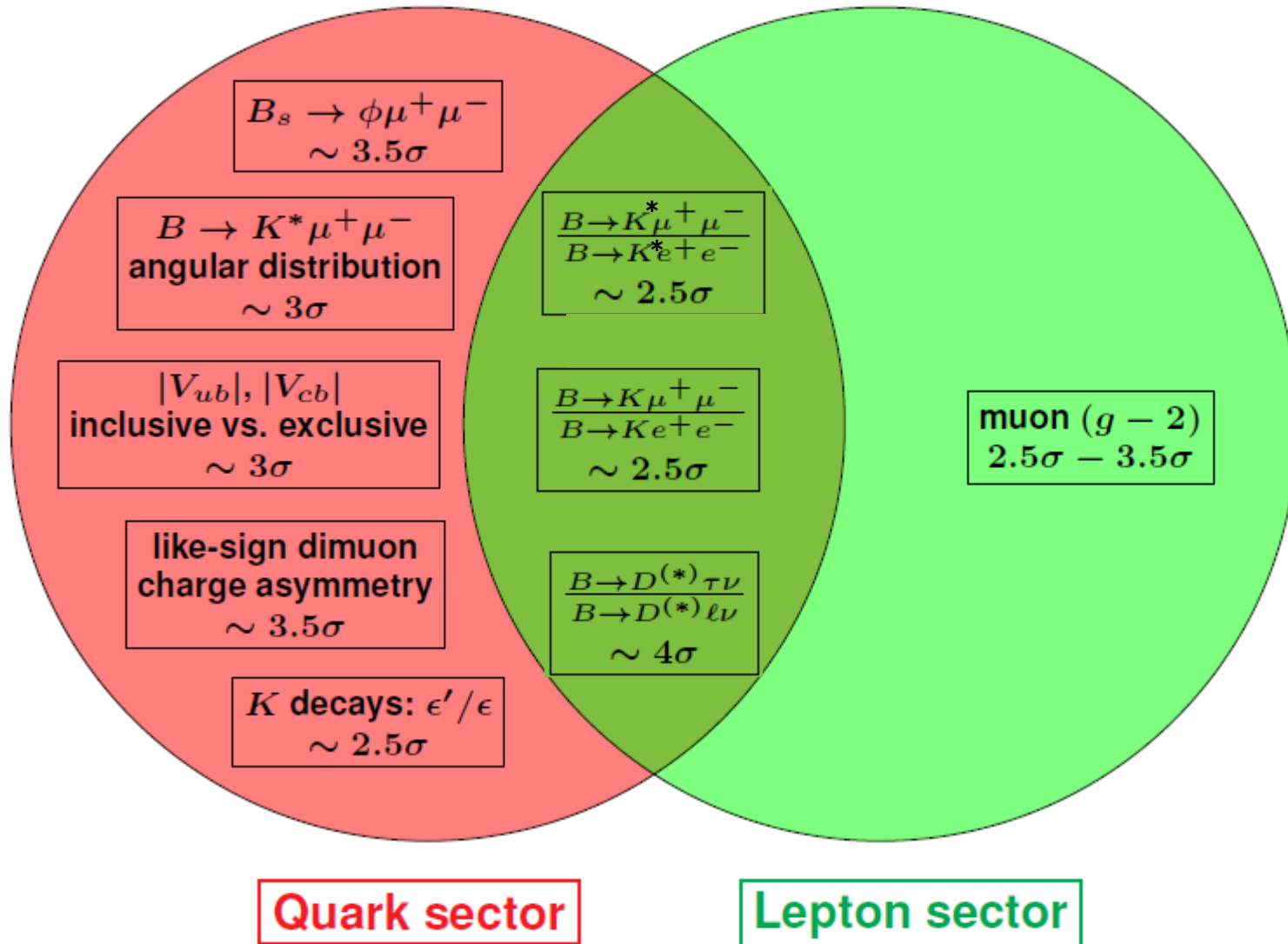
☺ Stable DM candidate: relic density by thermal freeze-out

☺ Signatures for Direct Searches at Atlas/CMS

**5<sup>th</sup> Red LHC Workshop, May 10-12, 2021**

# Flavour Anomalies up to now

## Hints of New Physics



# ☺ ***B-Anomalies: theoretically clean!***

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## ❖ *Breaking of Lepton Flavour Universality (LFU)*

➤ LFU from  $b \rightarrow s$  neutral currents:  $\mu$  vs  $e$

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

NEW  
2021

*See next talk from  
Alessandra Gioventu*

❖ New Physics effects are about 15% of the SM

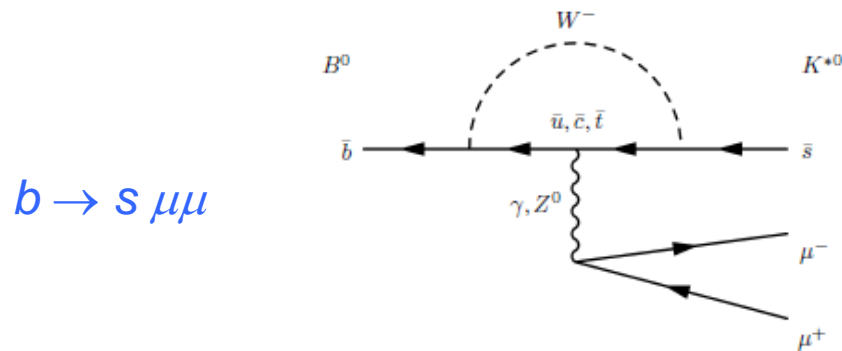
$\sim 3.1\sigma$  ?!

# ☺ **B-Anomalies: theoretically clean!**

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## ❖ *Breaking of Lepton Flavour Universality (LFU)*

➤ LFU from  $b \rightarrow s$  neutral currents:  $\mu$  vs  $e$



## Suppressed SM processes

☺ *FCNC processes*

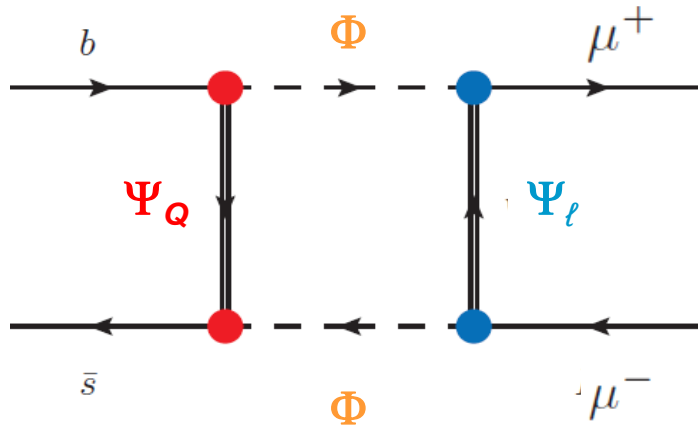
☺ NP at one-loop

**Not impossible!**

**Where we expect**

# $b \rightarrow s \mu^+ \mu^-$ : New Physics Models

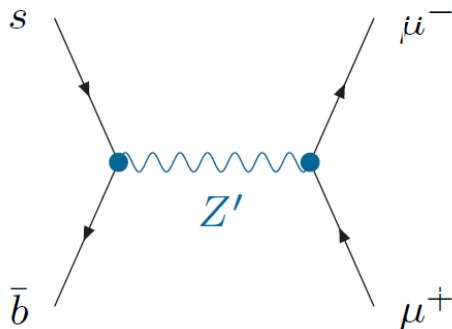
☺ Loop-level solutions to  $B$ -anomalies



**THIS TALK**

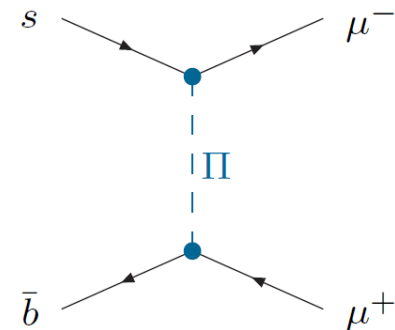
**SM at one-loop  
NP at one-loop  
It sounds good**

☹ tree-level solutions to  $B$ -anomalies



**$Z'$  models**

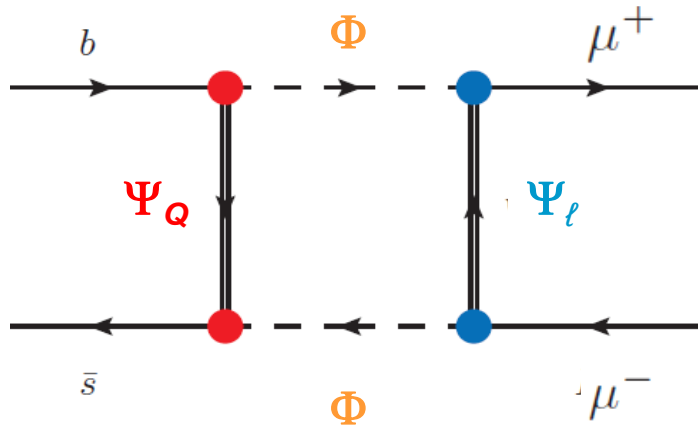
**SM at one-loop  
NP at tree-loop  
It sounds crazy**



**Leptoquarks**

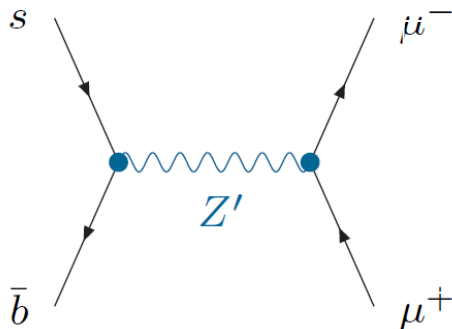
# Linking $b \rightarrow s \mu\mu$ anomalies to DM in loop models

☺ Loop-level solutions to  $B$ -anomalies



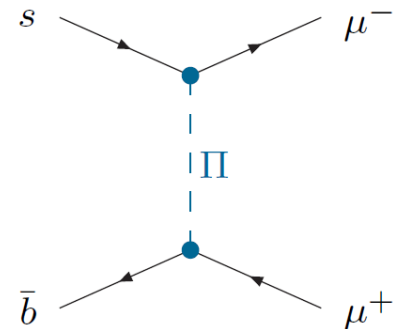
**DM candidate  
from one of the  
particles in the  
loops**

☹ tree-level solutions to  $B$ -anomalies



**$Z'$  models**

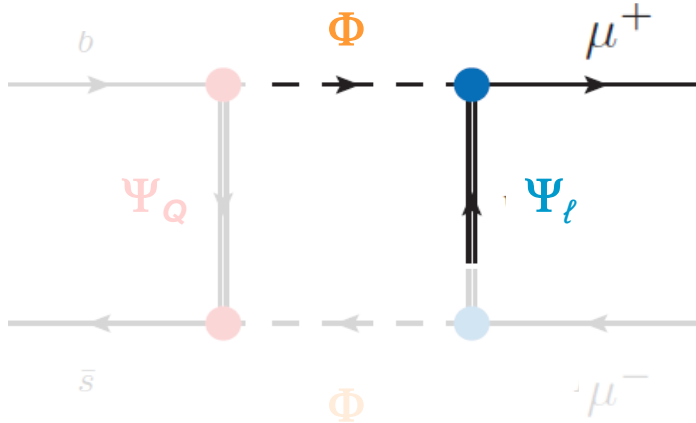
**No DM candidates**  
NP at tree-loop  
It sounds crazy



**Leptoquarks**

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

☺ Loop-level solutions to  $B$ -anomalies



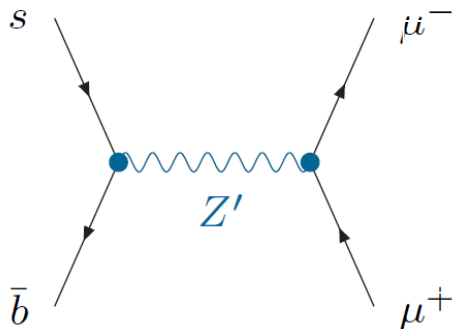
☺ **for  $M_\Psi > M_\Phi$**

$\Phi$  is **LSP**

Lightest Stable particle

→ DM candidate

☹ tree-level solutions to  $B$ -anomalies

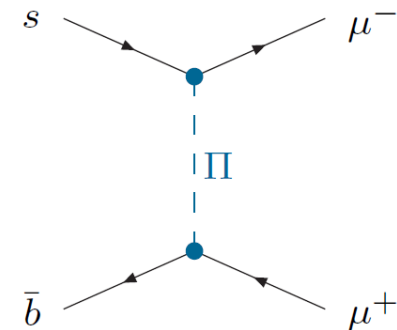


**$Z'$  models**

**No DM candidates**

NP at tree-loop

It sounds crazy



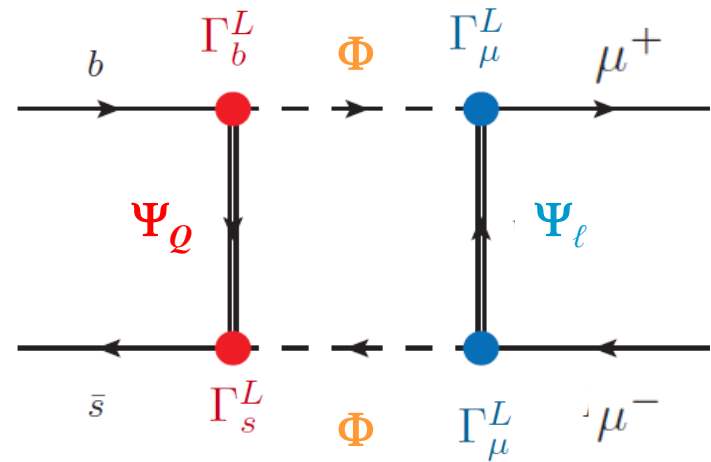
**Leptoquarks**

# Explaining $b \rightarrow s \mu^+ \mu^-$ by loop-models

## ❖ Minimal Setup:

➤ Three new fields:

- One scalar,  $\Phi$
- LH vector-like Quark  $\Psi_Q$
- LH vector-like Lepton  $\Psi_\ell$



Gripaios, Nardecchia, Renner '15

Arnan, Crivellin, Hofer, F.M '16

Cedeño, Cheek, Martin-Ramiro, Moreno '19

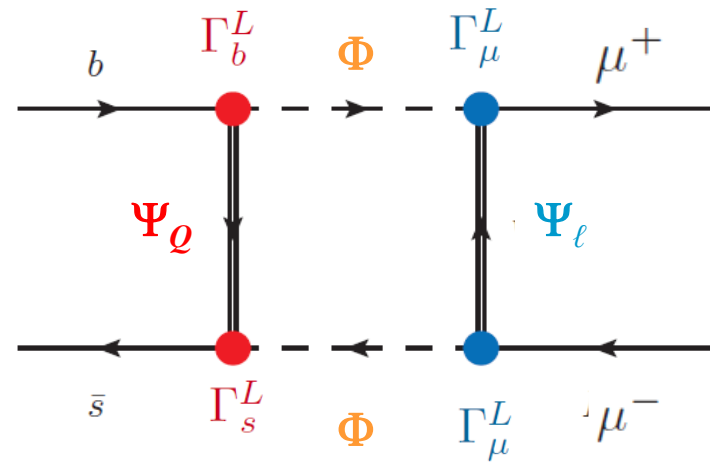


# Explaining $b \rightarrow s \mu^+ \mu^-$ by loop-models

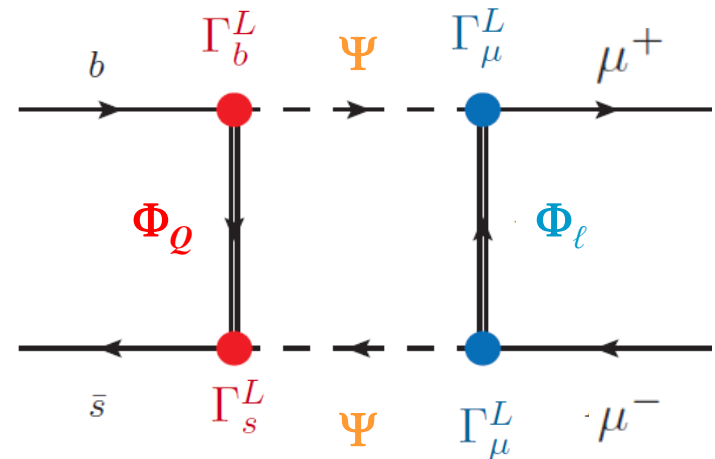
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(or vice versa)



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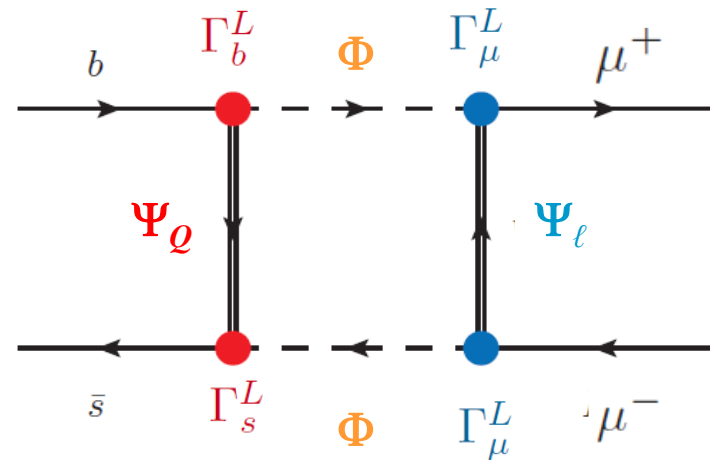
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(or vice versa)



## 😊 GOOD Characteristics:



$$c_9^{\text{NP}} = -c_{10}^{\text{NP}}$$

- scenario with left-handed couplings  $\Gamma_b^L, \Gamma_s^L, \Gamma_\mu^L$  allows for good description of  $b \rightarrow s \ell^+ \ell^-$  data:

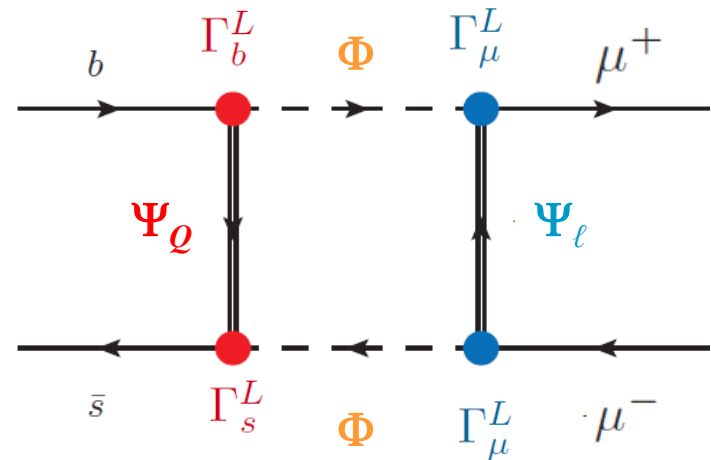
	$\mu_L$	$\mu_R$
$q_L$	$c_9^{\text{NP}} = -c_{10}^{\text{NP}} (4.6\sigma)$	$c_9^{\text{NP}} = c_{10}^{\text{NP}} (1.0\sigma)$
$q_R$	$c_{9'}^{\text{NP}} = -c_{10'}^{\text{NP}} (0.6\sigma)$	$c_{9'}^{\text{NP}} = c_{10'}^{\text{NP}} (0.1\sigma)$

# Explaining $b \rightarrow s \mu^+ \mu^-$ by loop-models

## ❖ Minimal Setup:

- Three new fields:
  - One scalar,  $\Phi$
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## 😊 GOOD Characteristics:

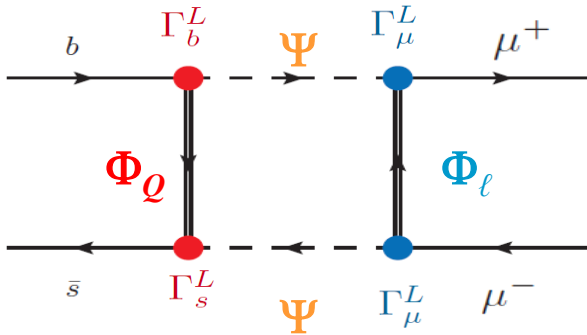


$$c_9^{\text{NP}} = -c_{10}^{\text{NP}}$$

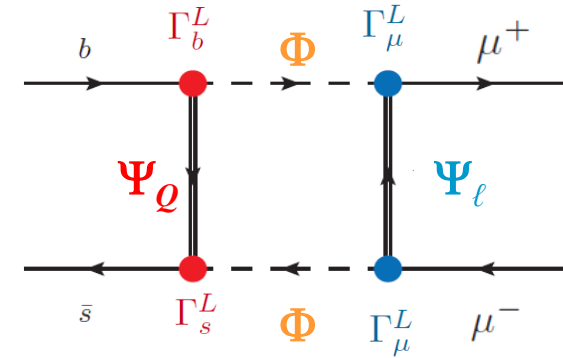
no additional sources of  $SU(2)_L$ -breaking:

- ▶ corrections to  $Z \rightarrow \mu^+ \mu^-$  proportional to  $m_Z^2/m_{\text{NP}}^2$ :  
1-2 orders of magn. below the sensitivity of LEP for  
 $m_{\text{NP}} \gtrsim 1 \text{ TeV}$

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



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



□ *F-model (fermion mediator)*

$\Phi_Q$	$\Phi_L$	$\Psi$
$(\mathbf{3}, \mathbf{2}, 7/6)$	$(\mathbf{1}, \mathbf{2}, 1/2)^*$	$(\mathbf{1}, \mathbf{1}, -1)$
$(\mathbf{3}, \mathbf{2}, 1/6)$	$(\mathbf{1}, \mathbf{2}, -1/2)^*$	$(\mathbf{1}, \mathbf{1}, 0)^*$
$(\mathbf{1}, \mathbf{2}, 1/2)^*$	$(\bar{\mathbf{3}}, \mathbf{2}, -1/6)$	$(\mathbf{3}, \mathbf{1}, -1/3)$
$(\mathbf{1}, \mathbf{2}, -1/2)^*$	$(\bar{\mathbf{3}}, \mathbf{2}, -7/6)$	$(\mathbf{3}, \mathbf{1}, 2/3)$
$(\mathbf{3}, \mathbf{1}, 2/3)$	$(\mathbf{1}, \mathbf{1}, 0)^*$	$(\mathbf{1}, \mathbf{2}, -1/2)$
$(\mathbf{1}, \mathbf{1}, 0)^*$	$(\bar{\mathbf{3}}, \mathbf{1}, -2/3)$	$(\mathbf{3}, \mathbf{2}, 1/6)$
$(\mathbf{3}, \mathbf{3}, 5/3)$	$(\mathbf{1}, \mathbf{3}, 1)^*$	$(\mathbf{1}, \mathbf{2}, -3/2)$
$(\mathbf{3}, \mathbf{3}, 2/3)$	$(\mathbf{1}, \mathbf{3}, 0)^*$	$(\mathbf{1}, \mathbf{2}, -1/2)$
$(\mathbf{3}, \mathbf{3}, -1/3)$	$(\mathbf{1}, \mathbf{3}, -1)^*$	$(\mathbf{1}, \mathbf{2}, 1/2)$
$(\mathbf{1}, \mathbf{3}, 1)^*$	$(\bar{\mathbf{3}}, \mathbf{3}, 1/3)$	$(\mathbf{3}, \mathbf{2}, -5/6)$
$(\mathbf{1}, \mathbf{3}, 0)^*$	$(\bar{\mathbf{3}}, \mathbf{3}, -2/3)$	$(\mathbf{3}, \mathbf{2}, 1/6)$
$(\mathbf{1}, \mathbf{3}, -1)^*$	$(\bar{\mathbf{3}}, \mathbf{3}, 5/3)$	$(\mathbf{3}, \mathbf{2}, 7/6)$

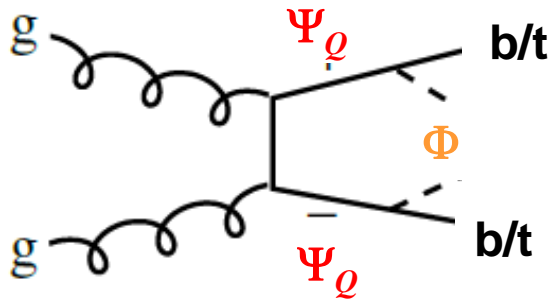
□ *S-model (scalar mediator)*

$\Psi_Q$	$\Psi_L$	$\Phi$
$(\mathbf{3}, \mathbf{2}, 1/6)$	$(\mathbf{1}, \mathbf{2}, -1/2)$	$(\mathbf{1}, \mathbf{1}, 0)^*$
$(\mathbf{3}, \mathbf{1}, 2/3)$	$(\mathbf{1}, \mathbf{1}, 0)^*$	$(\mathbf{1}, \mathbf{2}, -1/2)^*$
$(\mathbf{3}, \mathbf{1}, -1/3)$	$(\mathbf{1}, \mathbf{1}, -1)$	$(\mathbf{1}, \mathbf{2}, 1/2)^*$
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$(\mathbf{3}, \mathbf{3}, -1/3)$	$(\mathbf{1}, \mathbf{3}, -1)$	$(\mathbf{1}, \mathbf{2}, 1/2)^*$
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$(\mathbf{3}, \mathbf{2}, 7/6)$	$(\mathbf{1}, \mathbf{2}, 1/2)$	$(\mathbf{1}, \mathbf{3}, -1)^*$
$(\mathbf{3}, \mathbf{2}, 1/6)$	$(\mathbf{1}, \mathbf{2}, -1/2)$	$(\mathbf{1}, \mathbf{3}, 0)^*$
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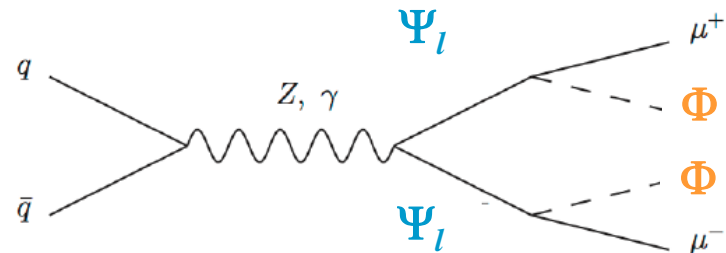
# Linking $b \rightarrow s \mu \mu$ anomalies to DM in loop models

## ❖ Collider Signatures

For  $M_\Phi < M_\Psi$



“Sbottom-like” production  
 **$bb/(tt) + MET$**

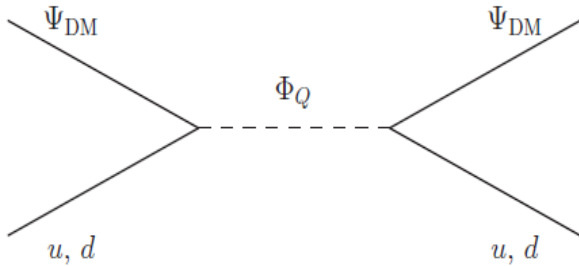


“Slepton-like” production  
 **$\mu\mu + MET$**

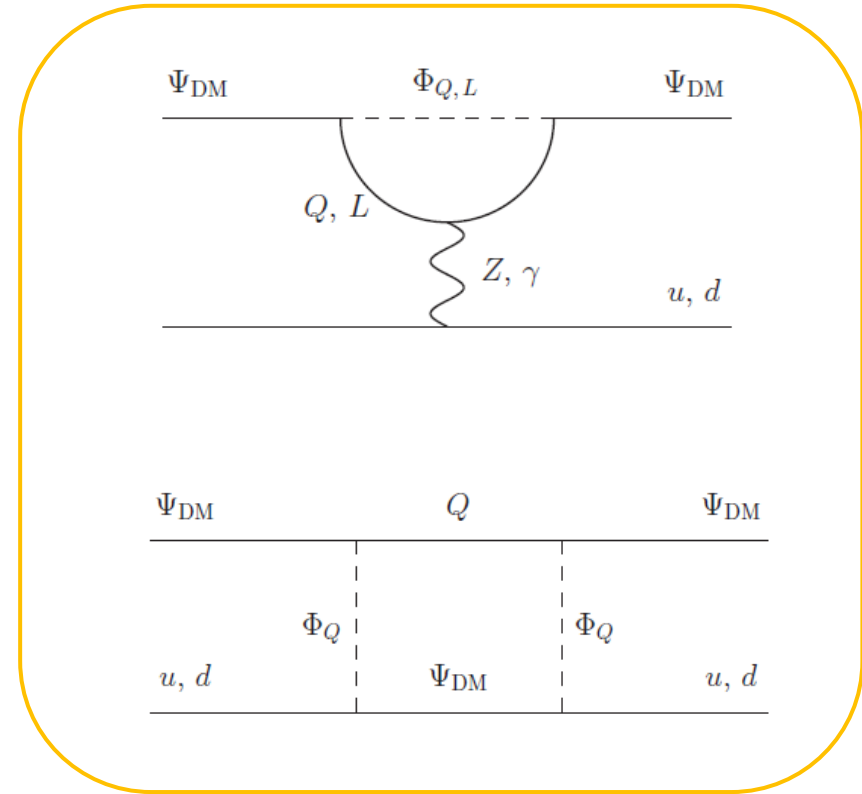
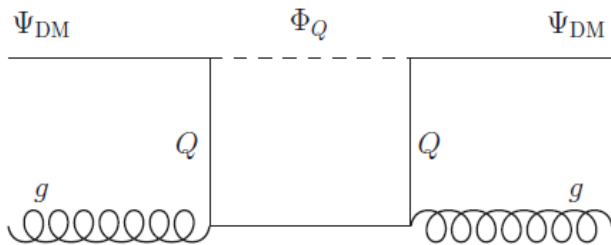
**Bounds from direct searches at LHC of sbottoms/sleptons, neutralinos & charginos.**

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

## ❖ DM Direct Detection



CKM suppressed  
(coupling with 1st generation absent)

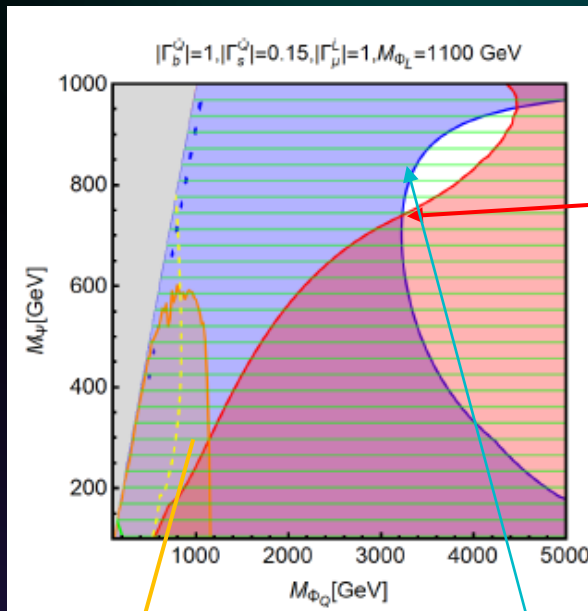


*Absent for Real and Majorana DM*

**Bounds from direct detection of WIMPs at the Xenon**

## Dirac DM

substantially ruled out by  
Direct Detection



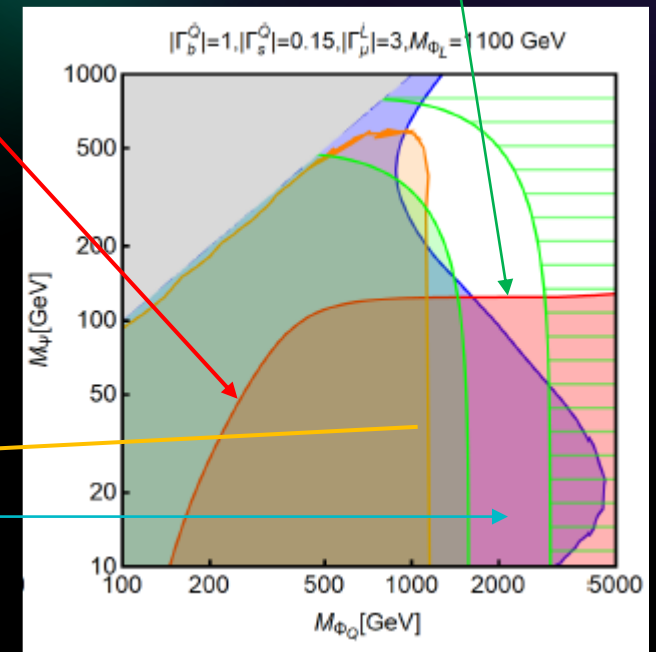
LHC excluded

XENON1T Excluded

## Majorana DM



☺ Viable fit of flavor anomalies



$\Omega h^2 > 0.12$

# Summary

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


$$b \rightarrow s \mu^+ \mu^-$$



*Solutions by dark loops  
link between DM and  
 $B$ -anomalies*

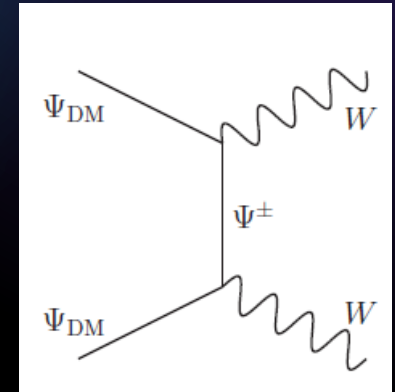
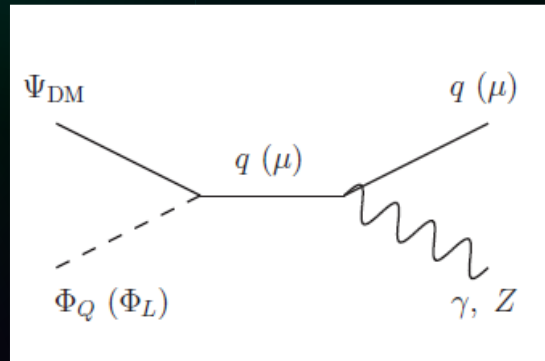
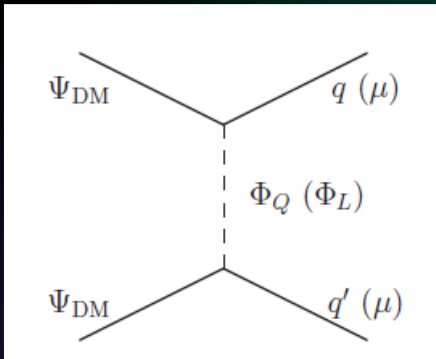
- ❖ Viable explanation of  $B$ -anomalies and thermal WIMP DM possible but:
  1. Real scalar and Majorana fermion DM favored to avoid DM Direct Detection.
  2. Singlet DM preferred to higher EW multiplet, since  $B$ -anomalies compatible to DM sensitively below the TeV.
  3. Sizable coupling with muon favored to have efficient enough annihilation.



Thanks

# Relic Density

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



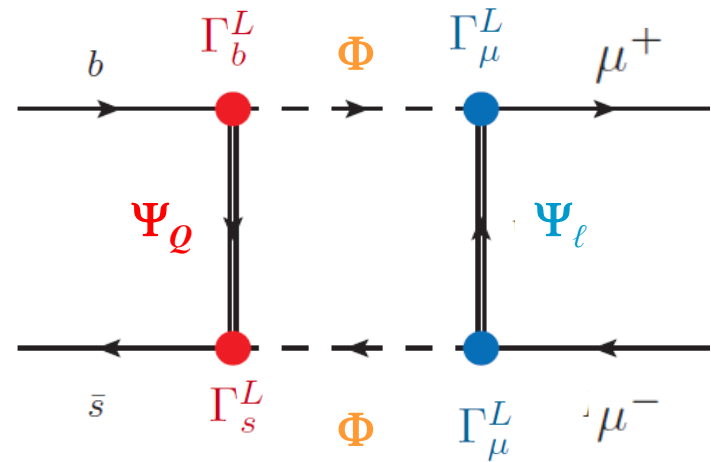
Present only if DM is part of SU(2) multiplet

# Explaining $b \rightarrow s \mu^+ \mu^-$ by box effects: $B_s - \bar{B}_s$ mixing

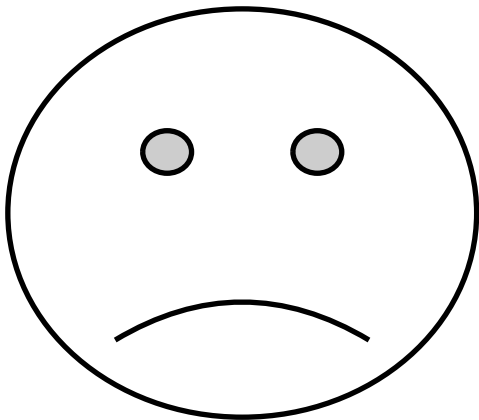
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(or vice versa)



## ⊗ Strongest constraint $B_s - \bar{B}_s$ mixing



Di Luzio, Kirk and Lenz '18