Flavor anomalies from a split dark sector

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Beyond Standard Model: From Theory to Experiment

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NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

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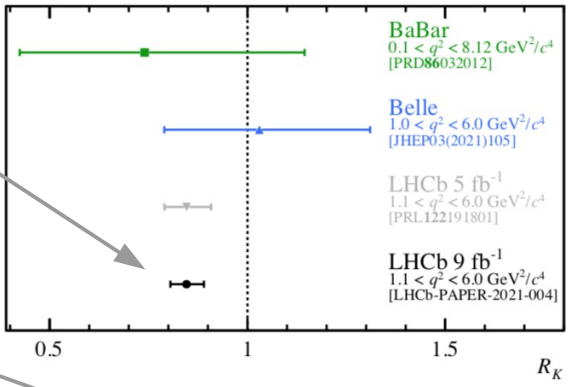
Flavor anomalies in b → s

- **lepton-flavor universality violation (LHCb: 3.1 σ)**

$$R_K = \frac{\mathrm{BR}(B^+ \to K^+\mu^+\mu^-)}{\mathrm{BR}(B^+ \to K^+e^+e^-)}$$

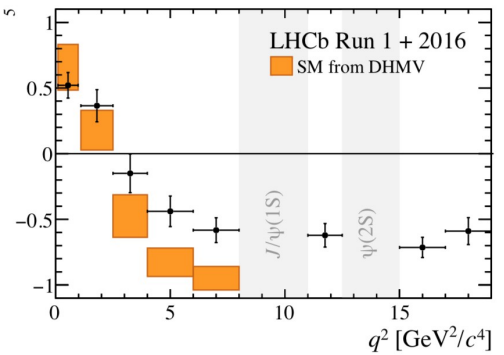
$$R_{K^*} = \frac{\mathrm{BR}(B^0 \to K^{0*}\mu^+\mu^-)}{\mathrm{BR}(B^0 \to K^{0*}e^+e^-)}$$

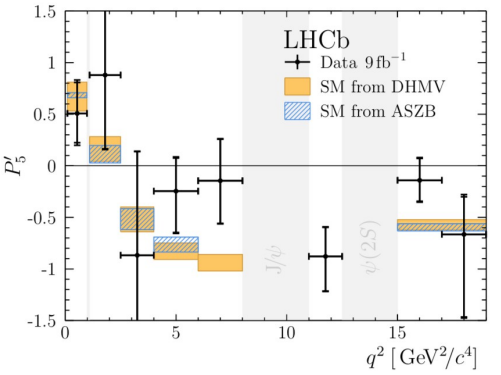
New result last week!



- **deviations in angular observables (LHCb, CMS: ~ 3 σ)**

$$B^0 \to K^{0*}\mu^+\mu^- \qquad B^+ \to K^{*+}\mu^+\mu^-$$



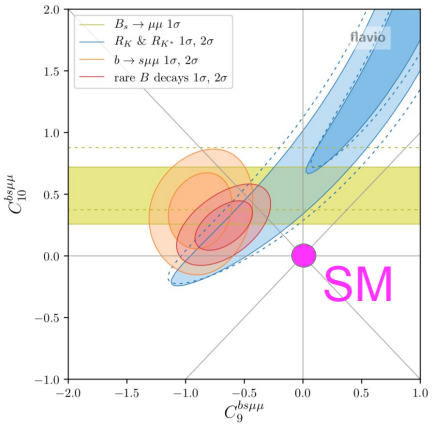


- **deviations in *b-s* mu mu branching ratios (LHCb: 2 - 3.5 σ)**

- **Strong preference for NP**

$$\mathcal{O}_9^{\mu\,(\prime)} = \frac{\alpha_{\mathrm{em}}}{4\pi}\left(\bar{s}\gamma_\rho P_{L(R)}b\right)\left(\bar{\mu}\gamma^\rho\mu\right),$$

$$\mathcal{O}_{10}^{\mu\,(\prime)} = \frac{\alpha_{\mathrm{em}}}{4\pi}\left(\bar{s}\gamma_\rho P_{L(R)}b\right)\left(\bar{\mu}\gamma^\rho\gamma^5\mu\right)$$



$$C_9^\mu = -C_{10}^\mu = -0.43 \pm 0.07$$

(Altmannshofer, Stangl, 2103.13370)

… Here we look at explanations with light states (~ GeV or less) …

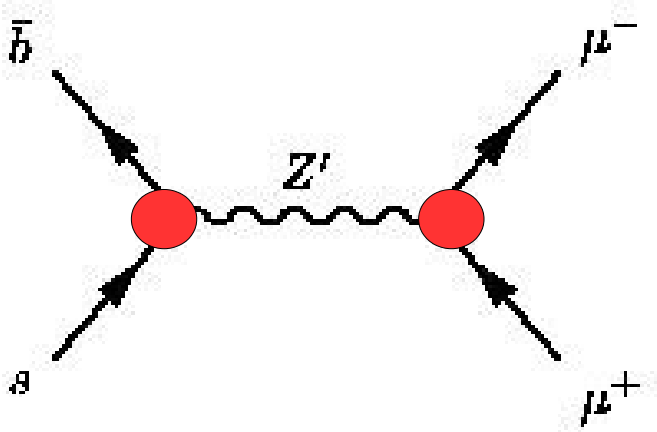
Literature

Sala and Straub 1704.06188

Alok *et al.* 1704.07397

Datta, Kumar, Liao, Marfatia 1702.01099, 1705.08423

Altmannshofer *et al.* 1711.07494



Sample solutions:

$$m_{Z'} \approx 2.5\,\text{GeV}$$

$$g_{bs} = 1.5 \times 10^{-8}$$

$$g_\mu^V \approx -0.44\, g_\mu^A = 10^{-2} - 10^{-1}$$

$$\Gamma_{Z'}/m_{Z'} > 10\% \quad \text{(1704.06188)}$$

$$m_{Z'} \approx 10\,\text{GeV}$$

$$g_{bs} \approx 5 \times 10^{-6}$$

$$g_\mu^V \approx 10^{-2} \quad \text{(1704.07397)}$$

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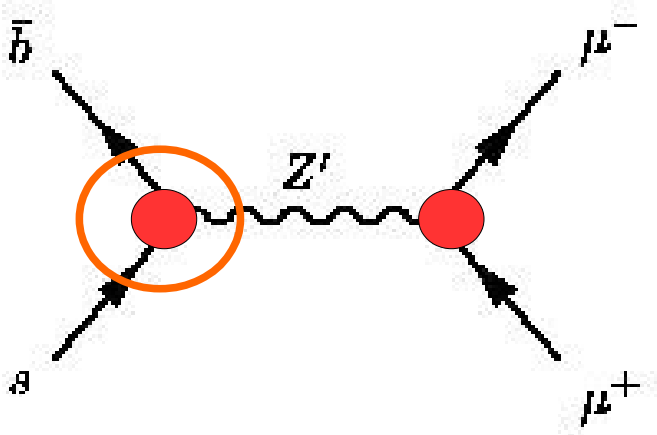

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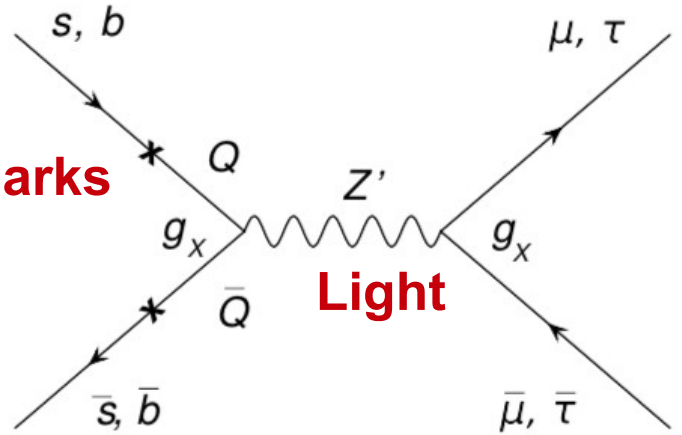
There must be a particle(s) with color integrated out ...

… A "split" BSM sector?

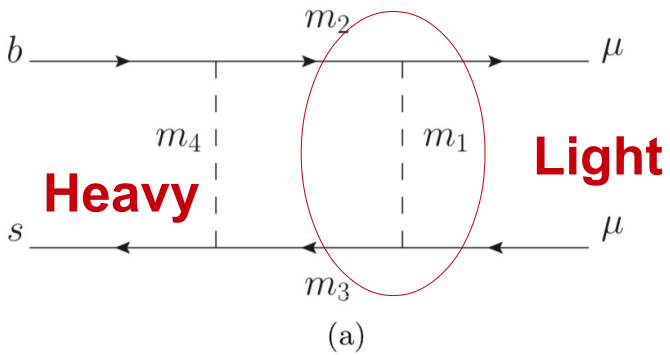
A split BSM sector

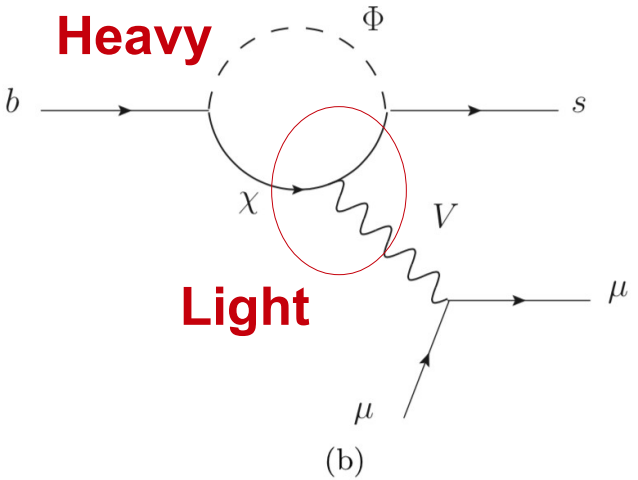
1. Tree level



Heavy VL quarks

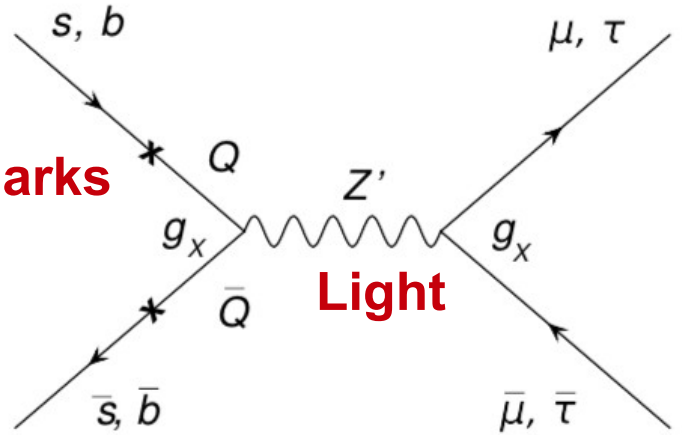
2. Loop level





A split BSM sector

1. Tree level

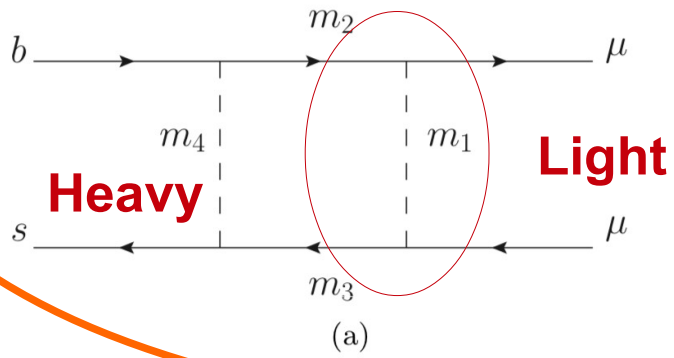


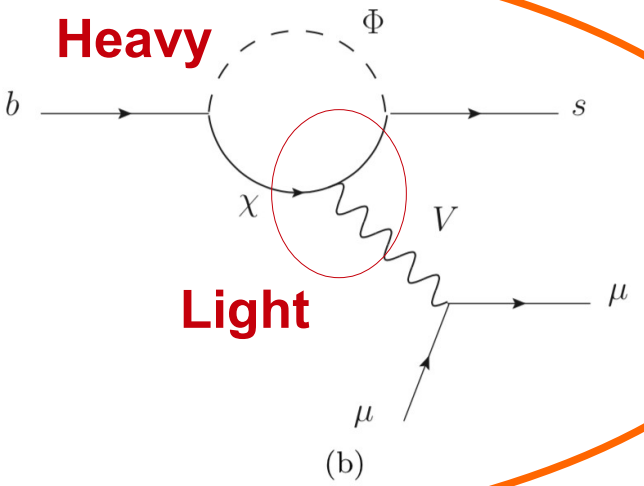
Heavy VL quarks

Light

2. Loop level

This work!





A split BSM sector

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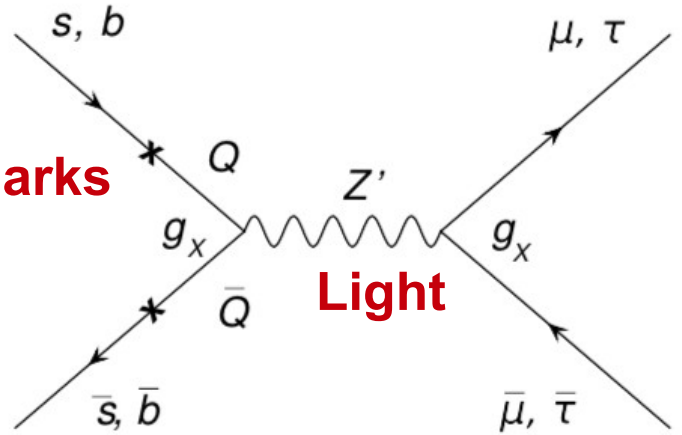
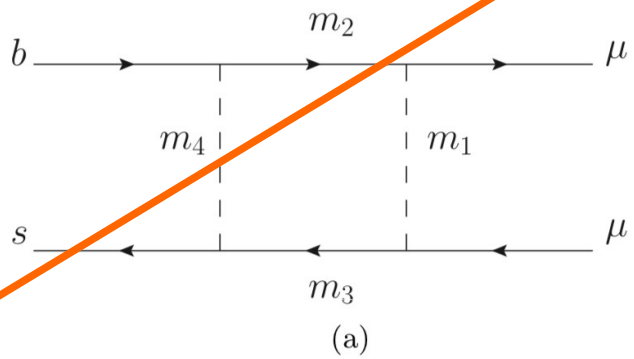


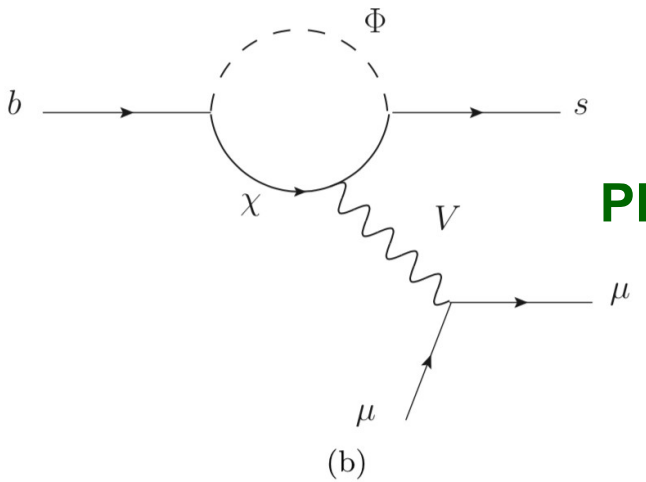
Heavy VL quarks

Light

2. Loop level

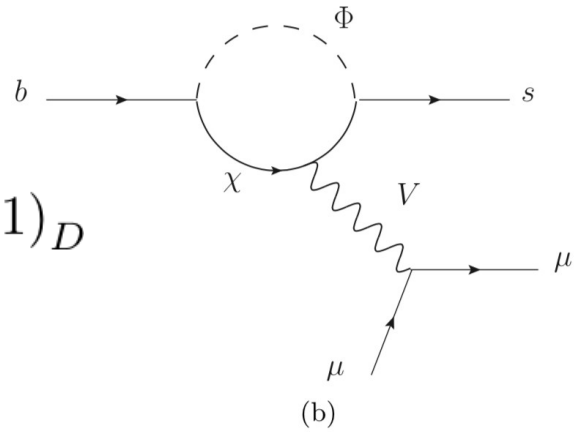
BOX: Light states 1,2,3
excluded by G-2 muon





PENGUIN OK!

Penguin diagram



New dark U(1) gauge: $\mathrm{SU}(3)_c \times \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y \times \mathrm{U}(1)_D$

New U(1)-charged particles: $\Phi : (\mathbf{3}, \mathbf{2}, 1/6, Q_\Phi)$

$\chi : (\mathbf{1}, \mathbf{1}, 0, -Q_\Phi)$

Lagrangian terms: $\mathcal{L} \supset y_{s(b)} \phi^* \bar{\chi} P_L s(b) + \mathrm{H.c.}$

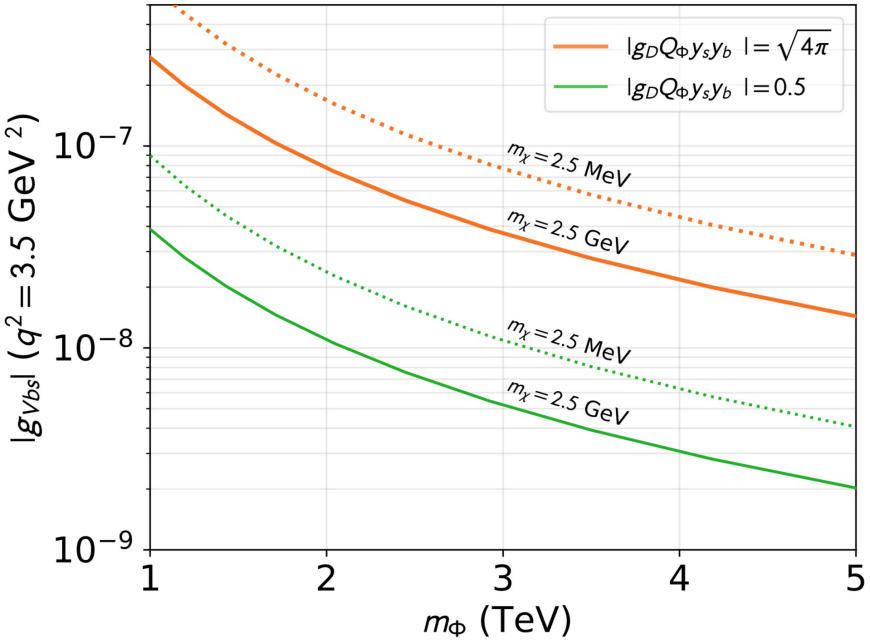
$\mathcal{L} \supset \left(g_\mu^V \bar{\mu} \gamma_\nu \mu + g_\mu^A \bar{\mu} \gamma_\nu \gamma_5 \mu \right) V^\nu$

It gives a q^2-dependent coupling:

$$g_{Vbs} \equiv -\tilde{g}\, q^2$$

where

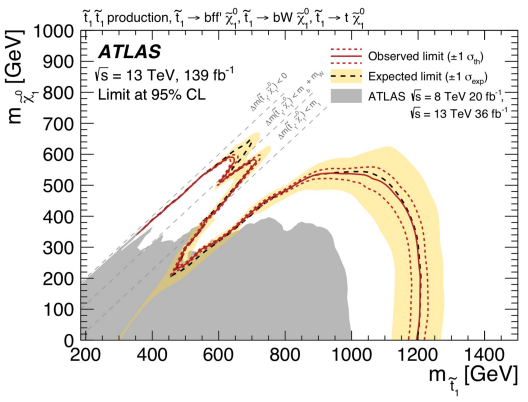
$$\tilde{g} = -\frac{g_D\, Q_\Phi}{16\pi^2 m_\Phi^2} \sum_i y_s^{i*} y_b^i \mathcal{F}(x_i)$$

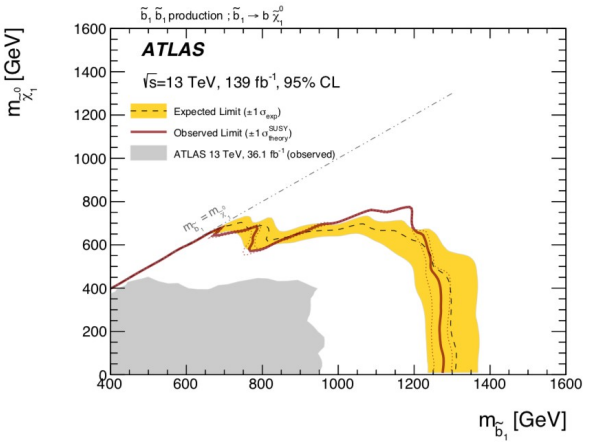


Most important constraints

- **On the scalar with color:**

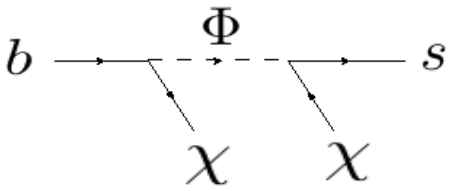
$$m_\Phi \gtrsim 1.2\,\mathrm{TeV}$$





- **On the singlet fermion:**

$$\Gamma_{B\to K\chi\chi} \approx \frac{f_+^2 |y_s|^2 |y_b|^2}{1536\pi^3} \frac{M_B^5}{m_\Phi^4}$$



$$\mathrm{BR}(B \to K^{*0}\,\bar{\nu}\nu)_{\mathrm{exp}} < 1.8 \times 10^{-5} \quad \Longrightarrow \quad |y_s^* y_b| \lesssim 10^{-2}\,(m_\Phi/\mathrm{TeV})^2$$

Too small !

Therefore we need... $m_\chi > \dfrac{M_B - M_K}{2} \approx 2.5\,\mathrm{GeV}$

- **On the *V* width:** $\Gamma_{V\to\mu\mu} + \Gamma_{V\to\chi'\chi'} + \ldots$

– Bin dependent numerical recast of differential $dBR(B \to K^{(*)}\nu\nu)$ at BaBar (1303.7464)
– Search for hidden sector bosons $B \to K^*\mu^+\mu^-$ at LHCb (1508.04094)

Fit results (*mV* region no. 1)

Global fit to

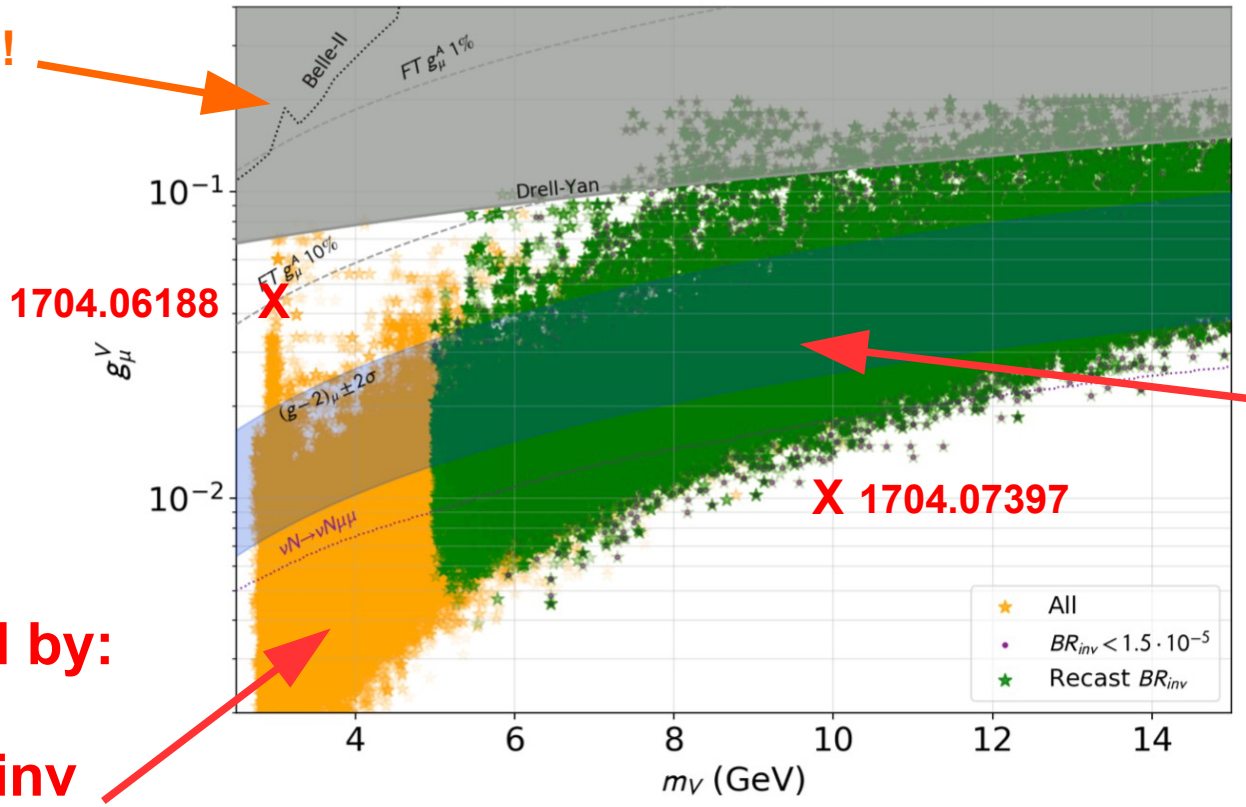
RK , ***RK**** , ***B → K* μ μ*** (*ang. observ.*) , ***Bs → μ μ*** , ***(g-2) μ***

with

$m_\Phi = 1\,\mathrm{TeV}$

$m_\chi = 2.5\,\mathrm{GeV}$

More data coming soon!



1704.06188 X

X **1704.07397**

Green is OK

No FT to fit g-2!

Excluded by:

B → K* + inv

B → K* μ μ

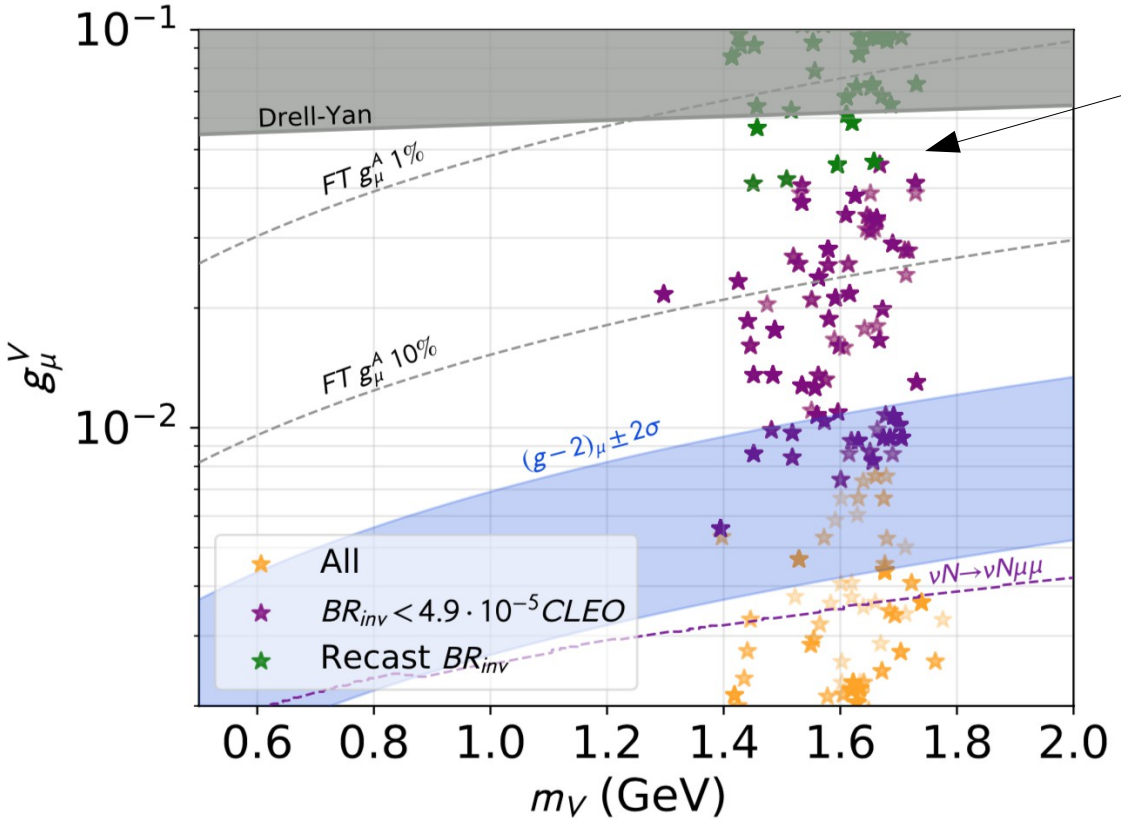
Fit results (*mV* region no. 2)

Global fit to

RK , ***RK**** , ***B → K* μ μ*** (*ang. observ.*) , ***Bs → μ μ*** , ***(g-2) μ***

with

$$m_\Phi = 1\,\mathrm{TeV}$$
$$m_\chi = 2.5\,\mathrm{GeV}$$



Limited number of viable points

(Some tension *Bs → μ μ* vs. *RK*, *RK**)**

Bonus feature if $m_{\chi_0} < m_\mu$:

Chi_0 is *forbidden dark matter* (*e.g.* D'Agnolo, Ruderman, 1505.07107)

$$\chi_0 \bar{\chi}_0 \to V^* \to \mu\bar{\mu}.$$

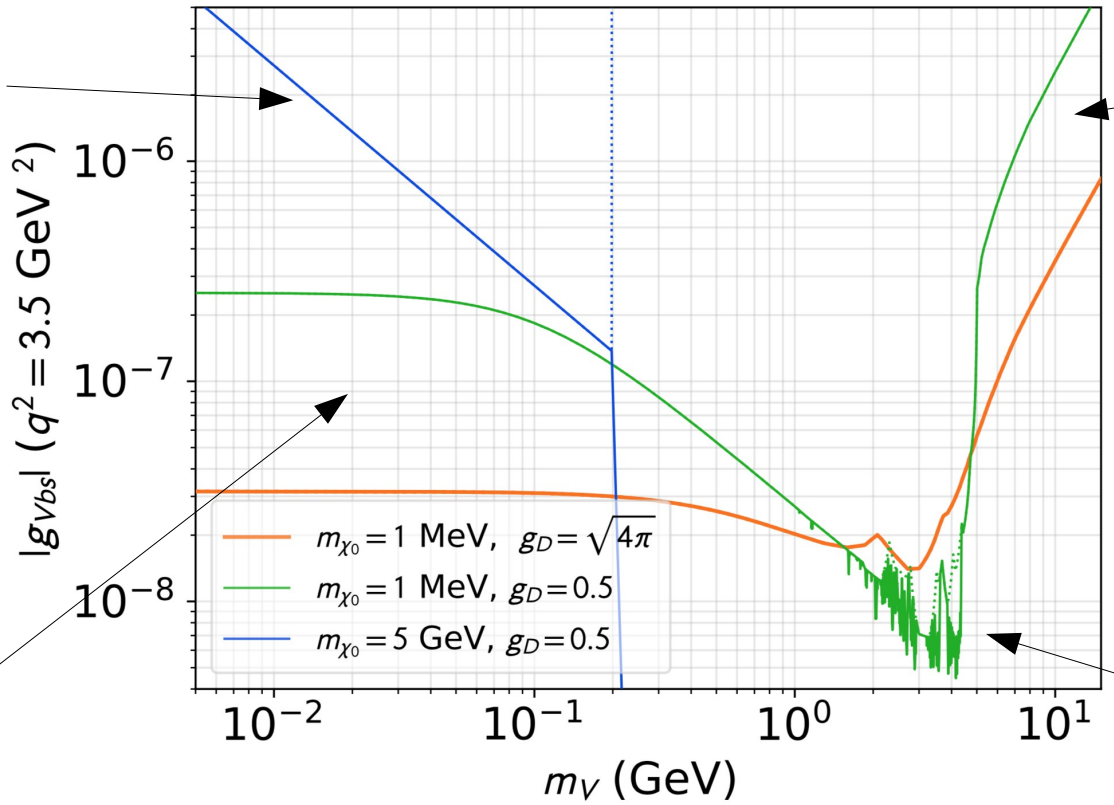
To take home

- In a “split” BSM sector the *b-s* interaction is generated *at the loop level* via Yukawa couplings of the heavy and light states, and a dark U(1) gauge group
- It naturally gives rise to a q^2 dependent effective coupling
- Constraints arise at the high and low scale. Flavor bounds from $B \to K$ + inv. and resonant $B \to K^*$ *mu+ mu-* imposed bin-by-bin
- The model fits to muon *(g-2)* with no FT of the couplings, and admits a DM candidate
- New data sets at Belle 2 poised to improve the bounds soon.

Backup

Numerical constraints

Upper bound on g_{Vbs} *as function of V mass* :



$\mathrm{BR}(B \to KV)$

$\mathrm{BR}(B \to K\chi_0\chi_0)$

$\mathrm{BR}(B \to K\chi_0\chi_0)$

$\mathrm{BR}(B \to K^*\mu^+\mu^-)$

More hints for BSM physics

- Deviations in differential branching ratios $\frac{d\mathrm{BR}}{dq^2}$ (LHCb, 2 σ – 3.5 σ)

$$B^0 \to K^{*0}\mu^+\mu^-$$
$$B^0 \to K^0\mu^+\mu^-$$
$$B^+ \to K^{*+}\mu^+\mu^-$$
$$B_s^0 \to \phi\mu^+\mu^-$$
$$\Lambda_b^0 \to \Lambda\,\mu^+\mu^-$$