

Flavor anomalies from a split dark sector

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in collaboration with
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JHEP 2008 (2020) 148 (arXiv: 2002.11150)
arXiv: 2105.XXXXX

XIV PPC International Workshop

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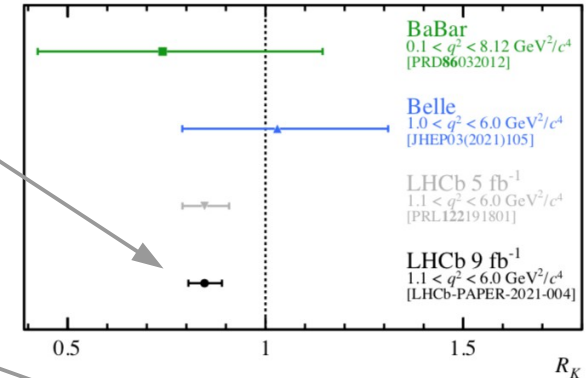
Flavor anomalies in $b \rightarrow s$

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

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

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

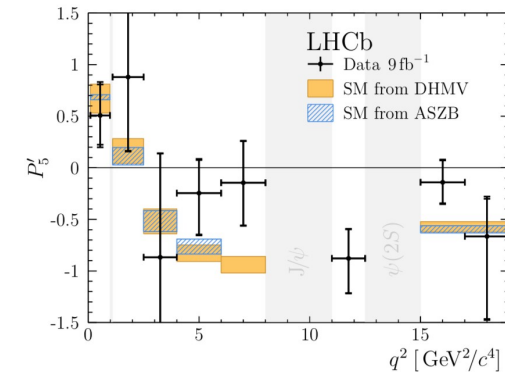
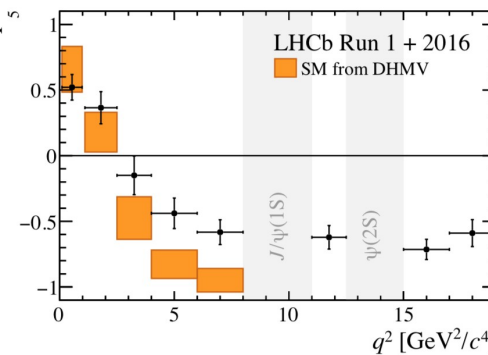
Updated March 2021!



- deviations in angular observables (LHCb, CMS: $\sim 3 \sigma$)

$$B^0 \rightarrow K^{0*} \mu^+ \mu^- \quad B^+ \rightarrow K^{*+} \mu^+ \mu^-$$

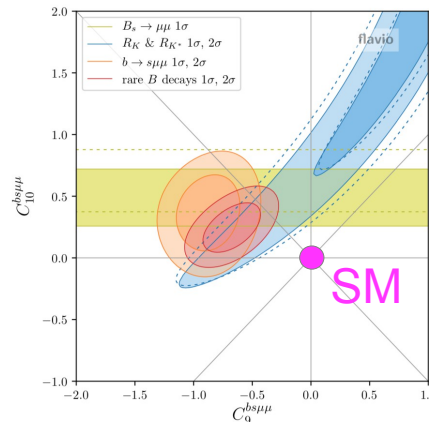
- deviations in b -s mu mu branching ratios (LHCb: 2 - 3.5 σ)



- Strong preference for NP**

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

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



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

(Altmannshofer, Stangl, 2103.13370)

Muon g-2 experiment

Measured value at BNL (2006):

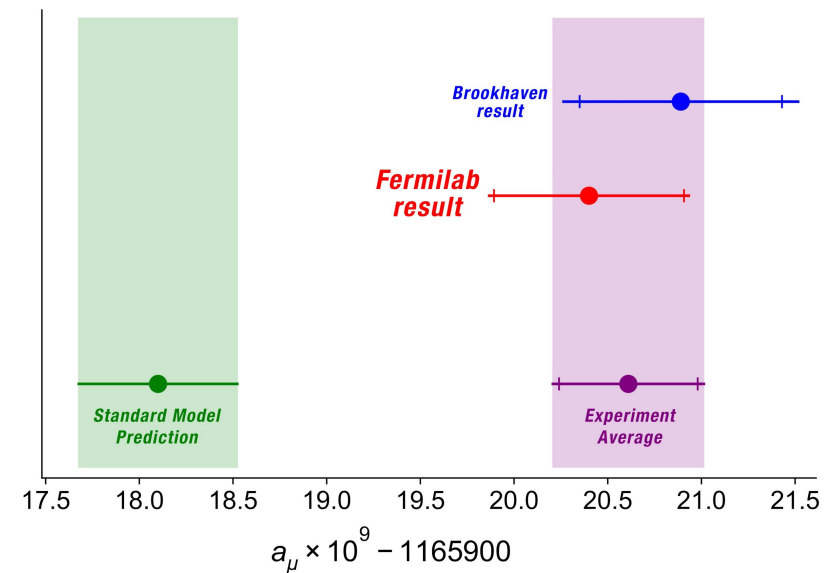
Bennet *et al*, Phys. Rev. D 73 (2006) 072003 (hep-ex/0602035)

$$a_{\mu}^{\text{BNL}} = (116592089 \pm 63) \times 10^{-11}$$

Measured value at FNAL (2021):

Muon g-2 Collaboration, Phys. Rev. Lett. 126 (2021) 141801

$$a_{\mu}^{\text{FNAL}} = (116592040 \pm 54) \times 10^{-11}$$



$$\Delta a_{\mu} = (25.1 \pm 5.9) \times 10^{-10}$$

discrepancy at $\sim 4.2 \sigma$!

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

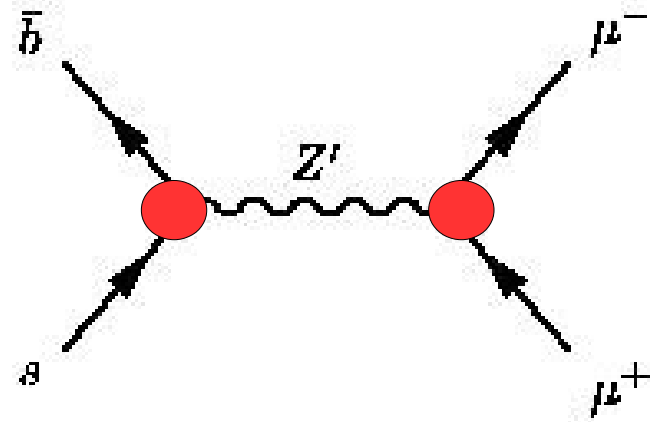
Literature

Sala and Straub 1704.06188

Alok *et al.* 1704.07397

Datta, Kumar, Liao, Marfatia 1702.01099, 1705.08423

Altmannshofer *et al.* 1711.07494



Typical solutions:

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

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

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

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

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

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

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

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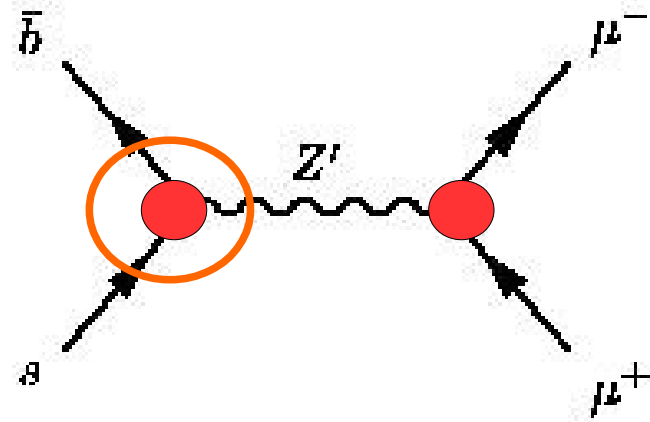
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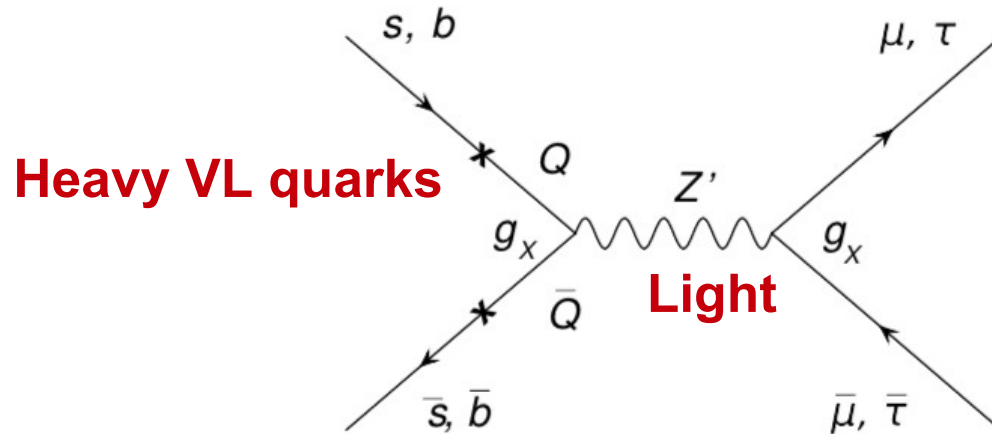
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There must be a particle(s) with color integrated out ...

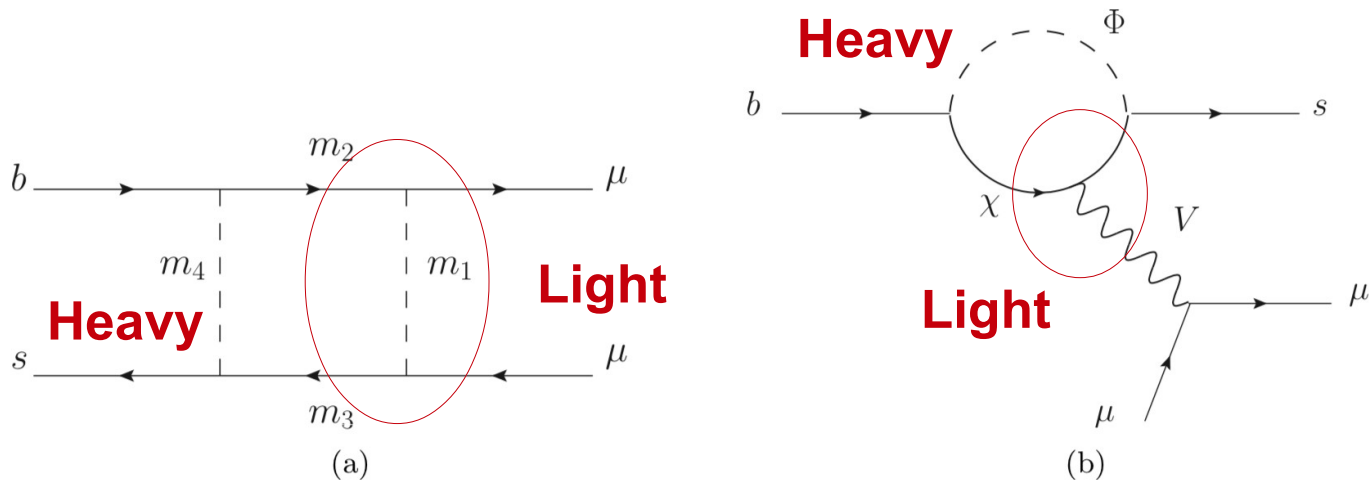
... A “split” BSM sector?

A split BSM sector

1. Tree level

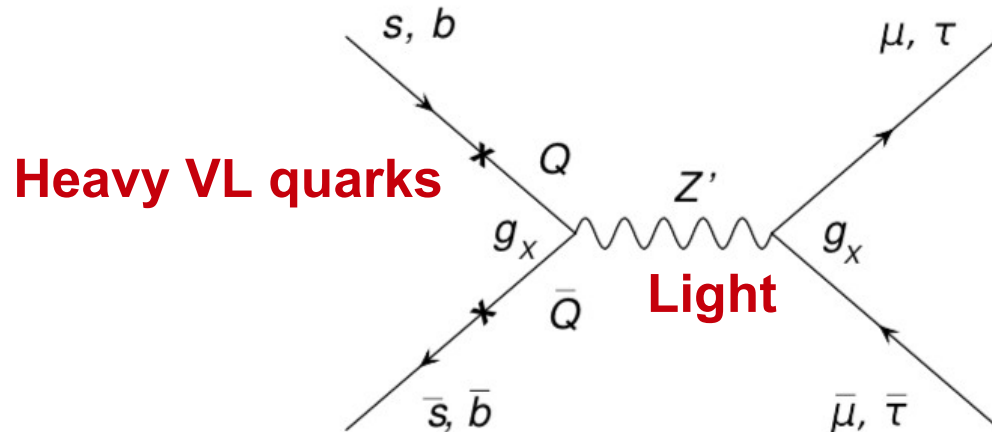


2. Loop level



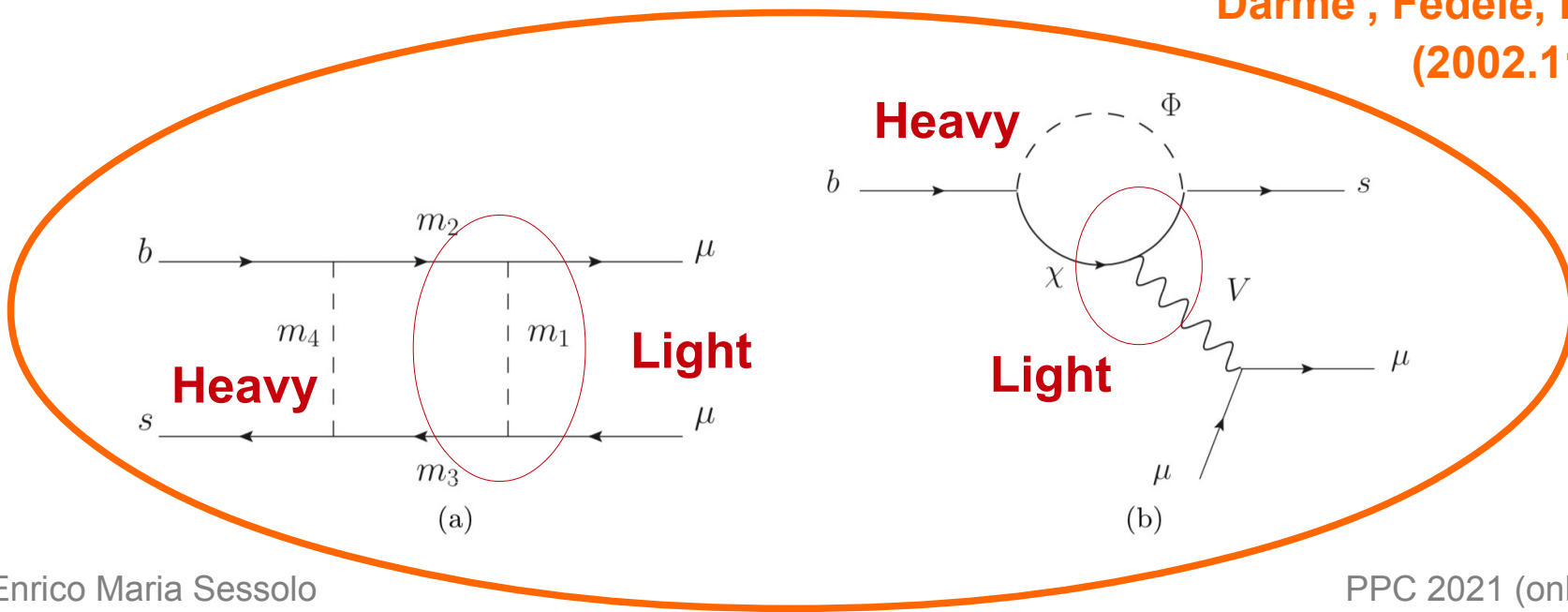
A split BSM sector

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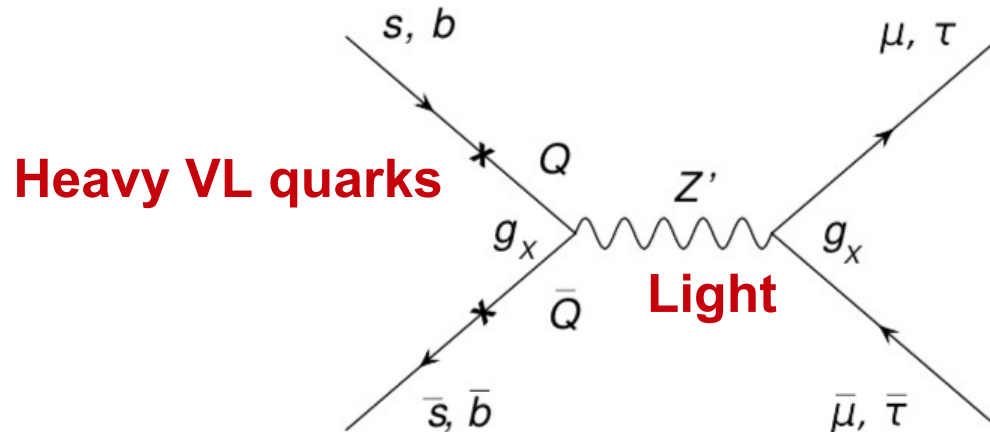
2. Loop level

Darme', Fedele, Kowalska, EMS
(2002.11150)



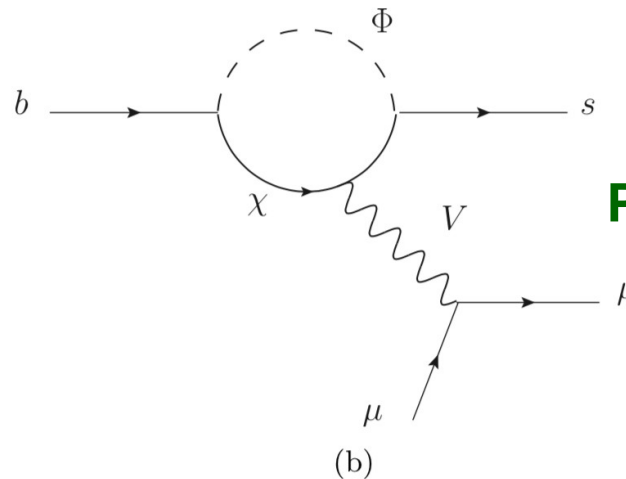
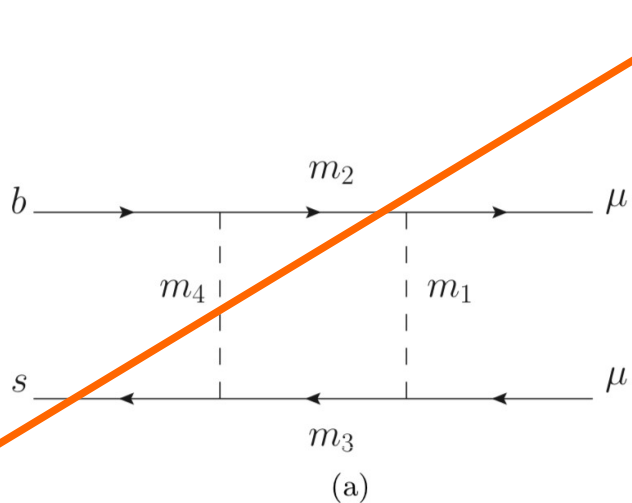
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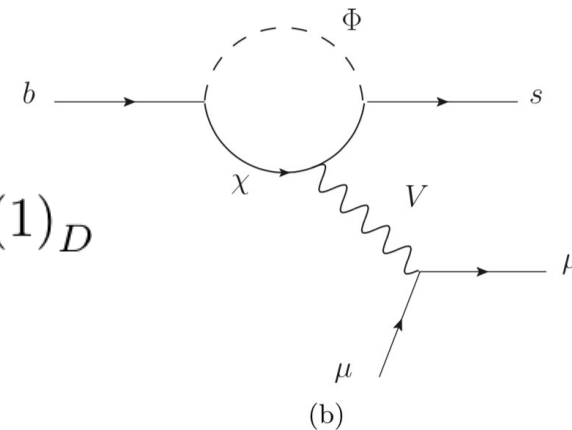
2. Loop level

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



PENGUIN OK!

Penguin diagram



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

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

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

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

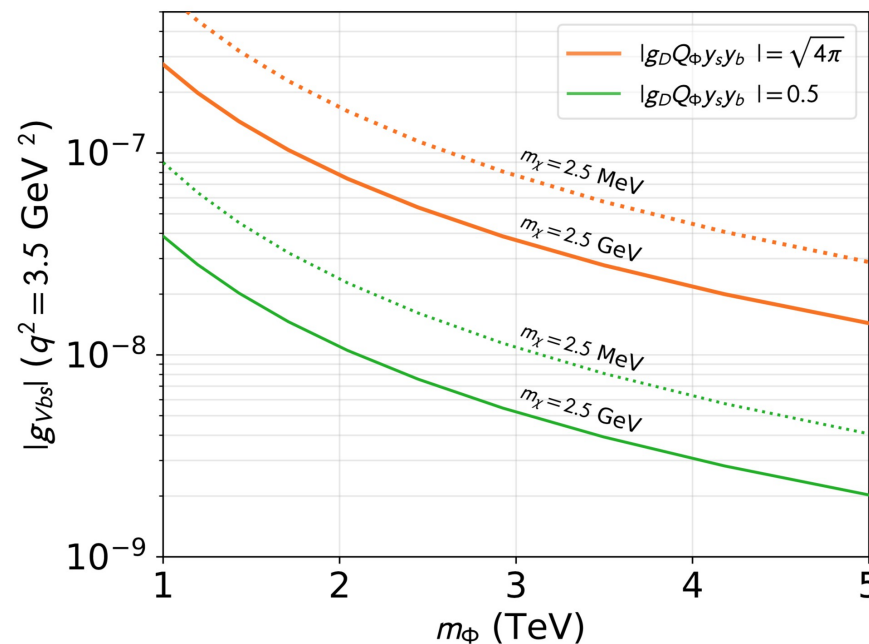
$\mathcal{L} \supset (g_\mu^V \bar{\mu} \gamma_\nu \mu + g_\mu^A \bar{\mu} \gamma_\nu \gamma_5 \mu) V^\nu$

It gives a q^2 -dependent coupling:

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

where

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



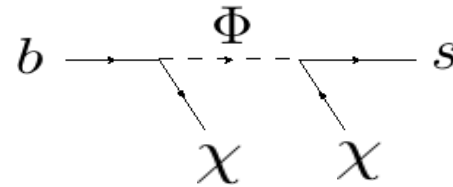
Most important constraints

- On the scalar with color:

$$m_\Phi \gtrsim 1.2 \text{ TeV}$$

- On the singlet fermion:

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



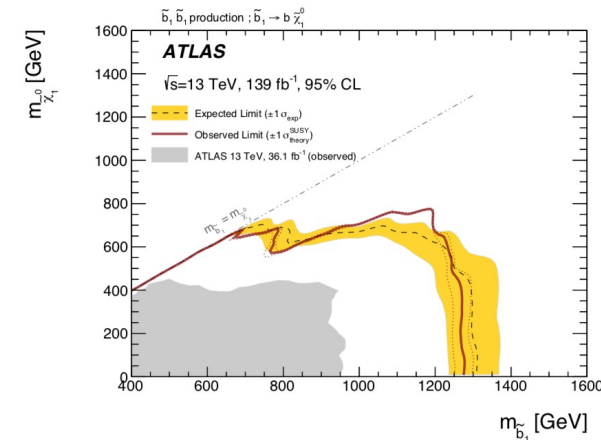
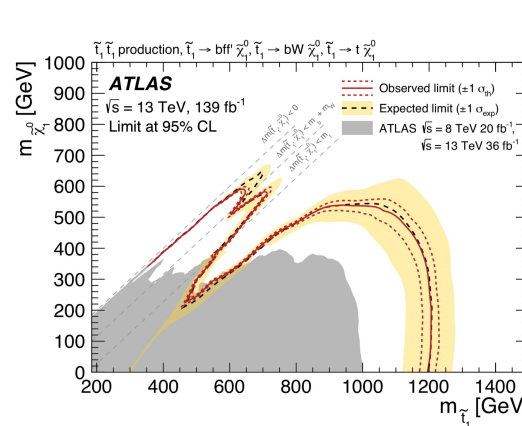
$$\text{BR}(B \rightarrow K^{*0} \bar{\nu} \nu)_{\text{exp}} < 1.8 \times 10^{-5} \quad \Rightarrow \quad |y_s^* y_b| \lesssim 10^{-2} (m_\Phi / \text{TeV})^2$$

Too small !

Therefore we need... $m_\chi > \frac{M_B - M_K}{2} \approx 2.5 \text{ GeV}$

- On the V width: $\Gamma_{V \rightarrow \mu \mu} + \Gamma_{V \rightarrow \chi' \chi'} + \dots$

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



Fit results (m_ν region no. 1)

Global fit to

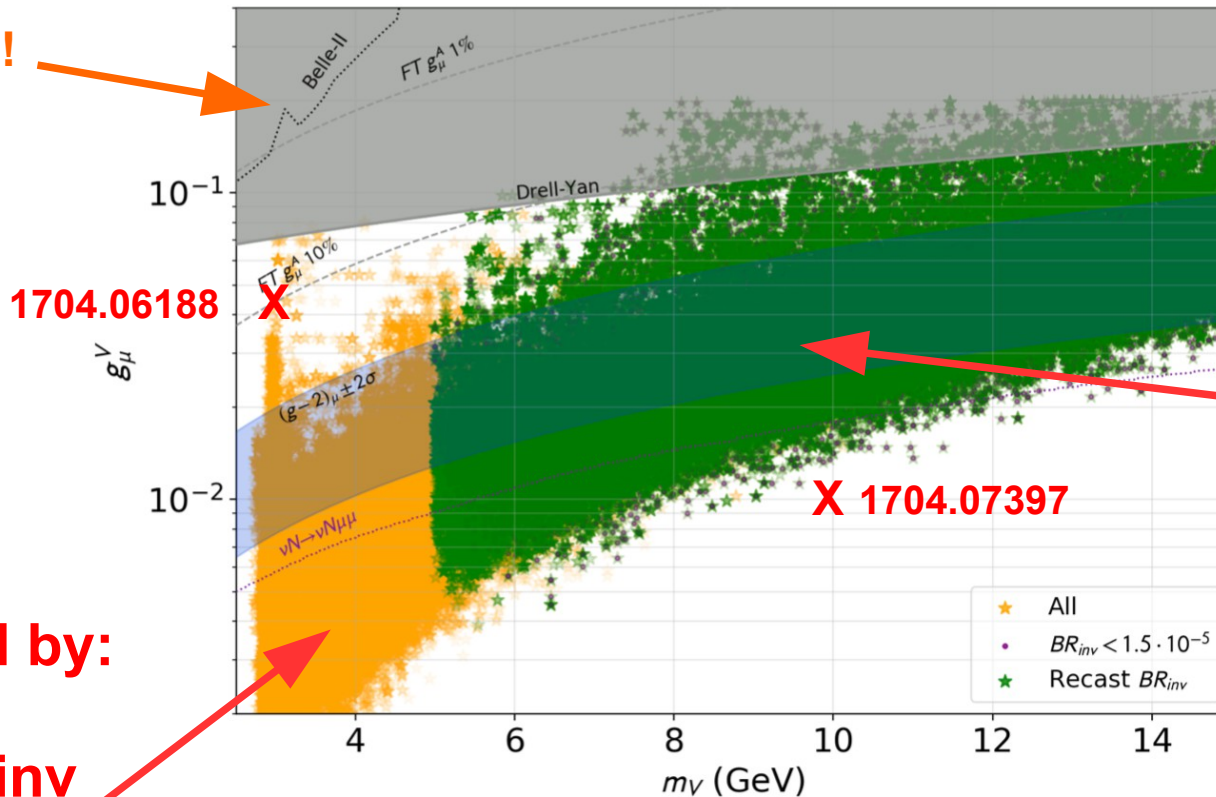
RK , RK^* , $B \rightarrow K^* \mu \mu$ (ang. observ.), $Bs \rightarrow \mu \mu$, $(g-2)_\mu$

with

$$m_\Phi = 1 \text{ TeV}$$

$$m_\chi = 2.5 \text{ GeV}$$

More data coming soon!



Excluded by:

$B \rightarrow K + \text{inv}$
 $B \rightarrow K^* \mu \mu$

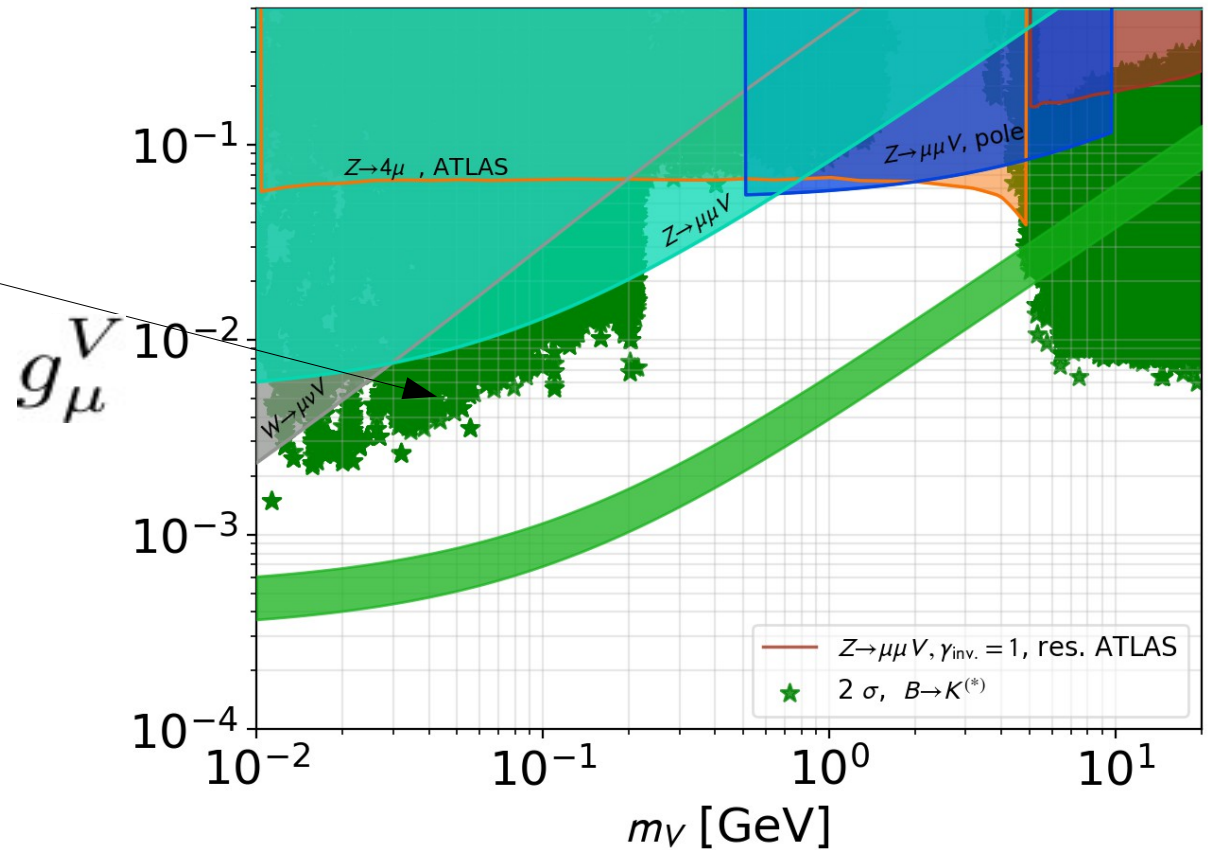
Green is OK

No FT to fit $g-2$!

Fit results (m_V region no. 2)

Darme', Fedele, Kowalska, EMS (2105.xxxxx)

Ultra-light region is very constrained
 ($B \rightarrow K, Bs \rightarrow \mu\mu, W/Z$ width)



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

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

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

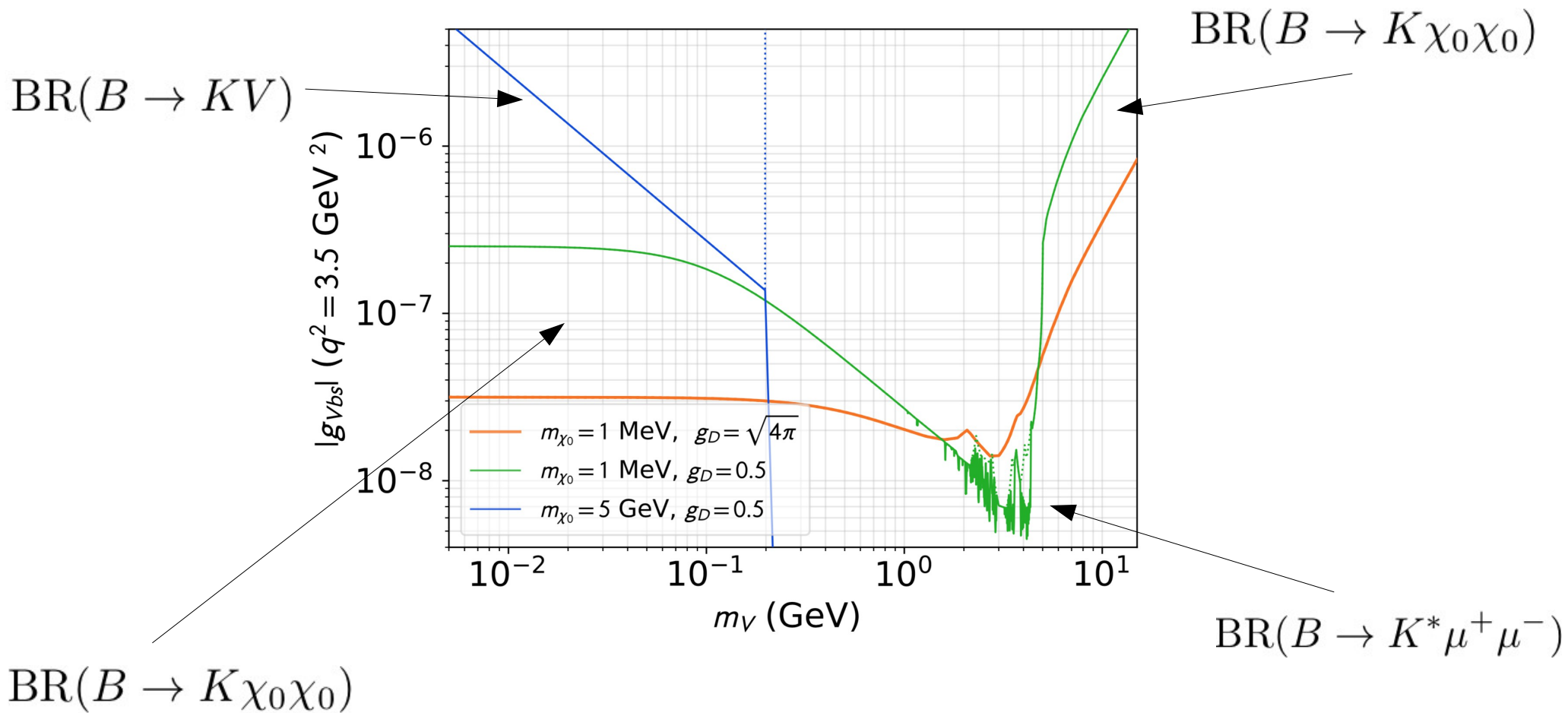
To take home

- 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 $B \rightarrow K + \text{inv.}$ and resonant $B \rightarrow K^* \mu^+ \mu^-$ 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 :



More hints for BSM physics

- Deviations in differential branching ratios $\frac{dB\mathcal{R}}{dq^2}$ (LHCb, $2\sigma - 3.5\sigma$)

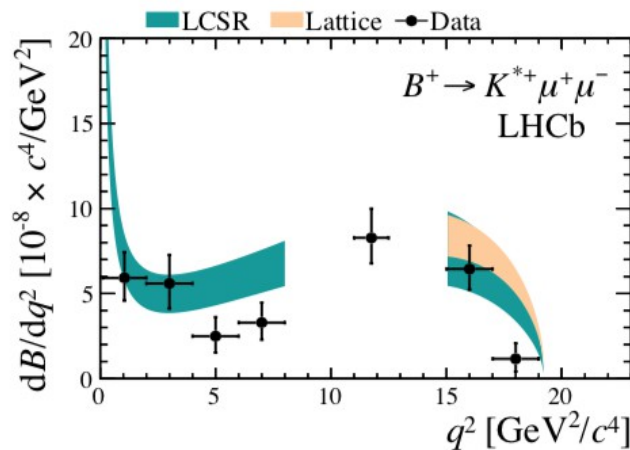
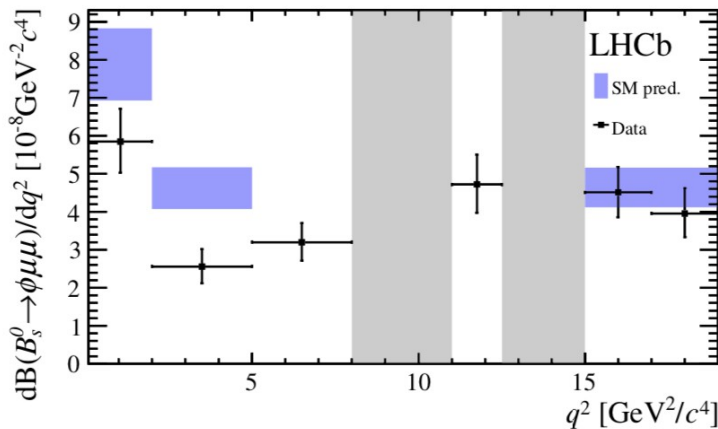
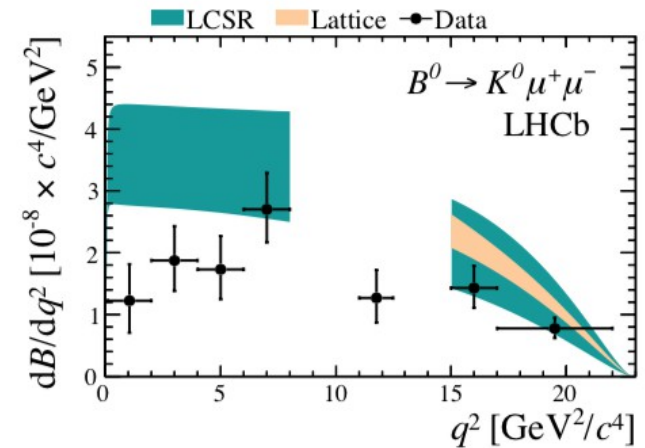
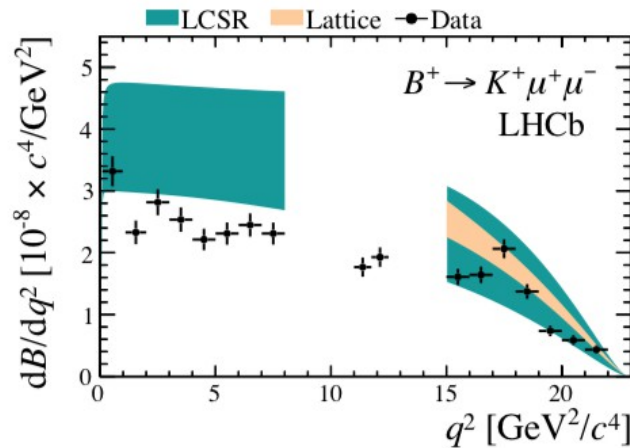
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$$B^+ \rightarrow K^{*+} \mu^+ \mu^-$$

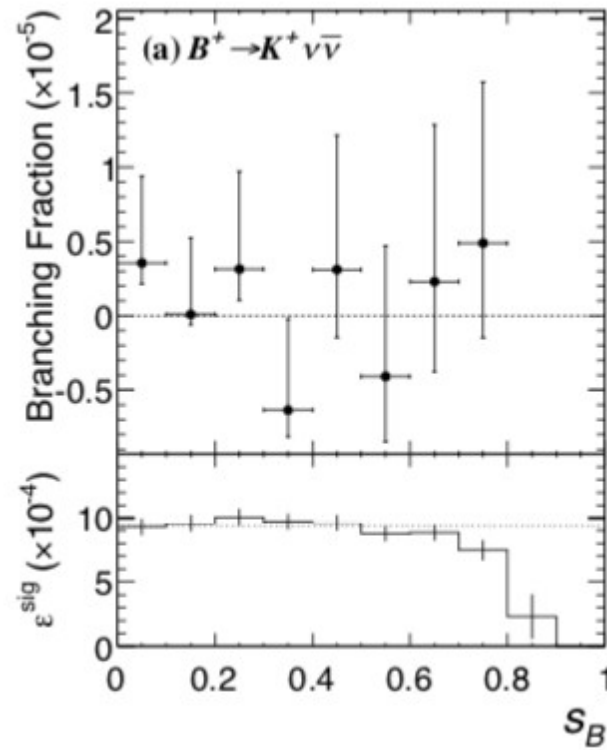
$$B_s^0 \rightarrow \phi \mu^+ \mu^-$$

$$\Lambda_b^0 \rightarrow \Lambda \mu^+ \mu^-$$



B → K bounds

Babar 1303.7465



LHCb 1508.04094

