Kobayashi-Maskawa Institute for the Origin of Particles and the Universe

Impact of the *b to s ll* anomalies on dark matter physics

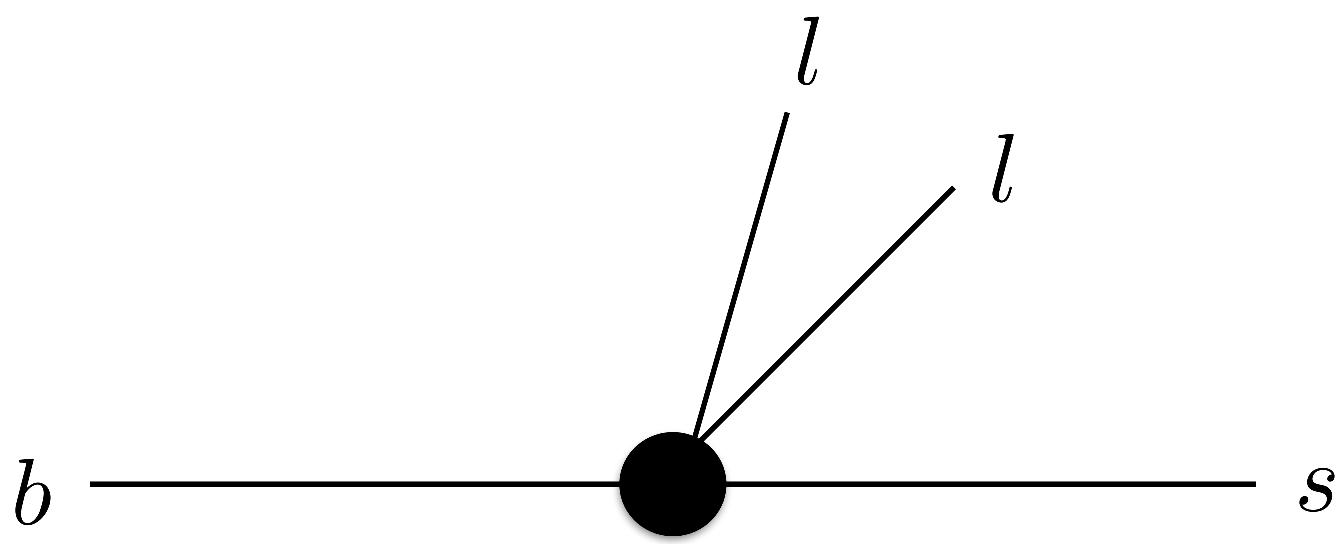
Yuji Omura (KMI, Nagoya)

Based on arXiv:1706.04344

J. Kawamura (U. of Tokyo), S. Okawa (Nagoya U.)

Introduction

My talk is motivated by the excesses in *b to s ll*



Observables

Lepton universality in $B^+ \to K^+ l^+ l^- \ (l = e,\ \mu)$ *(1406.6482)*

Angular analysis of $B_0 \to K_0^* \mu^+ \mu^-$ *(1308.1707; 1512.04442)*

Lepton universality in $B_0 \to K_0^* l^+ l^- \ (l = e,\ \mu)$ @LHCb.

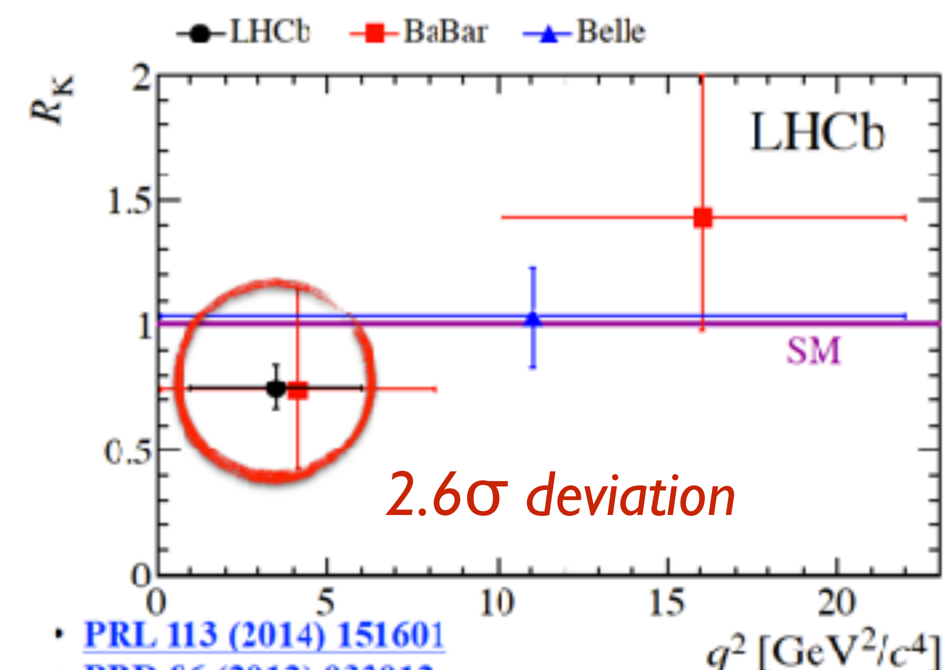
(Talk by Bifani@CERN, 2017.4.18;1705.05802)

Experimental results

- *Lepton universality in* $B^+ \to K^+ l^+ l^- \ (l = e,\ \mu)$ *(1406.6482)*

observable

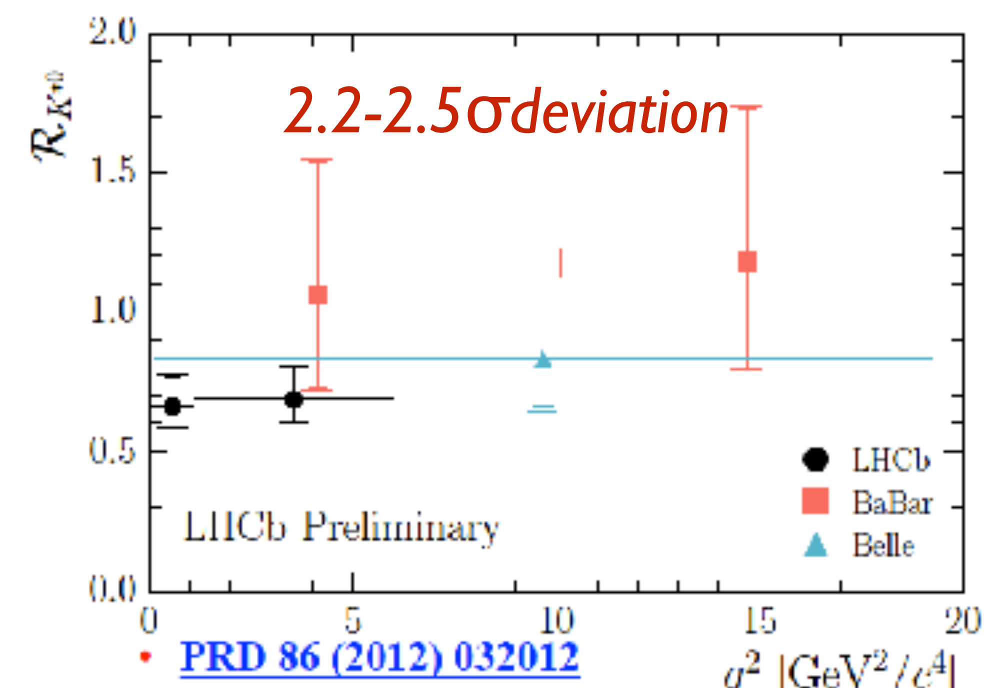
$$R_K = \frac{\int_{q^2_{\min}}^{q^2_{\max}} \frac{\mathrm{d}\Gamma[B^+ \to K^+ \mu^+ \mu^-]}{\mathrm{d}q^2} \mathrm{d}q^2}{\int_{q^2_{\min}}^{q^2_{\max}} \frac{\mathrm{d}\Gamma[B^+ \to K^+ e^+ e^-]}{\mathrm{d}q^2} \mathrm{d}q^2}$$



- PRL 113 (2014) 151601
- PRD 86 (2012) 032012
- PRL 103 (2009) 171801

- *Lepton universality in* $B_0 \to K_0^* \mu^+ \mu^-$

(Talk by Bifani@CERN, 2017.4.18;1705.05802)



- PRD 86 (2012) 032012
- PRL 103 (2009) 171801

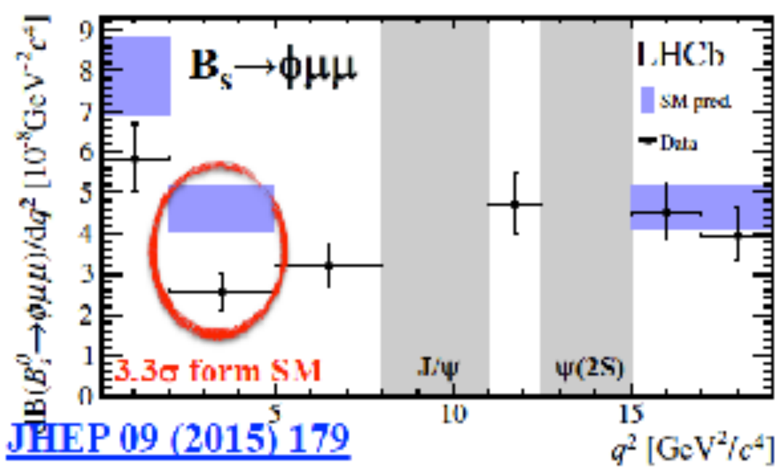
Other interesting and important points

- *B→K ee looks consistent* *(Hiller, Schmaltz 1408.1627;LHCb, 1406.6482)*

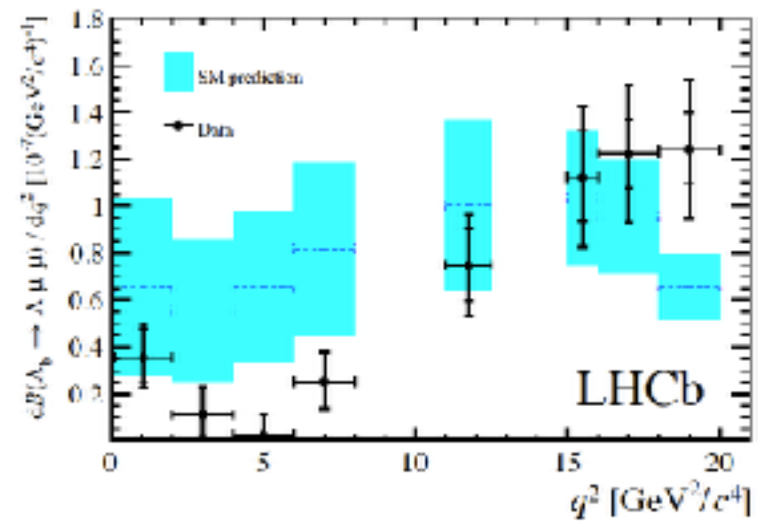
  ➡ *Smaller b→sμμ is suggested.*

- *Similar excesses are reported in* $B_s \to \phi\mu^+\mu^-$ *and* $\Lambda_b^0 \to \Lambda\mu^+\mu^-$

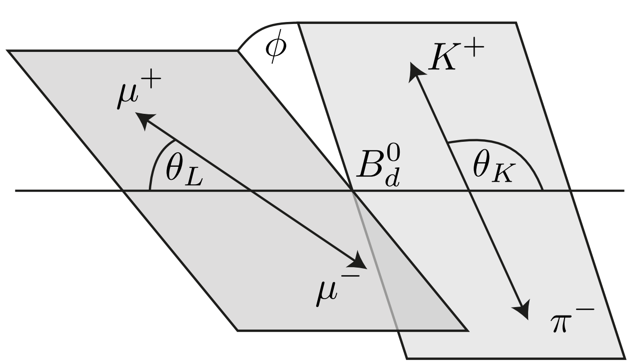
(1506.08777)

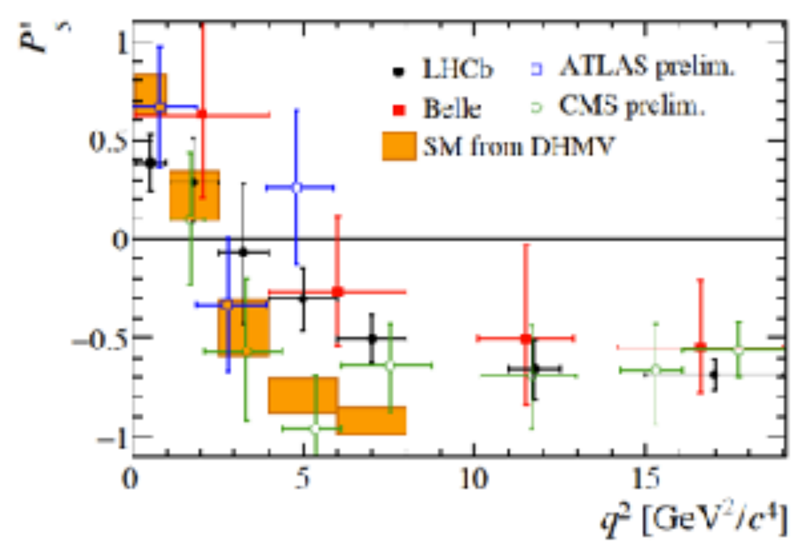


(1503.07138)



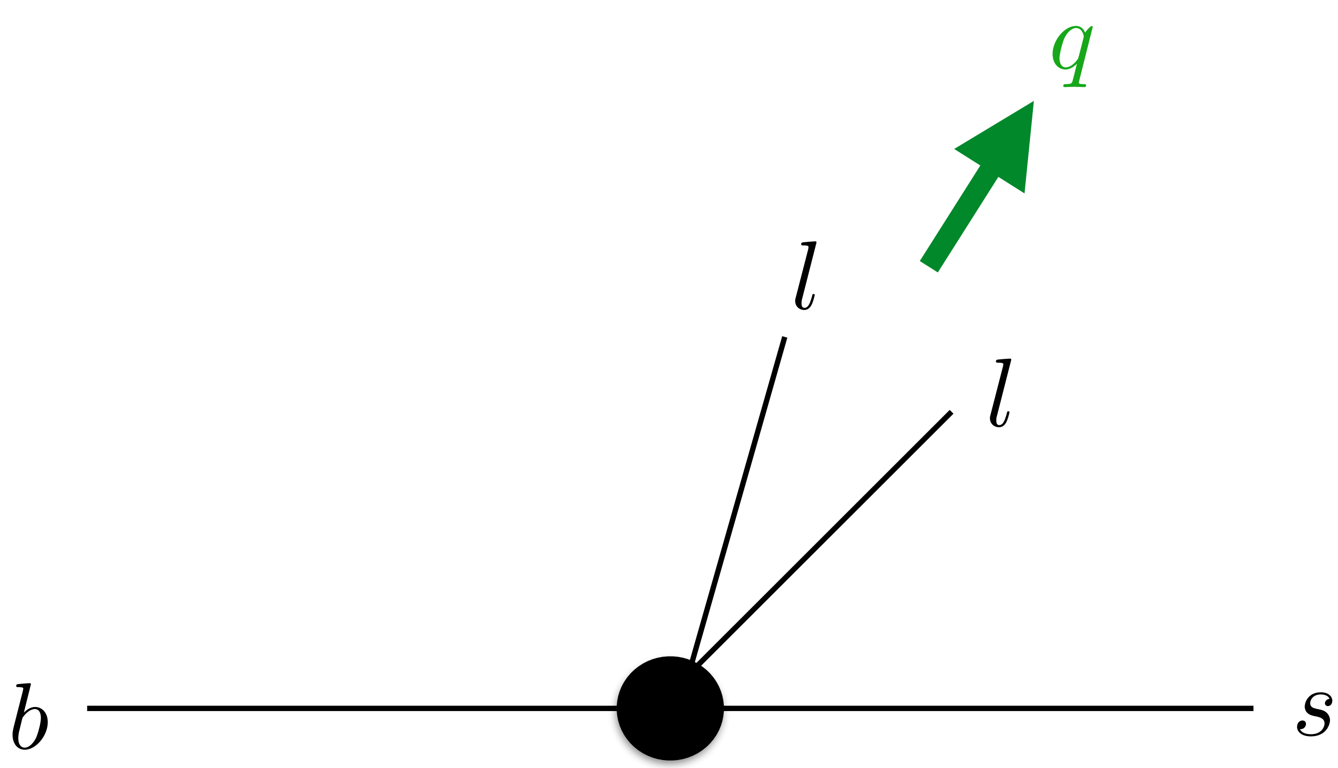
- *There are excesses in angular analysis of* $B_0 \to K_0^*\mu^+\mu^-$

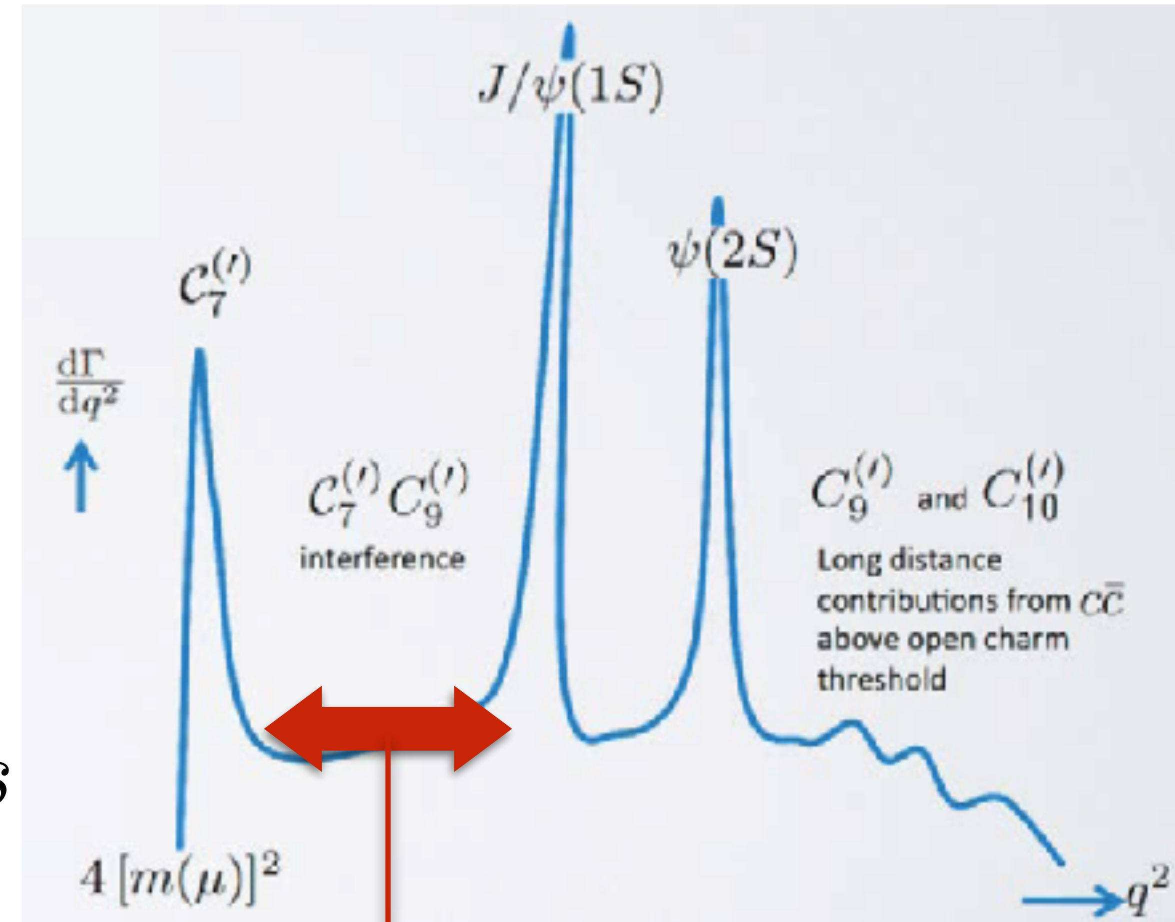




(Blake,Gersabeck, et al., 1703.10005)

- *The excesses are reported in specific q^2 region:*

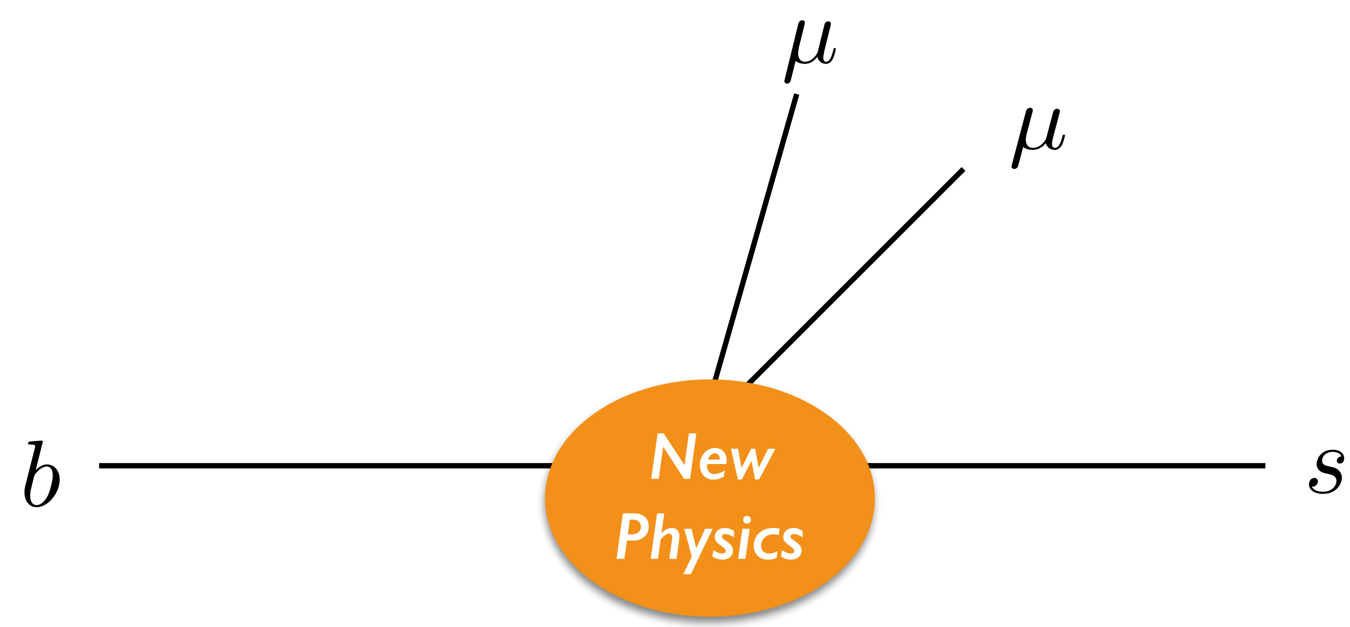




the excesses around here!

This region is sensitive to new physics!

There might be new physics in

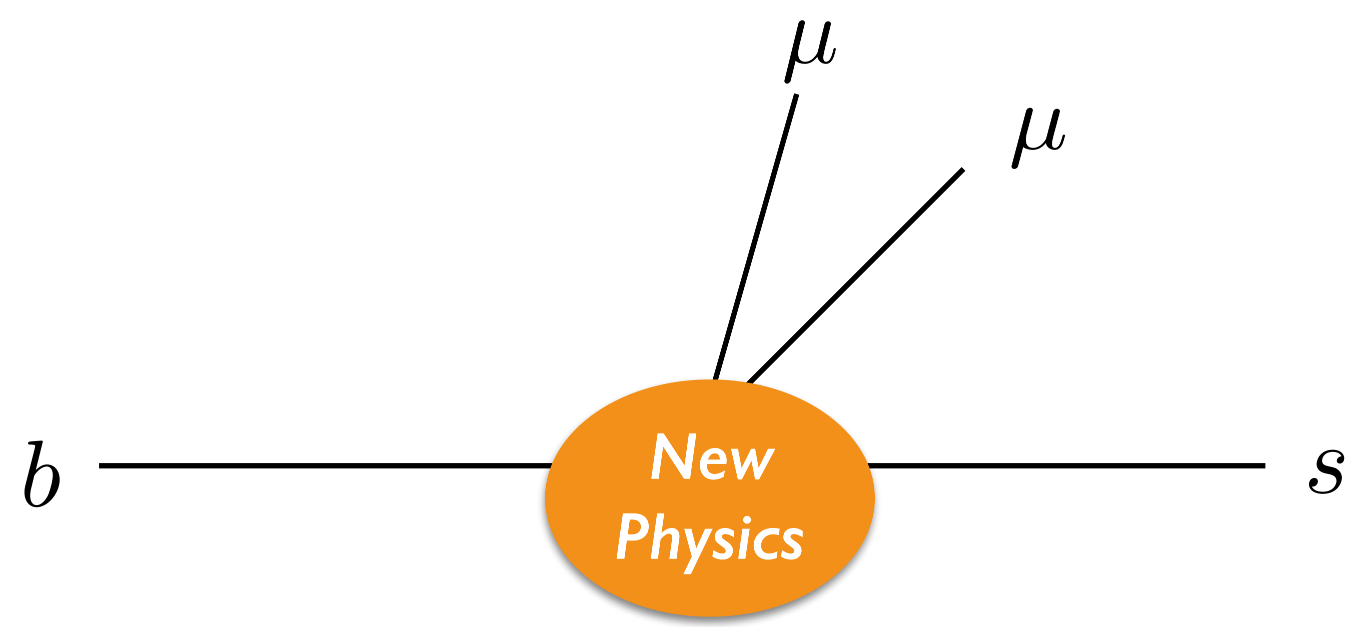


Q: Which kind of operators are favored?

$$\Delta\mathcal{H}_{NW} = -\underbrace{\frac{1}{\Lambda^2}}_{C_9}(\overline{s_L}\gamma_\mu b_L)(\mu\gamma^\mu\mu) - \underbrace{\frac{1}{\Lambda^2}}_{C_{10}}(\overline{s_L}\gamma_\mu b_L)(\mu\gamma^\mu\gamma_5\mu)$$

namely C_9 C_{10}

There might be new physics in



Q: Which kind of operators are favored?

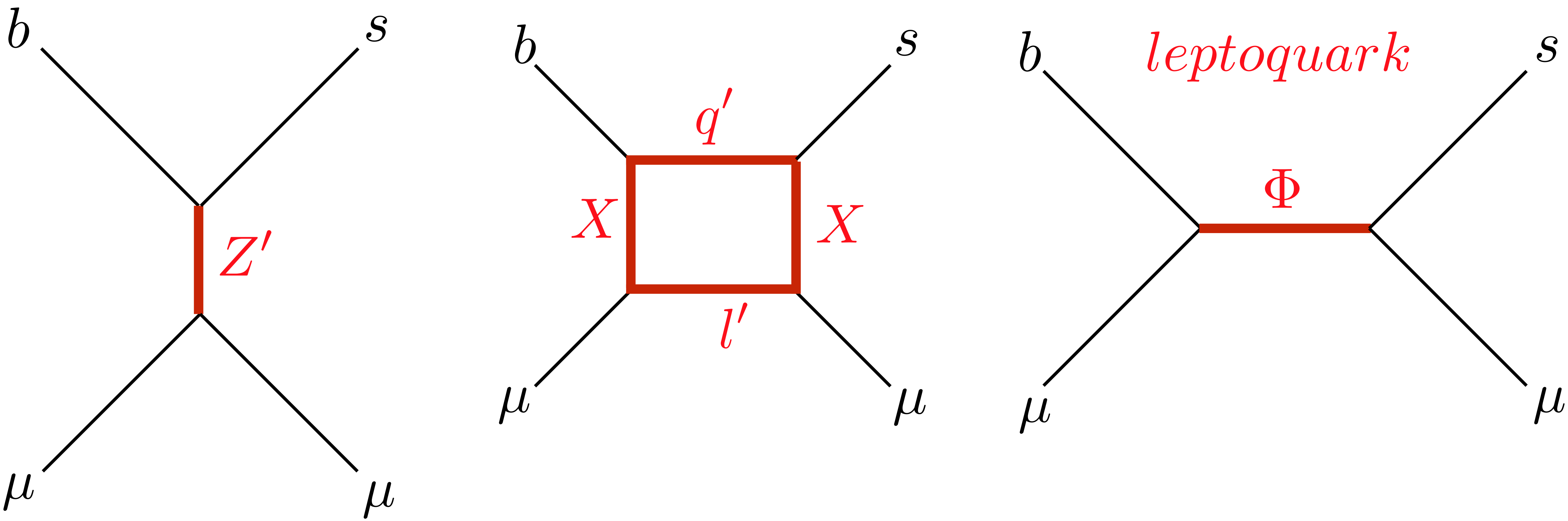
$$\Delta\mathcal{H}_{NW} = -\underbrace{\frac{1}{\Lambda^2}}_{C_9}(\overline{s_L}\gamma_\mu b_L)(\mu\gamma^\mu\mu) - \underbrace{\frac{1}{\Lambda^2}}_{C_{10}}(\overline{s_L}\gamma_\mu b_L)(\mu\gamma^\mu\gamma_5\mu)$$

namely

Q:How big is Λ?

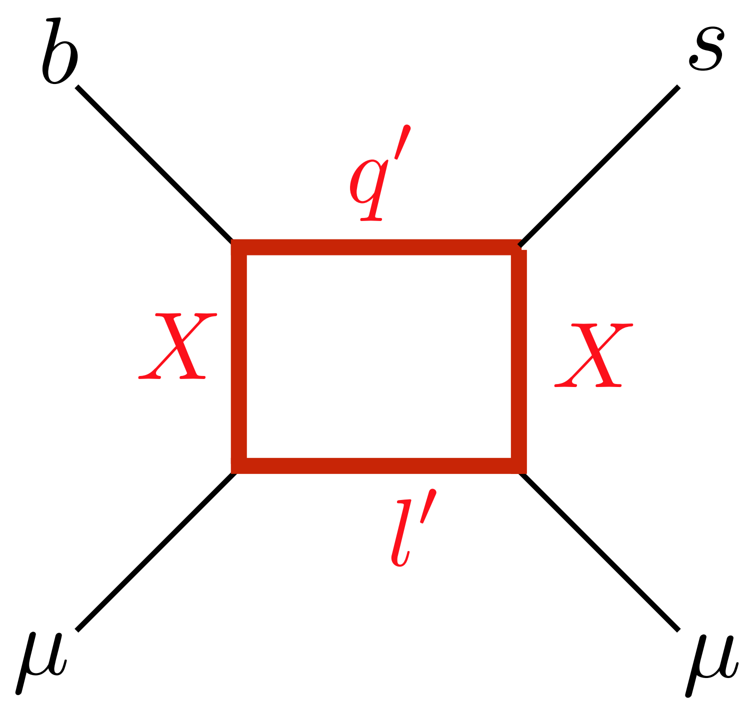
$\Lambda \approx 25\,\mathrm{TeV}$ (about 20 % of the SM contribution)

Q:What are the good candidates for new physics?



Q:What are the good candidates for new physics?

My talk



What is the prediction?

(in the case that X is DM.)

Setup

Just introduce SU(2)-doublet fermions and X:

(Kawamura,Okawa,YO,1706.04344)

Fields	spin	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_X$
Q'	$1/2$	$\mathbf{3}$	$\mathbf{2}$	$1/6$	1
L'	$1/2$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	1
X	0	$\mathbf{1}$	1	0	-1

$$m_X X^\dagger X + m_{Q'} \overline{Q'}_L Q'_R + m_{L'} \overline{L'}_L L'_R + \lambda_i^q \overline{Q'}_R X^\dagger Q_L^i + \lambda_\mu \overline{L'_R} X^\dagger \mu_L + h.c.$$

Just introduce SU(2)-doublet fermions and X:

(Kawamura,Okawa,YO,1706.04344)

Fields	spin	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_X$
Q'	$1/2$	$\mathbf{3}$	$\mathbf{2}$	$1/6$	1
L'	$1/2$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	1
X	0	$\mathbf{1}$	1	0	-1

$$m_X X^\dagger X + m_{Q'} \overline{Q'}_L Q'_R + m_{L'} \overline{L'}_L L'_R + \lambda_i^q \overline{Q'}_R X^\dagger Q_L^i + \lambda_\mu \overline{L'}_R X^\dagger \mu_L + h.c.$$

- *X is complex scalar DM.*

Just introduce SU(2)-doublet fermions and X:

(Kawamura,Okawa,YO,1706.04344)

Fields	spin	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_X$
Q'	$1/2$	$\mathbf{3}$	$\mathbf{2}$	$1/6$	1
L'	$1/2$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	1
X	0	$\mathbf{1}$	1	0	-1

$$m_X X^\dagger X + m_{Q'} \overline{Q'}_L Q'_R + m_{L'} \overline{L'}_L L'_R + \lambda_i^q \overline{Q'}_R X^\dagger Q_L^i + \lambda_\mu \overline{L'}_R X^\dagger \mu_L + h.c.$$

- *X is complex scalar DM.*
- *$\lambda^{(q)}_i$ are flavor-dependent couplings.*

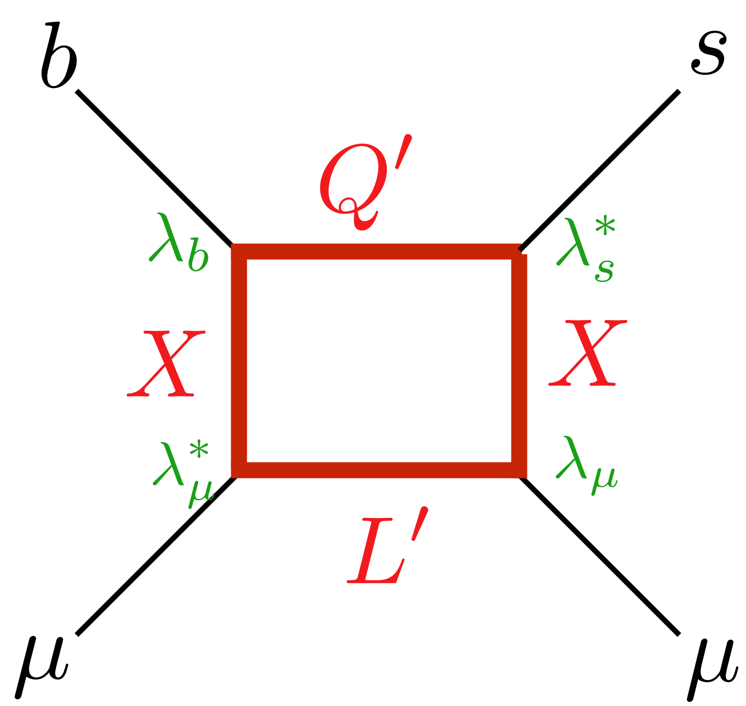
(Tune them to explain the excesses and avoid many flavor constraints.)

Just introduce SU(2)-doublet fermions and X:

(Kawamura,Okawa,YO,1706.04344)

Fields	spin	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_X$
Q'	$1/2$	$\mathbf{3}$	$\mathbf{2}$	$1/6$	1
L'	$1/2$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	1
X	0	$\mathbf{1}$	1	0	-1

$$m_X X^\dagger X + m_{Q'}\overline{Q'}_L Q'_R + m_{L'}\overline{L'}_L L'_R + \lambda_i^q \overline{Q'}_R X^\dagger Q_L^i + \lambda_\mu \overline{L'}_R X^\dagger \mu_L + h.c.$$



X: DM candidate

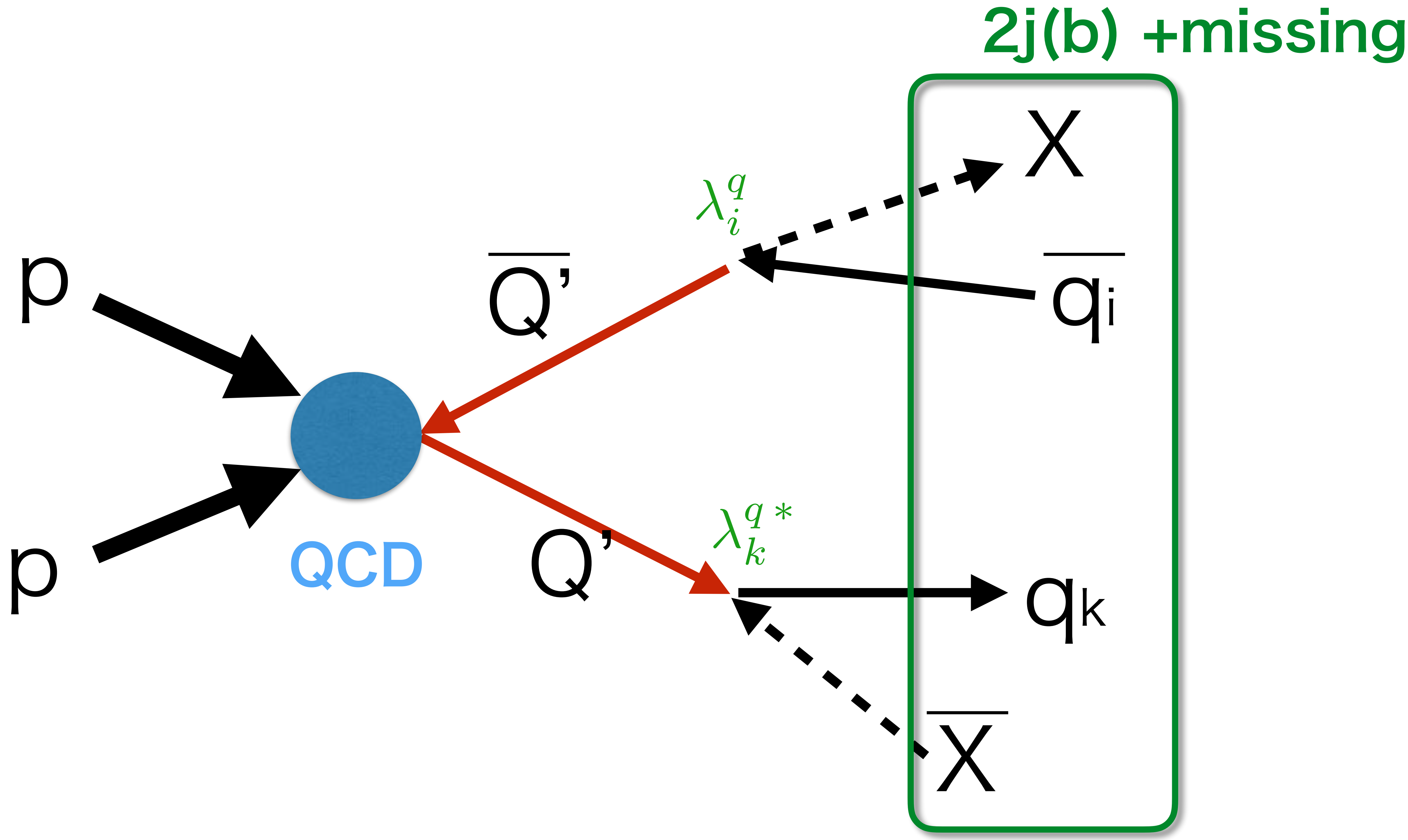
$$\Rightarrow \quad (\overline{s_L}\gamma^\mu b_L)(\overline{\mu_L}\gamma_\mu \mu_L)$$

Phenomenology

Constraints from LHC

(Kawamura,Okawa,YO,1706.04344)

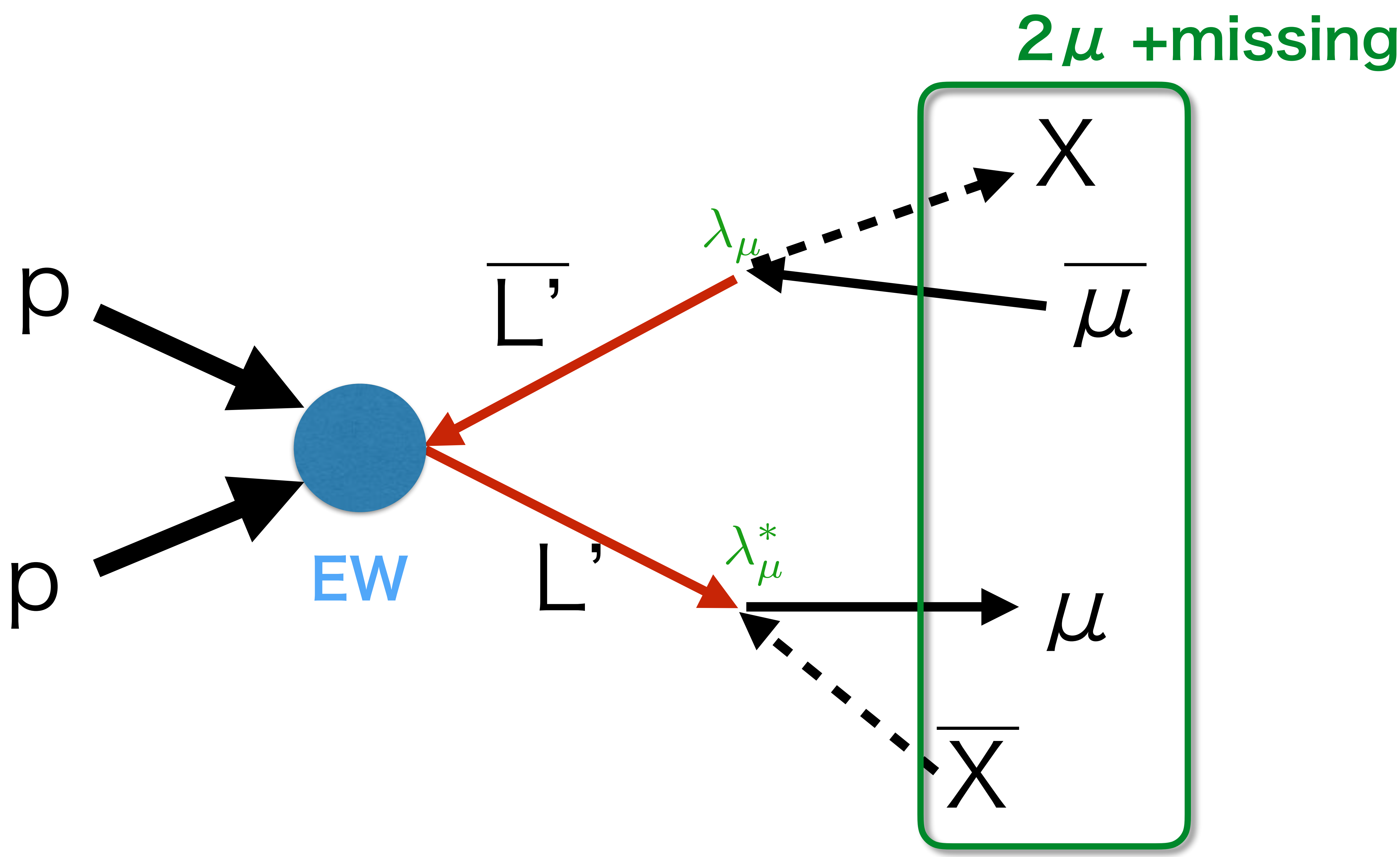
$$m_X X^\dagger X + m_{Q'}\overline{Q'}_L Q'_R + m_{L'}\overline{L'}_L L'_R + \lambda_i^q \overline{Q'}_R X^\dagger Q_L^i + \lambda_\mu \overline{L'_R} X^\dagger \mu_L + h.c.$$



Constraints from LHC

(Kawamura,Okawa,YO,1706.04344)

$$m_X X^\dagger X + m_{Q'}\overline{Q'}_L Q'_R + m_{L'}\overline{L'}_L L'_R + \lambda_i^q \overline{Q'}_R X^\dagger Q_L^i + \lambda_\mu \overline{L'_R} X^\dagger \mu_L + h.c.$$

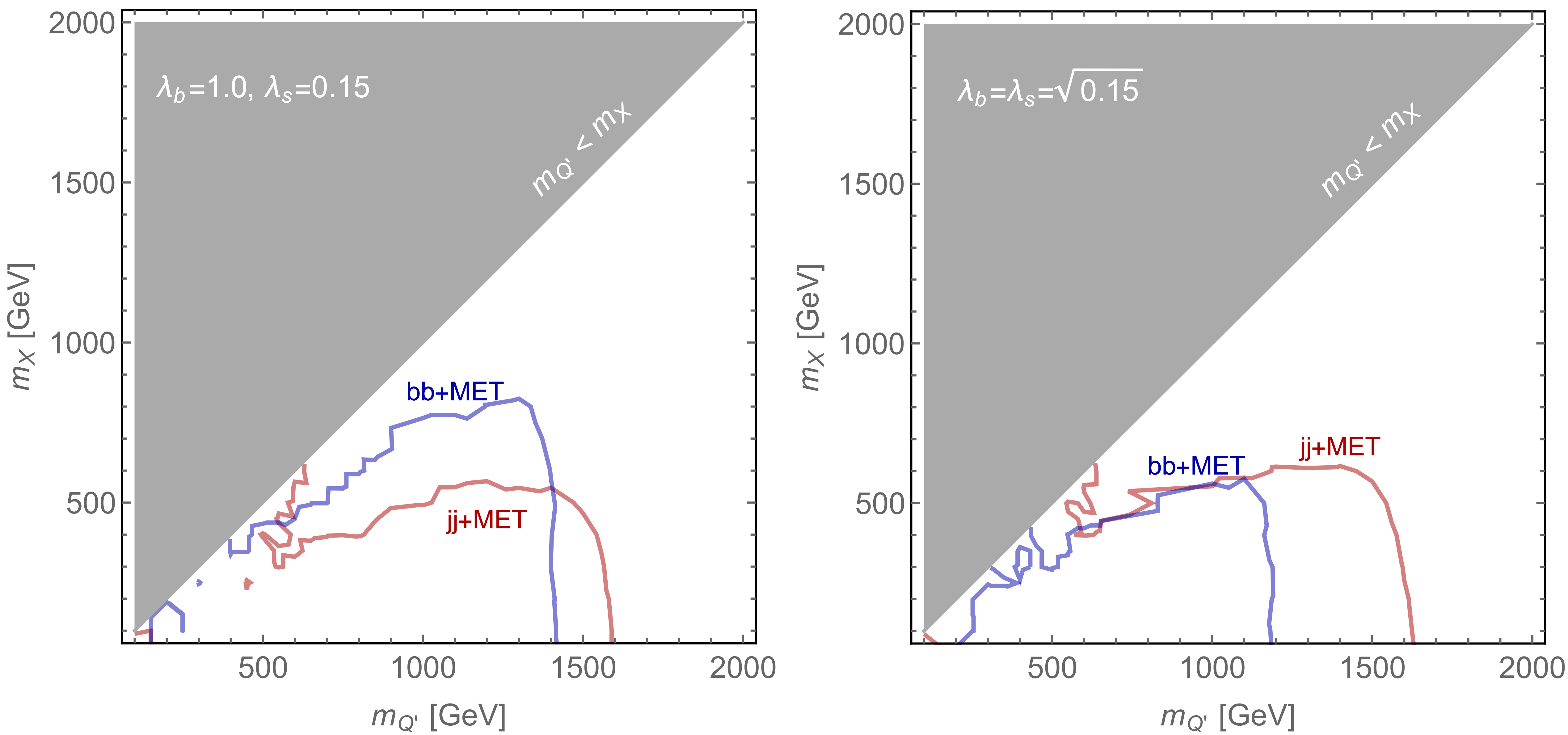


Constraints from LHC

(Kawamura, Okawa, YO, 1706.04344)

$$m_{Q'}\overline{Q'}_L Q'_R + m_{L'}\overline{L'}_L L'_R + \lambda_i^q \overline{Q'}_R X^\dagger Q_L^i + \lambda_\mu \overline{L'_R} X^\dagger \mu_L + h.c.$$

From 2j(b) +missing



From 2μ +missing

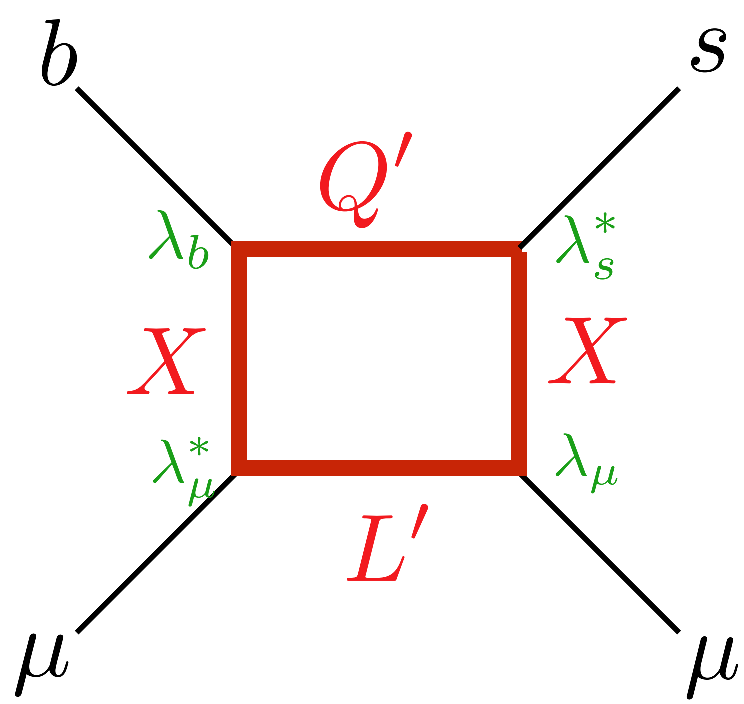
$$m_{L'} \gtrsim 500\,\text{GeV}$$

b →s ll (RK and RK*)

(Kawamura,Okawa,YO,1706.04344)

$$m_{Q'}\overline{Q'}_L Q'_R + m_{L'}\overline{L'}_L L'_R + \lambda_i^q \overline{Q'}_R X^\dagger Q_L^i + \lambda_\mu \overline{L'_R} X^\dagger \mu_L + h.c.$$

Box diagram gives b→sll :



X: DM candidate

$$c_{loop}\frac{|\lambda_\mu|^2\lambda_b\lambda_s^*}{m_{Q'}^2}(\overline{s_L}\gamma_\mu b_L)(\overline{\mu_L}\gamma^\mu\mu_L)$$

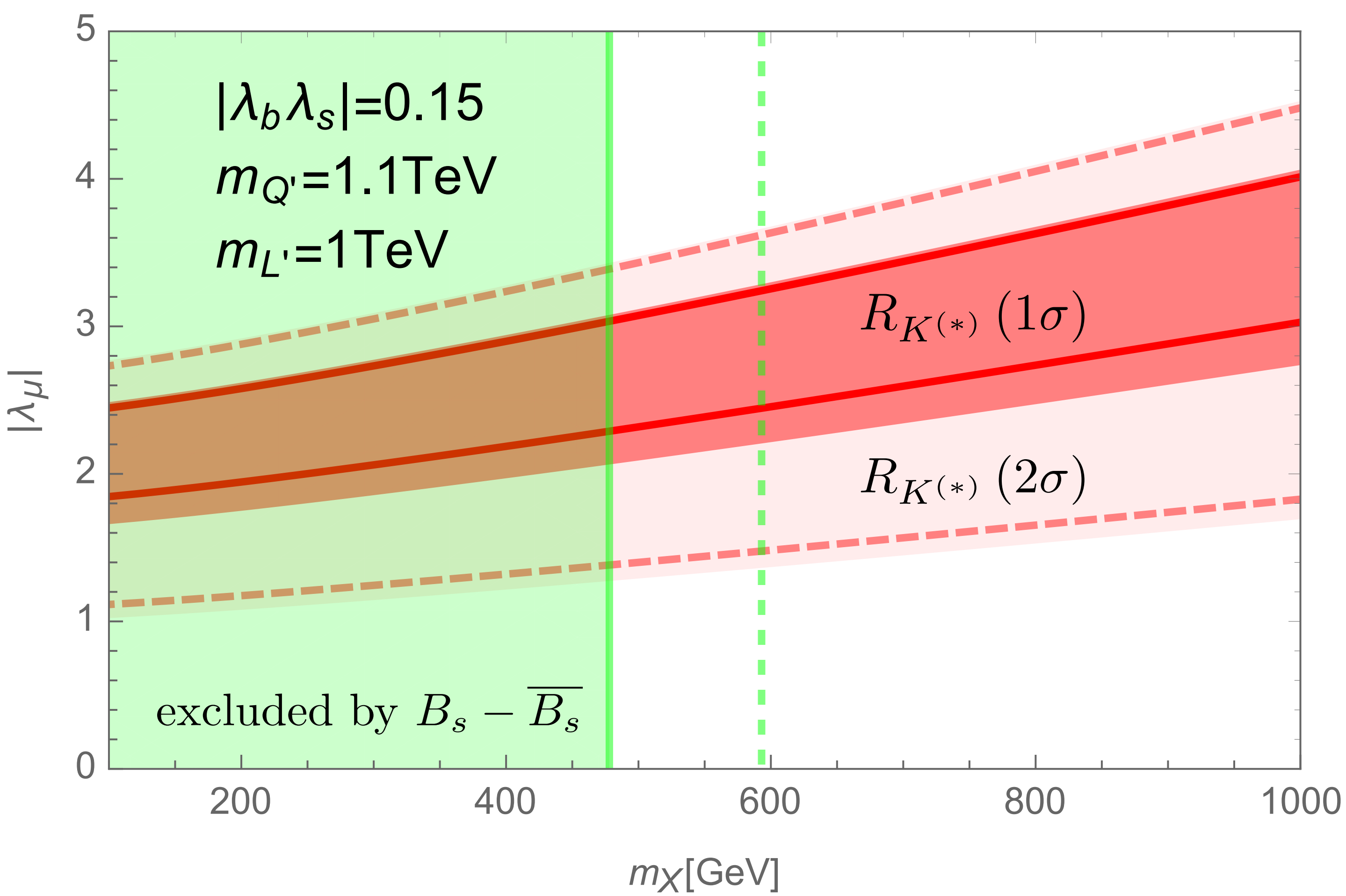
Large Yukawa is required

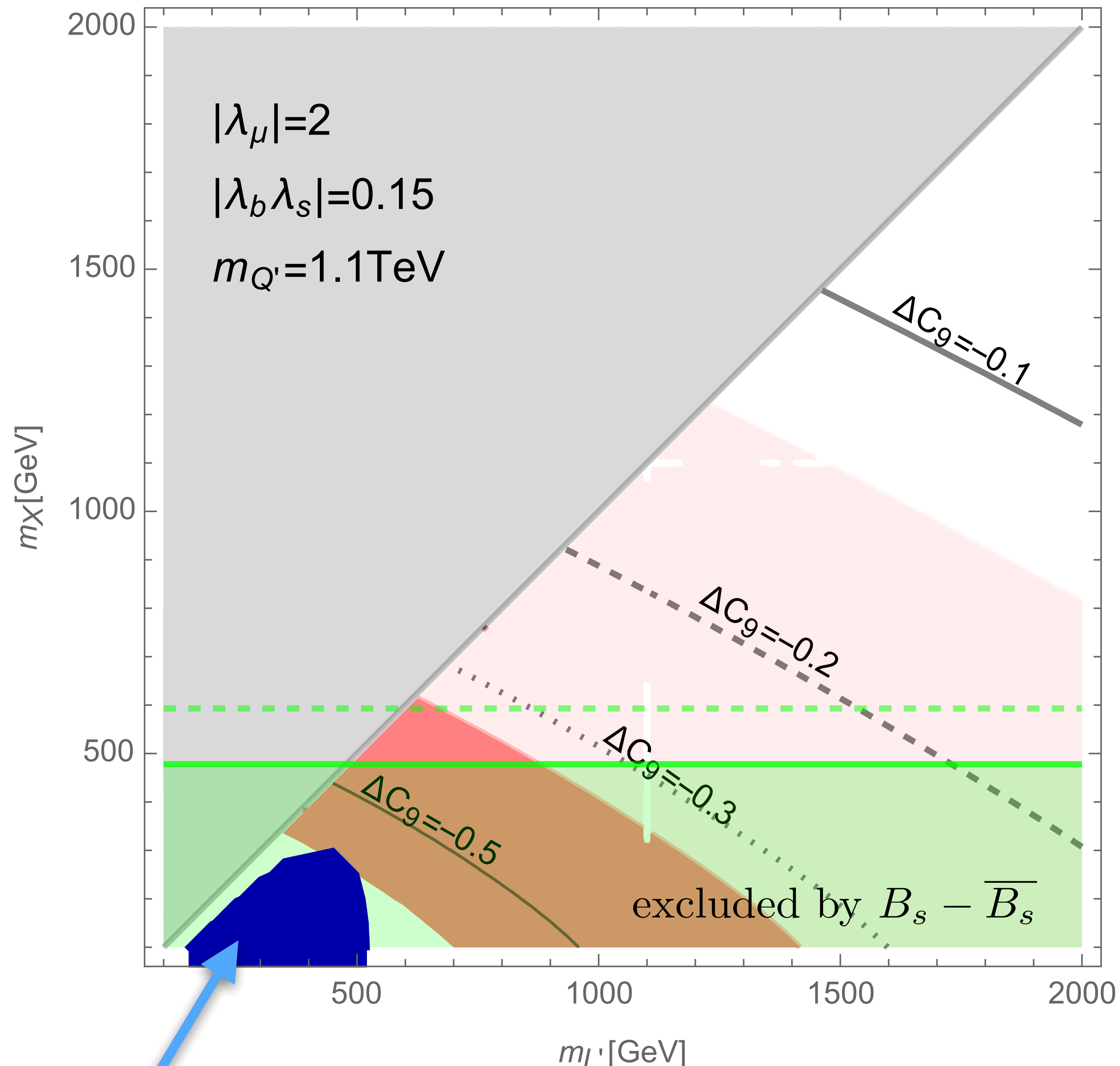
$b \to s\, ll$ (R_K and R_{K*})

(Kawamura,Okawa,YO,1706.04344)

$$m_{Q'}\overline{Q'}_L Q'_R + m_{L'}\overline{L'}_L L'_R + \lambda^q_i \overline{Q'}_R X^\dagger Q^i_L + \lambda_\mu \overline{L'_R} X^\dagger \mu_L + h.c.$$

Large Yukawa is required





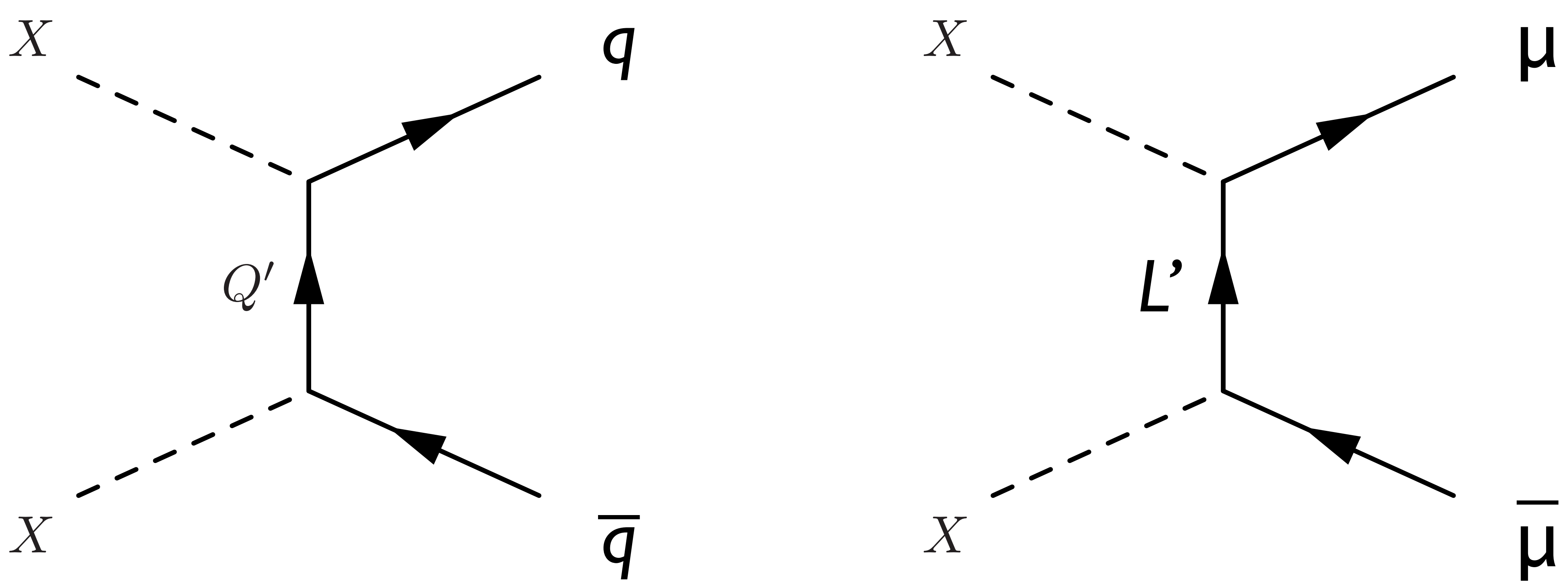
excluded by 2μ +missing

DM physics

Connection with DM physics

(Kawamura,Okawa,YO,1706.04344)

- *Large Yukawa is compatible with the relic density in scalar DM model.*

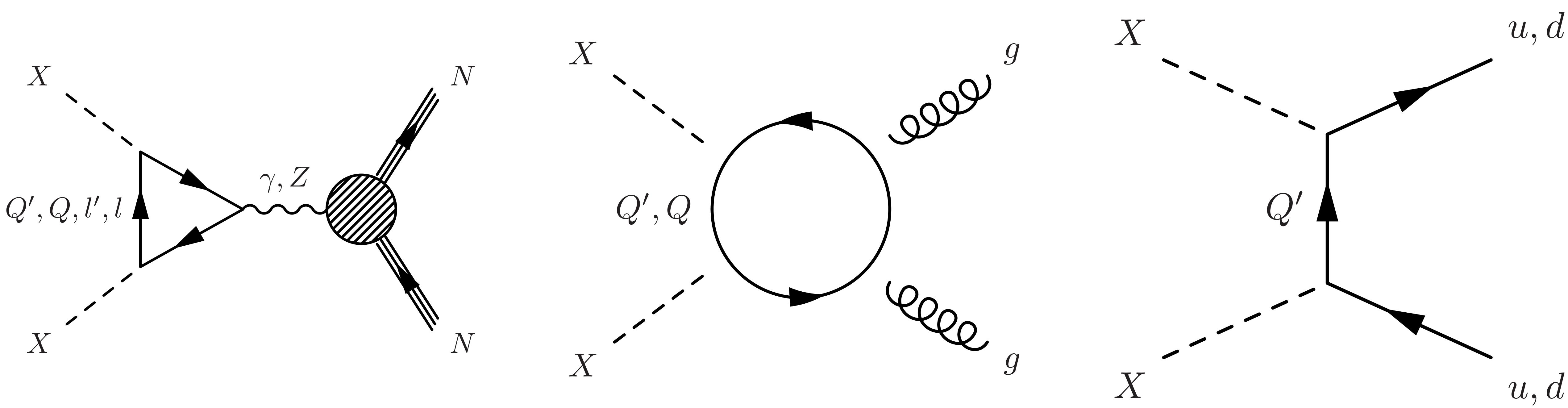


Connection with DM physics

(Kawamura,Okawa,YO,1706.04344)

- *Large Yukawa is compatible with the relic density in scalar DM model.*
- *Direct detection is at the one-loop, but sufficiently large!*

→*XENON1T will conclude this scenario!*

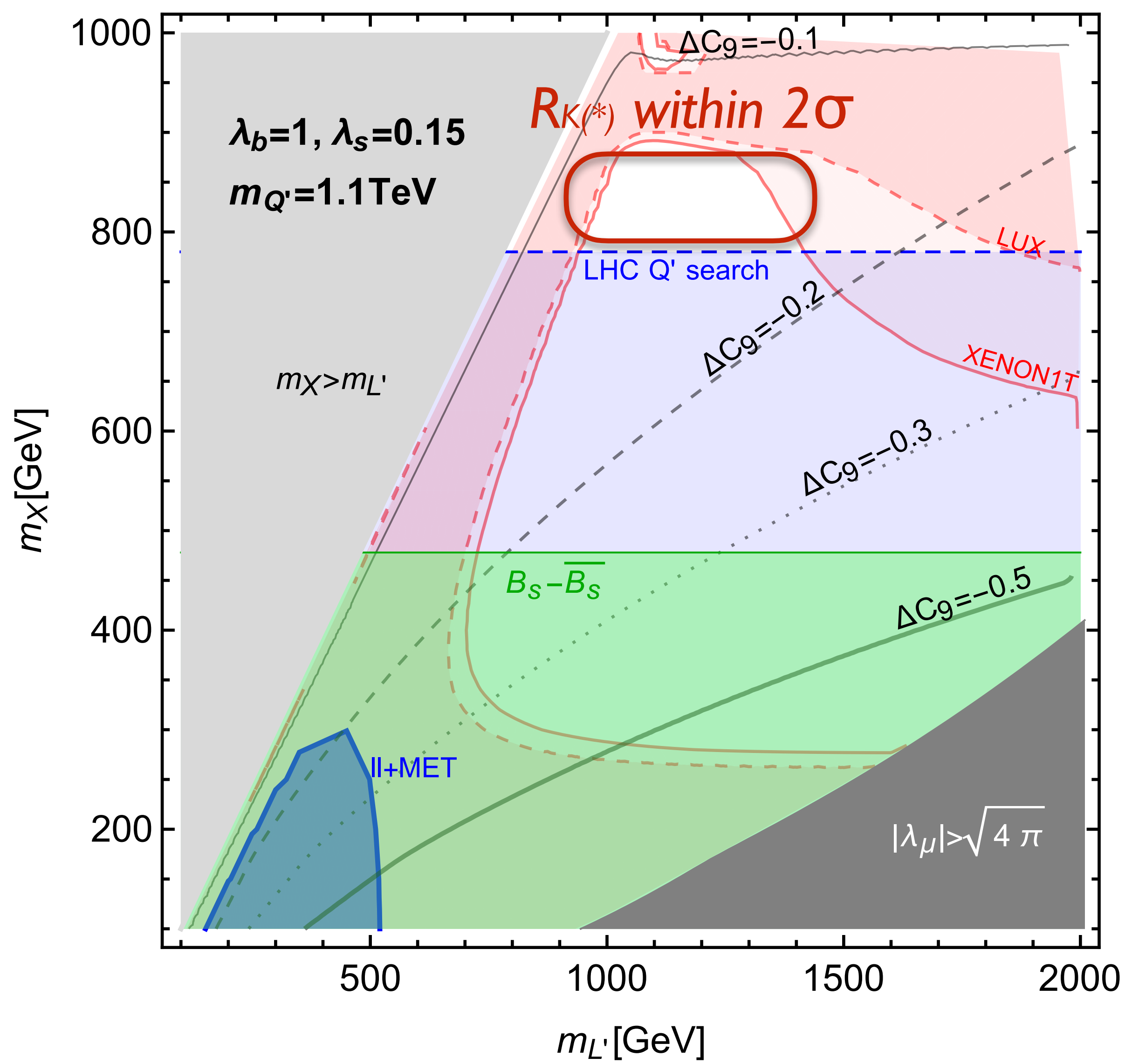


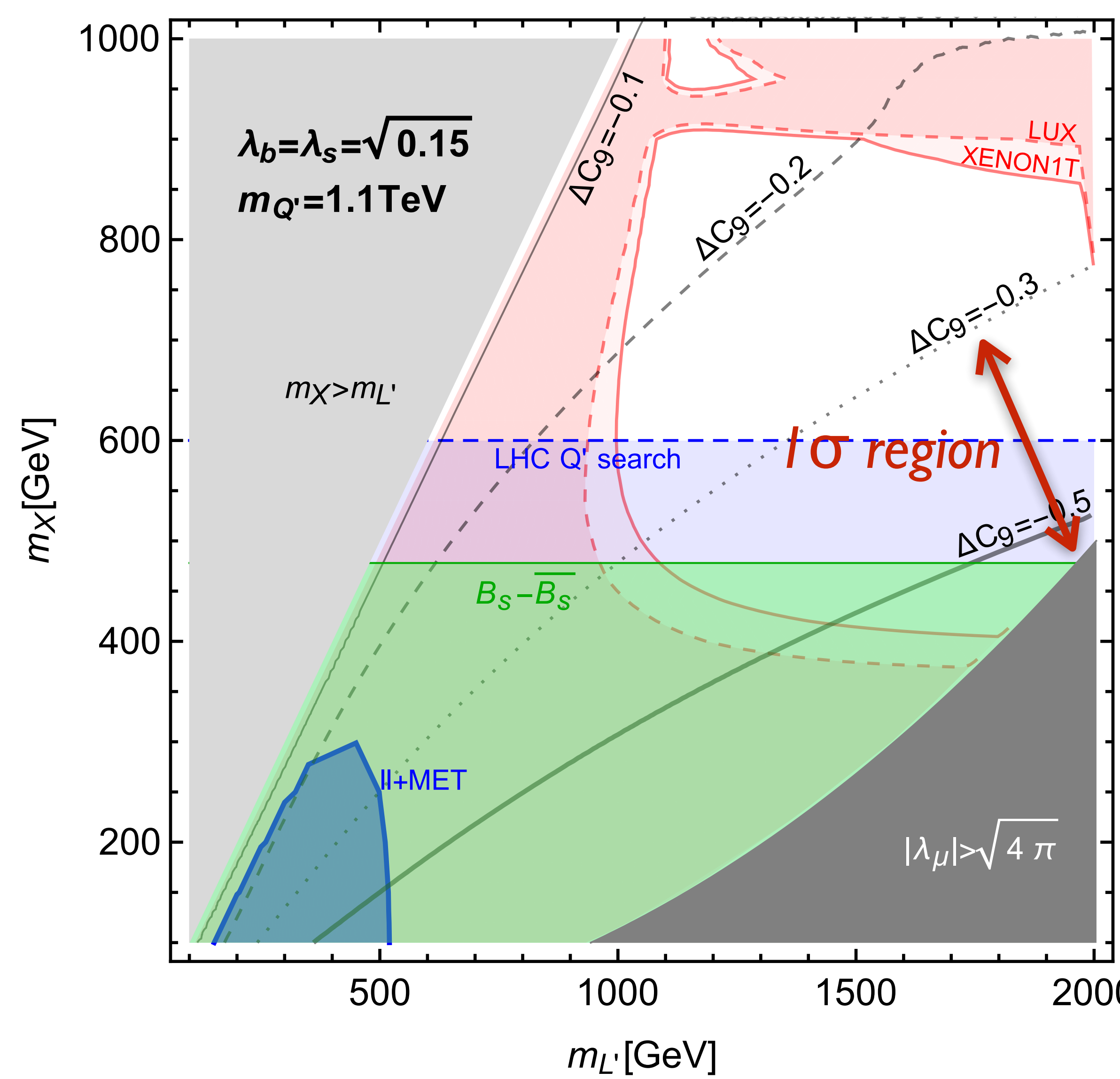
Connection with DM physics

(Kawamura,Okawa,YO,1706.04344)

- *Large Yukawa is compatible with the relic density in scalar DM model.*
- *Direct detection is at the one-loop, but sufficiently large!*

→*XENON1T will conclude this scenario!*





Summary

- Number of μ is less in b to sll processes@LHCb:

  → *This may be the signal of extra fermions and scalars which couple to μ.*

  → *This excess may give a hint to understand the hidden sector of our universe.*

- I show a simple setup motivated by the excesses.

  b to sll excesses require large μ coupling.

  Signals at LHC are SUSY-like: $m_{Q'} \gtrsim 1.5\,\mathrm{TeV},\ m_{L'} \gtrsim 500\,\mathrm{GeV}$

  $\text{when}\, m_X \lesssim 300\mathrm{GeV}$

  Large μ coupling can achieve the relic density if DM is scalar.

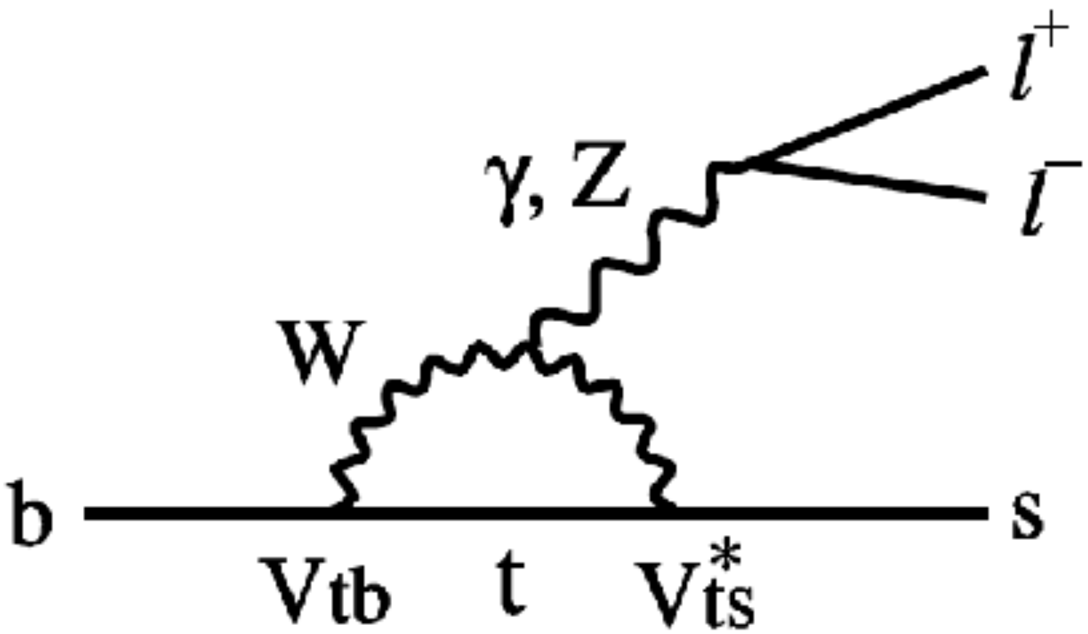
  Direct search for DM will conclude this setup!

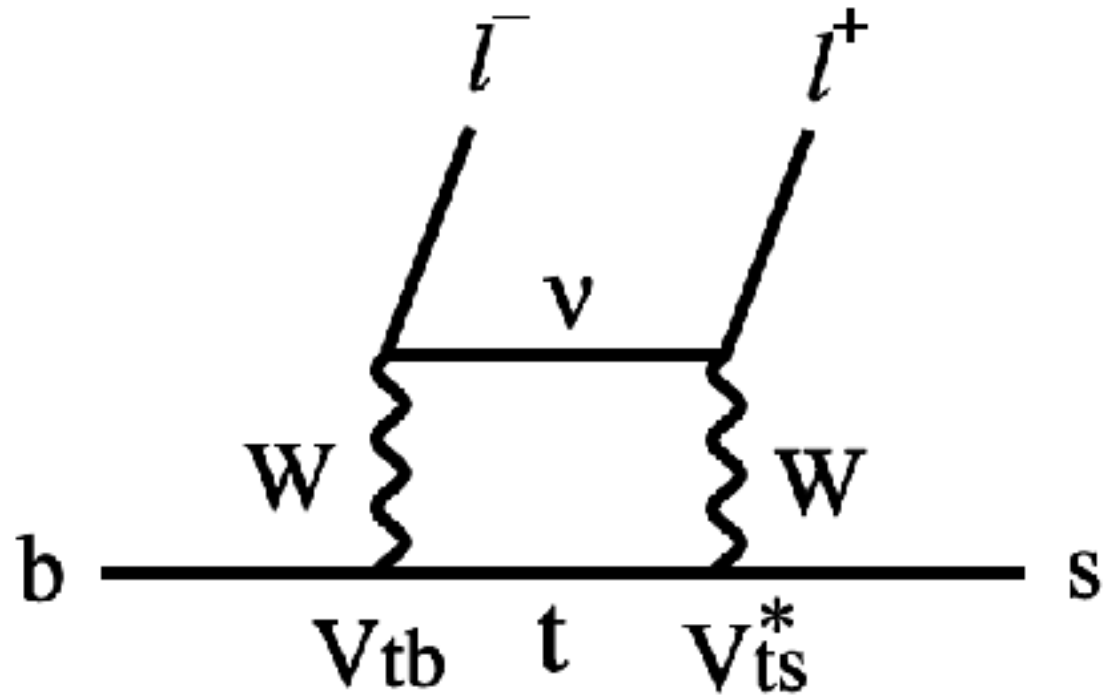
  Bs→μμ, B→Kνν are also good processes to prove this model.

END

Backup

In the Standard Model, the *b to s ll* is given by





effective Hamiltonian

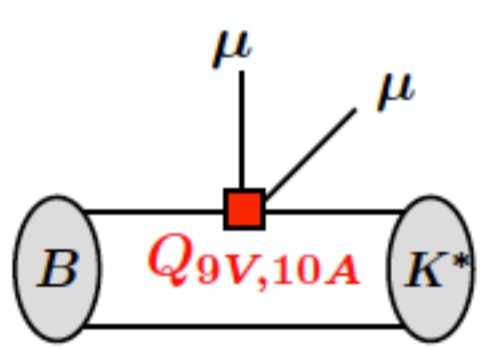
$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \mathcal{C}_i O_i$$

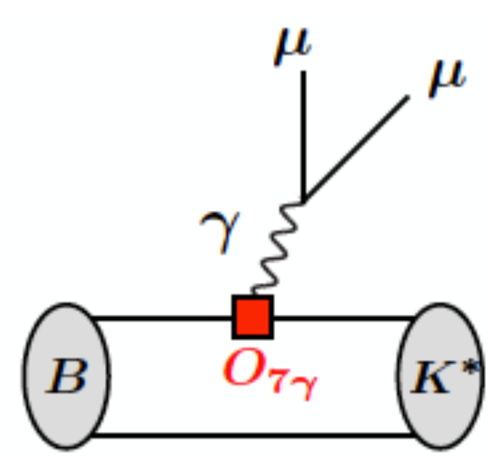
$$O_9 = \frac{e^2}{16\pi^2}(\bar{b}_L \gamma_\mu s_L)(\bar{\ell}\gamma^\mu \ell)$$

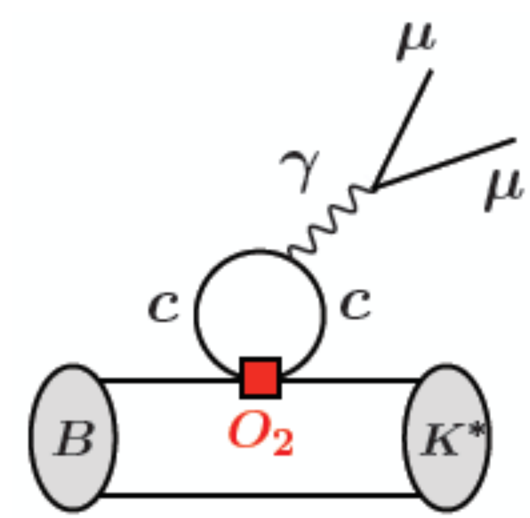
$$O_{10} = \frac{e^2}{16\pi^2}(\bar{b}_L \gamma_\mu s_L)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$$

$$O_{7\gamma} = \frac{e}{16\pi^2} m_b \bar{b}_R \sigma^{\mu\nu} s_L F_{\mu\nu}$$

$$O_2 = (\bar{b}_L \gamma_\mu c_L)(c_L \gamma^\mu s_L)$$



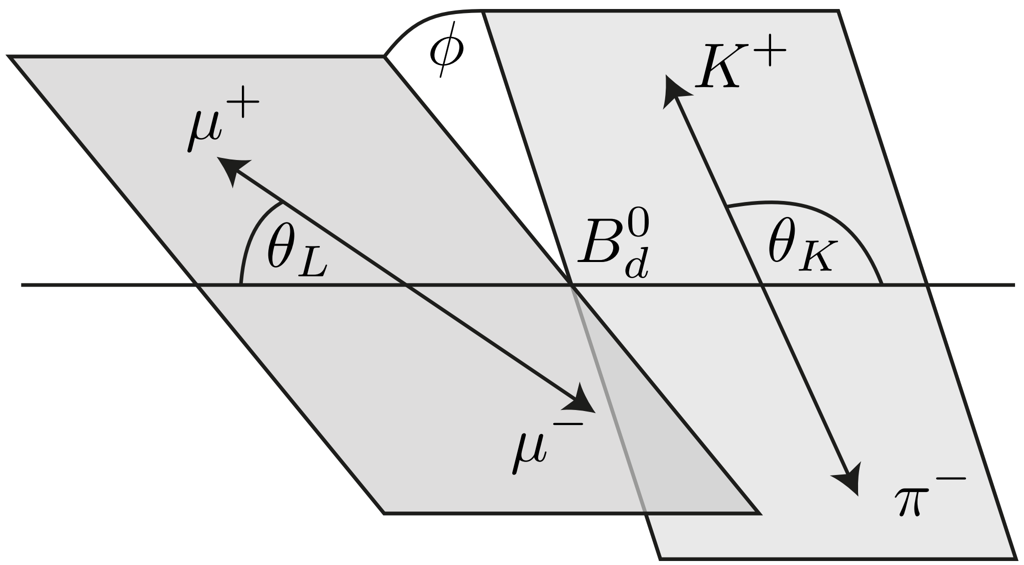




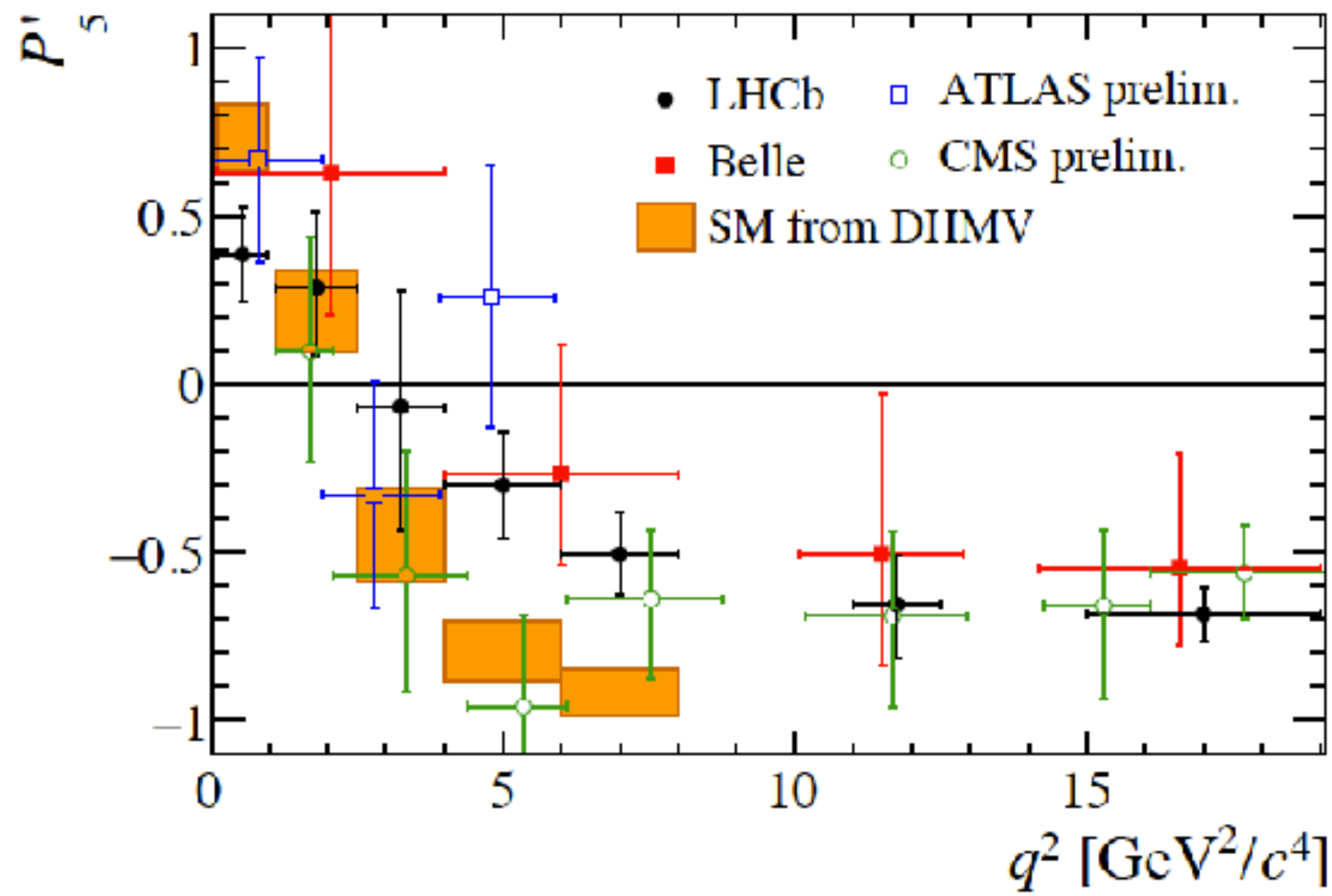
$$C_7 \sim -0.3,\ C_9 \sim 4,\ C_{10} \sim -4$$ in the SM.

Angular analysis of $B_0 \to K_0^* \mu^+ \mu^-$

(1308.1707; 1512.04442 ;ATLAS-CONF-2017-023;CMS-PAS-BPH-15-008)



(Blake,Gersabeck, et al., 1703.10005)



$$\frac{1}{\mathrm{d}\Gamma/dq^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K + \frac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_\mathrm{L}\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+ S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi$$
$$+ S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big],$$

Parameter dependence

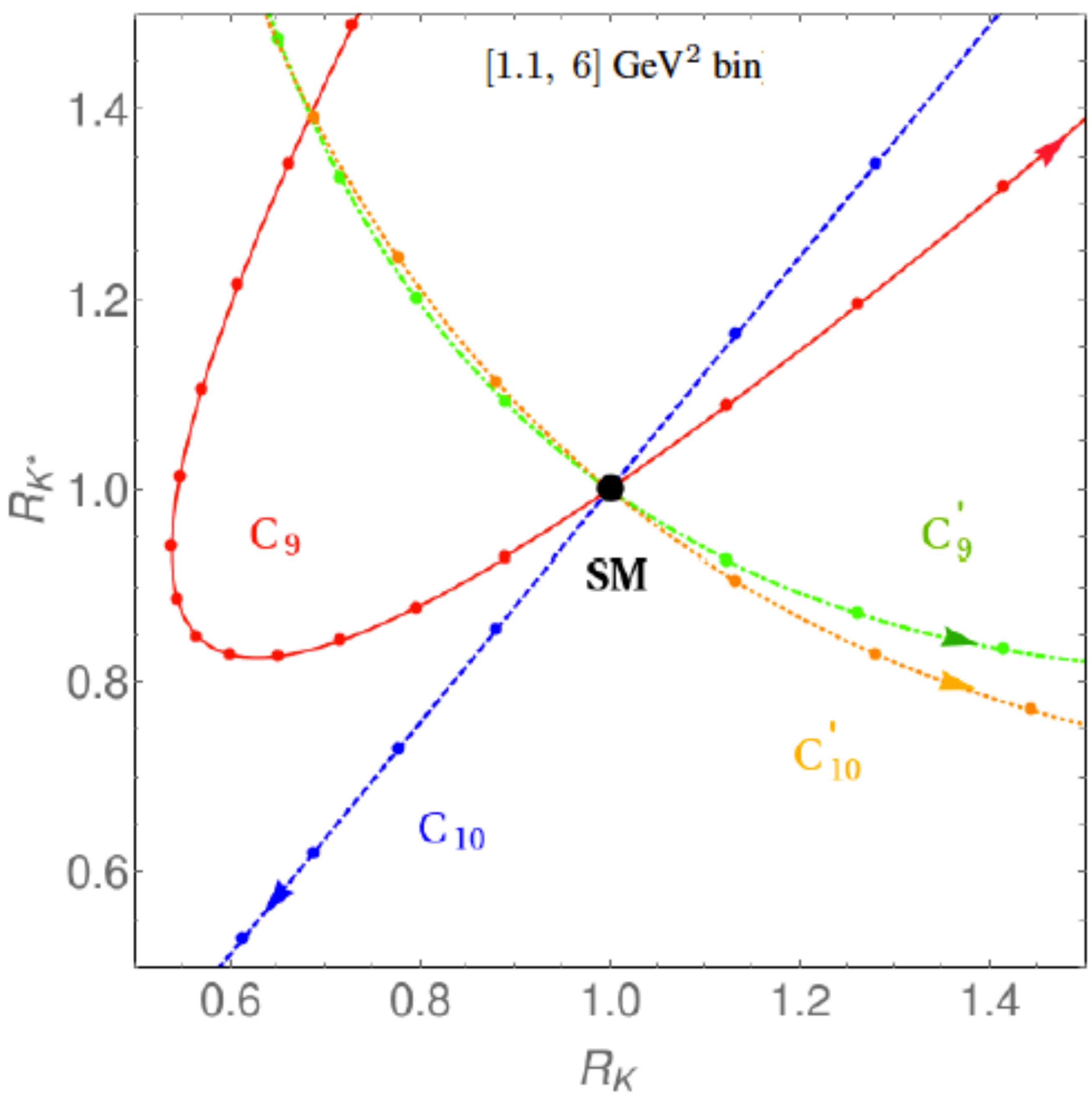
(Geng,Grinstein,et.al., 1704.05446)

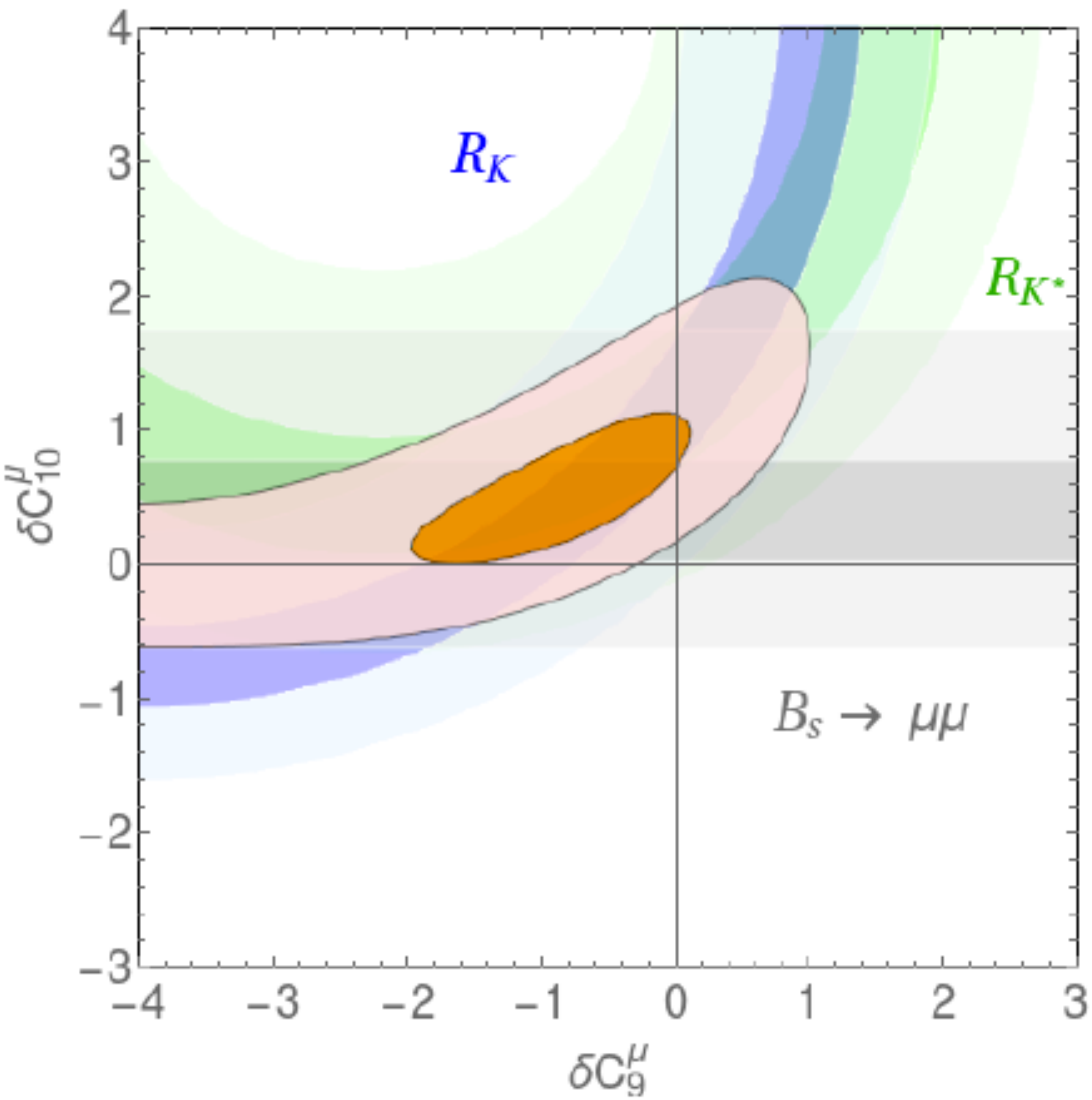
$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \frac{e^2}{16\pi^2}\left\{C_9^l(\overline{s_L}\gamma_\mu b_L)(\bar{l}\gamma^\mu l) + C_{10}^l(\overline{s_L}\gamma_\mu b_L)(\bar{l}\gamma^\mu\gamma_5 l) + h.c.\right\}$$

$$R_K = 0.745^{+0.090}_{-0.074} \pm 0.036 \quad q^2 \in [1,\ 6]\ \mathrm{GeV}^2$$

$$R_{K^*[1.1,\ 6]\ \mathrm{GeV}^2} = 0.685^{+0.113}_{-0.069} \pm 0.047$$

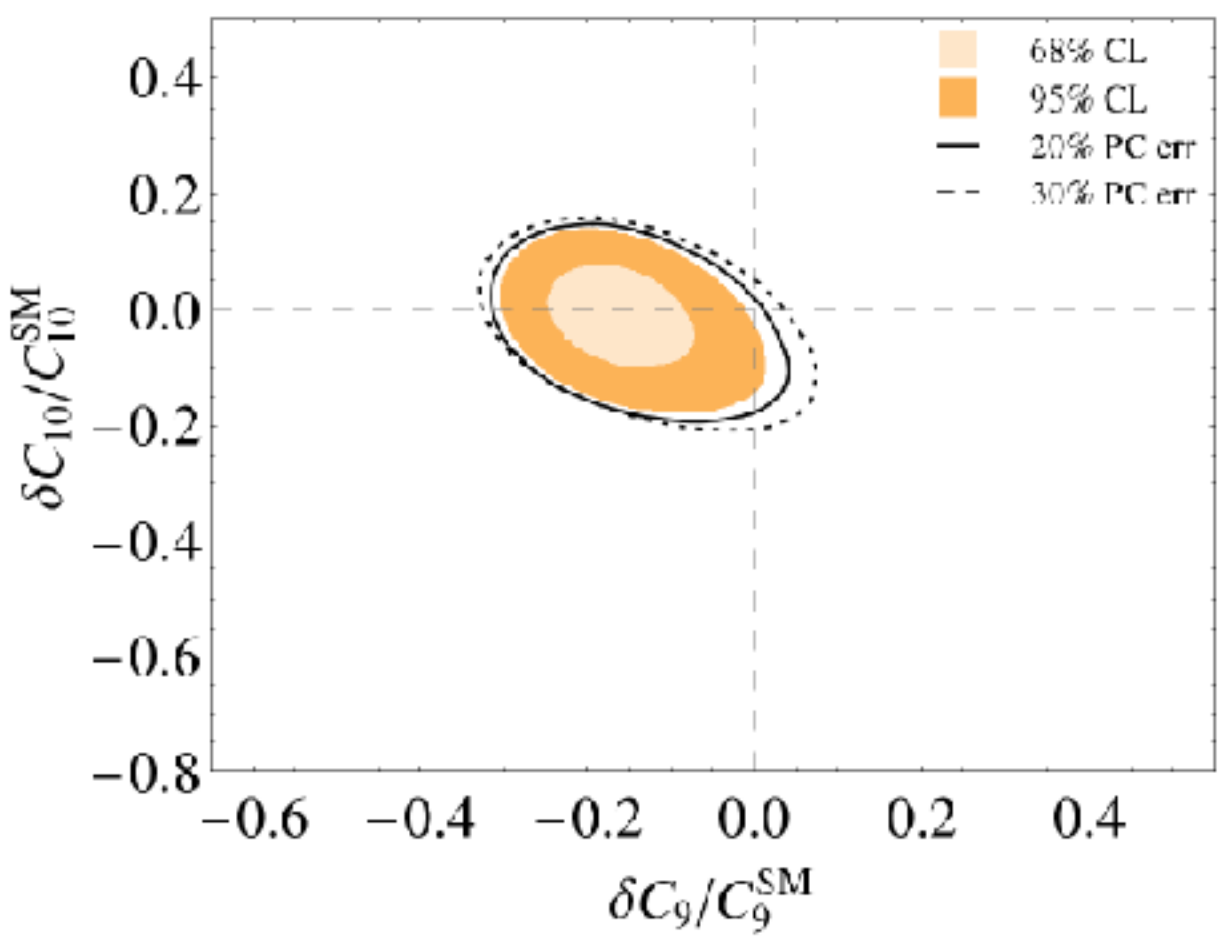
$C_9<0$, $C_{10}>0$



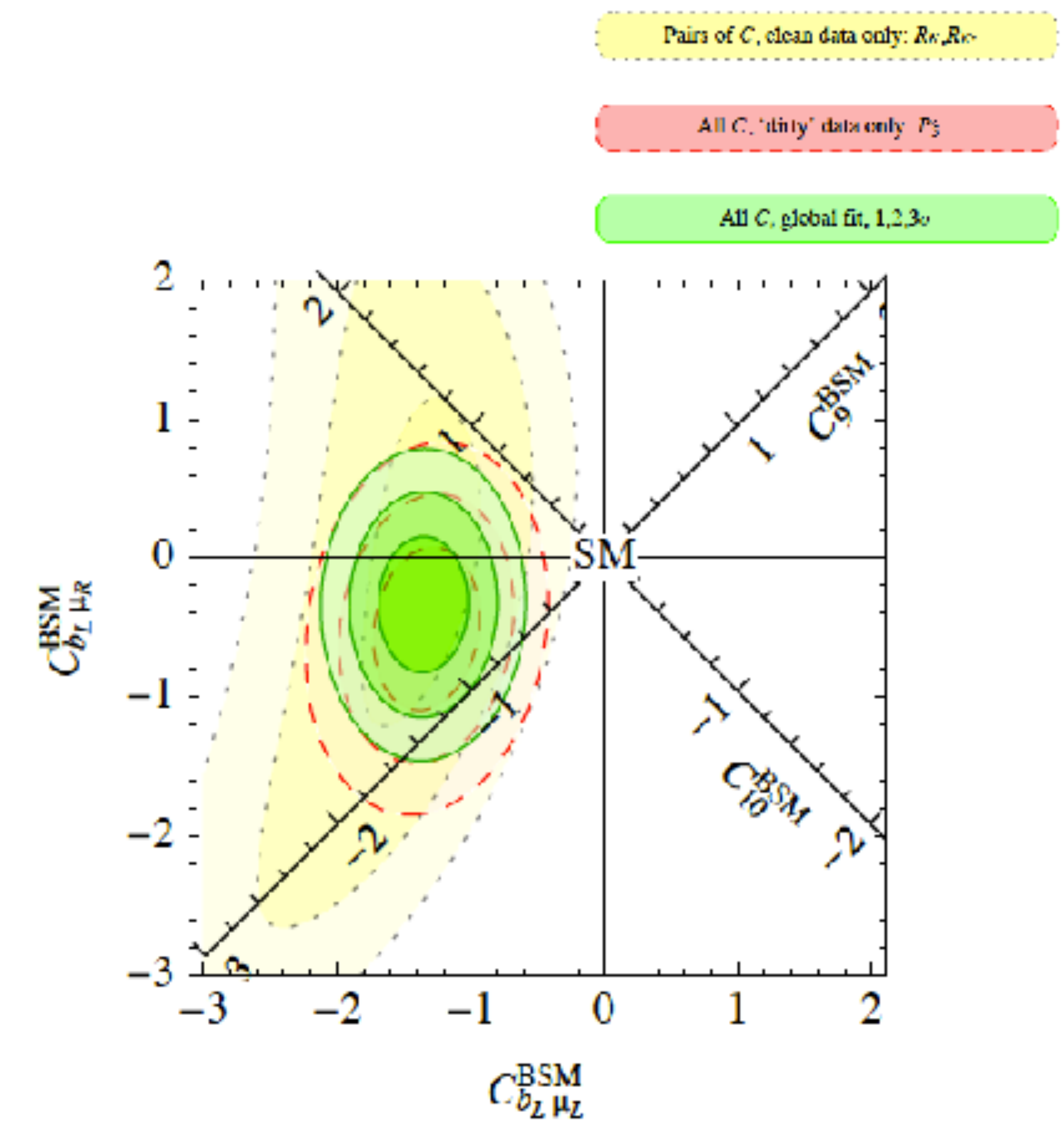


Global fitting

(Descotes-Genon,Matias,et al., 1307.5683;Hiller,Schmaltz,1408.1627;Altmannshofer,Staub, 1503.06199;Descotes-Genon,Matias,et al., 1510.04239;Altmannshofer,Stangle,et al., 1704.05435;D'Amico,Nardecchia et al.,1704.05438; etc.)



(Hurth,et al., 1603.00865)



(D'Amico,Nardecchia et al.,1704.05438)