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

Interplay between the LHC and flavor physics

(the B anomalies)

Yuji Omura (KMI)

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3. The new physics interpretations of the $B \to D^{(*)} l \nu$ anomalies.
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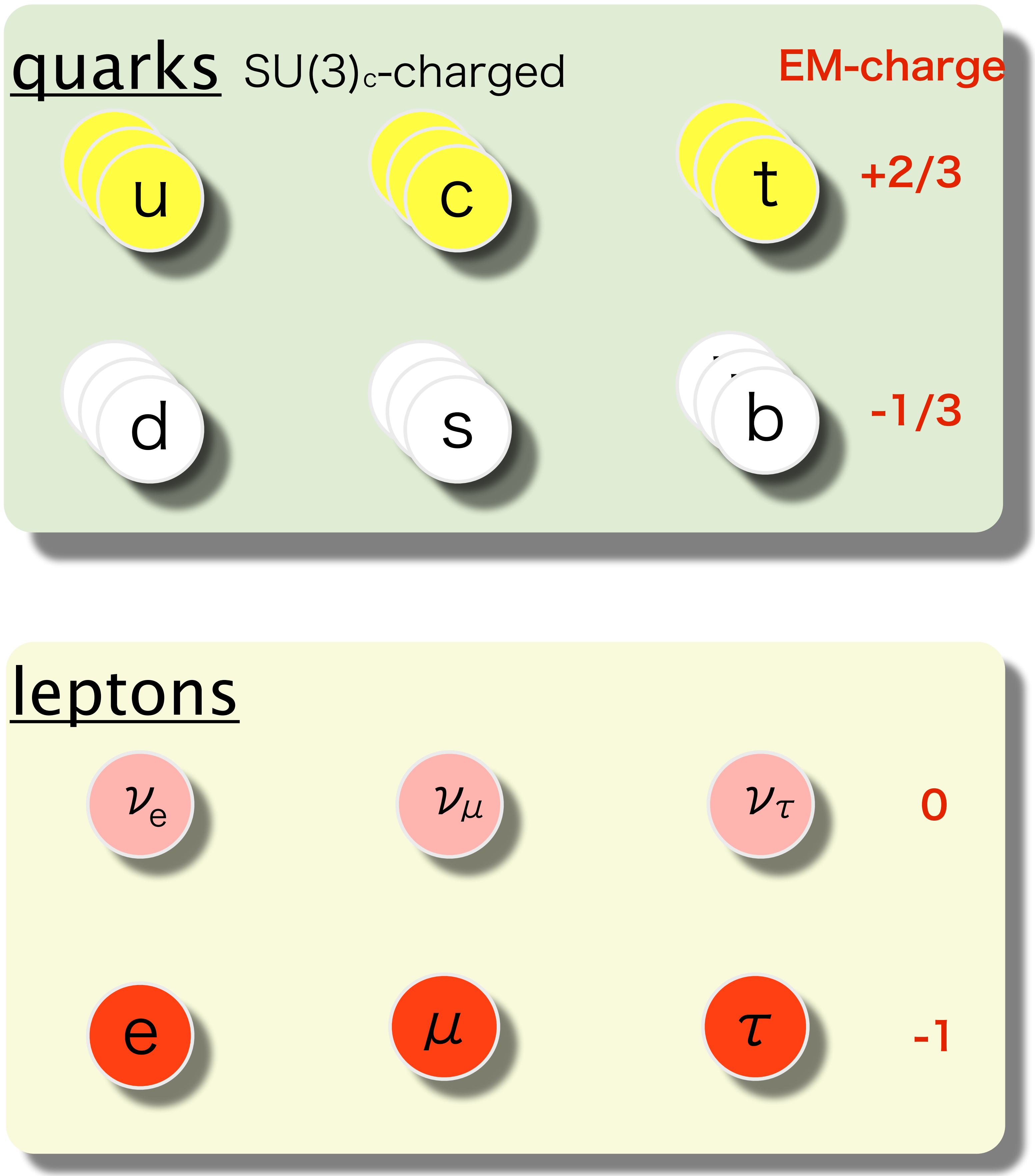
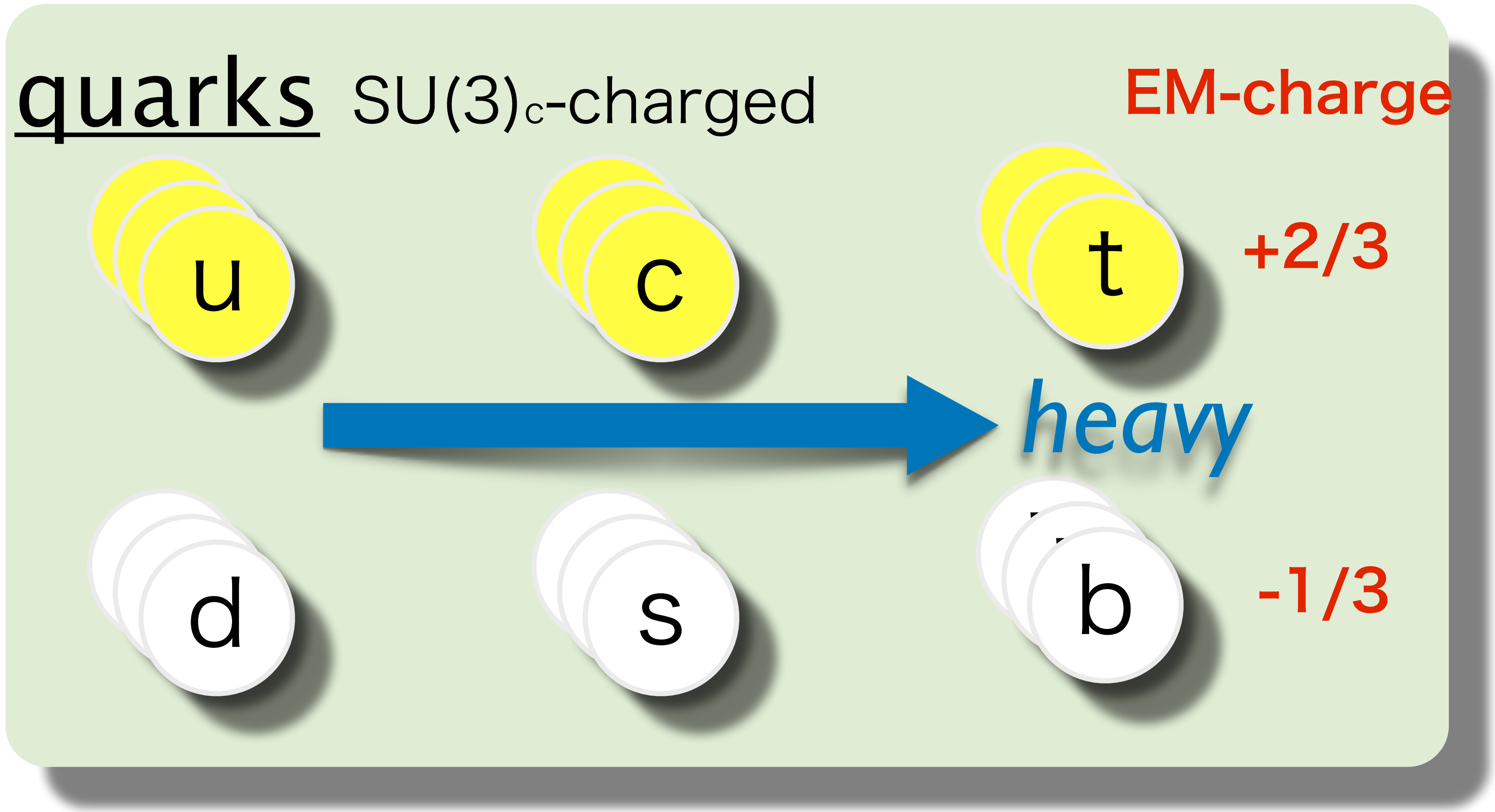
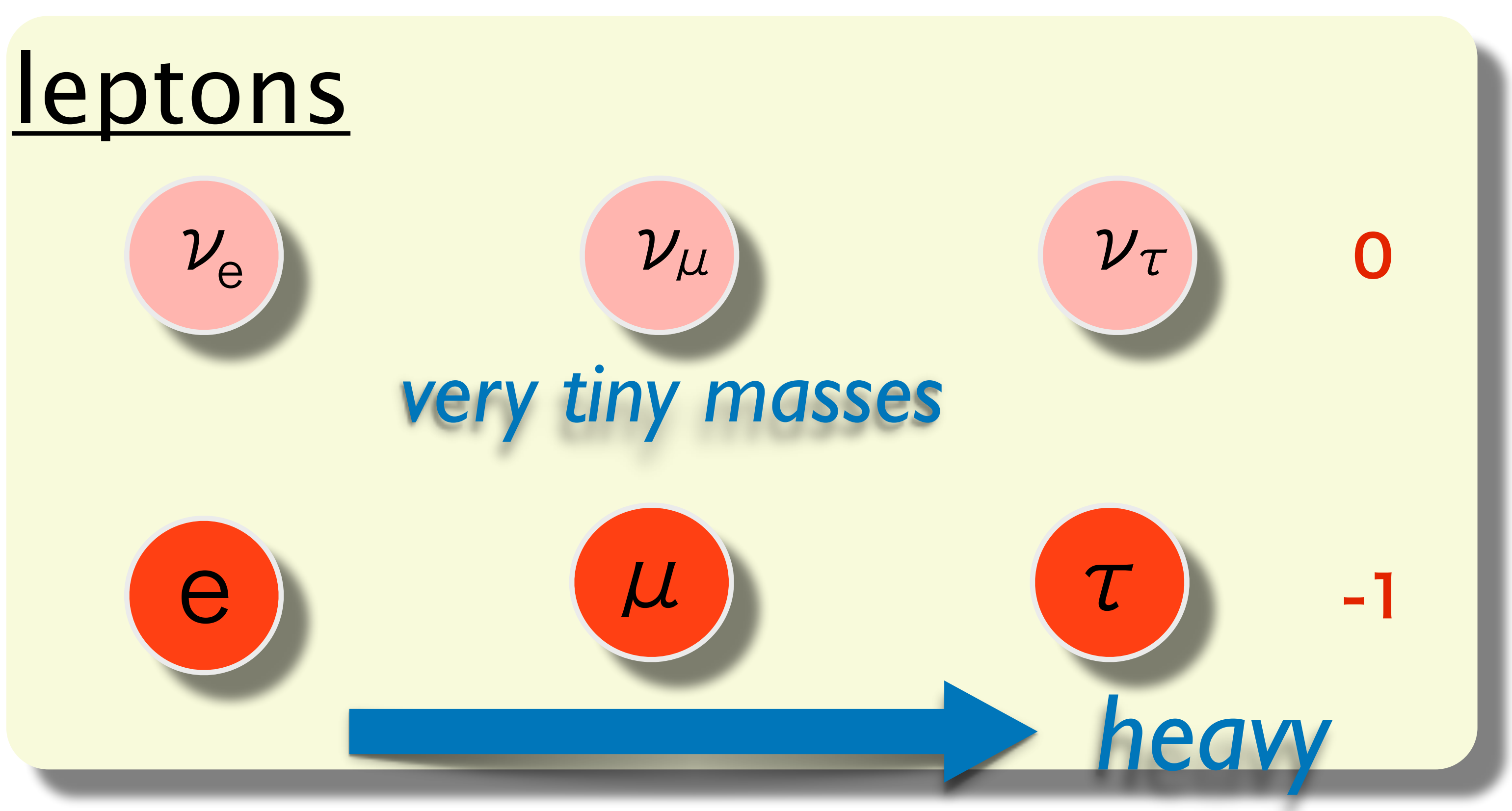
1. Introduction

Elementary particles have flavors!

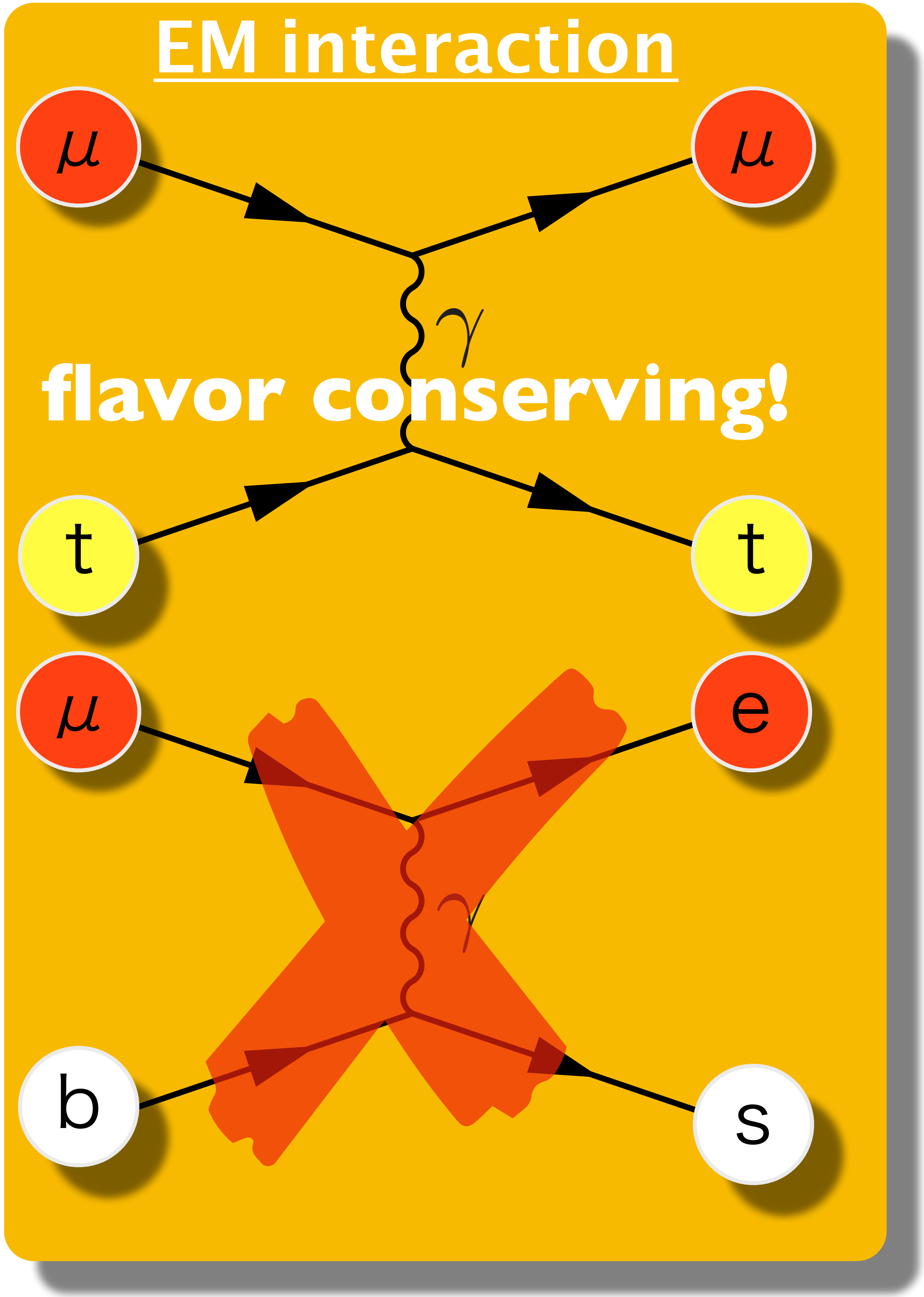


Masses are different!





The interaction and decay modes are also unique!



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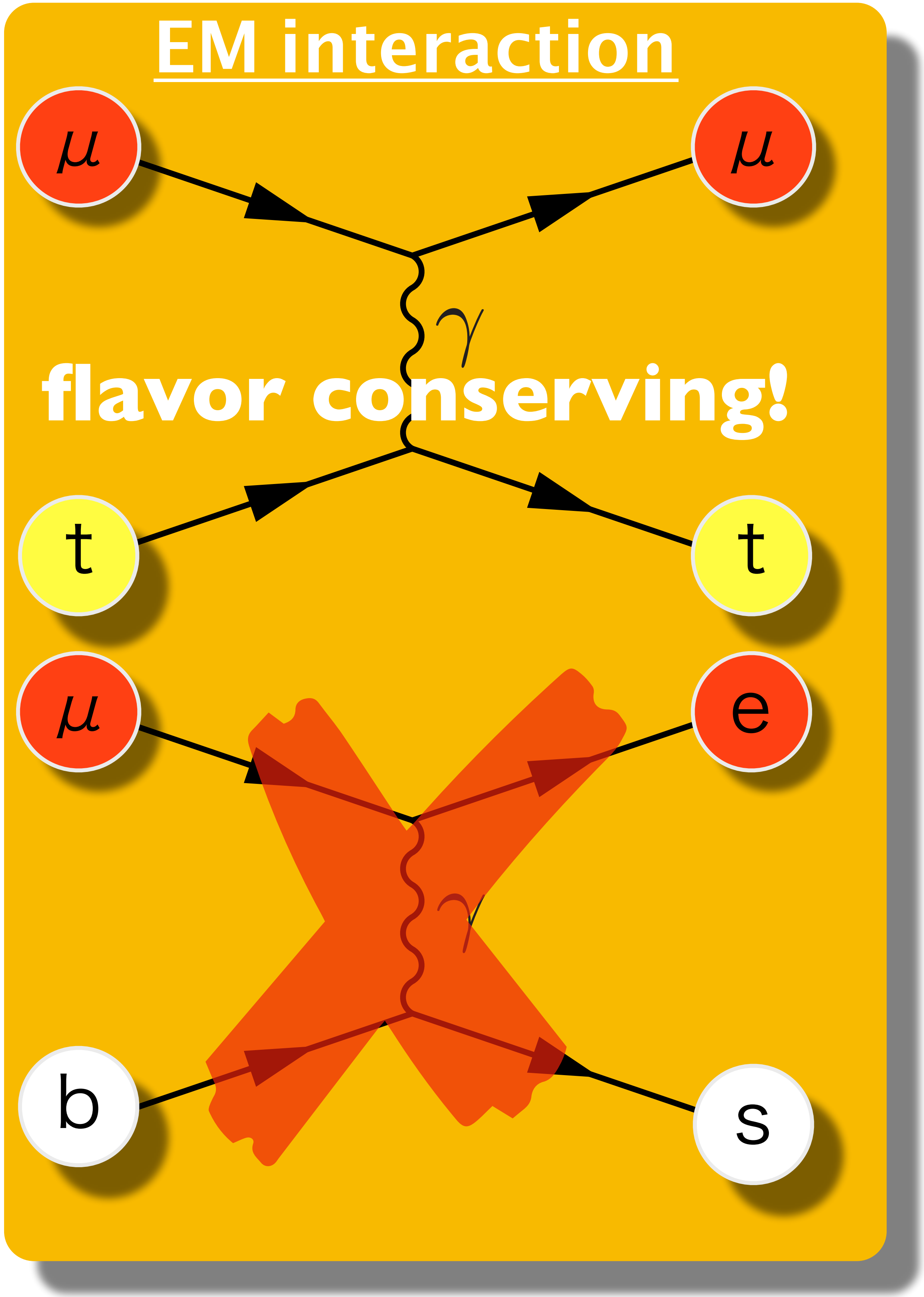

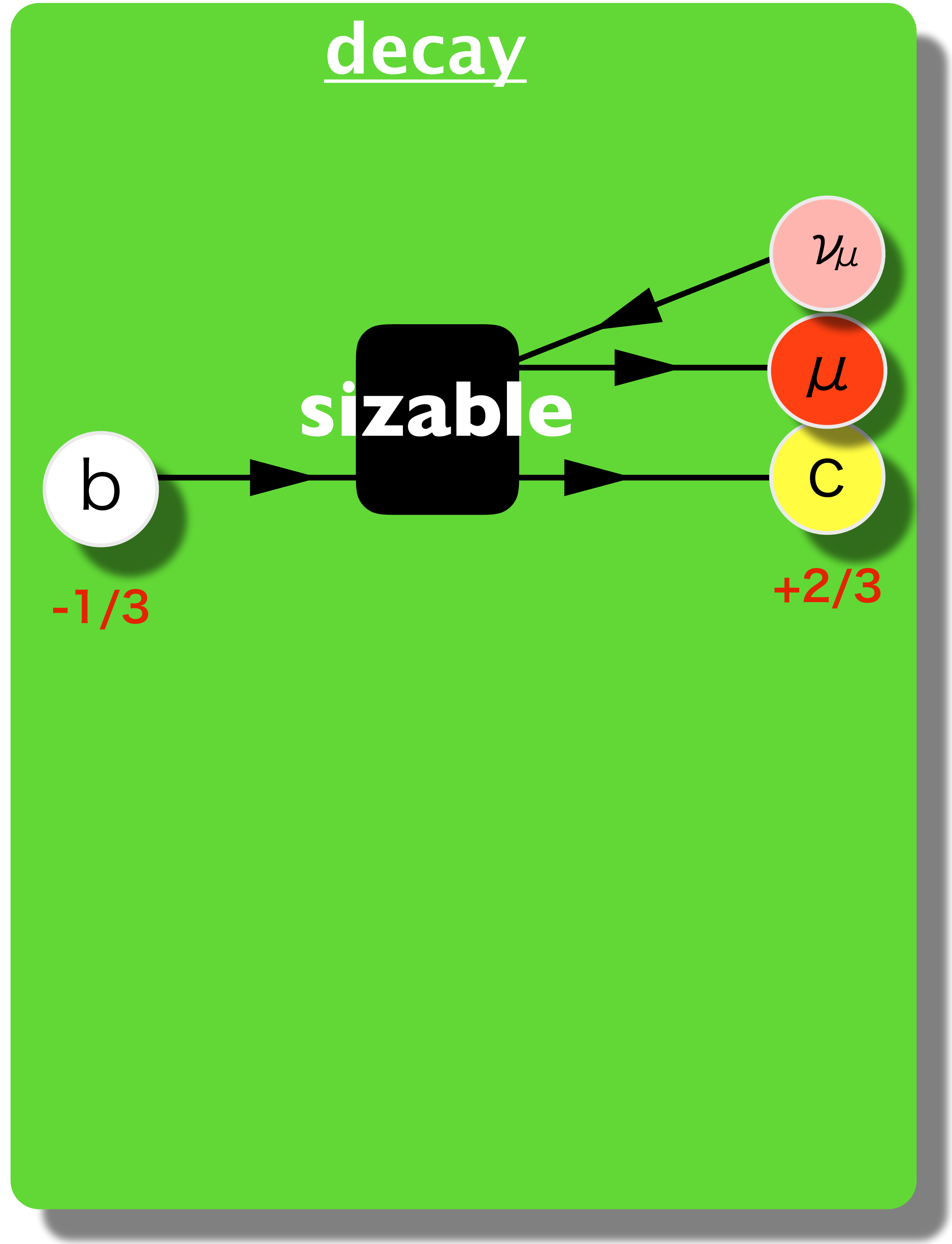

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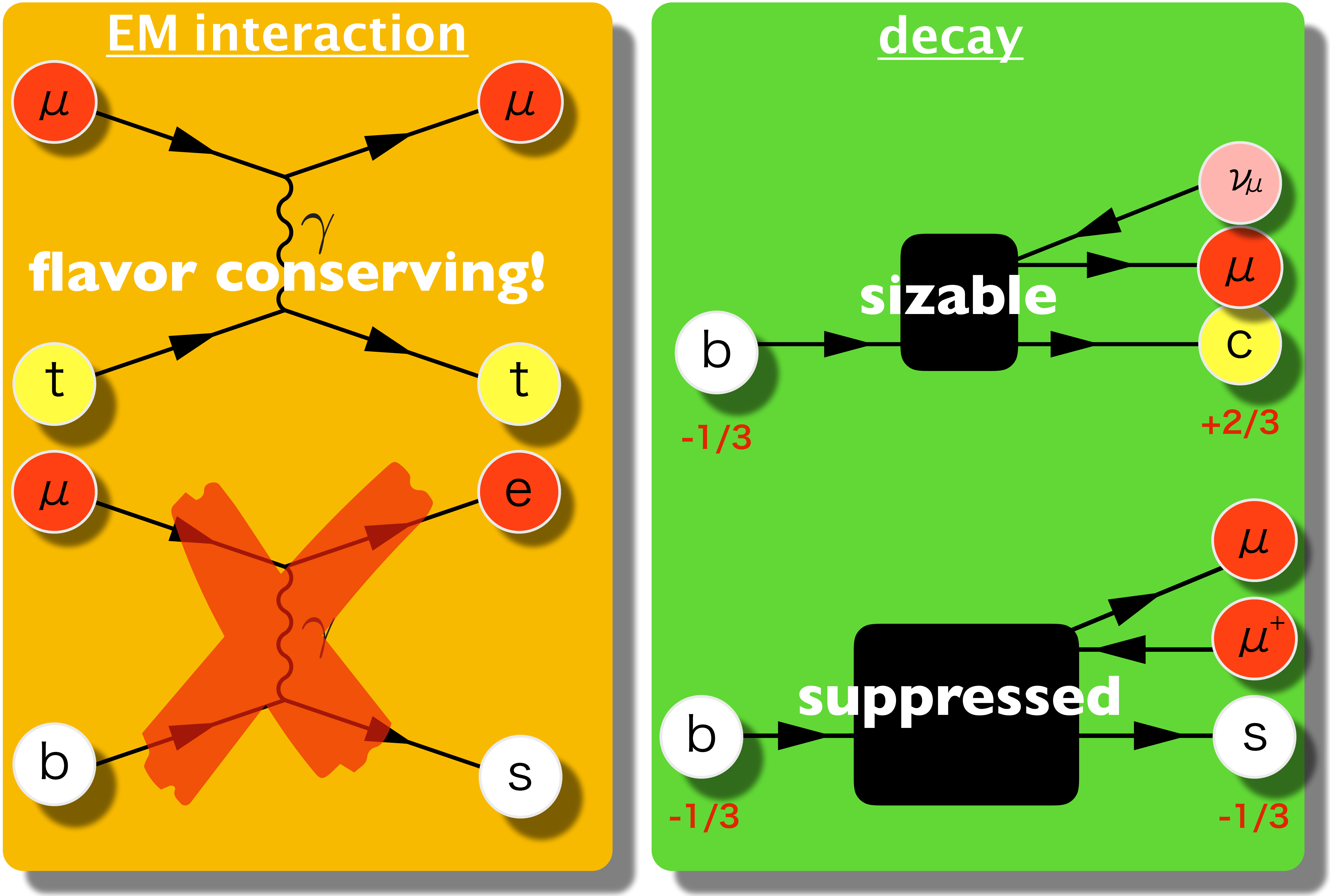

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The Standard Model (SM)

- SU(2)×U(1)→U(1)EM

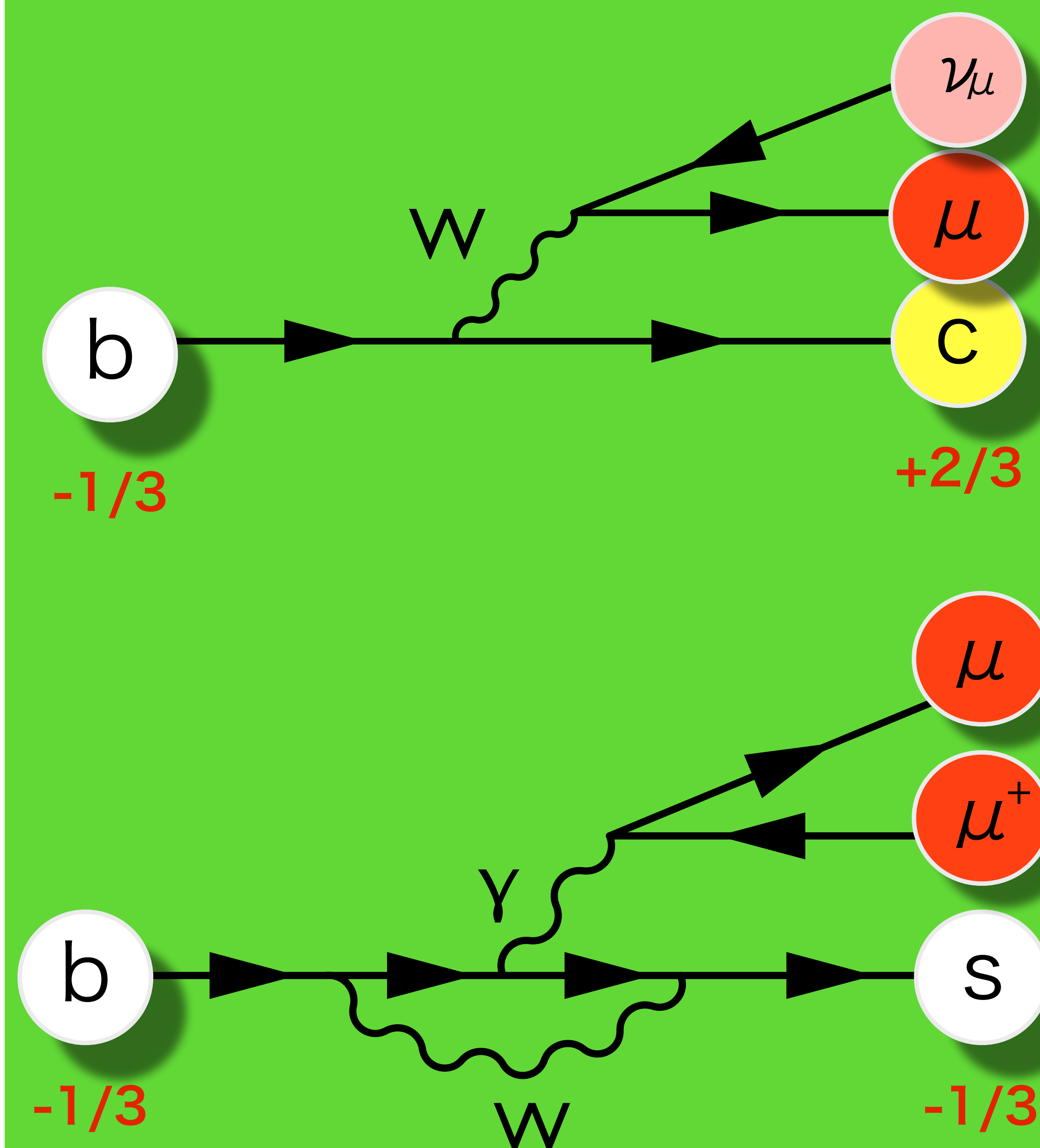
  Massive charged boson (W) is generated.

- W int. can change the flavor.

- The W int. is controlled by the CKM matrix.

  3×3 unitary matrix and close to the unit matrix.

The SM picture of decay



In many flavor processes, the experimental results
look consistent with Standard Model (SM) predictions,
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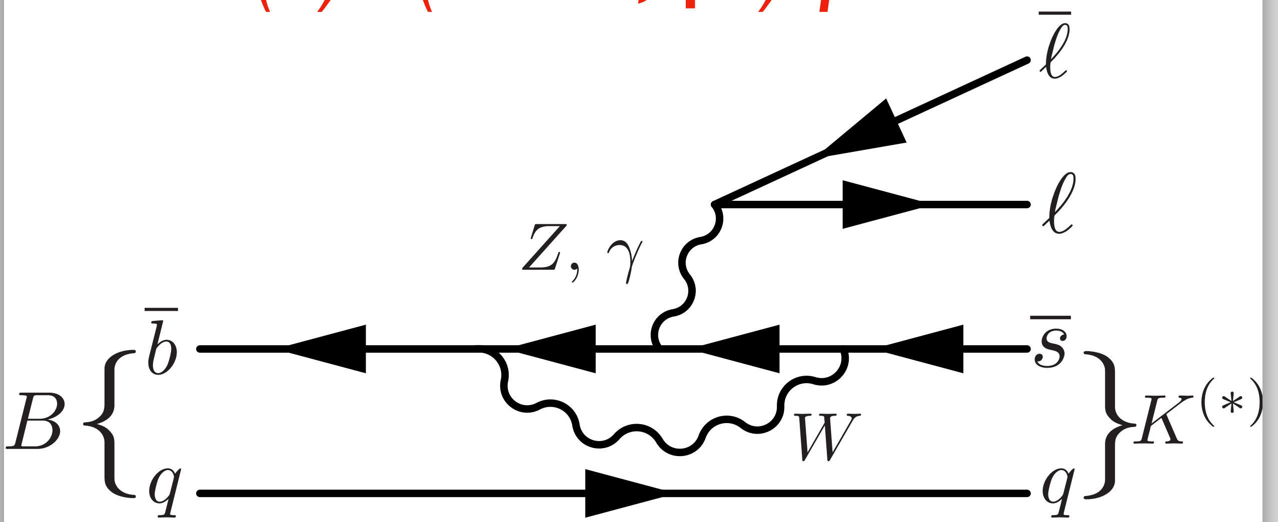
In many flavor processes, the experimental results look consistent with Standard Model (SM) predictions, although we (often) suffer from the theoretical uncertainties.

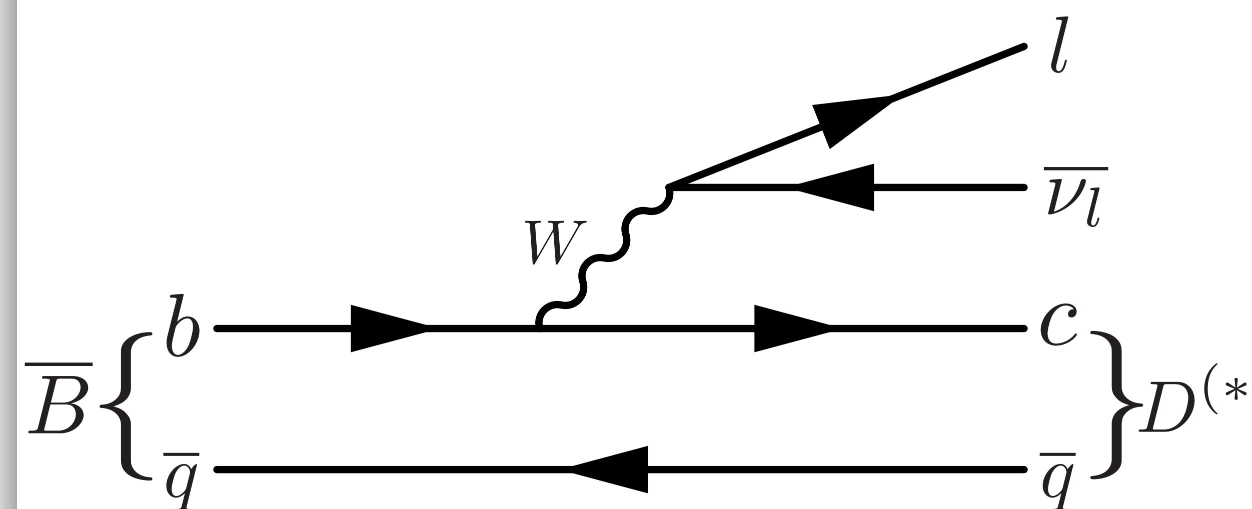
But we may (finally) find the physics beyond the SM.

Deviations from the SM predictions are reported in

$B \to K(*)ll$ (l = e, μ) processes

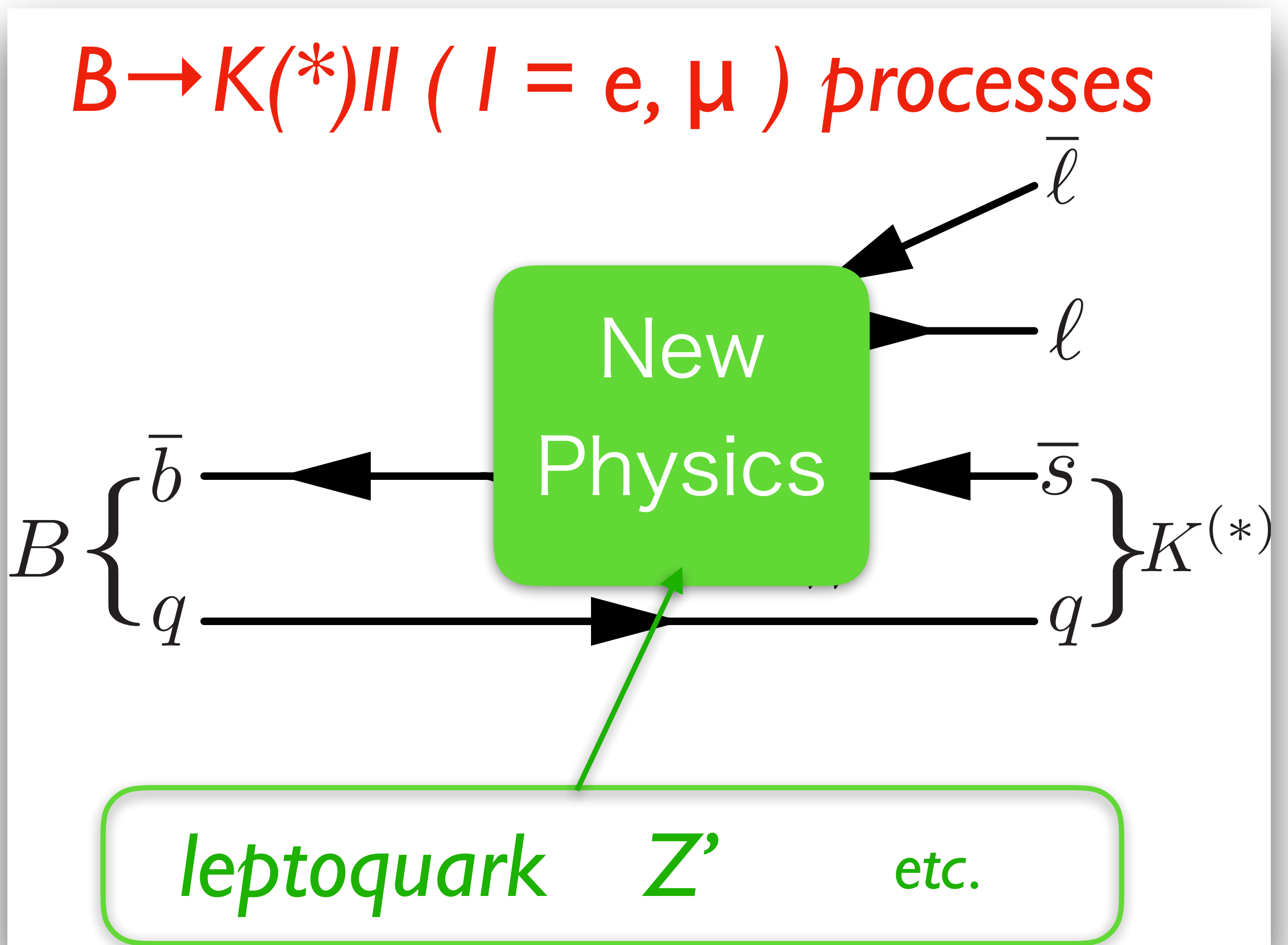


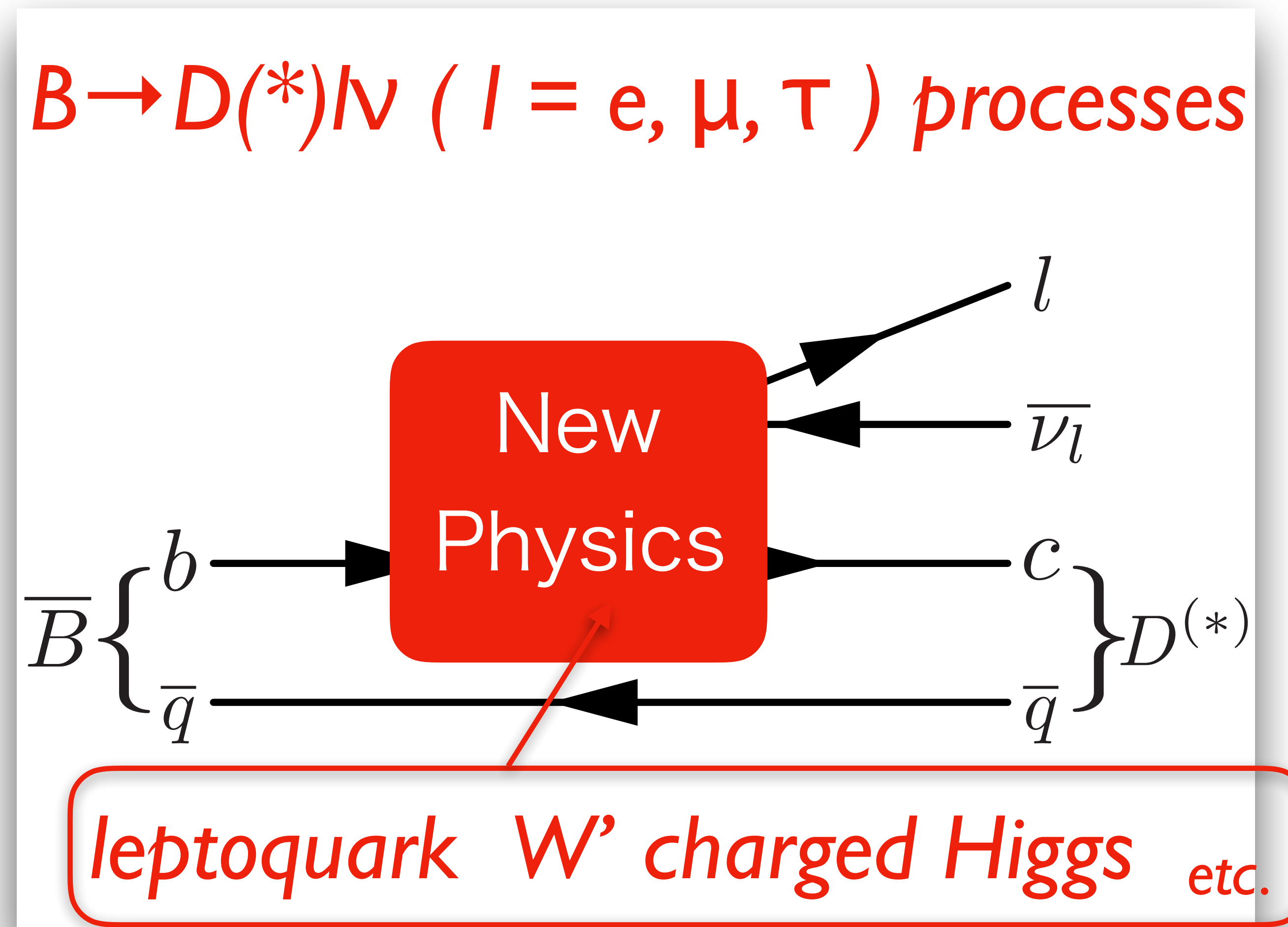
$B \to D(*)l\nu$ (l = e, μ, τ) processes



The deviations are reported in the observables that do not have large theoretical uncertainties.

Many new physics candidates!



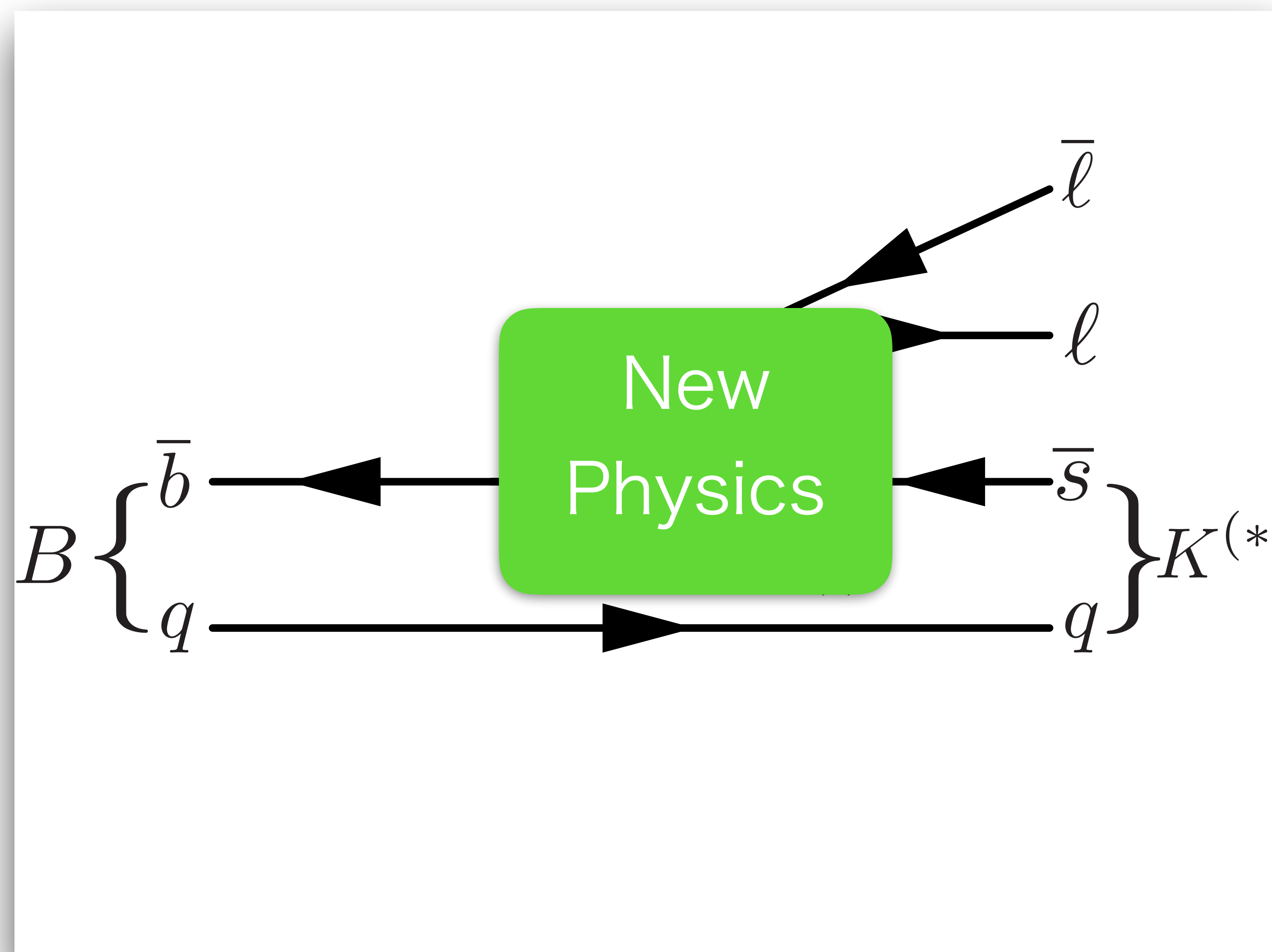


In my talk, I introduce

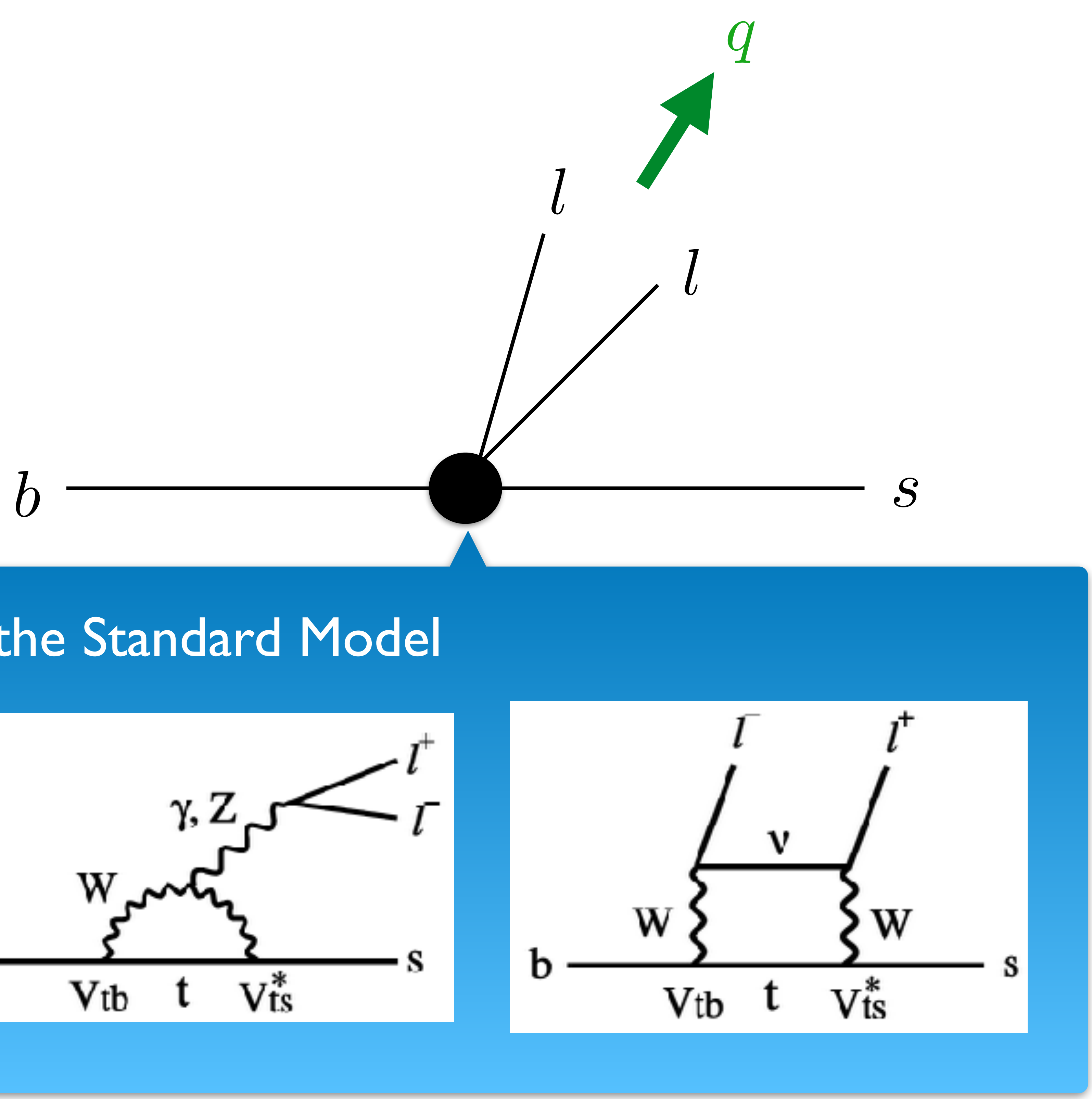
new physics possibilities

how to test them at the LHC etc..

2. The new physics interpretations of the B→K(*)ll anomalies



In the SM, the B ***to K(*) ll*** decays are caused by



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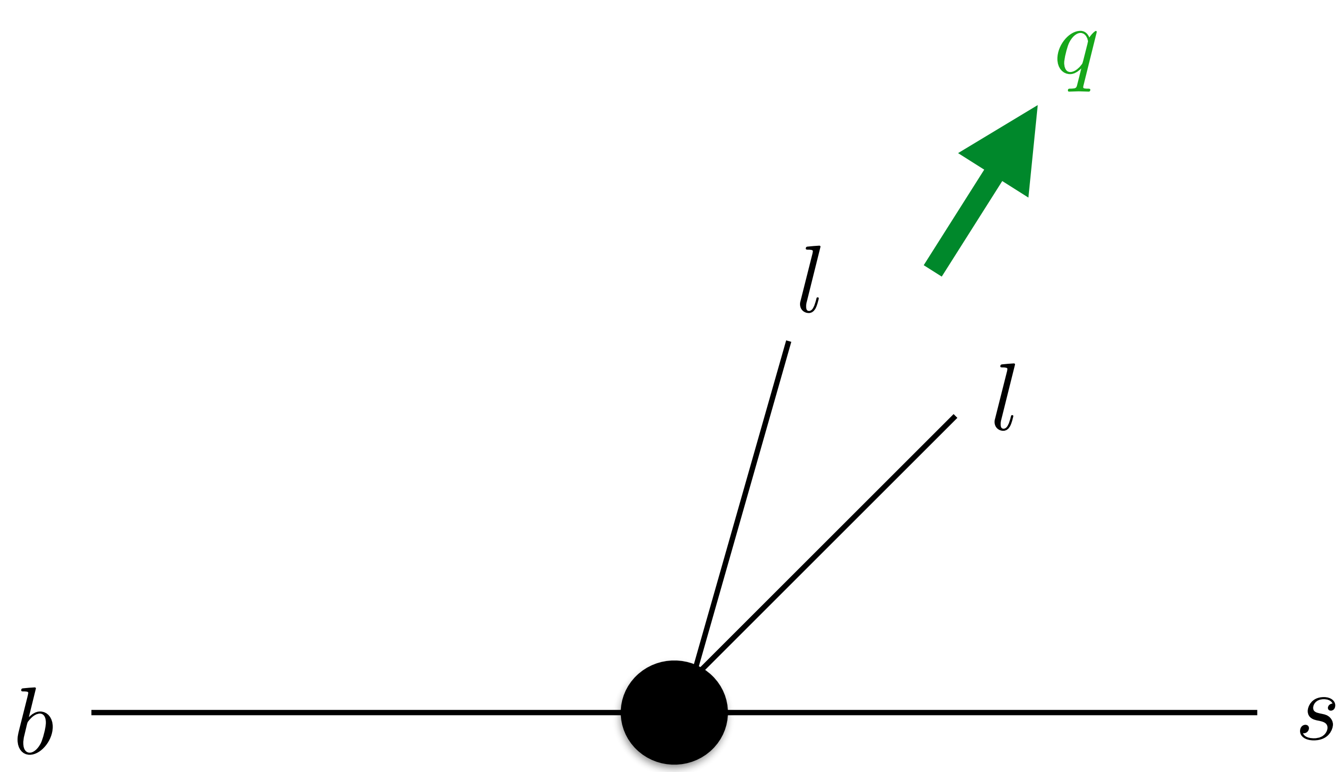
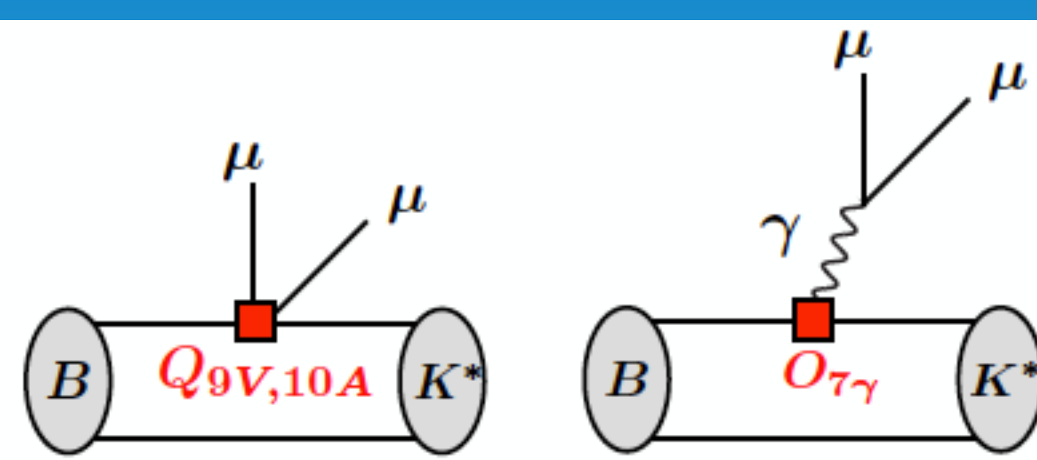


the operators in the Standard Model

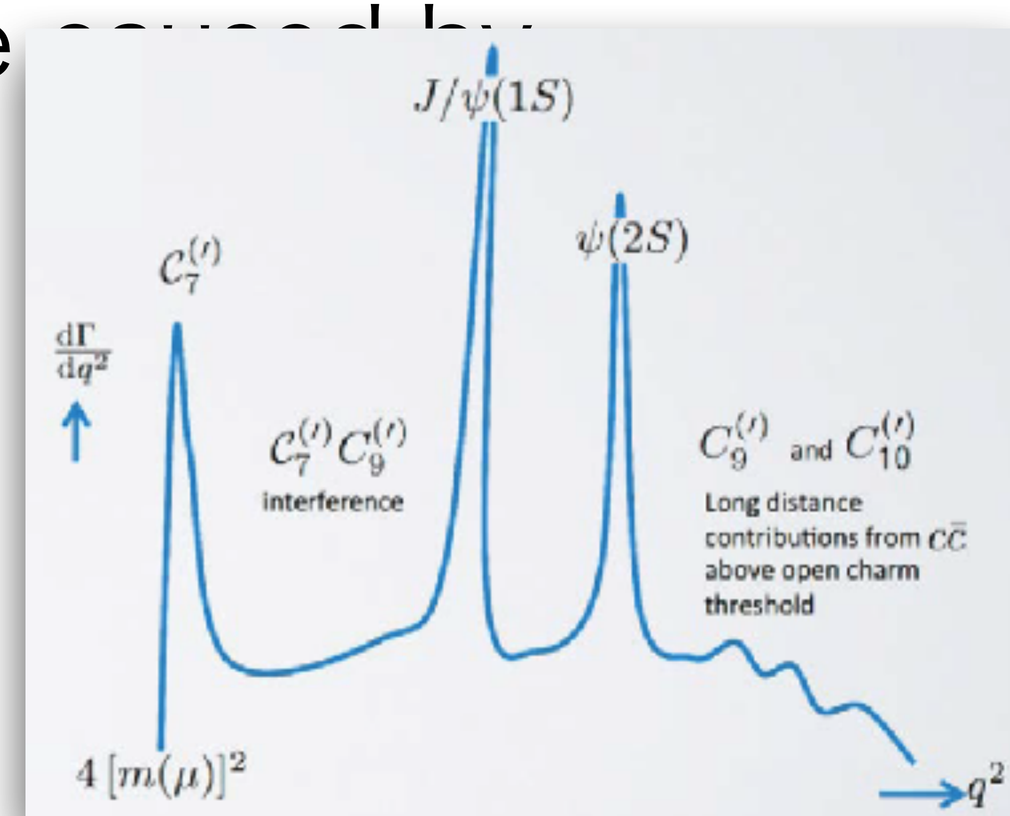
$$O_9 = \frac{e^2}{16\pi^2}(\bar{b}_L \gamma_\mu s_L)(\bar{\ell}\gamma^\mu \ell)$$

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

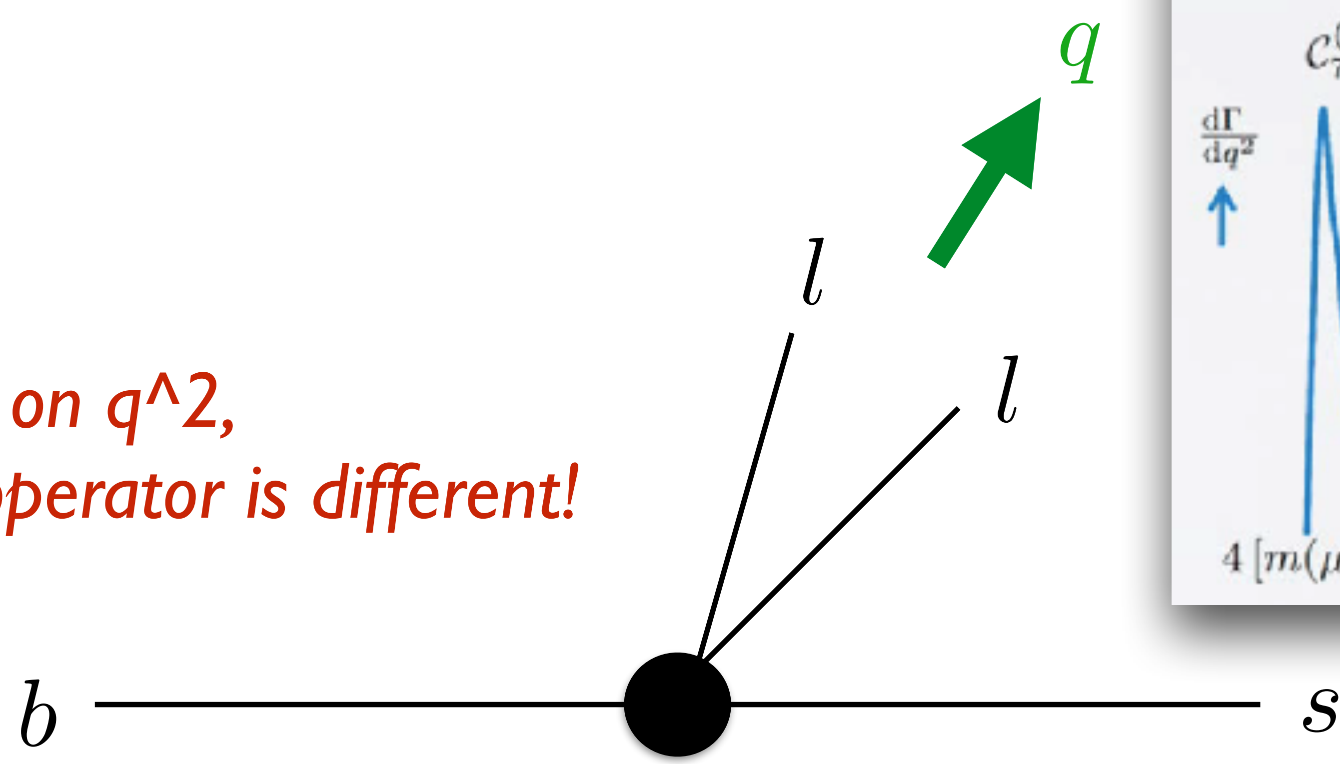
$$O_{7\gamma} = \frac{e}{16\pi^2} m_b \bar{b}_R \sigma^{\mu\nu} s_L F_{\mu\nu}$$



In the SM, the B *to K(*) ll* decays are



Depending on q^2,
dominant operator is different!



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relevant

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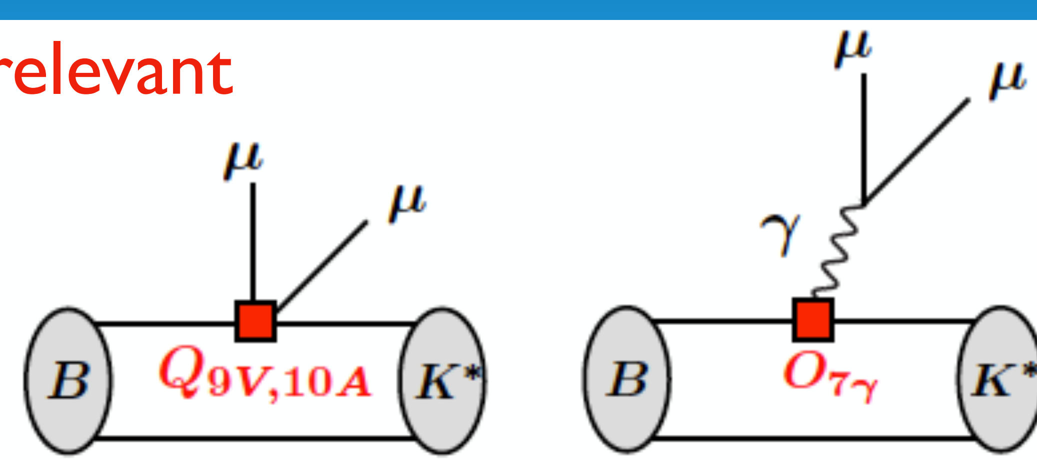
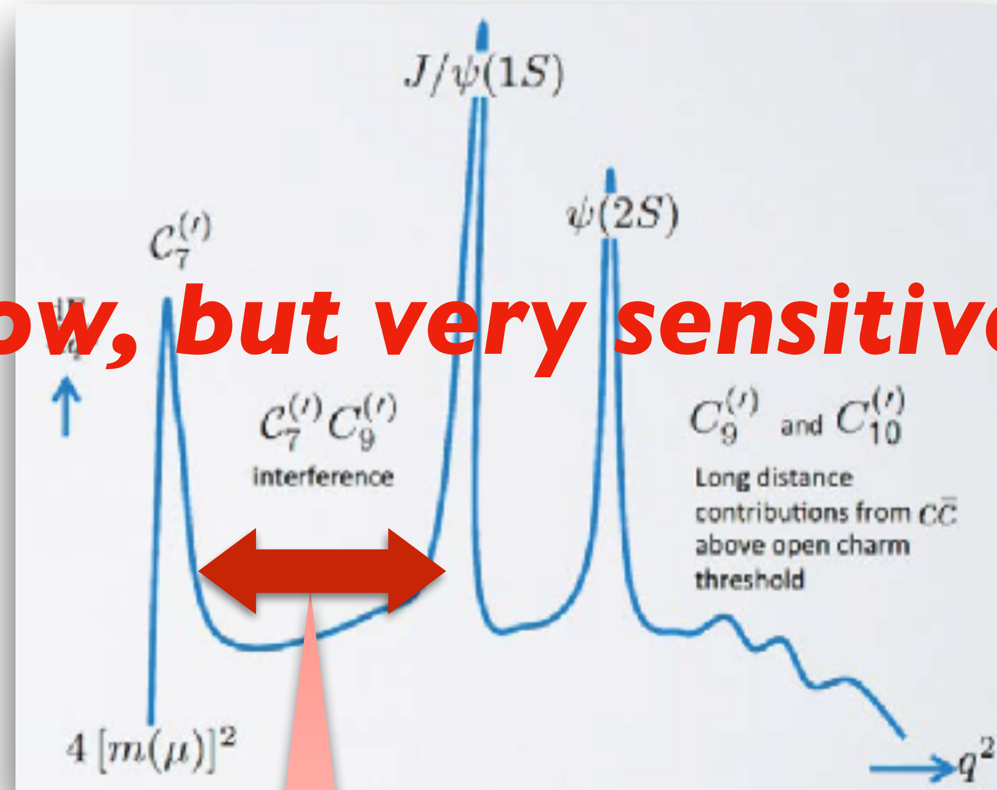


The observables where the excesses are reported in this q^2 region:



Looks very narrow, but very sensitive to new physics!

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

Lepton universality in $B_0 \to K_0^* l^+ l^- \; (l = e,\, \mu)$ *(1705.05802)*

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

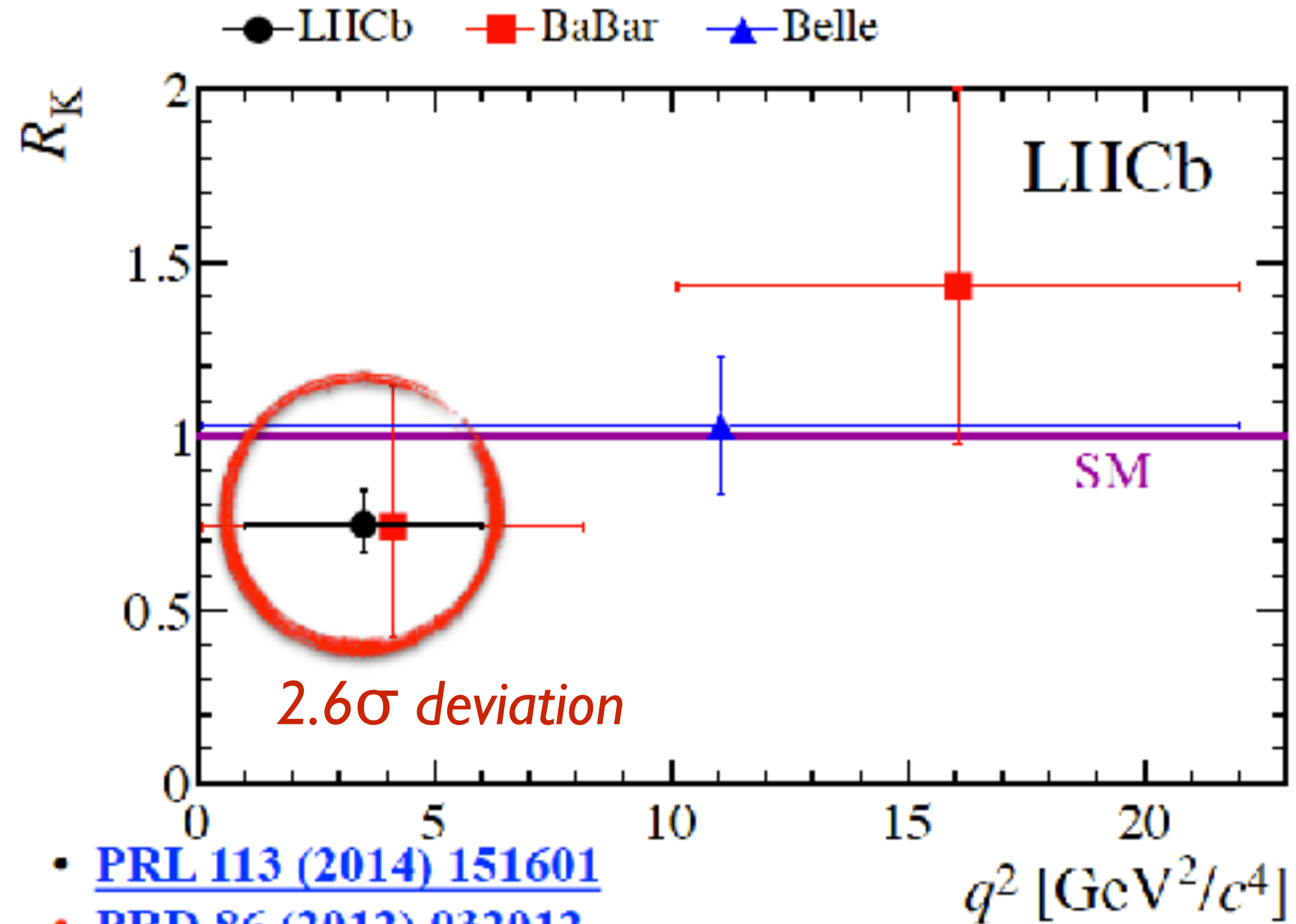
@LHCb experiment.

The deviations are reported in the observables that do not have large theoretical uncertainties.

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

observable

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

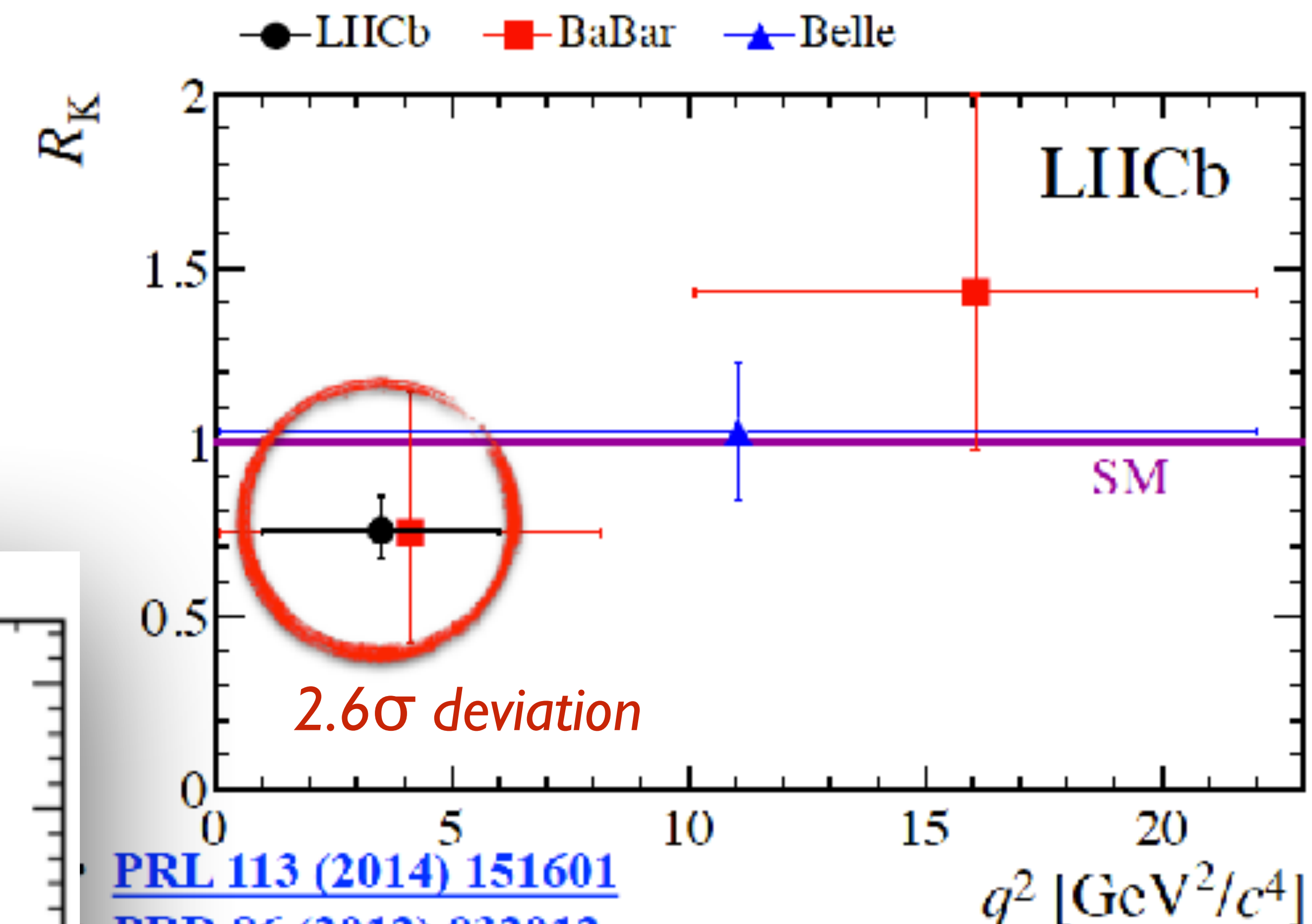


- PRL 113 (2014) 151601
- PRD 86 (2012) 032012
- PRL 103 (2009) 171801

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

observable

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



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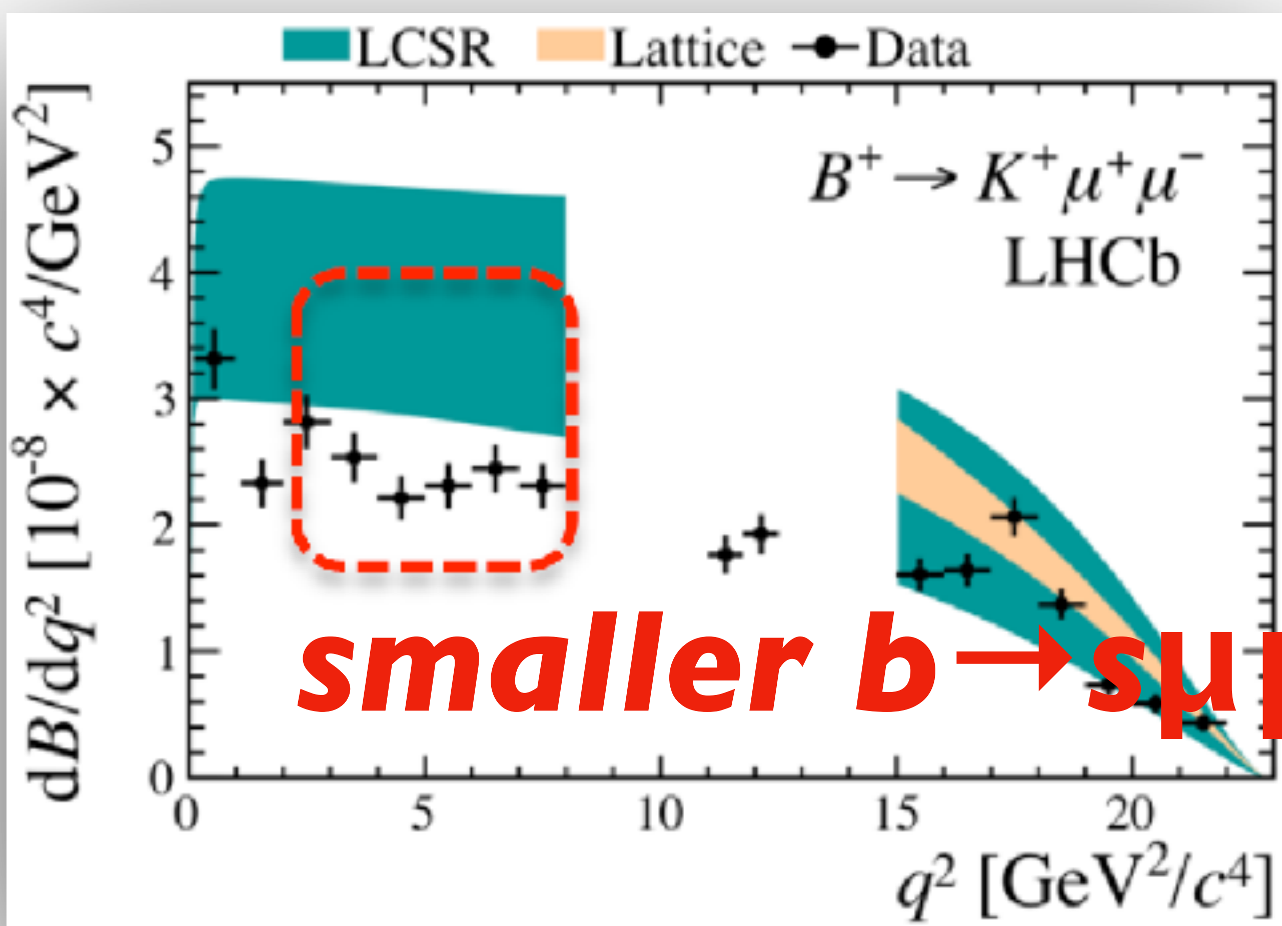
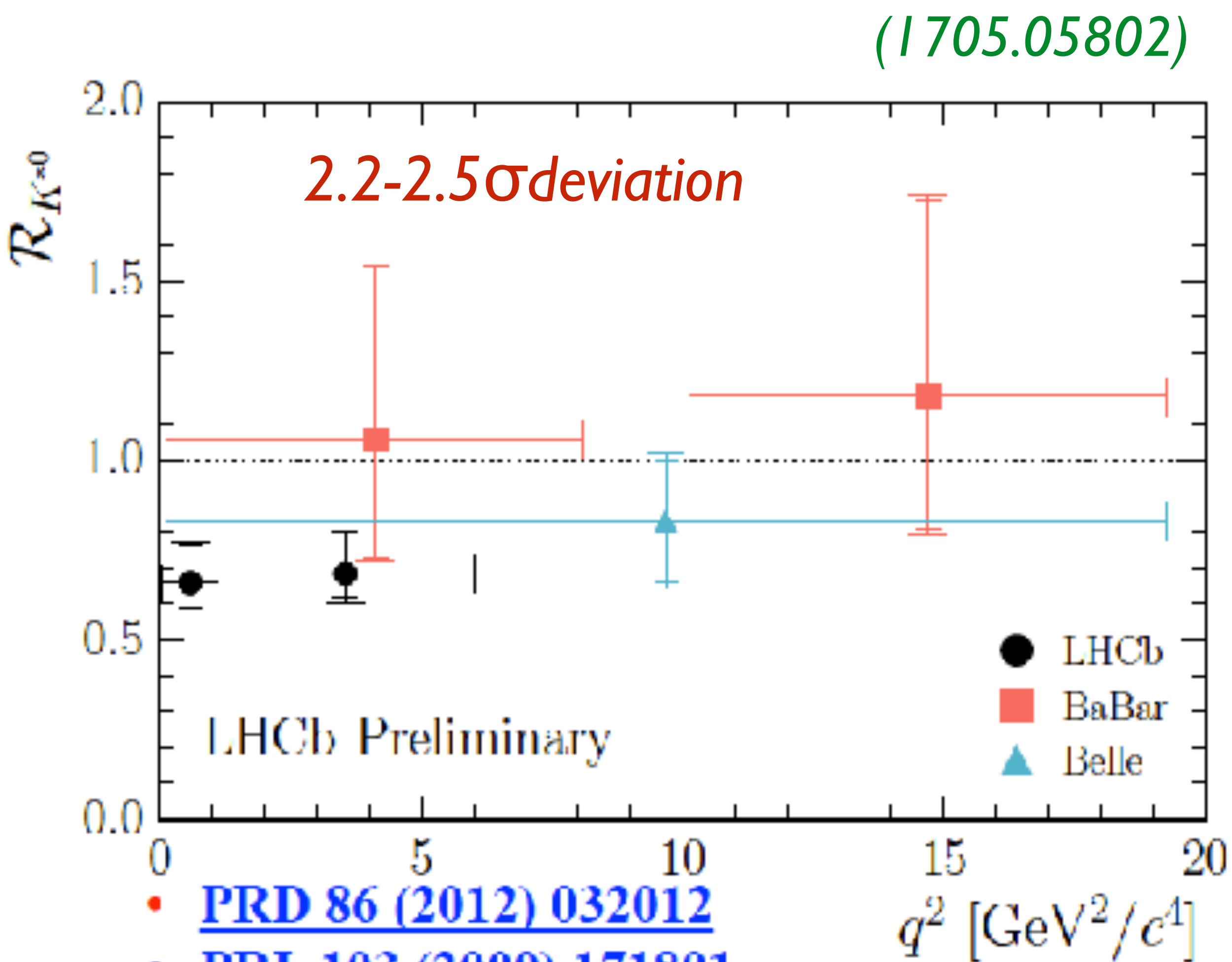


smaller b→sμμ is suggested.

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



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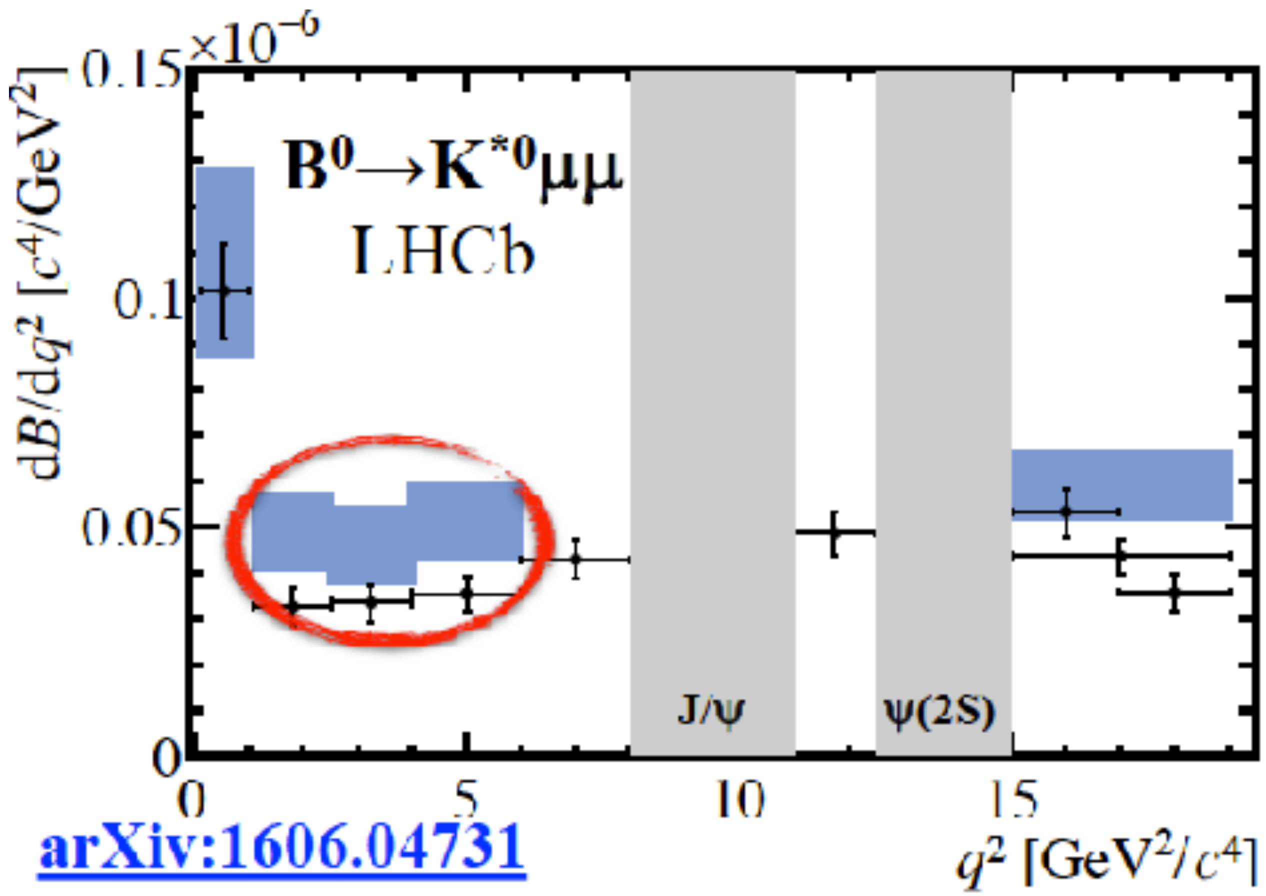


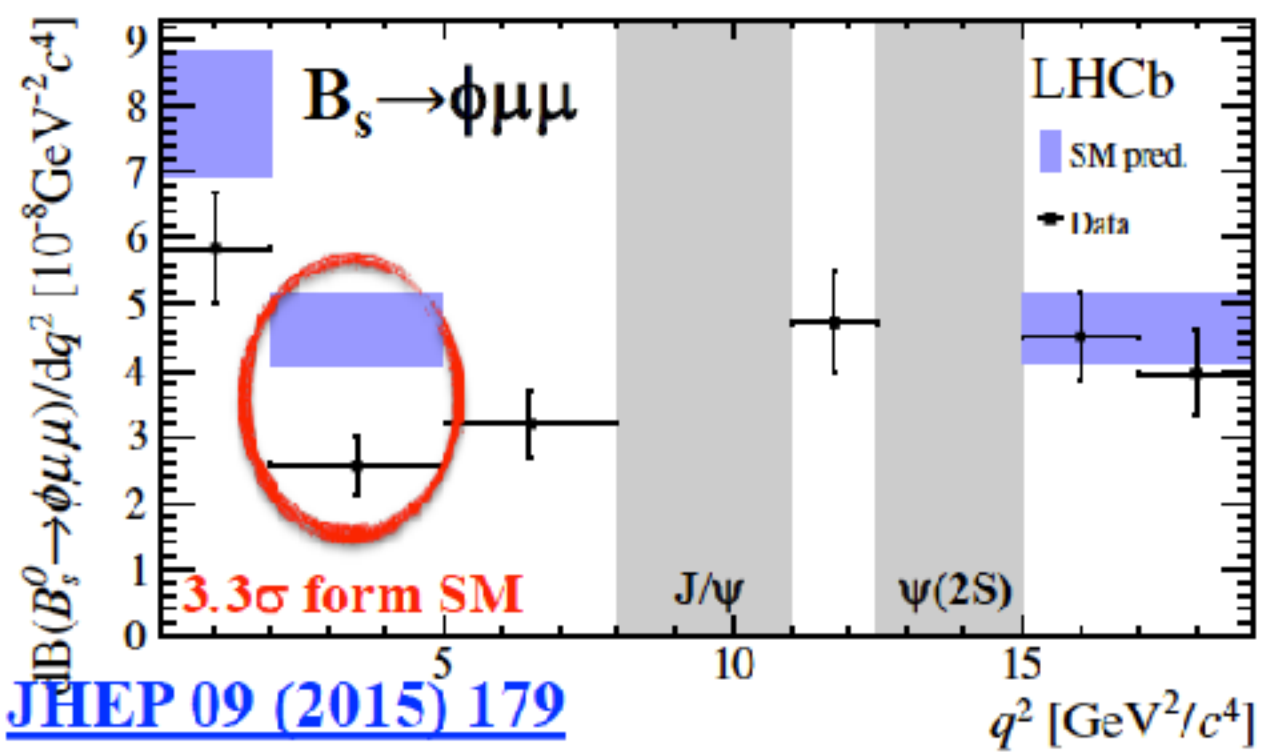
arXiv:1606.04731

smaller b→sμμ is suggested.

Other excesses caused by b→s$\mu\mu$

Branching ratio of $B_s \to \phi\mu^+\mu^-$

(1506.08777)



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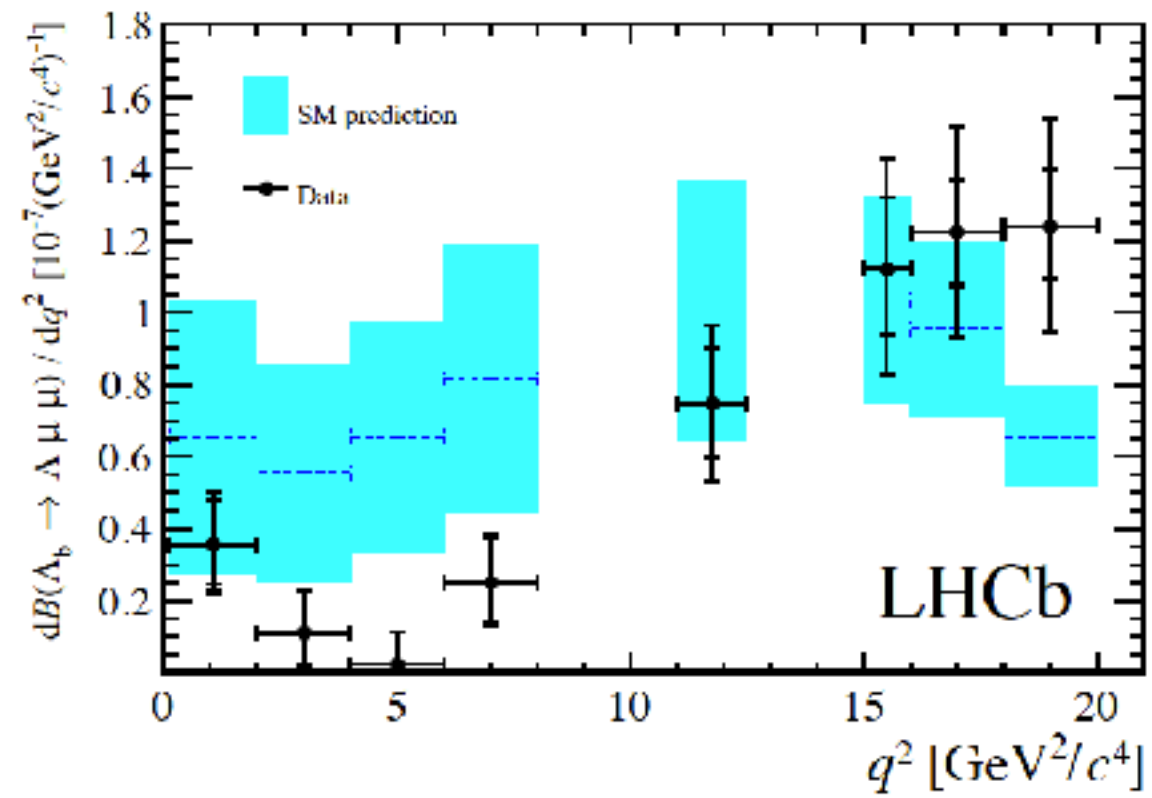
Branching ratio of $\Lambda_b^0 \to \Lambda\mu^+\mu^-$

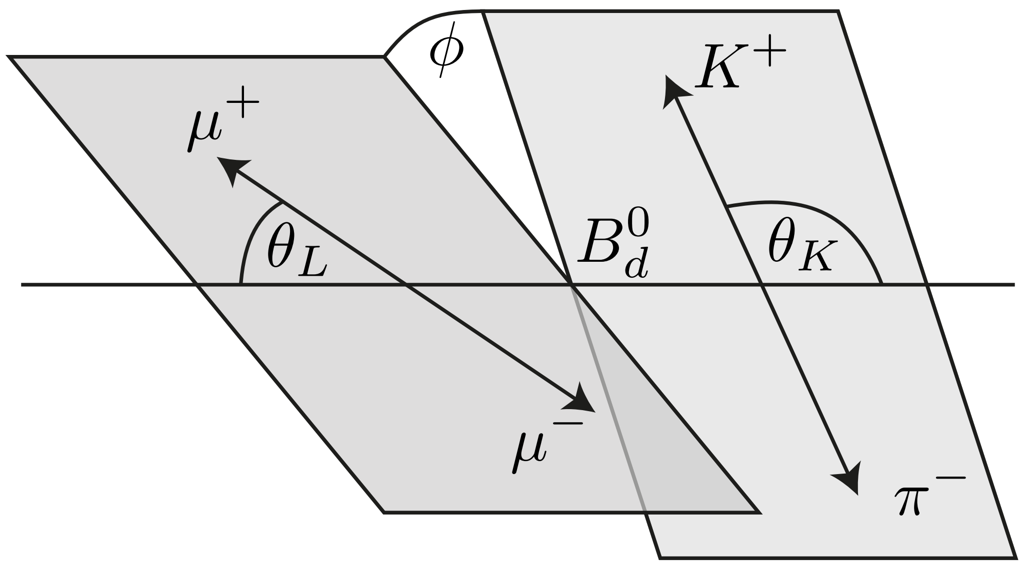
(1503.07138)



smaller b→sμμ is suggested.

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

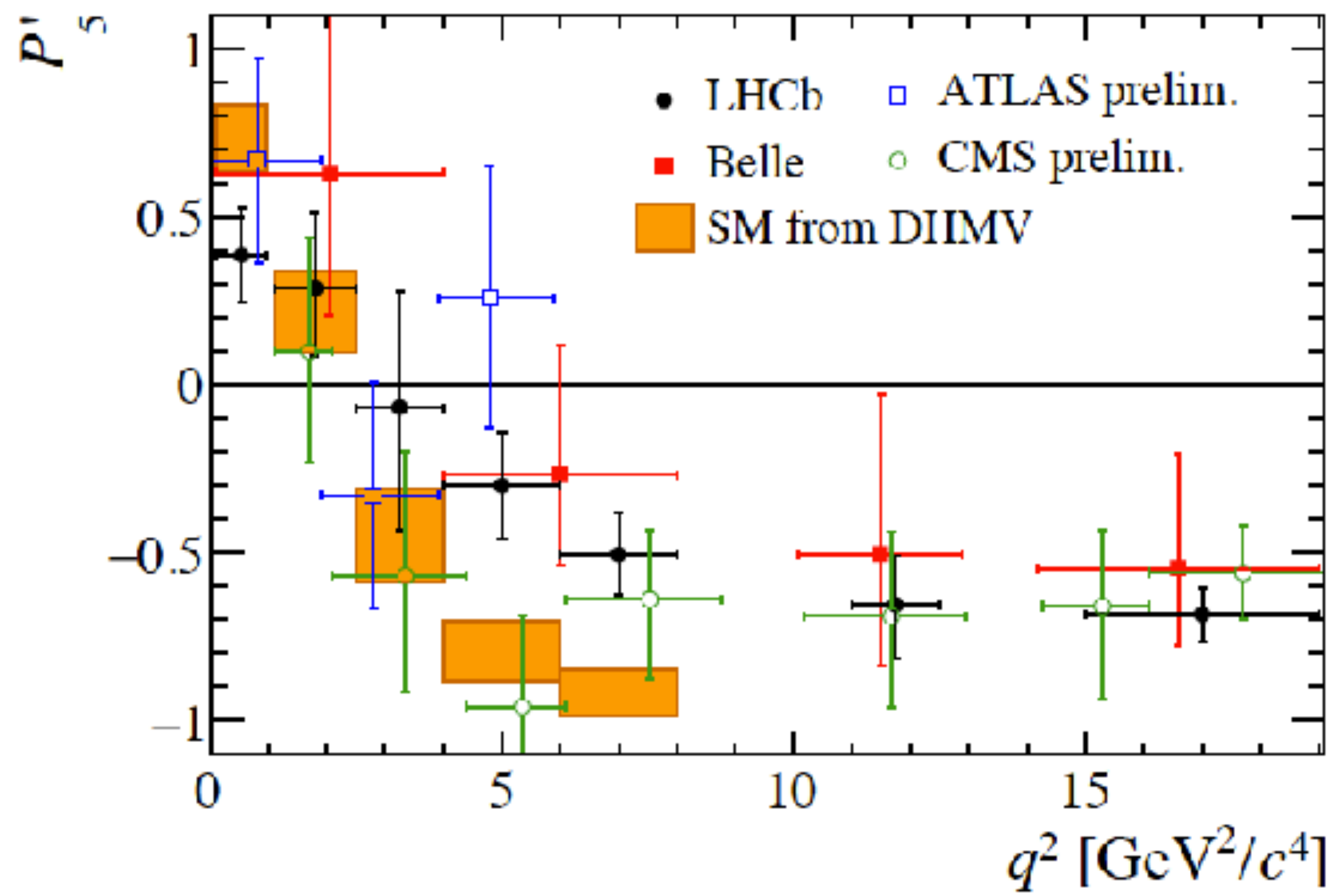
(1308.1707; 1512.04442; ATLAS-CONF-2017-023;CMS-PAS-BPH-15-008)



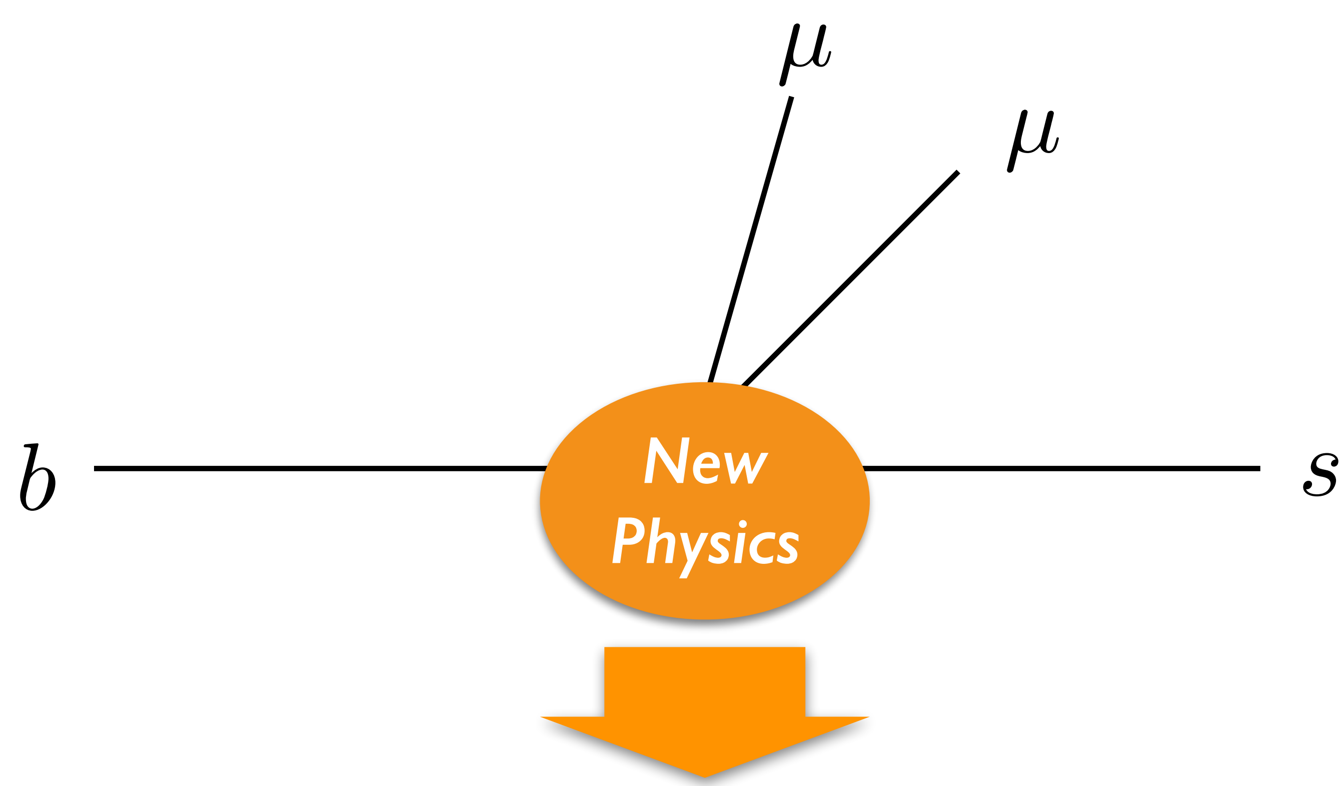
$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi\, dq^2}$$

$$= \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+ S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi$$
$$+ S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big],$$

(Blake,Gersabeck, et al., 1703.10005)



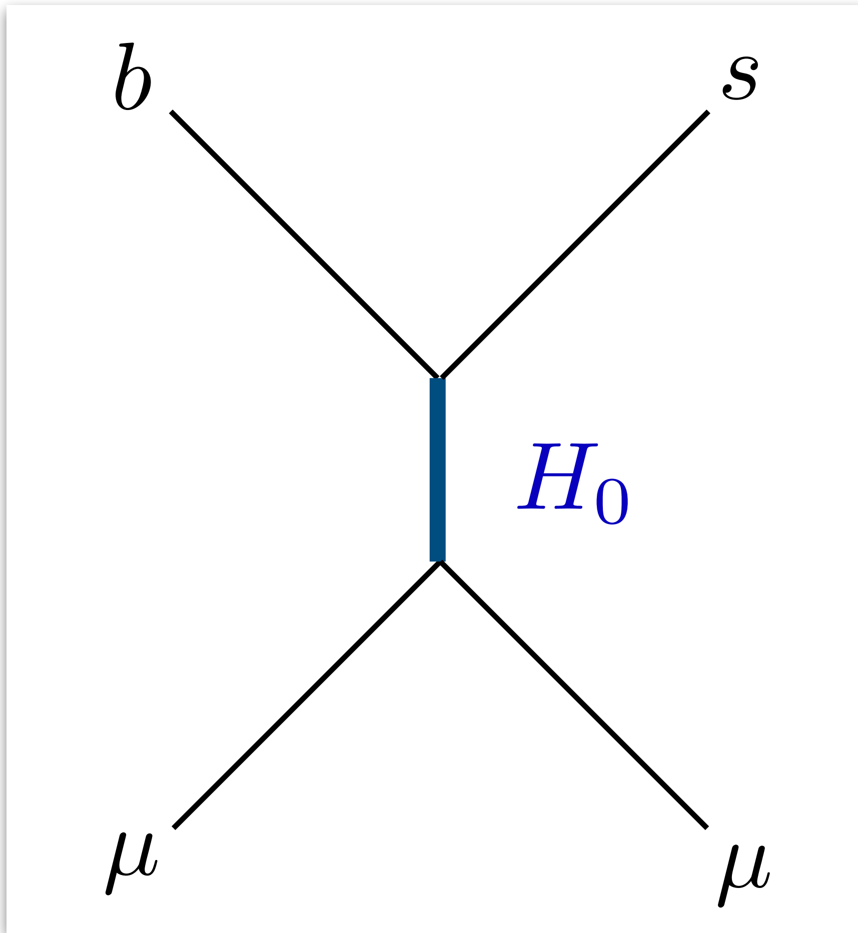
Many new physics interpretations have been proposed

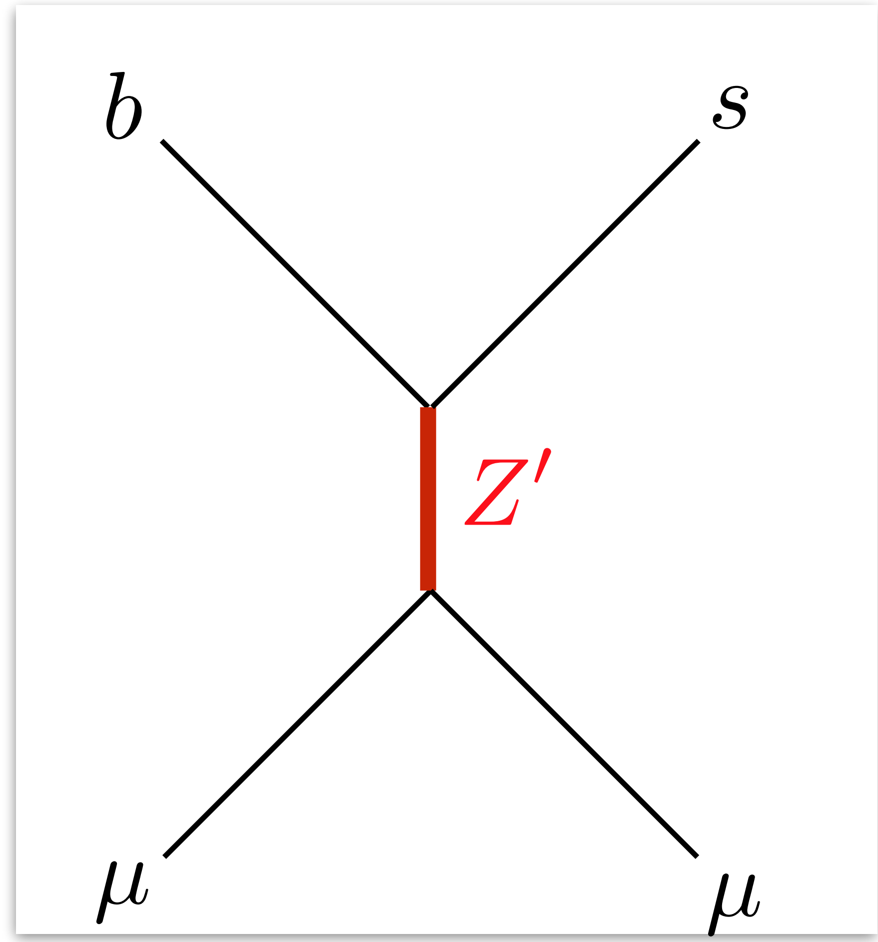


Depending on the new physics,
the spin structure is different.

$(\overline{s_I}\gamma_\mu b_I)(\overline{\mu}_J\gamma^\mu \mu_J)\ (I, J = L,\ R)$ etc.

demonstration





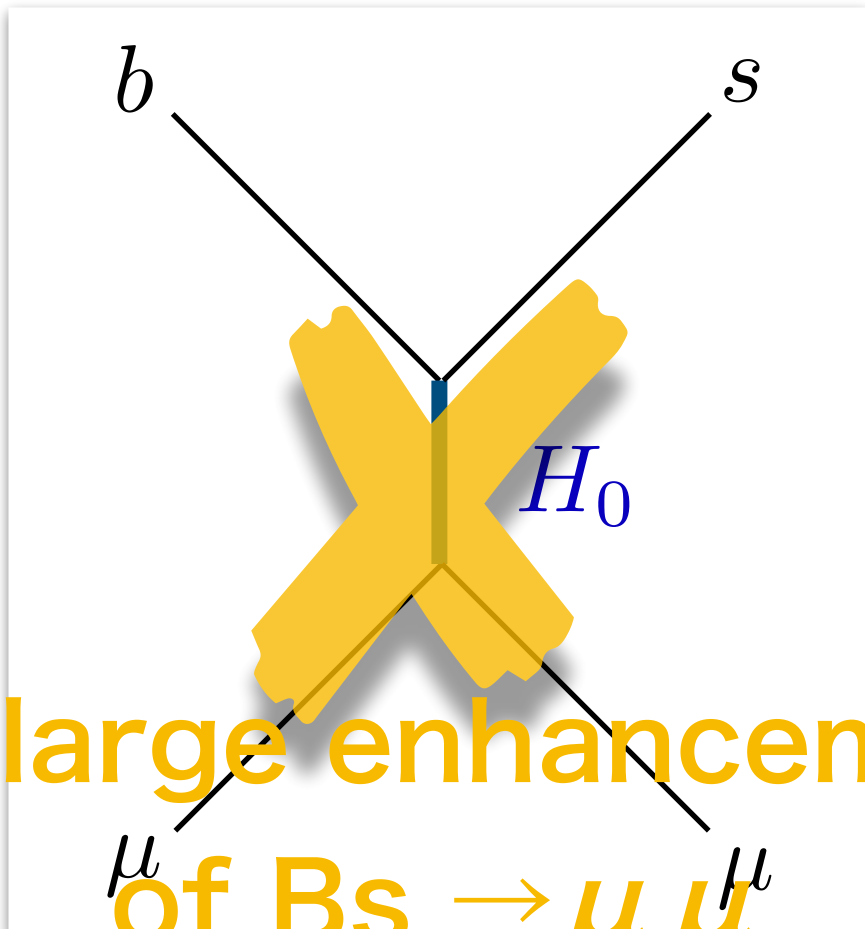
$$\frac{1}{\Lambda^2}(\overline{s_L} b_R)(\overline{\mu_R} \mu_L)$$

$$\frac{1}{\Lambda^2}(\overline{s_L}\gamma_\mu b_L)(\overline{\mu}\gamma^\mu \mu)$$

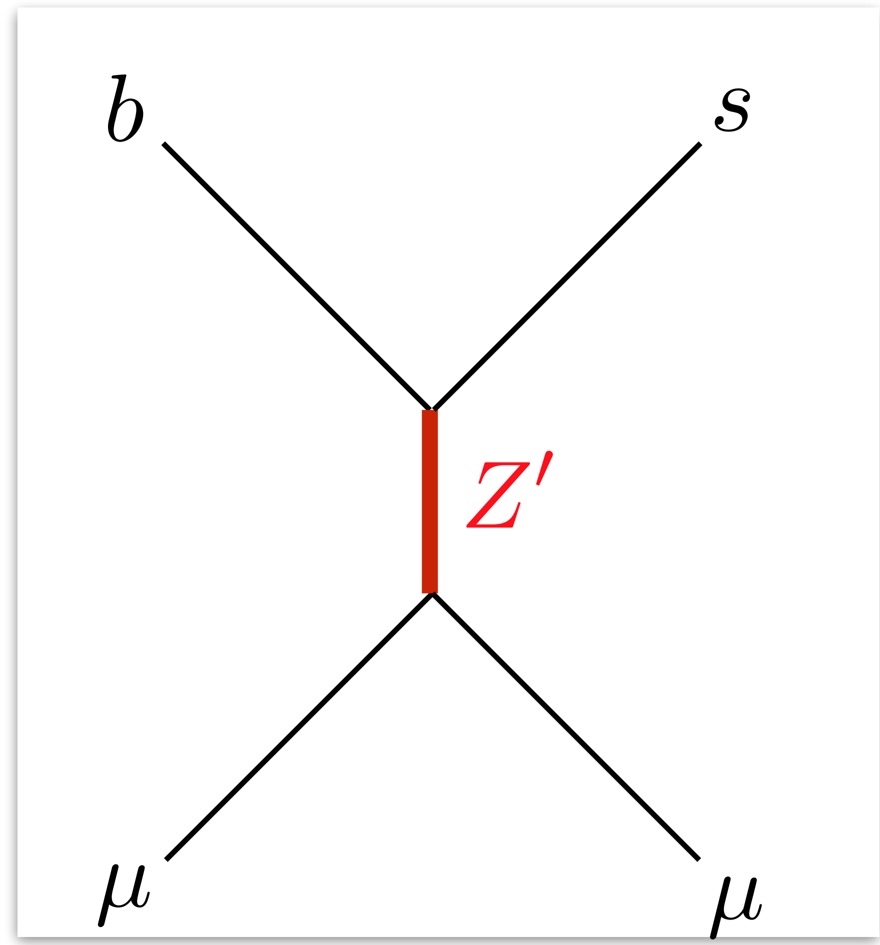
$$\frac{1}{\Lambda^2}(\overline{s_R}\gamma_\mu b_R)(\overline{\mu}\gamma^\mu \mu)$$

etc.

demonstration



too large enhancement of Bs $\to \mu\,\mu$



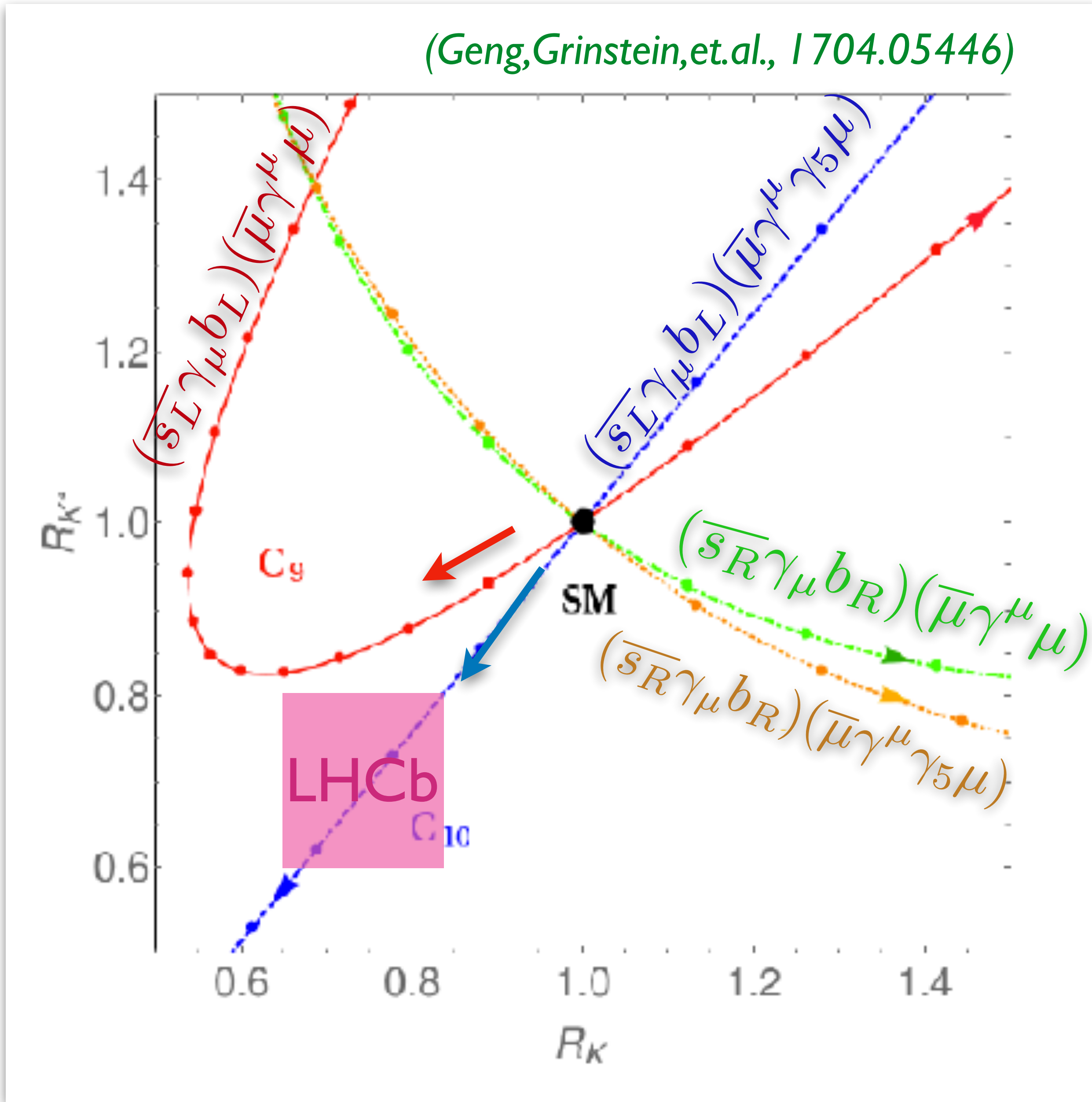
$$\frac{1}{\Lambda^2}(\overline{s_L} b_R)(\overline{\mu_R}\mu_L)$$

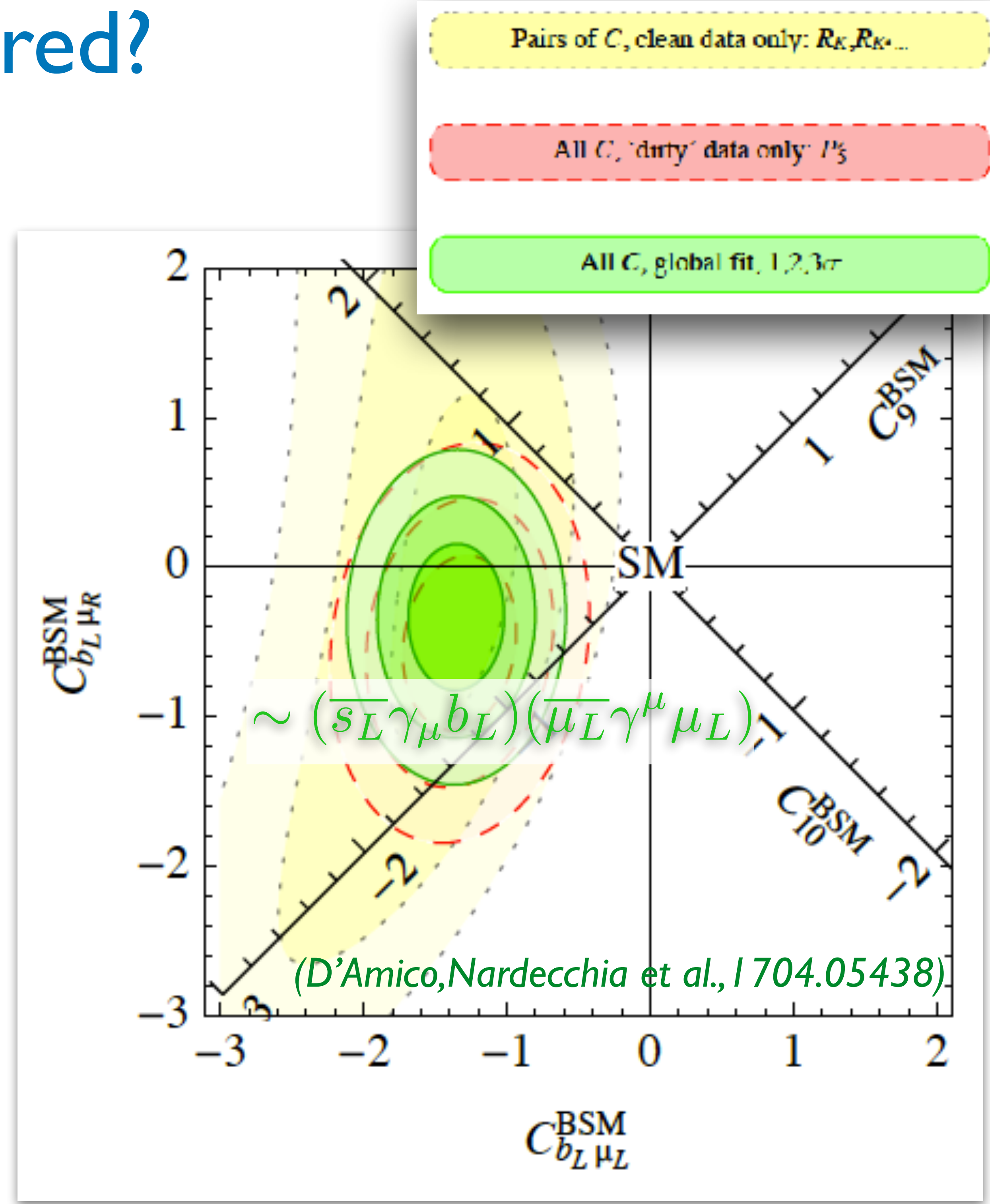
$$\frac{1}{\Lambda^2}(\overline{s_L}\gamma_\mu b_L)(\overline{\mu}\gamma^\mu \mu)$$

$$\frac{1}{\Lambda^2}(\overline{s_R}\gamma_\mu b_R)(\overline{\mu}\gamma^\mu \mu)$$

etc.

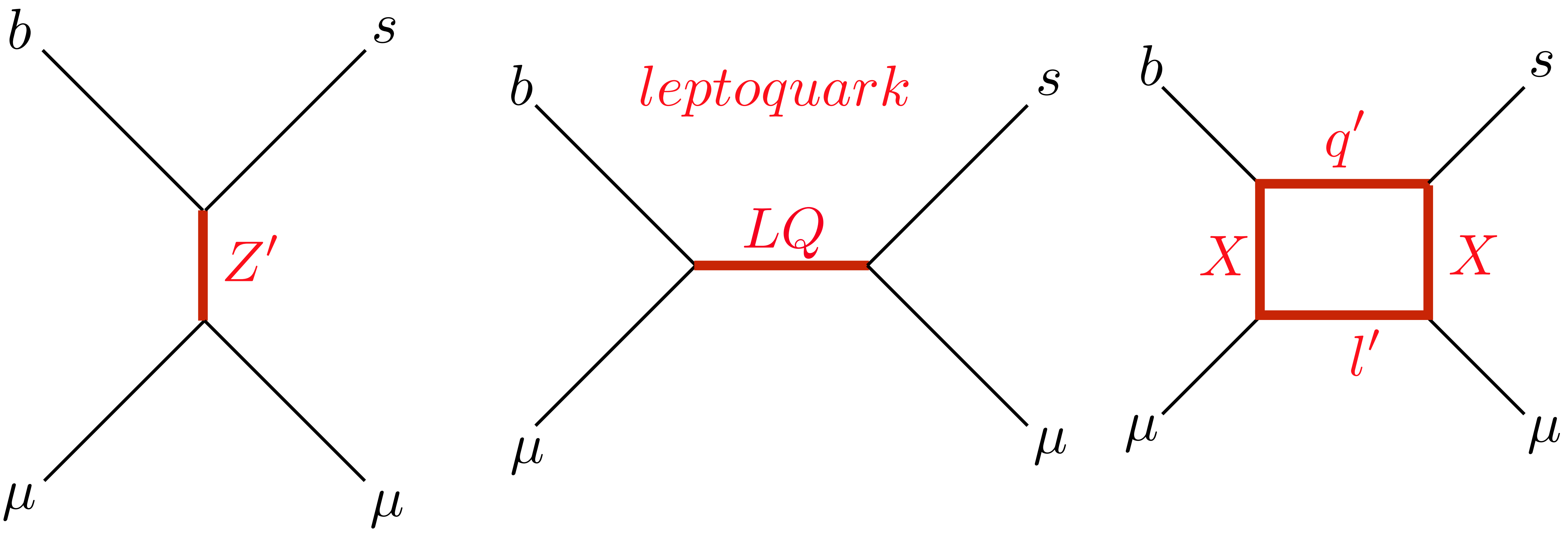
Which structure is favored?





The SM-like operators (*quarks are left-handed*) are favored and destructive interference with the SM is required.

Many possible new physic have been proposed:



Required NW scale is about $\Lambda \approx 25\,\mathrm{TeV}$

Let's see the Z' possibility!

If we introduce extra flavor-dependent U(1) symmetry,

$$\mathcal{L}_{Z'} = g' \hat{Z}'_\mu \left(q_i \, \overline{\hat{Q}^i_L} \gamma^\mu \hat{Q}^i_L + q^l_i \, \overline{l^i_L} \gamma^\mu l^i_L + q^e_i \, \overline{e^i_R} \gamma^\mu e^i_R \right)$$

mass eigenstate

$$g' Z'_\mu \left((g^u_L)_{ij} \overline{u^i_L} \gamma^\mu u^j_L + (g^d_L)_{ij} \overline{d^i_L} \gamma^\mu d^j_L + q^l_i \, \overline{l^i_L} \gamma^\mu l^i_L + q^e_i \, \overline{e^i_R} \gamma^\mu e^i_R \right)$$

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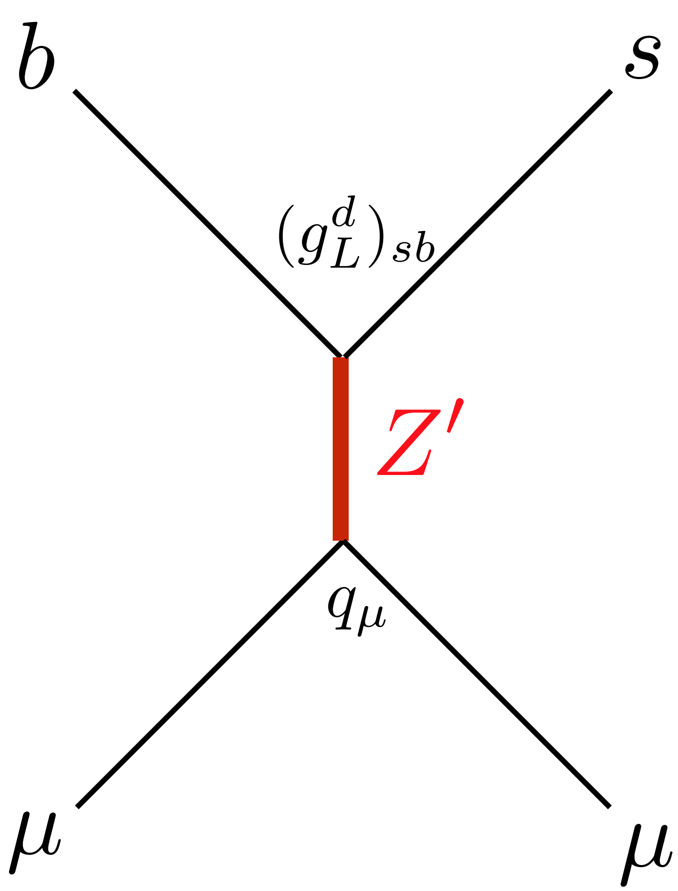
mass eigenstate

$$g' Z'_\mu \left((g^u_L)_{ij} \overline{u^i_L} \gamma^\mu u^j_L + (g^d_L)_{ij} \overline{d^i_L} \gamma^\mu d^j_L + q^l_i \overline{l^i_L} \gamma^\mu l^i_L + q^e_i \overline{e^i_R} \gamma^\mu e^i_R \right)$$



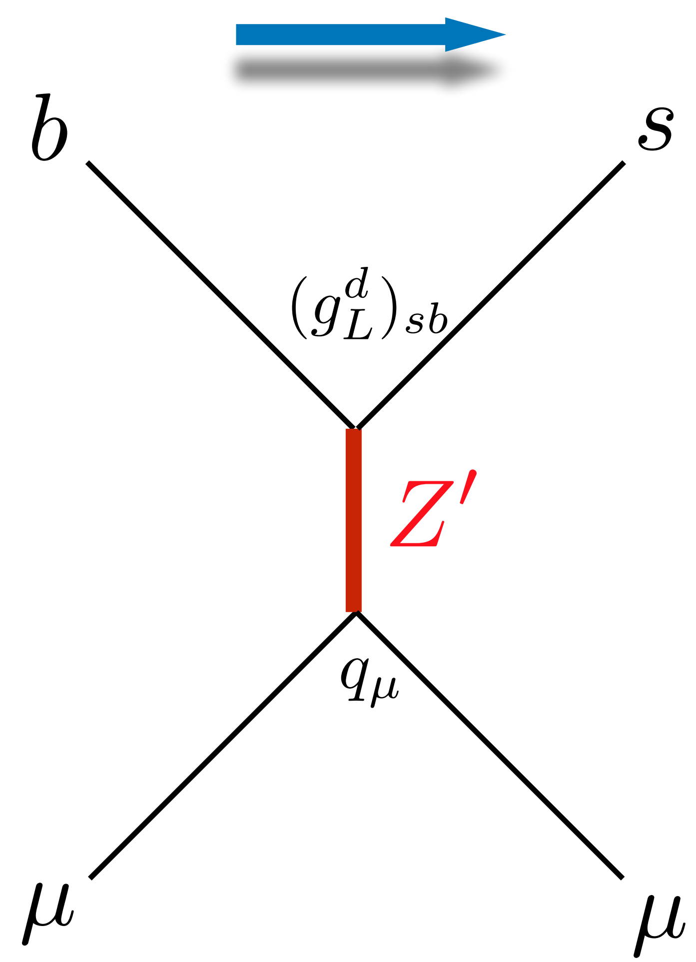
Z' scale should be around

$$\frac{M_{Z'}}{g'} \times \frac{1}{\sqrt{q_\mu (g^d_L)_{sb}}} \approx 25\ \mathrm{TeV}$$

Relation with the other processes

our interest

$B \to K(*)\mu\mu$



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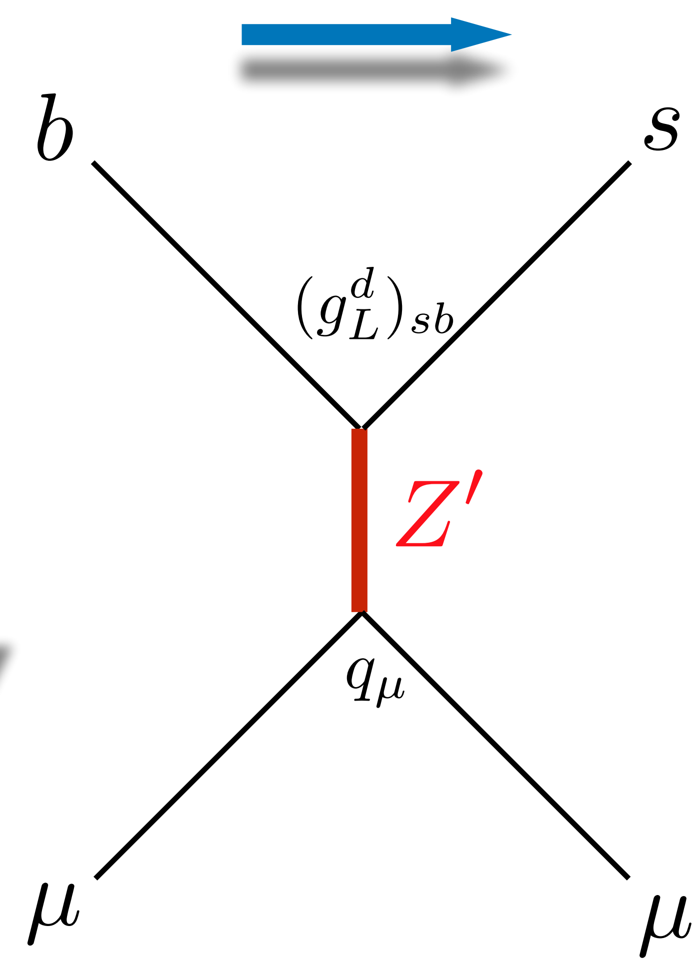


$B_s \to \mu\mu$

in flavor physics

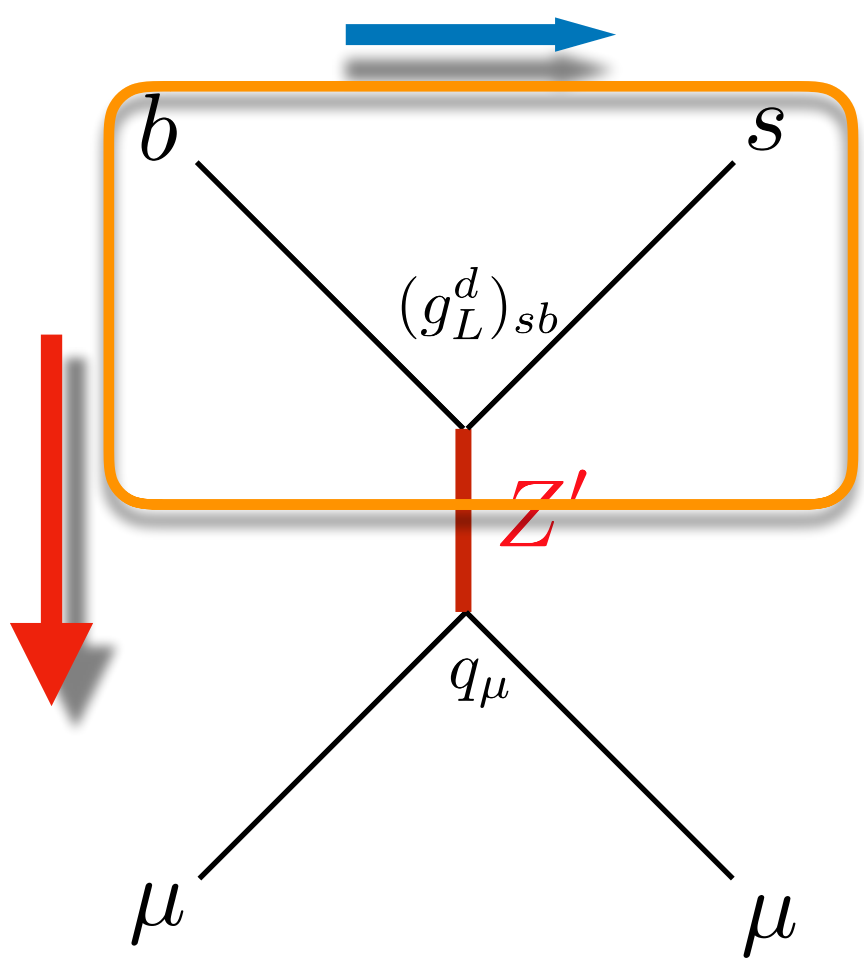
$pp \to Z' \to \mu\mu$

@LHC

Relation with the other processes

our interest

$B \to K(*)\mu\mu$



constrained by Bs-$\overline{\text{B}}$s mixing

$B_s \to \mu\mu$

in flavor physics

$pp \to Z' \to \mu\mu$

@LHC

Relation with the other processes

our interest

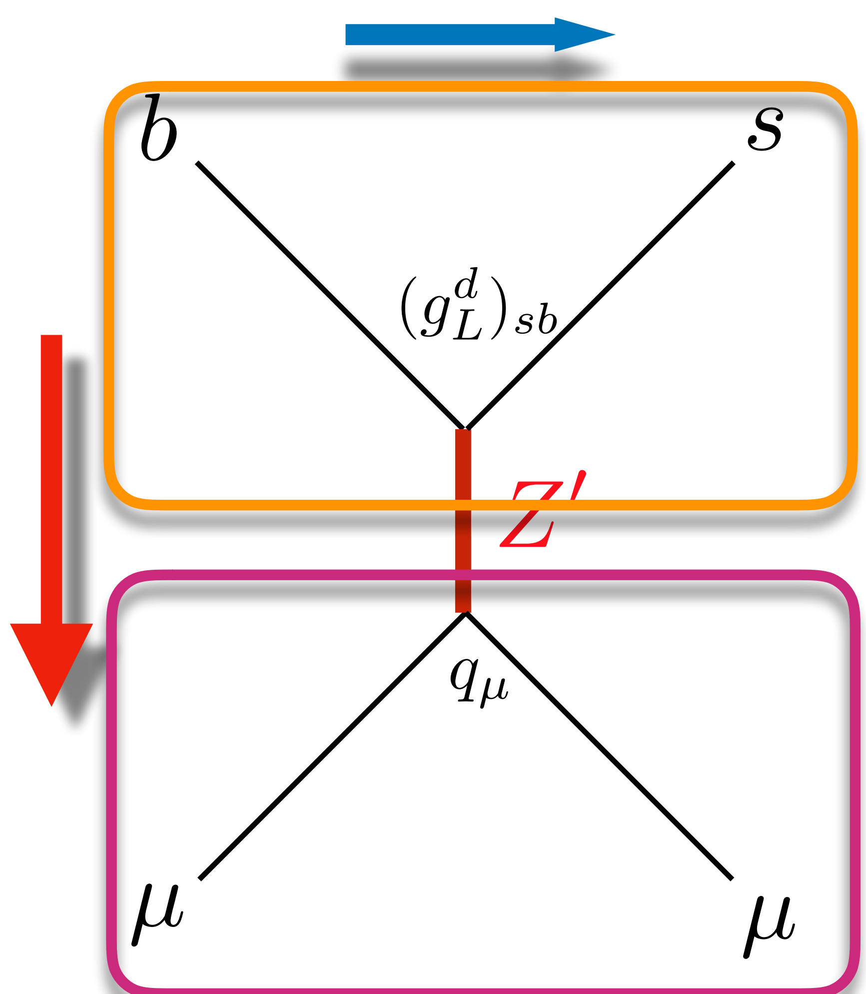
$B \to K(*)\mu\mu$

$B_s \to \mu\mu$

in flavor physics

$pp \to Z' \to \mu\mu$

@LHC



constrained by
Bs-$\overline{\text{Bs}}$ mixing

constrained by
$\nu N \to \nu N \mu\mu^+$

There are so many possibilities for the U(1)' charge assignments:

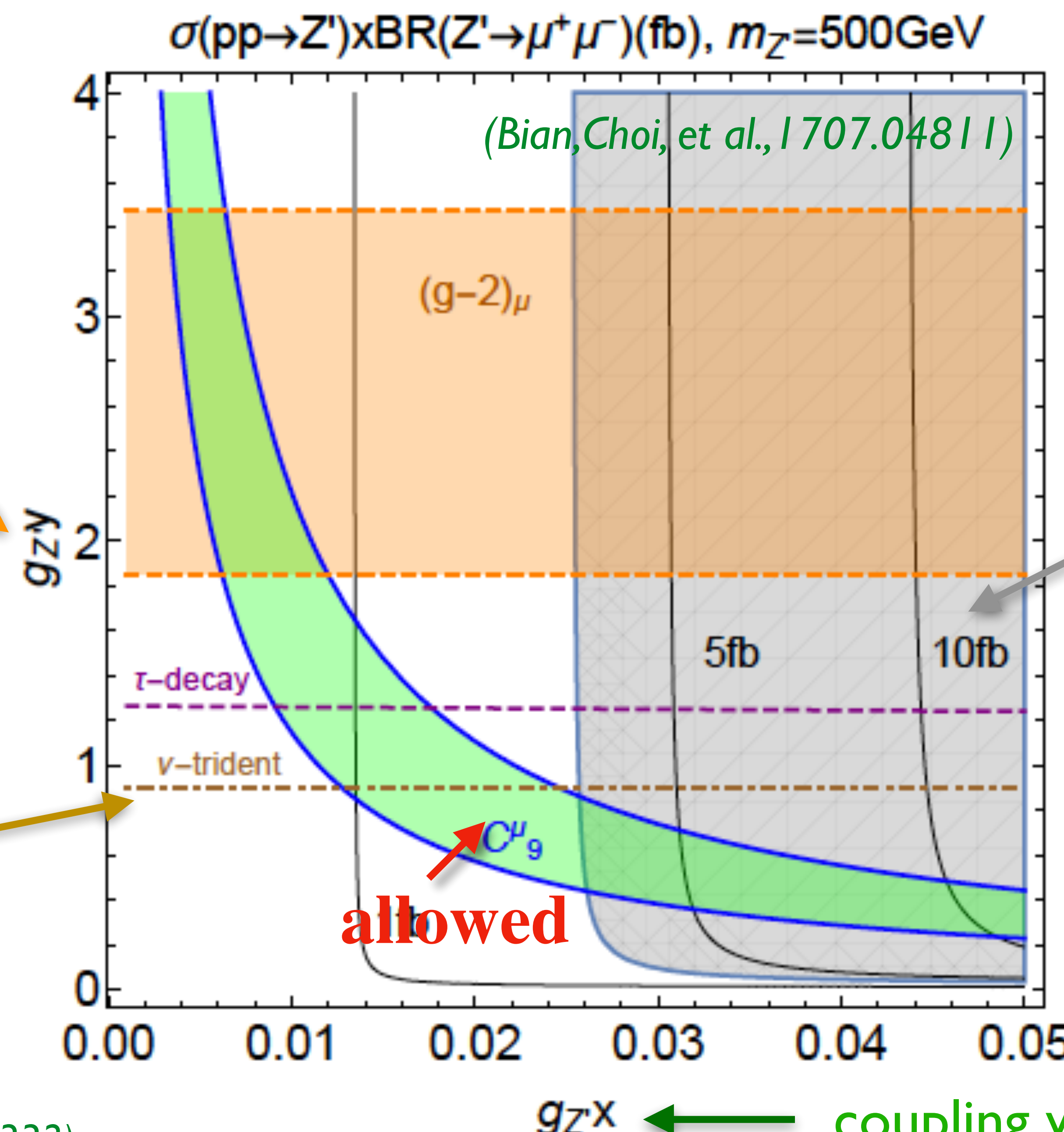
Flavor symmetry, *(P.Ko, YO, et al., 1702.08666;King, 1706.06100)*

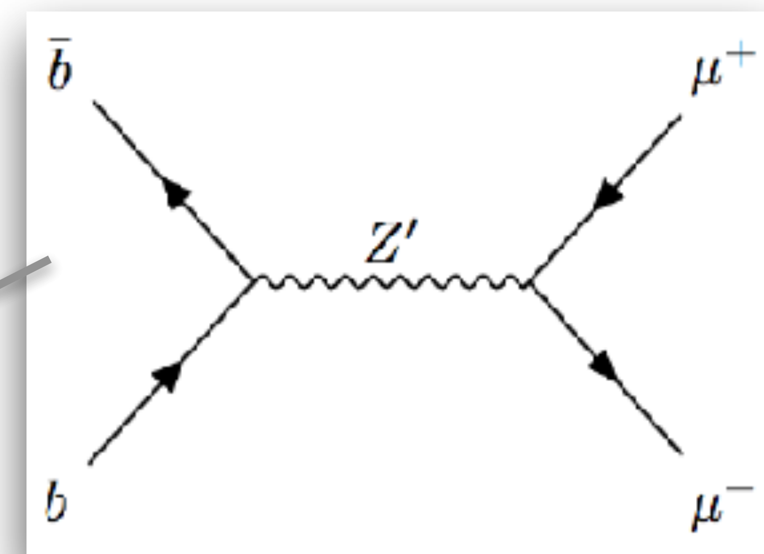
$U(1)_{\mu-\tau}$, Flavored $U(1)_{B-L}$, $U(1)_{\mu-\tau+x(B3-L3)}$

(Altmannshofer, Gori, et al., 1403.1269;Ko, Nomura, et al., 1702.02699;Alonso, Cox, et al. 1705.03858; Bonilla, Modak, et al., 1705.00915)

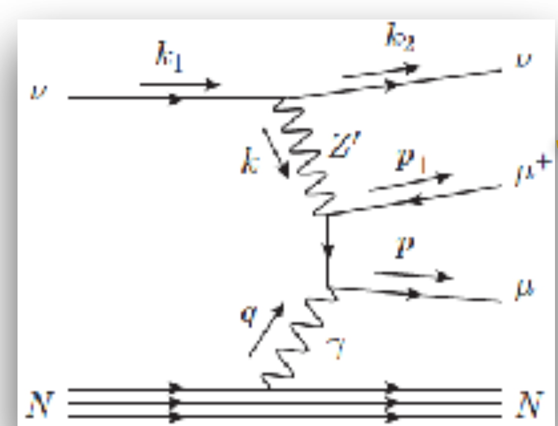
$U(1)_{y(\mu-\tau)+x(B3-L3)}$ model

coupling with μ





$36.1\ \mathrm{fb}^{-1}$ with $\sqrt{s} = 13\ \mathrm{TeV}$ (ATLAS)

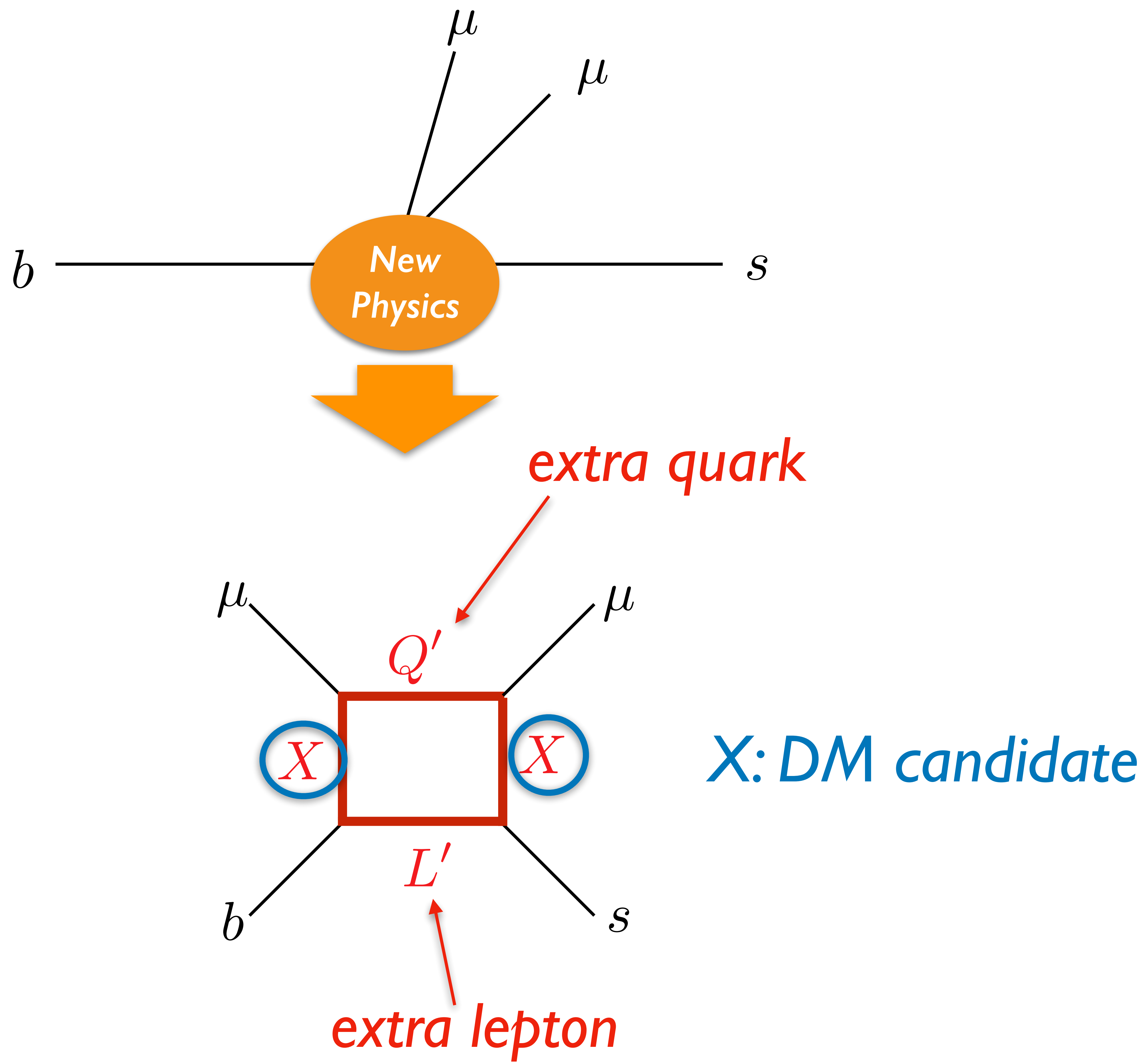


(Altmannshofer, Gori, et al., 1406.2332)

coupling with quarks

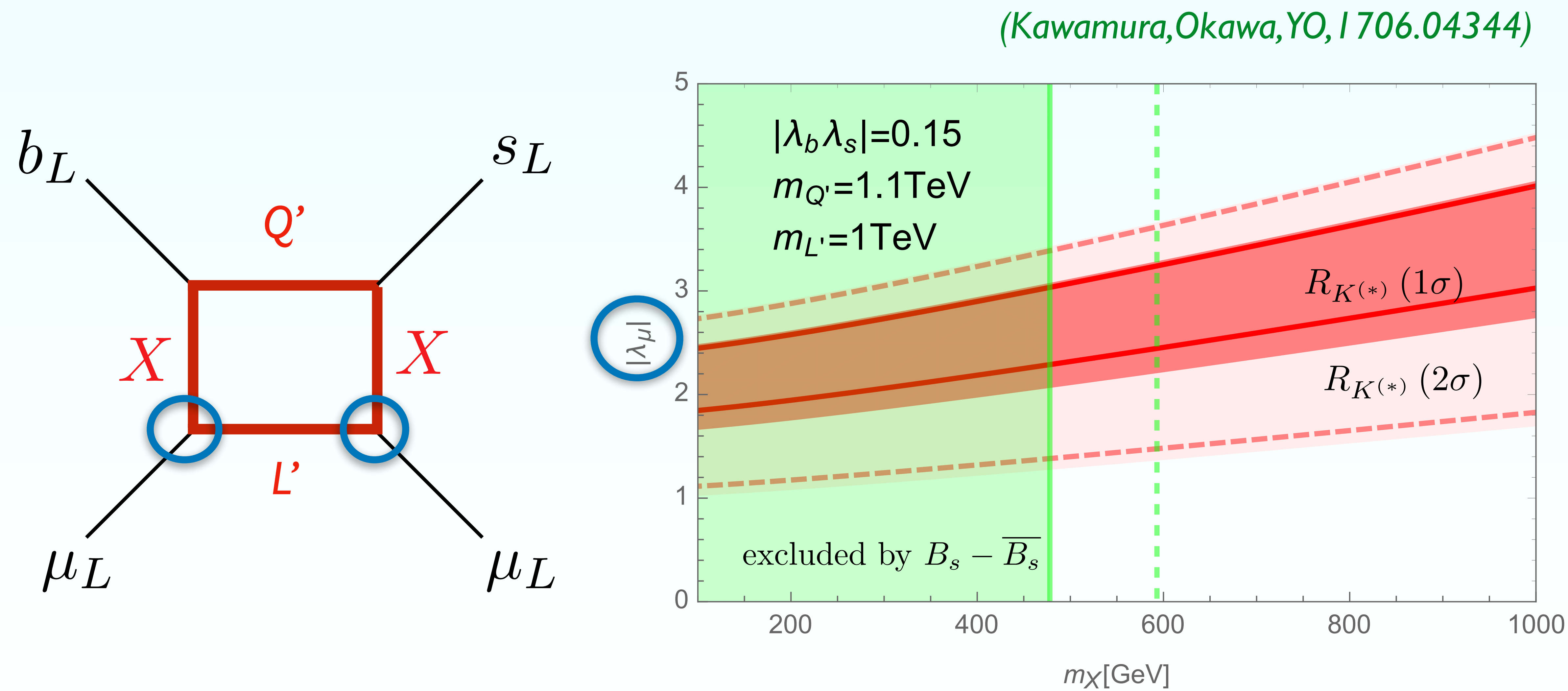
Another interesting possibility

Dark Matter may be hidden behind the excesses!



μ
μ
b
New Physics
s
extra quark
μ
μ
Q′
X
X
X: DM candidate
L′
b
s
extra lepton

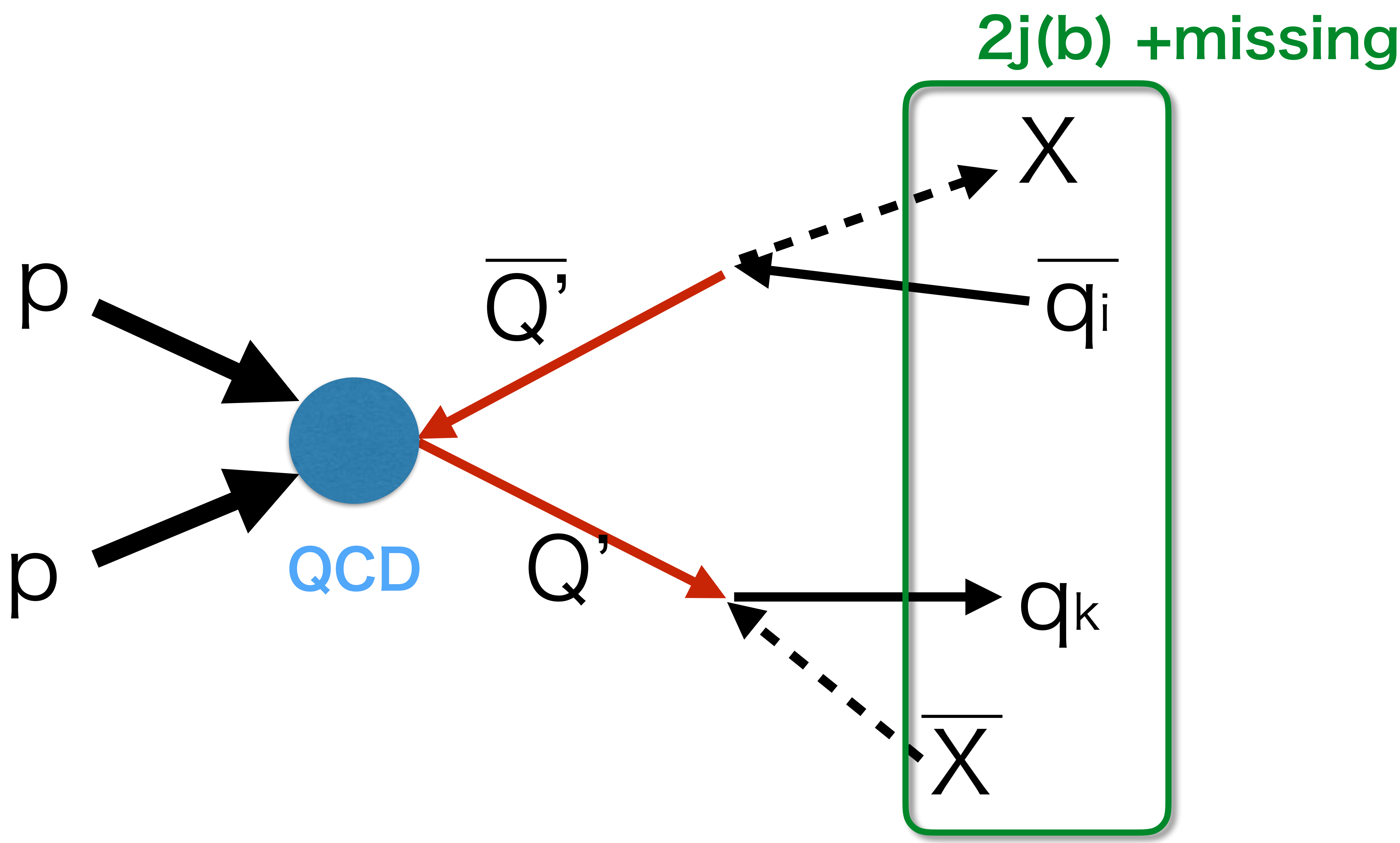
The explanation of the excesses



We can search for Q', L' and DM (X) at the LHC and the XENON!

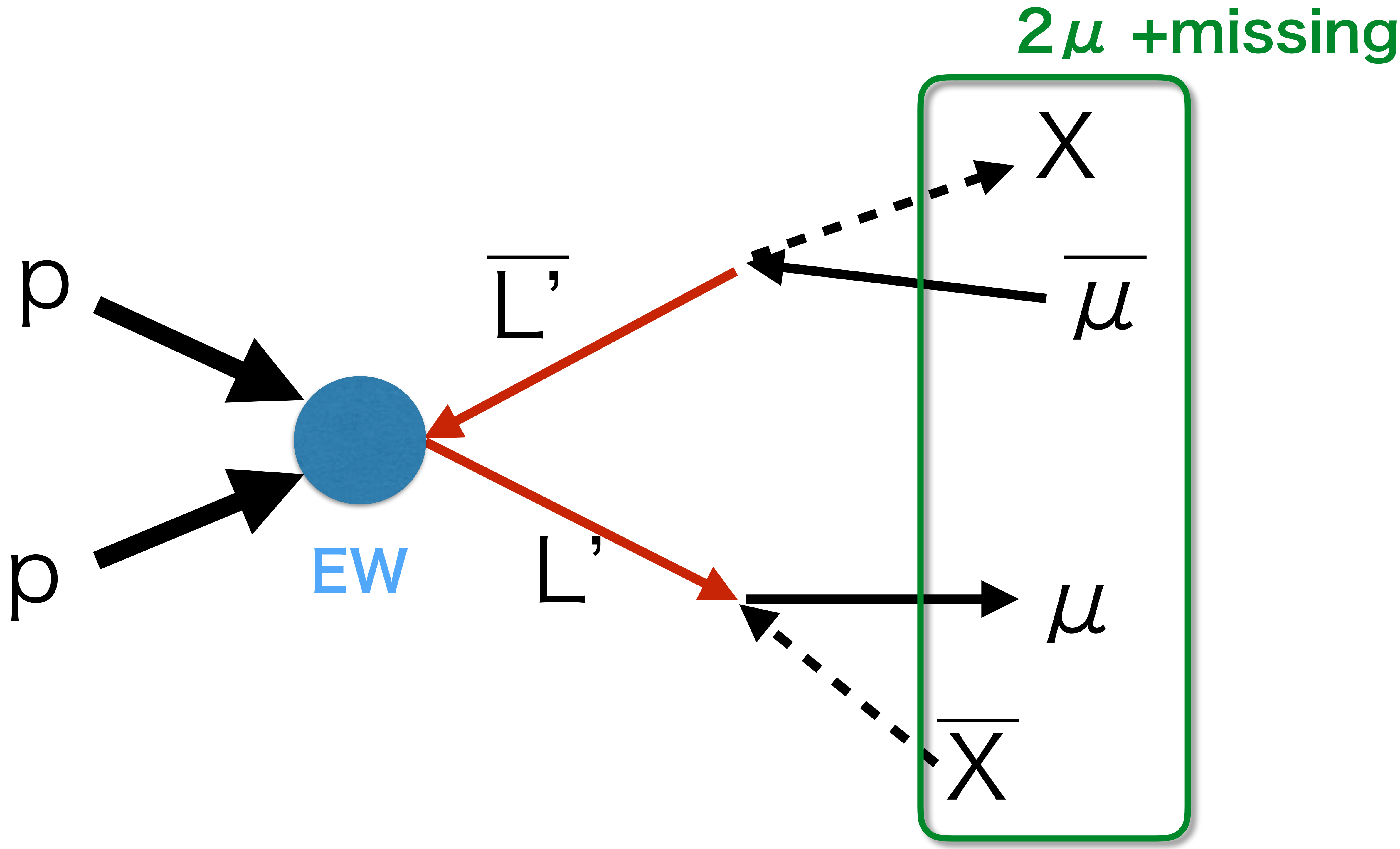
Search for Q' at the LHC

(Kawamura,Okawa,YO,1706.04344)



Search for L’ at the LHC

(Kawamura,Okawa,YO,1706.04344)

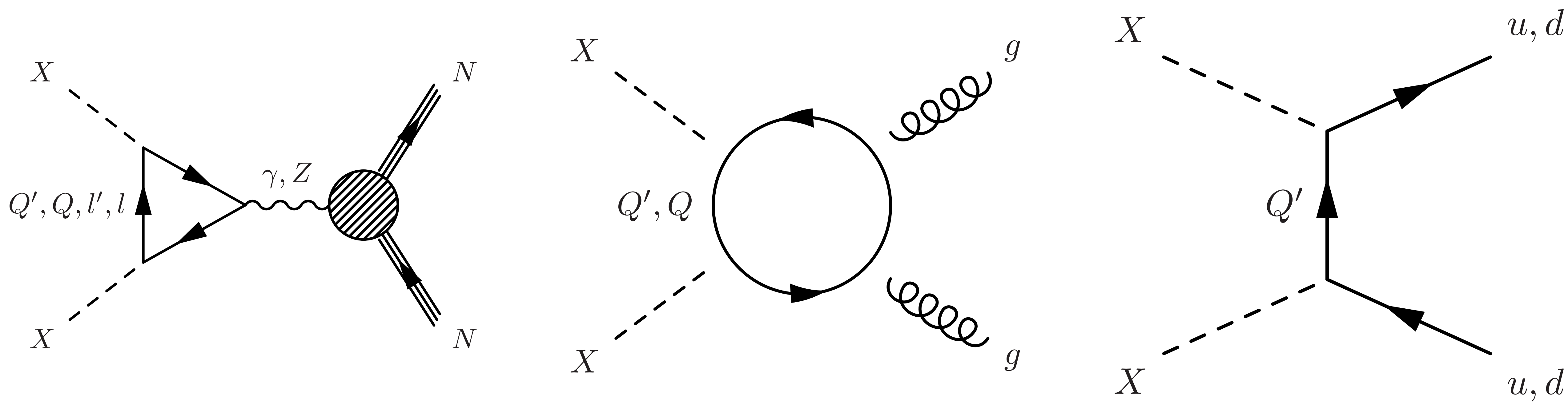


Search for DM

(Kawamura, Okawa, YO, 1706.04344)

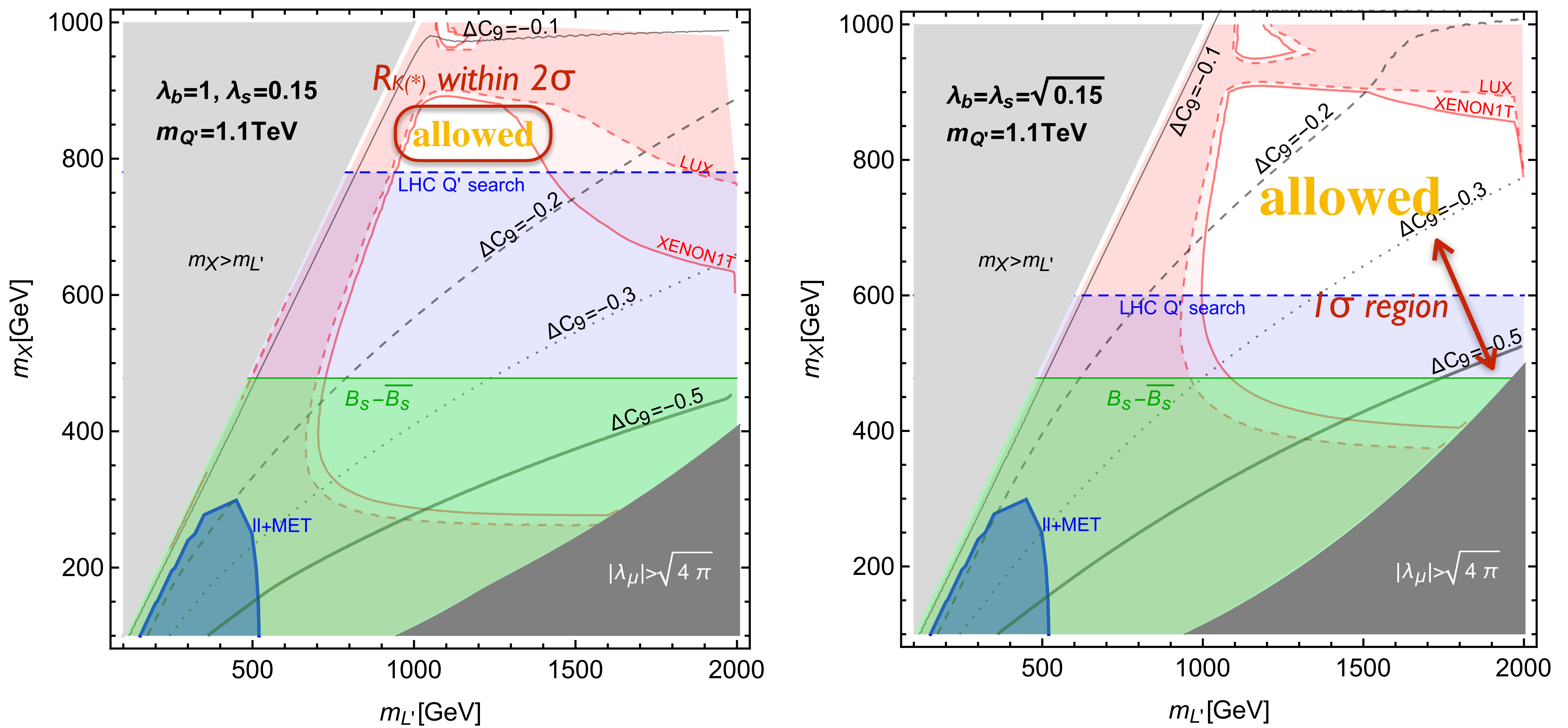
- *The relic density of DM (X) can be estimated.*
- *We can see the DM-nucleus scattering.*

→ *XENON1T will conclude this scenario!*

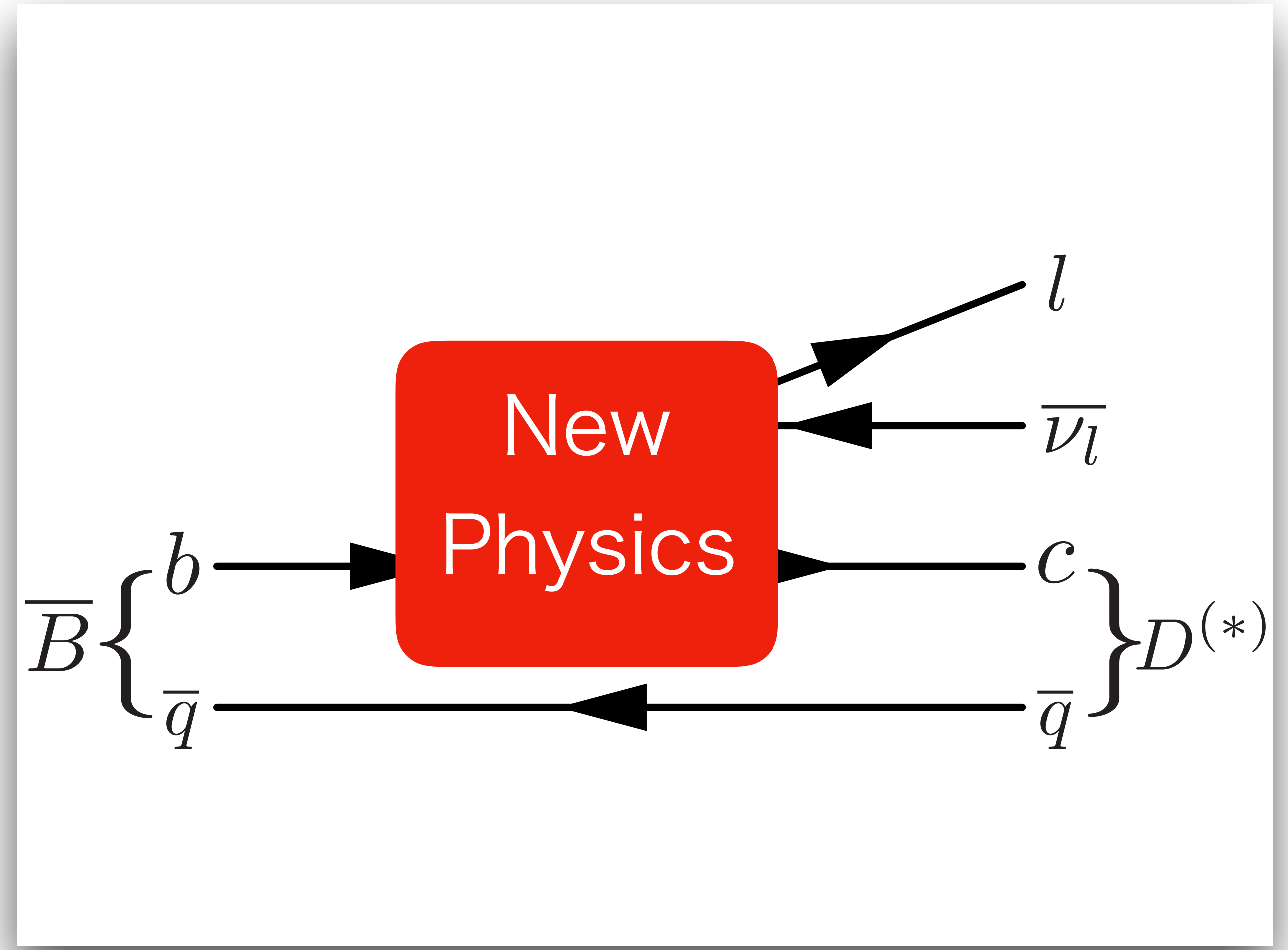


Interplay with DM and LHC physics

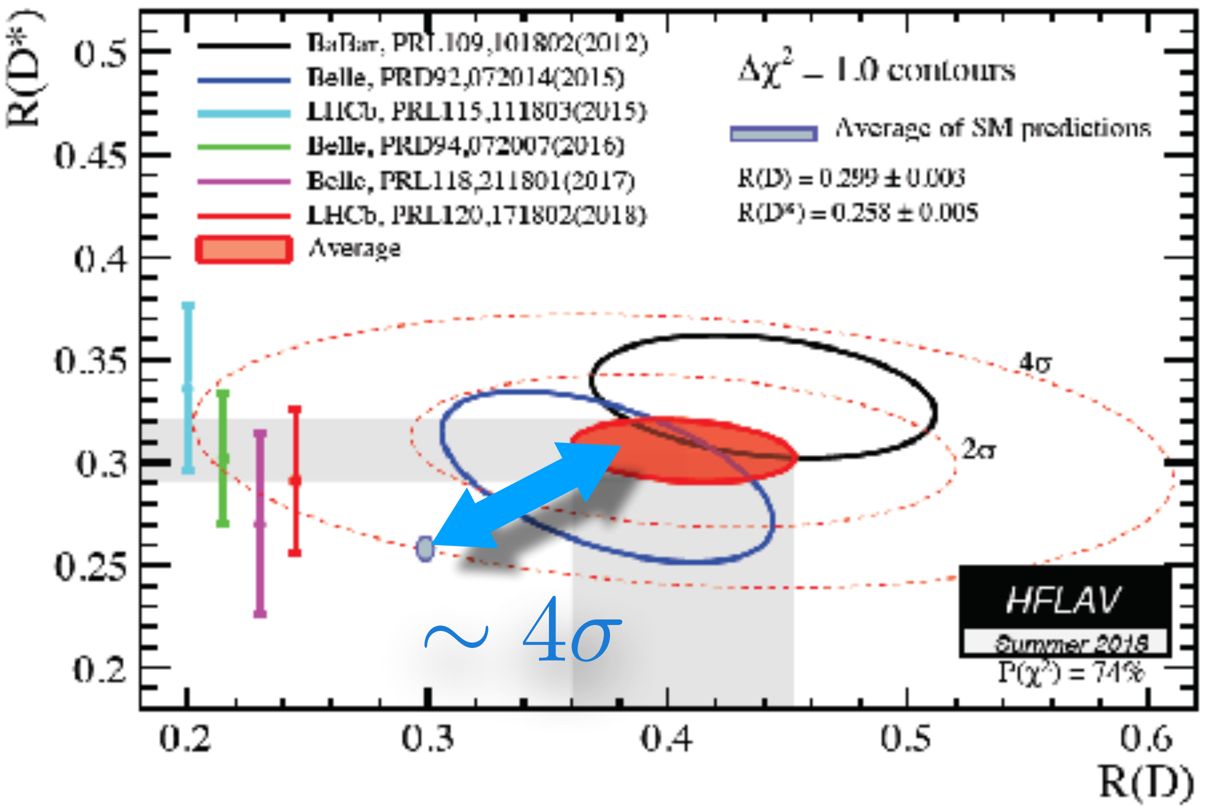
(Kawamura, Okawa, YO, 1706.04344)



3. The new physics interpretations of the B→D(*)lν anomalies



The violation of Lepton Flavor Universality (LFU) in B→D(*)lν is also deviated from the SM prediction.

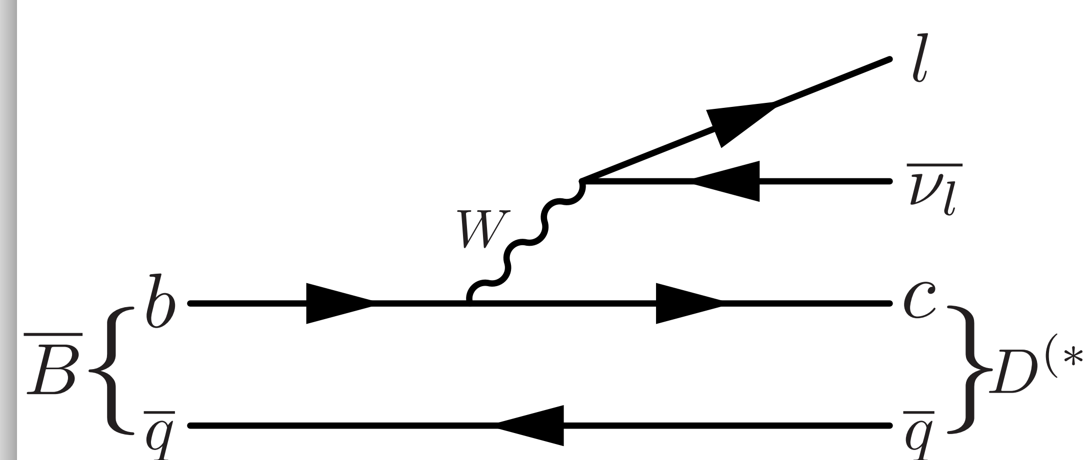


lepton universality of B→D(*)τν

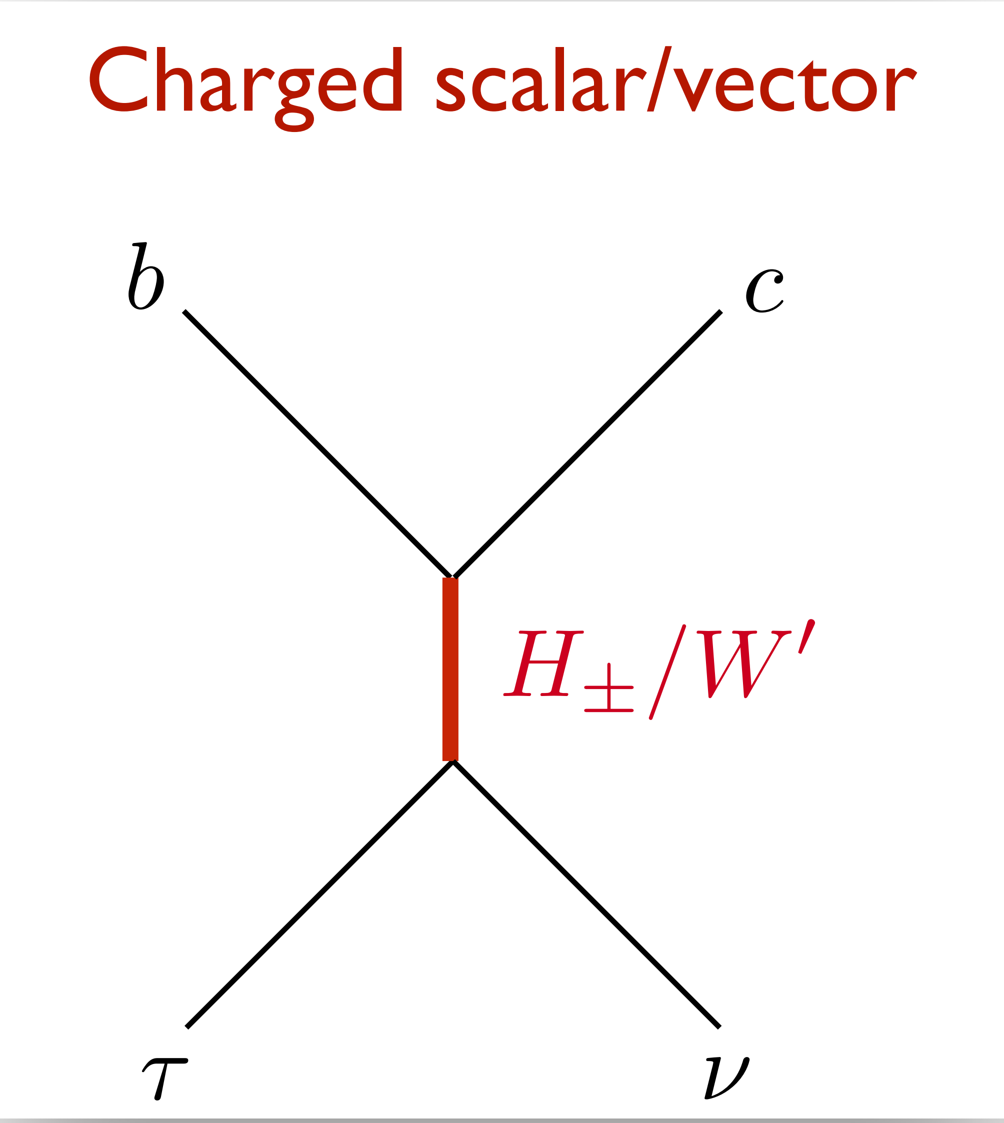
$$R(D^{(*)}) \equiv \frac{\Gamma(B \to D^{(*)}\tau\nu)}{\Gamma(B \to D^{(*)}\ell\nu)}$$

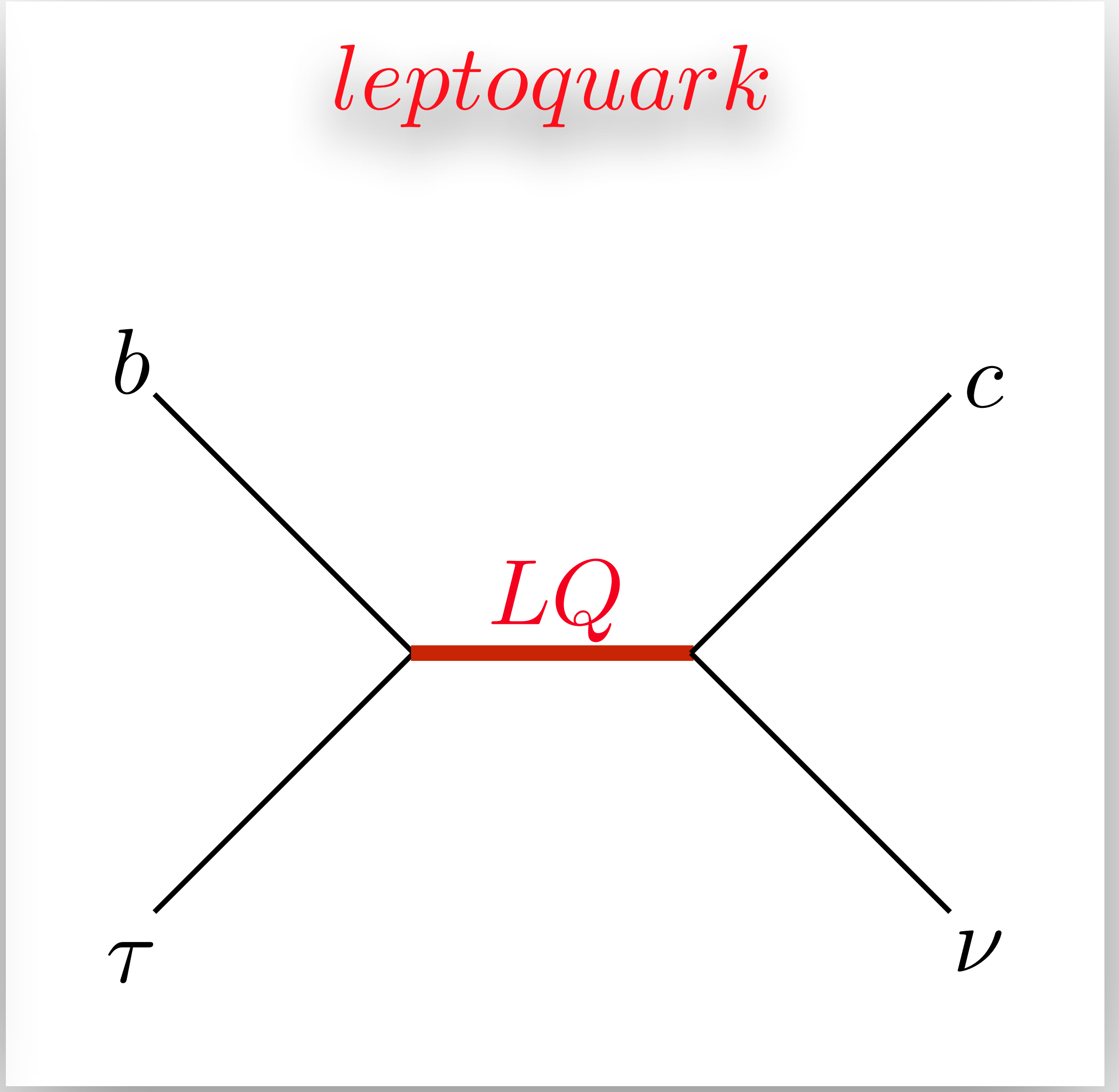
$$\text{where } \ell = e, \mu$$

In the SM,



New charged particles that interact with heavy flavors may exist





B→D(*)τν anomaly requires $\Lambda \approx 2.4\,\mathrm{TeV}$

that comparable to the weak int..

We could see them directly at the LHC!

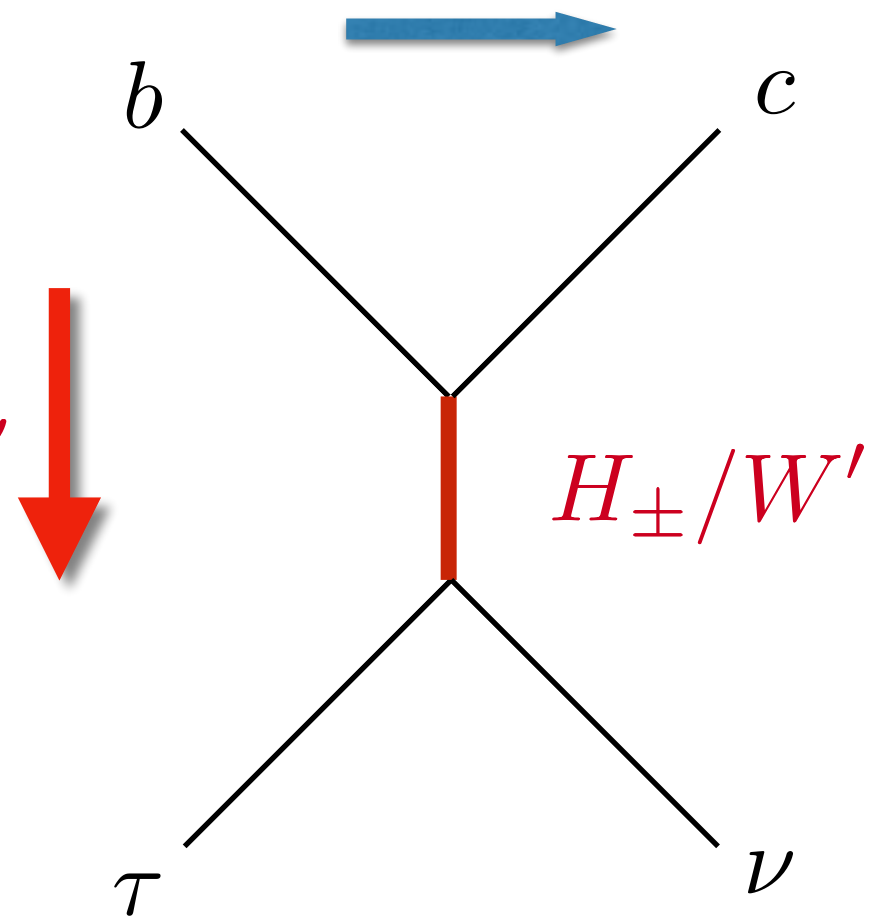
Interestingly, we can test both W’ and H+/- directly at the LHC!

(Iguro, YO, Takeuchi, 1810.05843)

$B \to D^* \tau \nu$

$pp \to H_{\pm}/W' \to \tau\nu$

@LHC



See Iguro’s poster!

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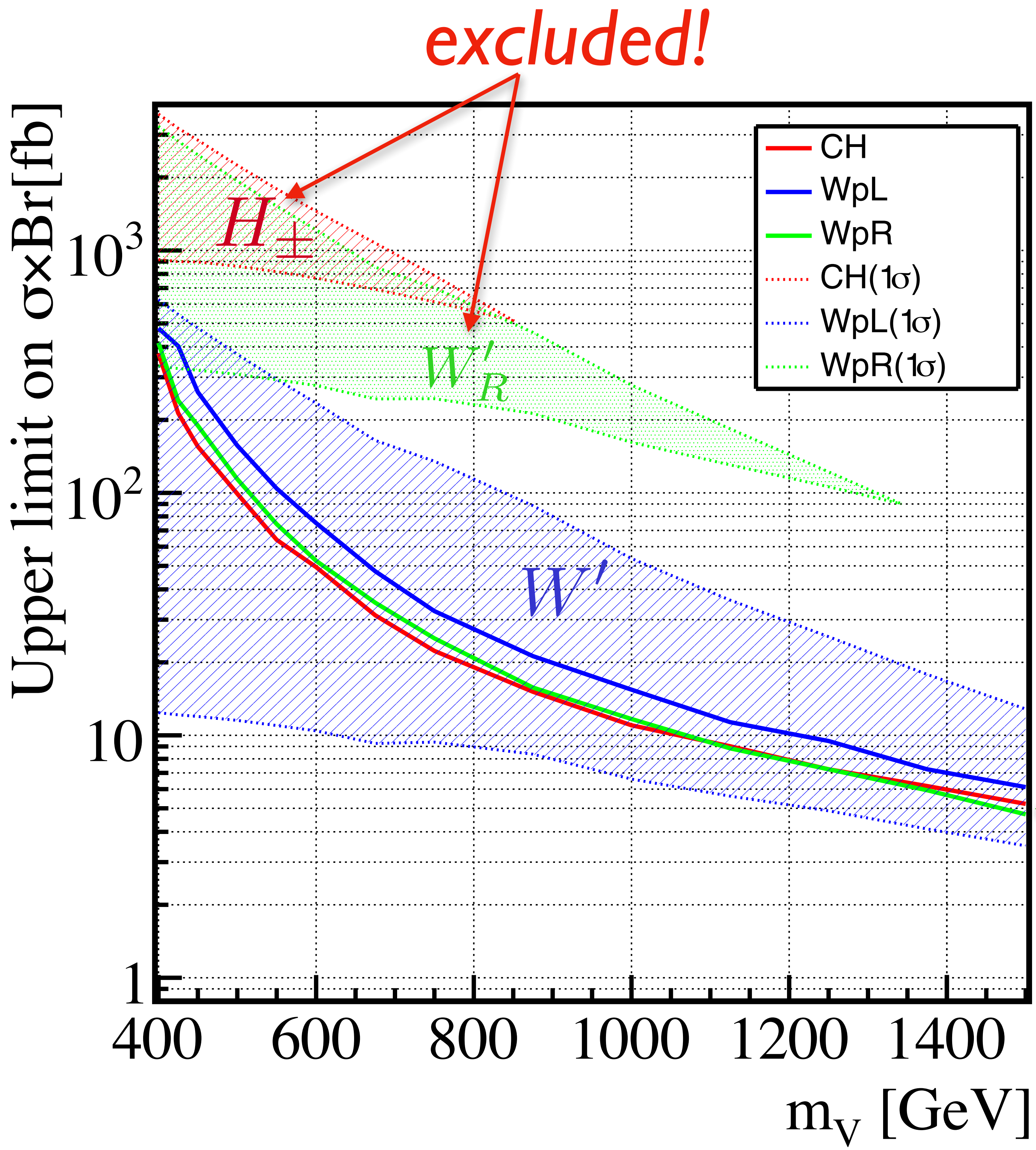
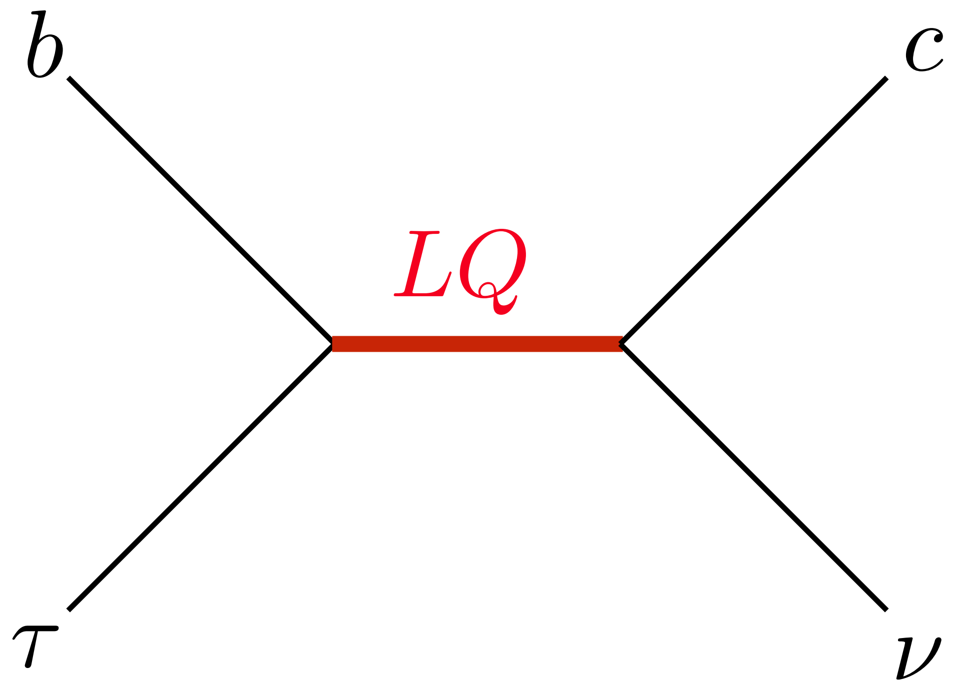


exclusion lines

based on 1807.11421 (CMS)

See Iguro’s poster!

Let's see another candidate, leptoquark!



Leptoquark, for instance, predicted by an unified theory:
SU(4)×SU(2)L×SU(2)R (breaks down to the SM at the energy)

(Calibbi,Crivellin,Li,arXiv:1709.00692.)

$$\mathcal{L}_{SU(4)} = g_U \begin{pmatrix} \overline{\hat{l}^I_L} & \overline{\hat{q}^{b\,I}_L} \end{pmatrix} \begin{pmatrix} B_\mu & \underbrace{U^{a\,\dagger}_\mu}_{LQ} \\ \underbrace{U^{\,b}_\mu}_{LQ} & G^{ba}_\mu \end{pmatrix} \gamma^\mu \begin{pmatrix} \hat{l}^I_L \\ \hat{q}^{a\,I}_L \end{pmatrix} \Rightarrow \kappa_{ij} \left(\overline{d^{b\,i}_L} \gamma_\mu e^j_L + (V_{CKM})_{ki} \overline{u^{b\,k}_L} \gamma_\mu \nu^j_L \right) U^{b\,\mu}$$

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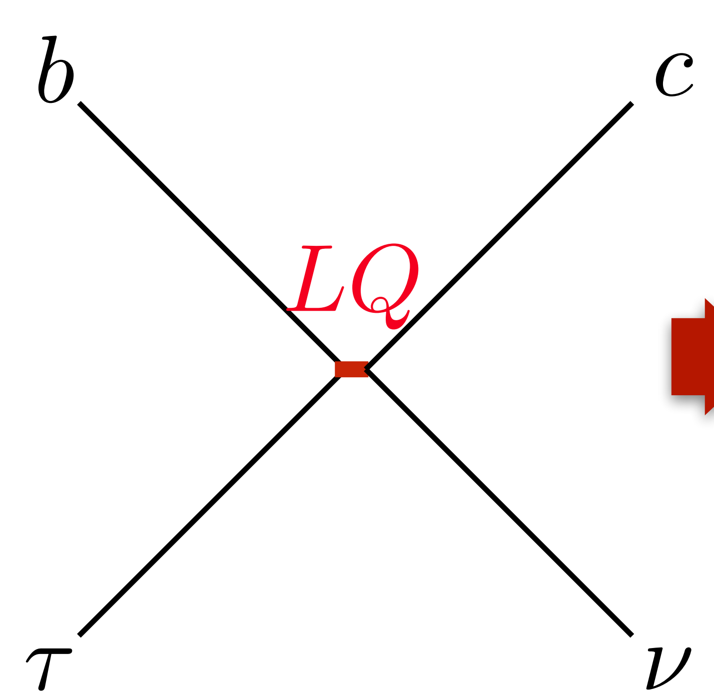
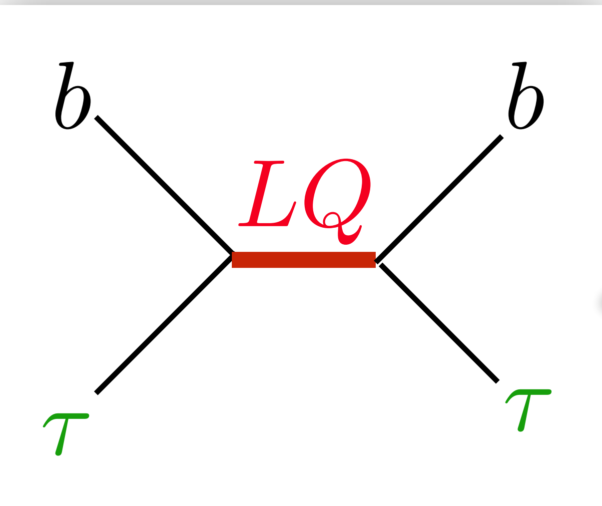
After integrating out the LQ, we obtain 4-fermi int.:

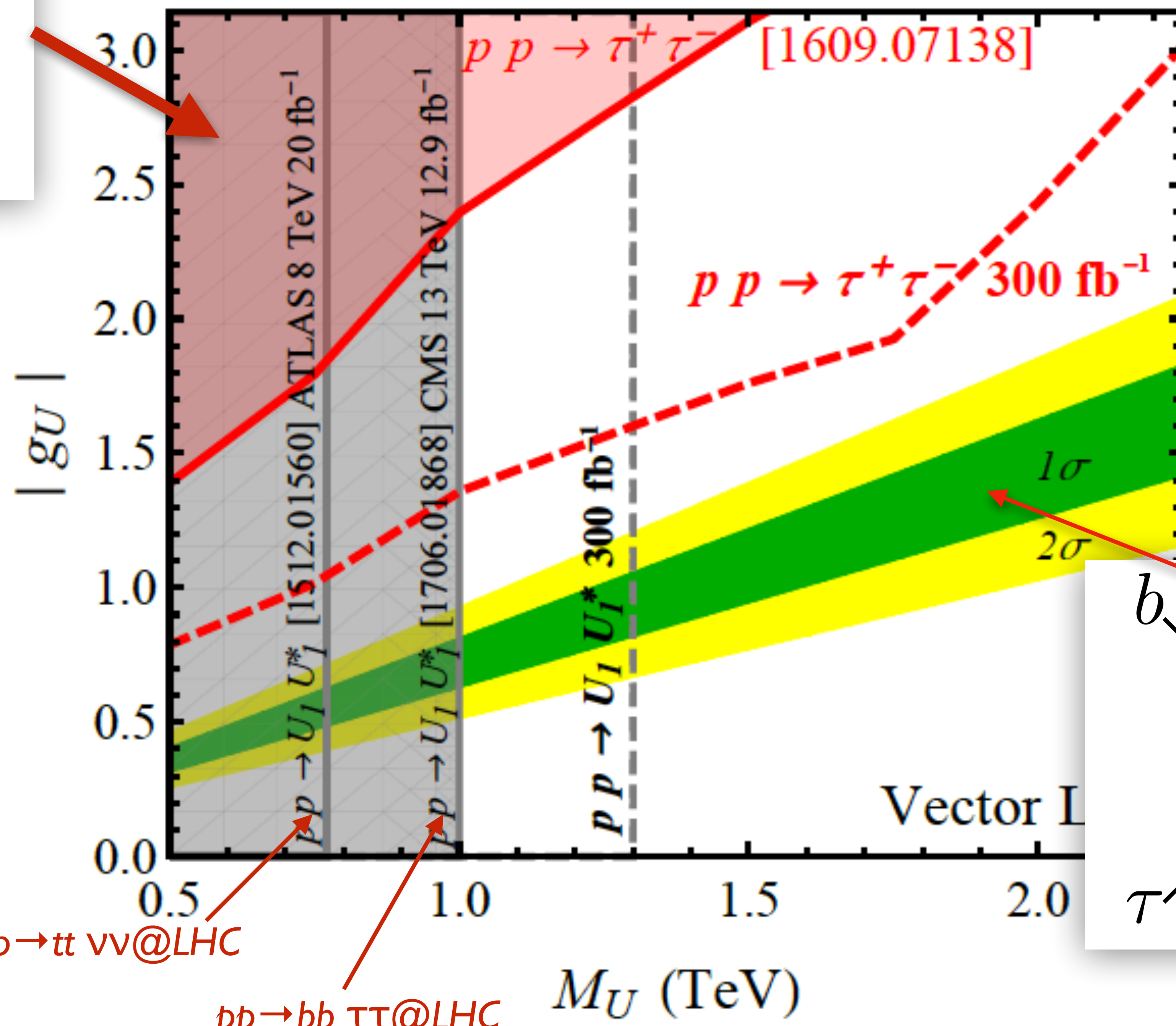


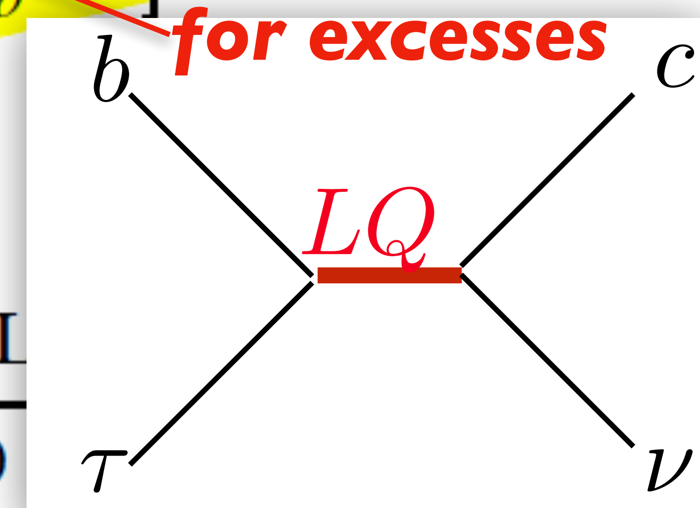
$$\Rightarrow (couplings) \times \frac{1}{M_U^2}$$

direct search for the leptoquark

(Buttazzo,Isidori,Greljo,Marzocca, 1706.07808)







See also Iguro's poster!

4. Summary and Discussion

- Flavor physics play an important role in testing not only the SM but also new physics beyond the SM.

- Interestingly, the lepton flavor universality is deviated from the SM prediction in

  $B \to K(*)\ ll$ (l = e, μ) processes

  $B \to D(*)\ l\nu$ (l = e, μ, τ) processes

- Motivated by these excesses, many new physics scenarios have been proposed. *Flavor physics indirectly searches new physics, so we have to prove the new physics using many observables in flavor, LHC and DM experiments.*

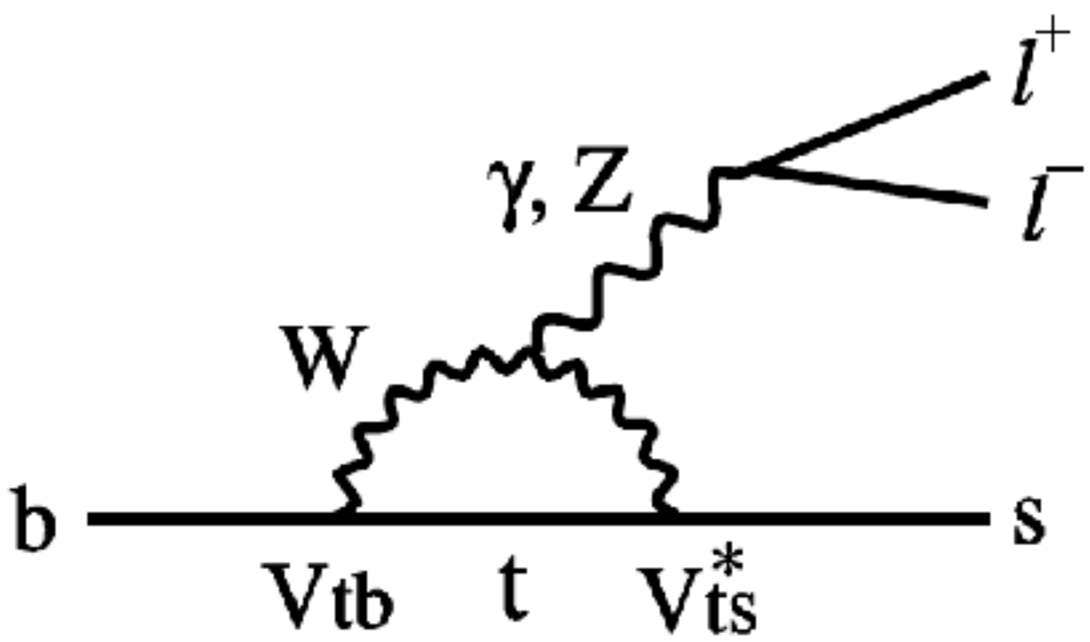
Charged Higgs is, for instance, almost killed by the LHC result.

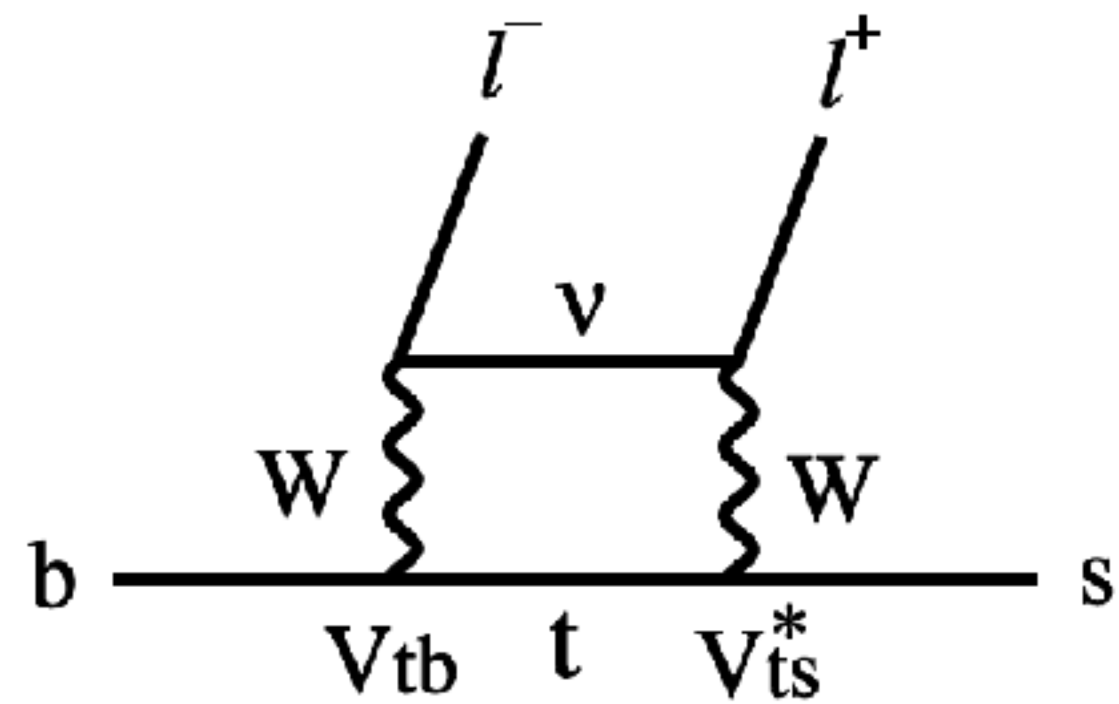
Please check Iguro's posters, too!

END

Backup

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





effective Hamiltonian

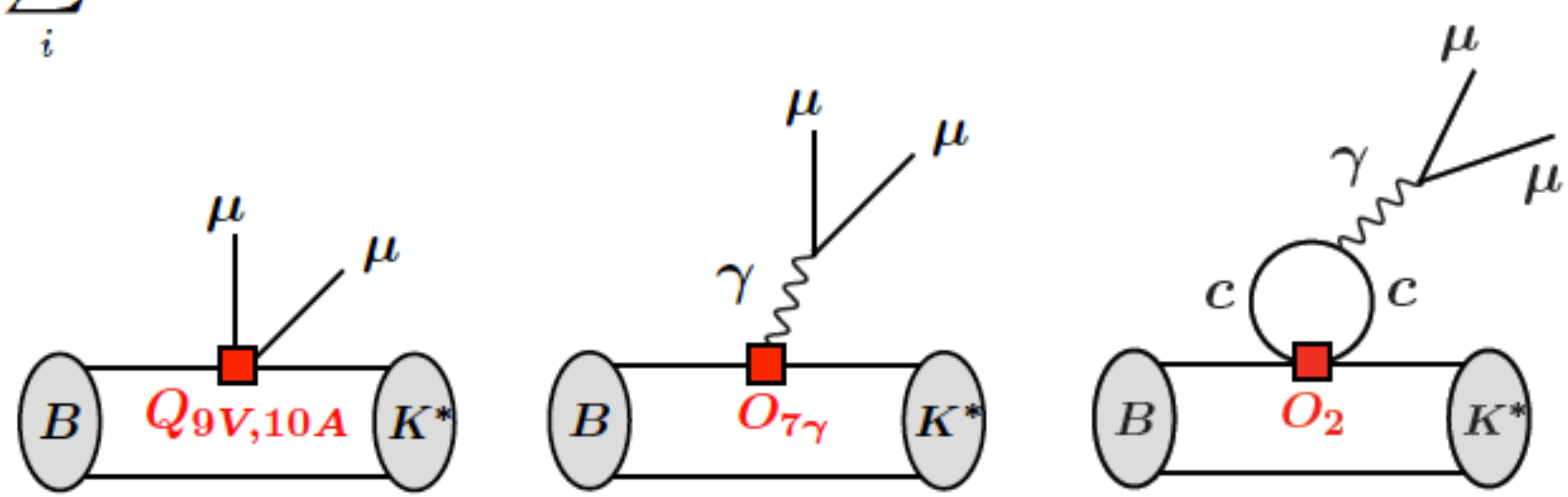
$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i O_i$$

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

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

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

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



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

Form factor in B→K(*)ll can be estimated in heavy quark and large E limit.

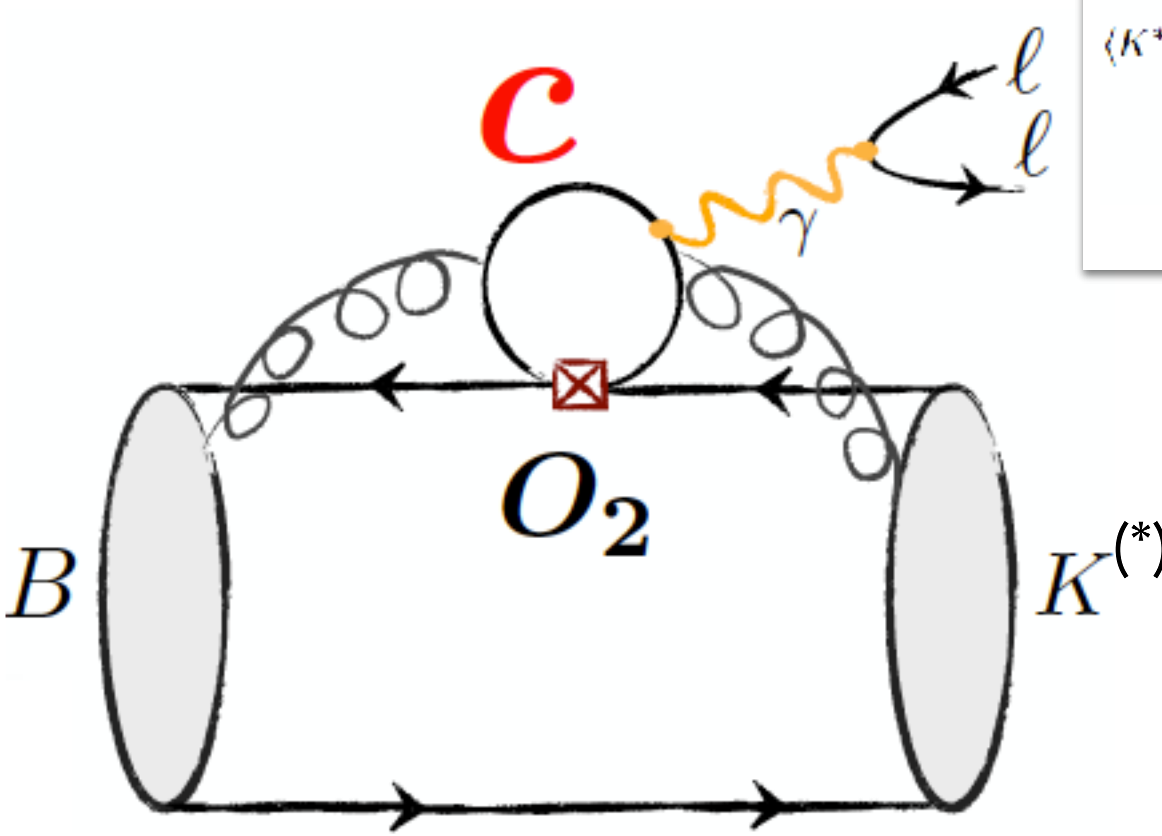
(hep-ph/9812358;1503.05534)

The 4-quark operator largely contributes via one-loop $\sim \mathcal{O}(10)\%$

$$\langle \bar{K}^*(k,\lambda)|s\gamma_\mu b|\bar{B}(p)\rangle = \epsilon_{\mu\nu\rho\sigma}\epsilon_\lambda^{*\nu} p^\rho k^\sigma \frac{2}{m_B + m_{K^*}} V(q^2)\,,$$

$$\langle K^*(k,\lambda)|\bar{s}\gamma_\mu\gamma_5 b|B(p)\rangle \quad i(\epsilon_\lambda^* \cdot q)\frac{2m_{K^*}q_\mu}{q^2}A_0(q^2) + i(m_B + m_{K^*})\left(\epsilon^*_{\lambda,\mu} - \frac{(\epsilon_\lambda^* \cdot q)q_\mu}{q^2}\right)A_1(q^2)$$

$$i(\epsilon_\lambda^* \cdot q)\left[\frac{(2p \quad q)_\mu}{m_B + m_{K^*}} \quad (m_B \quad m_{K^*})\frac{q_\mu}{q^2}\right]A_2(q^2)\,,$$



(Khodjamirian,et.al.,1006.4945)

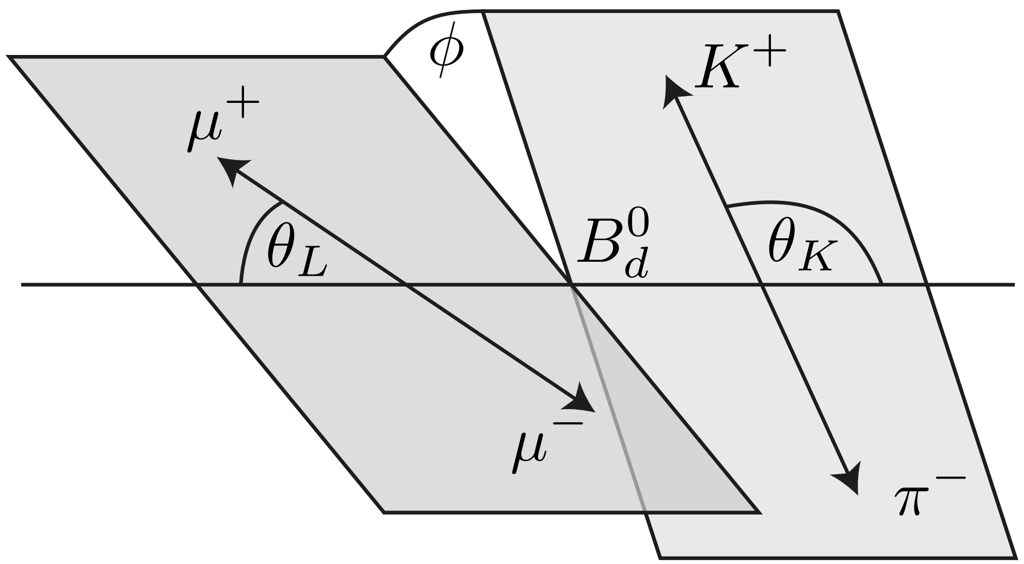
- *But excesses are reported in flavor universalities of B→K(*)ll,*

that is not relevant to the ambiguity.

- *Angular analysis would be relevant to the contribution.*

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

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



$$\langle \bar{K}^*(k,\lambda)|\bar{s}\gamma_\mu b|\bar{B}(p)\rangle = \epsilon_{\mu\nu\rho\sigma}\epsilon_\lambda^{*\nu} p^\rho k^\sigma \frac{2}{m_B + m_{K^*}} V(q^2),$$

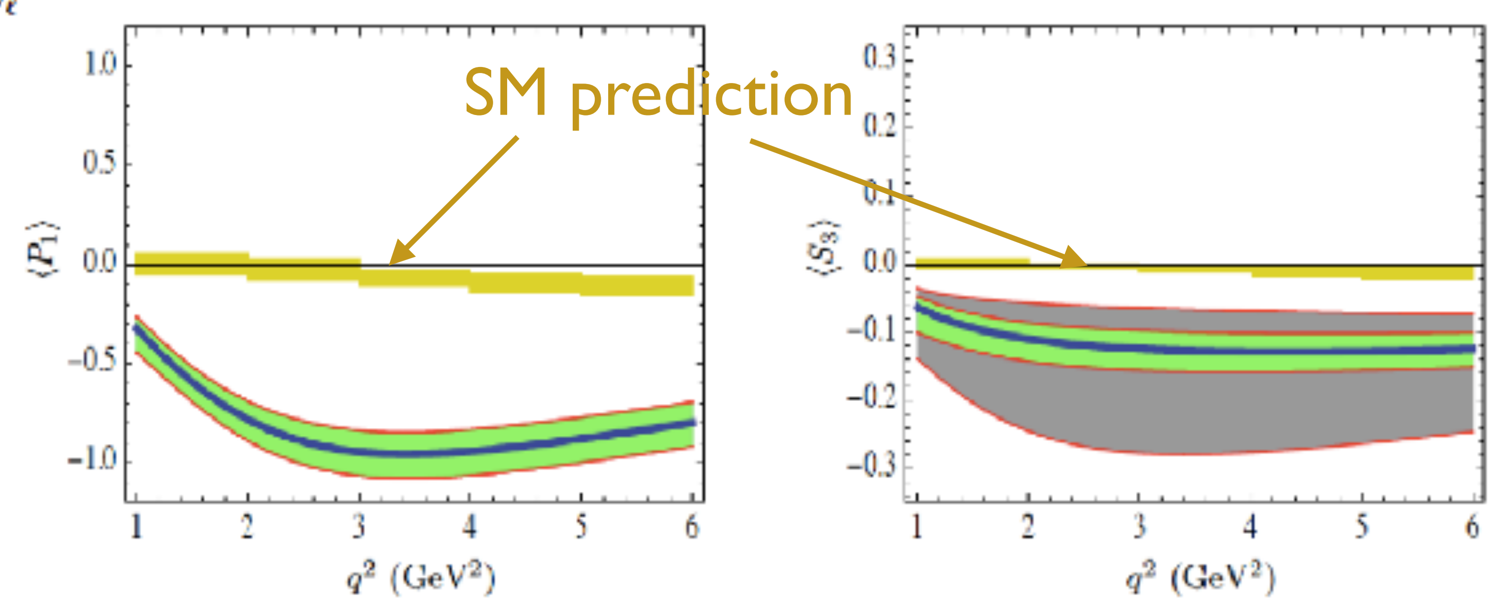
$$\langle \bar{K}^*(k,\lambda)|\bar{s}\gamma_\mu\gamma_5 b|\bar{B}(p)\rangle = i(\epsilon^*_\lambda \cdot q)\frac{2m_{K^*} q_\mu}{q^2} A_0(q^2) + i(m_B + m_{K^*})\left(\epsilon^*_{\lambda,\mu} - \frac{(\epsilon^*_\lambda \cdot q) q_\mu}{q^2}\right) A_1(q^2) - i(\epsilon^*_\lambda \cdot q)\left[\frac{(2p-q)_\mu}{m_B + m_{K^*}} - (m_B - m_{K^*})\frac{q_\mu}{q^2}\right] A_2(q^2),$$

Define the observables that are less sensitive to the choice of the form factors.

$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_\ell \, d\cos\theta_K \, d\phi \, dq^2}$$

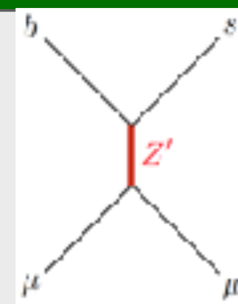
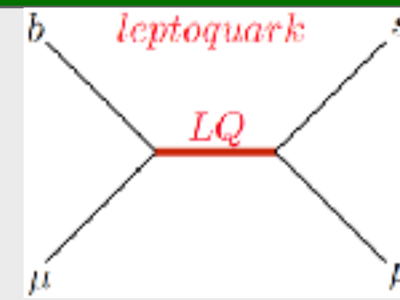
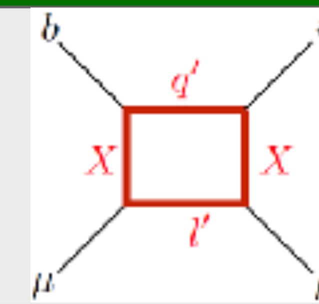
$$= \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi + S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big],$$

$$\frac{S_{3,6,9}}{F_T} \to P_{1,2,3} \quad , \quad \frac{S_{4,5,7}}{\sqrt{F_T F_L}} \to P'_{4,5,6}$$



(Descotes-Genon,et.al.,1207.2753)

Rough sketch of BSMs motivated by *b→sll anomalies*

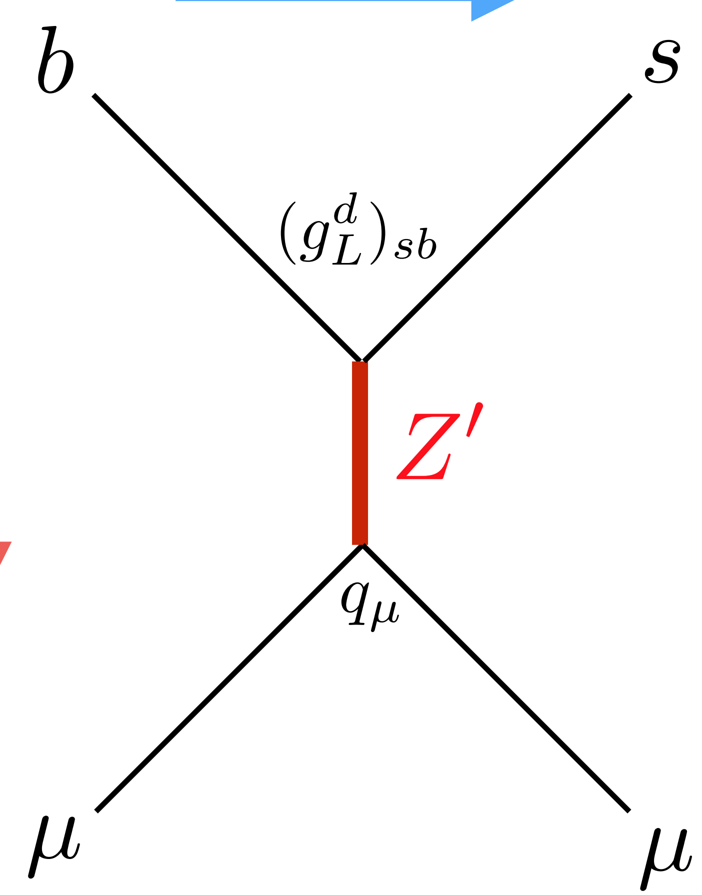
	Z’	Leptoquark	“Loop”
Contribution to B→K(*)ll			
Expected BSMs	For fermion masses *(Ko, Yu, Shigekami, YO,’17)* Motivated by GUT *(King, ’17)* $U(1)_{\mu-\tau}$, $U(1)_{(B-L)i}$ etc. *(Chen, Nomura, ’18; Bian, Choi, et.al.’17; Ellis, et.al, 17’; Alonso, Cox, et.al., ’17 etc.)*	Pati-Salam: $SU(4)\times SU(2)_L\times SU(2)_R$ *(Blanke, Crivellin,’18; Calibbi, Crivellin, Li,’17)* Composite *LQ* *(Gripaios, Nardecchia, Renner ’14; Barbieri, et.al., ’16; Matsuzaki, Nishiwaki, Watanabe, ’17; Cline, ’17)*	Inverse seesaw, Radiative seesaw *(Khalil, 17’; Cai, Gargalionis, et.al.,’17)* DM models *(Belanger, et.al,’15; Kawamura, Okawa, YO,’17)* SUSY *(Altmannshofer, Straub’13; Das, Hati, et.al.,’17)* LR gauged model *(Das, Hati, et.al.,’17)*
Bs-Bsbar mixing	Tree-level	1-loop	1-loop
signals@LHC	Z’ →μμ/ττ	ττ search, *LQ* search	search for q’/l’/X
Refs. for (g-2) μ	*Bian, Choi, Kang, Lee, 1707.04811; Allanach, Queiroz, et.al., 1511.07447, etc.*	*Bauer, Neubert, 1511.01900; Calibbi, Crivellin, Li, 1709.00692, etc.*	*Gripaios, et.al., 1509.05020; Poh, Raby, 1705.07007, etc.*
Other issues	b→sττ (for $U(1)_{\mu-\tau}$) ν→νμμ (trident production) B→Kνν How to achieve anomaly-free	b→clν: R(D(*)) b→sττ, b→sτμ	Very large μ-couplings DM search

Constraints from flavor physics

2. Bs→μμ

Excess reported

$B_s \to \mu\mu$

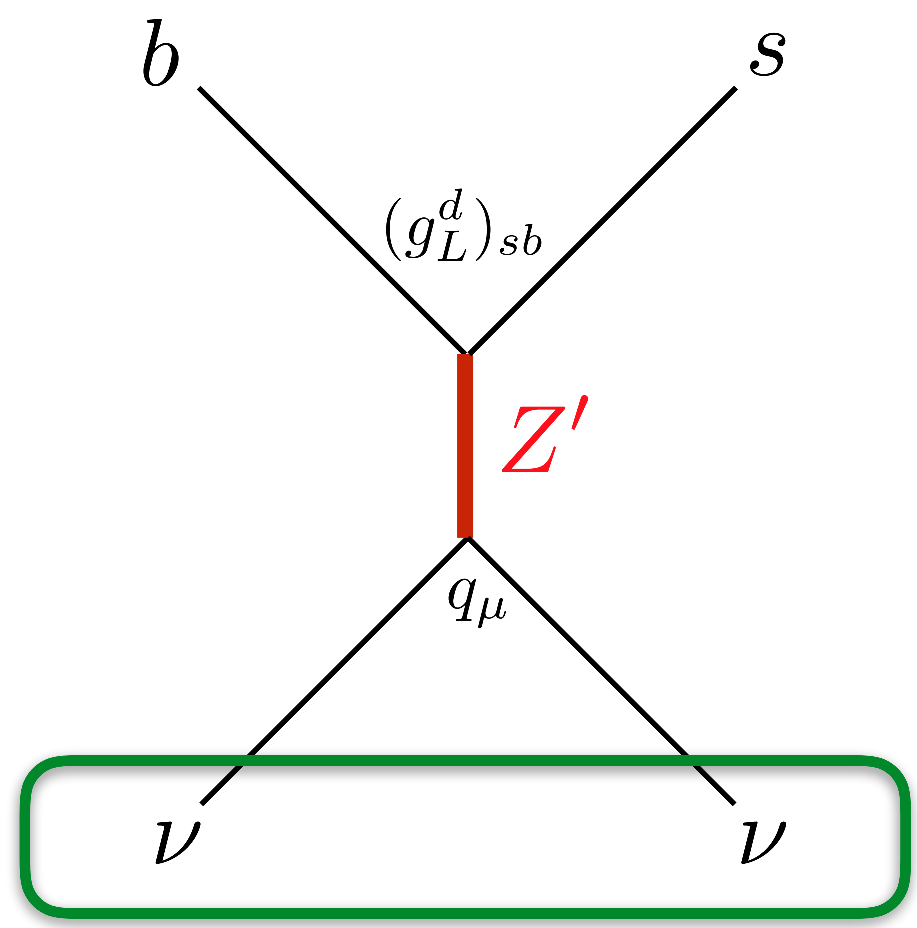


$\mathrm{BR}(B_s \to \mu\mu) = (3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}$ @LHCb

$BR(B_s \to \mu^+\mu^-)^{\mathrm{SM}} = (3.65 \pm 0.23) \times 10^{-9}$

The excesses predict suppressed Bs→μμ

3. B→K(*)νν



$b \to s\nu\nu$ *is also predicted.*

$(\overline{b_L}\gamma^\mu s_L)(\overline{\mu_L}\gamma_\mu \mu_L)$ → $(\overline{b_L}\gamma^\mu s_L)(\overline{\nu_L}\gamma_\mu \nu_L)$

Current status (1303.7465(BaBar), 1303.3719(Belle)):

Current upper limits are a factor 4.3 (K) and 4.4(K) above the SM predictions.*

B →D(*)l ν processes

$$\mathcal{H}_{\rm eff} = \frac{4G_F V_{cb}}{\sqrt{2}} J_{bc,\mu} \sum_{\ell=e,\mu,\tau} (\bar{\ell}\gamma^\mu P_L \nu_\ell) + \text{h.c.}$$

$$J^\mu_{bc} = \bar{c}\gamma^\mu P_L b + g_{SL} i\partial^\mu(\bar{c}P_L b) + g_{SR} i\partial^\mu(\bar{c}P_R b)$$

SM
leptoquark

charged Higgs appears

(Fajfer, et al., 1203.2654; Sakaki,Tanaka,1205.4908;Crivellin,et al., 1206.2634)

B →D*τν

$$\frac{d\Gamma_\tau}{dq^2} = \frac{G_F^2|V_{cb}|^2|\mathbf{p}|q^2}{96\pi^3 m_B^2}\left(1-\frac{m_\tau^2}{q^2}\right)^2\left[(|H_{++}|^2+|H_{--}|^2+|H_{00}|^2)\left(1+\frac{m_\tau^2}{2q^2}\right)+\frac{3}{2}\frac{m_\tau^2}{q^2}|H_{0t}|^2\right]$$

$$H_{0t} = H_{0t}^{\rm SM}\left[1+(g_{SR}-g_{SL})\frac{q^2}{m_b+m_c}\right]$$

B →Dτν

$$\frac{d\Gamma(\bar{B}\to D l^-\bar{\nu})}{dq^2} = \frac{G_F^2|V_{cb}|^2}{192\pi^3 m_B^3}\left(1-\frac{m_l^2}{q^2}\right)^2\sqrt{\lambda_D}$$
$$\times\left[\lambda_D\left(1+\frac{m_l^2}{2q^2}\right)^2 f_+(q^2) + \frac{3m_l^2}{2q^2}(m_B^2-m_D^2)^2 f_0^2(q^2)\left(1+\delta_{H^+}^{Dl}(q^2)\right)\right]$$

where $\lambda_D = (m_B^2 - m_D^2 - q^2)^2 - 4m_D^2 q^2$.

(Iguro,Tobe,1708.06176)

Bc decay also limit the charged scalar scenario strongly.

(Alonso,Grinstein,et al., 1611.06676;Akeroyd,Chen,1708.04072)