Loop Level Models

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Instant workshop on *B* meson anomalies

CERN, May 18, 2017

INTRODUCTION

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

G. Hiller, F. Kruger hep-ph/0310219

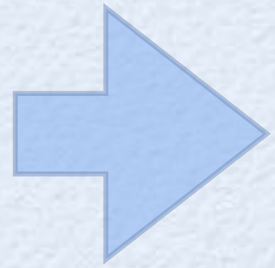
$$R^{\mathrm{SM}}_{K^{(*)}} = 1 + \mathcal{O}(m_\mu^2/m_b^2)$$

LHCb:

$$R_{K,[1,6]\mathrm{GeV}^2} = 0.745 \pm 0.090$$

$$R_{K^*,[0.045,1.1]\mathrm{GeV}^2} = 0.66^{+0.11}_{-0.07}$$

$$R_{K^*,[1.1,6]\mathrm{GeV}^2} = 0.69^{+0.12}_{-0.08}$$



(2.2-2.6)σ from the SM

INTRODUCTION

global fit of $b \to s\ell\ell$ data

$$C_9^{\mu,\mathrm{NP}} = -C_{10}^{\mu,\mathrm{NP}} \approx -0.64 \pm 0.15$$

Altmannshofer et al 1703.09189
Gen et al 1704.05446
Ciuchini et al 1704.05447
D'Amino et al 1704.05438
Altmannshofer et al 1704.05435
Capdevila et al 1704.05340

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NP effect is 15% of the SM

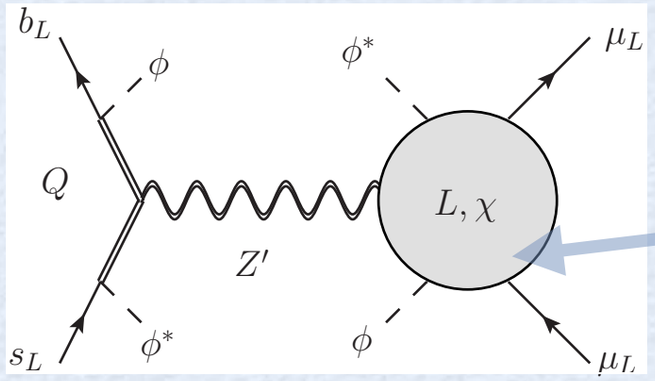
tree level
$c/\Lambda_i \sim 35$ TeV

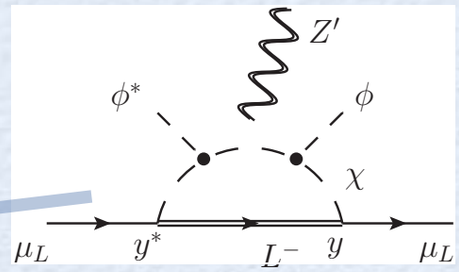
loop mediaed
$c/\Lambda_i \sim 3$TeV

loop+MFV
$\Lambda_i < 1$TeV

MUON ANOMALIES AND DARK MATTER

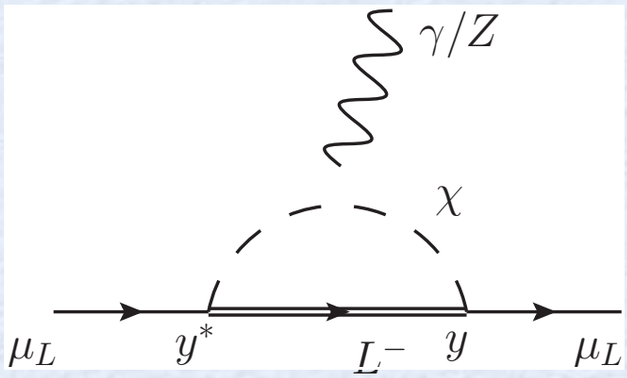
$b \to s\ell\ell$





forbidden tree level

$(g\text{-}2)_\mu$



$$m_{Z'} \lesssim 110 - 270\,\mathrm{GeV} \left(\frac{g'}{3}\right) \left(\frac{|y|}{3}\right)^2$$

vector like

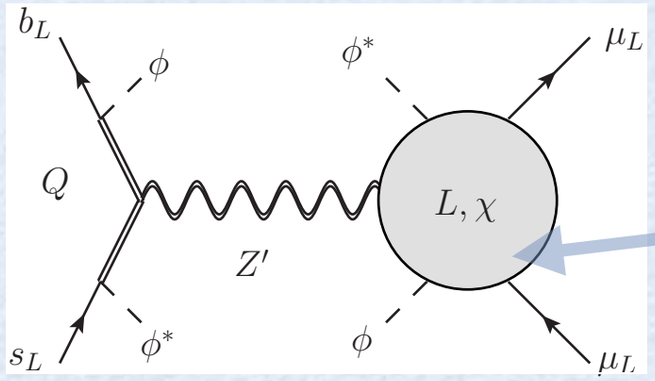
scalars

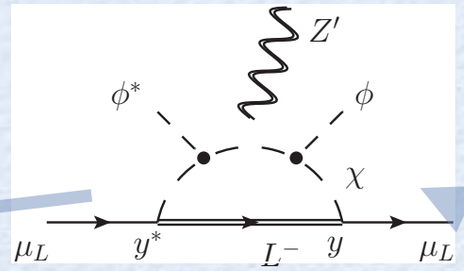
	spin	$\mathrm{SU}(3)_c$	$\mathrm{SU}(2)_L$	$\mathrm{U}(1)_Y$	$\mathrm{U}(1)_X$
$L,\ L^c$	$1/2$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	1
$Q,\ Q^c$	$1/2$	$\mathbf{3}$	$\mathbf{2}$	$1/6$	-2
ϕ	0	$\mathbf{1}$	$\mathbf{1}$	0	2
χ	0	$\mathbf{1}$	$\mathbf{1}$	0	-1

G. Belanger, C. Delaunay, S. Westhoff - 1507.06660

MUON ANOMALIES AND DARK MATTER

$b \to s\ell\ell$

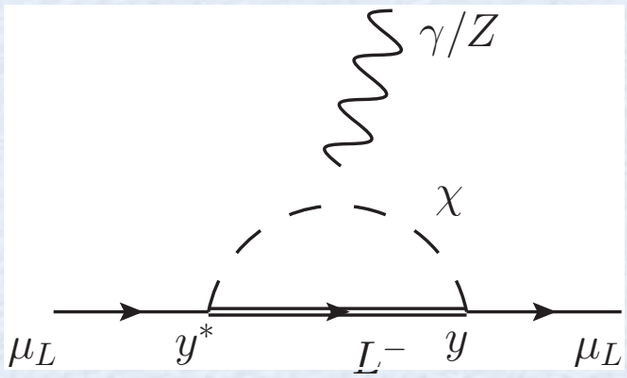




forbidden tree level

valid dark matter candidate

$(g\text{-}2)_\mu$



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vector like

scalars

	spin	$SU(3)_c$	S
$L,\ L^c$	1/2	**1**	
$Q,\ Q^c$	1/2	**3**	
ϕ	0	**1**	
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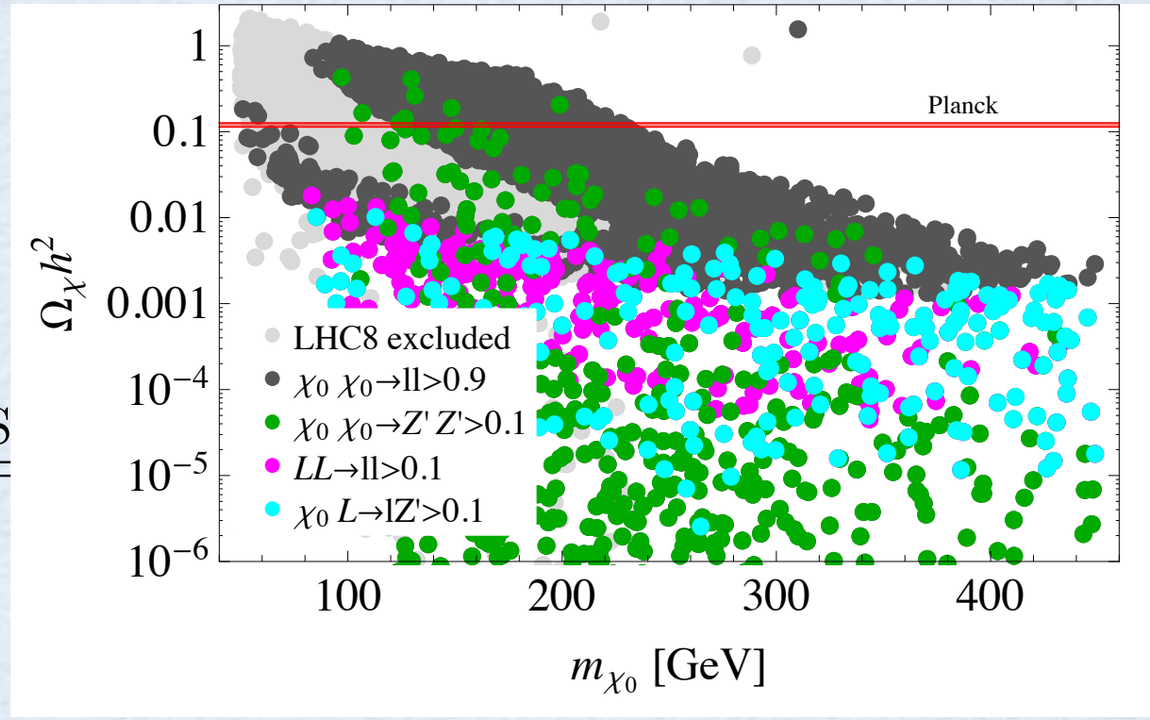

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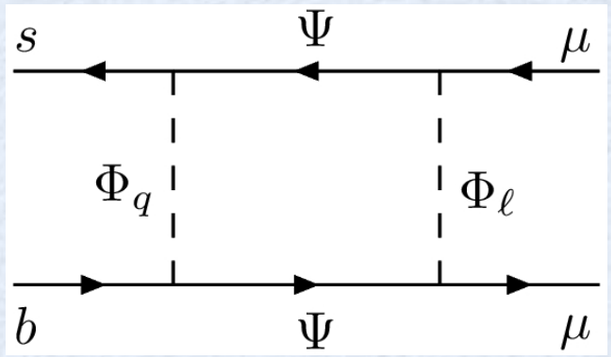
HEAVY PARTICLES IN THE BOX

$$\Psi \sim (1,4)_{3/2}$$
$$\Phi_q \sim (\bar{3},3)_{4/3}$$
$$\Psi_\ell \sim (1,3)_3$$

$$\alpha_i^q\, \overline{\Psi} Q_L^i \Phi_q + \alpha_i^\ell\, \overline{\Psi} L_L^i \Phi_\ell$$



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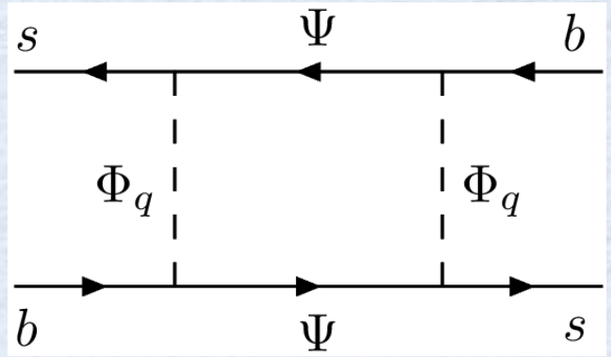

B_s mixing

B. Gripaions, M. Nardecchia, S. Renner - 1509.05020
P. Arnan, L. Hofer, F. Mesica, A. Crivellin - 1608.07832

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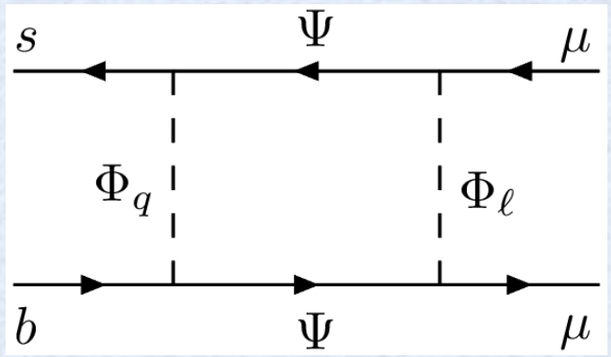

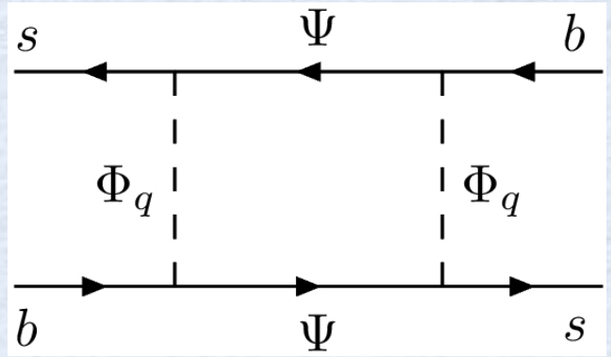

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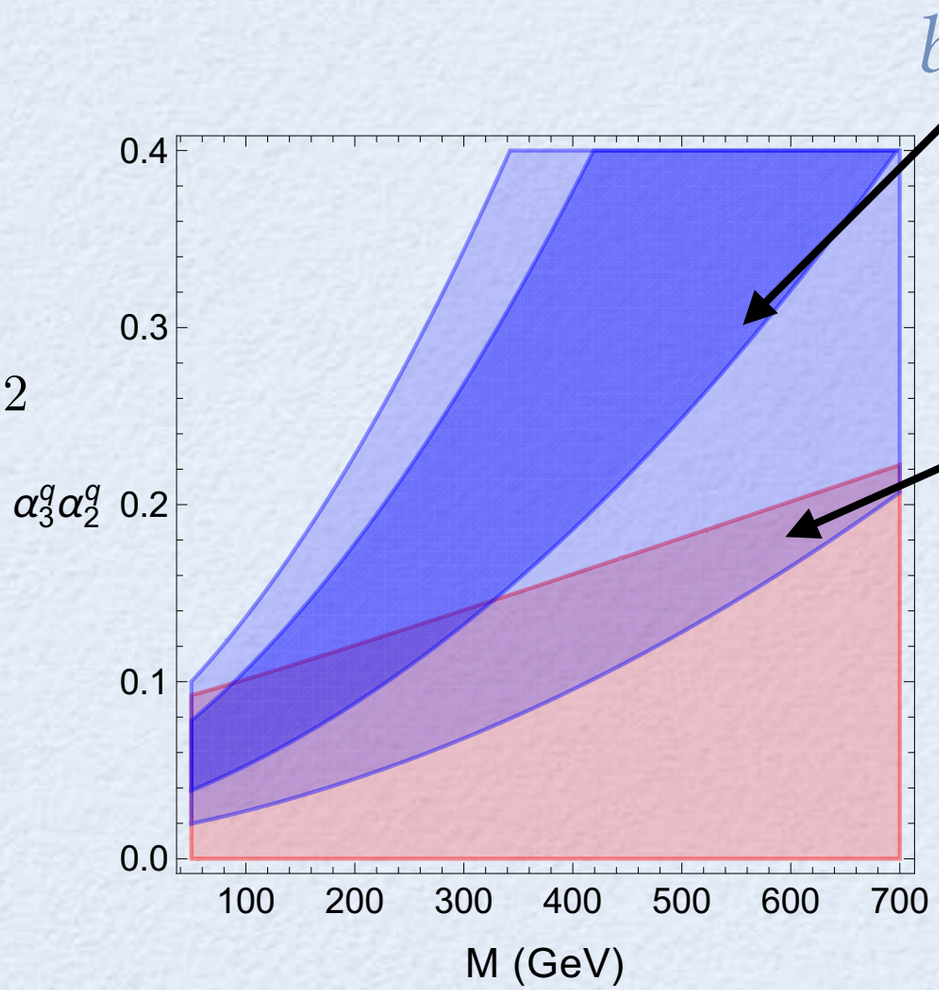

$\alpha_2^\ell = 1.2$

$M_\Psi = M,\ M_\ell = M + 200\ \text{GeV},\ M_q = M + 700\ \text{GeV}$

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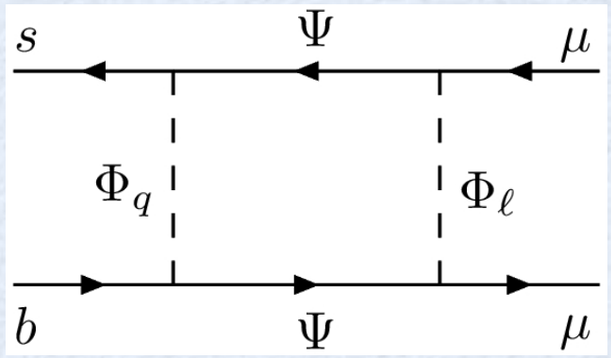

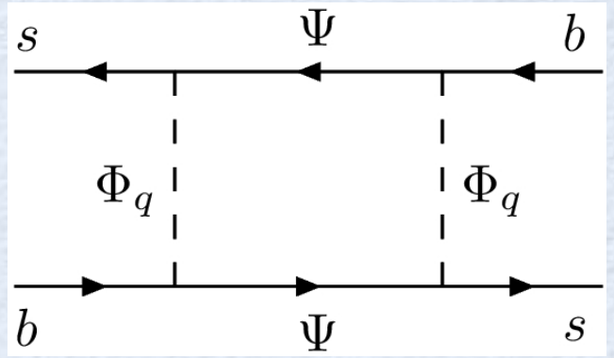

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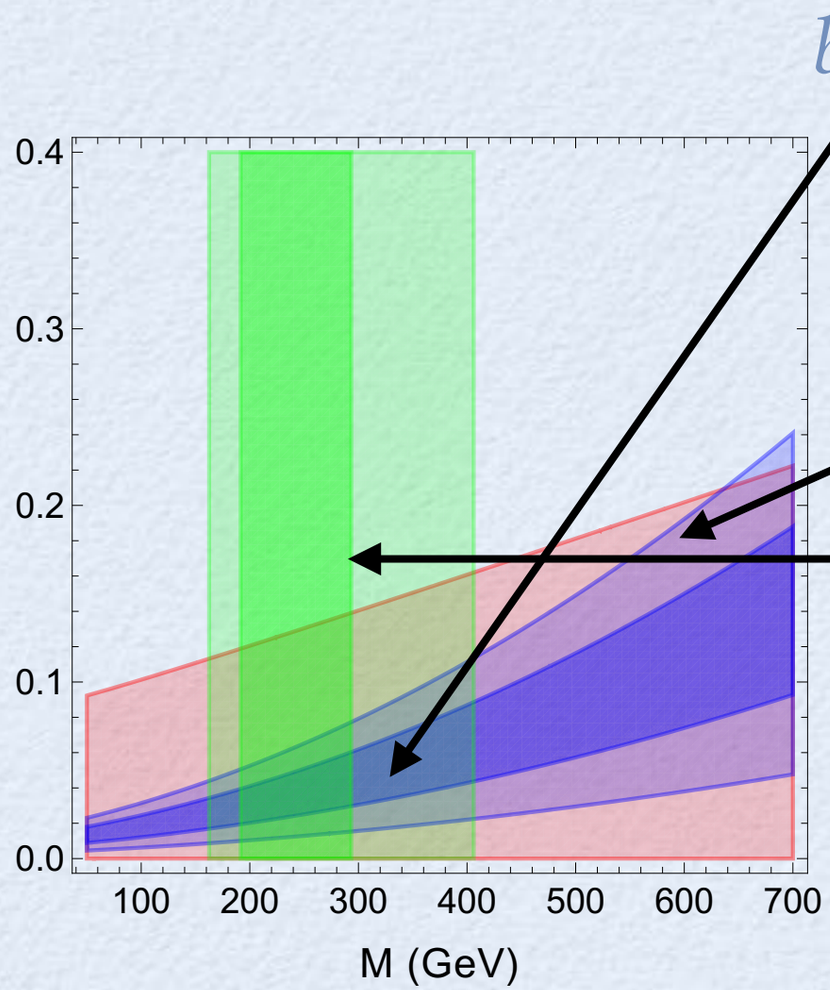
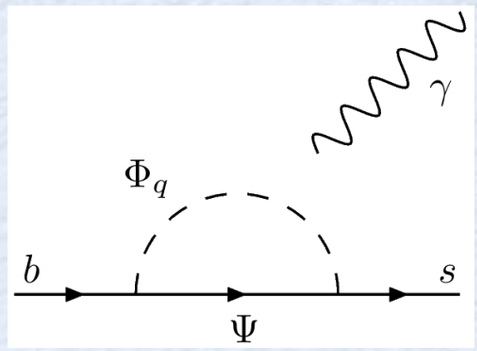


$\alpha_2^\ell = 2.5$



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P. Arnan, L. Hofer, F. Mesica, A. Crivellin - 1608.07832

Lepton flavor universality violation without new sources of quark flavor violation

J.F. Kamenik, YS, J. Zupan - 1704.06005

THE BASIC IDEA

use the SM FCNC mechanism

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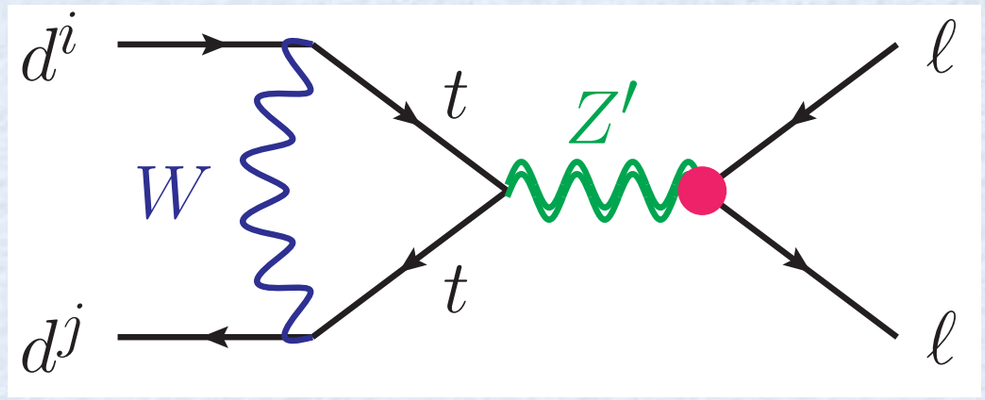
use the SM FCNC mechanism

Z′ which couples only to tops and muons



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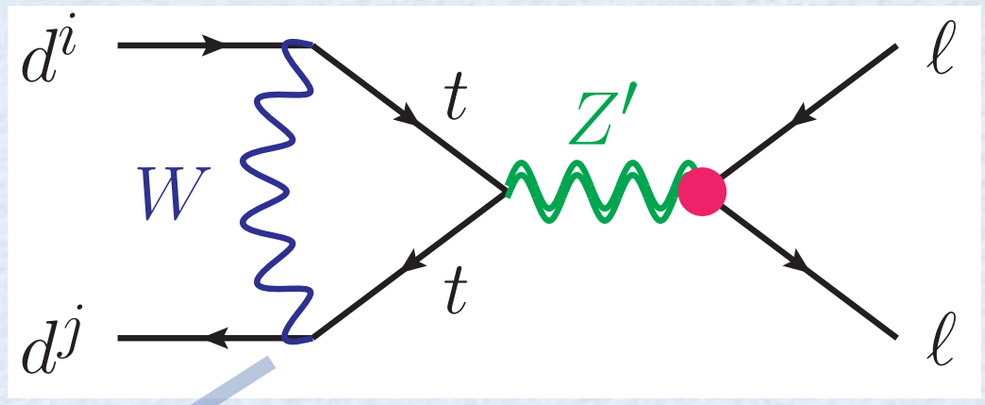

$b \to s$ transition

- V-A structure
- CKM suppressed
- MFV structure

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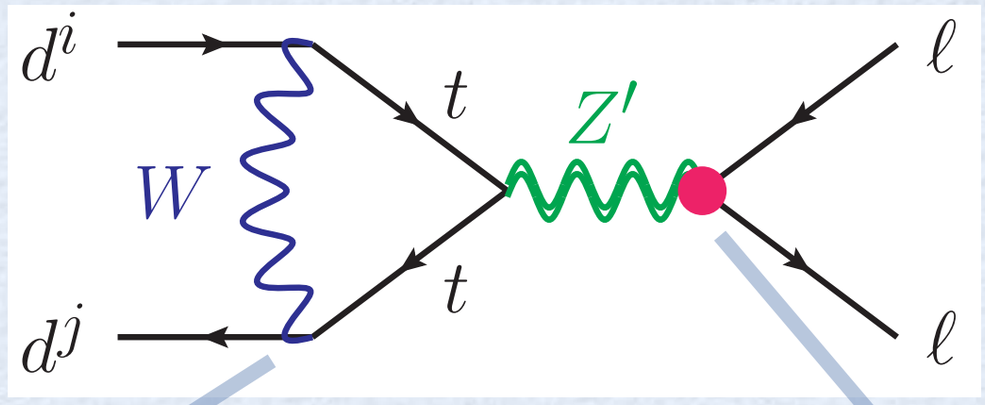


$b \to s$ transition

- V-A structure
- CKM suppressed
- MFV structure

$\ell\ell$ couplings:
dependents on the specific implementation

THE MINIMAL U(1)′ MODEL

SM + *U(1)′* + *T′* (vector like)

neutral under *U(1)′* charged under *U(1)′*

Z′/top (also muon) effective coupling from mixing

$$y_T^i \, \bar{T}' \, \Phi \, u_R^i$$

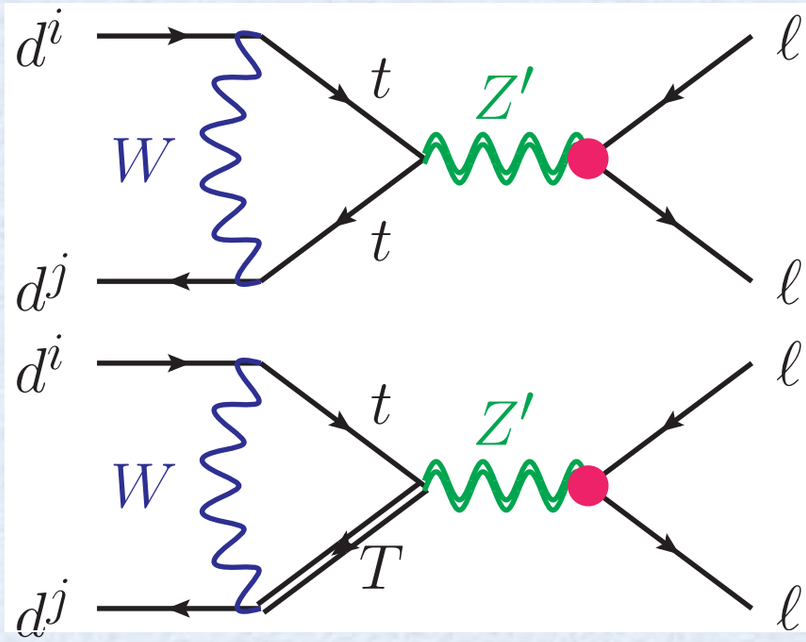
$y_T \sim (0,0,y^t_T)$

aligned with up sector

THE MINIMAL U(1)′ MODEL

SM + *U(1)′* + *T′* (vector like)

neutral under *U(1)′*



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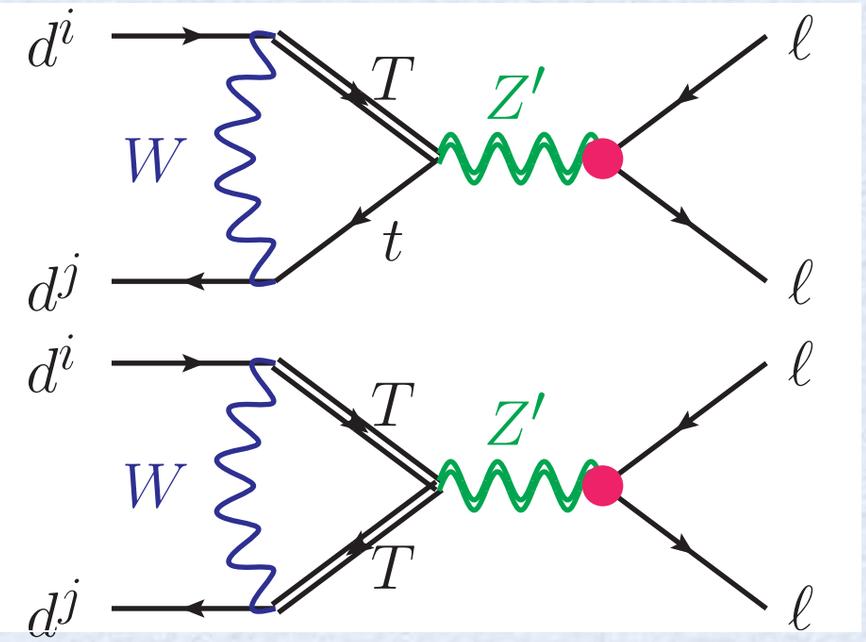


$$C_{9,10}^{\mu,\mathrm{NP}} = \frac{1}{2} q' q'_{\mu,V,A} \frac{m_t^2}{m_{Z'}^2} \frac{\tilde{g}^2}{e^2} s_R^2 \log\left(\frac{m_T^2}{m_W^2}\right) + \ldots \approx 0.4\,(\tilde{g}q')^2 \left(\frac{500\,\mathrm{GeV}}{m_{Z'}}\right)^2 \left(\frac{s_R}{0.3}\right)^2$$

$\tilde{g}$ - U(1)′ gauge coupling
q' - effective charge
s_R - top/*T′* mixing angle

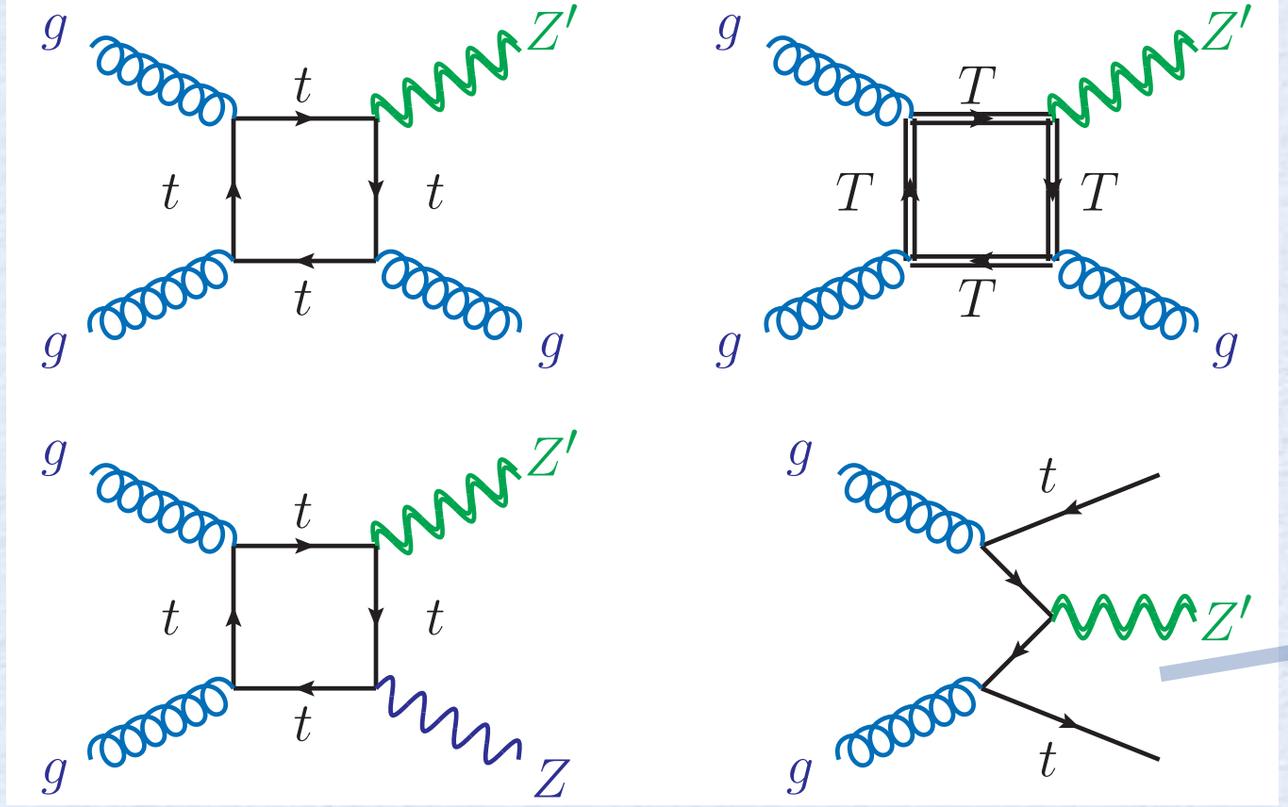
$q'_{\mu,V} = -q'_{\mu,A} = q'$
$m_T = 5 m_{Z'}$

THE MINIMAL U(1)′ MODEL

SM + *U(1)′* + *T′* (vector like)

$m_{Z'} <$ TeV

on-shell proaction
at LHC



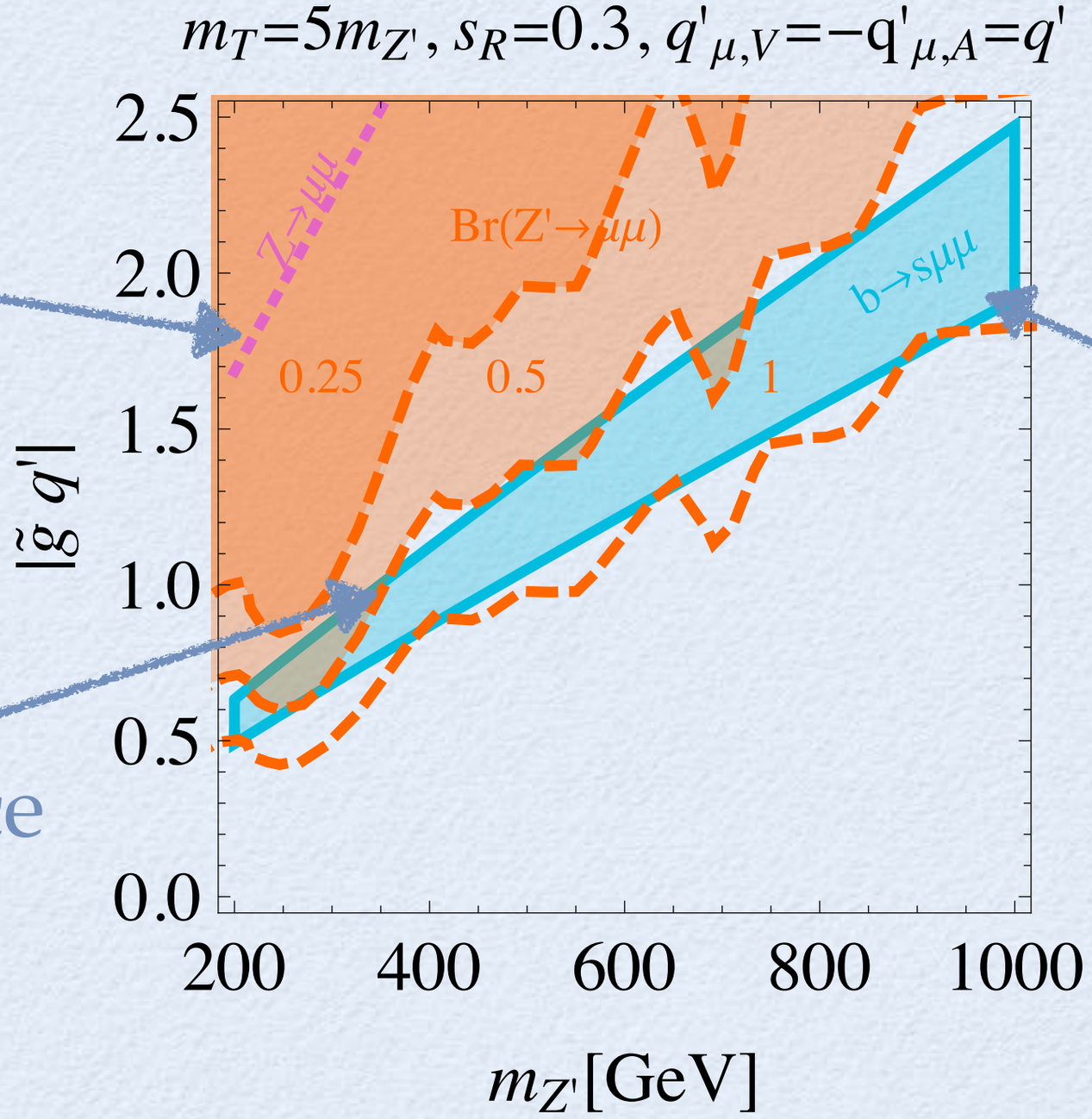
dominant for
$m_{Z'} > 300$GeV

THE MINIMAL U(1)′ MODEL

Z LFU (LEP)

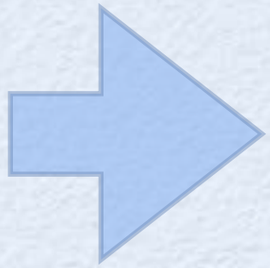
$\mu\mu$ resonance searches

$b\to s\ell\ell$ fit



BEYOND THE MINIMAL MODEL

Z'/τ coupling



smaller BR($Z' \to \mu\mu$)

$Z' \to \tau\tau$ search

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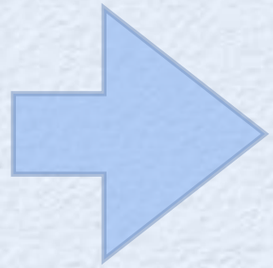

smaller BR($Z' \to \mu\mu$)

$Z' \to \tau\tau$ search

part of strongly interacting sector:

- *Z'* is the lighter vector resonance
- Z' couplings to fermion depend on compositeness
  (proportional to the fermion mass, BR($Z' \to \mu\mu$) is small)
- *U(1)'* is dynamically broken by a condensate, Φ

SUMMARY

- the $b \to s\ell\ell$ anomalies can be explained by loop mediated models, may be related to $(g\text{-}2)_\mu$ and/or dark matter
- the new physics can be below the TeV
- in Z' models which couples only to top and muons, the *V-A* structure (in quark sector) is a clear prediction and the FCNC are mediated by the top/W loop

BACKUP SLIDES

INTRODUCTION

effective Hamiltonian for $b\to s\ell\ell$ transitions

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \frac{e^2}{16\pi^2} \sum_i \left(C_i^\ell O_i^\ell + C_i'^\ell O_i'^\ell\right) + \text{h.c.}$$

$$O_9^\ell = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)$$
$$O_{10}^\ell = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\gamma_5 \ell)$$

$$C_i^\ell = C_i^{\ell,\rm SM} + C_i^{\ell,\rm NP}$$

SM predictions

$$C_9^{\mu,\rm SM} = -C_{10}^{\mu,\rm SM} \approx 4.27$$

Geng et al 1704.05446