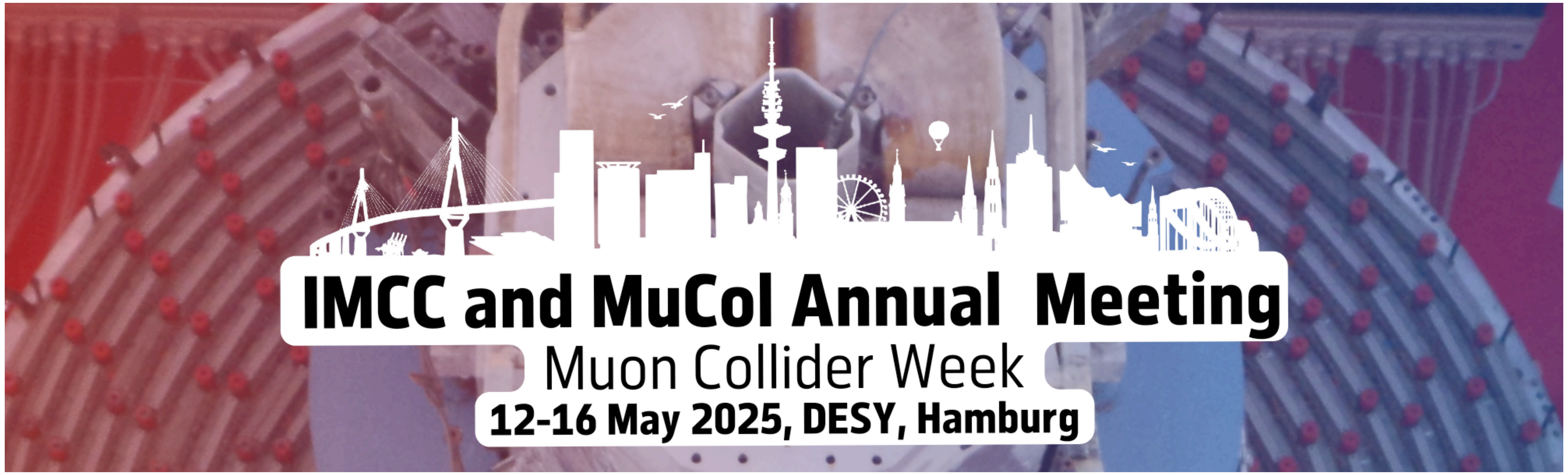

Muophobic forces at the muon collider

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Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

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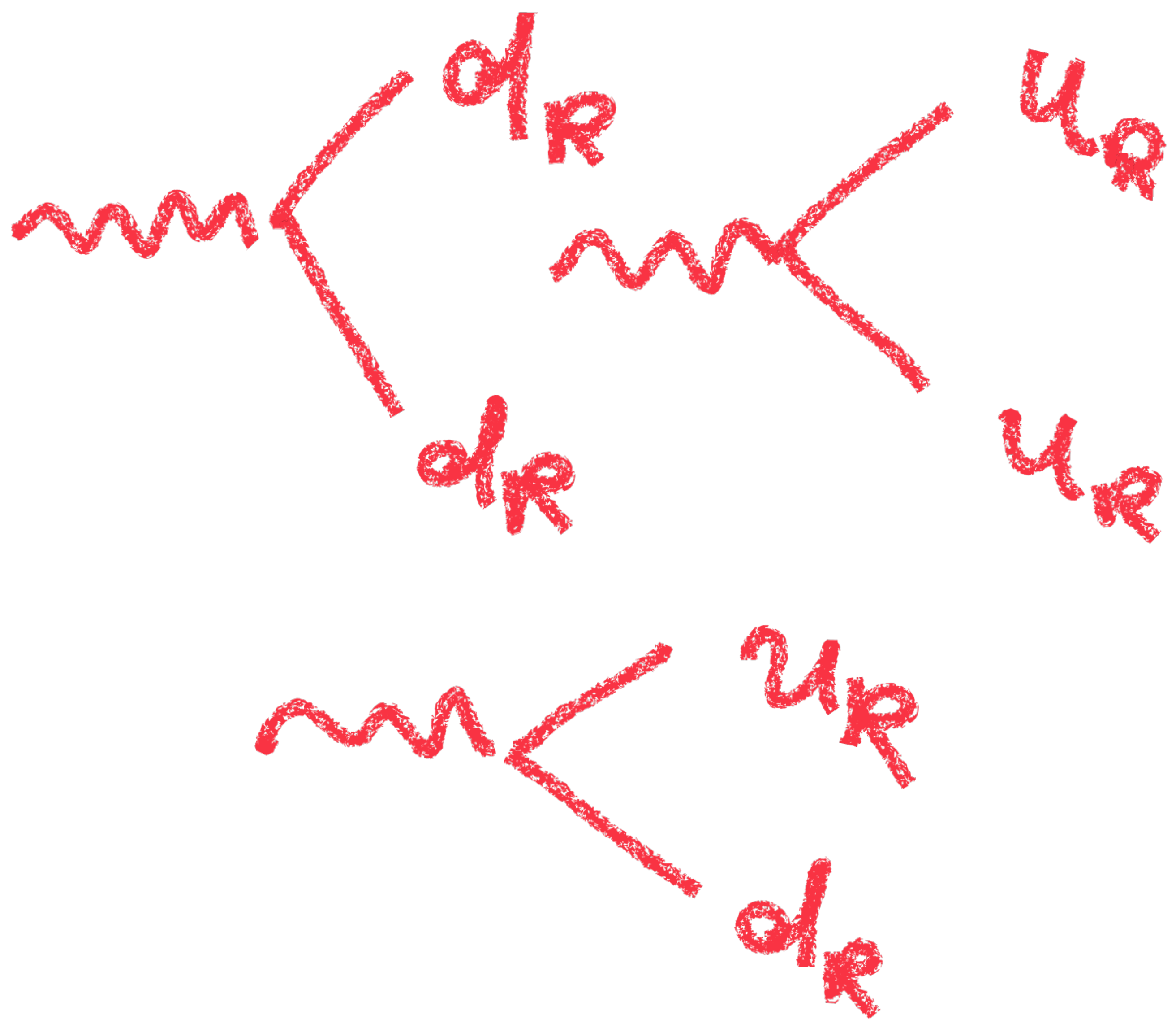
New Gauge Forces in BSM

- New forces arise in motivated extensions of the SM
- They come with new gauge bosons (both electrically charged and neutral)
- Example is to group all the right-handed fields of the SM, that are singlets under the gauge group of the SM $SU(3)_C \times SU(2)_W \times U(1)_Y$, and make them n-plets of a new $SU(2)_R \supset U(1)_Y$

$$u_R \sim \mathbf{1},\ d_R \sim \mathbf{1} \to \begin{pmatrix} u_R \\ d_R \end{pmatrix} \sim \mathbf{2}$$



New Gauge Forces in BSM

connected to flavor puzzle (?)

$$\left.\begin{array}{c} B_3 - L_3 \\ B_3 + L_3 \\ \mathcal{U}_3 \end{array}\right\}$$

coupled only to bottom and top quark, and tau and its neutrino

(each scenario has distinct couplings pattern →dramatic consequences)

B_3 coupled only to bottom and top quark

L_3 coupled only to tau and its neutrino

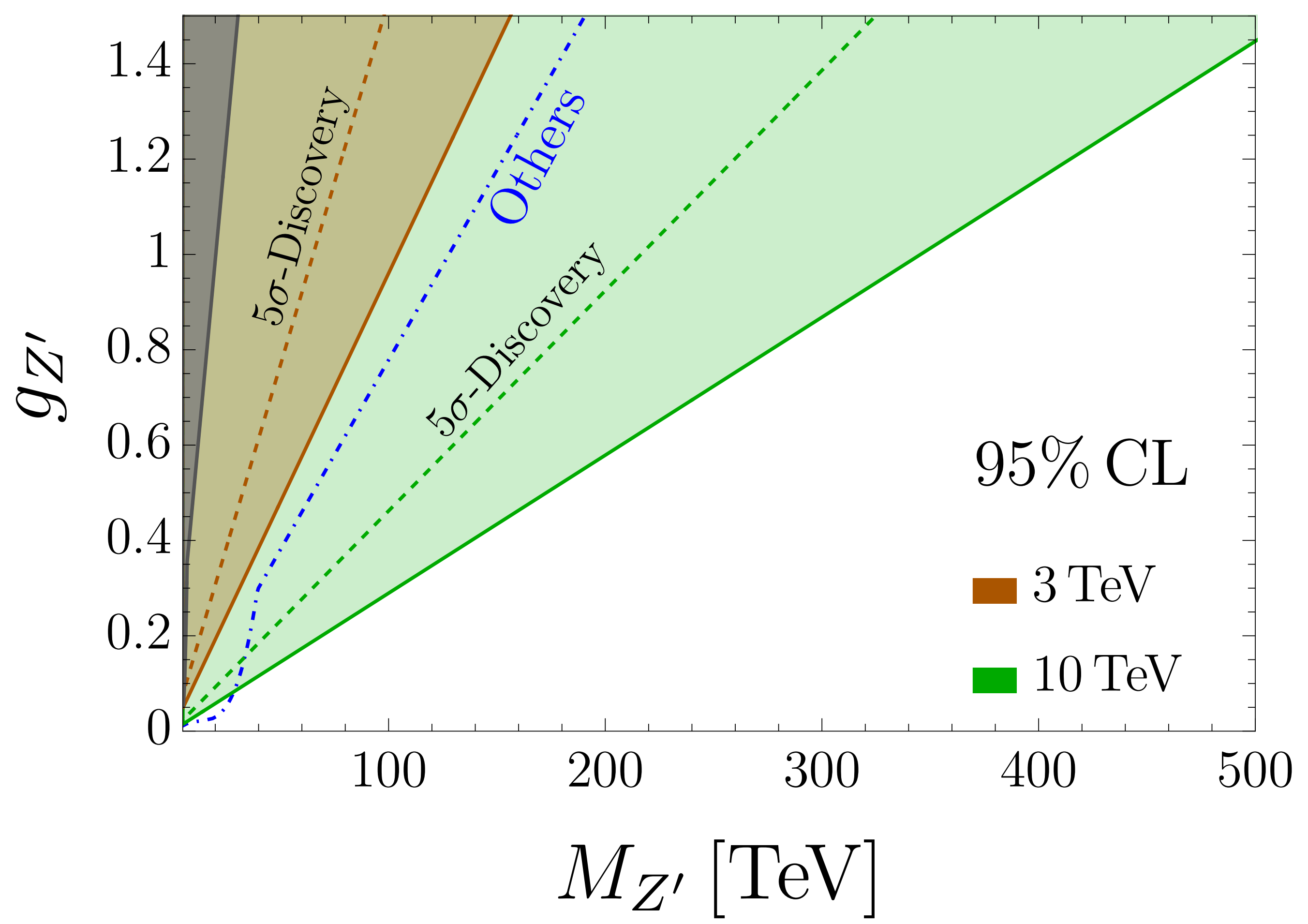
New Gauge Forces in BSM

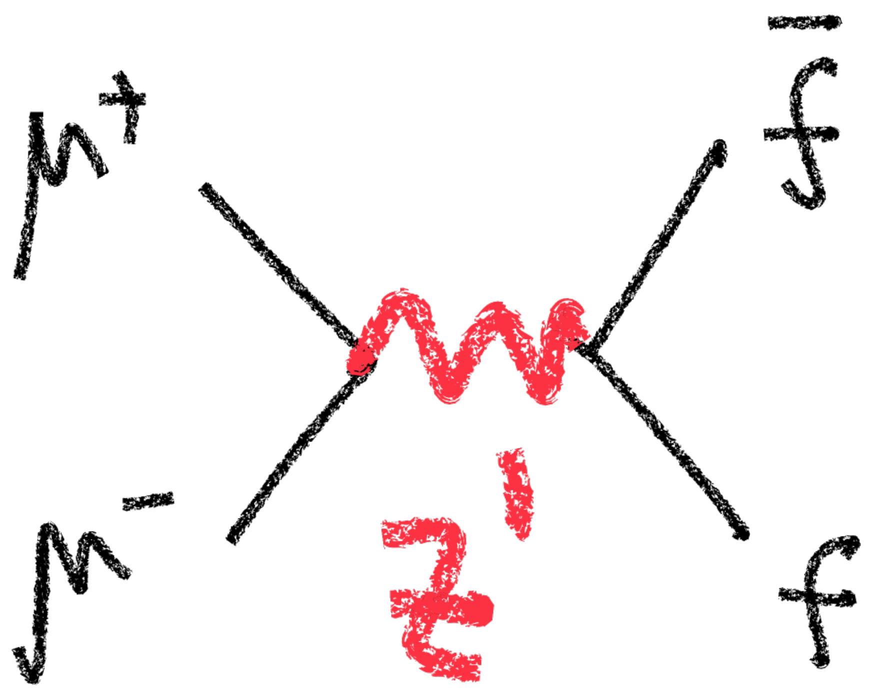
connected to flavor puzzle (?)

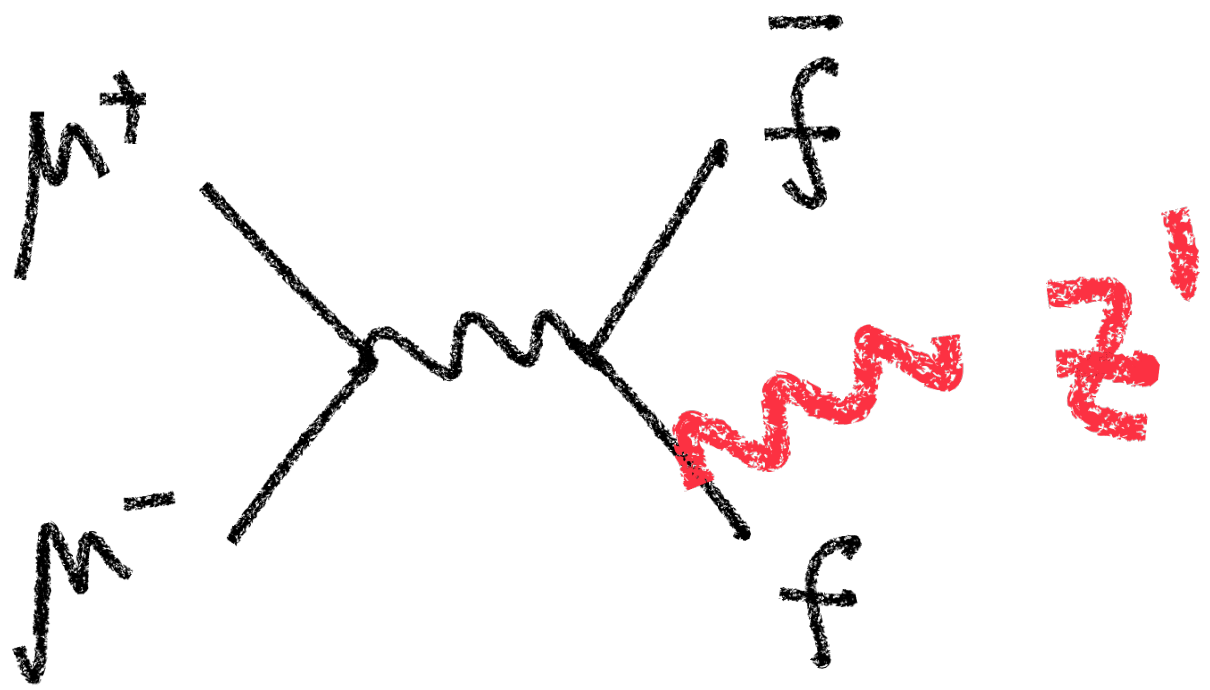
$B_3 - L_3$	$g_{Z'} \equiv 3 \cdot g_{V,q_{L,3}} = 3 \cdot g_{V,b_R} = 3 \cdot g_{V,t_R},$ $-g_{Z'} \equiv g_{V,\ell_{L,3}} = g_{V,\tau_R}.$
$B_3 + L_3$	$g_{Z'} \equiv 3 \cdot g_{V,q_{L,3}} = 3 \cdot g_{V,b_R} = 3 \cdot g_{V,t_R},$ $g_{Z'} \equiv g_{V,\ell_{L,3}} = g_{V,\tau_R}.$
$\mathscr{U}_3$	$g_{Z'} \equiv g_{V,q_{L,3}} = g_{V,b_R} = g_{V,t_R} = g_{V,\ell_{L,3}} = g_{V,\tau_R}.$
B_3	$g_{Z'} \equiv 3 \cdot g_{V,q_{L,3}} = 3 \cdot g_{V,b_R} = 3 \cdot g_{V,t_R}.$
L_3	$g_{Z'} \equiv g_{V,\ell_{L,3}} = g_{V,\tau_R}.$

New Gauge Forces in BSM

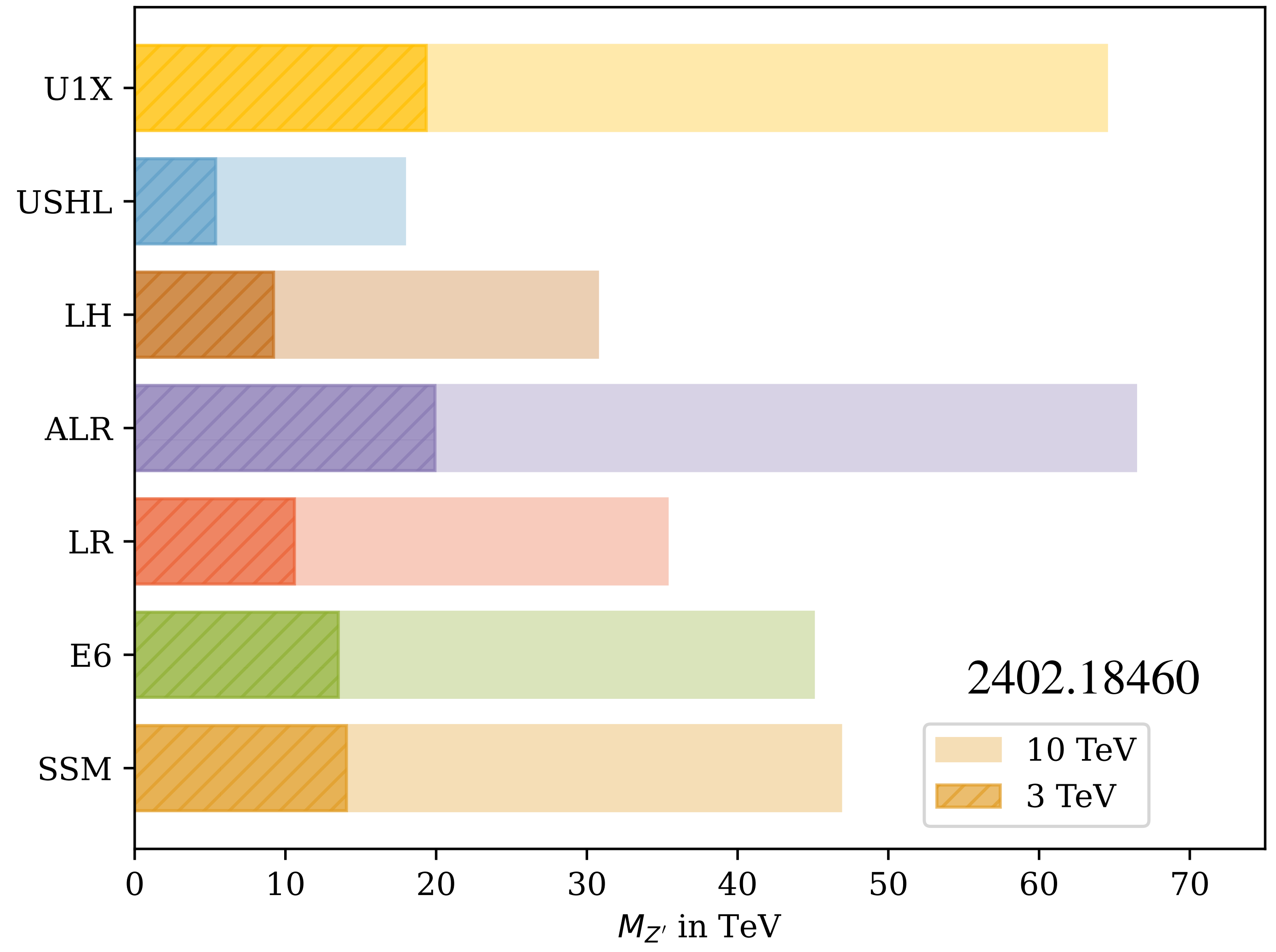
Indirect (Direct) search if heavier (lighter) than 10 TeV







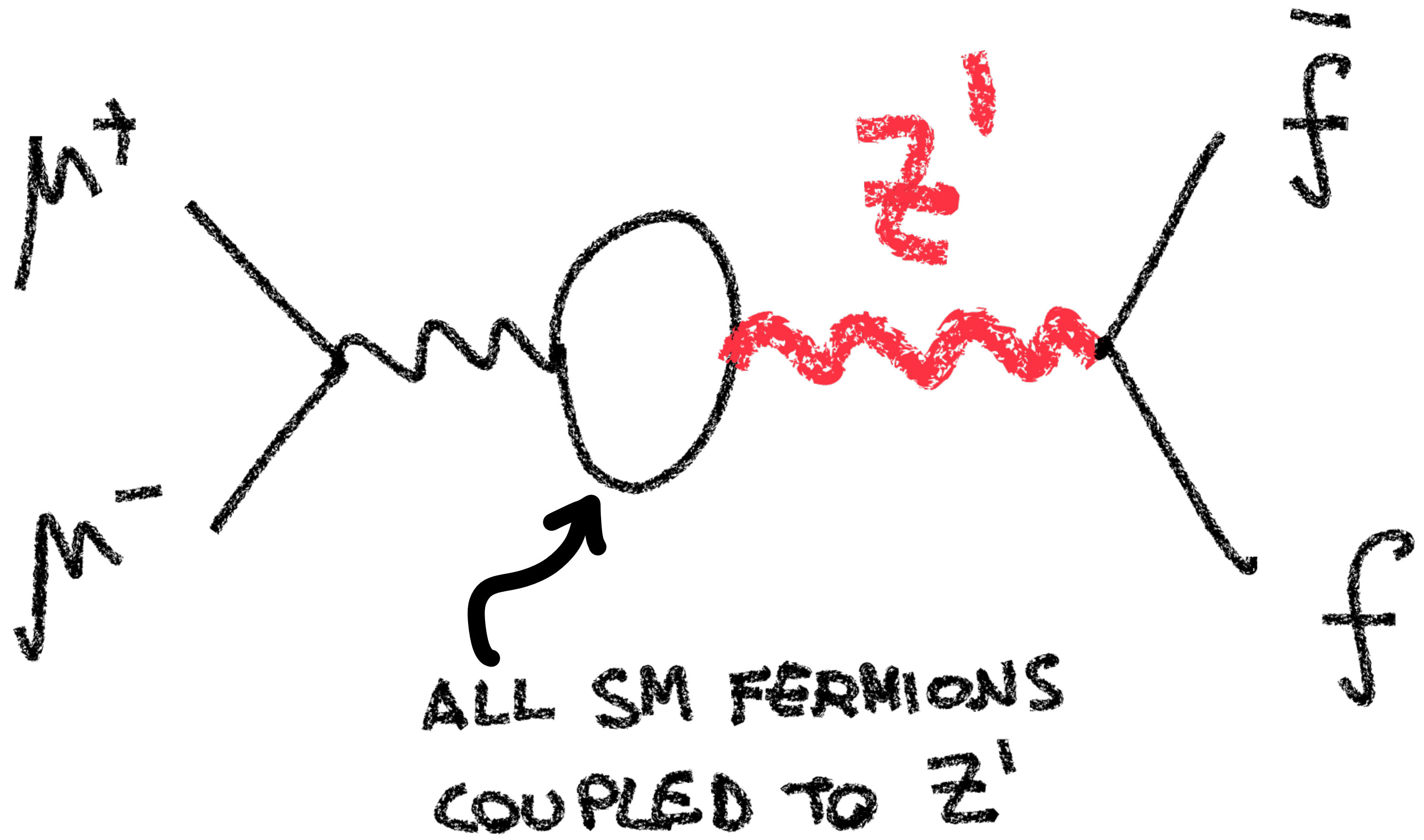
Do not need to assume muon coupling to Z'



2312.17427 for 6 and 8 TeV results

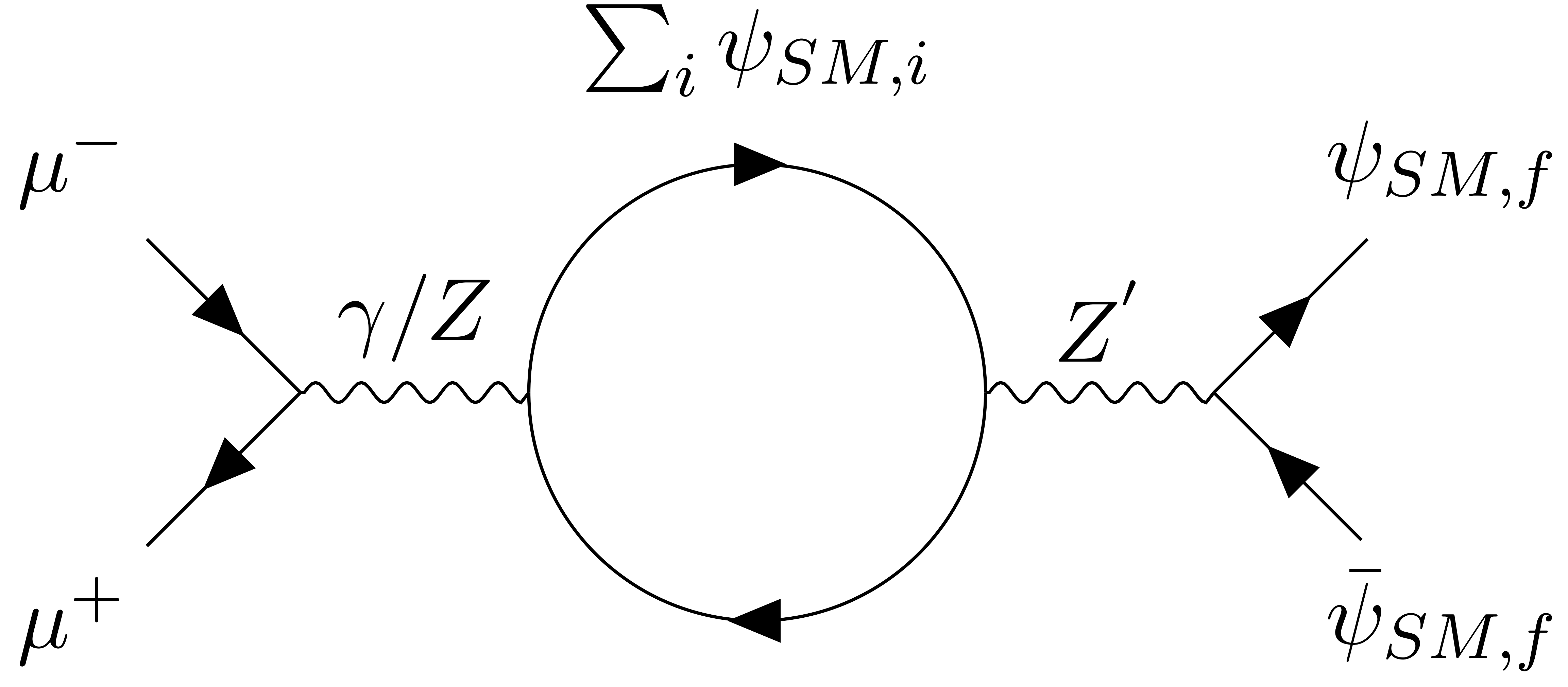
Model	$g_{Z'}$	$2v_l$	$2a_l$
SSM	$\frac{e}{s_W c_W}$	$2s_W^2 - \frac{1}{2}$	$-\frac{1}{2}$
E_6	$\frac{e}{c_W}$	$\frac{2\cos\beta}{\sqrt{6}}$	$\frac{\cos\beta}{\sqrt{6}} + \frac{\sqrt{10}\sin\beta}{6}$
LR	$\frac{e}{c_W}$	$\frac{1}{\alpha} - \frac{\alpha}{2}$	$\frac{\alpha}{2}$
ALR	$\frac{e}{s_W c_W \sqrt{1-2s_W^2}}$	$\frac{5}{2}s_W^2 - 1$	$-\frac{1}{2}s_W^2$
LH	$\frac{e}{s_W}$	$-\frac{c}{4s}$	$-\frac{c}{4s}$
USLH	$\frac{e}{c_W\sqrt{3-4s_W^2}}$	$\frac{1}{2} - 2s_W^2$	$\frac{1}{2}$
$U(1)_X$	$\frac{e}{4c_W}$	-8	2

Table 1: The Z' couplings to leptons in the models considered in this paper. The sine of the Weinberg angle is denoted by s_W. For the description of the models and the explanation of the model-specific parameters see the main text. The table and notation are adapted from [22].

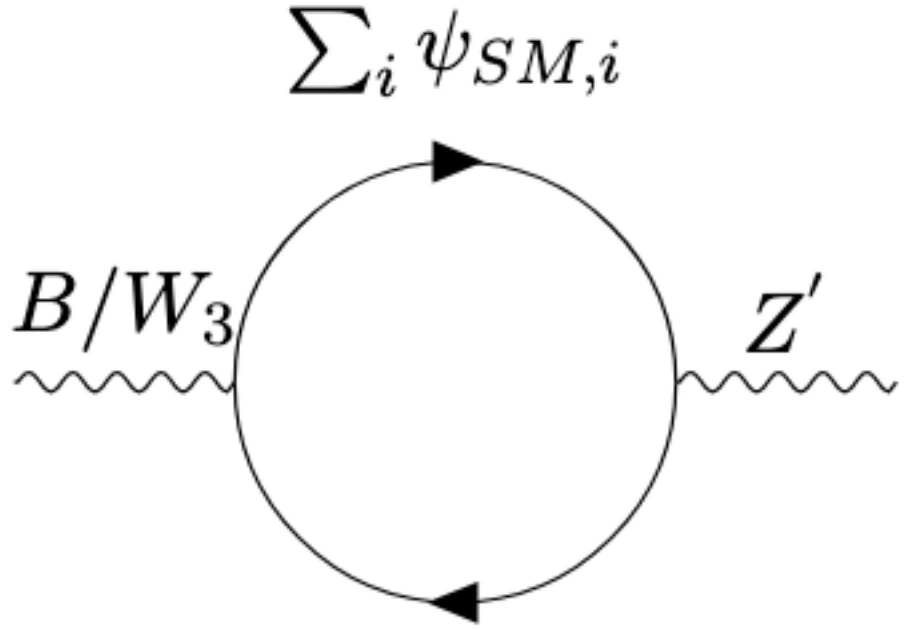


New Gauge Forces in BSM

connected to flavor puzzle (?)



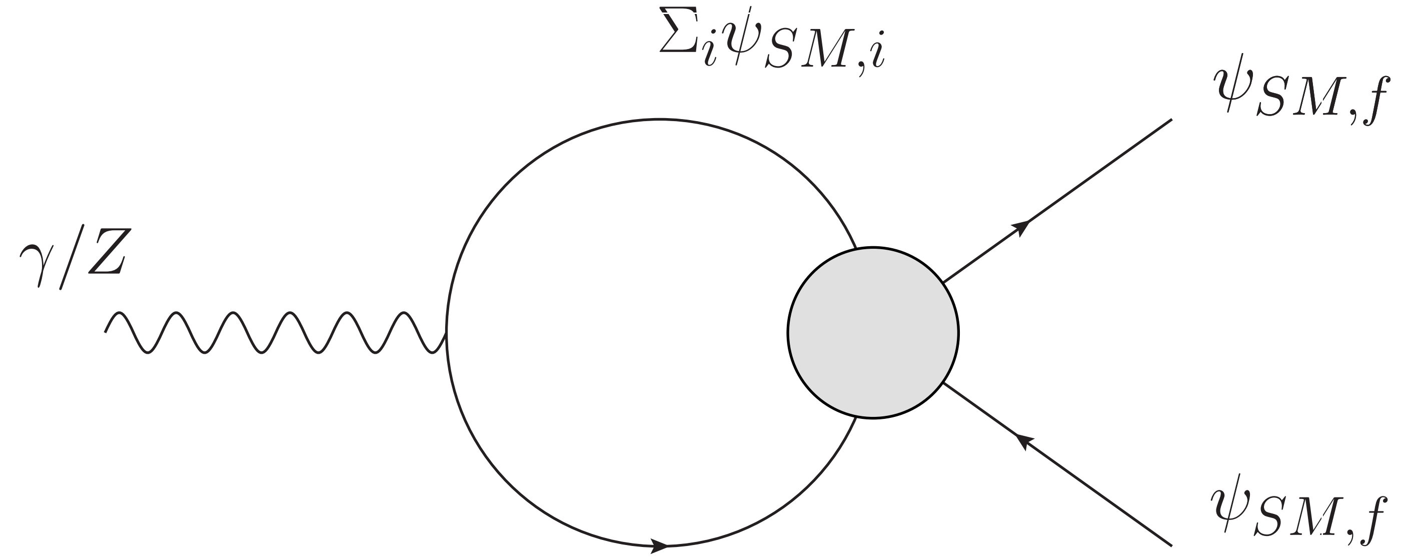
Even if Z' does not couple to muon directly, a coupling can be generated by loops



effectively we rely on a loop-level mixing between Z' and SM gauge bosons

New Gauge Forces in BSM

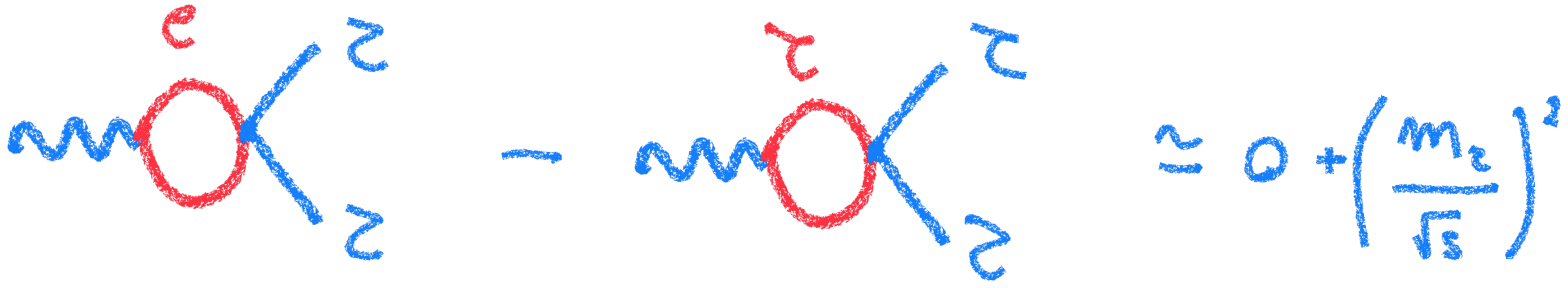
The crucial ingredient is the piece of the amplitude, which sums over intermediate fermions



Each intermediate state enters with its own SM charge and charge w.r.t. Z'

Cancellations of contributions are possible, and even expected in some cases

$L_e - L_\tau$



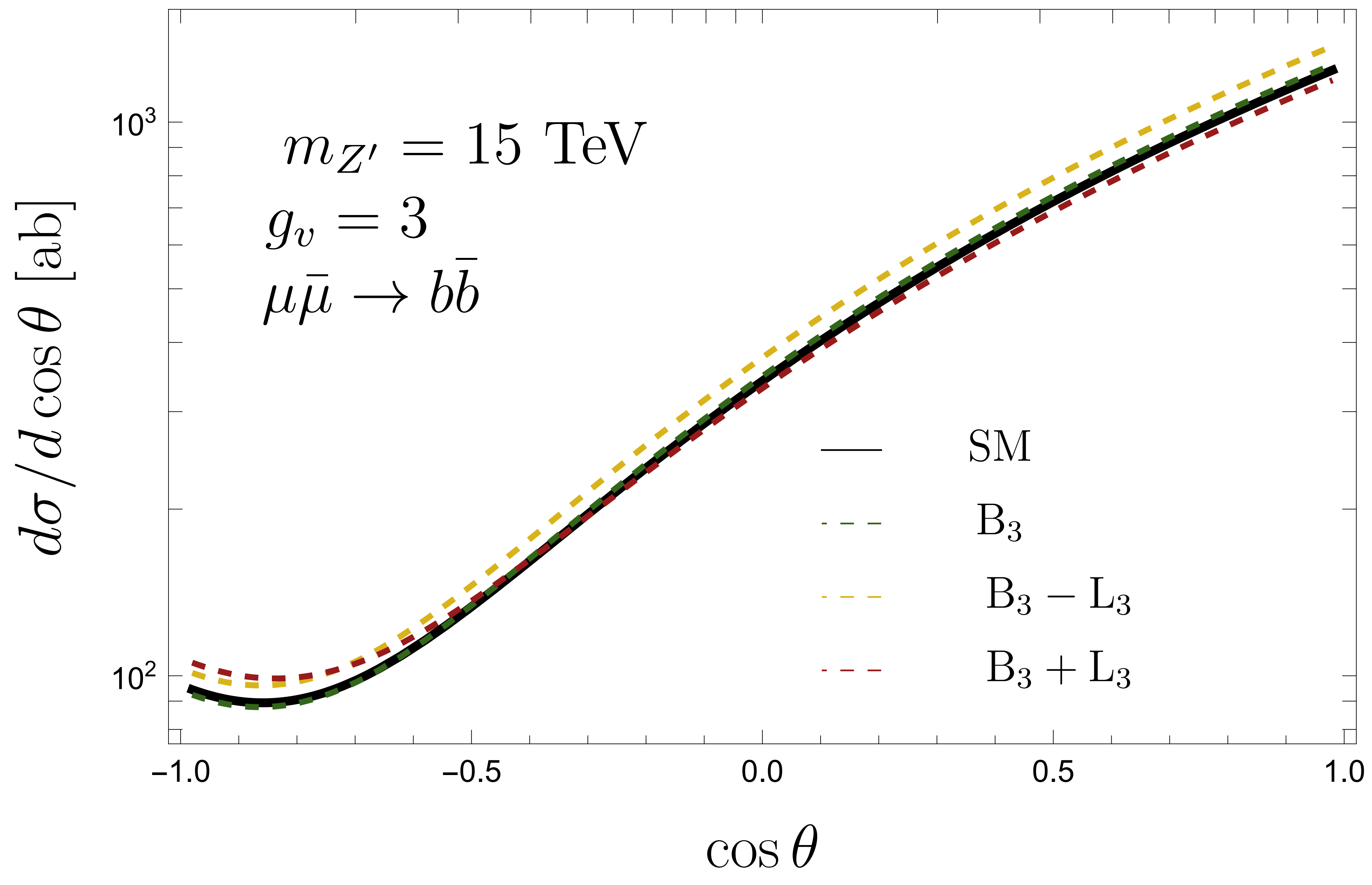
$SU(2)_R$

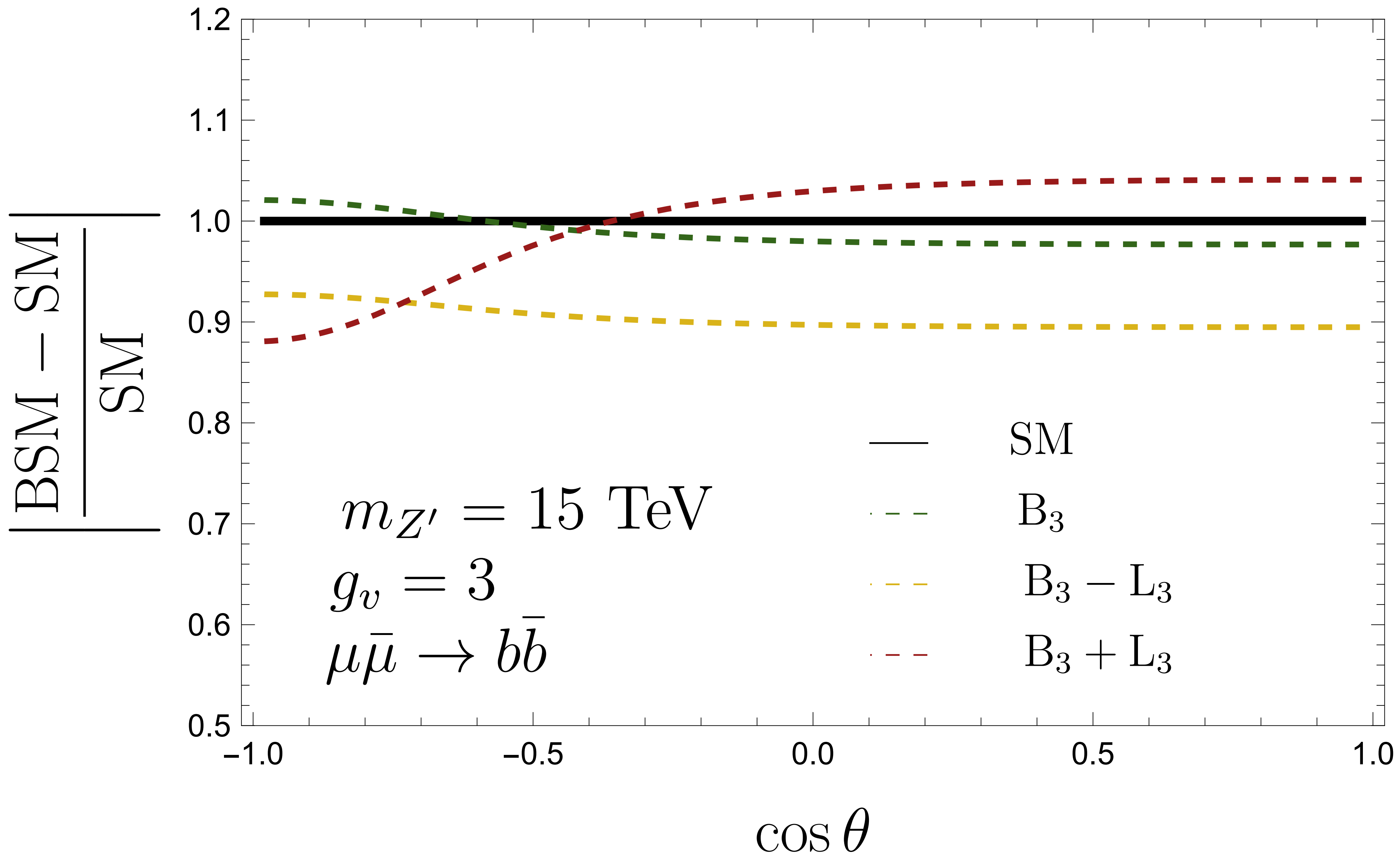
$\mathcal{U}_3$

$$g_1 \sum_{SM} N_c \, y_{SM} \equiv 0 + \left(\frac{m_t}{\sqrt{s}}\right)^2$$

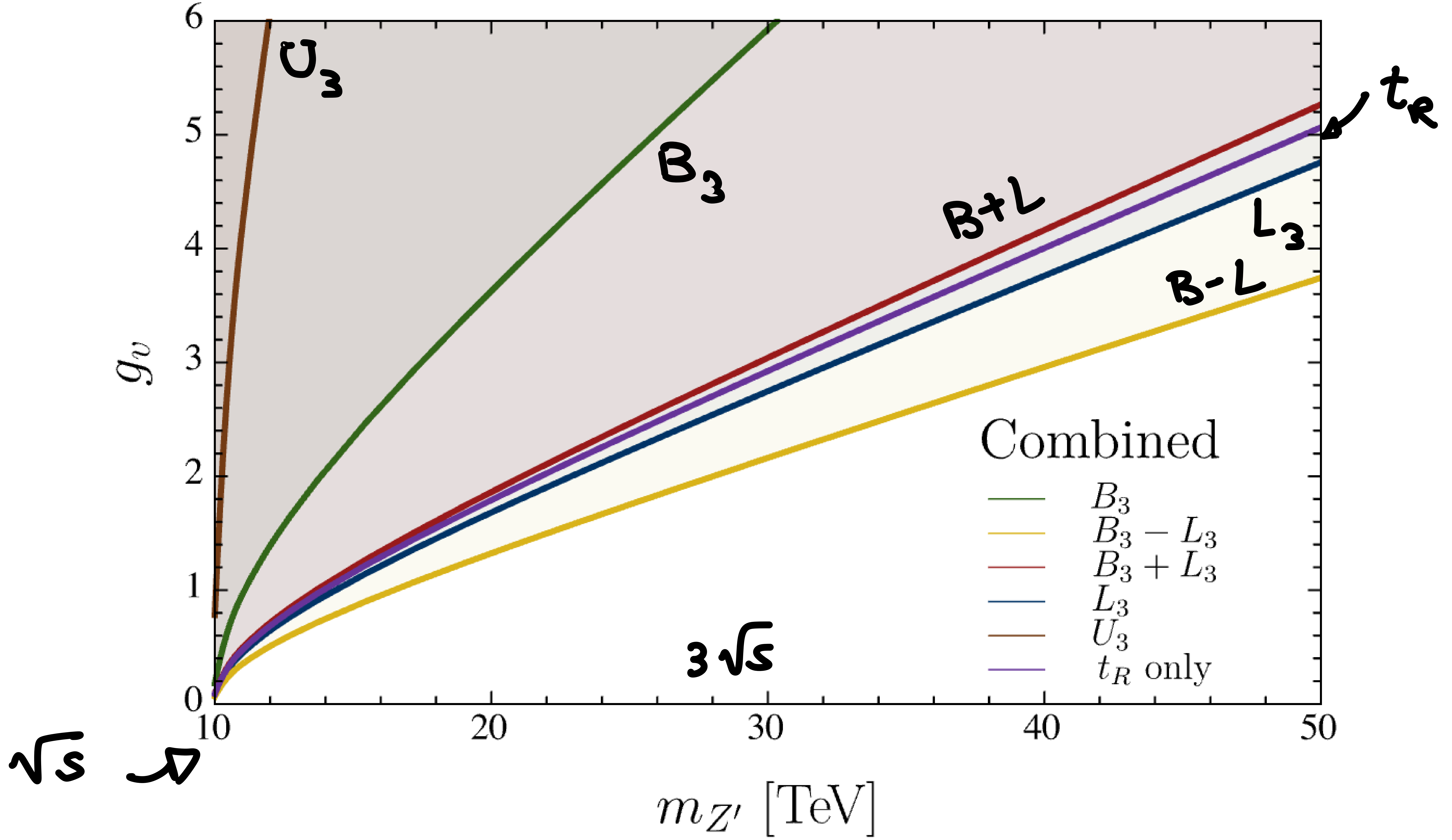
Indirect sensitivity

- We do not deal with $m_{Z'} < 10$ TeV as this should be addressed by a family of direct searches
- We go for $m_{Z'} > 10$ TeV
- Consider $b\bar{b}$, $\tau\tau$, and $t\bar{t}$ final states and check the size of the deviation for a given Z' mass and coupling with respect to the SM.
- So for analysis limited to equal couplings to left- and right-handed fermions



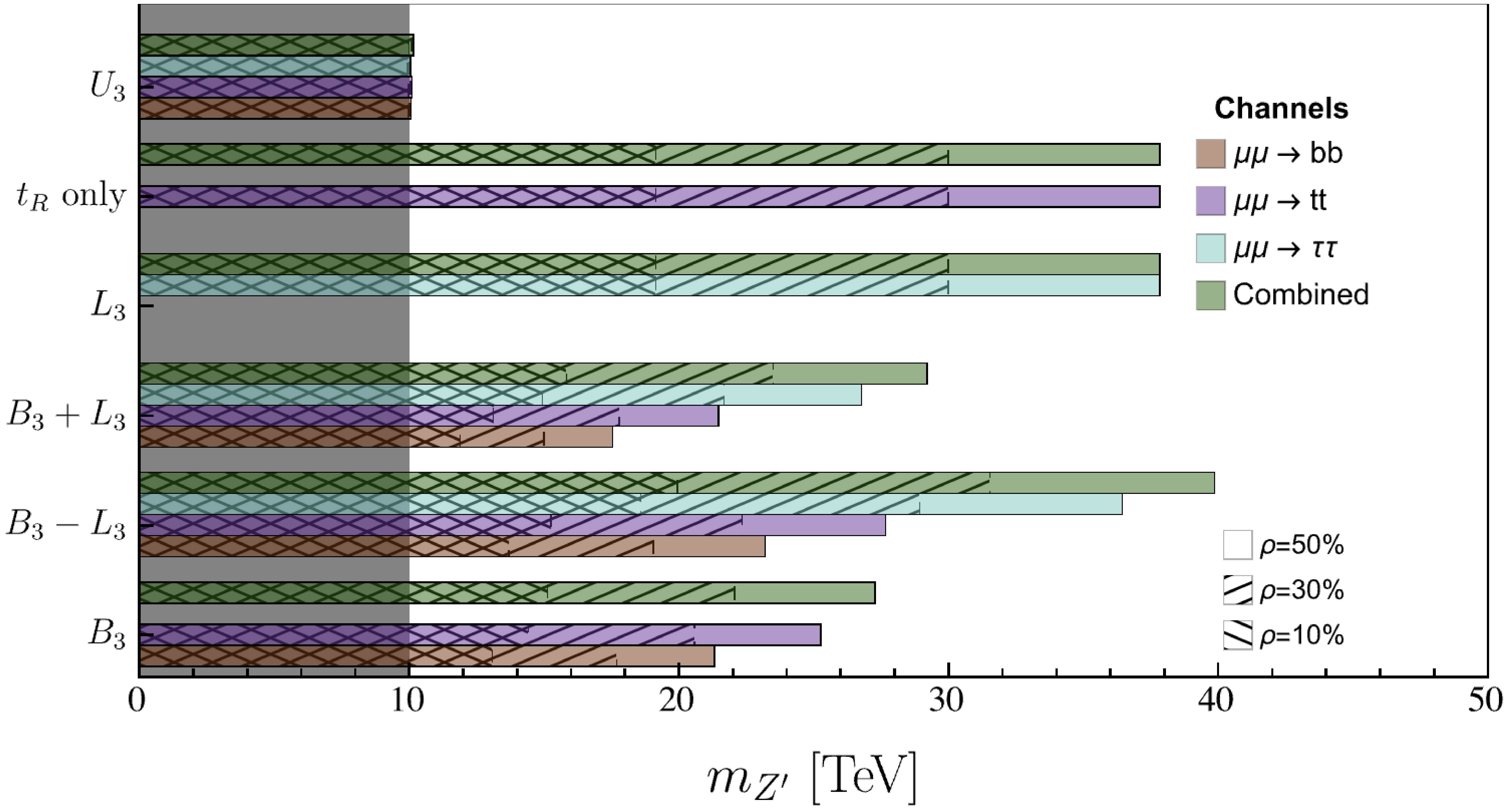


New Gauge Forces in BSM



Constraints from perturbativity

$$\Gamma(Z' \to f f) \propto \sum_f \frac{g^2}{8\pi} M_{Z'} < \rho M_{Z'} \qquad \rho = [0.1, 0.5]$$



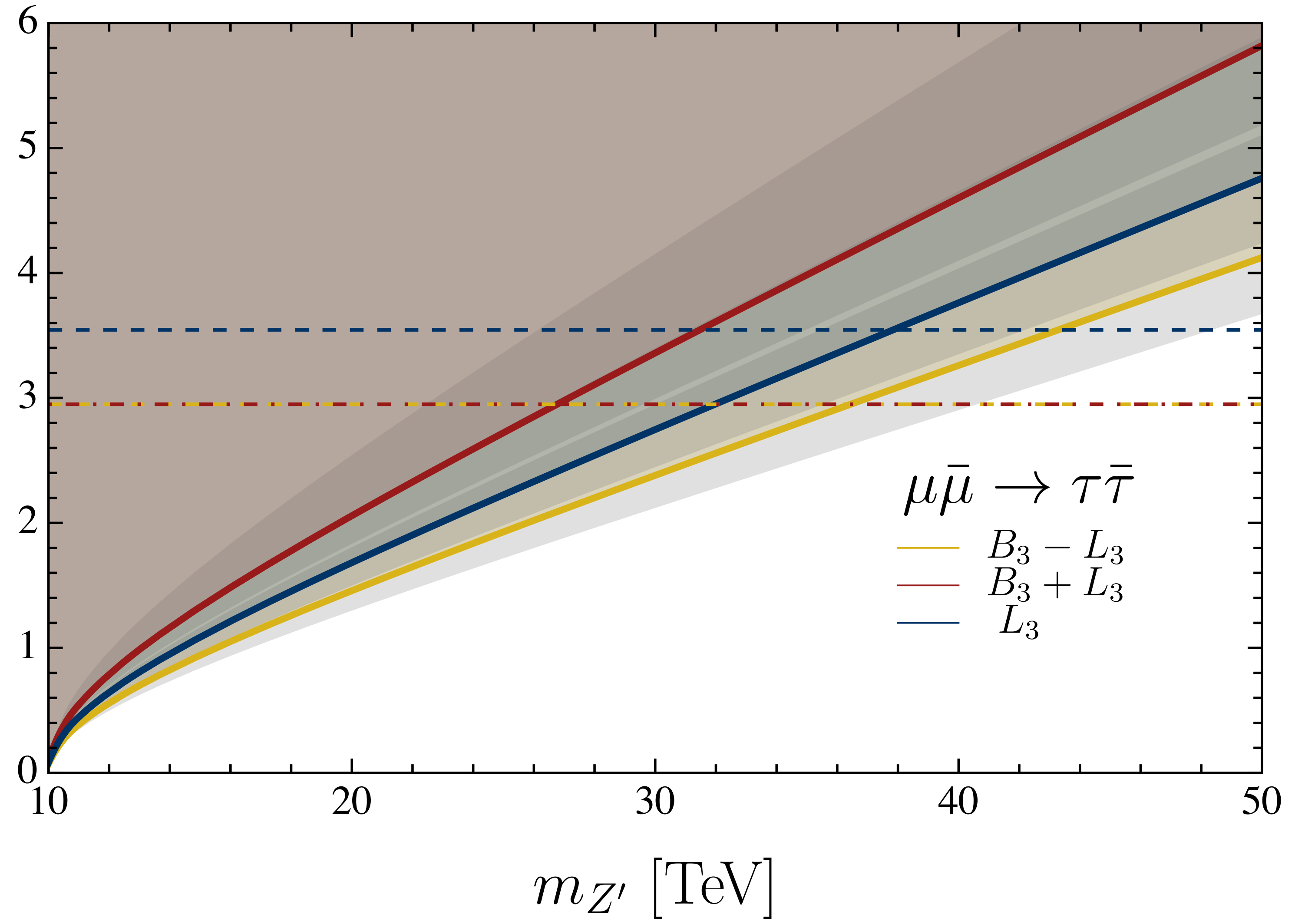
Outlook

- Physics case for the 10 TeV machine starts to be mature.
- Lots of refinement still needed (Detector Concept development, etc)
- Time to consider also "things you are not supposed to do" at the muon collider (muophobic and more!)

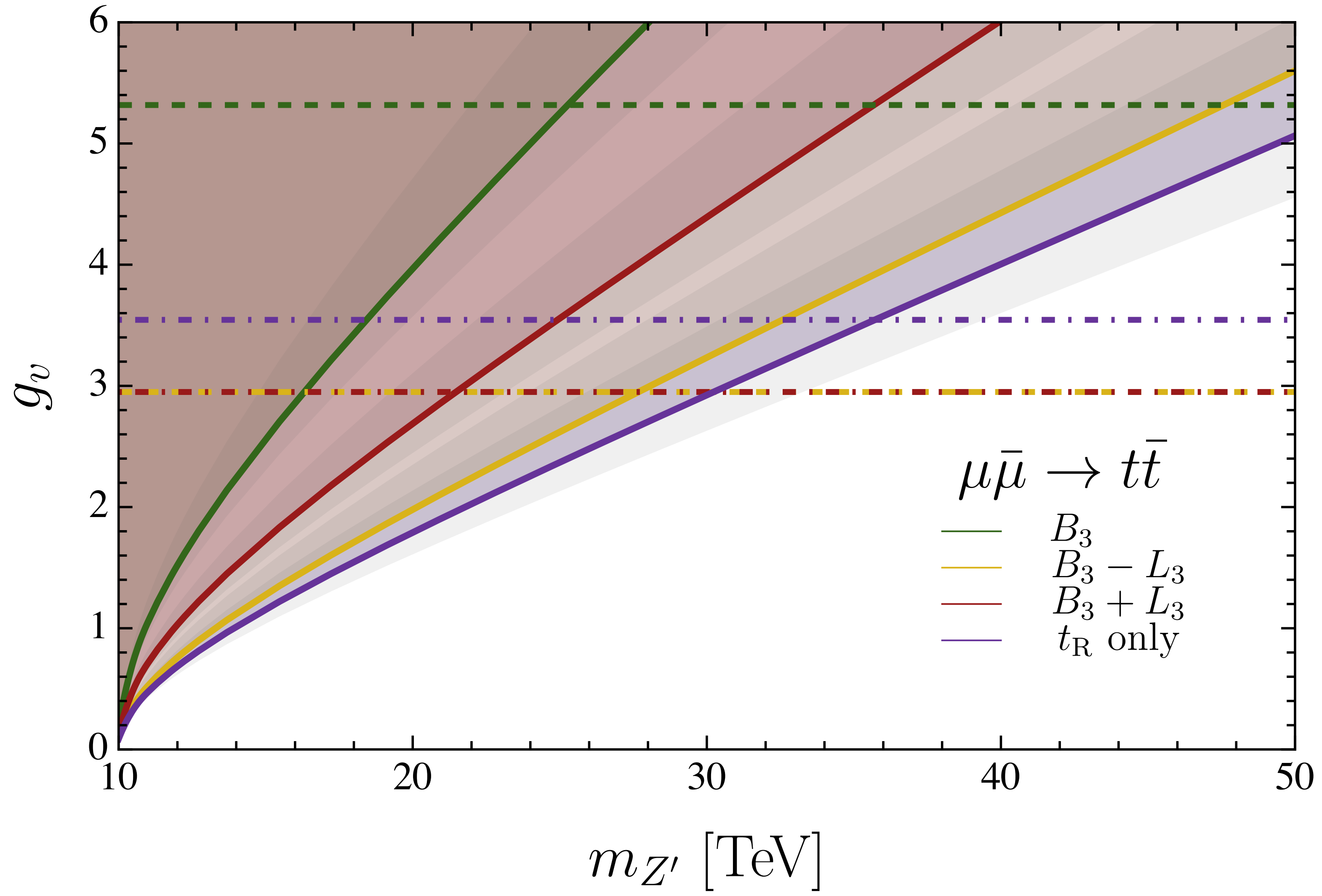
Conclusions

- New gauge forces are part of a wide set of extensions of the Standard Model
- They come in all size and shapes, hard to make a map and really focus on just one class of vector bosons. Can't really exclude any possibility a priori!
- If the new force carries is somehow not coupled to muons it might pose a problem for the muon collider! The typical example is a force mostly coupled to third generation fermions.
- Even in these "decoupled" scenarios muon collider is sensitive to loop effects
- Mass reach up to few times the center of mass energy for generic couplings structure!
- Some cases are problematic (cancellation of the interference, e.g. $L_e - L_\tau$, $\mathcal{U}_3$, ...)
- Potential to connect with Dark Matter phenomenology (similar to $\mu^+\mu^- \to \nu_\tau\nu_\tau + X$)

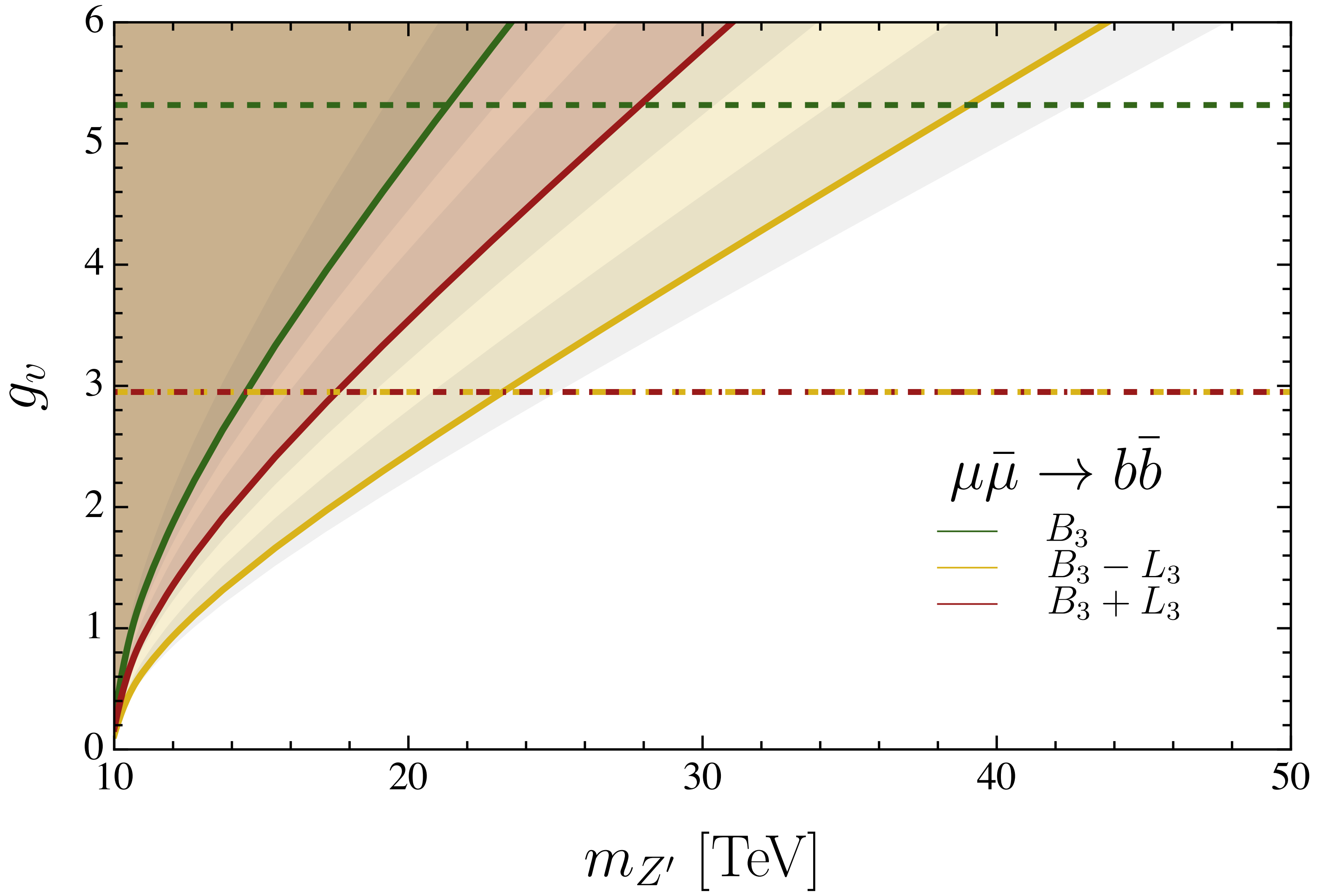
Thank you!



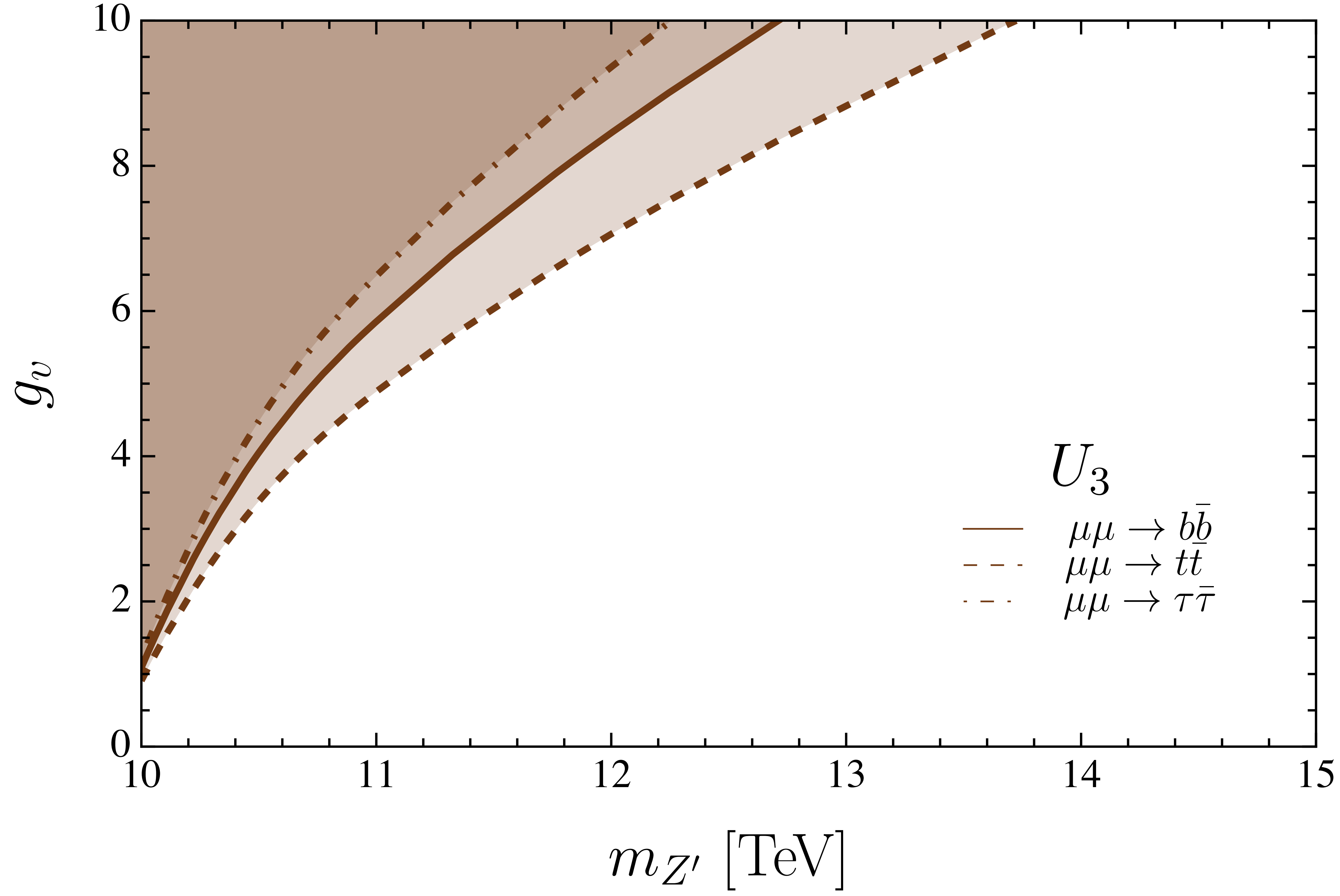
$\mu\bar{\mu} \to \tau\bar{\tau}$
$B_3 - L_3$
$B_3 + L_3$
L_3
$m_{Z'}$ [TeV]



g_v
$\mu\bar{\mu} \to t\bar{t}$
B_3
$B_3 - L_3$
$B_3 + L_3$
t_R only
$m_{Z'}$ [TeV]



g_v
$\mu\bar{\mu} \to b\bar{b}$
B_3
$B_3 - L_3$
$B_3 + L_3$
$m_{Z'}$ [TeV]



g_v
U_3
$\mu\mu \to b\bar{b}$
$\mu\mu \to t\bar{t}$
$\mu\mu \to \tau\bar{\tau}$
$m_{Z'}$ [TeV]