Ugly face of $B \to K^* \mu^+ \mu^-$

Global fits

Currently only real parts of Wilson coefficients constrained by $b \to s\gamma$ & $b \to s l^+ l^-$ data. Weak sensitivity to $\mathrm{Im}(\Delta C_7^{(\prime)})$ from $S_{K^*\gamma}$

Economic new-physics explanations (by Quim or David)

$$\Delta C_7 \sim 0$$

$$\Delta C_9 \sim -1.5 \quad \text{or} \quad \Delta C_9 \sim -1, \ \Delta C_9' \sim 1$$

$$\Delta C_{10} \sim 0$$

Since $C_9 \sim 4.1$ need new flavour dynamics that induces large, (destructive) effect proportional to $V_{ts}^* V_{tb}$ in vector operator(s), but is otherwise SM-like

This rules out:

MSSM, composite models, warped extra dimensions & other usual suspects

Why?

Modified Z sector

$\Delta g'_V \sim 1 - 4 s_W^2 \approx 0.08$ $\quad \Delta g'_A \sim -1$

gives wrong pattern $\Delta C_9 \ll \Delta C_{10}$

More generically

If only SU(2) invariant operators are around, get

$$\Delta C_9 \ll \Delta C_{10} \quad \text{or} \quad \Delta C_9 = \pm \Delta C_{10}$$

Seen pattern requires cancellations

LH & RH currents in B_s mixing

$$\Delta M_{12}^{s} \sim C_{LL} + C_{RR} + 9.7\, C_{LR}$$

Mixing constraints on models with both LH & RH couplings more severe

RH currents & MFV

$$\frac{\Delta C_q'}{\Delta C_q} \overset{\mathrm{MFV}}{\sim} \frac{\left(Y_d^\dagger Y_u Y_u^\dagger Y_d\right)_{23}}{\left(Y_u Y_u^\dagger\right)_{23}} \sim \frac{t_\beta^2 m_s m_b}{v^2} \ll 1$$

Generating a large effect $\Delta C_q'$ requires new flavour dynamics beyond MFV

Flavour alignment for LH currents

$$\mathcal{L} \supset \sum_{q=u,d} \left(g_L^q\right)_{ij} \, \bar{q}_L^i \, \not{Z}' \, q_L^j$$

$$\left(g_L^q\right)_{ij}^{I} = \mathrm{diag}\left(g_1, g_1, g_3\right)$$

Couple 3rd family different ($g_1 \neq g_3$)

Flavour alignment for LH currents

$$g_L^q = U_q^\dagger \left(g_L^q\right)^I U_q$$

$$V = U_u^\dagger U_d$$

Unitary rotations used to go to mass basis have to give CKM matrix

Up alignment

$$\mathcal{U}_u = 1, \quad \mathcal{U}_d = V$$

$$\Downarrow$$

$$A\left(d_L^i \to d_L^j Z'\right) \propto V_{tj}^* V_{ti}$$

up couplings flavour diagonal

Down misalignment

$$U_u = U_d V^\dagger , \quad U_d \simeq \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & V_{ts}^* \\ 0 & V_{ts} & V_{tb} \end{pmatrix}$$

$$\Downarrow$$

$$A(b_L \to s_L Z') \propto V_{ts}^* V_{tb}$$

no effect in $b_L \to d_L Z'$ & $s_L \to d_L Z'$

Whether effects in $b \to s$, $b \to d$ & $s \to d$ observables are correlated is determined by structure of new flavour spurions (U_u, U_d etc.) & thus very much model dependent

Z' models of type 3-3-1

For suitable Q normalisation get:

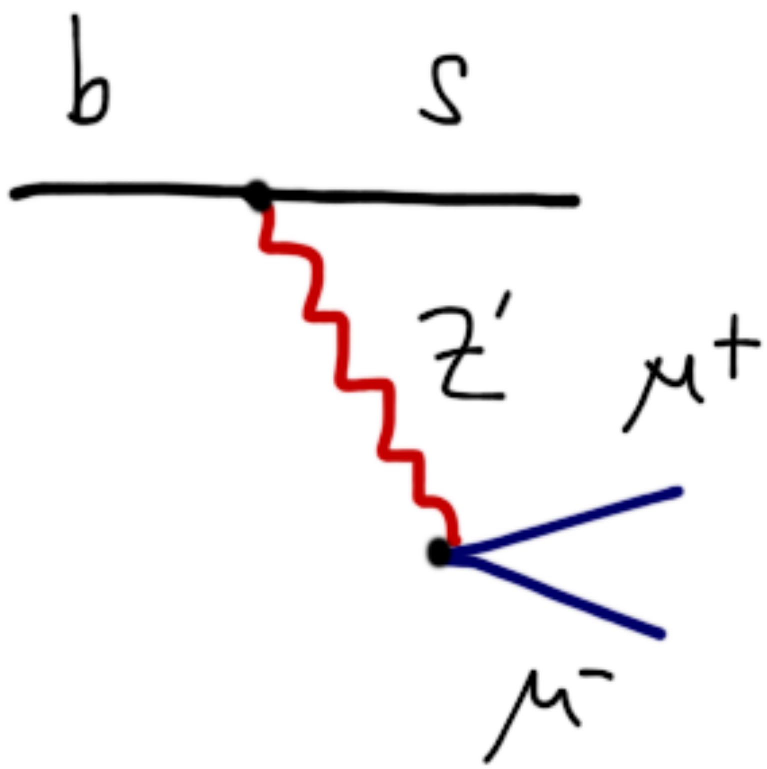
$$g_V^{\ell}\Big|^{\beta=-\sqrt{3}} \simeq 3.3\,g\,, \quad g_A^{\ell}\Big|^{\beta=-\sqrt{3}} \simeq -0.1\,g$$

pattern $\Delta C_9 \gg \Delta C_{10}$ reproduced

Z' models of type 3-3-1

"Landau pole" at 4 TeV of minimal model can be lifted by adding fermionic $SU(3)_L$ octets. This also allows to generate small neutrino masses via inverse see-saw

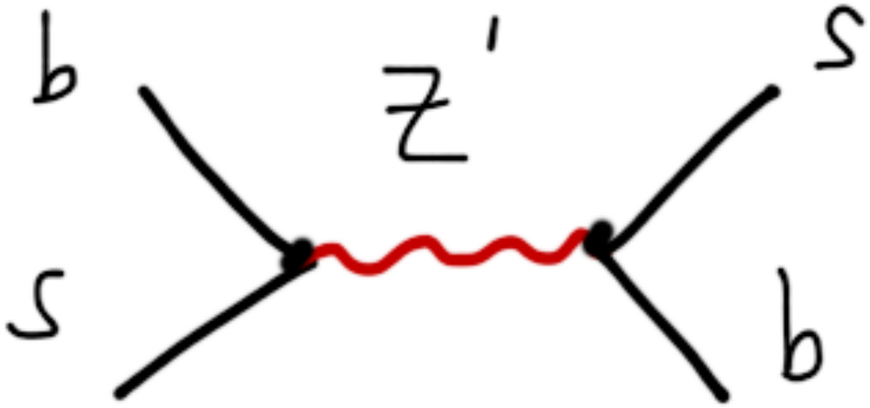
Z' models of type 3-3-1



$$M_{Z'} \in [5.7, 6.9] \text{ TeV}$$

$$\Delta C_9 = -\frac{2\pi}{3\alpha}\,\frac{1+8s_W^2}{1-4s_W^2}\,\frac{M_W^2}{M_{Z'}^2} \in [-1.9, -1.3]$$

Z' models of type 3-3-1



$$\Delta C_9 \gtrsim -1.3$$

$$\Delta C_9 \simeq -4.9\, \Delta_{B_s} \in -4.9\, [-0.16, 0.26]$$

Z' models of type 3-3-1

- ♡ −2% in $B_s \to \mu^+\mu^-$ (unobservable)
- ♡ +25% in $B \to K^* \nu\bar{\nu}$, ... (Belle II ?)
- ♡ "improvement" of $B \to \pi K$ puzzle
- ♡ −200% in ε'/ε if up alignment

Z' from $L_\mu - L_\tau$ (by Wolfgang)

Muon & tau number is anomaly free.
Gauging leads to:

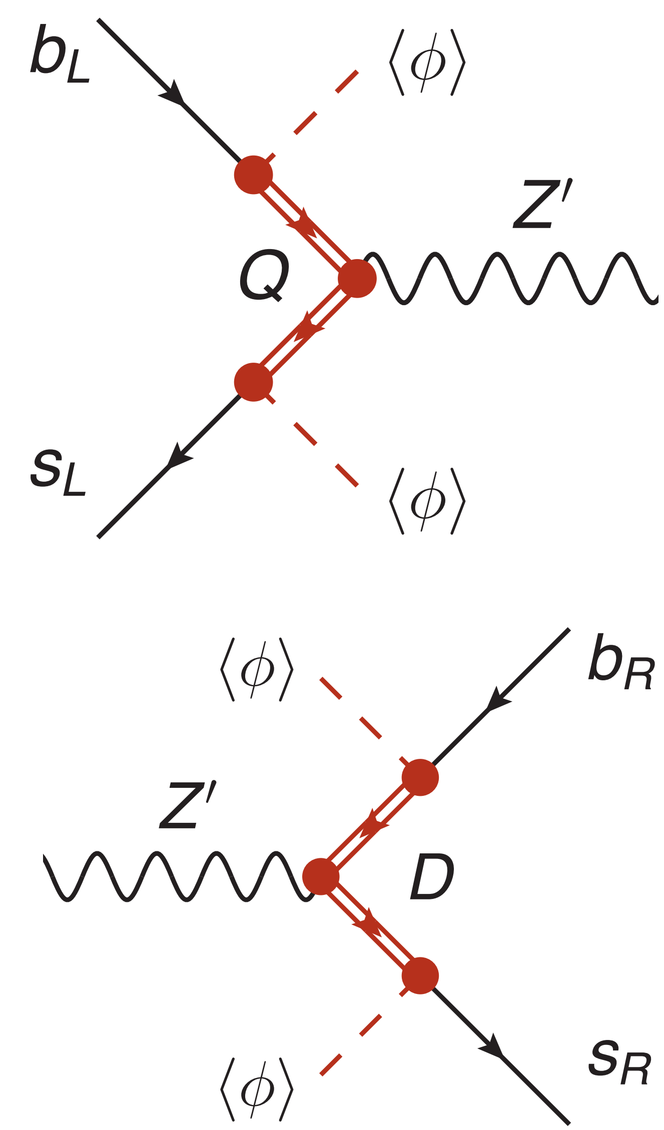
$$\mathcal{L} \supset g' \left(\bar{\mu} \not{Z}' \mu - \bar{\tau} \not{Z}' \tau \right)$$

No Z' coupling to electrons

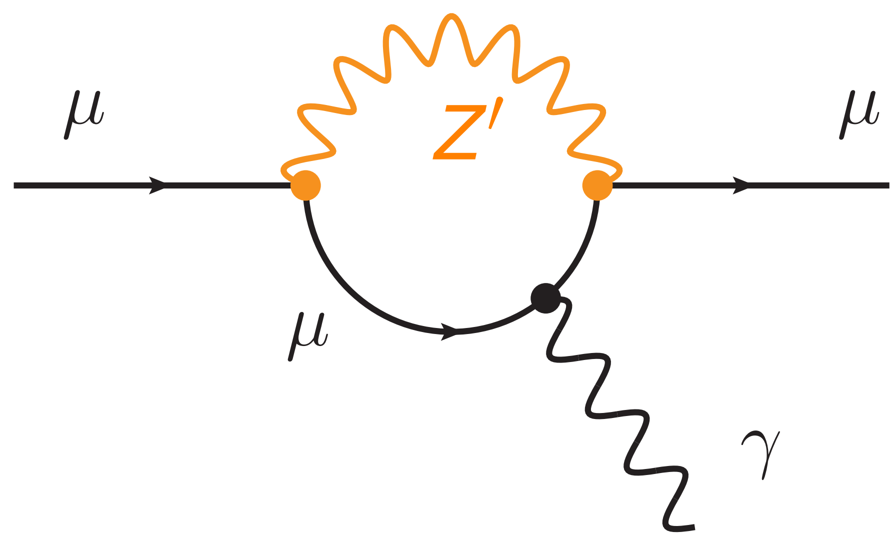
Z' from $L_\mu - L_\tau$ (by Wolfgang)

Z' couplings to quarks generated by mixing with heavy vector-like fermions.

Couplings treated as free parameters

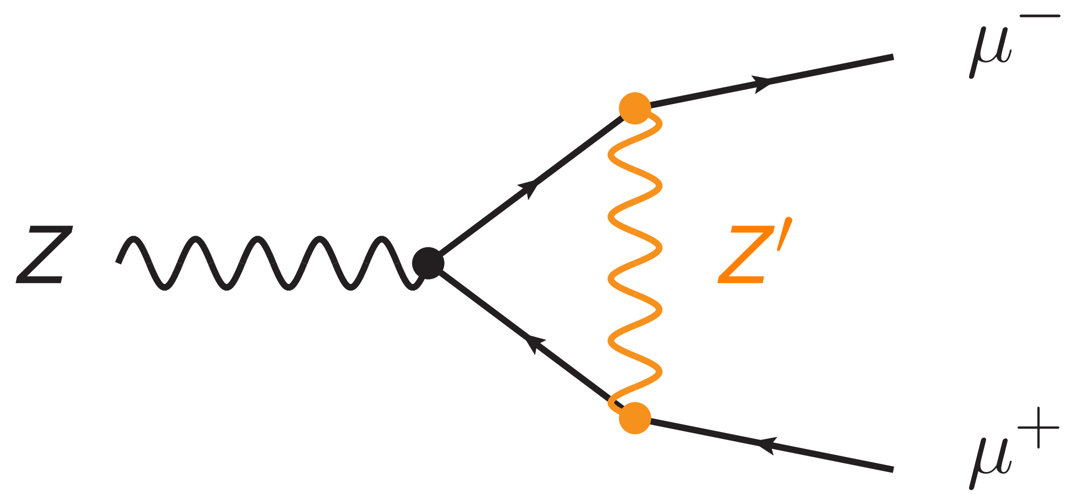


Constraints on leptonic couplings



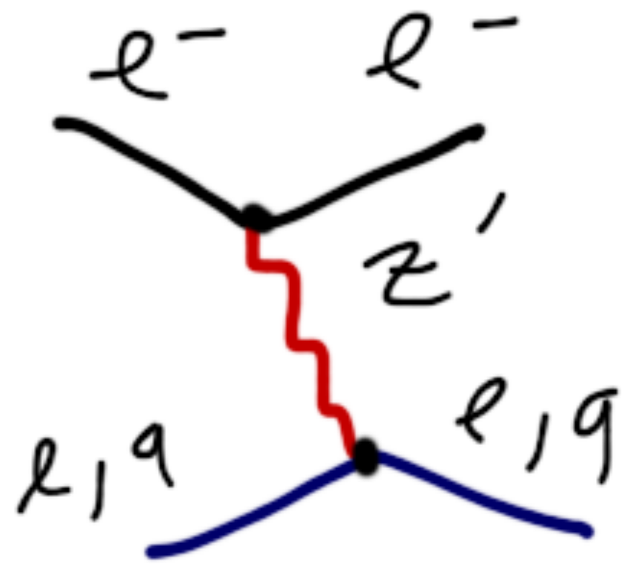
Z' with vector coupling to muon reduces g-2 tension, but Z' has to be light with mass between 10 GeV & 300 GeV

Constraints on leptonic couplings



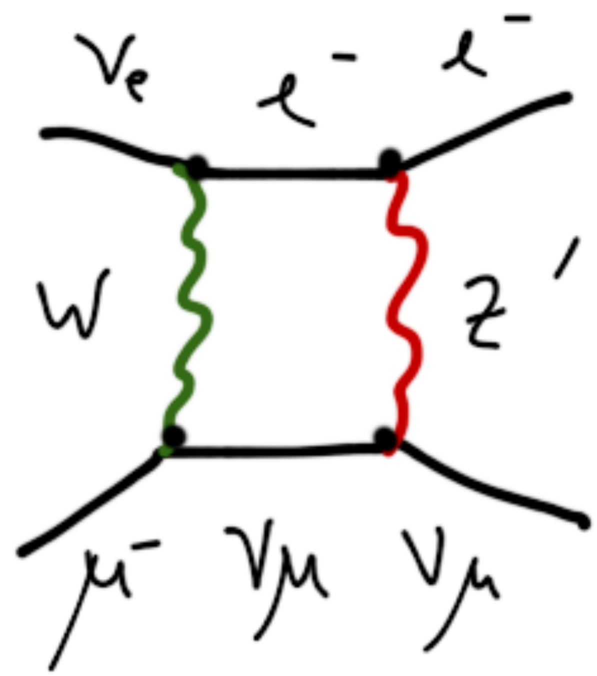
Light & not too weakly coupled Z' is also subject to strong constraints from electroweak precision observables

Constraints on leptonic couplings



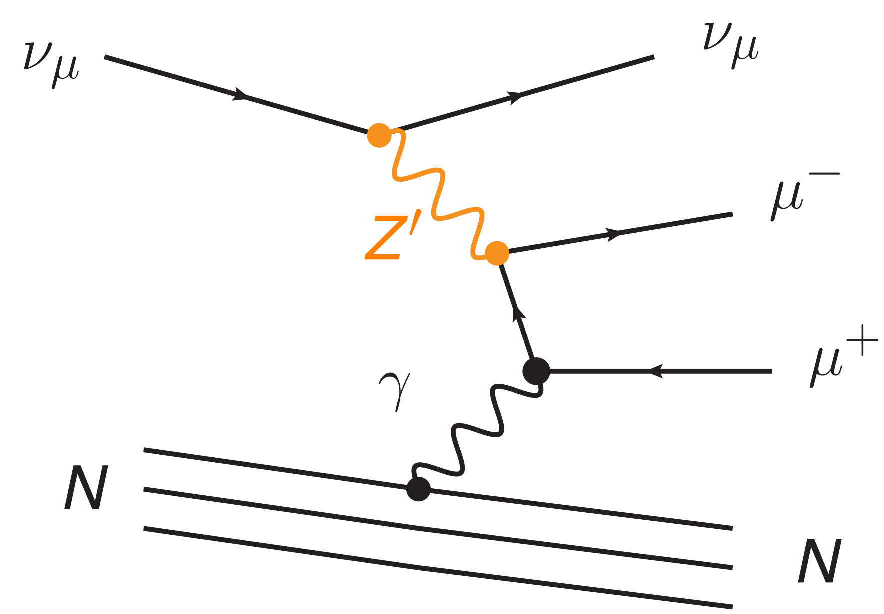
If Z' has both vector & axial couplings, $\not{P}$ violation experiments give bounds. E.g. for 3-3-1 Z' one has $M_{Z'} > 1.5$ TeV

Constraints on leptonic couplings



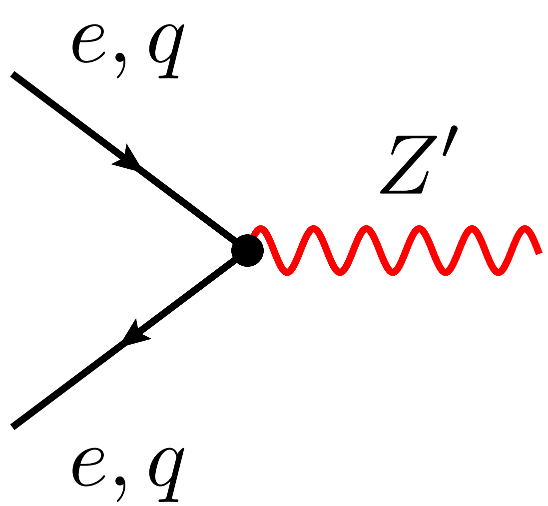
CKM unitarity, muon & tau decays lead to constraints. Depending on couplings mass scales up to $\mathcal{O}$(3 TeV) are probed

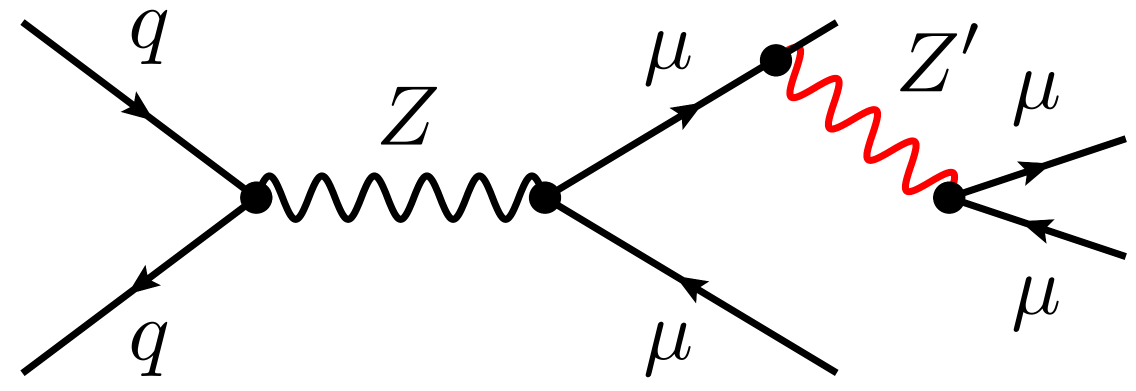
Constraints on leptonic couplings



Neutrino trident production turns out to be severe constraint for light $L_\mu - L_\tau$ Z'.
For heavier Z' less effective

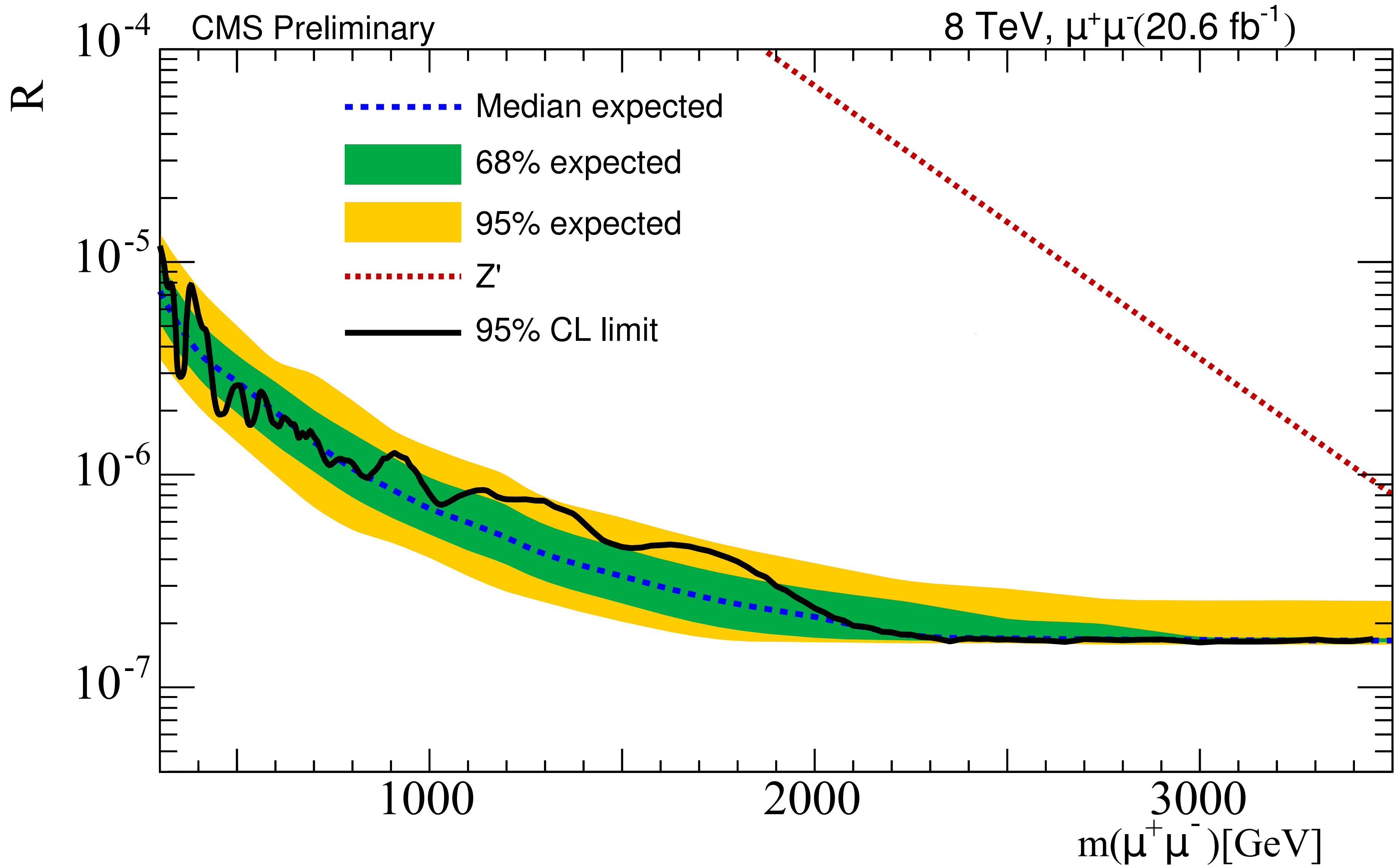
Direct constraints





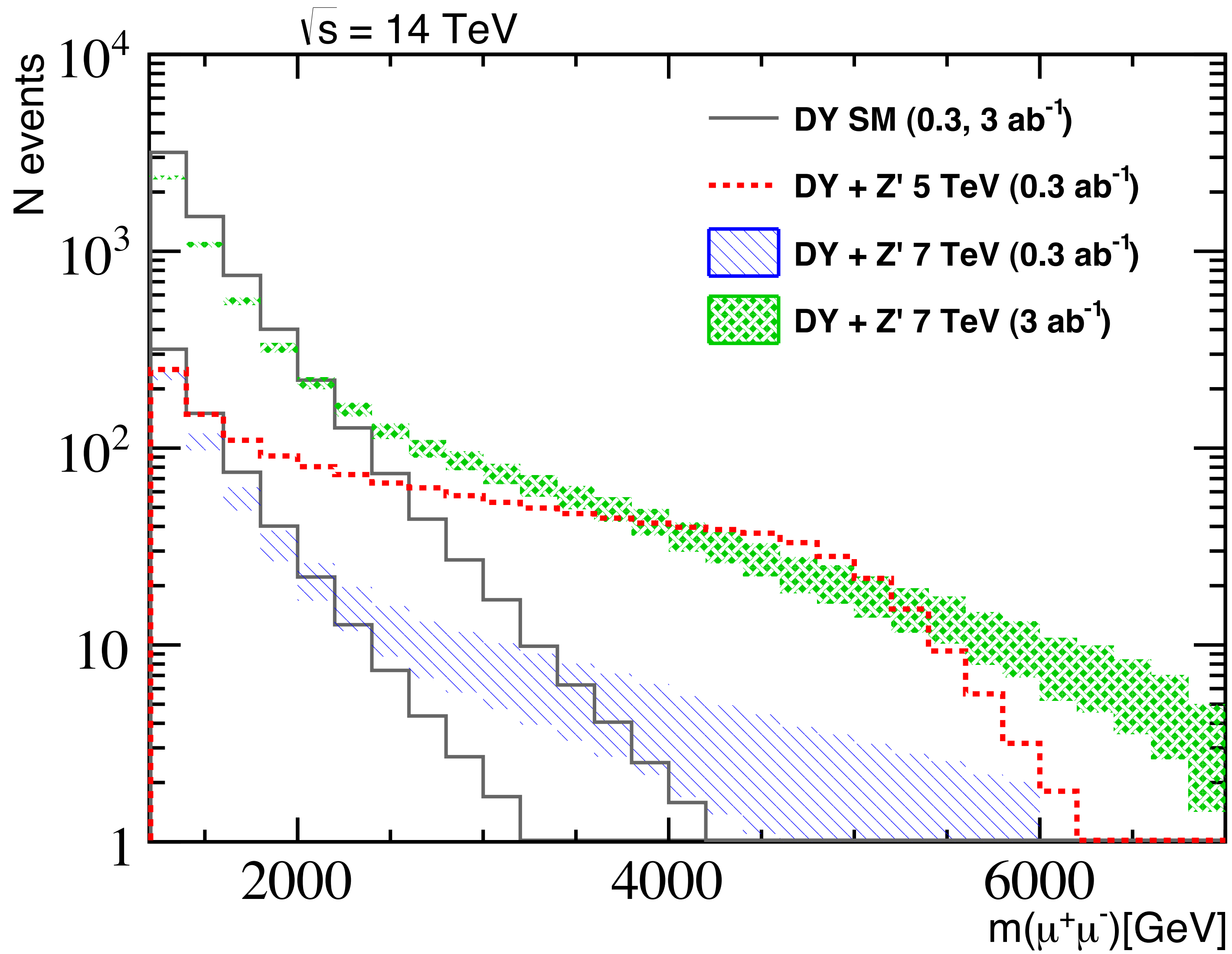
Depending on whether Z' boson couples to electrons & quarks or not can study direct DY production or Z -> 4l

Direct constraints: 3-3-1 Z'



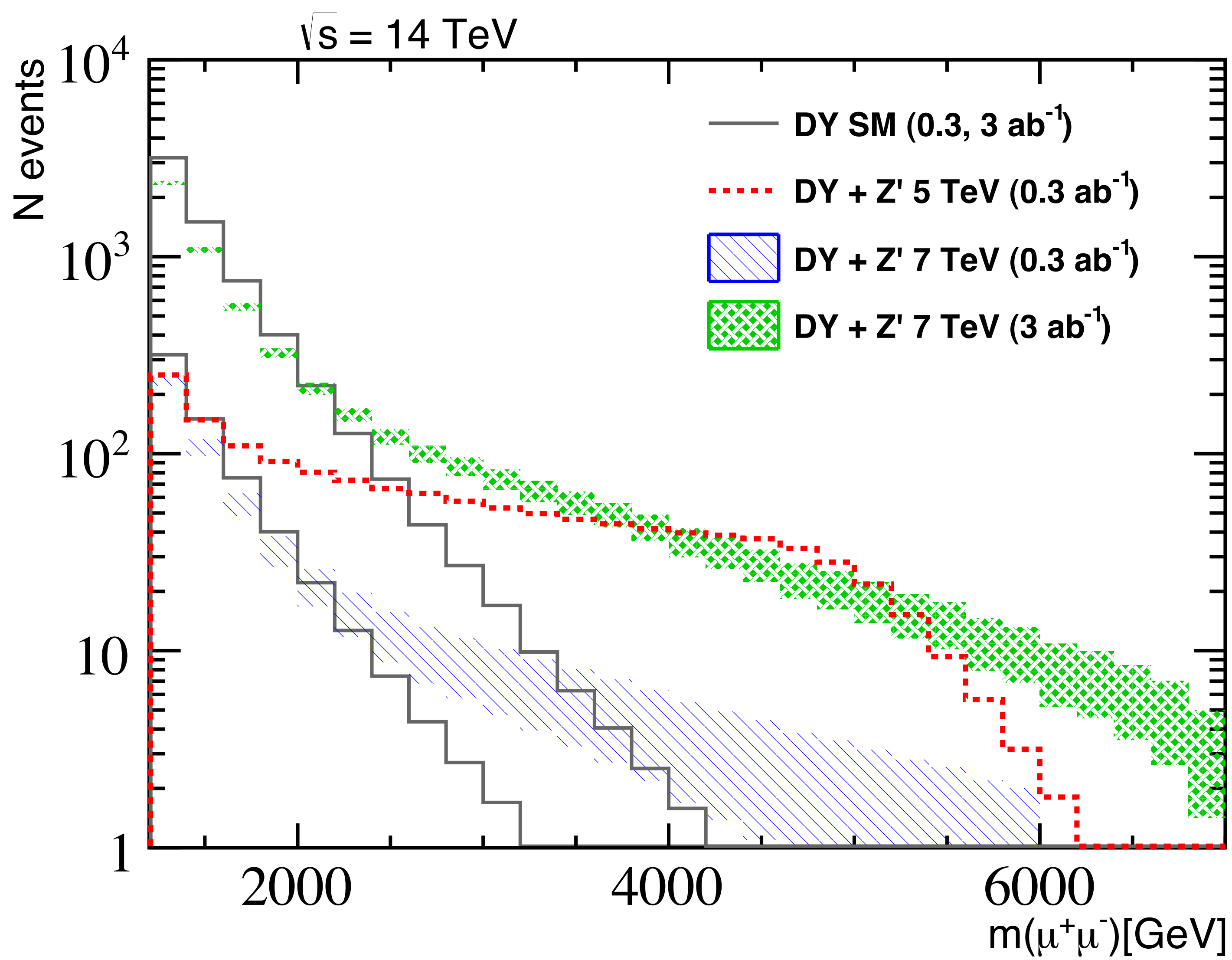
$\Rightarrow M_{Z'} \gtrsim 3.9\,\mathrm{TeV}$

Direct constraints: 3-3-1 Z′



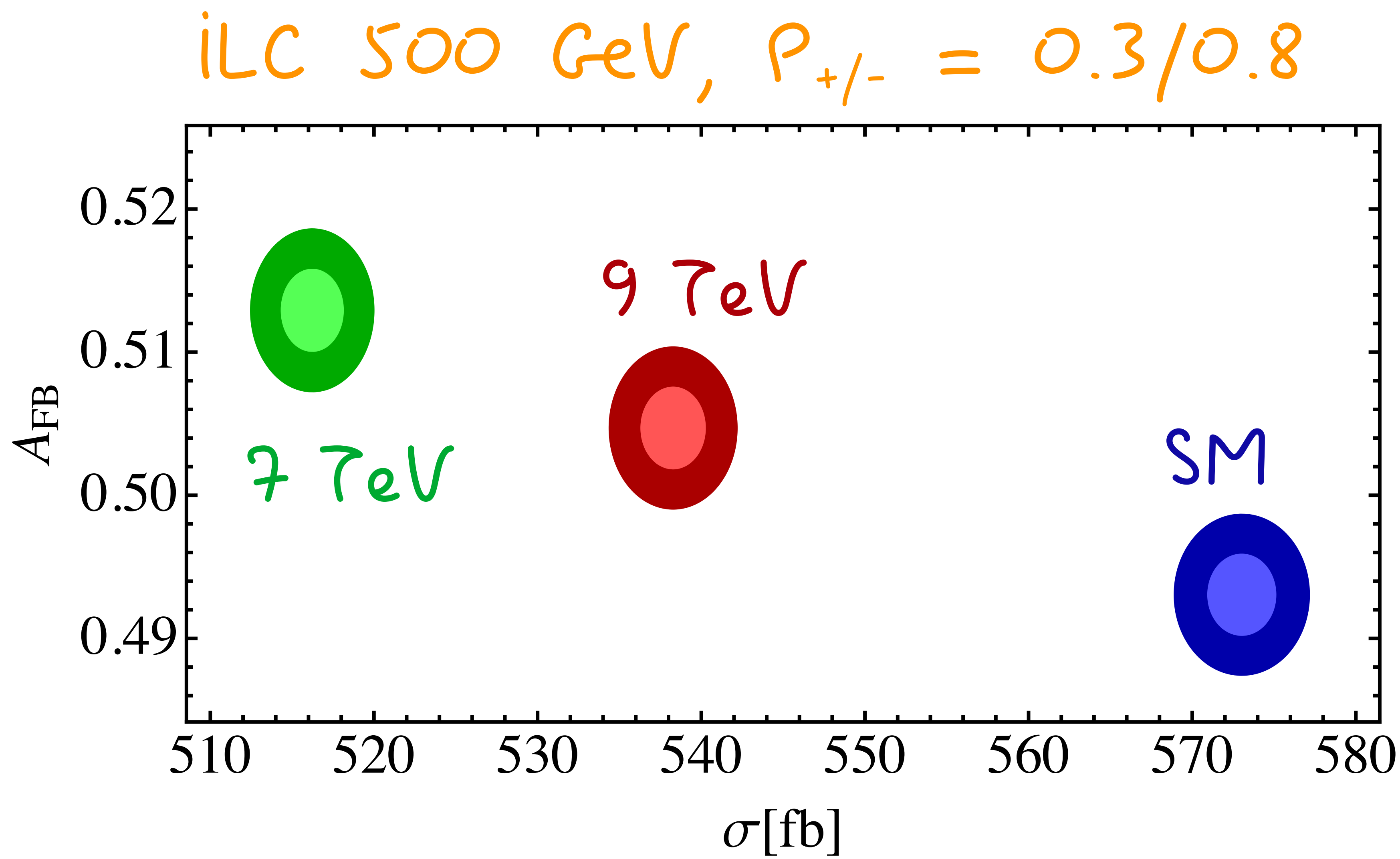
$\Rightarrow M_{Z'} > \mathcal{O}(7\,\text{TeV})$

Direct constraints: 3-3-1 Z'



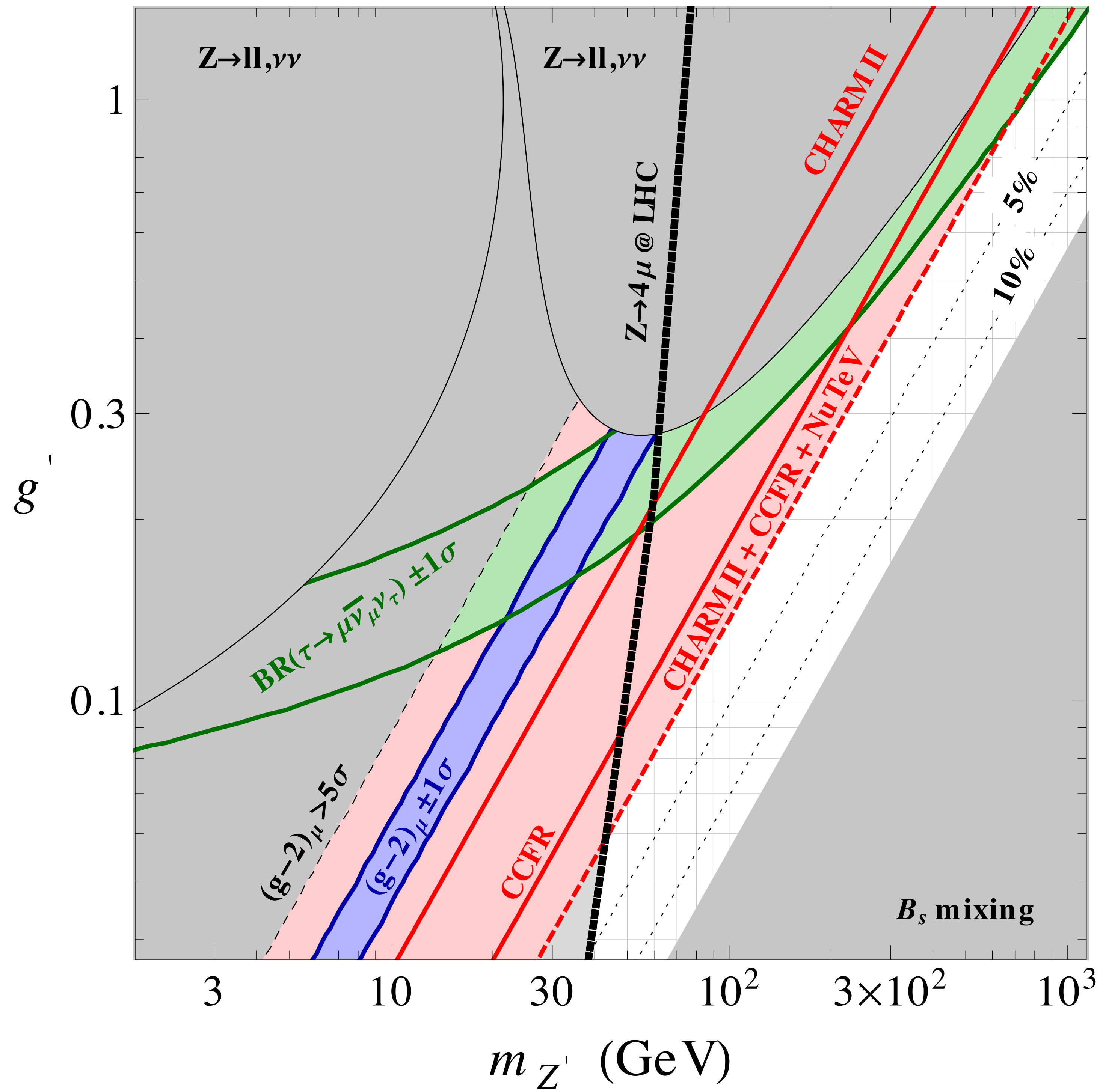
$\Rightarrow M_{Z'} > \mathcal{O}(7\,\mathrm{TeV})$

Direct constraints: 3-3-1 Z'

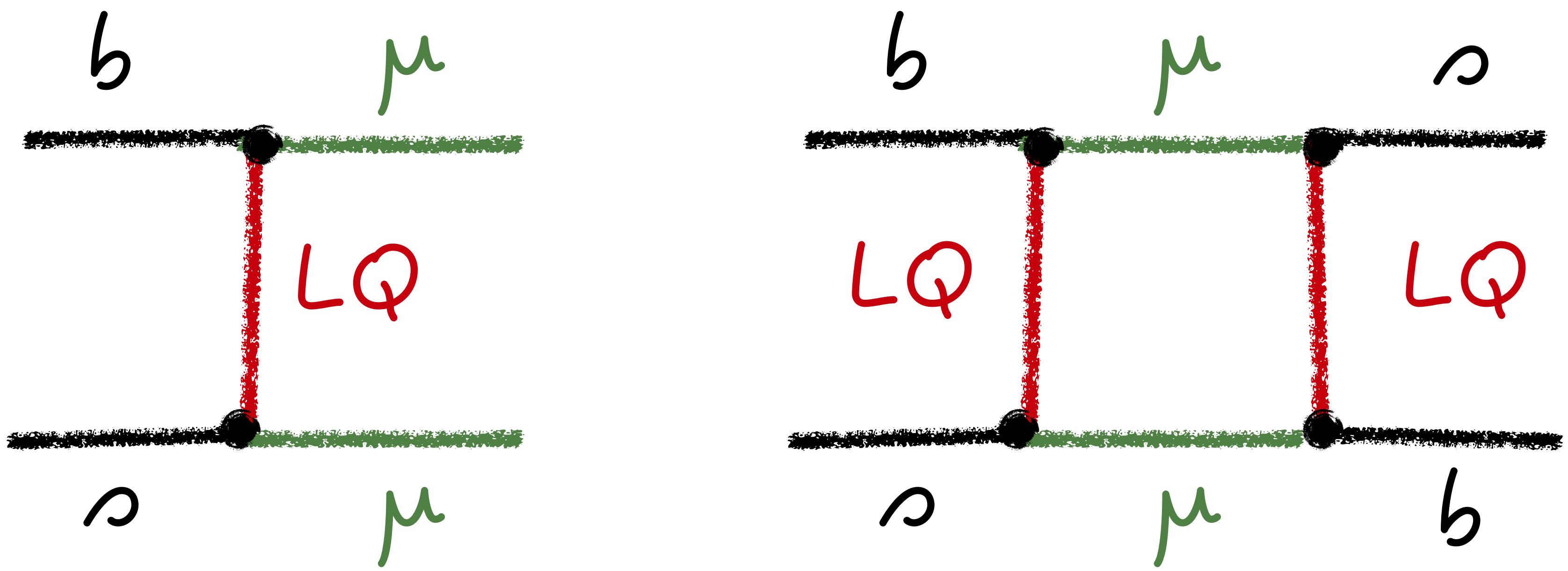


$\Longrightarrow M_{Z'} > \mathcal{O}(10\,\text{TeV})$

Z' from $L_\mu - L_\tau$: Summary



How to avoid B_s mixing constraint?



In case of lepto-quarks (LQs) $\Delta F=1$ transitions appear at tree level while $\Delta F=2$ processes loop suppressed

How to avoid B_s mixing constraint?

But need both a scalar & vector LQ, that are degenerate in mass & have CKM-aligned couplings to get pattern of anomaly. This all seems pretty ad hoc