Phenomenology of scalar leptoquarks: neutrino mass, $g-2$, and B-anomalies

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Leptoquarks (LQ)

- Coloured BSM particles, couple to a lepton and a quark.
- Can be scalar or vector.

Motivations 1

- Radiative Majorana mass of neutrinos.
- 4.2σ experimental excess on $(g-2)_\mu$.

$\Delta a_\mu^{Ex-SM} = (2.51 \pm 0.59) \times 10^{-9}$

Motivation 2

Contributes to b-decay anomalies:

- NC anomaly: $b \to s\mu^+\mu^-$
- CC anomaly: $b \to c\tau^-\bar{\nu}$

Model 1: $\widetilde{R}_2 + S_1$

$\widetilde{R}_2\,(3,2,1/6) = (\widetilde{R}_2^{2/3},\ \widetilde{R}_2^{-1/3})^T$, $S_1\,(\bar{3},1,1/3)$

$$\mathcal{L} \supset \mathcal{Y}_1^L\, \overline{Q}_L^c\, S_1\, (i\sigma_2)\, L_L + \mathcal{Y}_1^R\, \overline{u}_R^c\, S_1\, \ell_R + \mathcal{Y}_2\, \overline{d}_R\, \widetilde{R}_2^T (i\sigma_2)\, L_L + \kappa\, H^\dagger \widetilde{R}_2\, S_1 + h.c.\ [1]$$

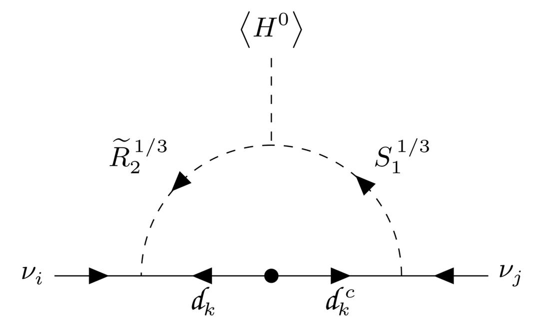
After EWSB, $\widetilde{R}_2^{-1/3}$ and $S_1^{-1/3}$ mix $\to$ $\tan 2\theta_{LQ} = \frac{-\sqrt{2}\kappa v_h}{m_S^2 - m_R^2}$

Mass eigenstates

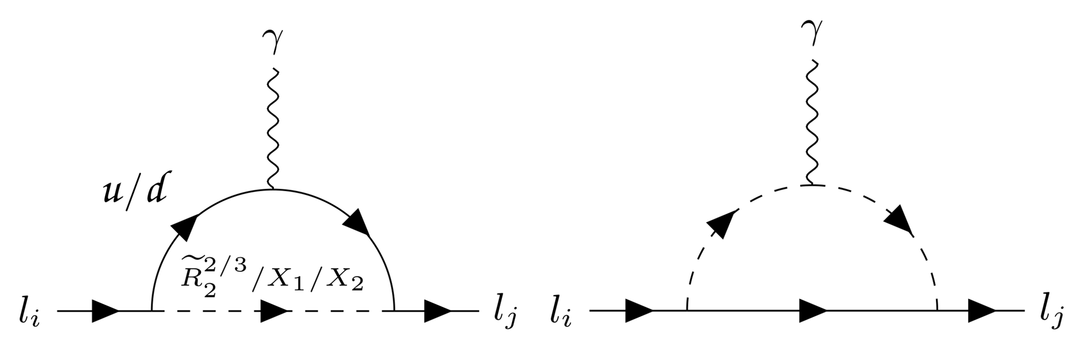
$\widetilde{R}_2^{+2/3}$: pure doublet

$X_1^{-1/3}$: mostly singlet

$X_2^{-1/3}$: mostly doublet



$$M_\nu \simeq \frac{3 \sin 2\theta_{LQ}}{32\pi^2} \ln\left(\frac{M_1^2}{M_2^2}\right) \times \left[\mathcal{Y}_1^L\, m_d\, \mathcal{Y}_2^T + \mathcal{Y}_2\, m_d\, (\mathcal{Y}_1^L)^T\right]$$



$(g-2)_\ell$

$\mu \to e\gamma$

other CLFV bounds

Benchmark: 3 sets of $\mathcal{Y}$, $M_{LQ} \sim 1.5$ TeV, $|\theta_{LQ}| \sim 0.618$ rad

Pair production at the LHC/FCC

SYMMETRIC PAIR

Model signatures

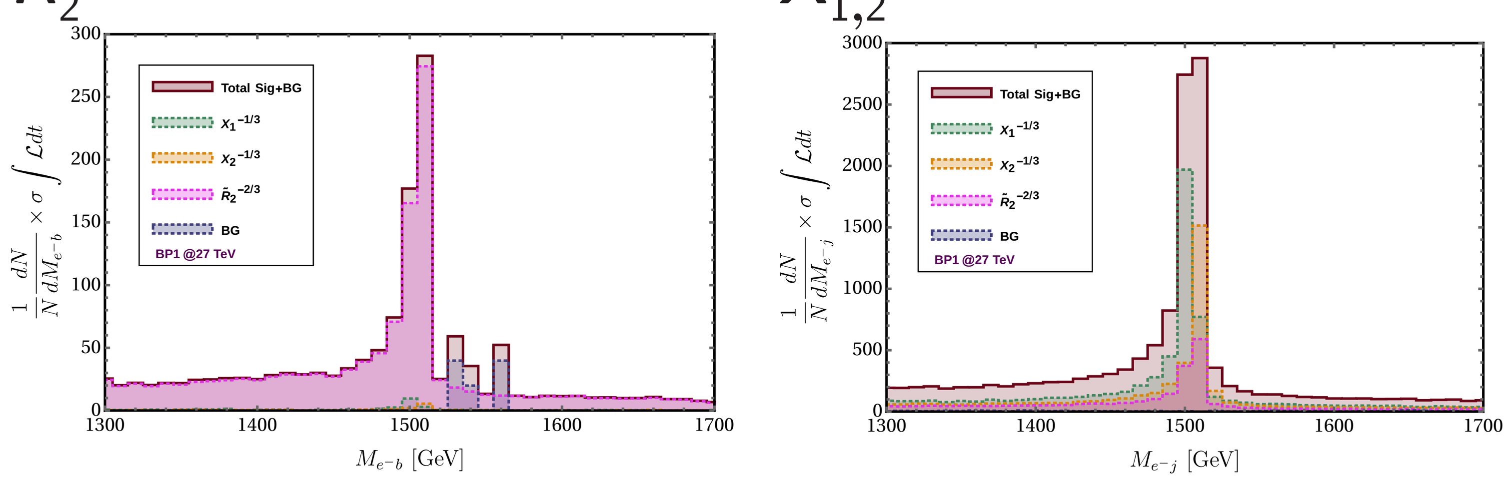
- 2 light- or c-jet + OSD
- 5σ at 14 TeV, 130 fb^{-1}

Distinguishing pure vs mixed LQ states

- $\widetilde{R}_2^{+2/3} \to d\,\ell^+$ via $\mathcal{Y}_2$ only, $X_{1,2}^{-1/3} \to u\ell^-,\ d\nu$ via $\mathcal{Y}_1^{L,R}$, $\mathcal{Y}_2$.
- Four complementary final states are analyzed
- discerns between $\widetilde{R}_2^{+2/3}$ and $X_{1,2}^{-1/3}$.
- Very difficult to segregate $X_1^{-1/3}$ and $X_2^{-1/3}$.

Invariant mass reconstruction

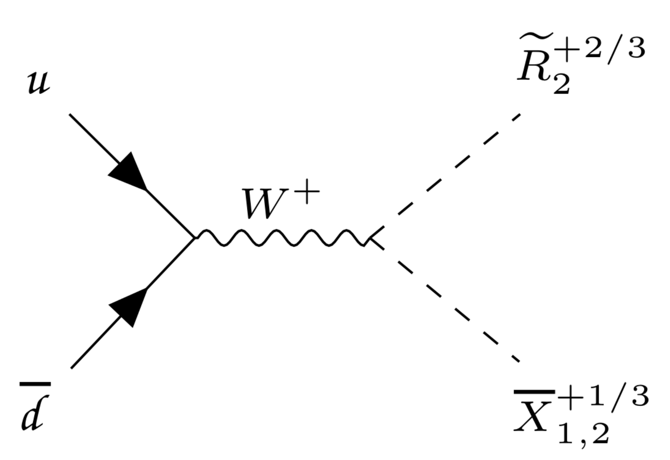
$\widetilde{R}_2^{+2/3}$ $\quad$ $X_{1,2}^{-1/3}$

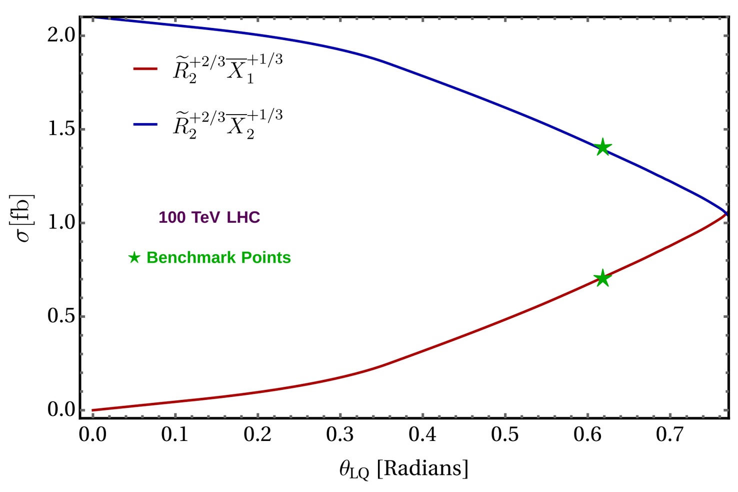


ASYMMETRIC PAIR

$pp \to W^+ \to \widetilde{R}_2^{+2/3} \overline{X}_{1,2}^{+1/3}$

More doublet % $\to$ higher σ_{Prod} $\to$ probe of θ_{LQ}





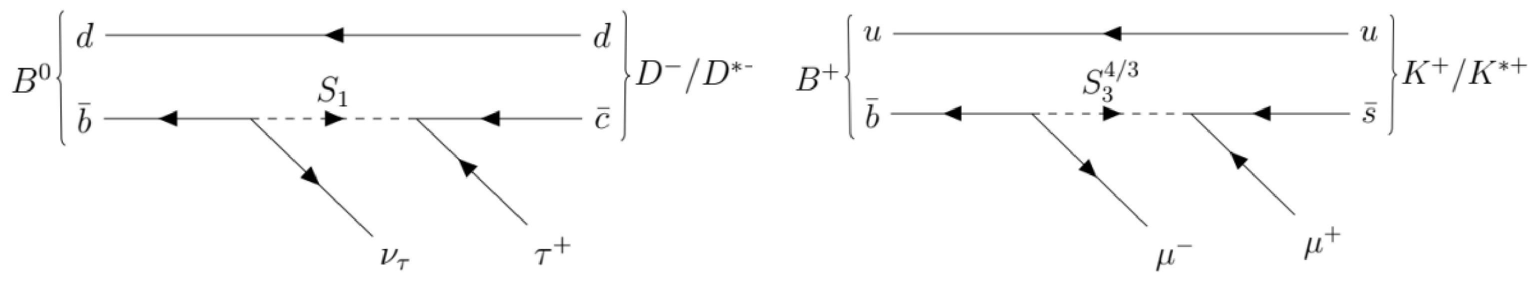
Model 2: S_1 and S_3 separately

$S_1\,(\bar{3},1,1/3)$

$$\mathcal{L}_{S_1} \supset \overline{Q^c}^i\, i\tau_2\, Y_{S_1}^{i\alpha} L^\alpha\, S_1 + \overline{u_R^c}^i\, Z_{S_1}^{i\alpha} \ell_R^\alpha\, S_1 + h.c.$$

$S_3(\bar{3},3,1/3) = (S_3^{4/3}, S_3^{1/3}, S_3^{-2/3})^T$

$$\mathcal{L}_{S_3} \supset \overline{Q^c}^i\, Y_{S_3}^{i\alpha}\, i\tau_2\, \tau \cdot S_3\, L^\alpha + h.c.\ [2]$$

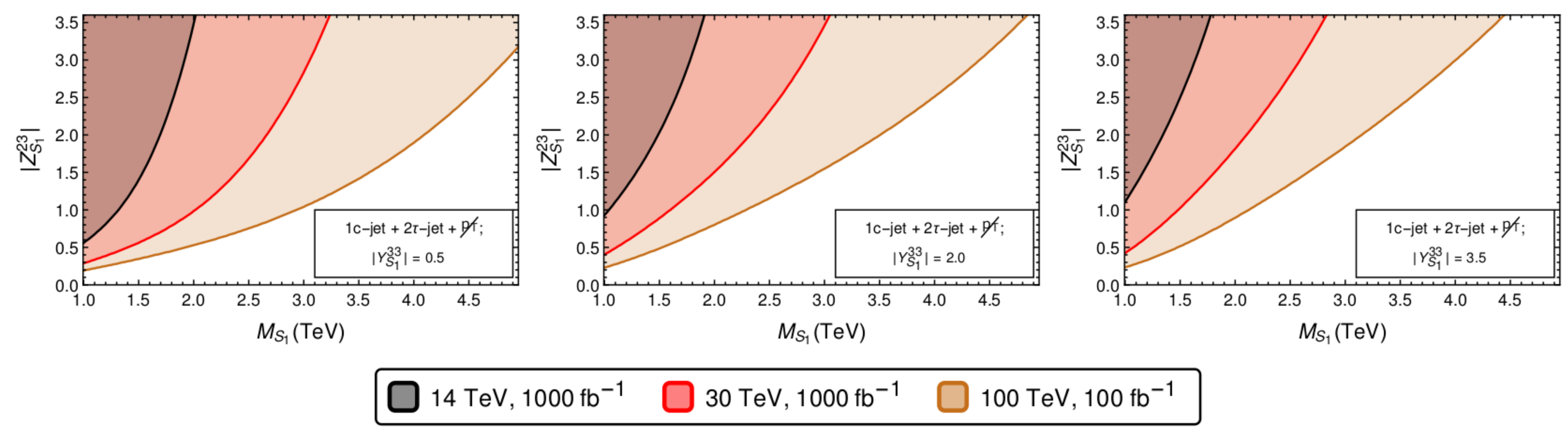


$Y_{S_1}^{33}, Z_{S_1}^{23}$: $b \to c\tau^-\bar{\nu}$ $\qquad$ $Y_{S_3}^{22}, Y_{S_3}^{32}$: $b \to s\mu^+\mu^-$

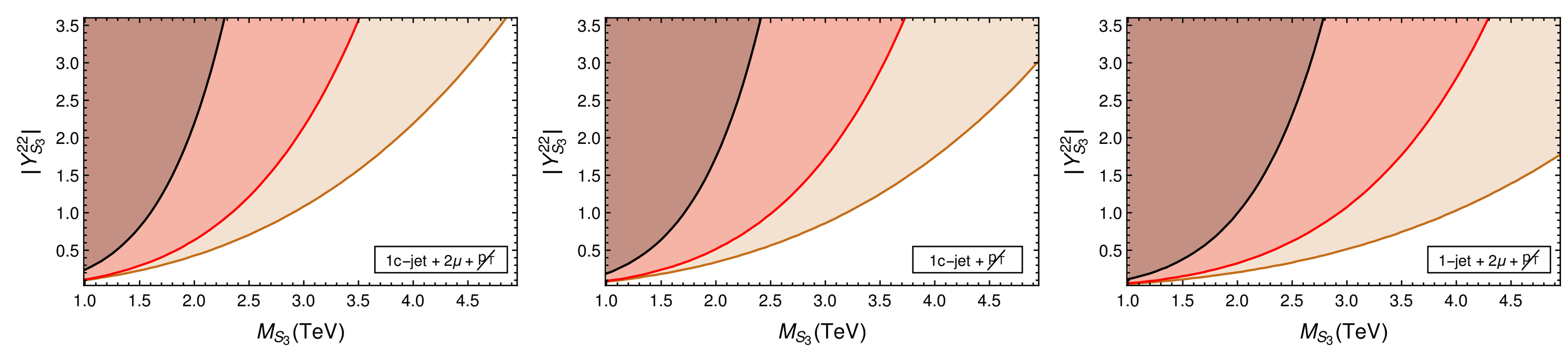
Single production at the LHC/FCC

$q - g \to LQ\,\ell/\nu$: direct probes of Y, Z.

Reach for S_1

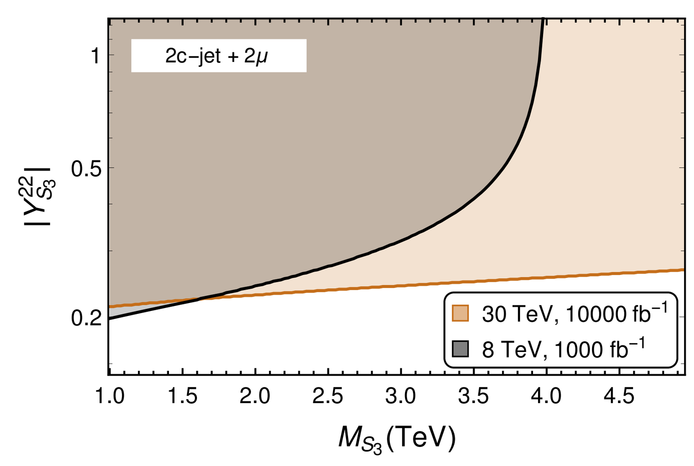


Reach for S_3



Pair production at a $\mu^+\mu^-$ collider

Reach for S_3 at muon collider



Advantages

No ISR QCD background

Cleaner signal

Better reach and precision

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Bibliography

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