Identifying Different Beyond the Standard Model Signatures at Present and Future Colliders

Saunak Dutta, Priyotosh Bandyopadhyay, Anirban Karan

Indian Institute of Technology Hyderabad

Objectives

- Standard Model (SM) is a successful theory to explain matter and interactions
- SM fails to address various observational discrepencies and theoretical inconsitencies
- Innumerous theories Byond the Standard Model (BSM) have been proposed to address them
- Identifying their signatures at particle colliders are the challenges we address

Perspectives

- We consider the Leptoquarks, motivated by B-Anomalies, Anomalous Magnetic Moments of the leptons, Vacuum Stability and so on
- The Leptoquarks are colored, spin 0 or 1 bosons with tree-level quark-lepton vertex
- Our goal has been seggregating them based on their respective spins, and based on their $SU(2)$ representations

Overview

- Scalar Leptoquarks
  - S_1 (**3**, **1**, -2/3)
  - $\tilde{S}_1$ (**3**, **1**, +8/3)
  - R_2 (**3**, **2**, +7/3)
  - $\tilde{R}_2$ (**3**, **2**, +1/3)
  - S_3 (**3**, **3**, +2/3)
- Vector Leptoquarks
  - $U_{1\mu}$ (**3**, **1**, +4/3)
  - $\tilde{U}_{1\mu}$ (**3**, **1**, +10/3)
  - $V_{2\mu}$ (**3**, **2**, +5/3)
  - $\tilde{V}_{2\mu}$ (**3**, **2**, -1/3)
  - $U_{3\mu}$ (**3**, **3**, +4/3)

The Key

- Angular Distribution of the scattered leptoquarks bear imprints of its spin and gauge representation depending on the scattering process

Spin Determination of Leptoquarks

- We consider the pair production, $pp \to \mathcal{LQ}\,\overline{\mathcal{LQ}}$ at LHC
- In the rest frame of interaction, the angular distribution of $\mathcal{LQ}$ has a unique shape depending on its spin
- We consider the leptoquark decay to charged lepton and a quark and reconstruct it from jet-lepton invariant mass
- We demand events with a pair of such reconstructed leptoquarks and determine the rest frame of interaction from their 4-momenta

We imposed the cumulative cuts as follows to optimise the signal over SM Background:

1. Topology: $\geq 1\ell^+ + 1\ell^- + 2j$
2. Z-veto: $\begin{cases} |M_{\ell^+\ell^-} - M_Z| > 10 \text{ GeV} \\ |M_{jj} - M_Z| > 10 \text{ GeV} \end{cases}$
3. Resonance Peak: $\begin{cases} |M_{\ell^+ j} - M_{\mathcal{LQ}}| \leq 10 \text{ GeV} \\ |M_{\ell^- j} - M_{\mathcal{LQ}}| \leq 10 \text{ GeV} \end{cases}$

Gauge Representation

- We consider the associated production:
  - $e^- p \to \mathcal{LQ}\,\gamma$ at LHeC and FCC-he
  - $e^-\gamma \to \mathcal{LQ}\,q$ at the proposed $e\gamma$ collider
- We exploit the notion of Zeros in Radiation Amplitude for processes involving photons to determine the leptoquark charge, instrumental to provide its $SU(2)$ representation
- For a given $SU(2)$ multiplet, members are seggregated by the charge of jets, originated from their decays
- Signatures at $e^- p$ and $e\gamma$ collisions are complementary for determining all Leptoquark candidates
- Condition for observing the Zero at
  - $e^- p$ collision: $|Q^{em}_{\mathcal{LQ}}| > 1$
  - $e\gamma$ collision: $|Q^{em}_{\mathcal{LQ}}| < 1$

Results

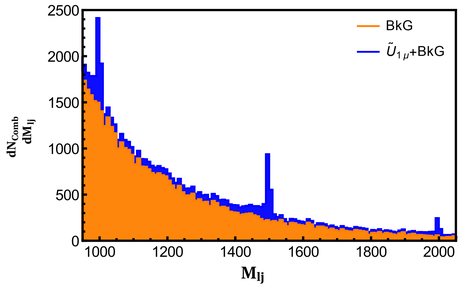

Figure 1: $M_{\ell j}$ peaks at $M_{\mathcal{LQ}}$s

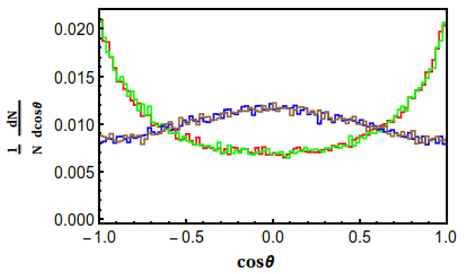

Figure 2: Spin 0 and 1 Leptoquarks have unique and distinct distributions

Seggregating Different Members from the same Multiplet

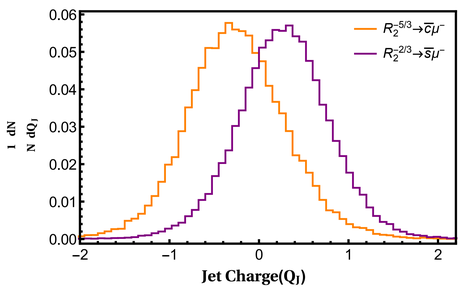

Figure 3: Different decay products of the members lead to different quarks, and hence the jets peak at different Q^{em}s

This aids at distinguishing the signal from the model background at different collision processes.

Zeros in Angular Distribution

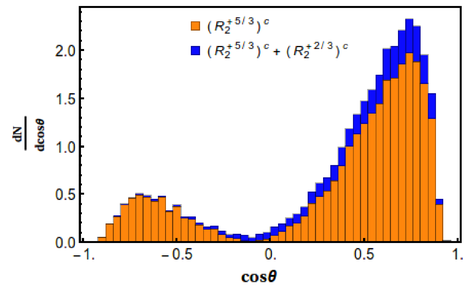

Figure 4: $R_2^{5/3}$ exhibits zero at $\cos\theta \sim -0.2$ at $e^- p$ collision where the other member, $R_2^{2/3}$ contributes to efface the minima

Conclusion

- All these angular distributions have been plotted at the rest frame of interaction
- Reconstruction of the scattered leptoquark(s) essential for reconstructing the rest frame of interaction
- This method needs modifications for processes involving $\not{E}_T$
- Angular Correlation rests an effective tool for New Physics Signatures in Present and Future Colliders

References

[1] P. Bandyopadhyay, S. Dutta, M. Jakkapu and A. Karan, [arXiv:2007.12997 [hep-ph]]

[2] P. Bandyopadhyay, S. Dutta and A. Karan, [arXiv:2012.13644 [hep-ph]]

[3] P. Bandyopadhyay, S. Dutta and A. Karan, Eur. Phys. J. C **80** (2020) no.6, 573

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