Probing the chirality of Leptoquark couplings in the light of R_{D^*}, R_{K^*} puzzle

(Work in progress with Dr. Yu Gao)

Joydeep Roy

Department of Physics and Astronomy

Wayne State University

Detroit, Michigan, U.S.A

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Outline

- Motivation
- Introduction to Leptoquarks (LQs)
- Contribution of LQs in solving the puzzle
- Production & decay of LQs
- Conclusion and Outlook

Motivation

- Mesons are particles made of a quark and an antiquark ($q\bar{q}$).
- Most common examples are:

Unflavored light mesons: $\pi^{\pm}(u\bar{d}), \eta(\frac{u\bar{u}+d\bar{d}-2s\bar{s}}{\sqrt{6}})$ etc,

Charmed mesons: $D^{*+}(c\bar{d}), D^{*0}(c\bar{u})$ etc,

Strange mesons: $K^{*+}(u\bar{s}), K^{*0}(d\bar{s})$ etc,

Bottom mesons: $B^{+}(u\bar{b}), B^{0}(d\bar{b})$ etc.

- Being lighter compared to baryons, they are easier to produce at the colliders.
- They are mostly unstable and thus easier to study their high-energy behavior.

Motivation

- Recently BaBar and Belle experiments measured the ratio of branching fractions of B meson decays:

$$R_{D^*} = \frac{\mathrm{Br}\,(\bar{B}\to D^*\tau^-\,\bar{\nu}_\tau)}{\mathrm{Br}\,(\bar{B}\to D^* l^- \bar{\nu}_l)}(l = e, \mu) = 0.316 \pm 0.016 \pm 0.010\ (\text{arXiv:1603.06711})\quad \boxed{R_{D^*}^{\mathrm{SM}} \cong 0.252 \pm 0.003}$$

$$R_{K^*} = \frac{\mathrm{Br}\,(B^0 \to K^{*0}\mu^+\mu^-)}{\mathrm{Br}\,(B^0 \to K^{*0}e^+e^-)} = \begin{cases} 0.660^{+0.110}_{-0.070}(\text{stat}) \pm 0.024(\text{syst}), 0.045 \le q^2 \le 1.1\ GeV^2 \\ 0.685^{+0.113}_{-0.069}(\text{stat}) \pm 0.047(\text{syst}), 1.1 \le q^2 \le 6.0\ GeV^2 \end{cases}$$

(arXiv:1704.07397) $\boxed{R_{K^*}^{\mathrm{SM}} \cong 0.93 \text{ at low } q^2, \approx 1 \text{ otherwise}}$

- Since these decays happen at the tree-level, new physics (NP) with new particle is required to explain these anomalies.

- Leptoquarks (LQs) are popular candidate for this NP.

Leptoquark (LQ)

- Leptoquarks are hypothetical fields that simultaneously couple or decay to a quark and a lepton.
- They carry both Baryon no. (B) and Lepton no. (L) and can turn quarks into leptons and vice versa.
- LQs can be of either scalar (spin-zero) or vector (spin-one) nature.
- There are six scalar and six vector LQ multiplets under the Standard Model gauge group.

Leptoquark (LQ)

$(SU(3), SU(2), U(1))$	Spin	Symbol	Type	F
$(\bar{\mathbf{3}}, \mathbf{3}, 1/3)$	0	S_3	$LL\,(S_1^L)$	-2
$(\mathbf{3}, \mathbf{2}, 7/6)$	0	R_2	$RL\,(S_{1/2}^L),\ LR\,(S_{1/2}^R)$	0
$(\mathbf{3}, \mathbf{2}, 1/6)$	0	$\tilde{R}_2$	$RL\,(\tilde{S}_{1/2}^L),\ \overline{LR}\,(\tilde{S}_{1/2}^{\bar{L}})$	0
$(\bar{\mathbf{3}}, \mathbf{1}, 4/3)$	0	$\tilde{S}_1$	$RR\,(\tilde{S}_0^R)$	-2
$(\bar{\mathbf{3}}, \mathbf{1}, 1/3)$	0	S_1	$LL\,(S_0^L),\ RR\,(S_0^R),\ \overline{RR}\,(S_0^{\bar{R}})$	-2
$(\bar{\mathbf{3}}, \mathbf{1}, -2/3)$	0	$\bar{S}_1$	$\overline{RR}\,(\bar{S}_0^{\bar{R}})$	-2
$(\mathbf{3}, \mathbf{3}, 2/3)$	1	U_3	$LL\,(V_1^L)$	0
$(\bar{\mathbf{3}}, \mathbf{2}, 5/6)$	1	V_2	$RL\,(V_{1/2}^L),\ LR\,(V_{1/2}^R)$	-2
$(\bar{\mathbf{3}}, \mathbf{2}, -1/6)$	1	$\tilde{V}_2$	$RL\,(\tilde{V}_{1/2}^L),\ \overline{LR}\,(\tilde{V}_{1/2}^{\bar{R}})$	-2
$(\mathbf{3}, \mathbf{1}, 5/3)$	1	$\tilde{U}_1$	$RR\,(\tilde{V}_0^R)$	0
$(\mathbf{3}, \mathbf{1}, 2/3)$	1	U_1	$LL\,(V_0^L),\ RR\,(V_0^R),\ \overline{RR}\,(V_0^{\bar{R}})$	0
$(\mathbf{3}, \mathbf{1}, -1/3)$	1	$\bar{U}_1$	$\overline{RR}\,(\bar{V}_0^{\bar{R}})$	0

List of Leptoquarks,
(arXiv:1603.04993)

LQ-Fermion interaction

$$\mathcal{L}^{LQ}_{Fermion} = C^{ij}_{LQ} \bar{Q}^{a}_{iL} \gamma^{\mu} \tau^{A} L_{jL} V^{a,A}_{\mu} + \mathrm{h.c.}$$

C^{ij}_{LQ} is LQ Coupling matrix with generation indices i, j

$Q_L (L_L)$ are left-handed quark (lepton) doublet

V^{a}_{μ} is the color triplet vector leptoquark

τ^{A} are the SU(2) generators, Pauli matrices

LQ-Gluon interaction

- The Vector LQ (V)-gluon interaction is given by this effective Lagrangian term

$$\mathcal{L}_{QCD}^{LQ} = -\frac{1}{2} F_{\mu\nu}^{\dagger} F_{\dagger}^{\mu\nu} + M_V^2 V_\mu^{\dagger} V^\mu - i\, g_s \kappa V_\mu^{\dagger} G^{\mu\nu} V_\nu$$

(arXiv:hep-ph-9609267)

LQ-Gluon interaction

$$\mathcal{L}_{QCD}^{LQ} = -\frac{1}{2}F_{\mu\nu}^{\dagger}F_{\dagger}^{\mu\nu} + M_V^2 V_\mu^{\dagger}V^\mu - i\, g_s \kappa V_\mu^{\dagger} G^{\mu\nu} V_\nu$$

$F^{\mu\nu} = D_\mu V_\nu - D_\nu V_\mu$, e.m. field strength tensor

$D_\mu = \partial_\mu - i g_s T_a G_\mu^a$, gauge covariant derivative of SU(3)

$G^{\mu\nu}$ is the Gluon field strength tensor

G_μ^a is the gluon field, T_a is the SU(3) generator

κ is anomalous chromomagnetic moment, usually 1.

Effective Lagrangian

- The effective Lagrangian would therefore take the form

$$\mathcal{L}^{LQ}_{effective} = \mathcal{L}_{\text{SM}} + \mathcal{L}^{LQ}_{Fermion} + \mathcal{L}^{LQ}_{QCD}$$

- This effective Lagrangian is not unique, other chiral terms can also be added.

Contribution of LQs

- Remember $D^{*+}(c\bar{d}), D^{*0}(c\bar{u})$ etc ; $K^{*+}(u\bar{s}), K^{*0}(d\bar{s})$ etc.

$$\bar{B} \to D^{*}\tau^{-}\,\bar{\nu}_{\tau} \Longrightarrow \mathrm{b} \to cl\bar{\nu}_{l}\ ;$$

$$B^{0} \to K^{*0}\mu^{+}\mu^{-} \Longrightarrow \mathrm{b} \to sl^{+}l^{-}$$

- In SM these transition are absent due to zero contribution to the Wilson Coefficients.
- $\mathcal{L}^{LQ}_{effective}$ can contribute non-zero values to the Wilson Coefficients via Fierz transformation.

Contribution of LQs

- Chirality of LQ couplings, C_{LQ}^{ij} are important in determining the contributing Wilson coefficients.

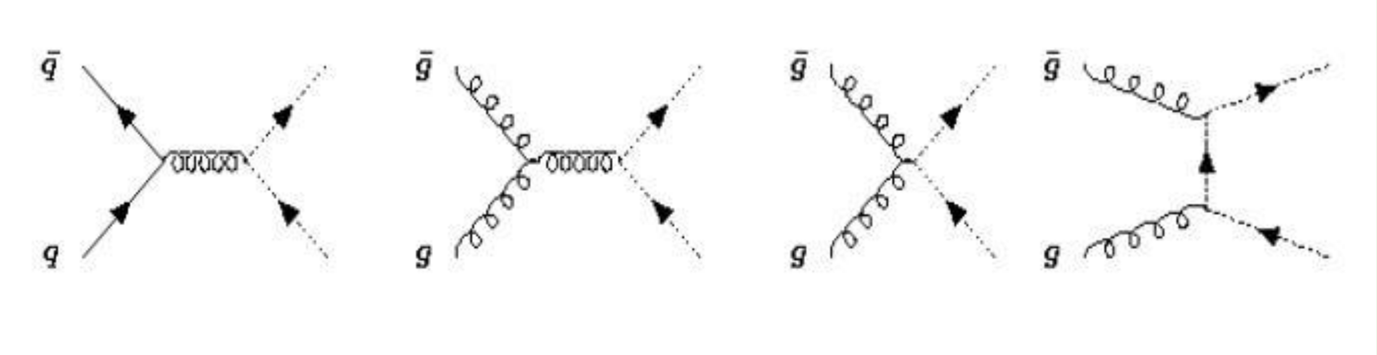
- This chirality can be tested by comparing with the known SM background.

- Therefore we need to look at the decay channel and understand the signal at the collider.

LQ Pair Production

- LQs can be produced either singly or in pairs in hadronic colliders.

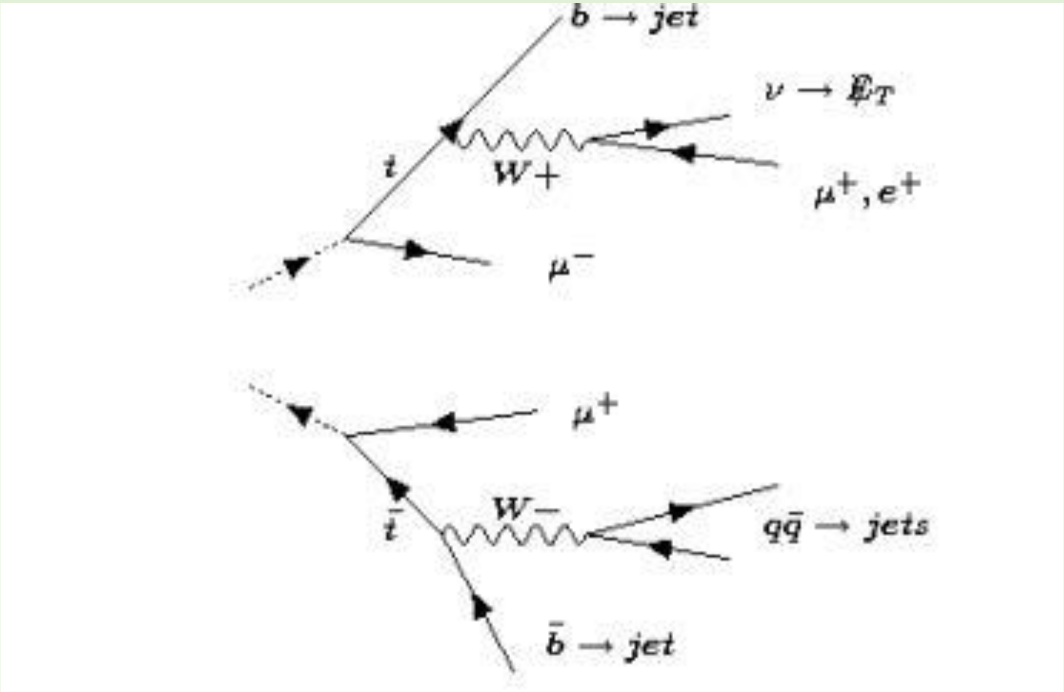
- Pair production proceeds via QCD interactions.



Lowest order diagrams for leptoquark pair production

arXiv:1102.4562

LQ Decay



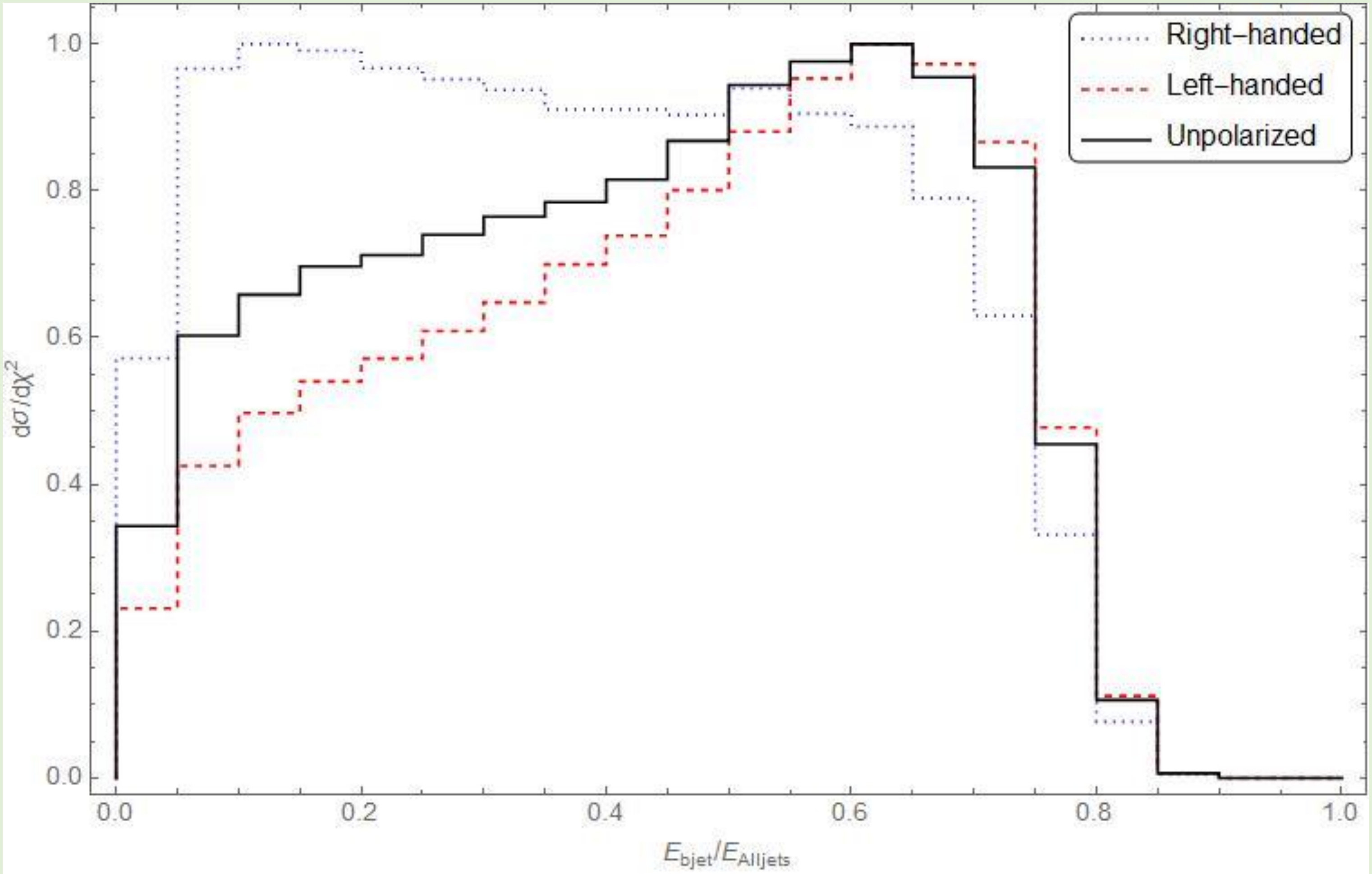
Possible decay chain for a pair of scalar leptoquarks

arXiv:1102.4562

Preliminary Results

- Left or right handed tops can be easily separated

Madgraph + Pythia + Delphes



Sample parton level $t\bar{t}$ Background

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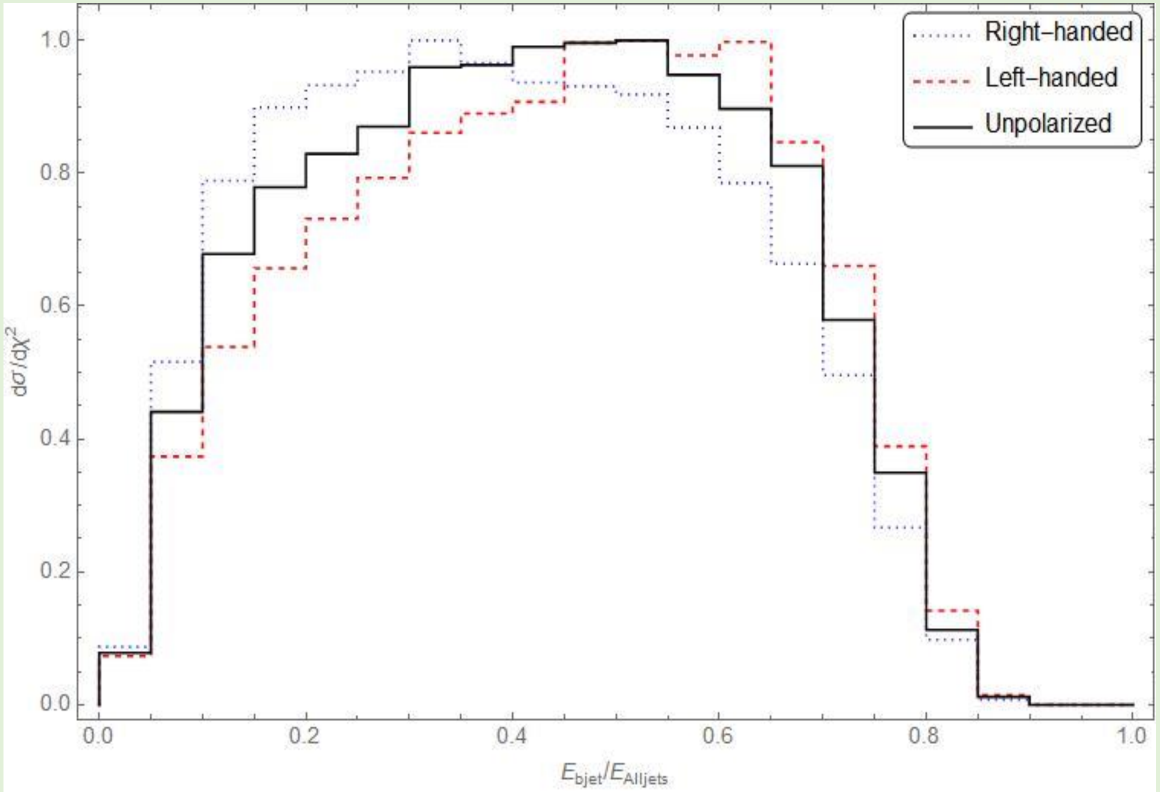
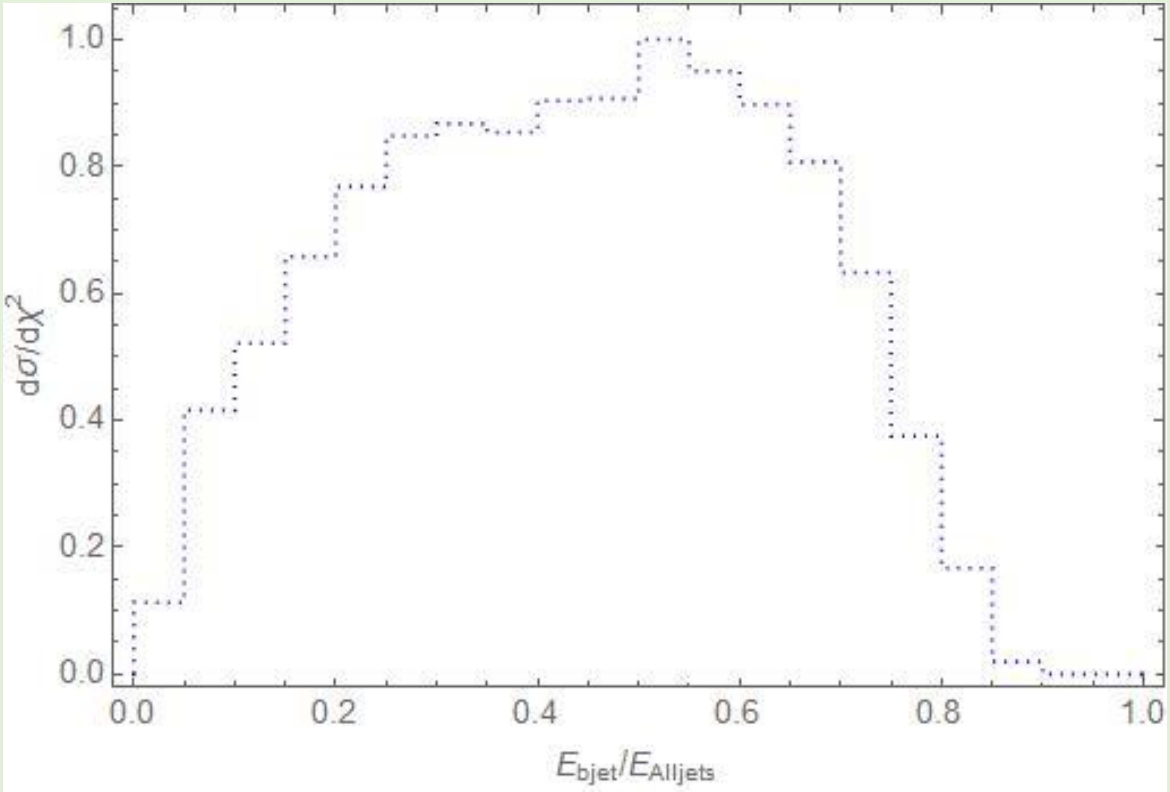
Madgraph + Pythia + Delphes



Sample detector level $t\bar{t}$ Background



Sample LQ analysis of $t\bar{t}$ Signal

Conclusion

- Experimental results from B-factory indicate the existence of New Physics (NP).
- LQs can generate additional Wilson coefficients which contribute to the NP and thus towards explaining the R_{D^*}, R_{K^*} puzzle.
- Chirality of reconstructed top quarks can probe the chirality of LQ coupling.

Outlook

- Top being the heaviest quark, decays before hadronization. We can reconstruct the $t\bar{t}$ masses and compare it with the unpolarized SM $t\bar{t}$ background.

- With current high luminosity used by LHC we can distinguish the chiral signals and probe the chirality of LQ.

- Similarly we can also add other chiral terms in the $\mathcal{L}_{effective}^{LQ}$ and probe the chirality of those LQs.

Thank you !