Precise probing and discrimination of third-generation scalar leptoquarks

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Various Scalar Leptoquark Models

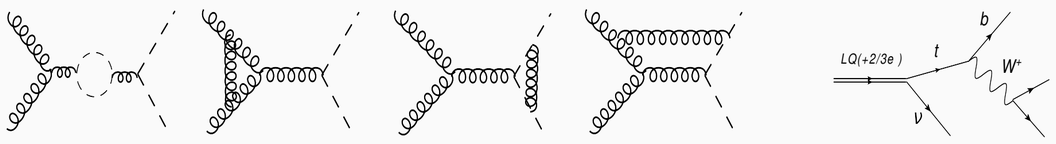
Models	$(SU(3)_c, SU(2)_L, U(1)_Y)$	Components & Decay
S_3	$(\bar{3}, 3, \frac{1}{3})$	$S_3^{\frac{4}{3}}(\tilde{b}, \tau^+),\ S_3^{\frac{1}{3}}((\tilde{t}, \tau^+), (\tilde{b}, \tilde{\nu}_\tau)),\ S_3^{-\frac{2}{3}}(\tilde{t}, \tilde{\nu}_\tau)$
R_2	$(3, 2, \frac{7}{6})$	$R_2^{\frac{5}{3}}(t, \tau^+),\ R_2^{\frac{2}{3}}((t, \tilde{\nu}_\tau), (b, \tau^+))$
$\tilde{R}_2$	$(3, 2, \frac{1}{6})$	$\tilde{R}_2^{\frac{2}{3}}((t, \tilde{N}_\tau), (b, \tau^+)),\ \tilde{R}_2^{-\frac{1}{3}}((b, \tilde{\nu}_\tau), (b, \tilde{N}_\tau))$
$\tilde{S}_1$	$(\bar{3}, 1, \frac{4}{3})$	$\tilde{S}_1^{\frac{4}{3}}(\tilde{b}, \tau^+)$
S_1	$(\bar{3}, 1, \frac{1}{3})$	$S_1^{\frac{1}{3}}((\tilde{t}, \tau^+), (\tilde{b}, \tilde{\nu}_\tau), (\tilde{b}, \tilde{N}_\tau))$
$\bar{S}_1$	$(\bar{3}, 1, -\frac{2}{3})$	$\bar{S}^{-\frac{2}{3}}(\tilde{t}, \tilde{N}_\tau)$

The SM fermions:

$Q_L \equiv (3, 2, \frac{1}{6}),\ L_L \equiv (1, 2, -\frac{1}{2})\ u_R \equiv (3, 1, \frac{2}{3}),\ d_R \equiv (3, 1, -\frac{1}{3}),\ e_R \equiv (1, 1, -1)$

Production and Decay at LHC

	$S_3^{\frac{2}{3}}$	$R_2^{\frac{2}{3}}$
$\mathcal{L}_{\rm Kin}$	$(D_\mu S)^\dagger (D^\mu S) - M_S^2 S^\dagger S$	
$\mathcal{L}_{\rm Int}$	$y_{S_{LL}} * t_L^{\bar{C}}\ v_\tau\ S_3^{-\frac{2}{3}} + h.c.$	$y_{R_{RL}} * \bar{t_R} v_\tau\ R_2^{\frac{2}{3}} + y_{R_{LR}} * \bar{b_L} \tau_R\ R_2^{\frac{2}{3}} + h.c.$
Decay	(t_L, ν_τ)	$((t_R, \tilde{\nu}_\tau), (b_L, \tau_R^+))$



Polarization variables

Angular variable in the top/antitop rest frame

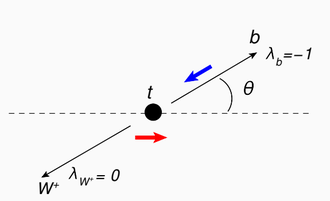
$$\frac{1}{\Gamma}\frac{d\Gamma}{\mathrm{dcos}\theta_{\rm i}} = \frac{1}{2}(1 + {\rm P_t}\ {\rm k_i}\ \cos\ \theta_{\rm i}) \quad \Big| \quad \frac{1}{\bar{\Gamma}}\frac{d\bar{\Gamma}}{\mathrm{dcos}\bar{\theta}_{\bar{\rm i}}} = \frac{1}{2}(1 + \bar{\rm P}_{\bar{\rm t}}\ \bar{\rm k}_{\bar{\rm i}}\ \cos\ \bar{\theta}_{\bar{\rm i}})$$

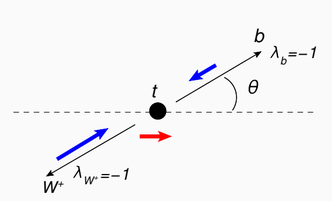
Energy variable in the Lab frame $z = \frac{E_b}{E_t}$

$$\frac{1}{\Gamma}\frac{d\Gamma}{dz} = \frac{1}{\beta_t}\frac{m_t^2}{m_t^2 - m_W^2}\left(1 - P_t\ k_b\frac{1}{\beta_t} + P_t\ k_b\frac{1}{\beta_t}\frac{2m_t^2}{m_t^2 - m_W^2}z\right)$$

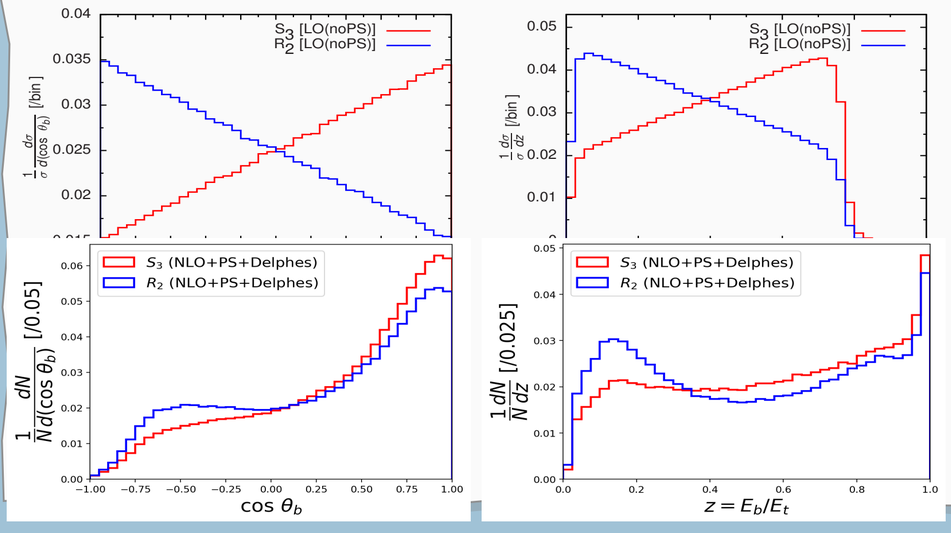
Daughters	b	W^+
k_i	-0.41	+0.41

$$, \qquad k_i = -\bar{k_{\bar{i}}}\ , \qquad \cos\theta_{\rm b} = \frac{1}{\beta_{\rm t}}\left(\frac{2{\rm m_t^2}}{{\rm m_t^2 - m_W^2}}{\rm z} - 1\right)$$

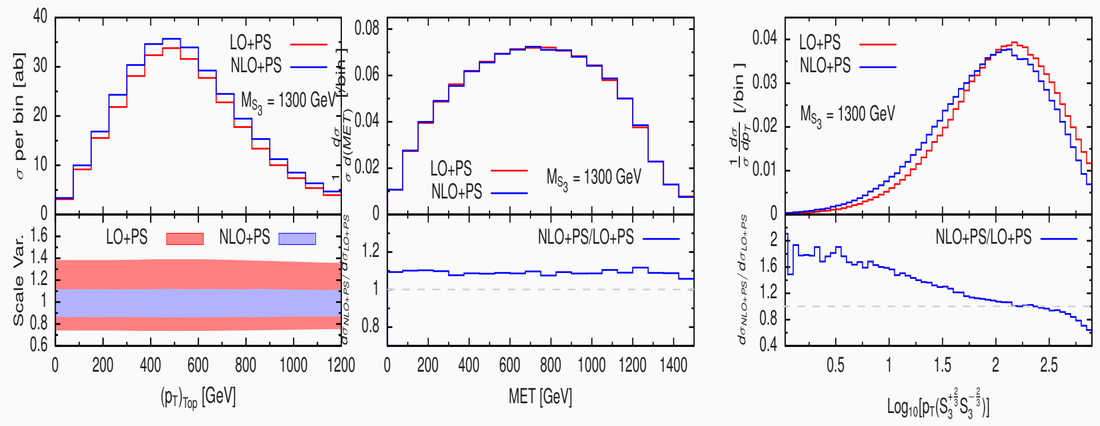




Distributions of Pol. Variables



NLO+PS Effects



Signal and Backgrounds with cuts

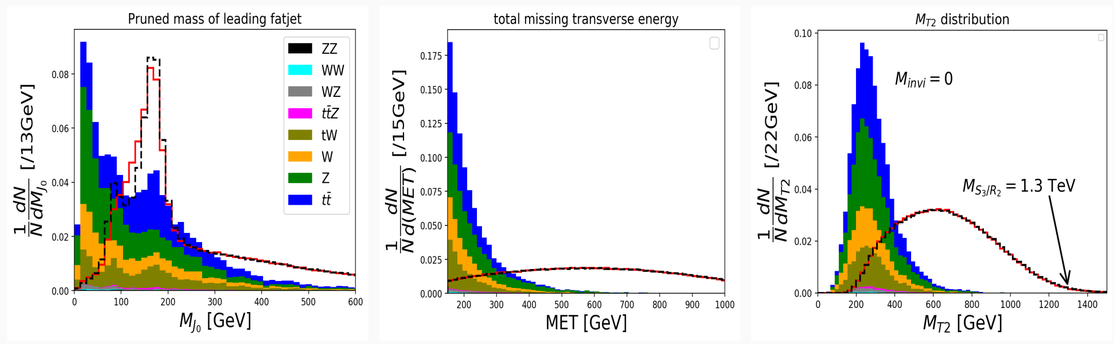
For LHC search, we choose two fat jets plus missing energy as the signature.

Cuts	S_3 (fb)	R_2 (fb)	Z+jets (fb)	W+jets (fb)	$t\bar{t}$+jets (fb)	tW+jets (fb)	tot BG (fb)
C1	0.2315 [100%]	0.232 [100%]	2517.99 [100%]	1366.91 [100%]	690.65 [100%]	366.91 [100%]	5073.4 [100%]
C2	0.2258 [97.54%]	0.2262 [97.5%]	1640.29 [65.14%]	762.59 [55.79%]	302.16 [43.75%]	152.52 [41.57%]	2934.4 [57.84%]
C3	0.1810 [78.19%]	0.1801 [77.63%]	241.73 [9.60%]	117.99 [8.63%]	230.94 [33.44%]	114.39 [31.18%]	720.2 [14.20%]
C4(MVA)	0.1047 [45.23%]	0.1033 [44.53%]	25.38 [1.01%]	17.33 [1.27%]	64.23 [9.30%]	27.45 [7.48%]	136.16 [2.68%]

C1: Preselection cuts C2: $\not{E}_T > 150$ GeV

C3: at least one b-tag within J_0 or J_1 , C4: $M_{J_0}, M_{J_1} > 120$ GeV

Kinematic Distributions



LHC Reach and Model Discrimination

$\mathcal{L} = 3ab^{-1}$	$S_3^{\frac{2}{3}}$	$R_2^{\frac{2}{3}}$
5σ discovery	1380 GeV	1370 GeV
2σ exclusion	1520 GeV	1520 GeV

In our analysis, with 140 fb^{-1} luminosity, 2σ exclusion limit on the mass is 1270 GeV.
For 1300 GeV mass, around 1700 fb^{-1} required for 5σ discovery.

$$\mathcal{L}({\rm E|O}) = \prod_{i=1}^{n} e^{-E_i} {E_i}^{O_i}/\Gamma(O_i + 1) \qquad Z_{M1|M2} = \sqrt{-2ln\frac{\mathcal{L}({\rm M1|M2})}{\mathcal{L}({\rm M2|M2})}}$$

$\mathcal{L}$	predicted	observed	Rejection Prob. (Z) (14 TeV)	Rejection Prob. (Z) (27 TeV)
$3ab^{-1}$	$R_2 + B$	$S_3 + B$	0.98 σ	6.45 σ
	$S_3 + B$	$R_2 + B$	1.01 σ	6.59 σ