Color Octet Scalar Phenomenology at the LHC

Ryan Gavin

Univ. of Wisconsin - Madison

with P Fileviez Pérez, T McElmurry, F Petriello

Pheno 2008

April 29, 2008

Outline

- single charged color octet scalar production at LHC
- motivation & background
- 1 TeV colored octet scalar
  - large $S/\sqrt{B}$
  - scalar/top/bottom Yukawa measurement
    - probe of GUT physics
  - analysis
- 1.5 TeV colored octet scalar
  - analysis

Motivation

- absence of flavor-changing neutral currents - new physics should obey principle of minimal flavor violation (MFV)
  - MFV: flavor structure of physics beyond SM should be completely determined by SM Yukawa structure
- bottom up & top down approaches
- extended scalar sector (A Manohar & M Wise)
  - $(1,2)_{1/2}$ & $(8,2)_{1/2}$
    - has SM Yukawa structure - preserves MFV
    - SM higgs and color octet scalar, respectively
- SU(5) Adjoint GUT (P Fileviez Pérez, H Iminniyaz, G Rodrigo)
  - predicts color octet scalar with SM flavor structure
  - octet scalar probes GUT properties
    - b - τ unification, proton decay

Model

- Color octet interactions with fermions

$$-\sqrt{2}\eta_U \bar{u}^i_R \frac{m^i_U}{v} T^A u^i_L S^{A0} + \text{h.c.}$$
$$+\sqrt{2}\eta_U \bar{u}^i_R \frac{m^i_U}{v} T^A V_{ij} d^j_L S^{A+} + \text{h.c.}$$
$$-\sqrt{2}\eta_D \bar{d}^i_R \frac{m^i_D}{v} T^A d^i_L S^{A0\dagger} + \text{h.c.}$$
$$-\sqrt{2}\eta_D \bar{d}^i_R \frac{m^i_D}{v} V^\dagger_{ij} T^A u^j_L S^{A-} + \text{h.c.}$$

(A Manohar & M Wise)

- new color octet states: S_R, S_I, S^+, S^-
- η_U & η_D parameterize strength of coupling to matter
  - direct probe to GUTs

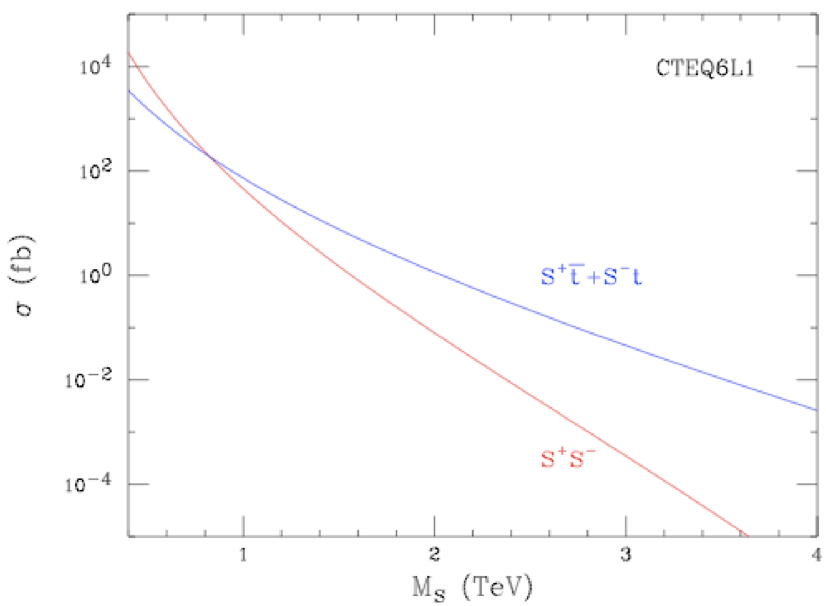
Single Production

- single charged octet production

$$g\,b \rightarrow S^-\,t \quad \& \quad g\,\bar{b} \rightarrow S^+\,\bar{t}$$

- assume η_U, η_D ~ 1
  - m_U coupling dominates $\sqrt{2}\eta_U \bar{u}_R^i \frac{m_U^i}{v} T^A V_{ij} d_L^j S^{A+} + \text{h.c.}$
- $S^+ \rightarrow W^+ S^0$, scalar cascade decay unlikely

  (M Gerbush, et al)
- BR: $S^+ \rightarrow t\bar{b}$ ~100%



Event Generation

- LO events
  - $pp \to S^{\pm}\overset{(-)}{t} \to t\bar{t}\overset{(-)}{b}$
    - $\sigma_{LO} \approx 93$ fb
  - backgrounds: $t\bar{t}$+jet, *W*+jets, QCD
  - $pp \to t\bar{t}j$
    - $\sigma_{LO} \approx 526$ pb
- generated using MadEvent to parton level
  - standard acceptance cuts

Detector 'Simulation'

- Gaussian smearing of E or p_T
  - jet-like objects (b-quark, light quarks, gluons)

$$\frac{\delta E}{E} = \frac{0.8}{\sqrt{E/\,\mathrm{GeV}}} \oplus 0.03$$

  - electrons

$$\frac{\delta E}{E} = \frac{0.1}{\sqrt{E/\,\mathrm{GeV}}} \oplus 0.007$$

  - muons

$$\frac{\delta p_T}{p_T} = 0.15\,\frac{p_T}{\mathrm{TeV}} \oplus 0.005$$

  - missing E_T defined by momentum balancing

Detector 'Simulation'

- 'jet' algorithm
  - iteratively combine final state partons with $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ < 0.4
  - combined objects tagged as jet
- *b*-jet tagging
  - b-tag eff = 60%
  - fake rate = 3%
    - study quite sensitive to fake rate

Top Reconstruction

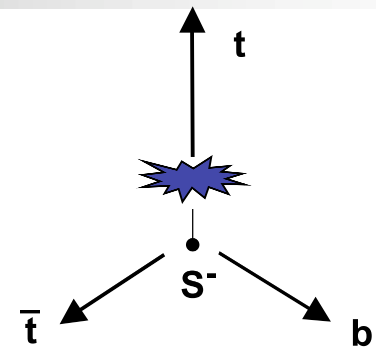
- only keep pure hadronic or single lepton (e or μ) events
- expect final state partons to be highly boosted
  - decay of tops highly collimated
- semi-leptonic top decay
  - find jet with smallest $\Delta R_{jet,lep} < \Delta R_{max}=0.6$
  - combine lepton and missing energy
    - *W* mass constraint to find longitudinal component
  - solve ambiguity by picking solution which gives smaller $\Delta R_{jet,W}$
  - tag as top-jet if m_{top} falls within 171±50 GeV

Top Reconstruction

- hadronic top decay
  - find two jets with smallest $\Delta R_{jet,jet} < \Delta R_{max}=0.8$
  - if $m_{jet,jet}$ falls within m_{top} window, tag as top
  - if $m_{jet,jet}$ falls within m_W window, 40-121 GeV temporarily tag as *W*
    - find jet with smallest $\Delta R_{W\_temp,jet} < \Delta R_{max}=0.8$
    - if $m_{W\_temp,jet}$ falls within m_{top}, tag as top
- algorithm continues until no further tops found

Analysis

- cuts
  - kinematic &
    'shape' (Mercedes Benz)



Cut	S/S_0	B/B_0	$S/\sqrt{B}$	S/B
$H_T > 1000$ GeV	0.483	0.0131	5.41	0.007
$p_{T_{t_1}}, p_{T_{b_1}} > 300$ GeV	0.0710	1.29×10^{-4}	8.01	0.097
$M_{b_1 t_1} > 900$ GeV	0.0679	1.10×10^{-4}	8.30	0.109
$\Delta R_{b_1 t_1} < 3.0$	0.0347	1.80×10^{-5}	10.49	0.341
$45^\circ < \theta_{t_1 b_1} < 135^\circ$, $\theta_{(t_1+b_1)b_2} > 90^\circ$	0.0183	4.50×10^{-5}	11.06	0.719

Analysis

- Estimate of error on measurement
  - error on $|\eta_U|^2$ - connection to GUTs

$$\frac{\delta S}{S} = \frac{\sqrt{S+B} \oplus F_S S \oplus F_B B}{S}$$

- F_S, F_B theoretical errors for signal and background
  - LO variation in σ_S & σ_B by scale variation 0.5μ & 2μ -

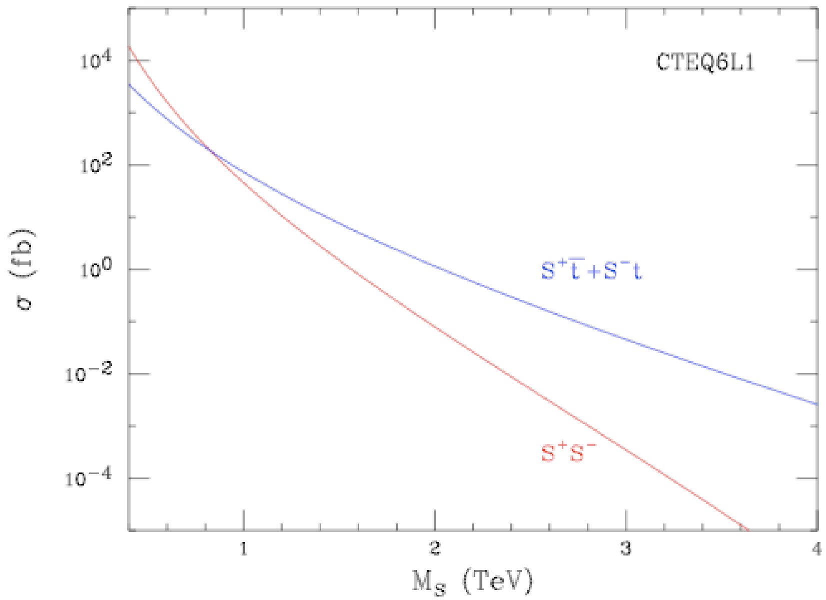
$F_{S,LO} \approx \pm 15\%$ &

$F_{B,LO} \approx \pm 40\%$

F_S	F_B	$\frac{\delta S}{S}$ $(100\,\mathrm{fb}^{-1})$	$\frac{\delta S}{S}$ $(1\,\mathrm{ab}^{-1})$
0	0	0.119	0.037
0.10	0.15	0.260	0.234
0.10	0.30	0.445	0.431
0.15	0.40	0.588	0.577

1.5 TeV Octet Scalar

- single production provides further reach for discovery of heavier octet scalar
- LO $\sigma \approx 10$ fb



- similar generation, simulation as 1 TeV octet
  - hadronic $\Delta R_{max} = 0.6$
- b-tag eff = 50%
- fake rate = 5%
  - very sensitive to fake rate

1.5 TeV Analysis

- cuts

Cut	S/S_0	B/B_0	$S/\sqrt{B}\,(100\text{fb}^{-1})$	$S/\sqrt{B}\,(1\text{ab}^{-1})$
$H_T > 1500$ GeV	0.402	1.3×10^{-3}	1.51	4.78
$p_{T_{t_1}} > 400, p_{T_{b_1}} > 500$ GeV	0.0521	1.71×10^{-5}	1.71	5.40
$M_{b_1 t_1} > 1300$ GeV	0.0507	1.54×10^{-5}	1.75	5.55
$\Delta R_{b_1 t_1} < \pi$	0.0409	7.74×10^{-6}	1.99	6.31

- discovery possible with 1 ab^{-1} of integrated luminosity

Summary

- single charged colored octet scalar production at $m_S \approx 1$ TeV
  - $S/\sqrt{B} \approx 11$
- direct probe of scalar/top/bottom Yukawa coupling (GUT probe)
  - $\Delta S/S \approx \pm 25\text{-}45\%$
  - need to understand $pp \rightarrow t\bar{t}j$ uncertainties
- single production dominates at $m_S \approx 1.5$ TeV
  - discovery at 1 ab^{-1} of integrated luminosity possible