Pulling Out All the Stops: Jet Substructure and Light Stops Decaying to Multijets

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@ DPF 2013
15 August 2013

*work in progress with Y. Bai and A. Katz*
“Very Natural” SUSY

particle mass

other stuff
(heavy stop, EWinos, Higgsinos, gluino, other squarks, etc)

light stop
\(m \lesssim \text{TeV}\)

e.g., Brust, Katz, Lawrence, Sundrum (1111.6670)
• Baryonic R-parity violation
  – \( \lambda^{''}_{3ij} \bar{t}_R d_R^i d_R^j \) (\( i \neq j \))
• 100% decays to 2 down-type quarks
  – prompt if \( \lambda^{''} > 10^{-7} \)
  – MFV: 96% contain bottom
• Direct pair production \( \Rightarrow \) fully jetty final-state
  – no handles like leptons or MET

* LNV decays also being explored. See e.g. Evans & Kats (1209.0764)
Alternatives to Direct Production

- Produced in gluino decay (⇒ associated top pair)
  - dileptonic tops (possibly same-sign)
  - semileptonic tops (jet multiplicity, $H_T$ tails, dijet resonance peak)
  - possibly high b-tag multiplicity (3 or 4)
- Produced in sbottom decay
  - extra leptonic handle from $\tilde{b} \rightarrow \tilde{t} W$
- Produced in heavier stop decay
  - not yet studied in detail
Pursuing Direct Production

- Much less model-dependent
  - rate and kinematics are only a function of stop mass
  - we will even ignore jet flavor (structure of $\lambda''$ coupling)...for now
  - not necessarily SUSY (generic diquark pair search)
- A benchmark for purely jetty searches
- Current limits are very weak
  - LEP: 90 GeV
  - Tevatron: 100 GeV
  - LHC: No limit!!
Trigger Creep at the LHC

*Alleviated by parked data. See also b-jet-triggered analysis proposed in Franceschini & Torre (1212.3622)*
Why Jet Substructure?

- Focus on high-pT “boosted” signal production
  - combinatoric ambiguities automatically resolved by $\Delta R$
  - generally better S/B (e.g., less $gg\rightarrow gggg$)
- Flexible partition of decay radiation to individual “quarks”
  - better rejection of uncorrelated radiation (pileup, ISR, UE)
  - better signal mass resolution
- Nearly scale-free procedure
  - bypasses conventional “4-jet” division of highly multibody hadronic phase space, not sensitive to 4-jet trigger thresholds
  - background processed into ~featureless spectrum
Basic Ingredients

- Select events with jet-$H_T$ trigger: offline $H_T > 900$
  - not very correlated with decay/shower kinematics
  - selects boosted stops for $m(\text{stop}) < 450$
- Pre-trim entire event to remove pileup
  - *Fixed* minijet $p_T$ threshold, tuned to remove $\langle N_{\text{PV}} \rangle = 20 \ p_T$-density
- Capture stop decays in $R = 1.5$ C/A jets
- Decluster into subjets using BDRS-like prescription
  - halt declustering when subjet $p_T$'s are not too asymmetric *and*
    neither has large $m/p_T$
  - original BDRS appears to give a biased QCD spectrum
- Impose kinematic cuts, and run a bump-hunt
  - lots of options for how to estimate the QCD continuum background
Example Event, $m(\text{stop}) = 100$

*events gridified to 0.1x0.1*
Cuts

- $H_T(\text{normal-jets}) > 900$
- declustered-jet mass asymmetry < 0.1
- CM $\cos(\Theta^*) < 0.3$
- $p_T(\text{softer-subjet}) / p_T(\text{harder-subjet}) > 0.3$
  - applied to each side independently
Average-Mass Spectra

Untagged

- W+jets
- tops
- QCD
- 100 GeV
- 200 GeV
- 300 GeV

At least 1 b-tag
(assuming ~100% BR to bd/bs)

- W+jets
- tops
- QCD
- 100 GeV
- 200 GeV
- 300 GeV

**Be careful of top background!**
A common strategy is to fit QCD with

\[
\frac{d\sigma}{dm_{\text{avg}}} = \frac{P_0(1 - m_{\text{avg}}/\sqrt{s})^P_1}{(m_{\text{avg}}/\sqrt{s})^{P_2 + P_3 \ln(m_{\text{avg}}/\sqrt{s})}}
\]

(but there are other ways...)

\[\text{(S+B)/B relative to stat errors)}\]
Summary

• SUSY may be hiding in plain sight!
  – $O(100 \text{ GeV})$ stop LSP is quite “natural”
  – fully jetty RPV decay is very difficult to spot

• Current LHC searches are not sensitive
  – multijet triggers make life difficult for $m(\text{stop}) \sim 100 \text{ GeV}$

• Jet substructure approach is extremely promising
  – focus on boosted stop pair production
  – big R $\Rightarrow$ broad mass range covered
  – $> 5\sigma$ sensitivity to 100 GeV in 2012
  – untagged exclusion up to almost 300 GeV
  – even better if stop decays to b-quarks

• This is an analysis that can be done now
Extras
ΔR Distributions

*Passing all basic cuts