Boosted Tops from Gluino Decays

Michael Saelim

Cornell University
Laboratory for
Elementary-Particle Physics

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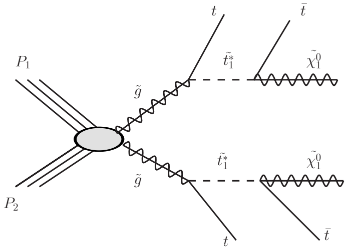
Based on the paper by
Joshua Berger, Maxim Perelstein, M.S., Andrew Spray
arXiv:1111.6594

One-slide overview



(figure credit: arXiv:1205.3933)

- LHC + naturalness $\Longrightarrow$ SUSY w/ light 3rd gen.
- Gluino pair-production signatures:

  4 boosted tops + MET
- Tagging boosted tops gives us low SM background
- Probe gluino masses up to 1 TeV @ 7 TeV LHC with $\int \mathcal{L} = 30\ \text{fb}^{-1}$

Boosted Tops from Gluino Decays

1. SUSY with light stops
2. Top tagging
3. Signal+Backgrounds
4. Results at 7 and 14 TeV

Boosted Tops from Gluino Decays

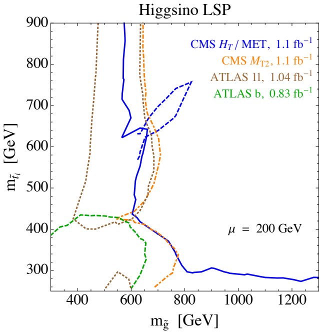
SUSY with light 3rd generation

$$\delta m_{H_u}^2|_{\text{stop, LL}} = -\frac{3}{8\pi^2}\, y_t^2\, (m_{Q_3}^2 + m_{u_3}^2 + |A_t|^2)\, \ln\left(\frac{\Lambda}{\text{TeV}}\right)$$

$$\delta m_{H_u}^2|_{\text{gluino, LL}} = -\frac{2}{\pi^2}\, y_t^2 \left(\frac{\alpha_s}{\pi}\right) |M_3|^2\, \ln^2\left(\frac{\Lambda}{\text{TeV}}\right)$$

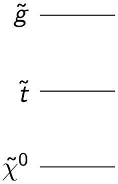
- MSSM w/ degenerate squarks: squarks and gluinos $>$ 1 TeV
  - Fine-tuning, unnatural EWSB
- But not all squarks are equal!
  - Stop @ 1L and gluino @ 2L are the most important for the Higgs
  - Consider models with light 3rd generation squarks and gluinos

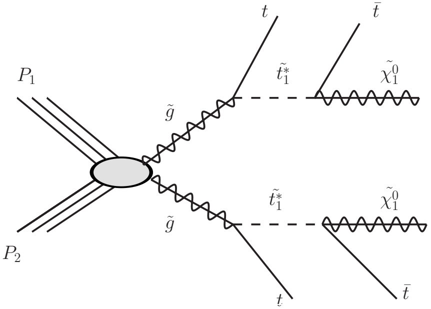
Papucci, Ruderman, and Weiler (arXiv:1110.6926)



- Reinterpreted results of LHC searches ($\sim 1\text{fb}^{-1}$) in terms of MSSM w/ light 3rd gen.
- Stops $>$ 2-300 GeV, Gluinos $>$ 600 GeV

Simplified model



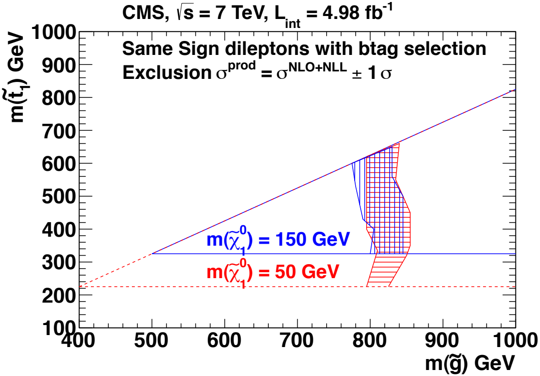


- Require $m(\tilde{g}) - m(\tilde{t})$ and $m(\tilde{t}) - m(\tilde{\chi}^0) > m(t)$ to get on-shell tops, and fix $m(\tilde{\chi}^0) = 60$ GeV
- 4 top + MET signal

(figure credit: arXiv:1205.3933)

- Boosted tops if mass separation is large enough

Update: CMS 4.98fb^{-1} bounds (arXiv:1205.3933)



(CMS PAS SUS-11-020, arXiv:1205.3933)

- SSDL+2b+MET
- gluinos > 800 GeV

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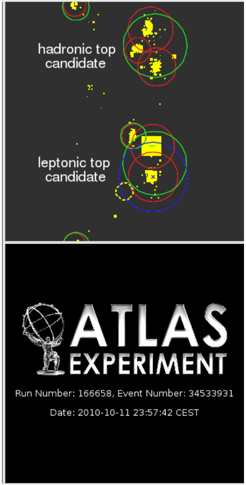
Tagging boosted tops



- Hadronic boosted tops have collimated decay products
- Cluster "fat jets" with $R \sim 1.0$
- Examine jet substructure and invariant mass of subjets

(figure credit: ATLAS-CONF-2011-073)

Johns Hopkins Top Tagger

- The first top tagging algorithm
- Kaplan, Rehermann, Schwartz, and Tweedie (arXiv: 0806.0848)
- Favored for tops with pT $\gtrsim$ 500 GeV
- Three steps:
  1. Clustering
  2. Declustering
  3. Substructure

Johns Hopkins Top Tagger: Clustering

- We recluster the jet with C/A into a fat jet of radius R
  - Start out with protojets corresponding to energy deposits in calorimeter cells
  - Iteratively bring together the two closest protojets in $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ until all remaining protojets are separated by $\Delta R \geq R$
  - We get a tree structure

Johns Hopkins Top Tagger: Declustering

- Iteratively decluster the jet to find up to 4 irreducible subjets
  - Irreducible subjets are hard enough and angularly separated enough
  - User defines pT scale $\delta_p p_T(\text{original fat jet})$ and angular scale δ_r
- Go backwards through C/A tree, splitting subjet j into j_1 and j_2.

Four cases:

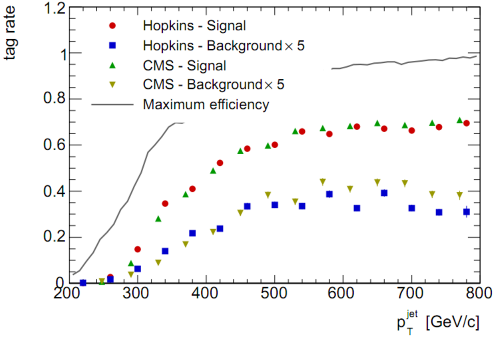
1. If j is an indivisible calorimeter cell, j is an irreducible subjet
2. If both j_1 and j_2 are softer than the p_T scale or closer than the angular scale, j is an irreducible subjet
3. If only j_1 or j_2 is softer than the p_T scale, throw it away and iterate on the harder subjet
4. If both j_1 and j_2 are harder than the pT scale, repeat algorithm on each until it finds irreducible subjets

Johns Hopkins Top Tagger: Substructure

- Require either 3 or 4 irreducible subjets
- Require $m_{\text{all subjets}}$ near m_{top}
- Require $m_{2\text{ subjets}}$ near m_W
- Cut on W helicity angle $\cos\theta_h$

Johns Hopkins Top Tagger: performance

- $R = 1.0$ anti-kt jets
- $\delta_p = 0.04$
- $\delta_r = 0.19$
- $160 < m_t < 265$ GeV
- $60 < m_W < 120$ GeV
- $\cos\theta_h < 0.95$



(BOOST 2010 workshop, arXiv:1012.5412)

- 50% tag rate, with only a few % mistag rate

Other top taggers

- CMS uses a top tagger based on Johns Hopkins (ex. CMS-EXO-11-006 $Z' \rightarrow t\bar{t}$)
- HEPTopTagger (Plehn, Spannowsky, Takeuchi, Zerwas – arXiv:1006.2833)
  - Based on BDRS Mass Drop + Filtering algorithm for 2-body decays
  - Favored for moderately boosted tops (200 GeV $< p_T <$ 500 GeV)
- Leptonic top tagging (Plehn, Spannowsky, Takeuchi – arXiv:1102.0557)
- N-subjettiness (Thaler, Van Tilburg – arXiv:1011.2268, arXiv:1108.2701)

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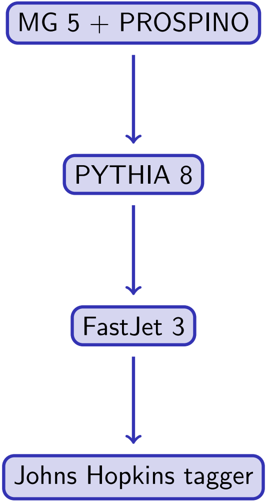
Signal simulation



- Gluino pair-production into 4 tops + $\not{E}_T$
- We require
  - ≥ 4 jets with $p_T > 100$ GeV,
  - some jets top-tagged,
  - and significant $\not{E}_T$

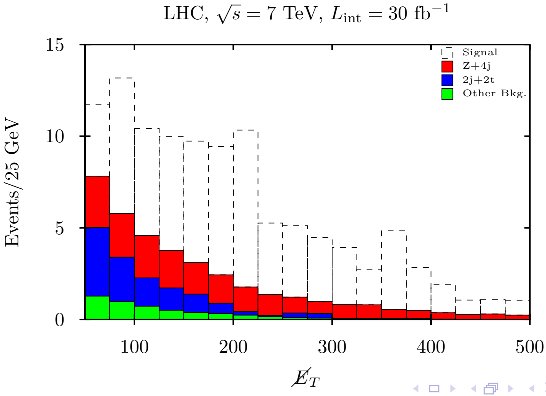
Background simulation

- Irreducible backgrounds:
  - n tops + $(4 - n)$ jets
  - n tops + $(4 - n)$ jets + leptonic W
  - n tops + $(4 - n)$ jets + invisible Z
- Reducible backgrounds:
  - Mistagging light jets as tops
- LO cross sections used; known K-factors are < 1
- p_T and $\not{E}_T$ cut efficiencies computed at parton level
- p_T-dependent tagging efficiencies and mistag rates from the BOOST2010 workshop used (arXiv:1012.5412)
  - Tended to overestimate backgrounds by a factor of 2

Boosted Tops from Gluino Decays

Cuts at 7 TeV and 30 fb^{-1}

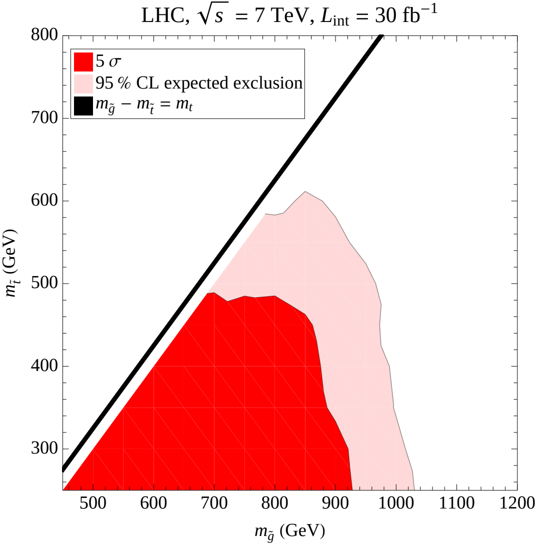
- Optimized for $(m(\tilde{g}), m(\tilde{t})) = (800, 400)$ GeV
  - ≥ 4 jets with $p_T > 100$ GeV
  - ≥ 2 of those have top tags
  - $\not{E}_T > 100$ GeV
- 32 signal events, S/B = 2.4, stat. sig. 6.8



Benchmark efficiencies at 7 TeV

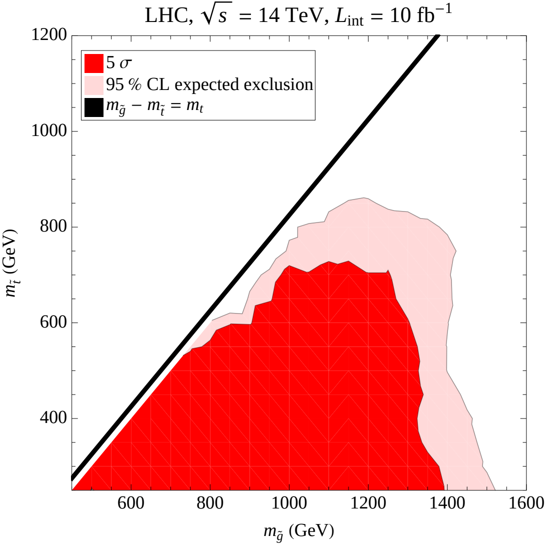
Process	$\sigma_{\rm tot}(fb)$	Eff(p_T) (%)	Eff(tag)	$\sigma_{\rm tag}$	Eff($\not{E}_T$)	$\sigma_{\rm all\ cuts}$
signal	61.5	37	6	1.31	81	1.06
$Z+4j$	2×10^5	0.2	0.1	0.44	66	0.29
$2t+2j$	5×10^4	3	0.3	5.7	2	0.10
$W+4j$	2×10^5	0.2	0.03	0.12	29	0.04
$Z+2t+2j$	50	4	1	0.02	72	0.02

Reach at 7 TeV and 30 fb^{-1}



- Probe $\tilde{g}$ mass up to 1 TeV
- 5σ up to $m(\tilde{g}) \sim 900$ GeV
- $S/B > 1$ throughout the probed region

Going to 14 TeV and 10 fb^{-1}



- Optimized for (1200, 600)
- ≥ 4 jets with $p_T > 100$ GeV
- ≥ 3 top tags
- $\not{E}_T > 175$ GeV
- $S/B > 10$

However. . .

- Detector effects/systematics not included
- Larger background samples needed
- QCD $4j$ $\not{E}_T$ tail needs studying

- But, the reach may be underestimated

Conclusion

- SUSY could be hiding if lightest colored super partner is stop
- Boosted top tagging provides excellent coverage of this scenario, including at 7 and 8 TeV
- Further experimental analysis is needed