Multiple *b*-jets reveal natural SUSY and the 125 GeV Higgs

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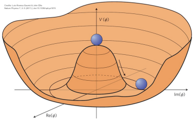


KITP Higgs Identification Miniprogram
21 December 2012

D. Berenstein, T. Liu, EP - 1211.4288

Overview

- Natural SUSY
- Simplified models
- Related work on $h \to b\bar{b}$
- Analysis
- Results
- Future directions

Motivation

- Want to know the full details of mass generation for fermions
- $h \to b\bar{b}$ seems obvious, but usually considered challenging
- Challenge can be overcome in SM using boosted higgs with jet substructure methods
- With well-motivated new physics, this search can be carried out in less-boosted region, without the need for jet substructure
- Consider simplified models in a natural SUSY context

Natural SUSY I

Pappucci, Ruderman, Weiler - 1110.6926

- In the MSSM at tree level,

$$-\frac{m_Z^2}{2} \sim |\mu|^2 + m_{H_u}^2$$

- To avoid fine-tuning, we need weak-scale SUSY
- Tolerances of fine-tuning place upper bound on μ

$$|\mu| \lesssim 200\,GeV \left(\frac{m_h}{120\,GeV}\right) \sqrt{0.2\Delta}$$

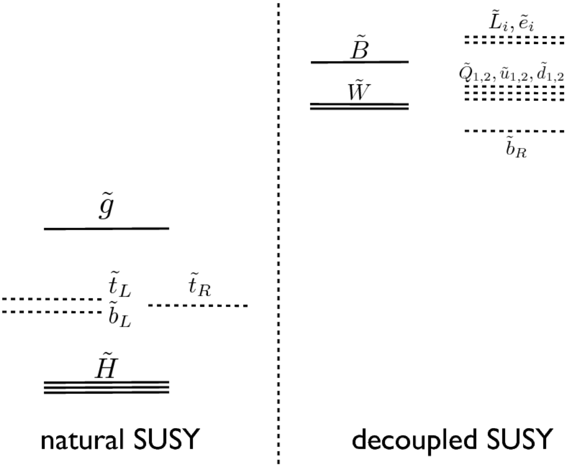
Natural SUSY II

$$\delta m_{H_u}^2 \mid_{\tilde{t}} = -\frac{3}{8\pi^2} y_t^2 \left(m_{Q_3}^2 + m_{u_3}^2 + |A_t|^2 \right) \log \left(\frac{\Lambda}{TeV} \right)$$

$$\delta m_{H_u}^2 \mid_{\tilde{g}} = -\frac{2}{\pi} y_t^2 \left(\frac{\alpha_s}{\pi} \right) |M_3|^2 \log^2 \left(\frac{\Lambda}{TeV} \right)$$

- Really, we only need $m_{\tilde{t}}$, $m_{\tilde{g}}$, $m_{\tilde{h}}$ not too heavy, since these contribute most
- $\implies$ first two sgenerations can decouple

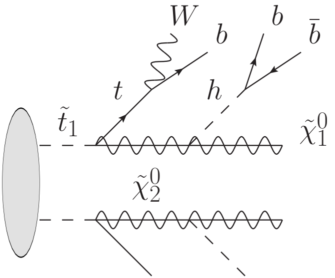
Natural SUSY III



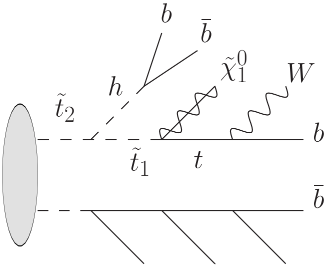
SUSY Cascades

- Stop production guarantees lots of *b*-jets

Case 1

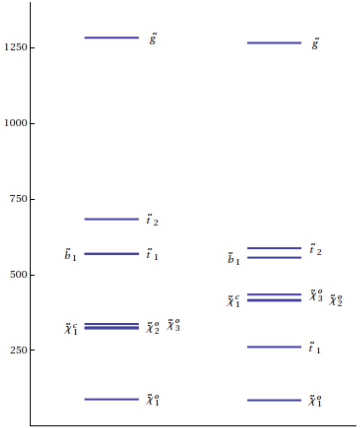


Case 2



- Case 1 is textbook
  (e.g Baer & Tata, *Weak-Scale Supersymmetry*)

Simplified models



Benchmarks	I (GeV)	II (GeV)
$m_{\tilde{g}}$	1281	1264
$m_{\tilde{t}_1}$	568	260
$m_{\tilde{t}_2}$	682	586
$m_{\tilde{b}_1}$	567	555
$m_{\tilde{\chi}_1^0}$	87	84
$m_{\tilde{\chi}_2^0}$	325	415
$m_{\tilde{\chi}_3^0}$	336	433
$m_{\tilde{\chi}_1^\pm}$	321	413
m_h	125	125
Benchmarks	I (%)	II (%)
$\mathrm{Br}(\tilde{t}_2 \to \tilde{t}_1 h)$	0	47
$\mathrm{Br}(\tilde{t}_1 \to \tilde{\chi}_1 ht)$	52	0
$\mathrm{Br}(h \to b\bar{b})$	61	61

Hadronic reconstruction

- Finding $h \to b\bar{b}$ in VH, $t\bar{t}h$ possible in SM with jet substructure (0802.2470, 0910.5472)
- Multiple b tagging has been considered before for higgs searches in new physics (hep-ph/0603200, 0912.4731, 1006.1656, 1103.4138, 1108.6329, 1204.2317)
- New physics studies require $\geq 3b$-jets in the final state
- Most also use jet substructure to reconstruct the hadronic higgs
- Is there another way?

Simulation framework

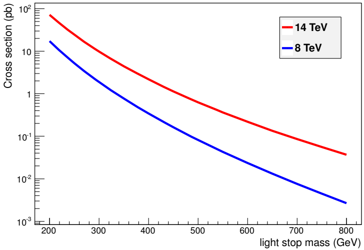
- SUSY-HIT $\rightarrow$ MadGraph+Pythia
- no detector simulation, but smearing and detector-level cuts
- no pileup - this will impact b-tagging and $\not{E}_T$ measurement
- parametrized b-tagging $\varepsilon \rightarrow 60\%$

Backgrounds

- $t\bar{t}b\bar{b}$ is important - always 4 b jets
- $t\bar{t}$+jets is less important - low $\not{E}_T$ in hadronic top decays
- $b\bar{b}b\bar{b}$+jets is less important because of low H_T and low $\not{E}_T$
- SUSY backgrounds from events without Higgs are less important - fewer jets & b tags
- COMBINATORICS! This is the dominant background after event-level cuts

Production cross sections

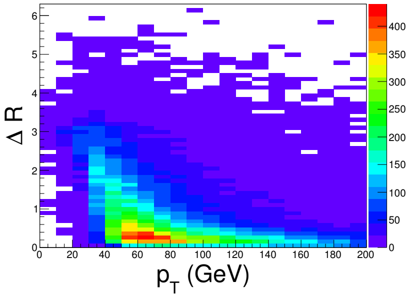
- $\tilde{t}$ cross sections are $\mathcal{O}$(1pb-0.1pb) at 14 TeV



- LO $t\bar{t}b\bar{b}$ cross section normalized to 8.9 pb; include K factor of 2.3

$t\bar{t}b\bar{b}$ distribution

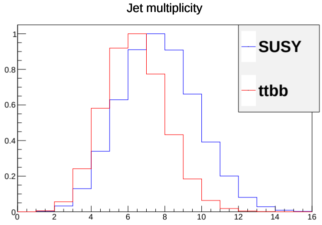
- multiple b-tagging requirement kills ttbb efficiently
- non-top b's come from gluon splitting, so softer, more collinear

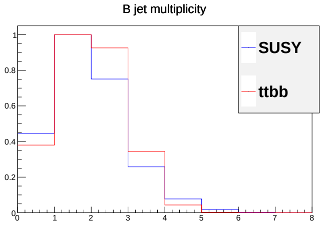


- extra b's fail the jet p_T cut, or are reconstructed as a single b-jet

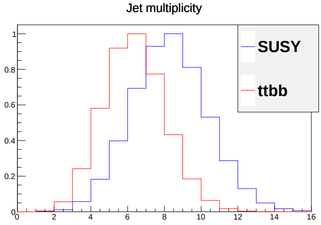
Event level kinematic distributions I

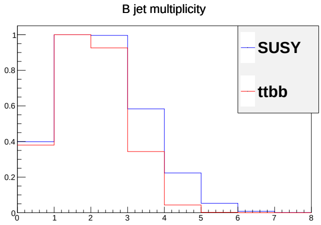
Case 1





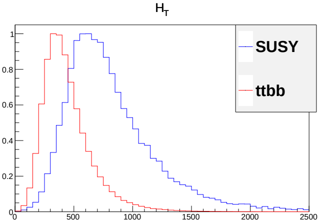
Case 2

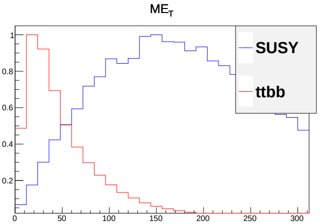




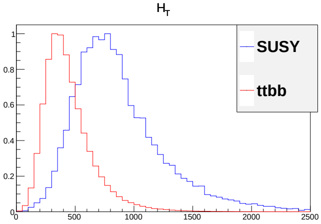
Event level kinematic distributions II

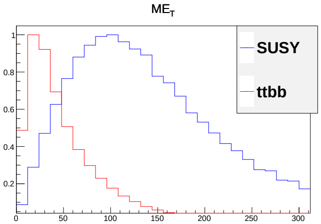
Case 1





Case 2





Event-level cuts

Case 1

- $n_j \geq 6$
- $n_b \geq 4$, $p_T > 30$ GeV for ≥ 1
- $\not{E}_T > 150$ GeV
- $H_T > 500$ GeV

Case 2

- $n_j \geq 6$
- $n_b \geq 4$, $p_T > 30$ GeV for ≥ 1
- $\not{E}_T > 120$ GeV
- $H_T > 650$ GeV

Event level cut flow

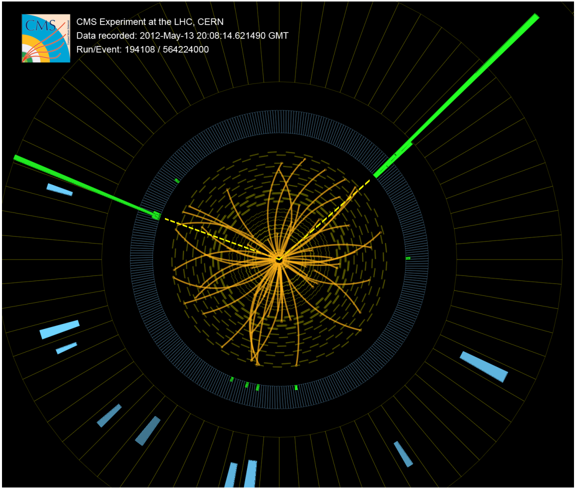
- 40/fb of 14 TeV data

$\sqrt{s} = 14$ TeV	$t\bar{t}$+jets	$t\bar{t}b\bar{b}$	Case I	Case II
Events	5.2×10^7	8.2×10^5	26176	822275
Cut 1	3.5×10^7	474234	20600	406331
Cut 2	88700	12077	961	824
Cut 3	51 / 79	442 / 796	567	436
Cut 4	29 / 23	351 / 366	547	389

- Natural SUSY revealed (at $\lesssim 20\sigma$ for ~ 40/fb)
- Or, relatively easy to kill this scenario

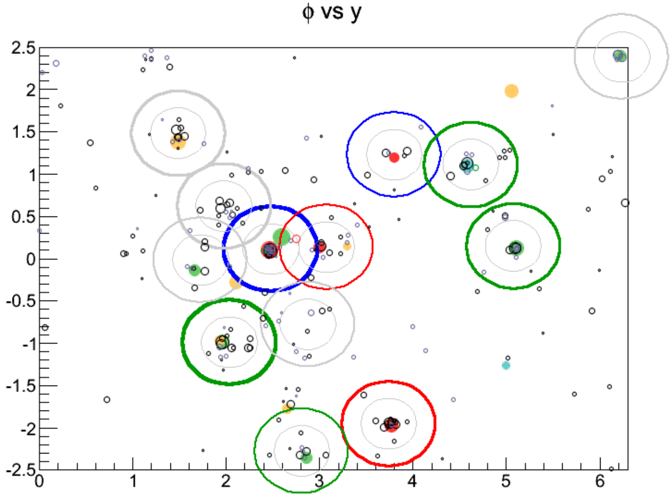
Busy events I

Want clean events...



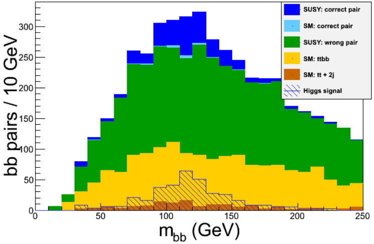
Busy events II

... but get messy events



The combinatorial problem

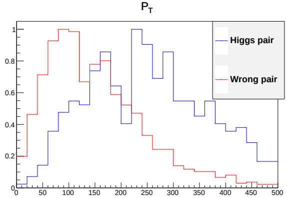
- At least 6 pairs to choose - if only 1 higgs, only 1 correct pair
- If we naively look at all pairs in the event, combinatorial background dominates (note: jet pairs are correlated here)

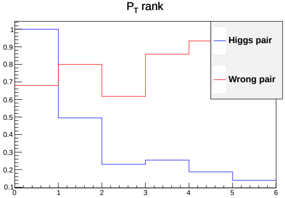


- How to choose the pair?

Pair p_T distribution and ranking

- jet pair p_T can discriminate the correct pair
- Ranking pairs by p_T is most effective





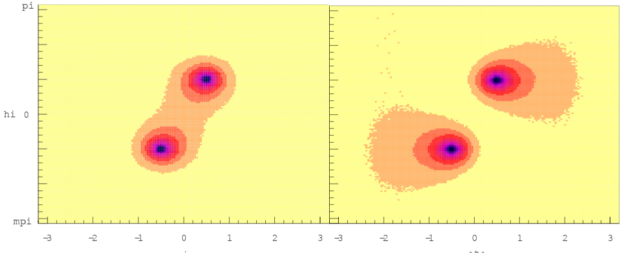
- Still want another variable, relatively independent of kinematics

Jet superstructure I

1001.5027 (J. Gallicchio, M. Schwartz)

- Pull is designed to find dijets from color singlet decays

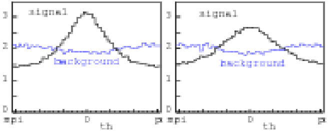
$$\vec{t} = \sum_{i \in \text{jet}} \frac{p_T^i |r_i|}{p_T^{\text{jet}}} \vec{r}_i$$



- For color singlets, θ_t is less

Jet superstructure II

- Standard deviation of pull angles for each pair exhibit a slight p_T dependence

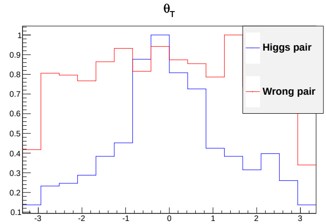


- Use all pull information available for each pair
- Construct a χ^2 variable as an effective pull angle

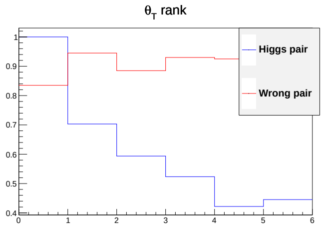
$$\theta_{eff} = \sqrt{\frac{\theta_{t,1}^2}{\sigma_{\theta_t}(p_{T,1})} + \frac{\theta_{t,2}^2}{\sigma_{\theta_t}(p_{T,2})}}$$

Jet superstructure III

- Effective pull angle distribution could be helpful

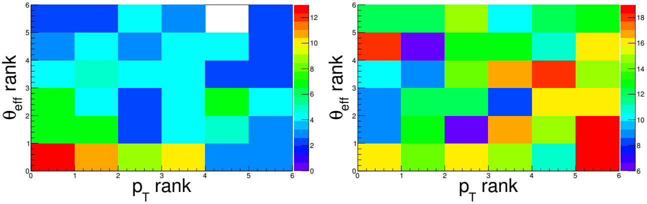


- As with p_T, rank jet pairs by θ_{eff}



Choosing the right pair

- Plot the pairs in the p_T-rank vs. θ_{eff}-rank plane.
- In the higgs mass window, a noticeable difference!



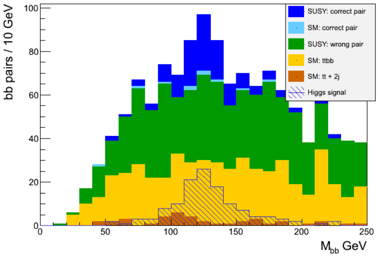
- Now we can cut!
- Take triangular region with p_T-rank + θ_{eff}-rank < 5

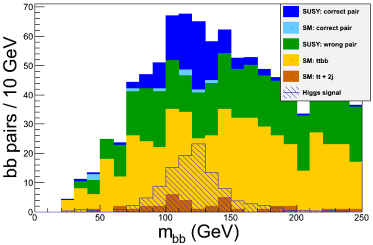
Measuring the significance

- Want to use multiple pairs per event (higgs pair may not be highest ranked)
- Pairs need to be uncorrelated
- Effective bin (mass window) is 40 GeV wide
- Choose multiple pairs per event if invariant masses differ by $\geq$ 40 GeV
- Select pairs from rank triangle, starting with highest p_T pair
- Admit additional pair i if $|m_i - m_j| > 40$ GeV for $j > i$

Invariant mass distributions

- Higgs revealed





- No assumption of m_h

Cut flow

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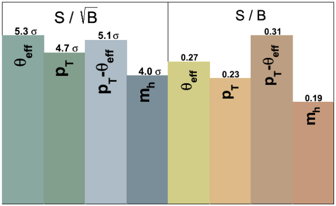
Cut 4	29 / 23	351 / 366	547	389
θ_{eff} rank	20 / 11	5+157 / 4+157	99+215	65+135
p_T rank	20 / 12	4+166 / 4+159	91+219	86+108
$p_T - \theta_{eff}$ plane	13 / 13	5+104 / 3+104	78+147	65+62

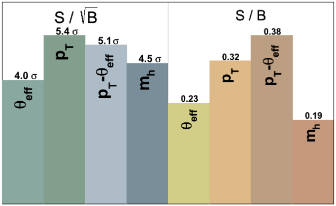
Sensitivity comparison

- Higgs revealed

Case 1



Case 2



- Best S/B is given by ranking plane method in both cases

Related scenarios

Important features:

- something like SM higgs $\leftrightarrow$ $h \to b\bar{b}$ dominates
- light top partner $\leftrightarrow$ additional jets, b-jets
- long lived neutral particle $\leftrightarrow$ $\not{E}_T$

Shared by:

- Randall-Sundrum with KK-parity
- little higgs with T-parity

Future directions

- Unfold events in detail to measure branching fractions
- Explicitly apply techniques to RS, LH models

Summary

- What is fermion mass generation mechanism? Need BR($h \to b\bar{b}$)
- New physics cascades can help via b-jet multiplicity, $\not{E}_T$
- Combinatorics can be overcome with kinematics and color flow
- (Re)discovery potential for 14 TeV LHC with < 1 year of data