Coup of Light
Stop and DM

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“Dark Matter” Session, 2012 summer CETUP program
Center for Theoretical Underground Physics and Related Areas (CETUP)
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OUTLINE

- Prologue - “Dark Matter” Sandwich
- Higgs-like boson at 125 GeV and Heavy 1st/2nd Generation Squarks → Light Stop and Light Stau
- Pheno Project #10: Light Stop
  
arXiv:1207.1873 … Stops via Tops (LHC8)
- Summary
I am hungry. Can you make the DM sandwich with any Standard Model particle?

No, Sir. But with neutralino?

"I CAN'T TELL YOU WHAT'S IN THE DARK MATTER SANDWICH. NO ONE KNOWS WHAT'S IN THE DARK MATTER SANDWICH."
DM SANDWICH

INVISIBLE SANDWICH
Keep in mind they are preliminary results; 
Keep in mind they are small numbers; 
Keep in mind we will run in the next year.
The current Higgs-like boson mass is SUSY-friendly …
“The maximum squark and gluino masses excluded by current LHC limits are \(~1\) TeV”

**SUSY@LHC 2012 and beyond**

- Heavier superpartners
- Stop squarks
- Direct neutralino/chargino production
- SUSY Higgs
- Make the dark matter connection

Joseph Lykken  
Fermilab  
USLUO Meeting 4 Nov 2011
My Daughter’s View

My last options...

By my daughter

I need $t$, $c_1$, $c_2$, …

Uh...Oh!
The hosts are in...

I need $\chi_1, \chi_2, …$

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Coup of Light Stop and Dark Matter
Stop Searches in Market

http://arxiv.org/abs/1203.4813 ... “mT2^W”
Yang Bai, Hsin-Chia Cheng, Jason Gallicchio, Jiayin Gu, “Stop the Top Background of the Stop Search”

http://arxiv.org/abs/1205.2696 ... Stop searches in 2012
Tilman Plehn, Michael Spannowsky, Michihisa Takeuchi, “Stop searches in 2012”

http://arxiv.org/abs/1205.5805 ... Stop degenerate case
Daniele S.M. Alves, Matthew R. Buckley, Patrick J. Fox, Joseph D. Lykken, and Chiu-Tien Yu, “Stops and MET: the shape of things to come”

http://arxiv.org/abs/1205.5808 ... Spin correlation for stop
Zhenyu Han, Andrey Katz, David Krohn, and Matthew Reece, “(Light) Stop Signs”

http://arxiv.org/abs/1205.5816 ... "FatJet" to tag top
David E. Kaplan, Keith Rehermann, Daniel Stolarski, “Searching for Direct Stop Production in Hadronic Top Data at the LHC”

http://arxiv.org/abs/1207.1873 ... Stops via Tops (LHC8)
Bhaskar Dutta, Teruki Kamon, Nikolay Kolev, Kuver Sinha, Kechen Wang, “Searching for Top Squarks at the LHC in Fully Hadronic Final State”
Pheno Project #10

ISAJET 7.80

$$m_{1/2}=500, \ m_0=3100, \ \tan\beta=30, \ A_0=-6000, \ m_{\text{top}}=173.1$$

(Stop1 Benchmark Point #3)

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Snapshot of Stop Searches

- **Final States**
  - Dilepton+Jets+MET
  - 1L+Jets+MET
  - Jets+MET
  - 4 tops

- **Techniques**
  - \( \alpha T \)
  - Razor
  - \( mT2 \)
  - TopTag (boosted top)
  - ...
  - M3

- ...

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SM Backgrounds

- TTbar + jets
- Single stop production
- W + jets
- Z + jets
- QCD

<table>
<thead>
<tr>
<th>t-channel</th>
<th>Associated tW production</th>
<th>s-channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma = 64.6^{+3.3}_{-2.6}$ (pb)</td>
<td>$\sigma = 15.7^{+1.3}_{-1.4}$ (pb)</td>
<td>$\sigma = 4.6 \pm 0.3$ (pb)</td>
</tr>
</tbody>
</table>

$\sqrt{s} = 7$ TeV

- Two tops along with MET.
- “Challenging”, but we need all hadronic channel (6 jets)
- $t \rightarrow jjb$ tag in one side, “W+b” tag in other ...

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Fully Hadronic State

Why? We have to show MET is not originated from a system of two top quarks.
Once we require large MET, a surviving decay mode of TTbar events is “Lepton+Jets+MET” …

6 jets (2 loose b’s) + MET + Lepton veto
- $p_T(e) > 10$, Iso < 5 GeV
- $p_T(\mu) > 10$, Iso < 5 GeV
- $p_T(\tau_h) > 20$, $\varepsilon = 60\%$, $f = 2\%$

Still a major surviving decay mode is “Lost Lepton” + Jets + MET mode
Baseline Selection

4 non b-jets (>100, >30's)
+ 2 loose b's (>30's)
+ MET (>100)

\[ \tilde{t} (450) \quad \tilde{\chi}_1^0 (100) \]

\[ \sigma = 160 \text{ fb} \]

**Baseline Selection Cuts**

\[ E_T > 50 \]

\[ t\bar{t} + 3 \text{jets} \]

\[ t\bar{t} + 4 \text{jets} \]
M(top) or M(TTbar) in Market

- Kinematical fit ($\chi^2$), NN
- M3
- FatJet/ TopTagger/ Cambridge-Aachen Algorithm
- mT2
- alphaT
- Razor
- Bi-Event Subtraction Technique (BEST)
Measurement of the $t\bar{t}$ production cross section in the fully hadronic decay channel in pp collisions at $\sqrt{s} = 7$ TeV

The CMS Collaboration

Abstract

This note presents a first measurement of the top quark pair production cross section in the fully hadronic decay channel at a center-of-mass energy of $\sqrt{s} = 7$ TeV using data corresponding to an integrated luminosity of 1.09 fb$^{-1}$ taken with the CMS detector. The cross section is determined from an unbinned maximum likelihood fit to the reconstructed top quark mass. The reconstruction of $t\bar{t}$ candidates is performed after a cut-based event selection using a kinematic fit. A data-driven technique is used to estimate the dominant background from QCD multijet production. The cross section measurement yields $\sigma_{t\bar{t}} = 136 \pm 20$ (stat.) $\pm 40$ (sys.) $\pm 8$ (lumi.) pb. This result is consistent with measurements in other decay channels and with the Standard Model prediction.

Kinematical Fits

$p_T > 60, 60, 60, 60, 50, 40$
(at least 2b jets)

Table 1: Number of events and the expected signal fraction in the data sample after each selection step. The expected signal fraction is taken from the simulation, assuming a cross section of 163 pb [17].

<table>
<thead>
<tr>
<th>Selection step</th>
<th>Events</th>
<th>Signal fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>At least 6 jets</td>
<td>248 109</td>
<td>2%</td>
</tr>
<tr>
<td>At least two b-tags</td>
<td>6 905</td>
<td>17%</td>
</tr>
<tr>
<td>Kinematic fit</td>
<td>1 620</td>
<td>32%</td>
</tr>
</tbody>
</table>

Figure 1: Result of the fit to the reconstructed top quark mass for the $t\bar{t}$ simulation (solid red line) and the multijet QCD estimated from data (dashed blue line). The uncertainty stated on the signal fraction $f_{sig}$ is only statistical.

Figure 4: (Left) Neural network output for simulated $t\bar{t}$ events and multijet events from data shown normalized to unity. (Right) Reconstructed top quark mass $m_{top}$ for b-tagged jet combinations observed in data (circles) passing the full event selection. For comparison the expected background (dashed blue line) and $t\bar{t}$ signal (solid red line) are shown, both normalized to the yields from the fit.
Measurement of the top quark mass in the muon+jets channel

The CMS Collaboration

Abstract

We present a measurement of the top quark mass using a sample of $t\bar{t}$ candidate events with one muon and at least four jets in the final state, collected by CMS in $pp$ collisions at $\sqrt{s} = 7$ TeV. From the full 2011 dataset, corresponding to an integrated luminosity of 4.7 fb$^{-1}$, 2391 candidate events are selected. Using a likelihood method, the top quark mass is measured from the kinematic configuration simultaneously with the jet energy scale (JES) to be $m_t = 172.6 \pm 0.6 \text{ (stat+JES)} \pm 1.2 \text{ (syst)}$ GeV.

Kinematical Fits in $\mu + \text{jets}$

Figure 2: Distribution of the fit probability of the kinematic fit. A cut is imposed at $P_{\text{fit}} > 0.2$ to enhance the fraction $f_{\text{corr}}$ of correct permutations. $P_{\text{fit}}$ is then used as a weight for each permutation in the subsequent steps. The vertical dashed line indicates the cut value of 0.2.

Figure 3: The upper row displays the reconstructed $W$ boson mass (a) and reconstructed top mass (b) for the hadronically decaying top quark before the cut on the kinematic fit probability. The lower row shows the reconstructed $W$ boson mass (c) and the top quark mass from the kinematic fit (d) after the fit probability cut and the weighting by $P_{\text{fit}}$. The simulated samples are rescaled to a luminosity of 4.7 fb$^{-1}$. For the $t\bar{t}$ normalisation a previous CMS cross-section measurement [16] is used, its uncertainty is indicated by the shaded area. The top quark mass in the simulation is 172.5 GeV.
We define as M3 the invariant mass of those three jets that yield the vectorial sum with maximum $p_T$, including exactly one b-tagged jet and two untagged jets. This observable is an estimator of the mass of the hadronically decaying top quark. We include all selected jets in the reconstruction of M3, i.e. not only the four leading jets. We take M2 as the invariant mass of the two untagged jets that were assigned to M3. M2 is an estimator of the mass of the hadronically decaying W boson. The resulting M3 and M2 distributions can be found in Fig. 4, which also shows the distribution of the event-wise mass difference $\Delta M_{32} = M3 - M2$. While M3 and M2 are strongly correlated, there is only a modest correlation between M2 and $\Delta M_{32}$. We therefore choose to use M2 and $\Delta M_{32}$ for a simultaneous measurement of $m_t$ and JES.

Figure 4: M3 (top left), M2 (top right) and $\Delta M_{32}$ (bottom) distributions for the muon+jets channel in data compared to the MC predictions, using the central sample with $m_t = 172.5$ GeV and JES = 1.
Cambridge-Aachen Algorithm

EXO-11-006-PAS

$Z' \rightarrow t\bar{t}$

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HEPTopTagger

Michihisa Takeuchi (Univ. Heidelberg), “Top Reconstruction for New Physics Search” (Feb 17, 2012)

$R_{C/A} < 1.5$

FatJet

Tagged

Efficiency

$p_T^{top} [GeV]$

Normalized by hadronic top

Tagged

FatJet

HEPTopTagger


- efficiency: ~ 30%, mistag: 2–4% (1–2% with pruning)

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Detection of $W \rightarrow jj$ and $t \rightarrow Wb$

**Bi-Event Subtraction Technique**

**Bi-Event Subtraction Technique at hadron colliders**

Bhaskar Dutta

Teruki Kamon

Abram Krislock, Nikolay Kolev, and Youngdo Oh

$pp \rightarrow t \bar{t} + j \rightarrow (W^+ b) \ (W^- \bar{b}) + j$

$pp \rightarrow W + jjj$

$\ell$ (lepton)

$\nu$ (neutrino)

**BEST:** "jet" mixing from two different events ($TT_{\text{bar}}, TT_{\text{bar}}, (TT_{\text{bar}}, W), (W, W)$)

**Count plots**

- $m_{jj}^{\text{same}}$ (GeV)
- $m_{jj}^{\text{bi}}$ (GeV)
- $m_{jj}^{\text{BEST}}$ (GeV)

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$M(TTbar) \text{ using } mT2$

$$M_{T2} \equiv \min \left\{ \max(M_{Ta}, M_{Tb}) \right\}$$

$p_T^a + p_T^b = E_T$

Figure 1: Normalized $m_{T2}$ distributions for the stop signal ($m_{\tau} = 340 \text{ GeV}$) and the $t\bar{t}$ background, after reconstructing two (real or fake) hadronic top quarks. The hypothetical LSP mass we set to $m_{\chi^0_1} = 0 \text{ GeV}$ (left) or to the correct value of $m_{\chi^0_1} = 98 \text{ GeV}$ (right).
Abstract: At the LHC, many new physics signatures feature the pair-production of massive particles with subsequent direct or cascading decays to weakly-interacting particles, such as SUSY scenarios with conserved R-parity or $H \to W(\ell\nu)W(\ell\nu)$. We present a set of dimension-less variables that can assist the early discovery of processes of this type in conjunction with a set of variables with mass dimension that will expedite the characterization of these processes.
Stop Search Strategy

arXiv:1207.1873 ... Stops via Tops (LHC8)

M3, twice
Final Selection

Reference Stop: \( \tilde{t} (400) \& \tilde{\chi}_1^0 (100) \)

Stage 1: Tagging top \( (j_1, j_2, b) \) using M3(twice)

Stage 2: Probing \( j'_1, j'_2, b' \) (lost lepton)

Stage 3: Clean-up Two Top system
Stage 1: Tagging 1\textsuperscript{st} Top

- $M_{3}^{\text{min}}$ vs $M_{3}(p_{T, bjj}^{\text{leading}})$
- \(~33\% \) more signal
- After $W$ mass cut

- $40 < M(jj) < 120$
- $120 < M(jj b) < 220$

- $p_{T}(t)$
- $p_{T}(\text{top}) > 200 \text{ GeV}$

- $p_{T}(W)$
- $M(jj b)$ top
- $M(jj b)$ stop

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Stage 2: Probing 2\textsuperscript{nd} Top

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Stage 3: Clean-ups

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Mixed-up

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Stage 4 & 5: Two-Top System

Baseline selection cuts:
4 jets + 2 loose b’s + MET

Final selection cuts
Stage 1: Tagging leading \( p_T \) top (\( j_1, j_2, b \))
Stage 2: Probing \( j_1', j_2', b' \) (lost lepton)
Stage 3: Clean-up system
Stage 4: W mass cut
Stage 5: Top mass cut

40 < \( M(jj) \) < 120 & 120 < \( M(jjb) \) < 220
Mixed-up

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Pheno #10 Summary (I)

TABLE V: Summary of effective cross sections (fb) for stop pair production and the SM background events in our stop search feasibility study. Masses and momenta are in GeV. "Other" sources of background include single top + jets, W + n jets and Z + n jets with 1 ≤ n ≤ 6. The significance is given at 50 fb⁻¹.

<table>
<thead>
<tr>
<th>m_{\tilde{t}} = 450</th>
<th>m_{\tilde{g}} = 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>Signal</td>
</tr>
<tr>
<td>Baseline Cuts (Sec. III.B)</td>
<td>160</td>
</tr>
<tr>
<td>E_T &gt; 195 GeV</td>
<td>2.52</td>
</tr>
<tr>
<td>System A: M3 (Sec. III.C)</td>
<td>1.61</td>
</tr>
<tr>
<td>Angular and M_T cuts (Sec. III.D)</td>
<td>0.62</td>
</tr>
<tr>
<td>System B: M3 (Sec. III.E)</td>
<td>0.25</td>
</tr>
<tr>
<td>Significance (S/√B)</td>
<td>0.12</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>√s = 8 TeV</th>
<th>\tilde{t}\bar{t}</th>
<th>QCD W+jets</th>
<th>Z+jets</th>
<th>S/B</th>
<th>S/√B_{10^{16} fb^{-1}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>m_{\tilde{t}}[GeV]</td>
<td>350</td>
<td>400</td>
<td>450</td>
<td>500</td>
<td>600</td>
</tr>
<tr>
<td>cross section [fb]</td>
<td>760</td>
<td>337</td>
<td>160</td>
<td>80.5</td>
<td>23.0</td>
</tr>
<tr>
<td>\ell veto</td>
<td>488</td>
<td>215</td>
<td>101</td>
<td>50.5</td>
<td>14.4</td>
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<tr>
<td>n_{\text{tag}} ≥ 2</td>
<td>167</td>
<td>88.3</td>
<td>48.0</td>
<td>25.6</td>
<td>8.71</td>
</tr>
<tr>
<td>\hat{E}_T &gt; 100 GeV</td>
<td>104</td>
<td>65.0</td>
<td>38.5</td>
<td>22.5</td>
<td>7.76</td>
</tr>
<tr>
<td>n_{\text{tag}} ≥ 1</td>
<td>27.5</td>
<td>18.5</td>
<td>11.87</td>
<td>7.60</td>
<td>2.91</td>
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<tr>
<td>n_{\text{tag}} ≥ 2</td>
<td>2.34</td>
<td>1.65</td>
<td>1.12</td>
<td>0.76</td>
<td>0.34</td>
</tr>
<tr>
<td>b-tag inside top</td>
<td>0.74</td>
<td>0.58</td>
<td>0.35</td>
<td>0.25</td>
<td>0.11</td>
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<tr>
<td>m_{T_2} &gt; 250 GeV</td>
<td>0.24</td>
<td>0.30</td>
<td>0.22</td>
<td>0.18</td>
<td>0.09</td>
</tr>
</tbody>
</table>

More or less consistent ...

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### Pheno #10 Summary (II)

<table>
<thead>
<tr>
<th>$m_{\tilde{t}}$</th>
<th>$m_{\tilde{\chi}^0_i}$</th>
<th>Signal</th>
<th>$tt + n(\leq 2)$jets</th>
<th>$tt + n(\geq 3)$jets</th>
<th>Others</th>
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<tr>
<td>$350$</td>
<td>$100$</td>
<td>$760$</td>
<td>$2.0 \times 10^5$</td>
<td>$0.24 \times 10^5$</td>
<td>$2.8 \times 10^6$</td>
</tr>
<tr>
<td>$m_{\tilde{\chi}^0_i} = 100$</td>
<td>Baseline Cuts (Sec. IIIIB)</td>
<td>$9.96$</td>
<td>$192$</td>
<td>$147$</td>
<td>$31.7$</td>
</tr>
<tr>
<td></td>
<td>$p_T &gt; 145$ GeV</td>
<td>$6.79$</td>
<td>$82.2$</td>
<td>$69.1$</td>
<td>$15.8$</td>
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<tr>
<td></td>
<td>System A: M3 (Sec. IIIIC)</td>
<td>$2.65$</td>
<td>$25.8$</td>
<td>$15.6$</td>
<td>$3.14$</td>
</tr>
<tr>
<td></td>
<td>Angular and $M_T$ cuts (Sec. IIIID)</td>
<td>$0.55$</td>
<td>$1.61$</td>
<td>$1.71$</td>
<td>$0.72$</td>
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<tr>
<td></td>
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<td>$0.25$</td>
<td>$0.40$</td>
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<td>$0.20$</td>
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<td></td>
<td>$\Delta \phi(h_{A,B}, p_T) &lt; 2.7$</td>
<td>$0.14$</td>
<td>$0.24$</td>
<td>$0.25$</td>
<td>$0.10$</td>
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<td></td>
<td>Significance ($S/\sqrt{B}$)</td>
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<td></td>
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<td>$1.29$</td>
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<tr>
<td>$400$</td>
<td>$100$</td>
<td>$337$</td>
<td>$2.0 \times 10^5$</td>
<td>$0.24 \times 10^5$</td>
<td>$2.8 \times 10^6$</td>
</tr>
<tr>
<td>$m_{\tilde{\chi}^0_i} = 100$</td>
<td>Baseline Cuts (Sec. IIIIB)</td>
<td>$5.55$</td>
<td>$192$</td>
<td>$147$</td>
<td>$31.7$</td>
</tr>
<tr>
<td></td>
<td>$p_T &gt; 170$ GeV</td>
<td>$3.62$</td>
<td>$53.4$</td>
<td>$47.0$</td>
<td>$11.1$</td>
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<tr>
<td></td>
<td>System A: M3 (Sec. IIIIC)</td>
<td>$1.46$</td>
<td>$15.4$</td>
<td>$9.73$</td>
<td>$1.82$</td>
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<td>$0.96$</td>
<td>$1.06$</td>
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<td>$0.20$</td>
<td>$0.26$</td>
<td>$0.28$</td>
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<td>Significance ($S/\sqrt{B}$)</td>
<td></td>
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<td>$450$</td>
<td>$100$</td>
<td>$160$</td>
<td>$2.0 \times 10^5$</td>
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<td>$m_{\tilde{\chi}^0_i} = 100$</td>
<td>Baseline Cuts (Sec. IIIIB)</td>
<td>$2.52$</td>
<td>$192$</td>
<td>$147$</td>
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<tr>
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<td>$p_T &gt; 195$ GeV</td>
<td>$1.61$</td>
<td>$34.5$</td>
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<td>$8.08$</td>
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<tr>
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<td>System A: M3 (Sec. IIIIC)</td>
<td>$0.62$</td>
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<td>Significance ($S/\sqrt{B}$)</td>
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<tr>
<td>$500$</td>
<td>$100$</td>
<td>$80.5$</td>
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<td>$147$</td>
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<td>$p_T &gt; 195$ GeV</td>
<td>$0.86$</td>
<td>$34.5$</td>
<td>$31.9$</td>
<td>$8.08$</td>
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<tr>
<td></td>
<td>System A: M3 (Sec. IIIIC)</td>
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<td>$9.17$</td>
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<td>$1.30$</td>
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<td>Angular and $M_T$ cuts (Sec. IIIID)</td>
<td>$0.15$</td>
<td>$0.55$</td>
<td>$0.69$</td>
<td>$0.40$</td>
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<tr>
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<td>System B: M3 (Sec. IIIIE)</td>
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<td>$0.17$</td>
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<td>$0.06$</td>
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<tr>
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<td>Significance ($S/\sqrt{B}$)</td>
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</tr>
<tr>
<td>$550$</td>
<td>$100$</td>
<td>$43.0$</td>
<td>$2.0 \times 10^5$</td>
<td>$0.24 \times 10^5$</td>
<td>$2.8 \times 10^6$</td>
</tr>
<tr>
<td>$m_{\tilde{\chi}^0_i} = 100$</td>
<td>Baseline Cuts (Sec. IIIIB)</td>
<td>$0.57$</td>
<td>$192$</td>
<td>$147$</td>
<td>$31.7$</td>
</tr>
<tr>
<td></td>
<td>$p_T &gt; 195$ GeV</td>
<td>$0.43$</td>
<td>$34.5$</td>
<td>$31.9$</td>
<td>$8.08$</td>
</tr>
<tr>
<td></td>
<td>System A: M3 (Sec. IIIIC)</td>
<td>$0.14$</td>
<td>$9.17$</td>
<td>$6.32$</td>
<td>$1.30$</td>
</tr>
<tr>
<td></td>
<td>Angular and $M_T$ cuts (Sec. IIIID)</td>
<td>$0.07$</td>
<td>$0.55$</td>
<td>$0.69$</td>
<td>$0.40$</td>
</tr>
<tr>
<td></td>
<td>System B: M3 (Sec. IIIIE)</td>
<td>$0.03$</td>
<td>$0.17$</td>
<td>$0.14$</td>
<td>$0.06$</td>
</tr>
<tr>
<td></td>
<td>Significance ($S/\sqrt{B}$)</td>
<td></td>
<td></td>
<td></td>
<td>$0.35$</td>
</tr>
</tbody>
</table>
Stop Searches in 2012


Stop searches in 2012

Tilman Plehn, Michael Spannowsky, and Michihisa Takeuchi

Institut für Theoretische Physik, Universität Heidelberg, Germany
IPPP, Department of Physics, Durham University, United Kingdom

For this year's 8 TeV run of the LHC we lay out different strategies to search for scalar top pairs. We show results for the hadronic and for the semi-leptonic channels based on hadronic top tagging. For the di-lepton channel we illustrate the impact of transverse mass variables. Each of our signal-to-background ratios ranges around unity for a stop mass around 400 GeV. The combined signal significances show that dedicated stop searches are becoming sensitive over a non-negligible part of parameter space.

Reasonably light top partners are necessary to solve the hierarchy problem. Therefore, searches for stops or other top partners are of paramount interest to LHC physics. In 2012 the LHC will gather at least $O(10)$ fb$^{-1}$ of data at 8 TeV. For four independent search channels we show how 2012 data will start to either find or exclude light top partners, decaying to top quarks and missing energy.

In the fully hadronic mode we study two strategies: tagging either one or two hadronic tops we find $S/B \sim 1$ for a stop mass of 400 GeV. Unfortunately, the statistical significance is rather modest, $S/\sqrt{B} = 1.5$ (two tags) and $S/\sqrt{B} = 3.0$ (one tag).

Searches for semi-leptonic or fully-leptonic top pairs are more promising. In the semi-leptonic mode we tag one top recoiling against an isolated lepton. After cutting on $m_T$ we find $S/B = 2.1$ and $S/\sqrt{B} = 5.4$. In the di-lepton mode a cut on $m_T^{lep}$ rejects almost all Standard Model backgrounds. This gives us a striking sensitivity of $S/B = 5.8$ and $S/\sqrt{B} = 15.8$.

Obviously, the fully leptonic mode is unlikely to conclusively reconstruct and confirm a top partner. However, the combination with the statistically less significant hadronic modes should allow us to establish a top partner signal in 2012.
Coup of Light Stop and Dark Matter
Summary

The dilepton and single lepton final states are considered as golden modes to detect an excess beyond the SM process. However, it is not provide an conclusive answer. [arXiv:1205.2696v1 [hep-ph]]

However, an observation of MET along with two top quarks in fully hadronic mode is important. Yes, it is a challenging mode.

[arXiv:1207.1873] A simple kinematical selection technique, M3, is used to tag top quarks in 3-jet system ($p_T > 200$ GeV) and shown to be effective as in an analysis using TopTagger.

M3 can be a complementary technique to search for stops for masses around 350 - 500 GeV.
Pheno Projects at A Glance

http://faculty.physics.tamu.edu/kamon/research/TEVpheno/
http://faculty.physics.tamu.edu/kamon/research/ILCpheno/
http://faculty.physics.tamu.edu/kamon/research/LHCpheno/


“Supersymmetry Parameter Analysis: SPA Convention and Project”

Focus Point (unpublished) … attempted to reconstruct two tops
arXiv:1203.3276 … accepted in PRD (LFV at LHC14)
arXiv:1207.1873 … Stops via Tops (LHC8)

Bs → μμ:
CDF PRL 107 (2011) 191801

SUSY Jets+MET+Taus at LHC7
CMS SUS-11-007-PAS
CMS SUS-12-004-Paper
(in preparation)

M(top) mass (SKKU + TAMU)

Bhaskar Dutta, Teruki Kamon, Nikolay Kolev, Kuver Sinha, Kechen Wang

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Teruki Kamon

Coup of Light Stop and Dark Matter
**Pheno to Experiments**

**Prediction in 2002**

**Prediction in 2008**

**PRL 100 (2008) 231802**

The primary SM backgrounds for the $2\tau + 2j + E_T$ final state (and the other two samples) are from $t\bar{t}$, $W +$ jets, $Z +$ jets and QCD production. The sample is selected using the following cuts [11]: (a) $N_\tau \geq 2$ ($|\eta| < 2.5$, $p_T^{\tau} > 20$ GeV, but $> 40$ GeV for the leading $\tau$); (b) $N_j \geq 2$ ($|\eta| < 2.5$, $E_T > 100$ GeV); (c) $E_T > 180$ GeV and $E_T^{\text{jet}} + E_T^{\text{miss}} > 600$ GeV; and (d) veto the event if any of the two leading jets are identified as $a b$ jet. In order to identify $\tilde{\chi}_1^0 \rightarrow \tau \tau \rightarrow \tau \tau \tilde{\chi}_1^0$ decays we categorize all pairs of $\tau$’s into same cuts!

**CMS-12-004-PAS**

**CMS-11-007-PAS**

Fig. 2. Illustrated 95% C.L. limits on the branching ratio for $B_s \rightarrow \mu^+\mu^-$ at CDF in Run II as a function of integrated luminosity. Solid (Case A) and dashed (Case B) curves are based on different assumptions on the signal selection efficiency and the background rejection power. See the text for details.
Dark Matter Connection!
Backup
B-Tagging (at CMS)

- Properties used to identify b-jets
  - Hard fragmentation functions
  - Relatively large mass
  - Long lifetime
  - Semi-leptonic decays

- b-Tagging Variables
  - 2D and 3D impact parameters (closest approach to primary vertex)
  - Flight distance
  - Invariant mass of tracks at vertex
  - Number of tracks at vertex (~ 5 for b)
  - Likelihood variables based on these parameters
  - ~70% eff. with light mistag rate ~ 2%
Tau-Tagging (at CMS)

- Tau leptons decay to hadrons ~ 65% of the time
- Tau identification to hadronic decays:

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Resonance</th>
<th>Mass (MeV/c^2)</th>
<th>Branching ratio(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau^- \rightarrow h^- v_\tau$</td>
<td></td>
<td></td>
<td>11.6 %</td>
</tr>
<tr>
<td>$\tau^- \rightarrow h^- \pi^0 v_\tau$</td>
<td>$\rho$</td>
<td>770</td>
<td>26.0 %</td>
</tr>
<tr>
<td>$\tau^- \rightarrow h^- \pi^0 \pi^0 v_\tau$</td>
<td>$a_1$</td>
<td>1200</td>
<td>10.8 %</td>
</tr>
<tr>
<td>$\tau^- \rightarrow h^- h^+ h^- v_\tau$</td>
<td>$a_1$</td>
<td>1200</td>
<td>9.8 %</td>
</tr>
<tr>
<td>$\tau^- \rightarrow h^- h^+ h^- \pi^0 v_\tau$</td>
<td></td>
<td></td>
<td>4.8 %</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>63.0%</strong></td>
</tr>
<tr>
<td><strong>Other hadronic modes</strong></td>
<td></td>
<td></td>
<td><strong>1.7%</strong></td>
</tr>
</tbody>
</table>

- Reconstruct decay modes using reconstructed PF particles

- Cut based: mass of the mesons, rejection against e/μ, and isolation
SUSY Mass Techniques

Christopher Lester et al., ICHEP2010, arXiv:1004.2732

- Missing momentum
- $M_{\text{eff}}, \text{Razor}, H_T$
- $\text{shat}_{\text{min}}$
- $M_{\text{TGEN}}$
- $M_{T2} / M_{\text{CT}}$
- $M_{T2}$ (with “kinks”)
- $M_{T2} / M_{\text{CT}}$ (parallel / perp)
- $M_{T2} / M_{\text{CT}}$ (“sub-system”)
- “Polynomial” constraints
- Multi-event polynomial constraints
- Whole dataset variables
- Max Likelihood / Matrix Element

TABLE I: Cartoons indicating various decay topologies, and relevant sections of this review. Dashed lines indicate ‘invisible’ particles which traverse the apparatus undetected. Blobs indicate decays which may (or may not) have proceeded via one or more on-mass-shell intermediates. References to sections should be considered indicative rather than exhaustive.
**Razor**

Christopher Rogan, “Kinematical variables towards new dynamics at the LHC”
arXiv:1006.2727v2 [hep-ph], CALT 68-2790

Abstract: At the LHC, many new physics signatures feature the pair-production of massive particles with subsequent direct or cascading decays to weakly-interacting particles, such as SUSY scenarios with conserved R-parity or $H \to W(\ell\ell\nu)W(\ell\ell\nu)$. We present a set of dimension-less variables that can assist the early discovery of processes of this type in conjunction with a set of variables with mass dimension that will expedite the characterization of these processes.

**SUS-11-024-PAS**

**SUS-12-009-PAS**