Stopping at the LHC with M3

Teruki Kamon

Collaboration with Bhaskar Dutta, Nikolay Kolev, Kuver Sinha, and Kechen Wang

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Texas A&M University
&
Department of Physics
Kyungpook National University

HEP Seminar
University of Hamburg/DESY
June 15, 2012
OUTLINE

- Prologue – Pheno Projects
- Light Higgs and Heavy 1st/2nd Generation Squarks → Light Stop and Light Stau
- Pheno Project #10: Light Stop
- Summary
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Focus Point (unpublished) … attempted to reconstruct two tops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:1112.3966 … accepted in PRD (Mirage at LHC14)
arXiv:1203.3276 … accepted in PRD (LFV at LHC14)
arXiv:12**.???? ... Stops via Tops (LHC8)

Bs → μμ:
CDF PRL 107 (2011) 191801

SUSY Jets+MET+Taus at LHC7
CMS SUS-11-007-PAS
CMS SUS-12-004/12-008-Paper (in preparation)

Pheno Projects at A Glance

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

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Stopping at the LHC with M3
Interesting Time!

**LEP + Tevatron**

- Theory uncertainty
  - $\Delta \alpha_{\text{had}}^{(S)}$
    - $0.02758 \pm 0.00035$
    - $0.02749 \pm 0.00012$
    - Incl. low $Q^2$ data

**LEP + Tevatron + LHC**

- Theory uncertainty
  - $\Delta \alpha_{\text{had}}^{(S)}$
    - $0.02750 \pm 0.00033$
    - $0.02749 \pm 0.00010$
    - Incl. low $Q^2$ data

Narrowing down the Higgs boson mass! The current SM Higgs mass region allowed by LHC+Tevatron+LEP is quite SUSY-friendly …

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But, ...

Keep in mind they are preliminary results;
Keep in mind they are small numbers;
Keep in mind we will run in the next year.
CMS 2011 Physics

CMS Preliminary \( L_{\text{int}} = 4.98 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV} \)

- Precision measurements
- Searches for new physics with MET
- No signs of new physics (yet)

Very rare decays

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"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
My Daughter’s View

My last options......

By my daughter

I need $\chi_1$, $\chi_2$, ...

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

I need $\tilde{t}$ ...

I need $\chi_1$, $\chi_2$, ...

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

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Stopping at the LHC with M3
Benchmark Point

ISAJET 7.80

\(m_{\tilde{t}_1/2}=500, m_{\tilde{g}}=3100, \tan\beta=30, A_0=-6000, m_{\text{top}}=173.1\)

(Stop 1 Benchmark Point #3)
Benchmark Point

ISAJET 7.80

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

(Stop 1 Benchmark Point #3)
Stop Searches in Market

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”
Snapshot of Stop Searches

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

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

- ...

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Stopping at the LHC with M3
SM Backgrounds

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

$\sqrt{s} = 7$ TeV

<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>

- Two tops along with MET.
- “Challenging”, but we need all hadronic channel
- $t \to jjb$ tag in one side, “W+b” tag in other ...
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
- \( p_T(e) > 10, \text{Iso} < 5 \text{ GeV} \)
- \( p_T(\mu) > 10, \text{Iso} < 5 \text{ GeV} \)
- \( p_T(\tau_h) > 20, \varepsilon = 60\%, f = 2\% \)

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

$E_T > 50$

$\tilde{t} (450) \& \tilde{\chi}_1^0 (100)$

Baseline Selection:
4 non b-jets (>100, >30's)
+ 2 loose b's (>30's)
+ MET (>200)

<table>
<thead>
<tr>
<th>S</th>
<th>B(top)</th>
<th>S/B</th>
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<td>78.0</td>
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M(top) in Market

- Kinematical fit ($\chi^2$)
- mT2
- M3
- FatJet/ TopTagger/ Cambridge-Aachen Algorithm
- 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 $1.09$ 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.) $\pm 40$ (syst.) $\pm 8$ (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 2 $b$ 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$^{-1}$ [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></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 $\sqrt{s} = 7 \text{ TeV}$. 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 $f_{\text{fit}}$ 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 $t\bar{t}$ normalization 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.
$\mathbf{M(TT\bar{b}) \text{ using } m_{T2}}$

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

$p_T^a + p_T^b = E_T$

Figure 1: Normalized $m_{T2}$ distributions for the stop signal ($m_{T} = 340$ GeV) and the $t\bar{t}$ background, after reconstructing two (real or fake) hadronic top quarks. The hypothetical LSP mass we set to $m_{\chi^0} = 0$ GeV (left) or to the correct value of $m_{\chi^0} = 98$ GeV (right).
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

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO11006Winter2012

EXO-11-006-PAS

\[ Z' \rightarrow t \bar{t} \]

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Stopping at the LHC with M3
HEPTopTagger

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

Efficiency

Normalized by hadronic top

$R_{C/A} < 1.5$

FatJet

Tagged

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Stopping at the LHC with M3
Detection of $W\rightarrow jj$ and $t\rightarrow Wb$

Bi-Event Subtraction Technique


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

$pp \rightarrow W + jjjjj$

BEST: "jet" mixing from two different events (TTbar, TTbar), (TTbar, W), (W, W)

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Stopping at the LHC with M3
Stop Search Strategy

1. q, \overline{q}'

2. b, \overline{t}, W

3. j

M3, twice

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Final Selection

Reference Stop: \( \tilde{\tau} (450) \& \tilde{\chi}_1^0 (100) \)

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

$E_T > 200$

$M_3$

Two entries / events

$40 < M(jj) < 120$

$M(jjb)$

$P_T(jjb)$

$M(jj)$

$M_3$

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Stopping at the LHC with M3
Stage 1: Tagging 1st Top

$E_T > 200$

$M_3$ twice

$M_3$ once

$\sim 33\%$ more signal

$40 < M(jj) < 120$

$120 < M(jj) < 220$

$p_T(t)$

$M(jj)$ top

$M(jj)$ stop

$p_T(top) > 200$ GeV

$p_T(W)$

$M(jj)$ top

$M(jj)$ stop

<table>
<thead>
<tr>
<th>$S$</th>
<th>$B(top)$</th>
<th>$S/B$</th>
<th>$S/\sqrt{S+B}$</th>
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<tbody>
<tr>
<td>78.0</td>
<td>3498</td>
<td>0.022</td>
<td></td>
</tr>
<tr>
<td>29.8</td>
<td>794</td>
<td>0.038</td>
<td>1.04</td>
</tr>
</tbody>
</table>

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27
Stage 2: Probing 2nd Top

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Stopping at the LHC with M3
Stage 2: Probing 2nd Top

<table>
<thead>
<tr>
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<tr>
<td>12.9</td>
<td>63.9</td>
<td>0.20</td>
<td>1.47</td>
</tr>
</tbody>
</table>

**Δφ(b, MET)**

**M_T(b, MET)**

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Stage 3: Clean-ups

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Stopping at the LHC with M3
Stage 4 & 5: Clean-ups

Preliminary

<table>
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<tr>
<th>S</th>
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<td>12.9</td>
<td>63.9</td>
<td>0.20</td>
<td>1.47</td>
</tr>
<tr>
<td>12.4</td>
<td>52.7</td>
<td>0.24</td>
<td>1.54</td>
</tr>
<tr>
<td>7.4</td>
<td>26.0</td>
<td>0.28</td>
<td>1.28</td>
</tr>
<tr>
<td>6.1</td>
<td>18.6</td>
<td>0.33</td>
<td>1.22</td>
</tr>
</tbody>
</table>

Improving statistics

40 < M(jj) < 120
40 < M(jj) < 120 & 120 < M(jjb) < 220

M(jjb) sum
M(jjb) top
M(jjb) stop

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Stopping at the LHC with M3
Baseline selection cuts: 4 jets + 2 loose b’s + MET

Final selection cuts

Stage 1: Tagging leading pT top ($j_1, j_2, b$)
Stage 2: Probing $j_1', j_2', b'$ (lost lepton)
Stage 3: Clean-up Two Top system
Stage 4: W mass cut
Stage 5: top mass cut

<table>
<thead>
<tr>
<th>8 TeV</th>
<th>450 GeV Stop</th>
<th>S</th>
<th>B(top)</th>
<th>S/B</th>
<th>S/$\sqrt{(S+B)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline selection</td>
<td>78.0</td>
<td>3498</td>
<td>0.022</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>[1]</td>
<td>1st Top</td>
<td>29.8</td>
<td>793.8</td>
<td>0.038</td>
<td>1.04</td>
</tr>
<tr>
<td>[2]</td>
<td>2nd Top</td>
<td>12.9</td>
<td>63.9</td>
<td>0.20</td>
<td>1.47</td>
</tr>
<tr>
<td>[3]</td>
<td>Clean-up</td>
<td>12.4</td>
<td>52.7</td>
<td>0.24</td>
<td>1.54</td>
</tr>
<tr>
<td>[4]</td>
<td>W mass</td>
<td>7.4</td>
<td>26.0</td>
<td>0.28</td>
<td>1.28</td>
</tr>
<tr>
<td>[5]</td>
<td>Top mass</td>
<td>6.1</td>
<td>18.6</td>
<td>0.33</td>
<td>1.22</td>
</tr>
</tbody>
</table>
Define pre-selection cuts: 6 jets (2 loose b's) + MET

Final selection cuts

Stage 1: Tagging leading pT top (J1, J2, B)
Stage 2: Probing j1, j2, b (lost lepton)
Stage 3: Clean-up Two Top system
Stage 4: W mass cut
Stage 5: top mass cut

Analysis Summary (8 TeV, 50 fb⁻¹)

<table>
<thead>
<tr>
<th>√s = 8 TeV</th>
<th>t̅t̅</th>
<th>t̅t̅ QCD W+jets Z+jets</th>
<th>S/B</th>
<th>S/√(S+B) 10⁻³ fb⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>m_{t̅} [GeV]</td>
<td>350 400 450 500 600 700</td>
<td>2.3 • 10⁵ 6.5 • 10⁸ 1.6 • 10⁹ 1.2 • 10⁴</td>
<td></td>
<td>400</td>
</tr>
<tr>
<td>cross section [fb]</td>
<td>760 337 160 80.5 23.0 7.19</td>
<td>1.6 • 10⁵ 6.5 • 10³ 1.3 • 10⁶ 1.2 • 10²</td>
<td></td>
<td>&lt; 10⁻⁶   0.04</td>
</tr>
<tr>
<td>ℓ veto</td>
<td>488 215 101 50.5 14.4 4.46</td>
<td>1.6 • 10⁵ 6.5 • 10³ 1.3 • 10⁶ 1.2 • 10²</td>
<td></td>
<td>&lt; 10⁻⁶   0.03</td>
</tr>
<tr>
<td>m_{fat} ≥ 2</td>
<td>167 88.3 48.0 26.6 8.71 2.96</td>
<td>3.7 • 10⁴ 2.0 • 10⁷ 1.1 • 10⁵ 1.3 • 10³</td>
<td></td>
<td>&lt; 10⁻⁵   0.06</td>
</tr>
<tr>
<td>p_T &gt; 100 GeV</td>
<td>104 65.0 38.5 22.5 7.76 2.74</td>
<td>1.6 • 10³ 2.0 • 10⁵ 1.9 • 10³ 694</td>
<td></td>
<td>3 • 10⁻⁴ 0.45</td>
</tr>
<tr>
<td>m_{tag} ≥ 1</td>
<td>27.5 18.5 11.87 7.60 2.91 1.12</td>
<td>375 2.5 • 10³ 36.7 17.0</td>
<td></td>
<td>6 • 10⁻³ 1.1</td>
</tr>
<tr>
<td>m_{tag} ≥ 2</td>
<td>2.34 1.65 1.12 0.76 0.34 0.14</td>
<td>6.40 18 0.5 -</td>
<td></td>
<td>0.07   1.0</td>
</tr>
<tr>
<td>b_tag inside top</td>
<td>0.74 0.58 0.35 0.25 0.11 0.05</td>
<td>1.93 0.18 -</td>
<td></td>
<td>0.27   1.3</td>
</tr>
<tr>
<td>m_{T2} &gt; 250 GeV</td>
<td>0.24 0.30 0.22 0.18 0.09 0.04</td>
<td>0.34 0.03 -</td>
<td></td>
<td>0.79   1.5</td>
</tr>
</tbody>
</table>

Table II: Analysis flow for the two-top analysis. All numbers are given in fb. The symbol “−” denotes less than 0.01 fb.
Stop searches in 2012

Tilman Plehn,¹ Michael Spannowsky,² and Michihisa Takeuchi¹

¹Institut für Theoretische Physik, Universität Heidelberg, Germany
²IPPP, 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 $m_{T2}^{lept}$ 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.
### Stop Searches in 2012 (II)

<table>
<thead>
<tr>
<th>$\sqrt{s} = 8$ TeV</th>
<th>$\tilde{t}\tilde{t}^*$</th>
<th>$t\bar{t}$</th>
<th>QCD</th>
<th>$W+$jets</th>
<th>$Z+$jets</th>
<th>$S/B$</th>
<th>$S/\sqrt{B}_{10^{fb}}$</th>
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<td></td>
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<tr>
<td>$n_{fat} \geq 2$</td>
<td>167 88.3 48.0 26.6 8.71 2.96</td>
<td>1.6 $\cdot$ 10^3 2.0 $\cdot$ 10^5 1.9 $\cdot$ 10^3</td>
<td>694</td>
<td>3 $\cdot$ 10^{-4}</td>
<td>0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$p_T &gt; 100$ GeV</td>
<td>104 65.0 38.5 22.5 7.76 2.74</td>
<td>375 2.5 $\cdot$ 10^3 36.7</td>
<td>17.0</td>
<td>6 $\cdot$ 10^{-3}</td>
<td>1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$n_{tag} \geq 1$</td>
<td>27.5 18.5 11.87 7.60 2.91 1.12</td>
<td>6.40 18</td>
<td>0.5</td>
<td>-</td>
<td>0.07</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>$n_{tag} \geq 2$</td>
<td>2.34 1.65 1.12 0.76 0.34 0.14</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.27</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>$b$-tag inside top</td>
<td>0.71 0.58 0.35 0.25 0.11 0.05</td>
<td>1.93</td>
<td>0.18</td>
<td>-</td>
<td>-</td>
<td>0.79</td>
<td>1.5</td>
</tr>
<tr>
<td>$m_{T_2} &gt; 250$ GeV</td>
<td>0.24 0.30 0.22 0.18 0.09 0.04</td>
<td>0.34</td>
<td>0.03</td>
<td>-</td>
<td>-</td>
<td>0.79</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table II: Analysis flow for the two-top analysis. All numbers are given in fb. The symbol “-” denotes less than 0.01 fb.

Decreasing, because of FatJet?
**Summary**

arXiv:1205.2696v1 [hep-ph] ... The dilepton final state is considered as a golden mode to detect an excess beyond the SM process. However, it is not provide an conclusive answer.

All-hadronic mode would be a key, but challenging, mode where one requires to detect two top quarks.

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.
Backup
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/c²)</th>
<th>Branching ratio(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau^- \rightarrow h^- \nu_\tau$</td>
<td></td>
<td></td>
<td>11.6 %</td>
</tr>
<tr>
<td>$\tau^- \rightarrow h^- \pi^0 \nu_\tau$</td>
<td>$\rho$</td>
<td>770</td>
<td>26.0 %</td>
</tr>
<tr>
<td>$\tau^- \rightarrow h^- h^0 \nu_\tau$</td>
<td>$a_1$</td>
<td>1200</td>
<td>10.8 %</td>
</tr>
<tr>
<td>$\tau^- \rightarrow h^- h^+ h^- \nu_\tau$</td>
<td>$a_1$</td>
<td>1200</td>
<td>9.8 %</td>
</tr>
<tr>
<td>$\tau^- \rightarrow h^- h^0 h^- \pi^0 \nu_\tau$</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>Other hadronic modes</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 $e/\mu$, and isolation
Any Further Improvements?

$m_{\text{LSP}} = 100$

Figure 1: Normalized $m_{T2}$ distributions for the stop signal ($m_t = 340$ GeV) and the $t\bar{t}$ background, after reconstructing two (real or fake) hadronic top quarks. The hypothetical LSP mass we set to $m_{\chi_1^0} = 0$ GeV (left) or to the correct value of $m_{\chi_1^0} = 98$ GeV (right).
SUSY Mass Techniques

Christopher Lester et al., ICHEP2010, arXiv:1004.2732

- Missing momentum
- $M_{\text{eff}}$, Razor, $H_T$
- $s_{\text{min}}$
- $M_{\text{TGEN}}$
- $M_{T2} / M_{\text{CT}}$
- $M_{T2}$ (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

Few assumptions

Many assumptions

Teruki Kamon

Tops and Stops