Search for Heavy Top at CDF

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CDF Collaboration

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Tevatron and CDF detector

- $\sim 1.4 \text{ fb}^{-1}$ delivered
- Expect to collect 6–8 fb$^{-1}$ by 2009
- New heavy particle discovery reach up to masses of $\sim 1 \text{ TeV}$
- This analysis uses 760 pb$^{-1}$
Theoretical Motivations

- **Heavy Top** appears in many theories
- Usually too heavy for Tevatron
  - e. g. Little Higgs (heavy Top with mass ~1–2 TeV)
    - (hep-ph/0310039,0402037,0520225)
- **Possible 4-th generation quark** with mass of few hundreds GeV
  - Consistent with EWK data
  - Oblique corrections drive Higgs Mass to ~ 500 GeV
    - (C. He et al, hep-ph/0102144)
  - Almost degenerate $b^\prime$ and $t^\prime$ masses: $M(t^\prime) - M(b^\prime) < M(W)$
  - Decays as top! $t^\prime \rightarrow Wq$ (q=d,c,b)
- **New mirror quarks** with not necessarily same properties as first three generations
  - “Beautiful Mirrors”: new heavy quarks decaying into $Wb$
  - Motivated by data
    - (C. Wagner, hep-ph/0109097)
EWK precision data

- Precision data is not consistent with SM!
  - $A_{FB}^b$ - b–quark forward–backward asymmetry
    ~2.9 $\sigma$ away
  - Not a big deal?
  - $\sin \theta_W$ leptonic is ~3.6 $\sigma$ away from $\sin \theta_W$ hadronic
- Suppose $A_{FB}^b$ measurement has larger uncertainty or systematically off, and we force:
  $$\sin \theta_W,_{had} = \sin \theta_W,_{lep}$$
Higgs Mass fit

Higgs would be already discovered!

M. Chanowitz, hep-ph/0104024
Beautiful mirror quarks

- New physics in $Z \rightarrow bb$? Different coupling of the $b$-quark to $Z$?
  - (C. Wagner, hep-ph/0109097)
- Mirror quarks of $b$-quarks improve the fit
  - couple to $b$'s and less to $d$'s or $c$'s
- Two scenarios: with and without top mirror quarks

Perfect for Tevatron searches

Might have to wait for LHC
t’ Decay and Event Selection

Decays as top only heavier!

- high $P_T$ e or $\mu$: $P_T > 20$ GeV/c
- Use Lepton + Jets Decay Mode
- Four high $E_T$ jets: $E_T > 15$ GeV, $|\eta| < 2.0$

Missing $E_T > 20$ GeV - Restrictions on direction.

We search for it in the top quark sample!

Same event selection as for top, no b–tagging requirement
Analysis Strategy

- Main backgrounds: W+jets and ttbar
- Others: QCD, EWK (WZ,WW,Z+jets,single top) ~ 8%
- Assume top mass = 175 GeV and constrain ttbar(Pythia) to theoretical cross section 6.7±0.9 pb
- Allow W+jets normalization float freely and perform kinematic fit
- Use the following kinematic quantities
  1. \( H_T = \sum E_{T,jets} + E_{T,lepton} + E_T \)
  2. \( M_{reco} \) – reconstructed mass as in Top Mass Fitter:

\[
\chi^2 = \sum_{i=\ell,Ajets} \left( \frac{p_T^{i,\text{fit}} - p_T^{i,\text{meas}}}{\sigma_i} \right)^2 + \sum_{j=x,y} \left( \frac{p_j^{UE,\text{fit}} - p_j^{UE,\text{meas}}}{\sigma_j} \right)^2 + \frac{(M_{jj} - M_W)^2}{\Gamma_W^2} + \frac{(M_{\ell\nu} - M_W)^2}{\Gamma_W^2} + \frac{(M_{b\ell\nu} - M_t)^2}{\Gamma_t^2} + \frac{(M_{b\ell\nu} - M_t)^2}{\Gamma_t^2}.
\]
Analysis Strategy (cont.)

- Quasi model-independent variables retain sensitivity to other possible beyond SM events
- Perform a binned Likelihood Fit
- Scan Likelihood as a function of $t'$ cross section
- Include systematic effects as nuisance parameters ($\sigma_{tt}$, Luminosity, lepton ID efficiencies, MC/data scale factors, Jet Energy Scale, Q2 scale, initial/final state radiation, PDF)
- Maximize Likelihood with respect to all them – profiling method
Handling Systematics

\[ \mathcal{L}(\sigma_{t'}|n_i) = \prod_{i,k} P(n_i|\mu_i) \times G(\nu_k|\tilde{\nu}_k, \sigma_{\nu_k}) \]

- Effects evaluated based on measuring how the \( \sigma_{t'} \) changed given \( t' \) existed
- The shifts measured by drawing “pseudo-experiments” from shifted templates and fitted to nominal

- Jet Energy Scale (JES):
  - Obtain JES \( \pm 1\sigma \) shifted templates by shifting JES upward and downward
  - Include the shape transformation due to variation of \( \nu_{\text{JES}} \) into the fit

Template Morphing
Systematic Effects

<table>
<thead>
<tr>
<th>Effect</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet Energy Scale</td>
<td>Template Morphing</td>
</tr>
<tr>
<td>Q$^2$ Scale</td>
<td>$\delta\sigma_t &lt; 1.25$ pb</td>
</tr>
<tr>
<td>Lepton Isolation</td>
<td>2%</td>
</tr>
<tr>
<td>Lepton ID</td>
<td>0.7%</td>
</tr>
<tr>
<td>ISR/FSR</td>
<td>$\delta\sigma_t=0.2$ pb</td>
</tr>
<tr>
<td>Luminosity</td>
<td>5.8%</td>
</tr>
<tr>
<td>QCD Background</td>
<td>negligible</td>
</tr>
<tr>
<td>PDF</td>
<td>1.0%</td>
</tr>
<tr>
<td>Theory</td>
<td>10%</td>
</tr>
</tbody>
</table>
Looking at the data: 95% CL Limits

- Theory curve from
  - Bonciani et al. hep-ph/9801375
  - Mangano et al. hep-ph/0303085

- Expected limits obtained using pseudo-data

- Exclude with 95% CL region of $t'$ masses below 258 GeV
Data Fit for $m_{t'} = 350 / 400$ GeV

Expect $\approx 1.3$ events for $m(t') = 400$ GeV at 760 pb$^{-1}$ luminosity
Significance of an Excess

- A priori chose high-$H_T$, $M_{\text{reco}}$ signal region with \approx 1\% of SM events
  - All overflow bins + 2 high $H_T$, $M_{\text{reco}}$ bins
- Expect 6.8 events—observe 7 events
Event Displays of 4 events at the high Mass tail
Run 194323
Event 9830702

\( p_T(\mu): 159 \text{ GeV} \)

\( E_T: 177 \text{ GeV} \)

\( E_T: 82.3 \text{ GeV} \)

\( E_T: 29.8 \text{ GeV} \)

\( E_T: 192 \text{ GeV} \) (b-tagged)

\( H_T: 785 \text{ GeV} \)

\( M_{\text{rec}}: 474 \text{ GeV} \)

\( E_T: 177 \text{ GeV} \)

\( E_T: 135 \text{ GeV} \)

\( E_T: 192 \text{ GeV} \) (b-tagged)
Final Remarks

- The analysis is based on 760 pb−1 of integrated luminosity
- CDF is currently analyzing 1.2 fb−1 of data
- See new results at winter conferences
Backup Slides
# Results

<table>
<thead>
<tr>
<th>Mass (GeV)</th>
<th>Expected Limit (pb)</th>
<th>Actual Limit (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>175</td>
<td>2.93 ± 1.05</td>
<td>4.86</td>
</tr>
<tr>
<td>200</td>
<td>1.70 ± 0.57</td>
<td>2.36</td>
</tr>
<tr>
<td>225</td>
<td>0.92 ± 0.40</td>
<td>1.01</td>
</tr>
<tr>
<td>250</td>
<td>0.54 ± 0.24</td>
<td>0.68</td>
</tr>
<tr>
<td>275</td>
<td>0.40 ± 0.15</td>
<td>0.64</td>
</tr>
<tr>
<td>300</td>
<td>0.28 ± 0.12</td>
<td>0.54</td>
</tr>
<tr>
<td>350</td>
<td>0.18 ± 0.07</td>
<td>0.50</td>
</tr>
<tr>
<td>400</td>
<td>0.13 ± 0.06</td>
<td>0.46</td>
</tr>
</tbody>
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