Prospects for Searches for Narrow Resonances Decaying to Top Quark Pairs

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Introduction

• Search for $Z' \rightarrow t\bar{t}b\bar{b}$ as model for narrow resonance
• All-hadronic and $l+jets$ channels
• Scenario : 14 TeV pp collider (300 fb$^{-1}$, 3000 fb$^{-1}$)

• Model :
  • Leptophobic topcolor $Z'$ [hep-ph/9911288]
  • 1.2% width
  • Cross-sections from [arXiv:1112.4928]

• All current limits < 2 TeV (using up to 14 fb$^{-1}$ at 8 TeV [ATLAS-CONF-2013-052])

• Strategy :
  • all-hadronic : reduce QCD with substructure & b-tagging
  • $l+jets$ : use substructure, b-tagging and lepton mini-isolation
I+jets analysis

• Boosted I+jets selection:
  • 1 fat jet ($p_T > 600$ GeV), top-tagged
  • 1 mini-isolated lepton, $p_T > 25$ GeV
  • $E_T^{\text{miss}} > 50$ GeV
  • 1 b-tagged skinny jet (anti-$k_t$ 0.5)
  • $\Delta R$ (fat jet, lepton) > 1.0
  • $\Delta R$ (fat jet, skinny jet) > 1.0
  • $\Delta R$ (skinny jet, lepton) < 1.0

• Analysis close to be finalized

• Showing only all-hadronic results here
Modeling

- **Z’**:  
  - 100k events with Pythia8  
  - $m = 2 \text{ TeV}, 3 \text{ TeV}, 4 \text{ TeV}, 5 \text{ TeV}$

- **ttbar**:  
  - 1M events with Herwig++  
  - $p_T > 650 \text{ GeV}$

- **QCD**:  
  - 1M events with Herwig++  
  - $p_T > 650 \text{ GeV}$

For **ttbar** and **QCD**: using Herwig++ cross section  
For **Z’**: additional k-factor 1.3

<table>
<thead>
<tr>
<th>sample</th>
<th>cross section</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z'$ (2 TeV)</td>
<td>$214 \cdot 10^{-3} \text{ pb}$</td>
</tr>
<tr>
<td>$Z'$ (3 TeV)</td>
<td>$23.2 \cdot 10^{-3} \text{ pb}$</td>
</tr>
<tr>
<td>$Z'$ (4 TeV)</td>
<td>$3.24 \cdot 10^{-3} \text{ pb}$</td>
</tr>
<tr>
<td>$Z'$ (5 TeV)</td>
<td>$0.553 \cdot 10^{-3} \text{ pb}$</td>
</tr>
<tr>
<td>$t\bar{t}$ ($p_T &gt; 650 \text{ GeV}$)</td>
<td>$1.28 \text{ pb}$</td>
</tr>
<tr>
<td>QCD multijet ($p_T &gt; 650 \text{ GeV}$)</td>
<td>$170 \text{ pb}$</td>
</tr>
</tbody>
</table>

- Delphes 3.0.9 (private version by Jim Dolen including substructure variables)  
- $\mu = 0, 50, 140$
Selection

- 2 C/A R=0.8 jets with
  - $p_T > 750$ GeV
  - $|\eta| < 2.0$
  - top-tag : $Q_W > 70$ GeV $m_{\text{trimmed}} > 80$ GeV
  - b-tag : $\varepsilon = 0.83 \cdot \exp(-0.7 \cdot p_T[\text{TeV}])$
    $$f = 1 / (80 \cdot \exp(-0.9 \cdot p_T[\text{TeV}]))$$

- top-tagging optimized using $S / \sqrt{B}$: $Q_W, \sqrt{d_{12}}, \sqrt{d_{23}}, \tau_{32}, \tau_{21}, N_{\text{subjets}}, m_{\text{trimmed}}$

- b-tagging:
  - $\varepsilon = 50\% (30\%)$ @ 0.75 (1.5) TeV
  - $f = 2.5\% (5\%)$ @ 0.75 (1.5) TeV
  - increase $f$ by 1/3 (2/3) for $\mu = 50$ (140)

- input to statistical analysis: invariant di-jet mass in $\pm 500$ GeV window around $Z'$ mass

$\mu = 50, 14$ TeV, 300 fb$^{-1}$

$Z'$ (3 TeV)

ttbar

QCD

m$_{jj}$ [GeV]
Limit Setting and Systematic Uncertainties

- Calculating expected 95% CL limits on $Z'$ production
- Bayesian Analysis Toolkit [arXiv:0808.2552]
- Statistical uncertainty on limits from 1000 sets of pseudo-data

- Systematic uncertainties:
  - QCD expected to be DD

<table>
<thead>
<tr>
<th></th>
<th>value</th>
<th>process</th>
</tr>
</thead>
<tbody>
<tr>
<td>ttbar normalization</td>
<td>±10%</td>
<td>ttbar</td>
</tr>
<tr>
<td>QCD normalization</td>
<td>±50%</td>
<td>QCD</td>
</tr>
<tr>
<td>JES</td>
<td>±2%</td>
<td>$Z'$, ttbar</td>
</tr>
<tr>
<td>b-tagging efficiency</td>
<td>±10%</td>
<td>$Z'$, ttbar</td>
</tr>
</tbody>
</table>
• Results at $\mu = 0$
• Systematic uncertainties decrease sensitivity
Results (2/3)

- With systematics
- Increasing pile-up decreases sensitivity

\[ \mu = 0 \]

\[ \mu = 50 \]

\[ \mu = 140 \]
### Results (3/3)

<table>
<thead>
<tr>
<th>Energy (TeV)</th>
<th>( \mu = 50 )</th>
<th>( \mu = 140 )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>stat.</td>
<td>stat.+syst.</td>
</tr>
<tr>
<td>2</td>
<td>16 fb</td>
<td>29 fb</td>
</tr>
<tr>
<td>3</td>
<td>6.7 fb</td>
<td>13 fb</td>
</tr>
<tr>
<td>4</td>
<td>5.7 fb</td>
<td>11 fb</td>
</tr>
<tr>
<td>5</td>
<td>7.6 fb</td>
<td>13.3 fb</td>
</tr>
<tr>
<td>Mass reach (95% CL)</td>
<td>3.9 TeV</td>
<td><strong>3.7 TeV</strong></td>
</tr>
</tbody>
</table>

\( \mu = 50 \), with systematics

\( \mu = 140 \), with systematics

\[ \text{mass reach (95\% CL)} \]

**remark:** TGraph interpolates linearly – also in log plots → for mass reach cf. table!

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**Resonances Decaying to Top Quark Pairs**
Summary

- Presented prospects for search for ttbar resonances at 14 TeV
- Using substructure
- Using more realistic assumptions on b-tagging than implemented in Delphes
- Including main systematic uncertainties

- 300 fb$^{-1}$: reach sensitivity to $O(11 - 13 \text{ fb}^{-1})$ for resonance masses of 3 – 5 TeV
- 3000 fb$^{-1}$: reach sensitivity to $O(4 – 5 \text{ fb}^{-1})$ for resonance masses of 3 – 5 TeV

- Expect to exclude leptophobic topcolor $Z'$ ($\Gamma = 1.2\%$) up to 3.7 (4.1) TeV for 300 (3000) fb$^{-1}$

- Searches for top resonances will benefit from running at 14 TeV
- For even higher mass reach will probably need more refined analysis strategies (entering the regime where resolving substructure in fat jets is a challenge with given detector granularity)
Bonus
### Resonances Decaying to Top Quark Pairs

<table>
<thead>
<tr>
<th>Energy (TeV)</th>
<th>300 fb⁻¹ (μ = 0) stat.</th>
<th>300 fb⁻¹ (μ = 0) stat.+syst.</th>
<th>300 fb⁻¹ (μ = 50) stat.</th>
<th>300 fb⁻¹ (μ = 50) stat.+syst.</th>
<th>300 fb⁻¹ (μ = 140) stat.</th>
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<tbody>
<tr>
<td>2 TeV</td>
<td>16 fb</td>
<td>26 fb</td>
<td>16 fb</td>
<td>29 fb</td>
<td>17 fb</td>
<td>35 fb</td>
</tr>
<tr>
<td>3 TeV</td>
<td>6.4 fb</td>
<td>12 fb</td>
<td>6.7 fb</td>
<td>13 fb</td>
<td>7.2 fb</td>
<td>15 fb</td>
</tr>
<tr>
<td>4 TeV</td>
<td>5.3 fb</td>
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<td>7.6 fb</td>
<td>13.3 fb</td>
<td>8.5 fb</td>
<td>15 fb</td>
</tr>
<tr>
<td>Mass Reach (95% CL)</td>
<td>4.0 TeV</td>
<td>3.8 TeV</td>
<td>3.9 TeV</td>
<td>3.7 TeV</td>
<td>3.9 TeV</td>
<td>3.7 TeV</td>
</tr>
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</table>
## 3000 fb⁻¹

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<th>3000 fb⁻¹ (μ = 50)</th>
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Resonances Decaying to Top Quark Pairs
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$300 \text{ fb}^{-1}$ (stat.+syst.)

$\mu = 0$

$\mu = 50$

$\mu = 140$
3000 fb$^{-1}$ (stat.)

Resonances Decaying to Top Quark Pairs
$\mu = 0$

$\mu = 50$

$\mu = 140$