Search for $t\bar{t}$ resonances with ATLAS Detector

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Outline

- Physics Motivation
- Logistics
- Data/MC Samples, Selection Criteria
- Mass Reconstruction Methods
- QCD Background Estimate
- Data / MC Comparison
- Systematic Uncertainties
- Limits
Physics Motivation

• Top is the heaviest of known elementary particles
• Top resonances are predicted by several models
  ▪ **Sequential heavy Z’** [narrow, $\Gamma$=0.03M]
    ▪ SM Z boson-like [except mass which is a free parameter]
  ▪ **Topcolor Z’$
\not{t}$** [narrow, $\Gamma$=1.2%M but large $\sigma \times$ BR]
    ▪ $Z'$ couples strongly to 3$^{rd}$ generation quarks, with no coupling to leptons [leptophobic scenario]
  ▪ **Randall-Sundrum (RS) graviton G**$^*$ [narrow, $\Gamma$ <0.01M]
    ▪ Only $G^*$ is allowed to propagate in extra-dimensions
    ▪ resonance mass and coupling strength are free parameters
  ▪ **Kaluza-Klein gluon $g_{kk}$** in RS models [wide]
Benchmark Scenarios

• Topcolor $Z'$ (narrow)
  ▪ Chosen based on current experimental sensitivity
  ▪ Leptophobic **Model IV** ($f_1 = 1$, $f_2 = 0$), $\Gamma = 1.2\% \, M_{Z'}$

• Kaluza-Klein gluon (wide) from **RS Models**
  ▪ Strong coupling to top quark ($g_L = 1.0$, $g_R = 4.0$)
  ▪ KK gluon primarily decays into top pairs
  ▪ Signal can be interpreted as evidence of extra dimensions

• Previous Searches
  ▪ CDF and DØ exclude masses below $m = 900, 820$ GeV
  ▪ CMS (recent result in Moriond 2011)
Top Pair: Semi-leptonic Final State

- 1 lepton [electron or muon] \textbf{no tau}
- missing transverse energy
- 1 jet from leptonic top
- 3 jets from hadronic top, at least one b-tagged jet
- + additional jets from ISR/FSR

- Select good high pT lepton
- Large missing transverse energy
- Four (or more) good jets
- At least one of the jets identified as a b-jet
- Reconstruct ttbar invariant mass [Mass reconstruction methods]
• Using 200 pb\(^{-1}\) of collider data in 2011 by LHC
  - Correlates to data collected with all ATLAS subsystems operational and stable beam conditions
  - Uncertainty on luminosity (2010 estimate of 4.5%)
• Single lepton triggers used
  - Electron (threshold of 20 GeV) plateau at 25 GeV
  - Muon (threshold of 18 GeV) plateau at 20 GeV
**Simulation - Signal**

- Resonance Signal \([Z' \rightarrow \text{ttbar}]\)
  - **TopColor [Pythia]**
    
    | Mass [GeV] | 400 | 500 | 600 | 700 | 800 | 900 | 1000 |
    |------------|-----|-----|-----|-----|-----|-----|------|
    | \(\sigma \times \text{BR (pb)}\) | 37.8 | 20.5 | 10.0 | 5.0 | 2.8 | 1.6 | 1.0  |

  - **RS G* [Pythia]** \(k/M_{Pl} = 0.1\)
    
    | Mass [GeV] | 500 | 600 | 700 | 800 | 900 | 1000 | 1300 |
    |------------|-----|-----|-----|-----|-----|------|------|
    | \(\sigma \times \text{BR (pb)}\) | 6.32 | 3.14 | 1.53 | 0.77 | 0.39 | 0.21 | 0.004 |

  - **KK gluons from RS models [MADGRAPH + Pythia]**
    
    | Mass [GeV] | 500 | 700 | 1000 | 1500 |
    |------------|-----|-----|------|------|
    | \(\sigma \times \text{BR (pb)}\) | 56  | 17  | 3.4  | 0.4  |

  - **QBH (t, anti-t) [BLACKMAX]**
    - \(N = 6\) extra dimensions, simplest 2 body final state
    - \(M_{\text{threshold}} = 0.75\) (24% \(tt\)), 2.5 (38% \(tt\)) TeV
Simulation – EW Background

- ttbar [MC@NLO + Herwig/Jimmy]
  - 80.2 pb @ 7 TeV, KF=1.11

- EW single-top
  - s- (1.4 pb) and t- (21.5 pb) channels, Wt (14.6 pb)

- W+jets, Z+jets [Alpgen + Herwig/Jimmy]
  - 0-4Np exclusive, >=5Np inclusive KF=1.22 for all

- Diboson (Herwig + Jimmy)
  - WW (11.75 x 1.52), WZ (3.43 x 1.58), ZZ (0.98 x 1.2) [pb]
Event/Object Selection Criteria

• Isolated lepton with high transverse momentum
  ▪ Electron \( p_T > 25 \text{ GeV} \), Muon \( p_T > 20 \text{ GeV} \)

• Missing Transverse Energy (MET)
  ▪ Lepton+MET transverse mass \( > 25 \text{ GeV} \)
  ▪ MET \( > 35 \text{ GeV} \)

• Jets \( p_T > 25 \text{ GeV} \)
  ▪ Four (or more) calibrated jets, Anti-Kt (0.4 radius)

• B-tag – used identify b quark from top decay
  ▪ Secondary vertex tagger with 50% b-jet identification efficiency and good rejection rate for light jets
QCD Background

• Data-driven estimate for QCD background estimate
  ▪ Jet Electron / Anti-electron methods
    ▪ Jet triggered sample, require highly EM jet with associated tracks – to model the fake electron
    ▪ Electron triggered sample, electron fails quality requirement
• Templates are fitted to selected data in to obtain the QCD fractions.
Mass Reconstruction Methods - I

• Four hardest Jets [Simple method]
  ▪ 4 highest pT jets assumed to come from ttbar decay
  ▪ Solve for neutrino longitudinal momentum
  ▪ Choose smaller of the two solutions
    ▪ Impose W-boson mass constraint
    ▪ Ensure discriminant of quadratic equation is null
Mass Reconstruction Methods - II

- dRmin method [Reduce tails in mass spectrum]
  - Attempts to reduce long non-gaussian tails in mass resolution which is dominated by ISR/FSR
  - Among 4 leading good-jets, remove a jet that is close to a lepton or a jet satisfying \( \Delta R_{\text{min}} > 2.5 - 0.015m_j \)

![Data from ATLAS simulation](image.png)
## Event Yields – Data/MC

<table>
<thead>
<tr>
<th></th>
<th>Electron channel</th>
<th>Muon channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}$</td>
<td>724</td>
<td>988</td>
</tr>
<tr>
<td>Single top</td>
<td>36</td>
<td>50</td>
</tr>
<tr>
<td>$W$+jets</td>
<td>93</td>
<td>172</td>
</tr>
<tr>
<td>$Z$+jets</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Diboson</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total MC Background</td>
<td>861</td>
<td>1220</td>
</tr>
<tr>
<td>QCD Background</td>
<td>35</td>
<td>105</td>
</tr>
<tr>
<td>Total Expected</td>
<td>896</td>
<td>1325</td>
</tr>
<tr>
<td>Data observed</td>
<td>935</td>
<td>1396</td>
</tr>
<tr>
<td>$Z'$, $m = 500$ GeV</td>
<td>15</td>
<td>21</td>
</tr>
<tr>
<td>$g_{KK}$, $m = 700$ GeV</td>
<td>68</td>
<td>93</td>
</tr>
</tbody>
</table>
Data / Background Expectation

ATLAS Preliminary
$\int L dt = 200 \text{pb}^{-1}$

Events / GeV

Events / 25 GeV

Events / 20 GeV

08/10/2011  Venkat Kaushik  DPF 2011 14
Systematic Uncertainties

• Systematic uncertainties affecting the shape of ttbar invariant mass
  ▪ b-tagging efficiency (11 %)
  ▪ Jet energy scale and resolution and pileup effects (9 %)
  ▪ Electron energy scale and resolution
  ▪ Muon momentum scale and resolution
  ▪ W+jets, ttbar, singletop, diboson shape and normalization
  ▪ QCD normalization
  ▪ PDF uncertainties, Parton shower and hadronization model

• Systematic uncertainties affecting normalization
  ▪ Luminosity
  ▪ Trigger and object reconstruction efficiencies
Limits - I

- Use reconstructed $m(tt)$ to search for evidence of new physics
  - Null hypothesis: Data consistent with SM prediction
  - If so, set limits on max allowed cross-section for BSM processes for benchmark scenarios: function of $m(tt)$

- Statistical Approach: Bayesian
  - Define a likelihood function for each bin of $m(tt)$
  - Overall likelihood is product of all (including channels)
  - Calculate posterior probability density using Bayes theorem
  - Assume flat (or zero) prior for $\sigma \geq 0$ ($\sigma < 0$)
• Step 1: Test Null Hypothesis
  ▪ BumpHunter tool (G. Choudalakis dijet final states)
• Step 2: Set upper limits
  ▪ Upper limit is identified as 95% point of the posterior probability
  ▪ For including systematics – generate pseudo-experiments (5000 expts) and vary the Poisson mean in every bin subject to systematic uncertainties according to a Gaussian.
  ▪ Expected limits (based on MC expectation)
  ▪ Observed limits (based on Data)
• 95% C.L Upper Limits \( \sigma \times BR(Z' \rightarrow t\bar{t}) \)
  • Observed 38 pb to 3.2 pb
  • Expected 20 pb to 2.2 pb

• 95% C.L Upper Limits \( \sigma \times BR(g_{KK} \rightarrow t\bar{t}) \)
  • Observed 32 pb to 6.6 pb
  • Expected 24 pb to 2.9 pb
Summary

• Many BSM models predict existence of new resonances that decay into top quark pairs
  ▪ TopColor Z’ and RS $g_{KK}$ scenarios chosen for study
• 200 pb$^{-1}$ of data is analyzed
  ▪ ttbar invariant mass spectrum is reconstructed
  ▪ different reconstruction schemes compared
    ▪ Linearity and Resolution
  ▪ SM Background estimate using simulation
    ▪ QCD, W+jets estimate using data-driven approach
    ▪ Data and MC agreement consistent with SM prediction
  ▪ Limit set on cross-section x BR as a function of ttbar invariant mass
  ▪ Able to probe a ~ pb range for masses up to 1 TeV
BACKUP SLIDES
## Systematic Uncertainties -II

<table>
<thead>
<tr>
<th>Source</th>
<th>Top</th>
<th>W+jets</th>
<th>Other</th>
<th>$Z', m_Z' = 500$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet energy scale</td>
<td>+13%</td>
<td>+26%</td>
<td>+15%</td>
<td>+14%</td>
</tr>
<tr>
<td></td>
<td>-7.5%</td>
<td>-18%</td>
<td>-8.7%</td>
<td>-8.1%</td>
</tr>
<tr>
<td>Jet energy resolution</td>
<td>+12%</td>
<td>+20%</td>
<td>+36%</td>
<td>+14%</td>
</tr>
<tr>
<td>Jet reconstruction efficiency</td>
<td>-3.9%</td>
<td>-6.4%</td>
<td>-9.2%</td>
<td>-3.9%</td>
</tr>
<tr>
<td>$b$-jet energy scale</td>
<td>+5.3%</td>
<td>+4.6%</td>
<td>+2.2%</td>
<td>+5.3%</td>
</tr>
<tr>
<td></td>
<td>+3.5%</td>
<td>+2.6%</td>
<td>+6.8%</td>
<td>+3.4%</td>
</tr>
<tr>
<td>$b$-tagging efficiency (incl. mistag rate)</td>
<td>+20%</td>
<td>+46%</td>
<td>+34%</td>
<td>+21%</td>
</tr>
<tr>
<td></td>
<td>-18%</td>
<td>-41%</td>
<td>-34%</td>
<td>-19%</td>
</tr>
<tr>
<td>Top quark mass</td>
<td>+3.3%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>-5.0%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$m_{t\bar{t}}$ Shape</td>
<td>±4.0%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Parton shower &amp; Fragmentation</td>
<td>±5.8%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Final-state radiation (FSR)</td>
<td>+7.2%</td>
<td>-</td>
<td>-</td>
<td>+6.3%</td>
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<tr>
<td></td>
<td>-7.6%</td>
<td>-</td>
<td>-</td>
<td>-3.2%</td>
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<tr>
<td>Initial-state radiation (ISR)</td>
<td>+4.3%</td>
<td>-</td>
<td>-</td>
<td>+3.6%</td>
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<td></td>
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<td>-1.2%</td>
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<tr>
<td>ISR+FSR</td>
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<td>-</td>
<td>-</td>
<td>+2.5%</td>
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<tr>
<td></td>
<td>-4.1%</td>
<td>-</td>
<td>-</td>
<td>-4.2%</td>
</tr>
</tbody>
</table>