Searches in s-channel Single Top Quark Production at ATLAS

Barbara Alvarez Gonzalez
on behalf of the ATLAS Collaboration

ICHEP, July 6, 2012
OVERVIEW

- Introduction and motivation
- Present the results of two ATLAS analyses:
- Event selection and background estimation
  - Shared in both analyses
- Different techniques for signal extraction:
  - Cut-based
  - Template fit
- Summary
Introduction and Motivation

- **Single top was first observed at Fermilab in 2009 by CDF and D0**
- **In 2011, t-channel observations by ATLAS and CMS**
- Three production mechanisms:
  - t-channel ($\sigma=65\text{pb} @ 7\text{TeV LHC}$)
  - Wt ($\sigma=16\text{pb} @ 7\text{TeV LHC}$)
  - s-channel ($\sigma=5\text{pb} @ 7\text{TeV LHC}$)

- **s-channel single top:**
  - Tiny signal, $\sim 5$ times larger than at Tevatron
  - Very challenging
  - Sensitive probe to new physics processes ($W'$ bosons, charged Higgs bosons,...)
Use same selection and background estimation in both searches

**s-channel single top**

\[ W' \rightarrow tb \]

**Key Ingredients**
- Lepton identification
- \( b \)-tagging algorithms
- Jet energy scale
Event Selection

Data
- Single lepton (e/µ) triggers
  - 0.70/1.04 fb$^{-1}$ of ATLAS data

Event Selection
- One isolated lepton (e/µ)
  - $p_T > 25$ GeV
  - $|\eta| < 2.47$ electron / $|\eta| < 2.5$ muons
  - $E_T^{\text{miss}} > 25$ GeV
- Two energetic and central jets:
  - $|\eta| < 2.5$
  - $E_T > 25$ GeV
  - At least one $b$-tagged (57% eff.)
- Triangular cut:
  - $m_T(W) > 60$ GeV - $E_T^{\text{miss}}$

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Searches in s-channel single top

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Background Estimation: Classified in three groups

**Top and EWK Processes**
- Model from simulation
- Normalize to theory: \( N_{\text{events}} = \epsilon_{\text{evt}} \sigma \int L dt \)

**QCD Multijets**
- Model from data
- Normalize to data: \( E_T^{\text{miss}} \) fit

**W+jets: W+HF/light**
- Model from simulation
- Normalize to data
Background Estimation: QCD and $W$+jets

**QCD Method**
- Fitting the $E_T^{\text{miss}}$ distribution
- QCD shape taken from the jet-electron sample

**Jet-electron Candidate**
- A jet is misidentified as a lepton
- A lepton from semileptonic decay of a heavy hadron jet

**W$+$jets Method**
- Tag counting method
- The kinematic shape and acceptances are taken from simulation
- The overall normalization and the flavour composition are derived from data

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Signal estimation:
- Model from simulation
- Normalize to theory

\[ N_{\text{events}} = \epsilon_{\text{evt}} \sigma_{s-\text{channel}} \int L dt \]
Sequential cuts applied to isolate the s-channel signal

Used signal/√bkg as figure of merit

Cut-based Selection

- Double-tagged events
- $30 < m_{\text{top},j_2} < 247$ GeV/$c^2$
- $p_T(j_1,j_2) < 189$ GeV/$c$
- $m_T(\text{top}) < 111$ GeV
- $0.43 < \Delta R(b - \text{jet}_1, b - \text{jet}_2) < 3.6$
- $123 < m_{\text{top},j_1} < 788$ GeV/$c^2$
- $0.74 < \Delta R(b - \text{jet}_1, \text{lepton}) < 4.68$
Search for s-channel Single Top-Quark Production

Result

**Results**

- 16 signal & 289 background final events, $S/\sqrt{B} = 0.94$
- *Profile Likelihood* used to extract the cross section limit:
  \[
  \sigma_{s-chan} < 26.5 \text{ pb}
  \]

**Possible Improvements**

- Use the full LHC dataset
- Add single-tagged events
- New *b*-tagger (better c separation)
- Reduce systematic uncertainties

<table>
<thead>
<tr>
<th>Source of Systematic Uncertainties</th>
<th>$\Delta \sigma / \sigma$ [%] cut-based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data statistics</td>
<td>\pm 100</td>
</tr>
<tr>
<td>MC statistics</td>
<td>\pm 70</td>
</tr>
<tr>
<td>$b$-tagging</td>
<td>-30/+20</td>
</tr>
<tr>
<td>Jet and lepton modeling</td>
<td>-20/+10</td>
</tr>
<tr>
<td>MC generator modeling</td>
<td>-60/+20</td>
</tr>
<tr>
<td>Multijets normalization</td>
<td>\pm 40</td>
</tr>
<tr>
<td>Others</td>
<td>-10/+30</td>
</tr>
<tr>
<td>Luminosity</td>
<td>\pm 50</td>
</tr>
<tr>
<td>All systematics</td>
<td>-110/+90</td>
</tr>
<tr>
<td>Total uncertainty</td>
<td>-160/+150</td>
</tr>
</tbody>
</table>
Search for $tb$ Resonances

Benchmark Model

**Right-handed $W'_R$**

- A right-handed $W'_R$ with Standard Model-like couplings is chosen as the benchmark model for the search for $tb$ resonances.

- Next-to-leading-order (NLO) branching ratio and production $W'_R$ cross section values estimated by Zack Sullivan

<table>
<thead>
<tr>
<th>$m_{W'_R}$ [GeV]</th>
<th>$\mathcal{B}(W'_R \rightarrow tb)$</th>
<th>$\sigma \times \mathcal{B}$ [pb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>0.298 ± 0.002</td>
<td>54.6 ± 2.1</td>
</tr>
<tr>
<td>750</td>
<td>0.319 ± 0.001</td>
<td>10.9 ± 0.6</td>
</tr>
<tr>
<td>1000</td>
<td>0.326 ± 0.001</td>
<td>2.92 ± 0.18</td>
</tr>
<tr>
<td>1250</td>
<td>0.328 ± &lt; 0.001</td>
<td>0.91 ± 0.07</td>
</tr>
<tr>
<td>1500</td>
<td>0.330 ± &lt; 0.001</td>
<td>0.31 ± 0.03</td>
</tr>
<tr>
<td>1750</td>
<td>0.331 ± &lt; 0.001</td>
<td>0.11 ± 0.01</td>
</tr>
<tr>
<td>2000</td>
<td>0.332 ± &lt; 0.001</td>
<td>0.044 ± 0.005</td>
</tr>
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</table>

Same event selection and bkg estimation than the s-channel analysis

- **Pre-tagged**
- **Single-tagged**
- **Double-tagged**

### Single- and double-tagged events used in the analysis

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<tr>
<th>$m_{W'}$ [GeV]</th>
<th>Single-tagged</th>
<th>Double-tagged</th>
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<tbody>
<tr>
<td>500</td>
<td>973±37</td>
<td>455±17</td>
</tr>
<tr>
<td>750</td>
<td>174±9</td>
<td>77±4</td>
</tr>
<tr>
<td>1000</td>
<td>42±3</td>
<td>15±1</td>
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<td>1120±560</td>
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<td>$t\bar{t}$</td>
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<td>360±30</td>
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<td>120±10</td>
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<td>Diboson, Z+jets</td>
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<td><strong>Total prediction</strong></td>
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<td><strong>830±190</strong></td>
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<td>Data</td>
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Search for \( tb \) Resonances

**Background Modeling and Event Yields**

- **Same event selection and bkg estimation than the s-channel analysis**

**Pre-tagged**

**Single-tagged**

**Double-tagged**

- **Single- and double-tagged** events used in the analysis

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Search for *tb* Resonances

Bumphunter

- The BUMPHUNTER tool is used in this analysis ([http://arxiv.org/abs/1101.0390](http://arxiv.org/abs/1101.0390)) to search for any excess in the data events caused by *tb* resonances
- Data and MC comparisons over $m_{tb}$:
  - One **background template**
  - One **data template**
  - Single and double tagged events separate

![Single-tagged](image1)

![Double-tagged](image2)

- No significant data excess has been identified
Search for *tb* Resonances

**Results**

- **Set limits** on the $\sigma(pp \rightarrow W'_R) \times B(W'_R \rightarrow tb)$ at 95% CL
- Determined using Bayesian approach
- The method uses a **Binned Likelihood** function:

\[
L(data|\sigma B, \theta_i) = \prod_{k=1}^{N_{bin}} \frac{\mu_k^{n_k} e^{-\mu_k}}{n_k!} \prod_{i=1}^{N_{sys}} G(\theta_i, 0, 1)
\]

- **Observed (expected)** $\sigma \times B$ limits:
  6.1-1.0 (4.5-1.4) pb for $W'_R$
  masses from 0.5 to 2.0 TeV
- **Observed (expected) lower mass limit** is: $m_{W'_R} > 1.13\ (1.13)$ TeV

**Possible Improvements**

- Use the full **LHC** dataset
- Signal **optimization**
- Search also for **left-handed** $W'$
• Presented the latest ATLAS results on:
  • Search for s-Channel Single Top-Quark with 0.7 fb$^{-1}$
    \[ \sigma_{s-chan} < 26.5 \text{ pb} \]
  • Search for $tb$ resonances with 1.04 fb$^{-1}$
    \[ m_{W_R} > 1.13 \text{ TeV} \]

• Work ongoing to update and improve the results

• Focus on:
  • $b$-tagging algorithms
  • Optimization to \textit{isolate the signal} (more sophisticated techniques)
  • \textit{Reduce} the impact of systematics

Stay tuned for future results!!
THANK YOU
VERY MUCH
FOR YOUR ATTENTION!!
The s-channel single top results presented as a CONF Note:

- **Title:** Search for s-Channel Single Top-Quark Production in pp Collisions at sqrt(s) = 7 TeV
- **Authors:** ATLAS Collaboration
- **Report-no:** ATLAS-CONF-2011-118
- **Link:** https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-118/

The \( tb \) resonances research submitted to PRL:

- **Title:** Search for \( tb \) resonances in proton-proton collisions at sqrt(s) = 7 TeV with the ATLAS detector
- **Authors:** ATLAS Collaboration
- **Report-no:** CERN-PH-EP-2012-087
- **Link:** http://arxiv.org/abs/1205.1016
**Background Estimation: QCD Muon sample**

- $E_T^{\text{miss}}$ fitting method used for normalization
  - The **muon QCD shape**, on the fitting, is taken from the jet-electron sample.

- The **QCD shape** for the analysis is also taken from the jet-electron sample.
Search for $tb$ Resonances

Systematics

- ISR/FSR
- JES, JER, JETreco
- Lepton Scale factors
- PDF, Generator and Parton Shower
- $b$-tagging and Mistag scale factor
- $t\bar{t}$, $Wt$, t-chan, $Z+$jets and diboson theory cross section
- QCD normalization (50% and 100%)
- $m_{tb}$ shape
- $W+$jets shape
- $W+$jets normalization
- Lumi 3.7%