First observation of single top production in association with a W boson in pp collisions at 8 TeV by the CMS experiment

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Single Top at the LHC

Top quarks can be produced singly (through the electroweak interaction via three production channels) or in pairs:
- t-channel
- s-channel
- tW
- t̅t̅ pair

Top quark decays almost exclusively to a b quark and a W boson. In the dilepton final state, both W bosons decay into a lepton (e or μ) and a neutrino.

Final State:
- b-jet from top quark decay
- Two oppositely charged leptons (eμ/μμ/ee)
- E_\text{miss} from neutrinos

Jet Selection:
- Anti-k_t algorithm
- Transverse momentum p_T > 30 GeV
- Pseudorapidity |η| < 2.4
- Tagged as coming from a b quark (b-tagged) based on combined secondary vertex tagger

Lepton Selection:
- Transverse momentum p_T > 20 GeV
- Pseudorapidity |η| < 2.4
- Isolated from other particles
- Oppositely Charged

Signal and Control Regions:
- One tag: 1j1t
- Two tags: 2j1t, 2j2t
- Invariant mass of leptons, m_{eμ/μμ/ee} > 20 GeV
- Three regions (1j1t, 2j1t, 2j2t)

Event Selection

Numerous processes provide similar event signatures and have much larger cross sections:
- t̅t̅ pair
- Diboson W+W/W/Z
- Z+jets
- Single top

The most significant background is by far t̅t̅, the difference is only a matter of one b-jet at LO.

Backgrounds

Cross sections:
- LHC: pp @ 7 TeV
  - 63.9 ± 5.0
  - 15.6 ± 1.6
- LHC: pp @ 8 TeV
  - 87.2 ± 5.5
  - 22.2 ± 2.4

Cross sections for single top and top pair production at the LHC and Tevatron

This analysis studies the production of a single top quark in association with a W boson (tW). Evidence for this process was seen by both ATLAS and CMS using 7 TeV data. This analysis uses data collected by the CMS experiment at a center of mass energy of 8 TeV, corresponding to an integrated luminosity of 12.2 fb^{-1}.

Multivariate Analysis

After event selection a Boosted Decision Tree (BDT) was trained to discriminate between the tW signal and t̅t̅ background, using the input variables:

<table>
<thead>
<tr>
<th>Input variables selected based on discrimination power as well as agreement in data and MC.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of loose jets, n_{j}\leq 4 (temp)</td>
</tr>
<tr>
<td>Number of loose jets, n_{j}\leq 5 (temp)</td>
</tr>
<tr>
<td>Binary tag: b-tagged jet</td>
</tr>
<tr>
<td>Binary tag: non-b-tagged jet</td>
</tr>
<tr>
<td>Number of loose jets, n_{\text{jet}} &gt; 2 (temp)</td>
</tr>
<tr>
<td>Vector sum of all leptons, jets, and p_{T}\text{miss}</td>
</tr>
<tr>
<td>p_{T}\text{miss} of the leading, highest-boosted b</td>
</tr>
<tr>
<td>p_{T}\text{miss} of the leading jet</td>
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<tr>
<td>Ratio of p_{T}\text{miss} to 1/f_{W}</td>
</tr>
<tr>
<td>R_{0}</td>
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<tr>
<td>p_{T} of leading jet</td>
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<tr>
<td>R_{0} of leading jet</td>
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<tr>
<td>p_{T} of highest boost jet (for events with no loose jet present)</td>
</tr>
<tr>
<td>Rate of p_{T}\text{miss} to 1/f_{W}</td>
</tr>
<tr>
<td>R_{0} of leading jet and p_{T} of highest boost jet</td>
</tr>
<tr>
<td>Ratio of p_{T}\text{miss} to the R_{0} of the leading jet</td>
</tr>
</tbody>
</table>

Lepton Selection:
- Invariant Mass of leptons, m_{eμ/μμ/ee} > 20 GeV
- Veto event 81 < m_{eμ/μμ/ee} < 101 GeV

Additional Cuts:
- Invariant Mass of leptons, m_{eμ/μμ/ee} > 20 GeV
- Veto event 81 < m_{eμ/μμ/ee} < 101 GeV
- E_\text{miss} > 30 GeV

Event Selection:
- tW dilepton Feynman diagram

Distributions of number of loose jets (top) and p_{T}\text{miss} (bottom) variables in the 1j1t, 2j1t, and 2j2t regions

The BDT returns a single discriminant for each event. Signal-like events have a higher value, background-like events get a lower value.

Distributions of BDT discriminant in the 1j1t, 2j1t, and 2j2t regions

A binned likelihood fit to the shape of the BDT discriminant is performed to extract cross section and significance.

- Simultaneous fit to three channels (eμ/μμ/ee) and three regions (1j1t, 2j1t, 2j2t)
- Templates are taken from simulation
- Systematic uncertainties taken into account based on changes to shapes of templates and treated as nuisance parameters

Results

First observation at a significance of at least 5 σ. An excess of events is observed with a probability of 5 \times 10^{-8} coming from a background-only hypothesis.

Observation with significance of 6.1 σ

Expected significance of 5.4 ± 1.4 σ.

Number of events passing event selection for simulation and data for all three dilepton channels combined. Statistical (first) and systematic (second) uncertainties are quoted for simulation estimates

Cross section is measured to be σ = 23.4 ± 5.4 pb, in agreement with the standard model prediction of σ = 22.2 ± 0.6 ± 1.4 pb.\textsuperscript{b}

An estimate of the CKM matrix element, |V_{tb}|, is extracted under the assumption that |V_{cb}| is much larger than |V_{ub}| and |V_{ub}|

\[ |V_{tb}| = \frac{1.03 \pm 0.12\text{ (exp.) \pm 0.04\text{ (th.)}}}{1.0} \]

Cross-check analyses produce consistent results with those from the BDT analysis:

- Fit to the distribution of p_{T}\text{miss}
- Fit to event yields

References:

http://arxiv.org/pdf/1401.2942