Single top production at ATLAS and CMS

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La Thuile, 17-24 March, 2018
LHC is the top **factory**
- Large integrated luminosity accumulated by experiments
- Excellent detector performance
- Single-top analyses enter precision domain
- Investigation of rare processes

Single top quark production at the LHC

**t-channel**
- 73% @ 13 TeV

**tW-channel**
- 24% @ 13 TeV

Most recent results from **ATLAS and CMS**
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- Excellent detector performance
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**Single top quark production at the LHC**

- **t-channel**
  - 73% @ 13 TeV

- **tW-channel**
  - 24% @ 13 TeV

- **s-channel**
  - 3%

- **tZq-channel**
  - <1% @ 13 TeV

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### CMS Integrated Luminosity, pp

Data included from 2010-03-30 11:22 to 2017-11-10 14:09 UTC

- 2010, 7 TeV, 45.0 fb⁻¹
- 2011, 7 TeV, 6.1 fb⁻¹
- 2012, 8 TeV, 23.3 fb⁻¹
- 2015, 13 TeV, 4.2 fb⁻¹
- 2016, 13 TeV, 40.8 fb⁻¹
- 2017, 13 TeV, 51.0 fb⁻¹

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Most recent results from **ATLAS and CMS**
• Second largest single-top production mode at the LHC
• Sensitive to b quark PDF and CKM matrix element $V_{tb}$

• Typically studied decay mode:
  • 2 isolated high-$p_T$ leptons
  • 1 b tagged jet
  • $E_T$

• Simultaneous fit to the BDT output (in 1j1b and 2j1b) and sub-leading jet transverse momentum distributions is performed in order to extract signal and constrain systematics
Similar strategy employed by ATLAS earlier using 3.2 fb\(^{-1}\) of 2015 data

Main sources of systematic uncertainty

ATLAS:
- Jet-energy-scale
- ME generator choice

CMS:
- Lepton efficiency
- ME Scale variations

\[ \sigma_{\text{CMS}} = 63.1 \pm 1.8(\text{stat.}) \pm 6.0(\text{syst.}) \pm 2.1(\text{lumi.}) \text{ pb} \quad 10\% \]

\[ \sigma_{\text{ATLAS}} = 94 \pm 10(\text{stat.})^{+28}_{-22}(\text{syst.}) \pm 2(\text{lumi.}) \text{ pb} \quad 29\% \]

\[ \sigma_{\text{theory}} = 71.7 \pm 1.8(\text{scale}) \pm 3.4(\text{PDF}) \text{ pb} \quad 5\% \]

Both measurements consistent with the SM predictions
The first differential measurement of $tW$ production

- Measured cross sections as functions of:
  - $E(b)$, $m(l_1b)$, $m(l_2b)$
  - $E(llb)$, $m_T(ll
\nu\nu b)$

- Comparable statistical and systematic uncertainties

- Main sources of systematics:
  - $tt$, $tW$ modelling

- Reasonable agreement with MC predictions within uncertainties
- Slightly harder $E(llb)$ spectrum in data
tZ production

- Rare process: 2 orders of magnitude smaller than tW
- Sensitive to top-Z and triple gauge boson WWZ coupling
- Possible deviations may indicate physics beyond the Standard Model (FCNC, anomalous couplings)
- Typically studied decay mode:
  - 3 isolated high-\( p_T \) leptons
  - 1 b tagged jet
  - \( E_T^{miss} \)
- Main backgrounds from \( t\bar{t}V, WZ \) and non-prompt lepton production
tZ@13 TeV

arXiv:1710.03659

- 3l channel
- Z candidate
- 1 b jet and 1 untagged jet
- Search region:
  - $|m(ll) - m(Z)| > 10$ GeV
- Diboson control region:
  - 0 b jets
  - $m_T(l_W, \nu) > 60$ GeV
- $t\bar{t}$ control region:
  - ≥1 OSDF pair
  - No OSSF
  - 1 b jets

Signal is extracted from the fit to ANN output

ANN trained on the mixture of all backgrounds, except $t\bar{t}$

Modelling of the backgrounds is checked in dedicated validation regions
Similar analysis carried out by CMS using BDT with MEM weights included in the list of input variables (20% improvement in expected significance). BDT is trained on mixture of backgrounds.

Main sources of systematic uncertainty:

**ATLAS:**
- PDF and shower modelling of tZq
- JES

**CMS:**
- Backgrounds normalization
- Shower modelling of tZq

\[
\sigma_{\text{CMS}}(tllq) = 123^{+33}_{-31}\text{(stat.)}^{+29}_{-23}\text{(syst.)}\ \text{fb}\quad 3.7(3.1)\sigma \text{ obs.}(\text{exp.})
\]

\[
\sigma_{\text{ATLAS}}(tZq) = 600 \pm 170\text{(stat.)} \pm 140\text{(syst.)}\ \text{fb}\quad 4.2(5.4)\sigma \text{ obs.}(\text{exp.})
\]

- First evidence of tZq production from two collaborations
- Results are consistent with the SM predictions
Events with tZq signature can be used in searches for flavour-changing neutral currents:

- 3l channel
- Z candidate

Main sources of uncertainty:
- Event modelling
- Jet-energy-scale
- b-tagging

Stringent limits on the set of branching fractions, assuming one non-vanishing coupling at a time:

\[ \mathcal{B}(t \rightarrow uZ) < 0.024\% (0.015\%) \]

\[ \mathcal{B}(t \rightarrow cZ) < 0.045\% (0.037\%) \text{ obs.} (\text{exp.}) \]
Similar analysis of only top pair production events was carried out by ATLAS.

- Simultaneous template fit to the $\chi^2$ of the kinematic reconstruction.
- Main sources of uncertainty:
  - Event modelling
  - Jet-energy-scale

- ATLAS and CMS have similar experimental sensitivity

\[
\mathcal{B}(t \to uZ) < 0.017\% (0.024\%)
\]
\[
\mathcal{B}(t \to cZ) < 0.023\% (0.032\%) \quad \text{obs. (exp.)}
\]

- Stringent limits on the set of branching fractions, assuming one non-vanishing coupling at a time.
FCNC summary

- Searches for FCNC using 13 TeV datasets
- Channels involving Higgs and Z boson as the mediator of FC transition are explored
- Stringent constraints on FCNC in studied channels.
- Sensitivity to some BSM models can be achieved with larger datasets
SUMMARY

- Recent SM measurements using 13 TeV datasets
  - Inclusive and differential tW measurements and evidence for tZ production
  - Good agreement with the state-of-the-art theoretical predictions

- Single Top results sensitive to physics beyond the SM:
  - Searches for flavour-changing neutral currents
  - Unfortunately, no evidence for BSM physics so far
BACKUP
Single top quark production at the LHC

ATLAS+CMS Preliminary
LHCtopWG

Single top-quark production
November 2017

Inclusive cross-section [pb]

10^2

10

1

7 8 13

\sqrt{s} [TeV]

\begin{itemize}
  \item ATLAS t-channel
    \begin{itemize}
      \item PRD 95 (2017) 115001, EPJC 77 (2017) 531,
      \item JHEP 04 (2017) 066
    \end{itemize}
  \item CMS t-channel
    \begin{itemize}
      \item JHEP 12 (2012) 136, JHEP 06 (2014) 000,
      \item PLB 772 (2017) 752
    \end{itemize}
  \item ATLAS tW
    \begin{itemize}
      \item PLB 716 (2012) 142, JHEP 01 (2016) 064,
      \item arXiv:1612.07233
    \end{itemize}
  \item CMS tW
    \begin{itemize}
      \item PRL 112 (2014) 072001, PRL 118 (2017) 251802,
      \item PTEP 17-018
    \end{itemize}
  \item LHC combination, tW
    \begin{itemize}
      \item ATLAS-CONF-2016-023, CMS-PAS-TOP-15-019
    \end{itemize}
  \item ATLAS s-channel
    \begin{itemize}
      \item ATLAS-CONF-2011-018 95% CL,
      \item PLB 736 (2014) 236
    \end{itemize}
  \item CMS s-channel
    \begin{itemize}
      \item JHEP 05 (2016) 037 95% CL,
      \item 7+13 TeV combined 89% CL
    \end{itemize}
\end{itemize}

\begin{itemize}
  \item NNLO: PLB 736 (2014) 158
  \item scale uncertainty
  \item NLO + NNLL: PRD 84 (2011) 095003,
  \item tW: \textit{f} contribution removed
  \item scale @ PDF @ \alpha_s uncertainty
  \item NLO: NNPDF2.3lo
     \begin{itemize}
       \item \textit{f} delo, \textit{F}_{\textnormal{rem}}=0.60 GeV, \textit{p}_{t_{\textnormal{rem}}}^{\textnormal{min}}=0.65 GeV
     \end{itemize}
  \item scale uncertainty
  \item scale @ PDF @ \alpha_s uncertainty
  \item m_{t_{\textnormal{pole}}} = 172.5 GeV
\end{itemize}
FCNC summary

<table>
<thead>
<tr>
<th>Channel</th>
<th>ATLAS 8 (13) TeV</th>
<th>CMS 8 (13) TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t \rightarrow H_c$</td>
<td>5.6 (2.2) × 10^{-3}</td>
<td>4.0 × 10^{-3}</td>
</tr>
<tr>
<td>$t \rightarrow H_u$</td>
<td>5.6 (2.4) × 10^{-3}</td>
<td>5.5 × 10^{-3}</td>
</tr>
<tr>
<td>$t \rightarrow \gamma c$</td>
<td>1.7 × 10^{-4}</td>
<td></td>
</tr>
<tr>
<td>$t \rightarrow \gamma u$</td>
<td>1.3 × 10^{-4}</td>
<td></td>
</tr>
<tr>
<td>$t \rightarrow g c$</td>
<td>2.0 × 10^{-4}</td>
<td>4.1 × 10^{-4}</td>
</tr>
<tr>
<td>$t \rightarrow g u$</td>
<td>4.0 × 10^{-5}</td>
<td>2.0 × 10^{-5}</td>
</tr>
<tr>
<td>$t \rightarrow Z c$</td>
<td>7.0 (1.7) × 10^{-4}</td>
<td>4.9 (2.3) × 10^{-4}</td>
</tr>
<tr>
<td>$t \rightarrow Z u$</td>
<td>7.0 (2.3) × 10^{-4}</td>
<td>2.2 (1.7) × 10^{-4}</td>
</tr>
</tbody>
</table>

Stringent constraints on FCNC in different channels. Sensitivity to some BSM models can be achieved with larger datasets.