Top-Quark Properties
Measurements with the ATLAS Detector

1. Top-quark Charge Asymmetry
2. Search for Flavor Changing Neutral Currents (FCNC) in top-quark decays

Antonio Limosani
On behalf of the ATLAS collaboration
Understanding the top-quark @ LHC

- Heaviest particle, Yukawa coupling \( \approx 1 \)
- Potential role in electroweak symmetry breaking and beyond standard model physics (BSM)
- Top-quark properties are sensitive probes of BSM
  - **Charge asymmetry** in top-quark products
  - **Flavor Changing Neutral Currents** decays of top quarks
- Today showing results from 8 TeV proton proton collisions collected in Run 1 of the LHC

<table>
<thead>
<tr>
<th>Cross-section</th>
<th>@ ( \sqrt{s} = 8 \text{ TeV} )</th>
<th>pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma(gg \to tt) )</td>
<td>( \approx 212 )</td>
<td></td>
</tr>
<tr>
<td>( \sigma(q\bar{q} \to tt) )</td>
<td>( \approx 38 )</td>
<td></td>
</tr>
<tr>
<td>( \sigma(pp \to tt) )</td>
<td>( \approx 250 )</td>
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</table>
Top Quark Pair Charge Asymmetry

Measure anisotropy in (anti-)top production with respect to incoming (anti-)quark direction.
SM Asymmetries

- Standard Model QCD high order processes introduce charge asymmetry ($\alpha_s^3$)
- Interference
  - (a) & (b) : ISR and FSR
  - (c) & (d) : Box and tree
- Angle between incoming quark and outgoing top sensitive to interference
- Gluon-induced top production induces no asymmetries
BSM Asymmetries

BSM particle contributions to asymmetries

* To be visible in QCD top pair production new particle should couple strongly enough to both the 1st generation quarks and to the top quarks.

* To generate a charge asymmetry new particle should couple differently to left- and right-handed quarks.

**s-channel**

**Axigluon**
Delaunay, Gedalia, Lee, Perez & Ponton

**Kaluza-Klein excitation:**
Delaunay, Gedalia, Lee, Perez & Ponton

**t-channel**

**Gauge Boson**
Shelton, Zurek
Phys.Rev. D83 (2011) 091701

**Color triplet**
Ligeti, Tavares, Schmaltz
JHEP 1106 (2011) 109
15% of collisions are quark and anti-quark

Incoming quark direction not known in pp collisions

Valence quarks more likely than sea quarks

More valence quarks vs sea anti-quarks collisions

Valence quarks have larger fraction of momentum

\[ \Delta |y| = |y_t| - |y_{\bar{t}}| \]

\[ A^{t\bar{t}}_C = \frac{N(\Delta |y| > 0) - N(\Delta |y| < 0)}{N(\Delta |y| > 0) + N(\Delta |y| < 0)} \]

\[ A^{t\bar{t}}_C = 0.0111 \pm 0.0004 \text{ (NLO QCD)} \]

\[ \Delta |\eta| = |\eta_+| - |\eta_-| \]

\[ A^{ll}_C = \frac{N(\Delta |\eta| > 0) - N(\Delta |\eta| < 0)}{N(\Delta |\eta| > 0) + N(\Delta |\eta| < 0)} \]

\[ A^{ll}_C = 0.0064 \pm 0.0003 \text{ (NLO QCD)} \]
ATLAS Detector

Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker
Charge Asymmetry Measurements @ 8 TeV

Channels

lepton+jets $pp \rightarrow t\bar{t} \rightarrow W(\rightarrow l\nu)bW(\rightarrow qq)b$

dilepton $pp \rightarrow t\bar{t} \rightarrow W(\rightarrow l\nu)bW(\rightarrow l\nu)b$

Boosted lepton+jets $m_{t\bar{t}} > 750$ GeV

Reconstruction methods

lepton+jets Likelihood fit

dilepton KIN method

Boosted lepton+jets tailored technique

Interpretation

Iterative Bayesian unfolding to transform back to parton level: Fully Bayesian Unfolding (FBU): https://pypi.python.org/pypi/fbu/0.0.2

Systematics encoded into nuisance parameters and marginalised and none of the measurements are using regularization

Data

20.3/fb @ 8 TeV

Simulation top-pair

QCD NLO

Powheg-hvq (r233o)

CT10 PDF

$h(damp) = 172.5$ GeV
Charge Asymmetry @ 8 TeV l+jets

- Inclusive and differential measurements of the top-pair system in
  - invariant mass,
  - $p_T$ and
  - longitudinal boost $\beta_z$

- Consistent with SM expectations
- Constraining many BSM scenarios: $W'$ boson, a heavy axigluon ($G_\mu$), scalar isodoublet ($\phi$), colour-triplet scalar ($\omega^4$), and colour-sextet scalar ($\Omega^4$)

$A_C = 0.009 \pm 0.005$ (stat. + syst.)

- Statistical uncertainty dominates
- Leading systematic is signal modelling
**Boosted Tops @ 8 TeV l+jets**

- Boosted tops where top quark pair invariant mass $> 750$ GeV
- Boost favours $qq'$ top pair production providing higher sensitivity to SM asymmetry and BSM heavy particles
- Single large-$R$ jet and tagged using jet substructure variables.
- Hadronically decaying top quark is reconstructed as a single trimmed jet with $R = 1.0$.
- Selected jet must have $p_T > 300$ GeV, must be well separated from both the charged lepton ($\phi(l,\text{jet}_{R=1.0}) > 2.3$)
- Top-quark pair mass resolution is approximately 6% above 1 TeV
- Measurement agrees with SM
- Precision limited by signal modelling systematic uncertainty. Challenge to improve them in Run 2.

\[
m_{t\bar{t}} > 0.75 \text{ GeV} \\
-2 < \Delta|y| < 2 \\
A_C = (4.2 \pm 3.2)\% \\
\text{SM: } (1.60 \pm 0.04)\%
\]
Dilepton @ 8 TeV

- Two sets of observables
  - selected leptons
  - reconstructed top-quark pair system
- Inclusive and differential measurements in invariant mass, $p_T$ and longitudinal boost $\beta_z$
- Full phase space for comparisons at parton level
- Fiducial region using particle level objects (less model dependent by avoiding extrapolation)

Precision is dominated by statistical uncertainty

Measurements are compatible with the SM and do not exclude the two sets of BSM models considered
Flavour Changing Neutral Currents in Top

- In SM forbidden at tree level and highly suppressed $O(10^{-14})$ due to GIM mechanism
- BSM with new sources of flavour predict higher rates

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arXiv:1311.2028v1
FCNC $t \rightarrow H q @ 8$ TeV

- Isolated electron or muon, at least 4 jets

$$t \bar{t} \rightarrow W(\rightarrow l \nu)bH(\rightarrow bb)q$$

- Exploit high b-quark jet multiplicity

- Likelihood discriminant to suppress

$$t \bar{t} \rightarrow W(\rightarrow l \nu)bW(\rightarrow qq)b$$

- Define event categories based on jet, b-jet multiplicity

- No significant excess of events above background

- $\text{Br}(t \rightarrow Hc) < 5.6 (4.2) \times 10^{-3}$ observed(expected)

- $\text{Br}(t \rightarrow Hu) < 6.1 (6.4) \times 10^{-3}$ observed(expected)
FCNC $t \rightarrow Zq \ @ 8 \ TeV$

- 3 isolated electrons or muons, at least 2 jets, some missing transverse energy
- One or two b-tagged jets (mis-identified c from $t \rightarrow Zc$)
- Two or three reconstructed jets (third from ISR/FSR)
- Kinematics of the top quarks can be reconstructed from the corresponding decay particles; Form $\chi^2$ to determine neutrino $p_z$
- Control regions used to assign background modelling uncertainties, which are the dominant systematics.

$tt \rightarrow W(\rightarrow l\nu)bZ(\rightarrow ll)q$

$\begin{array}{|c|c|c|c|c|c|c|}
\hline
\text{Model} & \text{SM} & \text{QS} & \text{2HDM FC} & \text{2HDM MSSM} & \text{RS SUSY} & \text{RS} \\
\hline
\text{BR}(t \rightarrow qZ): & 10^{-14} & 10^{-4} & 10^{-6} & 10^{-10} & 10^{-7} & 10^{-6} & 10^{-5} \\
\hline
\end{array}$
**FCNC tops**

The t→qg coupling is also sensitive to 2HDMs.

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Summary

• ATLAS Charge asymmetry measurements consistent with SM, yet ruling out parameter space in many BSM scenarios

• ATLAS FCNC top decays providing improved upper limits and beginning to reach sensitivity of ruling out BSM scenarios

• Most run 1 measurements limited by statistics, look forward to Run 2 results, in particular with more highly boosted top-quarks
Top-pair Production Event

Objects

- Single lepton trigger
- Isolated lepton
- \( W \) using \( E_T^{\text{miss}} \)
- Anti-\( k_T \) R=0.4 jets
- At least one b-tagged jet

Backgrounds

- \( W + \text{jets} \) (data driven)
- QCD Multijet (data driven)
- Single Top, Z+jets, Diboson (MC)

Requirements for top charge measurement

- Measure b-jet charge
- Measure lepton charge
- Pair lepton and b-jet