TOP PROPERTIES AND MASS MEASUREMENTS WITH THE ATLAS DETECTOR.

Elizabeth Brost (NIU)
on behalf of the ATLAS Collaboration
THE TOP QUARK

- Heaviest fundamental particle
- Short lifetime - unique opportunity to study a bare quark
- High pair-production ($t\bar{t}$) rate at the LHC
  - categorize $t\bar{t}$ events by the $W$ boson decays ($\ell$+jets, dilepton, all-hadronic)
TOP PROPERTIES AND MASS MEASUREMENTS WITH ATLAS

- Charge asymmetry in $t\bar{t}$ events
- Top and $W$ polarization in $t\bar{t}$ events
- Searches for the flavor-changing neutral current
- Top quark mass measurements
CHARGE ASYMMETRY IN TTBAR EVENTS
CHARGE ASYMMETRY IN TTBAR EVENTS

WHAT IS CHARGE ASYMMETRY?

- Charge asymmetry $A_C = \frac{N(\Delta |y| > 0) - N(\Delta |y| < 0)}{N(\Delta |y| > 0) + N(\Delta |y| < 0)}$

- Standard Model: Top pair production via gluon fusion (dominant at LHC) is charge-symmetric. The difference in momentum carried by valence and sea quarks leads to a small, positive charge asymmetry @ LHC due to $q\bar{q} \to t\bar{t}$

- BSM: Heavy particles which couple to the $t\bar{t}$ system could induce a larger charge asymmetry $\to$ probe this scenario by measuring $A_C$ as a function of the $t\bar{t}$ mass, $m_{t\bar{t}}$

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CHARGE ASYMMETRY IN TTBAR EVENTS

DILEPTON (ARXIV:1604.05538)

- Measure charge asymmetry $A_C$ with two observables:
  - $A_{\ell\ell}^C$ - leptons only
  - $A_{t\bar{t}}^C$ - requires reconstruction of the $t\bar{t}$ system

- Differential measurements of $A_C$ with respect to $t\bar{t}$ mass ($m_{t\bar{t}}$), longitudinal boost ($\beta_{t\bar{t}}^z$), and transverse momentum ($p_T^{t\bar{t}}$)

- Inclusive measurements:
  - $A_{\ell\ell}^C = 0.008\pm0.006$ (SM: $0.0064\pm0.003$)
  - $A_{t\bar{t}}^C = 0.021\pm0.016$ (SM: $0.0111\pm0.0004$)
**CHARGE ASYMMETRY IN TTBAR EVENTS**

**ℓ+JETS (ARXIV:1509.02358)**

- **Selection:** 1 lepton (e or μ), ≥4 jets, MET
- **Differential measurements of** $A_C$ **with respect to** $t\bar{t}$ mass ($m_{t\bar{t}}$), longitudinal boost ($\beta_{z,t\bar{t}}$), and transverse momentum ($p_{T,t\bar{t}}$)
- **Inclusive** $A_C = 0.009\pm0.005$ (**SM:** $0.0111\pm0.0004$)
BOOSTED TOPOLOGY ($\ell$+JETS) (ARXIV:1512.06092)

- Reconstruct hadronic top quark candidate as one large jet

- Differential measurement of $A_C$ with respect to $t\bar{t}$ mass ($m_{t\bar{t}}$), for large $m_{t\bar{t}}$ (> 0.75 TeV)

- $A_C = 4.2 \pm 3.2\%$ (SM: $1.60 \pm 0.04\%$)

- -2 < $|y_t| - |y_{t\bar{t}}|$ < 2

- Can confirm or exclude new physics

![Graph showing $A_C$ vs $m_{t\bar{t}}$ interval]
POLARIZATION IN TTBAR EVENTS
TOP POLARIZATION (ARXIV:1307.6511)

- Measure top polarization in single- and di-lepton candidate $t\bar{t}$ events, for CP-conserving and CP-violating hypotheses.
- The top quarks decay before hadronization, so their polarization can be probed through their decay products.
- Results (SM: $\alpha_\ell P = \text{negligible}$):
  - $\alpha_\ell P_{\text{CPC}} = -0.035 \pm 0.014\text{(stat.)} \pm 0.037\text{(syst.)}$
  - $\alpha_\ell P_{\text{CPV}} = 0.020 \pm 0.016\text{(stat.)} ^{+0.013}_{-0.017}\text{(syst.)}$
Compare W boson helicity observables (cos θ*, W helicity fractions) in data to Standard Model expectations, for single- and di-lepton candidate t̄t̄ events

θ* = angle between charged lepton and bottom quark, boosted to W boson rest frame
THE FLAVOR-CHANGING NEUTRAL CURRENT
**WHY SEARCH FOR FCNC WITH TOP QUARKS?**

- FCNCs are forbidden at tree-level in the Standard Model
  - SM rate is not observable with current dataset
- Any observation of FCNC would be indicative of new physics
- Many processes to probe at the LHC, both in top quark production \( (qg \rightarrow t) \) and decay \( (t \rightarrow q\gamma, qZ, qH, \text{and } qg) \)

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<table>
<thead>
<tr>
<th>Process</th>
<th>SM</th>
<th>2HDM(FV)</th>
<th>2HDM(FC)</th>
<th>MSSM</th>
<th>RPV</th>
<th>RS</th>
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<tr>
<td>( t \rightarrow Zu )</td>
<td>(7 \times 10^{-17})</td>
<td>-</td>
<td>-</td>
<td>(\leq 10^{-7})</td>
<td>(\leq 10^{-6})</td>
<td>(\leq 10^{-5})</td>
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<tr>
<td>( t \rightarrow Zc )</td>
<td>(1 \times 10^{-14})</td>
<td>(\leq 10^{-6})</td>
<td>(\leq 10^{-10})</td>
<td>(\leq 10^{-7})</td>
<td>(\leq 10^{-6})</td>
<td>-</td>
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<tr>
<td>( t \rightarrow gu )</td>
<td>(4 \times 10^{-14})</td>
<td>-</td>
<td>-</td>
<td>(\leq 10^{-7})</td>
<td>(\leq 10^{-6})</td>
<td>-</td>
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<tr>
<td>( t \rightarrow gc )</td>
<td>(5 \times 10^{-12})</td>
<td>(\leq 10^{-4})</td>
<td>(\leq 10^{-8})</td>
<td>(\leq 10^{-7})</td>
<td>(\leq 10^{-6})</td>
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<tr>
<td>( t \rightarrow \gamma u )</td>
<td>(4 \times 10^{-16})</td>
<td>-</td>
<td>-</td>
<td>(\leq 10^{-8})</td>
<td>(\leq 10^{-9})</td>
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<td>( t \rightarrow \gamma c )</td>
<td>(5 \times 10^{-14})</td>
<td>(\leq 10^{-7})</td>
<td>(\leq 10^{-9})</td>
<td>(\leq 10^{-8})</td>
<td>(\leq 10^{-9})</td>
<td>(\leq 10^{-9})</td>
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<tr>
<td>( t \rightarrow hu )</td>
<td>(2 \times 10^{-17})</td>
<td>(6 \times 10^{-8})</td>
<td>-</td>
<td>(\leq 10^{-5})</td>
<td>(\leq 10^{-9})</td>
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<td>( t \rightarrow hc )</td>
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<td>(\leq 10^{-5})</td>
<td>(\leq 10^{-5})</td>
<td>(\leq 10^{-5})</td>
<td>(\leq 10^{-4})</td>
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*Snowmass Top Working Group Report*
THE FLAVOR-CHANGING NEUTRAL CURRENT (FCNC)

TOP FCNC $t \rightarrow qZ$ (ARXIV:1508.05796)

- Selection: 3 leptons, $\geq 2$ jets, 1/2 b-jets, MET
- Event reconstruction and ranking with $\chi^2$
- No excess observed, set limit:
  - $\text{BR}(t \rightarrow qZ) < 7 \times 10^{-4}$
THE FLAVOR-CHANGING NEUTRAL CURRENT (FCNC)

**TOP FCNC t → qH (ARXIV:1509.06047)**

- Combination of three searches for $t \rightarrow qH$:
  - $H \rightarrow WW^*/\tau\tau$ (multilepton)
  - $H \rightarrow \gamma\gamma$
  - $H \rightarrow b\bar{b}$

- Observed (expected) limits:
  - $\text{BR}(t \rightarrow cH) < 4.6 \times 10^{-3} (2.5 \times 10^{-3})$
  - $\text{BR}(t \rightarrow uH) < 4.5 \times 10^{-3} (2.9 \times 10^{-3})$
TOP FCNC $qg \rightarrow t$ (ARXIV:1509.00294)

- Search for FCNC in single top production
  - Can separate contributions from up, charm quarks
- Use neural network to separate signal from background
- Set limits:
  - $\text{BR}(t \rightarrow ug) < 4 \times 10^{-5}$
  - $\text{BR}(t \rightarrow cg) < 2 \times 10^{-4}$
TOP QUARK MASS
**TOP QUARK MASS MEASUREMENTS AT ATLAS**

**ATLAS** Preliminary $m_{\text{top}}$ summary - Mar. 2015, $L_{\text{int}} = 4.6 \text{ fb}^{-1} - 20.3 \text{ fb}^{-1}$

<table>
<thead>
<tr>
<th>Channel</th>
<th>Reference</th>
<th>$L_{\text{int}}$</th>
<th>$m_{\text{top}}$</th>
<th>(stat.)</th>
<th>(JSF + bJSF + syst.)</th>
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<tr>
<td>all jets</td>
<td>arXiv:1409.0832</td>
<td>$4.6 \text{ fb}^{-1}$</td>
<td>175.1 ± 1.8</td>
<td>± 1.2</td>
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<tr>
<td>single top</td>
<td>CONF-2014-055</td>
<td>$20.3 \text{ fb}^{-1}$</td>
<td>172.2 ± 2.1</td>
<td>± 2.0</td>
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<tr>
<td>$\rightarrow$ $t\bar{t}+\text{jets}$</td>
<td>arXiv:1503.05427</td>
<td>$4.7 \text{ fb}^{-1}$</td>
<td>172.33 ± 1.27</td>
<td>(0.23 ± 0.25 ± 0.67 ± 1.02)</td>
<td></td>
</tr>
<tr>
<td>$\rightarrow$ dilepton</td>
<td>arXiv:1503.05427</td>
<td>$4.7 \text{ fb}^{-1}$</td>
<td>173.79 ± 1.41</td>
<td>(0.54 ± 1.30)</td>
<td></td>
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</table>

- Which “top mass” is measured?
- **Template method** - measure top mass as defined in MC: Fit template parameters to data and extract $m_{\text{top}}$
- **Cross section method** - extract theoretically well-defined $m_{\text{top}}$ from top cross section measurement
TOP QUARK MASS

SINGLE TOP TEMPLATE METHOD (ATLAS-CONF-2014-055)

- Use a neural network to enhance fraction of events from single top t-channel
- Template method with $m(\ell b)$ as estimator is used to extract the top quark mass
- $m_{\text{top}} = 172.2 \pm 0.7(\text{stat.}) \pm 2.0(\text{syst.})$ GeV

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## Dilepton Xsection (arXiv:1406.5375)

- Measure $\sigma_{t\bar{t}}$ in $e\mu$ candidate $t\bar{t}$ events
  - $\sigma_{t\bar{t}}$ @ 7 TeV: $182.9 \pm 7.1$ pb
  - $\sigma_{t\bar{t}}$ @ 8 TeV: $242.4 \pm 10.3$ pb
- Extracted top pole mass: $m_{top} = 172.9^{+2.5}_{-2.6}$ GeV
CONCLUSION

TOP QUARK PROPERTIES AND MASS MEASUREMENTS WITH ATLAS

- Wide variety of top searches and measurements performed by ATLAS during LHC Run 1
- Top cross section increases by ~3 going from 8 to 13 TeV
- Looking forward to more top analyses with more data (more tops!) in Run 2

FOR MORE TOPS: HTTPS://TWIKI.CERN.CH/TWIKI/BIN/VIEW/ATLASPUBLIC/TOPPUBLICRESULTS
CHARGE ASYMMETRY IN TTBAR EVENTS

CHARGE ASYMMETRY VS. FORWARD-BACKWARD ASYMMETRY

- Charge asymmetry $A_C = \frac{N(\Delta |y| > 0) - N(\Delta |y| < 0)}{N(\Delta |y| > 0) + N(\Delta |y| < 0)}$

- **LHC:**
  - top quarks are (slightly) more forward
  - anti-top quarks are (slightly) more central

- **Forward-Backward asymmetry**

- **Tevatron:**
  - anti-top quarks are (slightly) more backward
  - top quarks are (slightly) more forward
**CHARGE ASYMMETRY IN TTBAR EVENTS**

**ℓ+JETS (ARXIV:1509.02358)**

- $A_C$ vs. $A_{FB}$ with SM and various BSM scenarios (right plot is zoomed in on interesting region)

- Inclusive $A_C$: $0.009\pm0.005$ (SM: $0.0111\pm0.0004$)
TOP POLARIZATION (ARXIV:1307.6511)

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TOP QUARK MASS

SINGLE TOP TEMPLATE METHOD (ATLAS-CONF-2014-055)

- Enhance signal region with t-channel top quarks by cutting at NN > 0.75
- $m_{\text{top}} = 172.2 \pm 0.7\text{(stat.)} \pm 2.0\text{(syst.) GeV}$
In $\bar{t}t + 1$ jet candidate events:

- extract top pole mass from top cross section

$m_{\text{top}} = 173.7 \pm 1.5\,\text{(stat)} \pm 1.4\,\text{(stat)}^{+1.0}_{-0.5}\,\text{(theory)}\,\text{GeV}$

(World Average: $173.34 \pm 0.76\,\text{GeV}$)