Top physics in ATLAS

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Overview

- Introduction: Top Quark
- Production
- Mass
- Properties and Searches
- Summary
LHC: Top quark factory

- Heaviest particle of the standard model
  - Life-time shorter than hadronization time
- Privileged window to search for new physics.
- The LHC is a top quark factory.
  - More than 12M tops have been produced.
- The large number of top events allow the study of its properties.

Top quark decays almost 100% of the time in $b+\bar{W}$.

Top quark events are classified according to the decay of the $W$ bosons.
Top Quark Production
Inclusive top pair production

Many measurements of the inclusive cross-section have been performed

Experimental uncertainties smaller than the theoretical ones (~1% more precise)

ATLAS Dilepton emu measurement is the most precise measurement to date

Good agreement of all measurements with SM predictions

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/TOP/
Inclusive top pair production

13 TeV

- First measurement using 13 TeV data.
- Similar method as used for the most precise Run 1 measurement.
- Simultaneous fit cross section, $b$-jet reconstruction and tagging efficiency.
- Dominating systs: integrated lumi, top pair modelling

$$\sigma_{t\bar{t}} = 825 \pm 49\ (stat) \pm 60\ (syst) \pm 83\ (lumi)\ pb$$

- Consistent with QCD NNLO predictions
Differential top pair production

8 TeV

- Total cross-section measurements show very good agreement with the SM
  - New physics could still affect the shape
- Measurements performed in two topologies

| Resolved Topology | Boosted Topology |
|-------------------|------------------|
| Top $p_T$          | $< 300$ GeV      | $> 300$ GeV     |
| Decay products     | Well separated and can be reconstructed individually | Not well separated |
| Reconstruction     | Top reconstructed from the decay products | Top reconstructed in a single large radius jet |

![Diagram of top quark decay products and reconstruction](image)
Differential top pair production

• Top-antitop differential cross section as a function of the mass, $p_T$, rapidity of the top pair system.
  – Measurement performed in a fiducial region
  – Using particle level tops observables
• Analysis performed in the lepton+jet channel
• Data softer than MC, observed as well in the parton level analysis
Differential top pair production

8 TeV

- First cross section measurement as a function of top $p_T$ (boosted)
- Semi-leptonic channel with $p_T$ of the hadronic top $> 300$ GeV
- Boosted hadronic top defined as a single large-R jet
- Fiducial (particle level tops) and total (parton tops) phase space measurements are performed
- Measured cross section in general lower than predictions, same behavior observed in the resolved analysis

Main uncertainties:
- large-R jet energy scale
Single top production

7 and 8 TeV

Several measurements at 7 and 8 TeV have been performed

- Cross section for $t$ and $Wt$ channels
- Differential cross-section in the $t$ channel
- Upper limit for the $s$ channel
- Top/antitop $t$-channel ratio

Results are compatible with NLO+ NNLL predictions

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/TOP/
ttW and ttZ production cross sections

- Final states with two, three or four leptons are considered
  - Simultaneous fit performed in 20 signal and control regions
- The background-only hypothesis with neither ttW nor ttZ production excluded at 7.1σ
- Measurement dominated by statistical uncertainties

**ATLAS-CONF-2015-012**
Top Mass Measurements
Mass measurements

- Mass of the top is a free parameter of the SM
- Typically the mass is measured in top pair events
  - Dilepton and lepton+jet channels
- Possible to use other topologies
  - Single top in t channel
- The measurements can be done using
  - Template Fit
    - Extract the MC mass
    - Multidimensional fit reduces the JES related uncertainties
  - Normalized differential cross section of $t\bar{t} + 1$ jet to extract the pole mass.
    - The “pole” in the top quark propagator
Mass measurements
\( t\bar{t} \rightarrow l+\text{jets} \) and \( t\bar{t} \rightarrow \text{dilepton} \quad 7 \text{ TeV} \)

- Lepton + jets channel uses a three-dimensional template
  - Determines the top quark mass, JSF and bJSF
  - ATLAS’s most precise measurement
- Dilepton channel uses a one dimensional fit
- The \( l+\text{jets} \) and dilepton results are combined

\[ m_{\text{top}} = 172.99 \pm 0.48(\text{stat}) \pm 0.78(\text{syst}) \]

Main uncertainties
- lepton+jets: JES, b-tagging
- Dilepton: JES, b-quark JES

arXiv:1503.05427 submitted to EPJC
Mass measurement in single-top

8 TeV

• First measurement of top mass in single top decays
  – Reduce systematic uncertainties
• Template method using the invariant mass of the lepton and $b$-jet
• Using neural network to optimize the purity ~50%
• Main uncertainties: JES, Hadronisation, $W+$jets bgr.

$m_{\text{top}} = 172.2 \pm 0.7(\text{stat.}) \pm 2.0(\text{syst.})\,\text{GeV}$
Pole mass measurement in $t\bar{t}+\text{jets}$

- Hard gluon radiation of top quark depends on mass of the top

\[ \mathcal{R}(m_t^{\text{pole}}, \rho_s) = \frac{1}{\sigma_{t\bar{t}+1\text{-jet}}} \frac{d\sigma_{t\bar{t}+1\text{-jet}}}{d\rho_s}(m_t^{\text{pole}}, \rho_s), \quad \rho_s = \frac{2m_0}{\sqrt{2s_{t\bar{t}+1\text{-jet}}}}, \]

- Unfold R + extract the pole mass using NLO calculation

- $t\bar{t}$ system is reconstructed by chi2 minimization

- Extra jet is required to have a $p_T > 50$ GeV

\[ m_t^{\text{pole}} = 173.7 \pm 1.5 \text{ (stat)} \pm 1.4 \text{ (syst)} \pm 1.0 \text{ (theory)} \text{ GeV} \]

Main systematic uncertainties:

- JES + b-quark JES
- ISR/FSR
- PDF
- Theory Uncertainties

This result represents the most precise measurement of the top-quark pole mass to date.

arXiv:1507.01769, subm. to JHEP
Pole mass measurement in $t \bar{t} + \text{jets}$

7 TeV and 8 TeV

| Method                                      | Mass (GeV) |
|---------------------------------------------|------------|
| D0 approx NNLO: MSTW08, 1.96 TeV 2009       | 169.1 ± 5.9|
| D0 approx NNLO: MSTW08, 1.96 TeV 2011       | 167.5 ± 4.7|
| CMS NNLO+NNLL: NNPDF2.3, 7 TeV 2013         | 176.7 ± 2.8|
| ATLAS NNLO+NNLL: PDF4LHC, 7 TeV 2014        | 171.4 ± 2.6|
| ATLAS NNLO+NNLL: PDF4LHC, 8 TeV 2014        | 174.1 ± 2.6|
| ATLAS NNLO+NNLL: PDF4LHC, 7-8 TeV 2014      | 172.9 ± 2.6|
| ATLAS NLO: $t \bar{t}$+1 jet, 7 TeV 2014*   | 173.7 ± 2.3|
| Direct reconstruction LHC+Tevatron 2014      | 173.3 ± 0.8|

$m_{t}^{pole}$ [GeV]
Top Properties and Searches
Spin Correlation

8 TeV

- Top pairs produced via the strong interaction are produced almost unpolarised
  - Spins are correlated and information transferred to decay products.
- The correlation is extracted from dilepton events
  - Difference in the azimuthal angle of the two leptons
  - Used to probe BSM
- Top squarks with masses between the top quark mass and 191 GeV are excluded at the 95% confidence level

Phys. Rev. Lett. 114, 142001 (2015)
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
FCNC in the trilepton channel

8 TeV

- Flavor changing neutral currents are predicted by the SM
  - Highly suppressed by the GIM mechanism

- Looking for tt events with one top quark $t \rightarrow qZ$ and the other $t \rightarrow bW$ with both bosons decaying leptonically

- Chi2 minimization is used for kinematic reconstruction and to discriminate signal and background

- No evidence of FCNC is found

- Observed upper limit on $t \rightarrow qZ$ branching ratio is established at $7 \times 10^{-4}$
Single top production via FCNC

8 TeV

• Search for single top production via $gu/c \rightarrow t$
• Only leptonic decay channel is considered
• NN used to discriminate signal and background
• Upper limit are established on
  – The cross section times branching ratio
  – The coupling constants

To be submitted
Summary

- ATLAS has performed multiple measurements on Top physics
  - Production, mass and properties
- All the results are in agreement with the SM
- Some properties have been used to exclude BSM models
- More exciting times are coming with 13 TeV
- Stay tuned for new results!

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults
Backup
Charge Asymmetry Measurement

7 TeV JHEP 05 (2015) 061

- At LO the standard model predicts a symmetric top pair production under charge conjugation
- At NLO a non-zero asymmetry is expected
- Effect can be measured in the l+jets or dilepton channel

Observables at LHC

Top based asymmetry
\[ \Delta |y| = |y_{top}| - |y_{antitop}| \]

Lepton based asymmetry
\[ \Delta |\eta| = |\eta^\ell_+| - |\eta^\ell_-| \]

- Latest results in the dilepton channel at 7 TeV
- Kinematic reconstruction is required in order to compute the top based asymmetry
Charge Asymmetry Measurement

7 TeV  JHEP 05 (2015) 061

• Analysis use unfolding procedure
  – Correct for reconstruction and detector acceptance.
• Results are compatible with the standard model predictions
• Statistically dominated
  – More statistics will probe new physics models
Spin Correlation

8 TeV

- The measurement of angular distribution is sensitive to supersymmetric top squark (stop) pair production
- Stop decays to a top and a very light neutralino, changing the spin correlation value

Phys. Rev. Lett. 114, 142001 (2015)
ATLAS

\[ \int \text{L} \text{d}t = 4.6 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV} \]

| Measurement        | \( f_{\text{SM}} \) ± (stat) ± (syst) |
|--------------------|----------------------------------------|
| \( \Delta \phi \) (dilepton) | 1.19 ± 0.09 ± 0.18                     |
| \( \Delta \phi \) (l+jets)   | 1.12 ± 0.11 ± 0.22                     |
| S-ratio             | 0.87 ± 0.11 ± 0.14                     |
| \( \cos(\theta_+) \cos(\theta_-) \) helicity basis | 0.75 ± 0.19 ± 0.23 |
| \( \cos(\theta_+) \cos(\theta_-) \) maximal basis | 0.83 ± 0.14 ± 0.18 |

Phys. Rev. D. 90, 112016 (2014)