Recent QCD Results from ATLAS at Phenomenology 2016

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10 May 16
1. Introduction to the ATLAS experiment
2. Overview of most recent QCD measurements
   1. The inelastic pp cross section at 13 TeV
   2. Diffractive dijet production with a large rapidity gap
   3. Z boson event shape
   4. Isolated inclusive photon cross section
   5. b quark pair production
3. Summary & Conclusions
ATLAS has published **60** jet, soft QCD and direct photon studies.

Extensive body of work, e.g.
- Inclusive jet production at 7, 8 and 13 TeV
- Jet fragmentation at 8 TeV

Working to better understand
- high-order effects
- non-perturbative “soft” regime

Recent QCD Results from ATLAS
Recent ATLAS QCD Results

Inelastic pp cross section
• No fundamental theory to make predictions
• Important for other studies of pp interactions

Diffractive dijet production with large rapidity gaps
• Probes our understanding of diffractive and doubly-diffractive processes

Z boson event shapes
• Underlying event structure in Z boson events
• Important for understanding interplay of soft and hard QCD

Inclusive photon differential cross section
• New measurement at 8 TeV
• Test of QCD and understanding of proton gluon density

b-quark pair production differential cross section
• Important to understand QCD b-quark production

Soft QCD

High $p_T$ QCD
1. Inelastic Cross Section

The pp inelastic cross section characterizes the strong interaction
- But cannot be derived from first principles
- Constraints come from general considerations

Dominated by low transverse momentum processes
\[ \xi \equiv \frac{M_X^2}{s} \]
- Analysis uses Minimum Bias Trigger System (MBTS)
- Counts single and double-diffractive events

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ATLAS-CONF-2015-038

First ATLAS Candidate Collision Event
Inelastic Cross Section

Performed a special low-luminosity run

\[ \sigma_{\text{inel}}(\xi > 10^{-6}) = \frac{N - N_{BG}}{\varepsilon_{\text{trig}} \times L} \times \frac{1 - f_{\xi < 10^{-6}}}{\varepsilon_{\text{sel}}} \]

- Use ratio of events passing single-sided and inclusive selection
- Donnachie & Landshoff model is best match to \( n_{\text{MBTS}} \) distribution – chosen as default model
- Extrapolate fiducial cross section to total phase space

<table>
<thead>
<tr>
<th>Factor</th>
<th>Value</th>
<th>Rel. unc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of selected events (N)</td>
<td>4159074</td>
<td>–</td>
</tr>
<tr>
<td>Number of background events (N_{BG})</td>
<td>43512</td>
<td>±100 %</td>
</tr>
<tr>
<td>Luminosity [\mu b^{-1}] (L)</td>
<td>62.9</td>
<td>±9 %</td>
</tr>
<tr>
<td>Trigger efficiency (\varepsilon_{\text{trig}})</td>
<td>99.7 %</td>
<td>±0.1 %</td>
</tr>
<tr>
<td>MC Correction factor ((1 - f_{\xi &lt; 10^{-6}}/\varepsilon_{\text{sel}})</td>
<td>0.993</td>
<td>±0.5 %</td>
</tr>
</tbody>
</table>

\[ \sigma_{\text{inel}} = 73.1 \pm 0.9(\text{exp.}) \pm 6.6(\text{lum.}) \pm 3.8(\text{extr.}) \text{ mb} \]
2. Dijets with Rapidity Gaps

Diffractive dijet production probes proton structure

- Measurements at ep and hadron colliders not reconciled
- Use existence of “rapidity gap” to isolate process
- Measure $\xi$, fraction of energy lost by $p$, by summing over all particles

Used dedicated low-L run

- Events free of multiple pp interactions
- Collected 6.8 nb$^{-1}$ at 7 TeV
- Select events with
  - 2 jets with $p_T > 20$ GeV and $|\eta|<2$
  - Use neutrals with $p_T>200$ MeV or charged particles with $p_T>500$ MeV to delimit gap
    - Gap $\Delta \eta^F$ is largest empty $\eta$ interval on either side up to $|\eta|=1.7$ on other side
Dijets with Rapidity Gaps

Data shows large non-diffractive component
- Dominates at small $\Delta\eta^F$ and high $\xi$
- Model-dependent analysis provides some constraints on relative mixture

Translate into measurement of the absorption of non-diffractive $\sigma$
- Use POMWIG MC to describe non-diffractive component, with rapidity gap survival probability

$$S^2 = 0.16 \pm 0.04 \text{(stat.)} \pm 0.08 \text{(exp. syst.)}$$
- Consistent with CMS and Tevatron measurements (but large uncertainty)
- Note that PYTHIA 8 can describe large $\Delta\eta^F$ data without suppression factor

3. Event Shapes in Z Boson Events

Underlying event (UE) in pp collisions important feature
- Many studies at Tevatron & LHC
- Important for understanding of hard-scattering process
- Models involve multi-parton interactions
- Rely on “tuning”

Use Z boson events
- Remove Z decay
- Measure charged track event observables sensitive to UE
- Study 4 observables as function of Z boson $p_T$
  - 0-6 GeV
  - 6-12 GeV
  - 12-25 GeV
  - > 25 GeV

\[ B \equiv \sum p_T \cdot e^{-|\eta|} \quad \text{Beam Thrust} \]
\[ T \equiv \max_{\hat{n}_T} \frac{\sum |\vec{p}_T \cdot \hat{n}_T|}{\sum p_T} \quad \text{Transverse Thrust} \]
\[ S \equiv \frac{\pi^2}{4} \min_{\vec{n}=(n_x,n_y,0)} \left[ \frac{\sum |\vec{p}_T \times \vec{n}|}{\sum p_T} \right]^2 \quad \text{Spherocity} \]
\[ F \equiv \frac{\lambda_1}{\lambda_2} \quad \text{where } \lambda_i \text{ eigenvalues of} \]
\[ M^{lin} \equiv \sum_i \frac{1}{p_{T,i}} \begin{pmatrix} p_{x,i}^2 & p_{x,i}p_{y,i} \\ p_{x,i}p_{y,i} & p_{y,i}^2 \end{pmatrix} \]

Submitted to EPJC, ArXiv:1602.08980
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10

Analysis used 1.1 fb\(^{-1}\) of 7 TeV collisions
- Identified Z bosons via \(\mu^+\mu^-\) & e+e- decays
- Removed Z boson tracks
- Corrected for pileup

See evolution with Z boson \(p_T\)
- Expect to see effects of Z+jet production in highest \(p_T\) bin
- Three lowest \(p_T\) bins have similar behaviour

Next step: compare with models
Compared to predictions:
- **SHERPA 2.2.0** at NLO with NNPDF 3.0
- **PYTHIA 8.212** at LO with NNPDF2.3
- **HERWIG 7.0** at NLO with MMHT2014

Employed default configurations
- **PYTHIA 8.212** used Monash 2013 tune

Overall conclusions
- **HERWIG** best with variables depending explicitly on # charged particles
- **PYTHIA** tends to do better on variables independent of # charged particles
- Low $p_T$ sample has greatest variance
- Generally, all generators do better in the high $p_T$ samples
- Overall, **PYTHIA** and **HERWIG** do better over most kinematic regimes
4. Inclusive Photon Cross Section

Isolated photon production important SM process
- Probes interplay of EW and QCD processes
- Probes the gluon PDF in proton
- Important background source to understand for other analyses

Measured differential cross section in 20 fb\(^{-1}\) of 8 TeV data
- Require isolation in \(\eta-\phi\) cone R=0.4
- Cross section shown in 4 different |\(\eta\)| bins
- Compared with JETPHOX generator with CT10 PDFs
- Overall agreement appears reasonable
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Inclusive Photon Cross Section

Detailed comparisons of differential cross sections against predictions by

- JetPhox CT10 – NLO
- PEtER
- PYTHIA
- SHERPA

PEtER best description

- Generally poor agreement in shape with other MC predictions
b-quark pair production first heavy flavour creation process studied

- Mixture of production diagrams
- Tests QCD heavy flavour calculations

Measured differential cross section in 4.2 fb$^{-1}$ of 7 TeV data

- Required two jets with $p_T > 20$ GeV and $|\eta| < 2.5$, both tagged as b-jets
- Required leading jet $p_T > 270$ GeV

Compared with POWHEG+PYTHIA, MC@NLO, PYTHIA AND SHERPA predictions

- Reasonable agreement with POWHEG
- Generally poor agreement with other calculations, both in shape and normalization

To be submitted: ATLAS-STDM-2013-03
Summary and Conclusions

Recent ATLAS measurements continue to probe QCD in both its non-perturbative and perturbative regime

1. Inelastic pp cross section
2. Diffractive dijet production with large rapidity gaps
3. Z boson event shapes
4. Inclusive photon differential cross section
5. b-quark pair production differential cross section

Give a “half-glass-full” picture of our understanding of QCD
• See good agreement in many challenging areas
• Still have discrepancies to resolve, especially soft QCD processes

Much to look forward to with next LHC data-taking run
Recent QCD Results from ATLAS

Backup Slides
ATLAS is one of 2 general-purpose experiments at the LHC

Collected data at 3 pp collision energies

- 7 TeV in 2011 $\rightarrow$ 4.6 fb$^{-1}$
- 8 TeV in 2012 $\rightarrow$ 20.2 fb$^{-1}$
- 13 TeV in 2015 $\rightarrow$ 3.2 fb$^{-1}$

Significant changes in running condition

- Increased pile-up
- Moved from 50 ns to 25 ns bunch spacing
High pT Z Boson Event Shapes

Event shape distributions for Z boson $p_T>25$ GeV

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More on b Quark Pair Production

Measured b-quark purity using b-tagging algorithm templates

- Employed likelihood fits to b and light flavour contributions

Measured differential cross sections in various variables
Inclusive Photons at 13 TeV

Made preliminary measurement of inclusive photon cross section at 13 TeV

- Similar analysis to 8 TeV
- Normalized background using non-isolated photon candidates
Inclusive Photon Cross Section

Comparison with JETPHOX, PYTHIA AND SHERPA generators