Recent QCD results from ATLAS

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On behalf of the ATLAS collaboration
Lake Louise Winter Institute 2016
Introduction

Initial state radiation

Hard scattering

Final state radiation

Hard $pp$-interaction ($\sqrt{s} = 7, 8, 13$ TeV)

Hadronization

Multi-parton interactions
High-$p_T$ jets

Hard scattering
Four-jet cross-section @ 8 TeV

JHEP12 (2015) 105

- Sherpa and HEJ in agreement with data
Four-jet cross-section @ 8 TeV

JHEP12 (2015) 105

• Some deviation of theory?
  – Mostly covered by uncertainties
Transverse energy-energy correlations


- Energy-weighted angular distribution of jets
  \[ \alpha_s(m_Z) = 0.1173 \]
  \[ \pm 0.0010 \text{ (exp.)} \]
  \[ +0.0063 \quad -0.0020 \text{ (scale)} \]
  \[ \pm 0.0017 \text{ (PDF)} \]
  \[ \pm 0.0002 \text{ (NPC)} \]

- NNLO pQCD prediction needed
Jet structure

Final state radiation

Hadronization
Number of charged particles in jets

arXiv:1602.00988

- Data between Pythia and Herwig++
- \( \langle n_{\text{charged}} \rangle \) higher for gluon jets
  - Increases faster with jet \( p_T \)
Underlying event studies

- Final state radiation
- Initial state radiation
- Interactions of beam remnants, additional parton-parton HS
DPI in four-jet events @ 7 TeV

\[ \sigma_{\text{DPS}} = \frac{1}{1 + \delta_{AB}} \left( \sigma_{2j}^A \sigma_{2j}^B \sigma_{\text{eff}} \right) \]

\[ \sigma_{\text{DPS}} = f_{\text{DPS}} \cdot \sigma_{4j} \]
DPI in four-jet events @ 7 TeV

ATLAS-CONF-2015-058

$\Delta p_T^{ij} = \frac{|\vec{p}_T^i + \vec{p}_T^j|}{p_T^i + p_T^j}$; $\Delta \phi_{ij} = |\phi_i - \phi_j|$; $\Delta y_{ij} = |y_i - y_j|$;

| $\phi_{1+2} - \phi_{3+4}$; | $\phi_{1+3} - \phi_{2+4}$; | $\phi_{1+4} - \phi_{2+3}$; |

Neural network

$\xi_{sDPS}$

\[ f_{DPS} = 0.084 \]

+0.054 (syst.)

−0.036

+0.009 (stat.)

−0.012
DPI in four-jet events @ 7 TeV

\[ \sigma_{\text{eff}} = 16.1^{+2.0}_{-1.5} \text{ (stat.)}^{+6.1}_{-6.8} \text{ (syst.) mb} \]

- Compatible with other measurements
- Large uncertainties
Minimum bias charged particle distributions @ 8 TeV

ATLAS-STDM-2014-19

- EPOS and Pythia+Monash: the best description
  - Still space for improvement!
Minimum bias charged particle distributions @ 8, 13 TeV


- 13 TeV: Valentina's Maria Cairo poster!
Conclusion:
Models describe data well!  ...but

- Four-jet cross-section
- Charged particles in jets
- Data between Pythia and Herwig++

Constraining power for some variables

Still space for improvement

Hard $pp$-interaction ($\sqrt{s} = 7, 8, 13$ TeV)
Back-up
ATLAS detector

Calorimeters

<table>
<thead>
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<th>η</th>
<th>&lt; 4.9</th>
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</table>

Inner detector

| η | < 2.5 |
Jet reconstruction with ATLAS (2012)

- Calorimeter cells $\rightarrow$ Topoclusters $\rightarrow$ Anti-$k_t$ jets
- Calibration:

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**EM or LCW constituent scale jets**
Jet finding applied to topological clusters at EM or LCW scale

**Origin Correction**
Changes the jet direction to point to the primary vertex. Does not affect $E$. 

**Jet area based pile-up correction**
Function of event pile-up energy density and jet area

**Residual pile-up correction**
Function of $\mu$ and NPV applied to the jet at constituent scale

**Absolute EtaJES**
Corrects the jet 4-vector to the particle level scale. Both the energy and direction are calibrated.

**Global sequential calibration**
Based on tracking and muon activity behind jets. Reduces flavour dependence and energy leakage effects.

**Residual in-situ calibration**
A final residual calibration is derived using in-situ measurements and is applied only to data
Jet reconstruction with ATLAS


- JES uncertainty of ~1% in 0.1 – 1.5 TeV!
  - Measured in-situ
Transverse energy-energy correlations

- TEEC:

\[
\frac{1}{\sigma} \frac{d\Sigma}{d(\cos \phi)} = \frac{1}{\sigma} \sum_{ij} \int \frac{d\sigma}{dx_i dx_j d(\cos \phi)} x_i x_j dx_i dx_j
\]

- Asymmetry of TEEC:

\[
\frac{1}{\sigma} \frac{d\Sigma^{\text{asym}}}{d(\cos \phi)} \equiv \frac{1}{\sigma} \frac{d\Sigma}{d(\cos \phi)} \bigg|_{\phi} - \frac{1}{\sigma} \frac{d\Sigma}{d(\cos \phi)} \bigg|_{\pi - \phi}
\]
Number of charged tracks in jets

\[ \langle n_{\text{charged}} \rangle = f_q f_q \langle n_{\text{charged}}^q \rangle + f_g f_g \langle n_{\text{charged}}^g \rangle \]

\[ \langle n_{\text{charged}}^c \rangle = f_q^c \langle n_{\text{charged}}^q \rangle + f_g^c \langle n_{\text{charged}}^g \rangle. \]
DPI in four-jet events @ 7 TeV

ATLAS-CONF-2015-058

• Discriminating variables

\[
\Delta_{ij}^{p_T} = \frac{|\vec{p}_T^i + \vec{p}_T^j|}{p_T^i + p_T^j}
\]

\[
\Delta\phi_{ij} = |\phi_i - \phi_j|
\]
Leading Track UE @ 13 TeV

ATLAS Preliminary
\( p_T > 0.5 \) GeV, \(|\eta| < 2.5\)
\( p_T^{\text{lead}} > 1 \) GeV

- Detector-level distributions, 170 \( \mu \)b\(^{-1}\)
- Plateau in transverse region described by UE tunes
Leading Track UE @ 13 TeV

ATL-PHYS-PUB-2015-019

- Detector-level distributions, 170 μb⁻¹
- Plateau in transverse region described by UE tunes
Minimum bias charged particle distributions @ 8 TeV

ATLAS-STDM-2014-19

- EPOS and A2: the best description
  - Still space for improvement!
Minimum bias charged particle distributions @ 8 TeV

ATLAS-STDM-2014-19

- EPOS and Monash: best agreement
  - Still space for improvement!
Inclusive-, di- and three-jet cross-sections @ 7 TeV

- Good agreement between data and NLO pQCD
- Correlation of stat. and syst. unc. determined

JHEP02 (2015) 153
JHEP05 (2014) 059
Inclusive jet cross-section @ 7 TeV

JHEP02 (2015) 153

- $R = 0.4$ jets
Dijet cross-section @ 7 TeV

JHEP05 (2014) 059

- \( R = 0.4 \) jets
Three-jet cross-section @ 7 TeV


- $R = 0.4$ jets
Shape of systematic uncertainty
Inclusive jet cross-section @ 7 TeV, JHEP02 (2015) 153

• Large systematic uncertainties are non-gaussian
Parton distribution functions

Incoming partons
Quantitative comparison data-theory

Inclusive jet cross-section @ 7 TeV, JHEP02 (2015) 153

<table>
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<th>$y$ ranges</th>
<th>NLO PDF set:</th>
<th>CT10</th>
<th>MSTW2008</th>
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</table>

- Anti-$k_t$, $R = 0.4$ jets
- ABM11 excluded: $p$-value < 0.1%
Qualitative comparison data-theory
Inclusive jet cross-section @ 13 TeV, ATLAS-CONF-2015-034

• Agreement for CT10, NNPDF3.0, MMHT