Measurements of single diffraction using forward proton tagging at ATLAS (based on ATLAS-CONF-2019-012) and the status of ATLAS elastic scattering measurements

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Forward protons tagging in ATLAS

Physics with forward protons

ALFA
elastic scattering

inclusive diffraction

exclusive production

two-photon processes

AFP
High-$\beta^*$ optics

- **Low $\beta^*$**
  - Strong focusing
  - High luminosity

- **High $\beta^*$**
  - Weak focusing
  - Low luminosity

**Beam crossing angle**

**Head-on beams**
Elastic events in ALFA

(Images of elastic event scatter plots with x-y coordinates and energy distribution)

ATLAS $\sqrt{s}=7$ TeV, 80 $\mu$b$^{-1}$

- $0.008 \text{ GeV}^2 < t < 0.01 \text{ GeV}^2$
- $0.05 \text{ GeV}^2 < t < 0.055 \text{ GeV}^2$
- $0.2 \text{ GeV}^2 < t < 0.3 \text{ GeV}^2$
Status of elastic analyses with ALFA

Ongoing elastic analyses:

- $\sqrt{s} = 8\text{ TeV}, \beta^* = 1000\text{ m} – \text{Coulomb-Nuclear Interference (CNI) region}$
  - final cross checks of systematic uncertainties
- $\sqrt{s} = 13\text{ TeV}, \beta^* = 2500\text{ m} \& 90\text{ m} – \text{CNI and dip region}$
  - working on vertical alignment
- $\sqrt{s} = 900\text{ GeV}, \beta^* = 100\text{ m} – \text{CNI regions}$
  - early stage

• Separation of diffractive processes from non-diffractive processes
• Full separation of single and double diffraction not possible
Measurement overview

• Data from special run: $\sqrt{s} = 8$ TeV, $\beta^* = 90$ m, $L = 1.67/nb$, $\mu < 0.08$

• Intact proton measured in ALFA

• Dissociated proton measured using ATLAS tracking detector

• Trigger: opposite side coincidence of the signal in ALFA and Minimum Bias Trigger Scintillator (MBTS)

• Acceptance
  • tracker: charged particles with
    • $p_T > 0.2$ GeV
    • $|\eta| < 2.5$
  • MBTS: charged particles with $2.1 < |\eta| < 3.8$
  • ALFA: protons with
    • $0.016 < |t| < 0.43$ GeV$^2$
    • $-4.0 < \log_{10} \xi < -1.6$
Kinematic variables

- $t$ – squared four-momentum transferred from the proton
  $$t \approx -p_T^2$$

- $\xi$ – momentum fraction of the proton carried by the pomeron
  $$\xi = 1 - E/E_0 = M_X^2/s \approx \sum_i (E^i \pm p_z^i)/\sqrt{s}$$

- $\Delta \eta$ – (pseudo)rapidity gap from the tracker edge
Event selection

- Exactly one reconstructed proton in two ALFA stations of the same armlet
- $3\sigma$ ellipse cut in ($x, \theta_x$) plane
- ID: at least one track and a reconstructed vertex
- MBTS: at least 5 (out of 16) counters above noise threshold
- Fiducial region of the measurement:
  
  \[
  0.016 < |t| < 0.43 \text{ GeV}^2 \\
  -4.0 < \log_{10} \xi < -1.6 \\
  (i.e. 80 < M_X < 1270 \text{ GeV})
  \]
Monte Carlo Generators

Main MC:
- PYTHIA8 A3 tune (ATL-PHYS-PUB-2016-017):
  - Proton PDF = NNPDF23 LO
  - Pomeron : PDF = H1 2006 Fit B; Flux: intercept: 1.06, slope: 0.25 (Donnachie-Landshoff)
  - SD for unfolding
  - CD, DD, ND for background subtraction
  - Elastics for ALFA Reconstruction efficiency

For systematics:
- PYTHIA 8 A2 tune (ATL-PHYS-PUB-2012-003)
- HERWIG 7.1:
  - Proton PDF = MMHT2014lo68cl
  - Pomeron : PDF = H1 2006 Fit A; Flux: intercept: 1.00, slope: 0.25
Overlay Background

- Coincidence between a proton in ALFA and activity in central ATLAS
- Source of protons: elastic scattering, beam halo
- Source of central activity: minimum bias events
- Largest background
- Data-driven estimate using strongly ND-enriched events
  - all 32 MBTS segments fired
  - shape in $t$ from ALFA in ND-enriched sample
  - shapes in $\xi$ and $\Delta \eta$ from MC events that pass full analysis selection

- Control region: nominal selection, but with protons in two armlets (dominated by elastics + ND)
Central Diffraction Background

- Dominant physics background: central diffraction
- Estimated from simulations
- Control region:
  - protons in two armlets
  - 2–10 MBTS segments fired
- Good description of normalizations and shapes
- Reweighting $\xi$ distributions to match the data, preserving normalization
Good description of shape and normalization after SD rescaling by 0.64
Systematic uncertainties

- Dominant: overlay background
- CD background shape (reweighting or not) and normalization (CDF data)
- Hadronisation model (PYTHIA vs HERWIG)
- Unfolding of instrumental effects
- Luminosity precision
Rapidity gap size distribution

- Unfolded hadron level cross sections after background subtraction
- Diffractive plateau is visible
- Increase at small rapidity gaps – limited acceptance of ATLAS tracker
- Decrease at large rapidity gaps – Loss of small-\(\xi\) events close to the \(\xi\)-edge (10\(^{-4}\))

MCs do not describe the overall cross section:

Monte Carlo model \(\sigma_{MC}/\sigma_{data}\)

- PYTHIA 8, A2 tune \(2.3\)
- PYTHIA 8, A3 tune \(1.5\)
- HERWIG 7.1 \(3.0\)
t distribution

- Measured exponential slope:
  
  \[ B = 7.60 \pm 0.23 \text{ (stat.)} \pm 0.22 \text{ (syst.) GeV}^{-2} \]

- In agreement with Pythia 8 prediction:
  PYTHIA8 A2: 7.82 GeV\(^{-2}\), PYTHIA8 A3: 7.10 GeV\(^{-2}\)

- Main systematic uncertainty from overlay background subtraction
\textbf{\(\xi\) distribution}

- Distribution fitted with:

\[
\frac{d\sigma}{d \log_{10} \xi} = \left( \frac{1}{\xi} \right)^{\alpha(0)-1} \frac{\exp(Bt_{\text{high}}) - \exp(Bt_{\text{low}})}{B}, \quad \text{with} \quad B = B_0 - 2\alpha' \log \xi
\]

- Measured Pomeron intercept

\[
\alpha(0) = 1.07 \pm 0.02 \text{ (stat.)} \pm 0.06 \text{ (syst.)} \pm 0.06 \text{ (}\alpha'\text{)}
\]

- Main systematic uncertainty from

\[
\alpha' = 0.25 \pm 0.25 \text{ GeV}^{-2}
\]

- MC generators:

  - \textit{PYTHIA 8 A3 (Donnachie-Landshoff)}: 
    \[
    \alpha(0) = 1.14
    \]
  - \textit{PYTHIA 8 A2 (Schuler-Sjostrand)}: 
    \[
    \alpha(0) = 1.00
    \]
Extrapolation to full $t$ range

- ATLAS data extrapolated to full $t$-range (gives a factor 1.18)
- A reasonable agreement in the overlap region
- Despite DD contribution in CMS results and different energies
Integrated cross sections

- The cross section integrated over the full fiducial range of the analysis:
  \[ 1.59 \pm 0.03 \text{ (stat.)} \pm 0.13 \text{ (syst.)} \text{ mb} \]

- Extrapolating to the full \( t \) range assuming the measured \( B \) value:
  \[ 1.88 \pm 0.15 \text{ mb} \]

- Extrapolating to full kinematic range using Pythia A2 and A3 (average):
  \[ 6.6 \text{ mb} \]

<table>
<thead>
<tr>
<th>Distribution</th>
<th>( \sigma_{SD}^{\text{fiducial}(\xi,t)} ) [mb]</th>
<th>( \sigma_{SD}^{t-\text{extrap}} ) [mb]</th>
<th>( \sigma_{SD}^{\xi,t-\text{extrap}} ) [mb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>1.59 \pm 0.13</td>
<td>1.88 \pm 0.15</td>
<td>6.6</td>
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<tr>
<td>Pythia8 A2 (Schüler-Sjostrand)</td>
<td>3.69</td>
<td>4.35</td>
<td>12.48</td>
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<tr>
<td>Pythia8 A3 (Donnachie-Landshoff)</td>
<td>2.52</td>
<td>2.98</td>
<td>12.48</td>
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<tr>
<td>Herwig7</td>
<td>4.96</td>
<td>6.11</td>
<td>24.0</td>
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</table>
Summary and conclusions

- ATLAS performed a measurement of the inclusive single diffractive dissociation process $p + p \rightarrow X + p$ at $\sqrt{s} = 8$ TeV.
- The final state protons are directly reconstructed.
- Differential cross sections are measured as a function of $\xi$, $t$ and $\Delta\eta$.
- Normalizations of tested MC generators significantly exceed the data.
- Shapes reasonably described by models.
- From a fit to $t$ distribution:

  $$B = 7.60 \pm 0.23 \text{ (stat.)} \pm 0.22 \text{ (syst.) GeV}^{-2}$$

- From a fit to $\xi$ distribution:

  $$\alpha(0) = 1.07 \pm 0.02 \text{ (stat.)} \pm 0.06 \text{ (syst.)} \pm 0.06 \text{ (}\alpha'\text{)}$$

- A good agreement in the overlap $\xi$ region with the CMS results.