Exclusive and Diffractive Processes with the ATLAS detector

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On behalf of the ATLAS Collaboration

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Exclusive and Diffractive Processes

- Identified through the presence of rapidity gaps, forward protons and the absence of charged particles in the tracking detector.

- In the absence of proton tagging, part of signature and corresponding information ‘lost’ with the proton(s).

- Present overview of previous ATLAS exclusive and diffractive analyses and outline prospects for the use of ‘proton-tagging’.
$\sqrt{s} = 7 \& 13$ TeV Exclusive Dilepton Production

LHC can be treated as a high energy $\gamma\gamma$ collider using the photons produced by the protons’ EM fields as a quasi-real beam of photons with small virtuality of $Q^2 < 0.1$ GeV$^2$ (Equivalent photon approximation – EPA)

Exclusivity requirement on charged particle tracks with near dilepton vertex;
- Remove $70 < m(l^+l^-) < 105$ GeV;
- $p_T(l^+l^-) < 1.5$ GeV to remove dissociative backgrounds

Fit to acoplanarity distribution used to scale background contributions

\[ \sqrt{s} = 7 \text{ & } 13 \text{ TeV Exclusive Dilepton Production} \]

**Cross-section measured, and \(d\sigma/dm(\mu\mu)\)**

- Exclusive dilepton cross-section predicted within QED with less than 2% uncertainty
- 10–20% suppression due to proton absorptive effects
  - Largely due to additional interactions between gluons in the protons/remnants
  - **Good agreement** provided by finite-size approach to correction which only allows photons outside of \(r_p = 0.64 \text{ fm}\) to initiate two-photon interaction
- Dominant uncertainty from template fit to acoplanarity shape (**reducible with proton tagging**)

\( \sqrt{s} = 8 \text{ TeV} \) Exclusive \( W^+W^- \) Production

- Measure rate of opposite sign/flavour charged leptons in final state
  - Rejects same-sign Drell–Yann and exclusive production

- Exclusivity requirement on charged particle tracks

- To reduce \( \gamma\gamma/Z/\gamma^* \rightarrow \tau\tau \), require \( p_T^{e\mu} > 30 \text{ GeV} \)

- \( \sigma(\gamma\gamma \rightarrow W^+W^- \rightarrow e^\pm\mu^\mp) = 6.9 \pm 2.2\text{(stat.)} \pm 1.4\text{(syst.)} \text{ fb} \)
  - Corresponds to 3\( \sigma \) evidence for SM production
  - No evidence of excess in the anomalous Quartic Gauge Coupling (aQGC) enhanced region (extracted at \( p_T^{e\mu} > 120 \text{ GeV} \) to reduce SM contribution)
**$\sqrt{s} = 7$ TeV Diffractive Dijets**

Dijet cross-section measured as a function of rapidity gap and $\xi$

- Single dissociative diffraction topology but with hard scattering between Pomeron and proton

- Dijet cross-section measurement as a function rapidity gap and $\xi$
  - $\xi$ calculated from calorimeter clusters
  - $\Delta\eta^F$ measured between calorimeter edge and clusters/tracks with $p_T > 200$ MeV
  - Performed at low pile up, $\sqrt{s} = 7$ TeV

- Diffraction dominant at $\Delta\eta > 2$

$$\tilde{\xi} \approx M_X^2 / s = \sum p_T e^{\pm\eta} / \sqrt{s}$$

$\sqrt{s} = 7$ TeV Diffractive Dijets

Rapidity gap survival probability measured

- Rapidity gap survival probability accounts for additional exchanges ‘spoiling’ the rapidity gap
  - Same as proton absorptive effects considered in exclusive dilepton analyses
- Extracted from lowest $\xi$ bin due to smallest ND contribution using POMWIG (not modelled in POMWIG, but exists in data)
  - $S^2 = 0.16 \pm 0.04$ (stat.) $\pm 0.08$ (syst.)
    - Large model uncertainties
  - Consistent with CMS, $S^2 = 0.12 \pm 0.05$ (LO)

AFP Overview

New ATLAS Forward Proton Detectors

- Operates in compliment to other ATLAS forward detectors (especially ALFA)
- Pairs of Roman Pot detectors with silicon precision tracking detectors and Cerenkov time of flight detectors
- AFP fully integrated into ATLAS TDAQ system
  - Can deliver first level triggers within 85 bunch crossing latency (fast air-core cables)

CERN-LHCC-2015-009, ATLAS-TDR-024
AFP Detectors

Tracking detectors in operation; Timing detectors to be installed

- Tracking detectors performed well in 2017
  - 3D silicon pixels (50 x 250 μm)
  - Resolution: in x ~ 6μm; in y ~ 30μm
  - Tilted by 14° to improve x (ξ) resolution

- Time of flight system is being commissioned – plans for this year
  - Will provide time of arrival resolution of ~ 25ps
  - Enables vertex discrimination in high pile up events of several mm
• Improvements on previous **diffractive analyses with a single tag:**
  ‣ Single diffractive dissociation with rapidity gaps
  ‣ Diffractive dijets

• Use double tag to measure inclusive central diffraction and exclusive production
  ‣ Resonance searches eg. glueballs

• Charged particle distributions in diffractive collisions

• Ultraperipheral collisions -> diffractive photoproduction
AFP Prospects: Nominal Runs

Testing new regions of QCD; rare EW physics; new physics

- Central exclusive QCD production (dijets)

- Exclusive production from $\gamma\gamma$
  - Dilepton; diboson (aQGC)
  - AFP can provide large background and systematic uncertainty reduction on previous measurements (dominant uncertainties in 7TeV dilepton, 8TeV WW and 13TeV dimuon)

- Searches for heavy new particles (heavy axions, WIMPS, charged Higgs, pair-produced BSM)
AFP Operation thus far

Data collected during special runs and nominal running

- Data collected during special runs (low pile up)
  - 2016 ($\sqrt{s} = 13$ TeV), only one sided tagging available
  - 2017 ($\sqrt{s} = 13$ TeV), one and two sided tagging available

- 2017 Nominal Running ($\sqrt{s} = 13$ TeV):
  - Fully installed (one and two sided tagging)
    - $\sim 32 fb^{-1}$ with $\mu \sim 50$
  - Tracking and DAQ working well
  - TOF still commissioning
**AFP First Analysis**

**First physics study: Single diffractive dijets**

- Special run taken in October 2016, $\mu \sim 0.3$, $\beta^* = 0.4$

- **Analysis strategy**: compare an AFP + jet ($p_T > 10$ GeV) triggered sample with minbias (scintillating tiles within central detector) + jet ($p_T > 10$ GeV) triggered sample

- **Event selection**:
  - At least one jet with $p_T > 20$ GeV and $|\eta| < 3.0$
  - Exactly one reconstructed primary vertex
  - $\geq 2$ tracks associated with primary vertex
  - Offline clean track in AFP required in AFP triggered sample
AFP First Analysis

AFP selects diffractively scattered events

- Same method of $\xi$ reconstruction as in $\sqrt{s} = 7$ TeV dijets analysis

- Observe clear enhancement in low $\xi$ region in AFP triggered sample, when compared to minbias sample

- Correlation between x-pixel position and $\xi$

\[ \xi_{\text{cal}} = \frac{1}{\sqrt{s}} \sum_i p_T^i e^{-\eta^i} \]
AFP First Analysis

Observe diffractive events at large rapidity gaps

- $\Delta \eta^F$ defined by size of region in $\eta$ between calorimeter acceptance ($\eta = -4.9$) and first cluster/track with $p_T > 200$ MeV (very similar to $\sqrt{s} = 7$ TeV analysis $\Delta \eta^F$)

- See clear enhancement in large gaps region in AFP triggered sample
  - Displays correlation between gaps and proton tags, as expected in diffractive scattering
Summary

Things are looking good for forward physics at ATLAS!

• Exclusive and diffractive processes measured at ATLAS
  ‣ Exclusive dilepton production cross-sections in good agreement with theory, $3\sigma$ evidence for exclusive WW production; rapidity gap survival probability estimated in diffractive dijets

• AFP installed on both sides of ATLAS in 2017
  ‣ Collected 32 fb$^{-1}$ data during nominal (high pile up) running as well as special (low pile up) runs
  ‣ Time of flight detectors still being commissioned

• Demonstrated that AFP is capable of selecting a highly diffractive–enriched sample

• Lots of prospects for improvement on current measurements and brand new analysis with AFP during LHC Run–II and beyond!
7TeV Dilepton

- Dominant uncertainty: Background modelling
8TeV WW production

Dominant systematic: Background determination and exclusivity selection

\[ a_{0,C}^W / \Lambda^2 \rightarrow \frac{a_{0,C}^W}{\Lambda^2} \frac{1}{\left(1 + \frac{m_{\gamma\gamma}^2}{\Lambda_{\text{cutoff}}^2}\right)^2} \]

<table>
<thead>
<tr>
<th>W^+W^- selection</th>
<th>Higgs boson selection</th>
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<tbody>
<tr>
<td>Preselection</td>
<td></td>
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<tr>
<td>Oppositely charged $e\mu$ final states</td>
<td>$p_T^{e1} &gt; 25$ GeV and $p_T^{e2} &gt; 20$ GeV, $p_T^{\tau1} &gt; 25$ GeV and $p_T^{\tau2} &gt; 15$ GeV</td>
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<tr>
<td>$p_T^{e\mu} &gt; 30$ GeV</td>
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<tr>
<td>Exclusivity selection, $\Delta_0^{\text{iso}}$</td>
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<tr>
<td>aQGC signal</td>
<td>$p_T^{e\mu} &gt; 120$ GeV</td>
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<tr>
<td>Spin-0 Higgs boson</td>
<td>–</td>
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Table 3: Selection criteria for the two analysis channels.
8TeV WW production

Why $p_{T}^{\mu\mu} > 30$ GeV:

Figure 7: Distribution of track multiplicities after requiring the exclusive $W^+W^-$ preselection (left) with no number of track dependent correction, and the $p_{T}^{\mu\mu}$ distribution of candidates that have 1–4 extra tracks (right), with the simulation including all appropriate correction factors such as $f_{nTracks}^{\text{sim}}$ (Table 4) for Drell-Yan and inclusive $W^+W^-$ production. The enriched inclusive $W^+W^-$ control region is the 1–4 extra-track region above $p_{T}^{\mu\mu} > 30$ GeV. The band around the Data/SM ratio of one illustrates the systemic uncertainties. The upward red arrows indicate ratios outside the plotting range.
13TeV Dimuon

Event selection
AFP Acceptance

- Acceptance varies with LHC beam conditions
  - High $\beta^*$ results in small beam divergence
    - Reduces focussing at IP but enables closer approach of Roman Pots

- Acceptances shown for different setups (without LHC collimator restriction at high $\xi$)

\[
\text{divergence} \propto \frac{1}{\sqrt{\beta^*}}
\]

- Good acceptance at high $\xi$ divergence

- $\beta^* = 0.55 \text{ m (nominal (collision) distance: 15}\sigma$}
- $\beta^* = 90 \text{ m (special (high-}\beta^*\text{) low pile up distance: 5}\sigma$}
- $\beta^* = 1000 \text{ m (special (high-}\beta^*\text{) low pile up distance: 5}\sigma$
Pixel hit distribution in AFP

From AFP tagged sample in dijets analysis