Measurements of diffractive and exclusive processes with ATLAS

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on behalf of the ATLAS Collaboration

2-8 Sep 2016
Outline

- Exclusive $\gamma \gamma \rightarrow \ell^+\ell^-$ Production at 7 TeV

- Exclusive $\gamma \gamma \rightarrow W^+W^-$ Production and Search for Exclusive Higgs Production at 8 TeV

- Diffractive Dijet Cross Sections at 7 TeV

- Feasibility Studies for Exclusive Jet Production with AFP
The ATLAS sub-detectors

ALFA: elastic protons measurement (see Hasko’s talk)

AFP: diffractive protons measurement. CERN-LHCC-2015-009
Single-arm installed, some diffractive data already taken!
Exclusive photon-induced processes: **Motivation**

- **Exclusive $\gamma\gamma \rightarrow X$ production** can be computed in QED+EWK with relatively small uncertainty (EPA)
  - True if we neglect proton absorptive corrections...

- **Exclusive $\gamma\gamma \rightarrow \ell^+\ell^-$ production**
  - Standard candle for photon-induced physics
  - Non-negligible background to Drell-Yan like reactions
  - Possible to use $pp (\gamma\gamma) \rightarrow pp \ell^+\ell^-$ for luminosity calibration at the LHC?

- **Exclusive $W^+W^-$**
  - Test of SM $\gamma\gamma WW$ quartic gauge coupling
  - Probe of anomalous quartic gauge couplings (aQGCs)

- **Exclusive (CEP) $gg \rightarrow$ Higgs $\rightarrow$ $W^+W^-$**
  - Similar final state as in exclusive $\gamma\gamma \rightarrow W^+W^-$ studies
  - Can be used for Higgs properties studies (low systematics due to the clean production environment)
Exclusive $\gamma\gamma \rightarrow l^+l^-$ production at 7 TeV, PLB 749 (2015) 242-261

Run 190644, Event 51422085
Time 2011-10-09, 16:29 CEST
Photon-induced processes: cross-section dominated by so-called single- and double-proton dissociative reactions. Non-negligible background for many analyses (low, high-mass DY, $\phi^*/p_T(Z)$ measurement, ...)

- **Preselection:**
  - $p_T^{\mu}>10$ GeV, $|\eta_{\mu}|<2.4$, $M_{\mu^+\mu^-}>20$ GeV
  - $p_T^e>12$ GeV, $|\eta_e|<2.4$, $M_{e^+e^-}>24$ GeV

- **Exclusive selection:**
  - 3 mm dilepton-vertex longitudinal isolation efficiency = 74%
  - $p_T$ of the dilepton system < 1.5 GeV
- **Signal extraction**: binned maximum-likelihood fit to the measured dilepton acoplanarity distribution

- Corresponding fiducial cross-sections:
  - \( \sigma_{\gamma\gamma \rightarrow e^+e^-}^{excl.} = 0.428 \pm 0.035 \text{(stat.)} \pm 0.018 \text{(syst.)} \) pb
  - \( \sigma_{\gamma\gamma \rightarrow \mu^+\mu^-}^{excl.} = 0.628 \pm 0.032 \text{(stat.)} \pm 0.021 \text{(syst.)} \) pb

- Theory predictions (QED-EPA), with absorptive corrections from [PLB 741 (2015) 66-70](20% effect)
  - \( \sigma_{\gamma\gamma \rightarrow e^+e^-}^{EPA, corr.} = 0.398 \pm 0.007 \text{(theo.)} \) pb
  - \( \sigma_{\gamma\gamma \rightarrow \mu^+\mu^-}^{EPA, corr.} = 0.638 \pm 0.011 \text{(theo.)} \) pb

- Agreement also with similar CMS measurement
Exclusive $\gamma\gamma \rightarrow W^+W^-$ and Search for Exclusive H at 8 TeV (arXiv:1607.03745) PRD 94 (2016) 032011

Run: 203432
Event: 53911100
2012-05-15 13:35:15 CEST
- **Event selection**

- $WW \rightarrow e\nu\mu\nu$ final states are considered

- 1 mm dilepton-vertex longitudinal isolation $\rightarrow$ efficiency $= 58 \pm 6\%$

- Full event selection criteria:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Excl $W^+W^-$</th>
<th>Excl Higgs</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_{T\text{lep}}^{\ell\mu}$</td>
<td>$&gt; 25, 20 \text{ GeV}$</td>
<td>$&gt; 25, 15 \text{ GeV}$</td>
</tr>
<tr>
<td>$m_{e\mu}$</td>
<td>$&gt; 20 \text{ GeV}$</td>
<td>$&gt; 10 \text{ GeV}$</td>
</tr>
<tr>
<td>$p_{T\ell\mu}^{\ell\mu}$</td>
<td>$&gt; 30 \text{ GeV}$</td>
<td>$&gt; 30 \text{ GeV}$</td>
</tr>
<tr>
<td>$\Delta z_0^{iso}$</td>
<td>1mm</td>
<td>1mm</td>
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<tr>
<td>$p_{T\ell\mu}^{\ell\mu}$ (aQGC)</td>
<td>$&gt; 120 \text{ GeV}$</td>
<td>-</td>
</tr>
<tr>
<td>$m_{e\mu}$</td>
<td>-</td>
<td>$&lt; 55 \text{ GeV}$</td>
</tr>
<tr>
<td>$\Delta \phi_{e\mu}$</td>
<td>-</td>
<td>$&lt; 1.8$</td>
</tr>
<tr>
<td>$m_T$</td>
<td>-</td>
<td>$&lt; 140 \text{ GeV}$</td>
</tr>
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Higgs selection: lower $p_T / \text{mass}$ requirement (one $W$ is off-shell)
Exclusive $\gamma\gamma \rightarrow W^+W^-$ and Search for Exclusive H at 8 TeV (arXiv:1607.03745)

- $\gamma\gamma \rightarrow \ell^+\ell^-$ validation

- Ratio of observed elastic $\gamma\gamma \rightarrow \ell^+\ell^-$ to bare EPA prediction:

$$f_{EL} = 0.76 \pm 0.04 \text{ (stat.)} \pm 0.10 \text{ (sys.)}$$

-> Suppression is stronger due to larger invariant mass being probed

- No simulation available for SD and DD $\gamma\gamma \rightarrow W^+W^-$ (and EL+SD+DD are mixed due to W decays):

  a correction factor is applied using $\gamma\gamma \rightarrow \ell^+\ell^-$ for $m_{\ell^+\ell^-} > 160$ GeV:

$$f_{\gamma} = \frac{N_{\text{Data}} - N_{\text{PowHEG Background}}}{N_{\text{HERWIG++ Elastic}}} \bigg|_{m_{\mu\mu}>160 \text{ GeV}}$$

$$= 3.30 \pm 0.22 \text{ (stat.)} \pm 0.06 \text{ (sys.)}$$
**Results ($\gamma\gamma \rightarrow W^+W^-$ and aQGCs)**

- **Exclusive $W^+W^-$ event yields:** Data = 23, Background = $8.3 \pm 2.6$, Signal = $9.3 \pm 1.2$
  -> Measurement significance of 3$\sigma$

- **aQGC event yields** [$p_T(\mu) > 120$ GeV]:
  Data = 1, Background = $0.37 \pm 0.13$
  SM Signal = $0.37 \pm 0.04$
  -> new aQGC limits are set
**Results (exclusive Higgs)**

- Exclusive and inclusive $W^+W^-$ are the dominant background

- Exclusive Higgs event yields: Data=6, Background = $3.0 \pm 0.8$, Signal = $0.023 \pm 0.003$

- Observed and expected limits:
  - $\sigma < 1.2 \text{ pb} @ 95\% \text{ CL (Observed)}$
  - $\sigma < 0.7 \text{ pb} @ 95\% \text{ CL (Expected)}$

- Upper limit = $400 \times$ predicted $\sigma$
  (predictions include just the elastic process)
Motivation

- Diffractive DIS at HERA: Diffractive parton densities dominated by gluon
- pp(pbar) collisions: Failure in comparison of Tevatron proton-tagged diffractive dijets with HERA DPDFs
  -> ’rapidity gap survival probability’ due to rescattering (absorptive corrections) breaks factorisation
- Kinematics and selection

- Low pile-up data sample from 2010 with $\sqrt{s}=7$ TeV and integrated luminosity of 6.8 nb
- Jets with anti-kT algorithm, $p_T > 20$ GeV, $|\eta| < 4.4$, R=0.4, 0.6
- Gaps characterised using $\Delta \eta_F$, based on tracks ($|\eta| < 2.5$, $p_T > 200$ MeV) and calocells ($|\eta| < 4.8$) that are >5$\sigma$ out of noise distribution
Event characteristics

- Diffractive proton energy loss ($\xi$) is extracted from energy deposits:

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

- Experimental resolution on $\log(\xi)$ is approximately 10%
Diffractive Dijet Production at 7 TeV, PLB 754 (2016) 214-234

**Results**

- Diffractive component is required for more complete description of data
- Pythia8 gives a good description of shape and normalization
- Rapidity gap survival factor is extracted in the context of POMWIG (and H1 2006 Fit B DPDFs):

\[ S^2 = 0.16 \pm 0.04 \text{ (stat.)} \pm 0.08 \text{ (exp. syst.)} \]
Feasibility Studies for Exclusive Jet Production with AFP, ATL-PHYS-PUB-2015-003
- **AFP detector status** (see Marek’s talk)

- Single-arm with 3 3D pixel detector layers (near station) and 4 layers (far station) fully integrated with ATLAS

- 300 b fill #4906 (10th of May 2016), AFP readout (20σ from the beam) but triggered by ATLAS ($\mu \approx 26, 2:16$ hrs)

- Low-$\mu$ run with dedicated AFP-based triggers is also recently recorded ($\approx 0.04 \, \text{pb}^{-1}$)
Motivation and feasibility results

- Constrains other exclusive productions (e.g. Higgs)
- Cross section measurement is possible, even with single-tag configuration:
  - $S/B = 10^4$ after applying all the selection requirements
  - ~400 events expected with 1pb$^{-1}$ of data
  - See also EPJC 75 (2015) 320
Summary

- **Exclusive (photon-induced) processes**
  - Cross sections of the exclusive $\gamma\gamma \rightarrow \ell^+\ell^-$ production have been measured
  - Observation is consistent with the suppression (20%) expected due to proton absorption contributions
  - Evidence of SM exclusive $\gamma\gamma \rightarrow W^+W^-$ production (significance of $3\sigma$)
  - No evidence for an excess in the kinematic region targeting aQGC
  - Limits on exclusive Higgs production cross section are also set

- **Diffractive Dijets**
  - Evidence for diffractive contribution in 7 TeV data
  - Detailed understanding heavily limited by poorly known non-diffractive contribution
  - Future prospects with dedicated proton spectrometers (AFP) are very promising