Measurements of diffractive and exclusive processes with ATLAS

Mateusz Dyndal (DESY)
on behalf of the ATLAS Collaboration

2-8 Sep 2016
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 $\gamma\gamma \to \ell^+\ell^-$ 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

Data / MC

Events / 1.5 GeV

\( \gamma\gamma \to l^+l^- \) production at 7 TeV, PLB 749 (2015) 242-261
• **Signal extraction**: binned maximum-likelihood fit to the measured dilepton acoplanarity distribution

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

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

• 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 → eνμν final states are considered

• 1 mm dilepton-vertex longitudinal isolation -> efficiency = 58 ± 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>$p_T^{lep}$</td>
<td>&gt; 25, 20 GeV</td>
<td>&gt; 25, 15 GeV</td>
</tr>
<tr>
<td>$m_{e\mu}$</td>
<td>&gt; 20 GeV</td>
<td>&gt; 10 GeV</td>
</tr>
<tr>
<td>$p_T^{e\mu}$</td>
<td>&gt; 30 GeV</td>
<td>&gt; 30 GeV</td>
</tr>
<tr>
<td>$\Delta z_0^{is}$</td>
<td>1mm</td>
<td>1mm</td>
</tr>
<tr>
<td>$p_T^{e\mu}$ (aQGC)</td>
<td>&gt; 120 GeV</td>
<td>-</td>
</tr>
<tr>
<td>$m_{e\mu}$</td>
<td>-</td>
<td>&lt; 55 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 GeV</td>
</tr>
</tbody>
</table>

Higgs selection: lower pT / 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:

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

$\rightarrow$ 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 ($\gamma\gamma \to W^+W^-$ 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 $[p_{T}(e\mu) > 120 \text{ GeV}]$: 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:
  - $\sigma < 1.2 \text{ pb} @ 95\% \text{ CL} \text{ (Observed)}$
  - $\sigma < 0.7 \text{ pb} @ 95\% \text{ CL} \text{ (Expected)}$

- Upper limit = $400 \times$ predicted $\sigma$
  (predictions include just the elastic process)
Diffractive Dijet Production at 7 TeV, PLB 754 (2016) 214-234
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:

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

- Experimental resolution on log($\xi$) is approximately 10%
**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):

\[
S^2 = 0.16 \pm 0.04 \text{ (stat.)} \pm 0.08 \text{ (exp. syst.)}
\]
- **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 (μ ≤ 26, 2:16 hrs)

- Low-μ run with dedicated AFP-based triggers is also recently recorded (≈0.04 pb⁻¹)
Feasibility Studies for Exclusive Jet Production with AFP, ATL-PHYS-PUB-2015-003

- **Motivation and feasibility results**
  - Constrain 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 $\gamma\gamma \to \ell^+\ell^-$ production have been measured
  - Observation is consistent with the suppression (20%) expected due to proton absorption contributions
  - Evidence of SM exclusive $\gamma\gamma \to W^+W^-$ 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