Studies of \(Z\gamma\) electroweak production in association with a high-mass di-jet system in \(pp\) collisions at \(\sqrt{s} = 8\) TeV with the ATLAS detector

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Motivation
- Test of the Electroweak (EWK) Sector
- search for anomalous quartic couplings (aQGC)
- First probe of neutral aQGC at ATLAS in \(Z\to\ell\ell\gamma\) process in two decay channels:
  - Charged lepton channel: cleaner final state, various fiducial cross sections measured (different fractions of EWK and QCD production) and aQGC limits
  - Neutrino channel: complex backgrounds but large branching ratio allows extraction of aQGC limits, cross-section measured only in high \(\gamma\) \(E_T\) region.

Z\(\gamma\) cross section measurement
- \(Z(\ell\ell)\gamma\) channel fid. cross section measured by a simultaneous likelihood fit to distributions of \(Z\)-centrality in CR and SR, constraining \(Z\gamma\) QCD bgd
- cross section measured in \(\nu\nu\gamma\) channel EWK-only in SR and EWK+QCD in both CR and SR
- \(Z(\nu\nu)\gamma\) fid. cross section measured in an aQGC sensitive high \(\gamma\) \(E_T\) region via log-likelihood fit

**Measured \(Z(\ell\ell)\gamma\) phase space**

- **Leptons**
  \(p_T^l > 25\) GeV and |\(p_T^l| < 2.5\)
  Dressed leptons, OS charge
- **Photon**
  \(p_T^\gamma > 15\) GeV, |\(p_T^\gamma| < 2.37\)
- **Photon Isolation**
  \(E_T^{\text{iso}} < 0.5 \times E_T^\gamma\)
  \(E_T^{\text{iso}} > 40\) GeV
- **Truth Jets/Outgoing Partons**
  \(p_T\) outgoing quarks or gluons
  \(\Delta R(f, \gamma) > 0.4\)
  \(\Delta R(f, \gamma) < 4.5\)
  \(m_{f\gamma} > 182\) GeV
  \(m_f > 40\) GeV

**Measured \(Z(\nu\nu)\gamma\) phase space**

- Neutrinos
  \(E_T^{\nu\nu} > 100\) GeV
- **Photon**
  \(p_T^\gamma > 150\) GeV, |\(p_T^\gamma| < 2.37\)
- **Photon Isolation**
  \(E_T^{\text{iso}} < 0.5 \times E_T^\gamma\)
- **Truth Jets/Outgoing Quarks**
  \(p_T\) outgoing quarks or gluons
  \(\Delta R(f, \gamma) > 0.4\)
  \(\Delta R(f, \gamma) < 4.5\)

**Event Kinematic Selection**

- \(|\Delta \phi^{ll}\gamma\gamma| < 2\)
- \(|\Delta R^{ll\gamma\gamma}\gamma\gamma| > 0\)
- \(|\Delta R^{ll\gamma\gamma}\gamma\gamma| < 1\)
- \(p_T^l > 150\) GeV
- \(\Delta R_l > 2.5\)
- \(\Delta R_{\gamma\gamma} < 0.3\)
- \(m_{ll\gamma\gamma} > 600\) GeV

**aQGCs Methodology**
- An effective field theory (EFT) \([2]\) with higher-dimensional operators is adopted to parameterize the anomalous couplings
- The charged anomalous couplings of \(WWWZ\gamma\) can be induced by \(f_{M,x}(x=0-7)\), \(f_{T,x}(x=0-7)\)
- Neutral aQGCs of \(ZZZ\gamma\) and \(ZZ\gamma\gamma\) also possible via \(f_{M,x}\)
- Photon \(E_T\) spectrum is sensitive to aQGCs.

**Reference:**