Studies of the diffractive photoproduction of isolated photons at HERA

Leszek Adamczyk

AGH - UST Cracow
On behalf of the ZEUS Collaboration
The world’s only electron/positron-proton collider

\[ E_e = 27.6 \, \text{GeV} \] and \[ E_p = 820(920) \, \text{GeV} \] (575, 460) HE(LE)

Total integrated luminosity 0.5 fb\(^{-1}\)

This analysis:

\[ E_e = 27.6 \, \text{GeV} \] and \[ E_p = 920 \, \text{GeV} \]

HERA-I (1998-2000) with integrated luminosity of 82 pb\(^{-1}\)

HERA-II (2004-2007) with integrated luminosity of 374 pb\(^{-1}\)
Diffraction in ep collisions

Deep Inelastic Scattering (DIS)

- $Q^2 = -q^2$ - virtuality of the photon
- $Q^2 \approx 0$ - photoproduction,
- $Q^2 \gg 0$ - DIS
- this analysis:
  scattered lepton undetected
  $Q^2 < 1$ GeV

Diffractive Scattering

- $x_{IP}$ - fraction of proton’s momentum carried by exchanged Pomeron
- $z_{IP}(\beta)$ - fraction of Pomeron momentum which takes part in the hard interaction
Hard (isolated) photons in $ep$ scattering

High $p_T$ (hard) photons have several origins:

- Produced in a hard partonic interaction often called "prompt" photons
- Radiated from the incoming or outgoing lepton
- Radiated from a quark within a jet
- Decay product of a hadron within a jet

We study photoproduced prompt photons arising from hard diffractive process:

- Prompt photons are relatively well isolated from other final state particles.
- Observation of prompt photons demonstrates the presence either of a quark in the Pomeron or of higher-order processes in which both the Pomeron and the incident photon couple to quarks.
- Above contrasts with diffractive dijet production, which is mainly sensitive to the gluon content of the Pomeron
Direct and resolved processes in photon-Pomeron interaction

Photon or Pomeron may act as a source of quarks and gluons, which then take part in the QCD scatter (resolved processes) and processes in which the photon or Pomeron interacts as a whole (direct processes)

\( x_\gamma \) - fraction of photon energy which takes part in the hard interaction

- **direct-resolved**  
  \( x_\gamma \approx 1; z_{IP} < 1 \)

- **resolved-resolved**  
  \( x_\gamma < 1; z_{IP} < 1 \)

- **direct-direct**  
  \( x_\gamma \approx 1; z_{IP} \approx 1 \)

\[
\begin{align*}
x_\gamma^{\text{meas}} &= \frac{(E-p_z)^\gamma+(E-p_z)^{\text{jet}}}{(E-p_z)^{\text{all}}} \\
z_{IP}^{\text{meas}} &= \frac{(E+p_z)^\gamma+(E+p_z)^{\text{jet}}}{(E+p_z)^{\text{all}}} 
\end{align*}
\]
Use the RAPGAP generator for correction and comparisons:

- Incoming photon is radiated from the electron using the equivalent-photon approximation.
- Resolved-Pomeron model (G. Ingelman and P. Schlein et al.)
- In direct photon processes, photon scatters elastically off a quark in the resolved Pomeron
- In resolved photon processes, gluon–quark and antiquark–quark scattering produce an outgoing photon and a jet
- Fragmentation uses the Lund string model as implemented in Pythia
- H1 2006 DPDF Fit B set is used to describe parton densities in the diffractively scattered proton.

Remarks:

- in H1 2006 QCD fit resolved Pomeron PDFs were obtained for $z_{IP} < 0.8$
- RAPGAP uses extrapolation to cover the entire $z_{IP}$ range.
Event selection

**photoproduction:**
- no electron with \( E > 3.5 \text{ GeV} \)
- inelasticity \( 0.2 < \frac{(E-p_z)^{all}}{2E_e} < 0.7 \)

**jet definition:**
- use \( k_T \)-cluster algorithm
- \( 4 < E_{jet}^T < 35 \text{ GeV} \)
- \( -1.5 < \eta_{jet}^T < 1.8 \)

**prompt photon candidate**
- \( E_{EMC}/(E_{EMC} + E_{HAC}) > 0.9 \)
- \( 5 < E_{T}^\gamma < 15 \text{ GeV} \)
- \( -0.7 < \eta_{\gamma} < 0.9 \)
- in jet: \( E_{\gamma}/E_{jet} > 0.9 \)

**diffraction:**
- \( \eta_{max} < 2.5 \) for ZEUS energy flow objects with energy above 0.4 GeV
- \( \chi_{IP}^{meas} = \frac{(E+p_z)^{all}}{2E_p} < 0.03 \)
Signal extraction

Prompt photon signal was extracted statistically for each cross-sections interval

- use energy-weighted width \( \langle \delta Z \rangle \), measured in the Z direction, of the BEMC energy cluster comprising photon candidate
- isolated-photon events was determined by a binned maximum likelihood fit to the distribution in the range \( 0.05 < \langle \delta Z \rangle < 0.8 \)

- HERA I: 91 (76 with jet(s)) prompt photons
- HERA I: 336 (311 with jet(s)) prompt photons

Most photons are accompanied by a jet.
A 70:30 mixture of direct:resolved photon events generated with Rapgap gives a reasonable description of the data and was employed in the following distributions.
Shape of $z_{IP}^{\text{meas}}$ does not agree
An excess seen at $z_{IP}^{\text{meas}} > 0.9$
Reweight RAPGAP to describe the shape

$\eta_{\text{max}}$ distribution better described by reweighthed RAPGAP
No significant effect of reweigting on other distributions
Results

Visible cross sections compared to RAPGAP normalized observed cross section.

Inclusive photons

- Distributions well reproduced by the RAPGAP MC
- Most photons are accompanied by a jet
Results

- RAPGAP missing some processes at high $z_{IP}$
- Evidence for direct Pomeron interactions
Direct Pomeron interactions dominantly for direct photons

* Good agreement in shape with all variables, also for $z_{IP} < 0.9$ and $z_{IP} > 0.9$
The first measurement of diffractively photoproduced prompt photons was presented.

Visible cross sections were calculated in $\eta_{\text{max}} < 2.5$ and $x_{IP} < 0.03$.

Most of the detected photons are accompanied by a jet.

The variable $z_{IP}$ shows a peak at high values that implies the presence of processes not modeled in RAPGAP.

- Evidence for direct Pomeron interactions
- Dominantly in the direct-photon channel

Kinematic variables are well described in shape by RAPGAP, confirming universality of PDF in diffractive DIS and diffractive prompt photon photoproduction.