DIFFRACTIVE PRODUCTION OF ISOLATED PHOTONS WITH THE ZEUS DETECTOR AT HERA

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Hard scattered photons are measured in the BCAL, which is finely segmented in the Z direction.

Photoproduction: No scattered electron observed, $0.2 < y_{JB} < 0.7$, usual cut

Diffraction: No energy in the forward region, $\eta_{max}^{EFO} < 2.5$ - Large Rapidity Gap (LRG)
\[ e^\pm + p \rightarrow (e^\pm) + \gamma + X + \text{[LRG]} + (p \text{ or } \text{pdiss}) \]

\[ \gamma^* + p \rightarrow \gamma + X + \text{[LRG]} + (p \text{ or } \text{pdiss}) \]

\{ \gamma^* - \text{quasi-real} \left( Q^2 < 1 \text{ GeV}^2, Q^2 \sim 10^{-5} \text{ GeV}^2 \right), \text{no scattered electron observed} \}

\[ \gamma - \text{isolated high } E_T \left( > 5 \text{ GeV} \right), \ X - \text{hadrons or jets} \]
The outgoing Photon
Photon candidates: groups of signals in cells in the BEMC. Each has a Z-position, $Z_{\text{CELL}}$. E-weighted mean of $Z_{\text{CELL}}$ is $Z_{\text{Mean}}$.

Task: to separate signal photons from background coming from photon decays of neutral mesons.

$$<dZ> = \text{E-weighted mean of } \left| Z_{\text{CELL}} - Z_{\text{Mean}} \right|.$$
Monte Carlo simulation

Uses the **RAPGAP** generator

Based on leading order parton-level QCD matrix elements.
Some higher orders are modelled by initial and final state leading-logarithm parton showers.
Fragmentation uses the Lund string model as implemented in PYTHIA.

The H1 2006 DPDF fit B set is used to describe the density of partons in the diffractively scattered proton.
For resolved photons, the SASGAM-2D pdf is used.
Examples of lowest-order “resolved–Pomeron” diagrams by which diffractive processes may generate a prompt photon

**Direct** incoming photon gives all its energy to the hard scatter \((x_\gamma = 1)\).

\[
\{ x_\gamma^{\text{meas}} = \frac{\Sigma_{\gamma + \text{jet}}(E - p_z)}{\Sigma_{\text{all EFOs}}(E - p_z)} \}
\]

**Resolved** incoming photon gives fraction \(x_\gamma\) of its energy.
Some kinematics:

\( x_{IP} = \) fraction of proton energy taken by Pomeron, measured as
\[
\frac{\Sigma_{all\ EFOs} \ (E + p_z)}{2 \ E_p}
\]

\( z_{IP} = \) fraction of Pomeron \(E + p_z\) taken by photon + jet measured as
\[
\frac{\Sigma_{\gamma + jet} \ (E + p_z)}{\Sigma_{all\ EFOs} \ (E + p_z)}
\]

\( \eta_{max} = \) maximum pseudorapidity of observed outgoing particles \((E > 0.4 \ GeV)\) (ignore forward proton).

**Diffractive processes are characterised by a low value of** \( \eta_{max} \) **and/or low** \( x_{IP} \).
Possible “direct Pomeron” interactions require a different type of diagram.

e.g.

Direct photon + “direct Pomeron”

Resolved photons also a possibility.

N.B. The proton may become dissociated in diffractive processes
1) The forward scattered proton is not measured in these analyses.

2) Remove non-diffractive events: $\eta_{\text{max}} < 2.5$ and $x_{IP} < 0.03$

$\eta_{\text{max}}$ is evaluated from ZEUS energy flow objects (EFOs), which combine tracking and calorimeter cluster information.

3) Remove remaining DIS events and Bethe-Heitler and DVCS events.

Exclude events with identified electron or $\leq 5$ EFOs

4) Remaining non-diffractive events neglected, could be 0-10% of our cross sections. Treated as a systematic.

5) **HERA I** data: use the FPC to remove much non-diffractive background.

It also suppressed many proton dissociation events.

- **Use HERA-I data to measure total cross section.** 82 pb$^{-1}$
- **Use HERA-II data to study shapes of distributions.** 374 pb$^{-1}$
**Hard photon candidate:**
- found with energy-clustering algorithm in BCAL: \( \frac{E_{\text{EMC}}}{E_{\text{EMC}} + E_{\text{HAD}}} > 0.9 \)
- \( E_{T\gamma} > 5 \text{ GeV} \)
- \(-0.7 < \eta_{\gamma} < 0.9 \) where \( \eta \equiv \text{pseudorapidity} \). (i.e. in ZEUS barrel calorimeter)
- **Isolated.** In the “jet” containing the photon candidate, the photon must contain at least 0.9 of the “jet” \( E_T \)

**Jets**
- use \( k_T \)-cluster algorithm
- \(-1.5 < \eta^{\text{jet}} < 1.8 \)
- \( E_{T^{\text{jet}}} > 4 \text{ GeV} \)
Fit the $x_\gamma$ distribution to direct and resolved RAPGAP components. A 70:30 mixture is found and used throughout.

\[
x_\gamma^{\text{meas}} = \frac{\sum_y + \text{jet} (E - p_z)}{\sum_{\text{all EFOs}} (E - p_z)}
\]
Plot $z_{IP}^{meas}$ and compare with RAPGAP

**Shape does not agree.**
An excess is seen in the top bin.
Can reweight Rapgap to describe the shape.

Unreweighted RAPGAP here normalised to $z_{IP}^{meas} < 0.9$ data. Otherwise, unless stated, RAPGAP is normalised to the full plotted range of data.

The $\eta_{\text{max}}$ distribution is described better by the reweighted Rapgap.

Red histogram shows what 10% of non-diffractive PYTHIA photoproduction (subject to present cuts) would look like. (Not added into the RAPGAP)
Results

Cross sections compared to RAPGAP normalised to total observed cross section. **Inner error bar is statistical.** Outer (total) is correlated across all points and includes normalisation and non-diffractive subtraction uncertainty.

Transverse energy of photon.

Shape of data well described by RAPGAP. **Most photons are accompanied by a jet.**
Cross section in $z_{IP}^{\text{meas}} = \frac{\Sigma_{Y + \text{jet}}(E + p_z)}{\Sigma_{\text{all EFOs}}(E + p_z)}$

Evidence for “direct” Pomeron interactions

Using HERA-I data, integrated cross section for $z_{IP}^{\text{meas}} < 0.9 = 0.68 \pm 0.14^{+0.06}_{-0.07}$ pb

RAPGAP gives 0.68 pb. No allowance for proton dissociation which is $\sim 16 \pm 4\%$. 
Cross sections for region $z_{IP}^{\text{meas}} < 0.9$ RAPGAP is normalised to data in this region.
Cross sections for region $z_{IP}^{\text{meas}} \geq 0.9$ RAPGAP is normalised to data in this region.
Summary

ZEUS have measured isolated ("prompt") photons in diffractive photoproduction, with an accompanying jet.

Cross sections for a diffractive region defined by cuts on $n_{\text{max}}$ and $x_{\text{IP}}$ have been evaluated.

Most of the detected photons are accompanied by a jet.

The variable $z_{\text{IP}}^{\text{meas}}$ shows a peak at high values that implies the presence of processes not currently modelled in RAPGAP. This gives evidence for a "direct-Pomeron" process Dominantly in the direct-photon channel.

In both regions of $z_{\text{IP}}^{\text{meas}}$ the cross sections of the kinematic variables are well described in shape by RAPGAP.
Backups
$\eta_{\text{max}}$ distribution for HERA II.