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Diffractive production of isolated photons with the ZEUS detector at HERA

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The photoproduction of isolated photons has been measured in diffractive events recorded by the ZEUS detector at HERA. Cross sections are evaluated in the photon transverse-energy and pseudorapidity ranges $5 < E_T^{\gamma} < 15$ GeV and $-0.7 < \eta^{\gamma} < 0.9$ inclusively and also with a jet with transverse energy and pseudorapidity in the ranges $4 < E_T^{jet} < 35$ GeV and $-1.5 < \eta^{jet} < 1.8$, using a total integrated electron–proton luminosity of 374 pb^{-1}. A number of kinematic variables were studied and compared to predictions from the RAPGAP Monte Carlo model. An excess of data is observed above the RAPGAP predictions for $z_{\mathbb{P}}^{\mathrm{meas}} > 0.9$, where $z_{\mathbb{P}}^{\mathrm{meas}}$ is the fraction of the longitudinal momentum of the colourless "Pomeron" exchange that is transferred to the photon–jet final state, giving evidence for direct Pomeron interactions.

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1. Introduction

The HERA *ep* collider took data during the period 1992 - 2007. Its rich physics output covered hard processes in the deep inelastic scattering (DIS) regime down to soft interactions in the photoproduction region [1]. Hard processes were studied also in the photoproduction regime when a high scale was present. In the present talk, results are presented of hard scattered isolated photons associated with jets in the photoproduction region. The photoptroduction regime is usually defined as a region where the four-momentum squared between the scatted and the incoming electron, Q^2, is less than 1 GeV^2. In this region no scattered electron is observed.

HERA also showed that diffraction, usually thought to be a soft process, is present also in hard processes [2] resulting in events with a large rapidity gap. The results presented in this talk are of isolated photons (called hereafter prompt photons) which are diffractively produced. Analyses of prompt photons in the DIS [3] and the non-diffractive photoproduction [4] regions have already been presented by the two HERA collaborations.

The reaction studied here can be written as

$$e^{\pm} + p \to (e^{\pm}) + \gamma + X + \mathrm{LRG} + (\mathrm{p\ \ or\ \ pdis}), \tag{1.1}$$

where LRG is a large rapidity gap and pdis stands for proton dissociation. The LRG is also expressed by a the variable η_{max}, which is the maximum pseudorapidity for energy-flow objects with energy of 0.4 GeV. Typially for diffraction events η_{max} <2.5. The brackets on the right-hand side of the reaction describe states that are not observed in the detector. The prompt photon has a high transverse energy, $E_T > 5$ GeV, and X represents hadrons or jets. The reaction (1.1) can be described as a reaction between the virtual photon, $\gamma*$ at thte electron vertex and the Pomeron, $I\!P$, at the proton vertex. The fraction of thte proton energy carried by the Pomeron is given to a good approximation by

$$x_{I\!P} = (E^{\mathrm{all}} + p_Z^{\mathrm{all}})/2E_p, \tag{1.2}$$

where E_p is the energy of the proton beam.

Having a hard scale, the partonic structure of their interaction can be studied. Both the exchanged photon and the Pomeron can act either as a whole (direct) or as a source of partons (resolved). These two classes of process, which are unambiguously defined only at the leading order (LO) of QCD, may be partially distinguished in events containing a high-E_T photon and a jet by means of the quantity

$$x_{\gamma}^{\mathrm{meas}} = \frac{E^{\gamma} + E^{\mathrm{jet}} - p_Z^{\gamma} - p_Z^{\mathrm{jet}}}{E^{\mathrm{all}} - p_Z^{\mathrm{all}}}, \tag{1.3}$$

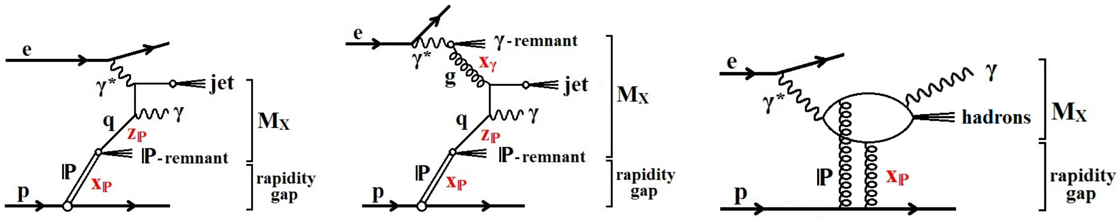
which measures the fraction of the incoming photon energy that is given to the outgoing photon and jet. The quantities E^{γ} and E^{jet} denote the energies of the outgoing photon and the jet, respectively, and p_Z denotes the corresponding longitudinal momenta. The suffix "all" refers to all objects that are measured in the detector or, in the case of simulations at the hadron level, all final-state particles except for the scattered beam electron and the outgoing proton. Events with a detected final-state electron are excluded from this analysis.

The Pomeron may be described analogously to the photon [5, 6]. The fraction of the Pomeron energy that takes part in the hard interaction that generates the outgoing photon and jet is given by [7]:

$$z_{I\!P}^{\rm meas} = \frac{E^{\gamma} + E^{\rm jet} + p_Z^{\gamma} + p_Z^{\rm jet}}{E^{\rm all} + p_Z^{\rm all}}, \tag{1.4}$$

where the quantities are as before, and $z_{I\!P} = 1$ corresponds to direct Pomeron events, which are equivalent to the presence of a delta-function in the parton distribution functions at $z_{I\!P} = 1$ [5, 6]. An event whose observed final state consists only of a prompt photon and a jet has $x^{\gamma} = z_{I\!P} = 1$.

Examples of diagrams describing the above processes are shown in Fig. 1. A reaction which proceeds through the interaction of a direct photon with a quark from a resolved Pomeron is shown in Fig. 1(a). In (b) a gluon from a resolved photon interacts with a quark from a resolved Pomeron. The interaction of a direct photon with a direct Pomeron is shown in Fig. 1(c).



(a) (b) (c)

Figure 1: Examples of diagrams for the diffractive production of a prompt photon and a jet in ep scattering from (a) direct (b) resolved photons, interacting with a resolved Pomeron. (c) Example of an interaction between a direct photon and a direct Pomeron.

The data used in this analysis is based on a data samples corresponding to an integrated luminosity of 374 pb^{-1}, taken during the years 2004–2007 with the ZEUS detector at HERA. During this period, HERA ran with electron and positron beams[1] of energy $E_e = 27.5$ GeV and a proton beam of energy $E_p = 920$ GeV.

2. The data

The following selections were made:

- the forward scattered proton was not measured;
- non-diffractive events were removed by the cuts η_{max} <2.5 and $x_{I\!P} < 0.03$;
- remaining DIS events were removed by excluding events with identified electrons;
- Bethe-Heitler ($ep \to ep\gamma$) and deeply virtual Compton events were removed;
- requirement was made for hard isolated photon candidates (E_T^{γ} >5 GeV) in the barrel calorimeter ($-0.7 < \eta^{\gamma} < 0.9$);
- high-p$_T$ jets, using a k_T algorithm, were required to be in the region $-1.5 < \eta^{jet} < 1.8$.

[1] Hereafter, "electron" refers to both electrons and positrons.

3. The outgoing prompt photon

The hard scattered photons can be extracted in a region of the detector which is finely segmented in the Z direction, namely the electromagnetic section of the ZEUS barrel calorimeter (BEMC), limiting the pseudorapidity of the photon to the region $-0.7 < \eta^\gamma < 0.9$. This fine granularity allows the use of shower-shape distributions to distinguish isolated photons from the product of neutral meson decays such as $\pi^0 \to \gamma\gamma$. To this end, a method was developed [3] to make use of the energy-weighted width, measured in the Z direction, of the BEMC energy cluster comprising the photon candidate,

$$\langle \delta Z \rangle = \sum_i E_i |Z_i - Z_{\rm cluster}| / (w_{\rm cell} \sum_i E_i), \tag{3.1}$$

where Z_i is the Z position of the centre of the i-th cell, $Z_{\rm cluster}$ is the energy-weighted centroid of the energy-flow-object cluster, $w_{\rm cell}$ is the width of the cell in the Z direction, and E_i is the energy recorded in the cell. The sum runs over all BEMC cells in the cluster.

As this analysis studies diffractive prompt photon events having a large rapidity gap, the RAPGAP Monte Carlo generator has been use to simulate the expectted δZ distribution of prompt photons coming from a signal event and the distribution of photons coming from the background. In each bin of each physical quantity, the data were fitted to a combination of photon signal and hadronic background. The data together with the fitted results, for events with photon candidastes and at least one jet, are shown in Fig. 2. A good fit to thte data is obtained allowing to extract statistically the photon signal.

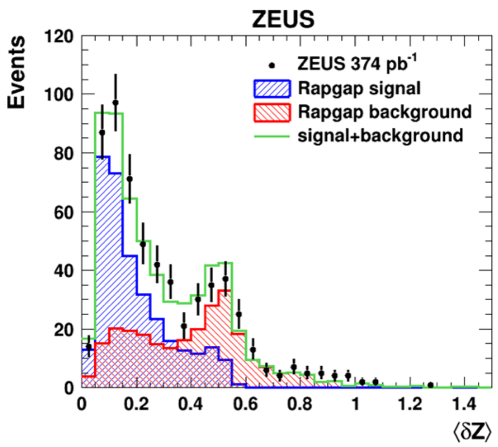


Figure 2: Distribution of $\langle \delta Z \rangle$ for selected diffractive events with a photon candidate and at least one jet. The error bars denote the statistical uncertainties on the data, which are compared to the fitted signal and background components from the MC. The unit of measurement of $\langle \delta Z \rangle$ is the width of one BEMC cell.

4. Results

After selecting the photon candidate events as described above, the distribution of the $x_\gamma^{\rm meas}$ is shown in Fig. 3. It peaks toward high $x_\gamma^{\rm meas}$ and a mixture of 70:30 of direct and resolved photon component events, as obtained from RAPGAP gives a reasonable description of the data.

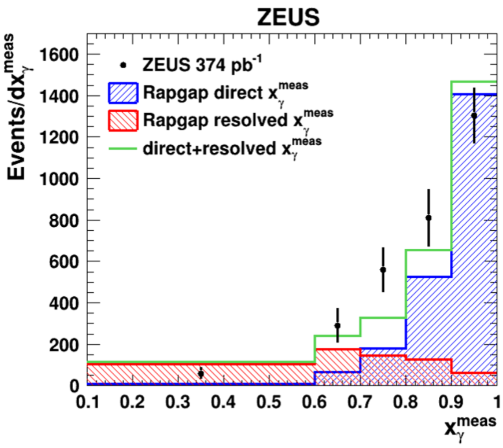


Figure 3: Events with a photon and at least one jet as a function of $x_\gamma^{\rm meas}$, per unit interval in $x_\gamma^{\rm meas}$, compared to a normalised 70:30 mixture of direct:resolved photon RAPGAP events without reweighting.

The distribution of $z_{\mathbb{P}}^{\rm meas}$ is shown in Fig. 4. A sharp peak is observed for $z_{\mathbb{P}}^{\rm meas} > 0.9$ in contrast to the prediction of the MC generator that described well the $x_\gamma^{\rm meas}$. The RAPGAP generator does not include the process of a direct Pomeron, as presented in Fig. 1(c). Agreement with the data is obtained by reweighting RAPGAP (a weight of 7 is applied to the direct photon component). The reweighted RAPGAP changes very little in the description of Fig. 3 and still provides an adequate description of the data.

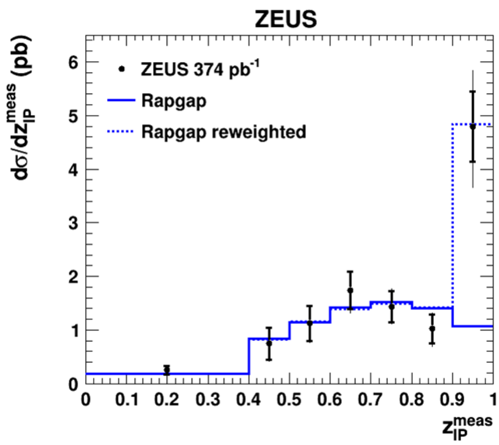


Figure 4: Differential cross section for isolated photon production accompanied by at least one jet, as a function of $z_{\mathbb{P}}^{\rm meas}$. The unreweighted RAPGAP prediction is normalised to the data integrated over the region $z_{\mathbb{P}}^{\rm meas} < 0.9$; the reweighted prediction is normalised to the full integrated data.

The excess observed for $z_{\mathbb{P}}^{\rm meas} > 0.9$ is evidence for the presence of a direct Pomeron interaction, predominantly in e direct photon channel.

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