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Measurement of isolated photons with high transverse energy in photoproduction at HERA

H1 Collaboration

Abstract

A measurement is presented of high E_T photons in quasi-real photon-proton collisions at HERA using the H1 detector. The isolated photon is produced together with a hadronic jet balancing in transverse energy (E_T). E_T and rapidity (η) distributions are shown in comparison with QCD expectation. The fraction x_γ of the photon energy participating in the collision is measured. It shows that the prompt photon process at HERA is dominated by the direct γp interaction as expected from QCD. The cross section for the process $\gamma P \to \gamma + X$ with $E_{T\gamma} > 5$ GeV and with $-1.2 < \eta_\gamma < 1.6$, in the H1 laboratory frame, was determined to be $\sigma = 104.8 \pm 5.9(stat) \pm 15.7(syst)$ pb.

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1 Introduction

The study of hard processes in quasi-real photoproduction at HERA is in lowest order (LO) QCD described by the interaction of the incoming photon or parton from the photon with a parton from the proton. Two classes of events are defined: direct processes in which the photon couples directly to a parton of the proton and resolved processes where a parton of the photon takes part in the interaction process. From this process two outgoing high p_t partons emerge which can then hadronise and form two jets. A number of studies have been carried out at HERA to study these di-jet events [1, 2, 3, 4].

The study of di-jets in photoproduction events allows the parton densities in the photon and the proton to be determined. Higher order QCD processes, for example final state QCD gluon radiation complicate the above picture and the extraction of parton densities. Prompt photon events in which a high-p_t photon is produced, are less dependent on e.g. the fragmentation process. Even though the cross section of this process is substantially smaller than for di-jet processes the observation of a particle originating of the hard subprocess makes this study interesting.

Prompt photon production in $p\bar{p}$ collisions allows the gluon content of the proton [5, 6] to be determined. At HERA the dominating contribution to the prompt-photon process comes from the direct contribution $\gamma q \rightarrow \gamma q$, therefore the main sensitivity lies on the quark content of the proton. The leading resolved process $gq \rightarrow \gamma q$ is sensitive to parton distributions in the photon and the proton. Observation of prompt-photon processes at HERA was already reported by ZEUS [7].

The data were taken in 1996 with the H1 detector operating at HERA, where 27.5 GeV positrons collide with 820 GeV protons. The integrated luminosity used for this analysis corresponds to 7.9 pb^{-1}.

2 Data selection

A detailed description of the H1 detector can be found elsewhere [8]. The photon is detected in the liquid argon (LAR) calorimeter with a fine granularity which covers the range between polar angles of 4^o and 153^o. The polar angle ϑ is measured with respect to the direction of the outgoing proton which defines the positive z-axis. The events were triggered by the requirement of an electromagnetic cluster in the calorimeter, a condition which is fully efficient for transverse energies above 10 GeV and 60% efficient at E_T=5 GeV. For all comparisons with Monte Carlo (MC) simulations the trigger efficiency is taken into account.

The photon candidate was identified by a compact electromagnetic cluster with $E_{T\gamma} > 5$ GeV in the pseudo-rapidity range $-1.2 < \eta_\gamma < 1.6$ with no track pointing to it. Deep inelastic scattering events (DIS) with an observed scattered electron in the detector were removed. y_{JB} is used to determine the remaining DIS contribution, where y_{JB} is the fraction of positron energy carried by the photon in the rest frame of the proton and is calculated from the sum $(E - p_z)$ over all calorimeter cells divided by the positron energy. y_{JB} is restricted to the range $y_{JB} < 0.7$ which ensures that no events with a scattered positron in the detector remains in the sample. A lower y cut $y_{JB} > 0.05$ removes remaining proton beam background. The contribution of DIS events to the final sample was estimated to be less than 1% from the shape of the y_{JB} distribution.

More stringent cuts plus isolation requirements were applied to remove background from hadronic jet events where a neutral meson, predominantly π^0, η and η', fakes a photon.

The isolation cuts are based both on the tracking and on the calorimetric measurement. No clusters above 0.5 GeV were allowed within a cone of radius $R = \sqrt{\Delta\eta^2 + \Delta\varphi^2} = 0.8$ around the photon candidate and no tracks within this cone to remove low energetic particles. Furthermore the total energy in this cone was restricted to 1.1 times the energy of the photon. The cone size was reduced in the forward region of the H1 detector. This is the direction of the outgoing proton. These isolation cuts remove most of the background from hadronic jet events where a neutral meson fakes a photon and reduces higher order effects where a photon is radiated from the final state quarks.

For the correction of the data and for comparison to the measured distributions PYTHIA 5.7 [9] event generator was used with the LO-GRV parton distribution functions for the photon and the proton [10, 11]. Hadronization was modelled with the LUND string fragmentation scheme (JETSET 7.4 [12]). For the investigation of the background di-jet events were simulated with the same event generator. This sample is henceforth referred to as the background MC sample. For all comparisons with data the Monte Carlo samples are normalised to the same luminosity as the data.

The remaining sample consists mainly of events with isolated photons and π^0 and η mesons. A cut on the transverse cluster size removes roughly 30% of the remaining misidentified π^0 and η faking a photon, because the two photons originating from a meson are likely to produce broader clusters. In Figure 1 a) the transverse cluster size is plotted for data, prompt-photon MC events, and for π^0 background MC events. Figure 1 b) shows the energy fraction in the first layer of the LAR calorimeter. Because the two photons from a π^0 have a higher conversion probability than a single photon, π^0s tend to deposit more energy in the first layer of the electromagnetic calorimeter. This explains the flatter distribution for the background MC in Figure 1 b). Both figures show that the estimated background is at the 20% level and both distributions are nicely described by a superposition of prompt-photon events with photoproduction background. The E_t and η distributions of the selected events are shown in Figure 2. Again good agreement between the Data and the MC distribution is observed.

3 Extraction of x_γ and x_p

For the reconstruction of x_γ, defined as the fraction of the photon energy entering the hard QCD subprocess and x_p, the momentum fraction carried by the parton in the proton, a sample was selected with a photon and a jet.

Jets were found with a cone algorithm with cone radius 1 and $E_{T\,Jet} >$4 GeV and $-0.5 < \eta_{Jet} < 2$ in the H1 laboratory system. Roughly 40% of the prompt-photon events have such a jet measured in the H1 detector. The $E_{T\,Jet}$ distribution and the azimuthal separation between jet and photon ($\Delta\varphi$) are shown in Figure 3. The jets and photons are well separated in φ which ensures that the kinematics are well measured.

x_γ is calculated from the transverse energy and the pseudorapidity of the photon and the jet $x_\gamma = (E_{T\gamma} \cdot e^{-\eta_\gamma} + E_{T\,Jet} \cdot e^{-\eta_{Jet}})/\Sigma_{all\ cluster}(E - p_z)$. Similarly x_p can be extracted as x_p $=(E_{T\gamma} \cdot e^{\eta_\gamma} + E_{T\,Jet} \cdot e^{\eta_{Jet}})/(2E_p)$. The remaining background is estimated from the background MC sample. It was already shown in figures 2 and 1 that the addition of 25% background to the prompt photon MC describes the shape of the measured distributions well. The background contribution was cross-checked with the ratios of the efficiency of the isolation cut for data, prompt-photon MC, and the background sample. On average the background contribution is 25$\pm$ 10% and does not vary with x_γ or x_p. It is subtracted binwise. The corrected x_γ and x_p distributions are shown in Figure 4 a) and b). The shaded area gives the expectation from prompt-photon MC and the triangles give the MC curve for the resolved prompt-photon signal.

The inner error bars show the statistical errors, the outer the statistical and systematical errors added in quadrature. Within errors the data are consistent with the Monte Carlo expectations. The sample is dominated by the direct process. At x_γ below 0.9 where the contribution from the resolved process is substantial the data lie above the MC expectation which is an indication for a higher parton density in the photon than modelled in the LO-GRV parameterisation.

4 Cross section

The cross section was evaluated for the process $\gamma P \rightarrow \gamma + X$ with $E_{T\gamma} > 5$ GeV and $-1.2 < \eta_\gamma < 1.6$ for $y_{JB} > 0.05$. The corrections factors were calculated from data and cross-checked with a sample containing a superposition of background events and prompt photon MC. The main contributions are the correction for the trigger efficiency and for the isolation cut.

The dominating systematic errors come from the uncertainty of the electromagnetic energy scale of 3% ($\pm$5%), the trigger efficiency at low energies ($\pm$ 6%), the isolation requirement ($\pm$ 6%) and the subtraction of the background ($\pm$ 10%).

The cross section for the process $\gamma P \rightarrow \gamma + X$ with $E_{T\gamma} > 5$ GeV and $-1.2 < \eta_\gamma < 1.6$ was measured to be $\sigma = 104.8 \pm 5.9(stat) \pm 15.7(syst)$ pb.

This is in broad agreement with QCD expectation, where a cross section in this E_T and η range of 84.1 pb is expected .

5 Conclusions

We have observed a signal of isolated photons with high transverse energy in the H1 detector. The x_γ distribution shows a strong peak close to 1 where the direct component is dominating. This is in agreement with QCD expectation.

The cross section for the production of prompt photons with $E_{T\gamma} > 5$ GeV, $-1.2 < \eta_\gamma < 1.6$ in the H1 laboratory frame and $y_{JB} > 0.05$ was determined to $\sigma = 104.8 \pm 5.9(stat) \pm 15.7(syst)$ pb and is in agreement with QCD expectation.

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Figures

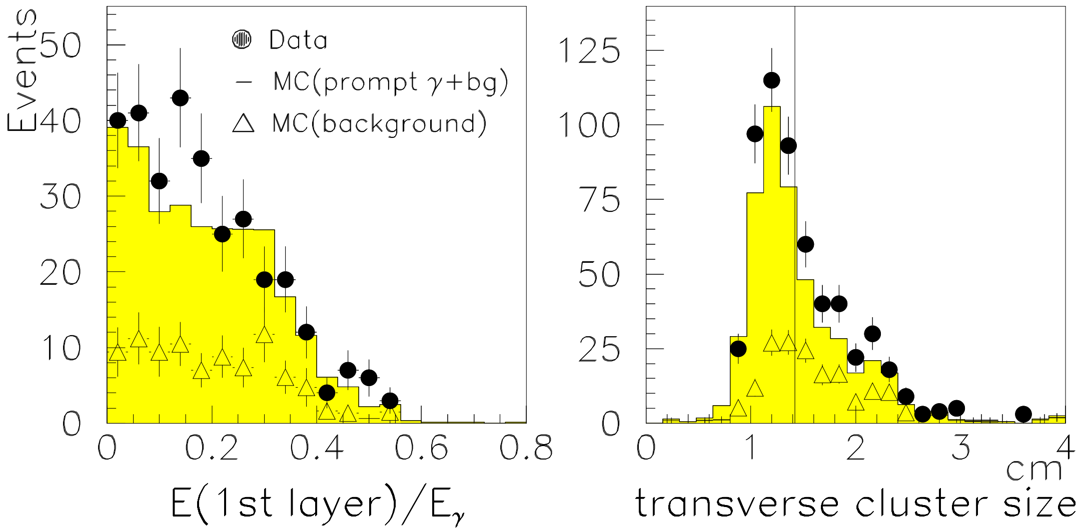

Figure 1: Different estimators for photon identification in the H1 calorimeter: a) Energy fraction deposited in the first layer of the calorimeter. b) Transverse cluster size, the line indicates the upper cut value. The full circles show the data, the triangle symbols correspond to the MC estimated background contribution and the shaded histogram to a superposition of prompt-photon MC and background.

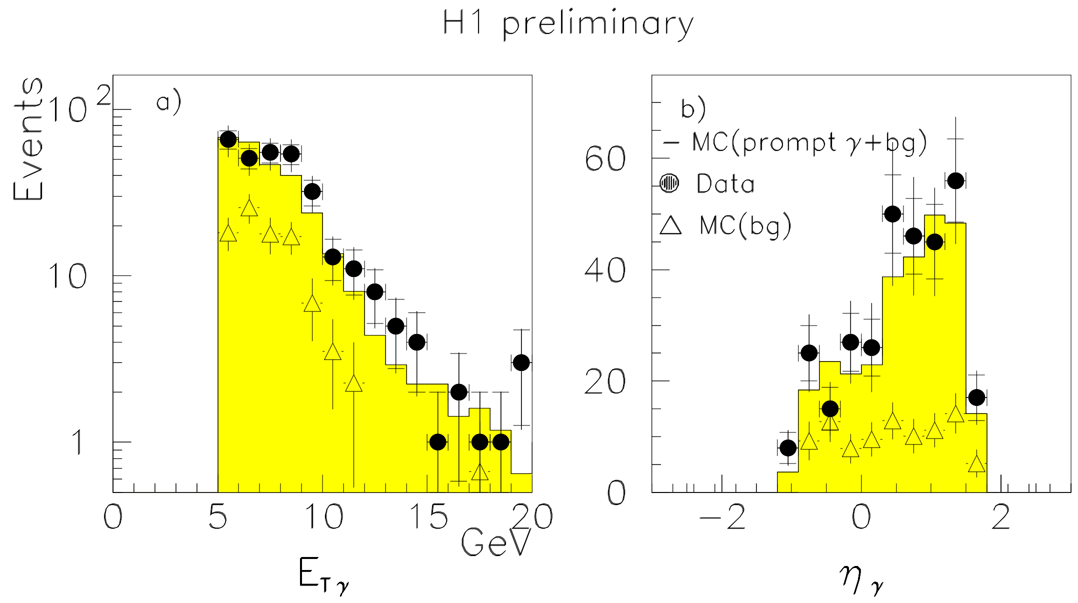

Figure 2: Transverse energy $E_T\gamma$ (a) and laboratory pseudorapidity η (b) distribution of the photon candidates. The full circles show the uncorrected data, the triangle symbols correspond to the MC estimated background contribution and the shaded histogram to a superposition of prompt-photon MC and background. The inner error bars show the statistical errors, the outer the statistical and systematical errors added in quadrature.

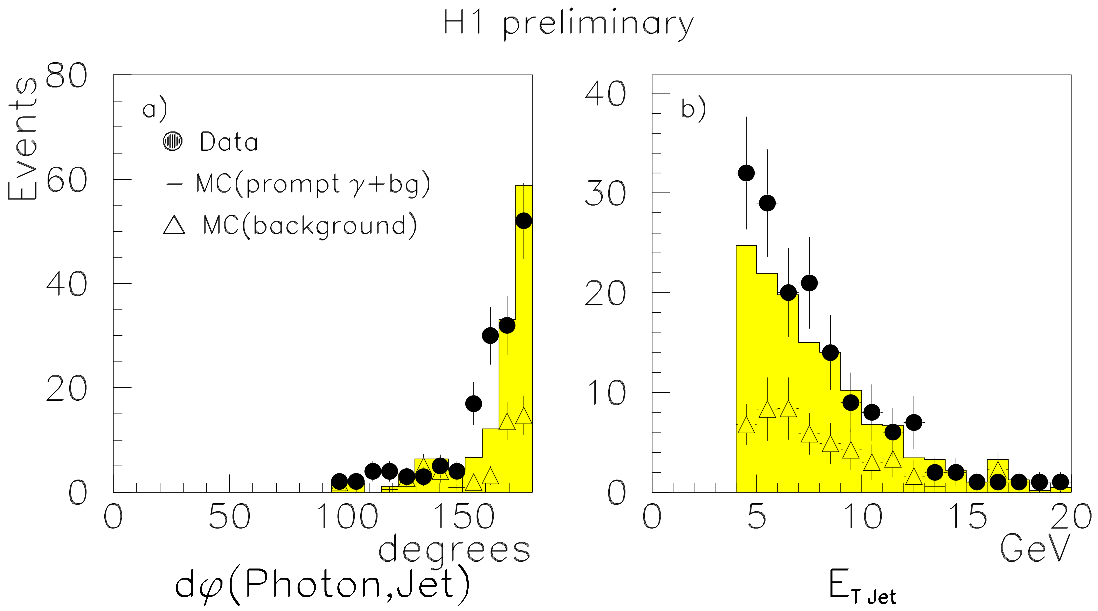

Figure 3: a) Separation in azimuth φ between the photon candidate and the jet, b) transverse energy spectrum of the jet. The full circles show the data, the triangle symbols correspond to the MC estimated background contribution and the shaded histogram to a superposition of prompt-photon MC and background.

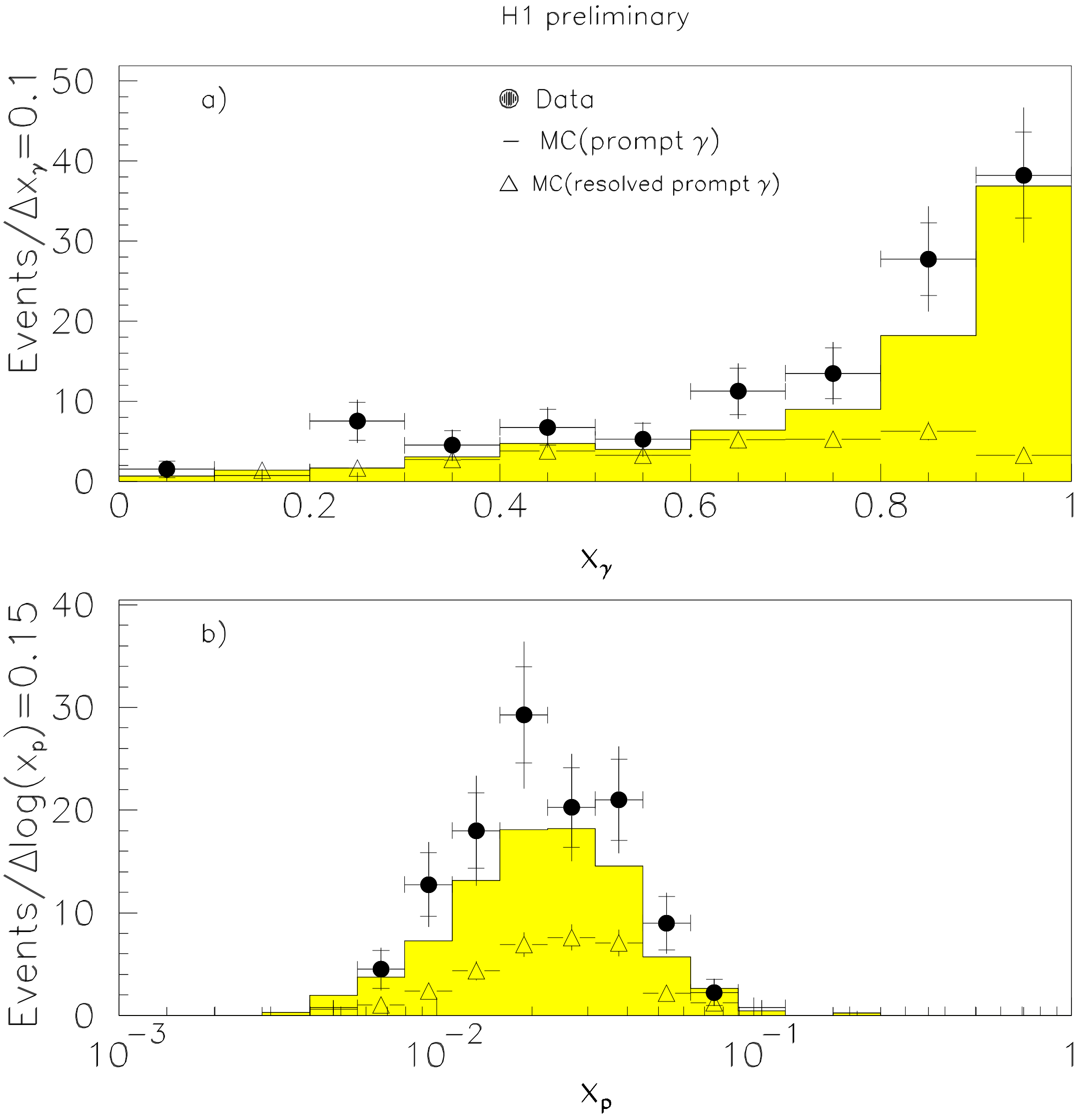

Figure 4: Distributions in a) x_γ and b) x_p extracted from the event sample with a photon and a jet. The full circles show the uncorrected data after background subtraction. The shaded histogram is the QCD expectation for prompt photon production including direct and resolved photon contributions. The triangle symbols show the resolved photon part only. The selected events have a photon with $E_{T\gamma} > 5$ GeV and $-1.2 < \eta_\gamma < 1.6$ and an accompanying jet with $E_{TJet} > 4$ GeV and $-0.5 < \eta_{Jet} < 2.0$. The inner error bars show the statistical errors, the outer the statistical and systematical errors added in quadrature.