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Inclusive Prompt Photon Production at HERA

H1 Collaboration

Abstract

Inclusive prompt photons are measured in photoproduction at HERA. Cross sections are presented as a function of transverse energy E_T^γ and pseudorapidity η^γ for $E_T^\gamma > 5$ GeV and $-1 < \eta^\gamma < 0.9$ in the γp center of mass energy range $142 < W < 266$ GeV. The data were taken with the H1 detector in the years 1996-2000. After selection of prompt photon candidates, a sizable amount of background from π^0 mesons remains and the γ signal is extracted by a likelihood technique using calorimetric shower shape variables. The results are compared to a NLO-QCD calculation and to the PYTHIA event generator.

1 Introduction

High energy ep collisions at HERA are dominated by electron scattering at small angles where a quasi real photon interacts with the proton. The interaction of the partons of the quasi real photon and of the proton can lead to the process of so called prompt photon emission which is sensitive to their partonic substructures. An isolated photon at large transverse energy E_T^γ can be measured directly which is in contrast to studies with jets where the partonic structure is hidden behind the non perturbative hadronisation process.

Recent next to leading (NLO) perturbative QCD (pQCD) calculations for inclusive production of isolated photons are available [1–3]. In such calculations the exchanged photon interacts either directly with the partons of the proton or as a resolved photon. Similarily the final state photon can be emitted in a hard partonic process or be emitted in a fragmentation process of a quark or gluon.

In this paper we confront measurements of inclusive prompt photon cross sections with NLO calculations using the program of Fontannaz, Guillet and Heinrich [1] and with the event generator PYTHIA [4] based on leading order QCD matrix elements and leading logarithmic parton showers. The results are also compared to data of the ZEUS collaboration [5].

2 Strategy of Data Analysis

Prompt photons are identified in the H1 liquid argon (LAr) calorimeter [6]. The main experimental difficulty is the separation of prompt photons from hadronic background, in particular from fake signals due to π^0 mesons, as for those, at high energies, the two energetic decay photons cannot be resolved in the calorimeter. The π^0 mesons are predominantly produced in jets, therefore an isolation requirement is applied for the γ candidates.

No track is allowed to point to the calorimetric energy cluster of the γ candidate to exclude events in which the cluster is faked by electrons. Neutral current (NC) deep inelastic scattering (DIS) background events are further reduced by requiring a significant energy loss in the electron[1] beam direction as expected in untagged photoproduction from the electron scattered under small angles.

After all selection cuts, the background is still of similar size as the prompt photon signal. The signal is thus extracted exploiting a combination of discriminating shower shape functions in a likelihood analysis. Distributions of the γ candidates are fitted by a sum of contributions of simulated photons, π^0 and η mesons. The signal extraction is performed independently in a grid of transverse energy E_T^γ and pseudorapidity η^γ. [2]

The data are corrected for detector effects by a detailed simulation of prompt photon production in the H1 detector using the PYTHIA event generator [4]. In contrast, the π^0 background estimate of PYTHIA is not used in the analysis. Only the η/π^0 fraction in the background ($\approx 5\%$ after selection) is taken from the generator.

[1]The term “electron” is used for electrons and positrons.

[2]The pseudorapidity η of an object with polar angle θ is given by $\eta = -\ln\ \tan(\theta/2)$, where θ is measured with respect to the z axis given by the proton beam direction.

3 Event Selection

The data have been collected with the H1 detector [7] at HERA in different data taking periods with electrons or positrons with energy $E_e = 27.5$ GeV collided with protons of energies $E_p = 820$ GeV or $E_p = 920$ GeV. The data correspond to an integrated luminosity of $102\ \mathrm{pb}^{-1}$ of which $28.8\ \mathrm{pb}^{-1}$ and $58.6\ \mathrm{pb}^{-1}$ are recorded in e^+p interactions at center of mass energies $\sqrt{s} = 300$ GeV and $\sqrt{s} = 318$ GeV respectively, and $14.9\ \mathrm{pb}^{-1}$ in e^-p interactions at $\sqrt{s} = 318$ GeV.

The main experimental requirements to select the prompt photon candidates are the following:

- The events are triggered by an electromagnetic cluster in the LAr calorimeter.
- A compact electromagnetic energy cluster, consistent with a γ shower, is reconstructed in the LAr calorimeter in the range $E_T^\gamma > 5$ GeV and $-1 < \eta^\gamma < 0.9$. No track is allowed to point to this cluster within a distance of 25 cm.
- Events with electron candidates are rejected.
- An event vertex is required to be within ± 35 cm of the nominal vertex position to remove non ep background.
- At least two tracks in the central tracker are required which assures good vertex reconstruction and suppresses QED Compton background.
- For the inelasticity $y = 1 - E_e'/E_e$ we require $0.2 < y < 0.7$, where E_e' is the energy of the non-detected scattered electron. The inelasticity is evaluated as $y = \sum (E - p_z)/2E_e$ where the sum runs over all detected final state particles. The range of y corresponds to the γp center of mass energy range $142 < W < 266$ GeV at $E_p = 920$ GeV.
- The γ candidate is required to be isolated. The transverse energy in a cone in (η, ϕ) of radius 1 around the γ candidate E_T^{cone} is required not to exceed $0.1 \cdot E_T^\gamma$, following the convention of [5].

4 Signal Extraction

A large part of the selected γ candidates have showers initiated by π^0 mesons. The fraction of prompt photons in the data is extracted by a shower shape analysis where the mean transverse shower radius given by $R = \sum_i r_i E_i / \sum_i E_i$ and the "shower hot core fraction" (HCF) are used to discriminate against background. Here r_i is the transverse distance of cell i with energy E_i measured with respect to the axis from the event vertex to the center of gravity of the shower. HCF is the energy fraction of the cluster which is contained in 4 or 8 contiguous cells including the cell of highest energy depending on calorimeter granularity. Likelihood functions based on the distributions of R and HCF are calculated for the data and for simulated samples of photons, π^0 mesons and η mesons separately in a grid of 6×6 bins in η^γ and E_T^γ. The contribution of the different particle types is then determined by independent fits to the data distributions. Hereby the η/π^0 fraction ($\approx 5\%$ after selection) is taken from PYTHIA.

Summing over the full η^γ, E_T^γ range we show in Fig. 1 the measured distributions of R and HCF and the simulated distributions of photons and background from π^0 and η mesons with the normalisations taken from the likelihood fits in the different bins. The data distribution is well described by the extracted signal and background components. The discrimination power decreases to high E_T^γ where R and HCF distributions of π^0 mesons and photons get more similar. Events with $E_T^\gamma > 10$ GeV are not included in the results presented below.

5 Systematic Uncertainties

For the prompt photon cross sections various systematic uncertainties were considered and the given total systematic error per bin is obtained by adding the different systematic errors in quadrature.

- The most important systematic errors are due to potentially inadequate simulation of the shower shapes. Uncertainties in the simulated distributions of R and HCF are established by comparison to electron candidates from NC DIS events. The resulting errors of the cross sections are typically $\pm 10\%$ to $\pm 20\%$.

- The uncertainties of the electromagnetic and hadronic energy scales and variations of the assumed E_T and η dependence of the single particles used in the shower simulations contribute errors smaller than 10% altogether.

- Background due to DIS electrons resulting from the tracker inefficiency (below 0.4% for the used track selection) leads to a subtraction of $(3.0 \pm 0.3)\%$ in the lowest η bin and at high E_T^γ , and is negligible otherwise.

- An overall uncertainty of $\pm 1.5\%$ of the luminosity measurement is not included in the shown results.

- To take account of uncertainties in the detector corrections obtained by simulation of the measurement using PYTHIA, the E_T^γ dependence in PYTHIA is varied leading to uncertainties below 3%. The sensitivity of the correction factors to the underlying event activity is studied by changing the relative weight of the PYTHIA events in proportion to the transverse energy in the isolation cone E_T^{cone} around the photon. Allowing a change for the relative event yield at the cut energy $E_T^{cone} = 0.1 \cdot E_T^\gamma$ by factors 0.5 and 2 leads to variations of the final results below 3% which are included in the systematic errors.

  It was verified that PYTHIA describes the dependence of the measured cross sections on the chosen cut on the isolation cone.

6 Results

The results are presented as ep cross sections [3] at $\sqrt{s} = 318$ GeV and $0.2 < y < 0.7$ for photon virtualities $Q^2 < 1$ GeV^2, including the photon isolation condition $E_T^{cone} = 0.1 \cdot E_T^{\gamma}$ (see above). Differential cross sections $\mathrm{d}\sigma/\mathrm{d}E_T^{\gamma}$ and $\mathrm{d}\sigma/\mathrm{d}\eta^{\gamma}$ are obtained by summation over the η^{γ} and E_T^{γ} bins respectively. The errors in the figures contain the statistical errors as obtained from the likelihood fits and the systematic errors added in quadrature.

The results are shown in Fig. 2 and compared to the NLO pQCD calculation of Fontannaz et al. [1] and the PYTHIA event generator [4]. In the NLO calculation the photon and proton parton densities AFG [8] and MRST2 [9] are used respectively. In PYTHIA the leading order QCD matrix elements are regulated by a minimum cut-off in transverse momentum which is set to 3 GeV. The parton densities GRV(LO) [10], [11] are used for photon and proton respectively. The program simulates multiple parton interactions (MI) and initial and final state radiation [4].

The NLO calculation describes the data quite well in the presented E_T^{γ} and η^{γ} ranges with a tendency to overshoot the data, especially at large η^{γ}. The PYTHIA simulation describes the data well in shape, is however low in normalisation. For comparison we show in Fig. 3 also the PYTHIA prediction without multiple interactions. It is interesting to note, that in this case the predictions at $0 < \eta^{\gamma} < 0.9$ are about 25% higher, showing that the cross section is reduced by the soft underlying event activity, as expected [1], due to the isolation cone condition $E_T^{cone} = 0.1 \cdot E_T^{\gamma}$ which is presently applied. Fig. 3 also shows besides the full PYTHIA prediction including MI, separately the component where a final state quark in di-jet events radiates a photon and the resolved interactions of the exchanged photon.

The data are compared[5] to the results of the ZEUS collaboration in Fig. 4 at $\sqrt{s} = 300$ GeV in the range $-0.7 < \eta^{\gamma} < 0.9$ and $0.2 < y < 0.9$. The data are consistent, but the H1 data are somewhat lower at small η^{γ}, where the ZEUS results appear to exceed the NLO calculation.

7 Conclusions

Results on inclusive prompt photon production have been presented. The cross sections $\mathrm{d}\sigma/\mathrm{d}E_T^{\gamma}$ and $\mathrm{d}\sigma/\mathrm{d}\eta^{\gamma}$ are roughly consistent with results from the ZEUS collaboration, but tend to be lower at negative η^{γ} . The data are quite well described in the covered η^{γ} and E_T^{γ} range by a NLO pQCD calculation, but the prediction is above the data in the forward region ($\eta^{\gamma} > 0.6$) which could be related to underlying event activity not contained in the NLO calculation. The cross sections produced with the PYTHIA event generator describe the data distribution well in shape with a normalisation that is about 30% low.

Acknowledgements

We are grateful to Gudrun Heinrich for discussions and for providing some results of the NLO QCD calculations.

[3]The cross sections obtained at $\sqrt{s} = 300$ GeV are transformed to $\sqrt{s} = 318$ GeV by corrections of about 4% taken from PYTHIA.

[4]Default parameters in version 6.15/70 were used, for the intrinsic k_T of initial state partons in the proton, $< k_T^2 >= 1$ GeV^2 was chosen.

[5]The H1 data are corrected for the extension of the upper edge of y from 0.7 to 0.9 using PYTHIA.

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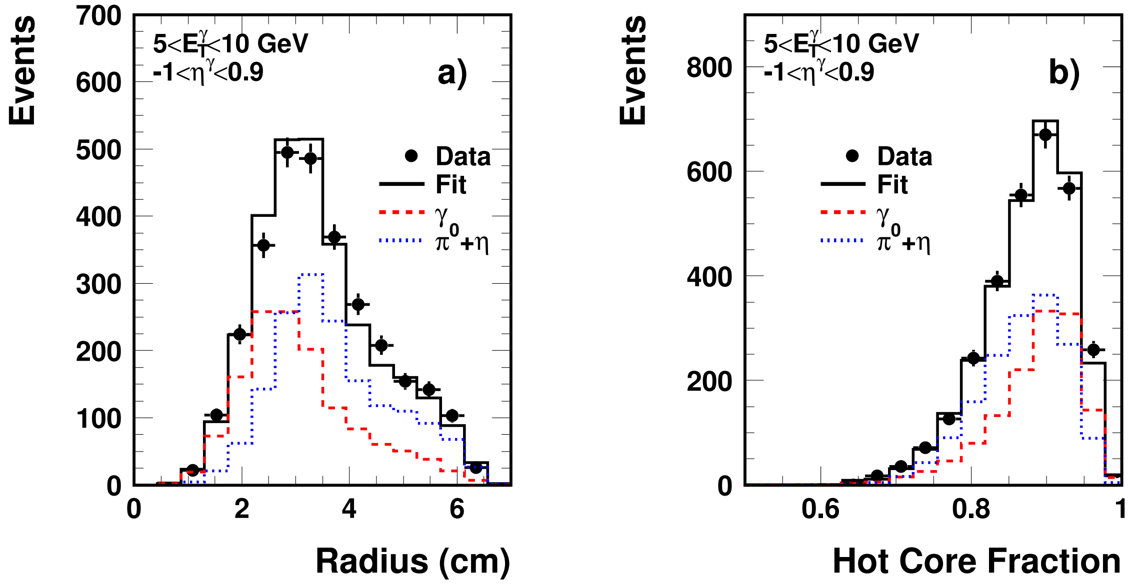

Figure 1: Distributions of the mean transverse shower radius R (a) and and the hot core fraction HCF (b) for the selected photon candidates (solid lines) summing over the full range for $-1 < \eta < 0.9$, $5 < E_T^\gamma < 10$ GeV. The simulated distributions for photons (dashed lines) and background ($\pi^0 + \eta$, dotted lines) are normalised by the likelihood fits.

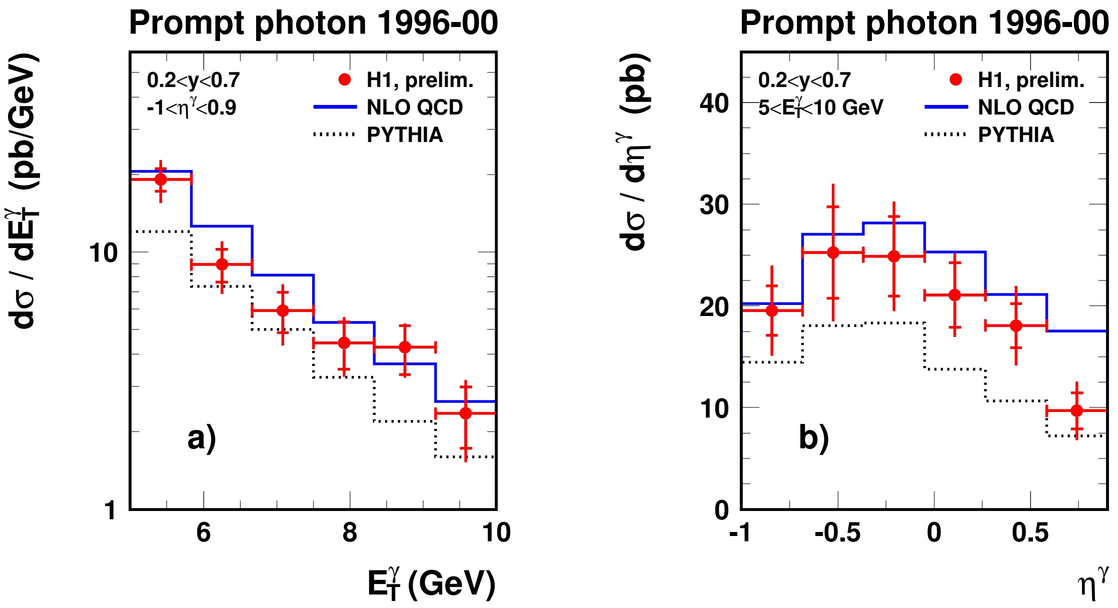

Figure 2: Prompt photon differential cross sections $\mathrm{d}\sigma/\mathrm{d}E_T^\gamma$ for $-1 < \eta^\gamma < 0.9$ (a) and $\mathrm{d}\sigma/\mathrm{d}\eta^\gamma$ for $5 < E_T^\gamma < 10$ GeV (b) at $\sqrt{s} = 318$ GeV and $0.2 < y < 0.7$ compared to the prediction of a NLO pQCD calculation [1] and the PYTHIA generator [4].

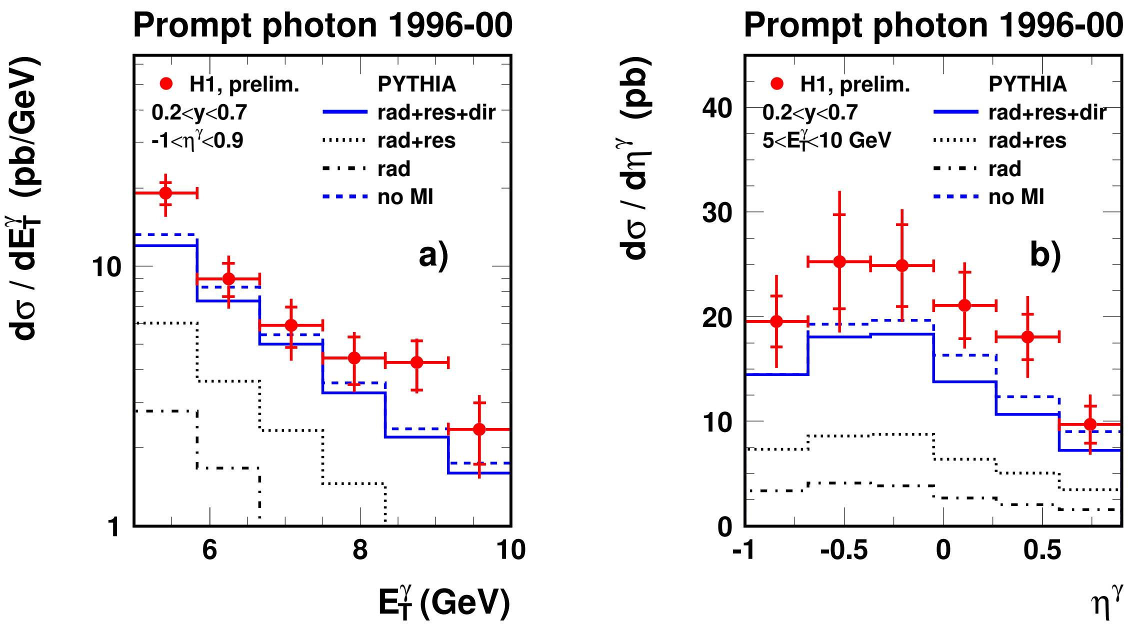

Figure 3: Prompt photon differential cross sections $\mathrm{d}\sigma/\mathrm{d}E_T^\gamma$ for $-1 < \eta^\gamma < 0.9$ (a) and $\mathrm{d}\sigma/\mathrm{d}\eta^\gamma$ for $5 < E_T^\gamma < 10$ GeV (b) at $\sqrt{s} = 318$ GeV and $0.2 < y < 0.7$ compared to the PYTHIA prediction including multiple interactions (full line) with the contributions from di-jet events where a final state quark radiates a photon (dashed-dotted) and this component summed with resolved photon events (dotted line). Also shown is the the full PYTHIA prediction without multiple interactions (dashed line).

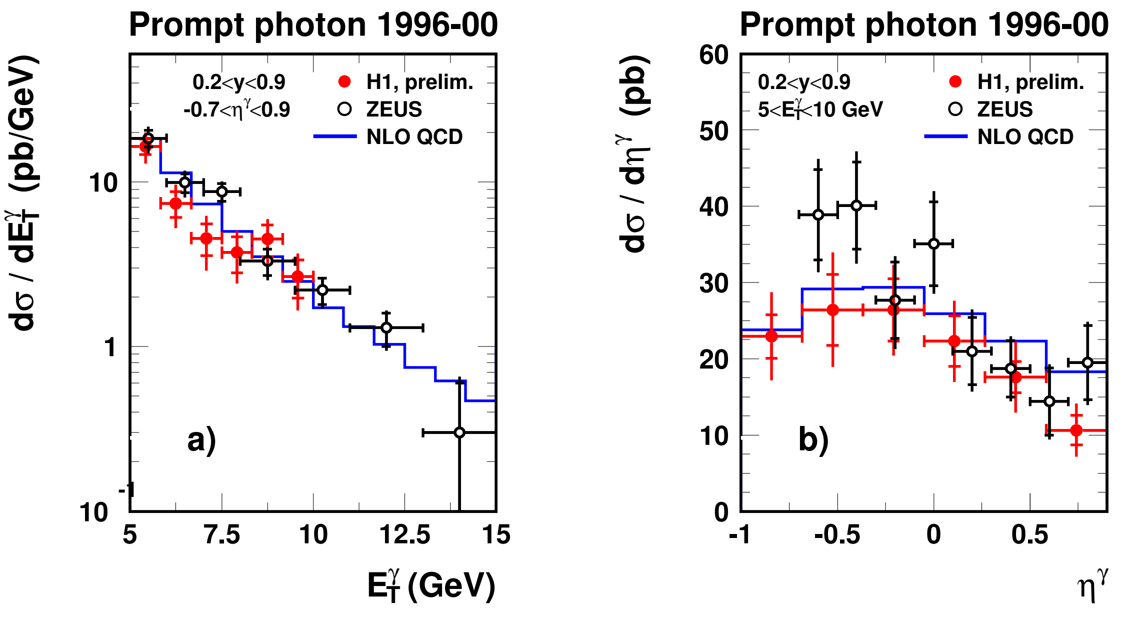

Figure 4: Prompt photon differential cross sections $\mathrm{d}\sigma/\mathrm{d}E_T^\gamma$ for $-0.7 < \eta^\gamma < 0.9$ (a) and $\mathrm{d}\sigma/\mathrm{d}\eta^\gamma$ for $5 < E_T^\gamma < 10$ GeV (b) corrected for $\sqrt{s} = 300$ GeV and $0.2 < y < 0.9$ compared to results of the ZEUS collaboration [5]. Also shown is the prediction of a NLO pQCD calculation [1].