307: Measurements of the structure of photons at HERA

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Abstract. Measurements of the structure of the photon with the H1 and ZEUS detector at HERA are presented. The double differential di-jet cross section is determined and an effective leading order parton distribution of the photon is extracted. A new method based on high p_T charged tracks is used to extract the gluon density of the photon. Cross sections of photoproduction events with high E_T photons are presented.

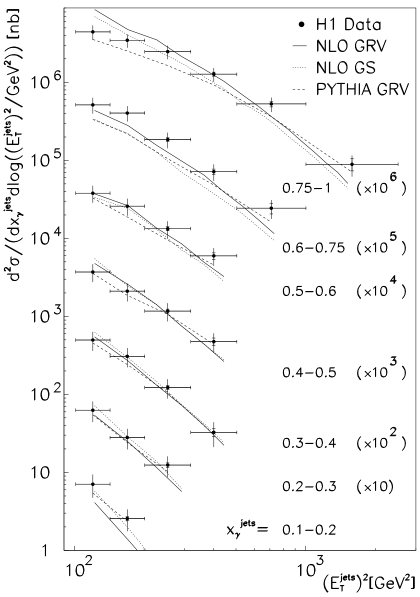
1 Introduction

The two experiments H1 and ZEUS at the positron-proton collider HERA (820 GeV proton, 27.5 GeV positrons) offer a unique possibility to study the structure of photons in a very large phase space. The study of hard processes in quasi-real photoproduction at HERA is in lowest order(LO) QCD described by the interaction of a parton from the proton with the incoming photon (direct process) or with a parton from the photon (resolved process). Both experiments analyse different final states, such as di-jet events, events with an isolated high p_T photon, so called prompt photon events, or high p_T charged tracks to investigate the structure of the photon.

2 Di-jet cross section and effective parton distribution

The double-differential di-jet cross section in photoproduction ($Q^2 < 4\,\mathrm{GeV}^2$) is measured with the H1 detector. Events were selected with two jets which were found using a cone algorithm with cone size R=0.7 and jet pseudorapidities in the range -0.5<η<2.5 in the laboratory system. The imbalance of the two highest E_T^{Jets} jets was required to be $\mid E_{T,1}^{Jets}$-$E_{T,2}^{Jets}\mid <$ 0.25 E_T^{Jets}. E_T^{Jets} is the average jet energy which had to be larger than 10 GeV. The fractional energy of the exchanged photon y is restricted to 0.2<y<0.83.

The measurement is shown in Figure 2a) as a function of the average transverse energy E_T^{Jets} in bins of x_γ^{Jets} the fraction of the photon momentum carried by the parton from the photon, as measured with the two jets: $x_\gamma^{Jets} = \Sigma_{jets} E_T^{Jet} e^{-\eta^{Jet}}/2E_\gamma$. The dominant systematical error comes from the uncertainty in the knowledge of the electromagnetic energy scale. Next-to-leading order QCD [1] calculations (GRV-HO [2] and GS96 [3] photon parton distributions) and leading order monte carlo simulations with parton showers (GRV-LO [2]) describe the data satisfactory except for the two highest x_γ^{Jets}



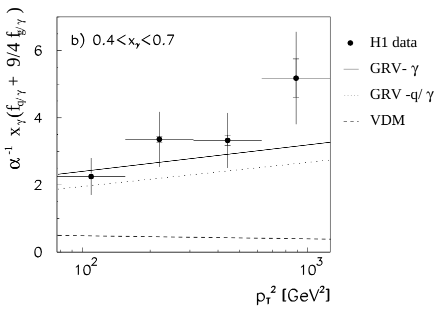


Fig. 1. a) Di-jet cross section as a function of the average jet energy squared $(E_T^{Jets})^2$ in bins of different fractional energy carried by the parton from the photon (x_γ^{Jets}). The data are compared to LO QCD simulation and two next to leading order calculations with different input structure functions. b) Leading order effective parton distribution in the photon as a function of the squared transverse momentum ${p_T}^2$ of the parton.

bins. Note that this high x_γ region was so far not accessible to measurements of the photon structure function by e^+e^-experiments.

Parton distributions of the photon at $x_\gamma \simeq 0.5$ are extracted using an approximation method [4]. The shape of the leading order matrix elements of the dominant partonic scattering processes qq→qq, qg→qg, and gg→gg are similar. Therefore the di-jet cross section is written as a product of one single effective subprocess M_{SES} and effective parton density functions f^γ_{eff} and f^p_{eff} which are a combination of quark and gluon densities.

$$f_{eff}(x, p_t^2) = \Sigma_q(q(x, p_t^2) + \bar{q}(x, p_t^2)) + 9/4 \cdot g(x, p_t^2)$$

p_T is the transverse momentum of the final state partons and is taken to be the scale of the process. With this ansatz f^γ_{eff} can be directly extracted from the data. The leading order effective parton distribution of the photon for $0.4 < x_\gamma < 0.7$ is shown in Figure 2b). The data rises with increasing p_T as is expected from the anomalous photon contribution [5]. The data are well reproduced by the GRV parametrization (full curve). This result extends the kinematic region of the measurement of the photon parton distributions to the scale of ${p_T}^2$= 1250 GeV^2 with a precision comparable to e^+e^-measurements. The dotted line shows the GRV contribution from the quarks alone which amounts to 80% at large x_γ. A purely hadronic description of the photon as modelled in the vector meson dominance model (VDM) does not describe the data in shape and magnitude (dashed line).

3 Gluon density in the photon

The first gluon distribution of the photon was measured by H1 using di-jet events [6]. A new approach uses high p_T charged tracks measured in the central region of the H1 detector (at least one track with p_T >2.6 GeV and $|\eta|$<1). Compared to the direct approach its advantage is the independence of the energy scale and reduced sensitivity to effects of multiple parton interactions.

x_γ^{rec} is calculated as $x_\gamma^{rec} = \Sigma_N p_z e^{-\eta}/E_\gamma$ where the sum runs over all tracks with p_T >2 GeV. An unfolding procedure [7] is used to reconstruct x_γ^{true}. As in the di-jet analysis [6] the extracted x_γ distribution shows a large contribution of processes which include gluons from the photon. In order to extract the leading order gluon distribution in the photon, quark induced processes as modelled by PYTHIA with LAC1 [8] parametrisation are subtracted. The resulting gluon distribution as a function of x_γ is shown in Figure 2 at a scale of $<{p_T}^2>$=38 GeV^2. The result is in good agreement with the di-jet measuement but has reduced errors. It confirms the rise of the gluon density with decreasing x_γ.

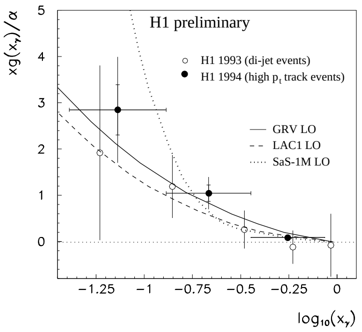


Fig. 2. Gluon distribution in the photon using high p_T charged particles (full circles). The measurement is compared to a previous measurement from H1 using di-jet events (open circles) which shows good agreement of the two methods. The full line shows the parametrisation of GRV, the dotted line SaS [9] and the dashed line LAC1.

4 Prompt photons

The production of prompt photons gives the opportunity to directly observe a particle from the hard subprocess, though with a substantially smaller cross section than di-jet production. Events are selected by both experiments with an isolated photon ($E_{T\gamma} > 5$ GeV) in a pseudorapidity range $-1.2(-0.7) < \eta_\gamma < 1.6(0.8)$ for H1 (ZEUS). Roughly 40% of the events have a jet measured in the detector which is needed for the determination of x_γ :$x_\gamma = (E_T^\gamma \cdot e^{-\eta^\gamma} + E_T^{Jet} \cdot e^{-\eta^{Jet}})/2E_\gamma$.

Isolation cuts and cuts on the cluster shape are applied to reduce background from hadronic jet events, where a neutral meson fakes a photon and from events with a photon radiated from a final state quarks. ZEUS estimates the remaining background from a fit to the distribution of the fractional energy deposited in the calorimeter cell with maximum energy. A photon deposits more than 75% of its energy in one cell, whereas π^0 or η tend to deposit their energy in several cells. A cross section is extracted by ZEUS for the sample with a jet($E_T^{Jet} > 5$ GeV, $-1.5 < \eta_{Jet} < 1.8$) for $x_\gamma > 0.8$ where the direct contribution is dominating: $\sigma_{\gamma p \to \gamma + Jet + X} = 15.3 \pm 3.8(stat) \pm 1.8(syst)$ pb which is in agreement with NLO calculations [10]: 14.05 pb (GS), 17.93 (GRV).

H1 estimates the background from Monte Carlo simulation to be of the order of 25%, it is subtracted binwise. The measured x_γ distribution is shown in Figure 3. 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 which was input for the Monte Carlo simulation. The cross section for the process $\gamma P \to \gamma + X$ ($E_{T\gamma} > 5$ GeV, $-1.2 < \eta_\gamma < 1.6$) 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.

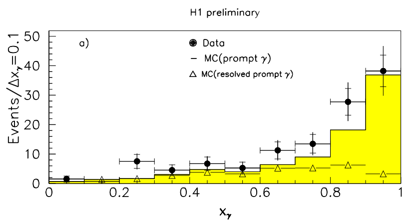


Fig. 3. x_γ distribution extracted from the event sample with a photon ($E_{T\gamma}$ > 5 GeV, -1.2 < η_γ < 1.6) and a jet (E_{TJet} > 4 GeV, -0.5 < η_{Jet} < 2.0). The full circles show uncorrected data after background subtraction. The shaded histogram is the QCD expectation for prompt photon production, the triangle symbols show the resolved photon part only.

5 Summary

Analyses of the structure of real photons were presented. The double differential di-jet cross section was presented and used to extract effective parton distributions with a precision comparable to e^+e^-data but at a higher scale. A logarithmic increase with ${p_T}^2$ is observed as predicted by perturbative QCD. A new method was presented to extract the gluon density in the photon using charged tracks. It is found to rise with decreasing x_γ. The prompt photon process was measured by both experiments and cross sections were given for the direct and the inclusive process.

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