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GLAS-PPE/2001-03  
April 2001

## Prompt Photons in Photoproduction at HERA

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### Abstract

The production of prompt photons in photoproduction reactions in the ZEUS experiment is discussed. Cross sections for inclusive prompt photons and for prompt photons accompanied by jets are compared with theory, and the latter are used to determine the effective transverse momentum of the quarks in the proton.

*Paper presented at the 9th International Workshop  
on Deep Inelastic Scattering,  
Bologna, 27 April - 1 May 2001*

arXiv:hep-ex/0107063v1 23 Jul 2001

# 1 Introduction.

The study of parton interactions is frequently hindered by the fact that outgoing quarks and gluons cannot be observed directly. Photons, however, referred to as “prompt photons”, can emerge as a primary product of hard parton processes without the hadronisation by which quarks and gluons form jets. In this way, they provide information that is relatively free from hadronisation uncertainties.

This talk summarises two recent analyses by ZEUS at HERA [1, 2], which present measurements of prompt photon cross sections in photoproduction.

# 2 Experimental method.

Prompt photons are measured in the ZEUS Barrel Calorimeter. The fine-grained, pointing geometry of the electromagnetic section allows photons to be distinguished from  $\pi^0$  and  $\eta^0$  backgrounds by first removing those candidates consisting of a broad cluster of fired cells. A statistical subtraction is then performed as a function of the fraction of the energy in the highest-energy cell. An isolation condition removes further background, and reduces the contribution from photons radiated from final-state quarks.

The integrated  $e^+p$  luminosity was  $38.6 \pm 0.6 \text{ pb}^{-1}$ , with  $E_e = 27.5 \text{ GeV}$  and  $E_p = 820 \text{ GeV}$ . The analysis employed energy-flow objects which combine information from calorimeter cells and measured tracks. The incoming virtual photon energy was estimated using  $y_{JB} = \sum(E - p_z)/2E_e$ , summing over all energy-flow objects in the event, each treated as equivalent to a massless particle. After correcting for energy losses, limits on  $y_{JB}$  were applied, corresponding to limits on the centre-of-mass  $\gamma p$  energy  $W$ . Events with a scattered beam positron in the calorimeter were rejected both explicitly and by the upper limit on  $y_{JB}$ .

Jets were reconstructed, using energy-flow objects, by means of the Lorentz-invariant  $k_T$ -clustering algorithm KTCLUS in the inclusive mode. The momenta of the objects comprising the jet were summed to obtain the total jet-momentum vector. An energy correction was applied.

After correction, the photons and jets were respectively required to have  $E_T^\gamma > 5 \text{ GeV}$  with  $-0.7 < \eta^\gamma < 0.9$ , and  $E_T^{\text{jet}} > 5 \text{ GeV}$  with  $-1.5 < \eta^{\text{jet}} < 1.8$ , where  $\eta$  is the laboratory pseudorapidity. The fraction of the incoming photon energy that takes part in the QCD subprocess was estimated as  $x_\gamma^{\text{meas}} = \sum_{\gamma, \text{jet}} (E - p_z)/2E_e y_{JB}$ , summing over the high-energy photon and the jet.

# 3 Inclusive photoproduction of prompt photons.

Figure 1 shows the inclusive prompt photon cross section as a function of  $\eta^\gamma$ . The magnitude is approximately described by PYTHIA; HERWIG is lower due to a smaller radiative contribution. The NLO parton-level calculations give a fair description. However at negative  $\eta^\gamma$ , all the models are low. The shape of the  $E_T^\gamma$  distribution is well described by each model. There are important contributions from the direct and resolved processes, and also from radiative processes.

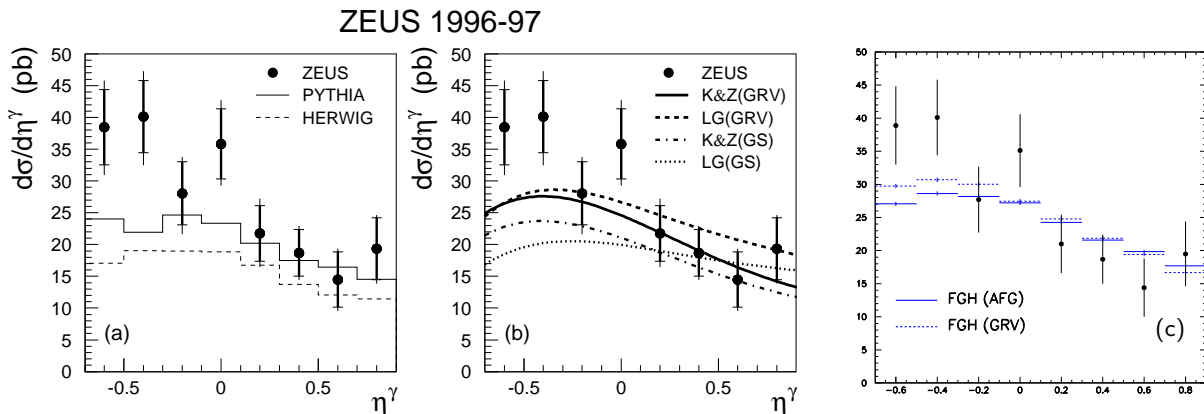


Figure 1: Inclusive prompt photon distribution in ZEUS for events in the range  $134 < W < 285 \text{ GeV}$ . The data are compared with (a) Hadronising Monte Carlos, (b) NLO calculations of Krawczyk and Zembrzusi (K&Z) and Gordon (LG), (c) the recent calculation of FGH [3]. Of the various photon parton distributions tested, that of GRV appears preferred.

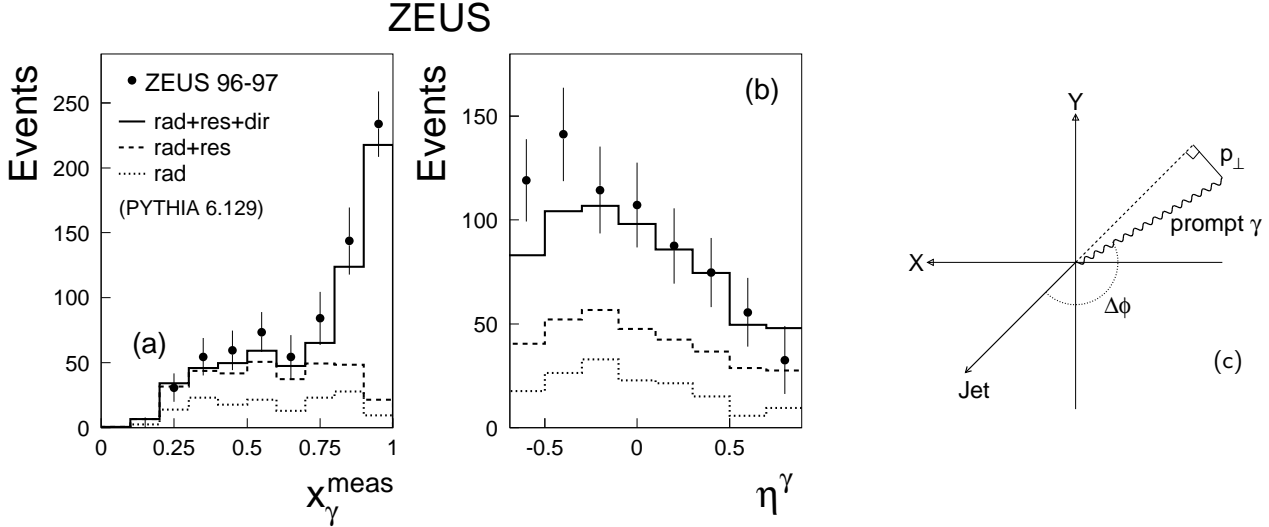


Figure 2: Distributions in (a)  $x_\gamma^{\text{meas}}$  and (b)  $\eta^\gamma$  when a jet and prompt photon are demanded, compared with PYTHIA predictions using the GRV photon PDF, for events in the range  $134 < W < 251$  GeV. (c) Kinematics of prompt photon relative to jet.

The recent FGH calculation [3], still at the parton level, contains the NLO terms in LG and also a box diagram term that is included in K&Z. It is a slight improvement, but again fails to account fully for the backward cross section. Varying the effective transverse momentum of the partons in the proton has been investigated, and seems unable to generate the effect. As shown below, there is no significant discrepancy when a jet is included in the cross section definition; it is therefore worth asking whether the processes which give a very forward-backward event need special theoretical treatment. A recent calculation [4] predicts a BFKL contribution of a suitable magnitude, namely  $d\sigma/d\eta^\gamma \approx 8$  pb, but with no backward peaking. It will be of interest to see whether the CCFM approach [5] can assist.

## 4 Prompt photons plus jets.

Figure 2 shows the distributions in  $x_\gamma^{\text{meas}}$  and  $\eta^\gamma$  obtained when a jet is demanded. The strong peak near unity in  $x_\gamma^{\text{meas}}$  is due to events in which the “direct photoproduction” process dominates. In photoproduction at leading order, the Compton process  $\gamma q \rightarrow \gamma q$  is the only direct prompt photon process. The distributions are well described by PYTHIA (c.f. Fig. 1a), giving no suggestion for large errors in the photon PDFs.

The condition  $x_\gamma^{\text{meas}} > 0.9$  selects events due mainly to the direct Compton process, and little affected by the incoming photon’s hadronic structure. In these events, the transverse momentum  $\langle p_\perp \rangle$  of the prompt photon perpendicular to the jet direction in the  $r\phi$  plane is sensitive to the momentum of the quarks in the proton, as is the azimuthal angle between the prompt photon and the jet (cf. Fig. 2c). The normalised distribution of  $\langle p_\perp \rangle$  was used to fit the PYTHIA parameter  $k_0$ , the so-called “intrinsic” parton momentum in the proton. A good fit is obtained (Fig. 3). By combining  $k_0$  with the effects of the initial-state parton showers, it is possible to obtain an overall value for the effective transverse momentum of the partons in the proton. The result is  $\langle k_T \rangle = 1.69 \pm 0.18^{+0.18}_{-0.20}$  GeV, as shown in Fig. 3c in comparison with data from a variety of other experiments.

The ZEUS result is consistent with the trend shown by all the measurements, namely that the value of  $\langle k_T \rangle$  rises with hadronic interaction energy. This may be attributed to the effects of initial-state gluon radiation, but a full theoretical description is still awaited.

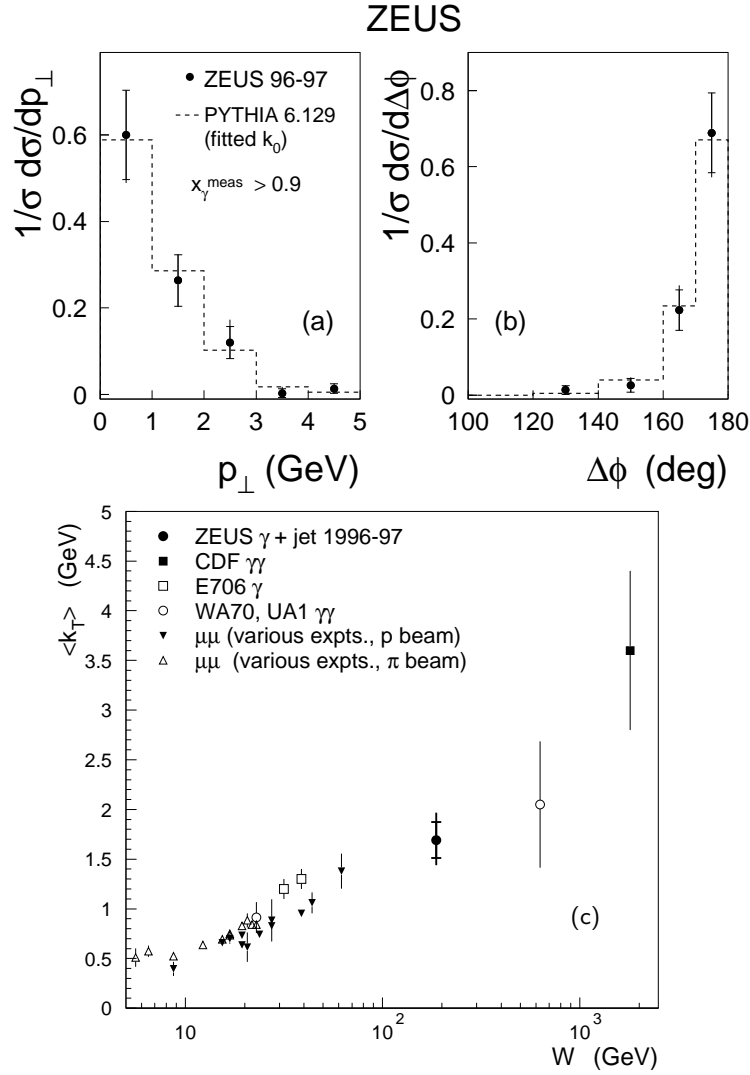


Figure 3: Normalised distributions of  $\langle p_{\perp} \rangle$  and  $\Delta\phi$  of photon relative to jet direction, together with fitted predictions from PYTHIA using optimised value of  $k_0$  (a,b). (c) Effective  $\langle k_T \rangle$  value in photoproduction in ZEUS, compared with results from other experiments. (See ref. 2 and further references therein.)

## References

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