PROCEEDINGS OF SCIENCE

Prompt photon production at HERA

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On behalf of the H1 and ZEUS collaborations

New results are presented on prompt photon production in photoproduction (H1) and DIS (ZEUS). These are compared to the predictions of collinear (DGLAP) factorisation and k_T-factorisation theories. The comparison tends to favour the k_T-factorisation approach.

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1. Isolated photons

New results are presented on prompt photon production in photoproduction [1] and deep inelastic scattering [2]. The data arise from 320 to 340 pb^{-1} of HERA-II collisions, including both e^+p and e^-p data sets These are used to test the predictions of various theories with collinear factorisation or k_T-factorisation. The comparison at low Q^2 and low x tends to favour the k_T-factorisation approach.

High-E_T isolated photon emission offers a new and reliable probe of dynamics in $e^\pm$-proton collisions. The photon is the only stable final state particle that couples to the quark line in the Feynman diagram. For this reason theorists refer to it as a 'prompt' photon (not coming from hadron decay). Experimentally one observes 'isolated' signals in the detector. In DIS events there are two hard scales, the Q^2 of the exchanged photon and the E_T of the observed photon. The observed photon can be radiated from a quark line (refered to as the QQ process) or the lepton line (LL process). The interference term (LQ process) is small for isolated photons and also changes sign between e^+p and e^-p collisions. The LQ term is therefore neglected in this work and e^+p and e^-p data sets are combined. Note that in the LL process the electron recoils against the high-E_T photon into the detector acceptance and the event is therefore classified as DIS. As a result the prompt-photon photoproduction data set contains only the QQ process. In this case the Feynman diagram can involve direct exchanged photons (coupling via the process $\gamma q \to \gamma q$) or resolved exchanged photons, which couple to gluons in the proton via the process $gq \to \gamma q$.)

Two stages are involved in extracting the isolated-photon signal. First the final-state electron is removed and the remaining calorimeter energy-flow objects (EFOs) are clustered into jets, using the inclusive-k_T algorithm with parameter $R_0 = 1.0$ [3]. One then looks at the ratio $R_\gamma = E(\gamma)/E(\gamma-\text{jet})$ where $E(\gamma)$ is the energy of the electromagnetic-calorimeter EFO, and $E(\gamma-\text{jet})$ is the energy of the jet that includes the electromagnetic cluster. Demanding $R_\gamma > 0.9$ eliminates a large fragmentation-dominated background. (The signal lies predominantly at $R_\gamma > 0.98$.)

The isolated electromagnetic EFO thus identified is dominated by unresolved clusters of two or more photons, mainly from $\pi^0 \to \gamma\gamma$ decay, which has a minimum opening angle given by $\sin\theta/2 = m(\pi^0)/E(\pi^0)$, giving a typical separation of a few cm in the electromagnetic calorimeter. One therefore needs to extract a narrow-EFO signal for isolated single photons. H1 use a discriminant method based on six shower-shape variables - transverse radius, symmetry and kurtosis, first layer energy fraction, hot core fraction and hottest cell fraction. The ZEUS work reported here uses the fine-granularity projective geometry of the barrel electromagnetic calorimeter to distinguish 1γ and 2γ peaks. Figure 1 shows the distribution in $\langle\delta Z\rangle = \Sigma E_i|Z_i - Z_{cluster}|/(w_{cell}\Sigma E_i)$. The fit is discussed below.

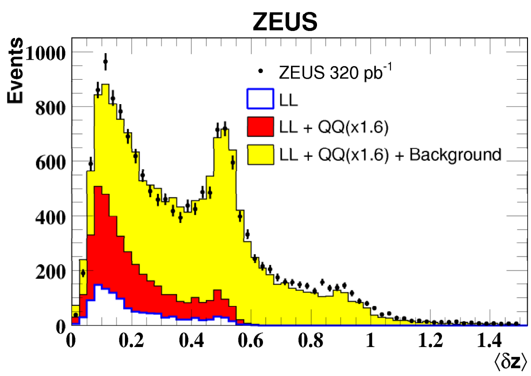

Figure 1: ZEUS shower z-width distribution

2. Photoproduction

H1 present results on inclusive γ and $(\gamma+\text{jet})$ in the kinematic range as follows. For the photon $6 < E^T < 15$ GeV and $-1.0 < \eta < 2.4$, $R_\gamma > 0.9$, $Q^2 < 1$ GeV^2, $0.1 < y_{JB} < 0.7$ and for jets $E^T(\text{jet}) > 4.5$ GeV and $-1.3 < \eta(\text{jet}) < 2.3$.

They compare their results to NLO QCD. Fontannaz, Guillet and Heinrich (FGH) use collinear factorisation and DGLAP evolution, include $(O(\alpha_s^2))$ and some higher terms and use MRST01 and AFG2 pdf's for p and γ [4]. H1 also compare their results to a k_T-factorisation calculation due to Lipatov and Zotov (LZ) [5] which uses direct and resolved integrated parton densities. In comparing the $(\gamma+\text{jet})$ data to theory hadronisation corrections (estimated using PYTHIA) are of order 8%.

Figure 2 includes the transverse energy and pseudorapidity distributions for the $(\gamma+\text{jet})$ final state compared to predictions. There is some tendency for the photon rapidity to favour LZ. This is also seen in earlier ZEUS results [6].

H1 separate the photon-plus-jet data into direct and resolved exchanged photons using photon and jet directions and the photon energy, (high and low values of x_γ^{LO}), and use these data sets to study azimuthal photon-jet correlations. In figure 2 $\Delta\phi$ is the difference in their azimuth angles and $p_\perp$ is the momentum in the transverse plane that, if added to the photon, would make its azimuth angle opposite to the jet. None of the theories describes these data well. Additional higher-order theory terms

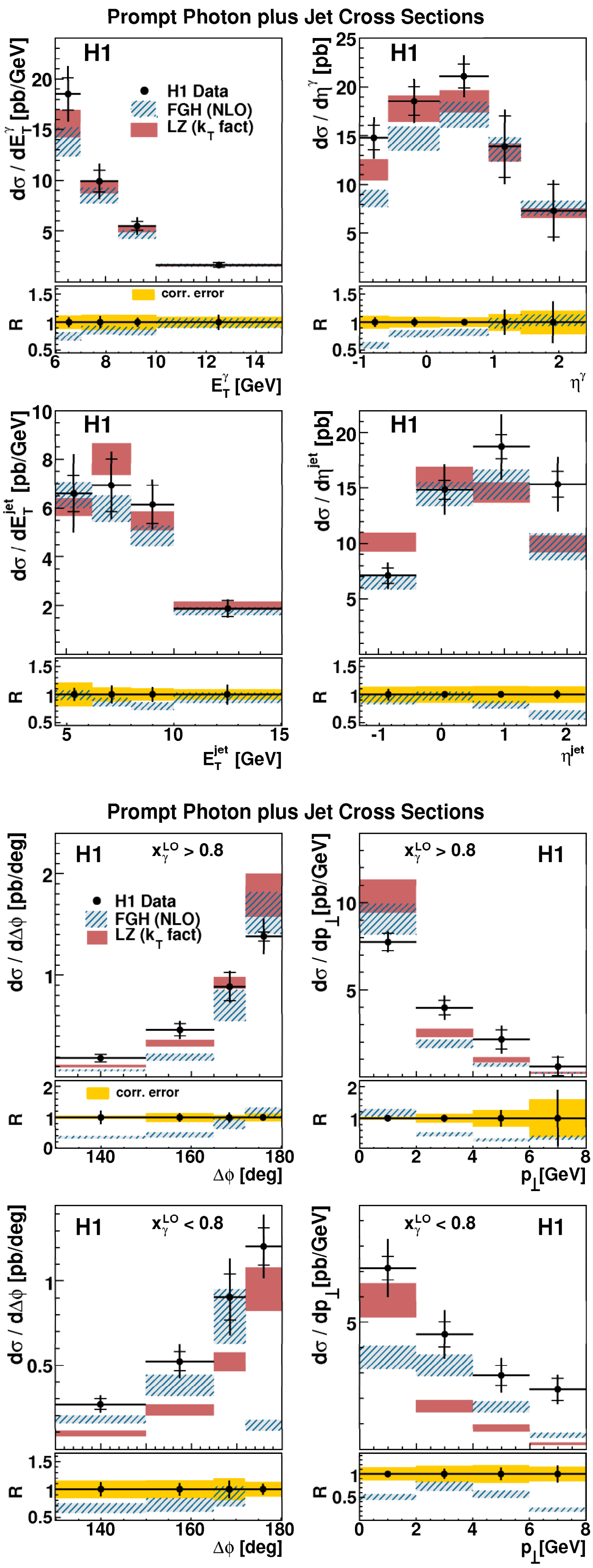

Figure 2: H1 results compared to theoretical predictions

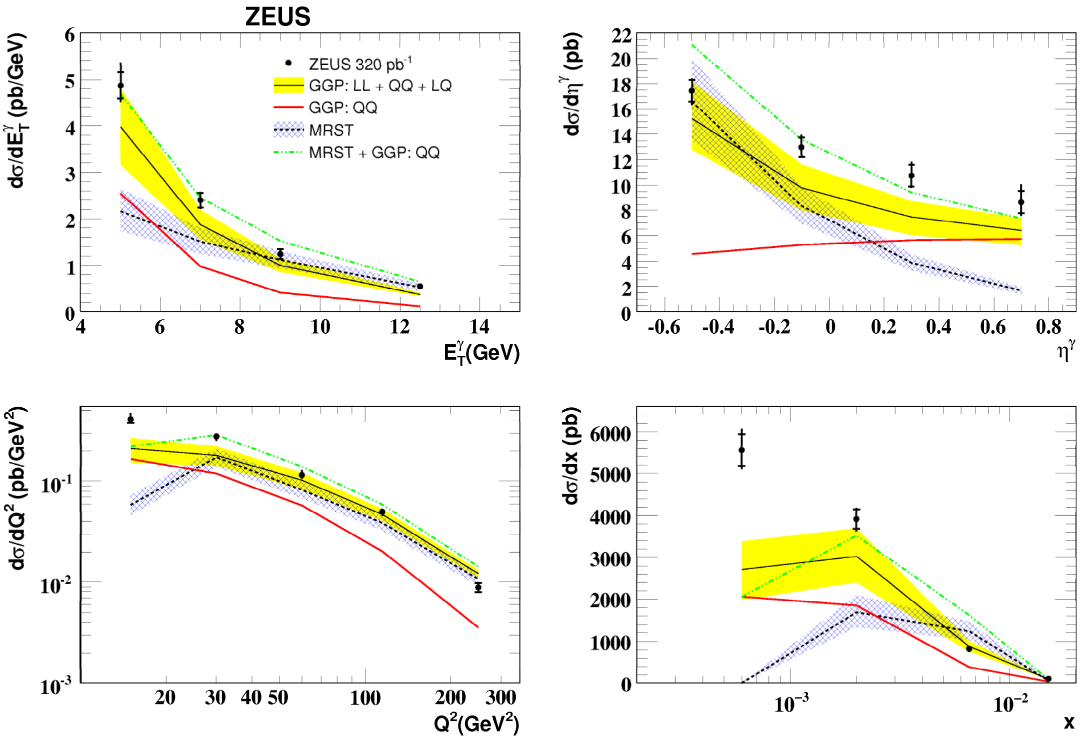

Figure 3: ZEUS DIS results and theoretical predictions

could improve the agreement.

3. Inclusive prompt photons in DIS

Figure 1 shows the ZEUS isolated photon candidates fitted as the sum of LL and QQ events, and hadronic background predicted by Monte Carlo. In this fit the purely leptonic events are assumed to be accurately calculated and the normalisation is held fixed, as is the hadronic background. One then needs to rescale the Monte Carlo QQ prediction by 1.6 to obtain the required number of events. This factor was then held fixed in the bin-by-bin signal extraction. (For practical reasons The Monte Carlo's used were PYTHIA6.416 for QQ and DJANGO6-HERACLES4.8.6-ARIADNE for LL and the hadronic background [2].) Figure 3 shows the data distributions for photon E_T, η, and for Q^2 and x. The photon kinematic range is $4 < E^T < 15$ GeV and $-0.7 < \eta < 0.9$, $R_\gamma > 0.9$, and $10 < Q^2 < 350\,\mathrm{GeV}^2$ (measured using the outgoing electron, which must have energy above 10 GeV and lie in the angular range 139.8° to 171.8°.) A cut on the final state hadronic mass to be above 5 GeV excludes DVCS events. The Monte Carlo predictions (not shown) describe E_T and η well, but fall below the data at low x and at low Q^2.

The results in figure 3 are compared to a number of theoretical predictions. GGP is the state-of-the-art $O(\alpha^3\alpha_s)$ collinear factorisation prediction [7]. The production of photons by jet fragmentation is included but is suppressed by the isolation cuts. MRST calculate $e-\gamma$ collisions where the γ is part of the photon structure [8]. This can be thought of as the LL process with radiative corrections to all orders. We therefore show also a prediction for GGP:QQ+MRST. This gives

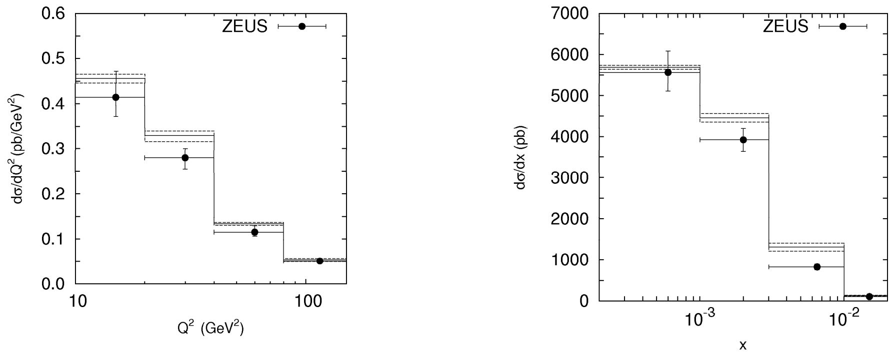

Figure 4: Baranov, Lipatov and Zotov predictions for Q^2 and x compared to ZEUS DIS results

a reasonable description of the data except at low Q^2 and at low x. Earlier H1 results on E_T, η, Q^2 show the same behaviour [9].

Baranov, Lipatov and Zotov have calculated inclusive prompt photon production using the k_T-factorisation approach ($eq* \rightarrow eq\gamma$) [10]. Compared to collinear factorisation, this is expected the increase the cross-section at low Q^2 and low x. The agreement with the data in figure 4 is impressive compared to figure 3.

Prompt photon production in DIS therefore tends to favour the validity of the k_T-factorisation approach. Photoproduction results do not disagree with this conclusion.

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