PROMPT PHOTONS AND PARTICLE MOMENTUM DISTRIBUTIONS AT HERA

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Recent results, obtained by the H1 and ZEUS collaborations, are presented on differential cross sections, for inclusive prompt photon production in DIS and for photoproduction of prompt photons accompanied by a hadronic jet. Also presented are cross sections of normalised scaled momentum distribution of charged final state hadrons, measured by H1 in DIS *ep* collisions at high Q^2 in the Breit frame of reference.

Keywords: Prompt photons; Charged particle multiplicity; HERA

1. Prompt photon production

1.1. *Introduction*

Isolated high transverse energy photons in the final state are a powerful tool for detailed studies of the Quantum Chromodynamics (QCD) in hard interaction processes and of the hadronic structure of the incoming particles.

The photons are called "prompt" if they are directly coupled to the interacting quarks, instead of being produced as hadronic decay products.

In contrast to jet measurements, where the partonic structure is obscured by the non-perturbative hadronisation process, prompt photons at large transverse energy E_T^γ can be directly related to the partonic event structure. Furthermore, the experimental uncertainties connected with the energy determination of an electromagnetic shower initiated by a photon are smaller compared to the measurement of a hadron jet. However, the cross section for prompt photon production is small and the identification of photons in the detector is not trivial.

Preliminary results for two analyses are presented here: An H1 study of inclusive prompt photons in deep inelastic scattering (DIS)[1], and a ZEUS study of prompt photons with an accompanying jet in photoproduction[2].

1.2. *Prompt Photon identification*

The main experimental difficulty is the separation of the prompt photons from hadronic background, in particular from signals due to π^0 mesons.

In the H1 analysis photons are identified in the liquid argon calorimeter by a compact electromagnetic cluster with no track pointing to it. The photon transverse energy E_T^γ and pseudorapidity η^γ are restricted to 3 GeV $< E_T^\gamma <$ 10 GeV and $-1.2 < \eta^\gamma < 1.8$. In order to compare with perturbative QCD (pQCD) calculations, the photon isolation requirement is defined in an infrared-safe way, using: $z = E^\gamma / E^{photonjet} > 0.9$, i.e. z is the ratio of the photon energy to the energy of the jet, which contains the photon. The photon signal is extracted by a shower shape analysis which uses six discriminating shower shape functions in a likelihood method.

In the ZEUS analysis photons are identified using the barrel preshower detector (BPRE). The BPRE prompt photon signal is determined using the conversion probability in the detector, known from a study of DVCS data[3].

The photon kinematic range is restricted

to $5 < E_T^\gamma < 16$ GeV and $-0.7 < \eta^\gamma < 1.1$, where positive η^γ corresponds to the proton beam direction. The photon isolation criteria are similar to the ones used in the H1 analysis. Hadronic jets were selected in the kinematic range $6 < E_T^{jet} < 17$ GeV and $-1.6 < \eta^{jet} < 2.4$.

1.3. *Results*

Differential cross sections for the production of isolated photons in DIS measured by H1 are shown in Fig. 1, as function of E_T^γ and η^γ. A new LO(α^3) calculation[4] gives a good description, although it lies slightly below the data. At large pseudorapidities the dominant contribution is radiation off the quark line (QQ), whereas in the backward region the radiation off the electron line (LL) dominates the cross section.

A comparison with predictions of the PYTHIA and HERWIG generators (radiation off the quark) plus photon radiation off the electron is also made[1]. Both generators describe the shape in E_T^γ well, but are lower in the absolute scale (factor 2.3 for PYTHIA and 2.6 for HERWIG). The η^γ distribution is better described by PYTHIA.

The ZEUS differential cross sections as functions of E_T^γ and η^γ for the prompt photons are shown in Fig. 2. Two next-to- order (NLO) pQCD predictions are compared to the data. In both calculations several photon and proton pdf's, and several fragmentation functions are used. The FGH (Fontannaz, Guillet and Heinrich)[5] calculation contains additional higher order corrections to the resolved photon process. Like the KZ (Krawczyk and Zembrzuski)[6] prediction, it describes the data rather well. However, they both underestimate the observed cross section at low E_T^γ and in the backward region. The difference between the data and the NLO QCD calculations is mainly observed in the $x_\gamma^{obs} < 0.75$ region (not shown), which is sensitive to the resolved photon contribution.

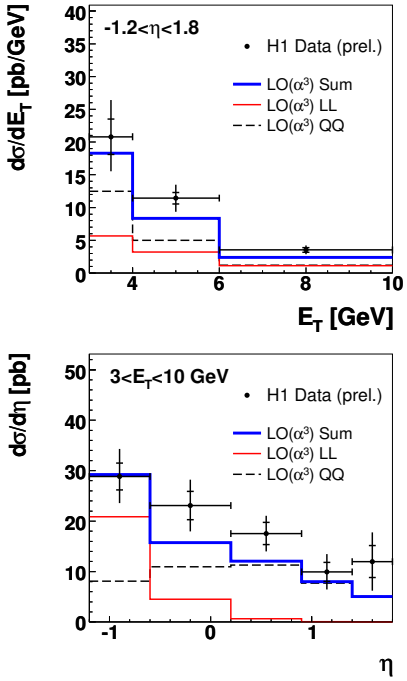

Fig. 1. Prompt photon differential cross sections $d\sigma/dE_T^\gamma$ for $-1.2 < \eta^\gamma < 1.8$ and $d\sigma/d\eta^\gamma$ for 3 GeV$< E_T^\gamma < 10$ GeV, for photon virtualities $Q^2 > 4$ GeV^2 and $y_e > 0.05$. Curves show an LO calculation with LL and QQ giving the contribution of radiation off the electron and the quark line respectively. As the interference is very small it is not shown, but included in the sum.

A comparison with the prediction of Lipatov and Zotov[7] (LZ), which is based on k_T-factorisation, corrected for hadronisation effects, is also shown. The LZ prediction gives the best description of the E_T^γ and η^γ cross sections. In particular, it describes the lowest E_T^γ region better than the KZ and FGH NLO predictions. PYTHIA and HERWIG do not rise as steeply at low E_T^γ as do the data and underestimate the measured cross section.

Since the largest difference between the NLO calculations and the data is observed in the region of low E_T^γ and low η^γ, the level of agreement with NLO QCD was verified by increasing the minimum transverse energy of prompt photons from 5 to 7 GeV.

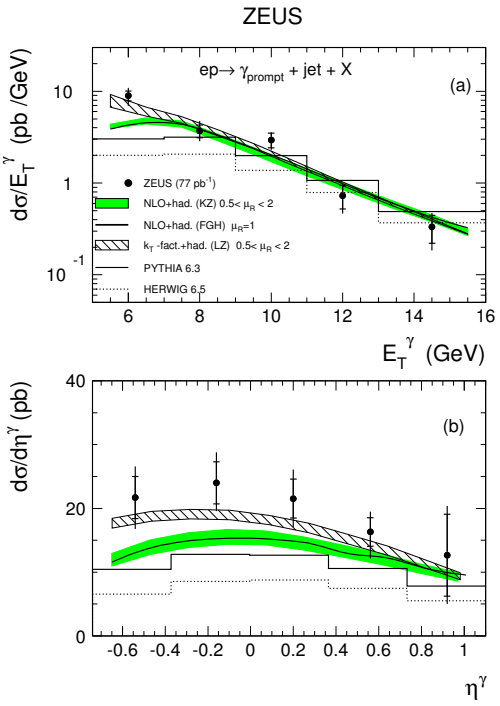

Fig. 2. The differential cross section for the prompt photon events with an accompanying jet as functions of E_T^γ and η^γ compared to theoretical QCD calculations (including hadronisation corrections). The shaded bands correspond to the uncertainty in the renormalisation scale which was changed by factors 0.5 and 2.

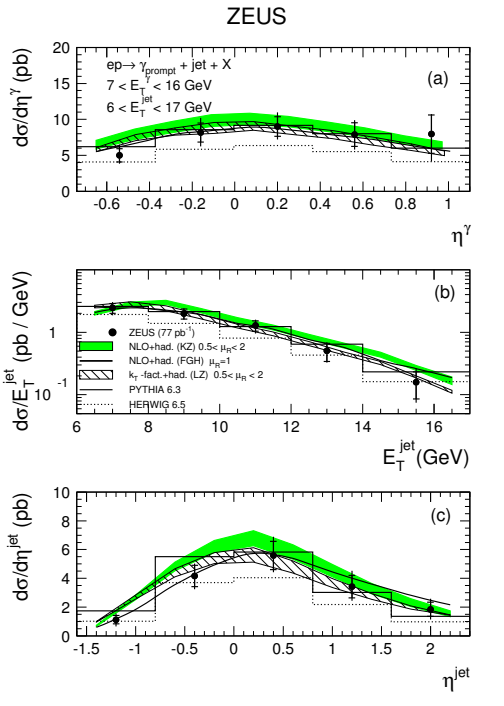

Fig. 3. The differential cross section for the γ + jet events as function of: a) η^γ, b) E_T^{jet} and c) η^{jet} compared to QCD calculations (with hadronisation corrections) and Monte Carlo models. The cut on E_T^γ is increased to 7 GeV.

In this case hadronisation corrections are expected to be smaller. As shown in Fig. 3 with $E_T^\gamma > 7$ GeV the NLO QCD and the LZ predictions all agree well with the data. The PYTHIA model then also agrees well, while HERWIG is still below the data.

2. Charged Particle Momentum distributions

In an H1 analysis[8] the process of parton fragmentation and hadronisation is studied using inclusive charged particle spectra in DIS. In the current region of the Breit frame a comparison with one hemisphere of e^+e^- annihilation offers a direct possibility to test quark fragmentation universality.

The energy scale for the current region, set by the virtual photon, is given by $Q/2$ and, for purpose of comparison, is taken to be equivalent to one half of the e^+e^- c.m. energy $E^*/2$.

In the Breit frame the scaled momentum variable x_p is defined to be $2p_h^\pm/Q$, where $p_h^\pm$ is the momentum of a charged particle. In e^+e^- annihilation events the equivalent variable is $2p_h^\pm/E^*$.

The use of much higher statistics now available at high Q as compared to previous studies[9,10], as well as an improved understanding of the H1 detector and associated systematics, provide a much improved measurement of the scaled momentum spectra. Results are now available up to $< Q > \sim 100$ GeV, close to the LEP-1 c.m. energy, and in

the full range of x_p ($0 < x_p < 1$).

In Fig. 4 the inclusive, event normalised, charged particle scaled momentum spectrum is shown as a function of Q for nine different bins of x_p. Also shown is a comparison to results from e^+e^- annihilation data (see references in ref. 8). As seen, the ep and e^+e^- data are in excellent agreement, which supports the concept of quark fragmentation universality.

Moving from low to high Q the x_p spectra become softer, i.e. there is a dramatic increase in the number of hadrons with a small share of the initial parton's momentum and a decrease of those hadrons with a large share. These scaling violations (parton splitting in QCD) are compatible to the scaling violations observed for the DIS structure functions.

In the RAPGAP simulation[11], also shown in Fig. 4, the Parton Shower model is implemented. It describes the fragmentation process as the splitting of parent partons into two daughters (e.g. $q \to qg, q \to qq, g \to qq$), the splitting continues with daughters going on to form parents. The evolution of the parton shower is based on leading $\log Q^2$ DGLAP splitting functions. RAPGAP gives a very good description of the ep scaled momentum spectra over the whole range of x_p.

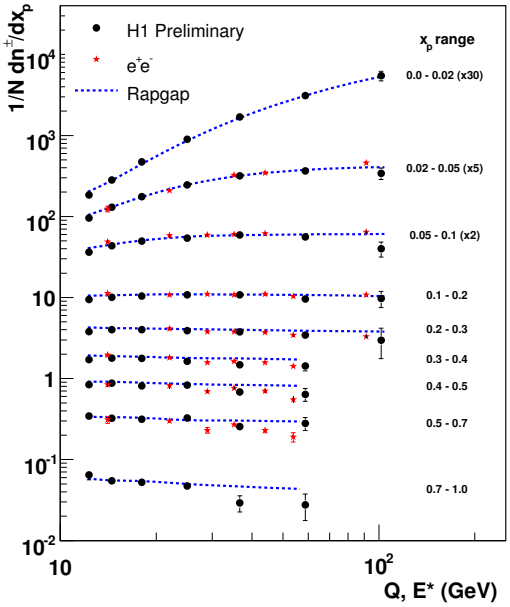

Fig. 4. H1 data for the event normalised inclusive scaled momentum spectrum as a function of Q for nine different x_p regions. Also shown are data from various e^+e^- experiments (taking $Q = E^*$). The DIS data are compared with the RAPGAP generator.

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