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## ISOLATED PROMPT PHOTON PRODUCTION AT HERA\*

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We study the expectations for prompt photon production rates at HERA in a fully consistent next-to-leading order (NLO) QCD analysis, taking into account the effects of experimental isolation requirements. In particular we examine the sensitivity of the isolated cross section to the photon's gluon content.

The utility of hadronic large- $p_T$  prompt photon production for providing constraints on the proton's gluon content has led to the suggestion that it may also prove useful in determining the photonic gluon distribution at HERA via the study of photoproduction of direct photons<sup>1</sup>. The process was subsequently studied quite extensively, with NLO QCD corrections to it partly taken into account<sup>1,2,3,4</sup>. The main shortcoming of all these studies was that only the fully inclusive cross section was considered. Since, however, HERA is a collider it will be necessary to perform isolation cuts in the experiments in order to unambiguously identify the photon signal from the huge hadronic background, just as it is necessary at existing hadron colliders<sup>5</sup>. Indeed, first reports on HERA prompt photon results<sup>6,7</sup> confirm this view. In order to make reliable and meaningful predictions it is crucial that the theoretical calculation correctly includes the experimental isolation constraints. This was done in<sup>8</sup> where the first complete NLO analysis, at the same time fully taking into account the effects of isolation, was presented. In the following we provide an update of our study<sup>8</sup>, for which we believe it is time now since most sets of parton distributions used in<sup>8</sup> have been updated in the meantime<sup>9,10,11,12</sup>. Furthermore, we will also more closely match cuts used in other HERA photoproduction experiments performed so far<sup>13</sup>, hereby making our predictions more realistic and more directly comparable to future data.

As with all photoproduction processes at HERA, there are two types of contributions to the cross section, the so-called direct and resolved contributions. In the case of prompt photon production there are two further subclasses in each category, which we label the fragmentation and non-fragmentation processes according to whether the prompt photon is produced directly in the hard scattering process or via fragmentation of a final state parton.

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The cross section for  $ep \rightarrow \gamma X$  can thus be schematically written as

$$d\sigma_{ep}^\gamma = \sum_{f_p, f_e, f} \int_{\otimes} f_p(x_p, M^2) f_e(x_e, M^2) d\hat{\sigma}_{f_p f_e}^f(p_\gamma, x_p, x_e, z, M^2, M_F^2) D_f^\gamma(z, M_F^2), \quad (1)$$

where  $f_p = q, \bar{q}, g$  and  $f_e, f = q, \bar{q}, g, \gamma$ . The 'electron structure function'  $f_e(x_e, M^2)$  at scale  $M$  is defined by the convolution

$$f_e(x_e, M^2) = \int_{x_e}^1 \frac{dy}{y} P_{\gamma/e}(y) f^\gamma\left(\frac{x_e}{y}, M^2\right), \quad (2)$$

where  $f^\gamma$  denotes the corresponding *photonic* parton distribution. The definition is readily extended to the direct case (' $f_e = \gamma$ ') by replacing  $f_e(x_e/y, M^2) \rightarrow \delta(1 - x_e/y)$ . The flux of quasi-real photons radiated from the electron beam is estimated in the Weizsäcker-Williams approximation,

$$P_{\gamma/e}(y) = \frac{\alpha_{em}}{2\pi} \left[ \frac{1 + (1-y)^2}{y} \right] \ln \frac{Q_{max}^2(1-y)}{m_e^2 y^2}, \quad (3)$$

where  $m_e$  is the electron mass. As in<sup>13</sup> we will use an upper cut  $Q_{max}^2 = 4 \text{ GeV}^2$  on the virtuality of the incoming photon, and we will also apply the  $y$ -cut  $0.2 \leq y \leq 0.8$  which will serve to bring our predictions closer to the actual experimental situation than in our previous study<sup>8</sup>. Finally, in Eq. (1)  $D_f^\gamma(z, M_F^2)$  is the fragmentation function at scale  $M_F$  for the fragmentation of parton  $f$  into a photon. We include in its definition the non-fragmentation case (' $f = \gamma$ ') where  $D_f^\gamma(z, M_F^2) \rightarrow \delta(1 - z)$ .

The isolation technique used at hadron colliders<sup>5</sup> is to define a cone centered on the photon with radius  $R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$ , inside which the allowed amount of hadronic energy is restricted to be below  $\epsilon E_\gamma$  with the prompt photon's energy  $E_\gamma$  and  $\epsilon \sim \mathcal{O}(0.1)$ . A cone isolation method has also been applied in the first experimental prompt photon studies at HERA<sup>6,7</sup>. In order to take into account the effects of isolation on the cross section (1) in NLO we use the analytical method of<sup>14</sup> which was extended to the HERA situation in<sup>8</sup>.

To see whether prompt photon production at HERA will give useful information on the parton, in particular the gluon, distributions of the photon we will compare the predictions obtained for two different NLO sets of photonic parton densities suggested in the literature, the GRV<sup>15</sup> and GS<sup>12</sup> (recent update) sets. On the proton side, we provide a comparison of the results obtained using the latest GRV(94)<sup>9</sup>, MRS(A')<sup>10</sup> and CTEQ(3M)<sup>11</sup> versions. All other ingredients and parameters for our analysis are chosen exactly as in our previous study<sup>8</sup>, with the exception of the Weizsäcker-Williams spectrum (see (3)). In particular, we choose the isolation parameters  $\epsilon = 0.1$ ,  $R = 0.4$ .

In Fig. 1(a) we show the fully inclusive and the isolated cross sections vs. the prompt photon's rapidity  $\eta$  at  $p_T = 5$  GeV, using GRV distributions throughout. We also illustrate the expected strong reduction of the fragmentation contribution (i.e., the sum of direct fragmentation and resolved fragmentation) due to isolation. Fig. 1(b) compares the corresponding resolved and

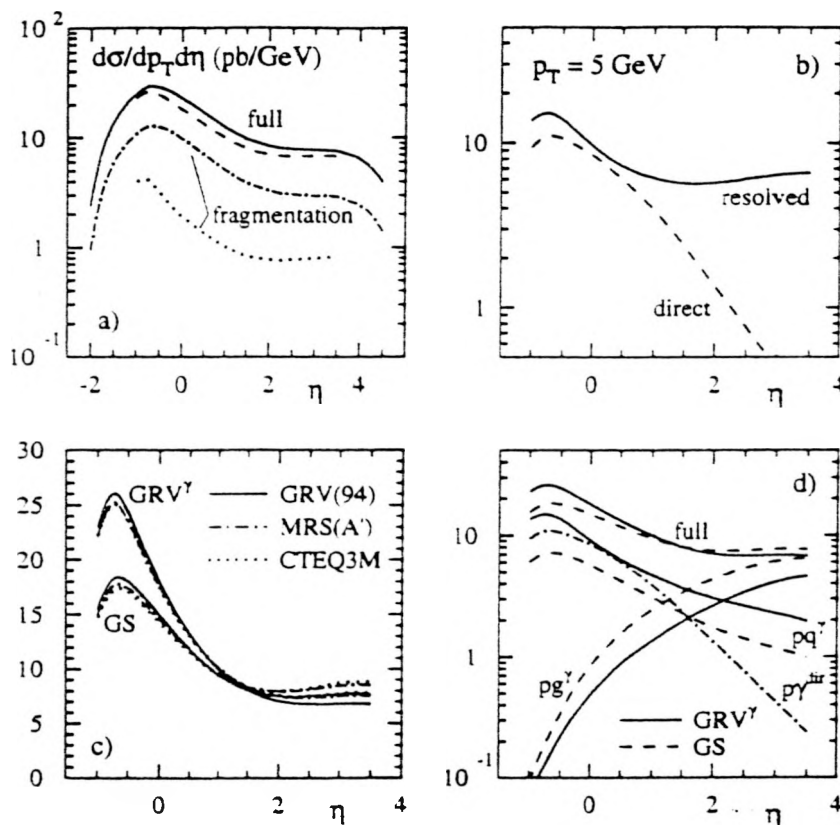


Figure 1: (a) Comparison of fully inclusive and isolated results for the full cross section and its fragmentation part. (b) Resolved and direct contributions to the isolated cross section. (c) Full isolated cross section for various sets of parton distributions of the proton and the photon. (d) Full isolated cross section and its decomposition according to Eq. (4) for GRV and GS photonic parton distributions.

direct contributions to the isolated cross section, both including their non-fragmentation as well as their fragmentation parts. The direct contribution is strongly peaked at negative rapidities, corresponding to the probing of the

proton at small  $x_p$  by an energetic photon. The resolved contribution remains sizeable and dominant also at positive  $\eta$ . It has two peaks: The one at  $\eta \approx 3$  corresponds to the probing of the photon distributions at rather small  $x_\gamma$ , and the cross section is expected to be sensitive to  $g^\gamma$  here. The somewhat larger peak around  $\eta \approx -1$  is due to the probing of the protonic gluon distribution at small  $x_p$  by the photonic quark distributions at large  $x_\gamma$ .

In Fig. 1(c) we study the sensitivity of the cross section to the proton and photon structure functions. It becomes obvious that there is a significant difference between the predictions given by the GRV and GS photonic parton distributions at negative  $\eta$ , where the uncertainties coming from the proton structure functions are rather small. To further analyze this issue, Fig. 1(d) shows the decomposition into the contributions of the subprocesses<sup>8</sup>

$$pg^\gamma \rightarrow \gamma X, \quad pq^\gamma \rightarrow \gamma X, \quad p\gamma^{\text{dir}} \rightarrow \gamma X, \quad (4)$$

using a fixed set (GRV) of proton structure functions. It becomes clear that differences between the photonic quark and gluon distributions in the two sets<sup>15,12</sup> show up rather strongly, but that they partly compensate in the sum. As expected, the processes involving  $g^\gamma$  dominate the cross section at large positive  $\eta$ . On the other hand, as Fig. 1(c) shows, the present uncertainties stemming from the proton's parton (in particular  $u$  quark) distributions will somewhat obscure the differences between the results for the two  $g^\gamma$  here.

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