Dijet cross section in photoproduction at HERA

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Abstract: We have built a Monte Carlo program describing the photoproduction of 2 and 3 jets at HERA. With desired cuts and cone algorithms, any cross section can be extracted from the generated events. We study the effect on the cross section of Higher Order QCD corrections.

1 Introduction

The importance of the photoproduction of jets at HERA arises from the possibility of probing the hadronic structure of the photon in a way complementary to the usual studies of the deep inelastic photon structure function. In the latter case, one can reach the very small-x domain of the parton densities in the photon and, in particular, directly measure the quark distributions whereas the gluon distribution is constrained by the evolution equations. On the contrary, in photoproduction reactions one directly probes the gluon density in the photon assuming the parton distributions in the proton are known from elsewhere. A simultaneous study of both processes should then lead to a precise determination of the photon structure very much in the same way as it does in purely hadronic reactions.

In the QCD-improved parton model, the jet cross sections are given by convolutions of the parton distribution functions with the hard subprocess cross sections. The more exclusive the cross section, the less numerous the convolutions, since the internal variables are more constrained by the final jet kinematics. For instance the dijet cross section, as a function of the transverse momentum $p_\perp$ and the jet rapidities η_3 and η_4, is given by a product if the subprocess is a $2 \to 2$ reaction [1] (Leading Logarithm approximation)

$$\frac{d\sigma}{dp_\perp^2 d\eta_3 d\eta_4} = \sum_{a,b} x_e\ F_e^a(x_e)\ x_p\ F_p^b(x_p) \frac{d\sigma}{dt}(ab \to p_3 p_4)\ , \tag{1}$$

$d\sigma/dt$ is the $a + b \to p_3 + p_4$ cross section, and $F_e^a(F_p^b)$ the parton distributions in the electron (proton). The direct contribution corresponds to $a = \gamma$ and F_e^γ is the Weizsäcker-Williams

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formula. In the resolved case, F_e^a is given by a convolution of F_e^γ with the parton distribution in the photon

$$F_e^a(x_e) = \int_0^1 dz\ dx_\gamma\ F_e^\gamma(z)\ F_\gamma^a(x_\gamma)\ \delta(x_\gamma z - x_e) \tag{2}$$

with $x_e = \frac{p_\perp(e^{-\eta_3}+e^{-\eta_4})}{2E_e}$ (E_e is the incident electron energy in the LAB frame). If the photon energy (zE_e) is known (for instance, by tagging the outgoing electron), we can write

$$\frac{d\sigma}{dx_\gamma} = \sum_{a,b} x_\gamma\ F_\gamma^a(x_\gamma) \int_0^1 dz\ dp_\perp^2 d\eta_3 d\eta_4\ \delta\left(x_\gamma - \frac{p_\perp\left(e^{-\eta_3}+e^{-\eta_4}\right)}{2zE_e}\right)\ F_e^\gamma(z)\ x_p\ F_p^b(x_p)\frac{d\sigma}{dt}\ . \tag{3}$$

Thus the dijet cross section written as a function of x_γ is proportional to the parton distribution in the photon $F_\gamma^a(x_\gamma)$.

Higher Order (HO) QCD corrections to the LL expression (3) blur the simple kinematics of formulae (1) to (3). There are contributions with three jets in the final state, and we can no longer fix x_γ, because the third jet is not observed. However we can follow the strategy of the ZEUS collaboration [2] which defines the variable

$$x_\gamma^{obs} = \left(p_{3\perp}e^{-\eta_3} + p_{4\perp}e^{-\eta_4}\right)/2E_\gamma \tag{4}$$

and observe the dijet cross section $d\sigma/dx_\gamma^{obs}$. However this definition of x_γ^{obs} constrains the phase space integration too much. An inclusive dijet cross section can only be a function of $p_\perp$, η_3 and η_4; the transverse momentum of the second jet cannot be observed without spoiling IR compensation between the virtual and real HO cross section. We therefore propose the infrared safe definition

$$x_\gamma^{LL} = p_{3\perp}\left(e^{-\eta_3} + e^{-\eta_4}\right)/2E_\gamma\ . \tag{5}$$

In the LL approximation, x_γ^{LL} is equal to x_γ (note that x_γ^{LL} can be larger than one at NLO); it is important to check how much the HO corrections change this simple picture, and if the determination of $F_\gamma^a(x_\gamma)$ from $d\sigma/dx_\gamma^{LL}$ remains accurate.

2 HO QCD corrections to the dijet cross section

HO corrections to the $2\to 2$ processes involve virtual corrections to these processes and $2\to 3$ real contributions. We perform these corrections by using a Maple [3] program originally written [4] in order to study dihadron production. The final three body phase-space, with parton of momenta p_3, p_4 and p_5, is divided into an initial collinear region with $p_{5\perp} \leq p_{5\perp}^{min}$, in a final collinear region with d_{35} or $d_{45} \leq R_c$ ($d_{ij} = (\Delta\varphi_{ij}^2 + \Delta\eta_{ij}^2)^{\frac{1}{2}}$) and in a 3-body region (without collinear and/or IR singularity). The collinear contribution are analytically calculated and the IR singularities are cancelled by the virtual contributions. The remaining collinear singularities are absorbed in the distribution functions. The collinear contributions contain large logarithms $\log^2 p_{5\perp}^{min}$ and $\log p_{5\perp}^{min} \log R_c$ of the unphysical cut-offs $p_{5\perp}^{min}$ and R_c which are cancelled by the 3-body contributions.

A Monte Carlo program [5] generates (with a weight equal to one) quasi $2\to 2$ events (according to the collinear and virtual contributions) and $2\to 3$ events. Then we perform histograms [6] of these events for any cross section we may want with any cone algorithm (with a physical cone radius $R > R_c$). We have checked this method by comparing the single inclusive jet cross section with a full analytical calculation [7]. In fig. 1 we see that agreement is quite good [8]. The Monte Carlo method leads to a dispersion of the predictions at large $p_\perp$ where the cross section is small. This effect can be corrected by slicing the $p_\perp$ range and generating events in each slice independently. We have also checked that the results in fig. 1 are independent of $p_{5\perp}^{min}$ and R_c. The values used in fig. 1 are $p_{5\perp}^{min} = 0.5$ GeV, $R_c = 0.1$ and $R = 1$.

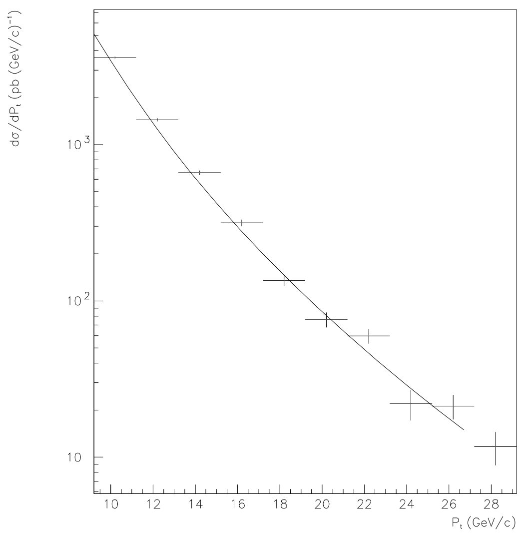

Figure 1: *Single jet inclusive cross section as a function of* $p_\perp$. *Comparison of the Monte Carlo results with those of ref. [7] (full line).*

3 Results for $d\sigma/dx_\gamma^{LL}$

In order to obtain $d\sigma/dx_\gamma^{LL}$, we histogram the Monte Carlo events with constraint (5) and cuts $p_{3,4\perp} \geq 9.2$ GeV and $-1 \leq \eta_{3,4} \leq 2$. The radius of the cone is $R = 1$. The scales used are $\mu_{renormalisation} = M_{factorisation} = p_\perp$ and the distribution functions are those of the ABFOW collaboration [9] and AFG collaboration [10]. The direct and resolved contributions are shown in fig. 2 and fig. 3. Note however that the splitting in direct and resolved parts is factorization scheme dependent and so is not physical at NLO.

The Born term leads to a peak at $x_\gamma^{LL} = 1$ in fig. 2 with $d\sigma^{born}/dx_\gamma^{LL} = 36232$ pb (with a resolution $\Delta x_\gamma^{LL} = 0.08$). It corresponds to the delta function which appears in (3) when $F_\gamma^a(x_\gamma) = \delta(1 - x_\gamma)$. When HO corrections are included, the height of the peak is decreased and we obtain the histogram of fig. 2. In fig. 3 we show the LL and NLO contributions of the resolved part. In the LL case, we still use NLO distribution functions and the shape of the spectrum is proportional to $F_\gamma^a(x_\gamma^{LL})$. With our choice of parameters, the HO corrections appear to be large. Obviously, changing the value of R, Δx_γ^{LL}, the cuts on η_3, η_4, $\cdots$ will affect the relative weight of HO corrections [11].

In conclusion, a quantitative determination of $F_\gamma^a(x_\gamma)$ from the dijet cross section should be possible.

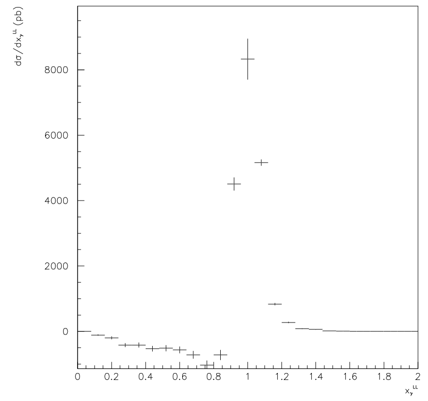

Figure 2: *Total contributions of the direct term.*

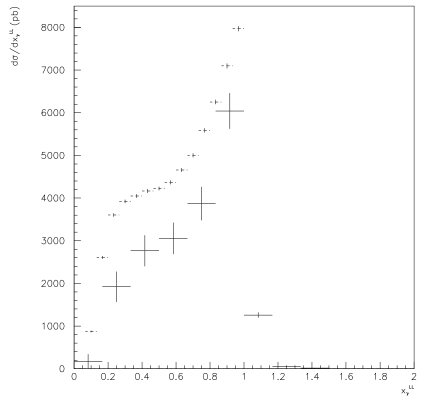

Figure 3: *LL (dashed) and total (full) contributions of the resolved part.*

4 Conclusion

We have built a Monte Carlo program, at NLO, describing the photoproduction of 2 and 3 jets at HERA. With desired experimental cuts and jet algorithms, any cross section can be extracted from the generated events.

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