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Measurement of the Di-Jet Cross Section in γp Collisions at HERA and Extraction of the Effective Parton Distribution in the Photon

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Abstract

The double differential di-jet cross section in photoproduction processes is measured as a function of the parton fractional energy x_γ^{jets} and of the transverse energy scale E_T of the jets. The effective leading order parton distribution of the photon is determined in the range $0.1 < x_\gamma < 0.7$ for scales between $63\,\mathrm{GeV}^2 < p_T^2 < 1000\,\mathrm{GeV}^2$. The scale dependence reflects the anomalous component of the photon.

1 Introduction

A small fraction of the photon-proton collisions at HERA have hard scattering processes with the production of two high E_T^{jet} jets in the hadronic final state. Such events are overall well described by QCD calculations [1]. The aim of this contribution is two fold: a measurement of the inclusive di-jet cross section and an extraction of the effective parton distribution of the photon from the data.

A QCD calculation of the di-jet cross section requires four components and four non-trivial observables:

$$\frac{d\sigma}{dy dx_\gamma dx_p \cos\theta^*} \sim \sum_{ij} \frac{f_{\gamma/e}}{y} \frac{f_{i/\gamma}}{x_\gamma} \frac{f_{j/p}}{x_p} \, |M_{ij}(\cos\theta^*)|^2 \tag{1}$$

The first term on the right hand side $f_{\gamma/e}$ gives the probability of finding a photon in the electron with fractional energy $y = E_\gamma/E_e$. The second (third) term $f_{i/\gamma}$ ($f_{j/p}$) gives the probability of finding a parton $i(j)$ in the photon (proton) with fractional energy $x_\gamma = E_i/E_\gamma$ ($x_p = E_j/E_p$). The last term contains the distribution of the parton scattering angle θ^* in the parton-parton center of mass system in form of the QCD matrix elements $M_{ij}(\cos\theta^*)$. The renormalisation μ_{ren} and factorisation μ_{fac} scales of the QCD calculation are usually chosen to be a multiple ξ of the transverse momentum p_T of the scattered partons: $\mu_{ren} = \mu_{fac} = \xi \, p_T$. In leading order QCD, p_T can be expressed by the four observables in equation (1):

$$p_T^2 = \frac{1}{4} s_{ep} \, y \, x_\gamma \, x_p \, \sin^2\theta^* \tag{2}$$

Here s_{ep} denotes the electron-proton center of mass energy available at HERA $\sqrt{s_{ep}} = 300\,\mathrm{GeV}$. In order to study observables closely related to the parton distributions in the photon, we choose to analyse differential distributions in x_γ and p_T and integrate over the remaining observables y and $\cos\theta^*$.

The QCD matrix elements for the most frequent resolved photon proton processes $qq \to qq, qg \to qg, gg \to gg$ have similar shapes. Therefore, the sum over the different parton processes in equation (1) can be replaced by a single effective subprocess [2]. The parton density in the photon is then replaced by an effective parton density of the form:

$$f_{i/\gamma} = \sum (q + \overline{q}) + \frac{9}{4} g \tag{3}$$

Here $q, \overline{q}, g$ are the quark, antiquark, and gluon densities in the photon. They depend on the parton fractional energy x_γ and the scale μ_{fac}. The factor 9/4 results from colour factors.

In the following we will first describe the measurement of the double differential hadronic di-jet cross section and then extract from the same data the effective parton distribution of the proton and its scale dependence.

2 Data Selection and Correction

A detailed description of the H1 detector can be found elsewhere [3]. This analysis is based on 1994 data with an integrated luminosity of $2\,\mathrm{pb}^{-1}$. The photoproduction events were selected by requiring that the scattered electron disappears in the beam pipe, undetected in the central detector (so-called untagged events). The photon virtuality is therefore restricted to $Q^2 < 4\,\mathrm{GeV}^2$. The scaled photon energy y was reconstructed from the final state hadrons with transverse energy E_T^h and pseudo-rapidity η^h by

$$y_{jb} = \frac{\sum E_T^h e^{-\eta^h}}{2E_e} \ . \tag{4}$$

After corrections the range of accepted photon energies is between $0.2 < y < 0.83$.
The jets were found using a cone algorithm [4] with cone size $R = 0.7$ and jet pseudo-rapidities in the range $-0.5 < \eta^{jet} < 2.5$. The jet transverse energy had to be above $E_T^{jet} > 8\,\mathrm{GeV}$. The rapidity difference between the two jets was required to be below $\Delta\eta < 1$ in order to integrate over a small interval of the parton scattering angle: $\tanh(\Delta\eta/2) = \cos\theta^*$. The corrections for detector effects were calculated using an unfolding procedure [5].

3 Di-Jet Cross Section

In figures 1,2 the ep double differential di-jet cross section is shown as a function of the fractional parton energy x_γ^{jets} and of the transverse energy E_T. Here x_γ^{jets} is defined by the two jets with the highest E_T^{jet} in the event:

$$x_\gamma^{jets} = \frac{E_T^{jet1} e^{-\eta^{jet1}} + E_T^{jet2} e^{-\eta^{jet2}}}{2 y_{jb} E_e} \tag{5}$$

For E_T the transverse energy of the second highest E_T^{jet} jet is used: $E_T = E_T^{jet2}$. The di-jet cross section was corrected for detector effects. Here no corrections for underlying event energy effects or parton effects were applied. The inner error bars reflect the statistical errors. The outer errors shown are the statistical and systematic errors added in quadrature. The main error contribution results from the uncertainty in the knowledge of the calorimeter energy scale.
The measured cross section is compared to a leading order QCD calculation of the PYTHIA generator with multiple parton interactions [6] using the GRV-LO parton distribution functions for the photon and the proton [7, 8]. The calculation gives an overall satisfactory description of the data, but falls low at large x_γ^{jets} and high E_T.

4 Effective Parton Distribution of the Photon

In Figure 3 the effective parton distribution of the photon (equation 3) is shown as a function of the leading order fractional parton energy x_γ and of the parton transverse momentum p_T. To get the effective parton distribution of the photon the di-jet data were corrected with the same unfolding procedure as used above, but now the data were corrected for underlying event energy effects [9], for fragmentation and parton shower effects [10] to the leading order parton level. The jet-parton correlations were calculated using the PYTHIA generator mentioned above. The resulting differential parton cross

section $d\sigma/dx_\gamma/d\log p_T^2$ was then compared with the leading order calculation of the PYTHIA generator. From this comparison the leading order effective parton distribution of the photon was extracted using a simple re-weighting procedure. The error bars contain the statistical and systematic errors added in quadrature. Here in addition to the error of the di-jet cross section the uncertainty in the underlying event energy distribution was included.
The effective parton distribution of the photon increases with the scale p_T^2 as expected from the anomalous component of the photon splitting into quark antiquark pairs [11]. The increase appears slightly steeper than expected from the GRV-LO effective parton distribution. In the GRV distribution the $9/4\,g$ contribution drops with x_γ and is around 20% at $0.4 < x_\gamma < 0.7$. In this x_γ region the increase is dominated by the quark content of the photon.

5 Summary

A new measurement of the di-jet cross section and its scale dependence was presented. For the first time, an effective parton distribution of the photon was extracted from the photoproduction di-jet data. Its scale dependence shows an increase with p_T^2 which is compatible with the logarithmic increase expected from the anomalous component in the photon.

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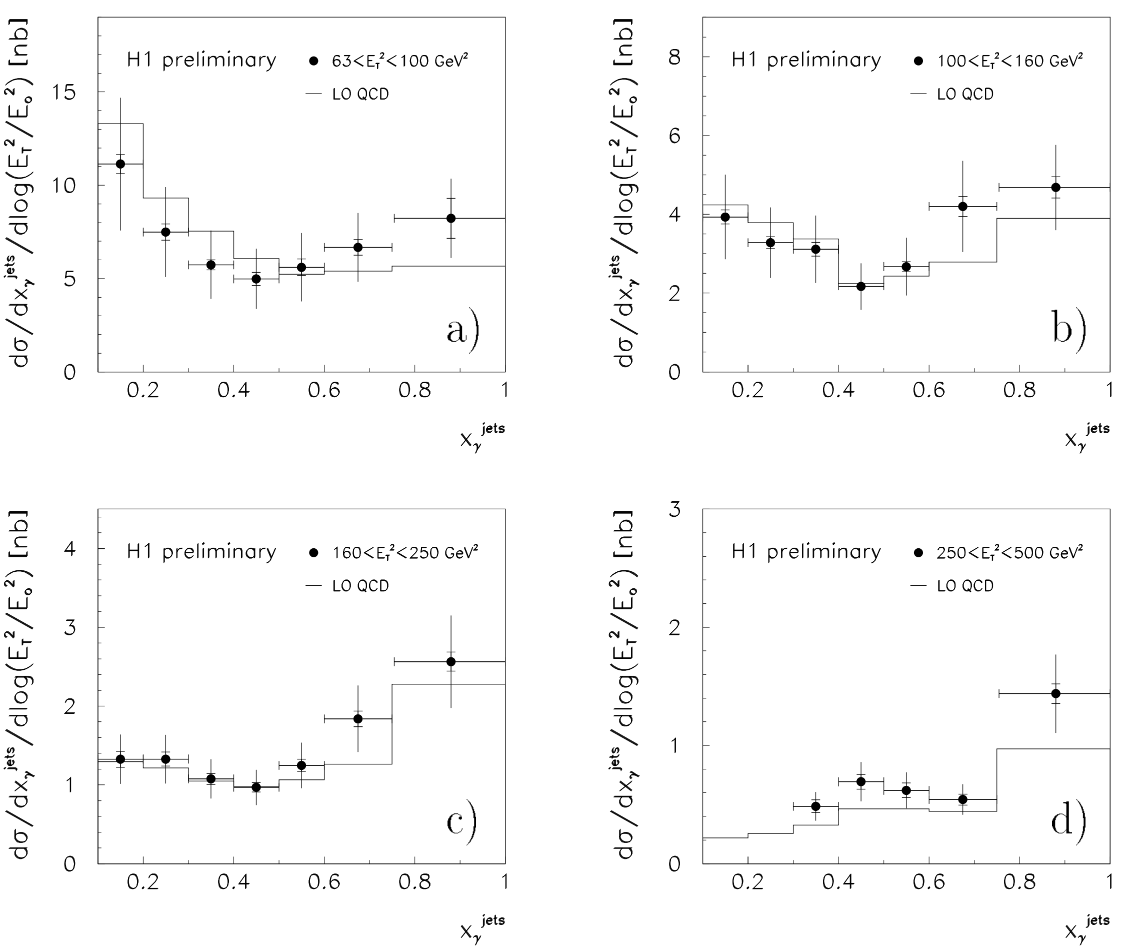

Figure 1: The measured differential di-jet ep cross section is shown as a function of the reconstructed parton fractional energy x_γ^{jets} in different bins of the jet transverse energy $63 < E_T^2 < 500\,\mathrm{GeV}^2$ (a-d, full circles, $E_\circ^2 = 1\,\mathrm{GeV}^2$). The cross section is integrated over the photon virtuality $Q^2 < 4\,\mathrm{GeV}^2$, the relative photon energy $0.2 < y < 0.83$ and the jet pseudo-rapidities in the HERA laboratory frame $-0.5 < \eta^{jet1,2} < 2.5$ and $\Delta\eta^{jets} < 1$. The data are compared to a LO QCD calculation of the PYTHIA generator with multiple interactions using the GRV-LO parton distribution functions for the proton and the photon (histogram).

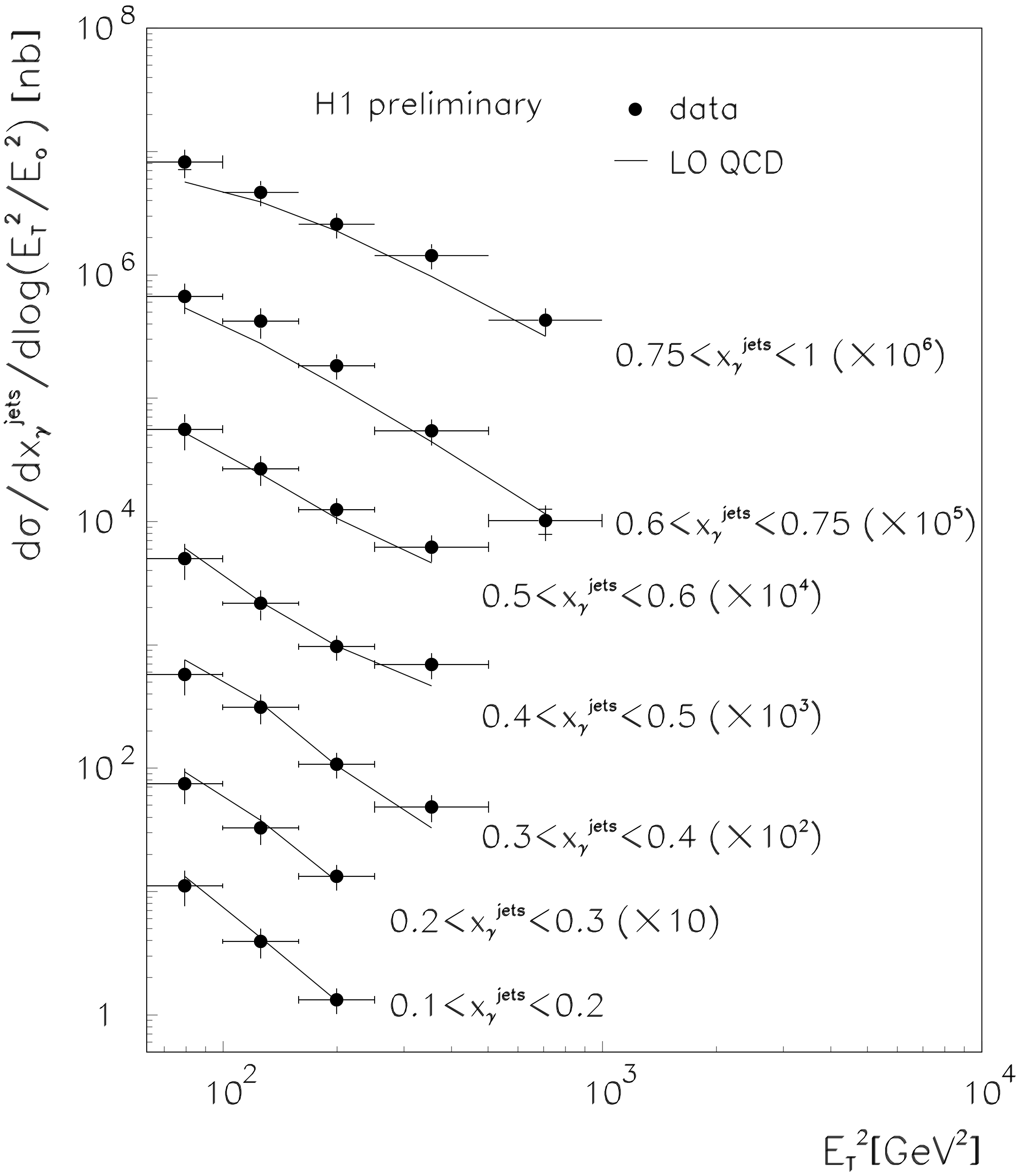

Figure 2: The measured differential di-jet ep cross section is shown as a function of the logarithm of the squared jet transverse energy $\log(E_T^2/E_\circ^2)$ in bins of the reconstructed parton fractional energy x_γ^{jets} (full circles, $E_\circ^2 = 1$ GeV^2). The cross section is integrated over the photon virtuality $Q^2 < 4\,\mathrm{GeV}^2$, the relative photon energy $0.2 < y < 0.83$ and the jet pseudo-rapidities in the HERA laboratory frame $-0.5 < \eta^{jet1,2} < 2.5$ and $\Delta\eta^{jets} < 1$. The data are compared to a LO QCD calculation of the PYTHIA generator with multiple interactions using the GRV-LO parton distribution functions for the proton and the photon (full curves).

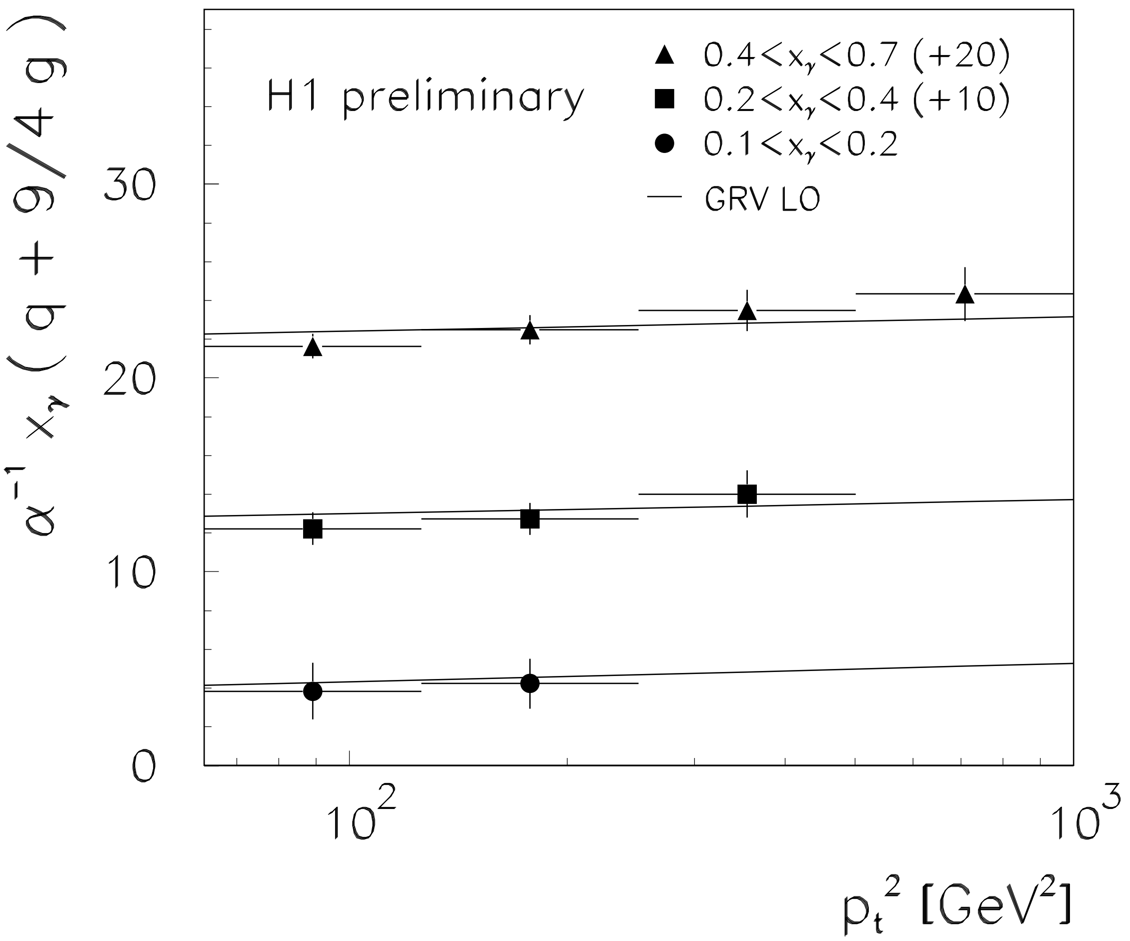

Figure 3: The extracted leading order effective parton distribution of the photon $x_\gamma f_{i/\gamma} = x_\gamma[\sum(q+\overline{q})+\frac{9}{4}g]$ was normalized to the fine structure constant α. The parton distribution is shown as a function of the squared parton transverse momentum p_T^2 in bins of the fractional parton energy x_γ. The data are compared to the effective parton distribution calculated with the GRV-LO parton distribution functions (full curves).