Measurement of the Gluon Distribution in Quasi-Real Photons at HERA *

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Abstract:

Photoproduction of 2-jets is measured with the H1 detector at HERA. The results are compared with a QCD calculation and constrain the parton distributions of the photon. The gluon distribution is derived in the range $0.04 \leq x_\gamma \leq 1$ at an average factorization scale of $75\,\mathrm{GeV}^2$.

1 Aim

Photoproduction of jets at HERA is studied with the H1 detector. The aim of this analysis [1] is to interpret the measured jet distributions in terms of the following three components of the photon using a QCD based Monte Carlo generator:

1. *Direct* photon processes where bare photons interact with partons of the proton (Fig.1a). The cross section is predicted by QCD theory, except for the parton distributions in the proton which are known from deep inelastic lepton-proton scattering to 15% accuracy in the relevant kinematic region [2].

2. *Resolved* photon processes with a *quark* on the photon side at the parton scattering processes (Fig.1b). The matrix elements of the parton scattering are predicted by QCD, whereas the parton densities of the photon and proton are used from deep inelastic scattering experiments. The largest uncertainty in the prediction of the jet cross section comes here from the quark distributions in the photon. The distributions have been determined from deep inelastic electron-photon scattering experiments at e^+e^- colliders with an accuracy of about 30% [3].

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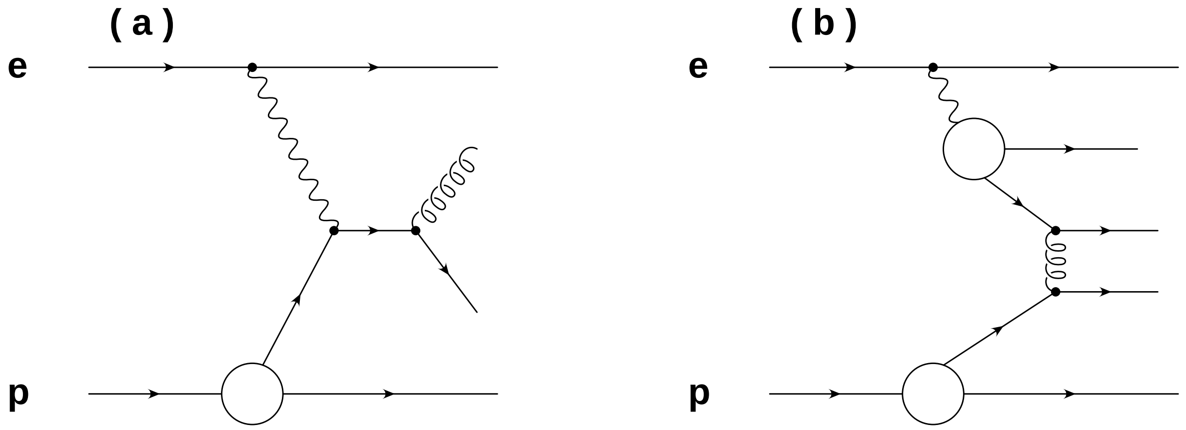

Figure 1: Examples of photoproduction processes: a) direct photon (QCD Compton), b) resolved photon process with a quark from the photon.

3. *Resolved* photon processes with a *gluon* from the photon. Also here the matrix elements of the parton scattering are predicted by QCD, but the gluon distribution in the photon is essentially unknown. Recent jet data from TRISTAN [4], HERA [5,6] and LEP [7] show that the gluon density can not be very high at large parton momenta $x_\gamma \geq 0.1$. x_γ is defined as the energy of the parton relative to the photon energy: $x_\gamma = E_{parton}/E_\gamma$. This analysis, for the first time, constrains the gluon distribution of the photon over a wide range of the parton momenta even below $x_\gamma \leq 0.1$ which is only possible at HERA so far.

2 Accessable range of the parton momentum x_γ using jets

In tree-level QCD calculations the fractional parton momentum x_γ can be reconstructed using the transverse momentum of the final state partons p_t, their pseudo-rapidities in the laboratory system η_1, η_2 ($\eta \geq 0$ in proton direction) and the energy of the photon E_γ:

$$x_\gamma = \frac{p_t}{2E_\gamma}(e^{-\eta_1} + e^{-\eta_2}) \tag{1}$$

Small x_γ is reached by large pseudo-rapidities of both partons. To have the jets of the partons contained in the detector requires $\eta_{max} \sim 2.5$. Using the photon energy $E_\gamma = 10\,\mathrm{GeV}$ a lower limit on x_γ can be estimated which depends on the transverse parton momentum p_t:

$$x_\gamma \geq p_t \times 0.01/\mathrm{GeV} \tag{2}$$

Therefore, to reach small parton momenta x_γ the p_t should be as small as possible.

Contrary to this requirement, perturbative QCD calculations use p_t as the relevant scale and demand large enough p_t to have small values of the strong coupling constant α_s. The smallest possible parton momentum p_t for perturbative calculations is of order $p_t \sim 2\,\mathrm{GeV}$. Therefore a lower limit for x_γ in jet events at HERA is of the order of $x_\gamma \geq 10^{-2}$. In this analysis the jets correspond to partons with average transverse momentum of $< p_t >\sim 8\,\mathrm{GeV}$.

3 Data selection

The event selection is restricted to quasi-real photons with negative momentum transfer squared $Q^2 \leq 0.01\,\mathrm{GeV}^2$ and photon-proton center of mass energies around $\sqrt{s} \sim 200\,\mathrm{GeV}$. The electron is detected in the small angle electron tagger, placed 33 m downstream of the main detector, such that the energy of the photon is precisely known. 2 jets are required using a cone algorithm [8] with transverse energies each above $E_t^{jet} \geq 7\,\mathrm{GeV}$ in a cone of size $R = 1$ and pseudo-rapidity between $0 \leq \eta^{jet} \leq 2.5$.

4 QCD generator

The Monte Carlo program PYTHIA generates photon-proton scattering [9] and is used here for the interpretation of the data. PYTHIA is based on leading order (LO) QCD matrix elements and includes initial and final state parton shower models. α_s was calculated in first order QCD using $\Lambda_{QCD} = 200$ MeV with 4 flavours. The renormalization and factorization scales were both set to the transverse momentum p_t produced in the parton-parton scattering with a cut-off at $p_t \geq 2\,\mathrm{GeV}$. The parton distributions of the photon and proton were both taken from the LO GRV parametrizations [10,11]. Fragmentation effects were simulated with JETSET [12].

Optionally PYTHIA allows for additional interactions between partons of the photon and proton spectators, so-called *multiple interactions* [13]. This option is used below and further studied in another contribution to this conference [14].

5 Jet energy

Conclusions on the photon structure from measured jets are essentially based on the comparisons of jet rates between data and QCD calculations. Since distributions of the transverse jet energy are steeply falling as $(E_t^{jet})^{-n}$ with $n = 5.5$ [5], any uncertainty in the knowledge of the jet energy badly affects the precision of the measured jet rate N: $\Delta N/N = n \times \Delta E_t/E_t$. Two items are of critical matters:

1. The H1 liquid Argon calorimeter energy scale for hadronic energies is currently known to 5% which leads to a 28% contribution to the systematic errors.

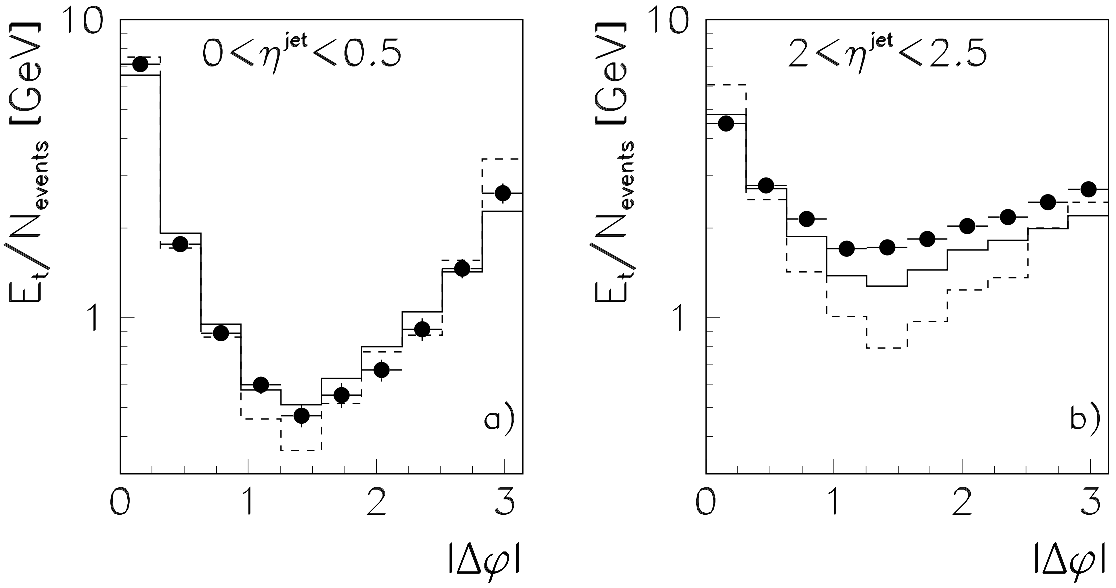

Figure 2: Transverse energy flow around the jet axis versus the azimuthal angle $\Delta\varphi$ for jets a) in the photon hemisphere, b) in the central photon-proton collision region. The jets are between $0 \leq \Delta\varphi \leq 1$, a part of the second jet is seen at $\Delta\varphi = \pi$. The points represent the data, the dashed histogram corresponds to PYTHIA without multiple interactions and the full histogram to PYTHIA with multiple interactions.

2. Compared to the QCD Monte Carlo calculations the data exhibit a larger energy flow outside of the jets (e.g. Fig.2b, $\Delta\varphi \sim 1.5$). Extrapolated into the region of the jet cone, this larger energy flow leads to a shift towards higher jet energies in the data, and consequently to higher jet rates. Similar effects have been observed in $\overline{p}p$ scattering (e.g. [15]). In this analysis the effect is corrected for by reducing the transverse jet energy using $E_t^{'jet} = E_t^{jet} - < E_t^{cor} >$. The average additional energy $< E_t^{cor} >$ is between 0.3 and 2.3 GeV depending on the rapidity of the jets. It is determined outside the jet cones from the difference in the transverse energy flow between the data (Fig.2: points) and the PYTHIA simulation without multiple interactions (Fig.2: dashed histogram). It corrects therefore only for the energy flow beyond the QCD radiation and fragmentation effects.

6 Distribution of the parton momentum x_γ

For the interpretation of the data, the measured 2-jet events are analysed as a function of the underlying parton momentum x_γ. The parton momentum in the data was first estimated using the jets by $x_\gamma^{vis} = 0.5 \left(E_t^{jet1} e^{-\eta^{jet1}} + E_t^{jet2} e^{-\eta^{jet2}} \right) / E_\gamma$. The distribution of the visible x_γ^{vis} was then corrected by an unfolding method [16] to the

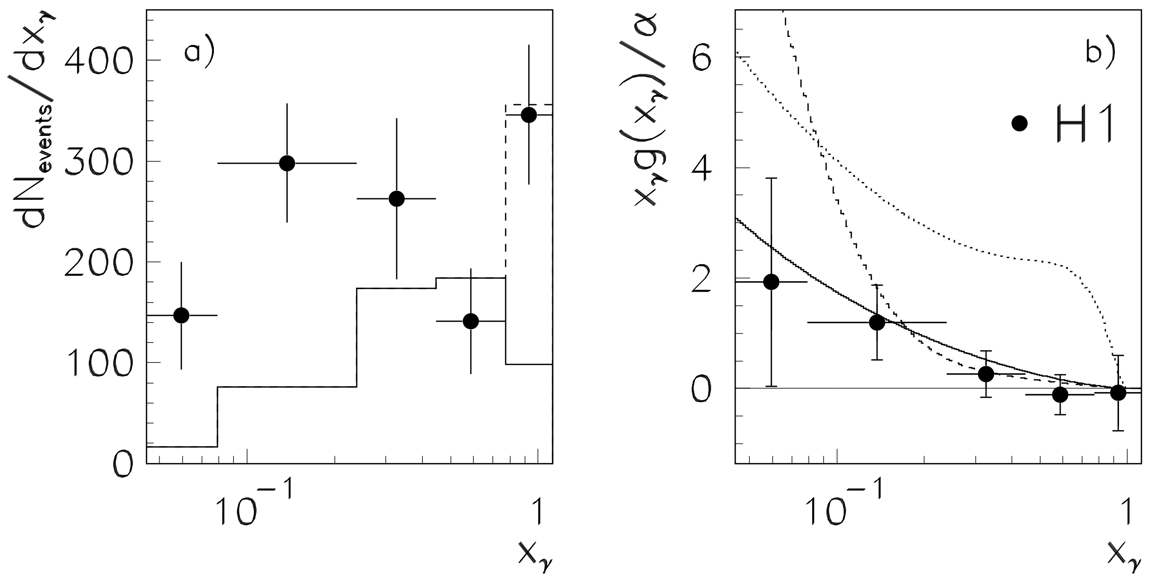

Figure 3: a) 2-jet distribution versus the corrected parton momentum from the photon. The points represent the data, the histograms are calculations using the PYTHIA QCD generator: direct photon processes (dashed) and processes initiated by a quark from the photon (full). b) Gluon distribution in the photon divided by the fine structure constant α at the average scale $< p_t^2 >= 75\,\mathrm{GeV}^2$. Also shown are parametrizations of GRV [11] (full line), LAC1 [17] (dashed line) and LAC3 [17] (dotted line).

true x_γ distribution defined in (1) using jet-parton correlations calculated with the PYTHIA generator. In Fig.3a the jet data (points) are compared with calculations of the PYTHIA generator:

1. Around $x_\gamma \sim 0.5$ the QCD calculation with quark distributions from $e\gamma$ scattering (full histogram) is compatible with the jet data observed in photoproduction. Essentially, in this kinematic range, the photon splits into a quark and an anti-quark, each carrying half of the photon energy.

2. The direct photon cross section (dashed histogram) is correctly predicted by the LO QCD calculation.

3. A gluon density in the photon is needed to explain the observed 2-jet rate at small parton momenta x_γ. Subtraction of the quark and direct photon contributions (full and dashed histogram) from the data (points) gives the rate of 2-jet events initiated by gluons from the photon side. Comparison with a calculated 2-jet distribution including gluons in the photon results in the measured gluon distribution of the photon which is shown in Fig.3b. Previous parametrizations were based only on $e\gamma$ scattering and are shown in the same figure. The measured gluon distribution is neither very large at high x_γ nor steeply rising towards small values of x_γ.

7 Conclusions and outlook

In summary, the gluon distribution of the photon has been determined for the first time over a wide range of the parton momentum $0.04 \leq x_\gamma \leq 1$ using jet events in photoproduction at HERA and jet-parton correlations as calculated with the PYTHIA generator.

In the next step, comparisons between photoproduction data and next-to-leading order (NLO) QCD calculations are required for precise conclusions on the photon structure. So far, comparisons between measured jet cross sections and NLO QCD calculations suffer from energy flow underlying the jet data which is not reproduced by the NLO calculations. Corrections need to be applied to the data or the calculations for relevant conclusions. The additional energy flow in the data comes from hadrons with small transverse momenta. Comparisons of measured inclusive charged particle cross sections with NLO QCD calculations are at large transverse particle momenta essentially independent of this additional component in the data. They are probably the preferred way to extract more precise information on the parton content of the photon.

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