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Gluon Density in the Photon Extracted Using High p_T Charged Particles in Photoproduction at HERA

H1 Collaboration

Abstract

Photoproduction data collected with the H1 experiment at HERA in 1994 are used to study the structure of the photon. A new method, based on high p_T charged particles, is employed to measure the x_γ distribution of the partons in the photon. The gluon content of the photon is extracted. The data are compared with a previous measurement of the gluon density based on high E_T jets. The gluon density is found to rise with decreasing x_γ.

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1 Introduction

The hadronic component of the photon has been established over 30 years ago [1]. In recent years its structure has been measured mainly in two photon interactions at e^+e^- colliders, in so called deep inelastic $e\gamma$ collisions[2]. These measurements are predominantely sensitive to the quark content of the photon, while the gluons enter via scaling violations, similar to structure function measurements of the proton. These data have been used to constrain parton distributions in the photon, which consequently still have a large uncertainty in the predictions for the gluon part.

Recently studies of jets and high p_T charged particles in photoproduction events at the ep collider HERA have shown sensitivity to the partonic content of the photon. Here the photon structure is probed by partons of the proton, rather than by a photon as in $e\gamma$ collisions, hence these data are sensitive to both the quark and gluon content of the photon. Leading order diagrams are shown in Fig. 1, for so called direct (Fig. 1a; the photon couples directly to the partons in the proton) and resolved (Fig. 1b; the partons of the hadronic component of the photon scatter on the partons of the proton) processes in photoproduction. Only the latter process contains information on the parton structure of the photon. In [3] a first measurement of the gluon content of the photon was presented, while in [4] an effective parton density for the photon was extracted.

In this paper the distribution of the momentum fraction $x_\gamma = E_{parton}/E_\gamma$ of the parton of the photon entering the hard scattering process shown in Fig. 1b, is measured and used to extract the gluon density in leading order in the photon. This analysis follows closely that presented in [3], where the kinematics of the hard scattering process was reconstructed by means of the jets measured in the detector. In this analysis he measured variable x_γ^{rec}, which is found to be correlated with the true value of x_γ of the parton entering the scattering, is based on charged tracks with a high transverse momentum p_T. This method thus avoids the two largest systematic errors entering in the jet analysis: the energy scale uncertainty of the calorimeter and the uncertainty of the jet energy measurement due to overlap with energy deposits from soft multiple interactions, which may occur on top of the hard scattering process. The drawback of this method is a stronger sensitivity to fragmentation uncertainties.

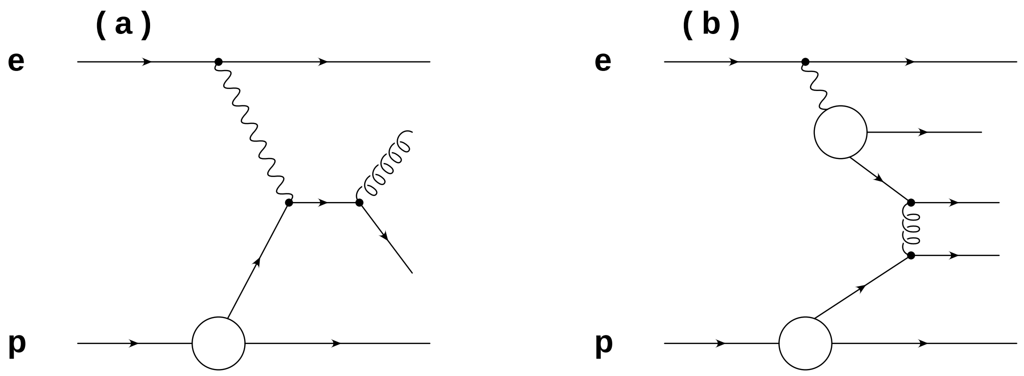

Figure 1: Examples of diagrams for direct (a) and resolved photon (b) processes in ep scattering.

2 Experimental Setup

The data are collected with the multi-purpose detector H1 [5] at the HERA collider. Positrons of 27.5 GeV collide on protons of 820 GeV. The total data sample corresponds to 1.35 ± 0.02 pb^{-1}.

A detailed description of the H1-detector has been given elsewhere [5]. Hence, only the components crucial for this particular analysis are described below.

The H1-luminosity system consists of an electron detector and a photon detector, located 33 m and 103 m from the interaction point in the electron beam direction (backward, i.e. downstream w.r.t. electron beam), respectively. The luminosity is determined from the rate of Bethe-Heitler $ep \rightarrow ep\gamma$ events by detecting the scattered electron and the photon. Both detectors are TlCl/TlBr crystal Čerenkov calorimeters with an energy resolution of $10\%/\sqrt{E}$. In addition, the electron detector tags also photoproduction events by detecting electrons scattered at small angles.

Measurements of charged tracks are provided by two cylindrical drift chambers [6], mounted concentrically around the beamline inside a homogeneous magnetic field of 1.15 Tesla. Up to 56 space points are measured for a track yielding particle charge and momentum from the track curvature in the polar angular range of $15°$ and $165°$. The resolution for the momentum measurement in the $x-y$ plane transverse to the beam direction (proton beam in $+z$ direction) is $\sigma(p_T)/p_T \approx \ 0.009 \cdot p_T \ (\mathrm{GeV}/c)^{-1} \ \oplus \ 0.015$.

The central tracking system is complemented by a forward tracking system. All trackers are surrounded by a fine grained liquid argon sampling calorimeter , consisting of an electromagnetic section with lead absorbers and a hadronic section with steel absorbers.

3 Event Selection

Photoproduction events are selected which have the scattered electron detected in the electron tagger, and consequently have a four momentum transfer $Q^2 < 10^{-2}$ GeV^2. Further, the events are required to have $0.3 < E_\gamma/E_e < 0.7$ where E_γ and E_e are the photon and electron beam energies respectively. An interaction vertex has to be reconstructed by tracks in the central tracker (CT) within 30 cm of its nominal position. These events were triggered with an energy deposit in the electron tagger in coincidence with a negatively charged track reconstructed by the drift chamber trigger.

For this analysis tracks from the central tracker are selected with a transverse momentum with respect of the beam axis of at least 2.0 GeV, a pseudorapidity measured in the HERA reference system of $|\eta = -\ln\tan\theta/2| < 1$ (with the polar angle θ measured with respect to the proton beam), a minimum track length of 30 cm and at least 30 hits are required. To minimize the systematic errors, sectors of the CT in φ which have shown a lower efficiency have been excluded from the analysis.

For this analysis events are kept which have at least one track reconstructed with a $p_T > 2.6$ GeV. In total 9378 events have been selected.

For all cuts corrections have been applied extracted from Monte Carlo studies but verified with real data. The total efficiency for a track is about 50%, mostly due to the exclusion of φ-regions in the tracker which is corrected with a simple geometrical correction factor.

4 Monte Carlo Simulation Programs

The PYTHIA 5.7 event generator [7] was used to simulate photon-proton interactions. As well as the leading-order cross section, PYTHIA includes initial- and final-state parton radiation effects which are calculated in the leading logarithmic approximation. The strong coupling constant α_s is calculated in first order QCD using $\Lambda_{\mathrm{QCD}} = 200\,\mathrm{MeV}$ for 4 quark flavours. Multiple parton interactions were generated in addition to the primary parton–parton scattering. They are calculated as leading-order QCD processes between partons from the photon and proton remnants. The transverse momentum of all parton–parton interactions was required to be above $p_T = 1.2\,\mathrm{GeV}$. This cut-off value (p_T^{min}) has been found to give an optimal description of the transverse energy flow outside the jets [8]. LAC1 and GRV-LO parameterizations were used for the parton distributions of the photon and GRV-LO for the proton [9, 10]. Hadronization was modelled with the LUND string fragmentation scheme (JETSET 7.4 [11]).

Since the kinematics of the hard scattering process will be related to the p_T values of the particles with high transverse momentum, it is imperative to study the fragmentation dependence of this measurement. A model with a different hadronization scheme, HERWIG [12] was used for this purpose. In this model the hadronization is based on cluster fragmentation. Other parameters, such as the parton densities for the photon and proton are taken the same as for PYTHIA. Both the LUND model and HERWIG were found to give a good description of the general features of fragmentation as measured in e^+e^- collisions at LEP.

5 The x_γ Distribution and Gluon Density in the Photon

For each event with at least one measured track of a charged particle with $p_T > 2.6$ GeV the variable x_γ^{rec} is calculated:

$$x_\gamma^{rec} = \frac{\sum p_T e^{-\eta}}{E_\gamma} \tag{1}$$

where the sum runs over all tracks with a $p_T > 2.0$ GeV. Monte Carlo studies show that the effect of multiple interactions is strongly reduced for such a p_T cut. At the same time the data stay safely away from the region which is affected by the p_T^{min} cut used in the Monte Carlo event generation.

Monte Carlo events are used to study the correlation between the measured x_γ^{rec} and the true x_γ, shown in Fig. 2. The generated events are fed into the detailed H1 simulation program and then subjected to the same reconstruction and analysis chain as the real data. The correlation is shown for the Monte Carlo events generated with the PYTHIA program, using the LAC1 for the structure function of the photon.

For the reconstruction of the true x_γ an unfolding procedure was used [13], following the analysis as detailed in [3]. Monte Carlo events generated with PYTHIA using the LAC1 parton densities have been used for the unfolding. The result is presented in three bins in x_γ which is imposed by the unfolding procedure, from bin-to-bin correlations. The resulting x_γ distribution is shown in Fig. 3, with statistical errors only. The dashed curve is the prediction of the PYTHIA model with the LAC1 parton distributions for the photon, the dotted curve shows the component of the event rate where only quarks from the photon side are involved. The quark distribution in the photon is rather well constrained from $e\gamma$ measurements as discussed above. The full calculation gives a fair description of the measurement, and a large contribution of gluon induced processes (from the photon side) is clearly confirmed [3].

The leading order gluon distribution in the photon is then obtained from the x_γ distribution as follows. The distribution of quark induced processes is subtracted from the data. Comparison with the distribution calculated for processes initiated by a gluon from the photon side, yields correction factors to be applied to the modelled distribution. The resulting gluon density is shown in Fig. 4. The average transverse momentum squared of the hard partonic scattering for this data sample amounts to $< p_T^2 >= 38$ GeV^2, as derived from Monte Carlo studies, and is taken as the scale for comparisons with parton densities. The total errors include statistical and systematic errors where all contributions have been added in quadrature. The systematic errors come from the following sources:

- The uncertainty in the quark density of the photon taken to be 15%.
- A variation of the unfolding parameters leads to a 10% uncertainty.
- The uncertainty from different fragmentation models used (PYTHIA, HERWIG) and different parton densities for the photon structure for the Monte Carlo events used for the unfolding (GRV, LAC1), contributing to maximally 20%.
- Residual effects from calibration and precise detector aligned are observed in the very small asymmetry in the rate of positive and negative charged tracks at large p_T, and are of the same size as the statistical errors.

The uncertainty in the parton densities of the proton is negligible compared to the uncertainties above.

The result is compared with the measurement based on the 1993 data, using jets instead of charged tracks. The measurements are found to be consistent. The improvement in precision of the measurement is clearly visible. The results confirms that the contribution of the gluon to the photon structure is significant. The gluon density tend to rise with decreasing x_γ. The result is compared with various parton distributions: LAC1, GRV, SaS. They are generally in agreement with the data.

6 Summary

High p_T charged tracks measured in photoproduction events with the H1 detector at HERA have been used to extract information on the hadronic structure of the photon. The x_γ distribution has been unfolded from the data. Charged tracks are used for the first time to extract the gluon density of the photon. The measurement is in agreement with an earlier H1 analysis using jets. The gluon density tends to increase with decreasing x_γ

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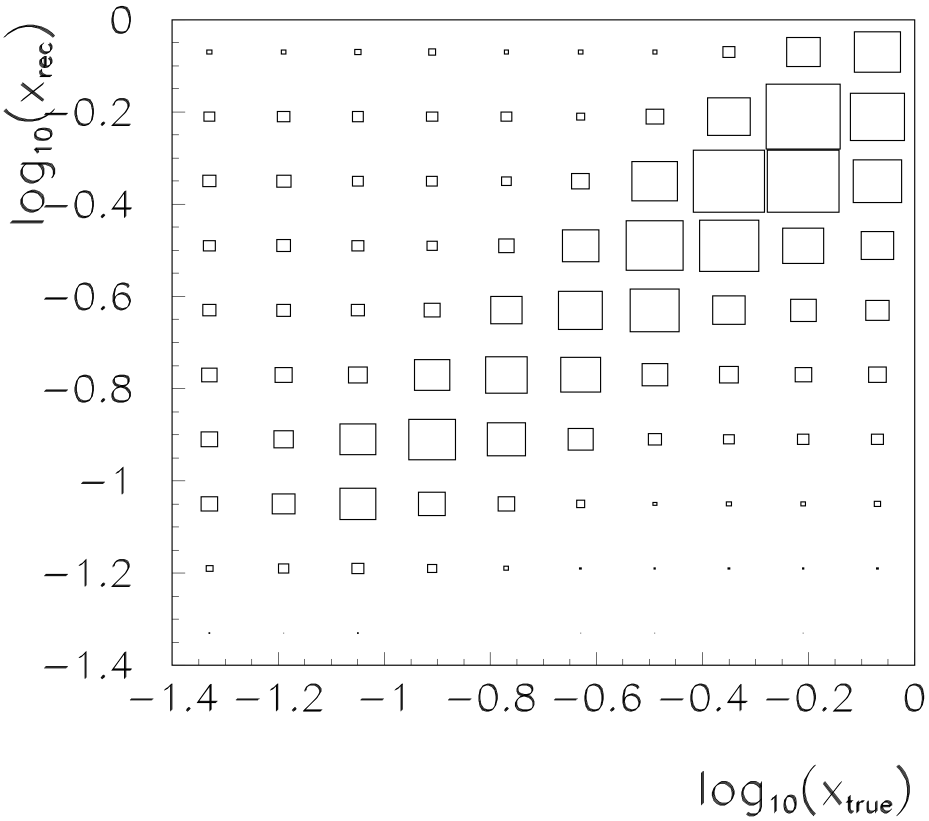

Figure 2: Correlation between reconstructed and true x_γ values, using the PYTHIA Monte Carlo with the LAC1 parton densities for the photon

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H1 PRELIMINARY

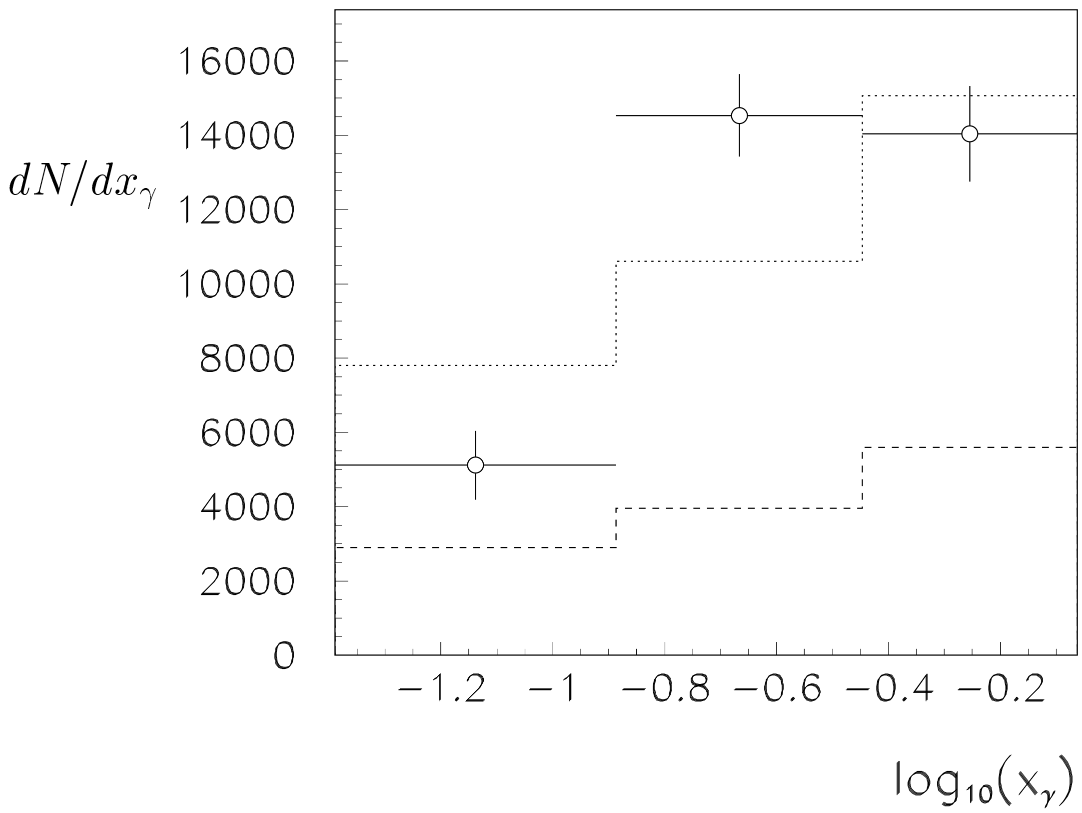

Figure 3: The preliminary x_γ distribution in the photon. The errors are statistical only. The curves are full (dotted line) and 'quark only' (dashed line) predictions of PYTHIA, using the LAC1 parton distributions of the photon.

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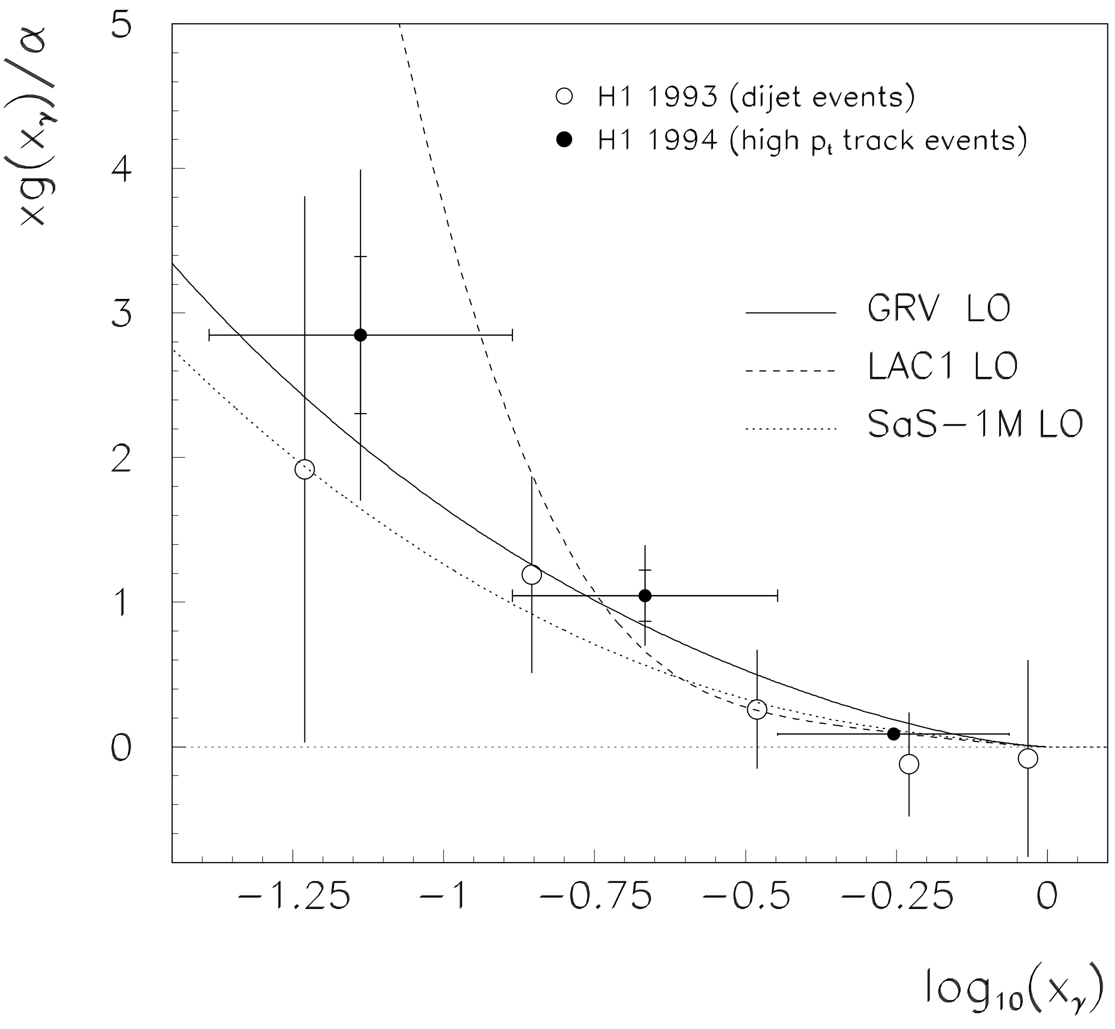

Figure 4: The preliminary gluon distribution in the photon. The inner error bars are statistical, the full bars are the statistical and systematical error added in quadrature. The curves are GRV (full line), SaS (dotted line) and LAC1 (dashed line).