Jet studies in deep inelastic *ep*- scattering at HERA

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Preliminary results obtained from QCD studies using jets in neutral current deep inelastic scattering events at HERA are presented. Firstly the strong coupling constant is determined in next to leading order based on jet rates giving $\alpha_s(M_z^2) = 0.121 \pm 0.015$. Secondly a leading order extraction of the gluon density in the proton using jet cross sections is performed.

1. Introduction

Deep inelastic electron proton scattering is studied, using data from the HERA *ep*- collider at DESY. This reaction can be written as $e(k)p(P) \rightarrow e'(k')X(h)$, where the symbols in brackets denote the particle four vectors. It is sketched in figure 1, which also introduces the basic kinematic quantities used later on.

At HERA electrons of 26.7 GeV momentum are scattered off protons of 820 GeV momentum. In the deep inelastic scattering (DIS) regime momentum transfers Q^2 ranging from $10 < Q^2 < 4000\ GeV^2$, $(Q^2 = -q^2)$ are considered here.

The two experiments H1 and ZEUS allow to observe the scattered electron (e') and also the hadronic final state (X), the main interest of the studies presented here.

In lowest order neutral current DIS events, jet production can be described as purely electromagnetic scattering of the electron off a quark via single photon exchange. In the studied Q^2 range, the exchange of the intermediate vector boson $Z°$ is highly suppressed due to its mass.

This scattering leads to (1+1)- jet events. One jet is caused by the scattered quark (1), the other by the leftover part of the proton (+1), which is only partially observed in the detectors.

Higher jet multiplicities are described in the framework of QCD. The corresponding cross sections are expressed as power series in α_s, such that the leading order (LO) contribution to (2+1)- jet events is at order $\mathcal{O}(\alpha_s)$. Two generic

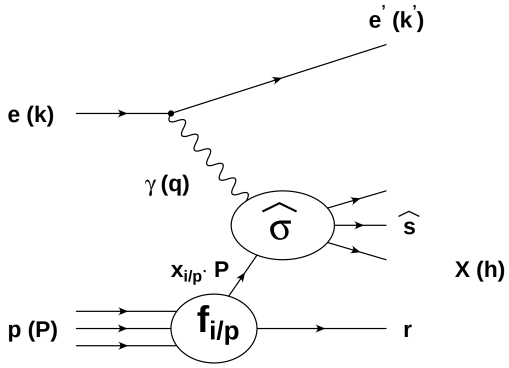

Figure 1. *Neutral current deep inelastic ep- scattering*

graphs contribute. One is gluon initiated (figure 2 a) and called boson gluon fusion (BGF), the other, the QCD Compton (QCDC) process (figure 2 b) is quark initiated. From the above stated it is clear that (2+1)- jet production is sensitive to both, $\alpha_s(Q^2)$ and the gluon density $f_{g/p}(x_{g/p}, \mu_f^2)$. Here $x_{i/p}$ (see figure 1) denotes the fractional momentum of the incoming parton i, either a quark (q) or a gluon (g), with respect to the momentum of the parent particle, the proton (p). μ_f^2 abbreviates the factorization scale.

In lowest order (1+1)- jet events, $x_{i/p}$ equals the Bjorken x variable, whereas in (2+1)- jet

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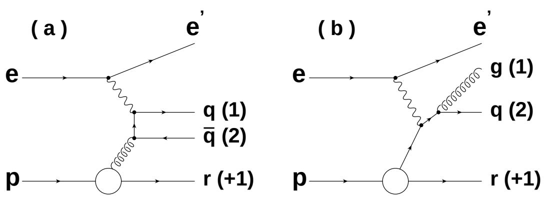

Figure 2. *The LO contributions to (2+1)- jet events*

events $x_{i/p}$ is always larger than x:

$$x_{i/p} \quad = \quad x(1 + \frac{\hat{s}}{Q^2}) \qquad (1)$$

In this equation $\hat{s}$ (see figure 1) denotes the invariant mass squared of the two hard partons, either $q\,\bar{q}$ or $q\,g$ (see figure 2).

In both studies the factorization scale μ_f^2 and the renormalization scale μ^2 are identified with the natural scale in DIS, the momentum transfer ($Q^2 = -q^2$) in the reaction.

For small values of Q^2 small values of x dominate and consequently small $x_{i/p}$ values are accessible. In this region the parton densities are only loosely constrained by experiments and the (2+1)- jet cross section is dominated by gluon initiated processes. At large Q^2 the parton densities are well constrained and the (2+1)- jet cross section is dominated by quark initiated processes. Therefore the gluon density determination concentrates on the low Q^2 region, whereas the determination of α_s is based on the high Q^2 part. The integrated luminosity used is $\approx 400\ nb^{-1}$.

2. Determination of α_s

Due to the varying momentum transfer Q^2 in DIS, the running of $\alpha_s(Q^2)$ can be studied at HERA by using only one observable. At H1 the fractional (2+1)- jet rate is chosen, defined for each bin in Q^2 as

$$R_{2+1}(Q^2, y_c) = \frac{\sigma_{2+1}(Q^2, y_c)}{\sigma(Q^2)} \qquad (2)$$

Here $\sigma(Q^2)$ represents the sum of (1+1)- jet and (2+1)- jet cross sections. y_c is defined as $y_c = m_{ij}^2/W^2$, where m_{ij}^2 is the invariant mass squared of two objects i, j and W^2 is the invariant mass of the hadronic system.

This rate is known theoretically up to $\mathcal{O}(\alpha_s^2)$ [1]. As demanded by the theoretical calculations available in the PROJET [2] and DISJET [3] Monte Carlos, jets are reconstructed using a modified JADE [4] algorithm. This algorithm takes into account the invisible part of the proton remnant, by including a pseudo particle in the clustering procedure representing the missing longitudinal momentum in the event [5]. The JADE recombination scheme in the laboratory frame with W^2 as the mass scale is used.

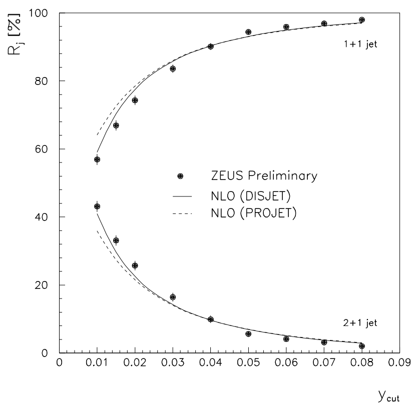

Figure 3. *Fractional jet rates as obtained by ZEUS in the kinematic domain* $160 < Q^2 < 1280$ GeV^2 *and* $0.01 < x < 0.1$, *compared to two theoretical calculations.*

Figure 3 shows the fractional jet rates, corrected to the parton jet level, as measured by ZEUS compared to PROJET and DISJET. The good description of the data by the theory allows to extract α_s. To suppress higher order effects modeled as parton showers in event generators, only jets in the region $10^\circ < \vartheta_{jet} < 160^\circ$ are accepted in the H1 analysis. All polar angles are calculated with respect to the incoming proton direction. To reduce the dependence on the parton densities, $x_{i/p} > 0.01$ is required.

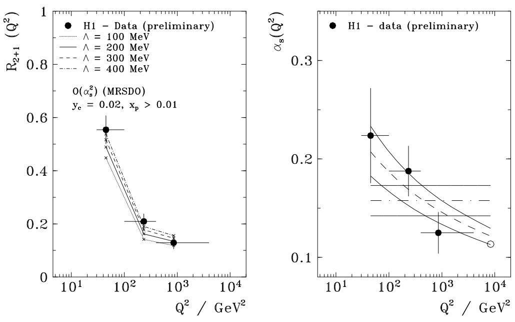

Figure 4. *The preliminary α_s measurement from H1 using the set MRSD0 as parton density parametrizations at $y_c = 0.02$ and $x_{i/p} > 0.01$.*

The event selection requires

- an electron candidate fulfilling $160^\circ < \vartheta_e < 172.5^\circ$, $30 < Q^2 < 100\ GeV^2$ and $E_e > 14\ GeV$, **or** an electron candidate with $10^\circ < \vartheta_e < 148^\circ$, and $Q^2 > 100$ and $y < 0.7$
- $W^2 > 5000\ GeV^2$

Figure 4 a compares the H1 measurement of $R_{2+1}(Q^2, y_c = 0.02)$, corrected to the parton level using LEPTO61 [6], to the NLO prediction from PROJET for various $\Lambda_{4,\overline{MS}}$ values assuming the set MRSD° [7] represents the correct parton density functions. This is translated into three measurements of $\alpha_s(Q^2)$ and fitted to the 2-loop solution of the renormalization group equation (falling band), and to the assumption of a constant α_s (horizontal band) figure 4 b. The running of $\alpha_s(Q^2)$ is preferred by the data.

Combining fits with different parton densities and extrapolating to $Q^2 = M_Z^2$ gives a preliminary value of $\alpha_s(M_Z^2) = 0.121 \pm 0.010_{stat} \pm 0.012_{sys}$ [8] consistent with the current world average [9,10]. The systematic error studied so far covers the effects of different parton density parametrizations, the y_c dependence, variation of the renormalization scale, and the uncertainty of the hadronic energy scale.

The systematic uncertainty of the procedure to correct the observed jet rate to the parton level jet rate, which can be important especially at low Q^2 is not yet included. This will be studied by using different QCD inspired event generators.

3. The gluon density in the proton

The analysis is based on jets defined by the cone algorithm used in the hadronic center of mass system. The cone algorithm sums energy in a $(\delta\eta, \delta\varphi)$ grid of the pseudorapidity (η), defined as $\eta \equiv -\log(\tan(\vartheta/2))$, and azimuthal angle (φ), starting from a prominent energy deposit and summing up to a distance of $R = \sqrt{\delta\eta^2 + \delta\varphi^2}$ around it. The radius chosen is $R = 1$ and the minimum transverse energy required for a jet is $3.5\ GeV$.

Events with an electron candidate fulfilling $12.5 < Q^2 < 80\ GeV^2$ and $E_e > 10\ GeV$, and $W^2 > 3000\ GeV^2$ are selected. The additional jet requirements are:

- 2 cone jets with $10^\circ < \vartheta_{jet} < 160^\circ$
- $\hat{s} > 100\ GeV^2$, calculated from the two jet system
- the difference in rapidity of the two jets to be smaller than 2

This selection yields 497 events. $x_{g/p}$ is measured by using Q^2 and x from the electron and the invariant mass of the two jet system. The resolution is 32 %. To derive the jet cross section for gluon initiated events the following procedure is applied. Based on LEPTO61, the background consisting of events which migrate from outside the selected phase space, defined in terms of electron and jet variables (see above), is statistically subtracted. The remaining cross sec-

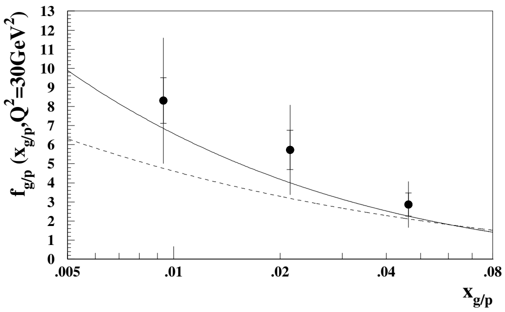

Figure 5. *The preliminary leading order gluon density in the proton from H1 compared the GRV LO (solid line) and CTEQ2pL (dashed line) LO parton densities.*

tion is corrected for acceptance using LEPTO61. By comparing to the LO cross sections based on the GRV LO parton densities, the gluon density is determined. The quark initiated processes are subtracted, and the gluon input parametrization is reweighted according to the ratio of the measured and predicted cross sections in three bins of $x_{g/p}$. The bin boundaries are $0.005, 0.015, 0.03$ and 0.08. Figure 5 compares the result to the GRV [12] and CTEQ2pL [13] LO gluon densities. The inner error bars indicate the statistical error.

Various sources of systematic errors are studied, e.g. the luminosity, the uncertainty of the calorimeter energy scale and the use of different QCD inspired models to calculate the background and the acceptance. In total these systematic errors amount to 26 %. Using different jet algorithms (k_T, JADE) leads to an additional error of 25%. The uncertainty due to a variation of the renormalization scale within $1/2 \cdot Q < \mu < 4 \cdot Q$ is 30 %. The total error is obtained as the quadratic sum of the statistical and all systematic errors.

4. Conclusions

Two studies, using jets in neutral current deep inelastic *ep*- scattering events at HERA, leading to preliminary H1 results, are performed.

The measurement of α_s using jet rates seems feasible and a preliminary value, $\alpha_s(M_Z^2) = 0.121 \pm 0.015$ is extracted. This value is consistent with other experiments, however the present determination does not yet contain the systematic error from all possible sources.

A LO gluon density in the region $0.005 < x_{g/p} < 0.08$ at a typical value of $Q^2 = 30\ GeV^2$, is obtained. It agrees with present parametrizations and in future it may constrain those further.

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