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Jets and α_s Measurements at HERA

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Jet cross sections in deep-inelastic ep scattering and photoproduction were measured with the H1 and ZEUS detectors at HERA using data collected in the years 1996-2007 and corresponding to an integrated luminosity of up to 395 pb^{-1}. All the measurements are well described by perturbative QCD calculations at next-to-leading order. The data were therefore used to extract precise values of the strong coupling constant α_s and test its energy-scale dependence.

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1. Introduction

In *ep* collisions, an electron or positron couples with a parton of the proton via the exchange of a boson with virtuality Q^2. Two kinematic regimes, photoproduction (γp), where the exchanged boson is quasi-real ($Q^2 \approx 0$ GeV^2), and deep-inelastic scattering (DIS, $Q^2 > 1$ GeV^2) can be distinguished. Measurements of the hadronic final state in DIS and γp using jets provide stringent tests of the theory of strong interactions, quantum chromo-dynamics (QCD), allow a determination of the strong coupling constant α_s and have the potential to constrain the proton parton distribution functions (PDFs) when used in global QCD analyses.

In this contribution, recent results from the H1 and ZEUS collaborations on jet production are presented and some of the achievements discussed. For the analyses shown here, a data sample of up to 395 pb^{-1} has been used.

2. Jet Production

The jet cross section $\sigma_{\rm jet}$ in *ep* collisions can be described symbolically in perturbative QCD (pQCD) as a series expansion in powers *m* of α_s,

$$\sigma_{\rm jet} = \sum_m \alpha_s^m (\mu_R) \sum_{a=q,\bar{q},g} f_{a/p}(x,\mu_F) \otimes \hat{\sigma}_{a,m}(x,\mu_R,\mu_F)(1+\delta_{\rm had}), \tag{2.1}$$

with coefficients which are convolutions of the PDFs $f_{a/p}$ for partons a inside the proton (and the partons inside the photon in case of γp) and the hard scattering matrix element $\hat{\sigma}$. The quantities $f_{a/p}$ and $\hat{\sigma}$ depend on x, which in lowest order corresponds to the fraction of proton momentum carried by the struck parton, and on the factorisation scale μ_F, that separates the perturbative part of the cross sections from the soft and non-perturbative contributions due to the proton structure. In order to account for non-perturbative corrections to the theoretical predictions, different leading-order Monte Carlo generators are used, providing different parton shower models and hadronisation corrections δ_{had}. These Monte Carlo programs are combined with a full detector simulation to correct the data for detector effects as well as for electroweak processes.

In DIS at HERA, jets are usually reconstructed using the infrared and collinear safe $k_\perp$ cluster algorithm [1] in the boson-quark collinear frame, the Breit frame. In this frame, QCD interactions can be separated from purely electroweak processes by identifying jets with a minimum transverse energy $E_T^{\rm jet}$.

3. Inclusive Jet Production in Photoproduction

In γp at HERA, the photon can either interact directly with a parton in the proton or act as a source of partons. The measurement of jet production in γp provides a testing ground for QCD predictions and allows the determination of α_s as well as its energy-scale dependence.

ZEUS released a new preliminary result [2] in which a new QCD analysis was performed on a previously published [3] inclusive-jet differential cross section versus the jet transverse energy, $E_T^{\rm jet}$. The $\alpha_s(M_Z)$ dependence of the NLO QCD prediction of this cross section is parametrised in each analysis bin i by a quadratic function according to $d\sigma_i/dE_T^{\rm jet} = A_i \cdot \alpha_S(M_Z) + B_i \cdot \alpha_S^2(M_Z)$, where A_i and B_i were determined by a χ^2 fit to the NLO QCD calculations. A value of $\alpha_s(M_Z)$ is then determined for the measured observable using this parameterisation. This procedure handles correctly the explicit α_s dependence of the partonic cross section and the implicit dependence of the PDFs while preserving the correlation between α_s and the PDFs. Compared to the previous extraction, recent parametrisations of the PDFs (MRST2001 [4] and GRV-HO [5]) with smaller uncertainties and a purely theoretical estimation of the uncertainties coming from higher orders [6] were used. The new extracted value, $\alpha_s(M_Z) = 0.1223 \pm 0.0001(\text{stat.})^{+0.0023}_{-0.0021}(\text{syst.}) \pm 0.0030(\text{th.})$, has a total uncertainty of 3.1% and it is the most precise determination at HERA so far.

4. Inclusive Jet Production at Low Q^2

In processes which involve large scales Q^2 or E_T^{jet}, the uncertainties on the theoretical predictions, estimated by varying the input parameters of the calculations, are typically small, and the jet cross section predictions at NLO are in good agreement with the data. With decreasing scales, higher order contributions are expected to become more important. It is therefore essential to study the reliability of existing pQCD predictions at low scales.

Inclusive jet cross sections were measured by the H1 Collaboration [7] at low Q^2, $5 < Q^2 < 100$ GeV^2, requiring a minimum E_T^{jet} of 5 GeV of the jets in the Breit frame. The uncertainties on the theoretical predictions arising from the renormalisation and factorisation scales, the uncertainty on α_s and the uncertainty on the PDFs were estimated.

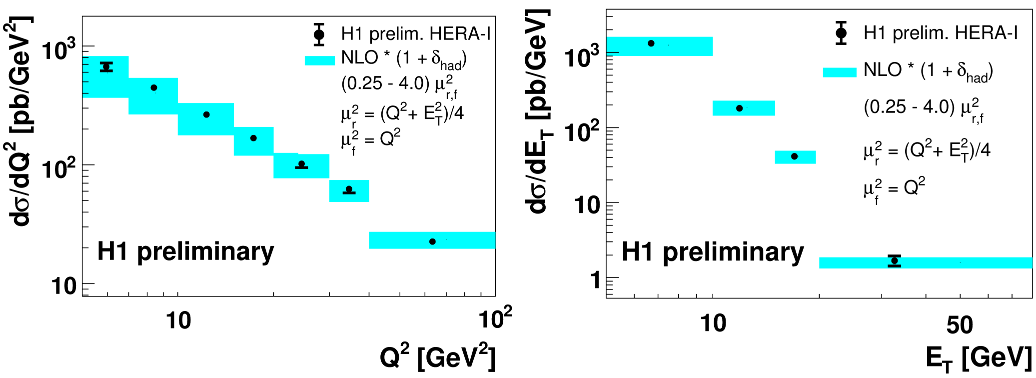

Figure 1: Inclusive-jet differential cross sections $d\sigma/dQ^2$ and $d\sigma/dE_T^{\text{jet}}$, compared with NLO QCD predictions corrected for hadronisation effects.

Figure 1 shows the inclusive jet differential cross sections $d\sigma/dQ^2$ and $d\sigma/dE_T^{\text{jet}}$ compared with NLO predictions. The band indicates the uncertainty on this prediction, which is dominated by the variation of the renormalisation and factorisation scales. The data are described by the NLO predictions, but the theoretical uncertainties are large and can amount to more than 30%. Thus, in order to perform more significant tests of the theory, predictions with orders beyond NLO are needed in pQCD in this region of the DIS phase space.

5. Multi-Jet Production at High Q^2

The generally high quality of the theoretical description of DIS jet cross sections at high Q^2 allows a precise extraction of α_s.

In a recent H1 measurement [8], the full HERA data set of 395 pb^{-1} was used to measure multi-jet production at $Q^2 > 150$ GeV^2. Single-inclusive, 2- and 3-jet cross sections, normalised to the inclusive neutral current DIS cross section, were measured. In this cross-section ratio the luminosity uncertainty cancels completely and other experimental uncertainties partially; therefore, a measurement with reduced systematic uncertainties is achieved. The data are well described by NLO QCD and thus used to extract α_s from a fit of the NLO predictions to the inclusive, 2- and 3-jet data.

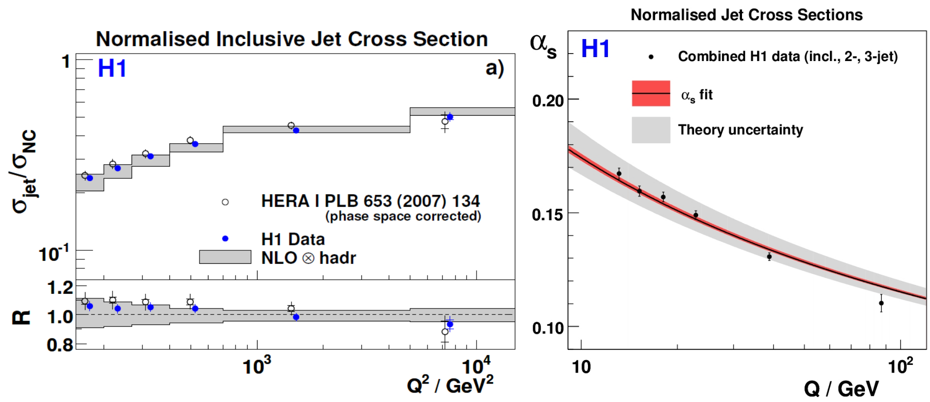

Figure 2: The α_s values determined from a combined fit of inclusive, 2- and 3-jet cross sections at high Q^2 as a function of Q compared to the predicted running of α_s.

In figure 2, the normalised inclusive jet cross sections $\sigma_{\rm jet}/\sigma_{\rm NC}$, which are, within the uncertainties, well described by the theoretical predictions, and the obtained values of α_s as a function of the scale Q are shown. The high Q^2 jet data show a running of the coupling which is well described by QCD predictions and yields $\alpha_s(M_Z) = 0.1168 \pm 0.0007(\text{exp.})^{+0.0046}_{-0.0030}(\text{th.}) \pm 0.0016(\text{PDF})$. This value is in good agreement with the α_s world average [9]. The uncertainty coming from the theory is significantly larger than the experimental. QCD calculations in NNLO could reduce this theory uncertainty.

6. Inclusive Jet Cross Sections at High Q^2

In order to determine the free parameter α_s of QCD, in a recent ZEUS analysis [10] of inclusive jet cross sections, the scale dependence of α_s was investigated and its value determined.

Figure 3 shows the double-differential inclusive jet cross sections $d\sigma/dE^{\rm jet}_{T,B}$ in several regions of Q^2 and the relative difference to NLO predictions. The data, for which the dominant uncertainty is given by the jet energy scale, are well described by the QCD prediction which is indicated as a hatched area. The uncertainty due the hadronisation (0.8%), terms beyond NLO (1.8%) and the PDF uncertainty (0.8%) are included in the hatched area. The μ_R uncertainty dominates except at high $E^{\rm jet}_{T,B}$ where the PDF uncertainty is dominant. Therefore the measurement has the potential to further constrain the gluon density in the proton in global QCD fits.

The strong coupling α_s was extracted by restricting the phase space to $Q^2 > 500$ GeV^2. In this region of Q^2, the experimental systematic uncertainties on the cross section are smaller than at lower Q^2, and the theoretical uncertainties are also minimised. The observed running was found

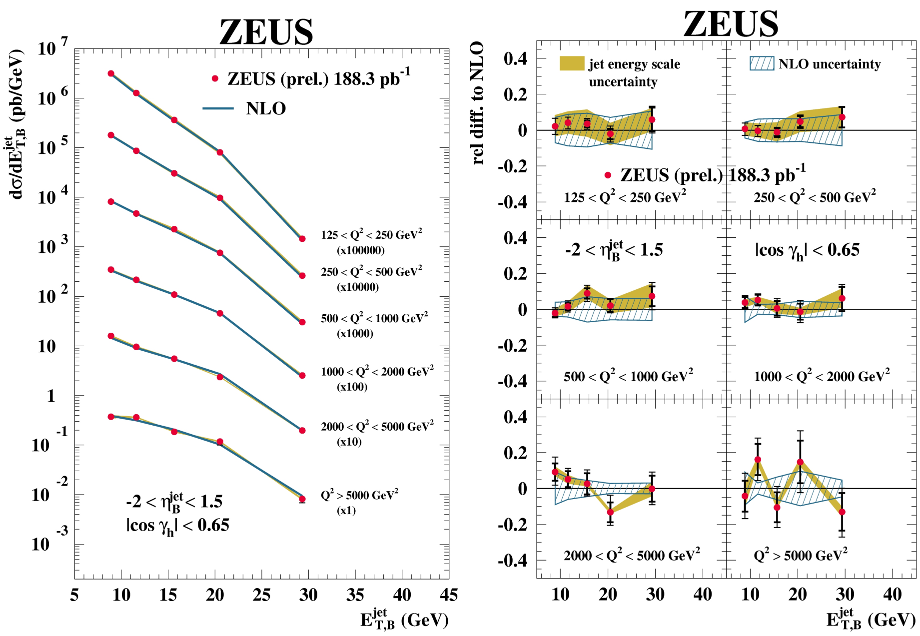

Figure 3: Inclusive jet cross sections in neutral current DIS as a function of $E_{T,B}^{\rm jet}$ in different regions of Q^2.

to be in good agreement with the QCD prediction. The obtained value is $\alpha_s(M_Z) = 0.1192 \pm 0.0009(\text{stat.})^{+0.0035}_{-0.0032}(\text{exp.})^{+0.0020}_{-0.0021}(\text{th.})$, which is within uncertainties in good agreement with the world average [9].

7. Summary

Recent jet results in photoproduction and DIS from the H1 and ZEUS collaborations were presented. The measurements are well described by pQCD calculations at NLO and the strong coupling constant α_s was extracted with high precision.

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