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Jet Production at HERA with ZEUS

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Cross sections for jet production in deep-inelastic electron-proton scattering and in photoproduction were measured with the ZEUS detector at HERA using an integrated luminosity of up to 374 pb^{-1}. The data were used to perform stringent tests of perturbative QCD predictions. The agreement between the measurements and the theory were found to be very good. Therefore, the data were exploited in a high-precision extraction of the strong coupling, α_s.

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1. Introduction

In ep collisions at HERA an electron or positron scattered with a parton from the proton by exchanging a gauge boson. The kinematic region of deep-inelastic scattering (DIS) can be distinguished from photoproduction (γp) by the virtuality of the boson, Q^2. In γp the boson is quasi real ($Q^2 \approx 0$ GeV^2) in contrast to DIS ($Q^2 > 1$ GeV^2). In γp in lowest order two types of processes exist: in direct processes the photon interacts directly with the parton from the proton whereas in resolved processes the photon exhibits a substructure and acts as a source of partons. Measurements of the hadronic final state using jets always played an important role in the understanding of the theory of the strong force – quantum chromodynamics (QCD). Since jets are the footprints of the partons involved in the partonic interactions, jet measurements allow to perform stringent tests of perturbative QCD (pQCD), to extract the strong coupling, α_s, and are sensitive to the parton distribution functions (PDFs) of the proton, and also of the photon in resolved γp. In this contribution recent results from the ZEUS collaboration on jet production are presented.

2. Jet Production at HERA

In pQCD the jet cross section is a function of the renormalisation scale, μ_R, and can be expressed as a series expansion in powers of α_s. The involved coefficients are convolutions of the PDFs[1] and of the lepton-parton cross section, $\hat{\sigma}$, which describes the short-distance structure of the interaction. Both quantities depend on the one hand on the factorisation scale, μ_F, which is the limit between contributions due to the proton structure and the hard interaction, and on the other hand on x. The latter is in lowest order equivalent to the fractional proton momentum carried by the struck parton. At HERA jets are typically reconstructed with the infrared and collinear safe $k_\perp$ cluster algorithm [1]. Jets are reconstructed either in the boson-quark collinear frame – the Breit frame – in which purely electroweak processes can be suppressed by requiring a minimum transverse energy, E_T^{jet}, or, in case of γp, in the laboratory frame.

3. Inclusive Jet and Dijet Production in Photoproduction

Owing to resolved photons in γp the hadronic final state is closer to that encountered in hadron-hadron collisions. Therefore, jets in γp are an interesting tool to study various aspects of QCD.

The ZEUS collaboration studied inclusive jet production [2] by selecting jets with the requirement of a minimum E_T^{jet} of 17 GeV. Figure 1a shows the differential inclusive-jet cross section $d\sigma/d\eta^{\mathrm{jet}}$ compared to pQCD predictions at next-to-leading order (NLO). The estimated theoretical uncertainties are included in the hatched area. The largest theoretical uncertainty is caused by missing higher orders in the calculations estimated by a variation of μ_R and amounts to about $\pm10\%$ ($< 7\%$) at low (high) E_T^{jet}. The uncertainty due to the photon PDFs has a similar size ($\pm10\%$) at low E_T^{jet} whereas at high E_T^{jet} the proton PDF uncertainty becomes large ($\pm5\%$). In contrast, the experimental uncertainties are typically smaller. The uncorrelated uncertainties are mostly smaller than $\pm4\%$ while the correlated ones are of the order of $5-10\%$ and are due to the jet energy scale uncertainty of $\pm1\%$. Except at high η^{jet}, where the predictions obtained with different photon

[1] In DIS the proton PDFs are involved whereas in resolved γp also the photon PDFs have to be considered.

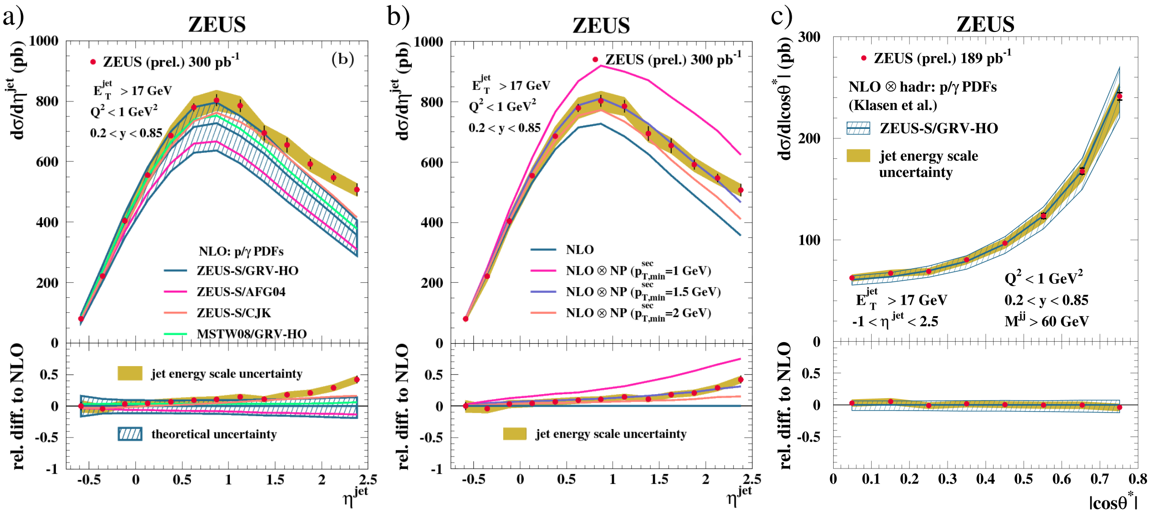

Figure 1: a,b) Inclusive jet cross sections in photoproduction as a function of $\eta^{\rm jet}$. b) Dijet cross sections in photoproduction as a function of $|\cos\theta^*|$.

PDFs differ significantly from each other as indicated by the solid lines in the figure, the agreement between the data and theory is very good. In addition in the high-$\eta^{\rm jet}$ region the influence of non-perturbative (NP) effects was investigated by applying to the NLO QCD calculations corrections extracted from the MC program PYTHIA [3]. This is depicted in figure 1b where the various solid lines correspond to different thresholds for secondary particle scattering in the PYTHIA model for multi-parton interactions (MIs). Since these effects depend strongly on $\eta^{\rm jet}$, the presence of MIs could have caused the observed degradation of the agreement between data and theory at high $\eta^{\rm jet}$.

The ZEUS collaboration measured dijet production [4] to study the underlying QCD dynamics. The dijet cross sections as a function of θ^*, which is the centre-of-mass scattering angle, are depicted in figure 1c and compared to the theory. Since the shape of the distribution of $d\sigma/d|\cos\theta^*|$ is related to the different nature of the propagator in resolved and direct processes, the good data description by the theory supports the fact that the concept of the resolved photon holds.

4. Inclusive Jet and Dijet Production in DIS

With rising energy scales Q^2 or $E_T^{\rm jet}$ of the involved processes, the theoretical uncertainties due to the choice of μ_R become relatively small. Hence, in recent studies single- and double-differential inclusive jet [5] and dijet [6] cross sections at high Q^2 in neutral-current DIS were measured.

Figure 2 shows the single-differential inclusive-jet cross section $d\sigma/dQ^2$ and the relative difference to NLO QCD predictions. The theory provides a good description of the data over the whole phase space investigated. As for the jet measurements in γp presented here, the dominant experimental systematic uncertainty is given by the jet energy scale and ranges from $\pm 2\%$ to $\pm 5\%$ at low or high Q^2, respectively. The theory uncertainties are mainly due to missing higher orders ($\pm 5\%$) and the PDF uncertainty ($< \pm 3\%$). Jets induced by the boson-gluon fusion process are sensitive to the gluon density in the proton. The gluon fractional contribution to dijet production was estimated and found to be $> 60\%$ ($> 40\%$) at lower (medium) Q^2. In order to possibly constrain the gluon density, inclusive dijet cross sections were measured as functions of $\mu_F^2 = Q^2$ and ξ, the

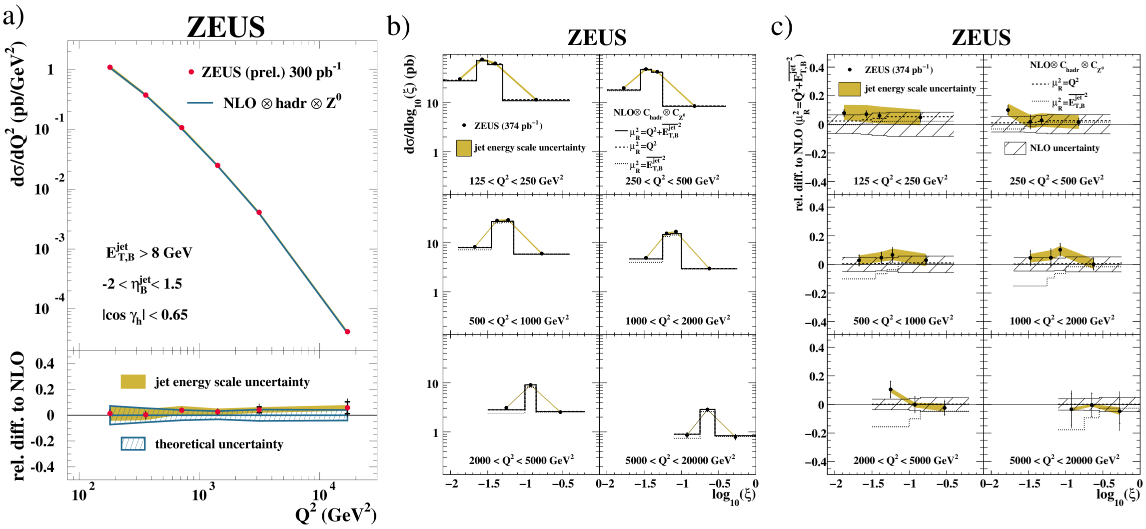

Figure 2: a,b) Inclusive jet cross sections in DIS as a function of Q^2. b,c) Dijet cross sections in DIS as a function of $\log_{10}\xi$ in regions of Q^2.

latter being the momentum fraction carried by the struck parton. The outcome of this measurement is depicted in figures 2b and 2c where the data are compared to NLO QCD calculations which provide a very good description of the data over the whole measured range.

Due to the small uncertainties in DIS and γp a precise extraction of α_s was performed. This was achieved by parametrising the jet cross sections according to a quadratic function, in order to preserve the correlation between α_s and the PDFs. In DIS the extraction was restricted to $Q^2 > 500$ GeV^2 to minimise the total uncertainty while in γp the range $21 < E_T^{\rm jet} < 71$ GeV was used to avoid contributions from NP effects and to omit regions with large PDF uncertainties.

The extracted values in DIS and γp, $\alpha_s(M_Z) = 0.1208^{+0.0037}_{-0.0032}(\text{exp.}) \pm 0.0022(\text{th.})$ and $\alpha_s(M_Z) = 0.1206^{+0.0023}_{-0.0022}(\text{exp.})^{+0.0042}_{-0.0033}(\text{th.})$, have a total uncertainty of $\pm 3.5\%$ or $\pm 4.0\%$, respectively, and are in very good agreement with each other and with the world average [7], $\alpha_s(M_Z) = 0.1184 \pm 0.0007$.

5. Summary and Conclusion

Recent jet results from the ZEUS collaboration were presented. The data are very well described by NLO QCD calculations. The value of $\alpha_s(M_Z)$ was extracted with very high precision.

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