Jets and $\alpha_s$ Measurements in DIS

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The inclusive, 2-jet and 3-jet jet cross sections at $5 < Q^2 < 100$ GeV$^2$ and the inclusive, 2-jet and 3-jet cross sections normalised to the NC DIS cross section at $150 < Q^2 < 15000$ GeV$^2$ are measured as function of $Q^2$ and $P_T$. The strong coupling is extracted.

1 Introduction

In contradiction to DIS cross section where $\alpha_s$ contributes indirectly (Fig. 1(a)), jet production cross sections directly depend on $\alpha_s$ through QCD Compton scattering (Fig. 1(b)) and boson-gluon fusion (Fig. 1(c)). This provides the possibility for an accurate determination of $\alpha_s$ from jet production data. The measurements are presented as both single and double differential cross sections in the variables $Q^2$ and jet transverse momentum $P_T$. The results agree well with NLO QCD calculations [1] corrected for hadronisation effects. The strong coupling $\alpha_s$ is extracted from a fit of the predictions to the data at low $Q^2$ ($5 < Q^2 < 100$ GeV$^2$) and at high $Q^2$ ($150 < Q^2 < 15000$ GeV$^2$). The running of $\alpha_s$ is tested in a wide range of $\mu_r$.

2 Experimental methods and cross section measurements

The data presented in this paper were taken with the H1 detector at electron/positron and proton beam energies of 27.6 GeV and 920 GeV, respectively. The data samples were collected in 1999-2000 with an integrated luminosity of 43.5 pb$^{-1}$ for low $Q^2$ and in 1999-2007 with an integrated luminosity of 395 pb$^{-1}$ for high $Q^2$. The inelasticity $y$ of the interaction is defined in the range $0.2 < y < 0.7$. Jets are defined with the inclusive $k_t$ algorithm in the Breit frame. Cuts on the jet pseudorapidity $\eta^L$ in the laboratory frame ($-1.0(-0.8) < \eta^L < 2.5(2.0)$ for low (high) $Q^2$) are applied to ensure that the jets are well contained within the acceptance of the calorimeter. To ensure the reliability of QCD predictions for the 2-jet and 3-jet sample [2], an additional cut on the invariant mass of the two leading jets ($M_{12} > 18(16)$ GeV for low (high))
$Q^2$) is applied. For the cross section extraction the experimental data is corrected for detector effects (resolution an efficiency) using Monte-Carlo event samples. The model uncertainties and the hadronic energy scale uncertainties are the dominant sources of experimental errors on the jet cross sections. The cross section normalisation to inclusive DIS data, applied to the high $Q^2$ data, allows to reduce systematic errors in most of the bins due to cancellation effects. Differential and double differential cross sections, corrected for detector and radiative effects are presented as function of $Q^2$ and $P_T$. Inclusive (normalised) double differential jet cross sections are presented in Fig.2 for low (high) $Q^2$. The band around the predictions shows the scale uncertainty of the NLO QCD calculations. In almost all the bins the scale uncertainty exceeds the total experimental error.

3 NLO QCD calculations. Strong coupling extraction

The data are compared with NLO QCD predictions, performed in the $\overline{\text{MS}}$ scheme for five massless quark flavors. The parton level calculations are corrected for hadronisation effects. The PDFs of the proton are taken from the CTEQ6.5M set. The factorisation scale is chosen as $\mu_f = \sqrt{Q^2 + P_T^2}$ (low scale) and $\mu_f = Q$ (high scale). The renormalisation scale is chosen as $\mu_r = \sqrt{(Q^2 + P_T^2)/2}$. Varying the scales $\mu_f$ and $\mu_r$ by factors in the range 1/2 to 2, scale uncertainties up to 10% (30% at $P_T < 10$ GeV and 20% at $P_T > 20$ GeV) are observed for the data at the high (low) $Q^2$. The uncertainties from PDFs and $\alpha_s$ are found to be small compared to these scale uncertainty. A fit of the (normalised) cross sections in bins of $Q^2$ and $P_T$ to NLO predictions is performed, in order to extract $\alpha_s$. The experimental errors and their correlations are taken into account using the Hessian method [3]. The results are consistent between different bins and combinations of bins. The same is true for combinations of inclusive, 2-jet or 3-jet measurements and for combining low and high $Q^2$ data. The theory error is estimated using the offset method, where the difference between $\alpha_s$ values obtained from fits under the variation of the theoretical uncertainties are studied.

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4 Conclusion

Measurements of the inclusive, 2-jet and 3-jet (normalised) cross sections in the Breit frame in DIS with $0.2 < y < 0.7$ are presented for low (high) $Q^2$. Calculations in NLO QCD corrected for hadronisation effects agree well with single and double differential cross sections as functions of the jet transverse momentum $P_T$ and the boson virtuality $Q^2$. It is observed that with a proper choice of the renormalisation scale, the theory is applicable for low $P_T$ and low $Q^2$. The strong coupling $\alpha_s(M_Z)$ is extracted separately for low and high $Q^2$ as well as for both datasets together. The experimentally most precise determination of $\alpha_s(M_Z)$ is derived from a fit to the normalised jets cross sections at high $Q^2$ alone, as the normalisation leads to significant cancellations of systematic effects:

$$\alpha_s(M_Z) = 0.1168 \pm 0.0007_{\text{exp}}^{+0.0046}_{-0.0030}(\text{th}) \pm 0.0016_{\text{pdf}}$$

Determination of $\alpha_s(M_Z)$ from a fit to the jets cross sections at low $Q^2$ alone gives:

$$\alpha_s(M_Z) = 0.1160 \pm 0.0014_{\text{exp}}^{+0.0033}_{-0.0020}(\text{th}) \pm 0.0016_{\text{pdf}}$$

The combined fit of high and low $Q^2$ data has somewhat better experimental precision, but suffers from increased scale uncertainties. The running of $\alpha_s$ and the small experimental errors are visualised in Fig.3, where the measurements are displayed as a function of $\mu_r$. It is remarkable that the total errors are essentially lower than theory prediction, hence setting a challenge for improved theoretical calculations.

References