JETS IN DEEP-INELASTIC SCATTERING AT HERA AND DETERMINATIONS OF $\alpha_s$*

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Several methods to extract the strong coupling constant $\alpha_s$ by means of highly energetic jets in Deep-Inelastic Scattering are presented. The results from the various methods agree with one another and with the world average. The errors are competitive to those achieved in $\alpha_s$ determinations in other processes such as proton-anti-proton scattering.

1. Introduction

Measurements of the hadronic final state in deeply inelastic $ep$ scattering (DIS) provide precision tests of quantum chromodynamics (QCD). At HERA data are collected over a wide range of the negative four-momentum-transfer $Q^2$, and the transverse energy $E_T$ of hadronic final state jets. As sketched in Eq. 1 the jet cross section can be expressed as a power series of $\alpha_s$ combined with a convolution of the hard matrix element, $\hat{\sigma}_{jet}$, and appropriate parton distribution functions of the proton.

$$\sigma_{jet} = \sum \alpha_s^n(\mu_r) \sum \hat{\sigma}_{jet}(\mu_r, \mu_f) \otimes \text{pdf}(\mu_f, ...),$$

(1)

with $\mu_r$ and $\mu_f$ being mass scales.

Fig. 1 shows diagrams of the leading order, here $O(\alpha_s)$, processes for dijet-production in DIS.

The accurate measurement of jet production, hence, allows for a precise determination of $\alpha_s$.

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Figure 1. Leading order diagrams for dijet production in $ep$ scattering. (a) photon-gluon fusion and (b) QCD-Compton process.

Figure 2. Single inclusive jet cross section as a function of $Q^2$ (left) and $E_{T,jet}$ (right) compared with NLO QCD predictions.

2. Single Inclusive Jet Cross Section

For this analysis it is required to identify at least one jet above a given transverse energy. Fig. 2 shows the measured single inclusive jet cross section as a function of $Q^2$ and the transverse energy of the jet as measured in the Breit-Frame compared with NLO-QCD calculations.\(^1\)

The data have a typical experimental uncertainty of 7% and are well reproduced by the theoretical predictions at large values of $E_T$ and $Q^2$. The NLO-QCD calculations, currently only available at the parton level, are corrected for hadronisation effects using LO models. These corrections are expected to be small at large $E_T$ and $Q^2$.\(^1\)
2.1. Determination of $\alpha_s$

The dependency of a generic jet cross section on $\alpha_s(M_Z)$ is parameterized in the corresponding analysis bins with the help of suitable NLO-QCD predictions featuring slightly different values of $\alpha_s(M_Z)$. By comparison of the parameterized cross section with the measured cross section the values for $\alpha_s$ are obtained. The resulting $\alpha_s(M_Z)$ from e.g. the single inclusive jet cross section for $Q^2 > 500$ GeV is found in the ZEUS analysis to be

$$\alpha_s(M_Z) = 0.1212 \pm 0.0017 \text{(stat.)}^{+0.0023}_{-0.0031} \text{(exp.)}^{+0.0030}_{-0.0027} \text{(theor.)}.$$  

The experimental error (exp.) is dominated by the uncertainty on the energy scale for the jet measurement. The largest contribution to the theoretical uncertainty (theor.) is given by a residual dependency on the renormalization scale $\mu_r$ which corresponds to uncertainties due to the contributions of terms beyond next-to-leading order.

In Figure 3 the result is displayed as a function of a mass scale $\mu$ together with other values of $\alpha_s$ extracted from DIS-jet data.

The expected running of $\alpha_s$ as a function of $\mu$ is clearly visible. In addition the figure demonstrates the compatibility of the resulting $\alpha_s$ values with those obtained in global fits.
3. Jet Substructure and Determination of $\alpha_s$

Jets appear as a collimated spray of particles which are combined to by dedicated algorithms. These particles are the end point of a cascade of successive particle emissions from the hard interaction to the hadronic final state.

The development of the cascade is governed by the strong coupling constant $\alpha_s$. An attempt is made to resolve subjets using dedicated algorithms within the identified jets. The amount of subjets is expected to depend on $\alpha_s$. Fig. 4 shows the number of subjets as a function of the jet-$E_T$ measured in the laboratory frame. The number of subjets decreases as the transverse energy of the jet increases. The transverse energy of the jet sets the scale for $\alpha_s$. Thus, the probability to radiate partons is small at large transverse energies. The data are well described by NLO-QCD calculations employing different parton pdfs featuring slightly different values of $\alpha_s(M_Z)$. For $E_T$ larger than 30 GeV the hadronization corrections become small allowing for a QCD analysis to determine $\alpha_s$ from subjet multiplicites. The resulting value is found by ZEUS to be

$$\alpha_s(M_Z) = 0.1187 \pm 0.0017^{+0.0024}_{-0.0009}\text{(stat.)} +0.0093_{-0.0076}\text{(exp.).}$$

4. 3-jet Cross Sections

3-jet cross sections are well suited for an extraction of $\alpha_s$ because the lowest order contribution to this event class is proportional to $\alpha_s^2$. The sensitivity to uncertainties due to proton pdf’s can be reduced by building the ratio $R_{3/2}$, i.e. the ratio of 3-jet to dijet cross sections. A measurement of this observable is shown in Fig. 5. While a minor sensitivity to variations of the pdf’s is observed the ratio is very sensitive to small variations of $\alpha_s$ which underlines the potential of this observable for future determinations of $\alpha_s$. 
5. Conclusion and Outlook

The analysis of jet events in DIS allows for precise measurements of the strong coupling constant $\alpha_s$. A compilation of results is given in Fig. 6. They have a major impact on the current world average value of $\alpha_s$. Ongoing analysis of HERA I $^6$ data as well as new data expected from HERA II open the possibility for $\alpha_s$ determinations including 3-jet cross sections.

Figure 6. $\alpha_s(M_Z)$ values obtained in DIS together with results from pp-collisions and the world average.

References

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