Jet Measurements and Determination of α_S at HERA

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The strong coupling constant α_S can be measured in deep inelastic ep scattering by employing various methods. Recent results on the extraction of α_S using jet and event shape observables are presented. The results are found to be in good agreement with other more inclusive measurements and the world average value.

1 Introduction

High energetic electron proton collisions provided by the HERA accelerator allow precision tests of Quantum Chromo Dynamics (QCD). The collected data spread over a wide range in negative four-momentum transfer Q^2 and transverse energy E_T of the jets in the hadronic final state. The jet production cross-section can be expressed as a convolution of the hard scattering matrix element $\hat{\sigma}_{QCD}$ with the proton parton density functions (PDFs):

$$\sigma_{jet} = \sum_{i=q,\bar{q},g} \int dx \; \mathrm{pdf}_i(x, \mu_f, \alpha_S) \otimes \hat{\sigma}_{QCD}(x, \mu_r, \mu_f, \alpha_S) \cdot (1 + \delta_{had}), \tag{1}$$

with μ_f being the factorisation scale, μ_r the renormalisation scale and δ_{had} the correction from parton to hadron level.

A suitable frame to study jet production in neutral current deep inelastic scattering at HERA is the Breit frame of reference, where in the Quark Parton Model (QPM) the struck quark and the virtual boson collide head on. Any observation of significant transverse energy in the final state can be attributed to higher order QCD processes.

[a] on behalf of the H1 and ZEUS collaborations

In order to determine α_S a Next-to-leading order (NLO) calculation is employed to provide the α_S dependence of the predicted cross-section, $\sigma^{theo} = A \cdot \alpha_S(M_Z) + B \cdot \alpha_S^2(M_Z)$ with parameters A and B which are determined by a fit. The measured cross-section is then used to obtain a value of $\alpha_S(M_Z)$ by employing this parametrisation.

2 Inclusive Jet Cross-Section

The inclusive jet analysis by the ZEUS collaboriation[1] used a data set of an integrated luminosity of $81.7\,\mathrm{pb}^{-1}$. Jets were found by the longitudinally invariant k_T algorithm applied in the Breit frame. For the event selection at least one jet with $E_T^{Breit} > 8\,\mathrm{GeV}$ and $Q^2 > 125\,\mathrm{GeV}^2$ were required. The cross-section has been measured single- and double differentially in Q^2, E_T and also the pseudorapidity η of the jets in the Breit frame. The cross-section as a function of Q^2 is compared to an NLO prediction based on the DISENT[2] package in Fig 1.

The uncertainties of the prediction are $\sim 7\,\%$. They arise from missing higher orders in the calculation and limited precision of the proton PDFs.

The measured cross-section has been corrected for detector effects and QED radiation by using a leading order (LO) Monte Carlo generator. The experimental uncertainties are dominated by the knowledge of the absolute hadronic energy scale of the calorimeter.

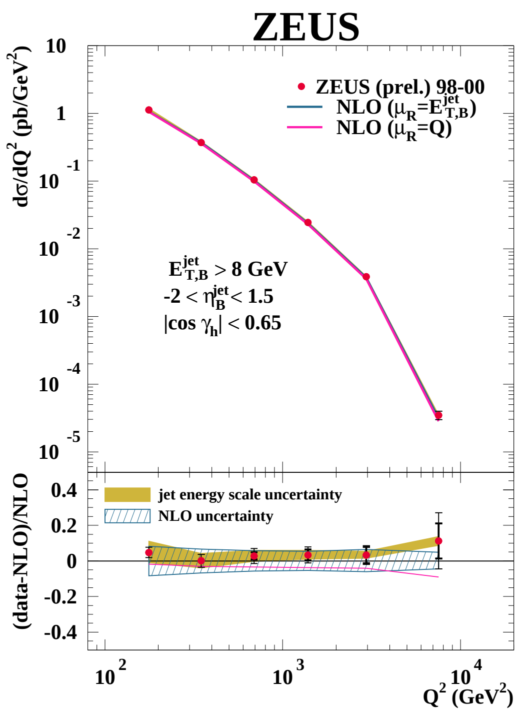

Figure 1: Inclusive jet cross-section as function of Q^2.

A very precise value for $\alpha_S(M_Z)$ has been extracted for $Q^2 > 500\,\mathrm{GeV}^2$, where theoretical uncertainties are small:

$$\alpha_S(M_Z) = 0.1196 \pm 0.0011(\mathrm{stat.})^{+0.0019}_{-0.0025}(\mathrm{exp.})^{+0.0029}_{-0.0017}(\mathrm{theo.}).$$

A very similar analysis[3] has been carried out by H1 collaboration using a data set of $61.25\,\mathrm{pb}^{-1}$ of luminosity. The most important selection criteria were $E_T^{Breit} > 7\,\mathrm{GeV}$ and $150\,\mathrm{GeV}^2 < Q^2 < 5000\,\mathrm{GeV}^2$. The NLO program used in the extraction of α_S was NLOJET++[4]. The obtained value for α_S is:

$$\alpha_S(M_Z) = 0.1197 \pm 0.0016(\mathrm{exp.})^{+0.0046}_{-0.0048}(\mathrm{theo.}).$$

3 Multi Jet Cross-Section

A measurement of the three jet cross-section is well suited for a determination of α_S since the lowest order contribution to the prediction for this event class is proportional α_S^2. Many uncertainties of the measurement cancel out if the three to two jet ratio $R_{3/2}$ is investigated.

A recent multi jet analysis[5] by the H1 Collaboration used a data set of $65.4\,\mathrm{pb}^{-1}$ of integrated luminosity. The considered kinematical domain was given by $150 < Q^2 < 15000\,\mathrm{GeV}^2$ and $E_T > 5\,\mathrm{GeV}$. To ensure an infra-red safe region for the NLO predictions an invariant jet mass $M_{3jet} > 25\,\mathrm{GeV}$ ($M_{2jet} > 25\,\mathrm{GeV}$) was required for the three (two) jet sample.

The NLO prediction has been calculated by employing the NLOJET++ package. Q^2 has been chosen for the squared renormalisation scale and it has been varied by a factor 4 to estimate the influence of missing higher order contributions.

Fig 2 (left) shows $R_{3/2}$ as a function of Q^2. As there are no electroweak effects included in the NLO prediction the observed deviation in the highest Q^2 bin is expected and the bin has been excluded therefore in the α_S extraction.

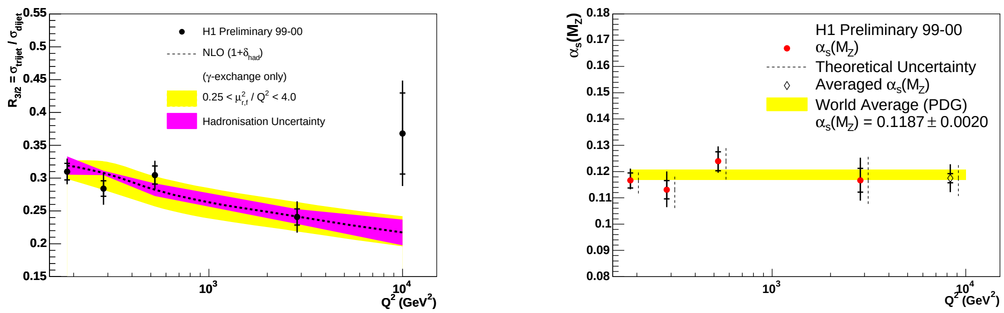

Figure 2: $R_{3/2}$ as a function of Q^2 (left). Extracted $\alpha_S(M_Z)$ values compared to the world average (right).

The $\alpha_S(M_Z)$ values for the remaining Q^2 bins are displayed in Fig 2 (right) together with an averaged value, which is found to be

$$\alpha_S(M_Z) = 0.1175 \pm 0.0017(\text{stat.}) \pm 0.0050(\text{exp.})^{+0.0054}_{-0.0068}(\text{theo.}).$$

This result and the ones presented in section 2 are in good agreement with the world average.

4 Event Shapes

In contrast to the jet measurements the method of event shapes considers characteristics of the complete final state. To avoid non-perturbative effects due to the proton remnant the event shape variables are usually defined in the current hemisphere of the Breit frame.

As an alternative approach to phenomenological models for the hadronisation a power correction technique has been developed[6]. Mean values (or differential distributions) get shifted by a constant:

$$\langle F \rangle = \langle F \rangle^{QCD} + a_F \mathcal{P}$$

where a_F is of order one and calculable perturbatively. The power correction term $\mathcal{P}$ is proportional to $1/Q$ and depends on a universal parameter α_0 and α_S.

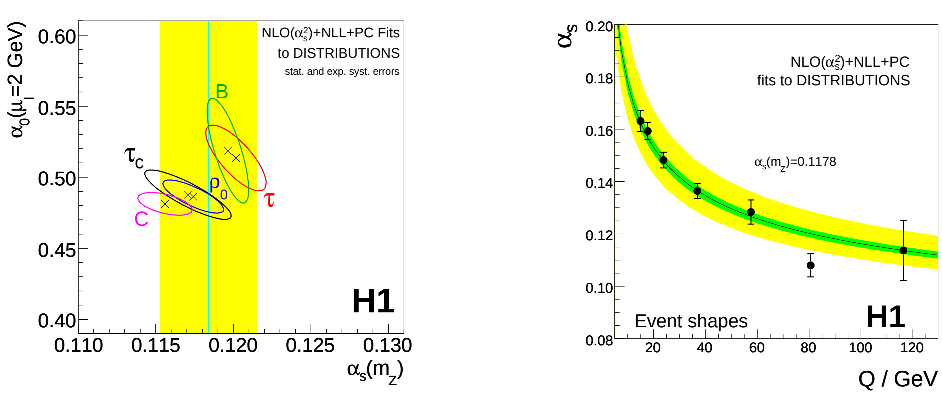

Figure 3: Fits to various differential event shape distributions in the (α_S, α_0) plane (left). Running $\alpha_S(Q)$ (right).

A recent H1 analysis[7] observed for event shape distributions a good agreement between the data points and fits based on an NLO-QCD calculation including a resummation supplemented by power corrections[8]. A χ^2 fit to these distributions allowed a simultaneous determination of α_0 and α_S. The result for various event shape variables is shown in Fig 3 (left). The results give a consistent value for α_S and support a universal α_0 parameter of about 0.5 as it is expected by theory. An averaging procedure gives:

$$\begin{aligned} \alpha_S(M_Z) &= 0.1198 \pm 0.0013(\mathrm{exp})^{+0.0056}_{-0.0043}(\mathrm{theo.}) \\ \alpha_0 &= 0.476 \pm 0.008(\mathrm{exp})^{+0.018}_{-0.059}(\mathrm{theo.})\,. \end{aligned}$$

In a slightly modified fit procedure values of $\alpha_S(Q)$ can be derived. The running of the strong coupling constant can be nicely observed in Fig 3 (right).

5 Summary

The strong coupling constant α_S has been extracted from various measurements performed by the H1 and ZEUS collaborations. The results are found to be well compatible with each other independent of the method and in excellent agreement with the world average. Fig 4 shows a comparison of the presented α_S extractions to a combined HERA value[9] and the world average, which up to now does not consider the HERA measurements.

With increased data sets presently collected at HERA-II the statistical and experimental uncertainties will be further reduced. Calculations including NNLO QCD contributions and electroweak effects are needed to reduce the theoretical uncertainties.

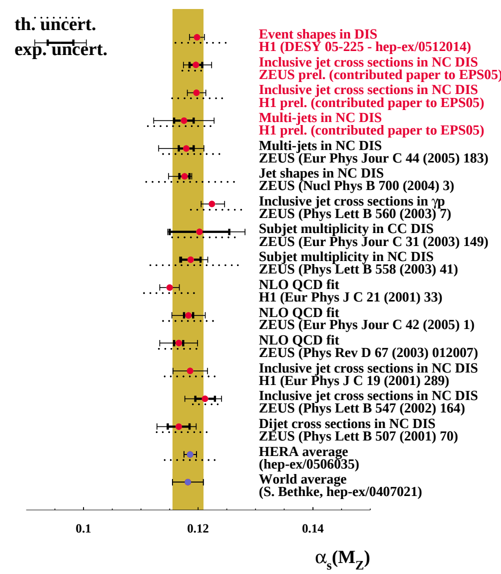

Figure 4: Comparison of α_S extractions from HERA.

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