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Jet production and measurements of α_S at HERA[*]

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Abstract

The inclusive jet, dijet and trijet production cross-sections in deep-inelastic scattering (DIS) at $\sqrt{s} = 320$ GeV have been measured at the electron-proton collider HERA by the H1 and ZEUS collaborations using data taken in 1998–2000. The jet cross-sections have been measured differentially in four-momentum transfer squared Q^2 and jet transverse energy in the Breit-frame $\mathrm{E}_{\mathrm{T,B}}$ with a typical precision of 5–10% limited by systematic uncertainties such as hadronization corrections and hadronic energy scale. All jet observables are well described by perturbative QCD (pQCD) predictions at next-to-leading order (NLO) within the estimated accuracy of these calculations which is limited by the absence higher orders, and which is in general inferior to the experimental precision. The values for the coupling constant α_S of the strong interaction as determined by fits of pQCD predictions to the inclusive jet cross-section and the trijet-to-dijet production ratio $R_{3/2}$ are consistent for both experiments and both observables, and also are in excellent agreement with the world average. Combining the individual measurements, a common value of $\alpha_S = 0.1186 \pm 0.0011(\text{experiment}) \pm 0.0050(\text{theory})$ is obtained.

1 Introduction

One of the many ways to determine α_S is through the measurement of jet production in DIS since the production cross section in leading order of n jets (not counting the proton remnant) is proportional to α_S^{n-1}. At HERA this measurement is particularly interesting since the hadronic final state is opened up in pseudo-rapidity. The measurements of jet production cross-section presented here have many points in common which facilitates comparison of the extracted values of α_S. In particular, jets are measured throughout using the longitudinally invariant k_T algorithm in the Breit-frame of reference, where in the naive quark parton model the struck quark and the virtual boson collide head-on. Hence, substantial transverse energy $\mathrm{E}_{\mathrm{T,B}}$ in the Breit frame stems necessarily from QCD radiation and provides a natural energy scale for the determination of α_S.

2 Measurements of inclusive and multi-jet cross-sections in DIS

In the H1 (ZEUS) inclusive-jet analysis, all jets in DIS events with $150 < \mathrm{Q}^2 < 5000\ \mathrm{GeV}^2$($\mathrm{Q}^2 > 125\ \mathrm{GeV}^2$) are counted if their transverse energy $\mathrm{E}_{\mathrm{T,B}}$ exceeds 7 GeV(8 GeV). Furthermore, the pseudo-rapidity of each jet in the laboratory frame (Breit frame) is required to lie between -1.0 and 2.5 (-2.0 and 1.5) in the H1 (ZEUS) analysis. The inclusive jet cross-section is measured single- and double-differentially in Q^2 and in $\mathrm{E}_{\mathrm{T,B}}$, and also differentially in the pseudo-rapidity $\eta_{\mathrm{T,B}}$ of the jet in the Breit frame (ZEUS analysis) [1, 2]. For the measurement of dijet and trijet cross-sections a lower minimal transverse energy of $\mathrm{E}_{\mathrm{T,B}} > 5$ GeV is required in both

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analyses, and jets in the same pseudo-rapidity interval as for the H1 inclusive jet analysis are considered. In order to ensure infrared-safeness of the QCD predictions for multi-jet cross-sections, the invariant mass of the 2 or 3 jets is required to be above 25 GeV. The H1 and ZEUS analyses differ in the kinematic range of the DIS events: $150 < \mathrm{Q}^2 < 15000$ GeV^2 for H1 and $10 < \mathrm{Q}^2 < 5000$ GeV^2 for ZEUS. The multi-jet cross-sections are measured differentially in Q^2 (H1) and Q^2, $\mathrm{E}_{\mathrm{T,B}}$, and $\eta_{\mathrm{T,B}}$(ZEUS), and the ratio $R_{3/2}$ of the trijet and the dijet cross-sections is measured as a function of Q^2 (fig. 2) [3, 4].

In all analyses, the data are corrected bin-by-bin for detector effects and QED radiation using fully simulated Monte Carlo events, using leading-order (LO) event generators. The dependence of the detector correction on the different models for parton showering — leading-log parton showers (as implemented in RAPGAP and LEPTO) and the colour-dipole model (as implemented in ARIADNE) — results in a systematic uncertainty of e.g. ±7% for the inclusive jet cross-section (ZEUS). A systematic error of comparable size stems from the uncertainty of the absolute energy scale of the hadronic calorimeters. It is evaluated by varying the calorimeter energy scale by ±2% for all events and fully resconstructing these (H1) or simply by varying the transverse energy of the jets' $\mathrm{E}_{\mathrm{T,B}}$ by ±1–3% depending on $\mathrm{E}_{\mathrm{T,B}}$ (ZEUS). Typically, this results in an uncertainty of 5% on the inclusive-jet cross-section as measured by ZEUS and of 1% (4%) on the dijet (trijet) cross-section as measured by H1. Other experimental uncertainties, such as systematic errors on the measurement of luminosity or on the reconstruction of the scattered electron, typically contribute to the overall experimental error on a level of 1–2 per-cent.

3 Comparison with perturbative QCD at next-to-leading order

The measured jet cross-sections are compared to NLO pQCD predictions calculated using the programs DISENT ($\mathcal{O}({\alpha_S}^2)$) and NLOJET++ ($\mathcal{O}({\alpha_S}^3)$). However, these codes do not include parton-showering and fragmentation, and deliver cross-section values for parton final states only. In order to compare these calculations to measured data, a hadronization correction factor is applied to the pQCD predictions as the ratio of the cross-sections for hadron and parton final states as calculated by the above mentioned event generators. This procedure relies on the assumption that the hadronisation correction is not significantly affected by the difference between LO and NLO parton final states. The theoretical error on this hadronization correction is estimated by comparing the correction coefficients obtained with the two different models for parton showering.

Perturbative QCD calculations at fixed order unavoidably exhibit an explicit dependence on the renormalisation scale μ_{R}reflecting the absence of higher orders in the perturbative expansion. It has been shown in these analyses that the QCD predictions for the discussed jet observables are not very sensitive to the particular choice for μ_{R} and the factorization scale μ_{F} among the possible scales of each event:Q^2, $\mathrm{E}_{\mathrm{T,B}}$, or an arithmetic combination of both, but rather to the absolute value of μ_{R}(cf. fig. 1). In order to assess the theoretical uncertainty on the jet cross-sections and α_S due to missing higher orders, the renormalization scale μ_{R} is varied. It has to be pointed out that the particular choice of varying μ_{R} up and down factor of 2 is a mere convention - that is followed in the presented analyses - but has no theoretical motivation. For the inclusive jet cross-section (e.g. ZEUS), the uncertainty resulting from the renormalization scale dependence (±5%) dominates over the other contributions, e.g parametrization of the proton PDF (±3%), to the overall error of the pQCD prediction. This is also true for the multi-jet cross-sections (e.g. H1): predicted cross-section for dijets (trijets) vary by as much as ±3% (±10%) with μ_{R} whereas the uncertainty from the hadronization correction is ±1% (±4%). The lower part of figure 1 demonstrates the good agreement of the NLO pQCD prediction with the measured inclusive jet cross-section (ZEUS) as it drops over five orders of magnitude on a wide range in Q^2. Theory and experiment are compatible within experimental error which are generally smaller than the estimated theoretical uncertainty. The good agreement holds for the multi-jet rates and their ratio as well, as can be seen on fig. 2 except at very high Q^2 where electro-weak effects are not accounted for in the NLO pQCD programs.

4 Determination of the strong coupling constant α_S

The strong coupling constant is determined by fitting the pQCD predictions as a function of α_S to the measured values of the jet observables, i.e. the cross-section value in a particular bin in Q^2 or $\mathrm{E}_{\mathrm{T,B}}$ or the ratio $R_{3/2}$. In practice, the pQCD prediction for each observable is parametrised as a second order polynomial in α_S (with vanishing constant term). Figure 3 shows the running $\alpha_S\,(\mathrm{E}_{\mathrm{T,B}})$ as extracted from the differential inclusive jet cross-section in $\mathrm{E}_{\mathrm{T,B}}$ (H1), and the corresponding value evolved to the Z^0-boson mass. By simultaneously fitting the observables over the range where they are well described by pQCD, and also taking partial correllations of systematic experimental and theory errors into account, an $\alpha_{\mathrm{S}}(\mathrm{m_Z})$-measurement is extracted for each of the four analyses:

		$\alpha_{\mathrm{S}}(\mathrm{m_Z})$	(exp. error: stat.,syst.)		(theory error)
Incl. Jets	H1	0.1197	±0.0016		$^{+0.0046}_{-0.0048}$
	ZEUS	0.1196	±0.0011	$^{+0.0019}_{-0.0025}$	$^{+0.0029}_{-0.0017}$
$R_{3/2}$	H1	0.1175	±0.0017	±0.0050	$^{+0.0054}_{-0.0068}$
	ZEUS	0.1179	±0.0013	$^{+0.0028}_{-0.0046}$	$^{+0.0064}_{-0.0046}$
HERA combined		**0.1186**	**± 0.0011**		**±0.0050**

For the same observable, both experiments obtain almost identical values of $\alpha_{\mathrm{S}}(\mathrm{m_Z})$ with slightly lower values and higher experimental uncertainty error for a measurement using $R_{3/2}$. Since all values are compatible within statistical and systematic errors, these measurements are combined to derive a common measurement for $\alpha_{\mathrm{S}}(\mathrm{m_Z})$ making a conservative hypothesis on error correlation. The combined HERA value for $\alpha_{\mathrm{S}}(\mathrm{m_Z})$ agrees well with the world average at a level of experimental precision competitive with the most precise measurements for jets. It should be noted that the error from the pQCD calculation is roughly five times higher than the experimental uncertainty for the combined $\alpha_{\mathrm{S}}(\mathrm{m_Z})$. Although the latter could probably be reduced by increased statistics and better understanding of systematical errors, future progress on the overall precision for α_S hinges on an improved estimation of contributiond beyond NLO to the pQCD predictions.

References

[1] H1 Collaboration, contributed paper No. 629 at this conference

[2] ZEUS Collaboration, contributed paper No. 375 at this conference

[3] H1 Collaboration, contributed paper No. 625 at this conference

[4] S. Chekanov et al., *European Physical Journal* **C44** (2005) 183-193 [`hep-ex/0502007`]

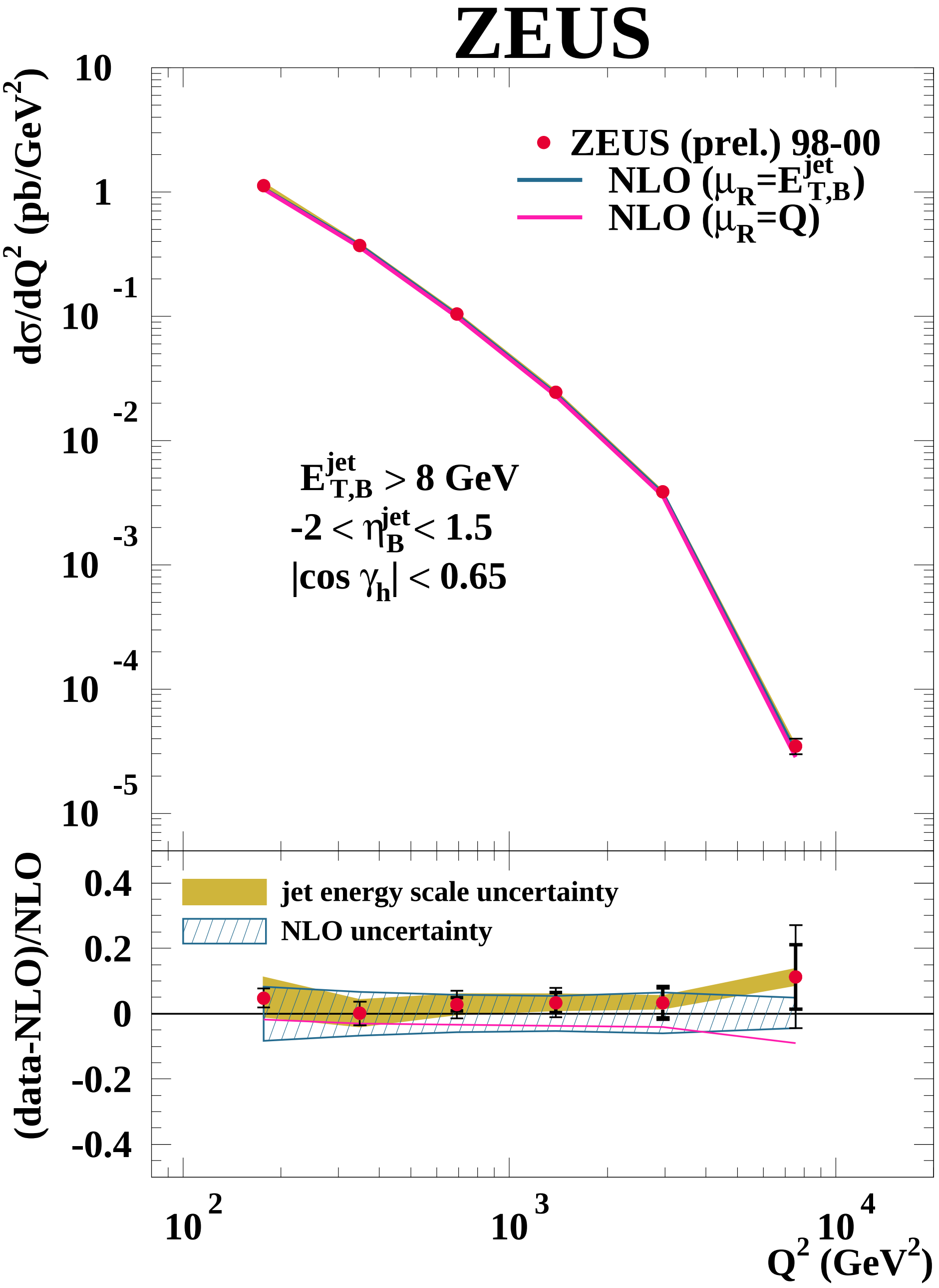

Figure 1: Differential inclusive Jet Cross-Section in Q^2

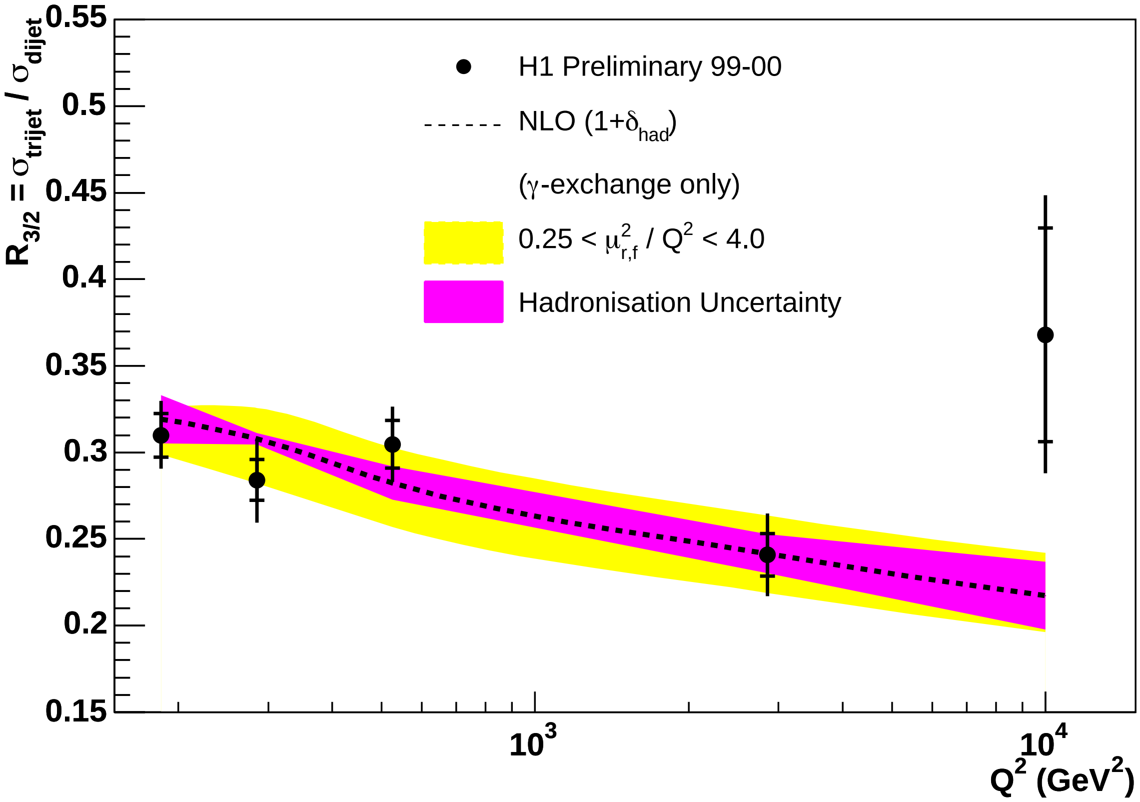

Figure 2: Trijet/dijet production ratio $R_{3/2}$ (H1)

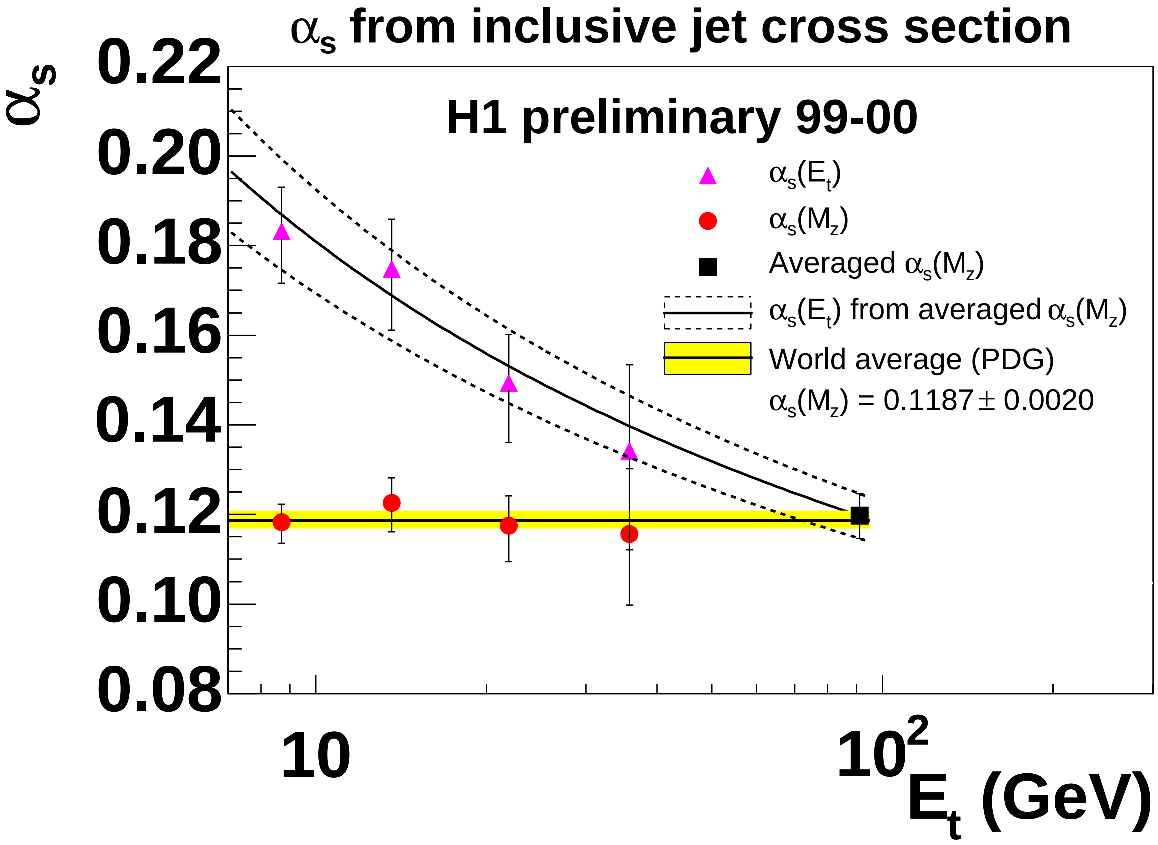

Figure 3: Running $\alpha_S\,(\mathrm{E_{T,B}})$ from inclusive jet σ