MEASUREMENT AND QCD ANALYSIS OF INCLUSIVE JET PRODUCTION IN DEEP INELASTIC SCATTERING AT HERA*

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A new measurement of inclusive jet cross sections in deep inelastic scattering using the ZEUS detector at the HERA collider is obtained. The data were taken at HERA 2 at a center-of-mass energy of 318 GeV and correspond to an integrated luminosity of 347 pb^{-1}. The measured jet cross sections are compared to previous measurements as well as NNLO QCD theory predictions. The measurement is used in a QCD analysis at NNLO accuracy to perform a simultaneous determination of parton distribution functions of the proton and the strong coupling constant, resulting in a value of $\alpha_{\mathrm{s}}(M_Z^2) = 0.1138 \pm 0.0014\ (\mathrm{exp/fit})\ ^{+0.0004}_{-0.0008}\ (\mathrm{model/param.})\ ^{+0.0008}_{-0.0007}\ (\mathrm{scale})$. A significantly improved accuracy is observed compared to similar measurements of the strong coupling constant.

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1. Introduction

The measurement of jet production in $e^{\pm}p$ scattering at HERA is an important input for the understanding of QCD and a well established tool to test perturbative QCD predictions. Jet cross sections can be used to precisely determine the strong coupling constant and its correlation to the gluon distribution function of the proton. Studies of inclusive jet production in neutral current (NC) deep inelastic scattering (DIS) events are especially suited for precision determinations.

In this paper, a double-differential measurement of inclusive jet cross sections in Q^2 and $p_{\perp,\mathrm{Breit}}$ in NC DIS events is presented, where Q^2 is the negative square of the momentum of the virtual exchanged boson and $p_{\perp,\mathrm{Breit}}$ is the transverse momentum of each jet in the Breit reference frame.

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The measured cross sections are then used in a next-to-next-to-leading-order (NNLO) QCD analysis to demonstrate their ability to further constrain the strong coupling constant [1].

2. Cross-section measurement

The inclusive jet cross sections are defined for NC DIS events in the kinematic region of $150\ \mathrm{GeV}^2 < Q^2 < 15000\ \mathrm{GeV}^2$ and $0.2 < y < 0.7$. Massless jets at the hadron level are identified using the $k_\perp$-algorithm in the $p_\perp$-weighted scheme and a radius parameter of $R = 1$. Each jet is required to fulfil the phase-space cuts $-1 < \eta_{\mathrm{lab}} < 2.5$ and $7\ \mathrm{GeV} < p_{\perp,\mathrm{Breit}} < 50\ \mathrm{GeV}$.

The response of the detector to hadron jets is modelled using two separate Monte Carlo (MC) samples, which differ in their models of the parton showering. The parton showering is simulated using either the colour-dipole model or a leading log parton cascade approach [1]. The data are corrected to the hadron level using bin-by-bin correction factors obtained from these simulations. Afterwards, the data are corrected to the QED Born level, by generating additional MC samples excluding QED-radiative effects and determining bin-by-bin correction factors.

3. Theory calculations

NNLO QCD predictions ($\mathcal{O}(\alpha_{\mathrm{s}}^3)$) for inclusive jet production in the Breit frame are available as calculated by the NNLOJet program [2]. For this analysis, predictions are computed using the HERAPDF2.0Jets NNLO PDF set [3] and using the associated value of $\alpha_{\mathrm{s}}(M_Z^2) = 0.1155$ for the strong coupling constant. For the central values, the factorisation and renormalisation scales are set to $\mu_{\mathrm{r}}^2 = \mu_{\mathrm{f}}^2 = Q^2 + p_\perp^2$. The jet calculations are done in the massless scheme, since massive calculations are not available.

The parton-level jet predictions are corrected to the hadron level using correction factors derived from the MC samples. The average of the correction factors determined from the two samples is used as a nominal correction and half their difference as hadronisation uncertainty of the predictions. This uncertainty reflects the differences in the corresponding parton showering and hadronisation procedures, and is assumed to cover also the differences between the LO+PS and NNLO partons in the jet clustering. The calculations are also corrected for Z^0 exchange and γZ^0 interference terms as derived from a separate MC sample.

The uncertainty of the factorisation and renormalisation scales is estimated using a six-point variation with rescaling factors 0.5 and 2. The fit, model, and parameterisation uncertainties of the HERAPDF2.0Jets NNLO PDF set are taken into account. The predictions by NNLOJet include uncertainties due to limited statistics during their generation. The scale, PDF, hadronisation, and statistical uncertainties are added in quadrature to obtain the total uncertainty of the NNLO QCD predictions.

4. Cross-section results

The double-differential inclusive jet cross section as a function of Q^2 and $p_{\perp,\mathrm{Breit}}$ is shown in Fig. 1. The combined uncertainty of the measurement is usually around 5%. In the highest $p_{\perp,\mathrm{Breit}}$ bin, it increases to around 15%.

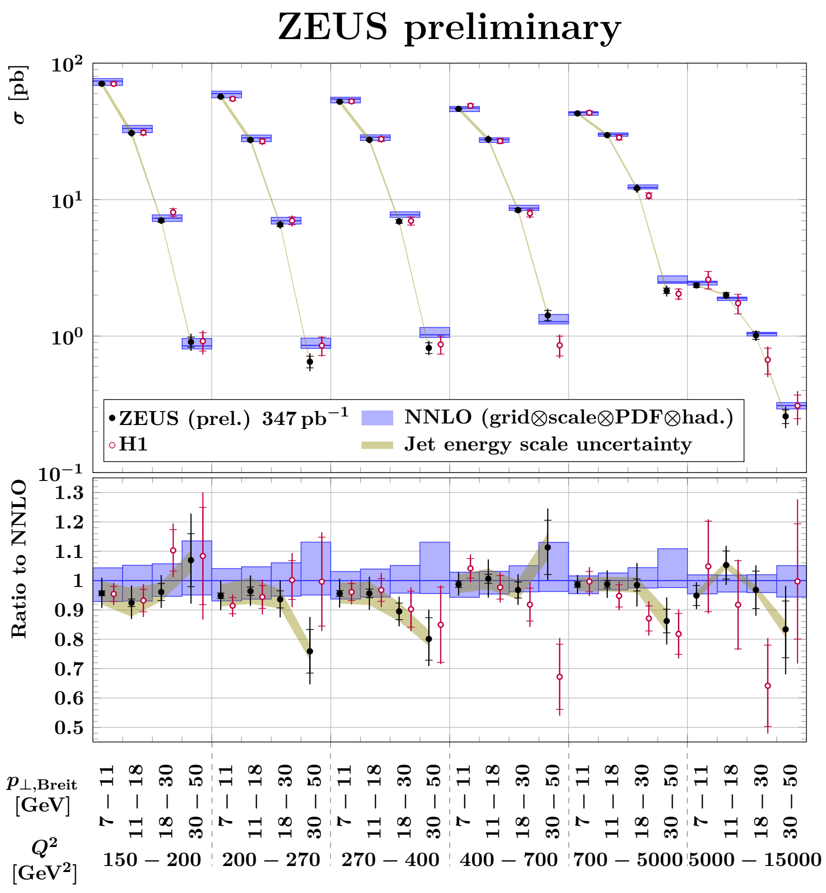

Fig. 1. The measured double-differential inclusive jet cross sections. Shown are the present measurement from ZEUS (full dots, black), the corresponding measurement from H1 (open dots, red) [4], and the NNLO QCD predictions (blue band). The inner error bars of the measurements show the statistical uncertainty and the outer error bars, the total statistical and systematic uncertainty. For the ZEUS measurement, the shaded band shows the uncertainty due to the jet energy scale.

The corresponding measurement from the H1 Collaboration [4] is also shown in the figure. It should be noted that the H1 measurement uses an unfolding procedure that introduces statistical correlations, which are often negative for neighbouring points. These correlations increase the apparent size of the uncertainty, but when taken into account the uncertainties of the two measurements are comparable.

The ZEUS data are very well compatible with the H1 measurement. Both measurements show similar trends relative to the theory predictions. Within the combined uncertainty, the predictions agree well with the measured cross sections. Overall, the predictions seem to overestimate the jet cross section slightly. At high $p_{\perp,\mathrm{Breit}}$, this difference increases.

5. Determination of the strong coupling constant

A fit of the strong coupling constant is performed at NNLO accuracy. The inclusion of additional jet data is expected to especially constrain the correlation between the strong coupling constant and the gluon distribution. To capture these correlations, a combined determination of $\alpha_\mathrm{s}(M_Z^2)$ and the PDFs is performed. The PDF parameterisation, model parameters, the central scale choices, and the treatment of theory-related uncertainties are taken from the recent HERAPDF analysis [3]. The input to the fit consisted of the H1+ZEUS combined inclusive DIS dataset, previous inclusive jet, and dijet measurements at ZEUS, as well as the newly measured inclusive jet cross sections. Statistical and systematic correlations between the inclusive jet and dijet measurement during the HERA 2 period are taken into account.

Using the standard scheme of fully correlated scale variations, the fit results in a value of

$$\alpha_\mathrm{s}\left(M_Z^2\right) = 0.1138 \pm 0.0014\,(\mathrm{exp/fit})\,^{+0.0004}_{-0.0008}\,(\mathrm{model/param.})\,^{+0.0012}_{-0.0005}\,(\mathrm{scale})\,,$$

where 'exp/fit' denotes the uncertainty of the fit, which includes the uncertainty in the experimental input. The model and parameterisation uncertainty is determined by repeating the fit with each of its parameters, in turn modified by its uncertainty and adding up the resulting variations.

The scale uncertainties obtained here are significantly smaller than the ones derived in similar determinations, *e.g.* the corresponding HERAPDF analysis [3]. This effect arises mostly because in this analysis only jet datasets at high Q^2 are used. Due to the treatment of the cross-section scale uncertainty as fully correlated across all phase-space regions, the inclusion of low-scale data leads to an increased uncertainty of $\alpha_\mathrm{s}(M_Z^2)$.

To further mitigate this problem, an alternative approach is investigated, in which the scale uncertainties of the jet part are calculated under the assumption that the cross-section uncertainty due to the scale variation is half-correlated/half-uncorrelated between bins and datasets [4, 5]. This is motivated by the fact that, while the scale dependence of neighbouring phase space bins is certainly very strongly correlated, the scale dependence of bins far away from each other in phase space, or for different final states, can be much less correlated or even anti-correlated.

Using this alternative approach, another reduction of the scale uncertainty of $\alpha_s(M_Z^2)$ is observed, resulting in a value of

$$\alpha_s\left(M_Z^2\right) = 0.1138 \pm 0.0014\ (\text{exp/fit})\ {}^{+0.0004}_{-0.0008}\ (\text{model/param.})\ {}^{+0.0008}_{-0.0007}\ (\text{scale})\,.$$

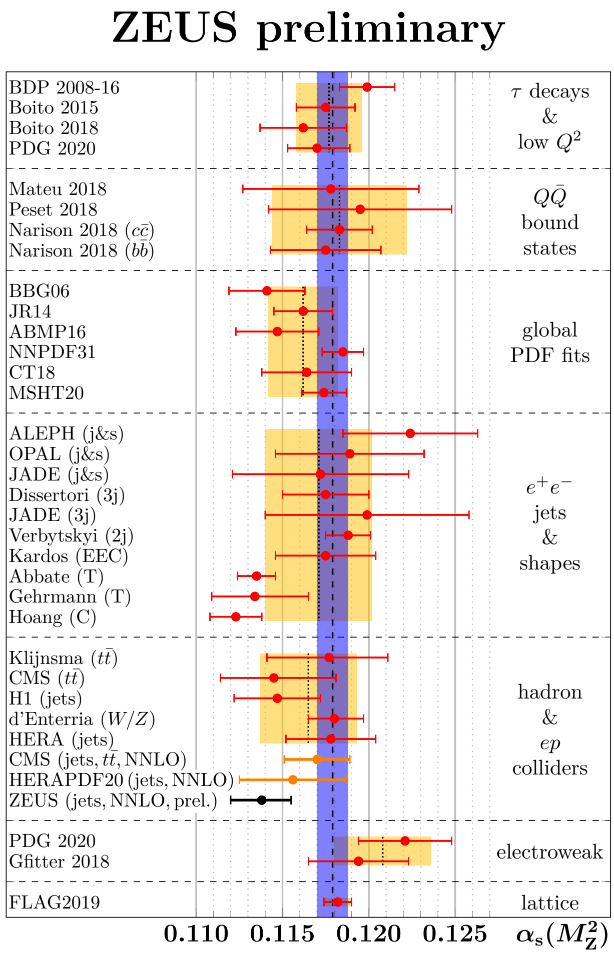

Fig. 2. Summary of different determinations of $\alpha_s(M_Z^2)$ at NNLO or higher order, adapted from PDG [6]. The red points are included in the PDG world average. The averages from each sub-field are shown as yellow bands and the world average as a blue band. The determination presented here is shown in black.

Since the fit does not contain any low-Q^2 jet data, the additional reduction is moderate. The half-correlated/half-uncorrelated approach is expected to make a more significant impact when using input data across a wider range in phase space.

A comparison of the current measurement to other determinations of $\alpha_{\rm s}(M_Z^2)$ is shown in Fig. 2. Due to the small scale uncertainty, the current analysis is among the most precise measurements at hadron colliders so far.

6. Conclusions

A double-differential measurement of the inclusive jet cross section in NC DIS events at ZEUS during HERA 2 was presented. The measured cross sections are very well compatible with previous measurements and with NNLO QCD predictions, and the uncertainties are competitive.

The small uncertainties of the measurement and the corresponding theory calculations make the dataset an ideal ingredient for precision determinations of the strong coupling constant in future QCD fits. The dataset was used in a new determination of the strong coupling constant. A significant reduction in the uncertainty is observed compared to similar determinations, which is due to the omission of low-Q^2 jet data in the fit as well as, to a lesser extent, an alternative treatment of the correlations in the scale uncertainties.

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