PROCEEDINGS OF SCIENCE

Precise predictions for the production of jets in DIS

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We give an overview of our calculation of jet-production processes in deep-inelastic lepton–proton scattering (DIS) at $\mathcal{O}(\alpha_s^3)$ both for the neutral- and the charged-current cases. Phenomenological results are presented for di-jet production at next-to-next-to-leading order (NNLO) and inclusive-jet production at N^{3}LO, which are compared to experimental measurements performed at HERA. The inclusion of higher-order corrections result in a substantial reduction of residual theory uncertainties and exhibit an improved agreement with data. These results pave the way for precision phenomenology using jet observables at future lepton–proton colliders.

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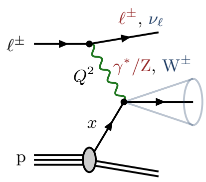
1. Introduction

The production of hadronic jets in deep-inelastic scattering (DIS) is sensitive both to the strong and electroweak sectors of the Standard Model and constitutes one of the most precise probes to study the inner structure of the proton. It further provides crucial constraints on the flavour composition of the proton and thus in the extraction of parton distribution functions (PDFs). Jet production in DIS proceeds through the scattering of a parton from the proton with a virtual gauge boson that mediates the interaction:

$$\mathrm{d}\sigma = \sum_a \int_0^1 \mathrm{d}x\; f_a(x)\; \mathrm{d}\hat{\sigma}_a \qquad \longleftrightarrow \tag{1.1}$$



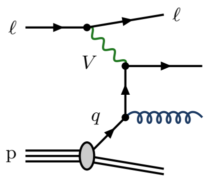
and the kinematics of the Born-level process is fully determined by the virtuality Q^2 of the gauge boson and the Bjorken-x variable. The neutral (γ^*/Z) and charged ($\mathrm{W}^\pm$) gauge-boson exchange processes are denoted as the neutral-current (NC) and charged-current (CC) processes, respectively.

Many jet-production measurements were performed at HERA I and II between 1994–2007, resulting in a large set of jet data that are essential in any PDF extraction. Proposed future lepton–proton colliders further offer new opportunities for precision QCD studies with an unprecedented kinematic reach. In order to fully exploit the available data as well as prepare for the anticipated precision requirements of future colliders, it is crucial to have theory predictions with the highest possible precision. In particular, fully differential predictions are essential to allow for a direct comparison between theory and experiment at the fiducial level.

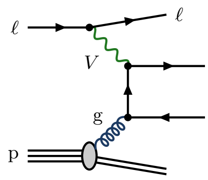
2. Jet Production in the Breit Frame and Di-jet Production at NNLO

Studying jet production in DIS with at least two resolved jets allows to obtain a direct handle on the gluon PDF as well as the strong coupling constant as can be seen from the underlying partonic channels that are given by:

QCD Compton Scattering:



, Boson–Gluon Fusion:



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Alternatively, inclusive jet production can be studied in the Breit frame of reference, where the virtual gauge boson and the incident hadron collide head-on and the presence of at least two partons arises as an implicit requirement.

Calculations at NNLO accuracy in perturbative QCD for the production of two jets were computed fully differentially using the antenna subtraction method [1] both for the NC [2, 3] and CC [4] cases. They are available within the NNLOJET framework, which is a parton-level Monte Carlo generator that allows for the calculation of predictions at this order with arbitrary fiducial cuts as well as the generation of differential distributions in the form of histograms.

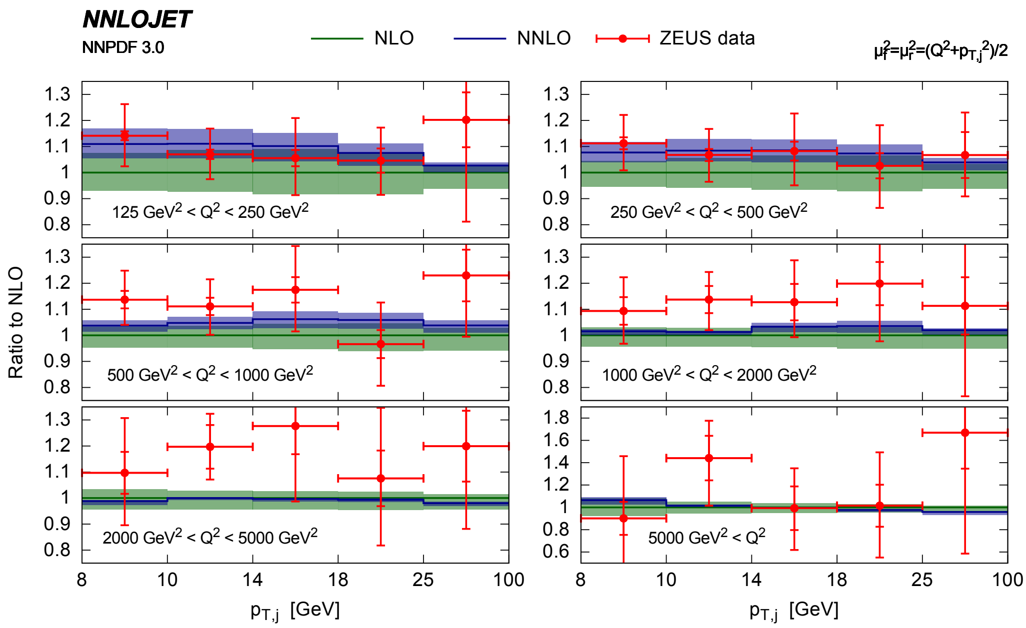

Figure 1: Inclusive jet production in the Breit frame for the NC DIS process as a function of p_{T} and Q^2 [3].

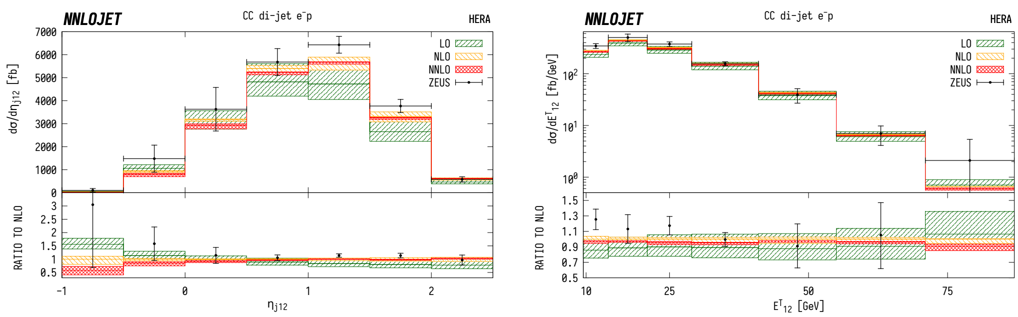

Figure 2: Pseudorapidity and transverse energy of the leading two jets in CC di-jet production [4].

In Fig. 1 we present inclusive-jet predictions in the Breit frame for the NC process, which are shown double-differentially in the transverse momentum of the jet ($p_{\mathrm{T},j}$) and the gauge-boson momentum transfer (Q^2). We observe sizeable NNLO corrections in the low-Q^2 bins, while at higher Q^2 the corrections are very small. The agreement with the data is visibly improved and the residual scale uncertainties at NNLO are greatly reduced compared to NLO. The impact of these results have already been used in a variety of studies, e.g., in the extraction of the strong coupling constant α_{s} [5, 6].

The related CC process is particularly interesting to gain insights into the flavour composition of the proton. Due to the neutrino in the final state, however, the Breit frame of reference cannot be fully reconstructed and the measurement is instead performed in the the laboratory frame but requiring two resolved jets. The results at NNLO are shown in Fig. 2 for the pseudo-rapidity (left) and the transverse energy (right) of the di-jet pair. Scale uncertainties are typically reduced by a factor of two when going from NLO to NNLO. The corrections are rather flat in E^{T}_{12}, while a distortion in the shape of $\eta_{j,12}$ can be observed that reduces jet production in the backwards direction.

3. Jet Production at N^{3}LO

The Projection-to-Born (P2B) method [7] allows to supplement the NNLO calculation for di-jet production of the previous section with the known DIS structure functions [8] in order to obtain fully differential predictions for jet production in DIS at N^{3}LO. In this context, the structure function can be identified as the integrated counterpart of the local counterterms that are introduced by the Born projection.

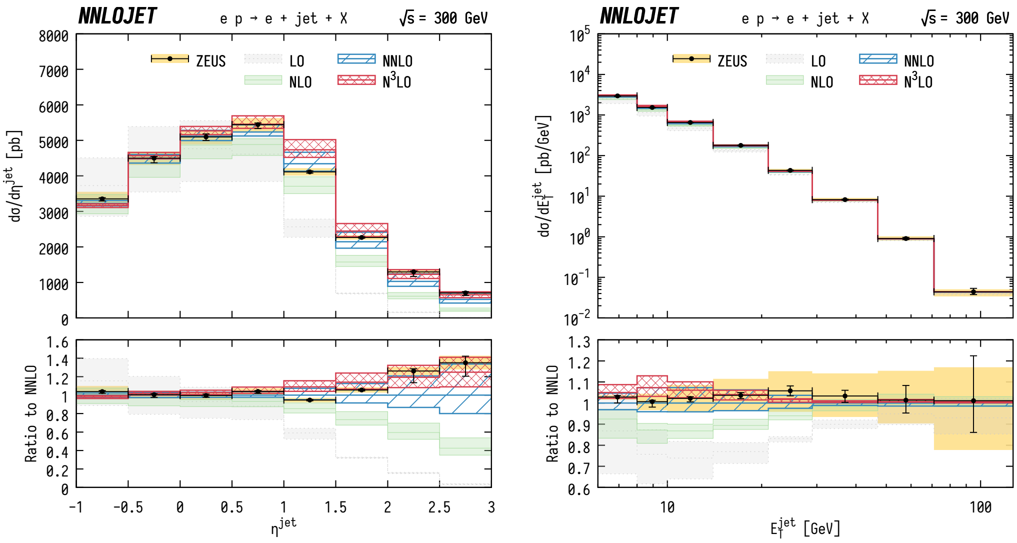

Figure 3: Inclusive-jet pseudorapidity and transverse energy in NC DIS up to N^{3}LO [9].

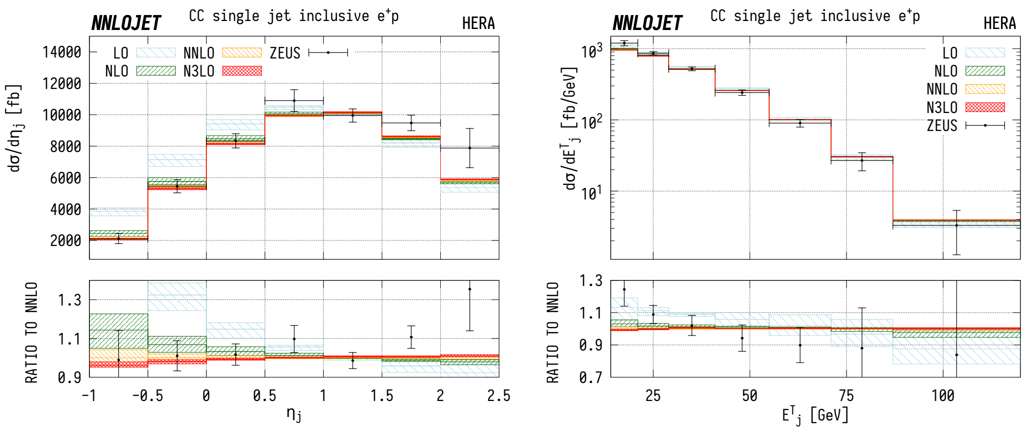

Figure 4: Inclusive-jet pseudorapidity and transverse energy in CC DIS up to N^{3}LO [10].

A proof-of-concept calculation extending the P2B method to third order in perturbative QCD was performed in Ref. [9] for the NC process. Predictions for the four consecutive perturibative orders (LO–N^{3}LO) are shown in Fig. 3 for the inclusive-jet pseudorapidity and transverse energy. Overlapping scale uncertainty bands between two successive orders is observed for the first time at N^{3}LO across the entire range in the considered observables. A comparison against the ZEUS experiment shows an improved description of the data points, in particular for the shape of the pseudorapidity distribution in the forward regime. Similar conclusions also hold for the CC case [10], shown in Fig. 4.

4. Conclusions

We have presented the current state-of-the-art calculation of fully differential $\mathcal{O}(\alpha_s^3)$ corrections for DIS jet production. This class of processes constitute one of the most precise probes of QCD and the proton structure, thus demanding precise theory predictions. Predictions at $\mathcal{O}(\alpha_s^3)$ have substantially reduced theory uncertainties and exhibit an excellent convergence of the perturbative calculation. A comparison with the measurements performed at HERA shows an improved description, supporting the importance of these corrections in order to fully exploit the available jet data. Finally, the corrections at this order are crucial in order to match the precision requirements of possible future colliders such as the LHeC and FCCep.

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