Determination of diffractive PDFs from a global QCD analysis of inclusive diffractive DIS and dijet cross-section measurements at HERA

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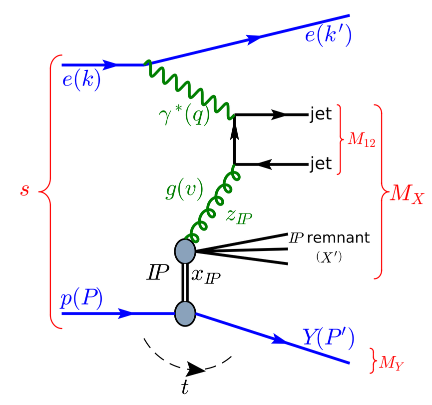
Abstract

We present an updated set of SKMHS diffractive parton distribution functions (PDFs). In addition to the diffractive deep-inelastic scattering (diffractive DIS) datasets, the recent diffractive dijet cross-section measurement by the H1 experiment from the HERA collider are added to the data sample. The new set of diffractive PDFs, entitled SKMHS23 and SKMHS23-dijet, are presented at NLO and NNLO accuracy in pQCD. Since the gluons directly contribute to jet production through the boson-gluon fusion process, the data on diffractive dijet production in inclusive DIS help constrain the gluon density, allowing for the determination of both the quark and gluon densities with better accuracy. The NLO and NNLO theory predictions are compared to the analyzed data showing excellent agreement. The effect arising from the inclusion of diffractive dijet data and higher-order QCD corrections on the extracted diffractive PDFs and data/theory agreements are clearly examined and discussed.

Framework

The cross section of diffractive dijet (jj) production, $e + p \to e + p + jj + X'$, is an important observable which can affect the behavior of diffractive PDFs. The inclusion of these data in the analysis is one of the main objective of this study. The Feynman diagram describing the diffractive dijet production in an electron-proton collision at HERA is shown in the Feynman diagram below.



Kinemitic variables are defined as below,

$$Q^2 = -q^2 = (k - k'^2), x = \frac{-q^2}{2P \cdot q},$$

$$y = \frac{P \cdot q}{P \cdot k}, x_{I\!P} = \frac{q \cdot (P - P')}{q \cdot P}$$

$$t = (P' - P)^2, \beta = \frac{x}{x_{I\!P}} = \frac{Q^2}{2q \cdot (P - P')}. \quad (1)$$

The factorization theorem of QCD can be employed for the diffractive processes so that the cross section of dijet production is given by the convolution of diffractive PDFs for proton $f^D_{i/p}$ with the partonic cross sections $d\hat{\sigma}$,

$$d\sigma(e + p \to e + p + jj + X') = \sum_i \int dt \int dx_{I\!P} \int dz_{I\!P} \times f^D_{i/p}(z_{I\!P}, \mu_F^2, x_{I\!P}, t) \otimes d\hat{\sigma}_{ei \to jj}(\hat{s}, \mu_R^2, \mu_F^2). \quad (2)$$

References

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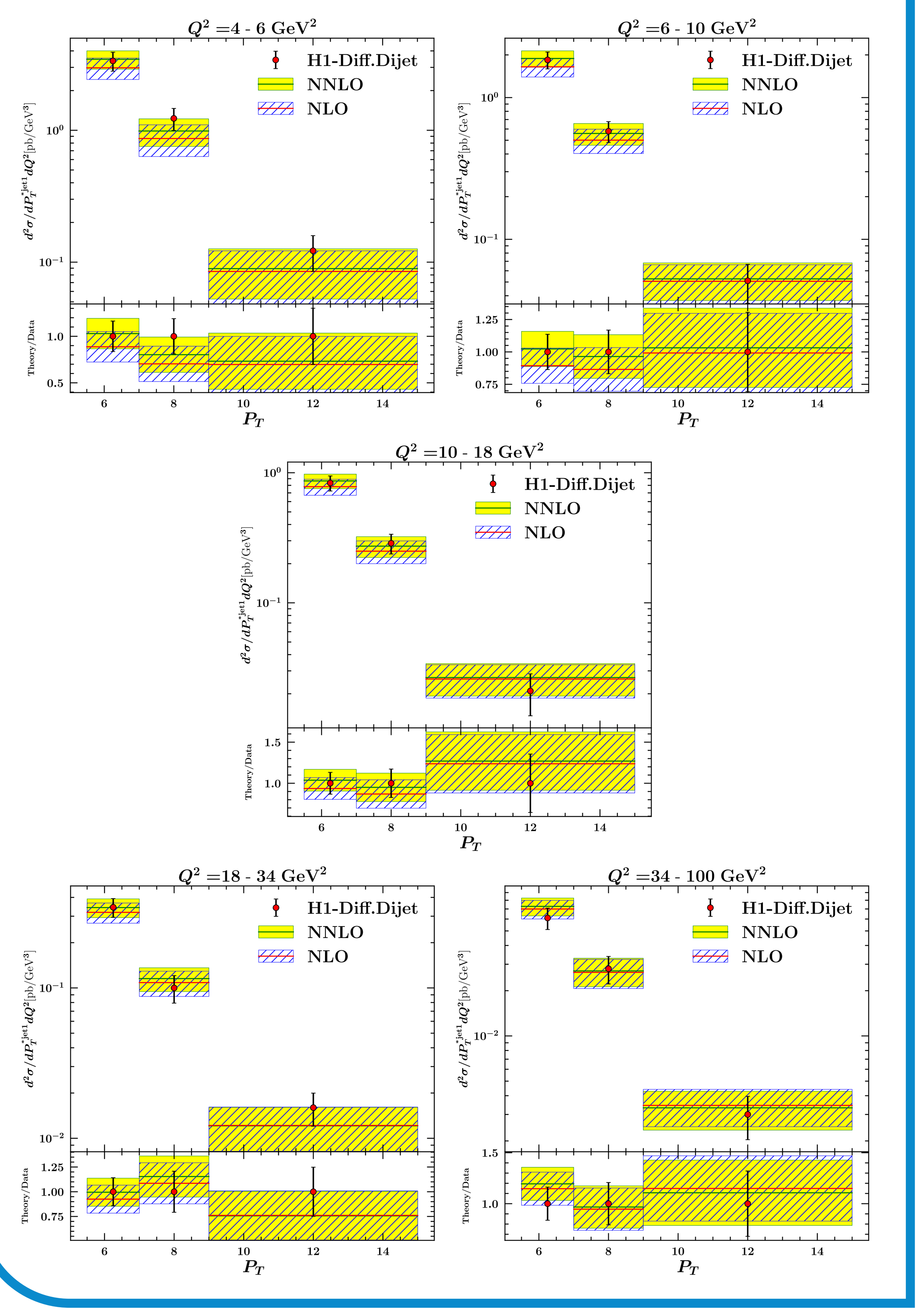
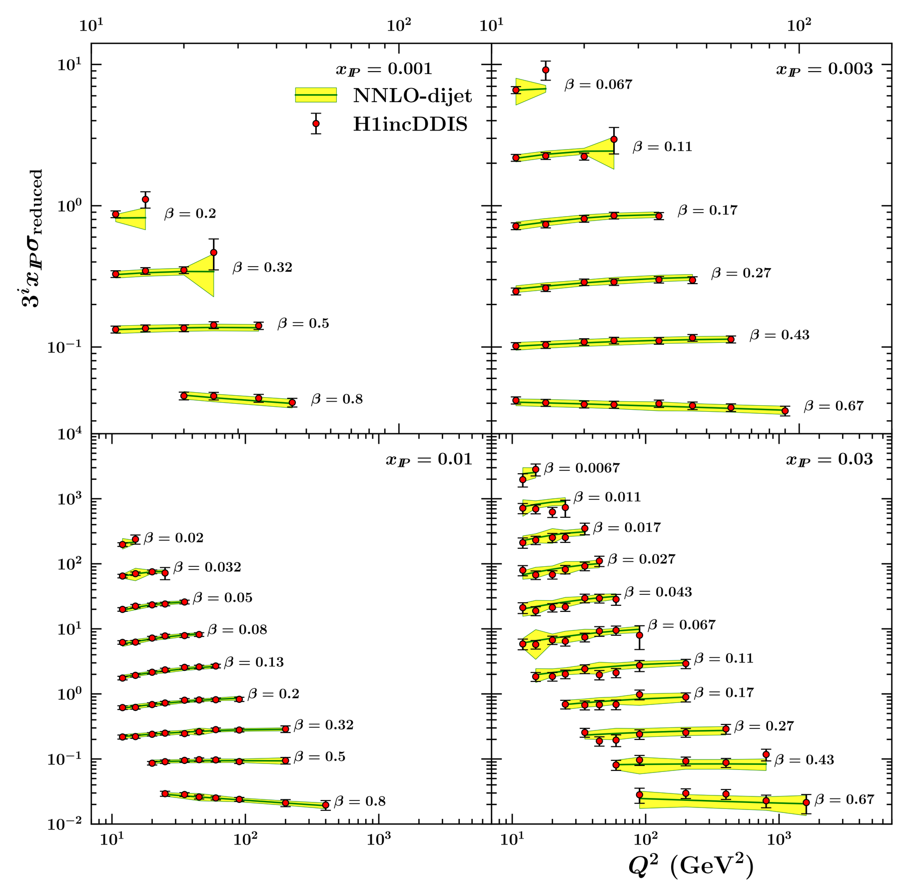
Phys. Rev. D **57**, 3051-3056 (1998) [erratum: Phys. Rev. D **61**, 019902 (2000)].
Phys. Rev. D **107**, 094038 (2023)

Fit Quality - DiJet

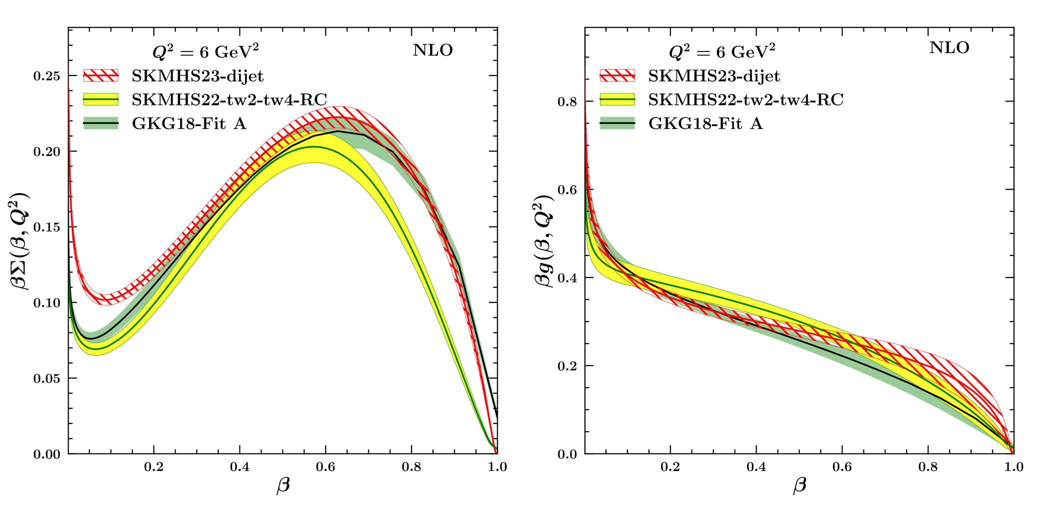


Fit Quality - Inclusive



Comparison of PDFs

Comparison between SKMHS23-dijet, GKG18 and SKMHS23 at Q^2 = 6 GeV^2 as a function of β, for gluon (left) and total singlet distributions (right).



For the case of the gluon density, overall good agreements between these three sets can be seen. However, the new analysis mostly affects the gluon density function over the large value of momentum fraction β. The differences in shape among the three diffractive PDFs sets are more marked in the case of the total singlet.

Discuss and Conclusion

In this work, we have presented `SKMHS23` and `SKMHS23-dijet`, the first determination of diffractive PDFs up to the next-to-next-to-leading order accuracy in perturbative QCD taking into account the inclusive DIS and di-jet DIS data. The data sets analyzed in this work include the combined H1 HERA-I and HERA-II LRG inclusive diffractive DIS data, H1 Low energy HERA-II LRG data, and more importantly the H1 HERA-II dijet LRG data. We have discussed the quality of `SKMHS23` and `SKMHS23-dijet` QCD fits and shown that the inclusion of QCD corrections up to the NNLO accuracy improves the description of the data. We have then examined the diffractive PDFs resulting from our QCD fits. We also highlighted their perturbative stability and observed a reduction of the diffractive PDFs uncertainties at NNLO with respect to the NLO case. Very good descriptions between the NLO and NNLO predictions based on `SKMHS23` and `SKMHS23-dijet` and the data points are observed over a wide range of $x_{I\!P}$ and β. The extracted diffractive PDFs are also compared with the results available in the literature, where largely good agreement is found. In our `SKMHS23` and `SKMHS23-dijet` analysis we have introduced some methodological improvements, and the theoretical framework applied in this work also features a number of further improvements. As we discussed, a well-established fitting methodology is used to provide a faithful representation of the diffractive experimental uncertainties, and to minimize any bias related to the parametrization of the diffractive PDFs and to the minimization of the fitting procedure.

The theoretical calculations have been done at NLO and NNLO accuracy for both inclusive and jet production using the `APFEL` and `fastNLO` schemes, and `Alpos` to perform the PDF fit. To consider the contribution from heavy quarks, we employed the `FONLL-B` and `FONLL-C` GM-VFNS approaches which provide a proper theory input for such contributions at NLO and NNLO accuracy, respectively.

The H1 HERA-II dijet LRG data are also added to the data sample, to constrain the gluon component which is weekly constrained from the inclusive diffractive DIS data. Hence, we expect that the determination of the gluon distribution is more reliable in our `SKMHS23-dijet` QCD fit, since the dijet from HERA-II are considered, which are directly sensitive to the gluon density.

The `SKMHS23` and `SKMHS23-dijet` analyses presented in this work represents the first step of a broader program. A number of updates and improvements are foreseen, and the `SKMHS23` and `SKMHS23-dijet` analyses presented in this article can be extended in several different directions. The most important one is to repeat the analysis described here and present a new combined QCD analysis of both recent data sets measured by the H1 and ZEUS collaborations at HERA, and the expected observables from the future colliders considering the large hadron-electron collider (LHeC) on the top of the list, to examine the effect of such data on the extracted diffractive PDFs.

The `SKMHS23` and `SKMHS23-dijet` NLO and NNLO diffractive PDFs sets presented in this work are available in the standard `LHAPDF` format from the authors upon request.