Uncertainties on diffractive parton distribution functions from fit to the HERA data

S. Taheri Monfared[1], *Ali N. Khorramian*[2,1], *S. Atashbar Tehrani*[1]

[1]School of Particles and Accelerators, Institute for Research in Fundamental Sciences (IPM), P.O.Box 19395-5531, Tehran, Iran
[2]Physics Department, Semnan University, Semnan, Iran

DOI: http://dx.doi.org/10.3204/DESY-PROC-2012-02/52

In the present QCD analysis, we use a wide range of the inclusive diffractive deep inelastic scattering observable based on different methods of data selections. Diffractive parton distribution and their uncertainty bands are determined from a global fit in the next-to-leading order (NLO). Predictions based on the extracted diffractive parton densities are compared to the available theoretical models. Satisfactory agreement exists.

1 Introduction

The diffractive deep inelastic scattering (DDIS) at HERA provide a very interesting sample of the interplay between hard and soft aspects of QCD interactions. On one side virtuality of the photon probe is large, while on the other side, the scattered proton remains almost intact, missing just a small fraction of its initial momentum.

The concept of diffractive parton distribution functions (DPDFs) plays an important role in the study of diffractive reactions in DIS and is essential input to calculations of hard diffractive processes at the LHC.

In this paper, we briefly reports the uncertainties of DPDFs extracted from the H1 and ZEUS data. An effective χ^2 function is used not only to obtain the best fit, but also to find the neighborhood of the global minimum in order to quantify the uncertainties. The need to quantify the uncertainties for new physics searches in the next generation of collider experiments has stimulated much interest among phenomenological groups in developing new approaches [1, 2]. We followed the approach introduced in Ref. [3].

2 Diffractive data

At HERA, diffractive events were selected either by the detection of the final state proton [4, 5, 6, 7, 8] or on the basis of a large rapidity gap between the system X and the outgoing proton [7, 9]. The diffractive contribution was also identified by the M_X method [10, 11] based on the shape of the mass distribution of the system X. Within the normalization uncertainties the results from the different methods agree reasonably well.

3 Uncertainties of DPDFs

We analyzed almost all HERA diffractive deep inelastic scattering data in the standard NLO parton model approach of the perturbative QCD. Our detailed fit procedure is available in Ref. [12, 13, 14]. Here, we focus on the propagation of uncertainty bands. The quality of fit is traditionally determined by the χ^2 of the fit to the data [15], which is minimized using the MINUIT package [16]. $\chi^2_{\rm global}$ is defined by

$$\chi^2_{\rm global}(p) = \sum_{i=1}^{n^{data}} \left[\left(\frac{1-\mathcal{N}_i}{\Delta\mathcal{N}_i} \right)^2 + \sum_{j=1}^{n^{data}} \left(\frac{\mathcal{N}_j \, F_{2,j}^{D,data} - F_{2,j}^{D,theor}(p)}{\mathcal{N}_j \, \Delta F_{2,j}^{D,data}} \right)^2 \right] , \tag{1}$$

where p denotes the set of independent parameters in the fit and n^{data} is the number of data points included. For the i^{th} experiment, $F_{2,j}^{D,data}$, $\Delta F_{2,j}^{D,data}$ and $F_{2,j}^{D,theor}$ denote the data value, measurement uncertainty and theoretical value for n^{th} data point. $\Delta\mathcal{N}_i$ is the experimental normalization uncertainty and $\mathcal{N}_i$ is an overall normalization factor for the data of experiment i. We allow for a relative normalization shift $\mathcal{N}_i$ between different data sets within uncertainties $\Delta\mathcal{N}_i$ quoted by the experiments.

The errors include systematic and statistical uncertainties, being the total experimental error evaluated in quadrature. We check the fit stability by performing the two approaches with statistical and systematics errors added in quadrature or with statistical errors only. For a given set of data, the results based on the fit with statistical or total errors are very close. When moving to a combined fit of all data sets, although DPDFs show small differences between both fits, using statistical errors lead to fit with a large χ^2.

There are clear procedures for propagating experimental uncertainties on the fitted data points through to the PDF uncertainties. The most common is the Hessian approach. In this case we can consider

$$\Delta\chi^2_{\rm global} \equiv \chi^2_{\rm global} - \chi^2_{\rm min} = \sum_{i,j} H_{ij}(a_i - a_i^{(0)})(a_j - a_j^{(0)}), \tag{2}$$

where the Hessian matrix is defined as

$$H_{ij} = \frac{1}{2} \frac{\partial^2 \chi^2_{\rm global}}{\partial a_i \partial a_j} \bigg|_{\rm min} . \tag{3}$$

The standard formula for linear error propagation is

$$(\Delta F)^2 = \Delta\chi^2 \sum_{i,j} \frac{\partial F}{\partial a_i} (H_{ij})^{-1} \frac{\partial F}{\partial a_j}. \tag{4}$$

Since the derivative of F with respect to each parameter a_i is required, this formula is not easily calculable. It can be improved by finding and rescaling the eigenvectors of H [17, 18, 3]. In term of the rescaled eigenvectors z_i, the increase in χ^2 is given by

$$\chi^2_{\rm global} - \chi^2_{\rm min} = \sum_i z_i^2 . \tag{5}$$

The uncertainty on a quantity is then obtained applying

$$(\Delta F)^2 = \frac{1}{2} \sum_i \left[F(S_i^+) - F(S_i^-)\right]^2, \tag{6}$$

where S_i^+ and S_i^- are PDF sets displaced along eigenvector directions by the given $\Delta\chi^2$. The uncertainties on our DPDFs following this method are presented in Figure 1. Our predictions are in fair agreement with the others.

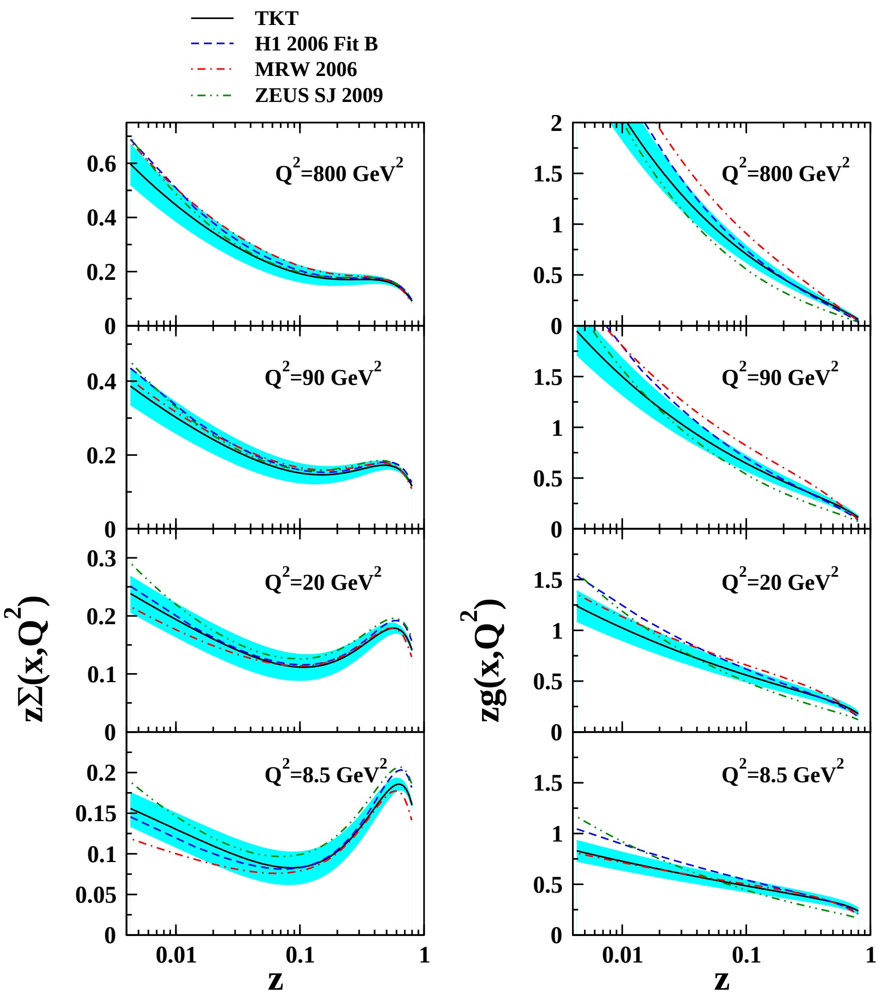

Figure 1: Comparison between the total quark singlet and gluon distributions obtained from our model (solid curve), H1 2006 DPDF Fit B (dashed curve) [9], ZEUS SJ (dashesd-dotted-dotted curve) [19] and MRW (dashesd-dotted curve) [20] at four different values of Q^2 as a function of z.

4 Conclusion

The cross sections and structure functions of the diffractive reaction from HERA have been measured in a very wide range of Q^2, β. Our predictions for all DPDFs using QCD fits to the almost all available HERA experimental data are in very good agreement with the other theoretical models. Our DPDF uncertainty bands are also calculated in different energy scales.

A FORTRAN package containing our Pomeron densities Σ and g with their errors at NLO in the $\overline{\text{MS}}$ scheme can be found in `http://particles.ipm.ir/links/QCD.htm`.

5 Acknowledgements

S. T. M. gratefully acknowledges the generous support of the organizing committee of DIS 2012 for providing the opportunity to attend the conference.

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