Towards Precision Determination of uPDFs

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The unintegrated Parton Density Function of the gluon is obtained from a fit to dijet production in DIS as measured at HERA. Reasonable descriptions of the measurements are obtained, and a first attempt to constrain the intrinsic transverse momentum distribution at small $k_\perp$ is presented [1].

1 Introduction

Unintegrated parton density functions (uPDFs) are best suited to study details of the hadronic final state in high energy ep and also in pp collisions (for a review see [2–8]). In general, the production cross section for jets, heavy quarks or gauge bosons can be written as a convolution of the uPDF $\mathcal{A}(x, k_\perp^2, \bar{q})$ with the partonic off-shell cross section $\hat{\sigma}(x_i, k_\perp^2)$, with $x_i, k_\perp$ being the longitudinal momentum fraction and the transverse momentum of the interacting parton i and $\bar{q}$ being the factorization scale. For example the cross section for $ep \to \text{jets} + X$ can be written as:

$$\frac{d\sigma^{jets}}{dE_T d\eta} = \sum_i \int\int\int dx_i \, dQ^2 d \ldots \cdot \left[dk_\perp^2 x_i \mathcal{A}(x_i, k_\perp^2, \bar{q})\right] \hat{\sigma}(x_i, k_\perp^2)$$

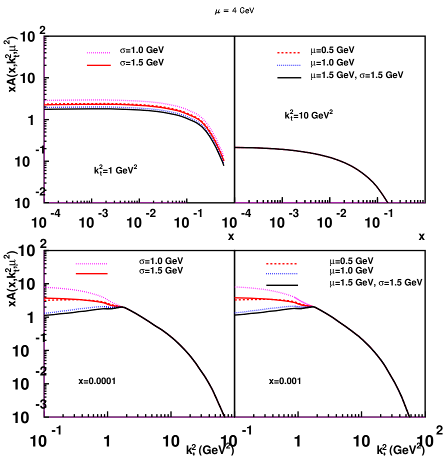

Figure 1: The unintegrated gluon distribution at a scale $\bar{q} = 4$ GeV for different values of μ and σ of the intrinsic $k_\perp$ distribution as a function of x for fixed $k_\perp$(top) and as a function of $k_\perp$ (bottom) for fixed x

At high energies, the gluon density is dominating for many processes, therefore here only the gluon uPDF is considered. It has already been shown in [9], that the predictions of the total cross section as well as differential distributions for heavy quark production at HERA and the LHC agree well in general with those coming from fixed NLO calculations. However, the details depend crucially on a precise knowledge of the uPDF. Therefore precision fits to inclusive and exclusive measurements have to be performed to determine precisely the free parameters of the uPDF: the starting distribution function at a low scale $Q_0 \sim 1$ GeV as well as parameters connected with α_s and details of the splitting functions for the perturbative evolution.

An overview and discussion of uPDFs is given in [4–6]. In a previous paper [10] the uPDF was determined from a pQCD fit using the CCFM evolution equation [11–14] to the structure function F_2 and F_2^c with acceptable χ^2/ndf. However, the small x behavior of the uPDF obtained from F_2^c was very different compared to the one obtained from F_2.

Here also measurements of high p_t-dijet production in DIS at HERA [15–17] are investigated.

2 The method

The unintegrated gluon density is determined by a convolution of the non-perturbative starting distribution $\mathcal{A}_0(x)$ and the CCFM evolution denoted by $\tilde{\mathcal{A}}\,(x, k_\perp, \bar{q})$:

$$x\mathcal{A}(x, k_\perp, \bar{q}) = \int dx' \mathcal{A}_0(x', k_\perp) \cdot \frac{x}{x'} \tilde{\mathcal{A}} \left(\frac{x}{x'}, k_\perp, \bar{q} \right)$$

In the perturbative evolution the gluon splitting function P_{gg} including non-singular terms (as described in detail in [18, 19]) is applied.

The distribution $\mathcal{A}_0$ is parameterized at the starting scale Q_0 by:

$$x\mathcal{A}_0(x, k_\perp) = N x^{-B_g} \cdot (1-x)^{C_g} (1 - D_g x) \cdot \exp\left[-\frac{(\mu - k_\perp)^2}{\sigma^2} \right] \quad (1)$$

The parameters N_g, B_g, C_g, D_g as well as μ, σ of $\mathcal{A}_0$ are free parameters which have to be constrained by measurements. It turns out, that C_g, D_g are not sensitive to the data considered here, and are therefore fixed to $C_g = 4$ and $D_g = 0$. The other parameters are determined by a fit [20] to measurements such to minimize the χ^2 defined by:

$$\chi^2 = \sum_i \left(\frac{(T - D)^2}{\sigma_i^{2\ stat} + \sigma_i^{2\ sys}} \right)$$

with T being the theory value and D the measurement with the corresponding statistical and systematic uncertainty.

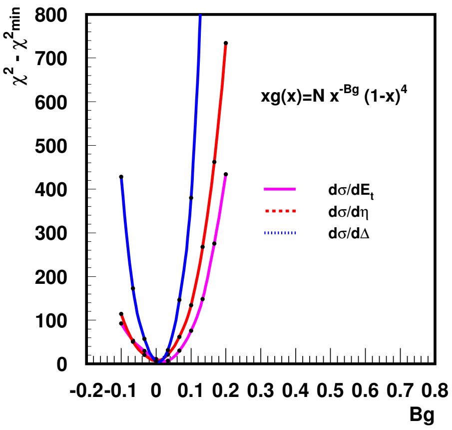

Figure 2: A scan in the parameter space of B_g for $\frac{d^3\sigma}{dQ^2 dx dE_t}$, $\frac{d^3\sigma}{dQ^2 dx d\Delta}$ and $\frac{d^3\sigma}{dQ^2 dx d\Delta\eta}$ as measured in [15].

3 The intrinsic $k_\perp$distribution

The Gaussian form with $\mu = 0$ and a width of $\sigma \sim 1.0$ GeV of the intrinsic $k_\perp$distribution in eq.(1) is an assumption to parameterize our ignorance about the small $k_\perp$behavior. In the saturation model of GBW [21] the uPDF vanishes for small $k_\perp$. Such a behavior can be mimicked by a Gaussian distribution with $\mu \sim Q_0$. The effect of choosing different μ is illustrated in Fig. 1.

4 Dijets in DIS

The sensitivity of the shape in x and the intrinsic $k_\perp$was studied for dijets in DIS [15] in the kinematic range of $5 < Q^2 < 100$ GeV^2, $10^{-4} < x < 10^{-2}$, $0.1 < y < 0.7$ and two jets with at least $E_t > 5$ GeV in the range $-1 < \eta < 2.5$. The differential cross sections $\frac{d\sigma}{dE_t}$, $\frac{d\sigma}{d\Delta\eta}$, with $\Delta\eta$ being the rapidity difference between the highest E_t jets are mainly sensitive to the x dependence of the uPDF. The same is observed for the cross section $\frac{d\sigma}{d\Delta}$ with $E_t > E_{t\ min} + \Delta$ and $E_{t\ min} = 5$ GeV. A scan over the parameter space of Bg is shown in Fig 2. With this choice of parameters the cross sections are well described, giving a reasonable χ^2/ndf. In Tab. 1 the χ^2/ndf are given for different values of Bg and the mean μ of the intrinsic $k_\perp$ distribution.

		χ^2/ndf		
Bg	μ [GeV]	$\frac{d\sigma}{dE_t}$	$\frac{d\sigma}{d\Delta\eta}$	$\frac{d\sigma}{d\Delta}$
0.025	1.5	68/37=1.8	102/35=2.3	267/89=3.0
0.25	1.5	95/37=2.5	113/35=2.5	306/89=3.4
0.025	0	63/37=1.7	93/35=2.1	284/89=3.2
0.25	0	99/37=2.7	123/35=2.7	345/89=3.9

Table 1: Quality of the description of the different differential cross sections using $Bg = 0.025$ and $Bg = 0.25$ together with $\sigma = 1.5$ GeV.

From Tab. 1 it is seen, that a value of $Bg = 0.025$ is preferred, and that the sensitivity of these measurements to the intrinsic $k_\perp$ distribution is very small.

However, the cross section as a function of $\Delta\phi$, where $\Delta\phi$ is the difference in azimuthal angle between the two leading jets in the hadronic center-of-mass frame, is directly sensitive to the transverse momentum of the incoming parton, and thus a crucial test of the uPDF.

In Fig. 3 we show a comparison of the measurement of [17] with the prediction of CASCADE using the uPDF determined before. A reasonable description of the measurement is achieved. Table 2 shows the χ^2/ndf obtained for these data and also to the azimuthal correlations from [16]. It is interesting to observe, that $\frac{d\sigma}{d\Delta\phi}$ gives also access to Bg, now with a preference to a much steeper initial gluon distribution. The measurement prefers a distribution which decreases for very small transverse momenta $k_\perp$. However it should be noted, that the form of the intrinsic $k_\perp$ distribution is not constrained.

		χ^2/ndf	
Bg	μ [GeV]	$\frac{d\sigma}{dQ^2 d\Delta\phi}$ (H1 prel)	$\frac{d\sigma}{d\Delta\phi}$ (dijets ZEUS)
0.025	1.5	163/29=5.6	332/19=17.5
0.25	1.5	128/29=4.4	234/19=12.3
0.025	0	200/29=6.9	417/19=22.0
0.25	0	237/29=8.2	338/19=17.8

Table 2: Quality of the description of $\frac{d\sigma}{d\Delta\phi}$ using $Bg = 0.025$ and $Bg = 0.25$ together with $\sigma = 1.5$ GeV by H1 [16] and ZEUS [17].

5 Conclusion

The shape of the starting gluon distribution in x and $k_\perp$ has been investigated with dijet events in DIS. Whereas the cross sections as a function of E_t prefer a soft gluon distribution ($Bg \sim 0.025$) and show little sensitivity to the intrinsic $k_\perp$ distribution, the cross sections as a function of $\Delta\phi$ prefer a much steeper gluon ($Bg \sim 0.25$) and show a clear preference to a intrinsic $k_\perp$ distribution which decreases for small $k_\perp$. The different x-slope of the initial gluon distribution, as already observed in fits to F_2 and F_2^c, is also observed in di-jet cross section measurement. Further investigations are obviously needed.

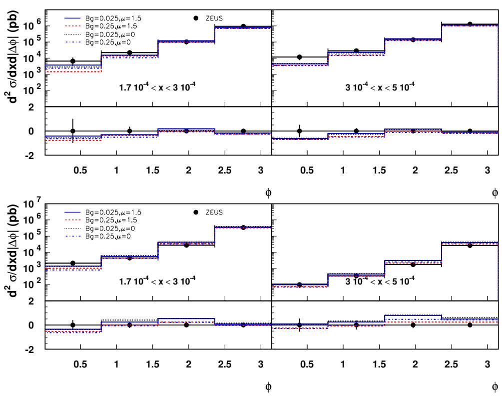

Figure 3: The cross section $\frac{d\sigma}{d\Delta\phi}$ as measured by [17] compared to predictions using CASCADE and the uPDF as in Tab. 2. The lower plots always show the ratio $R = \frac{theory-data}{data}$.

Acknowledgments

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References

[1] Slides:
http://indico.cern.ch/contributionDisplay.py?contribId=54&sessionId=6&confId=9499

[2] H. Jung, *Phys. Rev.* **D 65**, 034015 (2002). [hep-ph/0110034]

[3] H. Jung, *Mod. Phys. Lett.* **A19**, 1 (2004). [hep-ph/0311249]

[4] Small X Collaboration; B. Andersson *et al.*, *Eur. Phys. J.* **C 25**, 77 (2002). [hep-ph/0204115]

[5] Small X Collaboration, J. R. Andersen *et al.*, *Eur. Phys. J.* **C35**, 67 (2004). [hep-ph/0312333]

[6] Small X Collaboration, J. R. Andersen *et al.* (2006). [hep-ph/0604189]

[7] H. Jung. DIS 2004, Strbské Pleso, Slovakia, [hep-ph/0411287]

[8] J. Collins and H. Jung, *Need for fully unintegrated parton densities*, 2005. [hep-ph/0508280]

[9] S. Alekhin *et al.*, *Hera and the LHC - a workshop on the implications of HERA for LHC physics: Proceedings Part A and B*, 2005. [hep-ph/0601012,hep-ph/0601013], J. Baines *et al.* (2006). [hep-ph/0601164]

[10] H. Jung, A. V. Kotikov, A. V. Lipatov and N. P. Zotov, [hep-ph/0611093].

[11] M. Ciafaloni, *Nucl. Phys.* **B 296**, 49 (1988)

[12] S. Catani, F. Fiorani, and G. Marchesini, *Phys. Lett.* **B 234**, 339 (1990)

[13] S. Catani, F. Fiorani, and G. Marchesini, *Nucl. Phys.* **B 336**, 18 (1990)

[14] G. Marchesini, *Nucl. Phys.* **B 445**, 49 (1995)

[15] A. Aktas *et al.* [H1 Collaboration], Eur. Phys. J. C **33** (2004) 477 [hep-ex/0310019].

[16] M. Hansson [H1 Collaboration], "Decorrelation Of Dijets At Low X And Q**2," *Prepared for 14th International Workshop on Deep Inelastic Scattering (DIS 2006), Tsukuba, Japan, 20-24 Apr 2006*

[17] S. Chekanov *et al.* [ZEUS Collaboration], [hep-ex/0705.1931] .

[18] H. Jung, *Acta Phys. Polon.* **B33**, 2995 (2002). [hep-ph/0207239]

[19] M. Hansson and H. Jung. DIS 2003, St. Petersburg, Russia, [hep-ph/0309009]

[20] F. James and M. Roos, *Comput. Phys. Commun.* **10**, 343 (1975)

[21] K. Golec-Biernat and M. Wusthoff, Phys. Rev. D **60** (1999) 114023 [hep-ph/9903358].