Proceedings of the DIS'2004, Štrbské Pleso, Slovakia

UNINTEGRATED GLUON DENSITIES IN THE LDC MODEL

LEIF LÖNNBLAD
Department of Theoretical Physics, Lund University
Sölvegatan 14A, S-223 62 Lund, Sweden
E-mail: leif.lonnblad@thep.lu.se

I describe briefly the Linked Dipole Chain reformulation of the CCFM formalism and how to obtain unintegrated gluon densities within this model. I show some results where these densities are used to describe heavy quark production at the Tevatron and to predict the production of central exclusive Higgs at the LHC. The results turn out to be very sensitive to the treatment of non-leading terms, in particular the non-singular terms in the gluon splitting function.

1 Unintegrated gluon densities and the Linked Dipole Chain model

Collinear factorization has turned out to be an invaluable tool for calculating predictions from QCD. Especially for inclusive quantities the convolution of on-shell matrix elements (MEs) with parton densities evolved using DGLAP [1–4] has been very successful. However, for processes involving small-x and observables involving exclusive properties of the hadronic final state, the collinear factorization is expected to break down. For such calculations one expects $k_\perp$-factorization [5, 6], where off-shell MEs are convoluted with $k_\perp$-*unintegrated* parton densities (uPDFs) to be a better approximation. The uPDFs are then evolved using BFKL [7–9] (suitable for the asymptotic $x \to 0$ limit) or with CCFM [10–13] (which gives a smooth transition to DGLAP at larger x). $k_\perp$-factorization calculations are, however, not yet at the same level of sophistication as collinear ones. No complete NLO calculation is available and the number of different parameterizations of uPDFs is far from the large flora of PDFs available for the collinear case.

In this report I will present some calculations done using $k_\perp$-factorization with uPDFs evolved according to the Linked Dipole Chain (LDC) [14, 15] model. LDC is a reformulation and generalization of the CCFM model, and agrees with CCFM to leading double logarithmic accuracy. The main difference is that LDC uses an improved separation between initial- and final-state emissions, making the evolution forward–backward symmetric and cancels the notorious non-Sudakov form factor in CCFM. It also allows for straight-forward inclusions of non-singular terms in the gluon splitting function as well as quark-propagators in the evolution.

In the following I will first describe briefly how the LDC uPDFs are obtained and then some results where they are used to calculate heavy quark production at the Tevatron and exclusive Higgs production at the LHC.

LDC is implemented in the LDCMC [16] event generator which allows for generation of complete lepton–hadron DIS events. The program does not explicitly use uPDFs convoluted with off-shell MEs. Instead, as also quark propagators are allowed, the whole ladder including the top quark-box in the typical DIS diagram

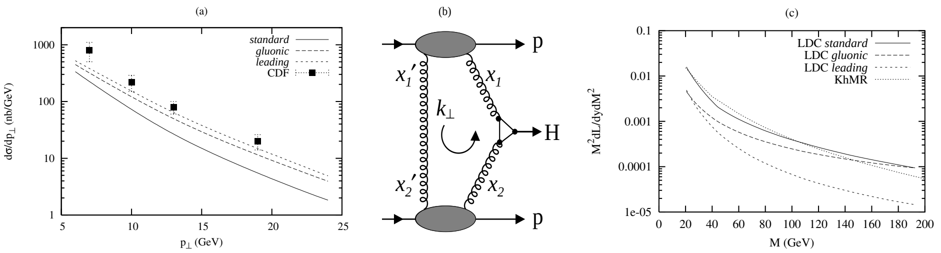

Figure 1. (a)The prediction for the B meson p_T spectrum for $|y_B| < 1$ at $\sqrt{s} = 1800$ GeV compared to the CDF data. The solid line is *gluonic*, dashed is *leading* and dotted line is *standard* versions. Experimental data are from CDF [23]. (b) The basic diagram for exclusive production of the Higgs. (c) The prediction for the luminosity function, eq. 2 using different uPDFs. The lines are the same as in (a), in addition is shown the result from KMR [24].

is generated according LDC evolution. This means that F_2 can be fitted directly by parameterizing the non-perturbative input parton densities. The resulting fits a quite satisfactory and for details I refer the reader to ref. [17].

Since the uPDFs are not used explicitly they are instead *measured* [17] by generating a large number of DIS events with LDCMC, and in the following we will use three different parameterizations corresponding to different choices of treating non-leading terms in the evolution:

- *standard* uses full splitting functions and quark propagators in the evolution.
- *gluonic* has only gluon propagators (except for the top quark box), but uses the full g→gg splitting function.
- *leading* also only uses gluon propagators but in the splitting function only the singular, $1/z$ and $1/(1-z)$ terms are included.

The reason for these choices is that while the *standard* choice gives a very good fit to F_2, it is not able to describe the rate of forward jets measured at HERA – a measurement which is probably the most sensitive to the actual $k_\perp$-evolution of partons in the proton. On the other hand *gluonic* and *leading* gives a poorer fit to F_2, especially for large x but *gluonic* results in an *integrated* gluon density which is very similar to the standard DGLAP parameterizations, and *leading* is the only choice which is able to reproduce forward jets at HERA.

The fact that forward jet rates can only be reproduced if non-singular terms are excluded from the splitting function is not particular to LDC, but is consistent with other CCFM calculations. See refs. [18, 19] for detailed discussions.

2 Heavy quarks at the Tevatron

Until recently the failure of NLO calculations to reproduce the B-meson $p_\perp$ spectrum measured at The Tevatron [20] was taken as an indication of the breakdown of collinear factorization, especially since the same spectrum was well described by $k_\perp$-factorization [21]. Although the discrepancy with collinear NLO calculations has since been cured [22], it is interesting to see if the $k_\perp$-factorization results can be confirmed with the LDC uPDFs.

In [25] results were presented for heavy quark production at the Tevatron using the LDC uPDFs. Both bottom and charm meson production as well as μ production from b-decays was investigated. Here I will only present the B-meson results since the other results give rise to very similar conclusions.

The $p_\perp$-spectra in figure 1a were calculated using the off-shell MEs obtained in [26–28] convoluted with the different LDC uPDFs and a standard Peterson fragmentation function with $\epsilon = 0.006$. Clearly the *standard* uPDF is far below the data while *leading* fits fairly well and *gluonic* is only slightly below. Probably also *standard* could be made to come closer to the data by adjusting the b-quark mass and/or the fragmentation function, but still the conclusion is that the treatment of non-leading terms influences very much the results.

3 Central exclusive Higgs production

The possibility to study exclusively produced Higgs at the LHC has recently sparked a lot of interest (see eg. [24] and references therein). The idea is to use the process pp$\to$p+H+p (where the + symbolizes a large rapidity gap) to get an extremely clean Higgs signal. To calculate the cross section one uses the diagram in figure 1b, where the colour exchange in a standard gg$\to$H production is neutralized by an additional gluon exchange with some finite $k_\perp$. The resulting formula is factorized into a luminosity function and the basic gg$\to$H matrix element and looks like

$$\sigma = \int \hat{\sigma}_{gg\to H}(M^2)\frac{\delta^2\mathcal{L}}{\delta y\delta\ln M^2}, dyd\ln M^2 \tag{1}$$

where the luminosity function

$$\frac{\delta^2\mathcal{L}}{\delta y\delta\ln M^2} = S^2\left[\frac{\pi}{(N_c^2-1)b}\int^{\frac{M^2}{4}}\frac{dk_\perp^2}{k_\perp^4}f_g(x_1,x_1',k_\perp^2,\frac{M^2}{4})f_g(x_2,x_2',k_\perp^2,\frac{M^2}{4})\right]^2 \tag{2}$$

takes into account the suppression of additional radiation which would destroy the gaps, see [24] for details. The main ingredient is the *off-diagonal* unintegrated gluon densities (oduPDF) $f_g(x,x',k_\perp^2,\mu^2)$ representing the amplitude corresponding to the probability to find a gluon with some $k_\perp$and some x when probed with a scale μ^2 together with an additional gluon with x' and $k_\perp$. These can be approximated, in the limit $x' \ll x$, using the KMR [29] prescription for obtaining uPDFs from the integrated ones, $xg(x,\mu^2)$ by:

$$f_g(x,x',k_\perp^2,\mu^2) \approx \frac{d}{d\ln k_\perp^2}\left[R_g xg(x,k_\perp^2)\sqrt{T(k_\perp^2,\mu^2)}\right], \tag{3}$$

where T is the Sudakov form factor giving the probability of no extra emissions above $k_\perp$, and R_g is obtained from the behavior of xg at small x [30].

In [31] it was shown how the LDC densities could be used to approximate the oduPDFs using the fact that they factorize into a one scale density and a Sudakov form factor, ie. $G(x,k_\perp^2,\mu^2) \approx G(x,k_\perp^2)\times\Delta_S(k_\perp^2,\mu^2)$, giving

$$f_g^{\mathrm{LDC}}(x,x',k_\perp^2,\mu^2) \approx R_g G(x,k_\perp^2)\sqrt{\Delta_S(k_\perp^2,\mu^2)}. \tag{4}$$

Using the parameterizations for the LDC uPDFs presented above the luminosity functions shown in figure 1c was obtained. It is clear that the result again is very sensitive to treatment of non-leading terms. The behavior comes from the fact that the luminosity function is proportional to the forth power of $k_\perp$distribution of gluons and most of the contribution comes from $k_\perp$'s around $2-3$ GeV. And while the distribution in the *standard* and *gluonic* versions as well as the KMR parameterization peaks at fairly low $k_\perp$, the *leading* peaks at larger $k_\perp$, a behavior which may be supported by the large rate of forward jets at HERA.

In conclusion the exclusive Higgs remains a very interesting production mechanism for LHC, but it is important to have a better control of the uPDFs before we can make reliable estimates of the cross section.

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