GLUON DISTRIBUTION FUNCTIONS IN THE $\boldsymbol{k}_\perp$-FACTORIZATION APPROACH*

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At small x, the effects of finite transverse momenta of partons inside a hadron become increasingly important, especially in analyses of jets and heavy-quark production. These effects can be systematically accounted for in a formalism based on $k_\perp$-factorization and unintegrated distribution functions. We present results for the integrated and unintegrated distribution functions obtained within the framework of the Linked Dipole Chain model. Comparisons are made to results obtained within other approaches.

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1. Introduction

The results presented in this talk have been obtained in collaboration with G. Gustafson and L. Lönnblad and are described in detail in [1].

There exist a couple of models which take into account large logarithms of both Q^2 and $1/x$ in DIS, reproducing DGLAP and BFKL in the relevant limits. These models frequently produce very different distribution functions, and an important problem is therefore how to make relevant comparisons between the different approaches.

One example is the CCFM [2] model, based on the $k_\perp$-factorization formalism. When including the suppressed contributions from non-$k_\perp$-ordered chains, it is important to specify which partons are to be regarded as initial-state emissions ISB, and which are to be regarded as final-state radiation FSB (giving negligible recoils and being described by Sudakov form factors). The exact ISB-FSB separation, as well as the definition and properties of the unintegrated parton distributions (that are not experimental observables),

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depend critically on the formalism used. In the CCFM model the ISB are ordered in angle (or rapidity) and energy (or q_+) with all other kinematically allowed emissions defined as FSB. Furthermore, the unintegrated gluon distribution function[1] $\mathcal{G}(x, k_\perp^2, \overline{q})$ depends on two scales: $k_\perp$, *i.e.* the transverse momentum of the incoming parton and $\overline{q}$, which determines an angle beyond which there is no (quasi-) real parton in the ISB chain.

Another example is the Linked Dipole Chain model (LDC) [3] which is based on the CCFM model, and agrees with this to leading double log accuracy. Here the ISB are ordered both in q_+ *and* q_- (thus also in angle or rapidity) with $q_{\perp i}$ satisfying $q_{\perp i} > \min(k_{\perp i}, k_{\perp, i-1})$, where q_i and k_i refer to the ISB and virtual links momenta, respectively. Thus, many of the ISB gluons of the CCFM model are treated as FSB in LDC. Therefore typical z-values are smaller in the LDC model, and most of the problem of angular ordering is postponed to the treatment of the FSB. To leading order in $\ln 1/x$ the result is determined by the $1/z$ pole of the gluon splitting function P_{gg}, and the LDC unintegrated distribution function $\mathcal{G}(x, k_\perp^2)$ depends on a single scale, $k_\perp^2$. Sub-leading effects due to the $1/(1-z)$ pole or the non-singular terms in P_{gg} are included via Sudakov form factors, which do depend on the angular region allowed for radiation. Thus also the LDC unintegrated distribution functions have a weak dependence on the scale $\overline{q}$ defined above. In LDC sub-leading corrections from quarks and non-singular terms in P_{gg} can be included in a rather straight-forward manner. The LDC-based LDCMC [4] reproduces F_2 data very well, not only the small-x HERA data but also higher-x data from fixed target experiments.

2. Results

Studies have shown that sub-leading corrections to the LDC parton densities, from quarks and non-singular terms in P_{gg}, can be largely compensated by slight modifications of the input distribution functions; in particular the results with and without quarks are almost identical. To facilitate comparison with CCFM-based results, we therefore concentrate on a version of the LDC model in which quark contributions are neglected. The non-perturbative input gluon density is parametrized by: $xg(x, k_{\perp 0}^2) = A(1-x)^b$, with $b = 4$ (called *gluonic*) or $b = 7$ (called *gluonic-2*), which both give good fits to F_2 data.

[1] In this talk we use $\mathcal{F}$ for the unintegrated parton distributions in general, and $\mathcal{G}$ for the unintegrated gluon distribution, both treated as densities in $\log 1/x$, *i.e.* $\mathcal{G}(x) = xG(x)$. For the integrated ones we use the standard notation f and g, respectively.

The LDC integrated and the unintegrated gluon distribution functions are related by:

$$xg(x,Q^2) = \int_{k_{\perp 0}^2}^{Q^2} \frac{dk_\perp^2}{k_\perp^2}\mathcal{G}(x,k_\perp^2,Q) + \int_{Q^2}^{Q^2/x} \frac{dk_\perp^2}{k_\perp^2}\mathcal{G}\left(x\frac{k_\perp^2}{Q^2},k_\perp^2,Q\right)\frac{Q^2}{k_\perp^2} + xg_0(x,Q_0^2)\times\Delta_{\mathrm{S}}\,.$$

The first term corresponds to struck gluons of transverse momenta below the virtuality of the probe, $k_\perp^2 < Q^2$, the second term to $k_\perp^2 > Q^2$ and the third term to the case when no evolution has taken place. The LDC $\mathcal{G}(x,k_\perp^2,Q)$ depends only very weakly upon the scale Q, via the Sudakov form factor. This can essentially be neglected in the first two terms, but needs to be included in the last term, which dominates for larger x-values.

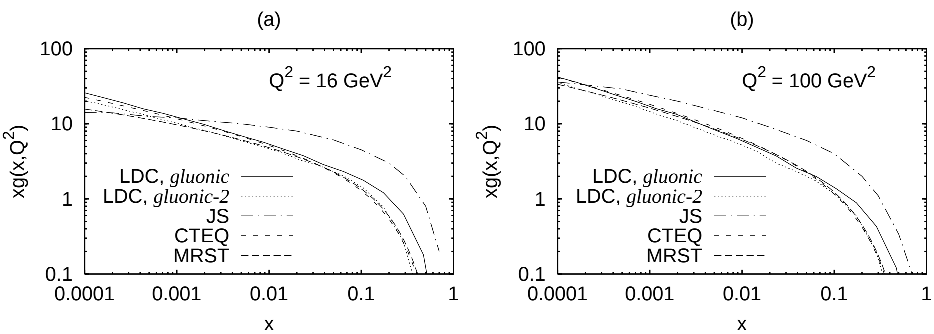

Fig. 1. The integrated gluon distribution functions for (a) $Q^2 = 16\,\mathrm{GeV}^2$ and (b) $Q^2 = 100\,\mathrm{GeV}^2$; LDC *gluonic* (full curve), LDC *gluonic-2* (dotted curve), JS (dash-dotted curve), CTEQ (short-dashed curve) and MRST (long-dashed curve).

In figure 1 we compare the LDC integrated gluon distribution functions of *gluonic* and *gluonic-2* to the results of the CCFM formalism obtained by Jung and Salam (JS) [5]. We see that LDC lies significantly below JS for large x, but above for smaller x-values. Also shown are the corresponding results for CTEQ5M1 [6] and MRST20011 [7]. Note that, while LDC and JS have been fitted to F_2 data only, CTEQ and MRST have been fitted to more data. For small x LDC agrees well with these latter curves; for larger x LDC *gluonic* lies above, while LDC *gluonic-2* agrees well with them.

Many schemes are presented in the literature to treat unintegrated parton distributions. Besides with the CCFM formalism (JS), we compare our results with the formalisms presented by Kwiecinski, Martin, and Stasto (KMS) [8] and by Kimber, Martin, and Ryskin (KMR) [9]. Both KMS and KMR are based on a unified DGLAP-BFKL evolution equation. In the KMS formalism the parton distribution is described by a single scale, $k_\perp$, and is assumed to satisfy the relation $xf(x,Q^2) = \int^{Q^2} \frac{dk_\perp^2}{k_\perp^2}\mathcal{F}(x,k_\perp^2)$; in KMR two-scale parton distributions are extracted. Finally we will compare to a simple derivative, as in KMS, of the integrated gluon density of the GRV98 [10] parameterization (dGRV).

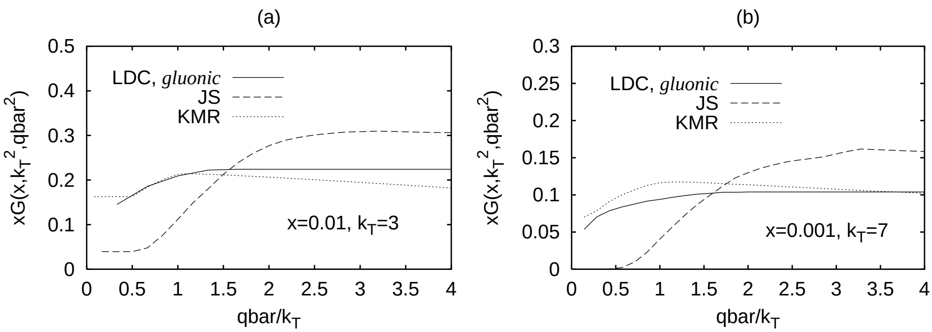

Fig. 2. The unintegrated gluon distribution functions as functions of $\overline{q}/k_\perp$ for (a) $x = 0.01$ and $k_\perp = 3\,\mathrm{GeV}$ and (b) $x = 0.001$ and $k_\perp = 7\,\mathrm{GeV}$; LDC *gluonic* (full curve), JS (long-dashed curve) and KMR (dotted curve).

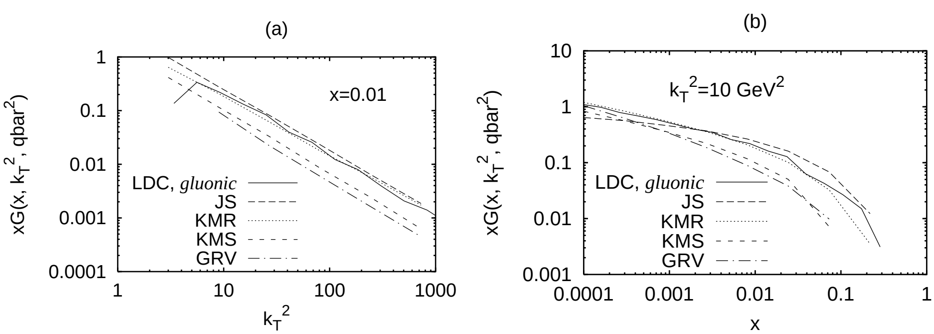

Fig. 3. The unintegrated gluon distribution functions: (a) $k_\perp^2$-dependence for $x = 0.01$, and (b) x-dependence for $k_\perp^2 = 10\,\mathrm{GeV}^2$. Results for LDC *gluonic* (full curve), JS (long-dashed curve) and KMR (dotted curve), with $\overline{q} = 2k_\perp$, shown together with the 1-scaled KMS (short-dashed curve) and dGRV (dash-dotted curve) results.

Figure 2 shows how the LDC, CCFM, and KMR unintegrated gluon distribution functions depend on the scale $\overline{q}$ for fixed $k_\perp$. We see that while this dependence is rather weak in the LDC model, it is very strong in the CCFM approach, as a consequence of the different separation between ISB and FSB. Also in the KMR formalism the $\overline{q}$-dependence is small. We note, however, that the CCFM result saturates for $\overline{q}$ above $2k_\perp$. In a hard-interaction event the relevant scale is $\overline{q}^2 \sim |\hat{t}|$ or $\hat{s}$, which are normally larger than $k_\perp^2$, often typically by a factor of this order. For this reason we want to argue that when comparing the different formalisms, it is more relevant to study the CCFM distributions for $\overline{q} \approx 2k_\perp$, rather than *e.g.* for $\overline{q} = k_\perp$. This is done in figure 3, which shows the unintegrated gluon distribution functions for $\overline{q} = 2k_\perp$, as functions of $k_\perp^2$ for fixed x and as functions x for fixed $k_\perp$; indeed we see a good agreement between the LDC, JS, and KMR results. In these figures we also show the one-scaled KMS and dGRV results. Although these earlier parameterizations are somewhat lower for larger x-values, we note a fair overall agreement between all five models.

3. Summary

Different formalisms for unintegrated parton distributions have often given very different results. Here we present results for integrated and unintegrated gluon distribution functions obtained within the LDC model. These are compared with those of other formalisms, in particular those of the CCFM model, and we demonstrate how to make a relevant comparison between the models. Indeed we find in this way a fair agreement between distributions obtained in different formalisms.

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