Diffraction dijet photoproduction is proposed as a probe of the off-diagonal gluon distribution and its evolution. Predictions for the transverse momentum distribution of the jets are given. Differences with DGLAP evolution are highlighted.

Off-diagonal (non-forward, off-forward, non-diagonal) parton distributions (OFPD’s) are generalizations of the conventional (diagonal) parton distributions. While the latter are related to the diagonal matrix elements of the twist-two quark or gluon operators \( \langle p | \ldots | p \rangle \), the OFPD’s characterize the matrix elements \( \langle p' | \ldots | p \rangle \) between the nucleon states with different momenta. We consider the unpolarized case and suppress polarization among the nucleon state characteristics. Although the OFPD’s in general cannot be regarded as particle densities, they provide important information about the nonperturbative structure of the nucleon. They are also indispensable in description of such processes as deeply virtual Compton scattering and hard diffractive electroproduction of vector mesons. These processes offer a possibility to determine the essentially nonperturbative OFPD’s. We propose another process, exclusive diffractive photoproduction of dijets with high values of transverse momenta, as a particularly good probe of the OFPD’s. The necessity for renormalization of the quark and gluon operators in the definition of the OFPD’s leads to evolution equations just as for the conventional parton distributions. The process we propose allows the study of off-diagonal evolution in a kinematical range which is not probed by the two other processes. Thus our process significantly increases the possibility of the experimental determination of the OFPD’s.

1 CROSS SECTION OF THE PROCESS

The amplitude for our process is shown in Fig. 1. Two jets with high values of transverse momenta \( \pm p_T \) are produced through the exchange of two gluons with longitudinal momentum fractions \( x \) and \( x' \) and transverse momentum \( k_T \). The first gluon is emitted from the proton, and the second is absorbed if
The cross section for the process is obtained by squaring the amplitude approximated by its imaginary part, taking into account the four different ways that the two gluons can couple to the quarks/jets. The quarks are assumed to be massless. Thus we obtain

\[ \frac{d\sigma_T}{d^2 p_T dt} \bigg|_{t=0} = \frac{\alpha^2}{6\pi p_T^2} \sum_q e_q^2 \int_{z_{\text{min}}}^{1-z_{\text{min}}} dz \left[ z^2 + (1-z)^2 \right] \left[ \phi_1(z, p_T) + \phi_1(1-z, p_T) \right]^2 , \]

where \( z \) is the fraction of the photon momentum carried by the quark. The impact factor \( \phi_1 \) is given by

\[ \phi_1(z, p_T) = \frac{\pi}{p_T^2} \int_0^\pi \frac{d\phi}{\pi} \frac{\partial G(x, x', k_T^2)}{\partial \ln k_T^2} \left\{ 1 - \left( \frac{1 - \tau^2}{1 + \tau^2 + 2\tau \cos \phi} \right) \right\} , \]

where \( \tau = k_T/p_T \) and \( G(x, x', k_T^2) \) is the off-diagonal gluon distribution in which the longitudinal momentum fractions are given by

\[ x = x_{p_T} + x' , \quad x' = \frac{p_T^2}{zW^2} \left\{ \tau^2 + 2\tau \cos \phi \right\} . \]

Here \( \phi \) is the angle between the transverse momentum vectors \( k_T \) and \( p_T \), and \( x_{p_T} = M^2/W^2 \) with the diffractive mass of the dijet system \( M^2 = p_T^2/(z(1-z)) \). The fraction \( x \) is always positive, and for \( \tau < 2 \) it varies in the range

\[ z x_{p_T} < x < 1 . \]
which leads to both $x' > 0$ (for $x > x_P$) and $x' < 0$ (for $x < x_P$). Thus we study the OFPD’s in the full kinematical range of the $x$ and $x'$ variables.

2 EVOLUTION EQUATIONS AND DIJET CROSS SECTION

The OFPD evolution equations do not mix different values of $\zeta \equiv x - x' = x_P$. Thus it is convenient to change the notation to $G_\zeta(x) \equiv G(x, x')$. After introducing the collective notation $\mathcal{F}_\zeta(x) \equiv (\Sigma_\zeta(x), G_\zeta(x))$ for the singlet and gluon off-diagonal distributions the evolution equations have the form

$$\frac{\mu}{\partial \mu} \mathcal{F}_\zeta(x, \mu) = \int_0^1 dz \mathcal{P}_\zeta(x, z; \mu) \mathcal{F}_\zeta(z, \mu).$$

Their explicit form can be found in [7]. Eqs. (5) combine features of the DGLAP evolution equations [9] for $x > \zeta$ and the ERBL evolution equations [10] for partonic distribution amplitudes for $x < \zeta$. This is shown in Fig. 3 where the off-diagonal evolution for the singlet $\Sigma_\zeta$, gluon $G_\zeta$ and $\partial G_\zeta/\partial \log(\mu^2)$ distributions (dashed curves) is compared with the DGLAP evolution (upper solid curves). The chosen initial distributions (lower solid curves) reflect the mixed nature of the off-diagonal distributions

$$\mathcal{F}_\zeta(x, \mu_0) = \theta(x - \zeta) \mathcal{F}_{AP}(x, \mu_0) + \theta(\zeta - x) \mathcal{F}_{BL}(x, \mu_0)$$

and ensure the necessary condition $\mathcal{F}_\zeta(0) = 0$. The recent MRST parametrization [11] is used for $\mathcal{F}_{AP}$, and $\mathcal{F}_{BL} \sim x^n(1 - x)^n$ where $n > 0$. 

Figure 2: The integrand of (2) and cross section (1) integrated over $t$ with $e^{6t}$, for different analyses. The solid curve and the lower points correspond to the simplified diagonal case and the dashed curve and the upper points to the full off-diagonal analysis.
In Fig. 2 we show the integrand of (2), and the cross section (1), for different assumptions about the gluon distribution and its evolution. In the first simplified case, shown by the solid lines, the diagonal $G_{\zeta=0}(x)$ distribution is evolved with the DGLAP equations from input (6). The angular integration in $\frac{d}{d\tau}$ gives the theta function $\Theta(\tau - 1)$ and cross section (1) has no contribution from $k_T < p_T$. In the second case the off-diagonal gluon distribution $G_{\zeta}(x)$ is evolved with (5) from input (6) (dashed lines). The main difference lies in the $\tau < 1$ region which now gives an important contribution to the cross section. The effect on the dijet cross section is shown by comparison of the lower points (simplified case) with the upper ones (off-diagonal analysis). Clearly the impact of the true off-diagonal analysis is significant. The details of the relation between the form of the integrand of (2) and the particular behaviour of the OFPD’s are discussed in (7).

Acknowledgments

Important discussions with A.V. Radyushkin, M.G. Ryskin and M. Wüsthoff, the Royal Society/NATO Fellowship and KBN grant no. 2 P03B 089 13 are gratefully acknowledged.

References

1. A.V. Radyushkin, Phys. Lett. B380 (1996) 417; Phys. Lett. B385 (1996) 333; Phys. Rev. D56 (1997) 5524.
2. X. Ji, Phys. Rev. Lett. 78 (1997) 610; Phys. Rev. D55 (1997) 7114.
3. J.C. Collins, L. Frankfurt, M. Strikman, Phys. Rev. D56 (1997) 2982.
4. P. Hoodbhoy, Phys. Rev. D56 (1997) 388; L. Mankiewicz, G. Piller, T. Weigl, hep-ph/9711227.
5. A.D. Martin, M.G. Ryskin, Phys. Rev. D57 (1998) 1 June.
6. N.N. Nikolaev, B.G. Zakharov, Phys. Lett. B332 (1994) 177.
7. K. Golec-Biernat, J. Kwieciński, A.D. Martin, hep-ph/9803464.
8. L. Frankfurt, A. Freund, V. Guzey, M. Strikman, hep-ph/9703449; A.V. Belitsky, B. Geyer, D. Müller, A.Schäfer, hep-ph/9710427.
9. V.N. Gribov, L.N. Lipatov, Sov. J. Nucl. Phys. 15 (1972) 438, 675; G. Altarelli, G. Parisi, Nucl. Phys.B126 (1977) 297; Yu.L. Dokshitzer, Sov. Phys. JETP 46 (1977) 641.
10. A.V. Efremov, A.V. Radyushkin, Phys. Lett. B94 (1980) 245; S.J. Brodsky, G.P. Lepage, Phys. Rev. D22 (1980) 2157.
11. A.D. Martin, W.J. Stirling, R.G. Roberts, R.S. Thorne, DTP/98/10, hep-ph/9803445, Eur. Phys. J. C (in press).
Figure 3: The OFDP’s at $\mu^2 = 10^2$ GeV$^2$ for $\zeta = x_F = 10^{-2}$ (dashed curves). The solid lines show the initial distributions at $\mu_0^2 = 1$ GeV$^2$ (lower curves) and effect of their DGLAP evolution to the same value of $\mu^2$ (upper curves).