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MULTI-PARTON LIGHT-CONE DISTRIBUTIONS IN TRANSVERSELY POLARIZED PROTONS

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ABSTRACT

Multiparton light-cone distributions of a transversely polarized proton are identified and relations among these are discussed. The twist-four contribution to the crossection for production of Drell-Yan lepton pairs in transversely polarized $p-p$ collisions is derived. Purely gluonic processes contributing upto the twist-three level are investigated by considering the production, also in polarized $p-p$ collisions, of χ_2 mesons whose subsequent decay into a J/ψ and photon reveals its initial polarization state.

Light-cone multiparton distributions are very important for characterizing the deep structure of hadrons. Being process independent quantities, they can be measured in a variety of experiments involving large momentum transfers. Much interest currently centres around the distribution $h_1(x)$, first identified by Ralston and Soper,[1] and elaborated upon by others[2-4] . $h_1(x)$ is a twist-two quantity, meaning that it enters into the crossection of a hard process, such as Drell-Yan pair production, unsuppressed by inverse powers of the hard momentum Q. Because it requires the struck quark to flip its chirality, it cannot be measured in the deeply inelastic scattering of leptons from a nucleon. However, it has been proposed that $h_1(x)$ be measured using transversely polarized beams at RHIC.[5]

Higher twist corrections in hard processes are known to be notoriously complicated, but are unfortunately necessary for deeper understanding if we are to ever proceed beyond the simple parton model. In recent work,[6] carried out in collaboration with X. Ji, a complete set of twist-four quark and gluon distributions of a transversely polarized nucleon have been identified. Relations between these are discussed using

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QCD equations of motion, and their contribution to $O(1/Q^2)$ to the Drell-Yan crossection for production of lepton pairs has been calculated. The results can be summarized as follows[6]:

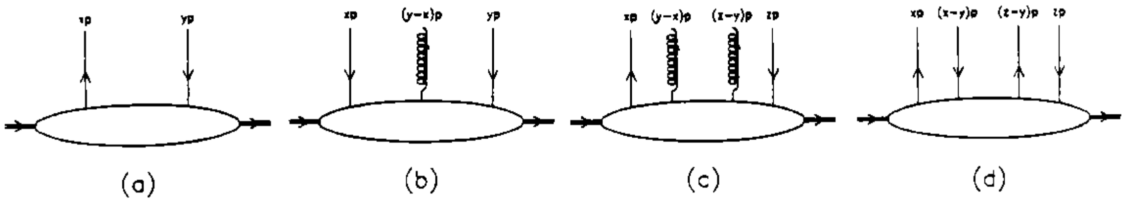

Fig. 1. Parton density matrices which contribute to a hard process at the twist-4 level.

Parton distributions are introduced through parton-hadron vertices. As shown in Fig. 1, the twist-four distributions in the light-cone gauge are contained in the vertices, which have up to four partons. Here the four-gluon vertex is absent because it cannot mix with the chiral-odd vertices shown. The two-quark vertex, shown in fig.1a, provides one twist-four distribution $h_3(x)$. There are four distributions, named $d_i(x,y)$ with i=1,2,3,4, associated with the two-quark-one-gluon vertex in fig. 1b. The two-quark-two-gluon vertex, fig. 1c, gives rise to three distributions named as $D_i(x,y,z)$ with i=1,2. The tensor structure which gives rise to each distribution is given in the ref 6, together with restrictions obtained from the requirement of PCT invariance. The QCD equations of motion on the light-cone impose further restrictions by specifying relations between distributions involving more light-cone momentum fractions and distributions involving fewer. Including the distributions identified in ref. 4 - i.e. $h_1(x), g_T(x), G_1(x,y)$, and $G_2(x,y)$ – a complete set is now available to deal with any hard process involving transversely polarized nucleons up to and including twist-four. As one application, we have calculated the twist-four part of the Drell-Yan cross section for transversely polarized nucleons. This could provide a framework to analyze corrections if an experiment to measure $h_1(x)$ is actually performed.[6]

Purely gluonic processes may be studied in a similar manner.[7] Since gauge invariance is an essential requirement, it is better to work with the field strength tensor $F^{\mu\nu}(x)$ rather than potentials. Consider, therefore, the correlation of field strength bilinears on the light-cone,

$$\Gamma^{\mu\nu,\alpha\beta} = \int \frac{d\lambda}{2\pi} e^{i\lambda x} \langle PS|F^{\mu\nu}(0)F^{\alpha\beta}(\lambda n)|PS\rangle. \tag{1}$$

In the above, n^μ is a null vector $n^2 = 0, n^+ = 0$, and P^μ and S^μ are the nucleon momentum and spin vectors with $P^2 = M^2$, $S^2 = -M^2$, and $P.S = 0$. Define another null vector p^μ with $p \cdot n = 1$. Then S^μ is,

$$S^\mu = S \cdot n p^\mu + S \cdot p n^\mu + \Sigma^\mu \tag{2}$$

with $\Sigma \cdot p = \Sigma \cdot n = 0$ and $\Sigma \cdot \Sigma = -M^2$ for a transversely polarized target. In the

$n \cdot A = 0$ gauge, the path ordered integral between the two operators, needed for gauge invariance, is unity.

Transverse spin for a $j = 1/2$ target is first encountered at the twist-3 level. Two new gluonic distributions, $H_1(x, Q^2)$ and $H_2(x, Q^2)$, can be identified in the CPT constrained decomposition of Γ,

$$\begin{aligned} \Gamma_3^{\mu\nu,\alpha\beta} &= \frac{1}{2} i H_1 \left(\epsilon^{\mu\alpha\rho\lambda} p^\mu p^\beta + \epsilon^{\nu\beta\rho\lambda} p^\mu p^\alpha - \epsilon^{\nu\alpha\rho\lambda} p^\mu p^\beta - \epsilon^{\mu\beta\rho\lambda} p^\nu p^\alpha \right) n_\rho \Sigma^\lambda \\ &+ \frac{1}{2} i H_2 \left(\epsilon^{\mu\nu\rho\lambda} \left(\Sigma^\alpha p^\beta - \Sigma^\beta p^\alpha \right) - \epsilon^{\alpha\beta\rho\lambda} \left(\Sigma^\mu p^\nu - \Sigma^\nu p^\mu \right) \right) p_\rho n_\lambda \qquad (3) \end{aligned}$$

That H_1 and H_2 are twist-3 distributions can be verified either by dimensional counting, or by noting that, upon projection, H_1 involves F^{+-} and H_2 involves F^{12}. That is, either a "bad" component of the field or a transverse derivative of a "good" component are involved. For further discussion, see ref. 7.

One possible way of measuring H_1 and H_2 appears to be the production of $\chi_2(3555)$ mesons in doubly transversely polarized $p - p$ collisions. The χ_2 is particularly attractive for this purpose since it is self-analyzing; the photon angular distribution in $\chi_2 \rightarrow J/\psi + \gamma$ enables different polarization states of the χ_2 to be distinguished. Although more elaborate methods can be devised, we have used a simple effective Lagrangian for the production of χ_2 mesons from gluon-gluon fusion,

$$\delta\mathcal{L} = \left(\frac{g_1}{M} F^{\mu\alpha} F^{\nu\alpha} + \frac{g_2}{M^3} D^\mu F^{\alpha\beta} D^\nu F_{\alpha\beta} + \ldots \right) \chi_{\mu\nu} \qquad (4)$$

The heavy meson has been represented by a local traceless tensor field. A simple calculation shows that, up to a numerical factor, g_1 is the amplitude for producing $J_z = \pm 2$ states and g_2 that for $J_z = 0$. These amplitudes can be related to the wavefunction at the origin in a non-relativistic model, or they can be extracted from experiment.

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References

1. J. Ralston and D.E. Soper, *Nucl. Phys.* **B152**, 109, (1979).
2. X. Artru and M. Mekhfi, *Z. Phys.* **C45**, 669, (1990).
3. R. L. Jaffe and X. Ji, *Phys. Rev. Lett.* **67**, 552, (1991).
4. R. L. Jaffe and X. Ji, *Nucl. Phys* **B375**, 527, (1992).
5. G. Bunce et al, *Part. World* **3**, 1, (1992).
6. P. Hoodbhoy and X. Ji, submitted to *Phys. Rev. D.*
7. R. Ali and P. Hoodbhoy, *Z. Phys.* **C57**, 325, (1993).