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Measuring nuclear gluon shadowing through three-jet production in electron–nucleus collisions

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Abstract. The possibility of studying the nuclear gluon distribution by looking at large transverse momentum jets in deep inelastic lepton scattering is investigated. Provided that a colliding beam of leptons and nuclei, rather than a fixed nuclear target, can be arranged, a clean measurement of gluon shadowing appears possible.

1. Introduction

The gluon contribution to deep inelastic lepton scattering from a hadron target can, in principle, be measured by classifying events according to the final state. Whereas γ–q scattering leads to single-jet events, γ–g scattering leads to two back-to-back jets in the CM system in the lowest order (figure 1). This has been the basis of a proposal for measuring the gluon content of a polarized proton by measuring the large transverse momentum jets [1]. Unfortunately, as pointed out by Manohar [2], this is not experimentally feasible for protons at rest in the laboratory. The problem is that, in the laboratory frame, for transverse momentum of order Q, the angle between the jets, $\sin\theta \sim M/Q$, becomes small for large Q. For smaller values of the transverse mementum, $\sin\theta \sim M/k_\perp$. This too does not lead to a satisfactory situation, because only events with $k_\perp \gg \langle k_\perp \rangle_{\rm intrinsic}$ ought to be considered in order to avoid contamination with the protons intrinsic transverse momentum. Thus, for a target at rest, two-jet events are difficult to separate from the dominant one-jet events.

A possible way out has been suggested by Manohar [2], who considers an experimental situation in which both the electron and the polarized proton are highly relativistic in the laboratory frame, an arrangement which may be possible at colliders such as HERA. The kinematics for this process suggest that the three jets (the third being the proton debris) will be distinguishable provided that the opening angle between any two jets exceeds a certain minimum value δ, and that the transverse-jet momentum fraction is large enough,

$$\lambda^2 \geqslant (1-\cos\delta)\frac{E_{\rm min}^2/E_{\rm p}^2}{2x(x+E_{\rm l}/E_{\rm p})}. \tag{1}$$

Here $\lambda^2 = k_\perp^2/Q^2$, $E_{\rm l}$ is the lepton energy, $E_{\rm p}$ is the proton energy, and $E_{\rm min}$ is the minimum energy of a jet which should be large compared to $\Lambda_{\rm QCD}$. It additionally obeys the restriction $E_{\rm min} \leqslant (\xi - x)E_{\rm p}$, where ξ is the longitudinal momentum

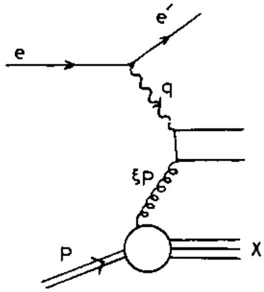

Figure 1. Scattering of a photon from a gluon carrying momentum fraction ξ of the hadron target.

fraction carried by the struck gluon. The requirement that perturbative QCD hold, $Q^2 \geqslant Q^2_{\min}$, translates into the condition that $x \geqslant x_{\min}$ for measurable 3-jet events, where $x_{\min} = Q^2_{\min}/4E_p E_l$.

2. Three-jet production

We now consider adapting the discussion of [2] for the purpose of measuring the unpolarized gluon distribution in a hadron. Again, the leading-order contribution from gluons is given by the Feynman diagram in figure 1. Working in parallel with [2], we find the three-jet contribution to $F_1(x)$ arising from a gluon distribution $g(\xi)$ to be

$$xF_1^{3\text{jet}}(x) = \frac{\alpha_s N_f}{8\pi} \int_{\xi_{\min}}^{\xi_{\max}} \frac{d\xi}{\xi} g(\xi) F(x, \xi) \tag{2}$$

where

$$\xi_{\min} = x + E_{\min}/E_p$$
$$\xi_{\max} = 1 - E_{\min}/E_p. \tag{3}$$

The kernel $F(x, \xi)$, with $z = x/\xi$ being the effective value of x for the parton subprocess, is

$$F(x, \xi) = [z^2 + (1-z)^2] \log \frac{1-z}{z\varepsilon(x)} + 2[\tfrac{1}{2} + z(1-z)] \tag{4}$$

where

$$\varepsilon(x) = \frac{E^2_{\min}(1 - \cos\delta)}{2xE_p(xE_p + E_l)} \ll 1 \tag{5}$$

is the lower transverse momentum cut-off.

To estimate the size of the three-jet contribution, it is instructive to consider 35 GeV electrons (which is the HERA value) in collision with a proton beam with various energies at a fixed value $Q^2 = 4\ \text{GeV}^2$. Each jet is assumed to have an energy in excess of 1 GeV. The angular size of the cone formed around a fast quark is approximately $\theta = \langle k_T \rangle / P_q \approx 0.3$ radians at $Q^2 = 4\,\text{GeV}^2$. Thus, the minimum opening angle δ, which is needed to identify individual jets, must exceed 0.6 radians. In figure 2, numerical values for $xF_1^{3\text{jet}}(x)$ are displayed using the simple model for the gluon distribution given in [3].

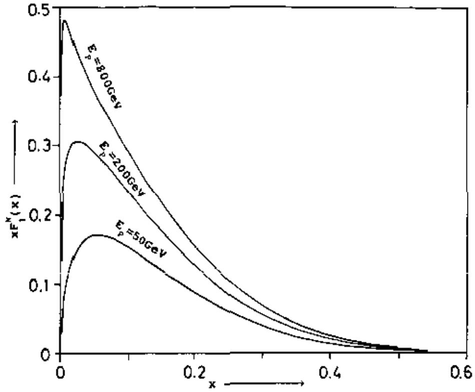

Figure 2. Three-jet contribution to $xF_1(x)$ for a nucleon with nucleon energy $E_p = 50\,\text{GeV}$, 200 GeV, and 800 GeV, and with other parameters as discussed in the text.

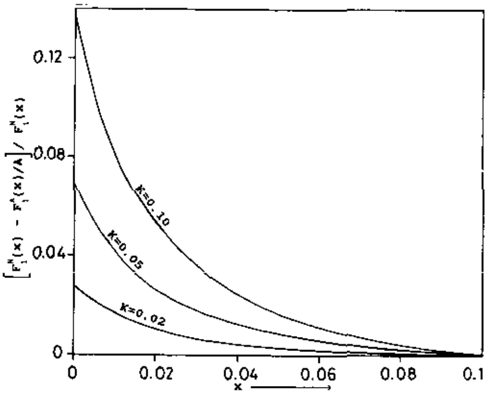

Figure 3. Relative shadowing for 50 GeV/nucleon ^{32}S ions for shadowing factors $K = 0.02$, 0.05, 0.1 and other parameters as discussed in the text.

The results (2)–(5) have immediate application to the nuclear gluon distribution provided that colliding beams of electrons and relativistic ions can be arranged. Nuclear gluons at small x are of particular interest since, for $x \leqslant 1/2MR$, partons are no longer confined to individual nucleons. Instead, they extend over the entire nucleus in the longitudinal direction as a consequence of which they undergo recombination, which leads to an altered (or shadowed) nuclear gluon distribution. A simple model has been proposed by Qui [3],

$$\frac{1}{A} g^A(\xi) = g(\xi) R_G(\xi, A)$$

where, at a fixed value of Q^2, the gluon shadowing factor is

$$R_G(\xi, A) = \begin{cases} 1 & x_n < \xi < 1 \\ 1 - K(A^{1/3} - 1) \dfrac{1/\xi - 1/x_n}{1/x_A - 1/x_n} & x_A \leqslant \xi \leqslant x_n \\ 1 - K(A^{1/3} - 1) & 0.001 < \xi < x_A. \end{cases}$$

The parameters x_n and x_A, for the nucleon and nucleus respectively, are $x_n = 1/(2rM)$ and $x_A = 1/(2RM)$. The constant K is essentially unknown and has, somewhat arbitrarily, been chosen to lie between 0.02 and 0.10 in [3] at a reference value of $Q_0^2 \approx 4\,\text{GeV}^2$.

To estimate the extent to which three-jet events could discriminate between different nuclear gluon distributions, we consider relativistic ^{32}S ions in collision with electrons with all parameters identical to the single nucleon case discussed above. Figures 3–5 show the relative shadowing for 50 GeV/nucleon, 200 GeV/nucleon and 800 GeV/nucleon ions for $K = 0.02$, 0.05, and 0.10. Increasing the ion energy much further leads to relatively little increase in the relative shadowing, which is fairly substantial even at the values shown.

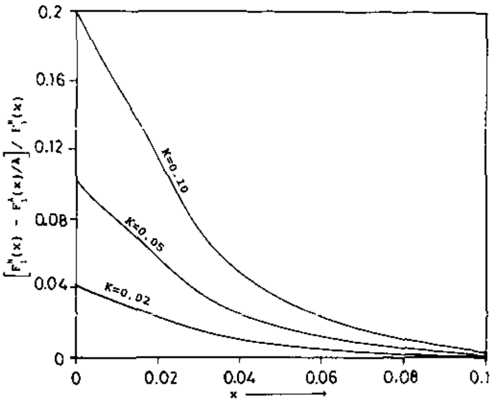

Figure 4. As in figure 3, but with $E_p =$ 200 Gev/nucleon.

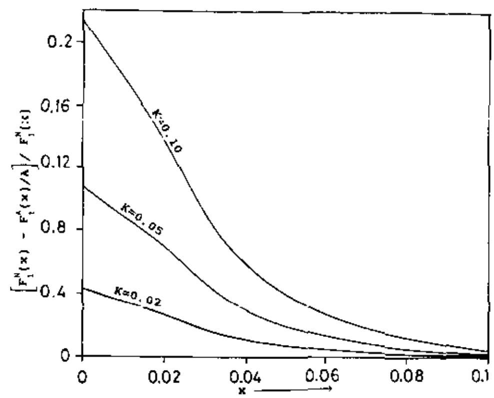

Figure 5. As in figure 3, but with $E_p =$ 800 GeV/nucleon.

3. Conclusion

It thus appears that the use of a relativistic nuclear target in deep inelastic scattering could enable the measurement of gluon shadowing. This method is, in principle, superior to using charmonium production from gluon fusion processes because final-state quark interactions are unimportant for jet measurement. In contrast, the heavy-quark system undergoes complicated A-dependent interactions as it makes its way out of the nucleus.

Acknowledgment

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References

[1] Carlitz R D, Collins J C and Mueller A H 1988 *Phys. Lett.* **214B** 224
[2] Manohar V A 1991 *Phys. Lett.* **255B** 579
[3] Qui J 1987 *Nucl. Phys.* B **291** 746