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Angular correlations in lepton-hadron scattering

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Angular correlations between the outgoing lepton and one of the outgoing fast hadrons in lepton-hadron scattering can give interesting information on quark-gluon dynamics.

Gluon corrections give rise to some interesting predictions for the final-state hadrons in lepton-hadron scattering.[1,2,3] The most noticeable of these is probably the expectation that at high energies a fraction of the events will show a two-jet structure in the current-fragmentation region. This structure will, however, be superimposed on the standard single jet along the direction of the virtual photon, and therefore it may not be easy to disentangle it from the usual background. Other effects may therefore be easier to detect experimentally, e.g., an increase with Q^2 in the average transverse momentum of the hadrons with respect to the virtual photon axis, or angular correlations between a produced fast hadron and the outgoing lepton. This point was recently emphasized by Georgi and Politzer.[2] In this paper we want to extend their considerations to neutrino-induced reactions and emphasize the interest of looking at terms proportional to $\cos^2\varphi$ in the differential cross section.

The φ dependence of the semi-inclusive differential cross section may be parametrized as

$$\frac{d\sigma}{dy\,dx\,dz\,d\varphi}=A+B\cos\varphi+C\cos^2\varphi\,, \tag{1}$$

where the notation for the kinematic variables is standard: y is the energy loss of the lepton divided by the incoming lepton energy, x is the Bjorken scaling variable, and z is the energy of the observed hadron divided by the energy loss of the lepton, φ is the angle between the transverse component of the produced hadron and the transverse component of the outgoing lepton.

The term A in (1) will contain the zeroth-order parton-model term so that gluon corrections will only affect it at the level of the quark-gluon coupling constant (say 10–20%). The term B gets contributions *only* from gluon corrections and was discussed extensively by Georgi and Politzer[2] who obtained the interesting result that for hard pions ($z\to 1$) and small values of the Bjorken variable x, the average value of $\cos\varphi$ becomes negative. In other kinematic regions the $\cos\varphi$ dependence will not be very noticeable since the gluon-jet contribution to B will tend to cancel the quark-jet contribution while the pair-creation term hardly produces any asymmetry at all; in the limit considered by Georgi and Politzer[2] it integrates out to give a zero contribution to the average $\cos\varphi$. The term C again gets contributions *only* from gluon corrections and furthermore the different contributions to it all add up. It may therefore be easier to detect experimentally. From the diagrams in Fig. 1 we obtain

$$\frac{d\sigma^{l+p\to l+h+\cdots}}{dy\,dx\,dz\,d\varphi}=\cos^2\varphi\frac{16\alpha^2(1-y)}{3\pi yQ^2}\alpha_s \times\sum_i Q_i^2\int_x^1\int_z^1\frac{dx_p}{x_p}\frac{dz_p}{z_p}\left[q_i\left(\frac{x}{x_p},Q^2\right)x_pz_pD^h_{q_i}\left(\frac{z}{z_p},Q^2\right)+q_i\left(\frac{x}{x_p},Q^2\right)x_p(1-z_p)D^h_G\left(\frac{z}{z_p},Q^2\right) + \tfrac{3}{4}G\left(\frac{x}{x_p},Q^2\right)x_p(1-x_p)D^h_{q_i}\left(\frac{z}{z_p},Q^2\right)\right] \tag{2}$$

$$+\text{ terms independent of }\varphi+\text{terms linear in }\cos\varphi\,.$$

The first two terms in the square brackets on the right-hand side of (2) come from hard bremsstrahlung of a gluon off a quark. The observed hadron can then either be produced from the outgoing quark (first term in the square brackets) or from the radiated gluon (second term in the square brackets). The third

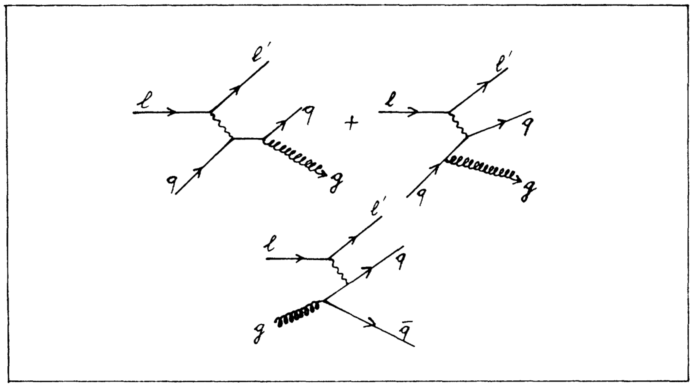


FIG. 1. Diagrams leading to angular correlations between the outgoing lepton and one of the outgoing fast hadrons.

term in the square brackets is due to quark pair creation by a gluon, where $G(x)$ is the number density of gluons in the proton. For the similar situation of neutrino scattering on an isoscalar nucleus $[N=(p+n)/2]$ one has

$$\frac{d\sigma^{\nu+N\to\mu^-+h}}{dy\,dx\,dz\,d\varphi}=\cos^2\varphi\,\frac{G_F{}^2MEx}{\pi}\,\frac{8\alpha_s}{3\pi^2}(1-y)$$
$$\times\int_x^1\frac{dx_p}{x_p}\int_z^1\frac{dz_p}{z_p}\Big\{\tfrac{1}{2}\Big[d\Big(\frac{x}{x_p},Q^2\Big)+u\Big(\frac{x}{x_p},Q^2\Big)\Big]\,x_pz_pD_u^h\Big(\frac{z}{z_p},Q^2\Big)$$
$$+\tfrac{1}{2}\Big[d\Big(\frac{x}{x_p},Q^2\Big)+u\Big(\frac{x}{x_p},Q^2\Big)\Big]\,x_p(1-z_p)D_G^h\Big(\frac{z}{z_p},Q^2\Big)$$
$$+\tfrac{3}{4}G\Big(\frac{x}{x_p},Q^2\Big)x_p(1-x_p)D_u^h\Big(\frac{z}{z_p},Q^2\Big)+\tfrac{1}{2}\Big[\bar d\Big(\frac{x}{x_p},Q^2\Big)+\bar u\Big(\frac{x}{x_p}\Big)\Big]x_pz_pD_{\bar d}^h\Big(\frac{z}{z_p},Q^2\Big)$$
$$+\tfrac{1}{2}\Big[\bar d\Big(\frac{x}{x_p},Q^2\Big)+\bar u\Big(\frac{x}{x_p},Q^2\Big)\Big]\,x_p(1-z_p)D_g^h\Big(\frac{z}{z_p},Q^2\Big)$$
$$+\tfrac{3}{4}G\Big(\frac{x}{x_p},Q^2\Big)\,x_p(1-x_p)D_{\bar d}^h\Big(\frac{z}{z_p},Q^2\Big)\Big\}$$
$$+\text{terms independent of }\varphi+\text{terms linear in }\cos\varphi. \qquad (3)$$

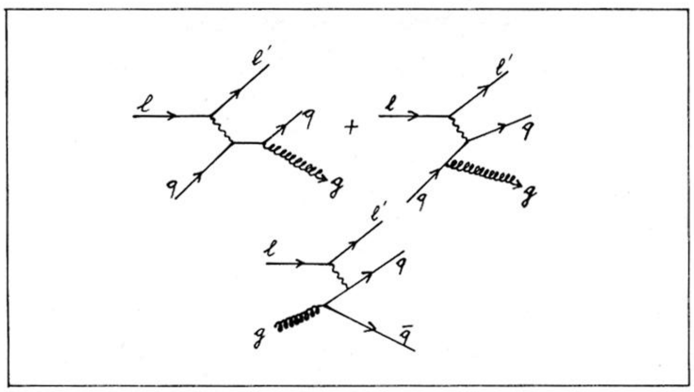
The first three terms on the right-hand side of (3) arise from scattering of the neutrino off a quark while in the last three terms the neutrino scatters off an antiquark. The corresponding expression for antineutrino scattering can be obtained by simply replacing in (3) u by d.

Numerical estimates of the different terms on the right-hand side in (2) and (3) show that each one of them is roughly of the same order of magnitude (except of course if antiquarks in the initial proton play a role). Except for the presence of the quark-gluon coupling constant α_s, these terms are not in themselves much smaller than the usual parton-model contribution to the φ-independent term. We therefore believe that the $\cos^2\varphi$ term stands a chance of being detected experimentally in the near future. If present it will give us direct positive confirmation of the presence of gluons and will allow us to get information on the gluon distribution function in the proton as well as on the gluon-fragmentation functions.

[1]J. Ellis, M. K. Gaillard, and G. G. Ross, Nucl. Phys. B111, 253 (1976).

[2]H. Georgi and H. D. Politzer, Phys. Rev. Lett. 40, 3 (1978).

[3]K. H. Craig and C. H. Llewellyn Smith, Phys. Lett. 72B, 349 (1978).



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