G. Ramalho · Franz Gross · M. T. Peña

Spin Structure Functions in a Covariant Spectator Quark Model

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Abstract We apply the covariant spectator quark–diquark model, already probed in the description of the nucleon elastic form factors, to the calculation of the deep inelastic scattering (DIS) spin-independent and spin-dependent structure functions of the nucleon. The nucleon wave function is given by a combination of quark–diquark orbital states, corresponding to S, D and P-waves. A simple form for the quark distribution function associated to the P and D waves is tested.

1 Introduction

Recently, the problem that usually goes under the label of “proton spin crisis” has been revisited [1] in light of the orbital motion of the constituent quarks. Following this perspective, we applied the covariant spectator quark–diquark model for the nucleon [2, 3] to the DIS limit, where the squared momentum transfer Q^2 and the photon energy ν in the nucleon rest frame are taken to infinity, while $x = \frac{Q^2}{2M\nu}$ is finite (M is the nucleon mass). In our model the quark-photon coupling is parametrized in terms of quark electromagnetic form factors [2] by assuming vector meson dominance.

The quark and diquark properties (spin, isospin and orbital angular momentum) are explicitly included in the nucleon wave function, Ψ_N , where the spectator diquark is taken to be on-mass-shell [2]. The nucleon wave function is written as the combination of three terms

$$\Psi_N = N [\Psi_S + a\Psi_D + b\Psi_P], \quad (1)$$

where Ψ_S , Ψ_D and Ψ_P describe respectively the S [2, 3], D [4, 5], and P [6] quark–diquark orbital states, and a and b are admixture coefficients.

2 Results for the Parton Distribution Functions

By using the wave function in Eq. (1), one can define the quark distribution functions $\tilde{f}_q(x)$, associated with the S- and P-partial waves, and $g(x)$, associated to the D-wave, as well as the two distribution functions $h_1(x)$

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G. Ramalho (✉)
CFTP, Instituto Superior Técnico, Av. Rovisco Pais 1, 1049-001 Lisbon, Portugal
E-mail: gilberto.ramalho@cftp.ist.utl.pt

F. Gross
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

M. T. Peña
CFTP and Department of Physics, Instituto Superior Técnico, Av. Rovisco Pais 1, 1049-001 Lisbon, Portugal

and $h_2(x)$ associated to the P-partial wave. An important feature of the model is that it gives a qualitative description of the Callen-Gross scaling, which relates W_1 , W_2 to $\tilde{f}_q$ [7]. The parton unpolarized, W_1 , W_2 , and polarized, g_1 , g_2 , distribution functions are then written as

$$\begin{aligned} \nu W_2(x) &= 2MxW_1(x) = e_I^2 x \tilde{f}_q(x) \\ g_1(x) &= \frac{5}{18} e_N \tilde{f}_q(x) - \frac{1}{9} (5 - \tau_3) a \eta g(x) + \delta_D \frac{5}{9} (1 - \tau_3) a \eta g(x) \\ g_2(x) &= \frac{1}{6} (5 - \tau_3) a \eta g(x) - \delta_D \frac{5}{6} (1 - \tau_3) a \eta g(x) + \frac{5}{18} e_N b [h_1(x) - h_2(x)], \end{aligned} \quad (2)$$

where $e_I^2 = \frac{1}{6} (5 + \tau_3)$ and $e_N = \frac{1}{2} (1 + \tau_3)$. In the previous equations η is the interference factor between the S- and D- spin-1 components of the wave function, and δ_D is a parameter which measures the asymmetry between the u and d distributions in the D-state wave function.

Although a good description of $\tilde{f}_q$ can be obtained by fitting the S-state component of the wave function to the unpolarized DIS data [2,6], with only this component in the wave function the valence quark contribution to the g_1^P structure function of the proton overestimates the data (dashed line in left panel of Fig. 1). But the addition of the D-state higher partial wave component helps to explain the data, and a perfect fit to the g_1^P data can be achieved if the D-state contribution is of the form $\frac{4}{9} \eta a g(x) = 1.2(1-x)^6$.

Fig. 1 Proton and neutron $g_1(x)$ structural functions. Data from Refs. [8–13]

Fig. 2 Proton and neutron $g_2(x)$ structural functions. Data from Refs. [9,12–14]

Another finding is that the g_1^n data, associated with the neutron, is well described only if one includes a large asymmetry between u and d distributions in the D-state wave function component ($\delta_D \approx \frac{1}{2}$). This is shown in the right panel of Fig. 1. Finally, the combination of P- and D-states, together with an asymmetry between the u and d distributions, provides contributions to g_2 , for both the neutron and proton cases, which are consistent with the available data. This is shown in Fig. 2.

3 Conclusions

The covariant spectator quark-diquark model reveals how the information contained in the DIS regime data can be related to different and important aspects of the nucleon wave function. The S-, P- and D-partial wave components of that wave function, as well as the asymmetry between u and d quark distributions, seem to be very promising features to be used in the interpretation of the DIS data [6].

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