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PROTON SPIN IN DEEP INELASTIC SCATTERING*

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So far, the analyses of the polarized structure functions of the proton and neutron have been limited to the evaluation of their integrals and comparing them to the prediction of the static-quark model of the nucleon. We extended our analysis to the x dependence of the polarized structure functions and observe that the measured structure function excellently agrees with the prediction of the static-quark model for Bjorken $x > 0.2$ and drops rapidly for $x < 0.2$. It is suggested that for Bjorken $x > 0.2$, electrons get scattered on the undamaged constituent quarks (alias valence quarks) denoted as quasi-elastic scattering on the constituent quarks and for $x < 0.2$, the constituent quarks fragment. In the fragmentation, strong interaction is involved which does not preserve the polarization.

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1. Introduction

The weak decays of the baryon octet are well-reproduced in the flavour SU3. The weak vector current transition is given by the Fermi coupling constant G_{F} multiplied by the cosine of the Cabbibo angle $\cos\theta_{\mathrm{C}}$ for the neutron decay and by $\sin\theta_{\mathrm{C}}$ for the hyperons decays. For the axial-vector transition (partially conserving axial-vector current), two experimental coupling constants g_A for the neutron decay and g_Σ for the hyperons decays have to be used in order to restore the SU3 symmetry [1] for this decay. The two coupling constants for constituent quarks are smaller than the coupling constants for the elementary quarks, witnessing that the angular momentum

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of the constituent quark is not carried entirely by the quark spin. Knowing the axial-vector transitions of the hyperons and neutron the spin carried by quarks in the baryon octet is uniquely determined. By means of the light cone algebra, taking into account the moving system and assuming that the strange quarks do not contribute to the polarization of the proton and neutron, Ellis and Jaffe [2] calculated the integrals of the polarized structure function for the proton

$$\int g_1^p(x)\mathrm{d}x = \frac{g_A}{6}(1-b) = 0.175 \tag{1}$$

and for the neutron

$$\int g_1^n(x)\mathrm{d}x = -\frac{g_A}{6}b = 0.023\,. \tag{2}$$

In the two equations, the parameter b reduces the integrals as a consequence of the fluctuations $p \to n + \pi^+$ and $n \to p + \pi^-$. Since the first measurement by the EMC Collaboration in 1989 [3] and following experiments of the SMC Collaboration [4], the NMC Collaboration [5], the HERMES Collaboration [6] and the COMPAS Collaboration [7], the integral of the proton polarized structure function strongly disagrees with the predicted value. The HERMES value for the integral is

$$\int g_1^p(x)\mathrm{d}x = 0.127 \pm 0.002 \pm 0.007 \pm 0.005\,. \tag{3}$$

2. Dependence of the polarized structure function on the Bjorken x

The difference between the quark polarization calculated on the light cone and in the rest frame of the nucleon is marginal. Therefore, we sketch the derivation of the quark polarization in the rest frame of the nucleon. For the three elementary uud quarks, the integral of the quark polarization is

$$\langle p\uparrow|\Sigma\sigma_{zi}|p\uparrow\rangle = 2\frac{g_A}{6}\langle p|p\rangle \tag{4}$$

and $g_A = \frac{5}{3}$ as can be found in any textbook of particle physics, for instant [8]. Identical expression (4) is valid for the restored SU3 if $g_A = 1.27$ is taken and the measured wave function for the valence quarks is used. The proportionality between the polarized and not polarized structure functions is valid in all models in which the 3-quark wave function factorizes in color $\times$ orbital $\times$ spin–isospin parts. The left-hand side of Eq. (4) corresponds to twice the integral over the polarized structure function, the right one, to the integral over the structure function of the valence quarks multiplied by the reducing factor. Omitting the integrals, the polarized structure function sounds

$$xg_2^p(x) = \frac{g_A}{6} F_2^{p(\mathrm{val})}(x)\,. \tag{5}$$

There is no direct measurement of the valence-quark structure function. With a single measurement of the structure function, it is not possible to single out the valence-quarks structure function. For the fit, too many parameters have to be assumed *ad hoc*. Particularly, the assumption for the ratio 2 : 1 for the u and d valence quarks used in all the fits neglects the pion fluctuation and leads to unrealistic results. The best reconstruction of the valence-quarks structure function taking into account the pion fluctuation can be obtained from the measurement of the Gottfried sum rule

$$\int \frac{1}{x}\left(F_2^p(x) - F_2^n(x)\right) = \frac{1}{3}(1-2a) \tag{6}$$

and a is the probability for the $p \to n + \pi^+$ fluctuation. In Fig. 1 we

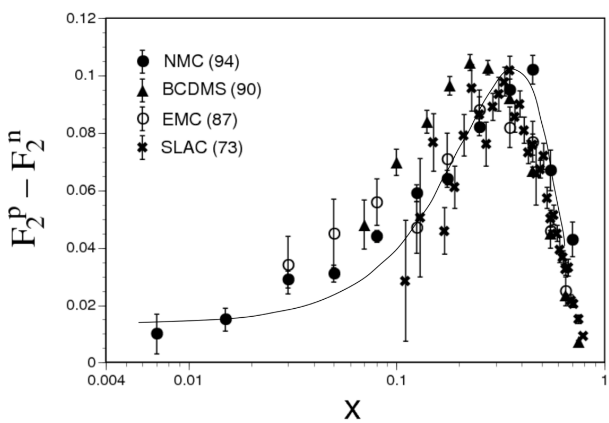

Fig. 1. Difference between the proton and neutron structure function. The fit has been done for the NMC data.

show the fit to the NMC data. From equation (6), we see that the pion fluctuation is deduced twice, once taken off the proton and ones shifted to the neutron. From equations (1) and (2), one sees how the missing integrals over the proton structure function appear in the integral of the neutron. The missing part of the structure function due to the pion fluctuation can be credibly restored by the measured neutron structure function. The full reconstruction is shown in Fig. 2. The following Fig. 3 shows the comparison between the prediction of the static model [2] and the polarized structure function by the experimental data. In fact, the full reconstruction of the

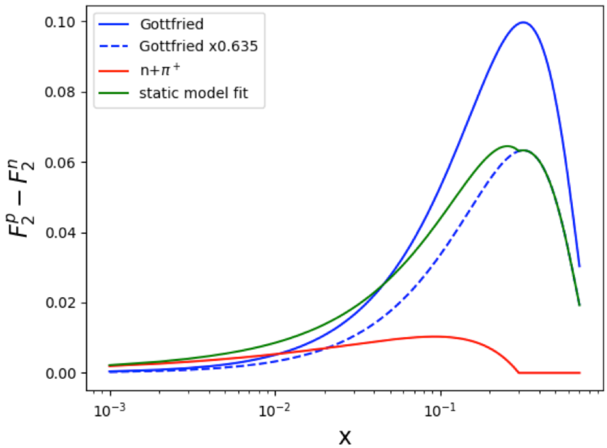

Fig. 2. Reconstructure of the polarized structure function of the static model.

predicted polarized structure was not necessary as we only wanted to show that for $x > 0.2$, the polarized structure function obtains the maximum possible value. On the other hand, the full reconstruction shows that the integral over the polarized structure function amounts to about half of the predicted integral which is in agreement with data.

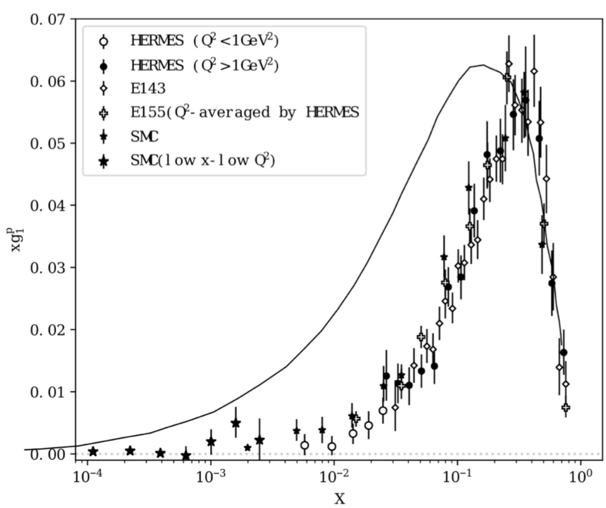

Fig. 3. Comparison of the prediction of the statical model and the data.

3. Discussion and conclusion

Figure (3) is strongly suggestive. At Bjorken $x = \frac{1}{3}$, one expects that the electrons get elastically scattered on the objects with a mass of one third of the nucleon mass. It is rather plausible to identify the events which conserve the quark spin with the elastic scattering of electrons on the bound constituent quarks denoted usually as quasi-elastic scattering. In Fig. 4, the quasi-elastic scattering on an undamaged constituent quark, scattering on a fraction of a constituent quark and scattering on the quark–antiquark pairs is shown. In the interpretation of the DIS measurements, it is assumed

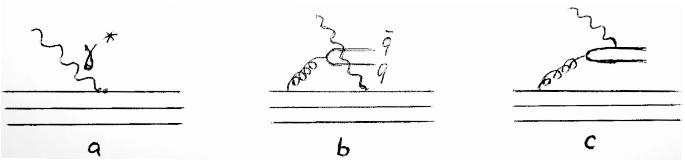

Fig. 4. (a) Quasi-elastic scattering on the constituent quark, (b) scattering on a fraction of the constituent quark and (c) scattering on the quark–antiquark pairs.

that the nucleon is completely dissolved in the current quarks and gluons. From the identification of the valence quarks in the structure functions it is, however, obvious that they are composed objects and only as the wholes carry the spin of the constituent quark. The undamaged constituent quark carries the spin of the current quark, the damaged — not necessarily. Even if the current quark of the damaged quark conserves the polarization, the damaged constituent quark as a whole does not. There is further important information that follows from the analysis of the polarization measurements in DIS. In the scattering experiments, the two scales of the hadrons are clearly demonstrated by the interplay between the soft and hard interaction as summarized in [9] and reported earlier in [10] and [11]. The interaction involving hadron substructure which is responsible for the hard interaction is dominated by the gluon exchange. Therefore, the members of the substructure were called gluon spots [10]. Identifying the gluon spots with the constituent quarks is rather obvious. Identifying the substructure of the light hadrons with the constituent quarks gives the models with three constituent quarks in a common mean-field theoretical justification.

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REFERENCES

[1] N. Cabbibo, E.C. Swallow, R. Winston, *Annu. Rev. Nucl. Part. Sci.* **53**, 39 (2003).

[2] J. Ellis, R. Jaffe, *Phys. Rev. D* **9**, 1444 (1974).

[3] J. Ashman *et al.*, *Nucl. Phys. B* **328**, 1 (1989).

[4] D. Adeva *et al.* [SMC Collaboration], *Phys. Rev. D* **58**, 112001 (1998).

[5] P. Amaudruz *et al.* [NMC Collaboration], *Phys. Rev. Lett.* **66**, 21 (1991).

[6] A. Airapetian *et al.* [HERMES Collaboration], *Phys. Rev. D* **75**, 012007 (2007).

[7] C. Adolph *et al.* [COMPASS Collaboration], *Phys. Lett. B* **753**, 18 (2016) [arXiv:1503.08935 [hep-ex]].

[8] F.E. Close, *An Introduction to Quarks and Partons*, Academic Press Inc., 1979.

[9] B. Kopeliovich, I. Potashnikova, B. Povh, I. Schmitt, *Phys. Rev. D* **76**, 094020 (2007).

[10] B. Kopeliovich, B. Povh, *J. Phys. G: Nucl. Part. Phys.* **30**, S999 (2004).

[11] B. Kopeliovich, A. Schäfer, A. Tarasov, *Phys. Rev. D* **62**, 054022 (2000).