MEASUREMENT OF THE INTERFERENCE STRUCTURE FUNCTION $xG_3(x)$ IN MUON–NUCLEON SCATTERING

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The interference structure function $xG_3(x)$ has been measured for the first time scattering positive and negative muons of opposite helicity off a carbon target. The x dependence observed for Q^2 between 40 and 180 (GeV/c^2) is in good agreement with predictions of the quark–parton model. The measured ratio $2(a_\mathrm{u}Q_\mathrm{u} + a_\mathrm{d}Q_\mathrm{d})/(Q_\mathrm{u}^2 + Q_\mathrm{d}^2) = 1.87 \pm 0.25$ (stat.) $\pm$ 0.24 (syst.) is consistent with the hypothesis of fractional quark charges and determines the sign of $Q_\mathrm{u} - Q_\mathrm{d}$ to be positive.

Deep inelastic scattering of charged leptons has provided valuable information about the hadron structure through measurements of the one-photon exchange cross section σ_0 [1]. At the energies presently available the weak interaction is dwarfed by the electromagnetic one. However, their interference can be used to probe in a novel way the nucleon. The interference between the photon and Z_0 boson exchange gives rise to a cross section which depends on the charge and polarization (λ) of the beam. We have isolated this contribution by measuring over a wide range of Q^2 and x the asymmetry

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$$B = \frac{\sigma^+(-\lambda) - \sigma^-(+\lambda)}{\sigma^+(-\lambda) + \sigma^-(+\lambda)} . \qquad (1)$$

The cross sections σ^+ and σ^- are obtained in the deep inelastic scattering of positive and negative muons off a 40 m long carbon target at incoming energies of 200 GeV ($|\lambda| = 0.81$) and 120 GeV ($|\lambda| = 0.66$) [2].

The cross-section difference $\sigma^+(-\lambda) - \sigma^-(+\lambda)$ due to the electroweak interference can be expressed in terms of a structure function xG_3 [3]

$$\mathrm{d}^2\sigma^+/\mathrm{d}Q^2\,\mathrm{d}x - \mathrm{d}^2\sigma^-/\mathrm{d}Q^2\,\mathrm{d}x = \Delta\sigma$$
$$= 2(G/\sqrt{2})\,\alpha(1/Q^2x)(a_\mu - \lambda v_\mu)[1-(1-y)^2]\,xG_3 . \qquad (2)$$

Here v_μ (a_μ) is the vector (axial-vector) neutral-current coupling of the muon to the Z_0 and x, y are the familiar scaling variables. In the Glashow–Weinberg–Salam theory the muon couplings are determined to be $v_\mu = -0.04$ (for $\sin^2\theta = 0.23$) and $a_\mu = -1/2$. Therefore experimental values of $\Delta\sigma$ can be used to extract xG_3 which in the quark–parton model is given by

$$xG_3 = 2x \sum a_q Q_q (q - \bar{q}) , \qquad (3)$$

where a_q are the axial-vector quark couplings to the Z_0, Q_q the electric charges of the quarks and q ($\bar{q}$) the quark (antiquark) distribution functions.

At ep collider machines reaching four-momentum transfers of the order of 10^4 (GeV/c^2) the contributions due to the Z_0 exchange will be comparable to the one-photon exchange part [4]. Therefore the axial-vector interference structure function xG_3 will essentially play the role of xF_3 measured in neutrino experiments [5].

In this paper we present the first measurement of this interference structure function. The experiment was performed at the CERN SPS with the 50 m long toroidal muon spectrometer described elsewhere [6]. A description of the data taking procedure can be found in the report on the B-asymmetry measurement [2].

The calculation of xG_3 is based on 1.5 million deep inelastic muon–carbon interactions with $Q^2 > 40$ (GeV/c^2) at 200 GeV beam energy. Despite the high statistics available, the study is limited to the x dependence of xG_3 because the result is derived from the $\mu^+ - \mu^-$ cross-section difference which amounts to only about 1% of σ_0. The data were corrected for geometric acceptance and resolution smearing using a Monte-Carlo simulation of the experiment which included beam-phase space, multiple scattering, energy losses in the target and spectrometer, electromagnetic background associated with the muon track, simulation of hadronic showers and small detector inefficiencies. A correction was performed for charge dependent contributions due to the interference between single and double photon exchange and bremsstrahlung at the leptonic and hadronic vertices the size of which is shown in fig. 1 [4]. The parton-model calculation of the radiative corrections depends on the choice of parton distributions and quark masses. The resulting uncertainty is negligible compared to the statistical errors of xG_3.

The relative normalization of the μ^+ and μ^- data represents a crucial problem for the measurement of a small cross-section difference. However, this problem can be solved by using the theoretical prediction that the asymmetry (eq. (1)) has to vanish at $Q^2 = 0$. More precisely, B is proportional to $g(y)\,Q^2$ where $g(y) = [1-(1-y)^2]/[1+(1-y)^2]$. A straight line fit $B = a + bg(y)\,Q^2$ to the data gives an intercept compatible with zero, i.e. $a = (0.15 \pm 0.17(\text{stat.}) \pm$

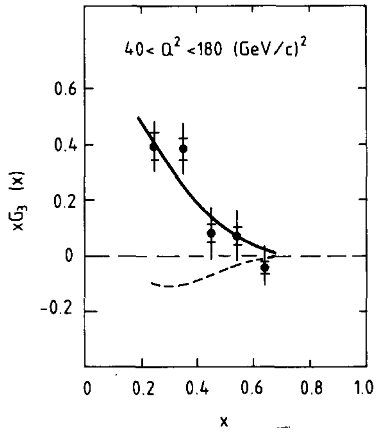

Fig. 1. Axial-vector interference structure function $xG_3(x)$ measured at 200 GeV incoming muon energy. The full error bars represent the statistical and systematic errors added in quadrature and the inner bars show the systematic errors alone. The solid curve represents the theoretical prediction $xG_3 = \frac{9}{5}F_2$ based on our measurement of F_2 [7]. The dashed curve shows the contribution of radiative processes which has been subtracted from the data.

0.20(syst.)) × 10^{-2} [2]. For the calculation of xG_3 we have used the theoretical prediction $a = 0$ to determine the relative normalization. The measured xG_3 function is shown in fig. 1. Without any theoretical input the resulting xG_3 would have been about 20% smaller. A parametrization $xG_3 = \alpha(1-x)^{\beta}$ yields $\alpha = 1.2 \pm 0.4$(stat.) ± 0.2(syst.) and $\beta = 3.5 \pm 1.0$(stat.) ± 0.2(syst.). The systematic error includes effects from natural charge asymmetries of matter, halo contamination and from instrumental sources due to polarity reversals (see ref. [2]).

Neglecting small sea-quark effects, the ratio of xG_3 to the electromagnetic structure function F_2 measured at $x > 0.2$ is predicted to be constant for isoscalar targets, namely

$$xG_3/F_2 = 2(a_uQ_u + a_dQ_d)/(Q_u^2 + Q_d^2)\,, \tag{4}$$

which in the standard model is equal to $\frac{9}{5}$. This is confirmed comparing the x dependence of F_2 [7] with xG_3 (see fig. 1). We find for the ratio (eq. (4)) a value of 1.87 ± 0.25(stat.) ± 0.24(syst.) which increases by about 7% if F_2 is corrected for sea-quark contributions. It is worth noting that the measured value is independent of the Monte-Carlo simulation since the acceptance correction cancels in the ratio xG_3/F_2. Using $a_u = -a_d = 1/2$, this result is in agreement with the hypothesis of fractional quark charges and represents a measurement of the sign of $Q_u - Q_d$.

References

[1] H. Montgomery and J. Drees, Ann. Rev. Nucl. Part. Sci. 33 (1983) 383.
[2] A. Argento et al., Phys. Lett. 120B (1983) 245.
[3] E. Derman, Phys. Rev. D7 (1973) 2755.
[4] D.Yu. Bardin, O.M. Fedorenko and N.M. Shumeiko, J. Phys. G7 (1981) 1331.
[5] M. Klein and T. Riemann, Berlin preprint PHE 83-08 (1983), Z. Phys. C, to be published.
[6] D. Bollini et al., Nucl. Instrum. Methods 204 (1982) 333.
[7] D. Bollini et al., Phys. Lett. 104 (1981) 41.