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

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ABSTRACT

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 $2(a_u Q_u + a_d Q_d)/(Q_u^2 + Q_d^2) = 1.87 \pm 0.25(\text{stat}) \pm 0.42(\text{syst})$ is consistent with the hypothesis of fractional quark charges and determines the sign of $Q_u - Q_d$ to be positive.

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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

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

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]

$$\frac{d^2 \sigma^+}{dQ^2 dx} - \frac{d^2 \sigma^-}{dQ^2 dx} = \Delta\sigma = 2 \frac{G}{\sqrt{2}} \alpha \cdot \frac{1}{Q^2 x} \cdot (a_\mu - \lambda v_\mu) \cdot (1 - (1-y)^2) xG_3 \quad (2)$$

Here $v_\mu (a_\mu)$ 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

$$xG_3 = 2 \times \sum_q a_q Q_q (q - \bar{q}) \quad (3)$$

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/c²) 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 [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, a cross check can be obtained from the Q^2 dependence of the asymmetry (eq. 1) which is predicted 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. $a = (.15 \pm .17(\text{stat}) \pm .20(\text{syst}))10^{-2}$ [2]. For the calculation of xG_3

we have used the theoretical prediction $a = 0$ as a constraint. The effect of this constraint is a shift of xG_3 , as large as the statistical error at low x and smaller at $x > 0.4$.

The measured xG_3 function is shown in fig. 1. A parametrization $xG_3 = \alpha(1-x)^\beta$ yields $\alpha = 1.2 \pm 0.4(\text{stat}) \pm 0.2(\text{syst})$ and $\beta = 3.5 \pm 1.0(\text{stat}) \pm 0.2(\text{syst})$. The systematic error includes the normalization uncertainty, effects from natural charge asymmetries of matter and from instrumental sources due to polarity reversals (see [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

$$\frac{xG_3}{F_2} = \frac{2(a_u Q_u + a_d Q_d)}{Q_u^2 + Q_d^2} \quad (4)$$

which in the standard model is equal to $9/5$. 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 $1.87 \pm 0.25(\text{stat}) \pm 0.42(\text{syst})$ where the systematic error is dominated by the normalization uncertainty. This 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 $Q_u - Q_d$.

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FIG. 1