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

BCDMS Collaboration

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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

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

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]

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

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

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

where a_q are the axial-vector quark couplings to the Z_0, Q_q are 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 $(\mathrm{GeV}/c^2)^2$ 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/.

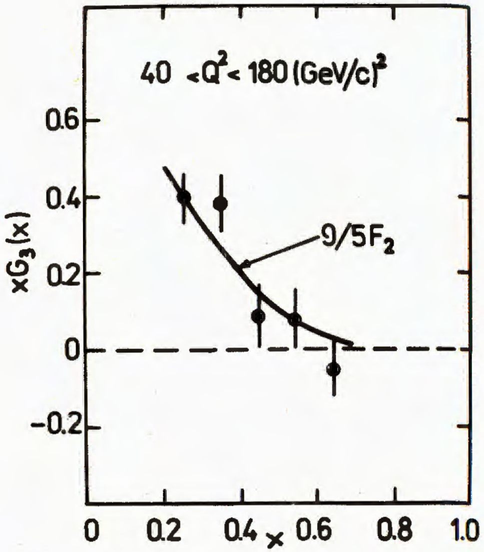
The calculation of xG_3 is based on 1.5 million deep inelastic muon-carbon interactions with $Q^2 > 40$ $(GeV/c^2)^2$ at 200 GeV beam energy. Despite the high statistics available, the study is limited to the x dependence of xG_3 because the result is derived from the $\mu^+ - \mu^-$ cross-section difference 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 straightline fit $B = a + bg(y)Q^2$ to the data gives an intercept compatible with zero, i.e., $a = (0.15 \pm 0.17(stat) \pm 0.20\ (syst)) \cdot 10^{-2}$ /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 the figure. A parametrization $xG_3 = \alpha(1-x)^\beta$ yields $\alpha = 1.2 \pm 0.4(stat) \pm 0.2(syst)$ and $\beta = 3.5 \pm 1.0(stat) \pm 0.2(syst)$. 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

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



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 the figure). We find for the ratio (eq.4) a value of 1.87 ± 0.25 (stat) ± 0.42(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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Арджента А. и др. E1-84-30
Измерение интерференционной структурной функции в мюон-нуклонном рассеянии

Экспериментальные данные по глубоконеупругому рассеянию /ГНР/ положительных и отрицательных мюонов на углероде при энергии 200 ГэВ, которые были получены в ЦЕРН сотрудничеством Болонья-ЦЕРН-Дубна-Мюнхен-Сакле, были использованы для выделения той части сечения ГНР мюонов, которая обусловлена интерференцией между обменом фотоном и Z^0 -бозоном. Изучение зависимости этой части сечения от масштабной переменной x дало возможность впервые получить значения интерференционной структурной функции $xG_3(x)$ в области значений квадрата передаваемого 4-импульса Q^2 между 40 и 180 $(ГэВ/c^2)^2$. Предсказания кварк-партонной модели для отношения стурктурных функций $xG_3(x)/F_2(x)$ хорошо согласуются с полученным экспериментальным результатом при условии, что заряды кварков дробны, а знак разности $Q_u - Q_d$ положителен.

Препринт Объединенного института ядерных исследований. Дубна 1984

Argento A. et al. E1-84-30
Measurement of the Interference Structure Function in Muon-Nucleon Scattering

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 $(GeV/c^2)^2$ is in good agreement with the predictions of the quark-parton model. The measured ratio $2(a_uQ_u+a_dQ_d)/(Q_u^2+Q_d^2)=1.87\pm0.25$ (stat) $\pm$ 0.42 (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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