NEW RESULTS ON THE SPIN DEPENDENT STRUCTURE FUNCTION $g_1$ OF THE PROTON

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We present a new measurement of the spin dependent structure function $g_1$ of the proton in the kinematic range $0.003 < x < 0.7$ and $Q^2 > 1.0$ GeV$^2$ for 1996 data. Compared with our previous measurement of $g_1^f$, in 1993, we obtained greater than 3 times the equivalent statistics. These preliminary results are compatible with our previous results, so they are combined. To evolve the structure functions from the measured $Q^2$ of the data to a fixed $Q^2$ of 10 GeV$^2$ we use a next-to-leading order perturbative QCD analysis. The first moment $\Gamma^f_1$ is then calculated, and using our results for $\Gamma^f_1$ we test the Bjorken and Ellis-Jaffe sum rules.
1 Introduction

The spin of the nucleon (spin $\frac{1}{2}$) consists of the quark spin, gluon spin and angular momentum of the quarks and gluons. Polarized deep inelastic scattering is a powerful tool to study the spin structure of the nucleon. The virtual photon-nucleon asymmetry $A_1$,

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}},$$  \hspace{1cm} (1)$$
is the cross section asymmetry for the absorption of virtual photons with spin antiparallel (total spin 1/2 for photon nucleon system) with respect to absorption with spin parallel (total spin 3/2 for photon nucleon system) to the nucleon's spin. The experiment measures the lepton-nucleon cross section asymmetry $A_{1||}$, which is related to $A_1$, and the spin dependent structure function $g_1$, by

$$A_{1||} = D(A_1 + \eta A_2), \quad g_1 = \frac{F_2}{2x(1 + R)}(A_1 + \gamma A_2).$$  \hspace{1cm} (2)$$
The depolarization factor, $D$, is a primarily kinematic factor which accounts for the fact that the exchanged virtual photons are only partially polarized. The $\eta$ and $\gamma$ terms are kinematic factors which are small for SMC's kinematic range, and so the terms proportional to $A_2$ (measured to be consistent with zero) are neglected in our calculation of $g_1$, but are accounted for in the systematic errors. For $F_2$ and $R$, which are the spin independent structure functions, the parametrizations are used from NMC (for $F_2$) [1] and SLAC (for $R$) [2]. In the Quark Parton Model (QPM), the spin structure function, $g_1$, has a simple interpretation in terms of the polarized quark distributions:

$$g_1(x) = \frac{1}{2} \sum F_q \left[ q_1(x) - q_2(x) \right].$$  \hspace{1cm} (3)$$
The first moment, $\Gamma_1$, is particularly interesting. The Bjorken sum rule [3] relates the difference of the first moments for the proton and neutron to the nucleon beta decay constant, $\Gamma_\pi^p - \Gamma_\pi^n = |g_\pi|/6$, and is a fundamental tenet of QCD. The Ellis-Jaffe sum rule [4] makes separate predictions for $\Gamma_\pi^p$, $\Gamma_\pi^n$ and $\Gamma_\pi^d$ by assuming SU(3) flavor symmetry and a non-polarized strange quark sea.

The SMC experiment has measured the spin-dependent structure function $g_1$ using muon-nucleon polarized deep inelastic scattering since 1992 [5,6,7,8,9]. In this paper, the preliminary results from the 1996 measurement for the proton, as well as the combination of this data with our previous proton and deuteron data, are presented.

2 The SMC Experiment

The SMC experiment at CERN used a 190GeV polarized $\mu^+$ beam obtained from the weak decay of the $\pi^+$. The beam polarization was approximately -0.80 [9]. A large polarized target system consisting of two target cells in the beam, each of which was 65cm long and 5cm in diameter, was used. They were polarized oppositely, and their spin direction was reversed every 5 hours which minimizes the effects of the acceptance variations of the spectrometer in the asymmetry calculation. In 1996 ammonia [10] was used as the target material, which had an average proton polarization of approximately 0.89. The advantage of ammonia compared with $p$-butanol [11], which was used in 1993, is that ammonia has a greater proportion of polarizable protons.
The SMC spectrometer consists of more than 150 planes of proportional chambers, drift chambers, streamer tubes and scintillator hodoscopes. Having this large number of detectors ensures a redundancy in the tracking which minimizes the systematic errors. The track and hence momentum is measured for both the beam and scattered muons (which are identified by their passage through iron absorbers).

In 1996 SMC obtained approximately 9 million inclusive events after cuts. This is approximately twice the number of events for 1993 [9], which was the other year in which SMC obtained proton data (using a p-butanol target). This together with the advantage of ammonia over p-butanol results in greater than 3 times the equivalent statistics for 1996 compared with 1993.

3 Results

In figure 1 the results are shown for $A_\ell^p$ which is obtained from the measured lepton-nucleon cross section asymmetry, $A_{11}$, by equation 1 (neglecting the term proportional to $A_2$). 1993 and 1996 data are shown separately for 2 different $Q^2$ cuts. For the $g_1$ and $\Gamma_1$ analysis, only data is used which has a $Q^2 > 1.0$ GeV$^2$, which corresponds to an $x$ range of 0.003 < $x$ < 0.7.

We also have data at lower $Q^2$ which is presented in figure 1 for data with a $Q^2 > 0.2$ GeV$^2$ which extends the $x$ range down to 0.0008. As can be seen from the left figure, the 1996 data dominates statistically over the 1993 data, and the two data sets are compatible within the errors. We then combine the data sets and compare them with other experimental data in the right figure. It can be seen that the E143 data is more precise in the common $x$ region with SMC, but SMC goes much lower in $x$, which is relevant for the evaluation of the first moment. It should be noted that the average $Q^2$ for the SMC and EMC [12] data is approximately 10 GeV$^2$, whereas it is approximately 3 GeV$^2$ for the E143 [13,14,15,16] data.

![Figure 1](image-url)

Figure 1: Left: $A_\ell^p$ at measured $Q^2$ for SMC 1993 and 1996 data separately. The statistical errors are shown as bars, and the shaded bar underneath shows the systematic errors. The solid circles and squares show SMC data of $Q^2 < 1.0$ GeV$^2$. Right: $A_\ell^p$ at measured $Q^2$ for all SMC proton data, as well as for E143 and EMC.
A very relevant question which is addressed by figure 2 is whether there is any $Q^2$ dependence in the data. Within the accuracy of the data, and the $Q^2$ range of each x-bin there seems to be no $Q^2$ trend to the data.

Figure 2: $A_1^p$ at different $Q^2$ values for each of our x-bins, including the 3 additional x bins for $Q^2 > 0.2$.

In order to obtain $g_1$ at the measured $Q^2$ equation 1 is used with $F_2$ and $R$ evaluated at the $x$ and $Q^2$ of the $A_1$ points. This is presented in figure 3. However, in order to extract $\Gamma_1$, evolution from the measured $Q^2_m$ to a fixed $Q^2_0$ is needed as are low and high $x$ extrapolations in the unmeasured range. Previously we assumed $A_1$ to be $Q^2$ independent and used equation 1 with $F_2$ and $R$ evaluated at the fixed $Q^2$ we desired. This assumption is consistent with what is presented in figure 2. However, QCD does predict different $Q^2$ dependence for $g_1$ and $F_1$. ($\frac{d}{dQ^2} = \frac{1}{1+\gamma A_2}$). If one neglects the $\gamma$ terms, as was done with equation 1, one sees that $\frac{d}{dQ^2} \approx A_1$. We now estimate the $Q^2$ dependence of $g_1$ from the Altarelli-Parisi evolution equations using the QCD splitting and coefficient functions at next-to-leading order. We use a program written by Ball, Forte and Ridolfi [17,18] to fit $g_1$ for published E142 [19], EMC [12], and E143 [13,14,15,16] data as well as SMC data for the deuteron [8] and proton, including the preliminary 1996 data. The $g_1(x,Q^2_m)$ is evaluated using the fit,

$$g_1(Q^2_m) = g_1(Q^2_0) + [g_1^{nt}(Q^2_0) - g_1^{nt}(Q^2_m)].$$

In figure 3 the curves are the fits at the measured $Q^2$ of the data.
Figure 3. The polarized structure function $g_1$ at the measured $Q^2$-values for the proton, the deuteron and the neutron. The curves show the QCD-fit to the SMC, E143 and E142 data.

For the high $x$ extrapolation, $0.7 < x < 1$, we assume $A_1^p = 0.7 \pm 0.3$ which is consistent both with the data and the bound $A_1 < 1$. The high $x$ range contributes little to the integral, but the situation for the low $x$ range is more critical. For the low $x$ extrapolation, $0 < x < 0.003$, we assume $g_1^f(x) = \text{constant}$ at $Q_0^2$, where the constant is obtained by averaging the two lowest $x$ data points. This is consistent with Regge theory [20] which predicts $g_1 = \text{const} \cdot x^\alpha$ with $0 \leq \alpha \leq 0.5$. This procedure for the low $x$ extrapolation is undergoing a lot of discussion at the moment since the validity of Regge type behavior is increasingly being questioned (for example, see [21]).

Evolving the data points to $Q_0^2 = 10 \text{ GeV}^2$ (which corresponds to the average $Q^2$ of the SMC data), integrating over the measured range and extrapolating to $x \to 1$ and $x \to 0$, yields the summarized results for the first moments in table 1 for all SMC data.

4 Conclusions

We have presented preliminary results of a new measurement of the spin structure function $g_1^p$ from polarized deep inelastic muon-proton scattering. Our 1996 data is in good agreement
Table 1: The results of the combined analysis of all SMC data at $Q^2 = 10$ GeV$^2$ for the first moments of $g_1$ compared to the theoretical predictions.

<table>
<thead>
<tr>
<th>$Q^2 = 10$ GeV$^2$</th>
<th>$\Gamma^0_1$</th>
<th>$\Gamma^4_1$</th>
<th>$\Gamma^0_1 - \Gamma^4_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
<td>0.149 ± 0.012</td>
<td>0.040 ± 0.008</td>
<td>0.211 ± 0.026</td>
</tr>
<tr>
<td>Theory</td>
<td>0.170 ± 0.003</td>
<td>0.071 ± 0.004</td>
<td>0.187 ± 0.002</td>
</tr>
</tbody>
</table>

with our 1993 data, so we combine them. Our precision on $g_1$ is significantly increased because of an increase of greater than 3 times the equivalent statistics for 1996 over 1993. In Table 1, we find that the first moment, $\Gamma^0_1$, disagrees with the Ellis-Jaffe sum rule by about 2 standard deviations for the proton and 4 standard deviations for the deuteron. Our result for $\Gamma^0_1 - \Gamma^4_1$, in the last column of table 1, confirms the Bjorken sum rule.

References