SLAC E155
A PRECISION MEASUREMENT OF POLARIZED STRUCTURE FUNCTION g_1 OF PROTON AND DEUTERON

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The E155 experiment at the Stanford Linear Accelerator Center (SLAC) has performed a precision measurement of the proton and deuteron spin structure function g_1 using deep inelastic scattering of polarized electrons on polarized $^{15}NH_3$ and ^6LiD. For the kinematic range $0.014 < x < 0.9$ and 1 GeV^2 $< Q^2 <$ 17 GeV^2, the resulting integrals yield $\int_{0.014}^{0.9} g_1^p(x)dx = 0.114 \pm 0.002(stat) \pm 0.011(syst)$ and $\int_{0.014}^{0.9} g_1^d(x)dx = 0.034 \pm 0.002(stat) \pm 0.005(syst)$ at an average $Q^2 = 5$ GeV^2.These preliminary results are in reasonably good agreement with previous data. A large range of extrapolations can accomodate the singular behaviour of the structure function at low x , calling into question the usual methods to extrapolate to $x = 0$. The softer behaviour of the Bjorken sum rule allows us to test it.

1 Introduction

Polarized deep inelastic scattering (DIS) experiments probe the spin structure of the nucleon. They mainly focus on the determination of $\Delta\Sigma$, the quark contribution to the nucleon spin:

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

They can give also loose constraints on ΔG, the gluon contribution. Here, L_z stands for the orbital momentum. $\Delta\Sigma$ can be extracted from the measurement of the nucleon spin structure function g_1.

1.1 Measurement of the spin structure functions

The differential cross section for the one photon exchange process of inclusive polarized lepton-polarized hadron deep inelastic scattering cross section involves unpolarized structure fucntions F_1 and F_2 and the polarized one g_1 and g_2. If we consider leptons longitudinally polarized and a target longitudinally (transversally) polarized with respect to the incident beam direction, and denote $\uparrow\downarrow$ the longitudinal lepton polarization, and $\Uparrow\Downarrow$ ($\Leftarrow\Rightarrow$) the longitudinal (transverse) polarization of the target nucleon, we can form the lepton-nucleon asymmetries, namely $A_{||}$ and $A_{\perp}$ defined as

$$A_{||} = \frac{\frac{d^3\sigma^{\downarrow\Uparrow}}{dx\,dy\,d\Phi} - \frac{d^3\sigma^{\uparrow\Uparrow}}{dx\,dy\,d\Phi}}{\frac{d^3\sigma^{\downarrow\Uparrow}}{dx\,dy\,d\Phi} + \frac{d^3\sigma^{\uparrow\Uparrow}}{dx\,dy\,d\Phi}} \qquad A_{\perp} = \frac{\frac{d^3\sigma^{\downarrow\Leftarrow}}{dx\,dy\,d\Phi} - \frac{d^3\sigma^{\uparrow\Leftarrow}}{dx\,dy\,d\Phi}}{\frac{d^3\sigma^{\downarrow\Leftarrow}}{dx\,dy\,d\Phi} + \frac{d^3\sigma^{\uparrow\Leftarrow}}{dx\,dy\,d\Phi}}$$

If the beam and/or the target polarizations are reversed frequently, slow-varying factors (beam properties, detector efficiencies, acceptance...) cancel, therefore one can write the asymmetries in terms of counting rates. At SLAC, beam polarization is flip randomly on a pulse to pulse basis (120 Hz). The spin structure functions g_1 and g_2 are expressed as a function of these asymmetries and of the spin averaged structure function F_1, and are given by

$$g_1(x,Q^2) = \frac{F_1(x,Q^2)}{D'}\left(A_{||} + A_{\perp} tan\frac{\theta}{2}\right)$$
$$g_2(x,Q^2) = \frac{F_1(x,Q^2)}{D'}\frac{y}{2sin\theta}\left(\frac{E+E'cos\theta}{E'}A_{\perp} - A_{||}sin\theta\right)$$

1.2 The Bjorken sum rule

The integral of g_1 is of special interest to extract the Bjorken sum rule , derived in 1966 by Bjorken using current algebra. It is a fundamental prediction of QCD which connects the proton spin structure to the neutron lifetime. It has now been calculated up to the third order in QCD radiative corrections [1].

$$\Gamma_1^p - \Gamma_1^n = \int_0^1 g_1^p(x)dx - \int_0^1 g_1^n(x)dx$$
$$= \frac{1}{6}\frac{g_A}{g_V}\left[1 - \left(\frac{\alpha_s(Q^2)}{\pi}\right) - 3.58\left(\frac{\alpha_s(Q^2)}{\pi}\right)^2 - 20.22\left(\frac{\alpha_s(Q^2)}{\pi}\right)^3\right]$$

where α_s is the strong coupling constant, g_A and g_V are axial and vector coupling constants in neutron weak decay.

1.3 The quark contribution to the nucleon spin

In the naive parton model, g_1 can be interpreted as $g_1(x) = \frac{1}{2}\sum_f e_f^2 \Delta q_f$ where $\Delta q_f = \delta q_f(x) + \delta \overline{q}_f(x) = (q_f^{\uparrow} - q_f^{\downarrow})(x) + (\overline{q}_f^{\uparrow} - \overline{q}_f^{\downarrow})(x)$; $q_f^{\uparrow(\downarrow)}$ denotes the probability density to find a f flavoured quark with its spin aligned (anti-aligned) with the one of the nucleon it belongs to. At leading twist the first moment of $g_1(x,Q^2)$ can be expressed in terms of singlet (a_0) and non-singlet (a_3 and a_8) proton matrix elements of the axial current. Taking into account the QCD radiative corrections [1], it gives the following formula:

$$\Gamma_1^p = \int_0^1 g_1^p(x)dx = \left(\frac{1}{12}a_3 + \frac{1}{36}a_8\right)\left[1 - \left(\frac{\alpha_s}{\pi}\right) - 3.58\left(\frac{\alpha_s}{\pi}\right)^2 - 20.22\left(\frac{\alpha_s}{\pi}\right)^3\right]$$
$$+\frac{1}{9}a_0\left[1 - 0.33\left(\frac{\alpha_s}{\pi}\right) - 0.55\left(\frac{\alpha_s}{\pi}\right)^2\right]$$

a_3 and a_8 are obtained respectively from neutron and hyperon decay. The singlet part a_0 has both a quark and a gluon contribution, $a_0 = \Delta\Sigma - \frac{3\alpha_s}{2\pi}\Delta G$ where $\Delta\Sigma = \Delta u + \Delta d + \Delta s$ is the sum of the contributions of the different quark flavours to the nucleon spin. The maximum Q^2 of our experiment being 17 GeV^2 $< (2m_c)^2$, only the three lightest quark flavours are taken into account.

2 The E155 experiment

A large experimental program has been developped for twenty years at CERN (EMC, SMC) , SLAC and DESY (HERMES) recording data on proton, deuteron and neutron. At SLAC, E155 made the last precise g_1 measurement on proton and deuteron in the kinematic range $0.014 < x < 0.9$ and 1 GeV^2 $< Q^2 < 17$ GeV^2. The 49 GeV polarized electron beam had an average polarization of 82% .We used an ammonia target ($^{15}NH_3$) for the proton measurement, like in E143, and a new material ^6LiD for the deuteron measurement, which gives a better dilution factor and is about 10 times more resistant to radiation damage than $^{15}ND_3$. The scattered electrons were detected in three spectrometer arms for a better kinematic coverage. Two arms similar to those used in E154 were placed at 2.75^o and 5.5^o with respect to the beam axis. They consisted in hodoscope plans for tracking, threshold Cherenkov counters for hadronic background rejection and an electromagnetic shower counter to measure the scattered electrons' energy. Approximately 200 million DIS events have been collected in March-April 1997. Here, we present only preliminary results on g_1 from these two arms. A third arm has been added in E155 at 10^o for Q^2 dependence study purpose; the analysis of these data is in progress. In parallel of g_1 measurement, E155 took data on g_2 whose results are presented in an other contribution to this workshop.

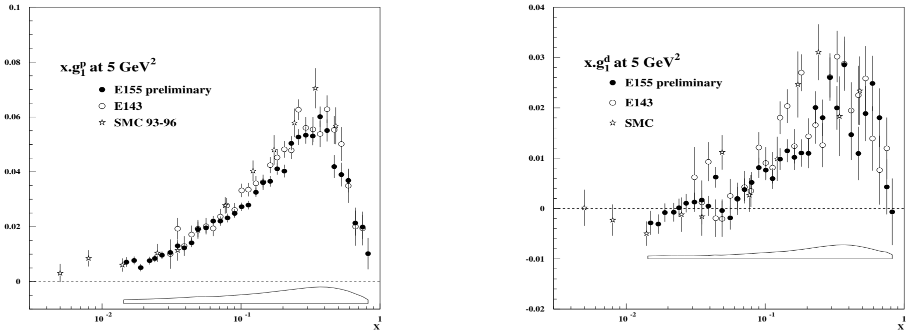

Figure 1: $x.g_1^p(\mathrm{x})$ and $x.g_1^d(x)$ evolved at $Q^2 = 5$ GeV^2; the area under the curve represents the integral of g_1. Error bars are statistical and the band area is systematic.

3 Results

3.1 Proton, deuteron and neutron structure function g_1 in the measured region

For these preliminary results, the combination of data from the two spectrometers and the evolution from the measured Q^2 to the common $Q^2 = 5$ GeV^2 are achieved assuming $\mathrm{g}_1/\mathrm{F}_1$ independent of Q^2.

Figure 1 shows proton and deuteron g_1 data along with SMC [2], [3] and final E143 [4] data. The integrals over the measured x range are found to be $\int_{0.014}^{0.9} g_1^p(x)dx = 0.114 \pm 0.002(stat) \pm 0.011(syst)$ and $\int_{0.014}^{0.9} g_1^d(x)dx = 0.034 \pm 0.002(stat) \pm 0.005(syst)$ at $Q^2 = 5$ GeV^2.

We can deduce g_1 neutron from proton and deuteron data, $g_1^n(x, Q^2) = 2g_1^d(x, Q^2)/(1 - 1.5.\omega_D) - g_1^p(x, Q^2)$ where ω_D is the probability that the deuteron will be in a D-state. The neutron spin structure function $g_1^n(x, Q^2)$ is shown on Fig.2 and compared to its quasi-direct measurement by E154 [5] using an ^{3}He polarized target. The integral over the measured x range is $\int_{0.014}^{0.9} g_1^n(x)dx = -0.041 \pm 0.006(stat) \pm 0.012(syst)$ at $Q^2 = 5$ GeV^2.

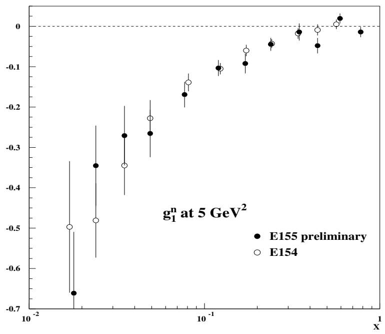

Figure 2: $g_1^n(\mathrm{x})$ evolved at $Q^2 = 5$ GeV^2.

The E155 preliminary results are in relatively good agreement with previous SLAC experiments' results, SMC and HERMES data.

3.2 Low x behaviour

We are interested in the integral over the full x range. The high x extrapolation is ruled by the quark counting rules and is supposed to behave like (1-x)^3; this contribution is almost negligible. The low x behaviour is questionable and even controversial. Attempts to fit different functional forms show a large variation in the contribution to the integral coming from low x. As an example, the neutron data seem to give large negative value in the low x domain where one doesn't know how to extrapolate.

3.3 Test of the Bjorken sum rule

The difference $(g_1^p - g_1^n)(x)$ is expected to behave much softer than the singlet counterpart due to its purely non-singlet, valence quark distribution nature (if we assume light sea isospin i.e $\Delta\overline{u} = \Delta\overline{d}$). The difference between proton and neutron spin structure functions integrated down to x = 0.014 tend to converge to the Bjorken sum rule prediction (within 1 standard deviation assuming a Regge type extrapolation).

4 Conclusion

Low x data are certainly needed to have a better control on $\Delta\Sigma$ and constrain ΔG but are not achievable in a short futur. In a different approach, RHIC experiments at Brookaven and COMPASS at CERN have the challenged goal to determine ΔG.

References

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