Future HERA Experiment with 800 GeV Polarized Protons

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Abstract

Measurement of spin-dependent asymmetries in the inclusive scattering of high energy polarized electrons by high energy polarized protons at HERA would be a natural and important extension of the polarized lepton-nucleon inclusive scattering experiments done with fixed targets at CERN and SLAC.

Extensive data on spin-dependent inclusive cross section asymmetries have been obtained from experiments at SLAC with polarized electrons ($E_e \simeq 20 - 29$ GeV) and at CERN with polarized muons ($E_\mu \simeq 190$ GeV) scattered by polarized targets of protons, deuterons and helium-3.[1] The asymmetry data obtained from the various experiments are in good agreement. Figure 1 shows the measured values of the virtual photon-proton asymmetry A_1^p, where $A_1^p \simeq \frac{1}{D}\left(\frac{d^2\sigma_A - d^2\sigma_P}{d^2\sigma_A + d^2\sigma_P}\right)$ in which $d^2\sigma_{A(P)}$ is the differential scattering cross section with antiparallel (parallel) lepton and proton spin directions, and D is a kinematic factor.[2], [3], [4]

The spin dependent structure function g_1^p is obtained from the relation:

$$g_1^p = F_1^p \; A_1^p \tag{1}$$

in which F_1^p is the spin independent structure function. Figure 2 shows the values of g_1^p using the evolved value of F_1^p but assuming A_1^p is independent of Q^2, which is consistent with the present data within its statistical errors. Particularly noteworthy is the apparent rise in g_1^p at low x. Additional data will be obtained in 1996 by the Spin Muon Collaboration at CERN, particularly to reduce the statistical errors at low x.

Calculation of $g_1(x, Q^2)$ is a problem requiring non-perturbative QCD, and theory has not yet solved this problem. For a fixed x the evolution of g_1 as a function of Q^2 can be evaluated by perturbative QCD for sufficiently large Q^2. At present the principal conclusions from polarized lepton-nucleon scattering are obtained with sum rules which involve the first moments Γ_1 of the structure functions, for example $\Gamma_1^p = \int_0^1 g_1^p(x,\ Q_0^2)dx$ in which Q_0 is a reference value.

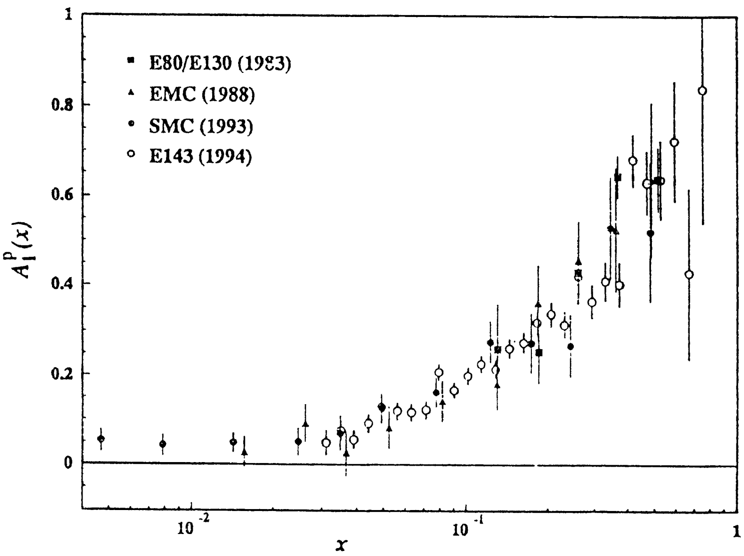

Figure 1. The virtual-photon proton cross section asymmetry A_1^p as a function of the Bjorken scaling variable x. Only statistical errors are shown with the data points.

Since the data of course extend only to some lower limit of x, it is necessary to extrapolate to x=0 in order to

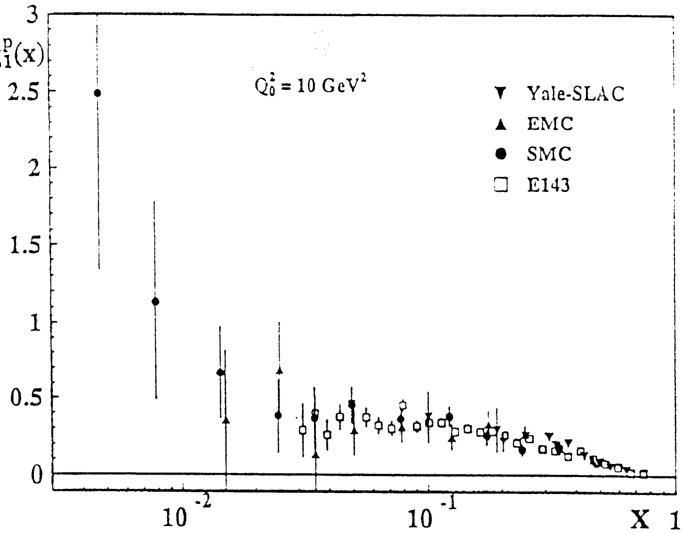

Figure 2. The spin dependent structure function $g_1^p(x)$ as a function of x evaluated at a common $Q_0^2 = 10\ GeV^2$. Only statistical errors are shown on the data points.

evaluate a first moment. Extrapolation is based on Regge theory and a plausible form [5] is $g_1 = Cx^{\alpha}$ in which C is a constant and $0 \leq \alpha \leq 0.5$. Some additional uncertainty arises because of the small values of $Q^2 (Q^2 \simeq 1\ GeV^2)$ for the low x values and hence of the possible importance of higher twist effects.

However despite these concerns, present data can be considered to confirm the fundamental Bjorken sum rule [6] at the 10% level. On the other hand, the model-dependent Ellis-Jaffe sum rules [7] for the first moments of the spin structure functions of the proton and neutron individually, which assume that the strange quarks in the nucleon are unpolarized, i.e. $\Delta s = 0$, and that $SU(3)_{flavor}$ symmetry applies, are violated. Figure 3 shows this violation for Γ_1^p. In the quark-parton model the implications are that the fraction of the proton spin due to quarks, $\Delta\Sigma$, is small - $\Delta\Sigma \simeq 0.2$ - and $\Delta s \simeq -0.12$.

A measurement at HERA in its high energy collider mode of spin dependent asymmetries in polarized electron-proton inclusive scattering would extend greatly the kinematic range in which $A_1^p(x, Q^2)$ and $g_1^p(x, Q^2)$ are known. Figure 4 shows the kinematic ranges covered in SLAC and CERN experiments and the full allowed range at HERA. Considerations of luminosity and the characteristics of the ZEUS and H1 detectors will determine the practical range in which

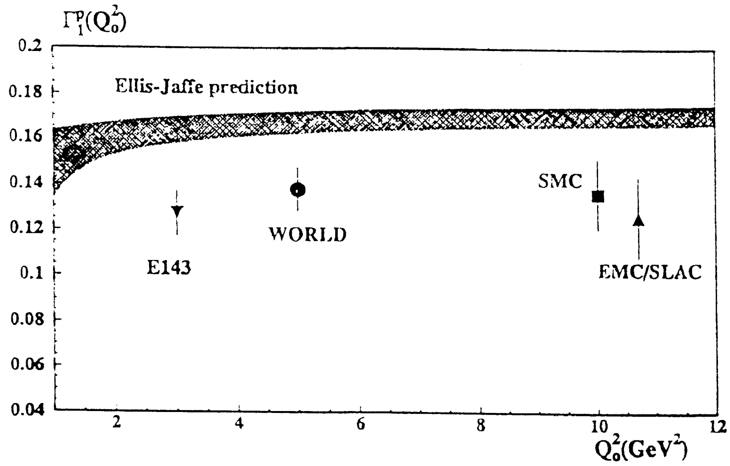

Figure 3. Comparison of the Ellis-Jaffe prediction for Γ_1^p with the experimental measurements. The theoretical uncertainty arises from uncertainties in α_s and in F/D; the experimental errors include statistical and systematic errors. E143 is the recent SLAC experiment. EMC/SLAC is a combination of early SLAC plus EMC CERN data and SMC is the recent CERN result.

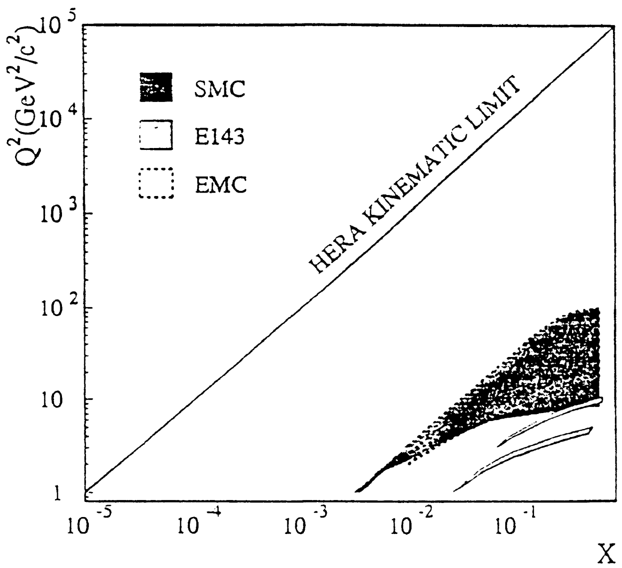

Figure 4. Kinematic range for different experiments.

significant data can be obtained.

At present (1995) with unpolarized protons a HERA luminosity of about 15 pb^{-1}/yr is achieved and some 3×10^6 electromagnetic inclusive scattering events can be expected. [8] The luminosity design goal is 100 pb^{-1}/yr and a substantial increase beyond 15 pb^{-1}/yr can be expected in later years. For low x $\sim 10^{-4}$ the Q^2 range is (2 to 6) GeV^2; for x ~ 10^{-3}, Q^2 is 3 to 30 GeV^2, and for x ~ 10^{-2}, Q^2 is 10 to 200 GeV^2.

With high energy polarized electron and proton beams the asymmetry A_1^p is obtained from the counting rate asymmetry Δ using

$$\Delta = P_e\ P_p\ DA_1^p \tag{2}$$

in which P_e = polarization of the electron beam, and P_p = polarization of the proton beam. Using $P_e = 0.6$ which has been achieved for the HERMES experiment and taking $P_p = 0.7$, which is the design value for polarized protons in RHIC, and with D $\simeq$ 1, we obtain

$$\Delta = 0.4\ A_1^p. \tag{3}$$

For the lowest x bin of the SMC experiment with x = 0.004 and Q^2 = 1 GeV^2, $A_1^p \simeq 0.05$ so that $\Delta = 0.02$. Hence some 2.5×10^3 counts are required to measure A_1^p with a 1 standard deviation statistical error. The dependence of A_1^p on x at low x is not known of course, but from Regge theory it would be expected to decrease at least as rapidly as x, implying that A_1^p will be small at low x and hence its measurement will require large numbers of events and excellent control of false asymmetries

The achievement of a high energy 800 GeV polarized proton beam at HERA for an acceptable cost is a challenging problem in accelerator physics at HERA. It is helpful that a project at Brookhaven National Laboratory [9] to produce polarized protons at energies up to 250 GeV in the RHIC rings is approved and funded with a cost of about $10 M for the two Siberian snakes and the spin rotators. At RHIC a proton polarization of 0.7 is expected with the same proton intensity as for unpolarized protons. For HERA as for RHIC a thermal energy polarized proton beam would be produced and then accelerated through various stages, retaining the polarization of the protons. For HERA the proton accelerator stages involve a linear accelerator to 50 MeV, a proton synchrotron to 7.5 GeV and the high energy ring to 820 GeV. In addition, proton polarimeters must be provided.

A successful polarized inclusive scattering experiment at HERA could provide a measurement of the virtual photon-proton asymmetry $A_1^p(x, Q^2)$ over an extended kinematic range including small x and high Q^2. This should provide an important study of the scaling behaviour of A_1^p, i.e. the dependence of $A_1^p(x, Q^2)$ on Q^2. This study might best be done at intermediate values of $x \sim 10^{-2}$ where CERN and SLAC data exist. Additional HERA data at low x and with high Q^2 where perturbative QCD is applicable would contribute importantly to our understanding of the proper extrapolation of g_1^p to $x = 0$, which is required for evaluation of the sum rules.

Perhaps the outstanding question related to the spin structure of the nucleon is the contribution of polarized gluons to the nucleon spin. HERA data together with fixed target data analyzed by perturbative QCD evolution could resolve this outstanding problem. [10]

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