Detector Effects on the Asymmetry A_1: The Measurability of the Polarized Structure Function g_1 of the Proton

C. Aidala, A. Deshpande, and V. Hughes
Yale University, Physics Dept., New Haven, CT 06520, U.S.A.

Abstract: The polarized structure function g_1 of the proton was found to be measurable with current HERA detectors. Results were calculated for the Bjorken scaling variable x between 10^{-5} and 10^{-2} and Q^2 between 1 and 1000 GeV^2. Simulated values of A_1 equaled the predicted values to within the statistical uncertainties calculated for a luminosity of 500 pb^{-1} with detector acceptance and event migration taken into account.

1 Introduction

Investigating the unpolarized and polarized structure functions of the proton is the key to further understanding of the composite nature of the proton and what relative contributions its constituents make to the proton spin.

Earlier fixed-target experiments have shown that only about 25% of the nucleon's spin is carried by its quark and antiquark constituents. Within the framework of perturbative-QCD, some part of nucleon spin is predicted to come from gluons, which are expected to have significant effects in the low x region. There are currently numerous competing models for the polarized structure function g_1, and these theories differ in the low x region. (Refer to [1].) This low x region falls within the kinematic range that would be accessible at polarized HERA. (Refer to Figure 1.)

The polarized structure function $g_1(x,Q^2)$ can be measured by deep-inelastic scattering of electrons off of protons. It is proportional to the difference in cross-section between protons with longitudinal spin directions opposite to and the same as the electron spin direction. Perturbative-QCD predicts asymmetries on the order of a few times 10^{-4} for x less than 10^{-3}. Energy loss of the electron in the detector due to multiple scattering creates an uncertainty in the energy and polar angle measured by the detector and thus an uncertainty in the reconstructed x and Q^2 of the event. This analysis seeks to determine whether asymmetries as small as those predicted by pQCD could be measured with present HERA detectors.

2 Methods

Spin structure function g_1 is proportional to A_m, a directly measured asymmetry.

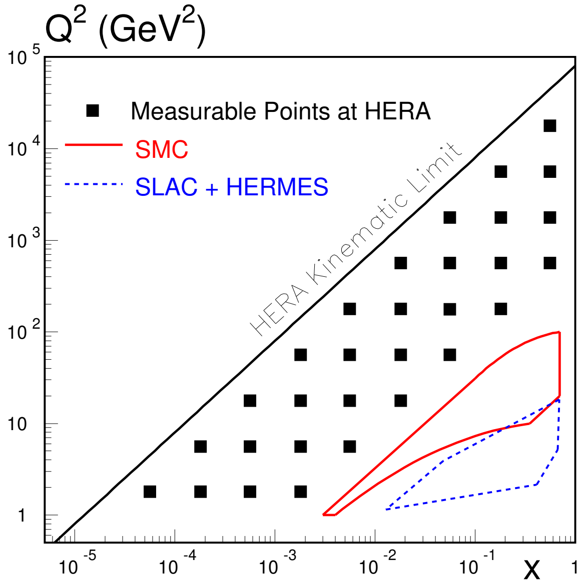

Figure 1: *Kinematic range accessible with polarized HERA.*

$$g_1(x, Q^2) = A_1 F_1 \quad (1)$$

$$A_1 = A_m / f P_p P_e D \quad (2)$$

$$A_m = (N_1 - N_2)/(N_1 + N_2) \quad (3)$$

where:

- F_1 is the unpolarized structure function of the proton
- f is the dilution factor for the proton target sample, equal to 1 for a proton beam
- P_p and P_e are the polarizations of the proton and electron beams
- D is the depolarization factor
- N_1 (N_2) is the number of events in which colliding beams have opposite (same) spin directions

From a paper by A. Deshpande et al. [1], the pQCD predictions of A_1 were taken for x between 10^{-5} and 10^{-2} and Q^2 between 1 and 1000 GeV^2. Statistical uncertainties dA_1 were calculated for a luminosity of 500 pb^{-1}, taking detector acceptance into account. Beam polarizations of 0.7 were used, and beam energies were 25 and 800 GeV for the electron and proton, respectively. The x-Q^2 region was divided into half-decade bins, fourteen of which were used for the current investigation. For their configuration, refer to the efficiency and purity figures 3a and b. Values of A_1 and dA_1 were given by [1] for the center of each bin.

From A_1 and dA_1, values for N_1 and N_2 were obtained algebraically, to be put through a HERA fast detector simulation [2]. For simulation purposes, the conditions assumed by the original study [1] were considered. To reduce statistical error, a luminosity of 50 $\times$ 500 pb^{-1} was used.

Within each bin, N_1 (N_2) events were run through the detector simulation. The simulation took into consideration detector acceptance, vertex distribution, dead material, and energy and angle smearing, but not trigger or selection efficiencies. Given E, polar angle θ, and azimuthal angle ϕ of the scattered electron, it output E', θ', and ϕ' measured by the detector. From E' and θ' yielded by the detector simulation, events were reconstructed based on the scattered electron. Using electron reconstruction, x' and (Q^2)' are given by

$$y' = 1 - (E'/2E_e)(1 - cos\theta') \quad (4)$$

$$x' = E'(1 + cos\theta')/2E_p y' \quad (5)$$

$$(Q^2)' = 2E_e E'(1 + cos\theta') \quad (6)$$

For each bin, the efficiency and purity were calculated, and A_1' was calculated for bins 1 through 10. The contribution to events reconstructed in bins 1-10 was calculated from events generated in bins 1-14, one half-decade in x and Q^2 beyond bins 7-10. In an experimental measurement, there would likely be relatively small contributions to bins 8-10 from the next column of constant x as well.

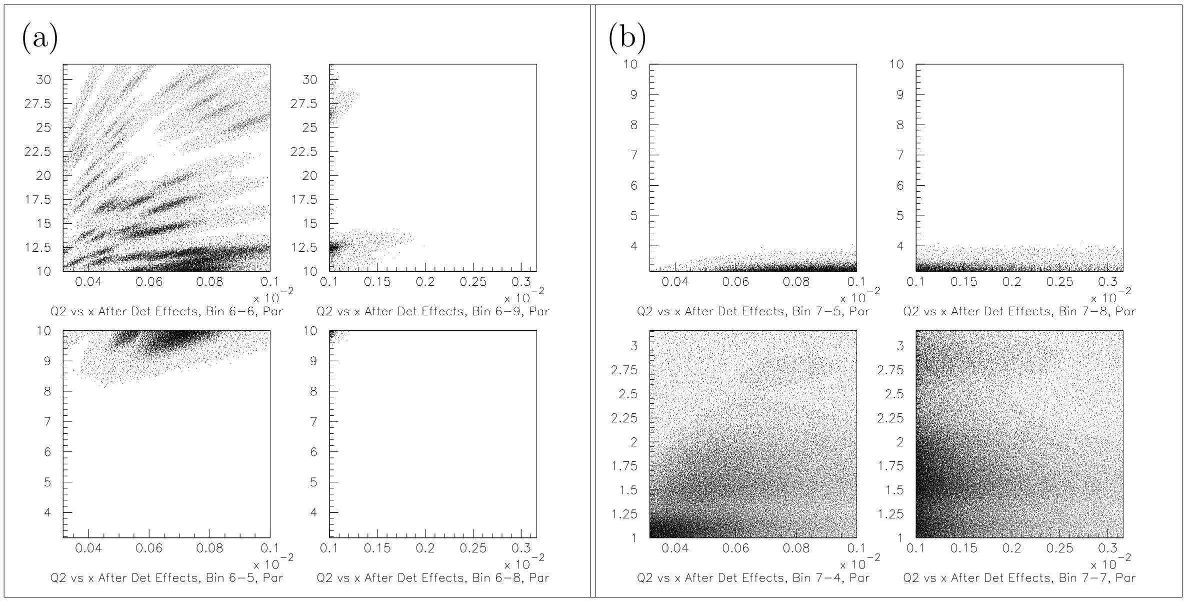

Figure 2: *Event migration due to detector effects. (a) Bin 6, y close to 1. (b) Bin 7, $y << 1$.*

$$\text{Efficiency} = \frac{\text{No. of events measured within bin that were generated within bin}}{\text{No. of events generated within bin}}$$

$$\text{Purity} = \frac{\text{No. of events measured within bin that were generated within bin}}{\text{No. of events measured within bin}}$$

3 Results

Event migration:

There was a low migration rate (5–15%) out of bins close to the $y = 1$ line. The direction of migration was primarily diagonal in the x-Q^2 plane, along lines of constant y. There was a high migration rate (40–80%) for bins farther from $y = 1$. In this region, migration was primarily to lower x. Refer to Figures 2a and b to see detector effects on events generated in different regions of y. Refer to Figures 3a and b for the efficiency and purity of each bin.

The large migration rate for bins with $y << 1$ was understood to be due to electron event reconstruction. High event migration at $y << 1$ has been found to be reduced by hadronic reconstruction methods [3, 4]. This approach is a topic for further investigation.

For all bins, the calculated values of A_1 after detector effects were within 1σ of the values predicted by the pQCD analysis. (Refer to Table 1.)

4 Conclusions

The asymmetries after detector effects are consistent with the pre-detector asymmetries, within the pre-detector statistical uncertainties. Assuming the pQCD analysis, the asymmetry A_1 and thus the polarized structure function g_1 are measurable at polarized HERA for x between 10^{-5} and 10^{-2} and Q^2 between 1 and 1000 GeV^2, using current detectors. Electron reconstruction is adequate over the entire x-Q^2 range. However, in order to obtain the minimum possible x-Q^2 migration of events, other reconstruction methods should be used for regions of low y.

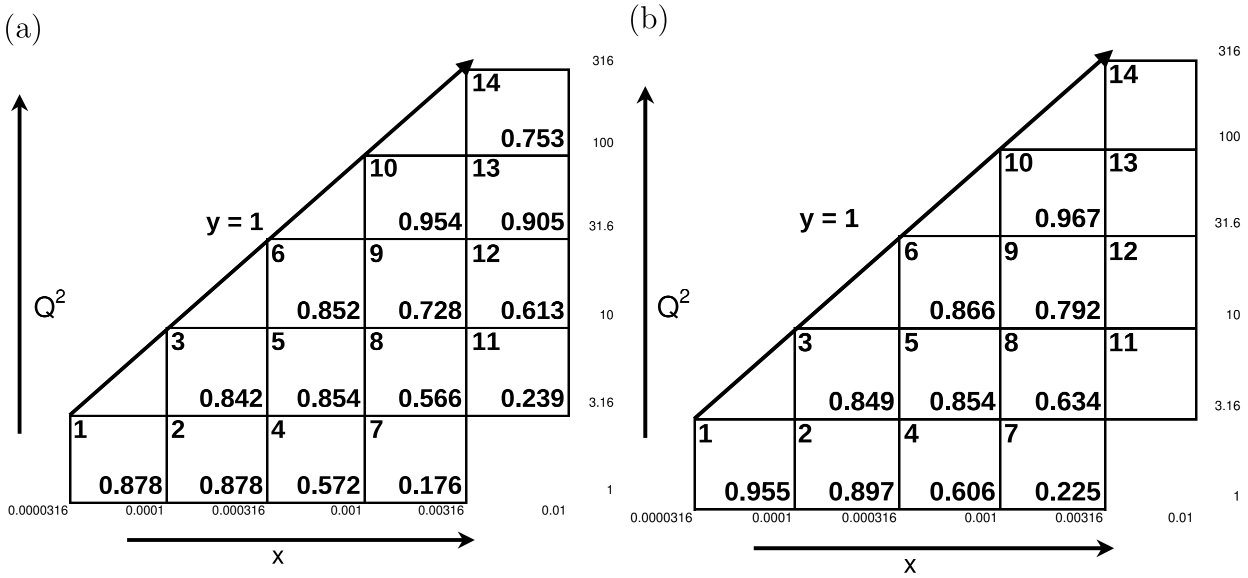

Figure 3: *(a) Efficiencies of bins 1-14. (b) Purities of bins 1-10.*

Bin	$A_1{}^{gen}$	$A_1{}^{det}$	dA_1 [1]	$(A_1^{det} - A_1^{gen})/dA_1$
1	-0.00166	-0.00169	0.001057	-0.028
2	-0.00123	-0.00124	0.003735	-0.0027
3	-0.00200	-0.00199	0.001320	0.0076
4	-0.00506	-0.00498	0.012791	0.0063
5	-0.00123	-0.00123	0.004468	0.0045
6	-0.00051	-0.00050	0.001895	0.0053
7	-0.05083	-0.05331	0.044559	-0.056
8	-0.00189	-0.00141	0.015860	0.030
9	-0.00457	-0.00452	0.006627	0.0075
10	0.00175	0.00172	0.003119	-0.0069

Table 1: *Detector effects on A_1; change of the detected asymmetry from the generated asymmetry. $A_1{}^{gen}$ and $A_1{}^{det}$ are the simulation values of A_1 before and after detector effects. dA_1 is taken from reference [1].*

References

[1] A. Deshpande et al., Measurements of $g_1(x,Q^2)$ at HERA, Polarized HERA Workshop Proceedings, DESY-Proceedings-1998-01.

[2] J. Contreras, Tools for fast detector simulation. For details see web page: http://www.desy.de:8888/~gehrt/heraspin/

[3] U. Bassler and G. Bernardi, *Nucl. Instrum. Methods* A **426**, 583 (1999).

[4] U. Bassler and G. Bernardi, *Nucl. Instrum. Methods* A **361**, 197 (1995).