Measurement of the Deuteron Elastic Structure Functions up to Large Momentum Transfers

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Abstract

The cross section for elastic electron-deuteron scattering was measured in JLab experiment 91-026. The deuteron elastic structure functions $A(Q^2)$ and $B(Q^2)$ have been extracted from this data. The final results for the "electric" structure function, $A(Q^2)$, in the range of $0.7 \leq Q^2 \leq 6.0$ (GeV/c)^2, are presented. Preliminary results for the "magnetic" structure function, $B(Q^2)$, are presented in the range of $0.7 \leq Q^2 \leq 1.35$ (GeV/c)^2. These data are compared with theoretical predictions of both meson-nucleon and quark-gluon based models.

Measurements of the deuteron elastic structure functions are essential for the understanding of the internal structure and dynamics of the nuclear two-body system. In particular, they offer unique opportunities to test models of the short-range component of the nucleon-nucleon interaction, meson-exchange currents (MEC) and isobaric configurations as well as the possible influence of explicit quark degrees of freedom.

The cross section for elastic electron-deuteron scattering is described by

$$\frac{d\sigma}{d\Omega} = \sigma_m[A(Q^2) + B(Q^2)\tan^2(\theta/2)], \tag{1}$$

where σ_m is the Mott cross section, $Q^2 \approx 4EE'\sin^2(\theta/2)$ the four-momentum transfer squared and θ the electron scattering angle. From Eq. 1 we see that $A(Q^2)$ and $B(Q^2)$ can be separated by measuring the cross section at different electron scattering angles while keeping the momentum transfer constant (Rosenbluth separation technique). The structure functions $A(Q^2)$ and $B(Q^2)$ can be expressed in terms of the charge monopole, charge quadrupole and magnetic dipole form factors of the deuteron (F_C, F_Q and F_M, respectively):

$$A(Q^2) = F_C^2(Q^2) + \frac{8}{9}\tau^2 F_Q^2(Q^2) + \frac{2}{3}\tau F_M^2(Q^2) \tag{2}$$

$$B(Q^2) = \frac{4}{3}\tau(1+\tau)F_M^2(Q^2) \tag{3}$$

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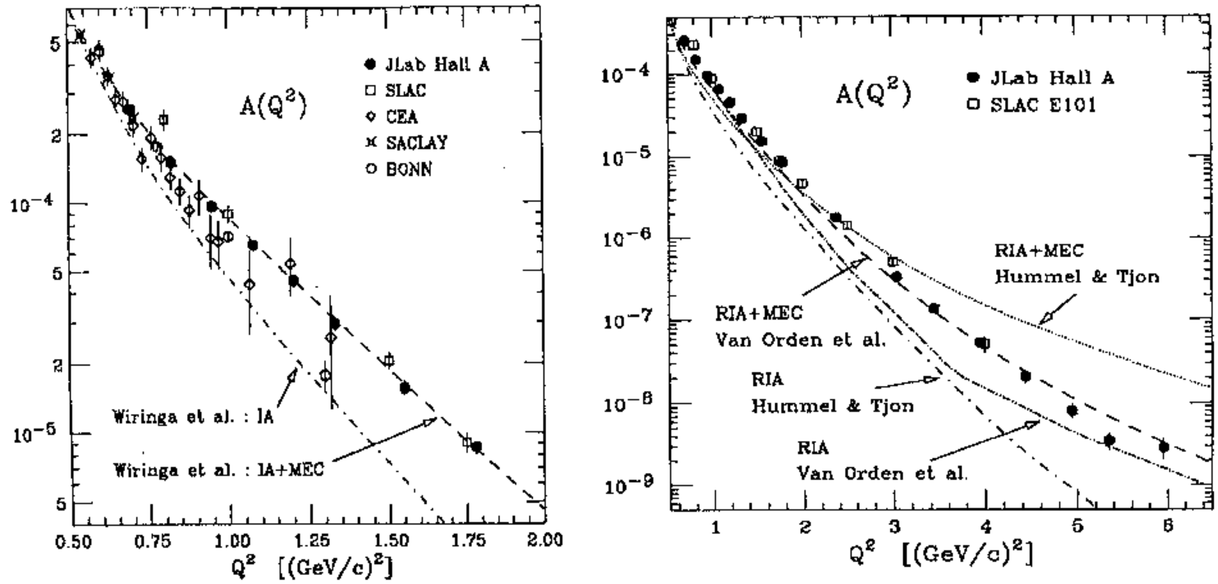

Figure 1: The deuteron elastic structure function from this experiment; on the left the "low" Q^2 data, along with the previous data from SLAC [2], Saclay [3], CEA [4] and Bonn [5] and the theoretical calculations of ref. [6]; on the right our full $A(Q^2)$ data set and previous SLAC data [2], compared to the theoretical calculations of refs. [7] and [8].

where $\tau = Q^2/4M_d^2$ and M_d is the deuteron mass. $B(Q^2)$ is a direct measure of the magnetic form factor, whereas polarization observables are needed to separate F_C and F_Q.

This experiment was performed in Hall A at Jefferson Laboratory in a double-arm exclusive measurement where the scattered electrons were detected in the Electron Arm High Resolution Spectrometer (HRSE) and the recoil deuterons were detected in the Hadron Arm High Resolution Spectrometer (HRSH). The detector package in the HRSE consisted of two vertical drift chambers for particle tracking, two planes of trigger scintillators, and a CO_2 gas Cherenkov detector and a segmented lead-glass calorimeter for particle identification. Electrons were identified from a minimal signal in the Cherenkov counter and an energy deposited in the calorimeter consistent with the particle tracking. The HRSH detector package consisted of two vertical drift chambers and two planes of trigger scintillators. Coincidence events were identified using the relative time-of-flight between the electron and deuteron triggers. An electron beam of 100% duty factor, 5 to 120 μA intensity and 3.2 to 4.4 GeV energy were scattered off a 15 cm long liquid deuterium target, thus providing a record high luminosity of 4.7 $\times$ 10^{38} atoms/cm^2/s. The beam was rastered on the target at high frequency. The target was maintained at a temperature of 22 K and a pressure of 22 psia. A 15 cm liquid hydrogen target, maintained at 19 K and 27 psia, was used for calibration runs. Other Hall A instrumentation included two beam current monitors to determine the charge incident on the target and several beam position monitors to monitor the beam position and angle at the target on an event-by-event basis.

The effective double-arm acceptance was evaluated with a Monte Carlo code that simulated elastic (e,p) and (e,d) scattering under the conditions of our measurements. The (e,p) elastic cross section measured with (without) the acceptance-defining collimators was found to agree, on average, within 0.3% with (to be higher by 2.6% than) the world data set. Values for $A(Q^2)$ were extracted in the range of $0.7 \leq Q^2 \leq 6.0$ (GeV/c)^2 from the measured e-d cross sections under the assumption that $B(Q^2)$ does not contribute to the cross section (supported by the existing $B(Q^2)$ data [1]). The extracted $A(Q^2)$ values are shown in Figures 1 and 2. The error bars include statistical (ranging from $\pm$ 1% to $\pm$ 28% at 6 (GeV/c)^2) and systematic

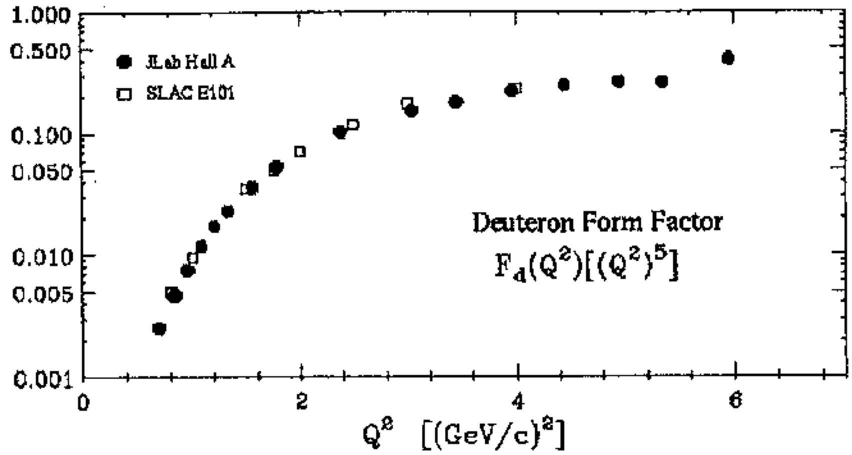

Figure 2: $F_d \equiv \sqrt{A(Q^2)} \times (Q^2)^5$ from this experiment and from SLAC E101 [2]. Above $Q^2 \approx 4$ (GeV/c) F_d exhibits a behavior, consistent with the onset of scaling.

($\pm$ 5.9%) uncertainties added in quadrature. The left half of Figure 1 shows our $A(Q^2)$ data up to 2 (GeV/c)^2, together with previous SLAC [2], Saclay [3], CEA [4], and Bonn [5] data. Our data agree with the trend of the SLAC and Saclay data. Also shown is an Impulse Approximation (IA) prediction [6], both with and without Meson Exchange Current (MEC) contributions included. The right half of Figure 1 shows the complete data set, together with previous SLAC data [2] and theoretical calculations. Our results agree very well with previous SLAC data and continue to follow the trend of a smooth fall-off versus momentum transfer. Shown are two relativistic impulse approximation (RIA) calculations with and without meson exchange current terms included [7],[8]. The MEC terms for the two different groups differ in their choice of the coupling between the virtual photon and the exchanged mesons and in the form factor used to describe the vertex. At sufficiently high momentum transfers, dimensional scaling [9] and pQCD [10] predict that $F_d \equiv \sqrt{A(Q^2)}$ should fall off as $(Q^2)^{-5}$. Our data, along with the previous SLAC data, are shown in Figure 2, multiplied by $(Q^2)^5$. They exhibit a flattening above approximately Q^2=4 (GeV/c)^2, consistent with the onset of the predicted scaling behavior.

The preliminary results of our extraction of $B(Q^2)$ are shown in Figure 3, along with previous data from SLAC [1], Saclay [11] and Bonn [5]. The error bars include statistical and systematic uncertainties added in quadrature and range from 5% at 0.7 (GeV/c)^2 to 20% at 1.35 (GeV/c)^2. Also shown in Figure 3 are the theoretical predictions of Wiringa *et al.* [6] and Van Orden *et al.* [7]. The two models with MEC included have had success in describing our $A(Q^2)$ data (cf. Figure 1), but they either overestimate or underestimate our preliminary $B(Q^2)$ data.

We have measured the deuteron elastic electric and magnetic structure functions in Experiment 91-026 at Jefferson Lab. The high luminosity obtained has enabled the measurement of a record low cross section (2×10^{-41} cm^2/sr at Q^2= 6 (GeV/c)^2). We have thus extended the measured range of $A(Q^2)$ to 6 (GeV/c)^2 and significantly improved the precision of the $B(Q^2)$ data in the low momentum transfer range. The data have been compared to both meson-nucleon and quark-gluon model predictions. The results are indicative of a scaling behaviour above Q^2=4 (GeV/c)^2, but future measurements at higher Q^2 of $A(Q^2)$ and $B(Q^2)$ as well as of the elastic form factors of the helium isotopes are essential to test the validity of this apparent scaling behaviour.

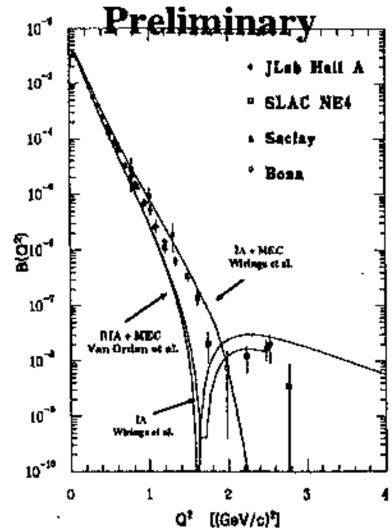

Figure 3: Preliminary results for the deuteron magnetic elastic structure function $B(Q^2)$ from this experiment. Also shown are existing SLAC [1], Saclay [11] and Bonn [5] data and the theoretical calculations of refs. [6] and [7].

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