# MEASUREMENTS OF THE DEUTERON ELASTIC STRUCTURE FUNCTION A($Q^2$) AT THE JEFFERSON LABORATORY

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The deuteron elastic structure function $A(Q^2)$ has been extracted in a range of $0.7 \leq Q^2 \leq 6.0$ (GeV/c)$^2$ from measurements of elastic electron-deuteron cross section.

Measurements of the deuteron electromagnetic form factors in elastic scattering offer unique opportunities to test models of short-range aspects of the nucleon-nucleon interaction, meson-exchange currents and isobaric configurations as well as possible quark degrees of freedom. The elastic electron-deuteron cross section is given by $d\sigma/d\Omega = \sigma_M \left[A(Q^2) + B(Q^2)\tan^2(\theta/2)\right]$ where $\theta$ is the electron scattering angle, $\sigma_M = \alpha^2 E' \cos^2(\theta/2)/[4E^3 \sin^4(\theta/2)]$ is the Mott cross section, $\alpha$ is the fine-structure constant, $E$ and $E'$ are the incident and scattered electron energies and $Q^2 = 4EE'\sin^2(\theta/2)$ is the four-momentum transfer squared. The deuteron elastic structure functions $A(Q^2)$ and $B(Q^2)$ are given in terms of the charge, quadrupole and magnetic form factors $F_c(Q^2)$, $F_q(Q^2)$ and $F_m(Q^2)$ by $A(Q^2) = F_c^2(Q^2) + (8/9)\tau^2 F_q^2(Q^2) + (2/3)\tau F_m^2(Q^2)$ and $B(Q^2) = (4/3)\tau(1+\tau)F_m^2(Q^2)$ with $\tau = Q^2/4M_d^2$. $M_d$ is the deuteron mass. The purpose of the experiment was to extend the previously measured kinematical range of $A(Q^2)$ and $B(Q^2)$ and to resolve inconsistencies in previous data sets[1,2,3] by measuring elastic electron-deuteron (e-d) cross sections for $0.7 \leq Q^2 \leq 6.0$ (GeV/c)$^2$. In this paper the results obtained for $A(Q^2)$ are presented.

The experiment was carried out in one of the experimental areas (Hall A) of the Thomas Jefferson National Accelerator Facility (JLab), using the Jlab's continuous electron beam with energies from 3.2 to 4.4 GeV, and currents from 5 to 120 $\mu$A. The beam current and energy uncertainties were estimated to be $\pm 2\%$ and $\pm 0.2\%$, respectively. Uncertainties due to beam position and angle at the target are negligible. The target system consisted of two 15 cm long cylindrical cells: one filled with liquid hydrogen, the other with liquid deuterium. Measured beam-induced density changes were $\sim 2\%$ at 120 $\mu$A. A 15 cm long "empty" target was used to measure possible contributions from the full cell end-caps to the measured cross sections. They were found to be

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negligible.

The scattered electrons and the recoil deutrons were detected in coincidence by two, magnetically identical, QQDQ High Resolution Spectrometers (HRS). The electrons were identified using an electromagnetic calorimeter and a gas Cherenkov counter, while the deutrons were identified using the time-of-flight technique. The coincidence trigger was based on scintillator hodoscopes and its efficiency ranged from 98% to 100%. Contributions from random coincidences were in general negligible.

Elastic electron-proton (e-p) cross sections were also measured in this experiment in order to check our understanding of spectrometer optics and double-arm acceptance.

The elastic e-p and e-d cross sections were calculated as $d\sigma/d\Omega = N_{ep(ed)} C_{eff}/(N_i N_t F\ \Delta\Omega)$ where $N_{ep(ed)}$ is the number of e-p(e-d) elastic events, $N_i$ is the number of incident electrons, $N_t$ is the number of target nuclei/cm$^2$, $\Delta\Omega$ is the effective acceptance including the spectrometer acceptance-dependent part of the radiative corrections, $F$ is the portion of the radiative corrections that depends only on $Q^2$ and target thickness, and $C_{eff}$ is a correction factor for detector and trigger inefficiencies (1-3%), computer dead time (typically 5%) and proton ($\sim$2%) and deuteron ($\sim$4%) absorption losses in the target and detectors. The effective double-arm acceptance $\Delta\Omega$ was evaluated with a Monte Carlo simulation.

The measured elastic e-p cross sections agree within $\pm$6% with the values calculated from a recent parameterization [4] of proton world data. Values of $A(Q^2)$ were then extracted from the measured e-d cross sections under the assumption that $B(Q^2)$ does not contribute to the cross sections (supported by the existing $B(Q^2)$ data). The extracted $A(Q^2)$ values are presented in Fig.1. The error bars represent statistical and systematic uncertainties added in quadrature. The statistical error ranged from $\pm$1% to $\pm$30%. The systematic error has been estimated to be $\sim \pm$8% and is dominated by the uncertainty in the double-arm acceptance ($\pm$6%).

In summary, we have measured the elastic deuteron structure function $A(Q^2)$ at large momentum transfers. The results have clarified inconsistencies in previous low $Q^2$ data. The precision of our data will provide severe constraints on theoretical calculations of the electromagnetic structure of the two-body nuclear system. The results are consistent with meson-nucleon calculations based on the relativistic impulse approximation augmented by meson-exchange currents.

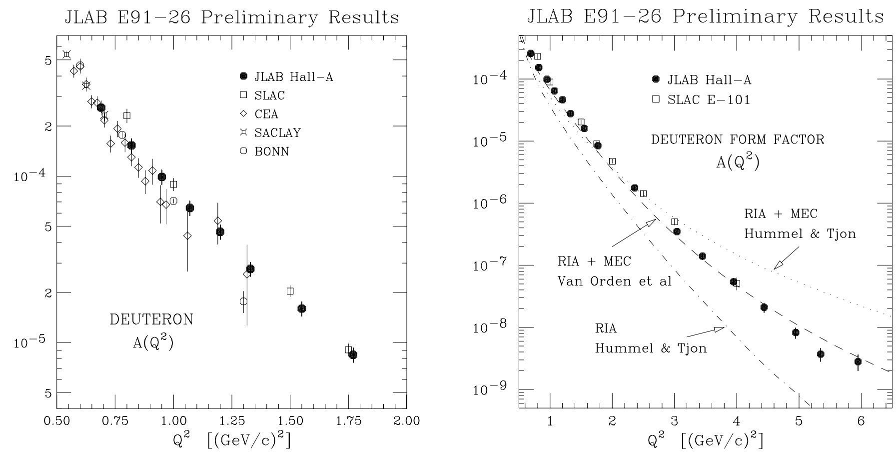


Figure 1: The left panel shows our data in the "low" $Q^2$ region. The previous measurements tend to show two long-standing diverging trends, one supported by the SLAC data [2] and the other by the CEA [1] and Bonn [3] data. Our data confirm the trend of the SLAC data. The right panel shows all of our data together with previous SLAC data. The two data sets agree well in the range of overlap. Theoretical calculations by Van Orden, Devine and Gross (VDG) [5] and Hummel and Tjon (HT) [6] are also shown. In the HT case, relativistic impulse approximation (RIA) calculations with and without meson-exchange currents (MEC) are shown. At large $Q^2$, the RIA calculation alone lacks enough strength to account for the data, and the model becomes very sensitive to the inclusion of MEC. In the HT model, the $\rho\gamma\pi$ and $\omega\varepsilon\gamma$ MEC are included with form factors given by the Vector Dominance Model (VMD). Although not shown, the VDG model has a similar behavior: the RIA alone lacks enough strength, and inclusion of a $\rho\gamma\pi$ MEC with VMD form factors overshoots the data. The VDG model shown includes a $\rho\gamma\pi$ MEC with form factors given by quark models [7,8].

## References


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