Parity Violation Inelastic Scattering Experiments at 6 GeV and 12 GeV Jefferson Lab

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We report on the measurement of parity-violating asymmetries in the deep inelastic scattering and nucleon resonance regions using inclusive scattering of longitudinally polarized electrons from an unpolarized deuterium target. The effective weak couplings C_{2q} are accessible through the deep-inelastic scattering measurements. Here we report a measurement of the parity-violating asymmetry, which yields a determination of $2C_{2u}$ - C_{2d} with an improved precision of a factor of five relative to the previous result. This result indicates evidence with 95% confidence that the $2C_{2u}$ - C_{2d} is non-zero. This experiment also provides the first parity-violation data covering the whole resonance region, which provide constraints on nucleon resonance models. Finally, the program to extend these measurements at Jefferson Lab in the 12 GeV era using the Solenoidal Large Intensity Device was also discussed.

1 Introduction

In parity-violating electron scattering (PVES), the PV asymmetry is given by the expression: $A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$, where σ_R (σ_L) represents the cross-section for scattering longitudinally polarized right-handed (left-handed) electrons. This observable is highly sensitive to studies beyond the standard model physics and the structure of both nuclei and nucleons [1]. In deep inelastic scattering (DIS), the asymmetry can be expressed (mostly model-independent) in terms of the variables $a_{1,3}\left(x, Q^2\right)$, which are related to the subatomic structure of the nucleus and the neutral-weak axial and vector coupling of the electron and the quark. Here, x is the Bjorken scaling variable, and Q^2 is the four-momentum transferred squared.

In the approximation where the electron exchanges only a single photon or Z boson with the target, simple expressions for $a_{1,3}$ can be expressed for a deuteron target in the valence quark model:

$$a_1 = \frac{6}{5}\left(2\mathrm{C}_{1\mathrm{u}} - \mathrm{C}_{1\mathrm{d}}\right), a_3 = \frac{6}{5}\left(2\mathrm{C}_{2\mathrm{u}} - \mathrm{C}_{2\mathrm{d}}\right).$$

The $C_{1u(1d)}$ and $C_{2u(2d)}$ represent the effective weak couplings between electrons and up (down) quarks. Sometimes, they are collectively expressed as C_{1q} and C_{2q}. The indices 1 and 2 correspond to if the coupling to the electron or quark is vector or axial-vector. C_{1q} is the (AV) combination of the electron's axial-vector weak charge and the quark's vector weak charge. Then C_{2q} is the (VA) combination of the electron's vector weak charge and the quark's axial-vector weak charge. The C_{2q} is sensitive to PV due to the quark chiral states and can only be direclty accessed in DIS, whereas, C_{1q} can also be obtained from elastic PVES. SLAC E122 [2] was the first PVES experiment and provided the first measurement for $\sin^2\theta_w$. It also established the gauge model of Weinberg, Glashow, and Salam as the correct theory for the electroweak interactions.

2 Experimental Procedure

The measurements reported at the conference were conducted using a 5−6 GeV longitudinally-polarized electron beam at Jefferson Lab. The beam current was ~ 100 μA with approximately 90% polarization. The electron beam was incident on a 20-cm long liquid deuterium target controlled at a temperature of 22 K. The scattered electrons were detected in a pair of spectrometers [3] that provided high precision measurements of their momentum and angle. For the majority of the run period, the spectrometers were set to detect DIS electrons [4]. However, additional data were also collected in four kinematic settings, which covered the entire nucleon resonance region [5]. Besides providing constraints on nucleon resonance models, these data also exhibited a feature known as "quark-hadron duality" [6] for electroweak observables for the first time.

3 Results

3.1 Nucleon resonance region

Figure 1 shows the measured PV asymmetries, scaled by $1/Q^2$, from $\vec{e}$-^{2}H scattering in the resonance region versus W. The vertical error bars represent the statistical uncertainties, whereas the horizontal bars indicate the RMS value of the W coverage for each bin. The shaded band near the bottom of the graph shows the experimental systematic uncertainties. The measured asymmetries are consistent with the three resonance models [7, 8, 9]. In Fig. 1, theory A (dashed lines), theory B (dotted lines) and theory C (solid lines) correspond to Refs. [7], [8] and [9], respectively. In the case of Theories B and C, there are three curves, which indicate the upper and lower bands and central values of the two calculations. These data also agree well with the DIS estimation (dash-double-dotted lines) using CTEQ-Jefferson Lab (CJ) [10] parton distribution fuction (PDF) fits. This agreement with the DIS calculation indicates that quark-hadron duality holds at the 10−15% level throughout the entire resonance region.

3.2 Deep inelastic region

In Fig. 2, the correlation plot of $2C_{2u}$ - C_{2d} versus $2C_{1u}$ - C_{1d} at $Q^2 = 0$ is shown as extracted from the measured asymmetry. The details of the extraction are presented in Ref. [4]. The new results are represented by the ellipse labeled "This measurement", and the results on $2C_{2u}$ - C_{2d} deviate from zero by 2σ. The yellow ellipse shows the results from the SLAC 122 experiment. The vertical band is the latest C_{1q} results [11]. The red ellipse is the combined result from all published measurements. The standard model expected value is represented by the black dot, which is in good agreement with all measured results.

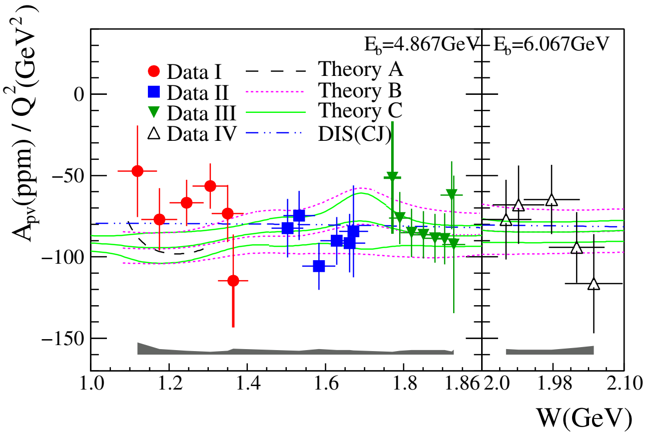

Figure 1: Invariant mass dependence of the measured $\vec{e}$-^{2}H parity-violating asymmetries in the nucleon resonance region. See text for details. Reproduced from Ref. [5].

4 Future Perspectives

With the upgrade of the Jefferson Lab electron beam, the PVDIS program will continue with the Solenoidal Large Intensity Device (SoLID) [12]. This device is a multi-purpose spectrometer with physics topics including PVDIS on proton and deuteron targets, semi-inclusive DIS on polarized proton and ^{3}He targets and threshold J/ψ production. The main motivation for the PVDIS experiment is to investigate possible new interactions beyond the Standard Model and to measure the PDF ratio d/u at high x. The experiment will obtain data over a wide kinematic range: $x > 0.2$, 2 GeV$^2 < Q^2 <$ 10 GeV^2 and will improve the measurement of the effective weak couplings by one order of magnitude compared with the 6 GeV results presented here.

5 Summary

In conclusion, recent results on the parity-violating asymmetries over the whole nucleon resonance region and in the deep-inelastic regime are reported. We have improved our knowledge on the electron-quark VA effective coupling term 2C_{2u} - C_{2d} by a factor of five. Our result is in agreement with the standard model prediction and is the first evidence that 2C_{2u} - C_{2d} deviates from zero at the 2σ level. Additionally, the nucleon resonance asymmetries agree with DIS-based calculations, indicating for the first time that quark-hadron duality may also exists in electroweak observables. The resonance data provide constraints on nucleon resonance models, which are relevant for background estimations to elastic PVES measurements. Finally, the construction of SoLID, to be used with the upgraded Jefferson Lab 12-GeV electron beam, will allow us to continue these measurements and improve our knowledge on C_{2q} by another order of magnitude.

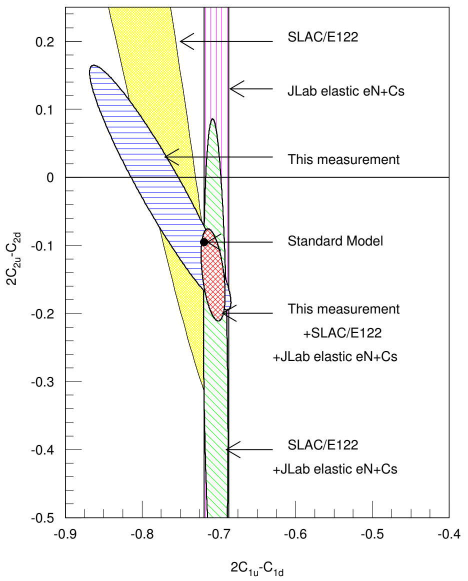

Figure 2: (color online) Comparison of current results (blue ellipse) compared with earlier experiments for the effective weak couplings. See text for details. Reproduced from Ref. [4].

Acknowledgments

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