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Parity violating deep inelastic scattering

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Summary. — Measurements of parity violation in electron scattering have provided a wealth of information on the nucleon, the nucleus and the electroweak interaction. Many of these measurement have been at relatively low four-momentum exchange (Q). The upgrade of the CEBAF beam energy at Thomas Jefferson National Accelerator Facility (JLab) to a maximum of 12 GeV will expand the kinematics in which PVES measurements can be made to include significantly more of the deep inelastic scattering (DIS) region. To take advantage of this, a new spectrometer, named SoLID, has been proposed. Measurements in the DIS region will provide new information on a variety of topics, including charge symmetry violation, higher twist contributions to proton structure and electroweak coupling constants. To differentiate between these effects, measurements with the SoLID spectrometer will simultaneously cover a large kinematic range in both $x_{\rm Bj}$ and Q^2.

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High-quality polarized electron beams have allowed measurement of parity violation in electron scattering (PVES) to become an important probe of the weak force and of the structure of the nucleon. Recently the HAPPEX [1, 2], G0 [3] and PREX [4] experiments at Thomas Jefferson National Accelerator Facility (JLab) have used PVES to explore the effects of intrinsic strangeness in the proton and the neutron radius in lead with asymmetries less than 7×10^{-7}. Currently, the $Q_{\rm Weak}$ experiment [5, 6] is measuring parity violation in electron-proton elastic scattering as a probe of electroweak couplings. The upgrade of the electron beam energy of the CEBAF accelerator at JLab to 12 GeV greatly increases the kinematic range available for experiments and will allow experiments to access more of the deep inelastic scattering (DIS) region. This talk will discuss measurements of parity violation in deep inelastic scattering (PVDIS) at JLab with the proposed SoLID spectrometer [7]. These measurements build on the JLab 6 GeV PVDIS experiment [8].

The electroweak Standard Model is remarkably successful in quantitatively describing the unification of the electromagnetic and weak interaction. There are, however, experimental hints [9, 10] that the Standard Model is not complete. Precision, low-energy experiments are an important element in the effort to elucidate the missing elements [11]. The couplings between leptons and quarks may be sensitive to these extensions [12].

The asymmetry in polarized electron scattering on unpolarized deuterium in DIS kinematics, $A^d_{\rm PVDIS}$, was first measured by Prescott *et al.* at SLAC [13, 14] and served to establish what is now known as *the* Standard Model of the electroweak interaction. This asymmetry can be expressed in terms of quark distribution functions of the target, and the couplings C_{1q} (axial electron × vector quark) and C_{2q} (vector electron × axial quark) that, within the context of the Standard Model, depend on the weak mixing angle, θ_W [15, 16]

$$\begin{aligned} C_{1u} &= g^e_A g^u_V = -\frac{1}{2} + \frac{4}{3}\sin^2\theta_W, & C_{1d} &= g^e_A g^d_V = \frac{1}{2} - \frac{2}{3}\sin^2\theta_W, \\ C_{2u} &= g^e_V g^u_A = -\frac{1}{2} + 2\sin^2\theta_W, & C_{2d} &= g^e_V g^d_A = \frac{1}{2} - 2\sin^2\theta_W. \end{aligned} \tag{1}$$

Ignoring the intrinsic charmed quark contribution, on an isoscalar target such as deuterium, the PVDIS asymmetry, $A^d_{\rm PVDIS}$, expressed in terms of these couplings, is

$$\begin{aligned} A^d_{\rm PVDIS} &= -\left(\frac{3G_F Q^2}{2\sqrt{2}\pi\alpha}\right)\frac{(2C_{1u} - C_{1d})\,[1 + R_s(x_{\rm Bj})] + Y\,(2C_{2u} - C_{2d})\,R_v(x_{\rm Bj})}{5 + R_v(x_{\rm Bj})} \\ &\approx 10^{-4}Q^2 \qquad (Q^2 \text{ in GeV}^2), \end{aligned} \tag{2}$$

where G_F is the Fermi constant; Q^2 is the negative photon invariant mass squared; $x_{\rm Bj}$ is the fractional momentum of the interacting quark; the kinematical factor Y is a function of the scattered electron energy, $R_v(x_{\rm Bj})$ and $R_s(x_{\rm Bj})$ depend solely on the quark distributions.

Data from the JLab $Q_{\rm Weak}$ experiment [5,6], combined with other measurements, primarily atomic parity violation (APV) in cesium [17], will determine the C_{1q} coefficients. The C_{2q} coefficients, however, are poorly known. Measurement of parity PVDIS is the best way to determine them. The current and projected knowledge of C_{1q} and C_{2q} is shown in fig. 1 [5, 6, 13, 14, 18, 19, 17].

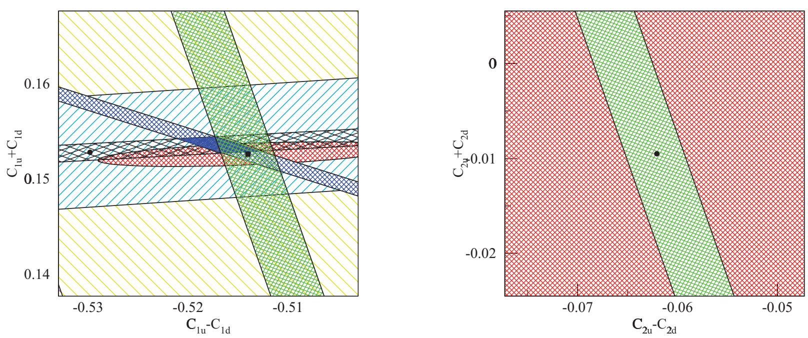

Fig. 1. – Present knowledge of C_{1q} (left) and C_{2q} (right) from thallium APV [18] (cyan), cesium APV [17, 19] (black, horizontal), Prescott's PVDIS measurement [13, 14] (yellow, encompassing most of the plot) and anticipated results from $Q_{\rm Weak}$ [5,6] (blue). In both, the green band shows the expected uncertainty from the SoLID PVDIS program, and the red ellipse shows the PDG's best fit [20]. In the C_2 plane, the ellipse covers an area much larger than the entire graph which was plotted on the same scale as the C_1 couplings for comparison.

TABLE I. – *The dependence of "new physics", CSV and higher-twist on the kinematic variables.*

	x_{Bj}	Y	Q^2
New Physics	No	Yes	No
CSV	Yes	No	No
Higher Twist	Yes	No	Yes

The interpretation of A^d_{PVDIS} in terms of the C_{iq} couplings given by eq. (2) is based on an assumption of electron-quark scattering. With high Q^2 and W^2, and moderate x_{Bj} this assumption is valid. Outside of these kinematics, additional terms in the higher-twist expansion may also contribute. In addition, current extractions of parton distributions assume no charge symmetry violation (CSV). Any CSV would change the measured A^d_{PVDIS} from the prediction of eq. (2). The dependence of A^d_{PVDIS} to these affects on kinematics is shown in table I.

Non-zero CSV effects have been allowed in some parton distribution fits. These fits tend to favor a *small* amount of CSV [21]. In addition, recent models of CSV also tend to favor a similar, small CSV [22]. Based on these, the size of the effect on A^d_{PVDIS} should be between 0.25% and 0.5%. Charge symmetry violation would likely be seen as an x_{Bj}-dependent but Q^2-independent difference in A^d_{PVDIS} from the predictions of eq. (2).

There is currently no experimental information on the contribution of higher-twist to PVDIS. The small amount of theoretical work which has been completed has shown the effects of higher-twist on A^d_{PVDIS} are small, but *possibly* not negligible [23, 24]. An interesting aspect of higher-twist contributions to PVDIS is that only a certain class of quark-quark correlations can produce an observable effect in the first term in eq. (2) [25, 26]. PVDIS is the only experiment that can access this class of higher-twist terms.

To address the need for a wide acceptance in both x_{Bj} and Q^2, a new, solenoidal spectrometer has been proposed [7]. The design is such that it will have kinematic acceptance to cover $0.2 < x_{\mathrm{Bj}} < 0.75$ and $2 < Q^2 < 10\,\mathrm{GeV}^2$. To achieve this acceptance, the spectrometer design is based on a large solenoid with a series of "baffles". These baffles select the scattered electrons with the appropriate momenta to spiral through them. Tracks are detected in a series of GEM chambers with particle identification given by a threshold Cherenkov counter and and electromagnetic calorimeter. The spectrometer is shown in fig. 2. The expected statistical sensitivity as a function of x_{Bj} and Q^2 is

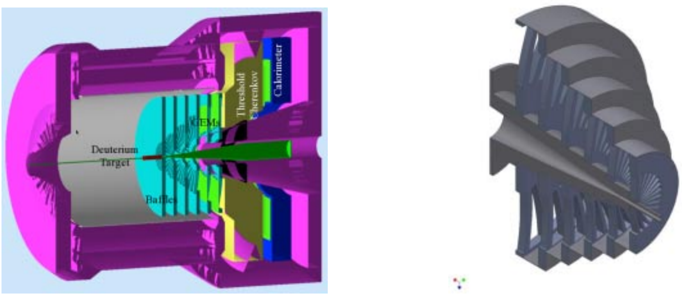

Fig. 2. – A diagram of the proposed SoLID spectrometer (left) and the "baffles" (right).

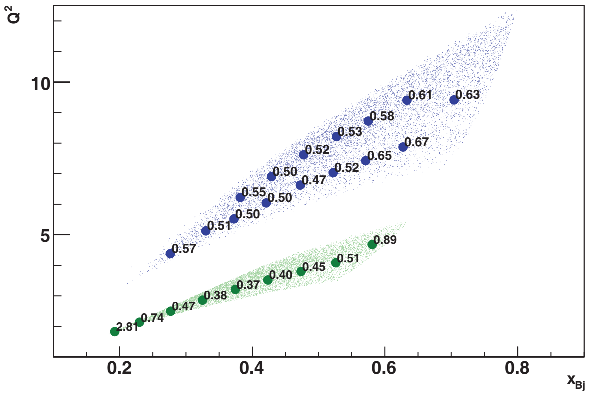

Fig. 3. – The expected statistical precision in $A^d_{\rm PVDIS}$ for bins in $x_{\rm Bj}$ and Q^2 are shown for two runs of 120 days at 11 GeV and 60 days at 6.6 GeV with a 50 μA beam and 85% polarization. The dots indicate the bin centers with the statistical precision in percent (%) [7].

shown in fig. 3 with the requirement that mass of the recoiling system, W be greater than 2 GeV. With this kinematic coverage, the differences between CSV, higher-twist and electroweak physics can be separated by fitting to the functional form [7]

$$A^d_{\rm PVDIS} = A^{\rm EW}_{\rm DIS}\left[1 + \beta_{\rm HT}\frac{1}{(1-x_{\rm Bj})^3 Q^2} + \beta_{\rm CSV} x^2_{\rm Bj}\right]. \tag{3}$$

Because of this relatively large asymmetry, $A^d_{\rm PVDIS} \approx 3\times 10^{-4}$ (depending on kinematics), many of the systematic effects, especially those related to beam induced false asymmetries, may be controlled easily by using now standard techniques. The dominant systematic uncertainty and the dominant technical challenge is the measurement of the beam polarization, where an uncertainty of less than 1% is necessary to be able to separate CSV, higher-twist and non-Standard Model effects. To address this, the SoLID Collaboration has proposed using both a Compton polarimeter [27] and an atomic hydrogen Møller polarimeter [28].

In addition to measuring PVDIS, other experiments have been approved by JLab that use the proposed SoLID spectrometer. These experiments will use the large luminosity and angular acceptance to measure semi-inclusive deep inelastic scattering (SIDIS) on a transversely [29] or longitudinally [30] polarized ^{3}He target.

A systematic set of $A^d_{\rm PVDIS}$ at JLab has been outlined using a new solenoid-based spectrometer named SoLID. This spectrometer will allow $A^d_{\rm PVDIS}$ to be measured over a large range in both $x_{\rm Bj}$ and Q^2. A statistical precision of 0.5% can be quickly achieved for these measurements, because of the relatively large asymmetry. From these measurements, limits or a measurement of CSV at the parton level and the contributions of higher order terms in the twist expansion will be extracted. Both of these effects are believed to be small; although neither has been well measured. After the extraction of CSV and higher-twist contributions, the measurement of $A^d_{\rm PVDIS}$ can be interpreted in terms of the C_{1q} and C_{2q} coupling coefficients.

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