Parity Violation in DIS at JLab with SoLID

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We present the physics case for precision measurements of PVDIS with the upgraded JLab 12 GeV beam by using a **So**lenoidal Large **I**intensity **D**evice (SoLID). The unique feature of SoLID, combining high luminosity and large acceptance, makes it possible to reach the high precision needed to have a high impact by using PVDIS to probe physics beyond the Standard Model. A measurement of PVDIS in deuterium will determine a fundamental coupling constant that is inaccessible with other means. PVDIS measurements can also access a number of topics in QCD physics, including searching for charge symmetry violation in the parton distribution functions, determining the d/u ratio in the proton without nuclear effects, and a clean extraction of higher-twist effects due to quark-quark correlations. SoLID allows a full exploitation of the physics potential of the JLab 12 GeV upgrade. In addition to PVDIS, it has a set of approved highly-rated experiments to study nucleon transverse spin and transverse structure by using polarized semi-inclusive DIS and to study non-perturbative gluon dynamics with J/Ψ production near threshold. A brief description of the SoLID spectrometer is also given.

I. EXECUTIVE SUMMARY

In the late 70's, Prescott *et al.* [1, 2] showed that the weak neutral current violates parity by measuring the non-zero asymmetry $A_{LR} = (\sigma_L - \sigma_R)/(\sigma_L + \sigma_R)$ for polarized electron-deuterium deep inelastic scattering. The experiment also set limits on the dependence of A_{LR} on the variable $y \equiv (E - E')/E$, which ruled out models invented to explain the negative results of the early atom parity violation (APV) experiments. Subsequent to these publications, Glashow, Salam, and Weinberg were awarded the Nobel prize for electroweak unification.

Parity violating electron scattering (PVES) from deuterium in the DIS region at large Bjorken x is an attractive reaction for searching for new physics since there the A_{LR} is approximately independent of hadron structure, and the remaining QCD effects, which are of great interest in themselves, can be isolated by their kinematic dependence. The asymmetry has the form $A/Q^2 = -[a_1 + a_3 f(y)]$, where $f(y) \approx [1 - (1 - y)^2]/[1 + (1 - y)^2]$ and $a_1 \propto 2C_{1u} - C_{1d}$ and $a_3 \propto 2C_{2u} - C_{2d}$, where $C_{1q}(C_{2q})$ are four-Fermi coupling constants with axial(vector) electron currents and vector(axial) quark currents. At large y, A_{LR} is sensitive to the C_{2q}, which cannot be studied in low energy reactions because of large and uncertain radiative corrections. Experiments with atomic parity violation and PVES experiments including Qweak [3] have yielded precise measurements of the C_{1q}. The 6-GeV PVDIS collaboration [4] has recently published in Nature a new experimental result $2C_{2u} - C_{2d} = -0.145 \pm 0.068$, the first measurement sufficiently sensitive to show that the C_{2q} are non-zero as predicted by the SM.

It is important to improve the measurement of the C_{2q} to the level of the C_{1q}. This requires a facility with both high luminosity and large acceptance which leads to the idea of SoLID. [5, 6]. We have developed a preliminary conceptual design of a spectrometer, SoLID (left panel of Fig. 1), to reach this goal [7]. The apparatus can measure A_{PV} for about 20 kinematic points with $x > 0.4$ and a range of Q^2 with a statistical precision of about 0.5%.

One way to quantify the reach of various experiments is to quote mass limits suitable for composite models [8], where the couplings are on the order of $4\pi/\Lambda^2$ with Λ is the compositeness mass scale. Such limits for the 6-GeV PVDIS collaboration and the SoLID PVDIS experiment [9] are shown in the right panel of Fig. 1. The mass limits are on the scale probed by the LHC, but have the unique feature that they have a very specific helicity structure. For example, a lepto-phobic Z' [10] can only contributes to the C_{2q}. In addition, a broken U(1) gauge symmetry in the dark matter sector can induce a change in $\sin^2\theta_W$ that can be observed in low Q^2 PVES experiments [11].

Uncertainties in hadron structure, including charge symmetry violation (CSV) in the PDF's [12] and Q^2-dependence due to higher twist effects [13], which would be of concern for a single kinematic point. With a wide kinematic range

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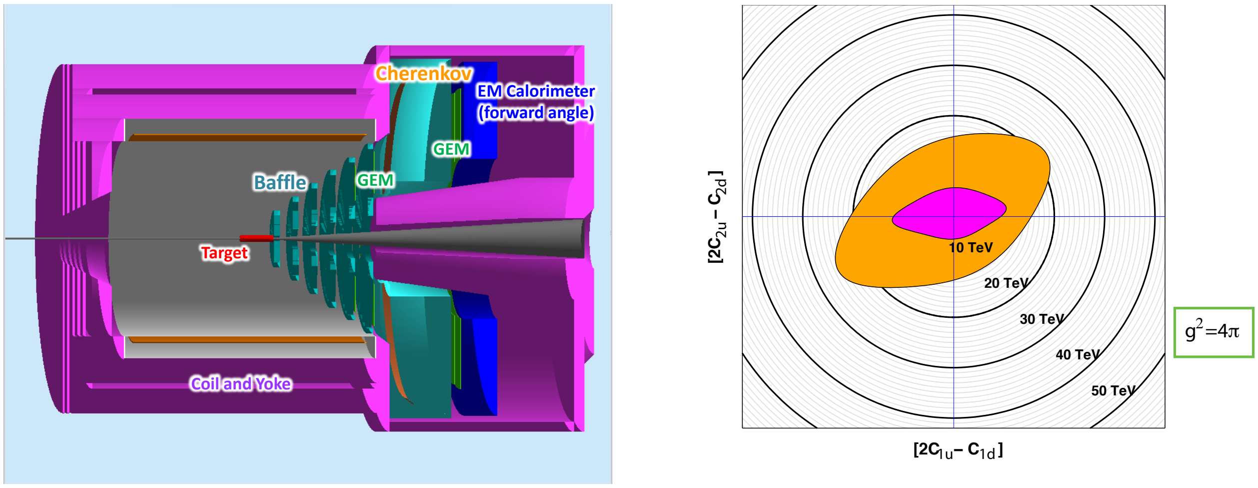

FIG. 1: Left panel: SoLID apparatus. Scattered electrons spiral through the baffles and are detected by GEM's and identified with a Cerenkov counter and an EM calorimeter. Right panel: Projected mass limits for composite models. Purple region is excluded by published data and the orange region is the projected result with SoLID and final Qweak result.

in both x and Q^2, we can separate out these effects. We note that if these hadronic effects are large enough to be observed by SoLID, they will constitute important discoveries in and of themselves. Further, by using a ^{48}C target, the SoLID spectrometer can observe a possible isovector EMC [14] effect that is predicted to be large enough [15] to explain the NuTeV anomaly [16].

The SoLID spectrometer is part of the parity-violation program at JLab cited in Recommendation I of the 2007 NSAC Long Range Plan. It is part of the SM initiative listed on p. 76 and described in more detail on p. 87 of the above document. SoLID is also designed to provide a rich program in Semi-Inclusive Deep Inelastic Scattering (SIDIS) to measure Transverse Momentum Dependent Parton Distributions (TMD's) and also J/Ψ production. The unique feature of combining large acceptance and high luminosity of the SoLID makes it possible to exploit the full potential of the JLab 12 GeV to perform precision study of the nucleon structure structure and QCD dynamics. A set of SIDIS experiments will map the transverse structure of the nucleon with unprecedented precision. Threshold J/Ψ production will provide important information on non-perturbative gluon dynamics.

II. MAIN BODY OF PAPER

A. Phenomenology

The fundamental parity-violating weak neutral current Lagrangian can be approximated as a four fermion contact interaction:

$$\mathcal{L}^{ef}_{\rm NC} = \frac{1}{2v^2}\left(\bar{e}\gamma^\mu\gamma^5 e \sum_{q=u,d} g^{eq}_{AV}\bar{q}\gamma_\mu q + \bar{e}\gamma^\mu e \sum_{q=u,d} g^{eq}_{VA}\bar{q}\gamma_\mu\gamma^5 q\right) \, , \tag{1}$$

where $v = (\sqrt{2}G_F)^{-1/2}$=246.22 GeV with G_F the Fermi constant. For the SM at the tree level,

$$g^{eu}_{AV} = C_{1u} = -\frac{1}{2} + \frac{4}{3}\sin^2\theta_W; \quad g^{ed}_{AV} = C_{1d} = \frac{1}{2} - \frac{2}{3}\sin^2\theta_W$$

$$[g^{eu}_{VA} = C_{2u} = g^{ed}_{VA} = -C_{2d} = \frac{1}{2} - 2\sin^2\theta_W .$$

The g's and the more familiar constants C_{ij} differ in terms of the radiative corrections that have been applied.

In this notation, the asymmetry for PVDIS in deuteron can be written approximately as

$$A^{\rm DIS}_{LR} = -\frac{3}{20\pi\alpha(Q)}\frac{Q^2}{v^2}\left[(2g^{eu}_{AV} - g^{ed}_{AV}) + (2g^{eu}_{VA} - g^{ed}_{VA})\frac{1-(1-y)^2}{1+(1-y)^2}\right] , \tag{2}$$

where the PDF and many other possible corrections cancel due to the isoscalar nature of the target. The SoLID spectrometer is designed to have large acceptance at large y, so that A_{PV} is very sensitive to the g^{ei}_{VA} couplings. We note that precision measurements of the g^{ei}_{VA} are only possible with PVDIS since uncertain radiative corrections are important for precesses at lower values of Q^2.

B. Physics beyond the SM

There are many possible scenarios for physics beyond the standard model. For new physics at high energy, the result is a modification of the couplings defined above. Another scenario discussed below involves a light dark Z boson that introduces modifications to the couplings only at low energies.

1. *New Physics Scales*

We can denote the contribution of new physics to the electroweak couplings by

$$g^{eq}_{AV}/(2v^2) \to g^{eq}_{AV}/(2v^2) + 4\pi/(\Lambda^{eq}_{AV})^2, \text{etc.}$$

The energy scale of the new physics is given by the Λ^{eq}_{AV}. The 4π coupling in the numerator is a convention invented to characterize theories with composite sub-structure that is strongly coupled [8]. Applying the formalism to theories with $g_{new} \neq 4\pi$ is trivial. Typical compositeness analyses use single Lorentz and flavor structures. Since we are working with several Lorentz structures and two quark flavors, it is suitable to rotate both the operators and coefficients so that

$$\sum_{k,l=V,A,m} (g^{eq}_{kl})^2 = N \sum_{k,l=L,R,m} (g^{eq}_{kl})^2,$$

where $N = 1$, whereas Ref [8] ignored isospin and used $N = 4$. As shown in Fig. 1, SoLID has sensitivity for its particular Lorentz structure at the 20 TeV level, whereas recent limits, for example from ATLAS [17], which are sensitive to parity-conserving Lorentz structures, are at the 10 TeV level.

2. *Leptophobic Z' Bosons*

The interesting possibility that there are extra Z bosons called Z's is as old as the Standard Model (SM). Many models have been proposed, often based on larger symmetry groups than $SU(3) \times SU(2) \times U(1)$. This particular class of models has the following features in common:

1. The Z' bosons couple to ordinary fermions, especially light quarks, electrons and muons.
2. The couplings are weak, so the resonances are narrow.
3. The signature for these particles is easy to calculate both for precision low-energy experiments and high-energy collider experiments.

Narrow resonances are easy to detect at a hadron collider because they are produced by the collisions of light quarks and decay into easily-detected lepton pairs. Nevertheless, before the LHC era, the strongest bounds for these particles often came from precision low-energy experiments, especially parity violation in atoms (APV) [18, 19]. More recently, data from the LHC has pushed the mass bounds on these particles to the 2 TeV range. As a consequence, these models are now out of reach for proposed precision tests. By contrast, the LHC signature for compositeness have more background and less selectivity, and low energy PDVIS experiments are still competitive.

An interesting variation on the Z' is the so-called leptophobic Z', which has the defining feature that it has no direct couplings to leptons. One specific model, which was developed to explain an excess in di-quark production in the 100 GeV mass region observed at Fermilab [20], is based on the $E(6)$ group. An interesting feature of this model that distinguishes it from older versions is that it also couples to dark matter and is relevant to dark matter experiments [21]. For example, the Z' could be the particle exchanged in experiments designed to detect dark matter. In terms of low energy experiments, the leptophobic Z' has the feature that the coupling to electrons occurs through quark loops connecting to photons (see Fig. 2), and hence the coupling is strictly vector. As a consequence, it has no effect on the C_1's and can only be detected in PV experiments such as SoLID-PVDIS that are sensitive to the

C_2's [10, 22]. An interesting point is that for such low-mass Z's, the LHC is not particularly sensitive, as shown in the right panel of Fig 2 which is taken from Ref [23]. Note that this analysis does not include the latest Fermilab or LHC data.

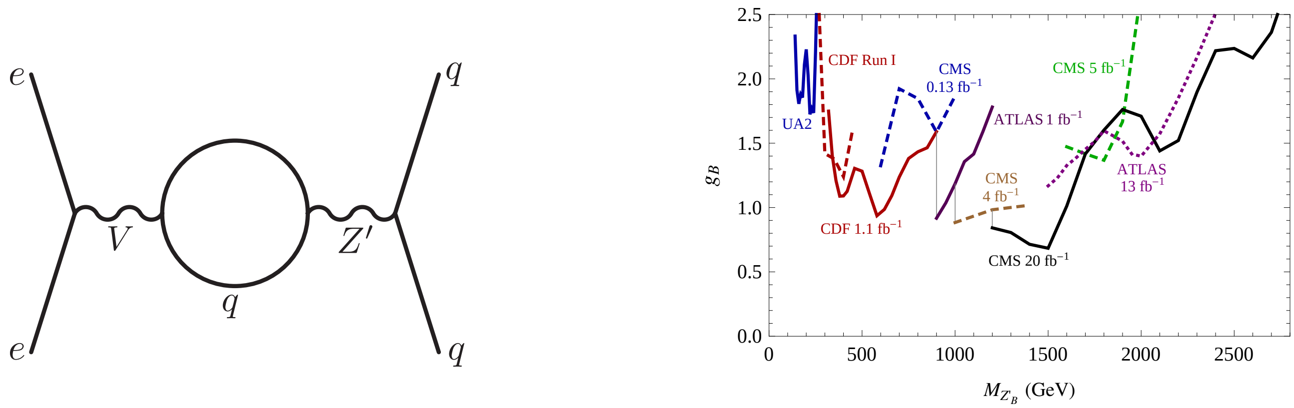

FIG. 2: Left panel: Diagram for the coupling of the leptophobic Z' corresponding to the C_2's. The electrons couple to quark loops which couple to the Z'. Right panel: Limits on leptophobic Z's from collider data. The LHC data only limits the higher mass regions.

A final analysis of the Fermilab data, including more integrated luminosity [24], has set limits on a possible signal at a level about a factor of 5 lower than that of Ref [20], ruling out the above specific model with its specific parameters as a significant contribution to the C_2's. More recently, there has been considerable interest in the idea that Z's provide one of the few bridges between ordinary and dark matter. In this field, there is little data and hence there are a hugh amount of freedom in constructing models. For example, the Z' could have decay modes to over dark particles and hence be hard to search for in hadron collider experiments [11]. Another approach considers composite Z' bosons [25]. For these scenarios, SoLID-PVDIS can provide a unique window into possible new physics.

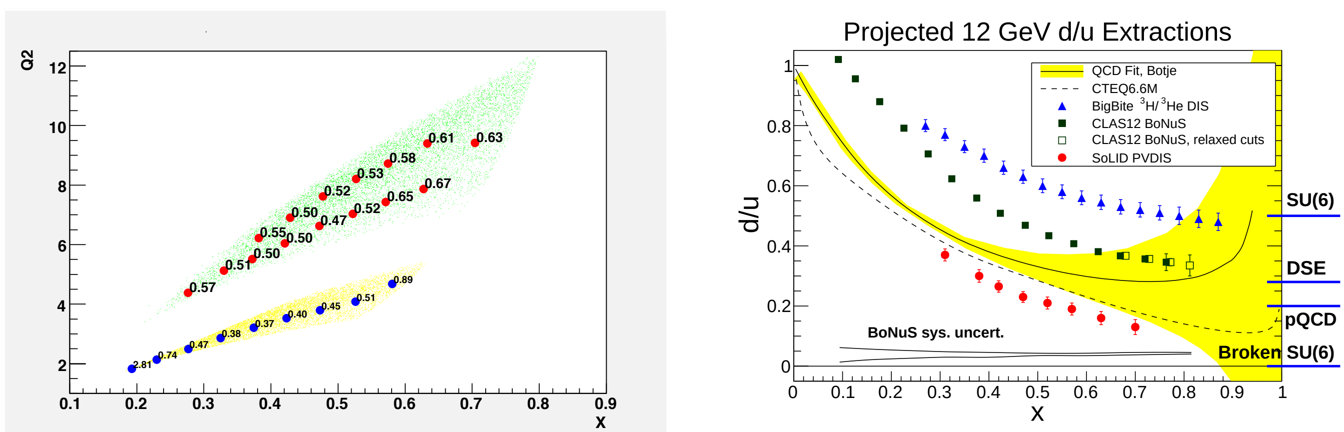

FIG. 3: Left panel: Anticipated statistical precision for SoLID in the PVDIS configuration. Top band is data obtained at 11 Gev and bottom band is data taken with 6.6 GeVbeam. Right panel: Projection precision for the d/u ratio obtained with a hydrogen target.

3. *Dark Bosons*

Another possibility for New Physics is the existence of a new particle called a dark Z_d boson. In some scenarios, the particle can have very low mass, on the order of only tens of MeV. Such a particle could explain the $g-2$ anomaly in the case that the dark boson has invisible decays. The idea is that kinetic mixing between the SM $U(1)_Y$ and the dark $U(1)_d$ with constant ϵ and also mass mixing with the SM Z with parameter $\epsilon_Z \equiv (M_{Zd}/M_Z)\delta$. The result is that $\sin^2\theta_W$ at low energies is modified to [11]

$$\Delta \sin^2\theta_W(Q^2) \sim -0.42\epsilon\delta \frac{M_Z}{M_{Zd}} \left(\frac{M_{Zd}^2}{Q^2 + M_{Zd}^2}\right).$$

The sensitivity of many experiments to these scenarios depends on whether or not the Z_d decays to visible particles such as $e+e-$ pairs or to invisible particles and also on a possible interference between kinetic and mass mixing. Additional model dependence arises from different possibilities for the charge corresponding to the $U(1)_d$. SoLID-PVDIS has the potential to show that any anomaly in $\sin^2\theta_W$ that might be observed in lower Q^2 experiments [26] has vanished at $Q^2 > 1$ (GeV/c)^2. In addition, limits for the case where the dark boson mass is at the several GeV scale are weak. SoLID covers a large range of Q^2

C. Charge Symmetry Violation

Charge symmetry violation (CSV) in the PDF's are an important possible QCD effect that may be large enough to explain the apparent inconsistency of the NuTeV experiment [16] with the SM[12, 27]. Another interesting possibility is the presence of an isovector EMC [14] effect that causes a "pseudo" CSV in nuclei with more neutrons than protons. This effect can be observed by using a ^{48}Ca target with the SoLID apparatus. Another important possible effect is Q^2-dependence due to higher twist (HT) effects [13]. In the deuteron, A_{PV} has the special feature that HT can only be due to quark-quark correlations; all other diagrams cancel in the ratio.

D. Measurement of the PDF d/u Independent of Nuclear Structure

A measurement of $A_{LR}^{\rm DIS}$ on a proton target is sensitive [6] to the ratio of the d to u quark PDF. The standard determination of the d/u ratio relies on fully inclusive DIS on a proton target compared to a deuteron target. In the large x region, nuclear corrections in the deuteron target lead to large uncertainties in the d/u ratio. However, they can be completely eliminated if the d/u ratio is obtained from the proton target alone. For this reason, precision measurements of $A_{LR}^{\rm DIS}$ on a proton target can be a powerful probe of the d/u ratio.

A_{LR} for a proton target at leading twist takes the form,

$$A_{LR}^p \sim -\frac{1}{4\pi\alpha}\frac{Q^2}{v^2}\left[\frac{12\, g_{AV}^{eu} - 6\, g_{AV}^{ed}\; d/u}{4 + d/u}\right] ,$$

As in the case of the deuteron asymmetry, other hadronic corrections can affect the extraction of the d/u ratio. The data will be complementary to proposed experiments at JLab including one using mirror ^{3}H and ^{3}He nuclei to minimize nuclear effects in extracting F_2^n/F_2^p [28], and the BONUS experiment [29] by tagging slow moving proton to minimize nuclear effects in extracting F_2^n.

E. The Full SoLID Program

The SoLID spectrometer also has many other applications for physics at JLab. The facilities designed for the JLab 12 GeV upgrade include detectors designed for either large acceptance (CLASS and glueX) or high luminosity (Spectrometers in Halls A and C). However, there are a number of impotent physics issues that can only be addressed by a spectrometer that can provide both high acceptance together with high luminosity together. Based on new technologies that have recently become available, the SoLID collaboration has proposeded and designed such a device. Already 4 experiments with an "A" rating and one with an "A$^-$" rating have been approved by the JLab PAC. The physics program is broad. In addition to PVDIS studies, the facility can provide detailed SIDIS measurements as well as a measurement of the small cross section for J/Ψ production near threshold.

1. SIDIS Program

Understanding the internal structure of nucleon and nucleus in terms of quarks and gluons, the fundamental degrees of freedom of Quantum Chromodynamics (QCD), has been, and still is, the frontier of subatomic physics research. In

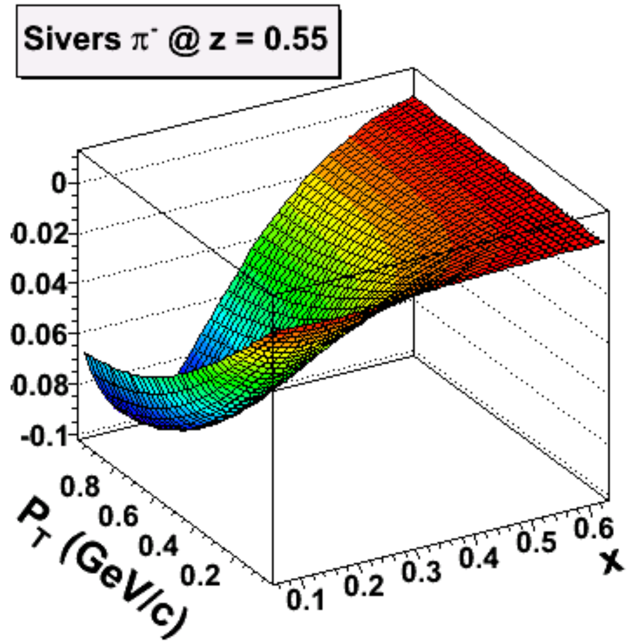

FIG. 4: Typicsl TMD, showing the nature of possible structure that can be observed with fine binning.

recent years, the hadronic physics community has advanced its investigation of partonic structure of hadrons beyond the one-dimensional parton distribution functions (PDFs) by exploring the motion and spatial distributions of the partons in the direction perpendicular to the momentum of the parent hadron. Such efforts are closely connected to the study and extraction of two new types of parton distribution functions concerning the tomography of the nucleon. They are the transverse-momentum-dependent parton distributions (TMDs), and the generalized parton distributions (GPDs), providing new information about the rich dynamics of QCD.

Knowledge of TMDs is essential to unfold the full momentum and spin structure of the nucleon. The TMDs represent the confined motion of partons inside the nucleon and allow reconstruction of the nucleon structure in three-dimensional momentum space, thereby leading to exploration and study of new structure, new dynamics, and new phenomena. Most TMDs and related observables are due to couplings of the transverse momentum of quarks with the spin of the nucleon (or the quark). Spin-orbit correlations in QCD similar to those in hydrogen atoms, can therefore be studied. Among the eight leading-twist TMDs, three survive the integration over the transverse momenta of the quarks, and they are the unpolarized and the longitudinally polarized (helicity) TMDs, and the transversely polarized quark distribution function (transversity). Among these three, the transversity is the least known. Its lowest moment defines the tensor charge, a fundamental quantity related to the spin of the nucleon, therefore providing an excellent testing ground for lattice QCD predictions. The remaining five leading-twist TMDs would vanish in the absence of parton orbital angular momentum, therefore, they provide quantitative information about the orbital angular momentum (OAM) of the partons inside the nucleon. The origin of some TMDs and related spin asymmetries, at the partonic level, depends on fundamental properties of QCD, such as its color gauge invariance, which lead to predictions that can be tested experimentally.

The Jefferson Lab 12 GeV energy upgrade and the SoLID detector with the combination of a large acceptance and high luminosity provides a golden opportunity to perform precision measurements of both the single and double spin asymmetries in semi-inclusive deep inelastic scattering, allowing multi-dimensional binning in all relevant kinematic quantities, from polarized ^{3}He ("neutron") and polarized proton targets to extract TMDs with unprecedented precision and flavor separation in the valence quark region. Fig. 5 is an illustration showing the high precision of the projected measurement from a transversely polarized ^{3}He target as a function of Björken x, and pion transverse momentum for an example z, and Q^2 bin, among a total number of 1400 projected data points. Also shown are our published results from the 6 GeV experiment [30] for comparison. Such high precision will provide benchmark tests of dynamical lattice QCD predictions for the tensor charge of the u and d quark, provide quantitative information about quark OAM inside the nucleon, and uncover crucial information about the dynamics of QCD. Furthermore, the SoLID dihadron program, which will take data parasitically with the SIDIS program, will complement the SIDIS measurements nicely,

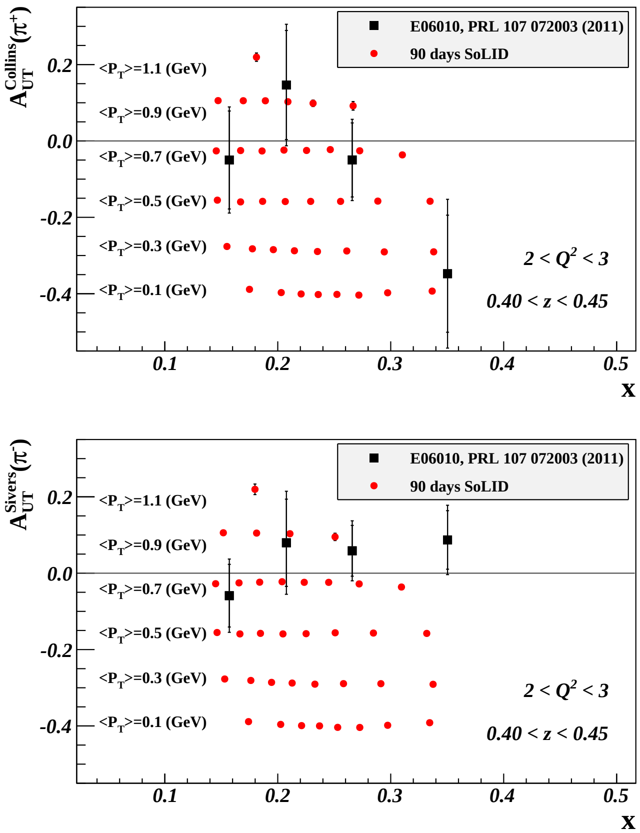

FIG. 5: Top panel: The projected Jefferson Lab 12-GeV SoLID measurement of the Collins asymmetry for π^+ from a transversely polarized ^{3}He target for a z bin of 0.4 to 0.45, and a Q^2 bin of 2 to 3 $(\text{GeV/c})^2$ as a function of π^+ transverse momentum, and Björken x. Also shown are the published result from the 6 GeV experiment [30]. Bottom panel: the projected measurement for the Sivers asymmetry for π^- together with the published results from [30].

particularly in the extraction of the transversity TMD.

The top panel of Fig. 6 is a compilation of our current, model-dependent knowledge about the u and d quark tensor charges determined from analyses [32–34] of existing data (shown as points 2-5), the projected results from the JLab SoLID program within the same model [35] (point 1), together with predictions based on lattice QCD [36, 37] (points 6, and 7), Dyson-Schwinger equations [38, 39] (points 8 and 9), and from various models [40–44] (points 10 - 15). The model dependent uncertainty in the latest extraction [32] is shown as a grey band. In the bottom panel of Fig. 6, we show as an example, the projected measurements of the pretzelocity asymmetry on the neutron (^3He) for both π^+ and π^- together with predictions from S. Boffi *et al.* [31], where contributions from interference of the S-D, and P-P orbital angular momentum states are shown together with the total. It is clear that the projected high precision results from SoLID at 12-GeV JLab will provide powerful tests of LQCD predictions, and much needed quantitative information about quark OAM inside the nucleon.

III. THRESHOLD ELECTROPRODUCTION OF THE J/Ψ ON A NUCLEON

While significant progress has been achieved in exploring QCD in its perturbative regime, much remains to be understood in the strong regime where the theory is hardly tractable. Lattice QCD, offers real hope for serious progress in unraveling the structure of nucleons. However, given the approximations required to mitigate the limitation of existing computing power for full fledged *ab initio* calculations of key observables, a hand in hand collaboration between experimental measurements and calculations is important.

A natural and basic question to ask in nuclear physics is, how is the mass of the nucleon shared among its constituents and their interactions? In two important papers Ji [45, 46] answered the question by providing what he called "A QCD

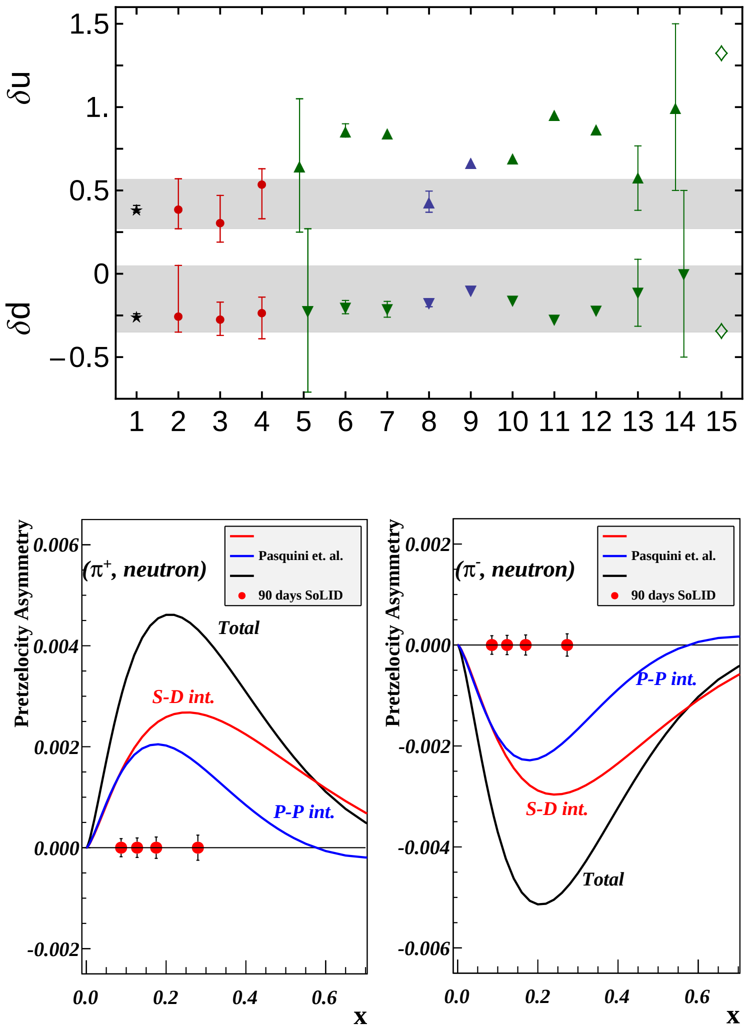

FIG. 6: Top panel: The projected Jefferson Lab 12-GeV SoLID determination of the tensor charge of u and d quark (black points) together with model dependent extractions of these quantities based on the existing data. Also shown are predictions from lattice QCD, Dyson-Schwinger Equations, and various models. Bottom panel: The projected pretzelocity asymmetry measurement from a transversely polarized ^{3}He target ("neutron") together with predictions from Boffi and Pasquini *et al.* [31] at a Q^2 value of 2.5 GeV^2.

analysis of the mass structure of the nucleon". Using the energy-momentum tensor in QCD it was shown that one can partition the mass of the nucleon among four terms identified as the kinetic and potential energy of the quarks, the kinetic and potential energy of the gluons, the quarks masses and the conformal (trace) anomaly. The wealth of deep inelastic scattering data was used to estimate the first three terms at a scale of 1 GeV^2, while the fourth (conformal anomaly) term was estimated, assuming the nucleon mass sum rule, to contribute roughly 20% to the nucleon mass, and this is quite significant. It is worth noting that this term is scale independent which implies that as we probe the nucleon with higher resolution (Q^2 or higher energy scale) the partition of the mass between quark and gluon energies is modified while the conformal anomaly piece remains the same. This first indirect estimation of the conformal anomaly contribution to the nucleon mass was an important step forward in understanding the low energy regime of the gluonic structure of the nucleon and QCD, however, neither direct measurements nor lattice calculations of this term have been attempted yet.

With the 12 GeV upgrade at Jefferson Lab combined with the large acceptance of the SoLID spectrometer [7], designed to operate in a high luminosity environment, there is a unique opportunity to make a measurement directly sensitive to the anomaly contribution to the J/ψ-nucleon interaction at low energy [47, 48] which will be achieved

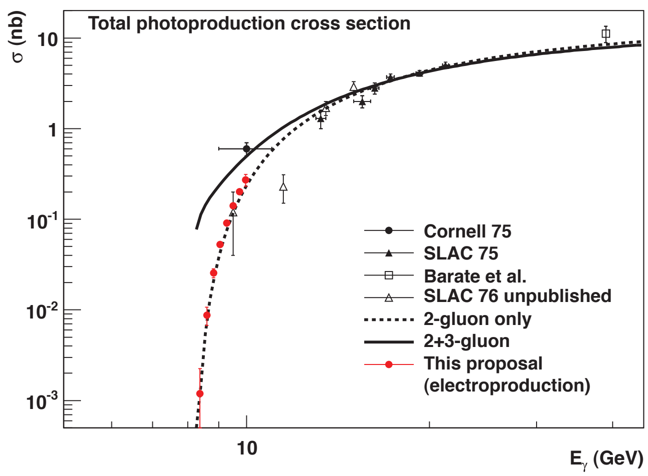

FIG. 7: Total J/ψ photoproduction cross section versus photon energy in the threshold region, except for the proposed electroproduction measurement (filled red circles) where the data are plotted as a function of the equivalent photon energy.

by measuring the exclusive electroproduction of J/ψ near threshold on a proton. With minimal reconfiguration of the semi-inclusive deep inelastic scattering (SIDIS) set up of SoLID, we can perform measurements of the differential electroproduction cross sections near threshold as a function of the four-momentum transfer to the nucleon ($|t - t_{min}|$). From these measurements, the total virtual-photon absorption cross section is evaluated in the region close to the threshold of J/ψ production (see Fig. 7). The strength of the conformal anomaly contribution to the low energy J/ψ-nucleon interaction is reflected in the rate with which the total cross section rises (or falls), in the threshold region, as a function of photon energy. Models of the J/ψ production mechanism and its low energy interaction with the nucleon have also been proposed based on two or three gluon exchanges [49], they can be tested too.

Lattice QCD calculation of the anomaly contribution to the nucleon mass in tandem with the proposed measurement will be available in time to fully gauge our understanding of the nucleon mass from QCD.

Beyond accessing the trace anomaly the measurement of electroproduction of the J/ψ near threshold opens a host of important questions related to the gluonic structure of the nucleon. What is the strength of the J/ψ-nucleon interaction near threshold? It is unique in nuclear physics that one can investigate an interaction between two color neutral objects, the nucleon and the J/ψ that is purely gluonic. In this case the interaction force can be considered to be a color Van der Waals force in analogy to atomic physics. Furthermore, at low energy we do not fully understand the production mechanism of quarkonium (J/ψ, Υ) on a nucleon.

The J/ψ physics program at threshold using SoLID is unique in its important impact on our understanding of the low energy structure of the nucleon. From understanding where a large fraction of the nucleon mass originates from (conformal anomaly) to exploring the existence of "color Van der Waals forces" as well as the production mechanism of the J/ψ, SoLID offers the best tool and promise to reach this physics.

IV. OVERVIEW OF SOLID INSTRUMENTATION

The SoLID (Solenoidal Large Intensity Device) project will develop a large acceptance spectrometer/detector system capable of handling very high rates. It is designed to satisfy the requirements of five approved highly rated experiments, that require both high luminosity and large acceptance, to exploit the full potential of the Jefferson Lab 12 GeV upgrade. The base equipment composing the SoLID project includes two configurations: the "SIDIS&J/ψ" configuration and the "PVDIS" configuration. Although the geometrical layouts for the detectors are not the same in the two configurations, most components of the following list of the SoLID base equipment are in common:

1. A solenoidal magnet with a power supply and cryogenic system, now identified as the CLEO-II magnet. With some modifications as described in the pCDR[7], this magnet meets the experimental requirements.

2. GEM detectors for tracking: These are planned to be provided by a SoLID Chinese Collaboration. Five Chinese institutions (USTC, CIAE, Tsinghua, Lanzhou and IMP), in collaboration with US groups (UVa and Temple),

have committed to perform R&D and plan to apply for funding from the Chinese funding agencies to construct the GEMs for the SoLID project.

3. An electromagnetic calorimeter for electron identification. (In the SIDIS configuration, it is separated into two sectors, a forward sector and a large-angle sector).
4. A light gas Cherenkov detector for electron identification.
5. A heavy gas Cherenkov detector for pion (hadron) identification. This is for the SIDIS configuration only.
6. A MRPC (Multi-Gap Resistive Plate Chamber) detector serving as a time-of-flight (TOF) detector for pion (hadron) identification. This is for the SIDIS configuration only. The Chinese groups (Tsinghua and USTC), in collaboration with US groups (Duke and Rutgers), have agreed to perform R&D and apply for funding to construct the required MRPC detector for the SoLID project.
7. A set of baffles to reduce background. This is for the PVDIS configuration only.
8. A data acquisition system (DAQ) with online farm capability.
9. Supporting structures for the magnet and the detectors.
10. Requisite Hall A infrastructure to accommodate the functioning of the above.

The five approved experiments in the SoLID research program would require the SoLID base equipment, as well as the components outside the base equipment of the SoLID project. The following lists such additional equipment that is either standard and existing at JLab or that will be available for experiments planned before the SoLID experiments:

1. For SIDIS transversely, and longitudinally polarized ^{3}He: The existing polarized ^{3}He target with performance already achieved from the 6 GeV experiment is required.
2. For J/ψ the standard cryogenic LH2 target system with modification in layout is required.
3. For PVDIS: A Compton polarimeter and a super-conducting Moller polarimeter (both also required by the MOLLER project and to be employed for the PREX experiment also) are assumed to be available.

The following items will be required for specific experiments:

1. For PVDIS: a custom, high-power cryotarget is required. Cryogenic cooling capability for the cryotarget (ESR2) is assumed to be available (required by the MOLLER project).
2. For the SIDIS-proton experiment: a transversely polarized proton target is needed. An initial study has been performed by Oxford which concluded that such a target with the specifications satisfying the SoLID experiment requirements is feasible.

V. CURRENT STATUS

The SoLID spectrometer was initially proposed in 2009 and approved in 2010 for two experiments: SIDIS experiment E12-10-006) and the PVDIS experiment E12-10-007. Both experiments aim to achieve high precision which require very high statistics. A spectrometer/detector system with a large acceptance and also able to handle high luminosity is required. Therefore SoLID is designed to have a large solid angle and broad momentum acceptance and can handle luminosity up to $10^{39}\text{s}^{-1}\text{cm}^{-2}$ with a baffle system in the PVDIS configuration and $10^{37}\text{s}^{-1}\text{cm}^{-2}$ without a baffle system in the SIDIS/ and J/ψ configuration. With these unique features, SoLID is ideal for inclusive and semi-inclusive DIS experiments and is also good for measurements of certain exclusive reactions. The SoLID base equipment consists of a solenoid magnet (CLEOII magnet), tracking detectors (GEMs), electron PID detectors (electromagnetic calorimeter and light gas Cěrenkov detector) and hadron PID detectors (MRPC, heavy gas Cěrenkov and EC), DAQ system, supporting structure and infrastruture needed for the spectrometer. Leveraging the unique capabilities of SoLID, currently, there are five highly rated (four "A" ratings and one "A$^-$") experiments approved using SoLID, along with two "parasitic" experiments.

The conceptual design has gone through many iterations, including various case studies, detailed simulations, pre-R&D testings and a number of internal reviews. Of the various internal reviews, it is worth mentioning the two brainstorming sessions in September 2011 and January 2012, organized by the JLab physics division, and the dry-run review in June 2012 with external experts. These reviews helped greatly in optimizing, improving and finalizing the conceptual design. Detailed simulations with realistic background (including neutron backgrounds) and pre-R&D activities focusing on the major challenges have significantly improved the reliability of the conceptual design. The JLab Hall A engineering group, working with the SoLID collaboration, performed studies on the modification of the CLEO-II magnet to satisfy the SoLID needs. The JLab management has formally requested the CLEO-II magnet and was approved by the management from the CLEO side. A recent site visit confirmed that the magnet is preserved in excellent shape. A plan for the extraction and transportation to JLab is in place. The final version of the pre-CDR[7] was submitted to JLab management in July 2014.

A. Summary

The SoLID spectrometer will be critical in order to meet the major challenges and opportunities central to the JLab 12 GeV physics program. JLab has had an excellent tradition in electroweak physics, and the SoLID spectrometer can continue the tradition, providing a test of the SM in a new region of parameter space and also address specific issues in nucleon structure including CSV and higher twist effects due to di-quarks. Again, the key to this program is high statistics in many bins. With the presently available facilities, any measurement would be unable to untangle these effects.

One key issue is through understanding of the three-dimensional structure of the nucleon in the valance region to uncover the rich QCD dynamics and discover new phenomena. Only detailed and systematic measurements of the TMD's using the combination of high luminosity and large acceptance giving good precision in a large number of kinematic bins can deliver the required information. The existing equipment requires averaging over larger kinematic regions which will likely miss many of the key details.

In addition, the J/Ψ physics program at threshold using SoLID is unique in its important impact on our understanding of the low energy structure of the nucleon, nuclei and QCD. This challenging process again requires high luminosity and also the ability to measure several particles in coincidence.

The SoLID spectrometer is able to achieve the remarkable performance required by the above physics by using a number of new developments in instrumentation, including large area GEM tracking detectors, new PMT's that can operate for a gas Cerenkov in a moderate magnetic field, and pipeline electronics, recently developed for JLab Hall D, that can handle the high rates and deal efficiently with dead-time and pileup problems.

In summary, the SoLID spectrometer is a remarkably flexible device that can greatly enhance the physics output of the JLab upgrade in a number of exciting areas. In addition, it will provide a proving ground for some of the important technologies that will be crucial for moving forward towards a future EIC.

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