E12-10-006 Jeopardy Update to PAC50

Target Single Spin Asymmetry in Semi-Inclusive Deep-Inelastic $(e, e'\pi^{\pm})$ Reaction on a Transversely Polarized ^{3}He Target at 8.8 and 11 GeV

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1 Introduction

Experiment E12-10-006 [1], a semi-inclusive deep inelastic scattering (SIDIS) measurement, was approved by PAC 35 with A rating at incident electron beam energies of 8.8 and 11 GeV by employing a transversely polarized ^{3}He target. This experiment will measure three target single-spin asymmetries (SSAs) of π^+/π^- produced in SIDIS processes using the proposed Solenoidal Large Intensity Device (SoLID) apparatus [2, 3]. Since the approval of E12-10-006, there have been five run-group experiments approved, and those are E12-10-006A on SIDIS di-hadron production, E12-11-108A/E12-10-006A on A_y measurement, E12-10-006B on deeply exclusive meson production, E12-10-006D on SIDIS kaon production, and E12-10-006E on g_2^n and d_2^n measurements. High precision results to be obtained will provide essential "neutron" information to the world data together with the upcoming results from the SoLID SIDIS experiment E12-11-007 on a longitudinally polarized ^{3}He target and its associated run-group experiment. We first describe the latest design of the SoLID apparatus and the SoLID status. Then we present an update on E12-10-006 experiment, followed by brief updates on the associated run-group experiments.

2 Progress on the SoLID Apparatus

Since the approval of five SoLID experiments with beam time and high rating by the JLab PAC, the collaboration has developed a Pre-CDR [3], which gives details on the SoLID apparatus as well as a cost estimate. In 2015, SoLID together with the approved experiments received a strong endorsement from the Nuclear Physics Long Range Plan. In September of 2019, the Pre-CDR successfully passed the second of two JLab Director's Reviews. The latter review covered a detailed cost estimate and detailed analysis, which concluded that all critical items were low risk. The Pre-CDR was the basis of the SoLID MIE submitted to the DOE in February of 2020. In 2020, the DOE funded a Pre-R&D plan, which has demonstrated that there are no show-stoppers in the design of SoLID. In March of 2021, the DOE performed the Science Review of SoLID. We give a brief overview of the features of the SoLID apparatus and pre-R&D progress below.

In the Pre-CDR, we have demonstrated that the apparatus can achieve the following goals:

1. High luminosity (10^{37} cm^{-2}s^{-1} for SIDIS and J/ψ, 10^{39} cm^{-2}s^{-1} for PVDIS with baffles);
2. Large acceptance: 2π in azimuthal angle ϕ; in polar angle θ: $8^\circ - 24^\circ$ for SIDIS and J/ψ, $22^\circ - 35^\circ$ for PVDIS; momentum range: $1 - 7$ GeV/c;
3. High rates (trigger rate limit 100 KHz for SIDIS and J/ψ, 600 KHz of the 30 sectors for PVDIS);
4. High background tolerance ($\sim$1 GHz, dominated by low energy photons/electrons);
5. High radiation environment tolerance (10^{2-3} krad);
6. Moderate resolutions ($1 - 2\%$ in momentum, $1 - 2$ mrad in θ, 6 mrad in ϕ);
7. Good electron PID, moderate pion PID (SIDIS), and demanding Kaon PID (SIDIS-Kaon, enhanced configuration);
8. High precision with low systematic effects.

• The SoLID apparatus in its SIDIS configuration with a ^{3}He target is shown in Fig. 1. Since the SoLID experiments were approved, the CLEOII magnet was chosen. It was moved to JLAB in 2016. JLAB is currently performing refurbishment of the magnet and preparing for a cold test to

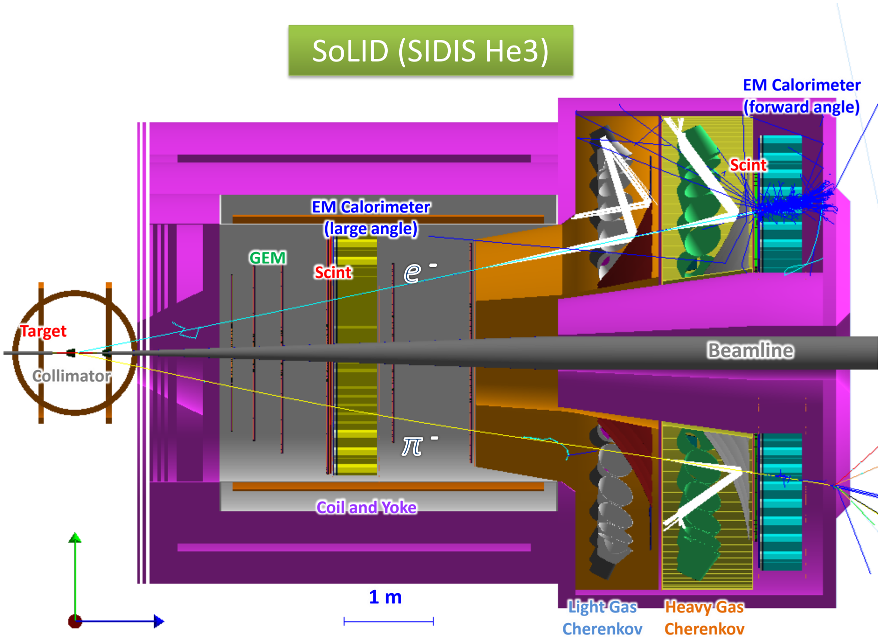

Figure 1: SoLID SIDIS Setup with ^{3}He target.

establish the magnet's operational condition. The cold test is scheduled to be completed before the end of 2022.

- Significant progress has been made in all subsystems. Components have been tested and shown to meet specifications. UVa group has built large GEM chambers with sizes as what SoLID needs. They also successfully built and operated GEM detectors for the PRad experiment and SBS experiment. During recent execution of the Pre-R&D plan, new VMM3 GEM readout chips were tested, which we plan to use instead of the obsolete APV25 chips listed in the original proposals. We have demonstrated that with the VMM3 chips operated in a mode with a 25 ns shaping time, the readout can handle the high rates required for the SoLID experiments.

- A prototype Čerenkov was tested with a beam at JLab Hall C in 2020, both at low rates and also at high rates equal to those expected in the SoLID spectrometer. In both the low- and high-rate configurations, clean signals could be identified and Čerenkov with its readout system performed very well.

- The ECal prototype modules were successfully tested at the Fermilab Test Beam Facility in January of 2021. Data showed that the energy resolution of the 3-module setup reached the SoLID requirement of $\delta E/E = \sqrt{10\%}/\sqrt{E}$ and the position resolution exceeded the required 1 cm specification.

- The SoLID DAQ system is based on the JLab 12 GeV FADC base pipeline electronics, which now has been successfully used in Halls B and D. Special features of the JLab FADC required for SoLID, which were built into the JLab design but never used in previous applications, have now been successfully tested for all systems as part of the SoLID Pre-R&D plan.

- Currently, a beam test of a full set of the SoLID detector prototypes – GEM, LGC, ECal, DAQ and associated electronics – is in preparation. The goal of the test is to fully characterize the functionality of the detector system under a high-rate, high-radiation environment that is similar to SoLID operation.

- The SoLID simulation software, based on GEMC/GEANT4, is a single package that is used to model all approved experiments and run-group experiments. It is being used to optimize the design and evaluate the impact of the results from the past and ongoing tests. A Kalman Filter based track finding and fitting algorithm has been developed and tested with fully digitized GEM simulation data. Tracking resolutions with a good tracking efficiency have been obtained with the background taken into account. We are actively working on assembling simulation, reconstruction, and analysis into one software framework.

3 Update on Experiment E12-10-006

Transverse-momentum-dependent PDFs (TMDs) provide three-dimensional tomography of the nucleon structure in momentum space. The SIDIS process is a golden channel to study TMDs. For a precise determination of TMDs, measuring SIDIS processes in a wide kinematic range with high luminosity and large-acceptance is required for sophisticated multidimensional-binning analyses. SoLID is capable of handling high luminosity and large acceptance simultaneously aiming at unprecedentedly precise measurements of TMDs in the valence quark region through a slate of SIDIS measurements using transversely or longitudinally polarized ^{3}He, and transversely polarized NH_3 targets. In Experiment E12-10-006, three SSAs of π^+/π^- will be measured and they are in the leading twist formalism shown below

$$A_{UT} = A_{UT}^{\text{Collins}} \sin(\phi_h + \phi_S) + A_{UT}^{\text{Pretzelosity}} \sin(3\phi_h - \phi_S) + A_{UT}^{\text{Sivers}} \sin(\phi_h - \phi_S), \tag{1}$$

given by different angular modulations via the hadron azimuthal angle (ϕ_h) and the spin azimuthal angle (ϕ_S), both defined relative to the lepton scattering plane. A_{UT} is the non-separated transverse SSA standing in the left hand side of Eq. (1). Three TMDs (Transversity, Pretzelosity and Sivers) can be extracted with high precision from these three SSAs, in combination with the world data, for a global analysis. Tensor charge, a fundamental quantity of the nucleon that can be calculated by Lattice QCD, can be determined as following:

$$g_T^q = \int_0^1 \left[h_1^q(x) - h_1^{\bar{q}}(x) \right] dx, \tag{2}$$

where h_1 is the Transversity TMD. The lowest moment of Transversity defines the tensor charge, providing a benchmark testing for Lattice QCD predictions.

The experiment has been approved for 90 days of total beam time with 15 μA, 11/8.8 GeV electron beams on a 40-cm long, 10 amgs transversely polarized ^{3}He target.

The projected data from E12-10-006 will be binned into 4-D (x, P_{hT}, z, Q^2) kinematic bins. Below we present some of the updated projections presented to the DOE science review committee in March 2021. The sample projected E12-10-006 SSA results are presented in 4-dimensions for π^+ in Fig. 2 together with the EIC projections at a center-of-mass energy of 29 GeV for e-p collisions. The complete E12-10-006 data set can be binned into $\sim$ 1400 such 4-D kinematic bins as shown in Section 12 of the PAC 35 update of E12-10-006 [1]. The center of each projection point corresponds to the kinematic center of each x and Q^2 bin, and the error bar corresponds to the statistical uncertainty of the asymmetry for each (x, P_{hT}, z, Q^2) bin. The scale of the asymmetries and uncertainties is shown on the right-side axes of the figure. The complementarity between JLab SoLID and the EIC is clear, and projected results also highlight the precision of SoLID measurements.

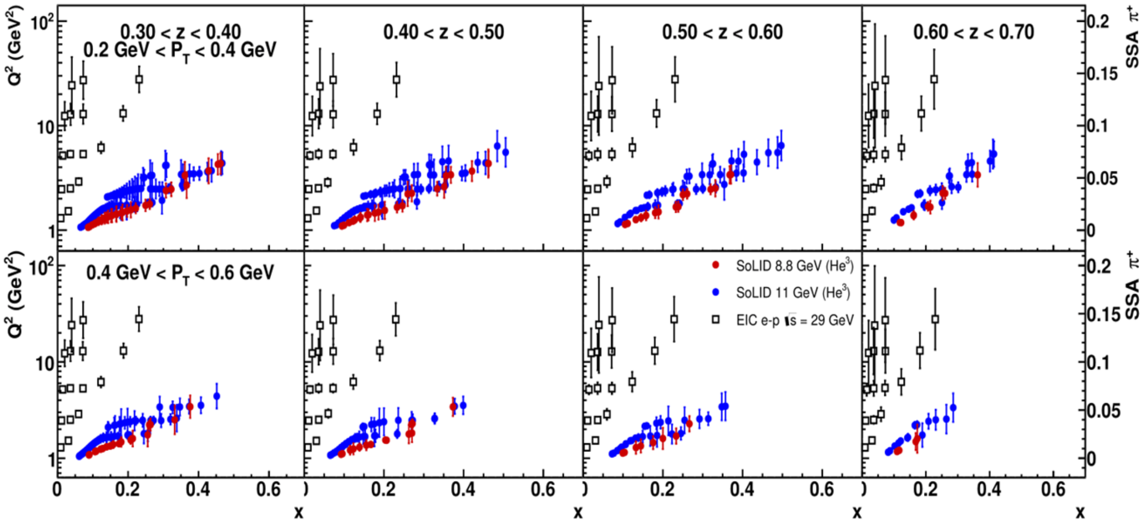

Figure 2: SoLID SIDIS projections of the π^+ SSA A_{UT} in various 4-D $(x, P_T \equiv P_{hT}, z, Q^2)$ bins (shown in the figure) from the trans.-pol. ^{3}He target. Also shown are projections at EIC kinematics with 29 GeV center-of-mass energy. The scale of the SSA and uncertainties is shown on the right-side axes of the figure. All the plots show how well both SoLID and EIC projections are synergistic towards each other, by covering different x and Q^2 ranges.

The upper panel of the left plot in Fig. 3 presents the E12-10-006 impact on the extracted Transversity TMDs for the u and d quarks based on the transversely polarized ^{3}He target for the SoLID enhanced configuration, where the enhanced configuration is obtained when the SoLID baseline configuration is added by the Multigap Resistive Plate Chambers (MRPCs) giving better PID capabilities [3]. The enhanced configuration is the proposed configuration in the original PAC approved experiments (E12-10-006, E12-11-007 and E12-11-108). The projected SoLID impact is shown by dark bands, while the current knowledge ("World") from a global analysis is shown as light colors for both the u (red) and the d quark (blue). The "World" represents all available SIDIS data from the COMPASS, HERMES experiments, JLab 6-GeV measurements, as well as e^+e^- annihilation data from the BELLE, BABAR, and BESIII experiments. The lower panel shows the improvements, manifested as the ratios between the uncertainties of the current world data and the SoLID projected uncertainties. All the results are plotted at a typical JLab12 scale $Q^2 = 2.4$ GeV^2, including both systematic and statistical uncertainties. The x-range between the two vertical dashed lines is directly measurable by SoLID. Similarly, the projected SoLID impact on Sivers TMDs for the u and d quarks is shown in the right plot of Fig. 3. The impact on the quark tensor charge determination from SoLID E12-10-006 including systematic uncertainties compared with that from a global fit of existing World data is shown in Fig 4. The corresponding tensor charge numbers are provided as $g^u_{T,\text{world}} = 0.548 \pm 0.112$, $g^d_{T,\text{world}} = -0.382 \pm 0.177$, $g^u_{T,\text{enhan.}} = 0.546 \pm 0.027$, $g^d_{T,\text{enhan.}} = -0.376 \pm 0.017$. Significant improvement will be achieved from E12-10-006 especially in the case of the d quark utilizing a transversely polarized ^{3}He target. When combined with SoLID SIDIS Experiment E12-11-108 [4] using a transversely polarized NH$_3$ target, the u and d quark tensor charge extraction will be further improved: $g^u_{T,\text{enhan.}} = 0.547 \pm 0.021$, $g^d_{T,\text{enhan.}} = -0.376 \pm 0.014$. They represent less than 4% relative uncertainty for the SoLID extraction of the u and d quark tensor charge, and should be compared to the 2019 FLAG review [5] of the Lattice QCD calculations where the corresponding numbers are 4% and 7% for u and d quark, respectively. Therefore, these results will provide a benchmark test of precise Lattice calculations.

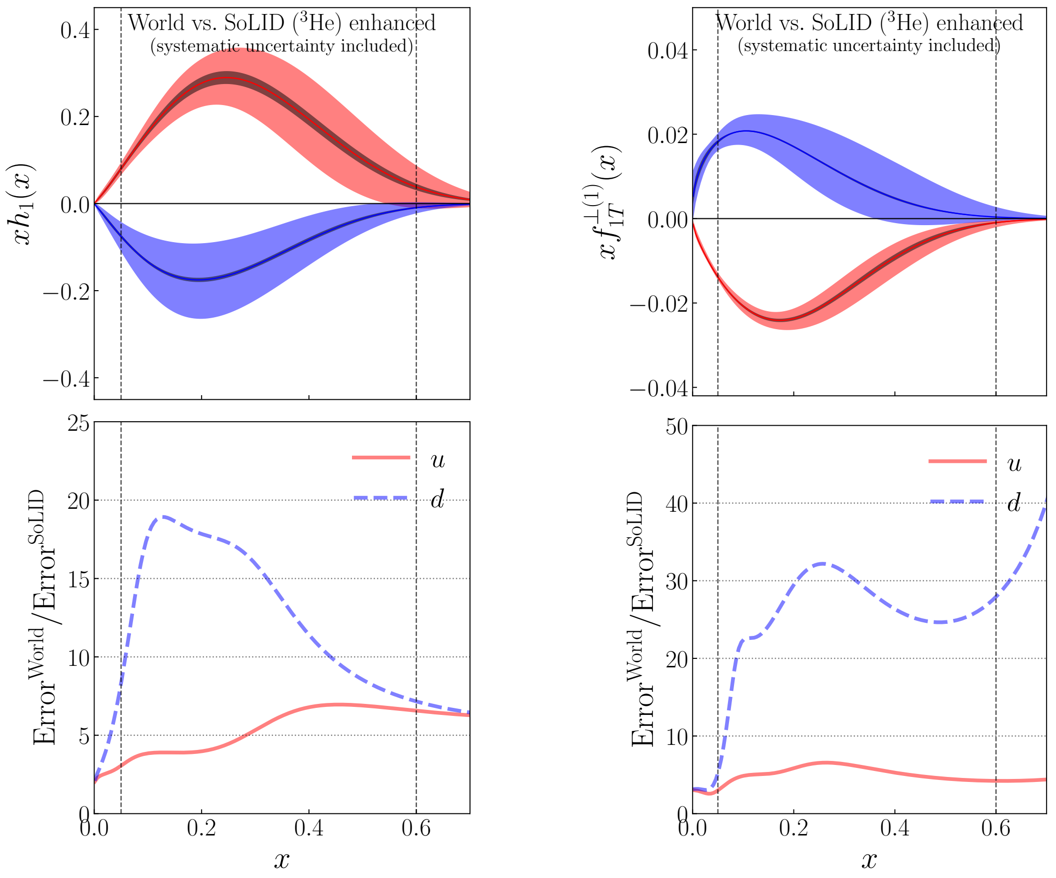

Figure 3: (Left panel) SoLID impact on the u and d quarks' Transversity TMD extractions from the SoLID experiment E12-10-006 compared with the world data (see text for details). (Right panel) SoLID impact on the u and d quarks' Sivers TMD extractions compared with the world data. The SoLID projections are obtained at the scale $Q^2 = 2.4$ GeV^2.

Quark tensor charges are also directly connected to quark electric dipole moments (EDM), and as such they are also connected to nucleon EDMs. The precise determination of the tensor charge from the SoLID SIDIS program when combined with the next generation of the nucleon electric dipole moment (EDM) searches will provide constraints on quark EDMs, and consequently will render an opportunity to search for new physics [6] beyond the Standard Model.

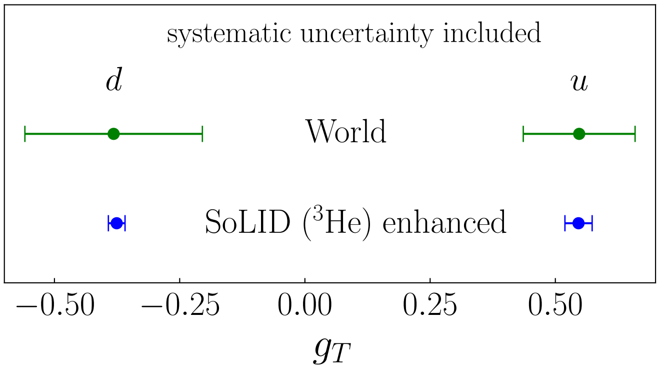

Figure 4: The impact on quark tensor charge from the SoLID experiment E12-10-006 compared with the World data. The SolID points are obtained at the scale $Q^2 = 2.4$ GeV^2.

4 Run group experiment on SIDIS Kaon: E12-10-006D

(**Spokespersons:** Tianbo Liu, Sanghwa Park, Yi Wang, Zhihong Ye (contact), Zhiwen Zhao)

While the JLab TMD program mostly focuses on measuring the pion production in SIDIS, the kaon production data are crucial to successfully decouple all light quark flavors. There are only limited kaon-SIDIS data from HERMES [7], COMPASS [8], and JLab Hall A collaborations [9], all of which are with poor precision and narrow kinematic coverage. In the run-group proposal [10], we will perform an offline analysis to extract the kaon-SIDIS events out from all the already approved SoLID pion-SIDIS measurements. The kaon events will be identified using the heavy-gas Čerenkov detector and the time-of-flight (TOF) information from the MRPC. A 20 ps time resolution of a new generation MRPC, which has been achieved with cosmic ray test by several groups [11, 12], should be able to perform $\pi^{\pm}/K^{\pm}$ separation up to a high hadron momentum (e.g. $P_h < 6.0\,GeV/c$), while the veto-signal from HGC can also effectively isolate $K^{\pm}$ from $\pi^{\pm}$. MRPC, which was later removed after the approval of the SIDIS proposals, is expected to be reinstalled to the enhanced SIDIS configuration with significant contributions from Chinese institutes and other funding resources.

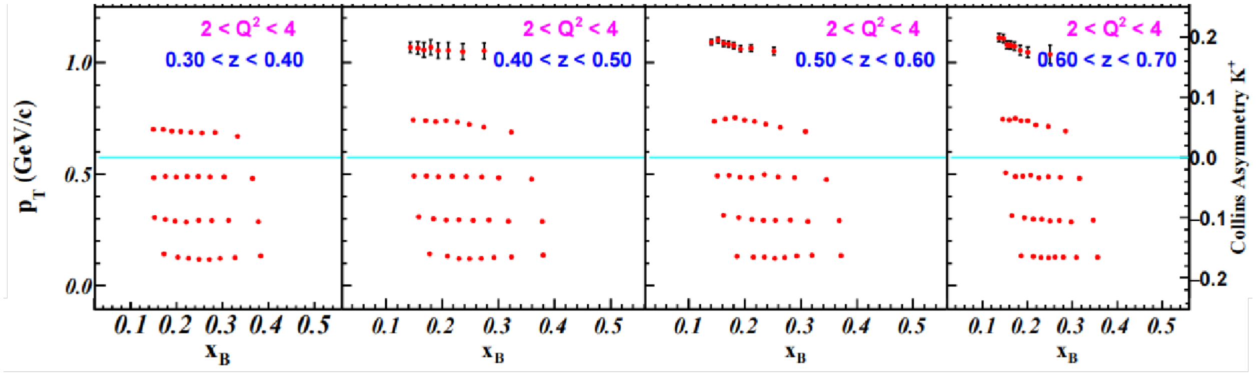

Figure 5: One Q^2 bin of the 4D (Q^2, z, p_T, x_B) binning projection and statistical uncertainties of the Collins asymmetry ($A_{UT}^{sin(\phi+\phi_S)}$) in $\vec{n}(e,e'K^+)$X with transversely polarized ^{3}He. The sizes of the uncertainties are indicated by the Y axis on the right. See the original proposal for all projection results.

Thanks to the high intensity and large acceptance features of the SoLID detector system, the new measurement will generate a large set of kaon data with great precision and a wide kinematic coverage in multiple dimensions as shown in Fig. 5. The combined analysis of both the pion and kaon SIDIS-data from both proton and neutron (^{3}He) targets on SoLID will allow us to systematically separate contributions from all light quarks, especially to isolate the sea-quark contributions. The systematic uncertainties can also be largely reduce since the pion and kaon SIDIS events are measured all together. Model estimation shows that at the SoLID kinematic about 20% of the kaon SIDIS events come from the current fragmentation region where the TMD factorization can be applied. The high-quality kaon data from SoLID are crucial for the validation of the model calculation. Our new measurement will provide high quality data for the continuous theoretical development of the TMD physics, and more importantly, provide strong guidance to future measurements on electron-ion collider (EIC), which will fully study the TMD of sea-quarks and gluons in a wider kinematic coverage and provide a more complete image of nucleon structures.

5 Run group experiment SIDIS Di-hadron: E12-10-006A

(**Spokespersons:** Jiang-ping Chen, Aurore Courtoy, Haiyan Gao, Anthony Thomas, Zhigang Xiao, Jixie Zhang (contact))

Di-hadron SIDIS is an important part of the 12 GeV JLab physics program. Di-hadron beam spin asymmetries provide a wide range of insights into nucleon structure and hadronization. It is one of the easy channels to access the leading-twist PDF $h1(x)$, the so-called transversity distribution function, and also the higher-twist PDFs $e(x)$, $h_L(x)$. The combination of the proton and neutron measurements on the transversity distribution function will also allow to operate a flavour separation.

In the process of $\ell(l)+N(P) \to \ell(l')+H_1(P_1)+H_2(P_2)+X$, the transversity distribution function $h1(x)$ is combined with a chiral-odd Di-hadron Fragmentation Function (DiFF), denoted as $H_1^{\sphericalangle\, q}$, which describes the correlation between the transverse polarization of the fragmenting quark with flavor q and the azimuthal orientation of the plane containing the momenta of the detected hadron pair. Contrary to the Collins mechanism, this effect survives after integration over quark transverse momenta and can be analyzed in the framework of col-linear factorization. Thus this analysis framework is much simpler compared to the traditional one in single-hadron fragmentation. DiFF can be extracted from electron-positron annihilation where two back-to-back jets are produced and a pair of hadrons are detected in each jet. They also appear in the observables describing the semi-inclusive production of two hadrons in deep-inelastic scattering of leptons off nucleons or in hadron-hadron collisions. The DiFFs also play a role in extending the knowledge of the nucleon col-linear picture beyond the leading twist. The same chiral-odd $H_1^{\sphericalangle}$ provides the cleanest access to the poorly known twist-3 parton distributions $e(x)$ and $h_L(x)$, which are directly connected to quark-gluon correlations.

Since the di-hadron proposal [13] was accepted in 2014, physicists continue working on improving DIFF [14, 15]. A preliminary measurement of the related di-hadron beam-spin asymmetry has been performed by the CLAS collaboration [16], leading to a preliminary extraction of e(x) [17] in good agreement with model calculations. Recent measurements at CLAS12 showed the first empirical evidence of nonzero $G_1^{\perp}$, the parton helicity-dependent di-hadron fragmentation function (DiFF) encoding spin-momentum correlations in hadronization [18]. This brings more attention to the di-hadron beam spin asymmetries,

6 Run group experiment on DEMP: E12-10-006B

(**Spokespersons:** Zafar Ahmed, Garth Huber (contact), Zhihong Ye)

E12-10-006B [19] uses SoLID, in conjunction with a polarized ^{3}He target, to probe the poorest-known GPD, $\tilde{E}$. $\tilde{E}$ involves the difference between left- and right-handed quarks, and corresponds to a process where the proton helicity is flipped [20]. $\tilde{E}$ is believed to contain an important pion pole contribution, and hence is optimally studied in Deep Exclusive Meson Production (DEMP).

Frankfurt et al. [21] identified the single spin asymmetry for exclusive $\pi^{\pm}$ production from a transversely polarized nucleon target as the most sensitive observable to probe the spin-flip $\tilde{E}$. The experimental access to $\tilde{E}$ is through the azimuthal variation of the emitted pions, where the relevant angles are ϕ between the scattering and reaction planes, and ϕ_s between the target polarization and

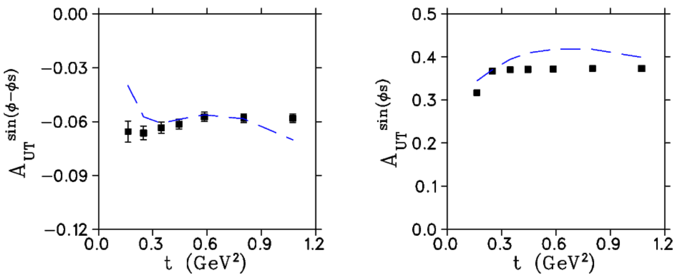

Figure 6: Projected uncertainties for $A_{UT}^{\sin(\phi-\phi_s)}$ and $A_{UT}^{\sin(\phi_s)}$ in the $\vec{n}(e,e'\pi^-)p$ reaction from a transversely polarized ^{3}He target and SoLID. The dashed curve represents the input asymmetry into the simulation, and the data points represent the extracted asymmetry moment values from an unbinned maximum likelihood (UML) analysis of simulated SoLID data.

the scattering plane. The $\sin(\phi-\phi_s)$ asymmetry, where $(\phi-\phi_s)$ is the angle between the target polarization vector and the reaction plane, is related to the parton-helicity-conserving part of the scattering process, and is sensitive to the interference between $\tilde{H}$ and $\tilde{E}$ [21, 22]. The reaction of interest is essentially $\vec{n}(e,e'\pi^-)p$ (after nuclear corrections are applied). The only previous data are from HERMES [23], for average values $\langle x_B \rangle = 0.13$, $\langle Q^2 \rangle = 2.38$ GeV^2. In comparison to HERMES, SoLID will probe higher Q^2 and x_B, with much smaller statistical errors over a wider range of t. Thus, the measurements should be more readily interpretable than those from HERMES, providing the first clear experimental signature of $\tilde{E}$.

In the DEMP reaction on a neutron, all three charged particles in the final state, e^-, π^- and p, can be cleanly measured by SoLID. Hence, contamination from other reactions, such as SIDIS and DEMP from the other two protons in ^{3}He, can be greatly eliminated. Further reduction in the background can be accomplished by reconstructing the missing momentum and missing mass of the recoil protons, via $\vec{p}_{miss} = \vec{q} - \vec{p}_\pi$, $M_{miss} = \sqrt{(\nu - E_\pi)^2 - (\vec{q} - \vec{p}_\pi)^2}$. Fig. 6 shows E12-10-006B [19] projections for the two most important transverse single spin asymmetry moments. The $\sin(\phi-\phi_s)$ moment (left) provides access to $\tilde{E}$ and is the primary motivation of the measurement. There is growing theoretical interest in the $\sin(\phi_s)$ moment (right), as it provides access to the higher-twist transversity GPD H_T. The agreement between the input and output fit values is very good, validating the unbinned maximum likelihood (UML) analysis procedure. The projected SoLID data are expected to be a considerable advance over the HERMES data in terms of kinematic coverage and statistical precision.

7 Run group experiment g2n and d2n: E12-10-006E

(**Spokespersons:** Chao Peng, Ye Tian (Contact))

The transverse polarized structure function $g_2(x,Q^2)$ probes transversely and also longitudinally polarized parton distributions inside the nucleon. It carries the information of quark–gluon interactions inside the nucleon. By neglecting quark masses, $g_2(x,Q^2)$ can be decoded by a leading twist–2 term and a higher twist term as follows:

$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \bar{g}_2(x,Q^2), \tag{3}$$

where twist–2 term g_2^{WW} was derived by Wandzura and Wilczek [24] and it only depends on well–measured g_1 [25, 26].

Matrix Element d_2 is the x^2 moment of $\bar{g}_2(x,Q^2)$. This quantity measures deviations of $g_2(x,Q^2)$ from the twist–2 term g_2^{WW}. At large Q2, where the operator product expansion (OPE) [27] becomes valid, one can access the twist–3 effects of quark–gluon correlations via the third moment of a linear combination of $g_1(x,Q^2)$ and $g_2(x,Q^2)$, presented as

$$d_2(Q^2) = 3\int_0^1 x^2[g_2(x,Q^2) - g_2^{WW}(x,Q^2)]dx = \int_0^1 x^2[2g_1(x,Q^2) + 3g_2(x,Q^2)]dx. \tag{4}$$

Due to the x^2–weighting, $d_2(Q^2)$ is particularly sensitive to the large–x behavior of $\bar{g}_2$ and provides us a clean way to access twist–3 contribution.

A precision measurement of neutron spin structure function $g_2(x,Q^2)$, running in parallel with this experiment and experiment E12-11-007 [28], has been approved as a run group proposal [29] by PAC48. High statistics data will be collected within a large kinematic coverage of Bjorken scaling $x > 0.1$ and four momentum transfer $1.5 < Q^2 < 10$ GeV^2 from inclusive scatterings of longitudinally polarized electrons off transversely and longitudinally polarized ^{3}He targets, at incident beam energies of 11 GeV and 8.8 GeV. In addition to mapping out the x and Q^2 evolution of g_2, the moment $d_2(Q^2)$, which is connected to the quark-gluon correlations within the nucleon, will be extracted with $1.5 < Q^2 < 6.5$ GeV^2. $d_2(Q^2)$ is one of the cleanest observables that can be used to test the theoretical calculations from lattice QCD and various nucleon structure models.

8 Run group experiment A_y: E12-10-006A

(**Spokespersons:** Todd Averett (contact), Alexandre Camsonne, Nilanga Liyanage)

The single spin asymmetry, A_y, will be obtained by scattering unpolarized electrons from a transversely polarized neutron (^{3}He) target in the DIS [30]. By measuring the azimuthal dependence of this asymmetry we can extract the two-photon exchange contribution in the absence of the typically dominant Born scattering [31]. This experiment will run in parallel with the SIDIS experiment above by collecting singles electron triggers.

The Feynman diagram for the TPEX process forms a loop with the nucleon intermediate state that contains the full response of the nucleon and must be modeled using e.g. parton-model predictions in the DIS. Predictions range from 10^{-4} to 10^{-2} with a positive or negative sign depending on model input and target nucleon.

An earlier experiment done using a 5.9 GeV beam in Hall A measured a neutron asymmetry of $(-1.09 \pm 0.38) \times 10^{-2}$ which is non-zero at the 2.89σ level [32]. A theoretical calculation from Metz *et al.* [33] requires experimental input for a so-called $q\gamma q$ correlator and changes sign based on the choice of input. The measured asymmetry agrees both in sign and magnitude using input from the Siver's transverse momentum distributions obtained in SIDIS, but disagrees in sign when using input extracted from the $p^{\uparrow}p \to \pi X$ reaction from hadron colliders. This sign mismatch is a key puzzle in hadronic spin physics [33].

We will measure A_y with statistical uncertainties of $\sim 10^{-4} - 10^{-2}$ from $Q^2 = 1.5 - 7.5$ providing a more precise result over a large kinematic range. See Fig. 7.

9 Summary

With SoLID SIDIS experiment E12-10-006, precision data in 4-D kinematic bins will be obtained on the Collins, Pretzelosity, and Sivers SSAs for the “neutron” using a transversely polarized

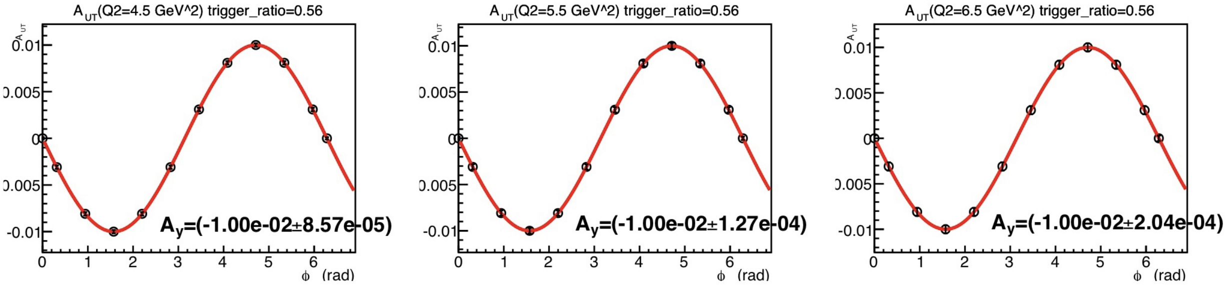

Figure 7: Expected uncertainties in A_{UT} vs. ϕ_S at different Q^2 at 11 GeV for the ^{3}He target. For each plot, the data over all values of x was combined. An arbitrary amplitude of 10^{-2} was chosen for the asymmetry.

^{3}He target through azimuthal angular dependence, allowing for access of Transversity, Sivers and Pretzelocity TMDs, uncovering orbital angular motion of the quarks inside in the nucleon, and the rich QCD dynamics. The Transversity SSA data from this experiment, when combined with data on the proton (from SIDIS-proton experiment E12-11-108) and more precise data on the Collins fragmentation from upcoming e^+e^- collision experiments, will allow for a significantly improved flavor separation of the Transversity and quark tensor charge. These quark tensor charges will directly confront the Lattice QCD predictions. The run group experiments will significantly enhance the broad impact in QCD physics related to the structure of the nucleon.

References

[1] J.-P. Chen, H. Gao (contact), X. Jiang, J. C. Peng, and X. Qian, Jefferson Lab Experiment E12-10-006, URL https://solid.jlab.org/experiments.html.

[2] J. P. Chen, H. Gao, T. K. Hemmick, Z. E. Meziani, and P. A. Souder (SoLID) (2014), 1409.7741.

[3] The SoLID Collaboration, Jefferson Lab Hall A SoLID Experiment, URL https://solid.jlab.org/DocDB/0002/000282/001/solid-precdr-2019Nov.pdf.

[4] K. Allada, J.-P. Chen, H. Gao (contact), and Z. E. Meziani, Jefferson Lab Experiment E12-11-108, URL https://solid.jlab.org/experiments.html.

[5] S. Aoki, Y. Aoki, D. Bečirević, T. Blum, G. Colangelo, S. Collins, M. D. Morte, P. Dimopoulos, S. Dürr, H. Fukaya, et al., The European Physical Journal C **80** (2020), URL https://doi.org/10.1140%2Fepjc%2Fs10052-019-7354-7.

[6] T. Liu, Z. Zhao, and H. Gao, Phys. Rev. D **97**, 074018 (2018), URL https://link.aps.org/doi/10.1103/PhysRevD.97.074018.

[7] A. Airapetian et al. (HERMES), Phys. Lett. B **693**, 11 (2010), 1006.4221.

[8] C. Adolph et al. (COMPASS), Phys. Lett. B **744**, 250 (2015), 1408.4405.

[9] Y. X. Zhao et al. (Jefferson Lab Hall A), Phys. Rev. C **90**, 055201 (2014), 1404.7204.

[10] T. Liu, S. Park, Y. Wang, Z. Ye (contact), and Z. Zhao, Jefferson Lab Run Group Experiment for E12-11-108 and E12-10-006, URL https://solid.jlab.org/experiments.html.

[11] E. RD2013-5, r&D Proposal for (Sub) 10 Picosecond Timing Detectors at the EIC, URL https://wiki.bnl.gov/conferences/images/3/38/PSTOF_EIC_July2014.pdf.

[12] Y. Wang, X. Fan, J. Wang, D. Gonzalez-Diaz, H. Chen, J. Chen, Y. Li, A. Camsonne, J. P. Chen, H. Gao, et al., Journal of Instrumentation **8**, P03003 (2013), URL https://doi.org/10.1088/1748-0221/8/03/p03003.

[13] J.-P. Chen, A. Courtoy, H. Gao, A. W. Thomas, Z. Xiao, and J. Zhang (contact), Jefferson Lab Run Group Experiment for E12-10-006, URL https://solid.jlab.org/experiments.html.

[14] S. Pisano and M. Radici, The European Physical Journal A **52**, 155–161 (2016), ISSN 1434-601X, URL https://doi.org/10.1140/epja/i2016-16155-5.

[15] X. Luo, H. Sun, J. Li, Y.-L. Xie, and Tichouk, Phys. Rev. D **100**, 094036 (2019), URL https://link.aps.org/doi/10.1103/PhysRevD.100.094036.

[16] S. Pisano, EPJ Web of Conferences for the 13th International Conference Meson-Nucleon Physics and the Structure of the Nucleon **73** (2014), URL https://doi.org/10.1051/epjconf/20147302008.

[17] A. Courtoy, URL https://arxiv.org/abs/1405.7659v1.

[18] C. Dilks, submission to SciPost Proceedings, URL https://arxiv.org/abs/2107.12965.

[19] Z. Ahmed, G. M. Huber (contact), and Z. Ye, Jefferson Lab Run Group Experiment for E12-10-006, URL https://solid.jlab.org/experiments.html.

[20] K. Goeke, M. V. Polyakov, and M. Vanderhaeghen, Prog. Part. Nucl. Phys. **47**, 401 (2001), hep-ph/0106012.

[21] L. L. Frankfurt, P. V. Pobylitsa, M. V. Polyakov, and M. Strikman, Phys. Rev. D **60**, 014010 (1999), hep-ph/9901429.

[22] M. Diehl and S. Sapeta, The European Physical Journal C **41**, 515–533 (2005), ISSN 1434-6052, URL http://dx.doi.org/10.1140/epjc/s2005-02242-9.

[23] A. Airapetian et al. (HERMES), Phys. Lett. B **682**, 345 (2010), 0907.2596.

[24] S. Wandzura et al., Physics Letters B **72**, 195 (1977).

[25] B. Adeva et al. (Spin Muon Collaboration), Phys. Rev. D **58**, 112001 (1998).

[26] K. Abe et al. (E143 Collaboration), Phys. Rev. D **58**, 112003 (1998).

[27] K. G. Wilson et al., Phys. Rev. **179**, 1499 (1969), URL https://link.aps.org/doi/10.1103/PhysRev.179.1499.

[28] J.-P. Chen (contact), J. Huang, Y. Qiang, and W. B. Yan, Jefferson Lab Experiment E12-11-007, URL https://solid.jlab.org/experiments.html.

[29] Y. Tian et al., *A run-group proposal submitted to PAC 48*, https://www.jlab.org/exp_prog/proposals/20/E12-11-007A_E12-10-006E_Proposal.pdf.

[30] T. Averett (contact), A. Camsonne, X. Jiang, N. Liyanage, and H. Yao, Jefferson Lab Run Group Experiment for E12-10-006 and E12-11-108, URL https://solid.jlab.org/experiments.html.

[31] N. Christ and T. D. Lee, Phys. Rev. **143**, 1310 (1966).

[32] J. Katich et al., Phys. Rev. Lett. **113**, 022502 (2014), 1311.0197.

[33] A. Metz, D. Pitonyak, A. Schäfer, M. Schlegel, W. Vogelsang, and J. Zhou, Phys. Rev. D **86**, 094039 (2012), URL https://link.aps.org/doi/10.1103/PhysRevD.86.094039.