GEMC simulations for SoLID/PAC Proposal

GH Draft: December 28, 2016

Abstract

Z. Ahmed, Zhihong Ye and GH submitted a SoLID Run-Group proposal "Measurement of Deep Exclusive π^- Production using a Transversely Polarized ^{3}He Target and the SoLID Spectrometer" to JLab PAC44 in 2016 [1]. The proposal was deemed to be of high scientific merit, but there were a large number of technical questions that were asked to be studied before final approval can be given. Our studies need to be sufficiently far advanced to present an update to the SoLID Collaboration at their spring meeting, with final submission of the revised proposal in advance of the PAC45 deadline. The deadline for submission of proposals to JLab PAC45 will be announced shortly and is expected to be in late May or early June 2017.

1 Summary of Items Identified in the 2016 Review

1. The simulations for this measurement may benefit from tracking DEMP events through the full SoLID GEANT4 simulation (GEMC), particularly for kinematics with the lowest momentum protons (300 MeV/c).

2. The collaboration should attempt to quantify the projected precision of the measured spin-dependent cross section. Although the asymmetry may have a smaller error bar, the spin-dependent cross section difference has a simpler interpretation. Measuring the spin-dependent cross section is also consistent with the opening sentence of Appendix A.

3. The extraction of the term $|\sigma^y_{TT}+2\epsilon\sigma^y_L|$ in Eqn. 8 from the other $\sin\beta$ and $\cos\beta$ terms requires good knowledge of the β-acceptance in each t-bin. This should be shown, in addition to the acceptance plots of Fig. 12.

4. There are a number of important theory issues raised by this proposal. These probably cannot be fully resolved before re-submission, but it will be important to have a clear dialog with relevant theorists (and experimentalists) in place... Both Goloskokov and Kroll, and Liutti and Goldstein, have published estimates of σ_T, based on transversity GPDs and a twist-3 helicity-flip pion distribution amplitude. One or the other of these theory groups should be engaged in a discussion of both the $|\sigma^y_L|$ and $|\sigma^y_{TT}|$ terms.

5. The committee is convinced that the SIDIS background is likely not a major problem. However, an alternate approach (rather than SIDIS fragmentation functions) could be used. The primary background channel under study is $^3\text{He}(e,e'\pi^-)pp$ with the two undetected protons as spectators. The continuum background that can leak under the quasi-exclusive peak can be of the form $e+n\rightarrow e'+\pi^-+\Delta^+$ with the Δ^+ decaying to $p+\pi^0$.

6. The effects of Fermi-smearing, detector resolution, ionization energy loss and bremsstrahlung need to be clarified. Although they seem to all be included in Figs. 15 and 16, it was not clear which curves included which effects.

7. The authors may want to switch off ^{3}He Fermi motion in their simulations and determine how large and in which kinematics they see a difference. Having evidence of non-negligible nuclear effects at an early stage would encourage theorists to extend now their calculations from inclusive to exclusive measurements for a timely and correct utilization of the data the authors propose to take. It would also be helpful to elaborate on the possible corrections in addition to Fermi motion, such as from binding and nucleon off-shell effects, as well as corrections beyond the impulse approximation from rescattering or final state interactions of the detected proton.

8. The QCD factorization theorem implies color transparency for the final state π^- in this proposal. Thus the $^3\text{He}(e, e'\pi^-)$ final state interactions (FSI) are identical with $^3\text{He}(e, e'p)$, just with a more exotic scattering amplitude. It is not practical to obtain full FSI calculations before resubmission, but a dialog should be started both with the groups doing FSI calculations, and the groups doing Deep Virtual calculations on light nuclei. Empirically, it will be useful to determine if the FSI 'peak' lies within the $^3\text{He}(e, e'\pi^-p)pp$ acceptance of this proposal.

9. Fermi-momentum is not just a kinematic effect. It also affects the DVMP amplitude. The ^{3}He momentum distribution $\rho(p)$ is plotted in Fig. 10 (Appendix A). The weighted distribution $p^2\rho(p)$ peaks at $p_n \approx$60 MeV/c. This means that the effective x_B is smeared by $\approx p_n/M \approx$6%. The significance of this effect should be discussed. Also, if the proton momentum resolution is good enough, it will be possible to correct for this effct, event-by-event.

2 Tasks

2.1 GEMC simulations

In order to address items #1-3, Ahmed has been getting familiar with tracking DEMP and SIDIS events through the full SoLID GEANT4 simulation. After implementing the SIDIS trigger for $e' + \pi^-$, he needs to create an "offline recoil proton filter", to search the events passing the SIDIS trigger for the low momentum proton, as we state in the proposal.

After this "recoil proton filter" is created, we need to pass both DEMP and SIDIS events through the filter and obtain absolute yield predictions (and statistical errors) for both types of events for the integrated luminosity stated in the proposal. This will allow a more realistic determination of the missing mass resolution and background cut effectiveness. Hopefully the DEMP/SIDIS events can be passed through the "proton filter" by early February, so the background and error estimate studies can proceed in earnest.

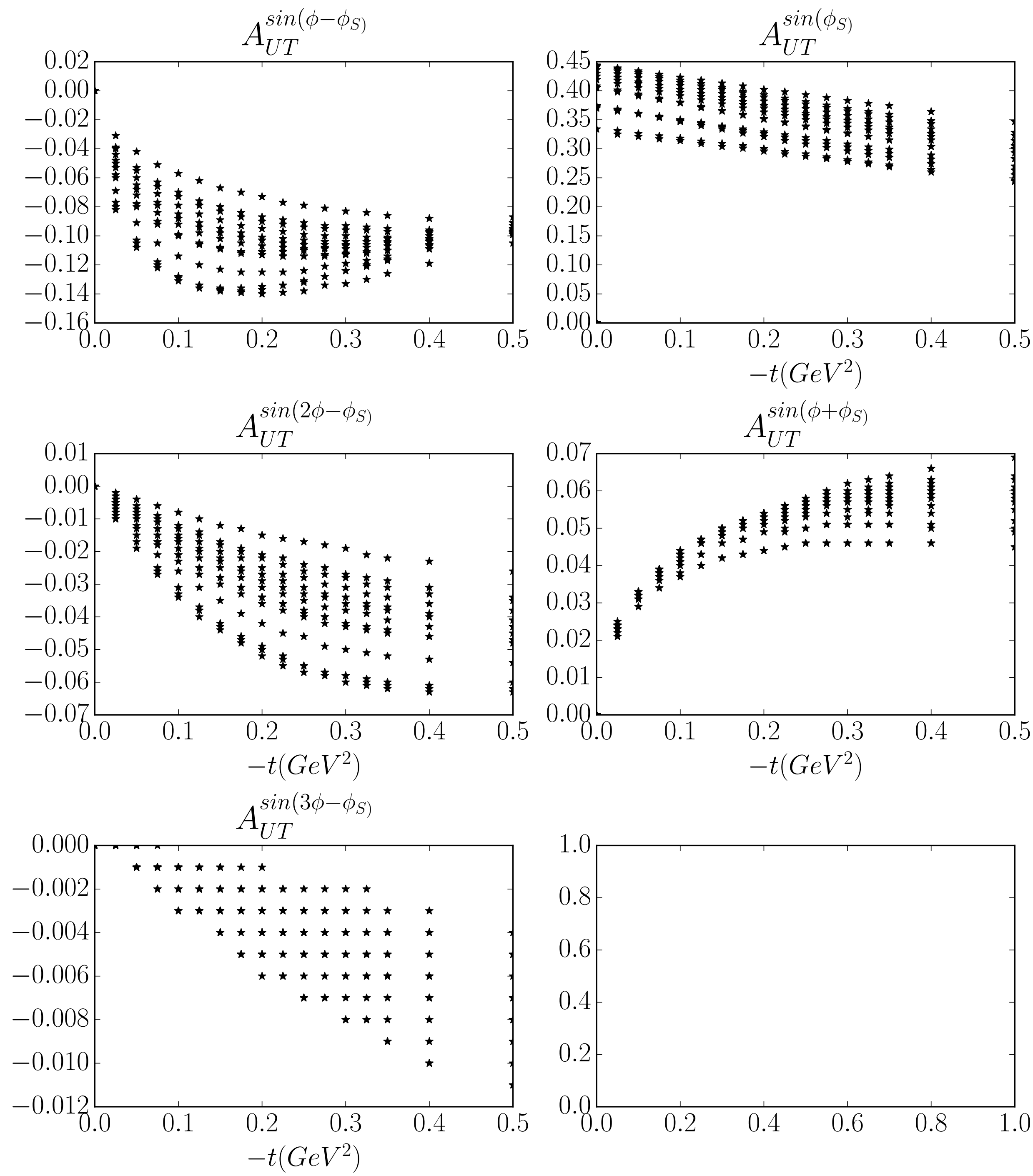

Figure 1: Asymmetries calculated for us by Goloskokov and Kroll, using the GPD-model of [2]. Each asymmetry is plotted versus $t' = |t - t_{min}|$ for the W, Q^2 bins of our proposal.

2.2 GPD-models

To address item #4, GH has communicated with Goloskokov and Kroll (GK) and in October they provided us with a new set of asymmetry calculations for the kinematics specific to our proposal.

These asymmetries are based on the GPD-model published in [2] and include the following 5 terms: $A_{UT}^{\sin(\phi-\phi_S)}$, $A_{UT}^{\sin(\phi_S)}$, $A_{UT}^{\sin(2\phi-\phi_S)}$, $A_{UT}^{\sin(\phi+\phi_S)}$, and $A_{UT}^{\sin(3\phi-\phi_S)}$. A plot of these asymmetries versus $t' = |t - t_{min}|$ for the W, Q^2 bins of our proposal is shown in Fig. 1.

These asymmetries are not yet built into Ahmed's DEMP event generator. Rory's first task is to parameterize these asymmetries in terms of a polynomial function of appropriate kinematical variables and help incorporate them into Ahmed's generator. Ahmed already has a parameterization of $A_{UT}^{\sin(\phi-\phi_S)}$ in the generator which can be used as a guide. Under Ahmed's supervision, Rory will need to test to make sure the parameterization not only closely reproduces the values provided by Goloskokov and Kroll, but also is well behaved over the full kinematical coverage of our SoLID experiment. (The sixth $A_{UT}^{\sin(2\phi+\phi_S)}$ asymmetry (not calculated by GK) is very nearly zero, and has already been incorporated by Ahmed into the DEMP event generator, based on a fit to the HERMES data [3].)

In the generator, these asymmetries need to be converted into cross sections via the formulae (see Ref. [3], p. 80):

$$\begin{aligned} A(\phi,\phi_S) &= \sum_{k=1}^{6} A_{UT}^{\sin(\mu\phi+\lambda\phi_S)_k} \sin(\mu\phi+\lambda\phi_S)_k \\ d\sigma(\phi,\phi_S) &= [1+|P_T|A(\phi,\phi_S)]d\sigma_{UU}(\phi), \\ d\sigma(\phi,\phi_S+\pi) &= [1-|P_T|A(\phi,\phi_S)]d\sigma_{UU}(\phi), \end{aligned} \tag{1}$$

where P_T is the polarization of the neutron in ^{3}He, after correcting for the various dilution factors.

This work (including testing) can proceed in parallel with Sec. 2.1 and hopefully can be largely completed by mid-February.

2.3 Azimuthal Asymmetry Analysis

Once the GEMC simulations with "recoil proton filter" and the GK asymmetries are incorporated in the event generator, we will be in a good position to address items #2, 3. For each t-bin, the absolutely normalized data ($d\sigma_{UT}$) need to be binned versus ϕ and ϕ_S and the asymmetries extracted via a 6-fold fit in a manner similar to Ref. [3]. It is extremely important to show that we can extract from the simulated data the same asymmetries as were input from the parameterization of the GK-model. This will allow us to demonstrate that the adequately understand the $\beta = (\phi - \phi_S)$ acceptance in each t-bin, and accurately estimate the statistical and systematic uncertainties of the experiment.

This work needs to be sufficiently far progressed to present to the SoLID Collaboration at their spring meeting (April or May). Final error bars are absolutely required in time for the expected PAC deadline in late May or early June. This step is very challenging and hopefully Zhihong can help with the fitting.

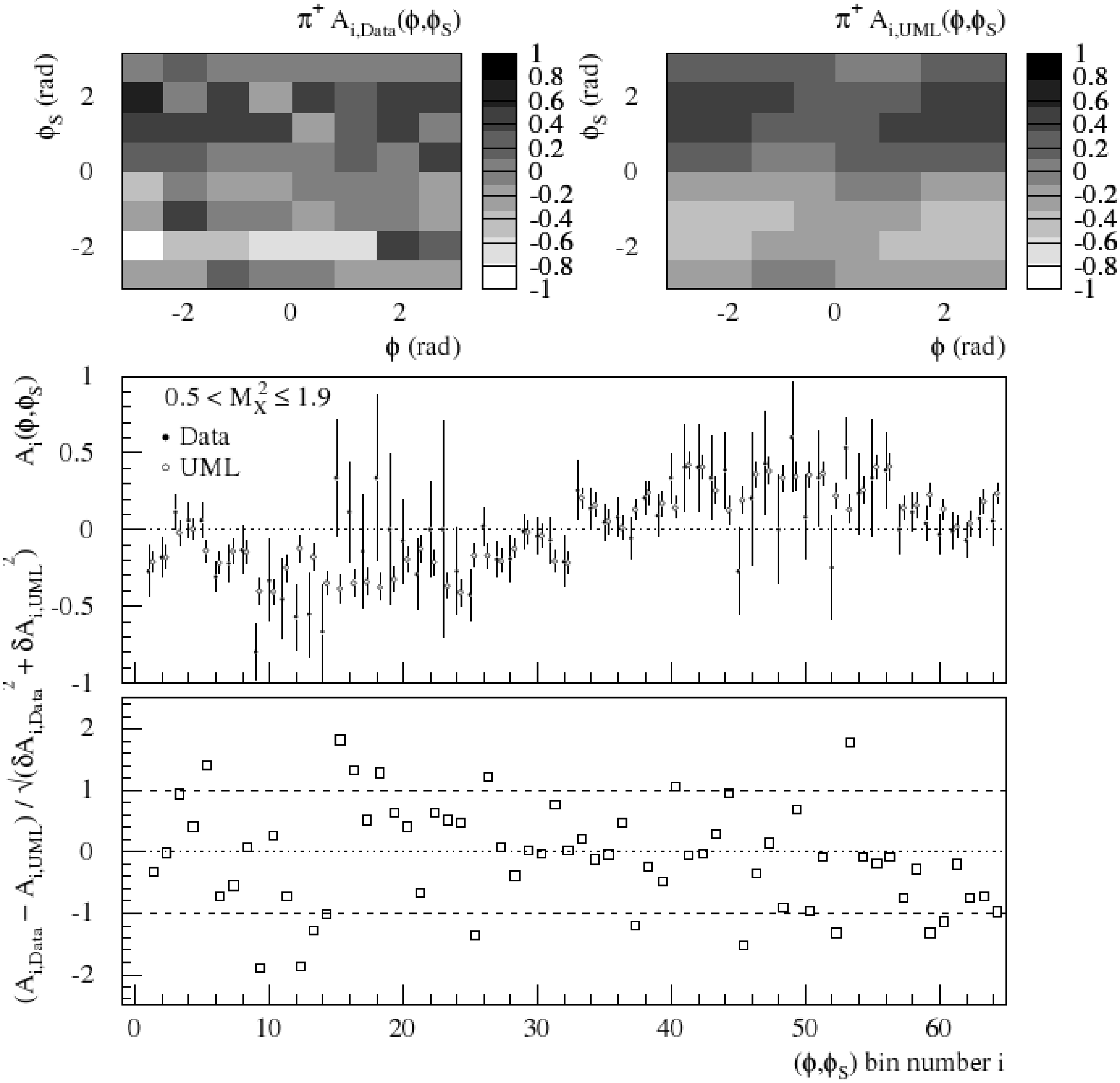

Figure 2: Two-dimensional grey-scale scatter plots for the $8 \times 8(\phi, \phi_S)$ bins (top), and as a function of the (ϕ, ϕ_S) bin number i (middle) for the HERMES data of Ref. [3]. These scatter plots are fit with the function in Eqn. 1 to determine the asymmetries from the data.

2.4 Final State Interactions (FSI)

To address items #5-9, GH has located his old Fortran routines which were used to estimate πN FSI, including the $l = 1$ distribution of the scattered $\pi^{\pm}$, p due to the P_{33} Δ resonance. These routines were successfully used to model nuclear FSI effects in Ref. [4]. These Fortran files can be found at [1], and GH will have to assist with their incorporation into the event generator.

The idea is to do two sets of simulations, one with FSI and one without, to investigate the effect upon background cut efficiency. Possibly it will also shed some light on the x_B smearing mentioned in item #9, and the FSI 'peak' discussed in item #8. This work can proceed after the work in Sec. 2.1 is completed, in parallel with Sec. 2.3. The result of these studies is not needed until the Collaboration meeting in April-May. We need to discuss who can lead this effort. I expect that Rory can contribute to either Sec. 2.3 or 2.4 after he is done with 2.2.

2.5 Updating the PAC Proposal

As the various studies are completed, the PAC proposal can be updated in steps. GH will oversee this work with the assistance of Ahmed and Zhihong.

References

[1] The final version of the PAC proposal and the associated review documents can be downloaded from $http://lichen.phys.uregina.ca/\sim huberg/solid/$.

[2] S.V Goloskokov, P. Kroll, Eur. Phys. J. **C65**, 137-151 (2010).
S.V Goloskokov, P. Kroll, Eur. Phys. J. **A 47**, 112 (2011).

[3] Ivana Hristova, "Transverse-Target Single-Spin Azimuthal Asymmetry in Hard Exclusive Electroproduction of Single Pions at HERMES", Ph.D. thesis, Humboldt University of Berlin, December 13, 2007.

[4] G.M. Huber, et al., Phys. Rev. C **68**, 065202 (2003).