Reply to the Report of 2015 SoLID Director's Review

The SoLID Collaboration

December 21, 2016

Contents

1 Introduction

A Director's review for SoLID was held in February, 2015. The review committee "felt that SoLID was in a good state to move forward, but also identified a number of areas where additional work will be needed." There is a total of 36 recommendations, see summary in Appendix E. After discussing the report with the Physics Division and JLab management, we decided that the first step was to address the recommendations necessary to move forward for the DOE Science Review. In the mean time, we will also address the remaining recommendations to the extent possible with the resources available.

We have completed the first step, which will be summarized below in section 2. It includes all the recommendations related to the three core measurements (SIDIS, PVDIS and J/ψ production) as well as the ones related to the general performance of the instrumentation to reach the scientific goals. We will also include the studies to other recommendations in section 3.

2 Recommendations Related to Science Case

2.1 PVDIS program

1. ***Recommendation 2:*** **Acceptances, efficiencies, and systematic uncertainties should be simulated for each of the core measurements**

   We now have a full Monte Carlo simulation that includes all elements of the PVDIS apparatus, layer by layer energy deposition in the electromagnetic calorimeter (EC) and optical physics in the light gas Cherenkov (LGC). At present we have preliminary GEM responses and tracking under realistic backgrounds, both of which are under continued development. We now also have recent data from newly constructed GEMs which are being employed at Jefferson Lab to refine our simulations. For the present results, true values of track hit positions in the GEMs are used. Neither the GEMs nor the calorimeter are segmented in the simulation. However, the GEM sector boundaries will be far from the baffle-defined signal regions, and the tracks entering the EC will not be parallel to the module boundaries, so the effects of GEM and EC segmentation on our acceptance are expected to be negligible.

   Input events to the Monte Carlo are electrons from a DIS generator using cross sections from CTEQ6 parton distribution fits [1]. Our analysis integrates primary electrons which reach the active area of the EC after passing through the active areas of all five GEMs and the front window of the LGC. The acceptance is shown in Fig. 1, as a function of p and θ and as a function of Q^2 and x_{bj}. Lines on these plots show the boundaries of the kinematic region of interest: $Q^2 > 6$ GeV^2, $W > 2$ GeV, and $x_{bj} > 0.55$. Our acceptance in this region is typically 40%.

   Contributions to the efficiency are as follows:

   Calorimeter: Efficiency of $\sim 95\%$ as reported in the pre-CDR.

   LGC: With the changes of the radiator gas and PMT quantum efficiency, new studies of the LGC efficiency need to be undertaken. Requiring ≥ 2 photoelectrons in each of ≥ 2 PMTs in the sector matching the EC yields 96% efficiency.

   Tracking: The GEM detection efficiency is 97% per plane. From our studies using a tree search algorithm with realistic and correlated superimposed backgrounds and our current model of digitization, a track finding efficiency of $\sim 90\%$ appears to be achievable. Development of the track finding software is continuing.

   Combining the above contributions yields an estimate of 82% for our overall efficiency.

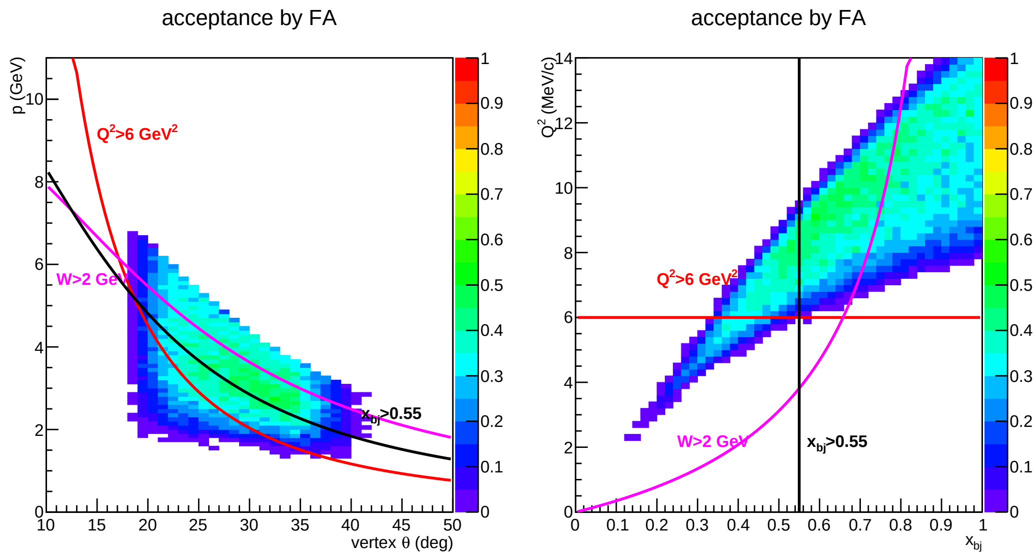

Figure 1: Left: PVDIS acceptance as a function of p and θ. Right: PVDIS acceptance as a function of Q^2 and x_{bj}. Curves show bounds of the kinematic range with $Q^2 > 6$ GeV^2, $W > 2$ GeV, and $x_{bj} > 0.55$.

The systematic errors on our measurement of the parity violating asymmetry are summarized in Table 1.

The systematic error on the polarization of the beam $\Delta P/P$ is projected in the pre-CDR to be better than 0.4%. The present state-of-the-art is given in Ref [2], which quotes an error of 0.6% and concludes that the goal of 0.4% is within reach. The major systematic in the pre-CDR is the laser polarization, which was estimated to be 0.3% but is listed in Ref. [2] to be below 0.2%. The higher analyzing power and large angles characteristic of the 11 GeV relative to the Qweak 1 GeV beam are one factor supporting the better precision for SoLID. Polarimetry is also important for MOLLER, and the experience gained with that experiment will give us plenty of experience in understanding systematic errors.

The radiative corrections are similar to those computed for the HERA experiments [3]. Many of the important radiative corrections come from tails of events at larger x, which are small for the SoLID high x kinematics. We have assembled a team including A. Aleksejevs, S. Barkanova, and W. Melnitchouk, who will assist in performing the necessary calculations. We estimate an error of 0.2% from radiative corrections.

Finally, systematics on the asymmetry due to reconstruction errors, including DAQ issues and particle identification, will be kept to the 0.2% level. The pion contamination is expected to be below 1% for most bins and the required corrections should be valid to at least 10% of that. Work on the DAQ is in progress to demonstrate that the pile-up and dead-time corrections can be kept to below 0.15%.

The total systematic error is 0.6%, unchanged from the proposal value, and allowing sufficient sensitivity to meet our physics goals.

2. ***Recommendation 3:*** **For the PVDIS measurements, the viability of the elastic scattering calibration procedure, which is used to make an absolute determination of Q^2, should be demonstrated by simulations for similar scattering angles to those probed in DIS, and with realistic misalignments**

Polarimetry	0.4
Q^2	0.2
Radiative corrections	0.2
Reconstruction errors	0.2
Total	0.6

Table 1: Summary of PVDIS systematic errors, in percent.

Our study of momentum calibration uses artificial displacements of GEM hits to make estimates of the systematic errors in track momentum reconstruction. The procedure to estimate momentum using pairs of GEM hits is most simply understood in the simple case of a uniform field and a thin target, in which the minimum distance between the beam axis and the line through two hits is linearly related to $1/p$. That distance is on the order of 10 cm, implying a need to calibrate the GEM transverse positions to the $\sim 100\mu$m level in order to achieve a momentum systematic error on $\Delta p/p$ of order 10^{-3}.

For a more realistic estimate we use a Monte Carlo simulation incorporating a realistic field and a long target. By using this simulation are able to study the effects on our momentum and angle reconstruction of all elementary displacements: lateral and transverse position shifts, and rotations in and perpendicular to the detector plane, of one or both GEMs. Results are shown in Table 2. Due to the symmetry of the apparatus, Q^2 is insensitive to all these misalignments in first order, except for single GEM angular displacement in-plane. We find we need to understand transverse GEM positions relative to straight tracks to within about 200 μm, and absolute positions parallel to the beam axis at the level of about 3 mm.

$1/p$ and θ residuals for GEMs 1, 4					
transform	GEM(s)	δp(mean)	δp(width)	$\delta\theta$(mean)	$\delta\theta$(width)
transverse displacement	1, 4	$-0.01\%/\mathrm{mm}$	$0.77\%/\mathrm{mm}$	$0.00\%/\mathrm{mm}$	$0.00\%/\mathrm{mm}$
	4	$0.00\%/\mathrm{mm}$	$0.76\%/\mathrm{mm}$	$0.00\%/\mathrm{mm}$	$0.08\%/\mathrm{mm}$
longitudinal displacement	1, 4	$0.05\%/\mathrm{mm}$	$0.00\%/\mathrm{mm}$	$0.00\%/\mathrm{mm}$	$0.00\%/\mathrm{mm}$
	4	$0.08\%/\mathrm{mm}$	$0.01\%/\mathrm{mm}$	$0.06\%/\mathrm{mm}$	$0.00\%/\mathrm{mm}$
in-plane rotation	1, 4	$0.00\%/\mathrm{mrad}$	$0.00\%/\mathrm{mrad}$	$0.00\%/\mathrm{mm}$	$0.00\%/\mathrm{mm}$
	4	$\mathbf{1.61\%/\ mrad}$	$0.15\%/\mathrm{mrad}$	$0.01\%/\mathrm{mm}$	$0.01\%/\mathrm{mm}$
out-of-plane rotation	1, 4	$0.00\%/\mathrm{mrad}$	$0.08\%/\mathrm{mrad}$	$0.00\%/\mathrm{mm}$	$0.03\%/\mathrm{mm}$
	4	$0.00\%/\mathrm{mrad}$	$0.09\%/\mathrm{mrad}$	$0.00\%/\mathrm{mm}$	$0.06\%/\mathrm{mm}$

Table 2: Momentum and angle reconstruction sensitivities to various displacements of GEMs 1 and 4: transverse, longitudinal, and rotational (in and perpendicular to the detector plane) displacements of both GEMs or of GEM 4 only. "δp(mean)" and "$\delta\theta$(mean)" are the changes in the mean of the $1/p$ and θ residuals and "δp(width)" and "$\delta\theta$(width)" are the changes in those residuals' width per unit displacement. Due to detector symmetry, the displacement to which we are most sensitive is single GEM in-plane rotation.

Within a GEM, strip positions relative to one another will be known to within 25 μm. With standard surveys, relative strip positions within a full GEM plane can be established to better than 500 μm. To achieve our resolution goal and to monitor possible motion of the tracking chambers, straight-through electrons with the magnetic field off and low energy photons with the field off and on, will be used to calibrate the relative transverse positions of the GEMs with the required precision. A thin carbon target about 10 cm upstream of the LD2 target has lines of sight to most of the area of the GEMs, as shown in Fig. 2. For x-ray studies, an absorber ring with holes, or conversely a set of absorbing beads mounted on a ring of light material, will provide the fiducials.

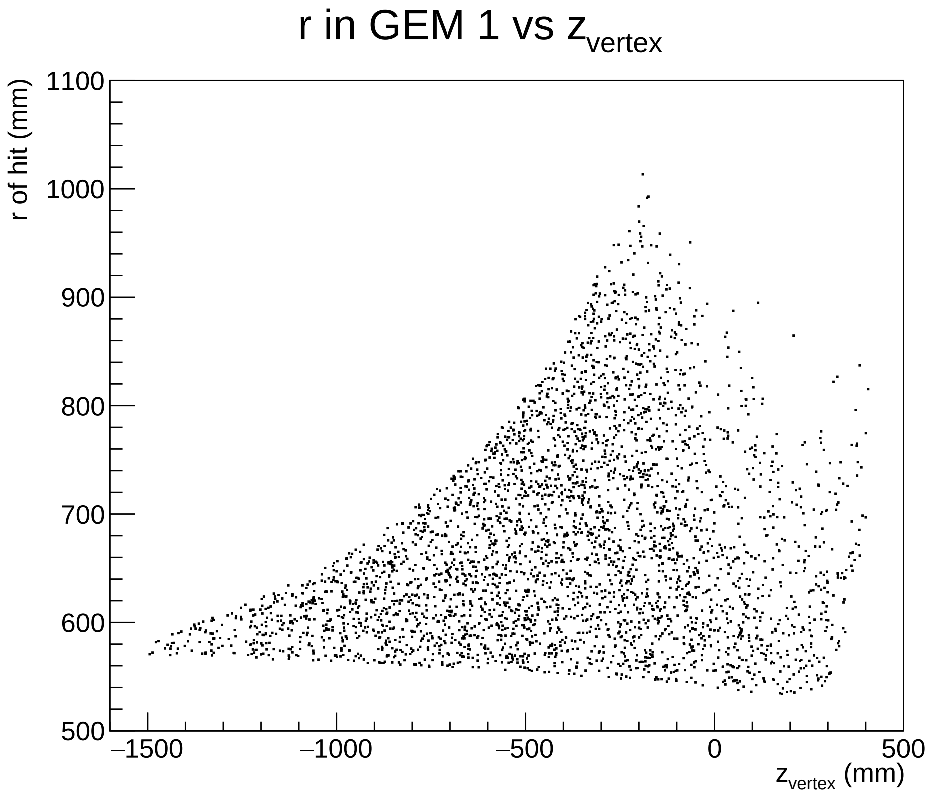

Figure 2: Radial coordinates of photon hits in GEM 1 versus vertex z position. Most of the detector area is covered for vertex at $z = -200$ mm, corresponding to a position about 10 cm upstream of the LD2 target. Similar results are seen in the other GEMs.

Once the positions of the GEMs are known, calibration of the momentum reconstruction can be done based on electron hydrogen elastic scattering data at 4.4 and 6.6 GeV beam energies as well as at different magnetic field settings. Clean separation of the elastic peak will be required. Figure 3 shows results from simulations where the green histograms are elastics and the blue histograms are the inelastic background from a Christy-Bosted parameterization [4]. Target and detector materials were included and momenta were smeared by 1% to simulate detector resolution. At both energies the elastic peaks are cleanly resolved. Rates are ample for calibration; see Fig. 4. At 6.6 GeV, the integrated rate is about 150 Hz per μA of beam current. At 50 μA, sufficient data can be collected in only a few minutes.

3. ***Recommendation 26:*** **It should be confirmed that the baffle design, including the support structure, is optimized for background rejection and signal acceptance. Furthermore the baffle design should minimize generation of secondary backgrounds. (Finding) Choice of material in the baffle appears not to have been optimized. A study of the effects of different material choices that incorporate physics signals, background levels and activation of the material could provide useful information.**

   We recently have undertaken studies of our baffle design including evaluation of materials, acceptance,

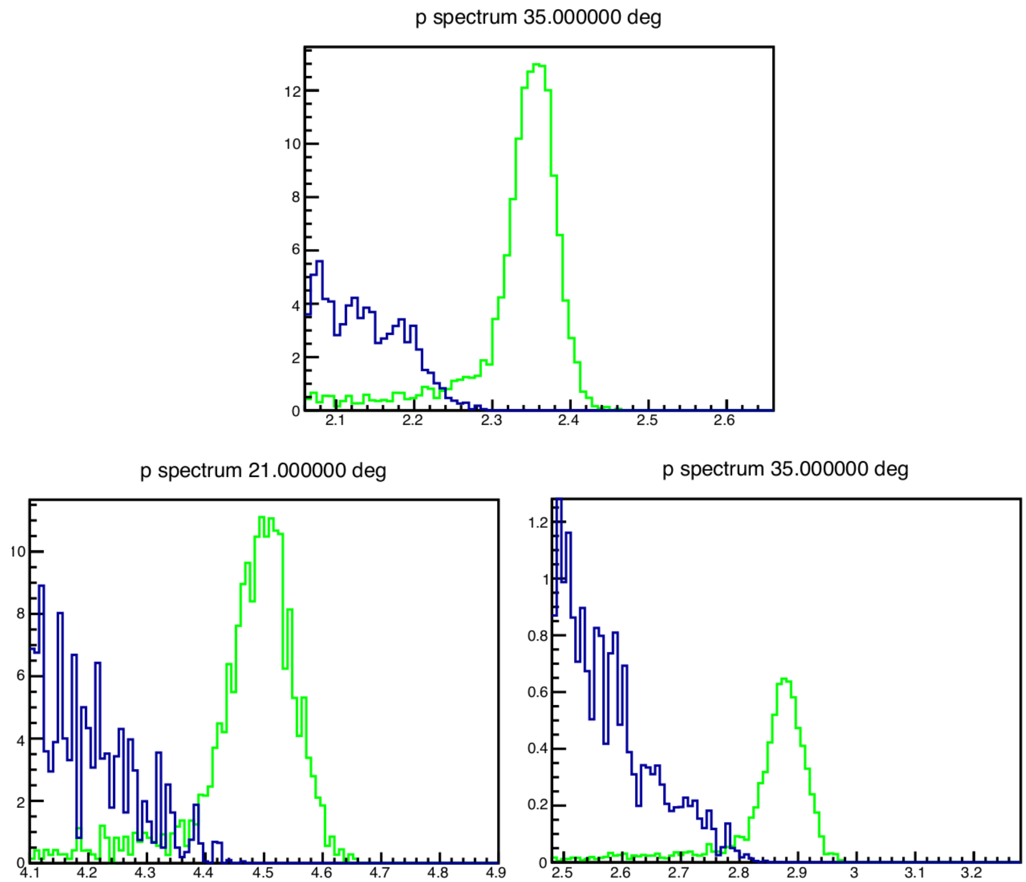

Figure 3: Elastic (green) and inelastic (blue) spectra for 4.4 GeV (top) and 6.6 GeV (bottom) electrons on a hydrogen target, at scattering angles of 21° (bottom left) and 35° (top and bottom right).

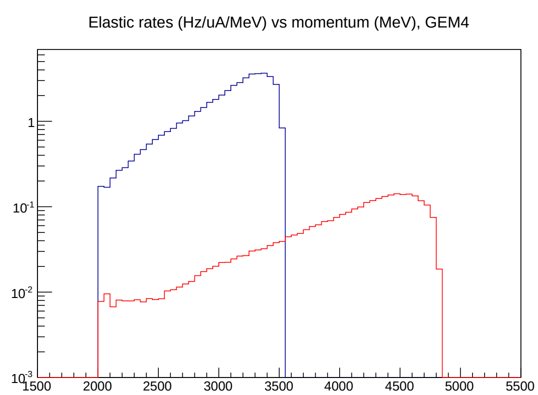

Figure 4: Elastic rates at GEM 4 for 4.4 GeV/c (blue line) and 6.6 GeV/c (red line) electrons on LH2, as a function of momentum in MeV/c. Rates are in Hz per μA per MeV/c. Target and detector materials are included.

and background reduction. While our baseline baffle design uses lead, other possibilities include copper or tungsten. These materials vary by a factor of 4 in radiation length. The variation in nuclear interaction length is smaller. See Table 3. Tungsten's high density and short interaction length is advantageous, however, its cost is higher and solid tungsten is difficult to machine. An easier approach to construction would be to use powdered tungsten which can be easily molded and glued.

	Copper	Lead	Tungsten powder	Solid tungsten
Radiation length (cm)	1.436	0.5612	0.583	0.3504
Nuclear interaction length (cm)	15.32	17.59	16.58	9.946
Machinability	Easy	Soft, needs support	Easy to mold and glue	Hard
Cost	Low	Low	High	High
EC trigger rate (kHz)	4.78e3	5.45e3	5.25e3	4.59e3
Neutron rate in EC (kHz)	3.35e7	4.7e7	4.0e7	2.9e7
Photon rate in last GEM (GHz/sector)	2.98	2.59	—	—

Table 3: Properties and performance of copper, lead, tungsten powder, and solid tungsten as baffle materials.

We have performed studies of trigger rates in the EC, rates of neutrons entering the EC, and rates of photons striking the last GEM with baffles constructed of different materials, but with the same geometry. All show fairly small differences, seen in Table 3. Lead provides a slightly lower photon rate than copper, while copper's hadron rates are slightly better. Powdered tungsten has a density only about 60% of solid tungsten, and consequently provides little or no performance advantage over lead.

An important background is photons from π^0 decay interacting in the baffles. When photons strike the baffles close to the "hot" edge of a slit, shower products can escape into the slit and from there thread through the slits in the remaining baffle plates. A modification we have considered is to remove material amounting to $0.6°$ in angular width from the hot edges on baffle plates 2, 4, 6, 8, and 10, allowing photons that would have hit near these slits to instead strike further from the hot edges on the next plate. Our simulations show a 16% reduction in photon rates above $p = 1$ GeV/c, and 26% reduction for $p > 10$ GeV/c. Removal of this material would increase the pion background, but by less than 10%.

We have performed detailed studies of track trajectories through the baffles to identify places where improvements in the baffle geometry can be made. One finding was that, for the upstream baffle plates, the solid ring at the inner radius and an angular constriction at small radius interfere with the acceptance for electrons produced at the downstream end of the target. For vertices at the upstream end of the target, acceptance was being lost due to the too-small outer radii of the upstream baffle plates.

Based on these studies we have developed a modified baffle design. Inner rings and angular constrictions on the first few plates have been removed, and outer radii of these plates have been increased. Shapes of the slits in all the plates were optimized, keeping the overall aperture in polar angle unchanged, but tightening up slits that were slightly too wide. The outcome of this program was a geometrical design, having modest acceptance improvements over our previous baffles while not significantly affecting photon rejection, which we believe to be optimal; see Figs. 5 and 6.

A detailed study of the activation of different materials suitable for the baffle has been done. The radiation levels for 3 different times from beam exposure and for each material has been studied and possible shielding scenario has been evaluated. Final selection of baffle material will likely be driven less by performance and more by activation and ease of construction.

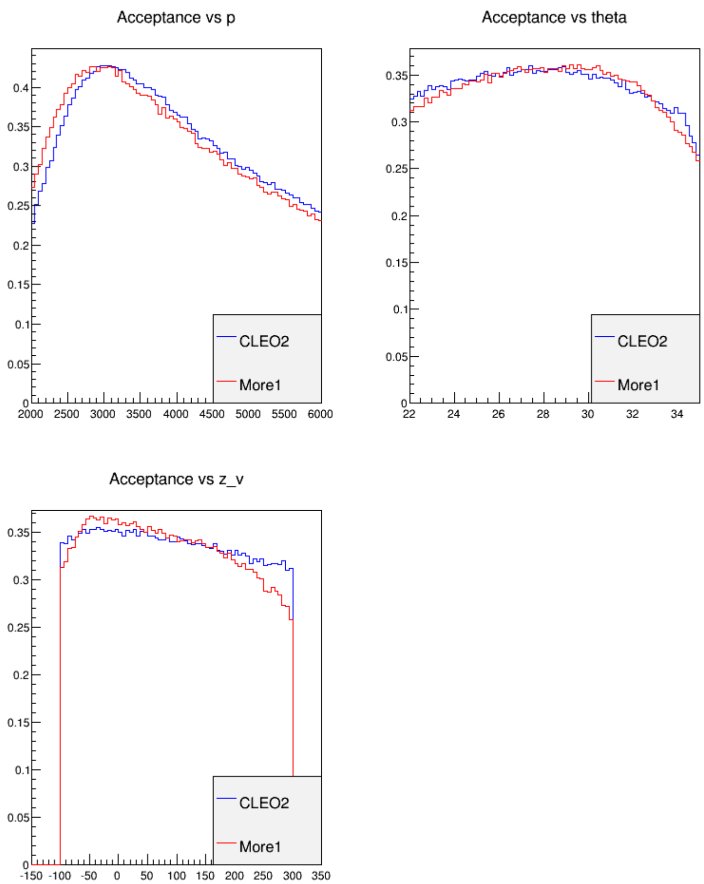

Figure 5: Geometric acceptance of the PVDIS baffles for DIS electrons with $Q^2 > 6$ GeV^2, $W > 2$ GeV, and $x_{bj} > 0.55$ versus momentum (top left), scattering angle (top right), and vertex position (bottom left). Blue (red) lines are acceptance for the optimized (previous) baffle design.

2.2 SIDIS program

1. ***Recommendation 2:* Acceptances, efficiencies, and systematic uncertainties should be simulated for each of the core measurements**

   The acceptance of SIDIS with a 40 cm long polarized ^{3}He target setup was studied by using the simulation software. The particles of interest recorded by the EC and GEM are compared to the original particles from a full length target to form their simple acceptance. For example, Figure 7 shows the acceptance at the forward angle detectors, large angle detectors, and combining the two.

   Most of sub-detectors' efficiencies are studied using the simulation and background effect is considered. MRPC efficiency has been tested under high rate environment. For SIDIS events, both electrons and charged pions need to be detected. The electrons detection efficiency includes sub-detectors EC (95%), Light Gas Cherenkov (93%), Scintillating Pad Detector (98%), and tracking by GEM (91%), and the overall efficiency is about 79%. The charged pions detection efficiency includes sub-detectors Heavy Gas Cherenkov (95%), MRPC (95%), and tracking by GEM (91%), and the overall efficiency is about 82%. Please note the efficiency is averaged over the full acceptance of SoLID and broad kinematics. We will continue to fine-tuning the design and the reconstruction algorithm to improve

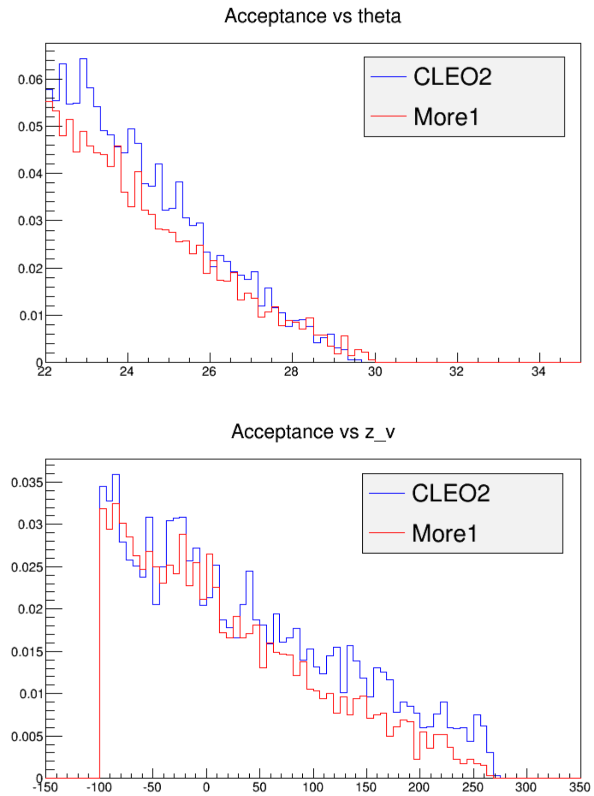

Figure 6: Geometric acceptance of the PVDIS baffles for photons versus scattering angle (top), and vertex position (bottom). Blue (red) lines are acceptance for the optimized (previous) baffle design.

the efficiency.

We have conducted a careful study of the systematic uncertainties of the SIDIS experiments and the results are presented below.

The SIDIS cross section is in general expressed as [5]

$$\frac{d\sigma}{dxdydzdP_{h\perp}^2 d\phi_h d\phi_S} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\left[F_{UU}(x,z,Q^2,P_{h\perp}) + \text{asymmetric terms}\right]. \tag{1}$$

In the simulation, we model the SIDIS cross section by assuming factorization to express the structure function as a convolution of TMD distribution and fragmentation functions

$$F_{UU}(x,z,Q^2,P_{h\perp}) = x\sum_a e_a^2 \int d^2k_\perp d^2p_\perp \delta^{(2)}(P_{h\perp} - p_\perp - zk_\perp) f_1^a(x,k_\perp) D_1^a(z,p_\perp). \tag{2}$$

The unpolarized TMD distribution function $f_1(x,k_\perp)$ and fragmentation function $D_1(z,p_\perp)$ are pa-

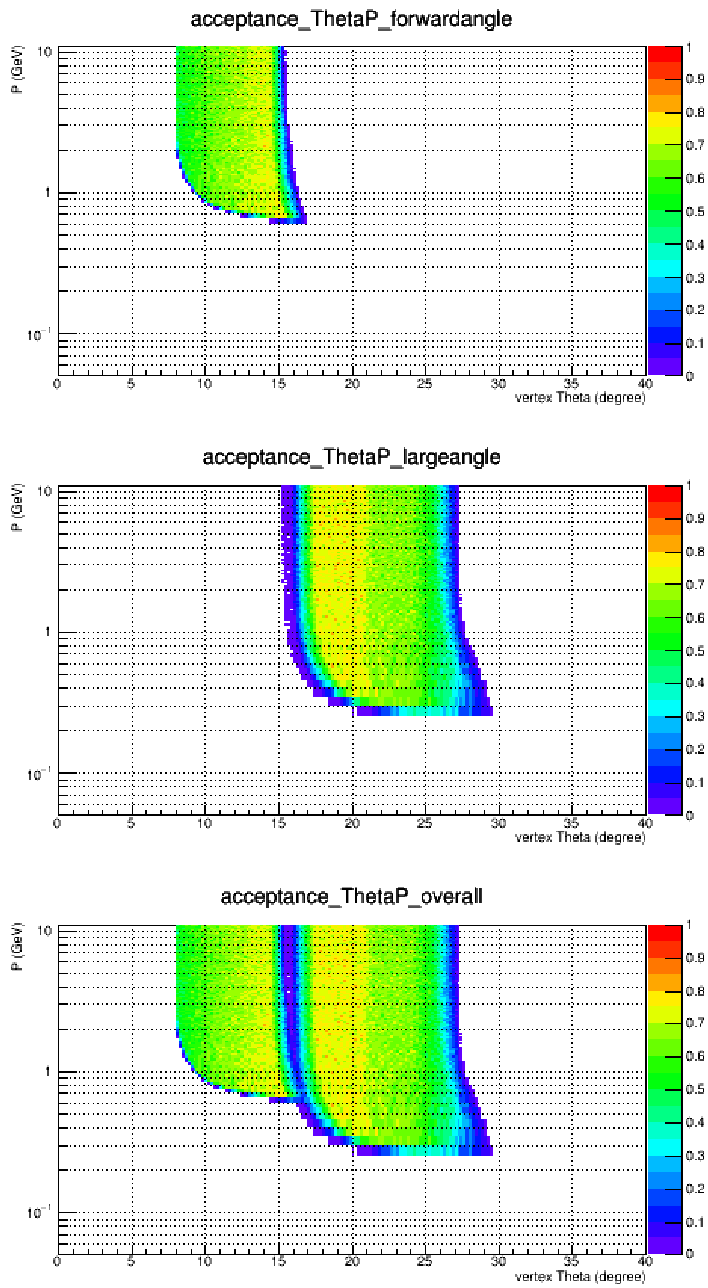

Figure 7: Geometric acceptance of electrons and charged pions for SoLID SIDIS setup with 40 cm polarized ^{3}He target. The first panel shows the forward angle acceptance, the second panel shows the large angle acceptance, and the third panel shows the combined acceptance.

rameterized as

$$f_1(x, k_\perp) = f_1(x, Q^2)\frac{e^{-k_\perp^2/\langle k_\perp^2\rangle}}{\pi\langle k_\perp^2\rangle}, \tag{3}$$

$$D_1(z, p_\perp) = D_1(z, Q^2)\frac{e^{-p_\perp^2/\langle p_\perp^2\rangle}}{\pi\langle p_\perp^2\rangle}, \tag{4}$$

where $f_1(x, Q^2)$ and $D_1(z, Q^2)$ are collinear distribution and fragmentation functions. In our simulation, we use CT14 leading order collinear PDF parameterization [6] and DSS leading order collinear FF parameterization [7]. The two parameters describing the transverse momentum dependence are chosen as $\langle k_\perp^2\rangle = 0.25$ and $\langle p_\perp^2\rangle = 0.20$ [8]. For the three leading twist single spin asymmetry (SSA) terms, the Sivers, the Collins, and the pretzelosity, we use the phenomenological models [9, 10, 11] as inputs to the simulation. To take into account the detector efficiency effect, we use 85% of the statistics for the estimation of the uncertainties.

Taking the advantage of the 2π azimuthal coverage, we are able to reduce the systematic uncertainties associated with luminosity and detection efficiencies by defining the target single spin asymmetry as

$$A_{UT}(\phi_h, \phi_S) = \frac{2}{P_1 + P_2}\frac{\sqrt{N_1(\phi_h, \phi_S)N_2(\phi_h, \phi_S + \pi)} - \sqrt{N_1(\phi_h, \phi_S + \pi)N_2(\phi_h, \phi_S)}}{\sqrt{N_1(\phi_h, \phi_S)N_2(\phi_h, \phi_S + \pi)} + \sqrt{N_1(\phi_h, \phi_S + \pi)N_2(\phi_h, \phi_S)}}, \tag{5}$$

where the subscripts $1, 2$ represents a target spin flip pair. $N_1(\phi_h, \phi_S)$ and $N_1(\phi_h, \phi_S + \pi)$ are taken at the same time with target polarization P_1, while $N_2(\phi_h, \phi_S)$ and $N_2(\phi_h, \phi_S + \pi)$ are taken at the same time with target polarization P_2. Thus, the luminosity at different times will be canceled. Since $N_1(\phi_h, \phi_S)$ and $N_2(\phi_h, \phi_S + \pi)$, $N_1(\phi_h, \phi_S + \pi)$ and $N_2(\phi_h, \phi_S)$ are taken in the same detector region, the acceptance and detector efficiency will also be canceled to the first order. The time-dependent detector efficiencies will be monitored with single electron and pion rates. With a ^{3}He target spin flip rate of every 10 minutes (20 minutes for each pair), we expect to control the time-dependent detector efficiency uncertainty to better than 1%. In 48 days with 11 GeV beam, we will have 3456 pairs, and in 21 days with 8.8 GeV beam, we will have 1512 pairs. Then, the systematic uncertainty of the raw asymmetry is estimated as $1.0\%/\sqrt{3456} = 1.7 \times 10^{-4}$ for 11 GeV data, and $1.0\%/\sqrt{1512} = 2.6 \times 10^{-4}$ for 8.8 GeV data. With a proton (ammonia) target spin flip rate of every 1 hour (2 hours for each pair), we expect to control the time-dependent detector efficiency uncertainty to under 2%. In 55 days with 11 GeV beam, we will have 660 pairs giving an estimated systematic uncertainty of $2.0\%/\sqrt{660} = 7.8 \times 10^{-4}$. In 27.5 days with 8.8 GeV beam, will have 330 pairs, and the systematic uncertainty is estimated as $2.0\%/\sqrt{330} = 1.1 \times 10^{-3}$. The derived absolute systematic uncertainties of the SSA data associated with the raw asymmetry are obtained by dividing these numbers by the target polarization and the dilution factor in each bin.

The knowledge of the target polarization is at the 3% level, and this translates to a 3% relative systematic uncertainty on the SSA data. The knowledge of the target polarization direction is about 0.2 degree. The effect on the polar angle will result in 6×10^{-6} relative uncertainty of SSA. The effect on the azimuthal angle is included into the uncertainty of the azimuthal angle ϕ_S together with the resolution effect.

The systematic uncertainties associated with detector resolutions are estimated based on the track fitting studies. The resolutions of the kinematic variables in the Trento convention for each bin are obtained by Monte Carlo sampling according to the resolutions of the lab frame variables shown in Figure 14. The resolutions of the kinematical variables in the Trento convention are summarized in Table 4. The systematic uncertainty associated with the resolution mostly come from the uncertainties of the azimuthal angles, ϕ_h and ϕ_S which affect the separation of the SSA terms. It is estimated by smearing the pseudo-data according to the resolution, separating the SSA term with the smeared pseudo-data, and then comparing them to the model input of the simulation. The absolute systematic uncertainty of the SSA due to the resolution is less than 1×10^{-4}, which is negligible when compared to other uncertainties.

Table 4: Resolution on kinematical variables in Trento convention with the ^{3}He target setup.

E_{beam} (GeV)	x	z	Q^2(GeV^2)	$P_{h\perp}$(GeV)	ϕ_h(rad)	ϕ_S(rad)
11	0.002	0.003	0.02	0.006	0.015	0.006
8.8	0.002	0.004	0.02	0.006	0.018	0.006

Nuclear effects will contribute the systematic uncertainty when we extract the SSA of the neutron from ^{3}He data. We derive the SSA of the neutron from that of ^{3}He as

$$A_n = \frac{A_{^3\text{He}} - 2P_p f_p A_p}{P_n f_n}, \tag{6}$$

where the SSA of proton A_p will also be measured with SoLID in the same kinematic region, and we assign 10% relative uncertainty of the knowledge of the proton SSA. The $f_{p/n}$ are dilution factors that will be measured with the hydrogen and the ^{3}He targets. The light-front spectral function of ^{3}He including the final state interaction effect was recently developed [12]. With a theoretical calculation of the nuclear effect of the SSAs in the SoLID kinematic region [13], we estimate that the relative uncertainty in the extraction of the neutron SSAs due to the nuclear effect is about $4 \sim 5\%$.

The random coincidence background is estimated using single electron and single pion rates. By assuming a 1 ns time resolution, we choose a plus-minus three-sigma time window of 6 ns. For the ^{3}He target, we also apply a three sigma vertex cut according to the track fitting results. As the SIDIS signal rate drops with increasing $P_{h\perp}$, we summarize the signal background ratio with respect to $P_{h\perp}$ in Table 5. The relative systematic uncertainties due to the random coincidence background are estimated by varying the background rate by 20% for each bin.

Table 5: The ratio of SIDIS signal and random coincidence background within 6 ns. These values are estimated with the ^{3}He target. Similar results are obtained for the proton target.

$P_{h\perp}$(GeV/c)	$[0.0, 0.2]$	$[0.2, 0.4]$	$[0.4, 0.6]$	$[0.6, 0.8]$	$[0.8, 1.0]$	$[1.0, 1.2]$
11 GeV beam (π^+)	110	160	150	105	75	40
11 GeV beam (π^-)	120	160	140	90	70	50
8.8 GeV beam (π^+)	75	95	80	50	45	
8.8 GeV beam (π^-)	65	95	75	50	45	

The radiative correction effect of SIDIS is simulated with HAPRAD, which was developed based on the QED calculation to one-loop level [14, 15]. The systematic uncertainties from the radiative corrections are estimated by varying the model parameters $\langle k_\perp^2 \rangle$ and $\langle p_\perp^2 \rangle$ of the SIDIS model in our simulation by a factor of 2 (multiplied and divided). This gives relative uncertainties of about 2.5% for the 11 GeV data and about 2% for the 8.8 GeV data.

2. ***Recommendation 8:*** **Better comparisons with the expected results on programs such as SBS**

and particularly CLAS12 are needed to clarify the need for the SoLID SIDIS program. Crisp demonstrations of the improvements possible with SoLID should be developed.

In Table 6, we compare the experimental conditions of the SIDIS experiments with SoLID, SBS, and CLAS12. The values of solid angle coverage in the table are simplified descriptions. A more realistic acceptance from GEMC is used for the estimation of the physics impact. Compared with SBS, the statistics of SIDIS events with SoLID are much better due to the large acceptance. This will allow us to have 4-dimensional bins with SoLID, while SBS will only have 3-dimensional bins.

Table 6: Comparison of the experimental conditions of SoLID, SBS, and CLAS12.

	SoLID	SBS	SoLID	CLAS12
Experiment	E12-10-006 Approved (A)	E12-09-018 Approved (A-)	E12-11-108 Approved (A)	C12-11-111 Conditional
Targets	^{3}He (“n”)	^{3}He (“n”)	NH_3 (“p”)	HDice (“p”)
Polarization (P)	65% (60% in beam)	65% (<60% in beam)	70%	60%
Dilution (f)	0.15∼0.3	0.15∼0.3	0.13	0.33×80%
Luminosity $(L\,\mathrm{cm}^{-2}\mathrm{s}^{-1})$	1.0×10^{36}	2.7×10^{36}	1.0×10^{35}	1.4×10^{33}
Solid angle $(\Omega_e \times \Omega_h\,\mathrm{sr}^2)$	0.482×0.139	0.044×0.063	0.482×0.139	1.14×1.16

A comparison of the Figure of Merit (FOM), which is calculated by the inverse square of the statistical uncertainties of the SSA, is shown in Figure 8. In these comparisons, we applied the same kinematic cuts of $W > 2.3\,\mathrm{GeV}$ and $0.3 < z < 0.7$. Compared with CLAS12, SoLID has higher statistics in smaller x region and has comparable (or a bit lower) statistics in larger x region. Compared with SBS, SoLID has higher statistics up to about $x \sim 0.55$, while SBS has more coverage in large x region.

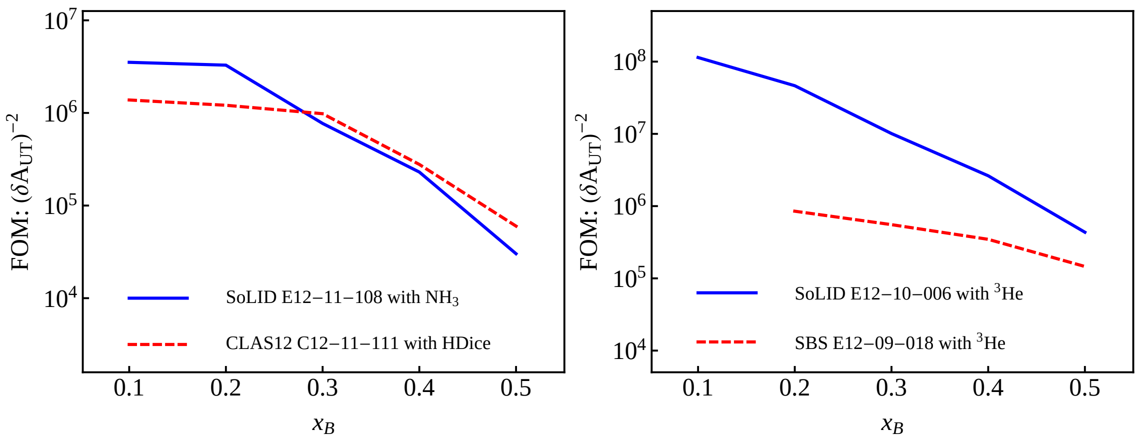

Figure 8: Comparison of the FOM. SoLID SIDIS experiment with the proton target is compared with CLAS12 in the left panel. SoLID SIDIS experiments with the neutron target are compared to the SBS experiment in the right panel. In both comparisons, the same kinematic cuts of $W > 2.3\,\text{GeV}$ and $0.3 < z < 0.7$ are applied.

The physics impact of SoLID is the precise measurement of the TMDs in the valance region. One highlight is the Collins SSA, which is related to the transversity distribution, which in turn is dominated by the valance quark distribution. It is related to quark transversity distribution, which is valence quark dominant. To compare the improvement on the determination of transversity, we model the transversity distributions with the recent global fit of Ref. [16], which includes the TMD evolution effect. We estimate the errors with the standard Hessian method [17]. The Hessian is the second derivatives of the χ^2 with respect to the parameters at the least χ^2 point. It reflects not only the uncertainties of the parameters but also the correlations of the parameters. The Hessian of the world data is obtained from the covariant matrix of the global fit [16]. The Hessians of SoLID, CLAS12, and SBS are calculated with the simulated data. To ensure that the SIDIS events are in the current fragmentation region, which can be described by TMD factorization, we adopt the recent theoretical study on the criteria of the current fragmentation kinematics [18] and only use the bins in the current fragmentation region to study the physics impact. The impacts on the transversity extractions are compared in Figure 9. In the comparison, only statistical uncertainties are used to compare with CLAS12 and SBS. The improvement from SoLID data including systematic errors is also shown in Figure 9. To remove the model dependence as much as possible, we take the ratio between the prior uncertainties and the post uncertainties to show the improvements from the SoLID, CLAS12, and SBS SIDIS experiments.

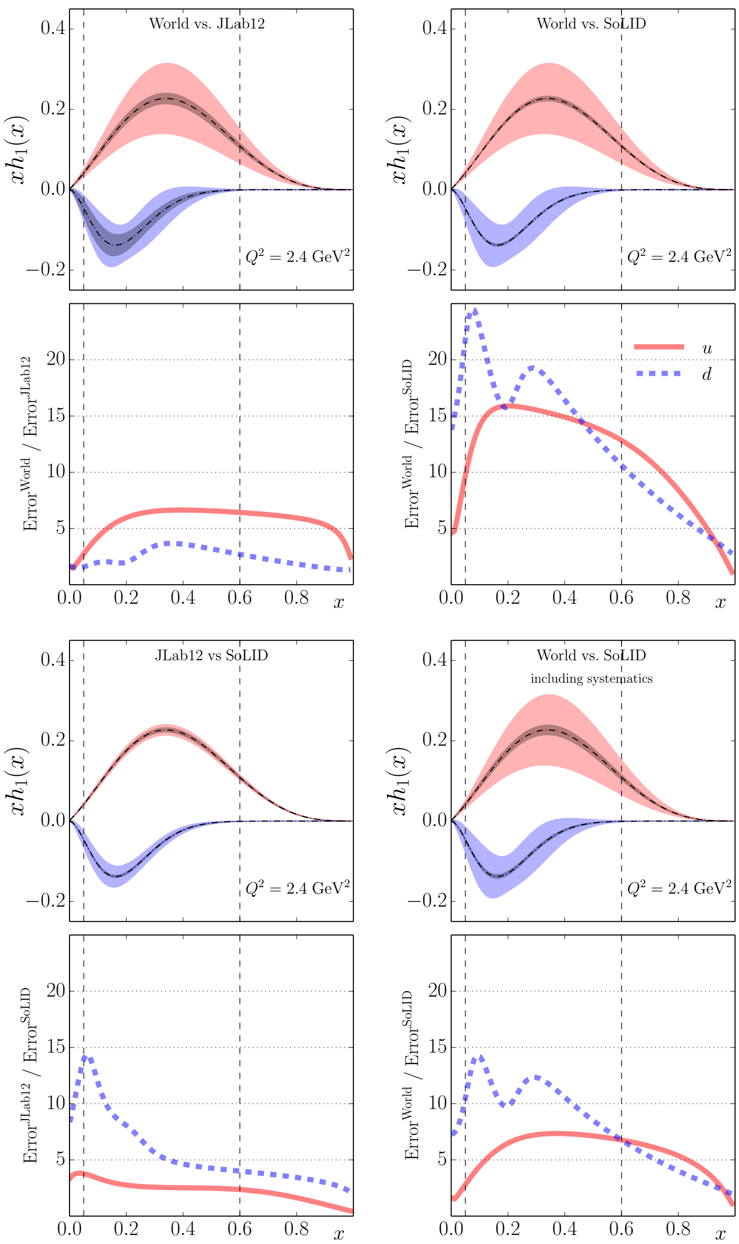

Figure 9: Comparison of the impact on the transversity extractions. The “World” represents all world available data by 2015, and the “JLab12” means the expected future data, i.e. CLAS12 and SBS, from JLab12 before SoLID. The upper left panel shows the improvement from future JLab12 data before SoLID on the base of world available data by 2015. The upper right panel shows the improvements from SoLID data. The lower left panel shows the further improvement from SoLID data after the expected JLab12 data before SoLID. The lower right panel shows the improvements from SoLID data including the systematic uncertainties. The current uncertainties are from the global fit [16], and the future uncertainties are obtained by including the pseudo-data from these experiments with only statistical errors for the first three, and with both statistical and systematic errors for the last one. The curves in the lower panels show the improvement, which is the ratio between the prior uncertainties and the post uncertainties. The x-range between the two vertical dashed lines is that which is directly measured by SoLID.

The tensor charge, which is the integral of transversity distributions, is a fundamental quantity in QCD. It describes the coupling between a nucleon and a tensor current. Note that in QCD, this correlation is different from the correlation between the longitudinal quark spin with the longitudinal spin of the nucleon which is measured by the structure function g1. The impact of the determination of the tensor charge from SoLID, CLAS12, and SBS are compared in Table 7. The improvements are shown in two ways, the typical measured x region by JLab-12 experiments and the full x region.

Table 7: Comparison of improvements to tensor charge extractions. "World" represents all world available data by 2015, and "JLab12" includes expected future data, i.e. CLAS12 and SBS, from JLab12 before SoLID. In the first three comparisons, only statistical errors are used, while in the last comparison both statistical and systematic errors are included. The values in the table give the ratio between the prior error and the post error. The measured region is the integral over x from 0.05 to 0.6, and the full region is the integral over x from 0 to 1.

	World vs. JLab12	World vs. SoLID	JLab12 vs. SoLID	World vs. SoLID including systematics
$\delta u^{\text{measured}}$	6.1	16	2.8	6.7
$\delta d^{\text{measured}}$	1.9	17	9.3	11
δu^{full}	5.4	16	3.0	5.9
δd^{full}	1.8	17	10	10

One of the advantages of SoLID SIDIS experiments is that the high statistics allows us to have four-dimensional bins. This will help study TMDs, which are three dimensional distributions. To show the impact of SoLID on TMD measurements, we take the Sivers function as an example. In the analysis, we do a global fit with both unpolarized multiplicity data and Sivers asymmetry data. The fitting result is used as the input model for future SoLID, CLAS12, and SBS pseudo-data. The uncertainties from the world data and from inclusion of SoLID, CLAS12, and SBS are estimated in the same framework. Similar to the case of transversity extraction, we only select the bins that pass the kinematic cuts of the current fragmentation criteria. In Figure 10, we show the improvement from SoLID on the extraction of the Sivers function, and compare it with CLAS12 and SBS.

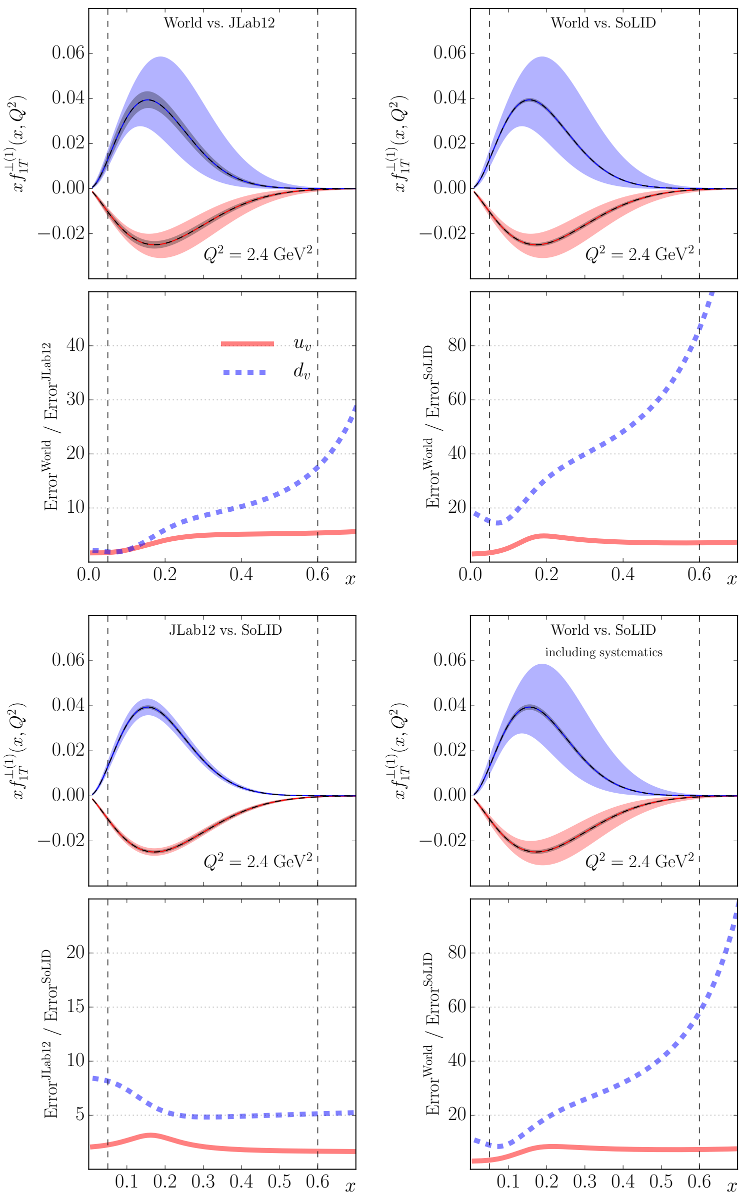

Figure 10: Comparison of the impact on the first transverse moment of the Sivers function. The "World" represents all world available data by 2015, and the "JLab12" means the expected future data, i.e. CLAS12 and SBS, from JLab12 before SoLID. The upper left panel shows the improvement from future JLab12 data before SoLID beyond the base of world available data by 2015. The upper right panel shows the improvements from SoLID data. The lower left panel shows the further improvement from SoLID data after the expected JLab12 data before SoLID. The lower right panel shows the improvements from SoLID data including the systematic uncertainties. The current uncertainties are from our new global fit to both unpolarized multiplicity data and Sivers asymmetry data, and the future uncertainties are obtained by including the pseudo-data from these experiments with only statistical errors for the first three, and with both statistical and systematic errors for the last one. The curves in the lower panels show the improvement, which means the ratio between the prior uncertainties and the post uncertainties. The x-range between the two vertical dashed lines is directly measured by SoLID.

2.3 J/ψ program

1. ***Recommendation 4:*** **Bin migration effects should be simulated for the measurements of the sharply rising J/ψ production cross section near threshold.**

   Recent simulation studies of J/ψ production have been performed including approximate radiative effects. External bremsstrahlung was applied to both the incident and scattered electrons. The incident electron radiation loss is calculated with the peaking approximation through the target material up to the reaction vertex. The external radiative loss for the scattered electron is calculated within the framework of Geant4/GEMC and folded into the total resolution smearing of the track. Internal bremsstrahlung is calculated according to the Q^2 dependent equivalent radiator method, and applied to both the incident and scattered electrons. These radiative calculations are well known and widely used and have historically described radiative losses with reasonable precision. A more robust and explicit calculation would allow for a more precise unfolding of the radiative losses, however such an endeavor is non-trivial and would require a significant investment of manpower. For the approximate calculations, one can see in Fig. 11 the effects of bin-migration along W, and the estimated correction needed to recover the unradiated cross-section. The plotted calculations were simulated with a 4-fold coincidence; the 3-fold coincidence has identical radiative losses (incident electron, scattered electron). Additionally, the internal radiative correction in the equivalent radiator method is near zero when in the quasi-real photon kinematics of the 2-fold coincidence measurement. We plan to continue developing our radiative corrections procedure with exact calculations, accurate unfolding, and tests of model dependence.

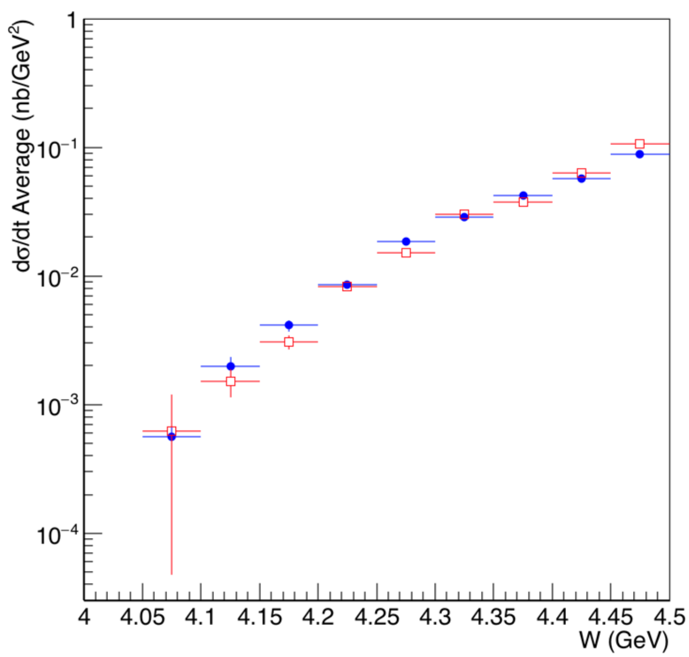

Figure 11: Simulation of cross-section including acceptance effects but no additional radiative losses (blue circles) for comparison with the expected cross-section measurement including acceptance smearing and all radiative effects listed in the text (red squares).

2. ***Recommendation 2:*** **Acceptances, efficiencies, and systematic uncertainties should be simulated**

for each of the core measurements

A physics generator which includes acceptance effects was developed for the experiment proposal and has since been extended to include resolution effects and the radiation effect approximations outlined above. Because the J/ψ experimental configuration is very similar to the SIDIS setup: a target position offset by 35cm being the only difference, the results are in-line with the SIDIS program shown in Figure 7.

Sub-detectors' efficiencies for the J/ψ experiment are similar to the SIDIS experiment and were studied using the same method. Either electrons or positrons detection efficiency includes sub-detectors EC (95%), Light Gas Cherenkov (93%), Scintillating Pad Detector (98%), and tracking by GEM (91%), and the overall efficiency is about 79%. Please note the efficiency is averaged over the full acceptance of SoLID and broad kinematics. We are working on tweaking the design and reconstruction algorithm to improve the efficiency.

As stated in the original proposal, we expected the systematic uncertainty would be dominated by acceptance ($<10\%$), with additional a couple percents from sub-detectors, luminosity, target windows and background contaminations. The total systematic uncertainty is about 11%. In the case of no radiative correction on the data, systematics due to total bin-migration effects can be estimated from Fig. 11. However, much of this systematic can be corrected by accurately simulating and properly unfolding the radiative effects (see section above).

3. ***Recommendation 5:*** **The signal and background trigger rates should be simulated for the J/ψ measurements.**

   Both signal and background trigger rates were studied before the proposal defense at JLab PAC39. Updated analysis of the J/ψ experiment's di-lepton trigger was preformed, similar to what the PVDIS and SIDIS ^{3}He programs have done. This simulated trigger study included the signal and combinatorial background from leptons, pions, and additional hadrons over both forward and large angle acceptance including the most up-to-date EC, LGC, and SPD response. The resulting di-lepton trigger is calculated to have a coincidence rate below 60 kHz, well below the 100 kHz trigger rate limit and in-line with the original PAC proposal estimates. This trigger rate applies to both the electroproduction and photoproduction of J/ψ, as well as the time-like Compton scattering process, which has an identical trigger condition.

2.4 GPD Program

1. ***Recommendation 10:*** **The SoLID collaboration should investigate the feasibility of carrying out a competitive GPD program. Such a program would seem particularly well suited to their open geometry and high luminosity. If SoLID's luminosity is sufficiently high to permit a program of precise Double Deeply Virtual Compton Scattering (DDVCS) measurements, it would make a groundbreaking contribution to GPD studies.**

   There are several GPD experiments in different stages of study/approval. As has been remarked elsewhere, a variety of hard exclusive measurements are needed to disentangle the contributions of the different GPDs, with the general Compton processes (DVCS, TCS, DDVCS) sensitive to various real and imaginary combinations of all four leading twist GPDs (Fig. 12), vector-meson Deep Exclusive Meson Production (DEMP) sensitive to the spin-average H, E GPDs and pseudoscalar-meson DEMP sensitive to the spin-difference $\tilde{H}$, $\tilde{E}$. The SoLID GPD program under investigation includes many of these reactions, and has the potential to greatly improve our understanding of nucleon structure.

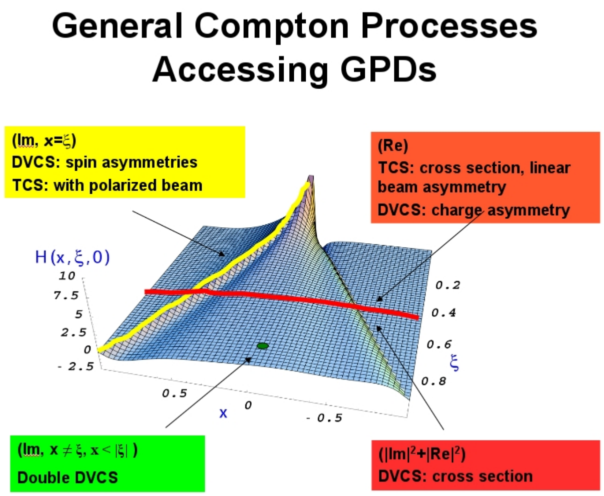

Figure 12: General Compton processes accessing GPDs.

Timelike Compton Scattering (TCS) from an unpolarized LH_2 target can provide information on the real (imaginary) parts of the Compton amplitude using unpolarized (circularly polarized) photons. In this case, the produced lepton pair sets the hard scale ($Q^2 > 4$ GeV^2) and the azimuthal asymmetry of the $\ell^+\ell^-$ plane with respect to the q-vector allows the separation of the GPD and Bethe-Heitler contributions. This has been approved as a run group experiment with the J/ψ experiment (E12-12-006A).

Double Deeply Virtual Compton Scattering (DDVCS) in the di-lepton channel on an unpolarized LH_2 target has been reviewed by PAC43 as LOI12-12-005. The solenoidal configuration is ideal for high luminosity, with a fully parasitic proposal (as part of the J/ψ run group) for the e^+e^- channel under preparation. Once this experiment has run, a later phase of measurements might include the $\mu^+\mu^-$ channel. A workshop at ECT Trento to refine the TCS and DDVCS physics program was held for October 24-28, 2016.

A possible Deeply Virtual Compton Scattering (DVCS) experiment on polarized ^{3}He is also under study. The 12 GeV polarized DVCS experiments to date utilize longitudinally (E12-06-119) and transversely (C12-12-010) polarized proton targets. No polarized neutron-DVCS experiment has been proposed at JLab to date, and SoLID could make a unique contribution here once the reaction exclusivity requirements and possible backgrounds are better understood. A complete set of SoLID DVCS data with both proton and neutron targets at varied polarization would be essential to control systematic uncertainties, perform flavor decomposition, and disentangle the different GPDs.

Deep Exclusive Meson (π^-) Production (DEMP) using a transversely polarized ^{3}He (neutron) target looks very promising. The transverse single-spin asymmetry in exclusive charged π production has been identified as the most sensitive observable to probe $\tilde{E}$. In this case, one fits the $\sin(\phi - \phi_S)$ dependence, where $(\phi - \phi_S)$ is the azimuthal difference between the π^- reaction plane and the polarized target. Theoretical calculations suggest higher twist corrections likely cancel in the asymmetry, allowing access to to GPDs at much lower value of Q^2 than typically required in DEMP reactions. This measurement has been proposed as a run group experiment with the transversely polarized ^{3}He SIDIS experiment (PR12-10-006B), and detailed studies on the expected uncertainties are underway.

This summary makes clear that the SoLID-SIDIS setup is indeed very attractive in terms of acceptance and luminosity, and will allow a Phase 1 GPD program to be initiated with minimal impact on the approved SoLID program. Once this has been executed, one could envision a later Phase 2 suite of GPD experiments with additional recoil detectors near the target (such as low momentum proton tagging for DEMP), dedicated configurations (for DDVCS), or improved EC resolution (to allow exclusive vector meson and π^0 measurements). These would require much more study, and are clearly beyond the scope of the present proposals.

2.5 Kaon identification

1. ***Recommendation 9:*** **The SoLID Collaboration should investigate the possibility of kaon identification, especially given their high luminosity.** ***Recommendation 17:*** **The collaboration is encouraged to explore the power of extended kaon identification (through Cherenkov or TOF).**

   A full RICH detector for kaon detection is likely to be too costly to consider. A high resolution TOF is a more practical solution. SoLID needs to do kaon identification over a momentum range of 1 GeV/c to 7 GeV/c. Given the 7.7 meter flight distance, a TOF time resolution of 20 ps is required to obtain a 3 sigma separation between pions and kaons. Two detector technologies that could give high resolution TOF are being investigated.

   The Large Area Picosecond Photodetector (LAPPD) collaboration [19] is developing large area detectors capable of time resolutions in the picosecond range. Such detectors use Micro Channel Plate photomultipiers, which have small paths for electrons, achieving better timing resolution than traditional PMTs. Resolutions of 20 ps for a single photoelectron have been achieved and resolutions of under 10 ps could be obtained for mulitple photoelectrons. The main drawback of Micro Channel Plate PMTs is the high cost per area. The LAPPD project is aiming to producing large area MCP PMTs with a cheaper microchannel plate, significantly reducing the cost for large area of detectors. Depending on the ultimates costs, this could be an option for SoLID.

   A second TOF option is improving the timing performance of the MRPC detector in SoLID. The baseline MRPC is designed to reach 80 ps. Improvement of the MRPC timing resolution would extend the momentum range of π/K identification to the full momentum range. Beam tests showed that current MRPC designs can reach 50 ps with test beam and 80 ps in high background area. There is ongoing EIC R&D [20] on Multi Gap Resistive Plate to improve the timing resolution. A thin gap MRPC prototype has been built and tested by BNL and University of Illinois, achieving a resolution of 20 ps. A joint Chinese collaboration for RHIC, SoLID and EIC for the next generation MRPC aims at 20 ps. Tsinghua University is planning to develop a prototype in the next coming year. Beam test and finalization of detector and electronics will be done the following year.

   Obtaining good timing resolution also depends on the electronics, both preamplificaiton of signals and digitization:

   EIC R&D at BNL is using 7 GHz bandwidth TI LMH5401 [20] amplifiers for preamplifiers. Tsinghua University will also develop its own amplifier chip which could drive lower costs and give a more compact footprint for the electronics with a multichannel amplifier chip.

   New sampling electronics, development of which is being motivated by MCP PMTs, can reach picosecond level timing resolution for multi-photons. The system is based on Switched Capacitor Arrays (SCAs), which continuously sample the detector signal on a circular array of capacitors. Sampling frequencies up to 10 GSamples/s have been reached. With a good calibration, a timing resolution of 1 ps has been achieved. The following table summarized the different available chips.

   One of the main drawbacks of the SCA is the inherent dead time to allow readout of all the samples for each trigger. A multi level array design will be implemented in the next generation of DRS5 or

Chip	Sample Frequency GHz	Bandwidth GHz	Samples	Channels	Readout MHz	Resolution ps
PSEC4	4 to 15	1.5	256	6	40 to 60	9
SAMPIC	3 to 8.2	1.6	64	16 or 8	80	5
DRS4	0.7 to 5 GHz	0.950	1024	9	33	1
DRS5	10	3	4096	32	300 ?	5 ?
PSEC5	5 to 15	1.5 to 2	32768	4	500?	5?

Table 8: Table summarizing the characteristics of different sampling chips available and future generation ones for DRS5 and PSEC5

PSEC5 chips. There is a joint effort from HEP/NP and a commercial company to offer a commercial modular system based on the future PSEC5. This is currently the best option with costs which could go as low as 15$ per channel.

Assuming a cost similar to SAMPIC (about 4 K$ for 32 channels) the additionnal cost for sampling electronics readout for 3,300 channels will be approximately an additional 500 K$. This would allow for electroncs that can perform at a resolution of 20 ps or better and have the ability to record the whole waveform of the detectors.

2.6 Simulation

1. ***Recommendation 1:*** **End-to-end simulations with realistic subsystem responses and material budgets, and complete track finding and reconstruction should be developed.**

2. ***Recommendation 7:*** **The development of a simulation framework with realistic reconstruction and analysis should be pursued with high priority and increased resources.**

3. ***Recommendation 16:*** **The collaboration is strongly encouraged to develop an end-to-end realistic simulation and reconstruction to further optimize cost and physics reach and derive clear performance requirements for the individual subdetectors.**

4. ***Recommendation 24:*** **Having a functional simulation and reconstruction routines as soon as possible should be a high priority in the software effort. Such software will pay off many times over in experimental design and avoiding pitfalls**

   We have made a lot of progress with SoLID simulation. And it allowed realistic simulations of performance of the core measurements and other important issues. We used a new event generator to have a better estimation of hadron background rate (see the appendix for details). The simulation framework we are using, GEMC, has evolved to work with the latest Geant4 version and includes many more features. Its basic idea remains the same though, which is making inputs like geometries, materials, detector responses and output file formats truly independent of the Geant4 based simulation code. The SoLID simulation has been taking advantage of the new GEMC development. The simulation of each individual subsystem has been developed by different groups using the same framework, and then all subsystems are combined into the whole SoLID simulation without any code change and at run time. We can also choose to turn off a subsystem or replace it with a different version in the whole simulation for testing. The entire code including production and development version is in version control systems. The PVDIS setup, SIDIS and J/ψ setup are shown in Figure 13.

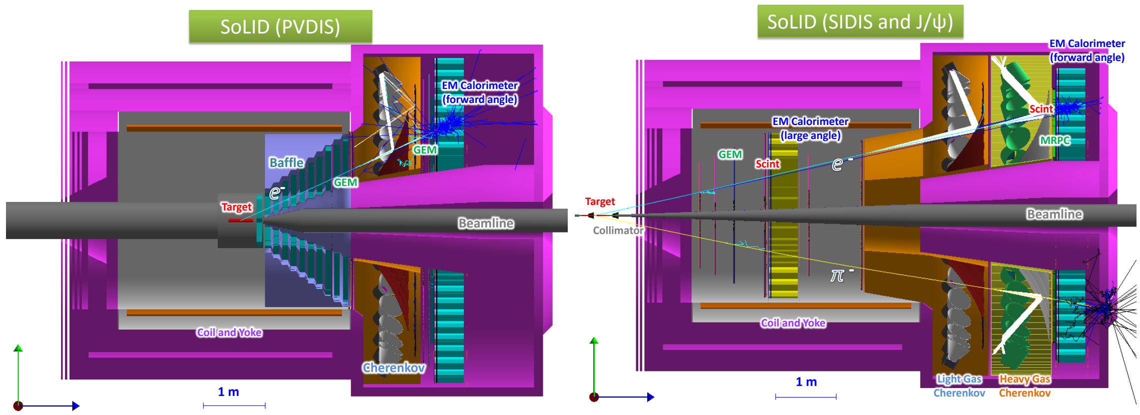

Figure 13: The two SoLID setups

The materials in all non-detector subsystems have been implemented. Detector subsystems have all materials and responses tailored to themselves. In addition to studies done by different groups for subsystems, we also produce the whole simulation output for various overall studies like acceptance, background, and trigger to ensure consistent results.

The simulation output is stored in ROOT trees. Each detector has a standalone tree and different trees are linked by the same tree index for one event. Then each tree is analyzed by a standalone ROOT script. Combining the set of ROOT scripts, we can analyze all SoLID sub-detectors and perform these overall studies.

In general, the SoLID simulation is an effort which will last the entire SoLID lifetime. We are still at its early stage. The simulation code will evolve with the Geant and GEMC development. SoLID's detector and engineering design will also evolve and they can be easily transferred into the simulation by a CAD model. Detector prototyping and tests will give direct input to the simulations and in turn improve the overall SoLID design.

The SoLID collaboration will try to adopt the event-processing framework, *art*, as its software framework. *art* currently uses generic Geant4 as its simulation engine and allow a flexible middle layer. We are exploring the possibility of using GEMC for the simulation layer of *art*.

2.7 Tracking

1. ***Recommendation 1:* End-to-end simulations with realistic subsystem responses and material budgets, and complete track finding and reconstruction should be developed.**

   SoLID tracking reconstruction requires an accurate and efficient track finder which is not only able to find hits that belong to signal tracks in a high-noise environment, but also has a relatively fast speed in order to satisfy the L3 trigger requirement. In addition, an accurate and robust track fitter is required in order to optimize the resolutions for the vertex variables and other track-related variables.

   In order to satisfy the requirements, a Kalman Filter (KF) based track finding and track fitting algorithm is being developed and tested with digitized GEM simulation data. Kalman Filter is a recursive fitting algorithm. In contrast with the well-known least square fit that provides only one set of parameters after fitting, the track parameters of the KF can evolve along the trajectory. There are three basic steps for the KF. Firstly, it predicts the measurement on the next measurement site by propagating the current track parameters. Secondly, the covariance matrices of current track parameters are propagated along the trajectory. And lastly, it filters the next measurement in order to improve the track parameters at the next measurement site. The local field information and errors due to multiple scattering can be collected during the first two steps of the algorithm. Thus, given that particle tracks in the SoLID detector will cross both fringe and uniform field, it is expected to perform better than other algorithms that have an explicit requirement on the global uniformity of the magnetic field.

The KF can be easily developed into a track finder and thus, achieving a concurrent track finding and fitting. This is done by adding two steps in the standard KF algorithm. First, an algorithm is needed to search for seeds, which are track segments that are able to provide initial estimations for the track parameters. This is needed in order to initialize the KF. Second, a set of arbitration rules are inserted before filtering in order to judge whether a hit belongs to the track. A straightforward rule is to require that the hit on the next measurement site should fall within a window around the prediction. An alternative rule is to cut on the increment of the χ^2 when a candidate hit is added [21].

Currently, the track finding algorithm is being developed and tested for SoLID-SIDIS configuration with ^{3}He target, for both single electron and single pion signal tracks. Based on only one time-sample from the APV25 and simplified GEM digitization simulation, the efficiency of the track finder and the chance of identifying all correct hits of a track can both reach above 90% for electron tracks in both forward angle and large angle region, and around 85% for pion tracks. The track finder also achieves a reasonable execution speed. Meanwhile, for the SoLID-PVDIS and SoLID-J/ψ configuration, similar track finding frameworks have been established also, and we are testing them. We will study the possibility of using the current tracking finding algorithm with looser conditions and improved speed to be used for track finding on a level 3 farm to reduce data size.

For track fitting, studies have been performed for the SoLID-SIDIS-J/ψ and SoLID-PVDIS configurations. The kinematic dependence of the various track resolutions for the SIDIS configuration is given in Figure 14 as an example. The results averaged over kinematics are summarized in Table 9. All SoLID physics programs used the track resolutions in their studies by directly applying the full kinematic dependent results. In order to have a conservative estimation, we multiply a safety factor of 1.5 to all results.

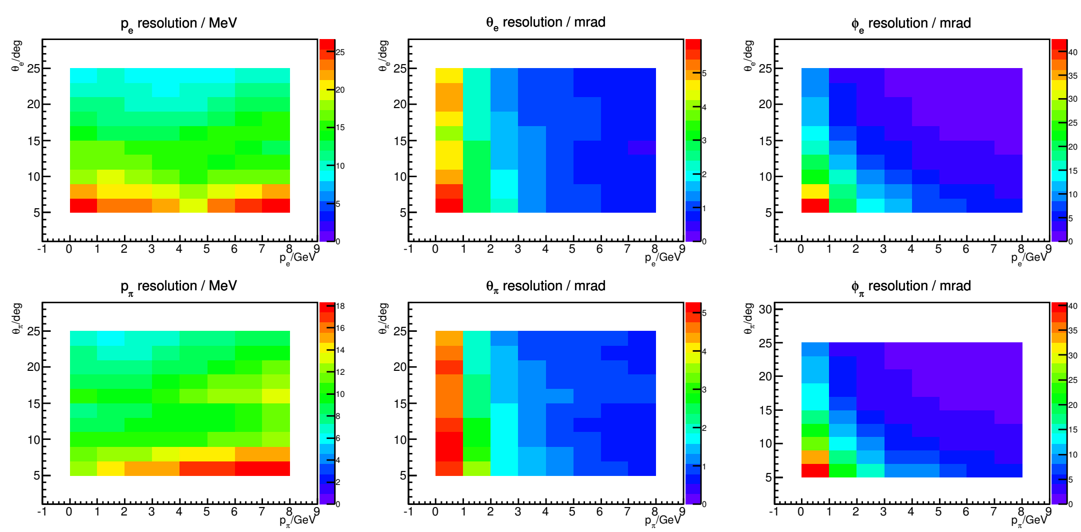

Figure 14: Resolution results by track fitting studies. The upper panels are the resolution of the electron kinematics. The lower panels are those of the pion kinematics. The variables are defined in lab frame with beam line as the z-axis.

Table 9: Track fitting results.

	θ angle (mrad)	ϕ angle (mrad)	Vertex z (cm)	Momentum (%)
SIDIS forward angle (e)	1.3	5.7	0.9	1.7
SIDIS forward angle (π)	1.2	5.2	0.9	1.1
SIDIS large angle (e)	1.0	1.7	0.5	1.2
PVDIS (e)	0.8	1.7	0.3	1.2

In order to obtain a more reliable result from the track reconstruction, it is crucial to simulate the responses of GEM detectors and related electronics to a highly realistic level. Such an effort was recently carried out, based on the existing SoLID GEM digitization program, by comparing simulated results with actual GEM detector experimental data from beam tests and highly ionizing x-ray test at UVa. The digitization parameters were fine tuned based on this study to work for both highly ionizing low energy photon signals and for MIP signals. This is critical for a reliable simulation of SoLID conditions as much of the background hits in SoLID GEM detectors are due to low energy photons.

2.8 DAQ

1. ***Recommendation 6:*** **The deadtime(s) in the DAQ chain should be modeled**

   The main concern with deadtime(s) is that a large deadtime would cause false asymmetries to the PVDIS measurement beyond the first order correction. The deadtime correction δ is proportional to event rates. For a given value of δ, the observed asymmetry A_0 is related to the actual asymmetry A according to $A_0 = (1 - \delta)A$. Therefore the deadtime uncertainty directly affects the uncertainty on the asymmetry measurement and must be determined precisely for the event rates of PVDIS.

   The FADC250 flash ADC, which is the primary component of the PVDIS trigger and DAQ, was designed to handle 200 kHz trigger rates. We have gained experience with the FADC250 from both bench tests and the Compton polarimeter. In the bench test that was carried out up to 277 kHz, the 3% asymmetry observed by FADC250 DAQ agreed with the asymmetry from scalers to within 100 ppm, or within a relative 0.33% level, see Fig. 15. The FADC250 is currently also in production use for the Hall A Compton Polarimeter. The deadtime of the Compton DAQ was measured to be about 2% at 20 kHz, and can be determined to better than relative 10%. For SoLID PVDIS DAQ, thanks to the pipeline method, we expect the total deadtime to be 150 ns per event (smaller than Compton), yielding a deadtime correction of 0.3% for the 20 kHz event rate of PVDIS. Determining this correction to a relative 10% level will limit the systematic uncertainty on the asymmetry to 0.03%, well below the value of the error budget for PVDIS.

   Furthermore, in the approximation of low rates (less than 200 KHz), the FADC's deadtime comes only from electronic deadtime and is fixed. Such deadtime can be modeled and simulated, as was done for E08-011, the completed 6 GeV PVDIS experiment [22]. This again gives us the confidence that the deadtime can be determined to a relative 10% level or better and the asymmetry uncertainty due to deadtimes will be well within the error budget for PVDIS.

2. ***Recommendation 21:*** **The plans for the High Level Trigger and the needs for slow control need to be worked out in detail and the implications for resources need to be evaluated.**

3. ***Recommendation 22:*** **The implications of the need for these resources in the context of availability of resources at the laboratory need to be understood.**

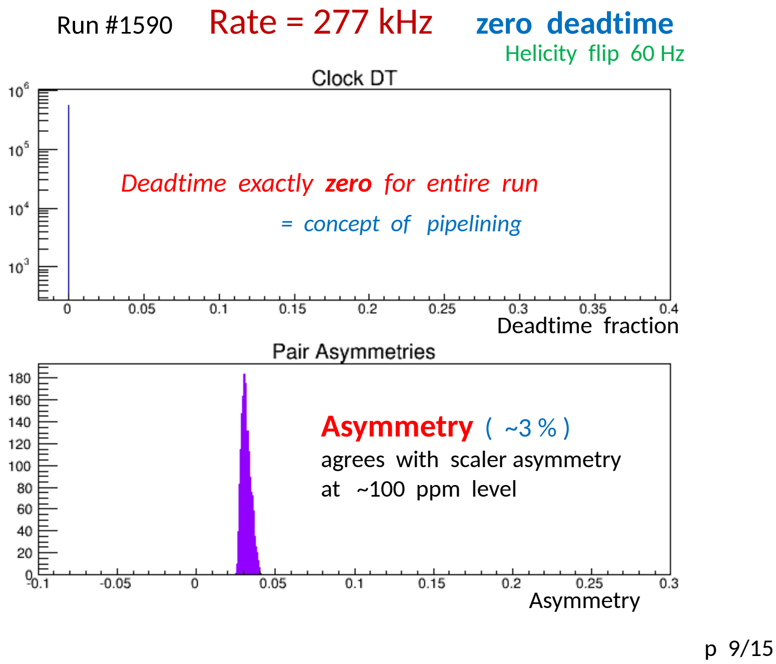

Figure 15: (top) Deadtime for FADC250 DAQ test running at 277 kHz. (bottom) Observed distribution of asymmetry of helicity flip pairs.

4. ***Recommendation 23:*** **Closer communication with the other JLab experiments and the JLab computing center is strongly encouraged.**

   In 2008, when SoLID was first proposed, the expected data transfer rates and data storage sizes could not have been handled without significant investments. However, continued drops in price and increases in performance of networking, storage and computing imply that the SoLID requirements will fit within the planned upgrade path for the JLab IT infrastructure.

   The trigger rates and occupancies have been updated with the current simulation and include GEM digitization. Table 10 summarizes the requirements for the SoLID experiments.

   These numbers assume minimal processing of the GEM data which constitutes the bulk of the data.

Experiment	PVDIS	SIDIS He3	J/PSI	SIDIS NH3
Trigger rate (limit) (kHz)	60×30	200	200	200
Trigger rate (expected) (kHz)	15×30	100	60	100
Data rate (GB/s)	6	3.9	4.7	3.9
Running time (days)	169	125	60	120
Total data (PB)	175.3	84.3	48.7	80.9
Tape price (K$)	274	131.7	76.2	126.4

Table 10: Rates, run times, data totals and tape price estimates for the approved SoLID experiments. For PVDIS, there are 30 sectors, and each has a separate DAQ.

Data reductions methods on the front end GEM FPGA are being developed so future data rates will be smaller. Updated numbers will be given once the different methods are implemented and tested. For the SIDIS experiment we expect a combined real and random coincidence trigger rate of 80 KHz and we can take an additional 20 kHz of prescaled single electrons. The DAQ is being designed to handle 200 kHz to have a safety margin.

Further data reduction could be achieved by doing tracking which would require an L3 farm.

The collaboration has held meetings with JLab Computer Center to discuss computing requirements for SoLID. The Computer Center has advised us to take into account technological developments expected by time of the running of the experiments.

A JLab network upgrade, completed in 2014, provided two 10 Gigabit Ethernet links between the Hall A counting house and the computer center. Upgrading these links to 40 Gigabit/sec before SoLID runs is planned. Silo (tape storage) upgrades are planned to accomodate Hall D data, allowing for 12 petabytes per year. Currently the silo system can hold up to 11,240 tapes giving, with compression, a current capacity of 47 PB using LTO6 drives. Adding a second silo is included in computer center budget planning for the next several years. This will give a storage capacity of 22,480 tapes and 48 drives. Assuming the evolution of LTO technology (Table 11), a fully upgraded data storage center will have a capacity of 1840 PB and handle data rates up to 52.8 GB/sec. Assuming the silo is fully upgraded it could hold up to 919 PB of data in the LTO10 technology with a 13.2 GB/s data rate per drive frame so 26.4 GB/s for the whole system. Each drive frame can have up to 12 drives, A second two frame silo system is already budgeted to be deployed when needed. This would give a total capacity of 1840 PB and data transfer rate 13.2 GB $\times\ 4 = 52.8$ GB/s, accomodating the needs of SoLID and the other halls.

LTO version	4	5	6	7	8	9	10
Availaibility	2008	2010	2012	2015	2018	2020	2023
Capacity/tape (TB)	0.8	1.5	2.5	6.25	12.8	25	48
Data rate/drive (MB/s)	120	140	200	300	472	708	1,100
Compression	2	2	2	2.5	2.5	2.5	2.5

Table 11: LTO tape drive evolution.

Assuming 28 weeks of running per year, and assuming the usual 50% efficiency, every experiment longer than 98 days will span over 2 fiscal years giving an average tape cost per year of 120 K$, a cost which can accomodated by the hall operations budget. The total amount of data from all SoLID running will total to about 390 PB representing about 21% of the future silo size.

Data volumes can be reduced with an L3 farm, reducing tape costs and reducing subsequent analysis times. With the increased bandwidth available from the counting house to the computer center, that farm could be located in the computer center. This would avoid the need for a dedicated SoLID L3 farm by using dynamic allocation of CPU cores shared with other applications.

Preliminary test of GEM reconstruction using Kalman filters give a maximum processing time of 20 ms/event with full background for SIDIS and about 10 ms for PVDIS. In order to do GEM reconstruction online, 4500 cores (during beam operations) for SIDIS and PVDIS would be required. This represents about $4000 \times 159 = 636$ K$ over 3 to 4 years which is consistent with current yearly IT operation investment without taking into account the price drop by a factor 2 every year.

Plans for slow controls are addressed in section 3.4.

2.9 Radiation

1. ***Recommendation 25:*** **Complete radiation calculations to determine activation and absorbed dose on components of concern and mitigate as appropriate.**
   (Finding) While the levels to damage electronics appear not to have been reached, the levels may still be high enough to disrupt data taking electronics. Experts should be consulted to understand at what level this becomes apparent.

   Some of the electronics and detectors used by the SoLID detector use technology that has already been tested in other facilities. The electronics was built in order to withstand a certain level of radiation and have been successfully tested at those facilities. In order to establish a safe limit for the SoLID electronics, the accumulated dose on the electronics was estimated and evaluated at this time and a safe limit was posed well below the current limit reached by those detectors (in order to account for the fact that our estimations are based just on simulations at the moment). This method was done in order to evaluate which parts of the electronics needed more attention and a more careful evaluation. Wherever the estimated radiation the will be close to the limit, a more detailed analysis is done and experts will be consulted.

2. **(Finding) The effect of radiation backgrounds on heating of the cryogens in the solenoid have not been investigated.**

   A detailed design of the Cryogens and coils of the CLEO II solenoid has been obtained and a detailed model that replicates key components of the magnet was constructed. Particular attention was put in well represent:

   (a) the 3-5 mm of stainless steel which is the inner bore of the cryostat
   (b) the 3-5 mm of aluminum thermal shield 3-5 cm beyond (1)
   (c) the 6+ mm of stainless steel which is the helium vessel
   (d) any winding forms left at the inner diameter of the coils
   (e) the copper matrix in which the Nb-Ti is embedded. Typical conductors of the era were 66-80% copper with balance Nb-Ti (2:1 to 4:1 Cu:SC).

   After updating the design, a detailed calculation was done with the PVDIS configuration with a deuterium target: This configuration, with the deuterium target inside the magnet, is the one between the different SoLID configurations which presents the highest flux of neutrons on the Coils. An integrated dose was calculated and determined using the cylindrical symmetry of the system and the flux calculated per cm^2 on the more susceptible parts of the magnet. An integrated dose of 10^{17} 1 MeV neutrons$/\mathrm{cm}^2$ is needed in order to start to see some modification on the Critical Current (I_c) of the magnet. A map of the integrated dose for the PVDIS and D_2 case was created and presents peaks for the integrated fluxes around 10^{14} 1 MeV neutrons$/\mathrm{cm}^2$, well below the tolerance level of the magnet. As a consequence, also if it is not known what is the current level of exposure reached by the CLEO-II solenoid, the full scientific outreach that is planned at this moment with SoLID does not seem to be going to affect considerably the lifetime of the coils of the magnet.

   More details on the studies can be found in Appendix A

3 Other Recommendations

3.1 Software in General

It is clearly more efficient to build any kind of end-to-end simulation and reconstruction framework for SoLID on already existing software. In fact, given limited manpower, the effort needed for developing a new framework from scratch would likely be prohibitive. Taking a collaborative approach would also follow recent trends in HEP [23] that have been motivated by the increasing complexity of software in the field.

With this in mind, we developed a number of requirements that a software framework suitable for SoLID should ideally satisfy. The SoLID framework should

- support all major components of the physics data processing chain, *viz.* simulation, digitization, reconstruction and physics analysis, within a *consistent* development and run-time environment;
- offer the capability to perform multi-pass data processing, where the output of one analysis pass can be used as the input for the next pass. This is typically achieved in physics frameworks by a clear separation of data and algorithms, where the data objects are persistable and saved to intermediate files. This capability is essential to minimize reprocessing of very large data sets. Regarding object persistence, the ROOT streamer model has essentially become the state of the art in the field;
- allow multiple processing chains in a single job, for example to run different track fitting, PID or physics analysis algorithms on the same data, again in view of efficiency;
- support interactive analysis of reconstructed quantities with ROOT, since ROOT will most likely be the data analysis package best known to and preferred by future SoLID collaborators;
- save extensive metadata to its output, for example database parameters used in previous analysis stages (if practical) and precise information about the data provenance;
- either directly support parallel computing, at least multi-threading, but preferably distributed processing, or be explicitly thread-safe and easily extensible to a dustributed model; and
- be readily available at this time, so that development can start without delay;

Obviously, we do not expect a perfect framework that satisfies all criteria to be available.

To arrive at a choice for SoLID, we evaluated a number of different, currently popular and available NP and HEP data analysis frameworks, developed both in-house by different JLab groups and by collaborations at other laboratories. Specifically, we studied

1. Podd (JLab Hall A/C) [24]
2. Clara (JLab Hall B) [25]
3. JANA (JLab Hall D) [26]
4. Fun4All (PHENIX/sPHENIX at BNL) [27]
5. FairRoot (GSI) [28]
6. *art* (FNAL) [29]

Of these, we have chosen *art*, the framework used by the Intensity Frontier experiments at Fermilab, as the most promising candidate for long-term SoLID simulation, reconstruction and analysis software development. We summarize our reasoning for this choice in the following.

Podd, while lightweight and user-friendly, offers no proper support for multi-pass analysis; even though ROOT objects can be made persistent, the architecture of this package does not lend itself easily to further processing of such data. Turning to Clara, although this framework supports distributed computing out of the box, clearly a major advantage, the overall Clara software collection also appears to be highly complex and only understood by few experts, busy with preparations for CLAS12 running in Hall B. Clara is also written primarily in Java, a language with which the SoLID collaboration lacks expertise and which is known to incur performance penalties. JANA appears to be lightweight and user-friendly, supportive of multi-pass analysis and fully multi-threaded. However, it was found to have design limitations of a different kind than Podd, for example incomplete support for multiple instances of modules and for multiple analysis chains in the same job. Additionally, similar to Clara, it uses a non-ROOT file format for object persistence. Finally, Fun4All, while lightweight and flexible, is rather poorly documented, thin on features and limited to the PHENIX community as its user base. Its code base is also the oldest of all the frameworks studied.

The remaining two frameworks, FairRoot and *art*, offer mostly benefits and few significant drawbacks, making them the best candidates for SoLID.

FairRoot appears well designed, broadly adopted by multiple collaborations (including current EIC detector design work), actively supported, and offers very good simulation support via ROOT's Virtual Monte Carlo interface. But it is also missing good user documentation, is written in a manifestly not thread-safe manner, and its user community is primarily located in Europe. Furthermore, FairRoot is extremely tightly integrated into ROOT, giving rise to concerns that an incompatible upgrade to ROOT, such as might happen with ROOT 7, could require extensive revisions to the framework as well.

art is a fork of the CMS framework from CERN. It is very well documented, especially at the user level, is the most modern of the frameworks studied, has been (re-)written in C++11 from the ground up, is largely independent of ROOT, fully thread-safe, has been adopted by about ten Fermilab experiments (DUNE, mu2e, etc.), is actively being developed, and arguably offers the most powerful analysis configuration features of all the frameworks. *art* is also the only one of frameworks we studied that has built-in support for data provenance tracking. On the other hand, *art* by default employs Fermilab's rather non-standard UPS and UPD build and code distribution systems, uses its own custom analysis configuration language (FHiCL), the code is somewhat complex, has a number of dependencies, and there is no direct built-in Monte Carlo support.

Both the FairRoot and *art* collaborations participate in the monthly ROOT planning meetings; as stakeholders, they provide direct into to the ROOT team to improve compatibility of the respective frameworks with ROOT. We see this as an encouraging sign for the expected longevity of these two frameworks in particular.

Neither FairRoot nor *art* are multi-threaded, but *art* is thread safe, and it is relatively easy to see how the framework could be parallelized. The heavy dependence of FairRoot on ROOT, with its many globals, effectively rules out a future multi-threaded version. The GSI FAIR experiments are considering moving to a new, concurrent framework, ALFA [30], which will presumably be in the upgrade path of FairRoot; we did not consider this option as it is not readily available at this time. The *art* team have announced interest in and developed ideas for multi-threading their framework at some point in the future [31].

Ultimately, *art*'s superior technical design, good documentation and embrace of widely adopted, state-of-the-art technologies (C++11/14, ROOT) were deciding factors for us. None of the studied frameworks appeared to be so complete as to be immediately ready for use by SoLID. However, regarding required development time, *art* appeared to offer the most benefits, not least because of its excellent documentation and large body of available example code.

At the time of this writing (October 2016), we are in the process of prototyping and testing simulation and analysis routines within *art*. The migration of exitsing SoLID software, most notably the simulations, to *art* may take several months after our intial testing is complete. We feel that it is particularly important at this early stage to design a consitent database interface for all software components, *i.e.* simulations, digitization, reconstruction and analysis. Additionally, a suitable data model for the various SoLID detectors needs to be implemented. Once this basic infrastructure is in place, porting of simulation and digitization algorithms is expected to be straightforward. We hope to complete the transition to *art* by mid-2017.

3.2 Detectors

1. ***Recommendation 11:*** **Develop an overall R&D plan for the project with a timeline**

   We have developed R&D plan for the project with a timeline. A two-year pre-R&D plan was also developed and submitted to DOE for funding in Summer 2016.

2. ***Recommendation 12:*** **Close interaction between the US and Chinese groups in the development of GEM foils to assure good quality control Is highly recommended.**

   We agree with the review committee that close collaboration between the CIAE group in China developing GEM foil fabrication capabilities and the US groups (UVa and Temple) is essential as the project moves forward. The ongoing China-USA SoLID GEM collaboration activities have included monthly phone meetings, discussion during SoLID collaboration meetings and hosting of Chinese visiting researchers at the GEM lab at UVa.

   A timetable is worked out with the CIAE group to lay out milestones for the fabrication of GEM foils with increasing active areas up to the full size of the largest SoLID modules. This timetable will also include goals for providing specific numbers of GEM foils produced in China to the Temple group for hole inspections and to the UVa and Temple groups for construction of test modules with these foils. The Chinese foils will be subjected to all acceptance criteria used for CERN GEM foils. The test modules will be evaluated under high luminosity conditions at the UVa x-ray test-stand as well as in beam tests at Jefferson lab. The two US groups will be closely interacting with the Chinese groups and giving them feedback during these evaluations. As part of the proposed SoLID pre-R&D program, funds have been requested for covering the cost of these Chinese GEM foils as well as for the fabrication of test modules.

3. ***Recommendation 13:*** **Investigate the schedule risk when GEM foils are not produced in a timely way and continue to pursue Tech--Etch as a potential supplier for the foils.**

   The current plan for SoLID calls for approximately 400 GEM foils. In the event the CIAE group is unable to meet the GEM foil production goals, the backup option is purchasing the required number of foils from CERN. The estimated cost of purchasing all 400 SoLID GEM foils from CERN will be approximately $ 650 k

   The CERN workshop has demonstrated the capability to produce the largest size GEM foils (113 cm x 44 cm) needed for SoLID. In fact, the UVa group recently used 123 cm x 55 cm GEM foils produced at CERN to build two large area GEM detectors; these detectors were successfully used for Jefferson Lab PRad experiment. Furthermore, CERN has the production capacity to deliver large orders of GEM foils in a timely manner. Over the last two years the CERN workshop produced and delivered approximately 140 large area GEM foils to UVa for SBS and PRad GEM modules; these foils were of high quality with about 90% of the foils passing the acceptance criteria. The manager of the CERN GEM workshop, Rui De Oliveira, has indicated that they have the capacity to deliver the required number of GEM foils for SoLID and with an order to produce the required number of foils they will hire the needed technicians to deliver the order in a timely manner.

While the R&D to produce large area single mask GEM foils has been suspended for the moment at Tech-Etch due to lack of large orders for such foils, Tech-Etch has indicated that in the event they receive a firm order for a large GEM production, they will be able to commit the resources for the required R&D and production.

Given these two backup options, the schedule risk due to a delay in Chinese GEM foils fabrication schedule will be rather low.

4. ***Recommendation 14:*** **The calorimeter group is encouraged to contact other groups (ALICE, LHCb and possibly CMS) to understand the detector design choices these groups have made and resources needed for construction.**

   We have contacted several groups, including Wayne State U. (ATLAS calorimeter), the Central China Normal University (CCNU, ALICE calorimeter), the UVa HEP group and the University of Iowa groups (CMS calorimeter upgrade), and we have had email contact also with the LHCb group from the beginning of the ECal planning. A short summary on what we have learned, both in the choice of material and the assembling/manufacturing procedure, is provided below. Details on the resources needed for construction and what we have learned about SiPMs are provided in Appendix B.

   Both ATLAS and ALICE calorimeters are based on the sampling or shashlyk technique and thus very similar to the shower portion of the calorimeter needed by SoLID. The choice of material includes the standard polysterene scintillators, lead absorbers, WLS fibers, and reflective layers. The main difference between SoLID and ATLAS or ALICE is on the layer thickness which is set by the required PID performance. For the shashlyk layer thickness, we have carried out extensive simulations and we have settled on alternating 1.5-mm thick scintillator and 0.5-mm thick lead layers. The total number of layers is determined by the total radiation length needed, and consists of 194 layers each of scintillator and lead for the SoLID calorimeter.

   The choice of the reflective layer differ among experiments and requires careful evaluation: ALICE used bond paper and ATLAS/LHCb used Tyvek sheets. For SoLID, so far we have tested the effect of printer paper, Tyvek, and spray-painting and mylar. The test is still ongoing and eventually the material for the reflective layer will be chosen based on friction, reflectivity, and the ease in manufacturing.

   Two Chinese collaborations (Shandong U. -SDU and Tsinghua U. -THU) have joined SoLID after the Director's review. They are in close communication with the CCNU group who participated in the ALICE calorimeter assembling. Both groups have visited the CCNU lab to learn details of their experience with the ALICE calorimeter assembling. In addition, the CCNU group is also considering joining the SoLID collaboration and if that happens, it will be of a great help to the SoLID calorimeter work.

   The CMS calorimeter upgrade will utilize LYSO crystals and the module size are very small. We learned from their design and experience, but it is less relevant to SoLID calorimeter than ALICE or ATLAS.

   We are also studying the choice of the light readout for the calorimeter and the SPD. So far our choices are regular PMTs for the calorimeter shower modules, multi-anode PMTs for the Preshower modules, and regular PMTs for the Shower modules. Another possible option is to use SiPMs, which have been widely used at the LHC as well as Hall D of JLab. A long summary of our learning on the SiPM readout is given in Appendix B. Our current conclusion is that using SiPM is possible for SoLID, but with additional complications. With the high background rate of SoLID, extensive cooling of SiPM, possibly to -70 °C, will be required to reduce the dark current to an acceptable level. Therefore at the moment our top choices are still PMTs as described above. On the other hand, this requires the use of clear fibers to guide the scintillating light outside of the field region of SoLID for reading out by PMTs. Once we have completed our prototype pre-R&D, the decision may still change depending on the actual light yield of the prototype. For example if the light yield is too low, we may need to eliminate the use of clear fibers and consider using SiPMs.

5. **Update on heavy gas Cherenkov**

   This is not a recommendation, but represents progress made by the collaboration. After the review, Prof. Garth Huber's group from University of Regina in Canada joined the HGC effort. We have successfully obtained total R&D funding about C$100k from the Canada Foundation for Innovation (CFI), in March 2016, and the Fedoruk Centre, in May 2016.

3.3 Magnets

1. ***Recommendation 18:*** **The Committee strongly recommends testing the CLEO magnet coils (cold test), power supply and controls, before installation in Hall A.**

   Jefferson Lab will develop a cold test requirements document and implementation plan prior to installing the magnet in Hall A. The cold test will be done without the iron yoke and thus at reduced operating parameters.

2. ***Recommendation 19:*** **A new magnet power supply should be included in the total cost Of SoLID**

   A new magnet power supply cost has been added to the SoLID costs. Cost basis is from recent purchases.

3. ***Recommendation 20:*** **Evaluate the schedule impact of mapping the magnetic field in situ in Hall A.**

   Mapping the magnetic field and evaluating the data will require additional 4-6 weeks in schedule with use of 2 technicians and 1 scientist/engineer for the duration. Additional funding will be required for the mapping apparatus, $200k.

4. ***Recommendation 33:*** **We strongly recommend tests at JLab of the CLEOII magnet coils (cold test), ideally with the new power supply and controls, before Installation into the hall.**

   Scheduling of the SoLID experiments will allow 1 year prior to installation for testing of the magnet.

5. ***Recommendation 31:*** **A cost benefit analysis for any systems being reused should be carried out, including the magnet power supply.**

   We have included the cost for new power supply, controls, transfer lines and supports. The only reuse will be some magnet yoke steel and the cryostat.

3.4 Slow Control

1. ***Recommendation 21:*** **The plans for the High Level Trigger and the needs for slow control need to be worked out in detail and the implications for resources need to be evaluated.**

   The plan for the High Level Trigger is included in the DAQ section

   Slow Controls typically covers the "infrastructure support" systems and logging for the detector package as a whole. This includes real-time controls and status monitoring of power, vacuum, temperatures, etc., in addition to integrated safety interlocks and alarm functions. Typical measurement and response times for such systems are on the order of a 100s of milliseconds to seconds. More rapid response times are also available if needed. Common examples of slow controls involve the high- and low-voltage power supplies for all detector apparatuses, gas composition and flow regulation, control of gain-monitoring systems, etc.

This section *excludes* any discussion of slow controls for the target and solenoid magnet. Slow controls for those systems will be designed and implemented by their respective working groups. The systems covered here involve only the SoLID detector subsystems.

Due to the obvious interdependence between the hardware and the software used to control it, details of several slow control components will need to wait until the hardware design is better developed (*eg.* gas systems). We will give an overview of some baseline requirements and expectations that the Collaboration will abide by to ensure slow controls development and implementation will proceed smoothly.

It is understood that any fast interlocks (*i.e.* millisec level or faster) that cross system boundaries need to be identified at the design stage. Examples may include tripping high-voltage if the gas flow is interrupted for the GEM system, disabling the flammable gas flows in the event of a fire alarm, etc.

(a) **General Requirements** The Collaboration agrees that all components must be able to interface with the EPICS (Experimental Physics and Industrial Control System) environment already present at Jefferson Lab. This imposes a common mid-level API for inter-system communication and allows the systems to take advantage of the well supported EPICS infrastructure at JLab. This includes local expert support from other experimental Halls (particularly Halls B & D), and the Accelerator Division for any necessary PLC, software and/or hardware IOC development, as well as taking advantage of JLab's EPICS data archiver "MYA".

(b) **Frontend GUIs** The graphical interface employed for all systems is expected to be based on the Control Systems Studio (CSS) environment. This is an Eclipse-based toolkit that is slowly replacing the legacy EDM/MEDM GUIs developed during JLab's 6 GeV period. Hall D and Hall B already make extensive use of the CSS toolkit, and Hall C will be migrating its legacy M/EDM GUIs as time permits.

    The BEAST alarm handler, part of the CSS system, will be used to monitor EPICS variables and alert shift crew and/or external experts of problems.

    Systems that require lower-latency response times than softIOCs and EPICS polling systems can provide will investigate the CompactRIO (cRIO) standard successfully used in Halls B & D.

    The Hall B slow controls development experience, in particular, has been well documented by those involved and will provide an excellent local repository of interface code and management processes that SoLID can leverage.

(c) **High/Low Voltage Controls** High Voltage hardware should be standardized as much as possible. CAEN and Wiener systems are both in use as JLab. They both come with integrated EPICS support and pre-existing software support on-site. Detector, sub-detector, and individual channel control and monitoring will be provided. Legacy LeCroy HV systems will *not* be supported.

(d) **DAQ Crate Control** It is desired to have realtime monitoring of VME and other data acquisition crate power systems and temperatures. All DAQ crates are expected to provide an integrated ethernet interface and EPICS support. Examples of such hardware include the Wiener 60xx series in common use across JLab.

(e) **Gas Systems Requirements** In addition to the necessary EPICS interface, the Collaboration agrees that the various gas subsystems (Cerenkovs, GEMs, MRPC) will standardize any hardware that requires software support. This includes items such as mass flow controllers (MFCs) and hardware process controllers, etc. This will allow for a common spares inventory and simplify control software development and maintenance.

(f) **Detector Systems** The following list runs through the various sub-detectors and summarizes the minimal slow controls involved.

- **EC**: HV control and monitoring.
- **FA/LASPD**: HV control and monitoring.
- **GEM Tracking**: HV/LV control and monitoring. The non-recirculating gas system will use Ar/CO_2 at STP and will employ a basic gas mixer system with flow monitoring and control.
- **LGC**: HV control and monitoring. The CO_2 gas employed operates at STP and will be served by a simple non-recirculating "flow-through" system.
- **HGC**: HV control and monitoring. The C_4F_{10} gas employed is expensive and used in large quantities. Such a system will require a somewhat sophisticated recapture/purification/recirculation infrastructure involving PLC/IOC controls that remain to be designed.
- **MRPC**: HV/LV control and monitoring. The MRPC gas system employs a 5% SF_6 + 90% R134 + 5% Isobutane mix that will likely require a recapture/recirculation infrastructure also involving a PLC/IOC system. This is still to be designed.

In addition to the above items, gain-monitoring systems have been discussed that would also require some nominal controls. It is not expected that such systems would be a significant burden.

(g) **Rough Cost / Labor Estimate**

Based on discussions with the Hall B Slow Controls support group we estimate a 1–1.5 FTE labor requirement to implement the slow controls for SoLID. This assumes a relatively small, dedicated Slow Controls group of 2 people employed full time that are have experience with the CSS system and underlying hardware. If "green" staff are brought on, the estimate should be expanded to 1.5–2 FTE. (Please note that the design, review, and installation costs of the associated hardware are *not* included here. This just covers the software interface implementation.)

3.5 General/Integration/Dependencies

1. ***Recommendation 23:*** **Closer communication with the other JLab experiments and the JLab computing center is strongly encouraged.**

   We have been in active communication with the JLab computer center regarding future computing needs for SoLID. Based on current trends, handling of data volumes at the expected scale of SoLID, 5–10 TB/year, is already manageable at JLab today, at least for two halls running simultaneously, and will likely be routine by the time SoLID runs.

   We are studying the existing JLab data analysis workflow management tools, SWIF [32], for SoLID computing. We also expect to learn much from the data handling and software experiences of other JLab halls. Substantial data for GlueX have begun to arrive in 2016. CLAS12 is expected to go into production mode in 2018. Further, the Hall A SBS program, which will also produce multi-PB data sets, will commence in 2019. The experiences of these groups, as they emerge, will inform future decisions we may have to make for SoLID software development.

   In the long run, it would likely be beneficial if SoLID software supported distributed or grid computing. We will keep this option in mind. Any advanced data processing capabilities would be developed in close collaboration with the computer center and the other halls, who are already exploring massively parallel approaches.

2. ***Recommendation 27:* Compare the resource levels you have assumed in some key areas (particularly in software, data acquisition and project management) to make sure the estimates align with other similar projects or there is a good reason they do not.**

   (a) Software

   A preliminary assessment of the effort required to carry out all SoLID offline computing-related tasks yields approximately 586 FTE-weeks. With contingency and overhead, explained below, this number increases to a total of 976 FTE-weeks, or about 22 FTE-years, assuming 44 work weeks per year per developer. A spreadsheet with this calculation can be found online [33].

   This estimate covers simulations, reconstruction, calibrations and alignment, data challenges, production and analysis, where "analysis" represents a baseline set of replay configurations (PVDIS, SIDIS-^{3}He, SIDIS-p, J/ψ), data quality checks, plots, production output variables, corrections, cuts and histograms. Not included in the estimate are DAQ software (firmware, front-end and trigger programming, run control etc.), online analysis and monitoring, and the intellectual effort to understand and interpret the results of the simulations and experimental data analysis. The latter is excluded because it is largely an open-ended creative process.

   For each covered area, we have counted the work required to develop the actual software, test the code and validate results, coordinate efforts (meetings, wikis and similar), write and generate user and developer-level documentation, and to configure and monitor offline computing operations (simulation and production passes, data challenges). The time estimates at this point are subjective best guesses, based on our experience with similar efforts. They assume expert developers who are fully familiar with all task requirements, programming languages, framework paradigms, library APIs, tools etc. This yields a sum of 586 FTE-weeks. A contingency of 25% is added to this total to account for missed tasks, time overruns, etc. Furthermore, since developers are never the ideal experts assumed above, we estimated an average "developer efficiency" of 75%, *i.e.* on average each developer is assumed to spend and extra 1/3 of the estimated task time on preparations such as collecting requirements and learning. A more precise estimate of this efficiency factor would have to be made on a task-by-task basis and under consideration of the personnel assignment to the task, which is incomplete at this time. With contingency and overhead, the total effort estimate is 976 FTE-weeks.

   In comparison to a similar project, GlueX have estimated their offline computing effort at 1866 FTE-weeks [34]. (This number excludes 110 FTE-weeks that GlueX allocate for "online" tasks (beamline commissioning and monitoring), which is outside of our scope.) It is unclear if the GlueX numbers include developer overhead, *i.e.* the time spent on task preparations and learning discussed above, but given the generous allowances made generally, we assume that they do.

   The offline computing manpower requirements estimated by GlueX and SoLID are summarized in Table 12. To make the GlueX estimates comparable to ours, certain numbers from the GlueX spreadsheet [34] were combined. Please see Appendix D for details.

   The SoLID simulation effort is estimated higher than in GlueX, possibly because the GlueX makes approximate estimates of time already spent on finished work, while SoLID is using a detailed breakdown of anticipated future tasks. Also, SoLID plans to integrate simulations into the overall software framework, while GlueX's simulations are standalone.

   The estimated SoLID effort for reconstruction is significantly lower than GlueX's. The difference is to a great extent due to the fact that SoLID proposes to adopt an existing framework rather than write a new one and that SoLID anticipates to reuse well-tested existing algorithms for standard tasks such as track fitting, *e.g.* from the `genfit` library, and calorimeter cluster reconstruction. Documentation effort is reduced in SoLID's case also due to the already very good user-level documentation of the

Task Group	Labor estimate (FTE-weeks) GlueX [34]	SoLID [33]	Main reasons for difference (see text)
Simulations	192	240	Simulations to be integrated into framework.
Reconstruction	787	355	Adoption of existing framework. Re-use of algorithms. Smaller number of subsystems.
Calibration	275	103	Smaller number of subsystems.
Production	275	155	Standard data format. Re-use of workflow tools.
Analysis	275	100	No PWA analysis and no grid implementation of analysis.
Data Challenges	62	23	No PWA data challenge.
Totals	1866	976	

Table 12: Offline computing manpower requirements estimated by SoLID and GlueX

proposed *art* framework. Furthermore, the difference can be attributed to the smaller number of detector subsystems in SoLID than in GlueX, 5 vs. 7, the lower complexity of these systems (one vs. two tracker systems, Cherenkovs vs. multiple calorimeter systems), and the more challenging multi-particle final state reconstruction and PID in GlueX. Lastly, a SoLID event viewer can be readily assembled from an existing MC geometry with minimal effort (days vs. months) using ROOT's `TEve` framework within *art*, as demonstrated by *art* example code.

Calibration effort for SoLID is also estimated lower than in GlueX, again in part due to fewer main detector systems, smaller channel counts and easier calibration of GEMs vs. drift chambers in SoLID.

The lower estimated time for Production (DST generation) is attributable to the fact that we do not anticipate spending time on developing and maintaining a custom file format (it is defined by *art*) and expect to be able to reuse the job control and workflow tools currently under development for GlueX and CLAS12.

Finally, SoLID estimates much lower analysis effort than GlueX because no kinematic fitting and PWA analysis is foreseen for SoLID nor is SoLID planning a grid implementation at this point as the JLab compute farm resources are expected to be sufficient for us. For similar reasons, our estimate for data challenges is lower.

(b) Data Acquisiton

With 12 GeV and SBS project upgrade winding down, SoLID will have more available support from Fast Electron, DAQ and IT groups and will also benefit of the Hall B and Hall D experiences running at 12 GeV. For more information, please refer to the DAQ section.

4 Summary

We have completed studies to address the recommendations necessary for the anticipated DOE Science Review. The acceptances, efficiencies and systematic uncertainties were simulated for each of the three core measurements (SIDIS, PVDIS and J/ψ production). For PVDIS, the viability of the calibration procedure to determine Q2 was studied including realistic misalignments. The design of the baffles was re-examined, including the choice of materials. For J/psi, bin migration effects and the signal to background trigger rates were simulated. For SIDIS, careful studies were performed to show the impact of SoLID compared to the world data, including optimistically projected JLab12 data from CLAS12 and SBS programs. Examples of physics reach that were chosen are the transversity/tensor charge and the Sivers distribution function.

The possibility of Kaon identification was studied as recommended by the committee. A cost effective option for kaon identification by using improved TOF with a next generation MRPC was chosen as an R&D project item for this purpose. A joint effort with other US projects (sPHENIX/EIC) and with Chinese groups (and seeking Chinese funding) is being pursued.

An extensive GPD program is being studied and partly proposed by both original SoLID collaboration members and by new groups joining SoLID collaboration, including new international collaborators (French and Canadian groups).

Realistic simulations, tracking and DAQ system developments showed that the scientific goals could be realized with the proposed instrumentation. Effect of the radiation damage was carefully evaluated. Meticulous magnet field modeling confirmed that the forces are tolerable and the fringe field at the polarized target location can be controlled to the desired level. Significant progress has also been made in the development of a full simulation and software framework.

In addition, we have also worked on most of the other recommendations, including the development of the GEM foil production in China and the risk factor, the communication with ”expert” groups in calorimeter design and R&D, the stability test of the conductivity of the MRPC glass. The CLEO-II magnet is being transported to JLab. The plan for testing, possibly a new power supply with possible in-situ mapping have all been studied. An initial study of the slow control system has been performed. A pre-R&D plan was developed and is being discussed with the JLab management and DOE. Pre-R&D activities for the detector subsystems are continuing. While the addition of pre-R&D funding from DOE has not yet realized due to budget uncertainty, we continue to have R&D support from international collaborations (China and Canada).

An update on the project cost and project management plan is not included in this reply. However, we intend to have it included in the update to the pCDR (to become a draft MIE) in a few months.

Appendix A Additional Information about Radiation

1. **(finding) While the effects of radiation on the front-end electronics has been examined, the effect on subsequent electronics, that may not be in the shielded hut appears to be an open question.**

   A more detailed study of the integrated radiation in the Hall with the SoLID spectrometer has been performed. In order to better estimate possible reflection and geometrical effects in mapping the radiation in different parts of the Hall the design was also updated to the more current position of the SoLID spectrometer in the Hall. High level of radiation that could start to affect commercial electronics is expected just around the beam-line, in the section between the SoLID magnet and the beam dump. At this moment placement of any electronics in this area is not planned. This is mainly due to the particular case of the SoLID detector, where the main part of the fluxes is focused inside the magnet, giving a strong primary shield to the Hall’s electronics.

2. **(finding) Detector designs should also consider the impact of activation and the ultimate disposal of radioactive material with the goal of making it possible to easily separate and dispose of the most active material. Lead is a hazardous material, activated lead is expensive to dispose of and lead may have other unintended consequences due to impurities in it.**

   Activation studies where performed and special attention was given to the activation induced on the first Lead Baffle, since for the geometry of the PVDIS experiment it is the one subject to the highest flux from the target (roughly 50% of the total flux in the same polar angle range), with also a high flux of neutrons in this area. For these reasons this baffle is the one that poses the highest impact for activation and ultimate disposal. The activation of the Lead baffle has been studied and possible shielding has been investigated. At first approximation a post-beam shielding with thickness of 8cm of Lead will be required in order to reduce the dose rate from this baffle to levels $<$ 10mrem/h (on the surface in contact of the shielding material). This thickness will not add much material to the existing baffle structure, since the first layer, closer to the target, is also the lighter one. When the final selection for the baffle material is determined the shielding material choice could change a little in order to better handle the different decay rates production to be shielded (with possible more attention needed in the secondary production of bremsstrahlung photons produced in beta and alpha decay).

3. **(finding) Significant radiation studies need to be completed, including a list of the main components and their activation levels based on several realistic running scenarios. These calculations will likely impact the design of support structures and how components are removed for the next experiment.**

   Further investigation on activation of different components and possible shielding configuration are being investigated at the moment. Priority has been given to the first layer of the baffle design for the PVDIS case, for the difficulty placed the geometry and the level of activation reached. Other materials, like for example the different SIDIS collimators will be outside the magnet, giving easier access for disposal and configuration change.

4. **(finding) Calculations of absorbed dose to various electronics under various realistic running scenarios and other potentially radiation sensitive components need to be completed and compared to component lifetimes and failure modes. For particularly sensitive electronics, beam tests might be appropriate if data are not available from other experiments.**

   At this level, nominal radiation accumulation doses for Semiconductors is used as estimate for accumulated impact of radiation on electronics. It is also true that similar electronics will undergo testing and running at comparable radiation levels at Thomas Jefferson Laboratory in previous experiments, giving us direct access to the different scenarios of the planned technology for SoLID.

More details and plots on the studies can be found in the talk
http://hallaweb.jlab.org/12GeV/SoLID/meeting_coll/2016_12/zana_solid_december2016.pdf

Appendix B Additional Information on the Calorimeter and SPD Study

In this section we provide more details in responding to the comment:

Recommendation 14: **The calorimeter group is encouraged to contact other groups (ALICE, LHCb and possibly CMS) to understand the detector design choices these groups have made and resources needed for construction.**

1. Our communication with Wayne State University (WSU): We learned a great detail about the ALICE module construction work from Dr. Tom Cormier (formerly at WSU, now at ORNL):

   Overview on time span and manpower: WSU built 16,000 modules for ATLAS, forming 4,000 towers. The construction took 3 years and involved ten technicians at the peak time. (Students are not a good options here because full-scale construction required full-time technicians). The biggest help Tom had was one formerly Russian IHEP person.

   Material: Scintillators were manufactured in Russia. All scintillators were made with the same size using injection molding. The projection shape of the ALICE module was accomplished by cutting the scintillators down to 76 different sizes at WSU. Lead sheets were from Vulcon GMS, produced directly at 76 sizes (hole positions remained the same, greatly reducing the cost). Fiber mirrors were attached after inserting the fibers into the module. Fiber ends were diamond-polished and then put into a sputtering machine for sputtering with aluminum. The finish was then ”rugged” to avoid peeling. For mirror-coating of the fibers, thermal evaporation of aluminum could not be used because it’s not structurally solid enough. Other options may work, such as eliminating the mirror completely or attaching a single mirror at the end of the module, but both will require R&D.

Engineering support was partly from LBNL and partly from other collaborators. Modules were supported only from the back because the shashlyk modules were within the solenoid, leaving no room in the front of the module for the support structure.

Commissioning and calibration: All modules were cosmic-tested to provide the starting HV, which turned out to be good to (2-3)%. The π^0 peak appeared right away without tuning.

Current status of the WSU lab: The WSU calorimeter detector lab was de-commissioned many yearse ago. Equipment was either recycled or disassembled. The only machine that could be loaned is the aluminum sputtering machine. But at our last email communication the WSU group did not know who owns the sputtering machine and could not start the loaning process. We will follow up on this when it is necessary to borrow the machine for mass production.

2. Communication with U. of Iowa:

   We had email communication with U. of Iowa including their engineer who is currently involved in the CMS calorimeter upgrade design. However, the SoLID ECal requirement and characteristics are very different from the CMS, and the chance of learning and mutual assistance is limited.

3. On the use of SiPMs: We have studied four other experiments or collaborations choices of the SiPM. These are summarized below. The most relevant are the LHCb tracker upgrade, the JLab’s EIC detector R&D effort, and the CMS calorimeter upgrade. These are summarized below:

   1) The LHCb tracker upgrade[35] (section 3.5) provided possibly the latest development on SiPM and its radiation damage. The radiation tests were done in the LHCb cavern, the neutron irradiation facility at Ljubljana, and with a Pu-Be neutron source. The neutron energy spectrum was simulated to mimic the LHCb running condition, with a peak at 2 MeV.

   - The noise of SiPM comes from: dark current, pixel cross-talk, and after pulsing. The dark count rate (DCR, measured above 0.5 photoelectron) increases strongly after irradiation and is the only radiation damage observed at the level of irradiation required for LHCb. The cross-talk and after-pulsing depend strongly on the detector technology. After-pulsing only occurs after < 10 ns (pixel recovery time) and is significantly reduced in the latest technology and contributes only a minor fraction to the total noise. Cross-talking can be reduced for new detectors with have so-called ”trenches” between pixels.
   - Both Hamamatsu and KEKEK have developed customized detectors for LHCb’s sci-fi tracker: trenched, with specific light yield, active area, area efficiency, etc, to fit the SciFi.
   - The increase of the DCR was found to depend linearly on the total fluence. For Hamamatsu the ”no trench” multi-channel arrays (Fig.3.23 left of [35]), DCR reaches an increase of factor 20 at 6×10^{11} neq/cm^2.
   - Effect of cooling (Fig.3.23 right of [35]): cooling by each 10 °C reduces DCR by factor two. There data were given for fully annealed detectors after slow annealing one week at +40 °C.

- Comparison between no annealing with with annealing (Fig.3.24 left of [35]): DCR with no annealing is about twice the current with slow annealing (one week at +40 °C), and with fast annealing (80 minutes at +80 °C) is about mid-way between the two. The effect of annealing is the same for new and standard technology devices.
- Comparison between new and standard technology (Fig.3.24 right of [35]): At -40 °C, trenched detectors have about half DCR of standard detectors.
- LHCb needs to run at -40 °C for the SiPM to last the whole duration, at a neutron background of close to $1 \times 10^{12}/\ \mathrm{cm}^2$. The background for SoLID operation is higher. If the background is at 2×10^{12} neq/cm^2, it will require cooling the SiPMs to -50 °C, or -60 °C at 4×10^{12} neq/cm^2, -70 °C at 8×10^{12} neq/cm^2, -80 °C at 1.6×10^{13} neq/cm^2, etc. The lastest SoLID simulation shows the background for the SPDs will likely require cooling of the SiPM to -70 °C o -80 °C. This can be done but will add complication to the engineering design. Also, note that the detector unit must be designed to increase the temperature to 40 °C for slow annealing or 80 °C for fast annealing. On the other hand, if the light yield of the module is too low, the use of SiPM may be required because it will eliminate the need of using clear fibers to guide the light outside of the solenoid field region.

2) The EIC detector R&D calorimeter consortium has useful information on the SiPM radiation hardness as well, although the radiation dose for the test was lower than that of LHCb tracker upgrade. According to Craig Woody's talk on EIC eRD1, Jan 2015 [36]:

- SiPMs were tested up to 0.3×10^9 n/cm^2 using 14 MeV neutrons at BNL. At this background dose, the DCR increases by factor 10-50 (10-20 for Hamamatsu, 45 for SensL, 45-50 for KETEK). The DCR increase is pixelsize-dependent, with the Hamamatsu 15-μm SiPM shows the least increase.
- SiPMs were tested up to 7×10^{10} n/cm^2 using > 6 MeV neutrons at LANCE. At this background dose, the DCR increases by 100-1000, can reach milli-Amp, also observed some loss of pixels.

3) We have also gathered information from Carl Zorn at JLab: "The estimated high energy fluence for Hall D is 3×10^8 n/cm^2 for 1-MeV-equivalent neutrons. At this level, the noise would rise to unacceptable levels within 3-4 years (dark rate increases by a factor of more than 10). Cooling the SiPMs to 5 °C (reduces DCR by 3) during operation will extend the SiPM lifetime to match the full 10 years running of GlueX.

4) We have talked to UVa's Prof. Brad Cox on the CMS calorimeter upgrade: the CMS upgrade will use W(inactive) +LSO (active). The modules are of very small size (about the size of a thumb). The advantage of the small size is the small attenuation in the optical elements, so with radiation damage the damage in the light signal is not severe. For readout, the background next to the calorimeter is about $1 \times 10^{14-15}$ but the SiPMs are located far away, where the background is about 1×10^{12}. The CMS group is also studying galium-based PM (larger gap than silicon).

Overall, the LHCb tracker upgrade's study is the most relevant to SoLID. And based on their results, we concluded that the use of SiPM for SoLID is possible with cooling down to -80 °C. This may become necessary if, once we carry out the pre-R&D test and prototyping of the calorimeter, the light yield is found to be low. For low light yield, the use of clear fibers to guide the light out of the field region for reading out by regular PMTs will not be feasible, and we may be required to use SiPMS to read the light signal directly behind the shashlyk modules.

Appendix C Event Generator

All of SoLID experiments require high luminosity. Their background and trigger rates are high. It is important to use realistic event generators as inputs to the simulation program to study them. For low energy electrons and photons, we study them by applying an electron beam on various targets directly in our Geant4 based simulation. For scattered high energy electrons, we use a generator according to CTEQ6 parton distribution fits. For hadrons, we used the Wiser fit [37, 38] based generator which often overestimates the cross sections at JLab beam energies. Now we use a new one based on JLab Hall D generator [39].

The Hall D photo-production generator uses various experimental data to generate photo-production cross sections on a proton target for photon energies below 3 GeV [40, 41]. It uses modified version of PYTHIA to generate cross sections of photo-production for photon energies above 3 GeV [40, 41]. The hall D generator is only a photo-production event generator. SoLID experiment requires electro-production generator. Hadron production in electron scattering on a nucleon target can originate either from real bremsstrahlung photon radiated in the target or from virtual photon interaction with the nucleons. The virtual contribution is approximated by Equivalent Photon Approximation (EPA) [42]. The Bremsstrahlung contribution is implemented following PDG-2012 [43, 44]. A more detailed overview of the hadron generators used for SoLID simulation is available from [39].

Appendix D Comparison of Software Manpower Estimates

For the comparison of software manpower estimates in Section 3.5 item 2(a), we combined certain line items of the GlueX offline computing effort document [34] as follows:

- The quoted “Simulations” effort includes “Geant3 simulation”, “Geant4 simulation” plus 1/4 of “Integration/QC” and “Coordination” (total of 16.5 FTE-weeks) from the Miscellaneous section.
- “Reconstruction” counts all of “Reconstruction” plus “DAQ Translation”, “Event Viewer”, “Documentation”, “Integration of Slow Controls”, 1/2 of “Recon/analysis code Q/A” and again 16.5 FTE-weeks for integration and coordination.
- “Calibration” is taken as the total of “Calibrations” plus 1/4 of “Integration/QC” (11 FTE-weeks).
- “Production” comprises “DST Generation”, “MC Studies for Detector Optimization” and again 11 FTE-weeks of “Integration/QC”.
- “Analysis” takes all of “Analysis” less 1/2 of “Recon/analysis code Q/A” already counted under “Reconstruction” plus 1/2 of “Coordination”.
- The “Data Challenges” estimate is taken as is.

In doing so, we hope to make the top-level categories approximately comparable.

Appendix E Summary of Recommendations from the 2015 SoLID Director’s Review

The SoLID Director’s Review was held at JLab on 23-24 February 2015. The committee consisted of: Paul Brindza (JLab), Marcel Demarteau (ANL), Nancy Grossman (ANL), David Mack (JLab), Richard Majka (Yale), Naomi Makins (UIUC), Curtis Meyer (CMU)(chair), Ernest Sichtermann (LBL), William Wisniewski (SLAC) and Bolek Wyslouch (MIT). A summary of all recommendations made by the committee is provided below, with each recommendation ordered by number to improve readability.

E.1 On the physics relevance and risks

On the completeness and credibility of the discussion of the experimental reach, including statistical, systematic and theoretical uncertainties

Recommendation 1: End-to-end simulations with realistic subsystem responses and material budgets, and complete track finding and reconstruction should be developed.

Recommendation 2: Acceptances, efficiencies, and systematic uncertainties should be simulated for each of the core measurements.

Recommendation 3: For the PVDIS measurements, the viability of the elastic scattering calibration procedure, to determine absolute Q^2 should be demonstrated by simulations for similar scattering angles to those probed in DIS, and with realistic misalignments.

Recommendation 4: Bin migration effects should be simulated for the measurements of the sharply rising J/ψ production cross section near threshold.

On the ability to handle the desired luminosities and backgrounds including impacts on both the apparatus and the beam line downstream of the target

Recommendation 5: The signal and background trigger rates should be simulated for the J/ψ measurements.

Recommendation 6: The dead-time(s) in the DAQ chain should be modeled.

Recommendation 7: The development of a simulation framework with realistic reconstruction and analysis should be pursued with high priority and increased resources.

On the implications for the relevance of the physics results in the context of possibly competing experiments at both Jefferson Lab and internationally.

Recommendation 8: Better comparisons with the expected results on programs such as SBS and particularly CLAS12 are needed to clarify the need for the SoLID SIDIS program. Crisp demonstrations of the improvements possible with SoLID should be developed.

Recommendation 9: The SoLID Collaboration should investigate the possibility of kaon identification, especially given their high luminosity.

Recommendation 10: The SoLID collaboration should investigate the feasibility of carrying out a competitive GPD program. Such a program would seem particularly well suited to their open geometry and high luminosity. If SoLIDs luminosity is sufficiently high to permit a program of precise Double Deeply Virtual Compton Scattering (DDVCS) measurements, it would make a groundbreaking contribution to GPD studies.

E.2 On the viability of approach and the experimental technique

On any R&D required to meet the technical challenges of the experiment

Recommendation 11: Develop an overall R&D plan for the project with a timeline.

Recommendation 12: Close interaction between the US and Chinese groups in the development of GEM foils to assure good quality control is highly recommended.

Recommendation 13: Investigate the schedule risk when GEM foils are not produced in a timely way and continue to pursue Tech-Etch as a potential supplier for the foils.

Recommendation 14: The calorimeter group is encouraged to contact other groups (ALICE, LHCb SiPMs and possibly CMS) to understand the detector design choices these groups have made and resources needed for construction.

Recommendation 15: The stability tests of the conductivity of the glass for the mRPCs should be extended for a much longer period and the risk associated with the R&D needs to be identified.

Recommendation 16: The collaboration is strongly encouraged to develop an end-to-end realistic simulation and reconstruction to further optimize cost and physics reach and derive clear performance requirements for the individual subdetectors.
Recommendation 17: The collaboration is encouraged to explore the power of extended kaon identification (through Cherenkov or TOF).

On the proposed magnet concept and choice, including magnet configuration modifications (if any), magnet cool-down and infrastructure requirements
Recommendation 18: The Committee strongly recommends testing the CLEO magnet coils (cold test), power supply and controls, before installation in Hall A.
Recommendation 19: A new magnet power supply should be included in the total cost of SoLID.
Recommendation 20: Evaluate the schedule impact of mapping the magnetic field in situ in Hall A.

On the proposed detector concept and associated electronics and data acquisition
Recommendation 21: The plans for the High Level Trigger and the needs for slow control need to be worked out in detail and the implications for resources need to be evaluated.
Recommendation 22: The implications of the need for these resources in the context of availability of resources at the laboratory need to be understood.
Recommendation 23: Closer communication with the other JLab experiments and the JLab computing center is strongly encouraged.
Recommendation 24: Having a functional simulation and reconstruction routines as soon as possible should be a high priority in the software effort. Such software will pay off many times over in experimental design and avoiding pitfalls.

On the beam line design, including collimation and shielding
Recommendation 25: Complete radiation calculations to determine activation and absorbed dose on components of concern and mitigate as appropriate.
Recommendation 26: It should be confirmed that the baffle design, including the support structure, is optimized for background rejection and signal acceptance. Furthermore the baffle design should minimize generation of secondary backgrounds.

On the cryogenic and polarized target system concepts and integration
No recommendation was presented in the report.

On the beam polarimetry requirements.
No recommendation was presented in the report.

E.3 On the understanding, completeness, and credibility of the resources needed for the SoLID project.

On the experience, expertise and quantity of the scientific and technical manpower for the project
Recommendation 27: Compare the resource levels you have assumed in some key areas (particularly in software, data acquisition and project management) to make sure the estimates align with other similar projects or there is a good reason they do not.
Recommendation 28: Redo the cost estimate using an average cost per type of resource.
Recommendation 29: Create a high level resource loaded schedule to get a more realistic schedule, funding and resource profile. This will also allow JLab to better determine their ability to support the FTE needs.

Recommendation 30: Revisit the comments of the 2012 Internal Review Report in conjunction with the recommendations from this report.

On utilities (power, cabling, LCW, cryogenics) requirements for the project
Recommendation 31: A cost benefit analysis for any systems being reused should be carried out, including the magnet power supply.
Recommendation 32: Appoint a small team to facilitate the integration planning for SoLID.

On requirements from Jefferson Lab on for instance engineering needs, electron beam, polarized source, and cryogenic target requirements
Recommendation 33: We strongly recommend tests at JLab of the CLEOII magnet coils (cold test), ideally with the new power supply and controls, before installation into the hall.
Recommendation 34: An effort should be made to clearly specify resources required from JLab that are not explicitly in the project (effort, non-effort, equipment, building space, etc.).

On general experiment installation and alignment issues, including potential interaction with other Hall A programs and operations
Recommendation 35: The project should develop a preliminary resource loaded schedule for the installation and the corresponding space-management plan for the hall floor.
Recommendation 36: The project should start planning the process of how to change from one SoLID configuration to another in order to better understand the time and effort involved and if there are any potential issues such as radiation levels.

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