PR12-21-006 Reply to Technical and Theory Review

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This document provides answers to technical and theory review comments of PR12-21-006, "Measurement of the Asymmetry $A_d^{e^+e^-}$ between e^+-^2H and e^--^2H Deep Inelastic Scattering Using SoLID and PEPPo at JLab". Some updates since submission will also be provided.

1 Reply to Theory Review Comment

We thank the JLab theory group for providing the brief review. This proposal is not without theoretical challenges, some require long-term collaboration with theory groups and a clear roadmap towards the precision needed to interpret the data. We will provide two related updates in Section 3.3.

2 Reply to Technical Review Comments

Our total beam time request is 104 days. There must be a typo in the Technical Review ("12" is shown as "Days requested for approval").

1. It is not yet known how well the energies of the pair-produced electron and positron beams can be set absolutely, or to one another. The 1E-4 requirement on the beam energies being similar may be challenging to achieve, the impact of the beam energies to the success of the experiment should be considered carefully.

   Answer:

   We have assumed an up to 5E-4 (not 1E-4) on the relative beam difference in the proposal. For known beam energy differences, the effect on the asymmetry can be calculated precisely by taking the cross section difference in DIS cross section between two beam energy values, and thus can be corrected. The impact of the 5E-4 beam energy difference was fully discussed in the proposal.

   Furthermore, we provide in Section 3.2 details on how the beam energy is "set" and new information on the 1×10^{-4} relative precision that *has* been achieved for real-time beam energy monitoring.

2. It will likely take several weeks to switch the accelerator configuration between electron and positron running, possibly resulting the electron and positron runs taking place in different years.

   Answer:

   The current plan for switching between e^- and e^+ runs, which require full reversal of all CEBAF magnets, indeed does not allow a fast switch between the two beam charges. This is not optimal for the proposed measurement, as doing e^- and e^+ runs months apart will make it extremely difficult to track all systematic effects. Instead, we plan to flip between e^- and e^+ runs multiple times, ideally weekly, during the measurement. As an example, the CERN experiment switched beam type every 12 days.

JLab's FFA – Fixed Field Alternating (Gradient) – working group has considered an expensive scheme which would provide simultaneous positron beams to three halls and allow changes from electrons to positrons in about a day. We urge JLab to fully explore this option in addition to less expensive ones that would not allow a fast switch between e^- and e^+ runs.

3. This proposal would utilize the 40 cm long cryotarget (liquid deuterium) proposed for the SoLID suite of experiments. This target will be a substantial, multi-year effort which will also be required for the PVDIS experiment.

   Answer:

   Yes, multi-year effort will be required to develop the target for both PVDIS and the proposed measurement.

4. Although polarized beam is not needed, the Compton polarimeter will be used to measure the (nominally low) beam polarization. Operation of the Compton polarimeter for positrons beams should be straightforward.

   Answer: Yes.

5. The proposal notes that target boiling effects are primarily driven by the raster size and this will be the same between runs. However, there is some evidence that target boiling effects can also depend on the intrinsic beam size. It might be prudent to plan to monitor the beam size at regular intervals to ensure no time dependence in the target boiling effects.

   Answer:

   We will consider frequent "harp scans" to monitor the intrinsic beam size. Additionally, we are considering a method to monitor target density fluctuation real-time by comparing beam monitors before and after the target, see Section 3.1.

6. The proposal assumes that the BCM response can be controlled at the 1% level over long periods (i.e. between the positron and electron run periods). Constraining the time dependence of the BCM response at this level will require regular, rather frequent, BCM calibration measurements. In addition, these measurements will likely require use of the Faraday cup in the injector and will be invasive to the other halls.

   Answer:

   We will consider frequent BCM calibrations, possibly carried out opportunistically during the run or as needed. We note that while we have assumed up to 1% beam intensity difference between e^+ and e^- runs, the proposed analysis method using a multi-parameter fit will separate the luminosity difference from other causes, and the method works even if the exact size of the luminosity difference is above 1% (provided it is not too much above).

7. Other possible sources that could change the electron/positron yields in a time dependent way include detector response, acceptance, readout electronics, and beam properties (trajectory and position).

   Answer:

   Beam trajectory and position are monitored real-time using the multiple BPMs in the Hall and its effect can be simulated and corrected. The possible slow drifts in detector response, acceptance, and readout electronics are indeed sources of potential systematic effects. Two such examples are detector PID performance and tracking efficiency. For PID performance, experience using Hall A and C data tell us that it can be studied on a run-to-run basis to high precision, and it should pose less of a problem if the pion contamination is reduced to a negligible level using both Cherenkov and EMCal and if the efficiency can be extracted from data real-time. For tracking efficiency, We have considered a two-prong approach: First we can use multiple detectors or the multiple GEM layers to study the efficiency of each layer. Secondly, we will use artificial input signals (pulsers) to track effects of background rates. In the ideal case, one records all physical particles hitting all the detectors (*e.g* using a streamline DAQ) and study their effects using a combination of simulation and data. Details of such studies can be planned out in advance and tested during SoLID SIDIS and PVDIS running, which will occur before the proposed measurement.

8. The proposal suggests a novel technique to minimize the sensitivity to factors (such as BCM response, beam energy, and detector efficiency) that would impact the relative (global) normalization of the positron and electron data sets. A key assumption is that none of these normalization factors introduce any point-to-point uncertainty (as a function of Q^2) to the asymmetry. The detector efficiency in particular could have acceptance-dependent efficiencies that change with time/run conditions. Even a 0.1% such point-to-point uncertainty have a significant impact on the expected precision.

   Answer:

   In fact, the effect of beam energy difference between e^+ and e^- runs will have a Q^2-dependent effect on the measured asymmetry. Fortunately, this dependence can be calculated precisely if the beam energy difference is known. Similarly, it is prudent to identify, understand, and measure all systematic effects that can introduce kinematic dependence of the asymmetry and correct for them. We have discussed a few such effects in the proposal and our answers above and we welcome everyone to make further suggestions for possible sources.

3 Progress Since May 24th Submission

3.1 Collaboration review and responses

The proposed measurement was presented to the SoLID Collaboration on June 11 and was endorsed by the SoLID Collaboration for conditional approval. The Hall A Collaboration Committee subsequently approved the proposal for Hall A Collaboration status. Report from the SoLID Review Committee is attached. In responding to comments and suggestions from the SoLID review, we have made the following draft plan regarding systematic effects.

- Regarding slow drifts in the detector system and the beam, and their effects on the measurement, we plan to study such effects by using recent or future high-precision PVES experimental data such as PREX-II and MOLLER. The idea is to form PV asymmetry using opposite helicity windows some time apart and compare the results with “ordinary” analysis. A by-product of such work is that one can modify the analysis and study slow drifts in the PV asymmetry itself over a long period of time. The latter can be used to constrain Lorentz violation in the weak vector-boson sector similar to what was done with HERA data [1] and projected for the FCC and LHeC [2], and thus has its own physics value.

- Regarding target density fluctuation (boiling effect), a suggestion was made to place beam monitors after the target and by comparing it with beam monitors before the target, one can track changes in the target density. Similar methods were used in the NPDgamma [3, 4] experiment (for its neutron beam) and it is the primary analysis method of the TRIUMF E497 experiment [5, 6] (for its proton beam). Developing and testing such after-target beam monitors for the electron beam at JLab will require dedicated R&D. While this method (once developed) will not control the target boiling effect to ppm level, it will provide data on the asymmetry that arise from target boiling and can be used to cross check the analysis.

- Regarding magnet repeatability, including mechanical stability under field reversal, we are planning a 3-step approach: First, we will study the field map calculated by Opera and the resulting force on the magnet in order to identify potential motion and improve the magnet support structure. Second, we will map out the SoLID field as soon as possible, reverse the magnet polarity, and repeat the measurement. Third, to account for mechanical motion of the magnet in our field maps, it is likely that we will need to design a laser-based tracking device to determine the relative position of the field mapper with respect to the magnet in the Hall A coordinate system.

3.2 Technical updates on beam energy monitoring

In the proposal we have assumed that each of the e^+ and e^- beam energies can be measured to 5×10^{-4} using existing Hall A beam energy measurement method, and that the relative difference between the two has an uncertainty also up to 5×10^{-4}. As a result, there is a beam energy term to be fitted using data as shown in Eq. (27), and the uncertainty in the fitted $2C_{3u} - C_{3d}$ using the Monte-Carlo fitting method is ±0.053 as shown in Eq. (35) of the proposal.

After discussing with accelerator and beamline experts, we learned that (1) the beam energy can be set at desired values by adjusting the arc dipoles and linacs; (2) the beam energy can be monitored real-time to a relative $(1-2)\times10^{-5}$ (should this be 10^{-4}?? need confirm) precision; and (3) there can be a slow drift (at the time scale of months) in the beam energy at the 10^{-3} level, possibly due to machine lengthening or shortening due to weather or other factors, but this slow drift can be corrected daily (or more frequently if needed). Correcting such drifts requires putting the beam into tune mode (invasive) for 10 minutes. An example of such real-time beam monitoring and long-term drift are given for GlueX (Hall D) Spring 2017 run on slides 3 and 17 of Ref. [7]. On slide 17, the beam energy was observed to fluctuate at ±1 MeV level for a 11.6 GeV beam, i.e. at 1×10^{-4}. (This fluctuation was due to a misbehaving cavity and is not typical in normal operations.)

In short, the beam energy can be monitored to 1×10^{-4} level and slow drifts corrected daily. In Hall A, there are accurately calibrated dipoles (against that ninth dipole used for energy measurement) so using this as a reference we can guarantee that both e^- and e^+ energies are within 1×10^{-4} even months apart [8]. For the proposed measurement, this means we can correct the effect from beam energy shift to the 1×10^{-4} level. At this level, the ΔA_{Eb} term becomes smaller or comparable to the statistical precision of the data and it is no longer possible to fit to this term from data. Instead, we fit data using only p_0 and p_1 terms of Eq. (27) and the resulting uncertainty is smaller. It also means that any Q^2-dependence from uncorrected higher twist or QED higher order effects will be visible in the measured asymmetries, providing a possibility to better constrain these effects.

3.3 Theory updates

At the meantime, theoretical work is ongoing and we list two updates below:

- Regarding Coulomb correction, we have adopted the method of [9] after the proposal submission deadline. Calculation based on this method shows the Coulomb effect would cause an up to 100 ppm asymmetry between e^+ and e^- scattering for our proposed measurement and it has little Q^2-dependence for most of the kinematic coverage where a high statistical precision is expected. Further research in this topic is needed to validate the approach of [9] for DIS with GeV-energy beam. However, if Coulomb effect exhibits little or no Q^2-dependence then our proposed data analysis method will not be affected by it.
- Extensive tests were performed to adapt the Monte Carlo tool of [10] for the fixed-target setting of SoLID.

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