Report on request for full approval of Hall A experiment C121-15-006.

B. Zihlmann (chair), J. Benesch, D. Mack, D. Meekins, S. Stepanyan

January 7, 2019

C12-15-006: Measurement of Tagged Deep Inelastic Scattering (TDIS)

This report will only address the content of the document with the title "*Request for Full Approval of Hall A Experiment C12-15-006*" and does not consider itself "*a laboratory convened rigorous technical review of the resulting optimized design*" as recommended in the PAC43 final report.

Conclusion

The presented new conceptual design of the experiment has a modified detector and target with respect to what has been presented to the PAC. It operates fully at room temperature obviating cryogenic fluids, and uses a multi-TPC (10 sub-chambers) with longitudinal drift to improve the signal to background ratio. The committee recognizes the improvements made to the original conceptual design, specifically:

- The proposed system now operates at room temperature which simplifies the design and construction.
- Significant progress has been made regarding the mechanical design of the system.
- A simulation with 10 tracks/module in GEANT4 to study the momentum resolution and tracking efficiencies has been performed.

The committee understands and appreciates the work that the collaboration has invested to further develop the conceptual design of the detector/target system. However, from the presented material it is clear that this concept is still in the early stages of development and many important issues, that could prevent a successful experiment, have not been fully addressed. Of particular concern are:

- Detailed simulations populating the recoil detector with ~ 150 tracks/module/trigger have not been performed.
- Background rates of this magnitude can present challenges to track reconstruction. This is especially true for forward going tracks ($\sim 45°$) where two or more subchambers will be involved to reconstruct a single track.
- Track reconstruction software specific to this application has not been developed. This software is required to reconstruct the momentum and vertex time and will be necessary to finalize the detector design.
- Both hydrogen and helium are likely to permeate through the thin Kapton sections of the target causing thickness, density, and contamination issues. As proposed the target cell with $20\mu m$ wall thickness will not safely contain hydrogen at 4 or even 3 atm.
- The presented detector performances shown in Fig. 4 do not look realistic. In the left graph of the figure the momentum resolution ($\Delta p/p$) peaks at $\sim 0\%$, while on the right graph high efficiency for 70 MeV/c protons is reported, when at 4.7 Tesla solenoid field 70 MeV/c protons even at $90°$ will not make into half of the chamber.
- Important details of the mechanical design have not been sufficiently determined. The proposed detector as presented in Figures 1 and 2 is not sufficient to build a prototype. Supports for foils will impact detection of low energy protons.

Recommendations

Based on what is presented, we cannot conclude that a successful experiment using the proposed detector/target system is possible. Before full approval of the experiment, we recommend that the laboratory convene a technical review of a more mature and optimized conceptual design. As such, the committee recommends that the collaboration should:

- Proceed with more realistic detector design incorporating mechanical details such as support structures

- Perform full simulations, including timing of signals
- Present an effective and tested tracking algorithm in a simulated high background environment (150 tracks/module/trigger).

More detailed comments on the proposed conceptual design are given below.

Rate estimate

The rate of background protons is estimated to be 1000 MHz, there is no mention of the source of these protons or their momentum-angular distributions in the document. The number of pad-hits (~ 3000) and the average hit rate per pad (1 MHz) are estimated based on this rate. This estimate assumes 5×5 mm^2 pad size and an average of 20 pads per track. The last number does not agree with studies presented in Fig. 5 of the document, where only high energy tracks have path length ~ 100 mm or ~ 20 pads, low momentum tracks have much longer path, ~ 150 mm or 30 pads.

There is a mention of other backgrounds, "secondary electrons, photons, pions and other particles", amounting to 1000 MHz "at the TPC detector location". It is not clear if these secondaries will produce hits in the detector. If it is possible to produce hits, then the above rates and pad-hits will be double.

The double pulse resolution is estimated to be 200 ns assuming 5 mm drift path length or 150 ns per pad (50 ns is added to the drift time to account for pulse-shaping). This assumes that a given track is aligned with the pad, which is not the case; it is a momentum-angle dependent parameter. At 30°, for example, the drift path length for a pad, even if track direction is aligned with the pad, will be 8.6 mm or 250 ns (with 50 ns of shaping time the total pulse width will be 300 ns).

The background rate for each electron trigger window that reconstruction has to deal with is estimated per chamber. But the correct parameter here should be the electron track vertex resolution since that will determine in which (how many) mTPC detector(s) to look for a coincidence proton.

Recoil Proton Detector

While the scattered electron is detected at forward angles of about 12° with the super big bite spectrometer(SBS) the recoiling low momentum spectator proton will be detected in coincidence with a segmented time projection chamber mTPC.

Detector Concept

A more complete design should be developed and considered in the simulations. Any necessary radial support structure as well as lateral struts along the inner radius will significantly impact the detector acceptance and efficiency but are likely required for a sufficiently rigid structure to provide stability for the GEM foils.

The proposed Kapton target and He space window thicknesses of 20 to 40 and 12 μm will allow permeation of hydrogen from the target (see below) into the detector gas volume. This raises the question of how pure the He/CH4 gas mixture is required to be and how it may impact the detector performance.

The proposed readout pads of dimension 5 mm by 5 mm are quite small and it may be rather difficult to reduce the pad size even more to accommodate the extremely high rates in the inner radii. Note that for a 3 layer GEM the electron shower width is already order 1 mm wide.

The current GEM system is based on two layers with a total gain of 2000. It is not obvious that such a gain in electron amplification is sufficient.

Tracking

The resulting occupancy in the mTPC is at the level of 70% with significant multi-hit probabilities of which many can not be resolved as the hit resolution is of order 200 ns. At more forward angles, this resolution may be significantly larger. Such a high occupancy requires detailed studies and software development to identify and reconstruct these multiple tracks in a single event. In addition, random hits from other charged particle tracks like pions that pass through the detector volume within the trigger readout window are not considered. Any additional noise hits, for example from very low energy photons, will have an impact on track identification and reconstruction efficiency as well.

Figures 4 and 5 are not sufficient to understand and characterize the track reconstruction. The track identification is not trivial given the high hit multiplicity. Note for example that the peaking of the momentum resolution at zero, as shown in Figure 4 left, is not realistic.

Realistic simulations coupled with a tracking algorithm is needed to understand how many chambers will be used for a single track reconstruction. At 45°, tracks will have 5 cm radial shift per chamber.At a radius of r=10 cm (only 5 cm inside the chamber) the circumference is 628 mm; with a 5 mm pad size there will be 125 pads hit. With a background of 150 tracks per 1.5 μs this means that all pads of the first $\sim$ 6 cm will have hit(s) which is highly problematic. This is if assume that the 1000 MHz proton background results from the elastic (radiative tail) scattering of electrons at very forward angles, so these background protons recoil at $\sim 80°$ and will uniformly populate pads at small radii.

Simulations

Presented studies are based on a solenoid magnetic field of 4.7 Tesla. It is not obvious that such a high magnetic field is the optimal choice. This seems to be true in particular for the lowest momenta recoil protons.

From quoted angular and momentum range of particles and the geometry of detectors in the SBS and the recoil TPC, it is not clear if the presented simulations are realistic. For example, electrons from the upstream end of the extended target will hit the solenoid yoke at 12°.

It is not clear how the results in Figures 4 and 5 were obtained, with 4.7 T field, 70 MeV/c protons will not make through half of the radial part of TPC even at 90°. As stated above, forward going tracks ($< 60°$) have to be reconstructed in 2 or more chambers, with complicated, energy-angle dependent efficiencies.

Calibration

Protons from elastic scattering will be used for mTPC calibration. As mentioned above, elastic protons will scatter at large angles and will be comfortably reconstructed in a single chamber, mostly going through the whole radius of the chamber. While protons from tDIS process will scattered at 30° to 60° . They will have very complicated reconstruction pattern which is energy/angle dependent (e.g. at 45° track radial path per chamber is only 5 cm).

Target

The evolution from a cryogenic system to a room temperature target significantly simplifies the design and construction. The choice of Kapton for the cell wall is advantageous from a proton energy loss viewpoint but, may cause issues as it will allow significant permeation of hydrogen into the surrounding volumes. It should be determined if the rate of permeation is acceptable or, if not, how to deal with this contamination. Unfortunately, the reverse process where He permeates into the target space is also likely. This contamination could be problematic in the hydrogen space.

The suggested length of the target as shown in Figure 7 is slightly longer than the recoil detector. However the thin wall section is significantly shorter resulting in more than half of the hydrogen space length surrounded by aluminum. This may cause a significant variation of the recoil detector acceptance as a function of z-vertex position along the beam line since no low momenta protons will make it through the aluminum tubes. As a consequence, the effective target length may be ill defined with this design.

The combination of cell wall thickness and internal pressure must be optimized. An internal pressure of 4 atm and a wall thickness of 20 μm gives a circumferential stress in the Kapton tube of

$$\sigma = P * d/(2t) \simeq 15\, ksi \tag{1}$$

This exceeds the listed yield strength by a factor of 1.5. Similarly an internal pressure of 3 atm will produce a stress in excess of yield by a factor of 1.1. Optimally, this factor of actual stress to listed yield strength should be no more than 2/3 but in this special case it certainly should not exceed 80%. Thus, a wall thickness of 40 μm should be considered as a minimum for a 4 atm target. Note that a failure of the target wall can potentially cause irreparable harm to the recoil detector.

DAQ

The proposed mTPC readout is based on the SAMPA ASIC developed at CERN. It is suggested to run the chip at a clock speed of 20MHz and read it out in trigger mode. The samples are read out in raw mode and transferred via a Front End Card (FEC) to a Common Readout Unit (CRU) where the samples are processed. It is stated that both these modules, FEC and CRU, can be acquired from CERN and ALICE.

It is not obvious how easily these electronics can be incorporated into a DAQ system at JLAB that is optimized to readout the SBS with a trigger system that runs on a sub harmonic of the accelerator frequency close to 250MHz.

The SBS spectrometer is the only detector in the system that provides sufficient timing resolution to resolve the RF bunch structure and provide a sufficiently accurate time to determine t_0 for the tracking in the mTPC.

We note that, as presented, the systematic error dominates the statistical uncertainty by nearly an order of magnitude. The collaboration should consider the possibility of operating at 31.1875 MHz with the same bunch charge. This is below the 40 MHz that the SAMPA system was designed for and might not significantly affect the physics if the PAC days were increased by a factor of two.