Chapter 5

Other Equipment Components in Hall B

5.1 Polarized Target Operation in CLAS^{++}

A significant portion of the physics program for CLAS^{++} requires use of a dynamically polarized solid state target for use as a polarized hydrogen or deuterium (neutron) target. A large program has already been carried out successfully with CLAS to measure inclusive polarized structure functions $g_1(x, Q^2)$ on the proton[232] or deuterium[233] and to study polarization observables in exclusive pion production from polarized protons and neutrons [234]. For these experiments the target was polarized parallel or anti-parallel to the electron beam direction. This configuration can be achieved in CLAS^{++} using two different options. These are briefly described below.

5.1.1 Polarized Target in Solenoid Magnet

Part of the program for CLAS^{++} is an extension of this program to higher energies. It will require use of a target polarized parallel or anti-parallel to the beam line. In CLAS^{++} this can be accomplished by adding some correction coils to the superconducting solenoid to improve the field uniformity around the target. The correction coils are needed since the solenoid magnet alone may not produce a sufficiently uniform magnetic field in a large enough volume around the target to achieve highly polarized protons or deuterons (neutrons). With this option, the complete central detector could be used for polarized target experiments, allowing nearly full coverage for particle detection. This arrangement will allow measurement of multi-hadron final states in addition to the scattered electron. The target cryostat will have to be re-designed to allow for its operation in a warm bore magnetic field environment.

5.1.2 Polarized Target with Helmholtz Coil Arrangement.

A second option is, to remove the entire central detector including the solenoid magnet with its iron flux return, and replace it with the existing polarized target magnet. This option will not require any changes on the CLAS polarized target, and will be adequate, and highly efficient for inclusive measurements. However, it would impose limitations on the kinematics accessible in hard exclusive processes. For example, the DVCS process is of highest interest at small momentum transfer t to the recoil proton. The Helmholtz coil would limit proton detection to angles $\leq 45^\circ$, while the minimum t is achieved at angles $60^\circ - 70^\circ$. Such limitations would significantly reduce the physics impact of these measurements.

5.1.3 Transversely Polarized Target.

The Helmholtz magnet has been used inside CLAS with a cryostat inserted from the upstream end of CLAS. This made it very difficult to achieve a configuration where the Helmholtz field is oriented transverse to the beamline. At the higher energies there is a significant interest in semi-inclusive/exclusive processes involving transversely polarized targets. In the CLAS^{++} configuration, and if the central detector is removed, the polarized target cryostat can be inserted from the top in between the torus coils which are no longer instrumented with tracking chambers. This provides a straight forward way of rotating the magnet by 90° to provide a transverse (to the beamline) polarization. As the magnetic field will deflect the incident beam vertically a magnetic chicane will be needed to compensate for that deflection. The chicane is to be inserted into the beamline upstream of CLAS^{++}. The Helmholtz coil geometry will restrict the acceptance for particle detection to the forward region.

The target polarization is usually required to be transverse not to the beamline but to the virtual photon direction. This may be accommodated in certain kinematics by rotating the field direction by a smaller than 90° angle. In any case, the kinematics accessible for a dynamically polarized solid state target with transverse field orientation and operating in an electron beam will always be more limited than for a longitudinally polarized target.

5.2 Beam Line

5.2.1 Introduction

There are no major changes in the beamline necessary for the main 12 GeV operation. The bulk of the beamline equipment will operate as designed or better with an electron beam of higher energy and current. The items that should work without major upgrades include the three nA RF beam position and current monitors, beam profile harps, beam charge asymmetry monitors, beam halo monitors, beam viewers and beam raster magnets. One beamline element that is not-upgradeable to 12GeV running is the tagger magnet. New beamline elements or existing equipment that needs modification for the upgrade are described in the following sections.

5.2.2 Faraday Cup

The Faraday cup (FC) currently installed in the Hall B beamline contains no provision for water cooling. With the increase in beam energy by a factor of 2, and with the increase in luminosity by a factor 10, which will mostly come from an increase in beam current, the total power absorbed in the FC could increase by a factor of 20. This will either require the implementation of some cooling capability into the Faraday cup, or limit the duration during which the FC can be exposed to the beam. Another, though less desirable, possibility could be to limit use of the Faraday cup to short periods of time, e.g. for calibrating the upstream beam current monitors, and to move the FC out of the beam after the calibration is completed. This in turn would require installation of a low power beam dump located downstream of the FC that would dump the electron beam during routine operation.

5.2.3 Møller Polarimeter

The Hall-B Møller polarimeter consists of a magnetized permadur target followed by two magnetic quadrupole magnets that deflect the electrons into scintillating fiber bundles. The maximum beam energy of the present polarimeter is given by the maximum field of the quadrupole magnets. This maximum is $\sim$ 8.5GeV. In order to achieve operations with an 12 GeV beam energy the polarimeter will need to be reconfigured. A combination of increasing the distance separating the two magnets and relocating the detector bundles further from the magnets should be sufficient for 11 GeV operation. The determination of the optimum configuration for operation with any beam energy between 3 and 11 GeV is ongoing.

5.2.4 Magnetic Chicane

Additional modifications will be needed when operating a polarized target in CLAS^{++} where the magnetic field is oriented transverse to the beam line. To compensate for the beam deflection of about 3.2° (at 12 GeV) in the polarized target field, a beam chicane will be needed. This chicane will be inserted into the beam line upstream of CLAS^{++}. The chicane needs to compensate for the 2 Tm integrated transverse magnetic field of the polarized target [1].

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[1] The chicane is not part of the equipment complement for the upgrade, however it is part of a proposal currently under development for an experiment at 6 GeV, and may therefore exist before the energy upgrade

5.2.5 Beam raster magnets

The currently installed beam raster system, which is used in conjunction with the polarized target is dimensioned sufficiently high to allow full rastering over a polarized target with the currently used dimensions of 1.5 cm diameter. The power supplies will be replaced with more powerful supplies.

5.3 Radial TPC Low Energy Particle Tracking Detector

Low momentum particles lose energy rapidly as they pass through any material, and therefore leave short tracks or no tracks at all in solid detector components. In a detector based on gas ionization, however, ionization trails of significant length are readily achieved as the particles pass entirely through, or gradually slow down and stop, in the detection medium. Multiple measurements along the track provide a wealth of information about the particle that created it. Therefore, a promising spectator or low energy recoil detector would be a gas chamber with appropriate geometry and minimum material content. It would provide position and timing information sufficient to identify particles and connect them to an outgoing electron sensed in CLAS. Associated information about the particle's energy loss rate (dE/dx) as it precipitated the ion trail would provide additional information for PID.

A gas chamber configuration that provides all of these needs is a Radial Time Projection Chamber (RTPC). A diagram of the proposed detector for the BoNuS experiment on CLAS is shown in Figure 5.1. (BoNuS studies neutron structure using a tagging of a very low energy backward going spectator protons). In outline, it consists of a pair of concentric cylinders with the annular space between the cylinders containing a sensitive gas. The cylinder axis would be placed along the beam line and target. Charged particles produced at sufficient angle pass through the gas and leave a trail of electron-ion pairs. An electric field between the cylinders forces the electrons to drift towards the outer cylinder where appropriate electrodes cause avalanche multiplication. The resulting signal is collected on the outer surface by either individual pads or a stereo arrangement of conductive strips. The locations of the pads (strips) provides position information (ϕ-z) for the collected drift electrons, and the times of their arrivals provide a measure of the radius (r) at which they were produced. A string of such measurements constitutes multiple position measurements along the particle's track. By recording the amount of charge produced along the track one can estimate dE/dx and thereby constrain the mass of the particle that produced it.

As shown in Figure 5.1, the sensitive volume of the BoNuS RTPC will be an annulus with inner radius $\simeq$ 4 cm and outer radius $\simeq$ 6 cm. The 20 cm length (shown in the figure) will extend beyond the target in order to provide coverage from

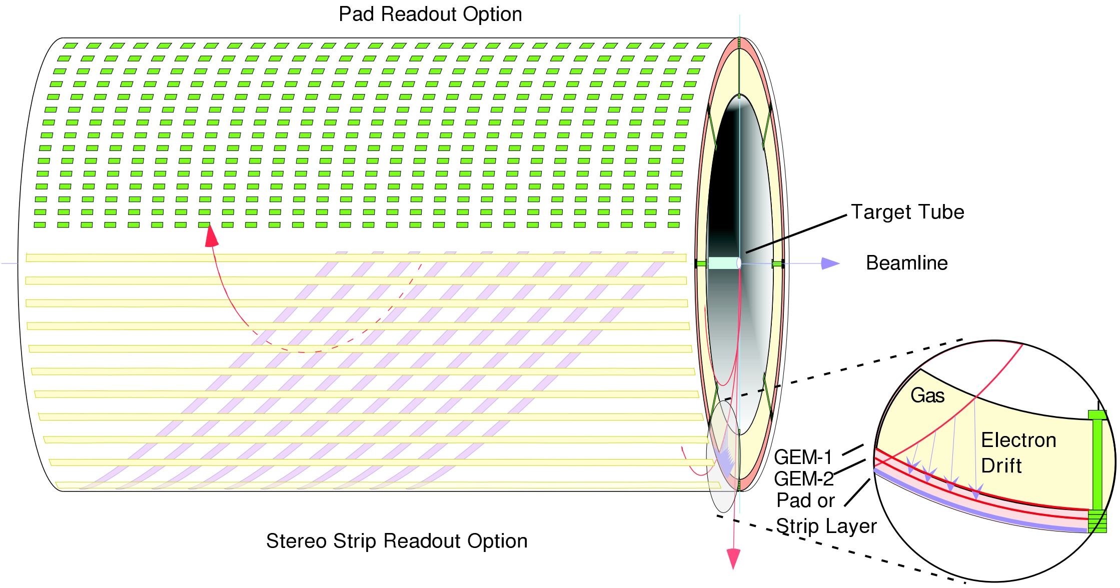

Figure 5.1: Sketch of the Radial Time Projection Chamber for BoNuS. In this figure the upper portion shows pad readout while the lower portion shows readout by two planes of strip electrodes providing stereo coordinate measurements.

90° to 160° for the entire target. The 4 cm space between the target vessel and the inner cylinder will be filled with helium to minimize the scattering and energy loss of particles before they enter the detector. This space also serves as a dead zone in which Møller electrons can be curled up without affecting any detector elements.

The inner cylinder of the RTPC, which serves both as a gas barrier and as the first drift electrode, will be thin gold-plated kapton. Outside $\simeq 2$ cm of sensitive gas will be the first of two Gas Electron Multipliers (GEM). Another $\simeq 0.2$ cm out will be the second GEM followed by the readout pads or strips $\simeq 0.2$ cm later. While each of these four cylindrical electrode assemblies will be largely self-supporting, they will be constrained by precisely machined endcaps and, periodically in azimuth, by radial frames. The frames will deaden a small and quantifiable part of the chamber volume.

GEMs were chosen as the readout sensors because they are mechanically simple and lend themselves naturally to a curved geometry. A GEM is fabricated by chemically etching closely spaced tiny holes through a kapton sheet clad on both surfaces with a thin layer of copper. A modest voltage (few hundred volts) between the two conductive layers produces a large electric field in the holes. Ionization electrons which enter the holes on the negative-biased side of the GEM initiate a gas avalanche within the holes resulting in a large number of electrons being emitted on the positive side. These secondary electrons can be directed onto a pickup electrode a short distance away, or into another GEM for further amplification. The pickup electrodes collect the resulting charge cloud. Electronics connected to these electrodes sense the charge and record its magnitude and time of arrival.

The electronics used to read out the RTPC must provide both charge and time information. This problem has been solved for the STAR FTPCs and the main STAR TPC by a system of charge pre-amplifiers whose output is fed to a switched capacitor array (SCA). The SCA is clocked at 5 MHz, causing the charge collected in each ˜200 ns interval to be transported in a bucket-brigade fashion through the chain of capacitors. Upon receipt of a trigger signal, charge stored in the appropriate capacitors is digitized and the results are passed to the data acquisition system. Readout of this system takes about 10 milliseconds. An upgrade is currently planned for the main TPC which will use flash ADCs and digital storage to significantly reduce the readout time. A very similar (or identical) readout system could be applied to the BoNuS RTPC. Discussions about this possibility are currently ongoing with members of the STAR collaboration.

5.4 Small Angle Electron Detection

Part of the physics program anticipated for 12 GeV requires the detection of scattered electrons in the range of 0.5° to 1.2° . The detection system is currently being designed for use at 6 GeV, and should be available before the upgrade. The hardware envisioned for 6 GeV is described in the following sections, this hardware should work without any modifications at the upgraded energies. In fact the backgrounds should be lower at higher energies.

The most obvious location for this detector system is at the apex of the forward carriage, 7m downstream of the CLAS target. The CLAS bore limits the θ angular coverage to a maximum of 1.2°, a particle with $\theta = 1.2^\circ$ is 15cm off the axis radially 7m from the target. The minimum θ of the angular range must be large enough that the electron is sufficiently removed from the scattered beam. A minimum θ of 0.5° results in an offset of 6cm from the scattered beam. Any detector must not disturb the scattered electron beam so that it impinges on the Faraday Cup.

5.4.1 Beampipe

A beam pipe that allows electrons with an angular range, $0^\circ < \theta < 1.2^\circ$, to be transported 7m from the target without any material obstructions must be designed. A thin Aluminum window just upstream of the low Q^2 tagging system with outer radius of $\sim$ 20cm and an inner radius of $\sim$ 4cm will allow the small angle electrons to enter the tagging system. The vacuum pipe will step down to 4cm diameter at this point and continue to the Faraday Cup. This transition will have to be carefully designed to minimize backgrounds in the detector.

5.4.2 The θ and ϕ Detector

The θ and ϕ of the electron will be measured with a detector just downstream of the thin Aluminum window. The electron rate for all ϕ is $\sim$ 1MHz at $\theta = 0.5°$ and $\sim$ 10kHz for $\theta = 1.2°$ at 10^{33}cm^{-2}sec^{-1}. Two detectors that provide a high rate capability and the required position resolution; they are scintillating fiber array or wire chamber.

A scintillating fiber array using 64 2mmx2mm fibers and multi-anode PMT's have been successfully used to measure the photon beam profile with individual fibers operating at 1Mhz of rate. A simple XYU array of fibers would provide a resolution of 600μm in X and Y, or a resolution 850μm radially (121μradians). The ϕ resolution does not benefit from the 7m lever arm, but $\tan\phi$ will have resolution of 3.3% for $\phi = 45°$ and $r = 6$cm. A more sophisticated geometry for the fibers which is designed to measure θ and ϕ (rather than x and y) might improve the resolution or reduce the channel count. 6 fiber arrays (XYU planes) (540 channels, 34 multi-anode PMT's) would be needed to for complete ϕ and θ coverage. The rate will be highest for those fibers at small θ and would be $\sim$ 1Mhz.

Another possibility would be to use a wire chamber design similar to that proposed by the CKM experiment at Fermilab. By using a 800μm wire pitch and low gain, the chambers can operate at 0.61Mhz. With a finer segmentation than 2mmx2mm fiber detectors, the rate per channel will be smaller. Approximately 1350 channels are needed.

5.4.3 Energy Measurement

To measure the energy or momentum of the electron there are two options. The first option uses a toriod magnetic field to bend the electrons away from the beam and onto a focal plane. A second option being pursued is to use a calorimeter of PbWO4 crystals to measure the electrons energy.

The energy of the electron is to be measured directly via a calorimeter directly downstream of the ϕ and θ detector. A calorimeter consisting of $PbWO_4$ crystals is placed directly downstream of the ϕ and θ detector would provide a energy measurement. The Mainz group has achieved $\frac{\sigma_E}{E}(\%) = \frac{1.54}{\sqrt{E}} + 0.3$. Using an 11GeV primary beam energy, a tagged 1GeV e^- in the calorimeter would measure ν with 0.2% error. A total of 150 2cmx2cm crystals would be needed. If the rate per crystal is determined by simulation or beam tests to be too high smaller crystals may be used (1cmx1cm).