OPTIONS FOR UPGRADING HALL B TO HIGHER ENERGY

Bernhard A. Mecking
Thomas Jefferson National Accelerator Facility

This contribution summarizes the discussions that have taken place in the Hall B community on the possibilities to upgrade the CLAS detector to higher energy operation. After reviewing the present capabilities of CLAS and the associated Hall B instrumentation, the limitations of the equipment are pointed out, especially in the context of the physics program at higher energy. Possibilities are discussed to overcome these limitations by modest changes to the present equipment.

1. INTRODUCTION

The primary mission of the CEBAF Large Acceptance Spectrometer, CLAS, in Hall B is to carry out experiments that require the detection of several, only loosely correlated particles in the hadronic final state, and measurements at limited luminosity. A broad physics program requiring electron energies up to 6 GeV has been approved by the Jefferson Lab Program Advisory Committee.

Jefferson Lab has developed a plan to increase the energy of the CEBAF accelerator to the 12 GeV range by the year 2006. In this context, the Hall B community has started to look into the upgrades necessary to maintain adequate performance of the Hall B instrumentation at higher energies.

2. THE CEBAF LARGE ACCEPTANCE SPECTROMETER CLAS

CLAS is a magnetic toroidal multi-gap spectrometer. Its magnetic field is generated by six superconducting coils arranged around the beam line to produce a field which is pointing primarily in the ϕ-direction. A view of the particle detection system in the direction of the beam (cut in the target region) is given in Figure 1, a top view in Figure 2. The detection system consists of drift chambers to determine the track of charged particles, gas Cerenkov counters for electron identification, scintillation counters for the trigger and for measuring time-of-flight, and electromagnetic calorimeters to detect showering particles like electrons and photons. The segments are individually instrumented to form six independent magnetic spectrometers. This facilitates pattern recognition and track reconstruction at high luminosity.

Charged particles are tracked by drift chambers whose wires are arranged in 3 regions: Region 1 in the field-free volume close to the target, Region 2 between the coils, and Region 3 outside of the coils. Each drift chamber region defines an independent track segment. The combination of axial wires oriented perpendicular to the beam axis, and stereo wires oriented at 6^0 with respect to the axial wires, allow a complete geometric reconstruction of charged tracks. For electron scattering experiments, a small normal-conducting toroid ('mini-torus') surrounding the target keeps (low momentum) charged electromagnetic background from reaching the Region 1 drift chamber.

The threshold gas Cerenkov counters are sensitive to particles with $\beta \geq 0.998$. In combination with the electromagnetic calorimeter they give good electron identification, sufficient even at large electron scattering angles where the π/e ratio becomes large. The location of the Cerenkov counters in front of the scintillation counters minimizes photon conversion and knock-on electrons.

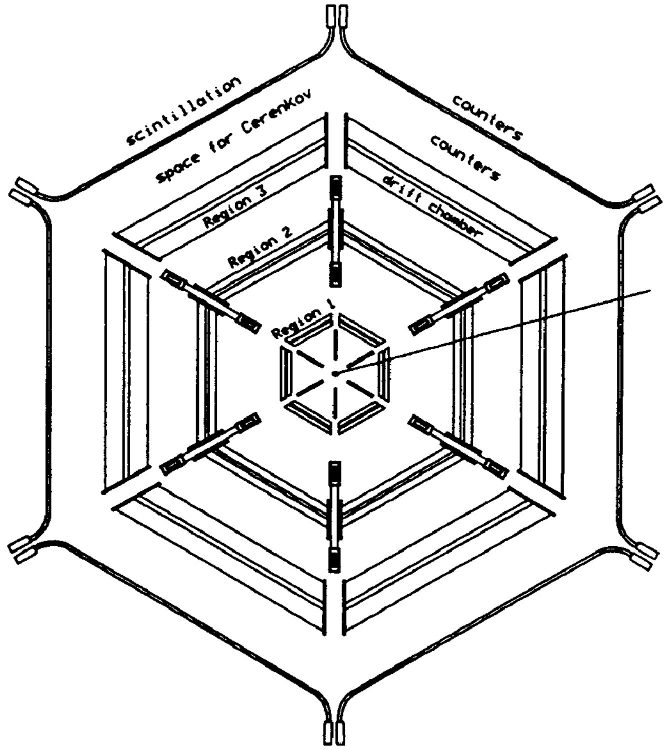

Figure 1. View of the CLAS Detector in the Beam Direction

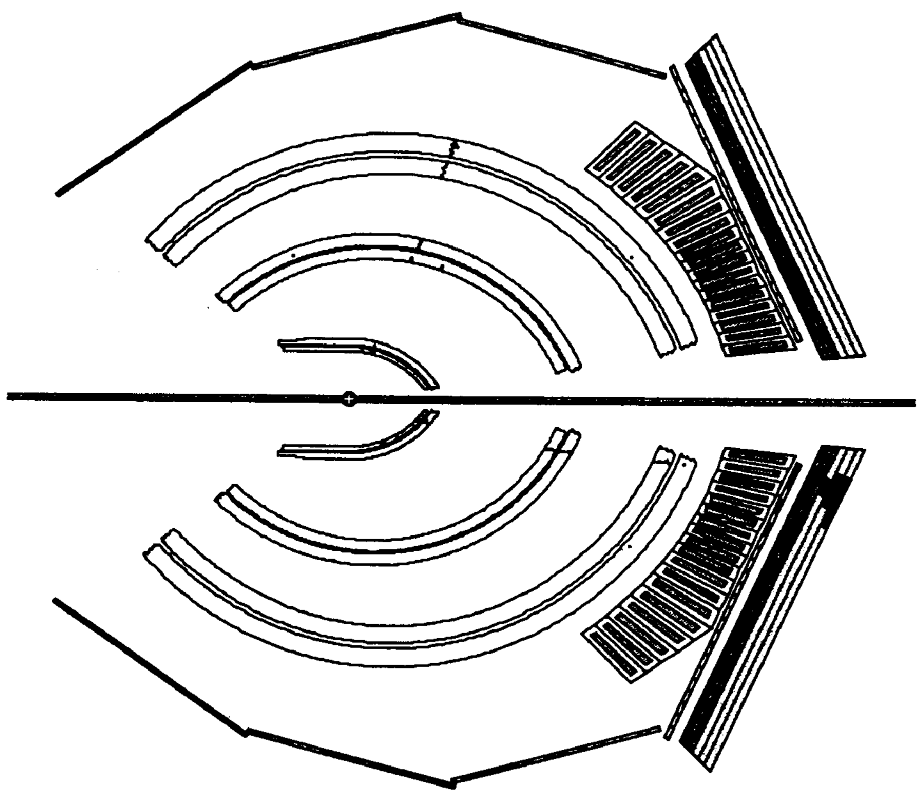

Figure 2. Top View of the CLAS Detection System

The scintillation counters serve the double purpose of contributing to the first level trigger and providing time-of-flight information. Each counter is viewed by phototubes at both ends for improved timing and position resolution.

The electromagnetic calorimeters are used for the identification of electrons and the detection of photons from the decay of hadrons, such as π^0, η, η', and Λ^*. The calorimeters are made of alternating layers of lead sheets as showering material and plastic scintillator strips. The calorimeters allow energy measurements for electromagnetic particles with a resolution $\sigma_E/E \leq 0.1/\sqrt{E(GeV)}$, and provide an angular resolution of ≤ 10 mrad. Six forward calorimeter segments provide coverage up to 45^o in all 6 sectors; two additional segments cover the angular range up to 75^o.

A Møller polarimeter to measure the polarization of the incident electron beam is located in the upstream beam tunnel. It is followed by a bremsstrahlung tagging spectrometer which occupies an enlarged tunnel section at the entrance of the hall. For tagged photon experiments, the primary electron beam is deflected vertically into a low-power beam dump. Equipment to monitor the tagged photon beam, e.g. a pair spectrometer and a total absorption counter, is located behind CLAS in the downstream tunnel section.

3. PRESENT CLAS PERFORMANCE

CLAS has been commissioned in 1997, and started taking production data in December 1997. Major production runs were executed for the following run groups:

- e1 run (1.6, 2.4, and 4.0 GeV electrons on a hydrogen target, single arm trigger on inclusive electrons)

- g1 run (1.8 and 2.5 GeV tagged photons on a hydrogen target, triggered on a single charged particle in CLAS in coincidence with the tagging system)

- g6 run (tagged photons produced by 4.0 GeV electrons on a hydrogen target, triggered on two charged particles in CLAS in coincidence with the tagging system).

The electron scattering experiments were routinely operating at a luminosity of $5 \cdot 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, typically limited by the capabilities of the data acquisition system (500 events/sec at that time). There is no reason to doubt that the design goal of $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ can be reached. Tagged photon experiments were operated around 10^7 tagged photons/sec, typically limited by accidental coincidences between CLAS and the bremsstrahlung tagging system.

3.1. Missing Mass Technique

The present CLAS program relies heavily on the identification of neutral particles in exclusive reactions such as:

$$ep \to ep\pi^0\ ,\ ep\eta,\ e\pi^+n$$

or

$$\gamma p \to K^+\Lambda,\ K^+\Sigma^0,\ K^+\Lambda^*$$

via the missing mass technique. As an example, Figure 3 shows the missing mass distribution for the process $ep \to epX$. The missing mass spectrum shows clear contributions from π^0, η, ρ, and ω production.

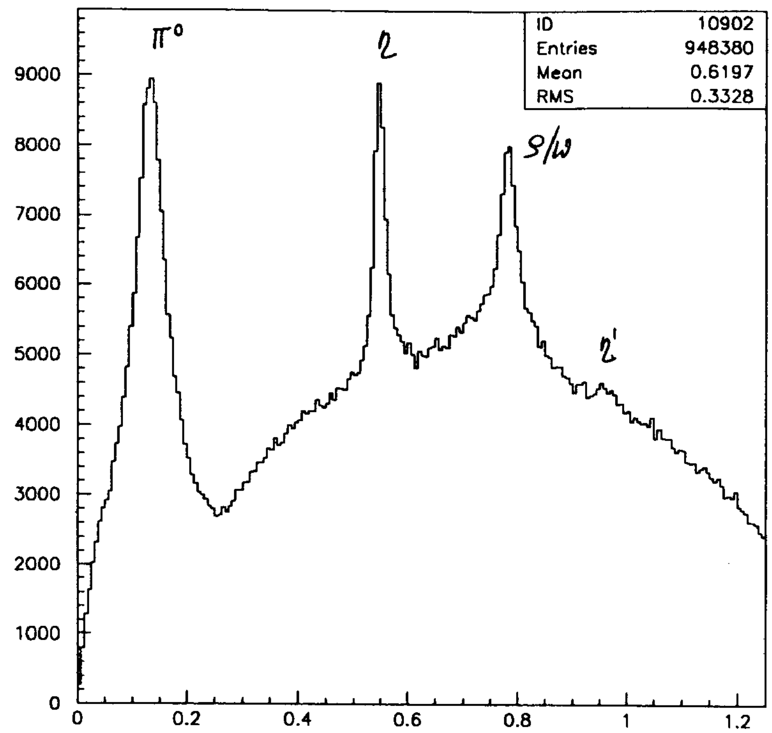

Figure 3. Missing Mass Distribution for $ep \rightarrow epX$ at $E_o = 4$ GeV

3.2. Particle Identification

Electron identification in CLAS relies on the combination of a signal from the threshold Cerenkov counter, and the energy deposition in the electromagnetic calorimeter matching the momentum as determined by the tracking chambers.

Mass determination for slower charged particles, like π, K, and p is accomplished through the combination of momentum and time-of-flight. As an example, Figure 4 shows the mass distribution for charged particles produced in coincidence with electrons in the process $ep \rightarrow e'X$. The mass spectrum shows clear contributions from pions, kaons, and protons.

3.3. Angular Coverage

Some fraction of the full solid angle is obstructed by the torus coils. Therefore, magnetic analysis is possible in the open gaps, only. Since the width of the torus coils is constant, the relative loss in ϕ-coverage increase with decreasing polar angle θ. Figure 5 shows the CLAS acceptance for full magnetic analysis of π^+ and π^- in the $\theta - \phi$–plane. Note that the acceptance depends on the polarity of the particle.

4. CLAS PHYSICS PROGRAM AT HIGH ENERGY

The CLAS physics program at high energy will be a logical continuation of the present program to higher masses for the produced particles, and to higher momentum transfer (see [1] for details). Typical examples include:

- meson transition form factors, e.g. $\omega \rightarrow \pi^0\gamma^*$, $A_2 \rightarrow \rho\pi$
- virtual Compton scattering, especially for large energy transfer to the final state photon
- measure higher moments of spin structure functions, i.e. determine $\int g(x, Q^2) \cdot x^n$

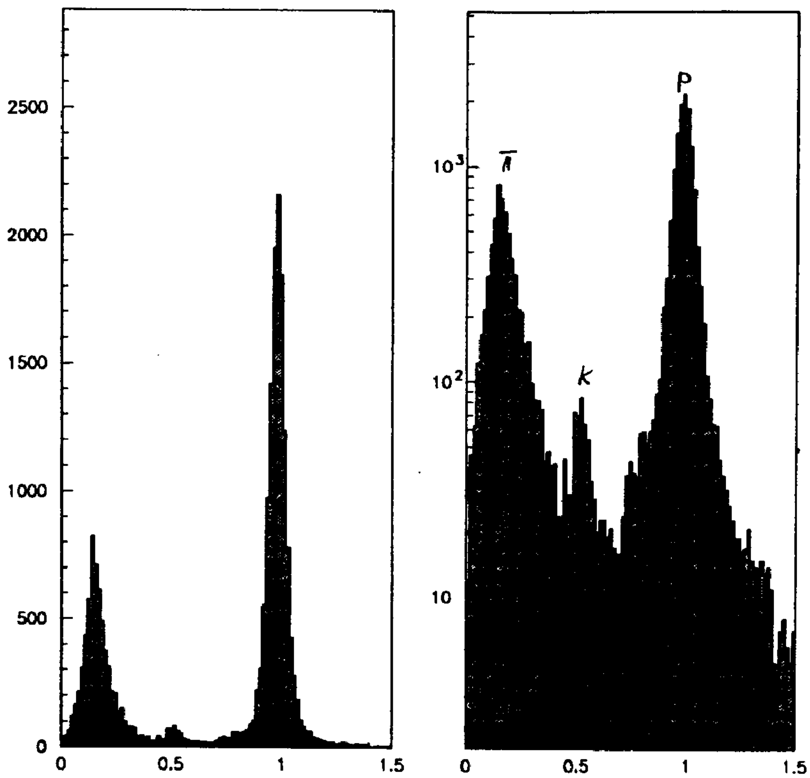

Figure 4. Mass Distribution for Charged Particles Produced in $ep \to eX$ at $E_o = 2.4$ GeV

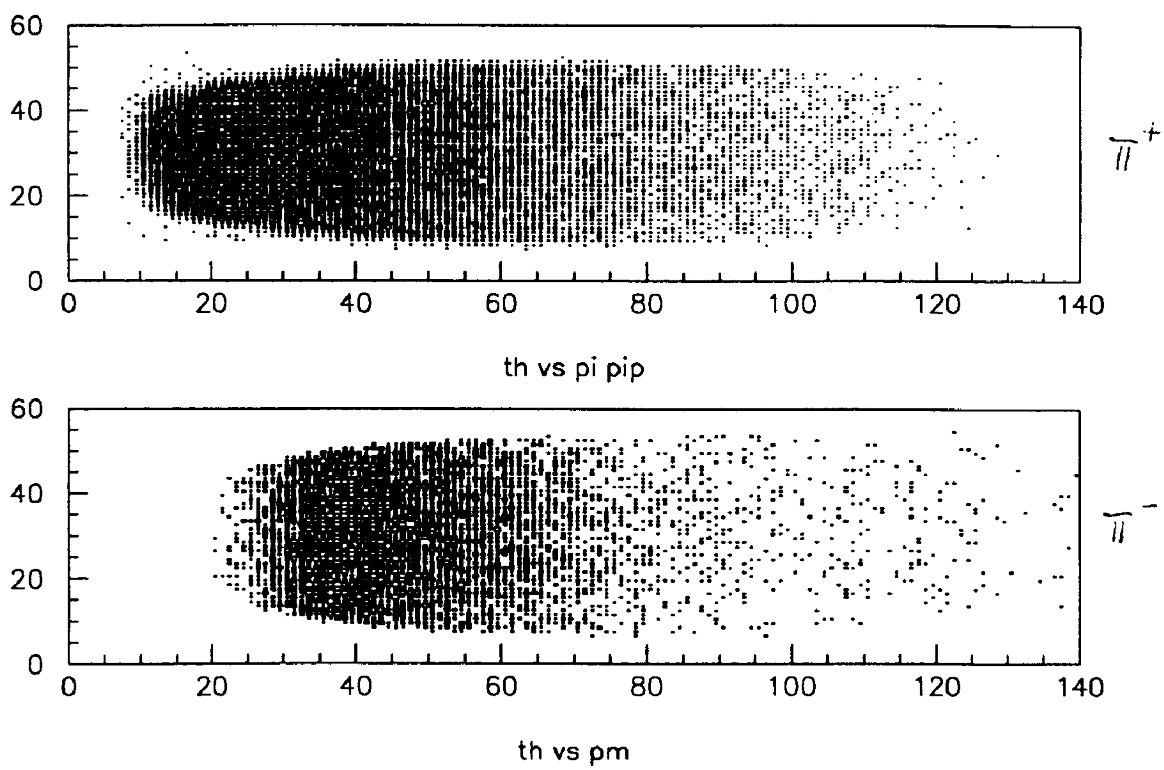

Figure 5. CLAS Acceptance for Charged Particles

- flavor tagging of polarized spin structure functions
- study multi-nucleon knock-out, and N* production and propagation in nuclei.

5. CLAS PERFORMANCE LIMITATIONS AT HIGH ENERGY

At high energy, the most notable new features are the increased particle multiplicity and the higher average momentum of the finals state particles. This causes the following problems for event reconstruction in CLAS:

- the missing mass technique is no longer as useful as at low energy
- particle identification via time-of-flight becomes more difficult
- the probability for detecting all particles in the final state becomes small.

The diminishing value of the missing mass technique at high energies requires a change in strategy: the missing mass technique needs to be replaced (or complemented) by a more complete detection of the hadronic final state. The angular coverage for particle detection is presently limited by the torus coils. In addition, the Region I mechanical structure and the mini-torus also make use of the shadow region in front of the coils. Therefore, a particle heading in the direction of a coil is not detected at all. As a minimum, one would like to determine the directions of all particles, charged or neutral. This would give the following analysis options:

- use of kinematical fitting procedures to determine the final state (see [5] for details)
- veto events with incomplete determination of the final state (this lowers the detection efficiency but avoids contaminating lower multiplicity final states).

6. HALL B UPGRADE POSSIBILITIES

The main thrust of the upgrade program is to maintain the capability of CLAS to identify exclusive final states at the higher energies.

6.1. Full Coverage Inner Tracking

The Region 1 drift chambers need to be replaced by a full coverage inner tracker. Reasonable design goals are $5^o \leq \theta \leq 120^o$ and full ϕ-coverage. For tagged photons, the design task would be relatively simple due to the low background environment. The real challenge is to design a system that can cope with the high background environment of an electron scattering experiment since the mini-torus can no longer be used. Magnetic shielding for the inner tracker (that does not produce a mechanical obstruction within the active solid angle) would be ideal. The following technical solutions have been contemplated to generate a magnetic shield with a longitudinal field:

- a thin, small diameter super-conducting solenoid surrounding the target and the beam line
- a super-conducting coil upstream of the target. Monte Carlo simulations for the 5 Tesla polarized target magnet show better shielding properties than the mini-torus magnet.

Design requirements for the inner tracker are high rate capability and low multiple scattering. An interesting possibility is the use of the emerging gas electron multiplier (GEM) technique that shows great promise for low-mass high rate tracking detectors. A radial drift space might be followed by a GEM amplification stage with pixel readout (see [4] for more details). A potential layout of the CLAS inner detector is shown in Fig. 6.

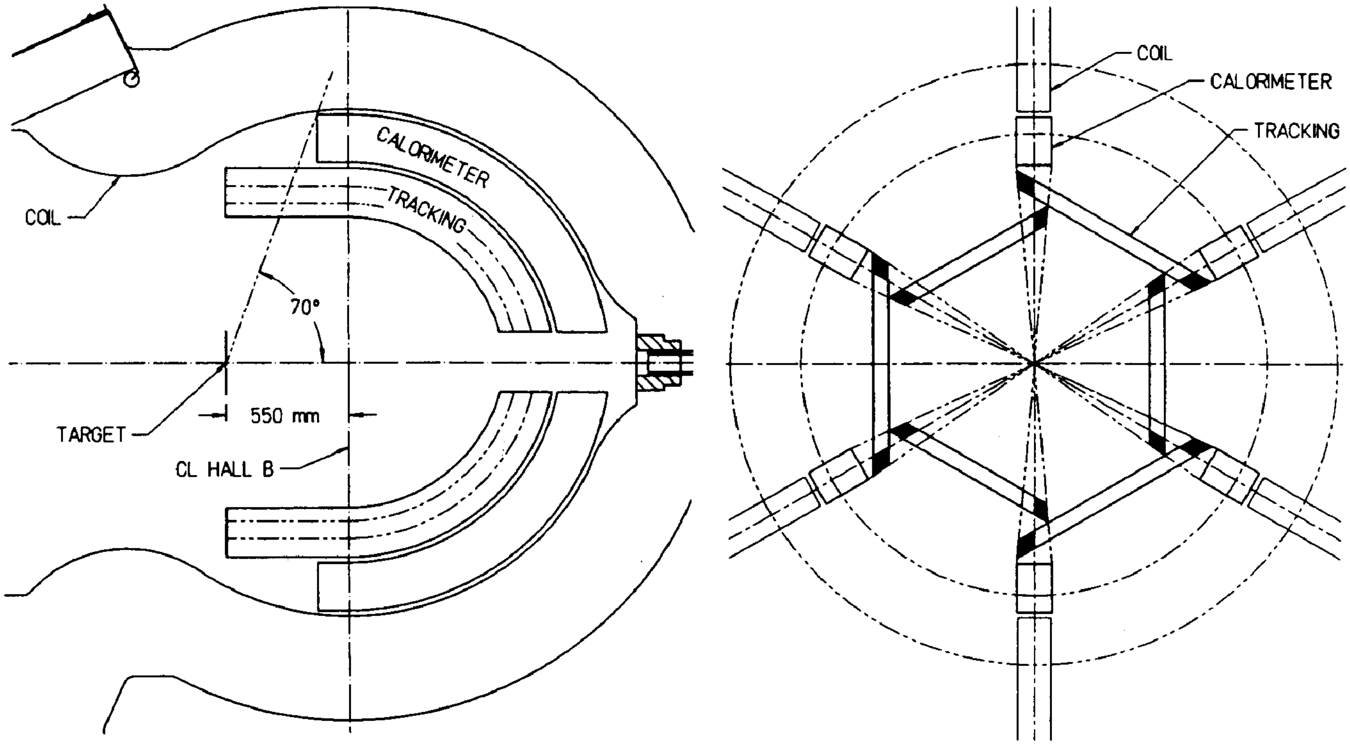

Figure 6. Potential Layout of the CLAS Inner Detector (left-hand side: transverse view, right-hand side: longitudinal view)

6.2. Inner Calorimetry

Like charged particles, neutral particles heading for the coils are not detected. Again one would like to determine the directions of all photons. The only practical solution is to cover the inside of the torus coils with photon detectors. The photon detector will have to be very compact since there is little space available. Ideally, the detector should also give some information on charged particles, like energy deposition, range, etc.

A possible solution is to install short radiation length crystals (e.g. lead tungstate) in the angular range between 5^o and 45^o to complement the forward calorimeters (see [2] for more details). An important open question is the choice of the readout technique.

6.3. Particle Identification

For K/π separation the present technique of combining momentum and time-of-flight is limited to a maximum momentum of about 2 GeV/c. Separation at higher momenta is best accomplished by the use of Cerenkov counters, most likely of the ring imaging type. Locating this device behind the Region 3 drift chambers would be ideal but seems impractical due to the large surface area that needs to be covered. An interesting question is whether a compact Cerenkov counter could be located between the target and the first tracking layer (see [7] for more details).

For e/π separation the present technique of combining energy deposition in the calorimeter and a signal in the Cerenkov counter will be limited to $p \leq 2.7$ GeV since the Cerenkov counters start recording pions. Possible solutions include the use of a lighter gas (but efficiency may be a problem) or to rely on the electromagnetic calorimeter alone. The relative calorimeter resolution improves with increasing energy; in addition, one can make use of the longitudinal and transverse energy deposition patterns which are different for e and π.

6.4. Tagging System

The present bremsstrahlung tagging system is limited to $E_{max} \leq 7$ GeV. The system is difficult to upgrade due to high field strength required to bend the primary electron beam into the 30^o degree dump line. A possible solution is to complement the present tagging system by a pre-tagger chicane which would channel the low energy half of the electron energy spectrum into the present tagging system, and would dump the primary beam (100 Watts) in the tunnel (see [3] for a more detailed discussion).

Another interesting possibility is to use electroproduction at very small Q^2 ('post-target tagging'). This is potentially a much more effective tagging method since one detects only electrons that have produced hadrons. The challenging aspect of this technique is the design of the electron spectrometer downstream of CLAS that needs to cover very small electron scattering angles, and still avoid the primary beam.

7. THE NEXT STEPS

A careful optimization of the Hall B upgrade plan is required, not only because of the limited funds available, but also because there may be conflicting requirements between different components within the Hall B program. The physics program in Hall B needs to be defined in coordination with the other halls to avoid duplication of efforts. Event generators for specific physics problems need to be developed. For a given detector concept, the detector response needs to be simulated and optimized. Detector prototypes will have to be built and tested under realistic conditions. Finally, priorities have to be determined based on the overall physics potential of the proposed upgrades.

8. SUMMARY

The possibilities to upgrade the CLAS detector have been reviewed in the context of the CEBAF physics program at energies up to 12 GeV. The main goal of the upgrade is to maintain CLAS' capability to identify exclusive final states at the higher energy. The proposed upgrade is focused on a redesign of the innermost detector package to give full coverage for charged and neutral particles.

REFERENCES

1. V. Burkert: Physics with CLAS at Energies up to 12 GeV, contribution to this workshop
2. V. Burkert: Electromagnetic Calorimeter Upgrade Possibilities for CLAS, contribution to this workshop
3. H. Crannell and D.I. Sober: Options for Energy Upgrade of the Hall-B Tagger, contribution to this workshop
4. H. Fenker: The Gas Electron Multiplier, a Hall B Region 1 Tracking Upgrade, contribution to this workshop
5. M. Ito: A Resolution Study for an Inner Detector for CLAS, contribution to this workshop
6. S. Stepanyan: CLAS Performance at High Energy, contribution to this workshop
7. P. Stoler: An Aerogel RICH Detector for CLAS, contribution to this workshop