# CLAS - A Large Acceptance Spectrometer for Intermediate Energy Electromagnetic Nuclear Physics

Will Brooks, for the CLAS Collaboration

Thomas Jefferson National Accelerator Facility
12000 Jefferson Avenue, Newport News VA 23606

The CEBAF Large Acceptance Spectrometer (CLAS) has been operating for nuclear physics experiments since December 1997. A description of its individual components and their specifications is given, followed by a description of the overall spectrometer performance and a summary of the types of physics data which have been taken to date.

## 1. Introduction

The Thomas Jefferson National Accelerator Facility (Jefferson Lab) is a superconducting electron accelerator which delivers a low-emittance, high resolution, 100% duty-cycle electron beam to three different experimental areas simultaneously. Presently, the maximum beam energy is 5.6 GeV, with a maximum current of 180 μA. Polarized beams of up to 60 μA at 80% polarization are routinely available.

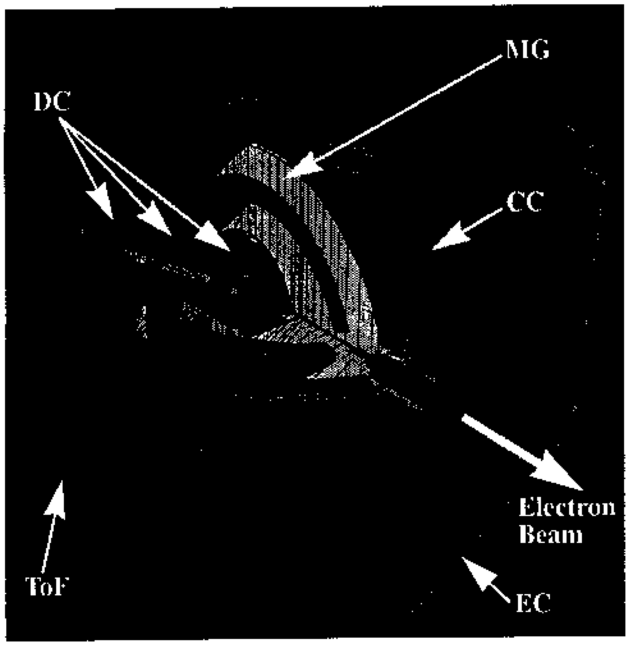

Figure 1. The CLAS, showing the major subsystems: superconducting magnet (MG), three layers of drift chambers (DC), a time-of-flight array (ToF), a Cerenkov counter assembly (CC), and electromagnetic shower calorimeters (EC).

The CLAS at Jefferson Lab is a unique facility designed to accommodate a very broad spectrum of physics measurements. The spectrometer is optimized for characterizing multiple particle final states over a wide kinematical range, with good momentum and angular resolution, and neutral and charged particle identification. Physics measurements have been performed with numerous combinations of targets, magnetic field settings, and beam energies, using photon and electron beams; more than nine billion triggers have been acquired to date. Targets include polarized and unpolarized cryogenic liquids and solids. The spectrometer contains six independently instrumented sectors, which in combination with Møller electron shielding allows it to withstand relatively high luminosities ($10^{34}$ /cm$^2$-s). A fast, distributed data acquisition system in combination with a highly configurable two-level trigger scheme permits data acquisition rates of up to 3 kHz with good event selectivity, producing up to half a terabyte of data per day.

The baryon physics program being carried out with CLAS includes studies of electromagnetic transition form factors of resonances, searches for exotic and missing states, asymmetries and sum rule studies, and hyperon production and decay, all in exclusive channels. Several analogous studies are being performed on nuclei, as well as studies of correlated multinucleon emission, measurements of nuclear transparency, and inclusive electron scattering on nuclei. The broad and continuous range in $Q^2$ and W accessible to CLAS permits physics measurements of unprecedented quality in these experiments. To date, CLAS has a total of 59 approved experiments.

## 2. Spectrometer Components

The CLAS consists of a large open-geometry six-coil superconducting magnet producing a toroidal magnetic field, three separate drift chamber assemblies, a threshold Cerenkov counter, multi-purpose electromagnetic shower calorimeters, and a complete coverage of time-of-flight scintillation counters. In addition, there is a bremsstrahlung photon tagging facility for photon beam experiments. A drawing of the spectrometer is shown in Figure 1; the cutaway view exhibits the internal components.

The superconducting magnet produces a maximum integrated magnetic induction of 2.7 T-m at the forward angles, decreasing to 0.5 T-m at larger angles. Its geometry provides an unobstructed solid angle range of more than half of 4π, and essentially all detector support structure and on-board electronics is mounted in the 'shadow' of the coil cryostat, preserving the unobstructed volume. Besides the superconducting magnet, there is a small normal-conducting magnet producing a toroidal field immediately surrounding the target region for magnetic shielding of Møller electrons. This geometry preserves the zero-field region around the target as well as in the first drift chamber region.

The drift chambers are divided into 3 concentric 'regions'; Region 1 surrounds the target, Region 2 is in the full magnetic field region, and Region 3 is in the outermost (low field) region. Thus the directions of the charged particles are determined before, during, and after bending. In total there are 35,148 sense wires arranged in a hexagonal cell geometry. Each region has two sets of wires ('superlayers'). The 'axial' superlayers are perpendicular to the beam axis and measure the polar angle of the track, while the 'stereo' superlayers are oriented at 6 degrees to measure the azimuthal angle. The total number of wire layers is 34. The chambers subtend polar angles from 8 to 142 degrees.

The intrinsic position resolution of the drift chamber system has been demonstrated to be approximately 200 μm in a given cell; in practice, 350-400 μm has been achieved for the overall system. This value is limited by the quality of detector alignment and calibrations, which are gradually improving. The momentum resolution achievable at lower particle momenta (<2.5 GeV) is completely dominated by multiple scattering through the 0.6-1 g/cm$^2$ thickness of the combination of target cell, gas window, and chamber gas. For higher particle momenta, the intrinsic position resolution dominates the momentum resolution, which is <1%. Vertex resolutions of 2.0 mm have been achieved; angular resolutions are currently limited to 10 mradians due to sector-to-sector alignment uncertainties. Occupancies for typical electron beam experiments range from 1 - 3%, while for photon beam experiments they are even smaller.

The electromagnetic shower calorimeters are lead-scintillator sampling calorimeters 16 radiation lengths thick. In total there are 1808 electronic channels. They subtend a polar angle range of 8 - 45 degrees in four sectors, and 8 - 70 degrees in two sectors. They are constructed in a projective geometry to maximize position resolution for neutral particles, and are segmented longitudinally into two submodules for improved electron-pion discrimination; the electron-pion rejection factor is approximately 0.01. The intrinsic energy resolution for showering particles is $10\%/\sqrt{E}$, with approximately a 3 cm position resolution at 1 GeV. These detectors have up to 60% efficiency for detecting high momentum neutrons. Because they have better than half-nanosecond intrinsic timing resolution, neutron-photon discrimination may be performed, as well as measurement of the neutron momentum.

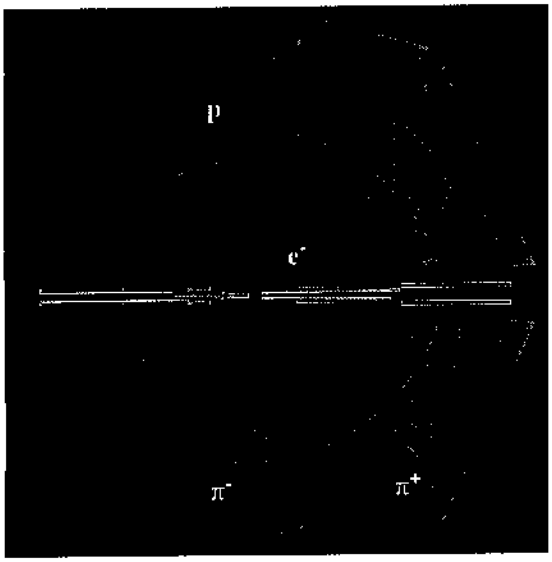

Figure 2. An $ep \rightarrow e'\pi^+\pi^- p$ event seen in a horizontal slice through CLAS.

The threshold Cerenkov counter array uses $C_4F_{10}$ gas, which has a pion threshold of 2.8 GeV. The light is collected via an array of ultralight hyperbolic and elliptical mirrors which focus rays into a Winston cone in front of a 5" photomultiplier tube with typically 2 or 3 reflections. In total there are 216 phototubes. The detector is located 4 m from the target, and subtends polar angles from 8 to 45 degrees and azimuthal angles within each sector of ±25 degrees. The average number of photoelectrons per electron ranges from 8 to 10; the threshold is typically set to 0.2 photoelectrons. The electron efficiency can be systematically measured during routine data taking using elastic e-p scattering. It is typically better than 99% in the fiducial regions.

The time-of-flight scintillators are fabricated from BC408, 5 cm thick, and subtend the full range of angles covered by the drift chambers. 342 separate detectors are read out from both ends. They have an intrinsic timing resolution ranging from 60 to 160 ps, depending on the detector length; in practice, 140 ps has been obtained as an average value for electrons under normal running conditions.

The Level 1 trigger can incorporate signals from the calorimeters, Cerenkov counters, time-of-flight counters, and the bremsstrahlung tagging system. The Level 2 trigger incorporates track information from the drift chambers.

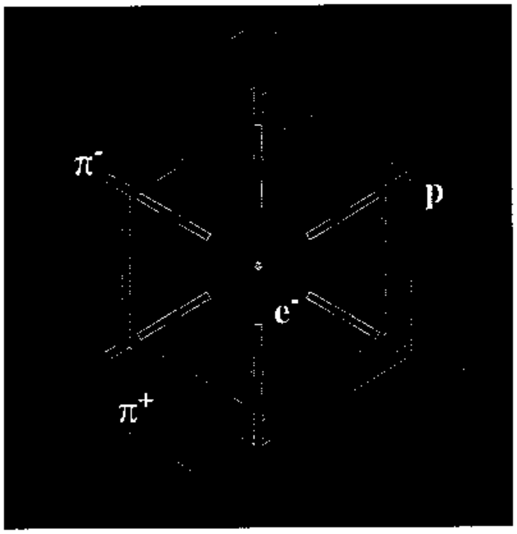

Figure 3. The event from Figure 2, seen in a vertical slice through CLAS.

## 3. Spectrometer Performance

A typical event is shown in Figures 2 and 3. The channel shown is $ep \rightarrow e'\pi^+\pi^- p$. The view shown in Figure 2 consists of a horizontal slice through the middle of the detector, while

Figure 3 is a vertical slice through the detector, perpendicular to the beamline, at the target location.

Typical running conditions for electron beam experiments include: a 10 nA beam on a 5 cm liquid hydrogen target, resulting in a Møller electron rate of approximately $10^9$ Hz, an hadronic production rate of approximately $10^6$ Hz, and a trigger rate of 2 - 3 kHz with a 10% dead time, using a single electron trigger (a Cerenkov counter hit and the calorimeter energy sum above threshold). Data rates to disk are typically 10 Mbytes/s. The electron selectivity varies widely, depending on the beam energy and trigger selection. Using the Level 1 trigger it averages from 40 - 50%, improving significantly when the Level 2 trigger is also employed.

Typical conditions for photon beam experiments: $10^7$ tagged photons per second incident on a 18 cm cryogenic target cell, resulting in a trigger rate of 2-3 kHz, dead times of 10%, and an accidental rate ranging from 25 - 50% (reduced to a few percent after off-line analysis).

Charged particle identification is performed by the time-of-flight technique, resulting in very well separated pions and protons, and a 5:1 peak-to-background ratio for kaons. Neutral particle identification is accomplished in the electromagnetic shower calorimeter, where time-of-flight is used to distinguish photons from neutrons, and to calculate neutron momentum.

Missing mass resolutions of 10 - 20 MeV have been demonstrated for, e.g., electroproduced $\Lambda$, $\Sigma^o$, $\eta$, and $\omega$ from the proton with a 4 GeV beam. The resolution improves for lower beam energies, as seen in both photoproduction and electroproduction.

## 4. Physics Measurements

A wide variety of measurements has already been carried out using CLAS in the first nineteen months of operation. The data acquisition is organized by 'run periods,' where experiments which share common running conditions take data simultaneously. These run periods include ('h' = hadron, X = anything):

- **g5**: photofission total cross section on heavy nuclei; data taking completed, analysis underway.
- **e1a**: $e + p \rightarrow e' + X$ (13 experiments); 3 complete analysis passes finished.
- **g1a,b**: $\gamma + p \rightarrow h + X$ (6 experiments); first analysis pass completed for g1a.
- **g6a,b**: $\gamma + p \rightarrow \phi(1019) + X, \gamma + p \rightarrow hhhh$ (2 experiments); data taking completed, g6a analyzed.
- **eg1**: $\vec{e} + \vec{p}(\vec{D}) \rightarrow e' + X$ (4 experiments); first pass analysis nearing completion.
- **e1b**: $\vec{e} + p \rightarrow e' + X$ (13 experiments); calibration complete, analysis pass beginning.
- **e2**: $\vec{e} + {}^3He, {}^4He, C, Fe \rightarrow e' + X$ (8 experiments); analysis is underway.

The data calibration and analysis passes are performed at Jefferson Lab on the off-line compute farm, which is presently equipped with 115 fast CPU's; further expansion is planned.

## 5. Conclusions

CLAS is operating well and has met all its essential design goals. A huge volume of high-quality data from a variety of experiments has already been obtained, and analysis is well underway. Many preliminary results are now available, a number of which are included as contributions to this conference proceedings. The first CLAS publication is anticipated soon.