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Detailed Report on the Design and Operation of the Calibration System for the Forward Calorimeter for the CLAS detector

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A system has been installed in Hall B[a] for the calibration of the photomultiplier tubes of the forward calorimeter, EC[b], of the CLAS[c] detector package. This article will detail the features of the system and describe its operation. The system was designed and assembled under the direction of Dr. K. Giovanetti, James Madison University Physics Department. Undergraduate students did a major portion of the work. Jefferson Lab[d] scientists and staff were also critical contributors. Several components were produced in the JMU machine shop under the watchful eye of M. Stearns. Kyungpook National University students tuned and tested the system. The construction was funded by a SURA[e] grant. Most of the manpower was provided through National Science Foundation funding[f].

Overview of the Detector

The EC will be used primarily to detect electrons, photons, and double photon events coming from π_o or η decay and neutrons. The detector consists of alternating layers of scintillator sheets and lead sheets. The arrangement and readout of the detector gives positional information by providing 36 separate channels for three views u, v, and w as well as dividing the energy deposition longitudinally into forward and backward components. Therefore each calorimeter module has (36 x 3 x 2) 216 photomultiplier tubes. The EC detector consists of six individual triangular modules (1296 photomultiplier tubes total) mounted downstream of the target on the

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[a] CEBAF is the 4 GeV electron accelerator at Thomas Jefferson National Accelerator Facility.

[b] EC, Electromagnetic Calorimeters, are part of the CLAS detector package that covers angles forward angles.

[c] CLAS, CEBAF Large Acceptance Spectrometer is located in Hall B experimental end station at CEBAF.

[d] Thomas Jefferson National Accelerator Facility in Newport News, Virginia

[e] Southeastern University Research Association

[f] Grants PHY-921507 and PHY-9600454

forward carriage. They cover outgoing forward angles from about 10° to 45 °. The detector relies on calorimetry (energy deposition), positional sensitivity and timing to measure the characteristics of incident particles. Energy deposition is enhanced for electrons and photons by the thin lead sheets that separate the layers of scintillators. Electrons and photons at typical CEBAF energies produce electromagnetic showers in these lead sheets. Heavy charged particles like protons, pions and kaons, as minimum ionizing particles, will produce small signals in the detector. Neutrons through hadronic interaction produce small but measurable signals about 60% of the time. A more complete description of the calorimeter can be found elsewhere.

The importance of detector calibration/monitoring varies, depending on the particle detected and the goals of the experiment. In general, calibration of the calorimeters will involve a series of different tests. The detector's response to specific real events, the results of specialized calibration runs and measurements made with calibration systems will be combined to establish the operating parameters of the CLAS calorimeters over time. The highest priority for the laser calibration system is to monitor the photomultiplier tube, PMT, gains. In order to accomplish this goal, light of a known intensity is injected into a group of photomultiplier tubes through optical fibers. Their response to this light is used to establish their gains. Because the light pulse duration is short, a partial measurement of the time response for the detector is possible. This report will focus on the laser calibration system and will provide a detailed description of the operation and control of this system. Some of the general issues of calibration are discussed in a more general calibration document[1].

Light Source

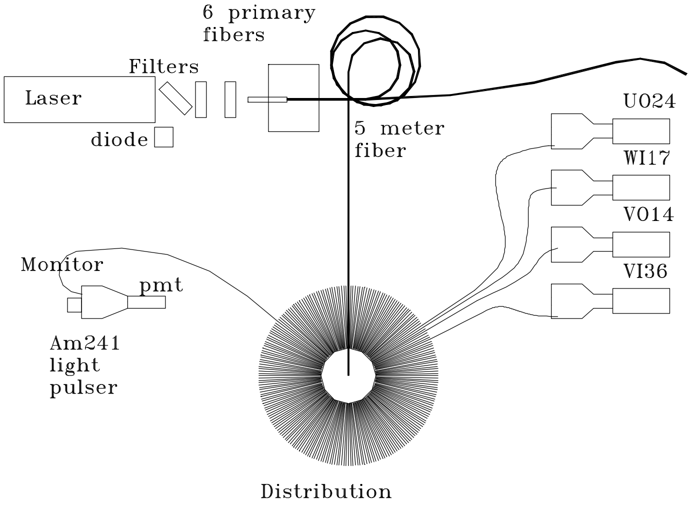
The primary light source for the calibration system should produce a high intensity short duration burst of light. The requirement that the pulse be of short duration allows the calibration system to probe both the time and the energy response. In addition, the frequency of the source is important. Calibrations are typically more relevant when they mimic as closely as possible real events. The light that arrives at the photomultiplier should therefore be in the 400 nm range (blue light) and have a duration of less than 1 nsec. The method employed for obtaining a closely matched light spectrum is to use a primary UV light source that excites a secondary source of light, a scintillator. The light pulse at the photomultiplier tube is then similar to that produced by particles passing through the detector. In addition, the secondary source helps to eliminate spatial variations in the light source that make monitoring the intensity of the light difficult.

Energy per Pulse	100×10^{-6} Joules
Pulse Duration	500×10^{-12} seconds
Wavelength	337×10^{-9} meters
# of Photons per Pulse	1.7×10^{14} photons
Repetition Rate	1-50 Hertz
Beam Dimensions	5.5x3.1 mm
Beam Divergence	6 x 3 mrad ½ angle
Stability	5%

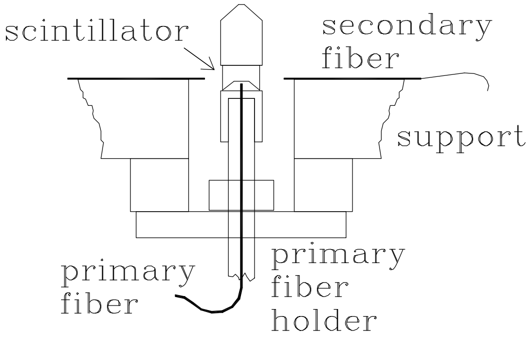
A nitrogen laser was chosen as the primary source. The characteristics of the LN203C Photonics laser are shown in the accompanying table. The laser produces a short UV pulse that is used to excite a small scintillator. The resulting light flash from the scintillator is very similar to the signals generated in the detector.

Light Distribution

The primary UV pulse from the laser is transported to distribution points on the back of each EC triangle. The laser has been placed on the highest level of the support platform (forward carriage) for the EC. A schematic view of the laser, primary fibers, monitors and secondary distribution system is shown in the figure below.



The primary light pulse is transported to the distribution points via optical fiber[g]. The six primary fibers were cleaved and bundled into a 2x3 array, which is positioned in the laser beam. The distance from laser to the distribution points is approximately 5 meters. The fibers were run through metal conduit to protect the fiber and to minimize fiber displacement over time. Figure below shows how the fiber is mounted at the distribution point so as to illuminate a plastic scintillator[h].



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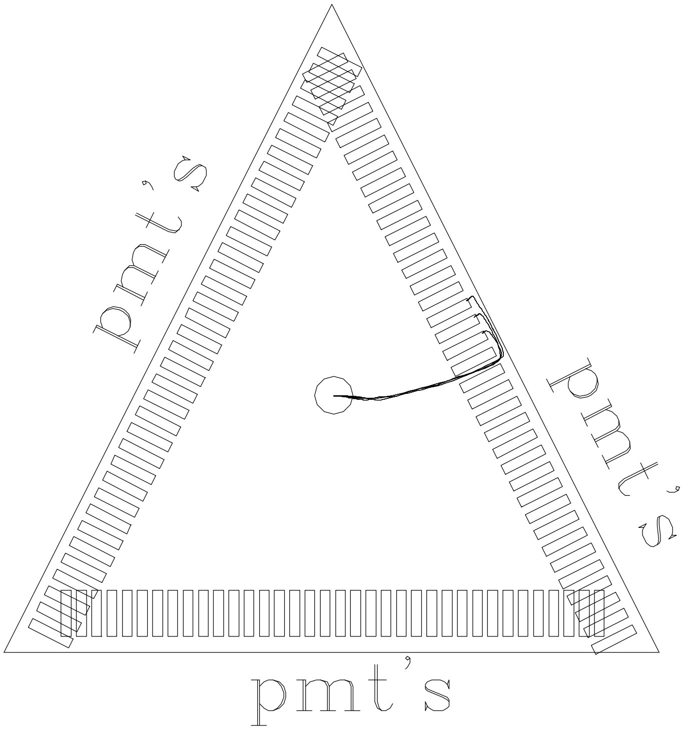
[g] Plastic clad silica fibers from Fiberguide Industries were used. Fibers are step index fibers with 800µm diameter core, 950µm diameter cladding and a 1400µm diameter tefzel jacket.

[h] Bicron 412 polished plastic 9 mm diameter scintillator rod is used.

The figure above shows the fiber holder that secures the fiber in place and the plastic delrin cylinder, which fixes the fiber in the holder. The scintillator was threaded so it could be attached to the delrin cylinder. A final delrin cap was mounted on top of the scintillator. A detailed drawing of the scintillator assembly is located in an appendix. This assembly was supported by an optical mount, which is secured to an aluminum plate so that the scintillator is at the center of the plate. Small adjustments of the scintillator position can be made using adjustments on the optical fiber mount.

The aluminum support plate served as a holder for the secondary fibers. Grooves were machined on the plate's top surface to accommodate the secondary fibers. Each secondary fiber was placed in a small diameter 6" long stainless steel tube[i] and fixed in the tube with glue[j]. The grooves served to align the fibers along radii that point back to the center of the plate. The distance of each fiber from the center could be individually adjusted. The fibers were secured by two small machine screws, which clamp down on the stainless steel tubes. The scintillator then served as secondary light source centered in a wagon wheel array of adjustable secondary fibers. Secondary fibers[k] were installed for each photomultiplier tube. A sketch illustrating the fiber location is shown below.



The fibers were pulled from the distribution location to the PMT covers and then strung to the individual PMT's. Plastic coverings and plastic tubing protect the fibers. Each fiber was cleaved

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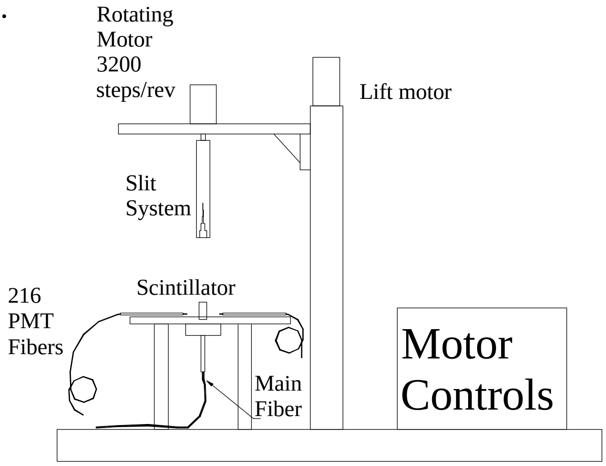
[i] The stainless tubes (HTX-24-6) with outer/inner diameter of .022/.012 inches were purchased from Small Parts Inc.

[j] The same glue was used to secure fiber lightguides to the final plastic guide.

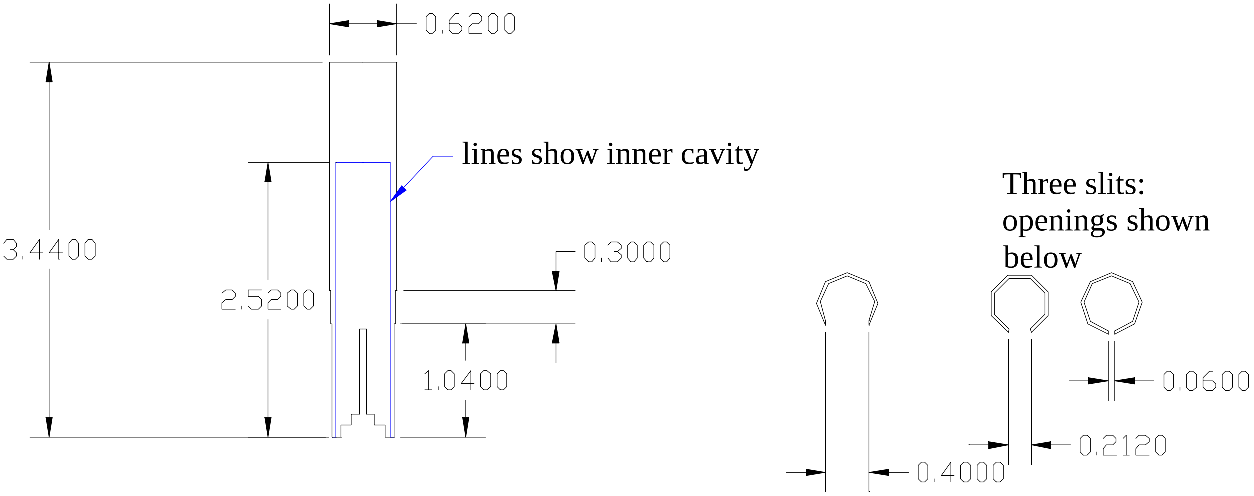
[k] All silica fibers from Fiberguide Industries SFS100/140 were used. Fibers are step index fibers which have a 100μm diameter core, 140μm diameter cladding and a 250μm diameter acrylic jacket.

and then shrink-wrapped to a thin metal rod. A small hole was hand drilled on the corner of each PMT lightguide and the fiber inserted and secured with UV curing glue[j]. The intensity of light as viewed through the lightguide was used to optimize the alignment of the fiber in the guide. The variation in light transmission among the fibers was fairly large. The intensity of the light pulse arriving at each PMT was therefore tuned by examining each individual PMT response to a laser pulse and moving the fiber towards or away from the scintillator[2]. Adjustments were made after the entire system was installed and the EC detectors had been mounted on the forward carriage support structure. The PMT voltages used during this process had been adjusted using cosmic rays.

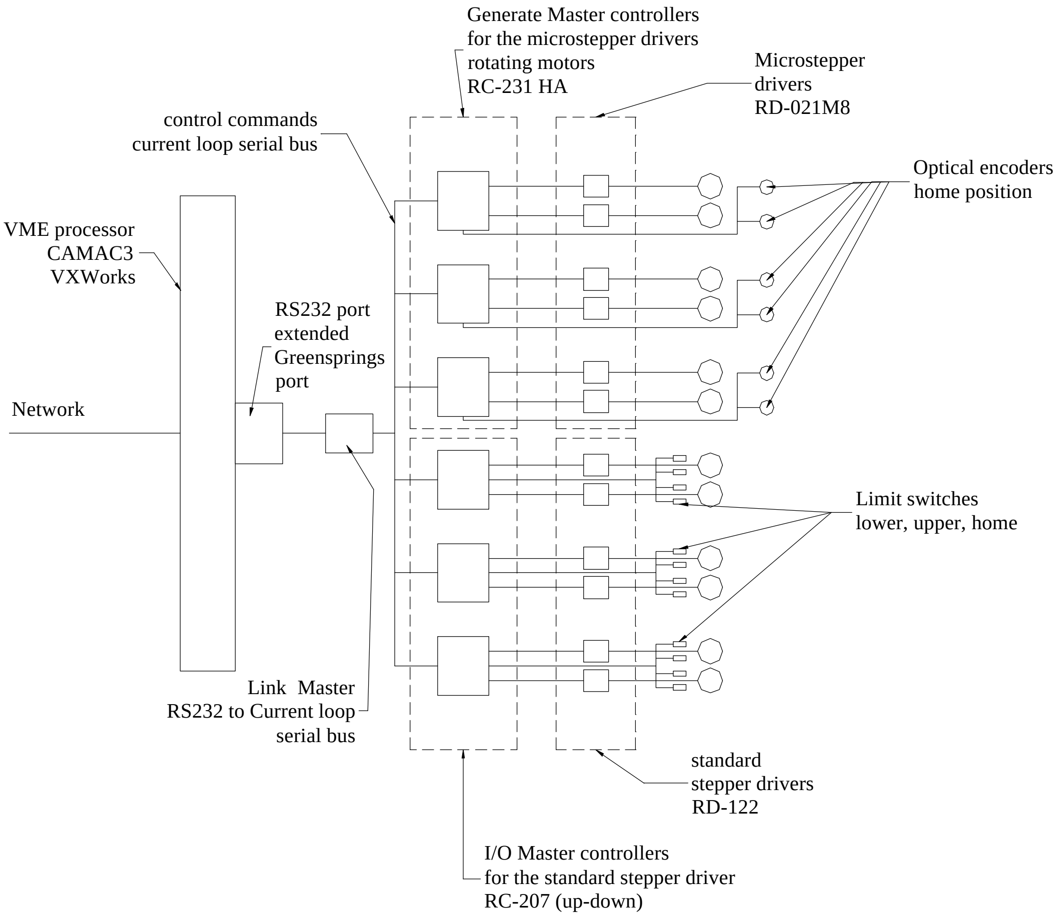
In order to be able to control the illumination of groups of fibers a slit system was incorporated into the secondary distribution assembly. The drawing below shows the support table for the fibers and the slit system.



Two motors position slits so that the light from the scintillator may be blocked. A translation table and motor lifts the slit up and down. A micro-stepping stepper motor rotates the slit. A more detailed drawing of the slit pattern is shown below.



A small thin metal custom slit aperture is clamped over the top opening[l]. This metal sheet has 3, 3 mm long slits with widths of 100 µm, 200 µm, and 500 µm. There are therefore five slits that can be positioned. When using the slit system each slit should be positioned so that it is centered vertically in the plane of the secondary fibers. The slit can then be rotated to control which fibers receive the light produced by a laser pulse. The motor control system is shown below.



Twelve motors are required, two motors (translate, rotate) for each of the six sectors. One stepper motor controller[m] drives two motors and their associated sensors (limit switches, home sensor and encoders). Communication with the controllers is done using an RS-232 serial port. The RS-232 serial line is converted to current loop protocol at the Link Master. Commands are passed on this serial network to all controllers.

This same type of system is used to control the laser intensity. A Link Master receives standard RS-232 data and passes this data on to a motor controller. This controller drives a micro-stepping motor. The motor adjusts the amount of attenuation in the laser path by overlapping two

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[l] Metal sheet with apertures was manufactured by National Aperture Incorporated.

[m] A SEMIX system was chosen for stepper motor control. Details on the command format are contained in the manuals.

varying neutral density filters. There are two limit switches that indicate when the filters are at the end of their possible travel (CW limit and CCW limit). The process is similar to overlapping two wedges. Pushing the wedges together increases the overlapped thickness but at any position throughout the overlapped region the thickness is constant. The filter used provides sufficient attenuation at the maximum setting to completely block the laser. These motor controls are independent of the slit system and are considered part of the laser system.

Calibration trigger.

In order to determine when the laser fires a partially reflecting mirror deflects about 10% of the beam onto a photodiode. The signal generated in the photodiode is split into two equal signals. One signal is used as a trigger. The other is cabled into a standard readout channel for the calorimeter so that the laser pulse's time and intensity can be measured.

Controlling the calibration system

To record calibration events several steps must be completed.
1. Laser must be ready.
2. The laser filter must be adjusted.
3. The slit pattern must be positioned.
4. The EC detector and readout must be ready.
5. Data acquisition system, CODA, must be running and configured to record EC events.
6. The laser trigger bit must be enabled.
7. A pulse must be generated to fire the laser.

Steps 4 and 5 are part of the general procedures for recording data with the CLAS detector. Details of these steps can be found elsewhere[3]. Steps 1,2,3,6 and 7 are specific to the calibration system. All control and initialization is performed using a networked computer (CAMAC3) that is located in a VME crate on the third level of the forward carriage in Hall B at CEBAF. This computer is configured in the standard Hall B configuration. Vxworks, a real time operating system, is used. A set of commands can be downloaded over the network. These commands are compiled C subroutines. Downloaded commands (primitive commands) can be executed from within a remote process using the distributed programming extension of the TCL/TK language (DP commands) or directly by logging into CAMAC3 and typing the command name. The philosophy has been to keep these commands as simple as possible. Sophisticated algorithms are run on the data acquisition system computers. These algorithms use the DP commands to initiate a CAMAC3 primitive command. A list of some of the primitive commands available on CAMAC3 is shown in the table below.

Command Name	Command Function
The following commands address a CAMAC register.	
gason	Turns on nitrogen gas for laser.
gasoff	Turns gas off.
hp_pulseron	Enables a preset frequency pulser. Pulser begins firing.
hp_pulseroff	Disables pulser.

laser_enable	Output a pulse to enable laser.
laser_disable	Output a pulse to disable laser
lpoweron	Output a level (Nim) that closes a power relay for the laser system.
lpoweroff	Remove the level.
stepperon	Output a level (Nin) that closes a power relay for the slit system.
stepperoff	Remove Level.
The following commands use an RS-232 port.	
laser_motor_init	Initializes the communication channel that controls laser intensity.
cal_motor_init	Initializes the communication channel that controls slit system.
laser_motor	Sends a command string on laser intensity communication channel.
cal_motor	Sends a command string on slit system communication channel.
The following commands use a CAMAC pulser and buffers that store the pulse sequence.	
make_pulser_data	Generate a pulser control sequence for a given number of pulses and a given frequency.
load_pulser	Load the pulser control sequence in the CAMAC pulser.
dataway_start	Start the pulser.
The following commands address a VME I/O register.	
getstatus	Read status bits in a register.

The following diagram shows the hardware components and connections between the components. The lines show the links among the hardware modules. A description of these links is given in the following table.

Line	Use
N2 line (level 4)	The laser requires a continuous flow of nitrogen gas. Gas pressure is sensed by JMU control box and interlocked with laser enable.
Optical fibers (level 4)	The primary fibers channel UV laser pulse to the secondary distribution boxes.
Rs232 lines (level 3,4, dist. box)	A serial bus links the motor controllers. Motor commands are specially structured ascii strings, which can be passed to the controllers of the serial lines.
Standard coax	Standard coax routes the levels and pulses for the CAMAC register to the appropriate locations. Status is returned as a level to the CAMAC nim/ecl converter and passed to the VME register.
Network	A network links CAMAC3 and the TRIGGER to the outside world.
Laser control lines	Laser requires a special module and a 5-wire cable. The module enables and disables the laser, shows status, and provides an interlock.
Analog Signals	Photodiode signal is used to signify a laser event at the trigger module.
Power	A TJNAF controller provides power for the laser system. It can be controlled using a nim level. Power for the slit motors is provided by JMU power supply. It uses an on pulse or an off pulse for control.

CAMAC3, as shown in the diagram, is located on level 3 of the forward carriage. The basic commands loaded on this processor control the laser system by communicating with other modules in three ways: VME, CAMAC, or RS232. There are two VME modules used. One is a VME status register (TJNAF I/O register) and the other is a VME/CAMAC interface (Kbus interface) module. The bits of the register are individually set by the hardware to indicate status. The CAMAC interface uses a TJNAF supported set of commands to address any CAMAC module. Two CAMAC modules are used, an output register and a programmable pulser[n]. The register sends levels and pulses to the hardware. These signals, for example, are used to turn on power or enable the laser. The programmable pulser sends the arm/fire signal to the laser. The leading edge (TTL) of the pulse starts the charging circuits of the laser. The trailing edge, 35 msec later, fires the laser. A very general pulse sequence can be used but, usually, only the number of pulses and the frequency are adjusted.

Several of the hardware modules shown in the diagram were specially designed and built. The TJNAF control box and the TJNAF laser enable/disable module were built at TJNAF and are used in the control systems for both the EC laser calibration system and the TOF laser calibration[o] system. The TJNAF control box is designed to provide the power and the nitrogen gas flow for the laser. Levels from the CAMAC register determine its state. It also has a pressure-sensing switch that is wired into the laser interlock. This prevents the laser from operating without nitrogen. The laser enable/disable module uses special features of the laser electronics for interlocking laser operation, remote control and status sensing. Pulses from the CAMAC register generate the laser state transitions. The status is converted to nim levels, which are fed through a nim/ecl converter to a VME register. The JMU controller and JMU power supply were designed and built by JMU students. The controller is the predecessor to the TJNAF control box. It can be used as an alternate gas flow control module using a nim level. The JMU power supply provides the 5V and 40V power for the slit system. Two separate nim pulses drive the power on/off transitions. The status of the power supply is fed back into the VME register through the nim/ecl converter.

Boxes in the diagram labeled as motor controls represent the stepper motor systems described above. Two dedicated Rs232 ports control the slit system motors and the laser system motor.

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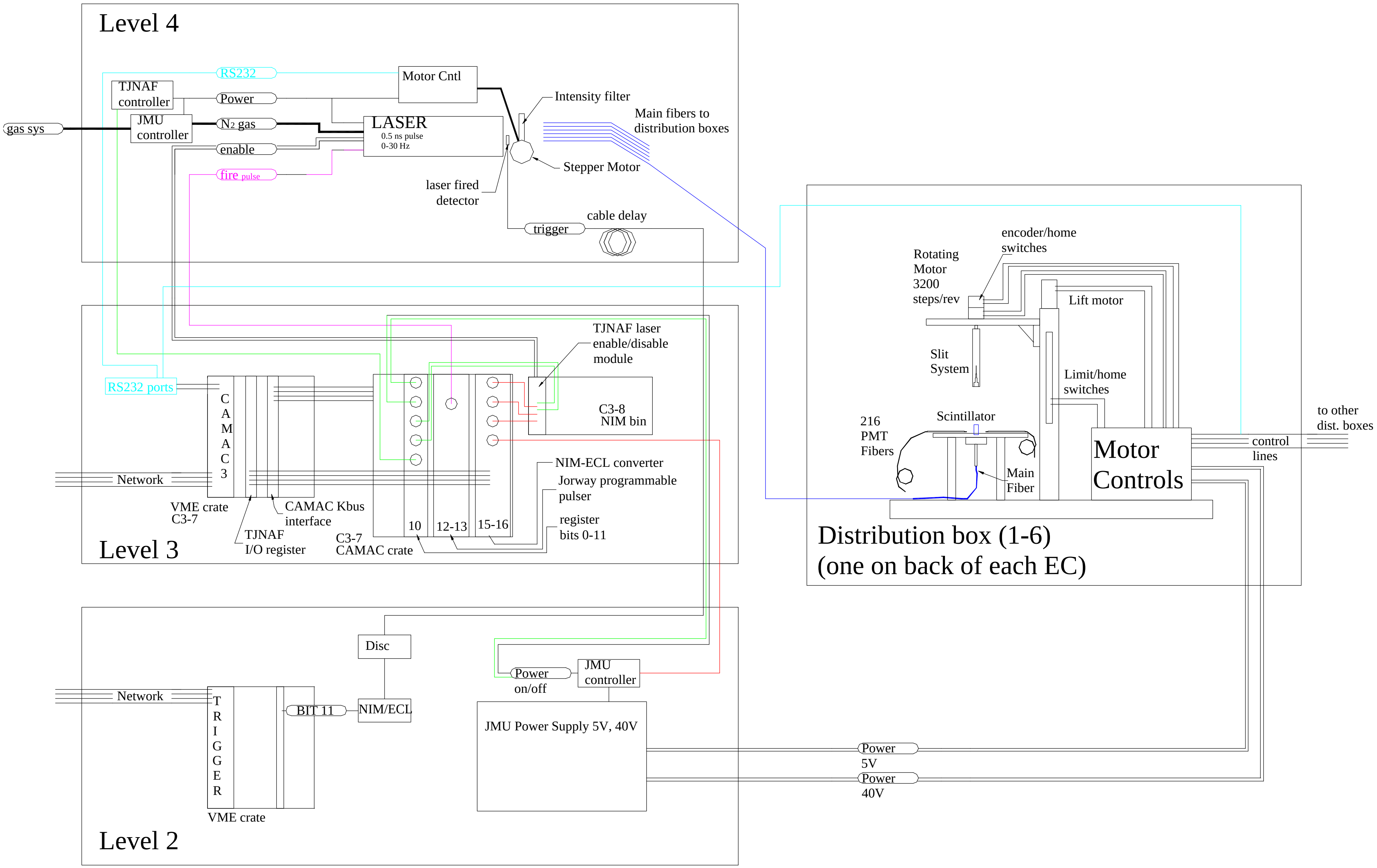
[n] A Jorway programmable pulser provides a wide range of programmable pulse sequences.

[o] The TOF subsystem of the CLAS detector uses a laser system for timing calibration.


Level 4
RS232
TJNAF controller
Power
Motor Cntl
Intensity filter
Main fibers to distribution boxes
gas sys
JMU controller
N2 gas
LASER
0.5 ns pulse
0-30 Hz
enable
fire pulse
Stepper Motor
laser fired detector
trigger
cable delay
Level 3
TJNAF laser enable/disable module
RS232 ports
CAMAC 3
C3-8 NIM bin
Network
NIM-ECL converter
Jorway programmable pulser
VME crate C3-7
CAMAC Kbus interface
10
12-13
15-16
register bits 0-11
TJNAF I/O register
C3-7 CAMAC crate
Level 3
Disc
Network
TRIGGER
BIT 11
NIM/ECL
Power on/off
JMU controller
JMU Power Supply 5V, 40V
VME crate
Level 2
Distribution box (1-6)
(one on back of each EC)
encoder/home switches
Rotating Motor 3200 steps/rev
Lift motor
Slit System
Limit/home switches
216 PMT Fibers
Scintillator
Main Fiber
Motor Controls
control lines
to other dist. boxes
Power 5V
Power 40V

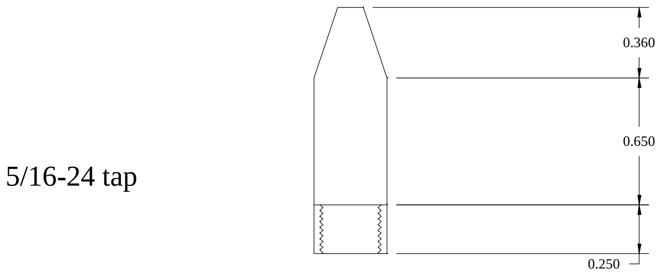
The system as shown above is capable of running simultaneously with an experiment or as a stand alone calibration run. A process called the unix_master initializes the calibration system, reads the settings and the schedule from a file, checks conditions, logs status and generates laser events by firing the laser with the pulser. This program runs on one of the main data acquisition platforms. Aside from the restriction that laser cannot operate at rates above 30 Hz, the firing sequence is arbitrary. As long as the laser trigger is enabled, the generated events will be recorded by the data acquisition system. When the data acquisition system is configured for a laser calibration run, the unix_master is started by the data acquisition system and the calibration is completely automated. The system should simply be monitored for failures. The progress and status can be monitored using JAVA displays that communicate with the unix_master. Alternatively TCL/TK scripts provide control and status.

Conclusion

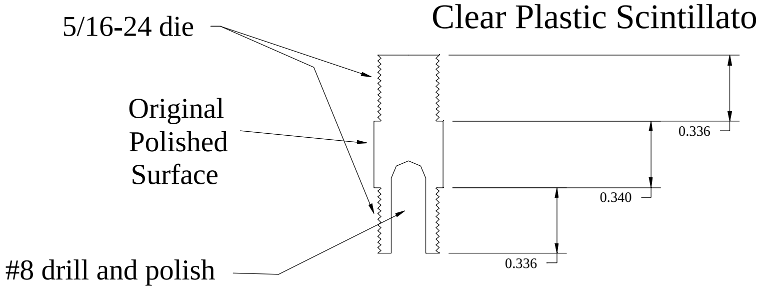
The system installed for EC calibration for the CLAS detector has been integrated into the standard control and recording operations for the CLAS detector. It is a versatile system and can be use in a variety of ways. Experience using the system and the detector should determine optimal useage and how well it can improve detector performance.

APPENDIX

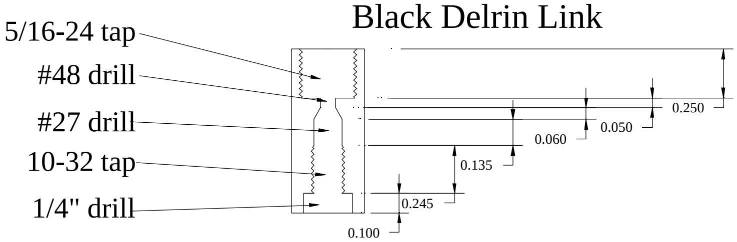
Black Delrin Cap



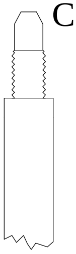
Clear Plastic Scintillator



Black Delrin Link



Commercial Fiber Holder



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[1] EGN group, Calibration Issues (General).

[2] A separate report contains a more detailed discussion of the results of alignment.

[3] Manuals describing CLAS operation and the operation of most subsystems can be found on the CLAS web pages.