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The KTeV PMT Laser Monitoring System

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ABSTRACT

The KTeV CsI electromagnetic calorimeter will be monitored *in situ* by a light pulser system. Pulsed light from a liquid dye scintillator, itself pumped by a Nd:YAG laser, will be injected into each PMT of the calorimeter. The system is designed to linearize the response of the combined PMT and readout electronics, as well monitor the gains of the PMT's.

1. Introduction

The KTeV (Kaons at the TeVatron) collaboration*is currently building a high-precision, pure CsI electromagnetic calorimeter[1] with sophisticated digital readout.[2] One of the goals of the calorimeter is linearity in response, i.e. $E_{true} = E_{meas}^{1-\alpha}$, where $\alpha < 0.5\%$. The purpose of the monitoring system is to measure *in situ* the combined PMT and readout electronics nonlinearities over the entire dynamic range, as well as rate-related gain drifts and other short-term drifts.

A prototype system has been installed at Fermilab. In addition, another prototype system was used during a CERN test beam run of a 25 channel system.[3] The results from these systems, concentrating on the stability and linearity measurements, are discussed in section 3.

The monitoring system will consist of light pulses, emitted from 4 liquid dye scintillators, injected into the calorimeter via 3100 quartz optical fibers. The liquid dye scintillators will be pumped by a frequency tripled Nd:YAG laser running at 5 Hz pulsed-mode. Hence, a light pulse (from the dye reemission) will be fanned-out in common to 775 channels. A liquid dye scintillator has been chosen such that its reemission matches in pulse shape to that of light from CsI, ensuring that the nonlinearities measured will be valid for real data.

The light pulses from the scintillators will be monitored independently by PIN photodiodes. These diodes have been measured to have good linearity and gain stability. A quartz filter wheel will control the light intensity common to all 4 scintillators. The intensity is such that each PMT channel will span an equivalent of 10^6 photoelectrons. Good pulse-to-pulse stability is achieved by keeping the location of the emission point (in the dye) stable in space. Hence, the measurement error from each laser pulse is limited predominantly by PMT photostatistics.

2. Design

*Chicago, Colorado, Elmhurst, Fermilab, Osaka, Rice, Rutgers, UCLA, UCSD, Virginia, and Wisconsin.

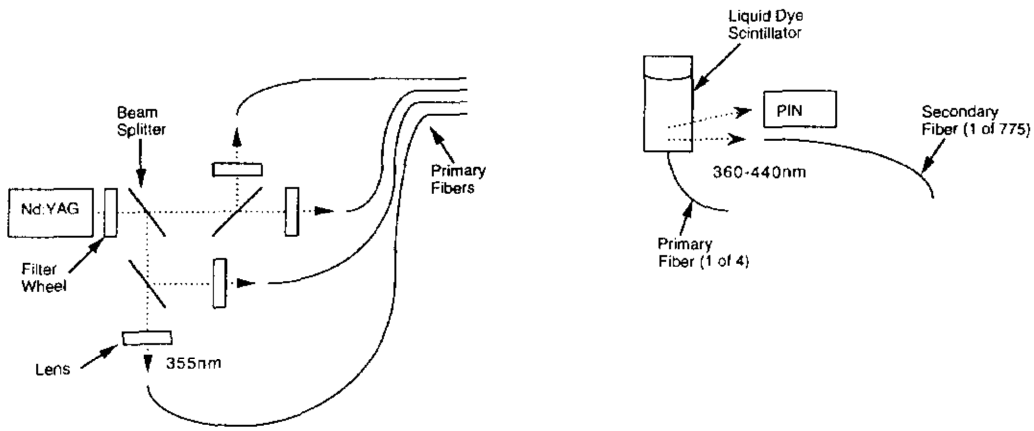

Figure 1: Conceptual Layout.

The conceptual layout is shown in figure 1. A 355 nm pulsed beam from a Continuum Surelite I f-3x Nd:YAG laser is split equally 4 ways and focused into 4 quartz *primary* optical fibers approximately 10 meters in length. 1 mm core CeramOptec Silica/Silica-Clad fibers will be used in order to handle high peak laser powers. Before the split, the beam traverses through a variable attenuation filter wheel. The wheel controls the light intensity common to all 4 fibers and allows one to 'scan' the light level over the required dynamic range. The focussing optics are 50 mm focal length lenses used to ensure efficient transfer of energy into each fiber.† The laser will run at 5 Hz pulsed mode at an energy $\approx$ 5 mJ/pulse.

Each of the 4 primary fibers terminate in a liquid dye scintillator of atleast 50 ml volume contained in a glass vessel spherical in shape. The termination is such that the fiber face will be mechanically locked and butted against the glass vessel wall. The liquid dye scintillator is Sodium Salicylate in Ethanol[4] with a concentration of 7 grams/liter. Prior to exposure to laser light, the scintillator will be bubbled with N_2 and then hermetically sealed in its vessel. The reemitted light spectrum has an average of 400 nm, a width of 40 nm, and a natural lifetime of 25.2 nsec. With this concentration, the 355 nm laser beam will be absorbed in a length of $\approx$ 1 mm. The exit angles of the rays is bounded by 15° due to the fiber critical transmission angle. Therefore the emission spot is a cone volume of 15° and hypotenus of 1 mm.

Viewing each dye will be 775 *secondary* 5 meter length, 600 μm core silica/plastic-clad-silica Spectran optical fibers. These secondary fibers will have pointing geometry and will be located $\approx$ 6 cm from the emission spot. Each of the 775 secondary fibers terminate at the back of a CsI crystal. Hence, light enters the PMT's via reflection from the internal surfaces present in the crystals. Since the reflection efficiencies and tube gains will vary channel-to-channel, the PMT charge outputs will also vary channel-to-channel. Equalizing the PMT charges can be achieved by individual adjustments of the distance between secondary fibers and the emission spot. The PMT's

†For high energy laser beams, it is important to focus the beams entirely into and illuminating 90% of the fiber core. Energy entering the cladding and jacket causes fiber damage.

also have UG11 filters which transmit light between 300-400 nm in order to block out the slow, long wavelength component of the pure CsI emission. Hence, only the dye spectrum between 360-400 nm is viewed by the PMT's.

The heart of the monitoring system are Hamamatsu R1722-02 PIN photodiodes which monitor the brightness the emission spots on a pulse-by-pulse basis. These unity gain devices will be operated with a reverse bias of -10 volts, and with a 1 kΩ series resistance to the output. These precautions serve to limit the output PIN current to ≤ 5 mA for a charge of 250 pC, which is important for maintaining good linearity. UG11 filters will also be used for spectral matching with the PMT's.

A crucial consideration is the readout electronics of the PIN diodes. No preamplifiers will be used. Since the PMT electronics readout will be a multi-ranging, 17-bit dynamic range device, one needs a device with comparable or better dynamic range. Although a final device has not been chosen, one that has given promising preliminary results is a 20-bit Burr-Brown DDC101 ADC operating at 1 msec gate.

3. Results and Discussions

In this section, results will be presented from a prototype setup at Fermilab, concentrating on PIN diode linearity and long term stability. Results will also be shown for another prototype system taken to CERN as part of a beam test, concentrating on how it was used for calibration.

For the Fermilab prototype, figure 2a shows the response of 2 PIN photodiodes (PIN1 and PIN2), each digitized by a LeCroy 2249W ADC, when they both view a common emission spot from a liquid dye scintillator. The light level has been varied over the range 50 to 1000 counts. The line-fit residual would show linearity better than 0.1%. However, an independent measurement of the linearity using a 2.5-to-1 technique[5] indicates a linearity of better than 0.5% for peak current < 3 mA (see figure 2b).

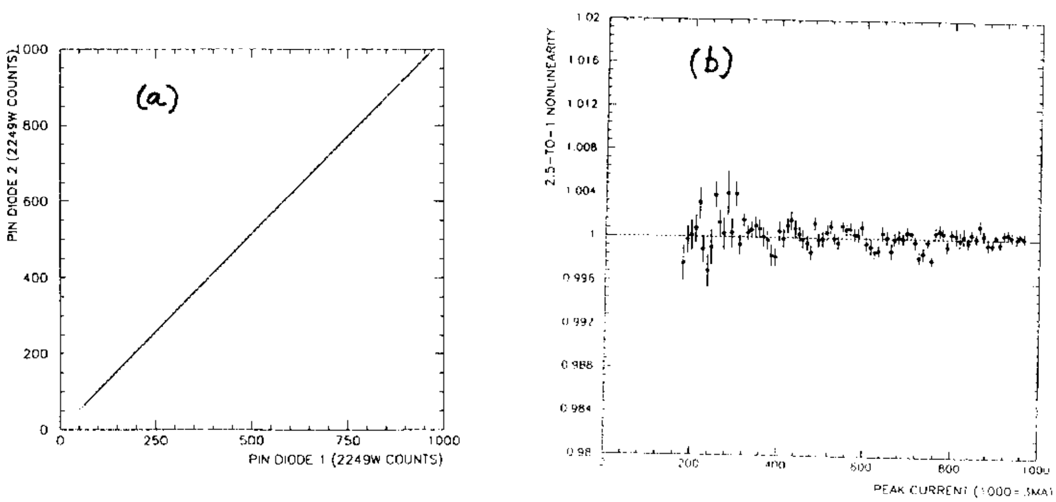

Figure 2: (a) Response of PIN2 vs. PIN1 and (b), a 2.5-to-1 measurement of the PIN nonlinearity.

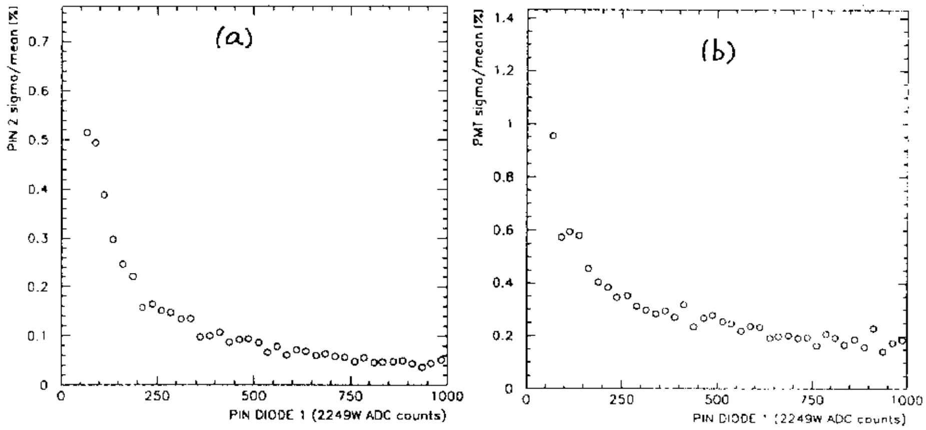

Figure 3: (a) rms(PIN2)/<PIN2> vs. PIN1 and (b), rms(PMT)/<PMT> vs. PIN1.

The accuracy from each laser pulse is reflected in the rms width of the curve in figure 2a. The smaller the percentage rms width, the more accurate the measurement. Figure 3a shows rms(PIN2)/<PIN2> as a function of PIN1. Hence, each laser pulse has a measurement error of 0.05% at 1000 PIN1 counts. The measurement error per pulse degrades at low light levels due to ADC noise and finite bin width. The photostatistical errors are negligibly small throughout the range since even at 10 2249W counts, the PIN diode measures 10^7 electron-hole pairs.

For photomultiplier tubes, the measurement errors have contribution from photostatistics. Figure 3b shows rms(PMT)/<PMT> as a function of PIN1, indicating a measurement error of 0.15% per pulse at 1000 PIN1 counts. Here, the PMT was a Hamamatsu R5364 operating at gain $\approx$ 5000 and also digitized with a LeCroy 2249W.

3.1. Stability

The stability of the system is gauged by how well two PIN diodes track other with time, i.e. for a stable system, the ratio of their signals is constant with time. An important limitation of the system dye damage due to the laser. Laser damage can be summarized as having the following effects:[6] (1) an overall decrease in the dye light output, and (2) a shift in the transmission wavelength cutoff of the solvent. The damage is expected to be worse for higher laser energy. Effect (1) is not a serious limitation. However, when the spectrum from the dye emission overlaps that of the transmission cutoff, effect (2) would cause an apparent spectral shift in the output of the dye. If the monitoring device and PMT's differ in spectral response, a shift in the dye spectrum would cause an apparent change in gain.

For the measurement of stability, two of the PIN diodes (PIN1 and PIN3) viewed the entire dye spectrum, while the other (PIN2) viewed only the spectrum between 360-400 nm. This allows sensitivity to spectral shifts in the dye. The liquid dye scintillator itself received 1 mJ/pulse. The running consisted of 30 minutes of 5 Hz running, followed by 15 minutes rest in order to observe recoveries. This cycle

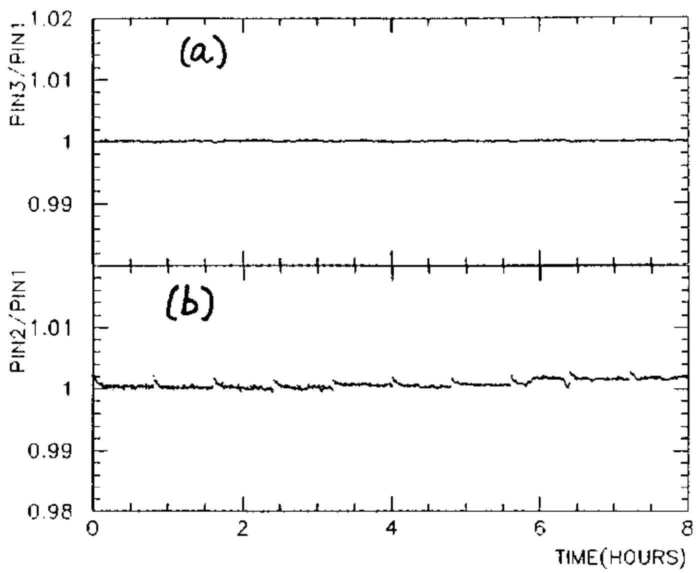

Figure 4: (a) Average PIN3/PIN1 vs. time and (b), average PIN2/PIN1 vs. time.

is repeated 10 times in one 8 hour running period. Figure 4a shows the average PIN3/PIN1 ratio as a function of time for 8 hours of running. Figure 4b shows the average PIN2/PIN1 ratio for the same running period. Based on these results, the system is stable to 0.1% over 8 hours. However, a small spectral shift is observed at the beginning of each 30 minute running period.

3.2. Operation of Device at Test Beam

At the CERN test beam, another prototype monitoring system was used for calibrating the combined PMT and prototype KTeV digitizer. While the preliminary testbeam results using this procedure have been given,[3] final details on the calibration will be published at a later time. The discussion that follows describes only the calibration procedure.

The prototype KTeV digitizer developed at Fermilab has 9 different sensitivity scales (or ranges), each twice as sensitive as its neighboring range. The device contains internal comparators which determine the range of validity for a given signal size. During the test beam, this prototype KTeV digitizer was operated such that the top of range 9 corresponds to 510 pC. Finally, an 8-bit FADC digitizes $(Q_{signal} + Q_{bias})/2^{n-1}$, where n is the range of validity, and Q_{bias} is a constant bias charge added to the signal. Ignoring nonlinearities, calibrating this device consisted of determining the sensitivity (slope) and comparator thresholds (intercepts) for each of the 9 ranges. A more complete description of the KTeV digitizer is given in the reference.[2]

Figure 5a shows the response of the 8-bit FADC versus PIN diode (digitized by a LeCroy 2249W) for a given laser scan. The lines show the FADC outputs as the range of validity switches between 6 through 9. Calibration of this device consisted of fitting for the slopes and intercepts of each of the 9 ranges. Hence, for a given FADC value and range, one then converts to a linear scale given by a PIN diode.

Since the 2249W has only 11 bits dynamic range, one lacks the ability to fully cover all 9 ranges in a single laser scan. To cover the more sensitive ranges, one

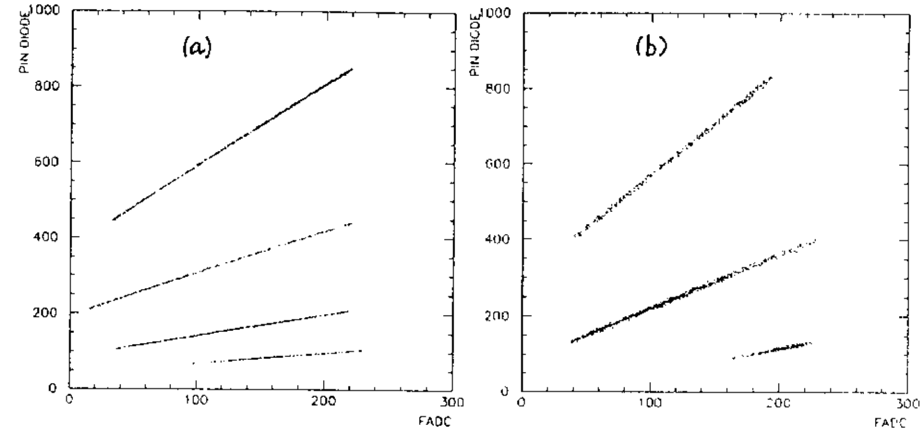

Figure 5: (a) PIN vs. FADC for ranges 6 through 9 and (b), PIN vs. FADC for ranges 2 to 4.

attenuates the light into the PMT's (using neutral density filters) *while* keeping the light into the PIN diode unattenuated. Figure 5b shows the ability of this technique to map the linearity of the lowest ranges of the KTeV digitizer. Finally, the data from scans of different filter values are merged together, thereby covering the full dynamic range of the KTeV device.

4. References

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