Hall D Note 068

Read-out System for a Barrel Calorimeter
(GlueX Project)

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Abstract

Photomultiplier tubes, hybrid photodiodes and silicon photomultipliers have been investigated under laboratory conditions as candidates for the read-out system of the HallD/GlueX barrel calorimeter at Jefferson Lab. The shapes of pulses among those read-out systems are presented here, with emphasis on the rise time and the pulse duration. The energy spectrum for a minimum ionizing particle traversing a scintillating fiber was measured with a photomultiplier tube and a silicon photomultiplier. The light output of a BC400 fast plastic scintillator, a double clad scintillating fiber with a 1 mm diameter and the OPTITRON light flasher were used as a source of light.

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I. INTRODUCTION

The electromagnetic barrel calorimeter is a crucial Hall D/GlueX [1] detector subsystem. The barrel calorimeter will be positioned immediately inside the superconducting solenoid, which constrains the outer radius to be 90 cm and results in an outer surface area of approximately 23 m^2. The barrel calorimeter must be thin, no more than 25 cm thick. This device is a key component of a hermetic system.

The goals of a read-out system for the electromagnetic barrel calorimeter are to obtain information about the energy of impinging particles (both neutral and charged), to determine the position of impact and to eventually use this information to restore the original parameters of the nuclear reaction products. As result, the read-out system has to have sufficiently good energy (about 1 %) and time resolution ($\approx$ 10 cm spatial resolution, that translates into a σ=150 ps for the Gaussian fit of a TDC spectrum).

As possible read-out systems for a barrel calorimeter, we have investigated these type of devices:

- traditional photomultiplier tube (PMT)
- hybrid photomultiplier diode (HPD)
- silicon photomultiplier (SiPM)

The barrel calorimeter is composed scintillating fibers embedded in a lead matrix and the peak emission of scintillation light from these fibers falls in the range of 300–500 nm. Additionally, there is a strong magnetic field ($\simeq$ 2 T) created by the surrounding superconducting solenoid. Finally, the anticipated count rate of events is about 10^6 events/s.

II. PHOTOMULTIPLIER TUBE

The photomultiplier tube (PMT) is a very versatile and sensitive detector of radiant energy in the ultra-violet, visible and near-infrared regions of the electromagnetic spectrum. Amplification ranging from 10^3 to as much as 10^8 provides output signal levels that are compatible with auxiliary electronic equipment without the need for additional signal amplification. A fast time response with rise time as short as a few nanoseconds, short

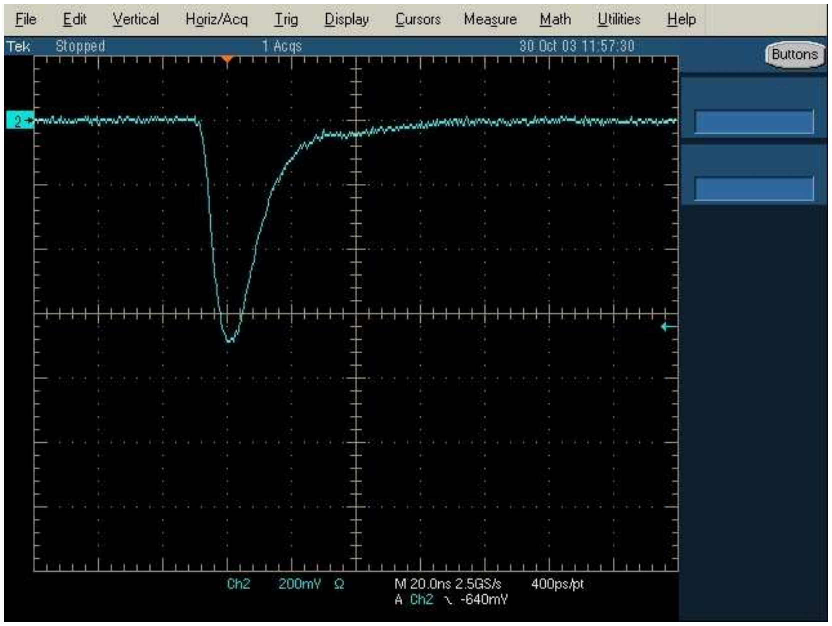

FIG. 1: A typical signal from a two inch PMT (^{137}Cs + 1 cm^3 scintillator, H.V.=1900 V).

pulse duration and good energy resolution implies a suitable read-out system for a barrel calorimeter.

The picture of a signal obtained from a typical two inch PMT (type BURLE 8575) is presented in Fig. 1. The signal has a 5–6 ns rise time and a 35 ns pulse duration. A 1900 V high voltage was supplied to the PMT. The PMT has measured the scintillating light output from a ^{137}Cs (E_γ = 661 keV) source detected in a 1 cm^3 fast scintillator. In this case, the ADC spectrum was measured with a LeCroy 2249A ADC and has a flat distribution up to channel 600 on a 1200 channel wide scale.

Unfortunately, such a PMT cannot operate properly in the high magnetic field Hall D environmental conditions. Nevertheless, in our next investigation, we will use the parameters of the signal from a PMT as reference data.

III. HYBRID PHOTODIODE

A hybrid photodiode (HPD) [2] or Hybrid Photomultiplier Tube (HPMT) is a novel light detector which combines a semitransparent photo-cathode with a semiconductor detector (reverse biased PIN Diode) in a vacuum tube. A photon that enters the tube through its entrance window can free an electron at the photo-cathode. The electron is accelerated by an electric field up to 8–15 keV energy (the energy depends on the supplied high voltage: 8–15 kV) and is detected by a reverse biased PIN Diode (silicon semiconductor detector).

In our measurements, we used a 25 mm proximity-focused, single-pixel Hybrid Photo Diode equipped with S20UV photo-cathode on a quartz input window (Model PP0350, Delft Electronic Products PV, DEP). This modification of HPD is optimized for light detection in strong magnetic fields.

The main parameters of a HPD (PP0350P) are follows:

1. gain - 1600 electrons/photo-electron
2. pixel capacitance - 200 pF
3. operating voltage - 8 kV
4. bias voltage for the diode - 80 V
5. overall size - diameter 52 mm, height - 17 mm

Because, the HPD has relatively small gain, the spectroscopy measurement requires a charge sensitive preamplifier with a low level of noise and a fast rise time. At present, tree different preamplifiers were constructed for the PP0350P HPD. The preamplifiers were developed at the University of Regina (CREMAT 101D [3]), Indiana University (OPA567 [4]) and TRINITI Institute (Russian Federation).

The CREMAT 101D charge sensitive preamplifier was used because the CR101D model combines a low noise with fast rise time performance. The minimum rise time of the CREMAT CR101D preamplifier is 12 ns, but because the PIN capacitance is about 200 pF, the total rise time of a signal going from CREMAT connected with the PP0350P HPD is about 170 ns. It is possible to decrease the rise time by changing the input capacity at the expense of signal amplitude. More detailed information on this is presented in a GlueX/HallD Design Reports [5,6].

The electronic circuit on the basis of the OPA657 amplifier was developed for us by Dr. Paul Smith from Indiana University (Bloomington). The OPA657 amplifier is not a charge sensitive preamplifier. The output signal from a current or voltage sensitive preamplifier is proportional to the ionization charge and is also inversely proportional to the input

FIG. 2: A picture of a typical signal from a HPD with an OPA preamplifier. The yellow line (channel 1) corresponds to the triggering signal, the blue line (channel 2) is the signal from the HPD + preamplifier and the red line (channel 3) is the signal from a PMT.

capacitance. Because the detector capacitance is usually a weak function of the temperature, the temperature drifts were causing drifts in the preamplifier gain and degradation of the energy resolution.

A picture of a typical signal from a HPD with a OPA preamplifier is shown in Fig. 2. The yellow line (curve 1 or channel 1) corresponds to the triggering signal, the blue line (curve 2 or channel 2) is the signal from a HPD + preamplifier and the red line (curve 3 or channel 3) is a signal from PMT.

The signal from preamplifier has relatively small amplitude (40 mV) and long duration (0.5 μs) in comparison with a signal from a PMT for the same level of input light (^{60}Co + 1 cm^3 scintillator in our case). With that pulse duration and 10^6 s^{-1} counte rate, the signals from a HPD + preamplifier will be overloaded and an additional electronic unit is required for the ADC spectrum measurements (for example: shaping amplifier).

The measurement of the time distribution for a HPD + preamplifier resulted in a distribution at least five times broader than that of a PMT. The σ's in a Gaussian fitting procedure were equal to 22.2 channels and 4.2 channels (1 ch = 50 ps) for HPD and PMT, respectively.

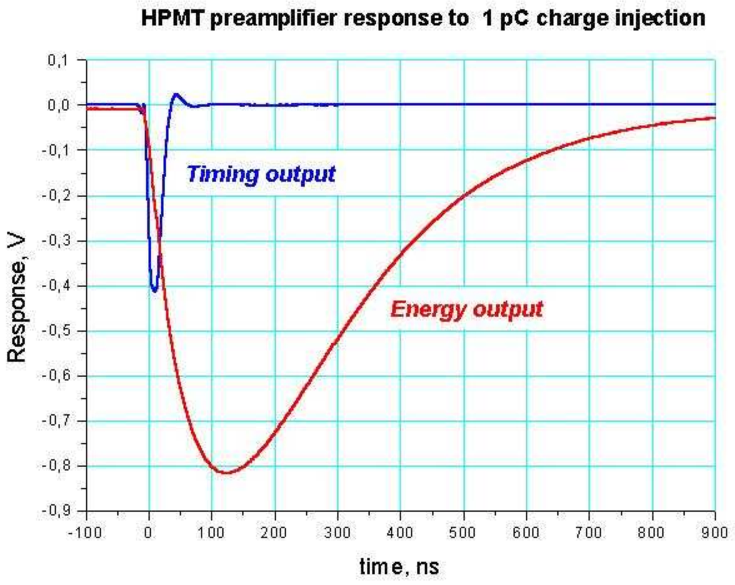

FIG. 3: HPD preamplifier response to 1pC charge injection.

The OPTITRON nanosecond broad spectrum optical pulse radiator (Model NR–1A) with a Nitrogen Plasma Discharge Tube was used as a source of light. The light pulses have a 1 ns rise time and a pulse duration of a few ns. A clear fiber with length about 5 m was used to transport the light from the OPTITRON pulse radiator to the sensitive surface of a PMT or a HPD.

The special charge sensitive preamplifier for PIN detector with 200 pF capacitance was developed for us in Moscow (Dr. A. Alekseyev). The charge sensitive preamplifier has two separate outputs for energy and time measurement. The response of a HPD + preamplifier to 1 pC charge injection is shown in Fig. 3.

IV. SILICON PHOTOMULTIPLIER

The Silicon Photomultiplier (SiPM) [7] is a multipixel silicon photodiode with a number of micropixels (typical size of 20–30 μm) joined together on a common substrate and working on common load. The pixels are electrically decoupled from each other by poli-silicon resistors located on the same substrate. The operational bias voltage is 10–15 V higher than the breakdown voltage, so each SiPM pixel operates in Geiger mode limited by the charge accumulated in pixel capacitance (typically 100 fF). The supplied bias voltage is 50–60 V.

FIG. 4: The shape of pulses from SiPM and PMT. A light flasher (OPTITRON) was used as a light source. The green and blue lines are signals from SiPM and PMT, respectively. The high voltage for the PMT was 1900V and the bias for the SiPM was 55.5 V.

Each pixel detects and amplifiers the charge from a photon independently, with a gain about 10^6. Essentially, each pixel operates digitally as a binary device, but the SiPM as whole is an analogue detector, that can measure the light intensity within the dynamic range of about 10^3 mm^{-2}. The total number of pixels is about 500, covering geometrically about 25 % of the total SiPM area of 1 mm^2.

The SiPM used in these tests was developed and produced by the Moscow Engineering and Physics Institute (Dr. B. Dolgoshein). The shape of signal, the time parameters and energy resolution were investigated and compared to the PMT (BURLE 8575) parameters.

Pulses from the SiPM and PMT are shown in Fig. 4. The OPTITRON light flasher (described in a previous section) was used as a light source. The green and blue lines are signals from the SiPM and PMT, respectively. The applied high voltage for the PMT was 1900 V and the bias for the SiPM was 55.5 V.

The signals from the SiPM and PMT have a similar structure, characterized by 1 ns and 4 ns rise times, respectively. The signal amplitude for the SiPM is about 300 mV, which implies that an additional amplifier is not required, and this signal was split and fed to an ADC (LeCroy 2249A) and a Constant Fraction Discriminator (CFD Tennelec TC455).

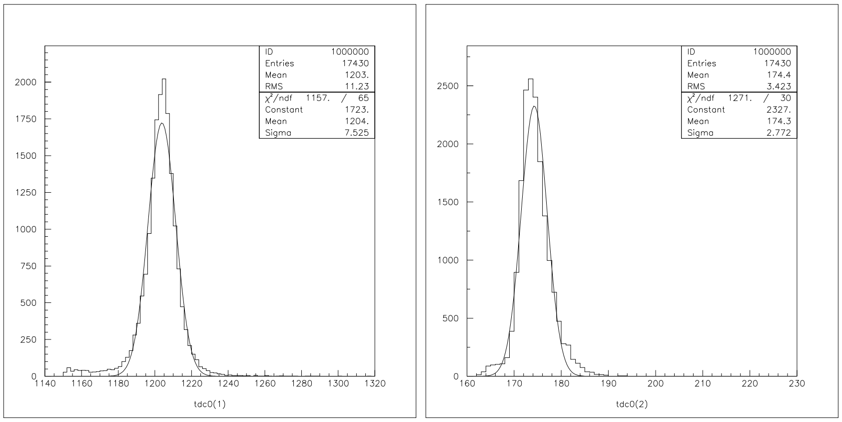

FIG. 5: The time distributions of pulses obtained from a PMT (left or tdc0(1)) and a SiPM (right or tdc0(2)). The spectra were fitted with a Gaussian function. The high voltage for PMT was 1900 V and the SiPM had a 55.5 V bias voltage.

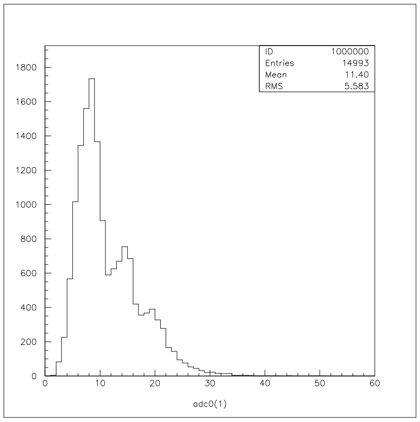

FIG. 6: SiPM pulse height spectrum for low intensity light pulses.

The time distributions of the pulses are shown in Fig. 5. In this measurement, the trigger signal from a light flasher acted as the 'start' signal for the TDC (LeCroy 2228A). The spectra were fitted with Gaussian functions, the time distribution for a SiPM has at least two times lower value of a Sigma (2.8 channels vs. 7.5 channels, or using the TDC conversion factor of 50 ps/channel, 140 ps vs. 375 ps) when compared to the PMT distribution. The high voltage for PMT was 1900 V and the SiPM had a 55.5 V bias voltage.

To investigate the energy resolution of the SiPM, we measured the spectrum from single photoelectrons created by the OPTITRON light flasher with neutral-density attenuation filters. For this measurement, we used a fast amplifier (LeCroy 612A) because the amplitude of signals from the SiPM was about 5–10 mV. Unfortunately, we could not eliminate

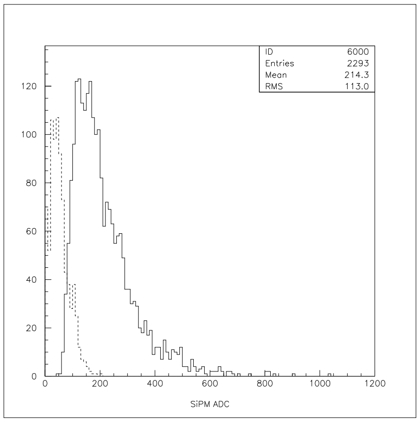

FIG. 7: The SiPM amplitude spectrum from a scintillating fiber irradiated by beta particles from ^{90}Sr radioactive izotope. The dashed line corresponds to the noise contribution when the ionization source was removed from the fiber.

completely the noise contribution from surrounded electronic equipment, and, as result, the signal amplitude distribution shown in Fig. 6 has only three peaks corresponding to 1, 2 and 3 photons detected by the SiPM. Traditional two inch PMT's cannot resolve single photoelectrons, although the five inch Burle 8854 PMT can produce similar to the SiPM high resolution spectra.

Fig. 7 shows the SiPM amplitude spectrum from a scintillating fiber irradiated by beta particles from ^{90}Sr radioactive isotope. The dashed line corresponds to the noise contribution when the ionization source was removed from the fiber. The electronics diagram is shown in Fig. 8. The high voltage for the PMT was 2300 V, the bias for a SiPM was 55.5 V and the activity of the ^{90}Sr radioactive isotope was 0.1 μCi. A special aluminium collimator for the beta particles was used. As a scintillating fiber we used the double clad Pol.hi.tech fiber with a 1 mm diameter.

V. CONCLUSION

Investigations of read-out systems for the GlueX barrel calorimeter were carried out at the University of Regina and are presented here. From these tests, it can be concluded that it is feasible to use a SiPM as a read-out system for the barrel calorimeter. SiPM's have better energy and time resolutions in comparison with PMT's and HPD's and are not

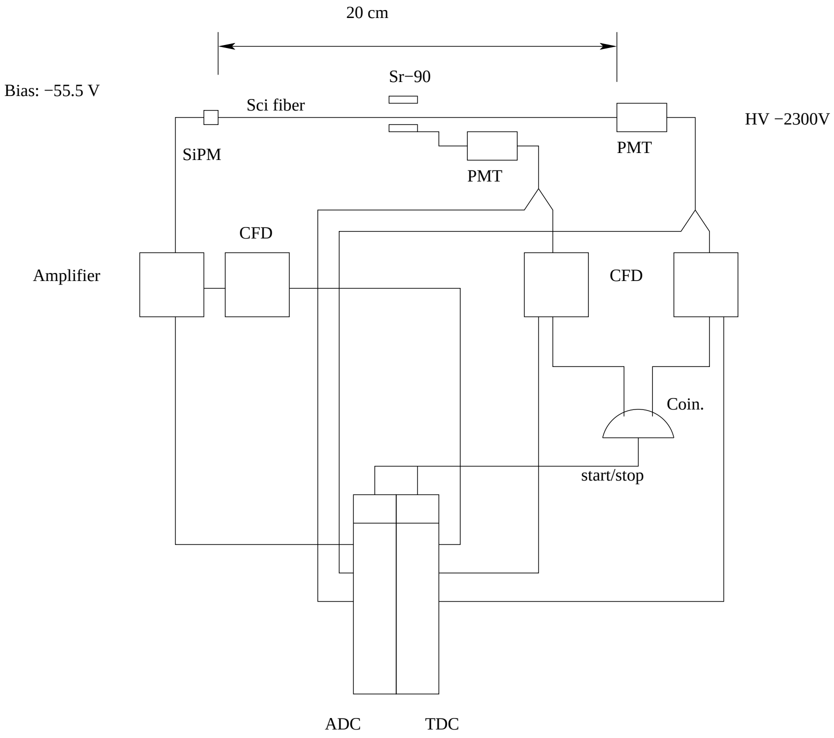

FIG. 8: The electronics schematic diagram of the experimental setup. The scintillating fiber is viewed by the SiPM at one end and by a PMT at the other end.

sensitive to a high magnetic field. Futhermore, SiPM's require a simple electronic sircuit and only a bias voltage (about 60 V) as opposed to a power supply voltage or a high voltage.

Our future plans for SiPM tests are:

- actual testing in a high magnetic field ($\simeq 2$ T)
- geometrical considerations of mounting (with or without a Winstone cone and wavelength shifters)
- Radiation Hardness Test
- Monte Carlo calculation the level of light signal from a barrel calorimeter
- test with a prototype calorimeter module with cosmic rays and under beam conditions

The SiPM is a very promising photodetector for a number of applications.

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