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Test of the PWO calorimeter prototype using Hall D Pair Spectrometer

Abstract

We performed a study of the 3x3 PWO calorimeter prototype using a secondary beam of electrons produced by the Hall D Pair Spectrometer. PWO crystals from two vendors SICCAS and CRYTUR were tested. These studies complement our previous measurements during the spring run of 2018, when the calorimeter prototype was instrumented with a built in divider and amplifier designed at Jefferson Lab []. The large gain of the amplifier (about a factor of 25) required to operate Hamamatsu R4125-01 PMTs at small high voltages (about 700 V) and, therefore, resulted in the degradation of the energy resolution. In the current test, the readout electronics was modified by bypassing the amplifier, which allowed us to increase the operational HV. The energy resolution for 4.7 GeV electrons was measured to be about 1.5 % for both SICCAS and CRYTUR crystals. The light yield for SICCAS crystals was found to be larger by about 6%.

1. Calorimeter Prototype

Fig. 1 shows a schematic view of the prototype mechanical structure. The prototype consists of a 3x3 matrix of PWO crystals, placed inside a brass box. The stack of crystals is fixed to the box using 3D-printed plastic holders. The front face of the prototype box is covered with a 2 mm thick plastic plate. The plastic mesh plate is placed in front of the crystal stack and is mounted to the prototype frame to prevent individual crystals from sliding in the forward direction. The crystals are wrapped with ESR reflector and a 30mkm thick Tedlar film to provide light tightness. Each crystal is coupled to a R4125-01 Hamamatsu PMT using an optical grease. The PMTs are attached to the crystals using two plastic holder plates. The front plate is attached to the side wall of the prototype frame and has nine holes allowing the PMT`s to slide in the forward direction towards crystals. The movable back PMT plate holds the PMTs and provides pressure needed for optical coupling using springs, which are connected between the plates in each corner. The back plate has holes for PMT pins, to attach dividers. The PMT is powered and read out using a HV divider with an integrated preamplifier designed at Jefferson Lab [1]. High voltage and signal cables are connected to the SHV and LEMO connectors installed in the back plate of the prototype box.

Our previous tests of the 3x3 calorimeter prototype, performed in spring of 2018, showed that the gain of the original divider-based amplifier was very large (a factor of 25), and thus required to operate PMTs at a relatively small voltage, between 650 V and 700 V. This voltage is significantly smaller than that recommended by Hamamatsu (of about 1.1 kV) for this type of PMT. The previous test of the prototype (and subsequent tests of the NPS large-scale prototype and Compton Calorimeter[2]) indicate the degradation of the energy resolution and some non-linearities of the calorimeter response for 'under voltaged' PMTs. In this prototype we test modified electronics, where the amplifier is bypassed. As a consequence, this allows us to increase HV to about 1.1 kV.

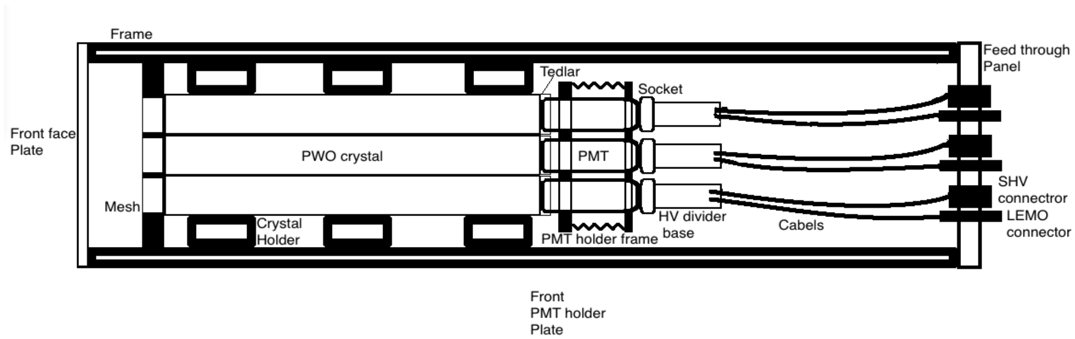

Fig. 1. Schematic view of the calorimeter prototype.

2. Hall D Pair Spectrometer and Prototype Installation

Performance of the calorimeter prototype was studied using secondary electrons provided by the Hall D Pair Spectrometer (PS)[3]. The schematic view of the Pair Spectrometer is presented in Fig. 2. Electron-positron pairs are created by beam photons in a 750 μm Beryllium converter. The produced leptons are deflected in a 1.5 T dipole magnet and are detected using two layers of scintillator counters positioned symmetrically with respect to the photon beam line. In each arm, there are 8 coarse counters and 145 high-granularity counters. The coarse counters are used in the trigger. The high-granularity hodoscope is used to measure the lepton momentum; the position of each counter corresponds to the specific energy of the deflected lepton. Each detector arm covers a momentum range of $e^{\pm}$ between 3.0 GeV/c and 6.2 GeV/c. The energy resolution of the pair spectrometer is estimated to be better than 0.6 %. The calorimeter prototype was positioned behind the PS as shown in Fig. 2.

The prototype of the TRD and GEM detectors placed in front of the calorimeter prototype did not allow to use the whole energy range of the pair spectrometer and limited the energy range to between 4 GeV and 5 GeV. The calorimeter prototype was aligned using a construction laser. The energy of electrons passing through the center of the middle module was measured using the PS hodoscope and corresponded to 4.7 GeV.

High voltages for nine prototype channels were provided by CAEN A1535SN module. Signals were digitized using fADC-250, which was installed in the existing the start counter VXS crate. Read out of the prototype was integrated to the global GlueX DAQ system. Data were collected in parallel with the GlueX, using the pair spectrometer trigger.

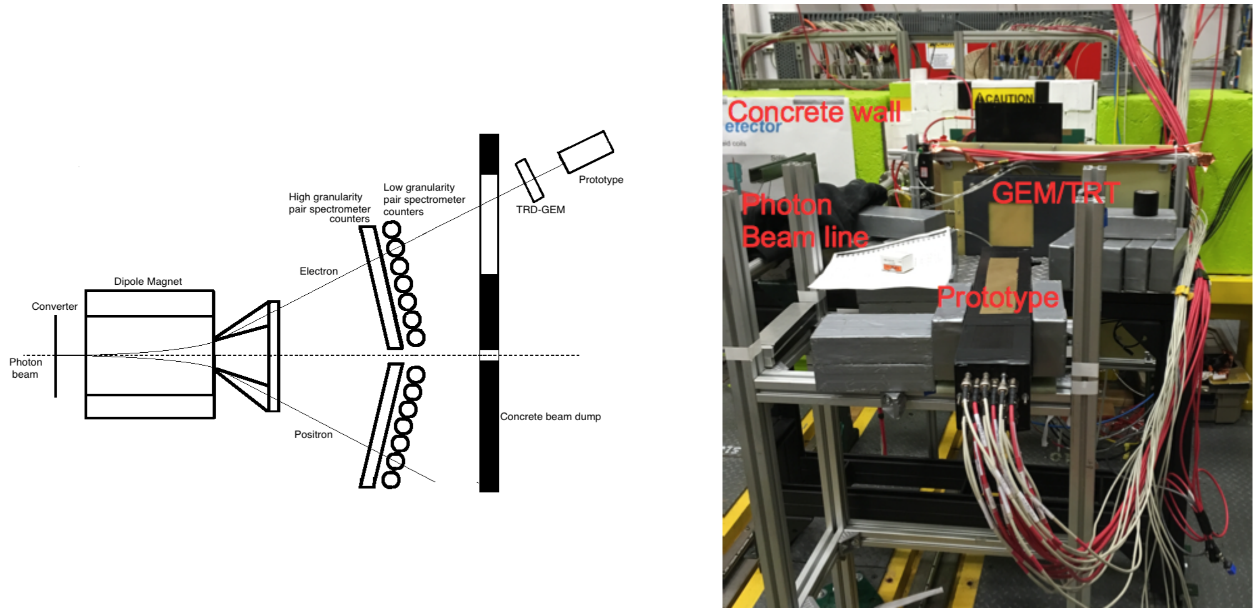

Fig. 2. Position of the calorimeter prototype behind the Hall D Pair Spectrometer

3. Beam Test

During the beam test, we set HV to about 1050 V for all calorimeter modules. For these voltages, signal amplitudes did not saturate the ADC range, whose maximum was set to 1 V. We read out signal pulse information from the ADC using two modes: signal waveforms without sparsification (no thresholds applied) and processed pulse information (pulse integral, peak amplitude). In the latter mode, the energy threshold of ~4 MeV was used. We did not observe any significant change in the energy resolution. Fig. 3 represents the fadc pulse peak amplitude for the central calorimeter cell as a function of the pair spectrometer hodoscope tile number. Each tile in the hodoscope corresponds to a specific electron energy. The energy of electrons hitting the center of the cell is 4.69 GeV.

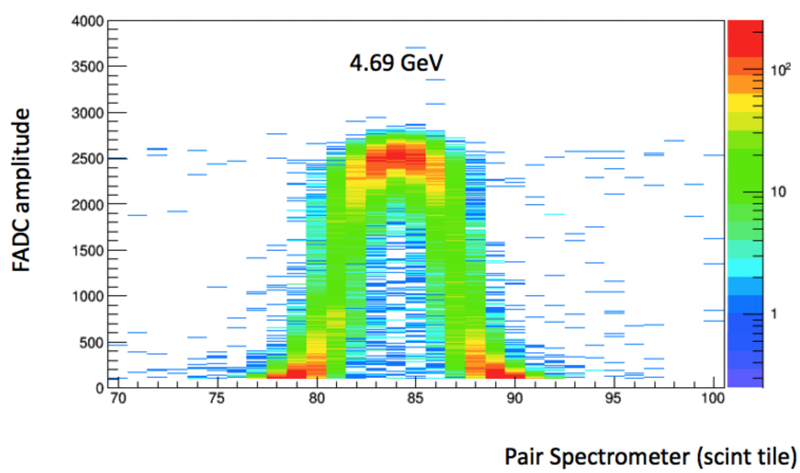

Fig. 3. Signal pulse peak amplitude in the central prototype module as a function of the Pair Spectrometer hodoscope tile number

3.1 Calibration and energy resolution

We calibrated the energy response (gain factors) of each calorimeter module using two independent methods:

- Direct energy calibration. Three modules in each row were calibrated by measuring energy depositions (in units of fadc counts) for electrons incident on the middle of each cell. Modules from other rows were subsequently calibrated by lowering and lifting the prototype by ±2 cm (the module size) and exposing corresponding rows to the beam.
- Using regression calibration. Calibration coefficients were obtained by minimizing the difference between the total energy deposited in the 3x3 calorimeter prototype and the electron energy reconstructed by the Pair Spectrometer. The calibration was performed for events where electrons hit the center of the middle module:

$$\sum_{events} \left(\sum_{i=1}^{Nseg} k_i A_i - E_{ps}\right)^2 \rightarrow min \quad (1),$$

where $Nseg$ is the number of modules in the cluster, k is the calibration coefficient, A is the signal pulse integral, and E_{ps} is the electron energy measured by the pair spectrometer. Equation (1) can be written as a linear system involving Nseg equations:

$$\frac{\partial\left(\sum_{events} \left(\sum_{i=1}^{Nseg} k_i A_i - E_{ps}\right)^2\right)}{\partial k_i} = 0 \quad (2),$$

The linear system can be expressed in the matrix form:

$$\begin{bmatrix} \sum_{events} A_1 A_1 & & \sum_{events} A_i A_1 & & \sum_{events} A_{Nseg} A_1 \\ \vdots & & \vdots & & \vdots \\ \sum_{events} A_1 A_j & \ddots & \sum_{events} A_i A_j & \ddots & \sum_{events} A_{Nseg} A_j \\ \vdots & & \vdots & & \vdots \\ \sum_{events} A_1 A_{Nseg} & & \sum_{events} A_i A_{Nseg} & & \sum_{events} A_{Nseg} A_{Nseg} \end{bmatrix} * \begin{bmatrix} k_1 \\ \vdots \\ k_j \\ \vdots \\ k_{Nseg} \end{bmatrix} = \begin{bmatrix} \sum_{events} E_{ps} A_1 \\ \vdots \\ \sum_{events} E_{ps} A_j \\ \vdots \\ \sum_{events} E_{ps} A_{Nseg} \end{bmatrix} \quad (3),$$

Matrix elements Ai in Eq (3) are filled event-by-event using pulse integrals reported by the fADCs. The distribution of the total energy deposited in the 3x3 calorimeter prototype before and after applying energy calibration is presented in Fig. 4. After calibration, the energy resolution was improved by a factor of 2. Gain factors computed with the two different calibration methods were found to be in a good agreement with each other.

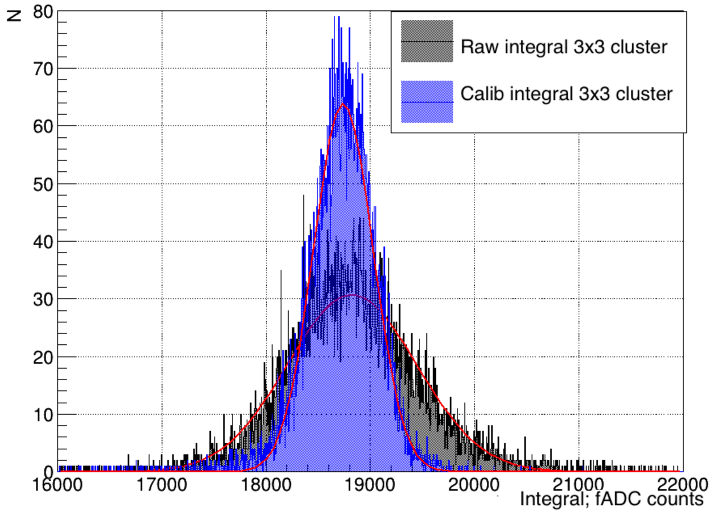

Fig. 4. Distribution of the total energy deposited in the 3 x 3 calorimeter in units of ADC counts before (black area) and after (blue area) calibration.

4. Results

The total energy reconstructed in the 3x3 calorimeter prototype instrumented with the original electronics (divider and amplifier with the gain of about 25) measured during the spring run of 2018 is presented in Fig. 5. Superimposed to the plot is a fit to the Gaussian function. The prototype was built using SICCAS crystals. The prototype dividers were operated at a relatively small high voltage of about 700 V. The energy resolution for ~4.7 GeV electrons was found to be about 2 %, which was somewhat large than expected.

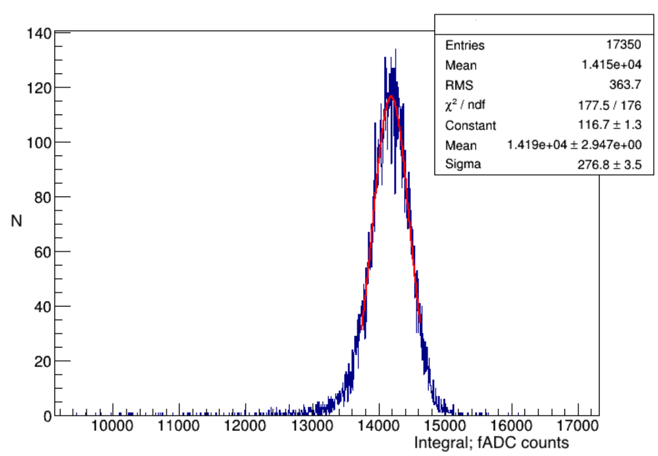

Fig. 5. Total energy deposition (in units of ADC counts) in the 3x3 calorimeter prototype measured in the spring run of 2018.

Fig. 6. a) and b) show reconstructed energy in the 3x3 calorimeter for ~4.7 GeV electrons incident on the middle of the central module. The calorimeter was constructed using CRYTUR and

SICCAS crystals and was tested during the spring run of 2019. The calorimeter was instrumented with modified electronics, where the divider-based amplifier was bypassed. This allows to increase HVs on the divider to about 1 kV, which is close to the HV recommended by Hamamatsu for R4125-01 PMTs. The measured resolution was ~1.6% and ~1.5% for CRYTUR, SICCAS crystals, respectively. The resolution is found to be in a good agreement with our subsequent measurements of the NPS large-scale prototype (Compton Calorimeter) and previous measurements of the HyCal calorimeter in Hall B. We also observed about 6 % larger light yield for SICCAS crystals, which can potentially account for slightly better energy resolution (Note: SICCAS crystals are known to have slightly larger light yield, though are less radiation resistant compared with CRYTUR crystals).

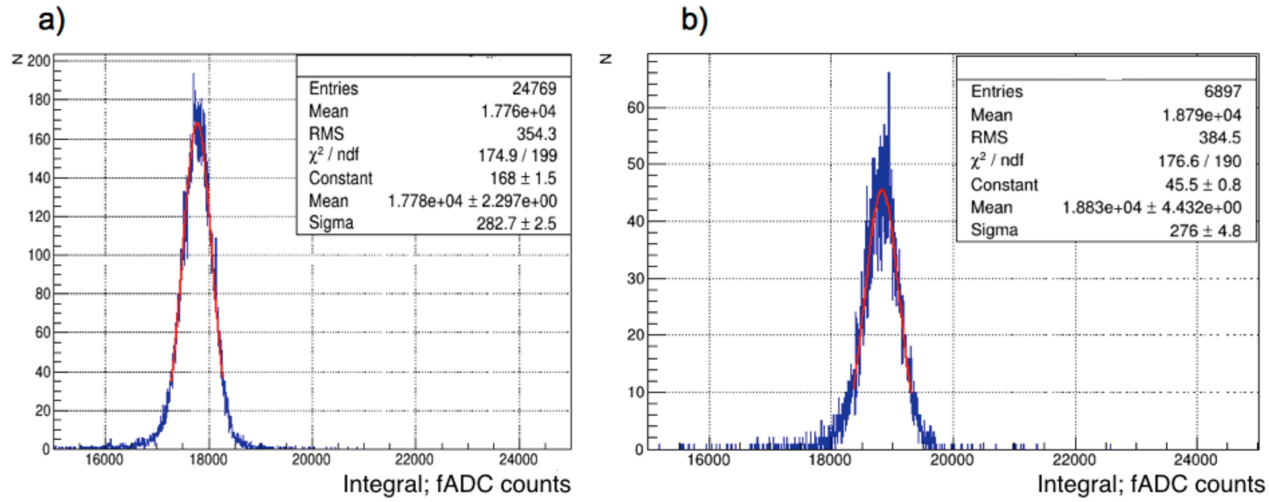

Fig. 6. Total energy reconstructed in the 3x3 calorimeter for 4.7 GeV electrons measured during the spring run of 2019: a) CRYTUR crystals, b) SICCAS crystals

Simple beam tests of the calorimeter prototype appeared to be interesting in estimating the energy resolution and comparing properties of the SICCAS and CRYTUR crystals. However, the relatively small energy range provided by the pair spectrometer did not allow us to study linearity of the divider and amplifier. These study were performed using the large scale prototype, the Compton Calorimeter and will be described in the new note, GlueX-doc-4000-v1.

References

[1] V. Popov, H. Mkrtchyan, New photomultiplier active base for Hall C Jefferson Lab Lead Tungstate Calorimeter, NSSS2012-1098

[2]

[3] F. Barbosa, C. Hutton, A. Sitnikov, A. Somov, S. Somov, I. Tolstukhin, Pair spectrometer hodoscope for Hall D at Jefferson Lab, Nucl. Instrum. & Meth. A795, 376-380 (2015)