WPJET4 Gamma Camera Upgrade (GCU)

D06	Evaluation of compact photon detector: **SiPM**, solid state device

Replacing the existing Gamma-ray detectors of the camera for improving the energy resolution and count rate capability needed for operation in the DT campaign. Target values are an energy resolution of 5% at 1.1 MeV and a count rate capability exceeding 500 kHz.

To design the best photon detector replacing the existing CsI:Tl scintillators coupled to PiN photodiode, three different sensitive light detection devices are taken into account: photodiode (PiN diode), Photomultiplier Tubes (PMTs) and silicon photomultipliers, often called SiPM.

Results from studies committed to a system based on photodiodes and photomultiplier tubes were presented in the D07 GCU report „Evaluation of compact photon detector: compact photomultiplier tubes, photodiodes”.

This report summarizes results obtained for a Multi Pixel Photon Counter (MPPC), one of the SiPM devices.

Multi Pixel Photon Counter (MPPC)

- **Advantages**
  - fast response
  - high gain resulting in good energy resolution
  - immunity to magnetic field
- **Main drawbacks**
  - gain sensitivity to temperature and voltage bias
  - limited dynamic range

Application of a MPPC photodetector has significant advantages in comparison with PiN-diode for scintillation readout, because MPPC has a large internal gain (~10^6) and PIN-diode gain is equal to unity. Therefore, MPPC output signal should be easily driven through 80 m cables even without a preamplifier. This useful feature results in a high count rate capability. However, there are few problems that need to be addressed:

- gain stabilization upon temperature fluctuations,
- correction for non-linear response at high gamma ray energy,
- evaluation of MPPC sensitivity to neutron damage.

In Fig. 1, a breakdown voltage as a function of MPPC temperature is shown. The 20 mm×15 mm cylindrical $CeBr_3$ scintillators coupled to MPPC was used in these measurements. A temperature difference of 1°C results in a MPPC voltage change of 0.0633 V.

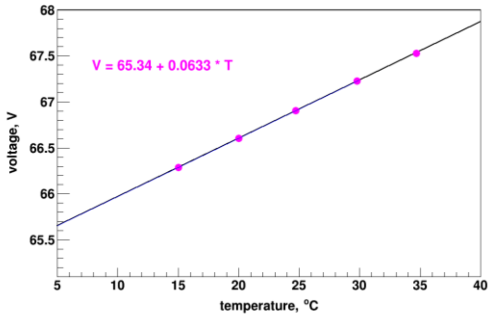

Fig. 1. Breakdown voltage as a function of MPPC temperature.

In Fig. 2 the spectrum measured at a constant temperature T=20°C is shown for two MPPC voltages: 65.7 and 66.0 V. Change in the MPPC voltage equal to 0.3 V corresponds to a shift in a ^{137}Cs peak position, equal to 345 analog-to-digital converter (ADC) channels of the used DAQ **Błąd! Nie można odnaleźć źródła odwołania.**. So, if the temperature difference is 1°C, the change in the peak position is about 70 channels and a voltage change equal to 0.0633 V is necessary to maintain a constant value of the MPPC gain.

In Fig. 3 a full energy peak position registered for 662 keV gamma-rays from a ^{137}Cs source as a function of bias voltage is shown.

Due to this very strong voltage-temperature dependence for MPPC-based detectors, a device for real-time temperature monitoring and MPPC gain stabilization was designed and produced at NCBJ. The MPPC Temperature Compensation Device (MTCD@NCBJ) is using a measured dependence of a breakdown voltage on temperature to maintain a constant value of the MPPC gain. MTCD@NCBJ provides a current limitation and filtering of the MPPC voltage and can supply an output voltage up to 80 V. All functions are controlled from a personal computer.

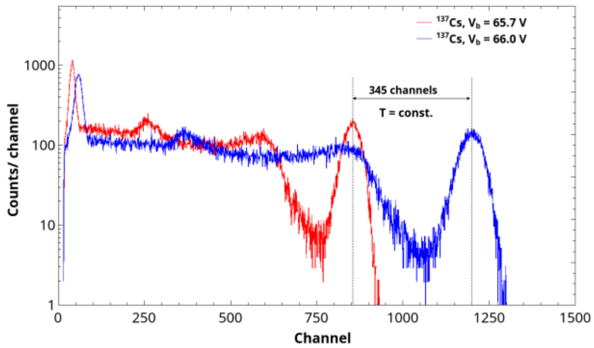

Fig. 2. ^{137}Cs spectra measured for two MPPC voltages: 65.7 and 66.0 V.

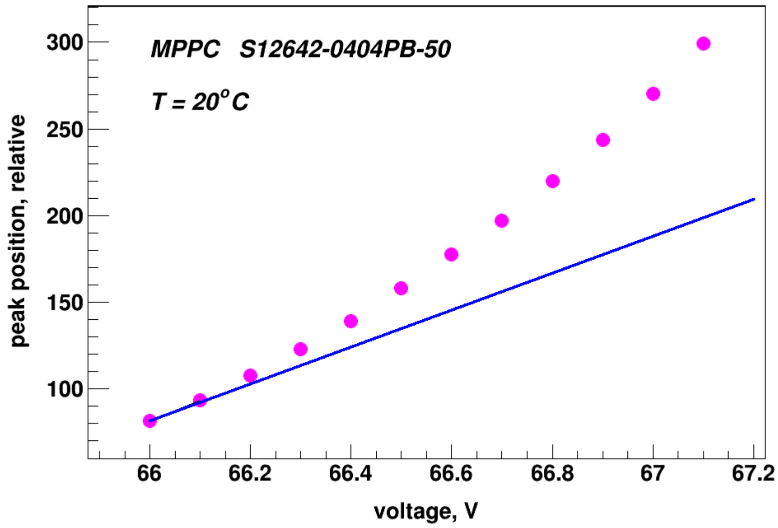

Fig. 3. Full energy peak position registered for 662 keV gamma-rays from a ^{137}Cs source as a function of bias voltage.

To evaluate a performance of a detector setup build with MPPC, measurements were done at JET.

Signals from MPPC were sent directly to the KN3G digitizer at JET. The MPPC bias voltage was set to -64.6 V. The 50 Ω termination was selected for digitizing the incoming signals. Several acquisitions were made at 2 different sampling rates, 50 Msps and 250 Msps, in two different operating modes:
i) raw data storage;
ii) segmented data storage (pulses).
We parametrized the shape of the pulse by a following equation:

$$U(t)=A*(1-\exp(-\ln(2)*(t-t_0)/t_{RISE}))*\exp(-\ln(2)*(t-t_0)/t_{FALL})+A_0 \quad (1)$$

where:

t_{RISE} - rise time,
t_{FALL} - fall time,
t_0 – time of start of the pulse,
A – amplitude of the pulse,
A_0 – amplitude offset.

The pulses have much lower amplitudes than obtained with the setup described above but still a very good SNR was observed. Moreover, the baseline was very stable. Thresholds for segmented data storage operating mode for both tested sampling acquisitions were easily found. Examples of signals registered for 50 Msps and 250 Msps are presented in Fig. 4 and 5. The 50 Ω impedance was used in the KN3G digitizer.

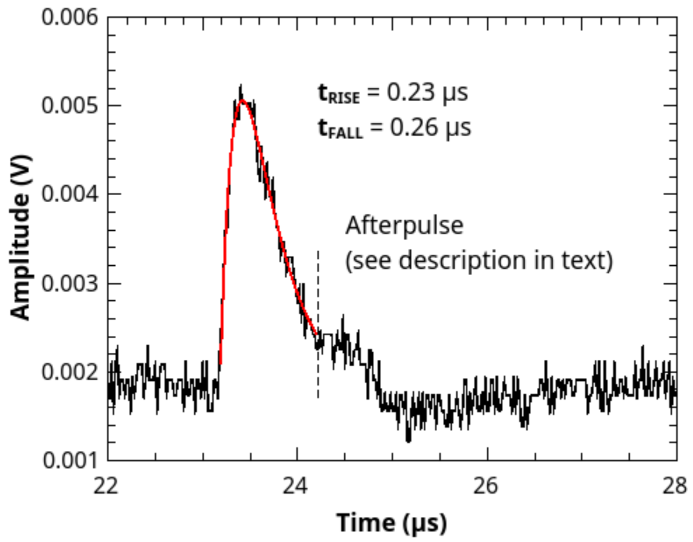

Fig. 4. Signal from MPPC, without a preamplifier, registered directly by the KN3G digitizer board at 50 Msps rate with 50 Ω termination. The red curve in the inset shows the best fit obtained with Eq. (1) for a rise and fall time of the signal equal to 0.23 μs and 0.26 μs, respectively.

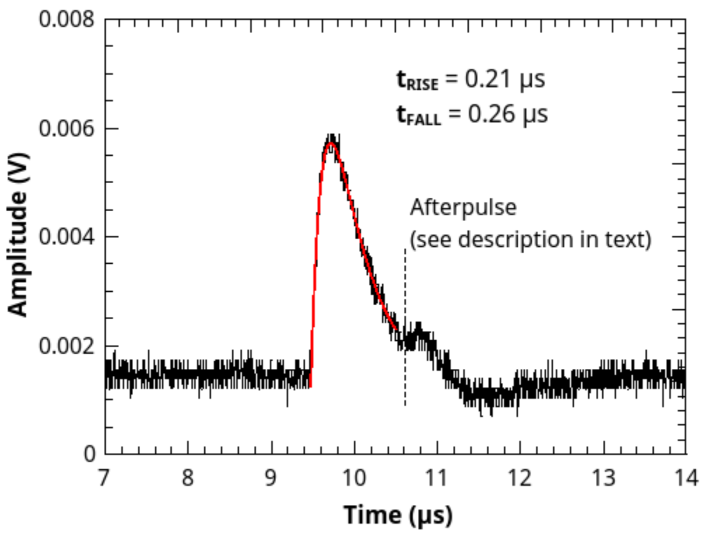

Fig. 5. Signal from MPPC, without a preamplifier, registered directly by the KN3G digitizer board at 250 Msps rate with 50 Ω termination. The red curve in the inset shows the best fit obtained with Eq. (1) for a rise and fall time of the signal equal to 0.21 μs and 0.26 μs, respectively.

Afterpulses were observed during measurements due to mismatch of a transmission cable impedance, equal to 75 Ω and a termination in our acquisition system equal to 50 Ω. These signals were delayed about 1 μs in comparison with main pulses.

The energy spectra of a ^{137}Cs source were built with a standard algorithm based on a pulse height, for both sampling rates. As an example in Fig. 6, the spectrum measured at 250 Msps rate is shown. 512 samples were used to store each pulse. The FWHM for 661.7 keV is equal to (7.6±0.1)%.

The energy resolution can be improved if a dedicated algorithm suitable for step like pulses is used, e.g., a trapezoidal filter.

To minimize observed reflection we decided to change short coaxial cables between the J1D cubicle and the KN3G digitizer board to new ones with impedance 75 Ω. The termination of KN3G digitizer was also changed to this value. The signal registered after these modifications is presented in Fig. 6.

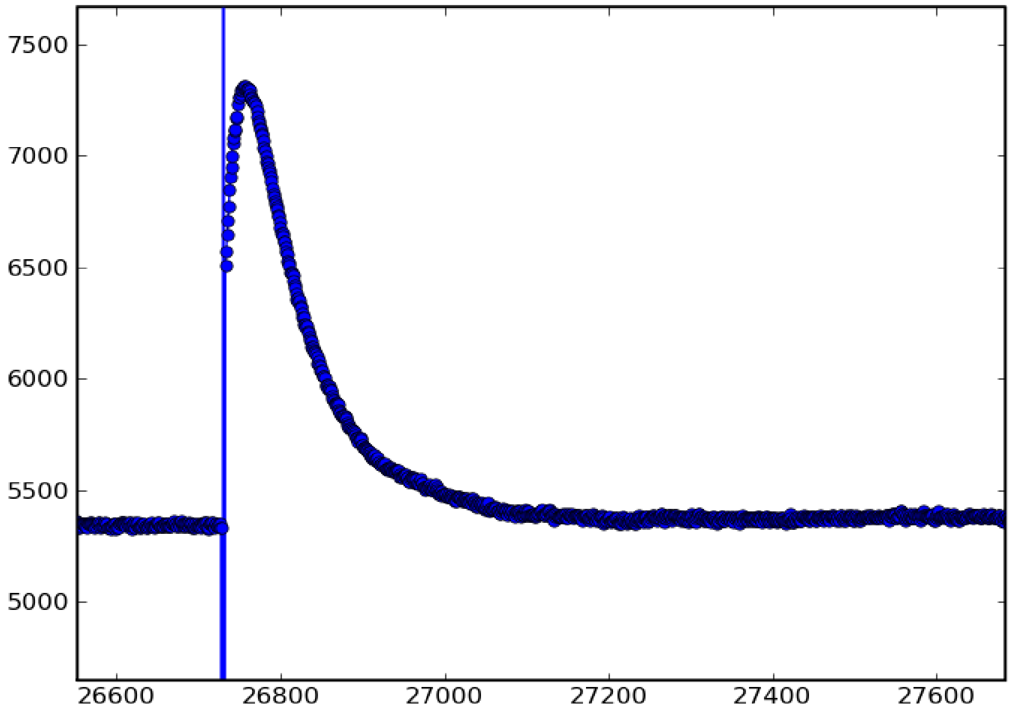

Fig. 6. Signal form MPPC based detector (ch 9) registered by KN3G digitizer. Digitizer was terminated by 75 Ω. Signals between J1D cubicle and KN3G digitizer were derived by 75 Ω coaxial cable. Single bin size corresponds to 5 ns length. Total length of the pulse is ~1.8 μs.

Due to the non-linearity of the MPPC, the energy calibration in a wide range is needed. We measured gamma energy spectra of ^{22}Na and AmBe sources for channel 9. Obtained spectra are presented in Fig. 7. Because of different gains in channels 1 and 3 of the KN3G digitizer, gamma energy spectrum of ^{22}Na was rescaled and adjusted to those from the AmBe source. The line 0.511 MeV, which is present in both spectra, was used as a reference point. This operation allows us to add an extra point (1.274 MeV line) in our calibration. Fig. 8 shows analyzed data and the non-linearity of MPPC based detectors. We observe good linearity only in energy range up to ~1.3 MeV. Above this level linearity is not maintained, so the energy of physical peaks cannot be estimated by simple extrapolation, like it was possible for CsI based detectors coupled to PIN diodes. Better accuracy of calibration may be obtained with a longer measurement time for both sources. Moreover additional calibration points can be added from natural background: 1.4 MeV from ^{40}K and 2.6 MeV from ^{208}Tl. These kinds of measurements should be done in the future for all 19 detectors.

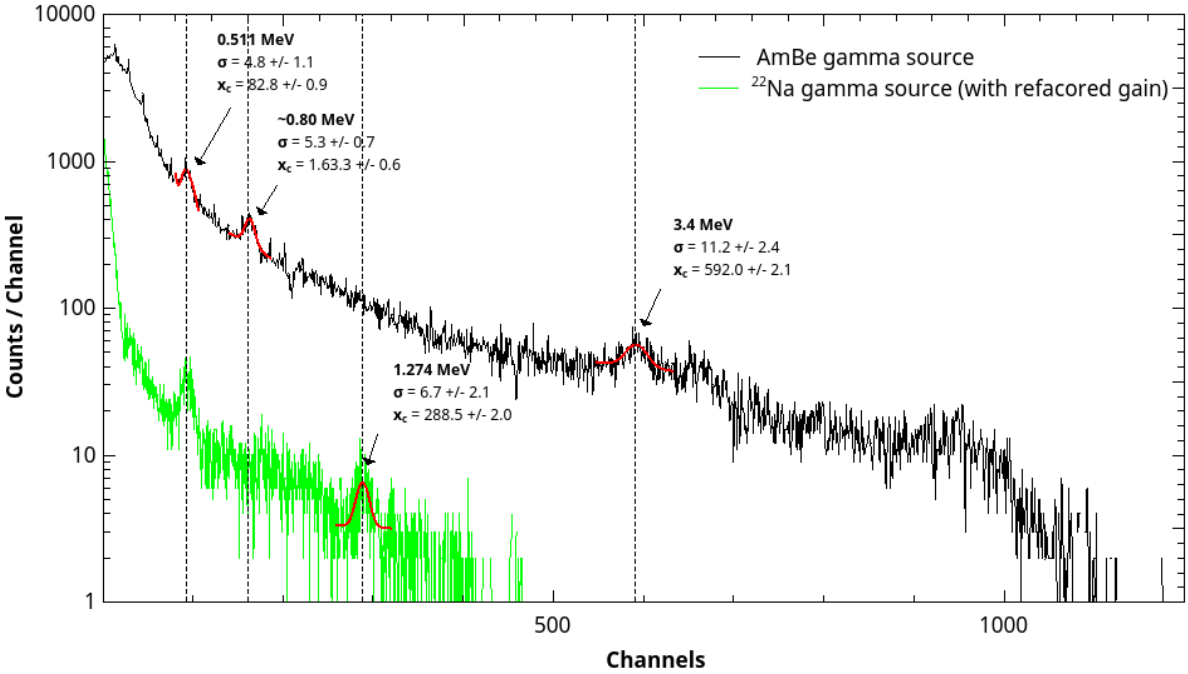

Fig 7. Gamma energy spectrum of AmBe and ^{22}Na. Both spectra from channel 9 were registered with the KN3G digitizer. Due to different gain for both channels of the KN3G digitizer, ^{22}Na energy spectrum was rescaled. As a reference point the 0.511 MeV line was used. Red lines correspond to fitted Gaussian functions. For each peak centroid and width (1 sigma) with one standard deviation value was obtained.

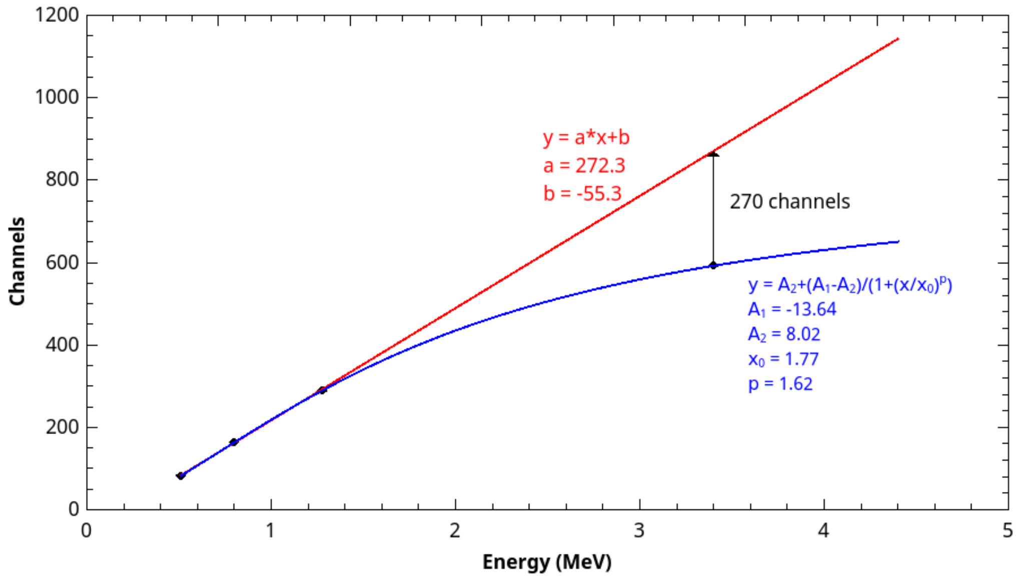

Fig. 8. The non-linearity in the energy scale of a MPPC based detector. Calibration points (black circles) were obtained for identified peaks in Fig. 7. Red line corresponds to linear fit based on first three points (range of 0.511 – 1.274 MeV). Blue curve is described by an arbitrary chosen equation to guide the eye.

Conclusions

1. From the obtained results it is concluded that setups based on a MPPC photodetector are the most suitable candidates for new prototype detectors. Detector are characterized by a good signal to noise ratio and short total length (~1 μs). These parameters allow to produce proper energy spectra with a good energy resolution, about 7-8% for full energy peak of ^{137}Cs.
2. Hardware for the triggering system of MTCD@NCBJ was positively tested at JET, software is under development.
3. Due to the non-linearity of MPPC, the energy calibration in a wide energy range for each detector should be done after installation at JET.

The report was prepared by the NCBJ team
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