Response of GAGG detectors with SiPM readout to high-energy gamma rays

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HYPATIA (HYbrid Photon detection Array To Investigate Atomic nuclei) is a planned new scintillator array to be used at the RIBF. The array will be a hybrid of two different materials, $CeBr_3$,[1)] and GAGG.[2)] These materials are expected to improve detection efficiency and energy resolution compared to DALI2$^+$.[3)]

For in-beam gamma-ray spectroscopy at the RIBF, typical lab frame gamma-ray energies extend to around ≈10 MeV. Silicon Photo-Multipliers (SiPMs)[4)] are planned to be used in the array. Due to the non-linearity of SiPMs,[5)] it is necessary to test whether these high-energy gamma-rays can be measured accurately and resolved from their escape peaks.

Gamma-rays of $E \leq$ 10.8 MeV were produced via the 992 keV resonance in the ^{27}Al$(p,\gamma)^{28}$Si reaction.[6)] The protons were ionized and accelerated to ≈1.05 MeV using the RIKEN Pelletron tandem accelerator.[7)] The setup was placed at BL-W15.[7)]

Eight $25 \times 25 \times 75$ mm^3 cuboid GAGG crystals were tested. For conciseness, the results for the two crystals from Kinheng (K1, K2) are shown. The crystals were wrapped in PTFE tape and coupled with SiPMs (S13361-6050AE-04[8)] for K1 and S13361-3050AE-08.[9)] for K2) The GAGG crystals were mounted into two 2×2 clusters with 3D-printed housing of the same dimensions as DALI detectors.[3)] A custom-built power supply and readout board were used to supply a temperature-corrected voltage and readout the SiPM signals. K1, and K2 were powered to voltages over breakdown of around 4.4 V, and 6.0 V, respectively. The signals were processed using a CAEN digitizer.[10)] The GAGG clusters were mounted on either side of the beam pipe centred on the target position. DALI2$^+$ detectors surrounded the clusters and were used as anti-compton shields.

The detectors were calibrated using stationary sources, ^{137}Cs, ^{88}Y and ^{60}Co; and the 2.8 MeV, 10.8 MeV (including its escape peaks) gamma-rays from ^{28}Si.[6)] Calibration functions included an exponential plus a constant for GAGG detectors and quadratics for DALI2$^+$ detectors. The calibration can be seen in Fig. 1 The peaks in the calibrated spectra were then fitted using a Gaussian function plus a quadratic background. The Gaussian parameters were used to determine the energy resolution of the full energy peaks used in the calibration.

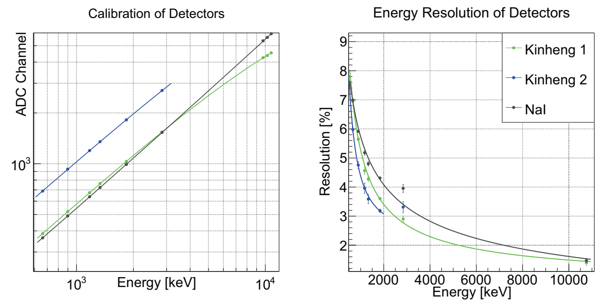

Fig. 1. (Left) ADC channel number for each peak with the corresponding calibration fits. (Right) Energy resolutions (FWHM) of the detectors at different gamma-ray energies. The two Kinheng crystals are compared to a representative DALI2$^+$ detector (NaI). The energy resolution curves were fitted using the function, $p_0 + p_1 E^{p_2}$.

The results of this analysis can be seen in Fig. 1. K2 saturated the dynamic range of the digitizer but performed well in the lower energy region. In contrast, K1 had a poorer energy resolution in the low-energy region, due to the lower applied bias voltage, nonetheless the 10.8 MeV gamma-ray was observed successfully. In contrast, K1 achieved an energy resolution of 1.4 ± 0.1% at 10.8 MeV, allowing for the separation of the full energy peak and escape peaks. While this performance is acceptable for HYPATIA, it could be improved by using a smaller SiPM pixel size.

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