Development of an offline energy calibration method for GAGG(Ce) calorimeter with cosmic rays

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The ONOKORO project aims to elucidate the mechanism of cluster formation in nuclei using the proton-induced cluster knockout reaction. The TOGAXSI telescope comprises GAGG(Ce) calorimeters and silicon strip detectors, and is under construction to realize cluster knockout measurement in inverse kinematics.[1)] To achieve a separation energy resolution of 2–3 MeV, the GAGG(Ce) calorimeters need to be calibrated within 1% accuracy.

It is crucial to establish the offline calibration method of the GAGG(Ce) calorimeter, because it is not feasible to calibrate more than 100 GAGG(Ce) crystals using expensive beams. However, the response only up to a few MeV can be calibrated using offline checking sources, while that from 100 MeV to 1 GeV is important for cluster knockout measurements. Thus, we have decided to use cosmic rays to fill this large gap, which provides typical energy deposit of 45 MeV and 154 MeV in horizontal and vertical injections, respectively.

The geometry of the GAGG(Ce) crystal is $35 \times 35 \times 120\ \mathrm{mm}^3$. Scintillation signals are read by photo diodes (Hamamatsu S3584-08) with light guides from both or single ends, for the detection of recoil protons and knocked-out clusters, respectively. The electric signals are then amplified and discriminated by a pre-amplifier (Mesytec MPR-32), and then digitized by the conventional VME modules (ADC V785 and TDC V1290). The cosmic rays were measured by employing the self-trigger scheme without any selection of the incident angle or position.

The energy loss of cosmic rays is known to follow the Landau distribution. Figure 1 illustrates the light output distribution of GAGG(Ce) for cosmic ray measurement. The distribution was fitted with two response functions: the simple Landau function and Landau function convoluted with the Gaussian function. The Landau function could not reproduce the behavior of the lower and higher tails. This is primarily because the intrinsic resolution of the detector is not reflected in the Landau function. Thus, we used the convoluted function to obtain a better result. The convoluted function improved χ^2 and better reproduced the lower tail; however, the higher tail and peak position were not reproduced well. This may be due to the position dependence of the detector response[2)] and trajectory distribution of cosmic rays, which yield an asymmetric effect in the smearing of the light output. Therefore, we are planning follow-up measurements that eliminate these factors by adding tracking detectors to measure the incident angle and position simultaneously.

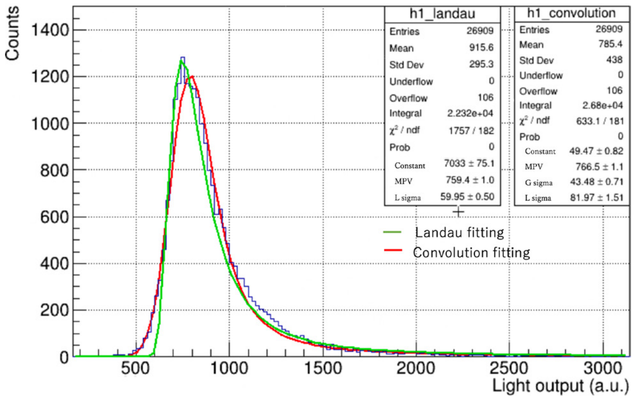

Fig. 1. Light output distribution of the GAGG(Ce) crystal for the cosmic ray measurement.

The most probable value of the convoluted function was considered as the peak position of the distribution. The peak positions of seven GAGG(Ce) detectors have a spread of 15%, which is consistent with the intrinsic variation of the light output per unit energy of the GAGG(Ce) crystals. The light output of these seven detectors was relatively calibrated so that the peak positions had the same value.

For three of the detectors, the accuracy of the calibration was evaluated to be 1% with the beam with known energy, which satisfies the requirement. We are planning further measurement with cosmic rays for more crystals.

References
1) Y. Kubota *et al.*, in this report.
2) R. Tsuji *et al.*, RIKEN Accel. Prog. Rep. **56**, 83 (2022).

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