Improved energy resolution for HYPATIA using multiplicity-based Doppler correction

J. S. Cachaya,[*1,*2] P. Doornenbal,[*1] and M. L. Cortés[*1] for HYPATIA Collaboration

To advance the study of radioactive nuclei with in-beam γ-ray spectroscopy at RIBF, the HYbrid Photon detector Array To Investigate Atomic nuclei (HYPATIA) array designed to be composed of HR-GAGG (Ce) and $CeBr_3$ scintillation crystals, is expected to replace the Detector Array for Low Intensity radiation 2 ($DALI2^+$). This upgrade aims to enhance energy and time resolution while also improving the peak-to-total ratio and detection efficiency.[1)]

A key challenge in γ-ray spectroscopy is Doppler correction, which is required to address energy shifts caused by γ-rays emitted in flight.[2)] This requires determining the emission angle, which depends on where the γ-ray was absorbed. This position is approximated using the geometrical center. The first interaction (FI) point can be calculated using detailed simulations, which represents the average location within the detector where γ-rays deposit most of their emission energy. The FI point provides a more accurate basis for Doppler corrections, which ensures reliable results across the array.

The Add-Back procedure is used to increase the peak-to-total ratio by interpreting γ-rays detected in neighboring crystals as scattering events from the same initial γ-ray.[3)] The energies are summed as if fully absorbed in the first detector, and the FI point is then used for Doppler correction. This method is effective, in improving the full energy peak (FEP) efficiency. However, the current method can still be refined. Given the way the FI point is determined, it translates to only considering events with a multiplicity of 1. Consequently, most interaction points for these events are near the center of the detector (Fig. 1, Left), where full energy deposition is more likely. For higher-multiplicity events, interactions occur closer to the edges (Fig. 1, Right), as this increases the likelihood of detecting the second γ-ray in a nearby detector.

In the HYPATIA project, we aim to improve the resolution by calculating the FI point based on event multiplicity. For multiplicity 1, the previously used FI point remains applicable, while for higher multiplicities, new FI points must be determined, considering both event multiplicity and the direction of the second γ-ray scatter. This adjustment is necessary because interaction points tend to cluster near detector edges, and simple averaging would place the FI point near the center, misrepresenting the actual interaction location. This method is expected to improve energy resolution for each multiplicity, which leads to an overall enhancement.

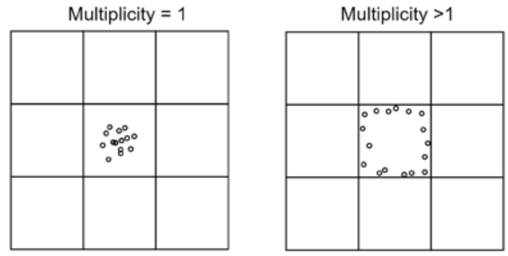

Fig. 1. Interaction points for γ-ray events: Multiplicity 1 (center), Multiplicity > 1 (near adjacent detectors).

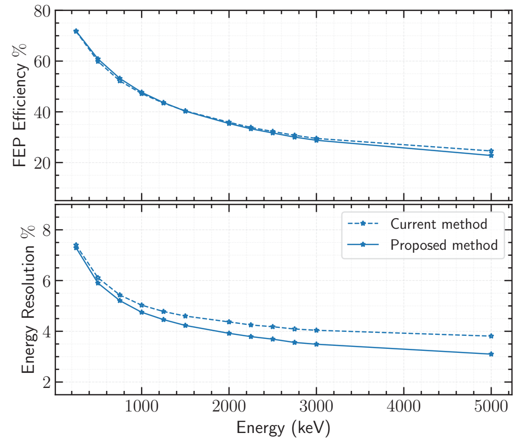

Fig. 2. Comparison of FEP efficiency and energy resolution vs. γ-ray energy for current and proposed Doppler-corrected methods, simulated at 100 MeV/nucleon using configuration 26.[1)]

Figure 2 shows the FEP efficiency and energy resolution obtained using the current and proposed methods from a simulation at 100 MeV/nucleon with configuration 26. The top panel illustrates that both methods yield similar results. The bottom panel reveals that the proposed method achieves lower energy resolution values, indicating better resolution. This difference becomes more noticeable with an increase in the γ-ray energy. Because, the averaged FI point aligns the corrected energies with the spectral peak but also introduces broadening in the current method, which degrades resolution. However, because of the longer absorption length of NaI (Tl) crystals and their size, this method is not applicable to the $DALI2^+$ array. Full implementation is still in progress.

References
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*1 RIKEN Nishina Center
*2 Department of Physics, National University of Colombia

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