Monte Carlo Simulations of the AGATA Demonstrator Array coupled to the PRISMA magnetic spectrometer

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The goal of the AGATA project is the construction of an array of high-purity germanium detectors with very high photopeak efficiency (larger that 40%) and peak-to-total ratio (larger than 50%) under a wide range of experimental conditions. Such values can only be achieved by operating the HPGe detectors in position-sensitive mode so as to be able to reconstruct the scattering path of each photon inside the crystals (this process is known as \(\gamma\)-ray tracking). The information on the interaction points within the detectors is extracted by comparing the observed signal shapes with “reference” signals corresponding to interactions taking place in known points. This process, known as pulse shape analysis, requires using electrically-segmented crystals and digital electronics. In the initial phase of the AGATA project, a subset of the array, known as the AGATA Demonstrator Array, will be built to prove that the pulse shape analysis and the \(\gamma\)-ray tracking data processing can actually be performed in real time, which is a key issue of the project. The AGATA Demonstrator Array will be composed of 15 crystals, arranged into 5 triple clusters, as shown in Figure 1, and will be first installed at the Laboratori Nazionali di Legnaro, where it will be coupled to the PRISMA magnetic spectrometer, replacing the CLARA array. The expected performance of the AGATA Demonstrator Array in terms of photopeak efficiency will be comparable to the existing arrays, with values ranging from 3% to 8% depending on the distance from the target at which the detectors will be placed. The major improvement will actually be the much better quality of the spectra, resulting from the 5 mm FWHM position resolution expected from the pulse shape analysis process. In order to perform Doppler correction in a proper way, it will be essential to exploit the full information provided by the PRISMA spectrometer, which can measure the vector velocity of the recoils on an event-by-event basis as well as provide full mass and charge selection.

The Doppler correction capabilities of the AGATA Demonstrator Array coupled to the PRISMA magnetic spectrometer were evaluated by means of Monte Carlo simulations. Detailed codes for the separate description of AGATA and PRISMA had been developed previously.

The code for AGATA \(^1\) is based on the Geant4 libraries and can describe in detail the response of the array for a range of standard experimental conditions via a simplified built-in event generator. For less standard cases or for a more sophisticated physical description of the experiment “realistic” events can be decoded from formatted files. The code does not include the tracking process, which must be performed with an additional program.

The code for PRISMA, instead, does not rely on external libraries. In its original implementation \(^2\), the code merely performs the transportation of ions from the target to the focal plane, relying on a detailed map of the magnetic field inside the quadrupole, which was calculated through finite elements methods, and on a simplified description of the magnetic fields inside the dipole. In the present work, the existing code for PRISMA has been extensively modified in order to accept the same input files as AGATA. The full focal plane information is obtained through stopping power calculations based on the Ziegler subroutines \(^3\). Rather than porting this code to our Geant4 standard, we decided to keep its original structure and mimic instead the future behaviour of the AGATA and PRISMA data acquisition systems. Both the codes for AGATA and PRISMA would process (in parallel) the same input events, producing separate outputs which are merged into a single file containing tracked gammas and ions. The merging of the two data streams is performed on the basis of the event number. The merged event can subsequently be analysed to produce gamma spectra in coincidence with given ions.

The full AGATA array was designed in order to produce a close approximation of an ideal spherical shell, with the detectors placed at approximately 24 cm from the target position. The Demonstrator Array will be a much more compact object. Since there are no collimators in front of each detector, contrary to what is done in case of “conventional” arrays, the detectors could be placed also at different target-detector distances than the design 24 cm value. In the case of the Demonstrator Array, this will be performed through a rigid displacement of the whole array. The closest foreseen target-detector distance, having therefore the largest photopeak efficiency, corresponds to a displacement of 10 cm towards the target position. In the following, we will refer with “Demo-14” to the array in this position and with “Demo-24” to the array at the nominal 24 cm distance.

FIG. 1. Pictorial view of the AGATA Demonstrator Array, composed of 15 detectors arranged into five triple clusters.
An example of the results obtained in the present work is presented in Figures 2 and 3. These simulated spectra were produced considering 1 MeV photons emitted by $^{90}\text{Zr}$ nuclei entering PRISMA with an average energy of 350 MeV and a Gaussian dispersion with FWHM=80 MeV. The values for the $^{90}\text{Zr}$ ions, as well as the maximum magnetic fields in the dipole and in the quadrupole and the pressure in the ionization chamber, were chosen to match the average distribution of ions and the PRISMA setting in an actual CLARA-PRISMA experiment. In Figure 2 the Demo-14 configuration is considered. Doppler correction of the detected $\gamma$-ray energies was performed using only the average value of the velocity module and direction of the nuclei detected in PRISMA, that is considering that the $^{90}\text{Zr}$ ions with an energy of 350 MeV recoil through the central trajectory. The obtained peak FWHM is 7.7 keV. Considering the same average 350 MeV energy but deducing the recoil direction from the start detector of PRISMA the peak FWHM reduces to 5.5 keV. If instead the full information from PRISMA is considered the peak FWHM improves to 3.0 keV. As shown by the spectra of Figure 3, where a simulated spectrum for CLARA is compared to the simulated spectra for the Demo-14 and Demo-24 configurations, this value is significantly better than the performance of CLARA coupled to PRISMA.

The peak FWHM for the AGATA Demonstrator Array is close, in both reported cases, to the intrinsic resolution of the detector. This proves that it will be possible to operate the AGATA Demonstrator Array at the close distance from the target position, where a photopeak efficiency of 8% is expected, without significant losses in spectrum quality. This result is a very encouraging starting point for the future campaign of experiments with the AGATA Demonstrator Array at the Laboratori Nazionali di Legnaro.