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Realistic simulations of the AGATA Demonstrator+PRISMA spectrometer

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ABSTRACT

The performance of the AGATA Demonstrator Array coupled to the PRISMA magnetic spectrometer has been evaluated consistently by using detailed Monte Carlo simulations of the two devices. Results for the multi-nucleon transfer reaction $^{48}Ca+^{208}Pb$ at 310 MeV beam energy are presented and discussed in this study. The present results suggest that the Doppler correction capabilities of the AGATA+PRISMA setup will be very close to the intrinsic energy resolution of the germanium detectors.

1. Introduction

The purpose of the AGATA project is the construction of an array of highly segmented high-purity germanium detectors with photopeak efficiency larger that 40% and peak-to-total ratio larger than 50% under a wide range of experimental conditions. Such performance values cannot be reached with conventional techniques, rather this array will be based on newly developed techniques known as pulse shape analysis and γ-ray tracking. 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 γ-ray tracking data processing can actually be performed in real time, which is a key matter of the project [1]. The AGATA Demonstrator is composed of 15 germanium crystals, grouped into 5 triple cryostats. It is presently starting operation at the Laboratori Nazionali di Legnaro (LNL), Italy, where it has replaced the CLARA array at the target point of the PRISMA magnetic spectrometer.

The expected performance of the AGATA Demonstrator Array in terms of photopeak efficiency will be comparable with existing conventional 4π arrays, with values ranging from 3% to 7% depending on the distance from the target at which the detectors will be placed [2]. The major improvement will actually take place

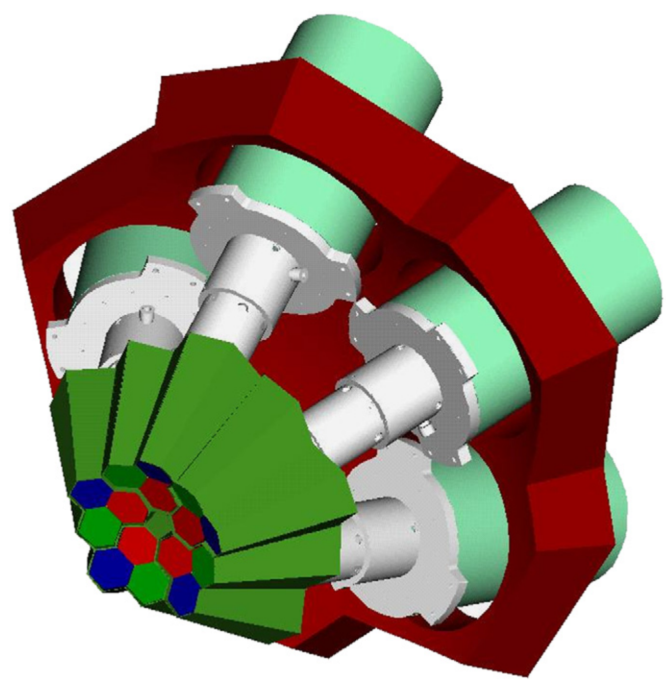

Fig. 1. Pictorial view of the AGATA Demonstrator Array, composed of 15 detectors arranged into five triple clusters.

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in the quality of the Doppler-corrected spectra, as a consequence of the 5 mm FWHM position resolution on the single interaction point expected from the pulse shape analysis process. In order to perform Doppler correction in a proper way, the information provided by the PRISMA magnetic spectrometer will be instrumental. PRISMA is a large-acceptance magnetic spectrometer for heavy ions, based on a quadrupole+dipole configuration, 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 excellent performance of PRISMA are obtained through a software reconstruction of the individual ion trajectories, starting from the basic information provided by position-sensitive detectors placed close to the target position and at the focal plane [3].

In this work, the results of the realistic Monte Carlo simulations for the AGATA Demonstrator+PRISMA setup are presented (Fig. 1).

1.1. The simulation codes

We will not discuss here the details concerning the Monte Carlo codes describing AGATA and PRISMA, which can be found elsewhere. The code for AGATA 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 or by decoding the event structure and sequence from formatted text files [4,5]. The code itself does not include the tracking process, which is essential to evaluate in a realistic way the performance of the array and which must be performed with an additional program, in our case the *mgt* tracking code [6]. The code for PRISMA, instead, does not rely on external libraries. In its original implementation, 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

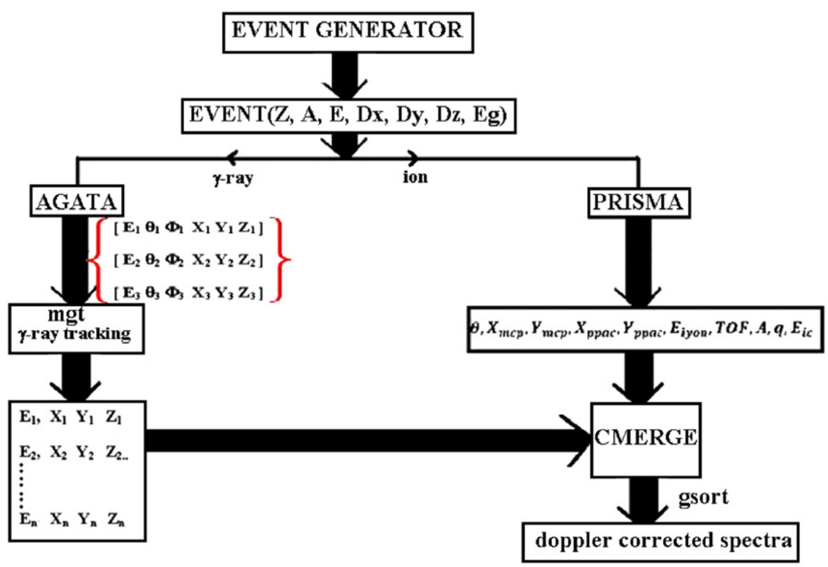

Fig. 2. Scheme of AGATA Demonstrator+PRISMA simulation.

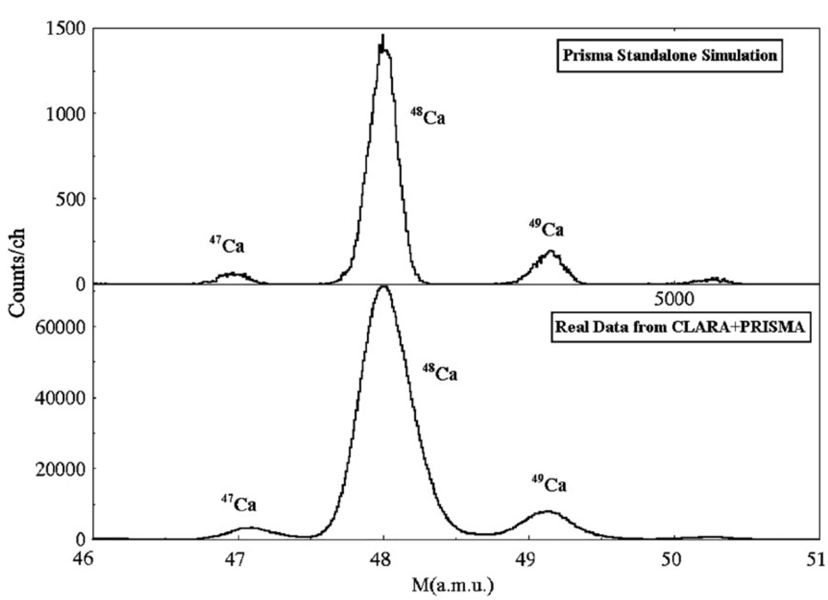

Fig. 3. The comparison results for Ca isotopes between PRISMA standalone simulation and real data from CLARA+PRISMA experiment.

was calculated through finite elements methods, and on a simplified description of the magnetic fields inside the dipole. In this work, the existing code for PRISMA has been modified in order to accept the same input files as AGATA. This actually mimics the future behaviour of the AGATA and PRISMA data acquisition systems. Both the codes for the AGATA and the PRISMA simulations can process the same input event file. The output of the AGATA simulation (after tracking) and of the PRISMA simulation are combined into a single event file by a merging code [7] combining the event fragments on the basis of the event number. The resulting event file, containing ion-gammas coincidences, can be analyzed by using other programs, in our case the GASP [8] data analysis package modified for the analysis of real data from the CLARA–PRISMA setup [9]. This simulation scheme is shown in Fig. 2.

2. Realistic event generator

In order to generate a realistic distribution for the ions entering PRISMA, experimental data from the ^{48}Ca(@310 MeV)+^{208}Pb multi-nucleon transfer reaction, studied previously with CLARA–PRISMA, were used. In the experiment, a 0.300 mg/cm^2 thick target was used and the spectrometer was placed at 61° with respect to the beam direction [10]. The basic idea was to "replay" the real data within the simulation and analyze its results in a consistent way to the experimental data. Any distortion in the resulting mass distributions would point to some problem with the simulation itself. This was performed by producing formatted event files in the format accepted by the simulations for AGATA and PRISMA, containing the sequence of ions entering PRISMA, each of them emitting a single photon, and by using the

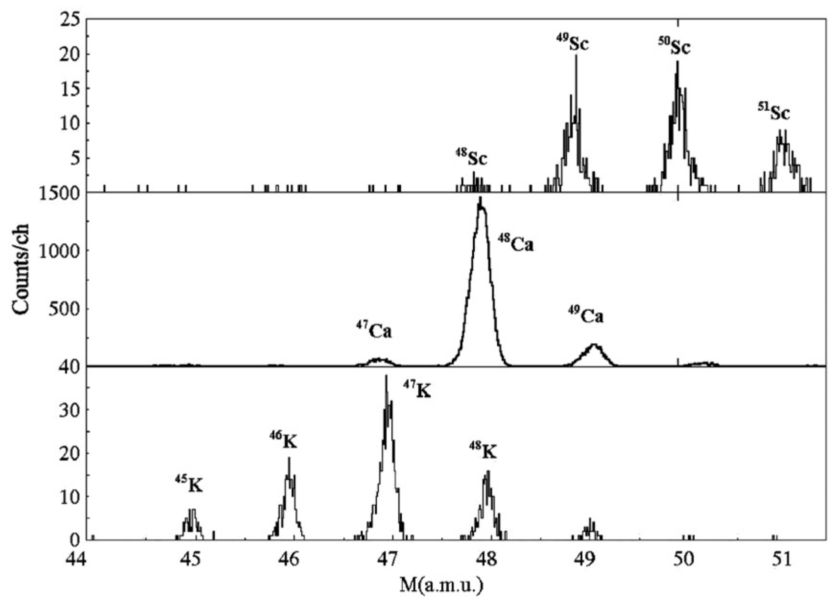

Fig. 4. The mass distributions of Sc, Ca, and K reaction products of the ^{48}Ca+^{208}Pb reaction at PRISMA simulation.

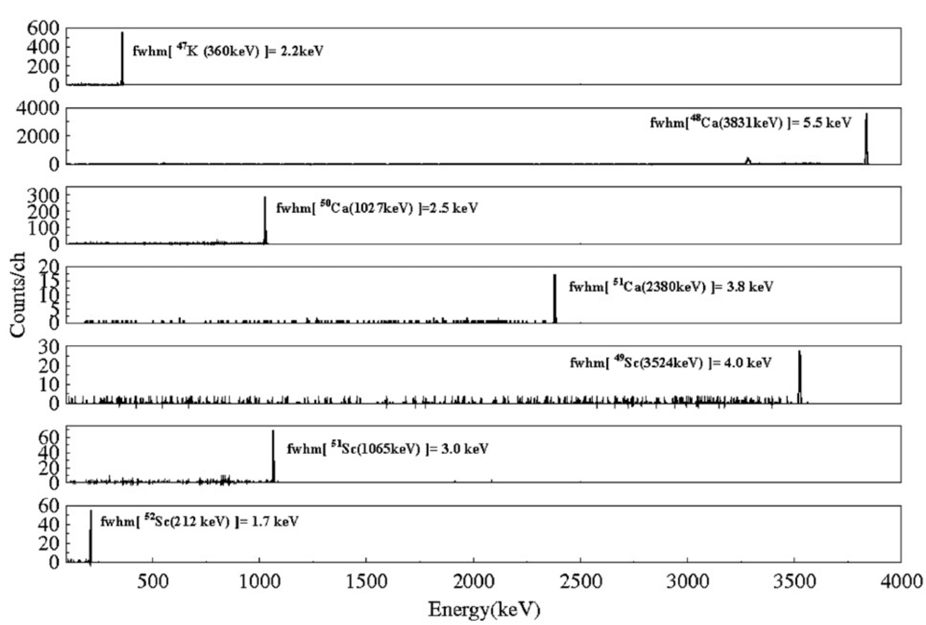

Fig. 5. Doppler-corrected peaks for the following ions: ^{47}K (360 keV), ^{48}Ca (3831.80 keV), ^{50}Ca (1027 keV), ^{51}Ca (2380 keV), ^{49}Sc (3524 keV), ^{51}Sc (1065 keV), ^{52}Sc (212 keV).

simulation codes as discussed previously. It should be remarked that the simulated data were analyzed for consistency with the same technique and the same data analysis code used for the actual PRISMA data.

The comparison of the mass spectra for the calcium isotopes obtained from the experimental data directly or after replay in the simulation is shown in Fig. 3. The relative intensities of each calcium isotopes are indeed conserved, suggesting that the simulation has no obvious problem. The resulting simulated mass spectra for the scandium, calcium, and potassium isotopes are instead shown in Fig. 4.

The next step involved including the AGATA Demonstrator in the above discussed simulation, placing the detectors 10 cm closer to the target position with respect to their nominal distance, and using the event-by-event information provided by PRISMA to perform proper Doppler correction. The results shown in Fig. 5 prove that indeed the intrinsic resolution of the germanium crystals is almost fully recovered. For instance, the Doppler-corrected FWHM of the 1027 keV transition in ^{50}Ca is 2.5 keV, which should be compared with the 2.2 at 1332 keV that were considered for the intrinsic germanium resolution.

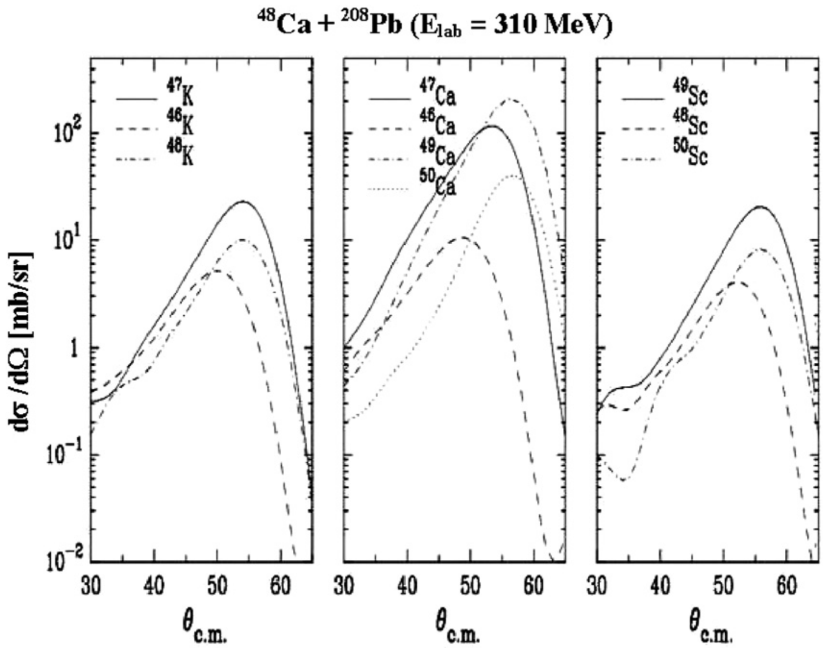

Fig. 6. Differential cross-sections and angular distributions calculated with the Grazing code for the ^{48}Ca (310 MeV)+^{208}Pb reaction. Data are calculated in the centre-of-mass reference frame.

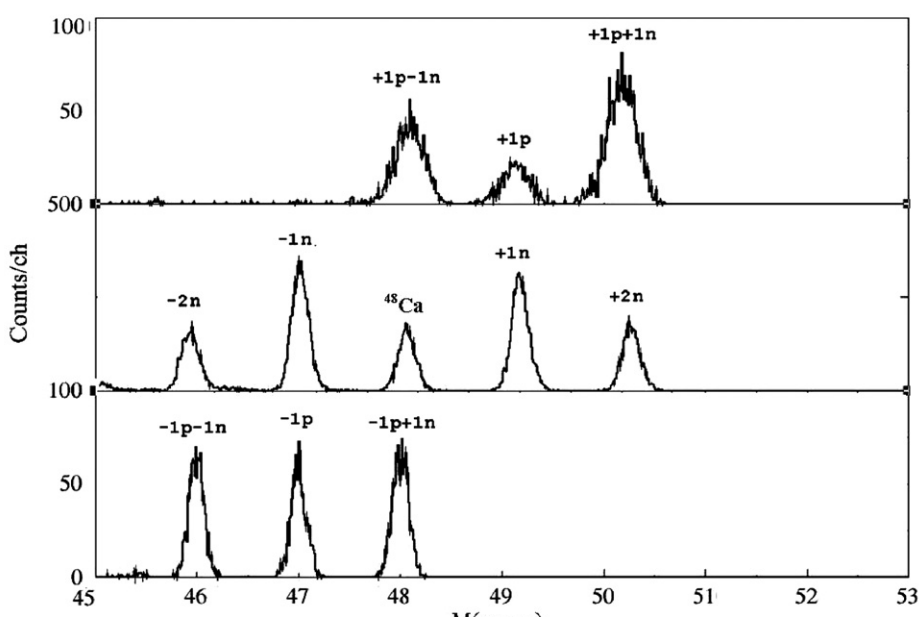

Fig. 7. Mass spectra of the simulated data.

3. Event generated by reaction model

Following the validation of the PRISMA simulation with experimental input data, an event generator for multi-nucleon transfer reactions was developed, based on the Grazing code [11,12]. Here we present results for the same ^{48}Ca+^{208}Pb reaction discussed above.

The Grazing code produces differential cross-sections, angular distributions, and total kinetic energy losses for all open channels of the reaction. In this case, the open channels are ^{46,47,48}K, ^{46,47,48,49,50}Ca, ^{48,49,50}Sc. Differential cross-sections for these channels are shown in Fig. 6. The ejectile nucleus is randomly selected according to these cross-sections. The cumulative distribution functions obtained from the angular distribution and the total kinetic energy loss (TKEL) data are used for random selection of the ejectile angle and excitation energy, respectively. Only the events in which energy and momentum are conserved are taken into account and it is assumed that the excitation energy is equally distributed between the ejectile and its partner nucleus. Only reaction products within the range of the start detector of PRISMA are accepted and the appropriate gamma-ray cascade, constrained by the excitation energy, is assigned to the nucleus of interest.

Figs. 7 and 8 show, respectively, the resulting simulated mass and velocity distribution for the ions, where the simulated data were analyzed as discussed above. The Doppler correction capabilities of the AGATA Demonstrator coupled to PRISMA are exemplified by the results for ^{46}Ca and ^{50}Ca shown in Figs. 9 and 10. The relevant data and FWHM values are tabulated in Table 1. Also in this case the FWHM of the Doppler-corrected spectra is very close to the intrinsic germanium resolution.

4. Conclusion

The Doppler correction capabilities of the AGATA+PRISMA setup have been evaluated through detailed Monte Carlo simulations, including realistic event generation based both on

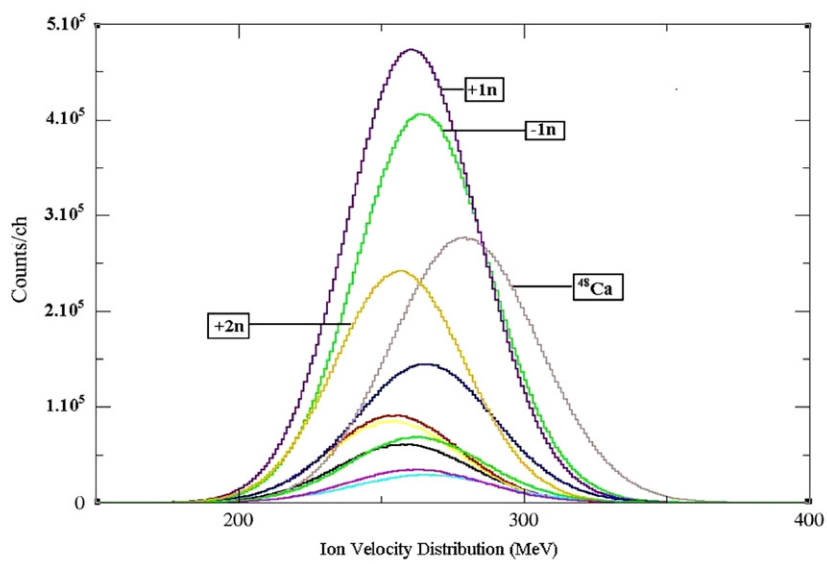

Fig. 8. Velocity distribution of the simulated data.

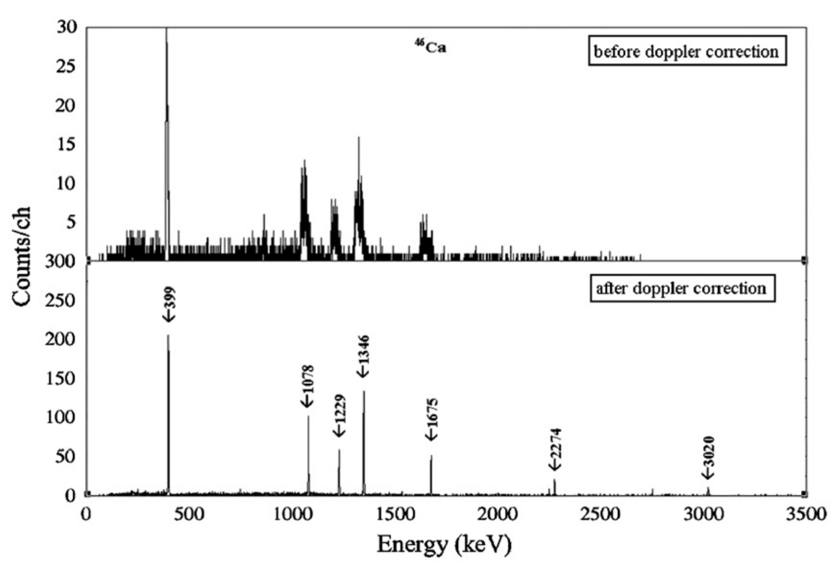

Fig. 9. Comparison between uncorrected and Doppler-corrected spectra for the ^{46}Ca isotope.

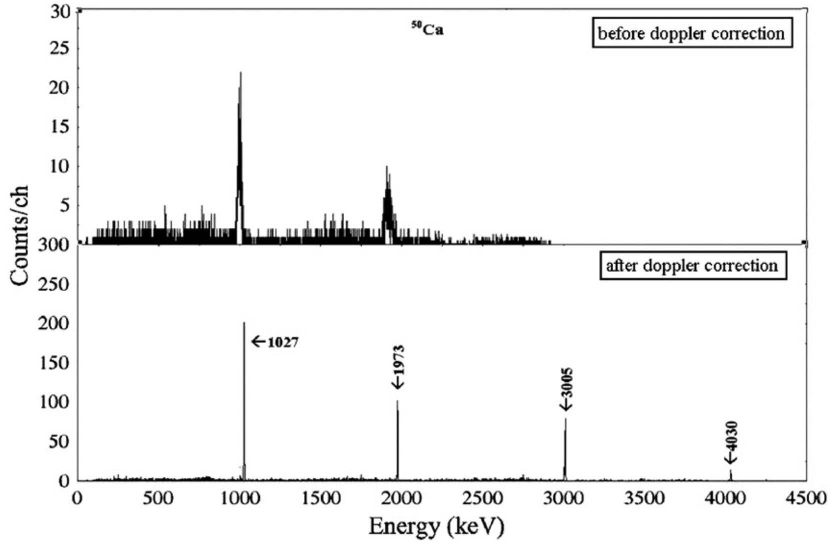

Fig. 10. Comparison between uncorrected and Doppler-corrected spectra for the ^{50}Ca isotope.

Table 1
The FWHM values of γ-ray energy lines, which appear with the Doppler correction at AGATA Demonstrator+PRISMA simulation for ^{46}Ca and ^{50}Ca isotopes.

Reaction products	γ-ray energy(keV)	Decay	The first level	The last level	Intensity (%)	Γ=FWHM (keV)
^{46}**Ca**	3020.0	E 2	6	1	63	**5.1**
	1675.0	M 1	6	2	100	**3.7**
	1346.0	E 2	2	1	100	**3.4**
	399.2	E 2	5	4	100	**2.4**
	1228.7	E 2	4	2	100	**3.1**
	1346.0	E 2	2	1	100	**3.4**
	1077.5	E 2	3	2	100	**3.2**
	1346.0	E 2	2	1	100	**3.6**
	2274.0	E 1	7	2	100	**3.5**
	1346.0	E 2	2	1	100	**3.4**
^{50}**Ca**	1973.0	–	3	2	100	**3.6**
	1027.0	E 2	2	1	100	**3.0**
	3005.0	–	6	2	100	**5.0**
	1027.0	E 2	2	1	100	**3.0**
	4030.0	–	6	1	100	**5.4**

experimental data and on reaction models. In all cases, the effective energy resolution including Doppler correction was found to be very close to the intrinsic resolution of the detectors, which is a very encouraging starting point for the future campaign of experiments with the AGATA Demonstrator Array presently starting at the Laboratori Nazionali di Legnaro, Italy.

Acknowledgement

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