In-beam test of the AGATA prototype triple cluster

F. Recchia\textsuperscript{1,2}, D. Bazzacco\textsuperscript{1}, E. Farnea\textsuperscript{1}, R. Venturelli\textsuperscript{1}, T. Beck\textsuperscript{3}, P. Bednarczyk\textsuperscript{3}, A. Bürger\textsuperscript{4}, A. Dewald\textsuperscript{5}, M. Dimmock\textsuperscript{6}, G. Duchêne\textsuperscript{7}, J. Eberth\textsuperscript{5}, T. Faul\textsuperscript{7}, A. Gadea\textsuperscript{8}, J. Geri\textsuperscript{9}, R. Gernhaeuser\textsuperscript{3}, K. Hauschild\textsuperscript{10}, A. Holler\textsuperscript{5}, P. Jones\textsuperscript{11}, R. Krücken\textsuperscript{9}, N. Kurz\textsuperscript{3}, J. Ljungvall\textsuperscript{12}, P. Maierbeek\textsuperscript{8}, D. Mengoni\textsuperscript{13}, J. Nyberg\textsuperscript{12}, L. Nelson\textsuperscript{9}, G. Pascoli\textsuperscript{1}, P. Reiter\textsuperscript{3}, H. Schaffner\textsuperscript{3}, M. Schlart\textsuperscript{9}, T. Steinhardt\textsuperscript{5}, O. Thelen\textsuperscript{5}, D. Weißhaar\textsuperscript{5}

\textsuperscript{1} INFN Padova  \textsuperscript{2} Univ. of Padova  \textsuperscript{3} GSI Darmstadt  \textsuperscript{4} CEA Saclay  \textsuperscript{5} IKP Koeln  \textsuperscript{6} Univ. of Liverpool  \textsuperscript{7} IReS Strasbourg  \textsuperscript{8} INFN Legnaro  \textsuperscript{9} TU München  \textsuperscript{10} CSNSM Orsay  \textsuperscript{11} JYFL Jyväskylä  \textsuperscript{12} Univ. of Uppsala  \textsuperscript{13} Univ. of Camerino

\section*{INTRODUCTION}

The most powerful $\gamma$-arrays of the present generation, namely EUROBALL [1] and GAMMASPHERE [2], having a photopeak efficiency of the order of 10\% and a peak-to-total ratio of the order of 50\%, are composed of hundreds of High Purity Germanium crystals surrounded by anti-Compton shields. Their performances are insufficient for the future studies using radioactive beams, but, on the other hand, it is not feasible to build an array with better performance based on the conventional technology. The next generation of arrays for in-beam $\gamma$-ray spectroscopy will be based instead on the novel concepts of pulse shape analysis (PSA) and $\gamma$-ray tracking. This implies identifying the energies and positions of the individual $\gamma$ interactions within the germanium crystals (PSA) and following the scattering path of the incoming photons. In the past few years, two projects have been started with the goal of building such an array: AGATA in Europe and GRETA in the USA. In particular, AGATA will be built out of 180 detectors grouped into 60 triple clusters, while the configuration for GRETA will comprise 120 crystals grouped into 30 quadruple clusters.

The performance of a tracking array depends critically on the precision with which the PSA algorithms identify the individual interaction points: the Doppler correction capability and the efficiency of the tracking algorithm strongly depend on the obtainable position resolution. For this reason it was considered of fundamental importance to determine experimentally such value for the prototype cluster detector of AGATA, consisting of three 36-fold electrically segmented HP-Ge crystals [3].

\section*{THE EXPERIMENT}

Any technique to measure the position resolution in a direct way implies determining the interaction points of the photons and comparing them with the corresponding values provided by the PSA algorithm. Although this is possible in principle, it is hardly feasible in practice since it relies on coincidence measurements and extremely tight collimated photon beams, resulting in very long measurement times to collect enough statistics.

In the recent past, the position resolution which can be obtained with PSA technique has been deduced from the Doppler correction capabilities of photons emitted in-flight following a nuclear reaction [4]. Since the Doppler broadening of the peaks depends both on the uncertainty on the photon direction and on the uncertainty of the vector velocity of the emitting nucleus, the position resolution can be evaluated, provided that the uncertainty on the source velocity is minimized, for instance by direct or indirect detection of the recoils.

The position resolution for the AGATA Triple Cluster prototype was measured in an in-beam experiment performed at IKP Köln using the inverse kinematic reaction \textsuperscript{48}Ti(d,p)\textsuperscript{49}Ti at 100 MeV beam energy. A double-sided silicon strip detector (DSSSD) was used to determine the direction of the protons (hence of recoils) on an event-by-event basis. The AGATA detector was placed as close as possible to the target position (about 10 cm) at 90 degree with respect to the beam axis to emphasize the improvement in effective energy resolution when performing PSA.

The data acquisition system was based on GSI MBS. The germanium signals were digitized using XIA-DGF modules (14 bit, 40 MHz); these cards provide, together with the shape of the signals, also a digital measured value for the net charge deposited inside each segment. The silicon detector data were acquired using VME analog electronics.

The trigger required a charged particle to be detected in coincidence with the germanium detector(s).

\section*{EXPERIMENTAL RESULTS COMPARED WITH SIMULATION}

The data were analyzed using the “\textit{Grid Search}” PSA algorithm [5]. This method, using a $\chi^2$ minimization between the recorded signal and the signals in a calculated basis, assumes at most a single interaction point per segment. The basis used, provided by the MGS collaboration [6], consists of a database containing the response of the detector to single location $\gamma$-ray interactions on a cubic grid covering the full germanium crystal.

All the data collected in the experiment have been analyzed. In Fig.1 the results for the 1382 keV of \textsuperscript{49}Ti are reported. In order to evaluate the enhancement in performance obtainable using segmented germanium detectors, the Doppler correction was performed assuming 3 different positions for the first $\gamma$ interaction, namely the
center of the detector (as usually done for non-segmented detectors), the center of the firing segment and the position of interaction given by PSA. The result for the energy resolution in the latter case is 5.2 keV FWHM. The analysis of the events where only the detector with the best intrinsic resolution is firing gives a resolution of 4.8 keV.

A Geant4 simulation [7] has been performed to evaluate the contributions to the Doppler broadening of all the sources of kinematic uncertainty. To estimate the straggling and the angular dispersion of the beam inside the target the Monte Carlo code SRIM [8] has been used. By the same method the interaction of the emitted proton with the target and the absorbers have been taken into account. All these effects, together with the finite resolution of the detectors, introduce uncertainty on the determination of the parameters used for Doppler correction and thus contribute to the Doppler broadening of the peaks. The positional resolution is assumed to be inversely proportional to the amount of energy deposited in the interaction, reflecting the different signal to noise ratio.

The experimental position resolution is extracted by comparison of the experimental FWHM and the simulated FWHM, calculated assuming different values of position resolution.

As shown in Fig. 2, our best experimental result, 4.8 keV, corresponds to a position resolution of 4.8 mm at 1382 keV.

CONCLUSION

Using PSA a good improvement in spectrum quality has been obtained and further analysis, still in progress, are giving even better results. The comparison with simulation gives an estimation for the position resolution of 4.8 mm FWHM for a 1382 keV γ-ray. This value is what expected for the capability of the AGATA array and in agreement with previous results obtained for other segmented germanium detectors [4].

M. Descovich, NIM A 553 (2005) 535