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The AGATA Project

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Abstract

For decades, the study of the gamma-ray decay from quantal states of the atomic nucleus has played a pivotal role in discovering and elucidating a wide range of phenomena. Each major technical advance in gamma-ray detection devices has resulted in significant new insights into the structure of nuclei. To date, these advances have culminated in the construction of 4π arrays of escape-suppressed spectrometers. The global consensus of opinion is that the next major step in γ-ray spectroscopy involves abandoning the concept of a physical suppression shield and achieving the ultimate goal of a 4π Ge ball using the technique of γ-ray energy tracking in electrically segmented Ge crystals. The resulting spectrometer will have an unparalleled level of detection power for nuclear electromagnetic radiation. Its sensitivity for selecting the weakest signals from exotic nuclear events will be enhanced by a factor of up to 1000 relative to its predecessors. It will have an unprecedented angular resolution making it ideally suited for high-energy resolution even at recoil velocities up to 50% of the velocity of light. Therefore, it is ideally suited to be used in conjunction with the new generation of radioactive beam accelerators or existing stable beam facilities. In Europe, a collaboration has been established to construct a 4π tracking spectrometer called AGATA (advanced gamma tracking array). This collaboration has signed a Memorandum of Understanding for the first phase of the project to perform the research and development necessary to finalize the technology for gamma-ray tracking and hence fully specify the full 4π spectrometer. The status of this first phase of the AGATA project will be reported.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

The worldwide consensus of opinion is that the next generation of gamma-ray spectroscopy instruments should be based on a tracking spectrometer. A tracking spectrometer involves measuring accurately the energy and position of every γ-ray interaction in electrically-segmented Ge crystals [1–3]. The ultimate goal is to build a 4π Ge ball which will have an unparalleled level of detection sensitivity to nuclear electromagnetic radiation. Given the importance of this development and its far-reaching implications, it is not surprising that a European collaboration has already been established to construct a 4π tracking spectrometer called AGATA (advanced gamma tracking array) [4–6]. In the recent long range plan for Nuclear Physics in Europe prepared by NuPECC, the AGATA project is regarded as one of the key instruments for nuclear structure research.

The new challenges for nuclear spectroscopy which provide the impetus for AGATA are emerging principally from the new generation of high intensity radioactive ion beam facilities currently being developed worldwide. These provide beams with energies spanning the Coulomb energy regime, typical of the European ISOL facilities (SPIRAL, REX-ISOLDE), to the intermediate and relativistic energy regimes of fragmentation facilities, such as SIS/FRS at GSI. AGATA is vital for these laboratories and for the planned major new facilities at GSI (FAIR), GANIL (SPIRAL II), Legnaro (SPES) and EURISOL. The science case for the full array is, to a major extent, the science case for the future of nuclear structure research itself. Indeed, many of the topics discussed at this conference will benefit enormously from AGATA. With AGATA's huge increases in resolving power and efficiency, it is the promised impact of this device, coupled to the new generation of radioactive beam facilities, which will permit access to the furthest reaches of the nuclear chart. The study of structure at the very limits of nuclear stability is crucial in order to answer some of the most pressing questions in the field. AGATA will be used to study for example (i) proton-rich nuclei at and beyond the proton drip line and the extension of the $N = Z$ line, (ii) neutron-rich nuclei towards the neutron drip line in medium-heavy elements, (iii) the heaviest elements towards new super-heavy elements, (iv) nuclei at the highest possible spins and temperature. AGATA will also have wide ranging applications in medical imaging, astrophysics, nuclear safeguards and radioactive waste monitoring.

In recent years several pilot projects in Europe [7] and the USA [2, 3] have shown that the principle of γ-ray tracking is feasible by establishing experimentally that it is possible to determine the position of an interaction with sufficient accuracy over a range of energies from tens of keV to several MeV. The first phase of AGATA is to prove that a tracking array can be realized by designing and building a sub-array of detector modules (called the demonstrator) and measuring the tracking performance in actual experiments. This demonstrator will represent a first generation tracking detector in its own right, while also acting as the crucial first step towards the full 4π array.

2. The elements of AGATA

The new technique of gamma-ray tracking involves measuring accurately the position and energy of all the γ-ray interaction points in the detector segments. Since most of the γ rays interact more than once within the crystal, the energy and angle relationship of the Compton scattering formula is used to track the path of a given γ ray. The full energy can then be retrieved by summing all the individual deposited energies for this γ ray. Very high efficiency can then be obtained in such a 4π spectrometer since there are minimal dead areas.

The realization of such a system will require the development of highly segmented germanium detectors, digital electronics, pulse shape analysis to extract energy, time and position information and tracking algorithms to reconstruct the full interaction.

3. The performance of AGATA

The optimum performance or sensitivity of a γ-ray spectrometer is obtained by maximizing the full energy or photopeak efficiency whilst maintaining the best spectrum quality. For AGATA

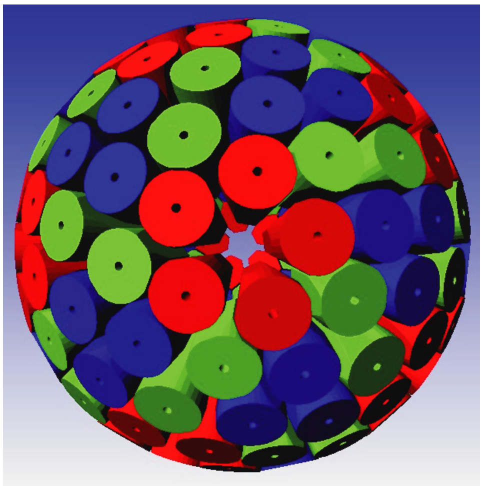

Figure 1. The 180 geometry of AGATA.

Table 1. The characteristics of the geometry of the 180 detector AGATA.

Number of crystal shapes	3
Number of cluster shapes	1
Number of clusters	60
Solid angle coverage (%)	82
Amount of Ge (kg)	362
Crystal face to centre distance (cm)	23.5
Number of electronics channels	6660

Table 2. The predicted performance of the 180 detector AGATA at 1 MeV.

Multiplicity	1	10	20	30
Efficiency (%)	43.3	33.9	30.5	28.1
Peak to total (%)	58.2	52.9	50.9	49.1

these quantities have to be maximized for both low and high multiplicities and low and high velocities (up to $\beta \approx 0.7$). In addition AGATA must have very good angular resolution to determine the emission direction of the detected γ ray, be able to run at very high rates, either because of high radioactivity or high beam intensities, and have sufficient inner space to allow additional detectors to be installed.

The performance of AGATA has been simulated using a Monte Carlo code based on GEANT4 which simulates the interaction of γ rays in the detectors and allows the inclusion of realistic shapes and passive materials [8, 9]. The chosen geometry is based on tiling the sphere with 180 hexagons and 12 pentagons. This is shown schematically in figure 1.

Table 1 summarizes the characteristics of the 180 detector geometry, and table 2 gives the calculated photopeak efficiency and peak-to-total at 1 MeV for various multiplicities. It should be noted that the performance of a γ-ray tracking array depends strongly on the pulse shape analysis and γ-ray tracking algorithms. The development and optimization of these is a major part of the AGATA project and it is expected that these performance figures will

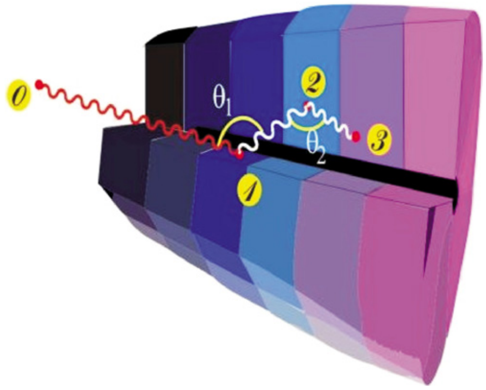

Figure 2. Schematic of the AGATA capsule and scattering within the crystal.

improve. Nevertheless, table 2 shows that the 180 detector spectrometer will have a very high efficiency and excellent spectral response even at high multiplicities. The geometry has a high granularity with an angular resolution of 1.25° which will be very important for Doppler corrections in high recoil velocity experiments.

The detectors of AGATA are highly-segmented coaxial Ge crystals. The crystals have a tapered ($\approx 8^\circ$) hexagonal geometry of length 9 cm and diameter before shaping of 8 cm (figure 2). Each crystal is encapsulated into a thin Al can using the same technology that is used for the Euroball Cluster [10, 11] and Miniball [12] detectors. The outer contact of each crystal is divided into 6×6 azimuthal and longitudinal segments to give 36 electronically independent outputs.

The AGATA collaboration has taken delivery of three symmetric hexagon capsules from the company Canberra Eurisys. These have a 10° tapering angle and are the same as have been purchased by the Gretina/GRETA project in the USA. The longitudinal segmentation scheme has segments in steps at 8, then 13, 15, 18, 18 and 18 mm from the front of the crystal. The first two capsules have been tested in a test cryostat at the University of Köln and excellent results have been obtained. Using preamplifiers developed by Köln and the GANIL laboratory, the measured energy resolutions are 0.9–1.1 keV at 122 keV and 1.9–2.1 keV at 1.3 MeV for the segment signals. For the core signals the energy resolution is 1.2 keV at 122 keV and 2.1 keV at 1.3 MeV. The overall cross talk of the whole system of 37 signals was measured to be below 10^{-3}. In-beam tests are planned to measure the performance of these detectors, in particular the position sensitivity that can be achieved. The position will be measured from the digitized outer segment signal, the radial position coming from the rise time and shape of the pulse and the azimuthal position from the relative magnitude of the transient charge signals that are induced in neighbouring segments. This simplified method was used for the Miniball detectors where a position resolution of 5 mm was achieved [12]. This is just sufficient for successful tracking [1] and preliminary indications are that the new AGATA detectors will have even better position resolution.

4. Data processing

AGATA requires a state-of-the-art and purpose-built digital electronics and associated data acquisition system to process the signals from the Ge detectors. The full system has to cope with over 6000 channels with the rate of each detector possibly up to 50 kHz. The electronics

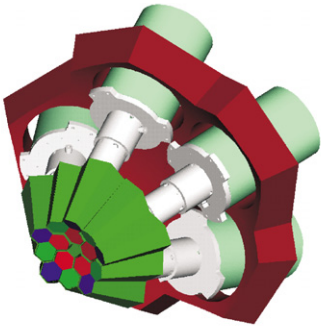

Figure 3. The AGATA demonstrator with five triple clusters.

principle of AGATA is to sample the 37 outputs from the segmented detectors with fast ADCs to preserve the full signal information in a clean environment so that accurate energy, time and position can be extracted. A farm of computers will be used to assemble the full data from all elements of the array, implement the pulse shape analysis algorithms to determine the position of the interactions, perform the tracking reconstruction and assemble the data for storage. The whole system shares a global time reference (clock) which is supplied by a global trigger and synchronization control system.

5. The demonstrator

The research and development phase of AGATA will construct the demonstrator, which will comprise the detectors, the electronics and acquisition system and all associated infrastructure. A view of a CAD image of a sub-array of five triple cluster modules (15 capsules) is shown in figure 3. The demonstrator will be tested with sources in the first instance and then in-beam either in stand-alone mode or coupled to existing ancillary detectors at various European laboratories. Discussions within AGATA are now taking place for the construction phases of the 4π instrument. It seems likely that AGATA will be built in phases, initially coupled to existing spectrometers. As new facilities come online AGATA will be ready to exploit the new physics opportunities they present.

6. Summary and outlook

AGATA will have an enormous impact on the understanding of the atomic nucleus. This radically new device will constitute a dramatic advance in γ-ray detection sensitivity that will enable the discovery of new phenomena, which are only populated in a tiny fraction of the total reaction cross section. Its unprecedented angular resolution will facilitate high-resolution spectroscopy with fast fragmentation beams giving access to the detailed structure of the most exotic nuclei that can be reached. Finally, the capability to operate at very high event rates will allow operation even for reactions with intense γ-ray backgrounds, which will be essential for the study of, for example, transuranic nuclei.

Acknowledgments

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