STUDY OF QUADRUPOLE CORRELATIONS IN $N = Z = 50$ REGION VIA LIFETIME MEASUREMENTS*

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During the AGATA campaign at GANIL, the neutron-deficient Sn region was populated via a multi-nucleon transfer reaction in order to directly measure the lifetime of the first excited states with a plunger device, providing complementary information to previous results obtained with Coulomb excitation experiments. The AGATA γ-ray array was used together with the VAMOS++ spectrometer to study the nuclei of interest.

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1. Introduction

The shell structure of nuclei with few nucleons outside the double-shell closure $Z = N = 50$ has attracted large interest in the last years. Several studies were performed in this region through investigation of electromagnetic moments to examine the robustness of the proton shell closure when $N = 50$ is approached. Due to the presence of low-lying isomers, this region was mainly studied via Coulomb excitation reactions [1, 2].

The experiment described in this manuscript was devoted to the determination of the reduced transition probability for ^{106,108}Sn with a complementary method by using the Recoil Distance Doppler-Shift (RDDS) method, providing, for the first time, a direct measurement of the lifetimes. The nuclei of interest were populated via multi-nucleon transfer reaction. Combining this reaction mechanism with a large angular acceptance magnetic spectrometer provided a clear channel selection in both mass (A) and atomic number (Z), and it also allowed to control the feeding from higher-lying states via a gate on the Total Kinetic Energy Loss (TKEL) [3].

2. Experiment

In the past, it was shown by Broda and collaborators [4] that neutron-deficient nuclei close to $N = Z = 50$ region can be populated via a multi-nucleon transfer reactions. In the reaction of interest for this experiment, an inverse kinematic was mandatory in order to properly identify the recoil and to fulfil the mechanical constrains of the spectrometer. Because of these technical requirements, the beam–target combination was optimised for the present lifetime measurement by choosing cadmium and molybdenum as beam and target, respectively.

During the AGATA campaign at GANIL (France), a ^{106}Cd beam impinged at an energy of 770 MeV onto a 0.715 mg/cm^2 thick ^{92}Mo target. For lifetime measurements, the RDDS method [5] was employed using the differential Cologne plunger, placing a 1.6 mg/cm^2 thick ^{24}Mg degrader after the target. The degrader thickness and material were chosen in order to reduce the recoil velocity by $\Delta\beta \approx 1\%$ and also to minimize the parasitic counting rate due to the reaction of the beam with the degrader.

The complete A and Z identification, together with the velocity vector for the projectile-like products were obtained on an event-by-event basis using the VAMOS++ spectrometer [6–8] placed at the grazing angle $\theta_{\mathrm{lab}} = 25°$. In coincidence with the spectrometer, the γ rays were detected by 8 AGATA Triple Clusters (ATC) [9] placed at backward angles in a compact configuration.

2.1. AGATA

AGATA represents the state-of-art γ-ray detectors and consists in a shell of HPGe crystals, each of them segmented electrically into 36 parts.

A full digital signal treatment allows to correct the presence of unstable segments and neutron damages [10], in order to achieve the best apparatus performances. While dead-segment correction restores the position identification inside the crystal, the neutron-damage correction improves significantly the energy resolution. For example, the detector 04B, whose energy resolution of the core was 4.26 keV at 1332 keV, improved the FWHM down to 3.42 keV thanks to the neutron-damage correction.

After these corrections, the Pulse-Shape Analysis (PSA) [11] can be performed, providing the γ-ray interaction points inside every single crystal. Then, with the PSA information, the path of the γ rays inside the AGATA array can be reconstructed by using the tracking algorithm, such as the Orsay Forward Tracking (OFT) algorithm [12]. In this algorithm, three parameters (the interaction-points angular resolution, the minimum probability for accepting singles and for having tracking) can be optimized in order to improve both the efficiency and the Peak-to-Total (P/T) ratio. As a result of the optimization, in figure 1, the comparison between the AGATA efficiency measured with a ^{152}Eu source is shown with and without tracking. In the energy region of low-lying transitions of the Sn isotopes, the tracking increases the efficiency up to 30%. On the other hand, for energies lower than 200 keV, the efficiency is dropping when applying the tracking: while

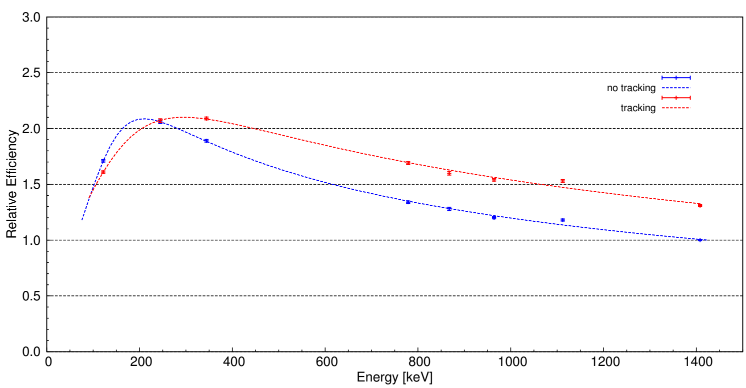

Fig. 1. (Colour on-line) AGATA relative efficiency as a function of γ-ray energy without (black/blue) and with (grey/red) tracking, measured with ^{152}Eu. The efficiency decrease at energies below 400 keV is due to the presence of 5 mm Cu absorbers in front of the detectors to reduce the X rays, coming mostly from the beam and the target. The efficiency curve obtained without the tracking is normalised to 1 for the 1408 keV transition energy.

rejecting bad events for improving P/T, also good ones are discarded because of the tracking parameters. Thus, these three parameters have to be optimised according to the goal of the experiment, being a compromise in order to have the best performances in the γ-ray energy region of interest.

When reconstructing the path of the γ rays, the AGATA array is considered as one global detector including the single ATCs. Thanks to the optimised tracking algorithm, the energy resolution of the array was 3.9 keV, measured with a ^{60}Co source at 1332 keV.

2.2. VAMOS++

The complete identification of the projectile-like fragments is provided by the magnetic spectrometer VAMOS++.

At the entrance of the spectrometer, the dual position sensitive Multi-Wire Proportional Counter [8] measures the direction of the recoils that are essential for defining the ions velocity vector. This entrance detector together with a Multi-Wire Parallel-Plate Avalanche Counter placed at the focal plane [7] measures the time of flight of the fragments. The trajectories are reconstructed event-by-event via the transfer-matrix method with the information about the focal plane position and direction of the ions, which are provided by two Drift Chambers. Just after the Drift Chamber, an Ionization Chamber (IC) is placed to measure the final kinetic energy and allows the Z identification.

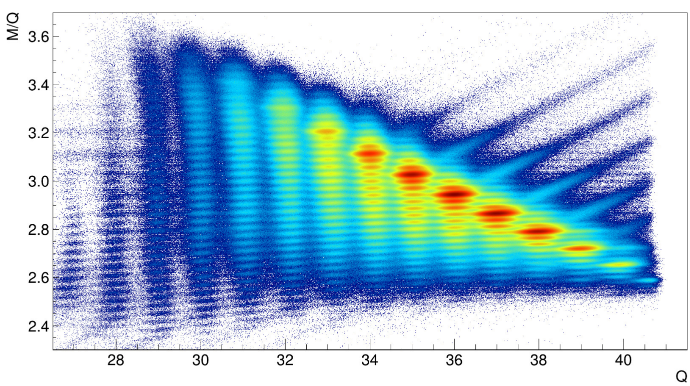

Fig. 2. Mass over charge state ratio as a function of the charge state: each bump represents the identified masses. The diagonal lines on the side are wrongly reconstructed trajectories.

From the relativistic Lorentz-force formula, by knowing the ion velocity and the magnetic rigidity, it is possible to first separate the recoils according to the ratio between their mass and charge state. Then, considering in first approximation that the energy loss inside the IC is equal to the kinetic energy of the ion, it is possible to obtain the charge state of the recoils. Finally, as it is shown in figure 2, by combining the kinematic information with the charge state, the ion mass can be obtained.

3. Results

By combining the information of the first interaction point in the AGATA detectors, provided by the γ-ray tracking algorithm, with the recoil velocity vector determined by VAMOS++, the Doppler correction of the emitted γ rays can be performed event-by-event.

The Doppler correction was optimised by correcting the recoil velocity ($\langle\beta\rangle \approx 11\%$) for the energy loss inside all the VAMOS++ gas detectors and also by estimating the effective target–AGATA distance. Then, by gating on the ^{60}Ni, produced via the fusion-fission reaction of ^{106}Cd and ^{24}Mg, the quality of the Doppler correction can be checked and compared to the resolution obtained with ^{60}Co source. After the optimisation, the FWHM at 1332 keV was 5.3 keV.

Thanks to the unique capabilities of AGATA and VAMOS++, it was possible to obtain an in-beam energy resolution just $\approx$ 30% higher than what had been obtained with radioactive sources. A good energy resolution is crucial for clearly separating the two components of each γ-ray transition when using RDDS method. As an example of this remarkable result, figure 3 presents the γ-ray energy spectrum of ^{108}Sn summing up all the plunger distances. Two components for both $4^+ \to 2^+$ and $2^+ \to 0^+$ transitions can be nicely seen.

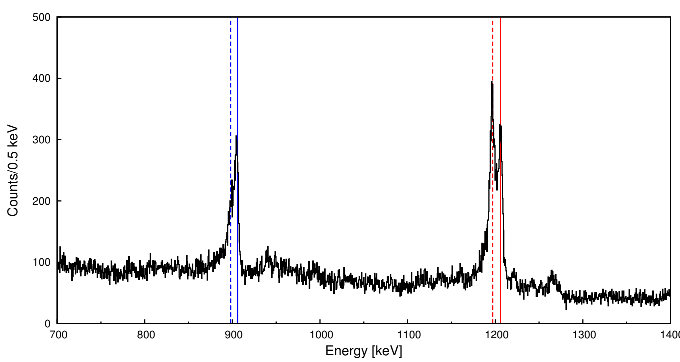

Fig. 3. (Colour on-line) Doppler-corrected γ-ray energy spectrum of ^{108}Sn for all the plunger distances: for the transition $4^+ \to 2^+$ (black/blue) and $2^+ \to 0^+$ (grey/red) both the unshifted (solid) and shifted (dashed) components are shown.

4. Conclusions

The neutron-deficient region close to $N = Z = 50$ shell closure has been successfully populated via a multi-nucleon transfer reaction. The AGATA array, coupled to the magnetic spectrometer VAMOS++, provided a clear selection of the channels of interest in coincidence with the emitted γ rays. Thanks to the good position sensitivity of the experimental apparatuses, an excellent in-beam γ-ray energy resolution of 0.4% at 1332 keV has been obtained. Further work is still necessary for extracting the lifetime of $^{106-108}$Sn and the region around.

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