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Study of shape coexistence in the ^{188}Hg isotope

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Summary. — Shape coexistence is a striking phenomenon that has attracted a large community and has been evidenced in many nuclear species where structures belonging to different deformations are observed coexisting within a typical energy range of nuclear excitation. Along the Z=80 isotopic chain, the ^{188}Hg nucleus is the *border-line* where the presence of this phenomenon is foreseen but has not been confirmed yet. For this reason, this nucleus has been studied in a two-steps experiment performed at the Laboratori Nazionali di Legnaro in order to measure the lifetimes of the low-lying states of the ^{188}Hg.

1. – The physical case

Shape coexistence is a phenomenon typical of many-body quantum systems that has gained a lot of interest in the recent years in the field of nuclear structure. In the atomic nucleus, it can be observed when at least two structures, belonging to different deformations, coexist within the typical energy range of nuclear excitations. While at first shape coexistence was considered an exotic phenomenon, now it has been observed in many regions of the nuclear chart and it is known to exibit islands of occurence [1]. The region where this phenomenon is most present is the neutron-deficient region near and at $Z = 82$. In particular the even isotopic chain of the polonium, lead and mercury have been extensively investigated since the seventies.

Looking at the mercury case, an intruder band (see Figure 1, on the right) comes particularly close to the ground-state band when approaching to the mid-shell and could compete with the main band in forming the low-lying states. A first hint of the presence of shape coexistence in this region comes from the observation of the rapid change in the mean-square radius between the ^{181}Hg (N=101) and the ^{185}Hg (N=105), shown in Figure 1 (left). A more incisive proof comes from the reduced transition probabilites B(E2) that give information about the internal structure of the nucleus and on its collectivity.

The presence of shape coexistence in the even isotopes $^{180-186}$Hg was confirmed via Coulomb excitation and/or lifetime measurement experiments in recent years, while for

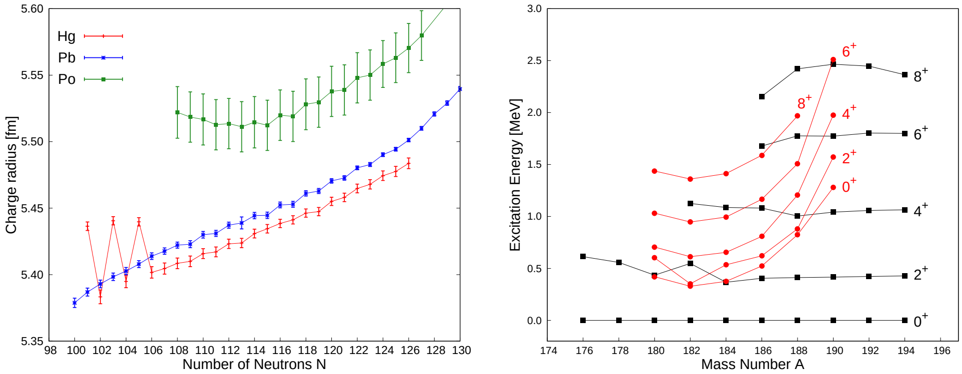

Fig. 1. – (Left) The mean-square radius for the polonium (Z=84), lead (Z=82) and mercury (Z=80) isotopes. The rapid change between the ^{181}Hg (N=101) and the ^{185}Hg (N=105) was considered the first hint of the presence of shape coexistence. Data taken from Ref. [2,3]. (Right) The excitation energies of the low-lying states in the mercury isotopic chain. The intruder band (red), which belongs to a prolate-deformed structure, comes particularly close to the ground-state band when approaching to the mid-shell. Data taken from Ref. [4].

the neutron deficient nuclei with $A < 180$ and for more stable isotopes ($A > 194$) the phenomenon was not observed. In the region in between, it was not possible to either confirm or deny the presence of shape coexistence. However, from theoretical calculations the ^{188}Hg is expected to be the heaviest even isotope to exhibit shape coexistence, so the study of this nucleus is of great interest to shed light on the mechanism behind this phenomenon.

2. – Experimental details

The low-lying states lifetime of ^{188}Hg were measured for the first time at the Laboratori Nazionali di Legnaro (Italy) by using the Recoil-Distance Doppler-Shift method. The nucleus of interest was studied via two fusion-evaporation reactions employing a ^{34}S beam, which impinged in one case on a ^{160}Gd target at the energy of 185 MeV and in the other on a ^{158}Gd target at the energy of 165 MeV.

The emitted γ rays were detected by the γ-ray spectrometer GALILEO, that consists of 25 Compton-shielded high purity germanium detectors (HPGe) [5]. The efficiency of the HPGe is highly dependent on the energy and in particular it presents a maximum around 200 keV and then it decreases significantly with the increasing of the energy. In Figure 2 (left), the efficiency of the GALILEO array is studied using seven different calibration sources, covering an energy range between 81 keV and 1836 keV. In the region of interest for the present experiment, namely from about 400 keV to 800 keV, the total efficiency of the array goes from a 4.5% at low energy to a 2.6% at high energy.

Each germanium detector is surrounded by eight bismuth germanate scrintillators (BGOs) that act as an anti-Compton shield. If the BGOs detect events with an amplitude above a certain threshold, it means that the photon does not lose all of its energy inside the HPGe and these events must be discarded. The threshold must be chosen carefully because a too permissive threshold would reduce the Peak-to-Total ratio (P/T), avoiding the identification of rarer channels, while a too selective threshold would reduce the

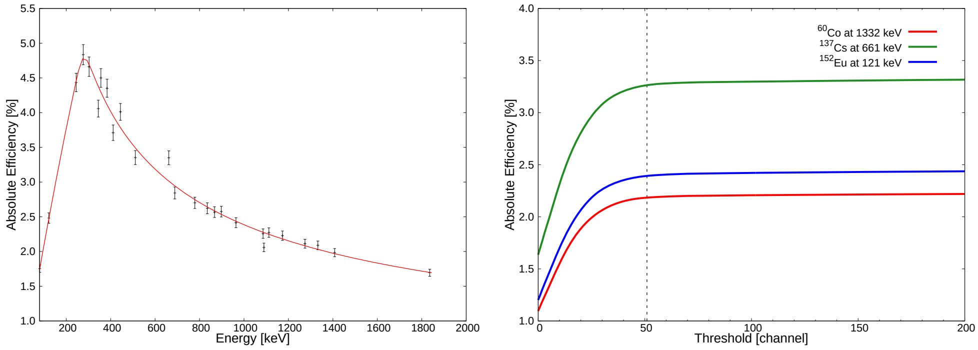

Fig. 2. – Features of the GALILEO spectrometer. (Left) The absolute efficiency of the array as a function of the energy. The experimental data were fitted using the RADWARE function (red line) [6]. (Right) The total efficiency of the array as a function of the threshold on the BGOs.

statistics. In order to determine a good compromise between these two conditions, a systematic study on the effects of the Compton suppression on the P/T ratio and on the efficiency is performed. In Figure 2 (right) it is possible to notice that the absolute efficiency of the array increases with the threshold and then reaches a plateau for a certain value around the 50th channel. This is the chosen threshold for the BGOs.

Thanks to the state-of-the-art digital electronics of GALILEO, during the experiment it was possible to record the signals trace and then to discriminate between single events and pile-up ones. In fact, if the energy measured with the full trace is higher than the one extracted with a short portion of the trace itself, it means that another γ ray entered the crystal during the acquisition time. In Figure 3 the long traces are compared to the short ones in the case of a calibration (left) and of a beam run (right). After the pile-up rejection, only the events having similar energy calculated with the two traces are selected.

More information about the experiment and the analysis can be found in Ref. [7, 8].

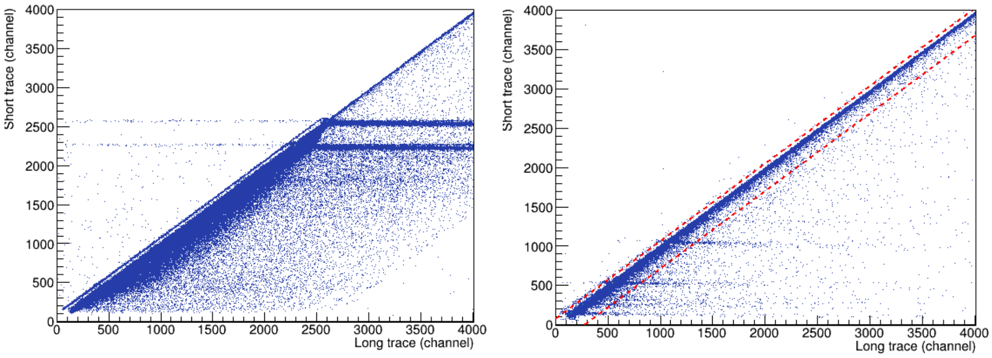

Fig. 3. – Comparison between the energy calculated with the long and the short trace in the case of a calibration run (left) and of a beam run (right). After the pile-up rejection, only the events having similar long-trace and short-trace energy (between red lines) are taken.

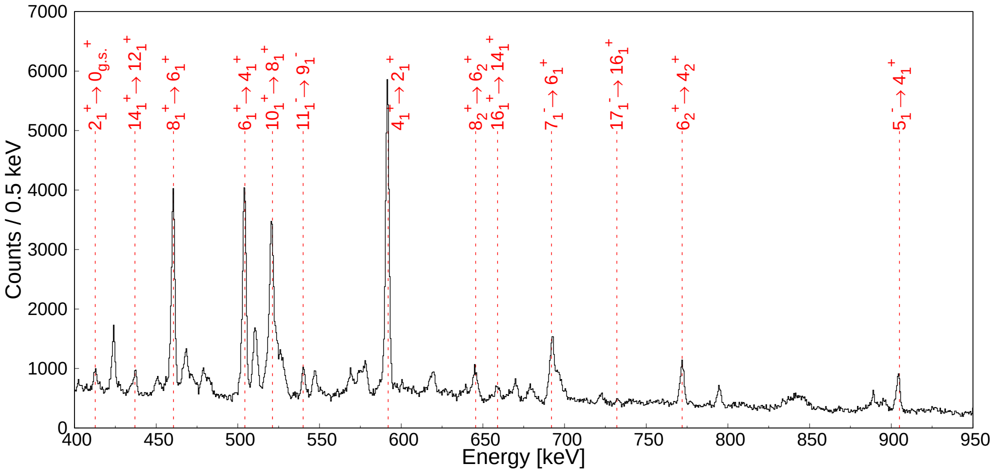

Fig. 4. – Gamma-ray energy spectrum of ^{188}Hg, obtained by gating on the stopped component of $2_1^+ \to 0_{g.s.}^+$ transition (412 keV). Some of the transitions identified during the analysis have been highlighted.

3. – Preliminary results

After the presorting of the experimental data, it was possible to identify several transitions of the ^{188}Hg, that are highlighted in Figure 4. The good resolution of the germanium detectors and the statistics allowed the lifetime measurements of some of the low-lying states, that will soon be published. These results, compared to the theoretical calculations, will help to shed light on the nature of the nucleus and on the eventual presence of shape coexistence in the ^{188}Hg isotope.

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