Isomers in neutron-rich lead isotopes populated via the fragmentation of ^{238}U at 1 GeV A

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Abstract. Neutron-rich nuclei beyond N = 126 in the lead region were populated by fragmenting a ^{238}U beam at 1 GeV A on a Be target and then separated by the Fragment Separator (FRS) at GSI. Their isomeric decays were observed, enabling study of the shell structure of neutron-rich nuclei around the Z=82 shell closure. Some preliminary results are reported in this paper.

1. Introduction

The experimental study of exotic nuclei has shown that significant changes of the known shell structure along the stability valley occur for very neutron-rich nuclei with mass numbers below 100. The two most accessible doubly-magic nuclei above mass A = 100 are ^{132}Sn (Z=50, N=82) and ^{208}Pb (Z = 82, N = 126). The evolution of the Z=50 shell above N=82, and in general the structure of nuclei around ^{132}Sn, is nowadays an object of intense research at radioactive beam facilities accelerating fission fragments around A = 140 [1, 2, 3]. On the other hand, due to experimental difficulties, little is known on the evolution of Z = 82 shell closure beyond N = 126 and neutron-rich nuclei around ^{208}Pb [4]. The study of these isotopes is relevant also for nuclear astrophysics, since the measurement of their β-decay half-lives will improve the understanding of the r-process stellar nucleosynthesis in heavy nuclei [5].

2. Experimental setup

The presence of long-lived isomeric states (from tens of nanoseconds to a few microseconds), predicted by shell-model calculations, offers an opportunity to study the structure of exotic heavy nuclei performing decay γ spectroscopy. Isomeric states in neutron-rich nuclei in the lead region were observed in Ref. [4, 6, 7]. In the present paper we report new results in the most neutron-rich lead region, obtained by exploiting the uniqueness of the FRS-RISING setup [8, 9, 10, 11] and the UNILAC-SIS accelerator facilities at GSI by using a 1 GeV A ^{238}U beam at an intensity of around 1.5×10^9 ions/spill. The $\sim$ 1 s spills were separated by $\sim$2 s without beam. The beam impinged on a 2.5 g/cm^2 Be target (followed by a 223 mg/cm^2 Nb stripper) and the isotopes resulting from the cold fragmentation reaction were separated and identified with the double-stage magnetic spectrometer FRS [8]. The FRS allows one to discriminate the magnetic rigidities of the fragments with a resolution sufficient to distinguish the masses of adjacent isotopes even at the high masses of interest (A $\sim$ 210-220). In this specific measurement, a significant experimental challenge was related to the fact that the magnetic rigidities of the primary beam charge states (mainly ^{238}U^{91+} and ^{238}U^{90+}) are similar to the magnetic rigidities of the fully-stripped neutron-rich lead isotopes, in particular ^{212}Pb and ^{214}Pb. As a result of the high yield of uranium ions (around 10^9 pps), this would lead to an unacceptably high counting rate in the detectors in the second focal plane, before the Al wedge-shaped degrader. In order to avoid the problem, a homogenous 2 g/cm^2 Al degrader was placed after the first dipole (S1), to exclude from the acceptance of the FRS the uranium charge states, enabling a standard counting rate in the S2 detectors. Slits in S1 and S2 were also partially inserted in the beam line of the spectrometer to cut the remaining contamination from the primary beam charge states and heavy fragments around radium. The 758 mg/cm^2 Al wedge-shaped degrader at the intermediate focal plane (S2) was set to produce a monochromatic beam. The identification in A/q is achieved through time of flight and focal-plane position measurements, while the atomic number is obtained from two ionization chambers. Finally, the comparison of the magnetic rigidities before and after the Al wedge-shaped degrader allows one to discriminate a possible change of the ion charge state. These measurements are sufficient to provide a complete identification of the isotopes event by event.

At the final focal plane (S4), the ions were slowed down in a thick degrader and then implanted

in a composite DSSSD detector system comprising 3 layers, each with three DSSSD pads [11, 12]. Every pad had a size of 5 × 5 cm^2 and a thickness of 1 mm. The purpose of this active stopper is to detect the position and time of an ion implantation and of a possible β-decay following the implantation. The DSSSD detector system was surrounded by the RISING γ spectrometer [9, 10], made of 105 germanium crystals arranged in 15 clusters with 7 crystals each. The efficiency of the array was 15 % at 662 keV and the time correlation between it and the active stopper will provide the means to perform both isomer spectroscopy and β-delayed γ-ray spectroscopy.

3. First preliminary results

The identification plot in Fig. 1 shows that nuclei in the region of interest up to ^{219}Bi, ^{218}Pb, ^{214}Tl and ^{210}Hg were successfully populated. Some results on the γ transitions following the isomeric decays of ^{208}Hg and ^{212}Pb will be reported in the following paragraphs .

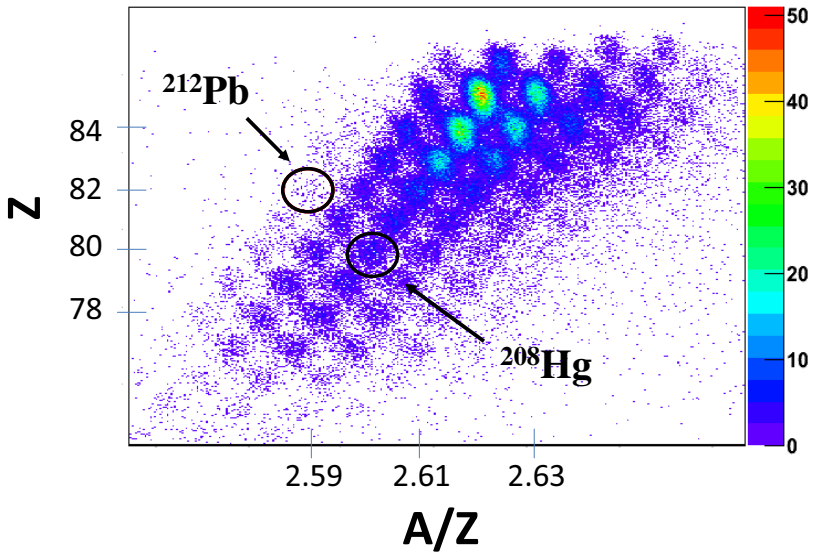

Figure 1. Identification plot for the region of interest. The measured atomic number Z is plotted versus the A/Z ratio (fully-stripped ions).

A preliminary analysis has been performed, with the aim of confirming previous results on isomers in this region, in order to assess the consistency of our ion identification and γ correlation. Figure 2 shows the delayed γ-ray spectrum obtained by gating on ^{208}Hg in the identification plot. In Ref. [6] a 8^+ isomer was reported, with a half life of 99(14) ns: in our case the statistics are lower because the spectrometer was set for more neutron-rich fragments (for comparison refer to Fig. 1 in Ref. [6]). The structure of ^{208}Hg is determined by its two-proton-hole two-neutron-particle character with respect to doubly-magic ^{208}Pb. All the states have a predominant $\nu g^2_{9/2}$ configuration. Also in our case, as in Ref. [6], the $8^+ \rightarrow 6^+$ transition could not be observed because of its low energy (<100 keV), below the detection threshold. Moreover in the low γ-energy region, which has a high background due to the bremsstrahlung from the implantation events, the time window to select the γ rays starts at later times with respect to higher γ energies ($\geq$ 200 keV). This results in a further cut of statistics at low energy in comparison with Ref. [6].

Figure 3 shows the delayed γ-ray spectrum obtained by gating on ^{212}Pb. This spectrum has to be compared with the one obtained in Ref. [4], which has lower statistics and no observation of the 806-keV line, due to the lower efficiency of the γ detector used in that experiment. In

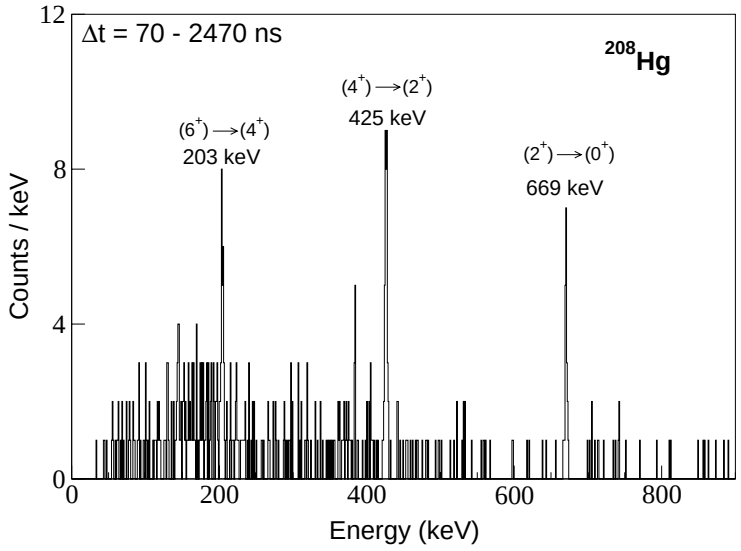

Figure 2. Delayed γ-ray spectrum for ^{208}Hg, time gated in the window Δt.

this case a 8^+ isomer was suggested, with a predominant $\nu g^2_{9/2}$ configuration, as expected from a seniority scheme. The $8^+ \rightarrow 6^+$ transition was not observed in our experiment, nor in Ref. [4], due to its low energy, for reasons given above. In Ref. [13] the transition was estimated to be 58 (14) keV. The known neutron-rich Pb isotopes ^{210,212}Pb in addition to the newly-populated ones (^{214,216,216}Pb) seem to suggest a seniority scheme for neutron-rich Pb nuclei beyond N = 126. The existence of a seniority scheme will be verified with the ongoing analysis of heavier Pb isotopes and with a comparison with shell-model calculations. In fact, new isomers were also observed in ^{214}Pb, ^{216}Pb and in nearby nuclei. The measurements of their lifetimes, and hence the B(E2) value from the isomeric states, will provide crucial information in understanding the nuclear structure in this region of the Segrè chart.

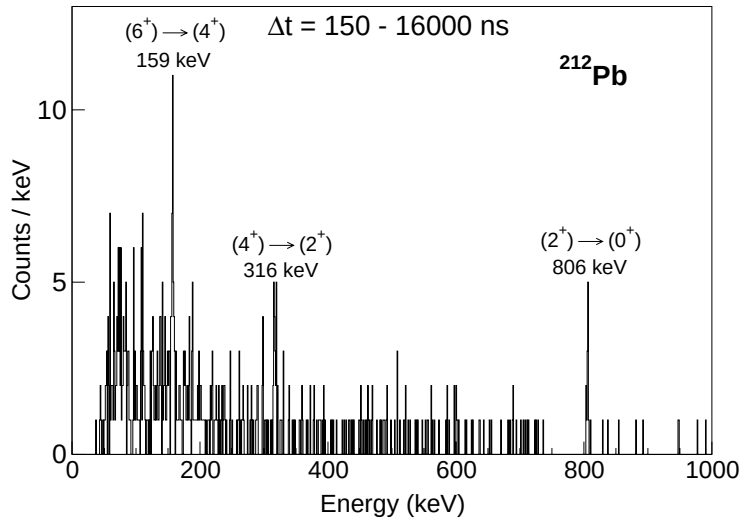

Figure 3. Delayed γ-ray spectrum for ^{212}Pb, time gated in the window Δt.

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