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Fission isomer studies with the FRS

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The 'island' of fission isomers identified in the actinide region (Z = 92 - 97, N = 141- 151) originates from multi-humped fission barriers, which can be described as the result of superimposing microscopic shell corrections to the macroscopic liquid drop barrier. For the first time, populating fission isomers by using the fragmentation of 1 GeV/u ^{238}U projectiles was tried rather than light particle induced reactions so far in use. Projectile fragmentation gives access to isotopes that are hard or impossible to reach by light particle reactions. In-flight separation with the fragment separator FRS allows studying fission isomers with half-lives as short as 100 ns. Most importantly, it provides beams with high purity and enables an event-by-event identification. Different detection methods, such as decay and mass spectrometry, have been used in the experiment to search for fission isomers within a half-live from 100 ns to 50 ms. The experiment to study fission isomers with the FRS at GSI has been performed within the framework of FAIR Phase-0.

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1. Introduction

Multi-humped fission barriers, as they occur in the actinide region, give rise to fission isomers [1, 2]. Such barrier shapes can be described as the result of superimposing microscopic shell corrections to the macroscopic liquid drop barrier [3]. Shell effects are also responsible for the existence of the so-called "island of stability" of superheavy nuclei. However, our current understanding is insufficient to, e.g., pinpoint the location of this island. Moreover, fission limits how heavy a nucleus can be. Therefore, fission isomers have been vital in helping us to understand the stability of superheavy nuclei.

There are 35 fission isomers found so far [2]. They were all studied by light particle induced reactions, which suffer from a huge background of prompt fission. The production cross sections of fission isomers are usually around μb and it is challenging to get targets to study the U and Np region. Instead of the light particle induced reactions, we report on fission isomers studies by using the fragmentation of 1 GeV/u ^{238}U projectiles. The goal is to investigate the fission isomer population probability with in-flight fragmentation reactions, and to study the not yet well-known fission isomer in ^{235}U, and to search for new fission isomers in the U and Np region.

2. Experiment

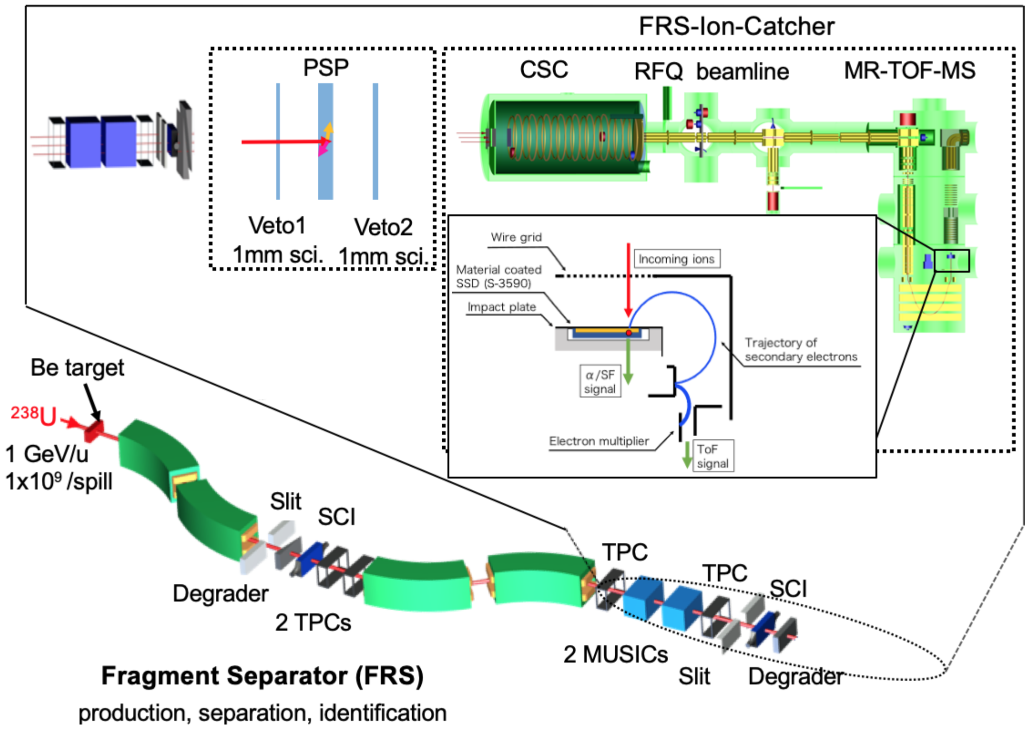

Figure 1: Setup of the experiment. Schematic view of the FRS with its standard detectors (i.e., plastic scintillator (SCI), time projection chamber (TPC), multiple sampling ionization chambers (MUSICs)), the position sensitive plastic scintillator (PSP), the FRS Ion Catcher and the α-TOF detector are shown. The PSP was installed on a movable platform and was moved out of the beamline when the FRS Ion Catcher was in use.

The experiment was performed at GSI Helmholtz Centre for Heavy Ion Research in Darmstadt, Germany. As shown in Fig. 1, the ^{238}U beam at an energy of 1 GeV/u from the synchrotron SIS-18 bombards a Be production target at the entrance of the fragment separator FRS [4]. Exotic nuclei including fission isomers produced via projectile fragmentation reactions are in-flight separated by the FRS and the ions of interest are transported to the final focal plane, where ions are slowed down by the degrader system and stopped either in a position sensitive plastic scintillator (PSP) or in the cryogenic stopping cell (CSC) [5, 6] of the FRS Ion Catcher [7, 8]. In-flight separation with the FRS offers fast production, therefore gives access to fission isomers with short half-lives. Moreover, the FRS provides beams with high purity and enables an event-by-event identification, which are both most important to study the fission isomers with low production cross-sections. Last but not least, the detection methods employing the PSP and the FRS Ion Catcher were carefully chosen to suppress the possible background as much as possible.

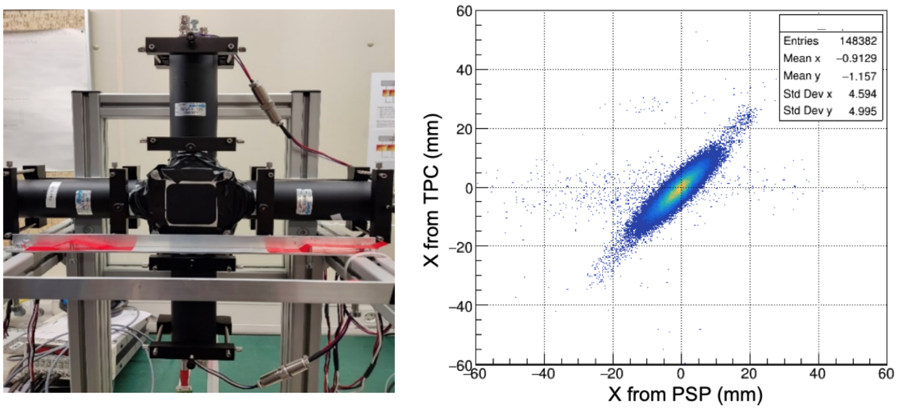

Figure 2: PSP and its position correlation with the one obtained from the FRS TPCs.

As shown in Fig. 2 (left panel), the PSP consists of a 5 mm thick fast plastic scintillator (with an active area of 60 mm x 60 mm) and four photomultiplier tubes (PMTs) as readout from the four edges. Hence, the incident particle hit position can be deduced from the timing difference between the faced PMTs. It can detect both the implantation of the ions of interest and the following decays from the fission isomers. With another two plastic scintillation detectors installed closely before and after the PSP, serving as the veto detectors, the implantation, punch-through and decay events can be distinguished. Due to its good timing characteristics, the PSP can cover the fission isomers with half-lives of ns to μs and handle up to MHz beam rates. The background suppression is on the one hand realized by using the event-by-event particle identification information from the FRS standard detectors, since the data acquisition system of the PSP and veto detectors was combined with the FRS one. On the other hand, the particle hit position information obtained from the PSP can be used to further suppress the background, since the ion implantation and the following decay from its fission isomer are expected to be position correlated. For example, the position in the x-axis obtained with the PSP is well correlated with the position information obtained from the FRS time projection chambers (TPCs) as shown in Fig. 2 (right panel). The PSP can reach a position resolution of 2.3 mm (σ).

The FRS-Ion-Catcher consists of the cryogenic stopping cell (CSC), the radio-frequency-

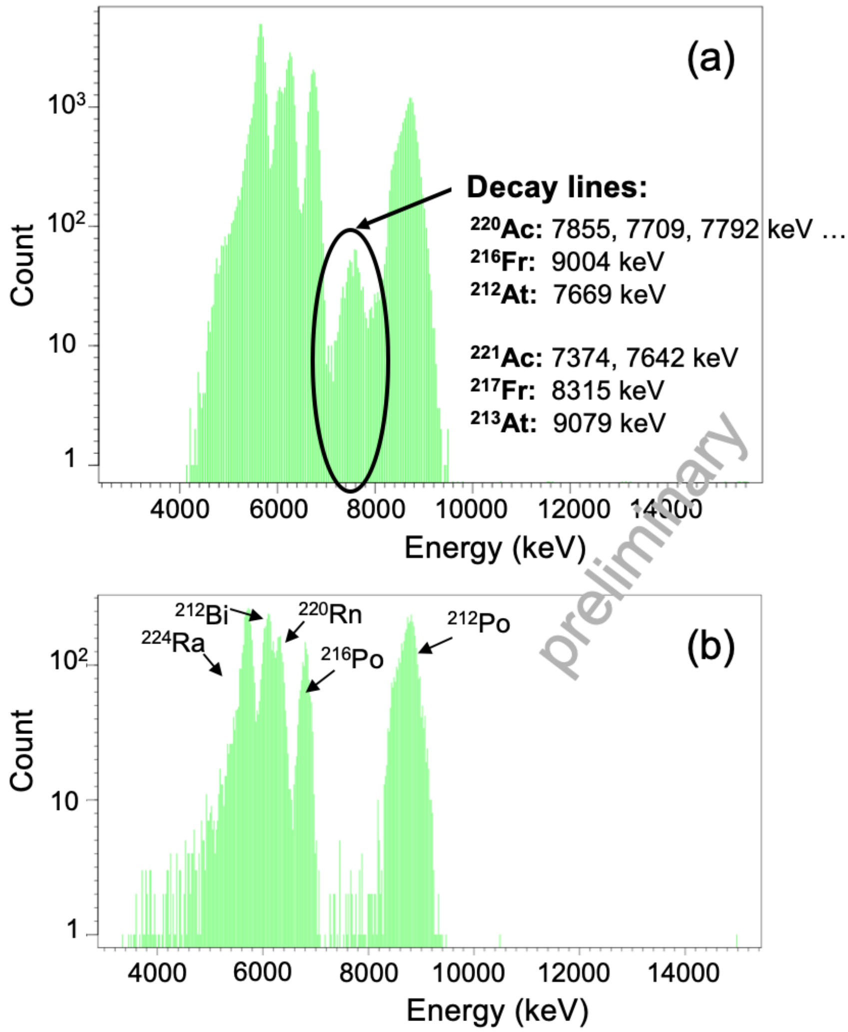

Figure 3: The pulse height signals of the α decays from the ions detected by the α-TOF detector. In contrast to the background spectra (b), the α lines from the decay chains of ^{220,221}Ac can be seen in (a).

quadrupole (RFQ) beamline and the multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS). In order to handle the high beam rate and allow for efficient data taking, the 1-meter-long DC-cage inside CSC was replaced by a shorter one with a length of about 50 cm. With this shorter and wider DC-cage, the CSC can handle a beam rate as high as 2×10^5 ions/s without any extraction efficiency loss. The stopped ions are extracted from the CSC and transported into the MR-TOF-MS with the RFQ beamline. The MR-TOF-MS was equipped with an α-TOF detector [9] as shown in the insert of Fig. 1. Thus, not only the identification and excitation energies of the fission isomers can be measured by the time-of-flight in the MR-TOF-MS, but also the pulse height of the following decay signals can be measured. As shown in Fig. 3 (a), with the ^{220,221}Ac stopped in the CSC and measured by the α-TOF detector, the α lines from their decay chains can be seen in addition to the background lines shown in Fig. 3 (b). This demonstrates that the α-TOF detector can detect decay products correctly and paves the way for using fission decay products to suppress the pronounced background other than the fission isomers.

3. Summary and Outlook

We have discussed fission isomer studies with the fragment separator FRS at GSI. For the first time, it was tried to populate fission isomers with the in-flight projectile fragmentation method, which is envisaged to access fission isomers hardly reachable by light particle induced reactions. Combining the FRS and different detection systems including the FRS Ion Catcher, we have the ability to study fission isomers with half-lives in the range of ns to ms.

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