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Development of a prototype detection system to investigate the fission mechanism of Fermium (Fm) isotopes

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Research Articles

Development of a prototype detection system to investigate the fission mechanism of Fermium (Fm) isotopes

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Abstract

The development of a prototype detection unit for measuring fission events in-beam is currently underway. Measurements associated with fission events include fission-fragment mass distributions (FFMD), fission-fragment angular distributions (FFAD), and total kinetic energy distribution (TKE). A systematic study of fission of the Fermium isotopes, 244Fm to 256Fm is being undertaken to investigate the dynamics of fission in this mass region.

Novel results from this systematic study are expected for this uncharted set of nucleus, which shows a unique transitional asymmetric to symmetric fission mass distribution.

Keywords: FFMD, FFAD, TKE

I. Introduction

The synthesis and the study of heavy and super-heavy elements are of considerable interest for the nuclear physics community in recent years. Leading laboratories around the world, involved in heavy ion research are investigating various techniques to populate and to study these exotic elements.

Intuitively, the simplest way to produce such a heavy element is from the fusion of two heavy nuclei. However, the dynamics of the formation of the compound nucleus becomes very complex with the heavy projectile and target system. In addition, the Coulomb repulsion between the interacting nuclei is substantially high. With modern accelerator facilities, it is possible to bring the two heavy nuclei into contact (by providing the kinetic energy to overcome their Coulomb repulsion), but the resulting system is unstable and elongates to a di-nucleus and separates into two fragments instead of equilibrating to more stable compact shapes and subsequent fission [1]. The survivability of such heavier compound with respect to the fission process is determined by the fission barrier height, which completely depends on nuclear shell characteristics in the heavier region. It is well known that the reaction channels in the heavy ion induced events are elastic and inelastic scatterings, deep inelastic reactions, fusion and de-excitation of a compound nucleus, fission, quasi-fission (QF), and fast fission (FF).

A major problem in formation of heavy element is the presence of non-equilibrium processes such as FF [2, 3], QF [4–10] and pre-equilibrium fission (PEF) [11, 12]. Experimentally, synthesis of heavier elements is severely hindered by fission and fission-like processes as discussed above [13, 14]. One of the main contributions, which prevent the compound nucleus process, is the presence of quasifission which can be inferred from large angular anisotropies [15] and/or wide mass distributions [8], which are inconsistent with equilibrated fusion-fission results. It is important to measure the above experimental observable very accurately. Our work will be one of the important approaches for the above purpose.

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II. Experimental technique

A. Experimental signature

In heavy ion induced reactions, a large number of reaction channels are opened and various nuclei are formed as reaction products. To investigate on the binary reaction channel, the experimental technique has to provide reliable identification of reaction products [16]. However, to understand the dynamics of heavy ion induced reactions much more information is needed such as energies, emission angles of formed fragments and of light particles accompanying the reaction. As there are many output reaction channels, it is necessary that the contribution of each process to the reaction cross-section be estimated in order to clarify the dynamics of interaction between two heavy nuclei [17].

Experientially, there are many observables to understand the reaction mechanism. Some of them are the energies of two binary fragments (2E), velocities of the fission fragments which leads to the mass identification using the time of flight (TOF) method, the velocity and energy of one fragment (V, E), and the velocities and energies of two fragments. Simultaneous measurement of all the above quantities needs special type of detection system.

The most exhaustive information on the binary products comes from the energy and velocity measurement. The use of conventional semiconductor detectors is not very helpful due to two main problems, low geometric efficiency and low radiation hardness. For sensitive measurement, a large-area position-sensitive semi-conductor detector is required, but the detector cost is often very high.

The alternative solution is the position sensitive ionization chambers, which are considerably easy to manufacture. They are also very good for the sensitivity to heavy ions and for endurance in high radiation environment. In addition, they are scalable to bigger dimensions and lead to better geometric efficiency. The only issue for the gas-filled detector systems is the scattering and energy loss of the detected particles from the foils enclosing the gas volume.

To overcome these shortcomings, we are developing a unique detection system, which is a transmission type detector, based on the mechanism of secondary emission of electrons. With this system, the TOF of the fission fragments can be measured with much better accuracy than the conventional systems. The details and the design of the system are as follows:

B. Detection system in details

A schematic of the detection system has been shown in figure 1. The detector has three main components (1) conversion foil for the generation of the secondary electron, (2) wire plane for the reflection of the electron, and (3) micro channel plate for detection.

When a heavy fragment passes through the conversion foil of the detector, they knock out electrons, which move in the beam direction. These electrons are called secondary electrons. These electrons travel the equal lengths from starting point till detection point; therefore, the output timing signal of the detector is position-independent. Carbon foils with a thickness of 20–40 $\mu g/cm^2$ will be used as the conversion foil. The thickness of the foil is very important as the particle lose energy as it passage through the conversion foil. For fission fragments, these losses in the foils that we will use are few MeV and due to collisions with atoms of the foil, the particles changes its directions, which appear to be negligible. Once the secondary electrons come out of the foil, they accelerate in the electric field between the foil and the accelerating grid and reach at the grids of the electrostatic mirror which deflect those electrons by 90° as shown in the figure 1, whereas the heavy fragments pass through all electrostatic fields generated by the grids without being deflected from its primary direction and practically without changing its initial velocity.

The deflected electrons strike the micro channel plate (MCP), which will amplify and provide a fast rise time signal. This signal will be our start signal. The un-deflected fragments will continue and strike a similar setup of bigger dimension, which provides the stop signal. The stop detector will also provide the position of the ion, where it will strike the detector. For this purpose, one can use the MCP or Silicon Photo multiplier (SiPm) with position sensing Silicon matrix. Combination of start and stop will provide the TOF and dividing the path by TOF we will get the velocity, which will provide the mass information using the Viola systematics [18]. The SiPm also provides the energy information directly from the calibrated pulse height. Thus, both the energy and mass of the detected fragment can be obtained simultaneously.

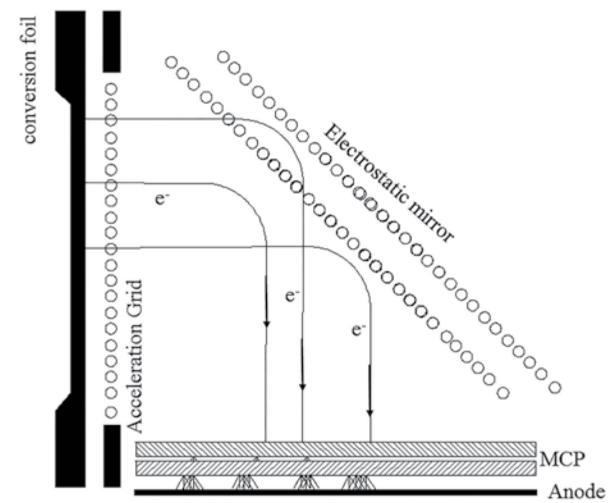

Figure1: The different components of the detection system. The start detector is shown here and the stop will be a replica of the start with bigger dimension. The conversion foil has been shown very clearly. The accelerating grid and the electrostatic mirror (45^0) w.r.t. electron path has presented. The secondary electron path has shown by the arrows. The MCP has been shown in the down. For the detail see the text.

III. Study of fermium isotopes

Fermium (Fm) is an actinide element. It is one of the heaviest elements that can be formed by neutron bombardment of lighter isotopes. Fermium is unstable with a very short lifetime. Thus, the measurements are possible in-beam as soon as the element is produced. Investigative studies in this mass region are sparse and a transitional behaviour in the fission fragment mass distribution (FFMD) from asymmetric to symmetric is predicted from the systematics. This heavy mass region is also interesting as the non-equilibrium process (QF) may play a significant role in the process. Based on the liquid drop model one expects the mass distribution should be symmetric for the fission of ^{244}Fm isotope which has been shown in figure 2, whereas according to systematic one expects asymmetric.

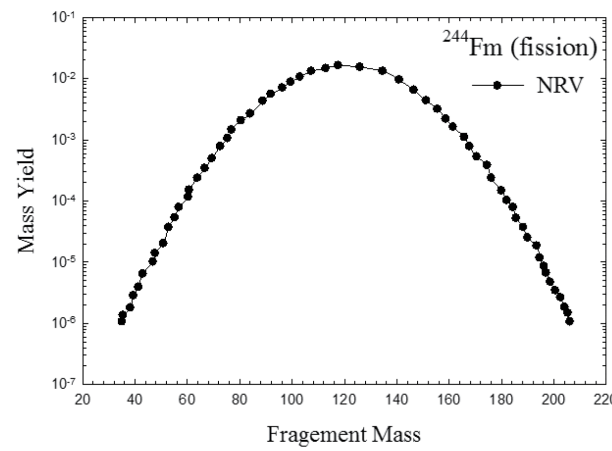

Figure 2: The predicted mass distribution of the fermium isotope (^{244}Fm) which shows the symmetric mass split contrast to the systematic prediction as asymmetric split.

IV. Summary and conclusion

Different reaction mechanisms are important to understand the formation of heavy and super-heavy nuclei. Each reaction process has an independent set of observables that are needed to be determined experimentally. A clear discussion has been presented for the different types of experimental observable. A completely different approach has been presented for the prototype detection system, which is based on the secondary electron emission for the detection of the mass and energy of the fission fragments. The interesting physics case of Fm isotopes is highlighted. The same detection system can be used for many other applications starting from imaging to defense purpose. Very soon the detection system will be ready and it will be used for the mass measurement.

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