Search for Collinear Multi Body Decays of Low Excited Nuclear Systems "An Overview"

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Abstract. Some years ago the Flerov Laboratory of Nuclear Reactions (FLNR) at The Joint Institute for Nuclear Research (JINR) while performing experiments at the FOBOS spectrometer observed some unusual structures in the mass-mass plots of ^{248}Cm(sf) and ^{252}Cf(sf) with a yield of -10^{5}-10^{6} with respects to binary fission [1]. These observations were treated as indications of new type of nuclear transformation which later came to be known as Collinear Cluster Tripartition or CCT. CCT is a ternary fission mode where the decay partners fly apart almost collinearly with at least one of them being the magic nucleus [2]. Soon after those observations a number of experiments have been carried by the Flerov group in search of the CCT phenomenon. This paper looks at the experimental work done over the years in search of the CCT mode, and highlights some important results of the experiments carried out by the Flerov group from the FOBOS setup to the current Light Ion Spectrometer (LIS) experimental setup.

1. Introduction

Nuclear fission is commonly known as a process where a heavy nucleus such as Uranium decays into two fragments of roughly equal mass. On occasion instead of decay into two parts a process known as binary fission, the nucleus can decay into three fragments. In this decay channel known as ternary fission, the nucleus splits into three fragments with the third particle being too light compared to the main fission fragments

2. Origins of CCT

One of the early experiments aimed at studying rare fission modes in spontaneous decay of ^{248}Cm and ^{252}Cf revealed a group of precisely paired heavy fragments with a large deficit of both total mass and total kinetic energy [1]. These events were detected very far from the locus associated with conventional binary fission (see selected area in figure.1) in the correlation plot of the fragment masses. The total yield of these rare events was about 10^{-6} to 10^{-5} of the whole body of data. Indications from these results was that the system was fissioning through an elongated and highly deformed three cluster like configuration with two light fragments on the extreme left and right flying apart along the chain axis while the middle and heavier fragment remained at rest as shown in figure 2 below.

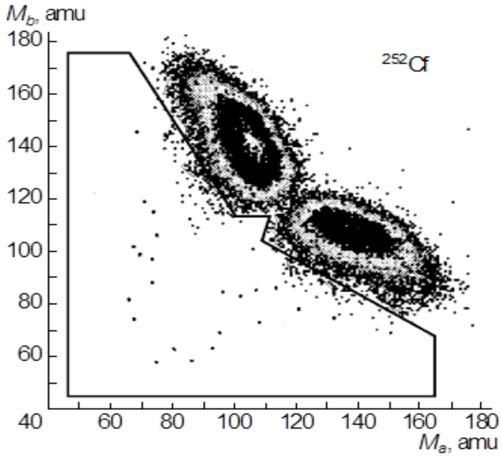

Figure 1. Mass-yield matrix Y (M_a, Mb) of fission fragments for ^{252}Cf (sf) [1].

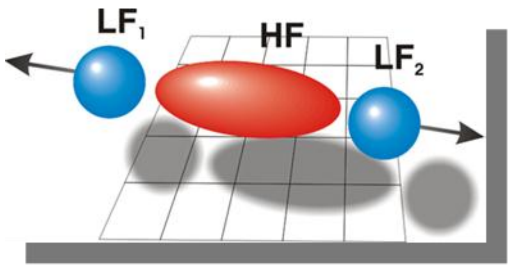

Figure 2.The proposed model of the fissioning system showing three cluster like configuration of the CCT fission system.

3. Evolution of the CCT Time-of-Flight Spectrometers

The FOBOS spectrometer was originally designed for reactions studies in direct kinematics and consisted of three consecutive shells of particle detectors. The inner detector shell consisted of 30 position sensitive avalanche counters (PSAC's) and a flight path of *50cm* between the target and shell. Further details of the setup can be found in [2]. Due to the low cross section of the process under study and other requirements, some modifications were carried out to the original FOBOS setup which included five big and one small standard FOBOS module for each arm, a specially designed three electrode start avalanche counter with a central electrode (cathode) combined with the fission fragment source of ^{252}Cf and a neutron belt (insert next to miniFOBOS setup) which was based on the proposed CCT model as shown in figure 2. These modifications and others which can be found in [2] made it possible to measure both the energies and velocity vectors of the coincident fragments and verify the validity of the proposed CCT model process.

Experimental manifestations of CCT in both the FOBOS and miniFOBOS setups were obtained in the framework of the missing mass approach where only two fragments were directly detected in coincidence and the third fragment identified by subtracting the masses of the two detected fragments from the initial mass of the system. The JYFL spectrometer was the first set up designed to detect all three partners directly. The setup included two arrays of PIN diodes with 19 elements each, two Micro Channel Plate based start detectors and a specially designed target holder. The PIN diodes provided both energy and timing stop signals. Further details of the setup can be found in [6]. The JYFL spectrometer made it possible to study the reaction of $^{238}U+^{4}He$ as an example of fusion-fission reaction.

In order to increase the reliability of detecting the three CCT partners directly, a new setup called Correlation Mosaics Energy-Time Array (COMETA) spectrometer was introduced. This is a double arm time-of-flight spectrometer that includes a Micro-Channel Plate (MCP) based “start” detector, two mosaics of eight PIN diodes each and a “neutron belt. The MCP based “start” detector is designed in such a way that the source is installed inside the detector. Each PIN diode in each mosaic provides both the energy and time signals. The “neutron belt” which comprises of 28 ^{3}He filled neutron counters is located in the plane perpendicular to the symmetry axis of the setup. Further details of the setup can be found in [4].

The current and latest experimental setup in the evolution of the time of flight spectrometers aimed at searching the CCT phenomenon is the Light Ions Spectrometer or LIS setup. The LIS setup is designed to overcome the plasma delay experienced in using silicon based detectors in measurement of fragment energy and velocity [7]. This double arm spectrometer makes use of MCP detectors to measure the time of flight of the fission fragments instead of PIN diodes as used in the COMETA setup. This eliminates the plasma delay effect encountered with silicon detectors. Complete details of the setup can be found in [7].

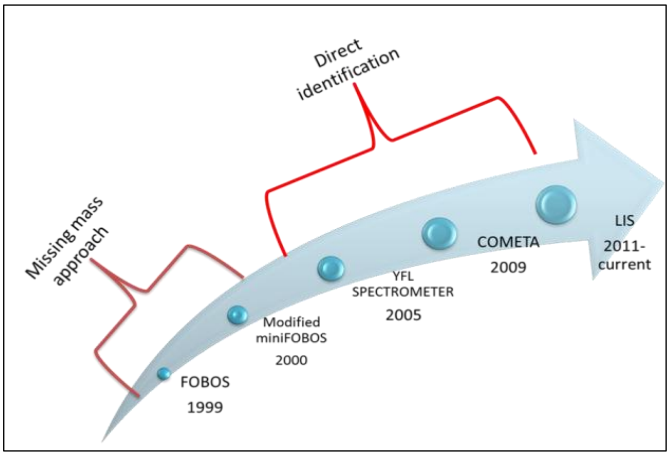

Figure 3. Time line indicating the evolution of the different set ups of CCT time of flight spectrometers over the years from 1999 to 2011.

Detection of the three CCT partners in the early FOBOS and miniFOBOS spectrometers made use of missing mass approach, meaning two partners are directly detected and the third identified by subtracting the two fission fragment masses from the total mass of the initial system. Identifying all three fragments directly was however the goal and the YFL spectrometer, the COMETA and lately the LIS spectrometer were all designed with the aim of directly detecting all three partners of the CCT fission decay mode. Figure 3 gives an approximate indication of the time-line of when each of the different spectrometers was introduced.

4. Results and discussion

Figure 4 is the two dimensional distribution (M_2-M_1) of the two registered masses of the coincident fragments obtained from the FOBOS setup. M_2 gives the distribution of the fragment mass from the side of the detector facing the dispersive (scattering) material. In this mass-mass distribution only collinear events with relative angles of around 180^0 are selected. The main feature of interests in the plot is the distinct bump indicated by the red arrow. This bump originates from the side of the arm facing the dispersive material and is located in a region corresponding to a large missing mass. This feature of the bump has been revealed repeatedly in all other CCT spectrometer setups.

A closer look at the region of the mass-mass distribution around the bump in figure.5 obtained with the COMETA setup reveals a rectangular structure below the locus of binary fission bounded by magic nucleus with masses namely ^{128}Sn(1), ^{68}Ni(2),^{72}Ni(3). The masses of the magic nuclei in the figure are indicated by the numbers in the brackets [3], [5]and [6].

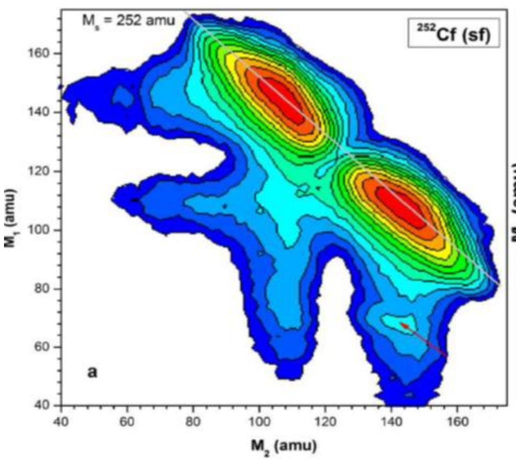

Figure 4. Contour map (in logarithmic scale) of the mass-mass distribution of the collinear fragments of ^{252}Cf detected in coincidence in the two opposite arms of the FOBOS spectrometer [2]

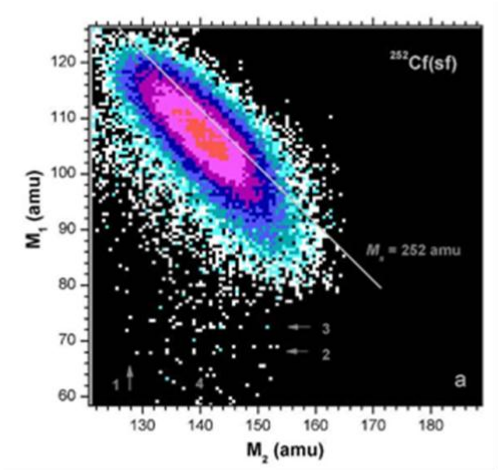

Figure 5. The region of the mass-mass distribution for the fission fragments of ^{252}Cf around the CCT bump with no additional gating [3] and [5].

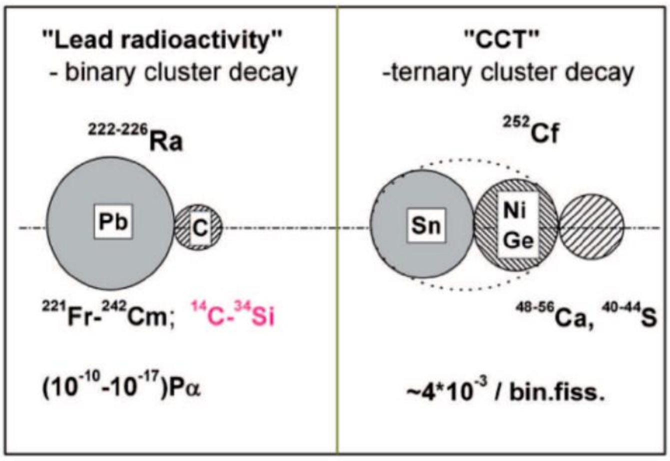

Figure 6. Comparison of lead radioactivity on the left with collinear cluster tripartition on the right [2]

5. Conclusion

The results given in figure 4 and figure 5 suggest the existence of a CCT mode which manifests itself through a peculiar bump corresponding to a specific missing mass in the FF mass-mass distribution. The results further give an indication of a decay mode in CCT that can be treated as a new type of cluster decay as compared to the well-known heavy ion or lead radioactivity. This suggested cluster scheme in comparison with lead radioactivity is shown in figure 6.

References

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