ARE THERE PHYSICAL SPECTATORS OF THE CCT PROCESS?

Yu.V. Pyatkov[1,2], D.V. Kamanin[1], A.A. Alexandrov[1], I.A. Alexandrova[1], N.A. Kondratyev[1], E.A. Kuznetsova[1], O.V. Strekalovsky[1], V.E. Zhuchko[1]

[1]Joint Institute for Nuclear Research, Dubna, Russia
[2]Moscow Engineering Physics Institute, Moscow, Russia

INTRODUCTION

In our recent publications [1] we have presented experimental evidences of existing of a new type of ternary decay of heavy low excited nuclei called by us collinear cluster tri-partition (CCT). The results were obtained in the frame of the "missing mass" approach. It means that only two from at least three decay partners were actually detected whereas a total mass of these fragments being less the mass of mother system serves a signature of multibody decay. Evidently direct detection of all CCT products proves to be a most convincing experimental approach but much complicated one because mosaic detection systems must be used to achieve the goal.

COMETA (Correlation Mosaic E–T Array) setup aimed at studying of rare multibody decays was put into operation recently in the Flerov Laboratory of the JINR. It is a double arm time-of-flight spectrometer which includes micro-channel plate (MCP) based "start" detector with the ^{252}Cf source inside, two mosaics of eight PIN diodes each and a "neutron belt" comprises 28 ^{3}He filled neutron counters. Below we discuss some results obtained at the COMETA setup.

LIGHT CHARGE PARTICLES ACCOMPANIED CCT: SPECTATORS OR PARTNERS OF THE DECAY?

In this section ternary events observed at the COMETA setup will be analyzed. It means that three fragments were really detected in coincidence in each event. The fission fragments (FFs) from such events are labeled as m_1, m_2, m_3 in an order of decreasing masses in each ternary event. Mass correlation plot for the masses m_1, m_2 is shown in fig. 1. It is observed only for the events where the fork of two fragments was detected in the spectrometer arm faced to the source backing.

Rectangular structure bounded by the magic nuclei is seen in the center of the plot. Missing masses are ranged from 4 (alpha particle) up to 48 amu. Another distribution (fig. 2) is convenient for testing mass conservation law in ternary decays. Normally experimental points must lie on the line Ms = 252 amu (where Ms is a total mass of all three decay partners i.e. $Ms = m_1 + m_2 + m_3$) within mass resolution of the spectrometer. It is not so for the bulk of the points presented in the typical Ms_{12}–m_3 distribution in fig. 2. It seems they form some families of events which met the condition $m_1 + m_2 = const$ what corresponds to the fixed mass of the third fragment. But only part of this fragment was actually detected almost in all the events presented. For instance, presumable configuration for the events marked by the circle is shown in the insert of fig. 2. Likely the middle fragment of the initially three body chain was clusterized into two lighter fragments in the scission point and only one of them (^{14}C) was detected.

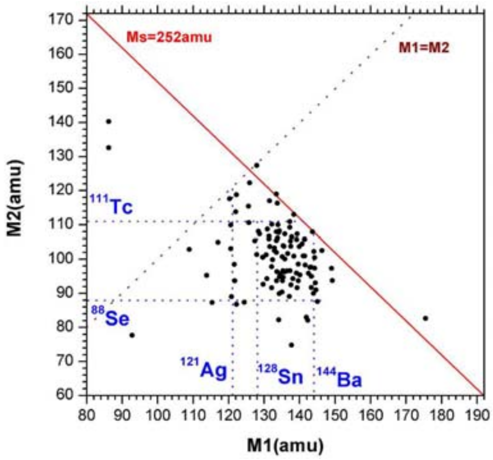

FIGURE 1. Correlation mass plot for two heavy partners of ternary decay. Rectangular structure in its center is bounded by the magic nuclei.

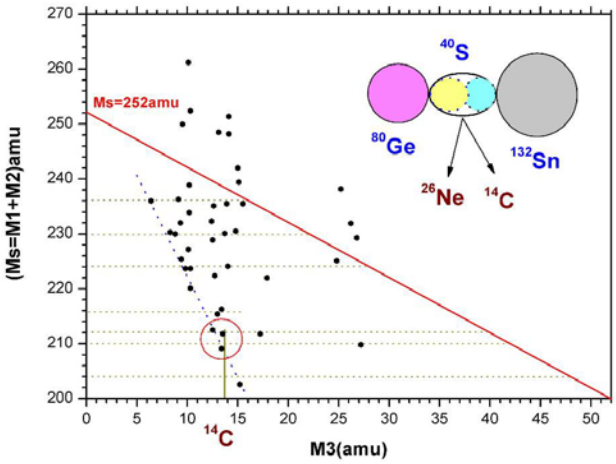

FIGURE 2. Typical distribution $Ms_{12} = m_1 + m_2$ vs. m_3. Presumable pre-scission configuration for the events underlined by the circle is presented in the insert. See text for details.

The following alternative scenario could give rise to the peculiarity mentioned (fig. 3).

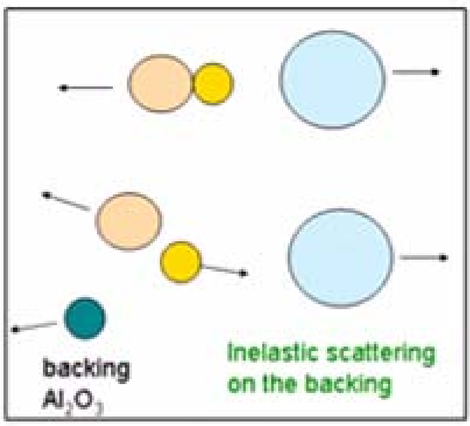

FIGURE 3. Possible way of forming a fork of two fragments flying in the same direction due to a breakup of the di-nuclear molecule in an inelastic scattering in the source backing.

After first rupture, for instance, in the configuration shown in the insert of fig. 2, ^{132}Sn nucleus and di-nuclear system Ge/S become free. Then a break- up of the molecule appears to occur due to inelastic scattering in the backing of the source. As a result the scattered Ge nucleus and knocked out ion of ^{27}Al or ^{16}O can be detected in the corresponding spectrometer arm while the ^{40}S nucleus flies in the opposite direction following ^{132}Sn nucleus. Similar process with even larger energy transfer is known as Coulomb fission [2]. The yield of such process is strongly dependent from the binding energy of the molecule and scattering angle. If the scenario under discussion is really realized a knocked out ion can be regarded as a specific spectator of the CCT process.

Summing up, the results obtained at the COMETA setup on direct detecting of three partners of at least ternary decay of ^{252}Cf (sf) can be treated in the frame of two following hypothesis. The first one is that the light detected fragment (m_3) can be some part of the middle clusterized fragment of the three-body chain-like pre-scission configuration in the

CCT channel. The second hypothesis treats m_3 as a mass of the ion knocked out from the source backing. The same inelastic scattering gives rise to the break-up of the di-nuclear molecule formed after first rupture of the pre-scission CCT configuration. In the latter case lightest detected fragment plays a role of the CCT spectator.

UNIDENTIFIED CCT SPECTATORS

Analysis of the data obtained at the COMETA setup let us to suppose that sometimes we have the “start” signals provided by the MCP based detector to be shifted as compared to the “normal” ones delivered by the accelerated electrons (mode_1 of the detector operation) (fig. 4). In order to test this hypothesis a series of dedicated experiments were carried out. In one of them the external accelerated greed of the electrostatic mirror was switched off (mode_2).

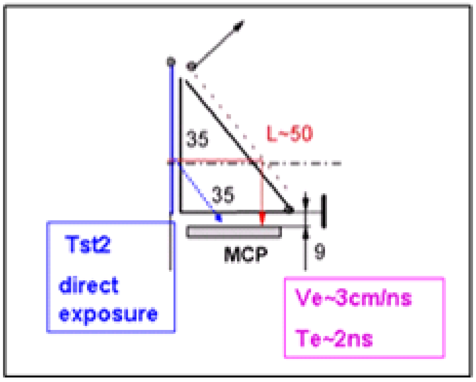

FIGURE 4. MCP based “start” detector. The MCP can be hit by the accelerated electrons produced by the ion passing through the detector or directly by some CCT spectator.

Nevertheless there were signals from the detector resulted from the direct exposure of the MCP by an unknown ionizing substance. Time-of-flight channel was previously calibrated at the usual operation of the timing detector (the mirror is switched in, mode_1). Typical time-of-flight (Te) of the path “emitting foil-MCP” and corresponding velocity of the electrons are marked in fig. 4. For a spectator time-of-flight of the direct path from the foil to the MCP is designated Tst2. FFs correlation mass-mass distribution obtained under condition that the “start” detector was operated in mode_2 is presented in fig. 5. The position of the loci of conventional binary fission known due to the calibration is marked by the ovals. As can be inferred from the figure direct hitting of the MCP can appear to occur by the CCT spectator which could be both faster ($Tst2 < Te$) or slower ($Tst2 > Te$) the accelerated electrons provided the signal in mode_1.

In the next experiments two “start” detectors were simultaneously used operated in mode_1 and mode_2 respectively. In this case Tst2 parameter was used for selecting of fission events. Mass-mass distribution of fission events under condition that slow spectator gave a signal in MCP 2 is presented in fig. 6. Rectangular structure bounded by magic nuclei is seen in the center of the plot. The upper boundary of the rectangle coincides with the line $M1 + M2 = const$ (missing ^{18}O nucleus). Similar line but starting from its low left corner (marked by the arrow) corresponds to the missing ^{34}Al nucleus. The structure was never observed before at another gating.

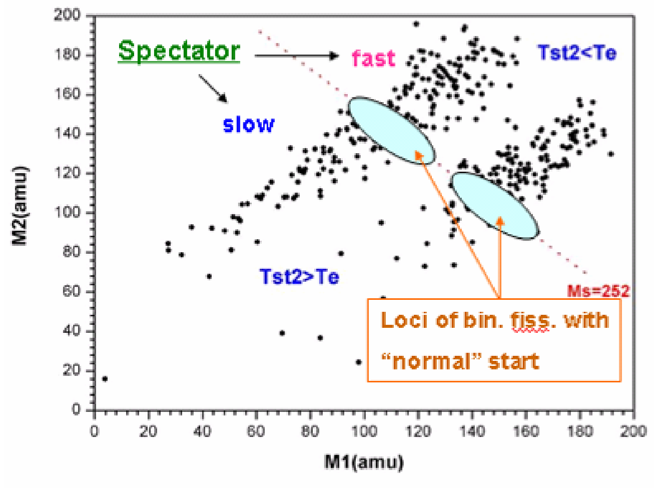

FIGURE 5. Correlation plot of the masses of fragments detected in coincidence in the opposite arms of the COMETA setup. See text for details.

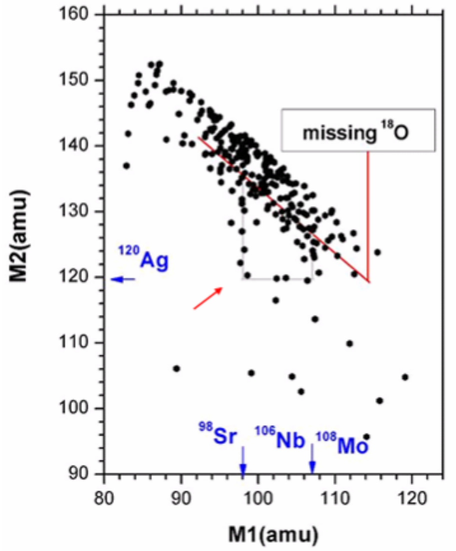

FIGURE 6. Mass-mass distribution of the fission events registered in coincidence with slow spectator. See text for details.

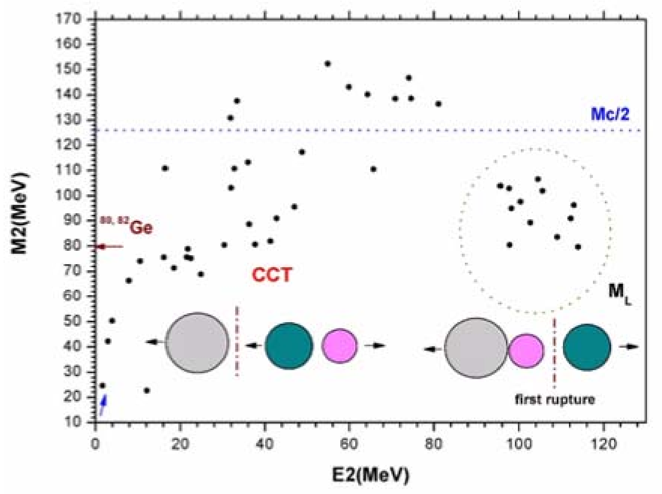

FIGURE 7. FFs mass-energy distribution in one of the spectrometer arms under condition that timing detector operated in mode_2 was heated by some spectator and total mass of two detected fragments is less than 252 amu. See text for details.

Mass-energy distribution of fission events which met the conditions that total mass of two detected fragments is less than 252 amu and some spectator heated the timing detector operated in mode_2 is shown in fig. 7. Two groups of events below the line Mc/2 where Mc is a mass of the decaying system are seen. They radically differ by the energy. The group of events inside the circle shows masses and energies typical for the fragments of the light mass peak of conventional binary fission. At the same time the fragments with similar masses can have the energies approximately 70 MeV lower. Keeping in mind that in fact according to the gating all the events presented in fig. 7 are ternary ones two different pre-scission configurations shown in the bottom of the plot give rise to the corresponding groups of the decay events under discussion. An interesting peculiarity of the low energy group of events should be stressed. There is a specific shoulder at the mass ~80amu associated with magic Ge nucleus. While pre-scission elongation of the decaying system increases due to Coulomb forces the mass of the light fragment (Ge) stays unchanged in some range of elongations and only then destroying of the Ge cluster appears to occur with the transfer of the nucleons to the heavy fragment.

In the frame of the experiments discussed in this section we cannot identify spectators used for the gating of fission events. Nevertheless, gated data contain original manifestations of different CCT modes. Thus it is promising way of revealing the CCT events to be developed in forthcoming experiments.

CONCLUSIONS

1. Experimental approaches additional to the missing mass method confirm the existence of the CCT decay channel.
2. New experimental information obtained gives evidence of a nontrivial scenario of the collinear cluster tri-partition process and structure of the lightest decay partner especially.
3. Further studying of the process stays an actual task.

REFERENCES

1. Yu.V. Pyatkov et al., Eur. Phys. J. A 45 (2010) 29.
2. L. Wilets et al., Phys. Rev. 156 (1967) 1349.