COLLINEAR CLUSTER TRI-PARTITION OF ^{252}Cf (sf) – EVIDENCES IN NEUTRON GATED DATA

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Abstract. Neutron gated data obtained using COMETA setup let us reveal rectangular-like structures in the mass-mass distribution of the fission fragments. The structures are bounded by the magic clusters. Such manifestation of clustering we have already observed earlier but for lighter clusters. Summing up all the results obtained we conclude that there is distinct mode of clustering of the fissioning system when it looks like nuclear molecule based on different pairs of magic light/heavy clusters.

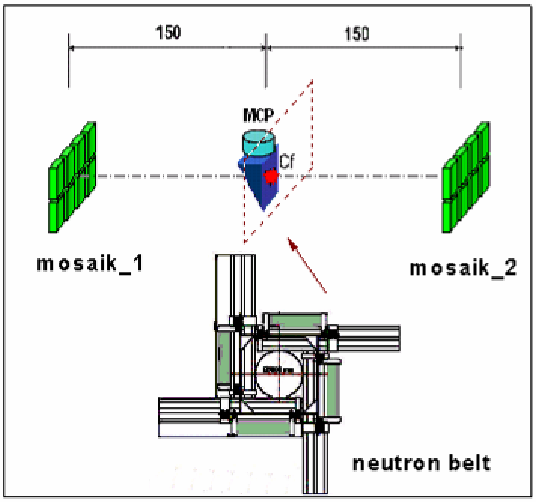
INTRODUCTION

In our previous experiments [1–3] we have observed multiple manifestations of new ternary decay of low and middle excited heavy nuclei called "collinear cluster tri-partition" (CCT) due to the features of the process observed. The unusual decay channel was revealed both in the frame of the "missing mass" method [1, 2] and directly i.e. when all three decay partners were detected [4]. In order to increase reliability of selecting of the CCT events additional identification parameter based on their experimental neutron multiplicity was introduced.

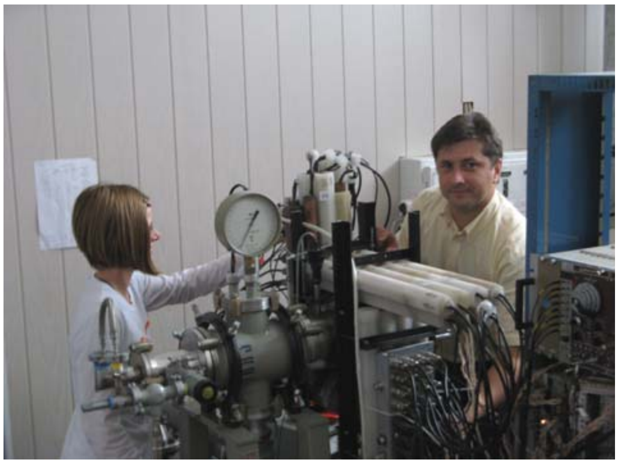
EXPERIMENT AND RESULTS

The experiment was performed at the Flerov Laboratory of the JINR using COMETA (Correlation Mosaic E-T Array) setup (fig. 1). It is 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 30 ^{3}He filled neutron counters. The geometry of the belt provides preferential detection of the neutrons emitted isotropically.

The spectrum of neutrons detected in coincidence with fission fragments (FF) is shown in fig. 2 where it is marked by the label "FF_gate" (curve "a"). It means that just fission event opened the gate for registration of neutrons. In order to control a background the gate of the same width was opened periodically by test generator (curve "b") with the frequency close to the mean counting rate of fission events. The spectrum of experimental neutron multiplicities (curve "a") can be treated as comprises a convolution of two functions. The first one is the spectrum of neutron multiplicities known from the literature [5] transformed into experimentally expected spectrum according to real experimental probability of detecting a neutron by the neutron belt of the COMETA setup (p_n). The second function presents the multiplicity of background neutrons (curve “b” in fig. 2). The value of p_n provided a best fit of the experimental spectrum of neutron multiplicities was estimated to be $p_n = (4.5 \pm 0.1)\%$. Modeling of the neutron belt performed previously using MCNP code gave $p_n = 5.23\%$ being in good agreement with the experimental value obtained. At the same time the registration efficiency for the neutrons emitted isotropically also obtained by modeling does not exceed 11.9%. Thus specific geometry of the neutron detector provides more then two fold preference for registration of “isotropic” neutrons reference to neutrons emitted from fully accelerated fragments.



a



b

c

FIGURE 1. Scheme of the COMETA setup (a), overall view of the spectrometer (b) and of the neutron belt (c).

The time-of-flight vs. energy (TOF-E) calibration and the calculation of the M_{TE} masses presented in [6] were used. In brief, the mass spectrum of binary decays, which depends on the measured variables and parameters for describing of pulse height defect, was forced to fit the known mass spectrum of ^{252}Cf fission.

Fission fragments (FF) mass-mass distribution drown for the events where three neutrons (n = 3) were detected is shown in fig. 3. The rectangle bounded by the magic nuclei attracts attention in the upper part of the figure. The tilted line corresponding to the fixed total mass of two detected fragments Ms = M1 + M2 = 208 amu (marked by the dash line) was also observed earlier.

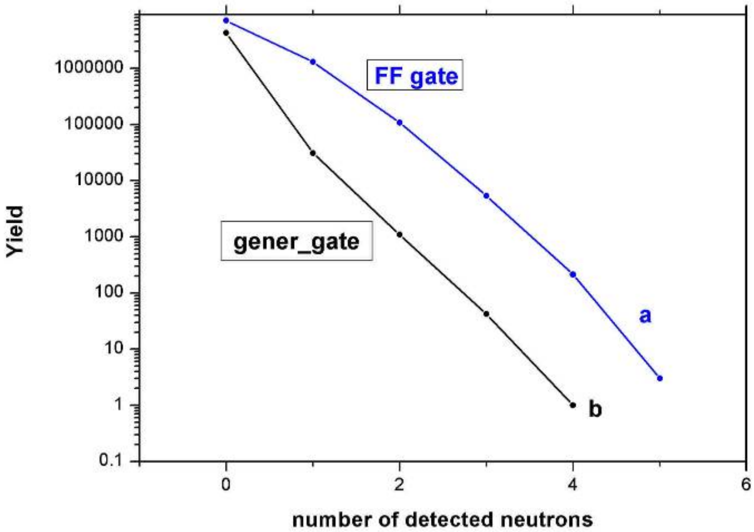


FIGURE 2. Number of neutrons detected in a time gate opened by the fission event and by the periodic generator (curves “a” and “b” respectively).

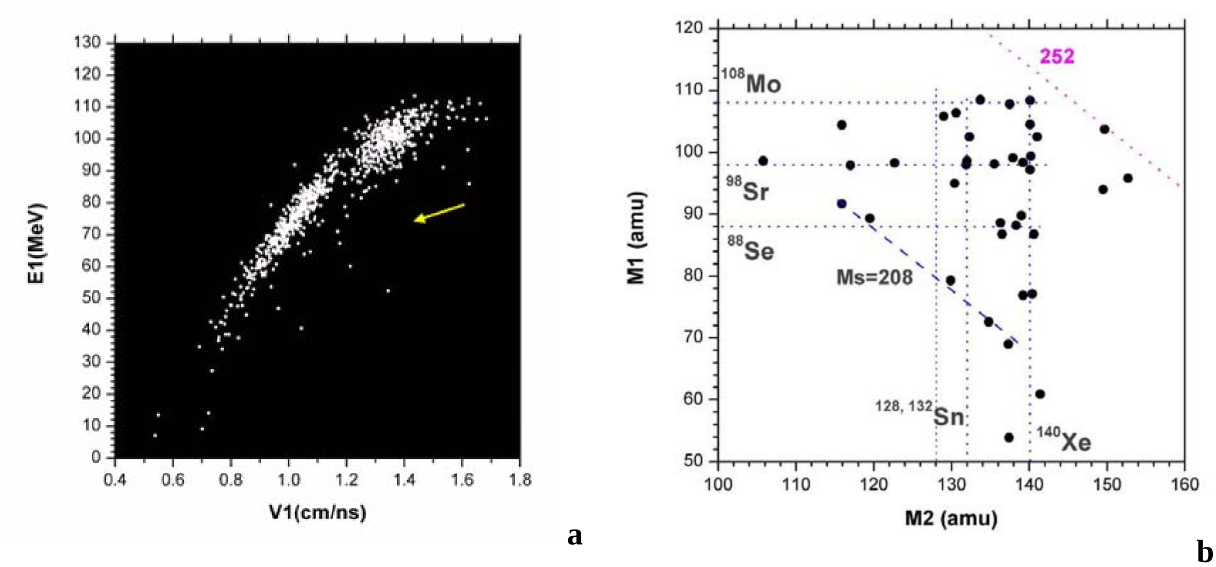
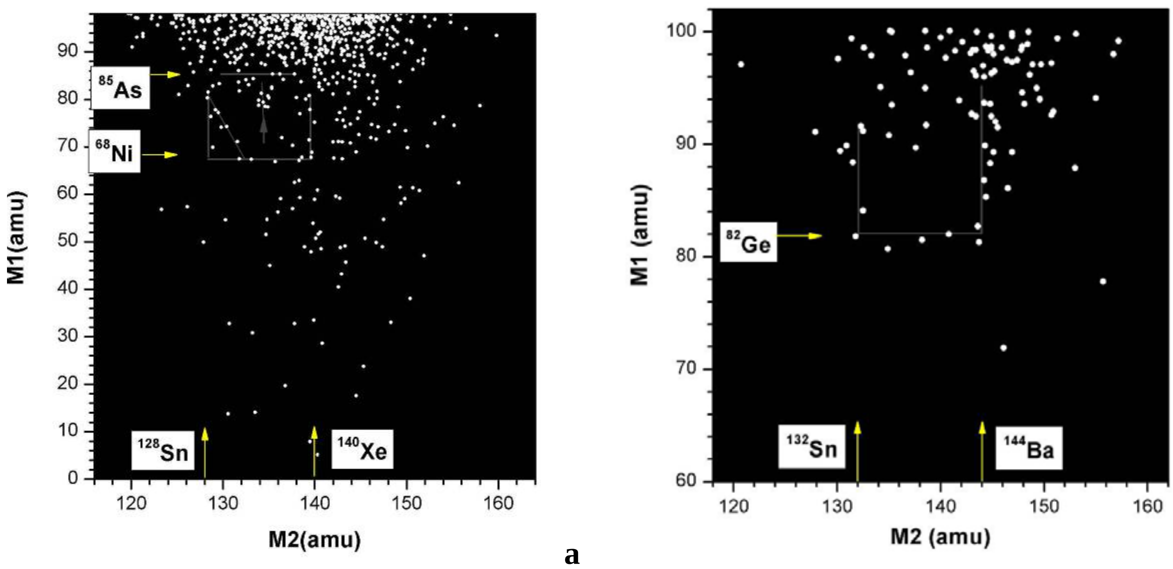


FIGURE 3. Velocity – energy distribution of the FF from ^{252}Cf (sf) under condition that three neutrons were detected in coincidence (a). Mass-mass plot for the events beyond the loci of conventional binary fission in previous distribution (b). Results were obtained at the COMETA setup.

DISCUSSION

Rectangular structures similar to this shown in fig. 3b were observed earlier in our experiment at the modified FOBOS spectrometer [7] but for other magic constituents. Corresponding structures are presented in fig. 4 for n ≥ 2 (a) and n ≥ 3 (b) respectively, where n is a number of neutrons detected in a fission event. It should be stressed that in any case the rectangular structures are observed only in the spectrometer arm faced to the backing of the Cf source where a specific bump is seen in the mass-mass correlation plot of the FF (fig. 5a)

[1]. We believe the bump to be connected with collinear ternary sequential decay of the initial system. Two fragments flying almost collinearly just after scission obtains angular spread in order of 1^0 due to multiple scattering in the backing. Then one of them can be lost due to the supporting mesh at the entrance to the ionization chamber. The mesh plays a role of “blocking medium”. Thus collinear tri-partition manifests itself in the frame of the missing mass method (fig. 5) exclusively thanks to sequential action of scattering and blocking mediums. In the present experiment the lightest partner of the ternary decay (fig. 3b) has much less mass than these in the previous case (fig. 4). It can be scattered at larger angle and lost for the detection in the mosaic.



a

b

FIGURE 4. Mass-mass plot for the events selected with the condition that more then two neutrons were detected ($n \geq 2$) in coincidence with the FF from ^{252}Cf (sf) (a), similar distribution for $n \geq 3$ (b). Results are obtained at the modified FOBOS spectrometer [8].

The evident difference between fig. 4 and fig. 3 consists in the masses of the light magic clusters namely ^{98}Sr and ^{108}Mo forming two opposite sides of the rectangle. Their manifestation in the CCT process is confirmed as well by our previous data [1]. Earlier we have discussed [1] only the bump 7 vividly seen in the FF mass-mass correlation plot without any processing (fig. 5a). Fig. 5c shows the complete difference of the spectra to be the projections of the events from boxes w1 and w2 (fig. 5a) onto M2 and M1 axises respectively. Along with the bump 7 some additional peaks are seen. For treating of the spectrum let us discuss, for instance, the origin of the bump 7. As was mentioned above it manifests itself in one spectrometer arm thanks to sequential action of scattering and blocking mediums while in the opposite arm similar CCT event will be detected as almost normal binary one. It means that one to one correspondence in areas must exist between bump 7 and its negative image in the mass range of binary FF. Such feature should be valid for any “bump” linked with different magic clusters. In other words each light FF observed normally in binary fission can fragment into the magic core and corresponding lighter constituent. At the same time maximal mass of the light fragment in the mass-asymmetric fission mode can not exceed 120 amu due to the known extreme stability of the complimentary heavy fragment (double magic ^{132}Sn).

This is just the feature observed in fig. 5a. The negative minimum at Mc/2 (fig. 5c) where Mc is the mass of the fissioning nucleus of ^{252}Cf shows that ternary fragmentation likely appears to occur in mass-symmetric fission mode as well. Position of the local peaks in fig. 5c can depend from possible shift in centers of the spectra in fig. 5b due to independent mass calibration in the opposite arms of the spectrometer. Fig. 5d demonstrates an absence of such shift. Second derivative of the mass spectrum linked with the gate w2 shows the same peaks as the difference spectrum in fig. 5c.

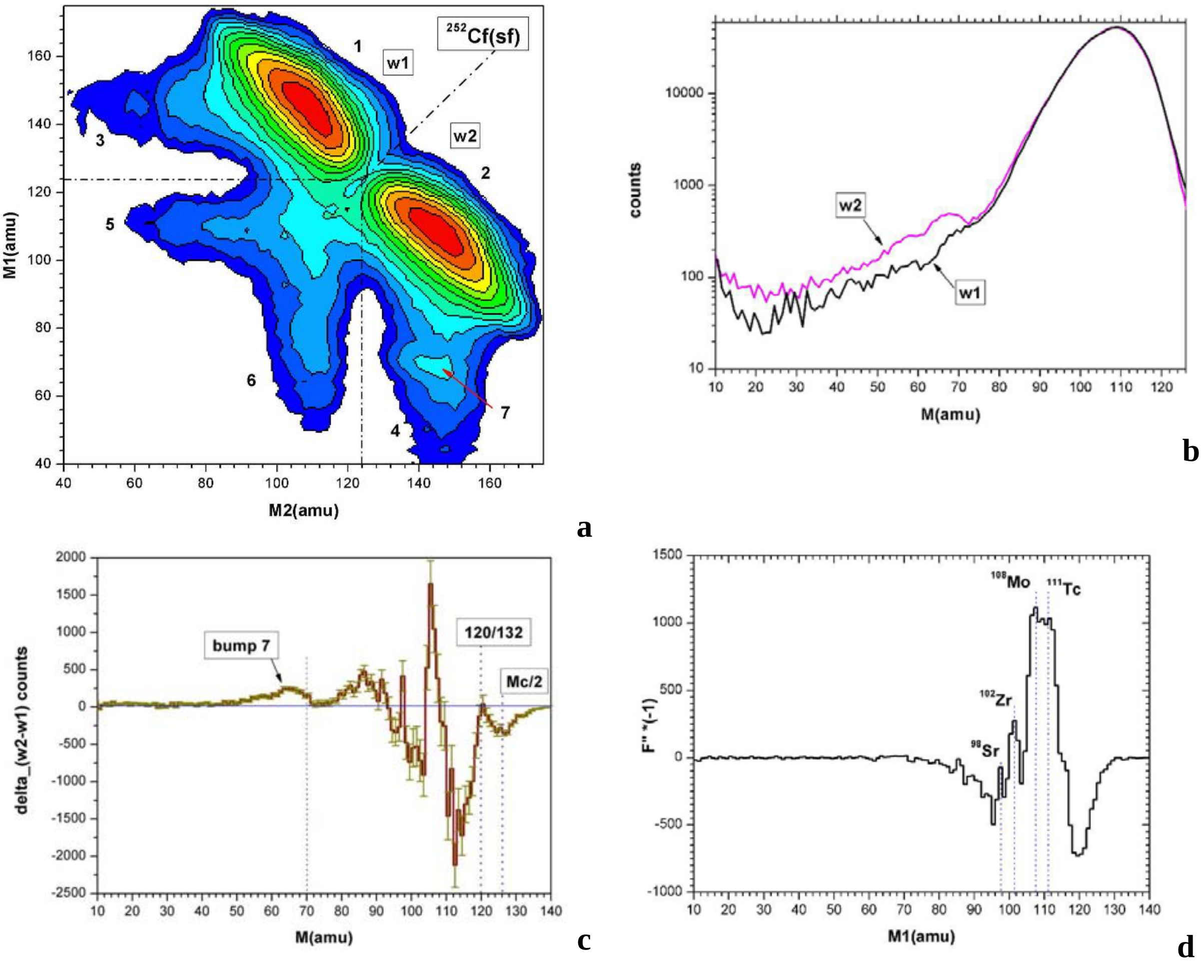


FIGURE 5. Mass-mass distribution (a), projections of the events from box w1 and box w2 onto M2 and M1 axises respectively (b), difference between these projections (c), second derivative of the spectrum being the projection of the events from box w2 onto M1 axis (d). See text for details.

CONCLUSION

New neutron gated data obtained at COMETA setup confirm the existence of the CCT modes manifesting themselves via specific rectangular structures bounded by magic clusters in the FF mass-mass distributions. Nuclear molecules based on pairs of magic light/heavy clusters stand behind the ternary modes discussed. Magic deformed ^{108}Mo [9] and ^{111}Tc [10] clusters show the maximal yield ($\geq 10^{-2}$/bin. fiss.) in the CCT process while $^{128, 132}$Sn play the role of the heavy ones.

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