NEW STEP IN SEARCHING FOR COLLINEAR TRIPARTITION IN ^{252}Cf (sf) AT THE FOBOS SETUP

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Abstract The phenomenon of collinear tripartition in spontaneous fission of ^{252}Cf have been studied at the modified FOBOS setup. The structures in the energy and mass correlations of the fission fragments gated by the large measured neutron multiplicity are treated as indication of collinear tripartition of ^{252}Cf. The preliminary analysis of the charge of fission fragments argues in favor of this conclusion.

The advanced experiment aimed at the investigation of collinear cluster tripartition of the ^{252}Cf nucleus is performed at the 4π spectrometer FOBOS [1] at Flerov Laboratory of the JINR. In previous experiments [2] aimed in particular to the search for mass-symmetric ternary and quaternary spontaneous decays of ^{248}Cm and ^{252}Cf a group of events with a large deficit both of the total mass and of the total kinetic energy have been detected . This group is remote from the locus connected to conventional binary fission in the correlation plot of the fragment masses (selected area, Fig.1) and its yield amounts in the lowest limit to ~10^{-6}-10^{-5} of the whole data body. However, this group comprises the precisely collinear pairs of heavy fragments. The mass-energy correlations for these rare events allow one to associate them with fission of the system via an elongated three-body chain–like configuration. In this case

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two outside fragments fly apart along the chain axis, while the middle fragment can stay almost in rest. The results obtained have been treated as an indication of collinear cluster tripartition (CCT) of the heavy nuclei under study. The most important tasks for searching for CCT and some preliminary results of the recent experiment are discussed below.

The main method problem manifested in the former experiments was a background of faulty events due to the partial lost of the energy of the fission fragments (FF) on supporting and coordinate grids of the FOBOS modules. In order to overcome this obstacle and to improve the quality of the data some modifications have been introduced into the experiment scheme. These modifications concerned the configuration of the detectors including the start detector, the electronics and also the data acquisition system.

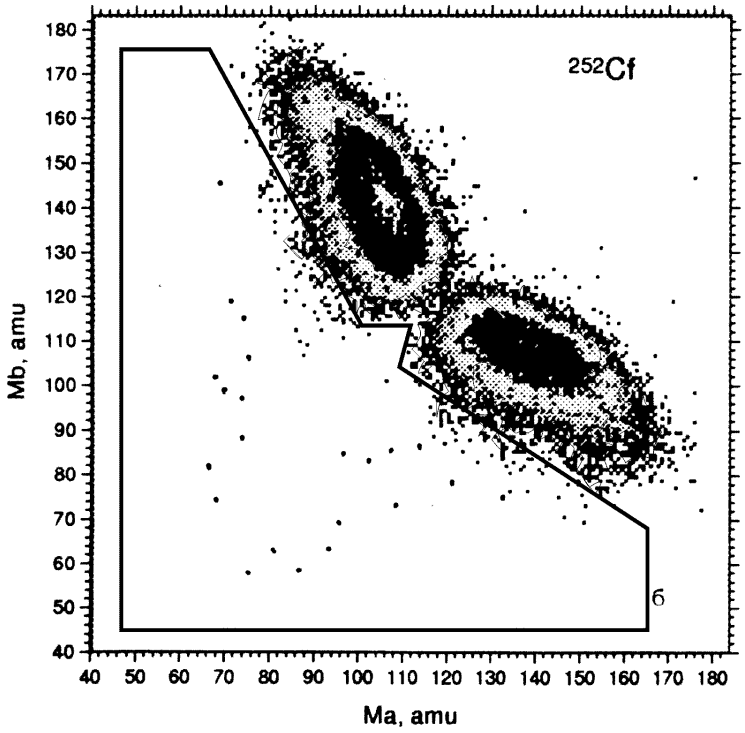

Fig. 1. Fission fragments mass-yields matrix Y(Ma,Mb) for ^{252}Cf(sf) decay.

The FF trigger consisted of two groups each containing six FOBOS modules used as a double-armed spectrometer for measuring the FF velocities (V) by means of their time-of-

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flight and their energies (E). Thus both the «2-V» and the «V-E» methods are accessible for the calculation of the FF masses. When using the latter method one do not need to use any a-priori assumptions concerning the process to be exclusively binary.

Such a double-armed configuration of the FOBOS spectrometer was enabled by the specially designed wide aperture start-detector with an internal FF source [3]. The full simmetrization of the spectrometer arms achieved due to such a start–detector essentially improves the quality of the data.

According to the model of the CCT process proposed in Ref. [2] the middle fragment of the three-body pre-scission chain borrows almost the whole deformation energy of the system. Being presumably in rest it would be an isotropic source of post-scission neutrons of a high multiplicity (~10) in the lab system. On the contrary, the neutrons emitted from the moving fission fragments are focused along the fission axis. In order to exploit this phenomenon for revealing the CCT events the "neutron belt" [4] consisting of 140 separate hexagonal modules based on ^{3}He-filled proportional counters was assembled in a plane being perpendicular to the symmetry axis of the spectrometer, which serves as the mean fission axis at the same time. The center of this belt coincides with the location of the FF source.

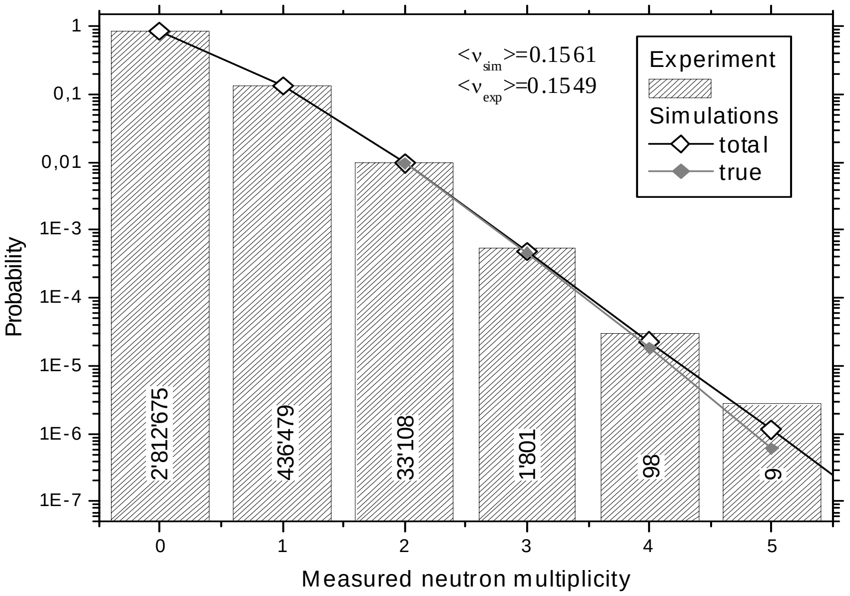

Fig. 2. The spectrum of frequency versus number of tripped neutron counters for the recorded fission events. The actual numbers of counts are labeled. “True” contribution is conditioned only by the number of emitted neutrons being not less than the measured multiplicity

The typical spectrum of frequency versus number of the tripped neutron counters for registered fission events is presented in Fig. 2. The function obtained agrees well with the theoretical calculations based on the known probabilities for emitting a certain number of neutrons per fission meaning the total registration efficiency of about 3.8% [4]. The overall registration efficiency for an isotropic source and, hence, for the neutrons from the CCT events, amounts to ~11%. A simple calculation accounting for this difference in the registration efficiencies and in the primary multiplicity spectra ascribed to the processes considered (see Ref. [4]) reveals that the registration probability for more than three neutrons from ordinary spontaneous fission in this geometry is lower by two orders of magnitude than the same probability for the CCT events.

Our empirical model described in [4] reproduces the shape of the multiplicity distribution from 0 to 3 precisely. In particular, the best fit presented in Fig. 2 delivers the average multiplicity differing from the experimental one only by the value of 0.001 and such a good reproducibility of the distribution shape is found to be stable against reasonable variations of the parameters of the model. The latter is extremely important for the tail of the distribution and, therefore, we checked the most important constants additionally by the simulations with the well-known MCNP code.

One should note that the lowest estimate of ~10^{-6}-10^{-5} of the yield of CCT with respect to ordinary fission formally assumes the contribution of at least 3-30 CCT events to the multiplicity spectrum in Fig. 2 and these events should contribute mainly to high-multiplicity values. On the other hand side, we didn’t include deliberately the contribution of CCT into our simulations and although there is no experimental data on the multiplicity 6 and higher the best fit misses surprisingly ~20 events for the measured values 4 and 5. Based on the statistics of 3 million events presented in Fig. 2 we wouldn’t insist, of course, on the evidence of some additional high-multiplicity process. However so far we expect such a manifestation of CCT the observed difference between the experiment and simulations is treated as an additional argument for searching the CCT events under the condition of $\nu_{exp}>3$.

In addition, according to our simulations the contribution of the true high-multiplicity events with $\nu_{emitted}>3$ to the measured multiplicity grater than 3 amounts to ~80% (Fig. 2) while the rest is mostly due to random coincidences with $\nu_{emitted}=3$. This mean the reliability of the experimental data selected by such a large number of fired neutron counters.

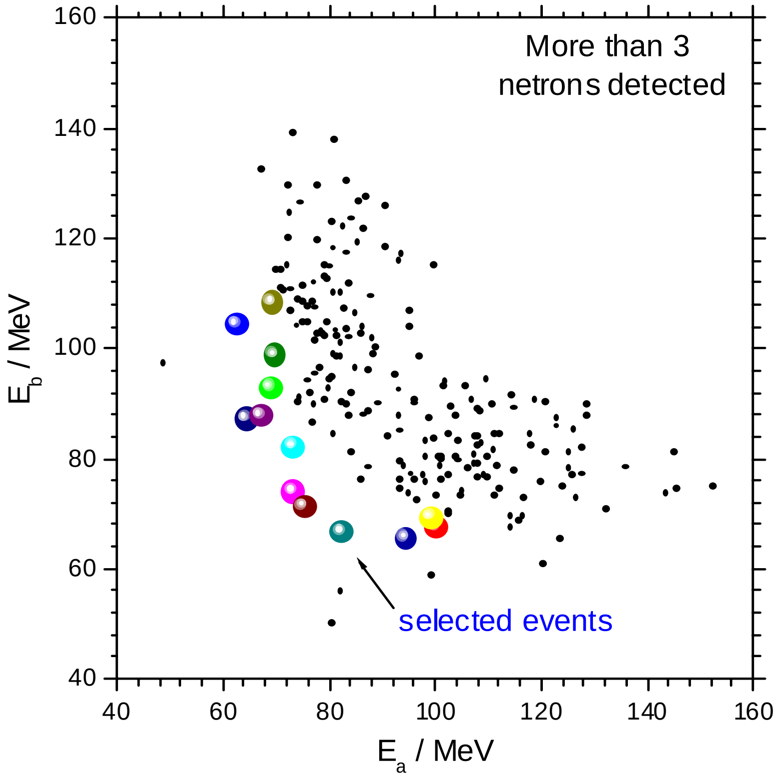

Fig.3. Energy distribution Y(Ea,Eb) of the complimentary fragments under the condition that at least 4 neutron counters were fired.

The first interesting result can be already discussed basing on a part of the whole data body counted $1.4*10^7$ events. Fig.3 depicts energy distribution Y(Ea,Eb) of the fragments detected in coincidence in two arms of the spectrometer (labeled **a** and **b**) selected by the large neutron multiplicity $\nu_{exp}>3$ as is it discussed above. The set of points which looks like parabola (denoted in Fig. 3 as selected events) attracts attention. For comparison, similar plot obtained for the events falling inside the contour shown in the Fig.1 is given in Fig.4, although this plot is not gated by the number of the fired neutron detectors. The events forming an angle-like structure in Fig.1, i.e. linked with tripartition, are connected by the parabolic curves.

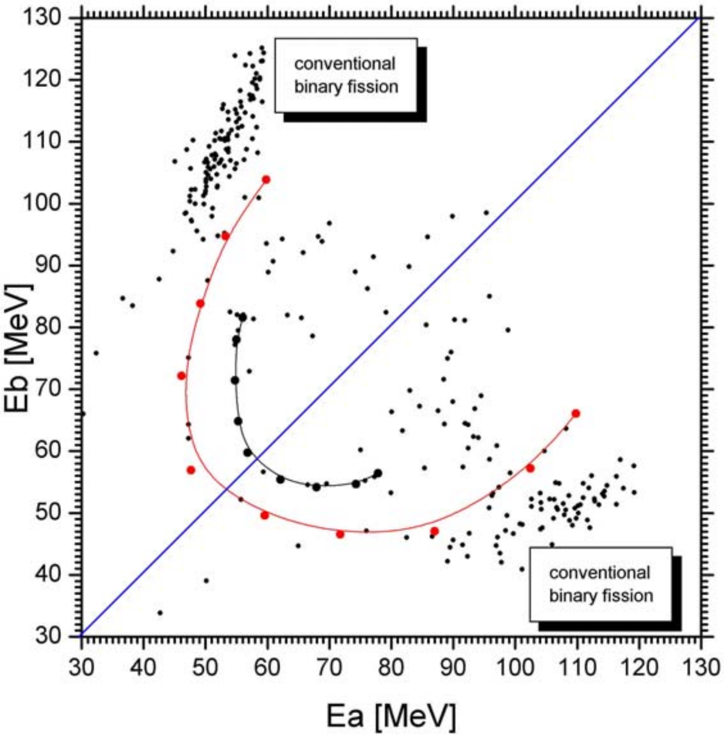

Fig.4. Energy distribution Y(Ea,Eb) of the complimentary fragments obtained for the events falling inside the contour marked in the Fig.1.

The serious test of the reliability of the CCT events is the low total charge of the both detected fragments, less than $Z_C/2$, where Z_C is a charge number of the fissioning nucleus. Unfortunately the Bragg-spectroscopy is out of rule for the heavy ions whose energy is typically less than 1 AMeV for the FF in spontaneous fission. In order to perform the test for the total charge an additional parameter was recorded for each fission fragment registered. This alternative method was proposed in Ref. [5]. It is based on measuring the delay between the time the fragments enter a Bragg ionization chamber (BIC) and the time the anode pulse crosses a given level, i.e. the parameter connected with the drift time of an electric charge in a BIC.

The distribution of the FF energy E_a versus drift time t_a obtained in our experiment for one of the detectors is shown in Fig. 5. The FF fall to the light and the heavy mass peaks which are easily distinguished. An individual charge at a given mass should look like a steep power function. Of course, numerical simulations and a direct calibration are needed for an accurate analysis of such a complicated parameter as t_a. Indeed, the drift time t_a is the function of the nuclear charge of the FF, its energy and, less pronounced, its mass simultaneously. However, preliminary conclusion can be drawn from the drift time *vs* energy plot shown in Fig. 6, which is accumulated under the same condition of the neutron multiplicity $\nu_{exp}>3$ as Fig. 3.

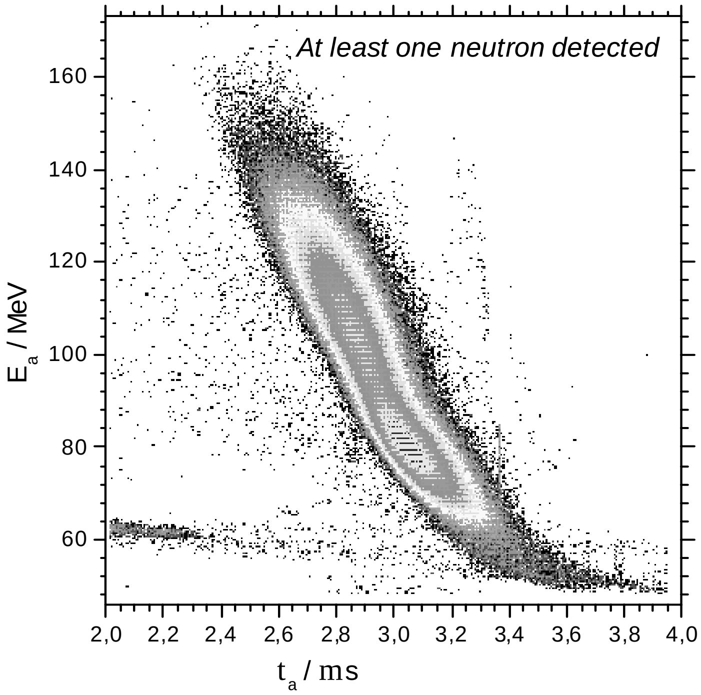

Fig. 5. The distribution of the FF energy versus drift time measured in a BIC when at least one neutron detector fired.

For a usual fission event one should expect that the measured total charge of complimentary FF is equal, on the average, to the charge of a Cf nucleus, i.e. $\langle Z_a \rangle + \langle Z_b \rangle = 98$. This should mean that the complimentary FF have to be found, on the average, on different sides from the line of the mean charge $\langle \tau_a \rangle$ in Fig. 6. However, all the selected events are located on the left and down from $\langle \tau_a \rangle$ thus revealing a lower mean fragment charge and no one is found on the other side. Hence, despite of a poor charge resolution the average total charge for the selected events is at least notably lower than 98 with a high probability. In order to make an ultimate conclusion on a total charge one should consider correlated FF pairs and trace down lines of individual charges.

Summarizing, we observe the structure linked presumably with collinear tripartition just in raw neutron gated data in Fig.3. This conclusion is proved by the total mass deficit observed and it seems to be confirmed by the preliminary analysis of the FF charge measured. This is the most inspiring result for the moment while processing of the data obtained is still in progress.

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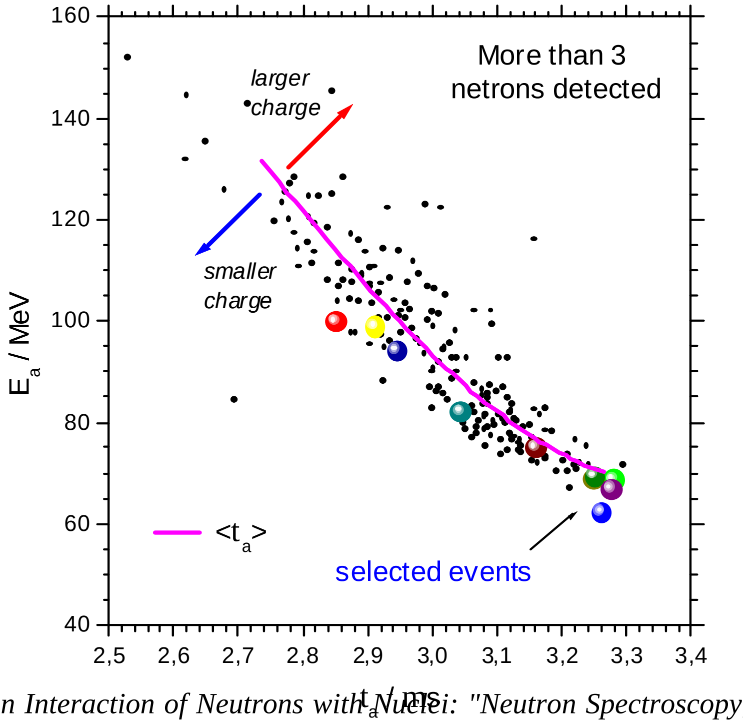

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Fig. 6. The same distribution as in Fig. 5 when at least four neutron detectors fired. The selected events are the same as in Fig. 3.

References:

1. H.-G. Ortlepp et al., Nucl. Instr. Meth. A **403**, 65 (1998)
2. Yu. V. Pyatkov et al., Proc. Int. Conf. on Nuclear Spectroscopy “Nuclear shells - 50 Years”, Dubna, 1999, edited by Yu.Ts. Oganessian and R.Kalpakchieva (World Sci., Singapore, 2000), p. 144
3. A. A. Alexandrov et al., “Heavy Ion Physics” FLNR JINR scientific report 1999-2000, Dubna, 2001, Ed. By A.G.Popeko, E7-2001-173, p.159
4. D. V. Kamanin et al., “Neutron belt of the FOBOS spectrometer”, in this book
5. A. Oed et al., Nucl. Instr. Meth. A **205**, 451 (1983)

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