Study of fission fragment's brake-up at passing through solid-state foils using Timepix3 pixel detectors (investigation project and first results)

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Introduction

In accordance with our previous experiments [1-3] at least some of the fragments of binary fission of weakly excited actinides are born in the state of isomers of the shape. A strongly deformed fragment is a weakly bound binary system (chape isomer) which breakup with a certain probability in the case of inelastic scattering in a solid foil even in tangential collisions with a large impact parameter. One of the breakup products is a magic core, for example $^{68, 72}$Ni. To designate the totality of the observed manifestations of such a process, we have proposed the term “collinear cluster tripartition (CCT)”.

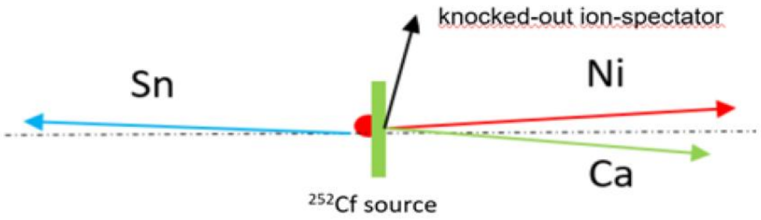

Fig. 1. Cinematics of the CCT process for the Sn-Ni-Ca partition chosen for example.

To construct an adequate model of the observed effects, a kinematically complete experiment with the measurement of masses, energies, and velocity vectors of all nuclei involved in the process is required. For this purpose, joint work with a group from the Czech Republic has begun on the use of their Tpx3 two-coordinate pixel detector with a spatial resolution of 55μ in studies of multibody decays.

Heavy ion mass spectrometry using this detector is an original and non-trivial methodological problem. Kinematics of the CCT process by an example of Sn-Ni-Ca partition of mother ^{252}Cf nucleus is illustrated by fig. 1. Ni-Ca clusters are formed due to the breakup of the intermediate Cd fragment from binary fission when it passes through the source backing. Knocked-out ion from the backing plays a role of the breakup spectator. Its energy does not exceed some MeV while the velocity vector is almost perpendicular to the fission axis.

Preliminary results

As the first step in study of the rare ternary decays using Timepix detectors the following first-day experiment was performed. Detection of the "folk" of two CCT partners (for instance, the Ni/Ca pair, fig. 2) which hit the Tpx3 detector for a short time interval and substantially differ by their energies gives evidence of the CCT event.

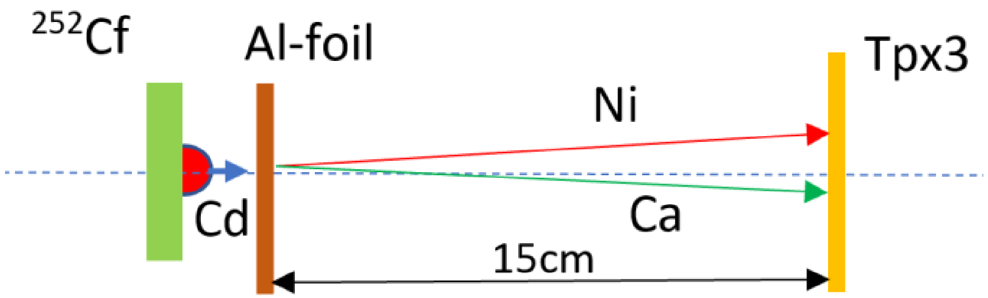

Fig. 2. Layout of the experimental setup **T**ernary **D**ecays **S**pectrometer (TDS-1). Partition ^{252}Cf → Sn+Cd → Ni+Ca is chosen for illustration.

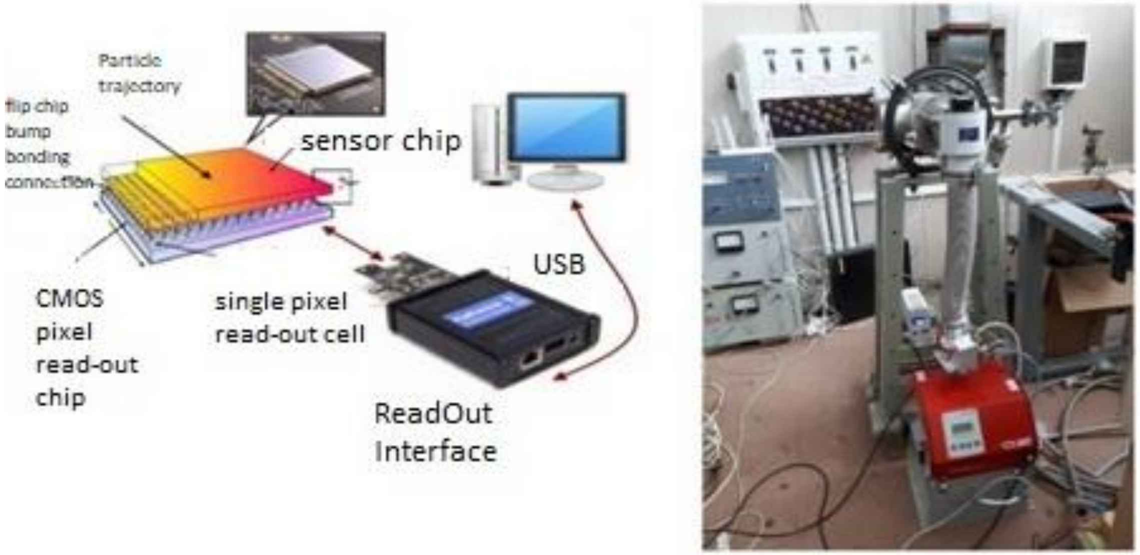

Fig. 3 Schematical view of Tpx3 detector with readout device Katerine (a), photo of the experimental setup TDS-1 (b).

A counting rate for the FFs from conventional binary fission ≈1s $^{-1}$. The fragments energies differ by about an order of magnitude (10/100 MeV). Difference in the time-of-flights of the Ni-like and Ca-like fragments is about 50 ns. The expected yield of the CCT events ≈ 10^{-4} /bin. fis. The expected angle between the fragments from the "folk" is in the range of 0.3^0 -2^0.

Initially the Timepix detectors were developed for registration of the soft x-ray photons. The ion energy in the range of some MeV can be estimated only indirectly using a number of activated pixels at registration of the ion (fig.4).

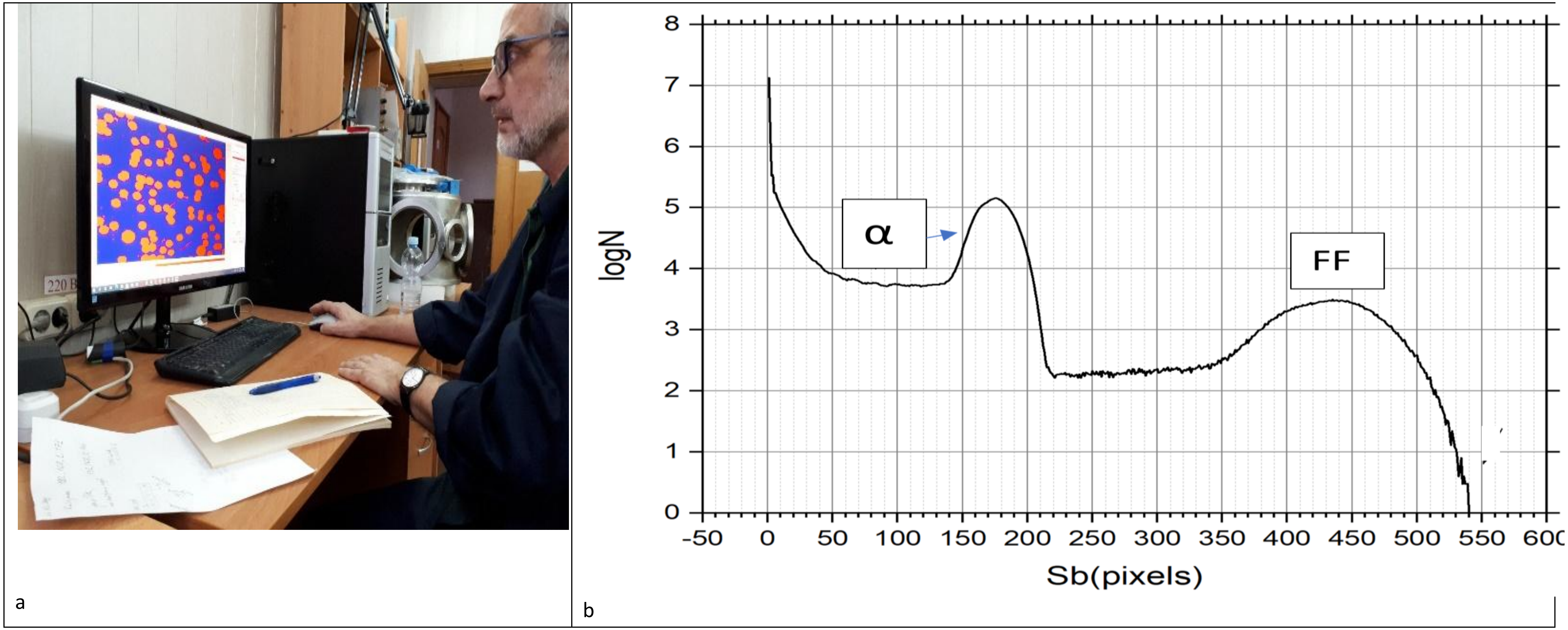

Fig.4. Images (blobs) of the of the fission fragments (FF) and alpha-particles (α) detected in Tpx-3 detector for some time (a), distribution of the detected particles by number of pixels activated by each particle.

An expected image of the event resulted from the registration of the fragment pair under condition that the open angle between their velocities is 0.3^0 is shown in fig.5. In the case of partial overlapping of the blobs the image of the pair should look like a pear.

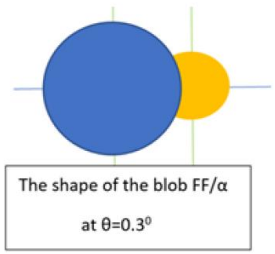

Fig.5. Expected image of the blob resulted from the registration of the pair FF/α.

In order to search for pear-shaped blobs among all registered different criteria of the blob shape were developed. Some of them are listed in the center of fig. 6. As can be inferred from the figure all three shape-parameters only slightly change with overlapping. At relatively large open angles ($\approx 0.4^0$and more) the detected pair displays as two resolved blobs. Varying the shape parameters of the searching procedure we investigated both possibilities. Typical result of the data processing is presented in fig. 7a. Each two blobs forming a pair are connected by an arrow which starts from the blob of earlier event. Time difference between the blobs in the pair must be less of some fixt value. One of the pair (number 10) attracts special attention. The shape of the corresponding blob is shown in fig. 7b.

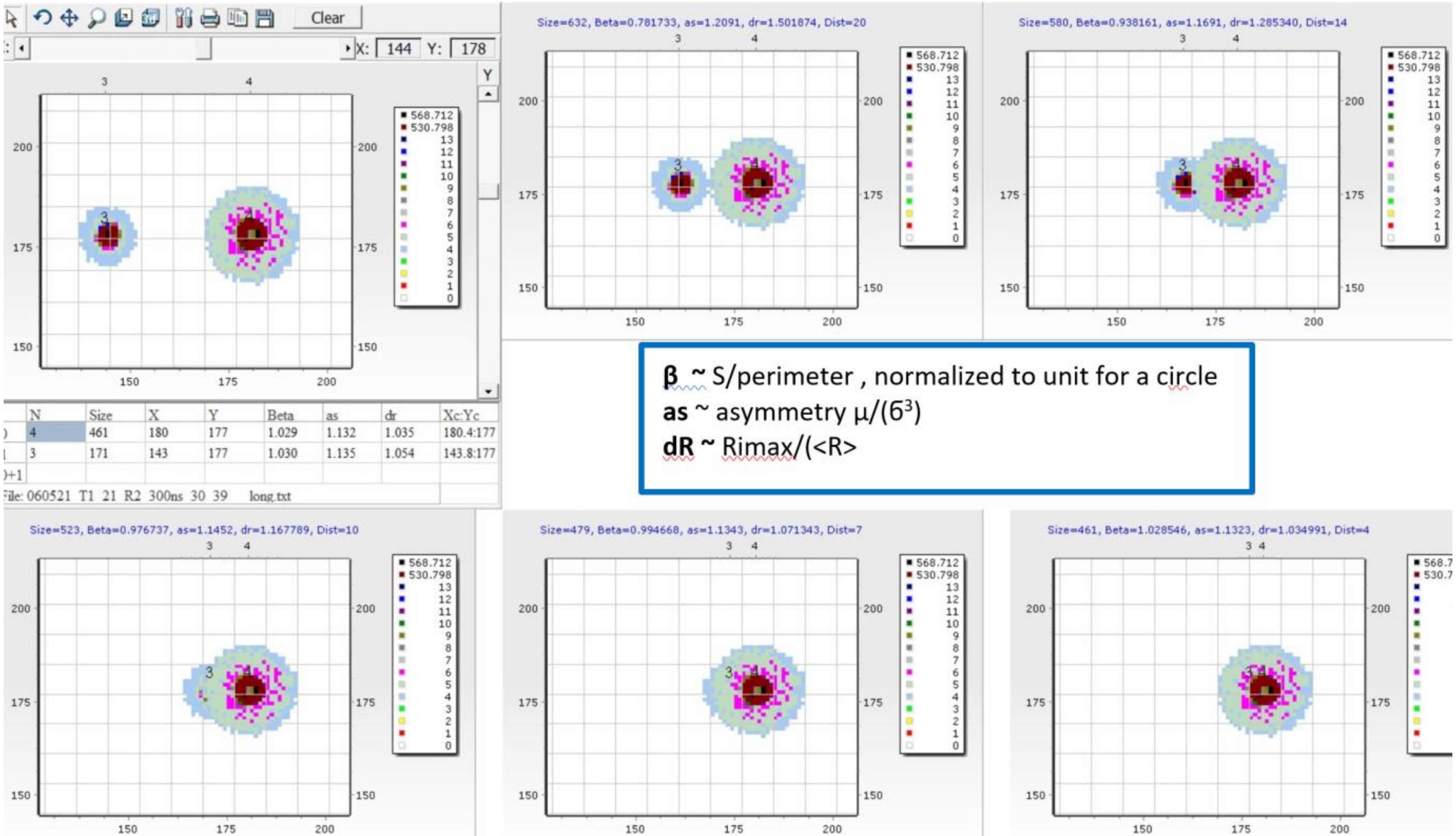

Fig.6. Library of the model pear- shaped blobs resulted from the presumable registration of typical FF and alpha-particle at different open angles between their velocities.

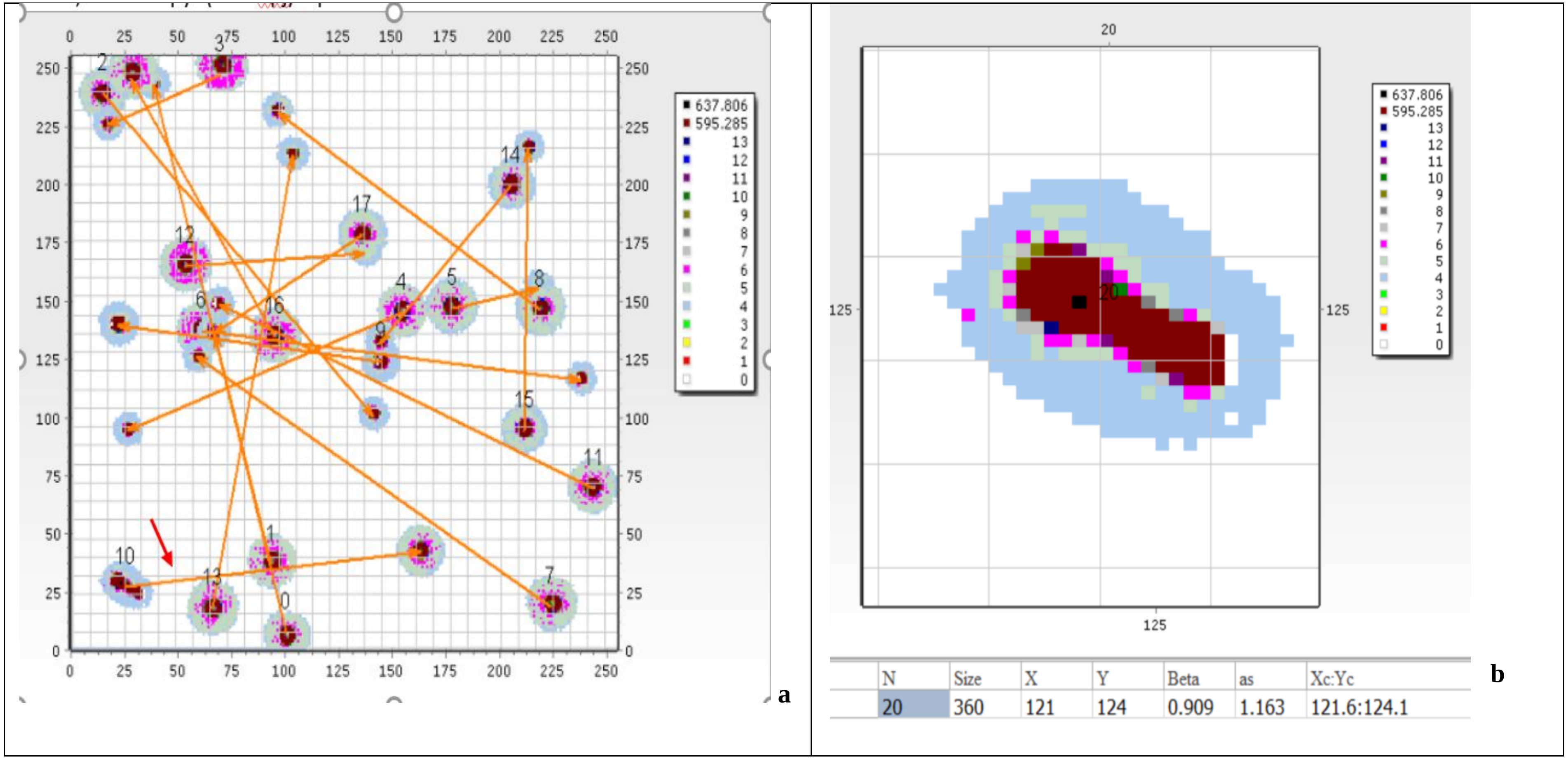

Fig.7. Typical result of the data processing (a), the shape of the blob 10 marked by the arrow in the left figure (b). Presumably this blob is due to the CCT event. The knocked-out ion- spectator was also detected (see the end of the arrow from blob 10).

Future nearest plans: modification of the TDS-1 setup – <u>Time-Of-Flight.</u>

1. Suppression of the background of alphas using TOF;
2. Searching for FFs pairs from CCT using the flight-pass of 30 cm long;
3. Using the corrected soft-ware for Tpx3.

The layout of the experimental setup (**T**ernary **D**ecays **S**pectrometer -TDS) is shown in fig.6, 7.

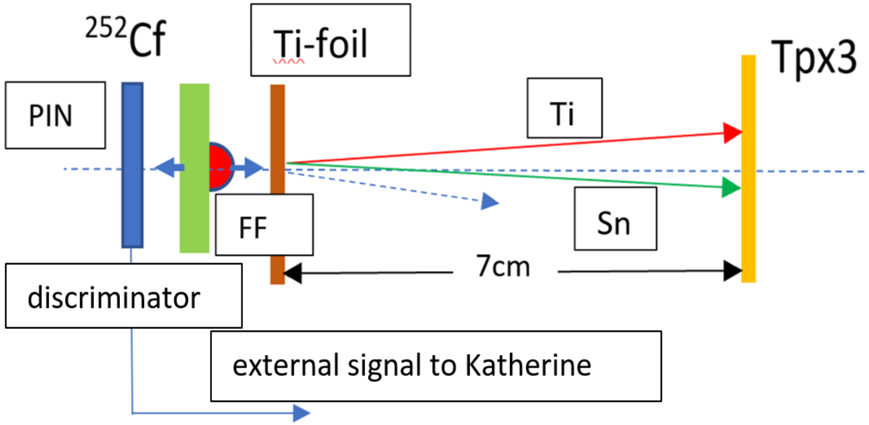

Fig. 8. Layout of the experimental setup (TDS-1M)

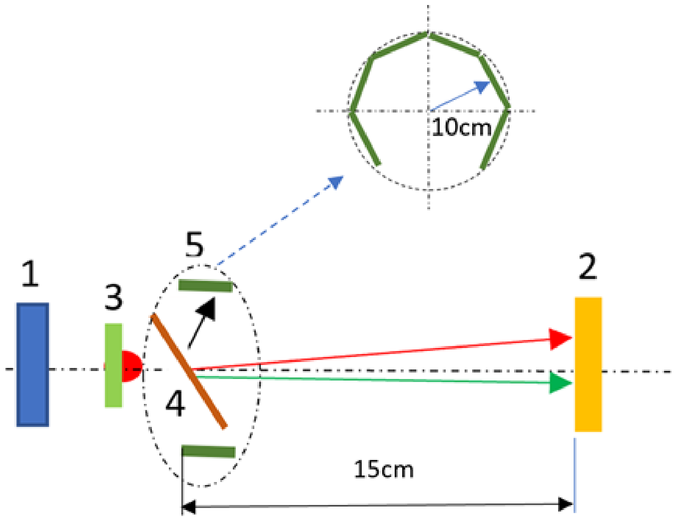

Fig. 9. Layout of the experimental setup (TDS). 1 – PIN-diode; 2 – Timepix3 device; 3- Cf source; 4 – thing foil (Al); 5 – PIN diodes ring. View of the ring directed at the FF beam in the insert above. For CCT mode Sn-Ni-Ca (as an example) FF velocity vectors are showed with arrows: red – Ni, green – Ca, black – Al scattered at large angle. Heavy fragment, Sn ion, hits the PIN diode (1) that is close to the source.

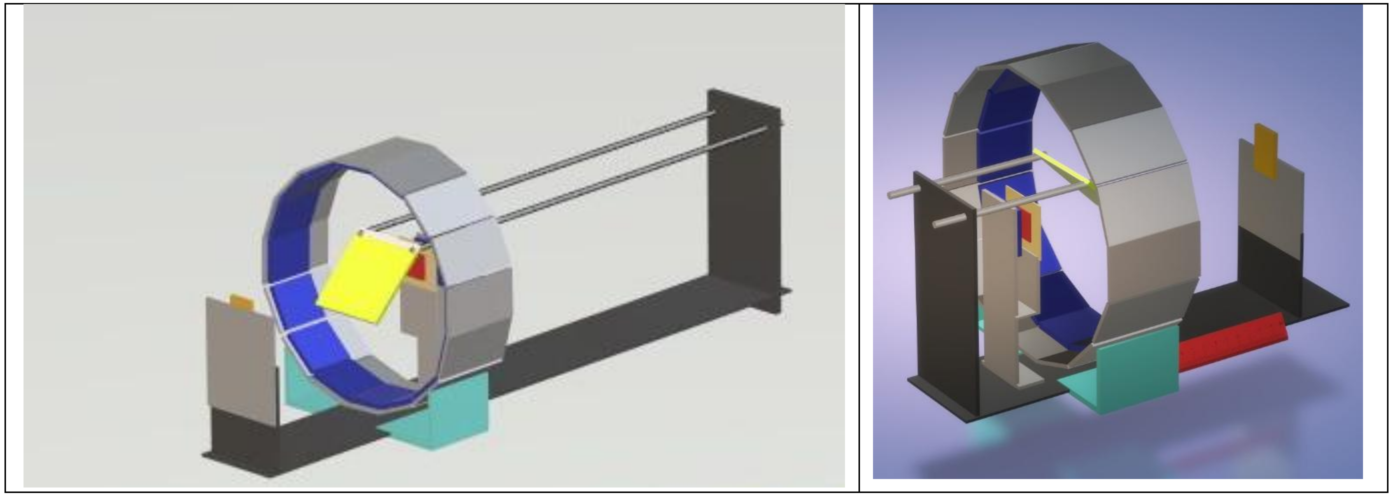

Fig. 10. 3D schematical view of the TDS. See fig.9 for details.

For reliable identification of the spectator-ion, we plan to measure its mass by time of flight method. The start signal is given by the fragment registered in the PIN diode (1) (fig.7,8), the stop signal and information about the particle energy are taken from one of the PIN diodes (5). Delayed coincidence between the PIN (1) and PIN (5) signals form a trigger signal for a multichannel flash-ADC (Amplitude to Digital Convertor) digitizer CAEN DT574 which provides digitization of the signals. The criteria for a trigger signal are such that the background from alpha particles (natural radioactivity, conventional ternary fission and polar emission) is reliably suppressed. If the ring (5) has a radius R = 10 cm, the flight times for the least energetic alpha particles of ^{252}Cf natural radioactivity and four 5 MeV Al ions knocked out of the foil differ by 10 ns. The distance from foil (4) to the Timepix3 (2) (15 cm) has been chosen so that the clusters of pixels (so called blob) from Ni and Ca ions would not overlap even if the angle between these fragments was 0.3^0. In order to improve the angle resolution, at the next stage of the experiment, the PIN (1) will be replaced with a Timepix device, in order to measure the coordinates of the point at which the fission occurs on the Cf source with an active spot radius of 5 mm.

The experimental setup (fig. 7,8) includes miscellaneous detectors operating with different read-out systems. Information from PIN diodes is obtained using the CAEN DT574 digitizer as digital images of the signals, which are further processed by a special complex of programs off-line. *But the problem of synchronization of Katherine TPX3 and flash-ADC is not solved so far.

References

1. **Yu.V.Pyatkov, D. V. Kamanin et al., Physics Procedia 74, 67 (2015).**
2. **4. D. V. Kamanin, Yu. V. Pyatkov, et al., 11th International Conference on Clustering Aspects of Nuclear Structure and Dynamics, Napoli, Italy May 23-27 2016, Journal of Physics: Conference Series 863, 2017, art. 012045.**
3. **A. O. Strekalovsky, Yu. V. Pyatkov, D. V. Kamanin, et al., Journal of Physics: Conference Series, v. 1390, 2019, 012010**