Investigation project: studying of fission fragment's brake-up while passing through solid state foils, using Timepix3 detector

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Physical problem

Ternary decays: collinear cluster tri-partition (CCT)

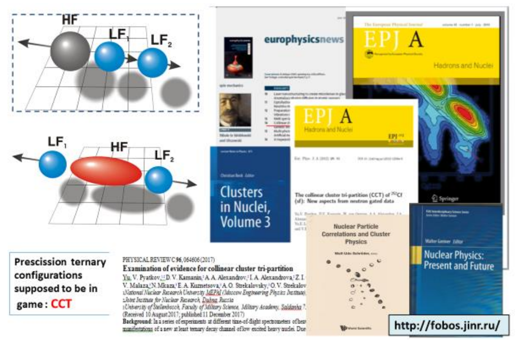


Fig. 1

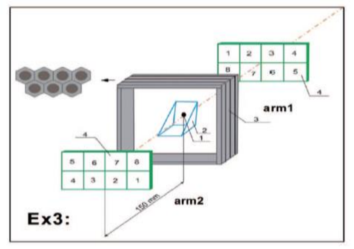


Fig.2. COMETA= COrrelation Mosaic E-T Array

Missing Mass Method

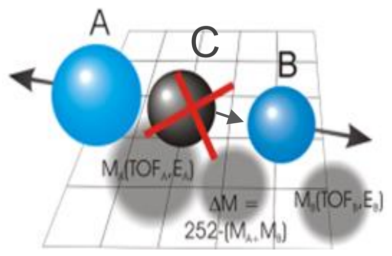


Fig. 3

Very little open angle between the fragments B&C does not allow their detection in adjacent detectors (fig. 4).

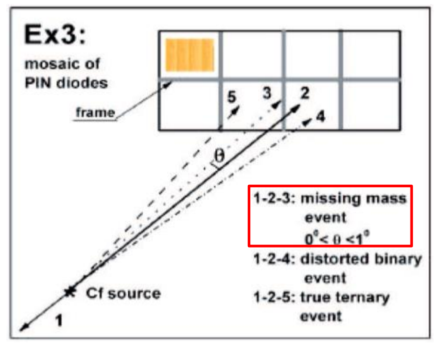


Fig. 4

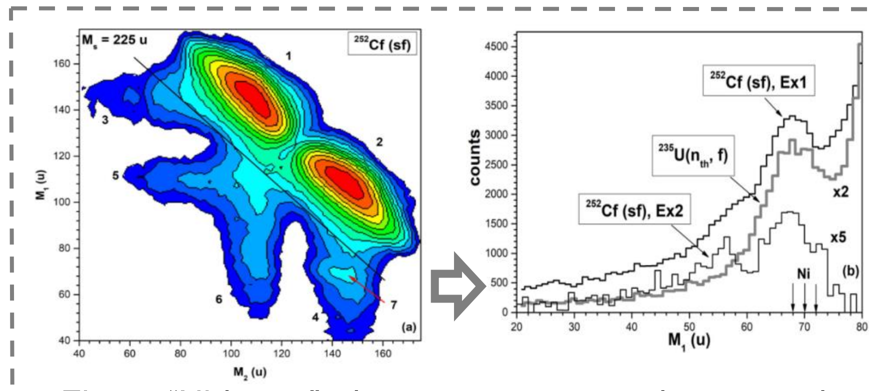
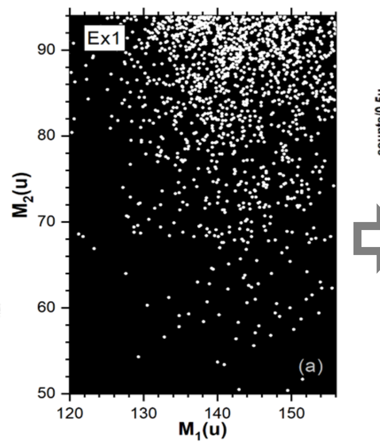


Fig. 5. "Ni-bump"- the most pronounced CCT mode. Observed only in the arm facing the source.



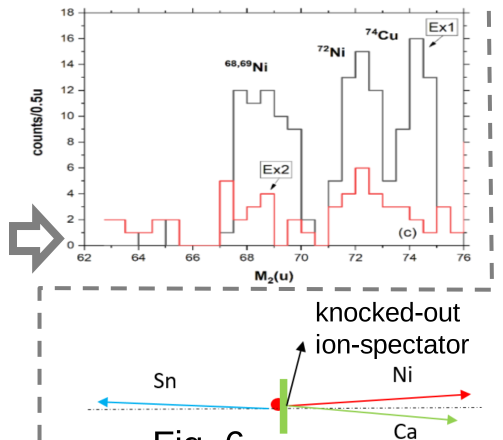


Fig. 6

Kinematics of the CCT process by an example of Sn-Ni-Ca partition (fig. 6). Ni-Ca clusters form due to the brake-up of the Cd fragment from binary fission when it passes through the source backing. Knocked-out ion from the backing - the brake-up spectator.

Timepix hybrid pixel detectors

Timepix are hybrid **two-dimensional pixel detectors.** The Timepix device consists of a semiconductor detector chip (300 μm thick silicon) bump-bonded to a readout chip. The detector chip is equipped with a single common backside electrode and a front side matrix of electrodes (256 x 256 square pixels of with pitch of 55 μm) of 1.4x1.4 cm² total active area. For Timepix3, timing accuracy is 1.6 ns. Each element of the matrix (pixel) is connected to its respective preamplifier, discriminator and digital counter integrated on the readout chip (Fig. 7). Timepix detectors allow measurement of both energy deposition and time of particles' arrival, which make it possible for position and energy-sensitive detection of hitting particles.

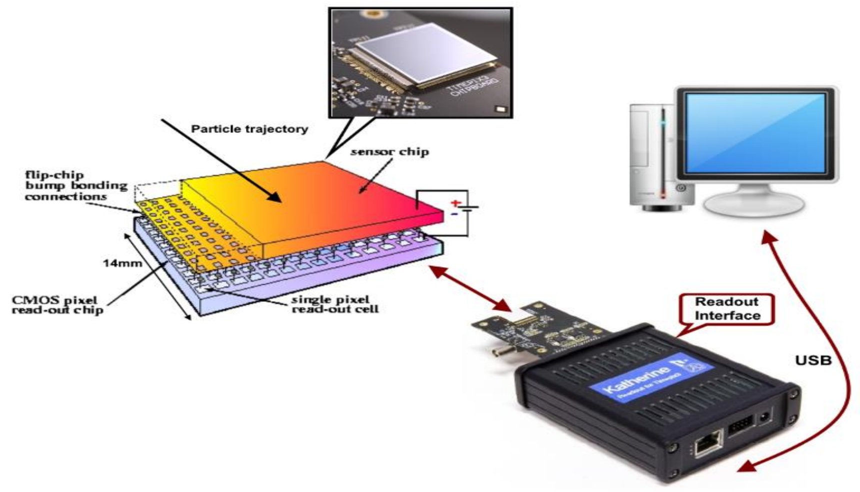


Fig. 7. Timepix3 Detector with readout device

The charge created by a heavy particle is spreading out during the charge collection process, mainly, due to diffusion. It is collected by several adjacent pixels generating a cluster (fig.8). The charge collected by each pixel in the cluster can be measured with the Timepix device:

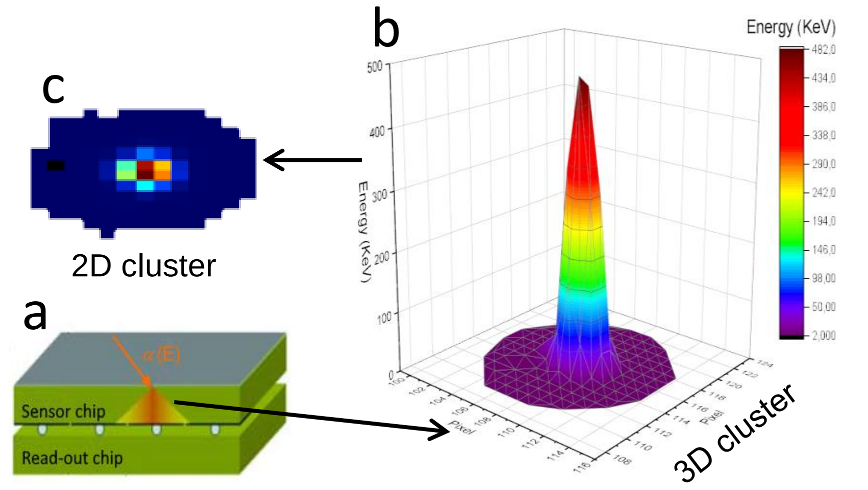


Fig. 8. a)- Generation of a cluster from α-particle in Timepix device; b), c)- A cluster of α-particle obtained at FLNR, JINR with Timepix3

Methods for calculating energy of a hitting particle with Timepix:

1. Direct calculation of the total charge by summation of all the fractional charges (in each pixel in the cluster). Under conventional detector settings, the pixel electronic signal deviates at ≈ 1 MeV/pixel and higher – Volcano effect: caldera like hollowing out of the measured energy deposition in the center of a cluster [1]. As a result, total measured energy of the particle is substantially lower than the one theoretically expected (fig. 8).

This effect can be suppressed, and the pixel ToT range expanded at least up to 100 MeV, by suitably fine tuning the Si- detector baseline and threshold levels together with applying the sensor bias voltage optimally low (fig. 9)

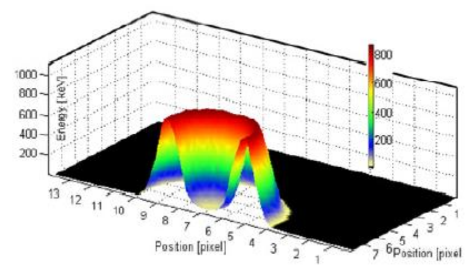


Fig. 8. Volcano effect in the detected 90 MeV ^{98}Zr ions as measured by Timepix [2].

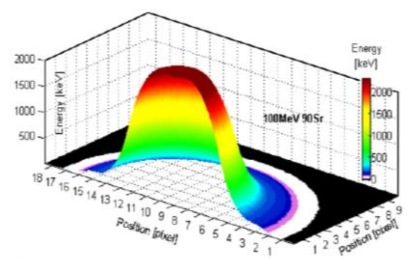


Fig. 9. Detection of 100 MeV 90Sr byTimepix with fine-tuned settings [2].

2. From cluster area (number of pixels) which determined by the kinetic energy and hitting power of the particle. Using the appropriate calibration, it is possible, for instance, to obtain energy distribution of FF from 252Cf(sf) (fig.10).

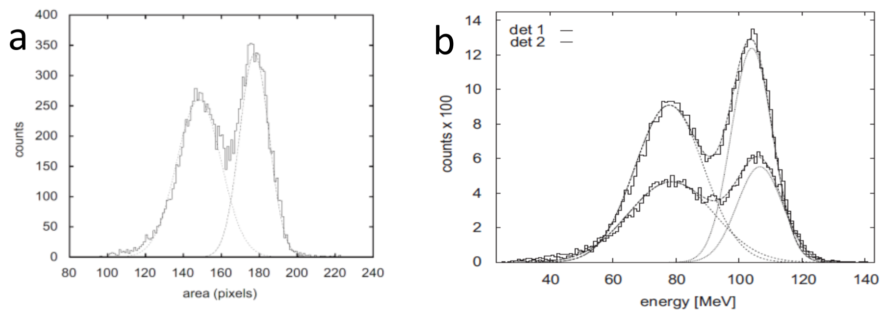


Fig. 10. Cluster area (number of pixels) distribution of fission fragments of spontaneous fission of ^{252}Cf as measured by Timepix (a). Fits by Gaussian distribution are included. b)- kinetic energy distribution obtained from spectrum a) after calibration [3]

3. Using signal from the backside electrode: collects the total charge generated from the entire detector. This mode of measurement is similar to that applied in PIN diodes. If two or more particles hit the detector during the time of signal conditioning a total energy of both particles are measured. It is a principal obstacle for the independent identification of the CCT partners as mentioned above.

References:

1. S.P. George et al 2018 JINST 13 P11014;
2. C. Granja, Z. Vykydal, Y. Kopatch, J. Jakubek, S. Pospıı, S.A. Telezhnikov, Positionsensitive spectroscopy of Cf fission fragments, 574 (2007) 472-478. http://dx.doi. org/10.1016/j.nima.2007.01.164.;
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4. А. О. Стрекаловский и др. *ЯДЕРНАЯ ФИЗИКА И ИНЖИНИРИНГ, 2015, том 6, № 5–6, с. 290–296;*
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Goal of the Experiment

Using Timepix3, in events with a reliably identified spectator-ion, register two clusters, significantly different from each other in the number of pixels, since the energies of the fragments that form them differ by about an order of magnitude. The expected angle between the fragments is in the range of 0.3^0-2^0.

Description of the experiment

As our previous studies have shown, the spectator of the CCT event is an ion knocked out of a thin (≈50 μg / cm2) foil on the path of a fragment at an angle close to 90^0 relative to the fission axis. The energy of such an ion does not exceed several MeV.

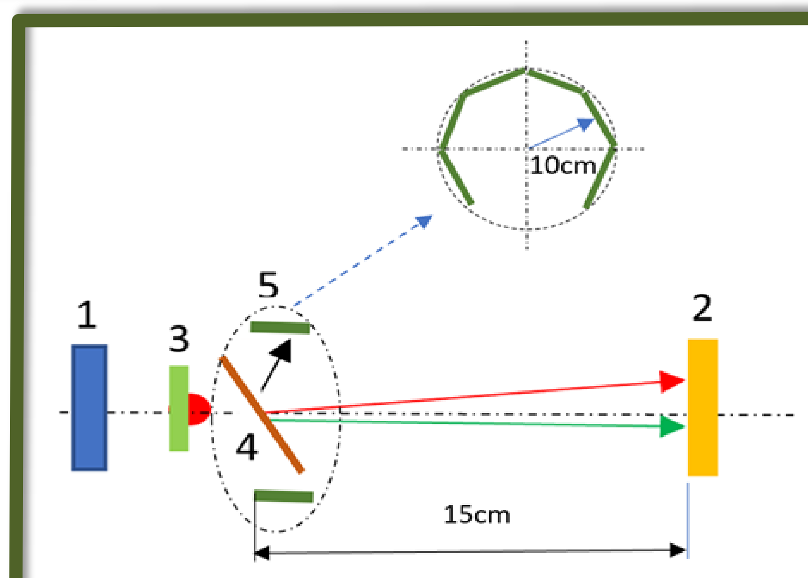

Fig. 11. Lay- out of the experimental setup. 1 – PIN-diode; 2 – Timepix3 device; 3- Cf source; 4 – thing foil (Al); 5 – PIN diodes ring. View of the ring directed at the FF beam in the insert above. For CCT mode Sn-Ni-Ca (as an example) FF velocity vectors are showed with arrows: red – Ni, green – Ca, black – Al scattered at large angle. Heavy fragment , Sn ion, hits the PIN diode (1) that is close to the source.

For reliable identification of the spectator-ion, we plan to measure its mass by time of flight. The start signal is given by the fragment registered in the PIN diode (1) (fig.11), 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 [4]. 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. 11) 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. Data from Timepix3 are obtained and transfered using the read-out interface Katherene (fig. 7). Synchronization of the read-out systems is required to form a single event. A similar problem was solved in [5].

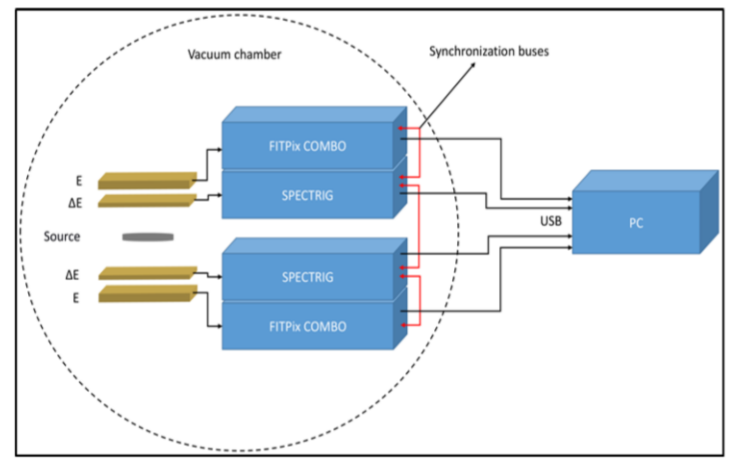

Fig.12. Schematic layout of the experimental setup for simultaneous measuring of the particle energy E by Timepix detectors and specific ionization losses ΔE with the help of a totally depleted transmission type silicon detectors [5].

A schematic view of the data acquisition system of the experimental setup, including two ΔE-E telescopes is shown in Fig.12. The specially designed FITPix COMBO device acquires a signal from the backside electrode and the pixel part of Timepix. Spectrig device (a modified version of FITPix COMBO), however, is used for the acquisition of signal from ΔE detector. The timestamp jitter obtained for the single telescope is 11 ns (sigma), while timestamp jitter between both telescopes is 13.18 ns (sigma). Synchronization of miscellaneous detectors with such a time spread is quite acceptable for the implementation in the experiment we are planning (Fig. 11).