OPTICS WITH FISSION FRAGMENTS

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Abstract: Charged-particle coincidence correlated measurements, such as angular correlations between main fission fragments and light charged particles measured with conventional detectors provide only partial and limited information. Many of these drawbacks arise from the standard solid state detectors used so far which can be solved simultaneously by usage of highly segmented single-quantum counting pixel detectors. The Timepix pixel device, which is equipped with energy and time sensitivity capability per pixel, provides high granularity, wide dynamic range and per pixel threshold. This detector operated with integrated USB-readout interfaces such as the USB 1.0 and FITPix devices and the data acquisition software tool Pixelman, both developed for the pixel detectors of the Medipix-family, enables a variety of instrumental configurations, visualization, real-time event-by-event selection as well as portability of operation for flexible measurements on different targets and setups. These features combined with event track analysis provide enhanced signal to noise ratio with a high suppression of background and unwanted events. Timepix can operate moreover as a ΔE detector with the capability to provide multi-parameter information (position, energy and time) for basically all types of ionizing particles in a wide dynamic range of energy (pixel energy threshold $\approx$ 4 keV), interaction/arrival time (timepix clock step $\geq$ 100 ns) and position (pixel size = 55 μm). High selectivity is achieved by spatial and time correlation in the same sensor. In addition, several detectors can be run in coincidence. The open and close exposition (shutter) time as well as the readout DAQ can be fully synchronized. For this purpose, there was assembled a modular multi-parameter, tunable and extendable coincidence detector array system based on two and more Timepix devices which can be coupled with supplementary detectors (solid state ΔE detectors and/or ionization chambers) for enhanced ion selectivity.

We used such system consisting from two Timepix detectors which were set opposite to each other and the source of ^{252}Cf between them. Analysis of pixel areas and time of particle detection provides unambiguous choice of fission fragment (FF) pares from spontaneous fission of ^{252}Cf. Information about positions of registered fragments allows to construct straight line between points of registered particles and to obtain a point on the source, from which these two fragments were emitted. In the analysis of all set of obtained pares there is a free parameter, namely the position of the source between two detectors. By changing the distance of the source between two detectors one can obtain the best image of the source spot. This is analogous to focusing in usual photography.

1. Introduction

The Timepix pixel device [1,2], which is equipped with energy and time sensitivity capability per pixel, provides high granularity, wide dynamic range and per pixel threshold. This detector operated with integrated USB-readout interfaces such as the USB 1.0 [3]

and FITPix USB 2.0 [4] devices and the data acquisition software tool Pixelman [5], both developed for the pixel detectors of the Medipix-family, enables a variety of instrumental configurations, visualization, real-time event-by-event selection as well as portability of operation for flexible measurements on different targets and setups. The detector can be thus used to selectively register the position and time-dependent processes for basically all types of ionizing particles in a wide dynamic range of energy (pixel energy threshold 4 keV), interaction/arrival time (timepix clock step $\geq$ 100 ns) and position (pixel size $\approx$ 55 μm). High selectivity is achieved by spatial and time correlation in the same sensor. The USB readout interfaces used for detector control and data acquisition can receive an external trigger from other detecting devices such as ionization chambers, scintillation and semiconductor detectors. Furthermore, the interface has been adapted to receive also an external clock [6] which is needed for the Timepix devices. In addition, several detectors can be run in coincidence. The open and close exposition (shutter) time as well as the readout DAQ can be fully synchronized.
In binary fission two fragments fly at 180 degrees to each other. If one can fix points of interaction of these fragments by the detection system, he can restore their trajectories. Timepix detectors are useful for this because they have good spatial and time resolution. To demonstrate this we performed an experiment with ^{252}Cf source to register pairs of fragments from spontaneous fission from the source. The principle of spatially correlated detection of two fission fragments (FF) in coincidence is shown in Fig.1.

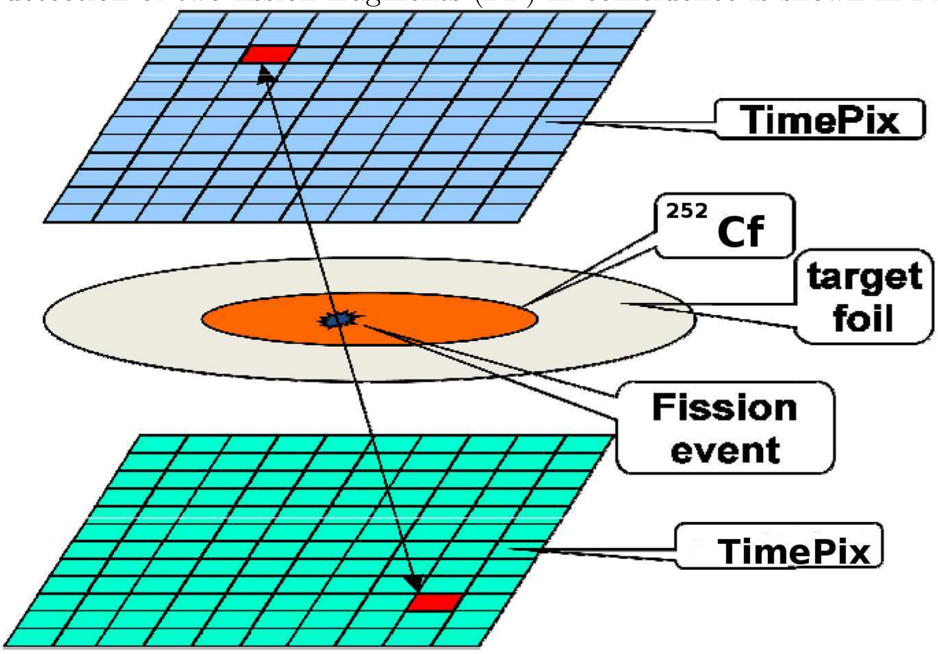

Fig.1. Principle of spatially correlated detection of two FF in coincidence.

Timepix detectors have two main different modes of operation: ToT (Time over Threshold) and ToA (Time of Arrival). In the first mode the detector registers the charge in each pixel and in the second mode each pixel provides the time between the signal arrival and the end of the frame time window. When two detectors are operated from one start pulse the simultaneously detected events must have the same ToA value. An example of simultaneously detected charged fragments is shown in Fig.2. Here detection in coincidence of two FF by two Timepix pixel detectors is imaged.

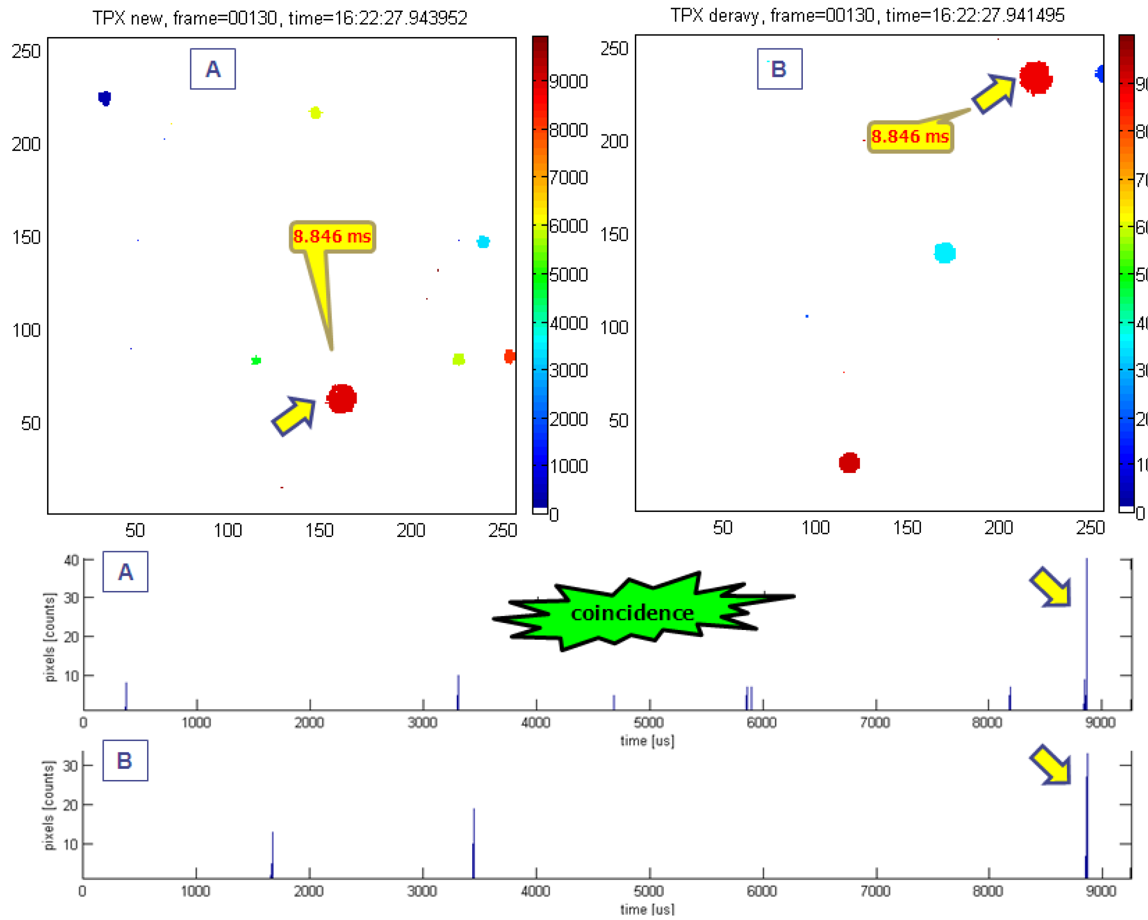

Fig.2. Synchronized frames from detectors A and B (up) and the temporal information from these frames (down). Red clusters have the same time values. They are pare of fragments.

2. Experimental

Two Timepix detectors which were set opposite to each other and the source of ^{252}Cf between them were placed in a vacuum chamber. The open (start) and close (stop) exposition signals were received from external device. As time of writing of frames of the USB 1.0 was such that about 4 frames can be written in 1 sec. time of exposition was selected as 1 sec. More than 10 fragments were registered in one frame with this exposition. The thresholds of all pixels was set high enough to eliminate all events except fission fragments. TOA mode of operation of Timepix detectors was selected to find coinciding clusters. As the counting range of each pixel is about 11000 ticks, the appropriate frequency of generators was selected for both detectors. About 47000 frames were collected in total during the experiment.

3. Processing of data

During the processing of data an additional selection was used according to the areas of clusters. In the text two detectors which were used in the experiment will be named

J06 and G09. In Fig.3 the spectra of areas from detectors J06 and G09 are shown where boundaries of extracting data are indicated.

As cluster of fragment is almost round figure mean weighted X and Y were used as the position of a cluster. Distributions of positions of pares on detectors J06 and G09 are shown in Fig.4. Part of the detector G09 was excluded because this detector had bad piece at the left upper corner.

Then, the position of the source was determined. In order to do it, the crossing points of straight lines between fragment pairs with the plane, which is parallel to the planes of detectors and lies between the detectors at some distance (named z) from the first detector (it was J06 detector) were calculated. The crossing points form a spot. We varied the distance z between the source plane and the first detector in order to find the minimal size (area) of the source spot. In Fig.5 the dependence of the spot area on z is shown. The distance between detectors is assumed to be 1. It is seen that the minimum of the spot area is at z=0.54. The distribution of points on the source plane which is at the distance 0.54 from detector J06 is shown in Fig.6.

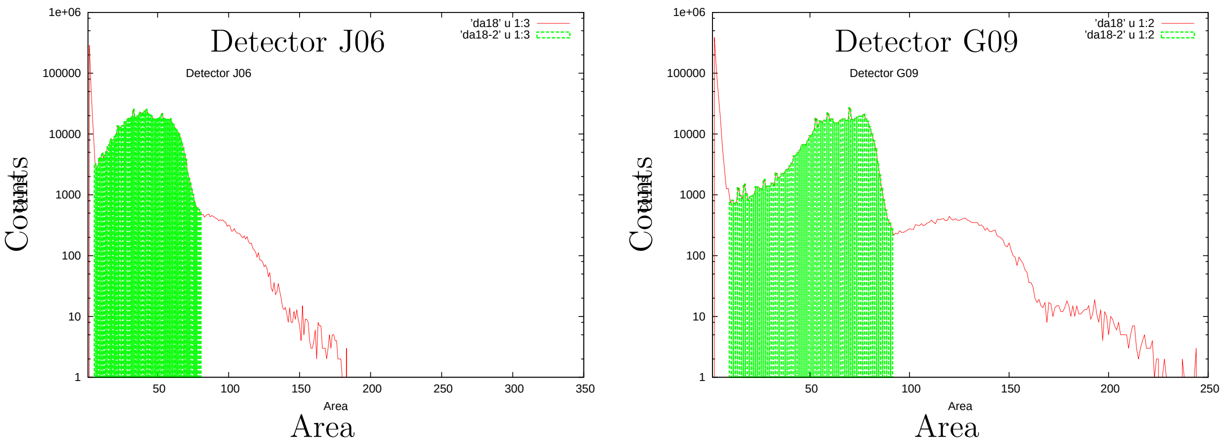

Fig.3. Distribution of areas of fission fragments on detectors J06 and G09 and intervals from which the information was obtained.

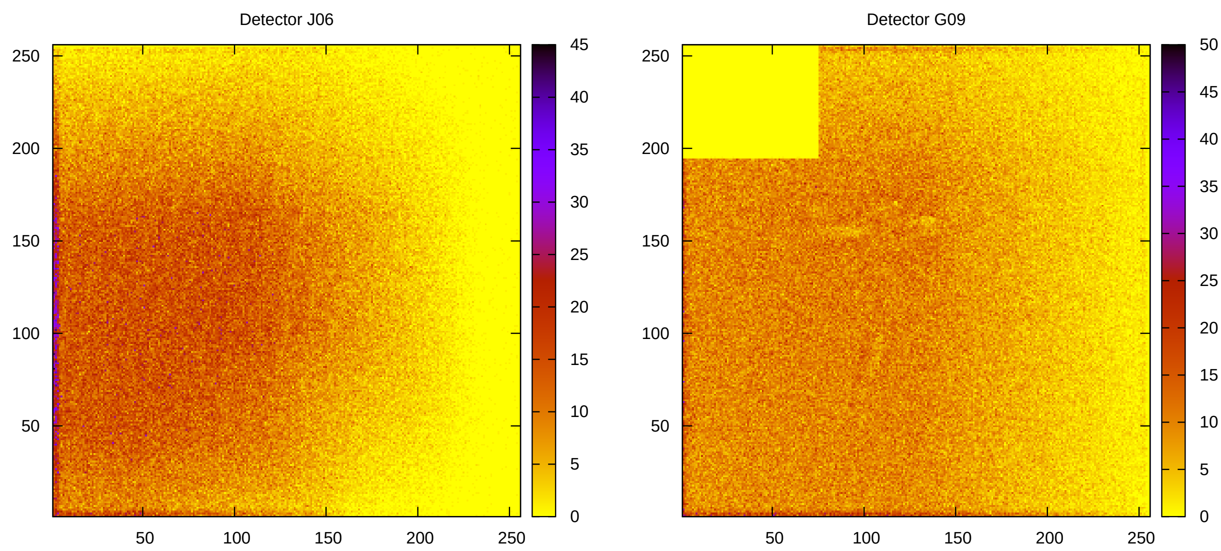

Fig.4. Distribution of fragments on detectors J06 and G09

Discussion

First we can discuss about properties of the detector G09. In our previous experiment with ^{252}Cf source it was found that this detector has bad areas. This is shown in Fig.7. Big statistics of α-clusters showed parts of detector from pixels of which the charge collection is bad. This effect is not seen in Fig.4 because of small statistics, big area of clusters and wide distribution of areas. But this property of detector G09 can not spoil picture in Fig.6. As in normal photography spots on lenses do not distort image but only degrade sharpness.

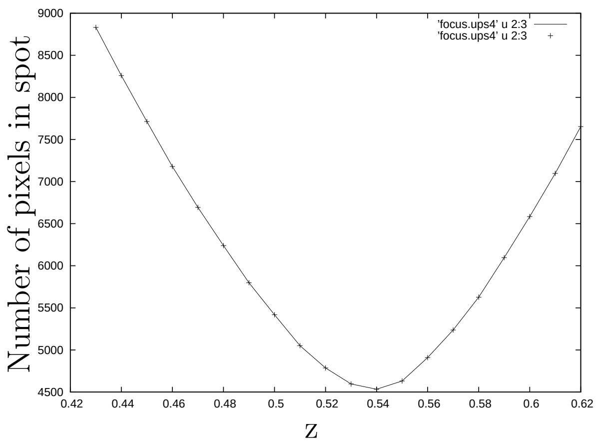

Fig.5. Dependance of the spot area at the source plane on the distance z

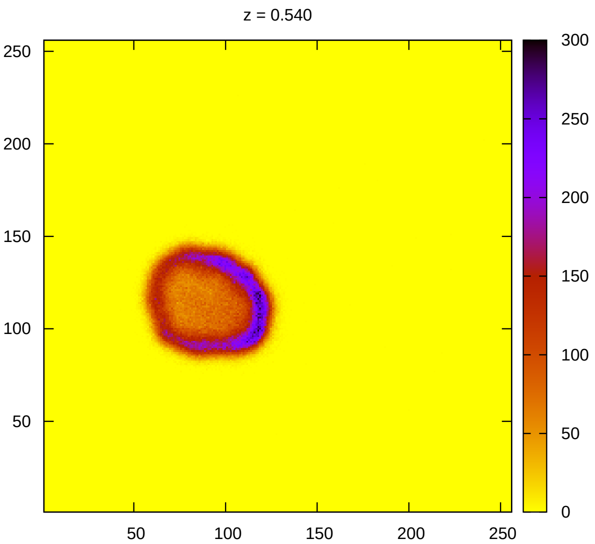

Fig.6. Distribution of points on the source plane which is at the distance z=0.54 from detector J06

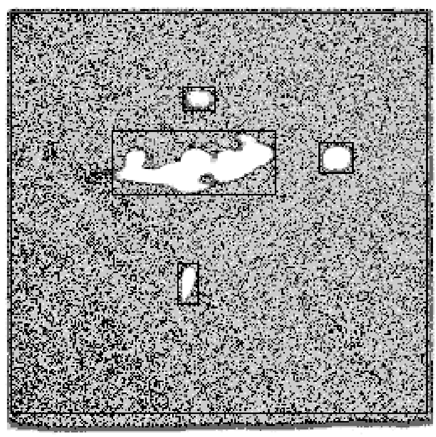

Fig.7. Distribution of α-clusters on detector G09 in our previous work with ^{252}Cf source.

Another topic which can be explained is existing of points on image in Fig.6 outside the main spot. To clarify this Fig.8 is shown. In this figure the data from Fig.6 were artificially changed. When statistics in pixel was more than 10, the value 10 was set. In this figure the points outside the main spot are visible. There are two sources for existing points outside the main spot. One is the result of ternary fission in which the third particle is formed and angle between fragments became not 180 degrees. Ternary fission is a rare phenomenon. Its yield is about 1/260 to binary fission [7]. The main part of light charged particles (LCP) in ternary fission are α-particles. Other particles are rare. As masses of the LCPs are small in comparison with fission fragments, the angle between the fragments changes slightly. Rough estimations say that this angle change is about 4 degrees. This can not change the positions of the fragments significantly and points on image must be close to the source spot and can form a "halo" around the spot. It is clearly seen in Fig.8.

The other source of points outside the main spot are random coincidences of time signals from the fragments. As full interval on the time scale is about 10000 and on one frame there are about 10 fragments, the probability of random coincidences is 2-3%. About 47000 frames were collected and number of random points can be about 1000. But this estimation is very rough.

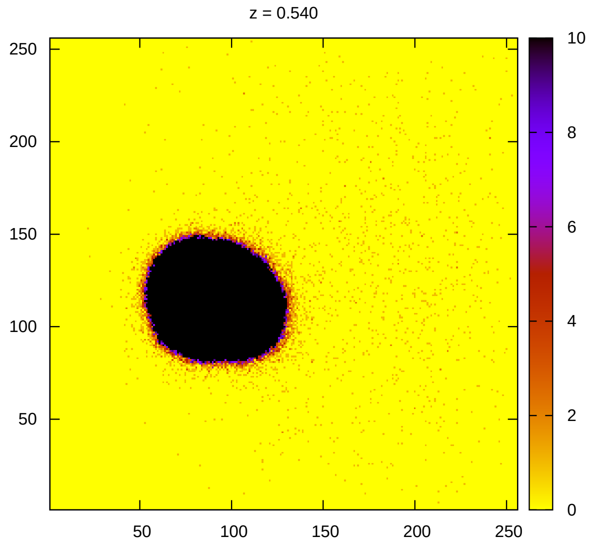

Fig.8. Image is as in Fig.6 but all pixels with statistics more than 10 are artificially set to 10

Conclusion

Two Timepix detectors were used in this work. Thanks to use of an external start and stop signals on detectors each two frames were synchronized and with the use of TOA modes of detectors operation about 440000 of pairs of fragments were registered. By constructing straight lines between positions of pares the image of the source of ^{252}Cf was obtained. This procedure is analogous to usual photography. The reasons for points on the source image outside the main spot were analyzed.

References

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