ONLINE COINCIDENCE DETECTION OF FISSION FRAGMENTS AND LIGHT CHARGED PARTICLES

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Abstract

With the goal to study angular correlations of rare fission decay, charged-particle spatial- and time-correlated measurements of fission fragments are being investigated with a modular multi-parameter coincidence system based on several pixel detectors Timepix. In addition to high granularity, wide dynamic range and per pixel threshold, Timepix provides energy and time sensitivity capability per pixel. The detector is operated with the integrated USB 2.0-based readout interface FITPix and the data acquisition software tool Pixelman. A number of coincidence setups and techniques were investigated. Triggered measurements are performed with an integrated spectrometric module with embedded analogue signal chain electronics. Demonstration of the technique is presented with a spontaneous fission source.

Motivation

Charged-particle coincidence studies such as angular correlations between ternary particles and main fission fragments provide so far only partial information such as energy cutoff, poor spatial resolution and narrow range of studied ion Z numbers. Many of these drawbacks which arise from the standard detectors used so far can be solved by highly segmented quantum counting pixel detectors. Desired tasks include measuring the angular distributions of light charged particles (LCP) and resolving different modes of rare fission decay (see Fig. 1).

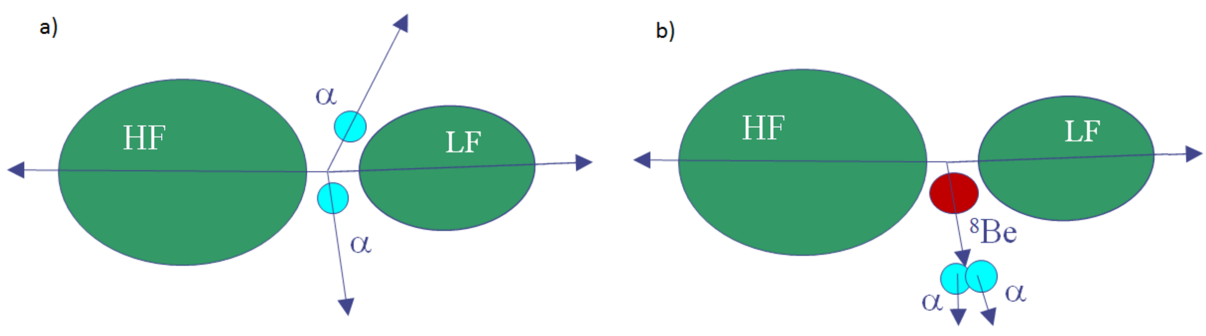

Figure 1: Two modes of quaternary fission: (a) true and (b) pseudo quaternary fission. Spatial information of the emitted light charged particles detected in coincidence gives the signature.

Rare fission decay with the emission of one (ternary fission) or two (quaternary fission) LCPs is a unique tool to explore the dynamics and structure of atomic nuclei by probing the fissioning system near the scission point and observing fissioning reaction and decay mechanisms [1]. Detailed spectroscopy of fission products is the necessary input for the understanding of fission configurations and dynamics of reaction mechanisms. Observables such as the angular momenta of LCPs correlated with the binary fragments are closely related to the dynamics of the fissioning system in its final stages [1–3].

Pixel Detector Timepix + FITPix Readout Interface + Pixelman Control/DAQ

The hybrid semiconductor pixel detector of the Medipix type [4] consists of a radiation sensitive sensor bump bonded to an ASIC readout chip with integrated electronics per pixel (see Fig. 2a). The chip is divided into an array of 256 × 256 pixels of 55 μm pitch with full sensor size 14 × 14 mm^2. Hybrid technology allows using sensors of different materials (Si, GaAs, CdTe) and thickness (300, 700, 1000 μm). Per–pixel pulse processing electronics provides fast and noise free images**.**

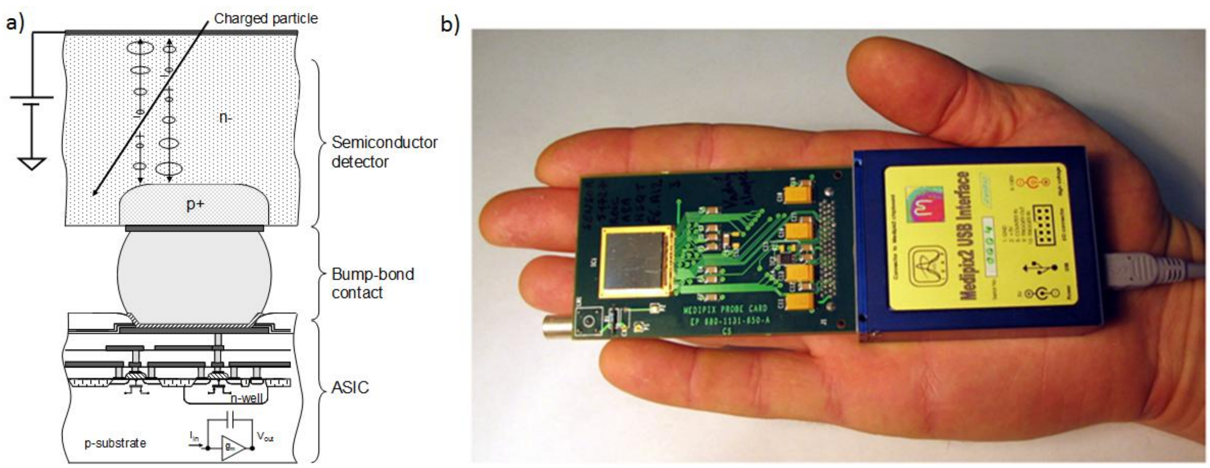

Figure 2: Left: Principle of the hybrid pixel detector Medipix with the semiconductor sensor bump-bonded to the readout ASIC chip containing integrated signal electronics per pixel. Right: Medipix/USB radiation camera assembled from the chipboard and USB–based readout interface (right). Data link to PC/notebook via USB port.

In addition to high granularity, wide dynamic range and per pixel threshold the Timepix device [5] provides energy and time sensitivity capability per pixel. The detector provides more complete information (position, energy, time, stopping power) for basically all types of ionizing particles. Per-pixel threshold is about 4 keV for a 300 μm silicon device. Interaction/arrival time can be determined with a step of 25 ns. For charged particles, the spatial resolution can reach, by event-by-event analysis and pattern recognition of the particle track, sub-pixel resolution down to few μm.

The pixel detector is operated with integrated USB-based readout interfaces such as the USB 1.0 [6] and FITPix [7] devices (see Fig. 2b) which provide control, power and DAQ. Operation and online visualization are enabled by the software package Pixelman [8,9]. The assembled system serves as an online radiation camera [10] for table-top and vacuum operation, portability and configurability of different measurements and setups.

Online Detection of Fission Fragments

The response of the Medipix2 detector to fission fragments were demonstrated [11]. The resolving power of the Timepix device to an alpha and spontaneous fission source (^{252}Cf) is shown in Fig. 3. Timepix allows applying timing and spectral correlated techniques in the same sensor for enhanced background suppression and unambiguous event–by–event detection. We have developed a variety of instrumental configurations, trigger architectures and multi-detector setups. These features combined with pattern recognition and event track analysis provide enhanced signal to noise ratio with marked suppression of background and unwanted events. As Fig. 3 shows, the spatial information can be correlated to the spectral information in order to distinguish desired events and suppress unwanted background.

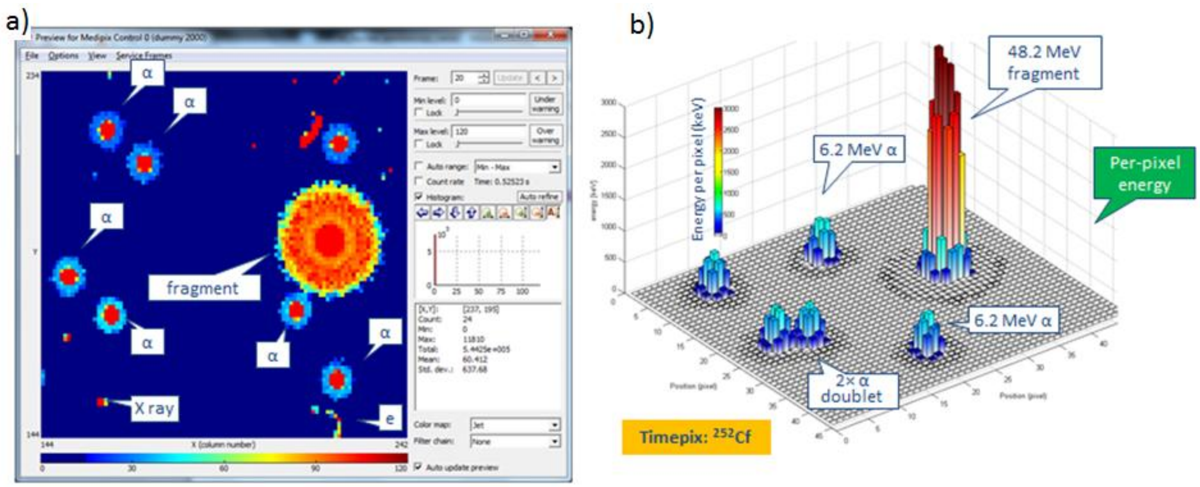

Figure 3: Left: Online visualization window of the Pixelman software showing the response to a ^{252}Cf source of the Timepix detector operated in energy (TOT) mode. Sensor region shown of about 80 × 80 pixels. Right: Detail of detection of a fission fragment and several α particles. Sensor region shown of about 45 × 45 pixels. In addition to the spatial 2D information the energy per pixel is recorded and can be displayed as a third axis by the vertical bar in color. Unwanted events such as α-decay particles, pile-ups, X-rays and electrons are clearly resolved by the spatial- and spectral-analysis (particle tracking and pattern recognition).

Coincidence Detection of Fission Fragments

In order to detect particles in coincidence, such as the two binary fission fragments or a LCP correlated to the binary fragments, we carried out measurements with two and also with four pixel detectors. The experimental layout with four detectors and a spontaneous fission source (^{252}Cf) carried out at the JINR Dubna is shown in Fig. 4. Description of the instrumentation is given in Ref. [12]. In addition to the trigger implementation, an integrated master module has been newly built [12] in order to validate the operation and synchronize the data readout when two and more detectors are connected. This synchronizing module provides fully correlated data readout among all detectors maximizing data taking and suppressing dead time but also significantly easing the offline data evaluation.

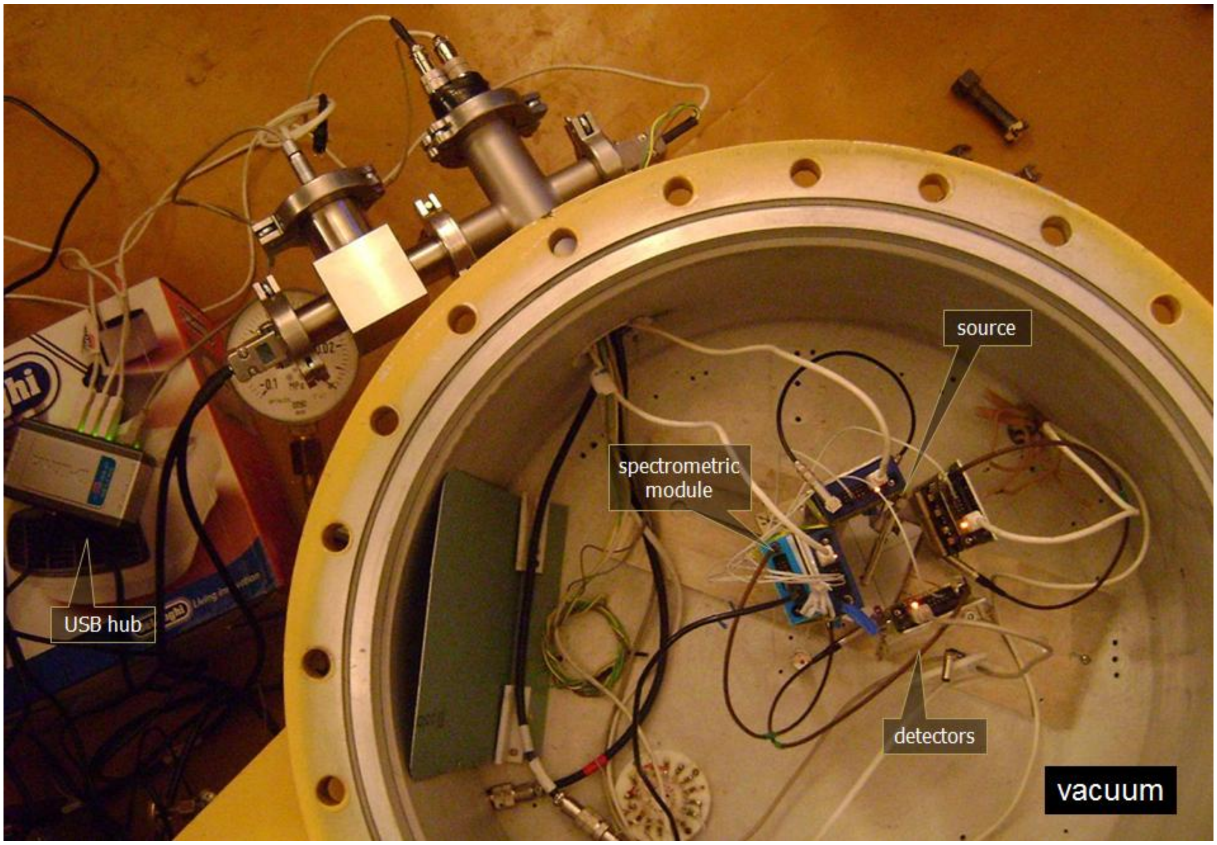

Figure 4: Experimental setup of coincidence detection of fission fragments with 4 pixel detectors in vacuum. The analog signal from one detector is processed by an integrated spectrometric module which triggers itself and all other detectors.

Several hardware techniques have been implemented and tested on various setups with a spontaneous fission source (^{252}Cf):

a) Software Trigger + Low Threshold + Short Exposure Time

In this approach, the detectors start simultaneously by trigger generated arbitrarily and sequentially by the readout interface of one of the detectors. The detectors are run with low per-pixel threshold and collect data in short exposure time (Fig. 5). Data shown were collected in Time mode in which the time of interaction (time stamp) of every event is registered and can coincidence events can be correlated among different detectors. In these measurements one detector acts as master and sequentially generates the trigger to all other detectors. This technique is useful when it is desired to register all types of radiation including low energy particles. The data count rate is limited by the dead time of the readout interfaces which is about 15 ms and also the USB 2.0 speed capacity and the performance of the PC. Up to about 10 and 20 fps per device can be collected with four and two detectors, respectively. Thus up to 10 and 20 sets of coincidence events can be recorded per second.

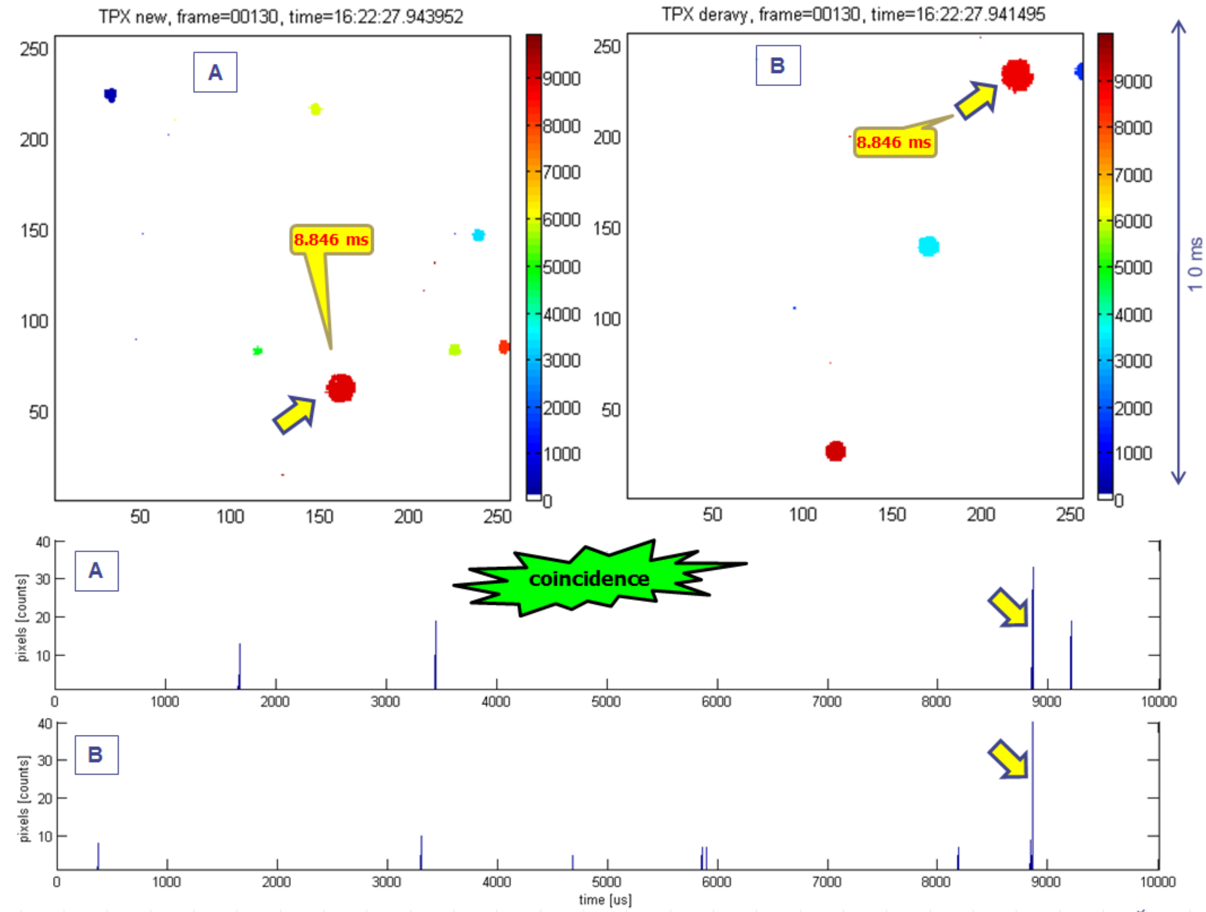

Figure 5: Detection in coincidence of two fission fragments from a ^{252}Cf source by two Timepix detectors in *<u>low pixel threshold</u>*. *Data taken in time mode and short exposure time (10 ms). The spatial information (top) correlates to the timestamp (bottom spectra). The time scale is displayed in color by the vertical scale in μs. The large clusters correspond to two binary fragments (appear in red at 8.846 ms). The small clusters are α particles from α decay of ^{252}Cf. The frames correspond to the full sensor area (256 × 256 pixels = 14 × 14 mm^2) of two Timepix detectors equipped with a 300 μm thick silicon sensor.*

b) Software Trigger + High Threshold + Long Exposure Time

In another approach, the per-pixel thresholds are raised in order to suppress unwanted events (Fig. 6) also allowing measuring for long exposure times. In this approach, only the fission fragments are registered. Unwanted events such as α-decay particles and electrons from interaction of γ rays in the sensor are fully suppressed and produce no signal. This approach thus maximizes the signal to noise ratio and count rate minimizing dead time. The count rate of desired events (correlated pairs of fragments) can be thus increased by a factor 10–100 compared to the technique above (a). This factor can be even higher with a higher activity source and/or closer target geometry.

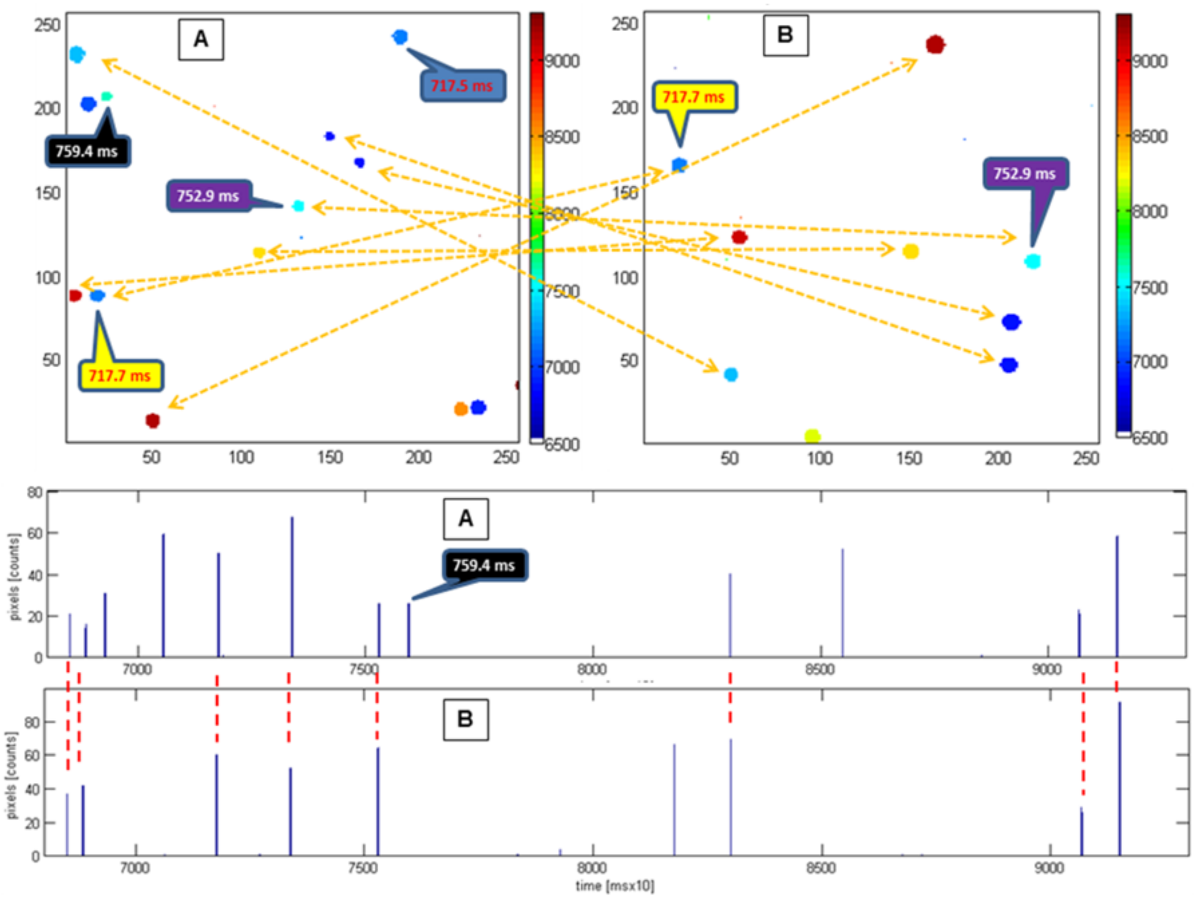

Figure 6: Spatial- and time-correlated detection in coincidence of correlated pairs of fission fragments by two Timepix detectors operated in <u>high pixel threshold</u> and long exposure time (300 ms). The spatial information is correlated to the time information (bottom). The pixels were operated in time mode registering the events interaction time. Correlated events are linked by straight dash arrows for illustration. The high threshold suppresses and effectively removes unwanted events such as α particles from α decay which allows for long exposure times.

c) <u>Hardware Trigger + Integrated Spectrometric Module</u>

Another technique implemented for online detection of fission fragments [13] makes use of the analogue signal of the common sensor of the pixel detector (called *back-side-pulse*) which can be used as an independent tool to control the start or end time of detector acquisition. With devoted spectrometric signal chain electronics and processing, this signal can be, like for standard p-i-n diodes, used to tag desired ions and provide a fast trigger. We employed a devoted spectrometric module built on an integrated and miniaturized chipboard which can be embedded into the USB 1.0 readout interface. This module is operated with a Windows running plugin application which loads and controls the sensor bias, sets the threshold level and displays and stores the module's MCA. The triggered detection of three fragments in coincidence is shown in Fig. 7. The data shown were collected in energy TOT mode. The short exposure times provide unambiguous identification of coincidence event and straightforward analysis.

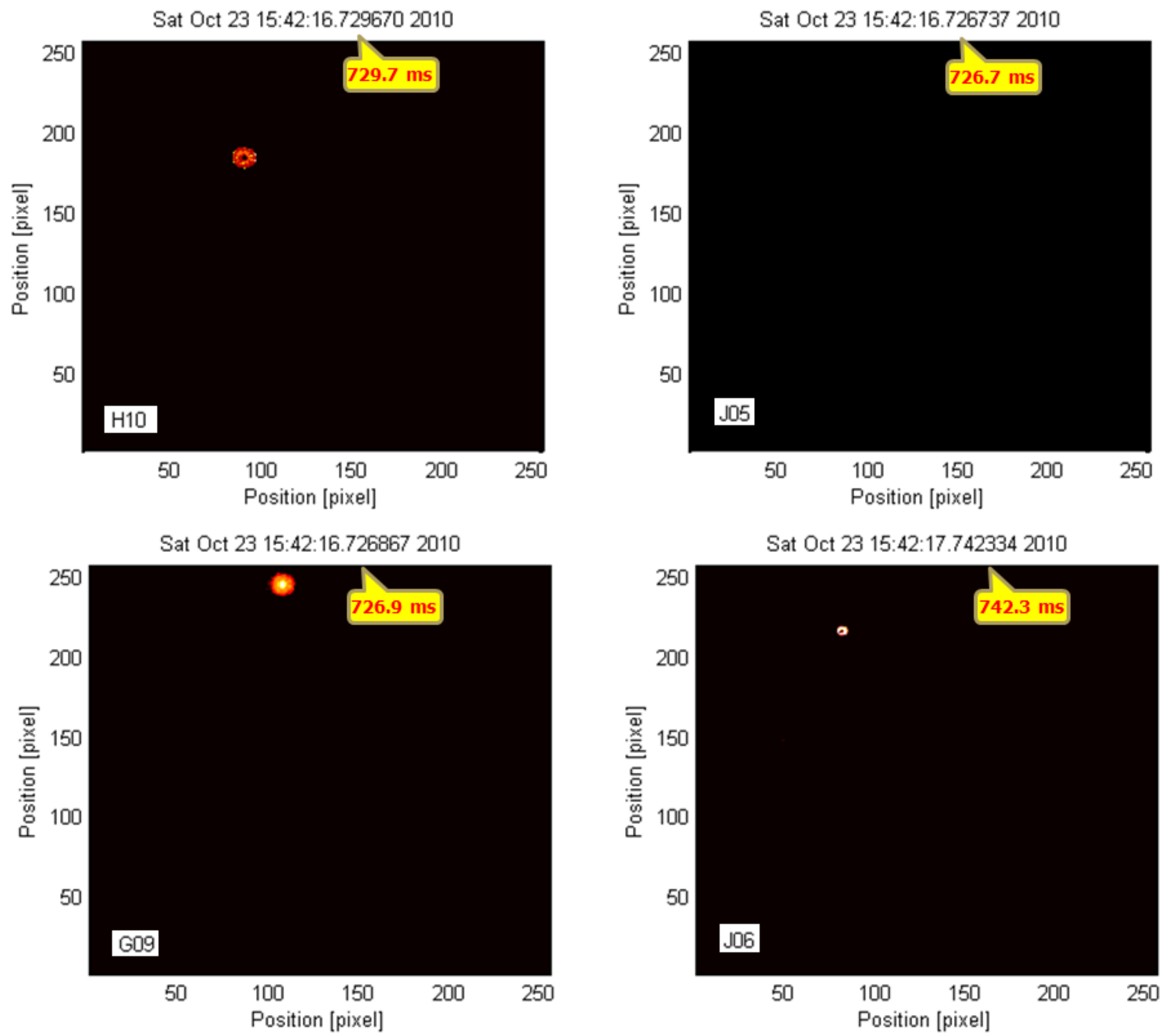

Figure 7: Detection of three fragments in coincidence using a setup of four pixel detectors (shown in Fig. 4) consisting of two Timepix devices (bottom) and two Medipix2 devices (top). Events measured in trigger mode (trigger signal generated by detector TPX J06) and short exposure time (1 ms). The timestamp of data transfer and storage at the measuring PC for each frame is indicated.

The time registry of transfer storage of the given frame in the measuring PC is included. The time shift between the triggering detector (master) and the triggered detectors (slave) is about 1–2 μs (trigger generation in the USB 1.0 interface) plus few tens of ns (processing time of trigger in the slave detectors). The data packages are then sent and stored at the measuring PC at yet greater different times (due to the data transfer and the data storage at the PC introduce further shifts) which can reach few tens of ms. During this interval the next trigger can be generated which means some of the detectors may not be ready to collect a new frame. This results in unsynchronized and incomplete sets of correlated data frames at the PC. Thus the need arises for a coincidence veto module [12] which can validate the status and synchronize the data readout of all detectors.

Source Target Image Reconstruction

The spatial information obtained from the coincidence detection of the main binary fragments can be used further – e.g. to visualize the distribution and determined density of source material in the target. The target used and its reconstructed image with the material density are shown in Fig. 8.

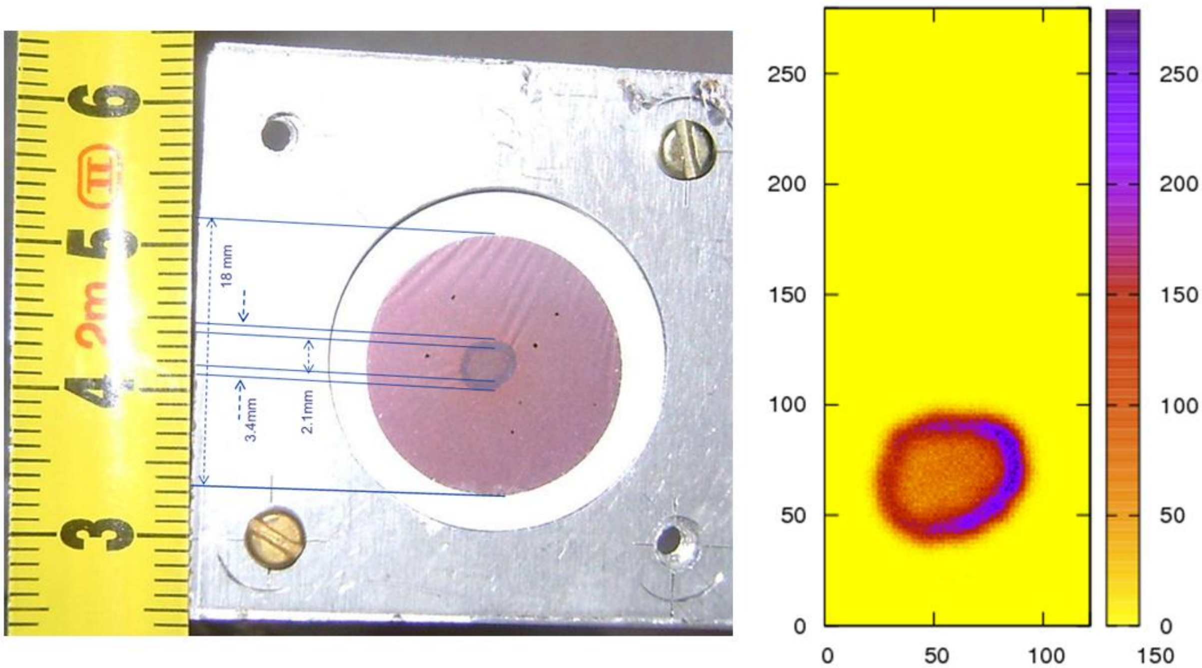

Figure 8: ^{252}Cf source target used (left) and its reconstructed image (right). The source size is 3.4 mm. The material distribution and spatial density are shown in color by the vertical bar.

Conclusions & Future work

The setup and operation of up to four pixel detectors have been implemented for spatial and time coincidence detection of correlated particles for spatially directional studies of rare fission decay. Several techniques have been constructed and demonstrated under a number of particular detector and experiment conditions such as trigger implementation, per-pixel threshold, sensor bias, and measurement exposure time. Fully synchronized data acquisition and readout require a devoted coincidence module to sever as arbiter for ready/busy/veto device monitoring. Analysis of angular distributions/correlations and data evaluation of ternary fission are underway. Long term measurements are planned for studies of low yield rate such as quaternary fission.

Acknowledgements

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References

[1] C. Wagemans, *The nuclear fission process*, CRC Press, USA (1991)
M.Mutterer, and J.Theobald, *Nuclear Decay Modes*, ed. D.N. Poenaru, IOP, UK (1996)

[2] F. Gonnenwein, A. Moller, M. Croni, et al., Nuovo Cimento A 110 - Nuclei particles and fields (1997) 1089-1095.

[3] L. Nowicki, E. Piasecki, J. Sobolewski, et al., Nuclear Physics A 375 (1982) 187-216.

[4] X. Llopart, M. Campbell, R. Dinapoli, D. San Segundo, E., Pernigotti, *Medipix2—a 64 k pixel readout chip with 55 mm square elements working in single photon counting mode*, IEEE Trans. Nucl. Sci. NS-49 (2002) 2279.

[5] X. Llopart, R. Ballabriga, M. Campbell, and W. Wong, *Timepix, A 65 k programmable pixel readout chip for arrival time, energy and/or photon counting measurements*, Nucl. Inst. and Meth. A 585 (2007) 106-108.

[6] Z. Vykydal, J. Jakubek, M. Platkevic, S. Pospisil, *USB Interface for Medipix2 Enabling Energy and Position Detection of Heavy Charged Particles*, Nucl. Instr. and Meth. A 563 (2006) 112-115.

[7] V. Kraus, M. Holik, J. Jakubek, M. Kroupa, P. Soukup, Z. Vykydal, *FITPix – Fast Interface for Timepix Pixel Detectors*, Journal of Instrumentation 6 (2011) C01079.

[8] T. Holy, J. Jakubek, S. Pospisil, J. Uher, D. Vavrik, Z. Vykydal, *Data acquisition and processing software package for Medipix-2 device*, Nucl. Instr. and Meth. A 563 (2006) 254-258.

[9] D. Tureček, T. Holý, J. Jakůbek, S. Pospíšil, Z. Vykydal, *Pixelman: a multi-platform data acquisition and processing software package for Medipix2, Timepix and Medipix3 detectors*, Journal of Instrumentation 6 (2011) C01046.

[10] Z. Vykydal, J. Jakubek, T. Holy, S. Pospisil, *A portable pixel detector operating as an active nuclear emulsion and its application for X-ray and neutron tomography*, 9th ICATPP 2005 Conf. Proc.(2006) 779-784; doi:10.1142/9789812773678_0123

[11] C. Granja, J. Jakůbek, S. Pospíšil, Z. Vykydal, Y. Kopatch, S. Telezhnikov, *Position-sensitive spectroscopy of ^{252}Cf fission fragments*, Nucl. Instr. and Meth. A 574 (2007) 472-478.

[12] V. Kraus, C. Granja, *Coincidence module for spectral and time correlated multi-particle detection with four pixel detectors Timepix*, in these Proceedings.

[13] C. Granja, V. Kraus, J. Jakubek, S. Pospisil, P. Masek, Z. Vykydal, M. Platkevic, Z. Kohout, Y. Kopatch, S.A. Telezhnikov, *Spatially Correlated and Coincidence Detection of Fission Fragments with the Pixel Detector Timepix*, Nuclear Science Symposium IEEE NSS/MIC, Knoxville, Conf. Record (2010) 1578-1584.