PROCEEDINGS OF SCIENCE

Position-Sensitive Coincidence Detection of Nuclear Reaction Products with Two Timepix Detectors and Synchronized Readout

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In low-energy nuclear reactions of astrophysical or fusion interest the spatial- and time-correlated detection of two and more reaction products can be a useful tool to discern reaction channels and determine partial reaction widths. For this purpose we employ a configurable array of Timepix detectors with trigger and synchronized readout by a custom-made coincidence unit. The instrumentation, developed initially for detection of fission fragments, is being implemented for neutron and light-ion induced reactions. Tests and demonstration of the technique with two Timepix detectors on p+p elastic scattering and on the reaction $^{11}B(p,\alpha)\alpha\alpha$ at the Van de Graaff (VdG) accelerator in Prague and the Tandem VdG accelerator of the KINR in Kiev, respectively, are presented.

X Latin American Symposium on Nuclear Physics and Applications (X LASNPA)
1-6 December 2013
Montevideo, Uruguay

[1] Speaker

PoS(X LASNPA)043

1. Introduction

Position-sensitive coincidence measurements of nuclear reaction products and fission fragments can provide valuable information on nuclear reaction mechanisms in direct and semi-compound nuclear reactions. Reaction Q-values, reaction mechanisms and partial reaction channels widths can be studied by energy sensitive and angular distribution measurements. Applicability of conventional radiation detectors is limited by energy detection cutoff, poor signal-to-noise ratio, limited or no spatial resolution. These drawbacks can be suppressed by highly segmented quantum counting pixel detectors. The subject of this work is to study rare fission decay channels in spontaneous (^{252}Cf) and neutron induced fission (^{235}U(n,f)) [1-2] as well as low-energy proton induced reactions on light nuclei such as ^{11}B(p,α)^{8}Be [3-4] by detecting decay and reaction products in coincidence with high spatial resolution [5] and enhanced signal to noise ratio [6]. In particular we aim at measuring the angular distributions of emitted particles. In this contribution the method and instrumentation developed for fission decay studies [6-7] is implemented for light ion induced nuclear reactions on light nuclei. The technique is demonstrated on the ^{1}H(p,p)^{1}H and ^{11}B(p,α)αα reactions.

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

The pixel detector Timepix [8] consists of a radiation sensitive semiconductor sensor bump bonded to an ASIC readout chip with integrated electronics per pixel. The chip consists of an array of 256 × 256 pixels (total 65.536 channels) of 55 µm pitch size and full sensor size 14mm×14mm. Per–pixel pulse processing electronics provides fast and noise free images. The detector is operated with integrated USB-based readout interfaces such as the USB 1.0 [9] and FITPix [10] devices which provide integrated control, power and DAQ. Operation and online visualization are enabled by the software package Pixelman [11-12]. The assembled system serves as an online compact radiation camera [13] for table-top and vacuum operation, portability and configurability.

Each pixel of the Timepix detector can be independently configured to operate in *counting mode* (the counter is incremented by one when the per-pixel deposited energy of the interacting particle crosses the per-pixel threshold level), *energy mode* (Time-over-Threshold ToT mode) where the counter is incremented continuously as long as the signal is above threshold and *Time mode* (Time-of-Arrival ToA mode) which registers the time of interaction of the particle signal in the given pixel (the counter is incremented continuously from the time the first hit arrives until the closure of the shutter (end of the time window or acquisition exposure)).

3. Multi-detector triggered operation and DAQ synchronization

For simultaneous operation and synchronized data readout of two and more pixel detectors an integrated coincidence synchronization module unit was constructed. The trigger signal can be driven either by the shutter start of the FITPix interface (digital trigger) from any of the detectors or from the analog signal of the one of the detectors common sensor electrode (analog trigger) via integrated back-side-pulse signal integrated module. The unit validates the trigger, controls the operation (shutter on, off), monitors the device status (busy/veto) and manages and synchronizes the readout of the pixel detectors. This way the detectors are operated and readout in sync generating correlated data files for all devices. The setup can be extended to silicon diodes and dE detectors to include trigger signal from these and other external devices including accelerator trigger.

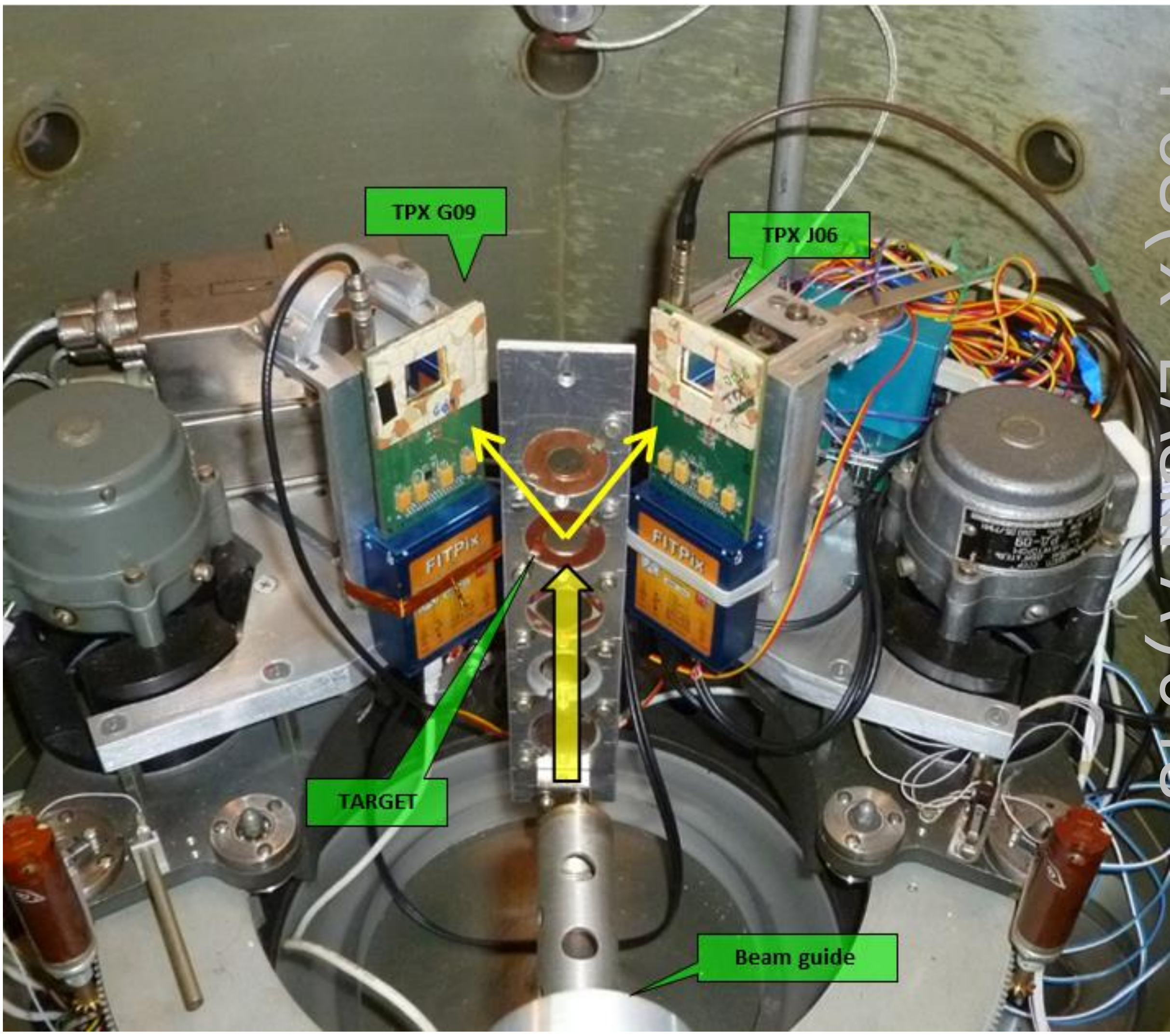

Fig. 1: Setup and geometry of the elastic scattering reaction p+p on a thin CH_2 target inside a vacuum experimental chamber at the Tandem VdG accelerator of the KINR, Kiev. Two Timepix detectors are placed at 45º along the beam axis.

4. Coincidence operation of two Timepix detectors with synchronized readout

Two Timepix detectors, each equipped with a 300 µm silicon sensor, were placed at varying angle along the beam axis for the test reactions studied (see Sec. 5 and Sec. 6) as shown in Fig. 1. The trigger and DAQ of the pixel detectors were controlled by the synchronizing module (Sec 3). Measurements were performed at the Van de Graaff accelerator of the IEAP CTU in Prague and at the Tandem Van de Graaff accelerator of the KINR, Kiev, respectively.

5.Spatial- and time-correlated detection of two particles: p+p elastic scattering

The detection and visualization of scattered and recoiled protons in coincidence in the p+p elastic scattering reaction at the IEAP CTU VdG in Prague is shown in Fig. 2. The layout shown in Fig. 1 was used. The spatial information (top plots) is correlated with the time spectra (bottom plots).

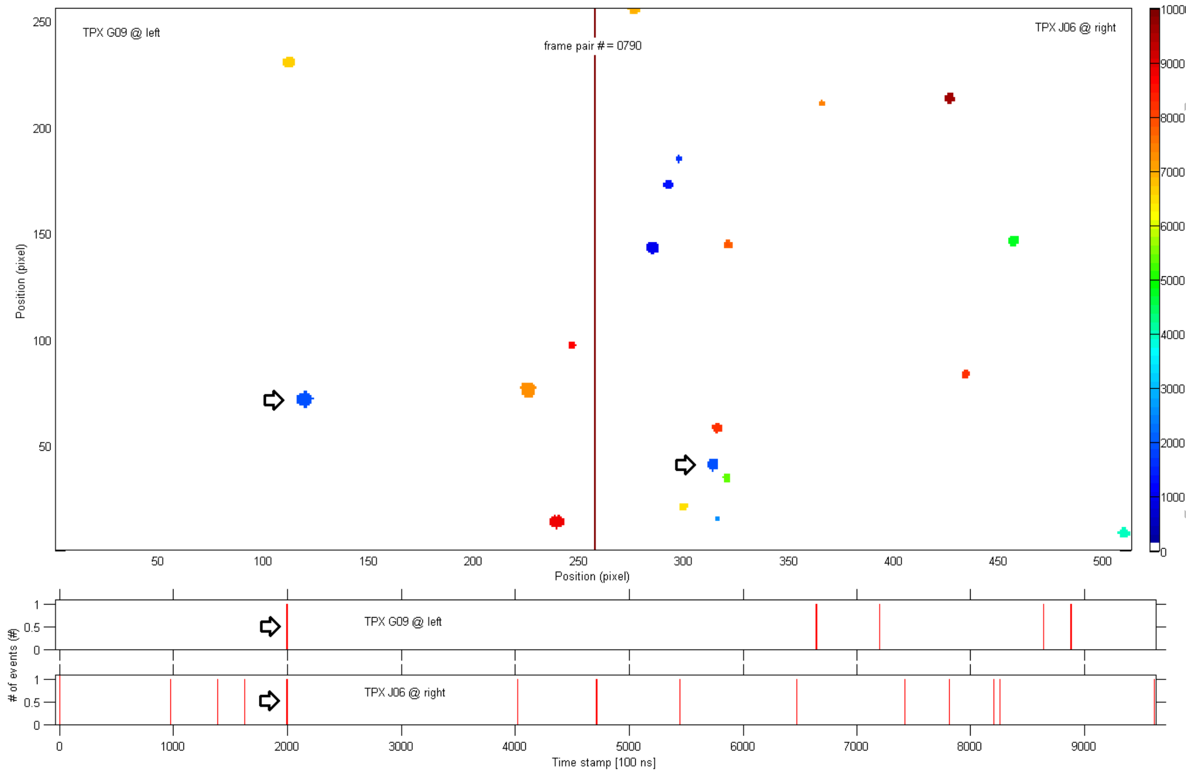

Fig. 2: Spatial-and time-correlated detection of reaction products from a 2.0 MeV proton beam onto a thin plastic (CH_2) target. Single events are registered in two separate pixel detectors (top) which are operated in time-of-arrival mode (shown in color) providing their time stamp which can be plotted in time spectra (bottom). A coincident pair is indicated by the arrows. Data shown were collected in 1 ms exposure time. The spatial information, the full 256 × 256 pixel matrix for each detector is displayed, is coupled to the time-correlated information given by the color scale and bottom axis (displayed full range 0–1000 μs).

For these measurements the Timepix detectors are operated in time-of-arrival (ToA) mode. The measured time of interaction of single particles is used as time stamp (displayed by the color bar on the spatial plot and in the horizontal axis in the time plot). For the detector measurement settings used (acquisition time 1 ms, clock frequency 10 MHz) the timing resolution was 100 ns. Correlated particles are found by their coincident time stamp (labeled by the arrows).

6. Spatial- and time-correlated detection of two particles: $^{11}B(p,\alpha)\alpha\alpha$

The detection of pairs of two particles in coincidence (of the three particles emitted) for the reaction p + ^{11}B with 2.65 MeV protons investigated at the Tandem VdG accelerator of the KINR in Kiev is shown in Fig. 3. A different layout (relative angle position) was used for this reaction.

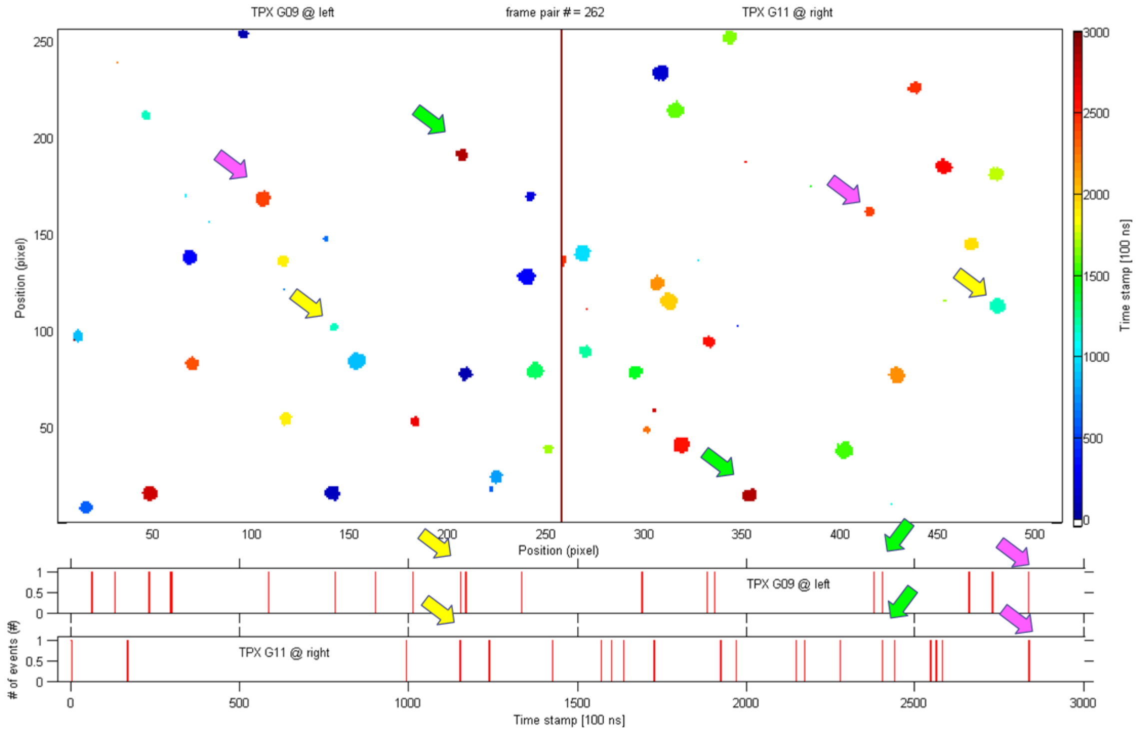

Fig. 3: Same as Fig. 2 for the reaction $^{11}B(p,\alpha)\alpha\alpha$ at the Tandem VdG of the KINR in Kiev. Three pairs of correlated events are indicated (color arrows).

7. Vertex reconstruction + interaction plane geometry

The distances and plane of interaction can be reconstructed from the measured positions of the detected particles. The projection of the interaction plane on the horizontal plane (z-axis along the beam axis, x-axis transversal to the beam axis) for the p+p reaction is shown in Fig. 4. The scattering angle is measured with spatial resolution at the pixel scale. Sub-pixel resolution down to few μm can be achieved. The spatial correlation among the pairs of coincident events is visible and demonstrates the principle and resolution of the technique.

8. Conclusions

Timepix allows applying a time and spatial correlated technique for background suppressed detection of correlated events. The method and instrumentation with two pixel detectors extended for particle induced reactions has been demonstrated on the elastically scattered and recoiled p+p reaction. Simultaneous detector operation and synchronized data acquisition are ensured by a coincidence module unit. The technique measures the scattering/reaction angle and allows reconstructing the plane of interaction. Angular distributions and spatial correlations of coincident events registered can be obtained with high spatial resolution. Further data evaluation and measurement of three-particle product channels in the reaction p+^{11}B are in progress.

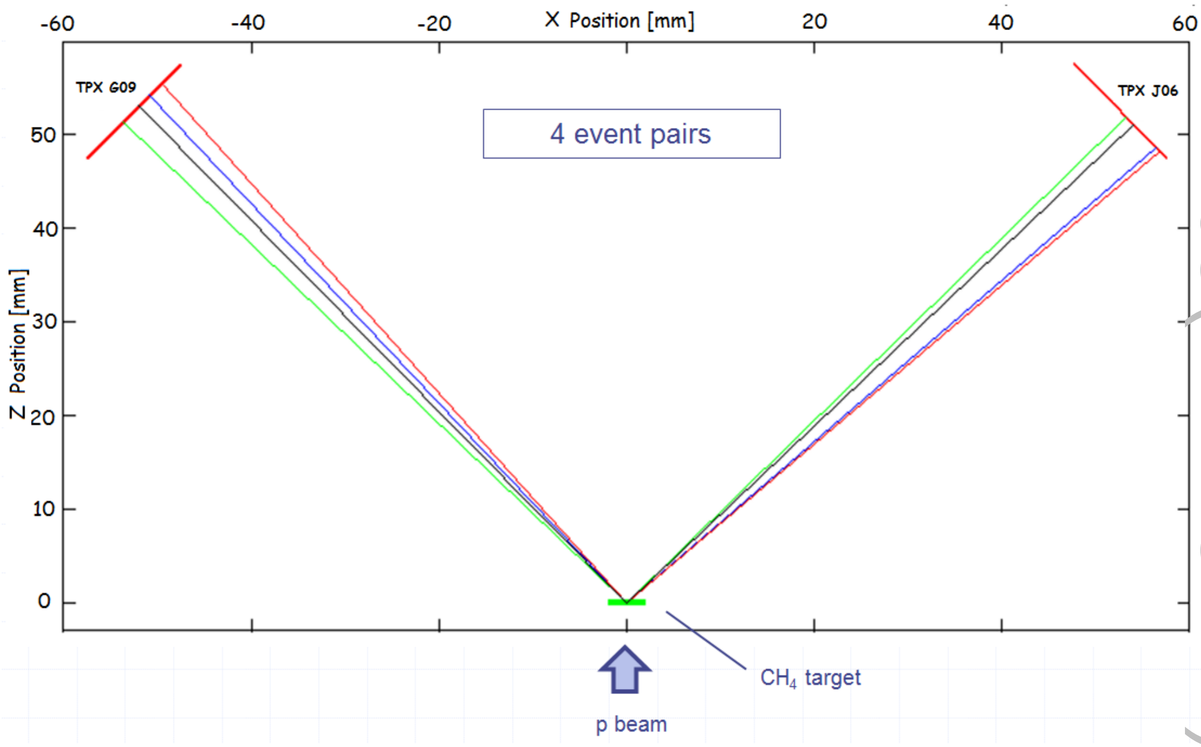

Fig. 4: Reconstruction of the plane of interaction of coincidence pairs in the reaction p+p. Four pairs are shown (each pair drawn in different color). The projection along the horizontal plane is displayed (z-axis along the beam axis, x-axis transversal to the beam axis).Distances, reconstructed trajectories, target holder backing and detector size are displayed in real spatial dimensions (in mm). The measured scattering angle between pairs of coincidence events is (nearly 90º).

Acknowledgments

Work funded by the MSMT Research Infrastructure Grant VdG light ion accelerator No. LM2011030 (149-120006M) of the Ministry of Education, Youth and Sports of the Czech Republic and in part by Research Grant Position- and Time-Sensitive Correlated Detection of Rare Fission Fragments No. 03-4-1104-2011/2016 from the Committee of the Czech Republic for Cooperation with JINR Dubna. Research performed in frame of the Medipix Collaboration.

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