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A PROGRAM FOR DATA ANALYSIS OF RARE FISSION MODE PROCESSES FROM NEUTRON-INDUCED AND SPONTANEOUS FISSIONS

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Abstract. Rare fission mode processes (ternary or quaternary fission) of low-energy and spontaneous fission of heavy nuclei, in which light charged particles are emitted, are the subject of intense experimental and theoretical studies, since these studies can be attributed to one of the main sources of information on the mechanism of nuclear fission. To study these processes, a detection system has been assembled, consisting of three semiconductor ΔE-E telescopes and a silicon detector. In addition, the program has been developed for proceeding experimental data. This paper has been dedicated to the program written on the basis of ROOT software consisting of many scripts to analyze and/or filtrate ternary and quaternary fission particles among different fission events. The program can proceed long collected files in ASCII and binary formats, correlate results from all detectors, give results on particle interaction time, coordinates, particle energy and its types. The performance of the program has been tested to proceed ternary fission data from 252Cf spontaneous fission source.

Keywords: *Ternary fission, quaternary fission, digital signal processing, Cf-252 spontanous fission source.*

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1. Introduction

The fission process of the atomic nucleus continues to attract a lot of attention from researchers in many laboratories of the world, despite more than half a century of studies on this unique phenomenon. Despite intensive research on nuclear fission processes in the past, many of them are still only partially studied. The ternary and quaternary fission (Ahmadov *et al*., 2015; Holik *et al*., 2018) are rare fission mode processes that are nowadays in the focus of further studies. Investigation of light charged particles (LCPs) emitted from the neck region during nuclear fission makes it possible to obtain information about the nucleus in an unusual extreme state near the point of rupture, as well as about the mechanism of nuclear fission (Jesinger *et al*., 2005). The two main fission fragments are accompanied by LCP in ternary fission (Ahmadov *et al*., 2015; Holik *et al*., 2018). Besides the two fission fragments, two LCPs are independently emitted in quaternary fission (Ahmadov *et al*., 2015; Holik *et al*., 2018). The probability of these processes leads to long-term experiments for a profound study of rare fission mode processes. Although powerful and fast detection systems are used for acquiring useful information, digital data processing is considered an important part of physics experiments. To select the required process (useful information) from the millions of recorded events, digital data processing is used, which produced a “pre-selection of candidates” (Holik *et al*., 2018). Because the processing of the experimental data is a complicated and time-consuming process, it is crucial to develop a program that can process data in a reasonable time. This article is focused on the development of a ROOT based data processing program consisting of many scripts for data from the long term measurements.

2. Experiment

To search for and study of rare processes in the Laboratory of Neutron Physics, JINR, an experimental setup has been developed. A picture of the experimental setup was shown in Fig. 1.

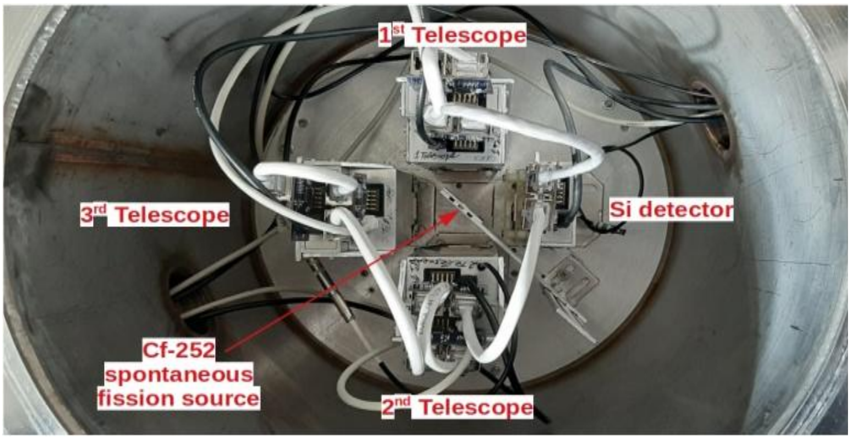

Fig. 1. A picture of the experimental setup for studying ternary and quaternary fission processes, consisting of three telescopes and a Si detector. The figure shows the placement of the target between the detectors

It represents the detection systems made of silicon detectors of different thicknesses, enclosed in a stainless steel fission vacuum chamber. The detection system consists of 3 particle telescopes and a pad Si detector. Charge particles were identified by the ΔE-E method (Jesinger *et al*., 2005; Carboni *et al*., 2012) using particle telescopes consisting of thin silicon Δ*E* detector and hybrid pixel silicon detector Timepix (Llopart *et al.,* 2007; Holik *et al.,* 2019) used as E detector. The ΔE detector has an area of 10×10 mm^2 and a thickness of 16 μm (www.micronsemiconductor.co.uk). The area and thickness of Timepix are 14×14 mm^2 and 600 μm, respectively. Timepix detectors were configured to work in time over threshold (TOT) mode, since other modes (time of arrival (TOA), counting (Holik *et al.*, 2016; Holik *et al.*, 2019) are also available. A pad Si detector was used to register main fission fragments from the source. The Si detector has an area of 10×10 mm^2 and a thickness of 300 μm. Timepix is assembled with the FITPix COMBO device (Holik *et al*., 2016; Holik *et al*., 2019) which is used to read out a signal from a common and pixel part of Timepix (both in parallel). For the same purpose Spectrig device (a modified version of FITPix COMBO) (Holik *et al*., 2016; Holik *et al*., 2019) is used for ΔE and Si detectors. The integrated readout interface FITPix (Holik *et al*., 2016; Holik *et al*., 2019; Kraus *et al*., 2011) is used to bias and control the Timepix detector, while Spectrig device by the Spectrig DAQ Control Tool (Holik *et al*., 2020). Pixel part of the Timepix is controlled via Pixelman software (Turecek *et al*., 2011). Both devices are plugged directly to any PC via USB port.

A ^{252}Cf spontaneous fission source with an intensity of 10 kBq in the form of a spot 3-5 mm in diameter was deposited on an Al_2O_3 substrate with density of 70 μg/cm^2. The source was placed in the center of the detector system. To absorb fission fragments and alpha particles from natural alpha decay of ^{252}Cf spontaneous source, Al foils with a thickness of 27 μm were placed in front of the telescopes except for the Si detector. Thus, the detectors registered only long-range light charged particles from ternary fission. The experiment was carried out under pressure of 1 mBar. The triggering system was configured in such a way that when a signal appeared in one of Δ*E* detectors, others capture signals simultaneously. One can get familiar with the triggering (Holik *et al*., 2018).

3. Results and discussion

Data processing was done offline by the program consisting of several scripts to extract valuable data. Fig. 2 demonstrates a simplified block diagram of data processing procedure and working principle of the scripts. About 108 events were collected during measurement time (5 days), and among them 104 events were valuable. The reason for the big difference is the selected triggering mode and the size of the detectors.

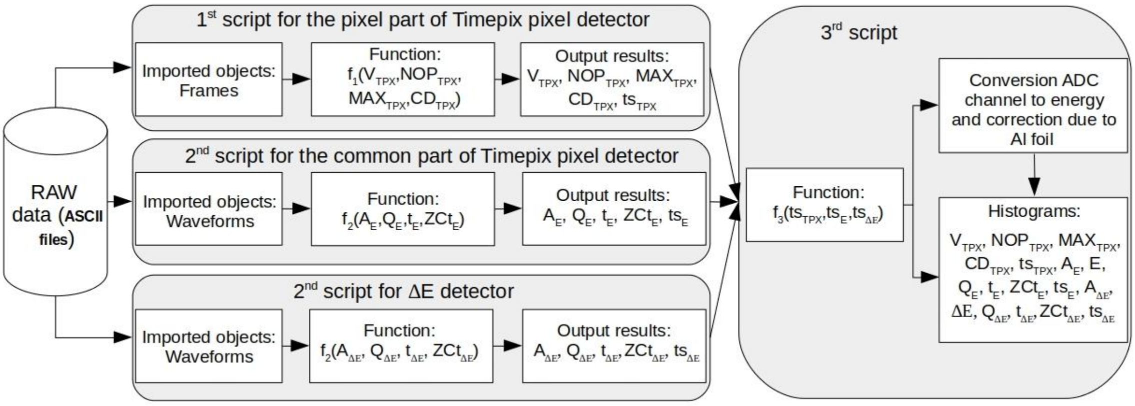

Fig. 2. Block diagram of data processing procedure

The first script: it reads frames and proceeds data from the pixel part of Timepix pixel detector. Pixel part of Timepix allowed identifying particles according to a pattern recognition method and to take information about interaction coordinate and time of particle with detector. The script searches circle clusters since charge particles create circle clusters in the pixel part of Timepix (see Fig. 3). It filtrates these clusters from other types of clusters using cluster volume (VTPX), number of pixels in a cluster (NOPTPX), maximum TOT in a cluster (MAXTPX), and cluster diameter (CDTPX). Fig. 3 presents 2D and 3D frame examples before and after processing data.

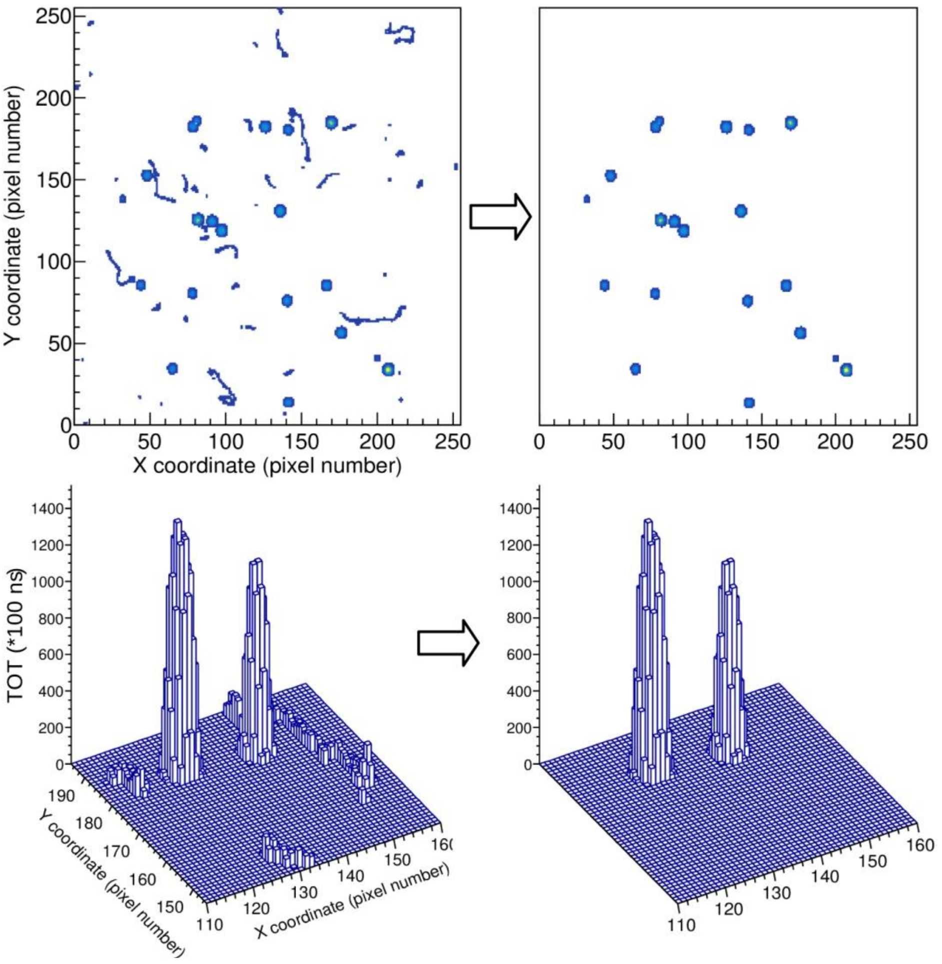

Fig.3. 2D (up) and 3D (bottom-zoomed) frame examples before and after processing data. In addition to the spatial (2D) information the energy registered per pixel is recorded and can be shown as a third axis by the vertical bar. Pile-ups as well as unwanted background such as X-rays and fast electrons are resolved

Timepix is a hybrid pixel detector consisting of 256*256 square pixels with a pitch of 55 um, in other words, 256*256 square small detectors. Therefore, in figures there are a lot of events in the frame since fission is a complicated process in which different particles are possible to be emitted. The script analyzes every frame and filtrates charge particles starting from the proton. Fig. 3 (right figures) shows how the script clearly filtrates the events.

The second script: it reads waveforms and analyzes the results from a common part of the Timepix, the ΔE and the Si detectors. The common part of Timepix works as a single pad detector since ΔE detector is a single pad detector, too. Signal from the detector is amplified and fed to a flash digitizer (with sampling frequency 100 MSa/s) used to convert the analog waveforms to digital. Raw data saved in binary and/or ASCII format in PC. The script analyzes signals according to their amplitudes (AE and AΔE), areas (QE and QΔE), offset times (ZCtE and ZCtΔE-zero crossing time) and widths (tE and tΔE) in order to filtrate pile-ups as well as unwanted background such as X-rays and fast electrons. Fig. 4 (middle and bottom) presents waveforms of signals and corresponding clusters (up).

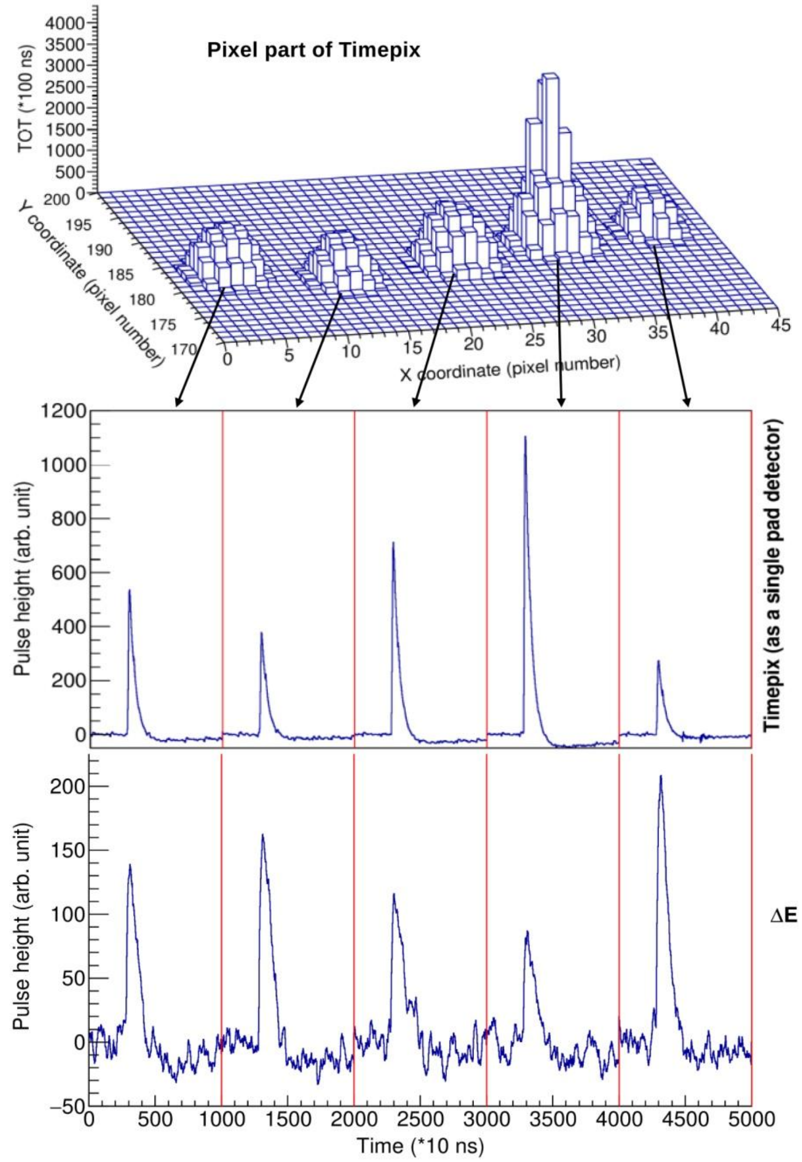

Fig. 4. Signal correlation mechanism after filtration of valuable events. Filtration was done by width, amplitude, area, offset time (zero crossing time), timestamp (~10 ns accuracy) assigned to events. The pixel part response (top) is correlated by common time-stamps to the analog signal waveform readout for Timepix (middle) and *ΔE* detector (bottom)

As shown in figure there is low amplitude in ΔE detector in case of high signal amplitude in E detector and vice versa. The transmission type ΔE detector detects the specific energy loss (ΔE), and the residual energy of particles (E) is recorded by Timepix. These conditions were taken into account, too. As a consequence, the script was used in the identification of the signals, the elimination of noise and background events, and retrieved information about amplitude, area, zero-crossing time and timestamp of waveform signals (tsE and tsΔE).

The third script: Specific synchronization bus was used to control a trigger signal and busy signal to allow an effective filtration of unpaired events while performing coincidence measurement. Despite using the synchronization system, random coincidences are possible in any experiments. Therefore, reducing random coincidences as much as possible is mandatory. The third script proceeds the results analyzed and filtered by the first two scripts. It searches offset times (in our case zero crossing times) and timestamps (tsTPX, tsE and tsΔE) assigned to each response of the detectors. Zero crossing times (ZCtE and ZCtΔE) carry valuable information in order to filtrate random coincidences. In case of random coincidence offset of signal is shifted right or left, although it is fixed. In case of random coincidence, the signal does not appear in fixed offset time. The analyzing procedure of the third script is demonstrated in figure 4. The script compares the results from all detectors and selects such events detected in a short time (10 ns). Energy calibration dependences and energy losses in Al foil were taken into account in the script. As a result, it gives the final results including 2D particle identification spectrum (ΔE-E in energy units) and energy spectra for particles. Although physical results are not the subject of the paper, we have shown only the energy spectrum of ternary alpha particles. Figure 5 shows the energy spectra of ternary alpha particles, measured with one of telescopes within 5 days.

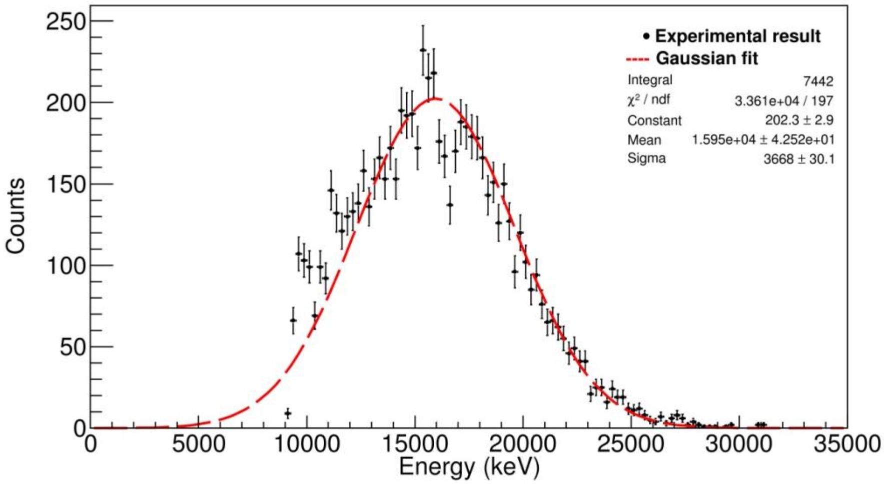

Fig. 5. Energy spectrum of ternary alpha particles from ^{252}Cf spontaneous fission source, obtained for one of the three telescopes

Energy spectra are corrected for losses in Al foil, calculated using the SRIM program (www.srim.org). A Gaussian curve fit was performed and average energy was found to be equal to 15.95 MeV±0.04. The measured energy distribution of alpha particles from ^{252}Cf ternary fission was compared with our old (Ahmadov *et al*., 2015) and the known literature data (Tishchenko *et al*., 2002; Loveland 1974).

4. Conclusion

The ROOT based program consisting of three scripts was developed to proceed data from ternary and quaternary fission of ^{252}Cf spontaneous fission source. The results obtained showed that the program can analyze data and retrieve valuable information from 7 detectors, and it can also be upgraded for more detectors. In the program, it was considered all main parameters of signal processing including width, amplitude, area, offset time (zero crossing time), timestamp of waveform signals. The program fast filtrated valuable data among about 10^8 events and correlated events related to each detector. It proceeded 1 GB data in ASCII format from 7 detectors within 20 seconds using single-threaded analysis by standard PC (Linux operating system). It was given obtained preliminary results that are in good agreement with our old (Ahmadov *et al.*, 2015) and other author's results (Tishchenko *et al.*, 2002; Loveland 1974) on ternary fission. This indicated that the program can be used for more complicated data processing planned to collect from quaternary fission of ^{252}Cf spontaneous fission source.

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