

# Application of the pulse-shape discrimination of the PiN type Si detectors in the neutron-rich nuclei investigation.

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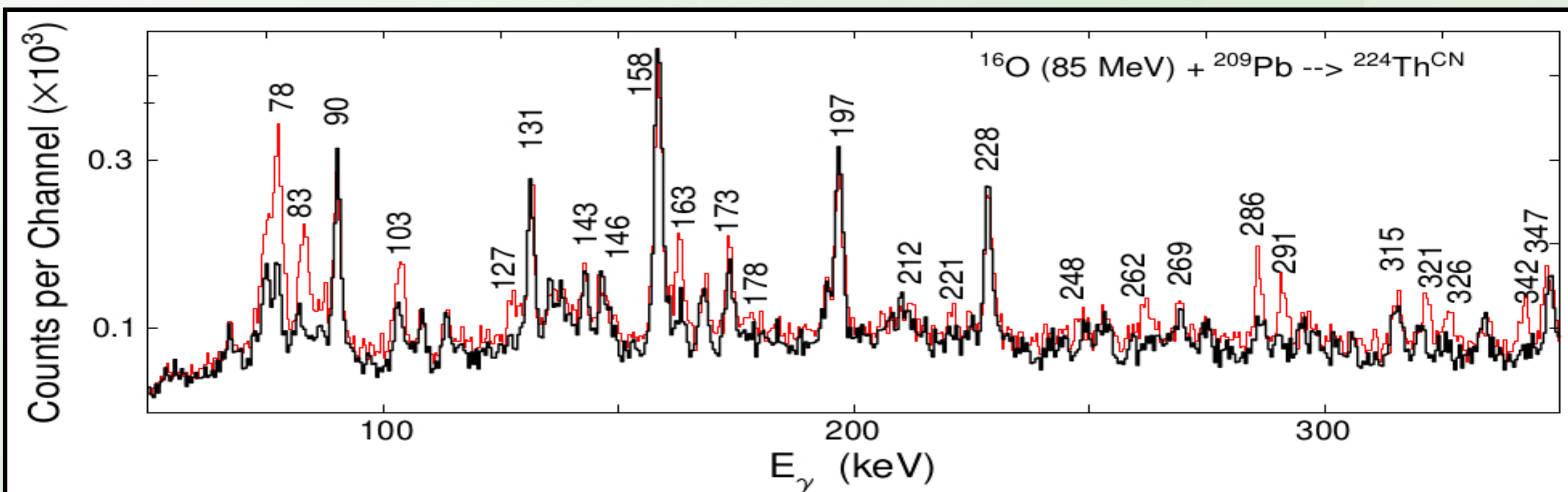
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## Abstract

An identification and discrimination of fission fragments by means of rise-time analysis technique with front and reversed n-type Si detectors was undertaken. The several tests and calibrations with  $^{252}\text{Cf}$  source were done before the fusion-evaporation reaction (e. g.  $^{16}\text{O} + ^{208}\text{Pb}$ ) will be investigated. A consequence of the rear-side injection mode is a strong variation of the charge-collection time with energy, charge, and mass number of the detected ion as it was noticed by G. Pausch et al. [1,2]. On the basis of results given in this papers the present measurements were initiated and are conducted with the aim to apply in the field of heavy-ion physics in conjunction with  $4\pi$  EAGLE gamma-array.

## Why do we want to identify fission fragments ?

Results of former experiments  $^{16}\text{O} + ^{208}\text{Pb}$  indicate a several delayed gamma-rays (Fig.1). In this reaction about fifty fission fragments were identified, most from the region of n-rich nuclei. Several lines (seen in red) are not ascribed to the proper mass, and the aim of this experiment is to identify them properly. In n-rich nuclei with  $A \sim 80-130$  a simultaneous existence of high and low j-orbitals, i. e.  $2p_{1/2}$ ,  $1g_{9/2}$  for protons and  $1g_{7/2}$ ,  $3s_{1/2}$ ,  $2d_{3/2}$ ,  $1h_{11/2}$  for neutrons, as well as collective structure favor possible isomerism. Examples of observed formerly gamma-rays half lives are shown in Table 1.

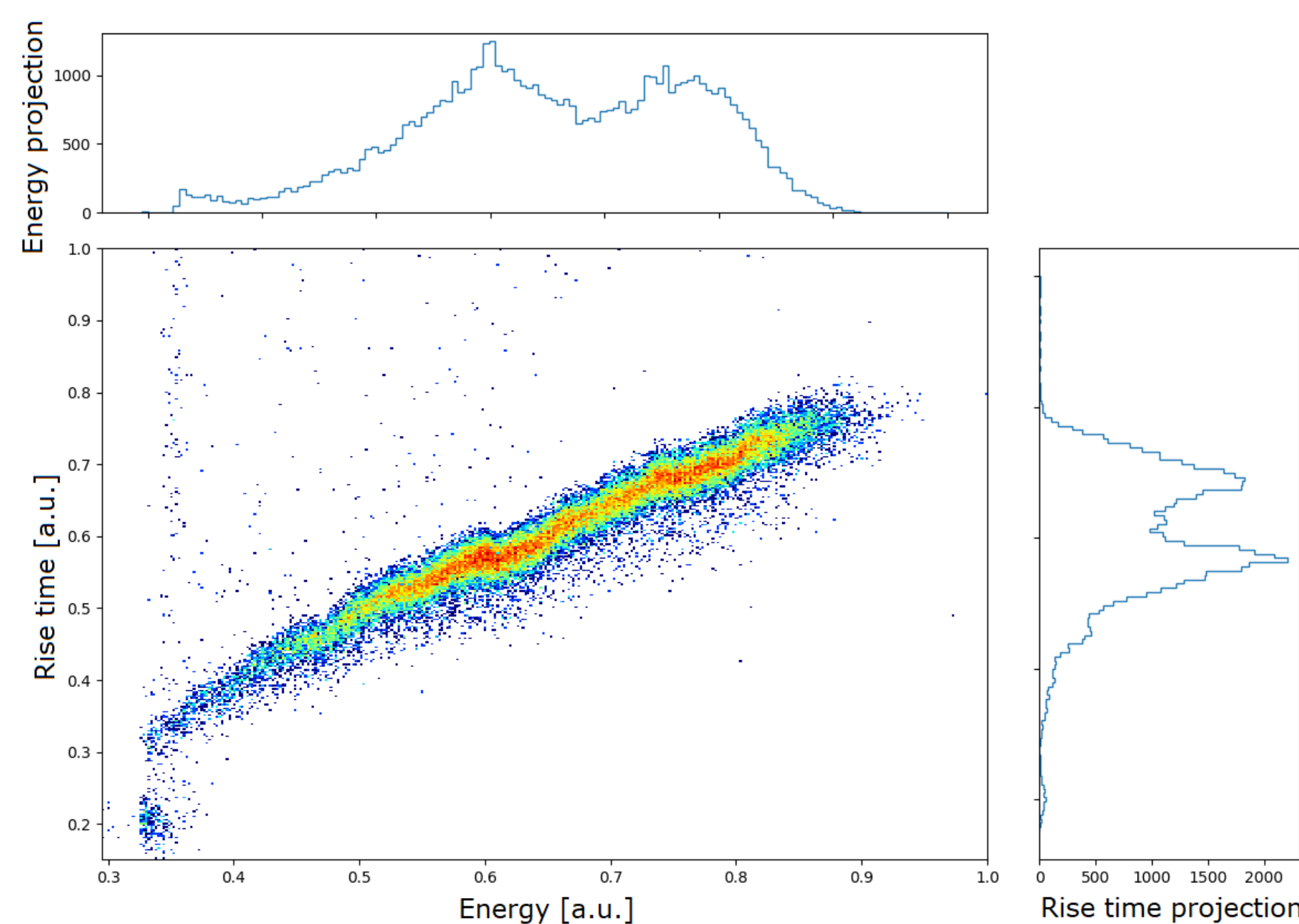


**Fig.1** Example of partial two gamma-ray spectra collected in two time gates – 0.3 ms (red) and 3.5 ms (black) after the cyclotron beam-off period. Several short lived gamma-rays are observed.

In order to identify isomeric states in fission fragments, it is planned to use fission fragment detectors to trigger the EAGLE array and isolate the delayed gamma-ray cascades, as well as to ascribe them to respective masses. Identification of fission fragment (FF) masses and energies has been, and still is a major concern in fission spectroscopic research. There are known several studies concerning the mass resolution like [3], where a mass of less then 1 amu for fission fragments is achievable, the other example is the ref. [4] showing the determination of FF masses by measuring velocities and kinetic energies using specially adapted TOF detectors and ionization chambers or semiconductor detectors.

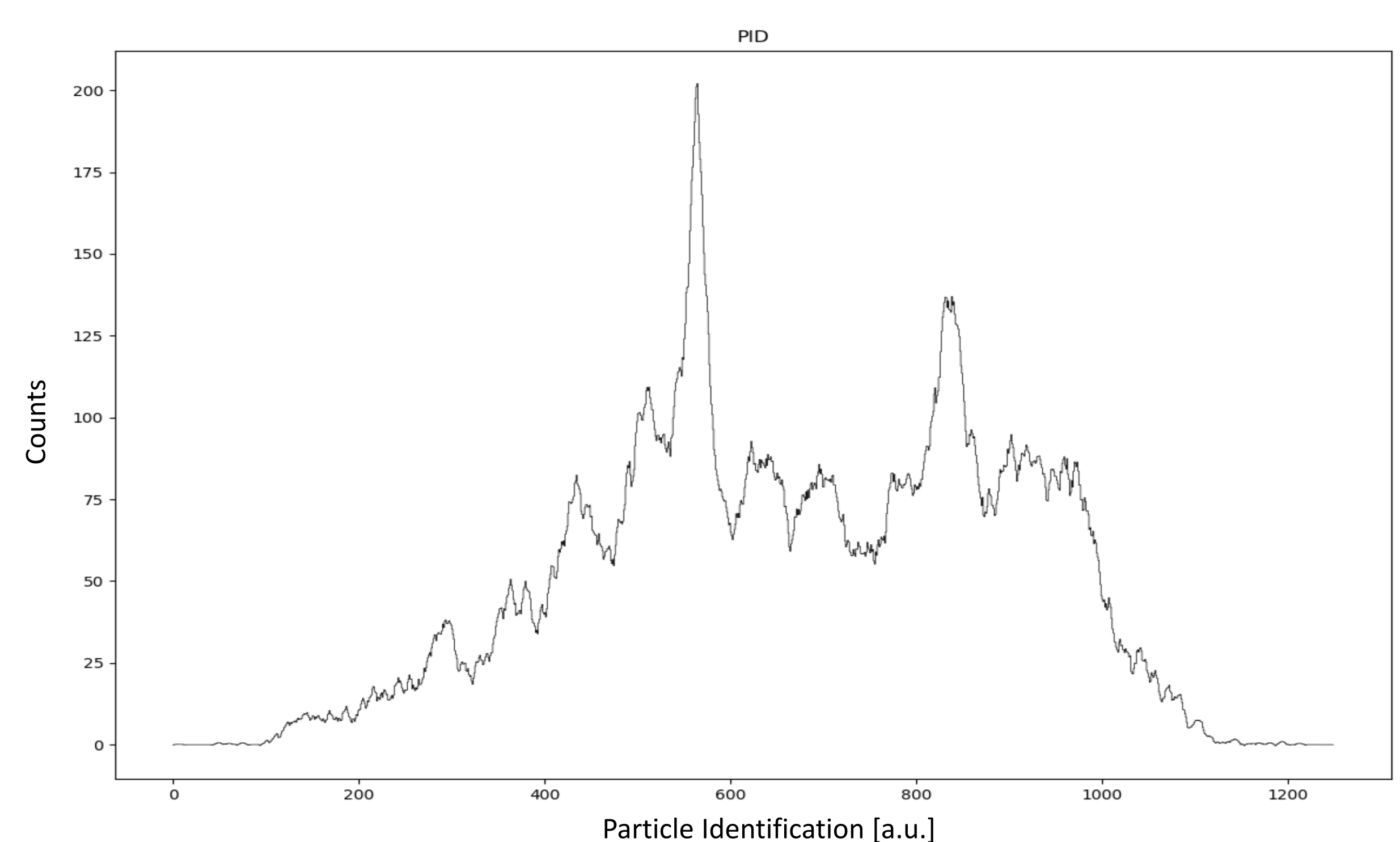
**Table 1.** List of few examples of gamma-rays supposed to be related with isomeric decays. The half-lives were estimated in the test experiment.

$E_\gamma$ [keV]	$T_{1/2}$ [ $\mu\text{sec}$ ]	Supposed isomers (not confirmed)
82	$79.4 \pm 2.2$	$^{105}\text{Te}$
248	$42.4 \pm 5.0$	coincidence with 291 keV, $^{109}\text{Pd}$
261	$104.3 \pm 2.5$	$^{125}\text{Cd}$ or $^{100}\text{Tc}$
269	$63.3 \pm 1.2$	$^{106}\text{Ru}$
286	$89.5 \pm 2.2$	$^{121}\text{Sb}$ or $^{76}\text{Se}$
291	$33.0 \pm 3.0$	coincidence with 248 keV, $^{109}\text{Pd}$
342	$112.4 \pm 1.5$	$^{206}\text{Pb}$ or $^{216}\text{Ra}$



**Fig.2** Rise time fraction vs energy 2D histogram obtained for the front contact PiN Si detector and fission fragments from  $^{252}\text{Cf}$  open source (center). Vertical axis (rise time fraction) projection (right). Horizontal axis (energy) projection (top).

In the Fig. 2 the 2D spectrum of the energy and rise time for the fission fragments from  $^{252}\text{Cf}$  open source measured at NCBJ laboratory is presented. During the measurements a Hamamatsu Si PiN diode detector of 300  $\mu\text{m}$  thickness, charge preamplifier, high performance digital oscilloscope and dedicated software for the analysis was used. In the figure the spectrum segmentation for the rise time fraction and energy is shown.



**Fig.3** Particle identification (PID) histogram for the fission fragments from  $^{252}\text{Cf}$  open source.

In the Fig. 3 is presented the cross projection of the 2D histogram from the FF plot of Fig. 2. Preliminarily, it is assumed that peaks on the PID figure represent Z-dependent fission fragments. Results of the energy vs. rise time analysis presented in the above plot are very unique for the PiN type front contact Si detectors.

## Research project objectives

The shape of the pulse collection in a solid-state detectors following the interaction of charged particles can be used for particle identification. The sensitivity of the pulse shape in the Si detectors depends on:

- the plasma erosion effect,
- the finite drift time of the charge carriers.

As a result, the charge-collection time increases monotonously with charge and mass number of the detected ions. The light fragments generate a current signal of longer duration and greater amplitude, which corresponds to a longer rise time of the charge signal. While the heavy fragments have a shorter pulse rise time and corresponding lower energy [5]. Identification of fission fragment masses and energies has been, and still is a major concern in fission spectroscopic research.

## Research project methodology

In order to identify isomeric states in fission fragments, it is planned to use fission fragment detectors in coincidence with EAGLE HPGe array. For that application we consider to use Si ball with reversed planar n-type Si detectors to trigger the EAGLE Ge detectors and compare them with the commercially available PiN, Hamamatsu S3590. Use of such configuration allows to isolate the delayed  $\gamma$ -ray cascades, as well as to ascribe them to respective masses. The possibility of FF masses separation was tested with  $^{252}\text{Cf}$  source checking the time difference ( $T_{\text{PSD}}$ ) with some selected rise time ratios (prompt to total) of the charge signal  $Q(t)$ .

Promising results obtained with  $^{252}\text{Cf}$  source motivated us to carry out an identification of n-rich FF in heavy ions induced fission at Heavy Ion Laboratory EAGLE detector array.

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[3] C. Guet et. al., Nuc. Inst. Meth. 150, (1978) 189.

- [4] A. Oed et. al., Nucl. Instr. Meth. 219 (1984) 569.  
[5] M.O. Frégeau et. al., Nucl. Instr. Meth. 817(2016) 35-41.