

Toward neutron /gamma discrimination with proportional counter using artificial intelligence

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Abstract— Extending the neutron detection capabilities of the ROSPEC SP2-1 proportional counter below 50 keV requires effective discrimination between neutron and gamma-ray signals at low energies. To address this challenge, we use a digital acquisition system, then apply signal processing and artificial intelligence techniques to analyze the data. The results showed that a CNN-based trained model can successfully distinguish noise from event signals in the recorded data. Key pulse features, such as rise time and amplitude, are extracted from the true signals to generate a two-dimensional plot of rise time versus amplitude, which facilitates the discrimination of neutron from gamma components. The application of the unsupervised clustering algorithm DBSCAN on this feature space shows limitations in accurately identifying low-amplitude gamma signals, while a measurement with only a gamma source confirms the presence of gamma events in the expected feature space. These results motivate the development of a supervised CNN-based approach to improve neutron/gamma discrimination.

Keywords —ROSPEC, neutron/ gamma discrimination, proportional counter, CNN, low-energy neutrons.

I. INTRODUCTION

THE Micro-irradiation, Neutron Metrology and Dosimetry Laboratory (i.e. the LMDN) from ASNR Cadarache in France, is responsible for the national references in the field of neutron dosimetry. For this purpose, LMDN produce reference neutron fields and has spectrometers to characterize them. Among these instruments is ROSPEC (ROtating SPECTrometer) [1], a multi-detector system comprising six spherical proportional counters designed for neutron detection and spectrometry across a wide energy range. Four of the counters, called SP2-1, SP2-4, SP2-10 and SP6, are designed to cover neutron energy ranges between 50 keV and 5 MeV. The fifth counter is a ³He-filled detector designed to detect thermal neutrons ($E < 25$ meV), while the final counter, ³He+¹⁰B, has a boron-coated inner surface for detecting neutrons between 1 eV and 10 keV.

The aim of this work is to improve the ROSPEC performance by extending the energy range below 50 keV. This can be achieved by implementing neutron/ gamma discrimination in SP2-1 proportional counter, so that gamma event can be identified and removed.

In the SP2 proportional counter, neutrons interact with the

hydrogen gas via elastic scattering. These interactions produce recoil protons, which can acquire energies up to that of the incident neutrons. The charged recoil protons produce primary ionization along its track until it is brought to rest by the gas.

Gamma rays interact within the chamber primarily through Compton scattering with the electrons of the gas atoms. The resulting recoil electron, which gains kinetic energy from the interaction, ionizes the gas along its path by producing ion-electron pairs. However, due to the limited stopping power of the gas, the electron can cross the entire chamber and deposits only a fraction of its total energy. As a result, there exists a maximum energy that an electron can deposit in the gas, independent of the initial gamma-ray energy. This limiting energy (approximately 50 keV), depending on the gas pressure, corresponds to the case where the electron's range is just equal to the chamber's diameter. Electrons with either lower or higher energy will ultimately deposit less energy in the gas.

In the SP2-1 proportional counter, with a diameter of 5.08 cm and operating at 0.748 atm gas pressure, electrons can deposit up to 18.2×10^{-3} MeV in the gas. This value was calculated using the ESTAR database [2], which provides electron stopping powers in various materials. To lower the minimum detectable neutron energy in the SP2-1 detector, currently set at 50 keV, which corresponds to the threshold defined by ROSPEC in analog acquisition mode, two main improvements will be implemented:

1. Switching from the default analog acquisition mode employed by ROSPEC to a digital acquisition mode, allowing access to raw data and enabling more flexible signal processing.
2. Applying neutron-gamma discrimination techniques for energies below the maximum gamma pulse energy 18.2 keV.

II. METHOD

A. Discrimination by Pulse Rise Time

The ranges in hydrogen are much lower for protons than for electrons of the same energy, in other words tracks will be much shorter for protons than electrons (indeed, electrons typically cross the entire chamber). The primary electrons generated along these tracks do not significantly contribute to the signal until they reach the narrow multiplication region near the central anode wire, where they generate secondary ionisation. If the particle's track is short, the primary electrons reach the

anode in a brief time window, resulting in a short pulse rise time. Conversely, for longer tracks, the spread in arrival times is wider, leading to a longer rise time. As a result, neutron interactions produce pulses with short rise time (typically around one microsecond or less), while gamma interactions can lead to rise time as long as four microseconds.

B. Proposed Method for Neutron/Gamma Discrimination

To discriminate neutrons from gamma rays by pulse rise time, we will record each detected signal and calculate its rise time and amplitude. These parameters are then used to create a two-dimensional distribution, rise time as a function of amplitude. A clustering algorithm, specifically the DBSCAN (Density-Based Spatial Clustering of Applications with Noise) [3], will be applied to this distribution to separate neutron events from gamma ray events.

A numerical acquisition system is used by coupling the preamplifier of the SP2-1 counter with a CAEN digitizer DT5730 [4]. We used Wavedump [5] software that enables real-time signal monitoring and waveform recording.

The recorded signals pass through four steps of data processing:

1) Noise elimination

To detect low-energy signals (< 18.2 keV), we need to lower the detection threshold, which will consequently increase background signals. Therefore, the first step is to eliminate noise from the data. One solution is to use an AI-based method called Convolutional Neural Network (CNN) [6]. To be efficient, the algorithm must be trained with simulated signals (sigmoid functions for neutrons and photons, and mixture of different operations on normal distribution for background signals). The CNN method applied to the measured data has proven to be effective, as it provides reliable probability estimates. These estimates are essential for setting a discrimination threshold (X) to classify gamma and neutron signals separately from noise. Specifically, a signal classified as a neutron or gamma with a probability $\geq X\%$ is accepted as such, while signals below this threshold are considered noise. Fig.1 illustrates an example of CNN results obtained using the SP2-1 proportional counter irradiated with a mono-energetic neutron source of 42 keV.

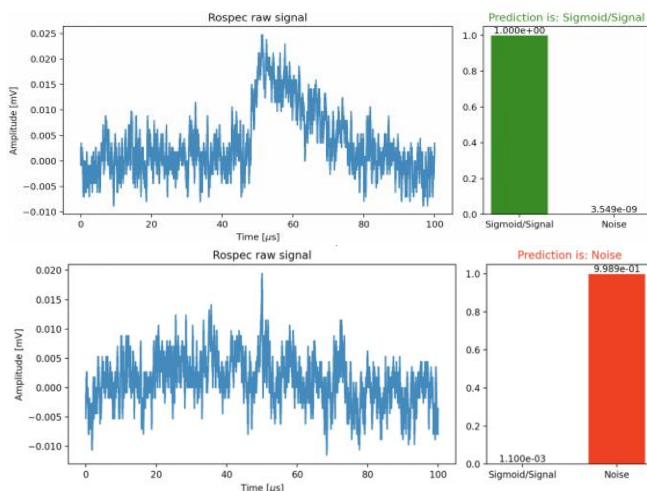


Fig.1. Discrimination between signal and noise by CNN method

2) Signal smoothing

Since the signals exhibit strong fluctuations due to noise caused by ROSPEC's electronics, and because we are detecting low-energy neutrons, these fluctuations become comparable to the signal amplitude. Therefore, it is necessary to smooth the signals to reduce these fluctuations and enable proper fitting. Fig. 2 shows an example of signal smoothing by applying a Savitzky-Golay filter.

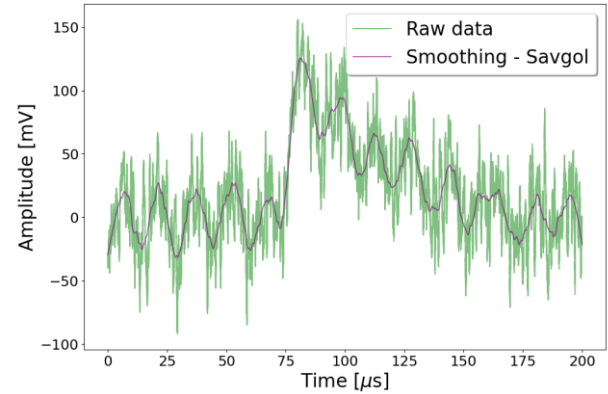


Fig. 2. Raw signal smoothing using Savitzky-Golay filter

3) Fitting the smoothed signal

The third step is to fit the smoothed signal. A typical output signal from the preamp associated to detection of a single event can be modeled by the mathematical expression:

$$f(t) = \begin{cases} b & \text{si } t > t_0 \\ A \left(e^{-\frac{t-t_0}{\tau_d}} - e^{-\frac{t-t_0}{\tau_r}} \right) + b & \text{si } t \leq t_0 \end{cases} \quad (1)$$

Where A is the amplitude related to energy deposited, t_0 is the pulse start time. τ_r and τ_d represent the rise and fall time, respectively. Fig. 3 shows the signal fitting using this model. This fit allows the extraction of pulse shape parameters such as amplitude and rise time, which will be used to generate the two-dimensional plot of rise time versus amplitude.

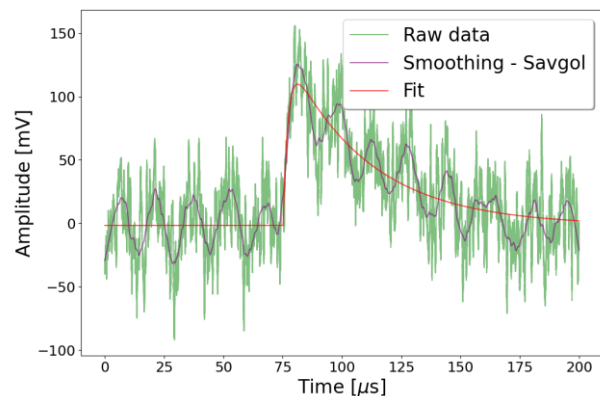


Fig. 3. Exponential fit of the smoothed signal

4) Applying DBSCAN method

The fourth step in the signal processing is applying the DBSCAN algorithm, implemented in Python, on the two-dimensional plot of rise time versus amplitude.

DBSCAN is a density-based clustering algorithm that groups together data points located in high-density regions, while labeling those in low-density areas as noise or outliers. It is particularly effective for detecting clusters of arbitrary shape without requiring the number of clusters in advance.

Consider a set of N data points $X \equiv \{x_n\}_{n=1}^N$. For each point x_n the algorithm defines its ϵ -neighborhood as follows:

$$N_\epsilon(x_n) = \{x \in X \mid d(x, x_n) < \epsilon\} \quad (2)$$

$N_\epsilon(x_n)$ are the data points that are at a distance smaller than ϵ from x_n . $d(\cdot, \cdot)$ is the Euclidean distance metric.

The algorithm is initialized with the distance metric $d(\cdot, \cdot)$, the neighborhood radius ϵ , and the minimum number of points minPts required to generate a cluster.

III. RESULTS

In this section, we present the measurements conducted to discriminate between neutrons and gamma rays using an AmBe neutron-gamma source and a Bi-207 gamma source. Although our objective is neutron/gamma discrimination with the ROSPEC SP2-1 proportional counter, we start by applying the method on the ROSPEC SP6 detector. This choice is justified by the fact that the AmBe source emits neutrons with a main energy around 4 MeV, which lies within the energy detection range of the SP6 counter.

Fig. 4 shows measurement when SP6 is irradiated by both AmBe and Bi-207 sources. In this figure we can distinguish two components which are low amplitude and high rise time for gammas, and high amplitude and low rise time for neutrons. In order to confirm that high rise time low amplitude events can be identified as gammas, another measurement has been done by using Bi-207 gamma source alone. The results are shown in Fig. 5, where blue dots belong to gammas from Bi-207 superimposed on the data taken previously when both AmBe and Bi-207 are present. The Bi-207 data occupy the same region of amplitude/rise time range as the high rise time locus in the previous measurement.

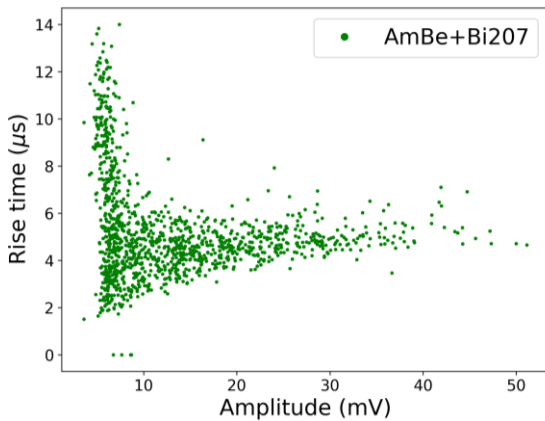


Fig. 4. Scatter plot showing the rise time and amplitude of pulses from SP6 exposed to both AmBe and Bi-207 sources.

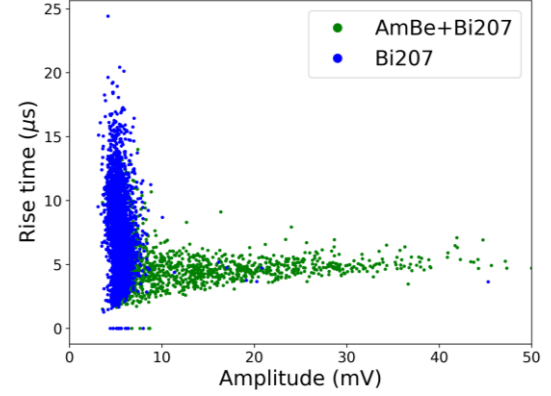


Fig. 5. Scatter plot showing the rise time and amplitude of pulses from SP6. The green dots correspond to data acquired with both AmBe and Bi-207 sources, while the blue dots represent a separate measurement with the Bi-207 source alone.

We applied the DBSCAN unsupervised machine learning clustering algorithm to distinguish between neutron and gamma clusters in the data shown in Fig. 4. The DBSCAN clustering result is presented in Fig. 6. All the points that are not part of a cluster (outliers) are labelled as noise. However, this method does not effectively identify gamma events in the region of low rise time and low amplitude. Nevertheless, when using the Bi-207 gamma source alone (Fig. 5), gamma events in this region could be clearly observed.

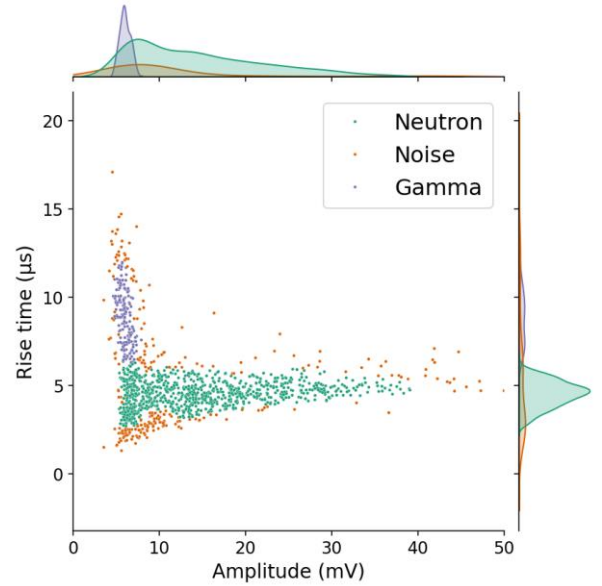


Fig. 6. DBSCAN clustering result.

IV. CONCLUSION

In this work, we proposed and implemented a method based on artificial intelligence to perform neutron/gamma discrimination in proportional counters, with the goal of extending the low-energy detection capabilities of the ROSPEC SP2-1 detector. By using digital acquisition, waveform processing, and a CNN-based method we were able to effectively separate noise from true signals and extract key pulse features such as rise time and amplitude. These parameters were then used in a clustering algorithm (DBSCAN)

to distinguish between neutron and gamma-ray events.

DBSCAN clustering showed limitations in identifying low-amplitude gamma events, the use of a gamma-only source validated their presence in the expected region. Therefore, in future work, we plan to use a supervised machine learning method by extending the CNN beyond noise classification to perform neutron/gamma discrimination.

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