PANDORA project - low-energy neutron detector with real-time neutron-gamma discrimination

L. Stuhl,[*1,2] M. Sasano,[*2] K. Yako,[*1] J. Yasuda,[*3] H. Baba,[*2] S. Ota,[*1] and T. Uesaka[*2]

Recent nuclear physics studies are increasingly focusing on the region far from the valley of stability, requiring an increase of the intensity of available exotic isotopes. This advancement opens up the possibility to investigate phenomena with low cross sections, such as charge-exchange reactions.

The (p, n) charge-exchange reaction at intermediate energies is a powerful tool to study the spin-isospin excitations of nuclei. The technique of inverse kinematics[1,2)] enables us to study the (p, n) reactions on exotic nuclei with high luminosity. In this technique, neutron detectors are used for measuring the time of flight (ToF) of low-energy (0.1–10 MeV) recoil neutrons. This method was successfully applied to study the Gamow–Teller strength distribution from ^{56}Ni[2,3)] and ^{132}Sn[4)] isotopes. In the latter experiment, the secondary beam intensity was 10^4 particles/s, the (p, n) reaction event rate was a few Hz, and the random gamma background produced an additional trigger rate of about 1 kHz.[4)] For future experiments with higher beam intensities, this background event rate will lead to higher trigger rates and a large dead time of data acquisition. To solve this problem, clear tagging of recoil neutrons in real time i necessary before recording the event data. Our work focuses on the development of the particle analyzer neutron detector of real-time acquisition (PANDORA). Our goals were

- in online data processing: to reduce the trigger rate by one order of magnitude by removing the random gamma background, leading to a smaller data size and the capability to handle high-intensity beams
- in offline analysis: to fully remove the gamma ray background using the pulse shape discrimination (PSD) parameter.

PANDORA consists of an EJ-299-34 plastic scintillator bar[5)] with dimensions of 2.5×5×30 cm^3 coupled to a Hamamatsu H7195 photomultiplier tube on each end. Detector signals from the anode output of both PMTs are read out with a digital data acquisition system (CAEN V1730 digitizer and digital pulse processing for pulse shape discrimination firmware). In order to measure the neutron kinetic energies using the ToF technique with an energy resolution of $\sim 5\%$ ΔE/E for neutron energies below 5 MeV, a ToF resolution better than 0.6 ns (FWHM) is required, while the angular resolution must be less then 1.5°.

The PSD parameter is defined as follows:

$$\mathrm{PSD} = \frac{Q_{Long} - Q_{Short}}{Q_{Long}}, \quad (1)$$

where Q_{Long} is the charge integrated in the long gate. Typically, it contains all charges in the signal. Q_{Short} is the charge integrated in the short gate. Defining PSD$_{mean}$ value as the arithmetic mean of PSD values of two single-end readouts, PANDORA exhibits PSD capability comparable to those presented in literature.

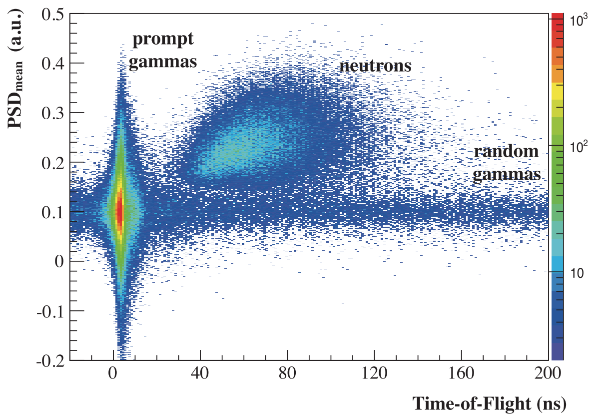

Fig. 1. PSD$_{mean}$ vs. ToF spectrum showing the separation of neutron- and gamma-like events. The sharp peak below 4 ns corresponds to prompt gamma rays, while the distribution in the higher ToF and PSD$_{mean}$ region corresponds to neutron-like events. A large random gamma background can also be observed.

The selection efficiency of neutrons or gammas can be defined as the ratio of the number of selected particles to the total number of detected particles. The ToF distributions acquired using a ^{252}Cf fission source proved that at a given PSD threshold (PSD$_{mean}$ = 0.15) and 10-keV$_{ee}$ detection threshold, the selection efficiency of PANDORA is 91±1% for all detected neutrons. It decreases to about 87±2% in the neutron kinetic energy region below 1 MeV. About 91±1% of the detected gamma-rays can be excluded resulting in background reduction by one order of magnitude.[6)]

*1 Center for Nuclear Study, University of Tokyo
*2 RIKEN Nishina Center
*3 Department of Physics, Kyushu University

References

1) G. Perdikakis et al. IEEE Trans. Nucl. Sci. **56**, 3 (2009).
2) M. Sasano et al., Phys. Rev. Lett. **107**, 202501 (2011).
3) M. Sasano et al., Phys. Rev. C **86**, 034324 (2012).
4) J. Yasuda, Study of Gamow-Teller transitions from ^{132}Sn via the (p,n) reaction in inverse kinematics, PhD thesis, Dept. of Physics, Kyushu University (2017).
5) N. Zaitseva et al., Nucl. Instr. Meth. A **668**, 88 (2012).
6) L. Stuhl et al., Nucl. Instr. Meth. A **866**, 164 (2017).