A MONTE CARLO SIMULATION OF THE EUROBALL NEUTRON WALL DETECTOR SYSTEM: HOW TO IDENTIFY SCATTERED NEUTRONS*

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A Monte Carlo simulation of the EUROBALL Neutron Wall has been performed using GEANT4 to study the problem of scattering of neutrons. It has proven possible to identify a large fraction of the scattered neutrons. This can be used to enhance the two neutron compared to the one neutron reaction channel in events where two neutrons have been detected by a factor as large as 35, to the cost of loosing 80% of intensity in the two neutron reaction channel. For events with three neutrons detected an enhancement of three neutron compared to two neutron reaction channels of 20 is possible to the cost of loosing 92% of the three neutron intensity. The results of the simulations have been compared to experimental data.

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1. Introduction

In experimental studies of the structure of neutron deficient nuclei far from the line of β stability, the identification of the nuclei produced in the heavy-ion fusion-evaporation reactions can be done by detecting the emitted particles. In such experiments a heavy ion fuses with a target nucleus to form a compound nucleus, which then emits particles to form a residual nucleus that finally emits γ radiation. The cross section for producing the neutron deficient nuclei is very small, due to the competition with charged particle evaporating channels. Therefore it is important to detect, with a high efficiency, the neutrons that are emitted when these nuclei are produced. One way of doing this is to use a large array of organic scintillator detectors such as the Neutron Wall [1, 2], an ancillary detector system used with the

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EUROBALL γ-ray spectrometer [3, 4]. To do γ-ray spectroscopy of nuclei lying close to the proton drip line it is also important to separate reaction channels with different numbers of emitted neutrons. This is complicated by the possibility that the neutrons can scatter between many detectors and give rise to a signal in a few of them. To better understand these multiple scattering processes in the Neutron Wall and, if possible, identify methods to improve the discrimination between channels with different number of neutrons emitted, the Neutron Wall detector array has been simulated using the Monte Carlo code GEANT4 [5].

2. Experiment and simulation

The Neutron Wall was simulated using a simplified geometry. The most important simplification was that the other detectors in the EUROBALL γ-ray spectrometer and the support structure were not included in the simulation. The Neutron Wall consists of 16 detectors, 15 pseudo hexagonal, subdivided into three detector segments, and one pentagonal detector, subdivided into five detector segments. The Neutron Wall covers $\sim 1\pi$ of the solid angle in the forward hemisphere of EUROBALL. It uses BC501A [6] as scintillator liquid and the thickness of the detector segments is 147 mm. This gives an intrinsic efficiency of about 50% at a neutron energy of 3 MeV. The Monte Carlo fusion-evaporation code evapOR was used to generate neutron emission spectra in the reaction ^{58}Ni (220 MeV) + ^{56}Fe (10 mg/cm^2) and neutrons sampled from such spectra were used as input to the GEANT4 simulation. In addition to the neutrons, one of the Neutron Wall detector segments were assumed to be hit by a γ ray that was mis-interpreted as a neutron every 200$^{\text{th}}$ event. For each simulated event the time of flight of the neutrons and the energy deposited in the Neutron Wall by the neutrons were stored.

The results of the simulation were compared to the experimental data obtained in a EUROBALL Neutron Wall experiment run with the same reaction.

3. Methods used to identify scattered neutrons

Two methods were used to identify scattered neutrons. The first method is based on the fact that scattering of one neutron between the detector segments are much more likely for detector segments which are close to each other. Therefore rejecting events in which two close lying detector segments fired, will increase the ratio of true two neutron events to events with one scattered neutron. This is usually called neighbor rejection. The second method uses the correlation of the distance and the time difference (Δ TOF). The distance is measured as the number of detector segments, $N_{\rm S}$, that are in between the firing segments. This is illustrated in figure 1. In this figure the problem of mis-interpreted γ rays is also seen. The two neutron events that are due to mis-interpreted γ rays have a time difference distribution that is much more similar to real two neutron events. These methods could also be generalized to three neutron events. This was however only tried using results from the simulations, because events with three neutrons could not be identified in the experiment.

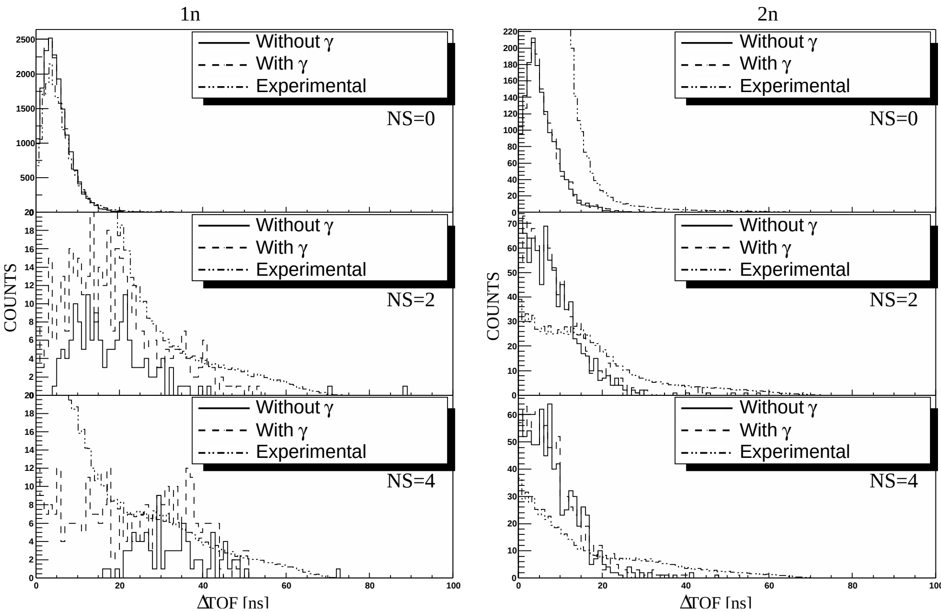

Fig. 1. The Δ TOF distribution for events with two neutrons detected as a function of the distance between firing detector segments measured as the number of detector segments (N_{S}) located between the firing detector segments for scattered single neutron (left) and two neutron (right) events. The experimental Δ TOF distribution is from a $2p2n$ particle gated data set.

4. Results and discussion

The enhancement ratio $R(x) = [I_{in,jn}(x)/I_{in,jn}] \,/\, [I_{kn,jn}(x)/I_{kn,jn}]$, is used to measure how accurately the scattered neutrons are identified. It is a double ratio between four experimental intensities, or in the case of the simulation, just the number of events that fit the correct criteria. The indices i and k tell how many neutrons were emitted in the reaction while the index j tells how many neutrons were detected. The x stands for any extra condition applied, such as a condition on the Δ TOF or on the distance N_{S} between the firing detectors. It is possible to enhance $2n$ reaction channels compared to $1n$ with a factor R of almost 35, with a reduction of the $2n$ intensity $\sim$ 85%. An enhancement factor for $3n$ reaction channels compared to $2n$

of about 20 is possible to achieve while loosing about 92% of the intensity. The results are summarized in Table I.

By comparing results from simulations including or excluding γ rays, it is clear that the mis-interpreted γ rays are responsible for a large deterioration in the correct identification of the number of neutrons that were emitted in a single reaction. It therefore seems that the shielding of the Neutron Wall against γ rays should have a high priority.

TABLE I

Enhancement of $2n$ and $3n$ events compared to scattered $1n$ and $2n$ events using neighbor rejection and $\Delta\,$TOF gates. Column 3–5 of the upper part of the table is the numerator of the ratio $R(x)$ for simulated data without γ rays included, simulated data with γ rays included, and experimental data, respectively. Column 6–8 is the ratio $R(N_{\mathrm{S}}, \Delta\,\mathrm{TOF})$ for the same three cases. The lower part shows the results for $3n$ events and contains no experimental data. The experimental results are from a $2p2n$ particle gated data set.

N_{S}	$\Delta\,$TOF Gate [ns]	$I_{2n,2n}(N_{\mathrm{S}}, \Delta\,\mathrm{TOF})/I_{2n,2n}$ [%]			$R(N_{\mathrm{S}}, \Delta\,\mathrm{TOF})$		
		Sim.	Sim. + γ	Exp.	Sim.	Sim. + γ	Exp.
≥1	>15	46	46	32.4(7)	56	14	5.2(9)
≥3	<10	35	35	21.0(5)	∞	23	34(3)
≥5	<15	16	16	8.7(1)	∞	22	36(5)
N_{S}	$\Delta\,$TOF Gate [ns]	$I_{3n,3n}(N_{\mathrm{S}}, \Delta\,\mathrm{TOF})/I_{3n,3n}$		$R(N_{\mathrm{S}}, \Delta\,\mathrm{TOF})$			
		No γ	γ	No γ		γ	
				$1n$	$2n$	$1n$	$2n$
≥2	<20	19	20	200	90	200	16
≥3	<20	8.2	7.7	∞	300	300	20

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