Comparison between experimental and calculation neutron spectra of the ^{197}Au(ɤ,n) reaction for 17 MeV polarized photon

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The double differential cross section (DDX) were obtained for the ^{197}Au(ɤ,sn) with 17 MeV polarized photons on a thin target was measured. The DDX were compared with the result of PHITS calculation. To reproduce relatively high energy neutron, a physics model should be implemented in addition to the evaporation model.

1. Introduction

Photo-neutron from photonuclear reaction has been studied [1, 2, 3]. In the previous study of our research group [1], the energy spectra of photo-neutrons, which were produced by the reaction of 17 MeV polarized photons on the Au target, were obtained at various angles. In this research, we observed the evaporation and direct components in the energy spectra. The angular distribution of the evaporation showed isotropic, while the direct component showed its dependence on the interaction angle between photon polarization and neutron emission [1].

These spectra are useful in the evaluation of the models and parameters of theoretical calculation. However, there is no comparison between experimental and calculation spectra. For comparison, the double differential cross section (DDX) is preferable than the neutron spectra from thick target because the self-attenuation effect can be avoided. In this study, we measured the DDX of the reaction of 17 MeV polarized photons on a thin Au target and compared the results with that of PHITS calculation.

2. Experiment

The experiment was performed at NewSUBARU-BL01, Hyogo-Japan[4][5]. Figure 1 indicates the schematic drawing of NewSUBARU-BL01. The 17 MeV linearly polarized photons were produced by the collision of the polarized laser and electron beam with the energy of 982.4 MeV. The beam current was 30 mA. A NdYVO4 laser system provided laser photons with a wavelength of 1.063 µm. The power was 20 W. The laser polarization direction was set to be parallel to the floor using $\lambda/4$ polarizer plate.

Figure 2 shows picture of experimental setup. Since the photo-neutron production per incident photon was considered, a plastic scintillator (thickness of 0.5 cm and surface area of 10 cm^2) was placed at 179.7 cm upstream from the target. The incident photon beam was collimated into the center of the target by using two collimators, C1 and C2. The Au target was prepared as a cylindrical pill whose

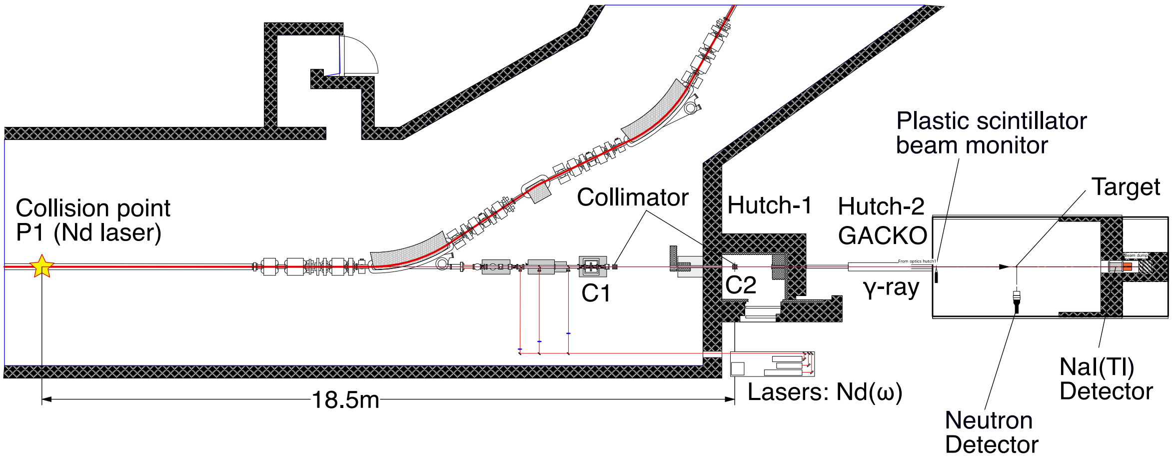

Figure 1. Schematic of NewSUBARU-BL01.

diameter and thickness were 1 cm. In order to detect the neutron emitted from the target, a cylindrical NE213 organic liquid scintillator ($12.7\ \mathrm{cm}^{\phi}\times 12.7\ \mathrm{cm}^{L}$) was set at 90 degrees (respected to the photon beam axis) and 59 cm distance from the target. The NE213 detector detected not only photo-neutrons from target but also gamma radiations. Thus, the pulse shape discrimination (PSD) method was realized to separate photo-neutron and gamma by obtaining the charge ratio of the whole and tail of the waveform. The energy of photo-neutron was measured by a time-of-flight (TOF) spectroscopy to build up an energy histogram. For PSD and TOF analysis, a Data Acquisition (DAQ) system based on VME standard was set up with QDC module to obtain the full charge and tail charge of signals from NE213, and, TDC to measure the time difference between the incident photon beam and NE213. The DAQ system also measured the charge of signals from the plastic scintillator.

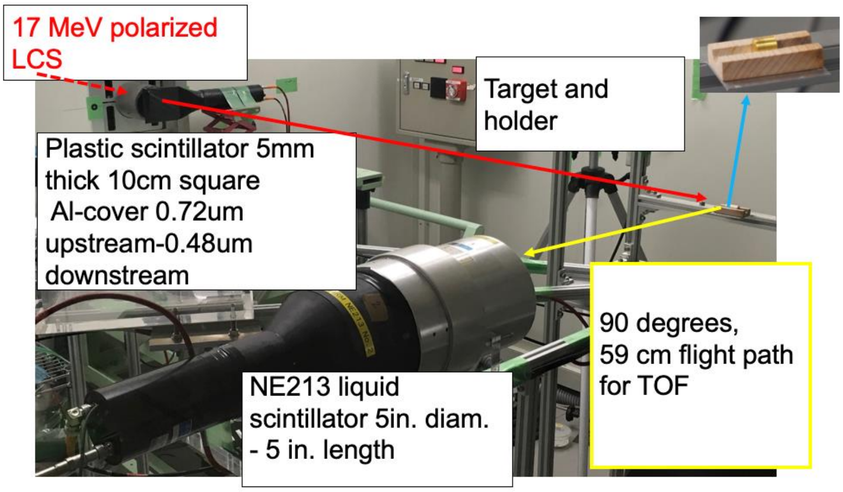

Figure 2 Picture of experimental setup

3. Data Analysis

We obtained the time of flight spectrum of neutron events by the PSD and TOF methods. The energy threshold employed for analysis was 0.25 MeVee. This threshold was determined by energy calibration using gamma radiations of ^{137}Cs, ^{22}Na, and ^{60}Co.

The time walk effect can significantly affect the TOF measurement as well as neutron energy. For time measurement, we used the constant-faction-discriminators (CFDs). Although the time walk effect was small when using CFDs, this effect was still essential in the energy measurement of photo-neutron. To minimize the time walk effect, the correction of TDC with the fitting function as the correlation of TDC and QDC was applied.

Figure 3 shows neutron gamma separation with total vs slow gates (left) and TOF vs the ratio of slow to total (right). We employ the later correlation, figure 2 right, for neutron and gamma separation.

The neutron energy histogram was obtained by converting the TOF histogram. The efficiency of the neutron detector was estimated by ^{252}Cf experiment and SCINFUL-QMD simulation [6] to evaluate the total number of neutrons emitted at 90 degrees from target. The energy spectrum was normalized by the solid angle, the number of incident photons and number of target atom. Photon attenuation in the target was taken into account using PHITS calculation. The double differential cross-section of the photo-neutron reaction was obtained by using the normalized data. In data analysis, the time resolution was 0.76 ns, and the energy resolution was less than 10%.

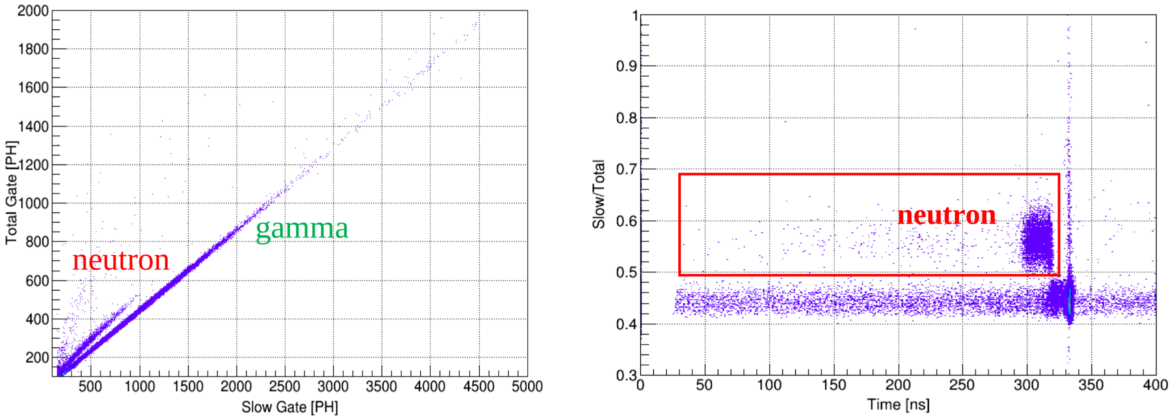

Figure 3. Neutron gamma separation with total vs slow gates (left) and TOF vs the ratio of slow to total (right).

PHITS (version 3.02) [7] was used to calculate the double differential cross section (DDX) of photo-neutron produced by the ^{197}Au(γ,sn) reaction for 17 MeV polarized photon. A cylinder Au target whose diameter and thickness were 5 μm was chosen to reduce the self-attenuation thickness effect of the target. The DDX was obtained on detector ring, whose width is 5 cm, placed at 90 degrees and 100 cm away from Au target.

Figure 4 shows a geometry of the DDX calculation in PHITS code. Neutron production from the nuclear reaction was calculated by Generalized Evaporation Model (GEM) model. Figure 5 indicates neutron flux distribution in PHITS calculation.

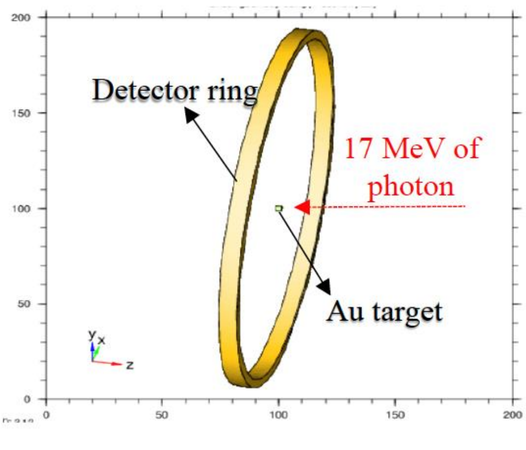

Figure 4 Geometry in PHITS

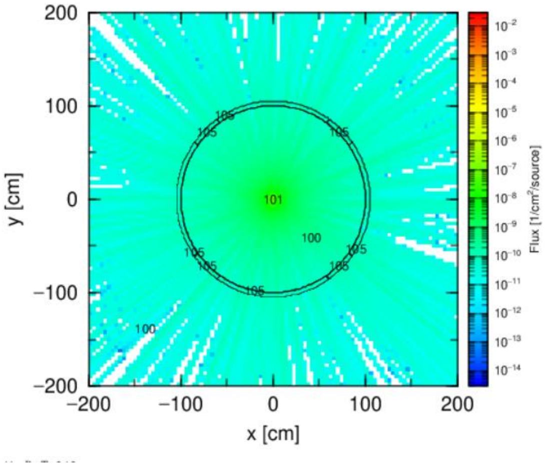

Figure 5 Neutron flux distribution

5. Result

Figure 6 shows DDXs obtained by experiment and PHITS calculation. In this figure, closed circles are the experimental data and the solid-line is the result of the calculation. The experimental spectrum shows two components evaporation and direct for energies of less and more than 4 MeV, respectively. In contrast, the calculation result shows only evaporation component, as expected. Thus, a model to reproduce the direct component should be included in the simulation for the photonuclear reaction. To develop the model, experimental data of DDXs are strongly desired for various target and energies.

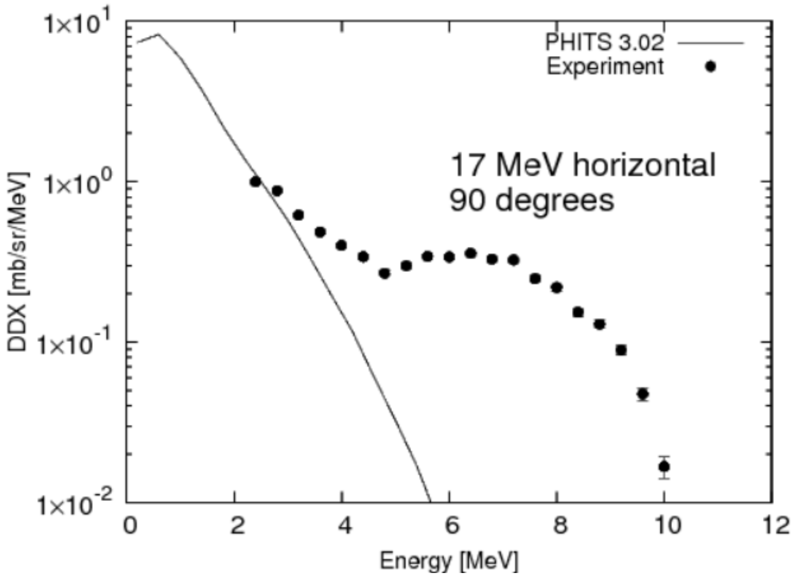

Figure 6. Experimental and calculation DDX

References

[1] Y.Kirihara, H.Nakashima, T.Sanami, Y.Namito, T.Itoga, S.Miyamoto, A.Takemoto, M.Yamaguchi and Y.Asano, Neutron emission spectrum from gold excited with 16.6 MeV linearly polarized mono energetic photons, Journal of Nuclear Science and Technology (Nov 2019), https://doi.org/10.1080/00223131.2019.1691073

[2] Horikawa K, Miyamoto S, Mochizuki T, et al. Neutron angular distribution in (γ, n) reactions with linearly polarized γ -ray beam generated by laser compton scattering. Phys Lett B. 2014;737:109–113.

[3] A.Agodi, Nuovo Cimento, 5, 21, (1) (1957)

[4] Y.Asano, S.Miyamoto. Shielding design of laser elec- tron photon beamlines at SPring-8. Prog Nucl Sci Tech. 2014;4:252–256.

[5] S.Miyamoto, Y.Asano, S.Amano, et al. Laser Compton back-scattering gamma-ray beamline on NewSUBARU. Radiat Meas. 2007;41:179–185.

[6] D.Satoh, S.Kunieda, Y.Iwamoto, et al. Development of SCINFUL-QMD code to calculate the neutron detec- tion efficiencies for liquid organic scintillator up to 3 GeV. Nucl Sci Tech. 2002;2:657–660.

[7] T.Sato, Y. Iwamoto, S. Hashimoto, T. Ogawa, T. Furuta, S. Abe, .T.Kai, P.Tsai, Norihiro Matsuda, Hiroshi Iwase, Nobuhiro Shigyo, Lembit Sihver and Koji Niita Features of Particle and Heavy Ion Transport code System (PHITS) version 3.02, J. Nucl. Sci. Technol., 2018, https://doi.org/10.1080/00223131.2017.1419890