読者の広場

新博士誕生

My Doctoral Research and Life Experience in Japan

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1. Accelerators: Risks and Usage

Accelerators are state-of-art machines leading the charged particles to relativistic speeds. Technology used in development of these accelerators is continuously upgraded, and they have been proved to provide benefits in fundamental research and applications for human life. On the other hand, beams in these accelerators can hit and irradiate the surrounding material via nuclear reactions. Products from irradiation processes are harmful for human tissues, so radiation shielding, and radiation control must always be considered to design and operate accelerators according to the knowledge of radioactivities induced by nuclear reactions and their secondary particle products.

For induced radioactivities, the construction material of the accelerators is irradiated via nuclear reactions and transform nuclides of the material to radioactive isotopes. For secondary particle production, various types of particles can be produced at different energies depending on the primary beam and the target material. Among secondary particles, neutrons are difficult to be shielded and produce extra exposure by activating other materials. To describe the phenomena properly in radiation control, we need enough basic data, hence, many researches have been carried out including experiments and theory calculations.

2. Photoneutron production in accelerators

The electron accelerators with energies higher than tens of MeV can produce high energy photons known as bremsstrahlung radiations due to electron beam dump. Through photonuclear reactions, those photons induce production of (photo)neutrons. In order to estimate the induced activity of these neutrons and perform shielding design, energy and angular distributions of neutrons are important. Monte Carlo simulation, evaluated nuclear data, and nuclear reaction models can be used to estimate the activity and shielding calculation. However, there is lack of experimental data on photoneutron production to validate these calculation tools.

In 1950s, there were many experiments set up to measure the cross section, energy, and angular distributions of photoneutrons [1-10]. Those experiments used bremsstrahlung and quasi-monoenergetic photon sources, which came with many disadvantages such as a huge background, continuous spectrum, and low intensity. In recent years, with the laser Compton scattering technology, one can study photoneutron production using a monoenergetic and linearly polarized photon beam. Recently, a research group at High Energy Accelerator Research Organization (KEK) has conducted a series of measurement of photoneutron productions using the laser Compton scattering photon source at NewSUBARU, Japan [10]. According to their study, polarization of photons causes anisotropic photoneutron emission, which is not accounted in current nuclear models when producing photoneutrons.

3. Experiment at NewSUBARU

The information on the energy and angular distributions of (γ, xn) reactions are extremely essential in shielding calculation and accelerator design. Additionally, the experimental data are an important resource to check the accuracy of Monte Carlo simulation tools, evaluated nuclear data, and nuclear reaction models. In this experiment, I measured the double differential cross section (DDX) of (γ, xn) reactions on different targets using linearly polarized monoenergetic photon beam at 14, 17, and 20 MeV [13]. Here, I only report the results at 17 MeV. For results of 14 and 20 MeV, one can read the reference [13]. The photon is generated at the BL-01, NewSUBARU, using the laser Comtpon scattering (LCS) technology.

Figure 1 shows the overview of the BL-01 at NewSUBARU. The electrons with 982.4 MeV energy are circulated in a storage ring, which is operated in the single bunch mode. A $NdYVO_4$ laser system generates photons with wavelength of 1.064 mm at 20 W. The laser photons are guided to the storage ring, collide with the electron bunches, and are backscattered as high-energy photons. These photons are collimated to Hutch 2, where I set up the target and neutron detectors to detect photoneutrons.

Figure 2 is the experimental setup in Hutch 2. On the upstream, a plastic scintillator is placed to monitor the photon beam. Most of the LCS photons penentrate through the plastic scintillator, are incident on the target, and induce photonuclear reactions. Neutrons produced at the target are detected by 6 neutron detectors surrounding the target. The neutron detectors are cylindrical with both diameter and length of 12.7 cm, filled with organic liquid scintillator NE213 (Nuclear Enterprises, Ltd., UK, or equivalent). They are placed horizontally at 30°, 60°, 90°, 120°, 150°, and vertically at 90°.

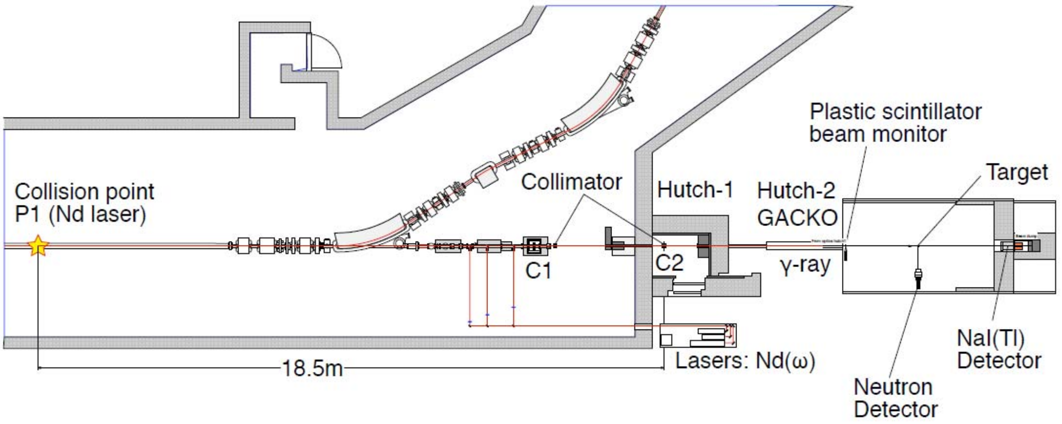

Fig. 1 Overview of laser Compton scattering set up at BL-01 NewSUBARU facility

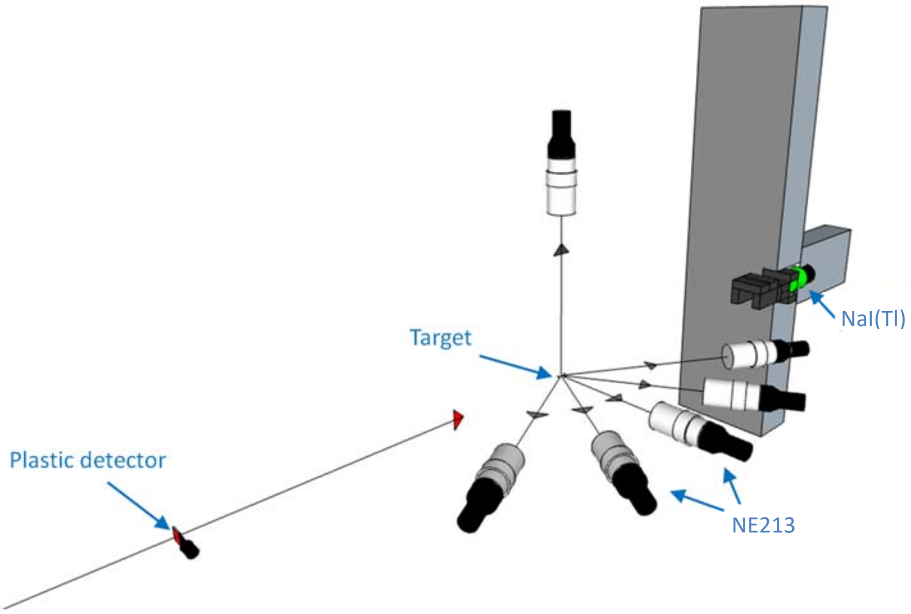

Fig. 2 Experimental setup to detect photoneutrons

On the downstream, a NaI(Tl) detector is placed and functioned as a beam absorber as well as beam intensity monitor. I respectively investigated the DDX of photoneutrons produced from different targets, including ^{nat}Pb, Au, ^{nat}Sn, ^{nat}Cu, ^{nat}Fe, and ^{nat}Ti. The target shape is cylindrical, diameter of 1 cm and thickness of 1-4 cm.

The data taking time is about 1-2 hours for every target, depending on the statistics. The g-rays are the background in this measurement, and we need to carry out pulse shape discrimination (PSD) measurement to distinguish neutrons and gammas. The energy of each neutron is measured using the time-of-flight (TOF) method. A Versa Module Europa (VME) data acquisition (DAQ) system is set up for collecting events from NE213 and plastic scintillator detectors. It includes charge-to-digital converter (QDC) and time-to-digital converter (TDC) modules for PSD and TOF purposes. The collected data are analyzed event-by-event using C++ and ROOT.

To distinguish between neutron and g-ray, for every signal, I calculated the ratio of the tail charge to the total charge, which are measured by the QDC modules. Figure 3 shows the charge ratio as a function of time-of-flight measured by the TDC. The gamma background events are clearly discriminated from the neutrons. By selecting proper ranges of charge ratio and TDC, neutrons can be selected.

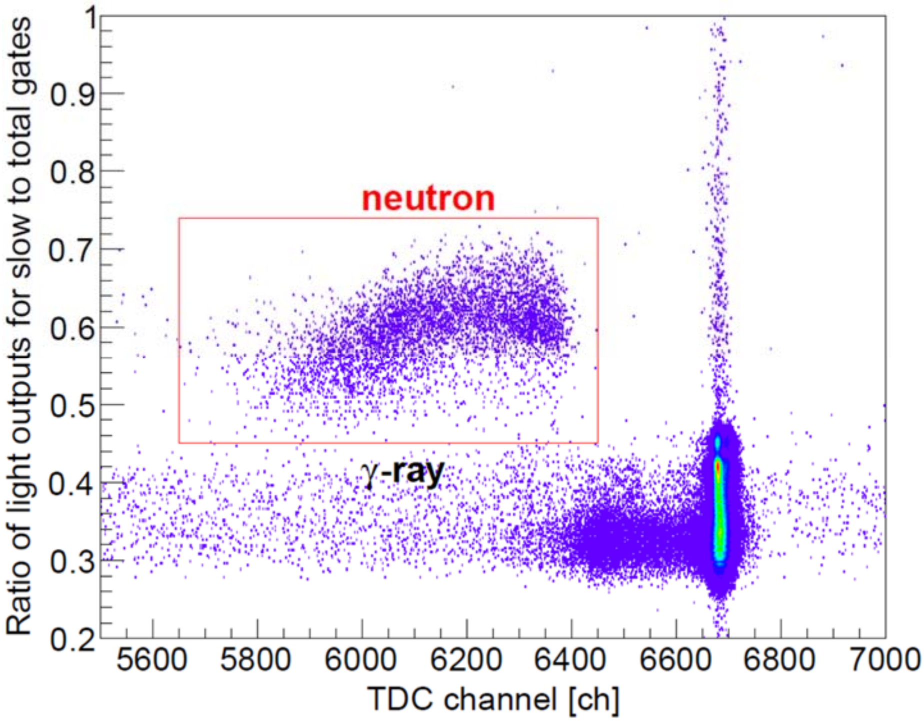

Fig. 3 Neutron-gamma seperation

In Figure 4, the TOF distributions of neutrons, γ-rays and both events are plotted in red, black, and blue, respectively. The resolution of the TOF system can be determined by the full-width at half-maximum of the prompt-gamma peak, which is 0.95 ns. The small peak at 6450 TDC channel in the γ-ray TOF distribution indicates photons back-scattered on the NaI(Tl) detector. With the TOF and the flight path distance from the center of target to each neutron detector, it is possible to calculate the energy of neutrons observed in NE213 detectors. In this experiment, the traveling time difference between photon and neutron ($\Delta t_{n-\gamma}$) is measured. Because neutrons arrive the NE213 detectors after photons, the TOF of neutron is calculated as a sum of TOF of photon and the traveling time difference: $TOF_n = TOF_\gamma + \Delta t_{n-\gamma}$.

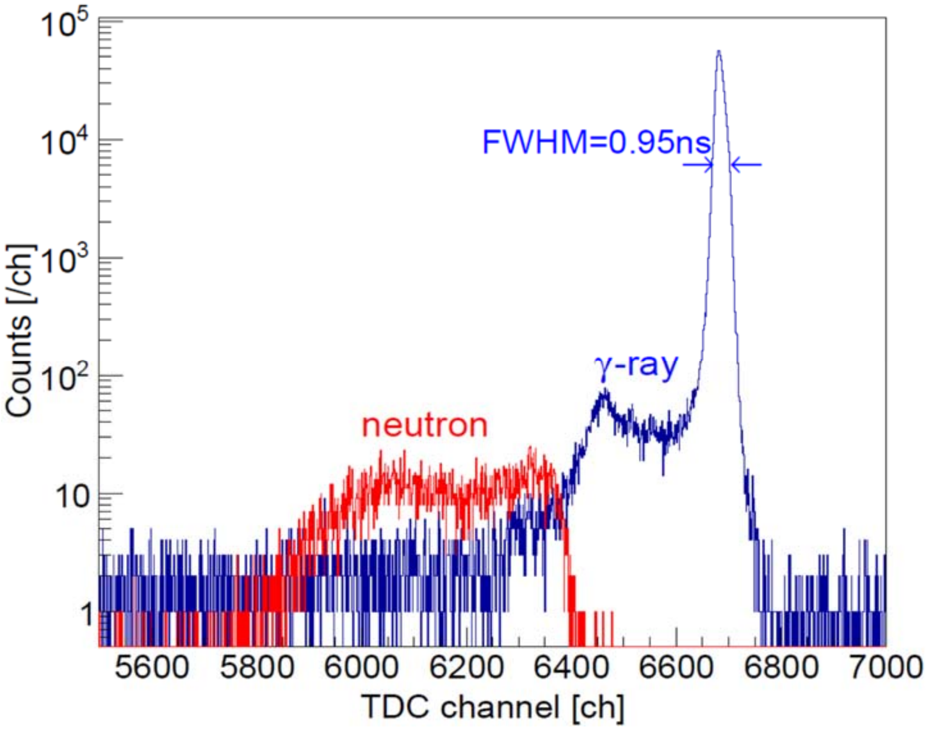

Fig. 4 Time-of-flight spectra of gamma (black), neutron (red) and sum of them (blue)

4. Results and discussion

For every target, the neutron TOF distributions obtained in every NE213 detector are normalized with solid angle, number of photons, the attenuation factors of photon and neutron in the target. Figure 5 shows the experimental results of the DDXs of the (γ, xn) reactions of 17 MeV linearly polarized photons on six targets, and the DDXs are measured at six different laboratory angles. The data points of DDXs are all above 2 MeV, which is about the energy threshold. The energy resolution of neutron detectors from 2 MeV to 8

MeV is ranging from 0.1 MeV to 0.6 MeV, which is equivalent to 5% to 7.5%.

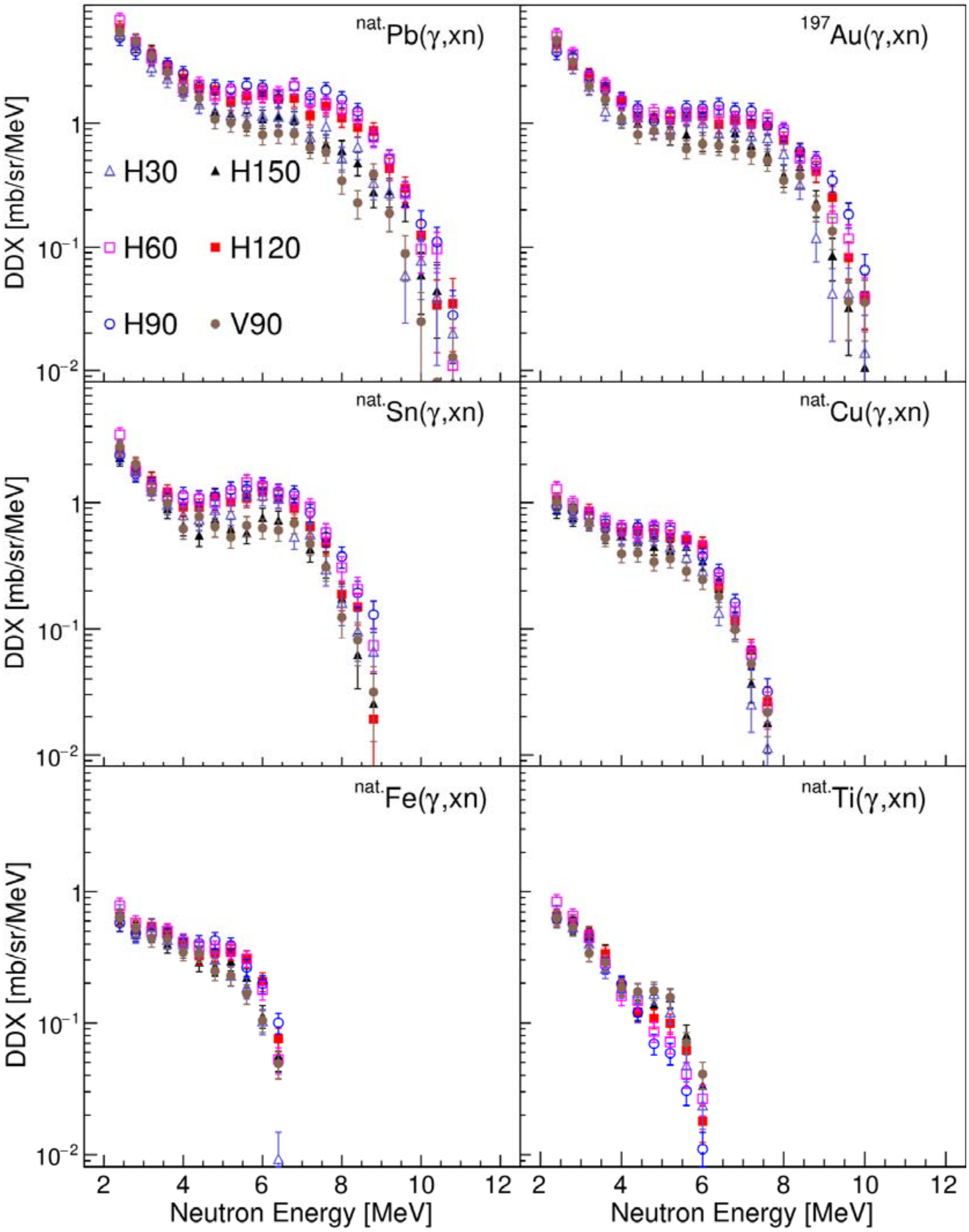

Fig. 5 Experimental results of DDXs of (γ, xn) reactions at six detector positions using 17 MeV linearly-polarlized photons on different targets

From the distributions of the DDX, there are two components: the low-energy component occupying from 2 MeV to around 4 MeV with the shape like the tail of Maxwellian distribution; and the high-energy component occurs in the energy range above 4 MeV. The high-energy component is also known as a direct and pre-equilibrium component [10]. The energy distribution obtained from Au(γ, xn) is consistent with the one reported in previous study [10]. The yield of high-energy component decreases with the smaller target mass number. For Pb, Au, Sn, Cu, and Fe targets, the maximum and minimum DDX values can be found at horizontal 90° and vertical 90°. However, for the Ti target, the minimum and maximum values are observed at horizontal 90° and vertical 90°. For more details on the study, one can check references [13] and [14].

5. Japan: a wonderland for living and research

According to the report in 2017, Japan had 1711 accelerators, 75.6% of them were linear accelerators, and most of linear accelerators were used in hospitals [11]. In my home country Vietnam, the number of cancers is increasing. Therefore, the number of linear accelerators used for radiation therapy is also increasing, such as 3 times increment from 2006 to 2013 [12]. In future, our government plans to invest more accelerators for radiation therapy. The information indicates the need of understanding nuclear models to reproduce photoneutron. To be prepared for the future of radiation therapy in my country, I want to study the phenomenon of photoneutron production, and experimental research is a crucial step for this purpose.

Before my Doctor course, I had two chances coming to Japan to attend short-term schools in Osaka University in 2016 (SAKURA program) and KEK in 2017 (ATHENA program). Since that time, Japan, in my eyes, has been a beautiful country, a perfect mixture of modern technology and amazing nature. On top of that, the two schools were fantastic, where I can find a lot of interests in scintillation detectors, data acquisition system, and pulse shape analysis. After the ATHENA program, Professor Sanami agreed to be my supervisor for my Doctor course.

In 2018, I left my home institution in Vietnam to come to KEK as a Doctoral student at Sokendai University. Under the supervision of Professor Toshiya Sanami and Professor Hirohito Yamazaki, I joined in the research project studying the photoneutron production with monoenergetic and linearly polarized photon source set up at BL-01, NewSUBARU, Hyogo, Japan. I inherited the knowledge and the techniques from the group, and expanded the investigation from medium to heavy target mass.

To me, coming to Japan is not only a great opportunity for doing research but also a good decision to enjoy the environment, beautiful nature, and unique culture. When I came to Japan, staff at Sokendai and KEK helped me to rent my first apartment in Tsukuba city, and to prepare documents to be a resident in Japan. For a person who lives far from home country and family, it means a lot to me. KEK lent me a bicycle, helping me enjoy a daily ride from my apartment to the KEK's Tsukuba campus. Before coming to KEK, I had practiced vegetarian for 3 years. After a hard-working day in the laboratory, I really enjoy cooking some delicious dishes using a large variety of fresh vegetables of Ibaraki prefecture. Indian and Chinese restaurants with vegetarian options are also perfect choices to hang out with friends. It must be a pity if we do not spend time for exploring the nature in Japan. I took many opportunities to visit different places in Japan, including Amanohashidate, Kyoto, Osaka, Nara, Toyama, and Hyogo after a business trip, a conference, or a trip to Spring-8 where I carried out my experiment.

For this new year, I visited pagodas in Nara and had amazing time there with all sightseeing and the vegan food (Figure 6). The New Year ceremony in the pagodas in Japan is similar to the ceremony in Viet Nam.

Fig. 6 New Year celebration for a vegetarian

6. Summary

I have experienced a great lifetime in Tsukuba city, Ibaraki prefecture, Japan, and studied an exciting experiment together with great physicists at the High Energy Accelerator Research Organization. For me, it was a life-changing experience, and Japan is obviously a great place for any young scientists starting their academic study and learning from the best people. It is also an opportunity to share your research with other researchers in Japan and all over the world. Thanks to the Atomic Energy Society of Japan (AESJ), I had a chance to share my study with other scientists.

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