The measurement of $^4\text{He}$ photodisintegration with MAIKo active target

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Abstract. The photodisintegration reactions of $^4\text{He}$ nuclei, i.e., $^4\text{He} (\gamma, pt)$ and $^4\text{He} (\gamma, ^3\text{He})n$, play crucial roles for the nucleosynthesis in the universe, but the result of previous experimental studies show sizable discrepancies. We performed the measurement of these reactions with the TPC-based MAIKo active target. The MAIKo active target enable us to detect, the sensitivity for the low energy decay particles emitted to full solid angle. The measurement were carried out at the New SUBARU synchrotron radiation facility, and the quasi-monochromatic pulsed photon beam were irradiated on MAIKo. The data analysis has been partially done. The number of true events were counted by tracking of recorded images, and the total flux of photon beams was determined by the analysis of the spectrum recorded by the NaI beam monitor.

1. Introduction

$^4\text{He}$ is the self-conjugate nucleus with doubly closed-shell structure and it plays crucial role not only in cluster phenomena, but also nucleosynthesis in the universe. It is pointed out that the cross sections of the $^4\text{He}$ photodisintegration reactions: $^4\text{He} (\gamma, pt)$ and $^4\text{He} (\gamma, ^3\text{He})n$ are important to clarify the scenarios of nucleosynthesis.

Firstly, the corsc section of this reaction is important from a view of nucleosynthesis driven by neutrinos in a supernova[1]. Two neutral current reactions $^4\text{He} (\nu, \nu'/p)^3\text{H}$ and $^4\text{He} (\nu, \nu'/n)^3\text{He}$ are the startig point of the neutrino driven process. Although it is difficult to measure these reactions directly, they are analogically understood by the photodisintegration reaction.

Secondly, this reaction may give us an insight into the big bang nucleosynthesis[2]. In order to solve a problem in which the promodial abundance of $^6\text{Li}$ is significantly underestimated by the standard big bang nucleosynthesis (BBN) theory, the possibility of the unconsidered cotribution from heavy relic particles produced before BBN era is pointed out. In this scenario, the radiative decay of relic particles plays a role of extra photon source, and these photons induce the photodisintegration reaction of $^4\text{He}$ to produce the seeds of $^6\text{Li}$. The validity of this scenario depends on the cross section of the $^4\text{He}$ photodisintegration.

The $^4\text{He}$ photodisintegration has long been caught a greate deal of attention and intensively studied by various researchers[3, 4], but the measured values of its cross sections have not been settled at the relaible values, yet. For both the $^4\text{He} (\gamma, pt)$ and $^4 (\gamma, ^3\text{He})n$ reactions, almost all the data show agreement in the higher energy region but discrepancy in the lower energy domain.
between the decay threshold at $E_\gamma \sim 20$ MeV and the giant dipole resonance (GDR) peak region around $E_\gamma \sim 26$ MeV. Especially, the data reported by T.Shima et al. shows the remarkably different trend\cite{5}, which suggests the peak of GDR is located at energies higher than 30 MeV. This astonishing result are obtained from the measurement with time projection chamber. It is necessary to verify this result by the same approach with more improved detector system.

In the present study, we measured the cross section of $^4$He photodisintegration in the energy regions between $E_\gamma = 22.3-33.3$ MeV. We used the quasi-monochromatic photon beam generated by laser Compton scattering technic and $4\pi$ acceptance gas based tracking detector, MAIKo active target.

2. Experimental Setup

The measurement was performed with the MAIKo active target shown in Fig.1\cite{6}. MAIKo has a great advantage for the decay particle measurement near the threshold. Basically, the operation principle of MAIKo is the same way as time projection chamber. The signals induced by the drift electrons were read out via the strip shaped electrodes on $\mu$-PIC\cite{7}. The detection gas filled in MAIKo consists of 98 % natural He and 2 % CF$_4$ with a total pressure 2 atm. Since the detection gas also plays a role of target of photon induced reactions simultaneously, all the photodisintegration reactions were occurred inside the sensitive region. MAIKo, therefore enable us to measure low energy charged particles over full-solid angle.

The experiment was carryied out at the synchrotron radiation facility New SUBARU \cite{8}. MAIKo was installed at the beam line 01 in this facility as shown in Fig.2. This beam line is designed for the experiment with the laser-Compton-scattering (LCS) photons\cite{9}. A LCS photon was produced by the head-on collision of linearly polarized Nd:YVO$_4$ laser in the 1st and 2nd harmonics ($\lambda = 1064,532$ nm) and a relativistic electrons ($E_e = 792 - 1147$ MeV) orbiting inside the storage ring. The lead collimator limits the scattering angle of photons, and only photons scattered to the very backword angle are transported to the MAIKo active target. The photon energy beam can be changed simply by changing the energy of laser and electrons, and the quasi-monochromaticity of beams are ensured by the collimation of scattering angle. For the beam flux determination, a NaI scintillation detector was installed at the downstream of MAIKo, and the photons passing through the MAIKo were measured.

3. Data Analysis

All the events recorded by MAIKo were classified by the shape of particle trajectories, and the number of $^4$He photodisintegration events was counted. A typical image of the $^4$He($\gamma,p\ell t$) event were shown in Fig.3. The background events caused by the photodisintegration of heavy nuclei (C,F) and a Compton scattered high energy electron were also observed. In order to eliminate background events, firstly, all these events were classified in accordance with the number of linear trajectories, and electron events which normaly consists of zigzag and thin...
trajectories were excluded. The qualities of classification procedure were assured event by event. Secondly, linear trajectories were fit by linear functions, and three dimensional trajectories were reconstructed. Finally, $^4\text{He}$ events were selected by the cut conditions required by kinematics. Thus the background-free event set were obtained.

Total flux of beam photons during the measurement was monitored with the NaI scintillation detector. A typical spectrum of the NaI detector is shown in Fig.4. Since the response time of the NaI scintillator is much shorter than the time interval between beam bunches but much longer than time spread of the beam bunch, photons in each bunch are observed as a pile-up event. Therefore, the pulse height of the NaI detector is discretized by the the number of photons in each beam bunch as seen in Fig.4. A response function of the NaI detector for one photon was measured with a low intensity photon beam, and response functions for multi photons were obtained by convoluting the single-photon response function. The average number of photons was determined by fitting the pulse height spectrum in Fig.4 with these response functions. Finally total photon flux was determined by the product of the measurement time, laser frequency, and average multiplicity.

The photodisintegration cross section are obtained from the number of events, total beam flux, and target thickness. The result at seven beam energies will be reported soon else where.

4. Summary

We carried out the measurement of $^4\text{He}$ photodistintegration: $^4\text{He}(\gamma,p\pi)$, $^4\text{He}(\gamma,^3\text{He})n$ cross section at seven energies between $E_{\gamma} = 22.3 - 33.3$ MeV. The measurement was performed with the LCS photon beams and MAIKo active target. The result will be reported soon else where.

References

[1] Suzuki T and Kajino T 2013 J. Phys. G: Nucl. Part. Phys. 40 083101
[2] Kusakabe M, Kajino T, Yoshida T, Shima T, Nagai Y and Kii T 2009 Phys. Rev. D 79 123513
[3] Raut R, Tornow W, Ahmed M W, Crowell A S, Kelley J H, Rusev G, Stave S C and Tonchev A P 2012 Phys. Rev. Lett. 108 042502
[4] Tornow W, Kelley J H, Raut R, Rusev G, Tonchev A P, Ahmed M W, Crowell A S and Stave S C 2012 Phys. Rev. C 85 061001
[5] Shima T, Naito S, Nagai Y, Baba T, Tamura K, Takahashi T, Kii T, Ohgaki H and Toyokawa H 2005 Phys. Rev. C 72 044004
[6] Furuno T et al. 2014 3rd Int. Workshop on "State of the Art in Nuclear Cluster Physics" (Yokohama: Kanto Gakuin University) 012042
[7] Ochi A, Nagayoshi T, Koishi S, Tanimori T, Nagae T and Nakamura M 2001 Nucl. Inst. Math. Phys. Res. A 478 196
[8] Ando A, Amano S, Hashimoto S, Kinosita H, Miyamoto S, Mochizuki T, Niibe M, Shoji Y, Terasawa M, Watanabe T and Kumagai N 1998 J. Synchrotron Radiation 5 342
[9] Miyamoto S, Asano Y, Amano S, Li D, Imasaki K, Kinugasa H, Shoji Y, Takagi T and Mochizuki T 2006 Radiation Measurements 41 S179