Energy calibration of tagged photons by the d(γ,π^-pp) reaction*

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Abstract The energy of tagged photons, which were provided from the internal photon tagging system of the Laboratory of Nuclear Science, Tohoku University, has been calibrated using the d(γ,π^-pp) reaction. Charged pions and protons in the final state were detected with the Neutral Kaon Spectrometer (NKS2). Photon energies were obtained from the reaction of d(γ,π^-pp). The derived photon energy was consistent with the design of the tagger system and the previous measurement using electron-positron pair production. The consistency demonstrates the performance of NKS2 and the capability of the photon energy calibration using d(γ,π^-pp).

Key words deuteron, pion photoproduction, tagged photon

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1 Introduction

The Neutral Kaon Spectrometer was developed for the study of photoproduction. The primary purpose is the neutral kaon photoproduction near the threshold [1–3], which is expected to greatly help to clarify the strangeness production process. The secondary goal is $\pi^+\pi^-$ photoproduction on nucleons and nuclei [4–8], which is an important tool to explore nuclear structure. A liquid deuterium target was used for the emphases on neutron study, to complement the proton case.

A deuteron is a loosely bound system of a proton and a neutron, and is a practical neutron target. Single pion productions on deuterons are accompanied by the kaon and $\pi^+\pi^-$ photoproduction process. The photoproduction channel on deuteron d(γ,π^-pp) is unique among single pion productions. Firstly, its three charged particles in the final states can be measured completely by NKS2, and can be distinguished from the background because of the two proton final states. Secondly, kinematically complete measurement of the d(γ,π^-pp) can be accomplished, which enables precise calibration of the energy of the incoming photons. This paper reports a new method of tagged photon energy calibration using a kinematically complete measurement of d(γ,π^-pp).

2 Experimental setup

The experiment was carried out at the Laboratory of Nuclear Science, Tohoku University. The electron beam from the linear accelerator was injected into the Stretcher-Booster ring and accelerated up to 1.2 GeV.

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Bremsstrahlung photons were produced by the internal radiator and tagged by the scintillation counters [9]. The designed energy of the tagged photons is

$$E_\gamma = 1.1030 - 0.0060 \times n, \tag{1}$$

and the measurement using electron-positron pair production [10] gives

$$E_\gamma = 1.1053 - 0.0061 \times n, \tag{2}$$

where n is the segment number of the tagger counters, and E_γ is in units of GeV.

The energy acceptance of each counter was designed as 6 MeV and the measurement shown in formula (2) has a systematic error of 10 MeV. See Ref. [9] for detaild information on the tagging system. The typical tagging rate was 1.5 MHz.

As shown in Fig. 1, NKS2 consists of a dipole magnet, two kinds of drift chambers, an inner hodoscope (IH), an outer hodoscope (OH), and electron veto counters (EV). The dipole magnet has a pole-gap of 680 mm in height and 1600 mm in diameter, which provides a magnetic flux intensity of 0.42 T in its center. IH and OH were employed to give trigger signals to the online data acquisition system and to measure the Time-Of-Fight (TOF) with a resolution about 0.4 ns (rms). A straw drift chamber (SDC) and a cylindrical drift chamber (CDC) were located outside of IH for charged particle tracking. They covered an angular range from −165° to 165° with respect to the beam line. A pre-mixed gas of 50% argon and 50% ethane was supplied to the drift chambers. The spatial resolution was 250 μm for SDC and 350 μm for CDC. The EV was employed to reduce the background produced by electrons and positrons coming from the upstream region. The trigger required more than two hits on IH, more than two hits on OH, a signal in the photon tagging system, and no hit on EV.

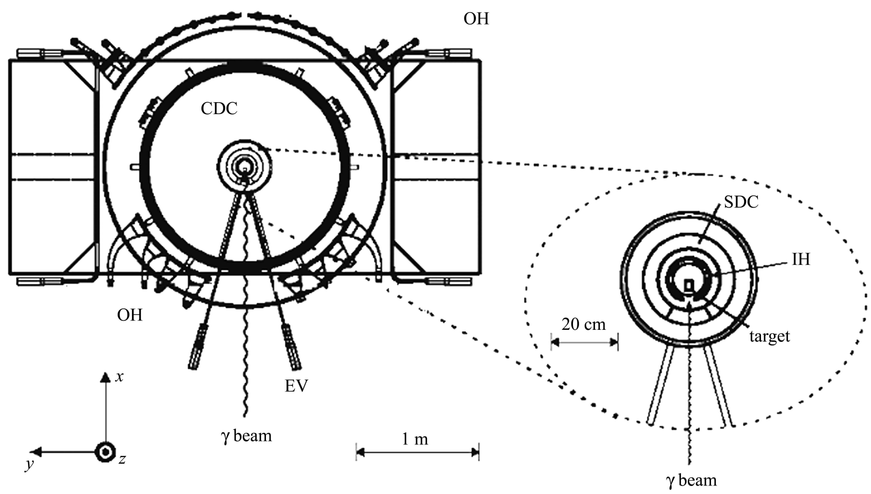

Fig. 1. Schematic drawing of NKS2. See details in the text.

Liquid deuterium was used as a target. The size of the aluminum target container was 30 mm in length, with a diameter of 50 mm. The target container was placed inside a vacuum chamber surrounded by super insulation. The entrance and exit windows of the target container and the vacuum chamber for the photon beam were covered by Upilex-S (UBE Industries, Tokyo, Japan). The target was located 0.5 cm upstream along the photon beam direction from the center of NKS2. The temperature was approximately kept at 19.1 K. The effective target thickness was 544 mg/cm^2.

3 Analysis and results

The tracks of charged particles were reconstructed by SDC+CDC analysis. The momentum of a charged particle was obtained from the curvature of its trajectory in the magnetic field. The velocity was given from the time difference between the IH and the OH signals and the length of the flight path. Then the masses of the charged particles were computed.

The effect of the materials in NKS2 was estimated with a Monte-Carlo simulation. The created particles were tracked through the NKS2 detector based on GEANT4, considering particle decay, energy losses, and multiple scattering from the detector components. The pions and protons were generated randomly from the target region located at the central part of NKS2, then passed through the target, the target container, IH, SDC, CDC, and OH in time sequence. The simulated responses of the detectors were recorded and analyzed in the same manner as for the experimental data. According to the simulation we can make a correction for the material effect, and obtain the momentum of protons and pions just after they were generated in the deuterium target. Correction of the effects of detector materials is essential for low energy protons, and makes the reaction kinematics better, as shown in Fig. 2.

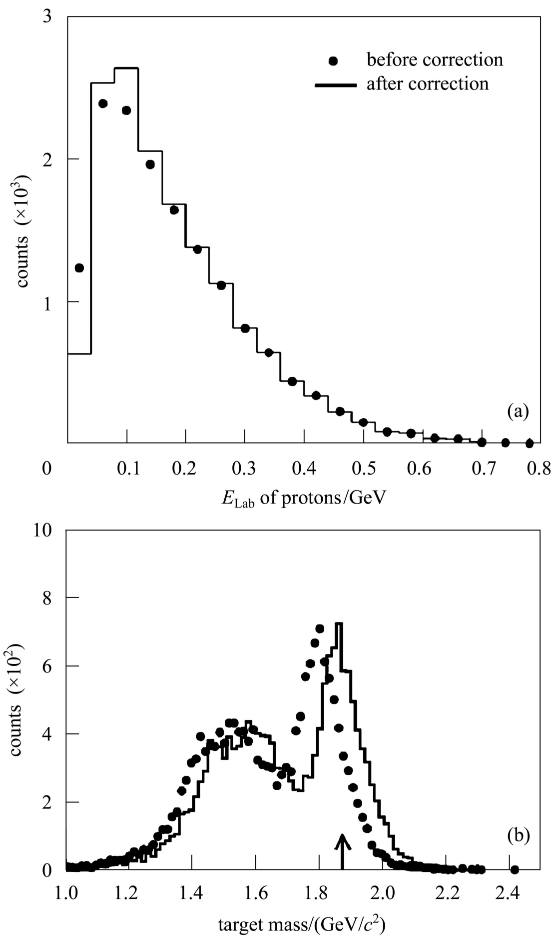

Fig. 2. Kinematical energy spectrum of protons (a) and reconstructed $\gamma X\rightarrow\pi^-pp$ target mass (b) before and after correction for the material effect. In the right figure, there are two peaks, the wider and lower one was mainly contributed by multi-pion productions, and the narrower and higher one denotes the reaction of d(γ,π^-pp); the designed tagged photon energy was used for the target mass reconstruction, and the arrow indicates a deuteron mass.

The events of d(γ,π^-pp) were selected by cutting the target and reaction kinematics. For the reaction kinematics, we select the 'target' mass of $\gamma X\rightarrow\pi^-pp$ to be a deuteron mass, namely 1.75–2.2 GeV/c^2, shown in Fig. 2.

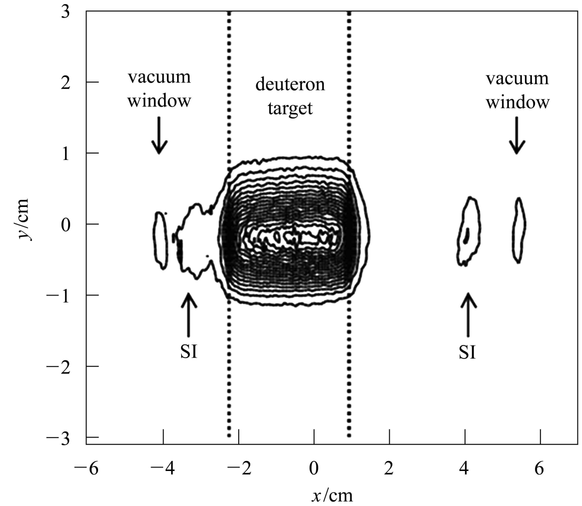

Fig. 3. Selection of vertex position. The x axis is along the photon beam line, and the y axis is vertical to the beam line, as described in Fig. 1. The broken lines indicate the selected target region. The SI (Super Insulation) and vacuum windows are also seen.

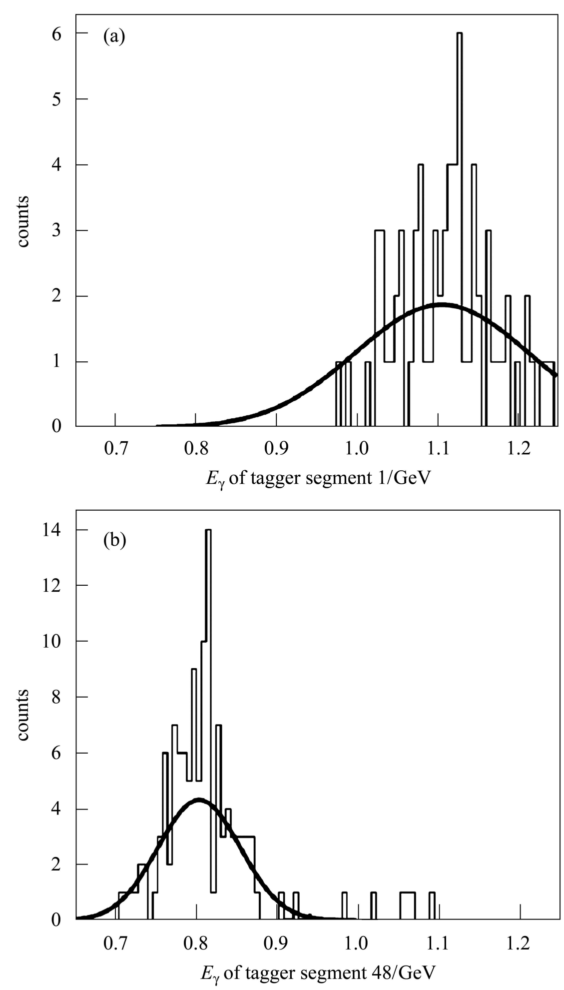

Fig. 4. The calculated E_γ for tagger segments 1 and 48. The curves are Gaussian fitting.

The designed tagged photon energy and the material effect correction energy of protons and pions were used for the target mass reconstruction. The selection of the reconstructed reaction vertex is illustrated in Fig. 3. The reconstructed vertexes reproduce the material distribution of the target system.

After the selection of d(γ,π^-pp), the energy of the incident photons was derived for each tagger segment. The typical energy spectra for segment 1 and segment 48 are shown in Fig. 4. The mean value of the Gaussian fitting gives the corresponding tagged photon energy.

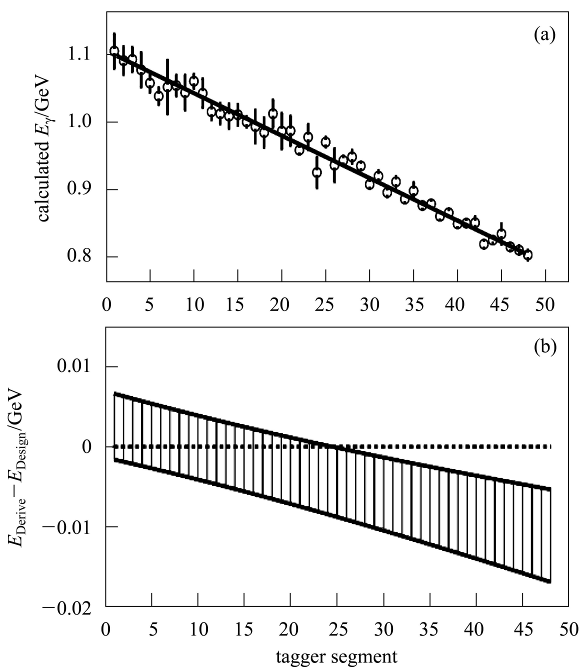

Fig. 5. Calibration of the photon tagging system. The errors showing in the (a) are the fitting error for each segment, the curve is a linear fitting; the (b) figure gives the propagation of the fitting for derived E_γ respecting to the designed E_γ.

With all 48 tagged photon energies, the photon tagging system can be calibrated. The derived energy of tagged photons is given by

$$E_\gamma = a - b\times n, \tag{3}$$

where a=1.1058±0.0040, b=(6.29±0.11)×10^{-3}, and E_γ is in units of GeV. The propagation of the fitting for the derived E_γ with respect to the designed one was also calculated. It is defined as

$$\varDelta(n) = \sqrt{0.004^2+(0.11\times10^{-3}\times(n-n_0))^2}\,, \tag{4}$$

where $n_0 = 10$ is the segment with minimum difference from the designed value, $\varDelta$ is in units of GeV.

From Fig. 5 (a), we can find the derived E_γ is consistent with the designed one and the previous measurement using the electron-positron pair production.

4 Summary

The photoproduction processes have been studied with NKS2 in an energy range from 0.8 to 1.1 GeV at LNS-Tohoku. The reaction d(γ,π^-pp) was selected for the calibration for the photon tagging system. The calibration, which is based on a complete kinematical measurement of the final state particles, agrees with the design of the tagging system and the previous measurement using the electron-positron pair production [10]. The agreement indicates that both NKS2 and the tagging system perform well. The possibility of photon energy calibration was thus exhibited using a complete kinematical measurement of the reaction of d(γ,π^-pp). This is the first report which calibrates the photon tagging system using hadron channels.

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