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Study of Charged Pion Photoproduction on Deuteron with Tagged Photons*

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Abstract: The reactions $\gamma d\rightarrow\pi^- pp$ and $\gamma d\rightarrow np\pi^+\pi^-$ have been studied in an energy range from 0.8 to 1.1 GeV at the tagged photon facility of Laboratory of Nuclear Science, Tohoku University. Charged pions and protons in the final state were measured by using the Neutral Kaon Spectrometer (NKS2). The analysis of the $\gamma d\rightarrow\pi^- pp$ was mainly used to check the acceptance of the NKS2 and to calibrate the tagged photon energy. The photoproduction of the $\Delta^{++}\Delta^-$ was identified in the $\gamma d\rightarrow np\pi^+\pi^-$ reaction. Since the data analyses are still in progress, we issue an interim report and preliminary results.

Key words: deuteron; double delta; pion photoproduction

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1 Introduction

Single and double charged pion photoproductions on the proton have been investigated extensively[1-4]. Since the deuteron is a loosely bound system of the proton and the neutron, the cross sections on neutron were obtained by using the deuterium bubble chambers[5,6]. They were about twice as large as that on the proton[7,8], and is understood as the sum of the contributions from the proton and neutron in the deuteron.

For double Δ excitations $\gamma d\rightarrow\Delta^{++}\Delta^-$, the energy of the photon is absorbed by two nucleons. The cross section obtained by Hirose et al.[9] is only half of that by Asai et al[10,11]. It must be studied in detail to understand the photon absorption mechanism especially in GeV energy region.

Kinematical complete reaction studies are important to understand the reaction process. The γd

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$\to \pi^-$ pp is one of the simplest processes that can be investigated by using the Neutral Kaon Spectrometer (NKS2)[12]. It is interested itself for studying medium effect of pion production in the deuteron.

In this article, we report the $\gamma d \to \pi^-$ pp and $\gamma d \to np\pi^+\pi^-$ reaction in an energy range from 0.8 to 1.1 GeV. We also pay attention to the $\Delta^{++}\Delta^-$ production process in $\gamma d \to np\pi^+\pi^-$ reaction.

2 Experimental Procedure

The experiments were carried out at Laboratory of Nuclear Science, Tohoku University, Japan. Electrons from the linear accelerator were injected into the Stretcher-Booster (STB) ring and accelerated up to 1.2 GeV. Bremsstrahlung photons were produced by the internal photon tagging system[13] which covered the photon energy range from 0.8 to 1.1 GeV. The photon energy was tagged by plastic scintillation hodoscopes. The energy width of each counter was about 6 MeV. The typical tagging rate was 2 MHz. The average photon tagging effciency, which was periodically monitored, was about 80%.

The liquid deuterium was used as the target. The aluminum target container has a length of 30 mm, a diameter of 50 mm and both ends were covered with 75 μm thick Upilex-S films. It was located at the center of the spectrometer. The temperature of the liquid deuterium was kept at 19.1 K. The effective thickness was 544 mg/cm^2.

As shown in Fig. 1. NKS2 is consisted of two kinds of drift chambers, inner hodoscopes (IH), outer hodoscopes (OH), and electron veto counters (EV). The magnetic field of 0.42 T was produced in the pole gap space of 680 mm in height

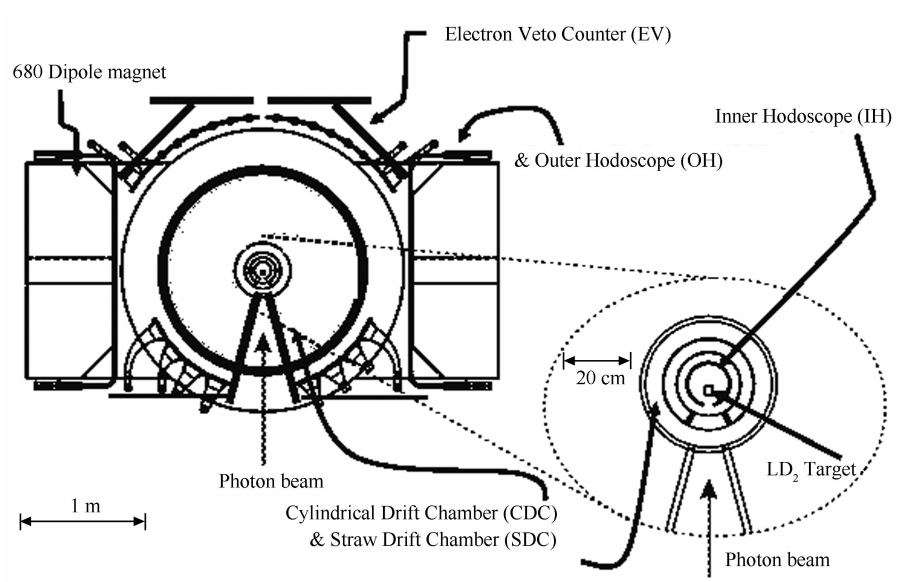

Fig. 1 Schematic drawing of NKS2.

and 1 600 mm in diameter. IH and OH were employed to give trigger signals to the online data acquisition system and to measure the Time-Of-Fight (TOF). The typical TOF resolution was 0.4 ns. A straw drift chamber (SDC) and a cylindrical drift chamber (CDC) were located outside of IH for the charged particle tracking. They covered an angular range from −165° to 165° to the beam line. Premixed gas of 50% argon and 50% ethane was supplied to the drift chambers. The EV counters were employed to reduce the background events produced by electrons and positrons. The trigger condition was the requirement of double hits on IH and OH together with a signal in the photon tagging system, and with no signal from the EV.

3 Data Analysis

Tracks of charged particles were reconstructed by SDC+CDC analysis. The momentum was obtained from the curvature in the magnetic field. The velocity was obtained between the time dierence between the IH and the OH signal and the length of the flight path. Then the momentum and the mass of the charged particle were obtained.

Fig. 2 shows the missing mass spectrum for the d(γ, $p\pi^+\pi^-$)X reaction. The peak corresponding to the neutron mass was selected as the d(γ, $p\pi^+\pi^-$)n reaction. As well as above, the peak of the missing mass spectrum for d(γ, $p\pi^-$)X which corresponds to the proton mass was selected as the d(γ, $p\pi^-$)p reaction.

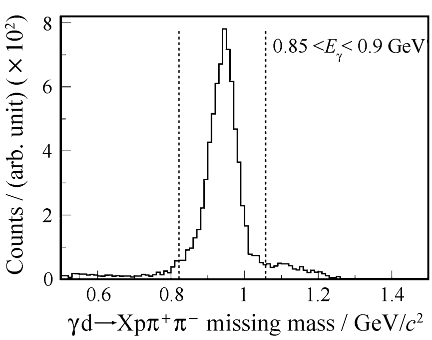

Fig. 2 The missing mass distribution for the d(γ, $p\pi^+\pi^-$)X reaction. The peak position and sigma ware 0.941 and 0.039 GeV. --- indicated the three-sigma cutting.

The Monte Carlo simulations are used to determine the acceptance of NKS2 and to perform the separation of reaction channels. We considered the $\Delta^{++}\pi^-$, $\Delta^0\pi^+$ channel and the three-body-phase-space(3BPS) as the channels in the γ"p" → $p\pi^+\pi^-$ reaction. The "p" denotes the bound proton in the deuteron. The angular distributions of Δ^{++} were taken from Ref. [3]. We assumed the isotropic angular distribution for p and π^+ in the rest frame of Δ^{++}. The $\Delta^0\pi^+$ channel were treated in the same manner as the $\Delta^{++}\pi^-$ channel described above. For the non-quasi free-process, the $\Delta^{++}\Delta^-$ channel and the four-body-phase-space were taken into account. We excluded $\Delta^+\Delta^0$-decay channel from our consideration because it is invisible in the present experiment. The sums of the simulated invariant mass distributions of the sub-channels were fitted to the experimental data with the mixing coefficients as the fitting parameters. Fig. 3 shows the invariant mass distributions for $p\pi^+$ in the γ"p" → $p\pi^+\pi^-$ reaction. The $\Delta^{++}\pi^-$ channel is a dominant process in this energy region[3,4]. The bump structure around 1.4 GeV/c^2 is thought to be the contribution from the $\Delta^0\pi^+$ channel.

The γ"p" → $p\pi^+\pi^-$ reaction was selected by the missing neutron momentum. Fig. 4 shows the

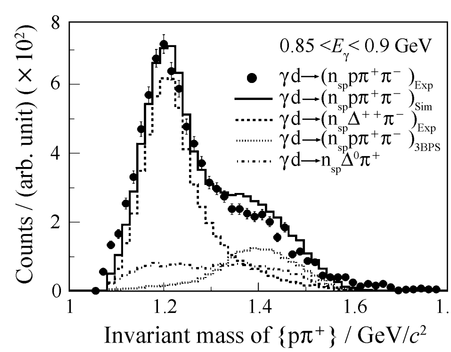

Fig. 3 Invariant mass distribution for the γ"p" → $p\pi^+\pi^-$ reaction. Curves are the subchannels. — is the sum of them. n_{sp} means the neutron in deuteron acts as a spectator.

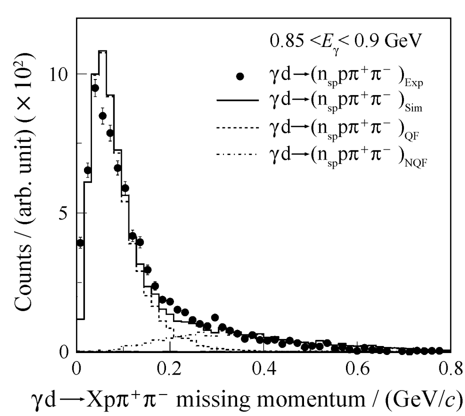

Fig. 4 The neutron momentum distribution for the d(γ, $p\pi^+\pi^-$)n reaction. ---, — • — and — denote the result of the Monte Carlo simulation for the quasi-free, non-quasi-free processes, and the sum of these processes respectively.

neutron momentum distribution for the d(γ, $p\pi^+\pi^-$)n reaction obtained as the missing momentum. Curves are obtained from the Monte Carlo simulation using nucleon momentum in the deuteron with the Hulthen wave function[14]. If the $p\pi^+\pi^-$ final state is produced through the quasi-free process, the neutron momentum (p_n) distribution will correspond to the dotted curve. We selected $p_n < 0.2$ GeV/c as the γ"p" → $p\pi^+\pi^-$ reaction. Fig. 5 shows the invariant mass of Nπ for the γd→$np\pi^+\pi^-$ reaction. Not only the peak of Δ^{++} but also that of Δ^- can be seen.

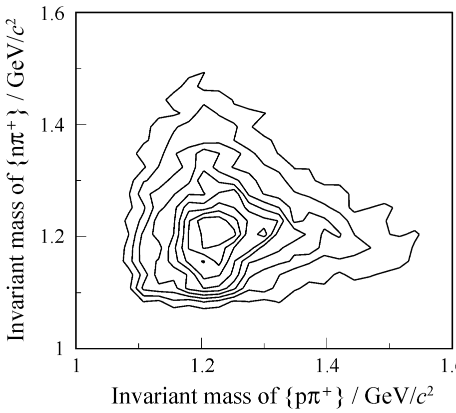

Fig. 5 The invariant mass of Nπ system for the γd→$np\pi^+\pi^-$ reaction. Both the peak of Δ^{++} and that of Δ^- can be seen.

4 Results and Discussion

The preliminary cross section for the γ"n" → $p\pi^-$ reaction is shown in Fig. 6. This is the data with the simplest final states that can be obtained with two charge trigger mode of the NKS2. They are compared with the previous work[6, 15, 16].

Fig. 7 shows the calibration of photon tagging system by the kinematical complete reaction γd→$\pi^+\pi^-$pp. The kinematics of final states of proton and pion were determined by the NKS2 system, and the deuteron was assumed in still state, then the energy of the incident photon was reconstructed. The dependency of the tagged photon energy on the segment of tagging finger scintillation hodoscope is

$$E_\gamma = 1.095 - n \times 0.0063, \quad (1)$$

where n is the array number of the hodoscopes, and E_γ is in unit of GeV.

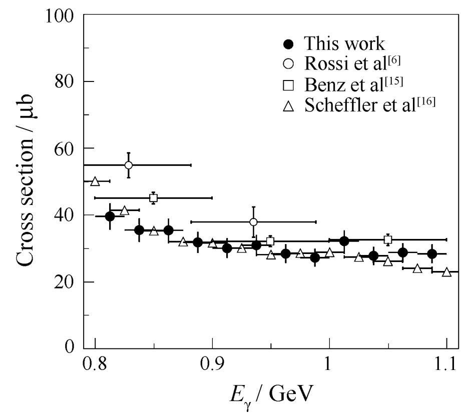

Fig. 6 The cross section for the γ"n" → $p\pi^-$ reaction.

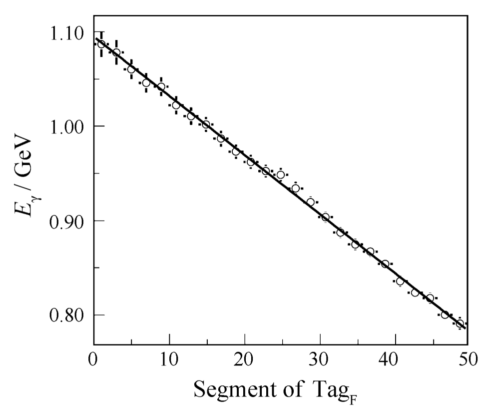

Fig. 7 Calibration of photon tagger system. The curve is the linear fitting.

5 Summary

The reaction γd→π^-pp and γd→$np\pi^+\pi^-$ were studied in an energy range from 0.8 to 1.1 GeV. The cross section for the γ"p" → $p\pi^+\pi^-$ reaction shows agreement with the previous data[6, 15, 16]. The calibration for photon tagging system based on the kinematical complete reaction γd→π^-pp agrees well with the design of the tagging system.

The cross section analysis for γd→π^-pp and γd→$np\pi^+\pi^-$ is still under way. Further measurement is proposed to investigate these processes in the energy region from 0.55 to 1.1 GeV.

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