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NON-STRANGE DIBARYONS STUDIED IN COHERENT DOUBLE NEUTRAL-MESON PHOTOPRODUCTION ON THE DEUTERON*

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We have investigated the $\gamma d \to \pi^0\pi^0 d$ reaction to study dibaryon resonances. The total cross section as a function of the γd center-of-mass energy shows resonance-like behavior peaked at around 2.47 and 2.63 GeV. The measured angular distribution of deuteron emission is rather flat, which cannot be reproduced by kinematics for quasi-free $\pi^0\pi^0$ production with deuteron coalescence. A clear peak is observed at 2.14 GeV in the $\pi^0 d$ invariant-mass distributions. The present work shows a sequential process $\gamma d \to R_{\rm IS} \to \pi^0 R_{\rm IV} \to \pi^0\pi^0 d$ is dominant with two 2.47- and 2.63-GeV isoscalar dibaryons ($R_{\rm IS}$) and a 2.14-GeV isovector dibaryon ($R_{\rm IV}$).

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1. Introduction

The structure of hadrons is one of the most important subjects to be studied in the non-perturbative domain of quantum chromodynamics. A $B = 2$ system (dibaryon) [1] is an interesting object to study its basic configuration from a molecule-like state consisting of two baryons to a spatially-compact hexaquark hadron state. Understanding dibaryons would not only give a clue to the solution of the current problem in hadron physics, but also provide an insight into the nuclear equation of state and the interior of a neutron star [2].

Recent observations of the $d^*(2380)$ dibaryon [3, 4] have opened the door to study non-strange dibaryons. It is important to establish the excitation spectrum of dibaryons to understand their internal structure. We study the $\gamma d \to \pi^0\pi^0 d$ reaction to observe intermediate dibaryon states. Possible production mechanisms for the $\gamma d \to \pi^0\pi^0 d$ reaction are classified as follows:

1. Dibaryon: sequential $\pi^0\pi^0$ emission from the deuteron with intermediate isoscalar dibaryon R_{IS} and isovector dibaryon R_{IV} ($\gamma d \to R_{\mathrm{IS}} \to \pi^0 R_{\mathrm{IV}} \to \pi^0\pi^0 d$).
2. QF-$\pi\pi$: $\pi^0\pi^0$ is photoproduced on the quasi-free (QF) participant nucleon N_{p}, followed by coalescence of N_{p} and spectator nucleon N_{s} into a deuteron.
3. QF-π: π^0 is photoproduced on N_{p}, followed by coalescence of N_{p} and N_{s} into R_{IV}, finally R_{IV} decays into $\pi^0 d$.
4. Direct-$\pi\pi$: $\pi^0\pi^0$ is directly photoproduced from the deuteron.

In the QF-$\pi\pi$ mechanism, the second π^0 should be emitted to compensate for the momentum given to N_{p} by the first emitted π^0 to coalesce into a deuteron. In this case, the angular distribution of deuteron emission in the γd center-of-mass (CM) frame shows strongly backward peaking. As for the QF-π mechanism, the condition to coalescence of R_{IV} makes the distribution sideway peaking at the incident photon energy around 1 GeV. A completely different rather flat distribution is obtained in the dibaryon and direct-$\pi\pi$ mechanisms.

2. Experiment

The total and differential cross sections were measured for the $\gamma d \to \pi^0\pi^0 d$ reaction using an energy-tagged bremsstrahlung photon beam ranging from 0.75 to 1.15 GeV [5] at the Research Center for Electron Photon Science (ELPH), Tohoku University, Japan. The target used in the experiment was liquid deuterium with a thickness of 45.9 mm. All the final-state particles in the $\gamma d \to \pi^0\pi^0 d$ reaction were measured with the FOREST detector [6].

FOREST consists of three different electromagnetic calorimeters (EMCs), and a plastic-scintillator hodoscope (PSH) is placed in front of each EMC to identify charged particles.

3. Results

The analysis of the $\gamma d \to \pi^0\pi^0 d$ reaction was made in the same way as in Ref. [7]. We selected the events containing four neutral particles and a charged particle, and applied a kinematic fit with six constraints: four-momentum conservation, and every $\gamma\gamma$-invariant mass being the π^0 mass. Events in which the χ^2 probability is higher than 0.4 were selected to reduce those from background processes. Figure 1 shows the total cross section σ as a function of the γd CM energy $W_{\gamma d}$. The excitation function is not monotonically increasing but shows resonance-like behavior peaked at around 2.47 and 2.63 GeV.

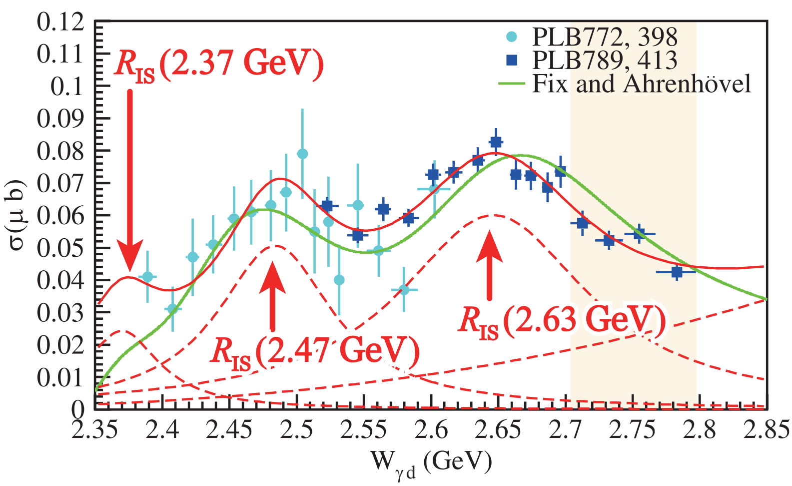

Fig. 1. (Color online) Total cross section σ as a function of $W_{\gamma d}$. The squares (blue) and circles (cyan) show σs obtained in the previous [7] and in the present work [8], respectively. The horizontal error of each data point corresponds to the coverage of the incident photon energy, and the vertical error shows the statistical error of σ. The solid curve (grey/green) shows a theoretical calculation given in Ref. [9] based on the QF-$\pi\pi$ mechanism. The solid curve (dark grey/red) shows the fitted function expressed by a sum of three Breit–Wigner peaks and phase-space contributions. Each contribution is shown as a dashed curve (dark grey/red).

A naive interpretation of this behavior may be a QF excitation of the nucleon, followed by coalescence into the deuteron. However, a rather-flat angular distribution of deuteron emission completely differs from the QF-$\pi\pi$ and QF-π mechanisms. In addition, the $\pi^0 d$ invariant-mass distributions shows a peak at 2.14 GeV. The present work suggests a sequential process $\gamma d \to R_{\rm IS} \to \pi^0 R_{\rm IV} \to \pi^0\pi^0 d$ is dominant with two 2.47- and 2.63-GeV $R_{\rm IS}$ and a 2.14-GeV $R_{\rm IV}$.

4. Summary

The total and differential cross sections have been measured for the $\gamma d \to \pi^0\pi^0 d$ reaction at $E_\gamma = 0.75$–1.15 GeV. The measured angular distribution of deuteron emission is rather flat, suggesting that a sequential process $\gamma d \to R_{\rm IS} \to \pi^0 R_{\rm IV} \to \pi^0\pi^0 d$ is dominant. The total cross section as a function of $W_{\gamma d}$ shows isoscalar dibaryons $R_{\rm IS}$ with masses of 2.47 and 2.63 GeV. The $\pi^0 d$ invariant-mass distributions show an isovector dibaryon $R_{\rm IV}$ with a mass of 2.14 GeV. The details of the analysis and discussion can be found elsewhere [8].

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REFERENCES

[1] H. Clement, *Prog. Part. Nucl. Phys.* **93**, 195 (2017).

[2] A. Akmal, V.R. Pandharipande, D.G. Ravenhall, *Phys. Rev. C* **58**, 1804 (1998).

[3] M. Bashkanov *et al.* [CELSIUS/WASA Collaboration], *Phys. Rev. Lett.* **102**, 052301 (2009).

[4] P. Adlarson *et al.* [WASA-at-COSY Collaboration], *Phys. Rev. Lett.* **106**, 242302 (2011).

[5] T. Ishikawa *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **622**, 1 (2010); **811**, 124 (2016); Y. Matsumura *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **902**, 103 (2018); Y. Obara *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **922**, 108 (2019).

[6] T. Ishikawa *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **832**, 108 (2016).

[7] T. Ishikawa *et al.*, *Phys. Lett. B* **772**, 398 (2017).

[8] T. Ishikawa *et al.*, *Phys. Lett. B* **789**, 413 (2019).

[9] A. Fix, H. Arenhövel, *Eur. Phys. J. A* **25**, 115 (2005).