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

T. Ishikawa, H. Fujimura, H. Fukasawa, R. Hashimoto
Q. He, Y. Honda, T. Iwata, S. Kaida, H. Kanda, J. Kasagi
A. Kawano, S. Kuwasaki, K. Maeda, S. Masumoto
M. Miyabe, F. Miyahara, K. Mochizuki, N. Muramatsu
A. Nakamura, K. Nawa, S. Ogushi, Y. Okada, Y. Onodera
K. Ozawa, Y. Sakamoto, M. Sato, H. Shimizu, H. Sugai
K. Suzuki, Y. Tajima, S. Takahashi, Y. Taniguchi
Y. Tsuchikawa, H. Yamazaki, R. Yamazaki, H.Y. Yoshida

Research Center for Electron Photon Science (ELPH), Tohoku University Sendai 982-0826, Japan
Department of Physics, Yamagata University, Yamagata 990-8560, Japan
Department of Physics, Tohoku University, Sendai 980-8578, Japan
Department of Information Science, Tohoku Gakuin University Sendai 981-3193, Japan
Department of Physics, University of Tokyo, Tokyo 113-0033, Japan
Institute of Particle and Nuclear Studies High Energy Accelerator Research Organization (KEK), Tsukuba 305-0801, Japan

(Received October 8, 2019)

We have investigated the $\gamma d \rightarrow \pi^0\pi^0 d$ reaction to study dibaryon resonances. The total cross section as a function of the $\gamma d$ 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 $\gamma d \rightarrow R_{IS} \rightarrow \pi^0 R_{IV} \rightarrow \pi^0\pi^0 d$ is dominant with two 2.47- and 2.63-GeV isoscalar dibaryons ($R_{IS}$) and a 2.14-GeV isovector dibaryon ($R_{IV}$).

DOI:10.5506/APhysPolB.51.329

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 $\gamma d \rightarrow \pi^0\pi^0d$ reaction to observe intermediate dibaryon states. Possible production mechanisms for the $\gamma d \rightarrow \pi^0\pi^0d$ 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 $R_{IV}$ ($\gamma d \rightarrow R_{IS} \rightarrow \pi^0R_{IV} \rightarrow \pi^0\pi^0d$).
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-$\pi$: $\pi^0$ is photoproduced on $N_p$, followed by coalescence of $N_p$ and $N_s$ into $R_{IV}$, finally $R_{IV}$ decays into $\pi^0d$.
4. Direct-$\pi\pi$: $\pi^0\pi^0$ is directly photoproduced from the deuteron.

In the QF-$\pi\pi$ mechanism, the second $\pi^0$ should be emitted to compensate for the momentum given to $N_p$ by the first emitted $\pi^0$ to coalesce into a deuteron. In this case, the angular distribution of deuteron emission in the $\gamma d$ center-of-mass (CM) frame shows strongly backward peaking. As for the QF-$\pi$ mechanism, the condition to coalescence of $R_{IV}$ makes the distribution sideways 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 $\gamma d \rightarrow \pi^0\pi^0d$ 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 $\gamma d \rightarrow \pi^0\pi^0d$ 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 $\gamma d \rightarrow \pi^0 \pi^0 d$ 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 $\pi^0$ mass. Events in which the $\chi^2$ probability is higher than 0.4 were selected to reduce those from background processes. Figure 1 shows the total cross section $\sigma$ as a function of the $\gamma d$ 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 $\sigma$ as a function of $W_{\gamma d}$. The squares (blue) and circles (cyan) show $\sigma$s 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 $\sigma$. 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).](image)

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-$\pi$ mechanisms. In addition, the $\pi^0 d$ invariant-mass distributions...
shows a peak at 2.14 GeV. The present work suggests a sequential process 
$\gamma d \rightarrow R_{IS} \rightarrow \pi^0 R_{IV} \rightarrow \pi^0\pi^0d$ is dominant with two 2.47- and 2.63-GeV $R_{IS}$
and a 2.14-GeV $R_{IV}$.

4. Summary

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

The authors express gratitude to the ELPH staff for assistance during the
FOREST experiments. This work was supported in part by JSPS KAKENHI
grants Nos. 17340063, 19002003, 24244022, 26400287, 16H02188, 19H01902,
and 19H05141.

REFERENCES