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Invariant mass distributions of the $\gamma n \rightarrow p\pi^-\pi^0$ reaction

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The invariant mass distributions of the $\gamma n \rightarrow p\pi^-\pi^0$ reaction have been determined from a measurement in the photon energy range $500-800$ MeV at the MAMI Mainz accelerator with the large acceptance detector DAPHNE and using a deuterium target. At the higher photon energies, the invariant mass spectra of the $(\pi^-\pi^0)$ system show a peak at larger invariant mass values, a signature of a $\pi\pi$ correlated emission in the final state. [S0556-2813(99)00310-6]

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I. INTRODUCTION

Our previous measurements of some double pion photoproduction reactions [1,2] have shown that the amplitudes of the $\gamma p \rightarrow p\pi^+\pi^-$ and $\gamma p \rightarrow p\pi^0\pi^0$ channels are fairly well reproduced by the models of Gomez Tejedor-Oset [3] (GTO) and Murphy-Laget [4] (ML). However, both of these models strongly underestimated the total cross sections of the other two measured double photoproduction channels, $\gamma p \rightarrow n\pi^+\pi^0$ and $\gamma + n \rightarrow p\pi^-\pi^0$.

These last reactions are, on the contrary, better reproduced by a more recent model by Ochi, Hirata, and Takaki [5] (OHT) which predicts that, in this case, an important role is played by the intermediate excitation of the ρN state.

Since the information given by the total cross section alone is limited, in order to obtain a deeper insight into the reaction mechanisms, we present in this paper the invariant mass distributions of the $\gamma n \rightarrow p\pi^-\pi^0$ reaction in the photon energy range 500–800 MeV obtained using a deuterium target.

II. EXPERIMENTAL SETUP

The experimental setup used for this measurement has already been previously described in detail [6,7] and we present here only its main characteristics. Photons were produced by bremsstrahlung of the 855 MeV electrons from the Mainz MAMI [8] accelerator on a thin nickel converter. The photon energy is determined by the Glasgow-Mainz tagging spectrometer, which analyzes in a 352 channel focal plane detector, the momentum of the electrons that have radiated the bremsstrahlung photon. This detector system is able to tag photons in the range from 50 to 800 MeV with a resolution of about 2 MeV [9]. The collimation of the photon beam gave an experimental tagging efficiency of about 55%. This value was continuously monitored throughout the experiment using an electron-positron-pair detector. In this way, the photon flux could be determined with an absolute precision of $\pm 2\%$.

The reaction products were detected using the large acceptance detector DAPHNE $(21° \leqslant \vartheta \leqslant 159°,\ 0° \leqslant \varphi \leqslant 360°)$ built by the CEA/DAPNIA-SPhN at Saclay and the INFN-sezione di Pavia [10]. Good definition of charged particle tracks is obtained by a central vertex detector consisting of three coaxial cylindrical multiwire proportional chambers, surrounded by a segmented $\Delta E - E - \Delta E$ plastic scintillator telescope for charged particle identification [11]. Finally, there is a scintillator-absorber sandwich which provides additional energy loss measurements of charged particles and allows the detection of neutral pions with a useful efficiency ($\simeq 40\%$ when at least one of the two photons of the π^0 decay is required).

The liquid deuterium target was contained in a 43-mm diameter, 275-mm-long Mylar cylinder with a wall thickness of 0.1 mm. The target density was stabilized and known to an accuracy of $\pm 0.5\%$ by means of an automatic pressure and temperature control system.

III. DATA ANALYSIS

In our previous paper [2], the quasifree $p\pi^-\pi^0$ events were identified by a triple coincidence between one proton, one pion and at least one gamma from the π^0 decay. The identification of the final state particles was the only requirement needed for the evaluation of the total cross section.

The determination of the invariant mass distributions requires, in addition to this, the knowledge, event by event, of the reaction kinematics. Since only the charged particle emission angles, the proton kinetic energy and the energy of the incoming photon were measured, the event kinematics could be reconstructed only by neglecting the recoil momentum of the spectator proton and the binding effects on the

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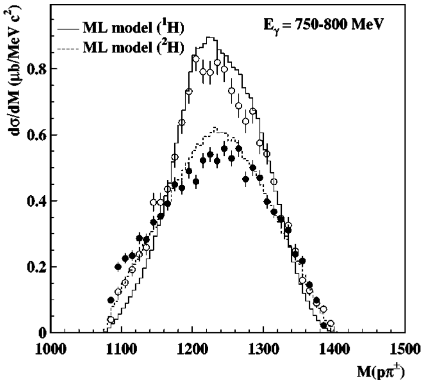

FIG. 1. The experimental invariant mass spectra for the $(p\pi^{\pm})$ systems from the $\gamma p \rightarrow p\pi^{+}\pi^{-}$ reaction between 750–800 MeV obtained both on hydrogen (open points) and deuterium (solid points) are compared with the predictions of the ML model (solid and dashed lines).

interacting neutron. With these assumptions, the energy and momentum conservation laws provided the kinematical constraints that were necessary to determine the four unmeasured parameters, i.e., the π^{-} and π^{0} kinetic energies and the π^{0} direction.

Because of the contraints that were imposed, the kinematical calculation rejected the parasitic events coming from the quasifree $\gamma n \rightarrow p\pi^{-}$ reaction when the emitted π^{-} gave rise to a secondary particle inside the detector materials which was identified as a photon.

However, neglecting the Fermi momentum and the binding energy induced two effects on the experimental invariant mass spectra. (i) A small deformation in their shape, due to the missing experimental information. The calculated information is slightly different from the values that would have been derived from an exact kinematical calculation. (ii) A loss of events which depends both on the photon energy and on the invariant mass value.

A correction to take these effects into account had then to be applied to our experimental invariant mass spectra in order to make a meaningful comparison with the model predictions. This correction was experimentally evaluated using the $\gamma p \rightarrow p\pi^{+}\pi^{-}$ reaction both on hydrogen and on deuterium.

The $p\pi^{+}\pi^{-}$ events were identified with a triple coincidence between one proton and two charged pions. For each event, the kinematical reconstruction was performed in a similar way as for the $p\pi^{-}\pi^{0}$ events by taking into account the angular information of only one of the two detected pions. Since no π^{+}/π^{-} separation is possible with our detector, the experimental invariant mass spectra of the $(p\pi^{\pm})$ and $(\pi^{+}\pi^{-})$ systems were calculated. This analysis was performed both on hydrogen, for which the kinematical reconstruction is exact, and on deuterium.

In Fig. 1 the experimental invariant mass spectra for the $(p\pi^{\pm})$ system in the photon energy range 750–800 MeV experimentally obtained both on hydrogen (open points) and deuterium (solid points) are shown. In the same figure, the experimental data are compared to the predictions of the ML model which compares well with the experimental total cross section and the invariant mass distributions of the $p\pi^{+}\pi^{-}$ channel in the measured photon energy range. In order to reproduce the invariant mass spectra obtained on deuterium, the effects of the Fermi motion and of the binding energy were included in the model, with the Fermi momentum distribution taken from Ref. [12]. The good agreement found between the experimental spectra and the model predictions gives confidence in the correctness of the analysis made for the $p\pi^{+}\pi^{-}$ channel.

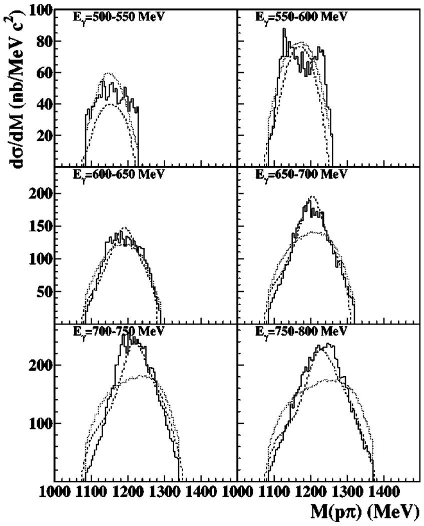

FIG. 2. The experimental invariant mass spectra for the $(p\pi^{0} + p\pi^{-})$ system are compared to the prediction of the OHT model (dashed line) and the TBPS distribution (dotted line).

For a given photon energy interval, we then applied to the experimental $(p\pi^{0}+p\pi^{-})$ and $(\pi^{-}\pi^{0})$ spectra from the $p\pi^{-}\pi^{0}$ channel a correction function which was respectively taken as equal to the measured ratios bewteen the $(p\pi^{\pm})$ and $(\pi^{+}\pi^{-})$ invariant mass spectra obtained using the deuterium and the hydrogen target. The global correction factor amounts to $\simeq 40\%$ of the number of experimental events at $E_{\gamma}=500$ MeV, decreasing to $\simeq 20\%$ at $E_{\gamma}=800$ MeV.

The experimental $p\pi^{-}\pi^{0}$ data were also corrected for the π^{0} detection efficiency. This quantity was evaluated using the GEANT code as a function of π^{0} momentum and emission angles and the corresponding correction was applied, on an event by event basis, using the π^{0} parameters deduced from the kinematical calculation. The small distortion of the π^{0} outgoing parameters produced by the kinematical calculation does not significantly affect the calculated efficiency, which shows only a weak dependence on the π^{0} emission parameters [6].

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental invariant mass spectra for the $(p\pi^{0} + p\pi^{-})$ and $(\pi^{-}\pi^{0})$ systems, corrected for the π^{0} detection efficiency and for the losses due to the kinematical calculation, are shown in Figs. 2 and 3 from $E_{\gamma}=500$ MeV to $E_{\gamma}=800$ MeV, and for photon energy intervals having a width of 50 MeV. The total measured yield obtained for each E_{γ}

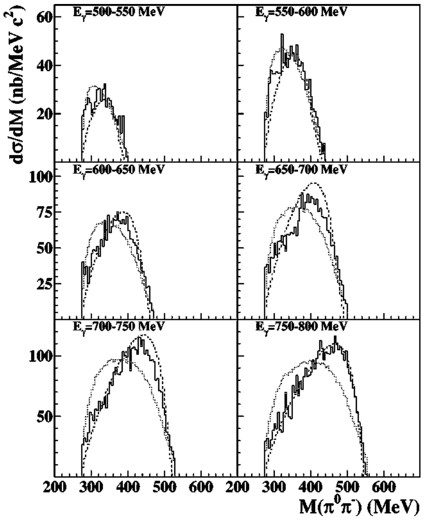

FIG. 3. As in Fig. 2, but for the $(\pi^- \pi^0)$ system.

bin from the integration of these invariant mass spectra is compared in Fig. 4 with our previous results [2], obtained with a different analysis. The two data sets agree to within the estimated systematic errors and this is a further confirmation that all the different corrections applied to the data were sufficiently well taken into account. In Figs. 2 and 3, our data are also compared with the predictions of the OHT model (solid lines), and of a uniform three-body phase space (TBPS) distribution normalized to the data (dotted lines).

The shapes of the experimental invariant mass spectra for the $(p\pi^0 + p\pi^-)$ system are significantly different from the predictions of the TBPS distribution. This is a clear indication that an important role is played by the intermediate excitation of a $\Delta\pi$ intermediate state.

The invariant mass spectra for the $(\pi^- \pi^0)$ system show, at the higher photon energies, a clear peak at the larger invariant mass values. This effect is an evidence of a $\pi\pi$ correlated emission in the final state and is clearly reproduced both in shape and in magnitude by the OHT model. The basic ingredients of this model are essentially the same as the ML and the GTO models. In these last two models the parameters which appear in the $N\rho$ contact term and in the $D_{13} \rightarrow N\rho$ decay were taken from the experimental $\pi\pi$ phase shift data in the $T=1, S=1$ state. In the OHT model, however, a finite range form factor was given to the $\rho\pi\pi$ vertex in order to reproduce the measured total cross section of the $\gamma p \rightarrow n\pi^+ \pi^0$ and $\gamma p \rightarrow p\pi^+ \pi^-$ channels. The modified $\pi\pi$ spectral function then gives a significant enhancement to the ρN contact term contribution in comparison to the predictions of other models. Whether this new spectral function has a physical meaning remains open to question.

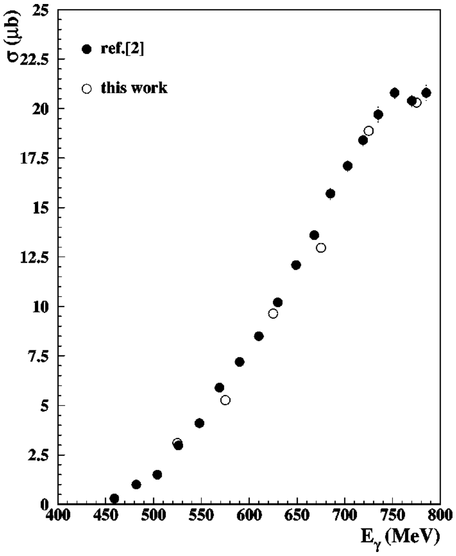

FIG. 4. The integrated cross section over the DAPHNE acceptance for the $\gamma n \rightarrow p\pi^- \pi^0$ reaction is compared to our previous results. Only statistical errors are shown.

Another process which could give a contribution is the correlated emission of the $(\pi\pi)$ system in the $T=2, S=0$ state. This mechanism should be important since the phase shifts δ_0^2 and δ_1^1 have comparable values in the photon energy region that is covered by our data [13]. Moreover this process, as the ρN contact term, can only contribute to the $\gamma p \rightarrow n\pi^+ \pi^0$ and $\gamma n \rightarrow p\pi^- \pi^0$ channels since, in these reactions, the intermediate $(\pi\pi)$ state is charged and can couple to the photon. However this possibility still needs to be investigated in a theoretical framework.

In conclusion, we have measured the invariant mass distributions for the $(p\pi^0 + p\pi^-)$ and $(\pi^- \pi^0)$ systems of the $\gamma n \rightarrow p\pi^- \pi^0$ reaction in the photon energy range 500–800 MeV. The invariant mass spectra of the $(\pi^- \pi^0)$ system show a strong final state correlation between the two emitted pions.

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