$2\pi^0$-PHOTOPRODUCTION ON NUCLEI*

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Double pion-photoproduction has been studied on p,^{12}C and $^{\rm nat}$Pb at incident photon energies up to 820 MeV at the MAMI facility in Mainz. The pions were detected in coincidence using the TAPS calorimeter. First preliminary results are available. The invariant mass distribution in the $2\pi^0$-photoproduction channel changes shape with increasing nuclear mass. This A dependence is not seen in the $\pi^0\pi^\pm$ channel. The shift is consistent with theoretical predictions for a partial restoration of chiral symmetry at normal nuclear matter density.

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1. Introduction

Chiral symmetry, a fundamental symmetry of Quantum Cromodynamics in the limit of massless quarks, is broken on the hadron level. There are, however, theoretical considerations [1] that chiral symmetry may be restored in nuclear matter, in particular for high nuclear densities and temperatures. When chiral symmetry is restored the masses of chiral partners become degenerate. This implies that the masses of the pion ($J^\pi = 0^-$) and the scalar–isoscalar σ-mode ($J^\pi = 0^+$), the chiral partner of the pion, become the same in the chiral limit. There exist different model calculations as to how this degeneracy is reached. One of them assumes that the σ-mass starts out with about 800 MeV and decreases with increasing nuclear density until the pion and the σ-meson become degenerate as they pass through the chiral phase transition [1] (see also figure 1). At low nuclear densities one can make the simple ansatz

$$m_\sigma(\rho) = m_\sigma\left(1 - \alpha\frac{\rho}{\rho_0}\right) ,$$

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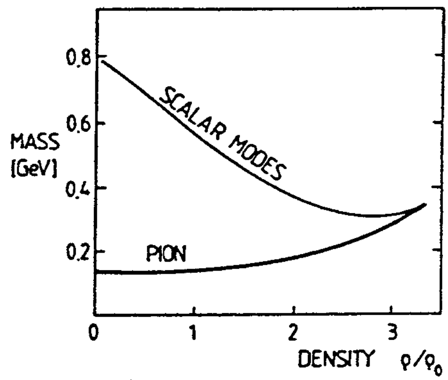

Fig. 1. The mass of the σ-meson decreases with increasing density until the pion and the σ become degenerate in mass. The figure is taken from [1].

where m_σ is the vacuum σ-meson mass. The main decay mode of the σ is the $2\pi^0$-channel. If the mass of the σ-mode is reduced with increasing nuclear density, the phase space for the π^0-decay becomes smaller and smaller, squeezing the $2\pi^0$ invariant mass distribution towards the $2\pi^0$ threshold. The resulting invariant mass distribution is shown in figure 2 [2]. A shift to

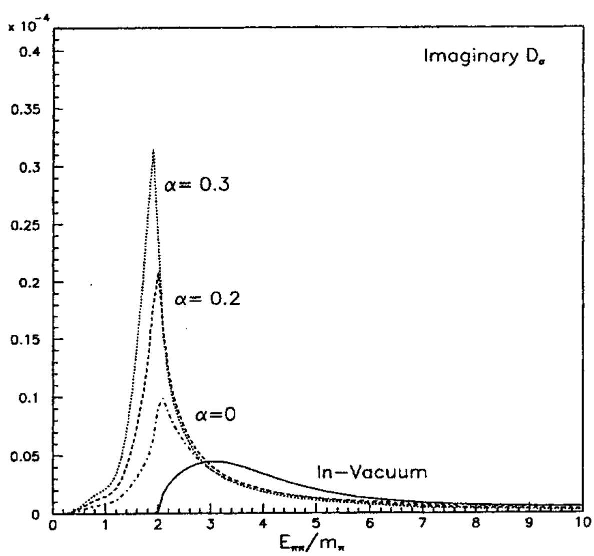

Fig. 2. Spectral function of the sigma meson in vacuum (full curve) and at normal nuclear matter density (the three other curves). The dashed curve ($\alpha = 0$) includes only the π-nucleus interaction and the other ones ($\alpha = 0.2,\ 0.3$) incorporate a dropping sigma mass as explained in the text [2].

lower invariant masses is observed. Consequently, in case of partial restoration of chiral symmetry in nuclear matter, one expects a shift of the $2\pi^0$ invariant mass distribution towards the two pion mass threshold with increasing nuclear mass number A.

The 2π invariant mass distributions in nuclei have already been studied in π-induced reactions, namely in the $(\pi^+, \pi^+\pi^-)$ reaction by the CHAOS collaboration [3] and in the $(\pi^-, \pi^0\pi^0)$ reaction by the Crystal Ball collaboration [4]. Both groups observe a change in the shape of the invariant mass spectrum for different targets.

2. Experiment

In the pion induced experiments, the kinetic energy of the pion beam was about 285 MeV. The mean free path of these pions is smaller than 1 fm, therefore the interaction will take place only at the surface of the nucleus and the two pion correlations are probed at half of the normal nuclear density or even less. The advantage of the using a photon beam is that the interaction takes place over the whole nucleus, *i.e.* the production of pion pairs occurs at normal nuclear density. The experiment was performed at the electron accelerator in Mainz. The MAMI facility reaches electron energies up to 882 MeV, electron bremsstrahlung photons were used for the photoproduction of pion pairs. The present study is limited to the photon energy range of 400–460 MeV. Neutral pions have been identified via their decay into two photons which have been registered in the photon detector TAPS.

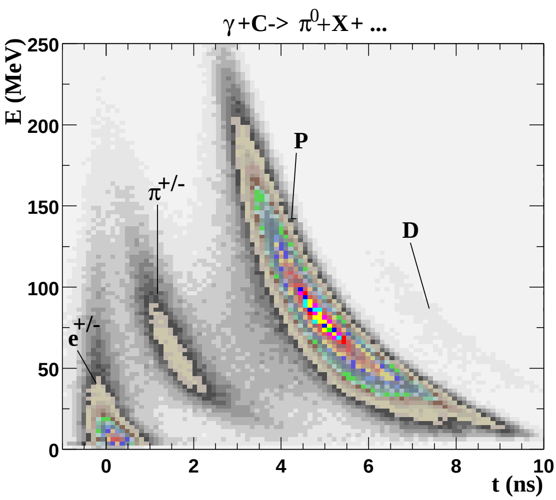

Fig. 3. Energy *versus* time spectrum of charged particles for the reaction (γ+C$\to$ π^0+X) is plotted. The branches of different particles are clearly separated.

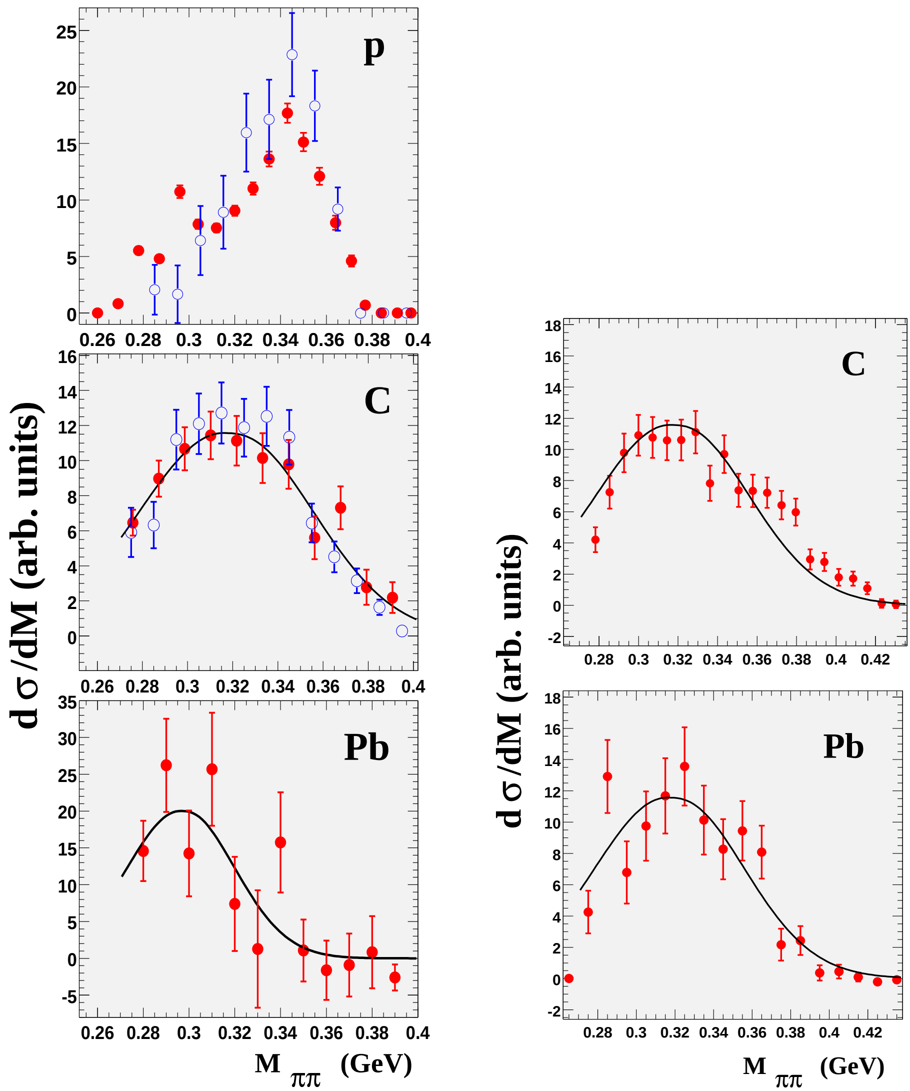

Fig. 4. (a) $2\pi^0$ invariant mass distribution for photon and π^- induced reactions on the proton and on nuclei. The open points are the Crystal Ball data [4] for a pion momentum of 408 MeV/c. The black points are the preliminary TAPS data in the photon beam region of 400–460 MeV, corresponding to the same $\sqrt{s} = 1300$ MeV as in the π-beam experiments. (b) $\pi^0\pi^\pm$ invariant mass distribution of the preliminary TAPS data. The solid curves represents fits to the data. The experimental distributions are arbitrarily normalized, only the shapes are compared.

The experiment shows agreement with the Crystal Ball data for incident photon energies between 400–460 MeV. The shape of the $2\pi^0$ invariant mass distribution changes from p to nuclei and with increasing A (see Fig. 4 (a)). This shift may be due to partial restoration of chiral symmetry. But it could also be due to final state interactions (FSI) of the pions. To check this possibility, another isospin channel of the 2π system has been investigated.

A σ cannot decay into $\pi^0\pi^\pm$, but if the shift in the mass distribution were due to final state interactions it should also be seen in this channel. Therefore the $\pi^0\pi^0$ channel was compared to the $\pi^0\pi^\pm$ channel. For events with one π^0, all charged particles were analyzed. In the energy *versus* time spectrum one can identify a pion band (see Fig. 3). As one cannot distinguish between π^+ and π^-, we consider both of them in the same way. $\pi^0\pi^\pm$ invariant mass spectra have been derived from the measured pion four-momentum vectors for C and Pb targets. For the carbon data, the $\pi^0\pi^\pm$ mass distribution looks similar to the $\pi^0\pi^0$ channel, while there is a difference for the lead data (see Fig. 4 (a)). No A dependence, however, is observed in the $\pi^0\pi^\pm$ invariant mass distribution (Fig. 4 (b)).

3. Conclusion

The photoproduction of pion pairs on the proton and on nuclei has been studied for $E_\gamma = 400$–460 MeV. A difference in the final state interaction of the pion pair with nuclei is observed, depending on the isospin. For the $I = J = 0$ $2\pi^0$ channel a shift of the $2\pi^0$ invariant mass distribution towards lower masses is observed. In the case of the $I = 1$ channel ($\pi^0\pi^\pm$) no such shift is found, demonstrating that final state interactions cannot account for this observation. The different behaviour of the mass distributions in the $I = 0$ and $I = 1$ channels is, however, consistent with the scenario of partial restoration of chiral symmetry. Further studies aiming at higher statistics are in preparation.

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