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MULTINUCLEON PION ABSORPTION CROSS SECTIONS ON N, Ar AND Xe IN THE DELTA RESONANCE REGION*

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The pion absorption reaction π^+ on Ar was studied at pion energies of 70, 118, 162, 239 and 330 MeV, and on N and Xe at 239 MeV. Absorption reaction channels with at least two energetic charged particles in the final state have been identified. Partial cross sections split according to the number of protons, neutrons and deuterons in the final state have been determined.

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1. Introduction

The 4π solid angle Large Acceptance Detector System (LADS) was built at PSI to study multi-nucleon pion absorption at energies around the Δ resonance [1]. A number of papers concerning pion absorption on the light nuclei ^{3}He and ^{4}He have been published by our collaboration (see *e.g.* [2]). In addition to the light target data, measurements with heavier targets, N, Ar and Xe, were also performed

In [3] and [4] we reported first heavy target results which showed the existence of the initial state interaction (ISI) in pion absorption. In the two-step ISI process the pion first scatters quasi-elastically off one nucleon before being absorbed on a nucleon pair.

More recently the heavy target data have been fully analyzed. Here we present the breakup of the absorption cross section into individual channels labelled according to the number of protons, neutrons and deuterons in the final state.

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The N and Xe data are presented for a single incident pion energy of 239 MeV, and the Ar data for the five pion energies 70, 118, 162 230 and 330 MeV.

2. Data analysis

Pion absorption events leading to final states with energetic protons, neutrons and deuterons were selected from the N, Ar and Xe target data. Absorption events were identified by requiring no pion in the final state. Charged pions were identified through the ΔE/E method and neutral pions through high energy (above 10 MeV) gamma rays. In order to discriminate against background only events with at least two well identified tracks (measured with MWPC) were analyzed. This meant that only events with at least two charged particles were taken into account.

The identified absorption events were split according to the number of protons, neutrons and deuterons in the final state. Particles with kinetic energy below 30 MeV were ignored. About 25 final states have been identified. In addition to the expected two nucleon ($2p$, $1p1d$) and three nucleon pion absorption ($3p$, $2p1n$) high multiplicity events have been also observed, *e.g.* $5p$, $2p3n$ or $3p1d1n$. All final states have been simultaneously analyzed with the help of Monte Carlo simulations. This procedure resulted in acceptance corrected cross sections for each of the considered final states. This acceptance correction includes extrapolation of the kinetic energy thresholds from 30 MeV to 0 MeV.

As an example we show the 3 proton final state (3p) following pion absorption on Argon at 239 MeV. Fig. 1 shows the missing energy, missing momentum, proton kinetic energy and proton angular distribution for the $3p$ final state. The measured distributions are shown with stars.

The solid line in Fig. 1 shows the Monte Carlo prediction for the $3p$ final state. The simulation takes into account the detector solid angle (incomplete 4π coverage), particle thresholds imposed during the data analysis (30 MeV) and other inefficiencies (*e.g.* reconstruction and reaction losses). The observed $3p$ event can originate from a $3p$ final state, $4p$ (when one proton escapes undetected), 3p1n (when the neutron is undetected) and others (*e.g.* $4p1n$, $3p2n$ *etc.*). The strengths of all Monte Carlo distributions were simultaneously varied to reproduce the observed final states. The difference in the shape of the various distributions is too small to unambiguously determine the strength of each reaction channel. However, since high multiplicity channels are also measured in the experiment, they can be accurately determined with a simultaneous fit. For example, the Monte Carlo $4p$ component in the measured $3p$ histogram, cannot vary too much since it has to simultaneously reproduce the measured 4p yield. This is a unique feature of LADS

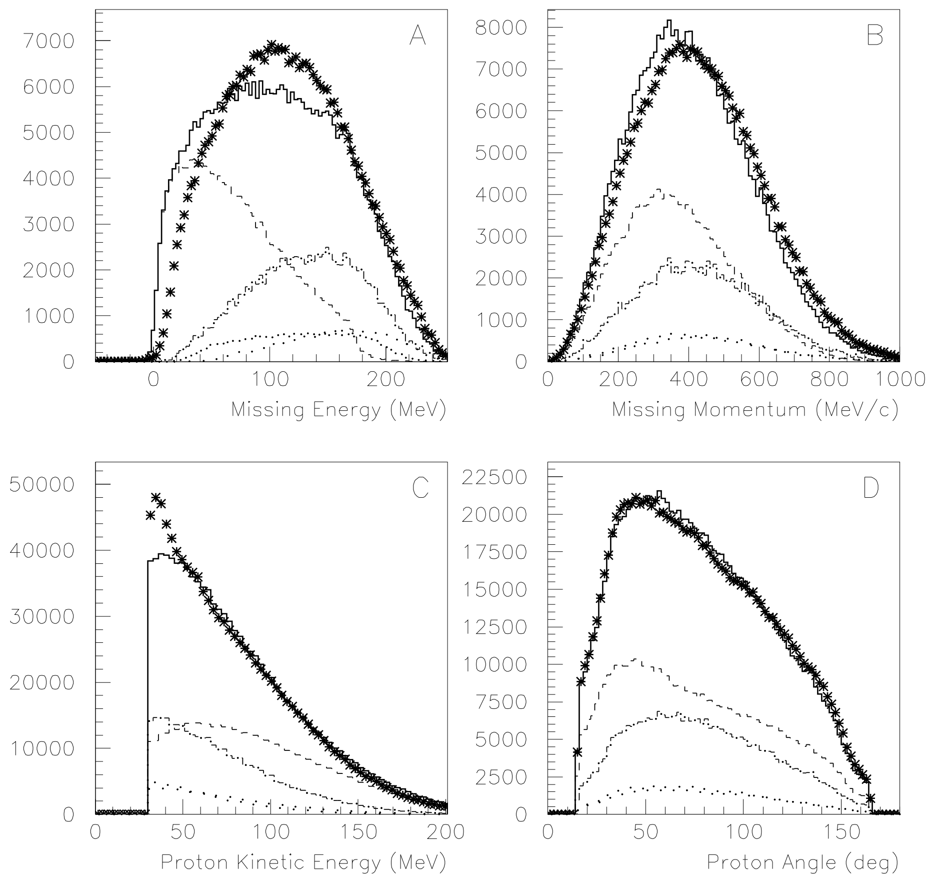

Fig. 1. The measured differential distributions for the $3p$ final state for the Ar target at 239 MeV pion energy : (A) missing mass, (B) missing momentum, (C) proton kinetic energy and (D) proton angular distribution. Stars show the experimental data and the solid line is the sum of the Monte Carlo simulations. Other lines show the different Monte Carlo contributions to the total; $3p$ (dashed), $3p1n$ (dashed-dotted), $4p$ (dotted) and $4p1n$ (wide-dotted).

where reaction channels up to high multiplicity were measured. Previous experiments usually could only measure 2 and 3 nucleon final states.

For the Monte Carlo models phase space distributions were used for all channels except $3p$ and $2p1n$ where a mixture of ISI, FSI (final state interaction) and phase space was used and $2p$ which was modelled by the QFA (quasi free two-nucleon absorption) distribution. Phase space distributions describe the data fairly well except for some deuteron channels which show strong non phase-space components.

The heavy recoil left after the pion absorption process is in general in an excited state. As suggested by Fig. 1(A) this excitation energy can be large. In our Monte Carlo simulations we assumed a flat excitation energy distribution from 0 to some maximum value, which *e.g.* for Ar at 239 MeV was 170 MeV.

3. Results

Cross sections determined by the procedure explained above are presented in Figures 2, 3 and 4. The shown cross sections are normalized, acceptance corrected and extrapolated to 0 MeV threshold.

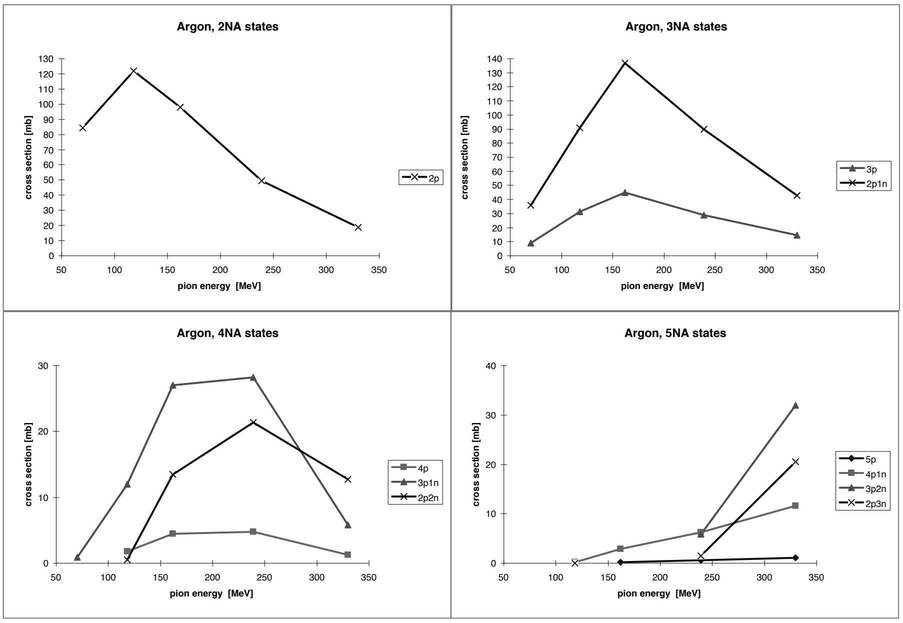

Fig. 2. Cross sections for final states with protons and neutrons on an Ar target as a function of pion energy. The various final states are grouped together according to the number of nucleons in the final state 2NA (2p), 3NA (3p, 2p1n), 4NA (4p, 3p1n, 2p2n) and 5NA (5p, 4p1n, 3p2n, 2p3n).

In Fig. 2 the measured cross sections for the proton and neutron final states are plotted versus the pion beam energy for the Argon target. For presentation clarity the final states are split according to the number of nucleons. 2NA corresponds to the well known $2p$ QFA reaction.

These results should be compared with model calculations (*e.g.* of the nuclear cascade type). Such calculations are not available at the moment, however some simple comments can be made.

- All final states show a resonance type behaviour as a function of pion energy.
- Final states with the same number of nucleons peak at roughly the same pion energy.
- The pion energy where the cross section peaks increases with the number of nucleons.
- The final states which include neutrons are usually much stronger than the final states with protons only.

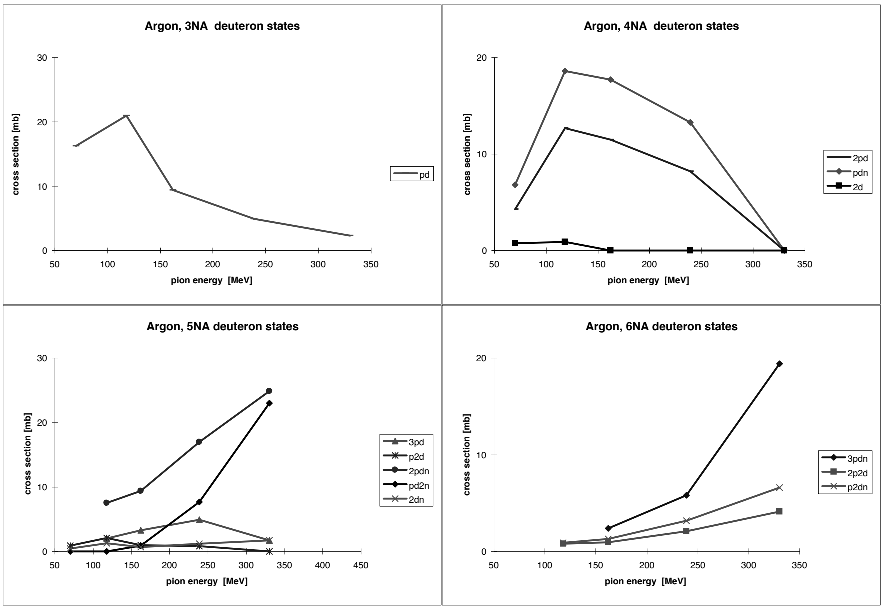

Fig. 3. Cross sections for final states with deuterons on an Ar target as a function of pion energy. The various final states are grouped together according to the number of nucleons in the final state 3NA ($1p1d$), 4NA ($2p1d$, $1p1d1n$, $2d$), 5NA ($3p1d$, $1p2d$, $2p1d1n$, $1p1d2n$, $2d1n$) and 6NA ($3p1d1n$, $2p2d$, $1p2d1n$).

The final states with deuterons are shown in Fig. 3. Here the systematic behaviour seen in the previous figure is less clear. However the points to be made are:

- Final states which include deuterons are a large part of the total absorption cross section, close to 1/3 at all pion energies.
- Some deuterons are emitted in very high multiplicity events *e.g.* 3p1d1n or 2p2d (which are both 6NA states).

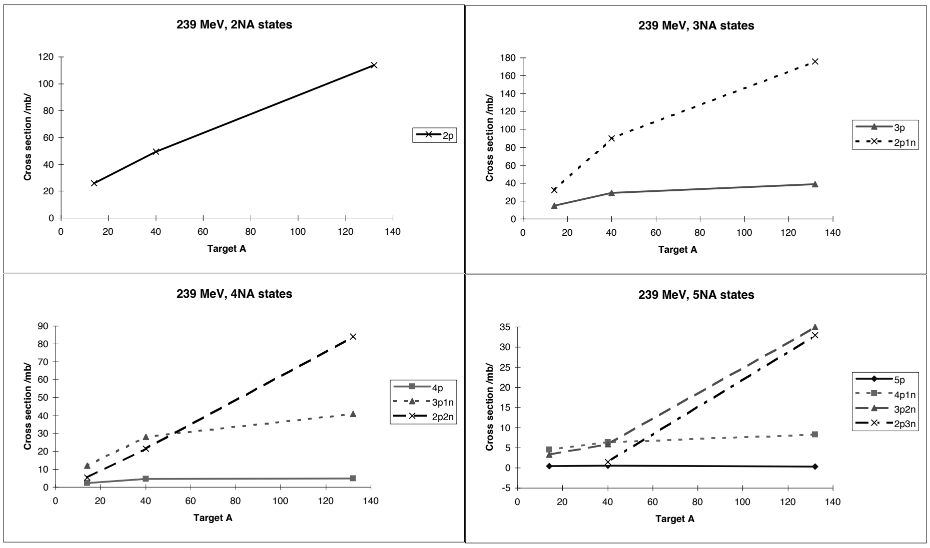

Fig. 4. Cross sections for final states with protons and neutrons at a pion energy of 239 MeV as a function of target mass. The various final states are grouped together according to the number of nucleons in the final state 2NA ($2p$), 3NA ($3p$, $2p1n$), 4NA ($4p$, $3p1n$, $2p2n$) and 5NA ($5p$, $4p1n$, $3p2n$, $2p3n$).

The cross section dependence on the target mass can be seen in Fig. 4 where the partial cross sections for the proton–neutron states are plotted at 239 MeV pion energy. Most cross sections rise smoothly with the target mass. The exceptions are the channels with only protons ($5p, 4p$) or those dominated by protons ($4p1n$) where the cross section seems to saturate for medium heavy targets.

The partial cross sections can be added together. The sum is in all cases within 15% from the previously measured total absorption cross sections. This means that in our analysis we do not miss any large part of the absorption cross section. The channels missed due to the experimental procedure are $1p1n/1d1n$ and $1p2n/1d2n$. These are expected to be small for π^+ induced reactions. In addition, absorption channels with heavier fragments (*e.g.* alpha particles) are ignored.

In conclusion we have determined the full break-up of the absorption cross section into individual channels. Many high multiplicity final states have been observed. Channels with neutrons are increasingly important with the pion energy (up to 80% for the highest energy). Final states with deuterons populate between 20% and 30% of the absorption cross section at all energies and for all targets.

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