TWO-STEP PROCESSES IN PION ABSORPTION*

Q. INGRAM

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The absorption of pions of energy about 100 to 300 MeV is discussed. The results presented here are the results of a collaboration between Basel, Karlsruhe, LAMPF, Maryland, MIT, NMSV Las Cruces, ODU, PSI and Zagreb.

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The interest in the dynamics of pion absorption is partly due its relation to pion exchange between nucleons, and thus to the nuclear force. Further, this reaction is about one half of the total pion-nucleus reaction and so is of importance in itself. In this talk only the absorption of pions of about 100 to 300 MeV are discussed. The results presented here are the results of a collaboration between Basel, Karlsruhe, LAMPF, Maryland, MIT, NMSV Las Cruces, ODU, PSI and Zagreb (see [8]).

The "elementary" reaction is the absorption of pions on a pair of nucleons in the nucleus, in a quasi-free version of the reaction on the deuteron; if just these two absorbing nucleons are involved they are ejected from the nucleus back-to-back and the residual nucleus has a spectator momentum distribution. This we call two-nucleon absorption (2NA), and the process is broadly understood [1, 2]. It is observed that in practice quite often three (or even more) nucleons are ejected from the nucleus energetically, and such a process we call three-nucleon absorption (3NA). How this happens is not understood.

Possible mechanisms of 3NA are often characterised as two-step processes - *e.g.* the pion scatters from one nucleon before undergoing a "normal" 2NA, which we term an Initial State Interaction (ISI) process, or after undergoing a direct 2NA one of the ejected nucleons scatters off and ejects a third one, which we term a Final State Interaction (FSI). Alternatively

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there might be processes which involve the three nucleons — or even require them to act — in a "single" interaction. Strictly one cannot separate such processes from each other, but if the ISI or FSI scatterings are sufficiently "hard" and separated from the accompanying 2NA, one might find a recognisable kinematic signature in the data.

Experimentally the absorption cross section is separated into 2NA and ($\geq$) 3NA by measuring the yield with the appropriate 2NA kinematic signature and making some smallish model-dependent extrapolation and/or background subtraction. In the energy region of this talk this yield is typically found to be 50–80 % of the total absorption cross section for the helium isotopes but less than about one third for nuclei heavier than carbon.

This measured 2NA yield may then be corrected for FSI with DWIA calculations, but after some controversy it is now accepted that this cannot account for the missing cross section in itself. The amount of ISI is less clear: although double quasi-free scattering is seen in pion inelastic and double charge exchange scattering, and although some model calculations [3, 4] suggest it should be very important in pion absorption, no strong kinematic signature of this process had been seen until recently. However, the experimental knowledge of the 3NA distributions has typically been rather poor, and also often inconsistent; in order to investigate these distributions better, the LADS detector was built. This is a near 4π solid angle non-magnetic cylindrical detector with plastic scintillator sectors to identify and measure the energy of (charged) particles in multi-nucleon final states [5]. It has an energy resolution of some 8 MeV and 10 MeV/c in the missing nucleus' mass and momentum. Thus it provides completeness, kinematic definition and high statistics. Total and partial absorption cross sections have been measured accurately [6].

In Fig. 1 the momentum distributions (divided by 3-nucleon phase space) of the lowest momentum proton following pion absorption on ^{3}He are shown for three pion energies; the data at each energy are arbitrarily normalised. The dots indicate the shape of the distribution expected for the spectator accompanying 2NA. At high momenta there is a large excess of yield over the spectator distribution, due to 3NA, and this contains some structure. In Figs 2-3 events are only included from the region above 240 MeV/c (30 MeV) in Fig. 1 - that is all protons in an event are required to have more than 30 MeV — to remove the otherwise dominating 2NA yield. Fig. 2 shows plots of proton momentum vs angle, in which enhancements can be seen around the kinematics of pion-nucleon scattering. This is a signature of ISI. Another signature can be seen (following the suggestion of ref [7] in the plot of the square of the pseudo-invariant mass of the absorbed particle, shown in Fig. 3, where a peak is seen near the pion mass squared. Prominent at 239 MeV it is reduced to a shoulder at 118 MeV; the data show that

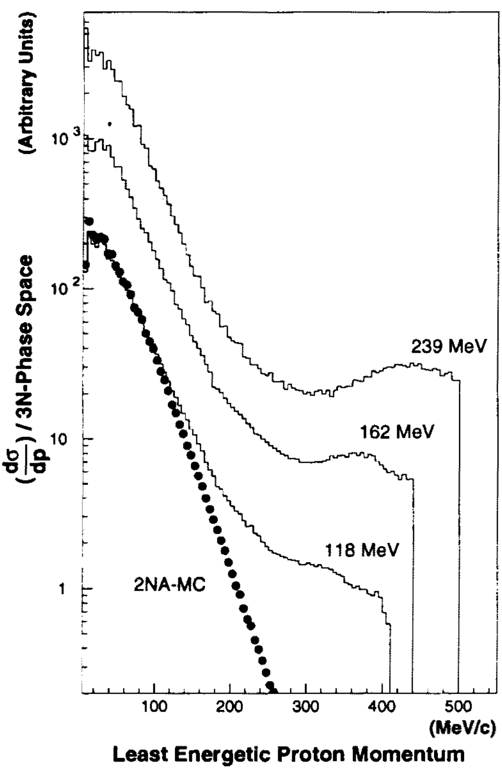

Fig. 1. The distributions in momentum of the least energetic proton, after the absorption of 118, 162 and 239 MeV pions by ^{3}He, corrected for the detector acceptance and divided by the 3N phase space. The distributions are arbitrarily normalised for each energy. The dots show the shape of the distribution expected for the spectator proton in a 2NA reaction.

this structure is clearly correlated with the indicated enhancement in the angle-momentum plot.

In order to analyse these distributions we made simulations of three processes: 2NA, the ISI and FSI processes. In addition 3N phase space distributions were generated. In each case the detector response was also simulated. It should be noted that the ISI and FSI simulations are very simple, using products of the free 2NA and pion-nucleon or nucleon-nucleon elastic cross sections. These distributions were then fitted to various data distributions with their normalisations as the only free parameters. The result of such a fit is included in Fig. 3. In general it was possible to achieve fair agreement with the data. Further, the fitting procedure showed a clear need for a substantial amount of the ISI simulation, which was confirmed by

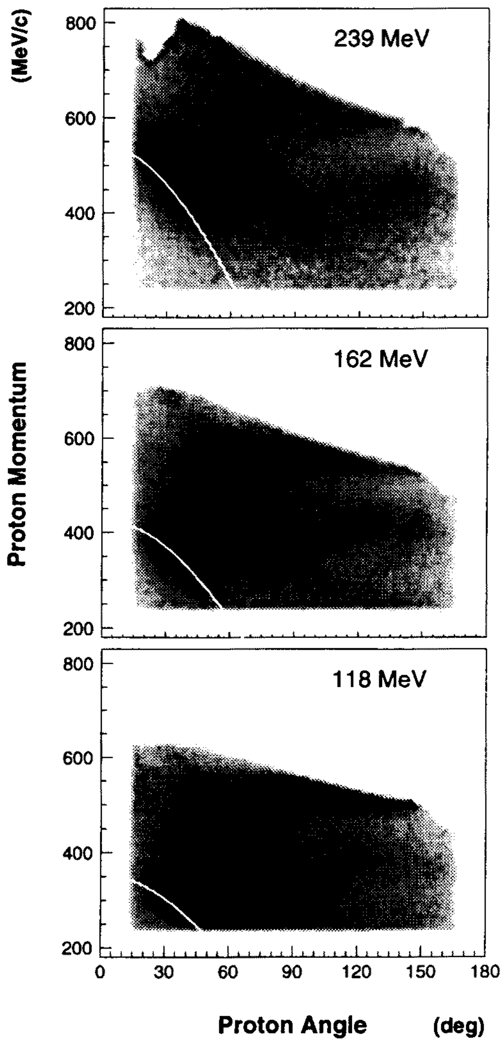

Fig. 2. For the absorption of π^+ by ^{3}He at three incident energies, the correlation between proton angle and momentum for all events in which all protons had at least 30 MeV kinetic energy and were between 15° and 165°. The data are corrected for the detector acceptance. In the forward and backward regions, the protons with the highest kinematically allowed momenta fall outside the acceptance. The white lines show the kinematics of free π^+-p scattering.

examination of the simulations and the data: there are strong qualitative features in the data (such as the peak near the pion mass squared in Fig. 3) shared with only the ISI simulation. On the other hand FSI was not so

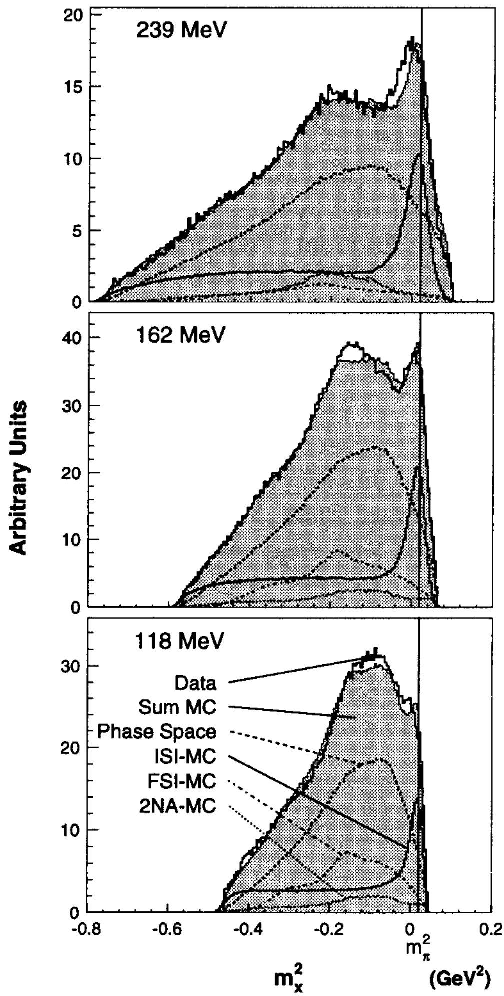

Fig. 3. The spectra of the square of the pseudo-invariant mass, m_x^2, after absorption on ^{3}He, for three incident pion energies, with the same cuts and corrections as applied to the data in Fig. 2. Also shown are the distributions from the simulations (2NA, FSI, ISI and phase space) and their sum, normalised from the fit to the data.

clearly distinguishable from 3N phase space. In this analysis some 15–30 % of the 3NA is attributed to ISI [8].

Examination of 3p final states following absorption on ^{4}He, N and Ar, show features similar to those seen in ^{3}He, when the restriction is applied that the unobserved energy be less than 50 MeV in order to reduce the number of events with a missing fast neutron. Indeed the distributions from ^{4}He are remarkably similar to those from ^{3}He. A preliminary analysis of the Ar data at 240 MeV again indicates a strong ISI yield in that part of the reaction.

In conclusion, a clear, substantial signature of an ISI component in 3NA has been seen. The majority of the 3NA yield was attributed to other processes in the simple analysis presented here, but there is sufficient structure in the data not reproduced well by these models that the true amount of ISI may well be significantly different. A more reliable interpretation of these data awaits a better theoretical approach, such as that presented at this meeting in the talk of H. Kamada.

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