ISSN 1330–0016
CODEN FIZBE7

LETTER TO THE EDITOR

PION ABSORPTION IN ^{4}He

M. PLANINIĆ[h], D. ANDROIĆ[h], G. BACKENSTOSS[a], D. BOSNAR[h], T. DOOLING[f], M. FURIĆ[h], P. A. M. GRAM[c], N. K. GREGORY[d], A. HOFFART[b,g], C. H. Q. INGRAM[g], A. KLEIN[f], K. KOCH[g], J. KÖHLER[a], B. KOTLIŃSKI[g], M. KROEDEL[a], G. KYLE[e], A. LEHMANN[a,g], A. O. MATEOS[d], K. MICHAELIAN[g], T. PETKOVIĆ[h], R. P. REDWINE[d], D. ROWNTREE[d], N. ŠIMIČEVIĆ[d], R. TREZECIAK[b], H. ULLRICH[b], H. J. WEYER[a,g], M. WILDI[a] and K. E. WILSON[d]
(LADS collaboration)

[a] *University of Basel, CH-4056 Basel, Switzerland*

[b] *University of Karlsruhe, D-7500 Karlsruhe, Germany*

[c] *LAMPF, Los Alamos NM 87545, U. S. A.*

[d] *Massachusetts Institute of Technology, Cambridge, MA 02139, U. S. A.*

[e] *New Mexico State University, Las Cruces, NM 88003, U. S. A.*

[f] *Old Dominion University, Norfolk, VA 23529, U. S. A.*

[g] *Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland*

[h] *University of Zagreb, HR-10000 Zagreb, Croatia*

Received 3 February 1999; Accepted 7 June 1999

This paper presents a large solid angle measurement of the positive pion absorption cross-section on ^{4}He and its decomposition into partial channels. A large fraction of the absorption cross-section at incident pion kinetic energies of T_{π^+}=70, 118, 162, 239, and 330 MeV is due to multinucleon channels.

PACS numbers: 25.80.Hp, 25.10.+s UDC 539.126

Keywords: positive pion absorption in ^{4}He, cross-sections of partial channels, multinucleon channels: (pp)d/pn, (pn)pp, (pd)p, (ppp)n, (ppn)p, (ppd), (pppn)

Pion absorption in nuclei is a very important reaction around the Δ resonance region which has an explicit connection to certain CEBAF physics: it forms typically about half of the π-nucleus reaction cross-section; thus it is also important in the interaction of other probes such as electrons in the GeV region. We know that an important mode in the absorption process involves an isoscalar nucleon pair in the absorption process (2NA), but a significant fraction of the total absorption cross-section leads to at least three energetic, unbound nucleons in the final state - multi-nucleon absorption (MNA). The existence of a three-nucleon pion absorption (3NA) mode was first established on the nucleus ^{3}He [1]. To clarify the question, whether this could be due to a new coherent mechanism, it is also important to know if and how the mode appears in heavier nuclei. In this context the nucleus ^{4}He is unique. Its nuclear density is already comparable to that of heavy nuclei and all important final state channels are open including the ones with fast deuterons.

The LADS 4π solid angle detector [2] was built at PSI to clarify the nature of MNA. It is a 4π detector, sensitive to protons, neutrons and deuterons, with the threshold for nucleon detection about 20 MeV. It also has good kinematic definition (ca 10 MeV FWHM) and neutral pion/neutron separation. The lack of at least one of these properties in all earlier experiments contributed significantly to ambiguity in the interpretation of their results.

The main purpose of this experiment was to determine the composition of the absorption cross-section. For this, but also to correct the raw data for detector inefficiencies and acceptance (mainly threshold) limitations, simulations of various reaction dynamics were used to generate raw distributions of protons, neutrons and deuterons. These were input into a simulation of the detector and passed through the same analysis chain as the real data. The resulting distributions, over various kinematic variables such as proton angle and energy, were then simultaneously fitted to the data with only their normalisations as free parameters. The integral(s) of the raw distributions thus normalised then provided total and partial absorption cross-sections. It should be noted that the models used here were simple semi-classical ones, but they reproduced the overall distributions well, and since the full correction for the detector inefficiency and acceptance limitations was typically only a factor of 2 - 3, the resulting cross-sections should be reliable.

The LADS results on ^{4}He [3,4], show substantial 3NA strength that becomes stronger with increasing incident pion energy (from about 33 % at 70 MeV to roughly 44 % at 239 MeV) . An example of the composition of absorption on ^{4}He is given in Table 1 [4]. Here it can be seen that in the 3NA channel the 2p1n final

TABLE 1. Composition of the π^+-^{4}He *absorption cross-section at 162* MeV *[4,5].*

Final state	% of σ_{abs}	Class	% of σ_{abs}
(pp)d/pn	47%		
(pn)pp	3%	2NA	54 ± 7%
(pd)p	4%		
(ppp)n	12%		
(ppn)p	21%	3NA	43 ± 7%
(ppd)	10%		
(pppn)	3%	4NA	3 ± 1%

state is almost twice as important as the 3p one; this "preference" for neutrons over protons is a general feature observed also in the heavier nuclei and at higher multiplicities. This isospin selectivity through the preference for the ppn over the ppp final state, is seen at all energies (Fig. 1) . It can also be seen that, while 3NA is strong, 4NA is weak.

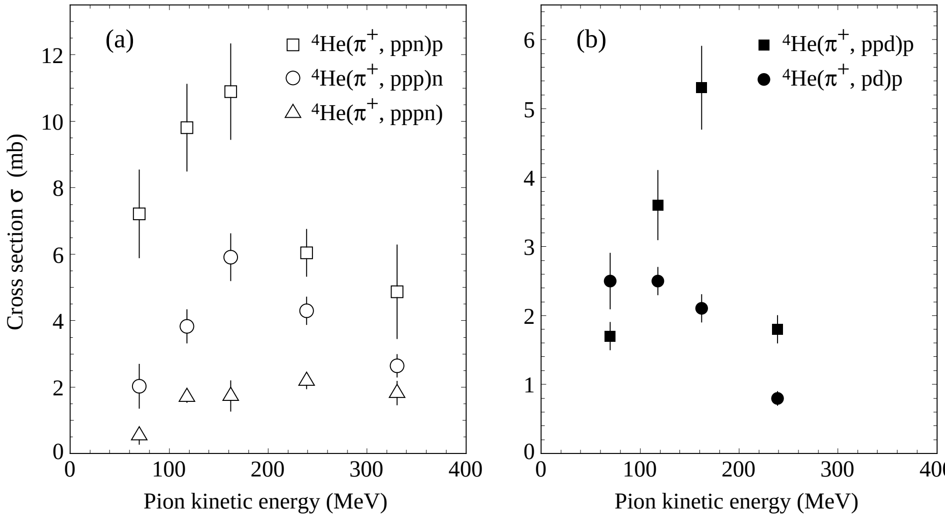

Fig. 1. (a) Decomposition of the ^{4}He pppn *yield according to the energetic final state particles.(b) Cross-sections of the deuteron final states.*

The ppd final state consists primarily of contributions from the (pd)p and (ppd) channels ((pd)p is the channel where one proton was only a spectator).

The distributions of the (pd)p channel could be described in two ways. In the first, they are consistent with the distributions of the model where pion is absorbed on a quasitriton [^{3}H(π^+,pd)] with one proton acting as a spectator [5]. In the second, they are consistent with being due to pick-up by an outgoing nucleon. Comparison of the differential distributions of the (pd)p channel with the model in which pion absorption takes place on a quasideuteron pair, followed by the pickup of a neutron by one of the outgoing protons shows that the overall agreement is good [5]. In such a picture the proton and deuteron are emitted roughly back-to-back with the deuteron preferentially at backward angles. The preference for the emission of the deuteron at backward angles can be qualitatively explained as being due to the smaller momentum transfer necessary for the pick-up reaction at these angles. The cross-section attributable to the (pd)p process falls steadily with increasing incident pion energy (Fig. 1) while the energy dependence of the (ppd) cross-section shows a broad resonancelike behaviour peaking somewhere around 160 MeV.

From an investigation of specific differential cross-sections we could conclude that there is a significant signal of the ISI (pion quasi-free scattering before absorption) mechanisms in the $3NA_{(ppn,ppp,ppd)}$ channels. However, our simple models suggest that this process (ISI) amounts to only some 30% of the full 3NA yield (or 10% of σ_{abs}). The remaining 70% of the 3NA yield is rather featureless, resembling three-nucleon phase space, and with no strong indication of another process such as proton-proton rescattering (FSI), and its origin remains unexplained. One may note that if the relative strengths of ISI and FSI reflect the elementary π- and N–N cross-sections, one would expect the latter to be weaker; a recent calculation by Kamada et al. [6] also suggests this.

As a summary, LADS has produced accurate total absorption cross-sections, and the first reliable partial cross-sections as a function of final state multiplicity for pion absorption on ^{4}He, from 70 to 330 MeV. In order to understand the substantial MNA yield, it remains imperative to have a realistic calculation of 3NA.

References

1) G. Backenstoss et al., Phys. Rev. Lett. **55** (1985) 2782;
2) T. Alteholz et al., Nucl. Instrum. Methods A **373** (1996) 374;
3) A. Lehmann et al., Phys. Rev. C **56** (1997) 1872;
4) A. O. Mateos et al, Phys. Rev. C **58** (1998) 942;
5) M. Planinić, Ph.D. thesis, University of Zagreb, in preparation;
6) H. Kamada et al., Phys. Rev. C **55** (1997) 2563.

PIONSKA APSORPCIJA U ^{4}He

Daju se ishodi mjerenja pod velikim prostornim kutom udarnog presjeka za apsorpciju pozitivnih piona u He^4 i razdjela na pojedine kanale. Velik dio apsorpcijskog udarnog presjeka za energije upadnih piona od T_{π^+}=70, 118, 162, 239 i 330 MeV je posljedica višenukleonskih kanala.