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MULTINUCLEON EMISSION FOLLOWING THE PION ABSORBTION IN N, Ar AND Xe

DARKO ANDROIĆ[h], G. BACKENSTOSS[a], DAMIR BOSNAR[h], T. DOOLING[f], 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. KOEHLER[a], B. KOTLIŃSKI[g], M. KRÖDEL[a], G. KYLE[e], A. LEHMANN [a,g], A. O. MATEOS[d], K. MICHAELIAN[g], TOMISLAV PETKOVIĆ[h], MIRKO PLANINIĆ[h], R. P. REDWINE[d], D. ROWNTREE[d], NEVEN ŠIMIČEVIĆ[d], R. TREZECIAK[b], H. ULLRICH[b], H. J. WEYER[a,g], M. WILDI[a] and K. E. WILSON[d]

[a]*University of Basel, CH-4056 Basel, Switzerland*
[b]*University of Karlsruhe, D-7500 Karlsruhe, Germany*
[c]*LAMPF, Los Alamos, NM 87545, USA*
[d]*Massachusetts Institute of Technology, Cambridge, MA 02139, USA*
[e]*New Mexico State University, Las Cruces, NM 88003, USA*
[f]*Old Dominion University, Norfolk, VA 23529, USA*
[g]*Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland*
[h]*University of Zagreb, HR-10000 Zagreb, Croatia*
(LADS Collaboration)

Dedicated to Professor Kseno Ilakovac on the occasion of his 70$^{\mathbf{th}}$ birthday

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Positive pion absorption was studied in an almost 4π geometry allowing simultaneous measurements of various charge and neutral multiplicities. Total absorption cross sections and its decomposition into the most important channels is determined. The results are presented for N, Ar and Xe nuclei at incident pion energies of 118,162 and 239 MeV. The role of multinucleon emission in the absorption process is emphasized.

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1. Introduction

For quite some time [1, 2], studies of mechanisms for pion absorption in nuclei have been concentrated around the well-known discrepancy between the total pion absorption cross section and the directly measured absorption cross section for the absorption on a nucleon pair [3, 4, 5]. Namely, for a long time, absorption on a nucleon pair was expected to dominate the absorption process. The simplest absorption mechanism on a single nucleon is suppressed as the energy/impulse to be released on the account of the absorbed pion mass does not match the nucleon Fermi momentum within the nucleus. The smallness of the absorption cross section on a single nucleon was also experimentally verified. Therefore, there was a prevailing expectation of the dominance of the pionic absorption by the absorption mode on two nucleons. However, the mentioned discrepancy between the total absorption cross section and its 2N-component, stimulated experimental developments aiming to carefully monitor the events with higher than two multiplicities. Instruments such as LADS at PSI and BGO ball at LAMPF have been developed for that purpose.

We report here the results on a large number of absorption channels accumulated at three incident pion energies (118, 162 and 239 MeV) with N, Ar and Xe targets. The comparison of contributions of various multiplicities explains the composition of the total absorption cross section. It also demonstrates the important role of the multinucleon emission that increases with the incident pion energy. This provides a crucial step in the solution of the long-standing puzzle.

2. *Experiment*

The data were accumulated at the Paul Scherrer Institute (PSI) using the Large Acceptance Detector System (LADS) [6] built to investigate the multinucleon pion absorption (see Fig. 1). The detector consisted of several laminated scintillator cylinders with coaxial wire chambers. The system possessed fine position resolution (e.g. 1° FWHM in angle). Gas targets were used to minimize the particle energy losses within the target ensuring clear vertex reconstruction. Applied gas pressure were 39, 29 and 19 bars for N, Ar, Xe targets respectively.

The details of our data treatment can be found elsewhere [7]; here we give only the basic procedures. Events with well defined vertices within the target region were analyzed. The timing and gain parameters were obtained from the ^{2}H and He runs. Events with a charged or neutral pion in final state were cut out. Absorption candidates were tagged according to the number of charged particles and neutrons in the final state. For charged particles, only those with energy higher than 30 MeV (for protons) could be detected.

Beside that, cut on energy for each neutron detected in final state is applied. So in final results 3N and 4N channels are populated with particles with energy threshold. This procedure ensures that low energy neutrons, especially present in xenon data, possibly comming from the highly excited nucleus, are cut out from high multiplicity channels and added to lower ones. This conservative procedure ensures that percentage of 2N contribution is certainly upper limit for two nucleon absorption.

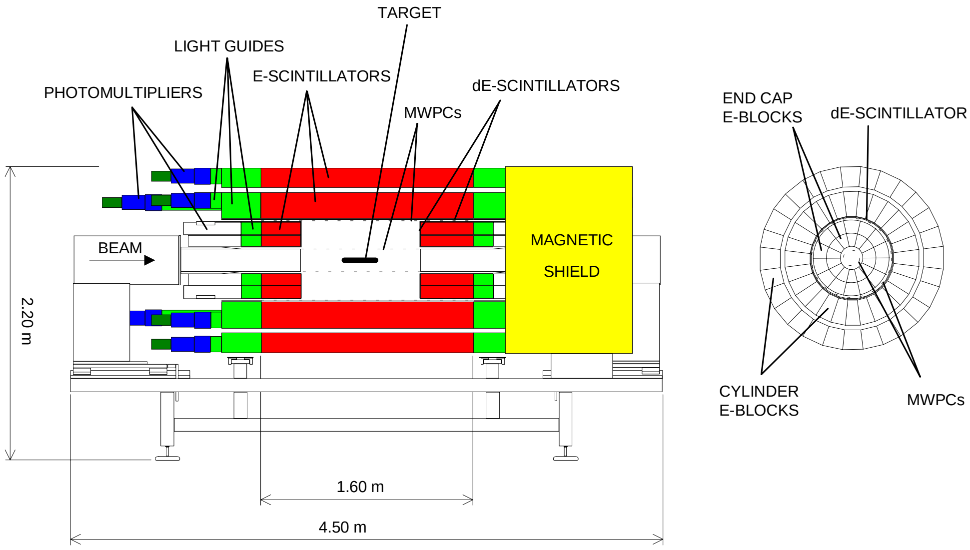

Fig. 1. The LADS detector.

3. *Results*

Common feature for all targets and energies analyzed is the significant difference between the detected particles energy and the available reaction energy. This can be explained either with undetected neutron(s) in final state or high excitation of recoiled nucleus. These two processes have no obvious signature in data for straightforward distinguishing. Only nitrogen data have direct 2NA signature. That means that only in nitrogen data portion of events comes with small excitation energy of remaining nucleus.

Successive subtraction is performed on histograms filled with detected events and final Monte Carlo correction is made for uncovered phase space. This procedure is main source of errors and depends on quality and quantity of available data.

First, we present the data on the raw experimental multiplicities for the pion absorption channels in the form of percentages with which a particular final absorption channel contributes to the total absorption cross section. In the next step, a correction is made for the migration of the events among these classes which occurs because of the inefficiency of the neutron detector. Finally, we lump together some channels in order to emphasize the contributions of the two nucleon (2N), three nucleon (3N) and four nucleon (4N) final states in the total cross section.

In Table 1, the starting percentages for various combinations of final particles (protons-p, deuterons-d and neutrons-n) are given. One can see that the three-nucleon emission provides a significant part of the absorption cross section.

TABLE 1. Experimental percentages of absorption channels. All protons have kinetic energy greater than 30 MeV and detection polar angle $15^\circ \leq \theta \leq 165^\circ$*. Channel contributions smaller than 0.1% are not given.*

Channel	Nitrogen			Argon			Xenon		
T_π(MeV)	**118**	**162**	**239**	**118**	**162**	**239**	**118**	**162**	**239**
pp	50.2	40.1	29.0	44.2	39.6	21.1	62.1	55.3	47.2
ppn	10.3	16.5	17.4	18.1	16.8	20.4	7.1	10.1	10.9
ppnn	1.1	2.8	2.9	3.4	6.1	10.1	1.2	0.8	0.7
ppnnn		0.2	0.2	0.5	1.2	2.9		0.1	0.1
pd	9.4	5.3	3.2	4.1	4.2	2.2	16.1	11.9	12.1
pdn	1.4	2.0	3.0	2.8	3.0	4.6	1.2	3.1	3.2
pdnn		0.1	0.2	0.4	0.9	1.9		0.1	
ppp	12.9	14.6	12.4	14.1	11.1	8.7	4.4	6.2	7.7
pppn	1.9	4.5	8.3	2.8	3.6	7.9	0.2		3.3
pppnn		0.2	2.1	0.3	1.1	2.3		1.3	
ppd	5.3	4.7	5.5	4.8	4.5	3.1	1.7	4.5	6.8
ppdn	1.8	1.2	2.7	0.6	1.2	3.0		0.6	0.9
ppdnn			0.6		0.3	0.9			
pppp	0.2	0.7	1.7	0.1	0.4	1.7	0.2	0.4	0.4
ppppn	0.1	0.3	1.1		0.3	1.9			
pppd	0.1	0.9	2.0		0.4	1.7			
pppdn		0.2	1.2		0.1	0.6			
pn	4.9	5.2	6.1	3.5	5.0	4.9	5.1	4.8	5.9
dn	0.4	0.5	0.4	0.3	0.2	0.1	0.7	0.8	0.8

In order to count properly events with, e.g., two protons and a neutron in the final state, with respect to those in which the detector registered two protons only, one must carefully treat events with one more neutron detected. Namely, their number should be compensated for the fact that in the simple counting of events with only two protons tagged, events with one emitted neutron are present but misidentified due to the inefficiency of the neutron detector. We know the angular and energy dependence of the neutron detection from our ^{4}He(π^+,pppn) measurements and we compensate for the inefficiency effects.

In Table 2, the total absorption cross sections are presented. In Fig. 2 is shown the decomposition of the total cross section according to the number of emitted nucleons. One observes that the 2N emission after pion absorption is never the only contribution to the total cross section. Also, as the energy increases, multiple emission of nucleons becomes more probable.

TABLE 2. Total pion absorption cross sections for the full solid angle. The values for argon and nitrogen are already published results [8]. Error differences are correlated with quality and quantity of relevant experimental data and procedures of extrapolation.

	Nitrogen	Argon	Xenon
118MeV	182 ± 10 mb	393 ± 21 mb	623 ± 140 mb
162MeV	163 ± 11 mb	366 ± 22 mb	736 ± 160 mb
239MeV	107 ± 10 mb	282 ± 21 mb	652 ± 100 mb

Nitrogen target shows common features of light nuclei. Pion absorption on them predominantly leads to the low excitation modes of the remaining nucleus. For heavy nuclei, in contrast, much higher excitations of the remaining nucleus is achieved. For this reason, some similarity between the nitrogen and xenon results should not be seriously pursued.

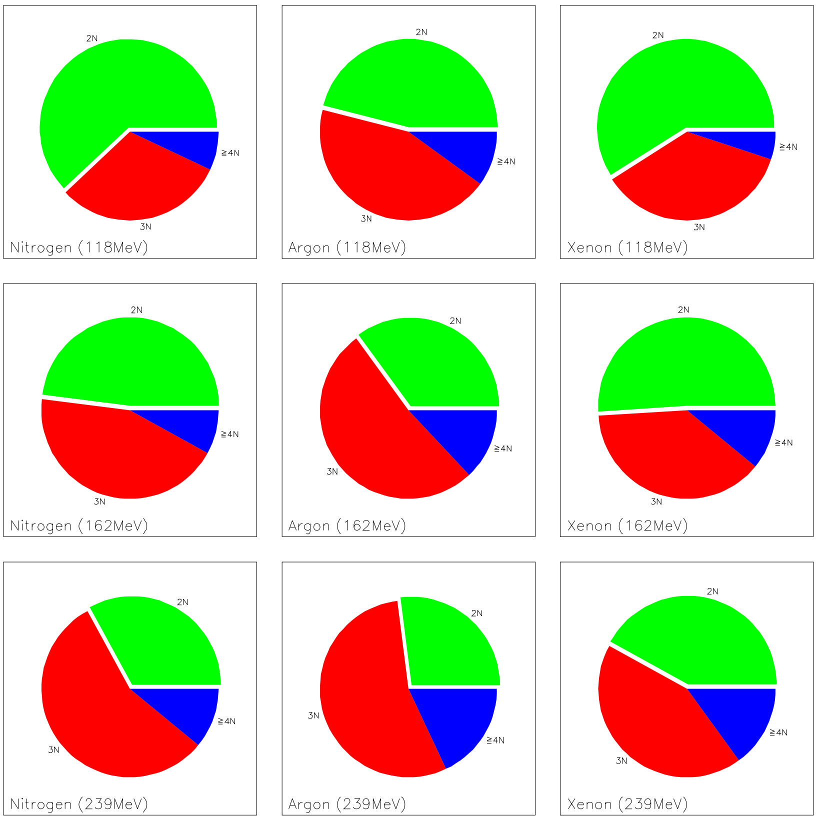

Fig. 2. Graphical presentation of multinucleon emission after absorption of a positive pion for different channels.

4. Conclusions

While in the early experiments the total absorption cross section was measured indirectly through the pion disappearance, we see through direct measurement that a large portion of the absorption events goes into the multiplicities higher than two. This component was previously unaccounted for in measurements with small solid angle detectors. While the detailed mechanisms of the multinucleon emission during the process of pion absorption still remain to be investigated, we now understand the origin of controversy plagueing the earlier measurements.

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VIŠENUKLEONSKA EMISIJA NAKON PIONSKE APSORPCIJE U N, Ar I Xe

Proučava se pionska apsorpcija s blizu 4π detekcijom koja dozvoljava istovremeno mjerenje raznih nabojskih i neutralnih višestrukosti. Odreduju se ukupni udarni presjeci i njihovo razlaganje u najvažnije kanale. Predstavljaju se rezultati za jezgre N, Ar i Xe na energijama 118,162 i 239 MeV. Ističe se uloga višenukleonske emisije u procesu apsorpcije.