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Few-Body Systems

Pion Absorption in Helium with the LADS Detector

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Abstract. Investigations on π–absorption on Helium reveal a substantial part of the absorption cross section to be multi–nucleon absorption. A careful search for different reaction mechanisms shows clear signatures of initial state interaction, whereas most of the multi–nucleon absorption follows a phase space like distribution. In comparable conditions the signatures look alike for either ^{3}He and ^{4}He. Fits of Monte Carlo simulations to the data give first results on the partial cross sections in ^{3}He.

1 Introduction

1.1 Motivation

π–absorption on nuclei is known to be a large fraction of the interaction cross section and therefore has been a field of interest for many years. Especially on light nuclei like ^{3}He and ^{4}He, there is the possibility to investigate the basic processes of π–absorption. The basic process seems to be understood, but earlier experiments have shown the existence of more complex mechanisms contributing to the absorption cross section [2, 3, 4, 5]. In this work, I'll concentrate on processes where more than two nucleons are involved.

1.2 Absorption Mechanisms

By energy and momentum conservation π–absorption is forbidden on a free nucleon and heavily suppressed on a single nucleon inside a nucleus. Therefore the simplest mechanism involves a nucleon pair on which the pion is absorbed. The remaining $(A-2)$–nucleus is acting as a spectator. This basic two nucleon absorption ($2N$A) is quite well understood and seems to be dominated by a rescattering process involving a formation of the Δ intermediate state. This basic mechanism can be seen in a momentum density distribution of the least energetic proton in the reaction $^3\mathrm{He}(\pi^+, ppp)$ like Fig. 1. In the plot the $2N$A

*complete list see e.g. [1]

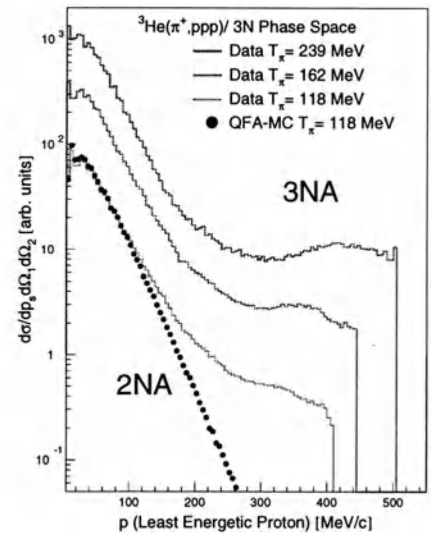

Figure 1. Acceptance Corrected Momentum Density Distribution of ^{3}He(π^+, ppp), T_π=239 MeV

also reported as Quasi Free Absorption (QFA) shows a fermi momentum distribution which rapidly decreases with increasing proton momentum. Note the y-axis is logarithmic. As a comparison at the lowest curve a QFA-simulation is plotted on top of the data. A clear deviation from the $2N$A picture is seen at higher proton momenta suggesting other mechanisms involving all nucleons. In ^{3}He those mechanisms will be referred to as three nucleon absorption ($3N$A), whereas in ^{4}He as multi–nucleon absorption (nNA). $3N$A (nNA) could be either multistep processes or some other process acting on all nucleons. Because of the phase space-like distribution at the low energy (118 MeV) it was suggested [2] that there exists a $3N$A process which can be described by a constant matrix element. But there is no conclusive theory available yet.

Earlier experiments did not identify multistep processes. The new data shows a structure at higher momenta, which depends on the pion energy. As the origin of this, we consider multistep processes where we distinguish in a simple approach two different mechanisms: Initial State Interaction (ISI), where the pion first scatters off one of the protons and is then absorbed on the remaining nucleon pair; or Final State Interaction (FSI) where the pion is absorbed first and one of the outgoing protons interacts with the spectator nucleon(s).

2 Experiment

To investigate multi–nucleon absorption, a 4π detector LADS (= Large Acceptance Detector System) has been built at PSI in Villigen Switzerland and experiments on different target nuclei (D, ^{3}He, ^{4}He, N, Ar, Xe) have been performed around the Δ-resonance energy. An extensive description of the detector will be published soon in NIM [6]. The advantage of LADS over previous experiments is the possibility of measuring multi–nucleon final states with complete information on all particles involved. Also good energy and angular resolution is obtained covering as much as 98% of the total solid angle. Having low proton thresholds gives an almost complete phase space coverage.

3 Analysis

3.1 Observables

One of the major points in the analysis is to give a convenient set of variables to describe multi–nucleon final states. In the case of ^{3}He it helps that the three protons form a plane in the CM-system. This plane and the orientation of the event in respect to this plane can be described by the Euler angles, where ξ describes the orientation of the plane relative to the incident pion and γ the rotation of the event in the plane. Because there is no polarization involved in our experiment, there is no dependence on the third Euler angle describing azimuthal properties. To describe the event completely it is sufficient to show in addition to ξ and γ two of the opening angles, or equivalently two of the particles' energies (Dalitz–plot).

In the case of the search for ISI, we have used the proposal of Salcedo et al. [7] to reconstruct the pseudo invariant mass of the intermediate pion. A contribution of ISI should show up as a peak in the pseudo invariant mass spectrum at the pion mass squared.

3.2 Monte Carlo Simulation

The simulations which were made to assist interpretation of the results used the CERN GEANT [8] package. All processes already discussed earlier were treated. The simulation also included the correct acceptance of the detector and all known losses due to reactions, particle misidentification, chamber efficiencies and reconstruction combinatorics. Tests in the $\pi d \rightarrow pp$ channel have shown good agreement with the data. All event generators including a $2N$A process (QFA,ISI,FSI) used a parametrization of the angular distribution by Ritchie et al. [9]. In addition the ISI-simulation used measured cross sections (SCATPI) [10] for πp knockout, whereas $N - N$ cross sections from SAID [11] were used for the FSI simulation.

In addition a three-body phase space simulation was done. The data shows a preference of multi–nucleon absorption to be in plane compared to phase space calculations. It can be shown that this can be linked to angular momentum in the same way as angular momentum is introduced by including a Legendre term in the angular distributions of the $2N$A [12]. Therefore, like in $2N$A, a second order Legendre term $P_2\{\cos(\xi)\}$ was introduced into the phase space simulation.

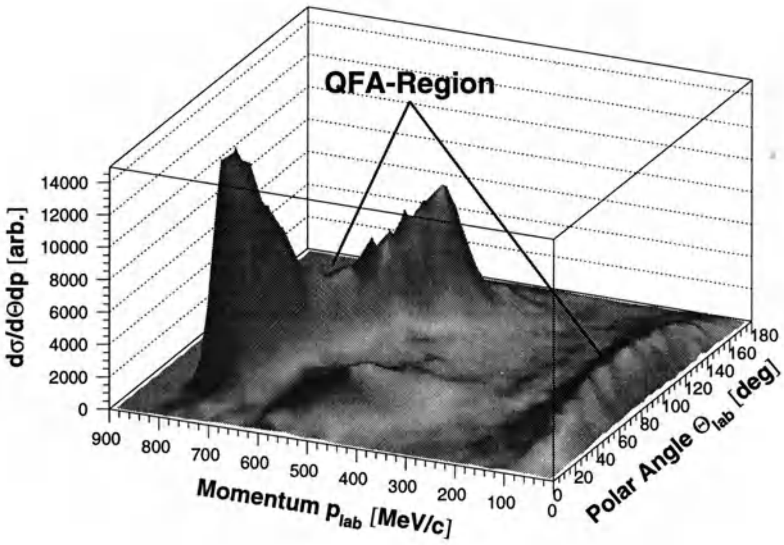

Figure 2. Θ_{lab} vs. p_{lab}, T_π=239 MeV

4 Results

4.1 ISI Signatures

A striking signature for ISI can be found in the correlation between the polar angle Θ and the momentum p in the lab–system. Figure 2 shows the Θ_{lab} vs. p_{lab} correlation of all protons in the reaction $^3\mathrm{He}(\pi^+,ppp)$ at T_π=239 MeV. One can clearly identify the regions of QFA, seen as two large peaks at high momenta showing the typical angular distribution as well as the broad bump of the spectator at low momenta. Beside these structures there is a band at forward angles visible which indicates πp knockout. Figure 3a) shows the same correlation but with a 30 MeV threshold on all protons to get rid of the QFA. On top of the distribution the free πp kinematics is drawn. As is seen the structure at forward angles agrees well with the kinematic line. Figure 3b) and c) show the correlation of the pseudo invariant mass squared m_x^2 versus p_{lab} and Θ_{lab} respectively. All possible combinations of m_x^2 are taken into account and plotted versus the remaining proton. For the ISI a peak is expected at the pion mass squared and indeed this structure is found in both plots. In addition a comparison of all plots shows that the structure in Fig. 3a) is reflected in the two other plots in the peaks at the pion mass squared. The simulation supports this picture by showing that this structure at forward angles can only be reproduced by the ISI simulation.

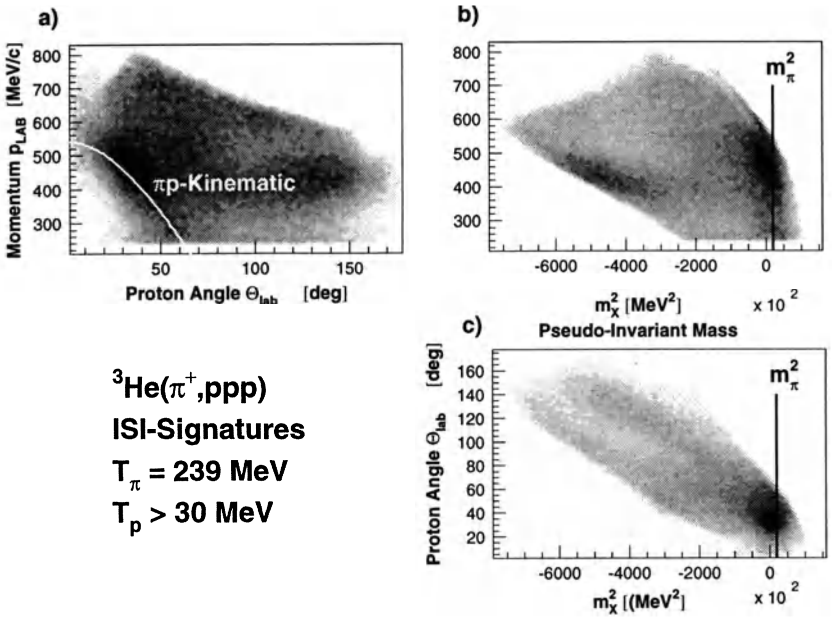

Figure 3. Signatures for ISI in ^{3}He(π^+, ppp), a) Θ_{lab} vs. p_{lab} , b) m_x^2 vs. p_{lab} , c) m_x^2 vs. Θ_{lab}

4.2 Fit Results

Various fits have been performed, to get the partial and the total cross sections on ^{3}He(π^+, ppp). As an example, Fig.4 shows the results for $T_\pi = 239$ MeV on m_x^2. The numbers give the relative absorption cross sections not acceptance corrected. The fit agrees well and it is clear that only the ISI simulation is able to explain the strong peak at the right. The variables used in this fit are $\gamma, \xi, \Delta\Theta_{\mathrm{max}}, \Delta\Theta_{\mathrm{min}}$, hence the complete set of variables discussed in 3.1. Table 1 gives a breakup of the ^{3}He absorption cross section. The results of the total cross sections based on the analysis of the partial cross sections agree

Table 1. Partial and Total Cross Sections of ^{3}He(π^+, ppp)

T_π	[MeV]	118		162		239	
σ_{Total}	[mb]	27.1 ± 0.8		23.9 ± 1.0		10.4 ± 0.7	
σ_{QFA}	[mb]	19.4 ± 1.0		15.9 ± 1.3		6.2 ± 0.6	
σ_{3N}	[mb]	7.7 ± 1.0		8.0 ± 1.2		4.2 ± 0.4	
$\sigma_{3N}^{\mathrm{PS}}$	[mb]	4.9 ± 1.1	64%	5.6 ± 1.2	70%	2.7 ± 1.1	65%
σ_{ISI}	[mb]	1.9 ± 0.6	25%	1.9 ± 0.8	24%	1.4 ± 0.4	33%
σ_{FSI}	[mb]	0.9 ± 0.6	11%	0.4 ± 0.8	6%	0.1 ± 0.5	2%

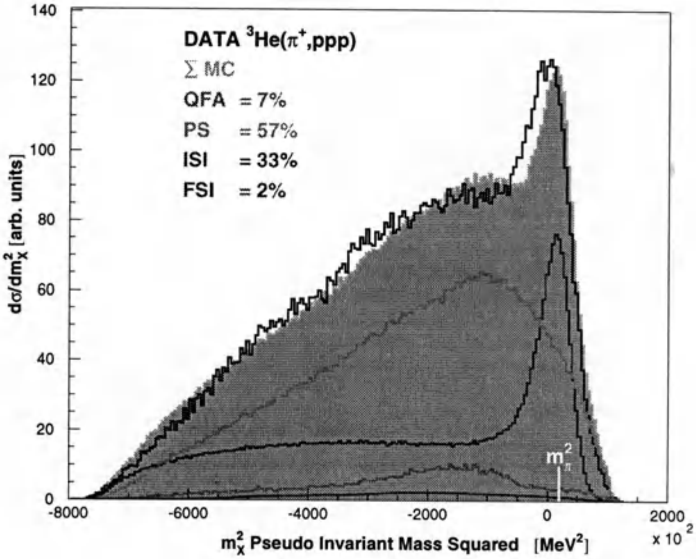

Figure 4. Fit of m_x^2 in $^3\mathrm{He}(\pi^+, ppp)$, $T_\pi = 239$ MeV, $T_p > 30$MeV

within errors with the numbers from [1]. Deviations in the breakup of the cross sections into $2N$A and $3N$A can be explained by the number of models taken into account in the fit. The error bars reflect the uncertainties using different sets of variables in the fit, and do not include errors on model dependencies. All numbers in Tab. 1 are preliminary.

The simulation can be used to correct for acceptance losses, as in Fig. 1. In Figs. 2,3 we do not use the acceptance correction. That is reflected in a small angle cut–off for QFA and a strong suppression at high momenta and small angles. For the fit, no acceptance correction was applied to the data, but the acceptance losses were included in the simulation. For the calculation of the results in Tab. 1, the acceptance correction is taken into account by using the simulation with and without the acceptance correction.

4.3 Comparisons to ^{4}He

To compare ^{4}He to ^{3}He, the same conditions on the data set are required. This can be achieved by limiting the analysis to those events where three protons are measured, and the extra nucleon (here the neutron) has a momentum lower than 200 MeV/c and is therefore considered as a spectator. The system of the three outgoing protons is selected as the reference system. This choice allows us to describe the event with the set of variables described in 3.1.

There is a striking similarity of the different plots of both isotopes. Especially the Θ_{lab} vs. p_{lab} plot and the complete set of variables (γ, ξ, $\Delta\Theta_{\max}$,

$\Delta\Theta_{\min}$) are almost identical. Only the peak in m_x^2 is not very pronounced in ^{4}He, but this can be explained by the broadening due to the extra nucleon, which is not completely at rest.

5 Summary

The present analysis shows for the first time a clear signature for ISI in the reactions ^{3}He(π^+, ppp) and ^{4}He(π^+, ppp)n. In the case of ^{3}He it is possible to evaluate the partial cross sections using simulations of simple reaction models. The strength of the ISI is between 20 and 35 % of the 3NA whereas FSI seems to be small. The remaining part of the 3NA cross section shows a phase space like behaviour where we still lack theoretical explanations. There is a strong indication that taking into account the orbital angular momentum brought by the pion explains the data better. The similarity of ^{3}He and the special case in ^{4}He described in 4.3 suggests that the same 3NA processes occur in ^{4}He as in ^{3}He.

The results of ^{3}He will be published soon [13], concentrating on the signatures of ISI, while theoretical calculations on the 3NA will be performed in the near future. These calculations will help to answer some of the still open questions in π–absorption.

References

1. T. Alteholz et al.: Phys. Rev. Lett. **73**, 1334 (1994)
2. P. Weber et al.: Nucl. Phys. **A534**, 541 (1991)
3. S. Mukhopadhyay et al.: Phys. Rev. **C43**, 957 (1991)
4. H.J. Weyer: Phys. Rep. **195**, 295 (1990)
5. R.D. McKeown et al.: Phys. Rev. **C24**, 211 (1981)
6. D. Androić et al.: Nucl. Inst. Meth. (in preparation)
7. L. Salcedo, E. Oset and D. Strottmann: Phys. Lett. **B208**, 339 (1988)
8. Application Software Group: Comp. Net. Div., CERN Geneva, Schweiz
9. B. Ritchie: Phys. Rev. **C49**, 553 (1991)
10. J.B. Walter, G.A. Rebka Jr.: Techn. Rep. LA-7731-MS LAMPF 1979
11. R.A. Arndt et al.: Phys. Rev. **D32**, 1085 (1985)
12. N. Simičević, A. Mateos: Phys. Rev. **C51**, 797 (1995)
13. D. Androić et al.: Phys. Lett. (in preparation)