Energy dependence of ^{58}Ni(π^+,π^-)^{58}Zn double charge exchange

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Differential cross sections for the double-isobaric analog-state transition in the ^{58}Ni(π^+,π^-) reaction were measured at 5° for eight incident energies between 120 and 292 MeV, inclusive. The results are compared with theoretical calculations and with previous data for $T = 1$ targets, and mass dependence is discussed.

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I. INTRODUCTION

Double charge exchange (DCX) on T=1 nuclei leading to double isobaric analog states (DIAS) has been an interesting subject in pion-nuclear physics [1–4]. In this reaction, two extra neutrons are converted into two protons, and this process should be a good probe to study correlations among nucleons. To date, measurements of the forward-angle excitation function of (π^+,π^-) DCX on T=1 targets have been reported for four nuclei. In Fig. 1, we display the DIAS data for these targets [2,3,5]. Additional measurements exist, at 292 MeV only, for targets of ^{30}Si [4], ^{34}S [4], and ^{58}Ni [4,6,7].

For ^{18}O, the energy dependence is that of a peak 60–80 MeV wide centered near 140 MeV and a monotonic increase of the cross section between 200 and 300 MeV. For ^{26}Mg and ^{42}Ca, the excitation function seems to have a similar trend, but the data are much sparser. The excitation function for ^{14}C appears to monotonically increase from a lower energy around 140 MeV up through 300 MeV. For all DIAS data, the dependence of the forward-angle cross section on target mass is roughly $A^{-10/3}$ [8], in agreement with the geometric model of Johnson [9]. However, if only $T = 1$ nuclei are considered, the A dependence [10] is $A^{-7/3}$, not $A^{-10/3}$.

In this paper, we present results of a recent measurement of the excitation function for ^{58}Ni(π^+,π^-)^{58}Zn (DIAS) and compare it with theoretical calculations. Mass dependence of DCX DIAS for T=1 targets is discussed.

II. EXPERIMENT

The experimental measurements were performed with the small-angle DCX setup at the EPICS channel of the Clinton P. Anderson Meson Physics Facility (LAMPF). The measurement was carried out at a laboratory angle of 5° for eight beam energies between 120 and 292 MeV. The targets used included three pieces of enriched ^{58}Ni metal (1.2, 0.6, and 3.7 g/cm^2, respectively). Normalizations of DCX cross sections were obtained by measuring relative yields for ^{1}H(π^+,π^+)^{1}H for all incident beam energies at a laboratory angle of 35° with three 0.07 g/cm^2 CH_2 targets, having the same sizes as the ^{58}Ni pieces.

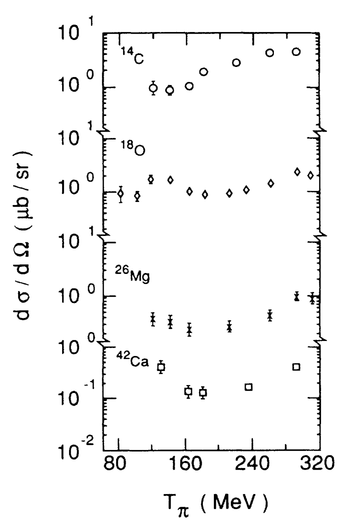

FIG. 1. Cross sections, at 5°, for double charge exchange on T=1 targets of ^{14}C, ^{18}O, ^{26}Mg, and ^{42}Ca. Data are from Refs. [1–5].

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TABLE I. Cross sections as a function of energy at 5° laboratory for ^{58}Ni(π^+,π^-)^{58}Zn (g.s.).

T_π (MeV)	$\frac{d\sigma}{d\Omega}$(nb/sr)
292	135±30
260	125±21
230	109±27
200	53±15
180	36±13
164	41±14
140	41±16
120	47±21

These yields were compared with cross sections calculated from π-nucleon phase shifts [11] to obtain absolute normalization factors.

The technique of computing the best weighted average of a set of measurements with poor statistics is not always clear. In the present data, we have three determinations of the cross section at each energy— from the three separate ^{58}Ni targets (two at 292 MeV). At each energy each cross section is given by $\sigma_i = \frac{Y_i}{q_i}$, where Y_i is the number of counts in the background-free ^{58}Zn (g.s.) and q_i contains all the normalization factors. The q_i are energy and run-time dependent, but the ratio of q_i's for the different targets is basically constant. To get a single cross section at each energy, we compute $\sigma = Y/q$, where $Y = \sum Y_i$, and $q = \sum q_i$.

III. RESULTS

The excitation function of ^{58}Ni(π^+,π^-)^{58}Zn (DIAS) is shown in Fig. 2, and cross sections are listed in Table I. The obvious peak around 140 MeV for ^{18}O is absent in the excitation function of ^{58}Ni. However, ^{58}Ni is not identical to ^{14}C either. Data for ^{58}Ni are compared with theoretical calculations in Fig. 3. These were performed with the code SHIN [2,10], using the sequential process, in which we have assumed different kinds of configurations. One is for a pure transition from $\nu(2p3/2)^2$ to $\pi(2p3/2)^2$

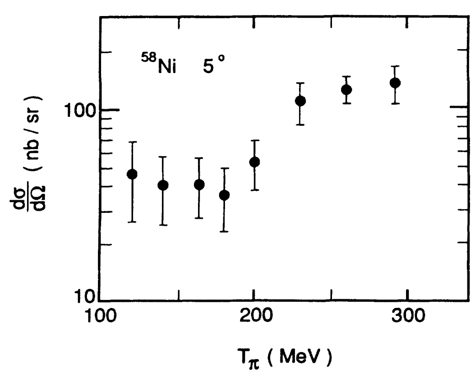

FIG. 2. Differential cross sections, at 5°, for DCX on ^{58}Ni, leading to the g.s. of ^{58}Zn—the DIAS of the target.

TABLE II. Two-body transition density matrix elements for ^{58}Ni→ ^{58}Zn (g.s.).

ν^π	$(2p3/2)^2$	$(1f5/2)^2$	$(2p1/2)^2$
$(2p3/2)^2$	0.5871	0.4333	0.2338
$(1f5/2)^2$	0.4333	0.3198	0.1728
$(2p1/2)^2$	0.2338	0.1728	0.0931

(solid curve in Fig. 3), the second is a transition from $\nu(2p1/2)^2$ to $\pi(2p1/2)^2$ (dashed curve), and the third from $\nu(1f5/2)^2$ to $\pi(1f5/2)^2$ (dotted curve). A calculation with configuration-mixed wave functions was carried out and is shown in Fig. 3 as the heavy solid curve. The configurations and amplitudes used in the latter calculation are listed in Table II. Previous measurements exist for ^{58}Ni (π^+,π^-)^{58}Zn (DIAS) at 292 MeV 5° [4,6,7]. The cross section of this work is compared with those in Table III.

In Fig. 4, forward-angle cross sections for transitions to double isobaric analog states as a function of target mass for T=1 target nuclei are shown with straight lines corresponding to an $(N-Z)(N-Z-1)A^{-7/3}$ mass dependence (solid lines), and $(N-Z)(N-Z-1)A^{-10/3}$ (dashed line for T_π = 292 MeV) for comparison. Obviously, as Seidl *et al.* pointed out, the $A^{-7/3}$ expression is better able to describe the data at both energies than $A^{-10/3}$ and the agreement with the curve is better at 292 MeV than at 164 MeV.

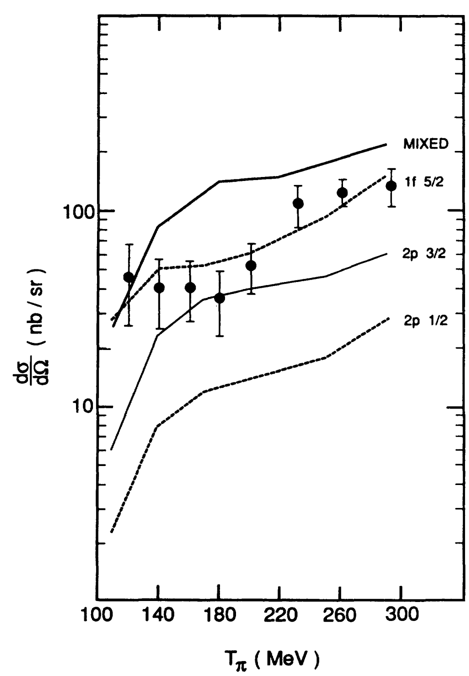

FIG. 3. The data of Fig. 2 compared with sequential calculations, assuming the pure configurations listed, and with the mixed transition amplitudes of Table II.

TABLE III. Double charge exchange cross section (nb/sr) for ^{58}Ni(π^+,π^-)^{58}Zn (g.s.) at 292 MeV and 5°.

Ref.	Cross section
11	110±17
4	152±28
Present	135±30
12	134±44
Wt. av.	125±13
$\sum$ counts/$\sum$ norm	127±13

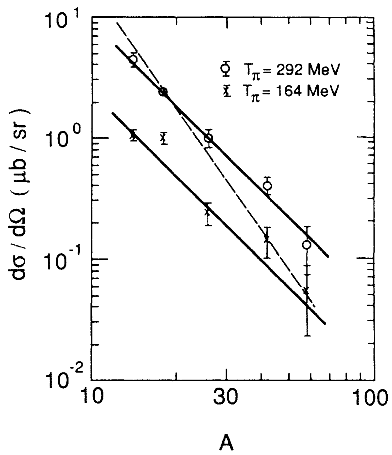

FIG. 4. DIAS cross section, at 5°, for T=1 nuclei plotted vs A, for T_π = 164 (crosses) and 292 MeV (circles). Solid lines go as $A^{-7/3}$, dashed line as $A^{-10/3}$.

IV. CONCLUSIONS

We have reported a new measurement of the cross section for ^{58}Ni(π^+,π^-)^{58}Zn (DIAS) as 292 MeV, 5°, and compared the results with previous data. We obtained data at several energies down to 120 MeV, and we have compared them with theoretical calculations, including different pure configurations and their mixture. For T=1 targets, the mass dependence of DCX (DIAS) at forward angle (5°) for both 164 and 292 MeV appears to be $A^{-7/3}$ instead of $A^{-10/3}$ for all targets.

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