π-^{13}C Scattering near the πN (3,3) Resonance

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(Received 12 September 1979)

π-^{13}C elastic and inelastic scattering was measured for both π^+ and π^- at 180 MeV. The π^-/π^+ ratio of inelastic cross sections approaches 1 in scattering to collective states, whereas this ratio differs significantly from 1 for other excited states. In particular, a value close to the one for pion scattering from free nucleons at the (3, 3) resonance was determined for the 9.5-MeV state.

The comparison of π^+ and π^- inelastic scattering near the πN (3, 3) resonance is a promising tool for the study of nuclear structure. Information on the contribution of proton and neutron distributions to the excitation of the nucleus may be gathered by exploiting the isospin property of the

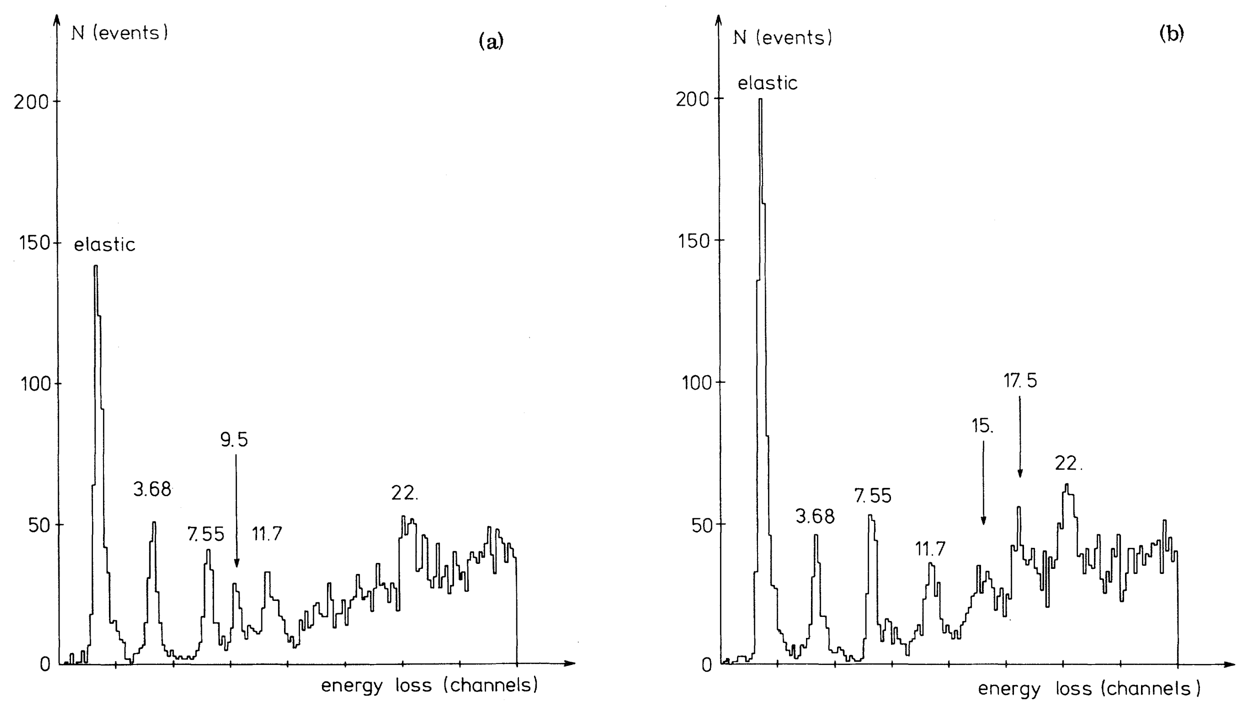

FIG. 1. (a) $\pi^- \to {}^{13}$C scattering spectrum measured at an incident pion energy of 180 MeV and a scattering angle of 81°. The elastic peak and excited states at 3.68, 7.55, 9.5, and 11.7 MeV are clearly visible. (b) $\pi^+ \to {}^{13}$C scattering spectrum measured at an incident pion energy of 180 MeV and a scattering angle of 81°. Note that in this spectrum the 9.5-MeV state is only excited very weakly, whereas there are sizable excitations of groups of states around 15.0 and 17.5 MeV.

πN interaction whereby the π^+ (π^-) interacts 3 times more strongly with a proton (neutron) than with a neutron (proton). Such a study was carried out, for example, on[1] ^{18}O where a ratio

$$R = \frac{d\sigma(\pi^-)/d\Omega}{d\sigma(\pi^+)/d\Omega} \cong 1.7$$

was found for the inelastic scattering to the first excited "shell-model state" at 1.98 MeV (2^+). For equal proton and neutron distributions this ratio should be 1.25, due simply to the two additional neutrons, provided that the impulse approximation is valid.

In this paper we present a π^+ and π^- elastic- and inelastic-scattering comparison on ^{13}C near the πN (3, 3) resonance. The experiment was carried out at the Swiss Institute of Nuclear Research (SIN) with use of the $\pi M1$ beam and pion spectrometer with the same apparatus and method used earlier.[2] A detailed description of the system is given in Albanèse *et al.*[3] Typical scattering spectra are shown in Figs. 1(a) and 1(b). The ^{13}C target used was a 322-mg cm^{-2} 99%-enriched carbon target covered on both sides by a thin (0.7 mg cm^{-2}) Mylar foil. Overall energy resolution was 500 keV full width at half maximum.

Data were taken for π^+ and π^- scattering on ^{13}C at a laboratory energy of 180 MeV. The angular distributions obtained are shown in Figs. 2 and 3. Relative normalization between π^+ and π^- data was calculated, taking beam composition into account. For absolute normalization purposes, measurements were also carried out with a 230-mg cm^{-2} polyethylene [$(CH_2)_n$] target and scaled against the known hydrogen cross section.[4] The overall absolute normalization error is less than 10%.

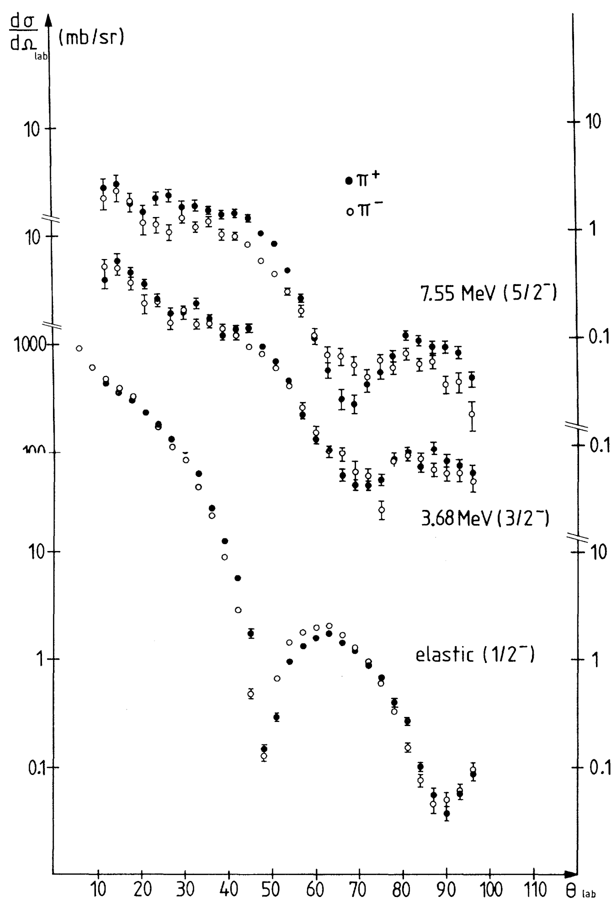

FIG. 2. Comparison of π^+- and π^--^{13}C elastic and inelastic (3.68- and 7.55-MeV excitation energy) scattering differential cross sections at 180 MeV vs the pion scattering angle in the laboratory system.

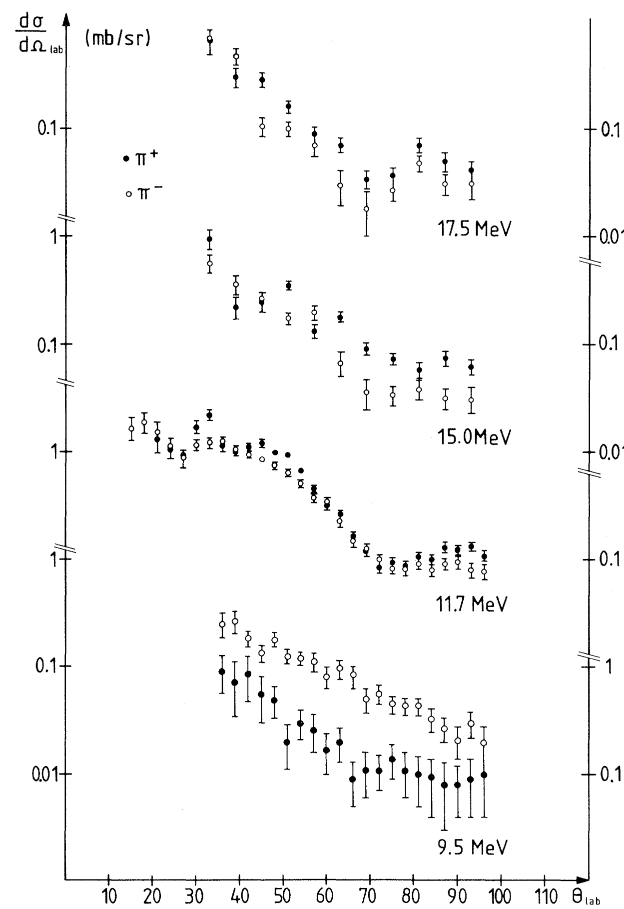

FIG. 3. Comparison of π^+- and π^--^{13}C inelastic scattering to the 9.5-MeV state and to groups of states at 11.7, 15.0, and 17.5 MeV.

The elastic angular distributions show the now-familiar behavior seen in other $N>Z$ nuclei such as ^{48}Ca (Ref. 2) or ^{18}O (Ref. 5), where there is a shift in the position of the first minimum to smaller angles for π^- scattering. This is because the $\pi^- n$ ($\pi^+ p$) elastic-scattering amplitude is approximately 3 times stronger than the corresponding $\pi^- p$ ($\pi^+ n$) amplitude. Consequently, the much stronger $\pi^- n$ ($\pi^+ p$) coupling should emphasize the effect of the neutron (proton) distribution of the nucleus.

The inelastic angular distributions show very interesting ratios $R = [d\sigma(\pi^-)/d\Omega]/[d\sigma(\pi^+)/d\Omega]$. These ratios are given in Table I. The lowest excited level in ^{13}C at 3.09 MeV ($\frac{1}{2}^+$) is known from the reaction[6] $^{12}C(d,p)$ to be a single-neutron state. However, it is only very weakly excited and we were therefore not able to extract any meaningful cross-section ratio. The states at 3.68 MeV ($\frac{3}{2}^-$) and 7.55 MeV ($\frac{5}{2}^-$) are of collective nature and often interpreted as a doublet obtained by coupling a $1p_{1/2}$ neutron to the first excited state of ^{12}C at 4.43 MeV (2^+). We find that both levels are strongly and almost equally excited for π^- and π^+. However, the 3.68-MeV transition could not be separated from the 3.85-MeV ($\frac{5}{2}^+$) single-particle state but we believe that this level also is only weakly excited. The 7.55-MeV level is part of a triplet we were not able to resolve. This might explain the somewhat stronger π^+ excitation at forward angles for this state.

The most striking result of our experiment is the ratio $R = 4.0^{+2.0}_{-0.7}$ obtained for the 9.5-MeV state which is nearly compatible with the free-pion–nucleon value of 9 at the (3, 3) resonance and significantly higher than the result $R \cong 1.7$ obtained[1] for inelastic pion scattering from the first excited "shell-model type" state at 1.98 MeV (2^+) in ^{18}O. Very little is known about this 9.5-MeV transition in ^{13}C. A tentative spin and parity assignment of $\frac{3}{2}^-$ was proposed by Hinterberger *et al.*[7] which is in contradiction to a high-spin state suggested by Holbrow *et al.*[8] with the reaction $^{10}B(^6Li, ^3He)^{13}C$ and by Anyas-Weiss *et al.*[9] with the reaction $^{11}B(^{11}B, ^9Li)^{13}N$. In addition little $M1$ strength could be detected in low-energy electron scattering. Dehnhard *et al.*[10] did an experiment similar to ours at a pion kinetic energy of 162 MeV and propose a $\frac{9}{2}^+$ assignment. However, this implies that the other members of this multiplet ($\frac{1}{2}^+$, $\frac{3}{2}^+$, $\frac{5}{2}^+$, and $\frac{7}{2}^+$) have to be located.

Furthermore, a group of levels is strongly excited at 11.7 MeV with a ratio R close to 1, and two groups of transitions were found around 15.0 and 17.6 MeV which are more strongly excited with π^+.

In conclusion, the most important result reported here is the ratio $R = 4.0^{+2.0}_{-0.7}$ obtained for the 9.5-MeV state, thus indicating an almost pure neutron transition. This confirms that pions can now be considered as a powerful tool to yield nuclear-structure information. However, the experimental and qualitative aspects presented here should be completed by detailed distorted-wave impulse-approximation calculations with microscopic descriptions of neutron and proton excitations.

We would like to thank E. Boschitz for supplying us with the ^{13}C target material. This work was supported in part by the Swiss National Science Foundation and the U. S. National Science Foundation.

TABLE I. Inelastic differential–cross-section ratio $R = [d\sigma(\pi^-)/d\Omega]/[d\sigma(\pi^+)/d\Omega]$ for several excited states or groups of excited states in ^{13}C. This ratio was calculated for each pair of points corresponding to the same scattering angle and averaged. This procedure is justified at 180 MeV, where $d\sigma(\pi^+ \to p)/d\Omega \approx 9 d\sigma(\pi^- \to p)/d\Omega$ for each scattering angle (Ref. 4). The asymmetry in the error of R for the 9.5-MeV transition is due to the small signal-to-background ratio in the π^+ spectra [Fig. 1(b)].

^{13}C excitation energy (MeV)	$R = \frac{d\sigma(\pi^-)/d\Omega}{d\sigma(\pi^+)/d\Omega}$
3.68	0.95 ± 0.05
7.55	0.86 ± 0.09
9.5	$4.0 \pm^{2.0}_{0.7}$
11.7	0.87 ± 0.04
15.0	0.74 ± 0.15
17.5	0.73 ± 0.12

[1]S. Iversen *et al.*, Phys. Rev. Lett. 40, 17 (1978), and Phys. Lett. 82B, 51 (1979); C. Lunke *et al.*, Phys. Lett. 78B, 201 (1978).

[2]J.-P. Egger *et al.*, Phys. Rev. Lett. 39, 1608 (1977).

[3]J.-P. Albanèse *et al.*, Nucl. Instrum. Methods 158, 363 (1979).

[4]P. J. Bussey *et al.*, Nucl. Phys. B58, 363 (1973).

[5]J. Jansen *et al.*, Phys. Lett. 77B, 359 (1978).

[6]S. E. Darden *et al.*, Nucl. Phys. A208, 77 (1973).

[7]F. Hinterberger *et al.*, Nucl. Phys. A106, 166 (1968).

[8]C. H. Holbrow *et al.*, Phys. Rev. C 9, 902 (1974).

[9]N. Anyas-Weiss *et al.*, Phys. Rep. 12C, 201 (1974).

[10]D. Dehnhard *et al.*, in Proceedings of the Eighth International Conference on High Energy Physics and Nuclear Structure, Vancouver, 1979 (unpublished), abstract 1D1.