EVIDENCE OF COHERENT π^+ PRODUCTION IN $(^3\mathrm{He}, t)$ REACTIONS*

R. Dahl[b], L. Farhi[a], W. Augustiniak[c], J.L. Boyard[a], M. Drews[b]
C. Ellegaard[b], C. Gaarde[b‡], T. Hennino[a], J. Jensen[b]
J.C. Jourdain[a], R. Kunne[a], J. Larsen[b], P. Radvanyi[a]
B. Ramstein[a], M. Roy-Stephan[a], M. Skousen[b], and P. Zupranski[c]

[a] Institut de Physique Nucléaire
IN2P3 (CNRS) F-91406 Orsay Cedex, France
[b] Niels Bohr Institute, University of Copenhagen
DK-2100 Copenhagen, Denmark
[c] Soltan Institute for Nuclear Studies
PL-00681 Warsaw, Poland
email: dahl@nbi.dk

(Received June 20, 1998)

Experimental evidence for coherent π^+ production in $^{12}\mathrm{C}(^3\mathrm{He}, t\pi^+)^{12}\mathrm{C}$ charge exchange reactions at 2 GeV is presented. The excited states of carbon are found to be suppressed relative to the ground state. Angular distributions show that the momentum of the coherent pions is directed along the momentum transfer.

PACS numbers: 13.60.Le

The nuclear response in the Δ resonance region has been a subject of intense investigation over the last decade. Charge exchange reactions at intermediate energy have provided a particularly useful tool since these reactions have the ability to probe the response in regions kinematically inaccessible to pion beams. The strong spin-longitudinal component of their interaction has provided valuable new information regarding pion-like modes in the nucleus. In contrast to experiments with both pion and electron beams, inclusive (p, n) and inclusive $(^3\mathrm{He}, t)$ reactions show a universal downward shift of the Δ peak on all nuclear targets [1, 2]. This led to the question of how much of this shift could be ascribed to attraction in the spin longitudinal channel.

* Presented at the Meson'98 and Conference on the Structure of Meson, Baryon and Nuclei, Cracow, Poland, May 26–June 2, 1998.
‡ Deceased

New light has been shed on this issue by exclusive $(^3\mathrm{He}, t)$ experiments on a variety of targets in which the decay products from the target were measured in coincidence with the ejectile [3]. It is now generally accepted that only a fraction of the downward shift of the Δ resonance can be attributed to a collective softening of the response due to residual attraction in the spin longitudinal channel. The decay channel in which a single pion is emitted and the nucleus remains in its ground state is theoretically found to be particularly sensitive to this collectivity [4–6]. This coherent pion decay channel was first observed in exclusive measurements but with insufficient energy resolution to resolve the ground state from the first excited states [7]. Therefore, it was not possible to determine the detailed energy transfer spectrum of the reaction, and the absolute cross section could not be measured. The present paper describes an experiment dedicated to the study of coherent pions (CP).

The Spes4-π experimental apparatus consists of two parts. The scattered triton is momentum analyzed in the forward spectrometer, Spes4, described in detail elsewhere [8]. The pion produced in coincidence with the triton is momentum analyzed in the spectrometer located in the target area. The energy and momentum transfer to the target, $(\omega, \vec{q})$, are calculated from the momentum of the ejectile. This, together with the measurement of the pion momentum $\vec{p}_\pi$, permits determination of both the excitation energy of the residual nucleus and the angular correlation between $\vec{p}_\pi$ and $\vec{q}$.

The SATURNE synchrotron at Saclay delivered a 2 GeV ^{3}He beam. The Spes4 spectrometer detecting the scattered triton was operated at two different central momentum settings corresponding to ranges in ω of 150 to 320 MeV and of 205 to 370 MeV with a resolution of 2 MeV. The horizontal scattering angle was in the range of $14 < \theta_t < 22$ mrad. The vertical scattering angle was not measured but was limited to ± 5.8 mrad by a set of two uranium slits.

The target was placed in a dipole magnet, Tethys, with a vertical opening of $\pm$ 25 cm with respect to the target position. The pions from the decay were momentum analyzed by the magnetic field of Tethys. Two different settings of Tethys were used, one for each Spes4 setting, to detect low and high momentum pions for the low and high ω range, respectively, since $E_\pi \approx \omega$ for the CP. The pion angle and momentum were determined from the position on the two multi wire proportional chambers (MWPC) located to the left of Tethys. Approximately 95% of the detected pions were ray-traced with a precision of better than 1 MeV/c and 1 degree. The pion detection efficiency of the MWPC was 95%. For particle identification, a hodoscope was placed behind the last chamber. The mass of the detected particle could be determined from its momentum and the time of flight. The

resolution thus obtained is 100 MeV (FWHM), which is sufficient to separate the pions from the proton background.

The left panel of figure 1 shows the excitation energy of the residual ^{12}C nucleus. The ground state peak dominates the spectrum. A small background and some pions from quasi-free Δ decay are also present. It should be mentioned that the acceptance suppresses the pions produced in quasi-free Δ decay relative to the CP because of the difference in the angular distributions of the decays [7]. A resolution of 6.5 MeV (FWHM) was obtained. The main contributions to the width come from the resolution of Spes4 and the energy loss in the target. The first exited state of ^{12}C at 4.4 MeV is not visible. The angular correlation between $\vec{q}$ and $\vec{p}_\pi$ could be

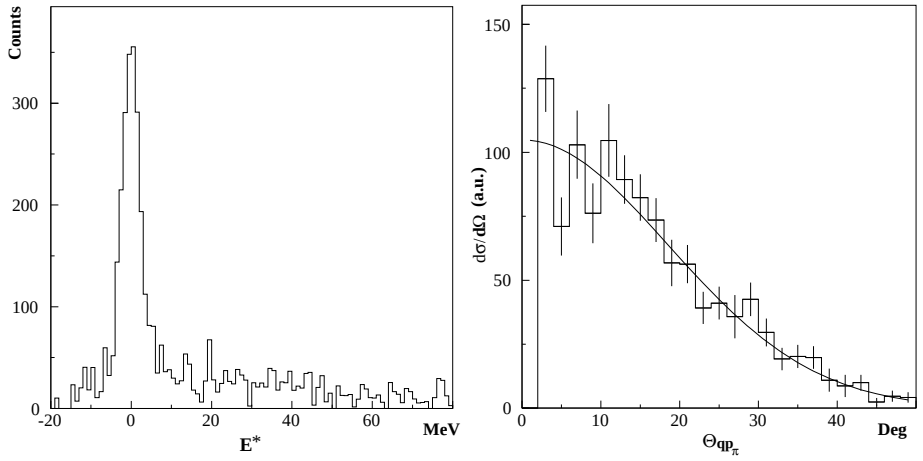

Fig. 1. Left panel: Excitation energy of ^{12}C. The ground state dominates the spectrum. Right panel: Angle between $\vec{q}$ and $\vec{p}_\pi$ with a gate around the ground state and a gate in energy transfer from 230 to 270 MeV. The full line is a Gaussian fit to the data, with a width 22 deg. Preliminary data.

extracted from the data for different ω bins and is shown in the right panel of figure 1 for an ω range from 230 to 270 MeV. The width of the angular distribution is in agreement both with that previously measured for the CP and with theoretical predictions [4–7].

The pions from the CP decay are found to be directed along the momentum transfer. This is a combined effect of the ^{12}C form factor and the spin longitudinal nature of both the excitation and de-excitation of the Δ resonance. The form factor favours small $|\vec{q} - \vec{p}_\pi|$ which is realized at small relative angle. The fact that the pions are emitted at small relative angle enhances the longitudinal response over the transverse, since the cross section for the former depends on $|\cos(\theta_{\vec{q}\vec{p}_\pi})|^2$ while the latter depends on

$|\sin(\theta_{\vec{q}\vec{p}_\pi})|^2$. Theoretical studies have indeed shown that the contribution to the CP from the transverse channel is small and broadens the angular distribution [9].

The hatched area in figure 2 shows the ω spectrum with a gate around the ^{12}C ground state. The full line is inclusive data. The peak position in the energy transfer spectrum and cross section of the CP decay channel is found to be sensitive to the strength of the attraction in the spin longitudinal channel [4–6]. Firm conclusions about the strength of the residual interaction can only be drawn when the cross section for the CP is determined. The absolute normalisation will be determined in a forthcoming analysis of the data.

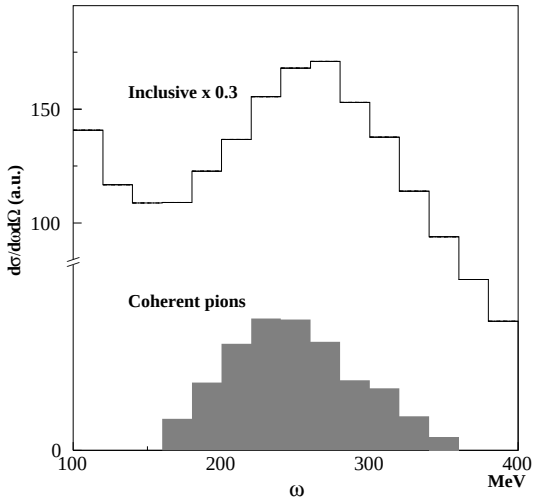

Fig. 2. The full line shows the inclusive measurement in arbitrary units. The hatched area shows the energy transfer spectrum of the CP. The CP are shifted downward in energy transfer relative to the inclusive data. Preliminary data.

In summary, we have demonstrated that the ground state gives the major part of the strength for single pion emission in charge exchange reactions. The pions are emitted along the momentum transfer due to their strong coupling to spin longitudinal modes in the nucleus. The strength of this coupling can be determined from the magnitude and peak position in the energy transfer of the CP.

This experiment was carried out at LNS, jointly operated by CEA/DSM and CNRS/IN2P3. This work had the benefit of the support of EU contract No ERBCHGECT 940055. R.D. thanks the Sarc Foundation for its financial support.

REFERENCES

[1] D. Contardo *et al.*, *Phys. Lett.*, **B168**, 331 (1986).
[2] D.A. Lind, *Can. J. Phys.* **65**, 637 (1987).
[3] T. Hennino *et al.*, *Phys. Lett.*, **B283**, 42 (1992).
[4] P. Fernandez de Cordoba *et al.*, *Phys. Lett.* **B319**, 416 (1993).
[5] M.A. Kagarlis, V.F. Dmitriev. *Phys. Lett.* **B408**, 12 (1997).
[6] T. Udagawa *et al.*, *Phys. Rev.* **C49**, 3162 (1994).
[7] T. Hennino *et al.*, *Phys. Lett.* **B303**, 236 (1993).
[8] M. Bedjidian *et al.*, *Nucl. Instr. Meth.* **A257**, 132 (1987).
[9] B. Körfgen, F. Osterfeld, T. Udagawa, *Phys. Rev.* **C50**, 1637 (1994).