Excitation function of the 15.11 MeV ($1^+, T=1$) state in ^{12}C from ($\pi, \pi'\gamma$) angular correlations

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The excitation function of the 15.11 MeV ($1^+, T=1$) state in ^{12}C has been measured by using the ($\pi, \pi'\gamma$) angular correlation technique. By this method, the background can be suppressed substantially. The relative cross section ratio of the 15.11 MeV ($1^+, T=1$) and the 12.71 MeV ($1^+, T=0$) state as a function of the pion incident energy is found to show a resonancelike behavior in the region of the Δ resonance, in agreement with previous measurements of Morris *et al.*

In the effort to understand the role of excited nucleons in a nucleus particular attention has been focused on pion inelastic scattering from the $T=0$ and $T=1$ states in ^{12}C at 12.71 and 15.11 MeV, respectively. They are the lowest 1^+ states in this nucleus. Their nuclear wave function is assumed to be described predominantly by a ($p_{1/2}p_{3/2}^{-1}$) configuration. Thus exploring the cross section ratio $R=\sigma(T=1)/\sigma(T=0)$ nuclear structure effects should widely cancel out. In the impulse approximation this ratio is predicted to be $\frac{1}{4}$.[1]

In a single arm pion scattering experiment the ratio R has been measured for different incident energies by Morris *et al.*[2] They found a significant enhancement of R near 180 MeV and suggested that this enhancement appears consistent with resonant excitation of Δ-hole wave function admixtures in the 15.11 MeV ($1^+, T=1$) state in ^{12}C. Recently their data have been used by Takaki[3] for comparison with calculations in the framework of the Δ-hole model.[4] These calculations are in qualitative agreement with the data in the Δ-resonance region. However, below and above the resonance there are serious deviations.

For the question of Δ excitations in ^{12}C appearing in the $1^+, T=1$ excitation of the 15.11 MeV state, the behavior of the ratio R as a function of the pion incident energy is of substantial interest. In the evaluation of the spectra of scattered pions there is no major problem with the 12.71 MeV ($1^+, T=0$) state. The 15.11 MeV ($1^+, T=1$) state, however, suffers from the fact that it is superimposed on a broad strongly excited state at 15.4 MeV, which leads to serious background problems.

In this note we describe another experimental access to the 15.11 MeV ($1^+, T=1$) state in ^{12}C exploiting its γ decay, by which it is distinguishable from the 15.4 MeV state. By measuring the scattered pions in coincidence with the deexcitation γ rays the double differential cross section $d^2\sigma/d\Omega_{\pi'}d\Omega_\gamma$ can be determined.

The double differential ($\pi, \pi'\gamma$) cross section is related to the differential (π, π') cross section by

$$d^2\sigma/d\Omega_{\pi'}d\Omega_\gamma=(1/4\pi)Wd\sigma/d\Omega_{\pi'} ,$$

where W is the angular correlation function in general dependent on the pion scattering angle and the γ emission angles.[5] Choosing the quantization axis perpendicular to the reaction plane and regarding the reaction as a $0^+ \rightarrow 1^+ \rightarrow 0^+$ transition due to Bohr's theorem,[6] only the $M=0$ magnetic substate of the excited 1^+ state is populated. In this case the angular correlation function is given by simply

$$W=(\tfrac{3}{2})\sin^2\theta_\gamma .$$

This means that W is constant for any arrangement, where the γ detectors are placed under the same angle with respect to the reaction plane (e.g., $W=\frac{3}{2}$ for "in-plane" angular correlations). Then the double differential cross section becomes direct proportional to the differential cross section.

In the present experiment we measured ($\pi, \pi'\gamma$) angular correlations for the 15.11 MeV ($1^+, T=1$) state in ^{12}C in and out of the reaction plane at different incident energies covering the region of the Δ resonance. The experiment was performed in the $\pi M1$ area at the Swiss Institute of Nuclear Research (SIN). The positive pions scattered from a graphite target with an area density of about 1.70 g/cm^2 were detected with the SUSI spectrometer facility[7] in coincidence with the corresponding deexcitation γ rays of ^{12}C. The γ rays were detected by six NaI detectors, three of them placed in the reaction plane and three of them at 45° below the reaction plane. The data were taken[8] at a pion momentum transfer of $q=0.47$ fm^{-1} for incident kinetic energies of 116, 140, 162, 180, and 226 MeV.

Figure 1 shows a spectrum of the scattered pions coincident with the 15.11 MeV deexcitation γ rays of ^{12}C. Although, as a result of random coincidences, the peak of elastically scattered pions remains the dominating peak in the spectrum (it is suppressed by a factor of about $5\cdot10^{-5}$) the background is reduced sufficiently so that the

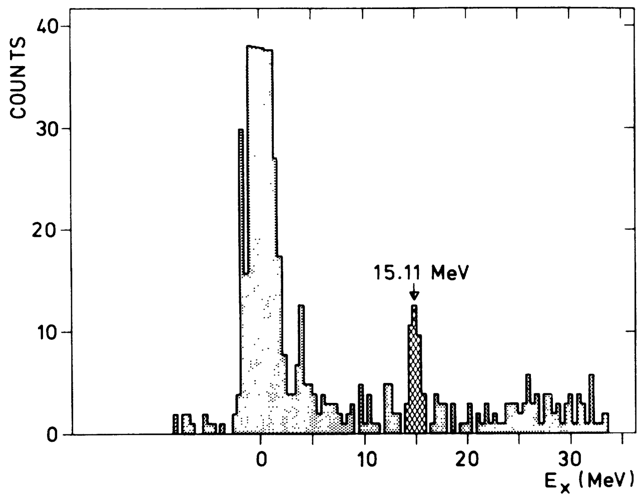

FIG. 1. Spectrum of pions with an incident energy of 140 MeV scattered from ^{12}C at a momentum transfer of $q=0.47$ fm^{-1} in coincidence with γ rays of an energy higher than 5 MeV.

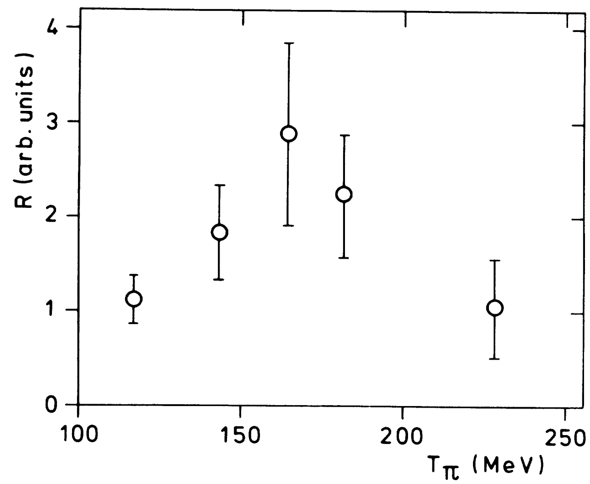

FIG. 2. Relative ratio of the cross sections for the 15.11 MeV $(1^+,T=1)$ and the 12.71 MeV $(1^+,T=0)$ state excited by inelastic pion scattering as a function of the incident kinetic energy.

15.11 MeV peak can clearly be separated.[8] A detailed description of the experimental setup together with the appropriate test procedures, monitoring systems, and data analysis is given elsewhere.[9]

In Fig. 2 the (relative) ratio R for the cross sections of the 15.11 and 12.71 MeV state is displayed. The data for the 12.71 MeV state, which is not accessible by our π'-γ coincidence measurements, are taken from Ref. 10. Already in Ref. 10 the possibility was reported that the ratio R for these two states is not $\frac{1}{4}$ and that it varies with incident pion energy. But also their excitation function of the 15.11 MeV state was not convincing again due to uncertainties from background contributions.

As we do not know the efficiency of our γ detectors for 15.11 MeV γ radiation absolutely the ratio R in Fig. 2 is given in arbitrary units. This incidentally saves us the consideration of the effect of isospin mixing, which would modify the value of $R=\frac{1}{4}$ and which is suppressed in Ref. 2 by averaging the spectra of positive and negative pion scattering. Nevertheless, from Fig. 2 it clearly can be seen that the ratio R exhibits a resonancelike structure over the incident pion energy despite the relative large errors, which here, however, are of pure statistical nature. If required, they can be further reduced by a dedicated experiment.[8] In the values of the relative ratio R shown in Fig. 2 the results of the in-plane and out-of-plane measurements are included. Their count rates differed by a factor of 2 as expected from the corresponding values of the angular correlation function.

In summary, the resonancelike behavior of the ratio of the inelastic pion scattering cross section to the 15.11 MeV $(1^+,T=1)$ and the 12.71 MeV $(1^+,T=0)$ state in ^{12}C in the region of the Δ resonance suggested in Ref. 2 is confirmed. We have shown a new experimental access to the 15.11 MeV state using the π'-γ angular correlation technique. Of course, this method needs more measuring time for a required statistical accuracy but it is able to eliminate systematical errors from unknown background contributions.

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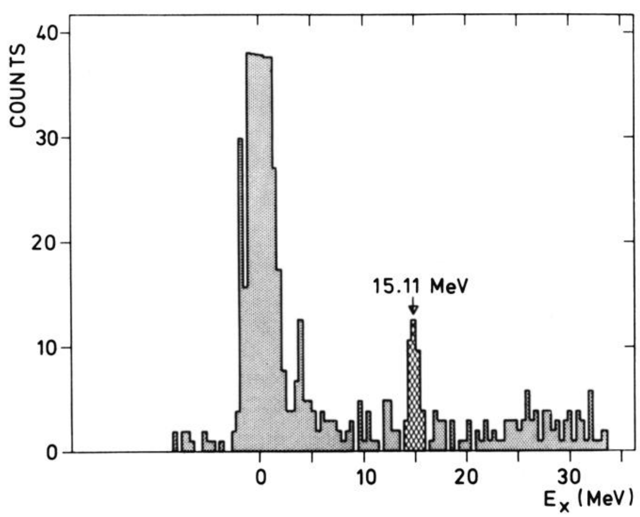

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