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Δ-RESONANCE DECAY AND ABSORPTION IN NUCLEI

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Δ resonance decay and absorption in nuclei

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ABSTRACT

We present data on the decay of the Δ resonance excited in ^{1}H, ^{2}H, ^{4}He , ^{12}C and ^{208}Pb by the (^{3}He, t) reaction at 2 GeV incident energy. The quasi-free decay of the Δ resonance and the absorption process are clearly observed. In addition, we find indication for a coherent process where a pion is emitted and the target nucleus is left in its ground state.

1. Introduction:

Inclusive charge exchange reactions on hydrogen and nuclei have been studied quite intensively at incident energies of about 1 GeV/nucleon at Gatchina [1], Lampf [2], Dubna [3], and Saturne [4]. Two common features of all these charge exchange reactions consist in a strong Δ excitation and a shift of the resonance excited in nuclei with respect to the free one. This effect is illustrated on fig. 1 in the case of the (^{3}He,t) reaction studied at Saturne. The energy transfer spectra have same position and same width, whichever the target from ^{12}C to ^{208}Pb and are shifted by 70 MeV towards low energy transfers with respect to the spectrum obtained on the proton target. Calculations of ref [5, 6, 7] performed for the (^{3}He,t) and (p,n) reactions have shown that about one half of this shift is due to Fermi motion or mean field effects. The other half comes from effects of Δ-hole correlations on the spin-longitudinal response function. However, Oset et al [8] stress that these approaches donot take into account processes such as projectile excitation or quasielastic processes which contribute in the low energy side of the energy transfer spectrum.

The study the Δ resonance decay channels in the nuclear medium can give more information about the origin of this shift and therefore put more constraints on these models.

Three different decay processes are expected: the quasifree process $\Delta \rightarrow \pi + N$, where the Δ decays without interacting with other target nucleons, the absorption process $\Delta N \rightarrow NN$, and the coherent process $A_\Delta \rightarrow \pi + A_{gs}$, where one pion is emitted and the nucleus is left in its ground state.

Some exclusive experiments have been carried out to study these different processes. At KEK, the exclusive (p,n) reaction has been studied at 800 MeV with the Fancy detector [9]. At Dubna, the (t,^{3}He) reaction has been performed at 2.24 GeV/nucleon with a streamer chamber[10]. At Laboratoire National Saturne, we have performed an exclusive (^{3}He,t) experiment at 2 GeV with the large acceptance Diogene detector. The results obtained on ^{1}H,^{2}H and ^{12}C, published in ref.[11, 12] are compared here to new data on ^{4}He and ^{208}Pb targets.

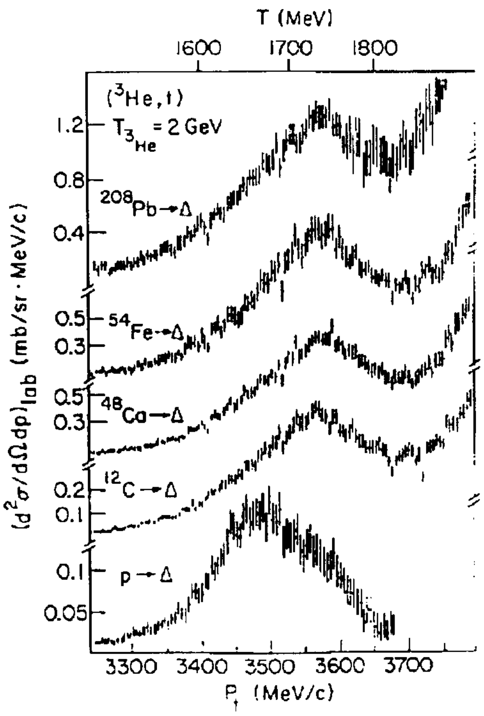


Fig.1: Energy transfer spectra for (^{3}He, t) reaction on nuclei at 2 GeV from ref [13]

2. Experimental set-up:

Triggered by the triton, the charged pions and/or protons emitted by the excited nucleus are detected in DIOGENE (fig. 2).

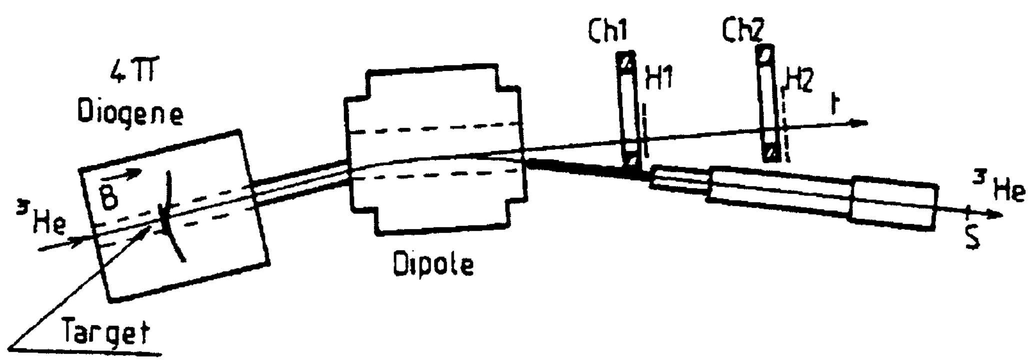


Fig.2: Experimental set-up.

The detecting arm for the tritons consists of a dipole magnet and two sets of drift chambers allowing for energy and angle measurement in the range 1.4 to 2 GeV and

0^0 to 4^0. The energy resolution (FWHM) for tritons is typically 25 MeV for solid wire targets. For liquid targets, the resolution is enlarged by the beam spot and amounts to 35 MeV . The angular resolution is 0.5 mrd. 99% of the deuterons produced by the ^{3}He break-up are hardware rejected by the trigger made by a coincidence between two scintillator hodoscopes located behind the drift chambers. The cylindrical "4π" detector, Diogène, originally built for nucleus-nucleus collision studies, consists of 10 trapezoidal drift chambers in a 1 T longitudinal magnetic field [14]. Combining track reconstruction and pulse height analysis, it allows particle identification and momentum vector measurement for particles with polar angle between 20^0 and 132^0 over the full azimuthal angular range. The momentum resolution (FWHM) is typically 18% for protons and 10% for pions; angles are measured with a precision of a few degrees. Typical values for the detection energy threshold obtained in our experiment were 15 MeV for pions and 35 MeV for protons. The experiment has been performed on liquid hydrogen (1.3 g/cm^2), liquid deuterium (3.1 g/cm^2), liquid helium 4 (1.125 g/cm^2), carbon (0.36 g/cm^2) and lead (1.135 g/cm^2) targets.

3. Classes of events:

The proportion of the different classes of events measured in DIOGENE for tritons with kinetic energy corresponding to the Δ bump, i.e. 140 MeV $< \omega =$ E(^{3}He) - E(t) $<$ 600 MeV, are shown in table 1.

Event type	^{1}H	^{2}H	^{4}He	^{12}C	^{208}Pb
none	20.4	33.9	23.1	23.3	38.7
$1\pi^+ + 1p$	35.7	10.0	8.2	7.2	2.3
$1\pi^+$	30.8	21.9	27.1	20.8	11.1
$1p$	5.4	20.3	18.5	25.5	32.3
$2p$	1.9	8.8	15.7	14.1	7.2
$3p$	0.1	0.3	1.3	1.4	.4
others	5.7	4.8	6.1	7.7	8.0
total	100.0	100.0	100.0	100.0	100.0

Table 1: Yields of the different classes of events measured in Diogène for the ^{1}H, ^{2}H, ^{4}He,^{12}C and ^{208}Pb targets in coïncidence with a triton with kinetic energy in the region of Δ resonance excitation (140 MeV $< \omega <$600 MeV).

On hydrogen, the only possible decay channel is $\Delta^{++} \rightarrow \pi^+ + p$. The occurrence of incomplete events is due to the acceptance cuts and ray-tracing inefficiencies in the DIOGENE detector. An additional 6% inefficiency due to in flight pion decay has been estimated using Monte-Carlo simulations. 2p and 3p events on ^{1}H target, as well as 3p events on ^{2}H target are due to target windows.

On ^{2}H, a significant two proton yield is measured. The rate of empty and 1 proton events is quite high because of a problem of pion detection inefficiency in this specific experiment on deuterium. On the helium target, there are more $2p$ events and even a significant fraction of events with three protons ($3p$). For ^{12}C and ^{208}Pb targets, both π^++p and 2p decrease for the benefit of events where no or only one particule is detected.

We will focus now on types of events where the particles detected in Diogene carry an important fraction of the energy transferred to the target and try to relate them to the different Δ resonance decay channels.

4. $1\pi^+ + 1$p events :

When $1\pi^+$ and 1p are detected in Diogene in coïncidence with the triton, the residual undetected nucleus has a very low excitation energy (fig. 3). The spectrum obtained in the case of the deuteron target where the residual nucleus is in fact a neutron shows the contribution of the resolutions to the width of these spectra.

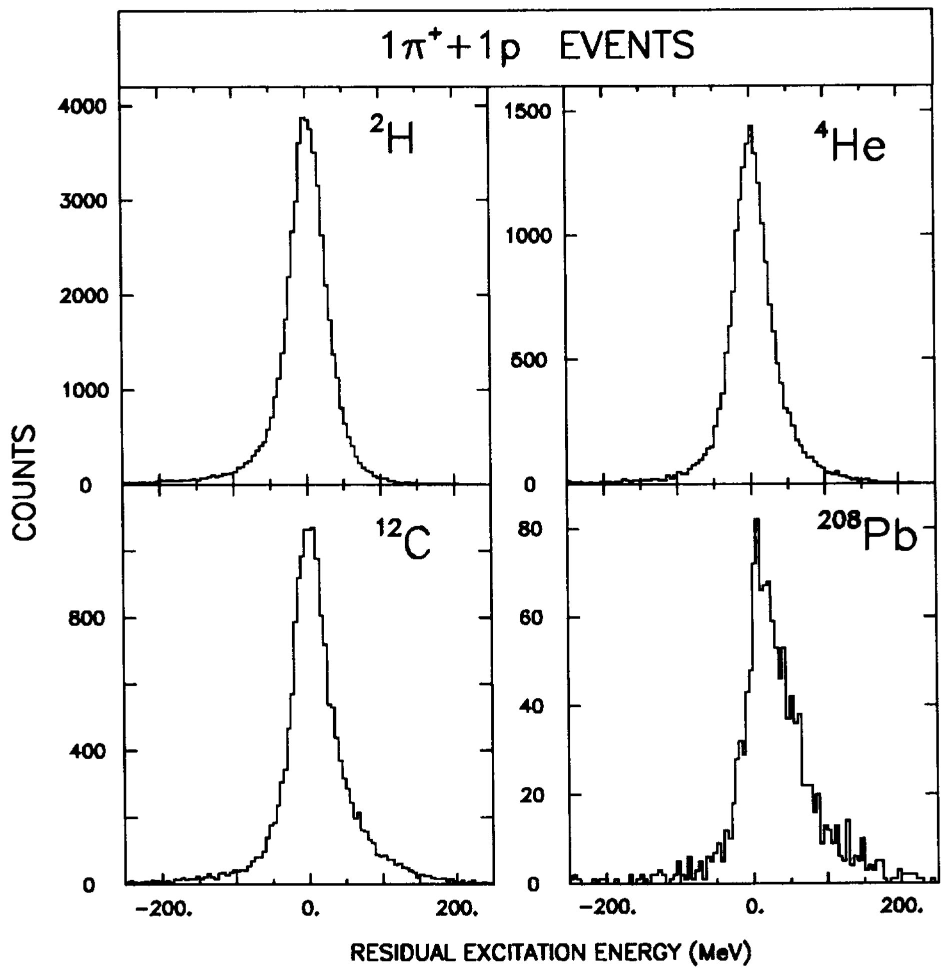
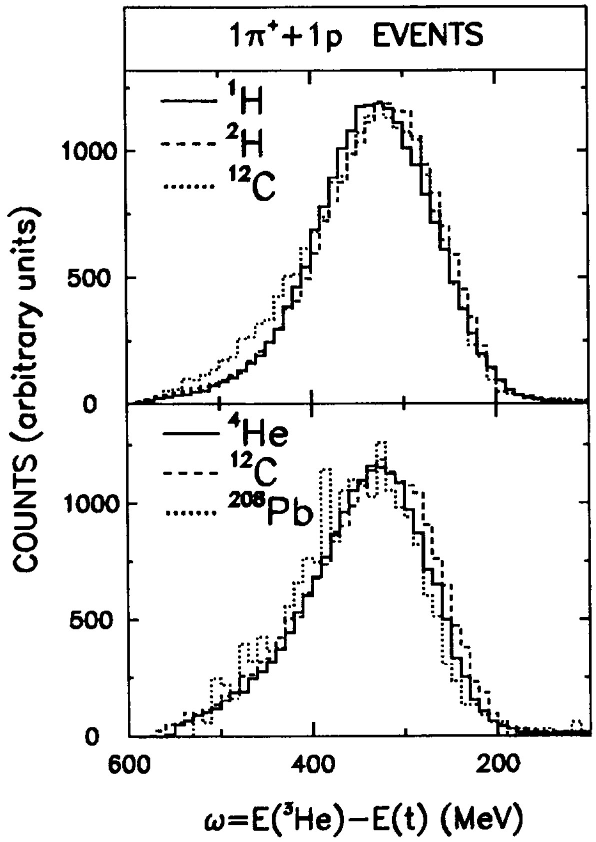


Fig.3: Excitation energy spectra of the undetected nucleus for $1\pi^+ + 1p$ events are shown for ^2H, ^4He, ^{12}C and ^{208}Pb targets.

Fig.4: Energy transfer spectra for π^++p events on ^{1}H, ^{2}H and ^{12}C targets (top) and ^{4}He ,^{12}C and ^{208}Pb targets (bottom)



The energy transfer spectrum has same position and width within 15 MeV on all the targets studied in our experiment (fig 4.). Both results show that these events select a quasi-free decay of the Δ resonance and do not contribute to the shift observed in inclusive data. Calculations of ref.[15, 16, 17] show that these π^++p events correspond to Δ's produced at the nucleus surface.

5. 2p events:

The energy transfer spectrum obtained for π^++p, 2p and 3p events are compared to the inclusive spectra on fig. 5. On ^{2}H , there is no apparent Δ bump for 2p events. This shows that the absorption of the Δ resonance in deuterium is weak.

On helium 4, a very clear structure is observed in the 2p spectrum, with an impressive 130 MeV shift with respect to the one observed in the π^++p events. This trend is also found for the ^{12}C and ^{208}Pb targets , but the maximum of the 2p spectrum is shifted towards higher ω values, as the mass of the target increases, whereas the π^++p spectrum stays at the same position. Cascade simulations performed in the case of ^{12}C target show that an important part of the shift between π^++p and 2p ω spectra is due to phase space effects[17]. However, these calculations fail to explain the low energy side of the 2p spectrum. Calculations by Osterfeld et al. [15] show that some strength in the 2p spectrum is produced in this region by the correlations. We are now trying to find a signal of these correlations in the 2 proton angular distributions.

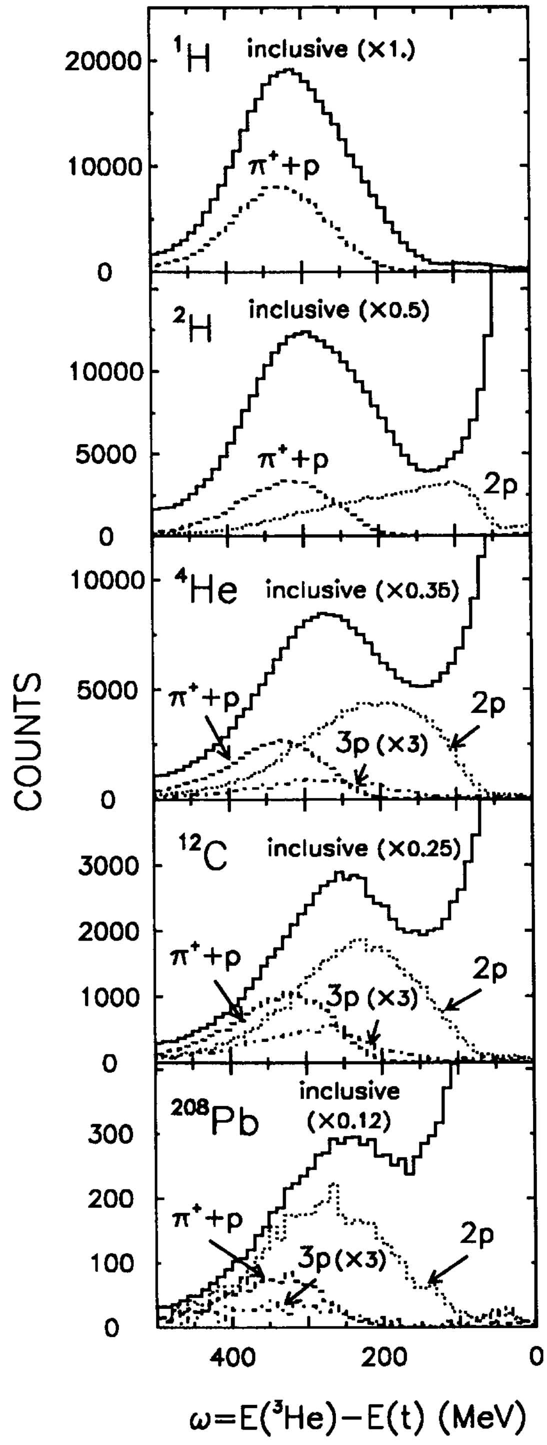


Fig.5: Energy transfer spectra for all events (full line), $1\pi^+ + 1p$ events (dashed line), 2p events (dotted line) and 3p events (dashed-dotted line) for ^{1}H, ^{2}H, ^{4}He, ^{12}C and ^{208}Pb targets.

The excitation energies of the residual undetected nucleus for these 2p events are shown on fig. 6. For the ^{4}He target, the mean excitation energy of the residual deuterium is less than 5 MeV, which means that the 2 protons carry most of the energy transferred to the target. On ^{12}C and ^{208}Pb targets, the residual nucleus is found with increasing excitation energies. The energy transferred to the target is thus shared among more and more nucleons. In the low energy transfer region, the 2 protons may then have too small an energy to be detected as 2p events and may then appear as 1p or empty events. This might explain that the observed 2p spectrum is shifted towards higher values. As stressed by Oset, some 2p events in heavy targets may also come from absorption of the real pion emitted in the decay of the Δ resonance, which process should appear at energy transfers around the position of the π^++p events and should then contribute to shift the 2p spectrum towards higher ω values [18]. A detailed analysis of the 2 proton correlations may help to evaluate the importance of this process.

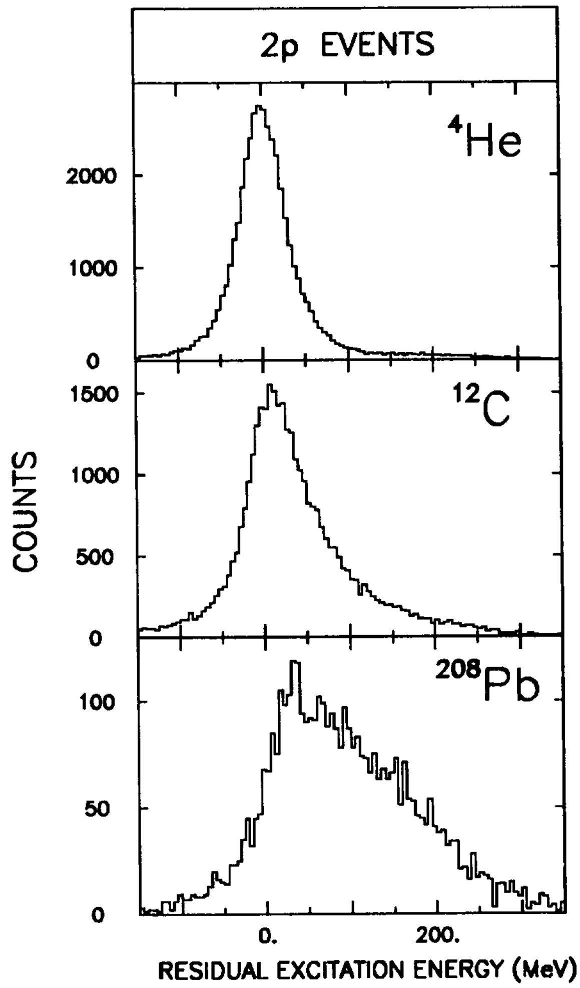


Fig.6: Excitation energy of the residual nucleus for 2p events.

A Δ bump is also present in the 3p spectrum (dashed-dotted line on fig.5) and is located at higher energy transfers, as expected, due to the energy threshold for one more proton to be detected in DIOGENE.

In the case of the ^{208}Pb target, the large excess of neutrons and the high number of rescatterings inside the nucleus might explain the overall decrease of the 2p and 3p events rate for the benefit of 1p or empty types of events.

6. $1\pi^+$ events:

The $1\pi^+$ events are expected to be due on the one hand to incoherent processes, such as quasi-free decay of the Δ resonance where the nucleon emitted is not detected, either because it is neutral or because of the Diogene acceptance cuts or inelastic processes where the target nucleus is left in an excited state. On the other hand, pions may be produced in a coherent process where the nucleus is left in its ground state. The excitation energies of the target nucleus obtained for $1\pi^+$ events on ^{4}He , ^{12}C and ^{208}Pb are shown on fig. 7. A clear enhancement is found around zero excitation energies in the case of ^{4}He and ^{12}C targets, about 30 MeV [17] lower than the maximum expected for the quasi-free process.

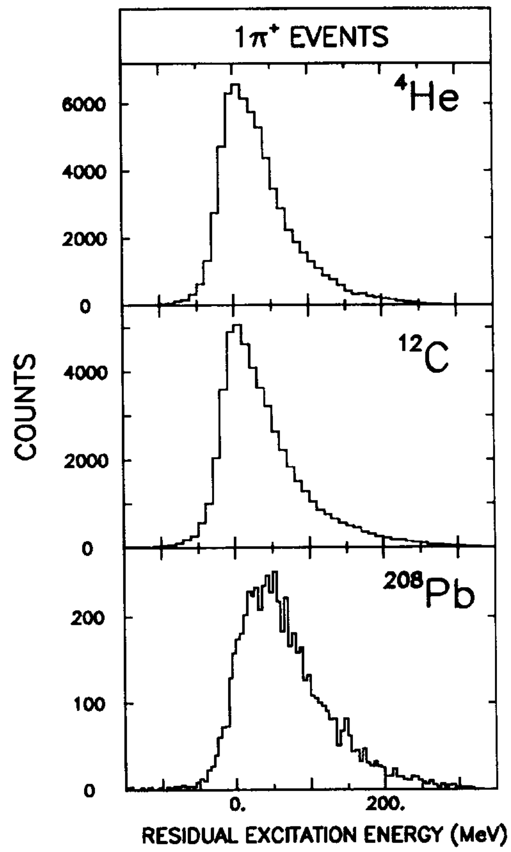


Fig.7: Excitation energies of the residual nucleus for $1\pi^+$ events for ^{4}He, ^{12}C and ^{208}Pb targets.

Although the resolution is not good enough to isolate the ground state, this result gives strong indication for coherent pion production. The pions corresponding to the lowest target excitation energies are found to be strongly peaked around the direction of the momentum transfer. For small triton angles, a very big fraction of them is thus emitted in the acceptance hole of the Diogene detector. Their angular distribution is shown on fig. 8 for tritons emitted at laboratory angles greater than 2.5^0 for which the momentum transfer points at angles larger than 27^0 in the laboratory (for ω=250 MeV) and therefore the acceptance cuts are smaller.

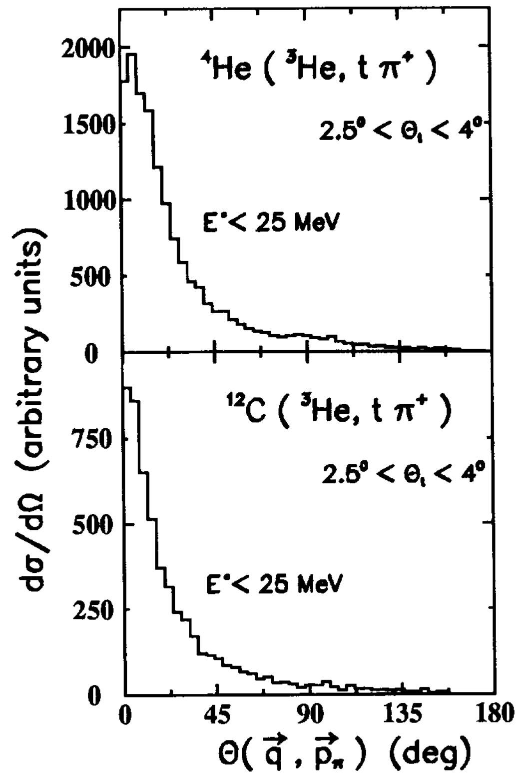


Fig.8: Distributions of the angle with respect to the momentum transfer direction of $1\pi^+$ events with residual excitation energy less than 25 MeV for ^{4}He (top), and ^{12}C (bottom) targets. Only events with triton angles between 2.5^0 and 4^0 are selected.

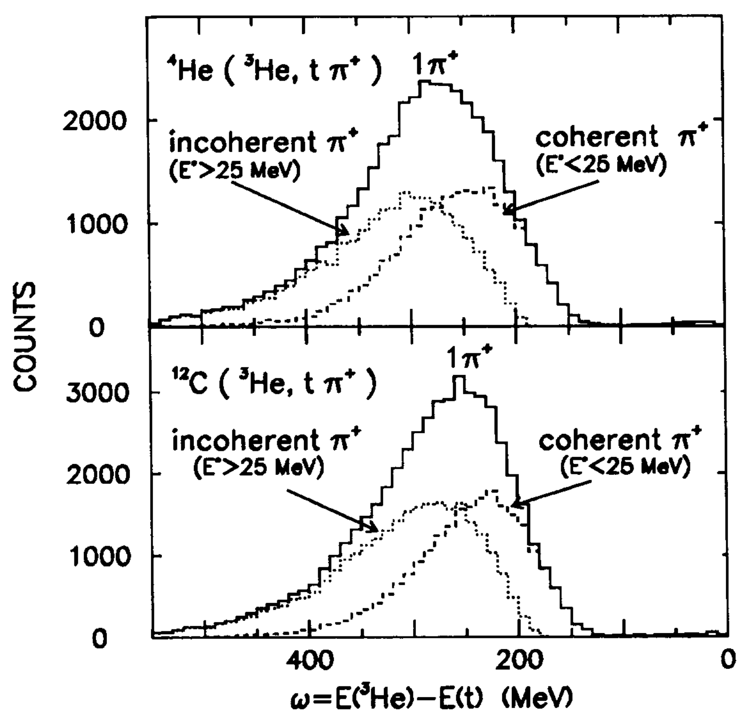


Fig.9: Energy transfer spectra for $1\pi^+$ events are displayed for ^{4}He (top) and ^{12}C targets (bottom). Full lines correspond to all events, dashed lines to events with excitation energy less than 25 MeV and dotted lines to events with excitation energy larger than 25 MeV.

After corrections for acceptance cuts, the width of these distributions are 24^0 for ^{4}He and 16^0 for ^{12}C. These events also correspond to lower energy transfers, as shown on fig. 9. Both features are in agreement with the predictions of Osterfeld et al [19] and Oset et al [20] for coherent pion production.

According to ref.[19], coherent pions are mainly produced by the longitudinal component of the interaction and are therefore very sensitive to the correlations.

7. Conclusion:

In conclusion, the study of the exclusive (^{3}He,t) reaction at 2 GeV on ^{1}H, ^{2}H , ^{4}He ^{12}C and ^{208}Pb allows to isolate three different decay channels.

a) Events where one pion and one proton are detected in coincidence with the forward emitted triton select a quasi-free excitation of the Δ resonance with the same energy transfer on nuclei and on the free nucleon.

b) The 2p events are related to the absorption process of the Δ resonance. This process dominates at lower energy transfers than the quasi-free process and might be sensitive to correlations. This decay channel involves an increasing number of nucleons as the mass of the target increases.

c) We find indications for the coherent process leading to emission of a pion and leaving the target nucleus in its ground state.

Due to the hole in acceptance at forward angles, Diogene is not well suited for the study of the coherent process. The new Spes IV π set-up, which is being built at Saturne and consists of a magnetic detection around the target point of the high resolution Spes IV spectrometer will allow a much more complete study of this process as a function of momentum and energy transfer and for different probes, such as (^{3}He, t), ($\vec{d}$,2p) and (^{12}C,^{12}N).

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