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Extracting the cross section angular distributions for ^{15}C high-energy resonance excited via the (^{18}O,^{16}O) two-neutron transfer reaction

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Abstract

The ^{13}C(^{18}O,^{16}O)^{15}C reaction has been studied at 84 MeV incident energy. The ejectiles have been momentum analized by the MAGNEX spectrometer and ^{15}C excitation energy spectra have been obtained up to about 20 MeV. In the region above the two-neutron separation energy, a bump has been observed at 13.7 MeV. The extracted cross section angular distribution for this structure, obtained by using different models for background, displays a clear oscillating pattern, typical of resonant state of the residual nucleus.

1 Introduction

In the last few years, a study of the structure of different nuclei was pursued at the Catania INFN-LNS laboratory by the (^{18}O,^{16}O) two-neutron transfer reaction at 84 MeV on different targets (^{12}C,^{13}C,^{9}Be,^{11}B,^{16}O), using the MAGNEX large acceptance magnetic spectrometer to detect the ejectiles. Thanks to its high resolution and large acceptance, high quality inclusive spectra were obtained, even in a largely unexplored region above the two-neutron emission threshold in the residual nucleus [1] [2] [3]. New phenomena appeared, such as the dominance of the direct one-step transfer of the two neutrons [4] and the presence of broad resonances at high excitation energy in the ^{14}C and ^{15}C spectra. These structures were recently identified as the first experimental signature of the Giant Pairing Vibration (GPV) [5] [6], predicted long time ago [7]. One of the key aspect in the investigation of the origin of such resonances was the multipolarity analysis on the cross section angular distributions, which suggested an $L = 0$ angular momentum transfer. In this paper the methods used to extract the cross section angular distributions for the ^{15}C GPV are described. In particular, since the GPV is found above the two-neutron separation energy ($S_{2n} = 9.394$ MeV) a careful evaluation of the background underneath it is mandatory.

2 The experiment

The ^{15}C nucleus was populated by the ^{13}C(^{18}O,^{16}O) two-neutron transfer reaction at 84 MeV incident energy. The ^{18}O^{6+} beam was produced and accelerated by the Tandem Van der Graaff facility of the INFN-Laboratori Nazionali del Sud in Catania. A 50 μg/cm^2 99 % enriched ^{13}C selfsupponting target was used. Supplementary runs with ^{12}C were recorded for estimating the background coming from ^{12}C impurities in the ^{13}C target. The ^{16}O ejectiles were momentum analyzed by the MAGNEX large acceptance magnetic spectrometer [8] covering a solid angle $\Omega \sim 50$ msr and momentum range Δp/p $\sim$ 24%. The ejectiles were identified event by event in atomic number (Z), atomic mass (A) and charge (q) by combining two techniques [9]: the standard $\Delta E - E$ correlation plot for the Z identification and the correlation between the horizontal position at the focal plane (X_{foc}) and the ejectile residual energy (E_{resid}) for the the mass identification, which exploits the properties of the Lorentz force. The horizontal and vertical positions and angles of the ^{16}O ejectiles at the focal plane were used as input for a 10^{th} order ray-reconstruction, based on the differential algebraic method implemented in MAGNEX [10]. The ray-reconstruction technique allows for an effective compensation of the high order aberrations connected with the large acceptance of the spectrometer. As a result, the initial phase space parameters at the target point are obtained, which are directly related to the momentum modulus and the scattering angle of the

detected ejectiles. The corresponding Q-values, or equivalently the excitation energy $E_x = Q_0 - Q$ (where Q_0 is the ground to ground state Q-value), were obtained by a missing mass determination using relativistic energy and momentum conservation laws, assuming a binary reaction. Examples of the reconstructed energy spectra for the ^{15}C nucleus can be found in refs. [5] [6]. In the region above S_{2n}, a new resonance appears, recently identified as the GPV [5] [6].
In order to extract the spectroscopic features of the resonance observed in the ^{15}C spectra above S_{2n}, a best-fit procedure with Gaussian shapes on a locally adjusted linear model for the 3-body continuum background (as shown in Fig.1-a) was assumed. The resonance was thus identified at $E_x = 13.7 \pm 0.1$ MeV with a full-width at half-maximum (FWHM) = 1.9 ± 0.3 MeV.

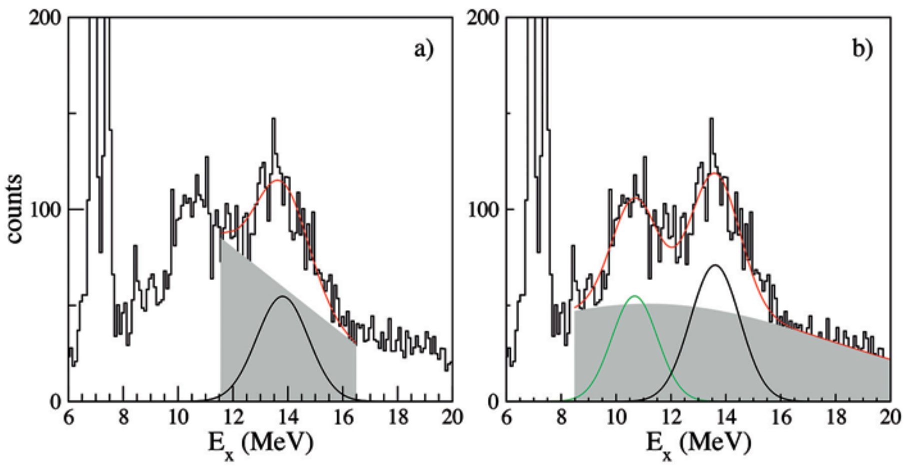

Figure 1: (Colour online) Models for the background underneath the ^{15}C GPV. a) linear background model (grey area), fitted bump (black gaussian) and the sum of them (red line); b) gaussian background model (grey area), fitted bumps (green and black gaussians) and the sum of them (red line).

3 GPV cross section angular distribution

The angular distributions of the absolute cross-section were deduced for the most intense transitions, including that populating the wide resonance observed above the two-neutron separation energy. The differential solid angle for the full spectrometer acceptance was carefully determined taking into account the overall transport efficiency, as described in ref. [11]. A dead-time coefficient of ∼30% was measured. An angular bin of 1° in the laboratory reference frame was chosen for the GPV angular distributions in order to achieve a good compromise between the statistical uncertainties in the number of counts, the background subtraction and the angular resolution. The contribution to the angular distributions due to the continuous background in the spectra was estimated at each angle by a least-squared approach with a Gaussian model shape superimposed on a linear background as shown in Fig.1-a. The adopted background model is consistent with two-neutron break-up calculations, performed considering an independent removal of the two neutrons, as described in ref. [12]. In order to carefully look at the projectile break-up contribution to the angular distribution, a comparison between the GPV angular distribution obtained without any background subtraction, the subtracted background and the final GPV distributions is shown in Fig.2. The oscillating pattern of the GPV angular distribution is slightly visible in the total one, since it is smoothed by the flat background underneath. Such a background has the same shape of that at about 18 MeV excitation energy (green left triangles in Fig.2), where no resonances are present.

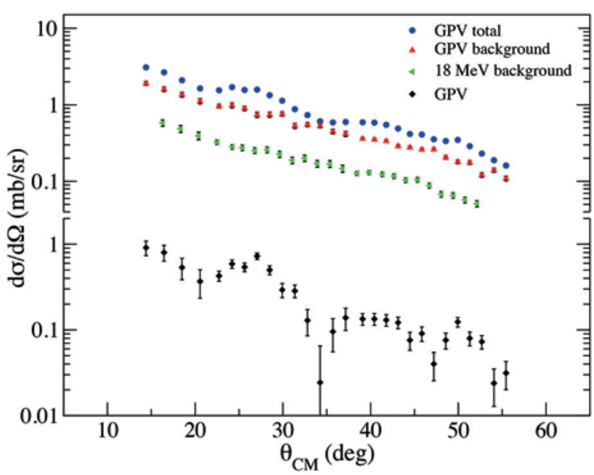

Figure 2: (Colour online) Comparison between the GPV distribution without any background subtraction (blue circles), the subtracted background underneath the GPV (red up triangles), the background present in the region at 18 MeV (green left triangles) and the final GPV (black diamonds) angular distributions for the ^{15}C residual nucleus.

We used different models for the background subtraction and the obtained results for the centroid and width of the resonances and also the shape of the angular distributions did not change within the quoted uncertainties. As an example, a second model for the background subtraction is show in Fig.1-b , which assumes a wide Gaussian (centroid = 11.2 MeV, FWHM = 16 MeV) for the background underneath the GPV (grey area) and a Gaussian model (green curve) for the structure at ∼11 MeV (centroid = 10.7 MeV, FWHM = 2 MeV) . A comparison between the GPV angular distributions obtained using different background models is shown in Fig.3. The first model (black diamonds) assumes the background shown in Fig.1-a and the second model (red triangles) correspond to that shown in Fig.1-b. The average between the two models is also shown (green squares). This comparison demonstrates that both the shape and the absolute value of the GPV cross section angular distribution are stable within the error bars. The observation of such clear and stable oscillations in the resonance angular distribution indicates that the structure correspond to a resonance of the residual ^{15}C nucleus, since it is characterized by a well-defined angular momentum. Moreover the presence of oscillations represents a first indication of an $L = 0$ transfer, as discussed in refs. [5] [6], in relation to the phenomenon described in ref. [13].

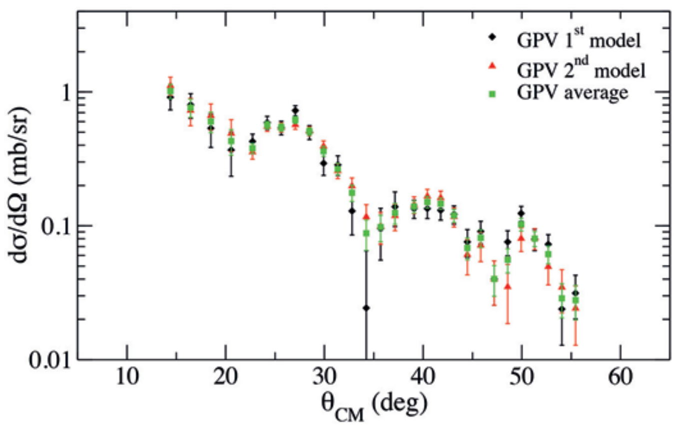

Figure 3: (Colour online) Comparison between the ^{15}C GPV angular distribution obtained assuming two different models (black diamonds and red triangles) for the background subtraction. The first model is shown in Fig.1-a and the second one is shown in Fig.1-b. The weighted average between the two models is shown as the green squares.

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References

[1] D. Carbone *et al.*, Phys. Rev. C 90 (2014) 064621.

[2] M. Cavallaro *et al.*, Phys. Rev. C 88 (2013) 054601.

[3] D. Nicolosi *et al.*, Acta Phys. Pol. B 44 (2013) 657.

[4] D. Carbone *et al.*, J. Phys.: Conf. Ser. 312, 082016 (2011).

[5] F. Cappuzzello *et al.*, Nat. Commun. 6, 6743 (2015) doi: 10.1038/ncomms7743.

[6] D. Carbone, Eur. Phys. J. Plus 130, 143 (2015).

[7] R. A. Broglia and D.R. Bes, Phys. Lett. B 69 (1977) 129.

[8] F. Cappuzzello, D. Carbone, M. Cavallaro and A. Cunsolo, Magnets: Types, Uses and Safety (Nova Publisher Inc., New York, 2011) pp. 1-63.

[9] F. Cappuzzello *et al.*, Nucl. Instr. Methods A 621 (2010) 419.

[10] F. Cappuzzello, D. Carbone and M. Cavallaro, Nucl. Instr. Methods A 638 (2011) 74.

[11] M. Cavallaro *et al.*, Nucl. Instr. Methods A 637 (2011) 77.

[12] F. Cappuzzello *et al.*, Phys. Lett. B 711 (2012) 347.

[13] S. Kahana and A. J. Baltz, Adv. Nucl. Phys. 9 (1977) 1.