^{8}Be NUCLEUS RESONANCES AT THE EXCITATION ENERGY $E_x < 35$ MeV IN THE THREE-PARTICLE REACTION $^{9}\mathrm{Be} + {}^{13}\mathrm{C} \rightarrow {}^{14}\mathrm{C} + \alpha + \alpha$

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The energy interval of ^{8}Be nucleus excitation up to 35 MeV has been studied in a kinematically complete experiment ^{9}Be(^{13}C,^{14}Cα)^{4}He. The well-known levels of ^{8}Be with $E_x(^{8}\mathrm{Be}) =$ 3.06, 11.35, 16.92, and 19.86 MeV were observed as the resonances of $\alpha-\alpha$ interaction. New excitation levels at the energies of about 15.3 and 29 MeV – and, probably, at 23.3 and 26.5 MeV – have been identified as those which correspond to $\alpha-\alpha$ configurations.

1. Introduction

The structure of a ^{8}Be nucleus is a subject of the permanent attention in experimental and theoretical studies. The reason is well-known: α-clusterization of light nuclei with $N \approx Z$, as well as their at least nearest isotopes, plays an important role for the explanation of the spectra of the excited states of those nuclei. Therefore, the exact experimental knowledge and the theoretical reproduction of all properties of this $\alpha-\alpha$ structure – the lightest among the so-called molecular configurations – is mandatory for every theory.

The spectrum of excited ^{8}Be states – both found experimentally and predicted theoretically – extends up to $E_x(^{8}\mathrm{Be}) \approx 50$ MeV, the latter value being probably the highest one in the spectra of excited levels of light nuclei [1]. Nevertheless, it is a unique fact that the energy characteristics of two first (2^+ and 4^+) excited levels of the ^{8}Be nucleus could not be unequivocally estimated for a long time. In all theories, these levels are unambiguously interpreted as those of the rotational band [1, 2], but only recently it has been possible to experimentally estimate the γ-transition $4^+ \rightarrow 2^+$ [3]. An anomaly in the relative energy spectra of two α-particles at $E_x \approx 0.6$ MeV [1], which is observed as a "bump" in many experiments, where the ^{8}Be nucleus is identified as a combination of two α-particles, is not predicted by any theory and has been discussed for a long time. The facts that the energy location of this "bump" is very close to the difference between decay thresholds $E_{\mathrm{th}}(^{9}\mathrm{Be} \rightarrow \alpha + {}^{5}\mathrm{He}) - E_{\mathrm{th}}(^{9}\mathrm{Be} \rightarrow n + {}^{8}\mathrm{Be}(2^+)) \approx 0.6$ MeV and that this effect is observed only in such processes, where the ^{9}Be decay channel is competitive or antecedent to the ^{8}Be decay one, gave rise to an attempt to explain such a resonance in the experimental relative energy spectrum of two α-particles as a result of the complicated interaction between those competing processes [4, 5].

The body of original approaches, which describe such a simple system as two α-particles, should be appended by modern theoretical works, where the ground state of the ^{8}Be nucleus, the second 0_2^+ levels of the ^{12}C (with $E_x \approx 7.65$ MeV) and ^{16}O (with $E_x \approx 14$ MeV) nuclei, and similar levels in other light nuclei, which lie near the relevant thresholds of their complete α-particle decays, are examined as condensed states of the α-particle system, i.e. as if the Pauli principle is valid within every individual particle only [7–14]. (Such a theoretical approach was a compelled response to long-term attempts to elucidate the properties of the second 0_2^+ level of the ^{12}C nucleus, which cannot be experimentally matched (identified) – until now – with the next rotational 2_2^+ level; the progress in this issue would help to estimate the deformation degree of the state concerned and the physical origin of its formation [15].) In such "condensation" theoretical approaches to the ground states of ^{12}C and ^{16}O nuclei, the latter are assumed to preserve their adopted cluster nature, while the following 0_2^+ states are also considered to relate to cluster structures but with different properties. The reliability of such an approach to ^{8}Be, the ground state of which is near-threshold to the $\alpha-\alpha$ decay, is especially important, because the nature of three first states of the ^{8}Be nucleus is accepted to be established unequivocally. Nevertheless, the properties of two first levels of ^{8}Be are also reproduced in the framework of such a gas-like model composed of two α-particles [16]. Experimental works concerning the studies of the ^{8}Be "condensed" states are also in progress [14].

For the ^{8}Be nucleus, there also exists a problem of reliability of low-energy "intruder" state (states) $(2^+, ?)$ at $E_x \approx 9$ MeV [1]. This issue has been discussed for a long time, since, while carrying out the R-matrix analysis of the experimental data on the elastic $\alpha - \alpha$ scattering and the corresponding β-decay of ^{8}Li and ^{8}B nuclei, which give rise to the formation of ^{8}Be, the result was obtained that all those data can be put in agreement only provided that there exists a broad state for ^{8}Be with an energy of about 10 MeV [17, 18]. Neither the α-cluster models constructed earlier nor the modern ones theoretically predict such a low-energy resonance [19, 20]. Special calculations were carried out in the framework of the model of shells with different nucleonic potentials in order to elucidate a possibility for such a state to exist. The results of some calculations testify that the ^{8}Be nucleus has no 2^+ levels lower than the excitation energy $E_x(^8\mathrm{Be}) \approx 16$ MeV, but a well-known one at $E_x \approx 3$ MeV [21, 22]. The results of other calculations demonstrate that such states can exist at $E_x \approx 12$ MeV [24]. The results of alternative R-matrix calculations of the β-decay of ^{8}Li and ^{8}B nuclei well reproduce almost the same set of experimental data, but do not include excited 2^+ levels with energies below $E_x \approx 26$ MeV except for those known at that time. However, the fitting was carried out with respect to another free parameter of the R-matrix approach, the channel radius [23], so that the magnitude of this parameter – more precisely, the issue what of its values is "more physical" – remains a subject of discussion [17, 18].

Such difficulties with "intruder" low-energy states in ^{8}Be comprised a basis for the recently executed global R-matrix analysis of experimental data on the angular scattering distributions and two-particle reactions, where the ^{8}Be nucleus is a composed system [25]. Other conclusions about the excited ^{8}Be states include the forecast of a very broad 2^+ state with $E_x \approx 16$ MeV and $\Gamma \approx 19$ MeV (!). We should emphasize that the experimental phase analysis [17, 18], which allowed a conclusion about the resonances at $E_x \approx 9$ MeV to be drawn, was executed for experimental angular distributions obtained in different experiments. This invokes an issue of the correct agreement between the absolute values of cross-sections, and a practically unresolved problem arises: how could it affect the shape of the energy dependence of phase shifts? The problems stated above testify that the experimental researches of the $\alpha - \alpha$ interaction and the spectrum of ^{8}Be excited states are actual for today as well.

In this work, the studies of the excitation spectrum of a ^{8}Be nucleus in the kinematically complete experiment ^{8}Be(^{13}C,^{14}Cα)^{4}He as resonances in the $\alpha - \alpha$ pair only have been carried out.

2. Experimental Part

The experimental part of the work was carried out at the Laboratorio Nazionale del Sud of the Istituto Nazionale di Fisica Nucleare (Catania, Italy), using the beam of ^{14}C nuclei generated by a tandem accelerator with a particle energy of 89.45 MeV. An outgoing ^{14}C particle was identified by a $\Delta E \times E$-spectrometer with a position-sensitive E-detector and a ΔE-detector 18.3 μm in thickness. The telescope had the angular apertures $\Delta\theta_{\mathrm{lab}} = 8 \div 16^\circ$ along the position-sensitive direction of an E-detector and $\Delta\varphi = -0.9 \div 0.9^\circ$ in the perpendicular direction. A particle in coincidence with ^{14}C, which determined a three-particle reaction, was registered by a complex of 48 position-sensitive detectors that were located on both sides along the beam propagation direction with the total angular apertures $\Delta\theta_{\mathrm{lab}} \approx 50^\circ$ along the position-sensitive direction of detectors, which, in its turn, was parallel to the position-sensitive direction of the semiconductor telescope, and $\Delta\varphi = -10 \div 10^\circ$ in the perpendicular direction. A more detailed description of the experiment can be found in works [26–28]. Gauging experiments evidenced for the experimental errors of about 50-keV and 0.2° of the determination of the energy and the angle, respectively, of registered particles in the laboratory coordinate system for all detectors.

The initial selection of events, which corresponded to the three-particle ^{8}Be(^{13}C,^{14}Cα)^{4}He processes, was executed using the Q-value spectrum of the process, which was calculated for the mass of an identified ^{14}C nucleus and provided that ^{4}He was a second coincident particle and an α-particle was a third one (see the procedure of calculations of the reaction Q value, e.g., in work [28]).

3. Experimental Results and Their Analysis

In Fig. 1,*a*, the distribution of events in the studied process is plotted on a two-dimensional coordinate plane: the calculated value of the Q-spectrum versus the particle registration angle in the laboratory coordinate system. Every event is represented twice: as a point with the kinematic parameters of ^{14}C in the telescope angle range $\Delta\theta_{\rm lab} = 8 \div 16^\circ$ and as a point with the kinematic parameters of the α-particle, which is in coincidence with ^{14}C, in one of the position-sensitive detectors. In Fig. 1,*b*, all events of the three-particle reaction are presented in a conventional form of one-dimensional Q-value spectrum.

The Q-value spectra demonstrate well-pronounced bands and peaks which correspond to three-particle reactions with a conversion through the ground state of ^{14}C (the obtained experimental value $Q_{ggg} \approx$ 6.5 MeV coincides, within the experimental error, with the theoretically calculated value $Q_{ggg}^{\rm theor} \approx 6.603$ MeV) and through one or several excited ^{14}C states belonging to the group of levels with an excitation energy of about 7 MeV [29].

The bases of the peaks in Fig. 1,*b* are very insignificant in general, being practically zero in the vicinity of peak Q_{000}. Such background conditions are provided by the sufficient time characteristics of the procedure and a natural factor – very high energy thresholds for those ^{14}C decay channels which do not include the formation of an α-particle; in particular, the lowest relevant thresholds are $E_{\rm th}(^{14}{\rm C} \to {}^{14}{\rm Be} + \alpha) \approx$ 12.0 MeV and $E_{\rm th}(^{8}{\rm Be} \to {}^{7}{\rm Li} + p) \approx 17.25$ MeV.

In Fig. 2, the two-dimensional distributions of events are depicted in the coordinates of the relative energies of particle pairs $\alpha - \alpha$ and $^{14}{\rm C} - \alpha$, which correspond to the processes that include the ground and excited ^{14}C states. Several horizontal lines, which correspond to the resonances of the ^{16}O nucleus considered as a pair $^{14}{\rm C} + \alpha$, reveal themselves at the relative energies of about 5.5 and 6.5 MeV (Fig. 2,*a*). Also well identified as vertical bands are resonances of the $\alpha - \alpha$ system, which

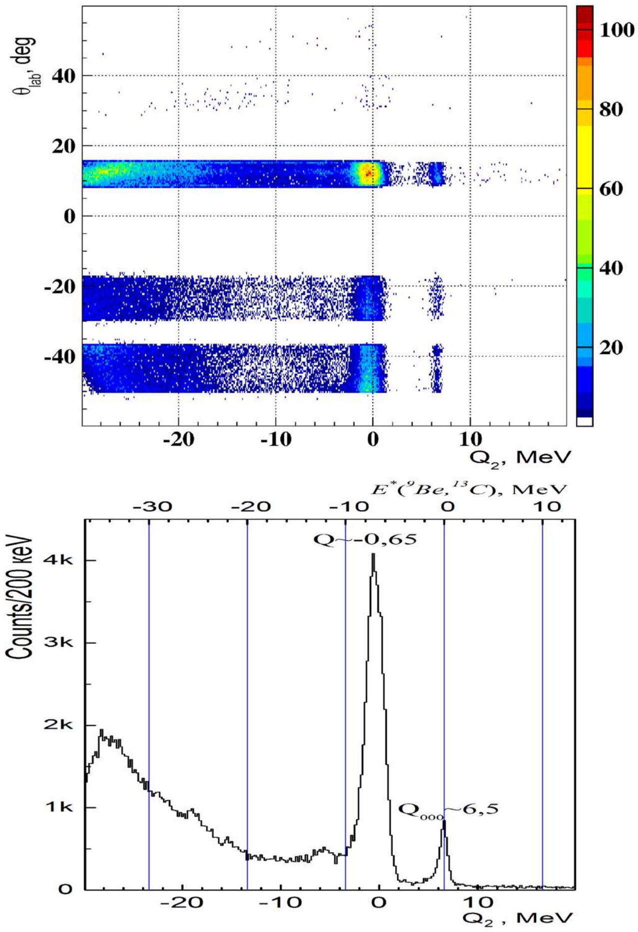

Fig. 1. Q-spectra of events which correspond to two-particle coincidences of ^{14}C nuclei with another unidentified particle and the calculated spectrum for the ^{8}Be(^{13}C,^{14}Cα)^{4}He reaction

correspond to the known 4^+ states with $E(^{8}{\rm Be}) \approx$ 11.4 MeV (Fig. 2,*b*) and in the energy interval $E(^{8}{\rm Be}) \approx 16 \div 17$ MeV (Fig. 2,*a*).

The fact that the other known (!) resonances in the $\alpha - \alpha$ system, which are feasible within the experimentally accessible range of the relative energy of this pair, are not observed explicitly in two-dimensional spectra (Fig. 2) can be explained by small magnitudes of their excitation cross-sections, as well as by such an effect, which is essential for coincidence experiments, as the dependences of the experimental resolution with respect to the relative energy on the value of the latter and the angular conditions of registration of the given event. It is particularly important to take these dependences into account in multidetector experiments with a wide angular aperture [30]. In Fig. 3,*a*, the

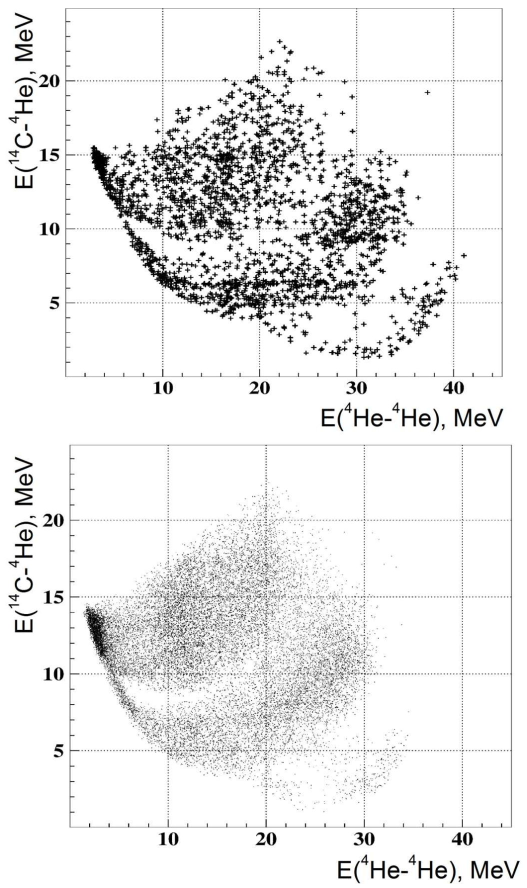

Fig. 2. Event distributions in the coordinates of relative energies $E(\alpha-\alpha)$ and $E(^{14}\mathrm{C}-\alpha)$ for the process with Q-reaction in the vicinity of 6.5 (a) and –0.65 MeV (b)

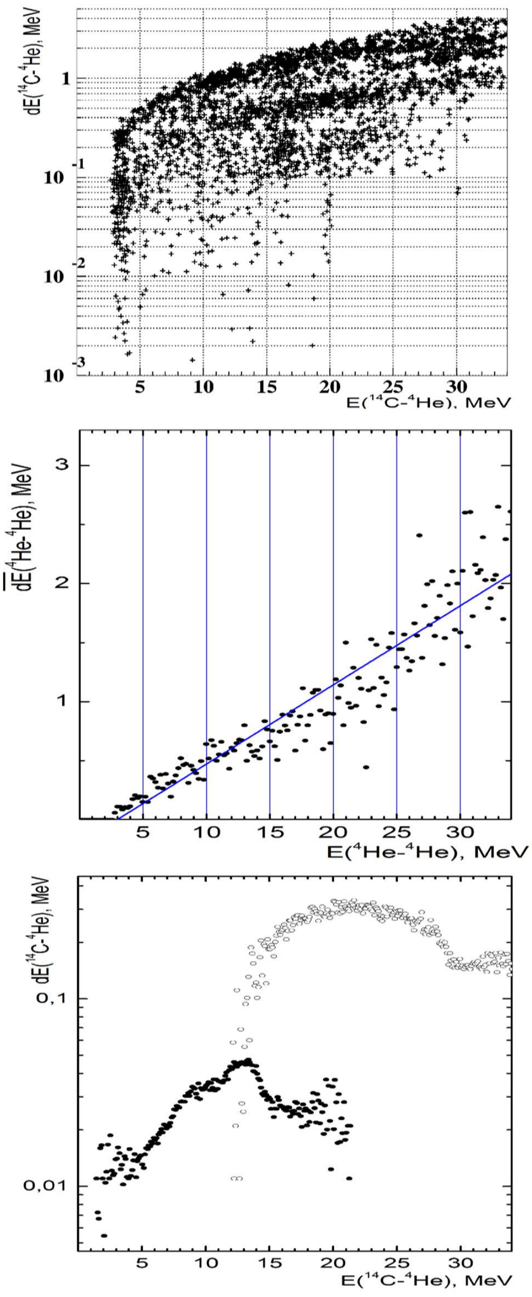

Fig. 3. Dependences of the relative energy determination error on the relative energy magnitude for an $\alpha-\alpha$ (a) and a $^{14}\mathrm{C}-\alpha$ (c) pair and the averaged resolution for the relative energy of the $\alpha-\alpha$ pair (b, points)

dependence of the experimental resolution on the relative energy $E(\alpha-\alpha)$ magnitude is shown. It was calculated making allowance for possible errors of the determination of the energy and the registration angles of a ^{14}C nucleus and a particle in coincidences in the laboratory coordinate system. Figure 3,b exhibits – as a parameter eligible for qualitative estimations only – the dependence of the experimental resolution of the relative energy on its magnitude only, that is, assuming the averaging over all other parameters. The experimental resolution for the relative energy in $^{14}\mathrm{C}-\alpha$ pairs turned out by one to two orders of magnitude lower than that for $\alpha-\alpha$ pairs (Fig. 3,c). Such a relationship between the errors is one of the reasons why experimental points in two-dimensional spectra are more neatly observed as line-shaped formations which correspond to ^{18}O resonances.

The problem of variable resolution for the relative energy, which is studied in the many-particle experiments, has been known since long ago. Nevertheless, it is the application of position-sensitive detectors, as was done in the experiment discussed, that enabled this effect to be estimated and made allowance for by a technique proposed by us in work [30].

In brief, the essence of the technique is as follows. While plotting one-dimensional spectra on the scale of the relative energy E_{12} with a constant energy step ΔE_{12}, every event with the corresponding values of the energy and the error of its determination (E^i_{12}, dE^i_{12}) is "smeared" by the formula $X(E_{12}) = A\exp\left[-\left(\frac{E_{12}-E^i_{12}}{dE^i_{12}}\right)^2\right]$, and the values obtained in such a manner are used for filling the corresponding columns of the histogram. (Here, A is the normalization parameter which is traditionally determined by the condition $\sum X(E_{12}) = 1$, where the summation is carried out over the whole range of the E_{12} scale.) It is evident that, for "conventional" spectra with a constant (independent of energy) experimental resolution and provided that the selected energy step of the spectrum is larger than the energy resolution, such a "conventional" spectrum would be identical to that calculated following the technique described above.

The choice of the energy step ΔE_{12} is also a specific procedure. The step could be selected from the range of very low values of the relative energy (Fig. 3,b), but, in this case, if the number of channels becomes larger, statistical reliability can be lost. Alternatively, one could select ΔE_{12} from the inteval of high relative energies, but, in this case, the energy structure would be lost. Certainly, it is more correct to analyze every spectral range with an energy step that corresponds to this range, although such a procedure is long-term.

Figure 4 exhibits the event distributions for the ^{9}Be+ ^{13}C $\rightarrow$ ^{14}C$_{\rm gs}$+α+α process in the coordinates of relative energy $E(\alpha-\alpha)$; the events were selected according to the condition 5.5 MeV $< Q <$ 7.5 MeV. The histogram in Fig. 4,a is an experimental spectrum plotted without taking the varying experimental resolution with respect to the relative energy $E(\alpha-\alpha)$ into account. Here, the solid curve represents the process registration efficiency by the given set of detectors calculated using the Monte-Carlo method [28].

There are several peaks in the spectrum (see Fig. 4,a), which fall within the energy interval of known excited ^{8}Be states $E_x \approx 16.6 \div 16.9$ MeV, lie at $E_x \approx 20.0$ MeV, and have a prevailing decay width with regard to the α-particle channel [1, 31]. One more peak is observed at the end of the registration interval; this peak corresponds to the first excited ^{8}Be state. Its position and width can be deformed owing to a drastic energy dependence of the registration efficiency. The explanation of other peaks in such a representation of the spectra (see Fig. 4,a) seems problematic.

The experimental spectra in Fig. 4,b and 4,c (dark points with indicated statistical error limits) represent the event distributions for the same process ^{9}Be(^{13}C,^{14}C$_{\rm g.s}\alpha$)^{4}He as in Fig. 4,a, but here they are reduced to a single common resolution with respect to the relative energy, $\Delta E = 500$ and 250 keV, respectively. Such values still preserve the statistical reliability of the numbers of channel events in the whole energy range.

While analyzing the one-dimensional spectra of the relative energies in many-particle reactions, there exists a problem of separation of a non-resonance (smooth) component in them. Such non-resonance component in the relative energy spectrum is mainly of the physical origin. First, it is the contribution of processes, which are energetically possible but include larger numbers of particles that the studied ones do. Second, it is a "trace" (contribution) of those resonances which can be realized in other pairs of particles. The application of position-sensitive detectors allows the researcher to work with wide angular apertures. Therefore, the contributions from resonances manifest themselves on the two-dimensional plane of the relative energies of particle pairs as lines that are perpendicular to the particle-pair energy axis [32, 33] (see Fig. 2,b), which differs from the case where the experiment is carried out without application of position-sensitive detectors. (The resonances of a third pair of particles will look like inclined lines in the spectrum of the relative energies of two other pairs.) The intensity of the event distribution along those lines is associated with the angular dependence of the process cross-section, which this resonance corresponds to. Therefore, in the one-dimensional spectrum of the relative energy of a pair of particles, the resonances that correspond to this pair would manifest themselves as peaks, while the resonances from other pairs as a continuous contribution (continuum).

In this work, we used the technique for the separation of a smooth, non-resonance component which was applied rather successfully while studying ^{9}Be(^{13}C,^{15}Cα)^{3}He spectra [30]. In particular, four to five points were selected randomly from the energy range under investigation, and the event numbers in this set of points were approximated by a polynomial of the second degree in energy. If the experimental values at these points deviated from their approximated values by more than the experimental statistical error, the former were replaced by the corresponding calculated values. It has been tested experimentally that, after a certain number of iterations, the further iterations did not change the shape of the non-resonance component of the spectrum

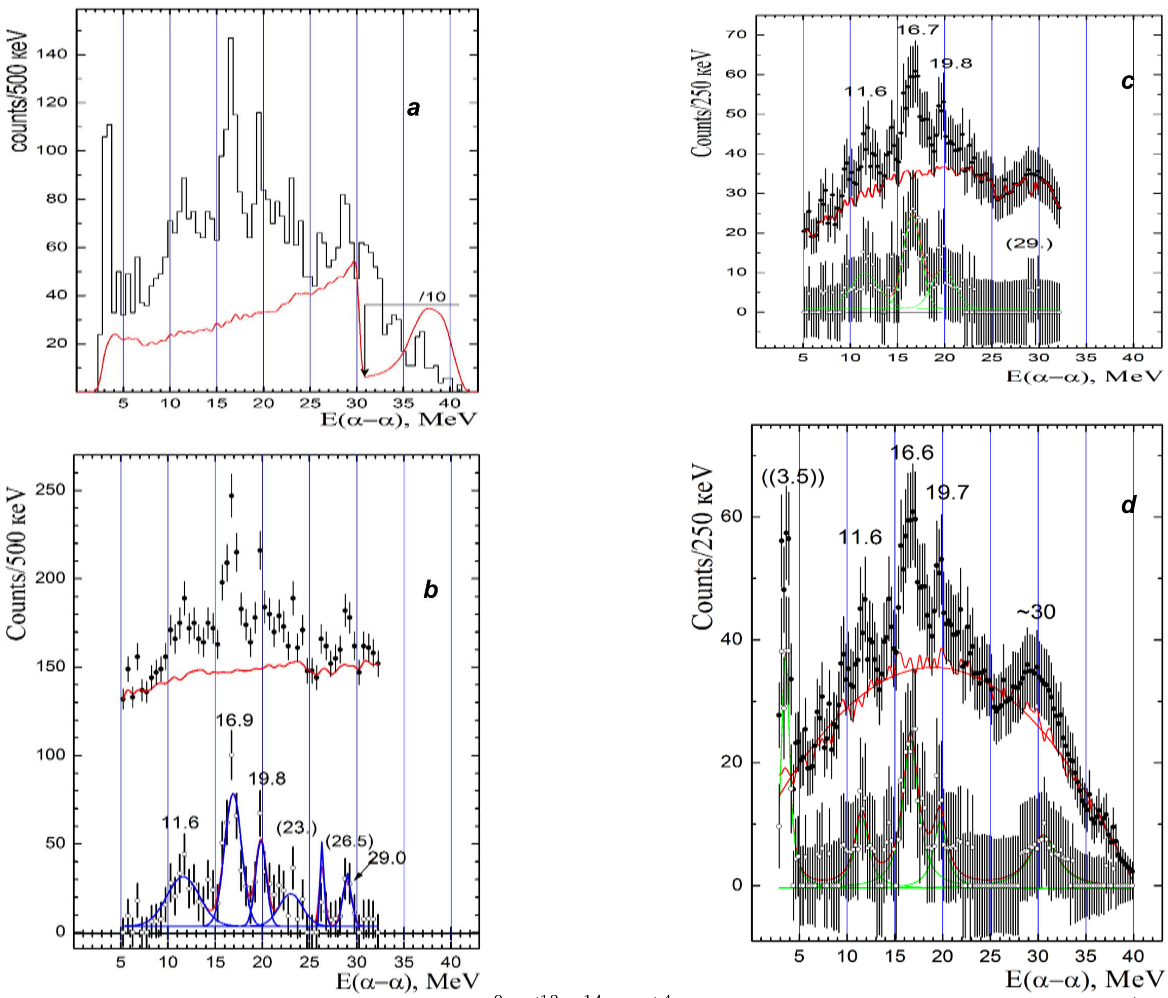

Fig. 4. Event distributions of the three-particle reaction ^{9}Be(^{13}C,^{14}C$_{gs}\alpha$)^{4}He on the scale of the pair relative energy $E(\alpha-\alpha)$ (see explanations in the text)

that had been separated following this technique. (In our case, the fulfillment of the condition that every point in the spectrum had been "engaged", on average, two to three times turned out sufficient.) Of course, in the framework of this technique, the shape of a separated smooth spectral component can depend on the energy range which is analyzed. Therefore, to analyze this spectrum, the whole energy range determined by a nonzero registration efficiency (see Fig. 4,*d*) was selected; separately, the analysis in the energy range $5 \div 33$ MeV, in which the registration efficiency was practically constant (Figs. 4,*b* and 4,*c*), was carried out. Note that the results obtained while estimating the resonance parameters turned out practically identical for different choices of energy ranges.

In Fig. 4 (panels *b*, *c*, and *d*), the dark points with designated statistical error limits represent the spectra that were calculated on the basis of the experimental one by using the method of "smearing" over the experimental resolution with respect to the relative energy $E(\alpha-\alpha)$. The solid curves correspond to separated non-resonance components in the spectra. The light points represent difference spectra which, in their turn, are approximated by the sets of Gaussian curves. The coordinates of the Gaussian curve centers are indicated above the tops of corresponding peaks. The parenthesized numbers mark those Gaussian curves, the omission of which allows one to reproduce, in principle, the general behavior of the spectrum, but the corresponding fitting procedure would result in a larger χ^2 value per point. The errors of the peak center determination did not exceed two energy steps in the histogram. (In Fig. 4,*d*, an additional curve is drawn; this curve corresponds to the non-resonance contribution calculated by fitting all the points by a polynomial of the same degree and illustrates how much the results of the given method can differ from the non-resonance contribution determined using spectral minima.)

The spectra in Fig. 4 allowed us to draw the following general conclusion: in the investigated range of ^{8}Be excitation, observed are peaks that correspond to the known levels with even spins and positive parity and have E_x = 3.06, 11.6, 16.62(?) + 16.92, and 19.86+20.1(?)+20.2(?) MeV [1]. Here, the interrogation mark means that the level with this energy may be indistinguishable from the neighbor ones for the selected energy step of the spectrum and under given experimental conditions.

No resonance was observed in the spectral region near 25 MeV, where the 2^+ and 4^+ excited states of ^{8}Be can manifest themselves at the energies $E_x \approx$ 25.2 and 25.5 MeV, respectively [1]. But, concerning those excited states of the ^{8}Be nucleus, it should be noted that the results of the phase analysis of the ^{4}He(α,α)^{4}He scattering testify that these states clearly manifest themselves only in the absorption factors, while the manifestations of corresponding resonances in the energy dependence of the real phase shifts are practically imperceptible [34]. Such a behavior of the phase shifts agrees with our data obtained; it testifies that the origin of resonances with $E_x \approx$ 25.2 and 25.5 MeV is not the $\alpha-\alpha$-cluster, and the variation of the absorption factors at those energies is a result of the reaction cross-section change [34]. Just this energy interval corresponds to the maximum of the $\alpha(\alpha,\mathrm{d})^{6}$Li reaction cross-section, and this circumstance is an extra evidence for that the excited ^{8}Be levels with $E_x \approx$ 25.2 and 25.5 MeV are most likely coupled with the d $-$ ^{6}Li structure [1].

In the spectra depicted in Fig. 4,*b*, three more levels of the ^{8}Be nucleus – not observed earlier – can be identified in the high energy range: at $E_x \approx$ 26.5, 29, and, probably, 23.3 MeV; the latter with a lower statistical confidence.

In Fig. 5,*a*, the distribution histogram of events that correspond to the process ^{9}Be(^{13}C,^{14}C$^{*}\alpha$)^{4}He ($-2.0 < Q < 1.5$) is plotted on the scale of relative energies $E(\alpha-\alpha)$ and without taking the variability of its experimental resolution into account. The solid curve shows the efficiency of registration in this process. The same spectrum is presented in Fig. 5,*b*, but provided that the resolution variability is made allowance for. The sufficient statistics allowed us to select the 50-keV energy step of the spectrum (the spectra with the energy steps of 25 and 100 keV retain the same features as this one has). Figure 5,*b* also presents the energy dependence of the registration efficiency plotted, together with its statistical errors, with the same energy step; the statistical errors correspond to the numbers of events generated in the course of calculations by the Monte-Carlo method. The other panels in Fig. 5 exhibit the difference spectra for the experimental spectrum plotted with the 50-keV energy step and its non-resonance part separated by two methods. Figure 5,*c* corresponds to the case where the non-resonance part was separated following the technique proposed in this work, and Fig. 5,*d* to the case where the non-resonance part was determined by the minima in the experimental spectrum as a polynomial of the second degree in energy. In both cases, in order to exclude the influences made by the drastic energy dependence of the registration efficiency at $E_x > 24$ MeV and a resonance that corresponds to the 2_1^+ state, the confined energy range $E_x = 6\div24$ MeV was analyzed.

Both spectra were approximated by the sets of Gaussian curves, whose parameters are quoted in Table (columns I correspond to Fig. 5,*c* and columns II to Fig. 5,*d*). The errors were evaluated according to the fitting results, but they were taken not less than the spectral energy step for the peak position and two energy steps for the peak width. The last column of Table also listed the known information on the ^{8}Be excited states with even spins and positive parity in this energy range.

The resonance positions, which were obtained taking the experimental errors into account, correspond to the known levels of the ^{8}Be nucleus with E_x = 11.3, 16.9, and 19.8 MeV. The fact that the intensity and the width of the peak at E_x = 19.8 MeV are larger in comparison with those for two other lower-energy peaks, which correspond to the known excited ^{8}Be states, may, to some extent, reflect its experimental overlapping with the resonances at E_x = 20.1 and 20.2 MeV [1].

In the energy intervals around 10 and 18 MeV (Figs. 5,*c* and *d*), there are some narrow peaks with low intensities. The inclusion of those peaks into the fitting procedure does not influence the quality of the total spectrum approximation and the corresponding

I		II		[1]
E_x (MeV)	Γ (MeV)	E_x (MeV)	Γ (MeV)	E_x (MeV)
11.4 ± 0.05	3.5 ± 0.1	11.3 ± 0.05	2.8 ± 0.1	11.35
15.3 ± 0.05	0.6 ± 0.1	15.3 ± 0.05	0.5 ± 0.1	?
16.8 ± 0.08	1.2 ± 0.2	16.9 ± 0.05	0.9 ± 0.1	16.92
19.8 ± 0.06	2.6 ± 0.2	19.8 ± 0.05	1.6 ± 0.1	19.86; 20.1; 20.2
23.4 ± 0.08	1.7 ± 0.3	(23.3)		22.2; (23.0)
(26.5)		(26)		(25.5)
(30)				(28.6), (32)

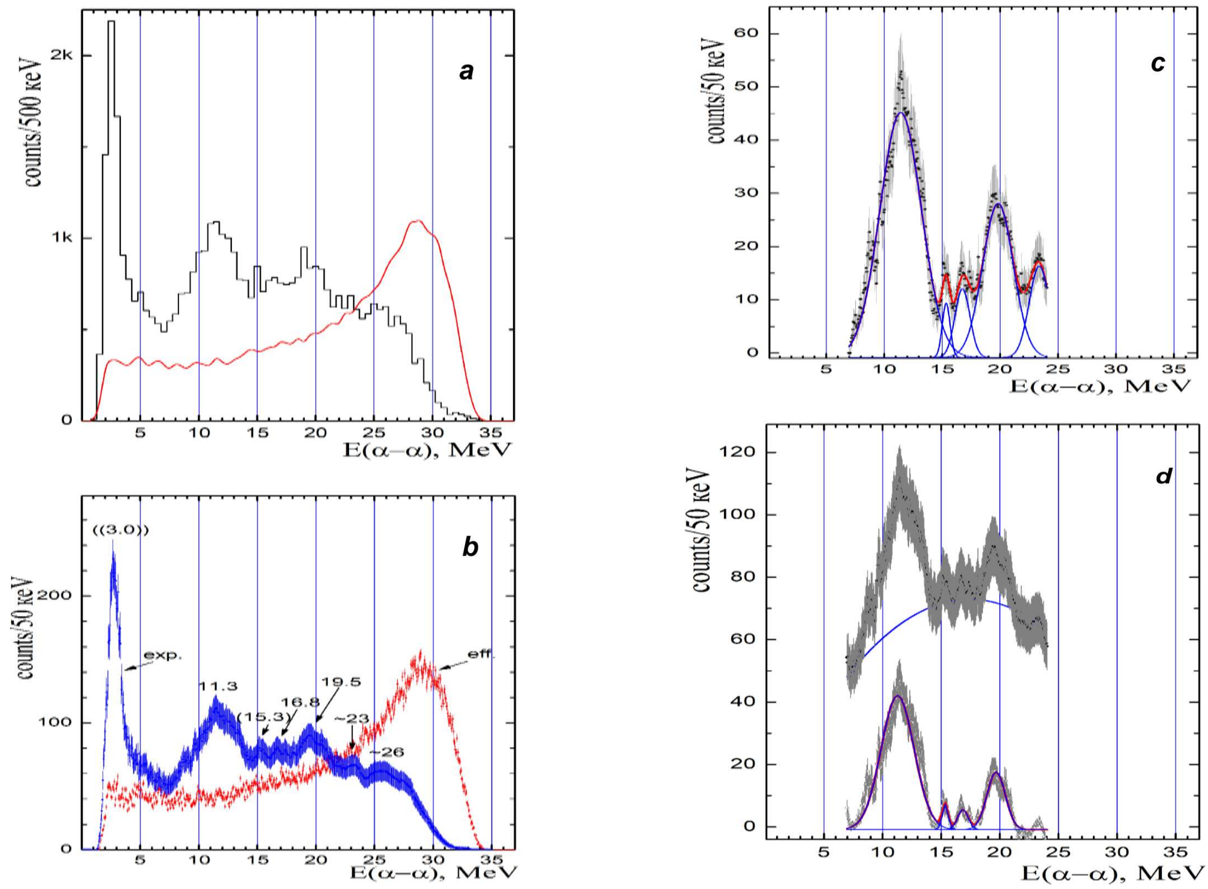

Fig. 5. Event distributions of the three-particle reaction ^{9}Be(^{13}C,^{14}C$^{*}\alpha$)^{4}He on the scale of the pair relative energy $E(\alpha-\alpha)$ (see explanations in the text)

numerical parameters, but makes fitting unstable and increases the parameter errors. At the same time, the intensities of those peaks and, chiefly, their widths are close to the fluctuations in the registration efficiency spectrum (Fig. 5,*b*) which are induced by technological intervals between the sensitive planes of detectors. In Table, the obtained position of the peak with $E_x \approx$ 16.8 MeV is related to the known excited state at 16.92 MeV [1] only, with a 16.6-MeV level being excluded. It was done for the following reason. Although both levels are 2^+ and isospin mixing $(0+1)$ was registered earlier for both of them [1], these are two levels with different isospins in theoretical calculations [35], and it is the level with $E_x \approx 16.9$ MeV that has an isospin $T = 0$.

The substantial difference of the spectrum of $\alpha-\alpha$ resonances obtained in this work from the known excitation spectrum of the ^{8}Be nucleus consists in the availability of a resonance at $E_x \approx 15.3$ MeV, the statistical reliability of which is equivalent to that of the peak that corresponds to a resonance with $E_x =$ 16.92 MeV. In order to explain the presence of the peak at $E_x \approx 15.3$ MeV, we may suggest that it corresponds to the excited state of the ^{8}Be nucleus with spin 0^+ which is of the common origin with the following levels 2^+ ($E_x = 16.9$ MeV) and 4^+ ($E_x = 19.86$ MeV), both having the isospin $T = 0$. If such an assumption is valid, the energy positions and the spins of the levels 0^+(?) ($E_x = 15.3$ MeV), 2^+ ($E_x = 16.9$ MeV), and 4^+ ($E_x = 19.86$ MeV) correspond to the rotational dependence.

4. Conclusions

In the framework of the kinematically complete research of the three-particle process $^{9}\mathrm{Be}+^{13}\mathrm{C} \rightarrow ^{14}\mathrm{C}+\alpha+\alpha$ and making use of position-sensitive detectors with a wide angular aperture, a non-discrete – in the energy step –

study of the spectrum of excited states of the ^{8}Be nucleus in the energy range $E_x < 35$ MeV as resonances of the $\alpha - \alpha$-cluster origin has been carried out for the first time. The known levels with even spin values, positive parity, and $E_x = 3.06$, 11.3, 16.92, and 19.86 MeV were identified. The energy parameters of those levels were evaluated. New excited states of the ^{8}Be nucleus were observed; they correspond to $\alpha - \alpha$ interaction at $E_x \approx 26.5$, 29, and, probably, 23.3 MeV. No excited ^{8}Be states as resonances of $\alpha - \alpha$ interaction were observed at $E_x \approx 25.2$ and 25.5 MeV. This result, as well as the results of evaluating the degree of manifestation of those levels in the energy dependences of the real and imaginary parts of phase shifts with $L = 2$ and 4 with respect to the elastic scattering ^{4}He$(\alpha,\alpha)^4$He, is explained by supposing that those levels have a structure that is different from the $\alpha - \alpha$ one.

The $\alpha - \alpha$ resonance at $E_x \approx 15.3$ MeV has been identified for the first time; the determination of its spin demands additional researches. At the same time, provided that its spin is 0^+, this resonance can be a generating one for a new rotational band of the excited ^{8}Be levels.

V.O. and O.G. thank the administration of the South Nuclear Laboratory (Catania, Italy) for the hospitality and the financial support during the execution of experiments.

The authors are grateful to Professor W. von Oertzen (Hahn–Meitner–Institut GmbH, Berlin, Germany) and his colleagues for the posed problem on the experimental study of the cluster structure of light isotopes of Be and to M. Milin (R. Bošković Institute, Zagreb, Croatia) for the useful discussions of results of the work.

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Received Received 11.10.06.
Translated from Ukrainian by O.I. Voitenko

РЕЗОНАНСИ ЯДРА ^{8}Be У ТРИЧАСТИНКОВІЙ РЕАКЦІЇ ^{9}Be+^{13}C $\rightarrow^{14}$ C $+ \alpha + \alpha$ У ДІАПАЗОНІ ЕНЕРГІЙ ЗБУДЖЕННЯ $E_x < 35$ MeB

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Р е з ю м е

У кінематично повному експерименті ^{9}Be(^{13}C, ^{14}Cα)^{4}He досліджено діапазон енергій збудження ядра ^{8}Be до 35 МеВ. В роботі спостерігалися як резонанси $\alpha-\alpha$-взаємодії відомі рівні ^{8}Be з $E_x(^8\mathrm{Be}) = 3,06$; 11,35; 16,92; 19,86 МеВ. Ідентифіковано нові рівні при $E_x(^8\mathrm{Be}) = 15{,}3$ та 29 МеВ і, можливо, при енергіях 23,3 та 26,5 МеВ, як такі, що відповідають $\alpha-\alpha$-конфігураціям.