Study of low energy resonances in $^{13}C+^{4}He$ interaction

V. Z. Goldberg, G. V. Rogachev, R. E. Tribble, N. A. Mynbayev,[1] A. K. Nurmukhanbetova,[1]
M. S. Golovkov,[2] V. N. Dzybin,[1] M. V. Koloberdyn,[3] and I. Ivanov[3]
[1]*Nazarbayev University Research and Innovation System, Astana, Kazakhstan*
[2]*Flerov Laboratory of Nuclear Reactions, JINR Dubna, Russia*
[3]*L. N. Gumylov Eurasian National University, Astana, Kazakhstan*

About half of all elements heavier than iron are produced in a stellar environment through the *s* process, which involves a series of subsequent neutron captures and *α* decays. The reaction $^{13}C(\alpha,n)^{16}O$ is considered to be the main source of neutrons for the *s* process at low temperatures in low mass stars in the asymptotic giant branch (AGB) [1]. Two factors determine the efficiency of this reaction: the abundance of ^{13}C and the rate of the $^{13}C(\alpha,n)^{16}O$ reaction (see [2], and references therein). The rate of the $^{13}C(\alpha,n)^{16}O$ reaction at temperatures of ~10^8 K is uncertain by ~300% [3] due to the prohibitively small reaction cross section at energies below 300 keV. *α* clustering may generally play a role in helium burning in astrophysical systems. Indeed, even if astrophysical reactions involving helium do not proceed through strong *α*-cluster states (because of high excitation energy), these states can provide an *α* width to the states that are closer to the region of astrophysical interest through configuration mixing [4].

The available data on the *α*-cluster states in neutron rich nuclei are scarce [5–9], but they give indications for the developed cluster structures with very large moments of inertia. The study of non-self-conjugate nuclei has an advantage in that one now can investigate isobaric analog states in mirror systems, using r/a beams. Comparison of the results for both systems can bring new spectroscopic information and shed light on such properties as the radii of the cluster states.

There are old measurements of low energy resonances in the $\alpha+^{13}C$ elastic scattering using a target with ~50% enrichment of ^{13}C. The data were obtained only at four angles, and the analysis was mainly qualitative (see [10] and references therein). Recently much more complete measurements were made by the Notre Dame group [11] However all previous measurements were made using forward kinematics when a tandem beam of *α* particles strikes a target of ^{13}C.

We made a study of the resonance $\alpha+^{13}C$ elastic scattering using the Thick Target Inverse Kinematics method (TTIK) (see [12] and references therein) at the DC-60 cyclotron at Astana. The advantage of the TTIK method is that an excitation function can be measured in a large interval using a "single" beam energy. It provides also a possibility to make measurements at zero degrees (180º cms) where the resonance cross section is the largest and the potential one is minimal. It is important that the TTIK method provides for an easier access to the low energy of interaction because of the kinematic increase of the energy of light recoils.

The measurements were made at initial energy of ^{13}C of 1.75 MeV/A. The data on the $\alpha+^{13}C$ elastic scattering excitation function were obtained using 16 Si detectors covering laboratory angles in the interval 0-30^0. The 180^0 cms (0^0 in the lab. system) is shown in Fig.1. It is seen in Fig.1 that there is a structure at low energies (less than 2 MeV) which has not been observed before. Additional measurements were made to find background contribution. It was found that the background is negligible

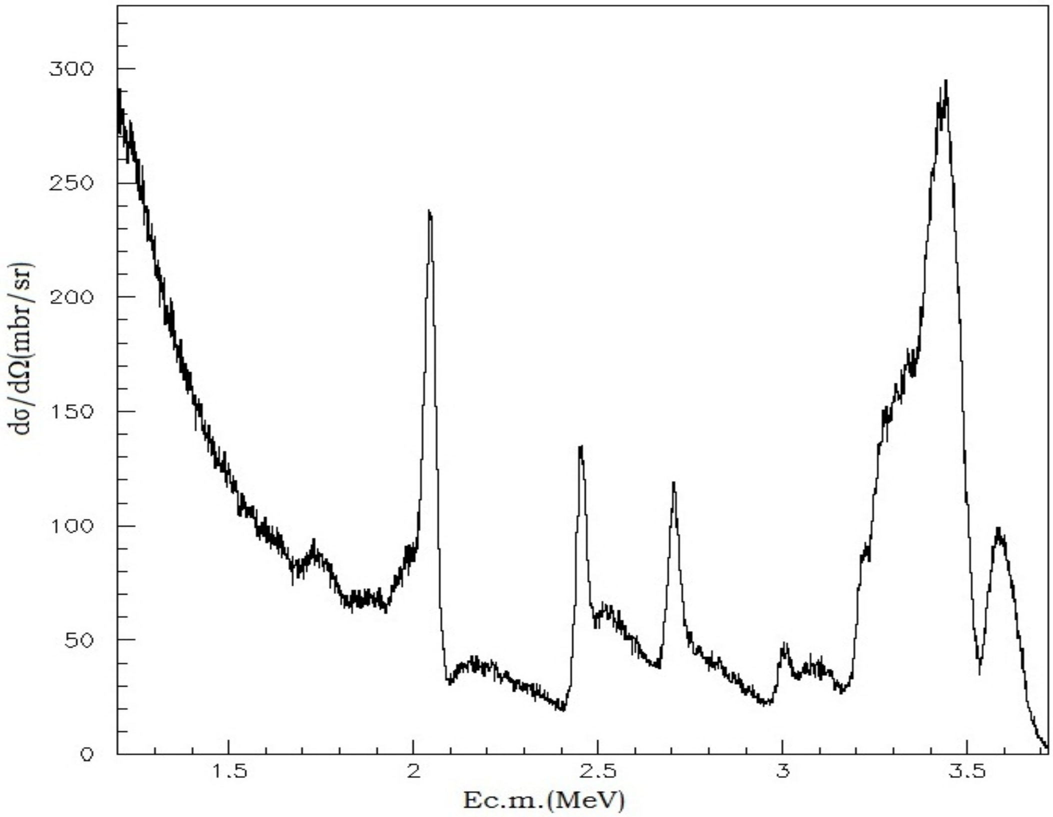

FIG. 1. Excitation function for the $\alpha + {}^{13}C$ elastic scattering at 180^0 degrees.

(also important was the absence of the reactions with ^{12}C which are always present in the conventional setup when ^{13}C target is used)

The complete multilevel *R*-matrix analysis of the data is in progress. It is worthwhile to note that it was the first nuclear physics experiment at the Astana cyclotron.

[1] I. Iben, Astrophys. J. **196**, 525 (1975).
[2] S. Goriely and L. Siess, Astron. Astrophys. **378**, L25 (2001).
[3] C. Angulo *et al.*, Nucl. Phys. **A656**, 3 (1999).
[4] X.D. Tang, *et al.*, Phys. Rev. Lett. **99**, 052502 (2007).
[5] M. Freer, *et al.*, Phys. Rev. Lett. **96**, 042501 (2006).
[6] A.A. Korsheninnikov *et al.*, Phys. Lett. **B343**, 53 (1995).
[7] V.Z. Goldberg *et al.*, Phys. Rev. C **69**, 024602 (2004).
[8] L. Buchmann, *et al.*, Phys. Rev. C **75**, 012804(R) (2007)
[9] E. Johnson *et al.*, Eur. Phys. J. A **42**, 135 (2009)
[10] G.W. Kerr, J.M. Morris, and J.R. Risser. Nucl. Phys. **A110**, 637 (1968).
[11] M. Heil *et al.*, Phys. Rev. C 78, 025803 (2008).
[12] V.Z. Goldberg *et al.*, Phys. Lett. B **692**, 307 (2010).