Decay of ^{12}C Hoyle state

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Introduction

Hoyle state is the exotic state of ^{12}C with excitation energy 7.654 MeV. This 3-α cluster state has been the pinnacle of nuclear research since its first prediction by Hoyle [1] back in 1954. It was predicted initially to be 3-α linear chain structure. Later many more theories have predicted different structures for the 3-α configuration however the structure is still largely unknown. Depending on the interaction, the α particles may arrange themselves in different ways. Different structure will result in different decay probabilities [2]. Using various analytical probes, one can differentiate between the sequential decay events and direct decay events. Knowing the direct decay component precisely is also important from nuclear astrophysics point of view. We here report one such attempt to distinguish between the different decay modes of Hoyle state. The highest statistics experiment till date by T. K. Rana *et al.* [3] puts the upper limit for direct decay at around 0.019%. However, recent calculations [2, 4] show that this limit can be even smaller. So, a better measurement with much higher statistics is required to concretely establish the value of direct decay branching ratio.

Experimental Details

The experiment was performed at the BARC-TIFR pelletron accelerator using 75 MeV ^{12}C beam. A self supporting $50\mu g/cm^2$ natural carbon target was used in the experiment. For detecting charged particles, three ΔE-E strip telescopes and a single E strip detector were used. All the detectors used were double sided silicon strip detectors (DSSD) thus providing the position information of the detected charged particles as well. The three DSSD telescopes on one side and the single E detector on the other side were placed so that measurement of complete kinematic events is possible. The data acquisition (DAQ) as well as data analysis was done using BARC developed LAMPS software. The trigger for the DAQ was generated when any one of three ΔE-E DSSDs in one side fires simultaneously with the single E detector placed in the opposite side. A Monte Carlo simulation was developed to study the reaction kinematics and the decay dynamics of the chosen reaction. The simulation thus allowed for the chosen optimized parameters for the experiment performed.

Data analysis and results

The energy, combined with position information gives the momentum vector of the detected particles in the laboratory frame. Proper timing and particle identification gates were applied to filter out valid α events, and events with three α events detected in the three DSSDs were chosen for further analysis. Using momenta of the three α particles, it was possible to find their momenta in ^{12}C frame. Using these momenta, α energies in the ^{12}C frame can also be calculated which then gives the excitation energy as described in Eq. 1.

$$E_x = E_{th} + \sum_{i=1}^{3} \frac{1}{2} m_i v_i^2 \qquad (1)$$

Using three alpha breakup threshold E_{th}=7.2747, the excitation spectrum generated is shown in Fig. 1. It is evident that both Hoyle state at 7.654 MeV that matches

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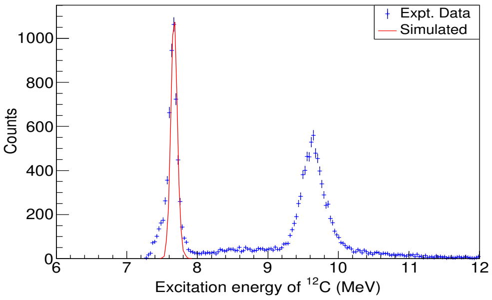

FIG. 1: The ^{12}C Excitation energy Spectrum reproduced by 3-alpha events in coincidence with scattered ^{12}C.

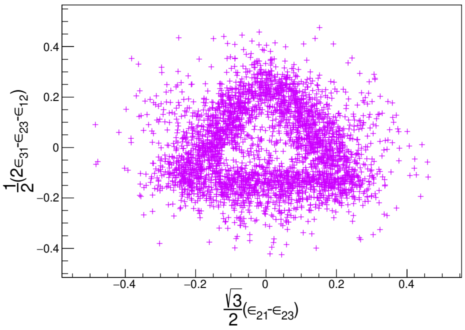

FIG. 3: Symmetric Dalitz Plot for the experimental data

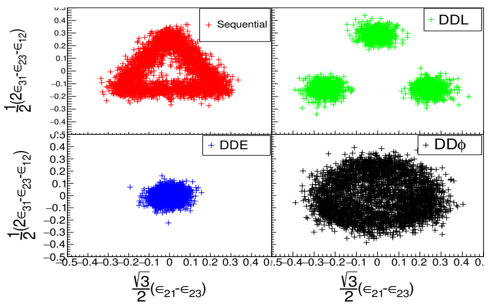

FIG. 2: Monte Carlo Simulated symmetric Dalitz plots for different decay modes, here ϵ_{ij} is the relative energy between i_{th} and j_{th} α particle

with the simulation (solid red line) as well as 9.64 MeV 3^- state are populated.

In order to differentiate between different decay modes, two different analysis techniques viz. dalitz plot technique and rms energy deviation plot techniques have been applied.

In order to simulate the decay mechanism, a Monte Carlo code has been developed which can produce Dalitz plots for different decay modes as can be seen in Fig. 2. When a three-body decay event proceeds via a two step process, the Dalitz plot should show a difference between direct and sequential process. The simulated plots should help in determining the decay mechanism in case of experimental data. Calculating the relative energies of the α particles, the experimental Dalitz plot also has been generated (Fig. 3), and it is clearly evident that the experimental data closely matches with the simulated sequential Dalitz plot although some contributions from DDϕ and DDE mode are visible. So, it can be concluded that the Hoyle state primarily decays sequentially. Further rms energy deviation plot technique has also been applied to characterize the decay process, however poor statistics and presence of random events hindered reaching any conclusive argument.

Conclusions

Excitation energy spectrum for recoil ^{12}C has been successfully reconstructed from the measured coincident 3-α decay events. A Monte Carlo simulation code has been developed to study the decay mechanism. The comparison between the experimental and simulated Dalitz plots show that the 3-α events are mainly produced by sequential decay, as expected. To obtain the contributions from direct decay modes a larger statistics in 3-α events is warranted.

References

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