Precision measurement for Effimov state near the 3α threshold in ^{12}C

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Introduction

The Efimov effect is a universal quantum phenomenon found in various fields of physics. Vitaly Efimov [1] discovered that when a three-body system is composed of an unbound nearly resonant two-body system interacting through short-range attractive interaction, but with s-wave scattering length that is much larger than the range of the interaction, an effective long-range three-body attraction will arise. This may result in an infinite family of three-body bound states. These states are known as Efimov states (ES) or Efimov trimers. The effective attractive interaction can be thought to be mediated between two particles by the third particle moving back and forth between the two. The first conclusive evidence of the Efimov effect was found in ultracold gas of caesium atoms in an external magnetic field [2]. So far, no clear ES has been found in nuclear systems, however, in his original work, Vitaly Efimov considered the 7.65 MeV, 0_2^+ Hoyle state to be an Efimov trimer due to unbound but resonant 2α subsystem (^{8}Be). However, three-body microscopic calculations suggests [3] that the Efimov attraction for the case of Hoyle state is very weak and may not support Efimov trimers. Recently, existence of an ES in ^{12}C near the 3α threshold was suggested in Ref. [4]. The excitation energy of the ES in this case corresponds to the mutual ^{8}Be resonance energy as given by,

$$E_{Efimov} = \frac{2}{3}\sum_{i\neq j}^{3} E_{ij} + E_{th} \qquad (1)$$

Putting, $E_{ij} = 0.092$ MeV and $E_{th} = 7.274$ MeV, the 3α breakup threshold, one arrives at $E_{Efimov} = 7.458$ MeV. In recent years, two measurements [5, 6] attempted to find any evidence of ES at 7.458 MeV. Ref. [5] concludes the nonexistence of any ES combining both α- and γ-decay channel, however, using only the α-decay channel, an upper limit of 0.69% was given for the ratio of Effimov state α-decay to the Hoyle state α-decay. Whereas in Ref. [6], the limit was concluded to be at most 0.2%. In both the works, the excitation function of ^{12}C is broad, suggesting poor resolution of the used detector setup. In the present work, we have revisited the problem with a much better experimental setup.

Experiment Details

To populate the Hoyle state, we bombarded 57 MeV ^{12}C pulsed beam on 25 μg/cm^2 natural carbon target. The experimental setup consisted of eight double-sided silicon strip detectors (DSSD) divided into two arrays, each consisting of four DSSDs and placed symmetrically at 50° with respect to the beam axis (FIG. 1). Trigger signal from the four DSSDs in each arrray was first logic ORed to produce trigger for the entire array then the two triggers from each array were ANDed and further filterd with RF signal to produce the MASTER trigger. The event rate was kept below 1 kHz to reduce contribution from random coincidences. To calibrate the detectors, Am-Pu and Th α source were used for lower energy

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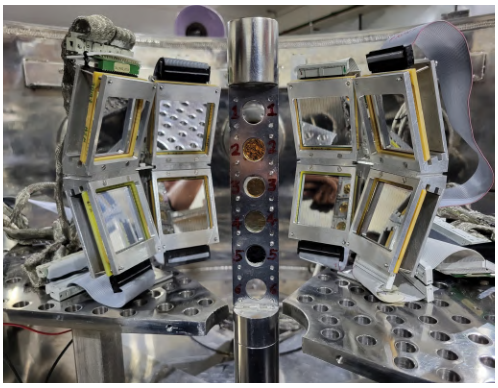

FIG. 1: Experimental setup consisting of eight DSSDs arranged in two arrays and placed symmetrically.

points and elastic counts from ^{197}Au with 35 MeV ^{12}C beam for higher energy points.

Data Analysis and Results

The data analysis involves first filtering out events by number of coincidences. Total four hits were demanded from the two arrays from a valid event with three from one of the array and the remaining one from the other array. Following selection of events with four hits, a kinematic gate was applied to all four particles which was generated beforehand using a Monte-Carlo breakup simulation code. Further, timing gate, momentum conservation gate and energy conservation gate (both for 7.65+g.s. and 7.65+4.44 channels) were applied. Events satisfying all these gates were considered truly complete kinematic and chosen for building the excitation energy spectrum.

FIG. 2 represents the ^{12}C excitation energy spectrum and is compared with that of Refs. [5, 6] along with the simulated spectrum which agrees very well with our data. The potential ES events satisfying the mutual ^{8}Be resonance are also shown in cyan which amounts to 37 counts. With ∼29000 Hoyle events, this gives the upper limit of α decay width ratio of the Effimov state to the Hoyle state to be 0.127%. Due to much better energy and angular resolution of our detector system, the Hoyle state peak at 7.65 MeV is by far the sharpest and as a result, our upper limit is a major improvement over the limits of 0.69% and 0.2% put forward by Ref. [5] and Ref. [6] respectively.

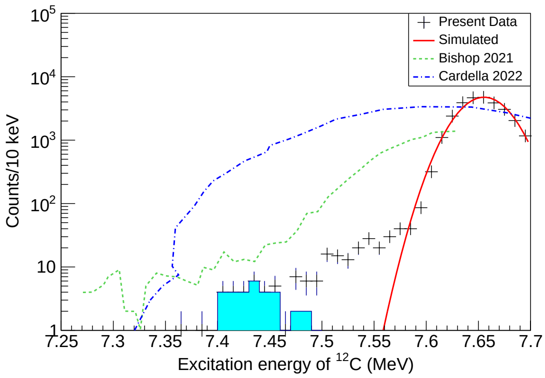

FIG. 2: Excitation energy spectrum of ^{12}C generated by complete kinematic events. The cyan filled area represents potential Efimov events.

Conclusion

We performed a precision experiment to determine the α-decay strength of the Efimov state in ^{12}C. We found a new upper limit of 0.127% for the α-decay width ratio of Efimov state to the Hoyle state which is smaller by a factor of ∼2 than the previous measurement [6] with reduced uncertainties. The newly found limit of α-decay branching ratio of the Efimov state will have a huge implication in the estimation of abundance of ^{12}C.

References

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