Study of the Hoyle state

Tapan Kumar Rana
Variable Energy Cyclotron Centre, 1/AF, Bidhan nagar, Kolkata - 700064, INDIA
email: tapan@vecc.gov.in

The famous Hoyle state, which is the second 0^+ state of ^{12}C at an excitation energy of 7.65 MeV, plays a key role behind the formation of ^{12}C. This state was first predicted by Fred Hoyle before its actual experimental observation. The prediction of the 7.65 MeV resonance state was a remarkable inference drawn from astrophysics to explain the elemental abundance in the solar system and it had a dramatic effect on the subsequent development of stellar nucleosynthesis and other branches of astrophysics.

The Hoyle state was predicted and experimentally observed six decades ago. Nevertheless, the structure of the state is still not known properly and is a matter of great interest, as it has been predicted to be very exotic in nature; it may have either linear three α chain configuration or dilute gas structure and it is even speculated that the state may be an example of a nuclear Bose-Einstein condensate. The present thesis consist of two parts, in the first part, in order to study the properties of hot nucleus formed in heavy ion reactions, a high resolution, low threshold, high granular charged particle detector array has been designed and developed and the details of which (mechanical design, fabrication, testing of different detectors, etc.) have been presented. In the second part, using part of the array elements, a high statistics, high resolution, and complete kinematical measurement has been performed at VECC to study the Hoyle state.

High resolution, high granularity, large solid angle coverage detector array is an essential tool for precise and complete kinematical experiments. Moreover, such an array is extremely useful for detailed charged particle spectroscopy experiments in medium (Fermi) energy domain. In order to perform such high resolution, high multiplicity kinematically complete experiments, an array of si-strip detector telescope has been developed at VECC. The detector array was designed in such a way that it should have large angular coverage with high granularity, capability of isotopic as well as mass identification of the fragments, and, as low as possible detection threshold. The array consists of 24 identical telescopes, each telescope is made up of three elements; first element is a 50μm, ΔE, Single-sided Silicon Strip Detector (SSSD : 16 strips, each of dimension 50 mm × 3 mm), second element is a 500/1000μm, ΔE/E, Double-sided Silicon Strip Detectors (DSSD : 16 strips (each 50 mm × 3 mm) per side in mutually orthogonal directions) and third element is CsI(Tl) detector (4 nos.), each of thickness 6 cm. The complete mechanical structure has been designed in such a way that the array, after complete assembly, forms a surface of a sphere of radius 20 cm, as shown in Fig. 1. Detailed characteristics of different elements of the telescope have been studied offline as well as in beams [1-2]. Now the array (full or part of it) is being used for physics experiment.

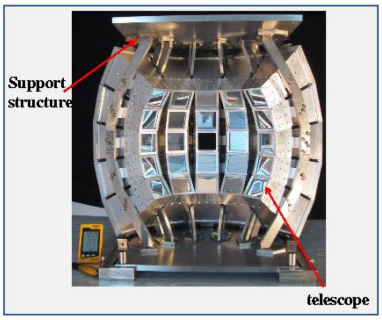

Fig. 1*: Charged particle detector array with all the detectors.*

The study of the decay mechanism of the Hoyle state has been performed in K130 cyclotron at VECC, in a complete kinematical experiment of inelastic scattering of α (60 MeV) on ^{12}C. Only completely detected events (events where all four α-particles, three from the decay of $^{12}C^*$, as well as the inelastically scattered one were detected separately) have been used for the present analysis to remove any ambiguity about the origin of the detected particles. The number of completely detected (4α) Hoyle state events in the present data was around 20000, which is nearly 4-10 times higher than the number of events considered in any earlier experiments.

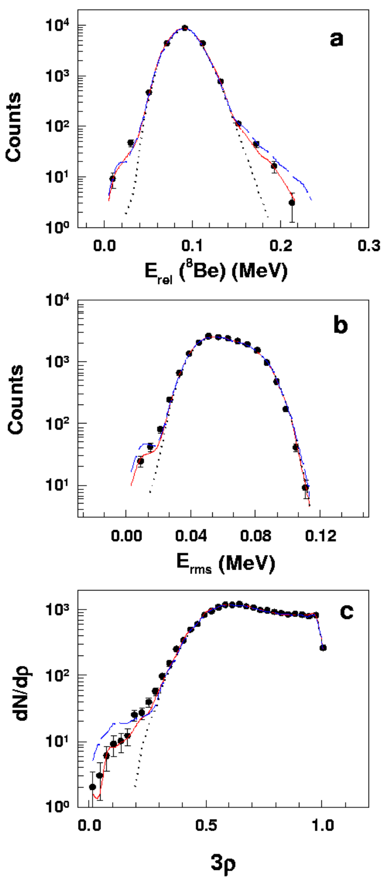

Fig. 2: *(a) The distribution of ^{8}Be like pairs. (b) The distribution of root mean square energy (c) The distribution of the radial projection of the symmetric Dalitz plot (see for the details in the Ref [3]).*

For quantitative estimation of the individual contributions of the three direct decay modes of the Hoyle state, an event-by-event Monte Carlo simulation program has been developed. Then, simultaneous optimization of three different distributions (as shown in Fig. 2, the relative energy of ^{8}Be like pairs, the root mean square energy deviation, and the radial projection of symmetric Dalitz plot) derived from the experimental data with those generated from a simulated event set has been performed to arrive at a consistent estimate of the contributions of various direct decay modes [3]. The optimization procedure was further repeated numerous times with different sets of simulated data sampled randomly from a much larger pool of simulated events to extract the distribution of the best-fit values and determine the contribution for each mode. The fitted spectra for all the distributions are shown in Fig. 2 (a,b,c). Simultaneous optimization of three different distributions using χ^2 minimization technique has led to the determination of non-zero branching ratios for direct decay in phase space (DDΦ: 0.60 ± 0.09 %), and direct decay with equal energy (DDE: 0.3 0 ± 0.1 %). The present study has also led to the estimation of upper limit for direct decay of linear chain (DDL: 0.1%) at 99.75 % confidence level [3-5].

In conclusion, a high resolution and highly granular si-strip detector array has been developed for the nuclear physics experiments and using part of the array elements, a high resolution, high statistics experiment has been performed to estimate the quantitative contribution of various decay modes of the Hoyle state.

I thank my colleagues, S. Bhattacharya, C. Bhattacharya, S. Kundu, K. Banerjee, T. K. Ghosh, G. Mukherjee, R. Pandey, P. Roy, H. Pai, A. Dey, S. Manna, V. Srivastava, M. Gohil, T. Roy, A. Chauduri, J. K. Meena, A. K. Saha, J. K. Sahoo, and R. M. Saha for their constant support to complete this work.

References

[1] T. K. Rana *et al.*, PRC 78, 027602 (2008).
[2] T. K. Rana *et al.*, IJMP E 20, 789 (2011).
[3] T. K. Rana *et al.*, PRC 88, 021601R (2013).
[4] T. K. Rana *et al.*,EPJWC 66, 03072 (2014).
[5] S. Bhattacharya, T. K. Rana *et al.*, Pramana J. Phys., 83, 673 (2014).