Radiative decay width of the Hoyle state through ^{12}C(p,p′) γ-γ reaction

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The ^{12}C is produced in stellar nucleosynthesis through the triple-alpha reaction, in which two alpha combine to form ^{8}Be and then it combines with another alpha to form ^{12}C. However in this process, ^{12}C is not formed in the ground state but at an excitation energy of 7.65 MeV, known as the Hoyle state [1]. This state is unbound and dominantly decays through α emission leading to the very short-lived ^{8}Be, which finally disintegrates into two α particles [2]. The stable ^{12}C is formed through the small radiative transition of the Hoyle state to its ground state. The radiative transition is the sum of cascade γ decay through first 2^+ state of ^{12}C (> 98.4%), electron-positron transition through E0 pair decay (~1.5%) and E2 pair decay (< 0.1%). Therefore, the most dominated route to form ^{12}C in ground state is the cascade γ decay of 3.21 MeV and 4.44 MeV. To estimate the more precise value of radiative transition width, several experiments have been performed previously around 1970. The average of all previous estimated (more reliable values) values was obtained as $4.1\mathrm{x}10^{-4}$ [3]. Till date, this value is used to estimate the synthesis of all elements through triple alpha reaction rate calculation. More recently, a new measurement [3] has been made with modern equipment and found a 34% higher rate compared to the previous measurements, which has a greater impact in whole nucleosynthesis process. Therefore, it needs further verification or confirmation with more statistics and using new technique.

An extensive experiment has been performed at the Variable Energy Cyclotron Centre to measure proton-γ-γ coincidences using proton beam of 10.6 MeV from the K-130 cyclo-

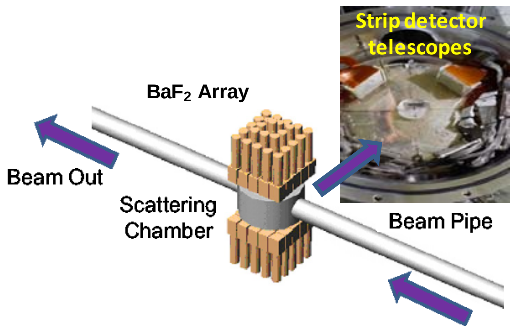

Fig. 1. The schematic view of experimental setup with BaF_2 detector array arranged in two 5x5 matrix and the silicon strip telescopes placed inside the chamber.

-tron on a ^{12}C target. The inelastic proton corresponding to the Hoyle state, were detected using two silicon strip telescopes [4] in coincidence with the two cascade γ rays detected using 50 element BaF_2 detector array [5]. Two silicon strip telescopes were placed on both side of beam axis at backward angles (centered at around 125° degrees) inside the small scattering chamber. The BaF_2 detector array was split into two blocks of 5x5 matrix each and were placed on the top and bottom of the scattering chamber. The schematic view of the setup is shown in Fig 1. Timing spectrum has been generated using start from the OR of two ΔE strip detectors and stop from the individual BaF_2 detectors which allowed selection of prompt proton-γ-γ coincidences. The master trigger was taken from the OR of the two ΔE Si-strip detectors. The trigger threshold was optimized to reduce the large contribution of scattered proton from the ground and the first excited state of ^{12}C. A natural ^{28}Si target was used for the estimation of

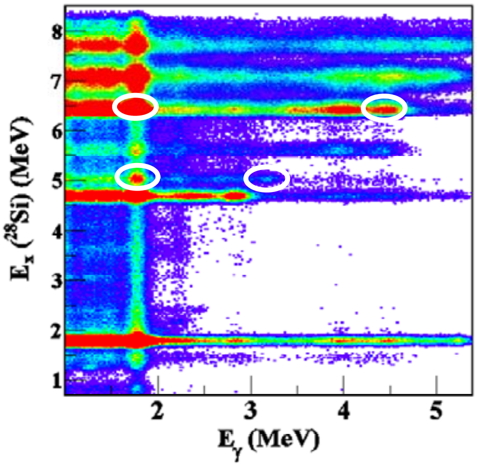

Fig. 2. Excitation energy of ^{28}Si reconstructed from singles proton events versus gamma energy in the BaF_2 detectors.

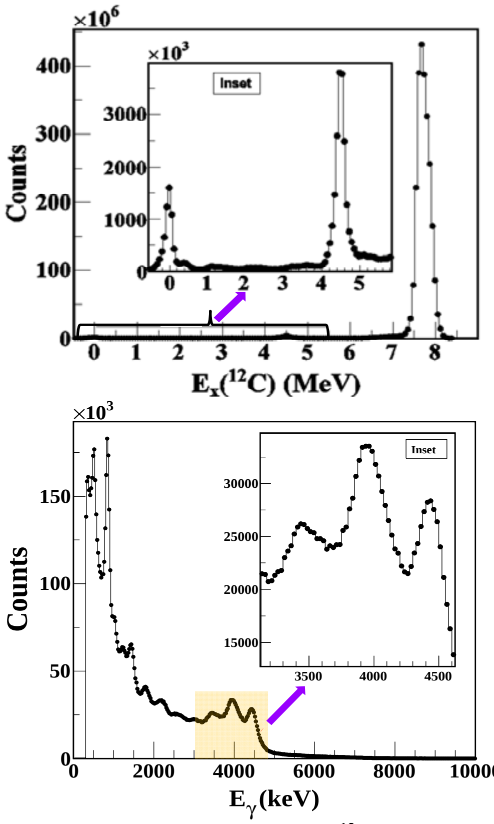

Fig. 3. (Top) Excitation energy of ^{12}C reconstructed from singles proton and (bottom) time gated singles γ spectrum in the ^{12}C(p,p′) reaction. In both the graphs, inset represents the expanded view of the region shown by arrows.

coincidence detection efficiency of the BaF_2 array using 4.98 MeV and 6.28 MeV states. A two-dimensional spectrum, highlighting the ^{28}Si excited state versus γ energy is shown in Fig 2. The two cascade gammas of energy 1.78 MeV and 3.20 MeV for 4.98 MeV state (100% γ-decay) and 1.78 and 4.5 MeV for 6.28 MeV state (88.2% γ-decay) are highlighted in Fig 2 (white circles). A detailed GEANT simulation has also been performed to evaluate the absolute photon detection efficiency and the γ-ray angular correlation.

Fig 3 shows the excitation energy of ^{12}C reconstructed from the singles proton spectra measured in the strip detector telescope (top). The peak at 7.65 MeV represents the excitation of the Hoyle state. As can be seen in the inset, the ground and the first excited states are reduced by a factor of two orders of magnitude compared to Hoyle state owing to our trigger condition. The time gated singles γ spectrum measured in the BaF_2 detectors is also shown in Fig 3 (bottom). Apart from the full energy peak at 4.44 MeV, the spectrum has broad distribution of events of single (at ~ 3.9 MeV) and double (at ~3.4 MeV) escape peaks, as well as Compton scattering. The transition probability of cascade γs of 3.21 MeV and 4.44 MeV is expected to be about 10,000 smaller compared to 4.44 MeV from the first excited state. However, 4.44 MeV excited state will only produce a single photon event. The detail analysis is under progress to extract the cascade γs in coincidence with the Hoyle state. The final results will be presented during the symposium.

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