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Study of resonances produced in light nuclei through two and multi particle correlations

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Abstract. CORRELATION experiment has been performed at INFN-LNS of Catania, using the 4π multi-detector CHIMERA, with the aim of exploring correlations between two and multi light particle produced in $^{12}C+^{24}Mg$ collisions at 35 AMeV. Particular attention has been paid to the decay mechanisms of Hoyle state, an excited resonant state of ^{12}C produced via the triple-α process and characterized by a pronounced molecular like structure with three α particles. The study of the Hoyle state is essential for nucleosynthesis, but it also represents a clearly isolated state that can be studied as a three-α cluster system.

1. Introduction

Heavy Ion collisions at intermediate energies represent an important tool to produce and to study systems in extreme conditions of temperature, density and excitation energies, thus they are the only terrestrial means to access the equation of state of asymmetric nuclear matter. The correlations between particles emitted during these reactions play a crucial role to understand involved dynamics and to investigate some of the spectroscopic properties of several species produced during the evolution of systems. Multi particle correlations have been used to explore the competition between sequential and direct decay mechanisms of resonances produces in these reactions; in particular here three α correlation has been analyzed to study the decay processes of Hoyle state, the second 0^+ excited state of ^{12}C at an energy of 7.65 MeV.

2. Experimental details and results

With the aim of exploring two- and multi-particle correlations in Heavy Ion Collision, an experiment has been performed at LNS-INFN of Catania; ^{12}C+^{24}Mg reaction at 35 AMeV has been investigated using the forward part of CHIMERA 4π array [1]. In order to isolate α particles resulting from decay of excited ^{12}C quasi-projectiles, a criterion has been imposed to restrict velocities of fragments.

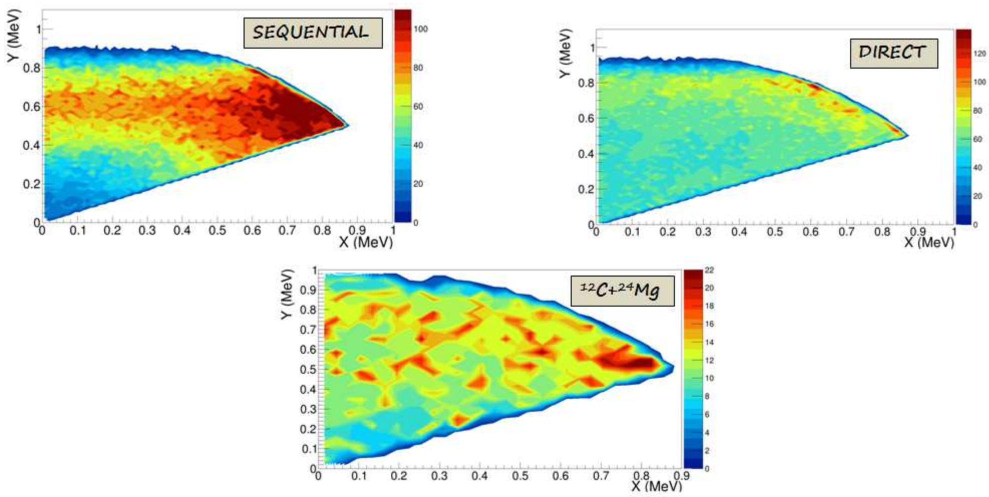

Figure 1. Symmetric Dalitz plots of simulated events for sequential (top left panel) and direct phase-space (top right panel) decay of Hoyle state. Bottom panel: symmetric Dalitz plot, corresponding to decay from Hoyle state region, constructed with experimental data collected in ^{12}C+ ^{24}Mg reaction.

To study the decay mechanisms of Hoyle state, Monte Carlo simulation has been performed for each decay scenario: sequential decay (SD ^{12}C$\rightarrow$^{8}Be-$\alpha$$\rightarrow$3$\alpha$) and direct mechanism (^{12}C$\rightarrow$3α) characterizing a uniform sampling of phase space by the decay products (DDΦ). In order to investigate the various decay modes, energy distributions of decay products have been analyzed adopting the symmetric Dalitz plots [2] constructed using following coordinates:

$$X = \sqrt{3}(\epsilon_j - \epsilon_k), \qquad Y = 2\epsilon_i - \epsilon_j - \epsilon_k, \tag{1}$$

where $\epsilon_{i,j,k} = E_{i,j,k}/(E_i + E_j + E_k)$ are the energies of particles in the center of mass reference frame, normalized to total decay energy. Fig. 1 shows symmetric Dalitz plots for simulated events corresponding to sequential decay (top left panel) and direct phase-space one, DDΦ (top right panel), of the Hoyle state. The same plot constructed using experimental data collected in ^{12}C+ ^{24}Mg reaction is reported in lower panel of Fig. 1; it exhibits a more uniform distribution that does not allow us to exclude any of the two decay mechanisms. For better evaluations, monodimensional ϵ_i distributions [3] have been used. ϵ_i is the highest normalized energy among those of the 3 α particles emitted from the region around the Hoyle state. In the case of the SD mechanism the distribution should have a peak around 0.5. In direct processes instead it should range between 1/3 and 2/3, corresponding to the case of three α particles with an equal energy, and the one of an α particle emitted in a direction opposite to that of the other two, respectively.

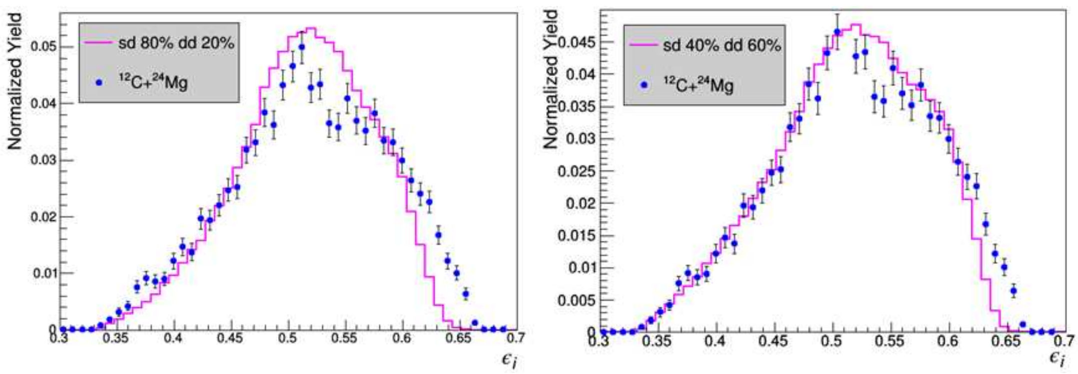

Figure 2. Fits of ϵ_i distribution constructed with experimental data. The different fits have been obtained using two combinations of percentages related to simulated sequential and direct decay mechanisms.

In order to obtain a quantitative estimation for the probability of each decay mechanism, the experimental ϵ_i distribution has been fitted with simulated events in which different percentages of direct and sequential decays have been introduced. Fig. 2 shows the fits of experimental data, relative to two different combinations of percentages related to sequential and direct decay mechanisms. The results reported in Fig. 2 allow us to confirm the presence of an important direct decay component that seems lower than 60% but also larger than 20%. These comparisons can not be used to extract the branching ratio for direct and sequential 3 α decay of Hoyle state, because of the limited energy and angular resolution. However they evidence a significant contribution of direct decay modes for the Hoyle state.

3. Conclusions

Multi-α correlations have been analyzed in peripheral $^{12}C+^{24}Mg$ reaction at 35 AMeV. The used strategy, based on Dalitz plot techniques, allows us to evaluate the relative contribution of two 3 α decay mechanisms of Hoyle state. The comparison with simulations evidences the contribution of a direct component in Hoyle state decay, already suggested in experiment performed with Heavy Ion collisions [4, 5]. This result could be related to in-medium effects on nuclear structure properties.

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