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COPLANAR TERNARY DECAY OF HYPER-DEFORMED NUCLEI OF MASS A=56*

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Using a kinematic coincidence method the coplanarity of ternary fission events from 56Ni compound nuclei formed in the 32S (164 MeV) + 24Mg reaction has been measured. Extremely narrow out-of-plane correlations are observed for two fragments emitted in either purely binary events or in events with a missing (ternary) mass consisting exclusively of α-particles. This observation is interpreted by a fission process through an elongated shape, where the lighter mass in the neck region remains at rest.

We have studied the fission events from the decay of the 56Ni compound nucleus at an excitation energy of $E^*_CN = 83.7$ MeV formed in the $^{32}$S + $^{24}$Mg reaction at $E_{lab} = 164$ MeV. A previous study [1, 2] has been reported for the 60Zn CN at the same excitation energy and a similar angular momentum range with the $^{36}$Ar + $^{24}$Mg entrance channel. The system $^{32}$S + $^{24}$Mg has been studied extensively by Sanders et al. [3], with the emphasis on the binary fission process. With the present result and those of Refs. [1, 2] we have observed the ternary fission decay of these nuclei, which competes with the binary fission due to the formation of hyper-deformed configurations.

The present experiment was performed at the VIVITRON Tandem accelerator of the IReS (Strasbourg) with the BRS-EUROBALL setup [1, 4] aimed at particle $\gamma$-spectroscopy. Two heavy fragments are registered in

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kinematical coincidence and identified by their charge $(Z_3, Z_4)$ in two large area position sensitive Bragg-ionisation chambers [1]. Correlations have been measured of two heavy ejectiles with respect to in-plane and out-of-plane scattering angles $\theta$ and $\varphi$, respectively. For the inclusive detection of “binary” exit channels with two heavy fragments, but with a definite choice of the missing mass and charge, very broad distributions are expected in the $\theta$ and $\varphi$ correlations, because of missing informations on the momenta of the unobserved third (and/or more) particles.

Reaction channels are in our case defined by the sum of the observed charges of the fragments $Z_{\text{total}} = Z_3 + Z_4$ with a well defined missing charge $\Delta Z = Z_{\text{CN}} - (Z_3+Z_4)$ varying from 0 to 8. The coplanarity condition is defined by the sum $\varphi_3 + \varphi_4 = 180^\circ$ (the reaction plane is spanned by the beam axis and the vectors of the two detected fragments). The out-of-plane correlation $N(\varphi_3, \varphi_4)$ of the selected events is uniquely determined with the BRS-detector system over a very wide angular range in the reaction plane ($\Delta \theta = 12^\circ - 46^\circ$, $\Delta \varphi = 2 \times 17.4^\circ$). The fragment yields $N(\varphi_3, \varphi_4)$ are plotted in Fig. 1 for different combinations of the charges and different missing charge $\Delta Z$ but for even total charge $Z_{\text{total}}$. The coplanarity condition is well fulfilled for binary events in form of a narrow peak at $180^\circ$, no narrow correlation is observed for $\Delta Z = 2$, as expected, the corresponding recoil widens the angular correlation (shown in the second column of Fig. 1), however, we observe that a narrow correlation peak appears consistently for larger missing charges with $\Delta Z = 4$ and 6.

For the binary decay processes ($\Delta Z = 0$) for different exit channels corresponding to a transfer of charges or different mass splits but with the same total charge (shown in the first column of Fig. 1), the out-of-plane angular correlations are sharp, with a smaller broader component, which must result from neutron evaporation. The expectation that for a sequential emission of several charged particles from the highly excited fragments, the $(\varphi_3-\varphi_4)$-correlations have to reveal increasing width with larger charge loss $\Delta Z > 0$, is only partially fulfilled with a broad component. However, for $\Delta Z = 4$ (which corresponds to two missing $\alpha$-particles) depicted in the third column, a very narrow component as sharp as in the binary cases, is observed together with a broad component. The latter is easily interpreted as resulting from uncorrelated sequential emission of typically two $\alpha$-particles or several nucleons, from either of the two fragments. Surprisingly the pattern of narrow correlations continues to appear with the cases of three missing $\alpha$-particles, where two components, a narrow peak (as in the case of a binary event) and a wider distribution (with increasing width for increasing missing mass), are observed.

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Figure 1. Out-of-plane angular correlations for binary decay and the respective non binary emission channels with missing 1a, 2a, and 3α-channels in the reaction 32S (164 MeV) + 24Mg. X-scale gives for each panel $G_3$–$G_4$ from $160^\circ$ to $200^\circ$. The numbers (like 10 + 12) indicate the charges of the both fragments.

On the other hand no such narrow peak appears for odd total charges. We can state that this indicates that the missing particles created in the neck zone appear as multiples of α-clusters (8Be, $^{12}$C*). Such behavior is predicted by the α-cluster model for the hyper-deformed $^{56}$Ni at high angular momenta [5].

The narrow width components around $G_3$–$G_4 = 180^\circ$ can originate from different fission mechanism assuming either:

i) a fission process after a fast emission of four, or even more, charges (plus neutrons),
ii) a process where particles must be emitted correlated in-plane by a process involving two primary heavy ejectiles,
iii) ternary fission with the missing mass from the neck (several α-particles) remaining at rest in the center-of-mass frame. This process produces a narrow ($G_3$–$G_4$)-correlation as in a standard binary decay, because the neck-particles carry no momentum in the centre of mass, and the emission angle ($G_3$+$G_4$) remains $180^\circ$.

For the first point binary fission to occur after emission of a first particle, we find that the fission probability has decreased drastically with decreasing excitation energy, and no second chance fission can be expected. Indeed, no significant contribution from a narrow peak in the ($G_3$–$G_4$)-correlations can be observed for the fragment-fragment coincidences with one missing α-particle ($Z_{\text{total}} - 2$) (see second column in Figure 2). For the second scenario involving a
correlated emission from the two fragments, the fact that the narrow correlations appear as strong for \( \Delta Z = 4, 6 \) makes it rather unlikely that such a very special correlation persist through all decays.

For the third scenario we conclude that in ternary fission with the third clustered fragment in the neck will consist of \( \alpha \)-particles which possess zero-momentum in the center-of-mass frame. The particles from the neck are expected to travel with the center-of-mass velocity in the beam direction (towards \( 0^\circ \)). A corresponding measurement, showing this phenomenon with one \( \alpha \)-particle from the neck, in the decay of \( ^{28}\text{Si} \) into \( ^{14}\text{C} + \alpha + ^{12}\text{C} \) has been reported by Scheurer et al. [6]. Whereas the study of the \( ^{28}\text{Si} + ^{24}\text{Mg} \) deep-inelastic scattering [7], leading to the three-body final states such as \( \alpha + ^{24}\text{Mg} + ^{24}\text{Mg} \) and \( \alpha + ^{28}\text{Ne} + ^{28}\text{Si} \) has shown that decay of unbound states of the fragments are involved, originating from a binary decay process.

We can conclude that the observation of the very narrow coplanar fission fragment coincidences in the present \( ^{32}\text{S} + ^{24}\text{Mg} \) data, in conjunction with the earlier work on the same phenomenon in Ref. [1], is a unique feature, which gives clear evidence for the occurrence of ternary decay processes of a hyper-deformed \( ^{56}\text{Ni} \) nucleus as predicted by Zhang et al. [5]. The competition of binary and ternary fission can be explained to occur for high angular momentum because of the large difference between the moments of inertia, giving the saddle points of almost equal height [8].

References


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