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Studying the decay of ^{46}Ti*: does different partner structure influence the competing mechanisms and the following compound nucleus decay?

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A useful tool to underline possible structure effects on the competition between different reaction mechanisms, which may change the expected decay chain probability, is the exclusive study of light charged particles emission from hot light composite systems. In particular, the influence of projectile structure may be evidenced by studying the competition between fast and thermal emissions. In this framework, the four reactions ^{16}O+^{30}Si, ^{18}O+^{28}Si, ^{19}F+^{27}Al at 7 MeV/u and ^{16}O+^{30}Si at 8 MeV/u have been carried out using the GARFIELD+RCo array at Legnaro National Laboratories. Some anomalies in the α-particle emission channels have been evidenced in the measurements reported above, showing in an exclusive way the observed effects related to the entrance channels. The experimental results are compared to statistical model predictions, for which the same filtering and complete event selection have been applied.

KEYWORDS: nuclear reactions, pre-equilibrium emissions, break-up, medium-mass nuclei, fusion-evaporation.

1. Introduction

In the past decades, improvements in the knowledge of the incomplete fusion reactions have been achieved [1–3]; nevertheless, a complete understanding of reaction mechanisms associated with the emission of the particles prior to the thermalization, like break-up and pre-equilibrium emissions, is still missing. Frequently, the term *incomplete fusion* has been employed to indicate that, somehow, particles are lost from the projectile and/or target before complete thermalization, which occurs up to the fusion of the remnants. At bombarding energy above 10 MeV/u, eventhough usually a complete thermalization occurs, the pre-equilibrium particle emission becomes an increasingly important process as a function of the bombarding energy; such particles are forward focused and emitted in the very early stages of the collision before the attainment of full statistical equilibrium of the compound system [4, 5]. Even in the energy region 5-10 MeV/u, fast emission processes have been observed when the structure of the projectile plays an importan role in the interaction with the target. This projectile break-up mechanism [6–9], as well as the pre-equilibrium, influences the subsequent formation and decay of the hot source.

Since several years, the NUCL-EX collaboration (INFN, Italy) has carried out an extensive research campaign on pre-equilibrium emission of light charged particles from hot nuclei [10–14]. In this framework, four reactions ^{16}O+^{30}Si at 7 and 8 MeV/u, ^{18}O+^{28}Si at 7 MeV/u and ^{19}F+^{27}Al at 7 MeV/u, forming the same compound nucleus (^{46}Ti*) in case of complete fusion, were investigated [15, 16]. The experiment was carried out at Legnaro National Laboratories (Italy) using the GARFIELD+RCo 4π array for charged particles, fully equipped with digital electronics [17]. For sake of comparison, the beam velocity was kept constant (7 MeV/u) for the three reactions, since the abundance of pre-equilibrium particles is demonstrated to be dependent on it [18]: in such a way, the non equilibrium processes are expected to be almost the same. The reaction ^{16}O+^{30}Si has been also measured at a beam energy of 8 MeV/u to populate the ^{46}Ti* at the same excitation energy of the ^{18}O+^{28}Si at 7 MeV/u to obtain a similar statistical component. The main characteristics of studied reactions, in case of complete fusion, are reported in Table I.

Table I. Summary of the main characteristics of the reactions.

Entrance channel	Mass asymmetry	E_{lab} MeV/u	CN	E^*_{CN} MeV
^{16}O+^{30}Si	0.30	7	^{46}Ti	88.0
^{16}O+^{30}Si	0.30	8	^{46}Ti	98.4
^{18}O+^{28}Si	0.22	7	^{46}Ti	98.5
^{19}F+^{27}Al	0.17	7	^{46}Ti	103.5

2. The Data Analysis

The complete analysis has been performed on an event-by-event basis; a detail description of this analysis is given in Ref. [15]. In the present work, we focus the attention on the complete events ($Z^{detected}_{TOT} = Z_{projectile} + Z_{Target}$). Furthermore, a more strict constrain has been imposed on data: we select the emission of light charged particles (LCP) in coincidence with one and only one fragment with Z_{frag}¿5 (ER); such events correspond to almost central collisions.

When we compare the experimental global observables (e.g. charge distribution and multiplicities of the emitted light charged particles) of the 4 reactions, a clear dependence of the yields on the excitation energy of the compound nucleus (E^*_{CN}) and on the center of mass velocity (v_{cm}) is observed. Similarly, the experimental angular distribution depends on v_{cm} (Fig. 1), even-though a strong over-production of LCP (more important in the case of the α-particles) appears at very forward angles (8.8^o-17.4^o).

In order to have a theoretical feedback, the experimental data have been compared with simulations performed with the statistical code GEMINI++ [19], which describes the decay of the excited

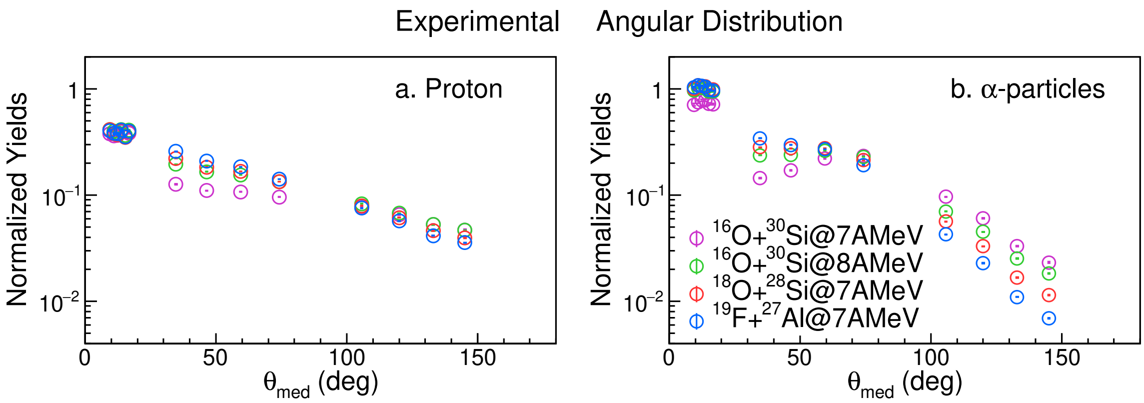

Fig. 1. Experimental angular distribution of protons (left panel) and α-particles (right panel) for the four studied reactions. The distributions are normalized to the number of complete events. The error bars are smaller than the size of the symbols showing experimental data.

compound nucleus. The simulated events were filtered through a software replica of the experimental setup and, then, selected in the same way of the experimental events [15].

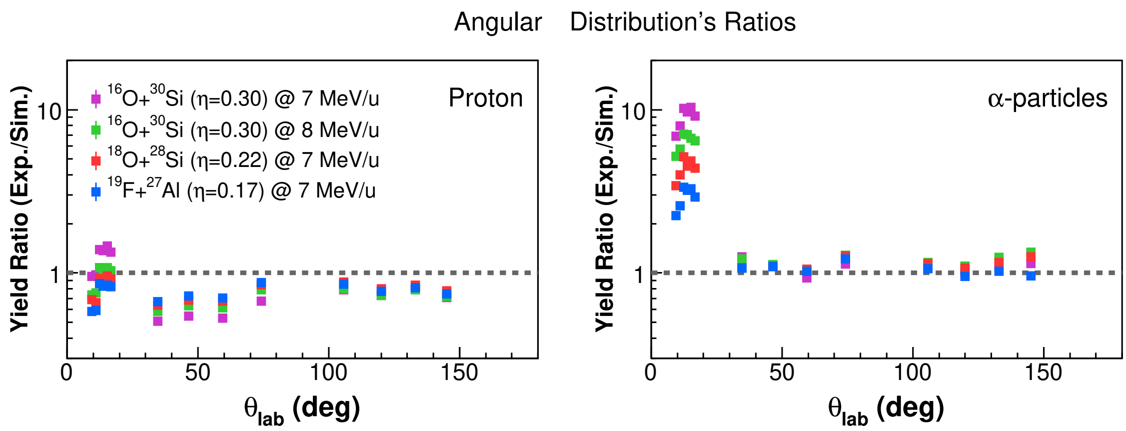

Fig. 2. Ratio of experimental and simulated proton (left panel) and α-particles (right panel) yields as a function of the detection angle of the particles for the four studied reactions.

In Fig. 2 the ratios between the experimental and simulated α-particles yields are shown as a function of the detection angle of the particles. As it can be observed, in the angular region from 29.5^o to 150.5^o, the experimental yields of α-particles are compatible with a statistical emission from the compound nucleus. Otherwise, the observed overproduction of experimental α-particles is present at very forward angles (8.8^o-17.4^o). According to the literature [18], such over-production of forward focused α-particles should be related to fast emissions from non-equilibrium processes, characterizing the early stage of the reactions; it depends both on the entrance channel mass asymmetry (η) and on the beam velocity (v_{beam}). However, in our case we observe some peculiar behavior: the α-energy spectra are reproduced in shape and the forward missing α-yields are distributed over all the possible energies [15].

Moreover, at variance with expectations, when we compare the results of the two reactions with the same η (same entrance channel: $^{16}O+^{30}Si$), we observe a larger ratio (Exp./GEMINI^{++}) of forward emitted α-particles yields (Fig. 2) in the case of the reaction at the lower v_{beam} (7 MeV/u). When comparing the three reactions with the same v_{beam} (7 MeV/u), an increase of the ratio at forward angles is seen as the η increases. Despite the small difference in η, this effect seems to be larger than expected, suggesting that the internal structure of the interacting nuclei may also play an important role. For the studied systems, the major part of the forward peaked α-particles is correlated to the exclusive channel with larger Z of residues. In particular, in the Ca-residue exit channels, a strong inversion of population of 1α + xn and 2p + xn channels is observed with respect to GEMINI^{++} [15].

3. Conclusion

We analyzed complete events of four reactions having different entrance channels (η) and/or different beam velocity (v_{beam}) and we observed some difference among the four studied reactions. Such differences can be ascribed to either entrance channels or structure properties of the reacting partners. Strong dissimilarities between experimental data and statistical model simulation are highlighted especially related to cluster-emission probability.

References

[1] K. A. Griffien et al., Phys. Rev. **C 37** 2502 (1988).
[2] J. Gomez del Campo et al., Phys. Rev. **C 60** 021601 (1999; **53** 222 (1996).
[3] M. Blann, Phys. Rev. **C 31** 1245 (1985).
[4] S. J. Luke, Phys. Rev. **C 48** 857 (1993).
[5] J. Cabrera, Phys. Rev. **C 68** 034613-1 (2003).
[6] X. Campi et al., Phys. Lett. **B 142** 8 (1984).
[7] J. Pouliot et al., Phys. Lett. **B 299** 210 (1993).
[8] D. Shapira et al., Phys. Rev. **C 55** 2448 (1997).
[9] W. D. M. Rae et al., Phys. Rev. **C 30** 158 (1984).
[10] T. Marchi et al. - Nuclear Particle Correlations And Cluster Physics **Ch. 20** 507 (2017).
[11] L. Morelli et al., Journ. of Phys. **G 41** 075107 (2014); 075108 (2014).
[12] D. Fabris et al., PoS **X LASNPA** 061 (2013).
[13] V.L. Kravchuk, et al. EPJ WoCs **2** 10006 (2010).
[14] O. V. Fotina et al., Int. Journ. Mod. Phys. **E 19** 1134 (2010).
[15] M. Cicerchia, PhD thesis (2018), University of Padova (Italy).
[16] M. Cicerchia, IL NUOVO CIMENTO 41 C (2018) 98.
[17] M. Bruno et al., EPJ **A 49** 128 (2013).
[18] P. E. Hodgson, Phys. Rep. **374** 1 (2003).
[19] R. J. Charity, Phys. Rev. **C 82** 014610 (2010); D. Mancusi et al., Phys. Rev. **C 82** 044610 (2010).