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Study of LCP emissions from ^{46}Ti*

M. Cicerchia([1])([2])([*]), F. Gramegna([1]), D. Fabris([3]), T. Marchi([1]),
M. Cinausero([1]), G. Mantovani([1])([2]), A. Caciolli([2])([3]), G. Collazuol([2])([3]),
D. Mengoni([2])([3]), M. Degerlier([4]), L. Morelli([5]), M. Bruno([6]),
M. D'Agostino([6]), C. Frosin([6]), S. Barlini([7]), S. Piantelli([7]),
M. Bini([7]), G. Pasquali([7]), P. Ottanelli([7]), G. Casini([7]), G. Pastore([7]),
A. Camaiani([7]), S. Valdré([7]), D. Gruyer([5]), N. Gelli([7]), A. Olmi([7]),
G. Poggi([7]), I. Lombardo([8]), D. Dell'Aquila([9]), S. Leoni([10]),
N. Cieplicka-Orynczak([11]), B. Fornal ([11]) and V. Kravchuk ([12])

([1]) *INFN, Legnaro National Laboratory - Legnaro (Pd), Italy*
([2]) *Padua University, Physics and Astronomy Department - Padua, Italy*
([3]) *INFN, Padua Department - Padua, Italy*
([4]) *Science and Art Faculty, Physics Department, Nevsehir Haci Bektas Veli Univ. - Nevsehir, Turkey*
([5]) *Grand Accélérateur National d'Ions Lourds - 14076 Caen, France*
([6]) *INFN, Bologna Department and University, Physics and Astronomy Department - Bologna, Italy*
([7]) *INFN, Florence Department and University, Physics and Astronomy Department - Florence, Italy*
([8]) *INFN, Catania Department - Catania, Italy*
([9]) *MSU Department of Physics and Astronomy - East Lansing, MI, USA*
([10]) *INFN, Milan Department and University, Physics and Astronomy Department - Milan, Italy*
([11]) *Institute of Nuclear Physics, Polish Academy of Sciences - Krakow, Poland*
([12]) *National Research Center "Kurchatov Institute" - Moscow, Russia*

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Summary. — The study of pre-equilibrium emitted particles is an useful tool to examine nuclear clustering; in order to study how possible cluster structures affect nuclear reactions, the NUCL-EX collaboration (INFN, Italy) is carrying out an extensive research campaign on pre-equilibrium emission of light charged particles from hot nuclei. In this framework, the reactions ^{16}O + ^{30}Si, ^{18}O + ^{28}Si and ^{19}F + ^{27}Al at 7 MeV/u have been measured at the GARFIELD+RCo array in Legnaro National Laboratories. After a general introduction on the experimental campaign, this contribution will focus on the analysis results obtained so far; effects related to the entrance channel and to the colliding ions cluster nature are emphasized through differences between the theoretical predictions and the experimental data.

([*]) E-mail: `cicerchia@lnl.infn.it`

1. – Introduction

Non-equilibrium processes, occuring in the early stages of the reaction, contribute to determine the features of the remaining hot thermalized sources; the fast emissions issued by these processes depend both on the entrance channel mass asymmetry and on the beam velocity [1]. For this purpose, a comparative study of four systems (^{16}O+^{30}Si, ^{18}O+^{28}Si and ^{19}F+^{27}Al at 7 MeV/u and ^{16}O+^{30}Si at 8 MeV/u) has been carrying out in the Legnaro National Laboratory (LNL) at GARFIELD plus Ring Counter (RCo) detector fully equipped with digital electronics [2,3]. Through central collisions and when the complete fusion occurs, the four studied cases all lead to the same compound nucleus, the excited ^{46}Ti, even if with slightly different excitation energies. Small differences in their de-excitation chain are expected, except for the cases ^{16}O+^{30}Si at 8 MeV/u and ^{18}O+^{28}Si at 7 MeV/u, which were chosen to populate the compound nucleus at the same excitation energy. On the other hand, the choice of the same beam energy (7 MeV/u) for three of the four reactions should imply that the contribution to the cross section from non equilibrium processes are similar, given the same projectile velocity [1]. The main characteristics of the four reactions are shown in Table I.

Since an evident Oxigen-contamination of the Si ($\sim$ 50%) and of the Al ($\sim$ 30%) targets have been observed, a very strict selection on experimental data was performed for the subsequent analysis considering only the events for which the total detected charge is larger than the 70%. As a consequence of this first data selection, the amount of the experimental selected events is around the 10% of the total detected events. A further selection was applied asking for the detection of the light charge particles in coincidence with one and only one evaporation residue with a charge heavier than 6; such events are produced by pure fusion-evaporation mechanism.

2. – The Data Analysis

The selected experimental observables have been compared with the simulations, produced with different codes based on theoretical models, to obtain a theoretical feedback. In particular, the code GEMINI^{++} by R. Charity [4] was used to describe the statistical decay of the compound nuclei produced in the reactions; in order to consider the effects of a possible deformation induced by temperature, different values of the parameter w (0.0, 1.0 and 1.1 fm) have been considered: this parameter permits to simulate the emission from nuclei with a convolution of barriers going from $r + dr$ to $r - dr$, where $dr = w\sqrt{T}$. In addition, the dynamical codes AMD, describing the cluster structure of the interacting particles and taking into accounts the particle-particle correlations, by A. Ono [5] and HIPSE, based on the sudden approximation, by D. Lacroix [6] were used to

Table I. – *The main charcteristic of the reactions.*

Entrance Channel	$E_{beam,lab}$ (MeV)	η	CN	E^* (MeV)
^{16}O+^{30}Si	111	0.30	^{46}Ti	88.0
^{16}O+^{30}Si	128	0.30	^{46}Ti	98.4
^{18}O+^{28}Si	126	0.22	^{46}Ti	98.5
^{19}F+^{27}Al	133	0.17	^{46}Ti	103.5

simulate the dynamical part of the reactions. The dynamical codes have been calculated up to an interaction time (500 fm/c in the AMD case) after which they are coupled to GEMINI^{++} as after burner, which follows the decay of any produced excited fragment.

A detailed analysis of experimental data in comparison with simulations has been done for selected observables for the four reactions. In this report, we focus on the analysis of the complete events, selected imposing a total detected charge corresponding to the total entrance channel charge ($Z_p + Z_T = 22$). In Fig. 1 the comparison of experimental and simulated angular distribution of protons (left panels) and α-particles

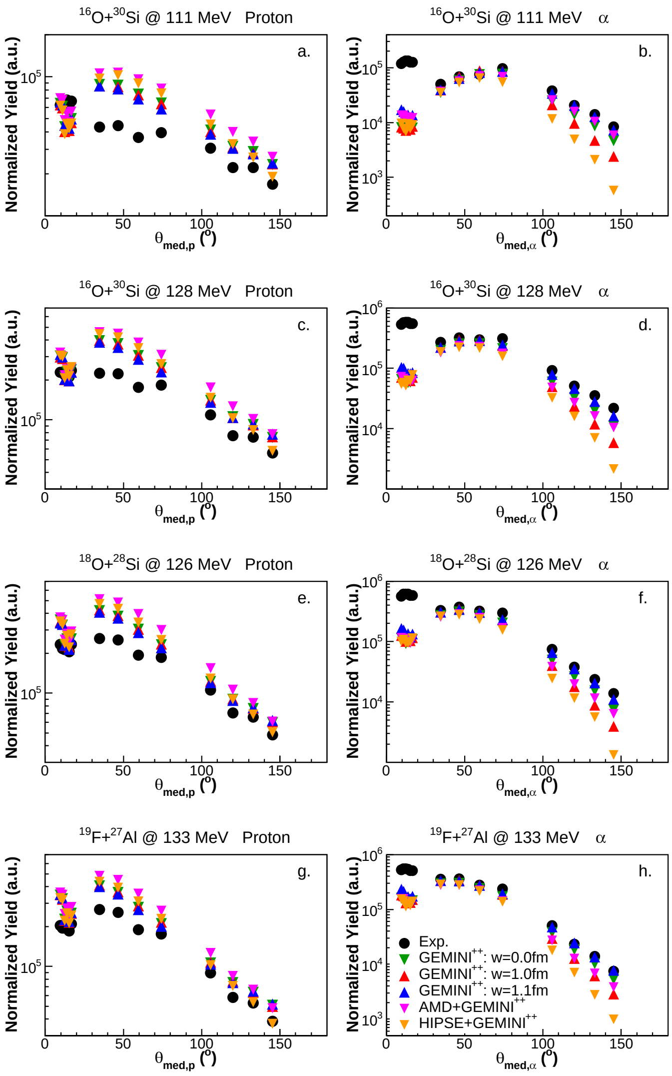

Fig. 1. – Comparison of experimental and simulated (GEMINI^{++} with $w = 0.0$ fm in green, with $w = 1.0$ fm in red, $w = 1.1$ fm in blue; AMD+GEMINI^{++} in pink; HIPSE+GEMINI^{++} in orange) proton and α angular distributions for the four reactions studied. See text for details.

(right panels) are presented for the four reactions: ^{16}O+^{30}Si at 111 MeV (panels a. and b.), ^{16}O+^{30}Si at 128 MeV (c. and d.) ^{18}O+^{28}Si at 126 MeV (e. and f.) and ^{19}F+^{27}Al at 133 MeV (g. and h.). The simulations are normalized to the relative number of residues: $\frac{\#_{res,exp}}{\#_{res,sim}}$. Starting from the angular distributions, all the simulations over-predict proton (left panels) in the $\theta_{lab} = 29.5^o \div 150.4^o$ angular range, corresponding to the GARFIELD angular range, while they are reasonably reproduced in the very forward region (RCo). The experimental underproduction of protons is more evident in the case of the ^{16}O+^{30}Si at 111 MeV, that is the reaction at lower excitation energy, and decreases increasing the excitation energy of the systems. On the contrary, the very forward angular region is well accounted for by all simulations in the cases of the two ^{16}O induced reactions (panel *a.* and *c.*), some differences appear in the ^{18}O+^{28}Si at 126 MeV case (panel *e.*) and finally all simulations overestimate the proton angular distributions (panel *g.*). For what concerns α-particles (right panels), the central angular region ($\theta_{lab} = 29.5^o \div 81.5^o$) is well accounted for by all the simulations; GEMINI^{++} with $w = 1.0$ fm and HIPSE+GEMINI^{++} do not reproduce neither the forward nor the backward directions, while the other three simulations are better describing the total distribution apart from the very forward angular region, totally underestimated. The large underestimation of α-particles in forward region ($\theta_{lab} = 8.8^o \div 17.4^o$) decreases increasing the excitation energy.

3. – Conclusions and Perspectives

In this paper, the attention has been focused on the complete events; differences between the experimental and the predicted observables put into evidence effects related to the entrance channels. In particular, the overproduction of α-particles of forward angles represents a signature of the onset of fast emission. To understand if the pre-equilibrium process is well accounted for by theory, a more quantitative analysis is needed. Indeed, the differences in specific multiplicity channels have been noticed with consequences on the branching ratios and Q-value distributions. Lastly, to complete this experimental campaign, new measurements of the same systems (^{16}O+^{30}Si, ^{18}O+^{28}Si and ^{19}F+^{27}Al) need to be carried out at higher energies (12-16 AMeV), where larger pre-equilibrium yields and higher excitation energies are foreseen: in fact, the analysis of correlations between LCP particles, especially in long α-decay chains ($M_\alpha \geq 3$) events, are necessary to constraint the dynamics and to draw conclusions on the differences among the studied systems and on their possible link to structural effects of the colliding partners. Further study on the same field will be done also using the new apparatus developed by our collaborations ATS and OSCAR [8].

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