Light Charged Particle Emission in the Reaction $^{16}$O+$^{116}$Sn at 192 MeV

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INTRODUCTION

The reaction $^{16}$O+$^{116}$Sn at 192 MeV was studied at the Legnaro National Laboratory using the GARFIELD-HECTOR array. The experiment is part of a campaign started in 2001 where coincidences between high energy $\gamma$-rays and light charged particles were recorded for a series of bombarding energies and for symmetric or asymmetric mass entrance channel reactions used to form the $^{132}$Ce nucleus [1, 2].

The main aim of the present measurement is related to the study of the dependence of the Dynamical Dipole emission [3] on beam energy. Moreover a further interesting point to be studied is related to the pre-equilibrium emission of light particles and its dependence on the beam velocity and/or the mass asymmetry in the entrance channel [4].

THE PHYSICAL CASE

Heavy Ion low energy nuclear collisions have been extensively studied in the past, devoting mainly the attention to the evaporation of light particles from thermalized sources. However the competition of fast particle emission starts to be relevant as the bombarding energy grows up, especially approaching the region above 10 MeV/n.

Pre-equilibrium models have been developed and are generally quite successful to describe spectra and cross sections of various types of nuclear reactions, where fast emission is involved. For nucleon and light-particle-induced reactions at lower energies, the exciton model is probably the most transparent one. However many experimental data are necessary to define the framework of fast emission, especially for those production processes which take place between the direct processes and the totally relaxed ones. The light particle products result as an underlying continuum spectrum, which is partially hidden in the maxwellian double differential energy spectra of light particles emitted by totally relaxed sources.

A hybrid model was already used to compare resulting double differential light charged particle energy spectra from the reaction $^{16}$O+$^{116}$Sn at 130 and 250 MeV and the $^{64}$Ni+$^{68}$Zn at 300, 400 and 500 MeV respectively [4].

A systematic study, where different projectile-target combinations together with different bombarding energies are used, can be important to fix the ingredient of the model calculations and to better understand the different stadium of the pre-equilibrium processes.

EXPERIMENTAL SETUP

One drift chamber of the GARFIELD apparatus has been used for the identification and measurement of the light charged particles [5,6]. It was coupled to the 8 large volume BaF$_2$ crystal scintillators of the HECTOR array, which were lodged in the backward emisphere with respect to the target, for the measurement of high energy $\gamma$-rays [7]. In the experiment, the fusion residues were measured using 4 boxes of PHOSWICH scintillators from the FIASCO setup [8]. Two additional groups of small BaF$_2$ scintillators from the HELENA array have been used. The first group was placed close to the target to provide a time reference, which was compared with the timing reference coming from the pulsed beam structure. The second was mounted in the forward direction to analyze the information on neutron emission which can be discriminated from $\gamma$-rays through Time of Flight (ToF) and Pulse Shape Analysis.

EXPERIMENTAL RESULTS

The light charged particle double differential energy spectra and angular distributions have been built, both in the case of inclusive and in the case of coincidence events. Coincident light charged particle energy spectra were sorted requiring that an Evaporation Residue (ER) was selected in the Time of Flight versus Fast signal from the phoswich detector system.
Fig. 1. Double differential energy spectrum for protons emitted in coincidence with ER, in the 192 MeV $^{16}$O + $^{116}$Sn reaction. The detection angular range is $\Delta \theta = 29^\circ - 41^\circ$. The histogram refers to experimental proton data, while the continuous line is the result of hybrid model [9] calculation, obtained by the sum of thermal evaporated particles (dot-dashed line) and pre-equilibrium emitted protons (dotted line).

Fig. 2. Same as fig. 1, but for $\alpha$-particles.

The experimental coincidence data have been compared with the hybrid model recently developed by O. Fotina, which is described in [9]. The preliminary results are in agreement with those obtained for the same entrance channel reactions performed at higher (250 MeV) and lower (130 MeV) bombarding energies [10]. In particular from the comparison of the proton spectra with the hybrid model a slight over-production of cross section predicted by the model (pre-equilibrium part) is present, especially at forward angles (see fig. 1).

On the contrary an opposite behavior can be observed in the case of $\alpha$-particles (see fig. 2): the production of fast $\alpha$-particles are well above the predicted pre-equilibrium cross section. This fact may be ascribed to the $\alpha$-clustering structure of the $^{16}$O projectile, which facilitates the pre-equilibrium emission of $\alpha$-particles with respect to that one of nucleons [11].

Further studies are under development, where the clustering structure of the projectile and/or the target can be taken into account in the model, considering a certain probability of clustering effect, linked to all possible configurations of the studied system. The pre-equilibrium emission is growing as a function of the bombarding energy, as expected when comparing the same system (asymmetric mass entrance channel reaction) at 130, 192 and 250 MeV incident energies, while for the symmetric case the percentage of pre-equilibrium emission is smaller, not only when comparing systems formed at the same excitation energy, but also when comparing the two systems at the same beam velocity (around 8 MeV/A in our cases) [4].

We plan in the next future to measure several reactions induced by projectiles with different probability of $\alpha$-clusterization (for example Oxygen or Fluorine induced reactions) and we expect that from the theoretical analysis of these experimental data and from the comparison it will be possible to extract information on the probability of $\alpha$-particle pre-formation in the projectile. The importance of the clustering structure is even more interesting going toward the study of exotic systems [12].

[12] V. Kravchuk et al., this Annual Report.