Vol. 48 (2017) *ACTA PHYSICA POLONICA B* No 3

CONSTRAINING HOT SOURCES IN CENTRAL HEAVY-ION COLLISIONS BELOW 20 MeV/u*

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(Received December 14, 2016)

Pre-equilibrium emissions affect the production of excited systems in nuclear reactions, thus modifying their properties which enter as input parameters in the comparison with statistical models. In this contribution, we discuss this subject referring to recent results from experiments performed at Legnaro National Laboratories (Italy) with the GARFIELD apparatus complemented with other detectors.

DOI:10.5506/APhysPolB.48.635

* Presented at the Zakopane Conference on Nuclear Physics "Extremes of the Nuclear Landscape", Zakopane, Poland, August 28–September 4, 2016.

1. Introduction

In this work, we consider three experiments in which the investigation of a non-statistical emission was relevant for the fusion-evaporation (F-E) reaction channel. First, we will examine a study on the Giant Dipole Resonance (GDR) evolution (experiment "I") in which the fusion reaction ^{48}Ti+^{40}Ca at three bombarding energies (6.25; 9.38; 12.5 MeV/u) [1] is considered. Here, it is very important to ascertain whether the pre-equilibrium contribution remains negligible at the three beam energies. If so, the complete fusion hypothesis can be safely used to estimate thermodynamical properties of the hot source and then follow its radiative decay to extract the GDR width and strength.

Then, some preliminary results from the analysis of ^{16}O+^{65}Cu and ^{19}F+^{62}Ni reactions at 16 MeV/u will be presented (experiment "II"). In this case, it will be described how the pre-equilibrium emission could be used to put into evidence α-cluster structure in nuclei, as discussed in [2].

Finally, an example at a higher energy will be shown, where signals of pre-equilibrium emission become more evident. The analysis of ^{32}S+^{40,48}Ca and ^{32}S+^{48}Ti reactions at 17.7 MeV/u will be presented (experiment "III") and the experimental data will be compared to statistical model simulations. As shown in [3], the pre-equilibrium emission appears in these reactions and can significantly affect the measured observables, in particular, the light-charged particle (LCP) energy distributions.

2. Experimental apparatus

The GARFIELD apparatus [4] consists of 96 telescopes (gas drift chamber as ΔE stage and CsI(Tl) as E_{res} stage) at forward angles (between 29.5 and 82.5) and 84 CsI(Tl) scintillators covering the angles between 97.5 and 150.5. Each ΔE–E_{res} telescope allows to identify fragments up to $Z = 16$ (without isotopic resolution), provided that they reach the CsI(Tl) detectors. The CsI(Tl) scintillators are read out by photodiodes and they are able to identify hydrogen and helium isotopes via the Pulse Shape Analysis.

During experiment "I", the backward chamber of GARFIELD was replaced by a group of eight BaF_2 scintillators (Hector setup [5–7]) for γ-rays. In the same experiment, the heavy products were detected by an array of 48 triple phoswiches of the Fiasco setup [8] which covered the polar region from 5 to 25. Thanks to the first fast plastic layer and to the large distance from the target (1.6 m), the phoswiches permitted the velocity measurement of the ejectiles from $Z = 1$ up to the evaporation residue (ER) with a good time resolution (of the order of ns).

During experiments "II" and "III", both GARFIELD chambers were used and the Ring Counter (RCo) apparatus was mounted instead of the phoswiches at forward angles (between 5.4 and 17.0). The RCo is a three layer detector: the first layer consists of an ionization chamber (IC) segmented in 8 sectors with a single gas volume filled with flowing CF_4; for each sector, a reverse mounted silicon strip detector with a thickness of about 300 μm is placed behind the IC, followed by 6 CsI(Tl) scintillators read out by photodiodes. Unitary charge resolution is obtained up to $Z \sim 30$, while isotopic discrimination is possible up to $Z \sim 15$ for the ions that punch through the silicon layer.

3. Results

A good reproduction of a non-statistical emission is fundamental to reconstruct the hot source (*i.e.* for GDR studies). To highlight this kind of emission, data were compared with results from statistical model codes (GEMINI++ [9] and PACE4). In this direction, for the experiment "I", a fine tuning of GEMINI++ parameters was performed at the lower bombarding energy [1], in the hypothesis of a pure complete fusion. When the energy increases, an excess of α-particle evaporation at forward angles also increases up to $\sim 20\%$ of the total emission, as shown in Fig. 1.

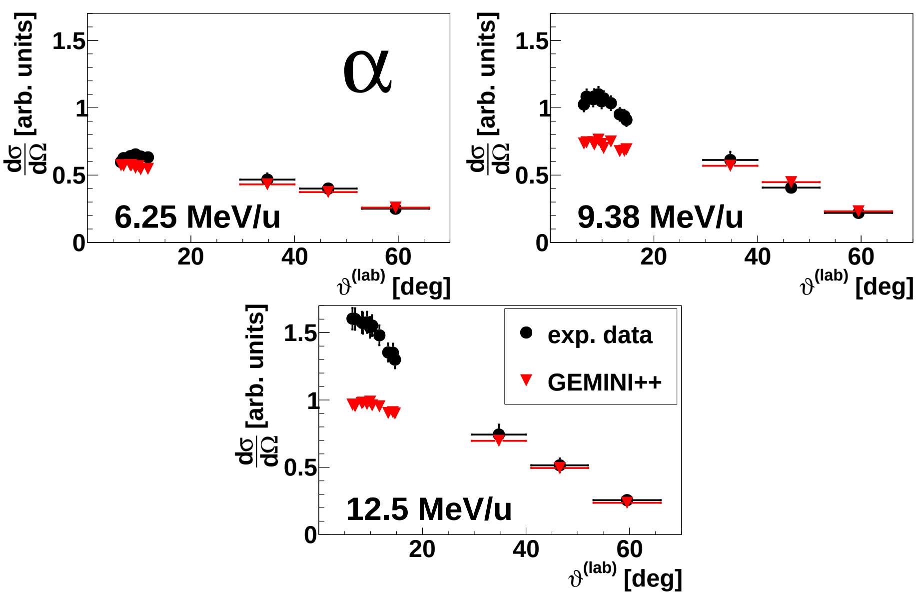

Fig. 1. Angular spectra of α-particles emitted in the F-E channel of the reaction ^{48}Ti+^{40}Ca (experiment "I").

As GEMINI++ is out of its optimal range at the higher energies of this campaign, the excess of α-particles at forward angles could come not only from pre-equilibrium emissions, but also from the contamination by processes that are not included in the code, such as Deep Inelastic Collisions (DIC). In the worst case (12.5 MeV/u), the upper limit of a non-statistical emission is only about 0.5 α-particles per event, thus justifying the assumption of negligible pre-equilibrium effects as done in [5] for the evaluation of the GDR strength.

Increasing the bombarding energy, non-statistical effects become stronger and these can be used to investigate the possible cluster structure of the projectile, if any. In the experiment "II", as shown in [2], the α-particle pre-equilibrium emissions were investigated in the systems ^{16}O+^{65}Cu and ^{19}F+^{62}Ni, aiming at highlighting a cluster structure of the ^{16}O projectile. Hints in that sense have been found and the work is in progress to find a quantitative estimate of cluster preformation probabilities. Collaborations with theoretical groups are in progress to reproduce pre-equilibrium emissions with dynamical codes such as Antisymmetrized Molecular Dynamics (AMD) [10] and Hybrid Exciton Model [11].

Finally, from preliminary analyses of the fusion-evaporation channel of experiment "III" [3], a strong disagreement of proton and α-energy spectra with respect to GEMINI++ simulations is evident at forward angles, as shown in Fig. 2. This fact can be interpreted as an evidence of pre-equilibrium emission (see for example [12]). Work is in progress to extract a quantitative estimation and to obtain the angular distribution of pre-equilibrium emitted particles.

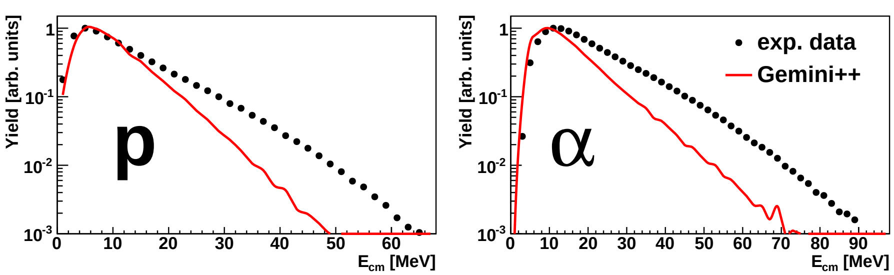

Fig. 2. Energy spectra of protons and α particles emitted between 7° and 17° in the F-E channel of the reaction ^{32}S+^{48}Ca at 17.7 MeV/u (experiment "III").

4. Conclusions

Pre-equilibrium emissions are an obstacle to the characterization of hot emitting sources, a condition which is necessary, for example, to study the GDR. The difference between the simulated statistical evaporation and the observed emission may be due to pre-equilibrium, but also to clustering effects that should be better understood also from a theoretical point of view. New simulations with Stochastic Mean Field (SMF) [13] and AMD dynamical codes are needed to improve the reproduction of pre-equilibrium emissions in order to better constrain the observed LCP emission.

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