Evaporation from Hot ^{88}Mo Compound Nuclei at High Excitation Energies

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INTRODUCTION

In the framework of a campaign devoted to study collective modes of nuclei with mass around $A = 100$ [1, 2], our group measured the fusion-evaporation and fusion-fission channels with a powerful array to obtain very exclusive events in which the heavier reaction products are detected together with energetic gamma rays and charged particles. The idea was to study the evolution of collective modes as a function of the angular momentum of the compound nucleus (CN) looking for possible abrupt shape changes from oblate to prolate (Jacobi Transition). The region of the Mo nuclei was chosen as a favourable one for this transition. Of course, to have reliable access to such kind of effects, possibly signaled by changes in the GDR spectrum, it is important to well characterize the reaction scenario as a function of the main parameters, for the various outgoing channels. As a part of this work, whose analysis is still in progress, in this report we concentrate on the results of the fusion evaporation channel associated to light particle emission.

THE EXPERIMENT

The experiment measured the products of the slightly asymmetric reaction ^{48}Ti $+^{40}$ Ca at three different energies. This choice allows to follow the evolution of the different channels and decay modes as a function of both the relative velocity (the possible onset of preequilibrium emissions must be controlled) and the final excitation and spin of the formed systems. Pulsed beams of ^{48}Ti at the three energies of 300, 450, 600 MeV hit ^{40}Ca targets (500 μg/cm^2) protected against oxydation by very thin Carbon foils (12 μg/cm^2). The detection array was composed of different parts. The eight big BaF_2 crystals of the HECTOR array measured gammas at backward angles while the forward emisphere GARFIELD chamber was complemented with a set of Phoswich detectors (48 modules of the Fiasco experiment [3]) consisting of three scintillator stages (200 μm very fast plastic, 5 mm fast plastic and 40 mm CsI(Tl)). We put into evidence that many detectors were equipped with specifically developed digital electronics [6, 7]. The signals of all the Phoswiches (from each photomultiplier anode) and of all CsI(Tl) detectors (from each charge preamplifier) of the GARFIELD array were sampled by fast ADC's and processed online by on-board DSP's in order to extract the relevant physical information. Data from DSP's were stored for off-line analysis. Also, the trigger sector of the experiment was of a very modern concept. The trigger system exploited programmable logic devices to achieve great versatility and monitoring capabilities. First, all logic signals produced by the various detectors were connected to a single VME board, equipped with a powerful FPGA. The logic on the FPGA was programmed in such a way to allow for assembling, selection, downscaling and counting of the needed triggers. Remote control and monitoring of this "trigger box" was also possible. Moreover, especially at the lowest 300 MeV energy, a strong yield of scattered projectiles corresponded to the forward scintillators. Again, we used another FPGA-based device to collect all the Phoswich signals and to put special conditions on event validation: most elastic ions were prevented from being acquired by simply choosing (via easy keyboard inputs) a twofold threshold gate for each Phoswich, thus rejecting low-lying noise and large signals due to scattered ions.

The above sketched powerful array and its digital electronics permits the efficient measurement of charged species. At forward angles, between 6 and 13 degrees, evaporation residues (ER) were identified on the basis of Light Output vs. ToF correlations of the type shown in figure 1, referring to one of the forward Phoswiches. The Y-axis corresponds to the short-gate integrated anode current for ions stopping in the first two plastic scintillator layers (a veto on the long-time gate mainly due to CsI components has been imposed). Also, the picture clearly shows other charged products collected at forward angles: helium and hydrogen species emitted by the ER are concentrated by the kinematics at high velocities (low ToF), while the tails of this species toward low energies correspond to particles associated to other processes (evaporation from Quasi-Target or from fusion-fission fragments). A significant yield of intermediate fragments is present in the plot. These fragments are mainly due to asymmetric fission splits and are not discussed here [5].

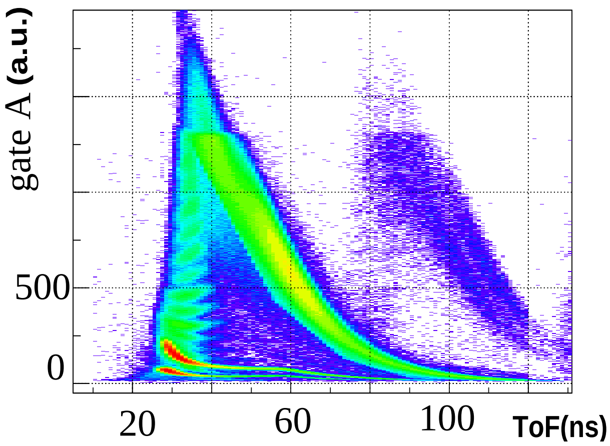

Fig. 1. Correlation plot of Short-gate integrated Light Output vs. ToF as seen from one of the Phoswiches.

We concentrate on the particles (LCP) which are emitted in coincidence with the ER and mostly detected in the GARFIELD crystals; reasonably, many LCP correspond to evaporation from the initial hot CN. This is exactly the basical information we want to start assessing here, i.e. how well the characteristics of these LCP fit with an evaporation scenario and whether there are traces of the onset of preequilibrium processes with increasing energy. For the comparison we use the well known statistical model GEMINI, recently upgraded [8].

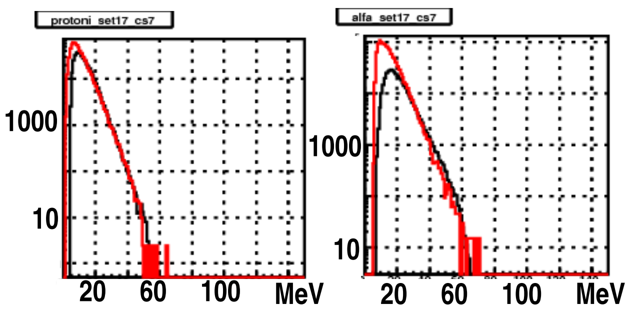

Fig. 2. CM-energy spectra measured (black, heavy) and simulated with GEMINI (red, light) for protons (left) and alphas between $\theta = 41°$ and $\theta = 52°$. The figure refers to one of the 24 azimuthal sectors of GARFIELD.

Figure 2 shows, for the reaction at 600MeV, proton (left) and alpha CM-energy spectra measured (black or heavy lines) in a GARFIELD module in coincidence with ER's seen in the Phoswiches. The LCP, stopped in the CsI, have been separated via pulse-shape analysis by the methods described in [4]. The figure refers to LCP measured in the region with polar limits 41-52° and covering 15° in azimuth. The red (or lighter) spectra correspond to the output of the GEMINI calculations, assuming complete fusion and thus well defined initial values of mass, charge and energy for the CN. The CN spin distribution has been taken of a triangular shape till the vanishing barrier limit (which is about $64\hbar$, lower than the grazing angular momentum value $L_{\rm graz}$ for the three energies). The standard input parameters of the code have been used and the events leading to fission have been disregarded here.

The simulated LCP events have been filtered by the geometric acceptance of GARFIELD; till now no energy thresholds have been introduced, which largely affect the low-energy region. Therefore this preliminary comparison can be performed in a semi-qualitative way, for instance by normalizing the spectra (measured and simulated) at a point well within the almost linear (in log scale) tail of the distribution. By this comparison, one can see that no major slope differences appear either for protons and alphas at all angles. This suggests that even at the highest 600 MeV bombarding energy, the emission of light species in coincidence with ER is ascribable to statistical binary decay of the hot source; moreover the apparent nice reproduction of the slopes of the spectra indicates that most default parameters assumed within GEMINI are substantially right for these hot nuclei (up to $E^* \approx 260$ MeV). The next step will be to produce a better software replica of the set-up in order to estimate its efficiency and then to access to the LCP multiplicities. This would allow for an accurate comparison with statistical models and, therefore, would permit to put limits on preequilibrium emissions when the beam energy rises from 300 to 600 MeV.

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