E^* and I selection techniques for hot nuclei studies

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One of the ambitions of hot nuclei studies is to trace the evolution of nuclear shapes in 2-dimensional space: excitation energy E^* and angular momentum I. A powerful probe for this is the γ-decay of Giant Dipole Resonance built on excited nuclear states populated in the fusion reaction. The drawback of this method is that fusion reactions with heavy ions populate nuclei at well-defined excitation energy, but with a broad distribution of angular momenta. Moreover, the high energy γ-rays are emitted not only from the compound nucleus, but from each step of the evaporation process. Consequently the spectra of the high energy γ-rays recorded in *inclusive* experiments contain information on GDR built on many excited states with various excitation energies and spins. Nevertheless in many experiments it has been possible to judge about the shape-change of a nucleus[1,2]. It is obvious, however, that the sensitivity of the GDR-decay method to the shapes of nuclei will be enhanced in *exclusive* experiments, where one selects excitation energy E^* and angular momentum I of the states on which the GDR is build.

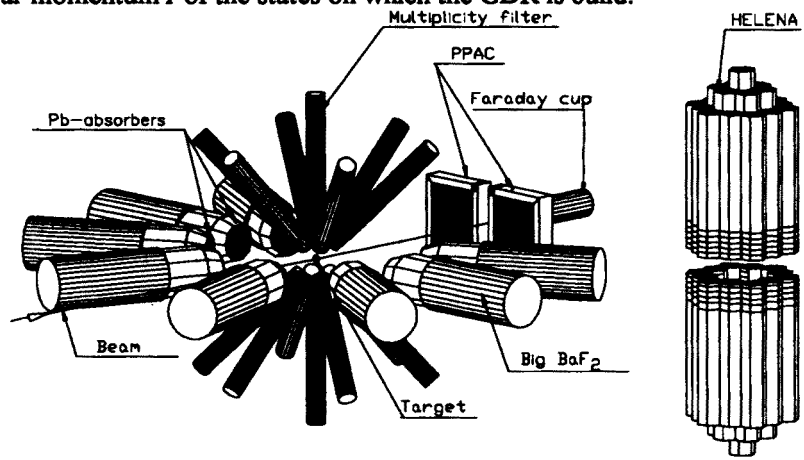

Fig.1 *Left: The complete HECTOR set-up with 8 single crystals of BaF_2 (17.5cm x 14.5cm ϕ), 2 PPAC particle counters used to identify fusion reaction and the multiplicity filter (14 small BaF_2). Right: The new multiplicity filter HELENA (38 BaF_2).*

In this contribution we present the phase-space selection techniques used for high energy γ-rays detection in experiments with the HECTOR array (eight large-volume BaF_2-crystals) in the Niels Bohr Institute. An overview of the experimental results with HECTOR is presented at this conference by Jens Jørgen Gaardhøje[3].

The spin selection is done by a multiplicity filter (see fig.1). Two types of multiplicity filters were used: one consisted of 14 small BaF_2-crystals with total efficiency of 20%, the other (called HELENA) - of 38 BaF_2-crystals with 71% total efficiency. The measurement of the filter's efficiency, as well as the conversion from the fold (number of activated elements in the filter) to the γ-ray multiplicity, was based on the calibration-simulation method similar to that described by Jääskeläinen *et al.*[4]. A source emitting 2 γ-rays in a cascade (^{60}Co or ^{207}Bi) was placed in the filter's centre. An external detector was used as a trigger, and the events were collected only if the 1.33 MeV γ-ray from the ^{60}Co source (or 1.06 MeV in the case of ^{207}Bi) gave a photopeak in it, ensuring that exactly *one* γ-ray (1.17 MeV or 570 keV for ^{60}Co or ^{207}Bi, respectively) was presented to the multiplicity filter. With this condition the events consisting of the analogue signal proportional to the fold were stored on tape in the list mode. The *0-fold* cases, when the γ-ray exposed to the filter escaped without interaction, were also included. Hence the collected fold-spectrum was the response of the filter to the γ-ray multiplicity $M=1$ (at the specific energy 1.17 MeV or 570 keV). The response to the multiplicity $M=k$ was generated, in the off-line analysis, by choosing randomly k events from the tape and summing up the amplitudes of the individual fold-signals. The relative normalization of the fold distributions for different M assumed a $2L+1$ (≈4M) dependence of the partial fusion cross-section on angular momentum.

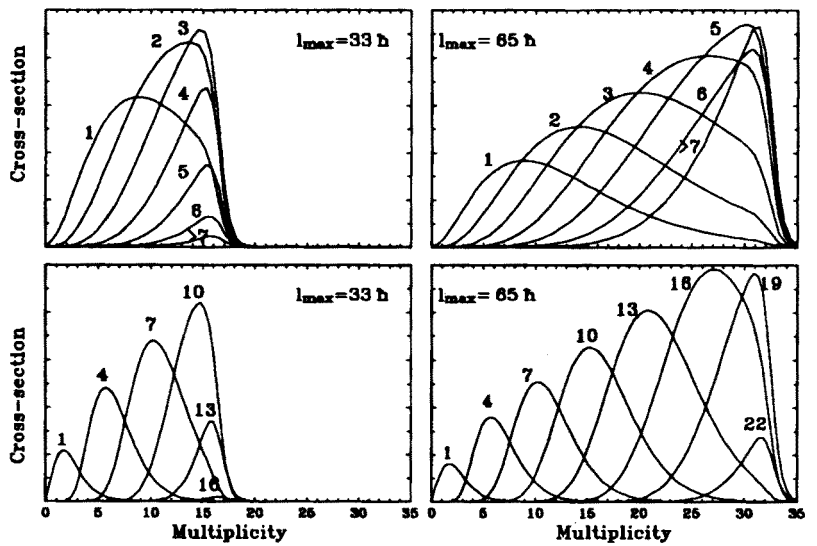

Fig.2 *The multiplicity distributions related to different folds. The two upper panels show the results for the 14-BaF_2 multiplicity filter, while the two lower - for HELENA. The two left panels correspond to reactions where l_{max}=33ħ; the two at the right corresponds to l_{max}=65ħ.*

The performance of both filters is illustrated in fig.2, where the multiplicity distributions for different folds are also shown in the case of reactions with 2 different maximal angular momenta of the system. The curves were calculated employing the formalism described in Refs.5,6 using the parameters obtained in the calibration. Although the multiplicity response of the 14 element multiplicity filter is limited, a reasonable sensitivity is possible for reaction populating nuclei with large angular momentum. Indeed, the angular distribution data for ^{162}Yb produced in the 225 MeV ^{48}Ti+^{114}Cd reaction demonstrate this selectivity. For example, the trend of the A_2-values averaged over the GDR low energy component (see fig.3) is consistent with the predicted increase of the (oblate) deformation. This can also be seen in the data for ^{110}Sn[7,8].

The selectivity of 14-element filter is definitely not good enough for the reaction with lower angular momentum transfer. For such cases the new multiplicity filter HELENA was used and the data are being analyzed.

It is also desirable to effectuate a selection on the excitation energy E^*. This can be done using a differential method[9]. The idea of it is illustrated in fig.4, where the spectra from the decay of two nuclei differing by one neutron: ^{162}Yb and ^{161}Yb, and having different excitation energy are compared. The excitation of the second nucleus, ^{161}Yb, is chosen to be equal to that remaining after the neutron evaporation from the first nucleus, ^{162}Yb. Thus, the gamma emission from the second nucleus represents the part of the γ-ray decay that is common to the two reactions. A subtraction of the two spectra results in a spectrum of the γ–rays which compete with the first neutron evaporated from the compound nucleus ^{162}Yb. With this method the excitation energy spread of the states, on which the GDR is built, is confined to the width of the GDR itself (5-8 MeV) and to a broadening due to the energy loss of the beam in the target.

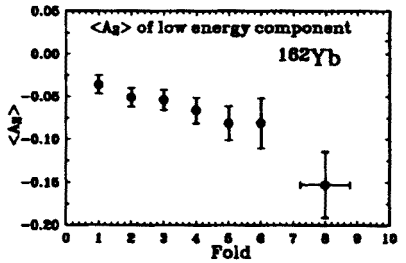

Fig.3 *Average values of the A_2- coefficient in the energy range 10+13 MeV, as obtained by gating on different folds.*

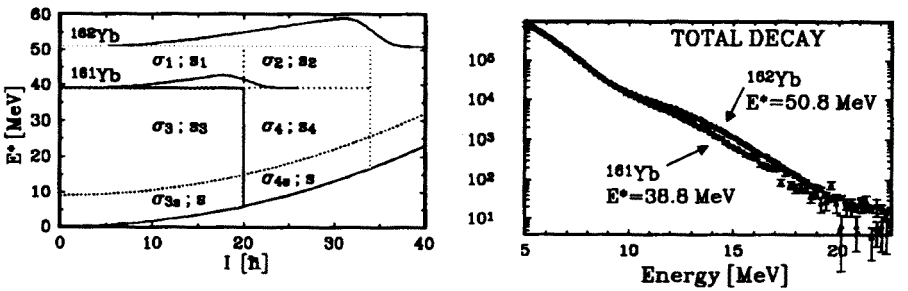

Fig.4 *Left: Schematic illustration of the E^* and I regions populated in two reactions. Each region is characterized by the cross section for γ-ray emission σ and the spectrum shape S. The subtraction method isolates the GDR decay from regions 1,2 and 4. Right: Measured angle-integrated gamma spectra in the two reactions.*

For such a procedure, however, the angular momentum distribution for both compound nuclei must be the same. This can be ensured by using a multiplicity filter with good resolution; by choosing particular combinations of target, projectile and bombarding energy; or by producing both nuclei with l_{max} beyond the critical angular momentum for fission and selecting (by means of, for example, a PPAC recoil detector) only those which survive the fission competition. If this is not the case, the difference spectrum will contain contributions from the angular momentum region not common to the two reactions. But even in this case, if one concentrates only on the properties of high-energy (15 MeV) γ-rays, the contribution of the *first-step* decay to the difference spectrum will be sizeable (77% in the case illustrated in fig.4). This comes from the fact that "contaminating" decays from the next steps are reduced due to the lower effective level density.

This is so far the only general, as far as one concerns compound nuclei for which the neutron evaporation channel is the dominant one, method to restrain the temperature spread of decaying nuclei. One should mention however two other methods, that can be applied in special cases. In the method proposed by the Amsterdam-Groningen group[10], one can select the γ-rays coming from compound nucleus only, making use of the fact that a high-spin isomer exists in this nucleus. The Kraków group[11] has studied light nuclei (A<60) at relatively low excitation energy (E*≈30 MeV). The average energy of the GDR in such mass region (E_{GDR}≈18 MeV) is almost twice the particle binding energy and the yrast-line is relatively steep. Therefore, when deexcitation started with the emission of a particle (neutron or proton), the average excitation energy accessible for further deexcitation was about 15 MeV, making the probability for the emission of a γ-ray from the GDR range (about 18 MeV) rather small. Consequently the measured high-energy γ-rays are restricted to those coming from the compound nucleus.

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