PERFORMANCES OF THE FUTURE MULTIDETECTOR PARIS ILLUSTRATED ON THE RADIATIVE CAPTURE PHYSICS CASE*

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The future γ-multidetector PARIS for SPIRAL2 will be an array composed of the recently developed $LaBr_3$ scintillators. It is dedicated to the study of the γ-radiation from hot nuclei. Different physics cases are proposed for this detector: one of them is the radiative capture of light-heavy ions. This paper presents a status of knowledge for this physics case and shows which improvements could be provided by the use of PARIS illustrated in the case of $^{12}C(^{16}O,\gamma)^{28}Si$.

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1. Radiative capture of light-heavy ion

Narrow resonances close to the Coulomb barrier have been observed in the $^{12}C+^{12}C$ and $^{12}C+^{16}O$ systems. A possible explanation of these resonances could be a large overlaps between the entrance channel and molecular states of the composite system. The radiative capture, which is the exclusive γ-decay part of the fusion process, allows to probe both the entrance channel by its overlap with the states of the composite nuclei and the nature of the states fed via electromagnetic transitions. This mechanism could then be ideal to highlight cluster states in medium mass system as suggested

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by Baye and Descouvemont [1]. Thus, the measurement of the complete γ-decay pattern of the radiative capture reactions is highly requested to study such a link between resonant cluster states and bound or quasi-bound cluster states. ^{12}C(^{12}C,γ)^{24}Mg and ^{12}C(^{16}O,γ)^{28}Si radiative capture experiments have been performed using highly efficient γ-detector (BGO) coupling to the very rejective 0°-spectrometer DRAGON. In both cases, the γ-spectra taken in coincidence with the ^{24}Mg (^{28}Si) recoil nucleus show an unknown bump around 10 MeV (14 MeV) respectively. The widths and energies of these bumps correspond to the feeding of at least three states just above the α-threshold [2, 3, 5]. Moreover, in the case of ^{12}C+^{16}O, the low-lying part of the γ-spectra shows important feedings of the 4_1^+ state at 4.18 MeV, 3_1^- octupolar state at 6.88 MeV and of the 4_3^+ prolate state at 9.16 MeV. These feedings are the first indication that the main contribution to the entrance channel comes from spins larger than $J = 4\hbar$ and that states with particular deformations, which are good candidates for ^{12}C–^{16}O configuration [4], are involved in the decay process. Nevertheless, a complete discussion of the experimental results can only be obtained by means of simulations taking into account both transmission and efficiency of the full apparatus. These calculations have been performed for three plausible scenarii: a fully statistical scenario involving the expected spin distribution in the entrance channel, a semi-statistical scenario involving a unique entrance spin and a cluster scenario given from theoretical calculations [1, 4]. The simulations allow us to eliminate the possibility of a fully statistical behavior. In both cases the total radiative capture cross-section to all the states is more than twice the one known to the g.s. band [6]. Unfortunately, the resolution of the BGO in the 10–15 MeV range is too poor to disentangle a semi-statistical behavior involving a large number of states or a feeding of few intermediate cluster states. The only way to get crucial information is to use another γ-detector with a better resolution in the 1–25 MeV range and with similar efficiency than the BGO-array. These two requests will be fulfilled by the future multidetector PARIS as it will be demonstrated in the next sections.

2. Radiative capture on PARIS

The multidetector PARIS [7], one of the future SPIRAL2 detectors, will be dedicated to the study of γ-radiation from hot nuclei. For efficiency and resolution requirements, three different elementary units are under study for this detector: pure $LaBr_3$ or $LaBr_3$ directly follow in a phoswich mode by CsI or NaI crystals. The tests of these modules show that due to the different decay times of the three crystals, a discrimination between the response of the two crystals of one module is possible. The final design either cubic or radial is under investigation. In the present GEANT4 simulation, the array is made of ∼ 180 modules of $\mathrm{LaBr_3}$ (2"×2"×2") followed by CsI (2"×2"×6") crystals in a semi-spherical design comprising 18 clusters of 9 modules and 6 clusters of 3 modules. This geometry is shown in Fig. 1 (left).

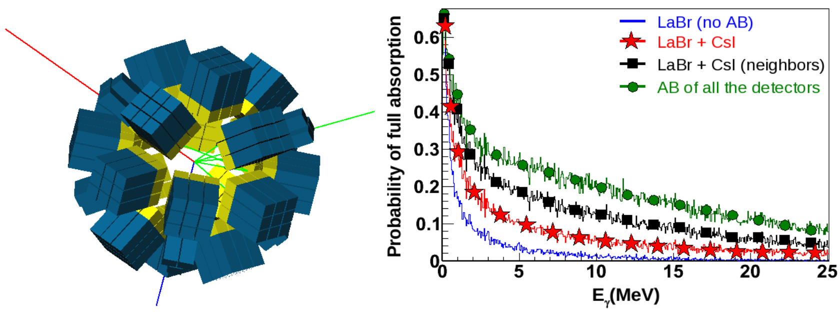

Fig. 1. (Color online) On the left: view of the 180 detectors of the EXOGAM-like configuration. On the right: Efficiency as a function of the Add-back (AB) algorithms used to reconstruct the γ-spectra (see text for more details).

The internal radius of the sphere is 23.5 cm. Fig. 1 (right) presents the expected probability of a full absorption in the array for different algorithm of reconstruction. The curve without markers corresponds to a total absorption ($E_\gamma \pm 1\%$) on single $\mathrm{LaBr_3}$ crystals, the curve with stars when the energies deposited in the $\mathrm{LaBr_3}$ or CsI part of one module are added, the curve with squares when the closest neighbors are added and the curve with circles when all the modules of the geometry are added. The optimal algorithm used for the analysis has to be chosen mainly depending on the energy and multiplicity of the γ emitted in the process. In the $^{12}\mathrm{C}(^{16}\mathrm{O},\gamma)^{28}\mathrm{Si}$ radiative capture case, at the bombarding energies used in the TRIUMF experiments, we expect γ-radiation mainly in 3 ranges of energies: 0–7 MeV, 13–15 MeV and 20–25 MeV with a γ-multiplicity around 4. The algorithm which minimizes the number of wrong crystal added and maximizes the number of complete reconstruction is the one when only the closest neighbors are added (curve with black squares in Fig. 1). In this condition, the efficiency of this geometry is 30% at 2 MeV, 12% at 15 MeV and 7.5% at 25 MeV.

Fig. 2 presents the γ-spectra that one should get by using the PARIS array for the $^{12}\mathrm{C}+^{16}\mathrm{O}$ case involving a cluster scenario (semi-statistical scenario) respectively. The main conclusion from the simulation is that measurements with PARIS will help to disentangle both scenarii. In the case of a cluster behavior the individual transition can be identified. In the case of a semi-statistical behavior from a 6^+ entrance state, the main states which should be involved, *i.e.* the $J \geq 4\hbar$ states, can also be identified even though the spectrum shows a more continuous feeding as expected for the statistical feeding of a large number of states. The radiative capture channel can be selected by imposing the calorimeter condition: $\sum E_\gamma \geq 20$ MeV. In this

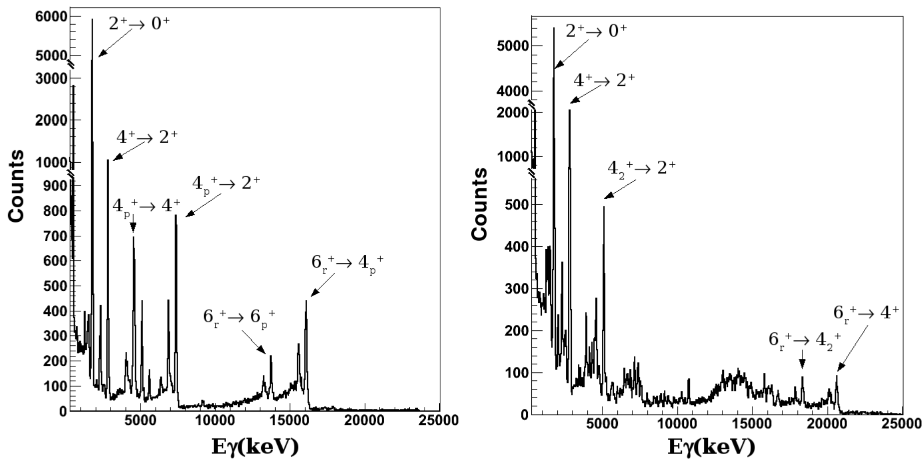

Fig. 2. On the left: simulated γ-spectra in PARIS for a cluster scenario involving the 4_p^+ and 6_p^+ of the prolate band. On the right: similar spectra for a statistical decay from a 6^+ resonant state (6_r^+).

condition almost 30% of the full γ-spectra is kept even with this geometry where only 67% (19%) of the full solid angle is covered at the entrance of the $LaBr_3$ shell (at the end of the CsI shell) respectively. This option is really promising with respect to the constraints imposed by the use of a spectrometer in which the charge state selection will reduce the γ-spectra by a factor of three. The same improvement is observed for the study of the ^{24}Mg case [8]. These simulations show that the future detector PARIS can be used in a calorimeter mode to fully understand the radiative capture γ-spectra and highlight the expected cluster feedings.

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