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First results with DIAMANT and EUROGAM

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Abstract. The coupling of efficient particle and γ detection arrays is a powerful tool to study the deexcitation of both compound and residual nuclei in fusion evaporation reactions. We show first results obtained coupling the DIAMANT (4π light charged particle array) and EUROGAM (4π γ array) detectors demonstrating the improvement in the resolving power by this combination. For γ rays of $\simeq$800keV improvements in the Doppler correction up to 50% have been reached for the 2α exit channel following the fusion of ^{32}S+^{58}Ni at 120 MeV bombarding energy ($\beta \simeq$3%).

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Light charged particle detectors used in nuclear reaction studies, are also an efficient tool in nuclear spectroscopy investigations [1] and the combination of an efficient light charged particle array to an efficient γ array opens new possibilities and push further the limits of observation [2]. The 4π multidetector, DIAMANT [3], has been designed to detect light particles (proton, α) and to fit into the 4π EUROGAM γ array [4].The coupling of these two arrays provides a unique way to study the deexcitation of the compound nucleus (CN) in the mass $\simeq$90 region as well as, for each reaction channel, the deexcitation of the residual nucleus (ER). We report here on the improvements obtained in γ-ray spectroscopy regarding the observational limits obtained for reaction channels with a very small cross section as well as the Doppler correction for the γ spectra.

DIAMANT [3] is based on 54 CsI detectors having an axial symmetry around the beam axis. Details on the geometry can be found in [3]. The CsI detectors, optically coupled via light guides to PIN diodes, are housed in a 18cm diameter chamber surrounded by EUROGAM. The EUROGAM II γ array included 30 Tapered and 24 Clover Anti-Comptoned Ge detectors. The data acquisition of these two arrays allowed to register the individual energies and time signals of all the Ge detectors as well as the particles parameters: energy, type of particle (using a cross over method), and time versus the EUROGAM Fast Trigger.

The experiment was done with a ^{32}S beam at 120 MeV from the VIVITRON accelerator at CRN Strasbourg. The ^{58}Ni target was a stack of two 400μg/cm^2 foils. Events were recorded when at least 4 Ge in EUROGAM and one detector in DIAMANT had fired. The geometrical efficiency of DIAMANT was $\simeq$95%; after the analysis the efficiencies obtained for an α detection was $\simeq$60%, that for a proton detection $\simeq$70%. In this reaction the ^{90}Ru CN decays via 12 reaction channels, the dominant ones being respectively: 3p (^{87}Nb ER) with 43.0%, 4p (^{86}Zr) with 24.6% and 2pα (^{84}Zr) with 22.4% of the total cross section. One of the weakest was the 2α channel leading to ^{82}Zr ER with only 0.2% of the total cross section.

When so many channels are opened it is of real importance to obtain the best ER selectivity for γ-ray spectroscopy. A clear improvement is provided by coupling DIAMANT to EUROGAM. A simple algebra has been developed [2] to provide estimates on the peak to background ratio (PTB) for γ-lines when using an escape suppressed Ge array alone or in coincidence with an ancillary detector. The PTB (F1) for a γ_1 peak is proportional to the resolving power (R_γ) of the Ge array [5] with $R_\gamma = P_T.SE/\delta E$, where P_T is the Peak to Total ratio, SE the mean separation energy between γ-lines and δE the resolution of the Ge detectors *including* the Doppler broadening. When using an ancillary detector with the Ge array the PTB (F'_1) is just $F'_1 = R_p F_1$ where R_p is the resolving power of the ancillary detector and accounts for changes in the properties of the γ-array (P'_T and δE'). Typical R_p values with DIAMANT, for various channels in the studied reaction, are: 6.3 (α,2p), 2.4 (3p), 245 (2α), all values well above unity. The observational limit [2] in the γ-spectra is inversely proportional to R_p. An illustration is given for the 2α channel in Fig.1 (see legend), which is unobservable in a total γ spectrum. With a selection of one α in DIAMANT, $R_p \simeq$30; Fig.1a shows the dominant (2p,α) channel γ-lines; selecting 2α, the (2p,α) γ-lines decreases by 100 and the 2α γ-lines show up with a 10 times better statistic than in Fig.1c (no background was subtracted in order to compare the PTB in each cases). In these spectra the Doppler correction was done assuming a

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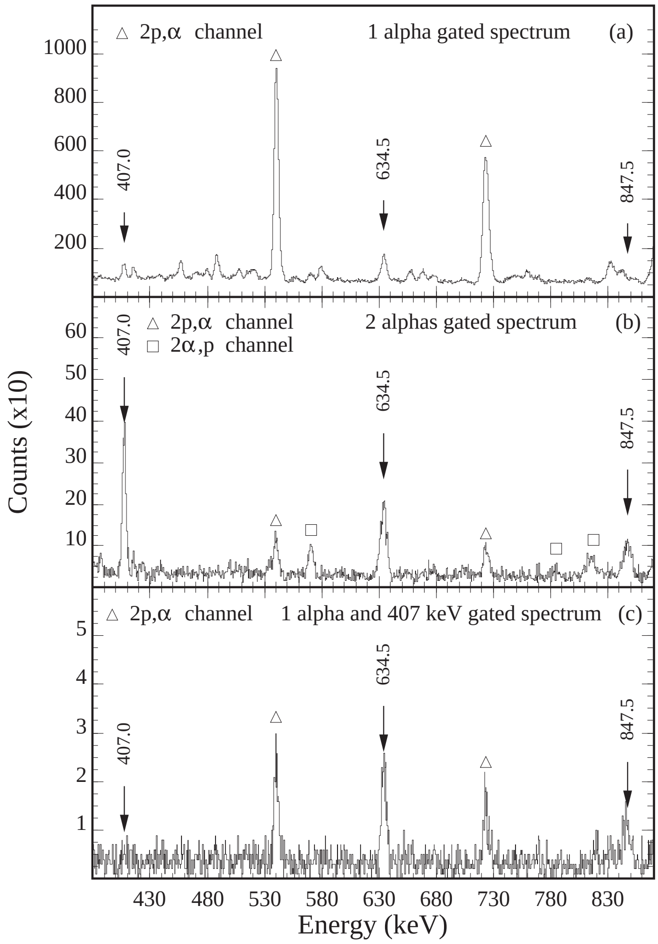

Fig. 1a–c. γ-spectra demonstrating the selectivity on the 2α channel for the ^{58}Ni(^{32}S,2α) reaction at 120MeV. *Arrows* note the 3 first γ transitions in the final nucleus ^{82}Zr. **a** spectrum gated by 1 α in DIAMANT. **b** same for a 2 α gate in DIAMANT. **c** same for 1α gate in DIAMANT and a 2^+-0^+ (407 keV) γ gate in EUROGAM

mean recoil velocity β; the resolution can be further improved using the method described hereafter.

As already stressed, the Doppler effect, leading to a broadening of the γ-lines can have drastic effects on the performances of a γ-array in spectroscopy studies. This effect is crucial when the recoiling nuclei have appreciable velocities ($\beta \geq$2%). Limitations on the Doppler correction are well known [5, 6]. For light charged particle channels an array such as DIAMANT is able to bring a significant improvement in the Doppler correction. For a γ-ray (E_0) emitted by the recoiling ER, the observed γ-energy (E_γ) depends on a) the angle (θ) between the Ge detector and the direction of the ER given by $\boldsymbol{\beta}/\beta$, b) on the absolute value β of the ER velocity by:

$$E_\gamma = E_0(1 + \beta \cos\theta) \tag{1}$$

$$\boldsymbol{\beta} = \frac{1}{m}\sqrt{\frac{2}{931.12}}\left(\sqrt{m_p E_p}\,\mathbf{u_p} - \sum \sqrt{m_i E_i}\,\mathbf{u_i}\right) \tag{2}$$

$\mathbf{u_p}$ and $\mathbf{u_i}$ stand for the unit vectors defining the direction of the projectile and the ith evaporated particle, m_p, m_i their mass and m the ER mass. The ability to identify with DIAMANT all the evaporated particles, their direction and their individual energies allows a full kinematic correction and hence the direction and velocity of the ER can be determined. This method improves notably the resolution of the γ-lines as shown in Table 1 giving a comparison of the full width at half maximum (fwhm) calculated with a mean β (as done in γ-arrays) versus the fwhm^{cor} obtained with DIAMANT.

Table 1. Comparison of the fwhm obtained with the mean β and the value (fwhm^{cor}) when correcting for the evaporated particles. The last column is the reduction factor deduced from fwhm and fwhm^{cor}

Reaction Channel	E_0 (keV)	fwhm (keV)	fwhm^{cor} (keV)	Reduction (%)
3p	780	4.9(1)	4.1(1)	16.3
	1779	12.5(1)	10.0(1)	20.0
4p	751	5.1(1)	4.2(1)	17.6
	1493	10.0(2)	7.4(3)	26.0
α,2p	723	5.8(2)	4.0(1)	31.1
	1506	10.9(1)	6.4(1)	41.3
α,3p	964	7.5(2)	4.5(1)	40.0
2α	633	7.1(2)	3.7(1)	47.8
	847	9.0(3)	4.5(2)	50.0

This improvement is related to the detection of the individual energies of the light particles and their direction of emission associated to the second term in Eq.(2), the reduction factor on the fwhm is ranging from 30 to 50% in channels involving α particle emission and it is 16-26% for xp channels, which is still valuable. The evolution of the reduction factor with the energy of the γ was of course expected from Eq.(1). This method is promising for γ studies in the mass region A$\simeq$40-100 were light charged particle emission is dominating and γ energies are well above 1 MeV.

In conclusion we have illustrated the improvements in studying the γ-decay of residual nuclei produced in light charged particles reaction channels by coupling the DIAMANT array with EUROGAM. Such a linking allows also, for the first time, precise particle-spectroscopic studies [7].

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