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HIGH ENERGY GAMMA RAYS IN ^{25}F

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Abstract

Structure of the neutron rich nucleus ^{25}F has been investigated through in-beam γ-ray spectroscopy of the fragmentation of a stable ^{36}S beam. The emitted γ-rays were detected by use of a BaF_2 array. In the high energy part of the spectrum a wide bump from 3 to 4.5 MeV energy has been observed corresponding to a set of γ rays, including their first and second escape peaks. In order to resolve the peaks and to determine the high energy structure of ^{25}F a line shape corresponding to the experimental conditions was produced via a Geant4 simulation. By use of such a line shape 4 γ rays were resolved in the high energy region, corresponding to 4 excited states instead of 2 proposed in the preliminary analysis of the data.

I. Introduction

At a first glance it might seem that fluorine isotopes, having a valence proton in addition to the single closed shell oxygen core, has a simple structure: their energy spectrum can be described by use of some single proton states coupled to the ground and excited states of the neighboring oxygen nuclei. In contrast, the fluorine isotopes surprised us in many cases.

^{19}F has a deformed ground state and also a very low energy negative parity state which shows a clear multi-particle-multi-hole nature in shell modell. Recently, the experimental proof for a bound $^{31}F_{22}$ [1] provided a new surprise. Since the drip line is reached at $N = 16$ for oxygen isotopes, observation of the N=22 fluorine isotope means that the addition of a single proton makes at least the $d_{3/2}$ neutron single-particle orbital bound. To bind an additional pair of neutrons above the N=20 shell closure, the assumption of strong proton-neutron correlation associated with multi-particle-multi-hole shell modell configuration is needed [2]. As a consequence, in addition to the normal excited states, exotic states may appear in lighter fluorine nuclei, too. Indeed, recently 2 bound excited states have been observed in ^{27}F [3], while no bound excited states are expected in it from the *sd* shell model [4].

As a part of the in-beam γ-spectroscopic investigations of neutron rich nuclei around the $N = 28$ [5, 6, 7], $N = 20$ [8, 9] and $N = 16$ [12, 13] subshell closures, we have investigated the structure of neutron rich ^{25}F nucleus. The experiment was performed at GANIL by in-beam γ-spectroscopic study of the fragmentation of the stable ^{36}S beam. Preliminary results on observation of 4 γ rays at 750,1700, 3300 and 3700 keV energies have been presented at different conferences [9, 10, 11]. From the study of the neutron knock out from ^{27}F [3] the existence of the two low energy lines at 727 and 1753 keV have been confirmed . In the present paper we report on the precise analysis of the high energy part of the spectrum needed to search for intruder configurations in ^{25}F.

II. Experimental methods

A $^{32}S^{16+}$ beam of 77 MeV*A energy and 15 enA intensity was frag-

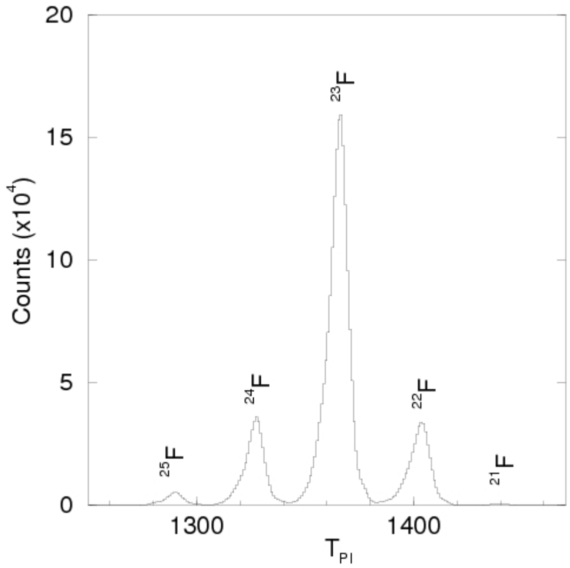

Figure 1: Time-of-flight spectrum of different fluorine isotopes measured between the cyclotron radio frequency pulse and the time signal of the plastic detector at the focal plane of the SPEG spectrograph.

mented on a ^{9}B target of 2.76 mg/cm^2 thickness. The emerging fragments were detected by the SPEG spectrometer, the magnetic rigidity of which was optimized for $A/Z = 8/3$ somewhat lower than the mass-to-charge-ratio of ^{25}F. Ionization and drift chambers, as well as a plastic scintillator were placed at the SPEG focal plane, providing information on the energy loss, total energy and time-of-flight for identification of the fragments. The quality of the mass separation is illustrated in Figure 1. It can be seen that the peaks corresponding to the fluorine isotopes with different masses are well separated. During the experiment about 78*10^3 ^{25}F nuclei were collected.

74 BaF_2 detectors surrounding the Be target detected the γ-rays from the identified fragments. The BaF_2 crystals were mounted symmetrically above and below the target at a mean distance of 21 cm, covering about

80% of the total solid angle.

During the fragmentation of the ^{36}S beam projectile-like and target-like fragments were produced together with a hot zone. The hot fragments de-excited by emission of neutrons and γ-rays in flight. The neutrons evaporated from the hot zone and from the excited fragments can hit the detectors. If they are energetic enough ($E_n > 15$ MeV), they cannot be distinguished from the γ-rays due to the short time-of-flight between the target and the detectors and the finite instrumental time resolution (~2 ns). As a result, some neutron background is visible in the γ-ray spectrum.

The γ spectra were corrected for the Doppler-shift caused by the large fragment velocity (v/c = 0.34). The additional information provided by the SPEG on the momenta of the fragments was also applied to improve the Doppler-correction. After these corrections, a full width at half maximum of about 12% has been achieved for the BaF_2 setup, which had a total photo-peak efficiency of ~20% at 1.3 MeV energy. As the detectors were closely packed, both the neutrons and the γ-rays could easily scatter from one detector to another. To decrease the background caused by the scattered particles, we used the array in anti-Compton mode, *i.e.*, all the events where at least 2 neighboring detectors fired at the same time were rejected.

III. Experimental results

The γ-ray spectrum obtained for ^{25}F is shown in Figure 2. In the spectrum a γ peak is observed at 750 keV followed by an other one at 1720 keV. In addition, a wider, slightly structured bump is visible between 3 and 4.5 MeV.

To resolve this bump, we first analyzed the energy dependence of the peak widths using single lines observed in different reaction channels. In the analysis a more or less linear energy dependence was observed as it is shown in Figure 3. Using this energy dependence of the peak width and assuming the usual Gaussian line shape, the bump can be resolved into five γ-rays with energies of 2850, 3200, 3480, 3800 and 4160 keV as it shown in Figure 4. As it can be seen in Figure 2, the spectrum is cut at about 600 keV, thus by use of the anti-Compton method events where the scattered out γ-ray has an energy lower than about 600 keV cannot be suppressed. Thus,

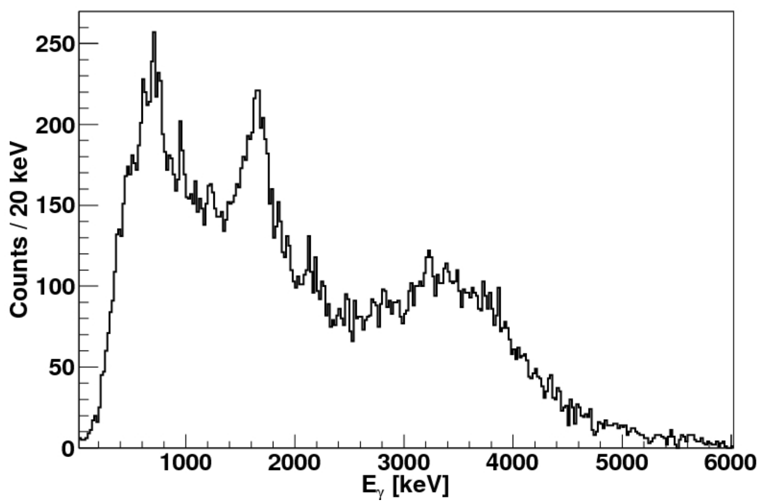

Figure 2: Doppler-corrected spectra of ^{25}F γ rays, which emerge from fragmentation reactions with Multiplicity = all.

the observation of the escape peaks cannot be avoided. As a consequence in addition to the *gamma* lines observed, the presence of their single and double escape components are also expected. Considering that the energy differences of the Gaussian components is about 300 keV, roughly each second peak sits on the escape peak of a higher energy *gamma* ray. Thus, the contamination from escape peaks may affect even the number of peaks needed to resolve the dump. To be able to produce a reliable decomposition a more precise line shape is needed.

To get a reasonable line shape the response of the BaF_2 array was simulated by use of the Geant4 package. In the simulation the energy dependence of the peak width, the cut off energy, as well as the Doppler shift and the Doppler correction was included. Implementation details can be found in Ref. [14]. From the simulation it was found that the intensity of the single escape peak is about half of the photo peak intensity for a γ line of about 3.5 MeV. Furthermore, the double escape peak was not found significant in the simulated spectrum.

Performing the decomposition of the bump by use of the simulated line

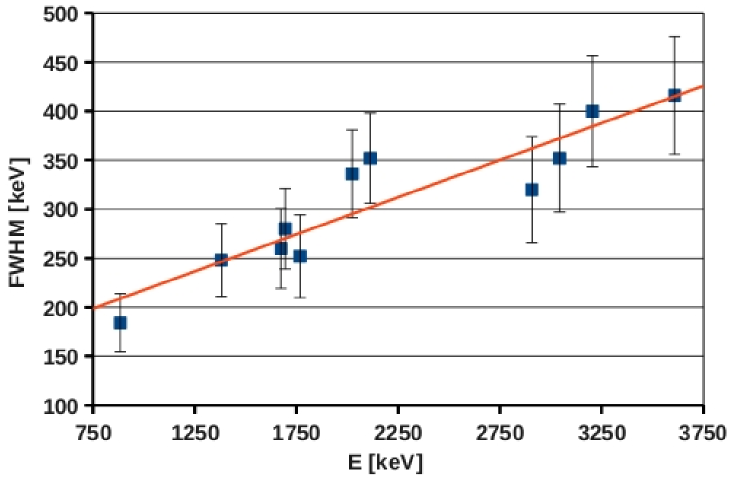

Figure 3: The energy depedence of the peak full width at half maximum for BaF2 detectors. The solid red line is the fit for experimental points where the linear equation is $FWHM(E) = 0.076 * E + 141.983$.

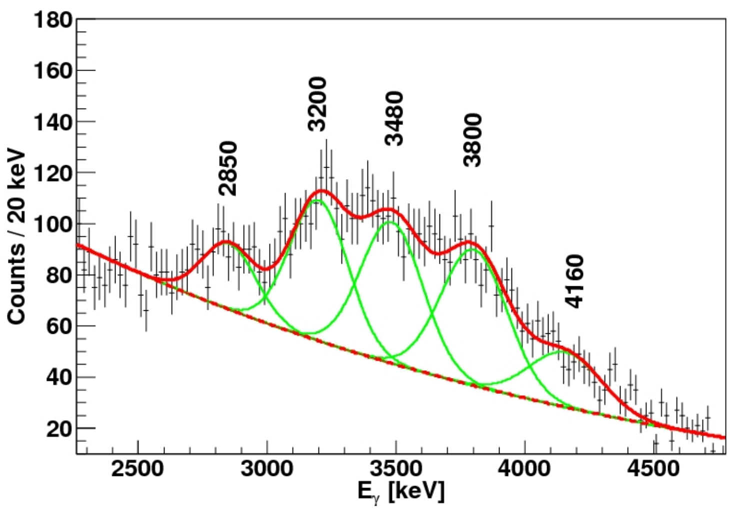

Figure 4: Doppler-corrected spectra of ^{25}F γ rays. The solid thicker red line is the final fit, which includes 7 Gaussian peaks marked as green lines and additional exponential backgrounds plotted as thinner dotted red line.

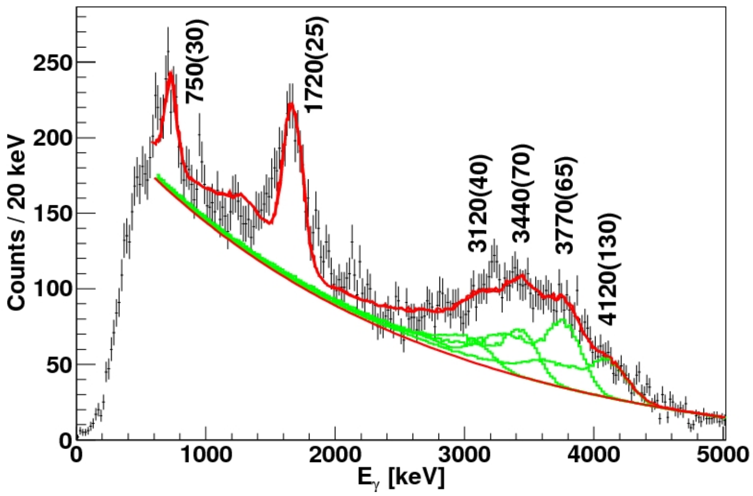

Figure 5: Doppler-corrected spectra of ^{25}F γ rays. The solid thicker red lines is the final fit, which includes the spectrum curves from the Geant4 simulation and additional exponential backgrounds plotted as thinner red line.

shape it was found that at least 4 γ rays are needed to obtain a good fit. Figure 5 clearly shows that the single escape peaks of the high energy γ rays overlap with the photo peaks of the lower energy transitions. The low energy tails of the higher energy *gamma*-rays make the lowest energy Gaussian peak unnecessary. The position of the remaining peaks is slightly shifted relative to the Gaussian fit, the obtained energy of the 4 γ rays are: 3120(40), 3440(70), 3770(65) and 4120(120) keV, which overlap with the energies obtained from the Gaussian fit within the error bars. Comparing the two fits, it is also clearly seen that the intensities obtained with the Gaussian fit strongly differ from the one got using the simulated line shapes.

IV. Conclusion

The shape of a photo peak in the γ-spectrum is often approxmated by a simple Gaussian. This approximation works well in may conditions, but having high energy *gamma* rays and stand alone detectors of a poor resolution consideration of the complete response of the detector set may be necessary. This was the case in our experiment where the γ rays were detected via the BaF_2 detectors of the Chateau de Crystal array. In order to decompose a bump of high energy γ rays the detector response was simulated by use of the GEANT4 package. Using the simulated line shape the high energy bump observed in the spectrum of ^{25}F has been resolved into 4 γ lines of 3120(40), 3440(70), 3770(65) and 4120(120) keV energy. These lines correspond to the decay of the states having the same energy. The number of states in this energy region is consistent with the predictions of the shell model calculations performed in the *sd* shell. Thus, there is no clear indication for the existence of intruder configurations below the neutron separation energy at 4.36 MeV in ^{25}F.

Acknowledgments

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