Simulation of Doppler Shapes of Gamma-ray Transition Peaks Using the Velocity Profiles of Emitting Residues

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Introduction

Lifetimes of the excited states of nuclei are much pursued in their spectroscopic investigations. The lifetime of a level is a manifestation of the overlap of its wave function to those associated with the neighbouring states. The level lifetime, and the transition probabilities extracted therefrom, thus provide for stringent test of model calculations on the microscopic configuration of the state and facilitates in constraining the same. Such applications have rendered the lifetime measurement to be of profound significance in the study of excited nuclei. It is known that the techniques for pursuing the same are subject to the range of lifetime being addressed. If the latter is between few tens of fs and few ps, as is commonly encountered for excited nuclei, the Doppler Shift Attenuation Method (DSAM) is the technique of choice. In typical implementations, the method is based on analyzing the Doppler shapes/shifts of gamma-ray transitions (peaks) emitted by nuclei traversing through the target and the backing media following their production in nuclear reactions. The shape of a transition peak represents the distribution of the respective decay events in time. The time (clock) commences with the production of the excited nuclei, and continues through their journey in the target and the backing media up to the eventual stop. Depending on the lifetime of the excited states, the nuclei or a proportion of their population may de-excite during the flight through the stopping media and exhibit Doppler shapes/shifts in the respective energy peaks. The analysis in DSAM proceeds through calculation of expected Doppler shape from inputs on the (i) simulated velocity profiles of the residues through the target and the backing media (ii) detection geometry and (iii) de-excitation scheme, followed by least-square fitting of the calculated shapes to the experimentally observed ones. The principal parameters of the fitting exercise are the lifetime of the state and that of the states feeding it, apart from the spectral parameters such as the background and peak heights. The feeders are either known from spectroscopy data or are modelled in the codes for Doppler shape analysis. The aforementioned velocity profiles of the residues, required in the analysis of the Doppler shapes, are simulated using Monte Carlo algorithms that use the stopping powers of the target and the backing media with respect to the residues. The uncertainties on the stopping powers and on the feeding information contribute maximally in the uncertainty on the lifetime results obtained through DSAM. However, in the recent years it has been possible to restrict the uncertainties on the stopping powers through use of updated models and simulations such as the ones reported by Das *et al.* [1]. The developments notwithstanding, it is sometimes obscure to ascertain the Doppler shapes of transition peaks in spectra following heavy-ion induced fusion-evaporation reactions wherein a number of nuclei may be populated and the same may de-excite through transitions of overlapping or closely placed energies. The lifetime and values of the associated parameters obtained from analysis of such complex spectra may need independent validation. This

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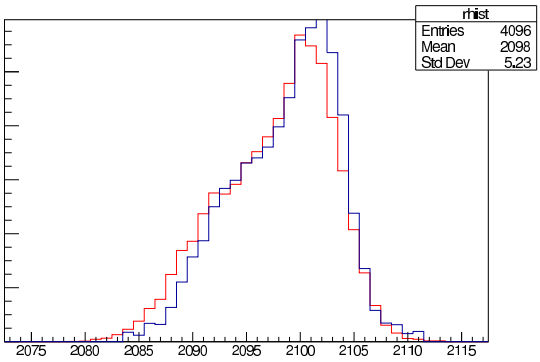

FIG. 1: Overlap of experimental (red) and simulated (blue) Doppler shaped gamma-ray transition peak.

work is about simulating Doppler shape of a gamma-ray peak of a given transition energy for a given value of lifetime of the de-exciting state and a given value of the feeding intensity and time. The velocity profiles of the emitting nuclei, as simulated independently, are provided as inputs for the present simulations.

Algorithm and Results

The methodology for the current simulations of Doppler shapes is based on simplistic implementation of Monte Carlo techniques. For a system of a single state with one feeder level, the inputs read-in are the transition energy de-exciting the former, the lifetime of the state, the intensity of the feeding and the lifetime of the feeder. The velocity profiles of the emitting nuclei, simulated independently, are read-in and these consist of variation of velocity (β) and direction (cosines) of a chosen number (typically $\sim$ 10000) of residues in uniform time steps (typically $\sim$ 1-2 fs). The other inputs include the detector angles and energy resolution. The decay probabilities of the feeder state and the state of interest, over a time step, are calculated from the respective lifetimes. The probability of feeding is calculated from the respective feeding intensity. The simulation proceeds through generation of random numbers, while looping over the number of nuclei in the ensemble, that are compared against different probabilities in order to check for the respective occurrence. For instance, if the random number generated for the feeding process is less than the respective probability, it is concluded that the respective nucleus is originating from the feeder state. This is followed by a looping over the time steps in the respective trajectory wherein at each step a random number is generated to check for the decay of the feeder. Once the feeder decay is met, it follows that the nucleus is in the actual state of interest and another random number is generated to check for the decay therefrom. On finding the decay from the main state, the corresponding time step in the velocity profile is identified and the Doppler shifted energy is calculated using the respective β and the direction cosine. The latter is used to calculate the relative angle between the direction of the emitting nucleus and the detector. The energy is corrected for the detector resolution using the Box-Muller transformation [2]. The simple simulation, as described in the preceding text, can nevertheless lead to superior overlap between the calculated and the experimental spectra, as has been illustrated in Fig. 1. The coding has been implemented in the ROOT [3] framework.

Outlook

Efforts are now in progress to extend the simulations to multiple feeder states for a single level as well as for a cascade of levels feeding the level of interest along with an independent side feeder. The same is expected to better represent a wider variety of de-excitation schemes and simulate the Doppler shapes observed therefrom.

References

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