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Precise test of the fast-timing technique: approaching the method's lower limit for lifetime measurements

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1. Experiment Summary

We propose to investigate the lowest lifetime measured with our on-line fast-timing technique by using a complementary measurement with the recoil-distance Doppler shift method. A very suitable approach for this lower limit investigation is the study of ^{168}Yb. In order to populate the excited states in ^{168}Yb, we plan to use the reaction ^{154}Sm(^{18}O,4nγ)^{168}Yb and focus on the study of the 6_1^+ state. The lifetime of this state was measured in a previous experiment using the in-beam fast-timing technique ($T_{1/2}$=10 (3) ps) and is, according to our knowledge, the lowest lifetime ever reported with this method. However, such a value, at the limit of the sensitivity of this method, requires an independent confirmation from a complementary technique. The recoil-distance Doppler shift method is ideally suited for the picosecond range and was used with great success in previous experiments at the Bucharest TANDEM accelerator. The measurement of lifetimes in the picosecond range and the corresponding electromagnetic transition rates extracted also represent a crucial test for different theoretical models which address the transitional region of the nuclear chart.

2. Introduction

One of the most important observables in nuclear spectroscopy is the lifetime of excited states. Directly linked to the transition probabilities, these quantities offer a direct insight into the nuclear matrix element of different transitions. This is the reason why a real test of different nuclear structure models is considered to be a good reproduction of the selection rules for nuclear transitions and their strengths.

Nuclear lifetimes cover a very wide range, typically from 10^{-15} to 10^{3} seconds. This is the reason why different techniques have been developed, each covering a certain range [1]. For the picosecond range various techniques have been developed, the most prominent one being the *ultra-fast timing technique* developed by H. Mach and collaborators [2]. The method is currently applicable down to a few picoseconds, but is limited only to beta-decay studies [3,4]. Other in-beam methods using γ- γ [5,6] or e^{-} - γ [7] coincidence have been reported in the literature and are used to measure typically lifetimes in the nanosecond range.

An improved in-beam fast timing technique has been proposed in Ref. [8]. This method uses the superior properties of the $LaBr_3(Ce)$ scintillators in combination with an array of HPGe detectors. The advantage of this method is the use of triple-gamma coincidence: the HPGe with its superior energy resolution is used to select the cascade of interest while the two scintillators are used to define the decay time spectra. At the time of Ref. [9] the lowest value reported with this technique was 47 (3) ps, and was decreased recently even more to 37 (3) ps, following a recent experiment [10].

This technique was employed in a previous study at the Bucharest TANDEM accelerator to measure lifetimes in the yrast band of ^{168}Yb using the ^{166}Er(α,2n) reaction [9]. Following the analysis method described in Ref. [8] the experiment determined the lifetimes for the 2^{+}, 4^{+}, and 6^{+} states. The decay time spectra for the 6_1^{+} state are presented in Fig.1. The value reported is 10 (3) ps, which brings this method to a much lower value than previously reported [8,10] and close to its lowest limit achievable.

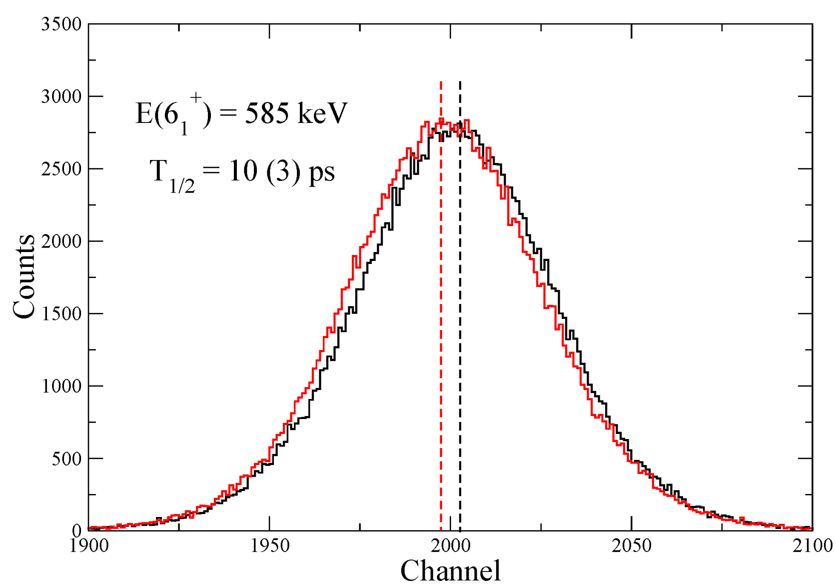

Fig.1. Time spectra for the 385-299 keV (exciting and de-exciting the first 6^{+} state) γ –rays in ^{168}Yb. A clear shift of the centroid can be seen corresponding to a lifetime of the 585 keV level.

Such a small lifetime can be regarded as doubtful, therefore its independent confirmation by a different method would be valuable. One can also shed light into this problem by examining the evolution of the lifetimes and their corresponding transitions probabilities for the first 6^+ state in the neighboring Yb isotopes. These evolutions are presented in Fig. 2 and show a rather smooth evolution over the entire isotopic chain. However, the error of this measurement is around 30% making difficult a precise evaluation of its place within the experimental systematics.

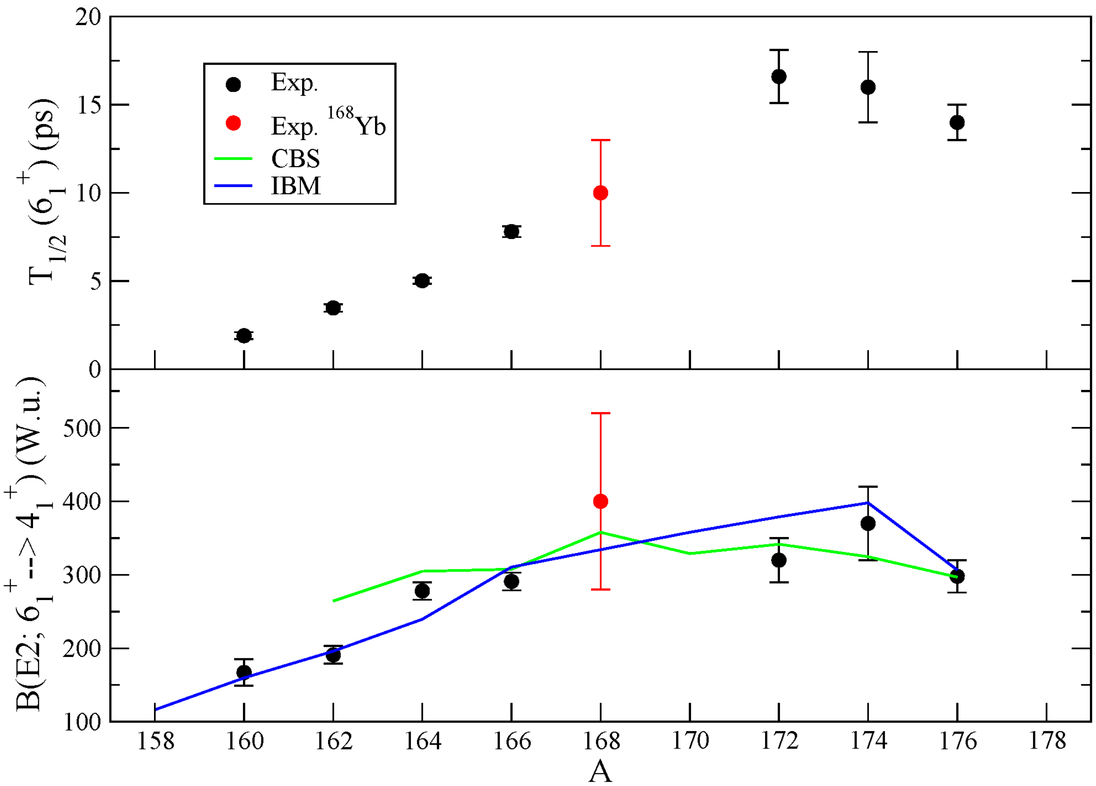

Fig.2. Evolution of the lifetimes for the first 6^+ level (upper panel) and their corresponding transition probabilities (lower panel) to the first 4^+ state in Yb isotopic chain. The red points indicate the values for ^{168}Yb measured in this work. The solid lines correspond to theoretical calculations performed within the confined beta-soft model [11] (CBS) and the interacting boson model [12] (IBM) framework, respectively.

The small value determined for the lifetime and the large uncertainty (compared to neighboring nuclei) requires an independent verification of the value reported and a decrease in the uncertainty. Both goals can be achieved by employing the recoil-distance Doppler shift (RDDS) method [13] which was used several times before in Bucharest [14]. In addition, similar experiments performed in neighboring nuclei gives a hint about the possibility of measuring lifetimes for other positive states as well [15,16]. We estimate that the lifetime of the first 8^+ state is about 2.5 ps while for the first 10^+ state is around 1 ps. At least the first value should be deduced quite easily from this experiment.

3. Experiment Description

We propose to measure the lifetime of the first 6^+ state in ^{168}Yb to test the lowest limit of lifetime measurements that can be achieved with the fast-timing technique described in Ref. [8]. The best method is to use a complementary approach, namely the differential decay recoil-distance Doppler shift method with the Köln-Bucharest Plunger device coupled to the ROSPHERE γ-spectrometer. There are two possible choices to populate yrast states in ^{168}Yb with an appreciable cross section while keeping the recoil velocity at a value around 1% of the speed of light. The first choice is ^{160}Gd(^{12}C,4*n*) reaction at an incident energy of 60 MeV, which has the advantage of the higher cross section, but the disadvantage of a smaller velocity of the recoils. The second choice is the ^{154}Sm(^{18}O,4*n*) reaction at an energy of 78 MeV which has the advantage of a larger recoil velocity. Thus the decision factor should lie in the properties of the target materials, which favor the second reaction. This is the reason why the following calculations are done for the ^{154}Sm(^{18}O,4*n*) reaction.

Since it is very difficult to produce self-supporting Sm target, a ^{154}Sm layer will be evaporated on a Au or Ta foil which will face the beam. Assuming a 0.5 mg/cm^2 ^{154}Sm target, a 1 pnA ^{18}O beam and production cross section of 100 mb, we will produce 1.2 x 10^3 ^{168}Yb nuclei per second. Taking into account the 1% efficiency of the Ge detectors, we expect to observe about 430 γ-γ coincidences for the $8_1^+ \rightarrow 6_1^+ \rightarrow 4_1^+$ cascade per hour. This expected rate would be sufficient to measure the lifetime of the 6^+ state in a coincidence RDDS experiment.

From the systematics of lifetime measurements in Yb isotopes, we expect the half-life of the 8_1^+ and 10_1^+ states of about 2.5 ps and 1 ps, respectively. We estimate that these two additional states can also be measured and their lifetime deduced. To obtain a high precision for the 6^+ state it is necessary to measure the intensities of the Doppler shifted and stopped components of the transitions for a sufficiently large number of target-to-stopper distances. The recoil velocity is calculated to be about 3 μm/ps, equivalent of 1% *c*. With the count rates estimated above, we approximate that a measuring time of 24 hours is needed per distance. To achieve a high precision for the lifetime of the 6^+ state we propose to measure at 10 plunger distances between 5 and 100 μm. Thus we require 10 days of beam time.

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