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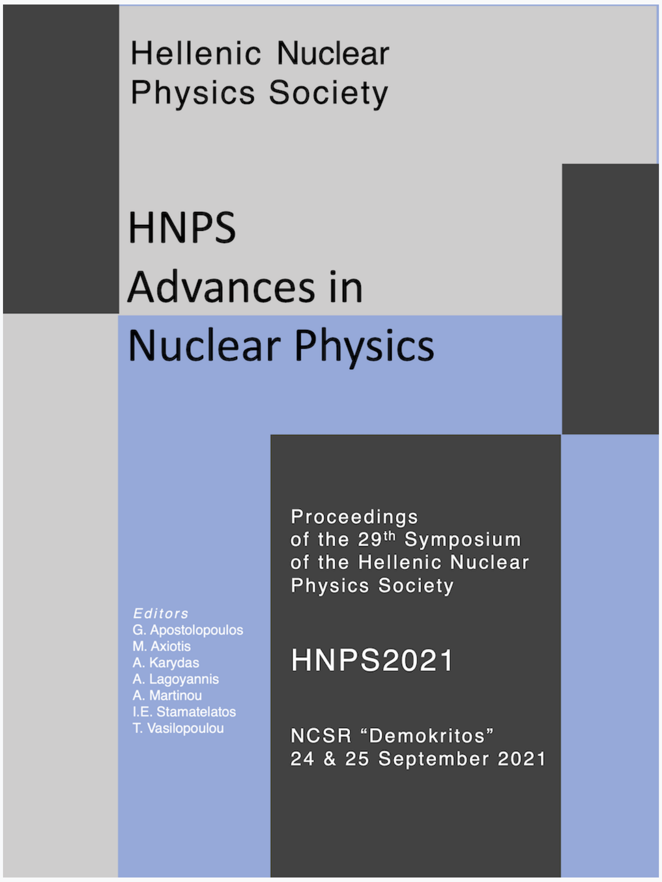

Nuclear Structure Investigations in Yb isotopes

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Nuclear Structure Investigations in Yb isotopes

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Abstract The medium-to-heavy mass ytterbium isotopes ($_{70}$Yb) in the rare-earth mass region are known to be well-deformed nuclei, which can be populated to very high spin, and are predicted to exhibit interesting phenomena, such as shape coexistence. The lack of any experimental information on the structure of the neutron-rich ^{180}Yb isotope and the lifetime of the 2_1^+ state of ^{178}Yb have greatly motivated this study, which can offer useful information for the collective behavior of neutrons and protons in neutron-rich Yb isotopes. A measurement was performed to investigate the population of excited states and a first measurement of the unknown 2_1^+ lifetime of ^{178}Yb by means of a two neutron-transfer reaction ^{176}Yb(^{18}O,^{16}O)^{178}Yb at energies 68-74 MeV using the ROSPHERE array at IFIN-HH, Romania.

Keywords *nuclear structure, rare earth, Yb isotopes, lifetimes, ROSPHERE*

INTRODUCTION

A test run was performed to investigate the population of excited states and attempt a measurement of the unknown first 2^+ lifetime of ^{178}Yb by means of a two neutron–transfer reaction. The Yb isotopes in the rare earth mass region around A=170 are known to exhibit distinct rotational properties, while shape coexistence is predicted to occur [1]. For example, having the ratio of the energy of the first 4^+ state over the energy of the first 2^+ state ($R_{4/2}$ ratio) equal to 3.27 [2], a value very close to the rotational limit of 3.33, ^{168}Yb displays most of the characteristic features of an axial rotor. Deformed nuclei can be schematically subdivided into prolate, oblate, and triaxial nuclei according to the size of the three principal axes of rotation in the ellipsoid. It is known that many nuclei in the rare–earth area are well deformed (e.g. with deformation β_2>0.2 in ground or low–lying states [2]). For ^{178,180}Yb no experimental data are available for the lifetimes and energy levels of the ground state, respectively (see Fig. 1).

EXPERIMENTAL DETAILS

The ^{18}O beam was hitting a natural Yb target at energies 68-74 MeV. The ^{nat}Yb target had a thickness of 2.5 mg/cm^2 backed by a 8.0 mg/cm^2 ^{209}Bi layer. The emitted γ rays were detected using the ROSPHERE [3] array at IFIN–HH, Romania, equipped with 15 HPGe and 10 $LaBr_3$:Ce detectors and in coincidence with emitted reaction particles detected in a six-element solar-cell array, SORCERER [4], see Fig. 2. The HPGe detectors were placed in the first, third and fifth ring of ROSPHERE at 37°, 90° and 143°, respectively.

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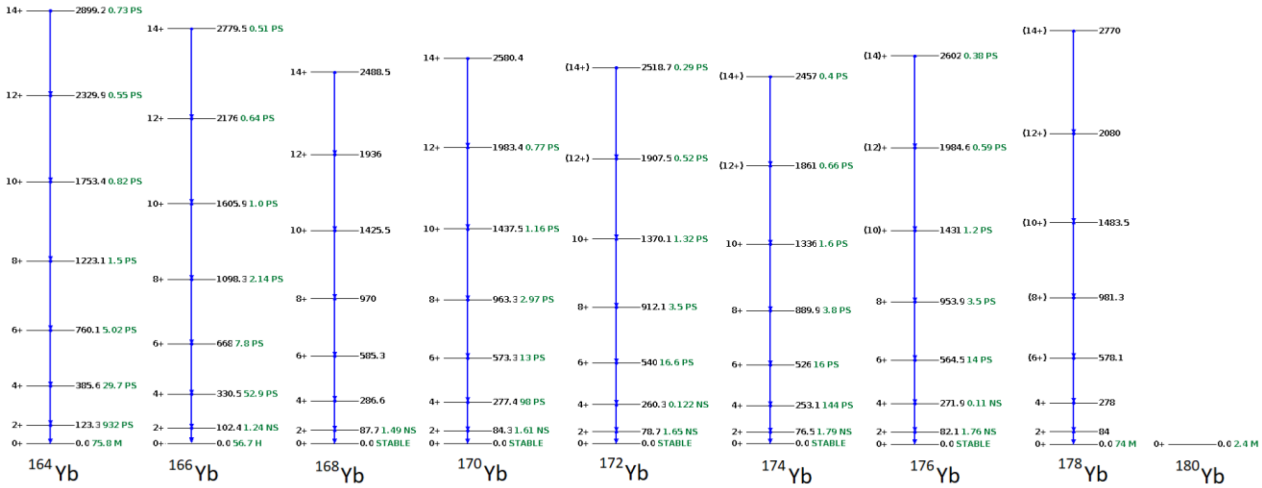

Figure 1. *Partial energy level spectrum of the ground state bands for the even-even Yb isotopes [2].*

Figure 2. *Solar cells for particle detection (left) and a partial view of the ROSPHERE array (right).*

The main goal was to populate the ground state band and measure the lifetime of the unknown 2_1^+ state of the unstable ^{178}Yb with the Fast Electronics Scintillators Timing (FEST) method [5]. To study these transitions, the γ-γ, γ-particle and γ-γ-particle concidence spectra has to be constructed due to the complex gamma spectra from all Yb isotopes in the target that were populated with the 2n-transfer reaction.

RESULTS AND DISCUSSION

The γ-γ spectrum in Fig. 3 is presented for the beam energy of 72 MeV, where we can observe several transitions inside the ground states of Yb isotopes up to spin 8^+, and some background transitions from the Ta shielding, as well. The photopeak at 78 keV includes a superposition of three different transitions coming from different Yb isotopes. The deconvolution can occur by setting coincidence conditions on the γ-particle and γ-γ-particle energy spectra to clear the spectra.

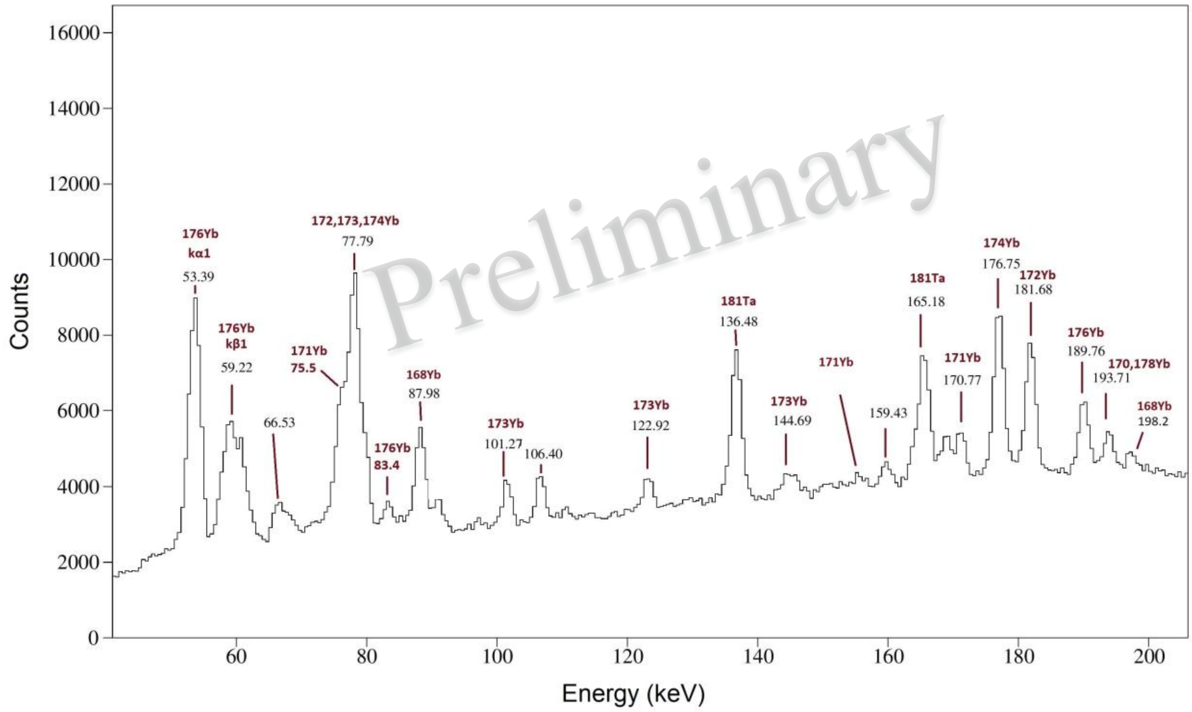

Figure 3. *Part of the γ-γ symmetric spectrum at 72 MeV beam energy.*

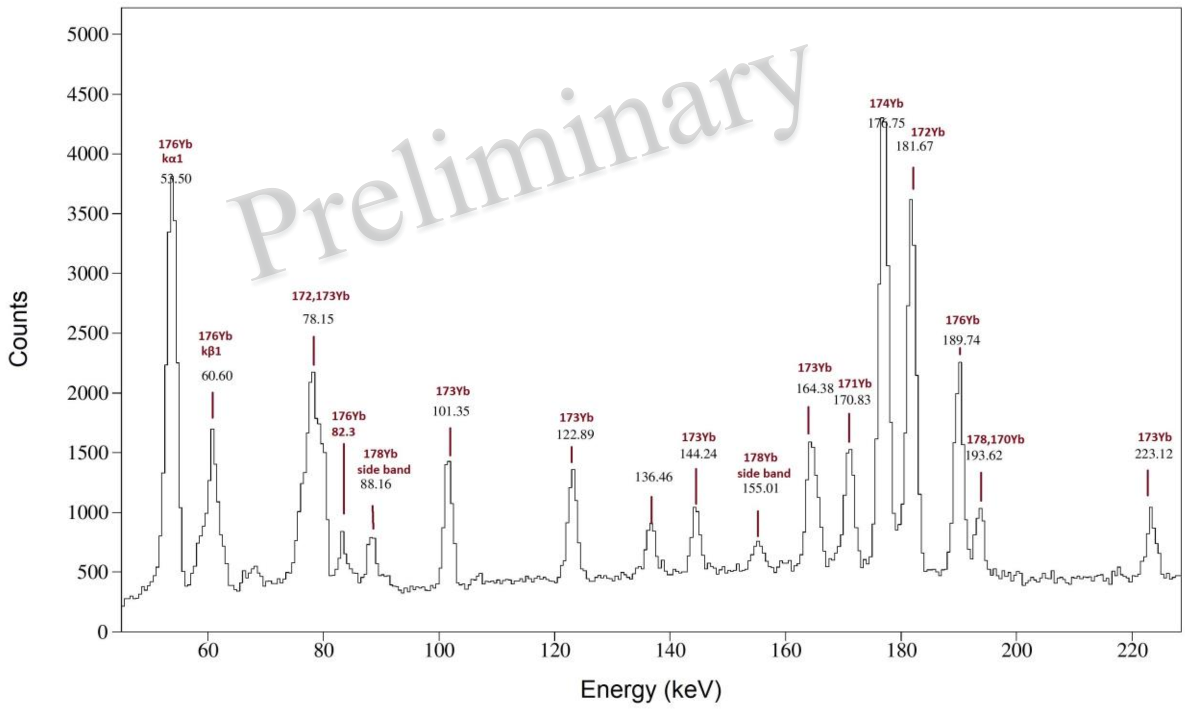

Figure 4. *Part of the γ-particle spectra at 72 MeV beam energy.*

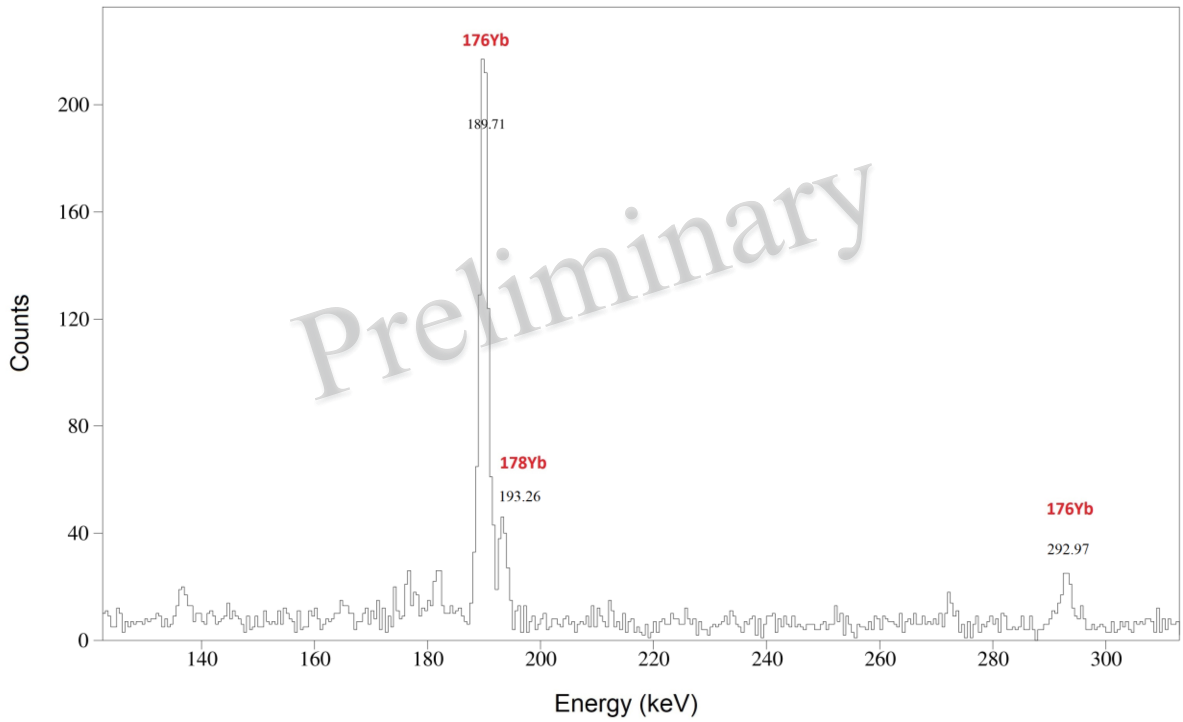

Figure 5. *Part of the γ-γ-particle spectra at 72 MeV beam energy with gate in the $2^+ \rightarrow 0^+$ transition at 84 keV.*

In Fig. 4, the γ-particle spectrum at 72 MeV beam energy is presented where only transitions from Yb isotopes were detected, without any background contamination. Fig. 5 shows the γ-γ-particle coincidence spectra as someone can focus on an exact gamma ray, for instance the 84 keV gamma transition of ^{178}Yb, where the ^{176}Yb cascade is also present. ^{170,176,178}Yb have very similar gamma ray energies for the 3 first transitions inside the ground state band (see Fig. 1). Due to the limited statistics involved, the lifetime measurement of the 2^+ state in ^{178}Yb becomes very difficult. Prior to constructing the γ-γ-ΔT coincidence spectra to measure the lifetime, a comparison of the HPGe and $LaBr_3$:Ce detectors is required to ensure the same energy peaks are visible in both plots. If peaks are observed for the excitation to and from this exact state, the measurement of the lifetime of this state becomes more certain (see Fig. 6).

As such, we can only propose a lower limit of the lifetime of the unknown 2_1^+ state in ^{178}Yb, $t_{1/2}$ = 0.42 (20) ns, by calculating the time difference between the delayed and the anti-delayed spectrum. With the present statistics at hand, an isotopic target of ^{176}Yb seems necessary to provide confidence to deduce this lifetime precisely, as much cleaner spectra will be available. Regardless, the method seems to work well in this case and a result for lifetime close to nanoseconds is acceptable for this nuclei considering known lifetimes of neighboring isotopes.

CONCLUSIONS

The experimental setup and preliminary results from the test run that took place in IFIN–HH, Romania are presented. A lower limit of the lifetime of the 2_1^+ state in ^{178}Yb by means of the 2n transfer reaction ^{176}Yb(^{18}O,^{16}O)^{178}Yb at energies 68-74 MeV using the ROSPHERE array was proposed. For ^{178,180}Yb, limited experimental data are available. Further investigation is required in this path to gain more information towards understanding the nuclear structure of these isotopes in the rare earth region as the neutron number increases.

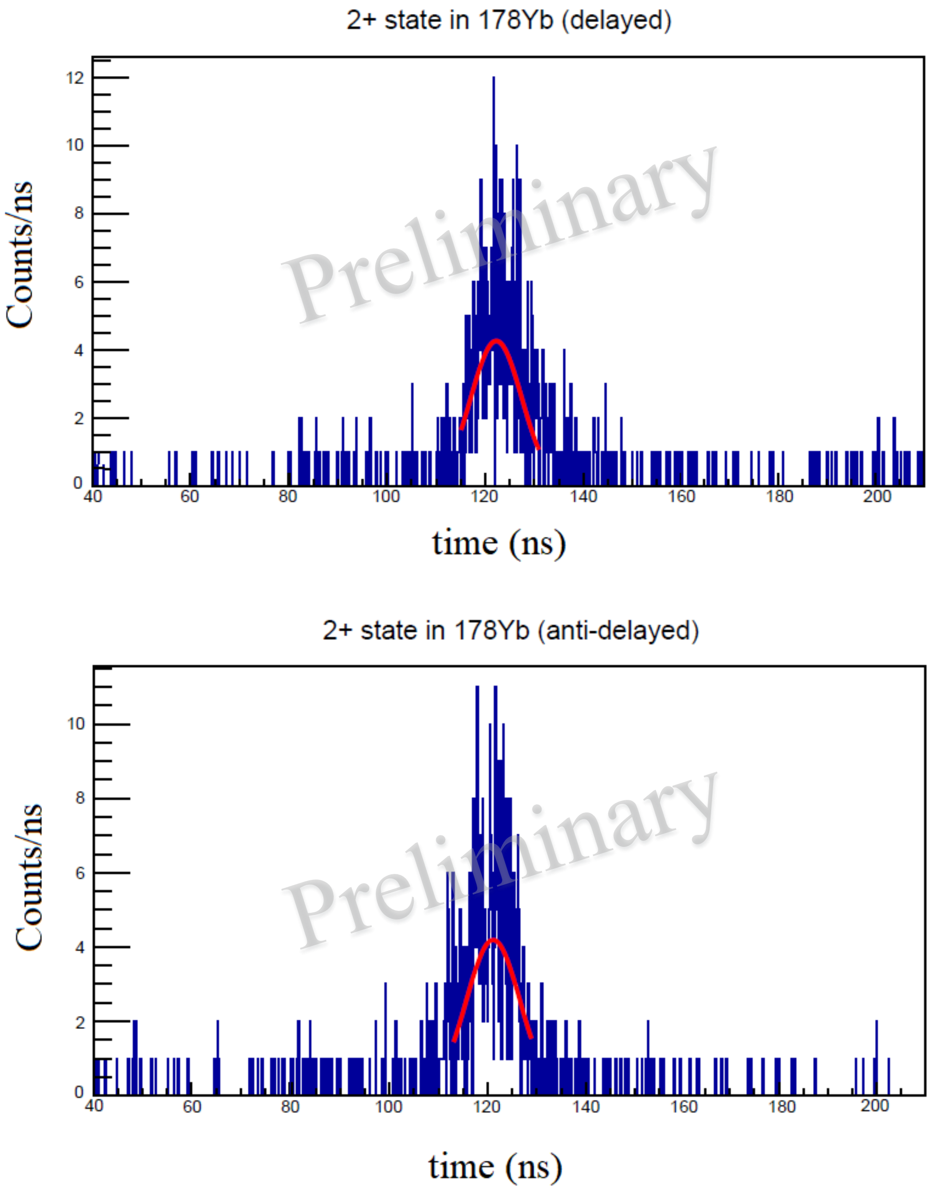

Figure 6. *γ-γ-ΔT spectra for the 2^+ state of the ^{178}Yb isotope.*

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