Journal of Physics: Conference Series **533** (2014) 012034 doi:10.1088/1742-6596/533/1/012034

Different collectivity in the two signatures of the $i_{13/2}$ stemming band in ^{167}Yb

P Petkov[1], K A Gladnishki[2], A Dewald[3], O Möller[4], I Deloncle[5], M Reese[4], C Fransen[3], M Hackstein[3], J Jolie[3], Th Pissulla[3], W Rother[3] and K O Zell[3]

[1]Bulgarian Academy of Sciences, Institute for Nuclear Research and Nuclear Energy, 1784 Sofia, Bulgaria
[2]Faculty of Physics, St. Kliment Ohridski University of Sofia, 1164 Sofia, Bulgaria
[3]Institut für Kernphysik, Universität zu Köln, D-50937 Köln, Germany
[4]Institut für Kernphysik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany
[5]CSNSM, IN2P3/CNRS and Université Paris-Sud, F-91405 Orsay Campus, France

E-mail: petkov@inrne.bas.bg

Abstract.
Six lifetimes have been determined in the $5/2^+[642]$ band from $\nu i_{13/2}$ parentage in ^{167}Yb by means of Recoil distance Doppler-shift (RDDS) measurements carried out at the Cologne FN tandem. The deduced transition strengths and the level scheme are reasonably described by Particle plus triaxial rotor model (PTRM) calculations except for the behavior of the quadrupole collectivity in the two signatures of the $5/2^+[642]$ band. In that band, the quadrupole collectivity of the favored signature is appreciably larger than this of the unfavored signature. The effect increases with increasing the spin. Naturally, the rigid PTRM cannot explain these features, but the structure of its wave functions suggests a possible solution. It is associated with the enhanced contribution of low-Ω orbitals from $\nu i_{13/2}$ parentage in the favored signature compared to the unfavored one. This could selectively increase the deformation of the favored signature band members and give rise to a dynamic shape coexistence taking place between the two signatures which needs quantitative explanation by future theoretical work.

The nucleus ^{167}Yb is well studied after numerous experimental and theoretical investigations in the past. The experimental findings are summarized in [1]. Very recently [2], the collectivity of the band structures was investigated at low (I$\sim$11/2$\hbar$) and medium (I$\leq$29/2$\hbar$) spins using Recoil distance Doppler-shift lifetime measurements. In Figure1, we present a partial level scheme of ^{167}Yb presenting the highly perturbed $5/2^+[642]$ band from an $i_{13/2}$ parentage. It consists of two signatures, α=1/2 (favored) and α=-1/2 (unfavored). In the literature, there are theoretical indications [3, 4] that different deformations could characterize the signature partners. Prior to the study described in reference [2], this effect was not established experimentally. In the present paper, we present shortly these experiment and data analysis, and concentrate on the collectivity of the $5/2^+[642]$ band. To populate excited states in ^{167}Yb, we used the reaction ^{154}Sm(^{18}O,5n). The beam, with an energy of E = 80 MeV, was provided by the FN tandem of the Institut für Kernphysik of the Cologne University. Details on the plunger experiment can be found in [2], here we remind only some general features of the setup. Deexciting γ-rays were recorded in coincidence by five large volume Germanium detectors positioned symmetrically at the backward angle of 143° and a Euroball cluster [5] detector positioned at 0° with respect to

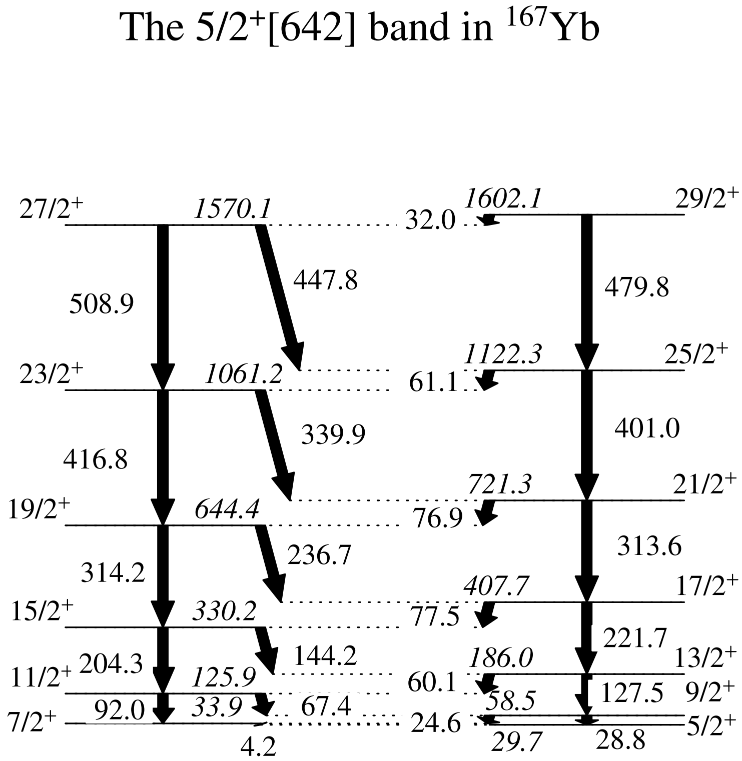

Figure 1. Partial level scheme of ^{167}Yb with the band investigated in the present work. The data are taken from reference [1].

the beam axis. The Germanium crystals were grouped in three rings, namely ring 0 (polar angle of 143° with respect to the beam axis), ring 1 (outer cluster segments at a polar angle of 29°) and ring 2 (central segment of the cluster at 0°). Data were taken for 21 target-to-stopper distances x in the range from 0.5 μm to 3001 μm. A total of about 8.0x10^9 unfolded double events were collected. After corrections for energy shifts and gain matching, the data were sorted into 4kx4k γ-γ coincidence matrices. Each matrix contains events where two γ-rays are registered by detectors belonging to a particular two-ring combination at a given distance. The normalization of the data taken at different target-to-stopper distances was performed using coincidence events corresponding to pairs of strong transitions in the yrast band of ^{168}Yb populated in the dominant 4n exit channel of the reaction ^{154}Sm+^{18}O (cf. reference [6]).

The RDDS method is a well established technique for the determination of picosecond lifetimes of excited nuclear states (see e.g. [7] and references therein). The data analyzing procedure used by us is described in references [8, 9]. It represents a concrete development within the framework of the Differential Decay Curve Method (DDCM) [10, 11]. In order to prepare spectra for further analysis, we used the procedure from reference [8], namely gates were set on the complete line shape (both shifted and unshifted components included) of the directly feeding transition and of the transition of interest, respectively. This approach solves the problem with the unknown (unobserved) feeding. In order to increase statistics, we summed up the spectra corresponding to gates set in the three independent rings.

In the procedure for the analysis, the background-subtracted line shapes corresponding to the transition of interest at all distances and the shifted decay curve

$$S_{ij}(t) = b_{ij} \int_0^t \lambda_i n_i(t')dt'. \qquad (1)$$

are fitted simultaneously. In eqs. 1, $n_i(t)$ is the population as function of time of the level of interest i, λ_i is its decay constant (the lifetime τ_i=$1/\lambda_i$) and b_{ij} is the branching ratio of the transition $i \to j$. The function $S_{ij}(t)$ is represented by second-order polynomials which are continuously interconnected at the borders of an arbitrarily chosen set of neighboring time-intervals. The fitting procedure consists in changing the borders of the time-intervals until the best reproduction of the spectra is achieved. More details can be found in references [8, 9] The final result for the lifetime for a particular ring combination is obtained by fitting a horizontal line through the points of the τ-curve (cf. references [10, 11]) within the region of sensitivity where the values are reliable. Then, these results are averaged while paying attention to possible systematic errors [9]. The derived lifetime values and the extracted reduced electromagnetic transition strengths are presented in [2].

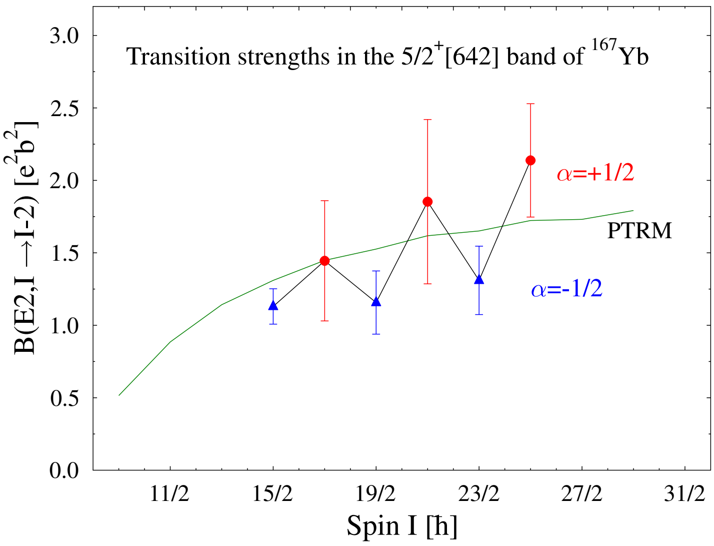

Figure 2. B(E2) transition strengths along the $5/2^+[642]$ band in ^{167}Yb compared to PTRM calculations. The solid line interconnecting the data points is to guide the eye.

Six lifetimes have been determined in both signature partners of the $5/2^+[642]$ band (three in each signature). Their knowledge allows to derive transition strengths which will be compared in the following to the results of PTRM calculations. The ytterbium nuclei in the A≈170 mass-region are believed to be well deformed and characterized by a stability against deformation changes induced by the rotation. Therefore till the back-banding region one may expect a reasonable description of the properties of ^{167}Yb by the PTRM. We used the version of the model described in reference [12] as implemented in the computer codes GAMPN, ASYRMO, PROBAMO and E1PROBAM presented in references [13, 14]. To describe the spectroscopic properties (excitation energies and transition strengths) of ^{167}Yb we varied the parameters ϵ, γ, ϵ_4 as well as $E(2_1^+)$ and the attenuation ζ of the Coriolis interaction. In this procedure, the best choice of the deformation parameters ϵ=0.26, γ=6°, ϵ_4=0.0 insured a reasonable reproduction of the positions of the band-heads observed at lower spin and of the intraband B(E2,I→I-2) values. The final results for the calculated level scheme were obtained by a fine tuning of the moments of inertia and the attenuation of the Coriolis interaction. In this way, the values $E(2_1^+)$=0.076 MeV and $\zeta(5/2^+[642])$=0.83 were obtained. An overall agreement between experiment and theory is observed, although the small spacings in the bottom of the $5/2^+[642]$ band are not completely reproduced (cf. [2]). In Figure2, the behavior of the B(E2) reduced transition probabilities within the $5/2^+[642]$ band is presented. The experimental quantities are compared to calculations within the PTRM. A striking feature of the data immediately emerges: the B(E2)'s in the two signatures of the band differ and this effect increases with increasing the spin. Although the relatively large error bars, the effect is systematic and very well seen at spins $23/2\hbar$ and $25/2\hbar$. At our knowledge, up to now there is not an experimental evidence for different deformation (collectivity) in the two signatures of a rotational band. In the literature, there are theoretical considerations predicting that the two signatures may have different quadrupole deformations (e.g. [3] for ^{79}Rb). For $\nu i_{13/2}$ based bands, this effect was studied systematically in [4] in relation with the signature splitting and predictions for the odd ytterbium isotopes can be found (Figure 4 in that work). The quadrupole deformation for ^{167}Yb is in agreement with the results from the present study, however, the unfavored signature is predicted to be a bit more deformed than the favored one, in disagreement with the experimental findings. It should be mentioned that the PTRM calculations of the present study predict some zig-zag behavior of the B(E2)'s, following the trend of the experiment, but the effect is very weak.

A possible way for explanation is suggested by the structure of the wave functions of the levels from the $5/2^+[642]$ band according to the PTRM calculations. The most interesting feature is the significant presence of the deformation-driving low-Ω orbitals ($1/2^+[660]$ and $3/2^+[651]$) in the wave functions of the favored signature, while their presence in the unfavored signature is much weaker. Thus, a calculation of the mean value of Ω for each level gives a nearly constant value $< \Omega > \sim 2.5\ \hbar$ in the unfavored signature. In the favored signature, $< \Omega >$ continuously decreases, and reaches about $2\ \hbar$ at spins 25/2 and 29/2. This involvement of low-Ω orbitals could lead dynamically to a larger deformation of the favored signature. In this sense, we could associate the observed behavior of the B(E2)'s in the $5/2^+[642]$ band of ^{167}Yb with a dynamic shape coexistence of the two signatures induced by the Coriolis interaction in the rotating nucleus. Of course, much more detailed theoretical considerations are needed to quantitatively explain the rotationally induced effect.

Acknowledgments

The authors are grateful to I.Ragnarsson and A.Gelberg for fruitful discussions. This work was supported by the Deutsche Forschung Gemeinschaft (DFG) within contracts No. Jo 391/8-1 and No. Jo 391/11-1. The authors are indebted for the support by the partnership agreement between the University of Cologne and University of Sofia financed by the DAAD. The authors are also grateful for the financial support of the Bulgarian Science Fund under contract DFNI-E 01/2.

References

[1] Baglin C M 2000 *Nuclear Data Sheets***90** 431
[2] Gladnishki K A *et al* 2013 *Nucl. Phys.* A **903** 1
[3] Bengtsson R, Nazarewicz W, Skeppstedt Ö and Wyss R 1991 *Nucl. Phys.* A **528** 215
[4] Mueller W F, Jensen H J, Reviol W, Riedinger L L, Yu C H, Zhang J Y, Nazarewicz W and Wyss R 1994 *Phys. Rev.* C **50** 1901
[5] Eberth J, Thomas H G, von Brentano P, Lieder R M, Jäger H M, Kämmerling H K, Berst M, Gutknecht D and Henck R 1996 *Nucl. Instr. Meth. Phys. Res.* A **369** 135
[6] Dewald A *et al Nucl. Phys.* A **545** 822
[7] Dewald D, Möller O and Petkov P 2012 *Prog. Part. Nucl. Phys.* **67** 786
[8] Gladnishki K A, Petkov P, Dewald A, Fransen C, Hackstein M, Jolie J, Pissulla Th, Rother W and Zell K O 2012 *Nucl. Phys.* A **877** 19
[9] Petkov P *et al* 2000 *Nucl. Phys.* A **674** 357
[10] Dewald A, Harissopulos S and von Brentano P 1989 *Z. Phys.* A **334** 163
[11] Böhm G, Dewald A, Petkov P and von Brentano P 1993 *Nucl. Instr. Meth. Phys. Res.* A **329** (248
[12] Larsson S E, Leander G and Ragnarsson I 1978 *Nucl. Phys.* A **307** 189
[13] Ragnarsson I and Semmes P B 1988 *Hyp. Int.* **43** 425
[14] Semmes P B, Computer manual, presented at Nuclear structure theory workshop, Oak Ridge, TN (August 5-16, 1991)