Eur. Phys. J. A **16**, 155–158 (2003)
DOI 10.1140/epja/i2002-10117-6

THE EUROPEAN PHYSICAL JOURNAL A

Short Note

First evidence for triaxial superdeformation in ^{161}Lu and ^{162}Lu

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Received: 18 October 2002 / Revised version: 15 November 2002 /
Published online: 4 February 2003 –
Communicated by D. Schwalm

Abstract. High-spin states in ^{161}Lu and ^{162}Lu have been investigated using the GASP γ-ray spectrometer array. Excited states in these nuclei have been populated through the ^{100}Mo(^{65}Cu, xn) reaction at a beam energy of 260 MeV. Four presumably triaxial superdeformed bands, three in ^{162}Lu and one in ^{161}Lu, have been observed. This is the first evidence for triaxial superdeformation in the two isotopes.

PACS. 21.10.-k Properties of nuclei; nuclear energy levels – 23.20.Lv Gamma transitions and level energies – 25.70.-z Low and intermediate energy heavy-ion reactions – 27.70.+q $150 \leq A \leq 189$

The nuclei around $N = 92$ and $Z = 72$ provide an opportunity to study superdeformed shapes for which a pronounced triaxiality ($\gamma \approx \pm 20°$) has been predicted theoretically [1–3]. In recent years, several rotational bands which may be associated with these shapes have been discovered in Lu and Hf isotopes [4–14]. In several cases the large deformation has been verified by lifetime measurements [4,10,13] and in one case, ^{163}Lu, the triaxiality has been proven by the discovery of the wobbling mode [15–17]. Wobbling is a rotational mode unique to a triaxial body. It had been predicted to occur in nuclei more than 25 years ago [18].

The theory has difficulties to predict the exact location of the shell gaps that are responsible for the triaxial superdeformed (TSD) minima in the total-energy surfaces of the nuclei in this mass region. Therefore, it is important to localize these shell gaps experimentally and to provide information on the position of the deformation-driving intruder orbitals.

In the present work, we show the results of a search for TSD structures in ^{161}Lu and ^{162}Lu which were predicted in the calculations. In previous work, normal-deformed energy level structures have been studied to high spins [19, 20], but no TSD bands have been reported. As shown in fig. 1, SD minima with positive and negative γ deformation ($\gamma \approx \pm 20°$) at high spin occur in total-energy surface calculations with the Ultimate Cranker (UC) computer code [3] based on a modified harmonic-oscillator potential. The triaxial minima are predicted for all combinations of parity and signature, and believed to have their origin in pronounced proton and neutron shell gaps combined with the deformation-driving effect of the proton $i_{13/2}$ intruder orbital [3,5]. The TSD configuration with positive γ deformation usually has lower energy than the one with negative γ.

A search for TSD structures in ^{161}Lu and ^{162}Lu was performed using the reaction ^{100}Mo(^{65}Cu, xn) at a beam

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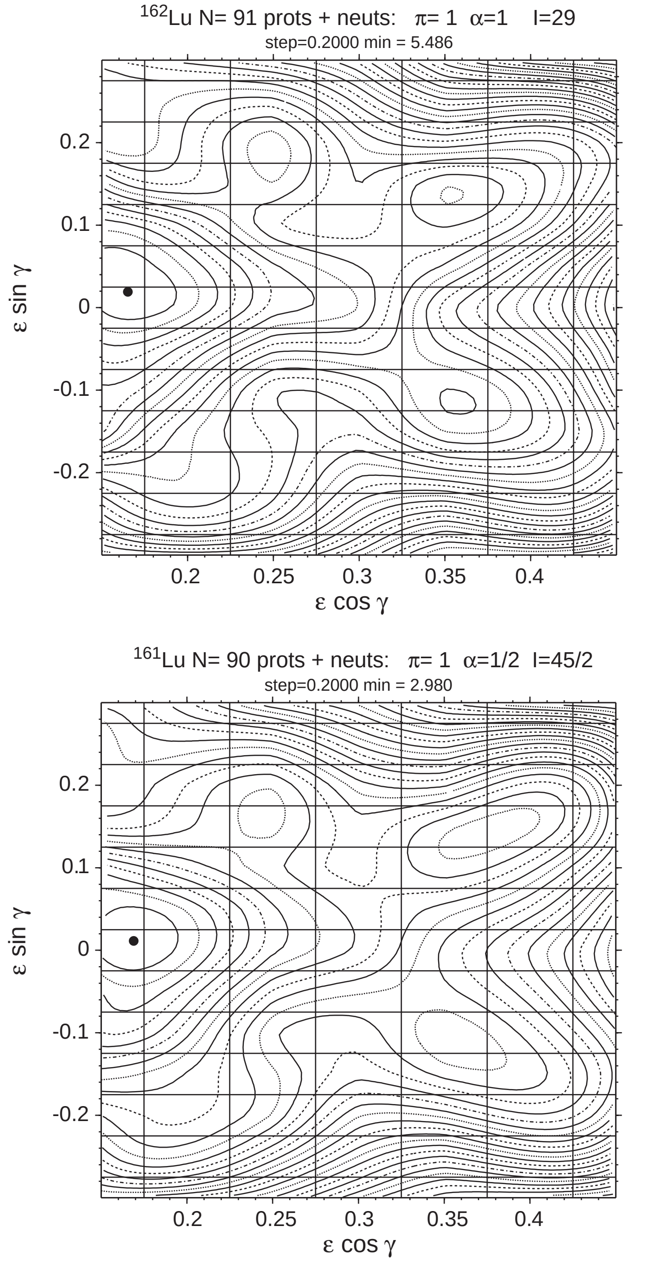

Fig. 1. Examples of potential-energy surfaces calculated with the Ultimate Cranker code [3] for the indicated configurations in ^{161,162}Lu.

energy of 260 MeV. The ^{65}Cu beam was provided by the Legnaro XTU tandem accelerator. The target consisted of a $600\,\mu$g/cm^2 thick self-supporting ^{100}Mo foil. The γ-rays were detected with the GASP spectrometer array consisting of 40 Compton-suppressed Ge detectors combined with an inner ball of 80 bismuth germanate (BGO) detectors. A total of $\sim 2.5 \cdot 10^9$ coincidence events were collected, requiring that two or more Ge detectors and eight or more BGO detectors of the inner ball showed a signal. The data contain information on high-spin states in ^{161,162}Lu, which are the main exit channels, as well as on several Yb and Tm isotopes.

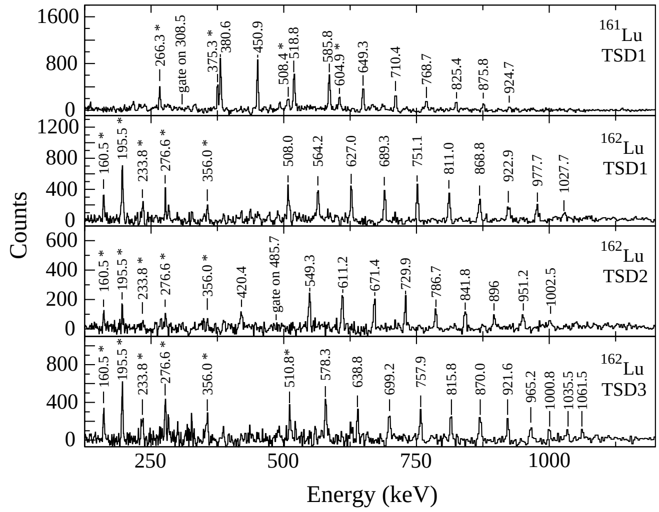

Fig. 2. Summed double-gated γ-ray coincidence spectra of the new TSD bands in ^{161}Lu and ^{162}Lu. For band TSD1 in ^{161}Lu and band TSD2 in ^{162}Lu one gate was set on the transition indicated in the spectra and the second gate was set on any of the other transitions of the bands. The spectra for TSD1 and TSD3 in ^{162}Lu were obtained by summing all double-gated spectra. Transitions belonging to the normal-deformed part of the level schemes are marked by asterisks.

In the off-line analysis two- and three-dimensional coincidence matrices were sorted and analysed with programs from the Radware package [21]. The analysis revealed four new bands, one in ^{161}Lu and three in ^{162}Lu, which show similar characteristics as the TSD bands in the heavier Lu isotopes. Figure 2 shows summed coincidence spectra for these four bands. The relative intensities of the bands are roughly estimated to be 1.4% for TSD1 in ^{161}Lu and 1.3%, 0.9% and 0.2% for TSD1, TSD2 and TSD3 in ^{162}Lu. Furthermore, directional correlation (DCO ratios) information was obtained by sorting two matrices, one with all detectors on one axis and the near-90° detectors on the other axis and one with all detectors *versus* the forward and backward detectors. The DCO ratios of the in-band transitions are compatible with stretched $E2$ multipolarity. The assignments of the bands to ^{161}Lu and ^{162}Lu are unambiguous due to the observation of known low-lying transitions in these isotopes in coincidence with the bands. However, no direct connections to the known normal-deformed (ND) states have been found. Thus, their spins, parities and excitation energies are not determined.

The new bands in ^{161}Lu and ^{162}Lu show great similarities to TSD bands in neighbouring ^{163}Lu and ^{164}Lu, respectively. Their dynamic moments of inertia, $J^{(2)}$, are similar to those in the heavier Lu isotopes [4–8,15–17]. In fig. 3 these values are compared to those of the strongest TSD bands in ^{163}Lu [16] and ^{164}Lu [6]. The similarity of the moments of inertia suggests that the new bands can also be associated with the potential-energy minimum at large deformation and $\gamma \approx \pm 20°$ (see fig. 1). However, a final proof has to come from lifetime measurements and

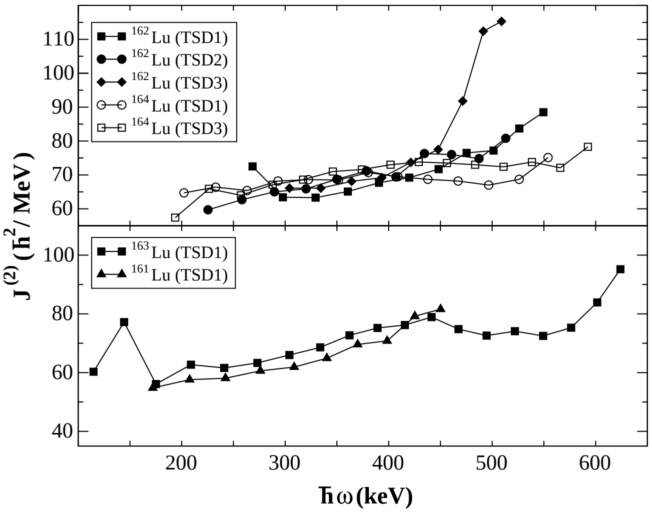

Fig. 3. Dynamic moments of inertia as a function of rotational frequency for TSD bands in $^{161\text{-}164}$Lu [6,16].

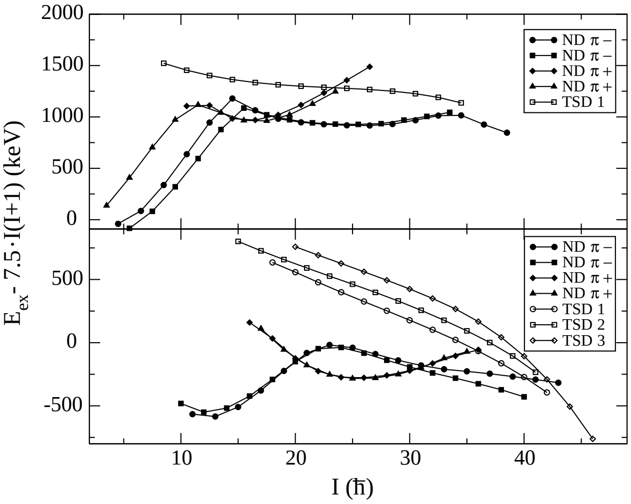

Fig. 4. Excitation energy, relative to a rigid rotational core, as a function of spin for the new TSD bands and several normal-deformed bands in ^{161}Lu (upper panel) and in ^{162}Lu (lower panel). The excitation energies and spins for the new TSD bands are estimates based on population intensities and on comparison to ^{163}Lu and ^{164}Lu.

from the observation of wobbling bands, the latter being the signature of triaxiality.

The new band TSD1 in ^{161}Lu is isospectral to TSD1 in ^{163}Lu [7,16]. Therefore, we may assume that the lowest observed γ ray of 308.5 keV is the $25/2^+ \rightarrow 21/2^+$ transition. TSD2 in ^{162}Lu is very similar to TSD3 in ^{164}Lu [6]. In this case, we assume that the 420.4 keV line corresponds to the $17^+ \rightarrow 15^+$ transition. Bands TSD1 and TSD3 in ^{162}Lu are similar in transition energy to TSD6 and TSD4 in ^{164}Lu [6], respectively, for which spin and parity have not been assigned.

Band TSD1 in ^{161}Lu decays, mainly at $I^\pi = (21/2^+)$, to negative-parity states and not by mixing with positive-parity states as it is the case in ^{163}Lu [7,16]. This is confirmed by the regular behaviour of $J^{(2)}$ at low spin, in contrast to the irregularities in ^{163}Lu caused by the mixing at $I^\pi = 21/2^+$ (see fig. 3). In the case of ^{162}Lu the three bands are in coincidence with the negative-parity ND states, which agrees with the decay of TSD3 in ^{164}Lu. It should be noted that the positive-parity ND band in ^{162}Lu [20] is of different structure than the one to which decay is observed from TSD1 in ^{164}Lu [6].

The resemblance of the TSD bands found in the present experiment to the previously known bands in ^{163,164}Lu is exploited to produce fig. 4 which shows an estimate of the excitation energies of the new bands and several ND bands in ^{161}Lu and ^{162}Lu, relative to a rigid rotational core, as a function of spin. As in the neighbouring isotopes [6,7,16], the excitation energies of the TSD bands relative to the ND structures is much smaller than found in the UC calculations. It has been suggested [6] that this may be due to an incorrect placement of the strongly deformation-driving proton $i_{13/2}$ intruder orbital in the $Z = 71$ isotopes in the calculations.

Triaxial superdeformation is now established experimentally in six Lu isotopes with mass numbers between 161 and 167 [4–9], but only in the three Hf isotopes ^{168}Hf, ^{170}Hf and ^{174}Hf [10–12]. In spite of various searches in the lighter Hf isotopes, no TSD band structures were found in these nuclei. In the Lu isotopes the TSD bands are generally populated more strongly than in the Hf isotopes. On the other hand, the calculations predict that the lighter Hf isotopes, in particular ^{164}Hf and ^{166}Hf, should show the deepest TSD energy minima in this mass region and, therefore, should be considered the best candidates to show TSD shapes. Apparently the UC calculations have difficulties to precisely predict the location of the TSD shell gaps. This is probably due to an insufficient knowledge of the model parameters that determine the position of the strongly deformation-driving orbitals $\pi i_{13/2}$, $\pi h_{9/2}$ and $\nu i_{13/2}$. The experimental information on the intensity of the TSD bands, which reflects their excitation energies relative to the ND structures in the nuclei of this mass region, may help to improve the mean-field calculations.

This work was supported by BMBF, Germany, contract no. 06 BN 907, by DFG, contract no. Hu 325/10, by the Danish Science Foundation and the EU, contract no. HPRI-CT-1999-000832, by the German Academic Exchange Service (DAAD) and by the A. von Humboldt foundation.

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