SEARCH FOR HYPERDEFORMATION IN LIGHT Xe NUCLEI*

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The ultimate search for hyperdeformation (HD) at high spins with the EUROBALL spectrometer was performed for ^{126}Ba as a hyper long (HLHD) experiment. The DIAMANT ancillary detector was used to tag γ-rays in coincidence with the emitted light charged particles. Using γ-energy correlation methods, the particle–xn-γ data have been analysed to search for hyperdeformed structures in the corresponding residual nuclei. Data in coincidence with one α particle indicate the presence of normal deformed collective bands up to very high spins and the possible occurrence of HD-like ridge structures in ^{122}Xe.

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1. Introduction

Under special conditions, atomic nuclei can possess very elongated, superdeformed (SD) shape at high angular momenta. The properties of the first experimentally observed discrete-line high spin SD band in ^{152}Dy [1], and those of the hundreds of SD bands, discovered since, in other mass regions [2], have been successfully interpreted in microscopic calculations by the appearance of SD-shell closures (see, *e.g.*, Ref. [3]) associated with a 2-nd minimum in the nuclear potential energy surface. These calculations also predicted the existence of hyperdeformation (HD), an even larger elongation, in some nuclei. In heavy nuclei the formation of HD shape may happen already at low spins, just before fission, which has recently been observed (see, *e.g.*, [4]). In medium-heavy nuclei, HD shapes are expected, however, to occur near the largest angular momenta which a nucleus could sustain preceding fission. As a consequence, the population of HD states is probably extremely weak and limited to a narrow spin range. Due to smaller barriers and a strong competition with fission, the HD rotational bands are expected to be shorter than seen for SD bands, and thereby also more difficult to find by search routines. It is, therefore, very difficult but challenging to find evidence for the existence of HD structures at high spins in the γ-ray continuum and, especially, to identify discrete-line HD bands.

The first search for the existence of HD shapes at high spins was made in the γ-energy correlation spectra of ^{152}Dy [5] and ^{147}Gd [6]. In both cases a (heavy-ion, proton–xn-γ)-type nuclear reaction was used, from which it was conjectured that charged-particle emission from the tip of HD nuclei may be enhanced relative to that from normal deformed nuclei. If so, tagging on charged particles may help much in the preferential selection of HD gammas. The follow-up experiments of this kind [7], and several others, using (heavy-ion, xn-γ)-type nuclear reactions, even under specially selected conditions, have not resulted in observing any discrete-line HD bands. However, we know today that the peaks in such bands will be ≈ 50 times weaker than the ridge intensities observed, and discussed in the following, pointing to a needed selectivity of $\leq 10^{-6}$, perhaps below the observation limits of EUROBALL and Gammasphere.

The four-week long ultimate HLHD experiment with EUROBALL [8] aimed at the collection of extremely high statistics in order to identify discrete-line HD transitions in the nucleus ^{126}Ba using (heavy-ion, xn)-type nuclear reaction. This nucleus has been selected on the basis of advanced liquid drop model calculations (LSD) [9], which show that Ba and Xe nuclei can undergo Jacobi transitions into stable hyperdeformed shapes above spin $70\,\hbar$, approaching the highest spins that nuclei could sustain in this mass region. Recent experimental data obtained with EUROBALL and Gammasphere showed, indeed, evidence of HD transitions in the continuum γ-ray spectra of ^{126}Ba and ^{126}Xe [10, 11].

In the HLHD experiment the calculated cross-section of the strongest charged-particle reaction channel, $(\alpha 2n)$, leading to ^{122}Xe was comparable with that of the xn channels (^{124}Ba). Therefore, a search for HD structures in the particle–xn channels was also attempted. The DIAMANT charged-particle ancillary detector array [12] was utilised to select the γ-rays in the particle–xn channels, and gave additional possibility to veto those particles in the xn database.

This contribution gives account of the first results obtained from the analysis of the particle–xn data of the HLHD experiment. The aim of the analysis, using γ-energy correlation methods, was two-fold: search for collective structures characteristic for HD shapes in Xe nuclei; try to find evidence for delayed α-emission, a possible sign for particle decay-out mode of the hyperdeformed band(s) of ^{126}Ba populated in the $2n$ reaction channel.

2. Experimental details and data analysis

To populate the highest-spin states in ^{126}Ba and nearby nuclei, the "cold" ^{64}Ni+^{64}Ni symmetric nuclear reaction was used at beam energies of 255 MeV and 261 MeV. Particle–γ^n and γ^n coincidences ($n \geq 3$) were detected by the EUROBALL-IV spectrometer (IReS, Strasbourg) and an upgraded version of the DIAMANT [12] ancillary detector array of 84 CsI(Tl) scintillation detectors covering $\approx 95\%$ of the full 4π solid angle. DIAMANT provided the energy, the type and a time reference signal for the light charged particles (protons and/or α's), detected in coincidence with γ-rays, using custom-made VXI particle discriminators [13]. The BGO InnerBall γ calorimeter was also utilised to measure the γ-multiplicity (Fold) and the total energy (SumEnergy) of the γ-ray cascades. By vetoing on the charged particles the selection of a clean "xn-γ" database was improved and the analysis as a function of Fold made more selective. The $\Delta E_\gamma = 52\,$keV of the ridge structures observed in the first experiment with Gammasphere was confirmed, and a fluctuation analysis became possible, which showed that the ridges consist of ≥ 10 rotational bands in ^{126}Ba [11, 14]. Surprisingly, the ridges are preferentially populated in the 261 MeV data in contrast to the 255 MeV data, where the ridges, if any, are extremely weak.

In the analysis presented here DIAMANT was used to select the "charged particle–xn-γ" coincidences, the particle–xn database, with the aim to trace if any sign of HD ridge structure exists or not in the γ-energy correlation spectra of the relevant nuclei. Fig. 1(a). shows a typical particle spectrum used for determining 2-dimensional gates for selecting γ-rays in coincidence with protons or α-particles. The main feature of the particle-gated total projection γ-ray spectra is a large E2-bump in the $E_\gamma = 1.2$–2.2 MeV quasi-continuum region, indicating an intense collectivity, especially in the 1α–xn and the 2α–xn channels (see. Fig. 1(b)).

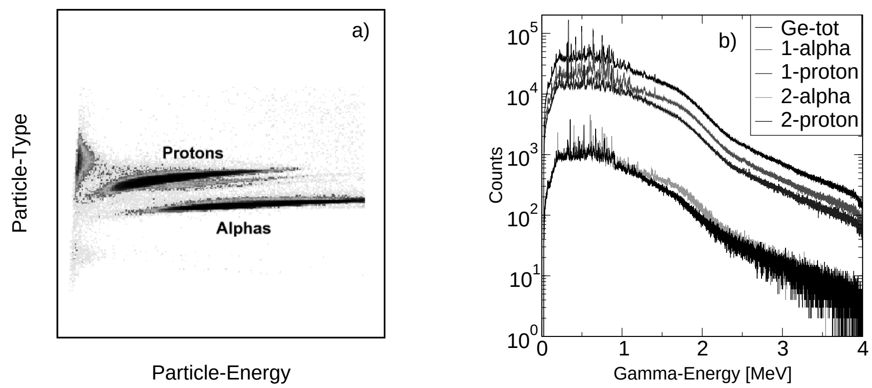

Fig. 1. (a) Particle-type *versus* energy spectrum used for determining particle gates for channel selection purposes. (b) Total projection Ge-spectra for the charged-particle channels; the order of legends corresponds to spectra from top to bottom.

To search for collective excitations in this data set, $E_{\gamma 1}$–$E_{\gamma 2}$ energy correlation spectra were created for the different exit channels ($1p$, $2p$, 1α, 2α, *etc.*), with different (high/low) gating conditions set on both the Fold and the SumEnergy. These spectra were unfolded for Compton scattering and then flattened by subtracting the remaining uncorrelated events using either the iterative or the COR background subtraction methods of Ref. [15]. Diagonal-cut spectra were created for those matrices which showed the presence of any ridge structure to extract the moment of inertia for the rotating nucleus from the measured distance between the ridges.

3. Results and discussion

The 261 MeV data have been analysed first as at this energy there is a higher chance to populate the narrow high-spin range where HD states may be populated (see discussion above [14]). The energy correlation matrices show the presence of well-developed normal deformed ridge structure for the 1α–xn channels, upto the spin range of 34–56$\hbar$, when high-Fold + high-SumEnergy selection is applied. Perpendicular cuts of 40 eV wide taken on this matrix also indicate the presence of a narrower ridge structure in the γ-energy range of 1400–1500 keV. To gain proper confidence for the origin of such HD-like collective structures a more selective analysis of the same data-set has been started using the Rotational Plane Mapping (RPM) technique [16], applying the equation $E_x + E_y - 2E_z = \delta = 8\,\mathrm{keV}$ to produce (E_x, E_y) 2-dimensional spectra, which in principle enhance the ridge structures relative to the background by a factor of 5.

Parts of the very promising results are shown as perpendicular cuts in Fig. 2 for the α–xn reaction (right panel) as compared to similar cuts obtained for the $2n$ evaporation leading to ^{126}Ba (left panel) [10,14]. It should be noted that the $2n$ results have been improved by subtracting similar spectra from the 255 MeV data-set, showing the high selectivity to the bombarding energy.

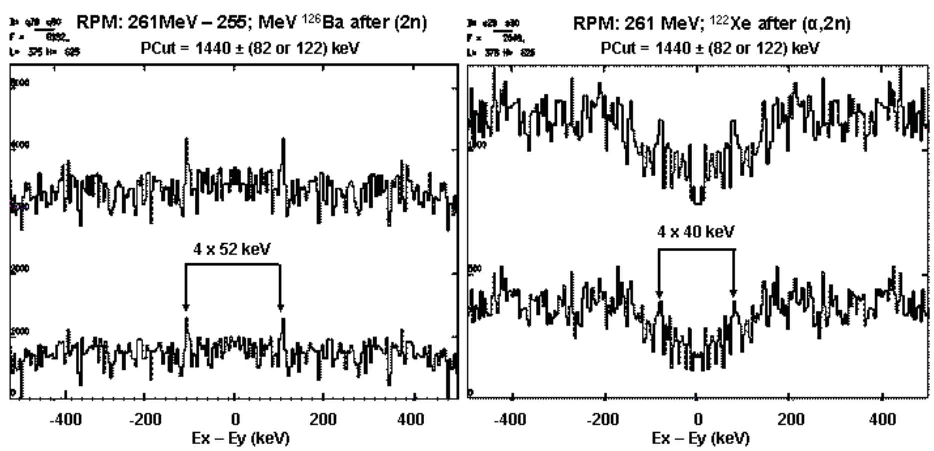

Fig. 2. Right: First results for the HD ridge structures observed by the RPM technique in coincidence with α-particles, presumably in ^{122}Xe as discussed in the text. Left: Similar results, shown for comparison, obtained by $2n$ reaction going to ^{126}Ba. The lower and upper spectra in both panels correspond to perpendicular cuts of $(E_x+E_y)/2 = 1440\pm 82\,\mathrm{keV}$, and $(E_x+E_y)/2 = 1440\pm 122\,\mathrm{keV}$, respectively.

A pair of peaks with $\Delta E_\gamma \approx 40\,\text{keV}$ separation is clearly visible in the present data, which most probably corresponds to a HD ridge structure. The large difference in the ridge separations for the two cases, $\Delta E_\gamma \approx 40\,\text{keV}$ for the α–xn case, in contrast to $\Delta E_\gamma \approx 52\,\text{keV}$ for ^{126}Ba, probably excludes that the newly observed ridge is related to delayed α-emission of the ^{126}Ba HD band(s) (for more details see. Fig. 5 and related text in Ref. [10]).

This result could, therefore, be interpreted as evidence for HD structures in Xe nuclei, most probably in ^{122}Xe. Although this would be in accordance with experimental observations [11], and with LSD and Ultimate Cranking predictions [9], further analysis is necessary to achieve a firm confirmation.

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