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Abstract

A superdeformed band has been observed in the ^{147}Tb nucleus which was produced with the reaction ^{100}Mo(^{51}V,4n)^{147}Tb at a bombarding energy of 230 MeV. The band configuration is assigned as $\pi 6^3 \nu 7^1$ with a total parity and signature of $(\pi, \alpha) = (-, +1/2)$.

27.60.+j, 23.20.Lv, 21.10.Re, 21.60.Ev

Stable nuclear shapes are often related to the existence of shell gaps, with superdeformed shapes being no exception. The systematic study of the gadolinium isotopes illustrated how the phenomenon of superdeformation may be related to the presence of intruder orbitals and shell gaps [1]. The present study begins to establish a link between superdeformation in ^{145}Tb and superdeformation in ^{150,151}Tb. Since the proton configuration of the former is $\pi 6^1 \otimes [404]^2_{9/2^+}$ [2] and that of the latter is $\pi 6^3$ [3,4], a change must take place somewhere along the series (such a change does not occur in the gadolinium chain). The systematics of particle configurations in the terbium isotopes are expanded by studying the properties of a newly discovered superdeformed band in the nucleus ^{147}Tb.

The experiment was performed at the Legnaro National Laboratory with the GASP spectrometer [5] and the charged-particle detector ISIS developed by a Padova-Legnaro collaboration. Gamma rays were detected in the GASP spectrometer, which consists of an array of 40 large-volume Compton-suppressed HPGe detectors and of an inner ball of 80 BGO crystals. The ISIS silicon ball is made of 40 ΔE-E telescopes (130 μm and 1000 μm thick respectively) covering a geometrical solid angle of $\sim$ 90% of 4π. The reaction was ^{51}V on ^{100}Mo at 230 MeV producing ^{146}Tb/^{147}Tb via the 5n/4n evaporation channels. The target consisted of two thin foils of 0.5 mg/cm^2 of ^{100}Mo. Approximately 10^9 γ-γ-γ Ge coincidence events were collected in eight days of beam time.

In the off-line analysis, events were selected with the conditions that no charged particles were detected in ISIS and that at least three suppressed HPGe detectors and ten detectors of the inner ball fired in coincidence. Techniques to search γ-γ-γ data sets for regularly spaced bands [6] and computer-assisted data analysis techniques to build level schemes [7] were used. Known superdeformed bands in ^{146}Gd [8], ^{147}Gd [1], and ^{143}Eu [9] were observed as well as a new superdeformed band consisting of 9 transitions with an average spacing of $\sim$ 57 keV. The new band was also observed in an analysis of two-fold coincidence events. This band was assigned to an xn channel because its strength was greater than any of the known bands of the charged particle channels; futhermore, it was tentatively assigned to either the 4n or 5n channel, corresponding to ^{146}Tb or ^{147}Tb, respectively. The entry conditions for other xn channels were not suitable for significantly populating superdeformed bands [1,10]. No other new superdeformed bands were found.

To assign the new band to either ^{146}Tb or ^{147}Tb, a second set of experiments was performed in which the two nuclei were studied with the reactions ^{113}Cd(^{37}Cl,4n)^{146}Tb and ^{114}Cd(^{37}Cl,4n)^{147}Tb at bombarding energies of 179 and 176 MeV, respectively. The ^{37}Cl beam was provided by the Tandem Accelerator Superconducting Cyclotron (TASCC) facility at the Chalk River Laboratories. The ^{113}Cd and ^{114}Cd targets each consisted of stacks of two thin foils $\sim$600 μg/cm^2, and γ rays were detected with the 8π spectrometer [11,12]. The 8π spectrometer data sets provided information regarding the K distributions (where K is the number of BGO elements that fired) which are sensitive to the reaction channel. The identification of a set of mutually coincident γ rays belonging to ^{146}Tb was then possible; the transitions were 390, 591, 706, and 818 keV (and have not been identified prior to this study). Also, a set of mutually coincident γ rays belonging to ^{147}Tb [13] was confirmed; namely 405, 697, 772, and 1266 keV. Gate lists were formed with the four γ rays associated with ^{146}Tb and with those associated with ^{147}Tb.

In replaying the particle-vetoed (mainly xn) GASP data, cuts of $K > 10$ and $K > 20$ were made. With the appropriate gate lists given above, γ-ray spectra were obtained for the most intensely populated structures in ^{146}Tb and ^{147}Tb by summing all combinations of the two-dimensional energy windows set on three-fold coincidence events. The intensities of the 818 keV line in ^{147}Tb and of the 697 keV line in ^{146}Tb were measured. The intensity of the new superdeformed band, relative to the 818 keV line in ^{146}Tb, was found to increase by a factor of about 5 between the data sets corresponding to the cuts $K > 10$ and $K > 20$. Relative to the 697 keV line in ^{147}Tb, the superdeformed band intensity was found to be independent of the K-cut. Given that K distributions for normal-deformed and superdeformed states are very similar [1], the ratio of the superdeformed band intensity in a given final nucleus relative to normal-deformed states in that same nucleus should be nearly independent of the K-cut. Therefore, the new band was assigned to the ^{147}Tb nucleus. A γ-ray spectrum associated with the new band is shown in Fig. 1. The intensity of the band was determined to be approximately 0.4% relative to the 4n channel. In comparison, optimum values typically measured for other yrast superdeformed bands in the $A \sim 150$ mass region are about 1%.

Total routhian surface (TRS) calculations were performed for ^{147}Tb and particle configurations were studied. The TRS for the $(\pi, \alpha) = (-, +1/2)$ configurations in ^{147}Tb is shown in the upper panel of Fig. 2. In these calculations, neutron and proton configurations were fixed to $(\pi, \alpha) = (-, 0)$ and $(\pi, \alpha) = (+, +1/2)$, respectively. Evidence of a superdeformed minimum located at $(\beta_2, \beta_4, \gamma) = (0.54, 0.07, 2.3°)$ is clear. Shown in the lower panel of Fig. 2 is the proton single-particle routhian for ^{147}Tb generated from Cranked Shell Model (CSM) calculations with a Woods-Saxon potential, the deformation parameters being fixed to those of the minimum seen in the TRS. The proton single-particle routhians suggest that, for the yrast configuration, the 6_3 intruder orbital should be occupied in the feeding region above $\hbar\omega \sim 0.5$ MeV. Therefore, the proton intruder configuration of ^{147}Tb may be assumed to be $\pi 6^3$, which means that the first three proton intruder orbitals $N = 6$ are occupied.

To assign the neutron configuration of the ^{147}Tb superdeformed band we consider the $\Im^{(2)}$ moment of inertia. The $\Im^{(2)}$ moments of inertia calculated from γ-ray transitions of superdeformed bands in ^{146}Gd [8] and ^{147}Tb are shown in Fig. 3. The peak in the $\Im^{(2)}$ of ^{146}Gd(a), due to the crossing of two $N = 6$ neutron orbitals [1], is not observed for either ^{146}Gd(b) or ^{147}Tb. Therefore, the neutron intruder configuration of ^{147}Tb is most likely the same as that of ^{146}Gd(b) and the band configuration is assigned as $\pi 6^3 \nu 7^1$ with a total parity and signature of $(\pi, \alpha) = (-, +1/2)$. The signature partner of the new band, corresponding to the neutron configuration of ^{146}Gd(a), should be populated with similar intensity but was not discovered in the present work.

In summary, a new superdeformed band has been found and assigned to the nucleus ^{147}Tb; it is the first superdeformed band to have been found in ^{147}Tb. The proton intruder configuration is suggested to be $\pi 6^3$, like that of the heavier terbium isotopes and unlike that of ^{145}Tb. Effective alignment calculations suggest that the neutron intruder configuration of ^{147}Tb is probably $\nu 7^1$ with a total parity and signature of $(\pi, \alpha) = (-, +1/2)$.

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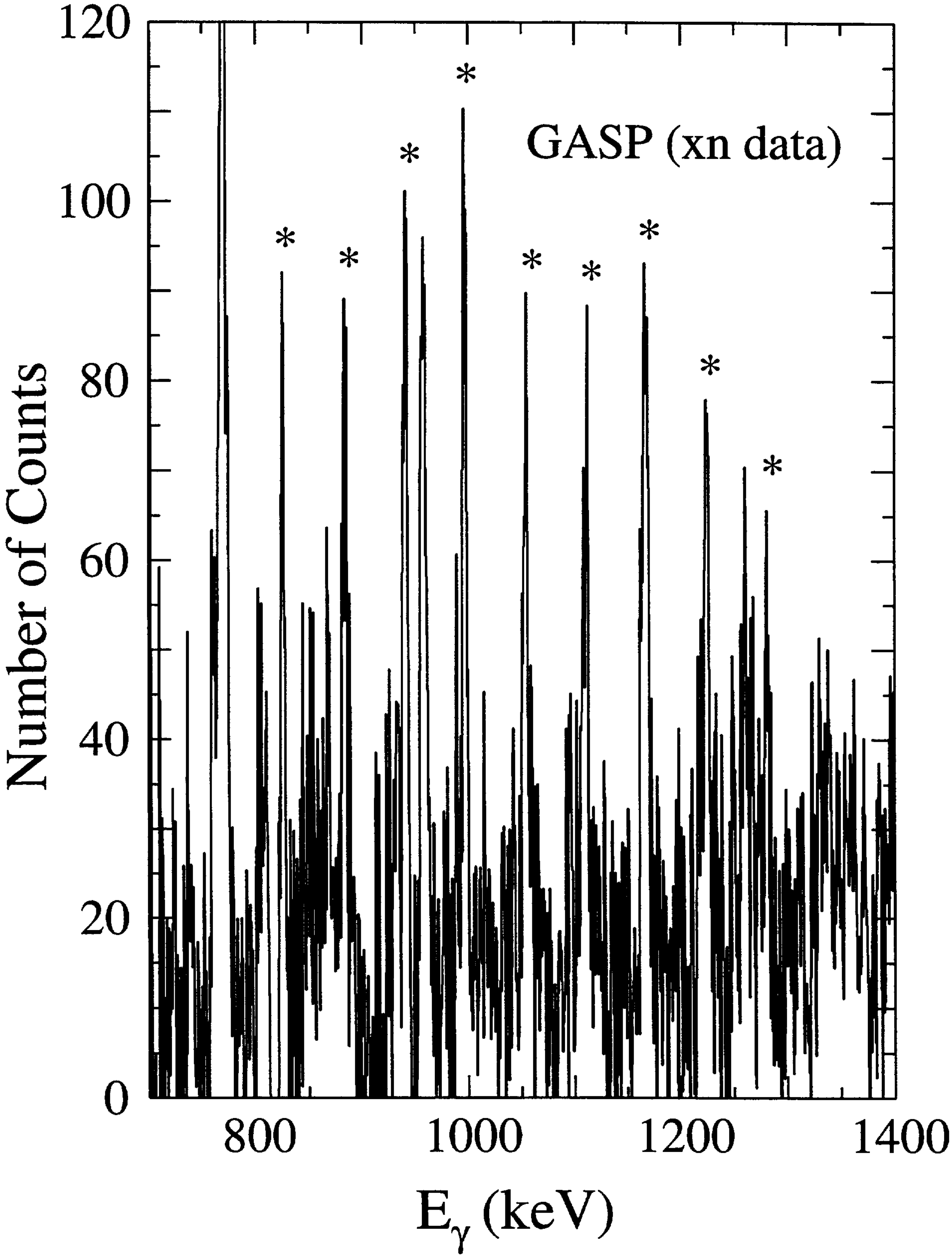
FIGURES

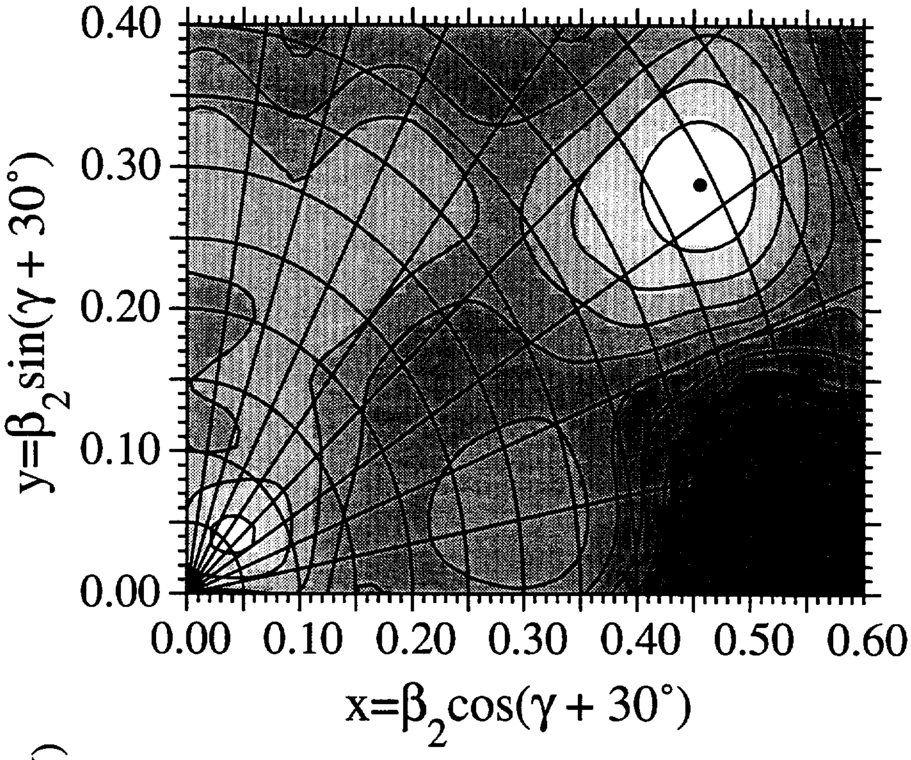
FIG. 1. Gamma-ray spectrum of the superdeformed band that has been assigned to ^{147}Tb. The spectrum was obtained by summing all combinations of two-dimensional energy windows set on three-fold coincidence events. A small fraction of the single-gated spectrum has been used for the background subtraction. The asterisks correspond to the superdeformed band members at 826, 884, 941, 998, 1055, 1111, 1167, 1224, and 1281 keV.

FIG. 2. Upper panel: total routhian surface (TRS) for the $(\pi, \alpha) = (-, +1/2)$ configuration in ^{147}Tb. The superdeformed minimum is located at $(\beta_2, \beta_4, \gamma) = (0.54, 0.07, 2.3°)$. Lower panel: proton single-particle routhian for ^{147}Tb generated from Cranked Shell Model (CSM) calculations based on the Woods-Saxon potential. Solid lines correspond to parity signature $(\pi, \alpha) = (+, +1/2)$, dotted lines to $(+, -1/2)$, dashed lines to $(-, -1/2)$, and dot-dashed lines to $(-, +1/2)$. Intruder orbitals and particle number that correspond to the energy gap have been labeled.

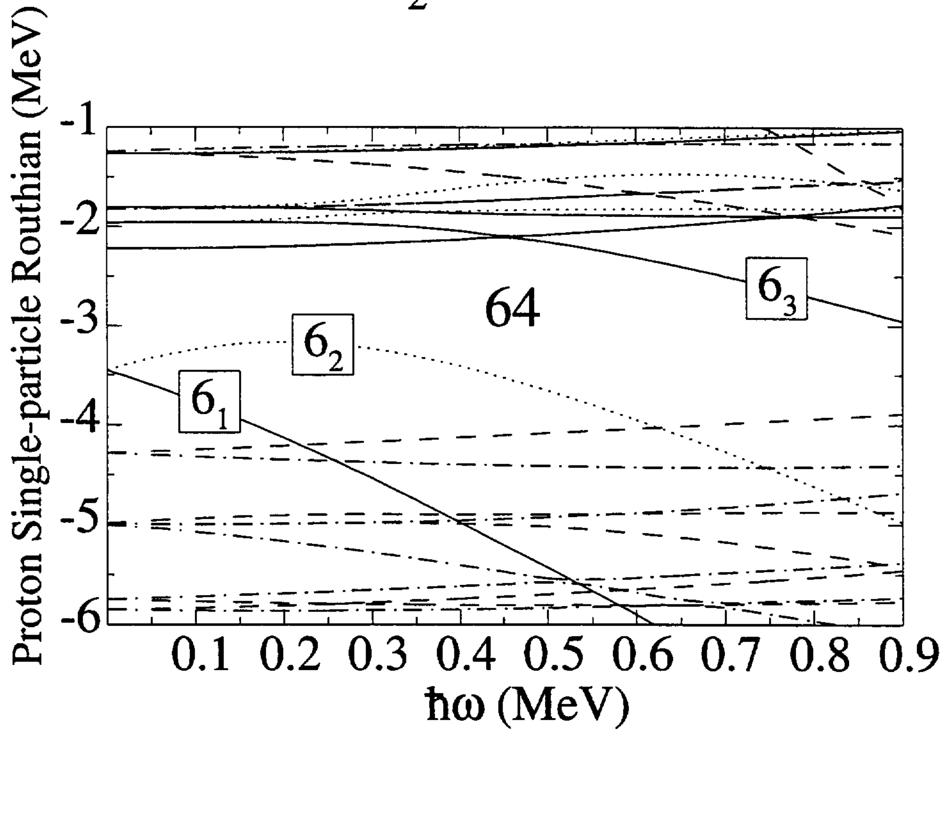
FIG. 3. Expermental $\Im^{(2)}$ moments of inertia for ^{146}Gd(a), ^{146}Gd(b), and ^{147}Tb.



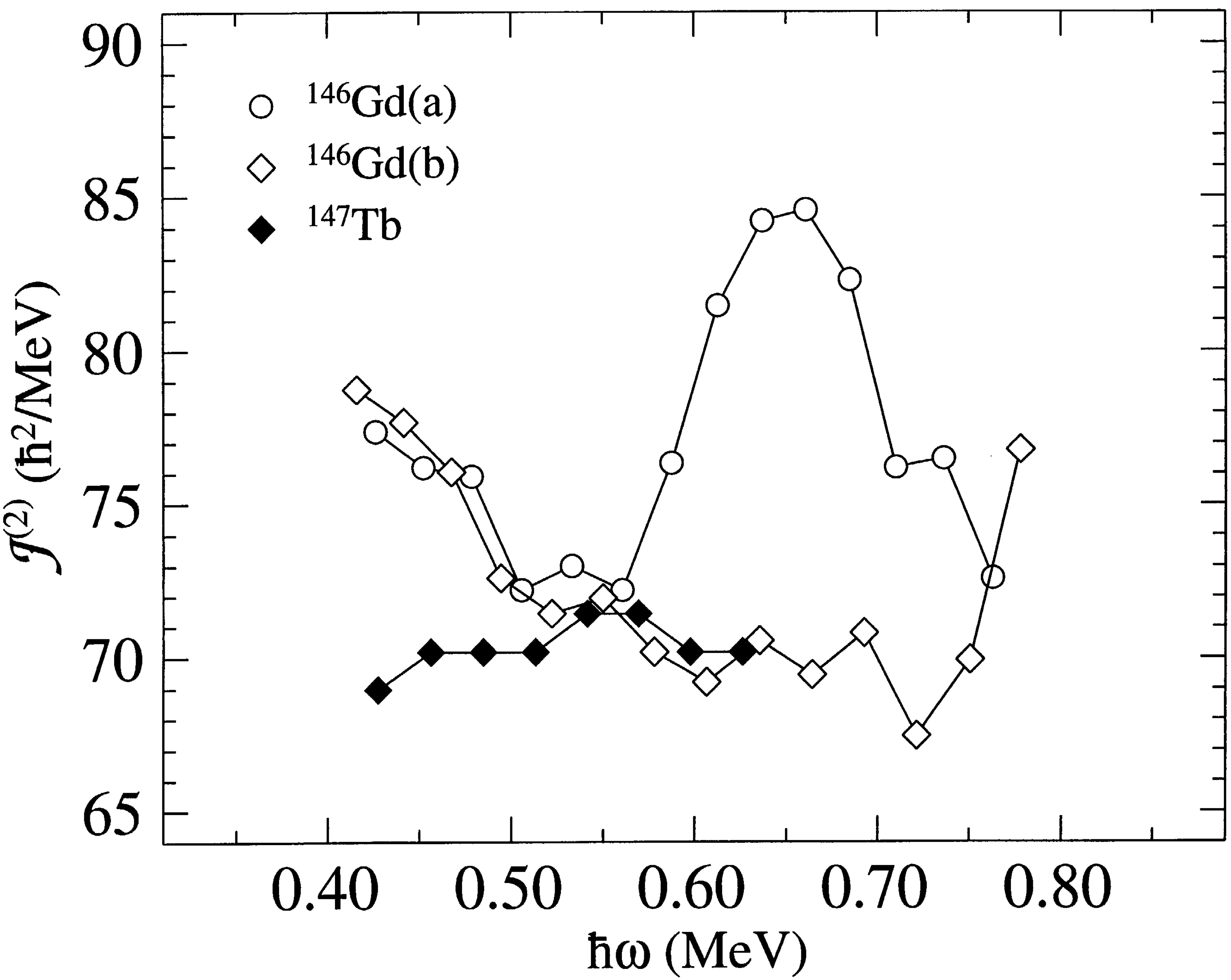
GASP (xn data)
Number of Counts
0
20
40
60
80
100
120
800
1000
1200
1400
E_γ (keV)



0.40
0.30
0.20
0.10
0.00
y=β2sin(γ + 30°)
0.00 0.10 0.20 0.30 0.40 0.50 0.60
x=β2cos(γ + 30°)



Proton Single-particle Routhian (MeV)
-1
-2
-3
-4
-5
-6
64
61
62
63
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
ħω (MeV)



90
85
80
75
70
65
146Gd(a)
146Gd(b)
147Tb
J(2) (ħ2/MeV)
0.40
0.50
0.60
0.70
0.80
ħω (MeV)