ガンマ線直線偏光測定による奇奇核の斜軸回転モードの研究

著者	小松原 哲郎
著者別名	Komatsubara Tetsuro
発行年	2000
URL	http://hdl.handle.net/2241/451

8。発表論文（代表３編）

Tandem Accelerator Center University of Tsukuba. Annual Report 1998
UTTAC-67 p.62-64(1999)

1.4 Development of gamma-ray linear polarimeter

T. Komatsubara. H. Ishiyama. T. Shizuma and K. Furuno

A measurement of linear polarization of gamma rays is crucial for parity assignment which provides important information about the configuration of single-particle orbital and/or collective motion in the nuclear structure. A scattering direction of Compton scattering contains an information of the linear polarization of the gamma rays. There are several reports[1-7] on the measurement of linear polarization by use of the Compton scattering with germanium detectors. In this report, a newly designed five-segmented germanium detector for the Tsukuba crystal ball system will be described.

In order to detect positions of the photon interactions inside of a single germanium crystal. the outer cathode is divided into five segments. Schematic view of the detector is shown in Fig. 1. The outer p-type ion-implanted contact of the crystal is longitudinally split in four segments and one circular segment on the front side. The diameter of the center segment is 35 mm. The outer diameter and length of the germanium crystal are 58 and 63 mm. respectively. An inner lithium diffused cathode is 10 mm diameter and 49 mm long. The high-purity germanium detector was produced by EURISYS MEASURES as the N-type coaxial detector. The characteristics are listed in Table 1.

The segmented anodes provide position signals of photon interactions. The total energy of an incident photon can be obtained from a sum signal of all segments by use of the inner cathode signal. The energy resolution and the relative efficiency at 1.3 MeV gamma-ray were measured to be 2.1 keV and 35%, respectively, at the distance of 25 cm from a ^{60}Co standard source. (The relative efficiency is a factor divided by 1.2×10^{-3} which is known as efficiency of 3in × 3in NaI scintillation counter.) A bias voltage of 3000 volts is applied to the inner anode. so that the total energy signal is ac coupled. The five individual anode signals are dc coupled.

In order to estimate sensitivity and efficiency for the linear polarization measurement. the cross section of Compton scattering is calculated. The differential cross section depends on the photon energy. the scattering angle θ. and the directions of electric vectors. It is given by the following Klein-Nishina's formula:

$$\frac{d\sigma}{d\Omega} = r_0^2 \left(\frac{\nu}{\nu_0}\right)^2 \left((\mathbf{e}_0 \cdot \mathbf{e}^*)^2 + \frac{(\nu_0 - \nu)^2}{4\nu\nu_0}\right).$$

with

$$h\nu = \frac{h\nu_0}{1 + \frac{h\nu_0}{m_0 c^2}(1 - \cos\theta)}.$$

where $(\mathbf{e}_0 \cdot \mathbf{e}^*)$ denotes a scalar product of the two electric vectors for the initial and scattered photons. The classical radius of electron is denoted by r_0. Frequencies of initial and scattered photons are denoted by ν_0 and ν, respectively. Total scattering cross section is sum of two components which are parallel and perpendicular to the scattering plane. They can be calculated by changing the vector $\mathbf{e}^*$.

When we define ϕ as an angle between initial electric vector and scattering plane, the cross section of the Compton scattering reaches the minimum and maximum at $\phi = 0°$ and $90°$, respectively. Ratios of the minimum and maximum values are plotted in Fig. 2 as a function of scattering angle θ for several photon energies. For the linear polarization measurements, the most sensitive angle is around $\theta = 90°$.

For more realistic estimation, a Monte-Carlo calculation has been done. In this calculation, cross sections of photo-electric effect are taken from reference 8. The volume of the center segment is assumed to be cylindrical shape of 35 mm in diameter and 14 mm thick. The initial gamma rays are emitted to z direction possessing linearly polarized electric vector in the direction of x axis. As the results of the calculation, ratios, sensitivities and efficiencies are shown in Fig. 3. The ratio and sensitivity are defined by

$$\text{ratio} = \frac{Y_y}{Y_x}$$

$$\text{sensitivity} = \frac{Y_y - Y_x}{Y_y + Y_x}$$

where Y_x and Y_y denote intensities of full energy peaks scattered to x and y directions, respectively. The efficiency is a ratio which is the sum of Y_x and Y_y divided by initial photon number entering to the detector through the collimator. In this figure, results for the five-segmented detector are compared to those for four-segmented type.

References

[1] Ch. Droste, et al., Nucl. Instr. and Meth. A378 (1996) 518-525

[2] L.M. Garcia-Raffi, et al., Nucl. Instr. and Meth. A359 (1995) 628-631

[3] A. von der Werth, et al., Nucl. Instr. and Meth. A357 (1995) 458-466

[4] P.M. Jones, et al., Nucl. Instr. and Meth. A362 (1995) 556-560

[5] J. Simpson, et al., Nucl. Instr. and Meth. 204 (1983) 463-469

[6] T. Aoki, et al., Nucl. Instr. and Meth. 128 (1975) 53-60

[7] T. Aoki, et al., Nucl. Instr. and Meth. 196 (1982) 421
[8] E. Strom et al., Nuclear Data Tables, Vol.7, (1970) 565

Type		N-type high-purity germanium
Crystal	diameter	ϕ58 mm
	length	63 mm
	dead layer	$\leq$ 0.5 μm
Outer anode		5 segmented
	dia. of center seg.	ϕ35 mm
Inner cathode	diameter	ϕ10 mm
	length	49 mm
End cap	Aluminium	0.75 mm thick
	distance to crystal	10 mm
Collimator (BGO-ACS)	diameter	ϕ 41.2 mm
	distance from src.	130 mm
	opening angle	$\theta_{1/2}$ = 9 degree
Reserver	volume	1.0 litter
	holding time	15 hours
Resolution	total	2.1 keV at 1.3 MeV
	individual	2.2 $\sim$ 4.0 keV
Efficiency	total	35 %
	individual	1.7 $\sim$ 3.9 %
High voltage		+ 3000 V
Pre-amp.	number	6
	type	PSC 821D

Table 1 Specification of the present five-segmented germanium detector

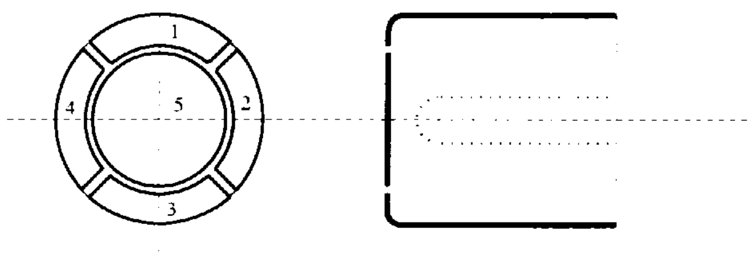

Fig.1 Schematic view of the five-segmented germanium detector.

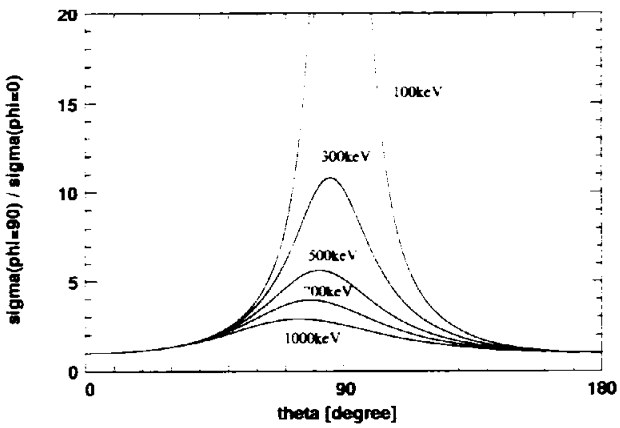

Fig.2 Ratio of Compton scattering cross sections of $\sigma(o = 90°)/\sigma(o = 0°)$, where o is an angle between electric vector of initial photon and scattering plane.

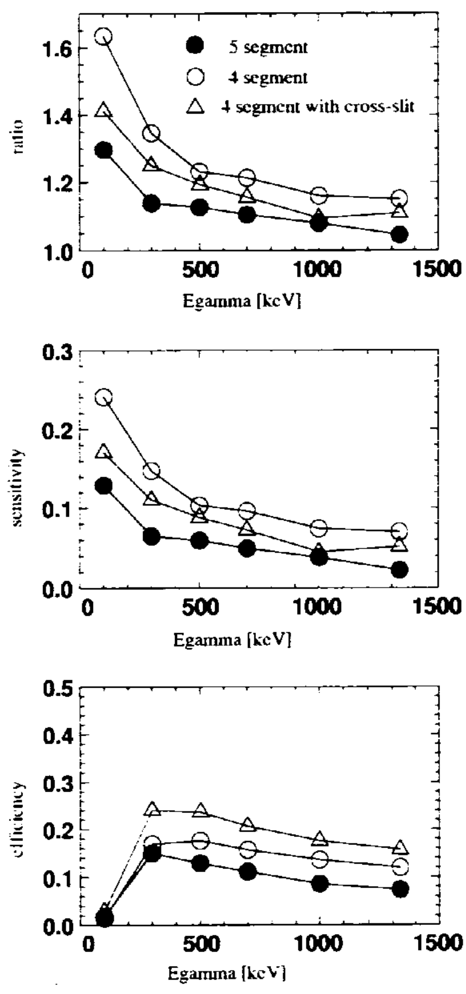

Fig.3 Results of Monte-Carlo simulations. Closed circles show the results for the five-segmented detector. Open circles are for four-segmented ones. Triangles are results for a four-segmented detector with cross-shape narrow-collimator of 10 mm width.

Tandem Accelerator Center University of Tsukuba. Annual Report 1997
UTTAC-66 p.9-12(1999)

1.2 Test experiments of gamma-ray linear polarimeter

T. Komatsubara, H. Ishiyama, Y. Sasaki, T. Jumatu, T. Shizuma and K. Furuno

In order to evaluate performances of a five-segmented germanium detector as a linear polarimeter for gamma-rays, coincidence measurements of cascade gamma-rays from ^{60}Co and in-beam gamma-ray measurements for ^{178}W were carried out. For the determination of segments of the five-segmented detector, an electric circuit with standard NIM modules was used which is shown in Fig. 1. Each individual signals from the five outer segments were fed by spectroscopic amplifier (model 572) with time constant of 1 μ sec. True signals were selected by the timing single channel analyzers (TSCA) which discriminate noise and spurious cross-talk signals. The out puts from the TSCA were used as position information recorded through CAMAC register under a coincidence condition in which two signals from a center segment and one surrounding segment should coincide within a resolving time of 0.5 μ sec. The total energies of the gamma-rays were measured by using the inner cathode signals with the coincidence condition.

A typical example of the cross-talk signal from pre-amplifier is shown in Fig. 2. Comparing to the normal signal shown in ch1, the spurious signal in ch2 is observed to be smaller without a tail of slow decay time component. The shape of the cross-talk signal is mostly bipolar shown as this example. When we decrease the discrimination level, more low energy gamma-rays can be measured, however, the signal can be contaminated by the cross-talk signals corresponding to high energy gamma-rays. Intensities of a coincident peak at 80 keV from ^{133}Ba source and a single peak at 1408 keV from ^{152}Eu source were measured by changing the discrimination level as shown in the Fig. 3. When the discrimination level is selected to be 50 keV, the energy range of the linear polarization measurement can be achieved to be from 80 to 1400 keV. The energy resolution (FWHM) at 1333 keV by using ^{60}Co source is typically to be 2.2 keV under the coincidence condition which is the same performance of the singles measurement.

For the measurements of cascade gamma-rays emitted by ^{60}Co, a NaI scintillator and the five-segmented germanium detector were located at x-axis and y-axis, respectively. When the first transition of 1172 keV was detected by the scintillator, polarization of the another 1333 keV transition was measured by the polarimeter as a coincident measurement. Since two transitions are $4^+ \rightarrow 2^+$ and $2^+ \rightarrow 0^+$ in the ^{60}Ni daughter nucleus, the second transition can be polarized in the x direction for this geometry. A value of polarization P is defined as

$$P = \frac{A_\perp - A_{||}}{A_\perp + A_{||}}$$

where $A_\perp$ and $A_{||}$ are probabilities of the orthogonal component of x- and z- direction, respectively. The theoretical value of the polarization can be calculated to be $P_0 = 1/6$ for the E2-E2 cascade.

Distances from the source to the detectors were 52 mm and 55 mm, for the scintillator and the polarimeter, respectively. Intensity of the ^{60}Co source was 263 kBq. The coincidence measurement was performed for 8 days with event rate of 70 count/sec. The polarization P was measured to be 0.0026 ± 0.0009 at 1333 keV. Sensitivity for polarization detection, which can be defined as P/P_0, is deduced to be 0.015 ± 0.006.

For in-beam gamma-ray measurements, linear polarizations of gamma-rays emitted from oriented compound nuclei of ^{178}W were measured by the five-segmented linear polarimeter. In order to create excited states in the ^{178}W, a self-supporting target of ^{170}Er of 2mg/cm^2 thick was irradiated by ^{12}C ion beam at a bombarding energy of 60 MeV. The excited states were produced by ^{170}Er(^{12}C, 4n)^{178}W reaction. The polarimeter was located at $\theta = 90°$ at a distance of 187 mm from the target to detector head. No heavy-metallic device was used for gamma-ray collimation.

Angular distributions of the same gamma-rays for ^{178}W were also measured by another single germanium detector at angles of $\theta = 30°, 45°, 60°, 75°$ and 90°. The angular distributions were fitted by Legendre polynomials to deduce A2 and A4 values of angular distribution parameters. An expectation value of linear polarization can be calculated by

$$P_0 = \text{sign}\frac{12A_2 + 5A_4}{8 - 4A_2 + 3A_4}$$

$$\text{sign} = \begin{cases} +1 & \text{for E2 transition} \\ -1 & \text{for M2 transition} \end{cases}$$

by use of the parameters of A_2 and A_4 for a case of pure quadrupole transition [1].

As results of both measurements, sensitivity (P/P_0) and efficiency are shown in Fig. 4 for the gamma-rays of 106-, 237-, 352-, 448-, 524- and 579-keV from ^{178}W nucleus and 1333-keV of ^{58}Ni. The results of the sensitivity is consistent to Monte-Carlo calculations.

REFERENCE

[1] H. Morinaga and T. Yamazaki, "In-Beam Gamma-Ray Spectroscopy" North-Holland (1976)

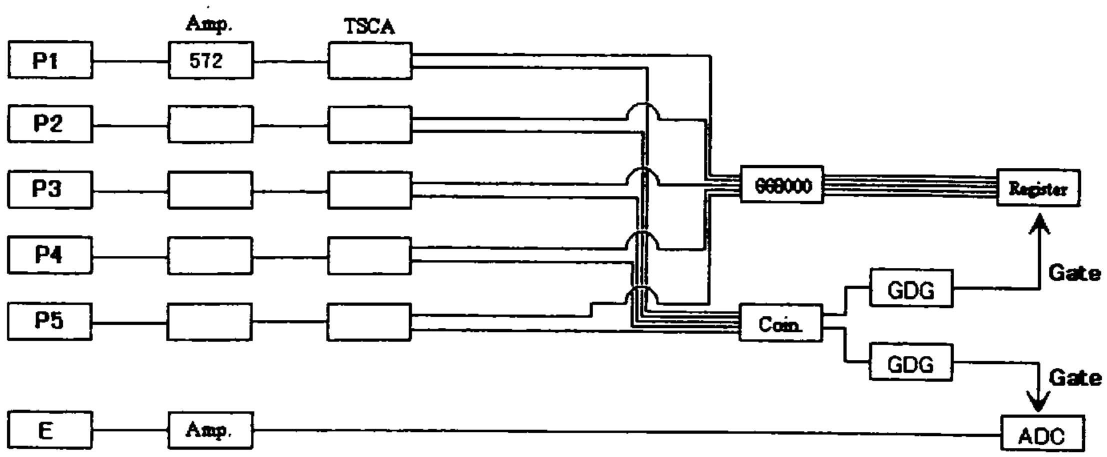

Fig. 1 A circuit diagram for linear polarization measurements.

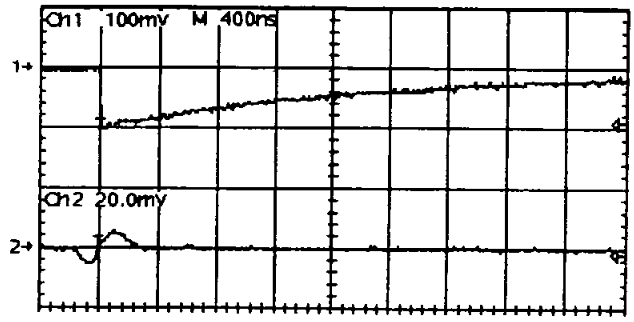

Fig. 2 Out put signals from one segment. Channel 1 shows a normal signal corresponding to the interaction in the same segment. Channel 2 is a typical cross talk signal derived by the other segment.

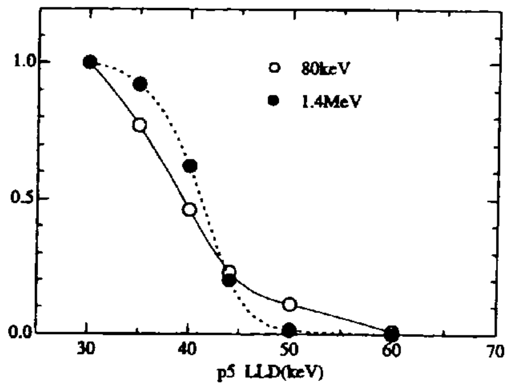

Fig. 3 Gamma-ray intensities measured by changing the discrimination level of the center segment. Open circles show the intensities of 80-keV peak from ^{133}Ba in coincidence spectra. Closed circles are the area of spurious peak at 1408-keV of ^{152}Eu observed in projection spectra. The 1408-keV peak is cased by cross talk.

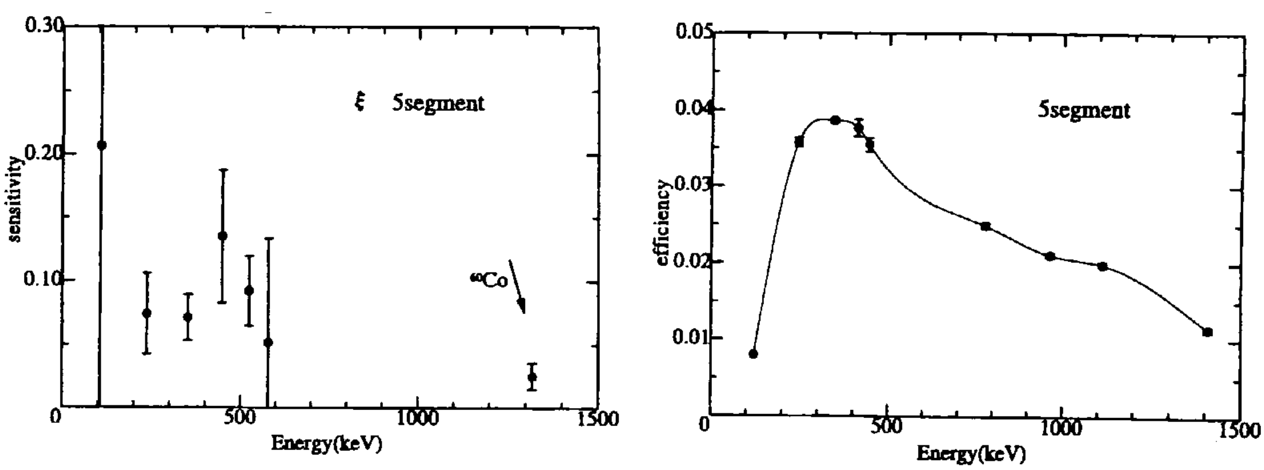

Fig. 4 Experimental results for five-segmented germanium detector for in-beam measurements of ^{178}W and cascade measurements of ^{60}Co source.

Contribution paper in Nuclear Structure '98. Gatlinburg
p.62 (1998)

Systematic study of odd-odd nuclei in mass 130 region

T. Komatsubara. T. Shizuma. K. Furuno
Tandem Accelerator Center. University of Tsukuba.
Tsukuba Ibaraki 305-8577. Japan

In several mass regions of doubly odd nuclei. the inverted signature splitting of excitation energy in rotational structures has been reported systematically[1.2]. Comparing the systematic behavior in mass A=130 and A=160 region. specific locations of valence nucleon orbitals have been turned out. in which one nucleon occupies low Ω orbital and other is in the middle one. Although the inverted features of the yrast bands were well established in cesium and lanthanum isotopes. recently Liu discussed discontinuities of spin values with changing neutron and/or proton numbers[3]. They deduced that level spins are not continuous between cesium and lanthanum isotopes. and isotopic discontinuity also arises in cesium isotopes. if the transition energies of E2 cascade are assumed to vary smoothly.

In order to extend the systematic study for the odd-odd cesium isotopes. gamma-ray measurements have been done for the ^{122}Cs nucleus. Gamma-gamma coincidence measurements. angular distributions and linear polarization measurements were carried out at Japanese Atomic Energy Research Institute (JAERI) and at Univ. of Tsukuba. In the following figure. inverted signature splitting is observed in the $\pi h_{11/2} \otimes \nu h_{11/2}$ band.

References
1) R. Bengtsson et al.. Nucl. Phys. A415 (1984) 189
2) T. Komatsubara et al.. Nucl. Phys. A577 (1993) 419c
3) Y. Liu et al.. Phys. Rev. C54 (1996) 719

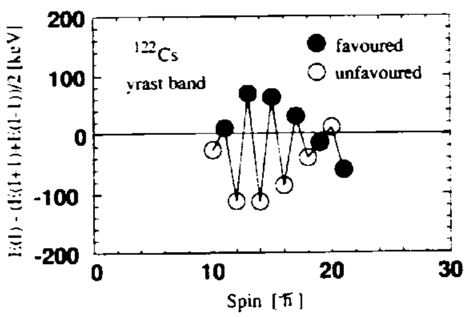

Figure: Signature splitting as a function of spin of levels for the $\pi h_{11/2} \otimes \nu h_{11/2}$ configuration in ^{122}Cs nucleus.