Study of an angular correlation of γ-rays emitted by ^{117}Sn(n,γ) reactions for T-violation search

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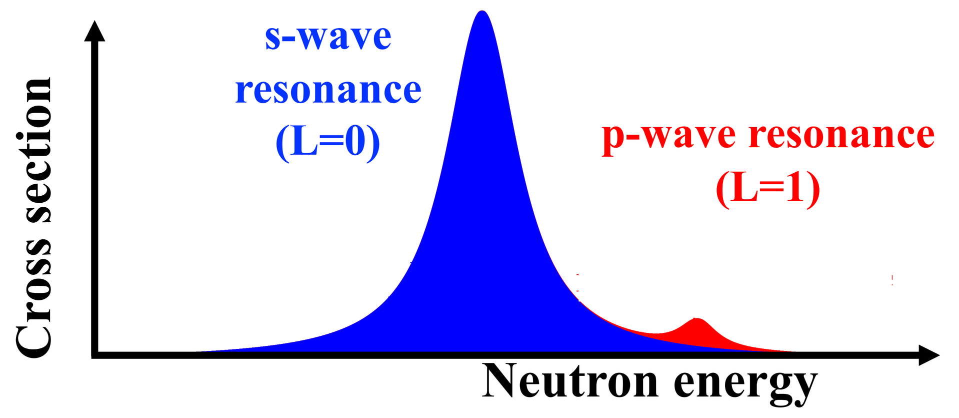
1. Introduction

Our goal is the discovery of T-violation in compound nuclear reactions.

Parity violation is enhanced in compound nuclear reactions with a factor of 10^6 compared to proton-proton scattering.
These enhancements are theoretically explained as an interference mechanism between an amplitude of a s-wave resonance and that of a p-wave resonance (s-p mixing)[1].
This mechanism could lead to an enhancement of T-violation in the compound nuclear reactions[2].

$$\Delta\sigma_{\mathrm{T}} = \kappa(J)\frac{W_{\mathrm{T}}}{W}\Delta\sigma_{\mathrm{P}}$$

- $\kappa(J)$: Spin factor (corresponding to an enhancement factor)
- W_{T}, W: T(P)-violating matrix element in fundamental process
- $\Delta\sigma_{\mathrm{T}}$, $\Delta\sigma_{\mathrm{P}}$: Magnitude of T(P)-violation in compound nuclear reaction



The experimental sensitivity for T-violation search depends on the value of κ(J).

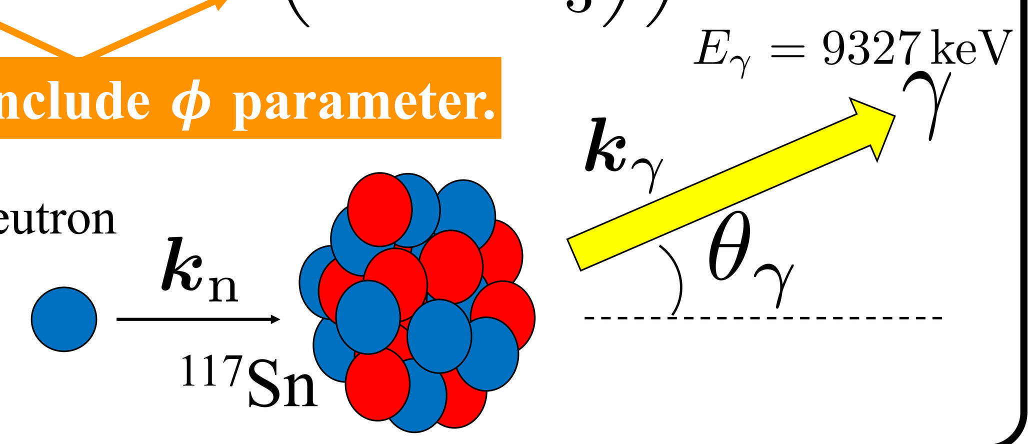
κ(J) is a function of ϕ parameter, which is a mixing angle of the total spin of neutron j=1/2 component and j=3/2 component in p-wave resonance.
→ According to Flambaum[1], ϕ can be determined by measuring the angular distribution of prompt γ-rays emitted from (n, γ) reaction.

The differential cross section of (n, γ) reaction for unpolarized neutron

$$\frac{d\sigma}{d\Omega} = \frac{1}{2}\left(a_0 + a_1\cos\theta_\gamma + a_3\left(\cos^2\theta_\gamma - \frac{1}{3}\right)\right)$$

These terms include ϕ parameter.

θ_γ : The angle between incident neutron and emitted γ-ray



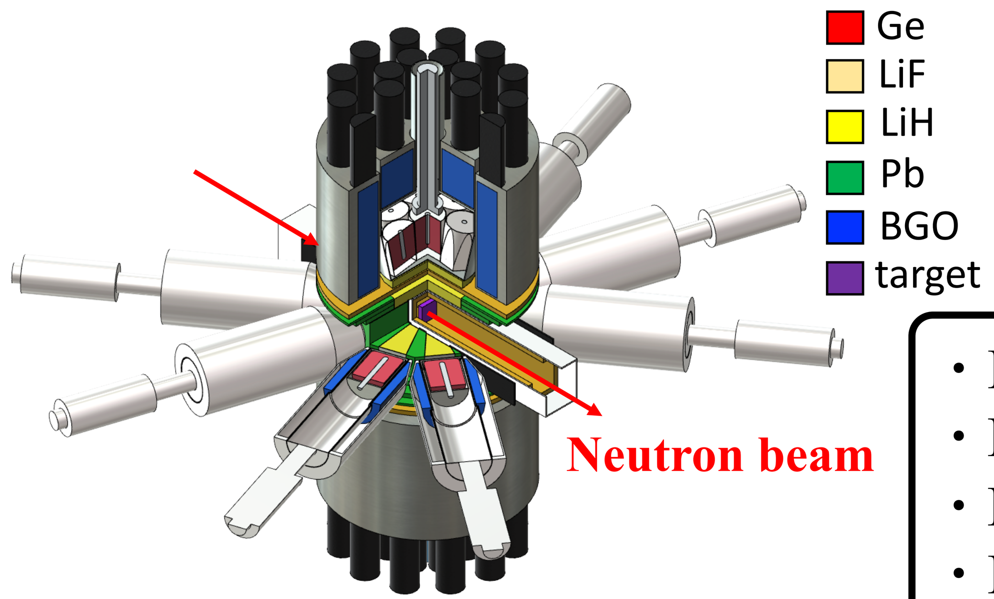
Purpose of this study

To verify Flambaum formalism and determine the values of ϕ parameter and κ(J) about ^{117}Sn, the following measurements must be conducted.

(A) Angular dependence of the shape of p-wave resonance by γ-rays with 9327 keV emitted from ^{117}Sn(n, γ) reaction.
(B) Resonance parameters (energy and width) of each resonance.
(C) Branching ratio of the direct transition to the ground state of ^{118}Sn.

[1] V. V. Flambaum et al, "Angular and polarization correlation in (n, γ) reaction", *Nuclear Physics* **A435** (1985) 352-380
[2] V. P. Gudkov, "On CP violation in nuclear reactions", *Physics Report* **212**, No 2 (1992) 77-105

2. Experiment



Ge detector assembly

The measurements were conducted at BL04 in J-PARC.
The nuclear target was surrounded with 22 Ge detectors.
These Ge detectors enable us to measure the gamma-ray energy and time-of-flight.

- Energy resolution: 2.4 keV(@1.3 MeV)
- Detection efficiency: 3.64%(@1.3 MeV)
- DAQ rate: ~310 kHz
- Energy range: $E_n > 0.0015$ eV
- Beam intensity: 9.3×10^5 n/cm²/sec ($0.9 < E_n < 1.1$ eV)

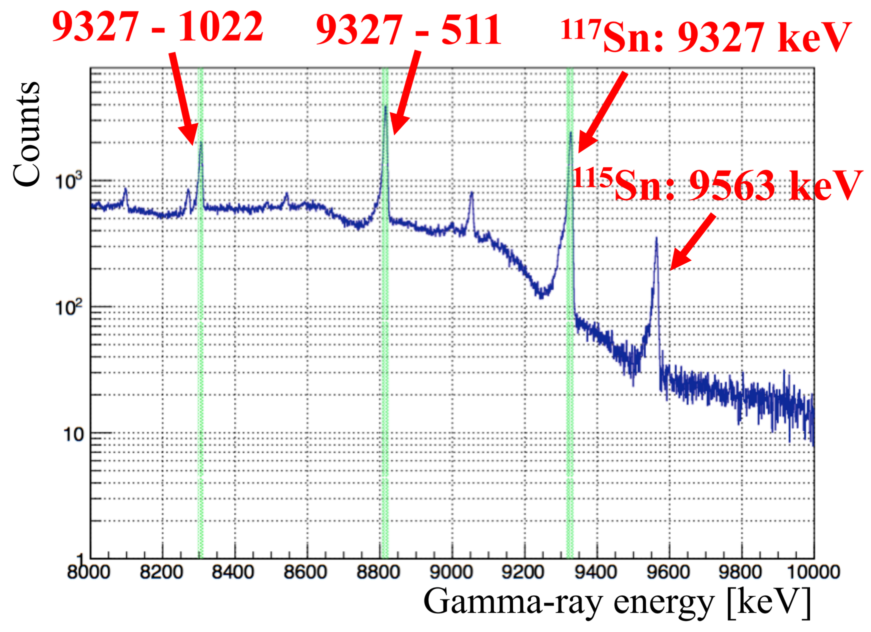
Target and measurement time of each experiment

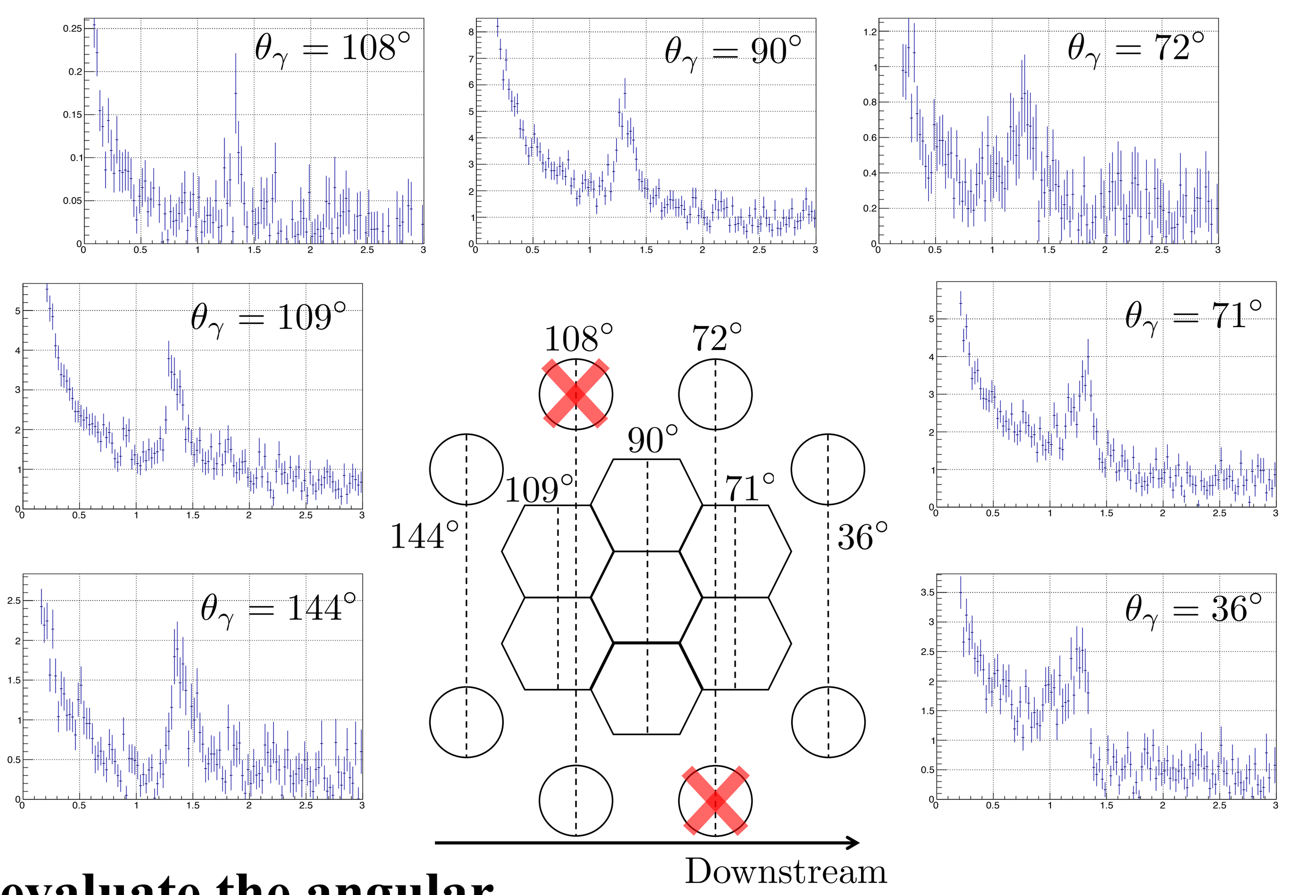
Measurement	Target	Measurement time
Angular dependence	^{nat}Sn (40×40×4 mm³)	65 hours (150 kW)
Resonance parameter	^{117}Sn 86% enrich 89 mg	6 hours (500 kW)
Branching Ratio	^{nat}Sn (40×40×1 mm³)	100 hours (500 kW)

3. Analysis

(A) Angular dependence

We used the peak with 9327 keV and its single- and double-escape peaks for analysis.
The shape of the p-wave resonance depends on the angle of the γ-rays emitted from compound state for incident neutron.

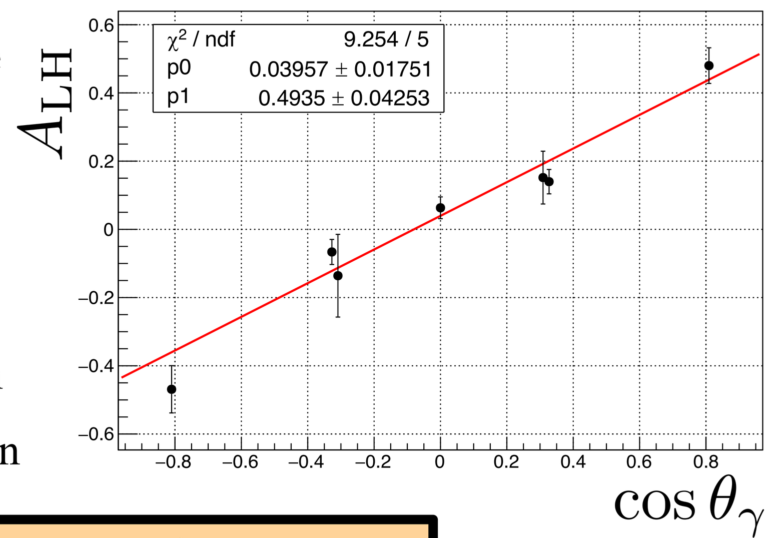




To evaluate the angular dependence quantitatively, the asymmetry A_{LH} is defined as follows.

$$A_{\mathrm{LH}} = \frac{N_{\mathrm{L}} - N_{\mathrm{H}}}{N_{\mathrm{L}} + N_{\mathrm{H}}}$$

N_{L} : Integrated value in low-energy region
N_{H} : Integrated value in high-energy region

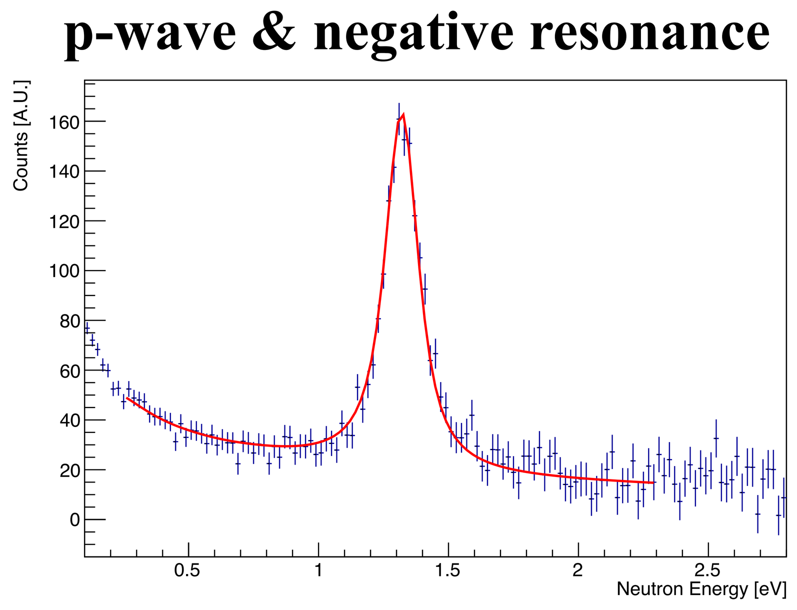


$$A_{\mathrm{LH}} = (0.494 \pm 0.043)\cos\theta_\gamma + (0.040 \pm 0.018)$$

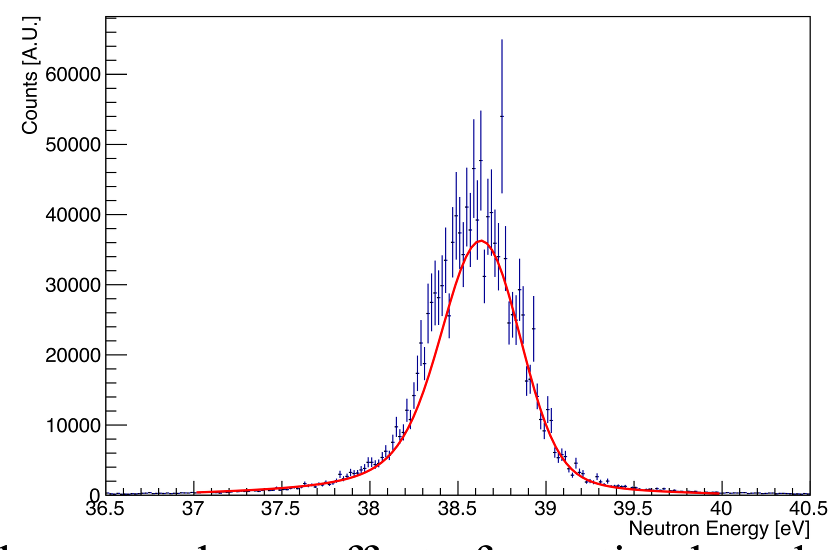
(B) Resonance parameter

Resonance parameters were determined by fitting.
Fitting function is the Breit-Wigner distribution convoluted the Doppler broadening effect and the time structure of pulsed neutron beam.

p-wave & negative resonance



s-wave resonance



There may be an effect of counting loss due to high count rate even if corrections are conducted.

(C) Branching ratio

Branching ratio of each resonance can be determined by fitting with a function fixed resonance parameters.
The following table shows the resonance parameters and the branching ratio (normalized the value of p-wave as 1) of each resonance.

E_0 [eV]	Γ^n [meV]	Γ^γ [meV]	Ratio
-29.2*	39.9*	77.0±2.0	21±1
1.331±0.002 (1.327±0.001*)	(1.48±0.09)×10⁻⁴*	133±5 (148±10*)	1.00
39.054±0.004 (38.80±0.05*)	4.13±0.20*	62.6±2.5 (100±15*)	(6.0±0.4)×10⁻²

Preliminary

Asterisk mark(*) means the value referred from TRIPLE group.

4. Summary

- **We are searching strong candidate nuclei which have the large κ(J).**
- **We conducted experiments for determining the κ(J) value of ^{117}Sn.**
- **The angular distribution has been observed significantly.**
- **The analysis for determining the resonance parameter and the branching ratio is ongoing.**
- **In the near future, the κ(J) value of ^{117}Sn will be determined.**