Study on magnetic field and pH response with angular correlation measurement of Yb-169 for double photon coincidence imaging

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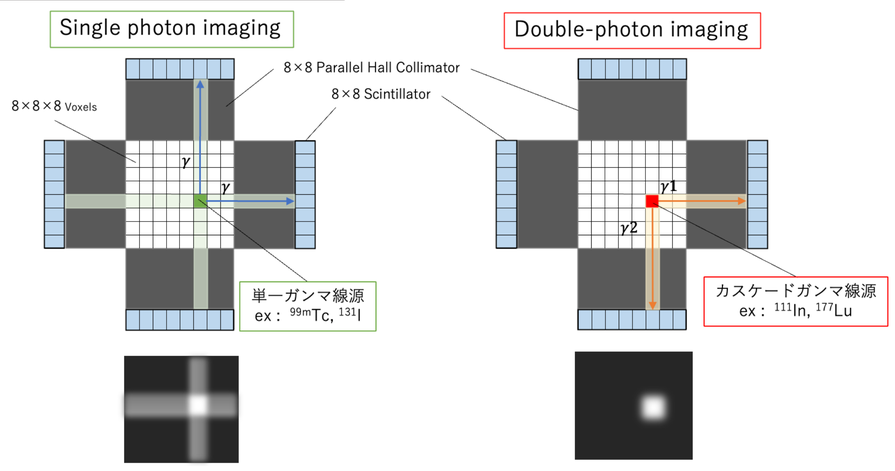
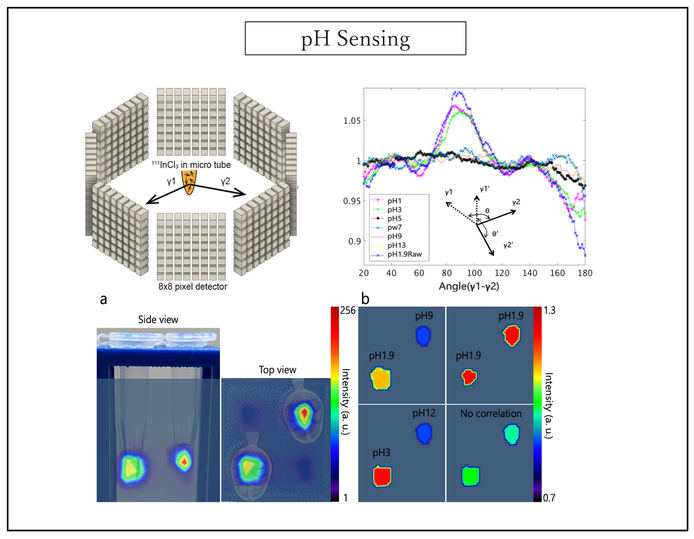
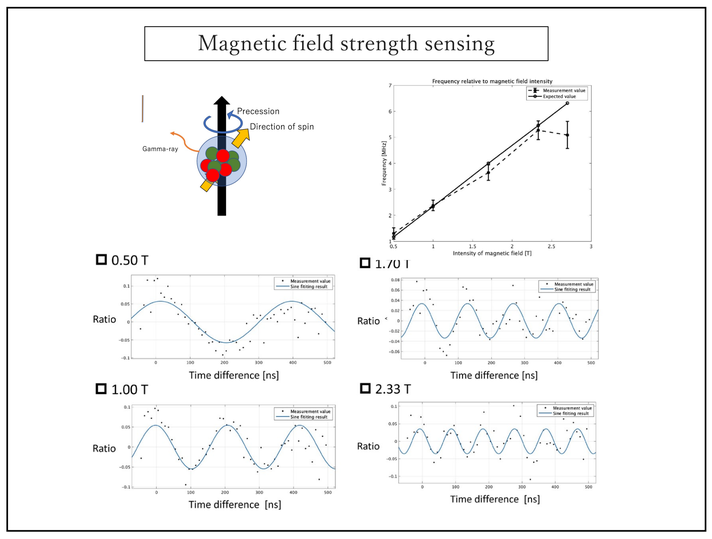
In medical nuclear imaging, a crucial technique involves detecting radiation emitted from the internal to external regions and visualizing its distribution. This non-invasive method allows for obtaining vital information about the internal body. We are developing imaging technology that utilizes angular correlation measurements as a novel nuclear medical imaging method.

In this study, we utilized Yb-169 as a multiphoton nuclide, which has a relatively long-lived intermediate state, instead of In-111 commonly used in clinical applications such as SPECT. The intermediate state during the decay of cascade nuclides exhibits a characteristic change in the emission angles of gamma rays under the influence of external fields such as magnetic and electric fields. By exploiting this property, we detected the precession motion of nuclei induced by the application of a static magnetic field and changes in solution pH through the oscillation of gamma ray angle correlation. Furthermore, by correlating the observed information of gamma ray angle correlation, the calculated frequency, and pre-known information about magnetic field strength or pH values, we obtained distribution information of radioactive isotopes (RI). In this experiment, we measured the angle correlation of Yb's coincidence events, quantified the temporal response changes when applying a magnetic field, and detected electric field gradients by altering the pH value.

Background







DPECT
(Double Photon Emission CT)

- Nuclear Medicine Imaging Technique Utilizing Two-Photon Emission Isotopes (Cascade Isotopes)
- High-resolution, high-quality, low-noise compared to SPECT

Cascade nuclide

- Multiple gamma rays emitted in a single decay event
- Having an intermediate state in the decay process
- In the intermediate state, nuclear spin undergoes perturbation due to external fields

Angular correlation

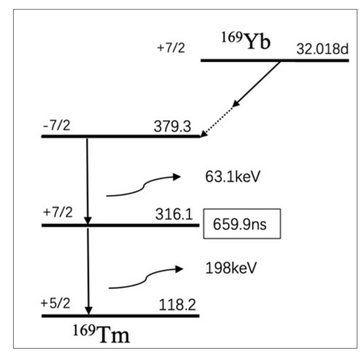
- Correlation of emission angles of the two released gamma rays
- Sensitive to electric and magnetic fields, changes depending on the local surrounding environment

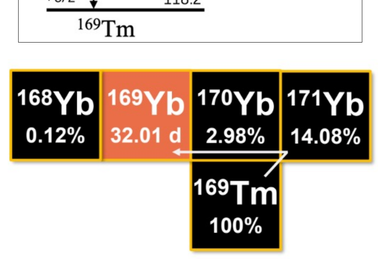
Purpose

・ Exploration and quantification of medical radioisotope tracers with larger perturbations to external fields

・ Due to its longer half-life compared to currently identified isotopes, when bound to antibodies, sustained accumulation information can be obtained over an extended period.

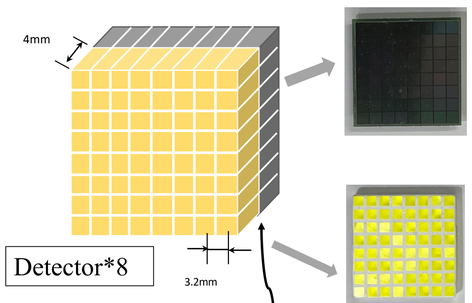
・To demonstrate the acquisition of detailed local information, in this experiment, we conducted simultaneous measurements of γ 1- γ 2 to determine angle correlations, measured Larmor precession motion, and calculated changes in electric field gradients due to pH alterations.





Experiment and Methods

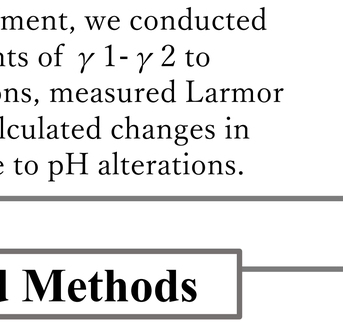
Measurement System



・8×8 MPPC (Multi Pixel Photon Counter --- Manufactured by Hamamatsu Photonics)

・8×8 GAGG $[Gd_3(Al,Ga)_5O_{12}(Ce)]$ Scintillator

Detector schematic diagram



dToT signal processing

Magnetic field generation device

dToT-board*8

dToT Method
(Dynamic time over threshold)
A method for determining the dynamically changing threshold and ToT (Time over Threshold) length with a strong correlation to energy 。

Pulse conversion

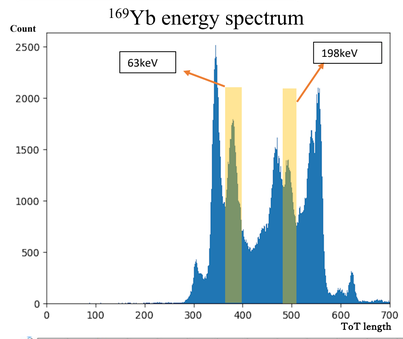
FPGA-DAQ*4

T0 generator*1

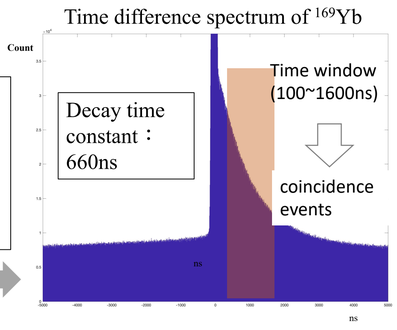
PC

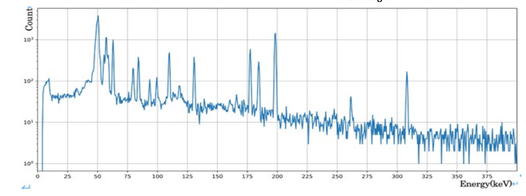
Readout circuit：
Simultaneously and independently read out 512 channels
・Channel number
・Energy information (ToT length)
・Timestamp information

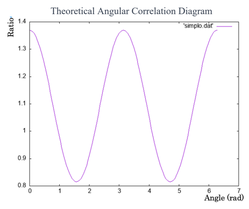
Result

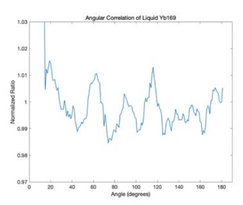


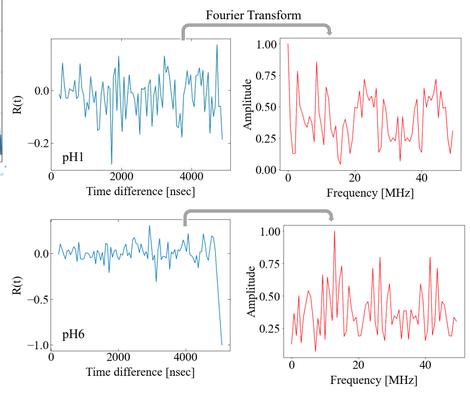
Sort the recording events for each 63keV and 198keV based on timestamps



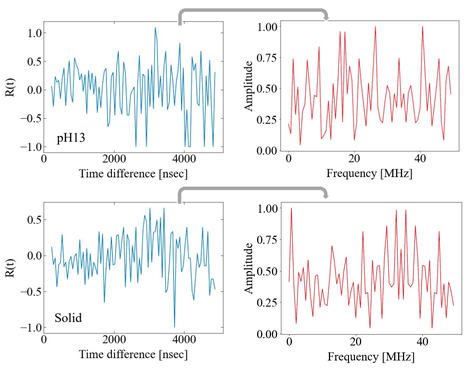


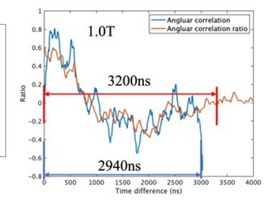


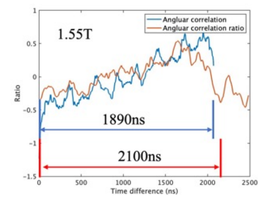




・The decay constant of 660 ns has been confirmed.
・Based on the experimental results, the precession period of Larmor motion has been successfully observed.
・ The difference between the angle correlation diagrams obtained in the experiment and those simulated can be attributed to the assumption of a vacuum in the simulation and the influence of nuclear quadrupole interactions. Additionally, the variation in electric field gradients due to pH has not been fully understood yet. So we are presenting a topic for future investigation.







The energy spectrum of the dToT system and the energy information obtained from the germanium detector revealed observable spectrum peaks at 63keV and 198keV, corresponding to emitted gamma rays. By extracting signals at these energy levels, a timing difference spectrum was generated based on the detection timing. Events within a time difference range of 100ns to 1600ns were identified as coincidence events. Data outside this time window (-300ns to -2300ns) were treated as data for calibration, considering factors such as geometric effects. Additionally, the calculation of emission angles relied on the detected energy, geometric information, and was determined through coordinate transformations and coordinate dot product calculations.

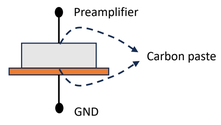
$$\vec{\omega} = \gamma\vec{B} = 0.3396MHz$$

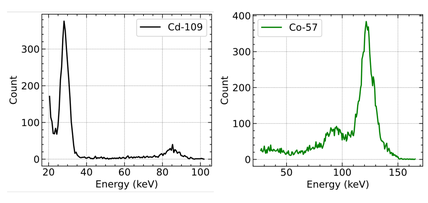
$$R(t) = \frac{N(180^\circ,t) - N(90^\circ,t)}{N(180^\circ,t) + N(90^\circ,t)} \cong \frac{3}{4}A_{22}\cos(2\omega_L t)$$

Table.1. Measured Larmor period and magnetic strength

Magnetic field intensity	1.0T	1.55T
Larmor frequency calculation value	0.3396MHz	0.5264MHz
Period theoretical value	2940ns	1890ns
Period experimental value	3200ns	2100ns
Difference	0.08	0.1

Future work





	Cd-109	Co-57
FWHM	3.1922	9.6001
Energy res.	3.763056	7.84899

・Due to the complexity of interfering factors' energy, we are introducing a method to clearly extract the energy—the developing a pixelated CdTe detector system with higher energy resolution than the current system.
・We will perform imaging or multi-nuclide simultaneous imaging of Yb bound through antibody binding.

Reference

T. Orita, K. Shimazoe, and H. Takahashi. "The dynamic time-over-threshold method for multi-channel APD based gamma-ray detectors.", *Phys. Rev. D*, 775, pp. 154-161, 2015.
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