NE 204: Advanced Concepts in Radiation Detection and Measurement

Experiment 5: Position Determination and Event Reconstruction in HPGe Strip Detectors

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Purpose

A planar HPGe detector with a double-sided orthogonal strip electrode structure is used to study methods for recovering the position of gamma-ray interactions within the detector. The ability to measure the deposited energies and associated positions of gamma-ray interactions is a critical component of many gamma-ray imaging methodologies, as well as gamma-ray tracking spectrometers for nuclear physics experiments such as GRETINA. Time correlation between signals from opposite electrodes can be used to determine the 2D position of gamma-ray interactions down to the strip pitch of the electrodes. Pulse shape analysis techniques can be used to further refine the lateral position resolution beyond the strip pitch. The "depth" of interactions is determined using the time difference of maximum induced signal current for correlated electrodes. In this lab, simple pulse shape analysis schema will be implemented to reconstruct the 3D position of a subset of gamma-ray interactions in a double-sided strip HPGe detector. Algorithms for determining the correct sequence of correlated gamma-ray events can be explored. Flood-field and collimated measurements can be used to evaluate the uniformity and point-spread functions of the position determination, respectively.

Approach

An HPGe detector with a double-sided strip segmented electrode structure fabricated by Mark Amman at LBNL will be used for this experiment. The segmentation is characterized by a strip pitch of 2 mm with a gap of 0.5 mm. The instrument is about 11 mm thick and has 37 strips plus a guard ring around each of the segmented electrodes. SIS3302 modules will be used to read out all 74 channels of the detector. The first critical component of the study includes the optimization of filter parameters, energy calibration, and characterization of energy resolution for each of the 74 readout channels. Next, time correlation is used to determine electrodes that record signal from the same gamma-ray event, and energy matching of correlated strips can be used to determine the lateral position of the interaction. Pulse shape analysis techniques can be explored for improving the lateral position resolution to values finer than the strip pitch. A digital time pick-off algorithm is to be implemented to determine the time of maximum induced current on each electrode, which serves as a proxy for the "arrival time" of the charge at that electrode due to the small pixel effect. This information is then used to determine the depth of the interaction along the axis orthogonal to the readout electrodes. Finally, algorithms can be implemented to attempt to recover the correct sequence of gamma-ray interactions for events with more than one recorded interaction.

Filter Optimization and Energy Calibration

Optimize the peaking and gap time for the trapezoidal filter implemented in the SIS3302 firmware using a procedure similar to that employed in lab 1. Note that the SIS3302 firmware does **not** allow tuning of the spectroscopic filter for individial channels. Repeat the optimization procedure with data from at least two strips (near center and nearer the edge) from each side of the detector to estimate optimal parameters for the entire system.

Required

- Optimize the peaking and gap time parameters for the trapezoidal filter developed in lab 1. Apply the optimum filter parameters to the one implemented in the SIS3302 firmware.
- Using standard gamma-ray check sources (^{241}Am, ^{133}Ba, ^{137}Cs), perform an energy calibration for each of the 74 channels.

Optional

- Perform the filter parameter optimization process in software for each of the 74 channels. Are the parameters constant for every strip strip location?
- Characterize the energy resolution performance of each of the 74 strips after energy calibration.

Gamma-Ray Event Determination

Determine the distribution of time intervals between the digitized signals from the electrodes. Use this information to experimentally determine a timing criterion for correlated signals.

Required

- Plot a histogram of the interval between the trigger times of signals recorded on all electrodes (sometimes referred to as a "time to next event" histogram), and explain any features in the distribution.
- From the plot, determine an inter-event timing interval for correlated signals. How does this value compare to the maximum charge collection time in the detector?
- Use the timing criteria and the calibrated energy depositions to reconstruct likely candidates for single-interaction events in the detector.

Optional

- Expand the event reconstruction approach from likely single-interaction events to include likely double-interaction and triple-interaction events.

Determining Interaction Depth

Determine the location of gamma-ray interactions in the dimension along the length of the crystal (orthogonal to the two electrodes).

Required

- Derive a time pick-off scheme to extract the "T-50" time from the digital signals.
- Use the difference in T-50 times ($\Delta T50$) from correlated signals to determine the depth of interactions.
- Using standard gamma-ray check sources, compare the depth profile computed using the above method to the expected attenuation at various gamma-ray energies.

Pulse Shape Analysis for Improved Lateral Position Resolution

The SIS3302 cards can be configured to accept both internal and external triggers. Use the "nearest neighbor" triggering functionality of the SIS3302 card to collect signals from strips adjacent to the charge-collecting electrode. These "transient" (i.e. zero total charge induction) signals can be used to improve the lateral position resolution via interpolation schema.

Optional

- Use the externally-triggered "neighbor" signals from non-collecting strips to develop and implement an interpolation scheme to improve the lateral position resolution.
- Evaluate your methodology in one dimension with a pinhole or line collimator.

Gamma-Ray Event Sequencing

For gamma-ray events that consist of more than one interaction in the detector, develop and experimentally evaluate methods for determining the correct ordering of the interactions.

Optional

- Can the appropriate sequence of individual gamma-ray interactions be determined from timing information alone? Why or why not?
- For double-interaction events, use Compton kinematics to attempt to determine the correct sequence of the two gamma-ray interactions. Is it possible to uniquely determine the correct sequence for double-interaction events? A subset of them?