Effective gap width and implications for position estimation in germanium strip detectors

Rose S. Perea[1,2], Oleg Ovchinnikov[1,2], Todd E. Peterson[1,2,3]

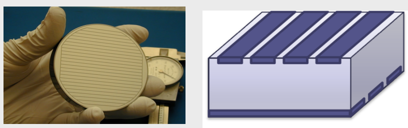
[1]Dept. of Physics and Astronomy, [2]Institute of Imaging Science (VUIIS), [3]Dept. of Radiology & Radiological Sciences
Vanderbilt University, Nashville, TN 37232, USA

rose.s.perea@vanderbilt.edu

INTRODUCTION

High-purity germanium (HPGe) double-sided strip detectors (DSSDs) have proven useful for gamma-ray imaging in medical, astronomy, and security applications.

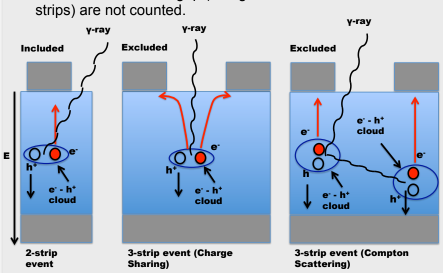
The DSSD configuration allows for finer spatial resolution than the strip pitch [1], however lateral position estimation can be complicated due to charge-sharing events and gap effects [2], [3].



Left: Image of HPGe DSSD crystal. Right: Schematic of DSSD configuration [4], our detector is similar, only round.

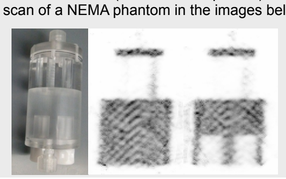
Lateral position estimation is done for 2-strip (one strip on each side) events only. Assumptions are:

- Counts across the strip width are uniform and
- Events that fall in the gap (charge shared between two strips) are not counted.



Schematic of different events in the HPGe detector. Left: A single event in which charge is collected on a single strip on both detector sides. Right: 2-strip collection on one side due to lateral diffusion of the electron cloud (middle) and a Compton scatter event (far right).

Counts lost to the gaps result in loss of sensitivity and create artifacts, as can be seen (checkerboard pattern) in the helical SPECT scan of a NEMA phantom in the images below [4]:



Left: NEMA IQ Phantom. Right: Image reconstruction slices of coronal (middle) and sagittal (far right) views.

Goals: To investigate the influence of the gap on charge collection and how that ultimately affects the current method of position estimation:

- Collect data via scanning of a collimated beam of radiation
- Generate a model to match the behavior of the strip events
  - Estimate the fraction of events that would occur in the strip under the radiation beam.
  - Work toward understanding how the distribution of counts across the strip are affected by the gap
    - Do different gap widths change the distribution?
  - Ultimately, try to make a better positioning algorithm

METHODS

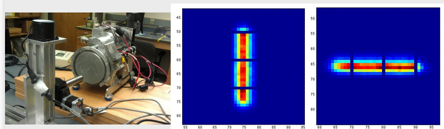
The HPGe Crystal + complete detector system (PHDS, Knoxville, TN) :

- 90 mm in diameter
- 16 x 16 Orthogonal strips
- 4.75 mm strip width with 0.25 mm gaps between strips

METHODS (Continued)

The Experiment:

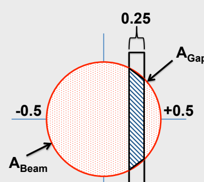
- A Collimated beam (~1 mm diameter) containing a capillary filled with 99mTc (starting activity ~1.69 mCi) was scanned across the detector in 300 steps (0.044 mm step size).



Left: Detector system with collimator on x, y, z stage. Right: Two – dimensional summed image of all 300 acquisitions stepping across the detector vertically (middle) and across the detector horizontally (far right).

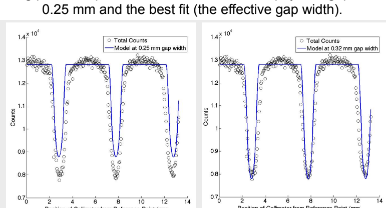
Geometrical Model: The fraction of events expected to fall within a strip under the radiation beam (F_{Events}) is calculated in the equation below (where the area of the beam (A_{Beam}) and the area of the gap (A_{Gap}) are represented in the schematic):

$$F_{Events} = \frac{A_{Beam} - A_{Gap}}{A_{Beam}}$$

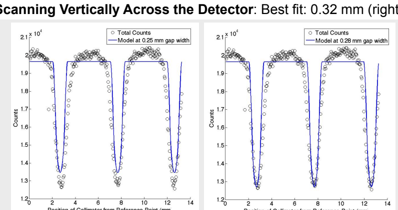


RESULTS and DISCUSSION

Model and Strip Data Comparisons vs. Beam Position: The following plots compare data to the model at the physical gap width of 0.25 mm and the best fit (the effective gap width).

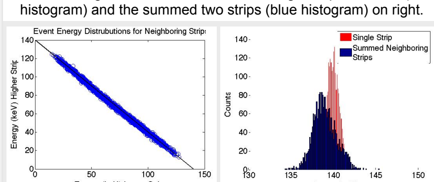


Scanning Vertically Across the Detector: Best fit: 0.32 mm (right)



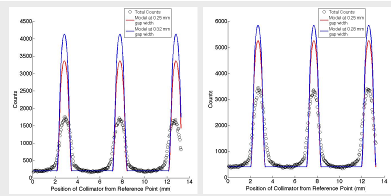
Scanning Horizontally Across the Detector: Best fit: 0.28 mm (right)

Counts in the Gap (Vertical Scan):
Energy distribution for events between two neighboring strips (left) and the energies of those events for the single strip collection (red histogram) and the summed two strips (blue histogram) on right.



RESULTS and DISCUSSION

Model and Gap Data Comparisons vs. Beam Position:
The following two plots compare the model at the physical gap width of 0.25 mm and the best fit (effective gap width) for the vertical scan (left) and the horizontal scan (right).



Geometric Model Comparisons:

- **The model comparison for both strip data sets** show that there is an effective gap width (0.32 mm for the vertical scan and 0.28 mm for the horizontal scan) that is larger than the physical gap width of 0.25 mm.
  - This implies that the strip edges are being affected by the gap, further out than the physical gap width.
- **Mismatching of the model** occurs at the roll off of the strip edge. We are further investigating other factors:
  - If the effective width changes by depth of interaction
  - Incorporating Compton scattering distributions (MCNP modeling)
  - Divergence of the radiation beam.
  - Charge collection loss (see last bullet below).
- **The model comparisons for both gap data sets** show that physical gap width and the best fit width overestimate the data, and also do not replicate the tailing of the peaks.
  - Some model overestimation is expected, since comparison of event energies between the neighboring strips show loss of some events due to the energy threshold of the system.
  - The energy distributions also show some charge loss when comparing the same events between the single strip and the two strips on the opposing side.
    - Other factors to investigate are similar to those listed above, especially depth of interaction (preliminary analysis indicates the model matches the peak at some depths).

CONCLUSION and NEXT STEPS

The finding of an effective gap width greater than the physical gap width implies that our current position estimation method is incorrect. The current assumption is that the events in a flood image are uniformly distributed across the strip. However, we see a reduction in events near the strip edge, possibly due to charge diffusion. This effect leads to possible mis-positioning of events falling within the strip.

- **Future work:**
  - Incorporate divergence of the beam and Compton scatter distribution into the current geometric model.
  - Investigate how the effective gap width changes with depth.
  - Model charge collection and signal generation processes using weighting potentials.

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