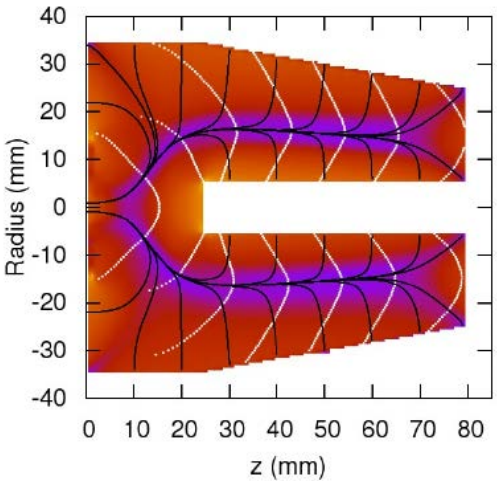
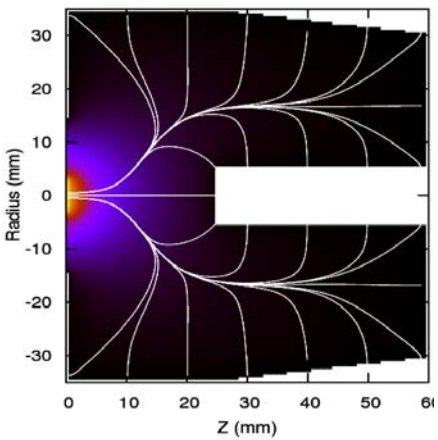
Segmented Point-Contact Detectors





David Radford

ORNL Physics Division

Final Symposium of the Sino-German GDT Cooperation

Schloss Ringberg

October 2015

Outline

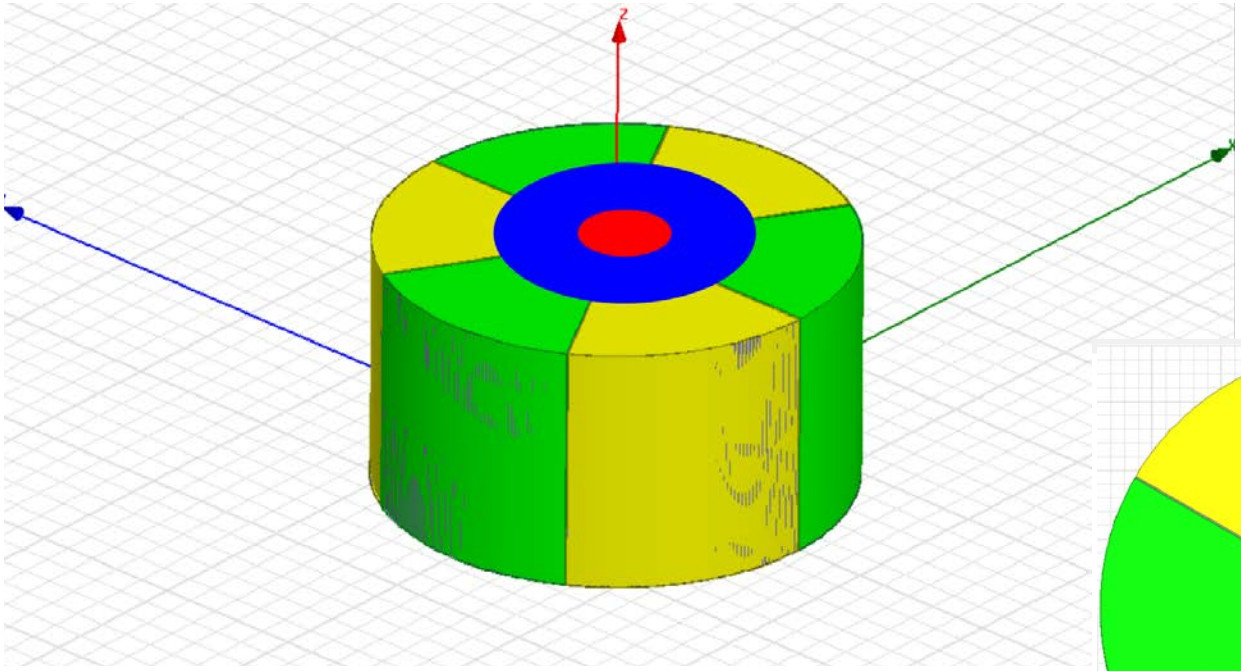
- Segmented point-contact detectors for gamma-ray tracking
  - Novel “inverted-coaxial” design
  - Position resolution, number of interactions
  - Energy resolution, signal decomposition
  - New development efforts at LBNL and Liverpool

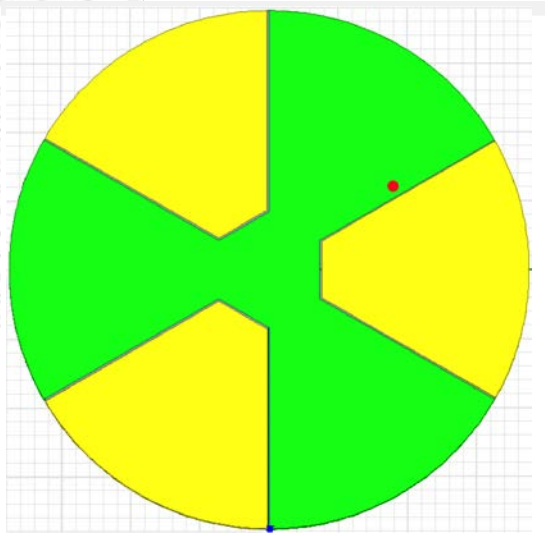
- Segmented point-contact detectors for 0νββ searches
  - Personal impressions

Munich Design

- Will be discussed in next few talks

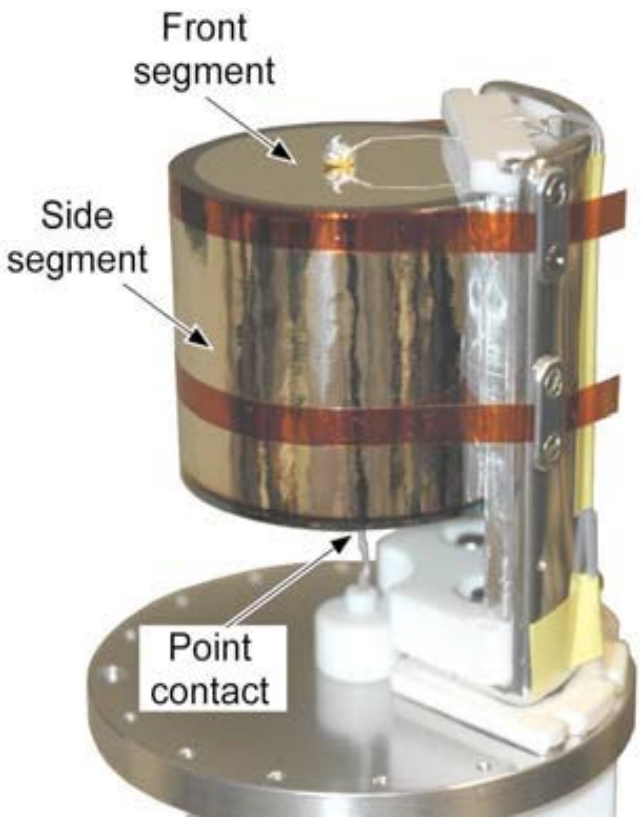
  Heng-Ye LIAO, Xiang LIU



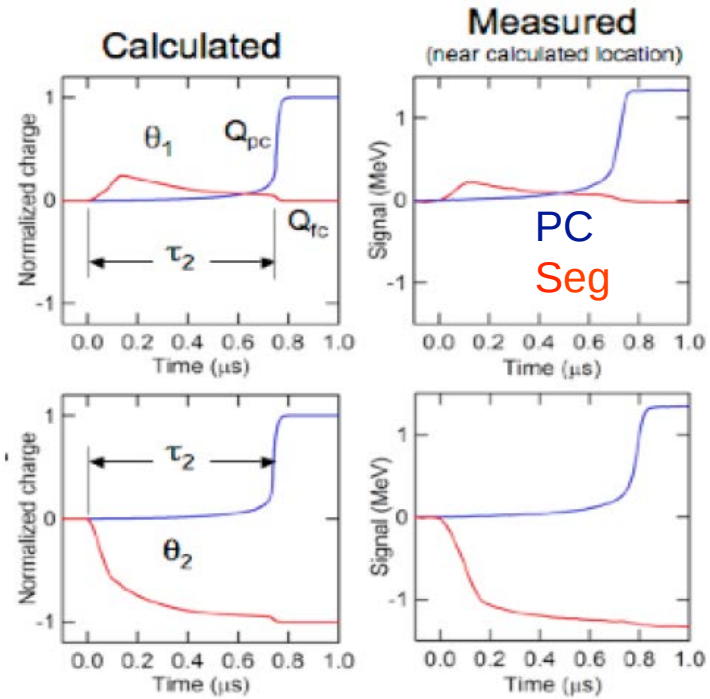


LBNL Design (SPPC)

M. Amman et al. (2009)



- Outer contact electrically segmented into two parts, one of which is instrumented
- Gives information on the interaction position (e.g. for fiducial cut)
- Waveform from segment tells time of start of charge drift (interaction time)



PC Detectors for AGATA or GRETA?

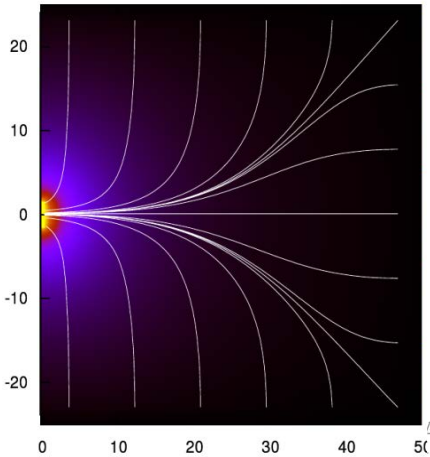
Those detectors are designed for 0νββ and DM searches

- But point-contact detectors have attractive features for classical nuclear structure physics (Reiter)

Three big problems:

- Long drift time gives very poor timing resolution in coincidence studies
- Need crystal length ~ 10 cm; cannot deplete using point contact geometry (Marian)
- Position sensitivity through segmentation requires drifting charges close to segmentation boundaries. Very poor in the center of a PC detector

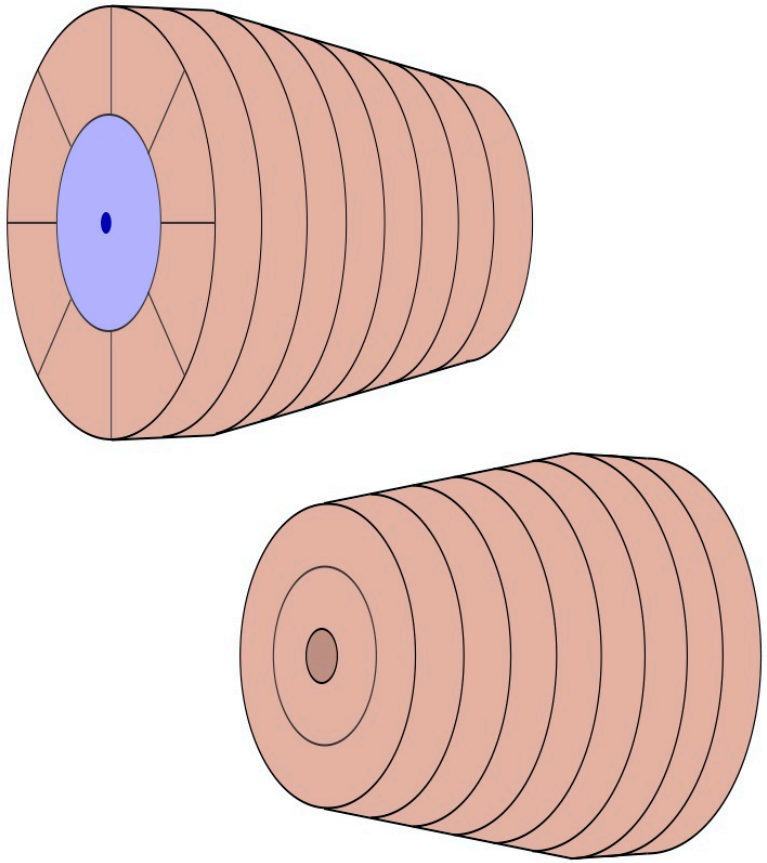
These problems can be solved with a radical new geometry, plus segmentation

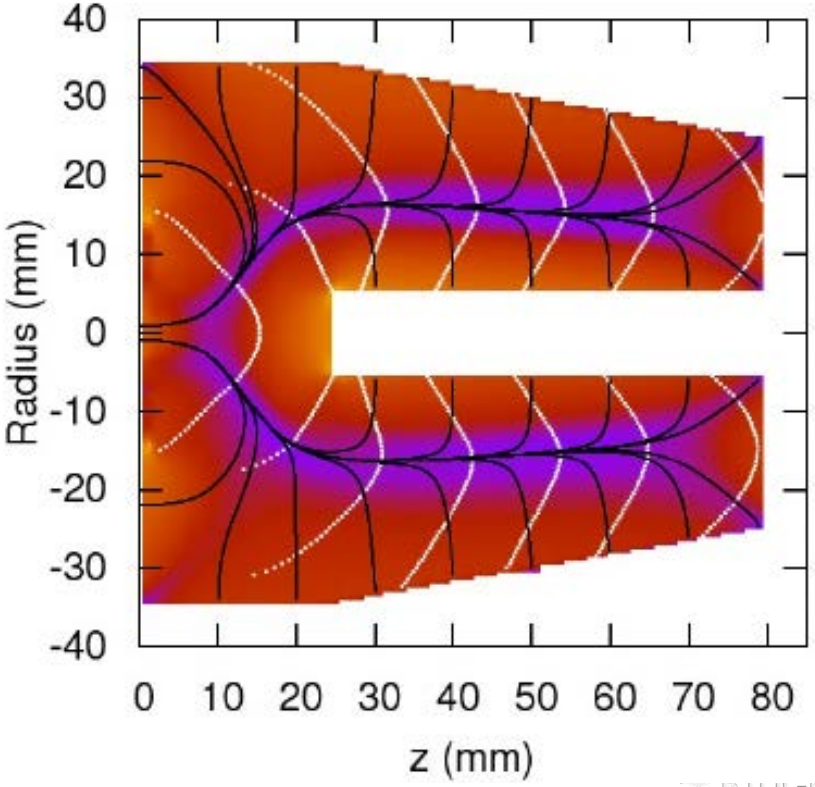


ORNL Segmented Point-Contact Design

- Total of 19 segments, 20 signals
- Central hole from front face to 25 mm from PC
- Longitudinal ring-style segments and pie-slice azimuthal segments separate the longitudinal and azimuthal directions

R.J. Cooper et al., NIM A 665 (2012) 25





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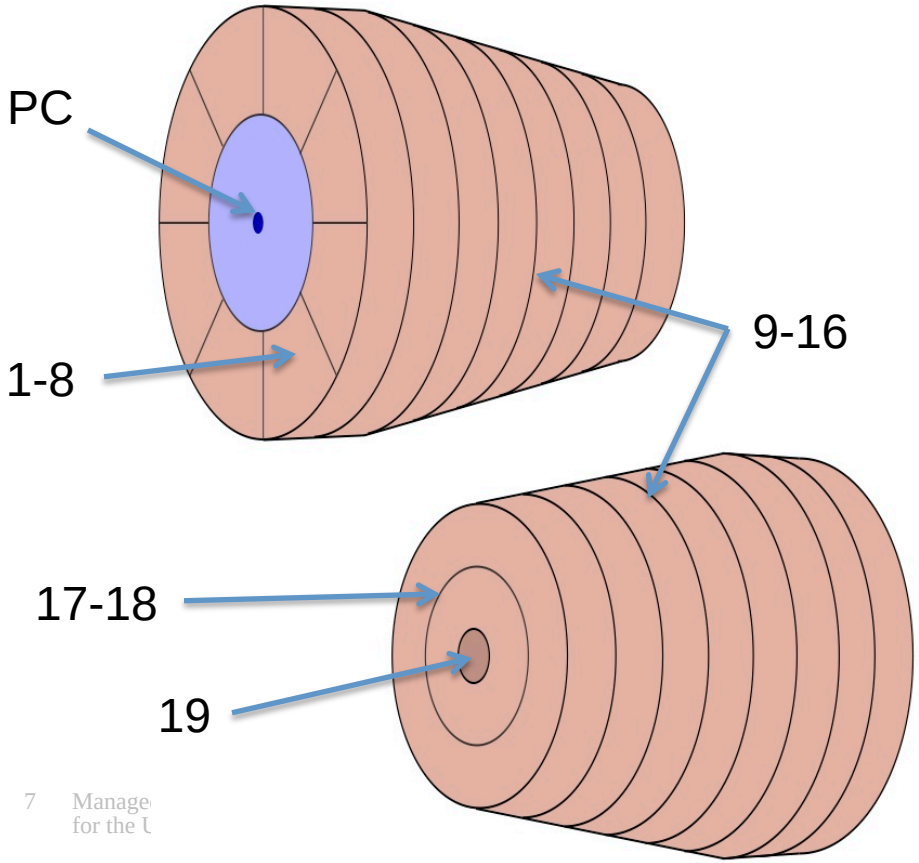
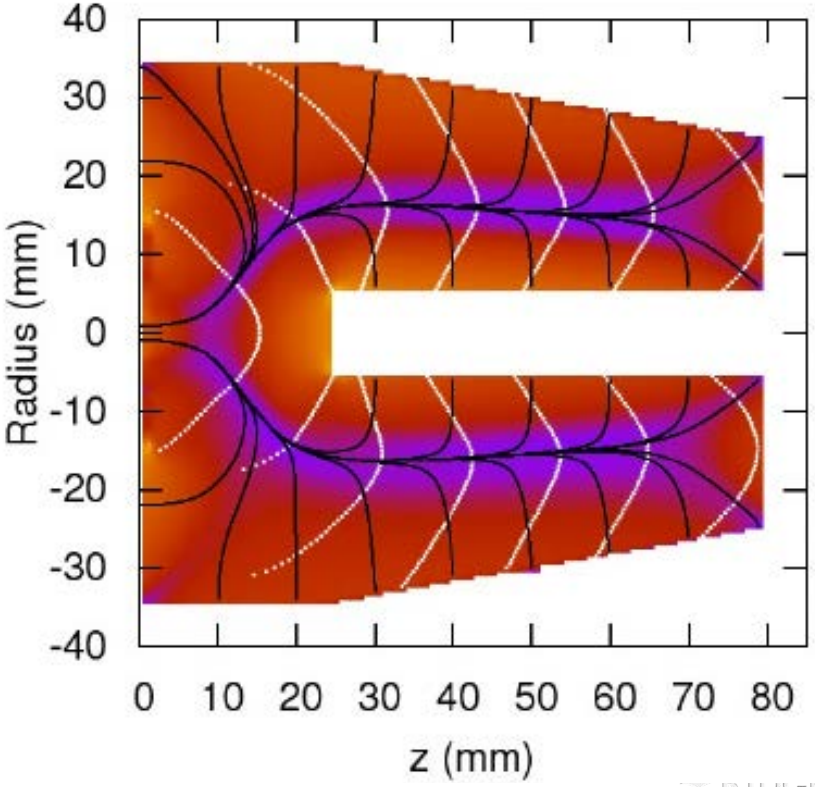
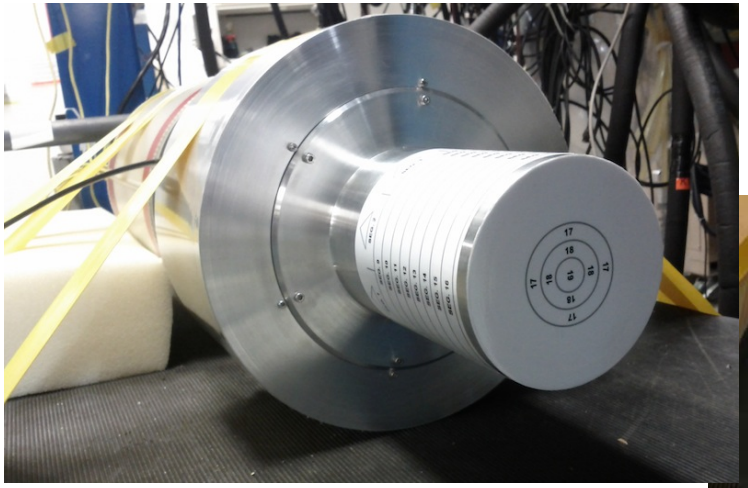




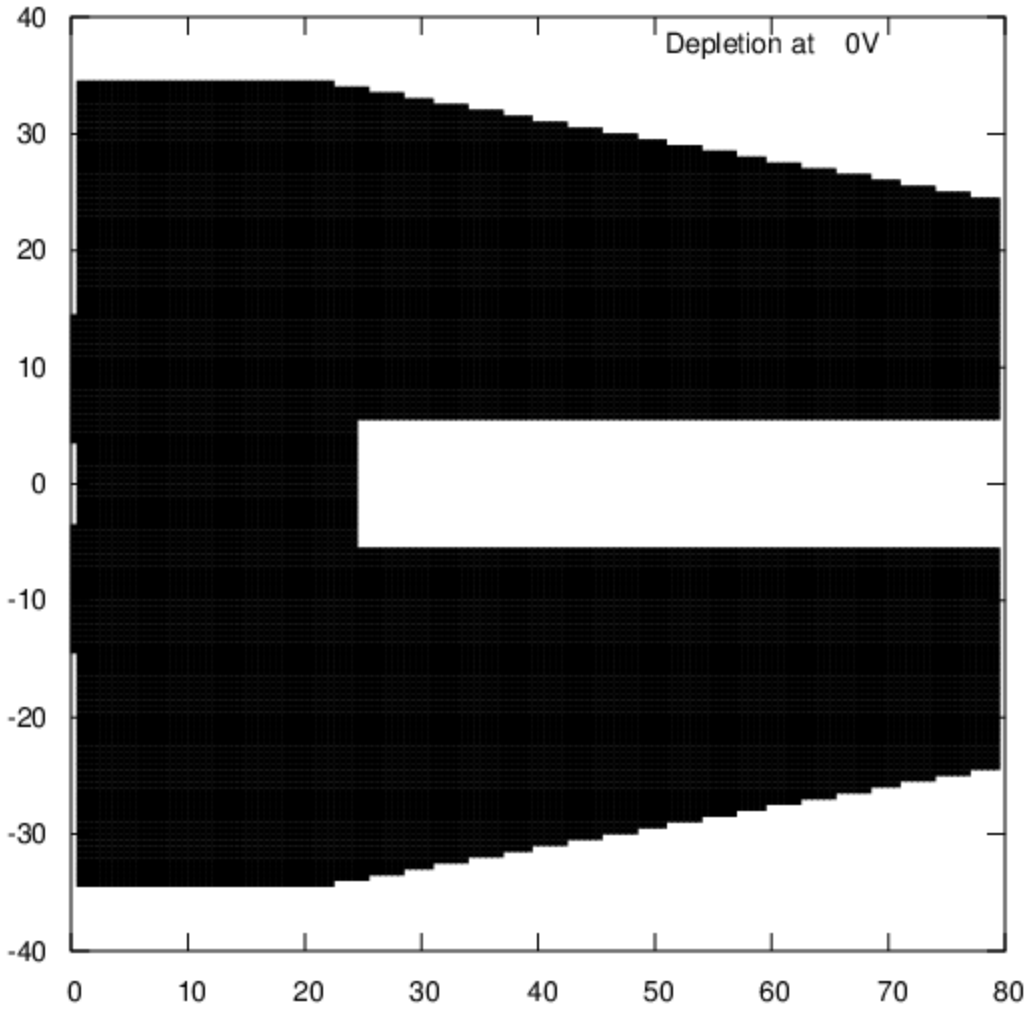
Segmented Prototype

- Produced by Canberra France
- 7 cm diameter, 8 cm long, 10-degree taper over 6 cm of length
- N-type crystal (chosen by manufacturer for segmentation reasons)
- Mounted in a scanning table for characterization measurements



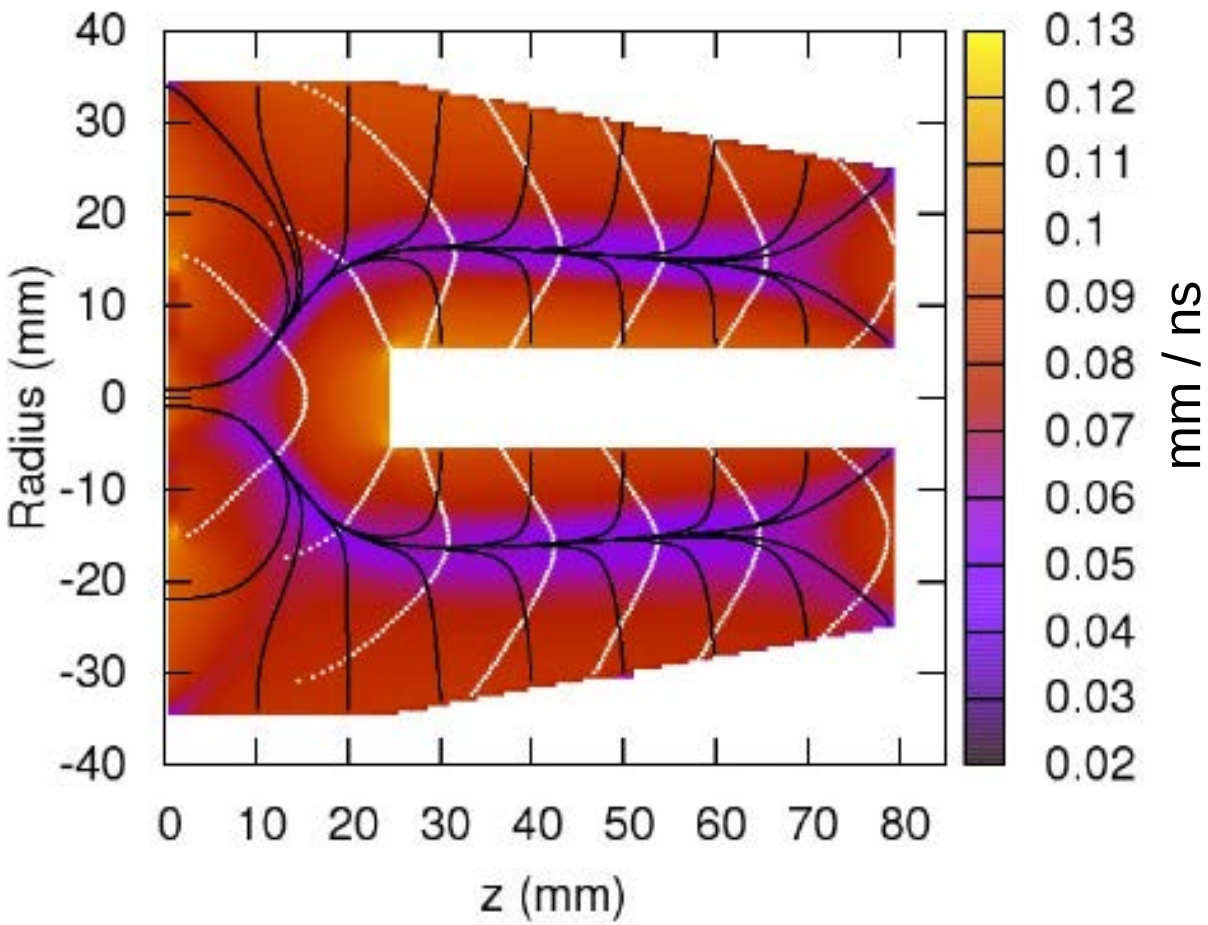
Depletion

- Depleted volume in 50V steps



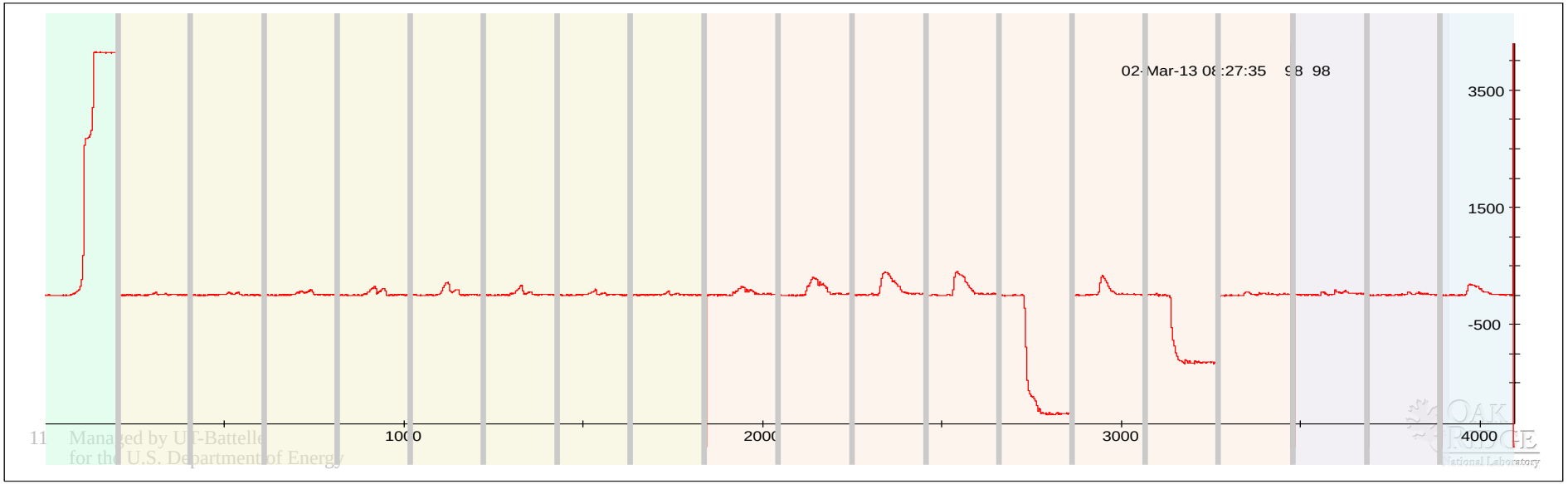
Calculated Charge Drift

- Drift speed in color (up to ~ 110 µm/ns)
- Drift paths in black
- Time contours (200 ns) in white; up to 1.5 µs



Segmented Prototype: First Measured Signals

- Twenty signals (PC plus 19 segments); 4µs shown for each signal



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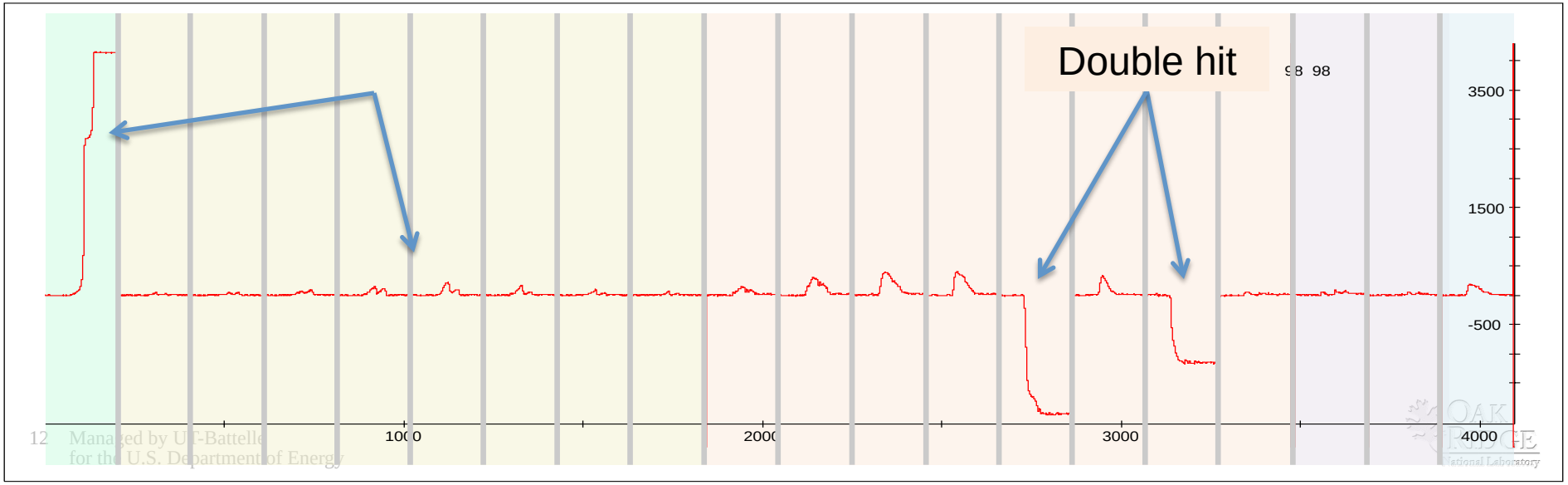
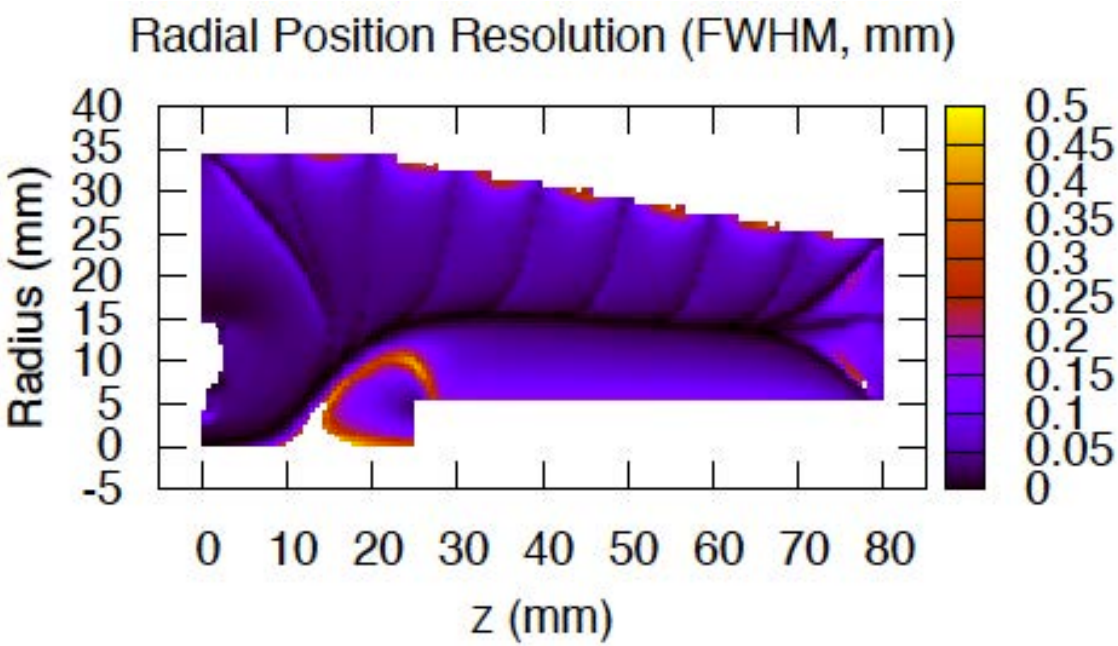
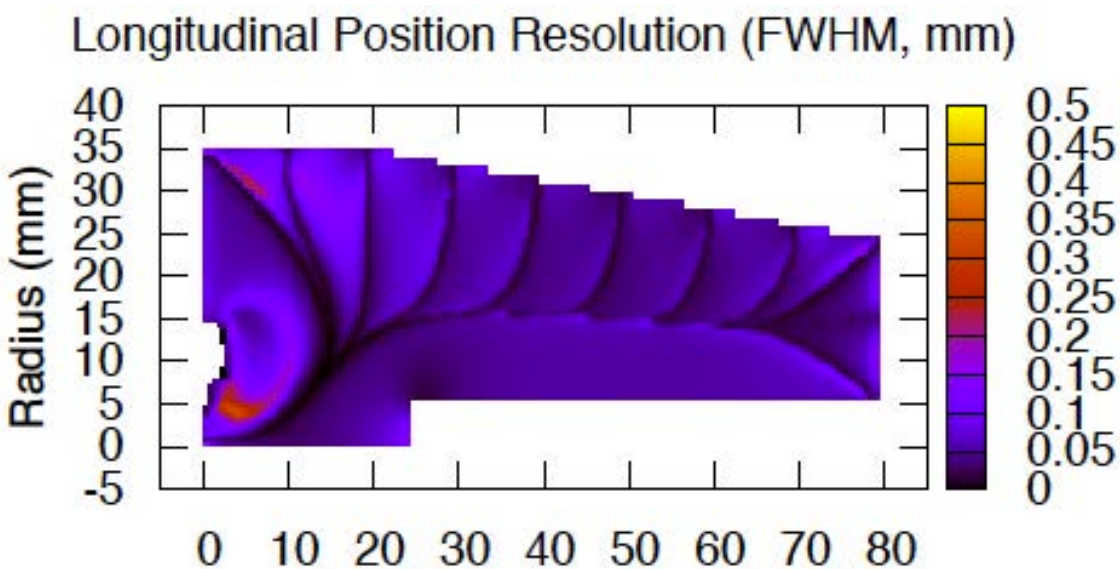


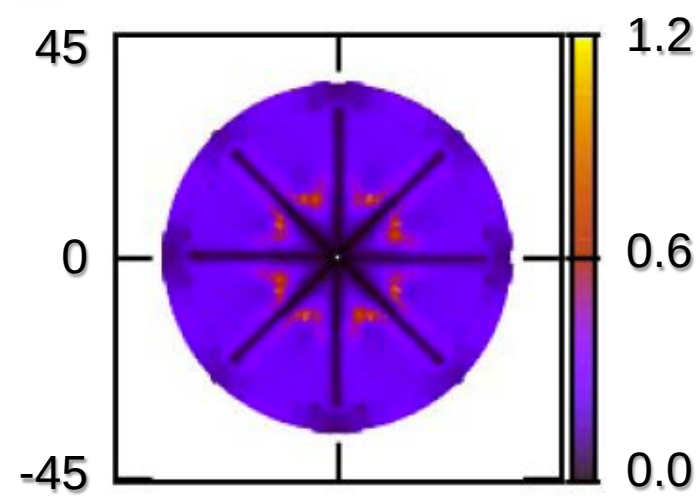
Theoretical Position Sensitivity



Best-case theoretical FWHM
for E ~ 300 keV,
preamp rise time ~ 70 ns
Point charges, no diffusion



Azimuthal resolution
at z = 5 mm

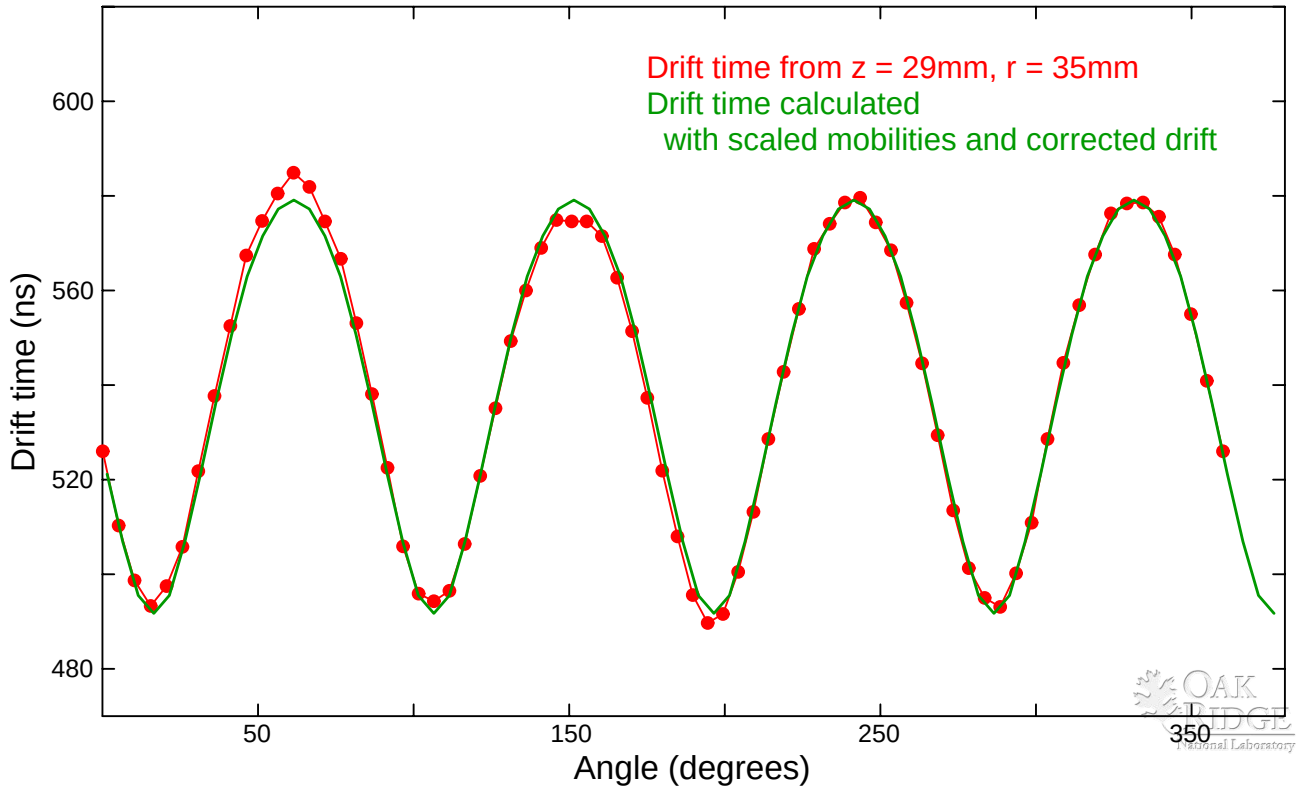


Excellent Position Sensitivity

- A factor of 3-4 better position resolution than GRETINA / AGATA
- Improvement comes from
  - Precise drift time information
    - Requires good Weighting Field in segments to get good start time!
      - Segments that are small in at least one dimension
  - Slower drift, therefore more sampling of segment WPs
  - Different (shorter) radial drift
  - Separation of longitudinal and azimuthal degrees of freedom
    - ➢ Smaller segmentation dimensions, even with fewer segments
- Can identify small regions of poorer resolution in sensitivity plots
- For gamma-ray tracking, much better information on the *number of interactions* is a big bonus

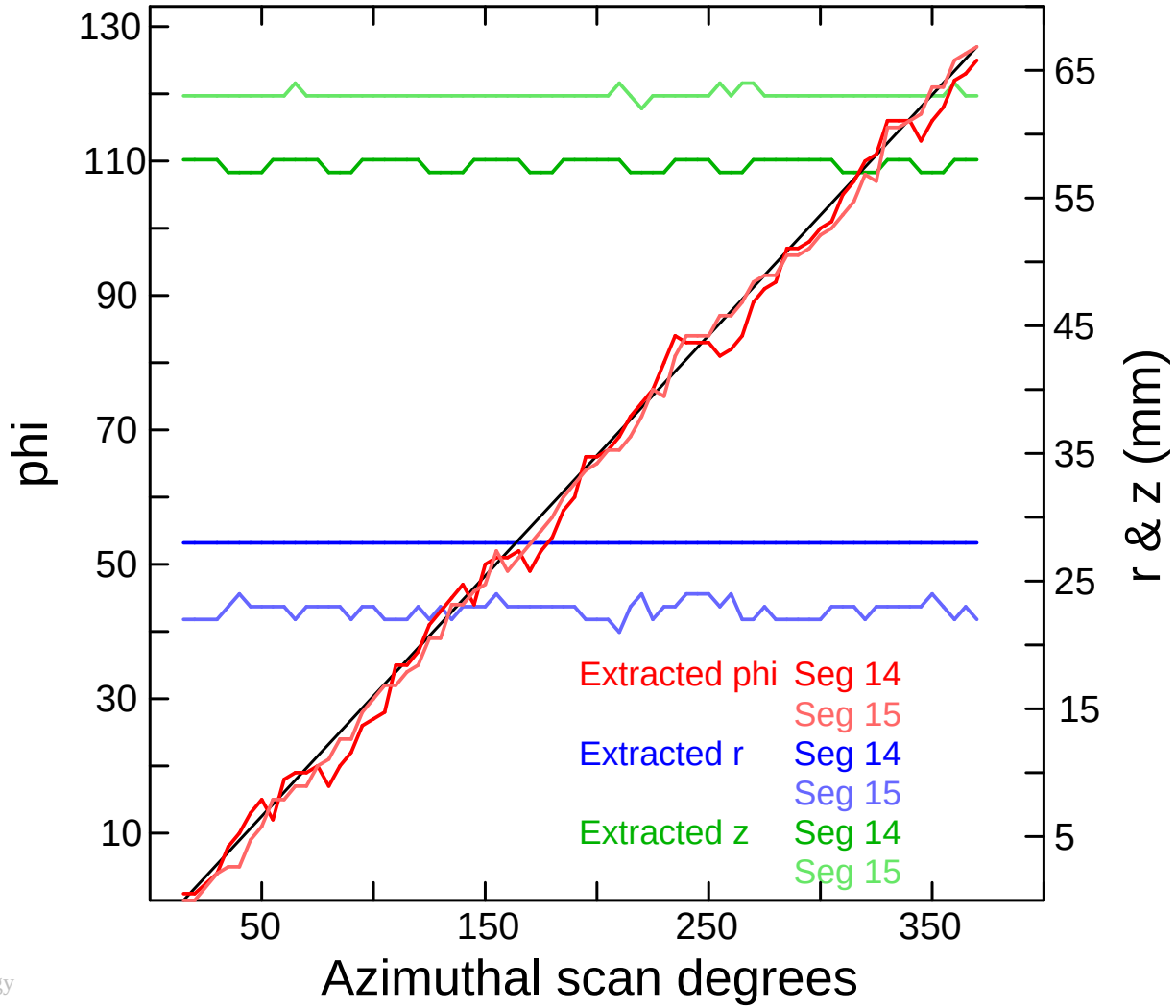
Drift Time: Azimuthal Scan

- Collimated Am source scanned around the circumference of the detector
- Scan along an azimuthal segment boundary, ➔ good start time
- Five minutes per point, highly reproducible (~ 1 ns)
  - ➢ Determine crystal axis to ~ 0.5 degrees
- Good fit requires adjusting both the electron mobilities (from literature) and directional asymmetry



Signal Decomposition

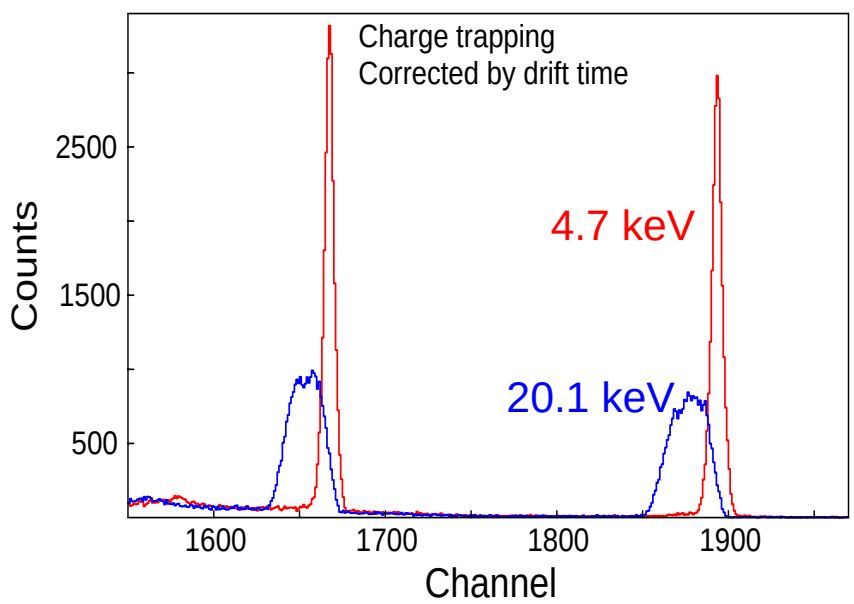
- Results of first test: 1mm x 1mm x 3° grid search



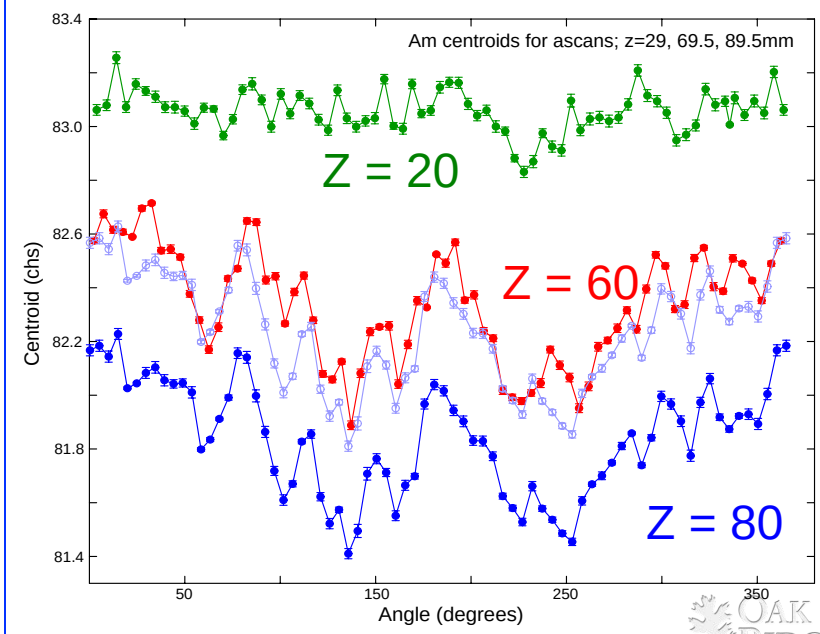
Problem: Energy Resolution

- Unsegmented p-type had excellent resolution; this detector is n-type.
- Long drift times give significant *trapping of electrons* while they are drifting to the point contact
- 15-20 keV FWHM at 1.33 MeV
- A simple correction factor that is linear in drift time gives good results
- Remaining degradation is from *azimuthal variation*; requires decomposition

Worst case, illumination from the side

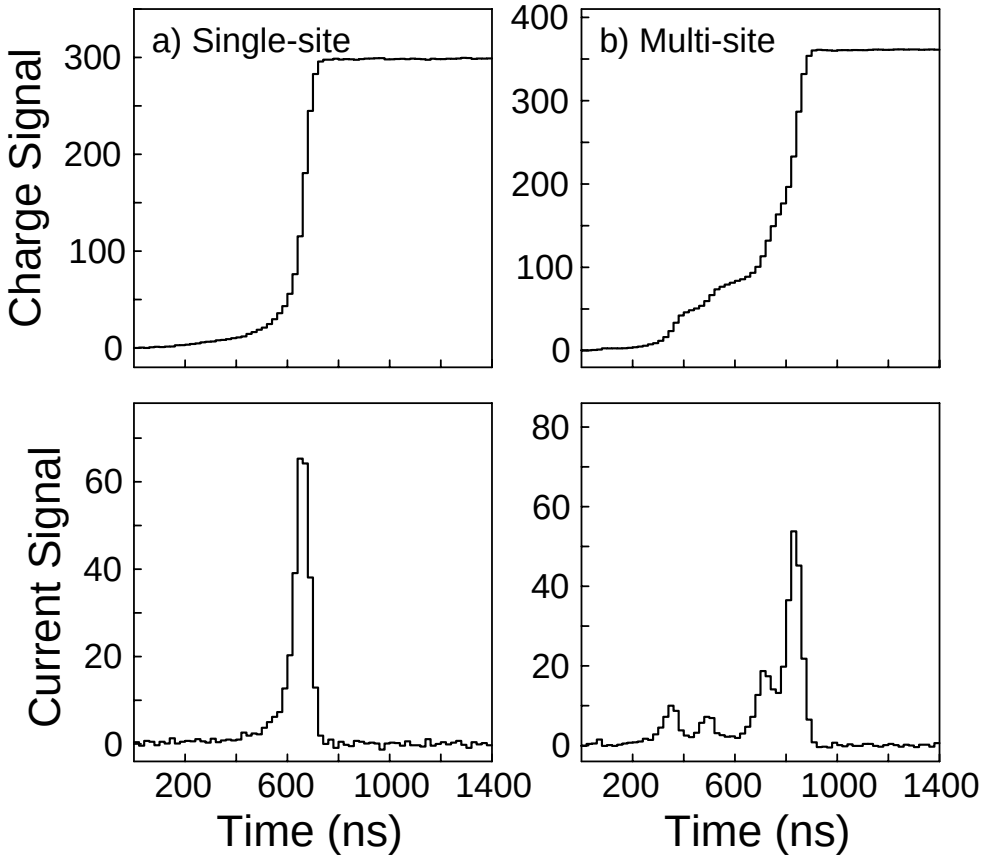


Peak position, azimuthal scans



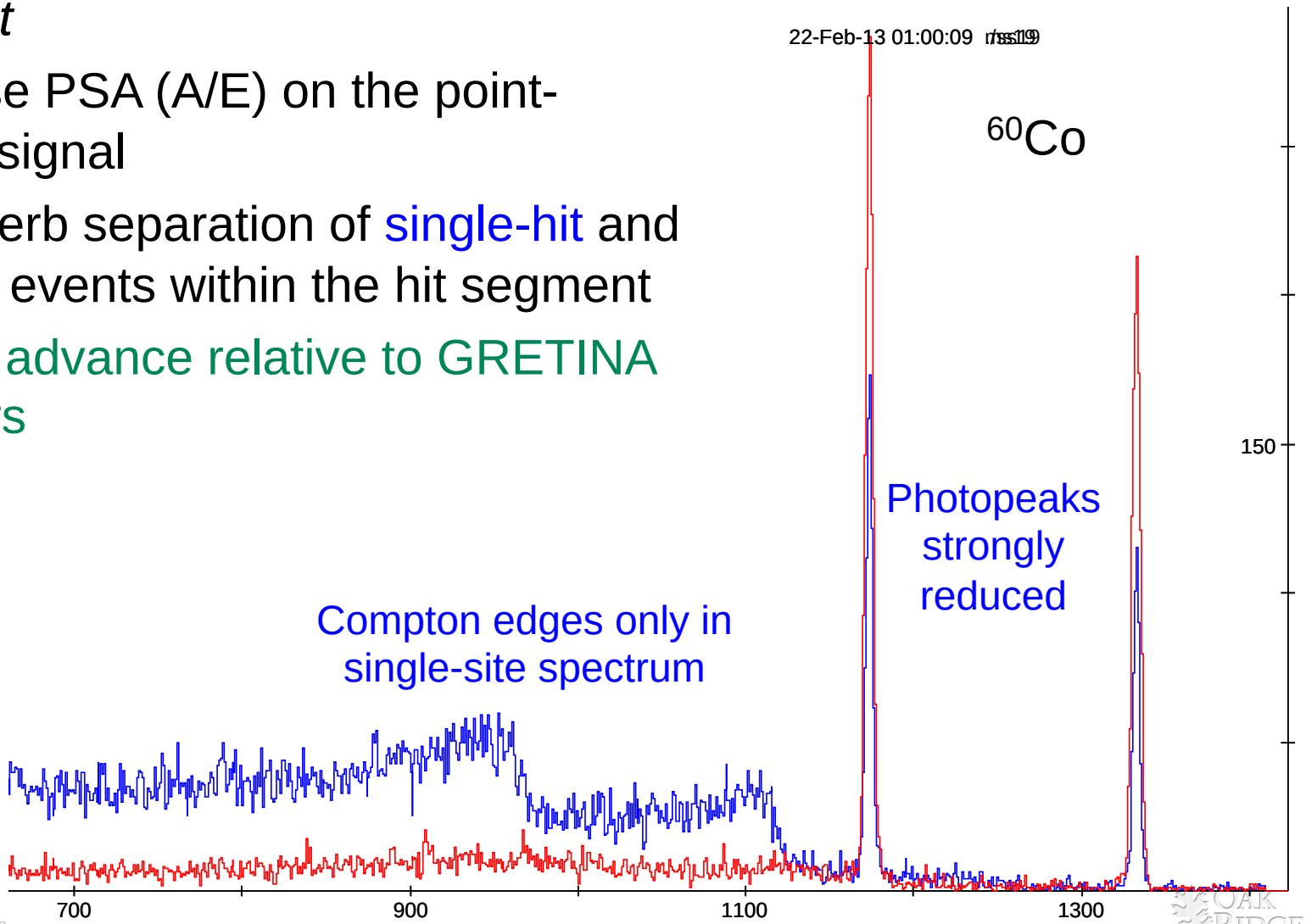
Number of Interactions

- For gamma-ray tracking, it is crucial that we know the *correct number of interactions*
- This is a difficult problem for GRETINA and AGATA, where more than multiple interactions often happen in the same segment



Number of Interactions: Segmented Prototype

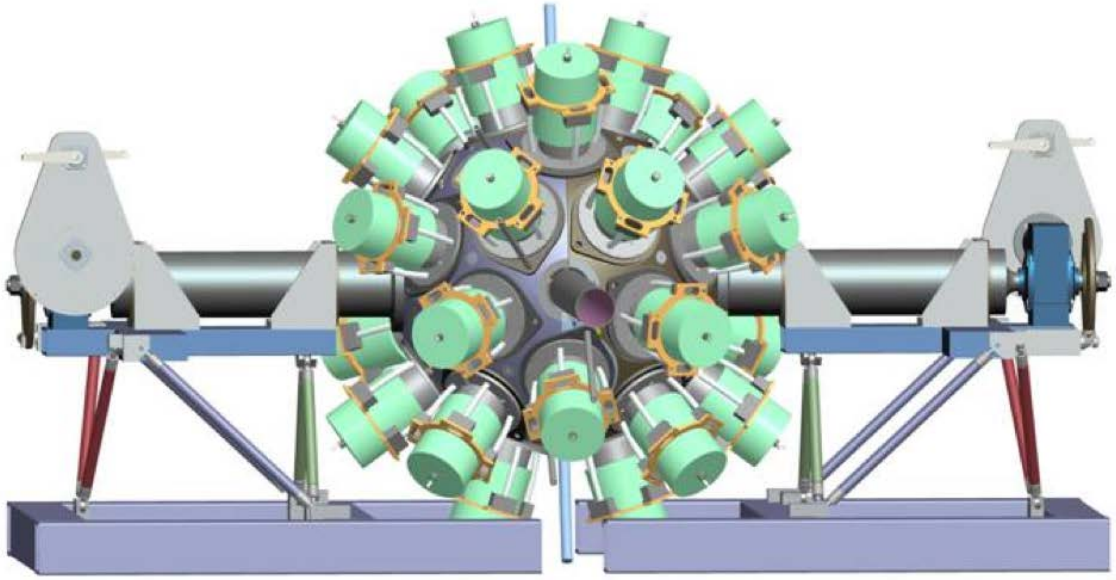
- Select events with only a *single hit segment*
- Then use PSA (A/E) on the point-contact signal
- Get superb separation of single-hit and multi-hit events within the hit segment
- A major advance relative to GRETINA detectors

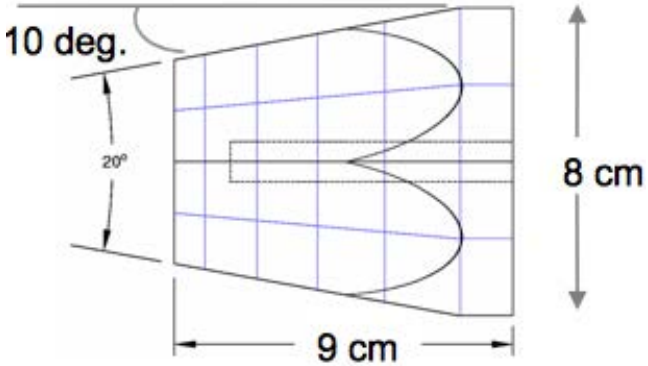


Towards GRETA

GRETA was given Critical Decision 0 (Mission Need) by DOE last week!

- GRETINA currently has 32 crystals (8 quad modules)
- GRETA will be the full 4π array of 120 crystals (30 quad modules)
- Could be completed by 2022 if construction begins in 2017





Segmented PC Detectors for GRETA?

- New *segmented p-type* prototype ordered by Liverpool group
  - SIGMA Project

- New effort on SPC detectors for GRETA at LBNL, including
  - 3D coincidence scans of ORNL prototype
  - Signal decomposition
  - Energy trapping correction

Segmentation for Rare-Event Searches?

A personal perspective

The good:

- Event localization
  - Some additional gamma background rejection
  - Could be used to locate background sources?
    - But need *many* events, so it would have to be a strong source
- Thin contacts; almost no dead layers
  - Less lost material, no uncertainty in fiducial mass
    - But need to worry about surface alphas
- Can locate crystal axes for Solar axions
    - But want a specific segmentation geometry

Segmentation for Rare-Event Searches?

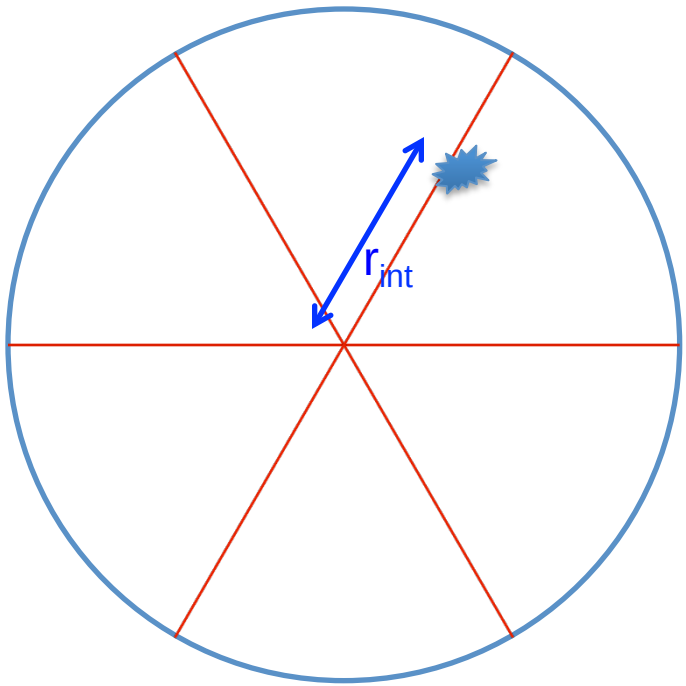
A personal perspective

The bad:

- Additional background sources
  - HV AC signal coupling capacitors
  - Additional LMFEs, cabling, connectors
- Reliability; Robustness under handling
- How much additional background rejection would they really give?
  - PPC PSA is extremely effective, much better than single-segment
  - Single-Compton-scatter of Tl 2614 keV line dominates remainder
  - Expect charge sharing between segments even for single-site events
    - Results in efficiency / fiducial loss

Rough Estimate of Efficiency Loss

- Gap is 0.5 mm
- Assume 120° spacing between segmentation lines, R = 35 mm
- Assume average charge-cloud diameter is ~ 1 mm at 2 MeV
- For uniform interaction density, $\langle r_{int} \rangle = \frac{2}{3} R = 23$ mm
- Then the fraction of single-site events with cloud on a gap is
  $\sim 6 * 2 \text{ mm} / 2\pi \langle r_{int} \rangle \sim 8\%$
  (more if we don't neglect the gap)
- So ~ 8% of single-site events could be misclassified as multi-segment events



Summary

- Novel inverted-coax design has real promise for greatly improved position sensitivity in tracking arrays
- Results for segmented prototype are extremely promising
  - Detailed validation of signal simulations
  - Much improved position sensitivity
  - Determination of number of interactions
  - Electron trapping from crystal dislocations is a problem for n-type dets
    - Requires signal decomposition for correction
  - Signal decomposition is in development
  - New p-type prototype on order
- Segmentation of PC detectors is unlikely to improve 0νββ searches
  - Minimization of readout components important
  - Simplicity wins?

Acknowledgements

Many, but especially

- I-Yang Lee (LBNL)
- Karin Lagergren, Ren Cooper, Mitch Allmond (ORNL)

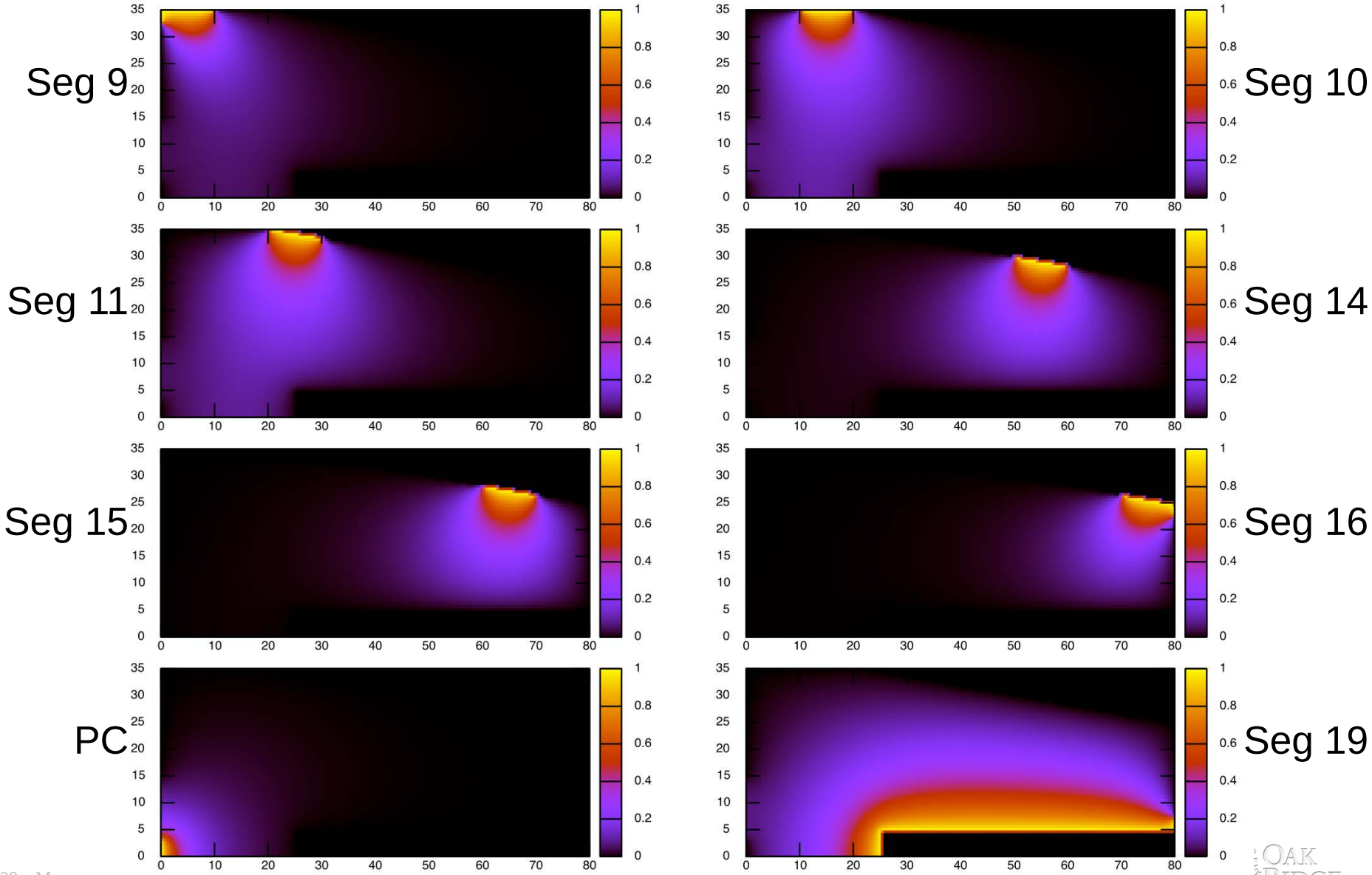
Conclusions for Gamma-ray Tracking

- Can use same crystal shapes as existing GRETINA detectors
- Signals are more constrained; reliable, precise basis calculations
- Better determination of *number* and positions of interactions
- Will yield better efficiency and Peak/Total from tracking
- Better Doppler-corrected energy resolution
- Excellent threshold and resolution at low energies
  - e.g. X-ray identification of atomic number for reaction products
- Fewer segments, no problem using cold FETs

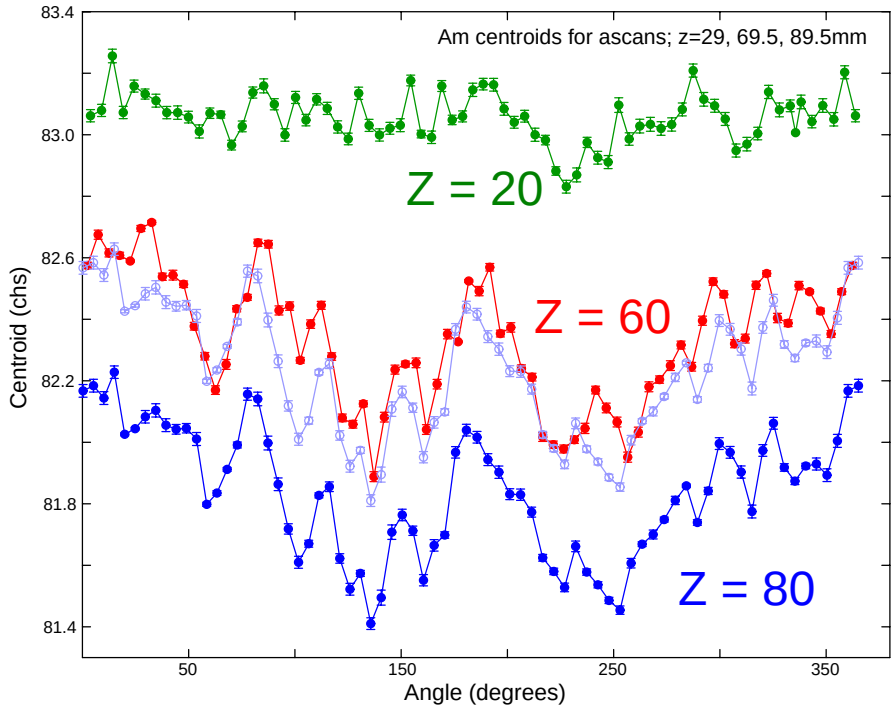
- Cost similar to GRETINA modules

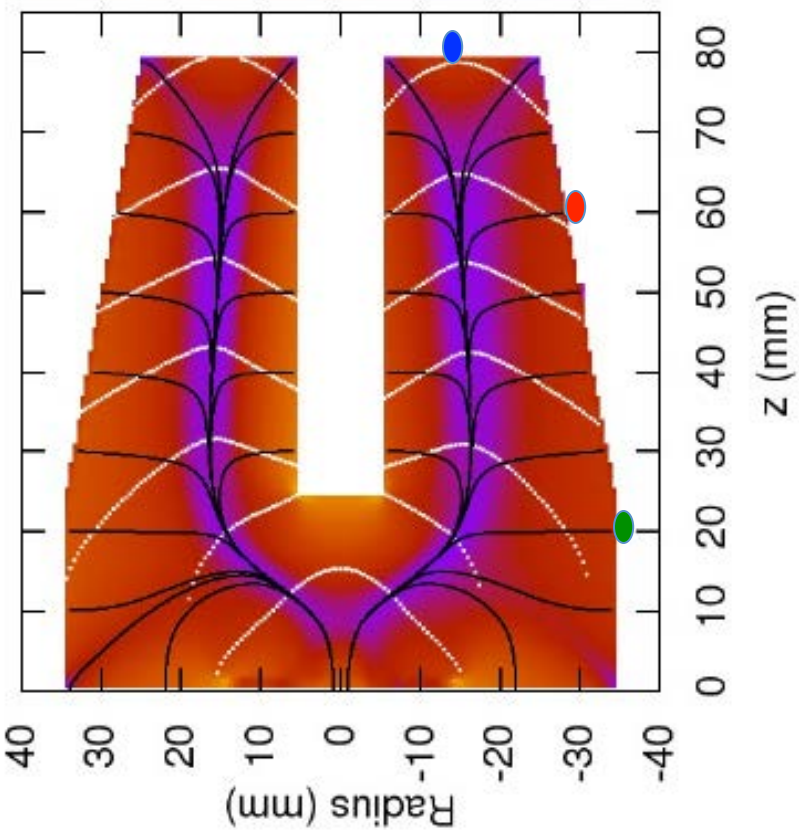
- Energy resolution requires further work for n-type detectors
- Long drift time reduces count-rate capability slightly
  - Still dominated by ~ 4 μs signal integration time for energy
- Signal decomposition requires more CPU cycles

Selected Weighting Potentials



Charge Trapping: Position Dependence



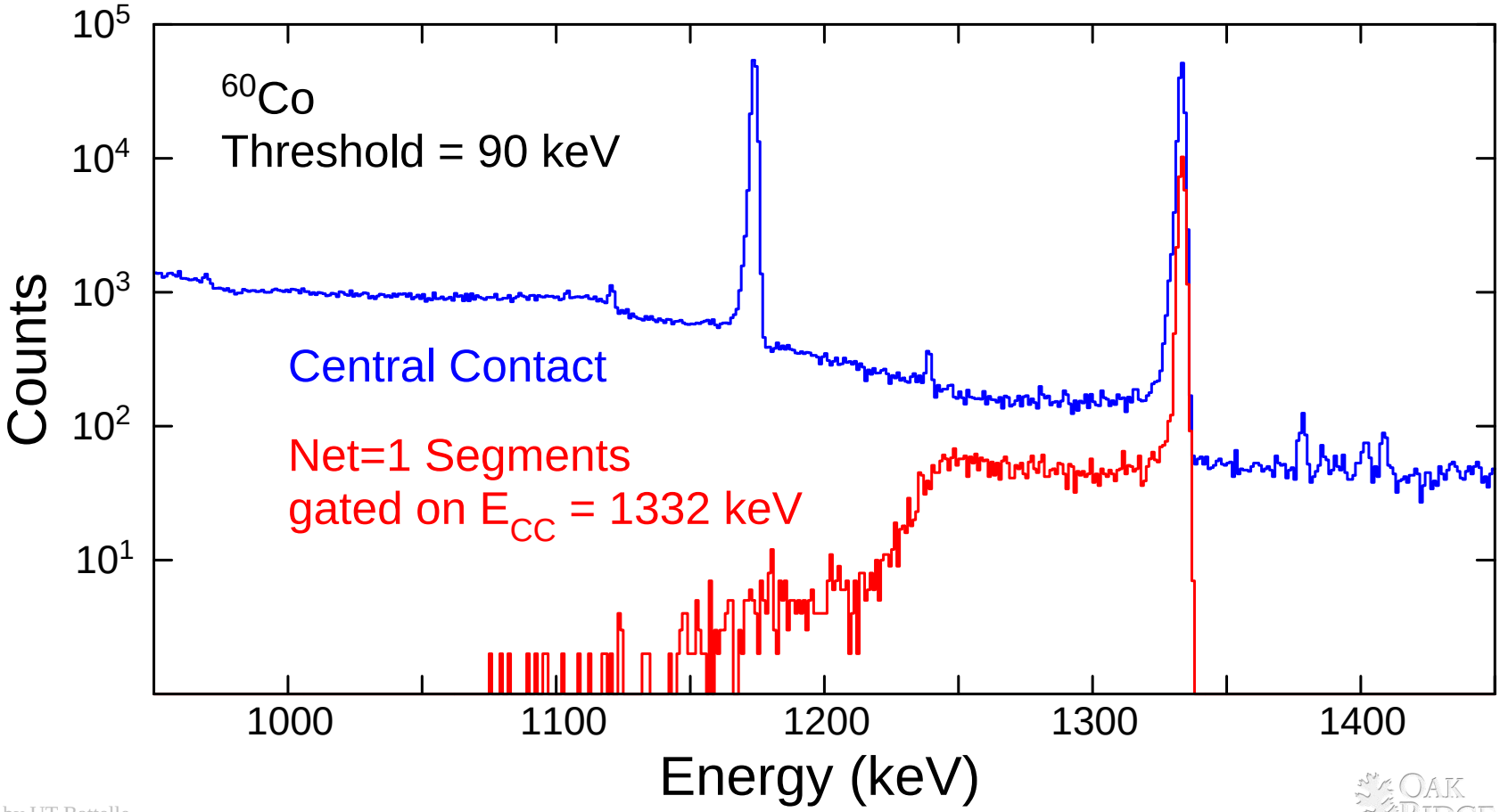


Hypothesis:

- Electrons spend most of the time drifting parallel to the z-axis
- Crystal dislocations also propagate along z
- So a single dislocation at a specific angle may trap multiple electrons
- Correction requires signal decomp. and detailed characterization

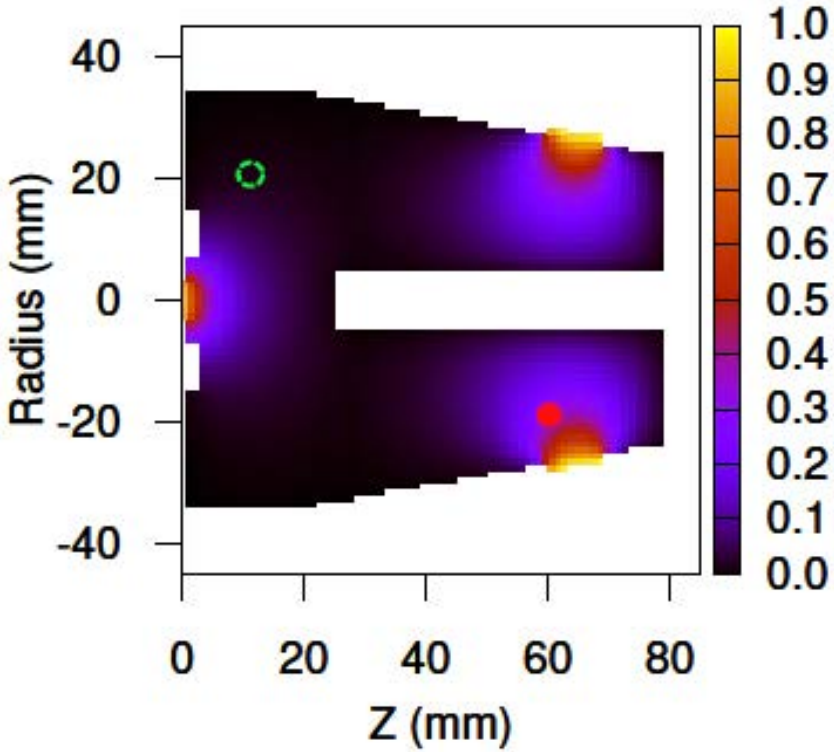
Segment Energy Threshold Effects in GRETINA

- ^{60}Co single-segment spectrum ("Net = 1") with gate on 1332 keV in core
- Segment threshold = 90 keV
- About 15% of counts are lost from the 1332-keV peak

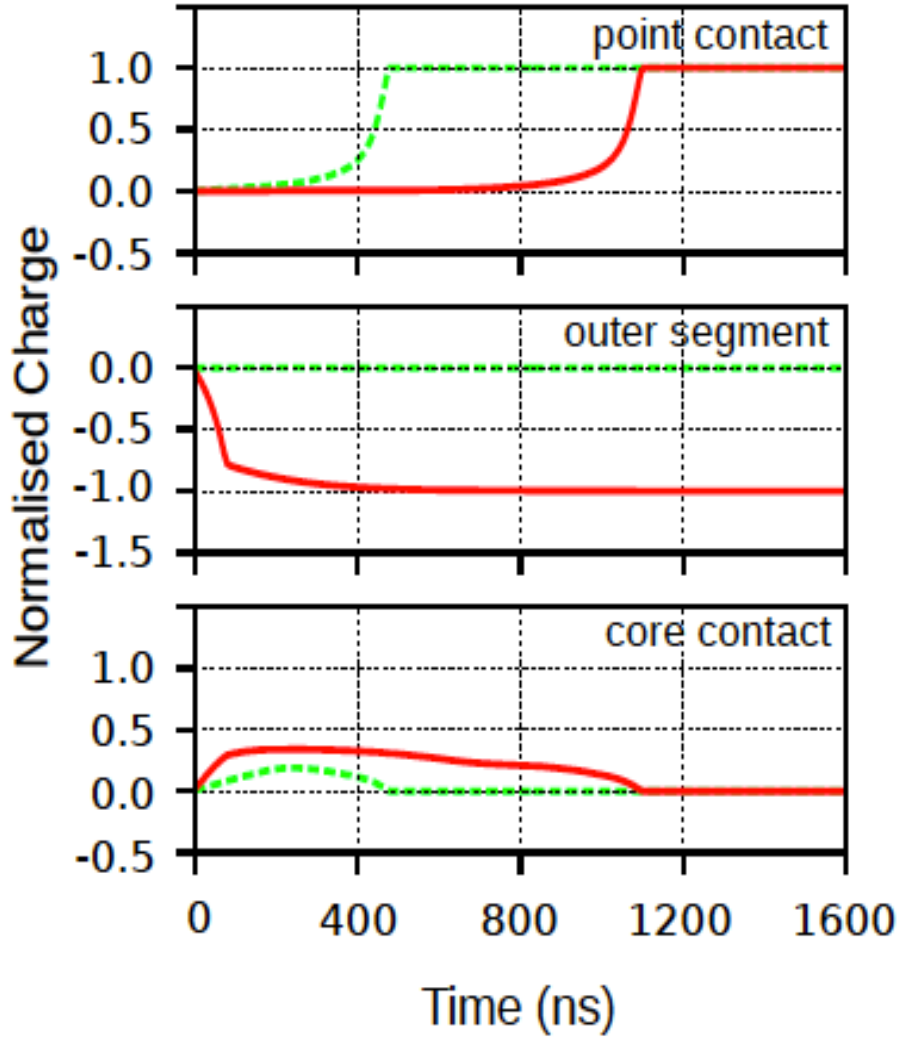


Calculated Signals

Weighting Potentials

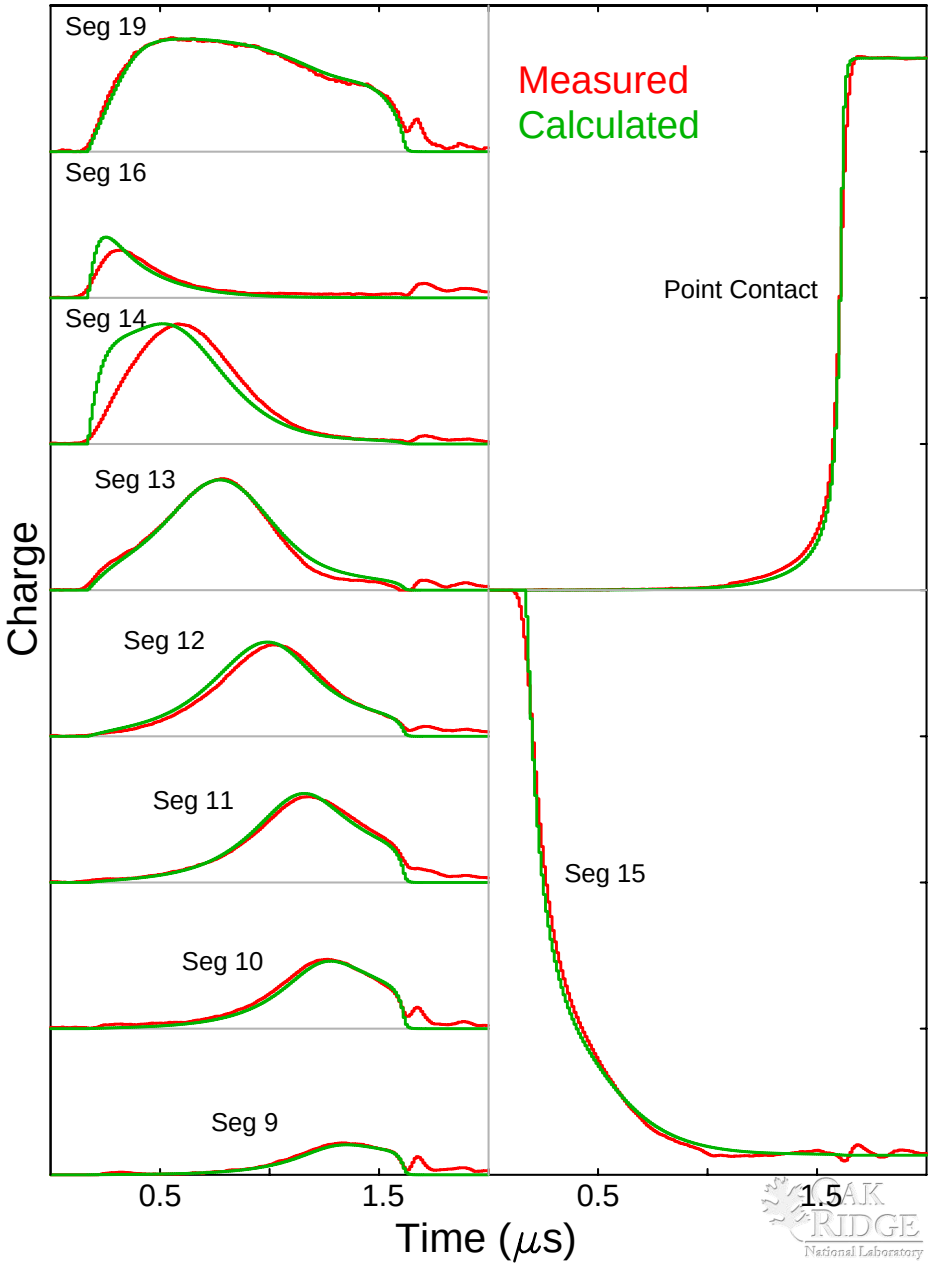


Signals from two different points



Performance: Calculated Signals

- Results of first test
- Simulation parameters not optimized
  - Impurity profile, temp.
  - Preamplifier response
- Next steps:
  - Add cross-talk
  - Finite size of charge cloud
- Longer term:
  - Local variations in impurity concentration?
  - Signal decomposition
  - Measure position resolution



Am "SuperPulses"

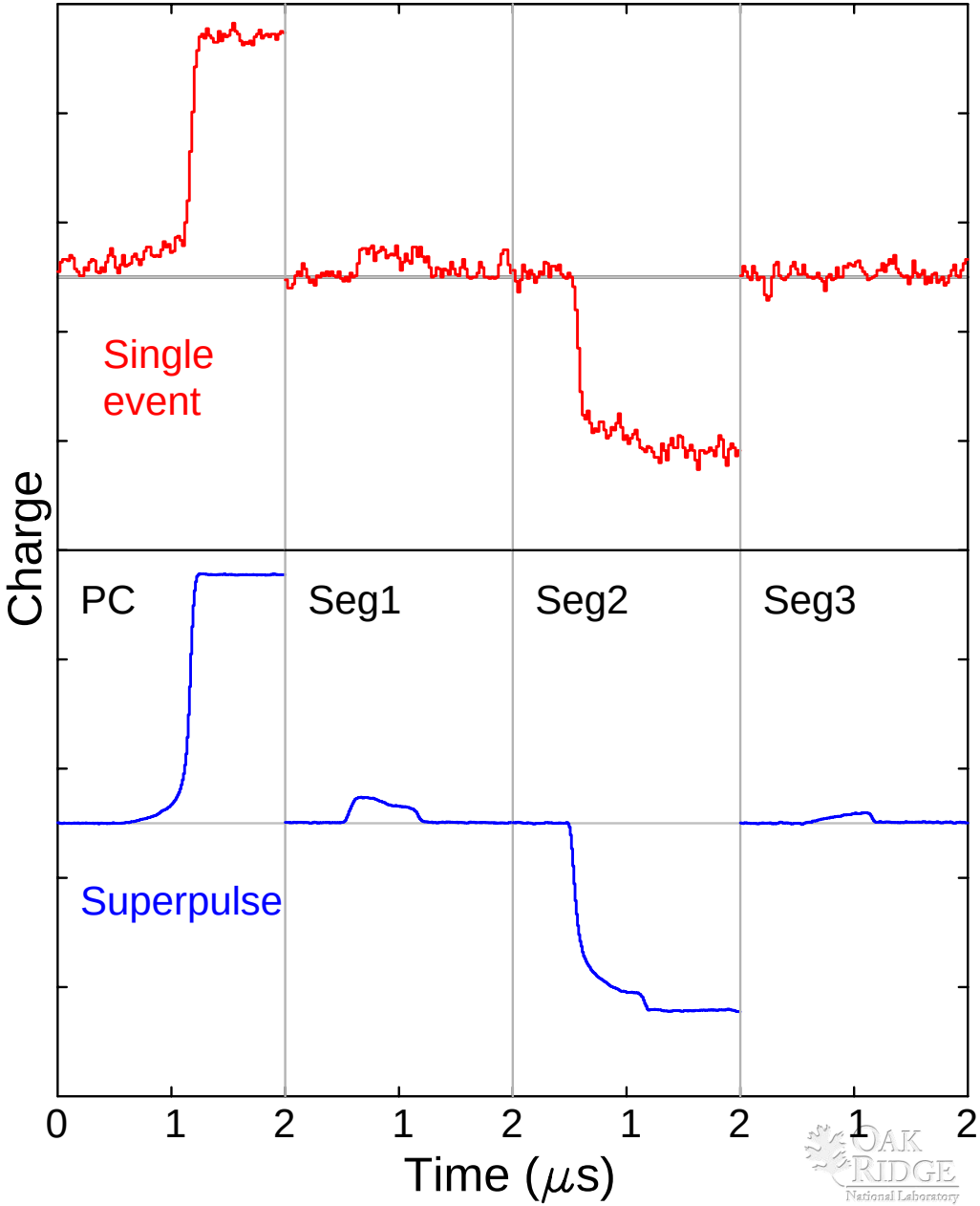
- Finely collimated Am source, directed at known location on the detector surface
- Resulting 60-keV signals have poor signal-to-noise ratio

➢ Select events with 60 keV in a single hit segment

➢ Use PSA to accept only single-site events

➢ Time-align events using the PC signal (at 60% time)

➢ Average the signals to reduce the noise to a negligible level

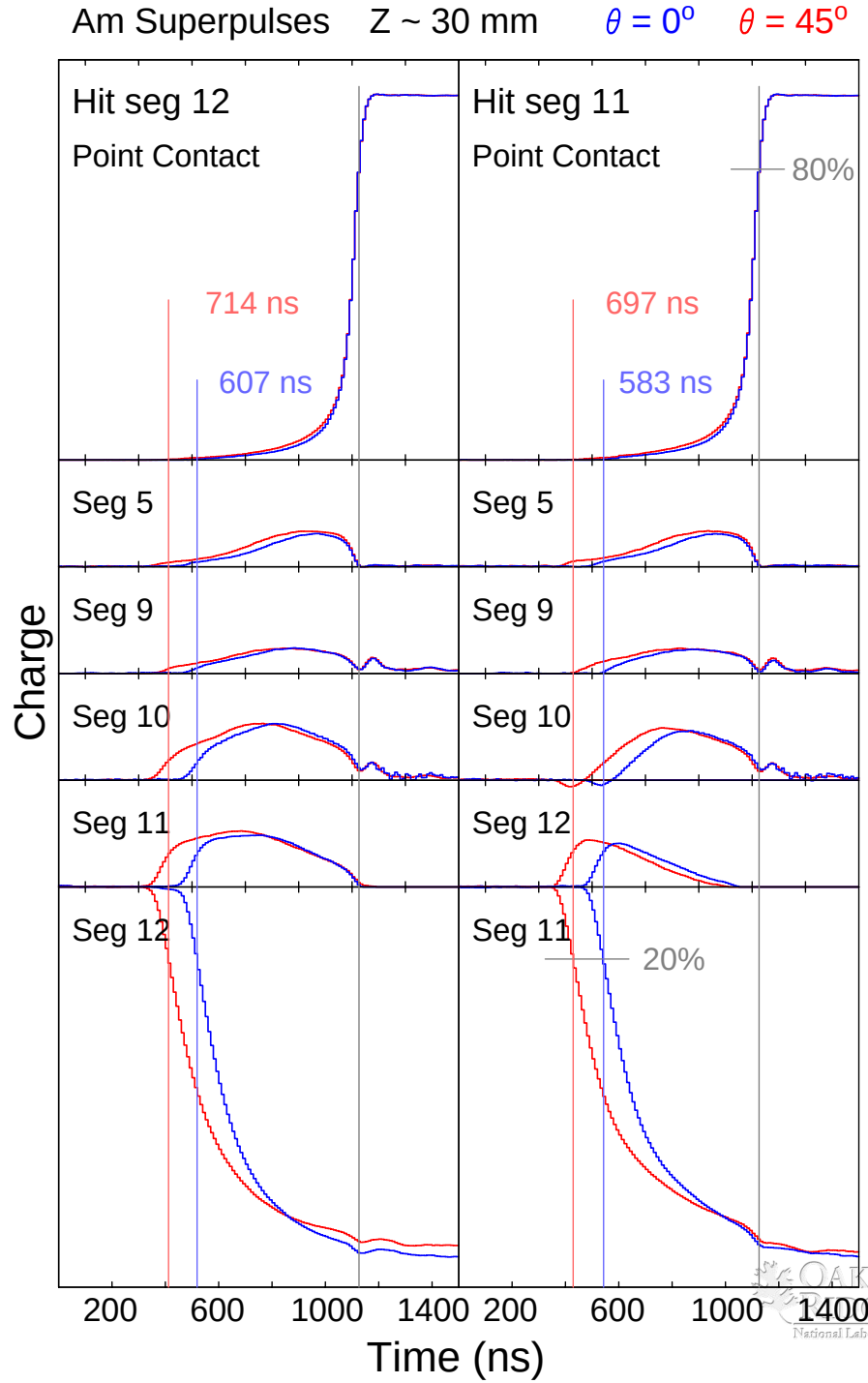


Extracting Drift Times
from SuperPulses

- Time from 20% of segment signal to 80% of point-contact signal
- Collimated spot overlaps the boundary between segments 11 and 12

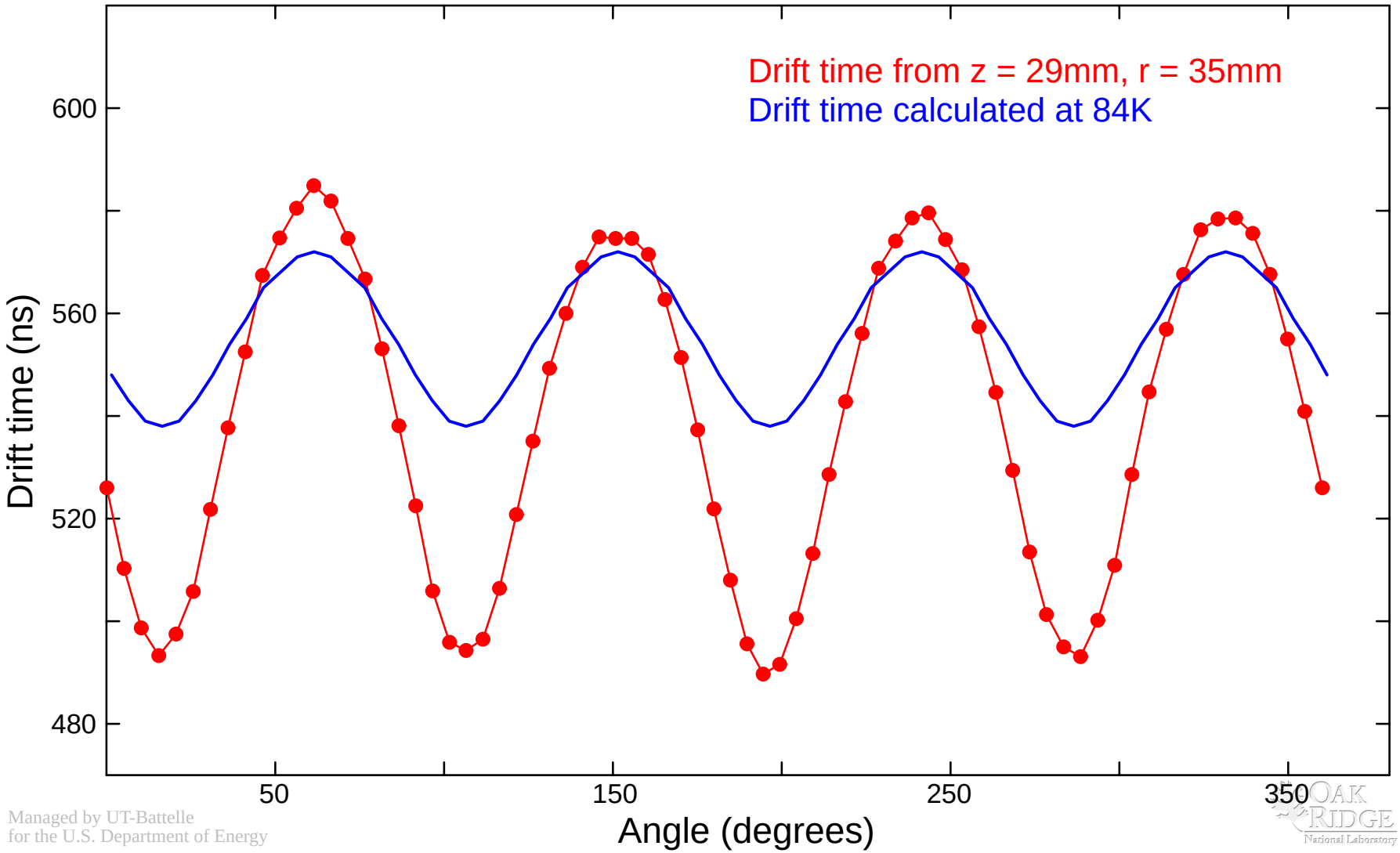
Blue: On crystal axis

Red: At 45 degrees to axis



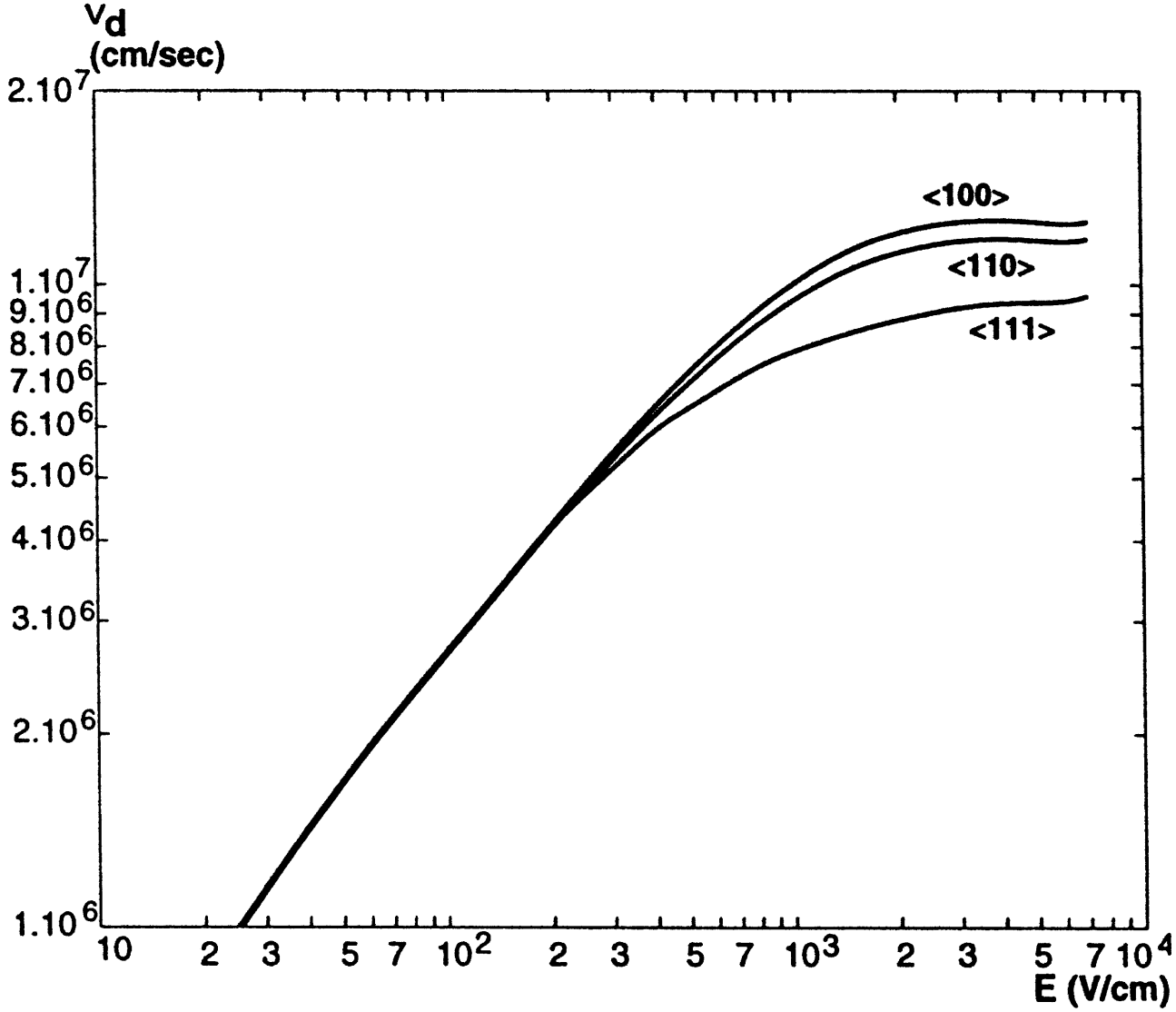
Azimuthal Scan – Measured and Calculated

- Collimated Am source scanned around the circumference of the detector
- Calculated drift times give far too small a variation with angle



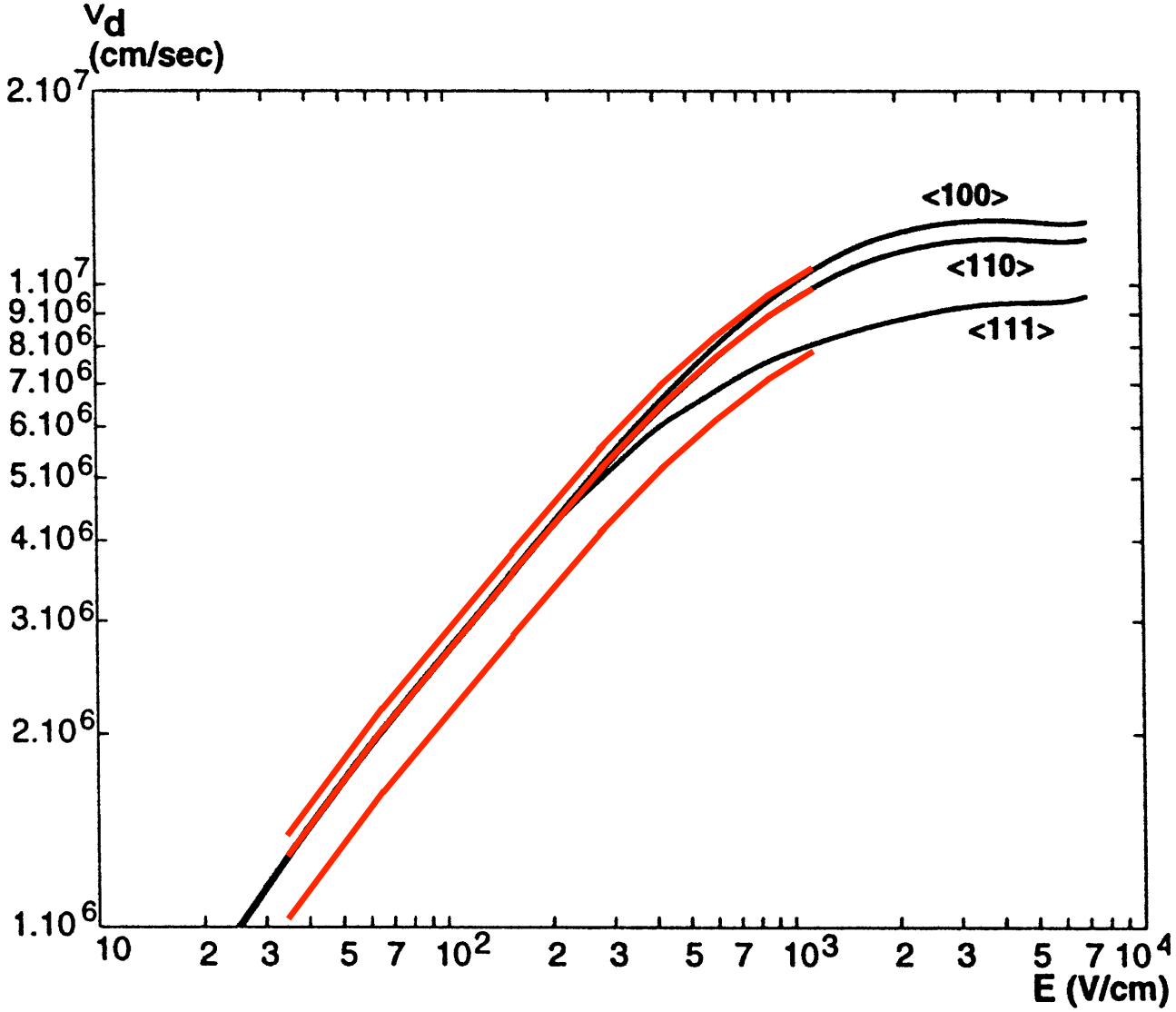
Standard Electron Mobilities

L. Mihailescu *et al.*, Nucl. Instrum. Meth. **A447** (2000) 350



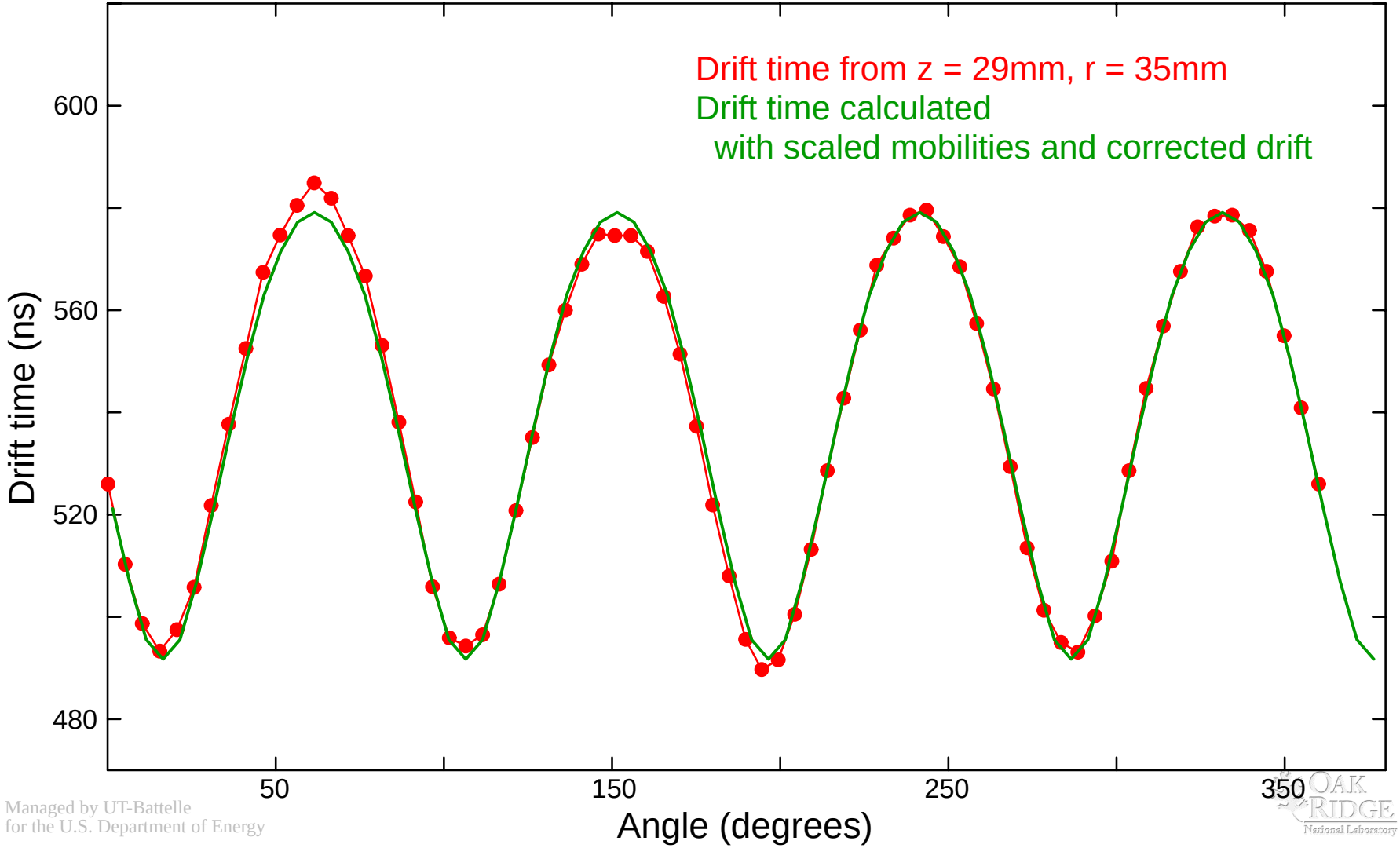
Modified Electron Mobilities

For E < 1000 V/cm, scale <110> up or down to get <100> or <111>



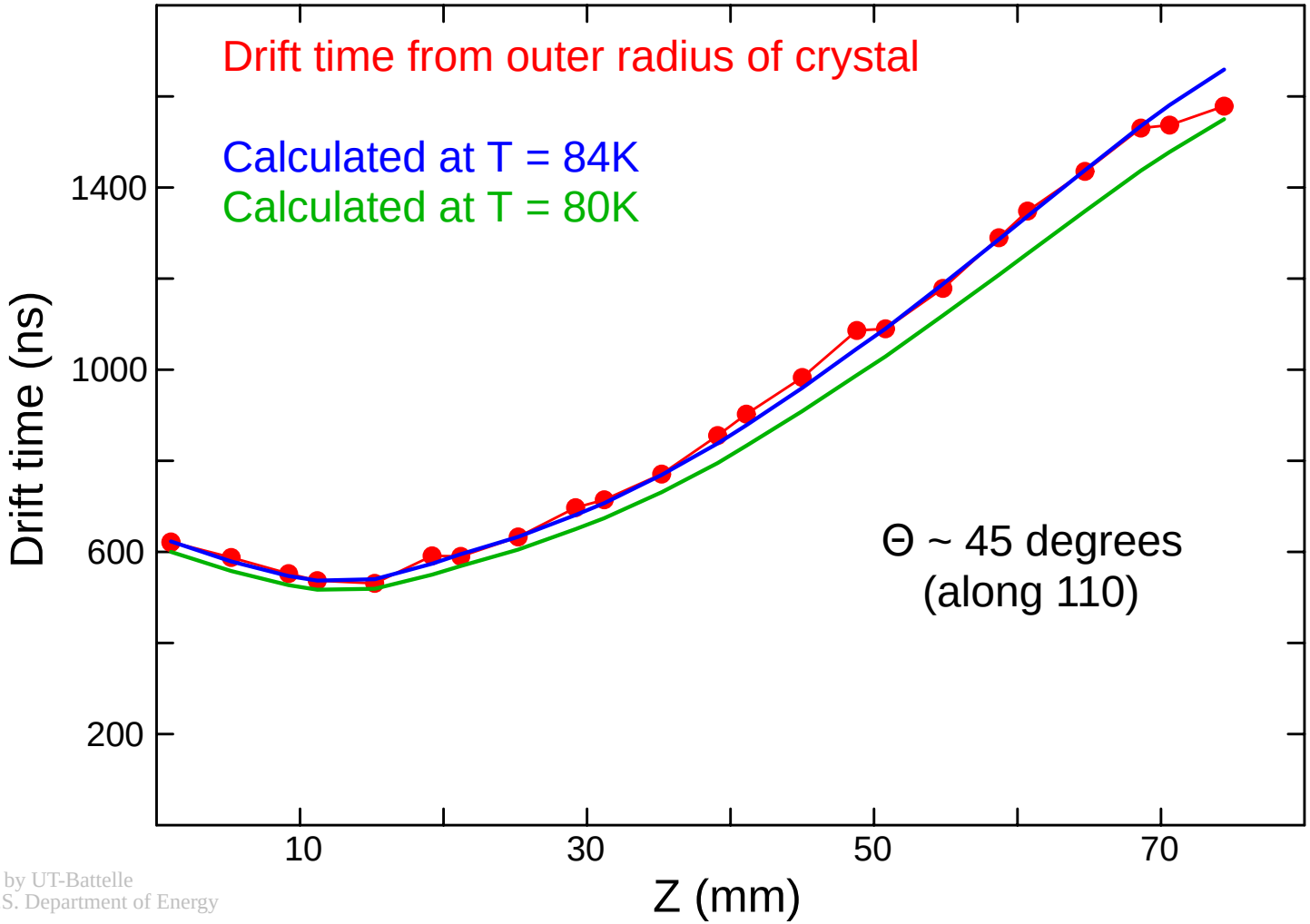
Azimuthal Scan with Modified Mobilities

Adjusting both the mobilities and the drift parameters gives the correct angular variation



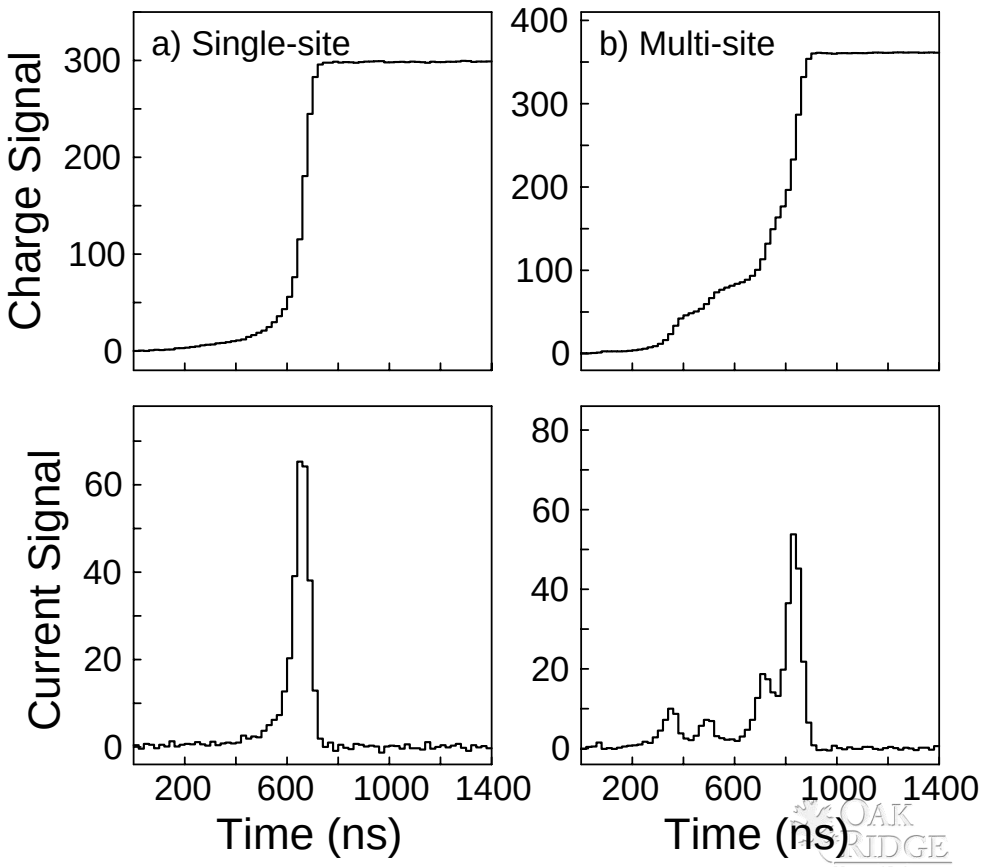
Longitudinal Scan

- Superpulse allows excellent determination of drift times
- Best-fit temperature depends on assumed impurity concentration gradient



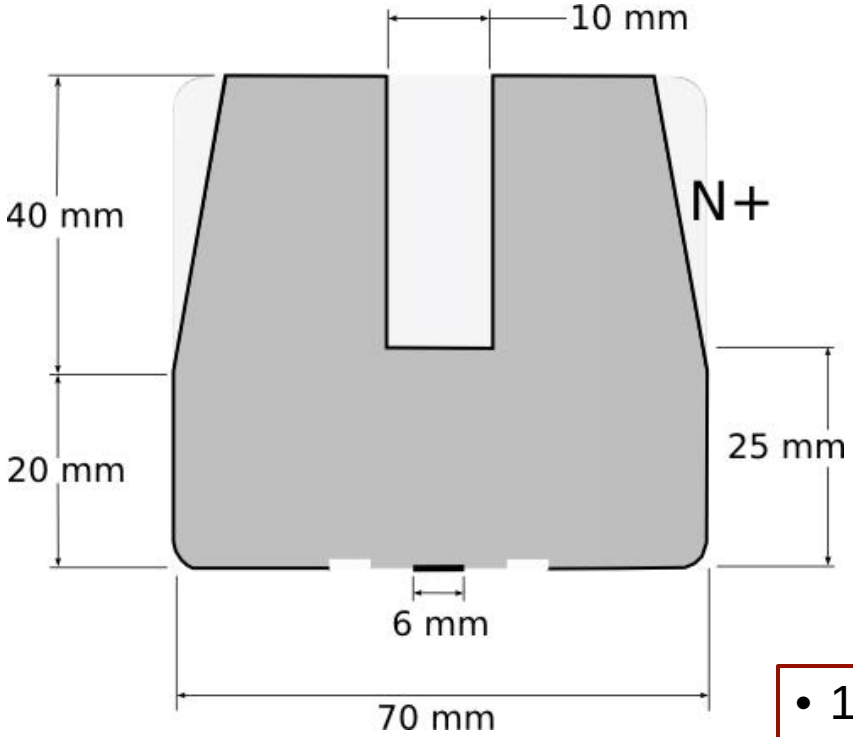
Multi-Site / Single-Site Discrimination

- Higher-energy gammas usually interact several times in detectors
- Long charge drift times and localized “weighting potential” give separate current pulse for each charge cloud
- Superb separation of single-hit and multi-hit events based on point-contact signal shape
- Important e.g. for 0νββ, where events of interest are single-site
- Important for gamma-ray tracking, where knowing the correct *number of interactions* is crucial



Unsegmented Prototype

- 70 mm x 60 mm tapered cylindrical detector
- Purchased with ARRA funds from DOE ONP
- Produced by Canberra Meriden (CT, USA)



Prototype has excellent resolution and efficiency

Depletion Voltage	(+) 2600 V
Operating Bias	(+) 3500 V
Leakage Current	<10.0 pA
Capacitance	~ 1 pF

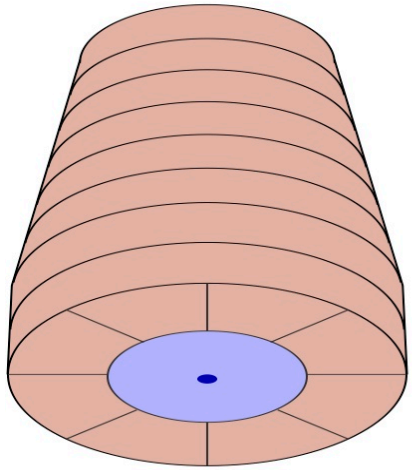
- 1.80 keV FWHM at 1332 keV (6μs shaping)
- 320 eV FWHM noise (6μs shaping)
- 44% relative efficiency

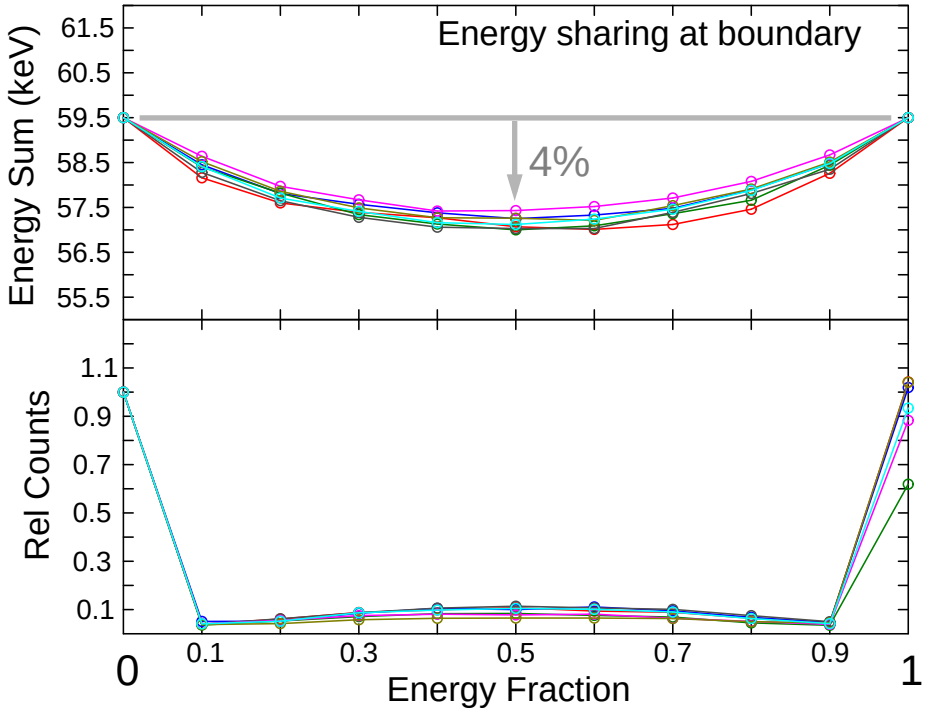
Segment Charge Sharing Effects

Study effect of energy loss at segment boundaries

- Tightly collimated Am source directed at a segmentation line
- Select events with 60 keV in point contact
- Calculate energy sharing and energy sums in neighboring segments

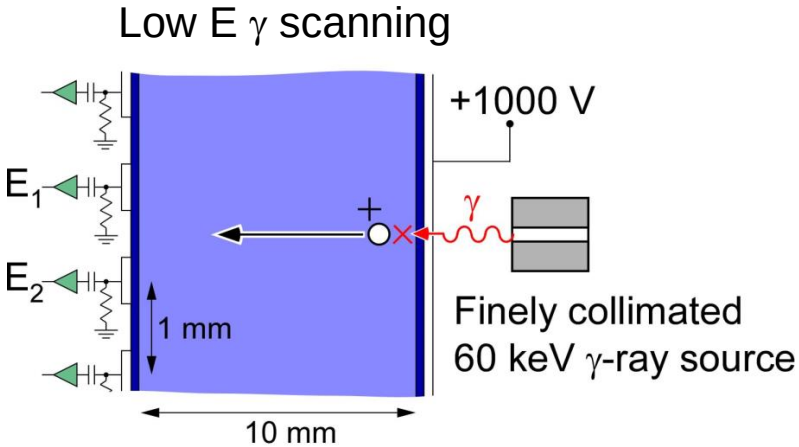
- Up to ~ 4% charge loss for events with energy sharing
  - Consistent results for all segment boundaries studied





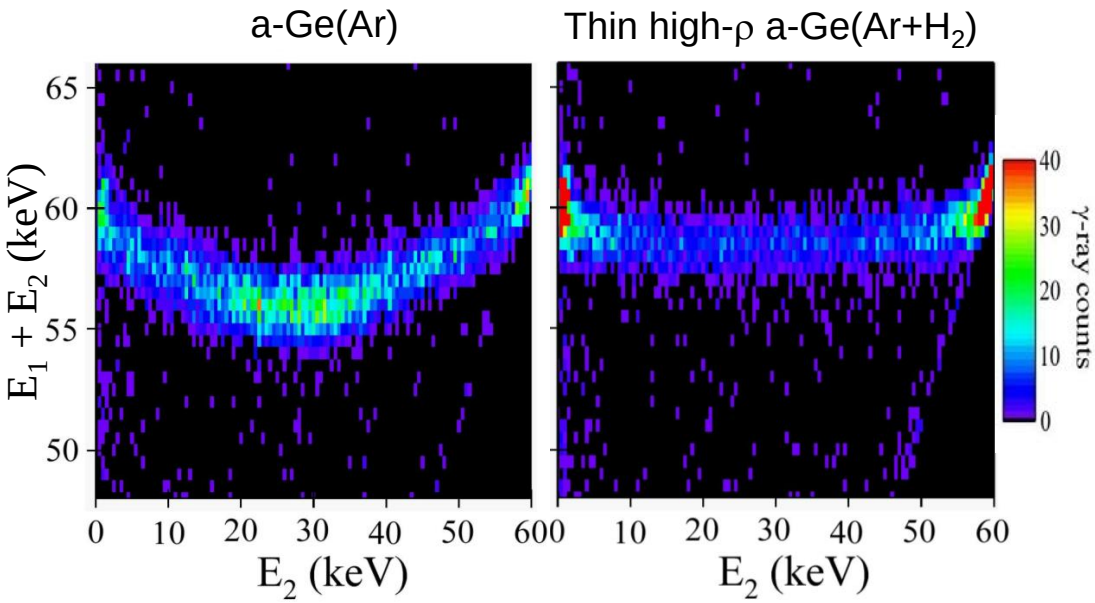
DSSD Segment Sum: Mark Amman

Inter-contact charge collection



Observations:

- Both a-Ge and a-Si films could be adjusted to inhibit inter-contact charge collection
- Sputter gas H_2 content and pressure are critical parameters: Q. Looker, M. Amman, K. Vetter, in preparation



Other solutions:

- Smaller gaps
- Etch away amorphous layer between electrodes: D. Protic and T. Krings, IEEE TNS 50, 998 (2003)
- Field shaping electrodes: M. Amman and P.N. Luke, NIM A 452, 155 (2000)
- Post acquisition correction

Origin

- Some of the charge is collected to the inter-segment gap, where any net field parallel to the surface is very weak
  - Sum of segment weighting potentials on gap < 1.0
  - The charge is eventually collected via diffusion or surface channel
  - But some remains outside the integration time window
- If the charge cloud overlaps the gap - even a little - some energy will be lost
- Effect can only be reduced by using a narrower inter-segment gap