Single Crystal Large Volume Position Sensitive HPGe Detectors

A novel design for large position-sensitive HPGe detectors

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HPGe Detectors

Hyper-Pure Ge (HPGe) detectors are the "gold standard" for gamma-ray spectroscopy

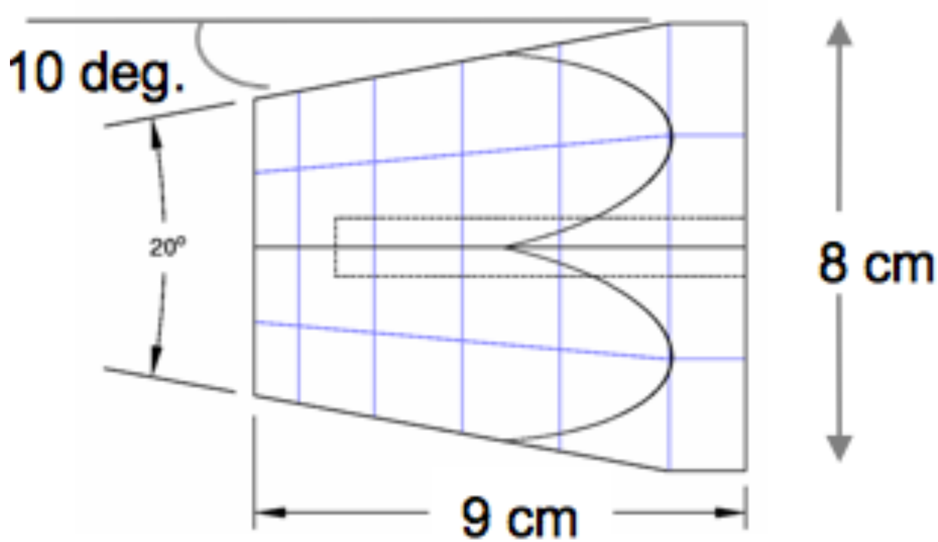
- Unsurpassed energy resolution
- Indispensible to in-beam nuclear structure studies for many decades; e.g. GammaSphere, GRETINA
- Standard closed-end coaxial geometry has been ubiquitous since the 1970s

Recent development of γ-ray tracking (GRETINA) depends on good position resolution through segmentation of detector electrodes

- Efficiency, peak-to-total ratio, and energy resolution of a γ-ray tracking array all depend strongly on the achieved position resolution
- Detectors with improved resolution and efficiency could be used for *Compton imaging,* with important applications in medical imaging, γ-ray astronomy, homeland security, etc.

GRETINA detectors

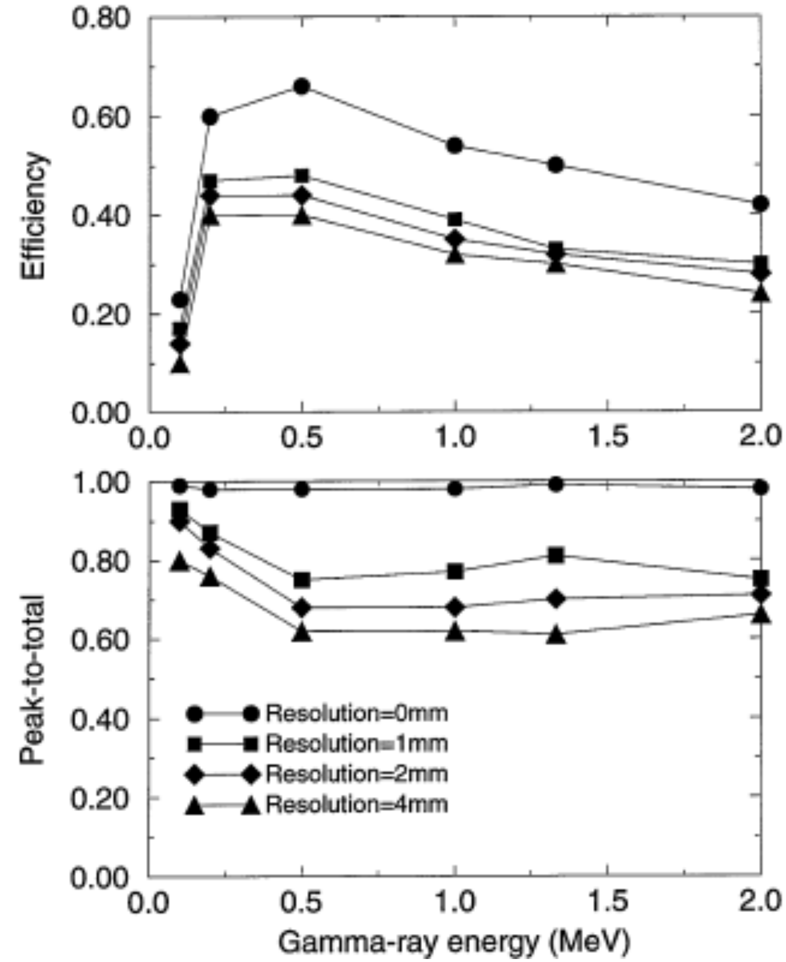
- Tapered irregular hexagons 8 x 9 cm
- Closed-end coaxial crystals, n-type
- 36-fold segmentation (6 azimuthal, 6 longitudinal)
- 37 signals (including central contact)



New Detector Geometries for GRETA?

- After signal decomposition, the position resolution from GRETINA detectors is 1-2 mm RMS
  (2.5 – 5 mm FWHM)
- Better position resolution would improve efficiency and P/T ratio
- Double-sided strip Ge detectors can provide resolution as good as ~ 0.1 mm, but are limited to about 20mm thickness

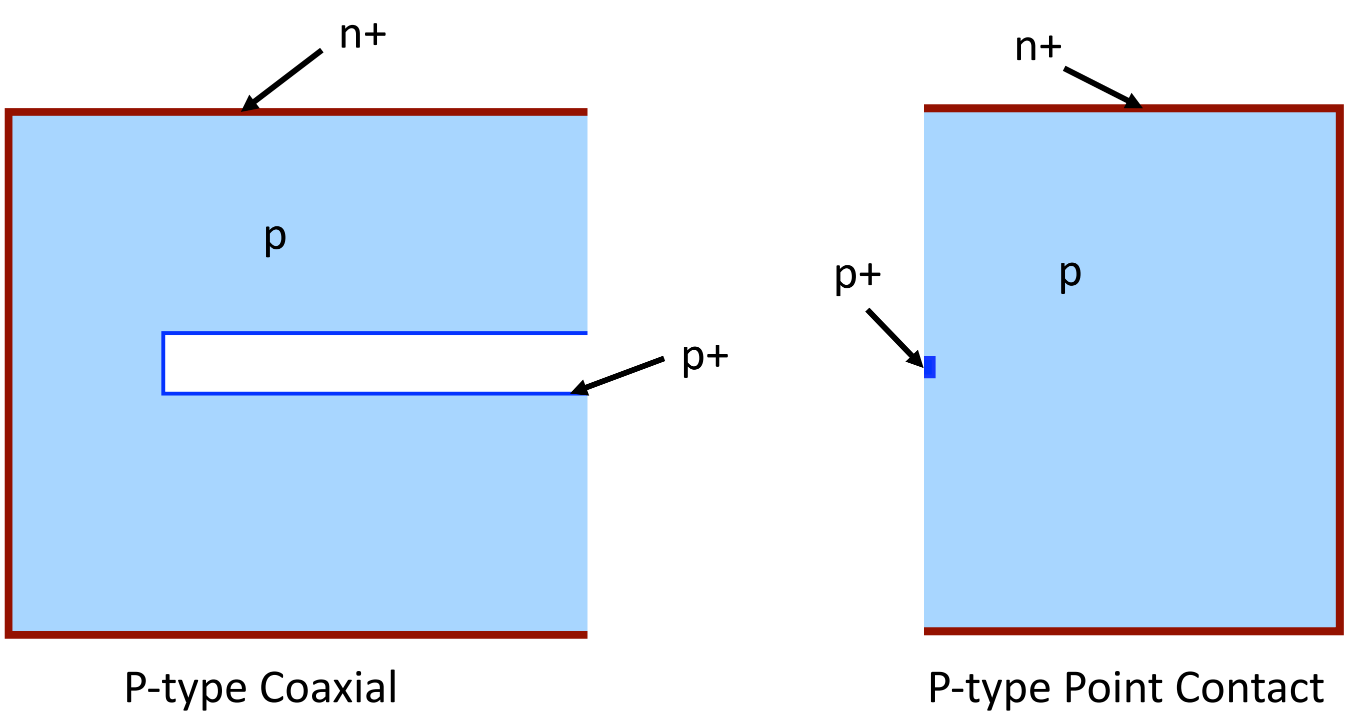
Can we build large detectors with better position resolution?



Recent Development: Point Contact Detectors

P-type Point-Contact (PPC) detectors

- No deep hole; small point-like central contact
- Length is shorter than standard coaxial detector
- Different interaction positions produce similar-shaped signals, but with different delays (drift times)
- Excellent discrimination between single-site and multi-site events
- Low capacitance (~ 1 pF) gives superb resolution at low energies

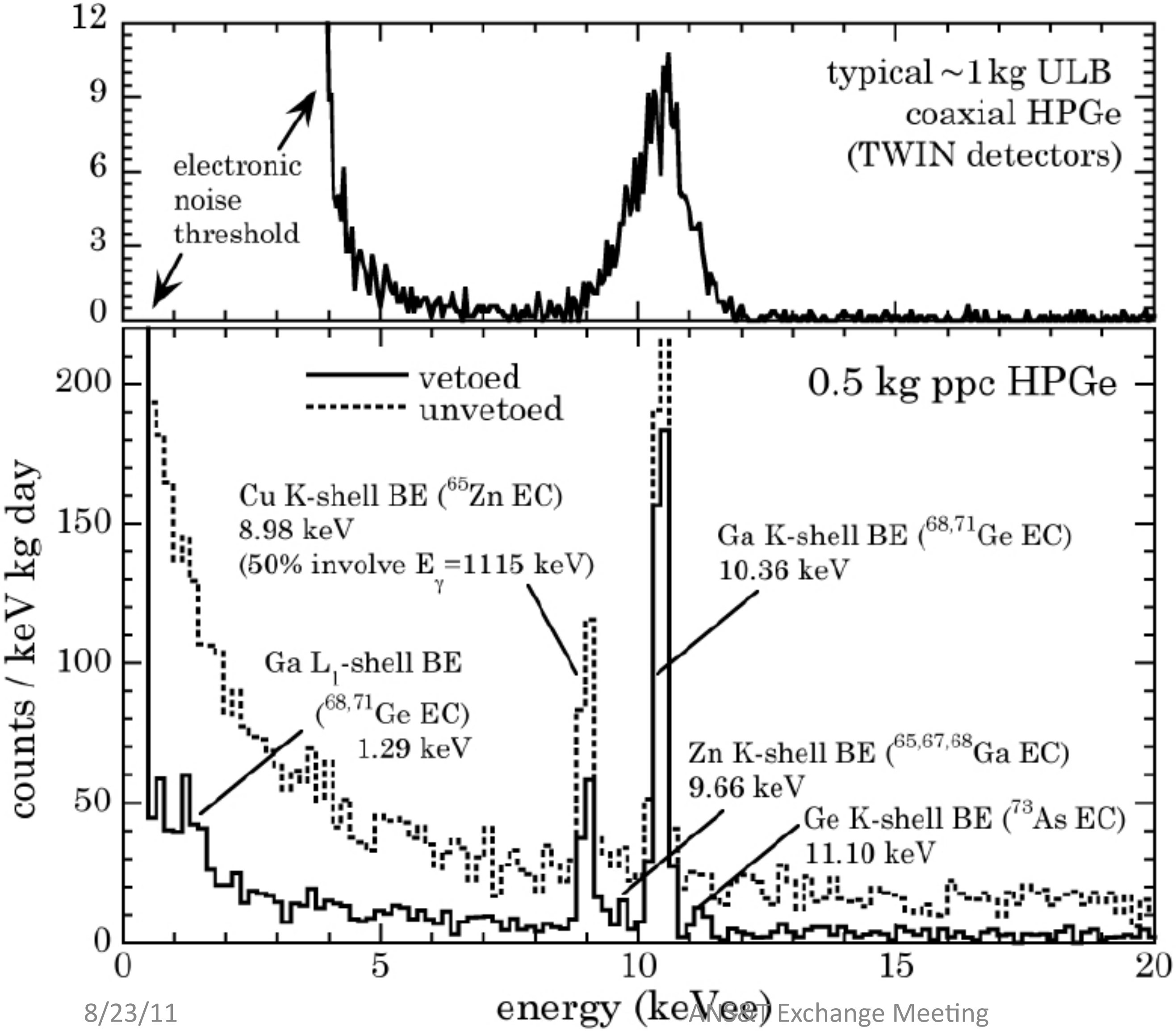


PPC Low-Energy Resolution

Juan Collar, University of Chicago

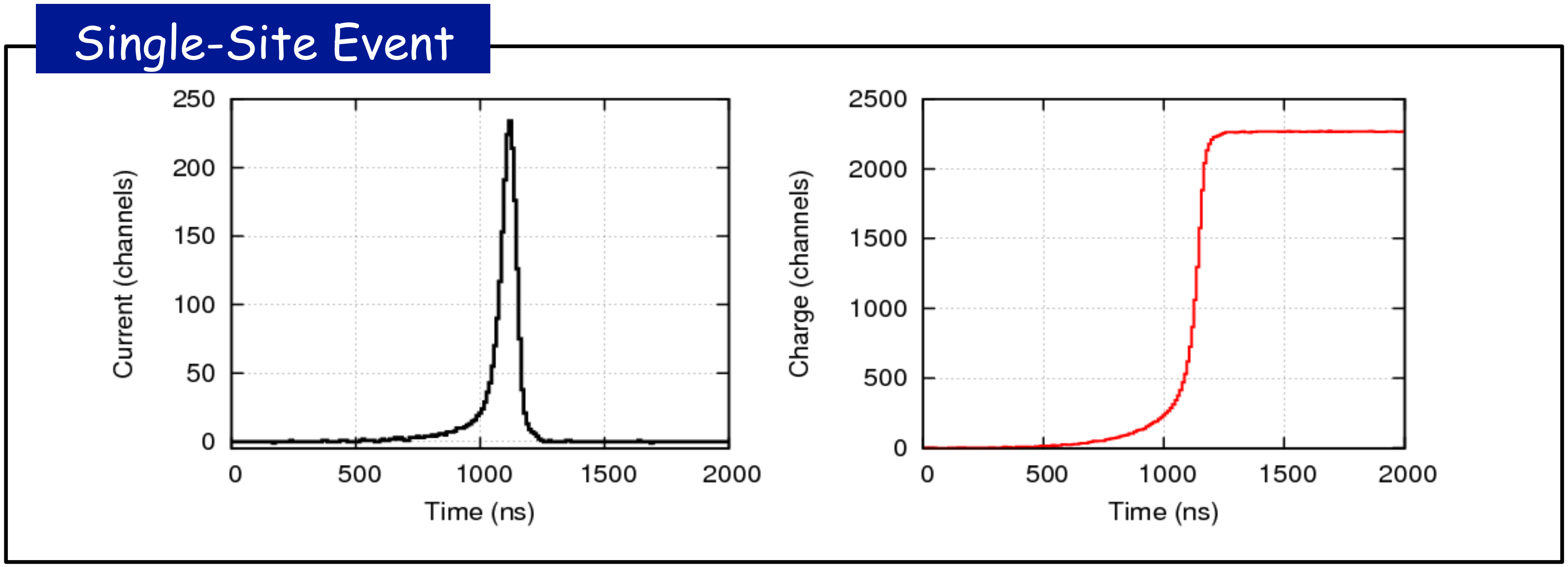
Threshold ~ 400 eV

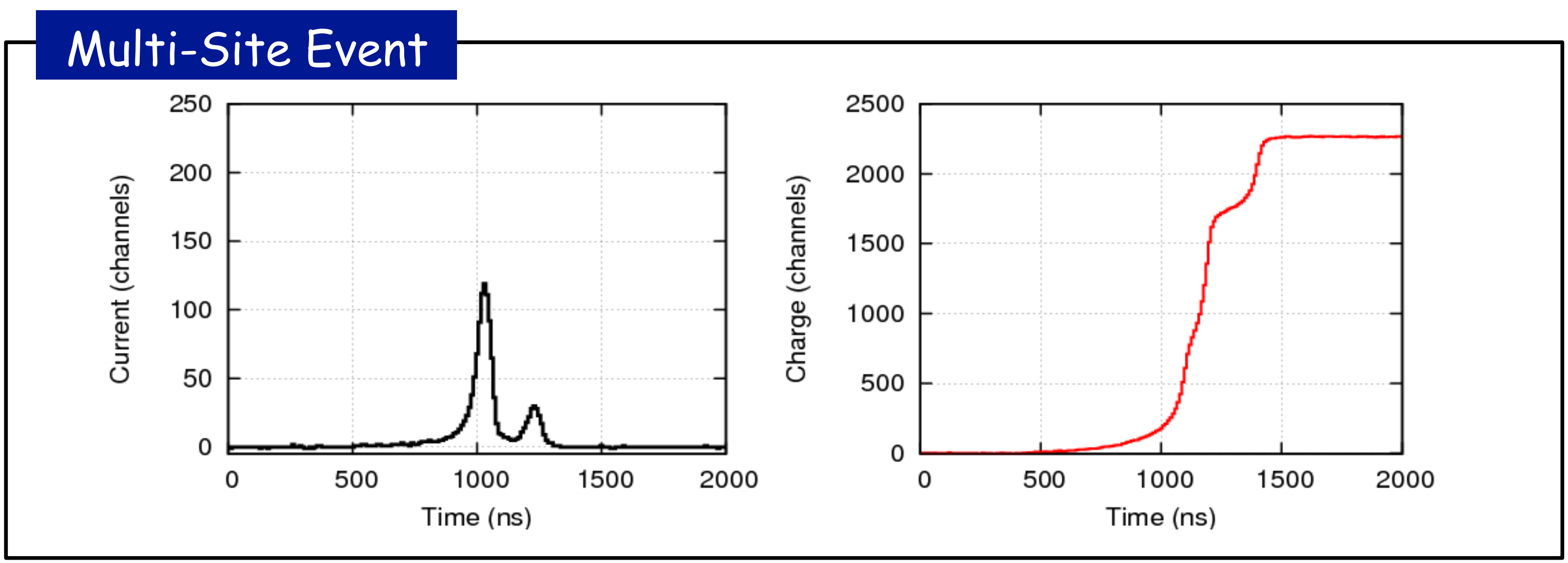
-- Goal is 100 eV



Pulse-Shape Response

PPC detectors are ideal for discrimination between single-site and multi-site events

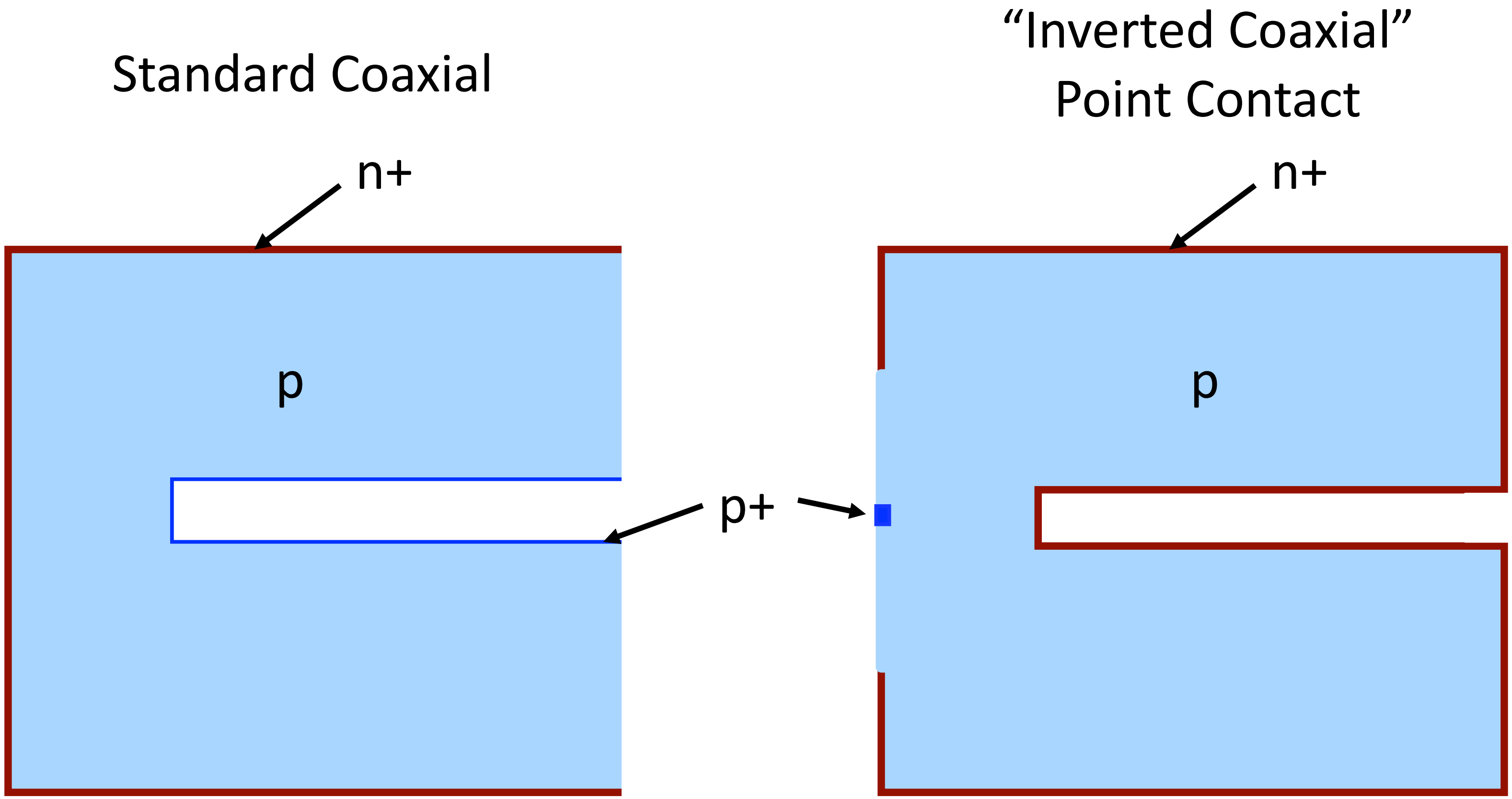




Novel Design: Large Point Contact Detectors

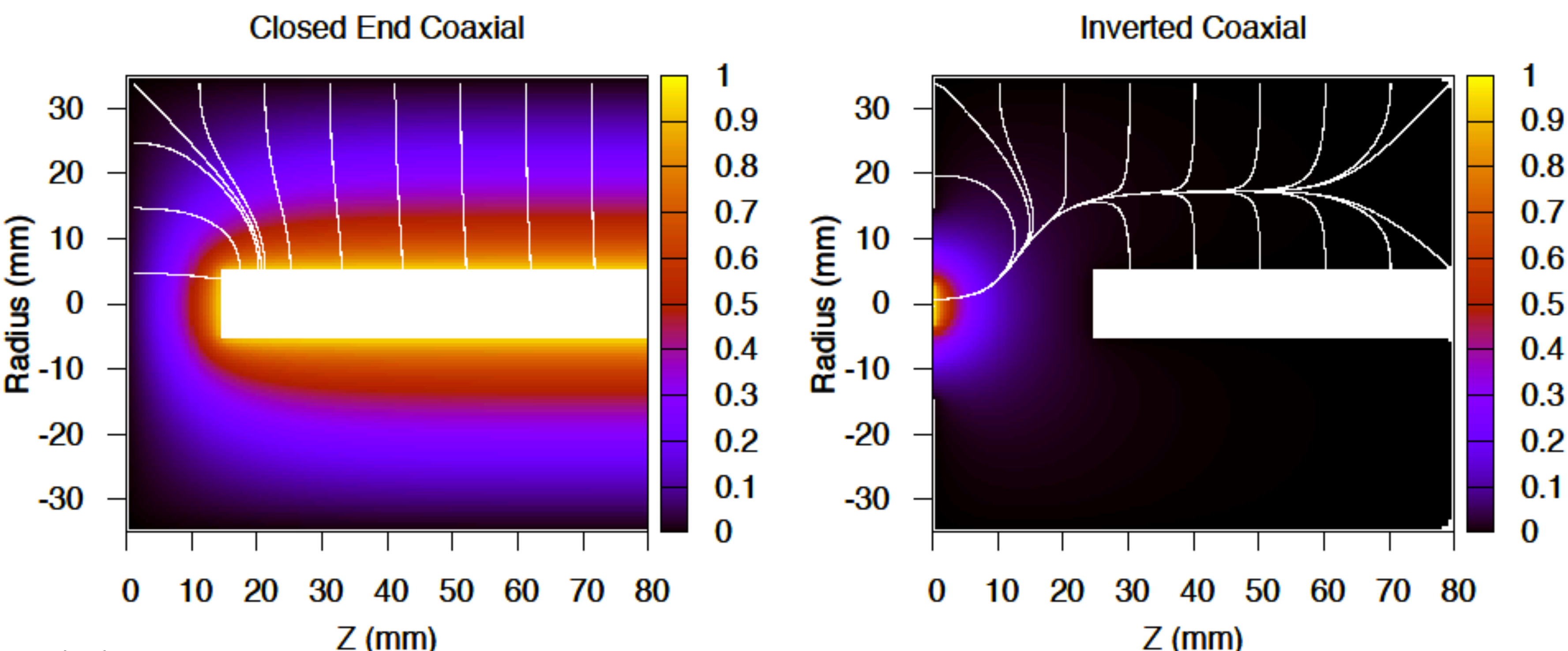
Normal point-contact detectors are limited in size by the depletion process
- Long crystals result in an undepleted region in the middle of the detector

To overcome this, we developed new "Inverted Coaxial" design



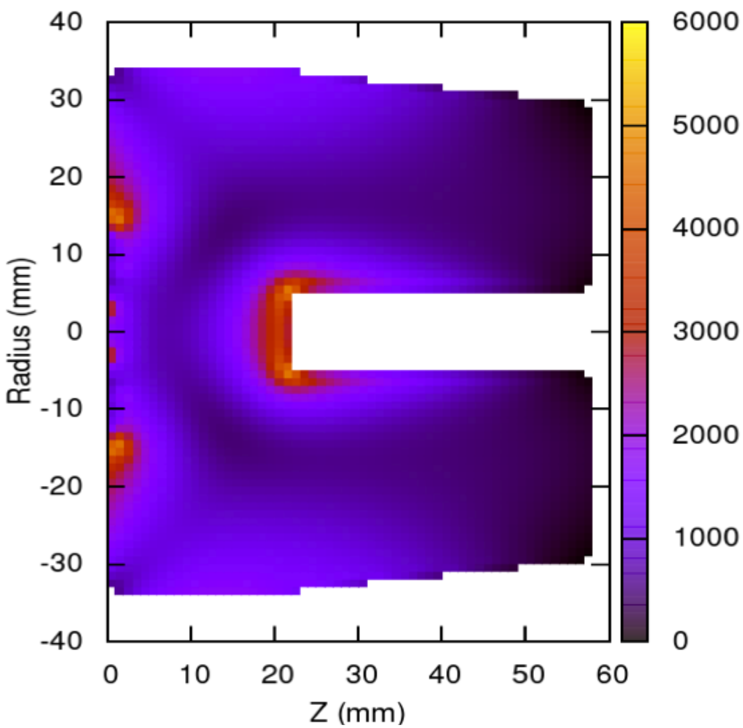
"Inverted Coaxial" Detectors

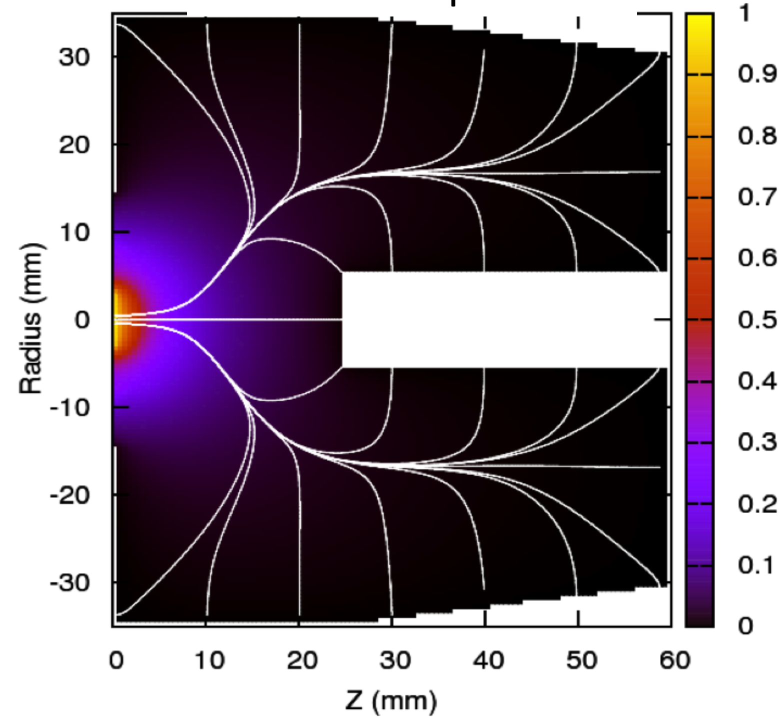
- Drift of charges is radically different from a normal coaxial detector
- Long drift times, up to 2 μs - essentially a Ge drift detector
- Signal shape is largely independent of interaction position, but with a delay that depends on drift distance
- Unsegmented detectors have poor timing resolution
- Very low noise due to low capacitance



"Inverted Coaxial" Detector

Adding a radial taper improves the longitudinal electric field, and therefore improves charge collection.





ANS&T proposal

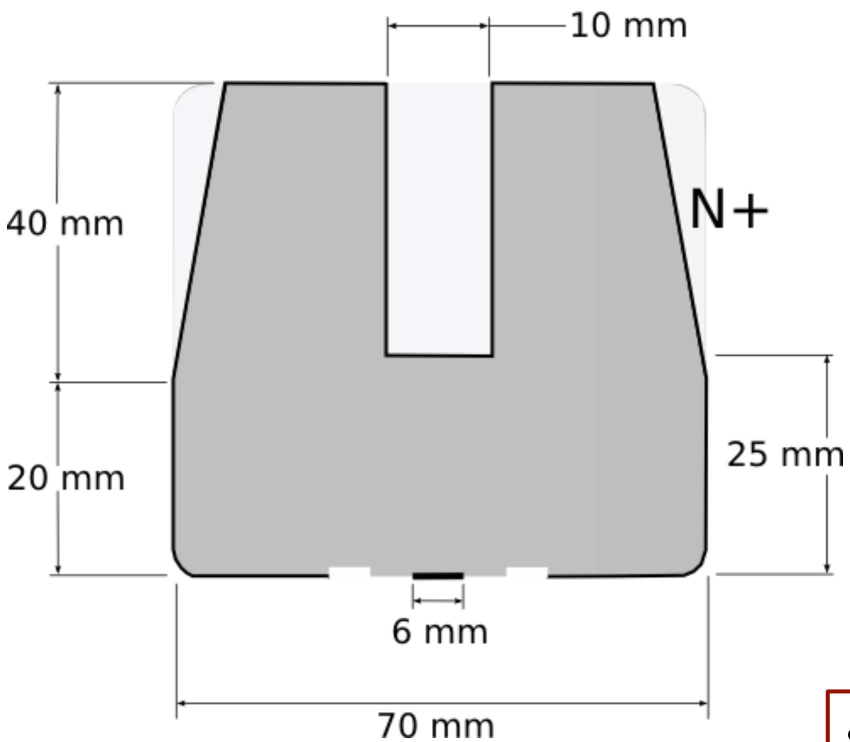
Single Crystal Large Volume Position Sensitive HPGe Detectors

- Design and procurement of an unsegmented prototype
- Characterization of unsegmented prototype
  - Comparison of observed data with simulations, to validate design and simulation codes
- Design and procurement of a segmented prototype
- Development of signal decomposition software
  - Digital signal processing to extract the number, positions, and energies of gamma-ray interactions inside the detector
- Characterization of segmented prototype
  - Measure signal waveforms
  - Use signal decomposition to determine position resolution
  - Attempt Compton-imaging

Unsegmented prototype

Ordered January 2010, from Canberra (CT)

Delivered October 2010



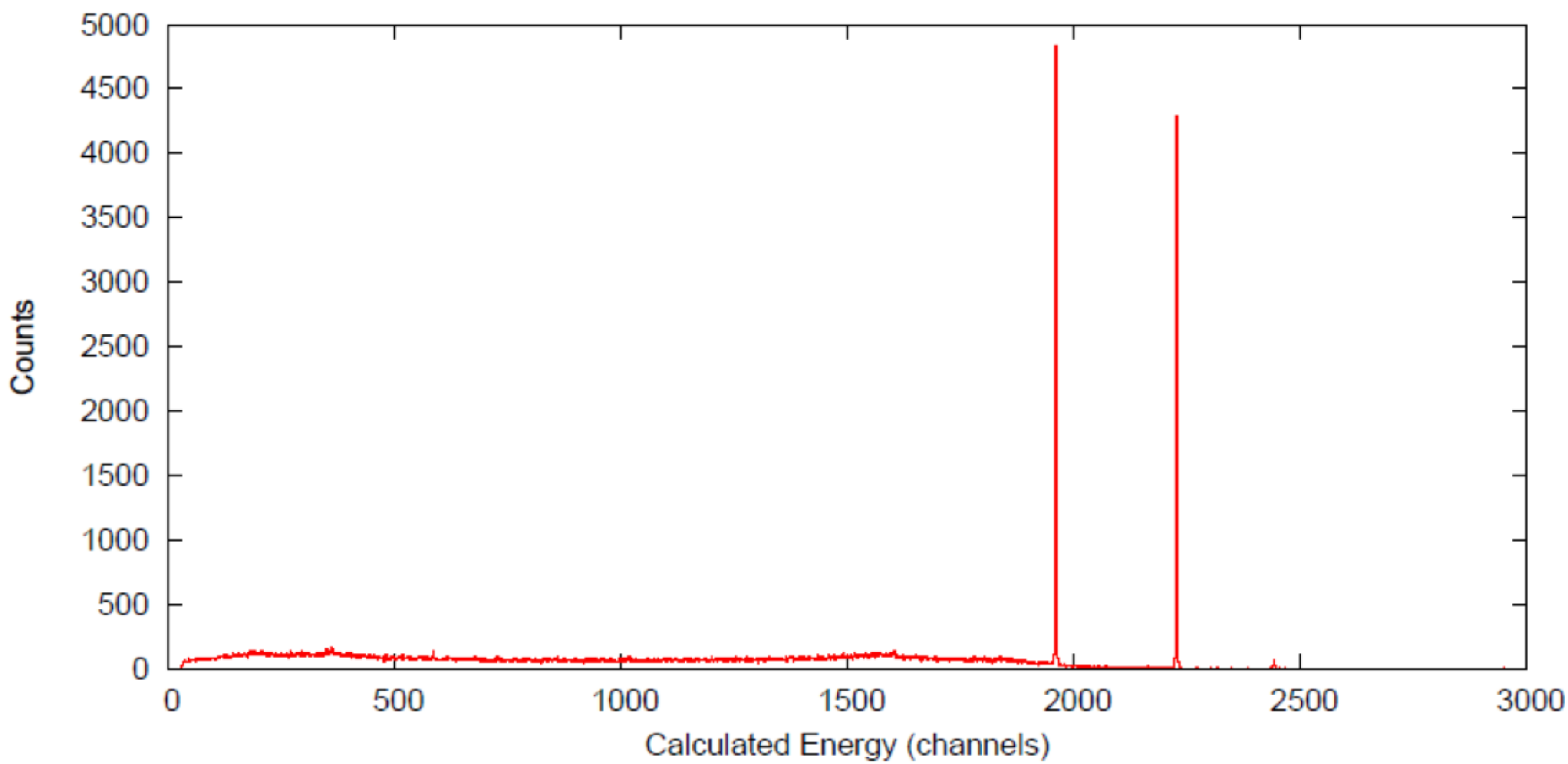
70 mm x 60 mm tapered cylindrical detector

- 10 degree taper
- 35 mm long x 10 mm diameter core
- 6 mm diameter point contact
- p-type

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

Unsegmented prototype



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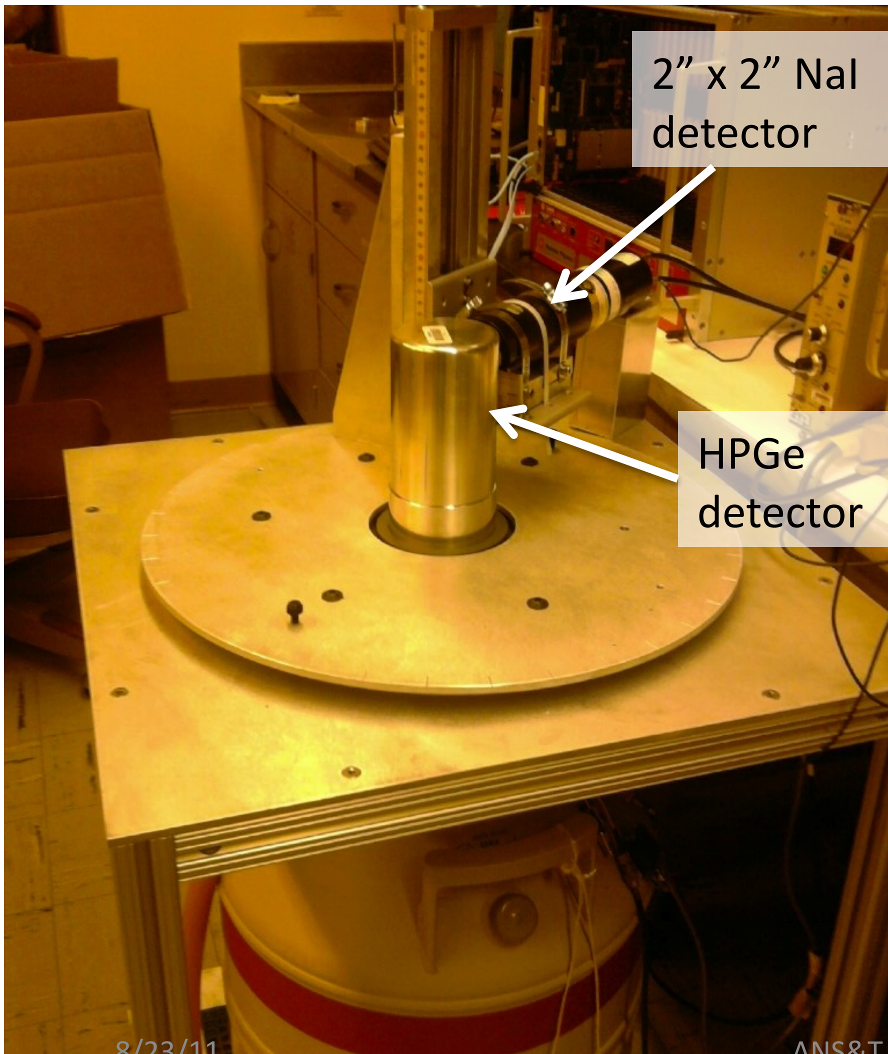
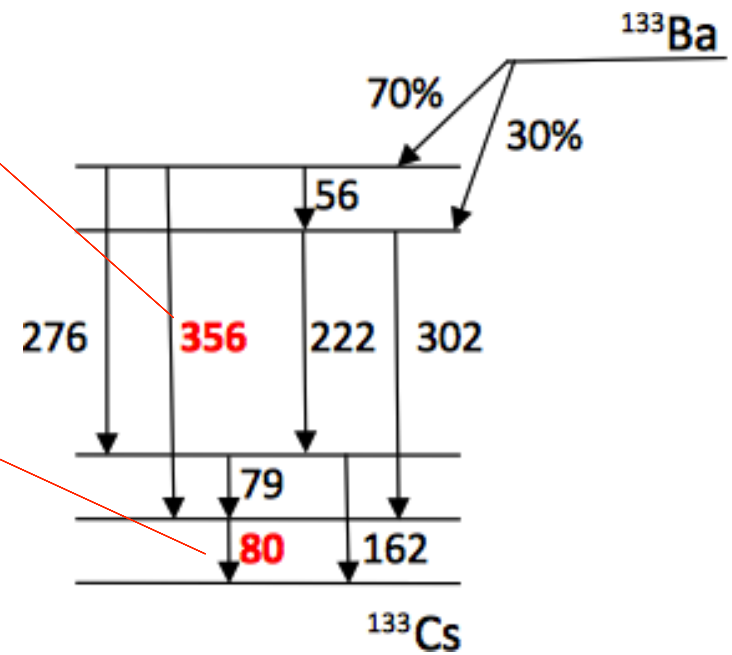
Characterization measurements

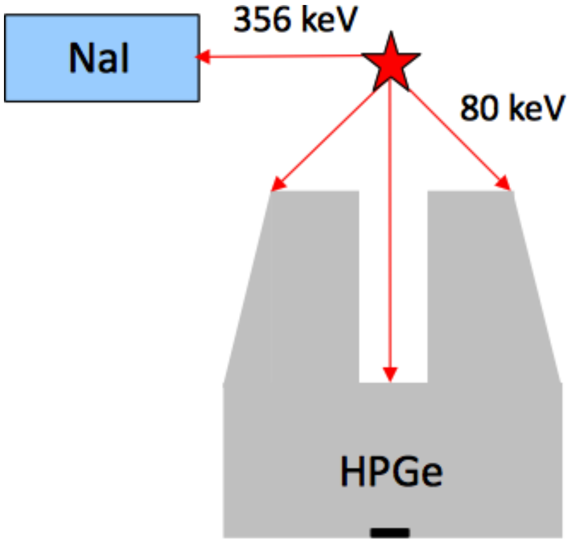
Coincidence measurements between HPGe and a NaI detector

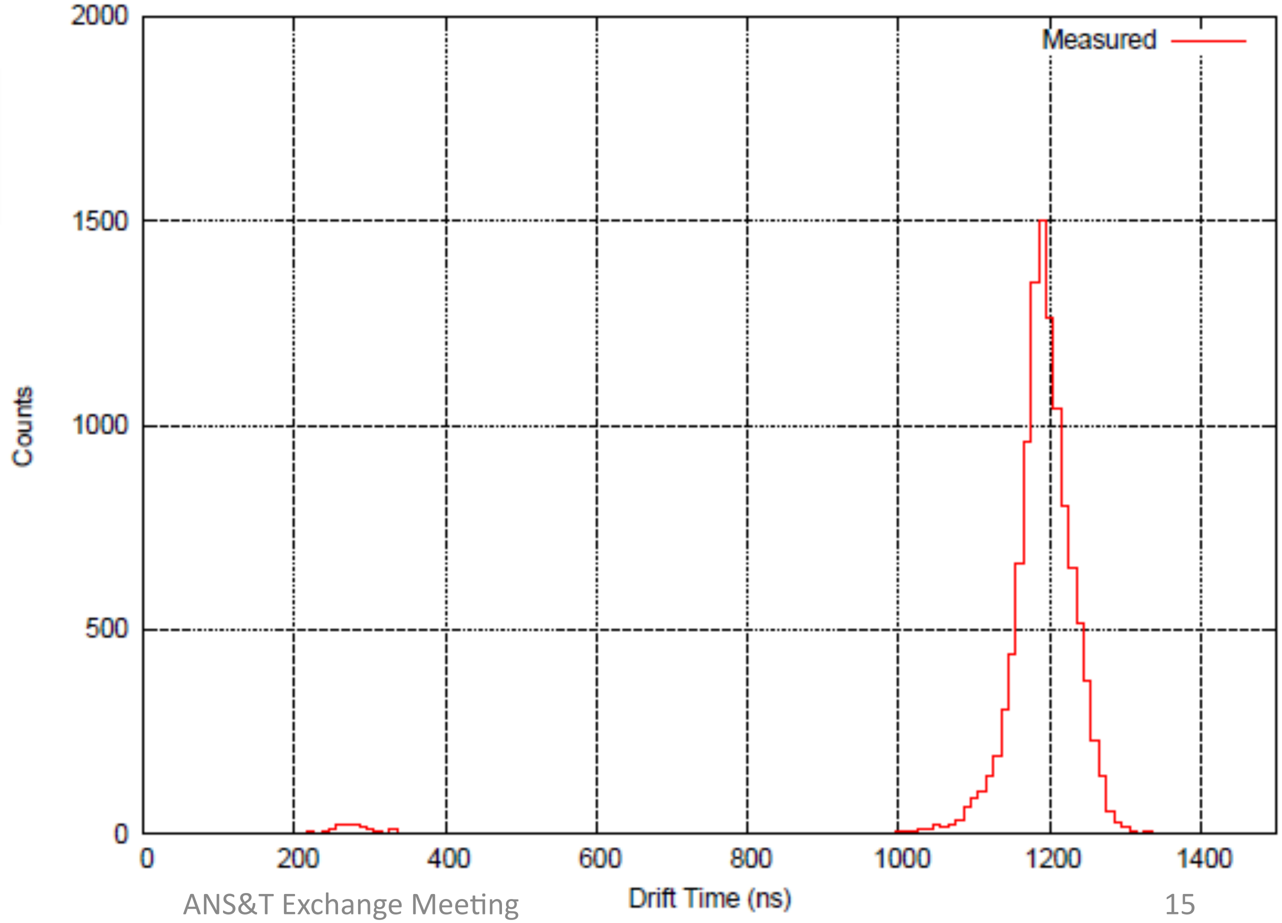
- Weak ^{133}Ba source
- NaI signal establishes start time of Ge signal and hence charge drift time





Measured drift times

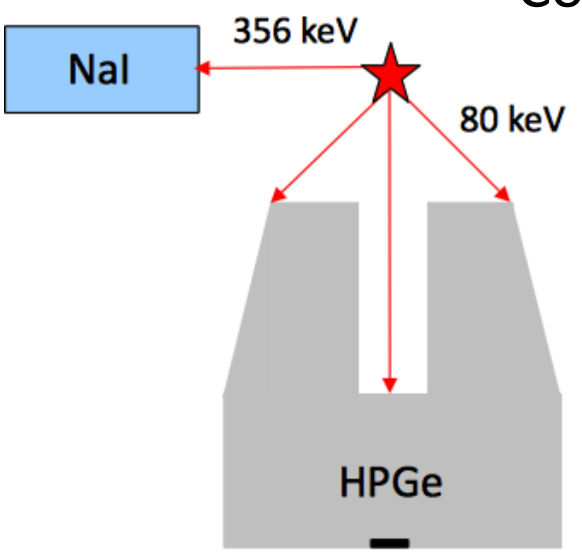


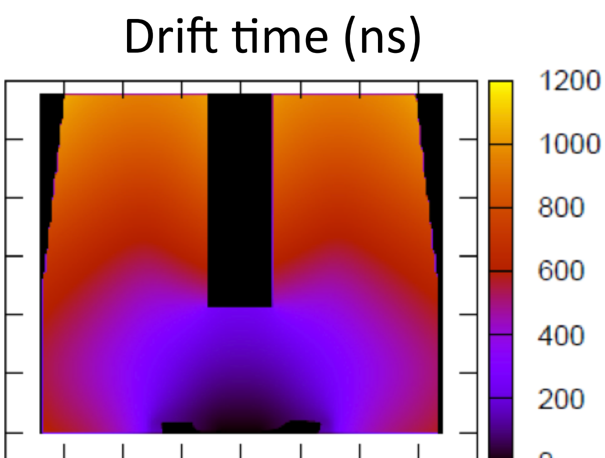


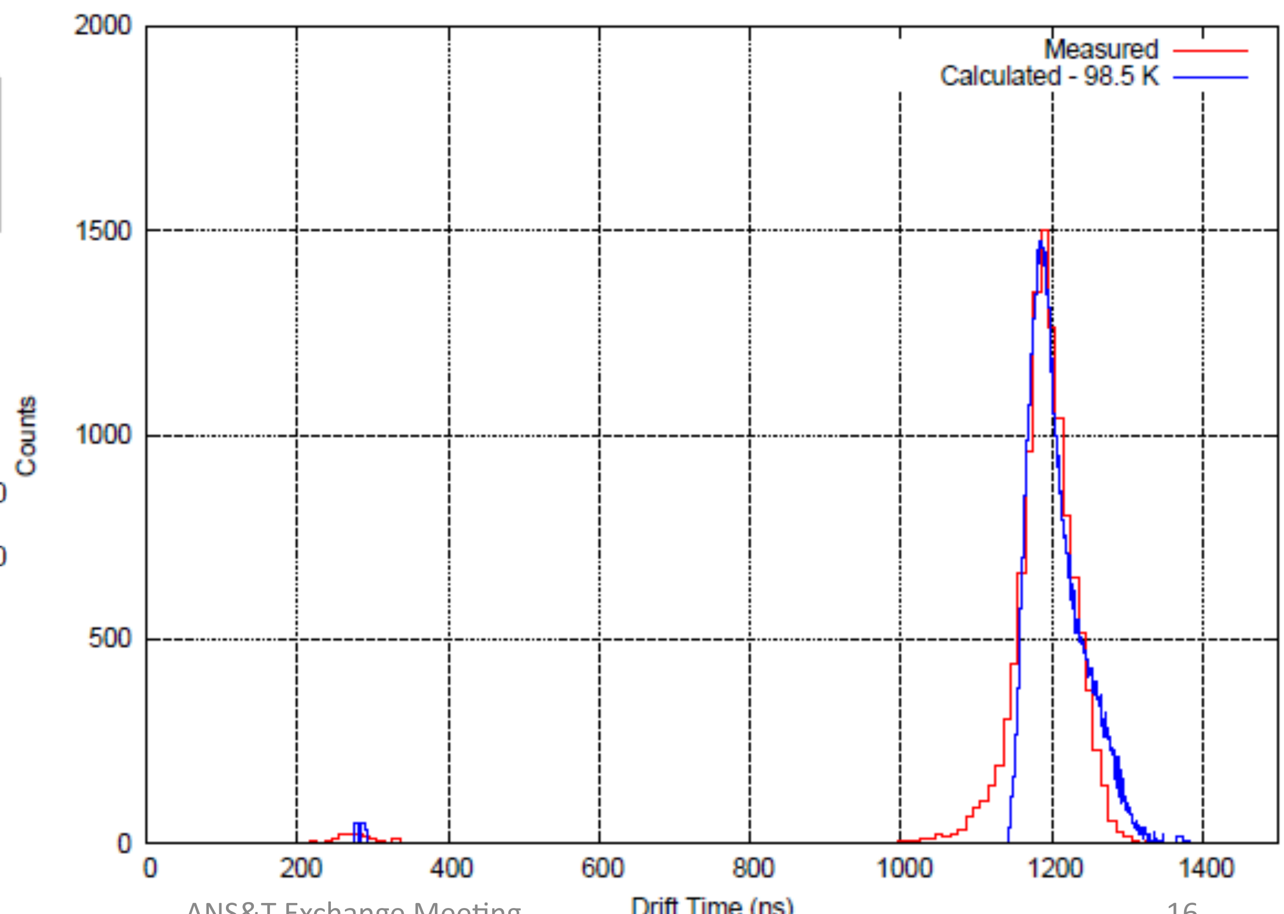
Measured drift times

Compare with calculated distribution of drift times

- Corrected for temperature dependence of hole mobility
- Good agreement with measured data
- Remaining discrepancies due to bulletization



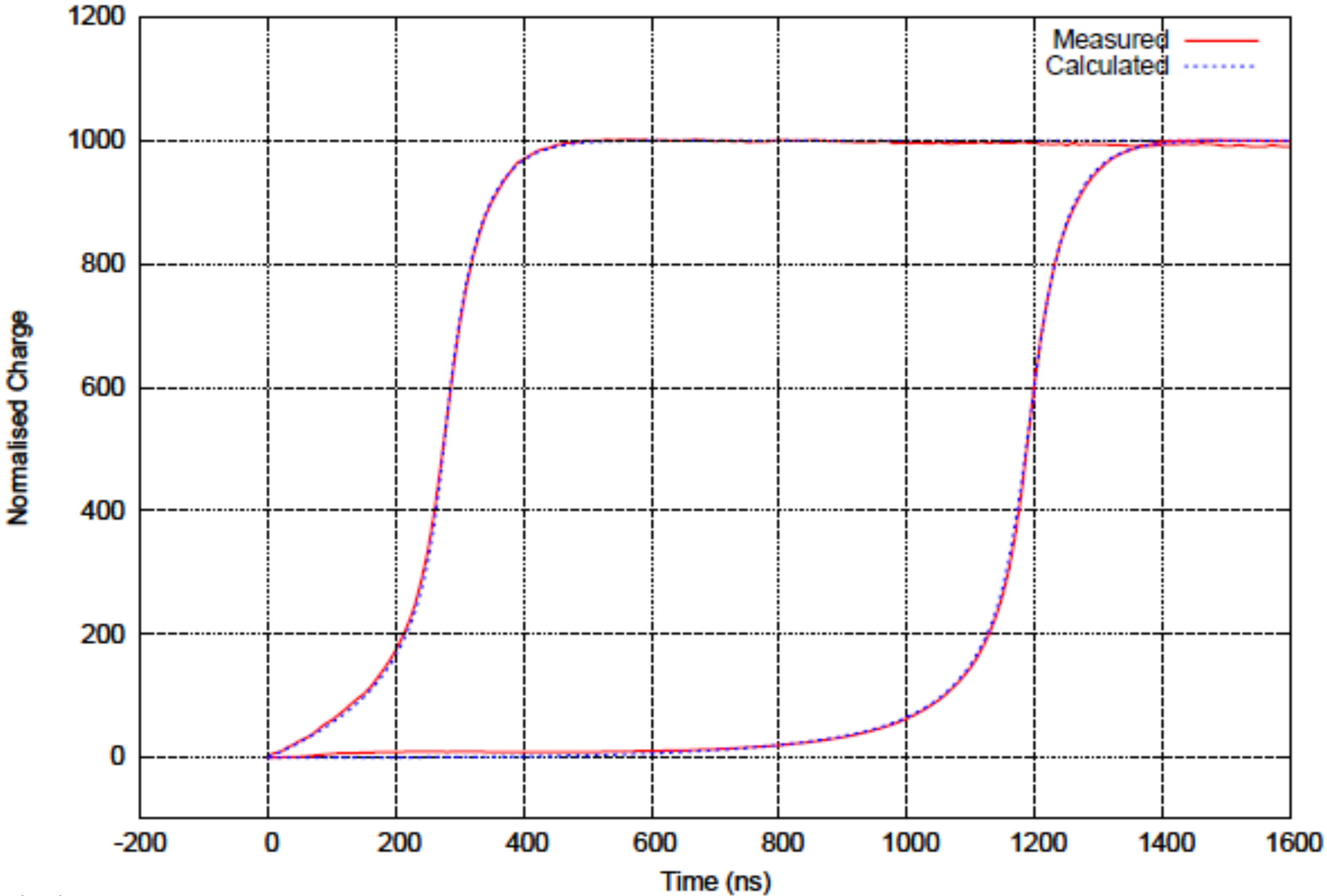




Calculated and Measured Signals

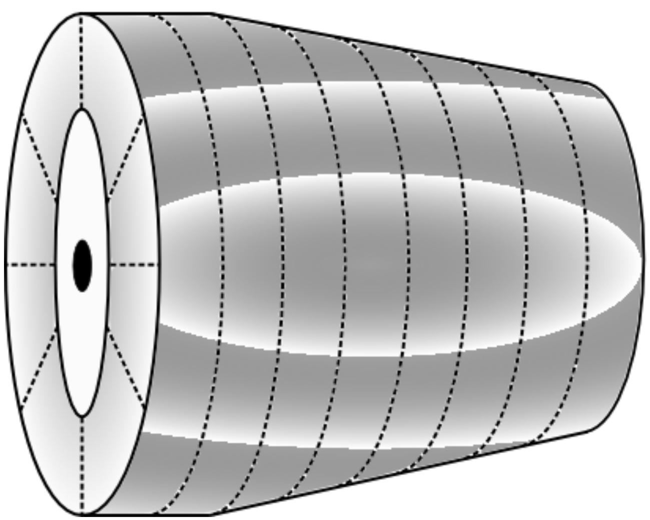
Time-aligned and averaged signals from the two groups

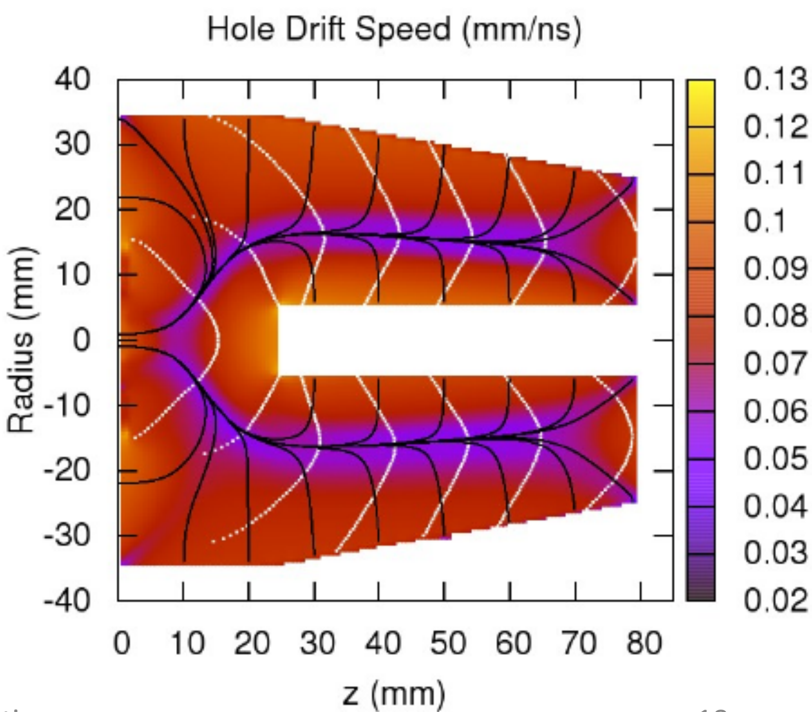
- Excellent agreement with both time and shape of signals



Segmented Design Complete

- Nineteen segments, total of 20 signals
- Segmentation allows a good determination of t_0, and hence the drift time and position, solely from the segment and CC signals
- Longitudinal ring-style segments and pie-slice azimuthal segments separate the longitudinal and azimuthal directions
- Segmented prototype ordered June 2011, from Canberra (Lingolsheim)
- 7 cm diameter, 8 cm long, n-type



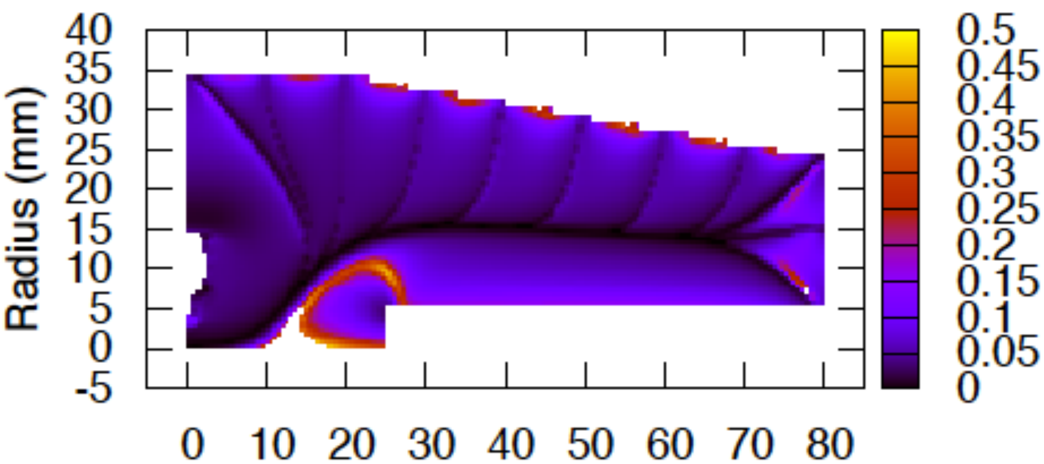


Calculated Position Sensitivity

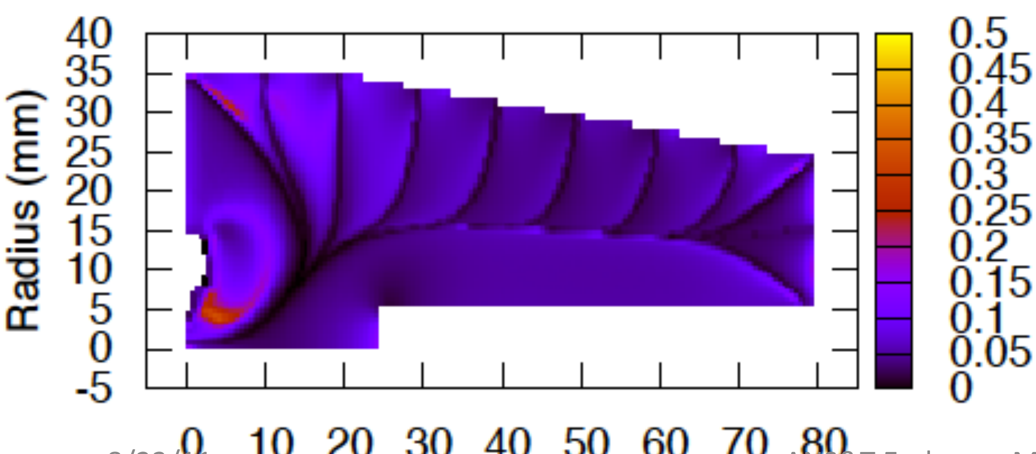
Average resolution (FWHM) < 0.5 mm

- Improvement of a factor of 3 – 4 relative to GRETINA

Radial Position Resolution (FWHM, mm)



Longitudinal Position Resolution (FWHM, mm)

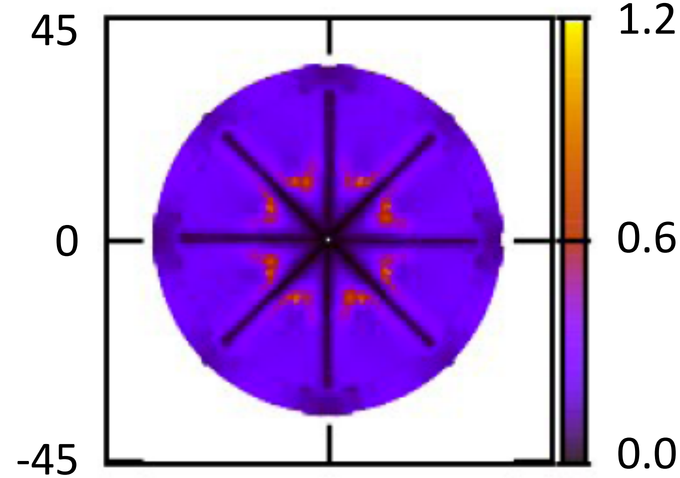


Best-case theoretical FWHM

for E ~ 300 keV

- Preamp rise time ~ 70 ns
- Point charges, no diffusion

Azimuthal resolution at z = 5 mm



Signal Decomposition

Signal decomposition code is required to extract positions and energies of gamma-ray interactions. This is a large component of the remaining scheduled work.

- GRETINA code will be adapted for use with these detectors
- Based on a library ("basis") of pre-calculated signals
- Measured signals are decomposed into a linear superposition of basis signals, event by event, in near-real time
- Basis signals include effects of preamplifier impulse response, plus two different types of cross-talk between signal channels
- Hybrid algorithm: Adaptive grid search + non-linear least squares

Budget and Workforce Training

	Costed / Committed	ETC	Total (k$)
Simulations and design	89	65	154
Unsegmented Prototype	96		96
Segmented Prototype	396		396
Testing and Characterization	44	60	114
Signal decomposition & imaging		140	140
Total	625	275	900

- Training of new workforce: Two postdoctoral researchers

  Ren Cooper, Karin Lagergren

  - Detector simulations, signal simulations
  - Digital DAQ system
  - Detector characterization

Schedule

Future milestones

- FY12 Q1 – Acceptance of segmented prototype
- FY12 Q2-Q3 – Characterization of segmented prototype
- FY12 Q2 – Programming of signal decomposition
- FY12 Q4 – Project completion

Summary

✓ Novel new detector geometries are being explored for making efficient, high-resolution position-sensitive gamma detectors

- Use long drift times to improve position determination
- Hope to achieve a factor of ~ 2-4 better position sensitivity, with fewer signals
- Better determination of *number* of interactions
- Will give better efficiency, P/T, and E-resolution in gamma-tracking arrays
- Superb energy resolution at low energies
- Can use same tapered-hexagonal geometry as GRETINA
- Requires digital signal processing
- Probably some degradation of count-rate capability
- Applications in gamma-ray astronomy, homeland security, and medical imaging?

- Unsegmented p-type prototype works extremely well
- Prototype n-type detector with 19 segments is on order