Single Crystal Large Volume Position Sensitive HPGe Detectors

A novel design for large position-sensitive HPGe detectors

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DOE-NP ANS&T Exchange Meeting
Rockville MD, August 2011
HPGe Detectors

Hyper-Pure Ge (HPGe) detectors are the “gold standard” for gamma-ray spectroscopy
• Unsurpassed energy resolution
• Indispensable 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 $\gamma$-ray tracking (GRETINA) depends on good position resolution through segmentation of detector electrodes
• Efficiency, peak-to-total ratio, and energy resolution of a $\gamma$-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, $\gamma$-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

typical ~1kg ULB coaxial HPGe (TWIN detectors)

Cu K-shell BE ($^{65}$Zn EC) 8.98 keV (50% involve $E_\gamma = 1115$ keV)
Ga L-shell BE ($^{68,71}$Ge EC) 1.29 keV
Ga K-shell BE ($^{68,71}$Ge EC) 10.36 keV
Zn K-shell BE ($^{65,67,68}$Ga EC) 9.66 keV
Ge K-shell BE ($^{73}$As EC) 11.10 keV

counts / keV kg day
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 (6 µs shaping)
• 320 eV FWHM noise (6 µs shaping)
• 44% relative efficiency
Unsegmented prototype

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- 320 eV FWHM noise (6μs shaping)
- 44% relative efficiency
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

356 keV
80 keV

Counts

Drift Time (ns)

0 200 400 600 800 1000 1200 1400

Measured

8/23/11
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 $E \sim 300$ keV
- Preamp rise time $\sim 70$ 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
• Training of new workforce: Two postdoctoral researchers
  Ren Cooper, Karin Lagergren
  • Detector simulations, signal simulations
  • Digital DAQ system
  • Detector characterization

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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