Gamma Ray Imaging Detectors

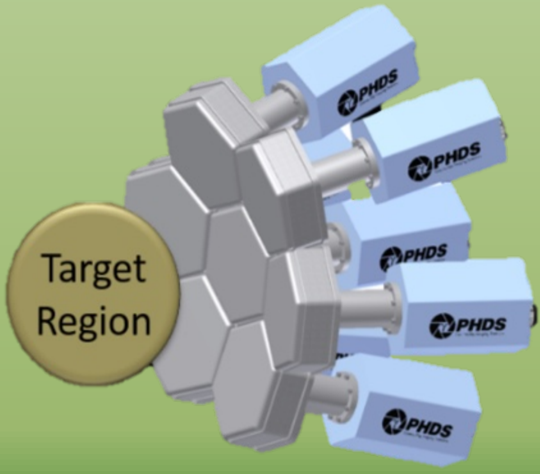
Pixel Array Germanium Detectors for Nuclear Physics (PAGe)

Grant Award Number: DE-SC0015137

Matthew Kiser PI , PHDS Co.

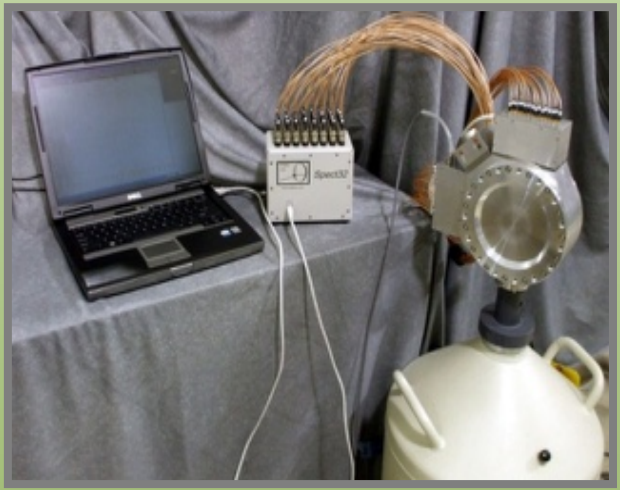
A collaboration with David Radford at Oak Ridge National Laboratory

- **PHDS Co. Introduction**
- **Motivations for Pixel Array Approach**
- **Prototype Pixel Detector Geometry**
- **Waveform (Signal) Decomposition**
- **Path Forward**



PHDS Co.

- Est. Fall 2004 – Nuclear and Solid State Physics Origin
  - History: Custom Nuclear-Physics Detectors
  - Recently: Modular HPGe Systems
- Complete Germanium Detector Manufacturing and R&D
  - Concept Design
  - Crystal Growth
  - Detector Fabrication
  - System Integration
  - Software application
  - Sales & Service



NPX (150 lbs.)

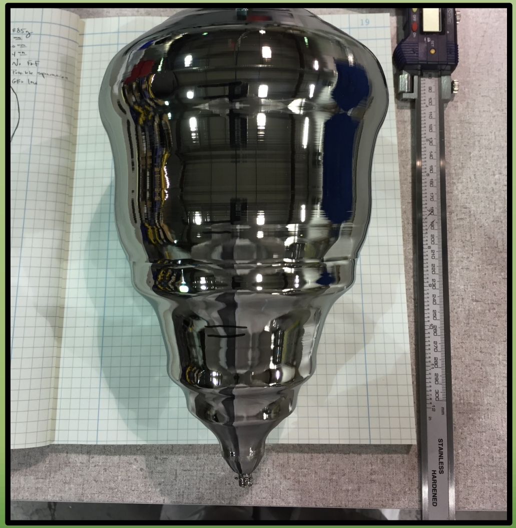
GeGI-5 (15 lbs.)

Active Detector is the same size

Make new HPGe detector capabilities available

Why Pixel Array Germanium?

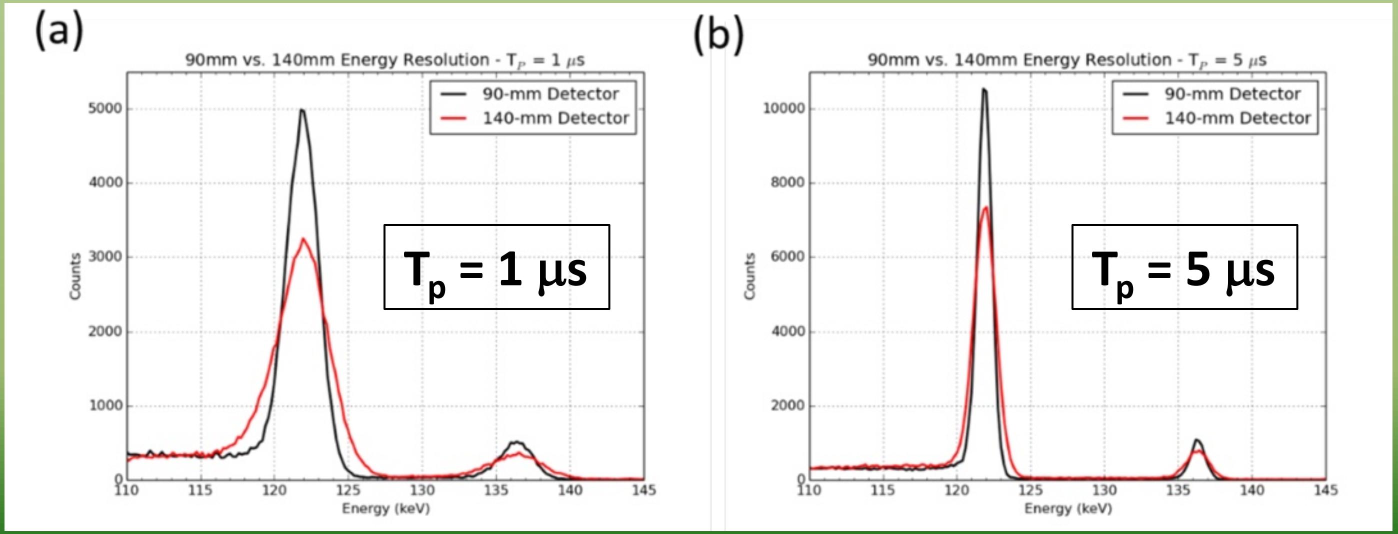
- PHDS growing ever-larger germanium crystals
- Investigating best strategy for fabricating position-sensitive gamma-ray detectors with excellent spectral and spatial resolution
- Traditionally orthogonal-strip design, but there are limitations



Orthogonal Strip Limitations

PHDS
Gamma Ray Imaging Detectors

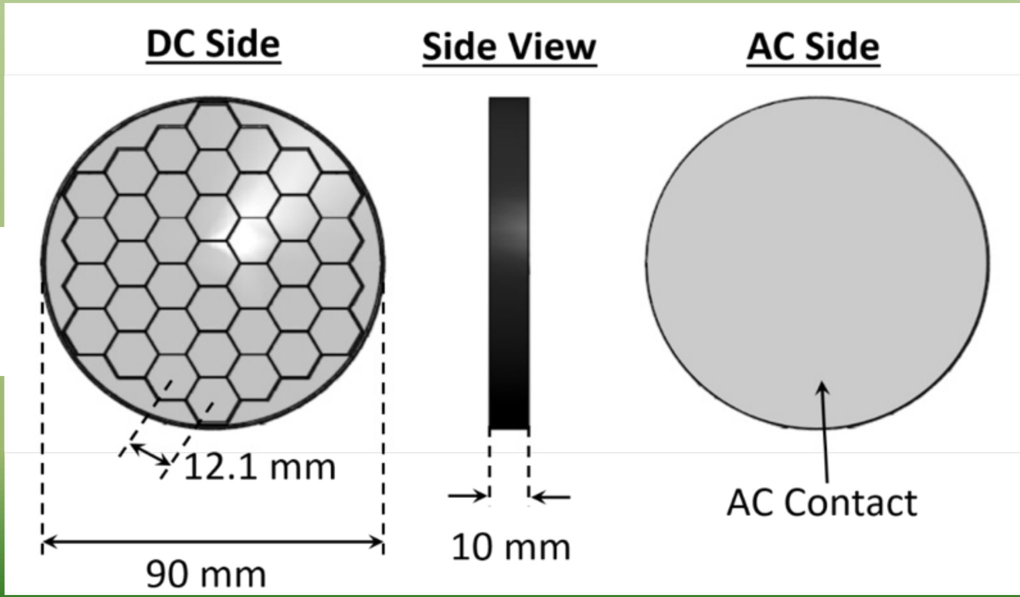
- Best obtainable high-frequency (series) noise when the capacitance of detector segment is not greater than that of the JFET
- Strips are necessarily longer (higher input capacitance) as detector area grows
  - 90-mm GeGI strips: 5-mm wide = 45 pF
  - 140-mm 16-channel strips: 7.75-mm wide = 76 pF
- Can make strips more narrow, but this solution is not readily scalable



Pixel Approach Advantages

- Design pixel geometry for minimal series noise
- Readily scalable: solution for 90-mm wafer the same as for 140+ mm wafer (at the expense of more data processing channels)
- Naturally gain count-rate capacity
- Apply well-tested waveform decomposition algorithms for optimal spatial resolution

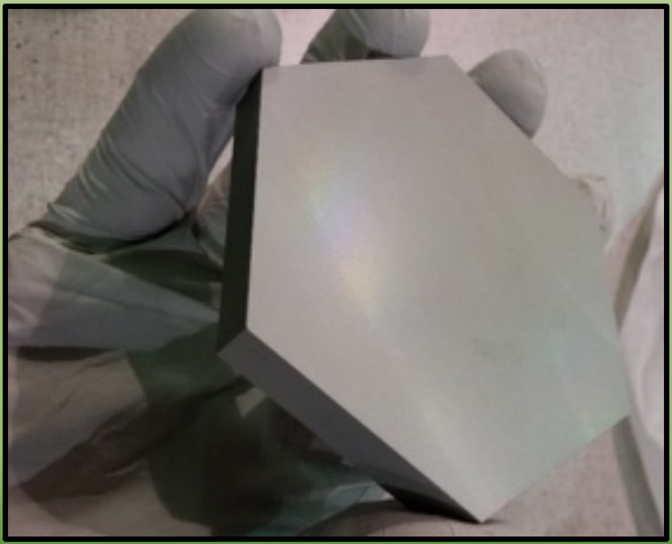
For Example (from Phase-I proposal):

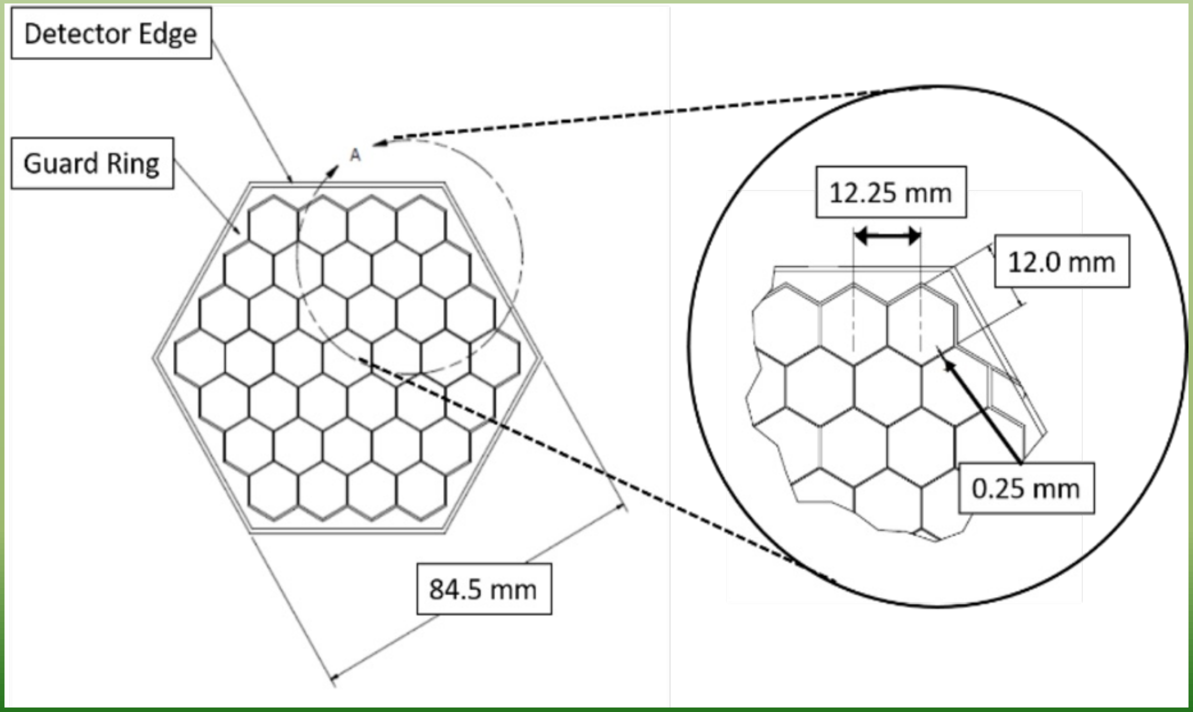


First Pixel Detector at PHDS

PHDS
Gamma Ray Imaging Detectors

- Based on modeling and existing research cryostat limitations, use 37 hexagonal pixels that form a hexagonal envelope
- Hexagonal wafer – fast cuts with minimal material loss; tile with minimal dead space between modules

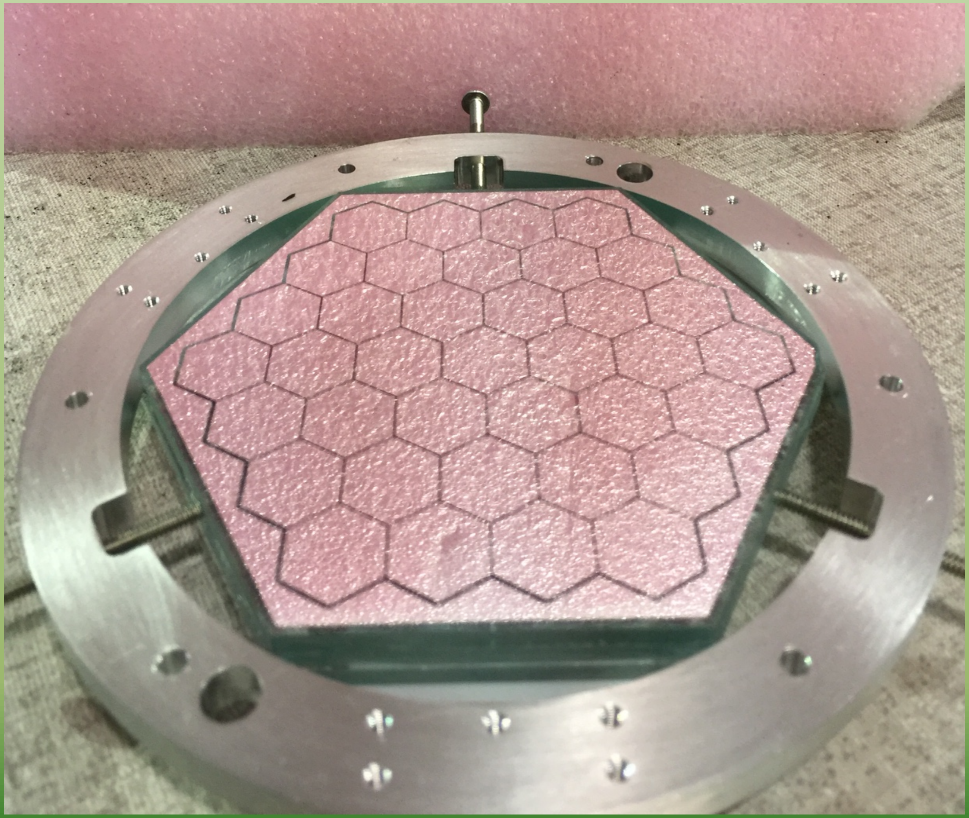




First Pixel Detector at PHDS

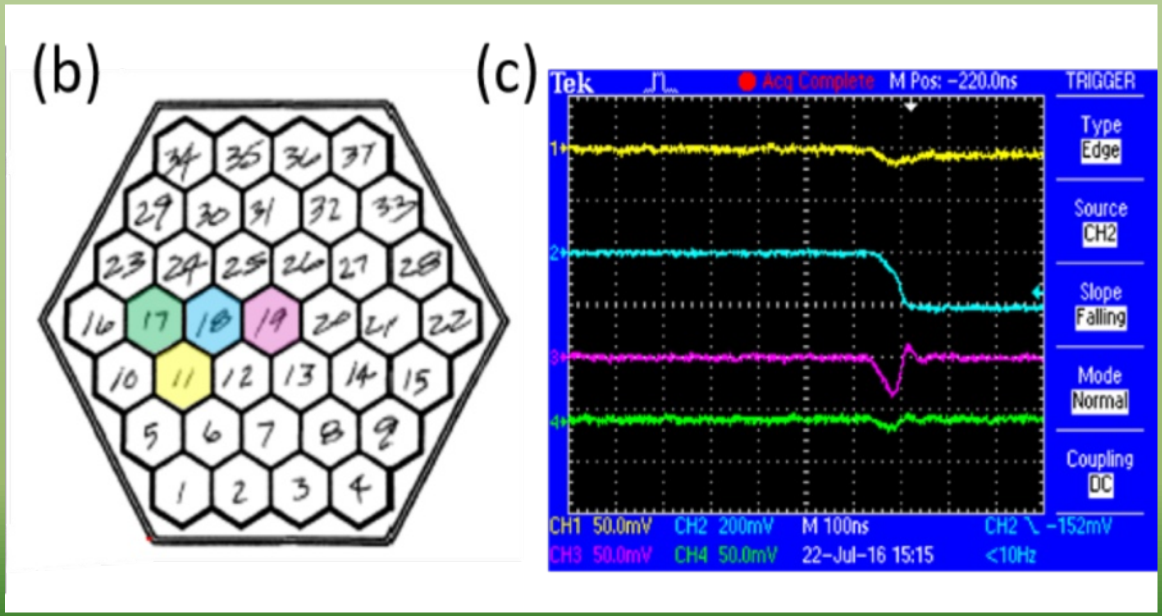
PHDS
Gamma Ray Imaging Detectors

- Use existing research cryostat with 36 feedthroughs
- Standard detector fabrication recipe using stainless steel thin metal mask (hex pixels)
- Instrument 33 pixels, AC guard ring, DC guard ring, and AC contact



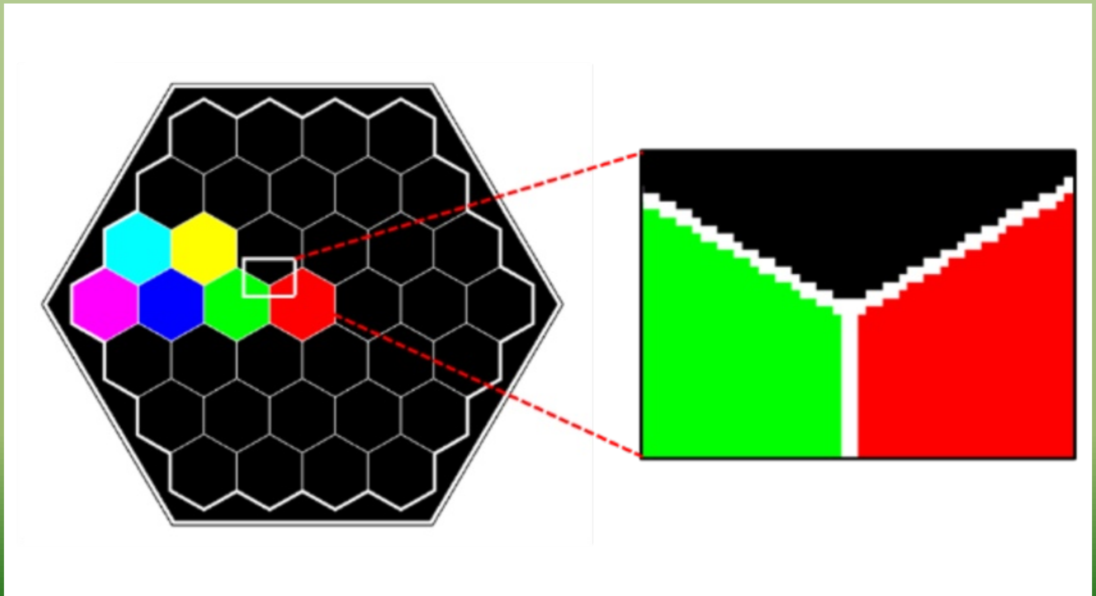
Pixel Waveform Decomposition

- Collaboration with David Radford at ORNL (leverage significant GRETINA development/experience)
- Uses a "signal basis" – a set of simulated signals
- Digital signal processing to determine the number, positions, and energies of gamma interactions in the crystal



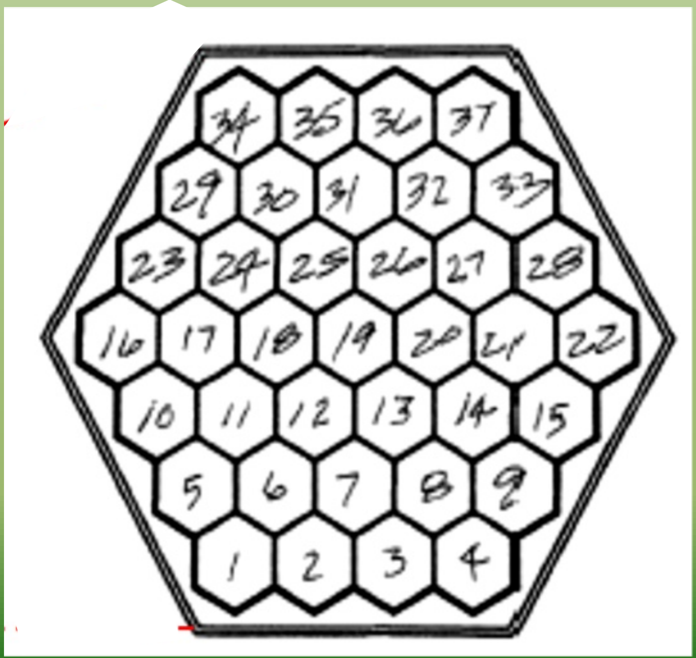
Step 1: Field Generator

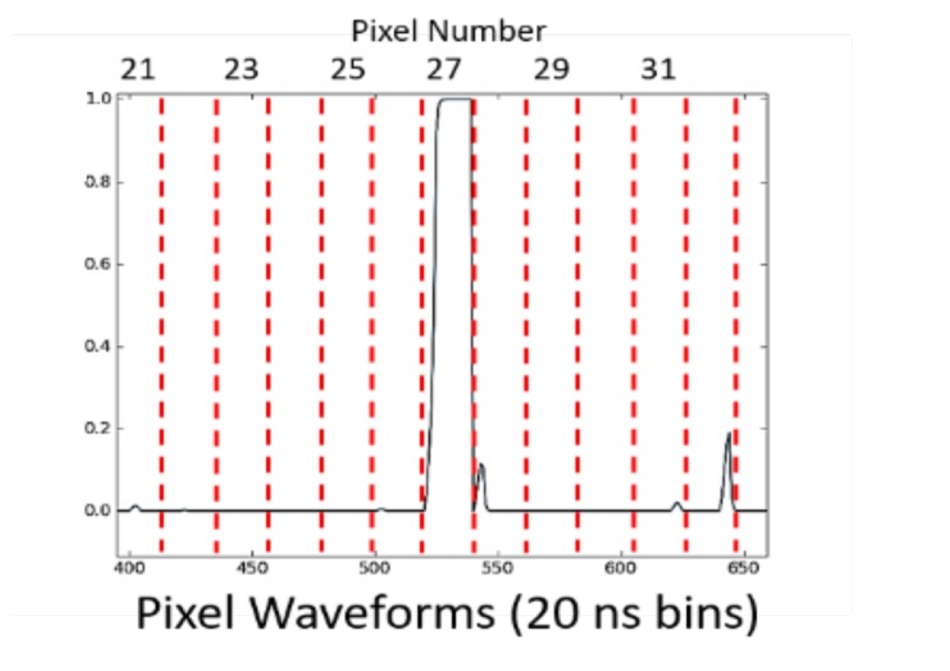
- Adapt existing weighting potential calculator to the pixel geometry – FIELDGEN-HEX
- Calculate weighting potential on 0.125-mm grid (3D)
- Based on symmetry of array, calculations only needed for 6 pixels
- Use weighting potential and detector operating parameters to generate charge waveform in each pixel for any gamma-ray interaction location in the detector



Step 2: Signal Generator (Basis Set)

- Generate set of basis signals used to fit measured pixel signals (SIGGEN-HEX)
- Each basis signal comprised of 20 samples of 20 ns
- Basis set generated on 0.5-mm grid
  - Expected spatial resolution on the order of mm
  - 376k signals in basis set

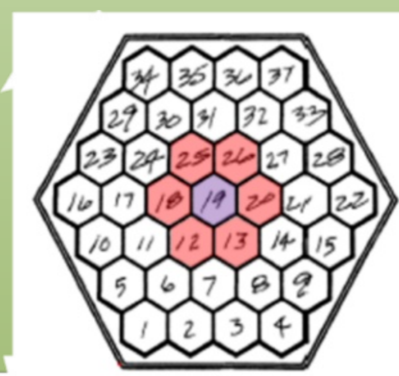


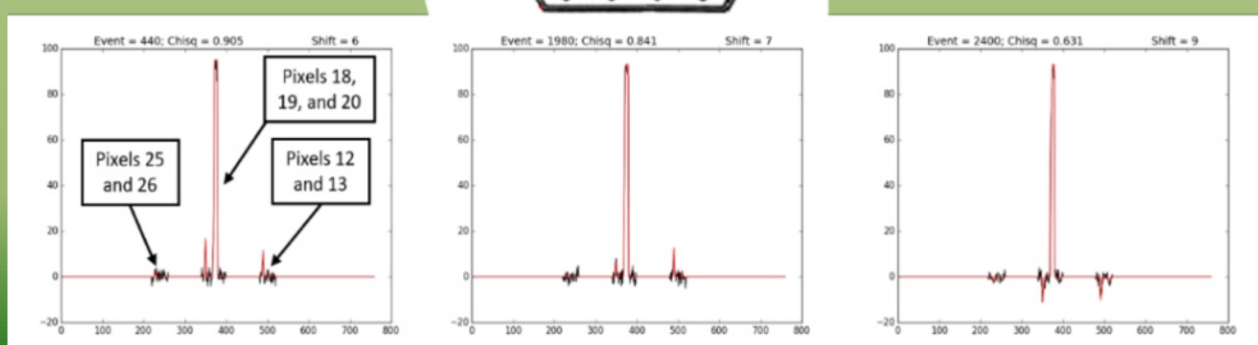


Step 3: Signal Decomposition

PHDS
Gamma Ray Imaging Detectors

- Phase I – single-site, coarse grid search
  - Select basis set element/position that best fits data
  - Simple χ^2 minimization on the grid locations
- Analyze photopeak data at 122 keV – most of these interactions are single-site
- Focus on central pixel (19) and nearest neighbors (12, 13, 18, 20, 25, 26)

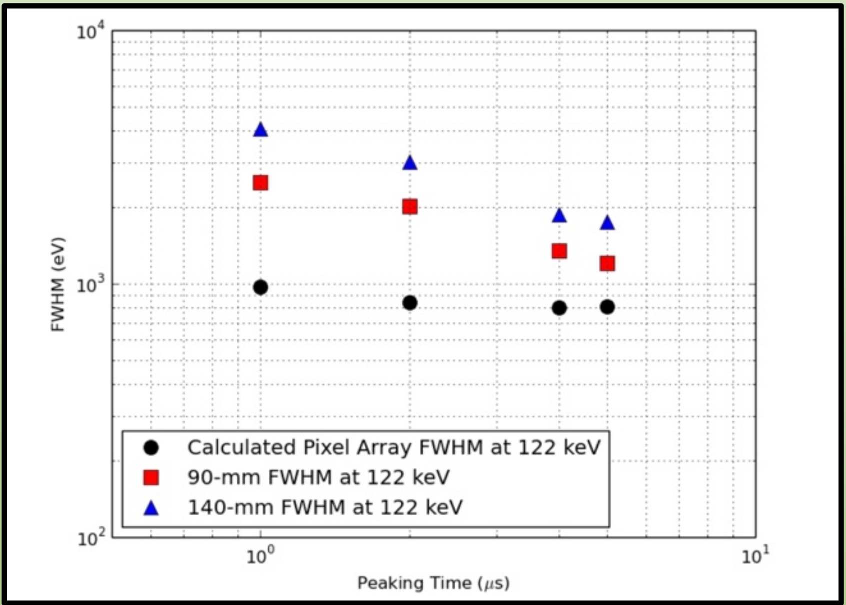


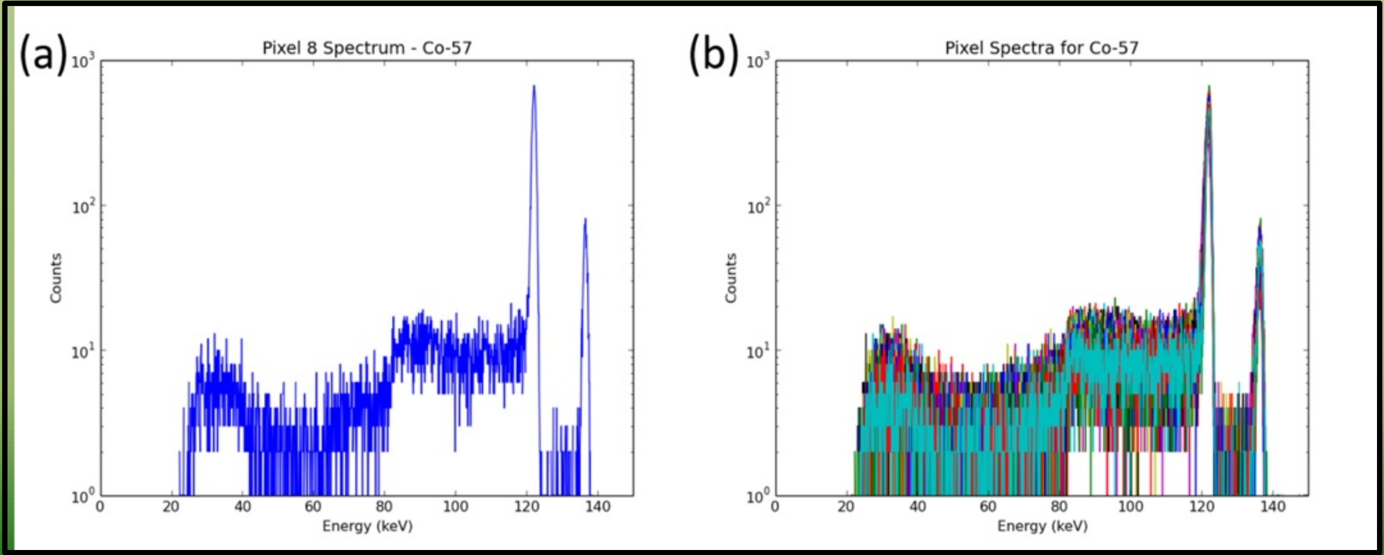


Energy Resolution

PHDS
Gamma Ray Imaging Detectors

- Expect energy resolution to be better than that of commercial GeGI strip based on reduced capacitance (~850 eV vs. 1.2 keV at 122 keV with $T_p = 5\ \mu s$)
- Energy resolution measured to be 0.90 – 1.35 keV across the full detector (at 122 keV)



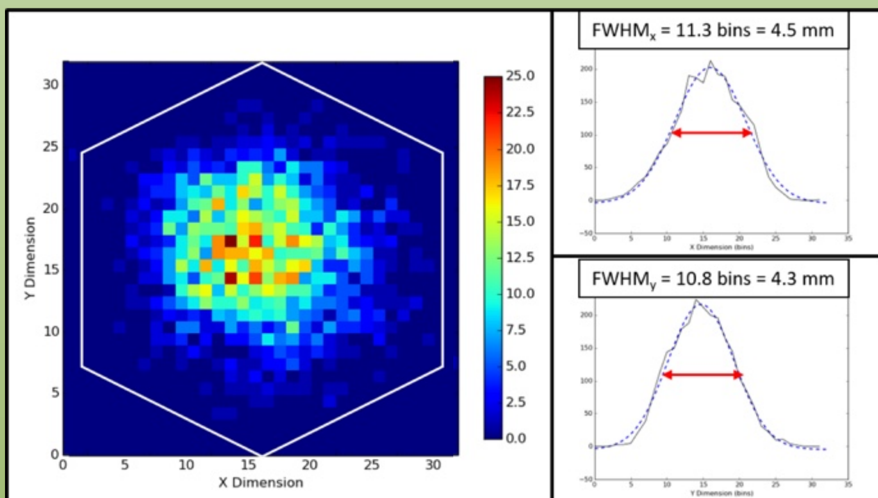


Spatial Resolution

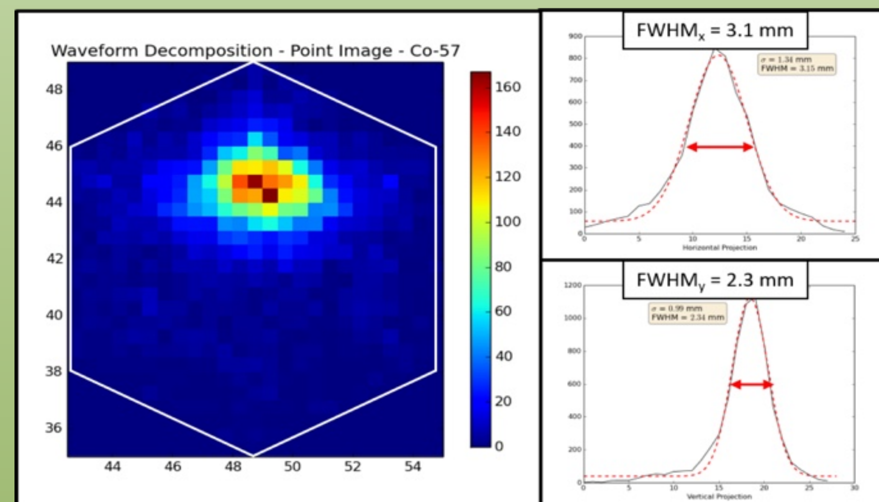
PHDS
Gamma Ray Imaging Detectors

- Commercial GeGI applies parametric interpolation of fast signal to calculate gamma-ray interaction location
- Compare this approach with 1st order waveform decomposition (4 spot locations on Pixel 19; 0.5-mm collimator)

Parametric Interpolation



Waveform Decomposition



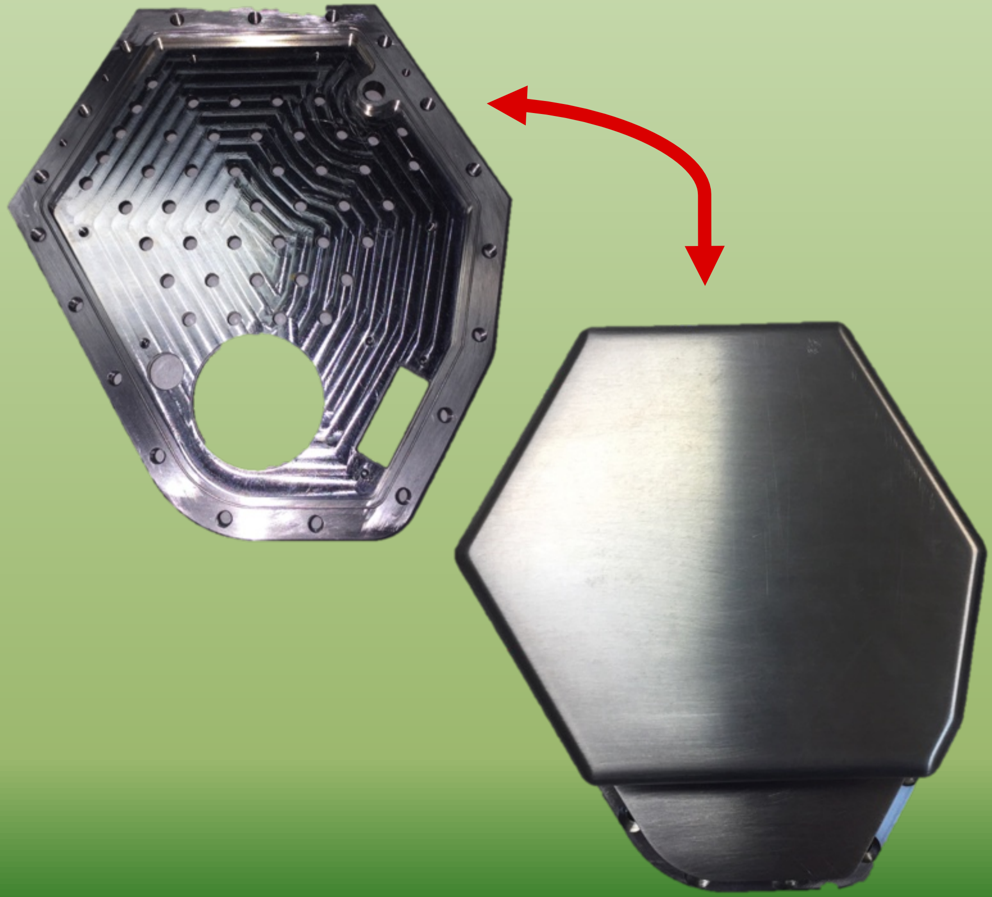
$FWHM_{x,y}$ = (4.4 +/- 0.2) mm
$FWHM_z$ = (2.0 +/- 0.1) mm

$FWHM_x$ = (3.1 +/- 0.2) mm
$FWHM_y$ = (2.5 +/- 0.2) mm
$FWHM_z$ = (3.0 +/- 0.5) mm

Phase II Prototype Detector

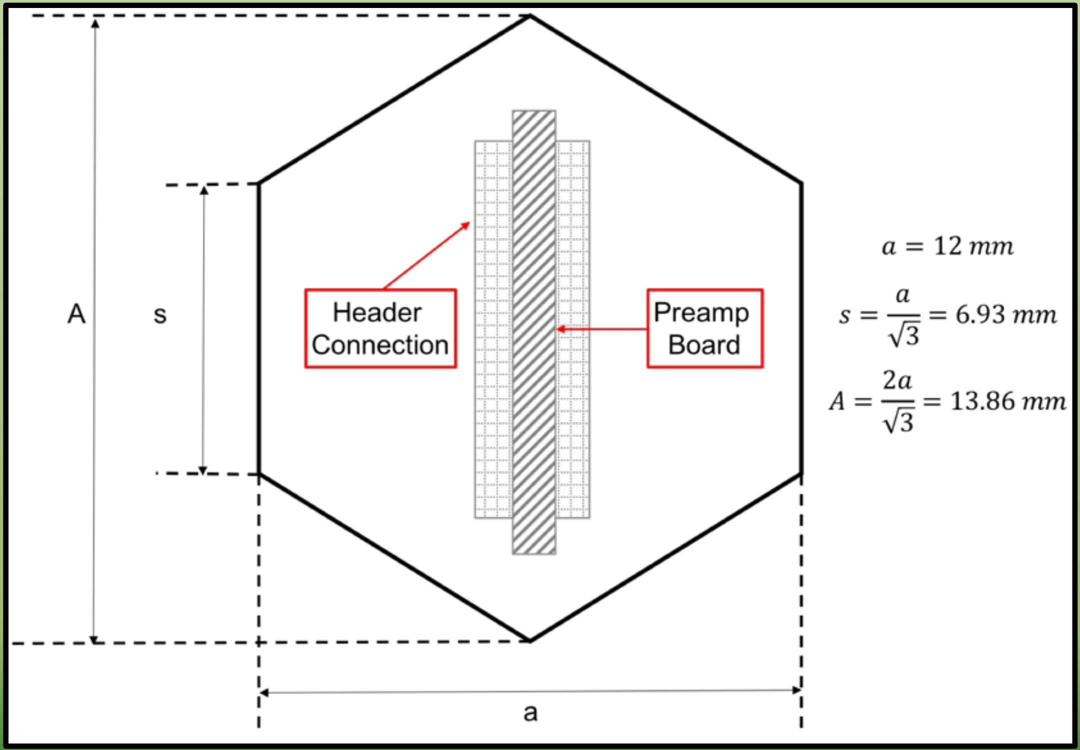
PHDS
Gamma Ray Imaging Detectors

- Compact design to facilitate close packing of arrays for large germanium detectors
- New, smaller form factor preamplifier design (next slide)



New Preamplifier Design

- Reduced footprint of preamplifier such that it fits in the "shadow" of a pixel
- Surface area reduced from 394 mm^2 to 200 mm^2
- <u>Fully tested/vetted and now used in commercial GeGI systems!</u>



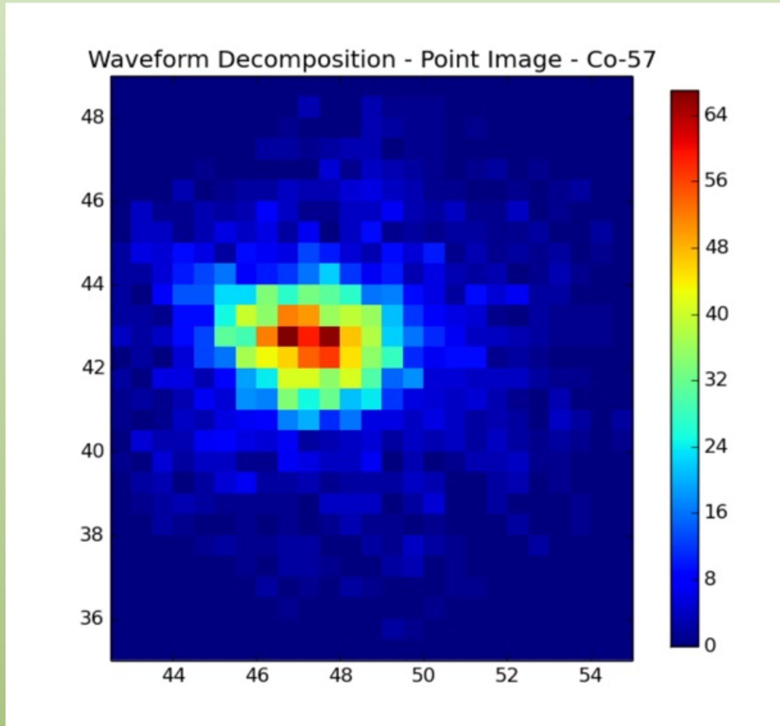
Phase II Signal Decomposition

Gamma Ray Imaging Detectors

- With the assistance of our collaborator, implement the full multi-site waveform decomposition algorithms employed in GRETINA
- Strengths:
  - Provides superior spatial resolution (relative to parametric interpolation)
  - Able to identify up to 2 interactions per segment (currently these are treated as single interactions)
  - Fast performance (even relative to simple Phase-I approach)
- Weaknesses:
  - Strongly relies on fidelity of the basis set
  - Poor determination of number of interactions
  - Significant effort required to adapt from GRETINA to Pixel Array (ongoing effort)

Single-Site Signal Decomposition

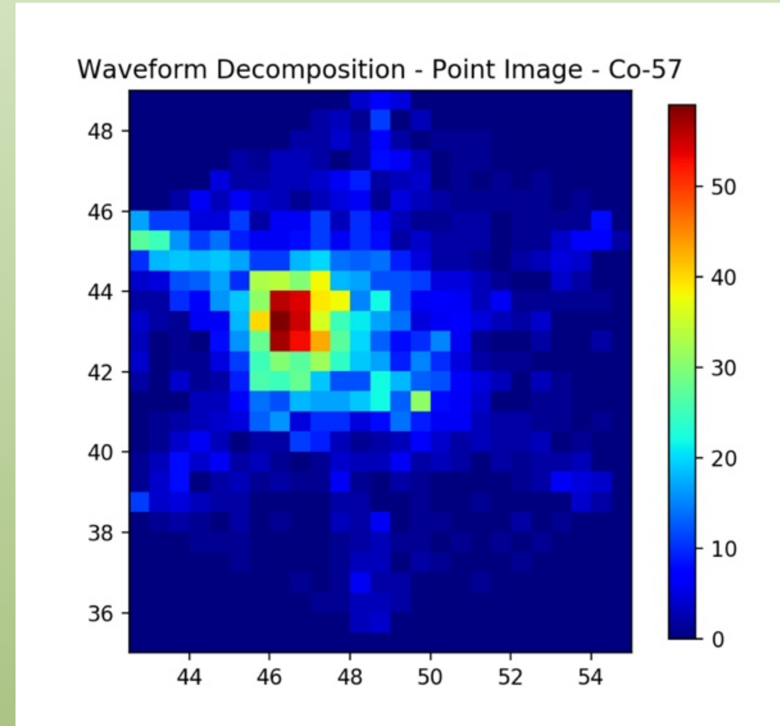
PHDS
Gamma Ray Imaging Detectors



<u>Phase-I (slow)</u>

$FWHM_x$ = 3.28 mm

$FWHM_y$ = 2.47 mm



<u>Phase-II (fast)</u>

$FWHM_x$ = 2.16 mm

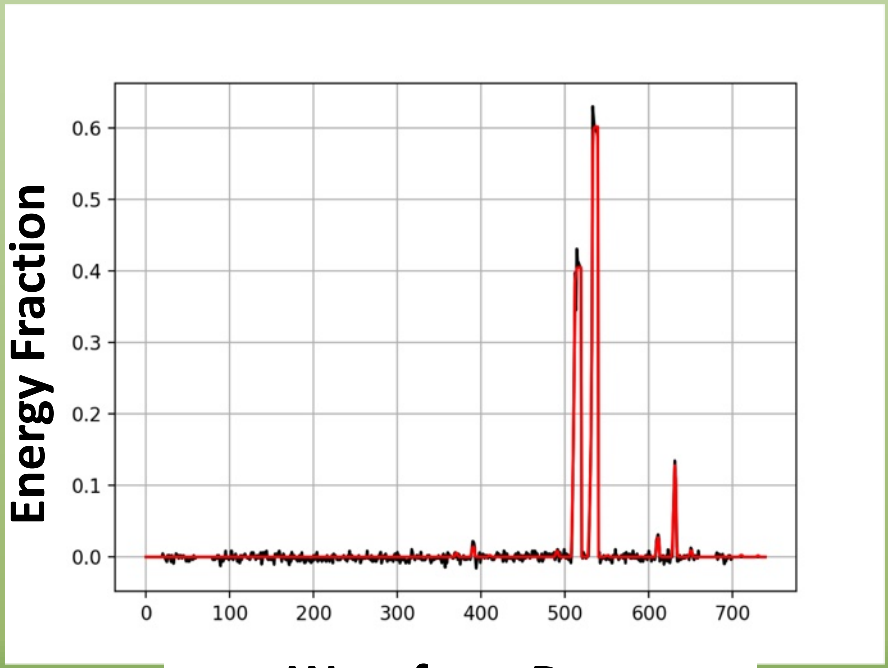
$FWHM_y$ = 2.28 mm

- Resolution based on Gaussian fit of row/column with max value
- Bin size is 0.5 mm in X and Y dimensions
- (Collimator is 0.5 mm diameter hole in 1/8” thick Pb)

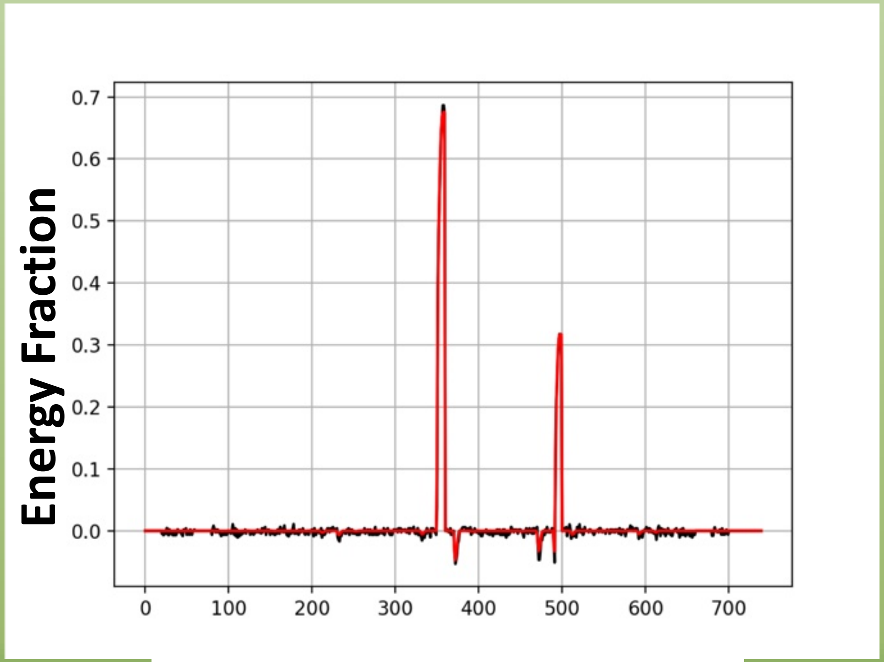
Multi-Pixel Signal Decomposition

PHDS
Gamma Ray Imaging Detectors

- Now looking at ^{137}Cs data with interactions in multiple pixels
- Currently working on geometry module that will more efficiently keep algorithm from "wandering" out of pixel
- Example data and fits below…



Waveform Data
37 Pixels x 20 Time Steps



Waveform Data
37 Pixels x 20 Time Steps

Next Steps

PHDS
Gamma Ray Imaging Detectors

- Finish assembling and load detector into prototype PAGe
  - All 37 pixels will be instrumented
  - For testing, two GeGI signal processing boards will be used (32-channel SPECT)

- Continue development of waveform decomposition for PAGe
  - Promising results thus far
  - Cross-talk appears to be minimal, but need to investigate this further

Questions?