Polaris 3-D Position-Sensitive CdZnTe Gamma-Ray Imaging Spectrometers

Zhong He

On behalf of the Orion group

University of Michigan and H3D Inc.

Los Alamos National Laboratory, P-25
August 12th, 2013

This project has been jointly funded by DOD DTRA and DOE NA-22
**Polaris Systems**

**Eighteen** 2×2×1.5 cm³ CdZnTe detectors

(108 cm³, 648 grams = 1.43 lb)

The two movies on Polaris operation, principle of gamma-ray imaging, and “Today and Tomorrow” were deleted since they take too much memory to be sent by E-mail (Please contact Zhong He at UM if people are particularly interested in those movies.)

**Performance Goals**

\[ \Delta E/E \leq 1\% \text{ FWHM (at 662 keV)} \]

Real-time $\gamma$ Imaging + isotope I.D.

\[
\cos \theta = 1 - \frac{E_1 m_e c^2}{(E_1 + E_2) \cdot E_2}
\]

Number of photons: 2033
Goals

Close to HPGe resolution at RT

Minimize impacts of imperfections of commercially available crystals

Real-time $\gamma$-ray imaging

Intelligent data analysis based on signature of radiation interactions

- Photo-electric absorption
- Compton scatters
- Pair production

- Muon

- Neutron?
Polaris 1.1 (GMI ASIC) – August 2010
$^{137}$Cs Energy Spectra of the 1\textsuperscript{st} Polaris system #1.1
(From all 18 detectors of Polaris, 24\degree C, uncollimated $^{137}$Cs)

Counts

Energy (keV)

- 1-pixel events
- 2-pixel events
- 3-pixel events
- 4-pixel events

662 keV

1.44\% FWHM

All events

$^{137}$Cs
2nd-Generation Polaris System v2.0 (BNL ASIC)
(From all 18 detectors, room-temperature, uncollimated $^{137}\text{Cs}$)

Single-pixel events

July 2012

Counts per keV

keV

662 keV

0.61% (4.0 keV) FWHM
2nd-Generation Polaris System v2.0 (BNL ASIC) (From all 18 detectors, room-temperature, uncollimated $^{137}$Cs)

- 662 keV
- 0.86% (5.7 keV) FWHM
- Peak-to-Compton ratio $\approx 20.5$

All events – no selection

July 2012
Gamma Imaging Capability

Azimuthal Angle (°)

Polar Angle (°)

Intensity of:

\[ ^{22}\text{Na} \quad ^{60}\text{Co} \quad ^{137}\text{Cs} \]

1 minute data EIDs.
Weiyi Wang

Yuefeng Zu

Willy Kaye

Chris Wahl

137Cs

22Na

60Co

137Cs

Target specific γ-Spec.

23 min. data EIID
Next-Generation
Digital Polaris Detectors
From analogue to **digital** detectors

CdZnTe or TlBr, ...

11×11 pixellated anodes

Pre-amp.

Shaping-amp.

Peak

ADC

10 – 80 MS/s

Timing Circuit

GM-I (Oslo) ASIC & Det. #4E-3

- Energy
- Depth

Trigger

Cathode

Graph showing channel triggered at 103,
Advantages of digital detectors

(1) **Sub-pixel position resolution** (better $\gamma$-ray energy & imaging resolutions) $\Delta x\ & \Delta y$ reduced from 1.72 mm pixel pitch → 0.3 mm FWHM at 662 keV (sub-pixel position resolution is inversely proportional to energy deposition)

(2) **Improved energy & position reconstruction using digital signal processing**, including on multiple-interaction events under the same anode pixel and significantly improved performance at higher gamma energies

(3) **More accurate event classification** (identifying photo-electric, Compton, pair production and charge particle interactions)

(4) **Lower power** (from ~3 mW/ch. on analogue ASIC to 1.65 mW/ch.)

(5) **Universal ASIC** for all room-temperature semiconductor detectors CdZnTe, HgI$_2$, TlBr, ...

**Acknowledgements/Deliverables**

**DOD DTRA** (Award #: HDTRA1-12-C-0034)
Support development on CdZnTe detectors & ASICs + staff

**U.S. DOE NA-22**
Support graduate students on digital algorithm development
Impact of improved electronic noise
2.5 keV $\rightarrow$ 2.0 keV FWHM
Close to HPGe resolution is possible

(1-pixel $^{137}$Cs spectrum of CZT #4E-1 & **BNL ASIC**)

FWHM = 0.48% 

(0 – 3 MeV)

662 keV

(no-collimation & at ambient temperatures)

32 keV Ba K$_\alpha$

36 keV Ba K$_\beta$

Unit volume = 6 cm$^3$

2 cm

1.5 cm

Using analogue BNL ASIC
Closer to HPGe resolution
(1-pixel $^{137}\text{Cs}$ spectrum of CZT #4E-1 & digital ASIC)

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>Cts</th>
</tr>
</thead>
<tbody>
<tr>
<td>662 keV</td>
<td></td>
</tr>
</tbody>
</table>

FWHM = 0.58% for all events

ASIC: 40 MHz Full Readout

Range: 0.3 – 0.8 %

FWHM = 0.41%
$^{228}\text{Th}$ Energy Spectra Polaris-2

- 1-pixel events, 1.64% FWHM @ 2.6 MeV
- 2-pixel events, 1.62% FWHM
- 3-pixel events, 1.73% FWHM
- 4-pixel events, 1.80% FWHM
- All events, 1.72% FWHM

Using GM-I analogue ASIC
Single-Pixel Energy Spectrum of $^{228}$Th & $^{135}$Eu on Detector #4E-1

- 1-pixel events, 0.27% FWHM @ 2.6 MeV
- 2-pixel events, 0.49% FWHM; 1 – 4 pixel events, 0.74% FWHM

Energy Spectrum for the Whole Bulk

Using GM-I digital ASIC

0.27% FWHM

2614 keV
Impact of sub-pixel position resolution
Real-Time Sub-Pixel Position Sensing

GM-I digital ASIC & CdZnTe detector #4E-3

662 keV Signal Amplitude versus Sub-Pixel Position

Depth = 20 (total 40 depth)  
Depth = 6 (total 40 depth)

Middle Z  
Close to anode
Improved Simple Back-Projection Gamma-Ray Imaging

\( ^{60}\text{Co} - 1.3 \text{ MeV} \)

Without sub-pixel position sensing  

With sub-pixel position sensing
High-Flux Experiment Results

Photopeak shift and spectral degradation vs. flux

Electron Drift Time vs. Flux

Incident Flux (photons/mm²/s)

Drift Time (ns)

Photopeak Position (keV)