Evaluation of a Compton Camera Concept Using the 3D CdZnTe Drift Strip Detectors

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Motivation: The MEV Gap

- The MeV domain remains largely unexplored and is difficult to probe due to:
  - Three energy-loss processes
  - Minimum cross-section
  - Rich instrumental background
The 3D CZT Drift Strip Detector Concept

- Electron only device
- 3D Position Capability
- Room temperature operation
- 2N readout channels provides 3D position capability
- Active volume: $20 \times 20 \times 5 \text{ mm}^3$
- Energy resolution: 1.6% @ 661.6 keV
- Position resolution:
  - X: 537 $\mu$m
  - Y: 378 $\mu$m
  - Z: 527 $\mu$m

Electrode geometry-Prototype detectors

- Strips:
  - Width = 0.15 mm
  - Gap = 0.25 mm

- Cathode strips:
  - Width = 1.9 mm
  - Gap = 0.1 mm

- Anode pitch: 1.6 mm

Event types

Single site event
- Photoelectric absorption
- Compton $\rightarrow$ Escape

Single cell double event
- Compton $\rightarrow$ Photoelectric absorption
- Compton $\rightarrow$ Compton $\rightarrow$ Escape

Multiple cell double event
- Compton $\rightarrow$ Photoelectric absorption
- Compton $\rightarrow$ Compton $\rightarrow$ Escape

- Pulse shape analysis to determine the event type

(a) Anode signal
(b) Cathode signal
(c) Drift strip signal
Single site event

$x$-position

\[ x_{\text{pos}} = 0.35 + \left[ x_{\text{trig}} + F \cdot \frac{A_{\text{DR}} - A_{\text{DL}}}{A_{\text{DR}} + A_{\text{DL}}} \right] \cdot P_{\text{an}} \cdot \frac{P_{\text{an}}}{2} \]

Position resolution in $x$-direction:

0.5mm FWHM$_{x\text{-pos}}$ @ 661.6 keV
Single site event $y$-position

\[
y_{\text{pos}} = \frac{\sum_{n=1}^{10} C_n}{A_m} \cdot d
\]

Position resolution in $y$-direction: 0.38mm FWHM$_{y\text{-pos}}$ @ 661.6 keV

(a) Anode charge signals.

(b) Cathode charge signals.
Single site event

**z-position**

(a) Cathode charged signals, and sum of signals of a single site event.

(b) Cathode pulse-heights as a function of z position.

**Position resolution in z-direction:**

\[ 0.5\text{mm FWHM}_{z-pos} @ 661.6\text{ keV} \]

Single site event
2D-images

Edge effect

Detector issues at dead-zone areas
- Possibly due to electrode deposition/surface passivation
- Weak and non-existing signals in these areas
Compton (double) events

- Electron drift time of multiple cell double events – used for position determination
Compton (double) events

$x$-position

- Some drift cells share drift-strips – time interval between collection allows for drift strip amplitude to be derived

(a) Anode charge signal

(b) Inverted drift strip current signal
Compton (double) events

$y$-position

- Induced charge on all cathodes from both moving charges $\rightarrow$ Single event method not possible
- Linear relationship between electron drift time and $y$-position utilized
Compton (double) events

**Z-position**

- Induced charge on all cathodes from both moving charges
  - Distance of at least 2mm between events in z-direction
    \[ \rightarrow \text{double peak in cathode amplitudes} \]
  - Fitting a double Gaussian

\[
f_{\text{doubleGauss}}(z) = c_1 \exp \left( -\frac{z - \mu_1}{2\sigma_1^2} \right) + c_2 \exp \left( -\frac{z - \mu_2}{2\sigma_2^2} \right)
\]

Assigning events with respect to induced signal of last collected event

(a) Cathode Charge Signals of double events with collection times, \(t_1\) and \(t_2\) marked.

(b) Cathode Amplitudes for double events. Black is total cathode amplitudes, and gray is amplitudes between \(t_1\) and \(t_2\).
Image reconstruction from Compton events from single detector prototype

• Experimental setup

\[(x_{\text{MEGAlib}}, y_{\text{MEGAlib}}, z_{\text{MEGAlib}}) = (1\text{cm}, -50\text{cm}, 0.235\text{cm})\]

\[(\theta, \phi) = (89.73^\circ, -88.85^\circ)\]
Image reconstruction from Compton events from a single detector prototype

- Experimental data reconstructed using MEGAlib, and image reconstruction using MEGAlib – ARM (Angular Resolution Measure) of **15.95** degrees with experimental data (photo-peak events– using only one single detector crystal (2cm x 2cm x 0.5cm)

Image reconstruction from Compton events from single detector prototype – using MEGAlib

• Simulation tool and reconstruction tool → MEGAlib
  • Simple simulation with detector and aluminium casing → Only double events with spacing of 0.2cm between each event → achievable angular resolution of 12.15 degrees.
Investigation of a simple Compton Camera Concept – High Energy Astrophysics

• Compton Camera Concept Simulation in Low Earth Orbit of Crab Nebula (not including trapped protons and electrons)

• $t_{\text{obs}} = 9300\text{s}$

https://github.com/zoglauer/megalib/tree/experimental/resource/examples/advanced/Background
Conclusion

• The detector prototype was characterized
  • Sub mm 3D position resolutions
  • Spectral resolution of 1.6% - prototype electronics
  • Small number of readout channels for 3D position determination
  • Multiple cell double event position and energy determination
  • Compton camera performance (reconstruction using MEGAlib) of single detector prototype of 15.95° ARM @661.6keV (photo-peak events).

• 3D CZT detector offers unique instrumentation e.g. as part of Compton telescopes opening up the MeV gap in high-energy astronomy

• Ongoing work
  • Algorithm implementation on hardware
  • Artificial neural network