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

DTU Space
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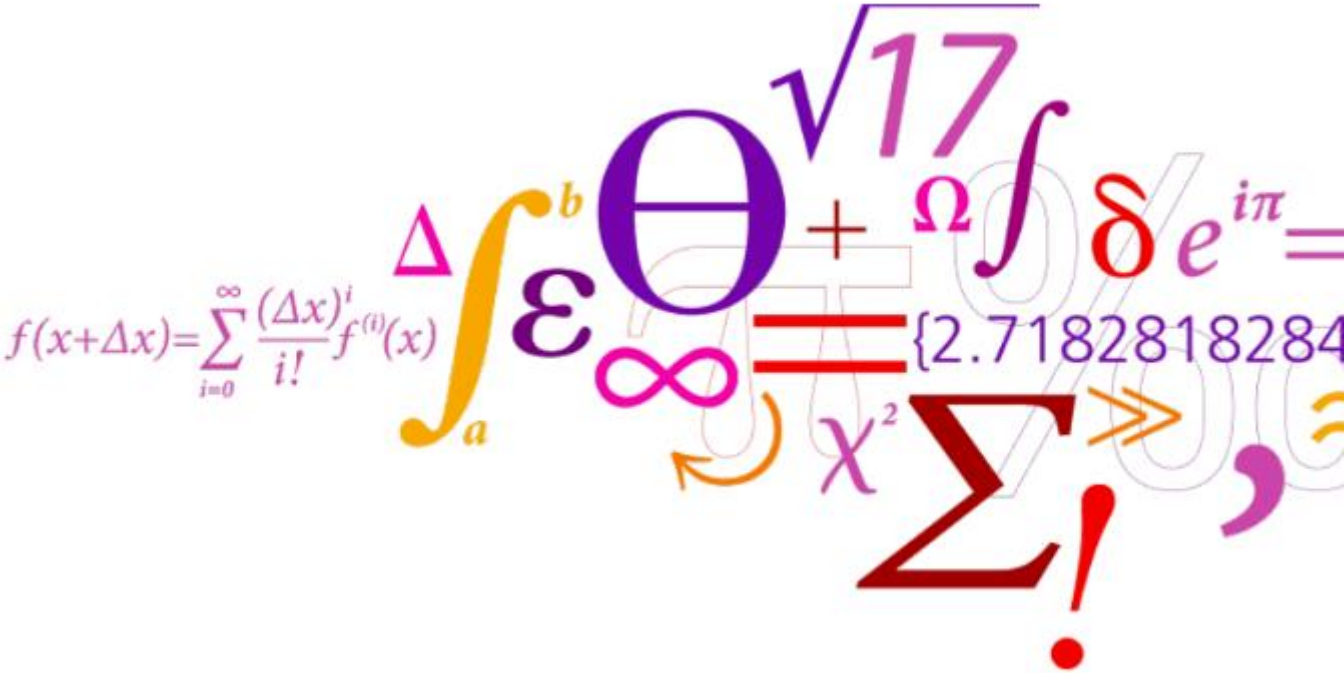
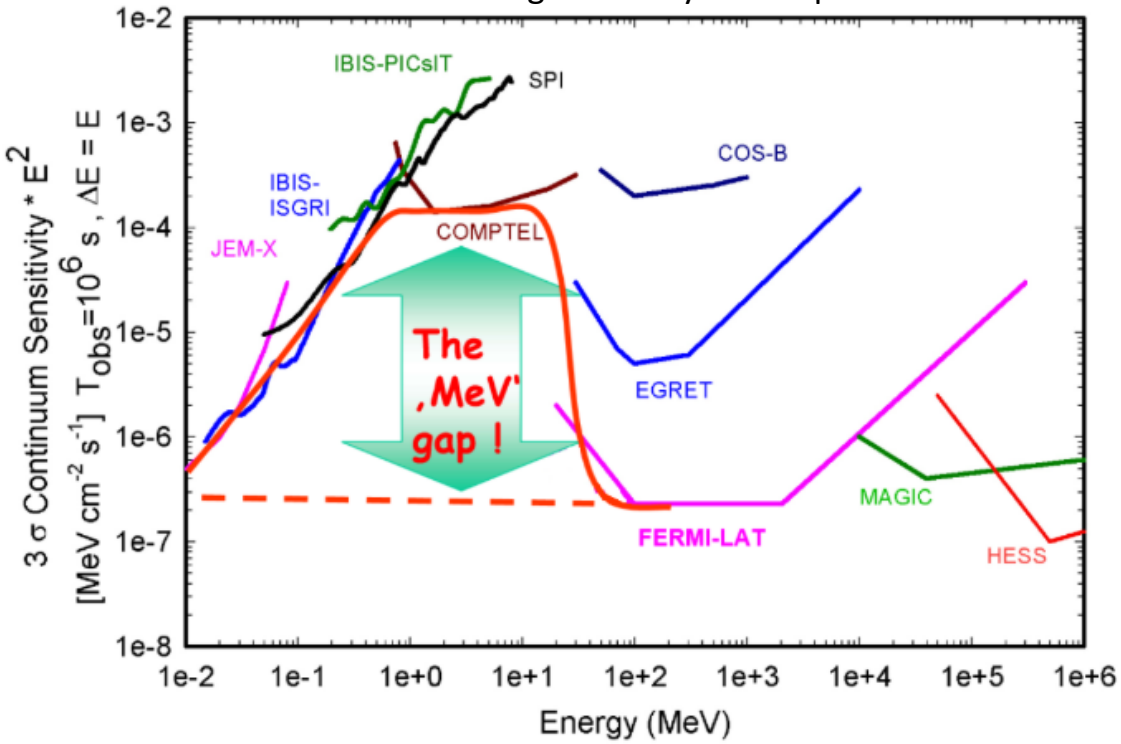


DTU Space
National Space Institute

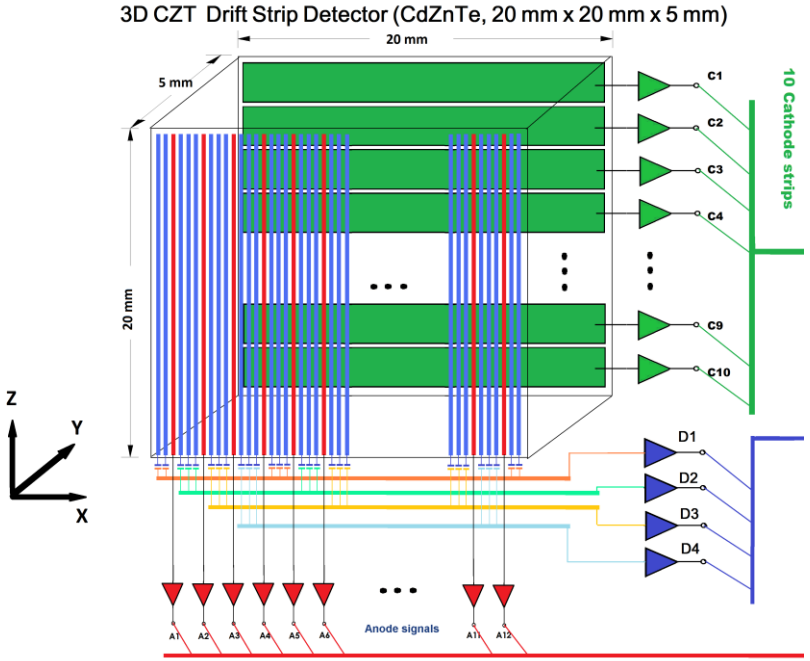
Motivation: The MEV Gap

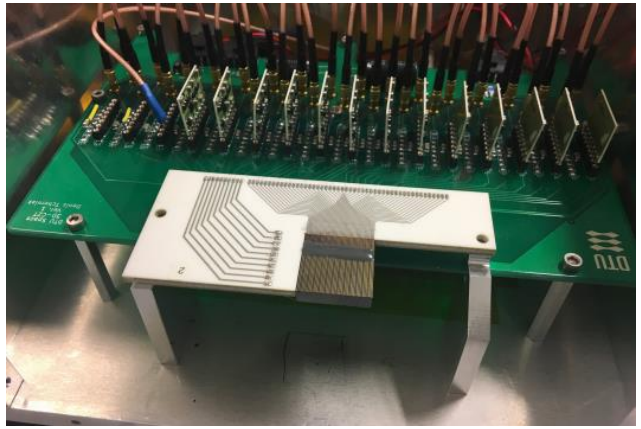
Continuum sensitivities of past and current
X- and gamma-ray telescopes



- 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: $20 \times 20 \times 5\ \mathrm{mm}^3$
- Energy resolution: 1.6% @ 661.6 keV
- Position resolution:
  - X: 537 μm
  - Y: 378 μm
  - Z: 527 μm

Electrode geometry-Prototype detectors

Strips :
Width =0.15 mm
Gap=0.25 mm

Cathode strips:
Width=1.9 mm
Gap=0.1 mm

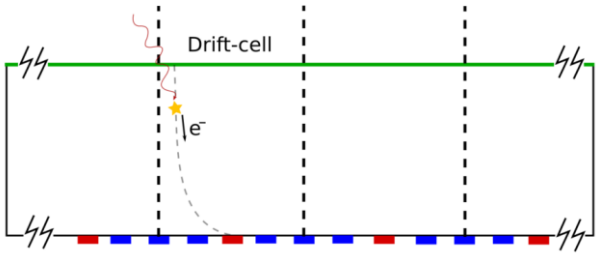
Anode pitch:
1.6 mm

[1] Budtz-Jørgensen, Carl, and Irfan Kuvvetli. "New Position Algorithms for the 3-D CZT Drift Detector." IEEE TNS, 64.6 (2017): 1611-1618
[2] I. Kuvvetli, C. Budtz-Jørgensen, "Charge Collection and Depth Sensing Investigation on CZT Drift Strip Detectors," IEEE NSS Conf. Rec. NSS '11 (R7-2), 2010
[3] I. Kuvvetli, C. Budtz-Jørgensen, et al., "A 3D CZT high resolution detector for X-and gamma-ray astronomy," Proc. of SPIE, Vol. 9154, 2014
[4] I. Kuvvetli, et al. "CZT drift strip detectors for high energy astrophysics." Nucl. Instr. and Meth. in Phys. Res. A: 624.2 (2010): 486-491.

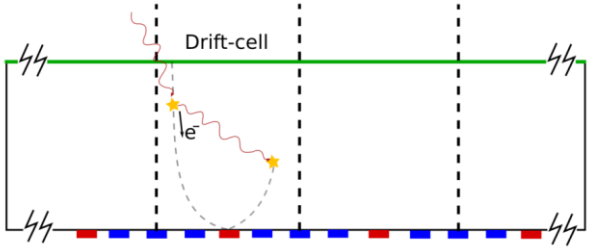
Event types

- Pulse shape analysis to determine the event type

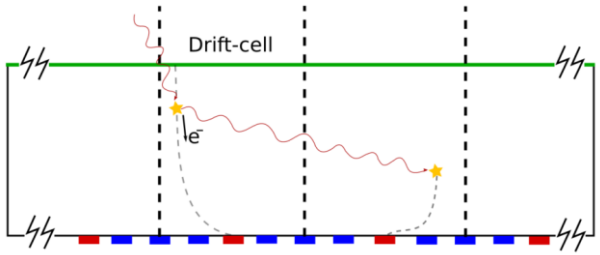
Single site event
- Photoelectric absorption
- Compton → Escape

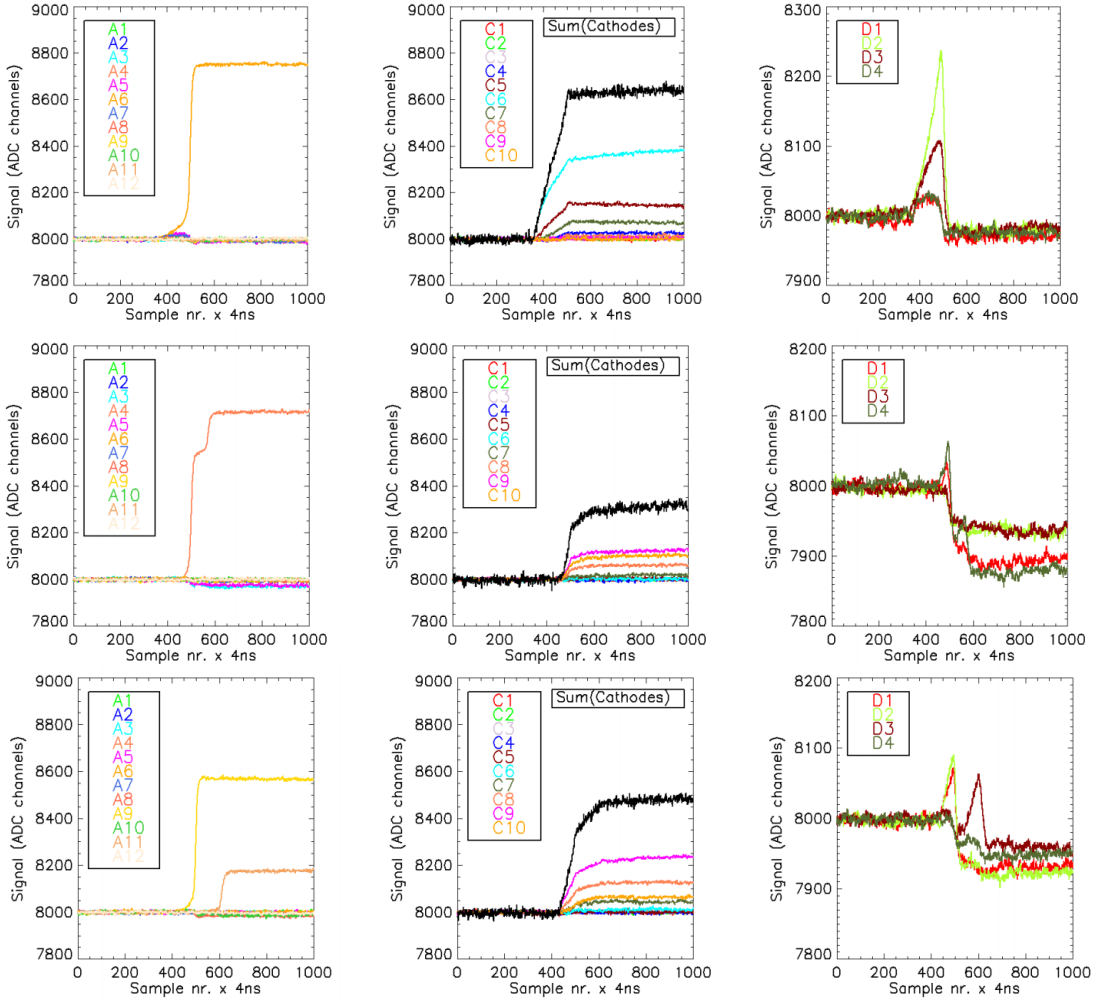


Single cell double event
- Compton → Photoelectric absorption
- Compton → Compton → Escape



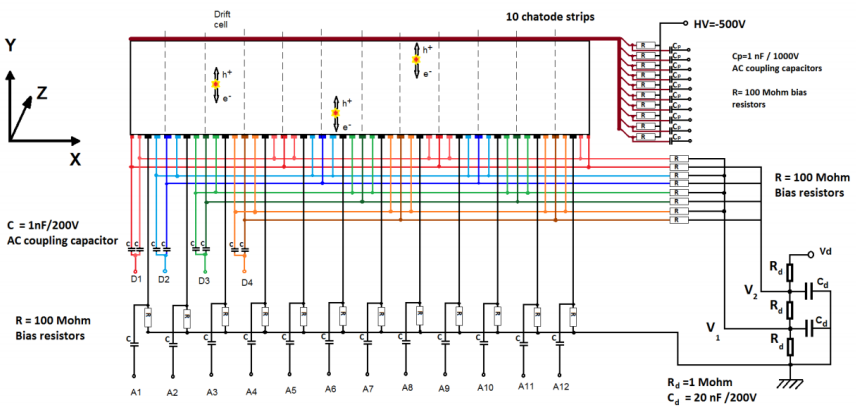
Multiple cell double event
- Compton → Photoelectric absorption
- Compton → Compton → Escape





(a) Anode signal (b) Cathode signal (c) Drift strip signal

Single site event
x-position

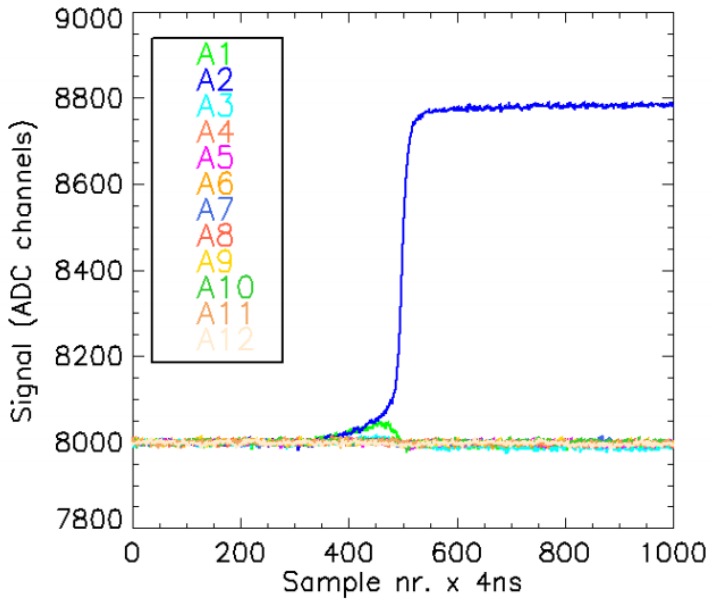


P_{an}=1.6 mm

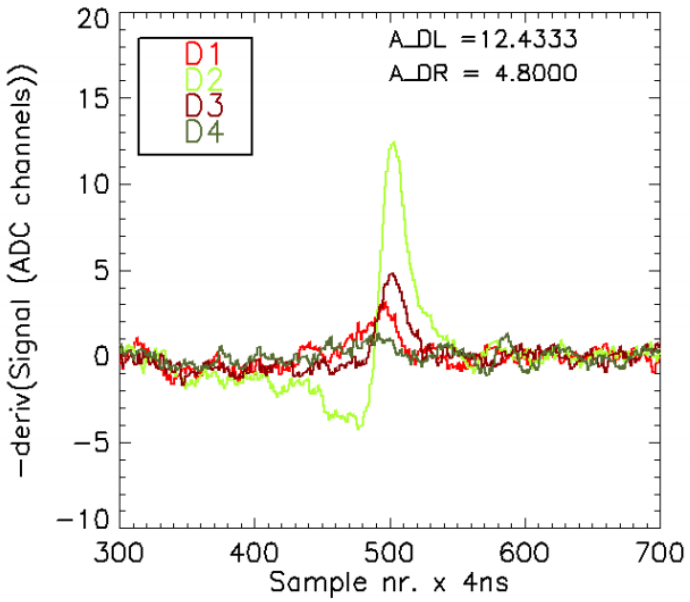
$$x_{\text{pos}} = 0.35 + \left[x_{\text{trig}} + F \cdot \frac{A_{\text{DR}} - A_{\text{DL}}}{A_{\text{DR}} + A_{\text{DL}}} \right] \cdot P_{\text{an}} - \frac{P_{\text{an}}}{2}$$

Position resolution in x-direction:

0.5mm $\text{FWHM}_{\text{x-pos}}$ @ 661.6 keV



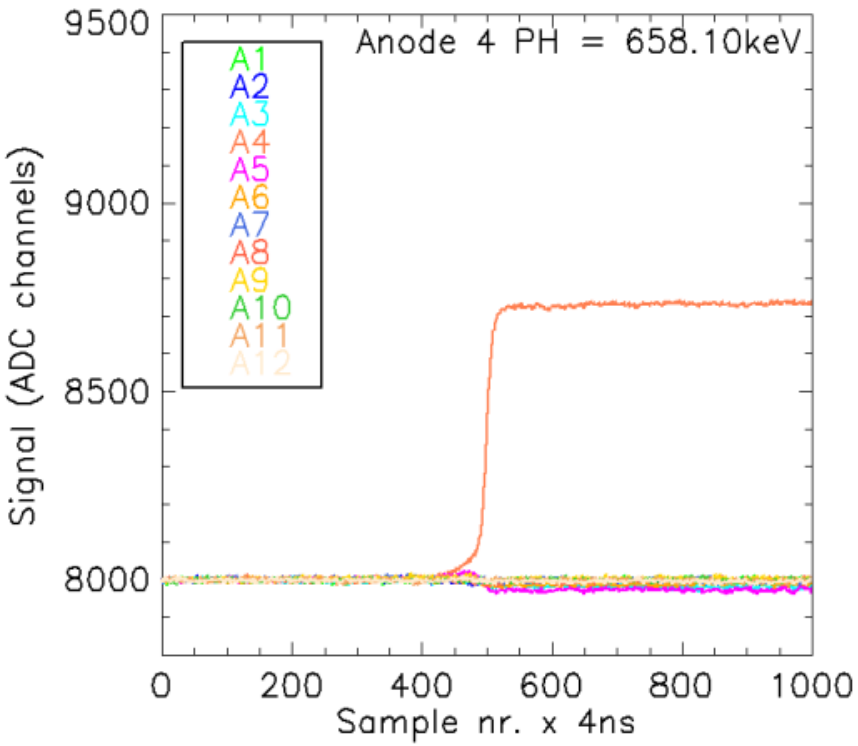
(a) Anode charge signal.



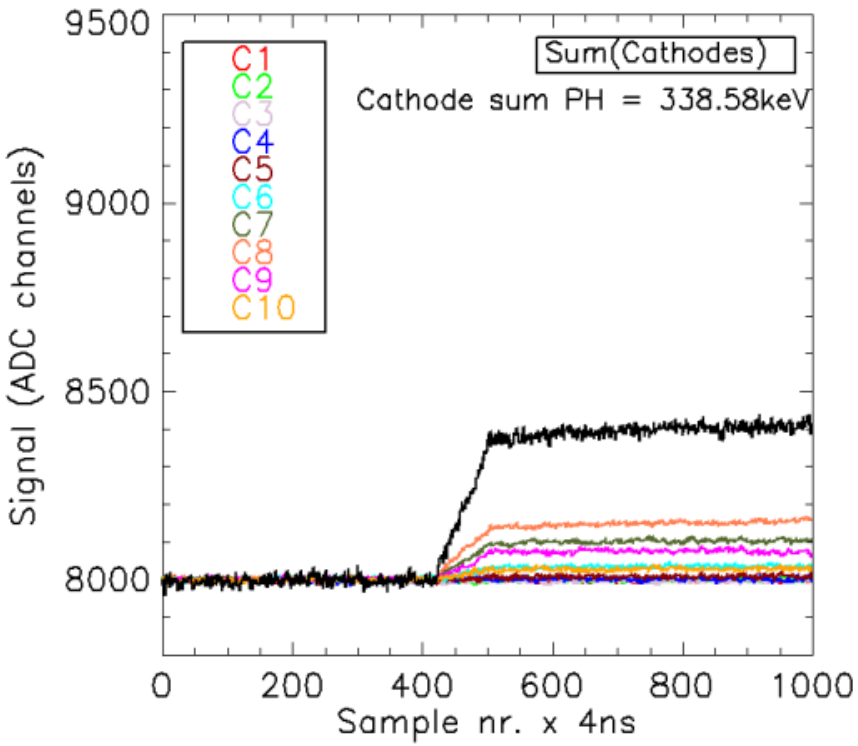
(b) Drift strip signals.

Single site event *y-position*

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



(a) Anode charge signals.

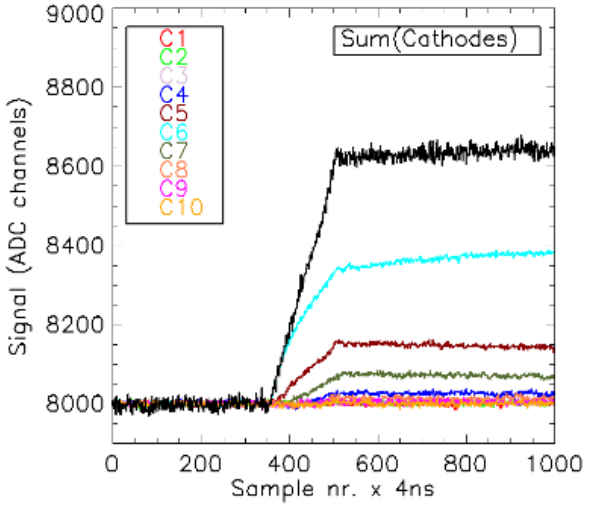


(b) Cathode charge signals.

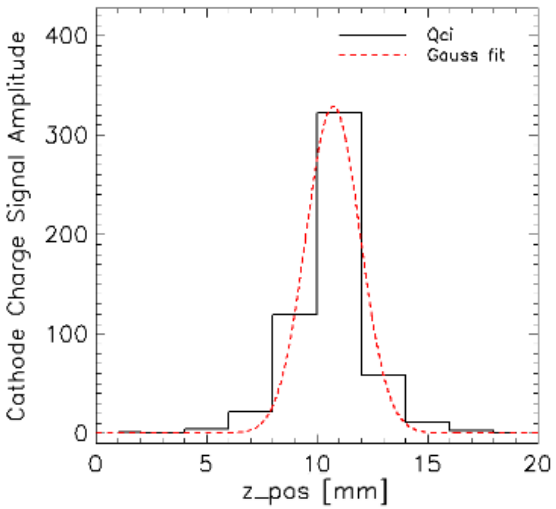
Position resolution in y-direction:

0.38mm $\text{FWHM}_{\text{y-pos}}$ @ 661.6 keV

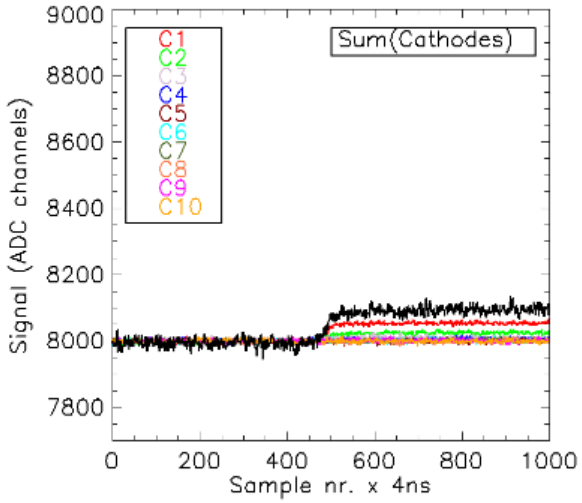
Single site event
z-position

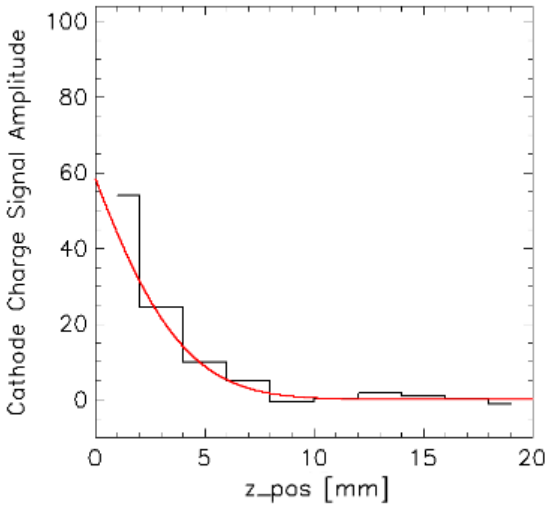


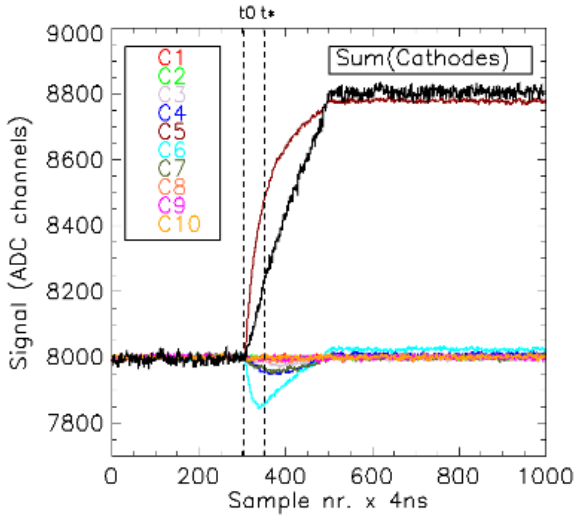
(a) Cathode charged signals, and sum of signals of a single cite event.

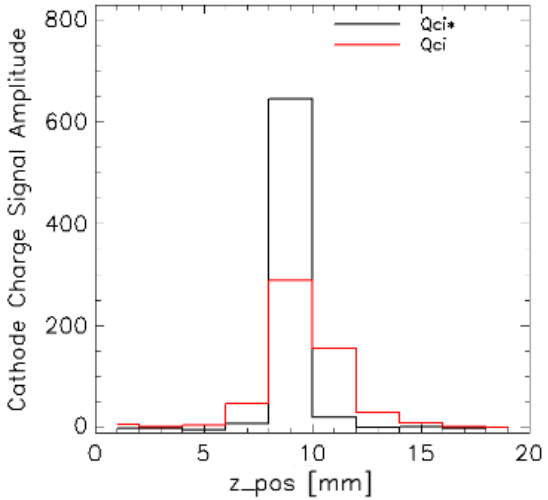


(b) Cathode pulse-heights as a function of z position.







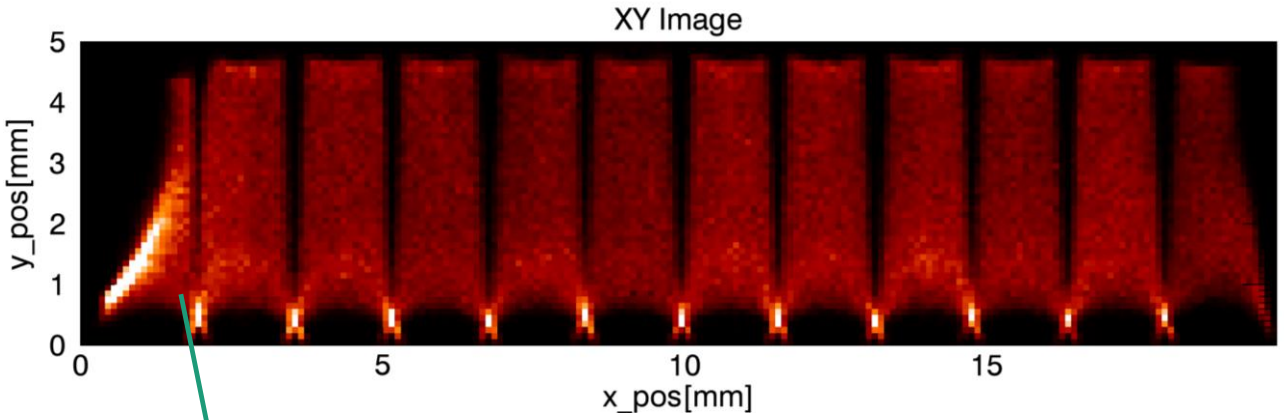


Position resolution in z-direction:

0.5mm $FWHM_{z\text{-}pos}$ @ 661.6 keV

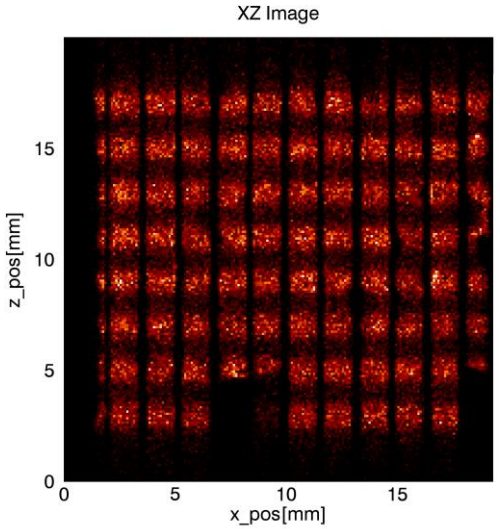
[1] Budtz-Jørgensen, Carl, and Irfan Kuvvetli. "New Position Algorithms for the 3-D CZT Drift Detector." IEEE TNS, 64.6 (2017): 1611-1618

Single site event
2D-images

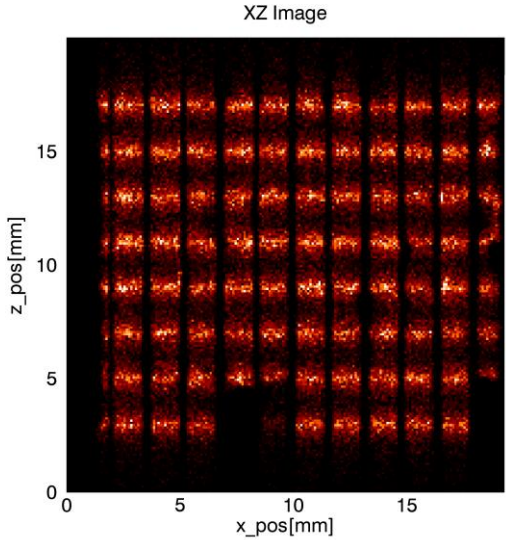


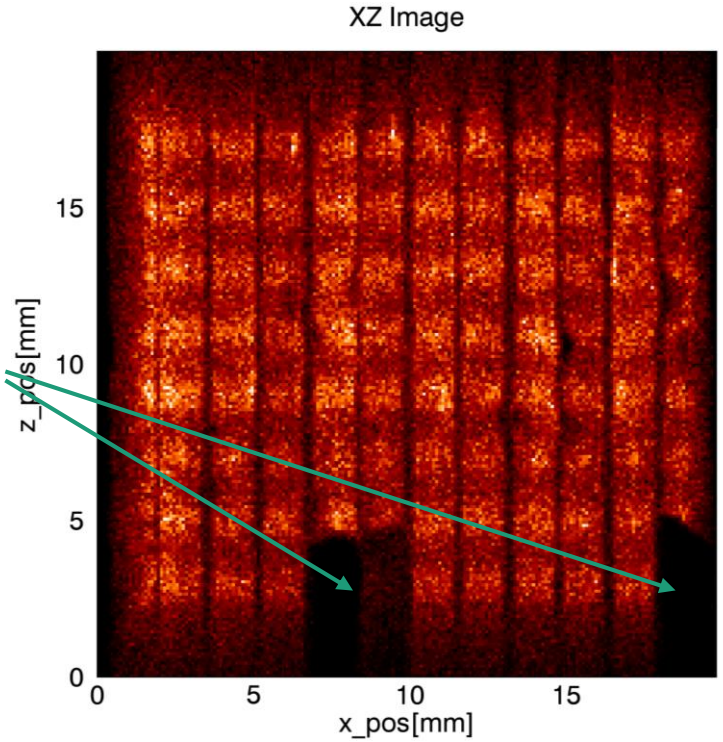
Edge effect

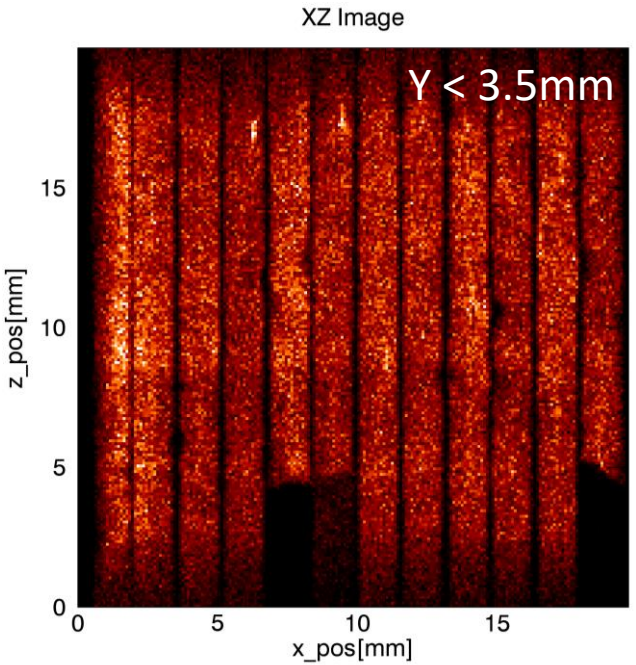
With z-correction



Without z-correction





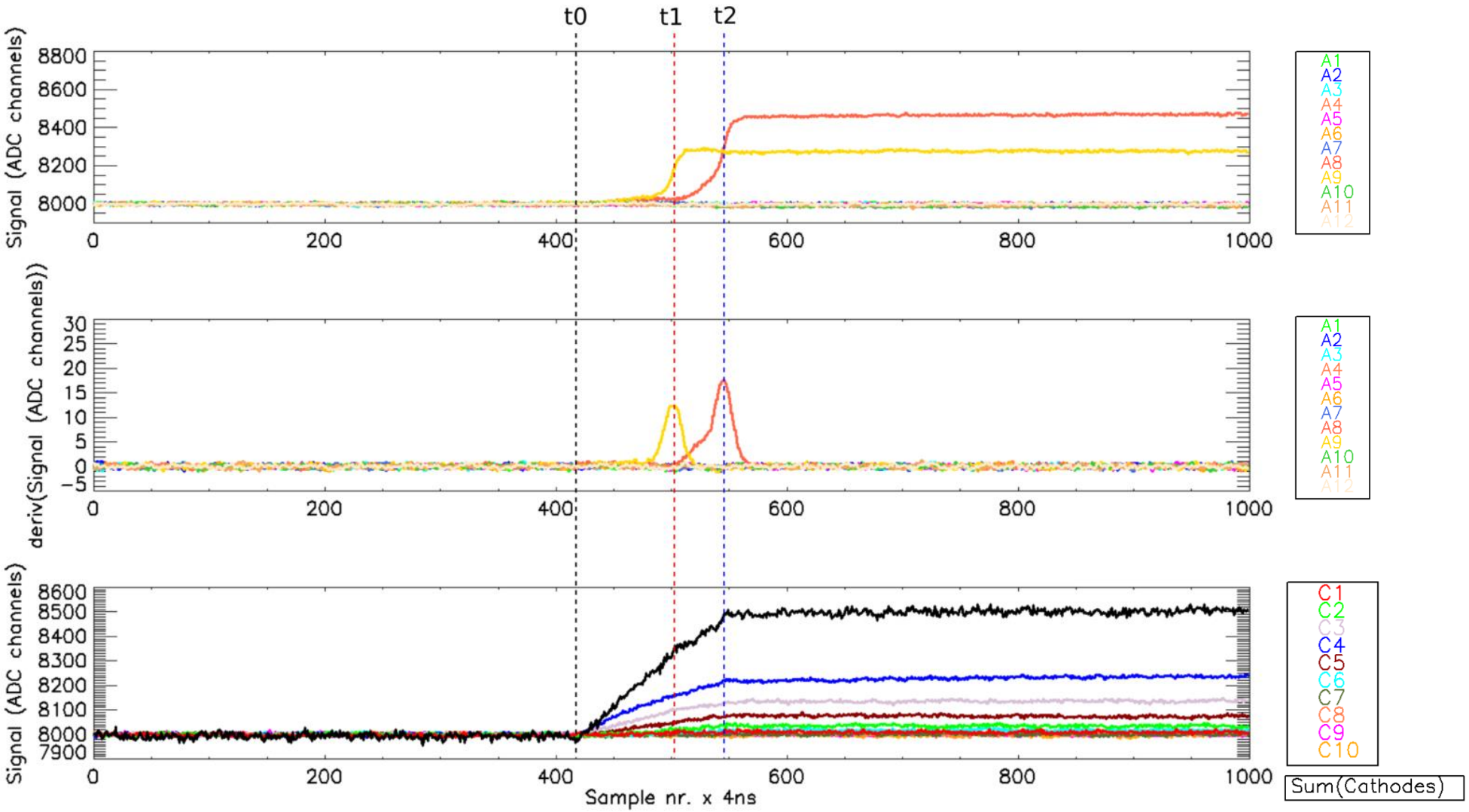


Detector issues at dead-zone areas

- Possibly due to electrode deposition/surface passivation
- Weak and non-existing signals in these areas

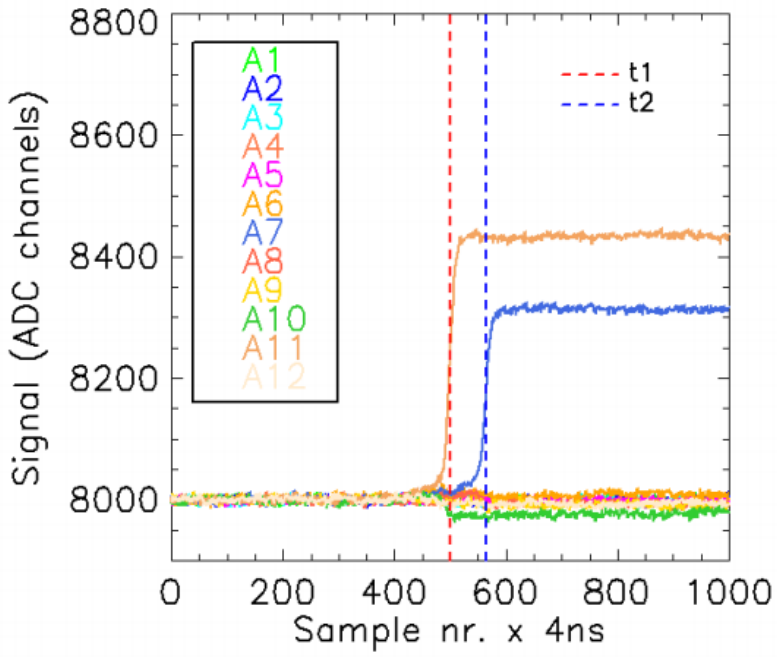
Compton (double) events

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

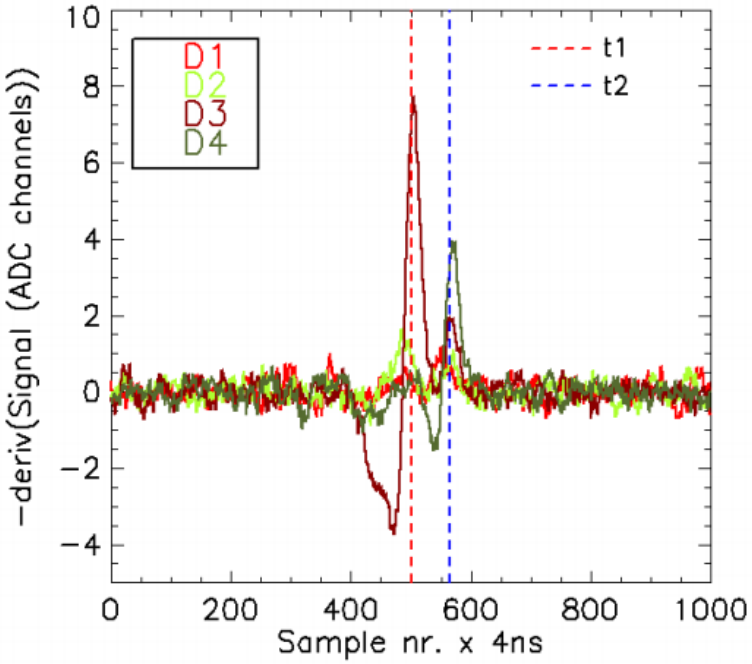


Compton (double) events
x-position

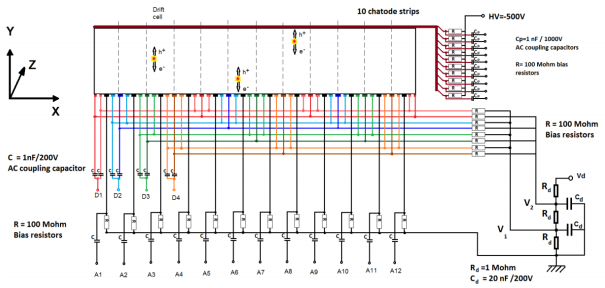
- Some drift cells share drift-strips – time interval between collection allows for drift strip amplitude to be derived



(a) Anode charge signal

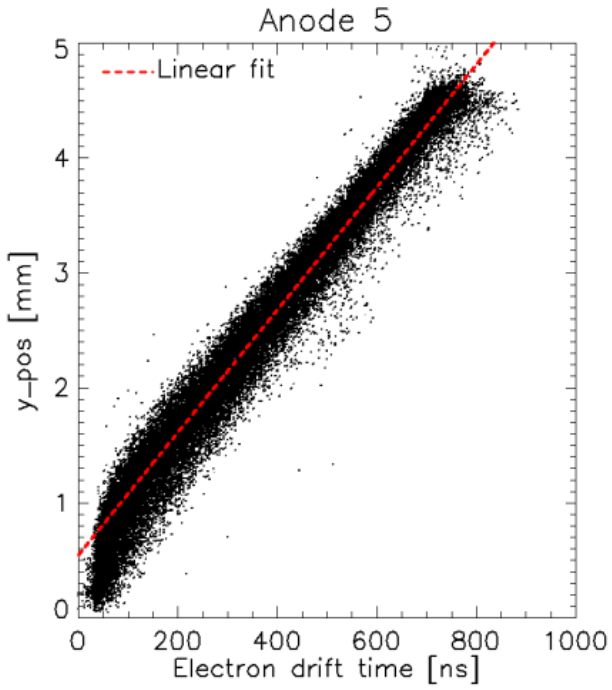


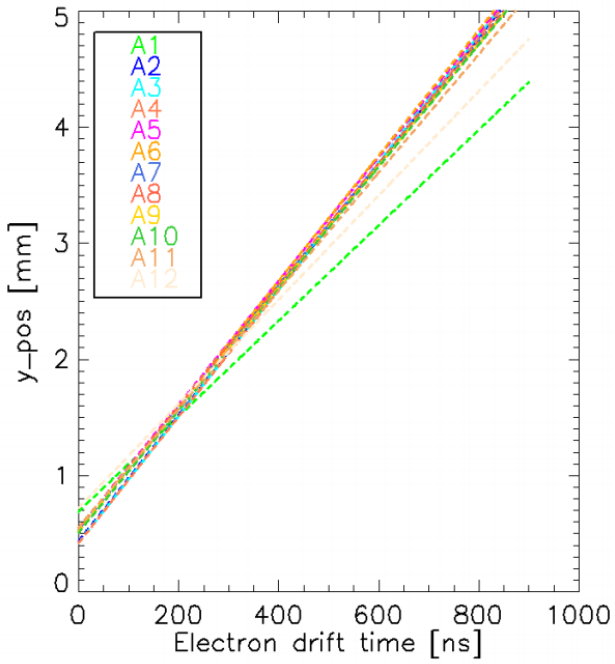
(b) Inverted drift strip current signal



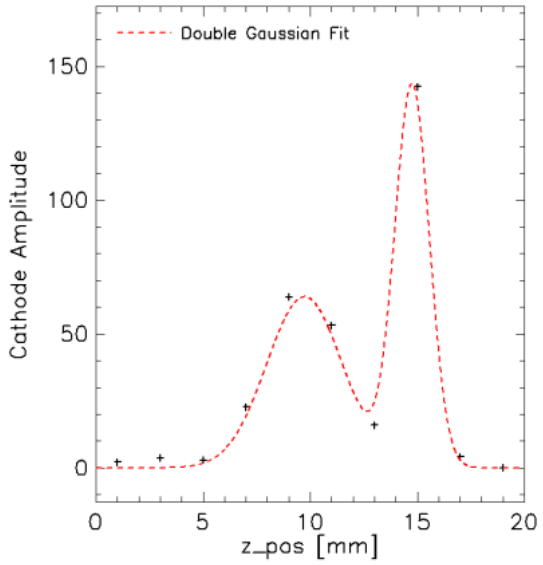
Compton (double) events
y-position

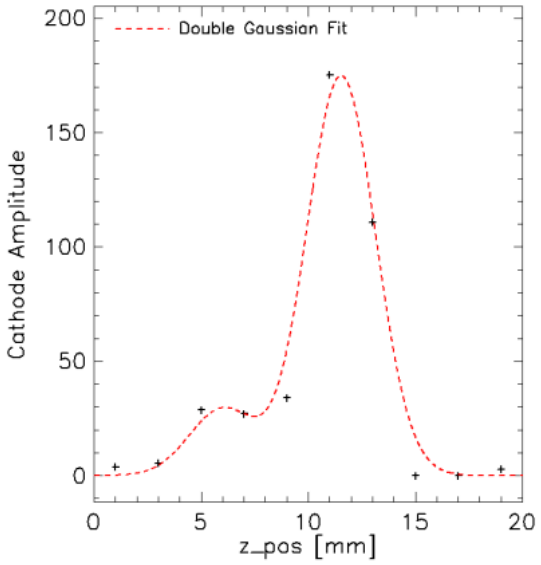
- Induced charge on all cathodes from both moving charges → Single event method not possible
- Linear relationship between electron drift time and y-position utilized





Compton (double) events
Z-position

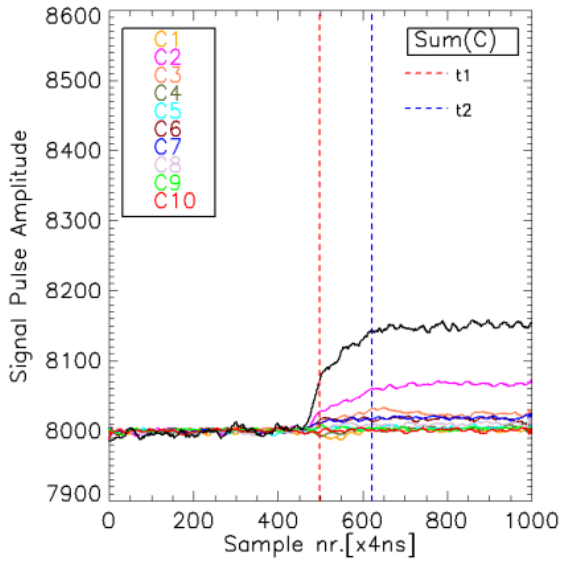




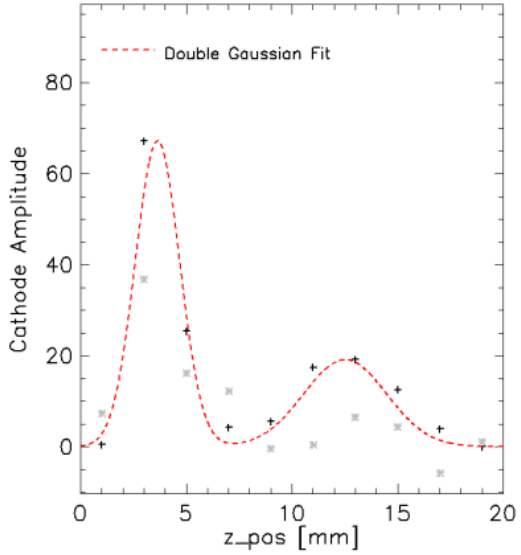
- Induced charge on all cathodes from both moving charges
  - Distance of at least 2mm between events in z-direction
    → double peak in cathode amplitudes
  - Fitting a double Gaussian

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

Assigning events with respect to induced signal of last collected event



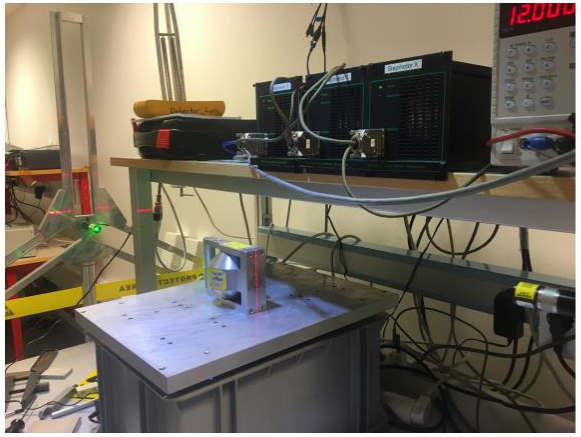
(a) Cathode Charge Signals of double events with collection times, t_1 and t_2 marked.

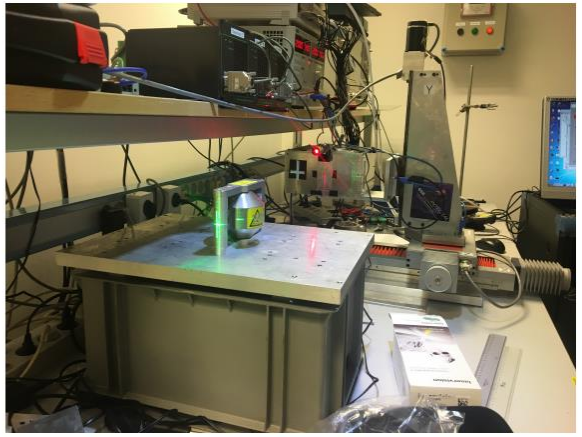


(b) Cathode Amplitudes for double events. Black is total cathode amplitudes, and gray is amplitudes between t_1 and t_2.

Image reconstruction from Compton events from single detector prototype

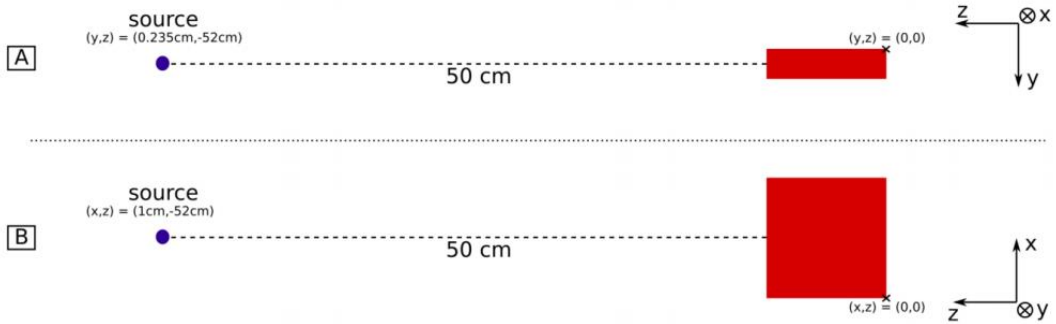
- Experimental setup

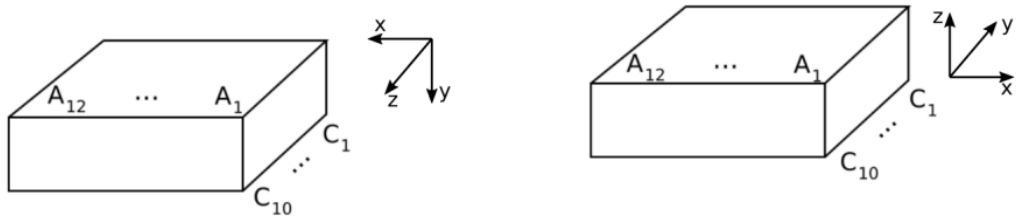




$$(x_{\mathrm{MEGAlib}}, y_{\mathrm{MEGAlib}}, z_{\mathrm{MEGAlib}}) = (1\mathrm{cm}, -50\mathrm{cm}, 0.235\mathrm{cm})$$

$$(\theta, \phi) = (89.73^\circ, -88.85^\circ)$$



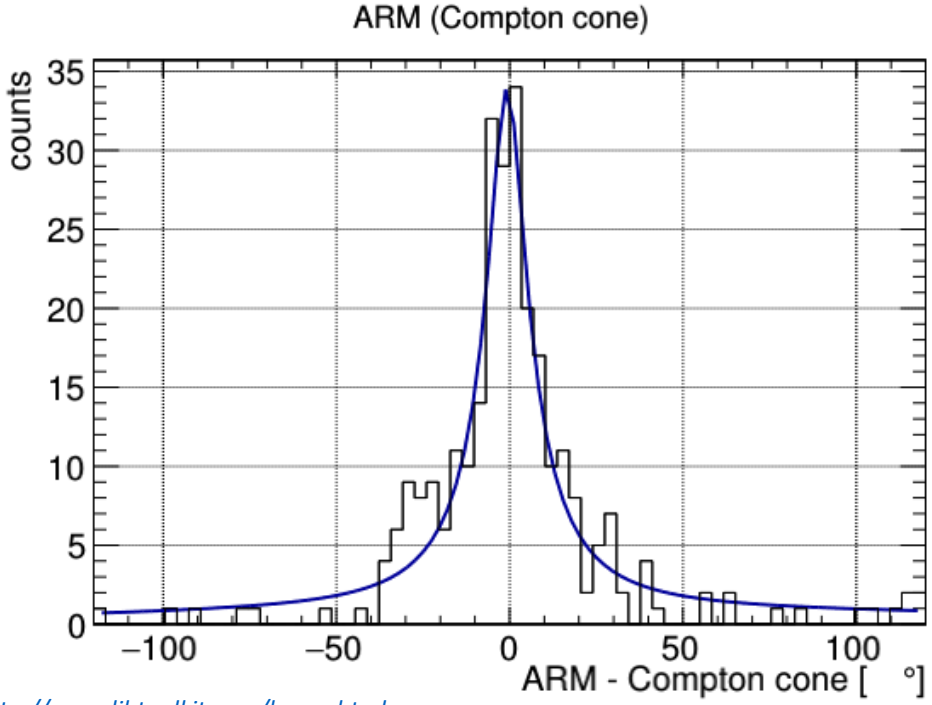


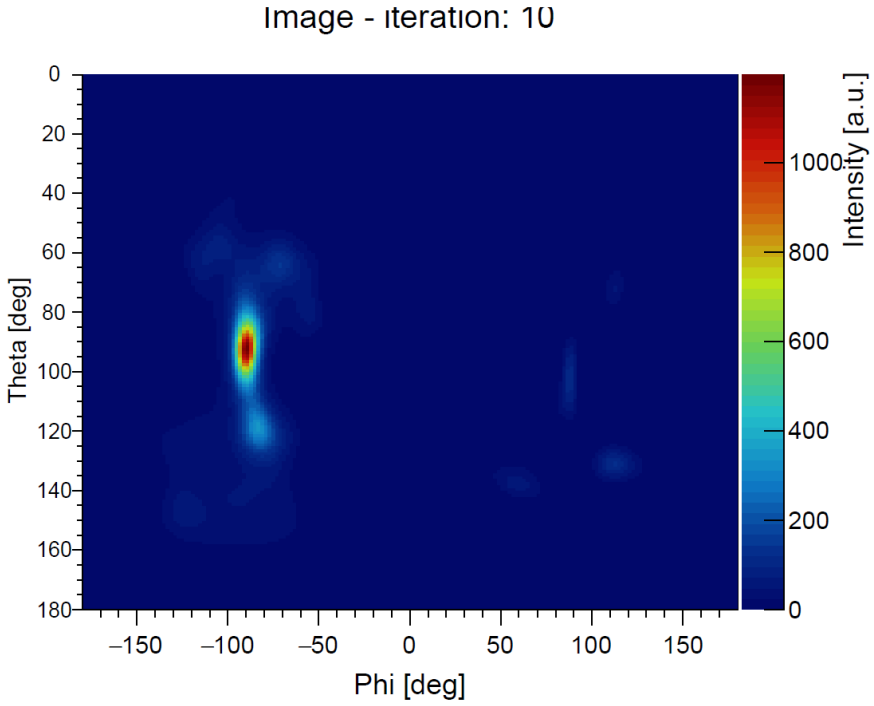
(a) Coordinate system of lab setup.

(b) Coordinate system of MEGAlib.

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)





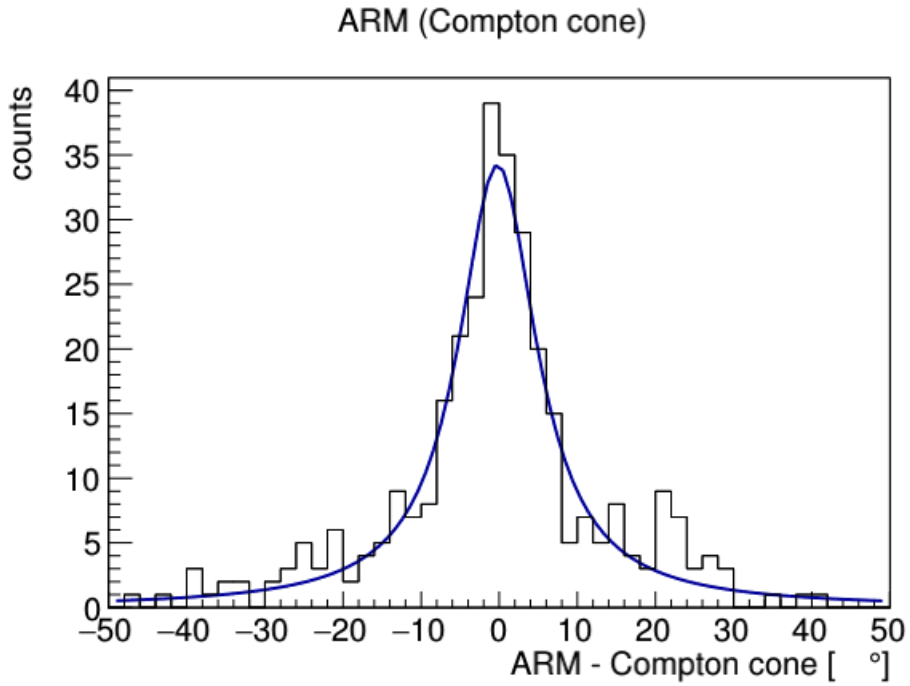
[5] http://megalibtoolkit.com/home.html

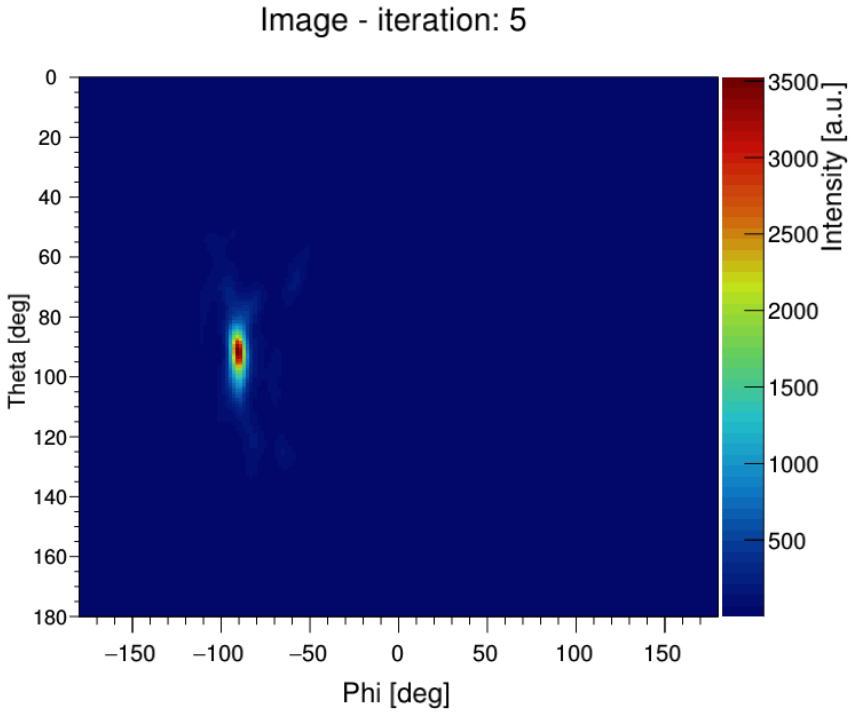
[6] Zoglauer, A., R. Andritschke, and F. Schopper. "MEGAlib–The medium energy gamma-ray astronomy library." New Astronomy Reviews 50.7-8 (2006): 629-632.

[7] Zoglauer, Andreas Christian. First Light for the next Generation of Compton and Pair telescopes. Diss. Technische Universität München, 2005.

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

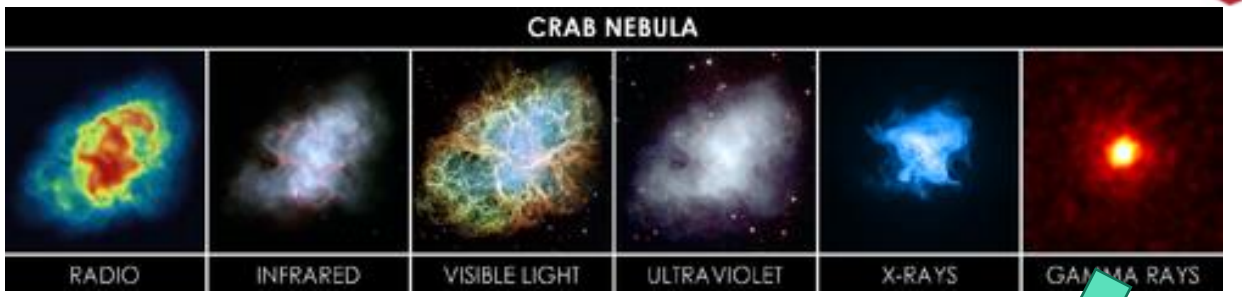
- Simulation tool and reconstruction tool → MEGAlib
  - Simple simulation with detector and aluminium casing → Only double events with spacing of 0.2cm between each event → achievable angular resolution of 12.15 degrees.

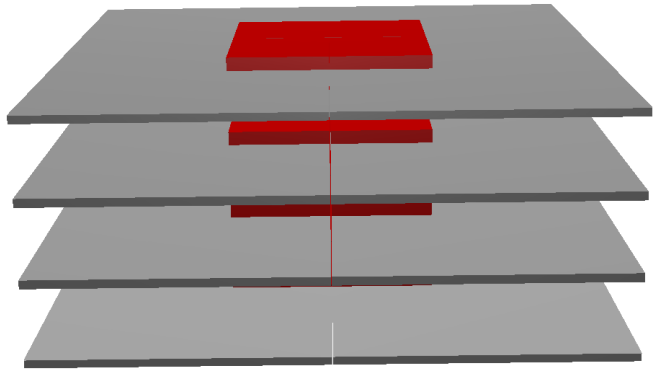




Investigation of a simple Compton Camera Concept – High Energy Astrophysics

- Compton Camera Concept Simulation in Low Earth Orbit of Crab Nebula (not including trapped protons and electrons)
- $t_{\mathrm{obs}} = 9300s$





LEO background

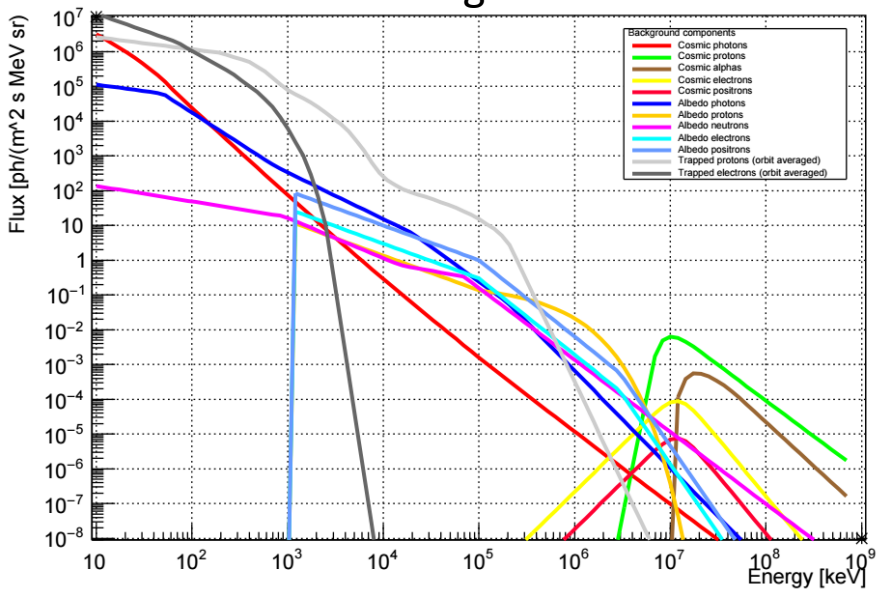
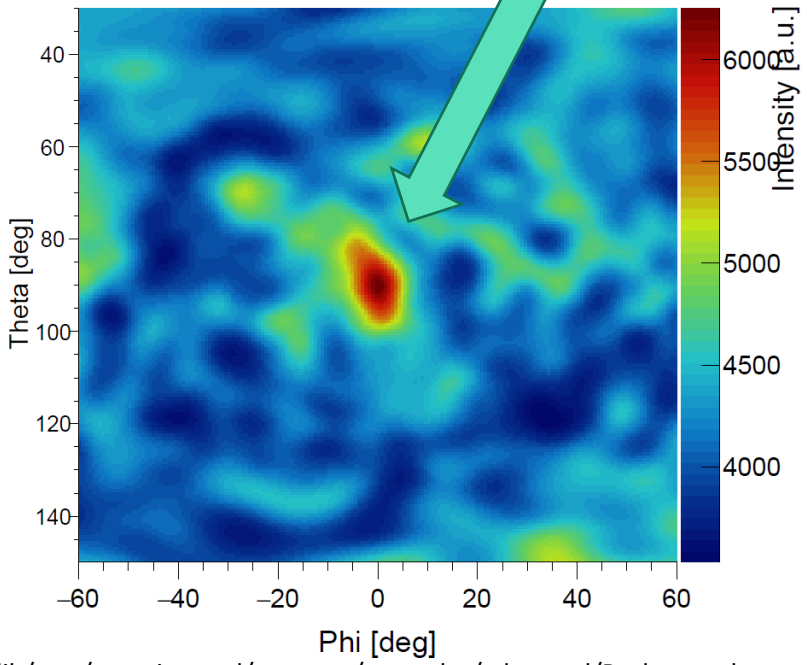


Image - iteration: 5



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 $\mathbf{15.95}^{\circ}$ 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