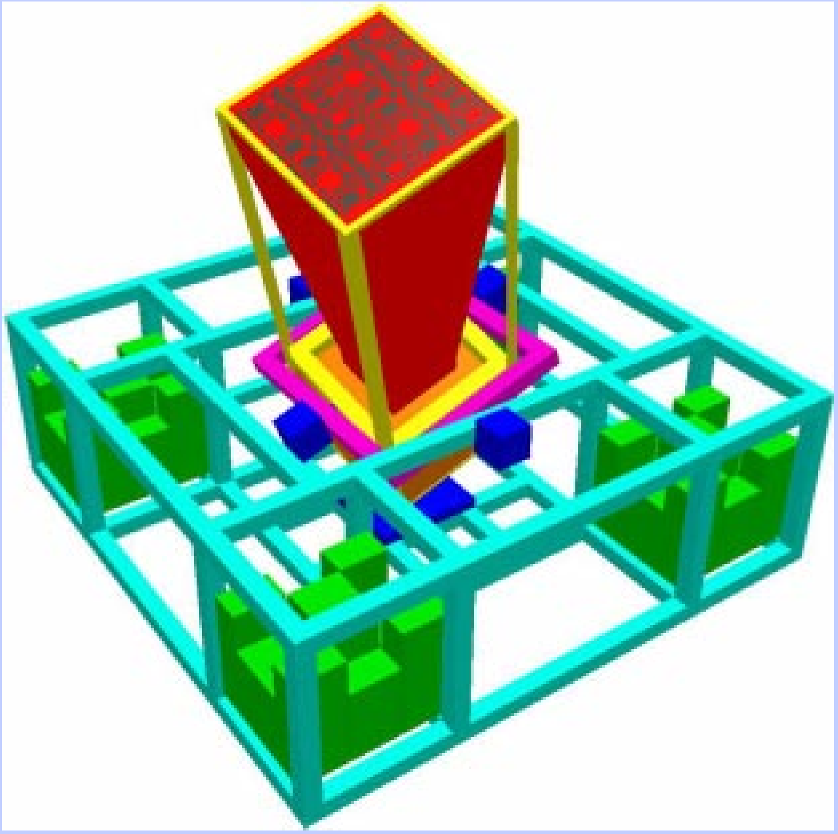
A Balloon-Borne Coded Aperture Telescope with Arc-Minute Angular Resolution at Hard X-Ray Energies

M. McConnell[1], P. Altice[2], M.B. Barakat[3], V. Boykin[1], M.L. Cherry[2], M. Elaasar[3], S.B. Ellison[2], T.G. Guzik[2], K. Johnston[3], R.M. Kippen[1], K. Larson[1], R.Lockwood[2], J.Macri[1], M. Mayer[1], B. Price[2], J. Ryan[1], and N. Zotov[3]

[1]University of New Hampshire, Durham, NH
[2]Louisiana State University, Baton Rouge, LA
[3]Louisiana Tech University, Ruston, LA



MARGIE

Minute of Arc Resolution Gamma-Ray Imaging Experiment

- **A balloon-borne coded-aperture telescope**
- **Angular resolution in range of 2 - 6 arc-minutes**
- **Energy range 20 - 600 keV**
- **Two detection plane technologies being developed:**
  - $\Rightarrow$ **CdZnTe strip detectors**
  - $\Rightarrow$ **CsI microfiber arrays**

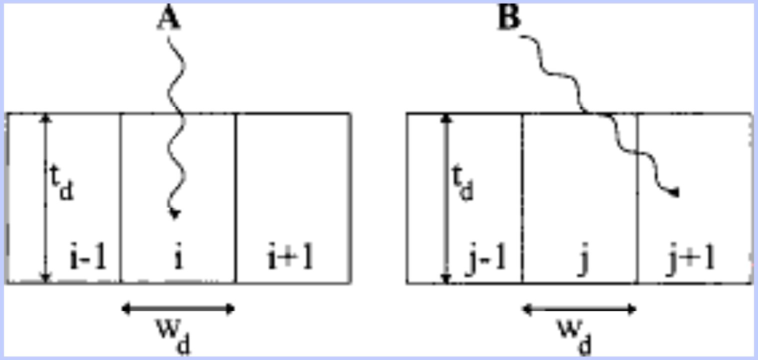
Imaging System Design Issues

- **Principle requirements:**
  - Arc-minute imaging on a balloon requires submillimeter pixels
  - Sensitivity requirements dictate large area (~1000 cm^2)
- **These two constraints imply:**
  - large number of pixels (~4×10^5)
  - large number of data processing channels
  - increased complexity (i.e., computing time) of data analysis
- **Trade-off between angular resolution and FoV:**
  - Resolution ~2′ implies a FoV (half-angle) ~ 6° (mask @ 1.5 m)
  - Resolution ~6′ implies a FoV (half-angle) ~30° (mask @ 30 cm)

Design Issues for a Large FoV

- **Mask Design:**
  - **Thinner mask elements are required to avoid distortions of the mask shadow.**

- **Detection Plane Design:**
  - **At large angles, the (x,y) interaction site may not correspond to the (x,y) location on the image plane.**



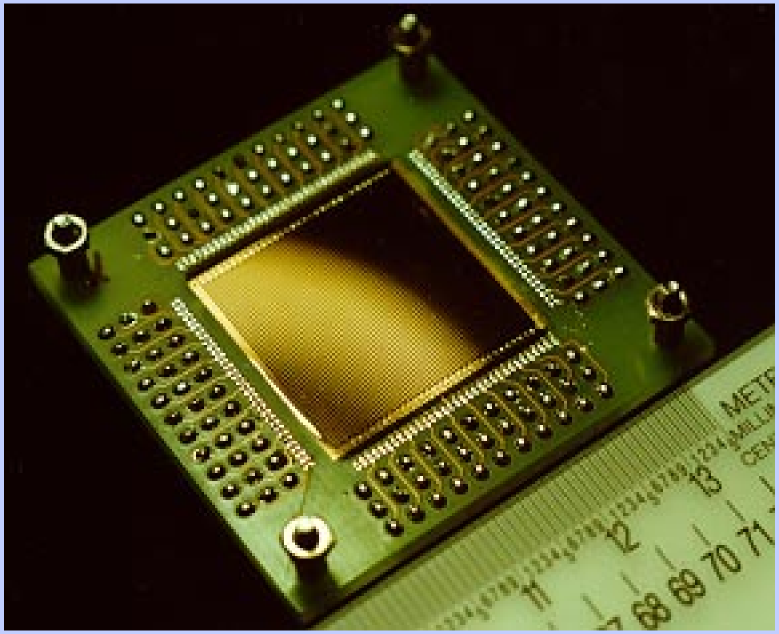
  - **"Pixel crosstalk" leads to degradation of imaging performance.**
  - **Can be used to place constraints on FoV (depends on E, θ).**
  - **Depth information can be useful in alleviating these constraints.**

Detector Development

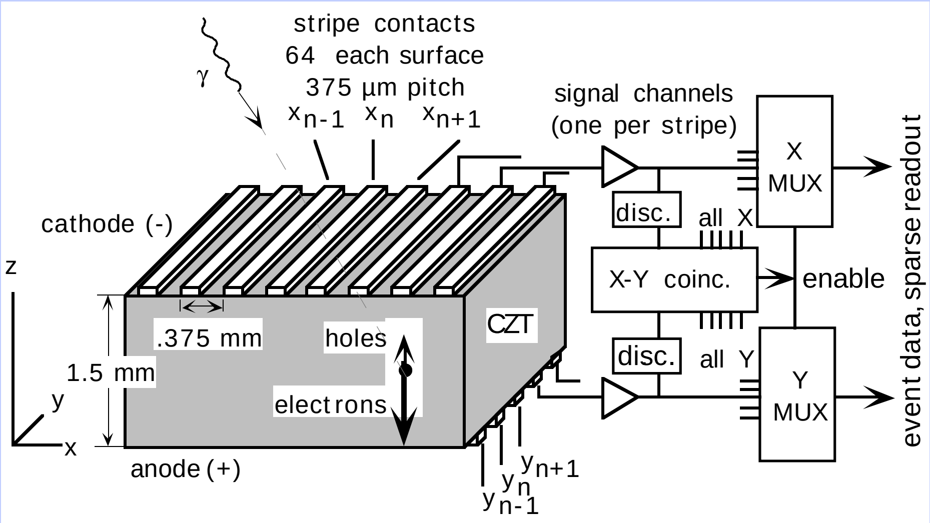
- **Detection plane requirements include:**
  - **spatial resolution < 500 μm**
  - **event-by-event timing (for anticoincidence)**
- **Two technologies are being developed:**
  - **room–temperature CdZnTe strip detectors (UNH) (Macri et al., SPIE Conf. 2859)**
  - **CsI microfiber array with CCD readout (LSU) (Cherry et al., SPIE Conf. 2806)**
- **Both designs will require the development of Application Specific IntegratedCircuits (ASICs):**
  - **ASICs for CdZnTe will be developed with Oak Ridge National Labs.**
  - **ASICs for CsI/CCD will be developed with Suni Imaging Microsystems.**

CdZnTe Strip Detector

sub-millimeter resolution imaging spectrometer



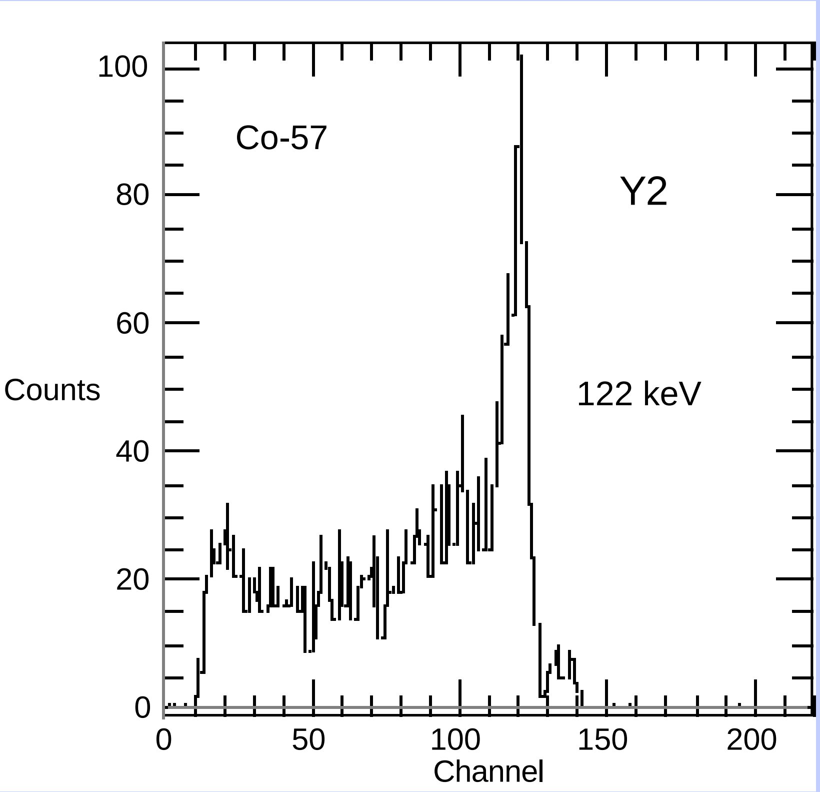
prototype strip detector
64 × 64 strips
0.375 mm pitch
24 mm × 24 mm active area
1.5 mm thick

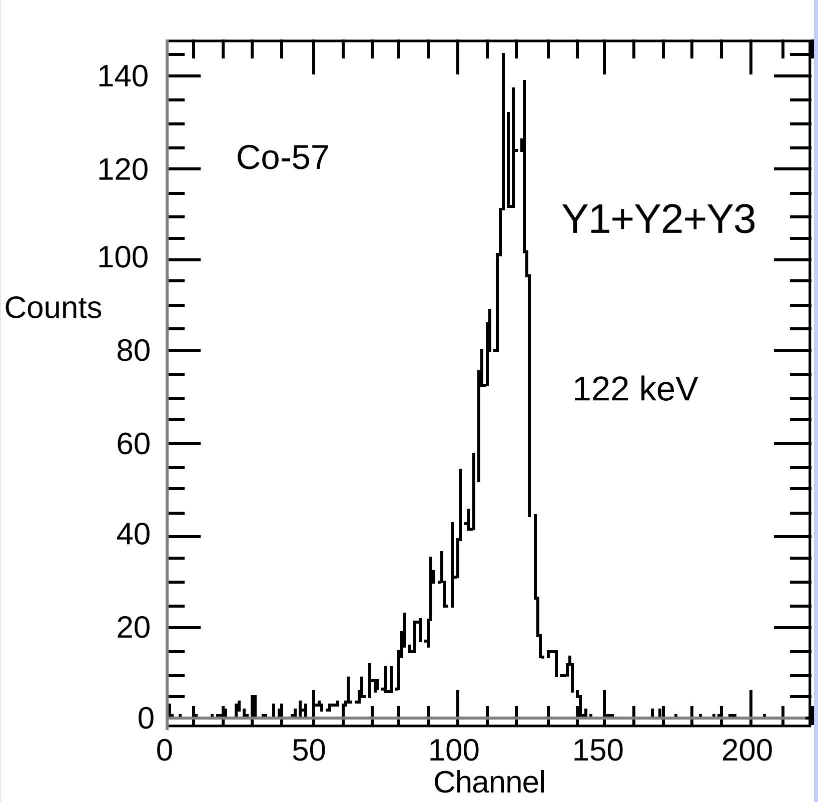


<u>Strip detector operating principles</u>:

- **Intersecting coordinates of coincident X-Y signals define event location "pixel".**
- **Energy determined from pulse height analysis of anode (Y strip) signals.**
- **Event-by-event processing.**

CdZnTe Spectral Response
single “pixel” and “pixel” plus neighbors



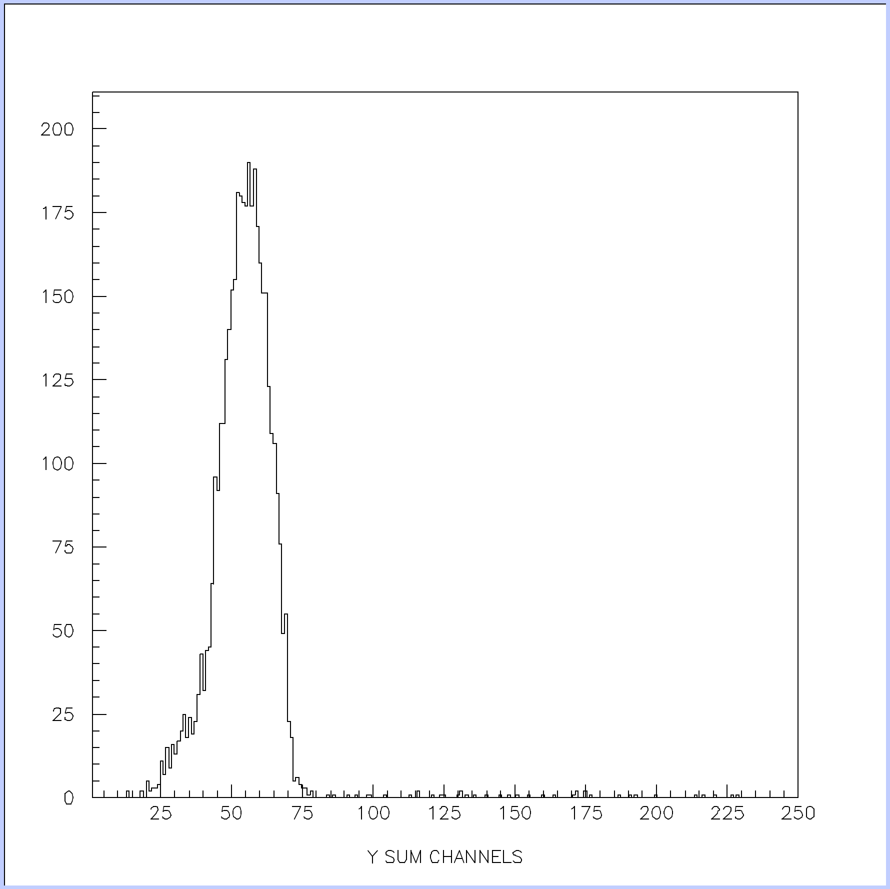


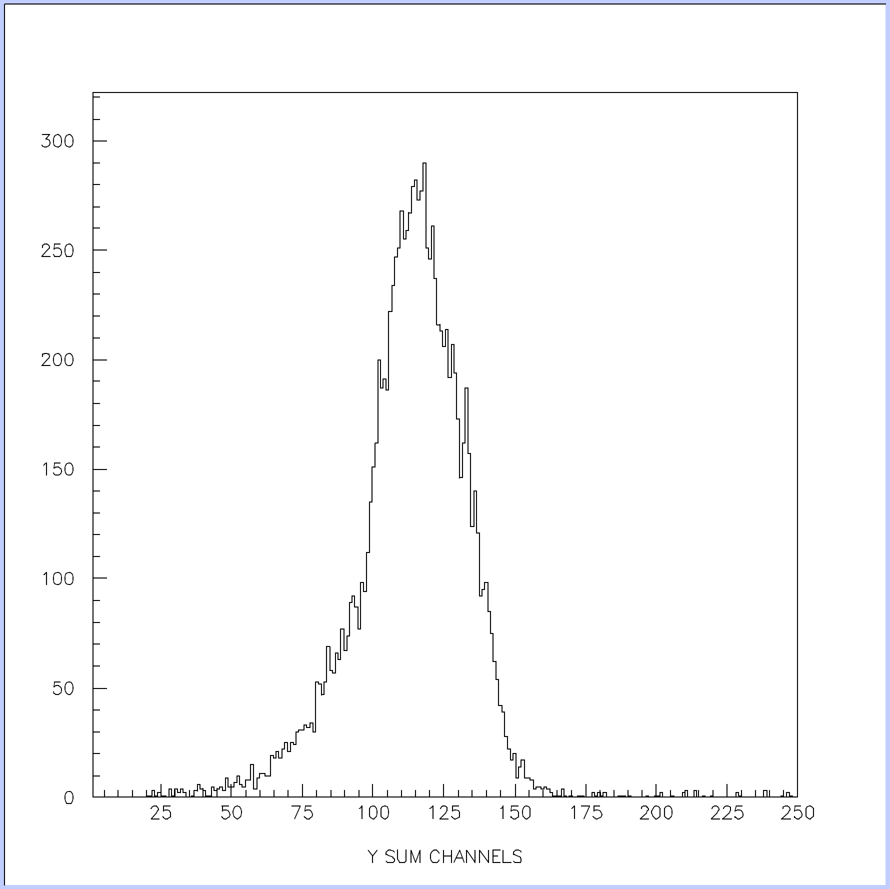
Pulse height spectrum of a single “pixel” defined by events with coincident signals in Y2 and X2.

Same data showing the spectrum from the sum of the trigger strip and the two adjacent strips.

CdZnTe Sum Spectrum

Spectra summed over an 8 $\times$ 8 strip test region (64 “pixels”).





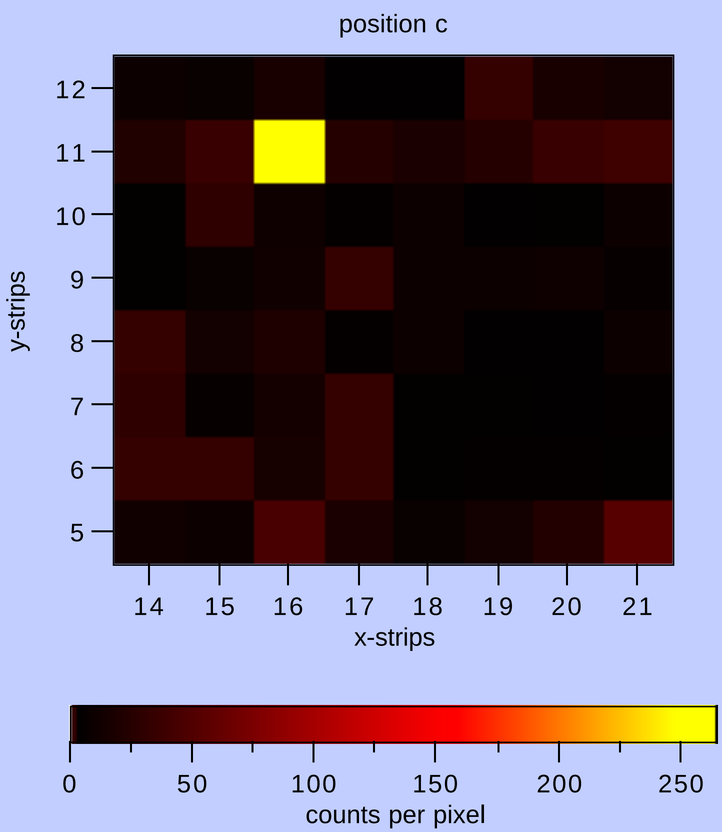
^{241}Am - 60 keV

^{57}Co - 122 keV

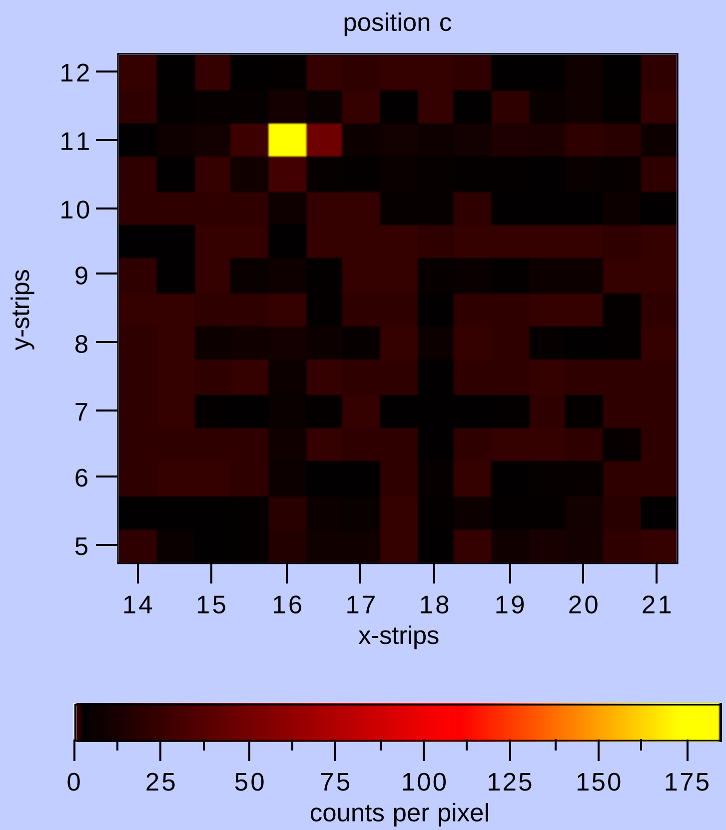
CdZnTe Spatial Resolution

Images obtained from an 8 × 8 region of the prototype detector.

Collimated beam (~200 μm) of 122 keV photons (^{57}Co).



"raw" 8 × 8 data
spatial resolution 375 μm

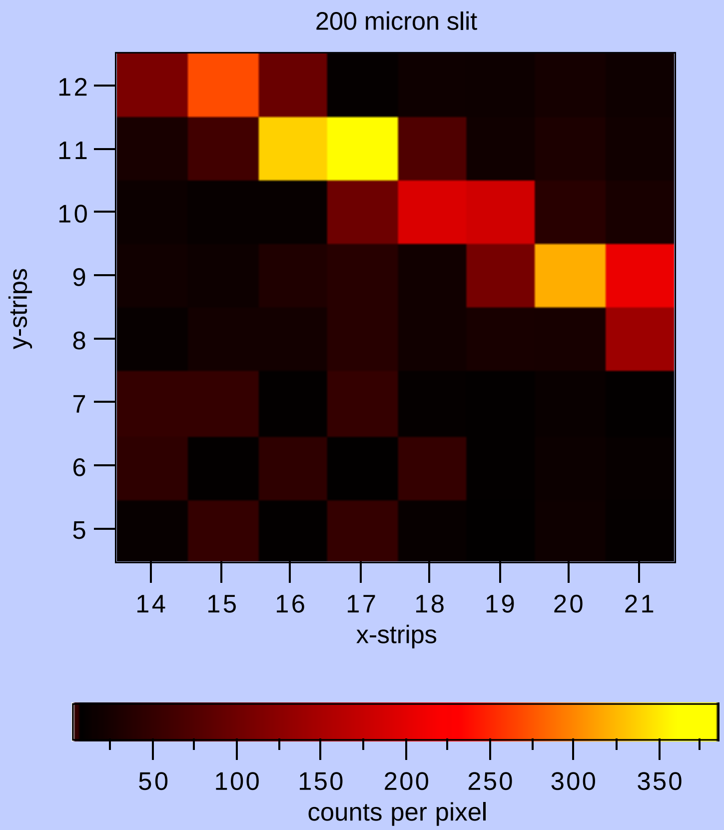


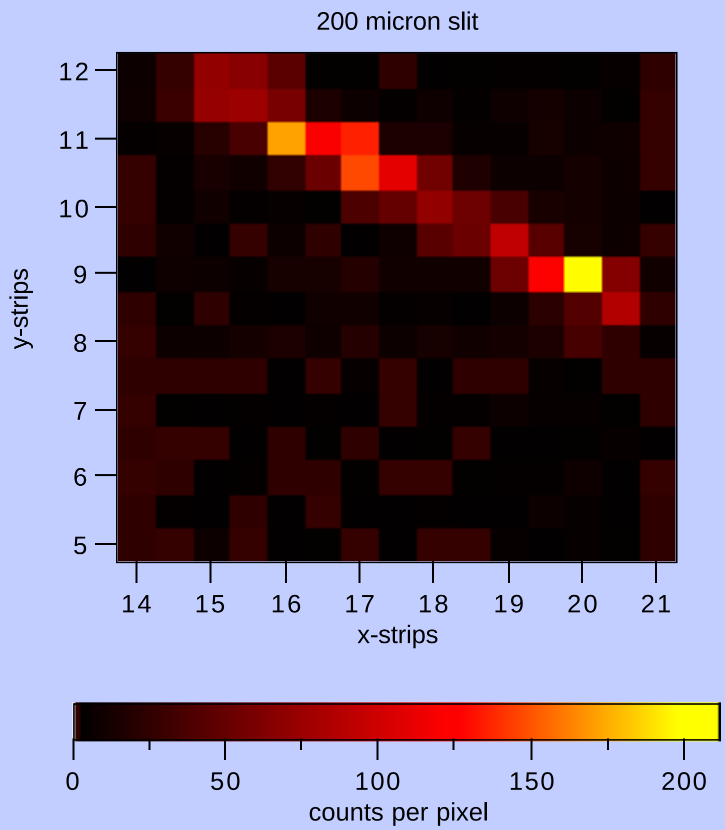
interpolated 16 × 16 data
spatial resolution 200 μm

CdZnTe Spatial Resolution

Images obtained from an 8 × 8 region of the prototype detector.

200 μm wide slit @ 122 keV (^{57}Co)





"raw" 8 × 8 data
spatial resolution 375 μm

interpolated 16 × 16 data
spatial resolution 200 μm

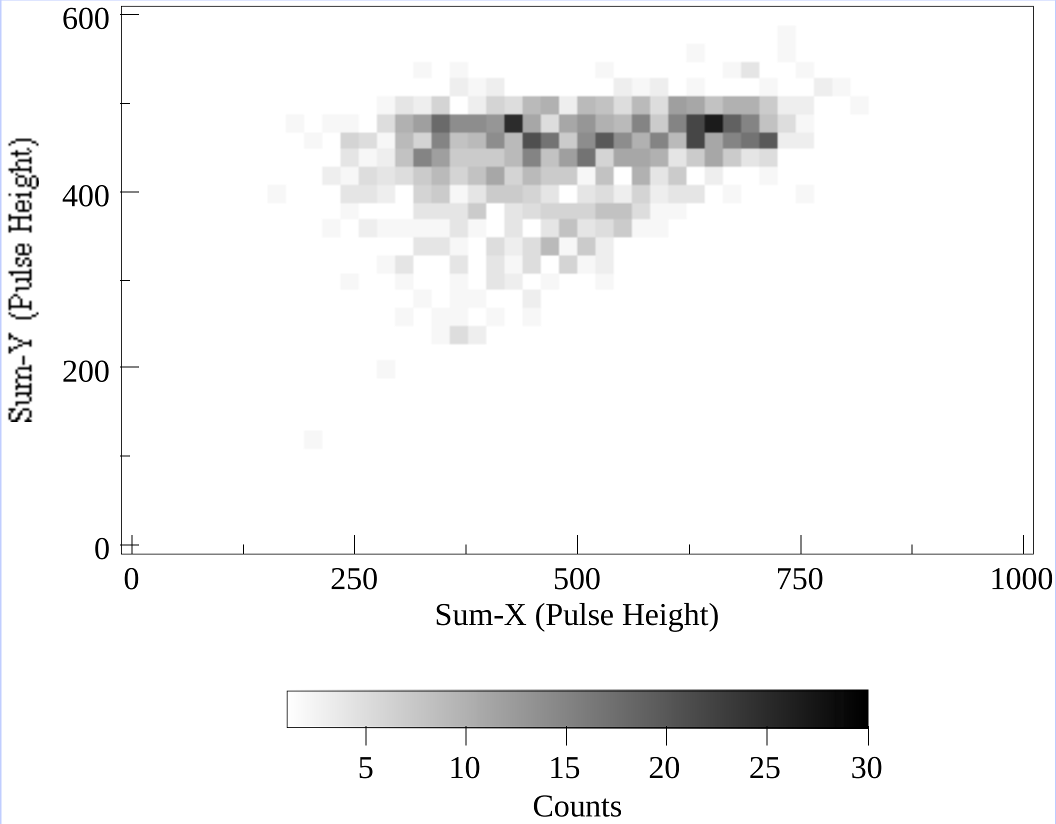
CdZnTe Depth Effect

Determining Depth of Interaction in Strip Detector

Data collected using 122 keV photons (^{57}Co) – interactions distributed uniformly in depth.

Electron collection efficiency (Y) is independent of depth and always greater than the hole collection efficiency (X).

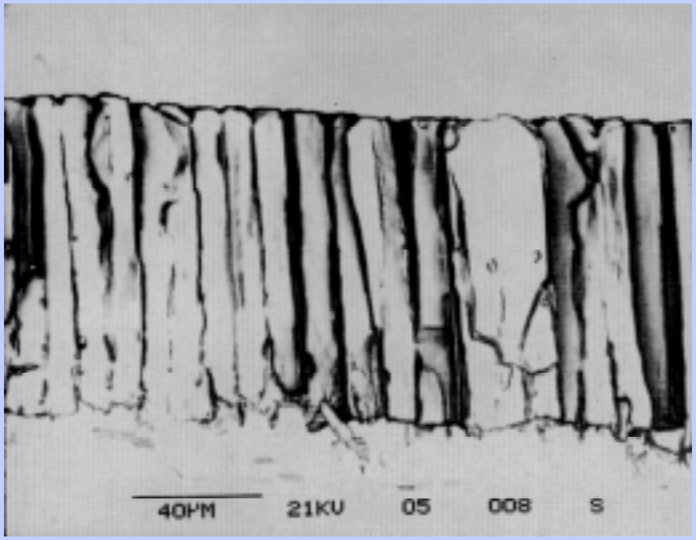
Hole collection efficiency (X) shows large variations that are attributed to the distribution of interaction depths.



This information can be used to constrain the depth of the photon energy deposit.

CsI Microfiber Detectors

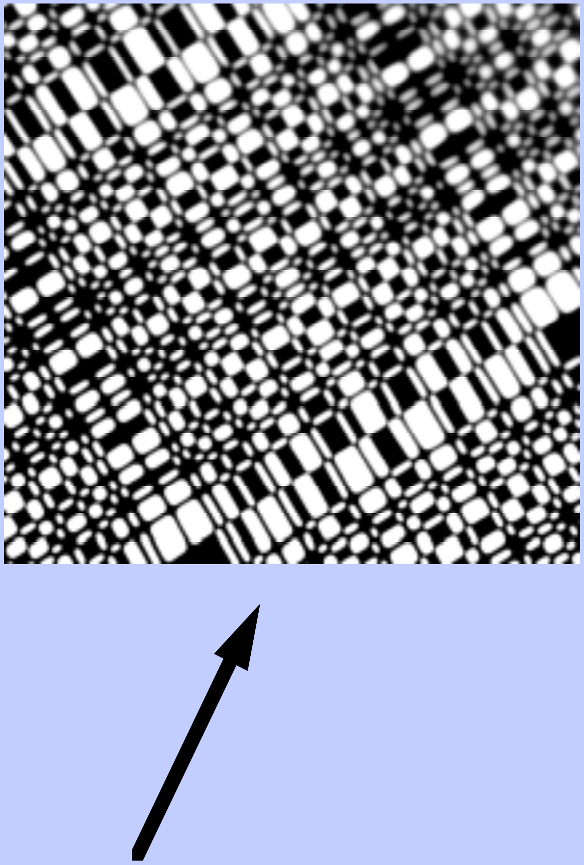
- CsI detectors can provide greater detection efficiences than CdZnTe at higher energies (thicker and higher-Z).
- High resolution CsI microfiber arrays (column thicknesses of ~10 μm) have been grown with depths up to 100 μm
- Thicker arrays (up to ~1 cm) can be made in a honeycomb lattice with ~300 μm elements.
- Readout can be achieved using CCDs with a high quantum efficiency.
- Use of a bi-directional CCD will improve readout time so that images of individual events can be obtained. (Cherry et al., SPIE Conf. 2806)



Scanning electron microscope picture of a 100μm thick CsI fiber layer.

Mask Fabrication

- MARGIE uses a 643 $\times$ 641 URA coded mask with 0.5 mm elements.
- A graded Tungsten mask will be used to achieve the necessary attenuation and to reduce the effects of X-ray flourescence in the Tungsten itself.
- We have developed and tested the procedures for producing large Tungsten masks using photolithographic etching techniques.
- This picture is an X-ray image of an etched Tungsten mask based on a 73 $\times$ 71 URA pattern with 0.5 mm pixels and a mask thickness of 0.5 mm.

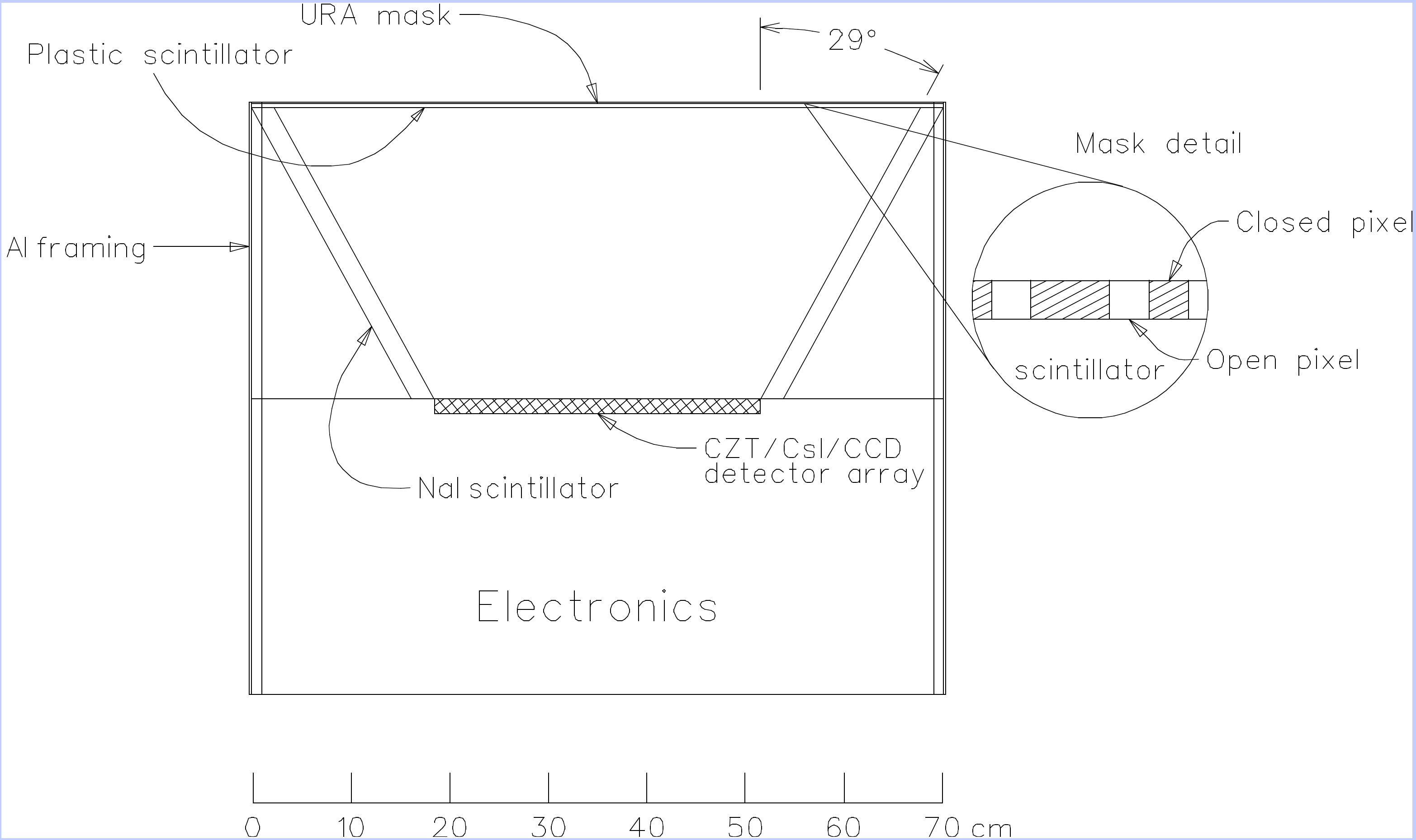


The X-ray image itself was taken with 40-50 keV X-rays from a dental X-ray machine using a 1mm thick CsI microfiber array with a CCD readout (one of two detection plane technologies being developed for MARGIE).

MARGIE Design

Initial Flight Configuration

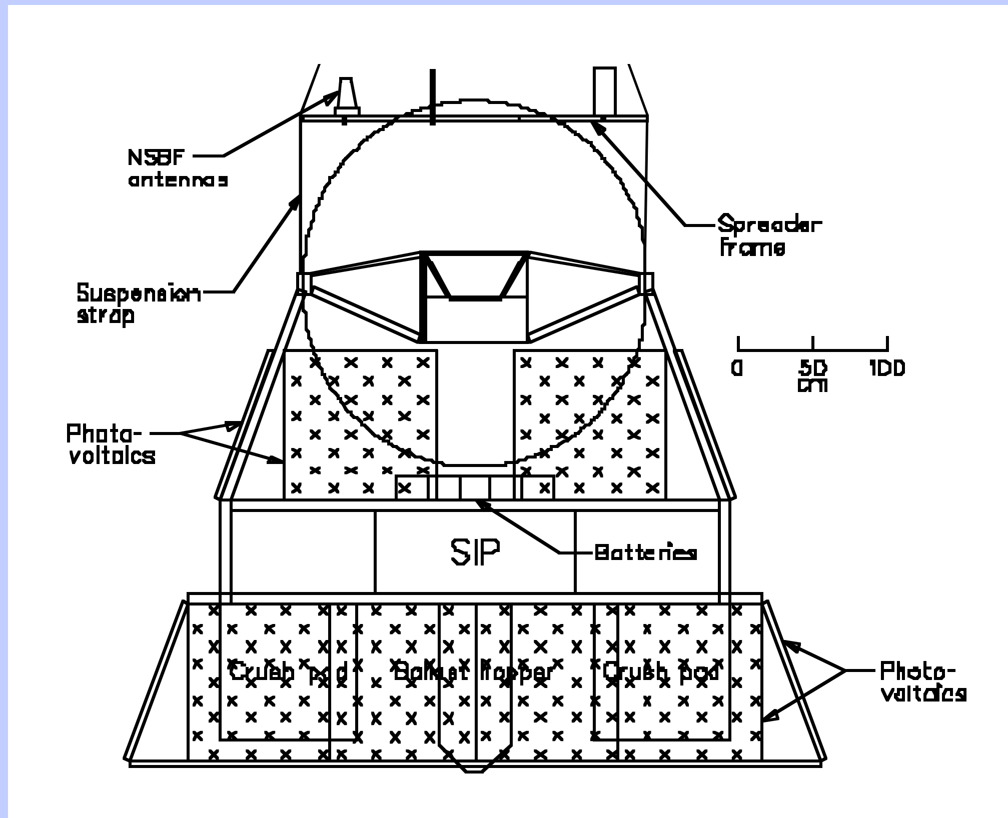
For the initial flight, MARGIE will be configured as a wide FoV instrument. The pointing requirements will be minimal and it will fit within the envelope of an available pressure vessel.



MARGIE Gondola

The MARGIE payload will fit within the constraints of either a short-duration (CONUS) flight or a long-duration (LDB) flight.

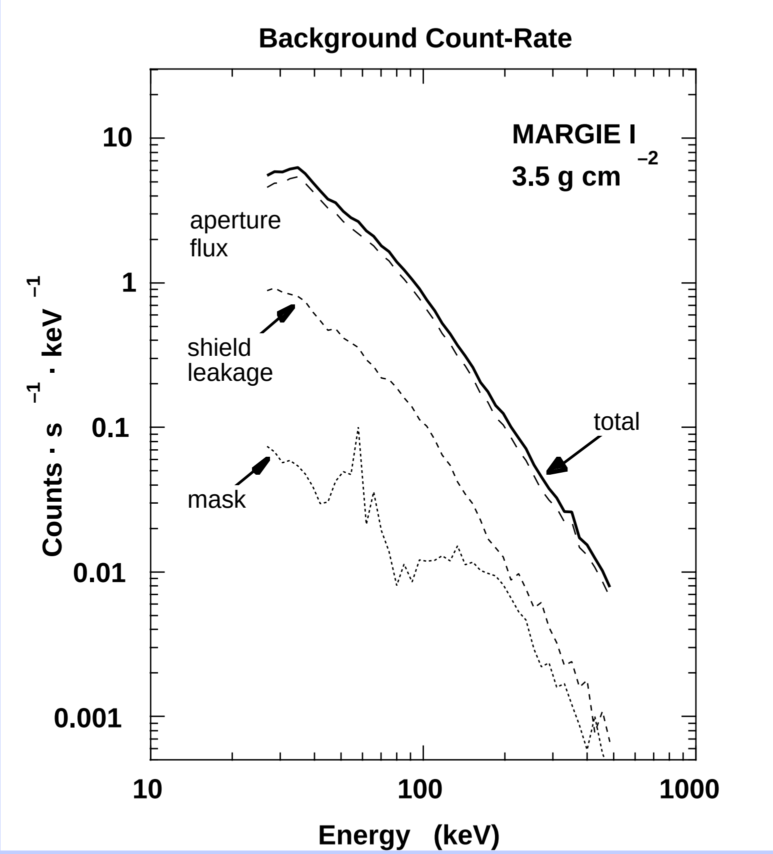
Kevlar pressure vessel undergoing pressure testing.

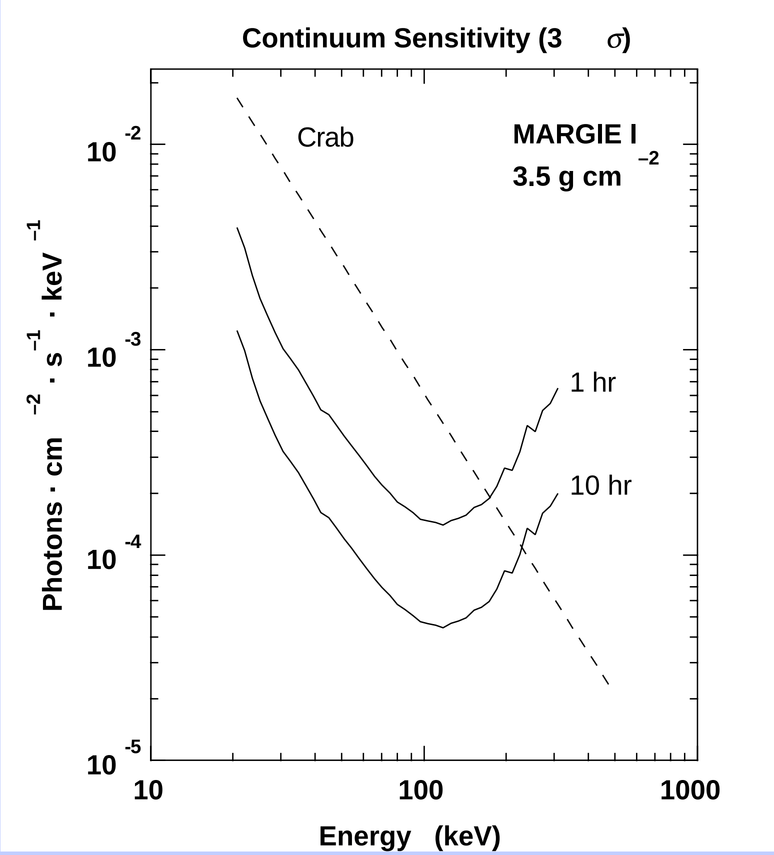


MARGIE Sensitivity

Initial Flight Configuration

The instrumental background for the intial MARGIE design, and the corresponding point source sensitivity, are shown below.





MARGIE Parameters
Initial Flight Configuration

Detection plane	Sensitive Area	760 cm^2
(CdZnTe strip detectors)	Thickness	1.5 mm
	Strip Pitch	375 μm
	Spatial Resolution	200 μm
	Timing Resolution	1 μs
	Shielding	NaI, 2 cm
Mask Pattern	643 × 641 URA	
(graded W)	Element Size	0.5 × 0.5 mm
	Thickness	~ 0.5 mm
Imaging Field-of-View (FoV)	29° (half-width)	
Angular Resolution	5.7′	
Spectral Energy Range	20-200 keV	
Energy Resolution	<8 keV FWHM @ 60 keV	
	<10 keV FWHM @ 122 keV	
Sensitivity (3σ)	46 mCrab (1hour) @ 30-50 keV	
	200 mCrab (1 hour) @ 150-200 keV	

Future Plans

- **MARGIE has recently been approved for another 3 years of funding through the NASA astrophysics SR&T program.**
- **The first MARGIE balloon flight would be a 1–2 day continental US turnaround flight utilizing the CdZnTe detection plane.**
- **Subsequent balloon flights would take advantage of the long–duration balloon capability and would utilize the CdZnTe and/or the CsI/CCD detection planes.**