Performance of a thick silicon γ–ray polarimeter

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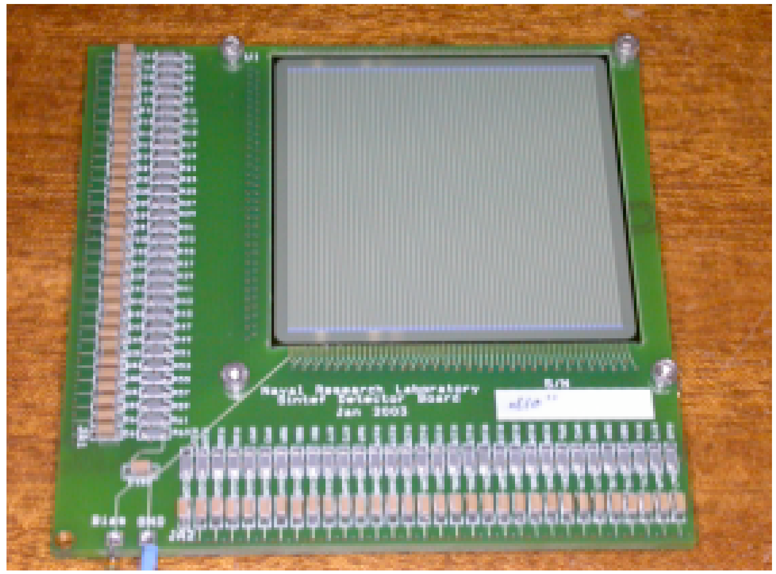
Introduction

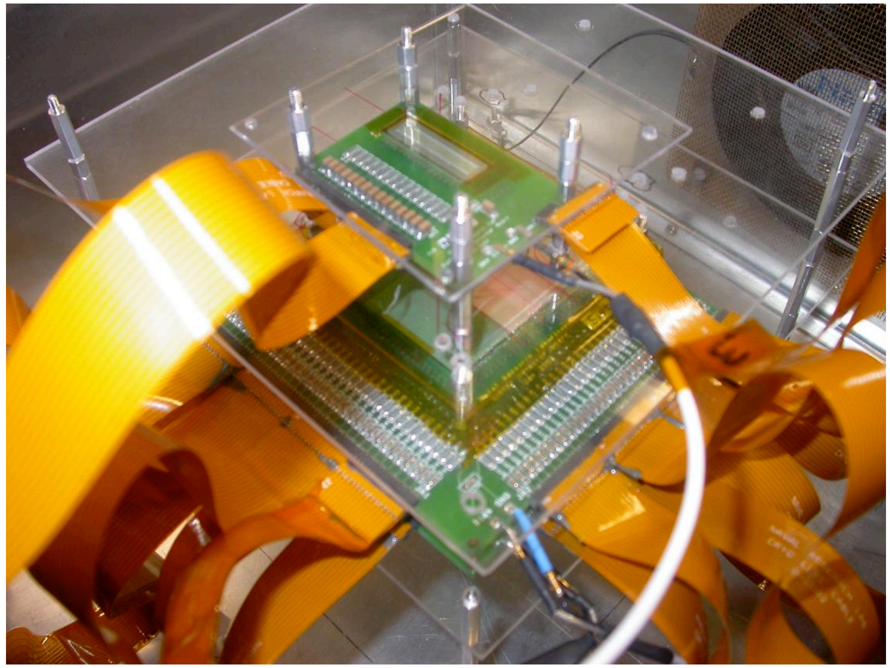
- Silicon double-sided strip detectors (DSSDs) are the basis of many designs for Compton telescopes.
- Silicon DSSDs are being considered for an Advanced Compton Telescope (ACT).
- Also under consideration for a large effective area X-ray timing mission.
- NRL has developed thicker (2 mm) intrinsic silicon detectors.
- Highly-segmented Si detectors make good polarimeters:
  - Low-Z active target and detector are one and the same
  - Good energy resolution without cooling
  - Imaging
  - Compton polarimetry
- Each layer acts as an in-plane polarimeter.
- Each pair of layers also acts as a polarimeter.

SINTEF Detector



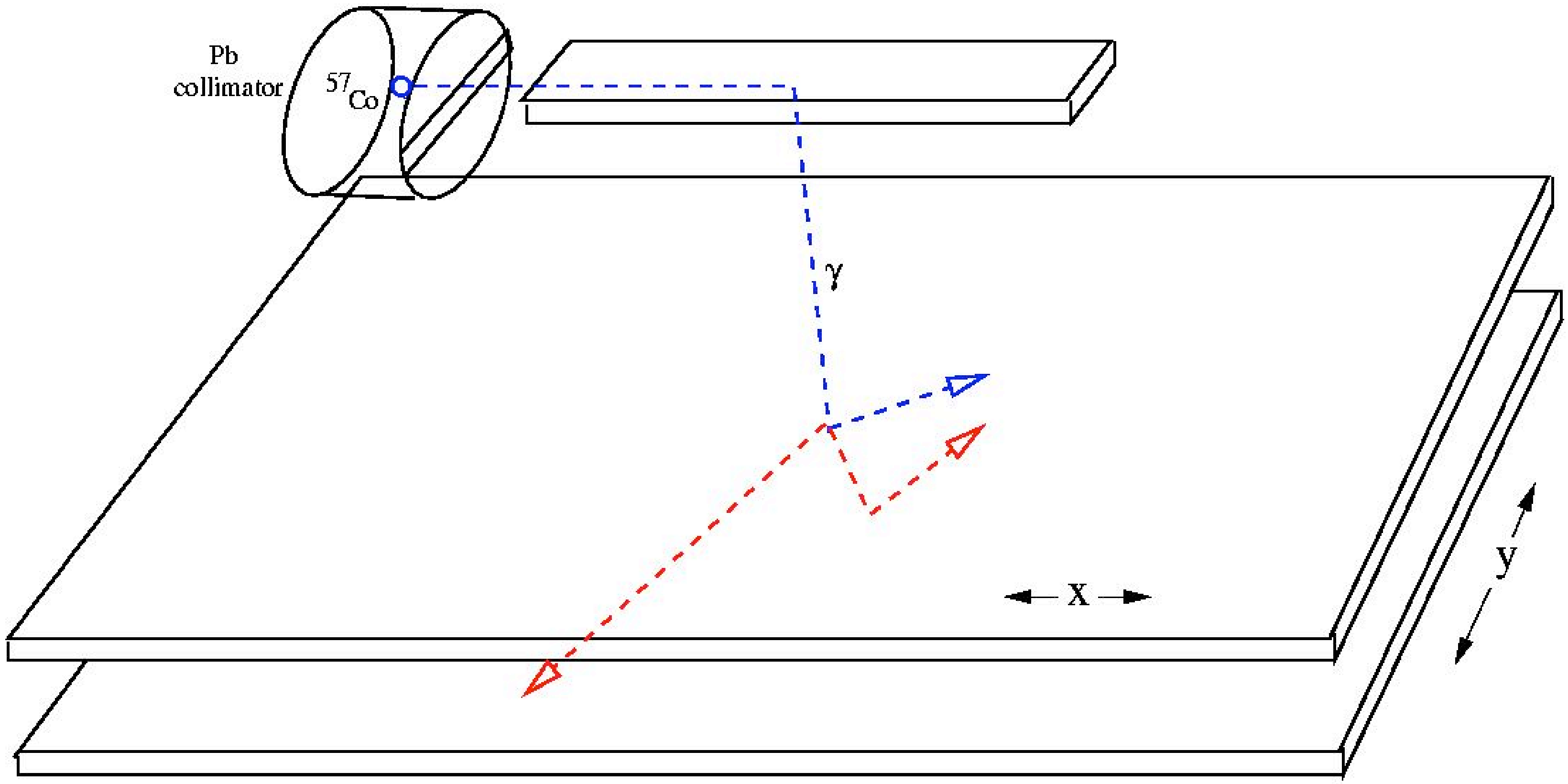
- 2 mm thick planar silicon DSSD.
- 64 x 64 strips, with 0.891 mm pitch
- DC-coupled to external components (50 MΩ, 800 pF).
- Room temperature leakage currents ~1.2 μA @800V.
- 3 mm guard ring structure with 23 floating rings.

Experimental Setup



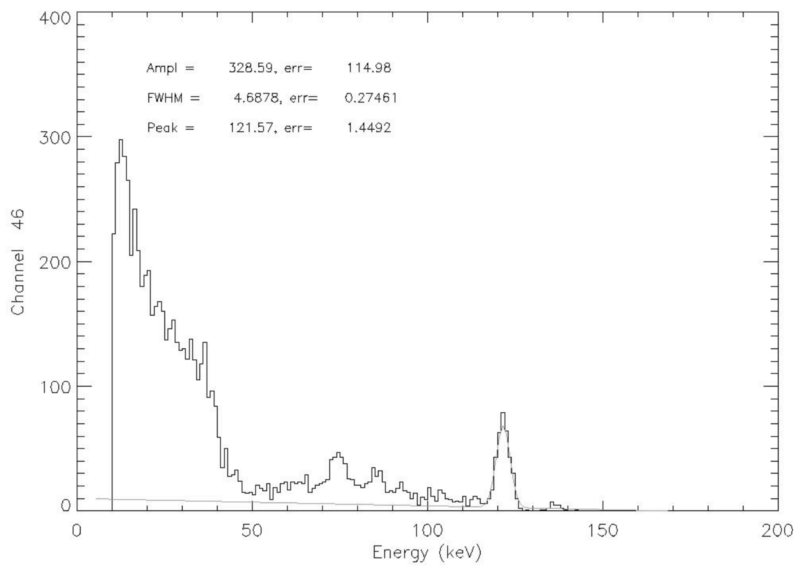
- eV5093 preamps, 64 per board.
- 16 channel NIM shapers (CAEN N568-B)
- VME ADCs (CAEN V785)
- Total of 296 channels of spectroscopy
- ASIC readout under development

Experimental Setup

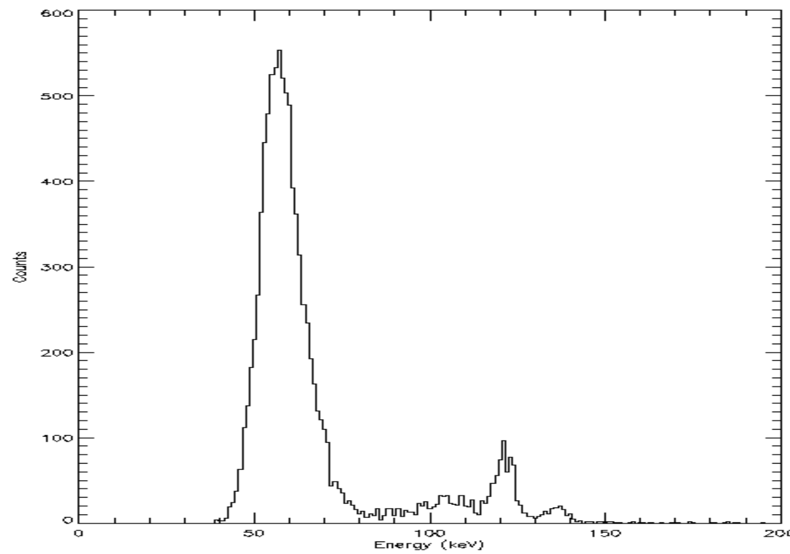


- 1 mCi ^{57}Co unpolarized source (122 keV) in Pb collimator
- Scattering target generates polarized γ–rays by Compton scattering
- Trigger on ground side strips (y–strips, denotes x–position of hits)
- Hardware coincidence between target and 1 or more bottom detectors

Spectra



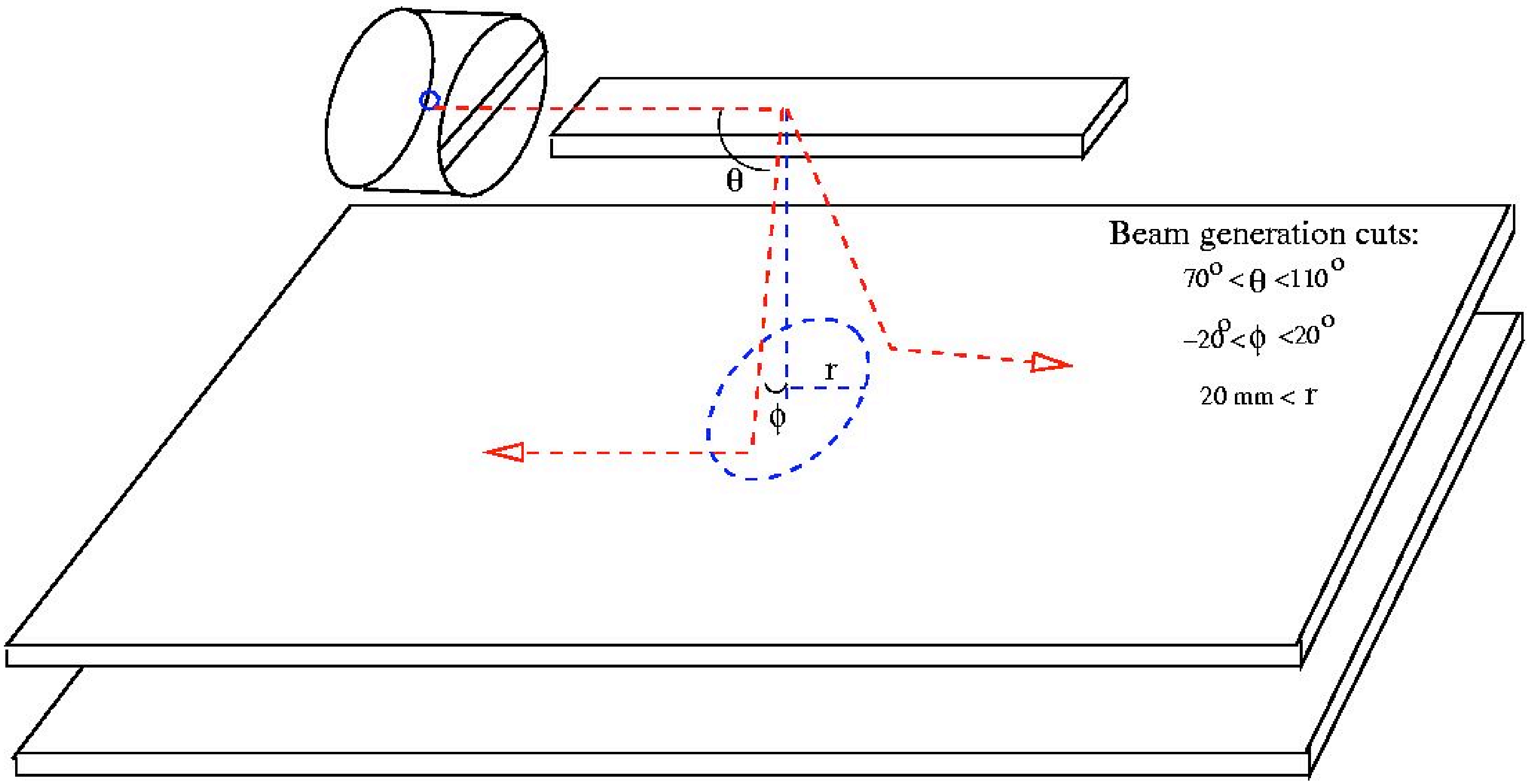
Single channel



Collected spectra

- Threshold for single channels = 12 keV
- Cooling to 0º C can reduce FWHM to 2 keV
- FWHM of composite events = 6 keV.

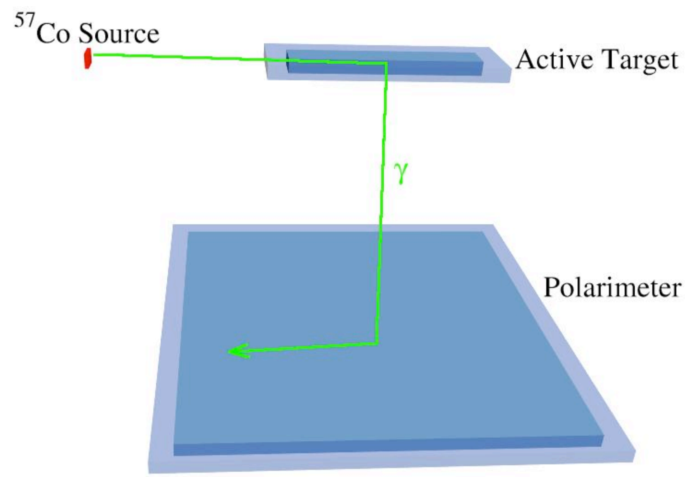
Cuts on collected events



Detector cuts:

- Matching energies in x and y strips (<2*fwhm).
- Energy thresholds (12 keV).
- Total energy (changes ordering).

GEANT4 simulations

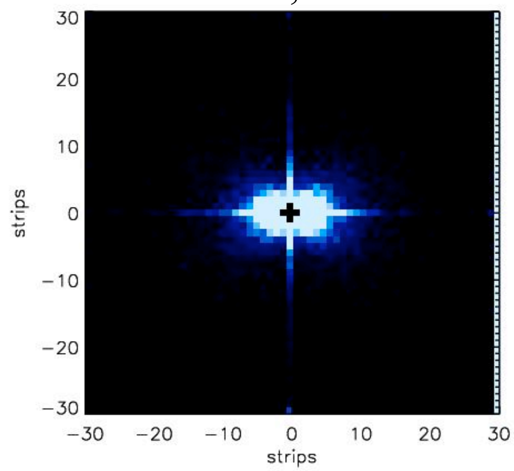


- GEANT4 simulations with polarization (no Doppler broadening).
- Simulated data recorded under “trigger” conditions to simulate the lab trigger coincidence.
- Simulated data reduced to format identical to that obtained in the lab (a list of strip hits and energies per event).
- Simulated data run through nearly identical analysis code for comparison to experimental data.

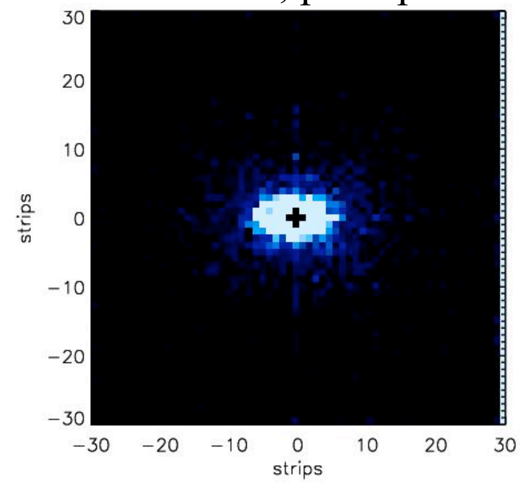
Experimental and simulated data

- Plot relative position of second hit with respect to first hit in polarimeter.
- Central cross is Nearest Neighbor exclusion (charge sharing events).

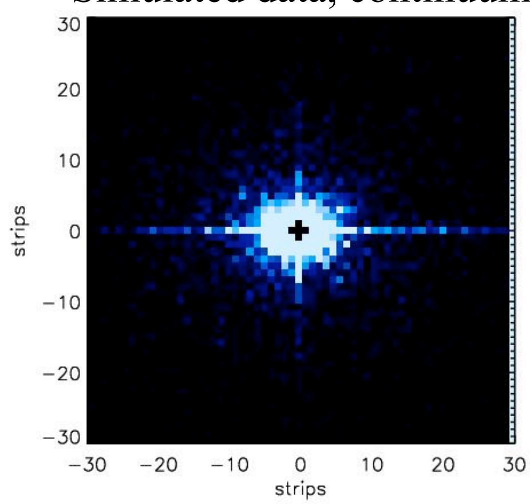
Scatter data, continuum



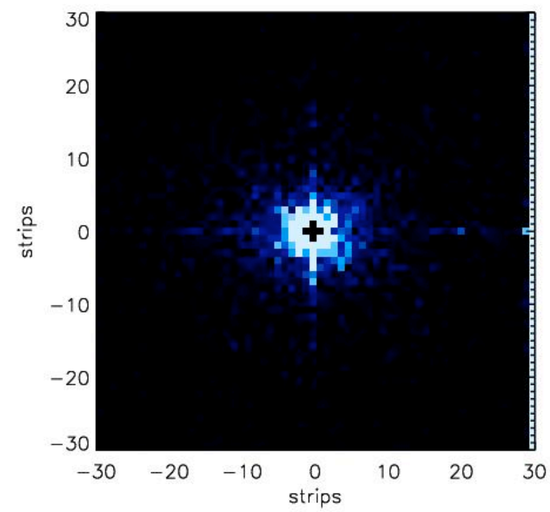
Scatter data, photopeak



Simulated data, continuum



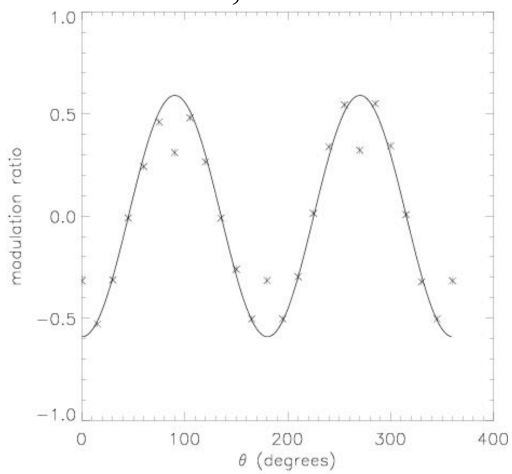
Simulated data, photopeak



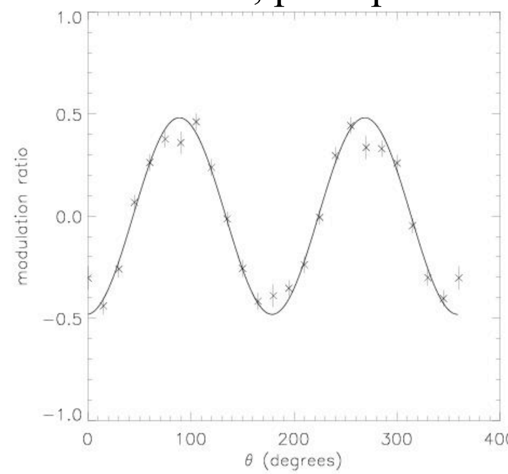
Modulation ratios

$R = (N_{\theta+90} - N_{\theta})/(N_{\theta+90} + N_{\theta})$

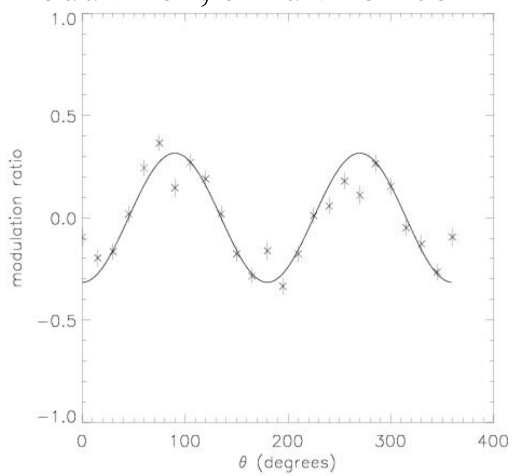
Modulation, continuum data



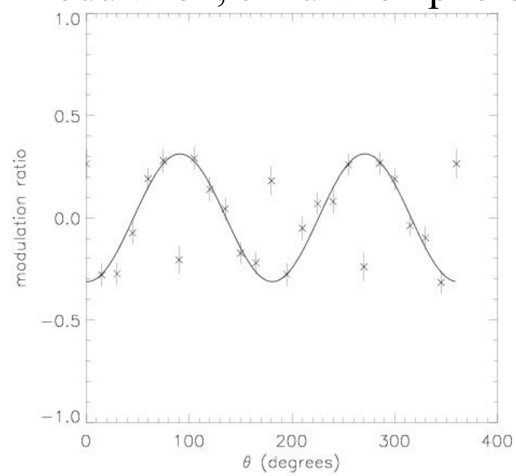
Modulation, photopeak data



Modulation, simulation continuum

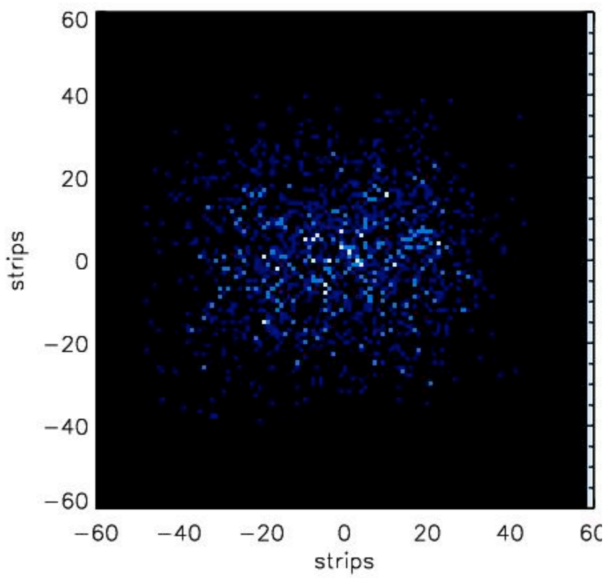


Modulation, simulation photopeak

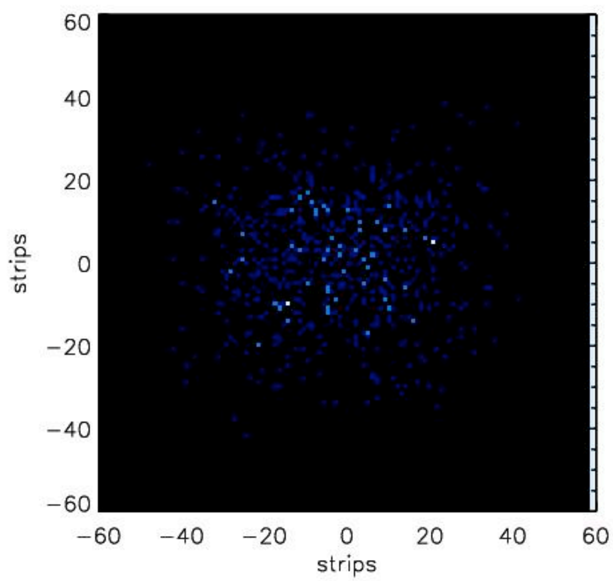


Events with 2 hits in 1 strip need special treatment

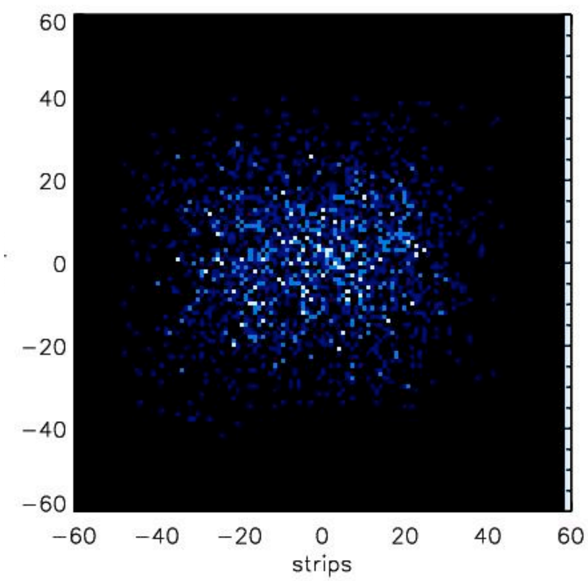
2-Layer Polarimeter



Forward scattering from top layer into bottom layer.



Back scattering from bottom layer.

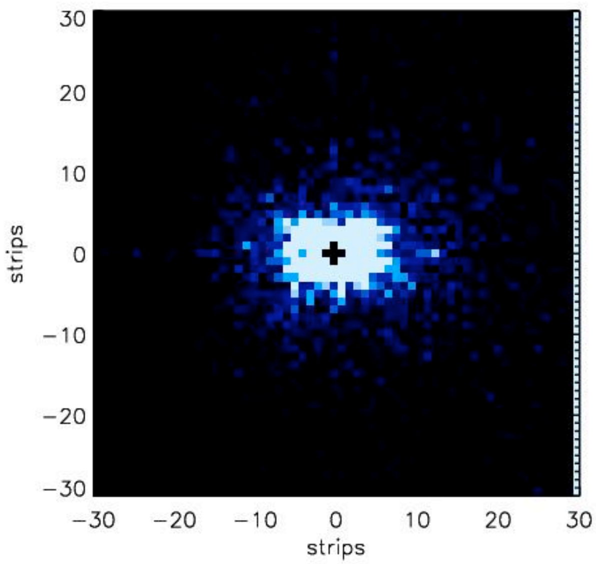


Combination of inter-layer scattering plots.

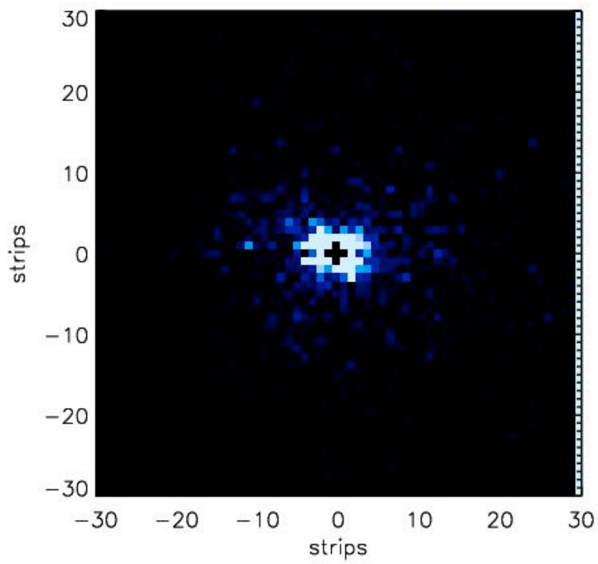
- More statistics in the forward scattering plot, as expected.
- Efficiency increases with layer number N nearly as N (N-1).
- Longer lever-arm for scattering angle (less attenuation).
- X-Y pairs unambiguous.

2-Layer scattering in plane

Continuum



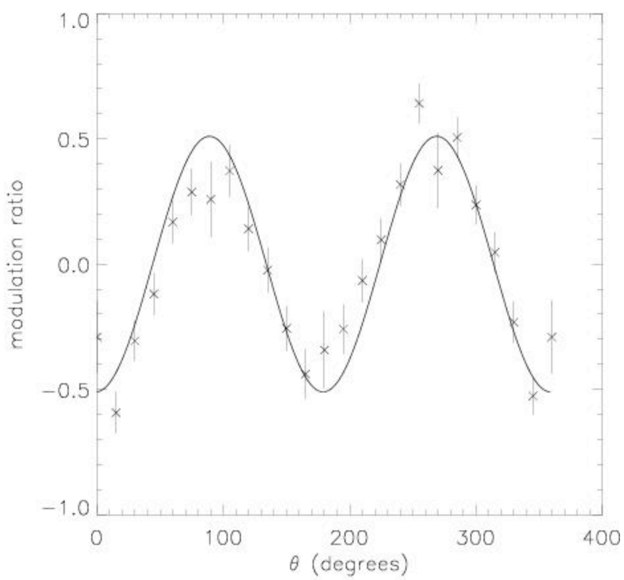
Photopeak



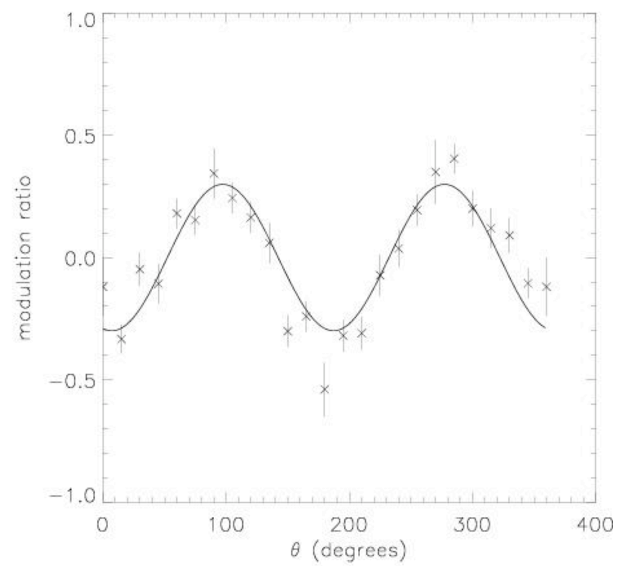
- Different r-cut between layers due to geometry (16 strips above, 20 below).
- In a space instrument, all layers would be equivalent.
- Statistics increase with more layers and/or a calorimeter.
- Data rate scales roughly as layer number.

Modulation ratios for 2-layer instrument

In-plane



Out-of-plane



•High polarization ratio.

•Short lever arm.

•High geometric efficiency for thick detectors (strip pitch < thickness).

•Data more difficult to process.

•Lower polarization ratio.

•Longer lever arm.

•Efficiency rises as ~N^2.

•Data simpler to process.

Conclusions

- Highly-segmented silicon detectors make excellent polarimeters.
- Source-testing with the current lab setup allows for simple characterization of the polarimeter.
- Triggering should be done on both sides of a DSSD to avoid systematic errors.
- Need to resolve discrepancy between data and simulations
- The efficiency of such an instrument increases dramatically with the number of detectors: more area, more layers, and the thickness of the layers (i.e. kilograms of active silicon).
- A real instruments could consist of 16 layers, with each layer having 4 detectors.

  Each detector would be 10 cm x 10 cm x 0.2 cm.

  The effective area of such a polarimeter would be ~80 cm^2 at 100 keV

  ~20 cm^2 at 1 MeV