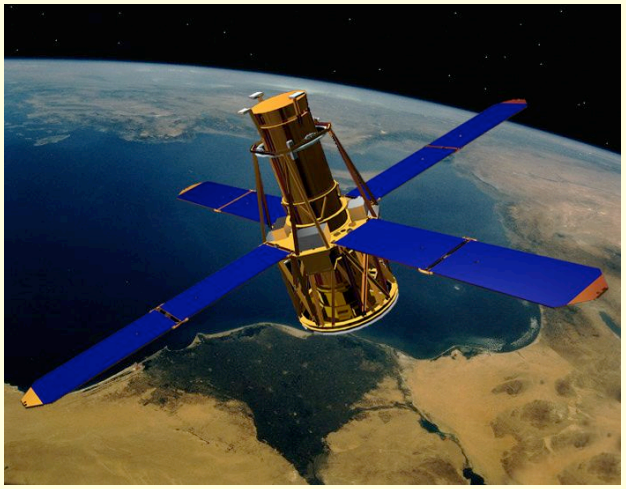
Measuring Hard X-Ray Polarization of Solar Flares with RHESSI



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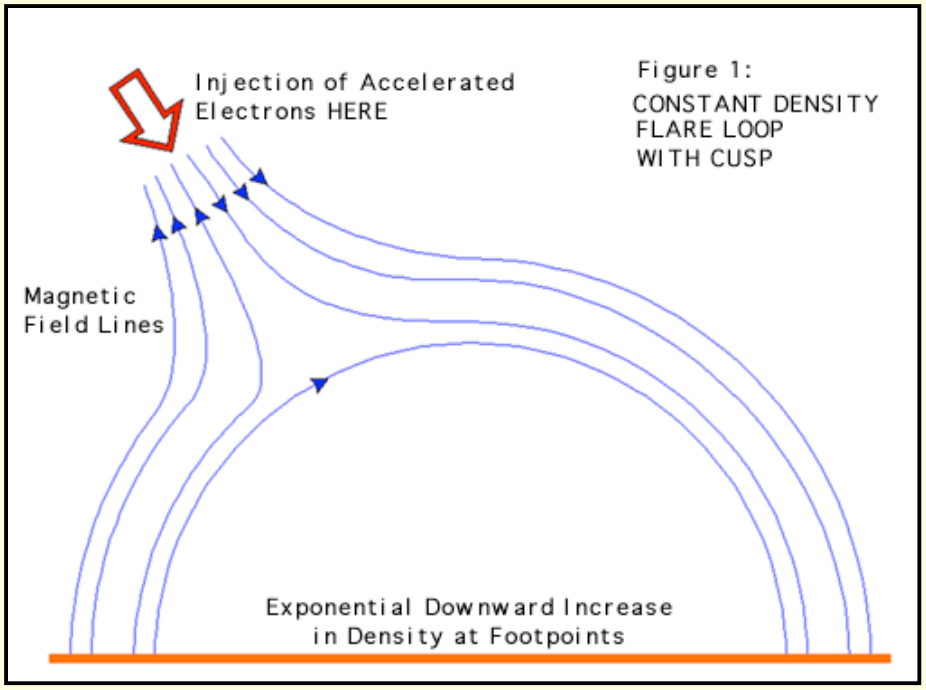
[3]Physics Department, University of Alabama, Huntsville, AL

Polarization in Solar Flares

The hard X-ray continuum is dominated by electron bremsstrahlung emission.

Measurements of hard X-ray polarization can shed light on the geometry of the acceleration process.



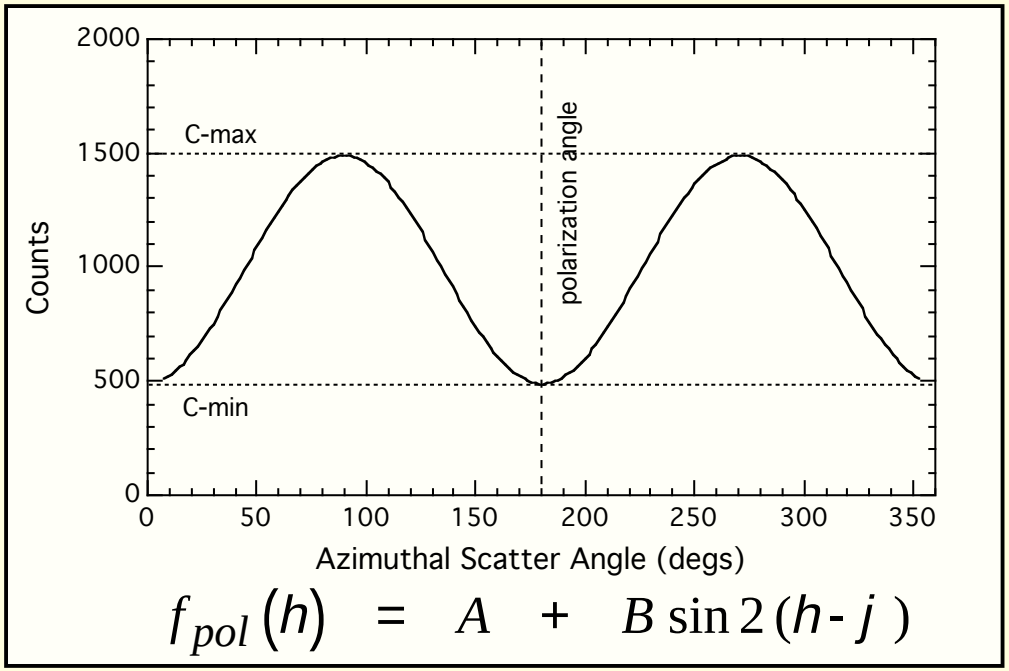
Model parameters include :

1) **pitch angle distribution**
2) **B-field geometry**
3) **viewing angle**
4) **atm density profile**

Models predict polarization levels as high as 20 or 30%.

The Polarization Signature

For a fixed Compton scatter angle (q), the azimuthal distribution of scattered photons contains the polarization signature.



$$f_{pol}(h) = A + B\sin 2(h - j)$$

Modulation factor

$$Q = \frac{C_{\max} - C_{\min}}{C_{\max} + C_{\min}} = \frac{B}{A}$$

Polarization Measurement

$$P = Q_P / Q_{100}$$

The *amplitude* of the modulation defines the *level of polarization*.

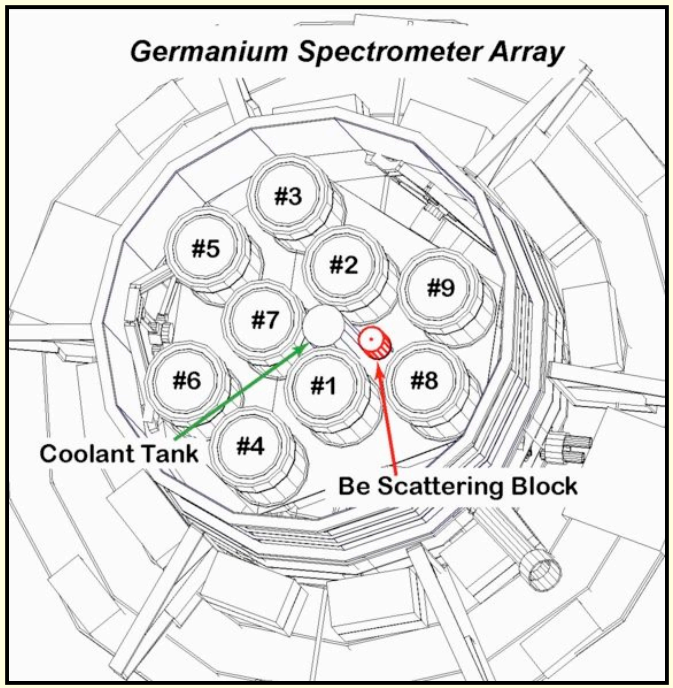
The scattering angle corresponding to the *minimum* of the distribution defines the *plane of polarization*.

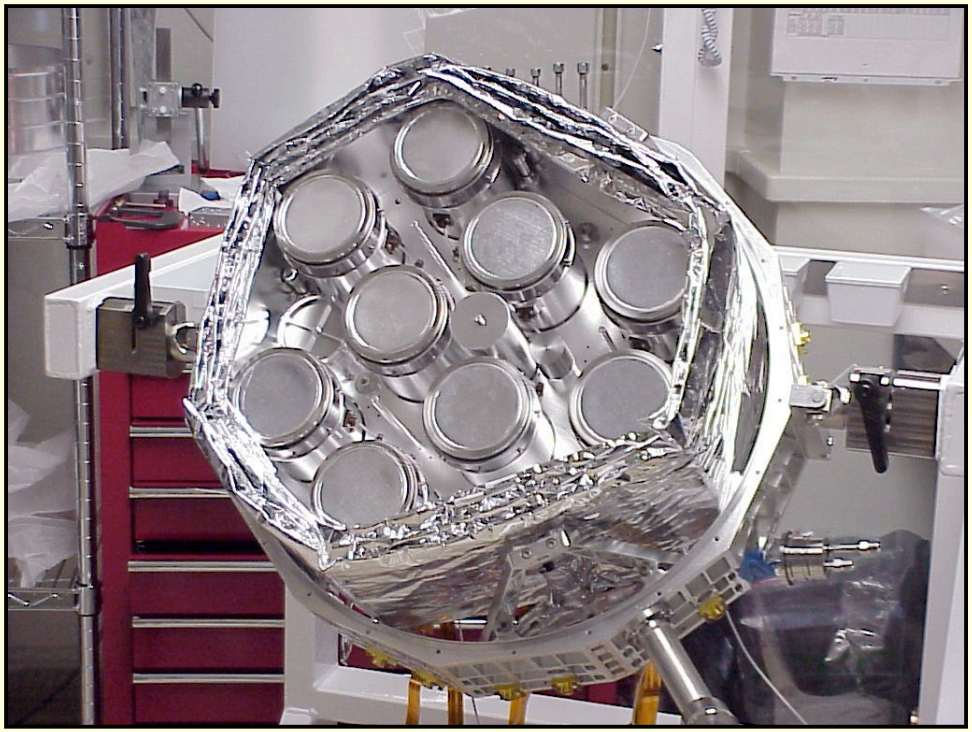
RHESSI as a Polarimeter (20 – 100 keV)

A small (3 cm diam by 3.5 cm high) cylinder of Be serves as scattering element.

The Ge detectors measure the distribution of the scattered radiation.

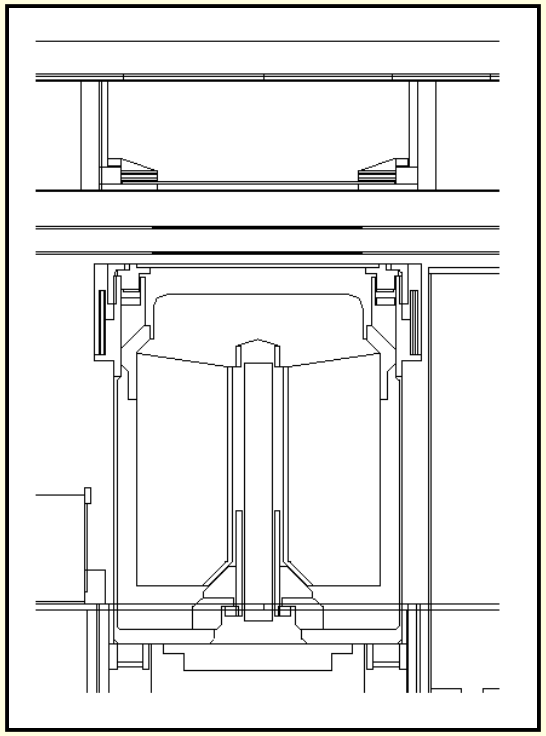
The rotation of the spacecraft rotation provides an effective method for fine sampling of the scatter distribution.



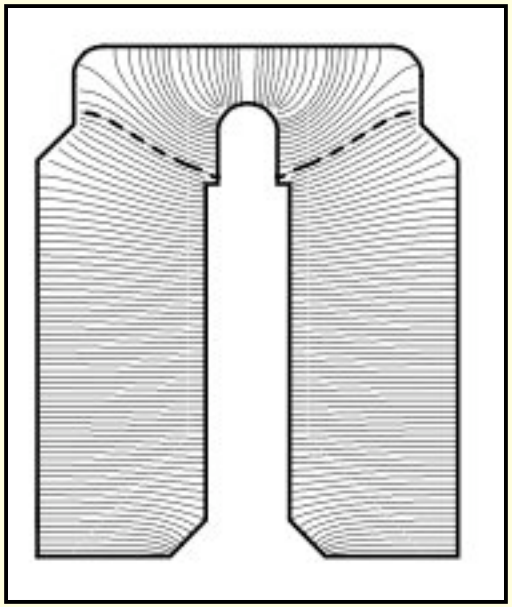


Segmented Ge detectors

The segmented nature of the Ge detectors means that low energy photons can reach the rear Ge segments only by scattering off other material.



Mechanical configuration of a Ge detector.



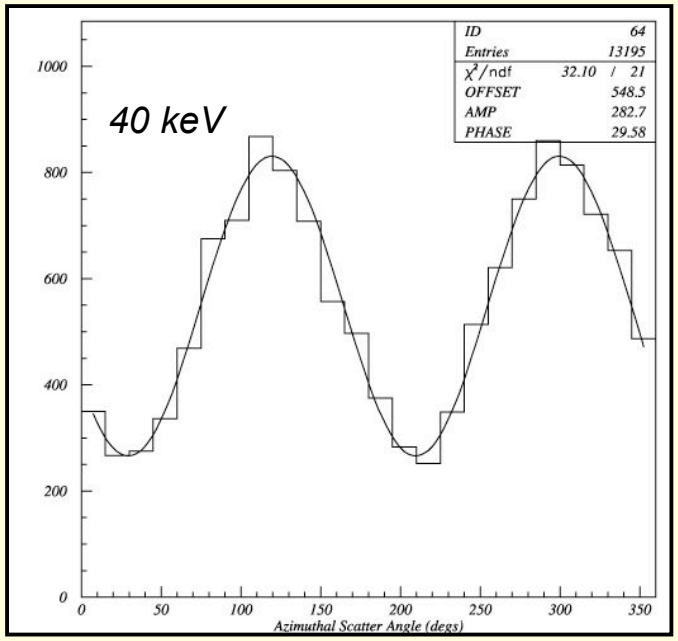
Field geometry of a Ge detector.

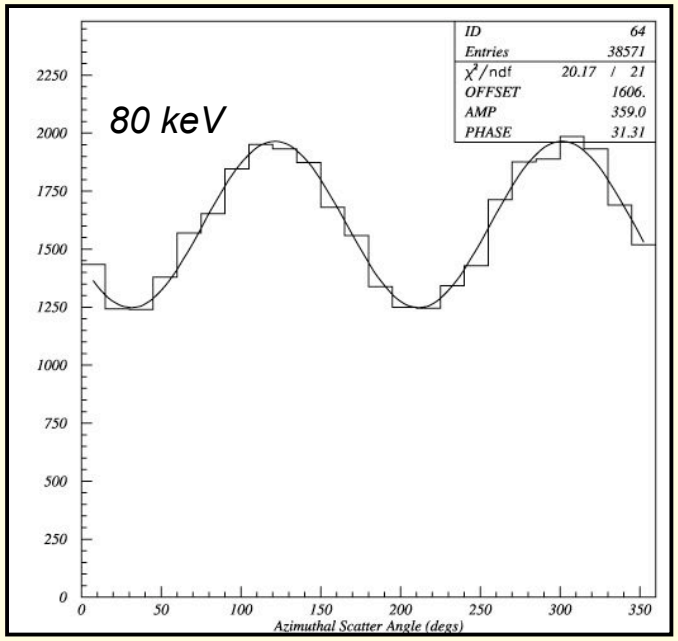
The Polarization Signal - Simulation Results

We have used a modified version of GEANT3 to carry out Monte Carlo simulations of the polarimetric capabilities of RHESSI.

A valid polarimeter event is one which produces a measurable energy deposit in the rear segment of Ge detectors 1, 8, or 9.

Detector 2 is not currently operating as a segmented detector.

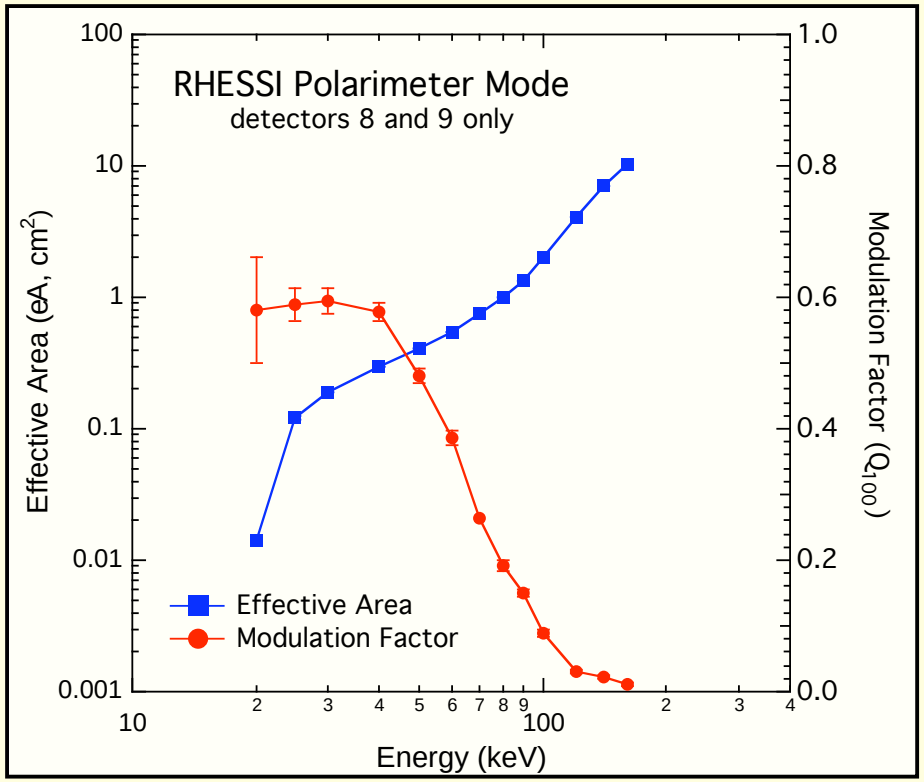


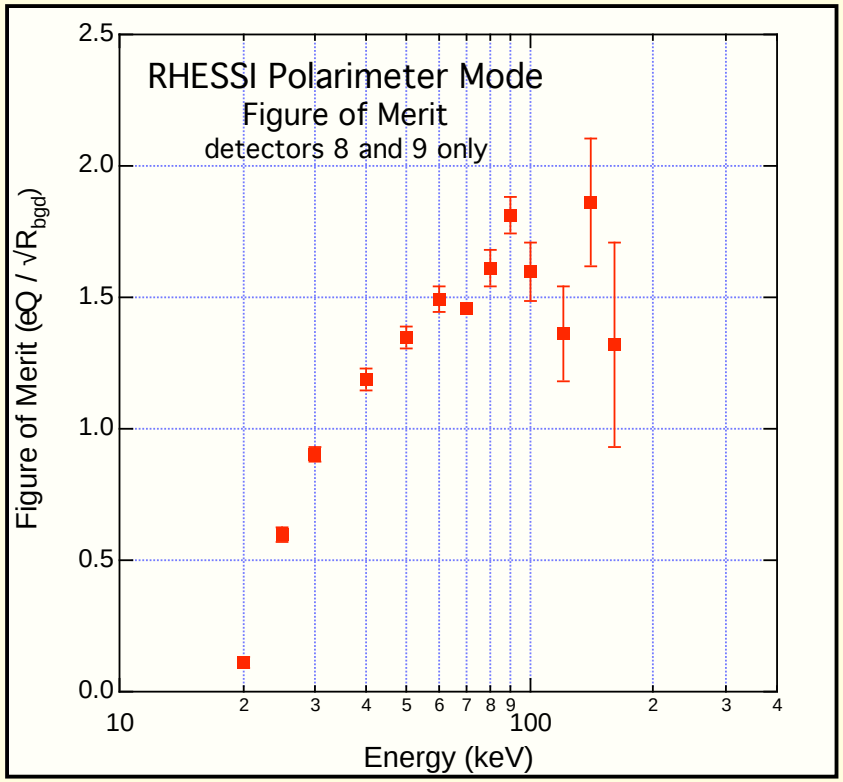


RHESSI Polarimeter Mode - Simulation Results

The Figure-of-Merit as defined here incorporates the effective area, the modulation factor and the relative background rate.

$$FoM = \frac{Q_{100}\, eA}{\sqrt{R_{bgd}}}$$





RHESSI Sensitivity to Solar Flare Polarization

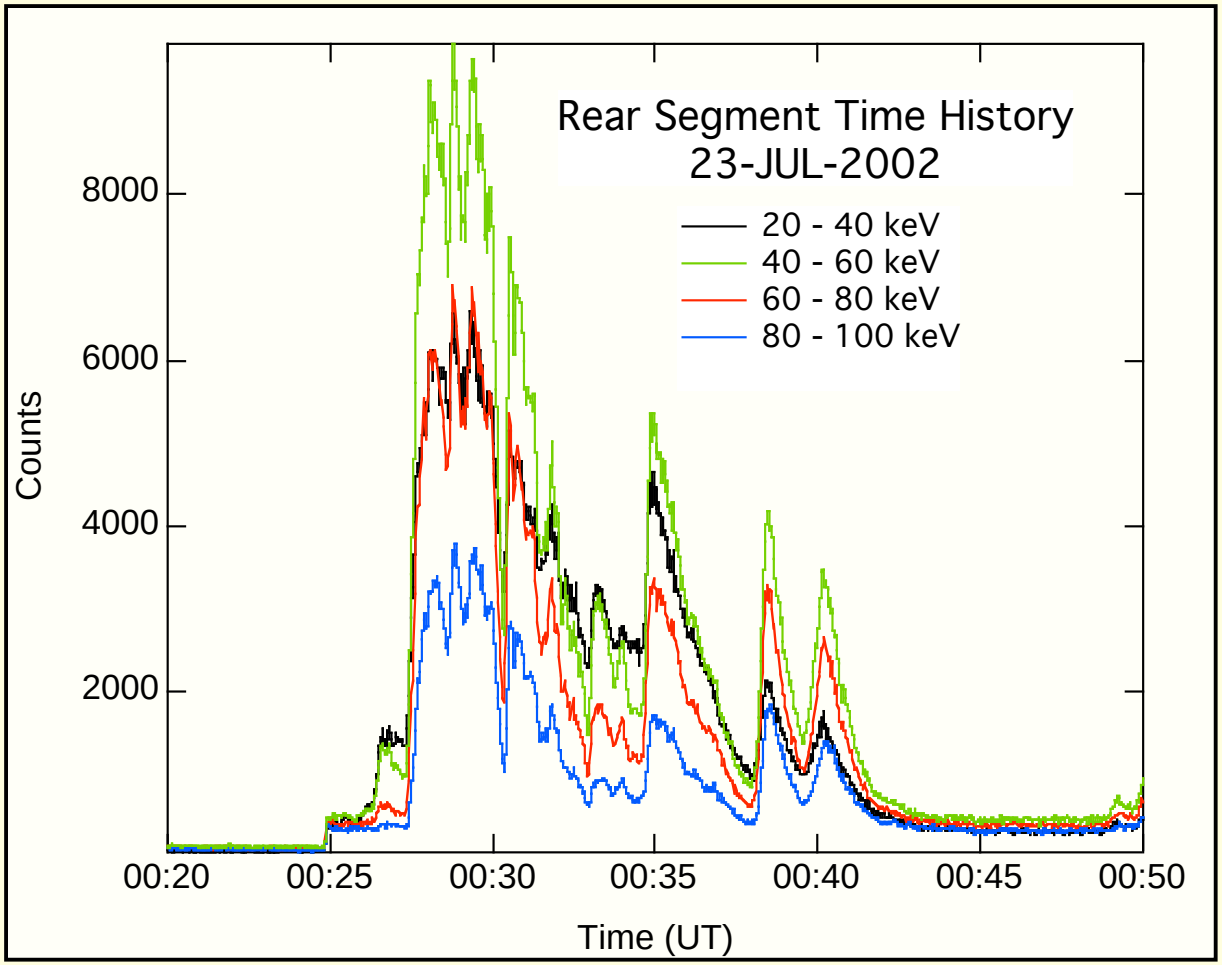
Minimum Detectable Polarization (MDP)

	Event Duration				
	20 sec	100 sec	200 sec	500 sec	1000 sec
X2 class flare					
20 – 40 keV	11%	5%	3%	2%	2%
40 – 60 keV	53%	24%	17%	11%	8%
60 – 80 keV	–	–	73%	46%	33%
X10 class flare					
20 – 40 keV	5%	2%	1%	1%	<1%
40 – 60 keV	17%	7%	5%	3%	2%
60 – 80 keV	61%	27%	19%	12%	9%

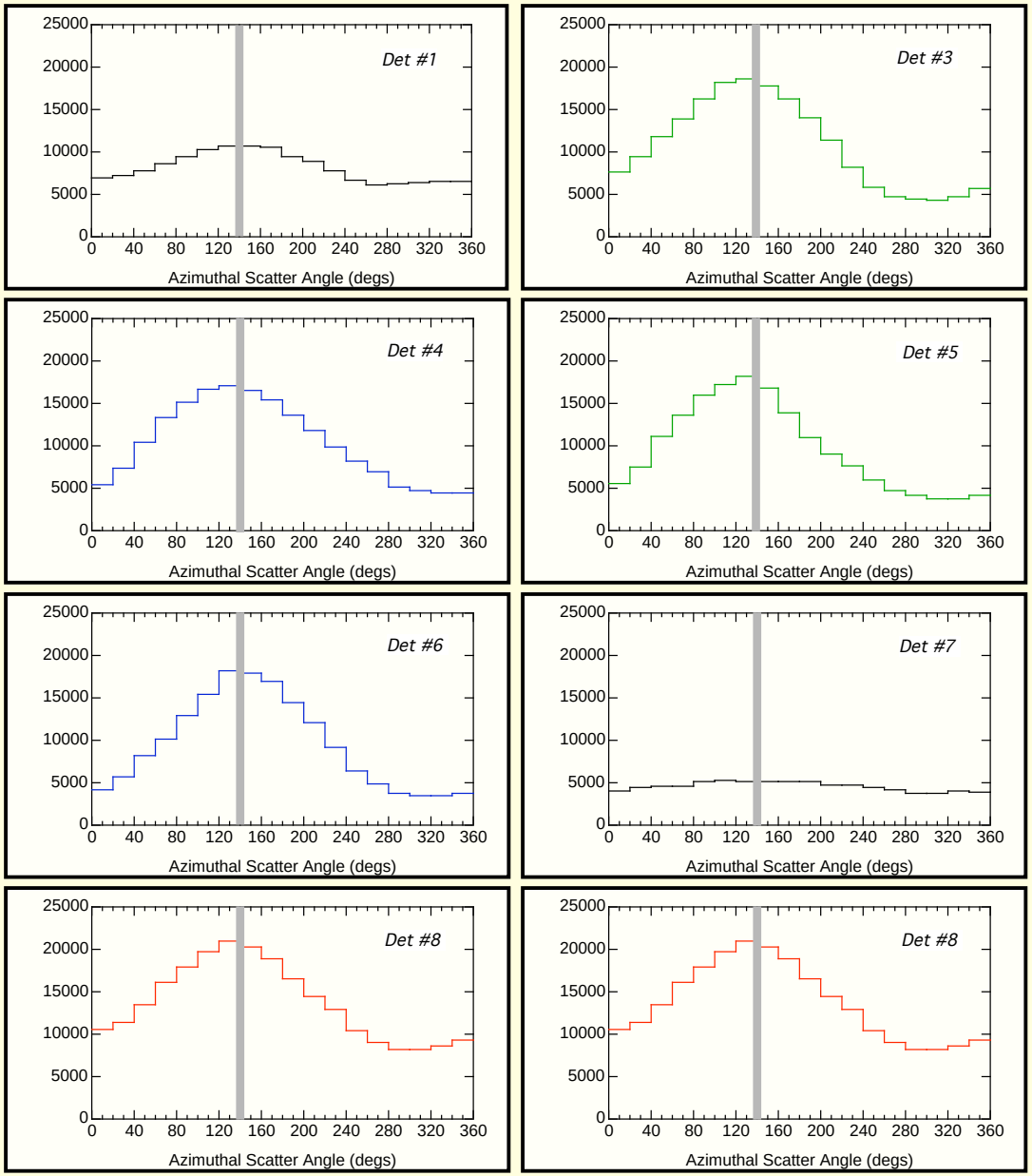
For M-class flares, sensitivity levels of 20-40% may still be achievable in the lowest energy bands.

Candidate Flare Events

There have been several X-class flares since the launch of RHESSI. The best candidate for polarization studies was the X4.8 event of 23-July-2002, which showed a large signal in the rear segments.

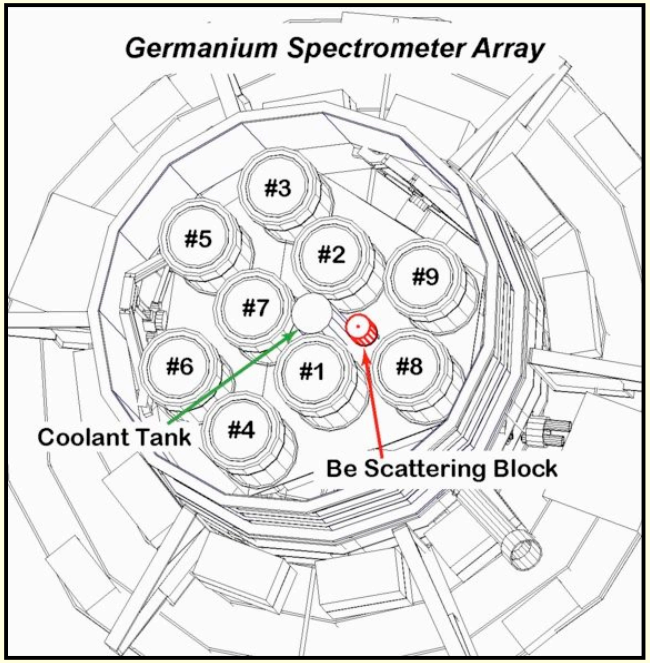


Nature of the RHESSI Data



X4.8 Flare - 23 July 2002
00:26 – 00:42 UT

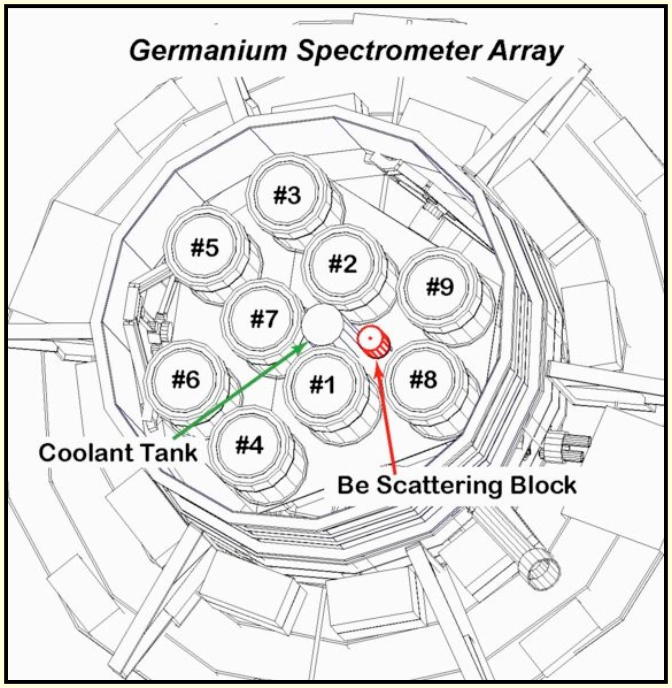
Rear Segment Data
(20 – 40 keV)
dominated by spin modulation of atmospheric background and albedo



An Initial Approach to RHESSI Analysis

Three pairs of detectors with similar background :
detectors 8/9, detectors 3/5 and detectors 4/6.

The data from detectors 3-6 can be used as background estimate for the polarimeter mode detectors 8/9.

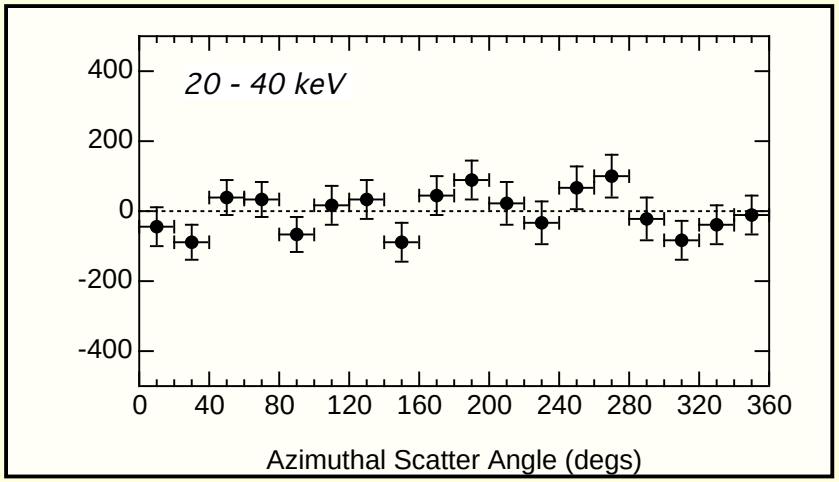


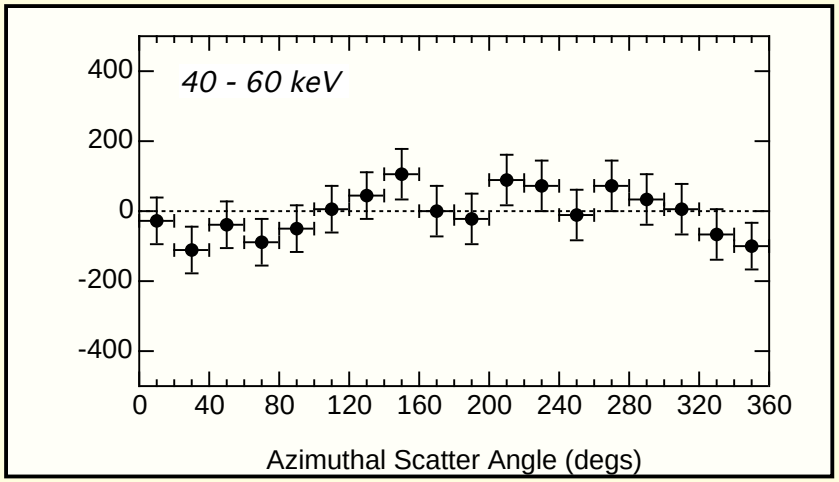
Limitations **:**

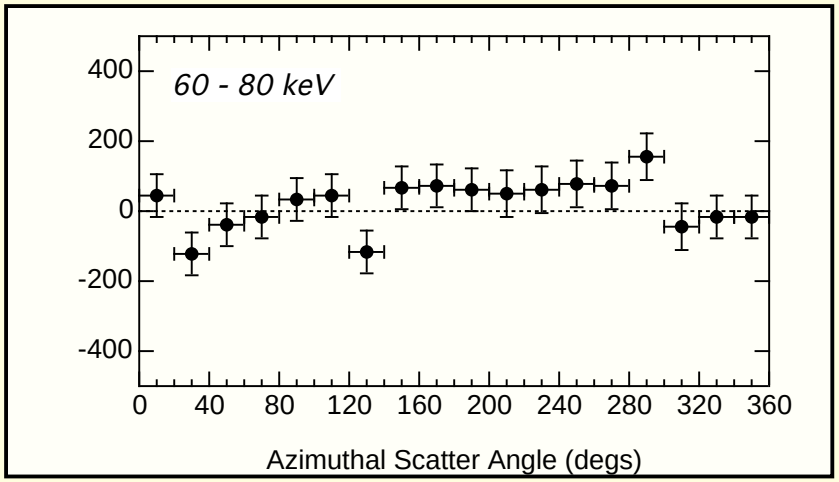
- **Does not use detector #1**
- **Assumes symmetric geometry**
- **No modeling of Earth albedo**

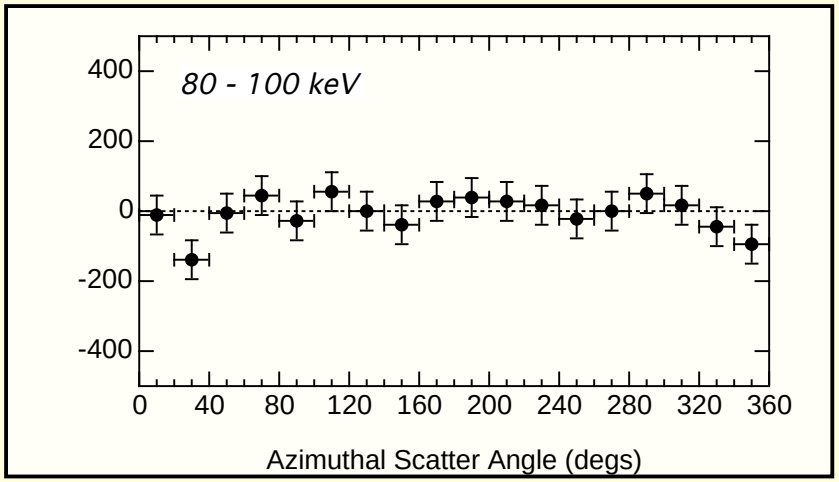
"Background" Subtracted Data

Non-Flare Interval, 17-Jul-2002, 17:32 - 17:45 UT





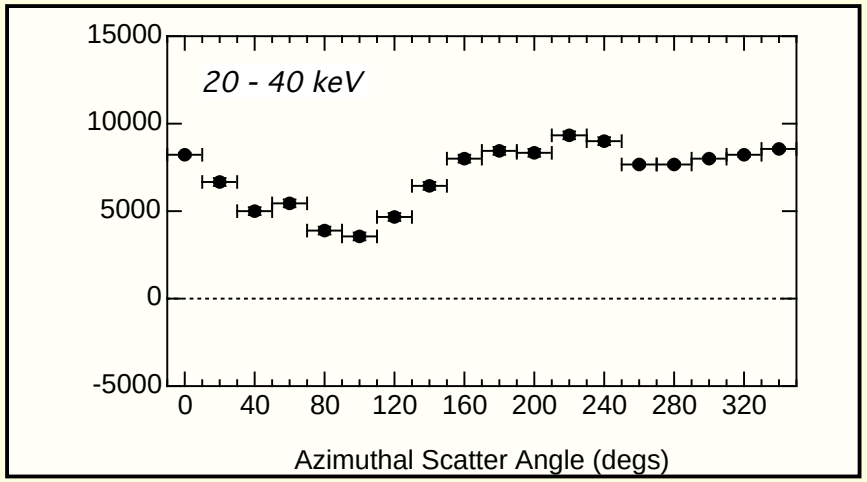


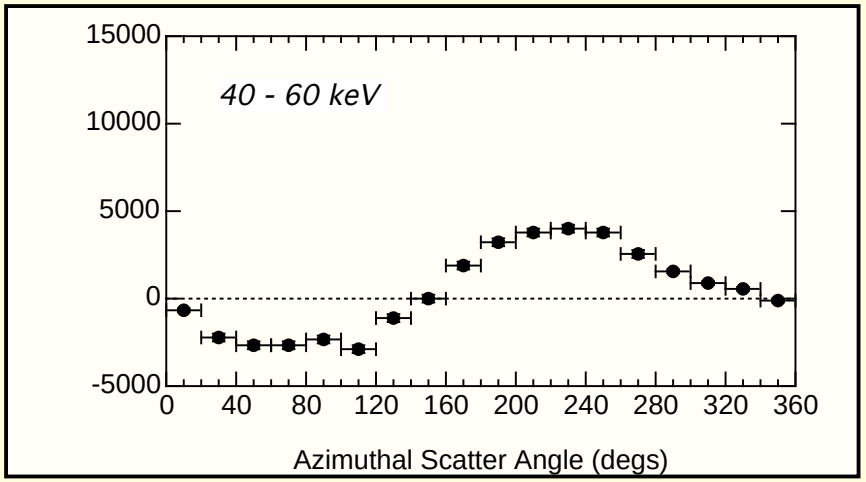


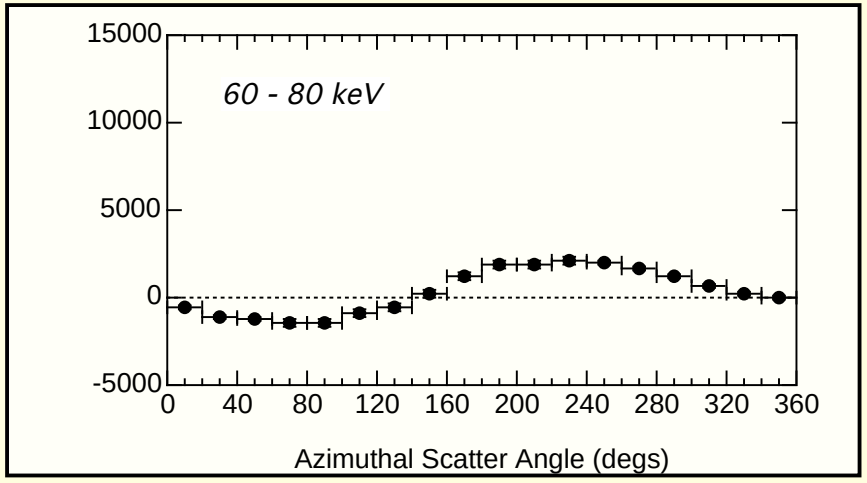
Normalization factors correct for relative detector efficiencies.

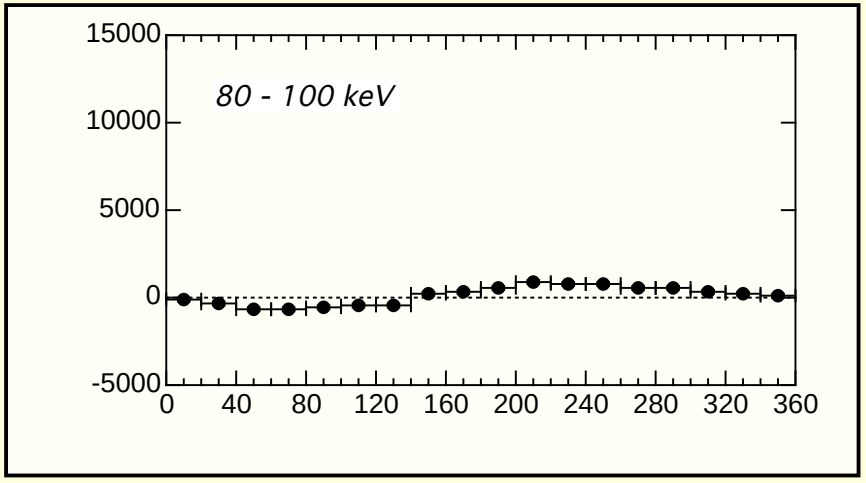
"Background" Subtracted Data

X4.8 Flare, 23 July 2002, 00:26 - 00:42 UT









Polarization Analysis

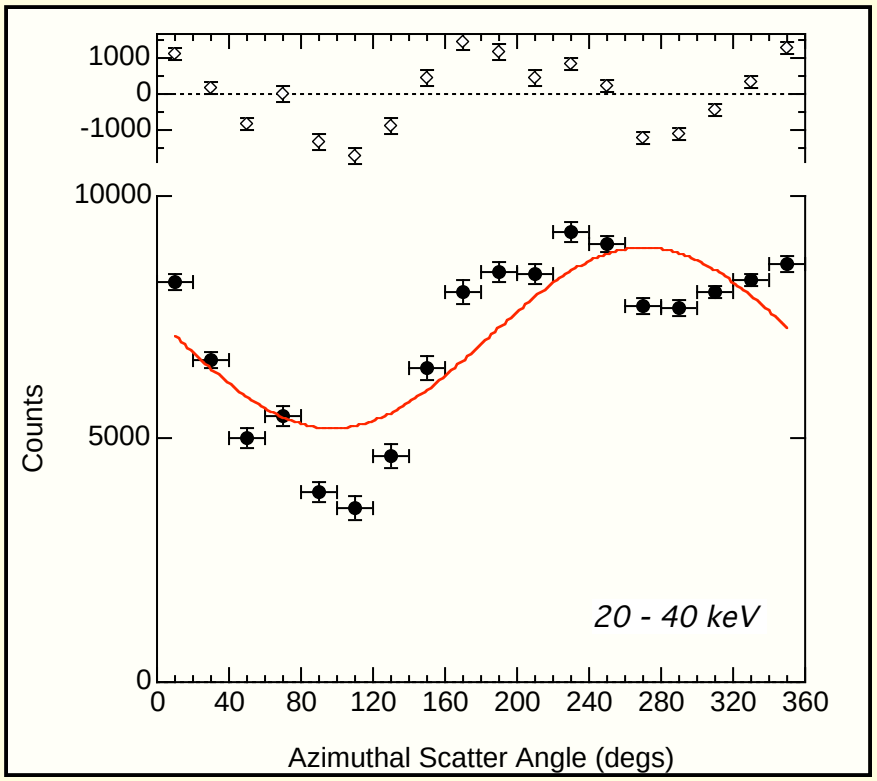
Two Component Analysis

$$f(h) = \underbrace{A + B\sin 2(h - j)}_{\text{Polarization signal}} + \underbrace{C\sin a(h - y)}_{\text{Systematic Component}}$$

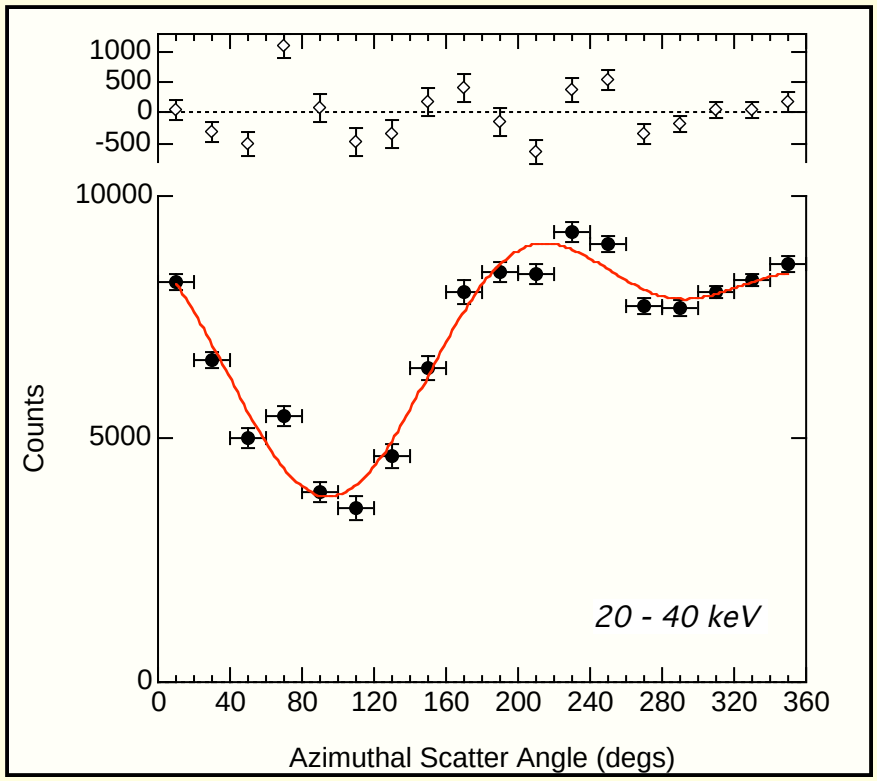
1. Systematic Component:
   - Single sinusoid component.
   - Dominates the response at high energies.
   - Not fully understood, but may be due to vignetting of the source by spacecraft rotation (collimation effects).
   - This component averages to zero.
2. Polarization Signal
   - Double sinusoid component.

Polarization Analysis : 20-40 keV

X4.8 Flare, 23 July 2002, 00:26 - 00:42 UT



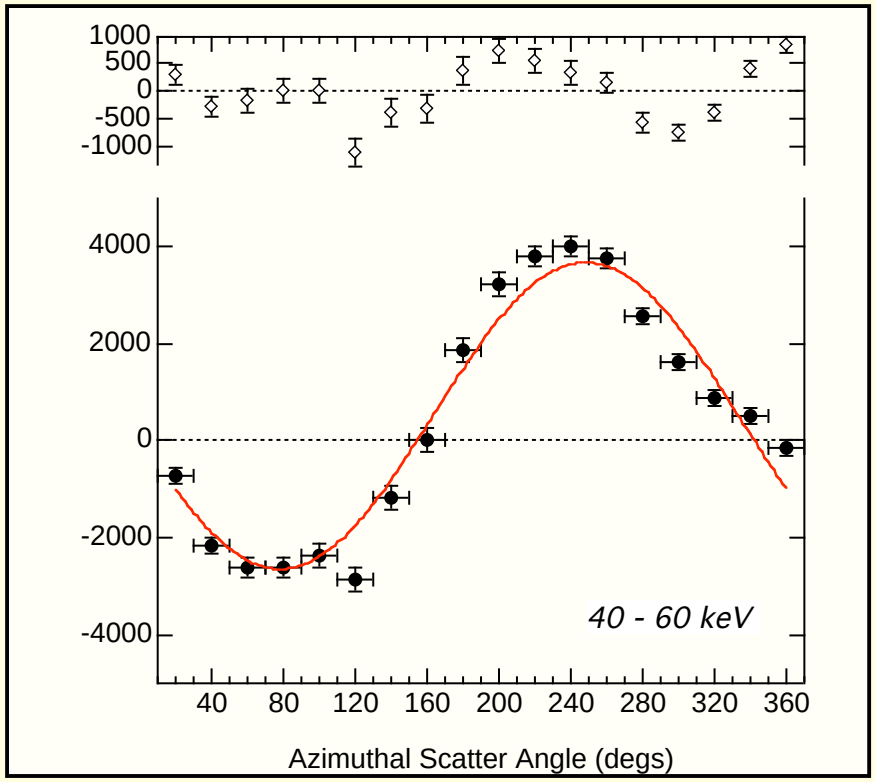
Systematic Component Only



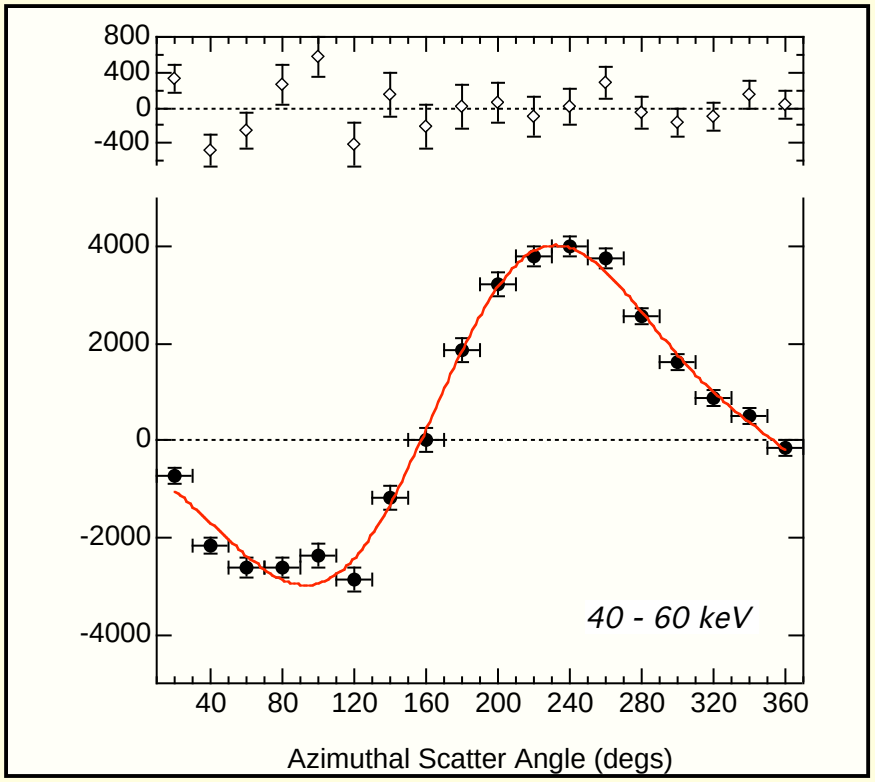
Systematic and Polarization Components

Polarization Analysis : 40-60 keV

X4.8 Flare, 23 July 2002, 00:26 - 00:42 UT



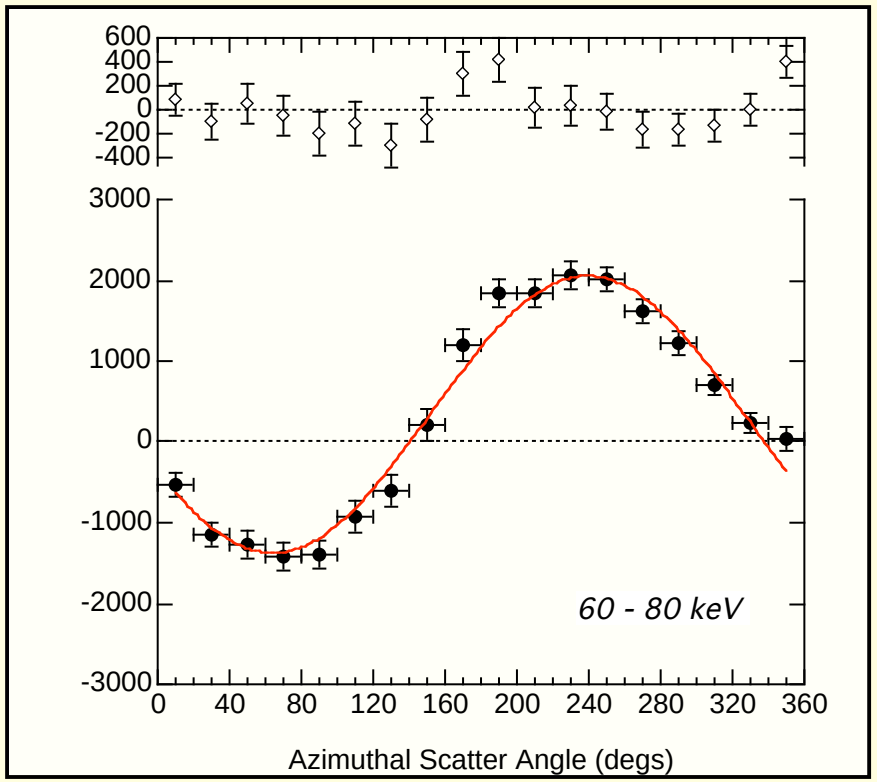
Systematic Component Only



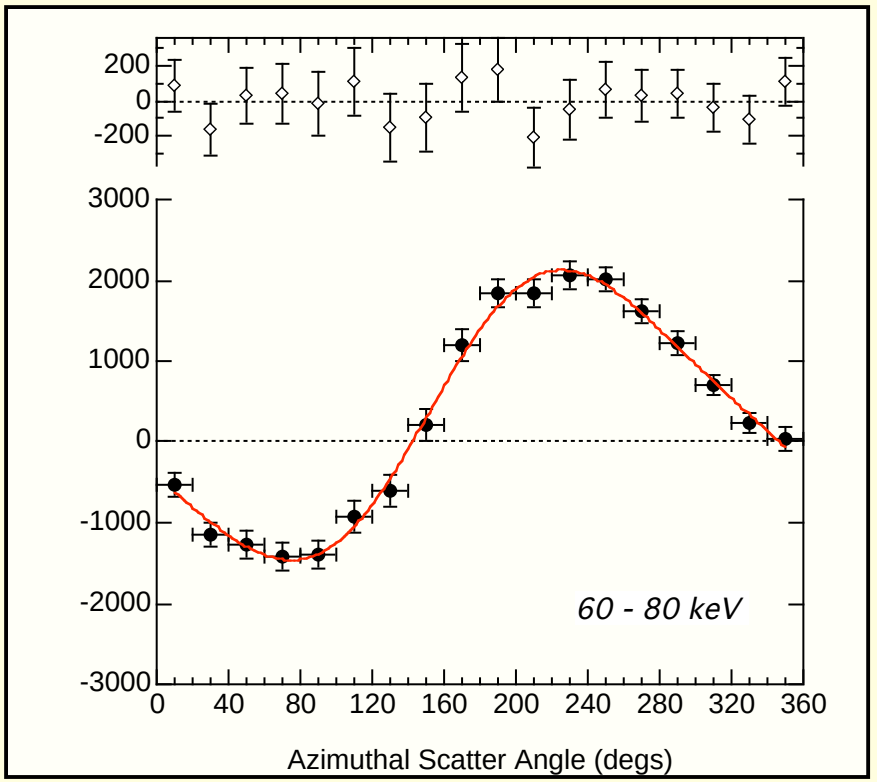
Systematic and Polarization Components

Polarization Analysis : 60-80 keV

X4.8 Flare, 23 July 2002, 00:26 - 00:42 UT



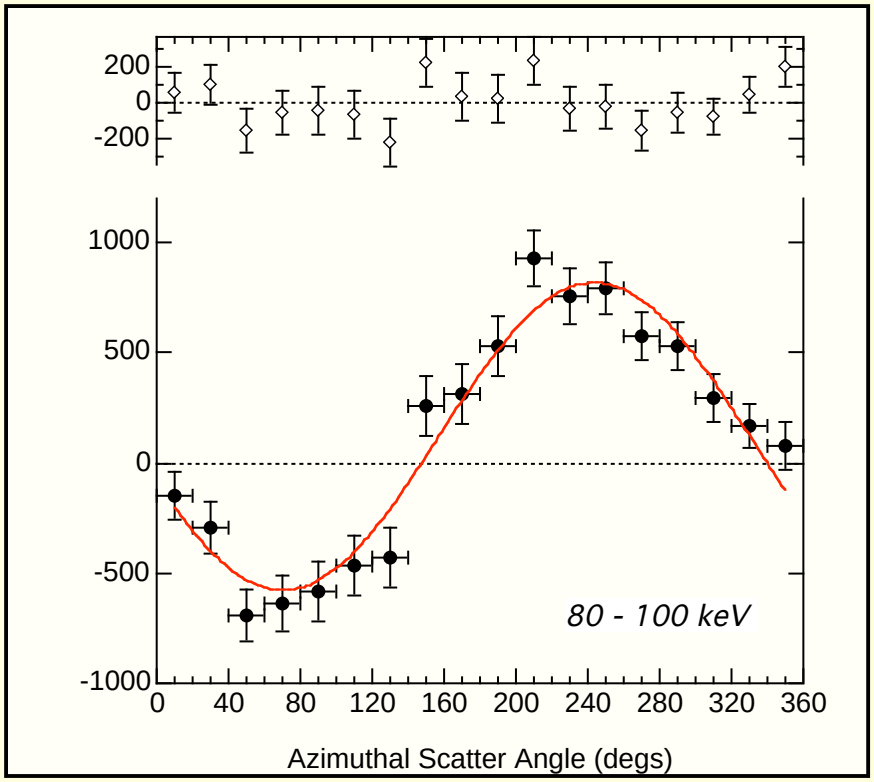
Systematic Component Only



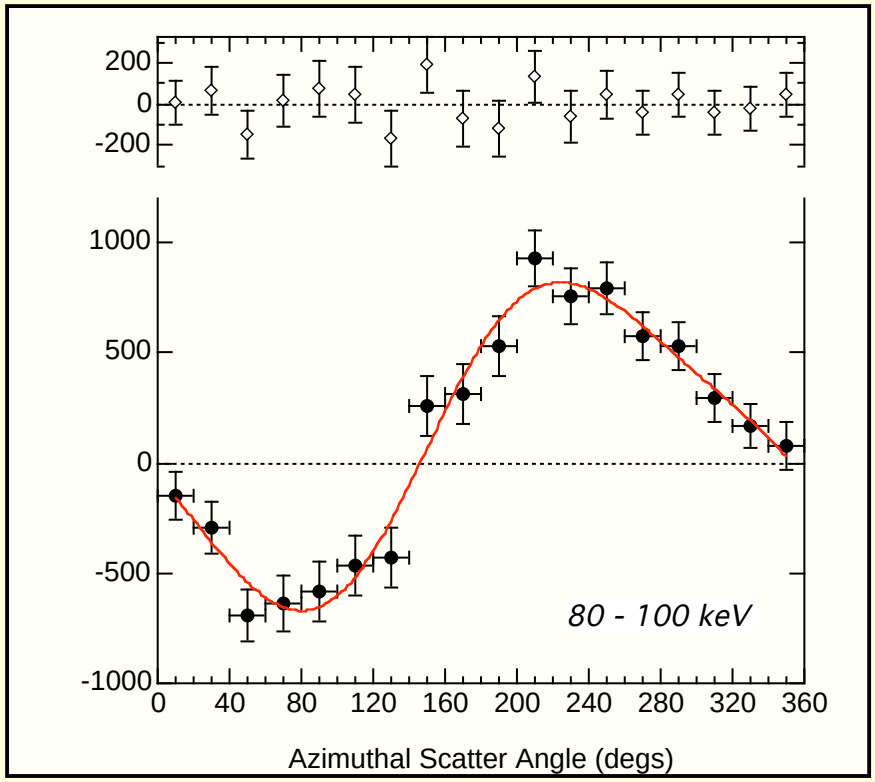
Systematic and Polarization Components

Polarization Analysis : 80-100 keV

X4.8 Flare, 23 July 2002, 00:26 - 00:42 UT



Systematic Component Only



Systematic and Polarization Components

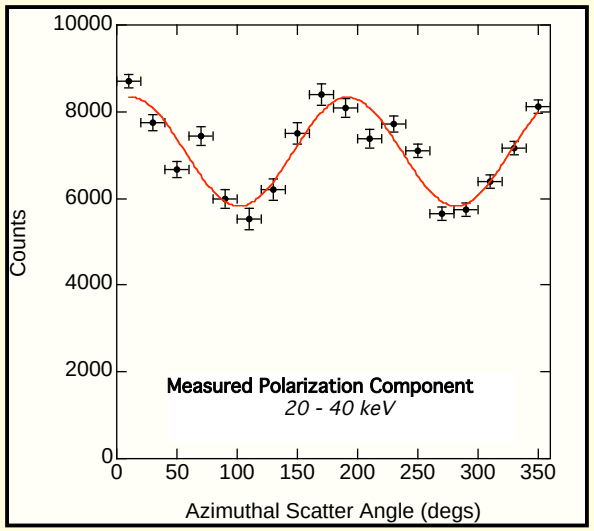
Polarization Results

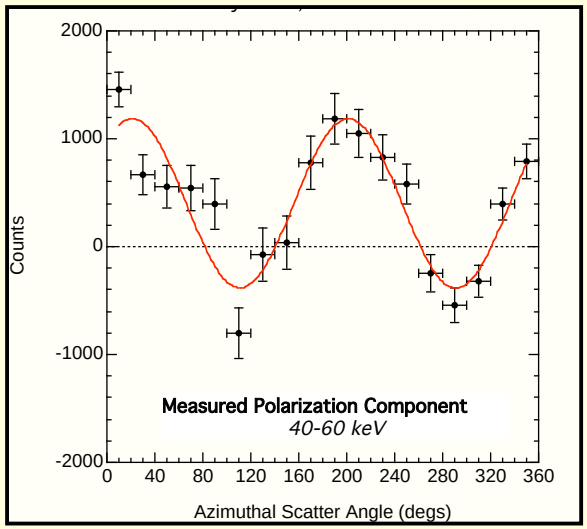
X4.8 Flare, 23 July 2002, 00:26 - 00:42 UT

$\mu_P = 0.18 \pm 0.05$

$\mu_{100} = 0.66$

$P = 27(\pm 7)\%$





$\mu_P = 1.95 \pm 0.33$

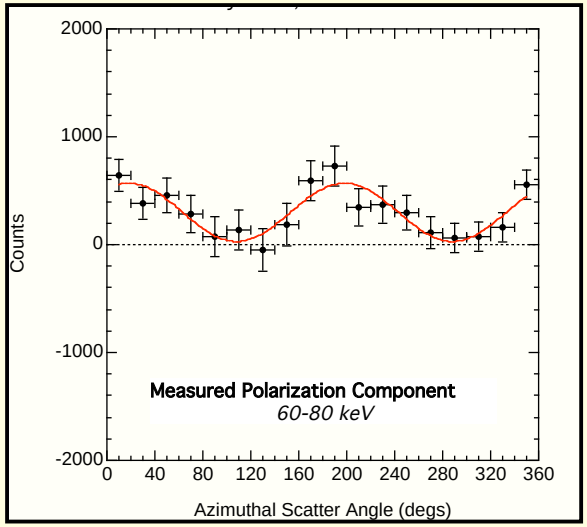
$\mu_{100} \approx 0.45$

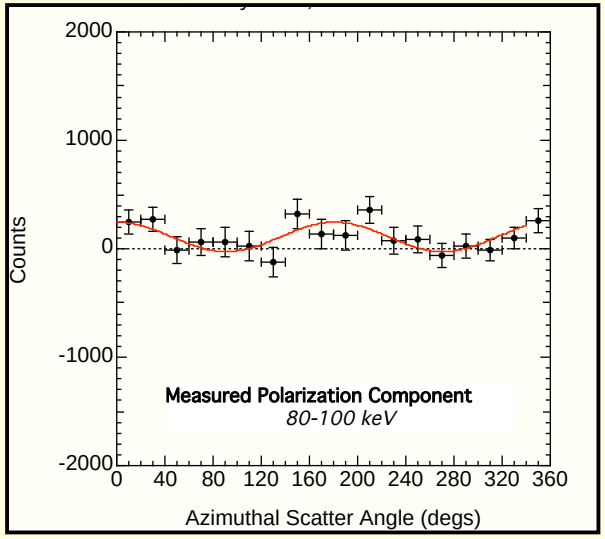
$P = ?!?$

$\mu_P = 0.90 \pm 0.26$

$\mu_{100} \approx 0.35$

$P = ?!?$





$\mu_P = 1.24 \pm 0.55$

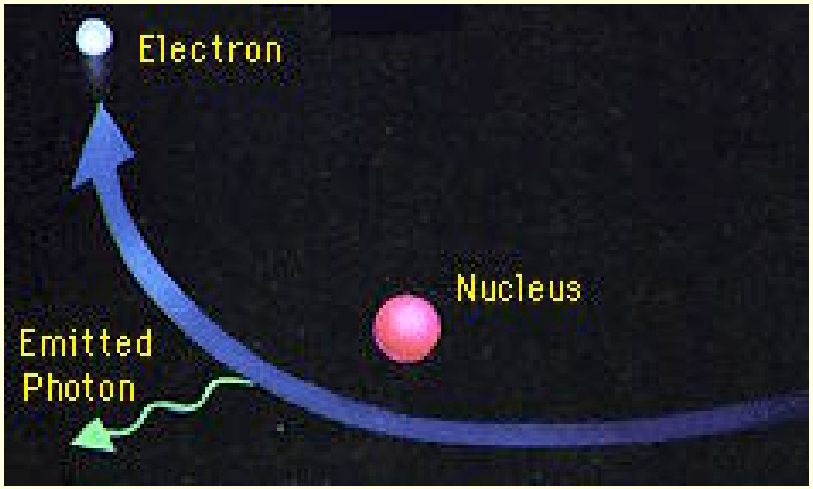
$\mu_{100} \approx 0.25$

$P = ?!?$

Summary

- Addition of a Be scattering block provides HESSI with significant polarimetric capability.
- Polarization sensitivity predicted to be less than a few percent for some X-class flares.
- Several X-class flares observed by RHESSI.
- Results from X4.8 flare of 23 July 2002:
  - ✓ Polarization signal for 20-40 keV suggests a very significant polarization level of 27%.
  - ✓ Modulations seen at higher energies are difficult to explain (not consistent with polarization signal?).
  - ✓ There may still be some residual systematics?!? Background subtraction problem?!? Currently being investigated…

Polarization of Bremsstrahlung Radiation



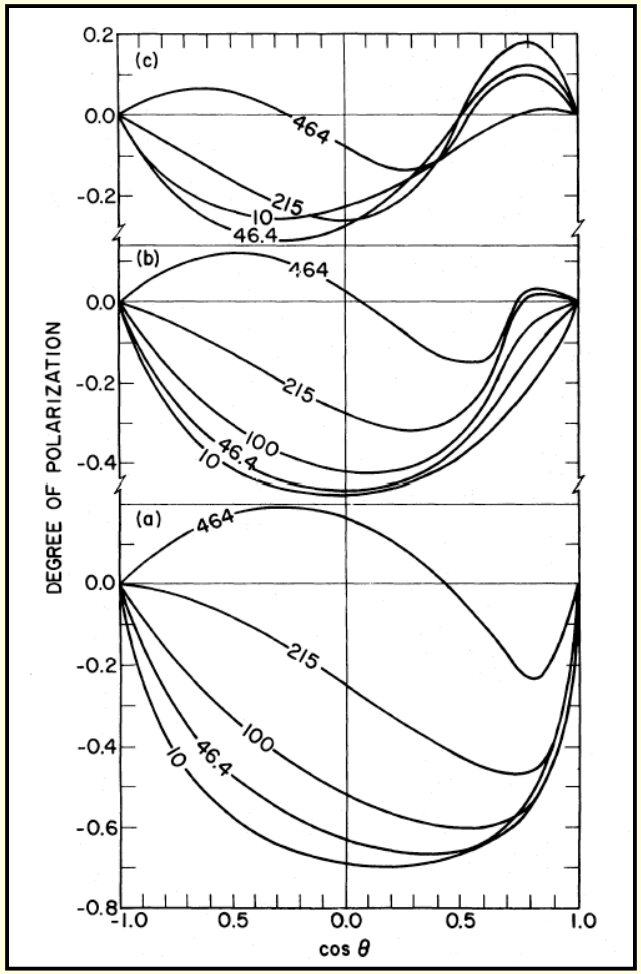
Photons tend to be emitted perpendicular to electron's plane of motion.

The polarization vector tends to be parallel to the direction of acceleration.

Degree of linear polarization can reach 80%.

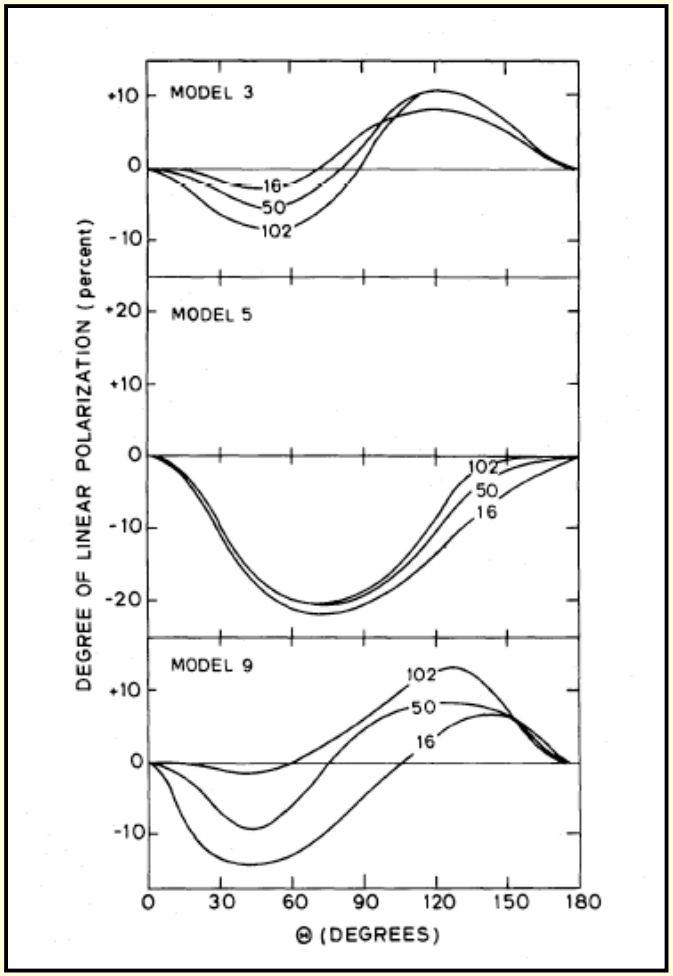
Predictions for Solar Flare Polarization

Single vertical (radial) flux tube



Langer and Petrosian (1977)

Integrated over a loop

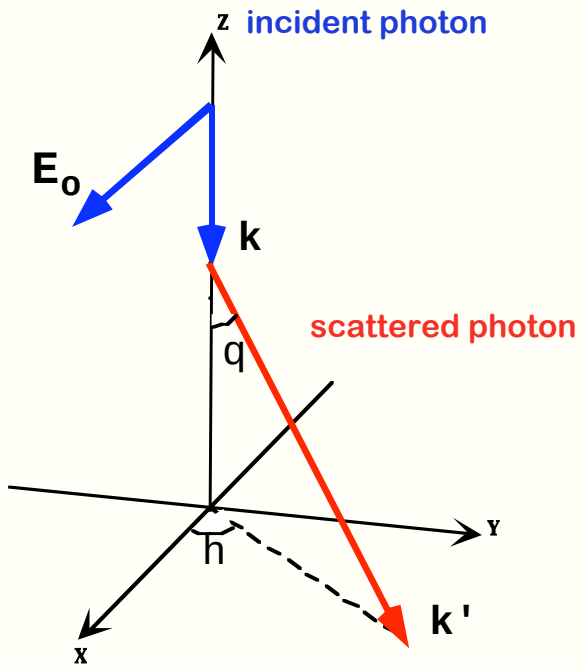


Leach and Petrosian (1983)

Basic Principles of Compton Polarimetry

Polarimetry relies on the fact that…

photons tend to Compton scatter at right angles to the incident polarization vector



$$ds = \frac{r_o^2}{2} dW \left(\frac{E\phi}{E_o} + \frac{E_o}{E\phi} - 2\sin^2 q \cos^2 h \right)$$

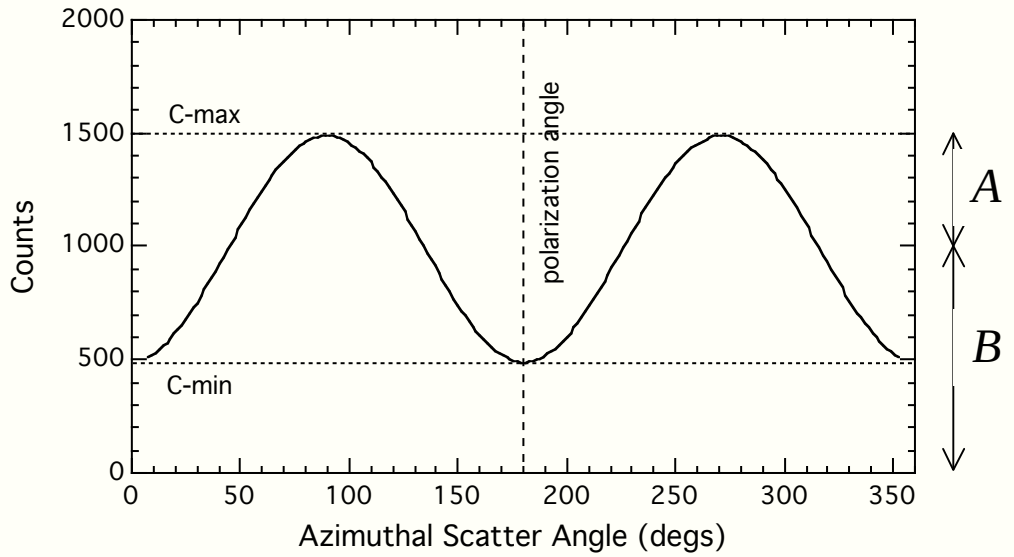
$$E\phi = \frac{E_o}{1 + \frac{E_o}{mc^2}(1 - \cos q)}$$

q is the Compton Scatter Angle, h is the Azimuthal Scatter Angle

Modulation Factor

Modulation Factor for a 100% polarized beam represents a figure-of-merit for the polarimeter :

$$Q = \frac{C_{max} - C_{min}}{C_{max} + C_{min}} = \frac{A}{B}$$



$$C(h) = A \cos 2(h - j) + B$$

Minimum Detectable Polarization (MDP)

$$MDP = \frac{n_s}{Q_{100} S}\sqrt{\frac{2(S+B)}{T}}$$

S = source counting rate

B = background counting rate

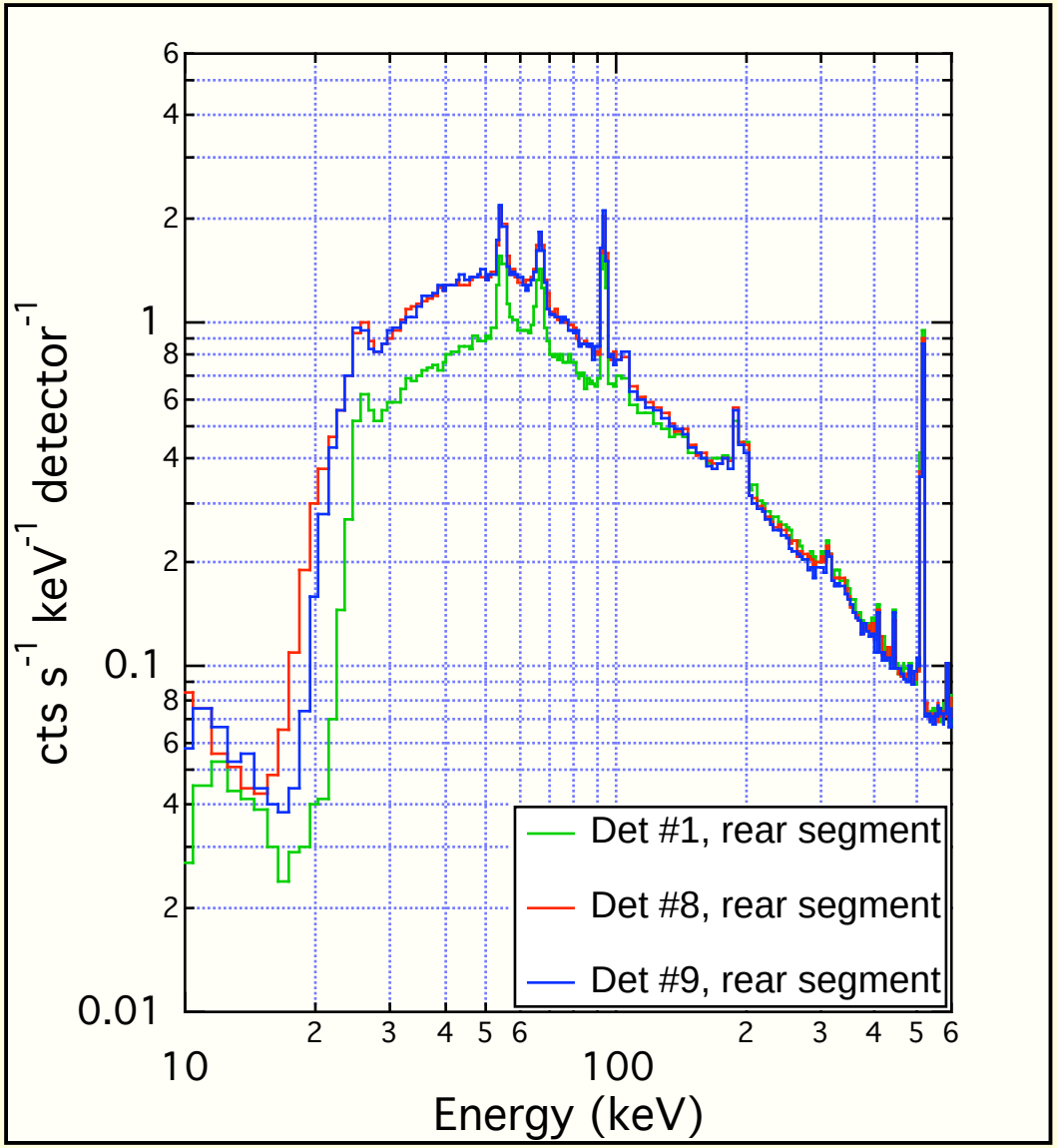
T = observation time

Q_{100} = modulation factor for 100% polarization

Sensitivity can be improved by :

1) Increasing S (efficiency or geometric area)
2) Decreasing B
3) Increasing T
4) Increasing Q_{100} (optimizing geometry)

Ambient (Non-Flare) Background

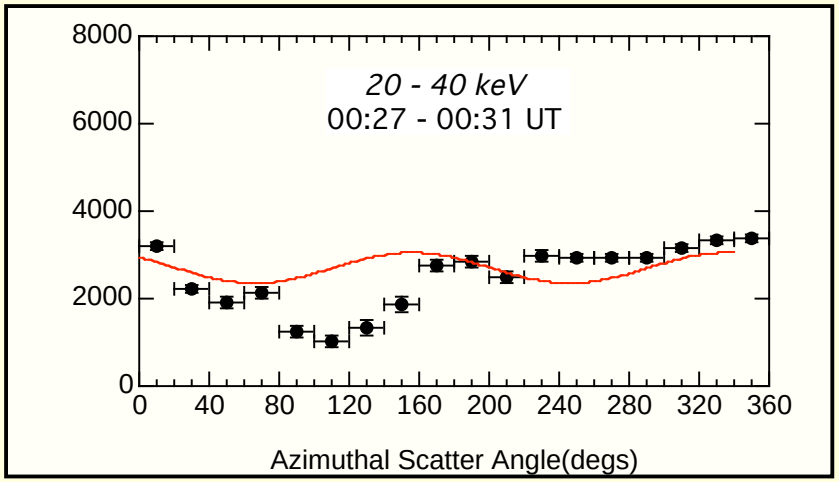


Sample background spectra for rear segments.

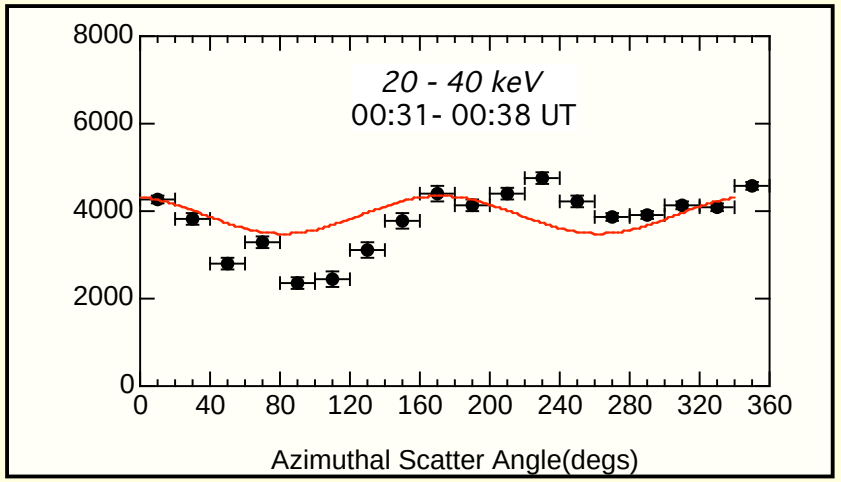
Data are shown here for the three detectors that are used in polarization studies.

First Results

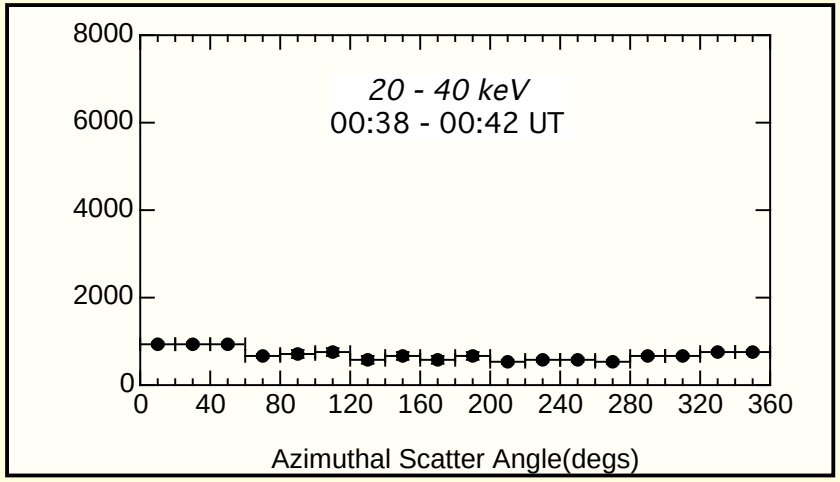
23 July 2002 : 20-40 keV



R (20-40 keV) ≈ R (40-60 keV)



R (20-40 keV) > R (40-60 keV)



R (20-40 keV) < R (40-60 keV)