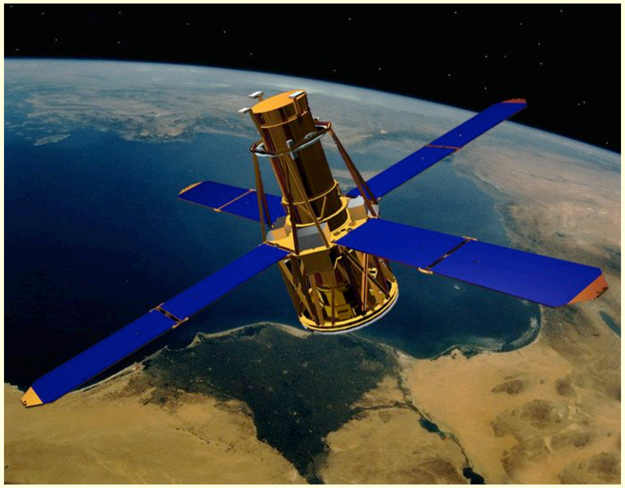
Hard X-Ray Solar Flare Polarimetry with RHESSI



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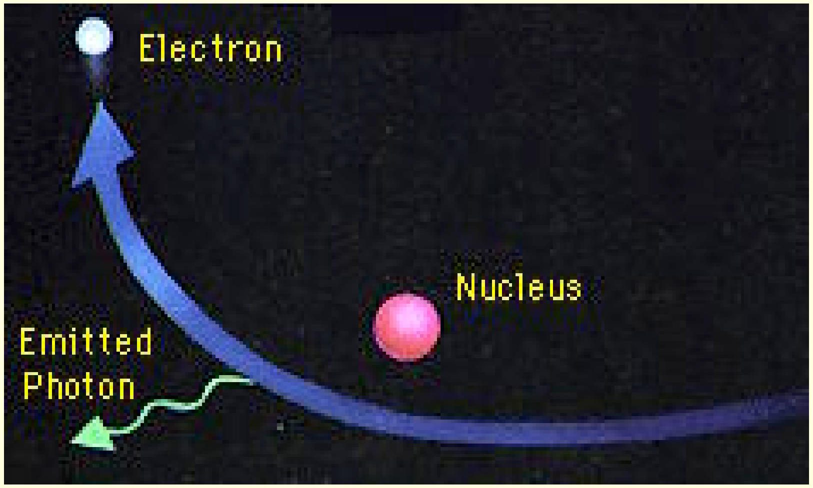
Polarization of Bremsstrahlung Radiation



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

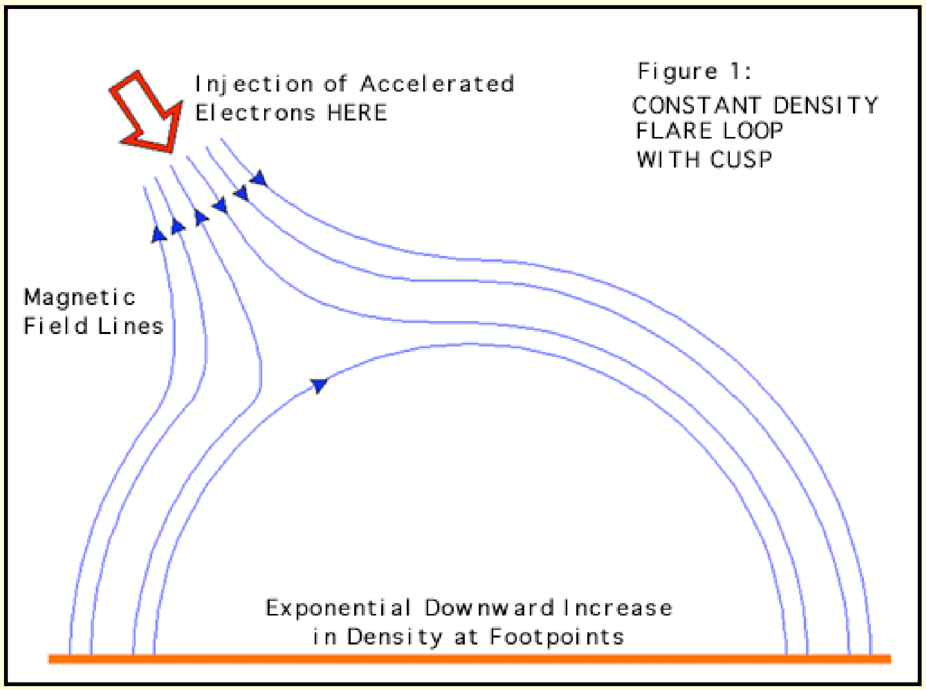
The polarization vector tends to be parallel to the direction of acceleration.

Degree of linear polarization can reach 80%.

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.



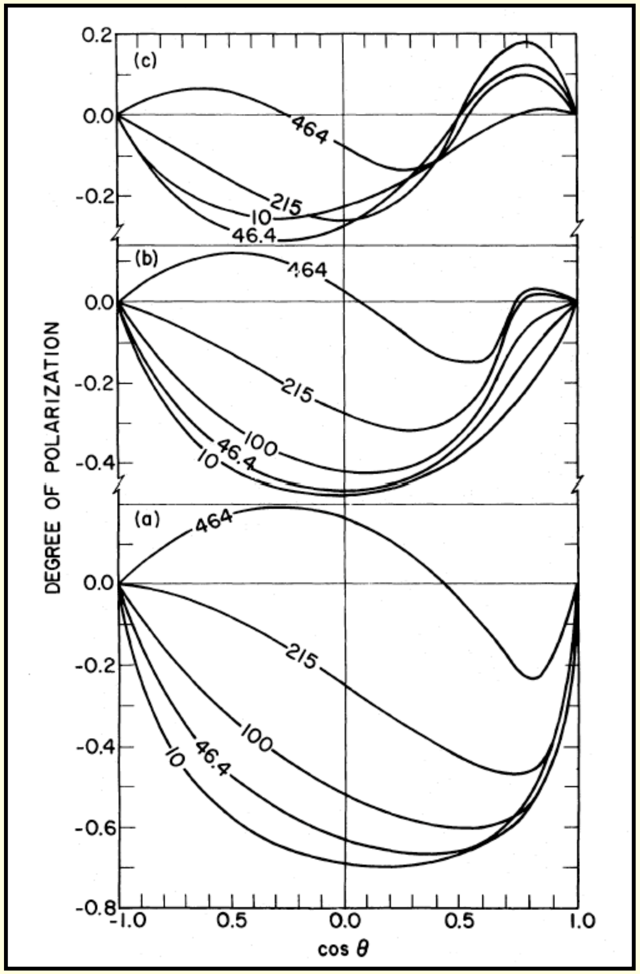
Model parameters include :

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%.

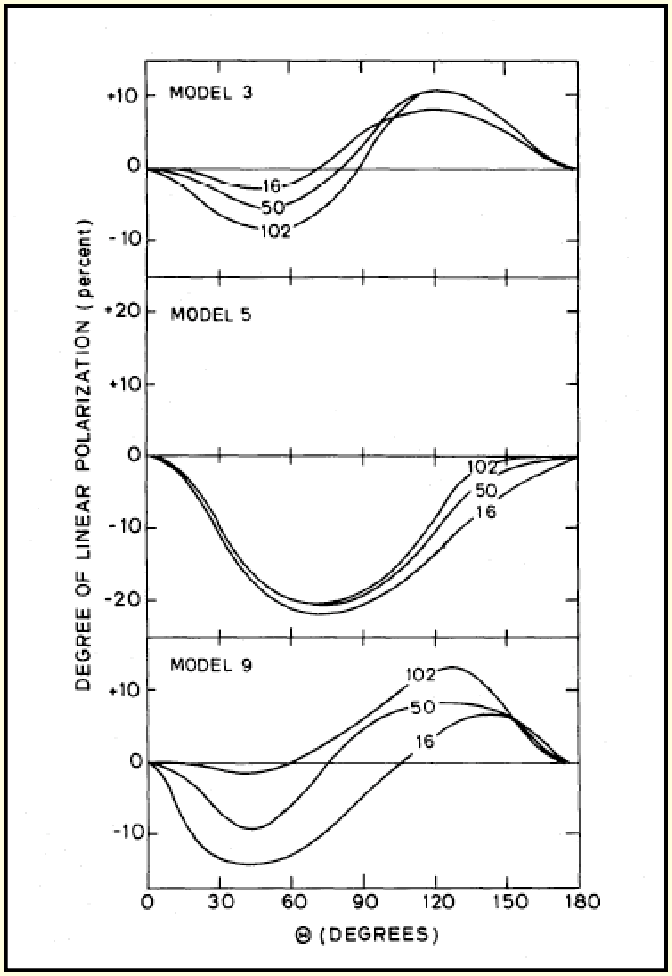
Predictions for Solar Flare Polarization

Single vertical (radial) flux tube



Langer and Petrosian (1977)

Integrated over a loop

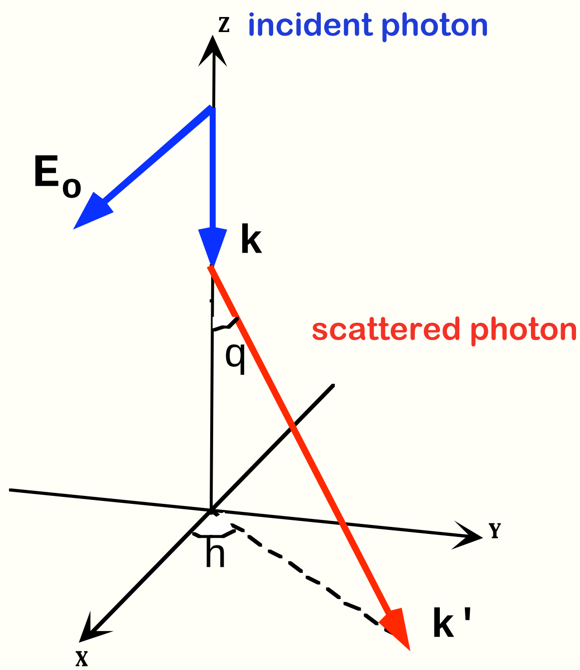


Leach and Petrosian (1983)

Basic Principles of Compton Polarimetry

Polarimetry relies on the fact that…

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



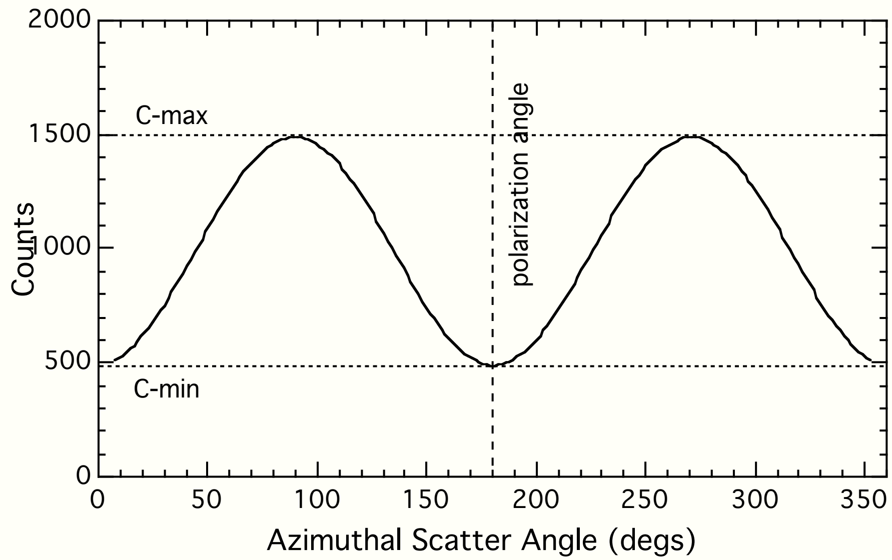
$$d\sigma = \frac{r_o^2}{2}\, d\Omega \left(\frac{E'}{E_o}\right)^2 \left[\frac{E_o}{E'} + \frac{E'}{E_o} - 2\sin^2\theta\cos^2\eta\right]$$

$$E' = \frac{E_o}{1 + \frac{E_o}{mc^2}\left(1 - \cos\theta\right)}$$

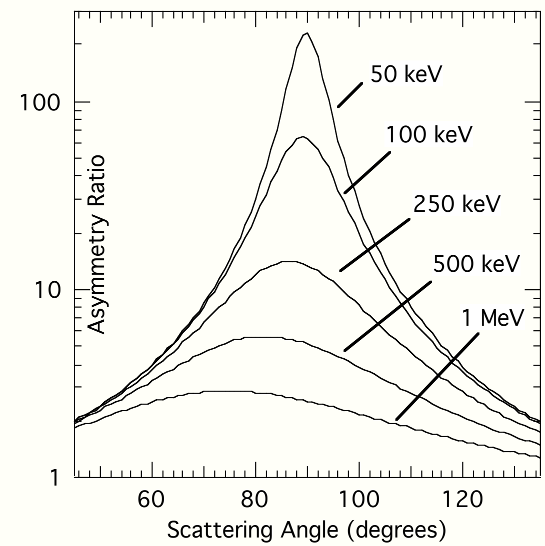
θ is the Compton Scatter Angle, η is the Azimuthal Scatter Angle

The Polarization Signature

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



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



Asymmetry Ratio

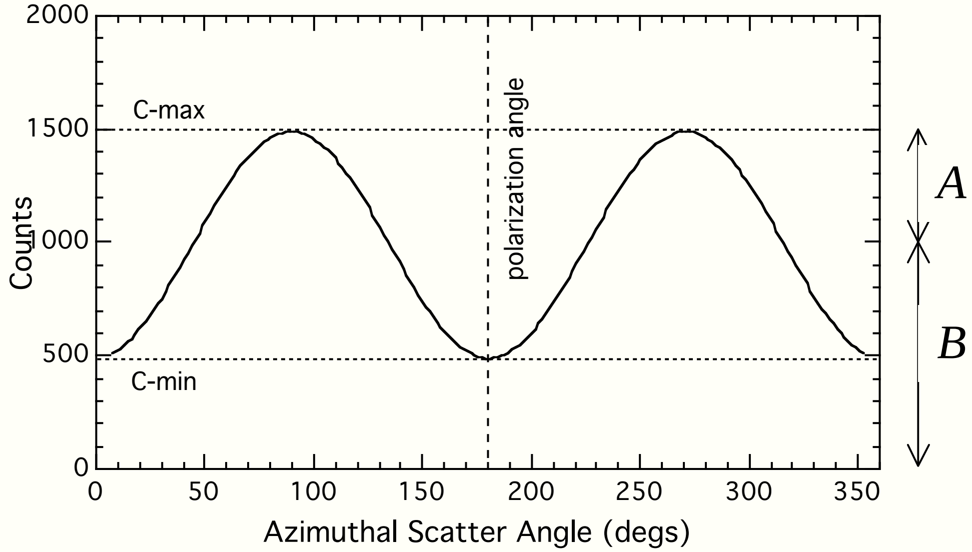
The *amplitude* of the modulation defines the *level of polarization*.

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

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

<u>Sensitivity can be improved by</u> :

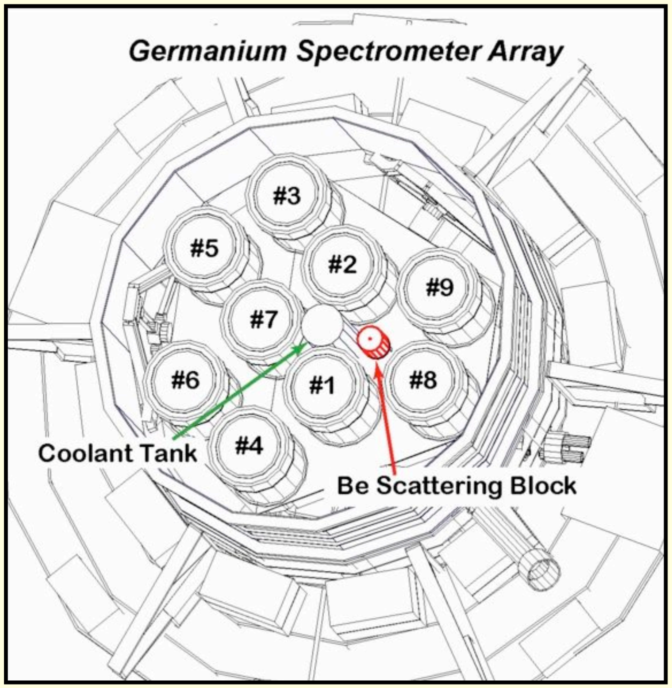
1) Increasing S (efficiency or geometric area)
2) Decreasing B
3) Increasing T
4) Increasing Q_{100} (optimizing geometry)

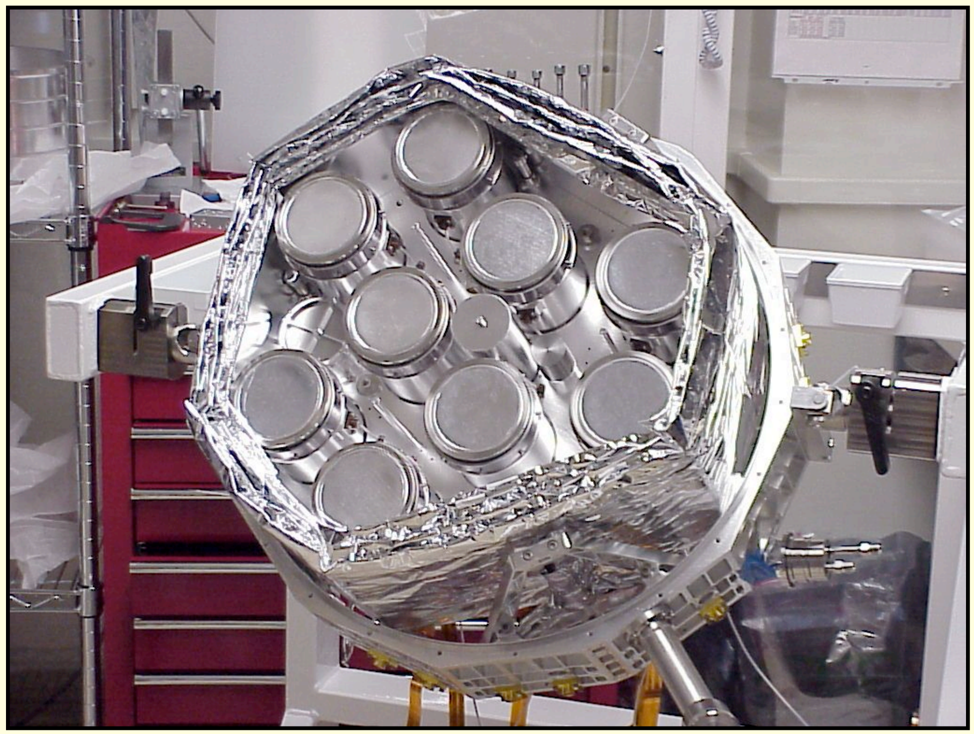
RHESSI as a Polarimeter (20 – 100 keV)

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.

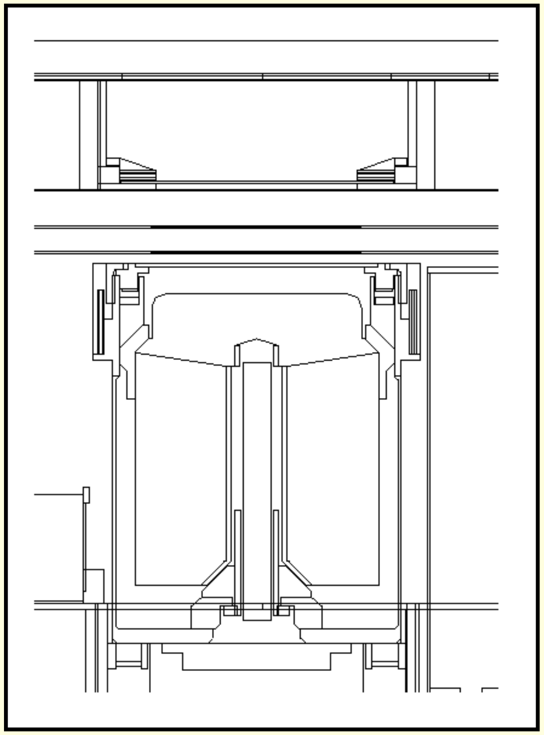
The rotation of the spacecraft rotation provides an effective method for fine sampling of the scatter distribution.



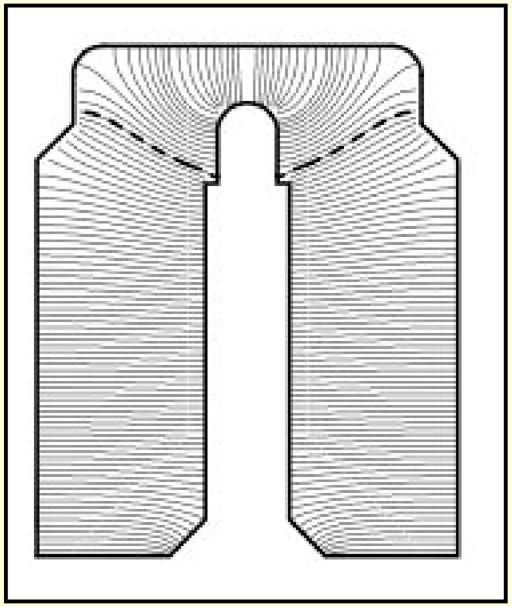


Segmented Ge detectors

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.

Monte Carlo Simulations

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

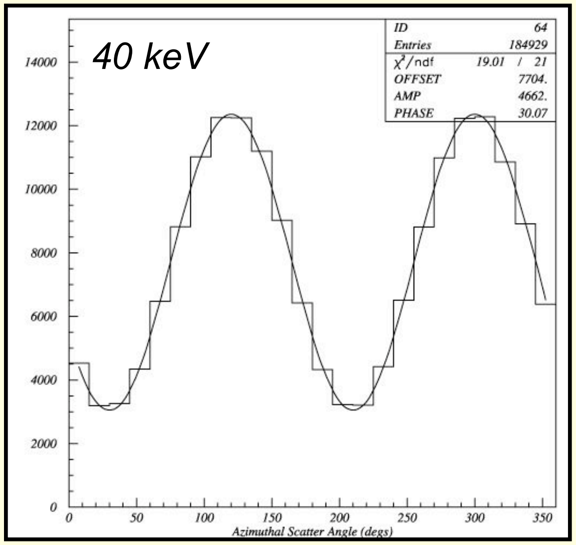
A valid polarimeter event is one which produces a measurable energy deposit in the rear segment of Ge detectors 1, 8, or 9.

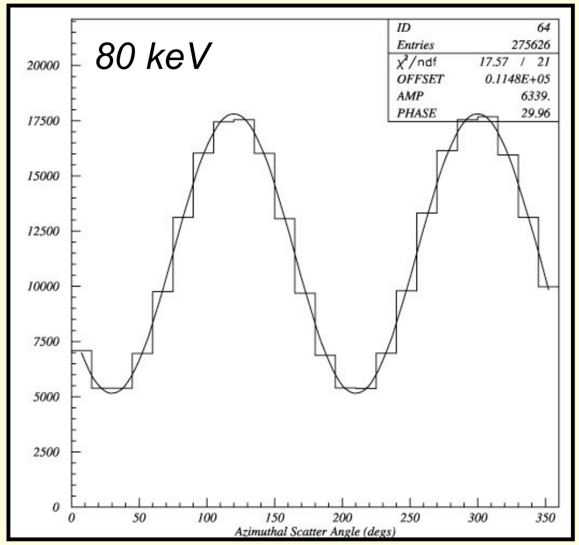
Detector 2 is not currently operating as a segmented detector.

We have simulated a very narrow beam (just covering the front surface area of the Be) to study the intrinsic polarimetry parameters of RHESSI.

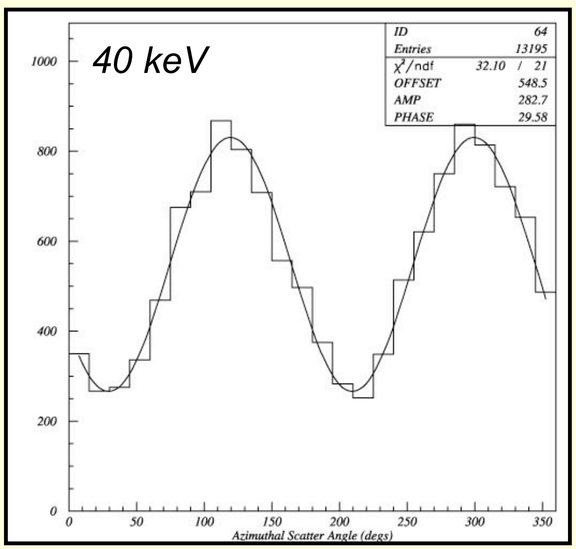
A broader beam (covering the full front surface of the telescope tube) has been used to study the effects of scattering into the rear Ge segments.

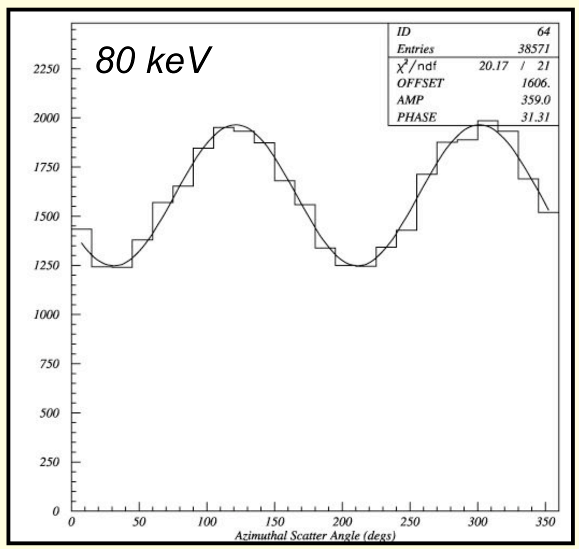
The Polarization Signal - Simulated Results





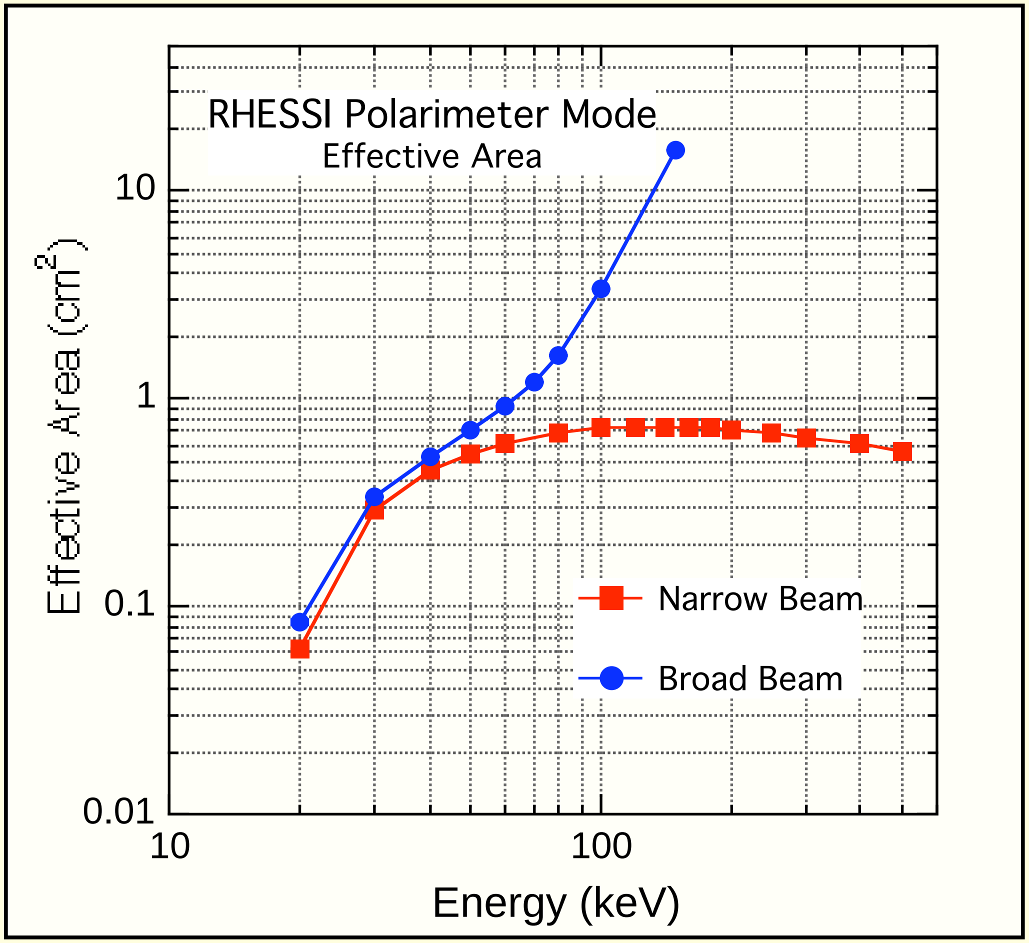
Top row shows results for narrow incident beam (no spacecraft scattering).





Bottom row shows results for wide incident beam (with spacecraft scattering). Note the significant degradation of signal at 80 keV.

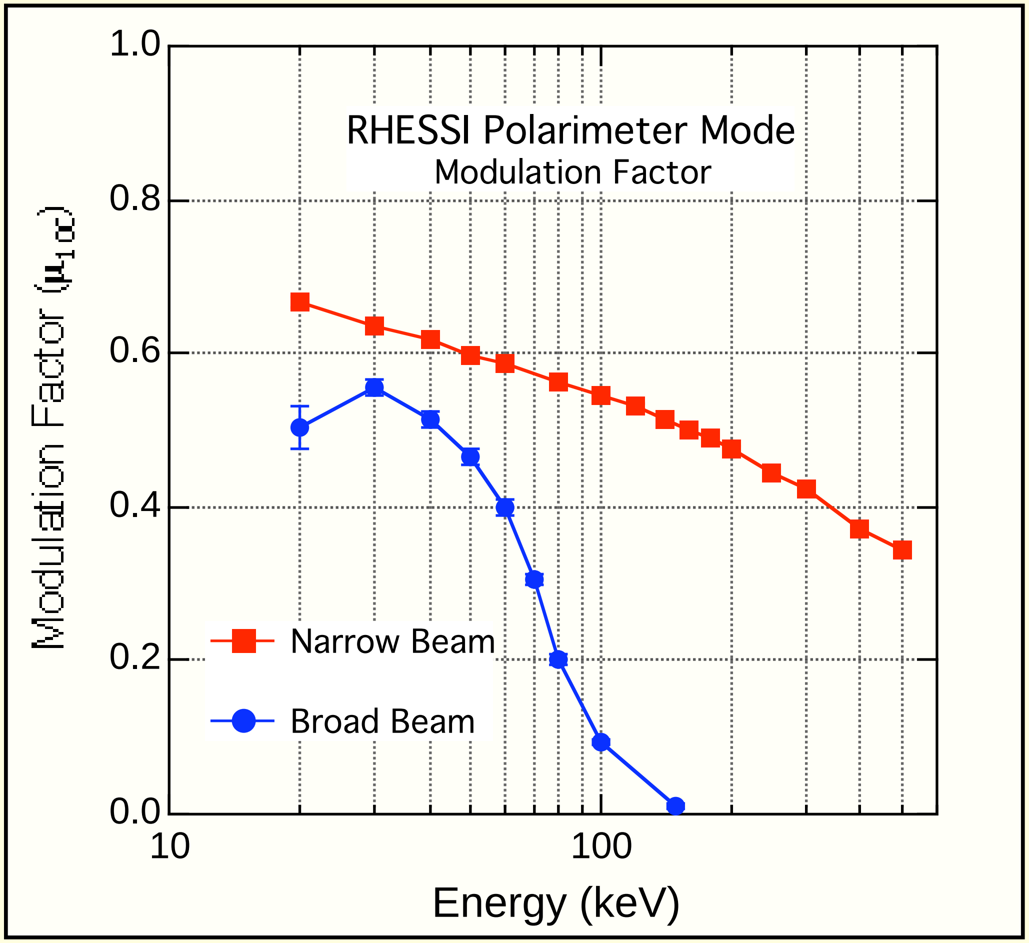
Polarimeter Mode – Effective Area



The effective area is defined for both a narrow beam and a broad beam.

The broad beam simulation incorporates the effects of scattering of solar flux into the rear Ge segments, which leads to an increase in effective area at higher energies .

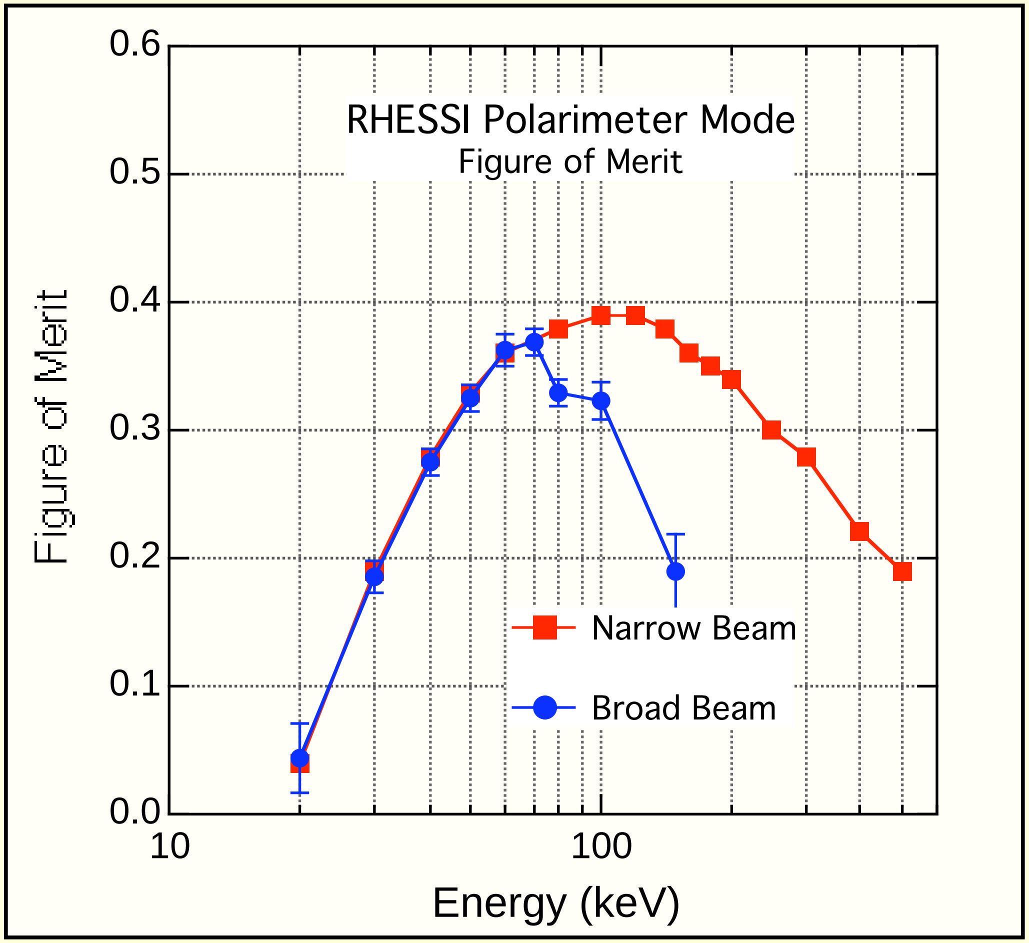
Polarimeter Mode – Modulation Factor



The modulation factor is a measure of the quality of the polarization signal.

Scattering of incident solar flux reduces the quality of the polarization signal. (The scattered flux is not modulated.)

Polarimeter Mode – Figure of Merit

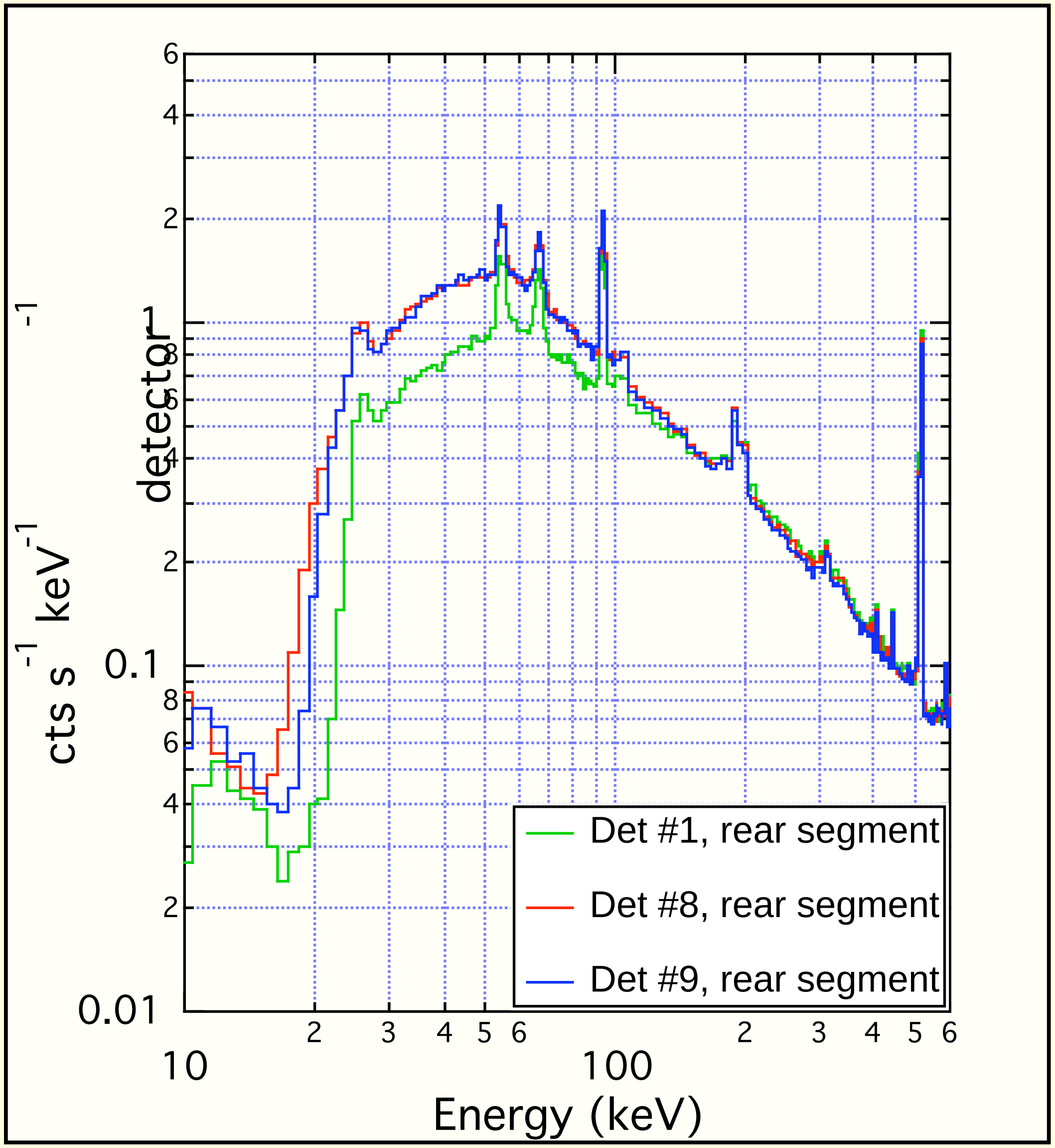


The figure-of-merit is a measure of the intrinsic capability to measure polarization.

Here, it is defined as the product of (effective area)$^{1/2}$ and the modulation factor.

As defined here, it does not incorporate the effects of detector background.

Ambient (Non-Flare) Background



Sample background spectra for rear segments.

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

HESSI Sensitivity to Solar Flare Polarization

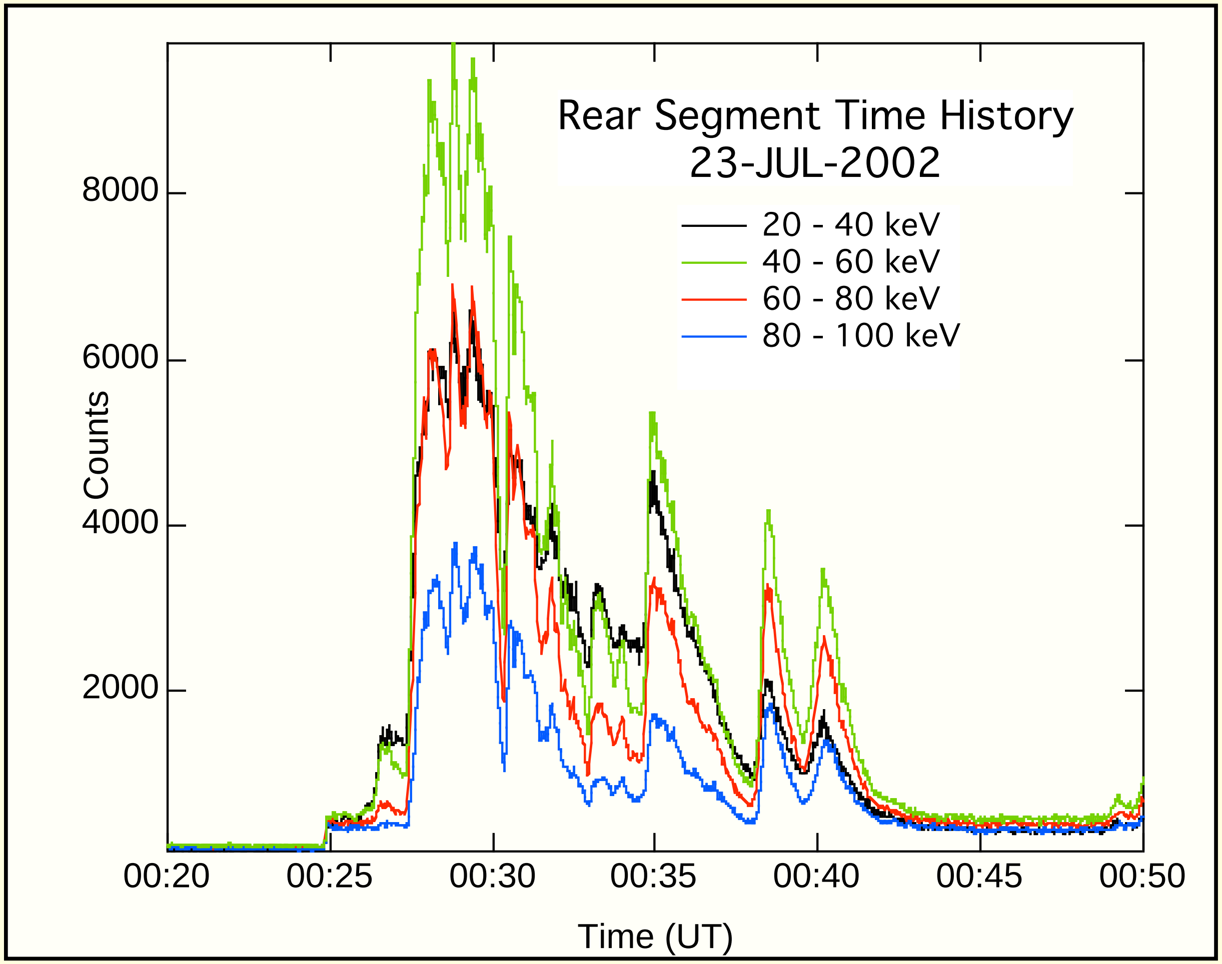
Minimum Detectable Polarization (MDP)

	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%

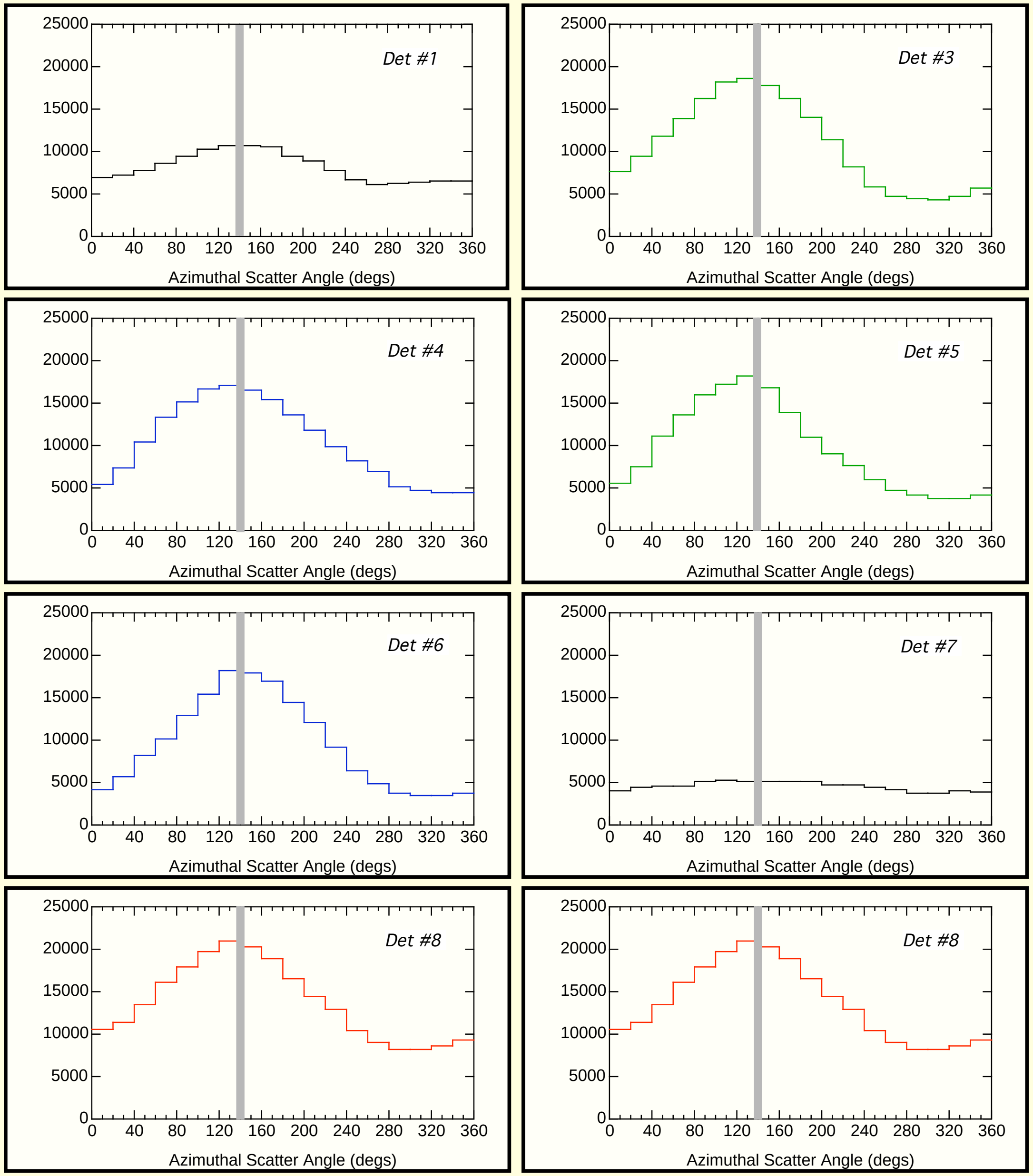
For M-class flares, sensitivity levels of 20-40% may still be achievable in the lowest energy bands.

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.



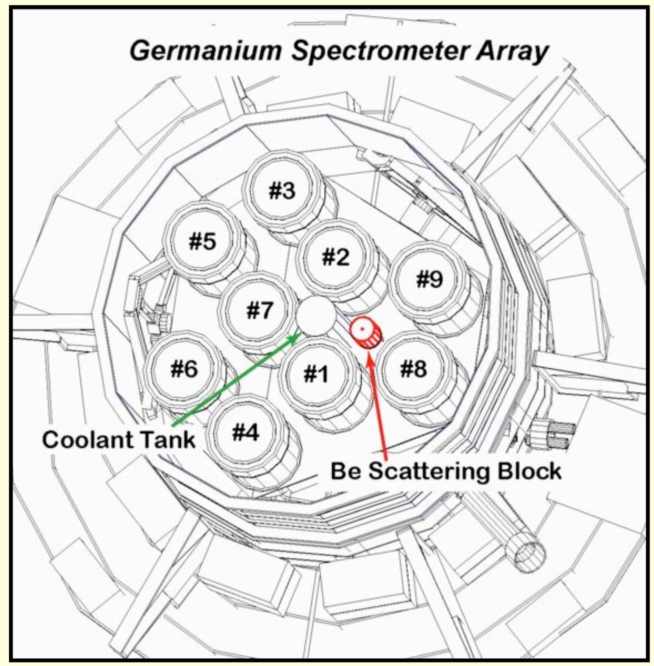
Nature of the RHESSI Data



Rear Segment Data
(20 – 40 keV)

X4.8 Flare - 23 July 2002

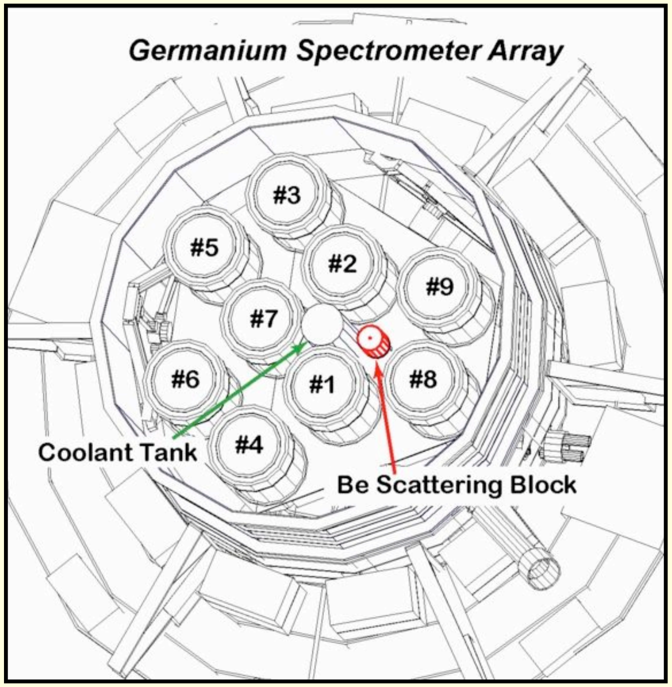
00:26 – 00:42 UT



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.

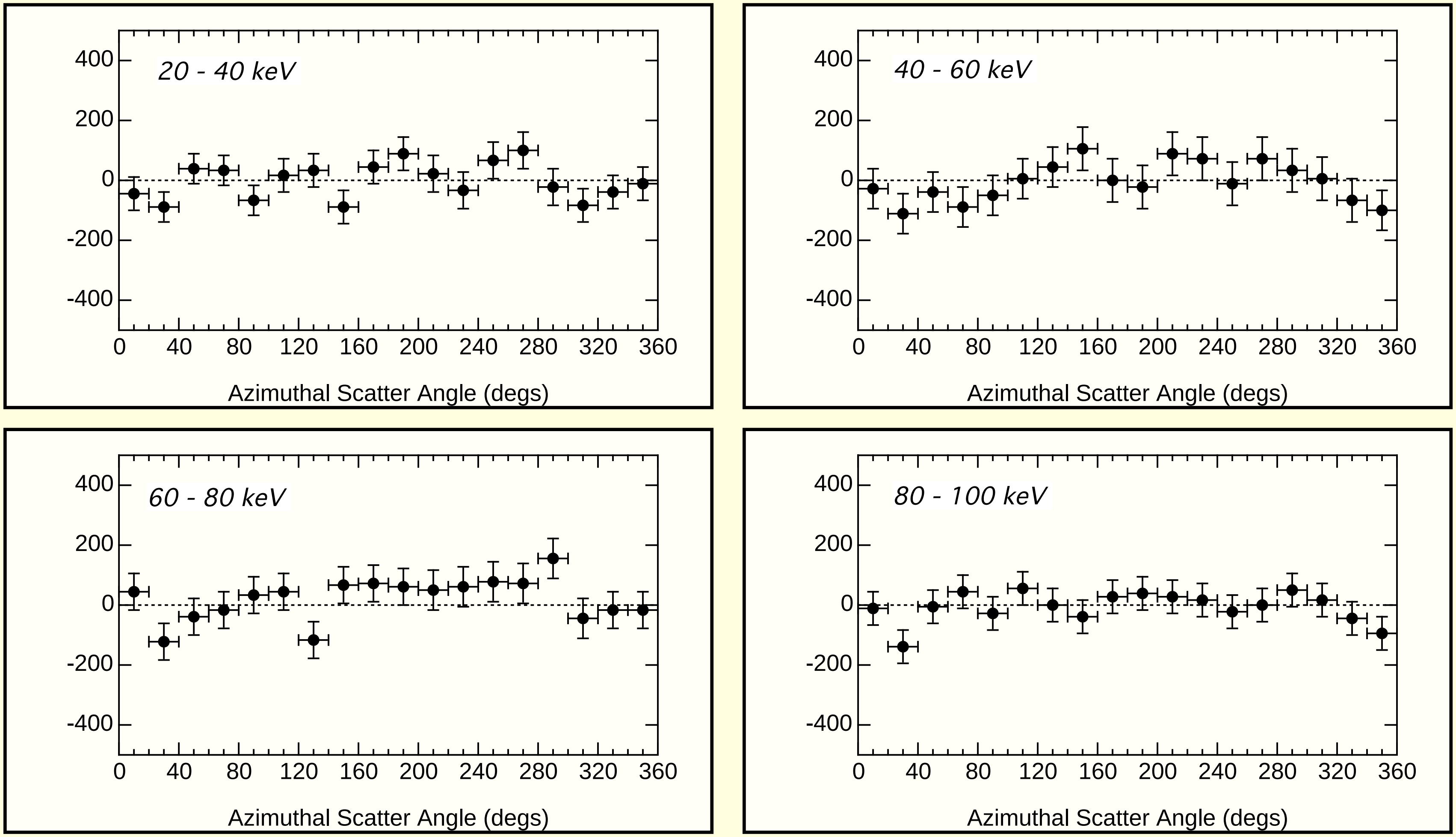


***Limitations* :**

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

"Background" Subtracted Data

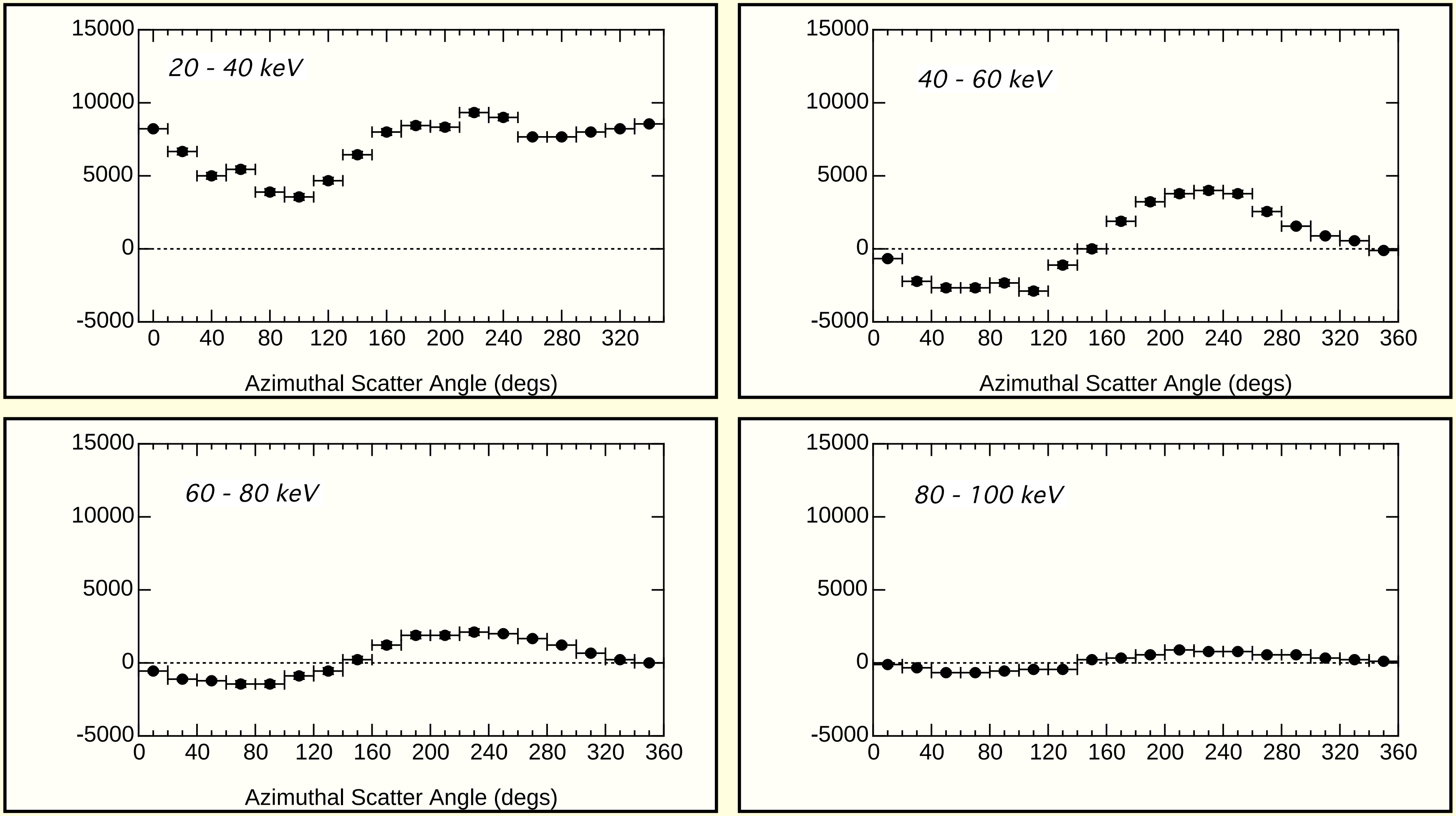
Non-Flare Interval, 17-Jul-2002, 17:32 - 17:45 UT



Normalization factors correct for relative detector efficiencies.

“Background” Subtracted Data

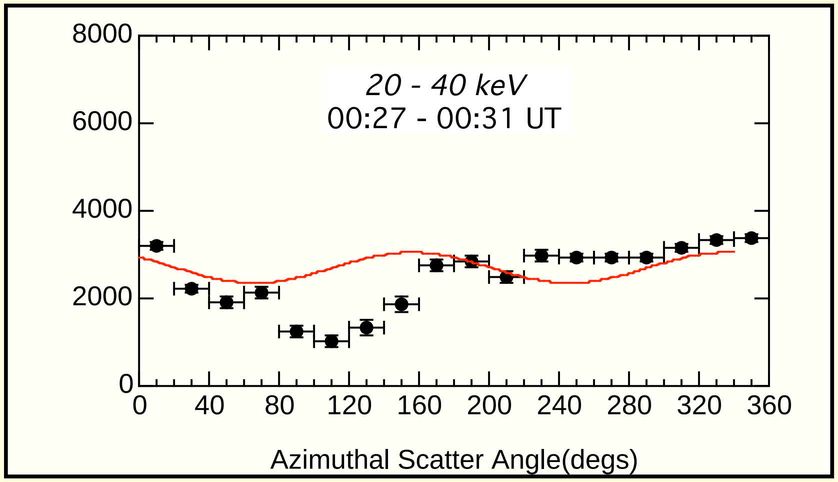
X4.8 Flare, 23 July 2002, 00:26 - 00:42 UT



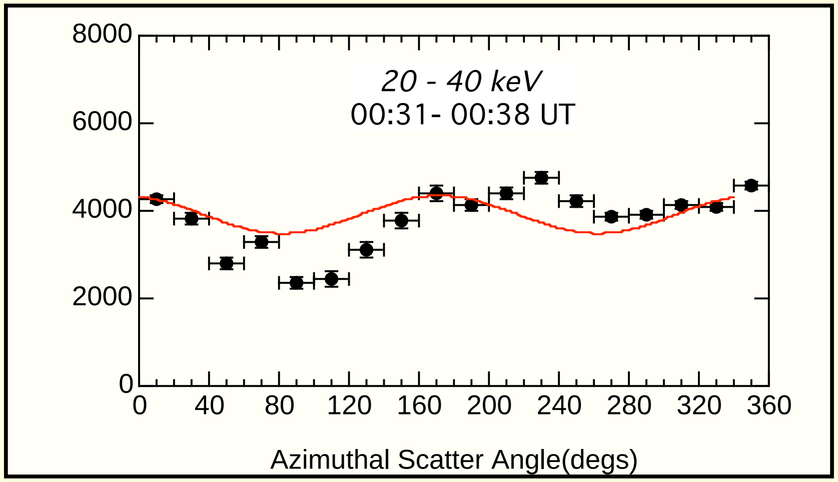
Systematic effects still need to be understood.

First Results

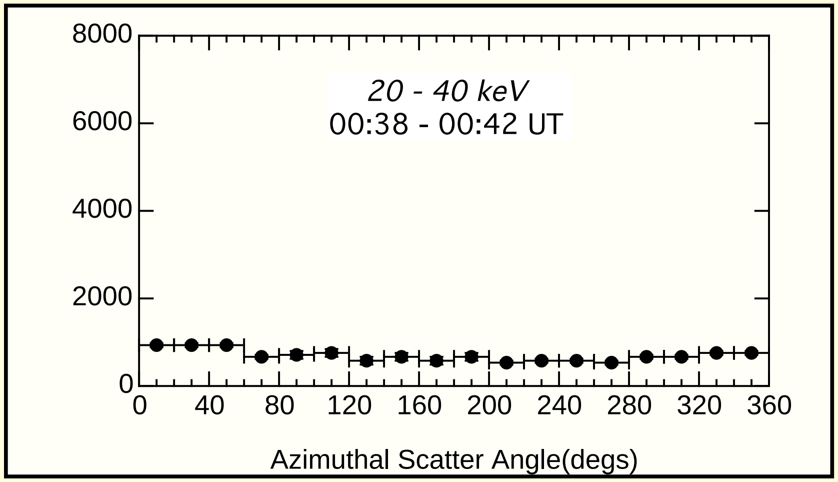
23 July 2002 : 20-40 keV



R (20-40 keV) ≈ R (40-60 keV)



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



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

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.
- First preliminary results are inconclusive. More work needed.

Work in progress:

1. Extension of current analysis to cover more events.
2. Incorporate simulation of Earth-scattered flux.
3. Expand the analysis to include all relevant detectors.
4. Investigation of polarization sensitivity for non-solar sources (gamma-ray bursts and the Crab pulsar).