Recent Laboratory Tests of a Hard X-Ray Solar Flare Polarimeter

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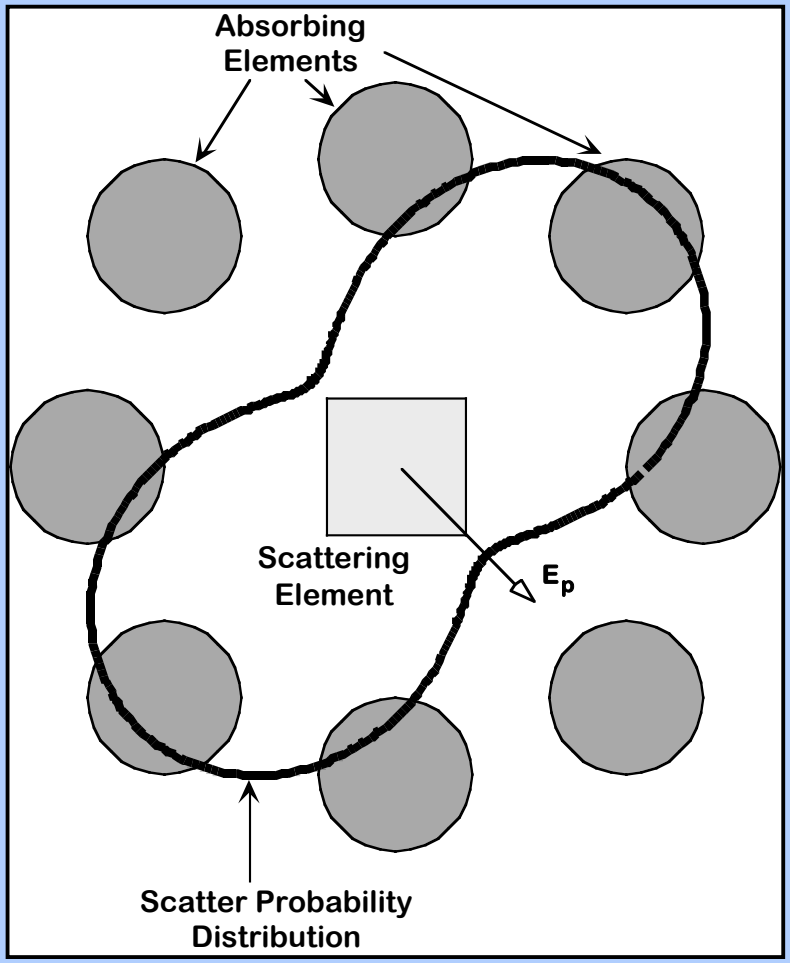
Polarization of Solar Flare Hard X-Rays

- **The hard X-ray continuum from solar flares results from electron bremsstrahlung emission, which is intrinsically polarized.**
- **Polarization measurements at 50-300 keV will provide information on the beaming of the accelerated electrons.**
- **Models typically predict polarization levels of up to ~10%.**
- **To date, polarization measurements have all been made at energies below ~30 keV, with generally inconsistent results.**
- **Measurements above ~100 keV will be required to avoid contamination by thermal X-rays.**

Compton Scatter Polarimetry

At hard X-ray energies (100 – 300 keV), a Compton-scattered photon tends to be ejected at right angles to the incident polarization vector.



A Compton scatter polarimeter consists of two basic components:

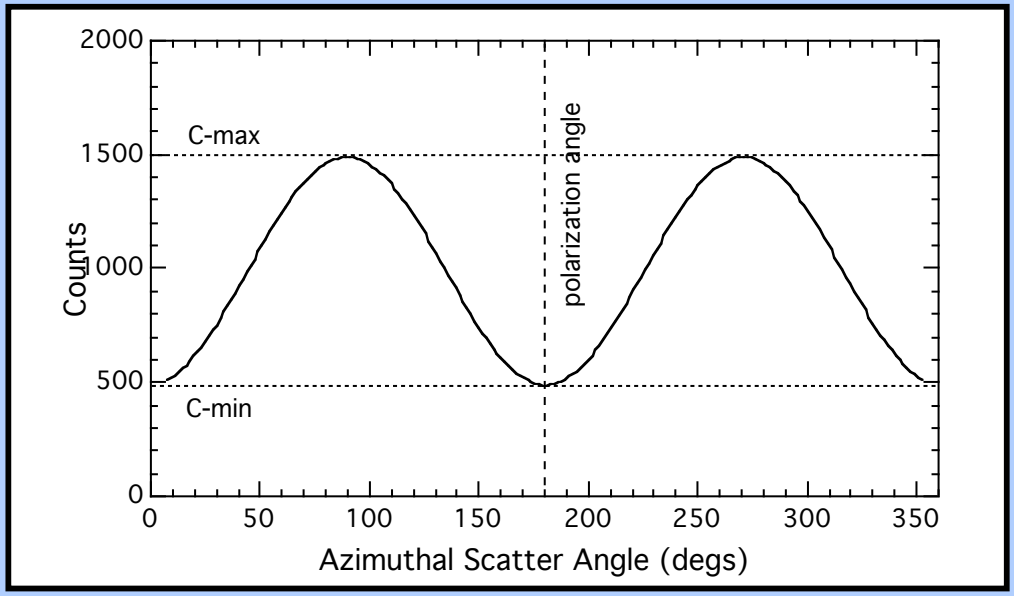
1) low-Z scattering detector(s) to provide Compton scattering medium

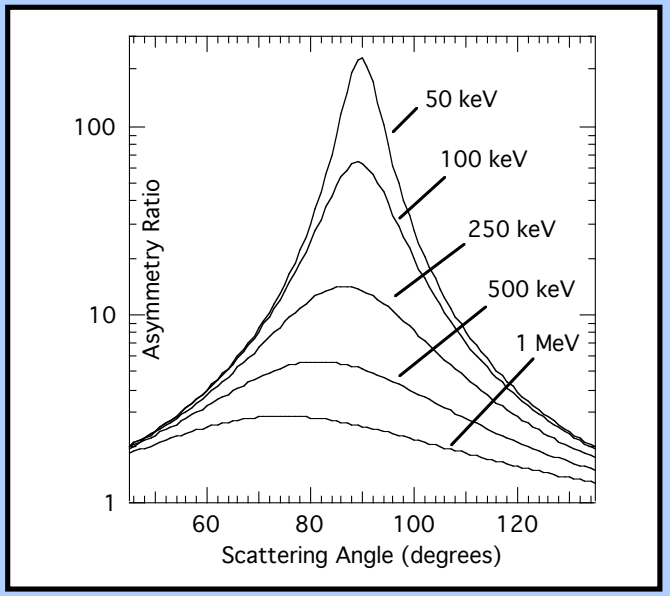
2) high-Z calorimeter detector(s) to absorb the scattered photon

The Polarization Signal

A Compton scatter polarimeter measures the angular distribution of the scattered photons in a plane which is perpendicular to the incident flux.

The asymmetry of this *azimuthal scatter angle distribution* can be exploited to measure the linear polarization of the incident flux.





The Polarization Measurement

An important figure-of-merit for a polarimeter is the polarization modulation factor. For 100% polarization, we define (via simulations),

$$\mu_{100} = \frac{C_{max}(100\%) - C_{min}(100\%)}{C_{max}(100\%) + C_{min}(100\%)}$$

In a real measurement, we compute the polarization (P) by comparing the measured scatter angle distribution with that expected for 100% polarization:

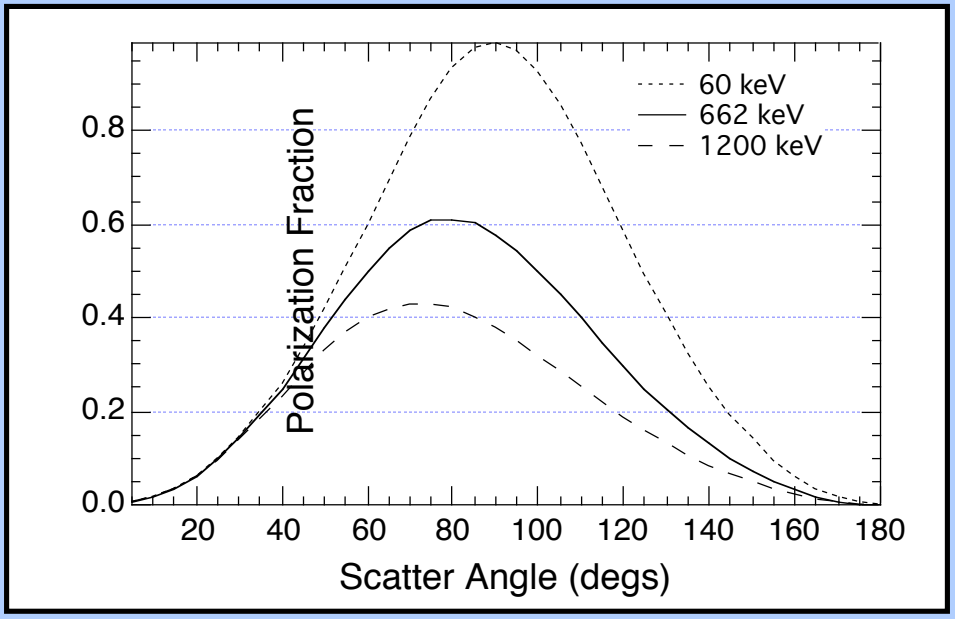
$$P = \frac{\mu_P}{\mu_{100}} = \left(\frac{1}{\mu_{100}}\right)\left(\frac{C_{max}(P) - C_{min}(P)}{C_{max}(P) + C_{min}(P)}\right)$$

where μ_{100} represents the modulation for the 100% polarization case and μ_P represents that of the measurement.

Generating a Polarized Beam

Polarized X-rays can be generated in the lab by Compton scattering photons from a -ray calibration source within a block of plastic scintillator.

A signal from the scintillator provides an electronic tag for each scattered photon, which can be used as a coincidence signal with the polarimeter.

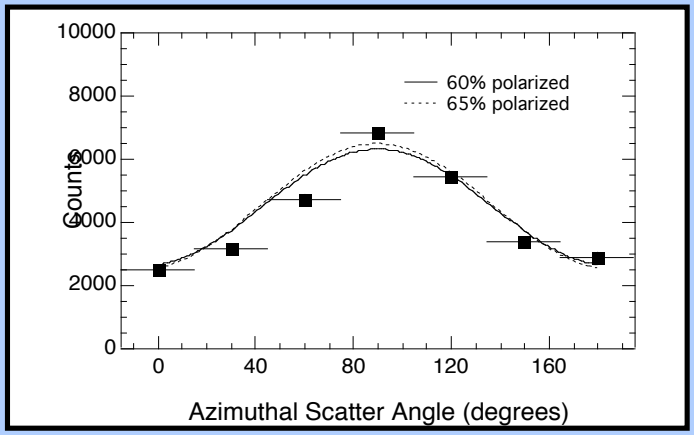


This graph shows the level of polarization that can be achieved for various input photon energies (corresponing to ^{241}Am, ^{137}Cs and ^{60}Co) and various scatter angles.

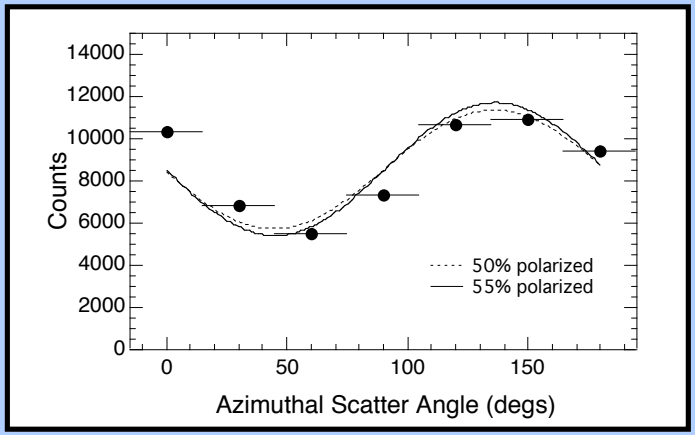
A 662 keV photon beam, scattered at 90°, is ~60% polarized; the scattered energy is 288 keV.

Laboratory Prototype

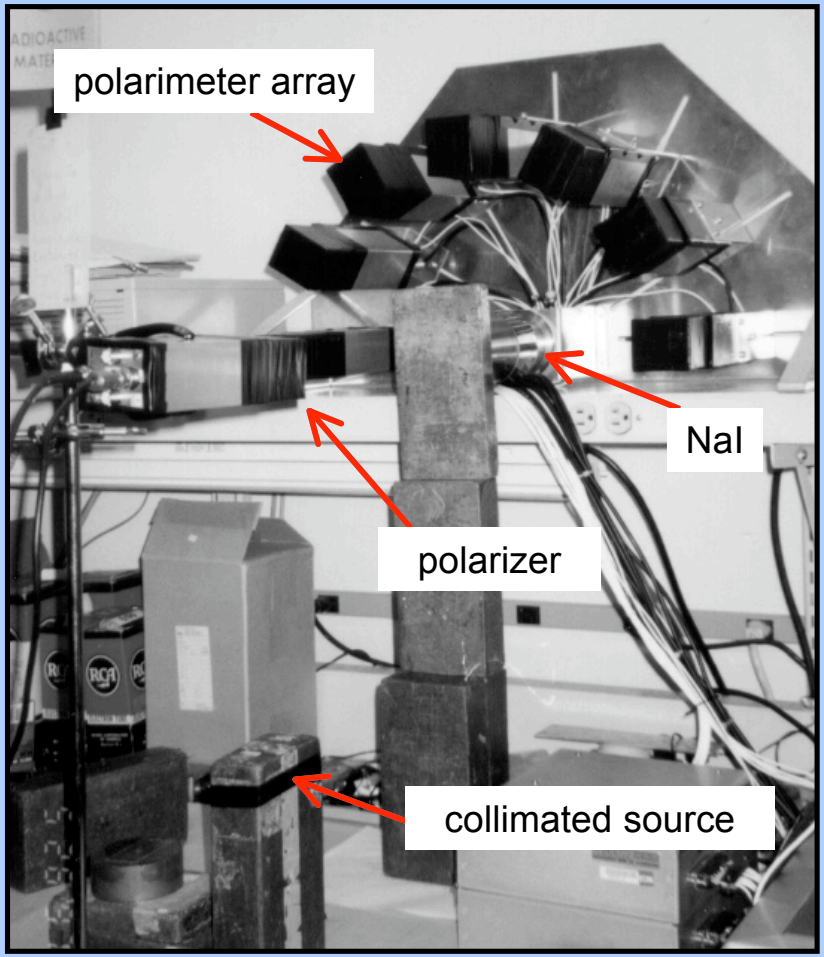
A simple laboratory prototype was used to demonstrate the basic principles and to validate our (GEANT-based) Monte Carlo simulations.



polarization angle ~ 0°



polarization angle ~ 45°



Design Considerations

Selection of Ideal Polarimeter Events **-**

- **Scatters only once in the plastic (no multiple scattering).**
- **Improves background rejection.**
- **Improves the modulation factor and the polarization sensitivity.**

Precise Determination of the Scatter Angle **-**

- **Requires precise measurement of interaction locations.**
- **Provides improved modulation factor and polarization sensitivity.**

Energy Resolution **-**

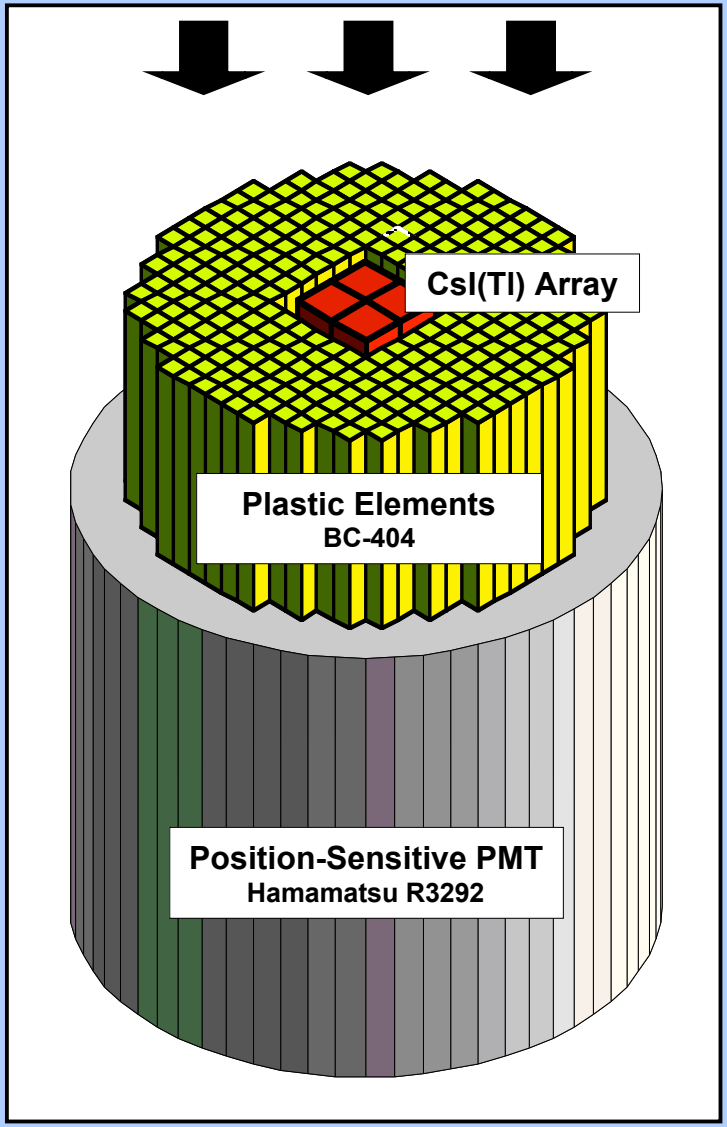
- **Less important (so far…)**

The Baseline SOLPOL Design

SOLar POLarimeter for Hard X-Rays

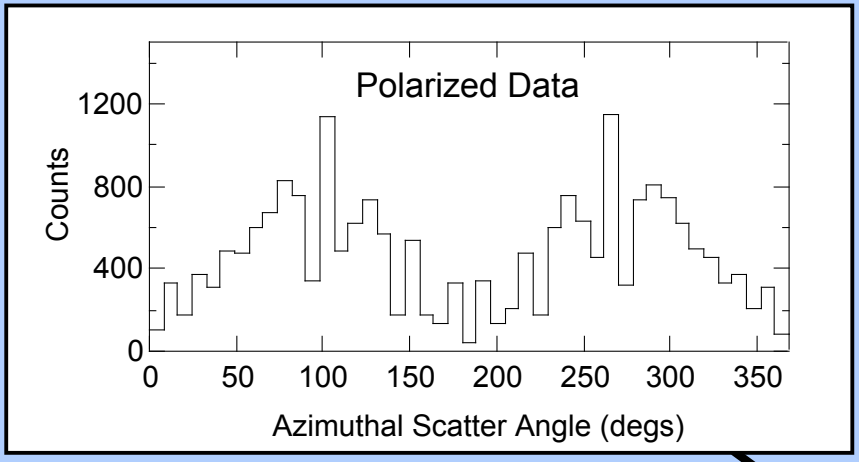
Plastic Scattering Elements:
- 280 element array of BC-404
- Each 5mm square by 5 cm long
- Readout provided a 5-inch PSPMT
- Hamamatsu R3292 PSMT

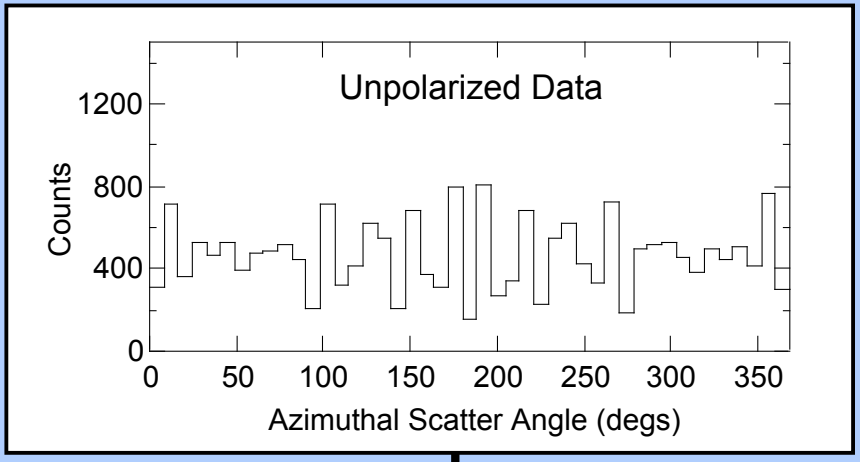
Calorimeter Elements:
- 4 element array of CsI(Tl)
- Each 1cm square by 5 cm long
- Readout provided by a MAPMT
- Hamamatsu R5900 MAPMT

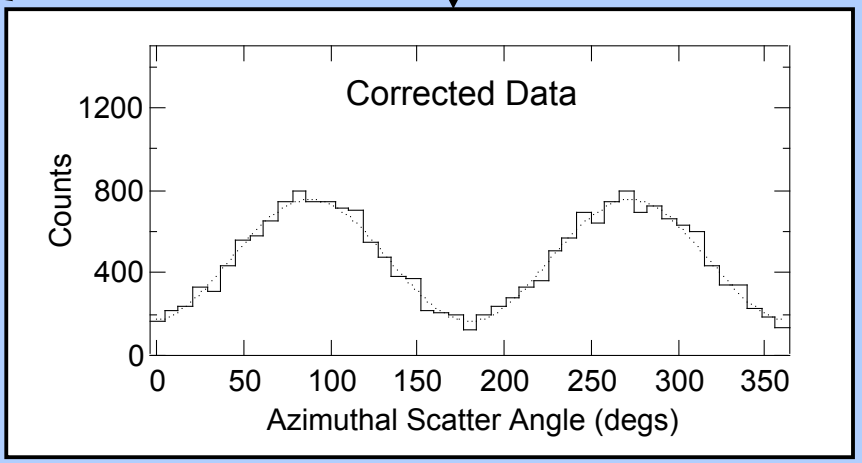


SOLPOL Polarimetric Response

Simulated Results for Monoenergetic On-Axis Beam at 150 keV



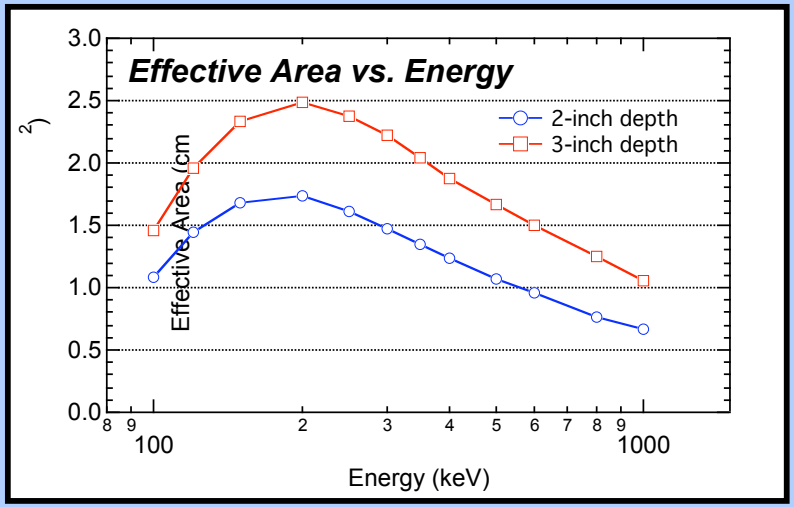


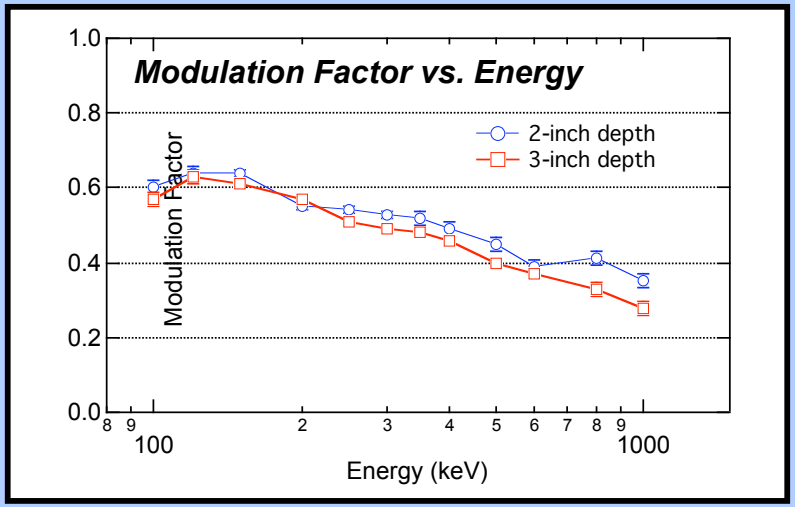


The simulated data for an unpolarized beam are used to correct for geometric effects and to extract the true modulation pattern from the data.

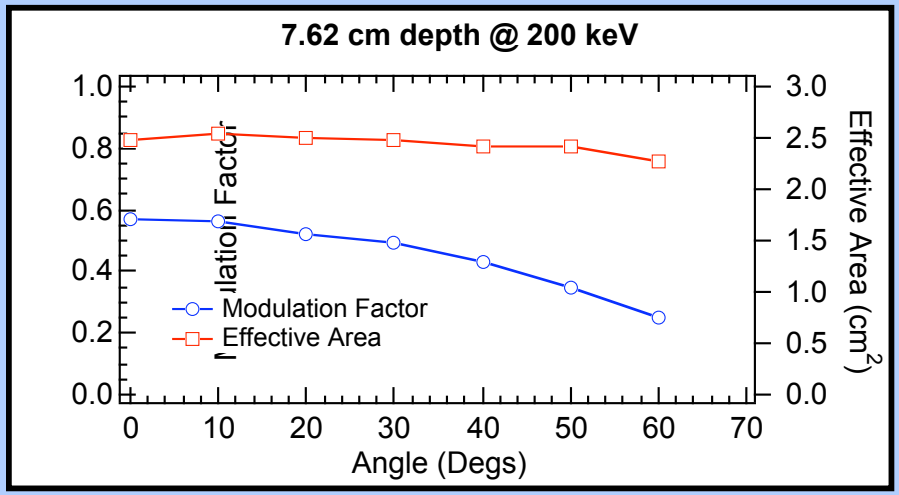
Simulated Performance

On-Axis Response



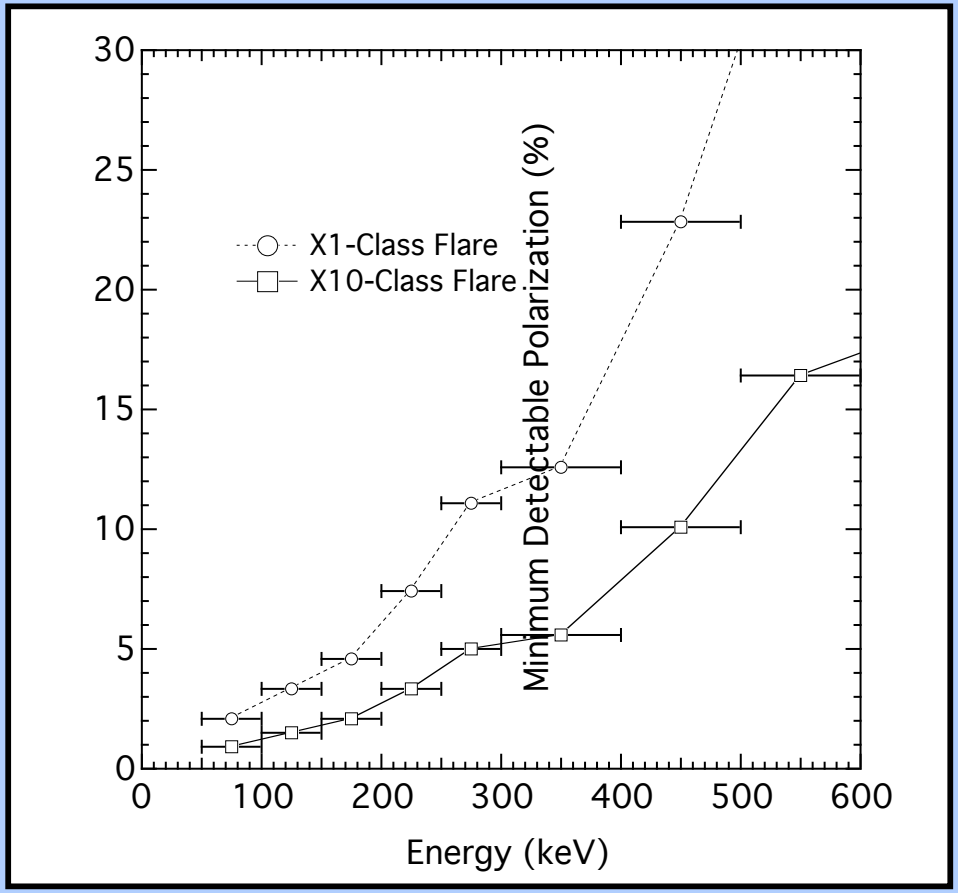


Off-Axis Response



Sensitivity to Solar Flare Emissions

An array of 4 modules would be provide a Minimum Detectable Polarization (MDP) of < 1% in the 50-300 keV energy range for all X-class flares.



This plot shows the sensitivity of a 16-element SOLPOL array, for several different energy bands.

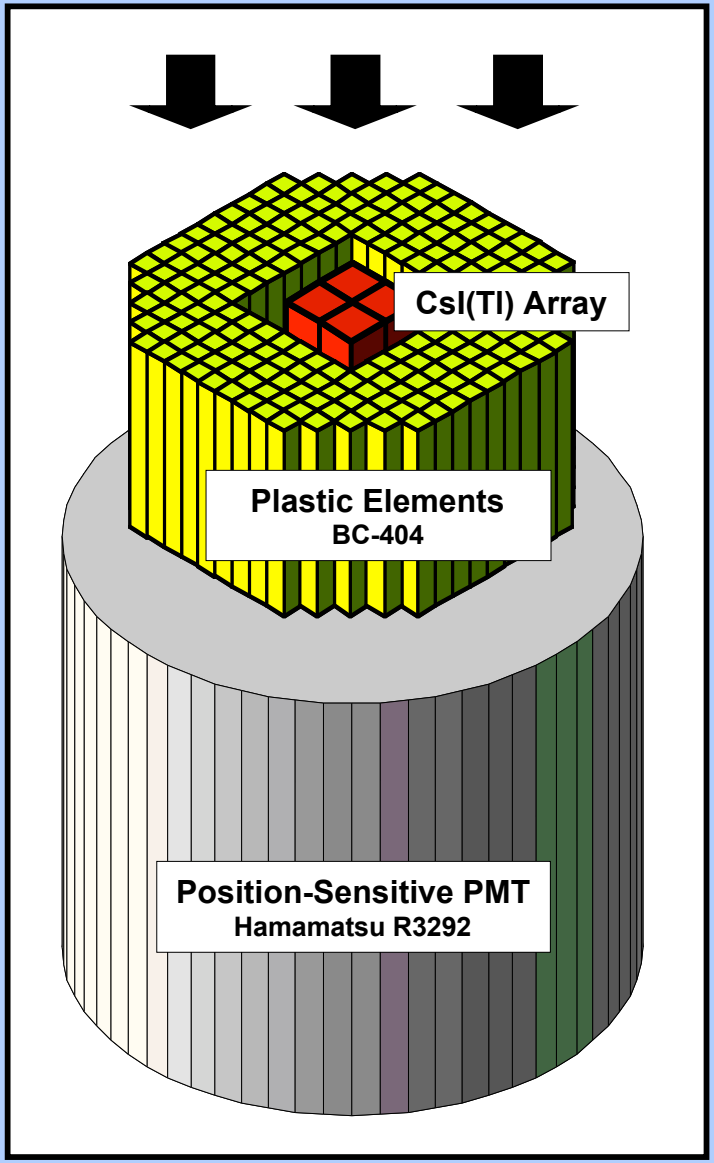
Shown are the sensitivity data for both an X1 and an X10 solar flare.

SOLPOL Science Model

Plastic Scattering Elements :
- 200 element array of BC-404
- Each element optically isolated
- Wrapped in Tyvek® and Kapton® tape
- Each 5mm square by 5 cm long
- Readout provided a 5-inch PSPMT
- Hamamatsu R3292 PSMT

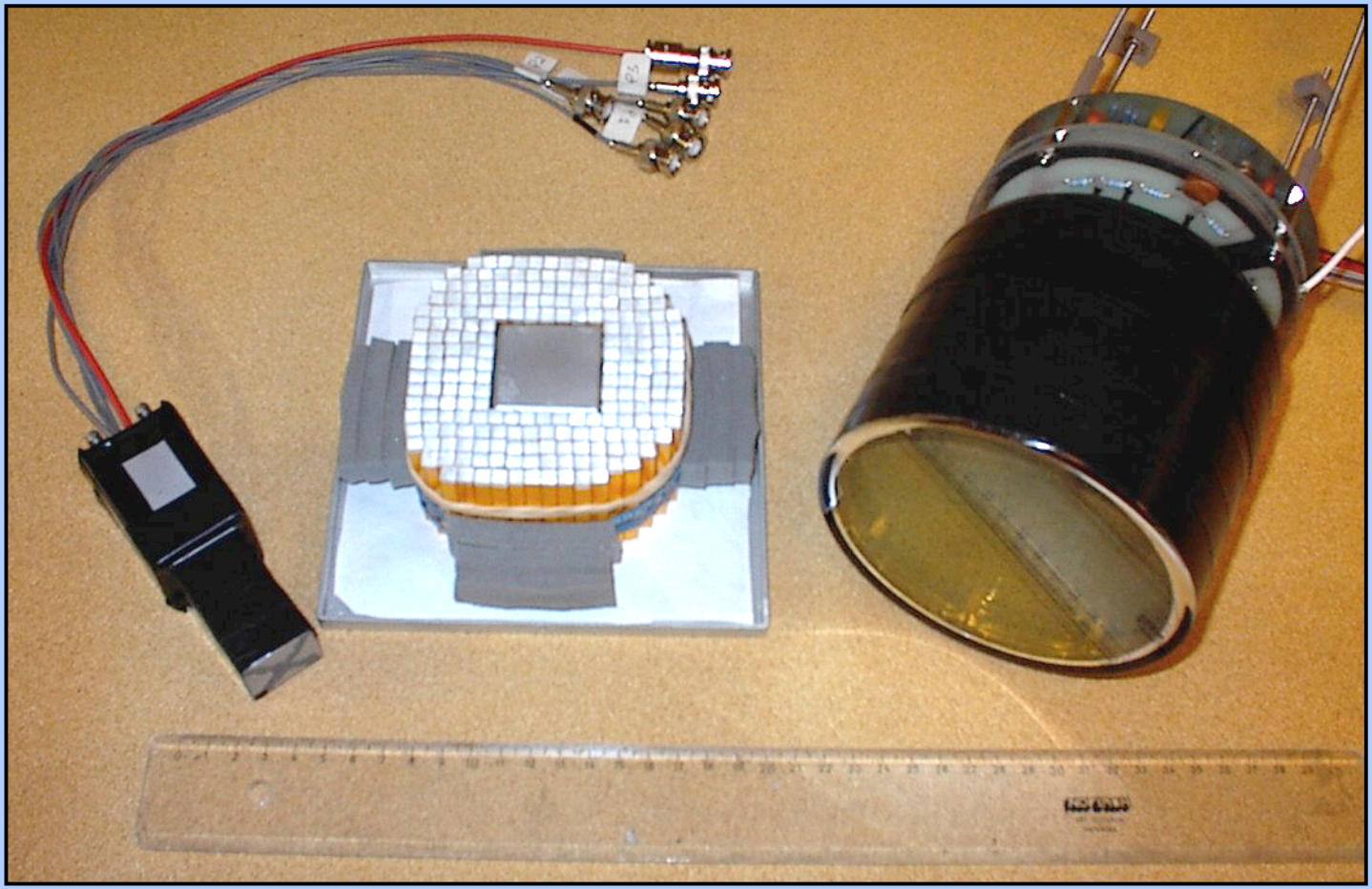
Calorimeter Elements :
- 4 element array of CsI(Tl)
- Each 1cm square by 5 cm long
- Readout provided by a MAPMT
- Hamamatsu R5900 MAPMT

PSPMT / Plastic Array Housing :
- 1mm thick aluminum
- Optically isolated from CsI/MAPMT



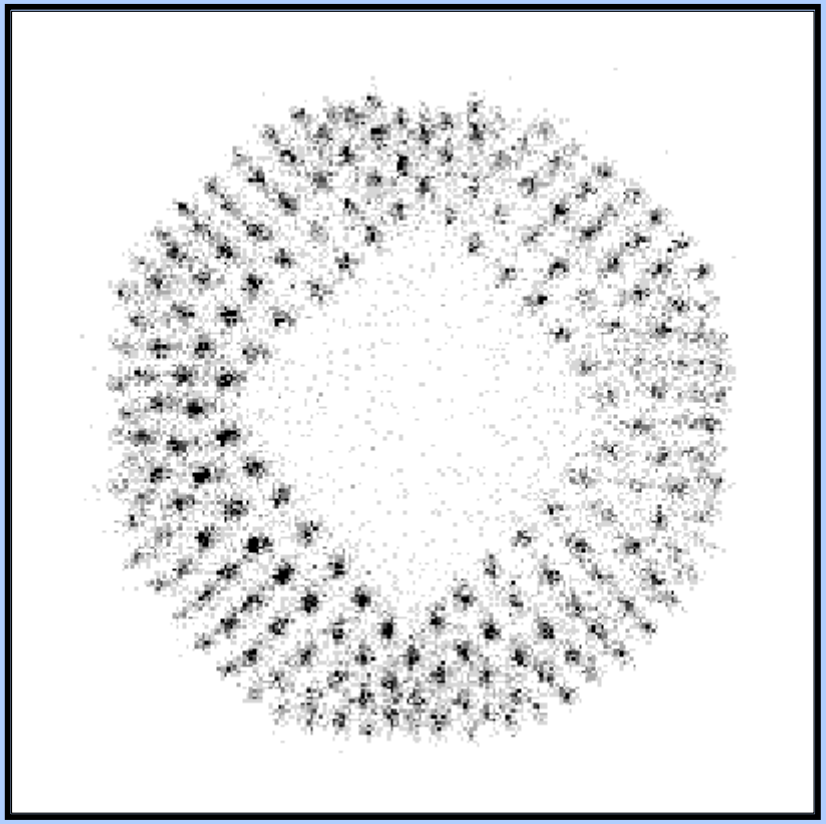
Science Model Components

This photo shows the MAPMT/CsI assembly, the array of plastic scattering elements and the 5-inch PSPMT.



Initial Results from Science Model

The spatial resolution in the PSPMT is sufficient to resolve the individual 5 mm plastic scattering elements.



Distribution of ^{137}Cs Events

This figure shows the spatial distribution of events in the plastic scintillator array.

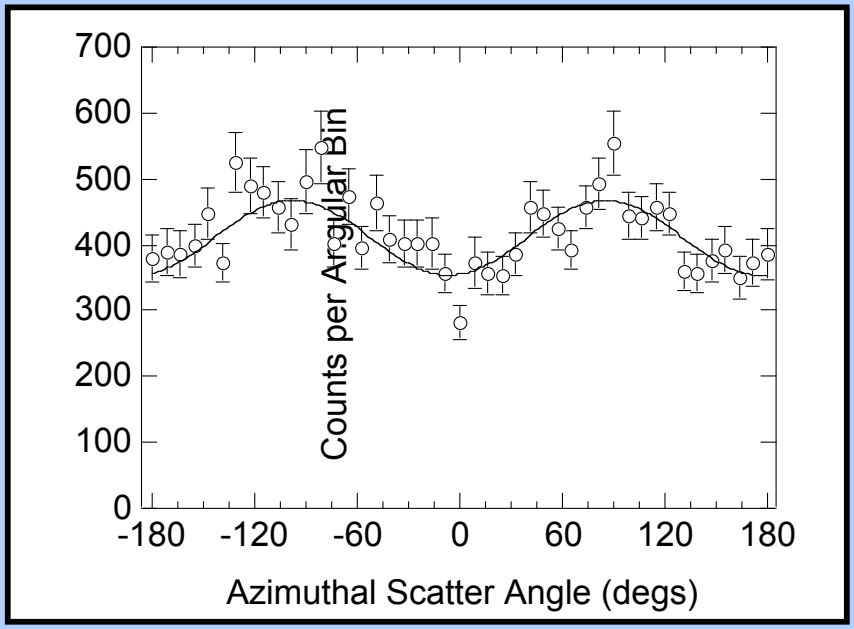
These are coincident events, representing photons that have scattered from one of the plastic elements into the central CsI array.

The individual plastic elements are clearly resolved, as is the square well for the central CsI array.

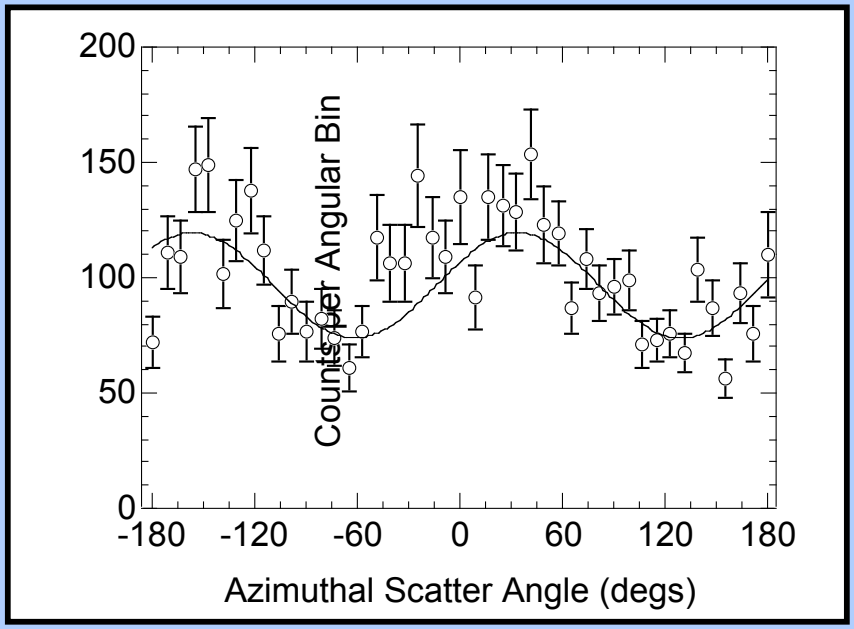
Initial Results from Science Model

Although limited in statistics, these results demonstrate the presence of a polarization signal. Further data will be required to evaluate the laboratory response of the science model.

polarization angle ~ 0°



polarization angle ~ 45°



Development Status

- ✔ We have developed a design for a compact polarimeter module that could be adapted to a variety of configurations.
- ✔ Initial testing of the new polarimeter design has so far yielded encouraging results.
- ✔ More complete testing of the science model will be performed once a replacement MAPMT is received.
- ✔ Long-term goal will be to develop a balloon payload based on this concept.
- ✔ This design could be used in an imaging polarimeter based on rotating modulation collimators. This could provide arc-second spatial resolution for spatially resolved polarization measurements.