GRB Polarization with RHESSI

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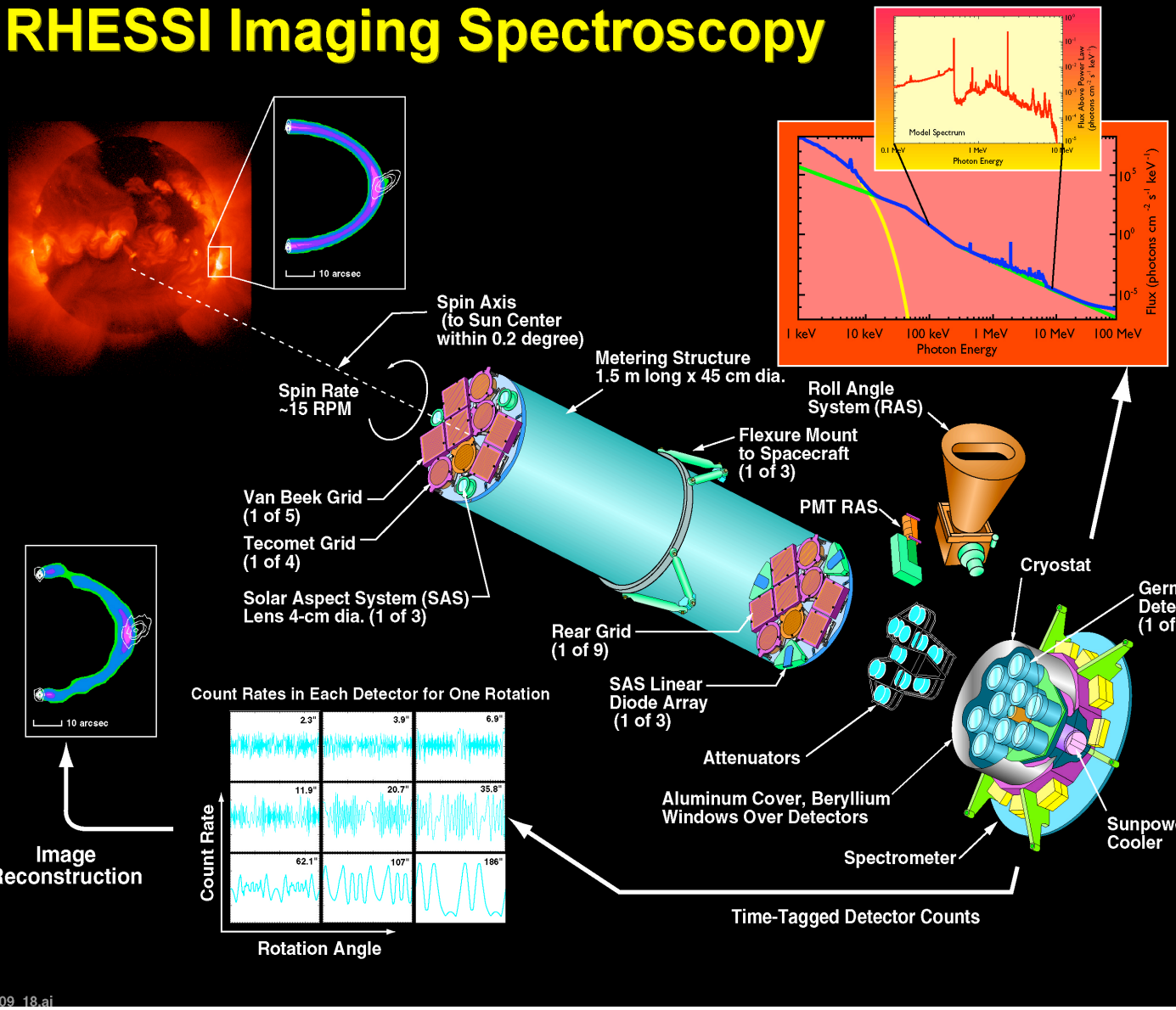
RHESSI Imaging Spectroscopy



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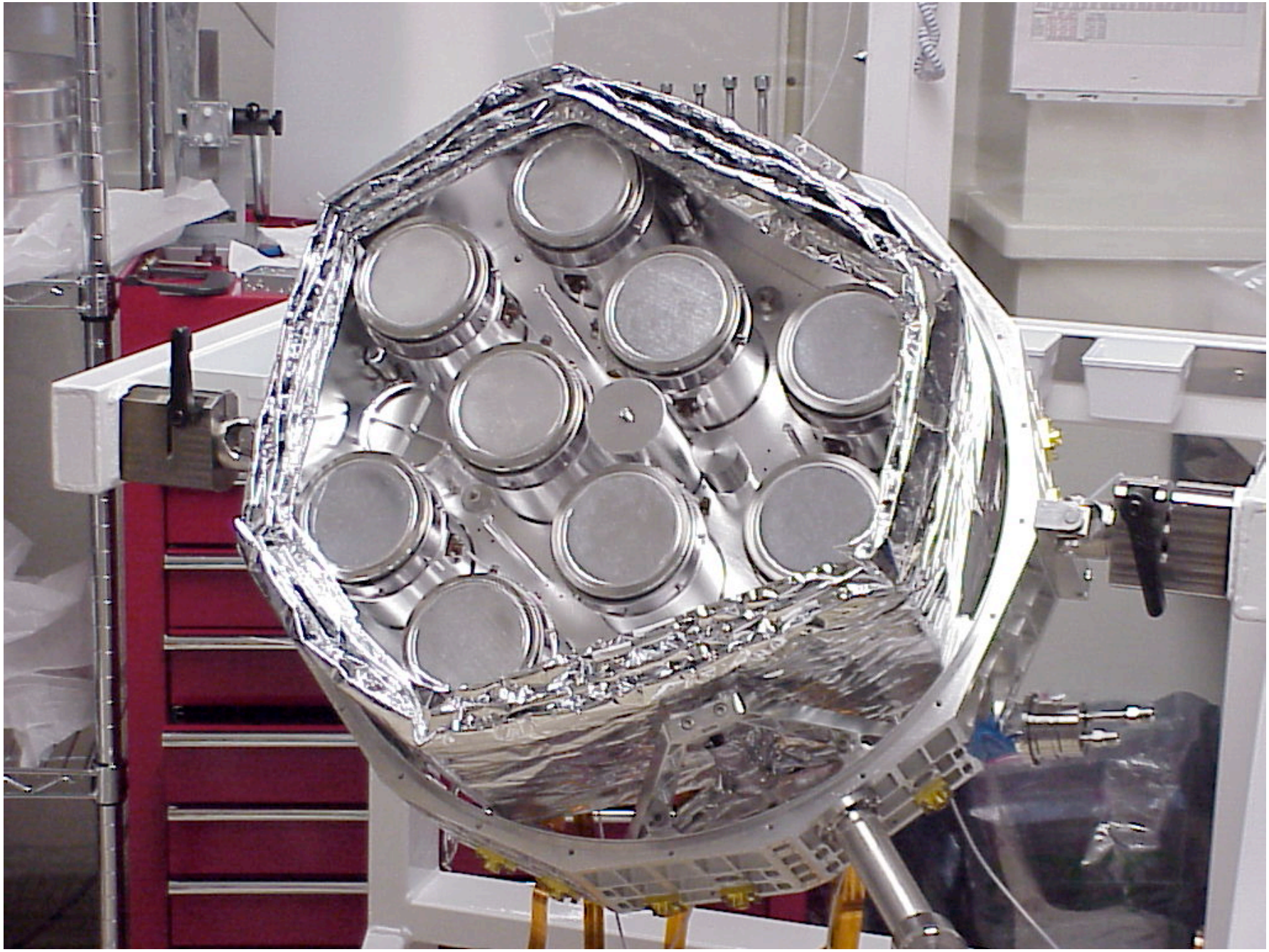
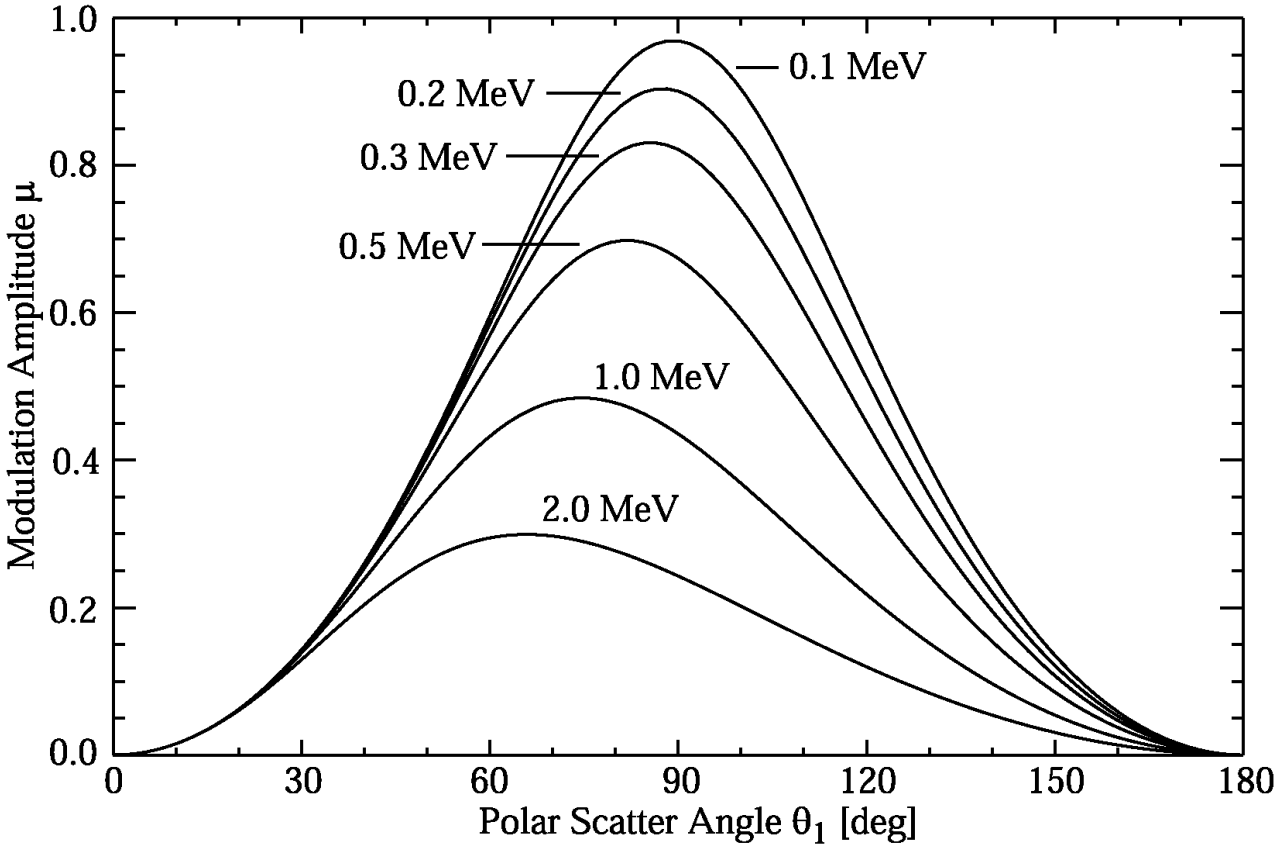


Compton Scattering Modulation, 100% Polarization

$$\mu = \frac{d\sigma_{\perp} - d\sigma_{\parallel}}{d\sigma_{\perp} + d\sigma_{\parallel}}$$

Klein-Nishina Differential Cross Section

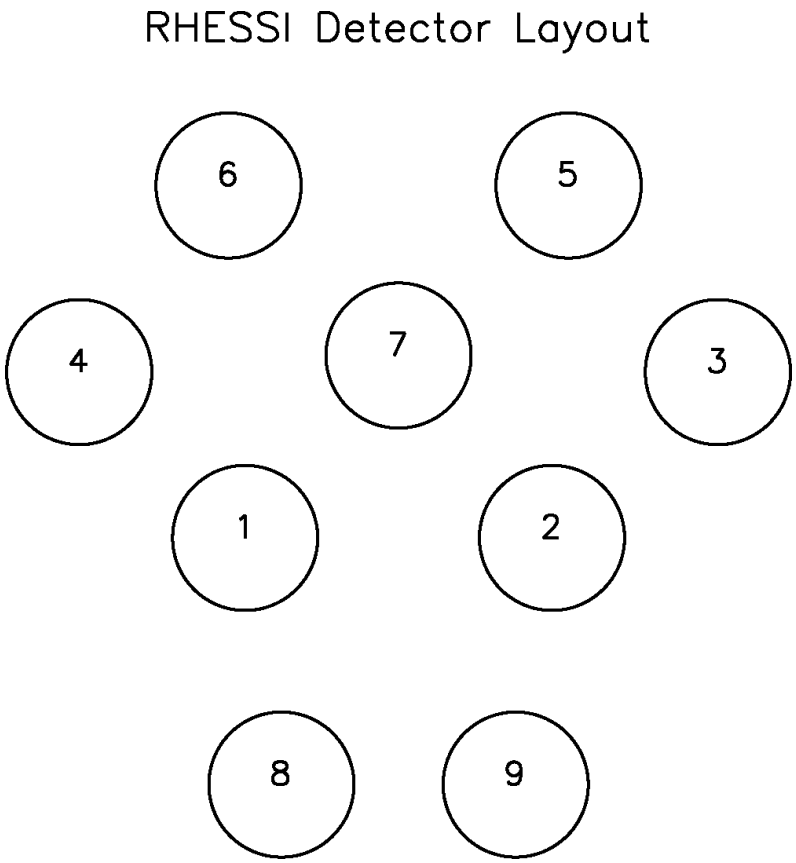


Highly modulated at large angles.

RHESSI as a γ-Ray Polarimeter

Not optimal, but most powerful yet:

- ~20 cm^2 effective area to scatters
- large modulation factor, μ_m~0.2
- 4-s rotation – many angles measured, systematics smooth out in _ rotation (more like 1/6 rotation).
- all-sky for GRBs
- detectors loosely grouped – decreases modulations by only 5%
- every interaction is sent to the ground, but *no coincidence flag*



Scatter Angle Distribution

Count rate S and fractional polarization Π_s:

$$\frac{dS}{d\phi} = \left(\frac{S}{2\pi}\right)\left[1 - \mu_m \Pi_s \cos\left(2\left(\phi - \eta\right)\right)\right]$$

- ϕ = scatter angle (relative to sky!)
- η = angle of polarization vector
- μ_m = instrument modulation factor
- 2ϕ repeats every 180

Measured amplitude A_m, binned:

$$\Pi_s = \frac{A_m}{\left(\frac{S}{N_{bin}}\right)\mu_m}$$

- A_m, S/N_{bin} measured
- μ_m modulation expected for 100% polarization

(Novick 1975, Lei, Dean & Hills 1997)

GRB021206

RHESSI, IPN Observations

25-200 keV fluence:

1.6×10^{-4} erg cm^{-2}

Peak flux:

2.9×10^{-5} erg cm^{-2} s^{-1}

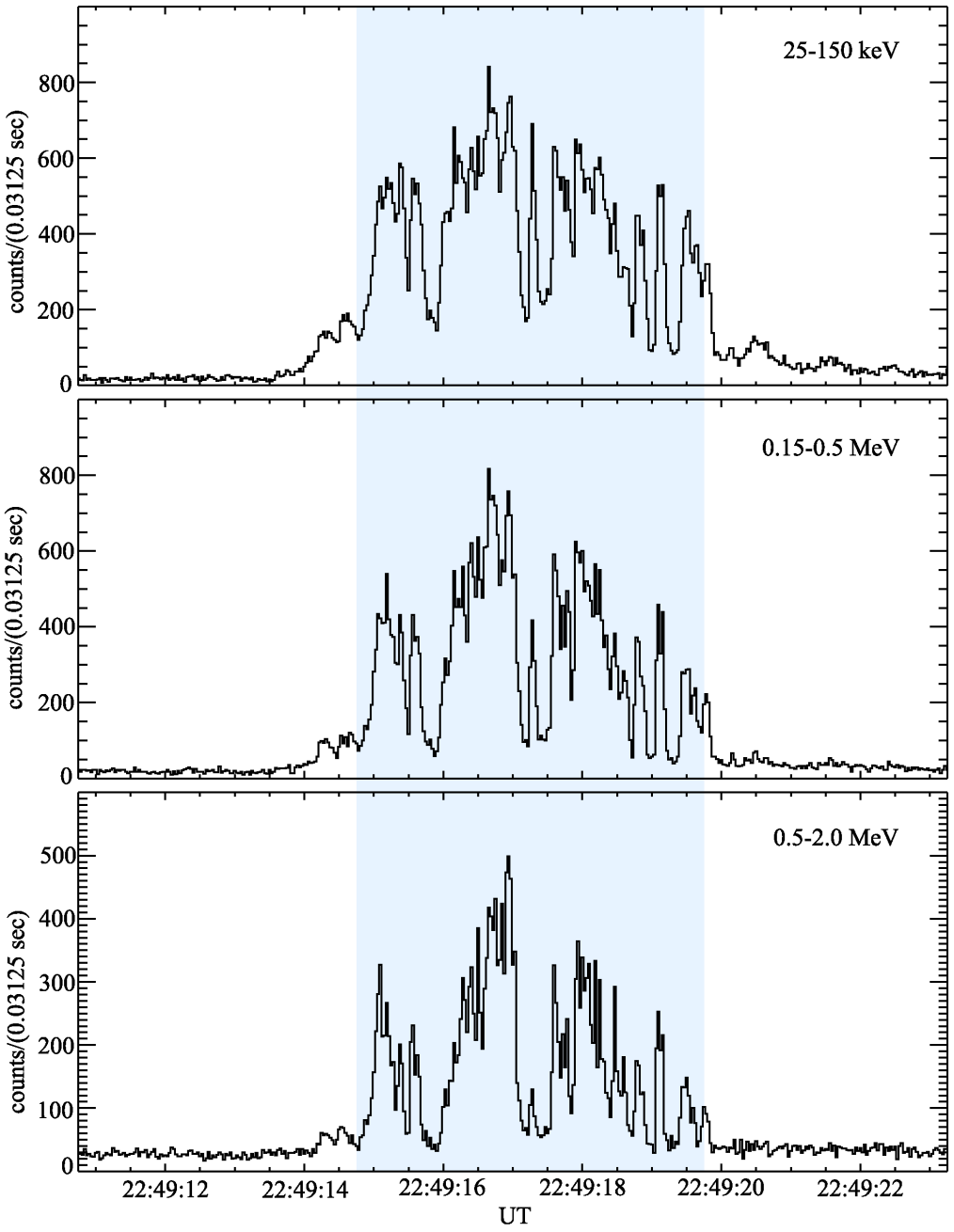
Localized:

18° off-solar

Polarization:

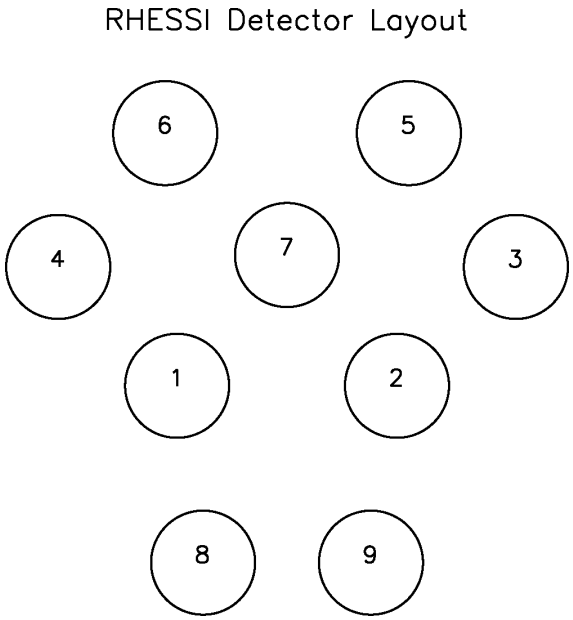
Statistics are here….

(Coburn & Boggs, 2003
Nature 432:415.)

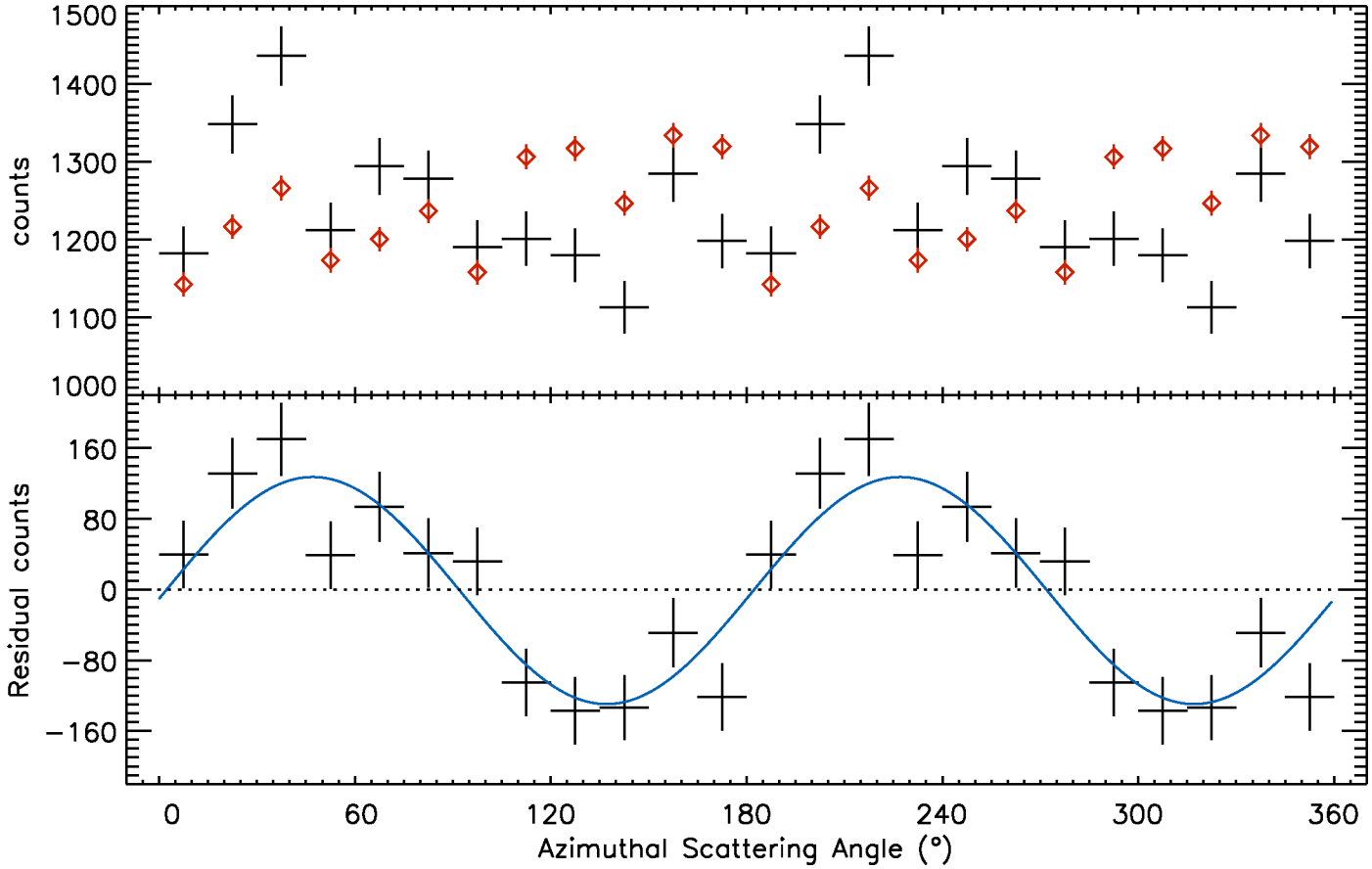


Polarization Analysis

- Independent analyses run in parallel
- Identify coincident 2-detector events (more in a minute)
- Energy cuts: > 30 keV in each detector, 0.15-2.0 MeV total
- Scatter angle from direction between detector-detector centers
- Correct each scatter for spacecraft rotation
- Histogram number counts vs. scatter angle



Measured Scatter Angle Distribution



Top: 5-s peak, corrected for spin; expected for nonpolarized GRB

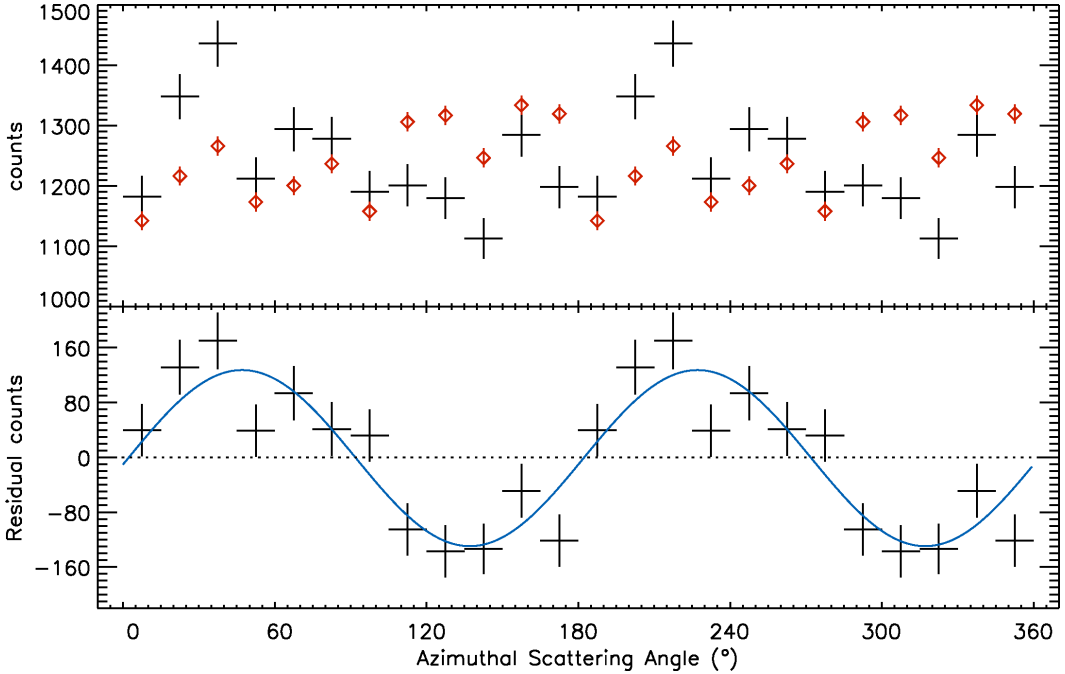
Bottom: residual; best-fit modulation

Correcting for the GRB Lightcurve: Monte Carlo Simulations

Procedure:

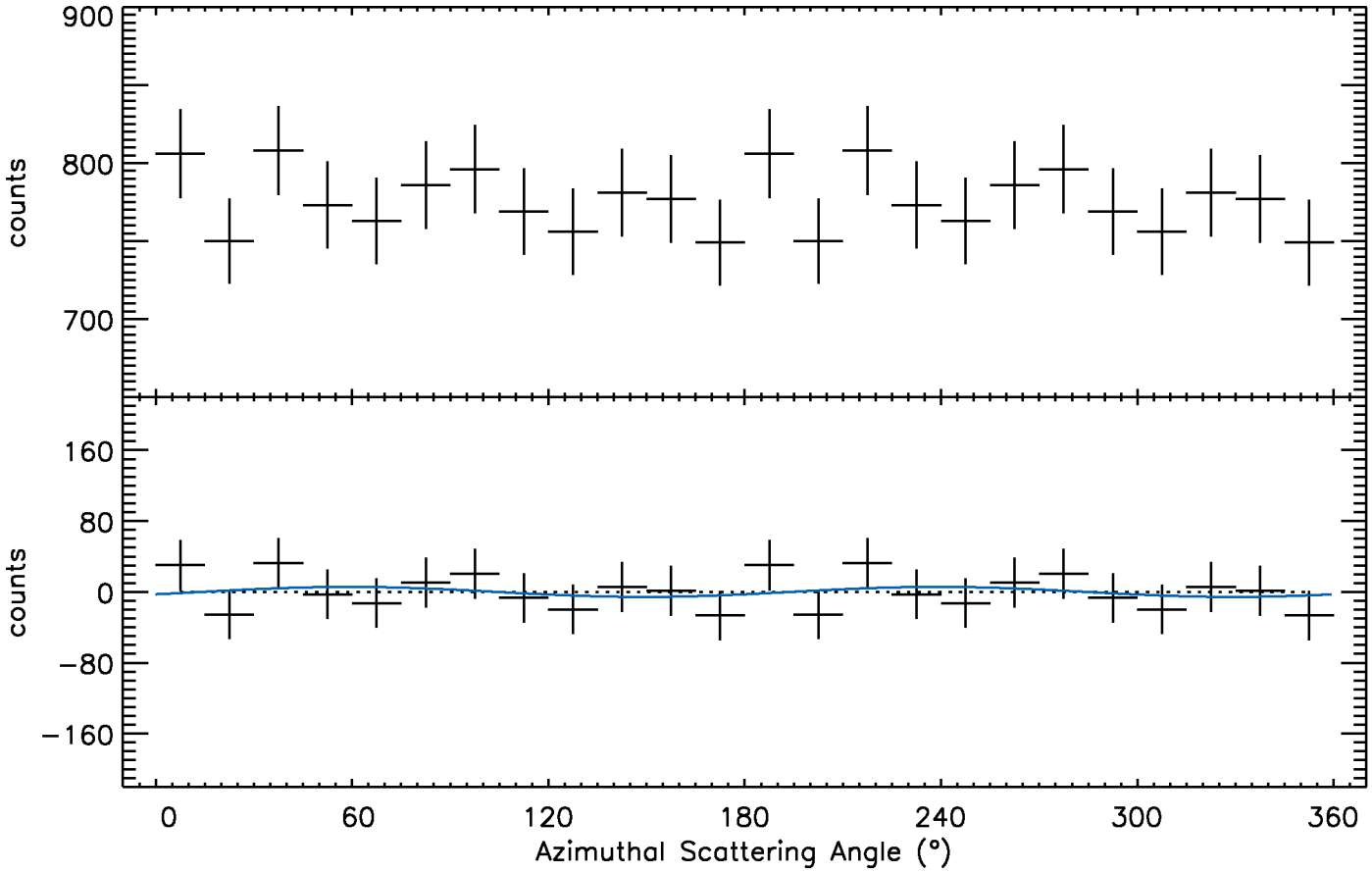
- RHESSI mass model developed under CERN GEANT package
- Measured single-event lightcurve (0.15-2.0 MeV) as template
- Used the average GRB spectrum as measured by RHESSI
- Source position provided by IPN
- Assumed an unpolarized source
- Ran 18×10^9 photons through the mass model
- Selected det/det events with same cuts as for the real data
- Binned to produce expected scatter-angle distribution for an unpolarized source
- Independent analysis was run in parallel for a sanity check

Polarization?



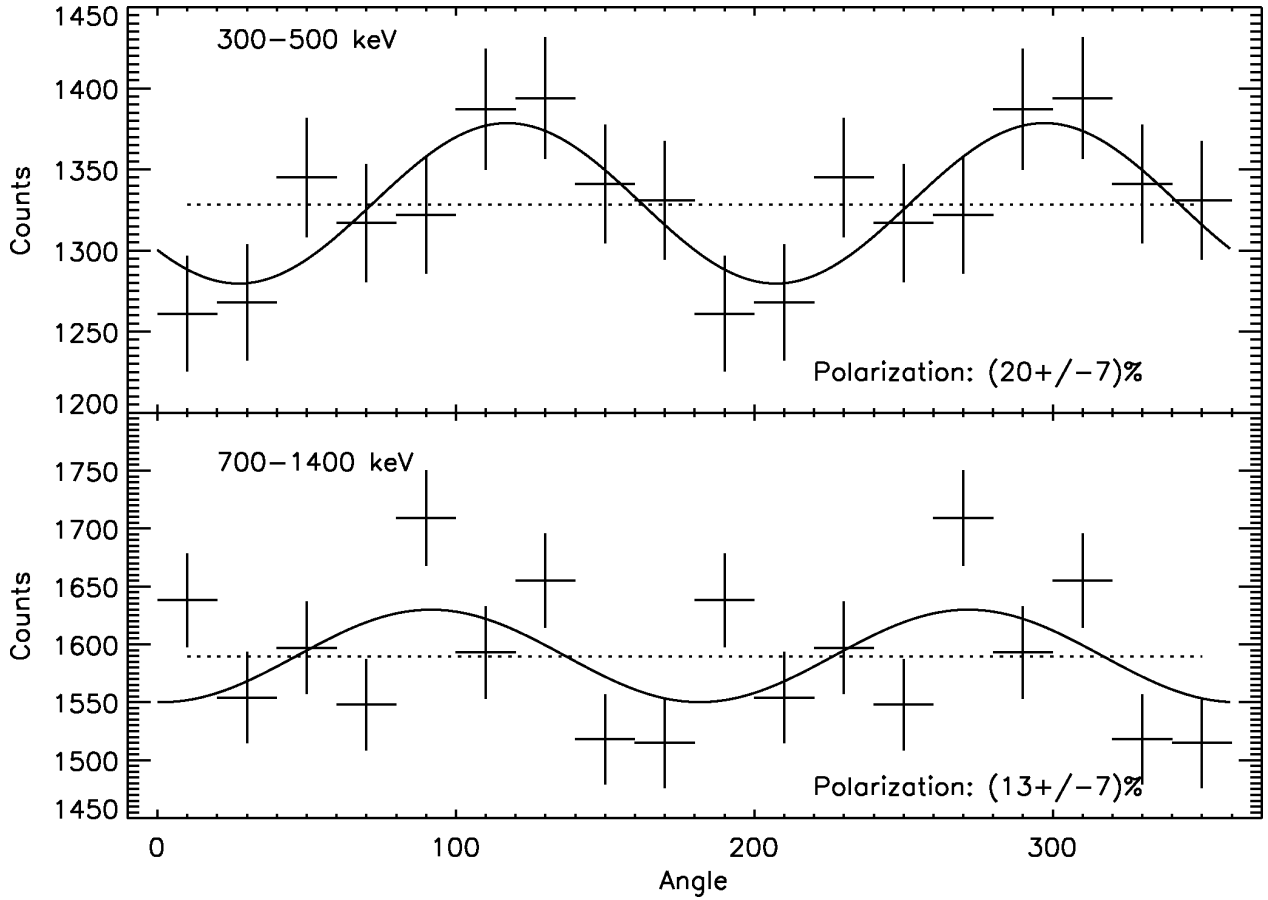
- No polarization: $\chi^2 = 83.5$, 11 d.o.f. – strongly ruled out
- Best-fit modulation: $\chi^2 = 16.9$, 9 d.o.f. (95%)
- Random chance of modulation: $< 10^{-8}$, ($> 5.7\sigma$ confidence)
- Corresponding polarization: 80 ± 20%
- Largest uncertainty: calibration uncertainty in $\mu_m = 0.19 \pm 0.04$
- Monte Carlos including polarization – preliminary results at least confirm consistency with our estimated μ_m.

Background Polarization?



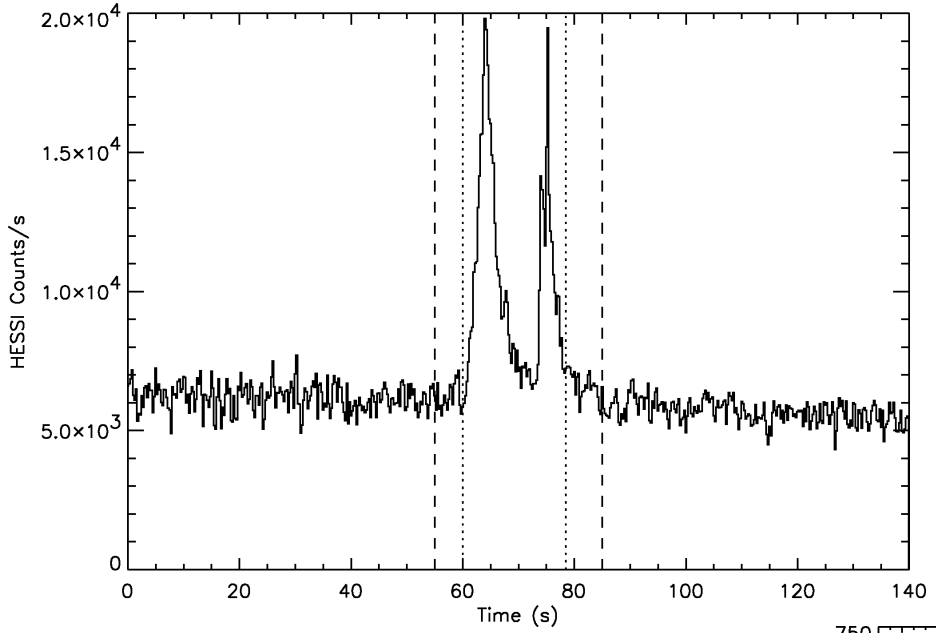
Appears 3 ± 9% polarized, consistent with zero.

Solar Flare Polarization (July 23, 2002)



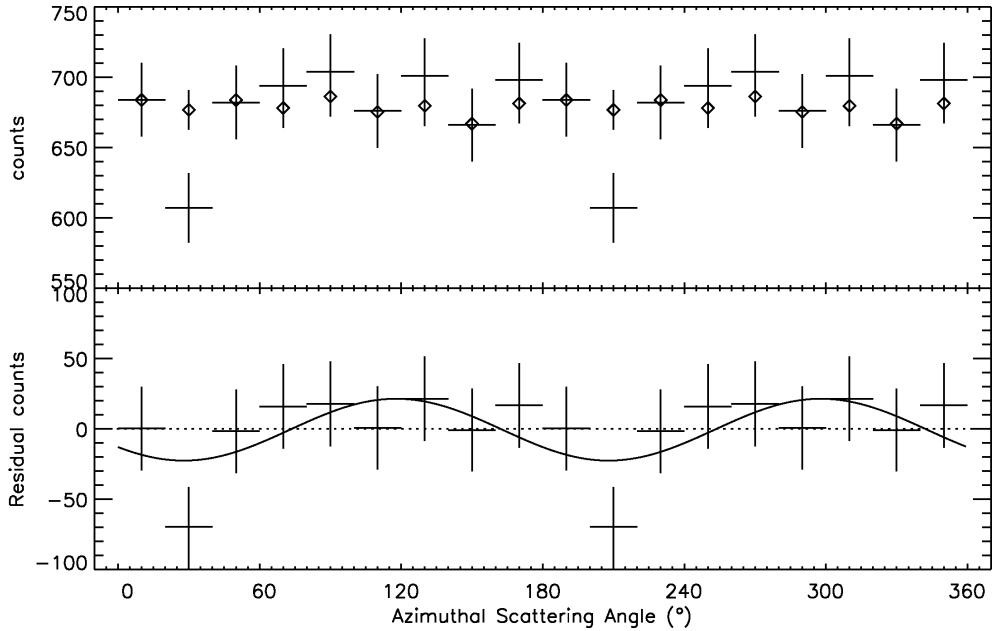
Independently verifiable 20-100 keV.

(McConnell et al. 2003)



GRB030329

Bright, but soft! And came in through the rear of RHESSI.



3σ upper limit of 80%

Conclusions

- We concluded GRB021206 appears to have been an electromagnetically driven outflow – too early to make generalizations.
- Measuring γ-ray polarization is becoming a real field of study. (Whether we actually measured here it or not….)
- We will continue this work with RHESSI, hoping for more bright GRBs and solar flares.
- Independent confirmation with INTEGRAL will hopefully occur sometime in the next 1-2 years (on another GRB, of course).
- Gamma-Ray polarization an excellent diagnostic.

Since our paper there has been much more theoretical work on this question! (Lyutikov et al. 2003; Granot 2003; Eichler & Levinson 2003; Nakar et al. 2003; Lazzati et al. 2003; Matsumiya & Ioka 2003)

Begin rebuttal to Rutledge:

Our Reproduction of RF04 Analysis Method

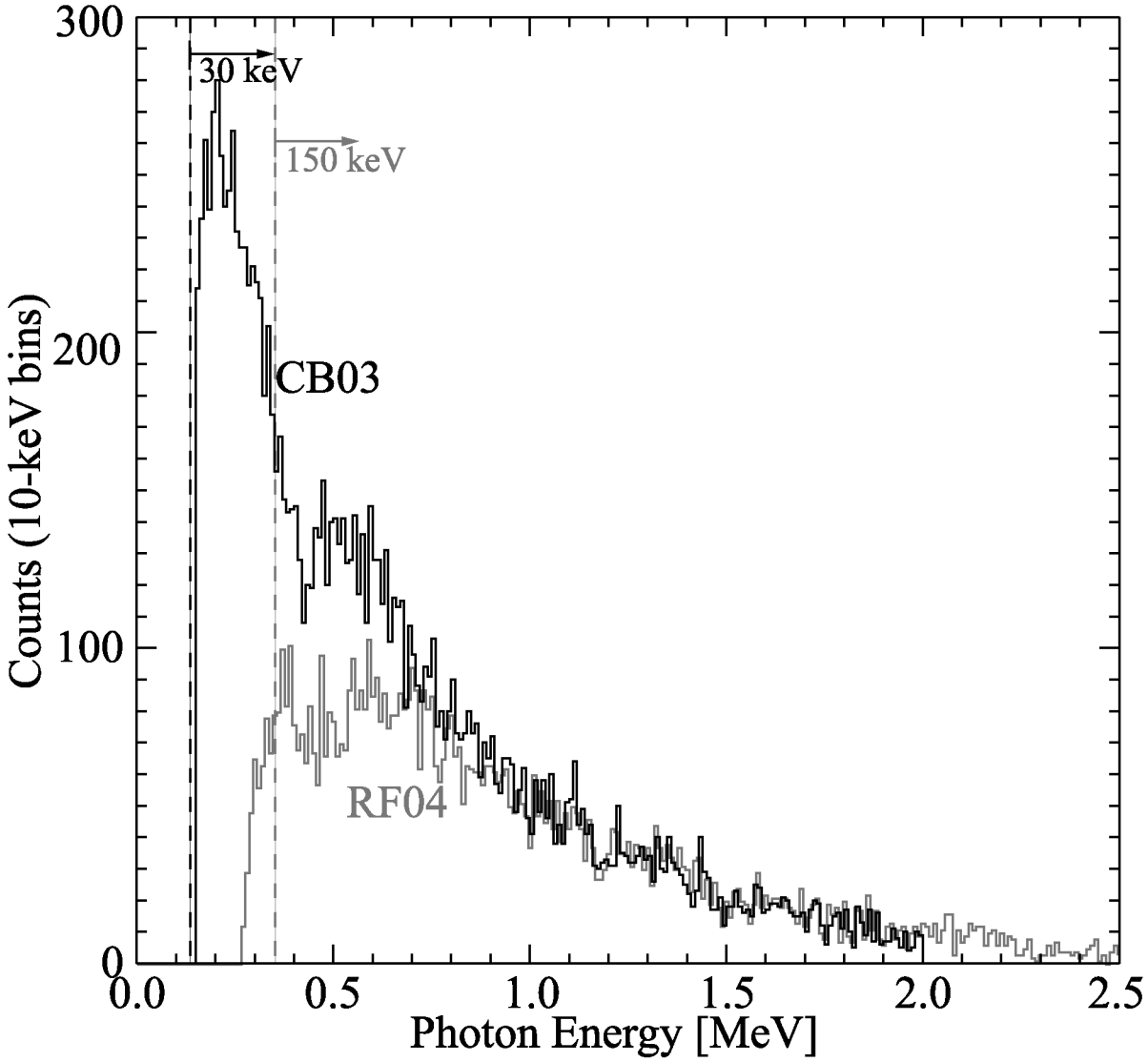
Data Cut	RF04 #Events	Reproduced #Events
1. Raw Counts	85387	85392
2. Combine F/R Coinc	83300	83305
3. Reject 3+ Coinc	81034	81039
4. # 3+ Rejected	719	719
5. 2-Det Coinc	8230	8231

- small differences likely due to 5-second time window shifts
- faithfully reproduced RF04 method
- substantial differences to the method of CB03

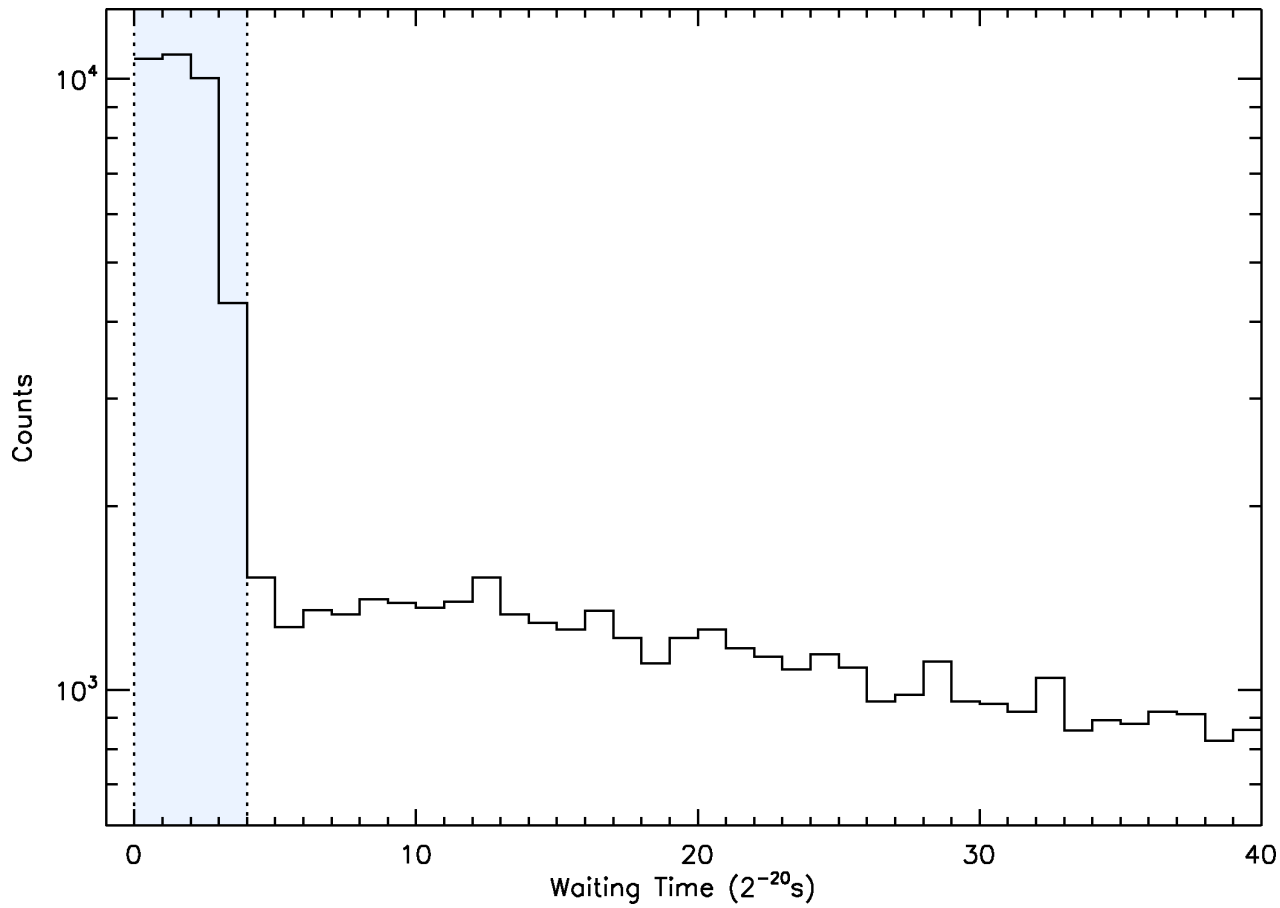
Eventlist → Modulation: Not Trivial Exercise

CB03	RF04
1. 0.15-2 MeV photons	0.15-2 MeV interactions
2. 4 bμs coincidence window	5 bμs coincidence window
3. Coincidences found all energies	0.15-2 MeV initial interaction cut
4. 30 keV min threshold for photons	0.15 MeV minimum threshold
5. Track Front/Rear coincidences	Combine F/R coincidences
6. Reject double F/R coincidence	Include double F/R coincidence
7. Correct RHESSI energy calibration	Obsolete energy_band function
8. Cut on total energies (0.15-2 MeV)	No cut on total energies
9. Measure scatter/chance coinc rate	Poisson statistics arguments
10. Follow charged particle, transistor reset flags	Ignore
11. Reject ambiguous coincidences	Single interactions in multiple events
12. Modulation relative to simulated 'null' 0% polarization distribution	Modulation relative to chance coincidence distribution

Coincidence Spectra: RF04 throw out signal below 0.4 MeV, where RHESSI is most sensitive!



4 or 5 bμs Coincidence Window?



RF04 "Duplication" of CB03

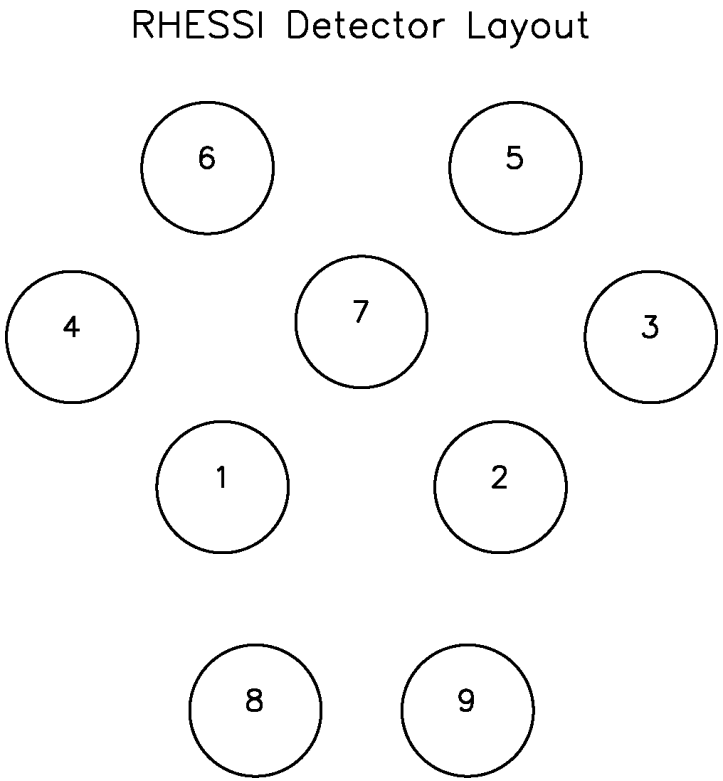
Data Cut	RF04 #Events	Reproduced #Events
1. Raw Counts	85387	85392
2. Combine F/R Coinc	?	83208
3. Reject 3+ Coinc	?	79266
4. # 3+ Rejected	1272	1261
5. 2-Det Coinc	10948	10958

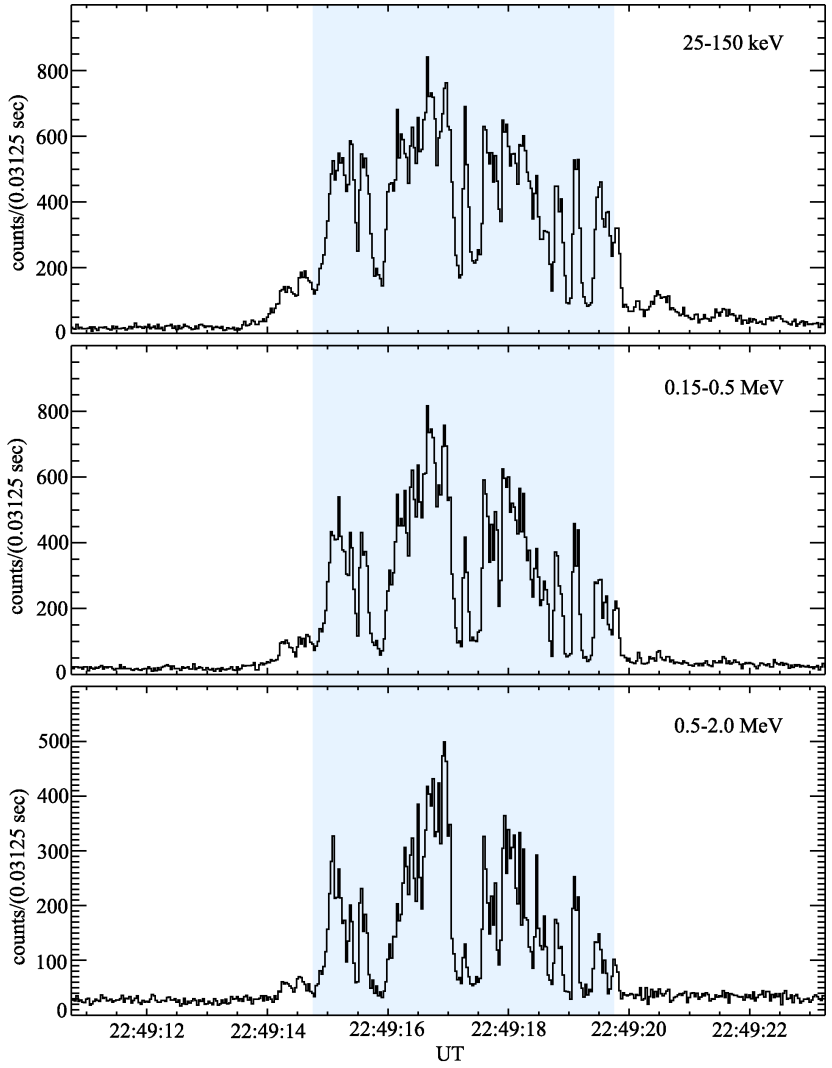
- RF04 use 8bμs coincident window (CB03 use 4 bμs)
- RF04 use 150 keV- 2 MeV interactions (CB03 use total energy)
- RF04 include 3+ detector coincidences – scatter angle undefined

Modulation relative to what?

CB03: 0% polarization distribution (GEANT3 w/ RHESSI mass model)

RF04: distribution from singles, weighting each detector pair equally





Predictions of RF04 Analysis w/ CB03 Data Cuts

Data Cut	Predicted #Events
1. Raw Counts	148209
2. Combine F/R Coinc	143093
3. Reject 3+ Coinc	137551
4. # 3+ Rejected	1764
5. 2 Detctor Coinc	17144
6. Photon Energy Range	15684

- 4bμs coincident window, 30 keV threshold, 0.15-2 MeV *photon* energy
- More coincident events than CB03!
- Several logical and technical problems in the analysis method
- CB03 Method using RF04 Data Cuts: 4938 coincidence events