RHESSI as Coincidence Mode Polarimeter for Gamma Ray Bursts

W.Hajdas PSI

Gamma Polarization – Observable to Explore

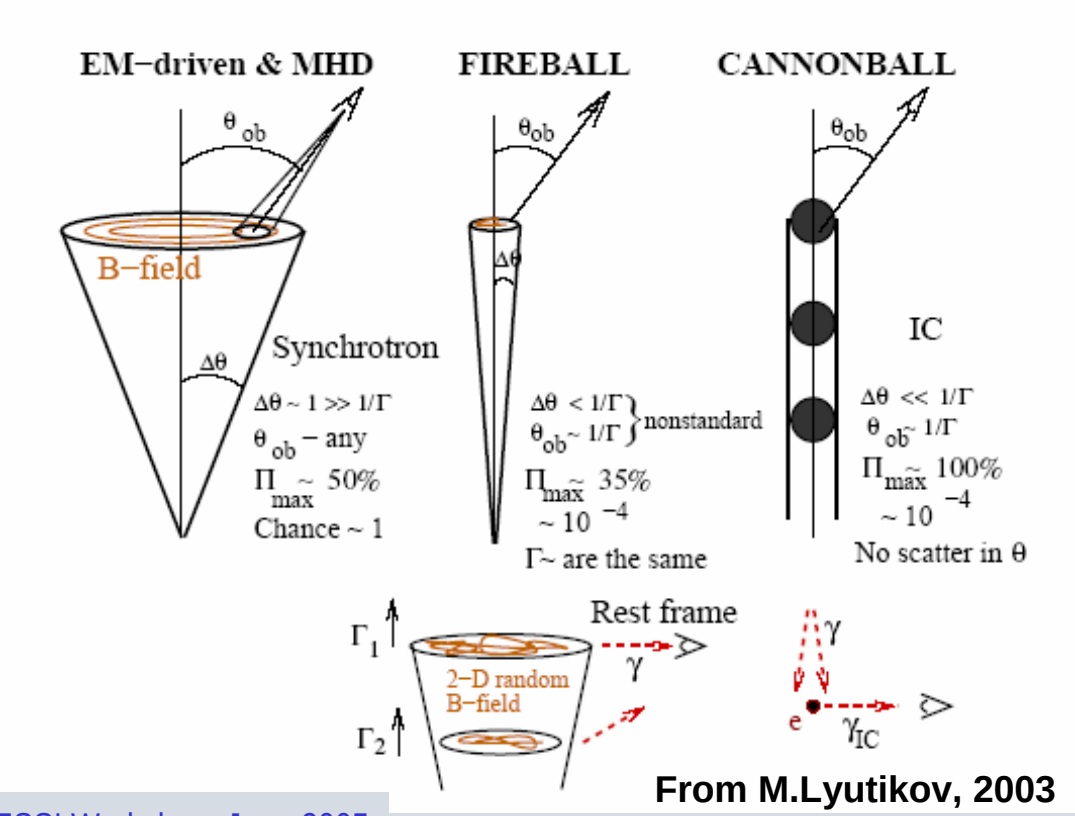
- Until recently polarization was neglected as:
  - theories predicted small polarization levels
  - detection in space proved very difficult
- Recent reports of high polarization of GRB (and solar flares) from RHESSI dramatically changed it
- And … present information from GRB observations, both prompt and afterglow, cannot pin down their mechanisms
- Thus … measurements of photon polarization can shed light on GRB phenomena
- Previous and current X or γ-rays missions were not able to measure polarization … despite of strong intentions of doing so
- Several such measurements are planned for future missions …

Theoretical Predictions

Fireball Model - high values excluded (P_{lin} ~ 10-20 %)

Cannonball Model - values from P_{lin} = 0 to P_{lin} = 100% are possible

Electromagnetic Model - typical polarization range P_{lin} ~ 50 %



From M.Lyutikov, 2003

See papers by authors discussing various models:

T.Piran, A.Dar, M.Lyutikov,

D.Eichler, G.Ghisellini, D.Lazzatti,

M.Medvedev, E.Rossi etc.

Case of the GRB021206 event

letter to nature, Nature, 22 May 2003

W. Coburn & St. E.Boggs, SSL Berkeley

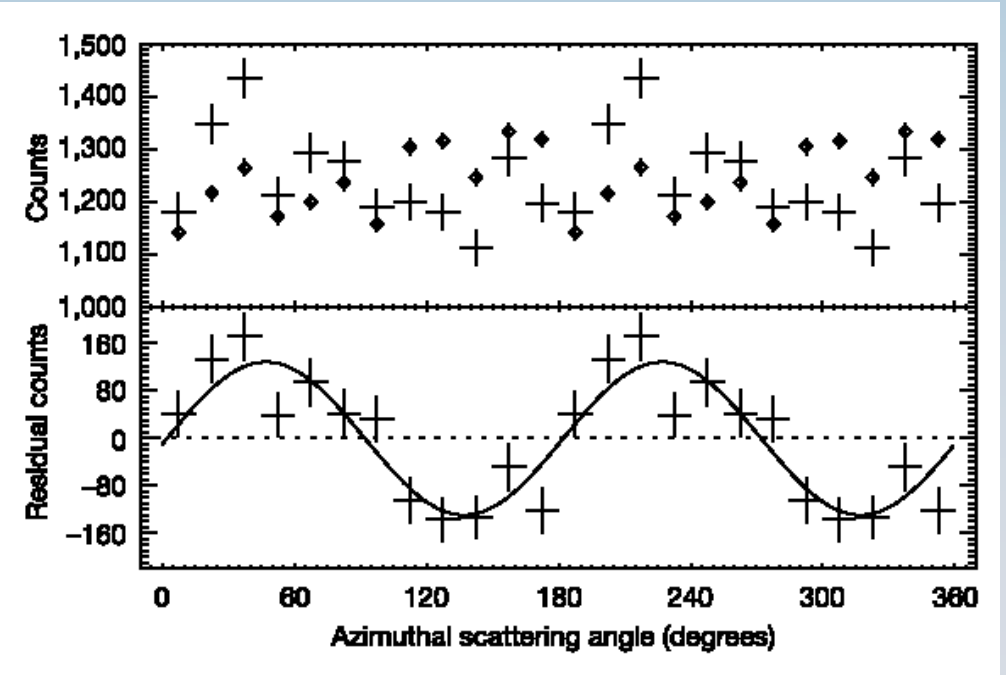
"Polarization of the prompt γ-ray emission from the γ-ray burst of 6 December 2002"

Analysis of RHESSI data

Linear polarization detected with a C.L. of 5.7σ

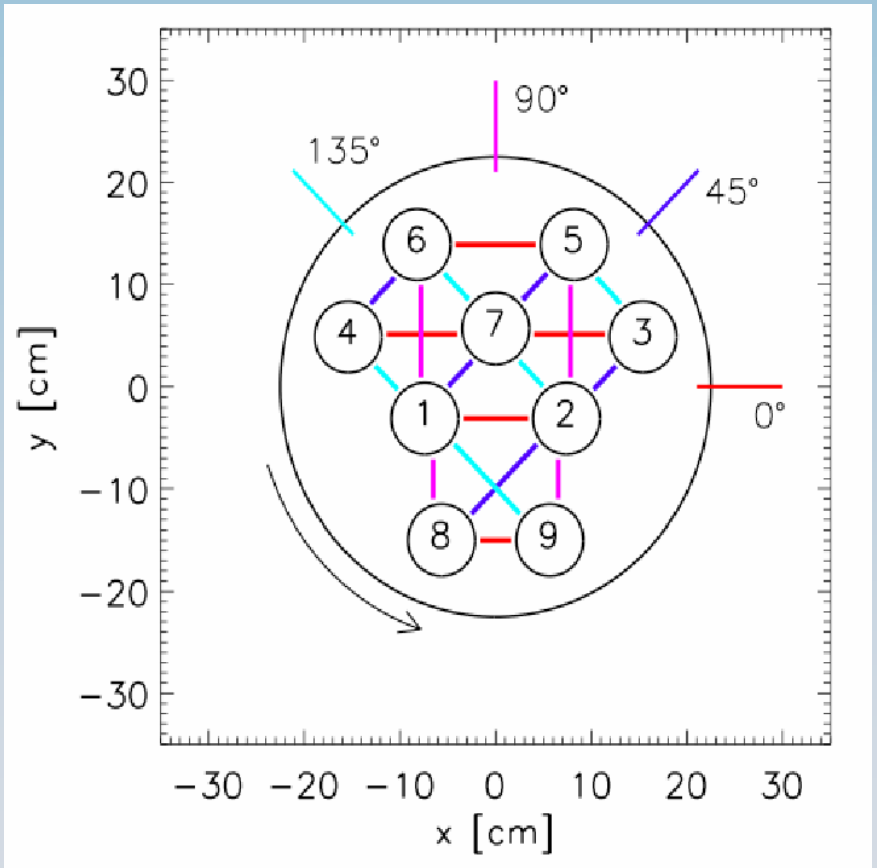
polarization degree is $P_{lin} = 80 \pm 20\%$

Huge impact on GRB theories but other papers revealed errors in analysis

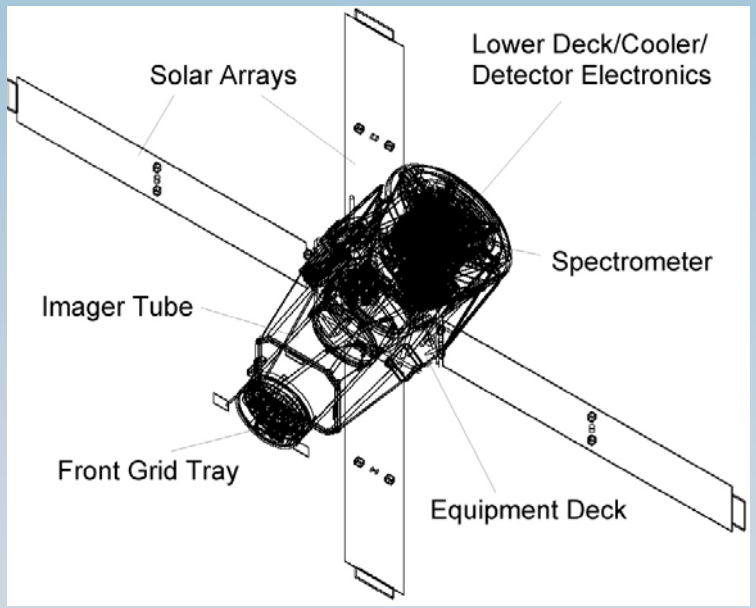


RHESSI as Coincidence Polarimeter

- For higher energies the scattering medium is one of the Ge detectors
- Another, close detector measures distribution of scattered radiation
- Rotation of the spacecraft provides sampling of the scatter distribution
- Large modulation factors feasible for near axis GRBs (front and rear)
- 18 detector pairs favorable for coincidence measurements (out of 36 combinations)

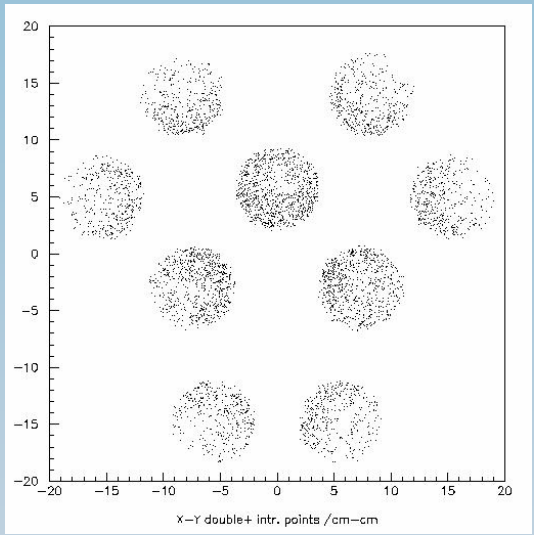


RHESSI Analyzing Power Modeling

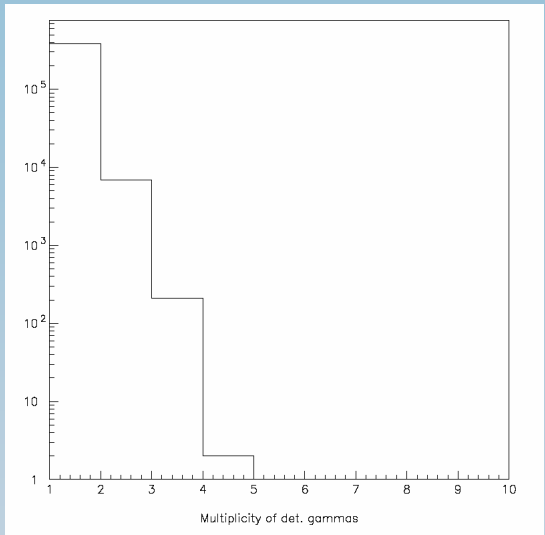


- Mass model constructed using GEANT3 (UCB – inner and PSI – outer parts)
- Spacecraft parts given with degree of details depending on distance from detectors
- Response matrix generated for all angles and energies (illuminating RHESSI with parallel flux of photons with predefined energy and direction)
- Set of polarization tracing routines was built in using GEANT4 approach

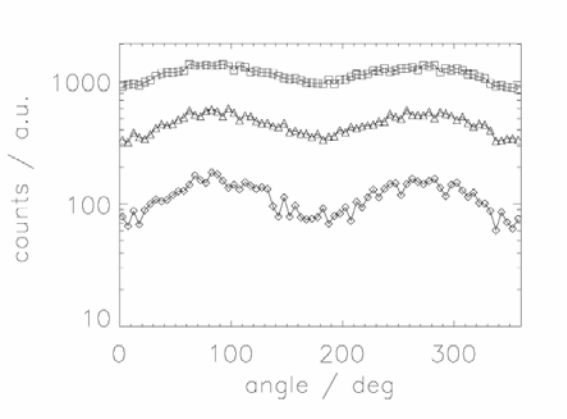
Analyzing Power Modeling – Main Features



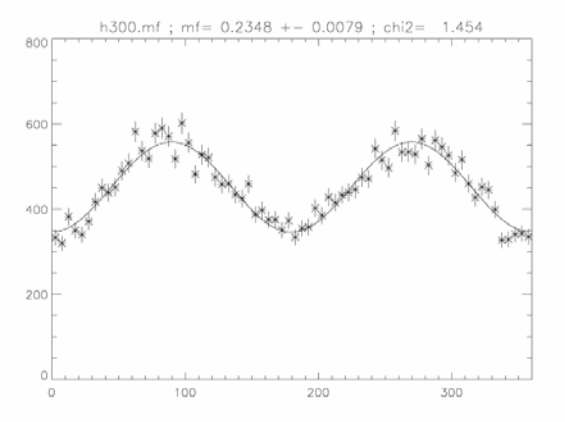
Double events XY distribution



Single photon detection multiplicity

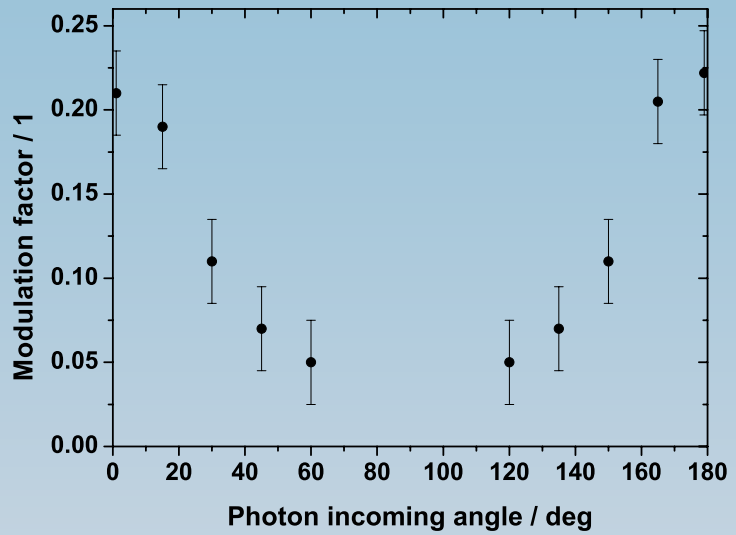


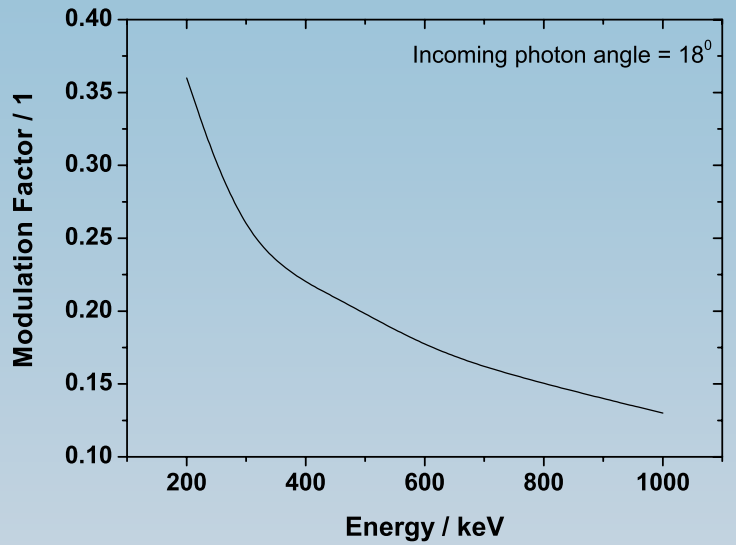
Modulation Factors for 200, 300 and 600 keV



Modulation Factor simulations and fit for 300 keV

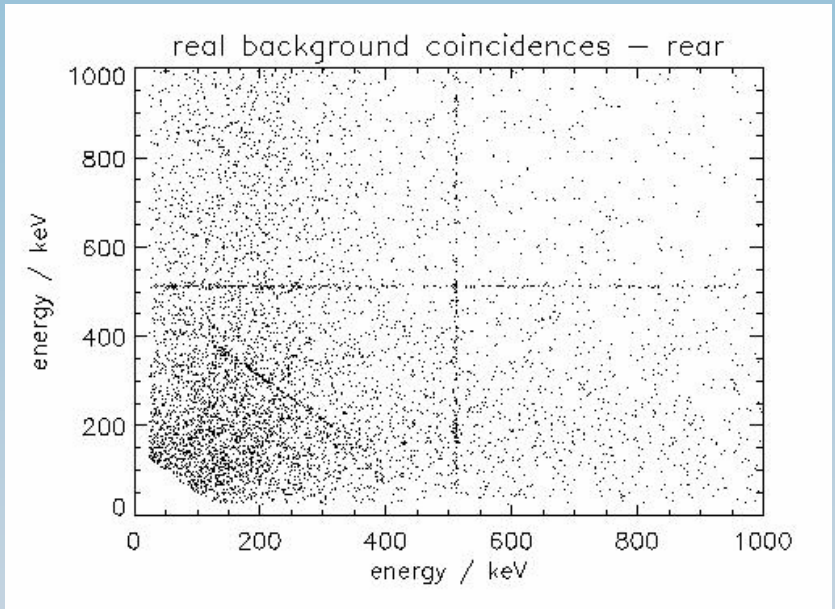
Angular and Energy Dependence

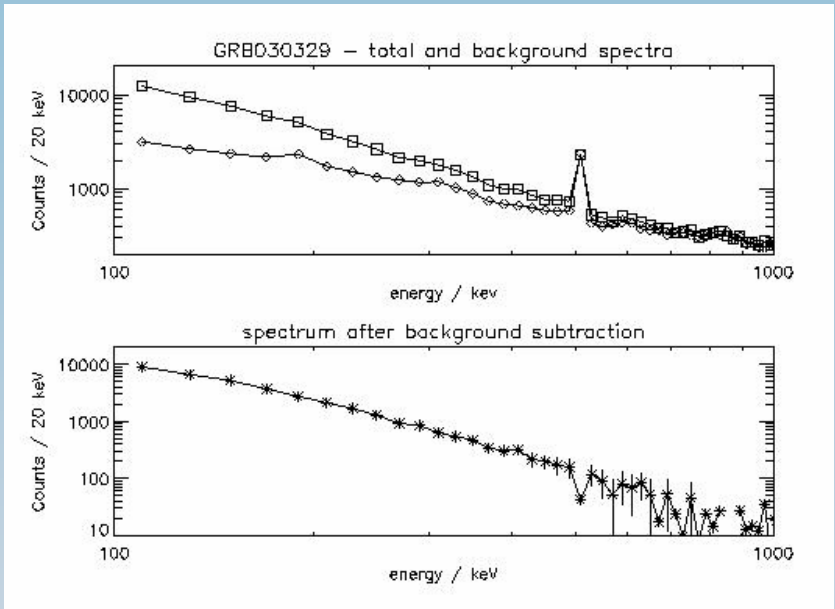




- Semi-sinusoidal modulation curve preserved within $\theta < 25°$ from axis
- Modulation factor decreases at higher energies
- Best candidates are strong and with most counts at lower energies (to counter for absorption and photo-effect)
- Typical modulation factor values for GRBs are around 0.2
- About 10 GRBs/year detected by RHESSI suited for analysis

Background Sources





1) real coincidences photons

diffuse background, cosmic-rays generated gammas from nuclear reactions – ca.120 events/sec (after energy cuts)

2) accidental coincidences

related with GRB itself, quadratic function of rate

3) GRB related real background

like Earth or spacecraft scattered photons

Minimum Detectable Polarization

$$MDP = \frac{n_\sigma}{MF \cdot R_{coi}(R_{sng})} \cdot \sqrt{\frac{2(R_{coi}(R_{sng}) + R_{accid}(R_{sng}) + R_{realbckg})}{T}}$$

- Minimum detectable polarization defined in terms of:

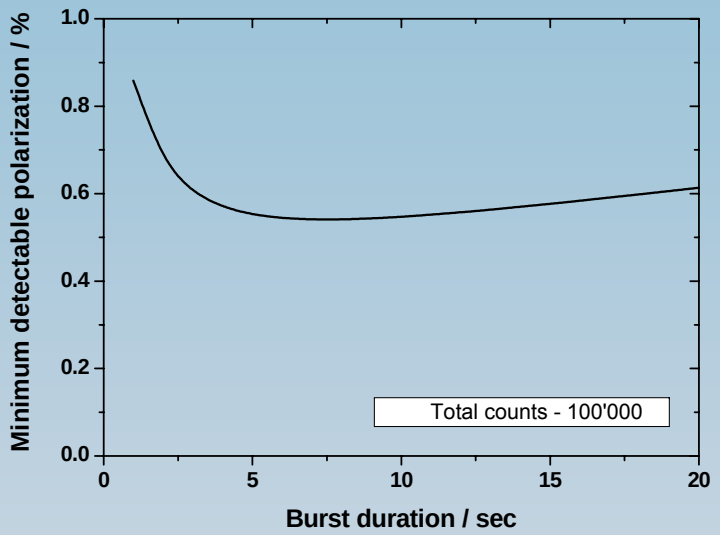
  1 - Source and background rates R_{coi}, R_{accid} and $R_{realbckg}$,
  2 - RHESSI Modulation Factor *MF*
  3 - Total event duration *T*

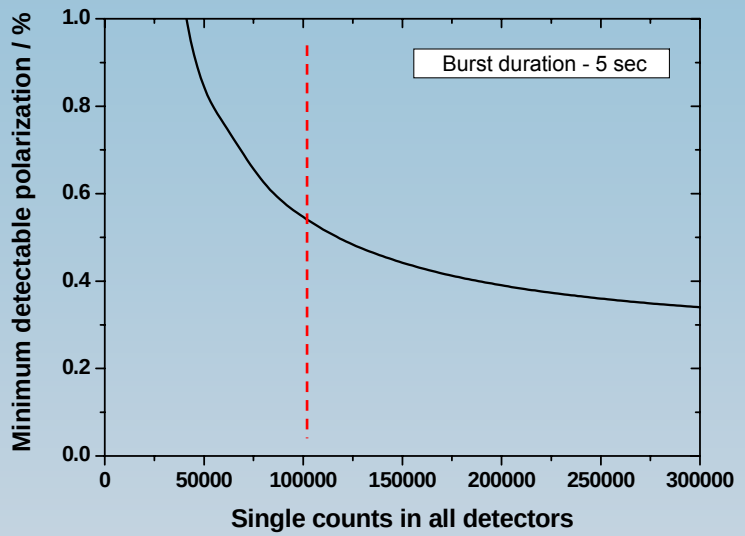
- Background is sum of real and accidental R_{accid} and $R_{realbckg}$ events with coincidence time of $\Delta t \approx 1.5$ μsec

- Both signal and accidental rates are direct functions of single detector rate R_{sng} (typical $R_{coi}/R_{sng} \approx 1.5$ %)

- n_σ indicates significance level

MDP – RHESSI Case





- Minimum detectable polarization as a function of the number of detected photons (left) and burst duration (right)
- Curves generated for power law GRB spectrum $f(E)=c\cdot E^{-2}$, (25 < E < 1500 keV),background included
- Red vertical line on the right indicates strongest GRB detected to date by RHESSI

Conclusions

1. Big area of RHESSI detectors does not lead into high efficiency for coincidence mode (only ≈ 1.5%, small $\Delta\Omega$ and Mean Free Path)
2. Average modulation factor MF is of about 0.2 for near axis events - one expects about 10 such GRB events per year
3. Typical coincidence time is 1-2 μsec - often too large (accidentals)
4. Minimum detectable polarization MDP after including background is of about 50% even for strongest bursts
5. Case of GRB021206, GRB030329 and GRB030519B – no hint for polarization as statistical errors too large for any conclusions
6. New optimized polarimeters are feasible and quickly needed