

POLAR a compact detector for measuring GRB polarization.

N. Produit^a, W. Hajdas^b, F. Barao^c, S. Deluit^a, C. Leluc^d, A. Mschedlishvili^b, M. Pohl^d,
D. Rapin^d, E. Suarez-Garcia^b, J.-P. Vialle^e, R. Walter^a and C. Wigger^b

(a) ISDC, Université de Genève, Switzerland

(b) PSI, Villigen, Switzerland

(c) LIP, Lisboa, Portugal.

(d) DPNC, Université de Genève, Switzerland

(e) LAPP/IN2P3/CNRS, Annecy, France

Presenter: N. Produit (Nicolas.Produit@obs.unige.ch), swi-produit-N-abs2-og15-poster

The POLAR detector is a simple and compact detector capable of measuring the polarization level of a typical gamma-ray burst (GRB). POLAR don't try to measure itself the sky coordinate of the incoming GRB but will rely on the availability of such information from other instruments. Simple plastic scintillator is used. Monte Carlo simulation show that a reliable and non biased polarization signal can be achieved. Fast coincidence techniques are used to reject the noise.

1. GRB polarization

GRB phenomenon still remains a mystery. Competing theoretical models like fireball [1], cannonball [2] or electromagnetic [3] make very different prediction about the polarization of the prompt γ -rays photons. Systematic bursts observations with a dedicated polarization detector would enable to discriminate between the different models.

To date, despite of many attempts, the polarization data remain very scarce and its measurements proved quite difficult. Well designed GRB polarimeter might be also very beneficial in studies of other hard X-ray and gamma ray sources like X-ray pulsars, neutron stars or AGNs. Currently, there are several laboratory projects aimed to build a hard X-ray polarimeter based on Compton scattering technique. They utilize various gamma detector arrays like e.g. low-high Z scintillator hybrids [4], homogeneous low Z fast plastics scintillators [5] or CdTe semiconductor pixel detectors [6].

2. Detector Design

The fast and precise localisation of GRB is nowadays provided rapidly and freely by many observatory (INTEGRAL, SWIFT, GCN). We foresee that this will be true also in the future. It is therefore not important that a detector is able, by itself, to localise the direction of a GRB.

Releasing the constrain of localisation is simplifying the design. We take here for granted that the position of the GRB are known and that the detector platform can tell where the detector is pointing. We can rely on Monte Carlo simulation to correct for the difference in response due to the position of each GRB. We will show (figure 3) that those corrections are small for a reasonable solid angle.

Following requirements and considerations guided us to the proposed detector design. The polarimeter should cover energy range characteristic for GRBs i.e. from few up to several hundred keV. It will have large effective area of at least few hundred cm² and high efficiency for the Compton scattering. Both can be assured by using low Z detector materials like e.g. light weight plastic scintillators. The modulation factor for polarization measurement will be kept high by selecting the single cell (pixel) size similar to the photon mean free path and by setting the energy threshold as low as possible. Above features should also be kept within possibly wide range of incoming gamma angles. This requirement would effectively cause an increase of the overall sensitivity

of the polarimeter to a large fraction of the sky. Moreover, the design should tolerate small angle scattering inevitable in the low-Z scintillators while the initial direction of the polarization vector should be roughly the same until a large angle scattering occurs.

With a good angular resolution defined by a suitable pixel cross section one will use the large angle scattering to determine polarization direction of the event. This will be done by selecting two coincidence events with largest energy depositions. Schematic view of the polarimeter design is shown in figure 1. The instrument is composed of 2304 plastic scintillator bars with dimension $4 \times 4 \times 200 \text{ mm}^3$. Scintillation light is converted by a mosaic of flat panel multianode photomultipliers (PM). Electronics, power supply, readout and communication units are behind PMs and serve also as a passive shield. Background events from cosmic rays can be rejected by analysing total energy deposition in the detector while the rate of accidental coincidences from the gamma background will be reduced both applying thin absorber material on the detector walls and by using fast scintillators and short coincidence widths.

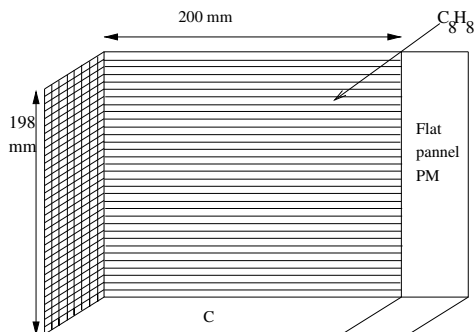


Figure 1. Schematic view of the detector scintillator array and photomultiplier on the right side.

3. Response Modelling

Detector response was simulated using GEANT4 code from CERN. The computer model consists of the scintillator array shielded by thin carbon sheets and coupled to the PM and read-out electronic blocks approximated by a 10 cm thick Aluminium box. Incoming photons have been generated uniformly over the area covering the whole detector and their entrance angles varied from 0 to 70° in the polar (θ) and from 0 to 45° in azimuth (ϕ) directions respectively. All generated photons were fully polarized while their energy was sampled from the Band [7] model distribution ($\alpha=1$, $\beta=2.5$ and $E_{peak}=200 \text{ keV}$) between 10 keV and 300 keV . On average, 14% of the events fulfil the double energy deposition coincidence required by the trigger and about 50% of such coincidences occur within 10 closest detection cells. Simulations also confirmed that photon interactions are dominated by the low energy Compton scattering with a small energy transfer to the electron and only a tiny change in the initial polarization direction for the scattered photon. However in every case where a large angle scattering occurs, a clear modulation of the azimuth scatter angle is observed as the direction of the Compton scattered photon is more likely to be perpendicular to the polarization direction. Simulations clearly indicate that it is sufficient to select only two most energetic processes and their corresponding cells. In addition, the line connecting both cells is well correlated with the outgoing azimuth photon direction for wide range of incoming photon polar angles. An example in figure 2 shows the reconstructed azimuth angle distribution for an intense GRB coming perpendicularly to the detector and with the polarization orientation along $\phi_{scat}=0^\circ$. The maximum signal rate for coincidences should be observed at scattering angles $\phi_{scat}=90^\circ$ as it is showed

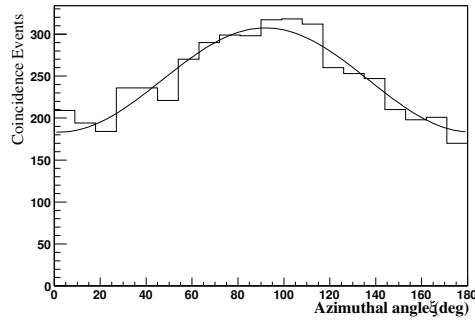


Figure 2. Azimuth angle distribution for the Compton scattered events from photons coming at $\theta=0^\circ$ and with the polarization direction along $\phi=0^\circ$.

in the figure 2. Depending on both photon energy and impinging angle, the modulation function can vary in a wide range though its sinus-like shape is always well preserved. For the Band function spectrum of GRB with the parameters as above, the modulation factor varies in the range from 0.32 to 0.22 for the photon incoming angles from $\theta=0$ to 70° (see Fig. 3 Left). Similar results were obtained for polarization vectors rotated along the ϕ angle. It confirms the requirement put on the polarization detector design to keep large values of modulation factors over a wide range of the gamma directions from the sky. Although the geometrical area of the detector reaches about 400 cm^2 , its effective size for Compton scattered events with the predefined Band type of the spectrum (as given by the geometrical surface multiplied by the photon detection probability) varies from 100 cm^2 down to 40 cm^2 , depending on the photon entrance angle. As shown in figure 3, the acceptance area changes relatively slowly over about $1.3 \pi \text{sr}$. Within this fiducial solid angle the average area is equal to about 80 cm^2 . Simulations show that these results are virtually independent on the photon azimuth incoming angle ϕ .

4. Background Reduction

The background photons are coming from the diffused X-ray sky, non-GRB gamma ray sources as well as from the induced radioactivity in the spacecraft and the detector itself. The X-ray diffused background can

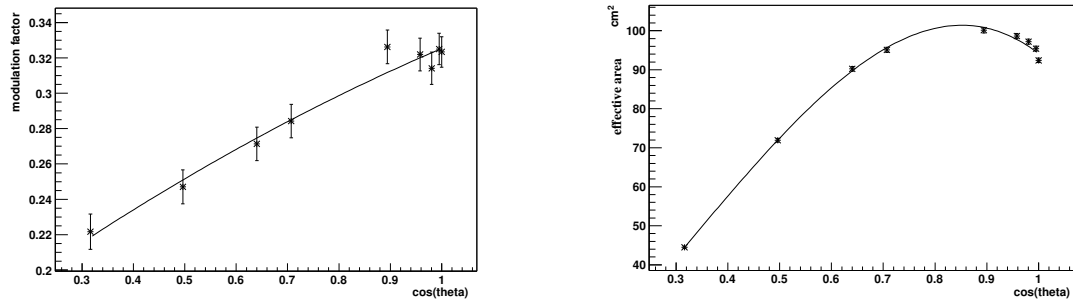


Figure 3. Left: GEANT4 simulations of the modulation factor as a function of the photon polar angle with polarization direction set in the plane $\phi=0^\circ$. Right: Effective area for Compton scattered photons with energies from 10 and 300 keV as a function of the incoming angle θ (ϕ was set to 0°).

dominate at lower energies and one will apply 1 mm thick carbon absorbers in front of the scintillator array. Other background contributions from the gamma ray sources like e.g. Crab nebula will have only a small fraction of the diffused X-ray background rate. The induced gamma background is expected to be negligible using estimates from the INTEGRAL and RHESSI satellites. The Cosmic Ray charged particle background will penetrate the whole detector but due to a very high energy deposition (at least 800 keV) one can get rid of it by setting the upper energy threshold.

5. Polarization Detection from Transients

The minimum detectable polarization for GRBs and other transient sources was estimated with the help of Monte Carlo calculations using typical parameters for both the burst and the background. Statistical fluctuations of the background and of the signal rate have been taken into account properly. Assuming 80 cm² effective detector area, POLAR instrument can determine just within 1 second the 50% polarization value (3σ level) for events with fluxes equal to about 15 photons s⁻¹ cm⁻². Fig. 4 shows the minimum detectable polarization values for GRBs as a function of the mean waiting time given in days. The predictions are based on the GUSBAD [8] catalog with a supposition that only about a third of all events will be in the detector field of view. According to figure 4, the proposed polarimeter would be able to measure the GRB polarization values from 20% up (3σ levels) for about 10 to 15 GRB per year.

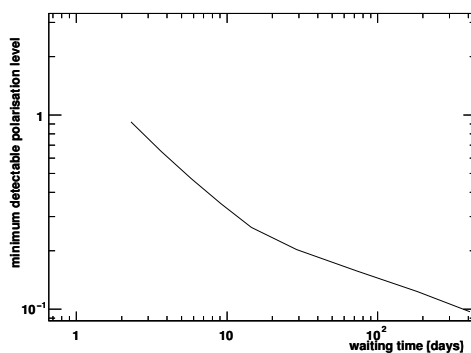


Figure 4. Minimum detectable polarization value of the GRB plotted as a function of the waiting time. Predictions are based on the previous GRB records.

References

- [1] Piran et al. Phys.Rept. 314 (1999) 575-667
- [2] S. Dado et al., astro-ph/0403015
- [3] M Lyutikov et al., Astrophys.J. 597 (2003) 998-1009
- [4] McConnel et al. Vestrand, IEEE Trans. Nucl. Sci. 46(4)
- [5] N. Produit astro-ph/0504605, accepted for publication in NIM
- [6] Caroli, E., et al. (2000), SPIE Conf. Proc., 4140, 573.
- [7] D. Band et al. ApJ 413:281-292, 1993
- [8] M. Schmidt, Astrophys.J. 616 (2004) 1072-1077