POLAR: Design of a novel X-ray polarimeter based on plastic scintillators and MAPMTs.


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Abstract

POLAR is a space-borne hard X-ray polarimeter designed to measure the linear polarization of the gamma-ray bursts (GRB) in the energy range 50-500 keV. In POLAR, the GRB photons undergo Compton scattering in a target made out of 1600 plastic scintillator bars. The azimuthal distribution of the scattered photons inside the target provides the information on the GRB polarization. To be able to measure polarization of photons with energy as low as 50keV, an energy threshold for each single channel of maximum 5keV is required. This introduces strong constraints in the photon collection efficiency. To improve it, detailed studies of the scintillator bar surfaces and the available wrapping materials have been performed using both Monte Carlo simulations and laboratory measurements. At present, a POLAR demonstration model (1/10 of the final design) is being tested in the laboratory. POLAR engineering-qualification model will be ready in 2010.

Description of POLAR

- Polarimeter based on Compton Scattering
- Incoming photon energy range: 50 keV – 500 keV
- Array of 40x40 plastic scintillators (6x6x200 mm³)
- Light, fast and low-Z plastic: BC400
- 25 MAPMT, H8500 Hamamatsu (each 8x8 anodes)
- Readout: ASIC + FPGA.
- Volume: 30x30x30 cm³; mass: 30 kg
- Mean power Consumption below 30 W
- Large field of view: more than 1/3 of the sky
- Large modulation factor: 40% (at 200 keV)
- Large effective area: 400 cm² (at 200 keV)

Method

- Large angle Compton scattering: azimuthal (ξ) distribution strongly modulated around photon polarization direction.
- Observe for each interacting photon: recoil e- from Compton scattering and scattered photon (by a second Compton scattering or photo electric effect) the 2 most energetic hits
- The line connecting them is well correlated with ξ.
- From ξ modulation curve POLARIZATION

Mass model (Geant4)

- Exact representation of the instrument
- Physical processes included: Low Energy (LE) Polarized Compton, Gamma Conversion, Photoelectric, elonisation, eBremsstrahlung

Results from mass-model:

- Compton scattering dominates
- Orbital Studies: Low Earth Orbit good orbit
- Background studies:
  - Cosmic Ray Protons: very low rate
  - Spectrum can be used for calibration
- Modulation factor (µ) dependence on energy, photomultiplier uniformity, gamma-ray incoming angle (θ)
- BATSE Catalog simulations:
  - Minimum Detectable Polarization (MDP) of 10% (3σ) for about 12 GRB/year, with energy fluence of 10^7 erg cm² s⁻¹

Light collection studies

Simulations with GEANT4 Optical Photons:

- 1 scintillator bar: 6x6x200 mm³
- Different wrapping materials:
  - Al-mirror (50 μm thick)
  - Al-foil with air gap
  - Teflon (50μm)
  - Reflective paint
  - No wrapping (air)

Results:

- ~45% of optical photons are collected
- Scintillator surface smoothness is very important

Laboratory

Several scintillator bars were tested sequentially, wrapped with different materials (Al-foil, Teflon, no wrapping, 3M® reflective foil).

Summary

- The Monte Carlo simulations show POLAR capabilities to measure GRB polarization (typical MDP ≈ 37%).
- Plastic bar light collection ~45%. Signal dependence on source position ~15%. Scintillator surface quality is crucial. Results obtained in laboratory confirm the simulations.
- Present status & Future tests:
  - Demo model (2 modules 8x8 bars each) is being tested in the laboratory. It will be exposed to polarized photons from PSI Synchrotron Light Source.
  - Physical processes included: Low Energy (LE) Polarized Compton, Gamma Conversion, Photoelectric, elonisation, eBremsstrahlung
- BATSE Catalog simulations:
  - Minimum Detectable Polarization (MDP) of 10% (3σ) for about 12 GRB/year, with energy fluence of 10^7 erg cm² s⁻¹

References: