30TH INTERNATIONAL COSMIC RAY CONFERENCE

The BGO anticoincidence system of the PoGOLite balloon-borne soft gamma-ray polarimeter

C. MARINI BETTOLO[1], M. PEARCE[1], M. KISS[1], W. KLAMRA[1], M. SIEGL[1]
ON BEHALF OF THE POGOLITE COLLABORATION
[1]*Department of Physics, KTH, Stockholm, Sweden*
cecilia@particle.kth.se

Abstract: The PoGOLite balloon-borne experiment applies well-type phoswich detector technology to measurements of soft gamma-ray polarization in the 25 keV - 80 keV energy range. The polarization is determined using Compton scattering and photoelectric absorption in an array of 217 plastic scintillators. This sensitive volume is surrounded by a segmented bismuth germanate oxide (BGO) anticoincidence shield, designed to reduce background from charged cosmic rays, primary and atmospheric gamma-rays, and atmospheric and instrumental neutrons. A total of 379 BGO crystals with three different geometries are used, giving an overall mass of approximately 250 kg. Tests of the BGO crystals are described and the overall design of the anticoincidence shield is reviewed.

Introduction

Polarised gamma-rays offer a unique and powerful diagnostic of a wide variety of sources including rotation-powered pulsars, accreting black holes and neutron stars, and jet dominated active galaxies [1]. The light-weight polarized Gamma-ray Observer (PoGOLite) is a balloon borne experiment designed to measure the polarization of soft gamma rays in the 25 keV - 80 keV energy range. PoGOLite will detect 20% polarization in a 200mCrab source in a 6 hour balloon observation [2]. The polarization is derived from the azimuthal distribution of Compton scattering angles in the sensitive volume of the instrument. The scattering angle will be measured by detecting coincident Compton scattering and photo-absorption sites in a hexagonal close-packed array of 217 phoswich detectors cells (PDC). Each PDC unit is composed of a thin-walled tube of slow plastic scintillator (active collimator), a solid rod of plastic scintillator (gamma-ray detector) and a short bismuth germanate oxide ($Bi_4Ge_3O_{12}$, BGO) crystal (bottom anticoincidence), as shown in figure 1. The 217 PDC units are surrounded by 54 BGO crystal assemblies (side anticoincidence shield, SAS). A 10 cm thick paraffin shield sur-

rounds the instrument (except the field of view), and is used to mitigate atmospheric neutron backgrounds.
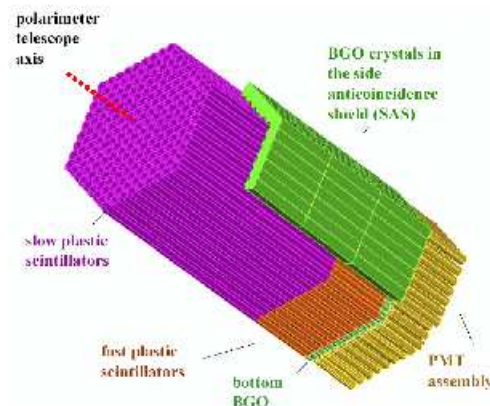

Figure 1: The PoGOLite polarimeter. The lateral green units are the SAS BGO crystals (not all crystals are shown for clarity), and the purple and orange items are the slow and fast scintillators, respectively. The bottom BGO crystals are also shown in green, and the PMTs are shown in yellow. The neutron shield is not shown.

Anticoincidence system

Signals coming from the SAS BGO crystals will be used to veto charged cosmic-rays, gamma-rays, and neutrons in the off-line analysis. Signals from the PDC BGO crystals are identified using waveform analysis in the trigger which selects Compton scattering/photo-absorption events. Potential background to the polarization measurement therefore comes from extraneous gamma-ray sources within the field-of-view, atmospheric and cosmic gamma-rays and charged particles that leak through the side and bottom BGO anti-coincidence systems, and neutrons produced in the atmosphere and the gondola structure. With an estimated SAS rate of about 100 kHz at float altitude, a simple SAS veto would reject about 6% of detected events by random coincidence. Segmentation of SAS allows SAS and PDC hits to be correlated, which will reduce the number of valid events rejected. Segmentation also allows study of possible asymmetries in the background and to make corrections in the off-line analysis. The anticoincidence threshold for the SAS BGO crystals is 75 keV.

The anticoincidence system of PoGOLite comprises an array of BGO crystals which covers the bottom and sides of the PoGOLite polarimeter, as shown in figure 1. The bottom BGO shield consists of an interlocking assembly of crystals with a hexagonal cross-section. Each crystal forms part of a PDC unit, and interfaces the photomultiplier tube (PMT) to the solid fast scintillator. Each of the 54 interlocking lateral anticoincidence elements consists of 3 crystals of pentagonal cross-section. All BGO crystal surfaces (except optical interfaces) are covered with a thin layer of $BaSO_4$ loaded resin ($\sim 100\ \mu$m thick) to provide optical isolation between adjacent BGO elements and to improve light yield. Once sanded flat, the $BaSO_4$ surface provides a well defined mechanical interface, allowing crystals to be integrated into the PoGO-Lite mechanics. The BGO crystals are supplied by the Nikolaev Institute of Inorganic Chemistry, Novosibirsk, Russia [3]. A typical BGO boule from which the PoGOLite crystals are cut is shown in figure 2. The total weight of the BGO crystals used in PoGOLite is approximately 250 kg.
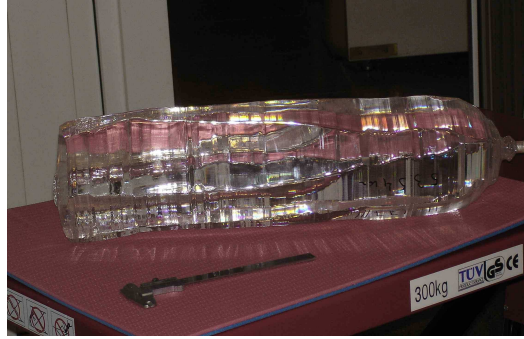

Figure 2: A boule of BGO from which the PoGO-Lite crystals are cut. This boule is approximately 80 cm long and 20 cm in diameter.

Bottom Anticoincidence System

The bottom BGO shield consists of 217 identical crystals, of length 4 cm and diameter ~3 cm, as shown in figure 3. Each crystal has a mass of ~160 g. The hexagonal section connects to the solid fast plastic scintillator in the PDC and the cylindrical end couples to the PMT. The entire PDC is read out by a single photomultiplier tube (Hamamatsu R7899EGKNP), and the different decay times of the scintillation light (slow plastic : ~285 ns, fast plastic : ~1.8 ns, and BGO : ~300 ns) allows the signals to be separated [4]. As well as being transparent to their own scintillation light (480 nm), the crystals must also be transparent to the scintillation light produced in the slow (435 nm) and fast (408 nm) plastic scintillators. The transparency has been monitored using a UV spectrometer. The BGO crystals are seated in an aluminium baseplate designed to ensure a close packing between adjacent PDC elements.

Side Anticoincidence System

Each of the 54 'towers' of the side anticoincidence system has a BGO mass of ~4.5 kg, is 600 mm long, and is built from three crystals, since it is difficult and uneconomical to grow crystals to full length. Two different crystal geometries are used, as shown in figure 3. The side shield is hexagonal in cross-section and covers two thirds of the height of the PDC elements. The corners and edges of
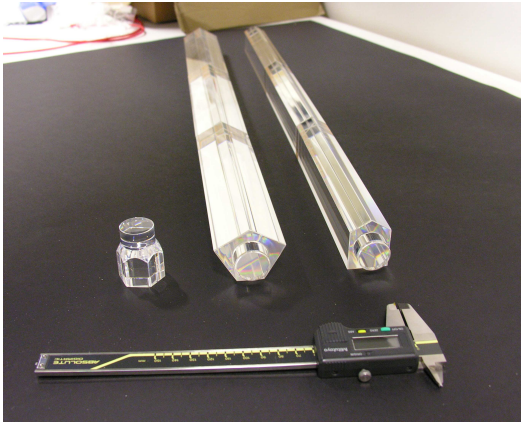
Figure 3: The three types of BGO crystals used for the PoGOLite anticoincidence system. A corner and edge side tower is shown (61 cm long), together with a bottom 'PDC' crystal (4 cm tall).

the PDC assembly are covered by BGO crystals with differing pentagonal geometry. Each tower of crystals of a given type is built from two upper crystals with flat ends and one lower piece which has a 23 mm diameter cylindrical protrusion and interfaces to a PMT (same type as used for PDC read out). The three BGO pieces within a tower are joined together with a UV transparent epoxy glue (EpoTek 301-2). The lateral anticoincidence system has its own mechanical support system which must locate the BGO towers accurately around the PDC assembly and ensure that the gap between adjacent BGO elements is minimised. A gap of $\sim 200 \mu$m is foreseen, which is due to the reflective $BaSO_4$ layer. A particular challenge in the design of the support is that it must withstand the significant forces associated with the parachute opening at the end of a flight and the subsequent landing. Careful thermal design is also necessary since BGO has a linear coefficient of expansion which is ~ 4 times less than (e.g.) aluminium.

Acceptance tests

Prior to the assembly of the anticoincidence systems, each shipment of BGO crystals undergoes acceptance testing consisting of a visual inspection, dimensional inspection, and measurement of
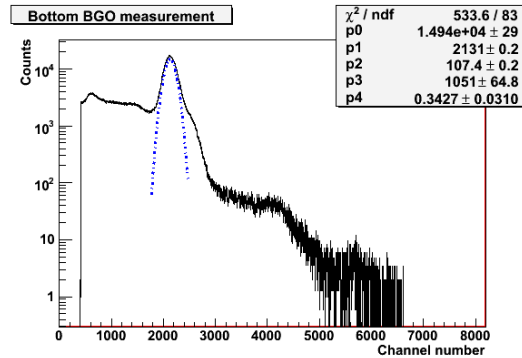

Figure 4: A typical energy spectrum of a ^{137}Cs source reconstructed using a bottom BGO crystal. The dotted line is a fitted Gaussian peak used to evaluate the peak position and width.

light yield using the 661 keV photopeak from a ^{137}Cs radioactive source. Small cylindrical samples are also archived from each boule, to allow boule parameters to be monitored independently from the cut crystals. The visual inspection requires that the crystals are transparent and without visible grain boundaries when viewed under strong lighting (UV component removed with filters). Furthermore, the surfaces must have a fine mirror-like polish, with no visible scratches, cracks or dents. The dimensions are checked to be within required tolerances using a standard micrometer caliper.

The method to determine light yield varies between the bottom and side BGO crystals due to the different crystal geometries. In each case, however, the light yield is specified in terms of the relative energy resolution for the 661 keV line, R=$\frac{\Delta E}{E}$, where E is the position of the peak maximum and ΔE is the corresponding full width at half maximum value. Figure 4 shows a typical energy spectrum reconstructed using a bottom BGO crystal. The origin of the shoulder at ~ 2500 channels is under investigation. The specific measurement technique and requirements for each type of BGO crystal is detailed in the remainder of this section.

During measurements, the bottom BGO crystals are placed in a 5 mm thick reflective teflon "cup" to maximise light collection and the cylindrical portion of the crystal is connected to a PMT (Photonis
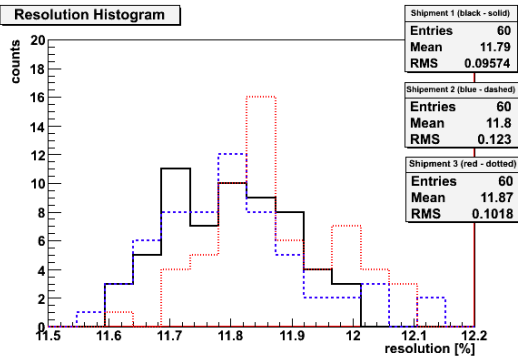
Figure 5: The distribution of the measured energy resolution for 180 bottom BGO crystals. The 3 histograms show the three different shipments (black-solid is the first, blue-dashed the second and red-dotted the third). The mean values are 11.8%, 11.8% and 11.9%, respectively.

XP5202/B) with a thin layer of optical grease. The entire assembly is made light-tight and the collimated ^{137}Cs source is directed towards the hexagonal face of the crystal directly opposite the the PMT. The output of the PMT is connected to a shaping amplifier which is is subsequently connected to a multichannel analyser. An energy spectrum is acquired for 10 minutes. To date 180 crystals have been tested and the distribution of the measured relative energy resolutions is shown in figure 5. The testing specification requires a relative resolution of at least 16% while the measured mean value for all crystals is 11.8%. No significant differences are seen between different crystal deliveries.

The side BGO crystals are 20 cm long and the measurements of energy resolution are done in different ways. The crystal is loosely wrapped in reflective Tyvek paper, and placed on a platform beneath which a collimated ^{137}Cs source moves along a rail, aligned with the axis of the crystal, and controlled by computer. Measurements take place within a light-proof box. The crystal is connected to the Photonis PMT with optical grease and the same data acquisition chain is used as described for the bottom BGO case. The relative energy resolution is measured for 5 different distances from the PMT (10 cm, 55 cm, 100 cm, 145 cm and 190 cm).
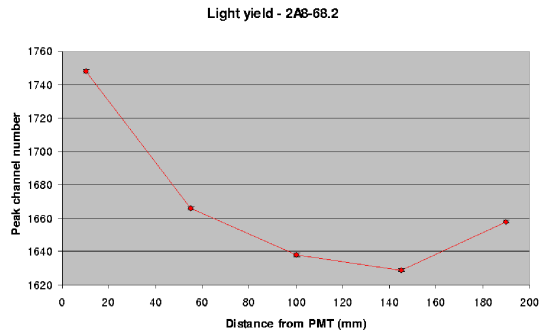

Figure 6: The reconstructed 661 keV peak position (arbitrary units) as a function of source position for a typical SAS crystal.

The typical behaviour is shown in figure 6. As expected, the light yield decreases as the source is moved away from the PMT but increases again at the furthest end. This behaviour is thought to be due to light trapping phenomena inside the crystal which has a high refractive index, n = 2.15. Computer simulations using GEANT4 are under way to understand the effect in detail. The relative energy resolution is required to be numerically less than 20% when the source is directed towards the geometrical centre of the rear flat face of the crystal. Furthermore, the position of the maximum of the 661 keV energy peak should not decrease by more than 5% (relative) when the ^{137}Cs beam illuminates positions 9 cm to the left or right of this central position. The light loss across a gluing boundary has also been studied and is found to be negligible compared to the overall trend of the light loss curve.

References

[1] M. Axelsson et al., astro-ph/07041603.

[2] M. Pearce et al., these proceedings.

[3] http: //www.che.nsk.su/index-en.html

[4] Y. Kanai et al., Nucl. Instr. and Meth. A 570 (2007) 61.