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Temperature effects in the ATIC BGO calorimeter

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Abstract

The Advanced Thin Ionization Calorimeter (ATIC) Balloon Experiment had a successful test flight and a science flight in 2000–01 and 2002–03 and an unsuccessful launch in 2005–06 from McMurdo, Antarctica, returning 16 and 19 days of flight data. ATIC is designed to measure the spectra of cosmic rays (protons to iron). The instrument is composed of a Silicon matrix detector followed by a carbon target interleaved with scintillator tracking layers and a segmented BGO calorimeter composed of 320 individual crystals totaling 18 radiation lengths to determine the particle energy. BGO (Bismuth Germanate) is an inorganic scintillation crystal and its light output depends not only on the energy deposited by particles but also on the temperature of the crystal. The temperature of balloon instruments during flight is not constant due to sun angle variations as well as differences in albedo from the ground. The change in output for a given energy deposit in the crystals in response to temperature variations was determined.

Keywords: Cosmic rays; High-altitude Ballooning; BGO temperature dependence

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1. Flight conditions

The ATIC Balloon instrument was designed to measure Cosmic ray spectra in the energy range from 100 GeV to 100 TeV for particles ranging from Hydrogen to Iron (Guzik et al., 1996). To cover this range the energy deposited in the BGO calorimeter ranges from a few MeV (Muons) to about 13 TeV (shower maximum at the largest angle). Cosmic ray muons are used to calibrate the absolute energy scale of the BGO calorimeter. A change in light output due to temperature changes would shift that scale.

The energy of a primary particle is derived from the total energy deposited in the calorimeter. A test at the particle accelerator at CERN was used to verify the energy determination (Ganel et al., 2005). The energy resolution measured during this test was 3% for 300-GeV electrons and 34% for 375-GeV protons, which is in agreement with the simulations (Ganel et al., 2005; Seo et al., 1996). The resolution for hadrons like protons is predominantly determined by the fluctuations in the first interactions due to the limited depth of the calorimeter.

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The ATIC instrument is flown in an insulated pressure vessel, which contains all detectors, and the entire electronics used to operate it. The calorimeter and its electronics, which is evenly distributed on all four sides and uses about 30 W of power, make up the bottom most part. A rotator is used to keep ATIC's solar panels pointed towards the sun during all phases of the flight except during ascent (the rotator does not have enough power to keep the instrument pointed in this phase).

Fig. 1 shows the temperature variations of the BGO calorimeter during the 2002/2003 flight. Starting at launch where the temperature is quite warm, cooling on ascent and settling into the day/night cycle of the flight. Shown are the temperatures of two opposing sides of the calorimeter, side 2 pointing towards the sun-side, side 4 away from the sun side. The bottom curve shows the difference between the two sides.

The output signal of BGO crystals like that of most inorganic scintillation crystals exhibits some dependence on its operating temperature (Melcher et al., 1985; Castoldi et al., 1998). This variation if uncorrected would shift the energy scale of the measured output of the ATIC BGO calorimeter. To correct this, its dependence was calibrated utilizing the thermal vacuum chamber at the Columbia Scientific Balloon Facility in Palestine, Texas.

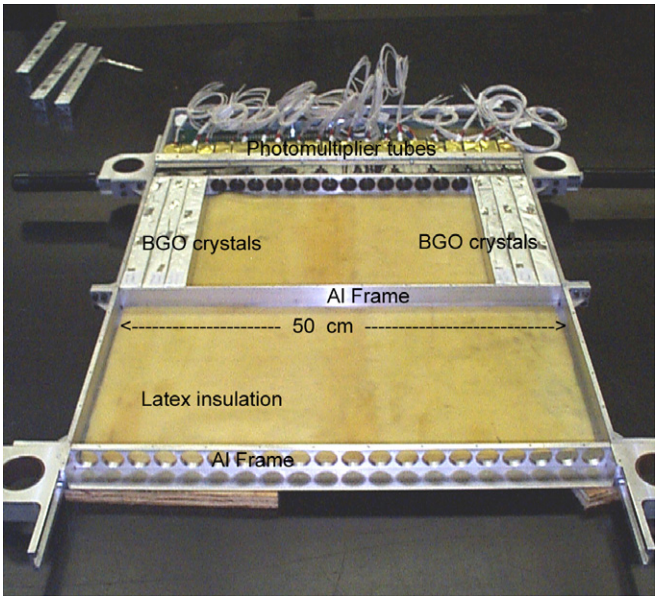

Fig. 2. One calorimeter tray open. The tray holds 40 BGO crystals, six of which are seen in the tray above.

2. The calorimeter trays

The individual BGO crystals of the ATIC Calorimeter, each 2.5 cm by 2.5 cm by 25 cm in size are wrapped in 25-μm-thick Teflon, and 25-μm aluminized Mylar foil for light tightness and viewed by a single photomultiplier tube, a Hamamatsu R5611-01 seen in the back of Fig. 2. A tray holds 40 crystals, six can be seen pointing towards the pmts. The top and bottom of each tray is lined with 0.5-mm thick latex to protect the crystals against shock and provide some thermal resistance. Once a tray is closed the BGO crystals are practically surrounded by aluminium, giving good thermal conductivity across the calorimeter. Aside from good thermal conductivity each tray is a self-contained unit and light enough to be lifted by two people during recovery of the instrument, an important aspect for balloon flights in Antarctica.

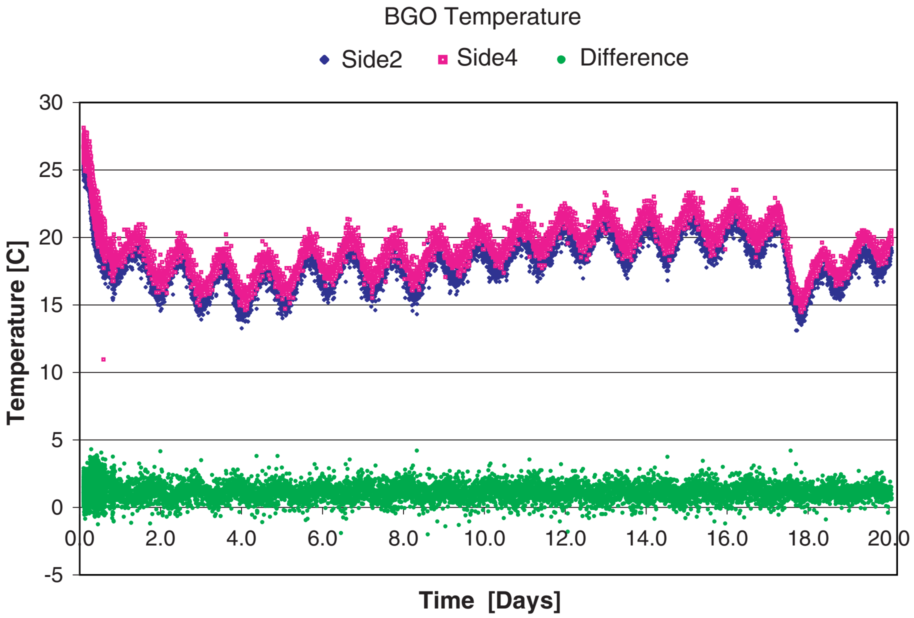

Fig. 1. The BGO temperature during the flight of ATIC 2.

3. The BGO calorimeter

The BGO calorimeter is made of ten stacked trays, covering an active area of 51 cm × 51 cm with alternating layers rotated 90° relative to each other forming X and Y layers. Fig. 3 shows the frames of the ten trays.

This design minimizes the thermal gradients so that the temperature variations during flight effect all BGO crystals uniformly as shown by the bottom curve in Fig. 1.

4. The set-up

In order to determine the temperature sensitivity of the ATIC calorimeter the ATIC instrument was taken to the CSBF in Palestine, TX and set up in their thermal vacuum chamber. Unfortunately, the chamber was too small to fit the entire instrument; the top two scintillators and the carbon target section were too wide to fit in. So the BGO calorimeter, two scintillator panels and the readout electronics including the entire flight electronics was set up on a cart and moved into the chamber. Fig. 4 shows the setup of the instrument in the thermal vacuum chamber.

5. The temperature calibration

The calorimeter was held at various temperatures (35, 23, 15, 1 °C) to within ±0.5 °C and cosmic ray muon data were collected for a duration of at least 2 h. The energy calibration of the ATIC calorimeter is derived from the pulse height measurement of the energy deposit of cosmic ray muons passing through the BGO crystals. The temperature sensitivity is derived in the same way. The position of the muon peak is determined for each crystal at each temperature. Fig. 5 shows the pulse height distributions of the muon data for an individual BGO crystal at these temperatures. The position of the muon peaks was determined by fitting a Landau distribution combined with an exponential distribution to the pulse height data.

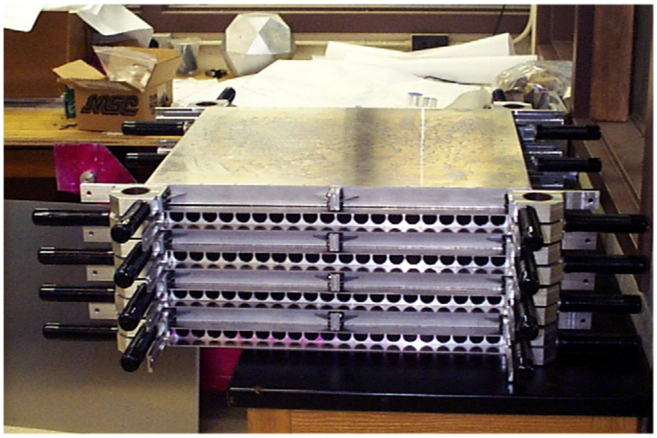

Fig. 3. Eight calorimeter trays stacked up.

Fig. 4. The set-up for the temperature calibration in the thermal vacuum chamber at CSBF, Palestine, TX.

For each individual BGO crystal a line was fitted to the peak position versus temperature (Fig. 6). The slope is the sensitivity of this particular crystal, in this case −2.2% per degree Celsius.

As an illustration of the variation from crystal to crystal Fig. 7 shows the slopes of the BGO crystals normalized to 0 Degree C. They centre at −1.86% per degree Celsius. This is higher than the value given by the manufacturer, formerly Bicron now Saint Gabin Crystals, 1.2%/°C (SGC_BGO_Data_Sheet[1]) because the calibration contains the sensitivity of the BGO crystal as well as that of the readout electronics (Pmt, base, ADC).

This correction is applied to each individual crystal gain for the energy calibration to compensate for temperature variations during the flight as well as to correct the difference between muon calibration and flight. Pedestals in the ADCs are measured periodically during the flight so that any variation is corrected using the flight data itself.

6. Conclusions

The temperature sensitivity of the BGO calorimeter was calibrated by utilizing the thermal vacuum chamber at the Columbia Scientific Balloon Facility in Palestine, Texas. This calibration is used to correct the Energy scale for the ATIC calorimeter at the temperatures experienced during its balloon flight in McMurdo, Antarctica. The calibration is for the BGO crystals in combination with readout electronics, an end-to-end calibration. Since the electronics was not calibrated separately it was not possible to derive the temperature sensitivity for the BGO crystals themselves. The uncertainties of this calibration add about

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[1] http://www.detectors.saint-gobain.com/Media/Documents/S0000000000000001004/SGC_BGO_Data_Sheet.pdf.

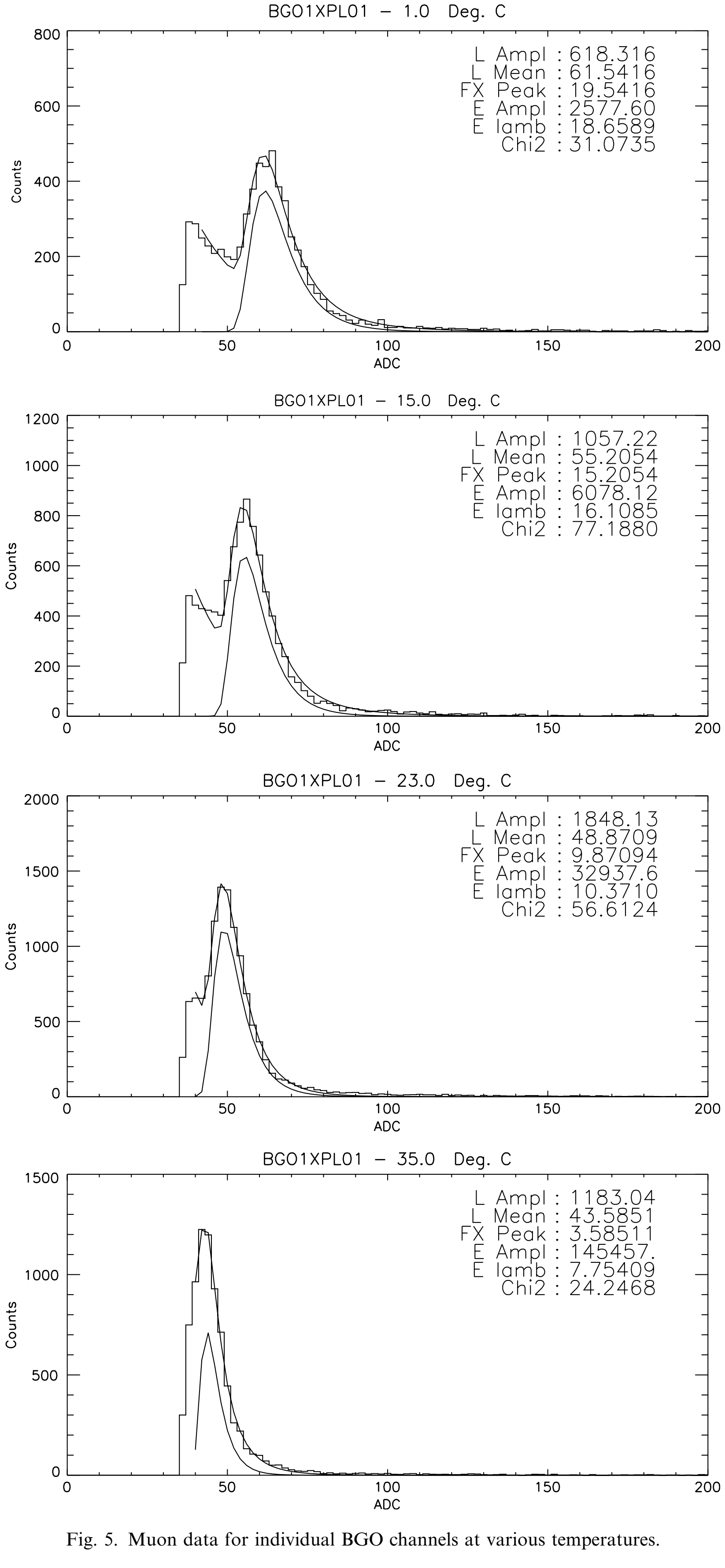

Fig. 5. Muon data for individual BGO channels at various temperatures.

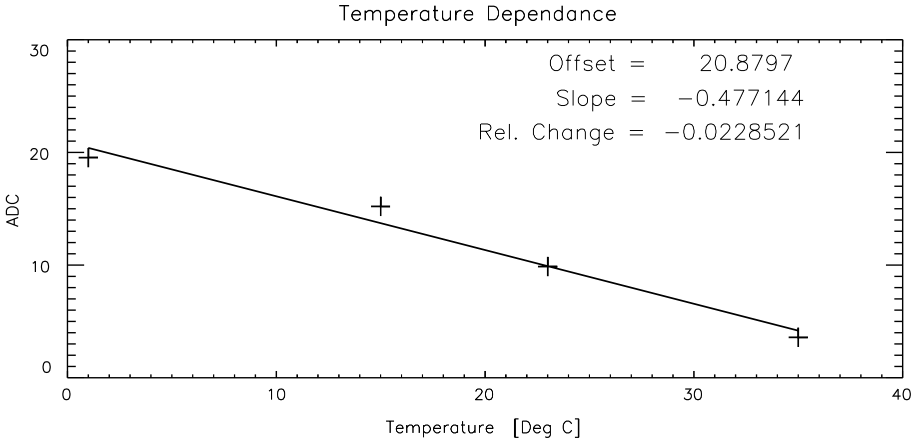

Fig. 6. Temperature sensitivity of one BGO crystal.

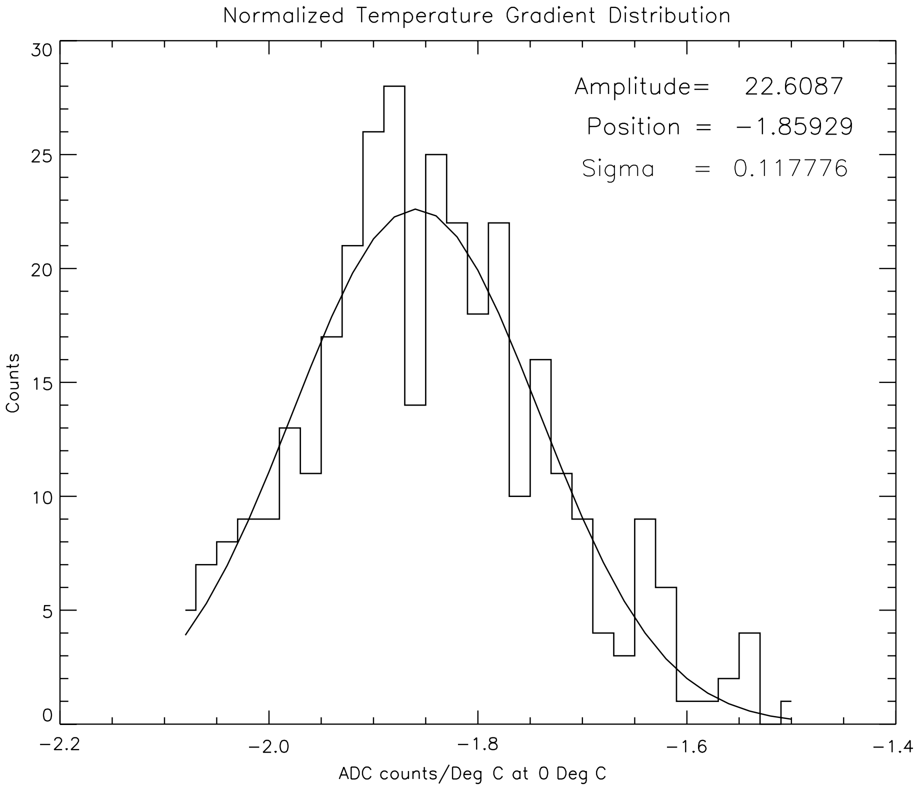

Fig. 7. Distribution of the sensitivity of individual crystals.

1.2% uncertainty to the resolution of the energy measurement of the calorimeter.

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