

Balloon-Flight Test of a Lanthanum Bromide Gamma-Ray Detector with Silicon Photomultiplier Readout

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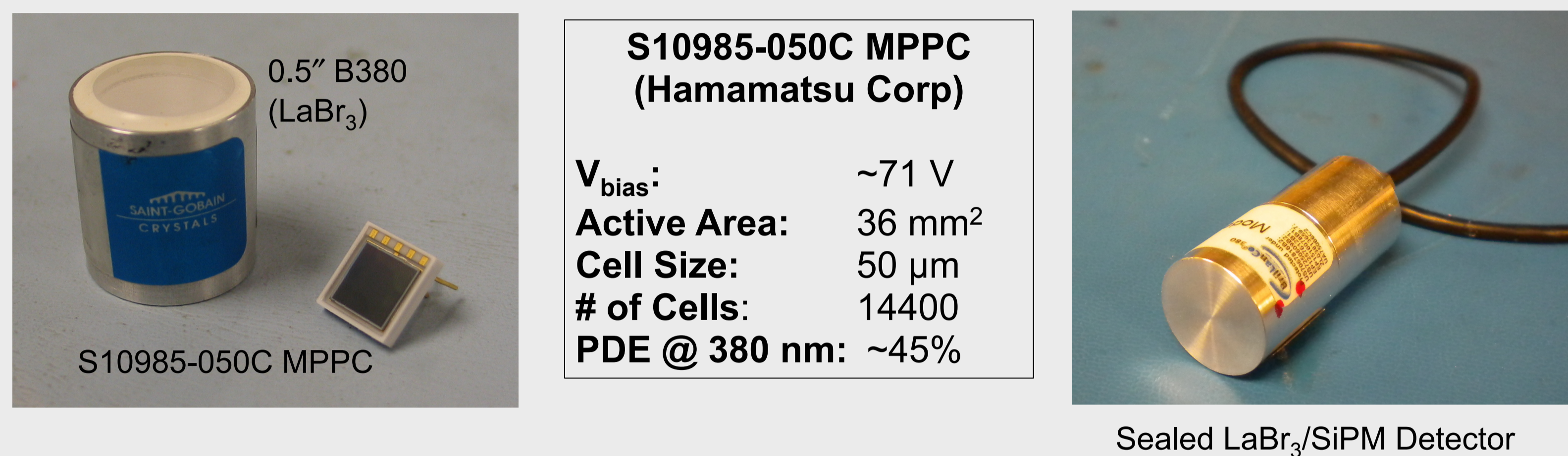
Abstract

New scintillator materials have been shown to hold great potential for low-cost, reliable gamma-ray detectors in high-energy astronomy and solar physics. New devices for the detection of scintillation light promise to make scintillator-based instruments even more attractive by reducing mass and power requirements. In particular, silicon photomultipliers (SiPMs) are commercially available that offer gains and quantum efficiencies similar to those of photomultiplier tubes (PMTs), but with greatly reduced mass, high ruggedness, low voltage requirements, and no sensitivity to magnetic fields. SiPMs have by now been shown to perform well as readouts for scintillator gamma-ray detectors in the laboratory. Before they may be used in space-based instruments, however, it must be shown that 1) sufficiently large light collecting areas may be fabricated without loss of performance; 2) the variability of the gain with temperature can be compensated for; and 3) that SiPMs are sufficiently robust and radiation hard. We present results from ongoing work to investigate whether SiPMs are appropriate for use in space, including data from the successful flight of a combined SiPM/LaBr₃ detector on a high-altitude scientific balloon, and the performance of larger gamma-ray spectrometers with improved light collection.

SiPM/LaBr₃ Detector

Due to our interest in performing gamma-ray spectroscopy with LaBr₃ ($\lambda_{\text{peak}} = 380 \text{ nm}$) we have focused on commercial SiPMs with good sensitivity at blue wavelengths, as characterized by the Photon Detection Efficiency (PDE).

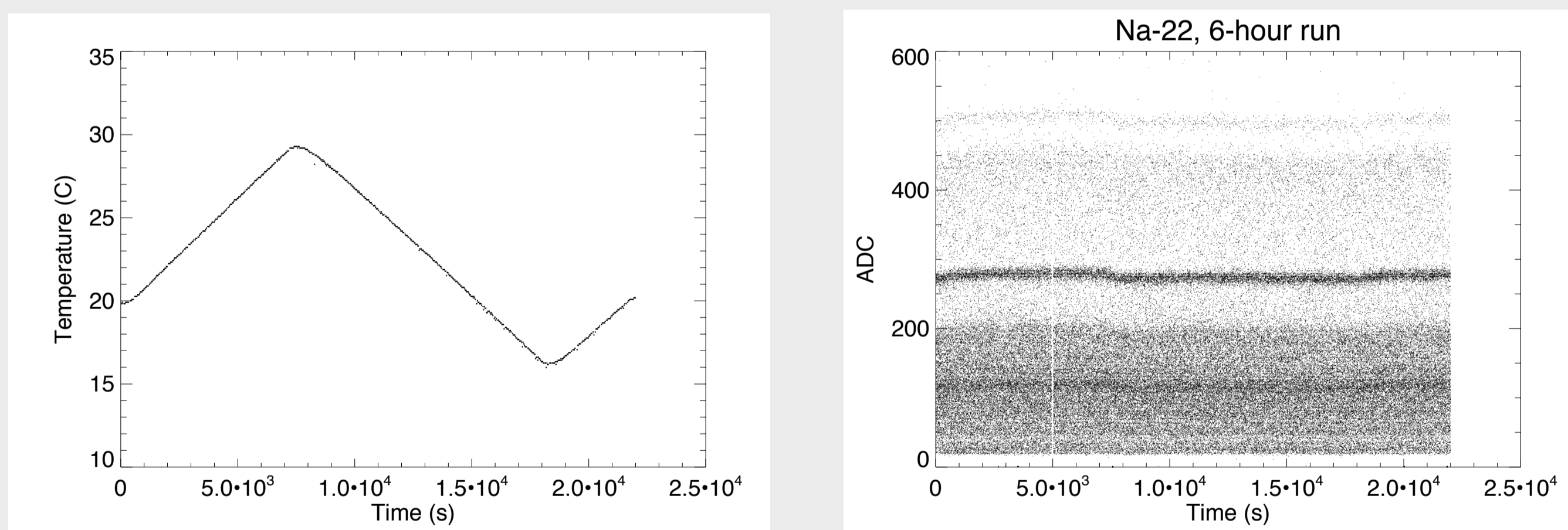
The largest blue-sensitive SiPM available at the time this work began was the 6 mm \times 6 mm Hamamatsu S10985-050C (actually a 2 \times 2 array of 3-mm SiPMs on a single chip):



After initial testing, we had the S10985 coupled directly to a 6 mm \times 6 mm \times 10 mm LaBr₃ crystal in a hermetically sealed package (this work was done by Saint-Gobain Crystals).

Laboratory Testing

The SiPM/LaBr₃ detector is read out using a custom processor board. The board features four input channels, an adjustable low-noise bias voltage supply, and an RS-232 interface, and is controlled by a PIC18F4620 processor. The gain as a function of temperature was measured using calibration sources in a thermal chamber, and voltage corrections were entered into a lookup table in the PIC processor's memory. This permits the SiPM bias voltage to be adjusted as a function of temperature to maintain constant gain:

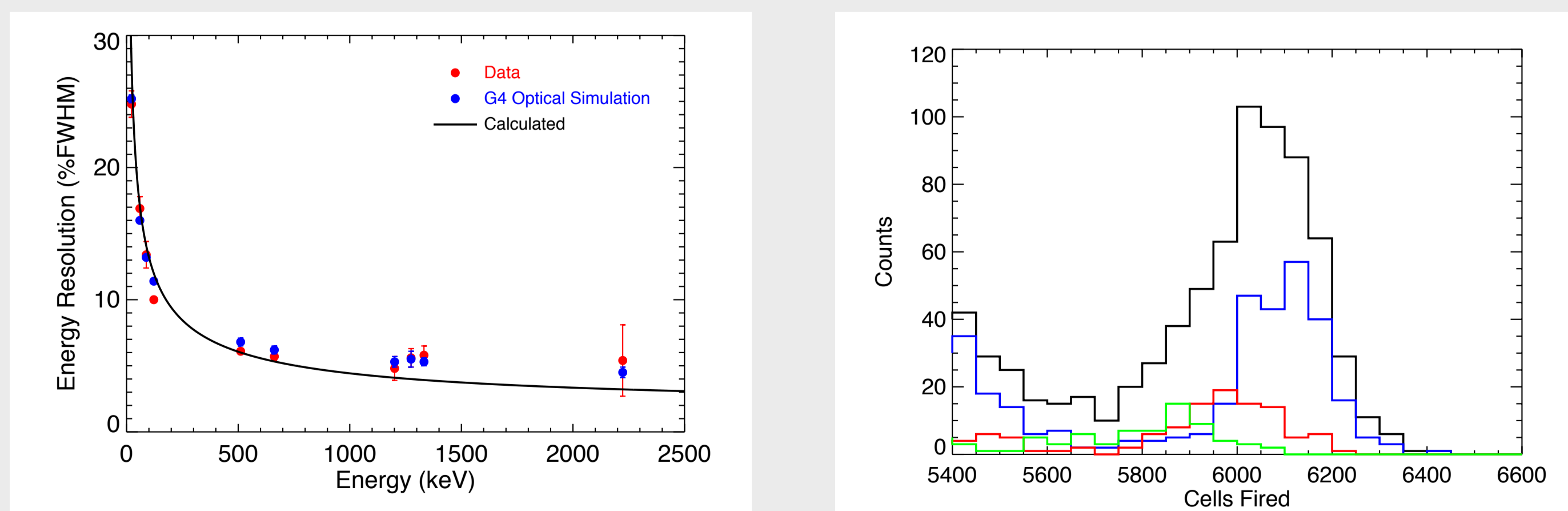


Temperature profile in thermal chamber

ADC vs. time for ²²Na source: the gain remains constant despite the temperature variation

The SiPM/LaBr₃ detector was calibrated at room temperature with radioactive sources. At the same time, Geant4 optical simulations were used to model the scintillation process and optical photon propagation and collection, including the SiPM PDE, cell recovery time, and cross talk and afterpulsing. The measured vs. simulated energy resolution are in good agreement from 22 keV to 2.2 MeV.

At high energy, the resolution for both data and simulations is worse than expected using the calculation of Christian et al. (2010, NIM-A, 624,449). The optical simulations indicate the this is due to saturation from events that occur very close to the SiPM, producing a low-energy tail.



Comparison between measured (red) and simulated (blue) energy resolution as a function of energy.

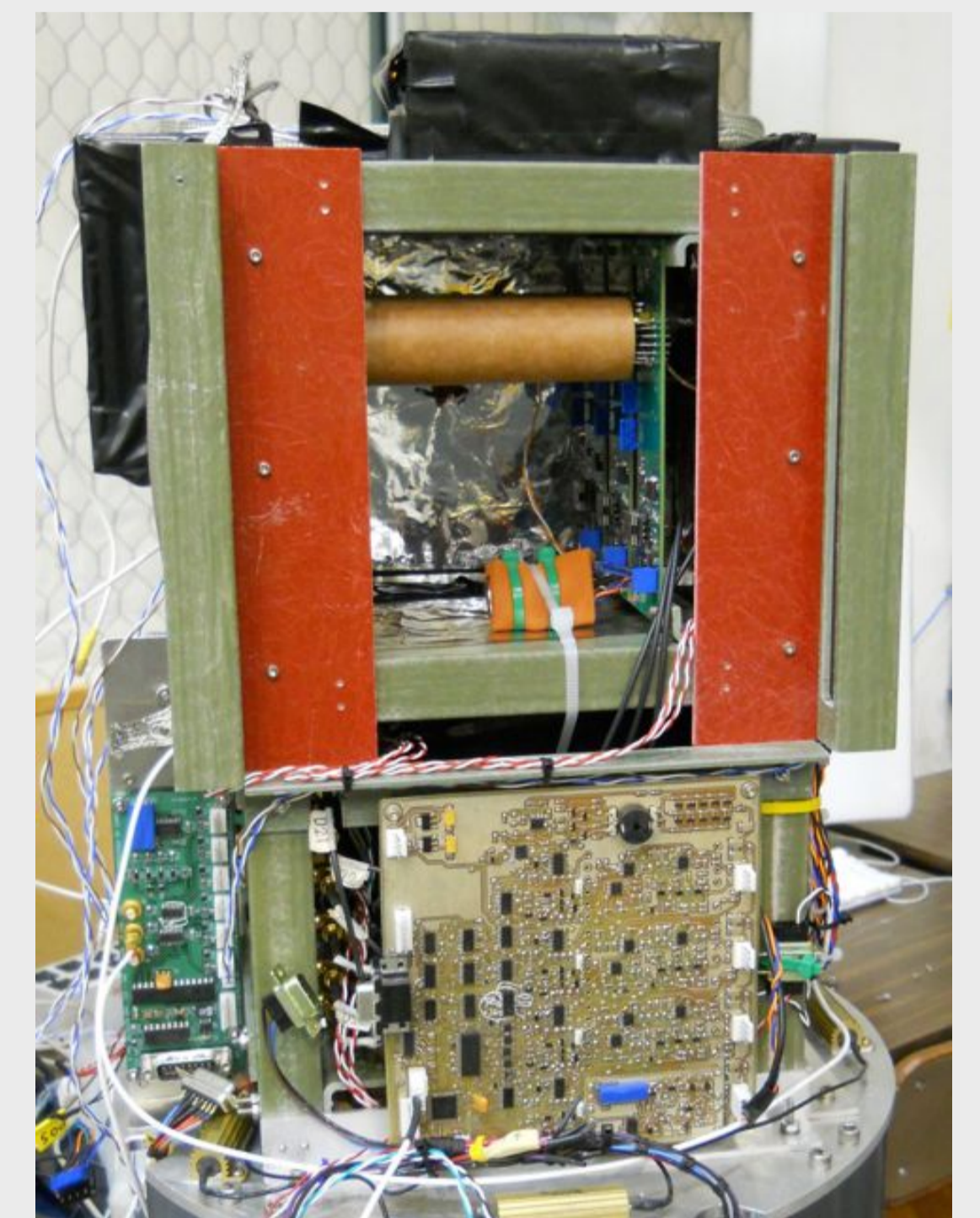
Simulated histograms of fired cells for 1333 keV photons: total (black), top 6 mm (blue), 2 mm below (red), and bottom 2 mm (green)

Balloon Flight

The SiPM/LaBr₃ detector was coupled to thermistor and flown as a piggyback instrument on the UNH GRAPE/FACTEL balloon payload. The payload was launched on Sept. 23, 2011 from Ft. Sumner, NM, and remained at float altitude for 26 hours. The goal was to demonstrate stable performance of the SiPM under realistic environmental conditions, including compensation for the gain variations due to changes in temperature.

The SiPM/LaBr₃ detector is visible at right, wrapped in orange neoprene insulation, with the custom readout and processor board directly below.

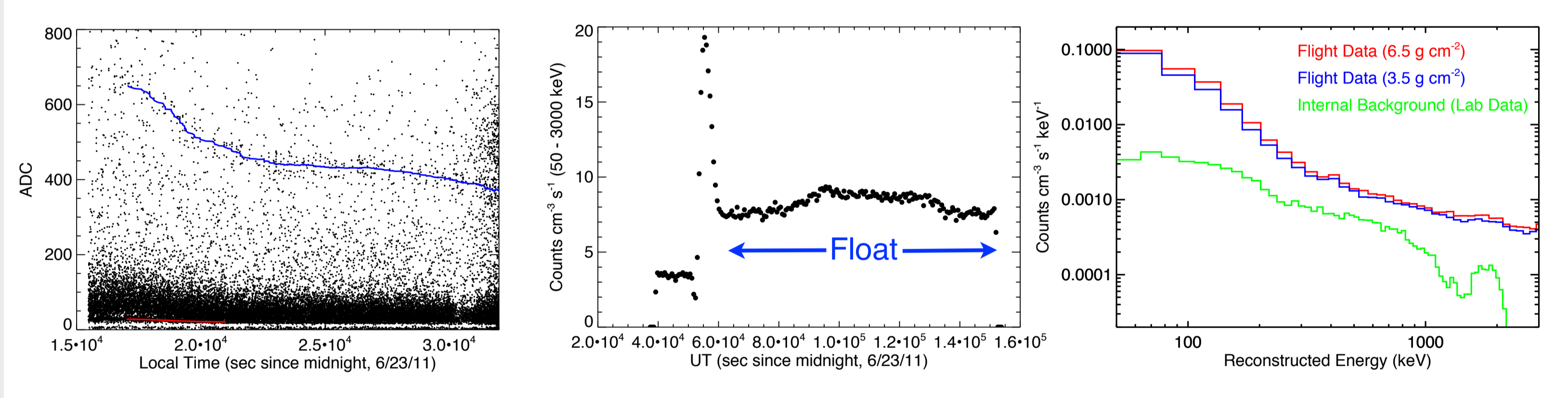
Unfortunately, the temperature compensation function of the processor board failed prior to flight and could not be fixed due to time constraints. Thus the gain of the SiPM did vary considerably as the temperature inside the FACTEL pressure vessel fluctuated.



We have been able to perform a rough gain vs. temperature correction by tracking the variation of LaBr₃ internal background features:

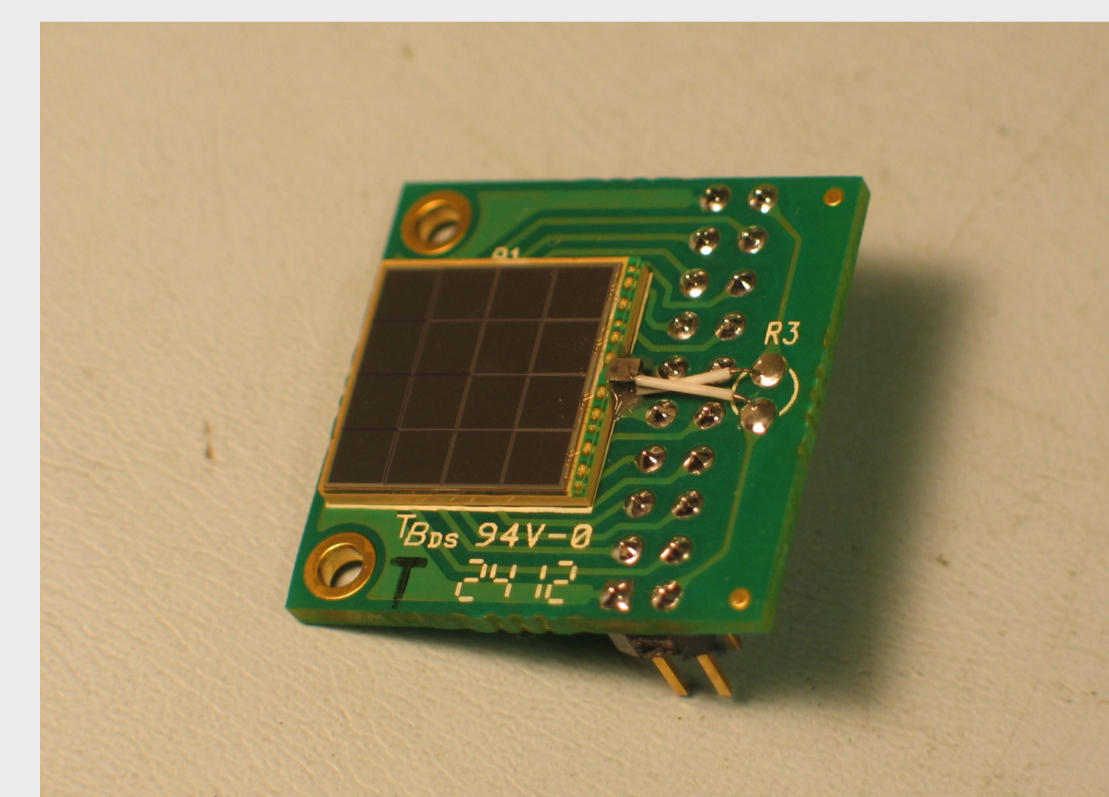
In this way we derived the count rate from 50 keV to 3 MeV. The rate shows the expected peak in the Pfozter maximum during ascent, and varies with atmospheric depth as expected during float.

Recorded background spectra at float, compared to the internal background spectrum measured in the lab. The energy scale is approximate.



The counting rate in the SiPM/LaBr₃ detector at an atmospheric depth of 3.5 g cm⁻² is $\sim 7.5 \text{ cts cm}^{-3} \text{ s}^{-1}$. This agrees well with the predicted rate of 5.9 cts cm⁻³ s⁻¹ from Monte Carlo simulations, plus the measured internal background rate of $\sim 1 \text{ ct cm}^{-3} \text{ s}^{-1}$. **We therefore conclude that the SiPM/LaBr₃ detector performed well during flight, despite the failure of the temperature compensation.**

New SiPM Array



We have begun testing a new, larger SiPM array, the 13 mm \times 13 mm Hamamatsu S11828-3344, consisting of a 4 \times 4 array of 3-mm SiPM elements. We have mounted this device on a custom array board using a solder reflow method, with a thermistor coupled directly to the chip.

We have performed preliminary measurements with the S11828-3344 coupled to a 13 mm \times 13 mm \times 13 mm LaBr₃ detector. The LaBr₃ is packaged with a 3 mm light guide to allow the scintillation light to spread out, preventing saturation of the SiPM. Initial tests confirm superior energy resolution compared to the previous detector.

