Background Modeling for the Balloon-Borne Gamma Ray Polarimeter Experiment (GRAPE)

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The Gamma Ray Polarimeter Experiment (GRAPE), a balloon borne Compton polarimeter for studying 50-300 keV gamma rays. The payload has flown twice (in 2011 and 2014) with the primary goal being to measure the polarization from the Crab Nebula/Pulsar. Understanding the background is a fundamental part of the the instrument design. The background arises from the interaction of cosmic ray and atmospheric radiations with the instrument. Published parameterizations of these various radiation components have been used to simulate the instrument background using the GEANT4 simulation toolkit. The initial simulations resulted in background estimates that were not consistent with the measured background. These discrepancies have been resolved by including the effects of optical crosstalk that is known to exist within each polarimeter module. For each balloon flight, the payload was comprised of an array of independent polarimeter modules. Each module consists of an array of small scintillator elements on the from end of a multi-anode PMT (MAPMT). Ideally, the light from each scintillator element is collected by one and only one anode of the MAPMT. However, there is a known issue with optical crosstalk that arises from light exiting the scintillator elements and spreading across several anodes. This crosstalk can result in the misclassification of recorded events. A model was developed to represent the crosstalk, which was subsequently incorporated into our simulations. The resulting simulations show significantly improved agreement with the measured background. Simulations with the crosstalk modeling are now being used to model the instrument response.

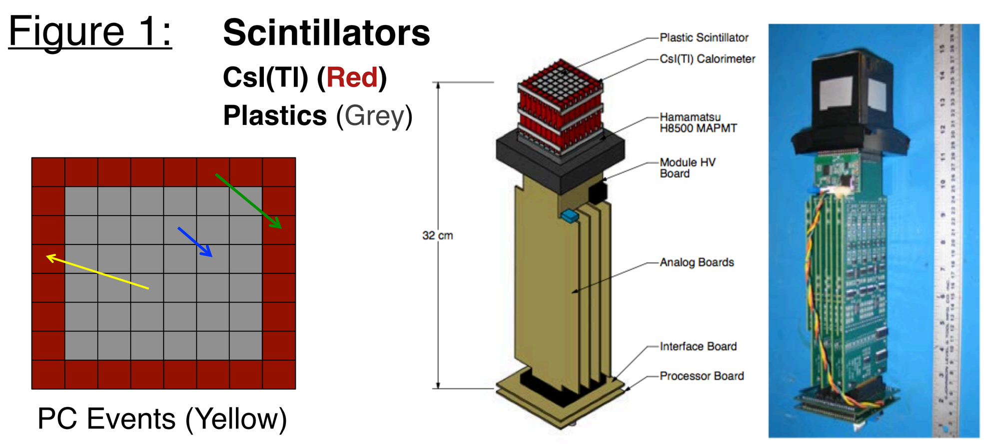
GRAPE

he Gamma RAy Polarimeter Experiment (GRAPE) is a balloon borne Compton polarimeter optimized for 50-300 keV gamma rays. GRAPE was flown initially in 2011. An improved version (improved shielding and larger detector arrays) was flown in 2014.

The configuration flown in 2014 had 24 detector modules (Figure 1). Each module consists of 36 plastic and 28 CsI(Tl) scintillator elements mounted on a multi-anode photo-multiplier tube (MAPMT). PC events are defined as events that interact in one plastic element and one CsI(Tl) element. Ideally, these are events in which a photon scatters from the plastic to the CsI(Tl). These are the events that carry with them the signature of polarization. The module array is completely enclosed by both active shielding (plastic scintillator) and passive lead shielding (Figure 2). Lead collimators are used to define a 20° FoV. This instrument assembly is inside a pressure vessel that is maintained at 1 atm pressure and can be moved in elevation. An inertia wheel assembly is used to point the entire gondola in azimuth.

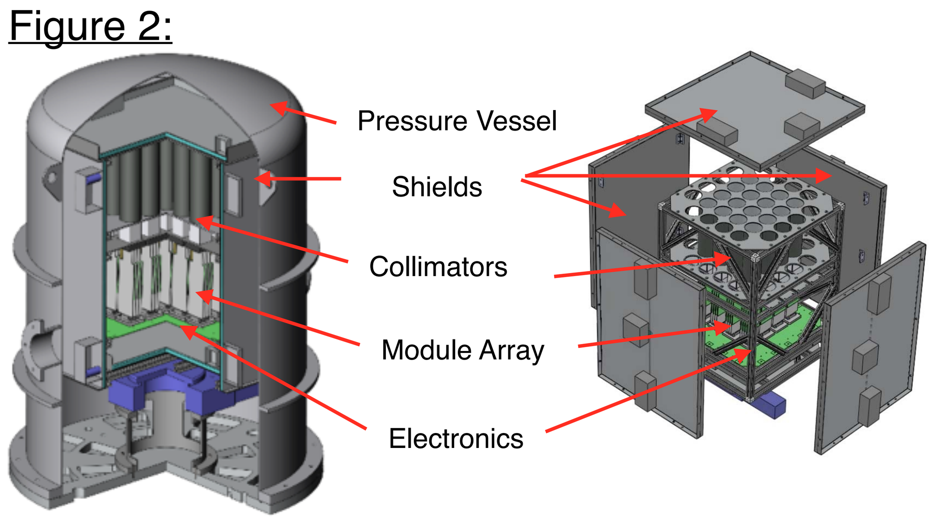
The GRAPE payload was launched on September 26th, 2014 from Fort Sumner, NM. During the flight, GRAPE observed the Sun, Cygnus X-1 and the Crab Nebula, along with two background regions in the sky that we refer to as BGD2 and BGD4 . The background regions were regions in the sky that did not have known sources above our sensitivity level. During the flight, the Sun was not active and Cygnus X-1 was at a low intensity state (as determined from Fermi-GBM data). So these data could also be used as background data. The payload spent 14.4 hours at float. The Crab was observed for only 1.8 hours. We chose Bgd4 for comparison between flight and simulation.

Figure 1:



Schematic vs Fabricated Module.

Figure 2:



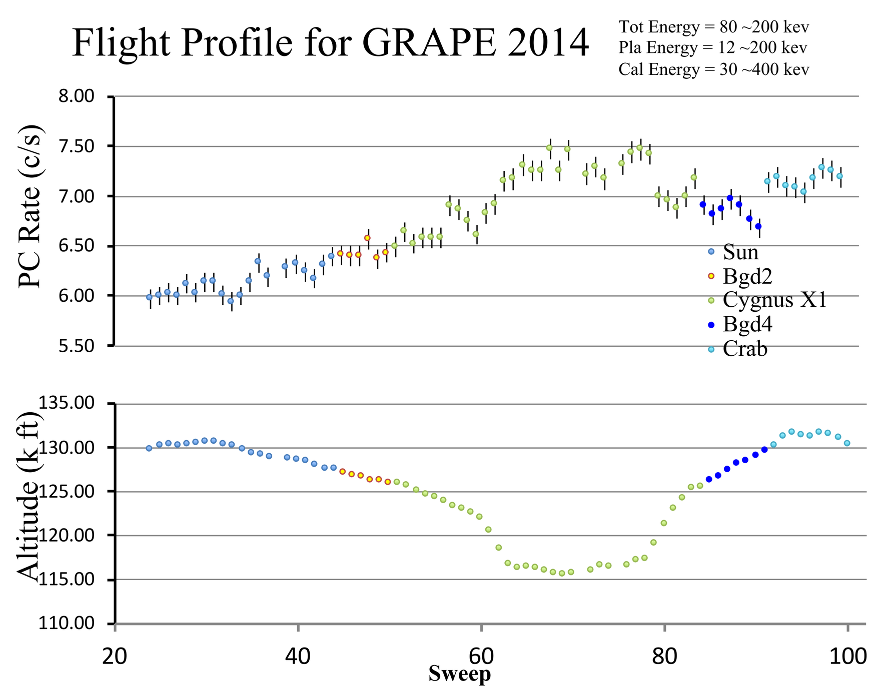


Figure 3: Flight profile for the Grape 2014 flight.

Input Background Spectra

The instrumental background comes from the radiation environment to which the payload is exposed. The background comprises of several different components.The relevant components consist of photons (gamma rays), and various subatomic particles (protons, electrons, positrons and neutrons). Some of these components come directly from deep space (cosmic rays). Some are generated by cosmic ray interactions in the atmosphere (secondaries). Parameterized spectra of each component are obtained from sources in the literature. The parameterizations of Gehrels et. al. [1] was used for gamma rays, Armstrong et. al. [2] for neutrons, and Mizuno et. al. [3] for electrons, positrons, and protons. This is shown in figure 4.

This input spectra is simulated using GEANT4 [4] toolkit for the GRAPE 2014 configuration. The resulting output is shown in figure6.The each individual components of the background as well as the total sum (black) is shown in figure.

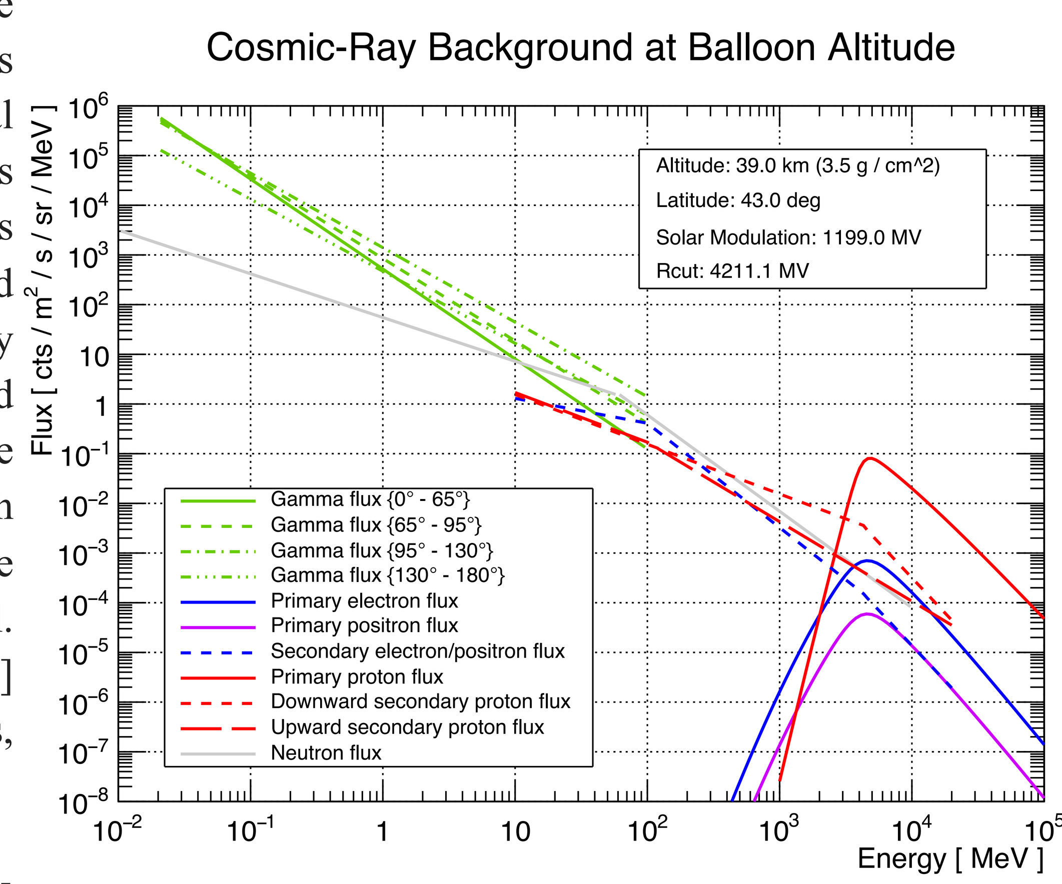


Figure 4: Input Spectra of background components.

Simulated Background

The simulated background spectra generated by each component are shown in Figure 6. The total **simulated background (black)** is the summation of each of the individual background components. We can see that the **measured flight background (blue)** significantly disagrees with the simulated background at higher energies (above ~150 keV). Optical signal cross talk between scintillator elements in within each module is hypothesized to be responsible for this disagreement.

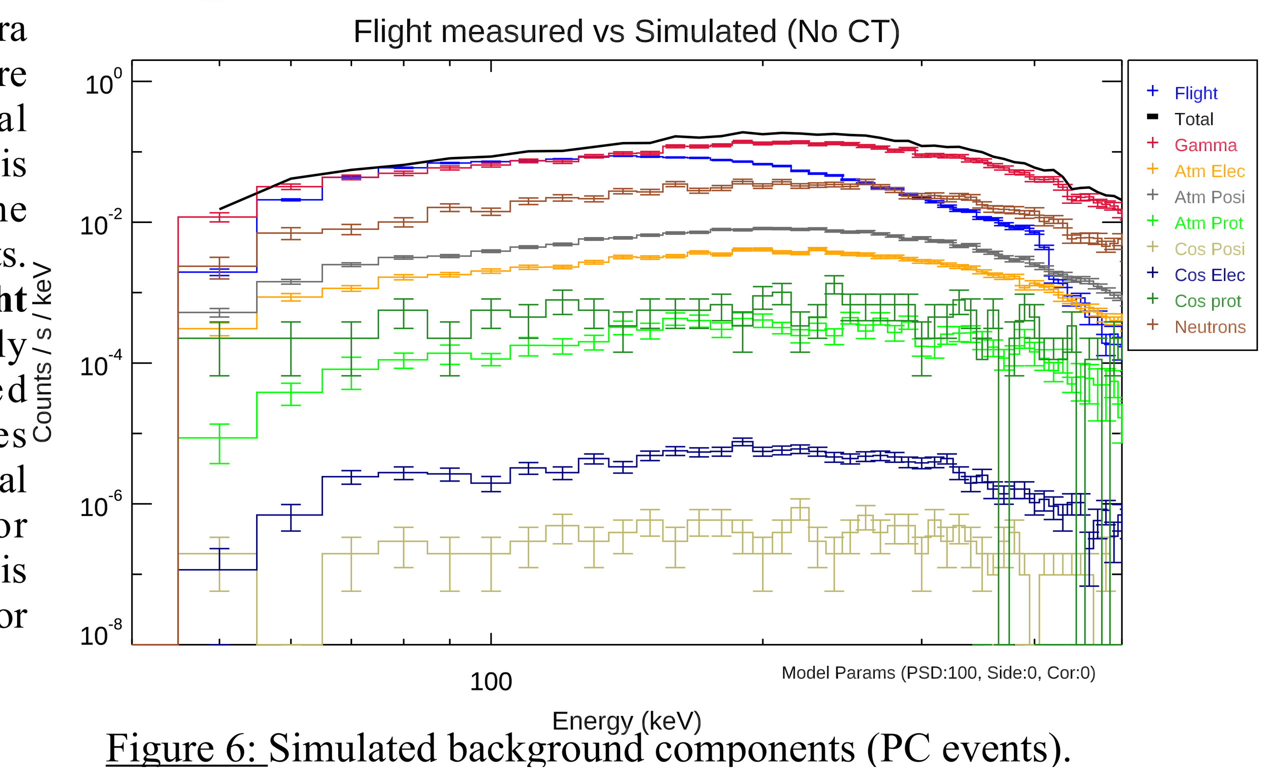


Figure 6: Simulated background components (PC events).

Cross-Talk Modeling

Optical cross-talk is a phenomenon that occurs at the 1.5mm thick glass window between the scintillator array and the MAPMT where the the scintillated light spills over to other (adjacent) anodes (Figure 7b, orange arrow) in addition to its respective anode (Green). This can lead to a misclassification of events (for example, triggering more than two anodes), which can explain the discrepancy between simulated and measured spectra as shown in Figure 6. We have therefore created a model to replicate this cross-talk effect and applied this to our simulations.

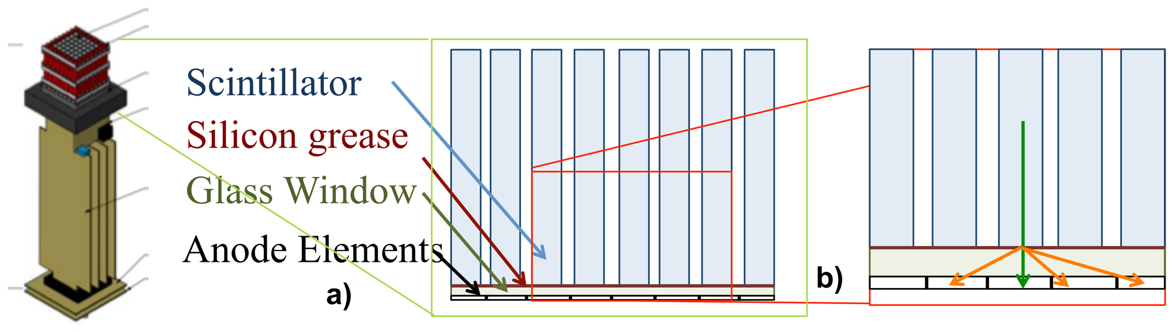


Figure 7a :(Left) shows where cross-talk occur.
Figure 7b: (Right) The green arrow shows an ideal trigger and orange arrows shows cross-talk.

We modeled the crosstalk by giving certain amount of light to neighboring anodes isotropically. This is much more clearly seen in figure 8. A primary anode (P) would give a certain amount of light to the eight adjacent neighbors. We further divided the parameters to side (S) and Corner (C) adjacent anodes which are two of the parameters in the crosstalk model. We expect a crosstalk 5-10%.

GRAPE already uses a Pulse Shape Discrimination (PSD) method to reject cross talk between different types of scintillators. It exploits the decay time difference plastics (1.8ns) and calorimeters(600ns). We suspect that this is not 100% efficient so we used this as one of our parameters for our model.

The best value of the parameters we found to be (PSD:95 Side:10 Cor:5). The resulting energy loss spectra is shown in figure 9. We can see that our simulated

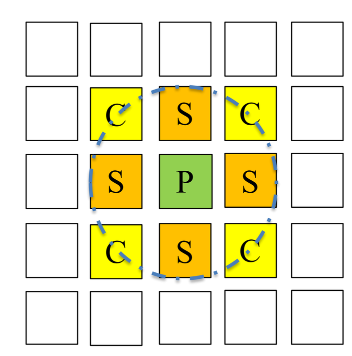


Figure 8: Picture showing the side adjacent and corner adjacent anodes.

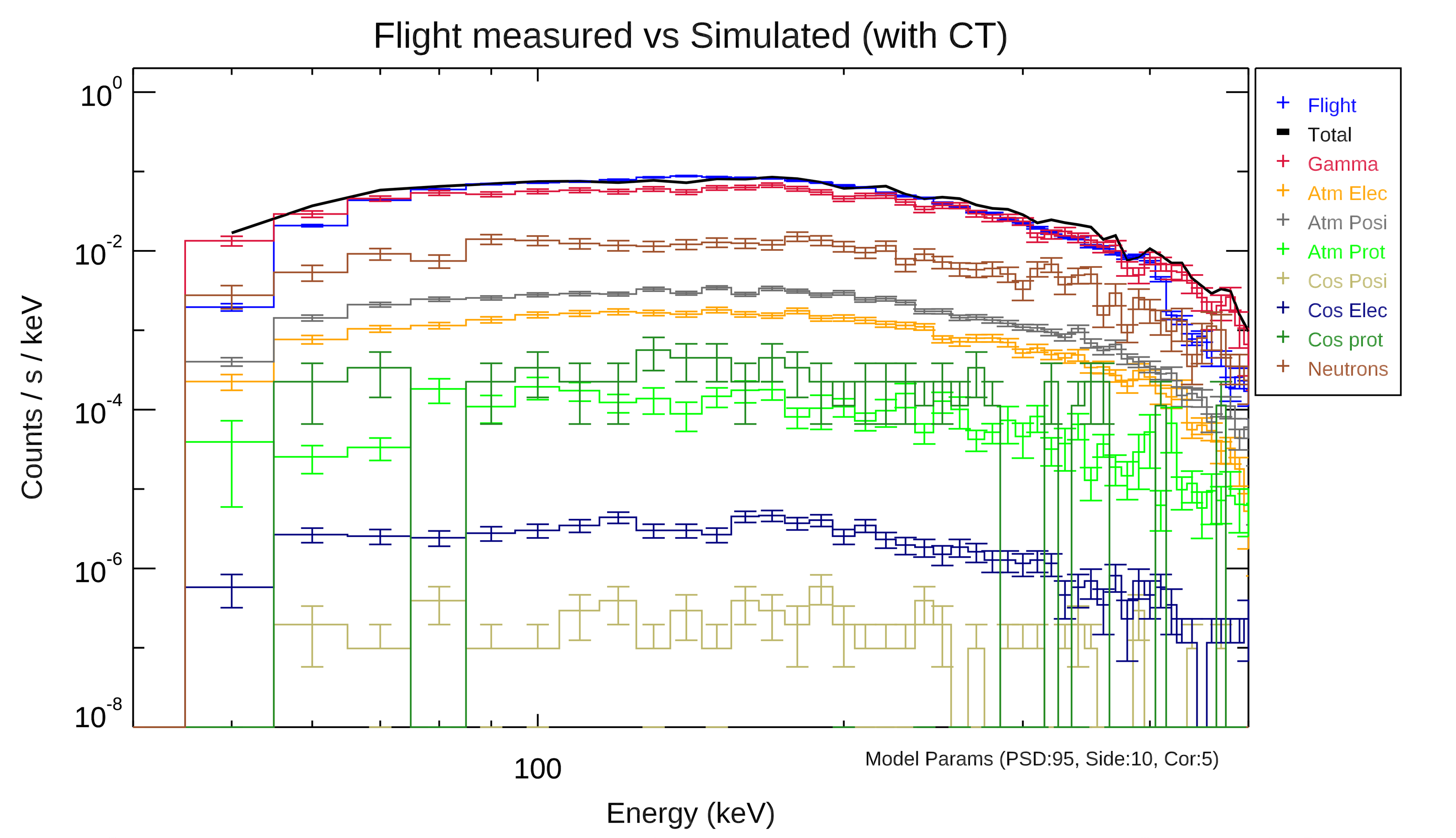


Figure9: Simulated background components (with cross-talk model) vs Flight Spectra (PC Events).

Summary

The effect of cross-talk is significant in our instrument, especially at higher energies. This effect has now been modeled and included in our simulations, resulting in a good agreement between simulated and flight data. Our ability to accurately model this background validates our simulations and gives us confidence in our ability to model the instrument response and accurately analyze the flight data.

[1] Gehrels, N. . Instrumental background in balloon-borne gamma-ray spectrometers and techniques for its reduction. Nuclear Instruments & Methods In Physics Research Section A-Accelerators Spectrometers Detectors And Associated Equipment, 1985.
[2] Armstrong, T. W. , Chandler, K. C. , and Barish, J. . Calculations of neutron flux spec- tra induced in the Earth's atmosphere by galactic cosmic rays. Journal of Geophysical Research, 1973.
[3] Mizuno, T. , Kamae, T. , Godfrey, G. , Handa, T. , Thompson, D. J. et al. Cosmic-ray background flux model based on a gamma-ray large area space telescope balloon flight engineering model. Astrophysical Journal, 2004.
[4] Agostinelli, S. , Allison, J. , Amako, K. , Apostolakis, J. , Araujo, H. et al. GEANT4- a simulation toolkit. Nuclear Instruments & Methods In Physics Research Section A- Accelerators Spectrometers Detectors And Associated Equipment, 2003.