Modeling the Background for Balloon Borne Experiments

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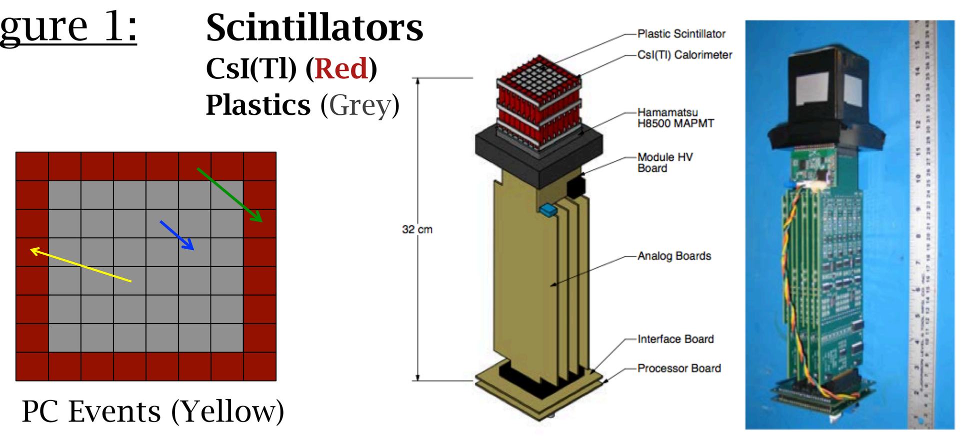
Balloon borne experiments are common in high energy astrophysics because they provide a means to make measurements at an altitude where the atmospheric attention is not significant. In these experiments, measurements are often dominated by background induced by the ambient radiation environment (high energy photons and cosmic rays). Accurate background modeling is crucial to the success of the experiment. There are numerous components that contribute to the background and must be considered in any modeling effort. The Gamma RAy Polarimeter Experiment (GRAPE), a balloon borne mission, was flown in the fall of 2014. Its primary goal was to measure the polarization of the Crab Nebula in the photon energy range of 50-500 keV. GRAPE collected extensive background data during its 16 hour flight. Published parameterizations of the various radiation components have been used to simulate the instrument background.

GRAPE

The Gamma RAy Polarimeter Experiment (GRAPE) is a balloon borne Compton polarimeter optimized for 50-500 keV gamma rays. GRAPE was flown initially in 2011. An improved version (with improved shielding and a larger detector array) 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). The grid of detector elements is designed to measure scattered photons. The distribution of the scattered photons provides a polarization measurement of the incident flux. PC events. the most dominant scatter event type, 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) element. 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.

Figure 1:



Schematic vs Fabricated Module.

Figure 2:

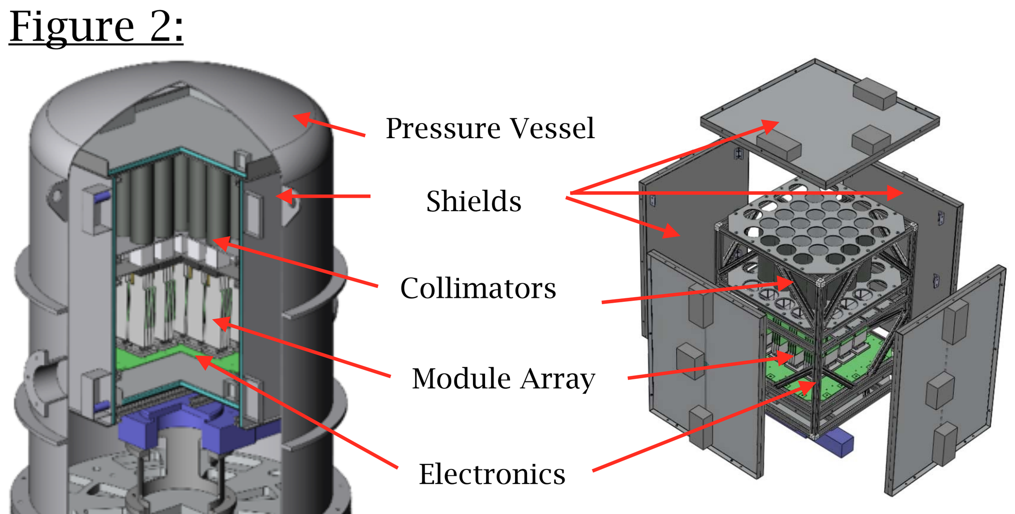


Figure 3:

2014 Flight

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.

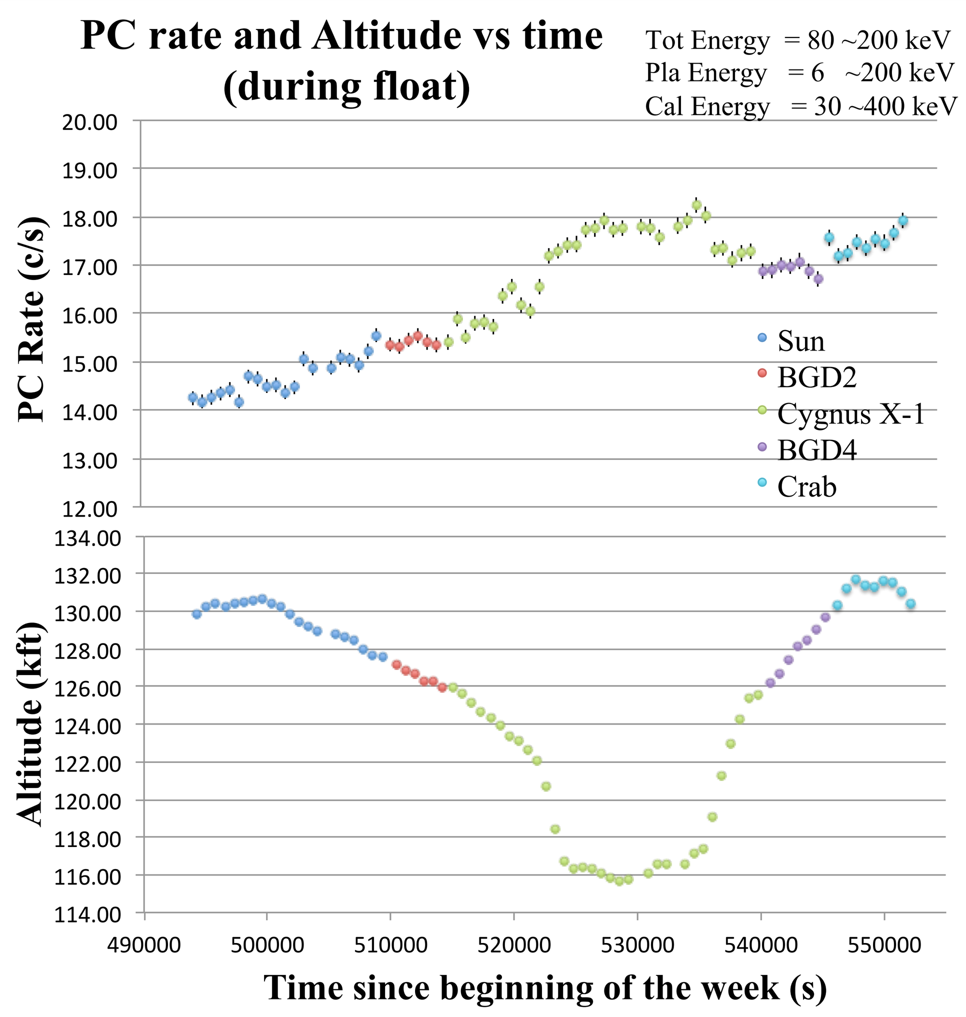


Figure 4: Flight profile for the Grape 2014 flight.

Input Background Spectra

The instrumental background comes from the radiation environment to which the payload is exposed. The radiation environment consists of several components, each of which contributes to the background. The relevant radiation 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.

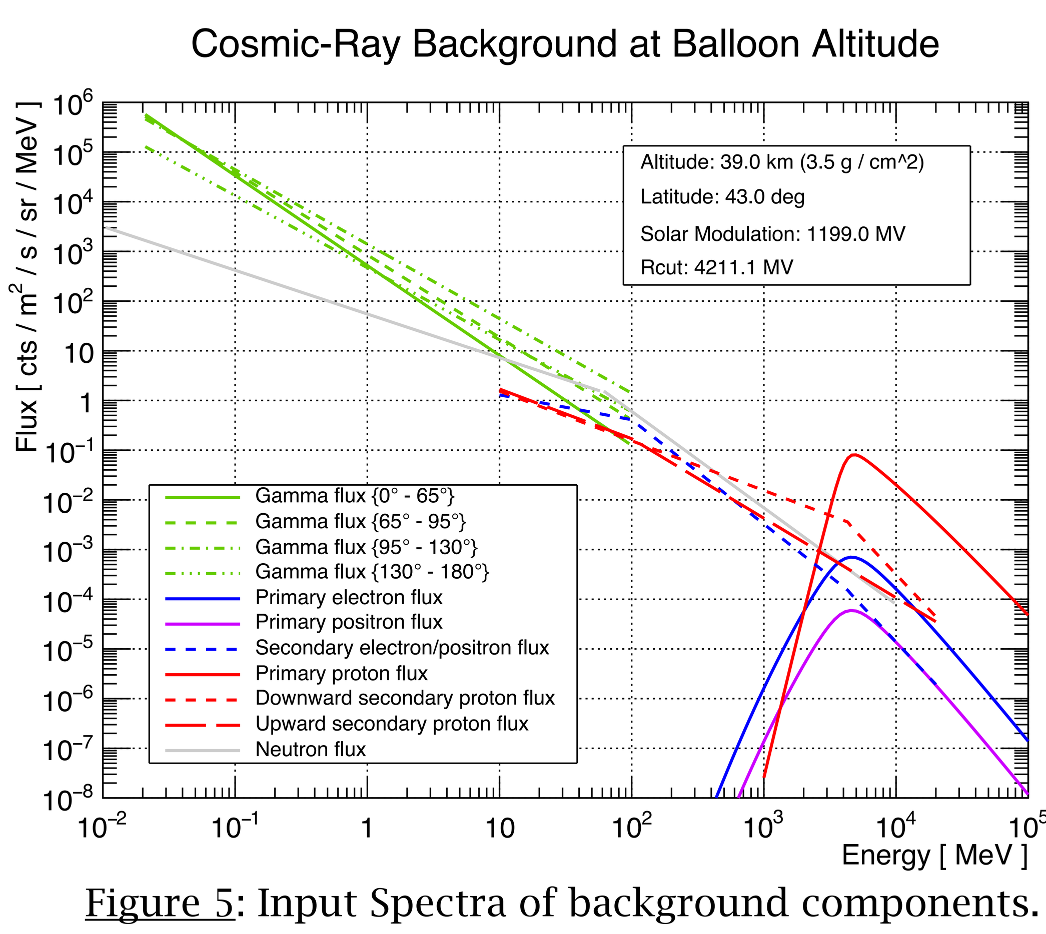


Figure 5: Input Spectra of background components.

Simulation (Geant4)

Background simulations were based on the use of GEANT4 toolkit, a toolkit for the simulation of the passage of particles through matter. This toolkit was created and is maintained by CERN, a European center for particle physics. Its areas of application include high energy, nuclear and accelerator physics as well as medical and space sciences.

The aforementioned background components are simulated using GEANT4 for the 2014 GRAPE configuration. The simulated background spectra generated by each component are shown in Figure 6. The total background (black) is the summation of each of the individual background components. The contribution of each of the simulated background components to the total background can also be seen. The measured background from the flight (blue) is also plotted in the same figure. We can see that the total simulated background significantly disagrees with the flight data 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.

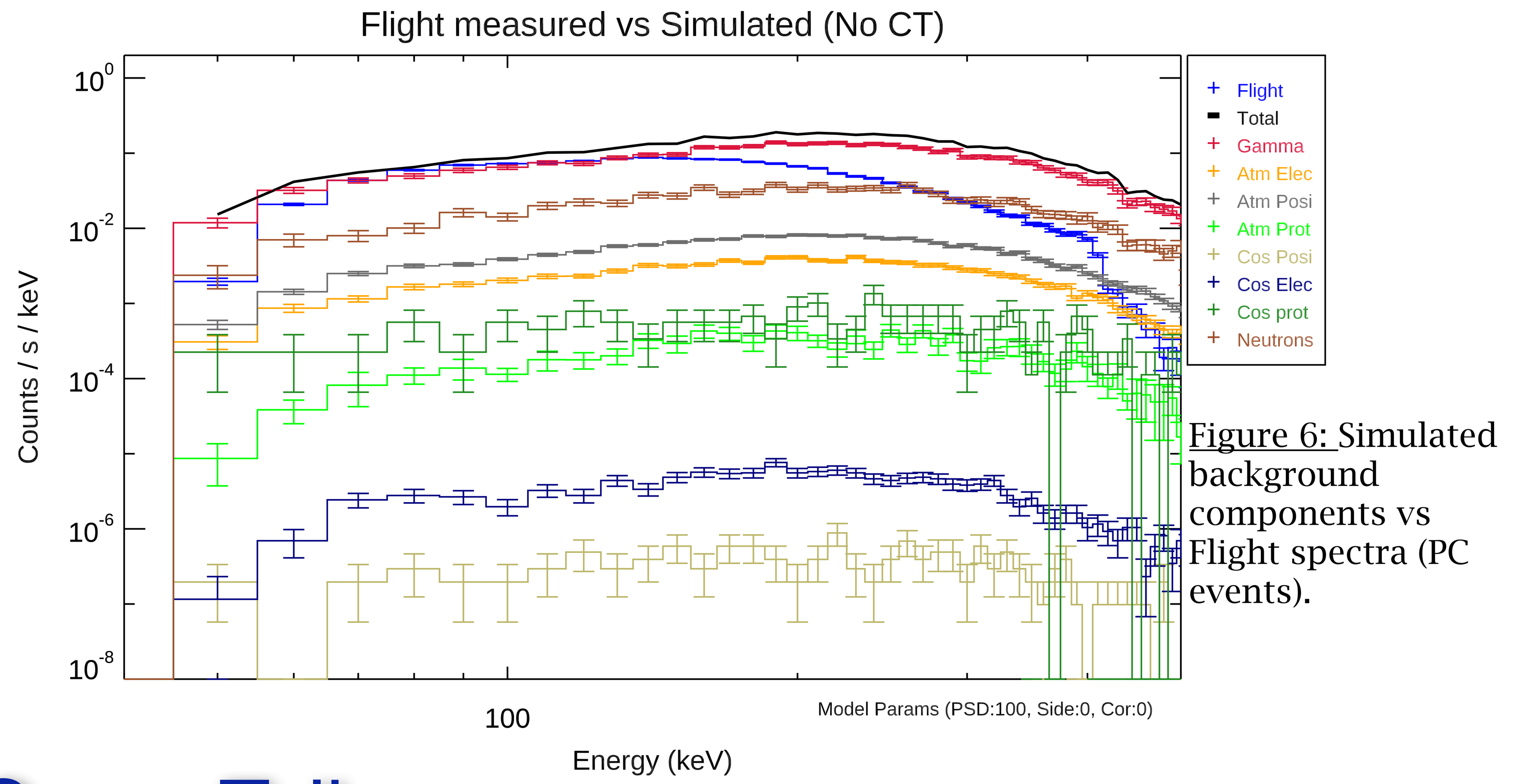


Figure 6: Simulated background components vs Flight spectra (PC events).

Cross-Talk

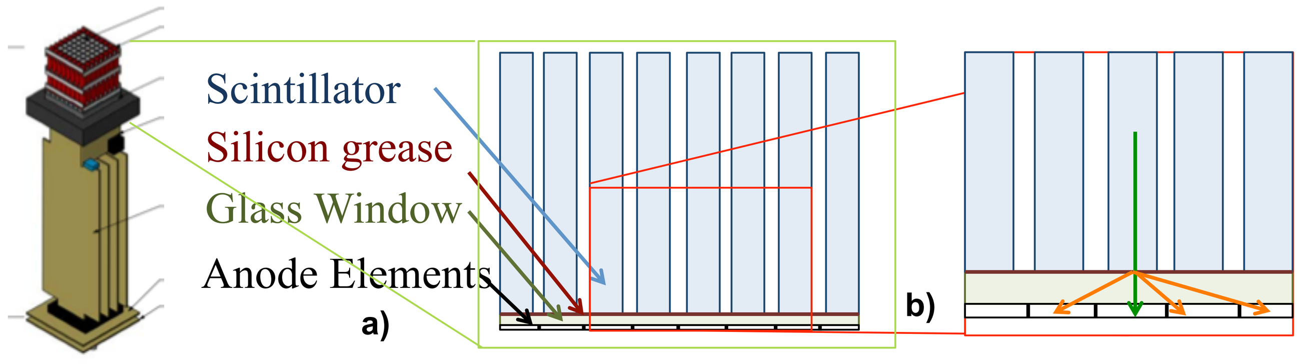


Figure 7a :(Left) shows where cross-talk occur. Figure 7b: (Right) The green arrow shows an ideal trigger and orange arrows shows cross-talk.

Light generated by the interaction of radiation within each scintillator element is registered in the MAPMT, which converts the light signal into an electrical impulse. Optical cross-talk is a phenomenon that occurs at the 1.5mm thick glass window between the scintillator array and the MAPMT. Typically all the light from a scintillator element goes to its respective anode in the MAPMT (Figure 7b, green arrow). During cross-talk, especially at higher energies, the scintillation light can also spill over to other (adjacent) anodes (Figure 7b, orange arrow). 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. The spectra that results from these improved simulations are shown in Figure 8. We can see that our simulated background now agrees with the measured flight background and verifies that we have a working model of the cross-talk.

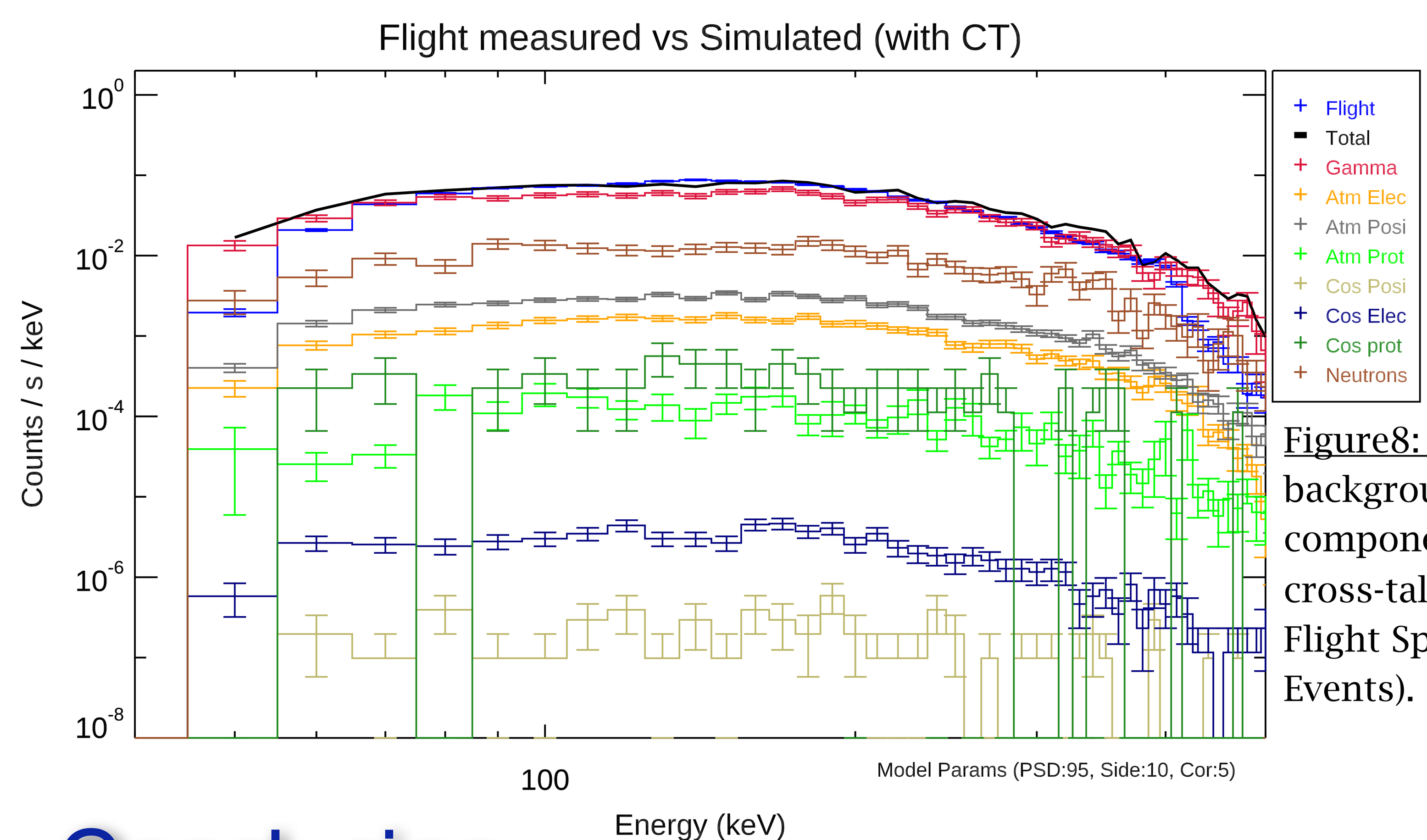


Figure8: Simulated background components (with cross-talk model) vs Flight Spectra (PC Events).

Conclusion

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.