Simulation of Van Allen Belt and Galactic Cosmic Ray Ionized Particle Tracks in a Si Timepix Detector

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Abstract: The Timepix readout chip is a hybrid pixel detector with over 65k independent pixel elements. Each pixel contains its own circuitry for charge collection, counting logic, and readout. When coupled with a Silicon detector layer, the Timepix chip is capable of measuring the charge, and thus energy, deposited in the Silicon detector layer. FLUKA simulations of energy deposition within the silicon layer have been carried out using models describing the particle flux within the Van Allen Radiation Belts as well as for Galactic Comic Ray particle interactions. Such simulations will be useful in characterizing the Timepix Si detector response in a mixed radiation field with application to similar detectors' future use as dosimeters and area monitors aboard manned spaceflight missions. The core technology is also applicable to purely scientific instrumentation.

Keywords: Timepix, GCR, galactic cosmic rays, trapped radiation, radiation belts, Van Allen.

1 Introduction

Timepix is a version of the technology developed by the Medipix2 Collaboration [1], which is based at CERN. It is a pixel-based ASIC wherein the electronics for each of the individual 55μ m square pixels is contained within the footprint of that pixel. The Timepix version of the Medipix2 detector has a charge-sensitive pre-amp and an associated discriminator attached to a logic unit capable of being employed in one of several different modes including as a simple counter for the number of times that the externally applied common threshold value has been exceeded (Medipix mode), as a Time to Digital Converter (TDC), or for the application described here, as a Wilkinson-type Analog to Digital Converter ADC. Each pixel has a 14-bit pseudo-random shift register for data storage and transfer, and there is an adjustable global "Shutter" that gates the data-taking active time.

The general properties of a Timepix-based device with a bump-bonded Silicon sensor attached have been described in [2], [3], and [4], and the use of the Timepix technology results in a highly versatile piece of hardware. Current ground based applications take advantage of the technology's dynamic range and radiation hard design. These same characteristics make it an ideal candidate for use in space radiation environments. To that end, work toward simulation of tracks from individual particles has begun in order to understand both the detector response as well as provide initial input for design of hardware and software based on the Timepix technology for use aboard both manned and unmanned space vehicles. While the initial intent is simulation of the space radiation environment, the same approach can be utilized with other radiation sources, and the method can be adapted to simulations of medical diagnostics as well as larger scale experiments utilizing the Timepix technology.

In this paper the fundamental approach for the simulation of tracks in a Timepix silicon detector is outlined and initial results are presented. In addition, several areas are identified that will allow enhancement in the simulation fidelity.

2 Methodology

The approach taken in the simulation of tracks for individual frames within the Timepix detector necessitates a time resolution on a scale sufficient to differentiate between points within the vehicle trajectory which are less than 1/10th of an orbit. This is necessary to differentiate between portions of the vehicle orbit that are well shielded and portions that traverse regions of the geomagnetic field open to the Van Allen belts and lower energy Galactic Cosmic Rays.

2.1 Trajectory Generation

The first task was to simulate the trajectory of interest for the vehicle. In this case we used trajectory information for the International Space Station which was readily available from both NASA's orbital elements website[5] and from CelesTrak[6].

The ISS orbit inclination is high enough that it traverses both the South Atlantic Anomaly and low rigidity cutoff regions, and as a result sees both inner and outer Van Allen belt populations, as well as accessing locations in the geomagnetic field containing lower energy GCR populations.

The Space Environment Information System (SPENVIS) [7] trajectory generation tool was used to generate the trajectory of interest. Latitude, Longitude, Altitude, as well as B and L coordinates were generated for one-minute increments along the orbit trajectory. Additionally, two line element historical data was used to interrogate the trajectory to identify 1/10th of an orbit track lengths that traversed both the geomagnetic cusp regions as well as well shielded regions of the vehicle orbit.

2.2 Particle Species and Energy Spectra

The SPENVIS radiation toolset was then used to gather the relevant model information. Such model information at each point is necessary to generate the particle track source information for use in the Monte Carlo code, but the method is not reliant upon the use of SPENVIS. Any differential spectra for the electrons or ions of interest can be sampled to produce data for use in the Monte Carlo codes.

Flux vs. energy spectra were generated and associated with each point in the vehicle trajectory. These spectra were read into a ROOT file structure[8]. ROOT was chosen because of the nature of the information structure and the availability of tools to interrogate the data after collection.

Upon entry into the ROOT data structure, each point in the vehicle trajectory then has associated orbital information as well as a differential energy spectrum for each of the particle species being included. Trapped protons and electrons, as well as GCR species through Fe are of interest for this simulation effort.

While trapped radiation models within SPENVIS provide information at each data point in the trajectory, the GCR information from SPENVIS requires slightly different processing based on limitations within the SPENVIS output. SPENVIS allows a minimum of 1/10th of an orbit to be generated as a trajectory segment. GCR spectra can only be generated for a segment of the trajectory and not for individual points within SPENVIS. Higher resolution methods for generating GCR spectra exist based on rigidity cutoffs [9].

A more robust implementation of the simulation will incorporate both the trapped models and rigidity cutoff estimates to generate a point by point data set. However for testing and initial implementation of the simulation, the tools within SPENVIS are an excellent resource.

2.3 Sampling

Once the relevant energy and fluence information was available, the spectra were sampled for each point of interest. The sampling routines can be modified to produce data as needed, but for initial tests of the simulation, a random, isotropic field is assumed for trapped particles, and a 2π solid angle is assumed for GCR particle incidence. As mentioned previously, the data sets used for sampling are generated for each point in the orbital track.

2.4 FLUKA Track Generation

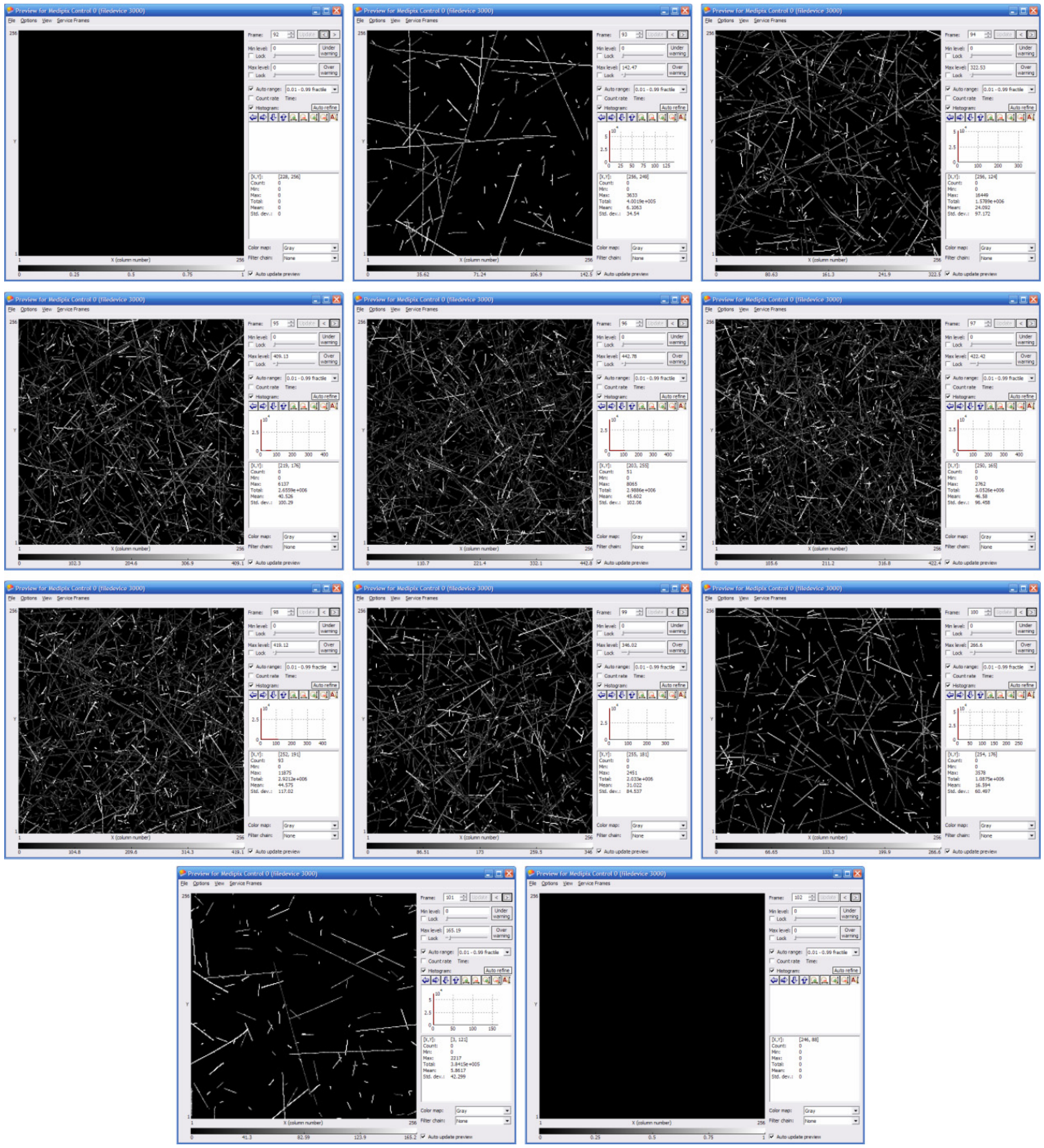
The resulting data are collated and organized into a format for use within FLUKA Monte-Carlo routines [10], [11]. FLUKA is capable of providing energy deposition, as well as the coordinates of the energy deposition, for all interactions from a simulated particle traversing a material. In this manner, the three-dimensional tracks can be simulated. Using such information along each track in conjunction with models for charge carrier production and charge drift in a material, the charge collected at the back plane of the detector can be simulated [12]. The resulting information can be parsed into pixel regions and can be compared directly with measured track information.

This simulation method is flexible in that the resulting data can be subdivided into any time division of interest. Each data point has an associated time stamp, and thus the simulation can replicate the acquisition parameters of the Timepix measurements.

3 Initial Results

Initial results of the simulation for trapped radiation populations have been used in the development of software for devices that will be flown aboard the International Space Station. These results did not incorporate charge carrier production or movement, nor did they include GCR components. Implementation of the GCR sampling is currently underway.

The series of frames shows simulated proton tracks incident on the Timepix detector as expected aboard the ISS. The simulation output data is formatted into data structures similar to what would be saved by the Pixelman software[13] during typical data acquisition which allows



for both display and further analysis of the simulation data.

Each frame has a collection time of 1 second, and the frames are spaced one minute apart. The orbital track associated with this series is passing through the South Atlantic Anomaly.

Electrons below a given energy were assumed to be shielded by the vehicle and were not propagated beyond the sampling phase of the simulation. This included most, if not all, of the sampled electrons, and no electron tracks were noted in the simulated frames.

4 Forward Work

Both the trapped radiation and GCR sampling described previously assume a very simplistic model for particle incidence upon a detector. Additional work is necessary to implement sampling methods that account for anisotropy in the trapped radiation distributions. And, as previously mentioned, the use of higher resolution methods to simulate GCR spectra at points in the orbital trajectory need to be implemented in the simulation.

The charge drift model described in [12] also requires further examination in relation to heavy ions in the Silicon Timepix detector stack. Verification of this model is planned forward work, with the goal of comparing model results to proton and heavy ion data taken with a Silicon Timepix detector at accelerators.

5 Conclusion

The method described for the simulation of particle tracks in silicon is of particular interest when applied to simulating Timepix measurement frames in a mixed field ionizing radiation environment such as Low Earth Orbit or beyond. The refinement of such methods are needed in order to provide a baseline set of tools for developing future hardware based on Timepix technology that will be used in a space radiation environment. While significant work still remains to provide a robust simulation toolset, the approach described here provides the groundwork for future development of such tools.

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