Verification of Dosimetry Measurements with Timepix Pixel Detectors for Space Applications

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Abstract:

The current capabilities of modern pixel-detector technology has provided the possibility to design a new generation of radiation monitors. Timepix detectors are semiconductor pixel detectors based on a hybrid configuration. As such, the read-out chip can be used with different types and thicknesses of sensors. For space radiation dosimetry applications, Timepix devices with 300 and 500 µm thick silicon sensors have been used by a collaboration between NASA and University of Houston to explore their performance. For that purpose, an extensive evaluation of the response of Timepix for such applications has been performed. Timepix-based devices were tested in many different environments both at ground-based accelerator facilities such as HIMAC (Heavy Ion Medical Accelerator in Chiba, Japan), and at NSRL (NASA Space Radiation Laboratory at Brookhaven National Laboratory in Upton, NY), as well as in space on board of the International Space Station (ISS). These tests have included a wide range of the particle types and energies, from protons through iron nuclei. The results have been compared both with other devices and theoretical values. This effort has demonstrated that Timepix-based detectors are exceptionally capable at providing accurate dosimetry measurements in this application as verified by the confirming correspondence with the other accepted techniques.

Summary:

The application of the semiconductor pixel detectors to dosimetry measurements has been studied since the advent of the earliest such devices. The recent progress in their design, which allows both the analog and digital processing of the signals within the footprint of each pixel, has made possible a substantial refinement in the application of these devices to radiation dosimetry. The application of monitors based on pixel detector technology has many advantages over prior methods. These modern pixel detectors allow the event-by-event measurement of the energy deposited by each traversing charged particle. In addition, by analyzing the visualized track that the particle left in the detector, one can obtain extra information such as the particle's total pathlength in the sensor, which leads to a direct measurement of the (Lineal Energy Transfer) LET. One can thus determine information regarding each particle's charge with an, estimate its energy and reconstruct the azimuthal and polar angles of the traversing particle's track. Such detailed information has previously been available only with large multi-detector telescope-like devices, whose size, power and mass would have been limiting for many dosimetry applications. The system we have developed uses a single layer pixel detector and provides all the extra information in

compact size with low power consumption – qualities especially important for space radiation applications.

The Timepix detector[1] that we have chosen to deploy in our space radiation dosimetry monitors is a semiconductor pixel detector developed by the CERN-based Medipix2 Collaboration. It has been used for a wide variety of applications ranging from X-ray spectral and phase contrast imaging to radiation monitoring. The low mass and low power consumption make Timepix a suitable option for space radiation dosimetry. With a pixel pitch of 55 μm, the Timepix possess enough spatial resolution to be used as a tracking device – in principle it operates as a solid state electronic bubble chamber or nuclear emulsion. Moreover when properly calibrated, it allows one to measure the energy that was deposited by radiation that traverses the silicon as seen in each pixel. One can thus have almost complete information about interacting particle that can be obtained by a single detector layer. While the Timepix can be used to measure either the magnitude or the time of arrival of the charge seen by each pixel, it cannot measure both in detail simultaneously. In both cases the detector is made live for some period of time and in the charge measuring mode the charge seen is summed when the gating “shutter” is “open.” Typically this is not an issue, because the charged particle fluence in the space environment is sufficiently small that 4 second “shutter” times are reasonable. Moreover this won’t be the issue for the next generation of the Timepix, known as the Timepix3, which will provide a shutter-free non-stop streaming of data virtually suppressing dead time and provide 3 ns or better timestamp for each pixel hit.

To verify the concept and prove the usefulness of the Timepix technology for space dosimetry a Station Development Test Objective (SDTO) has been undertaken by NASA. Currently, there are six Radiation Environment Monitor (REM) devices flying onboard of the International Space Station. Those units are measuring the radiation environment on the ISS with cumulative lifetime of over 5 years. As a part of the evaluation and certification procedure, the Timepix detector has been thoroughly tested in many different accelerator beams (HIMAC, NSRL) to cover a wide variety of particle types (from protons up to iron) and from stopping to relativistic energies. This report will present a summary of those measurements and comparison of the results obtained by the Timepix detector-based units with other standard dosimeters like the passive TLDs (Thermo-Luminescent Dosimeters) and active TEPCs (Tissue-Equivalent Proportional Chambers), etc. and theoretical values calculated from the number of particles. It will be shown that Timepix provides consistently reliable dose information for a wide variety of environments and is thus suitable to serve as a primary radiation monitor for space applications. It will be also shown that the extra information obtained by Timepix can be used for further improvement of the final dosimetry measurement over what has been previously obtainable.

[1] [1] X. Liopart, R. Ballabriga, M. Campbell, L. Tlustos and W. Wong, Nucl. Inst. And Meth. Phys. Res. A 581 (2007) 485.