The SpacePix radiation monitor (SXRM)

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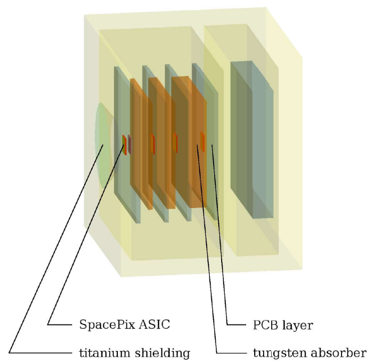
SXRM



Overview

SXRM is a concept of a compact multilayer space radiation detector. Its primary deployment area is the Earth orbit with a possible use in the Solar System. The abbreviation comes from **S**pacePi**X** **R**adiation **M**onitor, as the active element is a silicon pixel chip SpacePix ASIC.
The presented work consists of three fundamental parts:

- space radiation environment analysis,
- development of SpacePix and SXRM models in Geant4 [1] and AllpixSquared [2],
- simulation of space radiation passage.

Radiation environment analysis

The Spenvis [3] tool, provided by ESA, was used to approximate the eventual radiation in the target area and suggest the energy distribution of simulated particles. A polar orbit 400 km above the Earth surface was scanned to obtain energy spectra and fluxes of present electrons, protons, α particles and $^{56}_{26}$Fe ions.
Three main radiation sources are:

- Van Allen Belts - protons & electrons, models AP8, AE8,
- Galactic Cosmic Radiation - α particles & $^{56}_{26}$Fe ions, model ISO1530,
- Solar Particle Events - α particles & $^{56}_{26}$Fe ions, model CREME-96.

SpacePix ASIC

The active element used in a telescopic configuration of the SXRM detector is the SpacePix ASIC.
It is a radiation tolerant monolithic silicon pixel detector designed in a 180 nm SoI technology with a 60 µm pixel pitch. Each pixel has dimensions of $60 \times 60 \times 286\ \mu m^3$.
The whole matrix is covered with several thin layers of Si & SiO_2 underneath which a 30-µm-deep depleted zone is generated.

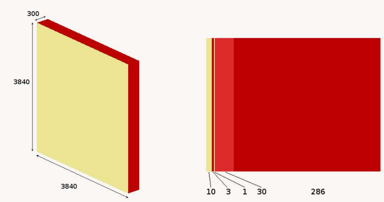


Figure: SpacePix ASIC and its pixel longitudinal section.

AllpixSquared simulations

- a depleted area is generated by square-based phosphor implant in each pixel
- electric field model of 3 × 3 SpacePix-pixel matrix was simulated in TCAD
- inner-pixel field was extracted
- importing the electric field, AllpixSquared tool was used to simulate the charge carriers transport

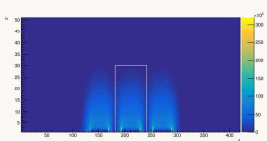


Figure: Cross section of TCAD electric field model converted to AllpixSquared.

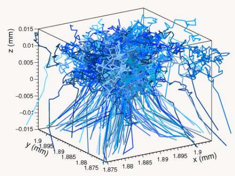


Figure: Propagation of free electrons emerged by ionising particle passage in SpacePix ASIC pixel.

Geant4 simulations

- simulations were conducted to suggest the amount of energy deposition in the depleted area
- a wide range of deposited charge was obtained (from 2 ke⁻ up to 10 Me⁻)
- usage of a logarithmic amplifier was suggested

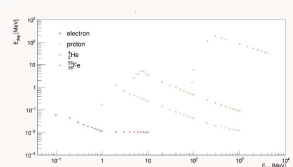


Figure: Energy deposited in the depleted area on initial particle energy dependency.

SXRM

The whole SXRM setup is placed in a chassis for whose construction are aluminium and Inconel600 alloy considered. The usage of multiple SpacePix layers interleaved with tungsten absorbers improves energy resolution as shown below.

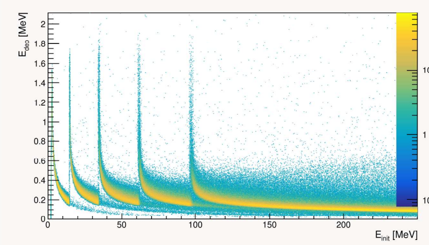


Figure: Dependency of energy E_{dep} deposited by traversing particle on its initial energy E_{init}. Simulated using protons with $E_{init} \in (0, 250)$ MeV. The sharp peaks highlight the presence of a new sensitive layer.

Based on the analysis of the deposited-on-initial energy dependencies for all investigated particles, the first approximation of the measurable initial particle energy ranges was suggested:

electrons	0.1 - 10	MeV,
protons	1.8 - 100	MeV,
α particles	7.8 - 400	MeV,
$^{56}_{26}$Fe ions	0.3 - 40	GeV.

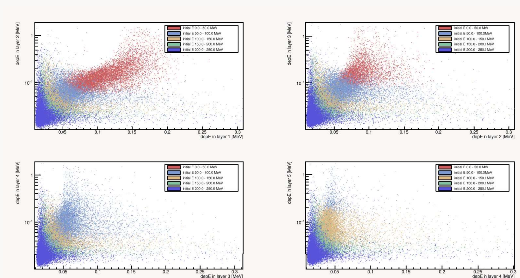
As several designs are considered, the aforementioned analysis results are also useful when selecting the best one with respect to the number of layers.

Conclusions and further development possibilities

Having detector models and thus virtually unlimited amount of training data, machine learning methods seem like a promising approach to the data reconstruction during the detector deployment. In this context the TMVA tool is to be examined in order to find the most suitable methods to determine the incoming particle energy and species. The considered are

- Boosted Decision Trees,
- Multilayer Perceptrons.

A potentially useful data analysis style is demonstrated on the coincidence measurement of 100.000 proton beam in the following picture. Hits in n-th & $n+1$-st SpacePix layer are presented in the scatter plot and categorized by their initial energy.
Multiple designs are currently being considered based on materials and geometric properties revealed by the simulations. After choosing the final one, the presented detector concept is to be manufactured and tested in appropriate cosmic environment.



References

[1] Agostinelli et al. "GEANT4—a simulation toolkit". In: *Nuclear instruments and methods in physics research section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 506.3 (2003), pp. 250–303.

[2] K. Wolters, S. Spannagel, and D. Hynds. "Allpix2 User Manual". In: (2018). URL: https://project-allpix-squared.web.cern.ch/project-allpix-squared/usermanual/allpix-manual.pdf.

[3] Heynderickx D. et al. "New radiation environment and effects models in the European Space Agency's Space Environment Information System (SPENVIS)". In: *Space Weather* 2.10 (). DOI: 10.1029/2004SW000073. eprint: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2004SW000073.

[4] M. Havranek et al. "X-CHIP-03 SoI MAPS sensor with hit counting and ADC mode". In: (Presented at IEEE NSS/MIC 2018).