2025 Beamline For Schools Experimental Proposal

Characterization of and Shielding Against Single Event Effects (SEEs) in EEPROMs

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Physics Olympiad Co-operation

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Introduction

Electronics in space are continuously exposed to cosmic rays—high-energy particles traveling through space at nearly the speed of light.[1]

The energy spectrum of cosmic rays peaks at approximately 300 MeV.[2] Of particular concern are the induced *Single Event Effects* (SEEs) at this energy. SEEs arise when a high-energy particle, either through direct or indirect ionization, produces a charge track within a semiconductor. SEEs can cause temporary malfunctions or even permanent device failure,[3] depending on the particle's energy.

To analyze a device's vulnerability to such effects, we define the key metric of interest: the *cross section*, $\sigma(E)$.

$$\sigma(E) = \frac{N_{\text{events}}}{\Phi}, \tag{1}$$

Equation 1: Definition of the SEE cross section, where N_{events} is the number of observed SEEs and Φ is the fluence—the number of incident particles per unit area

Typically, the cross section as a function of energy follows a *Weibull distribution*:

$$\sigma(E) = \sigma_{\text{sat}} \left\{ 1 - \exp\left(\left(\frac{E - Tr}{W} \right)^{S} \right) \right\}, \tag{2}$$

Equation 2: Weibull Distribution of SEE cross section. σ_{sat} is the *saturated cross section* (the asymptotic maximum value at high energies), Tr is the threshold energy, W is the width parameter, and S is the shape factor.[4]

Accurately determining σ_{sat} allows us to estimate the cross section at other energy levels.

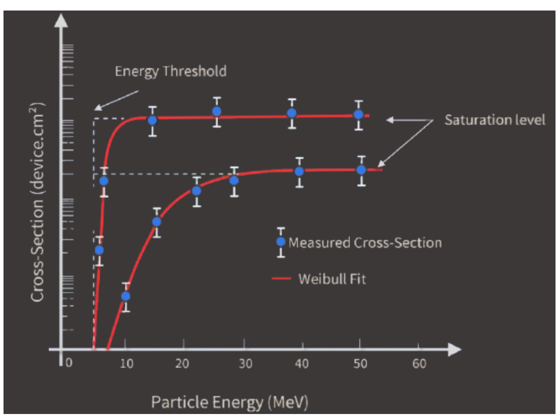

Figure 1. The cross section σ plotted against the particle energy.

We will investigate how various shielding materials can mitigate SEEs. We aim to focus on materials that are inexpensive and easily accessible, enabling cost-effective protection for both spaceborne electronics and accelerator systems such as those at the LHC.

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[1] [1] Scarsi, L. (1960). Cosmic radiation. *American Journal of Physics, 28*(3), 213-220. https://doi.org/10.1119/1.1935104

[2] [1] Scarsi, L. Cosmic radiation.

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Materials

For shielding, we aim to use a combination of high- and low-density materials to mitigate the effects of both primary and secondary cosmic rays. High-density materials are effective at attenuating primary radiation, while low-density materials help reduce the impact of secondary particles generated by nuclear interactions within the shielding [5]. The materials selected for testing include:

- **Concrete**: Due to its density and the possibility of incorporating high-atomic-number aggregates (e.g., barites, magnetites, and hematites), concrete serves as an effective and adaptable shielding material. Its durability and low cost make it ideal for large-scale applications.
- **Iron**: A dense metal well-suited for shielding against primary cosmic rays. It is lighter than some traditional shielding materials and generates minimal secondary radiation[6].
- **Aluminum**: Another high-density material, commonly used in spacecraft for radiation shielding. Its widespread use makes it a useful benchmark for comparison with our other candidate materials.
- **Plastic (Polyethylene)**: As a hydrogen-rich, low-density material, polyethylene effectively reduces secondary radiation. It has been successfully deployed as radiation shielding on the International Space Station[7]. It is also affordable and readily available.

Additionally, we will be using aerogel with other materials[8] to act as a thermal insulator to protect electronics from heat.

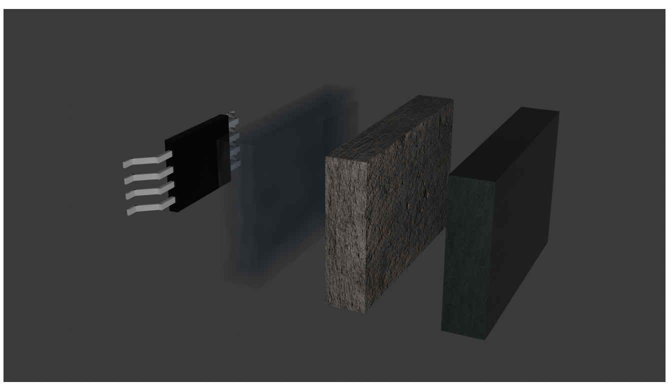

Figure 2. An example shielding setup, showcasing aerogel, concrete, and a high density metal.

PART

II

[5] [4] Navarrete, E. A., Kouzes, R. T., Ankney, A. S., Orrell, J. L., Berguson, T. J., & Troy, M. D. (2011). Cosmic ray interactions in shielding materials. `https://doi.org/10.2172/1025678`

[6] [4] Navarrete, et al. Cosmic ray interactions in shielding materials.

[7] [5] Durante, M. (2014). Space radiation protection: Destination Mars. *Life Sciences in Space Research*, *1*, 2–9. `https://doi.org/10.1016/j.lssr.2014.01.002`

[8] We also plan to extend our proposal if we go to CERN, to include multi-layer shielding tests (Figure 2) to check if the layers block different sets of radiation energies, potentially improving the shielding efficiency than if the same material was used twice in series.

Electronics

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III

For the electronics selected for irradiation, we chose memory chips due to their critical role in nearly all digital electronic systems. Specifically, we focused on electrically erasable programmable read-only memory (EEPROM) chips. EEPROMs are a type of nonvolatile memory that provide greater endurance in terms of read/write cycles and data retention compared to flash memory. These reliability characteristics are especially important for space applications, where EEPROMs have been employed in missions such as India's Chandrayaan lunar program.

EEPROMs operate using floating-gate transistors, which means radiation-induced effects like SEEs are typically localized—causing failures on a per-bit basis rather than device-wide errors.

To ensure compatibility with the beam's constraints, we selected the M95640-WDW6TP EEPROM, manufactured by STMicroelectronics. This device comes in a compact TSSOP-8 package, allowing us to place multiple ICs within the 2 cm diameter of the beam's focal region. This enables efficient testing through simultaneous irradiation trials.

Experimental Plan

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To quantify the damage done to the memory chips, we designed a PCB that enables us to write/read data from the M95640. Errors in the EEPROM can be detected by writing a known data sequence to memory, irradiating the chip, and then reading the data back to identify any discrepancies. Finally, we will attempt to reprogram and read from the EEPROM without irradiation to check for the presence of "stuck bits"—memory values that are permanently stuck and can no longer be changed. A greater number of stuck bits indicates a higher level of damage to the chip.

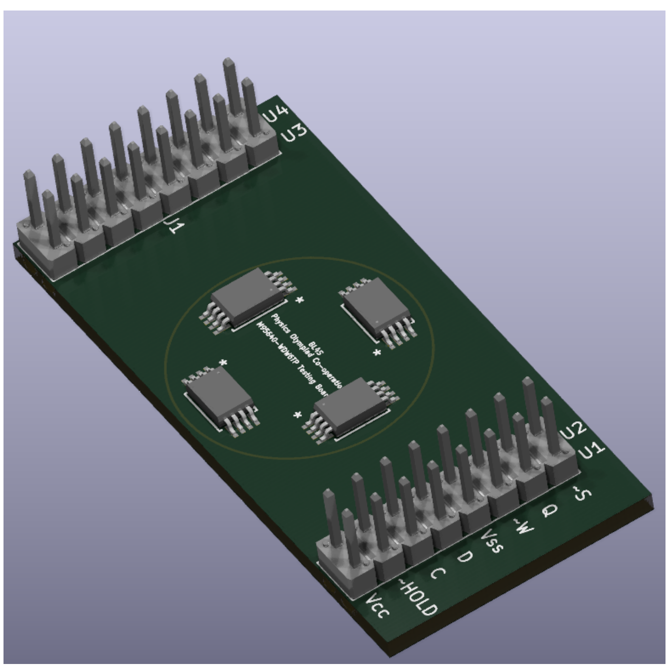

Figure 3. Interface PCB for M95640-WDW6TP

EEPROM Initialization and Irradiation Scheme

We will initialize all memory addresses of the four EEPROM chips with an alternating sequence of 1s and 0s. The chips will then be irradiated at CERN's T9 beamline using the positively charged beam, selecting particles with momenta between 0.6 GeV/c and 0.9 GeV/c.

This momentum range ensures the beam includes protons with energies between approximately 200 − 300 MeV, and pions, kaons with higher energy, allowing us to measure the saturated cross-section while replicating the typical energy spectrum of cosmic ray .[9]

[9] [1] Scarsi, L. Cosmic Radiation.

At this beam momentum, the total flux is sufficient to induce observable effects on the chips.

The irradiation will last for 10 minutes under continuous exposure to the T9 beam. After irradiation, we will read out the data from all memory addresses to determine the number of bits that flipped from their original values.

Finally, we will invert every bit in memory (i.e., flip all 1s to 0s and all 0s to 1s), and then reread the memory to identify bits that failed to flip correctly.

Evaluating Candidates for Shielding Materials

We aim to evaluate the effectiveness of various low-cost shielding materials in protecting against Single Event Effects (SEEs).

Table 1. Overview of experimental parameters for the shielding materials being tested

Material Tested	Thickness (cm)	Number of Trials	Beam Momentum (GeV/c)	Irradiation Time (min)
No shielding (Control)	N/A	10	0.6 - 0.9	10
Concrete	10	10	0.6 - 0.9	10
Iron	10	10	0.6 - 0.9	10
Aluminum	10	10	0.6 - 0.9	10
Polyethylene	10	10	0.6 - 0.9	10

Data Analysis

For each irradiation run, we will record the number of SEEs, specifically tracking Single Event Upsets (SEUs) and Single Event Latch-ups (SELs). Additionally, we will calculate the beam fluence, enabling us to determine the saturated SEE cross section of the EEPROM given by Equation (1)

To assess whether a given shielding material significantly reduces the SEE cross section compared to the unshielded control, we will use a two-sample t-test with a significance level of $p = 0.01$.

$$t = \frac{\bar{\sigma}_{\mathrm{o}} - \bar{\sigma}_{\mathrm{e}}}{\sqrt{s_{\mathrm{o}}^2/n_{\mathrm{o}} + s_{\mathrm{e}}^2/n_{\mathrm{e}}}} \tag{3}$$

Equation 3: Two-sample t-statistic comparing the mean SEE cross sections $\bar{\sigma}_{\mathrm{o}}$ (control) and $\bar{\sigma}_{\mathrm{e}}$ (experiment), with sample variances s_{o}^2 and s_{e}^2 and sample sizes n_{o} and n_{e} respectively.

From this, we will determine which of the shielding materials tested are statistically effective in reducing the SEE cross section in EEPROM devices.

Motivation

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V

Why We Want to Go

We are a group of eight students from India and USA, involved in the shared community of olympiad physics. This journey has introduced us to new fields outside of olympiad physics, allowing us to learn about and work on particle physics.

Getting to work hands-on and see our experiment come to life would act as a catalyst for both ourselves and others to pursue particle physics and related fields in the future, helping us promote physics research in our countries.

Our proposal would allow us to experiment various shielding materials, some of which are not regularly used for shielding from SEEs. Seeing it come to fruition would allow us to contribute into ensuring electronic safety in places like LHC and space satellites .

What We Hope to Gain

We hope to go to CERN to work on our experiment, beyond the the theoretical work we've been engaged in for the past months, which would introduce us to real word experience in experimental physics and the scientific method in general.

This would also enable us to interact with those working in the field and peers worldwide, giving us a peek into what's ahead.

Acknowledgments

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