Measuring the effect of cosmic rays on computer storage devices

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Abstract. We propose an experiment that measures how cosmic rays affect non-volatile computer storage devices (e.g., flash drives, SSDs, memory cards, e.t.c.). The T9 beamline is employed as a means to simulate the "primary" component of cosmic rays. The beam is directed towards a single storage device, whose contents are subsequently tested to determine possible degradation.

I. Introduction

Over the past two years our team has been involved with the Zero Robotics programming challenge, a competition organized jointly by M.I.T., N.A.S.A. and E.S.A. During our engagement with the programming of small satellites, we have often wondered about the effects of Cosmic Radiation (CR) on their electronics. As crazy as it sounds, any storage device can be harmed by cosmic radiation. If such an error occurs in space it may lead to loss of significant data, or (more importantly) it may compromise the operation of a critical spacecraft's system. Besides the fact that CERN is one of the few places on earth, where young students (who seek inspiration and excitement) can interact with top level scientists that unravel the laws of physics, it is also one of the few places where particles can be accelerated in order to simulate CR. Hence, naturally, when we found out about the BL4S competition we were excited! So please, let us bombard a flash drive, in the name of science, in order to see if our astronauts are indeed in danger.

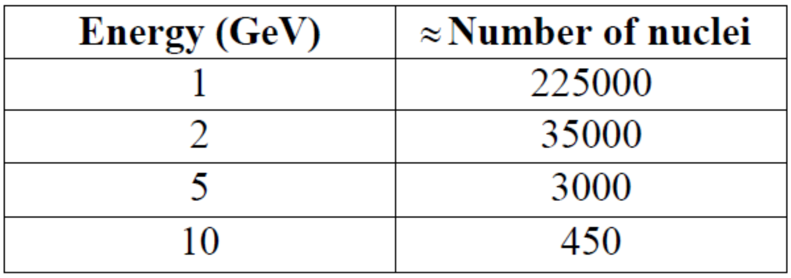
II. Cosmic Radiation

Cosmic Rays (CRs) are immensely high-energy radiation that it is composed primarily of high-energy protons and atomic nuclei (99%). When they enter earth's atmosphere they produce showers of secondary particles (i.e. muons, neutrinos, e.t.c).

CRs have sufficient energy to alter the states of circuit components in electronic integrated circuits, causing transient errors to occur, such as corrupted data in electronic memory devices, often referred to as "soft errors". Studies by IBM in the 1990s suggest that computers typically experience about one CR-induced error per 256 megabytes of RAM per month. Although the related experiments were not very detailed (partially due the inability to create CR particles), the papers do refer to a change in the probability of encountering errors when we increase the altitude. This implies that primary (rather than secondary) nucleons, which are more commonly found in higher altitudes, are the main cause of soft errors. Their intensity at the top of the terrestrial atmosphere in the energy range from several GeV to somewhat beyond 100 TeV is given approximately by

$$I_N \approx 1.8 \cdot 10^4 \cdot E^{-2,7} \quad \frac{nucleons}{m^2\, s\, sr}, \quad \textbf{(1)}$$

where E is the nucleon's energy. The following table gives an approximation of the absolute numbers of primary nuclei per second and m^2, for some energy levels.



Energy (GeV)	≈ Number of nuclei
1	225000
2	35000
5	3000
10	450

III. The experiment

In order to measure the effect of CR on non-volatile computer memory, we propose to employ the T9 beam line (as a means to simulate the primary spectra of cosmic radiation) to bombard a typical flash storage device. We plan to expose the device to several T9 energy levels (e.g., 1, 2, 5 and 10 GeV) for various time frames (ranging from seconds to one or two minutes) and measure the number of memory errors (e.g., by comparing the contents of the device's memory to an original). Hopefully, this will allow us to build measurement tables (that relate the number of soft errors to the number of passing nuclei) and design models that approximate the error rate produced by primary rays at certain energy levels (see Figure 1). We note that the T9 beam is considerably denser that the typical cosmic radiation. Hence, a single burst is actually equal to several hours (or days – depending on the energy level) of exposure in standard CR levels. We can measure this time using a simple formula:

$$T = \frac{N_{nuclei}}{2 \cdot \pi \cdot R^2 \cdot A_{nuclei}}, \qquad \textbf{(2)}$$

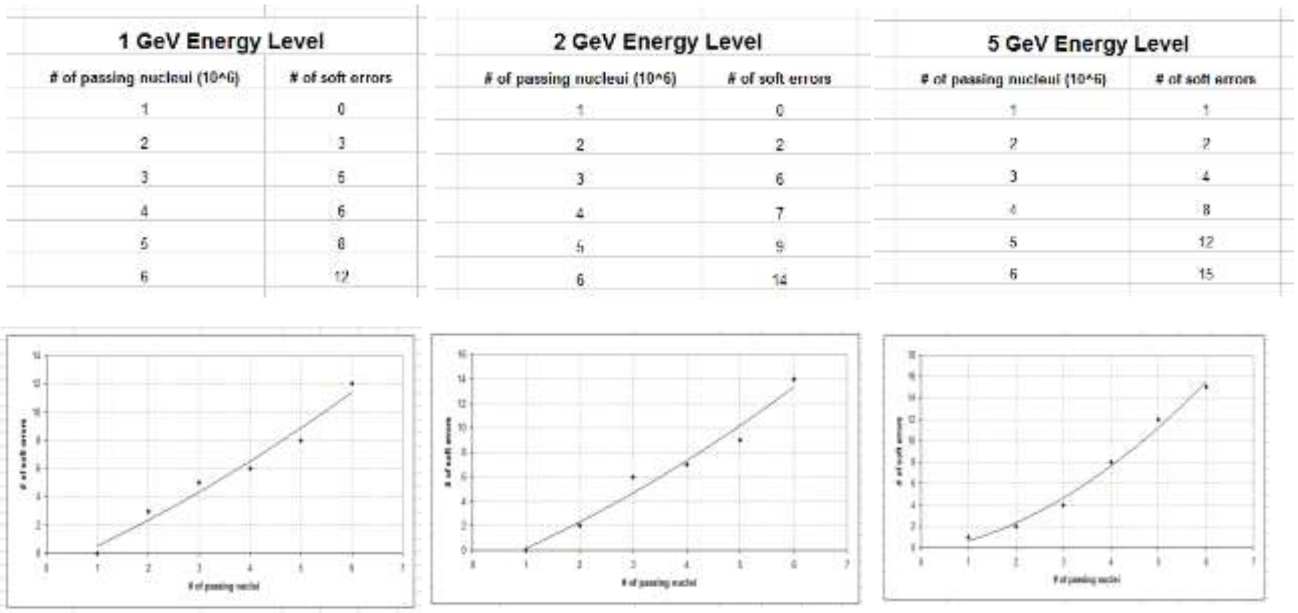
where N_{nuclei} is the actual the number of protons in the beam, R is the radius of the beam's cross section, A_{nuclei} is the number of particles per second and per m^2 of CR which relates to a given situation (e.g., a specific energy level, a specific altitude inside earth's atmosphere, e.t.c.) and T is the total exposure time (in CR) which corresponds to one T9 burst. If the experiment is successful, we may be able to derive a general (simplistic) law that will relate the soft error rate to the rate of primary CR nuclei (A_{nuclei}) for certain energy levels (Figure 2).

IV. The set-up

We ‘ll employ the positive beam of the PS, whereas a set of bending magnets and a collimator will be used to set-up the desired energy level (Figure 3). In the following, Cherenkov detectors are used as triggers (the readout is initiated if a large ammount of protons pass through) and two scintillators are used to determine the velocity and the number of protons. Afterwards, two quadrupole magnets (one horrizontal and one vertical) focus the beam so that it has a specific radius R and the beam is directed towards the storage device (this can be a typical flash drive or an EPROM memory, e.t.c.). Finally, a scintillator measures the number of protons that do not interact with the storage device. We note that the storage device (i.e. a usb adapter that can have different types of computer memory) is connected through a long usb cable (10 m) to a desktop computer that will measure the errors in the device’s memory. We also note that we have succesfully tested the proposed configuration (i.e. the connection of the storage device with the long usb cables). Results will be published online in real time.

V. Conclusions - Dissemination

We believe that our experiment might unravel usefull information regarding the effects of CR on storage devices. If we are to be selected, we plan to share the knoweldge and experience that we will gain with the local community and perform additional experiments using the cosmic ray detector (that CERN provides) inside the premises of our school (collaborating with other schools in our area). We will also design a blog to make our experience (and the results of our experiments) available online.



1 GeV Energy Level

# of passing nucleui (10^6)	# of soft errors
1	0
2	3
3	5
4	6
5	8
6	12

2 GeV Energy Level

# of passing nucleui (10^6)	# of soft errors
1	0
2	2
3	6
4	7
5	9
6	14

5 GeV Energy Level

# of passing nucleui (10^6)	# of soft errors
1	1
2	2
3	4
4	8
5	12
6	15

Figure 1. Examples of measurement tables (and corresponding figures with regression lines) with random entries.

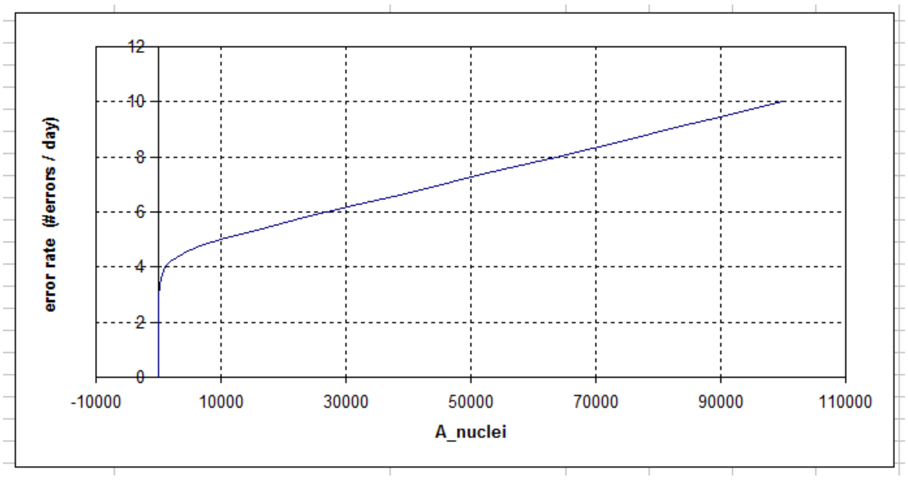


Figure 2. A close study of the results of the experiment may reveal a simple relation between the error rate and the rate of primary nuclei of CR. In this hypothetical example the relation is a linear one.

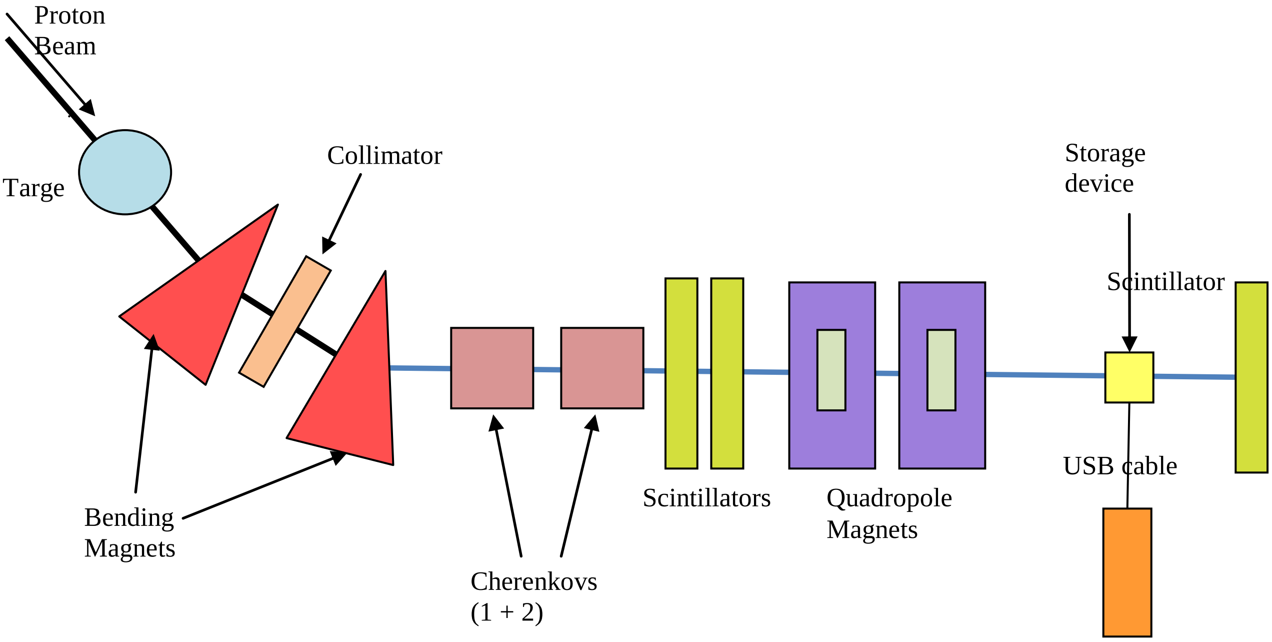


Figure 3. The experimental set-up for the PS.