Effects of Neutron Radiation on Solid State Drives

Milap Shah : Cisco Systems

Rick Wong : Cisco Systems

Pierre Chor Fung Chia : Cisco Systems

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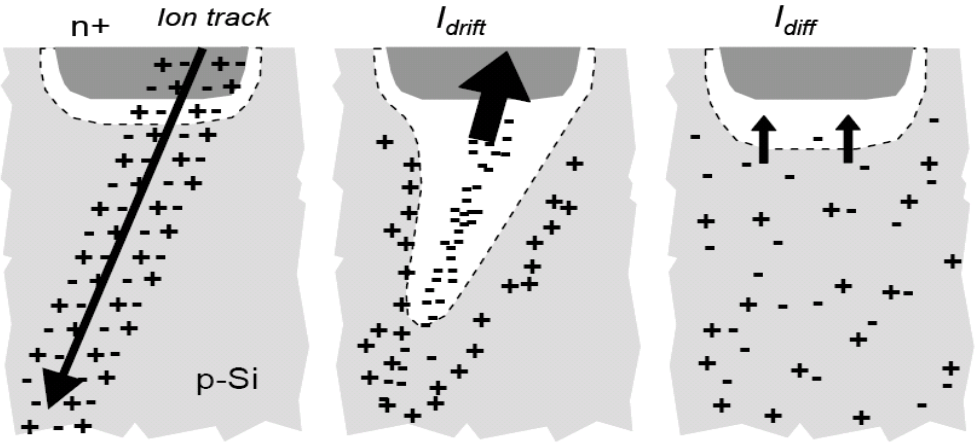
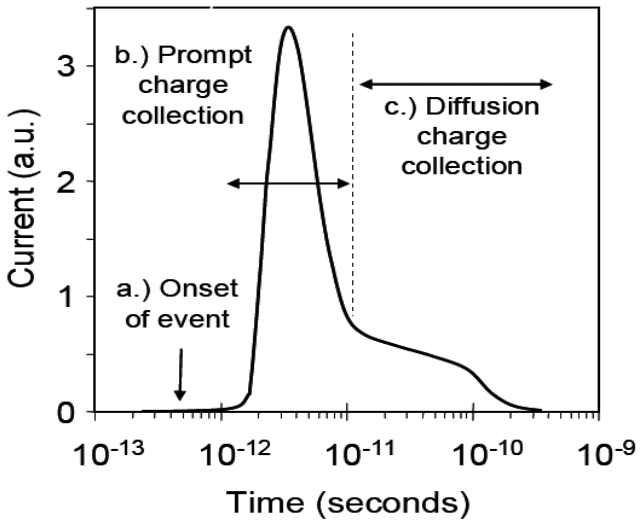
SEU Introduction

- Cause of Soft errors
  - a. Ion creates electron hole pairs in the silicon
  - b. Charges drift and collect at nodes, producing a prompt current
  - c. Later charges diffuse toward the nodes, producing lower current
- If the current is large enough, storage nodes such as SRAMs can switch states

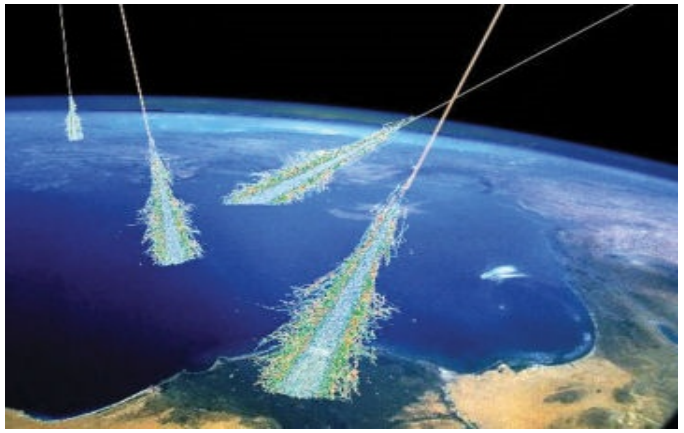


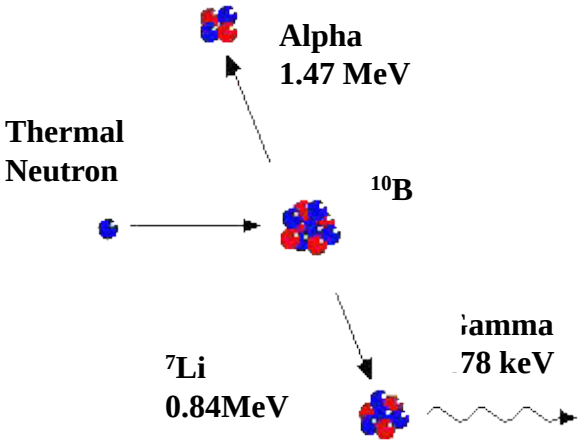


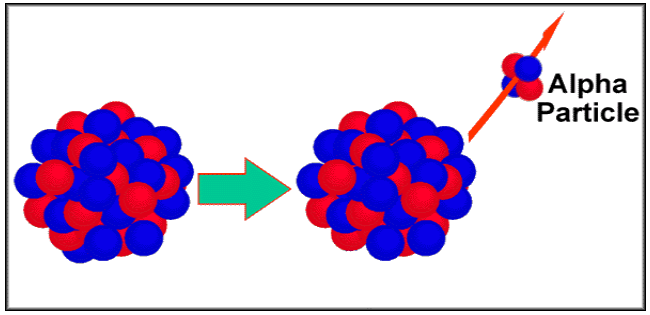
R. C. Baumann, ***IEEE Trans. Device Mater. Reliab.***, vol. 5(3), p. 305-316, Sept. 2005

Source of High Energy Particles

- **High energy cosmic neutrons**
  - **High energy particles from space collide with atmosphere form a shower of particles at terrestrial level**
  - **These high energy particles can collide with silicon atoms**
- Boron-10 Fission
  - B-10 captures a thermal neutron and fissions into a Li ion and an alpha particle
- Alpha particle
  - Ion emitted from Uranium and Thorium (and daughter species) decay
  - U and Th are trace contaminates in package materials; solder, underfill, molding compound

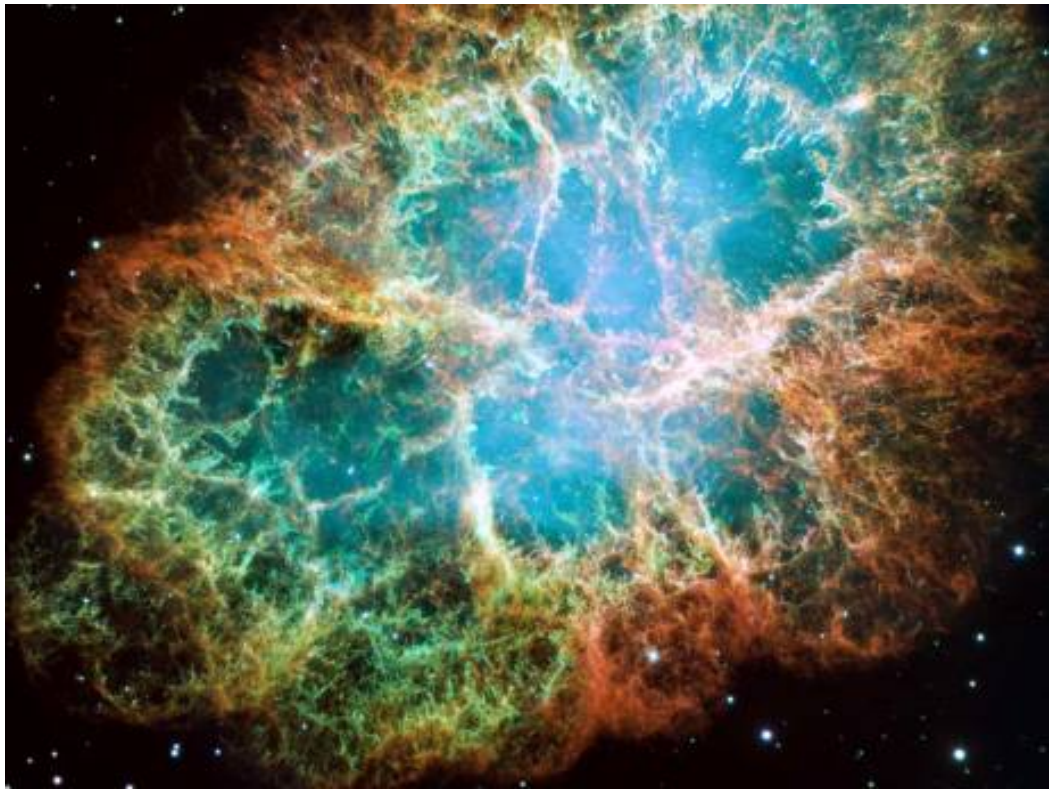






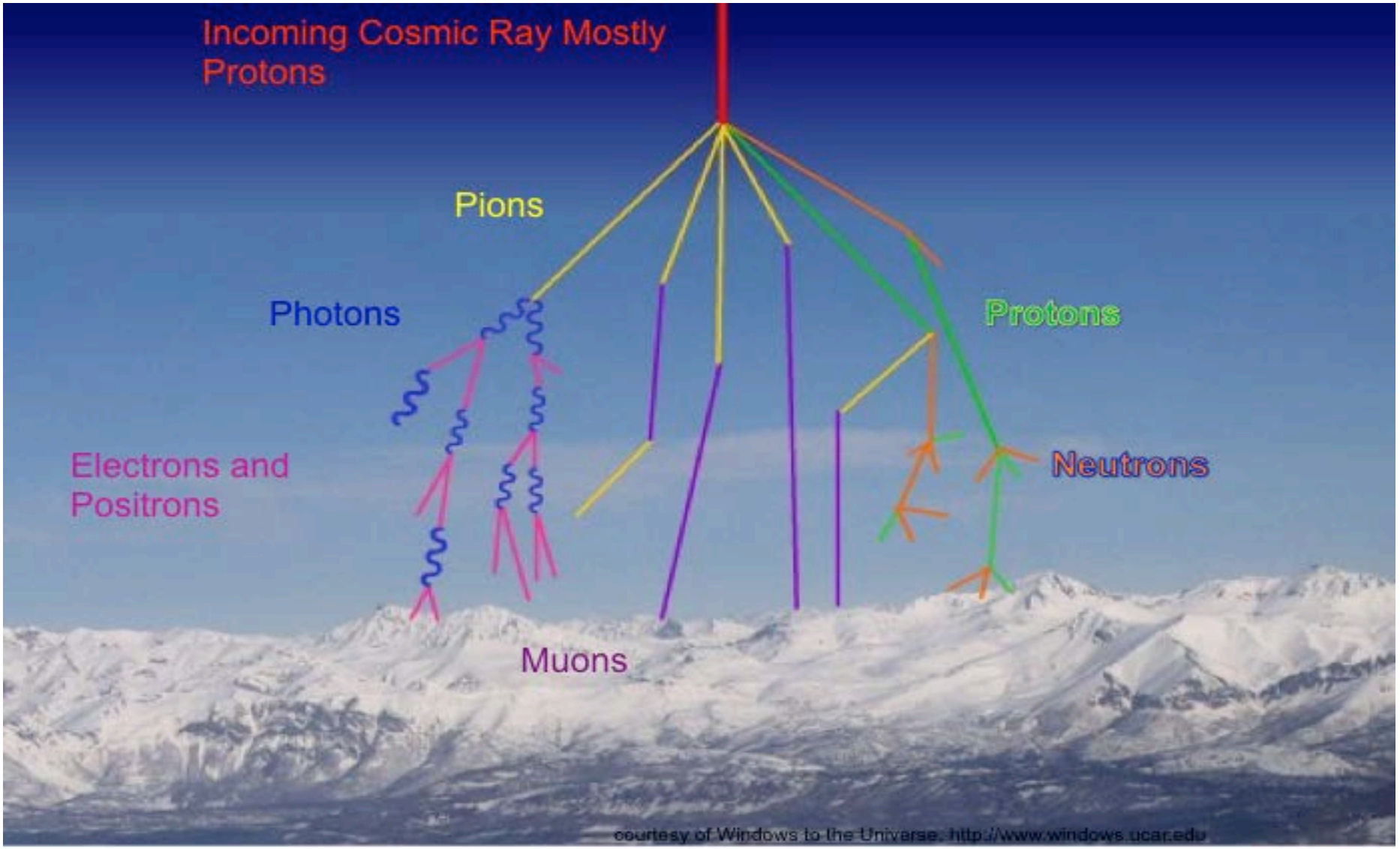
Source of Cosmic Particles

- Supernova accelerate cosmic particles to:
  - 100 MeV to 10 GeV
  - (up to 99.6% the speed of light)
- Particle energies can be up to 10^{20} eV

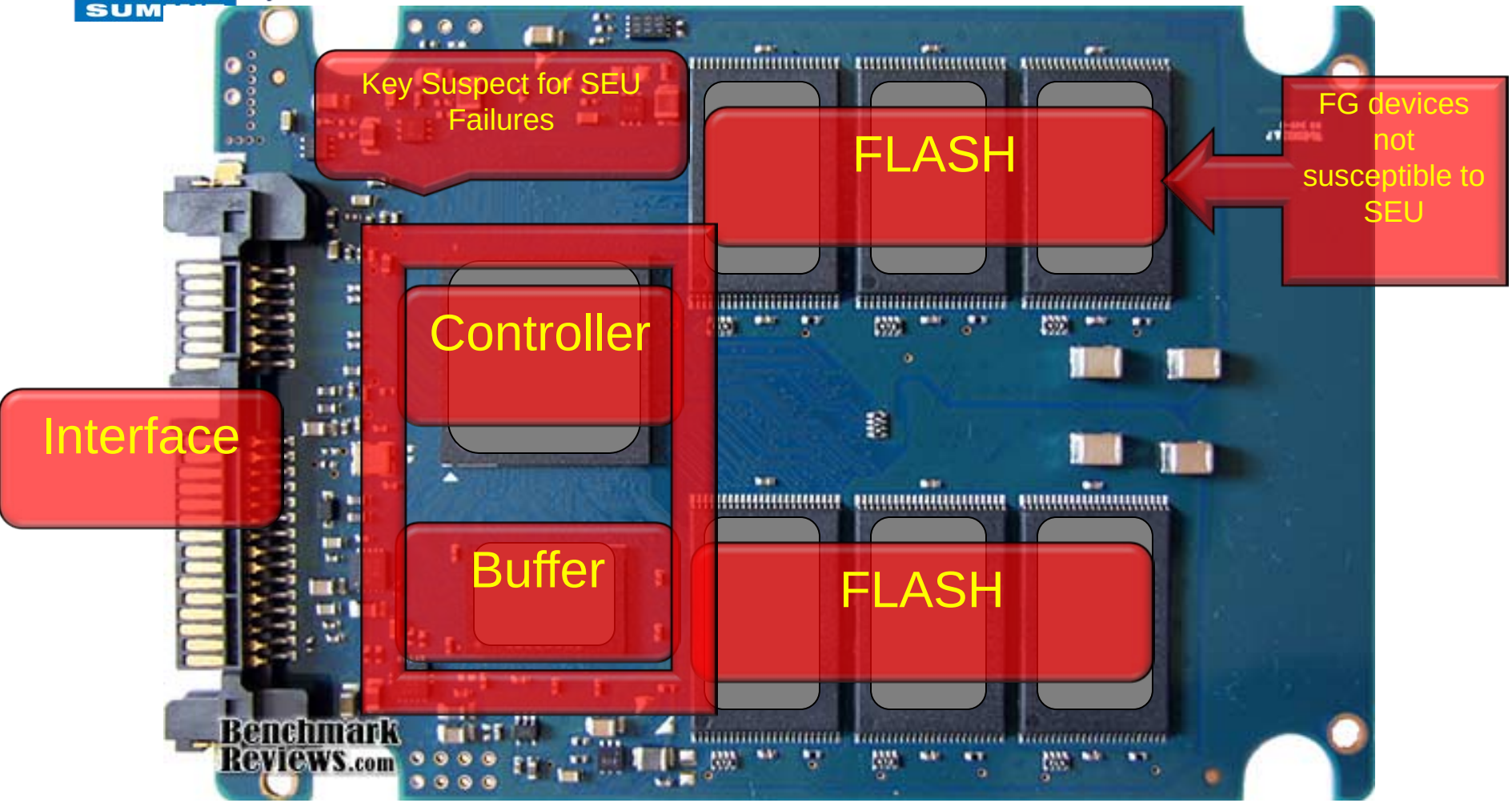


Crab Supernova

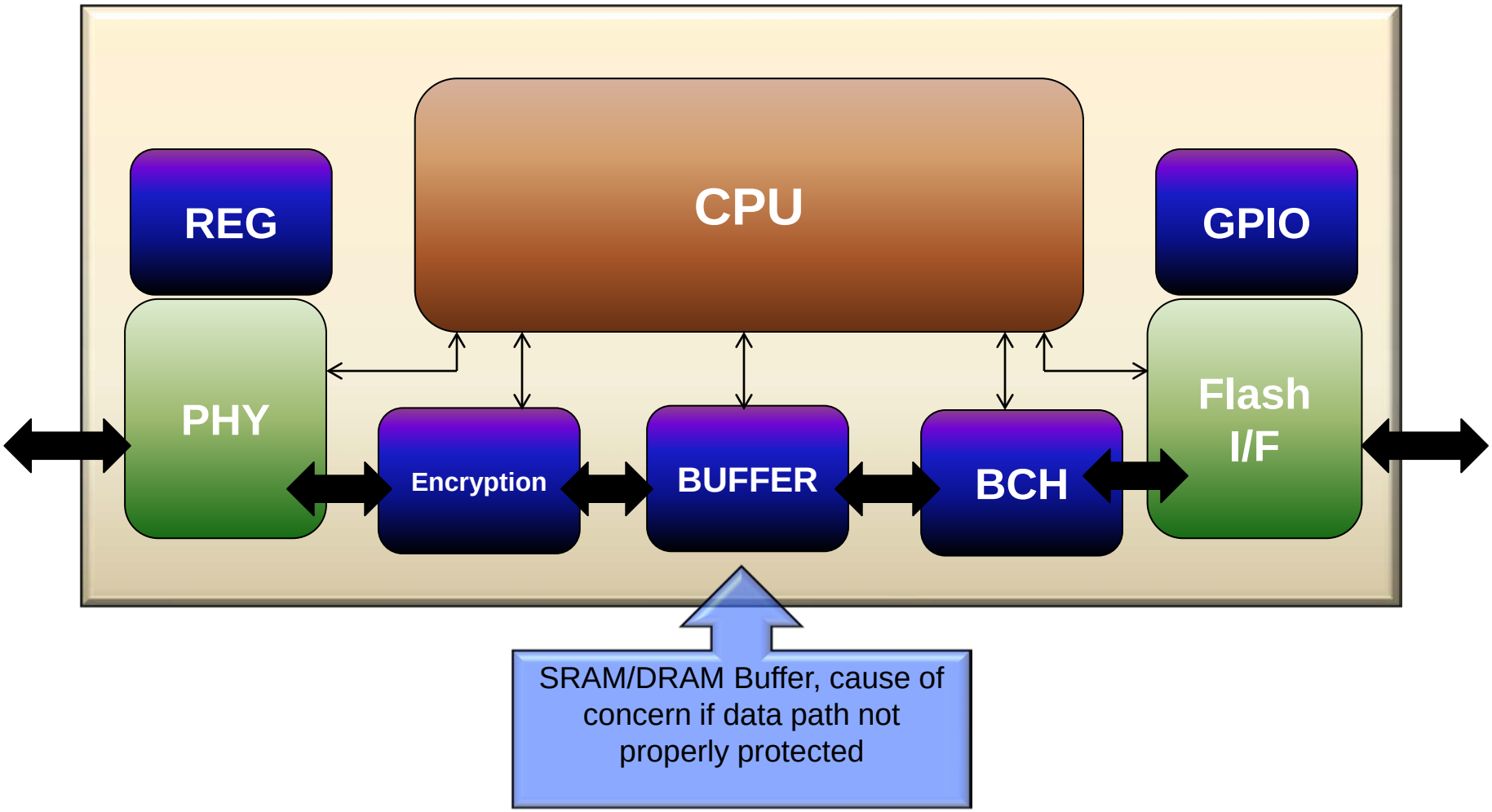
Cosmic Particle Shower on Earth



What is a Solid State Drive???



What's inside the SSD Controller



Why is this study required ???

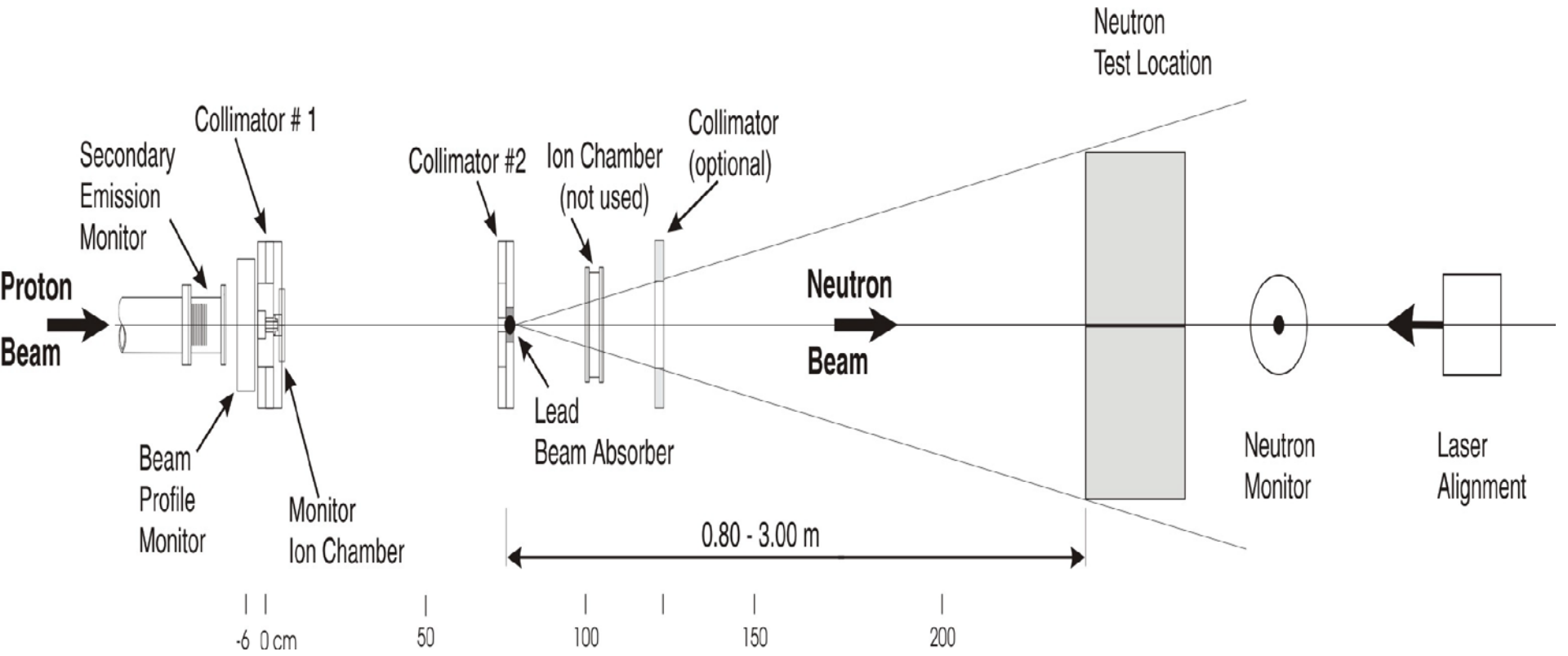
- SSD's are used for storing mission critical data (e.g. :Boot Image), - - Radiation caused SSD functional failure can result into catastrophic event.
- Least or No testing is performed by SSD Manufacturers to understand the impact of radiations on functionality of this drives.
- Study will provide valuable benchmarking data for drives under consideration for Enterprise usage.
- Results will help to unravel various failure modes in SSD under radiation environment, enabling proactive engagement between customer and SSD vendors to root cause the problem and implement corrective actions.

Test Details

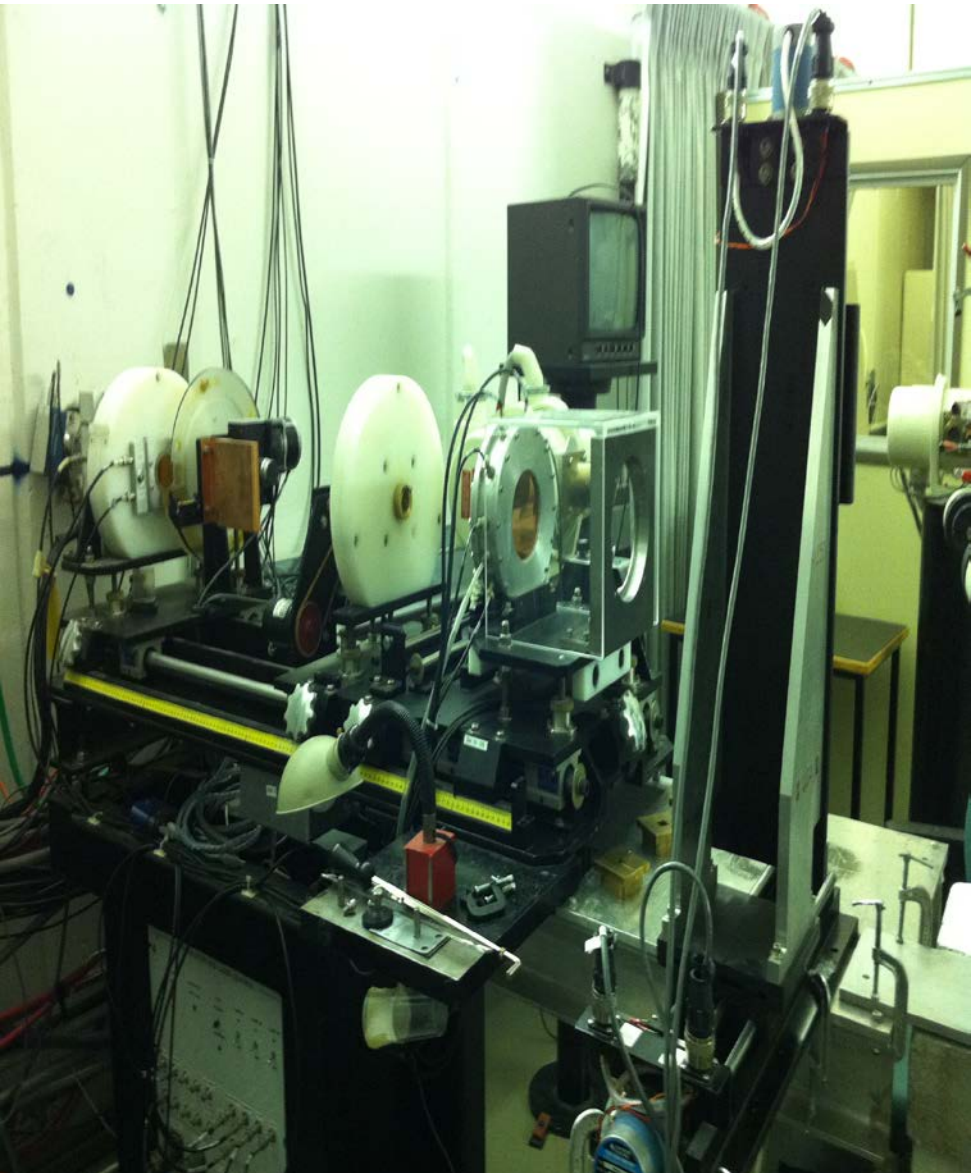
- Hardware & Software:
  - Mother Board: Asus M5A99X Evo.
  - CPU: AMD FX-8120.
  - Operating System: Windows 7-64 Professional.
  - Test SW: Burn-in Test and Crystal Disk

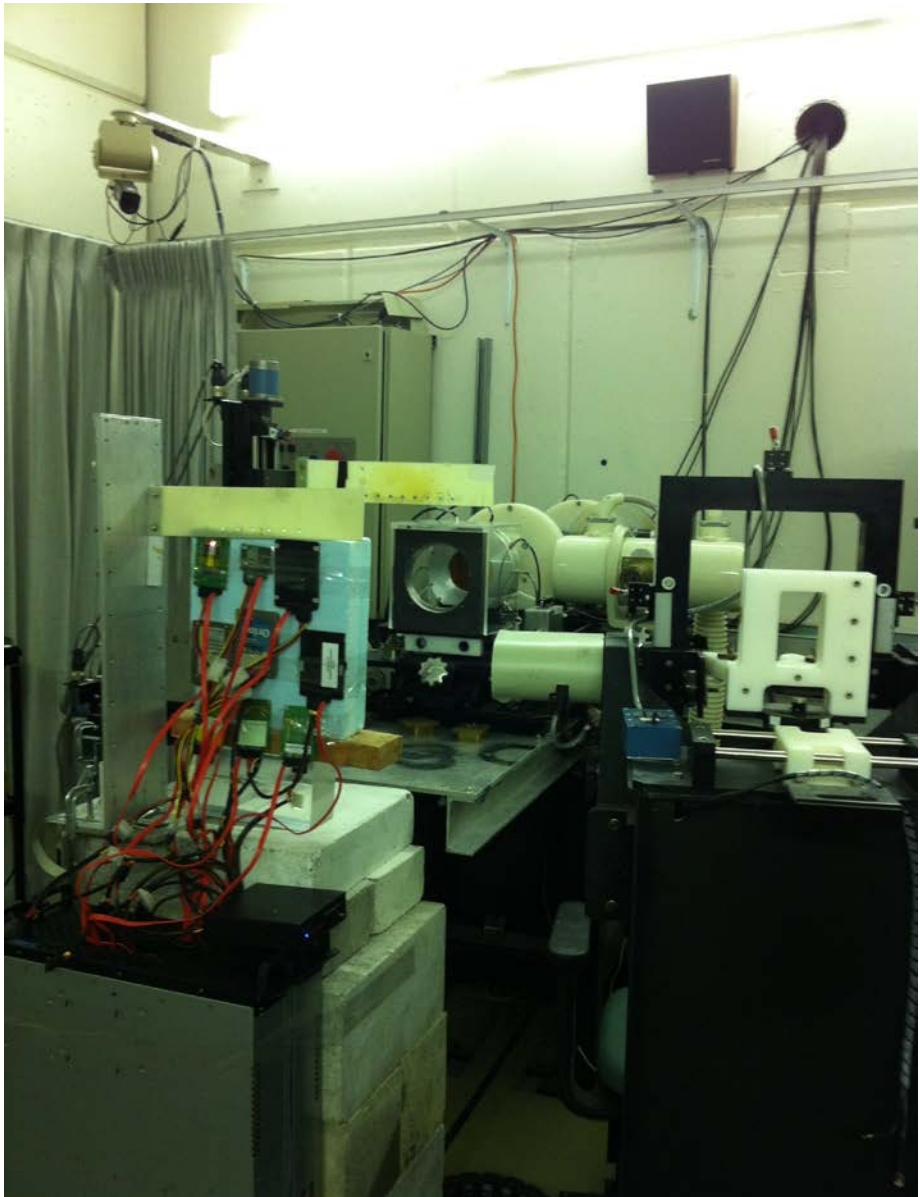
- Test
  - R/W Ratio : 50/50.
  - Transfer Block Size: 1024KB.
  - Sequential writes/Random Reads.
  - Que Dept (OIO): 1
  - Threads: 1

Test Setup



Source :E. W. Blackmore, “Development of a Large Area Neutron Beam for System Testing at TRIUMF”





Test Results

Drives Tested	Controller Buffer Type	UBER – Soft Error	Drive Disconnect – Critical Soft Error	Fit Rate - UBER	Fit Rate – Drive disconnect
Drive A	SRAM	0	4	0	3500
Drive B - SLC	SRAM	0	6	0	160
Drive B - MLC	SRAM	0	7	0	120
Drive C	SRAM	0	5	0	95
Drive D	SRAM	0	7	0	300
Drive E	DRAM	1	2	28	56
Drive F	DRAM	4	4	93	93
Drive G	SRAM	14	4	1700	490
Drive D(Shielded controller)	SRAM	0	1	0	47

Fit Rate Calculations

- FIT = $\frac{\text{No \# Failures}}{\text{Neutron Fluence (N/cm}^2\text{)}} * 13 * 1000000000$
  - Where
    - 13 = Neutron flux at NYC
- Neutron Fluence: $323.8 * \text{DIC count} * (2/N)^2$
  - Where
    - 323.8 = Neutron/cm^2/DIC count at 2m
    - DIC Count = (Diagnostic Ion Chamber) Count of Protons through the chamber.
    - N = Distance from target to beam. (this experiment it was 1.34m)

Interpretation of Results

- Failure Mode
  - UBER Soft Error : No of Uncorrectable Bit Errors reported by SSD.
  - Drive Disconnect (Critical Soft Error) : SSD drives stops responding to any further Host commands. (Drive becomes functional upon power cycle)

- Majority of failures were due to drive disconnect. Failure considered critical as it requires power cycle to recover the drive.
  - From System point of view this failures can result into fatal event if no provisions for soft reboot of drives are implemented.

- No Hard Errors were observed but few drives went into protect mode, inhibiting any future access to the drive.
  - Only firmware restore in field can unable access to the drives.
  - Catastrophic failure from system perspective. In field repair strategies needs to be deployed to handle such crashes.

Call for Actions

SSD Manufacturers.

- Conduct independent SEU analysis during engineering development phase to determine failure modes and implement corrective actions.
- Develop some infield repair methodology to help recover failing drives in the field.
- Publish Target SEU Hard & Soft Fit rate numbers in SSD Datasheet.

End Users.

- Deploy HW/SW capability to allow silent power cycle of SSD Drives without impairing overall functionality of a system.
- Deploy some redundancy for drives that stores critical data.

Future Plans

- Scrutinize failure logs with SSD Manufacturer to determine the actual cause of failure and implement corrective actions.
- Conduct isolated component level Neutron testing on SSD.
- Establish requirements for acceptable Hard and Soft FIT Rate for SSD.