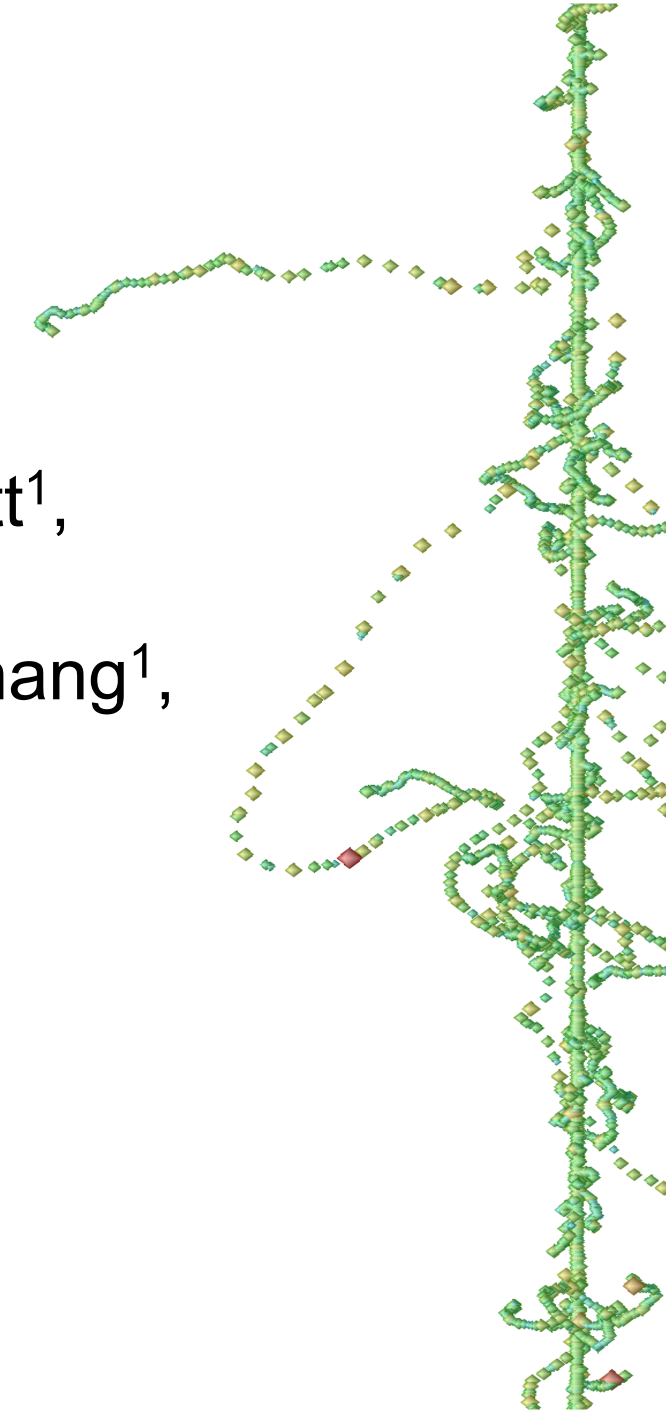
Applications of MRED



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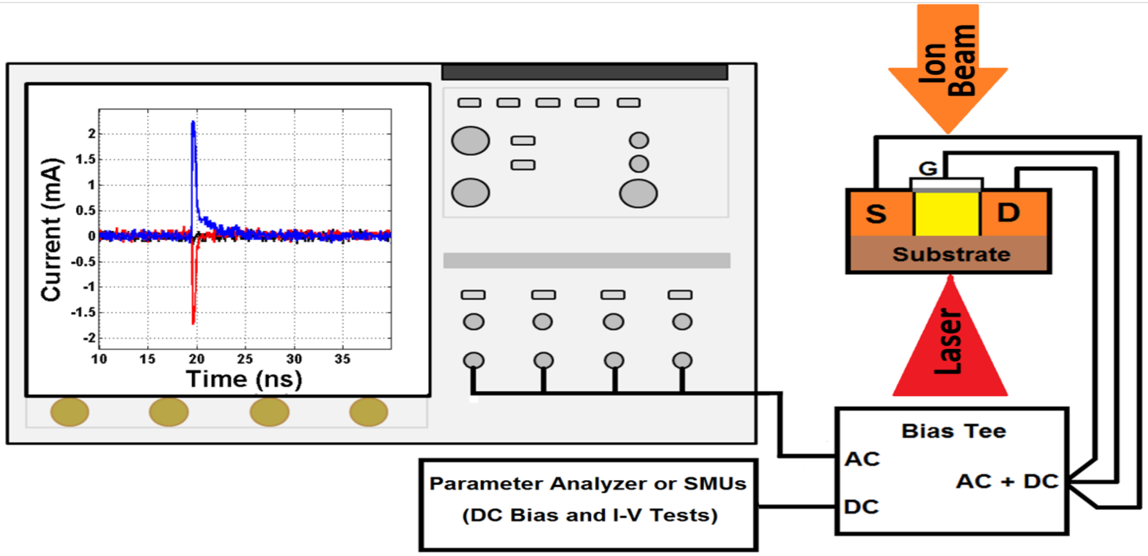
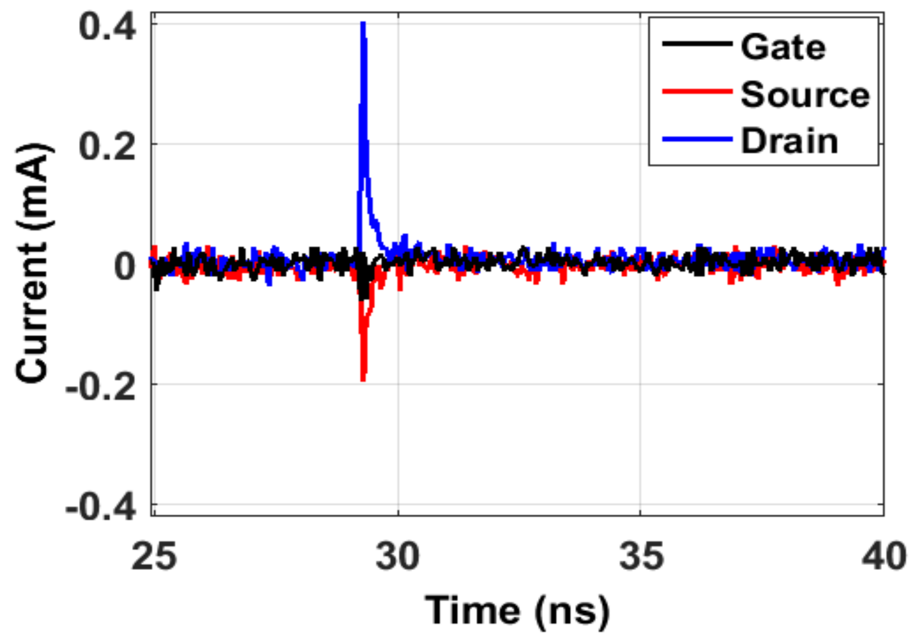
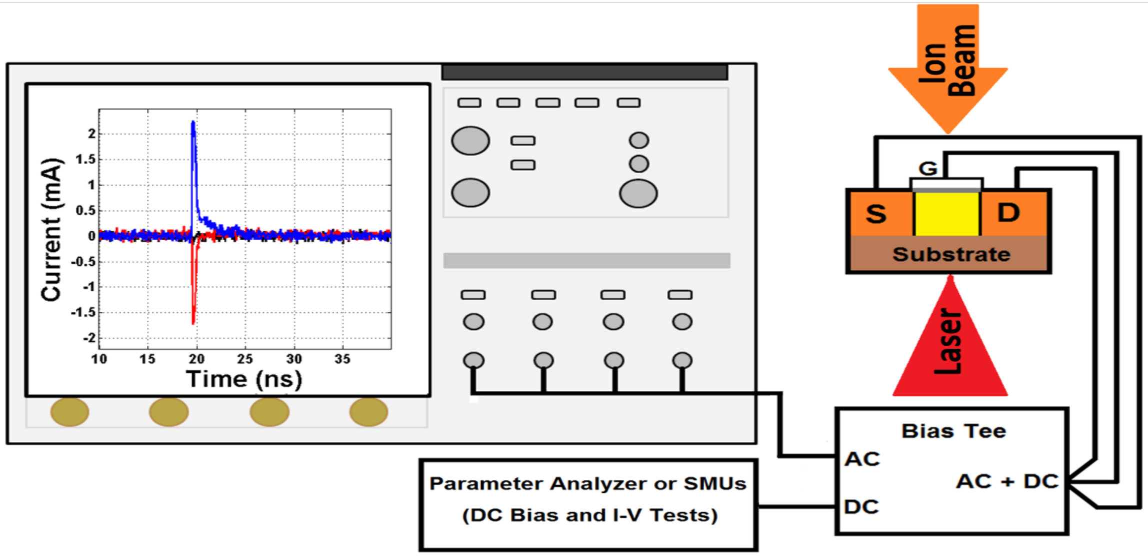
2. Lipscomb University, Nashville, TN, USA
3. Hill Air Force Base, USA
4. SLAC, Menlo Park, CA, USA

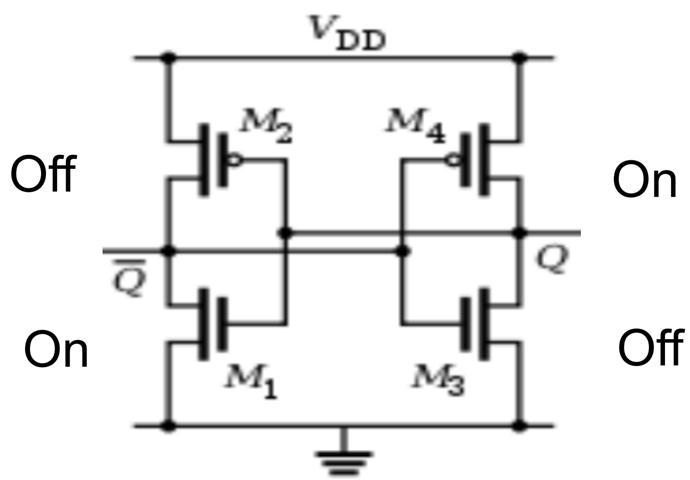
High-Speed Pulse Capture Setup



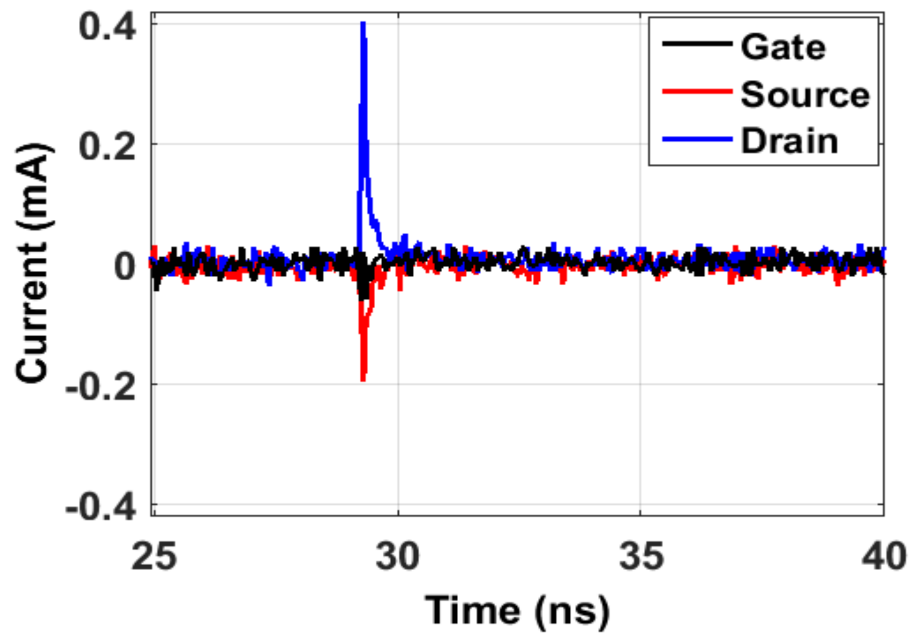


High-Speed Pulse Capture Setup and SEU

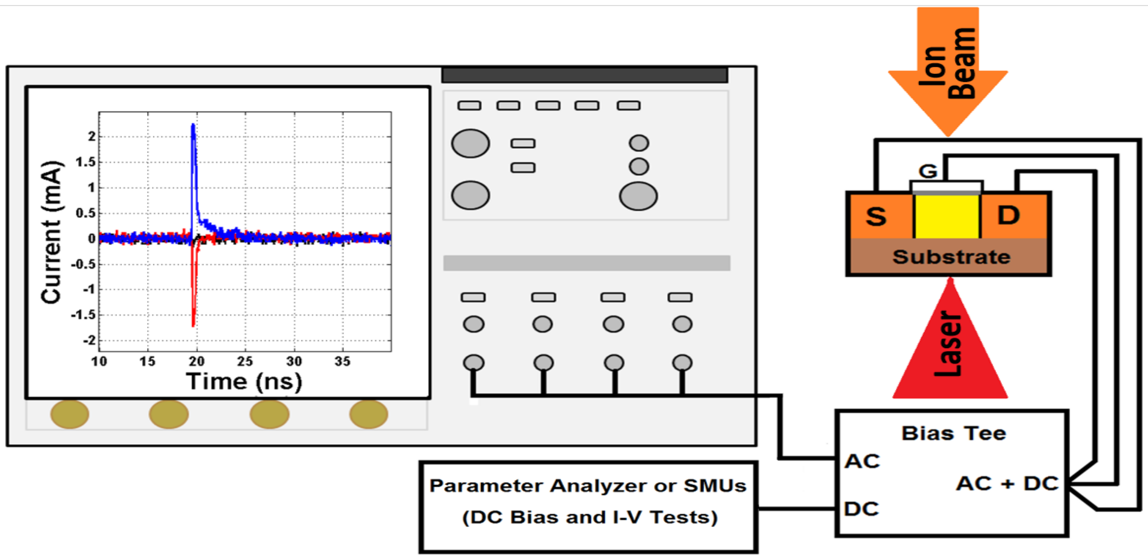


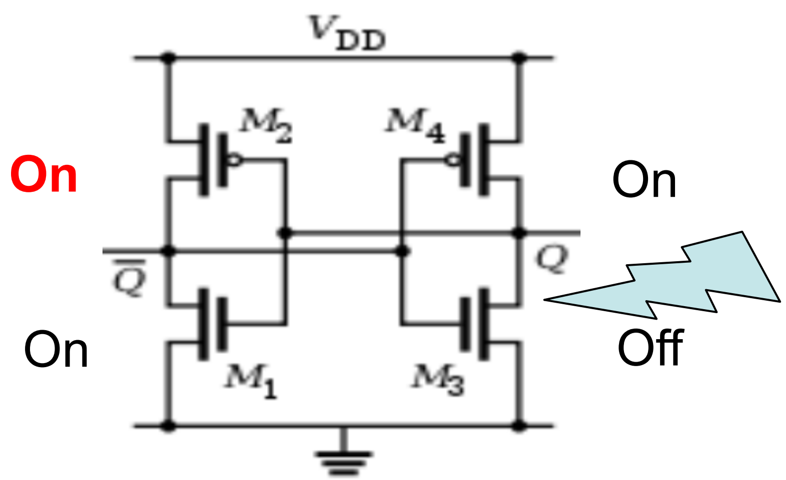


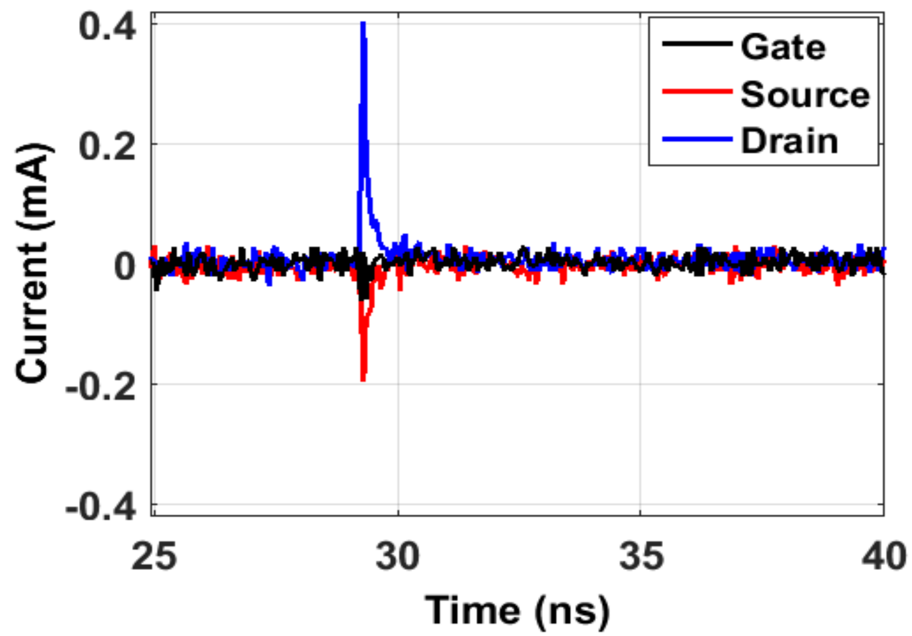
Zero Bit State



High-Speed Pulse Capture Setup







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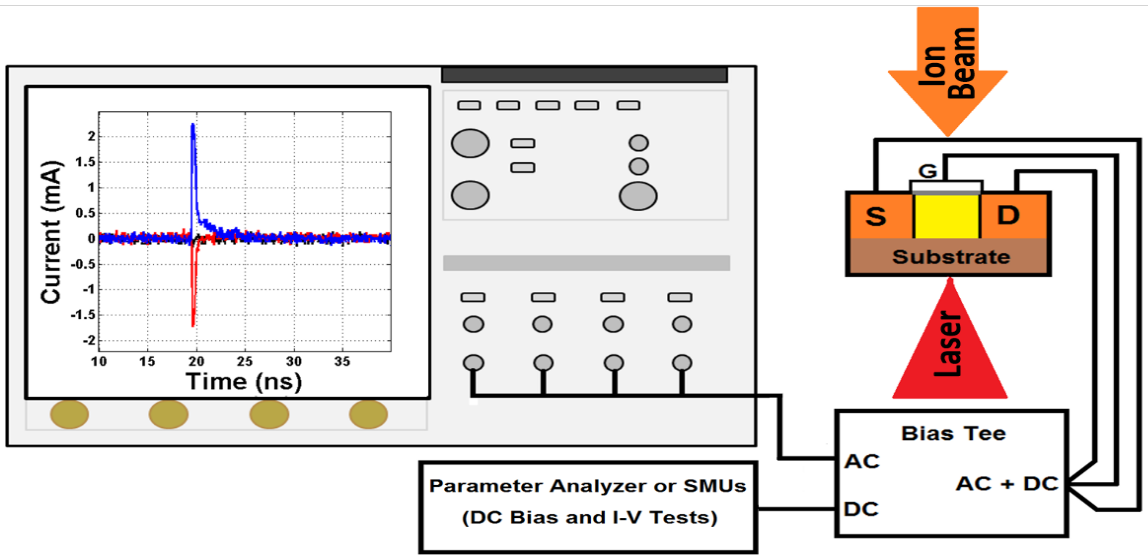
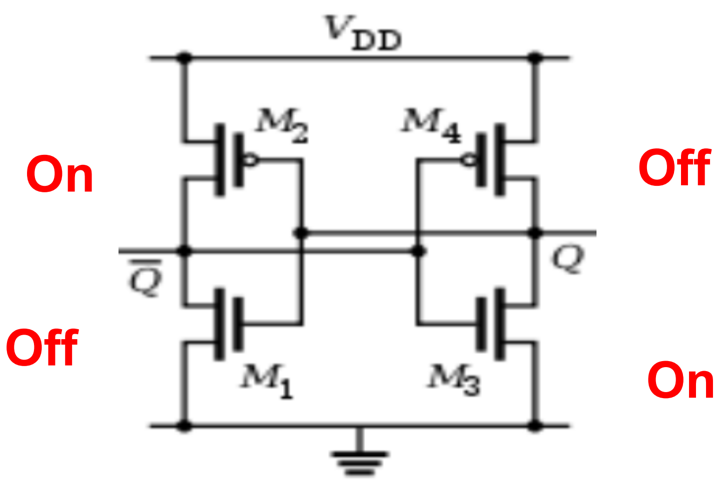
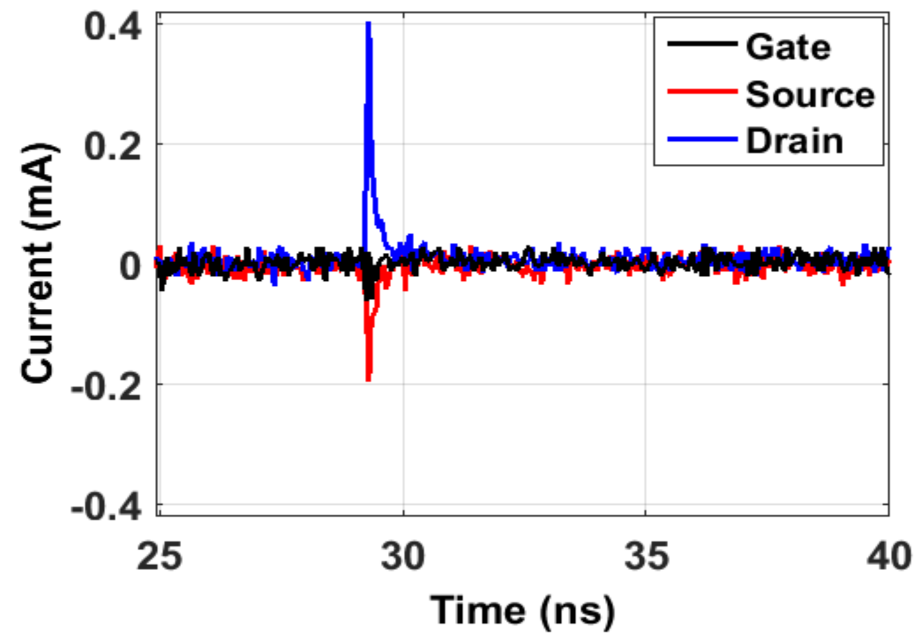




One Bit State

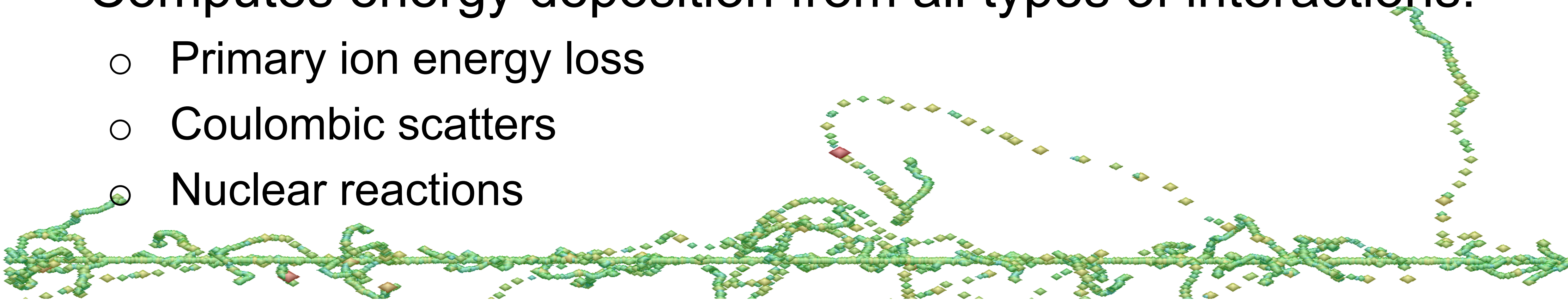


Monte-Carlo Radiation Transport Calculations

- Geant4: a toolkit for the simulation of the passage of particles through matter.

- MRED: Monte Carlo Radiative Energy Deposition
  - first generation Python/Geant4 application
  - Contains the best available physics

- Computes energy deposition from all types of interactions:
  - Primary ion energy loss
  - Coulombic scatters
  - Nuclear reactions

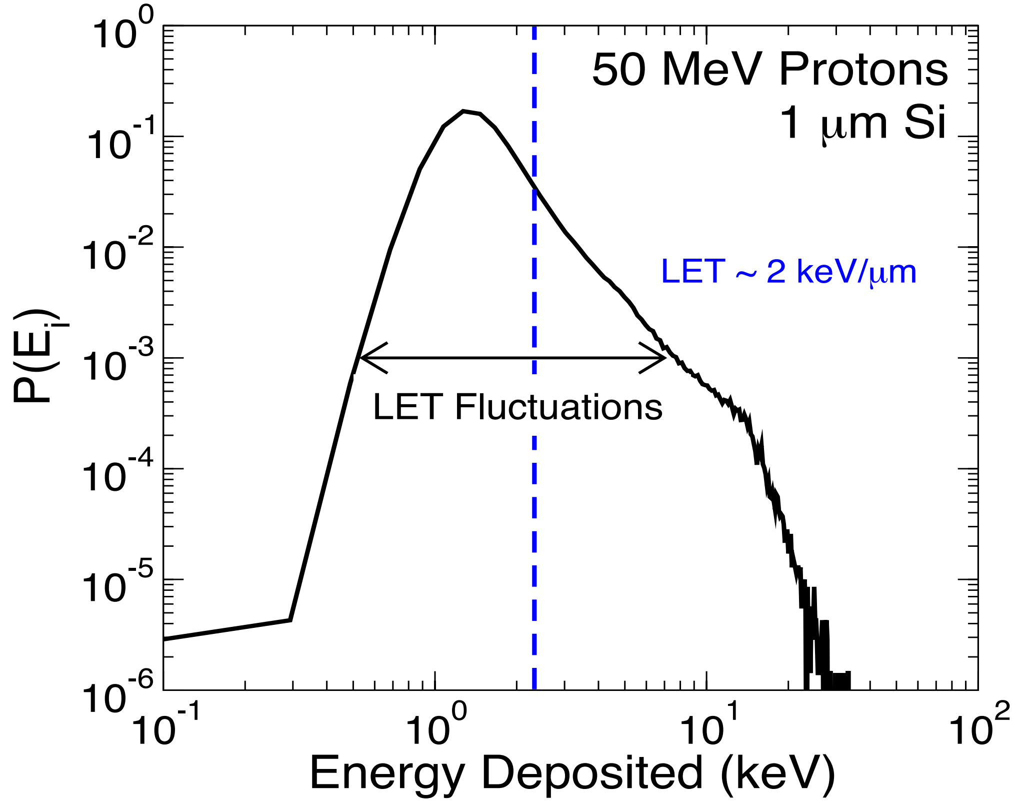


LET Metric and LET Fluctuations

LET: the *average* energy lost per unit path length

LET fluctuations (straggling): the variability in continuous energy loss of a single species and kinetic energy

- LET Fluctuations
  - Increase with decreased collection volume [5]
  - Large for lightly ionizing particles

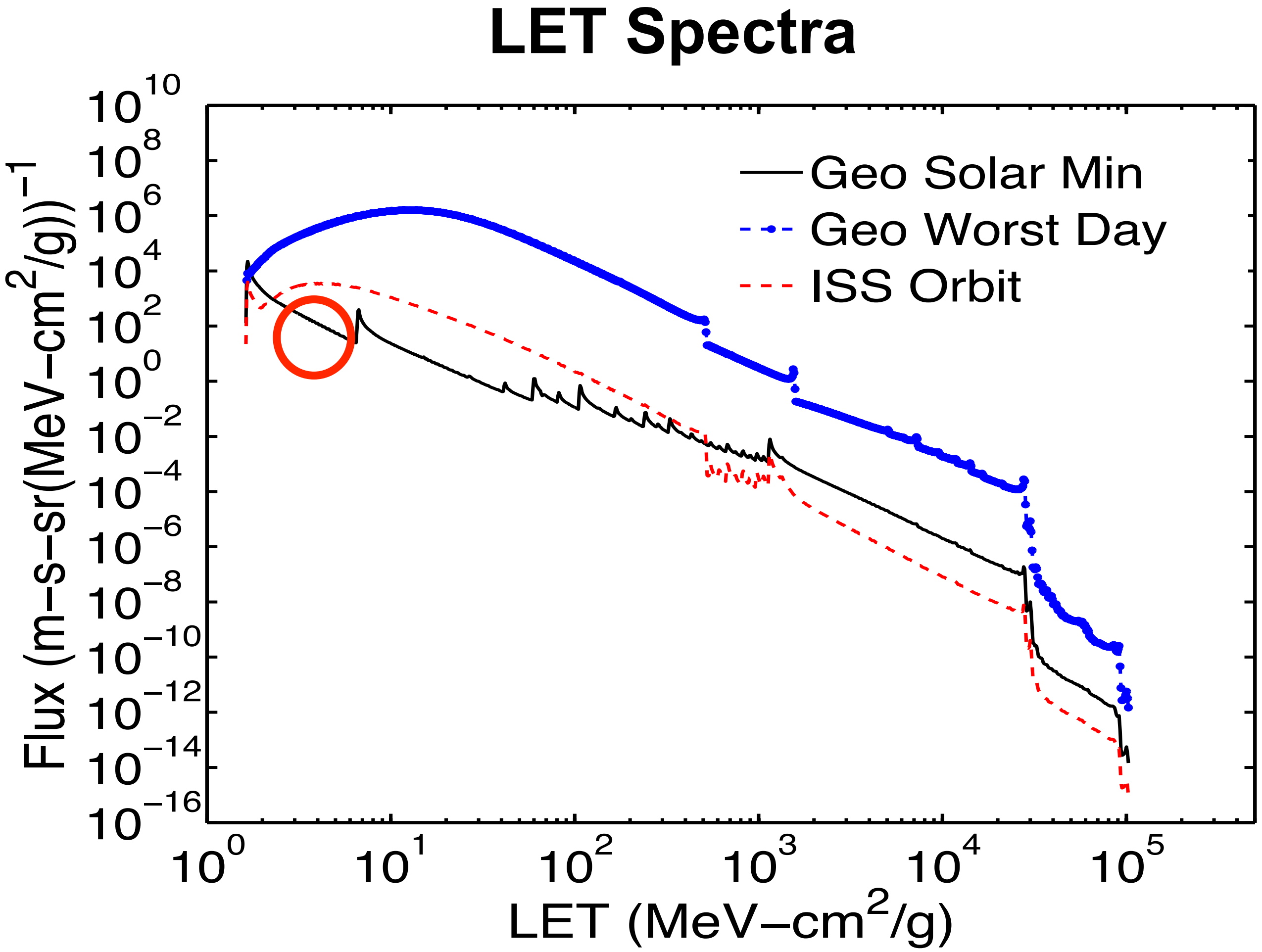


LET can be a poor representation of the distribution

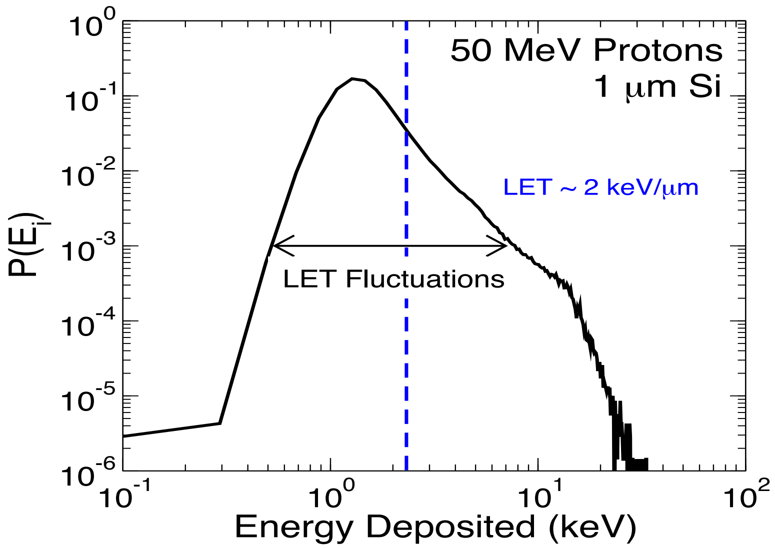
[5] H. Bichsel, *Nuclear Instruments and Methods in Physics Research A*, vol. 562, pp. 157–197, March 2006.

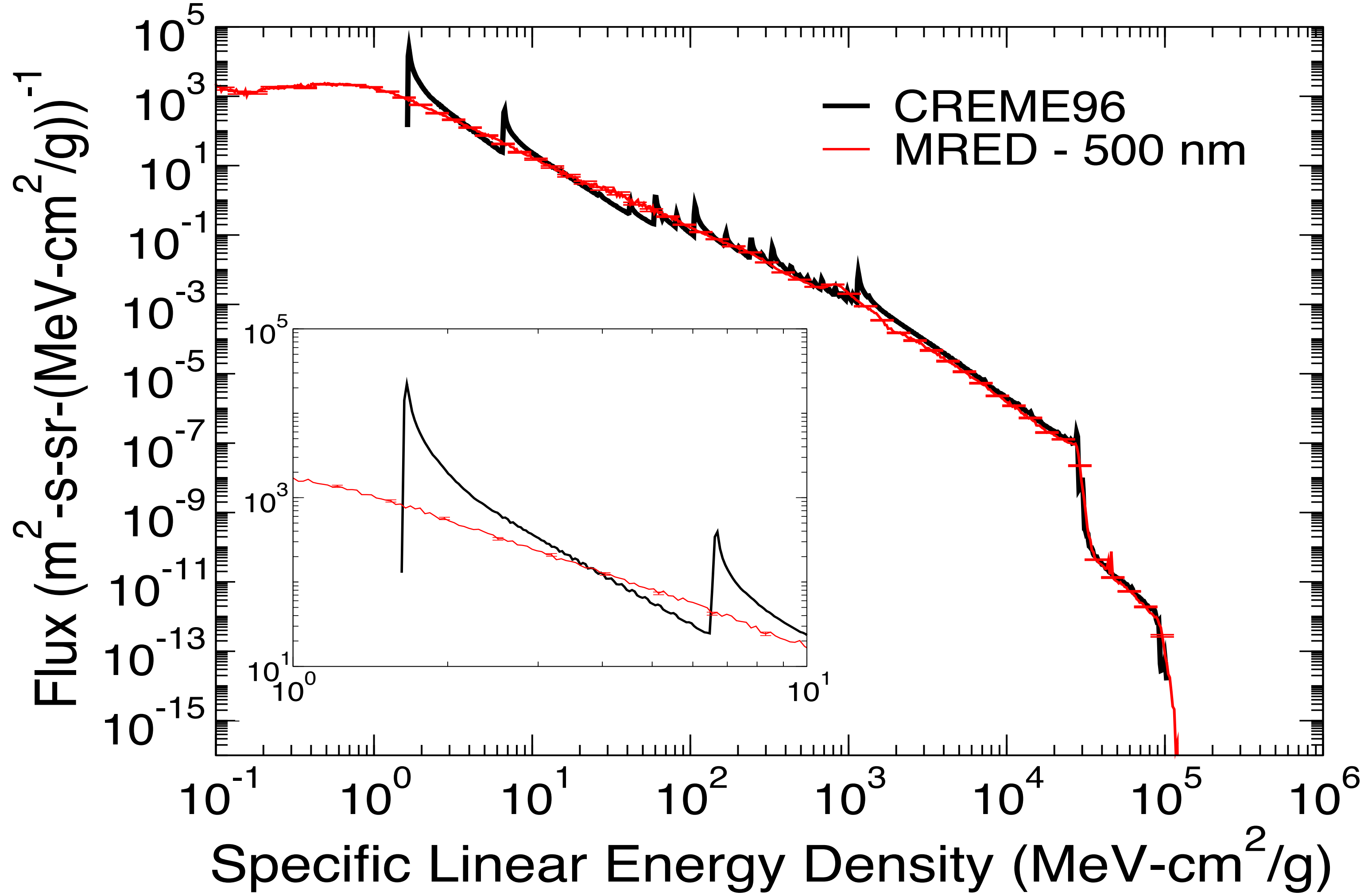
Environment Models & LET spectra

- ❑ Simplifying assumptions are used to compute SER predictions
  - Ions with the same LET will produce the same device response
  - Create environment model based on frequency versus LET



Physically Informed Environment Spectra

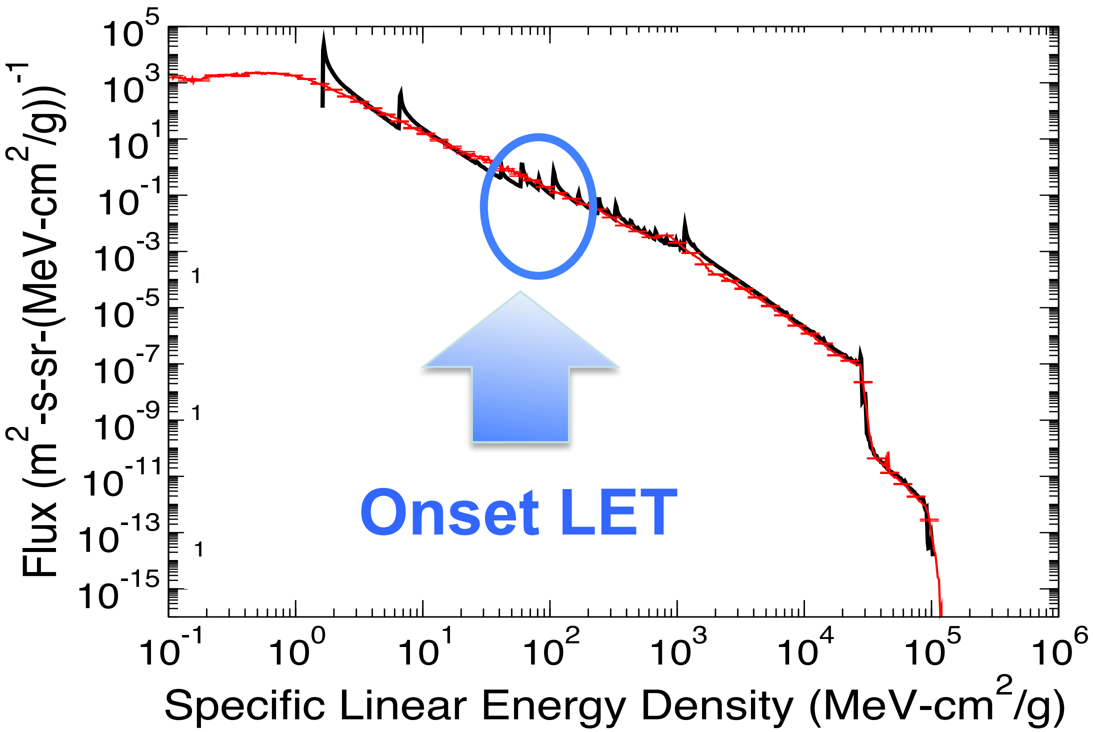




Implications of LET Fluctuations for SER Prediction

- Over prediction observed for CREME96 at GEO at solar minimum
  - Onset LET is in region dominated by LET fluctuations

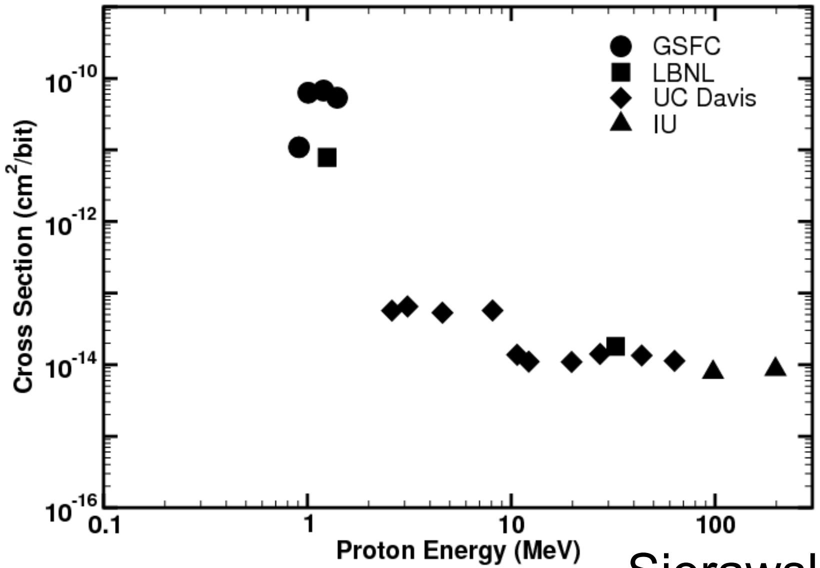
GEO Solar Minimum



Onset LET in region where
Fluctuations are large

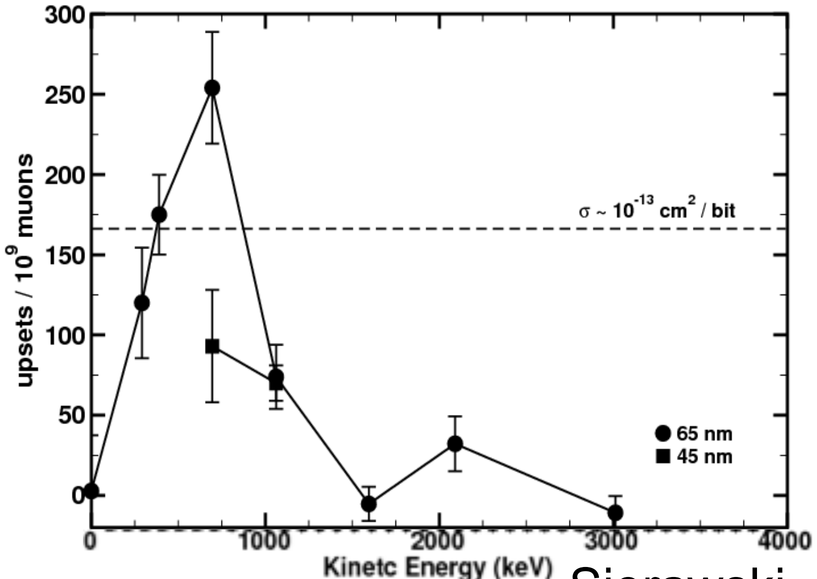
CREME96	SLED
1×10^{-7} bit-day^{-1}	2×10^{-8} bit-day^{-1}

SEUs from Lightly Ionizing Particles



Protons

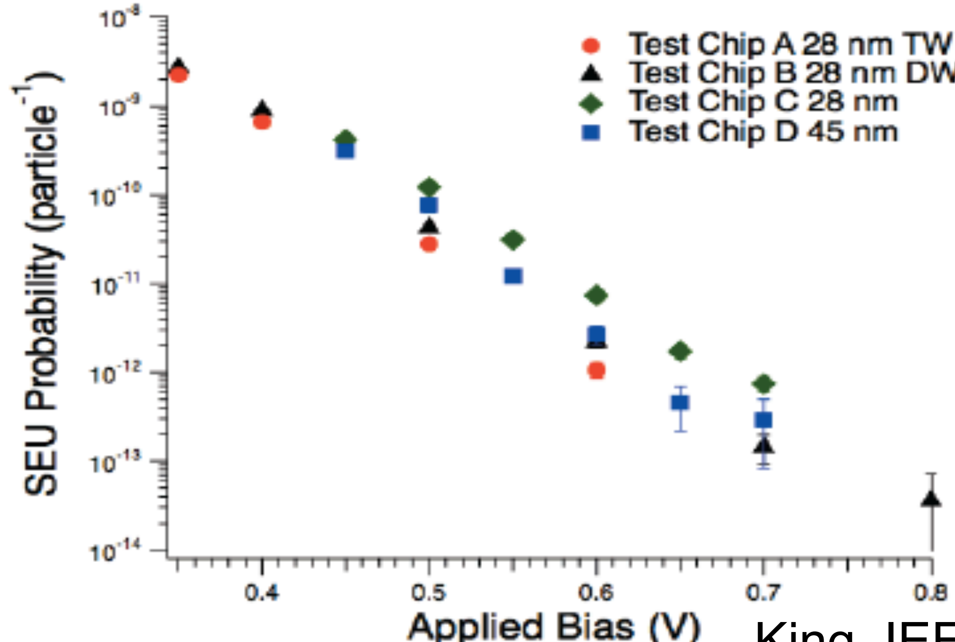
Sierawski, IEEE TNS 2009



Muons

Sierawski, IEEE TNS 2010

- Decreasing features sizes have lead to a reduction in critical charge
- With Q_{crit} < 1 fC SRAMs have become sensitive to effects from lightly ionizing particles



X-rays

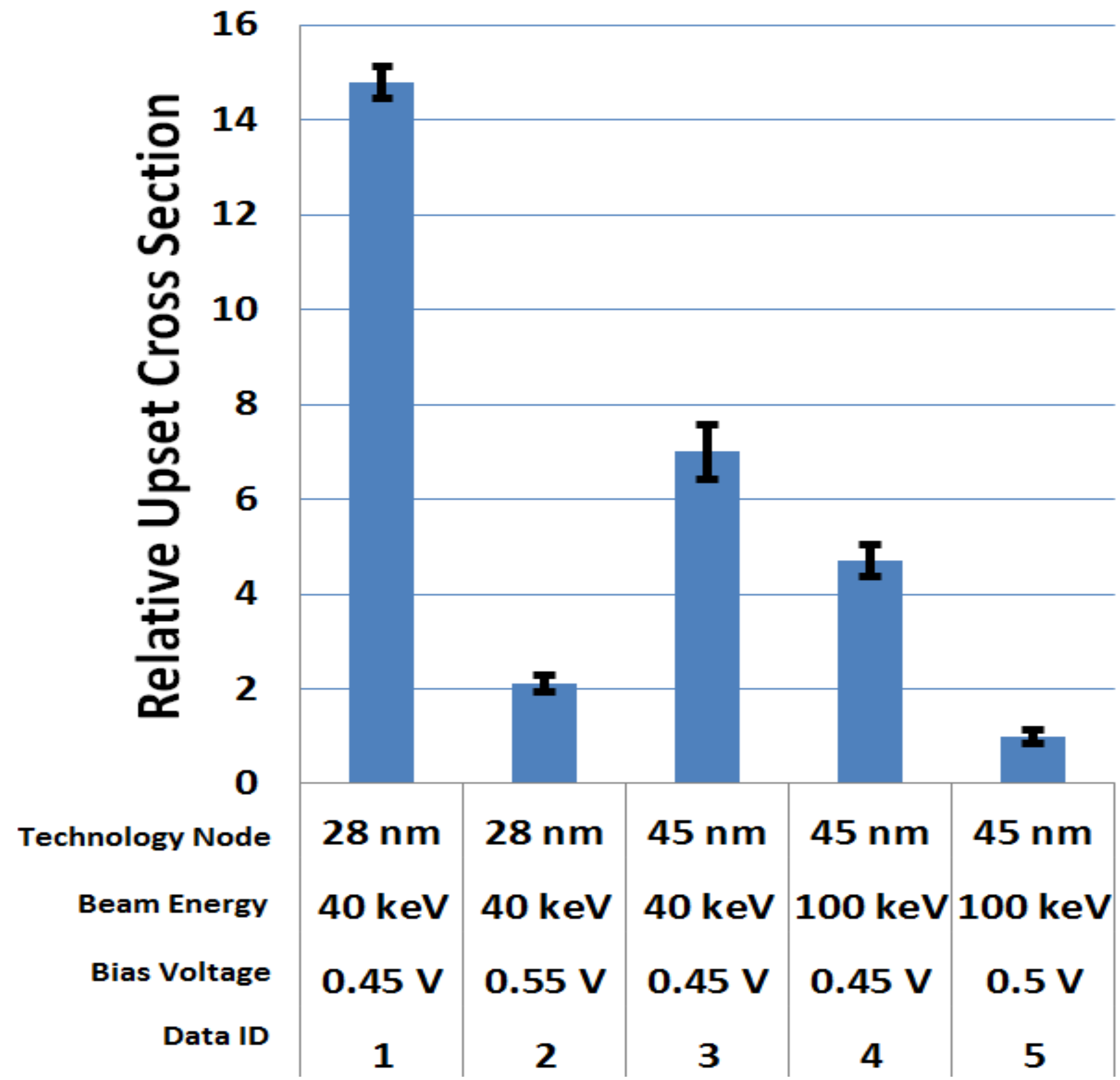
King, IEEE TNS 2013

Electron Irradiation Results

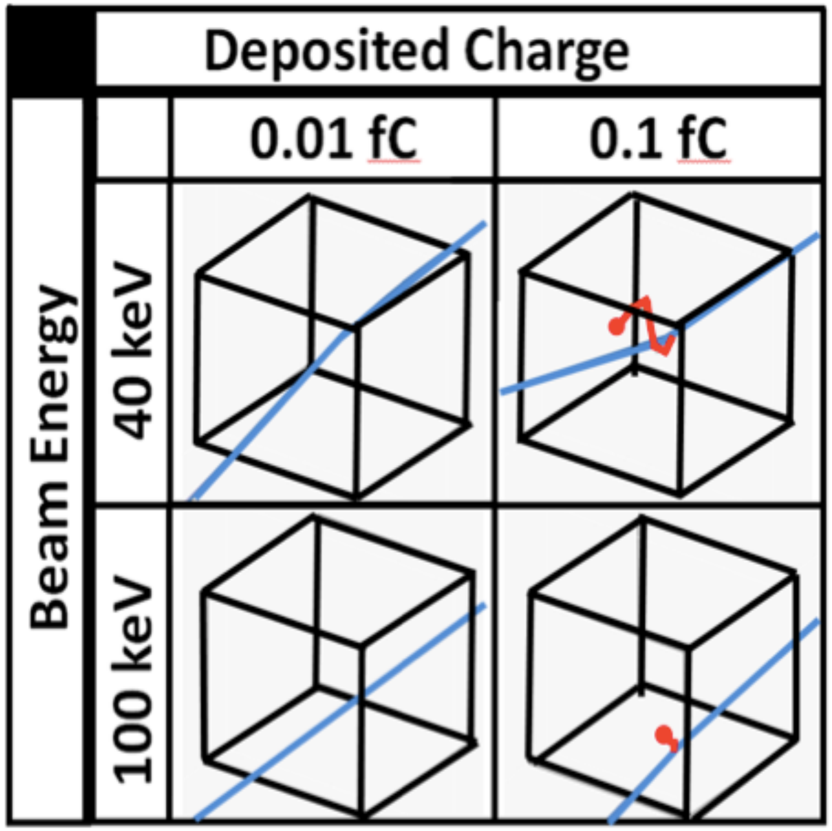
- **28 nm and 45 nm SRAMs**
- **100 keV and 40 keV electrons**

- **Cross Section = # upsets/fluence**

- **Reduced bias testing**
- **Devices were functional at reduced bias**

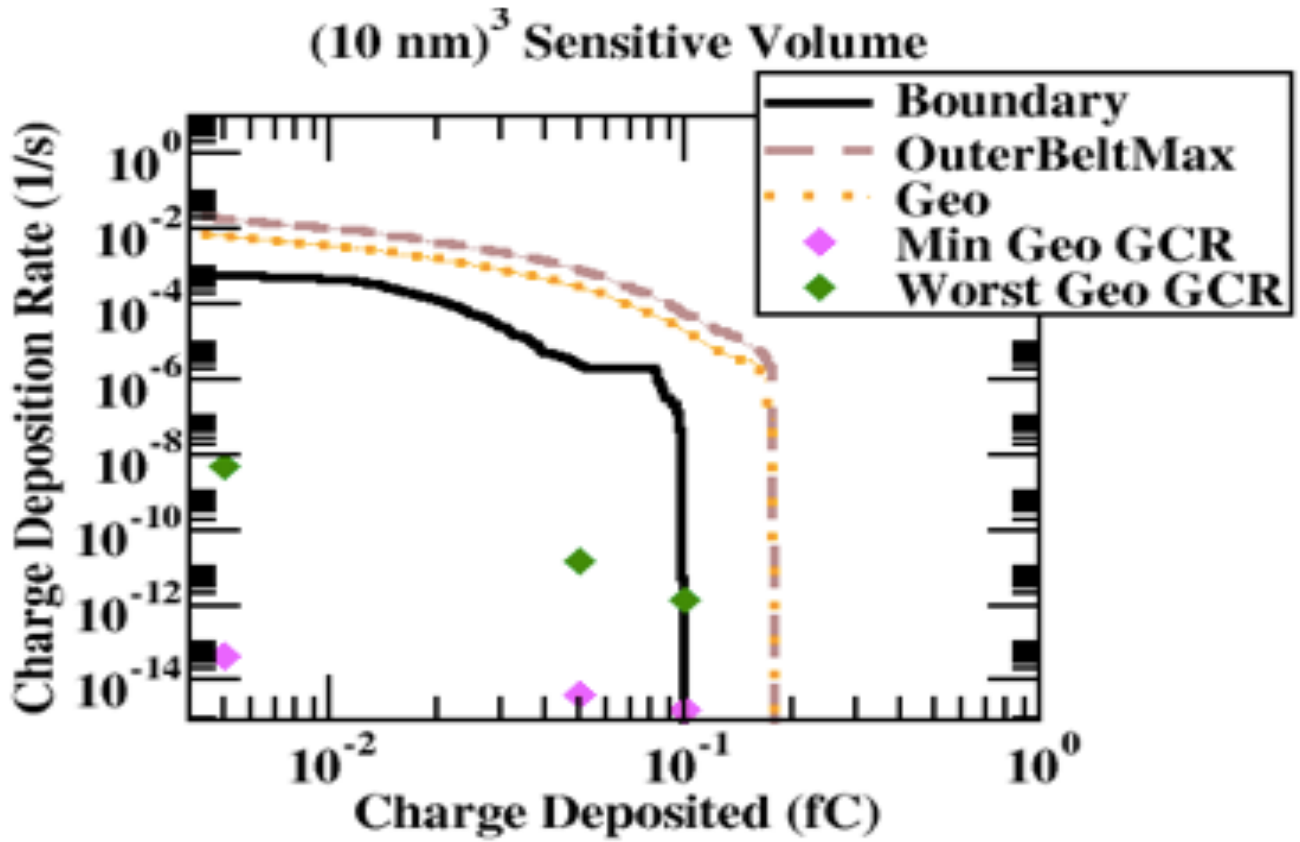


Single-Electron Induced SEU Mechanisms



- MRED Simulations of energy deposition
- Delta ray production required to induce SEUs

Estimated SEU rates: MEO and GEO

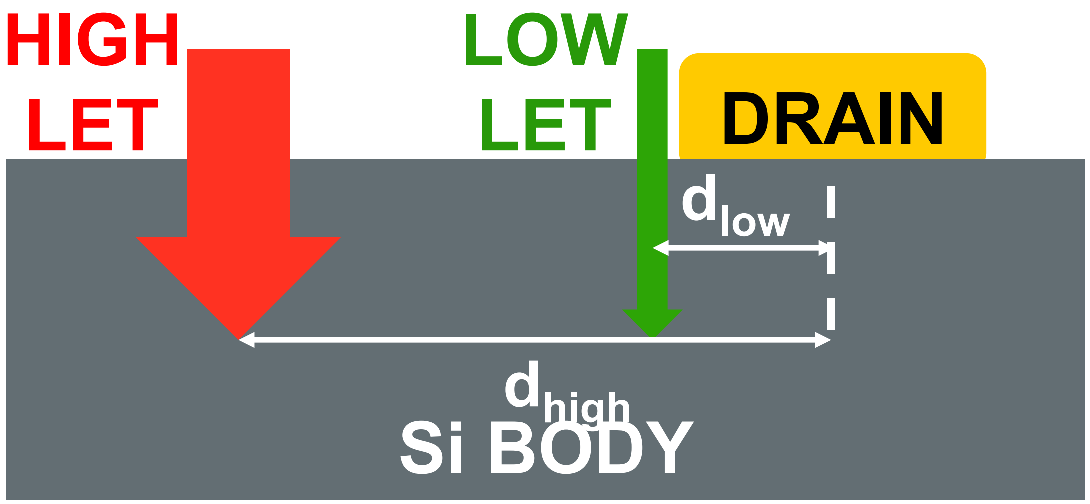


- **MEO and GEO: SEU rates are dominated by electron environment if device is sensitive to electron induce SEUs**
- **LEO (not shown): SEU rates are dominated by proton environment even when devices is sensitive to electron induce SEUs**

Predicting muon SEU results with MRED

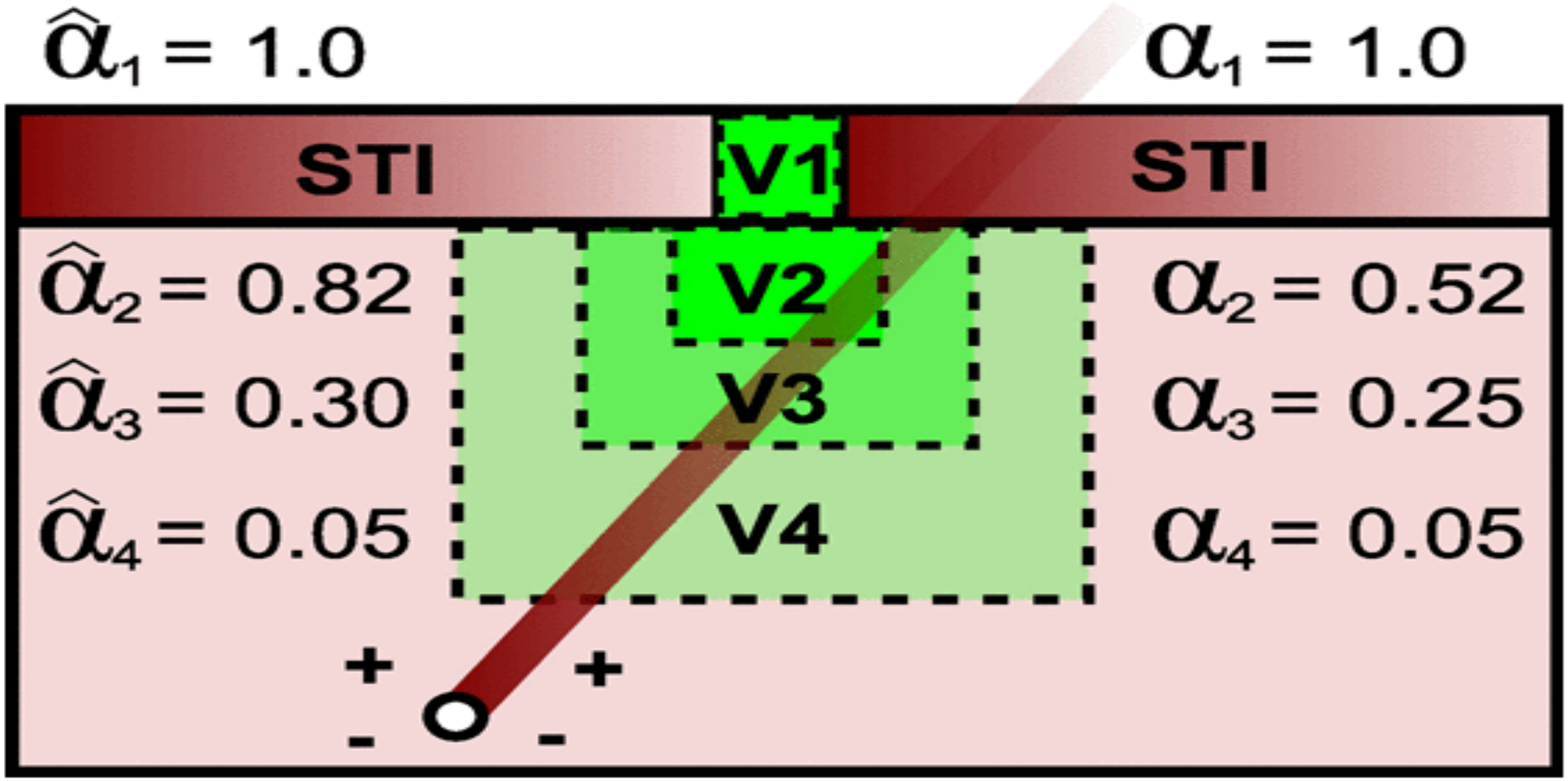
- Muons are produced from interactions between galactic cosmic rays and molecules in the atmosphere
- Terrestrially operated devices with low critical charge may be at risk for muon induced SEUs
- MRED simulations can be used to circumvent expensive muon testing

Heavy ion probing of sensitive regions



- Higher LET ions deposit more charge and can upset a device at distances further from the drain
- Differences between the cross-sections of high and low LET strikes can be used to map out sensitive volumes

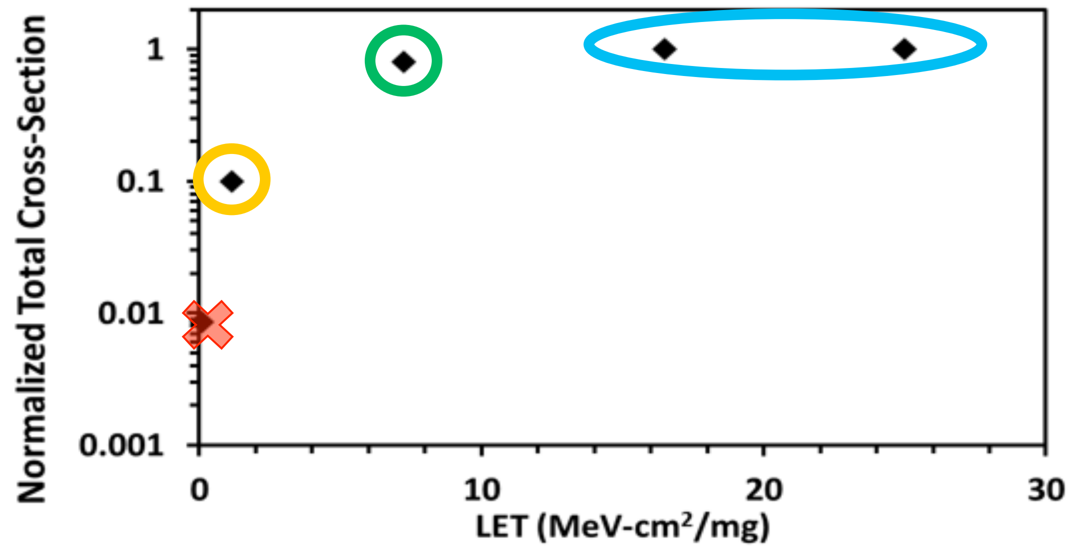
Producing SV models with heavy ion data



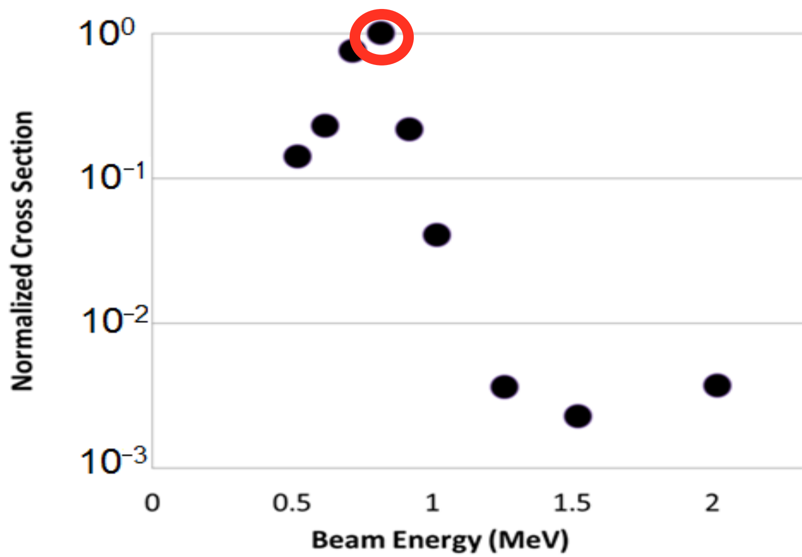
28 nm SRAM multi-SV model

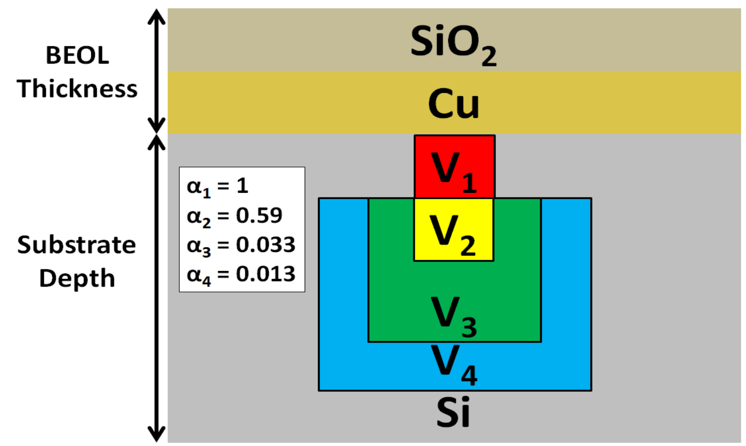
- Heavy ion data was used to calibrate volumes 2-4
- V1 was calibrated to the peak proton cross-section instead of manufacturer information

28nm Heavy Ion Data

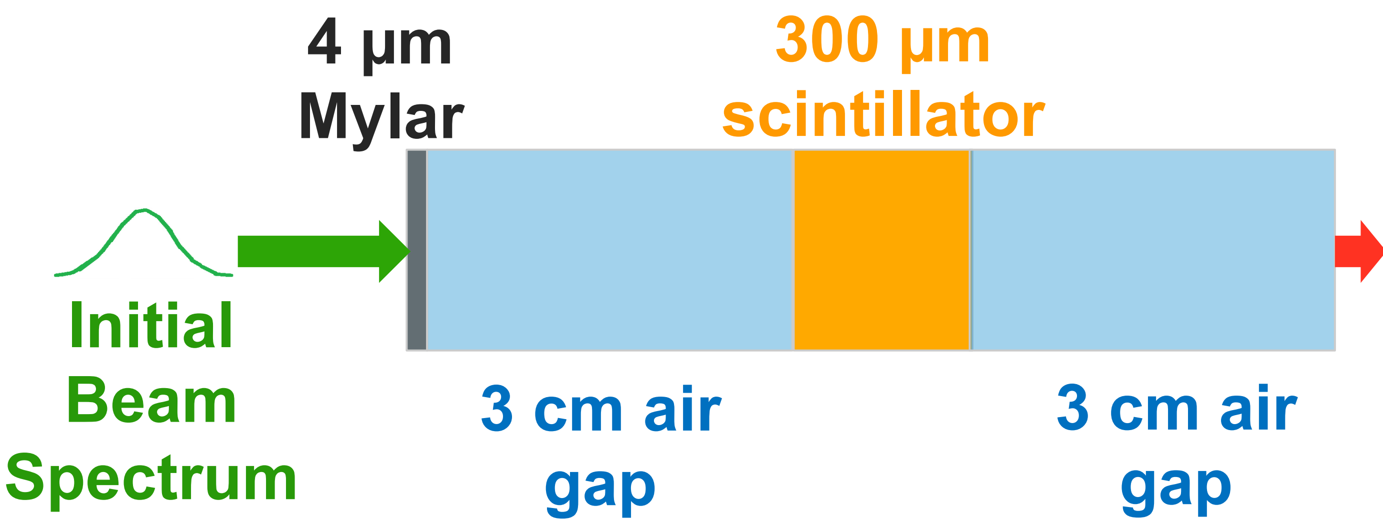


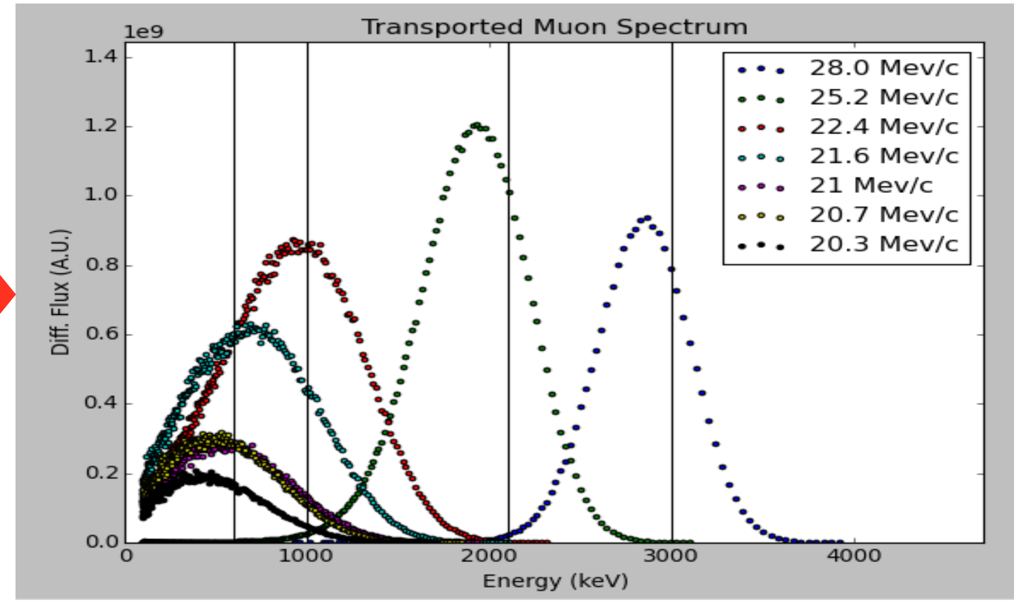
28nm Proton Data





Transporting the TRIUMF muon beam



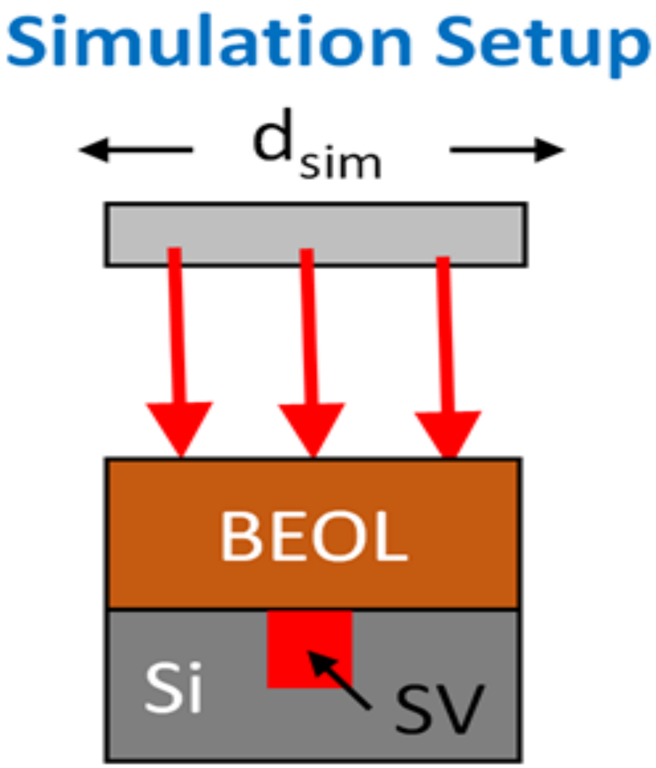


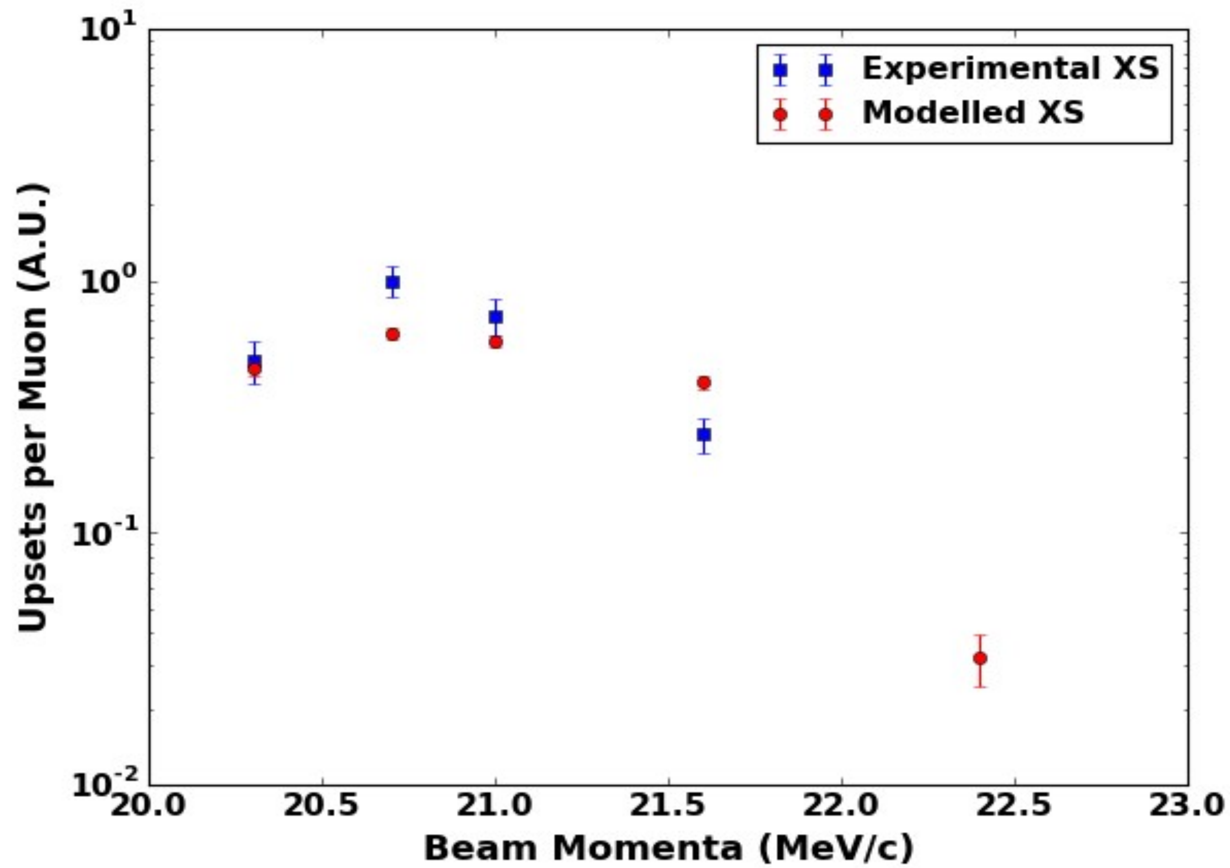
- In order simulation results to test data from the TRIUMF muon beam line, an accurate spectrum must be derived

- MRED simulations were performed transporting the initial muon beam through the materials between the device and the beam and then used in device level simulations

Muon simulations on 28 nm SRAM

- Spectra from previous slide were loaded into MRED
- Muons were simulated striking the device at normal incidence with randomly selected initial positions





AMSAT AO-85 (Fox-1A)

- **Launched on board Atlas 5 from Vandenberg, CA as part of ELaNa-12 program, EPSCoR development**
- **Carries Vulcan payload (1 LEP) with 8 x 4Mb SRAM (ISSI IS64WV25616B) experiment**
  - Broadcasts single event upsets, resets, power
- **Crowd-sourced science**
  - Largest ground network in the world?
- **The additional launches planned for 2017 and 2018**
  - Delivered spacecraft for two, third will be delivered in July 2017

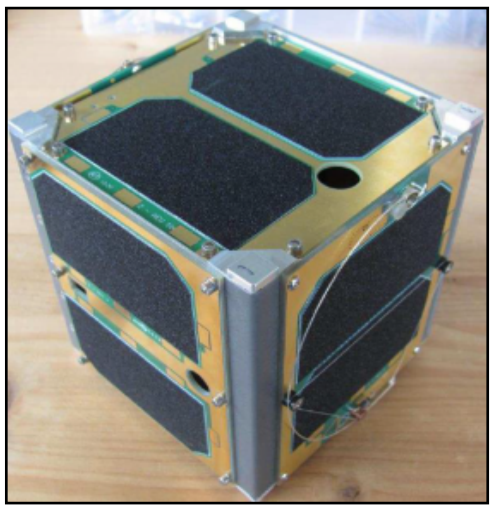


Image Credit: AMSAT


Image Credit: ULA


Image Credit: ULA

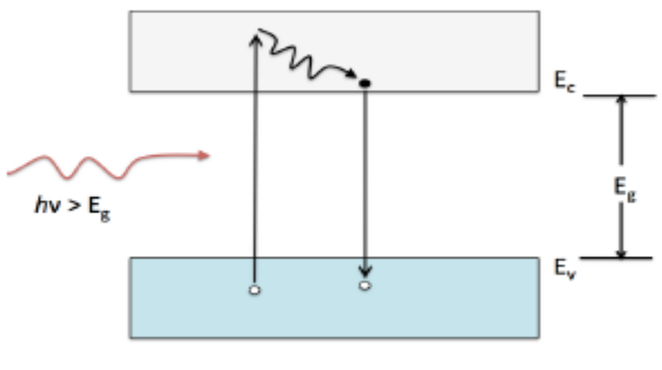
New Project

Develop an understanding of the charge generation by pulsed-laser irradiation with sufficient clarity that advanced device response is predictable from first principles physics and design information ?

Background: Laser Testing

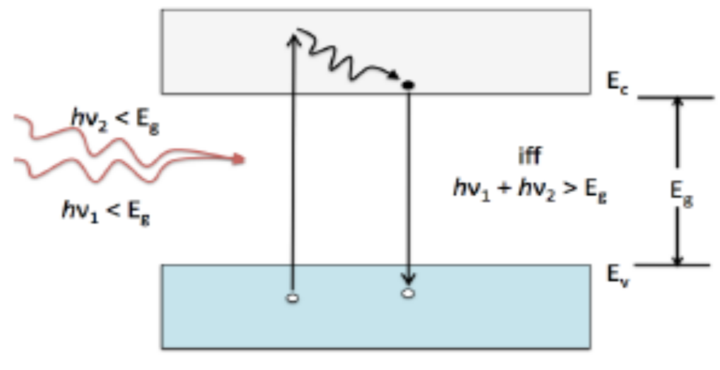
- Femtosecond pulsed lasers can be use to produce single-event effects (SEE) in electronic devices and circuits

Single Photon Absorption



(a)

Two Photon Absorption

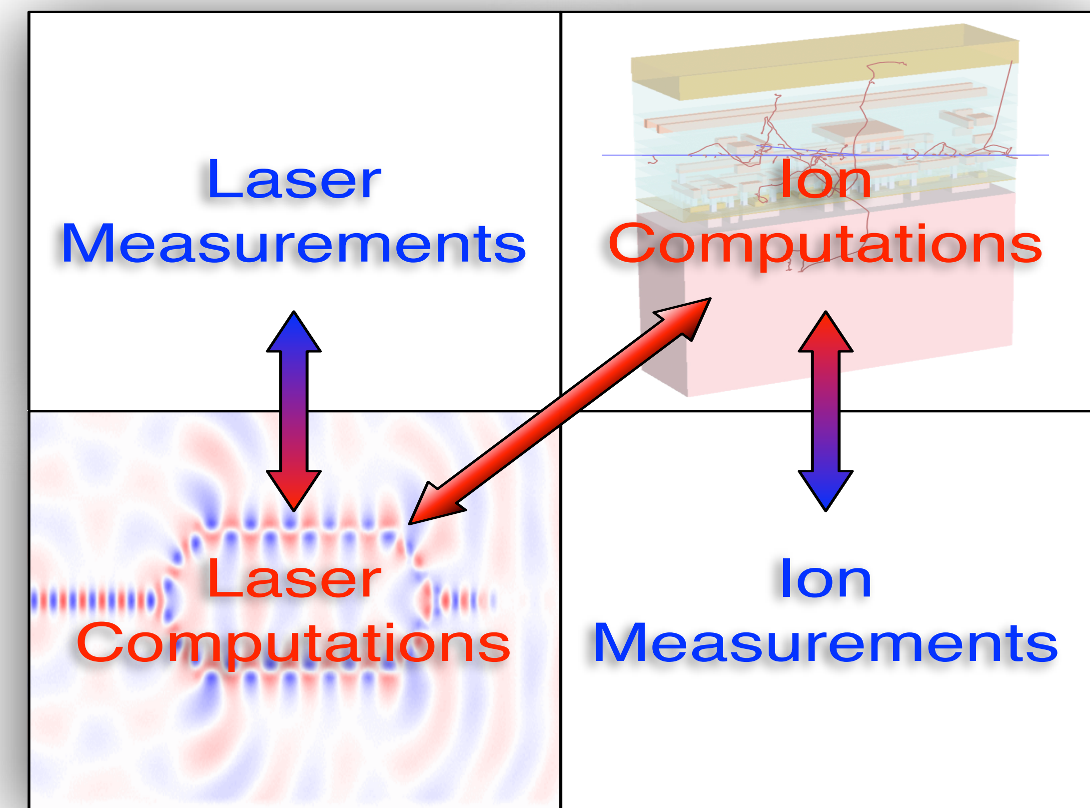


(b)

NRL group (McMorrow, Buchner, *et al.*) and others have published numerous papers on testing and modeling

SPA and TPA (IEEE Trans. Nucl. Sci., 1987 – 2016)

Approach:



Laser
Measurements
Ion
Computations
Laser
Computations
Ion
Measurements

Key References and Acknowledgements

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