Virtual Irradiation: Single Event Rate Prediction for Advanced Technologies

Kevin Warren[1], Andrew Sternberg[1], Brian Sierawski[1], Robert Reed[2], Robert Weller[2], Carl Carmichael[3], Gary Swift[3], JL DeJong[3] Joe Fabula[3], Lloyd Massengill[2]

[1]The Institute for Space and Defense Electronics at Vanderbilt University

[2]Electrical Engineering and Computer Science Department, Vanderbilt University

[3]Xilinx, Inc.

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Outline

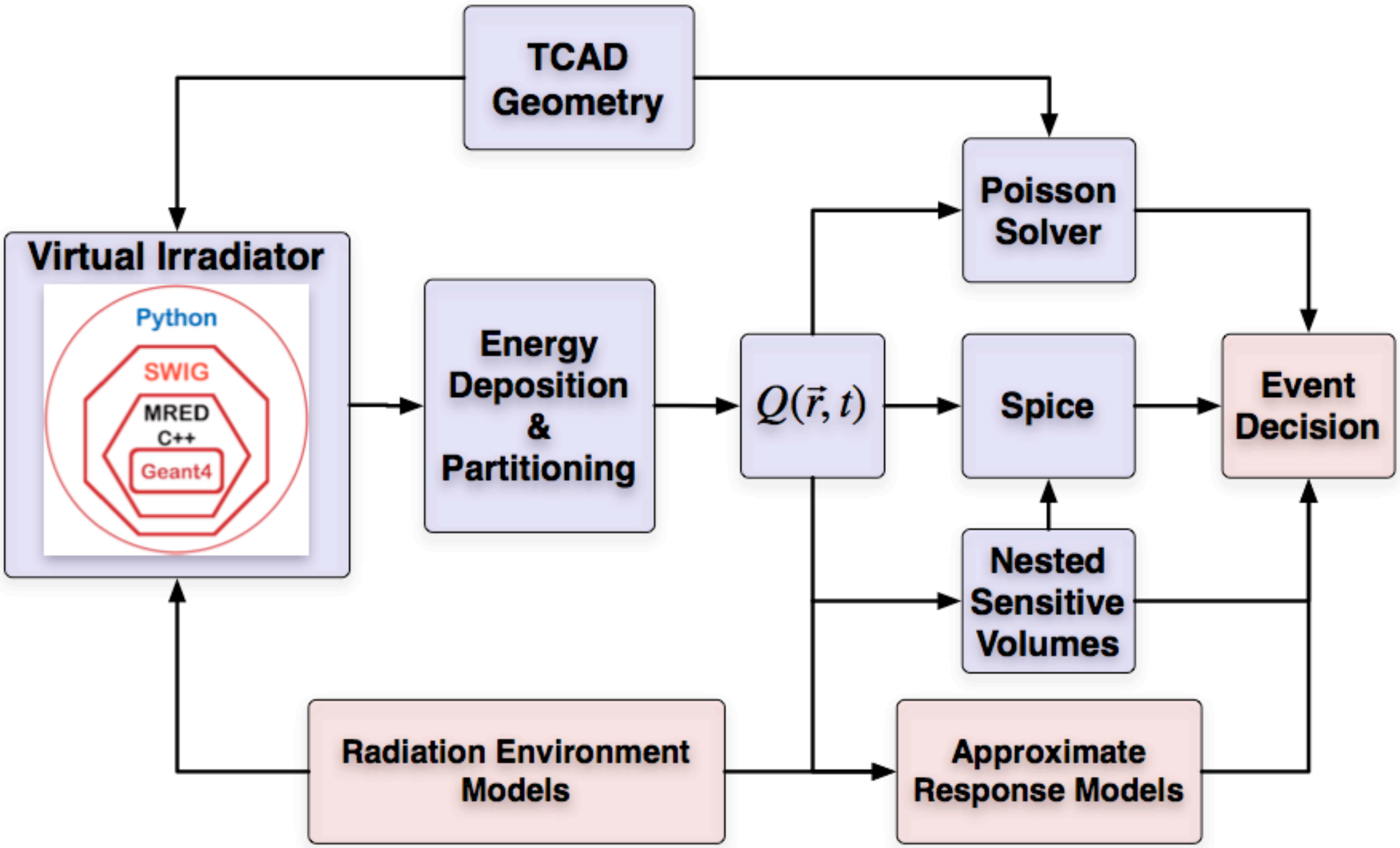
- Introduction to the concept of virtual irradiation and Vanderbilt University Monte-Carlo Radiative Energy Deposition (MRED) software.
- Incorporating Spice in the loop for virtualization and single event upset (SEU) rate predictions.
- Specific example application to the problem of multi-node charge collection to include heavy ion beam virtualization and error rate prediction.
- Conclusions and future development

Virtual Irradiation

"Virtual Irradiation" is the ability to simulate

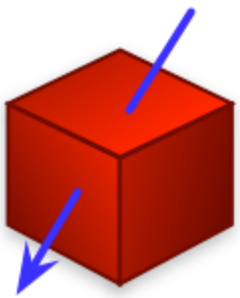
- Any man-made (*e.g.* test facility) or radiation environment.
- Transport of radiation through air, packaging, or other relevant material including back end of line (BEOL) stacks.
- Capture all relevant physical processes in target materials (electronic and nuclear interactions).
- Relate energy deposition in active silicon to a circuit level response.
- Track and tabulate the frequency of errors to calculate cross sections, error rates, or other pertinent parameters.

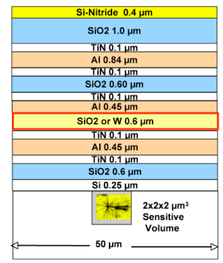
MRED Simulation Flow

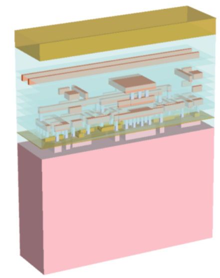


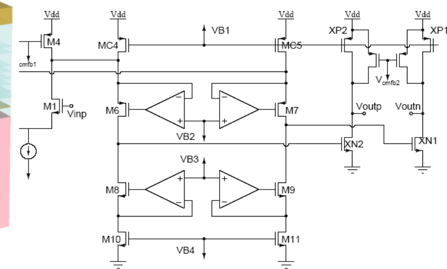
Contrasts: SEU Analysis

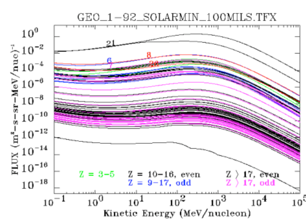
CREME96

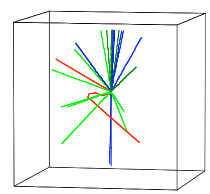
Device/Circuit/System Virtualization	
Radiation Event Generation	
Response Prediction	Path Length Distributions & Q_{crit}

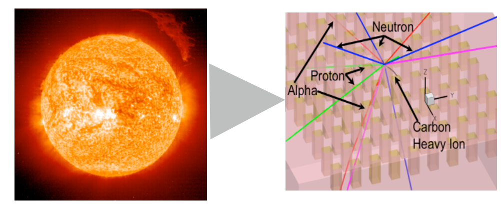










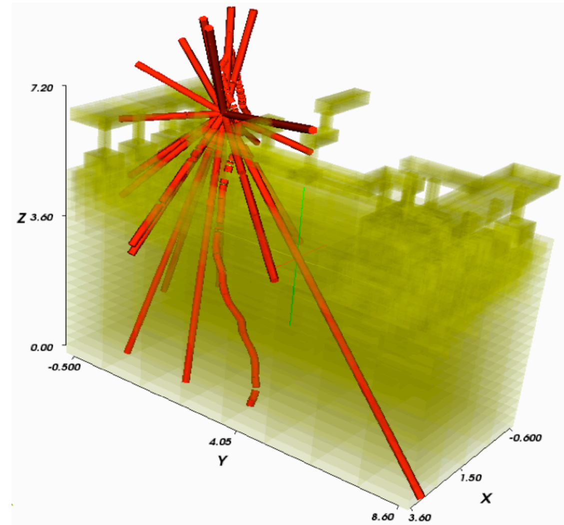


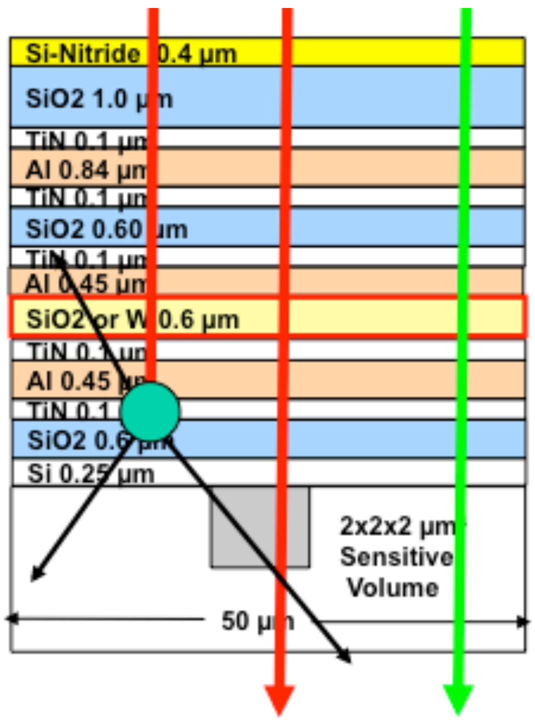
Multi-volume calorimetry + Charge-collection models + Critical charge

Calorimetry , TCAD or SPICE in the loop coincidence analysis

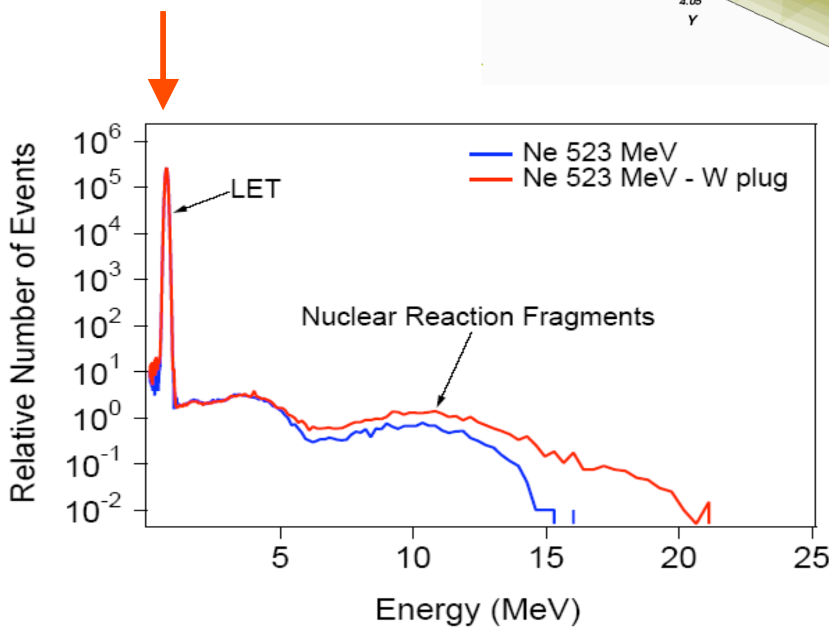
Key Concept: Calorimetry

In spite of advances, calorimetry remains the key thread linking radiation and response.

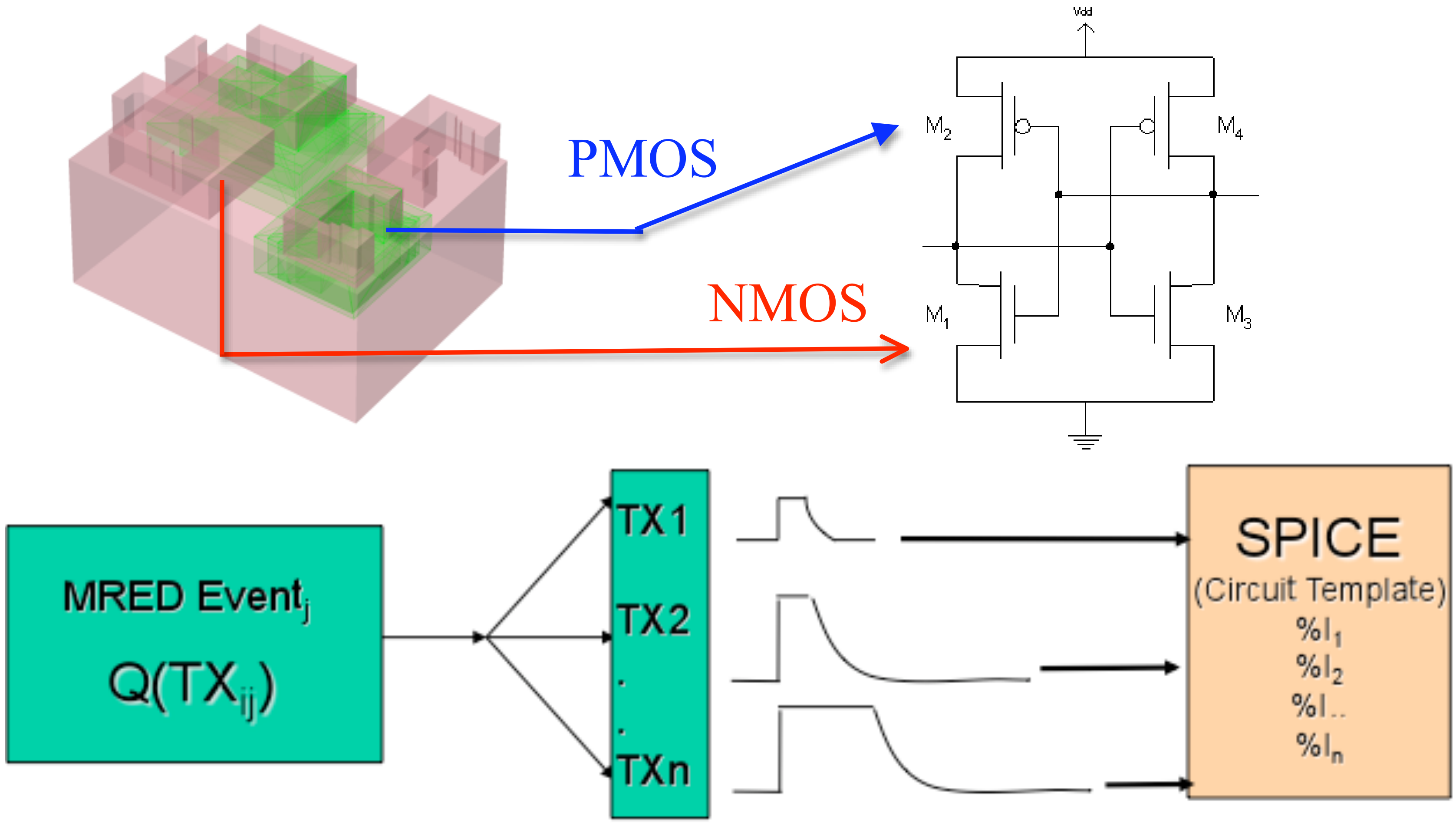




LET Contribution



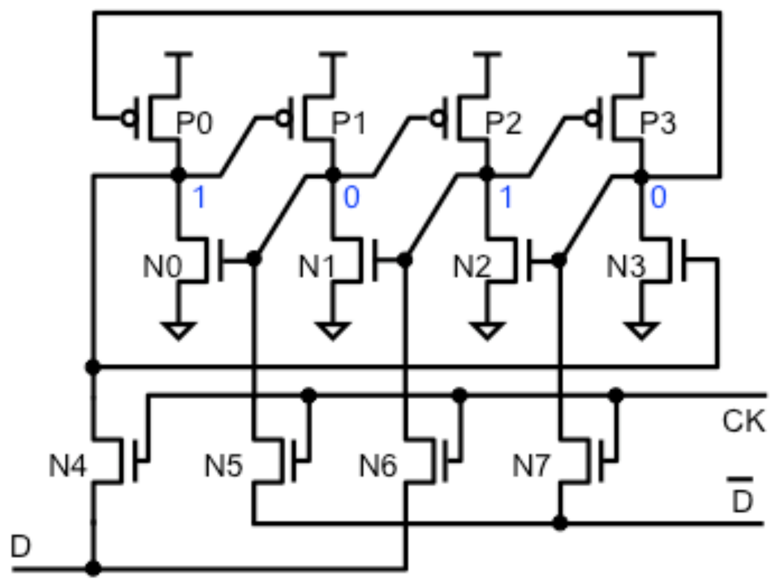
MRED-Spice Interface

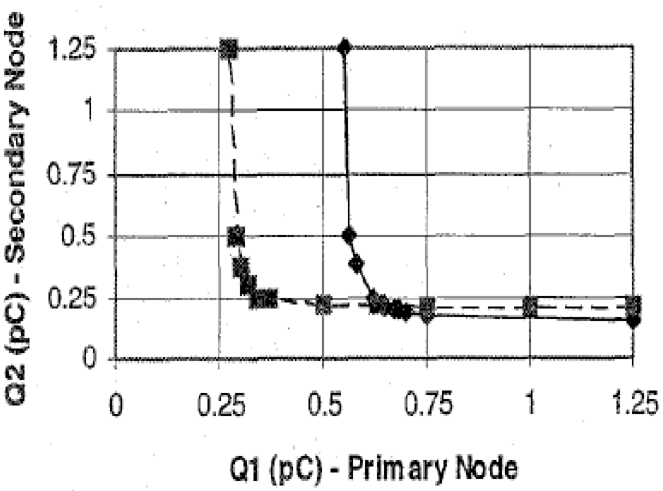


Spice simulation of the jth particle event

Spice and MRED - Motivation

- Single node upset mechanisms are relatively straightforward when determining critical charges (Q_{crit}).
- Becomes a time consuming problem when two or more nodes are involved in SEU process.
- <u>When multiple nodes are involved, the problem becomes one of coincidence and typical rate prediction methods don't apply (RPP).</u>

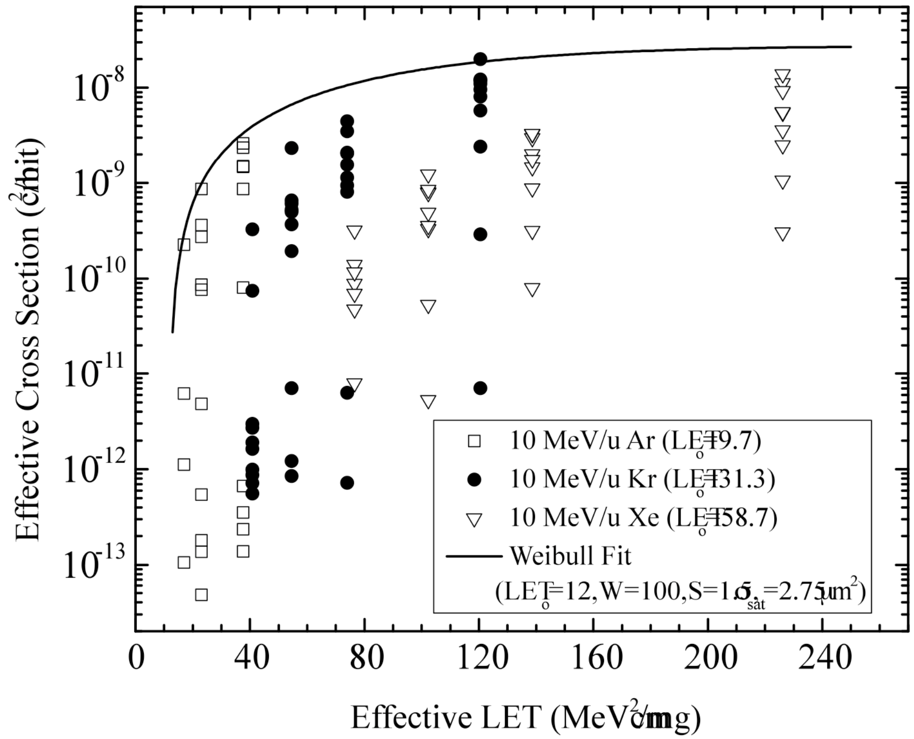


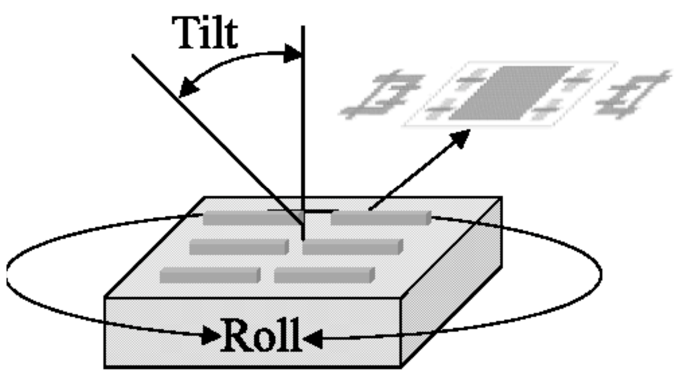


(R. Velazco, et al., "SEU-Hardened Storage Cell Validation Using a Pulsed Laser," IEEE Trans. Nucl. Sci., Vol 43, No 6, 1996. p 2843)

Multi-Node, Single Upset (MNSU) Processes

- MNSU may occur from:
  1. Coincident, multi-node strike
  2. Multi-node charge collection
  3. A combination of the above
- These processes can make for very complex heavy ion cross-section datasets.

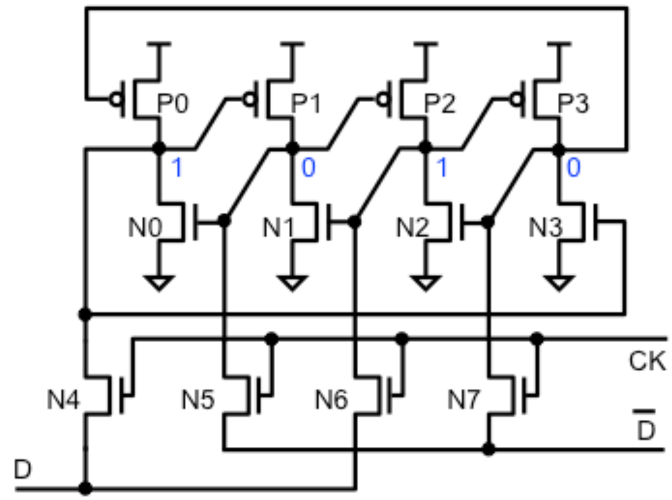




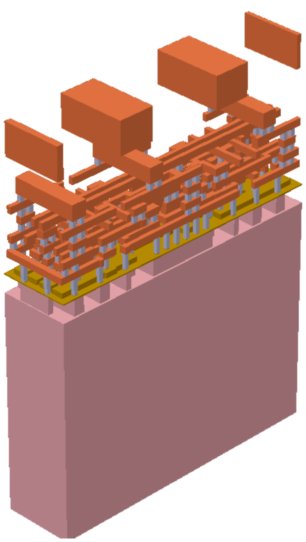
K.M. Warren,et al., "Monte-Carlo Based On-Orbit Single Event Upset Rate Prediction for a Radiation Hardened by Design Latch," *IEEE Trans. Nucl. Sci.*, Vol 54, No. 6. December 2007. pp 2419-2425.

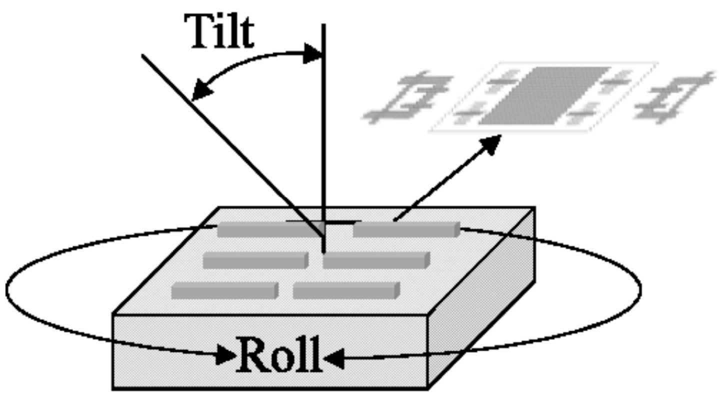
Case Study - SEU Resistant Latch (65 nm)

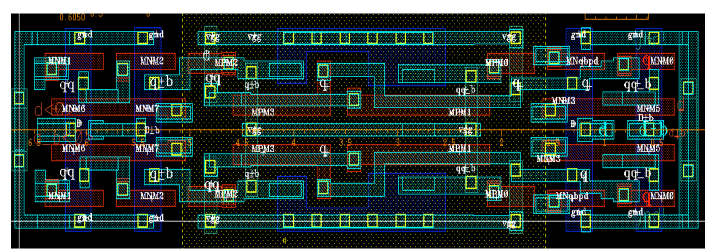
- A common approach to SEU hardening latches is to use static redundancy of the data state.
- A perturbation of one node potential will not upset the circuit cell.
- Concurrent charge collection (or deposition) across multiple nodes can upset the circuit.



T. Calin,et al, "Upset Hardened Memory Design for Submicron CMOS Technology," IEEE Trans. Nucl. Sci., Vol 43, No. 6, December 1996. pp 2874-2878.



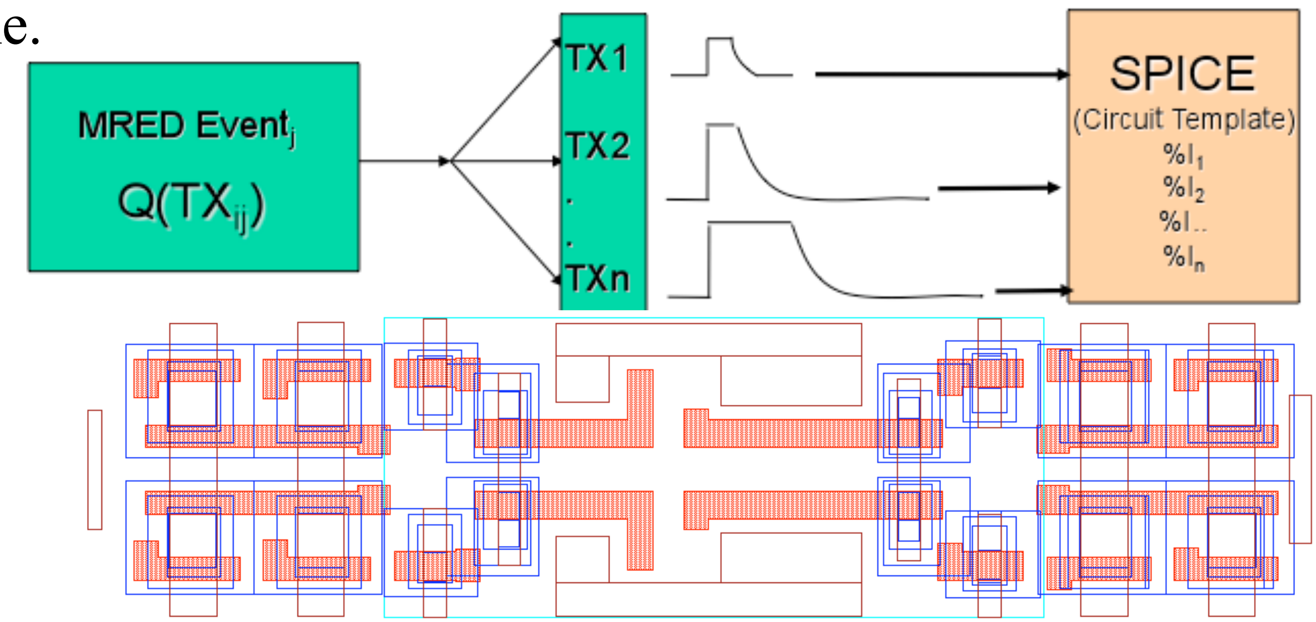




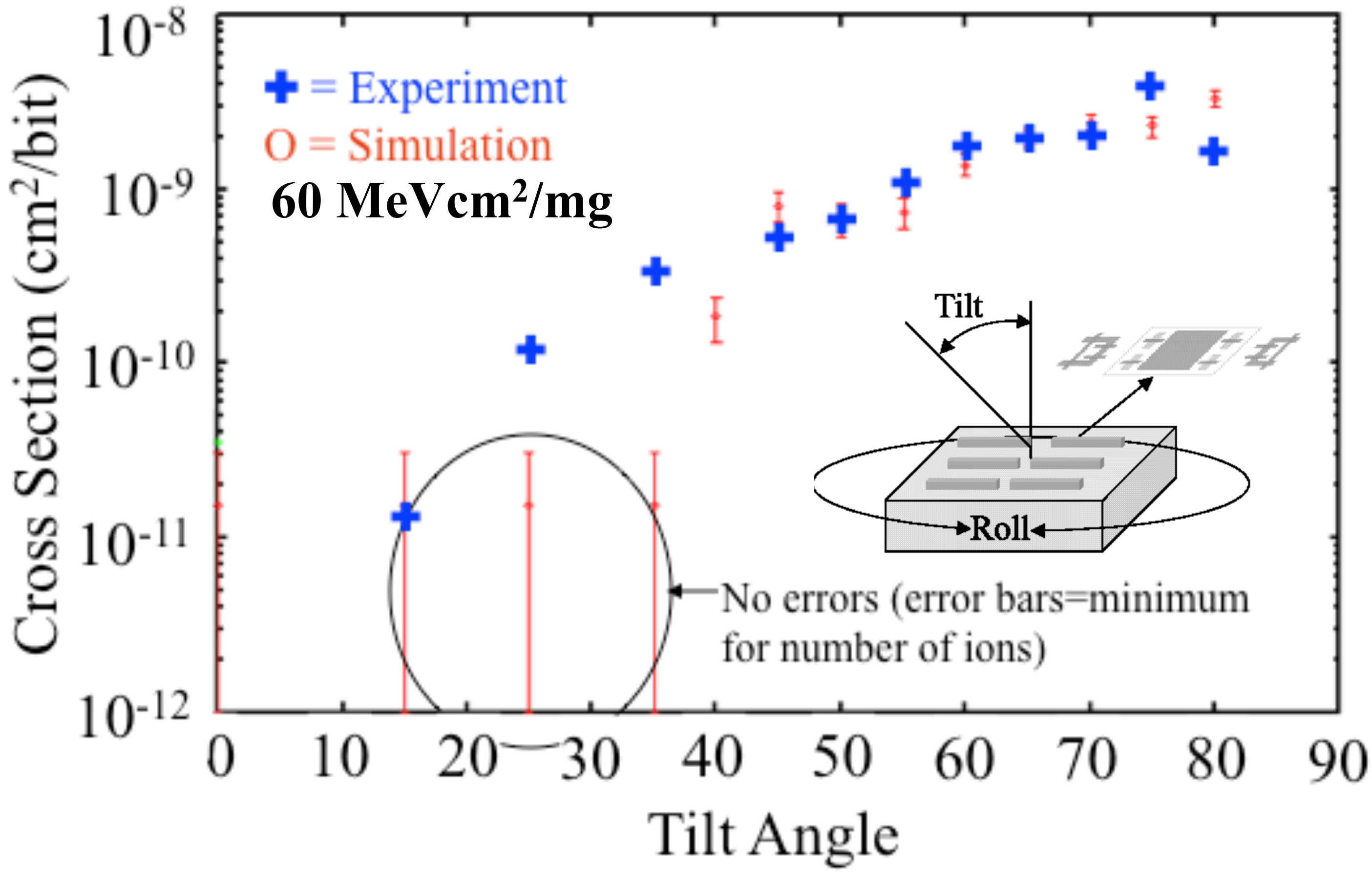
2-bit primitive structure

Solid Volume Placement and Parameters

- In MRED one can track energy deposition in any number of regions on an event by event basis.
- In this approach, a sensitive volume set was assigned to every transistor in the circuit.
- The energy deposited in each volume set was converted to charge and a current source for every event and evaluated in spice during run time.

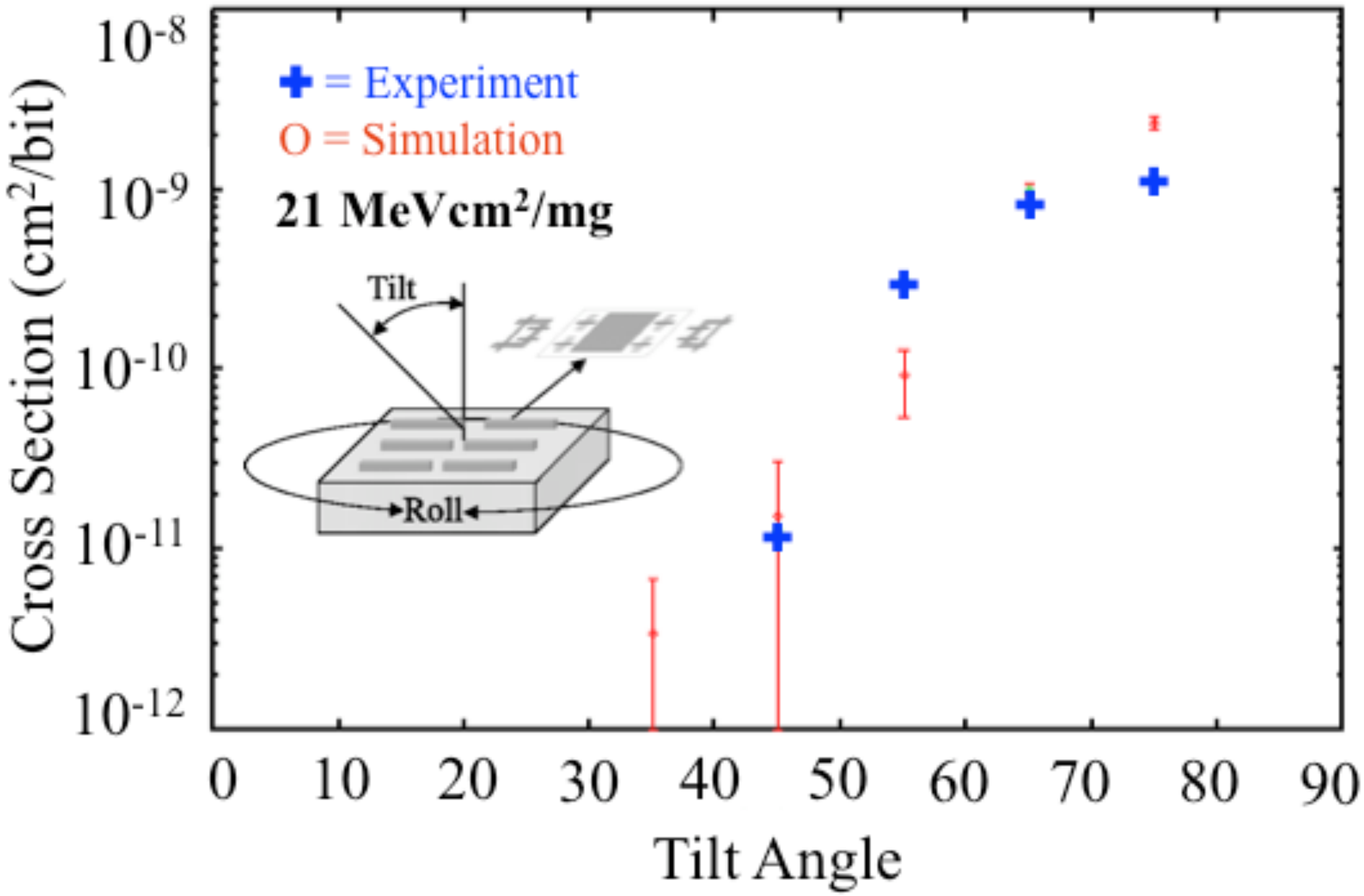


Results: Xenon Over Tilt at 180 Degrees of Roll

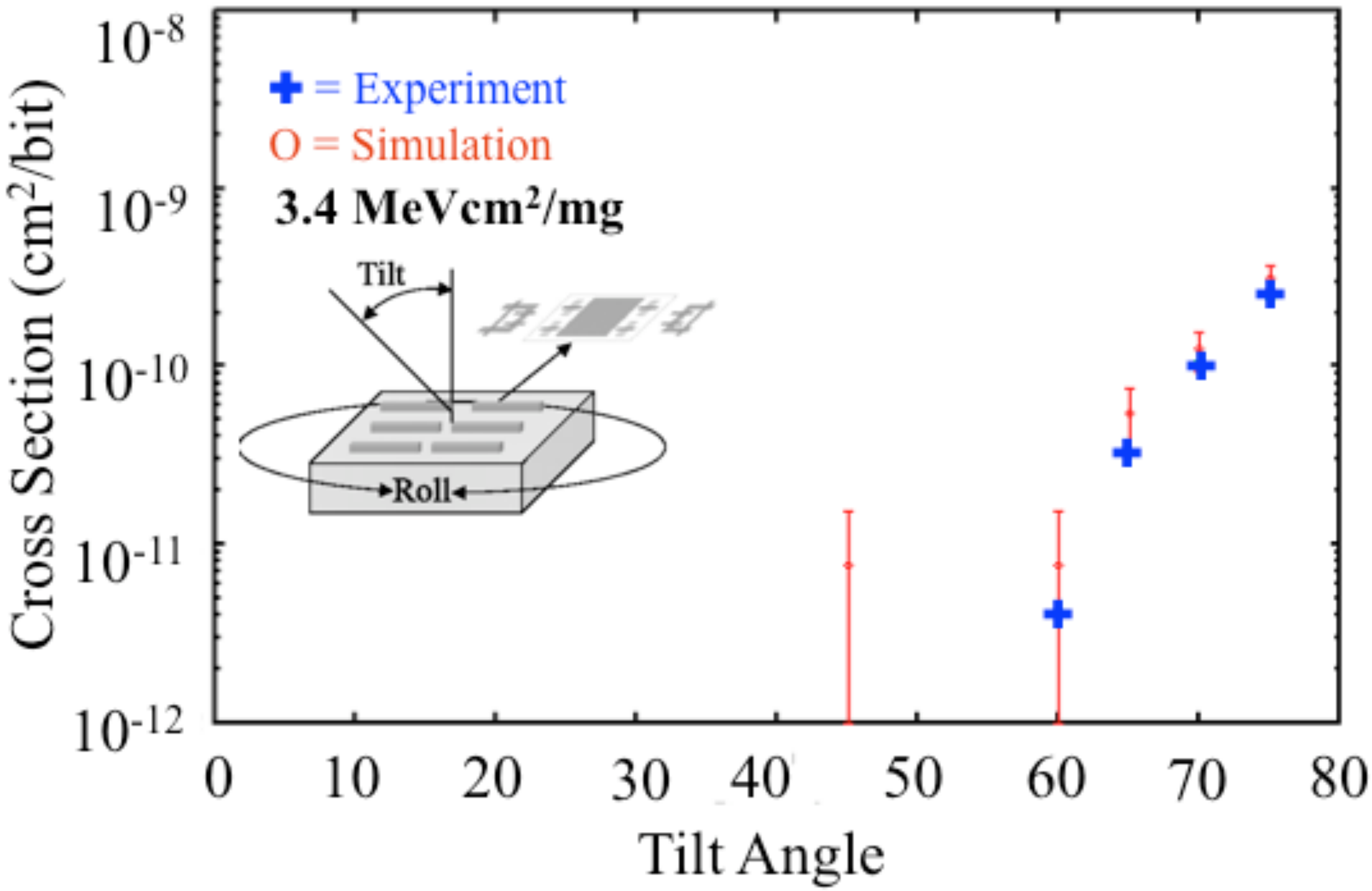


SEU cross-sections only become appreciable at steep tilt angles for high linear energy transfer (LET)

Copper over tilt @ 180 degree roll

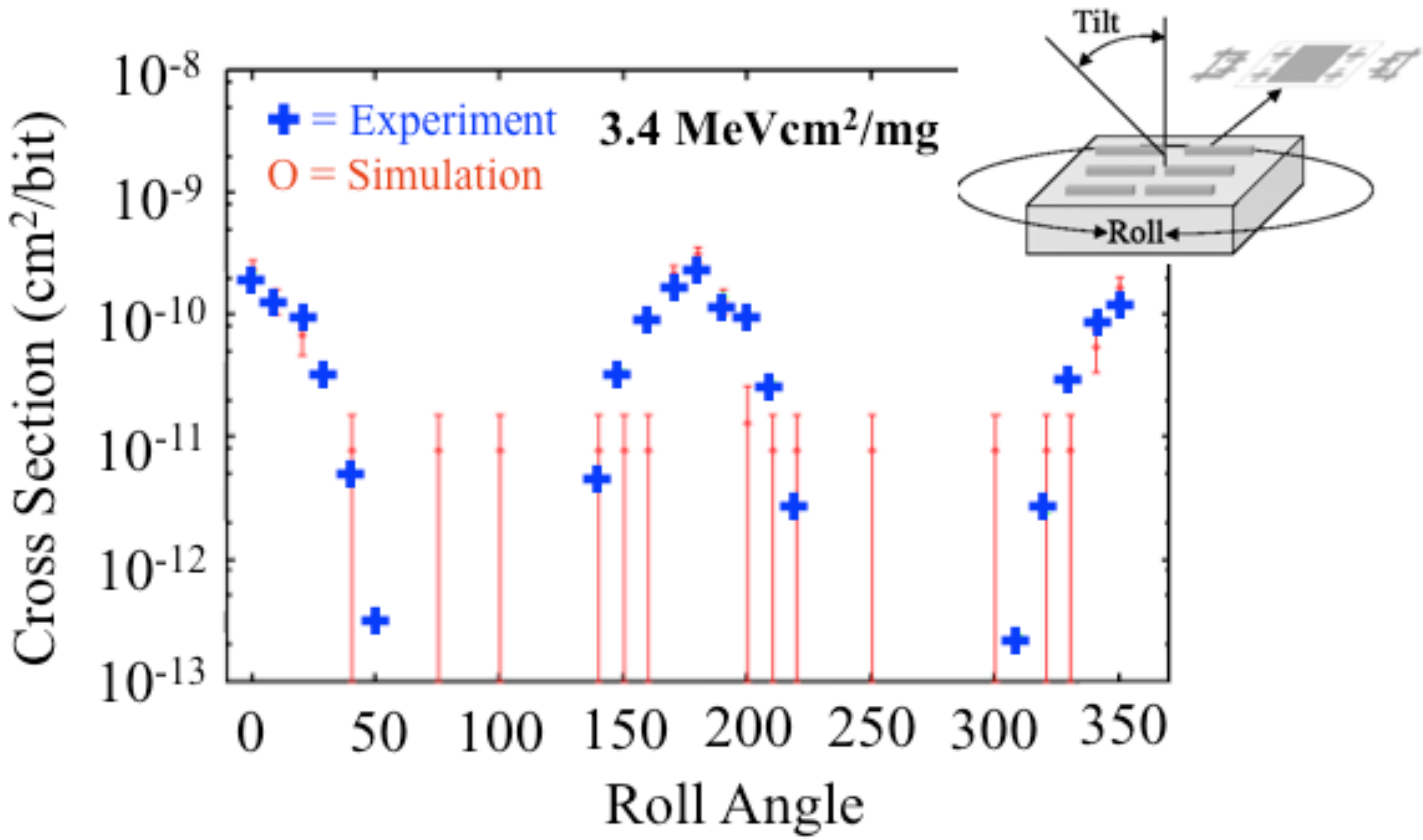


Neon over tilt at 180 degrees roll



Only the highest tilt angles are sensitive at very low LET

Neon Over Roll at 75 degree tilt

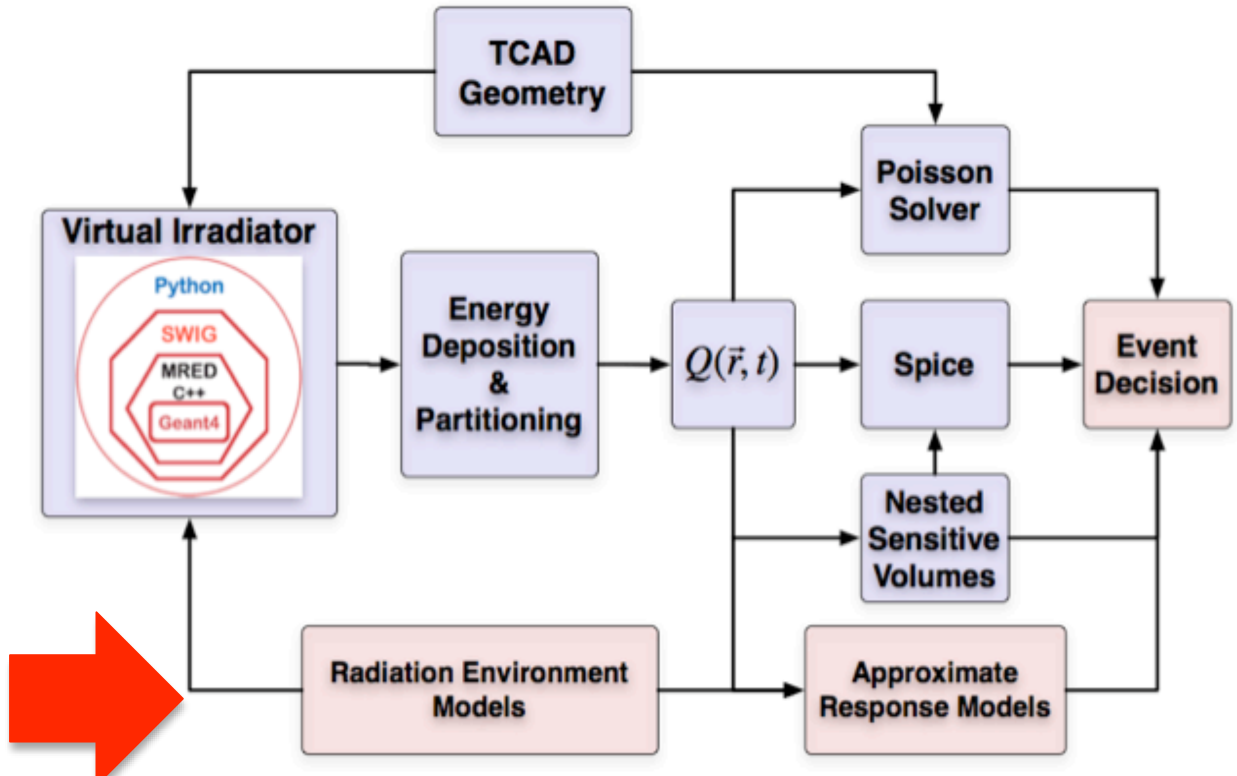


- Cross sections are highest along the long axis of the part – as expected, coincidence based errors are highly directional

Environment Virtualization

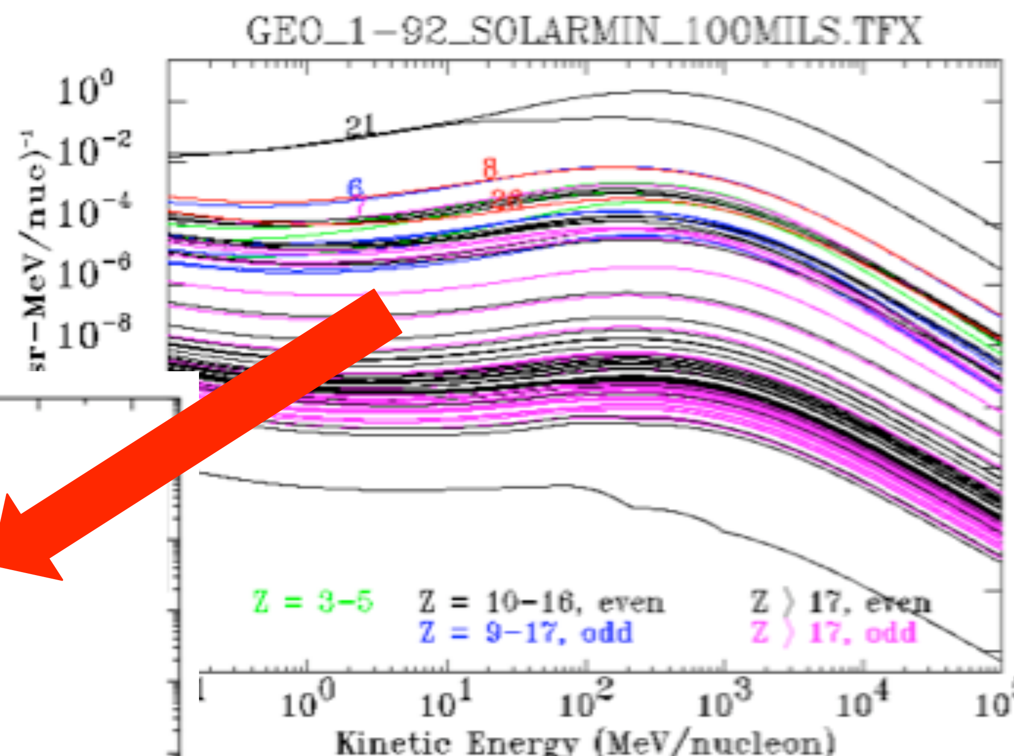
- The purpose of this work is ultimately not to reproduce data, but to provide insight into error mechanisms as well as predict single event upset rates in space, atmospheric, and terrestrial environments.

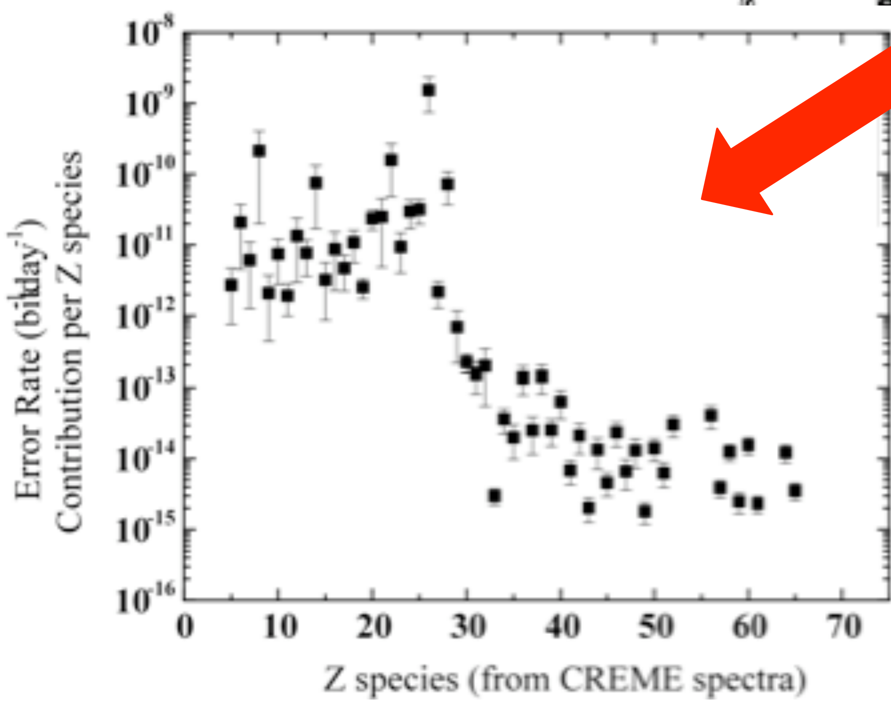
With MRED, the calibrated heavy ion model can be directly exposed to any environmental spectrum or spectra.



In Flight Error Rate Prediction

- MRED can be used to predict SEU rates for complex upset mechanisms





R.A. Reed, R.A. Weller, R. D. Schrimpf, M.H. Mendenhall, K.M. Warren, and L.W. Massengill, "Implications of Nuclear Reactions for Single Event Effects Test Methods and Analysis," IEEE Trans. Nucl. Sci., Vol 53, No. 6. December 2006. pp 3356-3362

Conclusions

- No hands-on Spice analysis had to be performed to determine Qcrit or combinations of Qcrit.
- Sensitive volume parameters and placements were adjusted to produce best agreement with data.
- Virtualization at the accelerator level provided insight into the upset mechanisms and sensitive node combinations.
  - Critical node spacing rules
  - Evaluate redesign and placement options
- The 'Spice in the MRED loop' approach produced good agreement with the experimental data after calibration
- One a model is calibrated, it can be used to predict an error rate in almost any environment (neutrons, protons, heavy ions, alpha)