Applications of MRED to Advanced Technologies

Robert A. Reed, Kevin M. Warren, Marcus H. Mendenhall, Brian D. Sierawski, Robert A. Weller, & Ronald D. Schrimpf

Institute for Space & Defense Electronics
Vanderbilt University

MURI Review - Vanderbilt - 25/May/2010

Sponsoring Agencies: AFOSR, DTRA, NASA

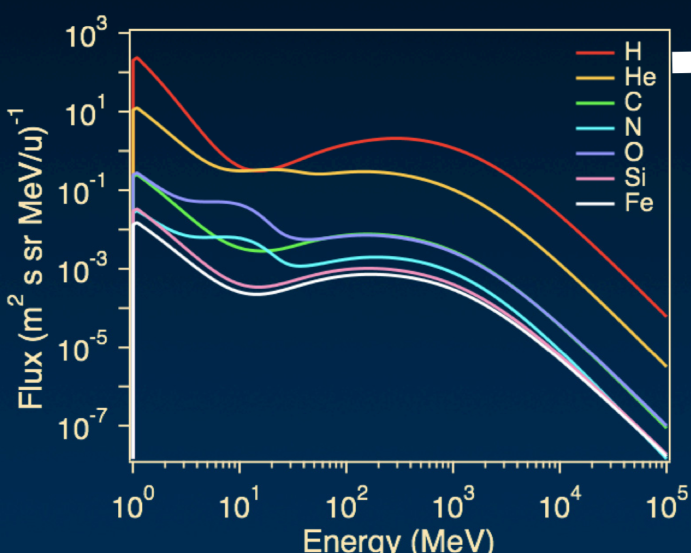
Overview

- The concept behind MRED
- What did we do? Examples:
  - New materials
  - New vulnerabilities
  - New prediction strategies
- What have we left undone?

Detailed Physical Simulation

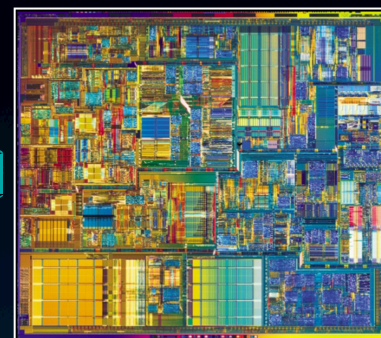
$$R_e(\xi) = \sum_{z} \int_{All\ E} dE\ \Phi(z,E) \oint dA \int_{\hat{n}\cdot\hat{u}<0} d\Omega(-\hat{n}(\vec{x})\cdot\hat{u})\ P_e(z,E,\hat{u},\vec{x};\xi)$$

Radiation Environments



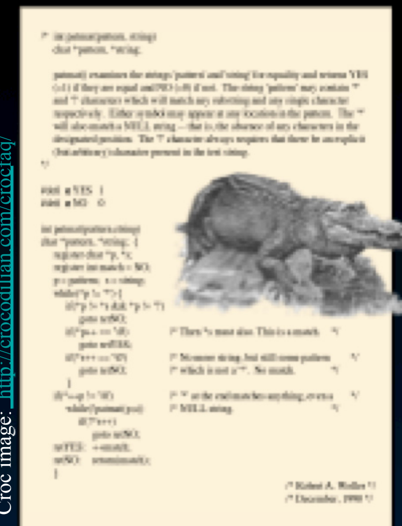
Devices

http://www.icknowledge.com/trends/p4(2).jpg



Algorithms

Croc image: http://crocodilian.com/crocfaq/

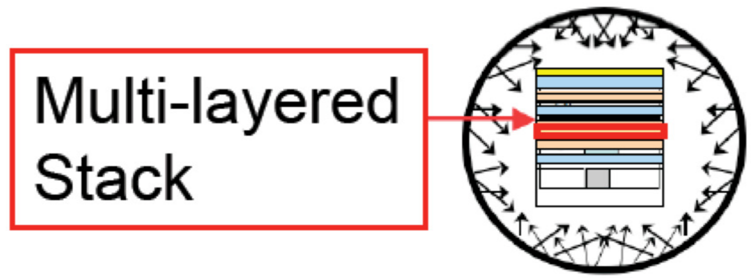


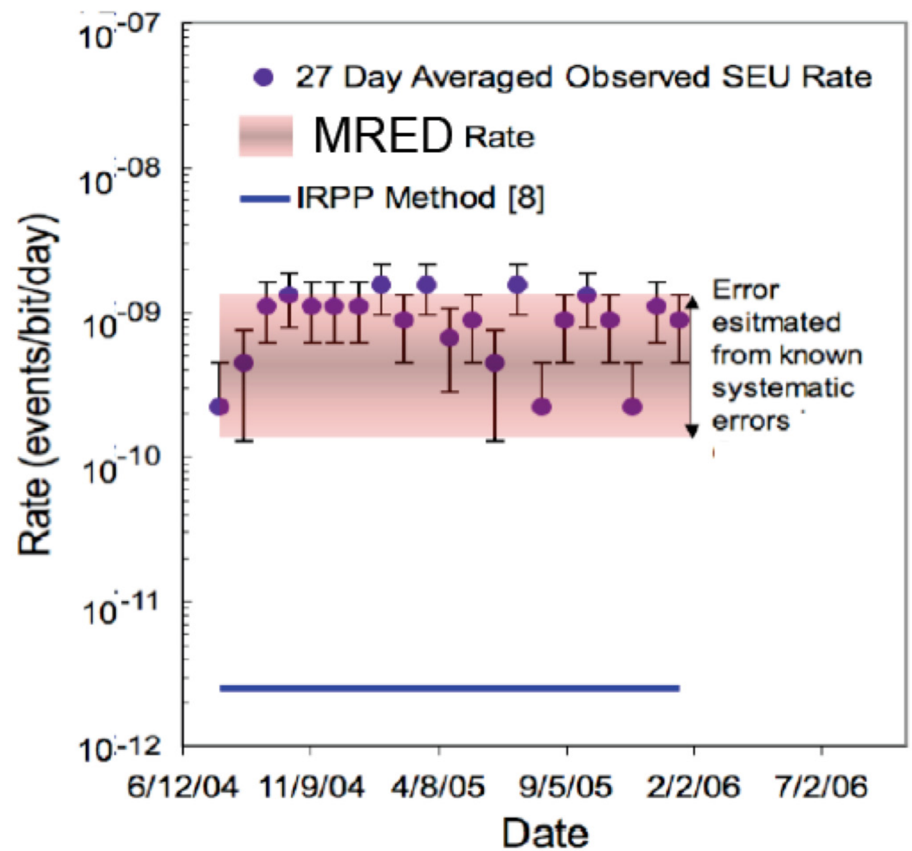
HPC

P_e

Nuclear Reactions – on orbit SER

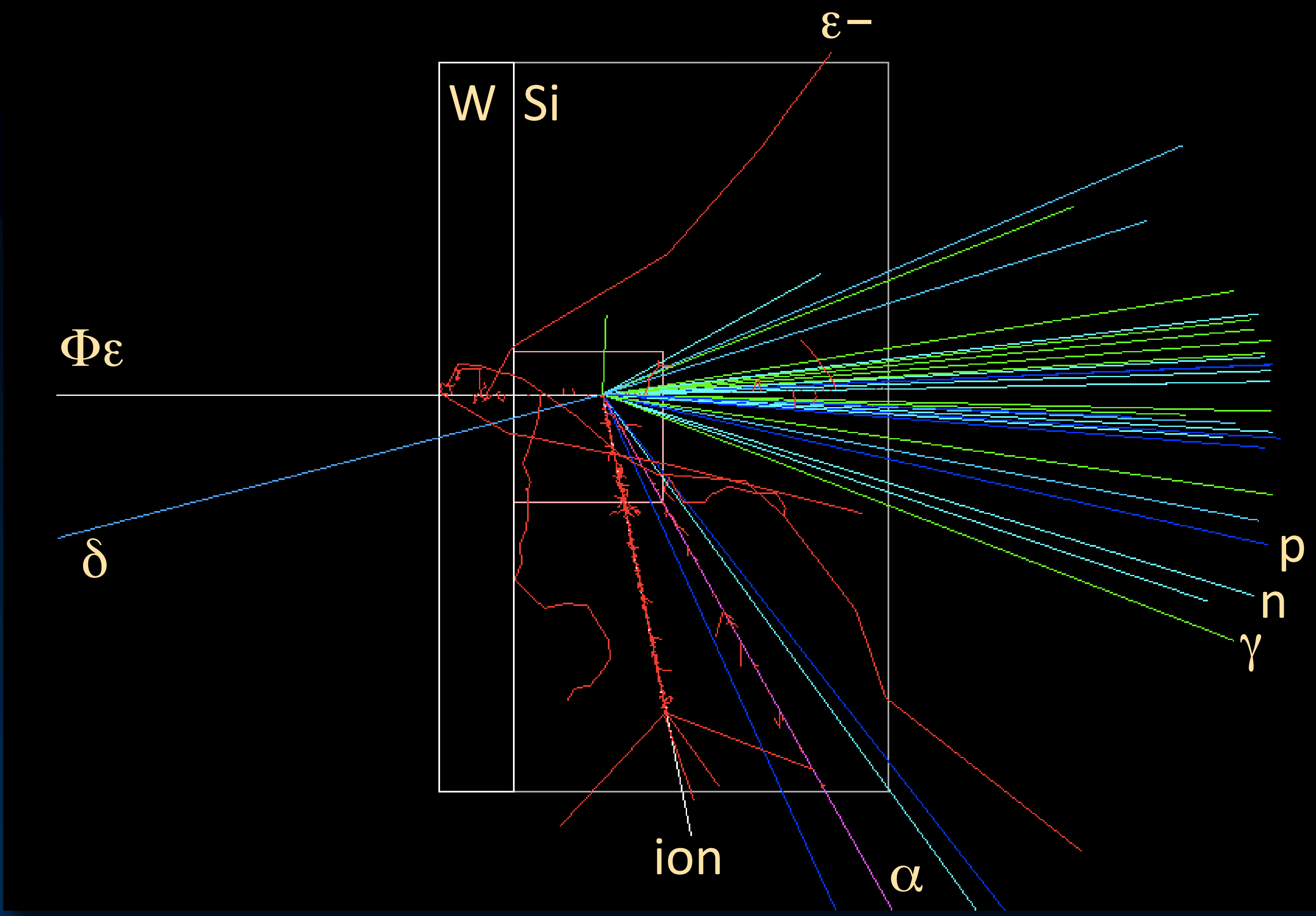
- Modeling nuclear reactions can be vital to predicting the correct on-orbit error rate.
- Direct ionization and IRPP method under-predict in flight SER by over 3 orders of magnitude.
- The MRED model dramatically improves the fidelity of the rate prediction.
- Test and analysis must be performed to correctly identify when the higher fidelity models are needed.



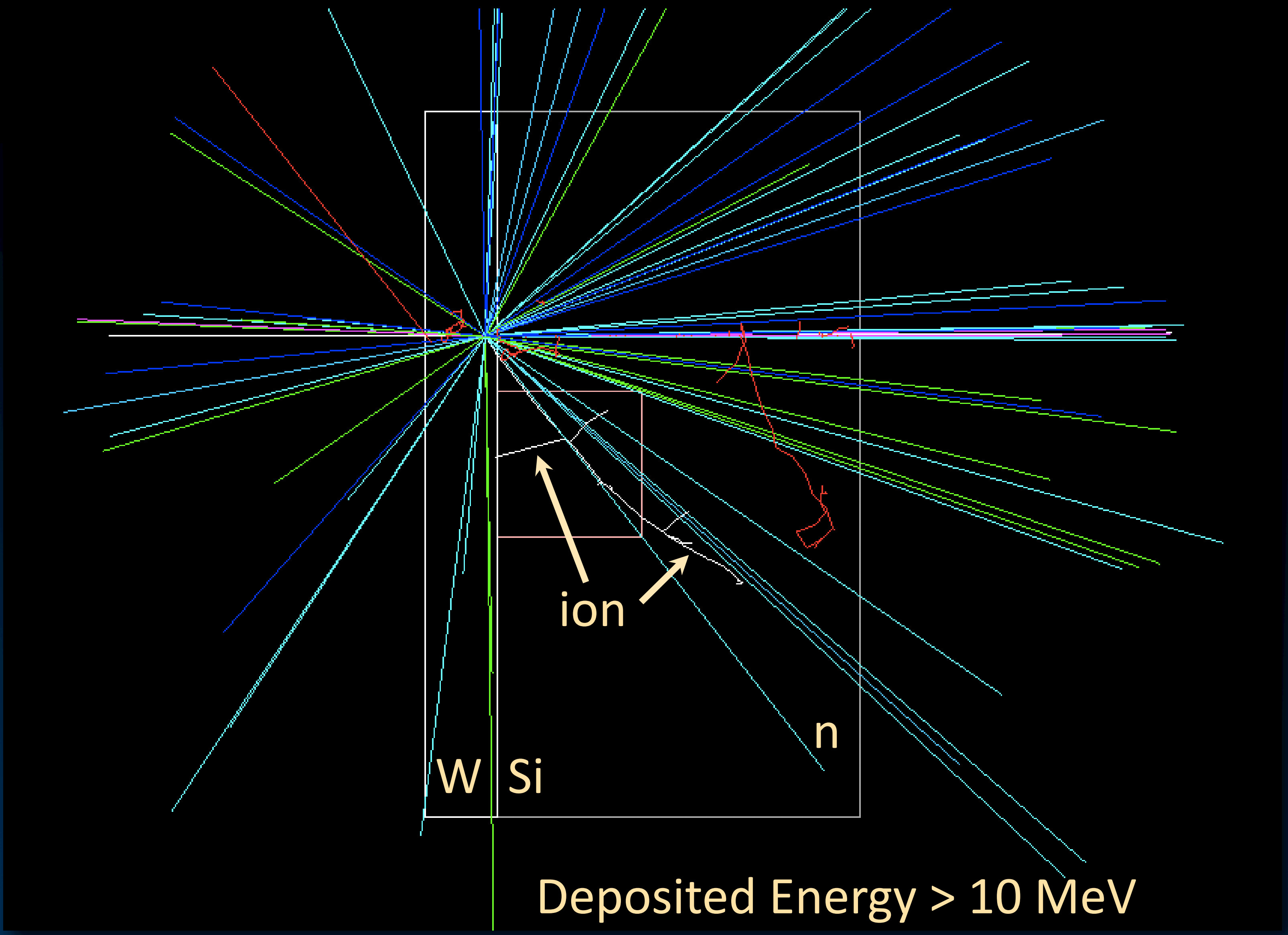


K. Warren *et al.* TNS 2005
R.A. Reed *et al.* TNS 2007

2 GeV/u Fe – Nuclear Reaction in the Si

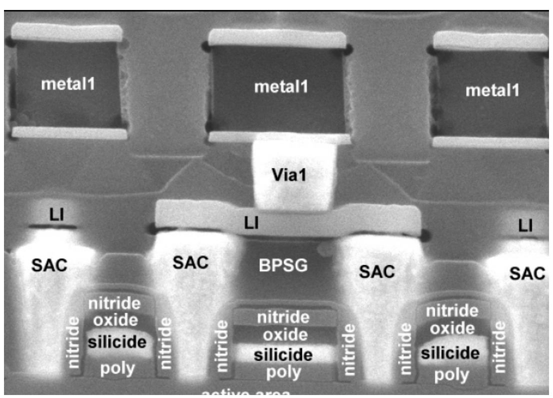


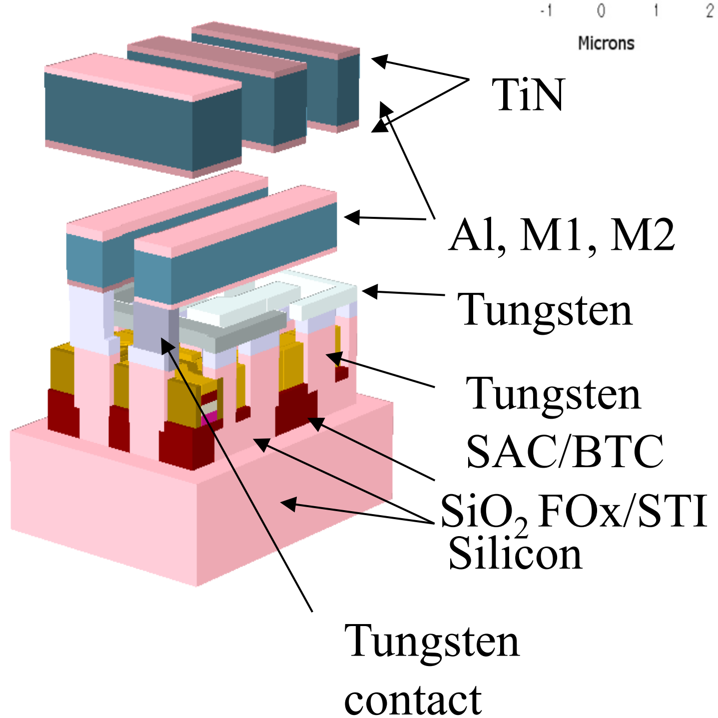
2 GeV/u Fe - Reaction in the W Layer

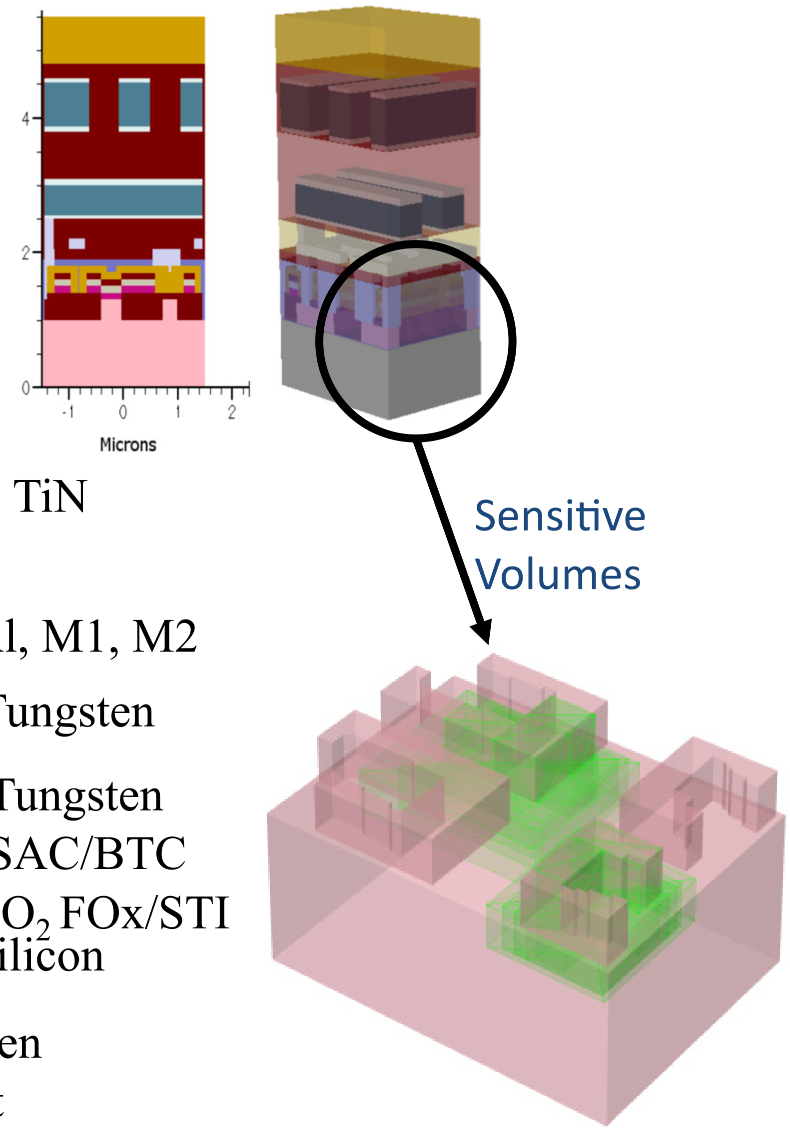


Effects of Adjacent Materials

- Energy loss is material dependent
- Need to know where to look and for how much

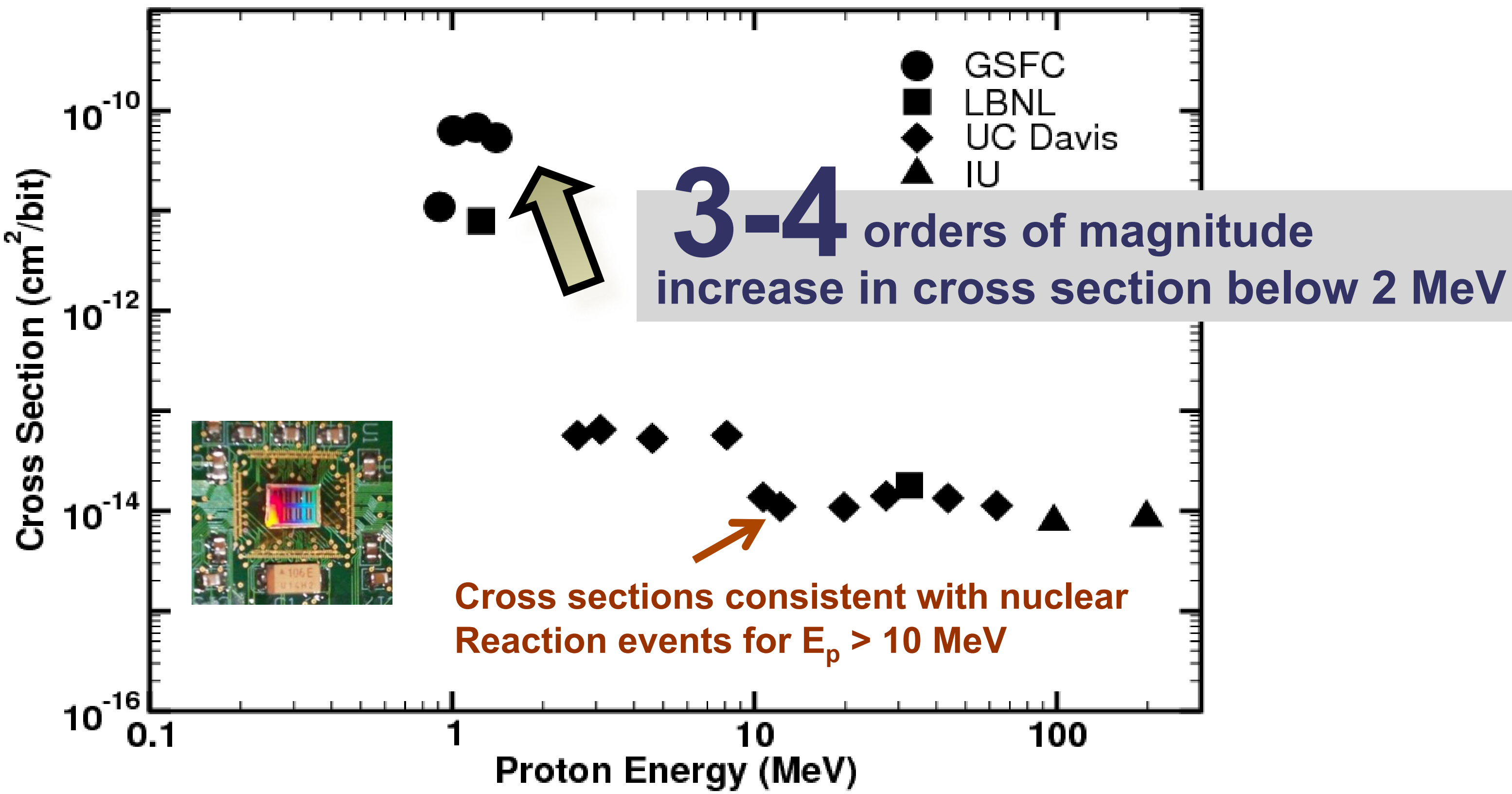






Low-Energy-Deposition Events (Proton SEE)

- Evidence of direct ionization from protons has been reported for IBM 65 nm SOI process [Rodbell TNS ‘07][Heidel TNS ’08].
  - Data collected by Vanderbilt and NASA on TI 65 nm bulk process shows proton sensitivity [Sierawski TNS ’09]



Multiple Sensitive Volumes

Correlating Energy Deposition and Collected Charge

- Total collected charge is the sum of the charge generated in each volume
- Size, location, and efficiencies of the volumes derived from layout, heavy ion or micro-beam SEU data, and/or TCAD simulation

$$Q_{coll} = \sum_{i=1}^{N} Q_{gen,SVi}\xi_i$$

S1

$Q_{coll} = (Q_{gen1})*\xi_1 + 0 + 0$

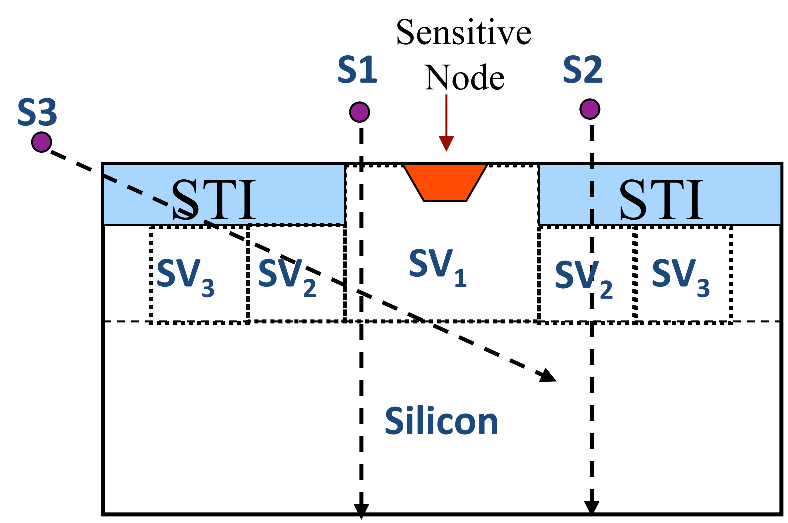
S2

$Q_{coll} = 0 + (Q_{gen2})*\xi_2 + 0$

S3

$Q_{coll} = (Q_{gen1})*\xi_1 + (Q_{gen2})*\xi_2 + (Q_{gen3})*\xi_3$

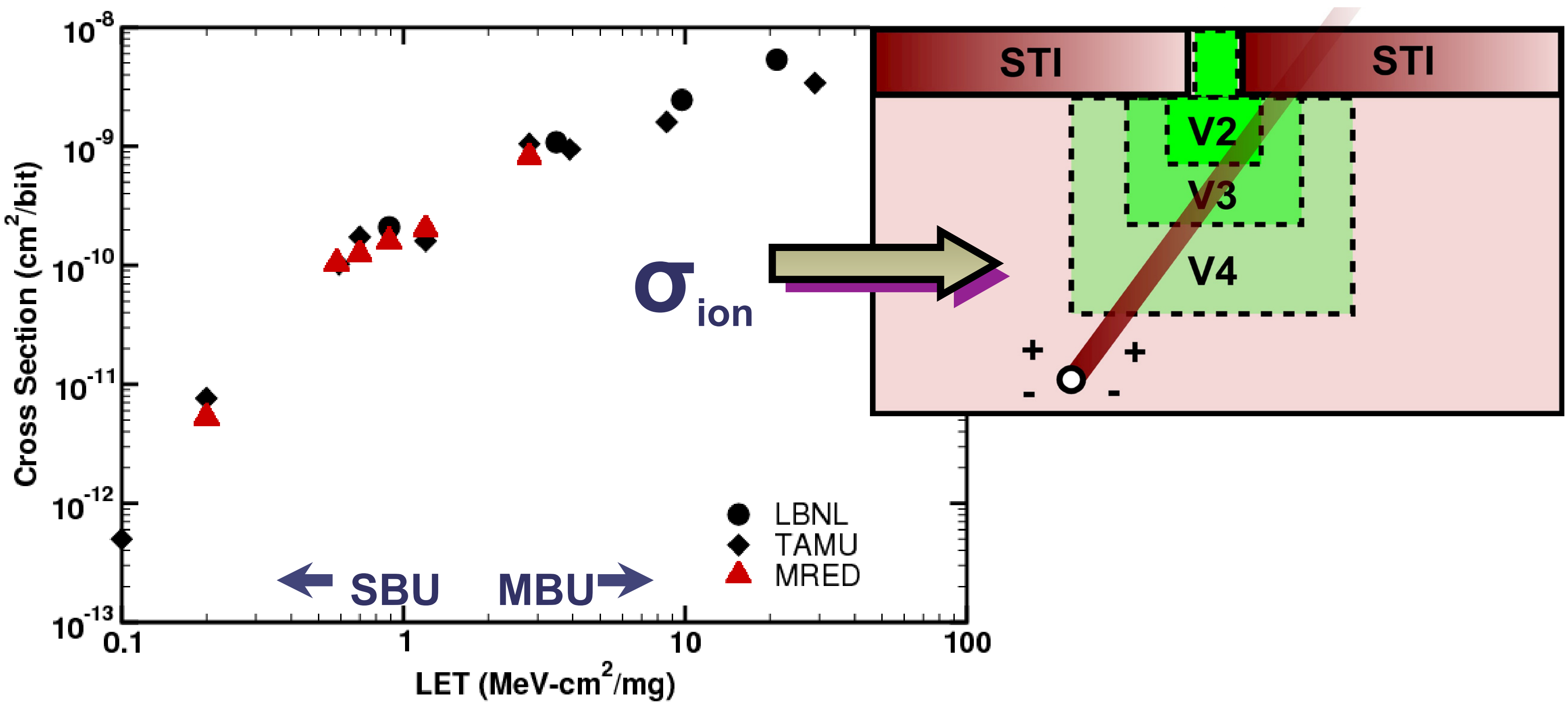
mRPP Model



K. M. Warren, *et al.*, EDL, vol. 28, pp. 180-182, 2007.

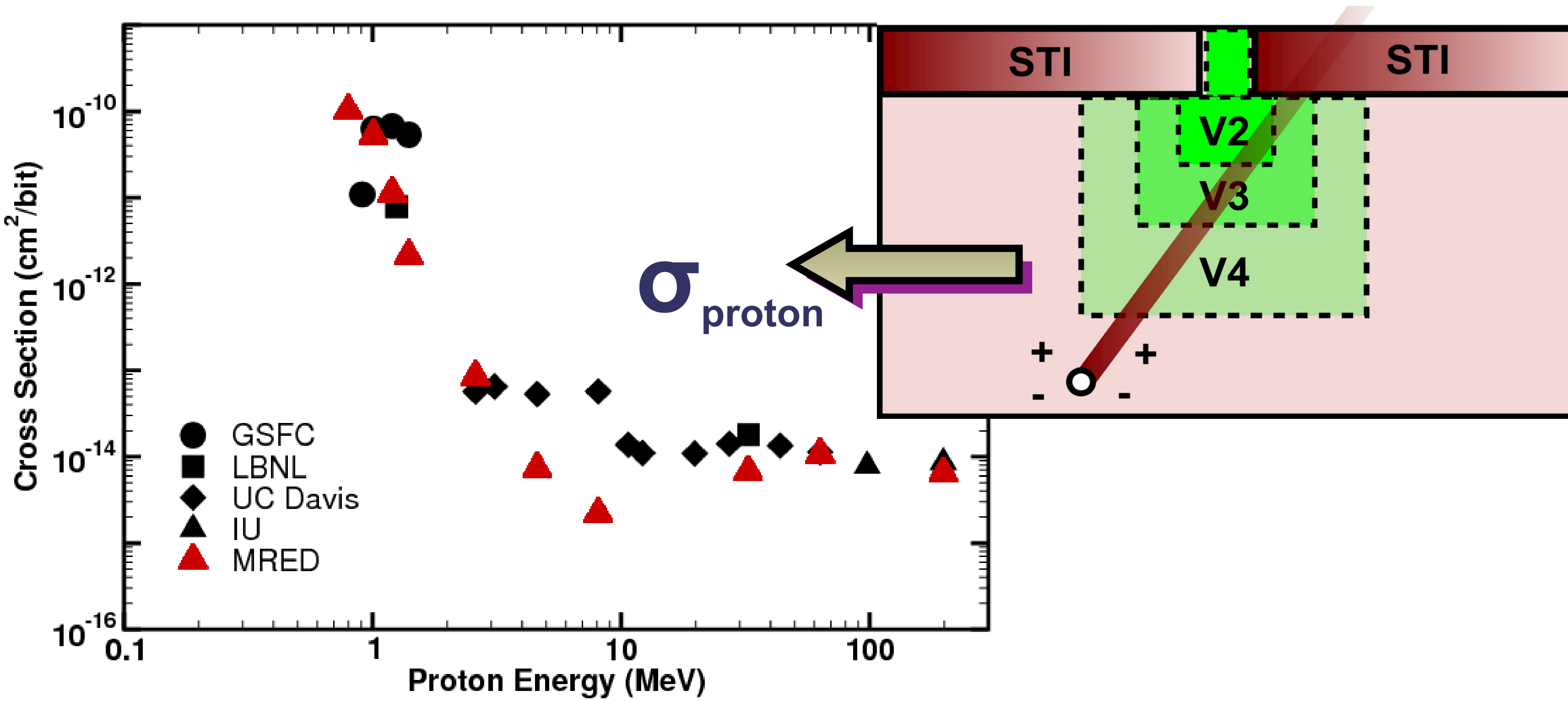
Heavy-Ion SEU Cross Sections

- Heavy-ion tests at TAMU revealed LET threshold less than 0.5 MeV-cm^2/mg confirming proton sensitivity
- Low-LET cross sections were used to calibrate an MRED multiple sensitive volume model
  - High-energy ions provide consistent energy deposition through a well-known stopping power thus characterizing the charge collection



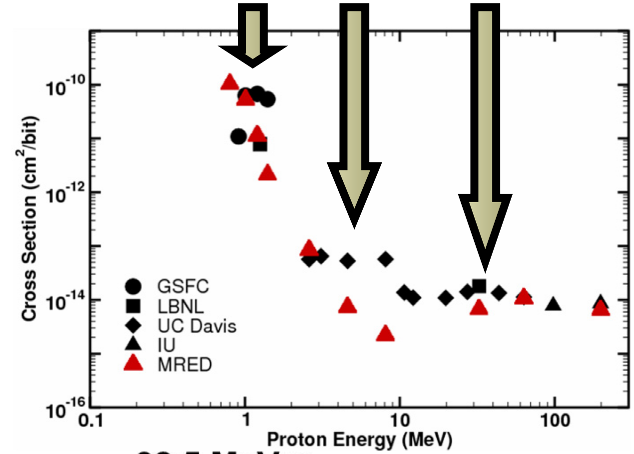
Proton Predictions

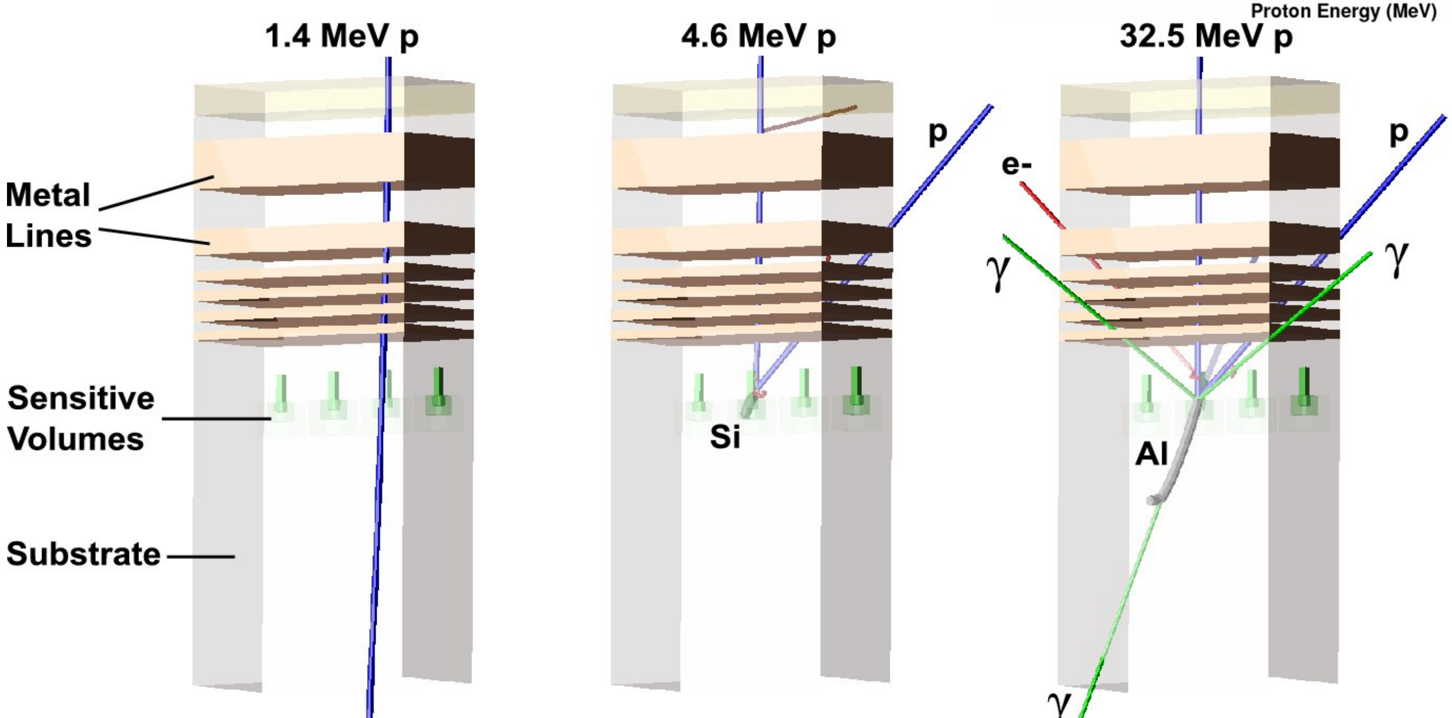
- Proton SEU cross sections were predicted for $E_p < 32.5$ MeV
  - Transport codes model the stochastic energy deposition and the sensitive volume model captures the process of charge collection
- Simulations include all relevant physical mechanisms of energy loss with no adjustable parameters



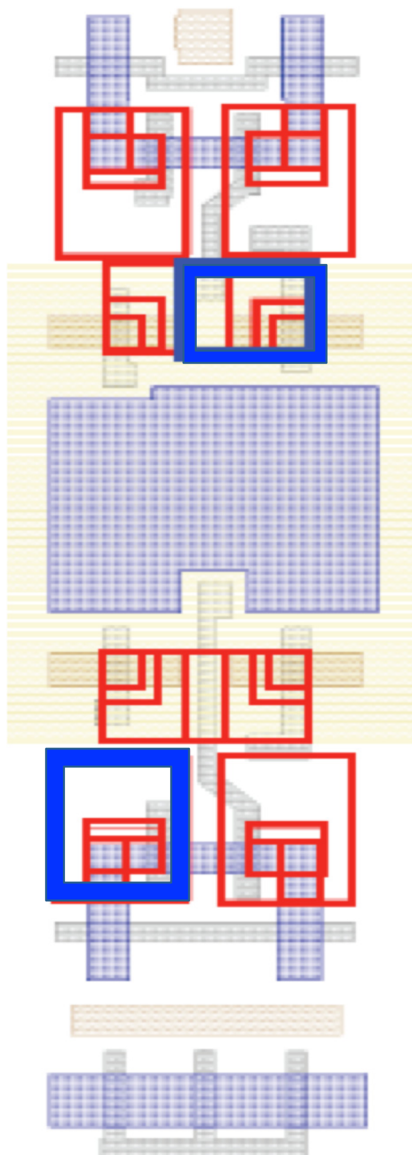
SEU Mechanisms

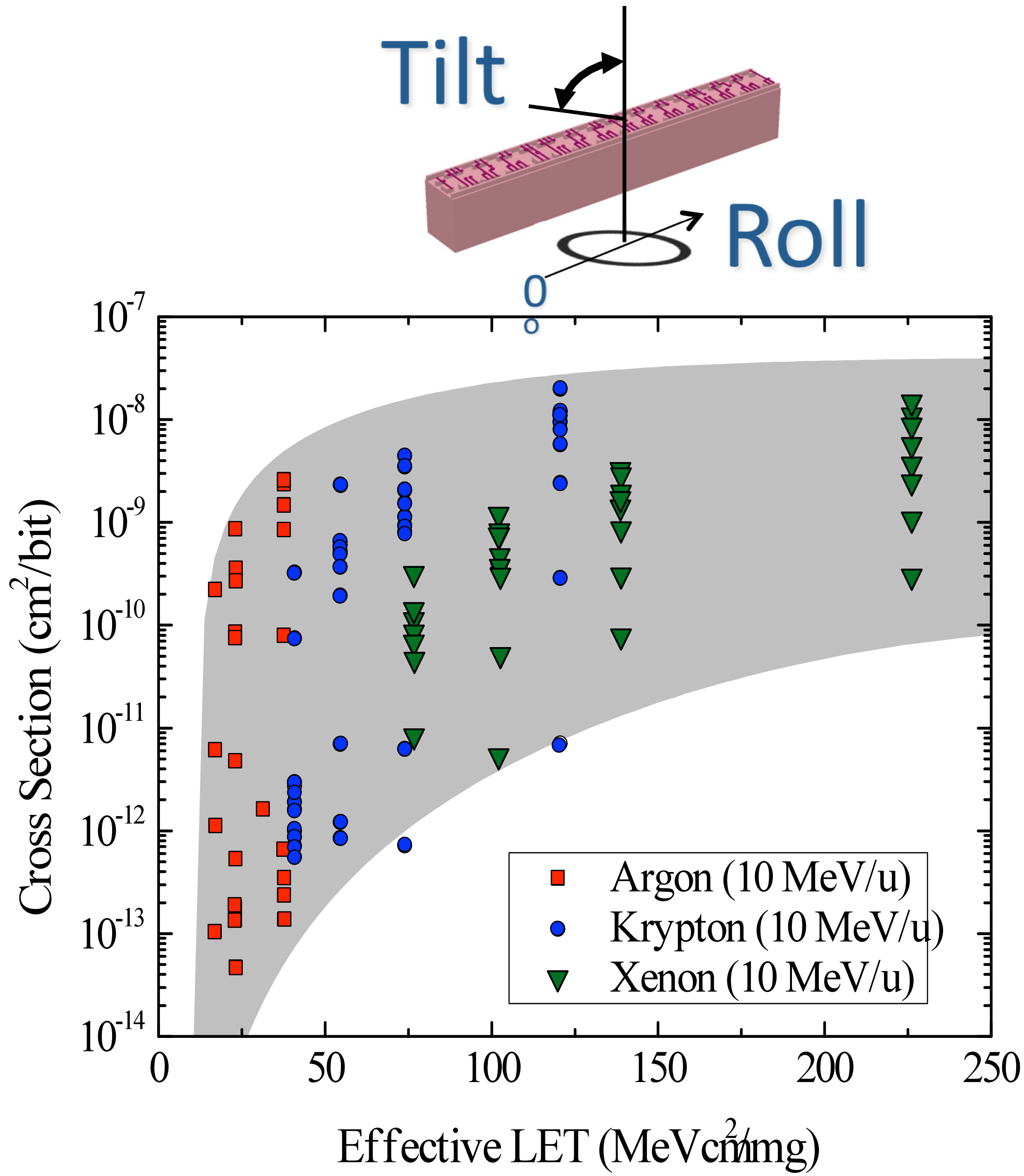
- MRED predicts the contribution of different mechanisms leading to upset over the full energy spectrum
  - Not solely spallation, direct ionization and scattering are important





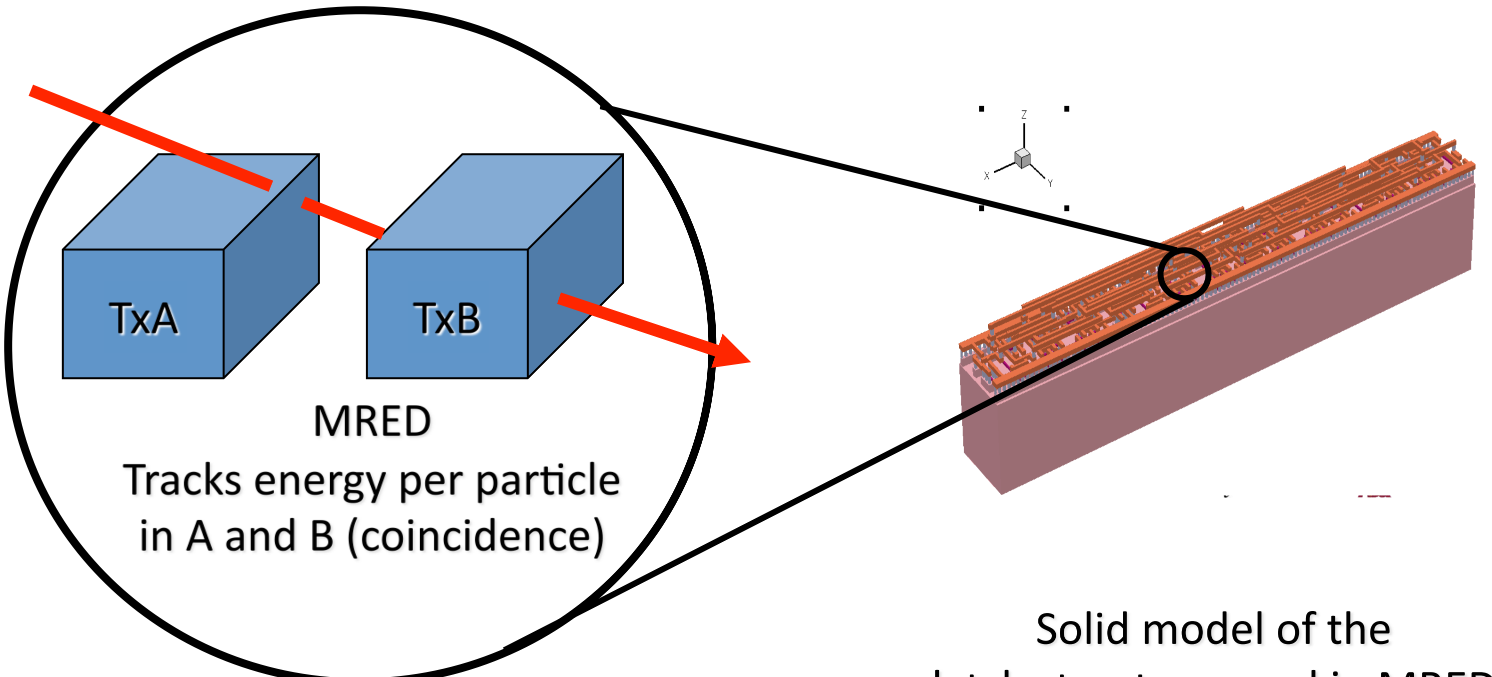
Circuit Requires Coincidence to Upset





Multi-Volume Energy Tracking

- Track energy deposition in complex solid models and in multiple regions
- Correlates energetic events in separate regions (sensitive volumes) of the device – Required for simulating multiple-node mechanisms



Solid model of the latch structure used in MRED

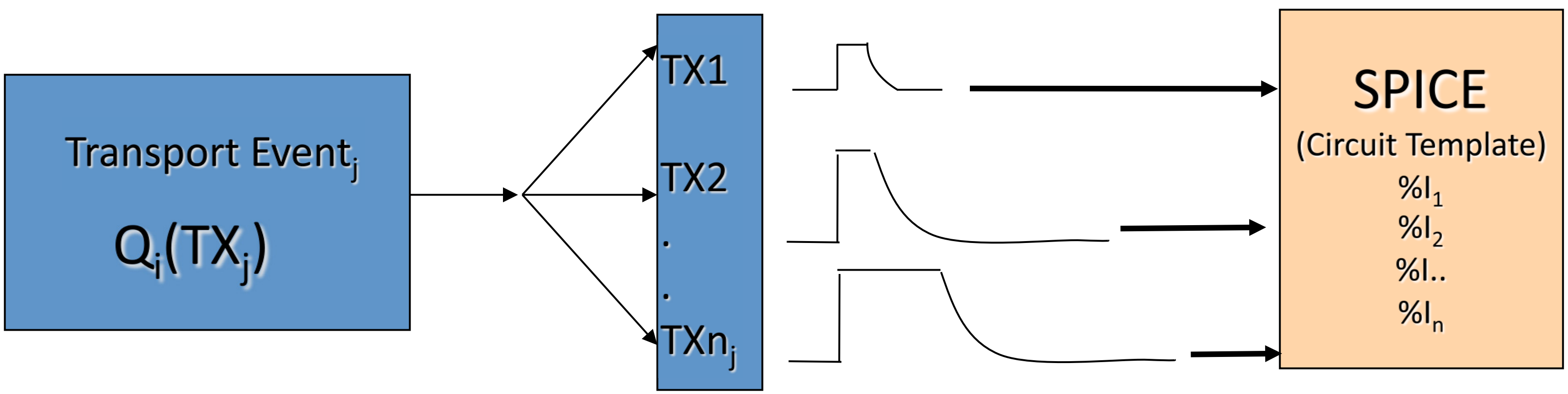
Circuit Simulation – Radiation Transport

- Direct Radiation Transport and SPICE integration can be used to determine if radiation event causes SEU
- After an event, each transistor's Q_{coll} is converted to a double exponential current pulse.
- Other current pulses are possible and are determined by analysis of the technology under investigation

Process is repeated for each event (i) for all transistors (j), each of which are composed of N_k volumes.
SEU analysis is performed at the circuit level for event i.

$$Q_{coll,i,j} = \frac{1}{22.5}\frac{pC}{MeV}\sum_{k=1}^{N_j}\alpha_{j,k}E_{dep,i,j,k}$$

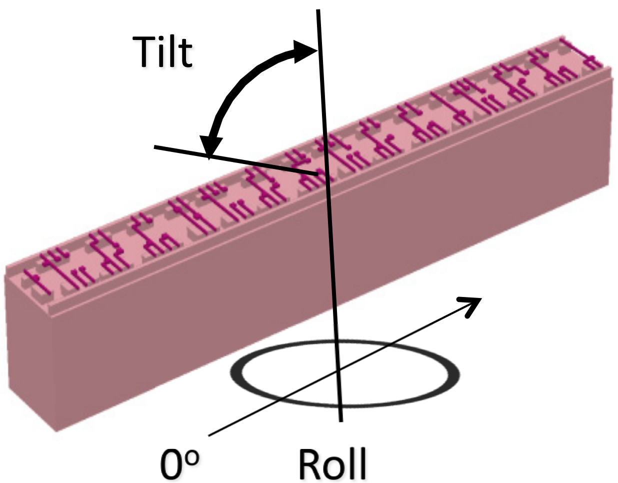
$$Q_{coll} = Q_1 + Q_2 = \int_{t_{d1}}^{t_{d2}} I_1(t)dt + \int_{t_{d2}}^{\infty} I_2(t)dt$$

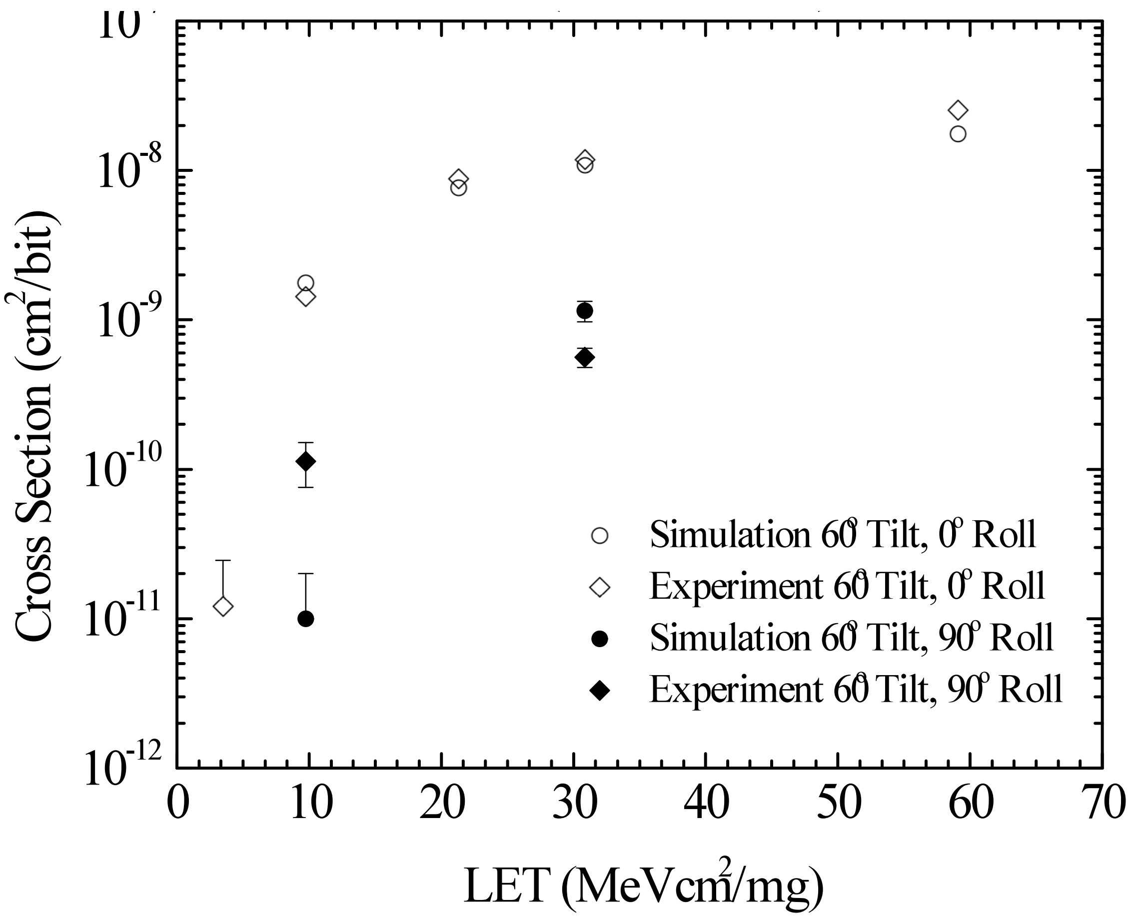


Spice simulation of the ith particle event

Heavy Ion SEU - 60 Degree Tilt

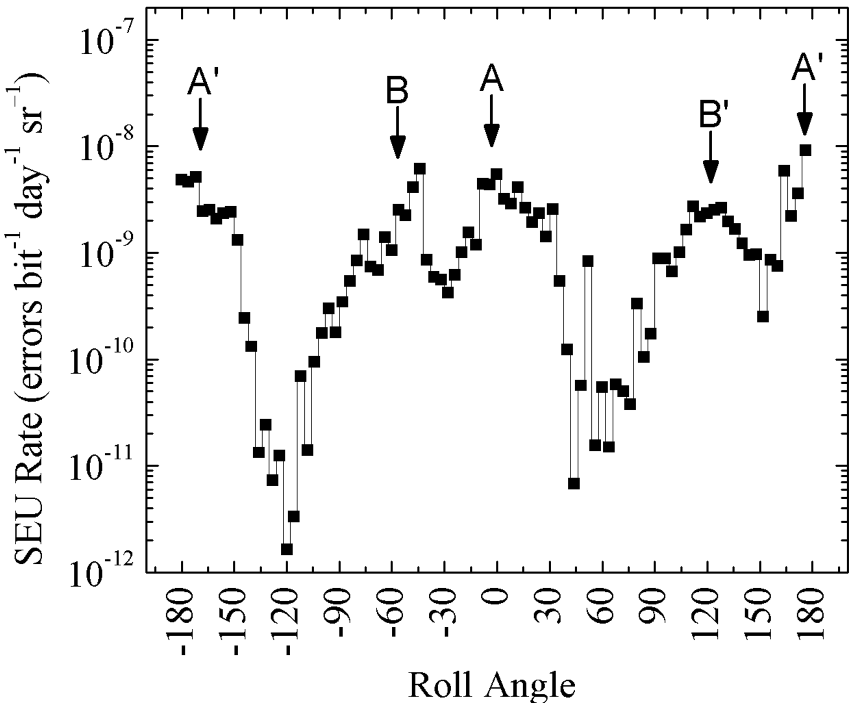
- Cross sections in both simulation and experiment are highly dependent on the Roll angle (60° tilt shown)

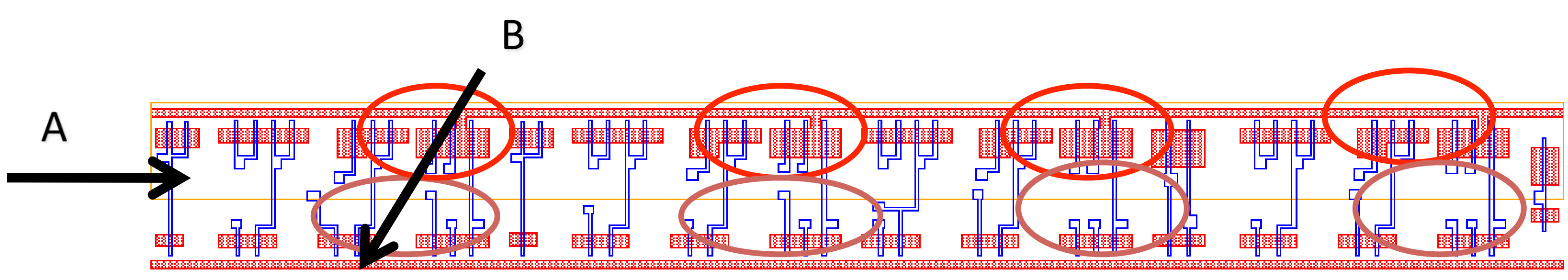




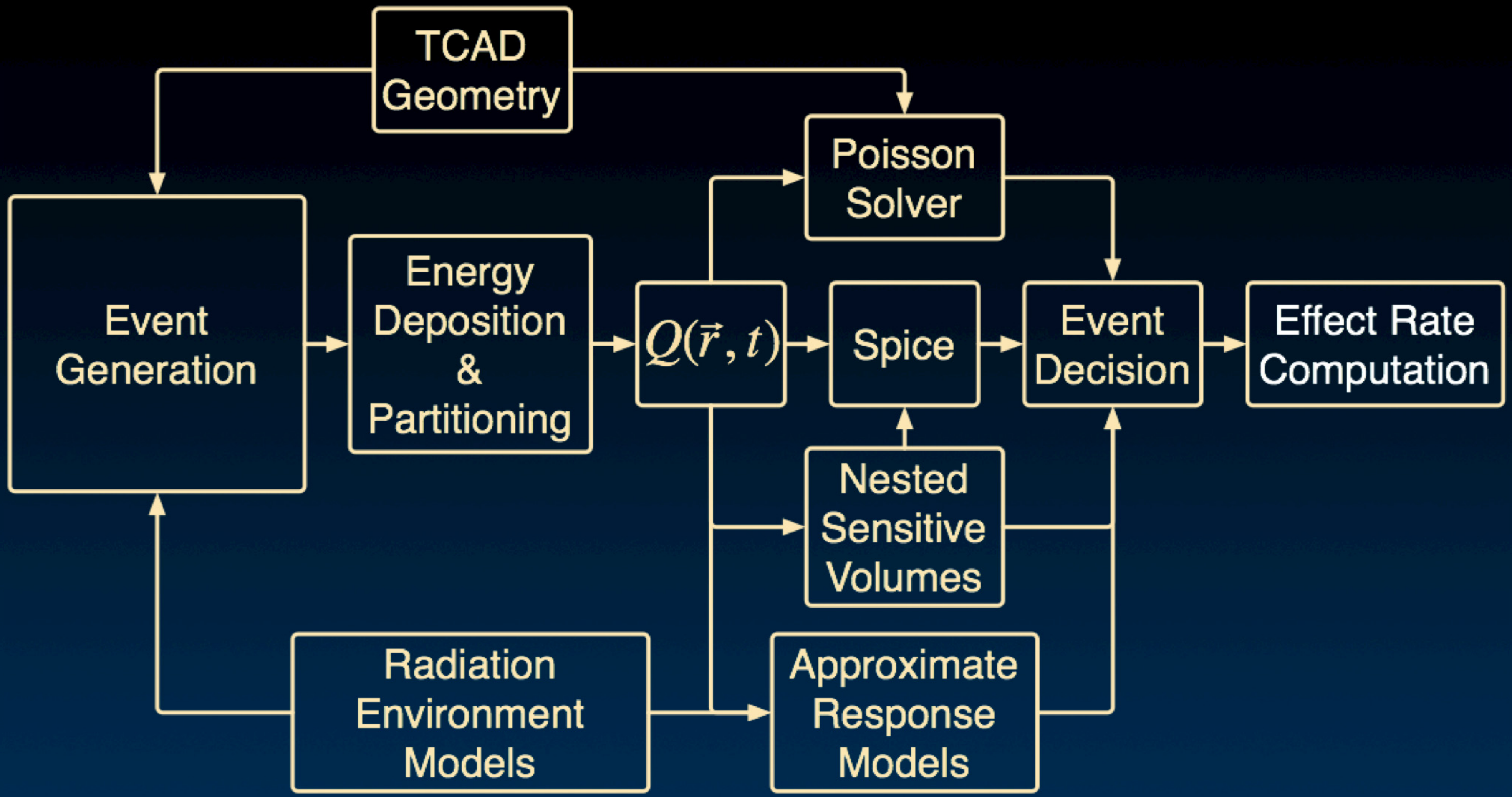
SEU Vulnerability - Layout Dependencies

- There is a clear pattern in the sensitive transistor IDs for the latch.
- Upsets are clustering around the same transistors in the master and slave stages
- Identify orientation effects on SEU rate





MRED – Where things stand…



What is left undone?

- The microscopic description of individual particle tracks
- Understanding of the "ballistic electron → eh pairs → thermal" sequence
- Remaining issues in predicting the nuclear final state
- Characterization of the energy deposition in materials like GaN
- Interaction of radiation quanta with molecule-size structures
- Computational efficiency and strategy (algorithms)
- Transition to system-level analysis and SEE rate prediction
- Terrestrial single event threats from exotic sources…