# Terrestrial Applications of MRED

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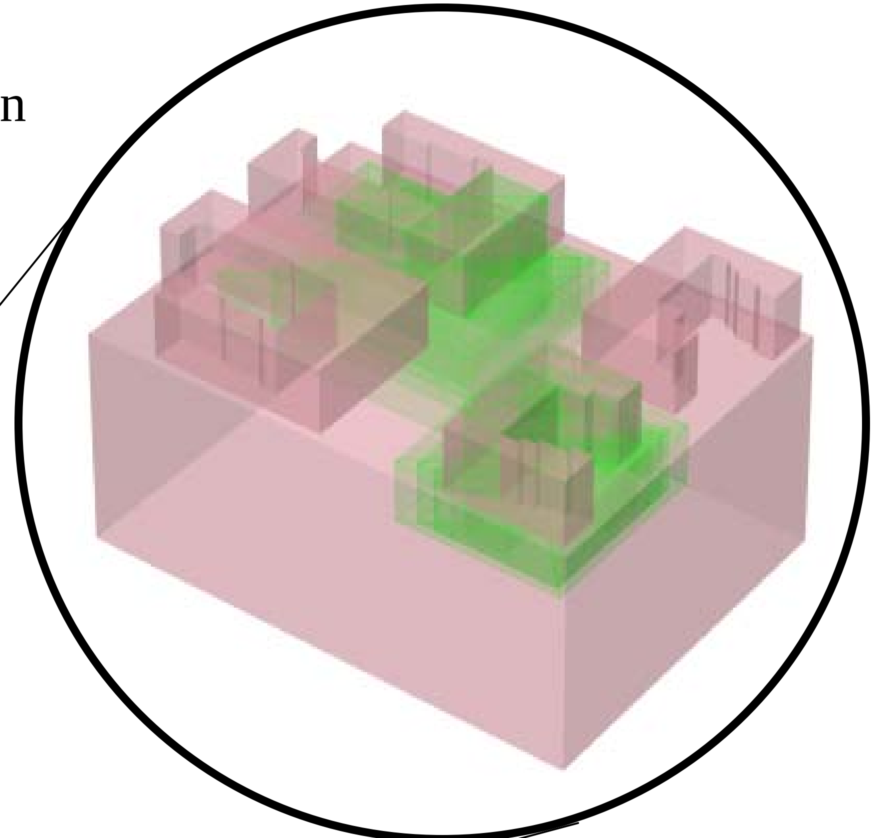
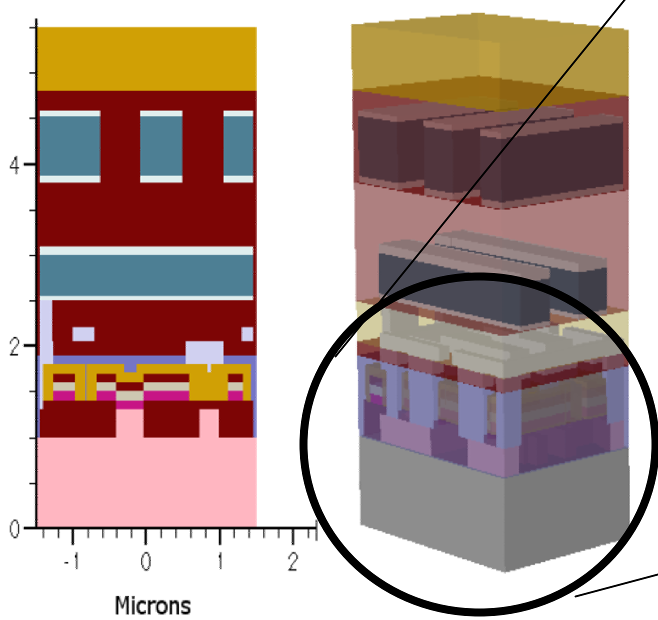
# Outline

- Introduction to Simulation Methodology
- Predicting error rates in the terrestrial environment
  - Comparison of neutron and proton SEU response
  - Virtual accelerated life testing for alpha SEE modeling, rate prediction and test methods.
  - Multiple bit errors – quantifying and evaluating MBU identification algorithms in the testing environment

# Case Study: 4Mbit 0.25 µm SRAM

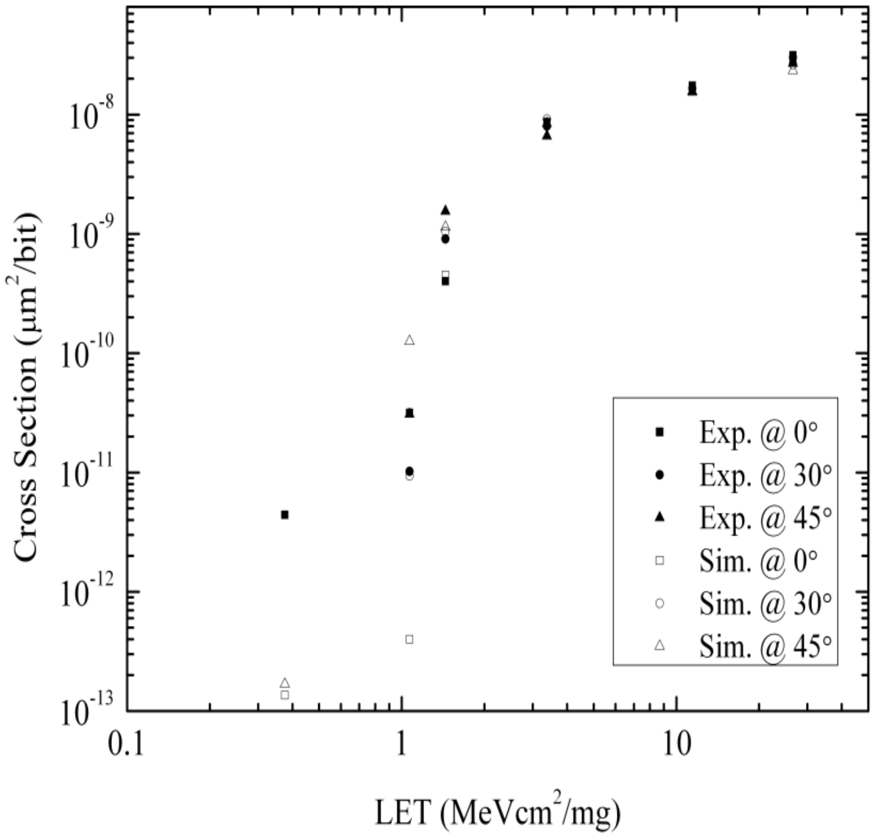
- Shown upper right in green are the sensitive volumes for this SRAM in the N and P transistors
- Simple single node upset mechanism
  - Off-state N or PMOS





# Heavy Ion Experiments

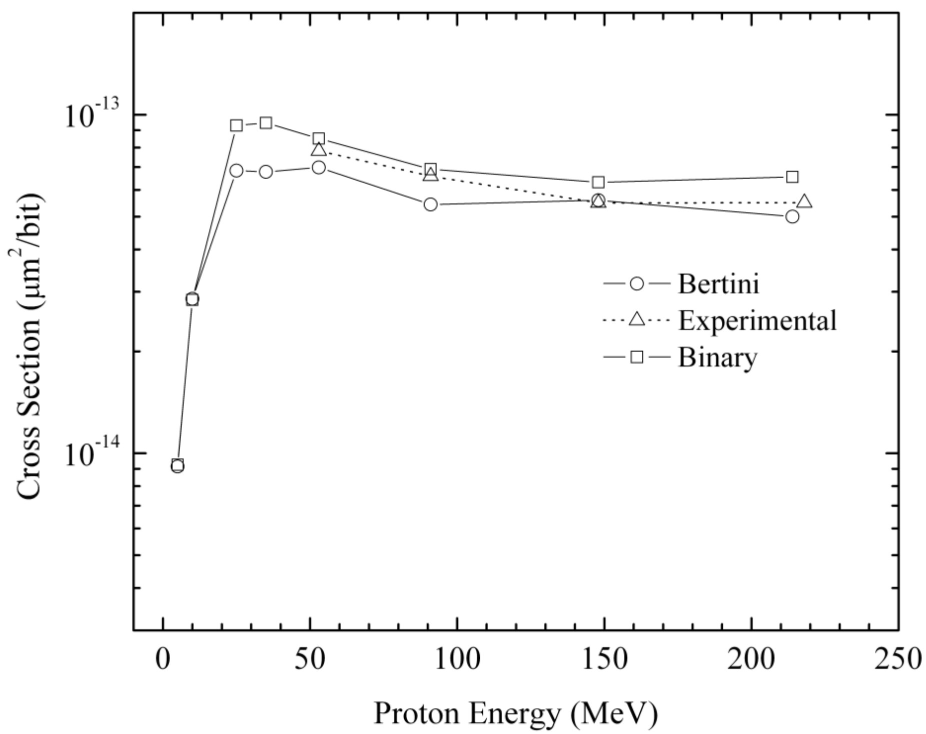
- Fine tuning the sensitive volume parameters and geometry is performed against heavy ion data.
- This is an empirical process but generally speaking those parameters have ended up being physically reasonable (well depths, epi depth, etc…)
- Depending on the level of complexity of the SEU mechanism and required fidelity, heavy ion calibration can be very quick or difficult




Heavy ion simulation and experimental data for the SRAM

# Evaluating the Model against Proton Data

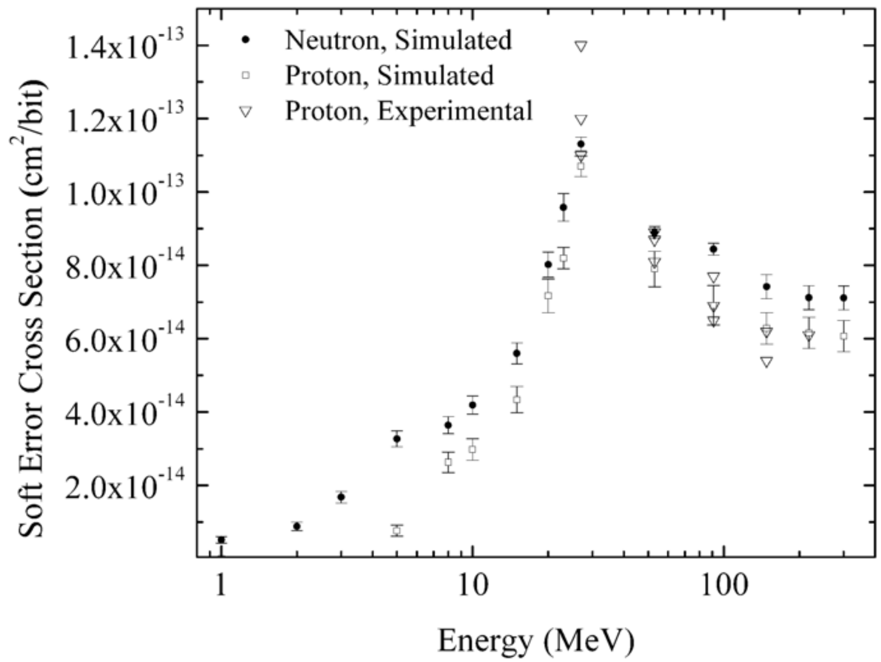
- Given the fidelity of the physics code in MRED (GEANT4), the exact same simulation can be performed by simply switching the beam type.
- To the right, the heavy ion calibrated model of the SRAM is irradiated with protons (virtually, of course).
- We picked two different models available in the GEANT toolkit
- Either agree very well with data with NO further calibration.




Experimental and simulated proton cross sections for the SRAM At 1.5V

# Comparing Neutrons and Protons at High Energy

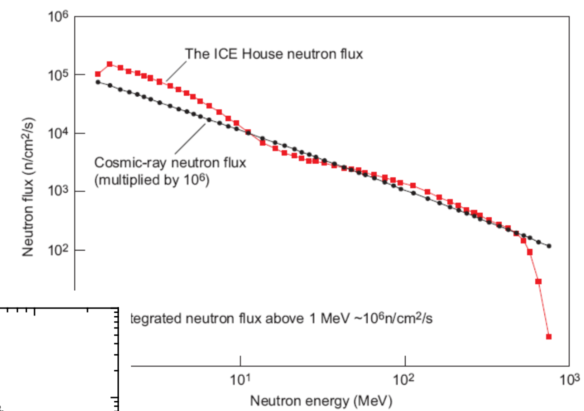
- Is predicting terrestrial neutron SER from proton data okay for this part?
- A simple first test was to switch the particle from 'proton' to 'neutron' in the beam statement of MRED.
- Not surprisingly the proton cross sections cut-off while the neutrons continue to tail off into the low energy realm.
- The question becomes, does this make a difference in SER prediction?

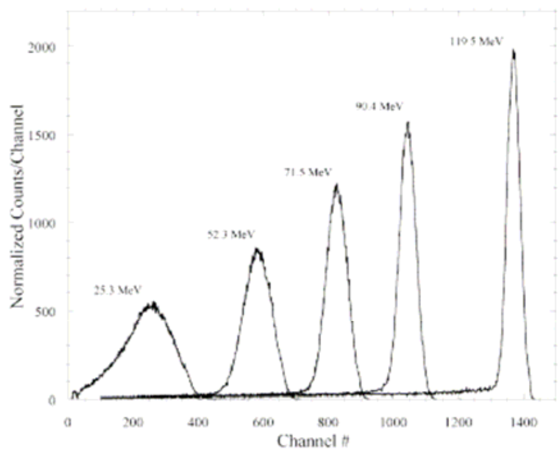


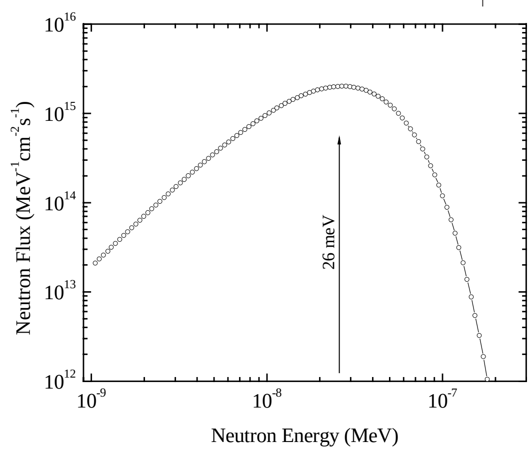

A comparison of the simulated neutron and proton cross sections over energy in the SRAM

# Investigating Test Methods (Facilities)

- What is the influence of facility specific energy profiles on cross sections and the predicted SER?
  - ICE House (WNR) – Terrestrial Neutrons
  - NIST Thermal Neutrons
  - Northeast Proton Therapy Center

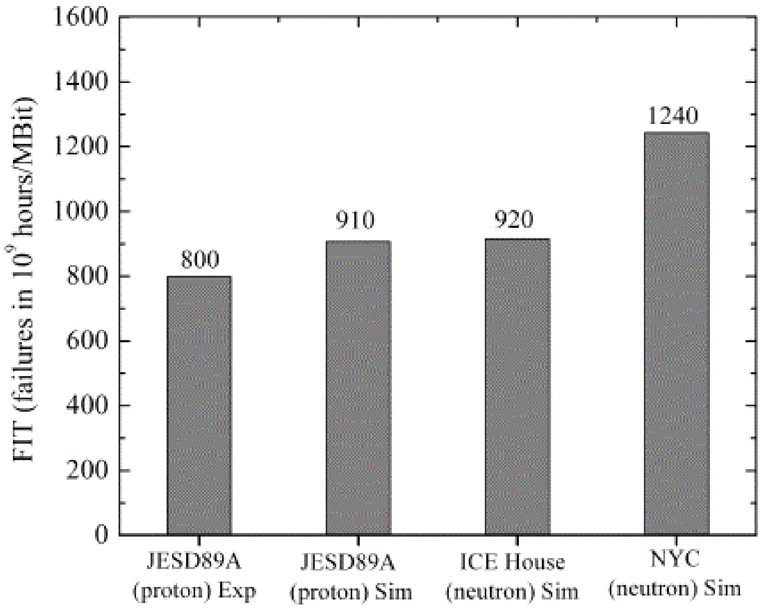


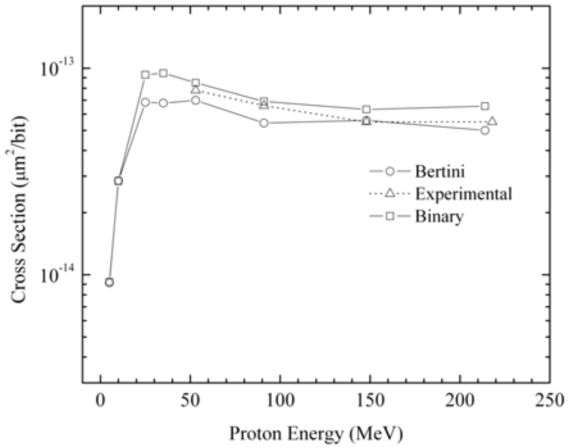



# Investigating Test Methods – SER Predictions

- Limitations of the test data result in an under predictions of the SER rate.
- Using a full range of simulated proton cross sections and the ICE House spectrum produce nearly identical results
- All under-predict the SER with respect to the true NYC spectrum.

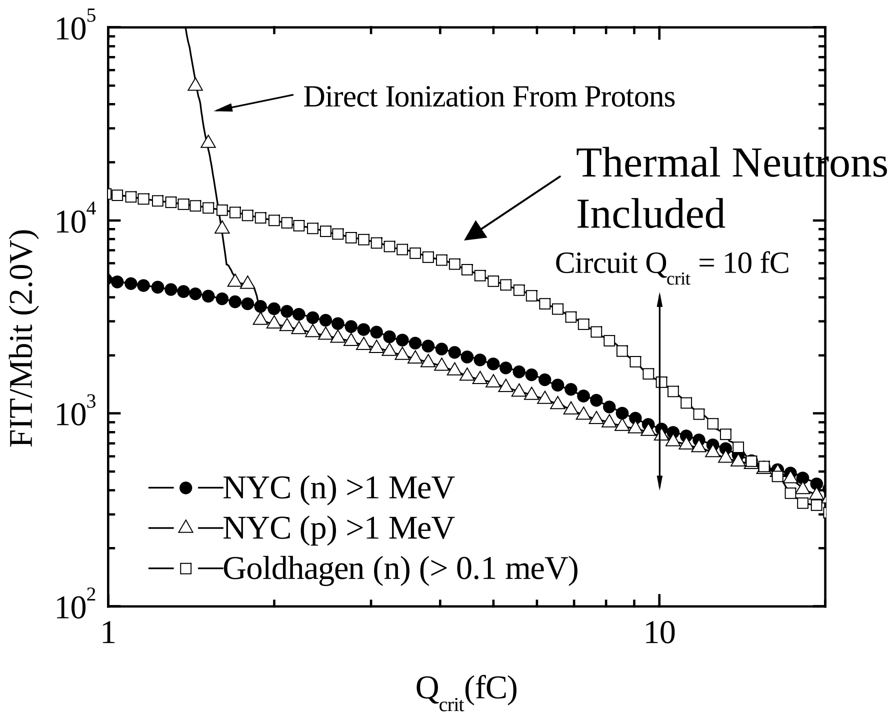



SER determination
for the SRAM using the NYC spectrum



# Investigating Test Methods

- A comparison of the energy deposition profile illustrates the similarity between neutron and protons for this part.
- A full neutron environment over all energy ranges from thermal to GeV produces a dramatic increase in the SER.
- The experimental thermal neutron cross section (NIST) is in good agreement with simulation results.
- Will these conclusions remain true?
  - Scaling and Density
  - Direct ionization from protons
  - How to predict the SER



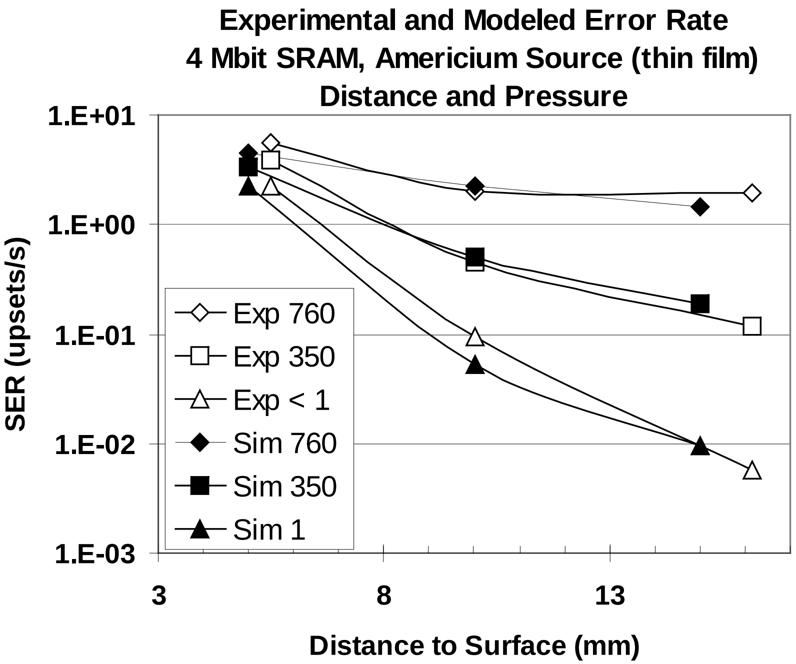

A comparison of the neutron and proton SER using the Goldhagen NYC flux.

# Investigating Test Methods (Alpha)

- Evaluate Packaging, purification techniques and decay chain evolution
  - Type and concentration of contaminant
  - Energy of alpha particles
- Identify relationship between technology nodes, processing steps, packaging materials

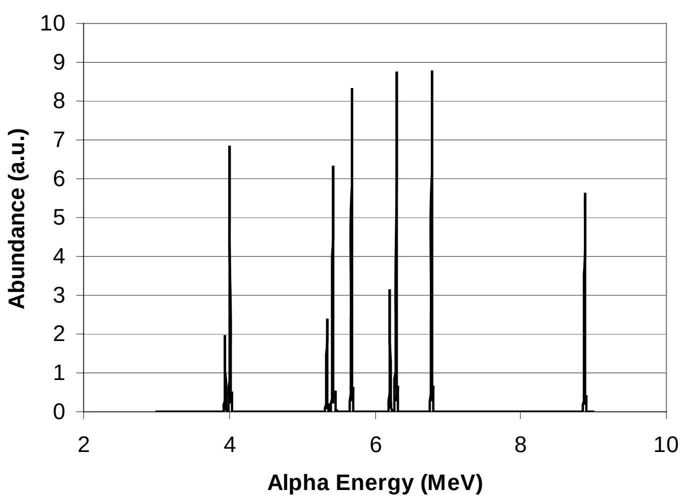
<u>MRED model</u>

- Simulate reduced pressure (air or other) environments
- Model thin and thick film sources (Am shown)
- Investigate passivation strategies for SER
- Evaluate effects of Distance (Test Method)

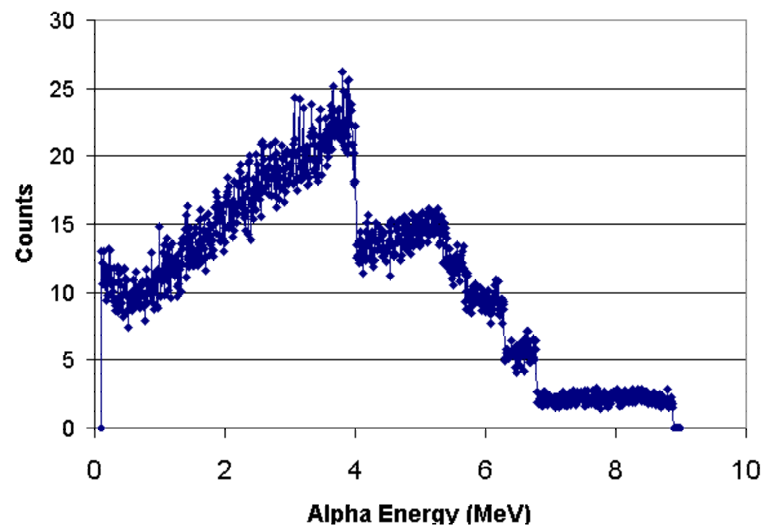


# Alpha Sources

- Calculation of high fidelity alpha spectra from decay chain calculations is being performed to evaluate test methods, namely source dependence on the predicted SER rate.
- Proper beam randomization and calibration has been successfully implemented for the case of a thick $^{232}$Th source in secular equilibrium (shown below)

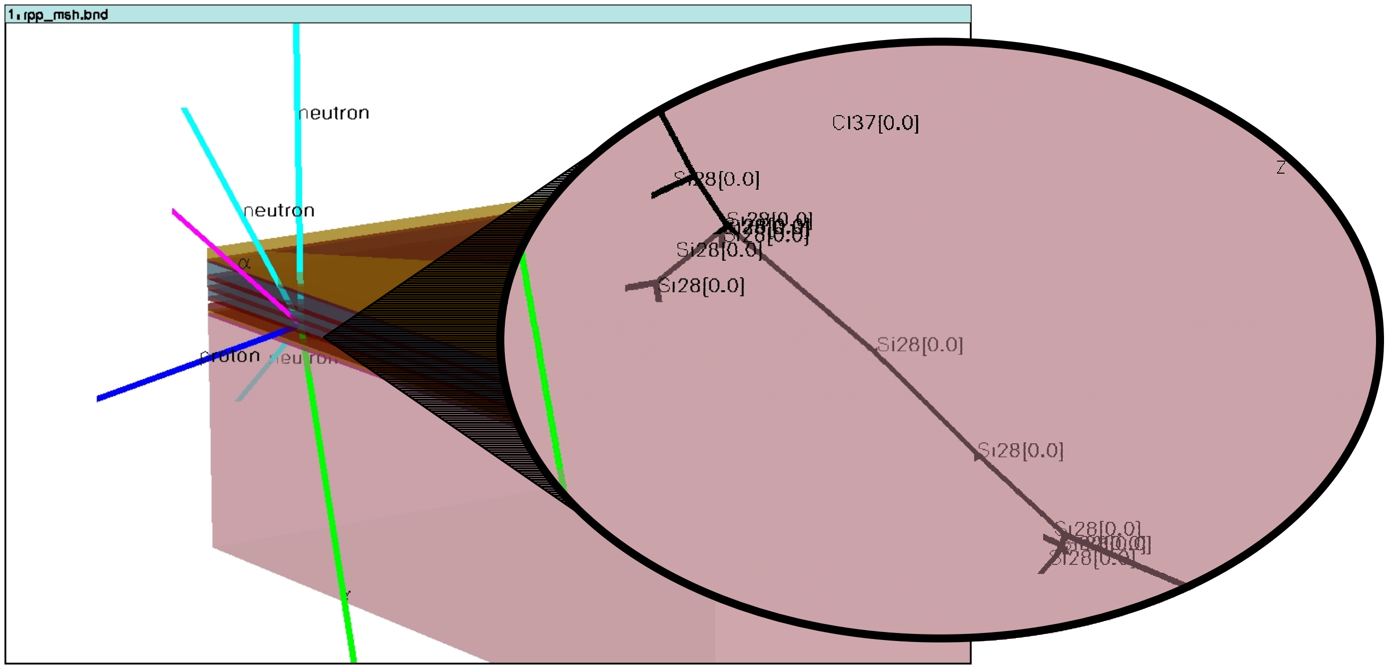



$^{232}$Th Source Spectrum




Energy deposition in Silicon

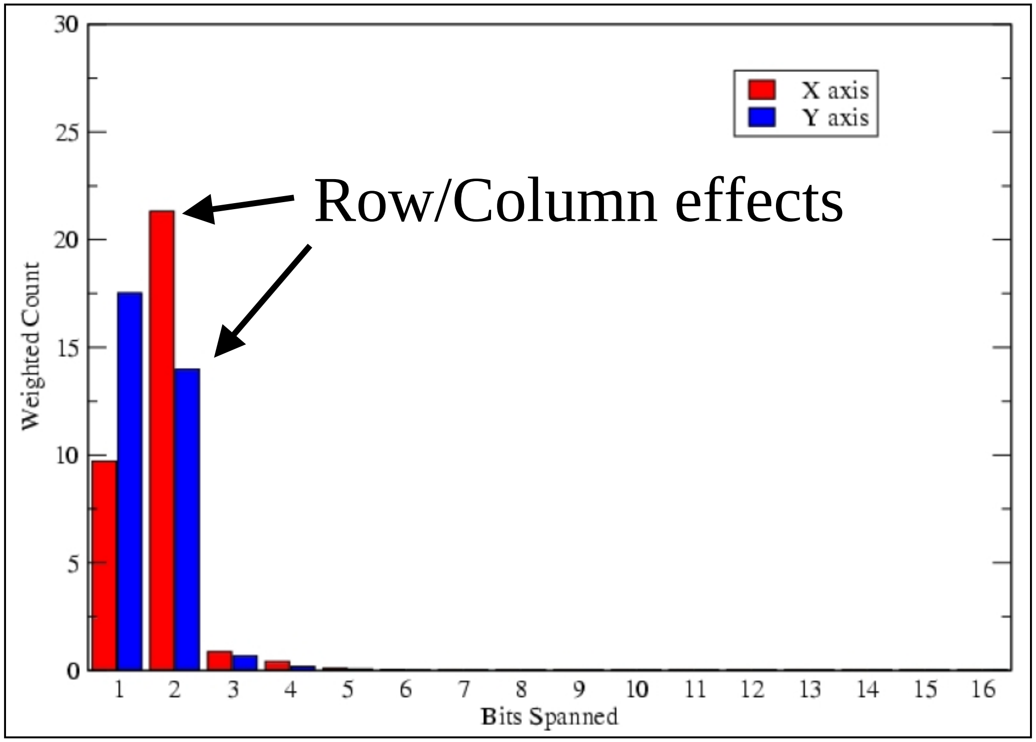
# MBU Analysis




- Device scaling, critical charges make multiple bit upsets more likely to occur as a result of nuclear reactions
  - Short range recoils and secondary particles can traverse greater number of bits
- Energy of incidence neutron can affect scattering angle
- Important for beam flux, data reduction
- Important for reporting of multiple cell error rate reflecting energetic terrestrial neutrons

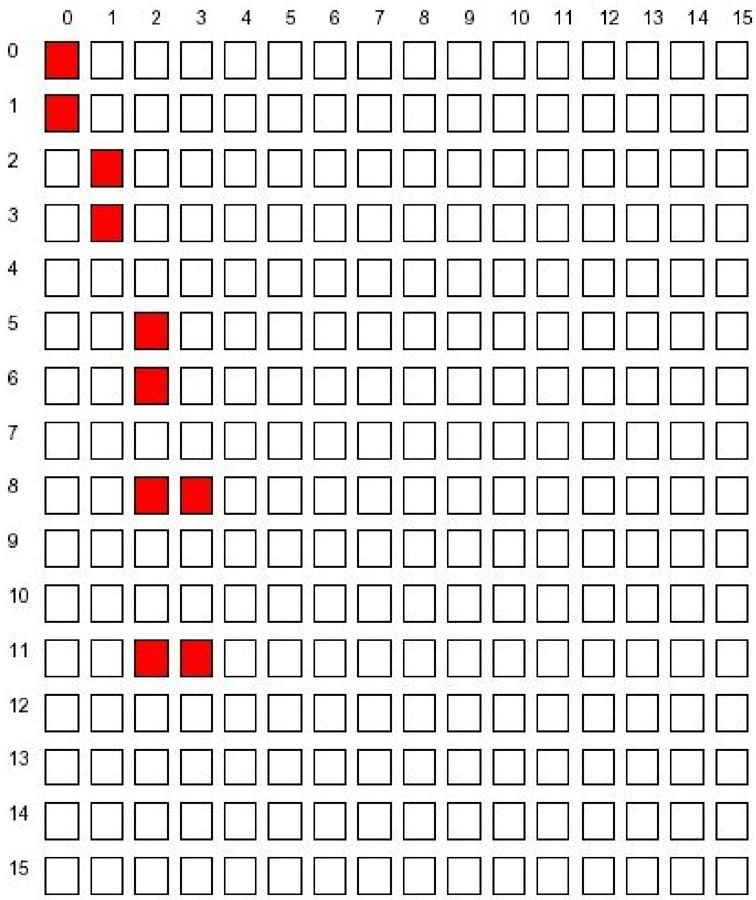
# MBU Analysis

- Difficult to tell MBU from multiple SBU
- Need to determine ‘physical proximity’
- MRED has capability to simulate large arrays of bits
- Example below indicates the the distance between errors for 2-bit upsets in a 130 nm technology



# MBU Analysis (Pattern Recognition)

- Bit interleaving strategies can be undermined by complex MBU patterns
- MRED can be programmed to identify and learn patterns
- Provide the user with probabilities and distributions of complex events
- Outputs information in graphical format for quick review
- The rates of these events can be determined by using environmental spectra
- Deviations of patterns from experiment to environment can be analyzed




22MeV neutron strike on simulated 16x16 SRAM, red indicate upset bits

# Summary

- MRED (Monte Carlo simulator)
  - Means for importing geometrically and compositionally accurate solid models
  - Unlimited materials specification capability (density, atomic composition, isotopic purification, etc…)
  - Flexible particle sampling algorithms for emulating beam and natural environments
  - Detailed physical models for direct and indirect ionization processes including radioactive decay
  - Unlimited means of tracking and logging energy deposition
    - Includes MBU rate prediction and pattern recognition
  - Currently being applied to 250nm, 130nm, 90nm and 65nm technologies