The Need for Modeling and High Energy

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Why ask Why ?

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- Why is lemon juice made with artificial flavor ..and dishwashing liquid made with real lemons?
- If nothing ever sticks to TEFLON how do they make TEFLON stick to the pan?
- Why does the sun lighten our hair, but darken our skin?
- Why doesn't glue stick to the inside of the bottle?

To make things work (better) or avoid failure, it is often necessary to perform additional experiments to understand WHY things happen, not just WHAT does (or does not) happen

Test as You Fly, Fly as You Test, and Demonstrate Margin

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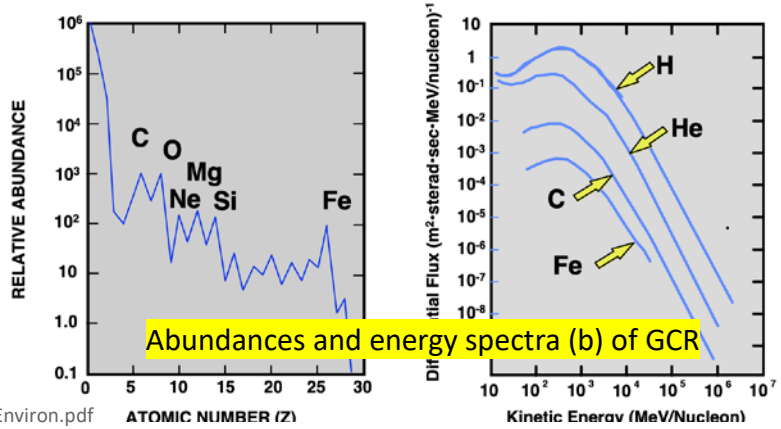
Test as You Fly, Fly as You Test, and Demonstrate Margin (1998) – NASA

http://llis.nasa.gov/lesson/1196

- The process of end-to-end system verification (either through testing, simulation, or analysis) may be compromised when it is not consistent with the mission profile (**plus margin and the appropriate off-design parameters**).
- Enforce the system-level test principle of "test as you fly, and fly as you test." Carefully **assess any planned violations** of this principle; if they are necessary, take alternate measures such as independent validation.
- When using simulations for system-level verification, **models must have been validated (e.g., supported by test**); and **sufficient parametric variations** in the simulations must be performed to ensure that adequate margins exist.

There is high energy radiation in space !



Abundances and energy spectra (b) of GCR

https://three.jsc.nasa.gov/concepts/SpaceRadiationEnviron.pdf

New Scaling Paradigm: Miniaturized Systems

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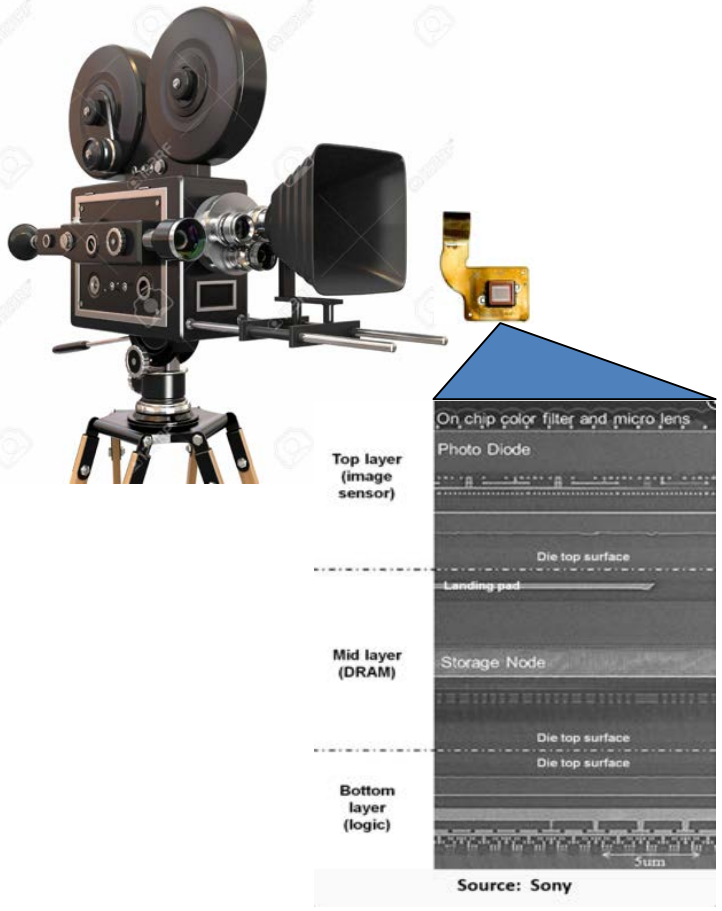
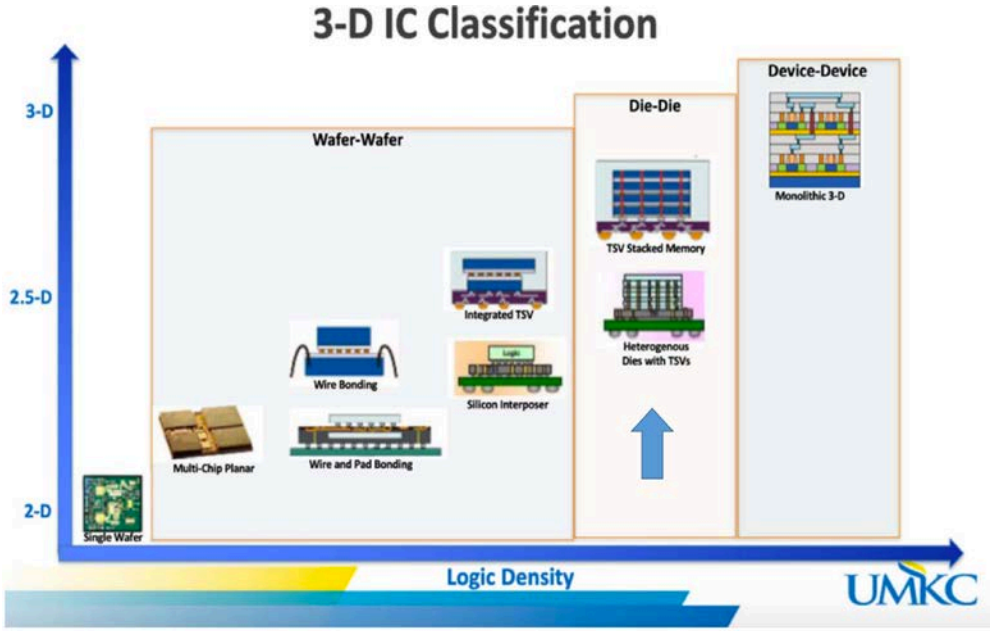
"Scaling" now means miniaturizing system functions (instead of just transistors) through more intimate physical integration schemes



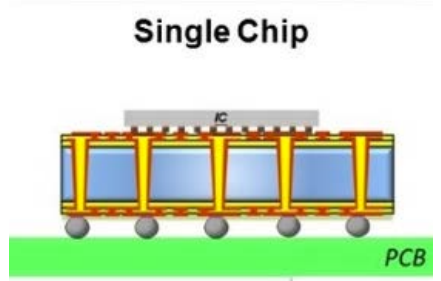


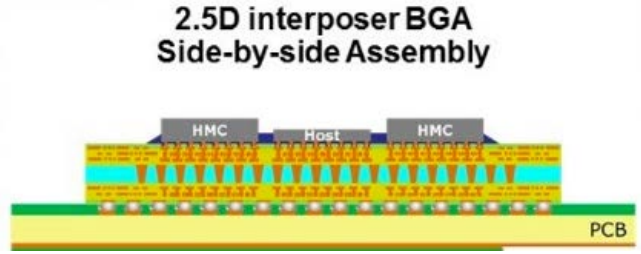
https://eps.ieee.org/images/files/HIR_2019/HIR1_ch06_a-d.pdf

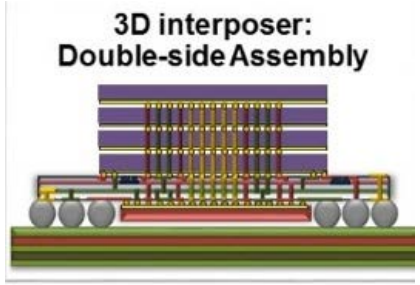
Radiation Characterization of Miniaturized Systems

We are testing systems, not parts

- Observable response may be a complex **convolution** of local environments and constituent device responses: *system represents a black box*
- **Physical** integration schemes impact internal "local" radiation environments
  - *Physical "packaging" is an inherent part of the functional integration scheme*
  - *Stacks may be thick (10's – 100's of μms, range issues)*
- **Functional** response may be coupled or decoupled from the physical integration, depending on degree of intimacy
  - *Integration options: package, wafer/die stacking, monolithic*







http://www.prc.gatech.edu/research/industryprograms/design

Radiation Effects Due to Physical Integration

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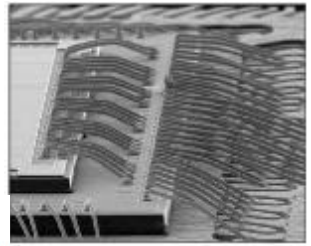
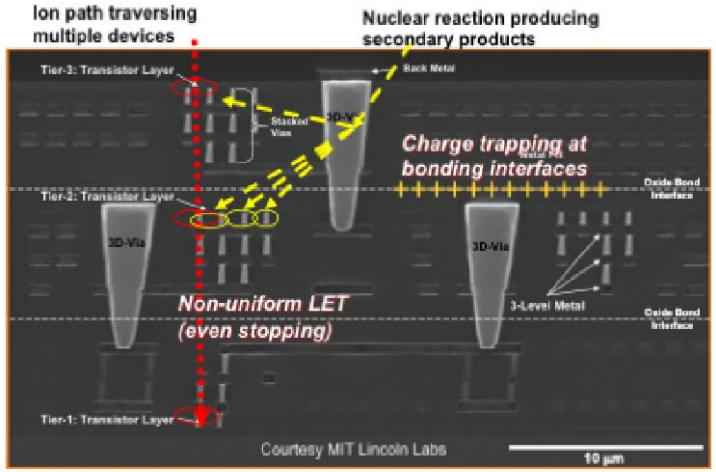
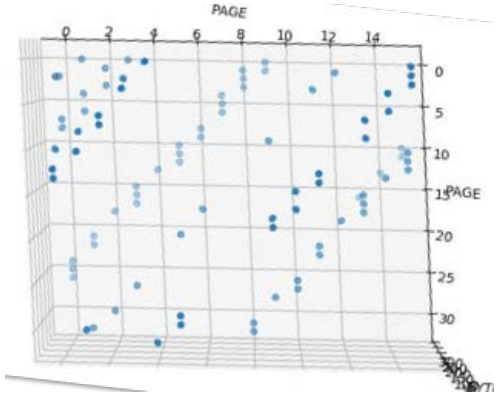
- Integration scheme can reduce or add shielding
- Stacking, bond wires, interposers, TSVs can alter "local" internal radiation environments
  - *Attenuation*
  - *Enhancement*
  - *Secondary products*
- New interfaces for charge trapping
- Thermal fab process differences and thermal profiles in stacks may impact the radiation response
- Multiple (~ simultaneous) events in 3D stacks (e.g. memories and more complex multi-function stacks)







https://nepp.nasa.gov/workshops/etw2019/talks/0619WED/1120%20-%20Wilcox%20-%202019-561-Wilcox-Presentation-NEPP-ETW_v2.pdf

Modeling as Part of a Characterization Approach

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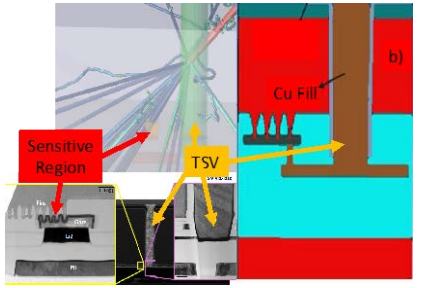
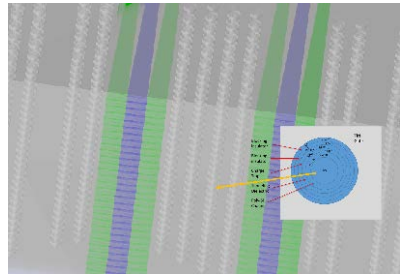
- **Physical stimulus (environments, transport, energy deposition)**
  - Determine “local” environments within the structure (e.g. SRIM, CRÈME, MRED, NOVICE)
  - Account for attenuation, enhancement, secondary production, stopping/rage limitations
- **Functional response (manifestation)**
  - Device, circuit, board, system level (TCAD, SPICE, System-C, SEAM, etc.)
  - Account for multi-device effects, parasitics, error propagation/masking





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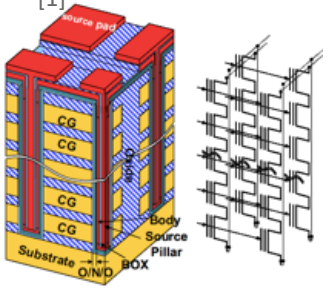

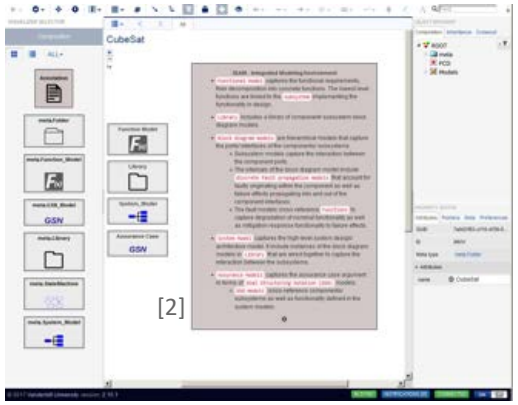

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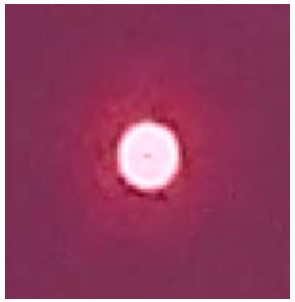

[1] M. Jeong *Et al.*," *2009 IEEE International Memory Workshop*, doi: 10.1109/IMW.2009.509057al

[2] https://modelbasedassurance.org

Physical Modeling for Test Planning and Analysis

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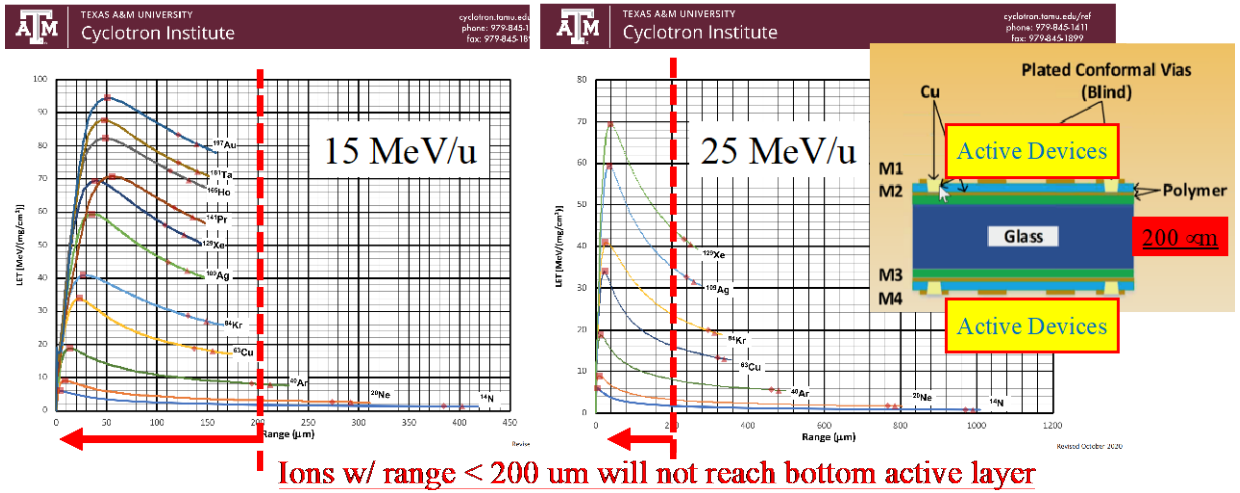
- **Considerations for complex, potentially thick structures:**
  - Non-constant LET (attenuation and/or enhancement/secondaries) can alter internal “local” environments within the structure
  - Angle of incident no longer translates to effective LET as in the past
  - Range considerations
- **Modeling (e.g. SRIM, MRED) can be used in test planning & data analysis**
  - Choice of facility/test conditions
  - Elucidating internal environments within the stack



Modeling for Analyses of Test Results in Circuits

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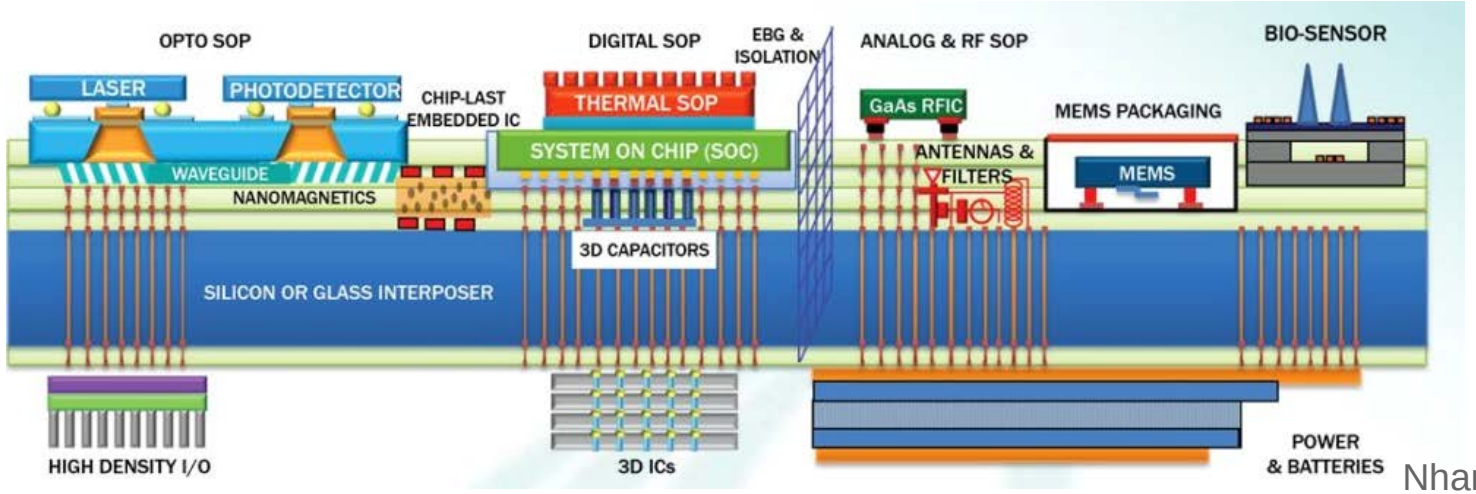
- **Observable response may be a complex convolution of the stimulus, physical architecture, and electrical coupling of the integrated functions**
  - More pronounced with heterogeneous technology and functional integration where single-events may induce transients in multiple regions nearly simultaneously
  - ***Propagating information across levels of hierarchy and systems-level simulation of radiation response is ongoing R&D***



Nhanced-semi.com

“Black Box” – Dealing with COTS

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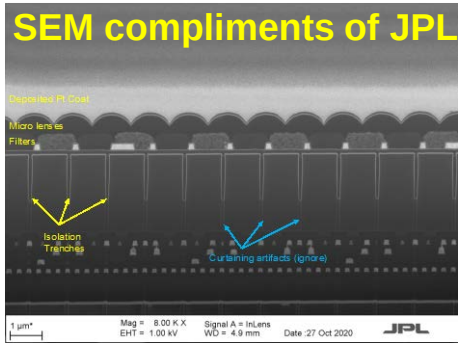
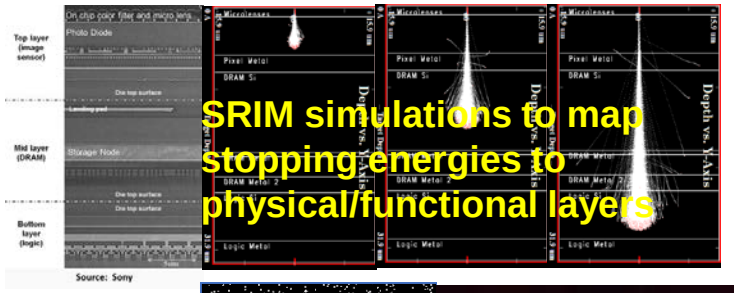
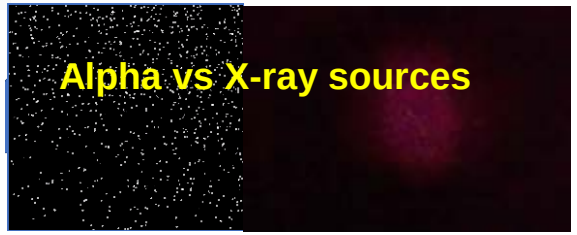
Example: 3D Stacked imager

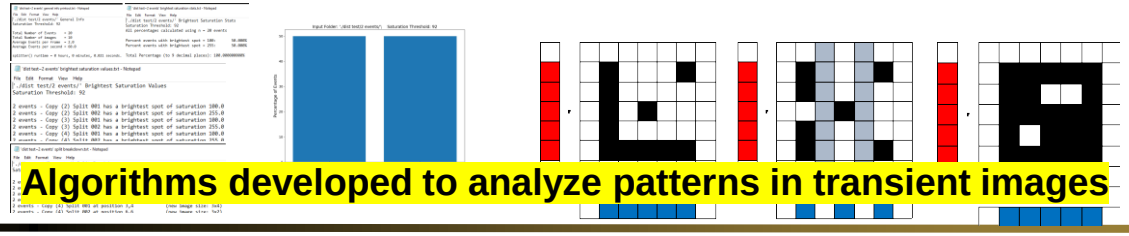
- Structure from physical analysis of DUT
- Co-extraction: analyses of response mechanisms from different test conditions and sources, e.g.:
  - Laser vs. pulsed X-ray vs. ions
  - Proton vs. Gamma or X-rays
  - Variable energy Bragg profiling
  - Selective energy deposition (multiple orientation, ranges)
- Using M&S to interpret results



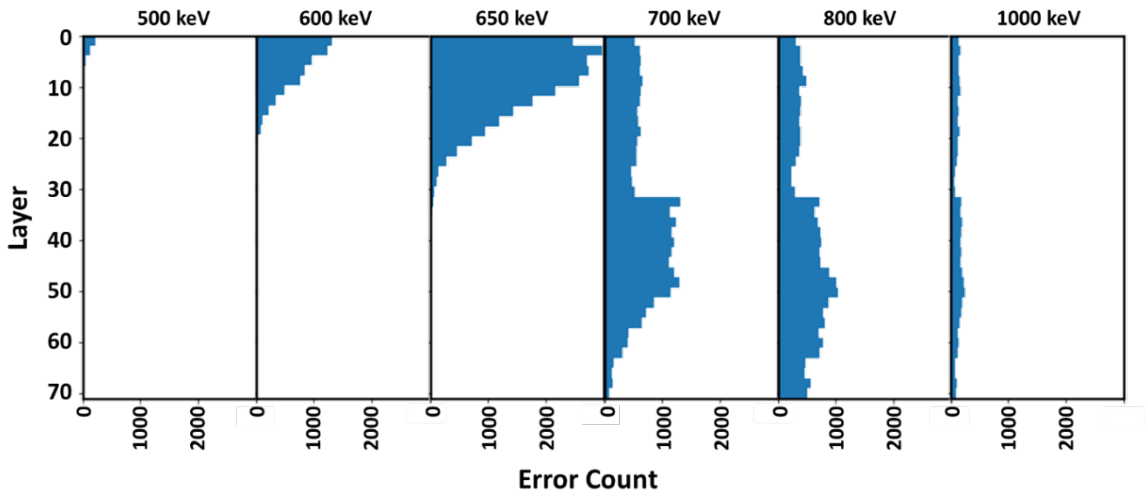


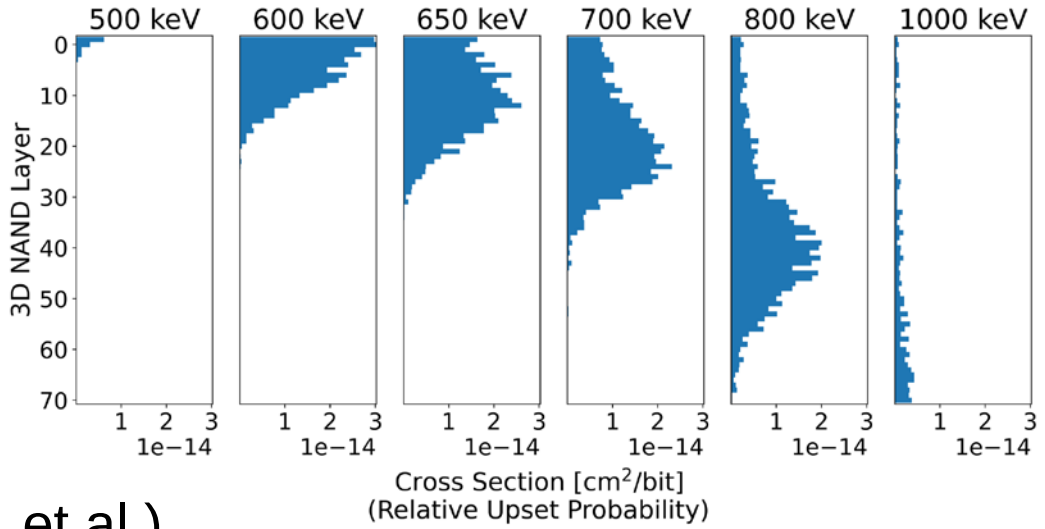
Pulsed X-rays at Aerospace Argonne national Labs facility



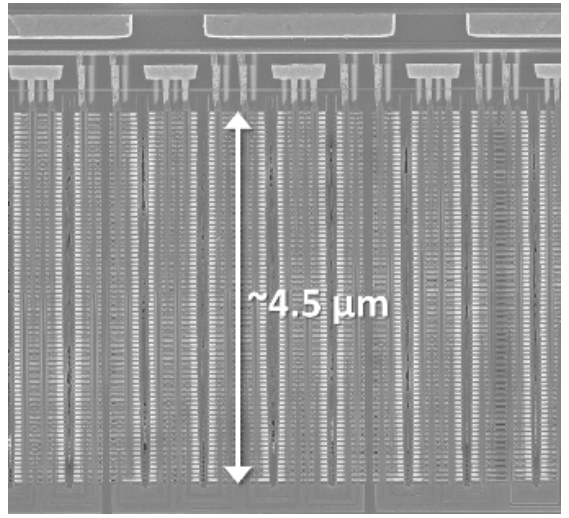


Insight from Experiment vs. Simulation – Stacked Memory





- Proton measurements by NGSFC (T. Wilcox, et al.) simulations by VU (M. Breeding, et al.) using MRED
  presented at 2020 IEEE NSREC, accepted for IEEE TNS
- Reasonable agreement in depth profiles
- **Source of measured errors in lower half of physical stack at higher energies (~ 700-800 keV) may be due to circuit architecture and are under investigation** *(physical vs. functional consideration)*



Summary

- There is high energy radiation in space that can penetrate systems
- New integration schemes include complex stacked (thick) physical structures with multiple coupled functions – all in the beam (environment) together
- High energy testing provides best representation of integrated device response in high energy environment
- Black-box systems present unique challenges
- Multi-level M&S provide requisite insight for test planning and interpretation of result

"Now, this is just a simulation of what the blocks will look like once they're assembled"

C. Darbyshire, New Yorker, 5/12/2003