National Aeronautics and Space Administration

Criticality of Low-Energy Protons in Single-Event Effects Testing of Highly-Scaled Technologies

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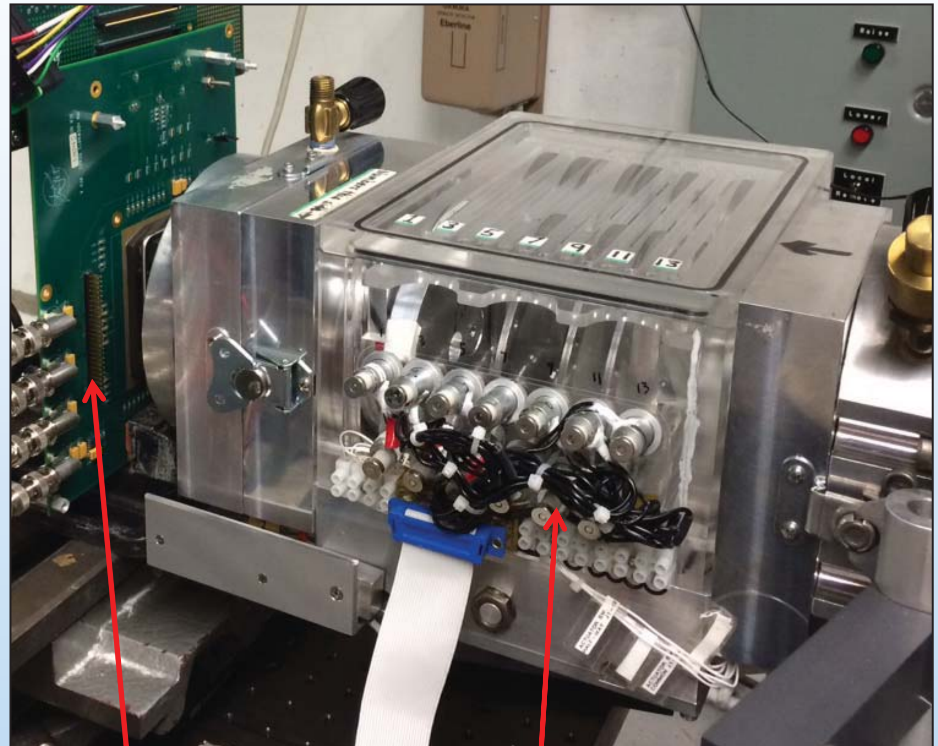
Outline

- **Introduction**
  - **Low-energy protons (LEPs)**
  - **Test facility setup**
- **Protons vs. alphas**
- **DUT is 32 nm SOI CMOS 128 Mb SRAM**
  - **DUT is in a flip-chip package**
  - **Beam enters through substrate**
- **SBU and MCU SRAM data**
- **Die thickness reverse engineering with SRIM**
- **Summary**

UC Davis CNL Test Setup



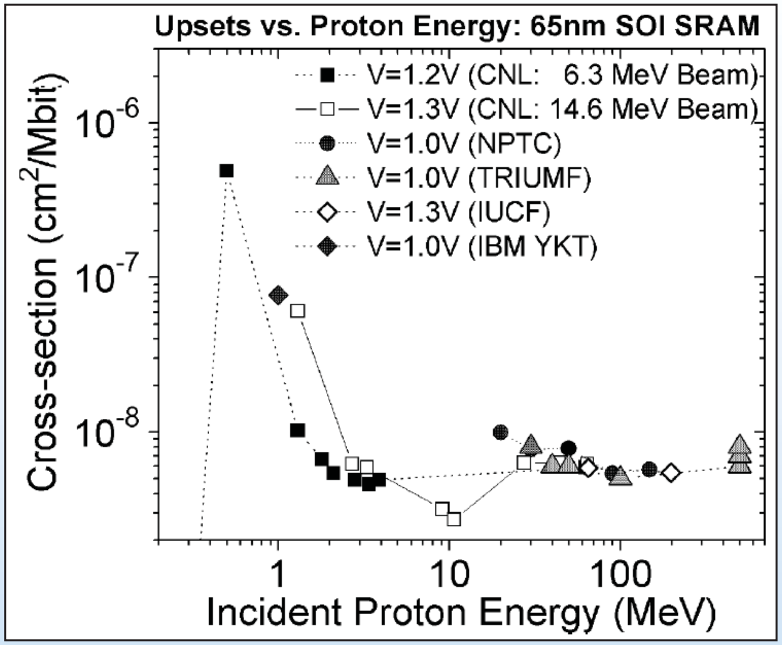
Test board

User-Controlled Degrader Foil Chamber

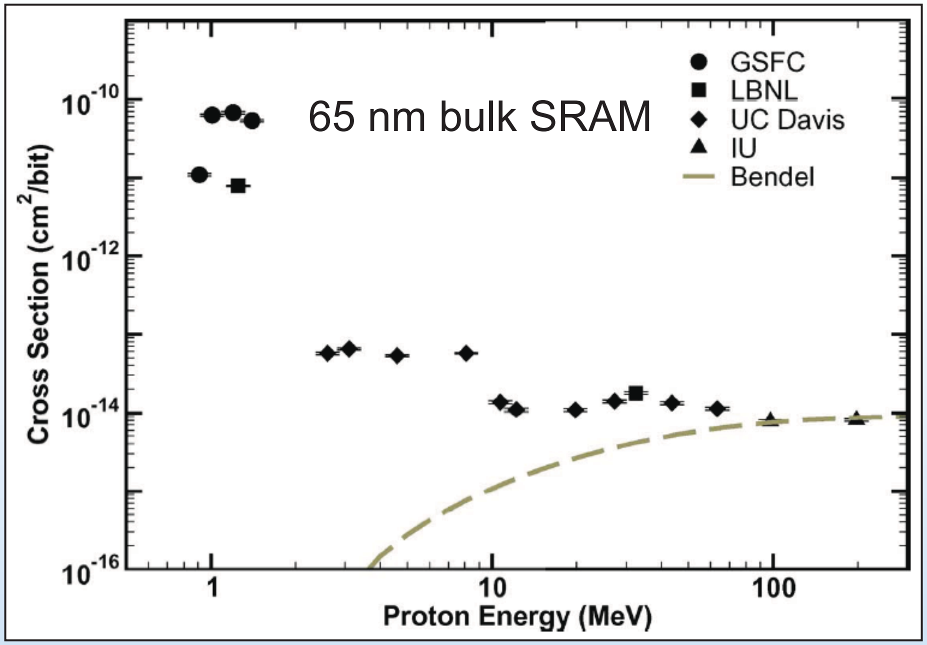
Objective

- **Question:**
  - If low-energy proton (LEP) single-event effects (SEE) are due to direct ionization of the primary particle, are there alternative ions for LEP hardness assurance testing?
- **Hypothesis:**
  - Alpha particles can replace LEPs for direct ionization single-event effects testing.
- **Our contention:**
  - LEPs produce unique SEE signatures and cannot be replaced by alpha particles or other likely high-energy light heavy ion candidates.

Early Low-Energy Proton Data



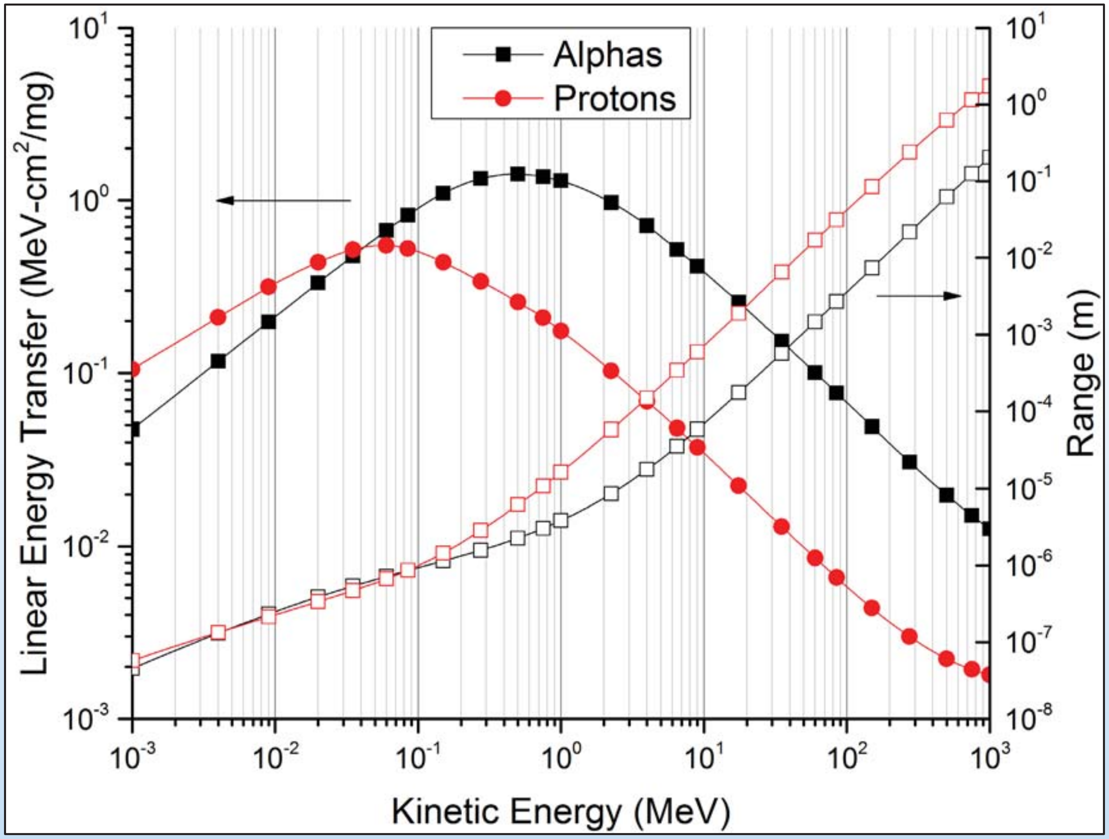
D. F. Heidel et al., IEEE TNS, vol. 6, 2008.



B. D. Sierawski et al., IEEE TNS, vol. 6, 2009.

- **First documented in 2007 (K. P. Rodbell *et al.*, *IEEE TNS*, vol. 6, 2007).**
- **Cross sections are plotted as a function of <u>incident</u> proton energy – inversely proportional to degrader thickness.**
  - **Several implications: changes to the energy distribution shape, flux depletion near end-of-range, etc.**

The Alpha (^{4}He) Alternative

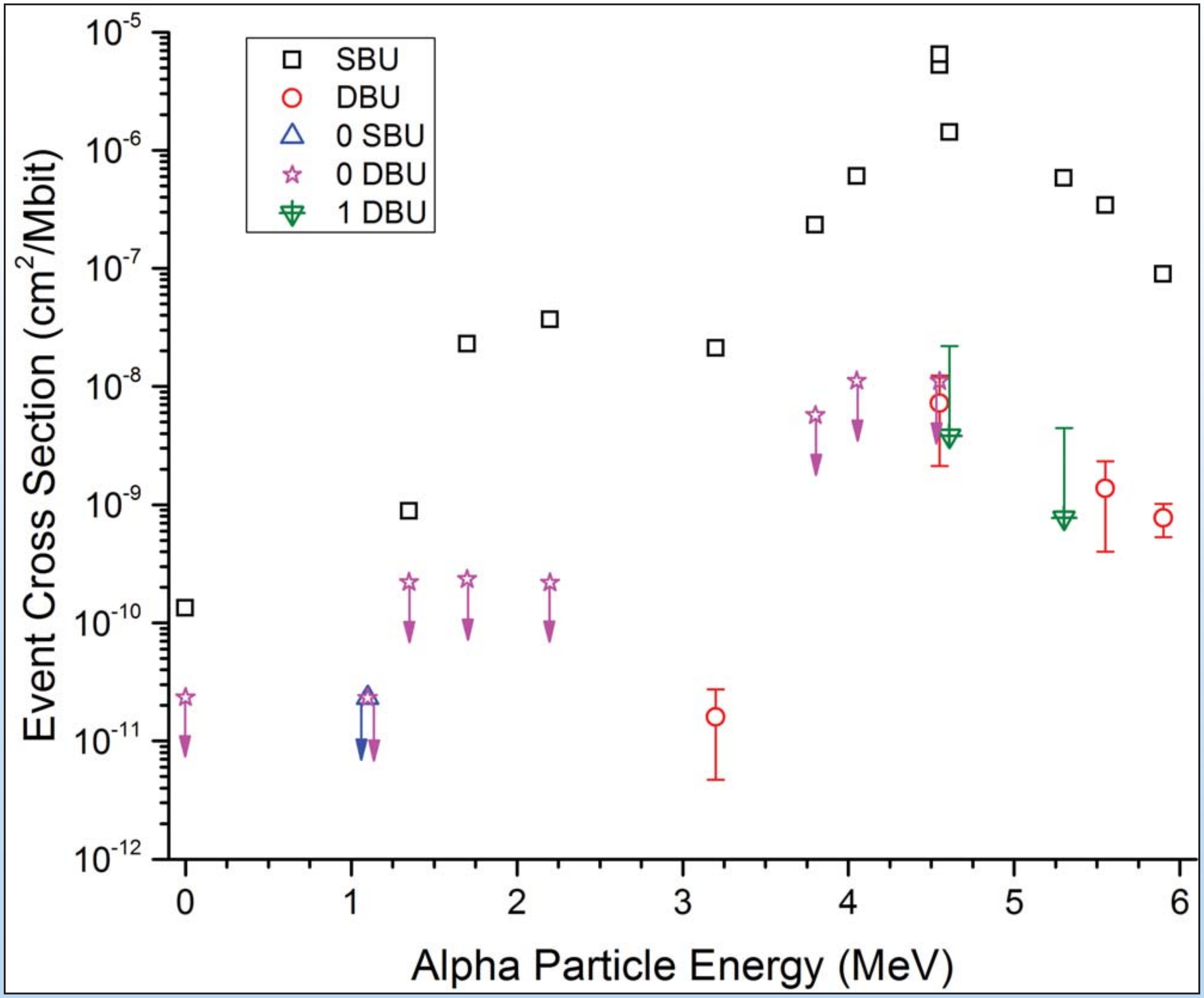


NIST ASTAR/PSTAR tool (ICRU Report 49, 1993).

- **<u>Hypothesis</u>: Alpha particles can replace LEPs for direct ionization single-event effects testing.**

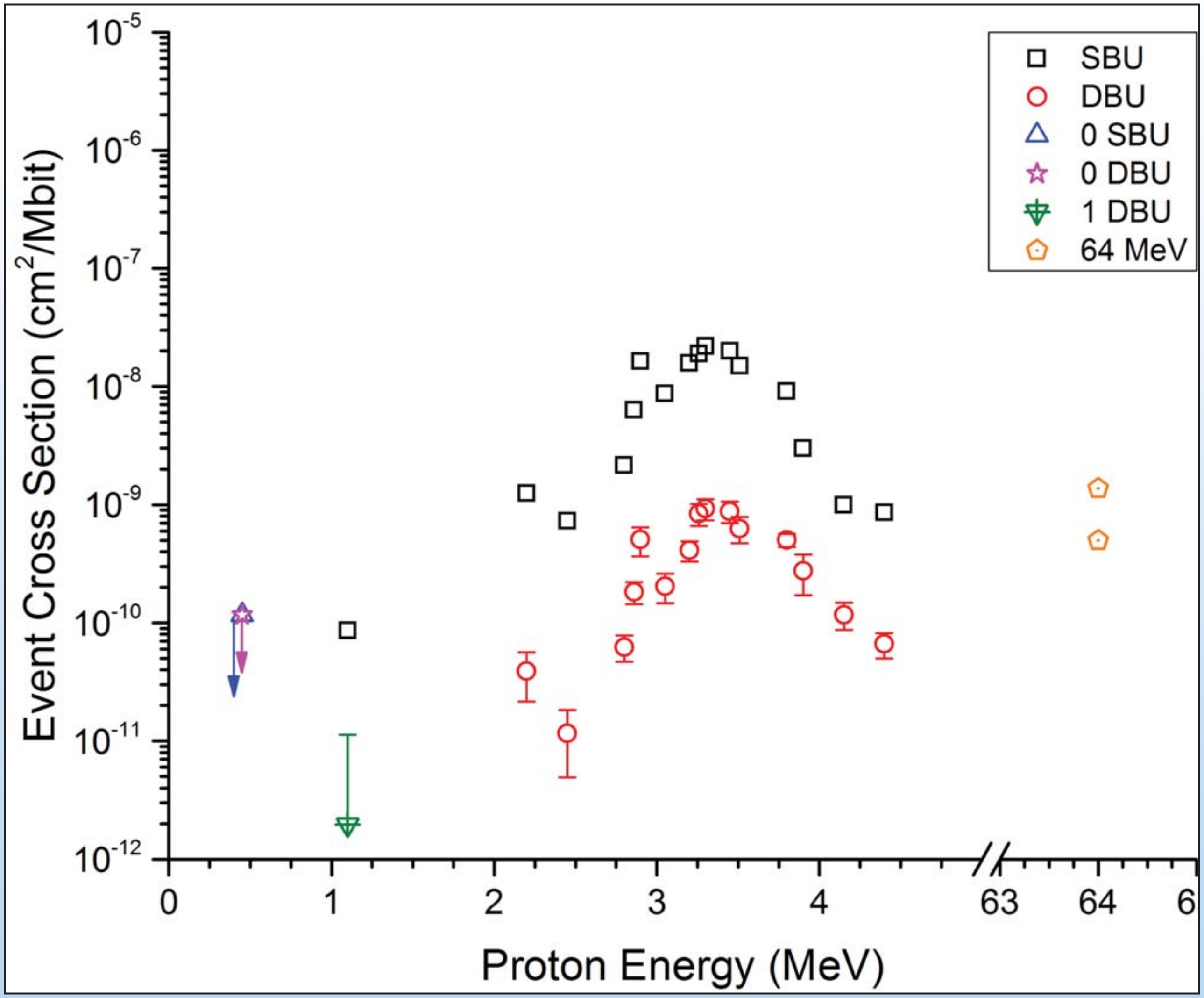
In the context of LEPs, mentioned as early as 2009 – B. D. Sierawski *et al.*, including J. Pellish.

30 MeV Alpha SEU Data
0x0000 Pattern



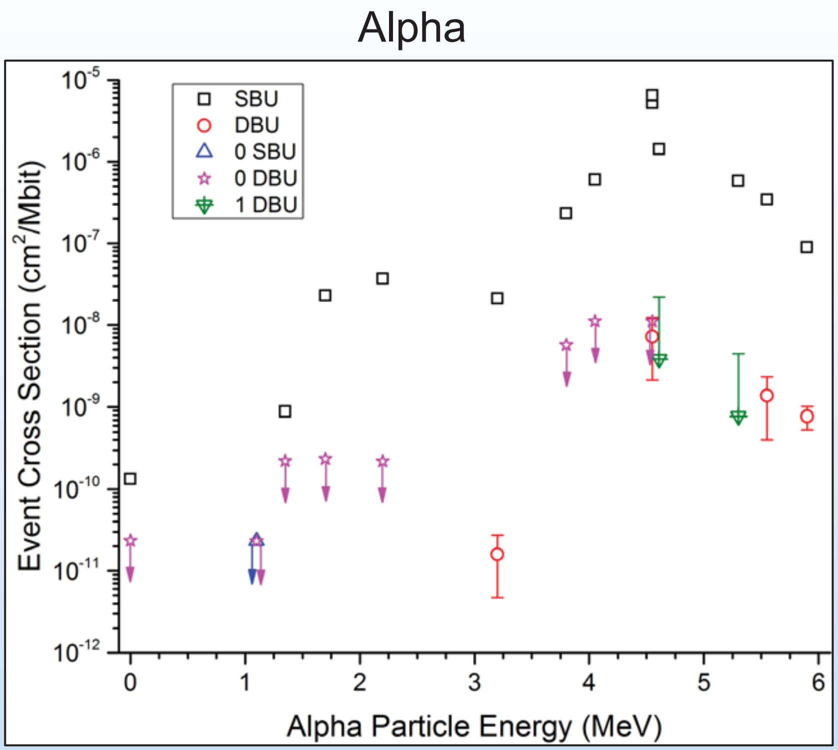
Error bars, if shown, are at the 90% confidence level.

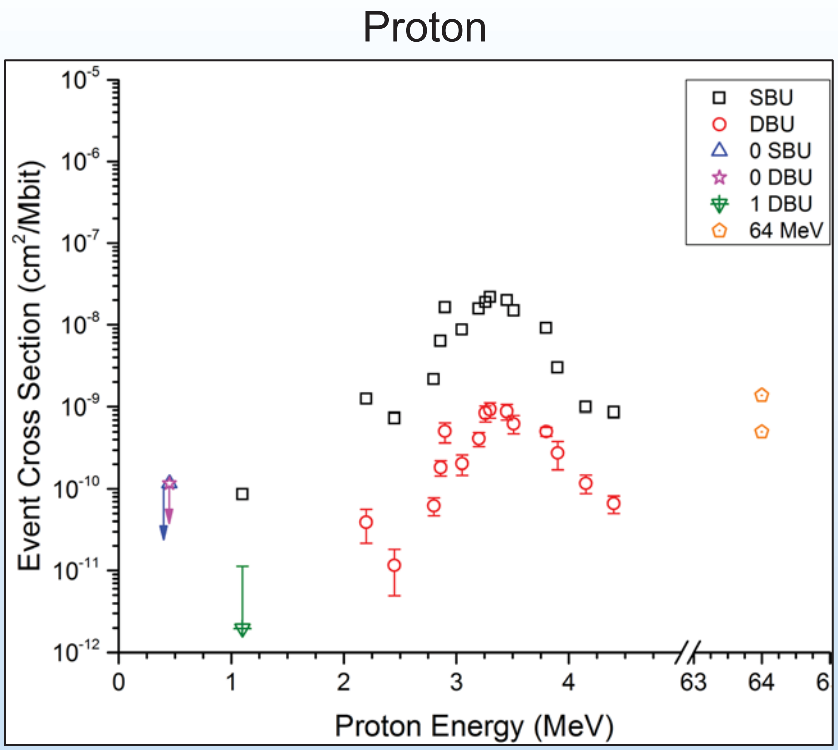
6.5 MeV Proton SEU Data 0x0000 Pattern



Error bars, if shown, are at the 90% confidence level.

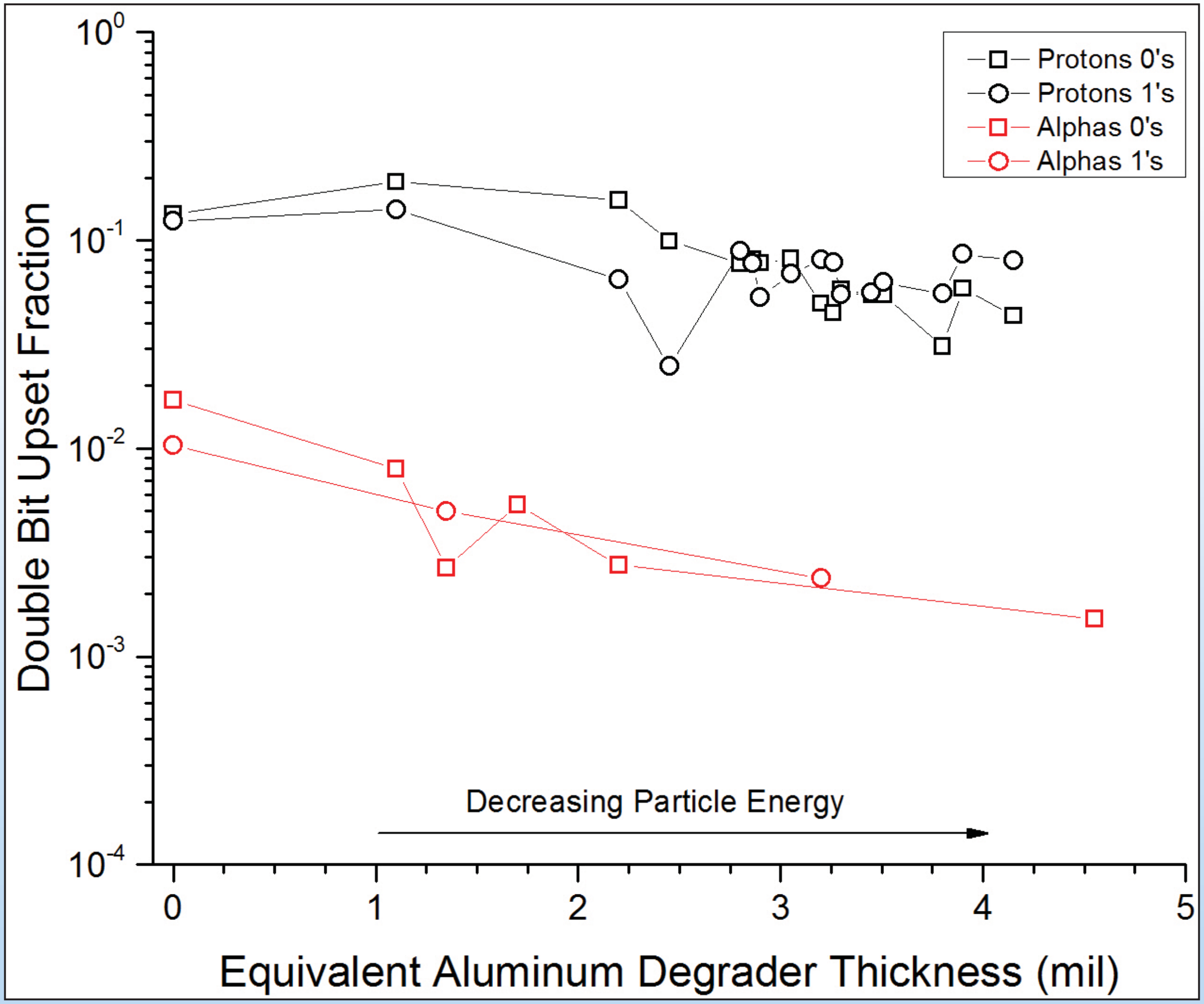
Data Comparison – Side-by-Side





- On the low-energy side of the Bragg peak, the cross sections are similar, but the type of events are not.
- One of the key features is the separation between SBUs and DBUs.

Alpha & Proton DBU Fraction



Shows both 0x0000 and 0xFFFF data patterns; includes multiplicity of DBU events.

Conclusions

- At this point, there appears to be no suitable proxy for the observed single-event effects produced by low-energy protons in highly-scaled technologies.
  - While alpha particle and proton SBU behavior appears to be proportional to LET, the MCU behavior is not.
    - Implications for radiation hardness assurance.
  - May be more room for compromise at CMOS technology nodes > 65 nm.
- Additional analysis techniques are covered in the manuscript and indicate several techniques to aid data reduction.
  - Many technologies are flip-chip (such as our SRAM DUT), and die thickness uncertainty has always been one of the larger sources of systematic error.

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- National Reconnaissance Office

Questions?

Acronyms

- CMOS: complementary metal oxide semiconductor
- CNL: Crocker Nuclear Laboratory
- CSDA: continuous slowing down approximation
- DBU: double-bit upset
- DUT: device under test
- IBM YKT: Yorktown Heights, NY
- ICRU: International Commission on Radiation Units & Measurements
- IEEE: Institute of Electrical and Electronics Engineers
- IUCF: Indiana University Cyclotron Facility
- LBNL: Lawrence Berkeley National Laboratory
- LEP: low-energy proton
- MCU: multi-cell upset (errors not necessarily in the same data word)
  - Different from multi-bit upset (MBU)
- NIST: National Institute of Standards and Technology
  - ASTAR and PSTAR are NIST tools, not acronyms
- NPTC: Northeast Proton Therapy Center
- SBU: single-bit upset
- SEEM: secondary electron emission monitor
- SEU: single-event upset
- SOI: silicon on insulator
- SRAM: static random access memory
- SRIM: Stopping and Range of Ions in Matter (software program)
- TNS: Transactions on Nuclear Science
- TRIUMF: not an acronym – formerly the Tri-University Meson Facility, Vancouver, Canada
- UC Davis: University of California at Davis