Low-Energy Proton Single Event Upsets in SRAMs

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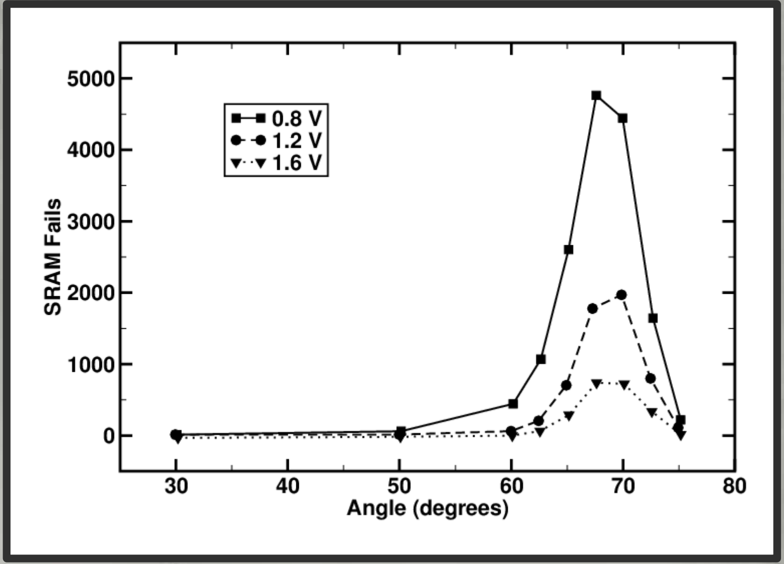
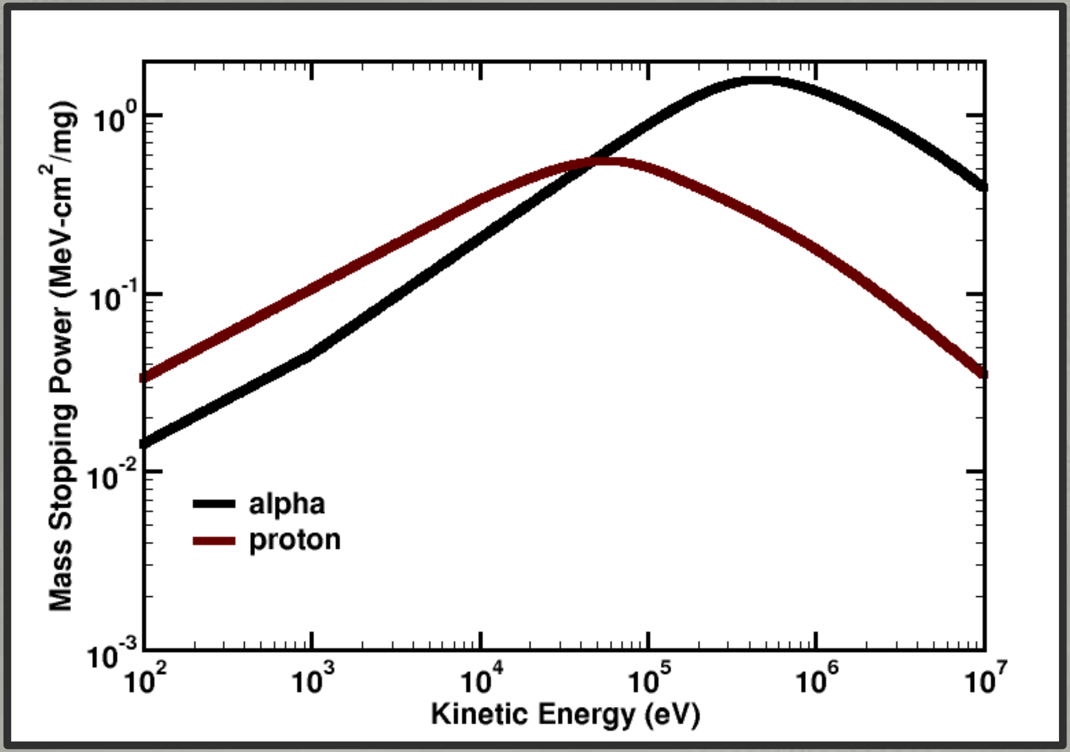
Proton-Induced SEU

- **Historically, alpha particles (Q=2e) and heavy ions (Q>2e) cause errors in microelectronics primarily through *electronic stopping*, energetic protons through *nuclear stopping***
- **Experimental data indicate protons are capable of causing errors due to ionization**
- **Stopping protons are predicted to be significant contributors to error rates in sub 65 nm processes**



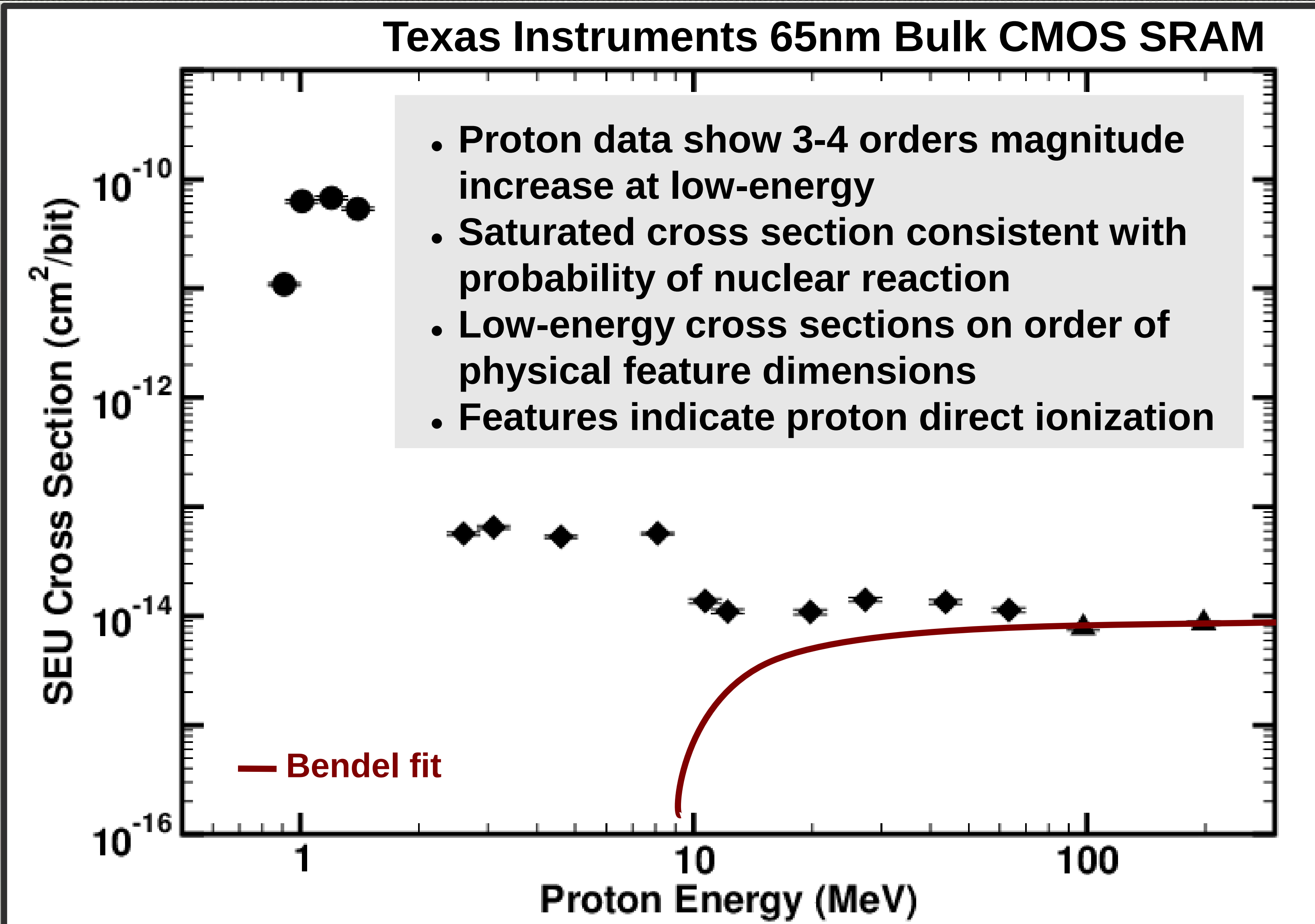
Rodbell, TNS. 2007

Electronic Stopping

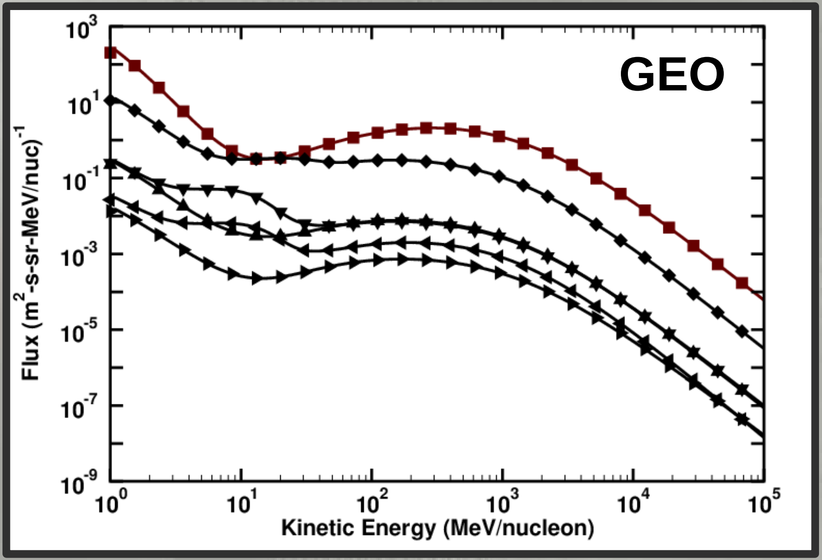


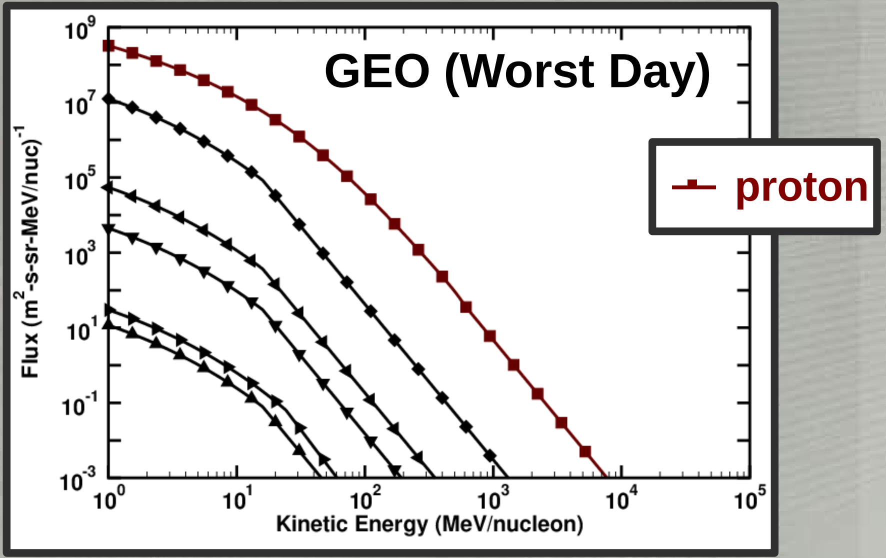
- Stopping power strongly dependent on particle charge and velocity
- Bragg peak identical for singly-charged particles ~0.5 MeV-cm^2/mg
- Threshold LETs decreasing in modern circuits
  - Further decreases will include greater range of particles and energy

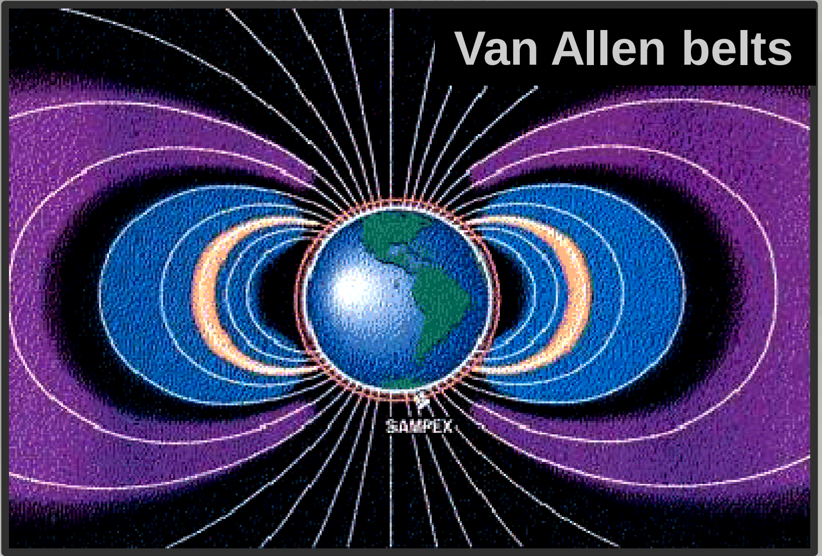
Proton SEU Cross Sections

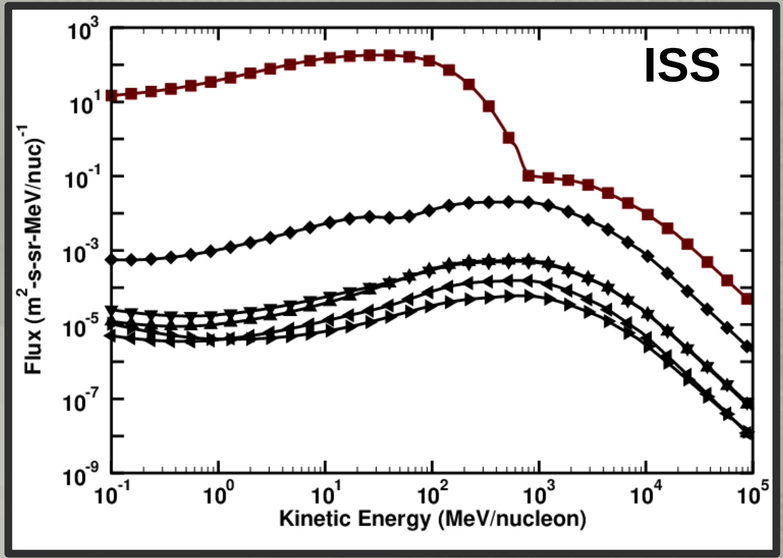


Space Environments

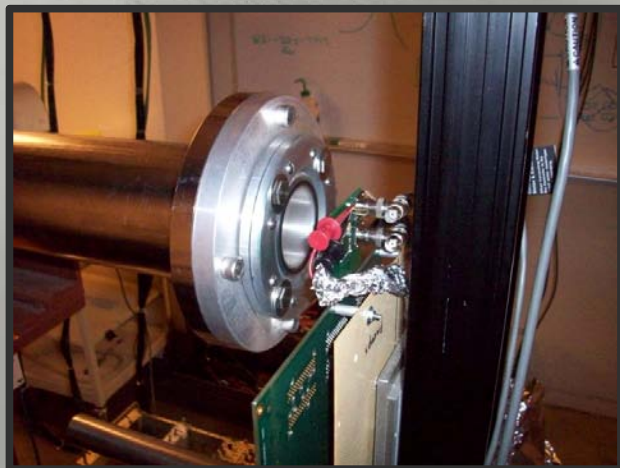


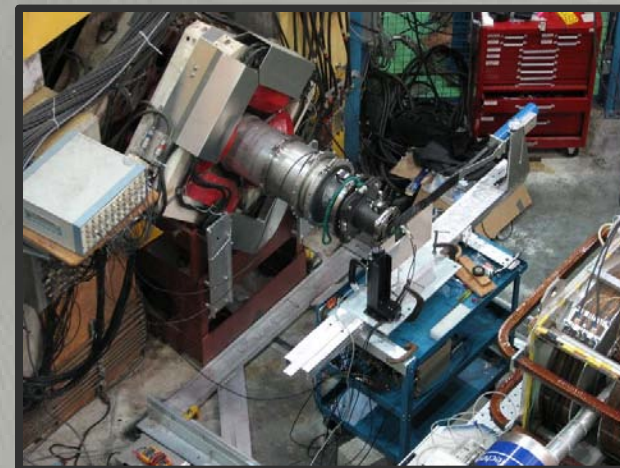






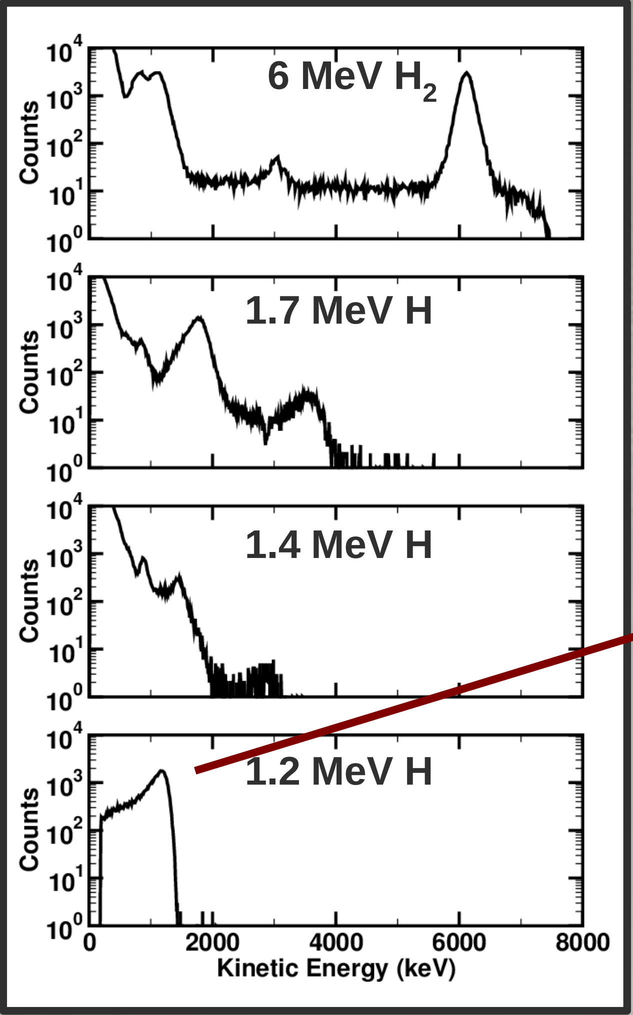
Devices Under Test

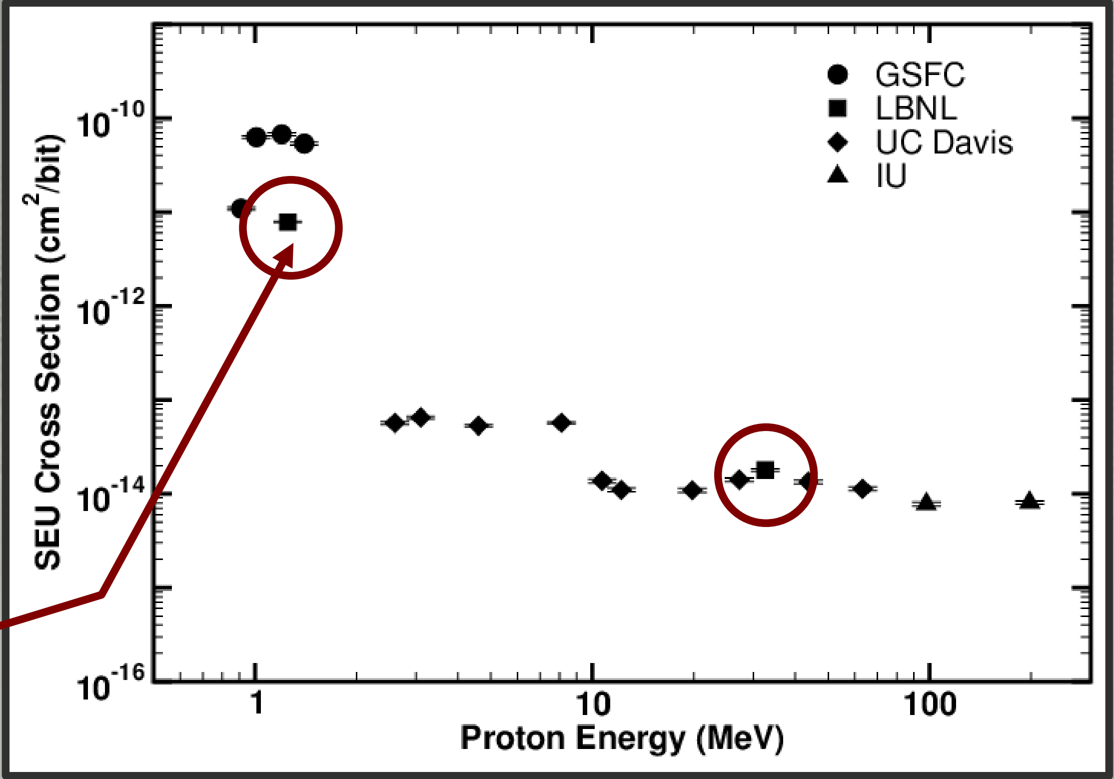




- **Bulk CMOS 6-transistor SRAMs**
  - **Texas Instruments 65 and 45 nm**
  - **Marvell Semiconductor 55 and 40 nn**
- **Tests conducted at Berkeley, Texas A&M, and TRIUMF**
- **Experiments performed in air, close to beam window**

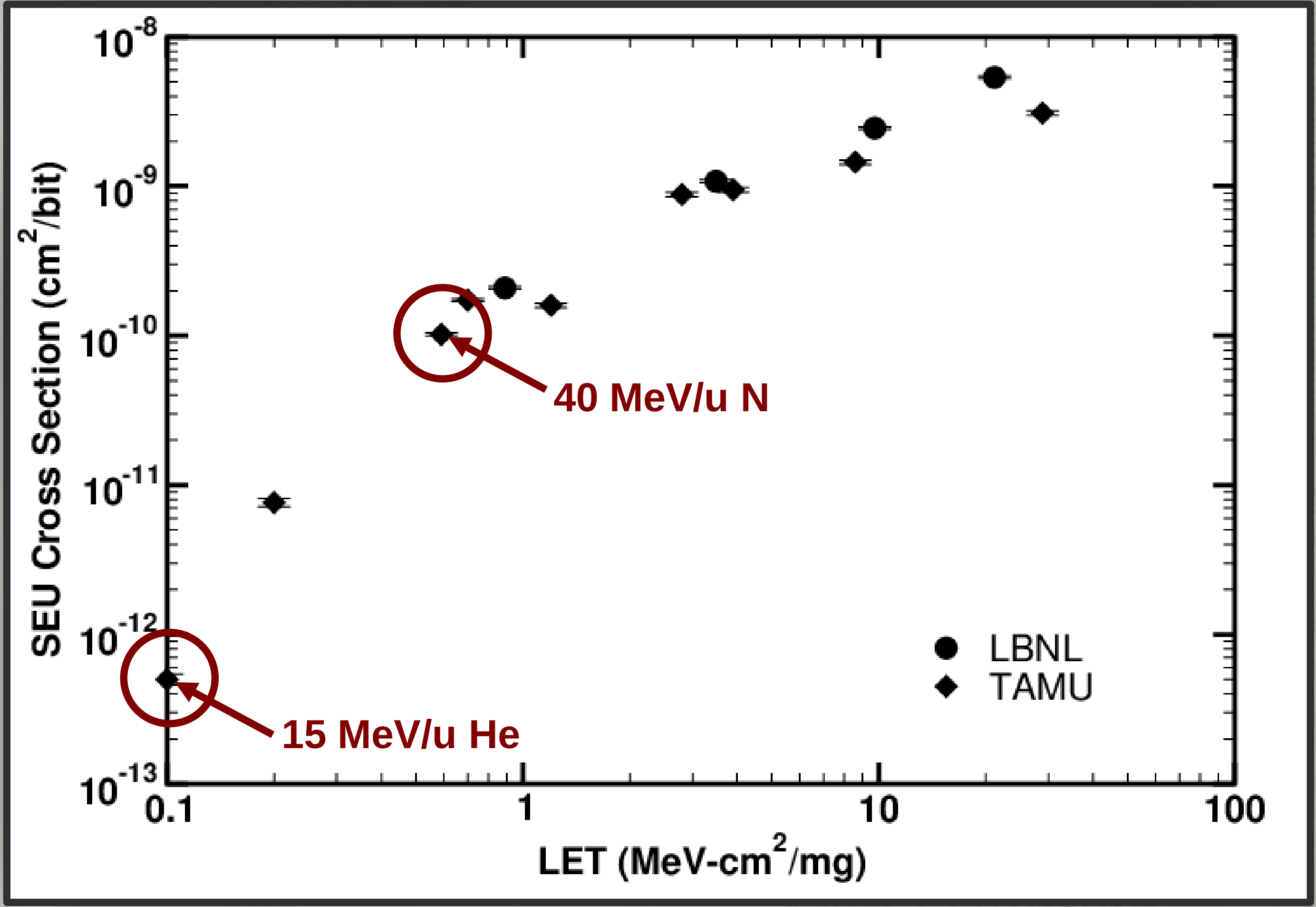
LBNL Proton Testing





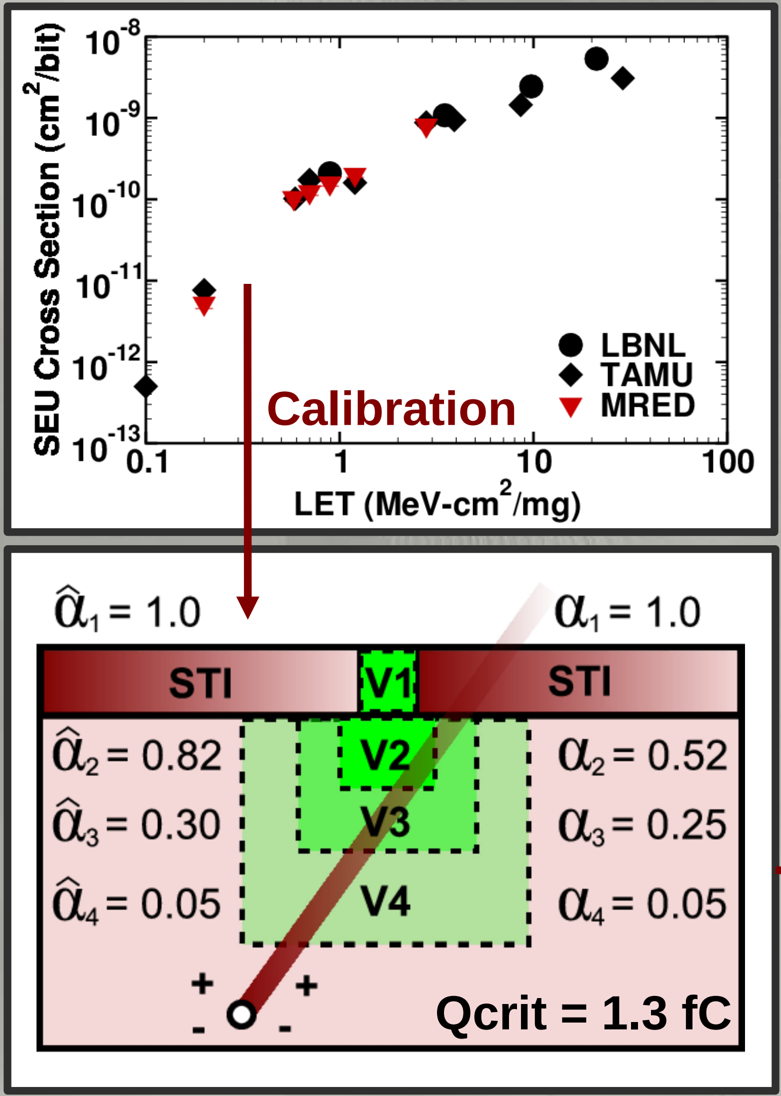
- GSFC Van de Graaff tests indicate elevated SEU cross section
- LBNL used to confirm direct ionization effect
- Low-energy test used custom 6 MeV H_2 beam
- Results rule out dosimetry issues
- Width of beam energy will affect rate predictions

Heavy Ion Test Results

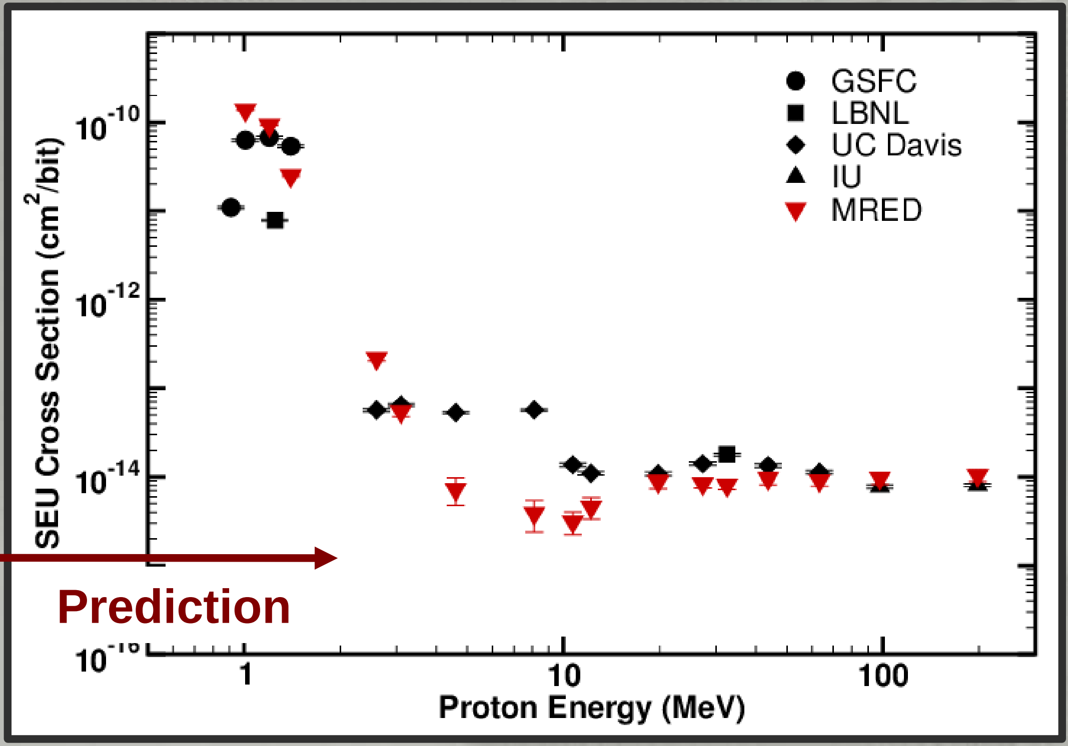


- **Heavy ion data demonstrate sensitivity to small quantities of charge**
- **Low-LET data require high-energy tests at TAMU**
- **Low-energy protons comparable with 0.5 MeV-cm^2/mg heavy ions**

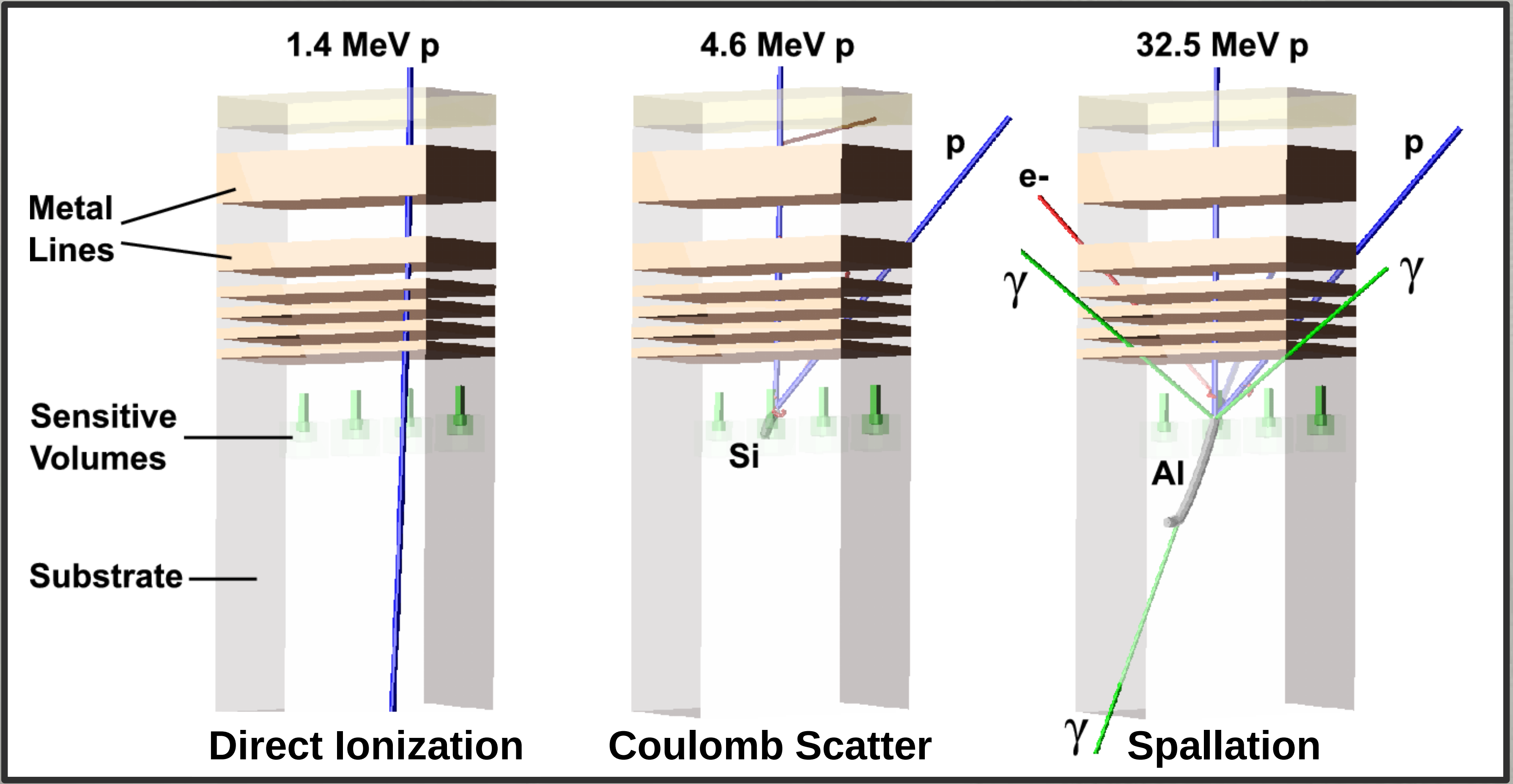
Single Event Upset Model



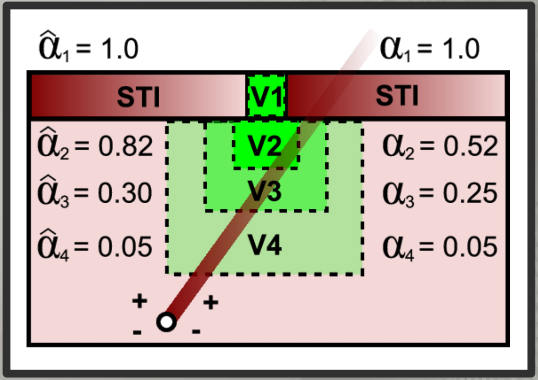
- Single bit cross sections correspond to physical device areas
- Low-LET heavy ion cross sections used to define sensitive area
  - Single, well-known stopping power
- MRED code predicts low-energy proton response

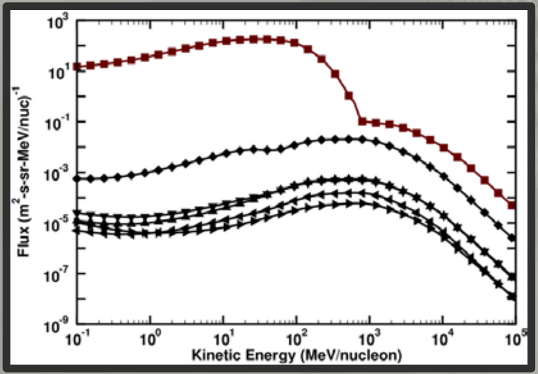


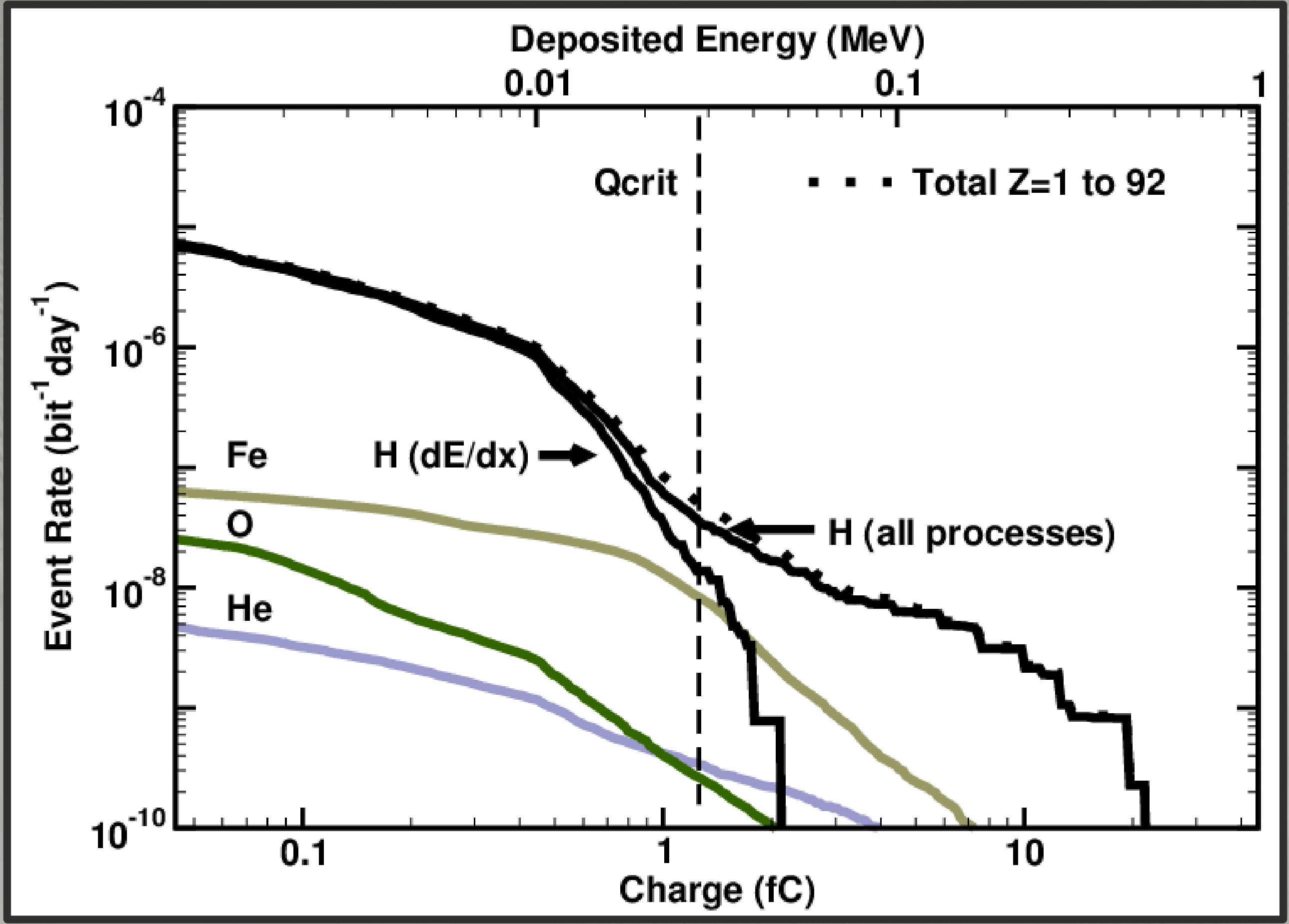
Proton Mechanisms



Contribution of Protons in ISS

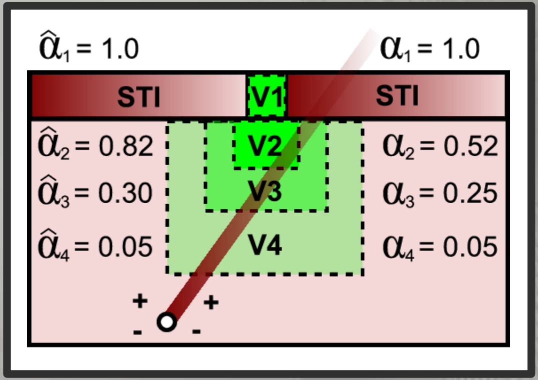


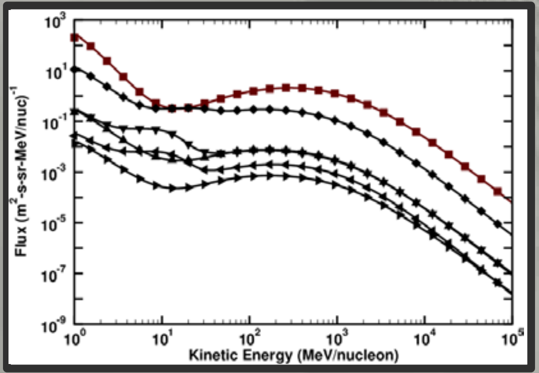


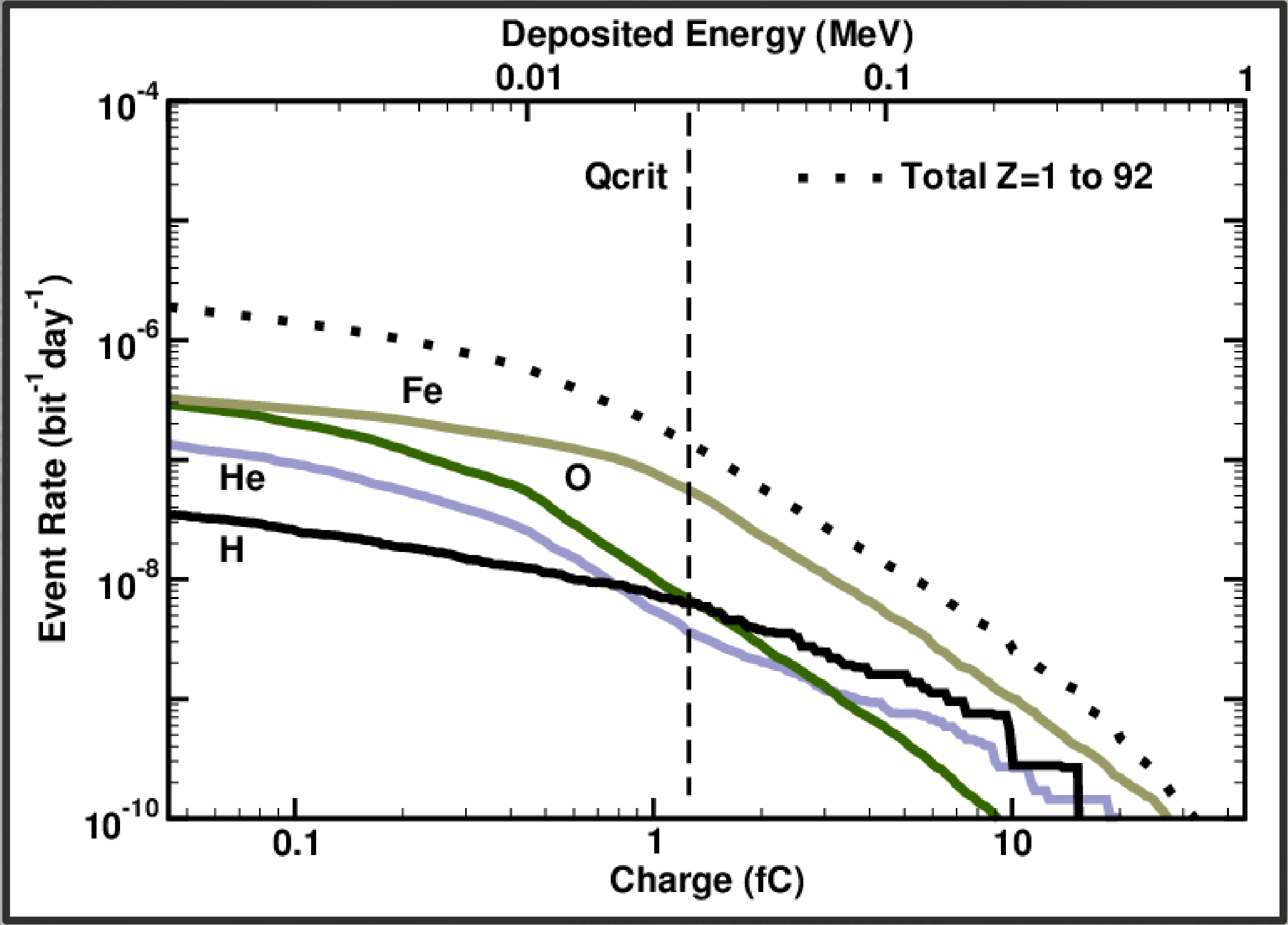


- Applying ISS environment to sensitive volume model reveals error rate as function of species and critical charge
- Direct ionization is becoming the dominant upset mechanism for protons

Contribution of Protons in GEO

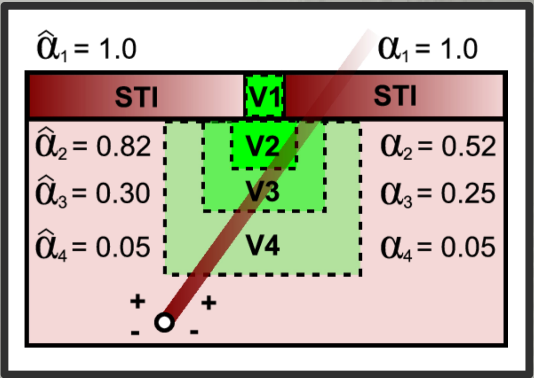


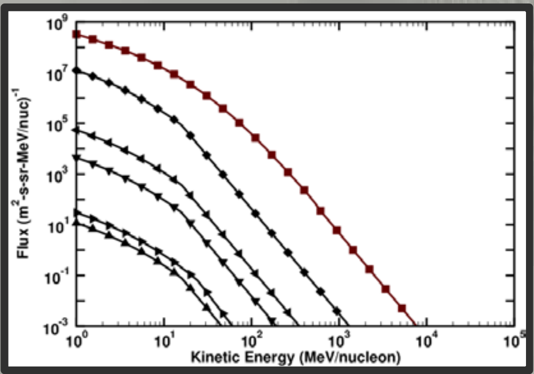


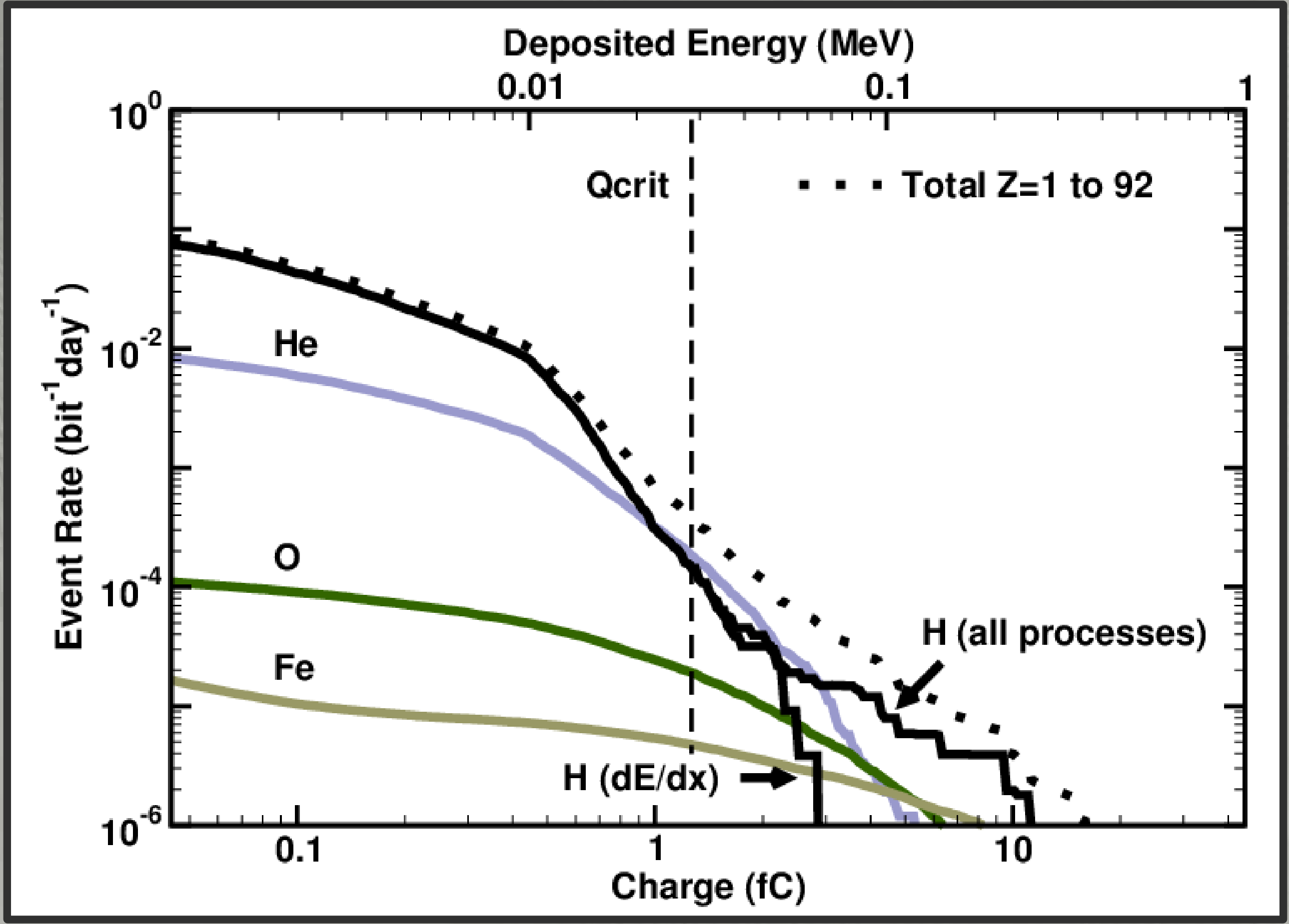


- Applying GEO environment shows iron and other common ions drive the error rate
- Proton flux too low to be an issue (in quiescent conditions)

Contribution of Worst Day Protons



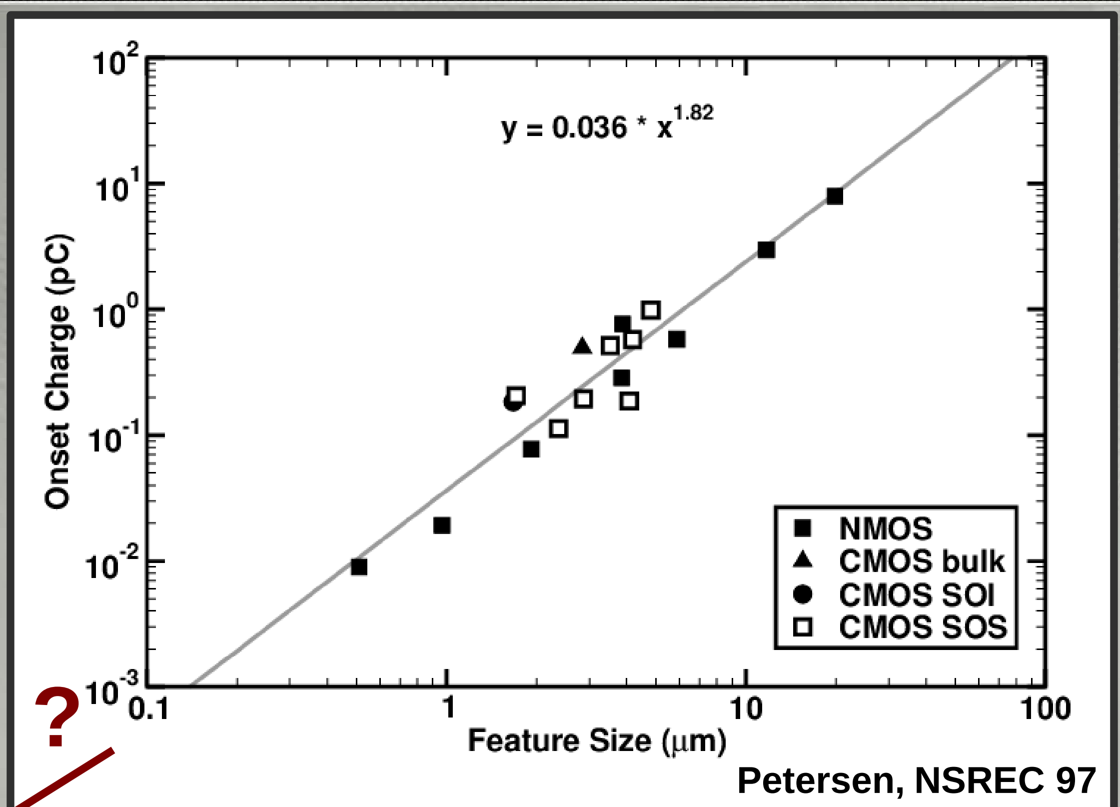




- Worst Day shows large contributions to error rate from both protons and alpha particles
- Need to assess impact on reliability

Scaling Trends

- Device sensitivity steadily decreasing
- Predictions of charge threshold based on ITRS and SPICE
- IBM published 65 nm SOI SRAM critical charge 0.21 – 0.27 fC



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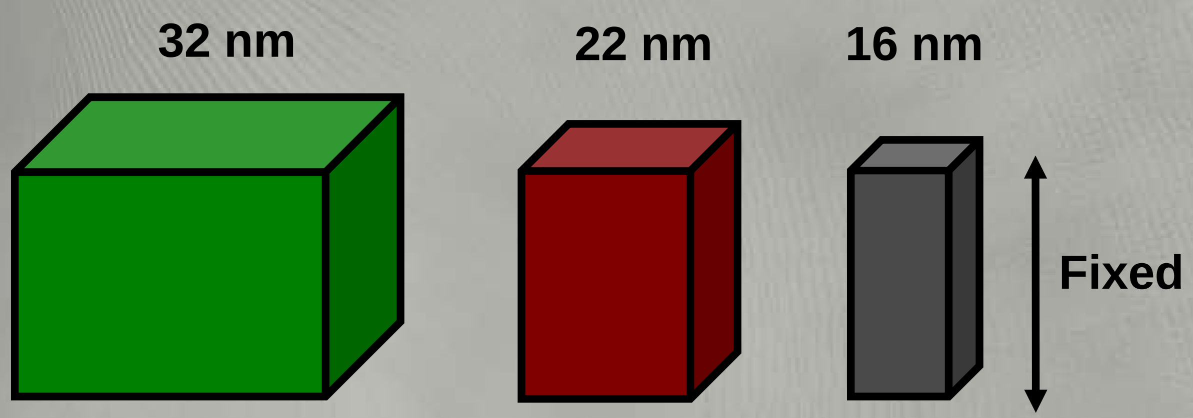
Technology (nm)	65	45	32	22	16
Vdd (V)	1.2	1.1	0.97	0.90	0.84
Capacitance (fC)	0.32	0.21	0.13	0.088	0.056
Spice Threshold (fC)	1.3	0.71	0.44	0.36	0.19

Predictive SEU Models

- **Protons already relevant at 65 nm**
- **What are the effects of scaling, process technologies?**



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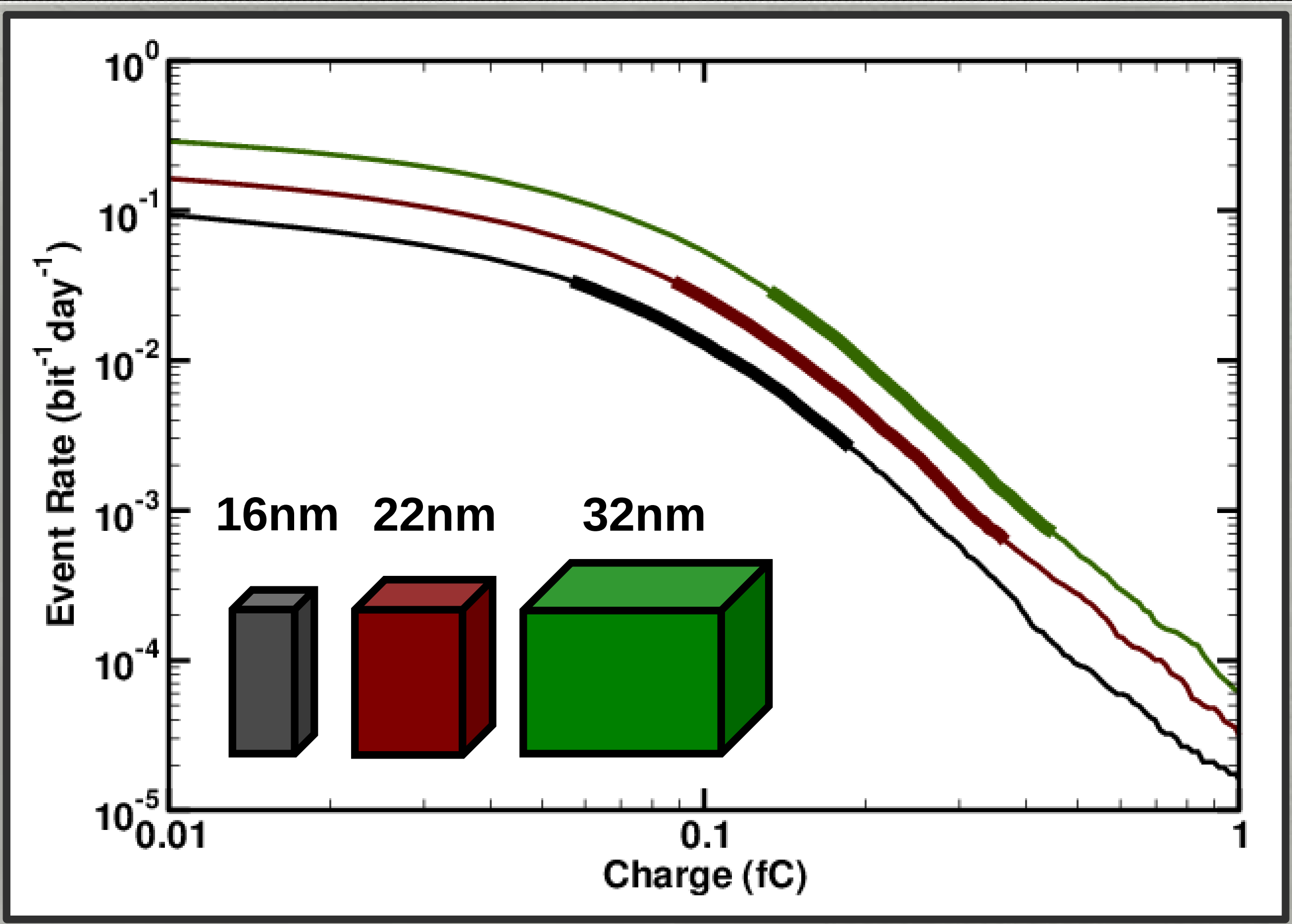
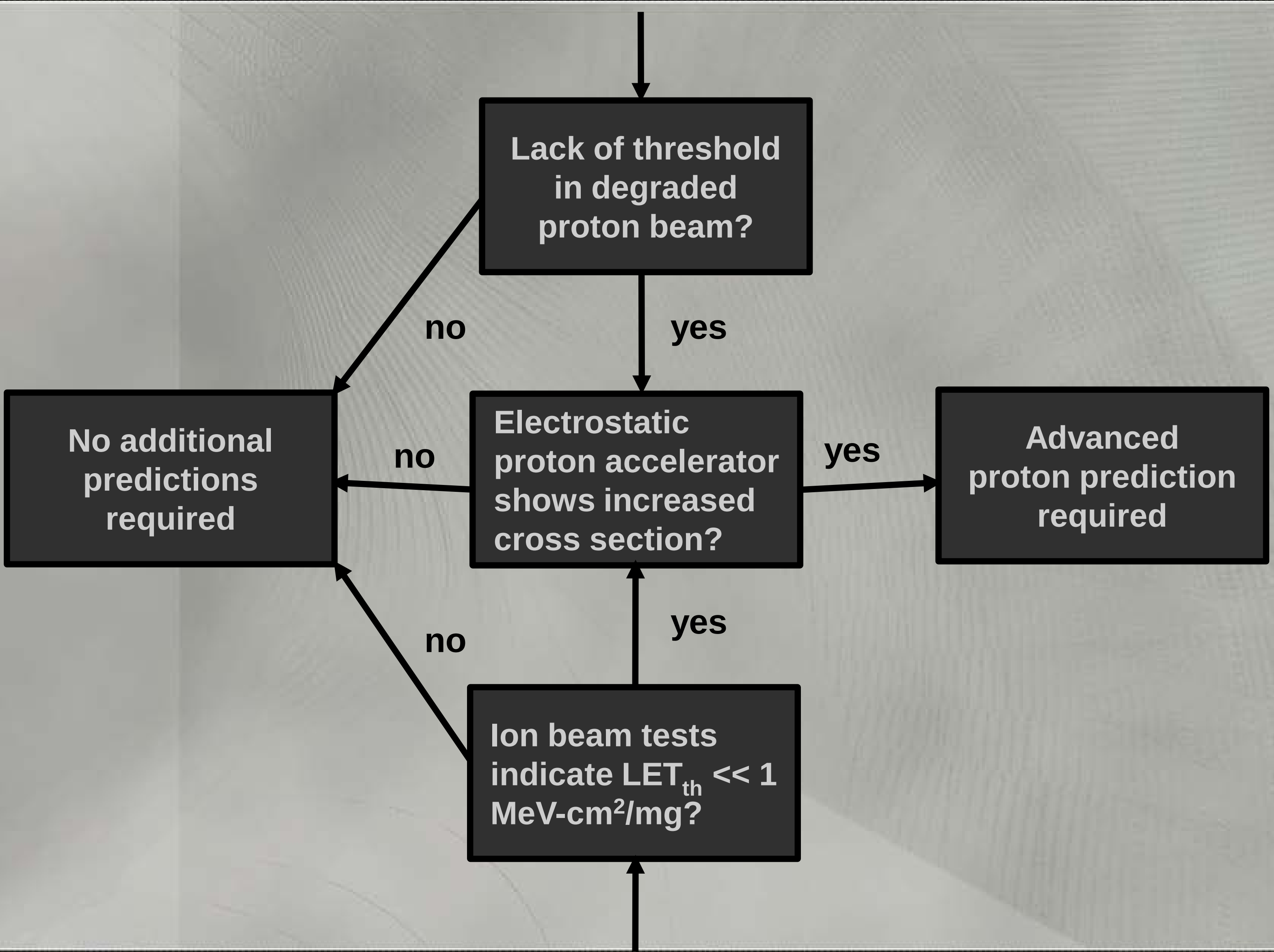
GEO Worst Day Protons



- Critical charge bounds define valid range in error rates
- Proton ionization contribution substantial, but relatively constant with scaling

Recommendations

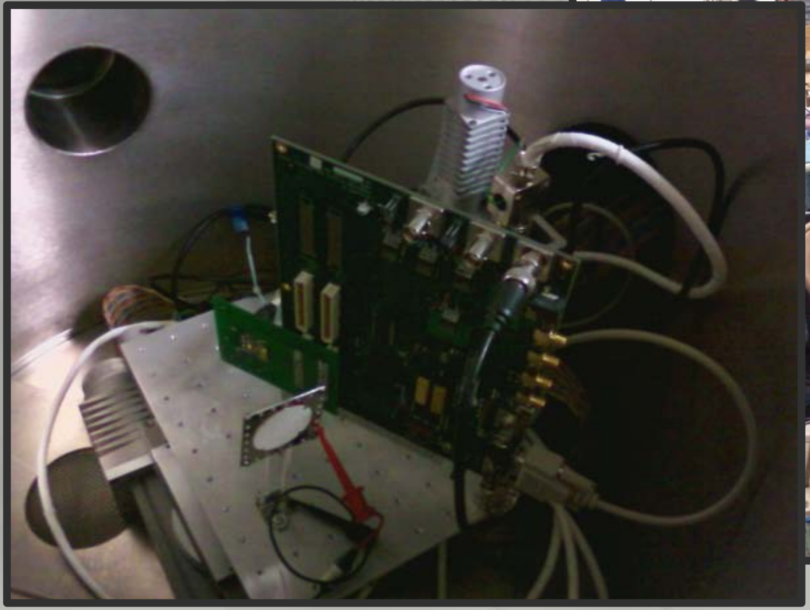


Proton SEU Characterization

- **Continuing relationship with Texas Instruments and NASA NEPP will investigate proton sensitivity of 28 and 20 nm bulk CMOS SRAMs**
- **Additional data for the evaluation of proton test methods, facilities, and SEU models will be collected**
- **Investigations will examine changes in SEU thresholds, trend with CMOS process technology – will low-energy tests be required for all future SRAMs?**

Vanderbilt Pelletron

- **Completion of beamline allows for low-energy single event tests on microelectronics in-vacuum**
  - **4 MeV protons**
  - **6 MeV alphas**
  - **10 MeV oxygen**



CubeSat Program

Our goal is to develop, fabricate, simulate, and operate a low cost on-orbit system to improve our understanding of the impact of space radiation environments on satellite components and systems.

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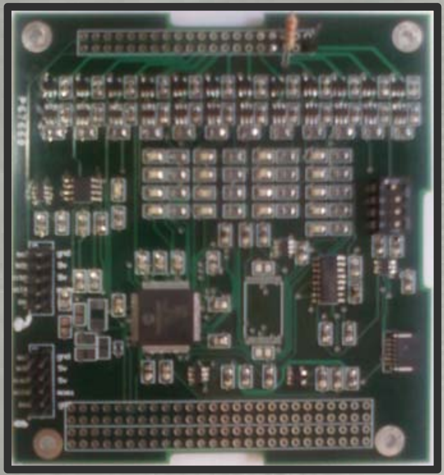

Payloads	**Independence**	**Woodland**
	2U CubeSat	1U CubeSat
	Partner: SLU (Argus – high)	Partner: AMSAT
	ElaNa launch summer 2013	ElaNa launch summer 2013

Low-Energy Proton (LEP) Experiment

- **Count on-orbit single event upsets in a COTS memory**
- **Complement on-orbit data with ground-based accelerated tests**
- **Evaluate proton test and error rate prediction methods**

Summary

- **Modern static random access memories have demonstrated elevated low-energy proton SEU cross sections sufficient to affect on-orbit error rates**
- **Established test methods and rate prediction tools do not properly account for this mechanism**
- **Test campaigns should accommodate for low-energy proton characterization of parts with no clear proton threshold or low-LET (< 1 MeV-cm^2/mg) threshold**
- **Radiation transport simulations provide best indication of on-orbit performance**