VANDERBILT School of Engineering

Generalized SiGe HBT Event Rate Predictions Using MRED

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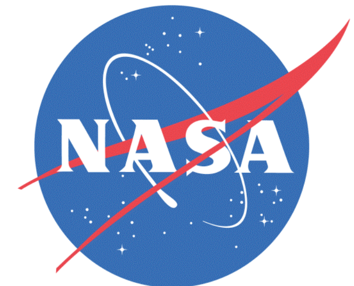

Preview

- Background
  - Review radiation response in behavior in SiGe HBTs

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  - Use physical device structures from broadbeam tests
  - Develop generalized radiation response model
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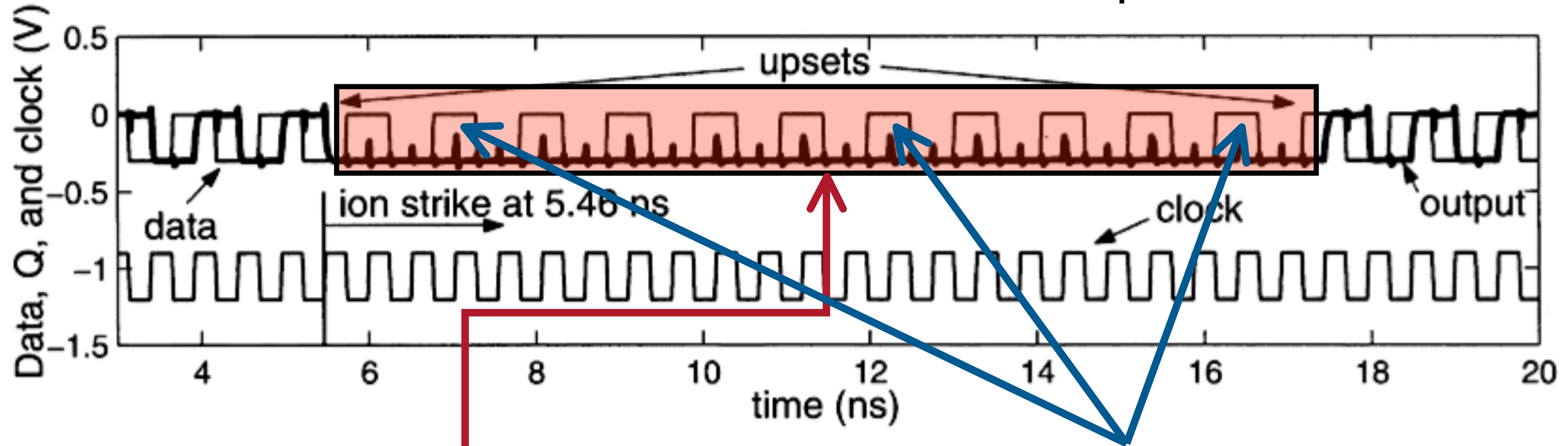
- Results
  - Calibrated to event cross section data (≥ 1 Gbit/s)
  - Calculated event rates for GEO and LEO orbits

Errors in High-Speed Digital Devices

R. Krithivasan, *et al.*, *IEEE Trans. Nucl. Sci.*, vol. 50, p. 2126, Dec. 2003.



Error Intervals (Events)

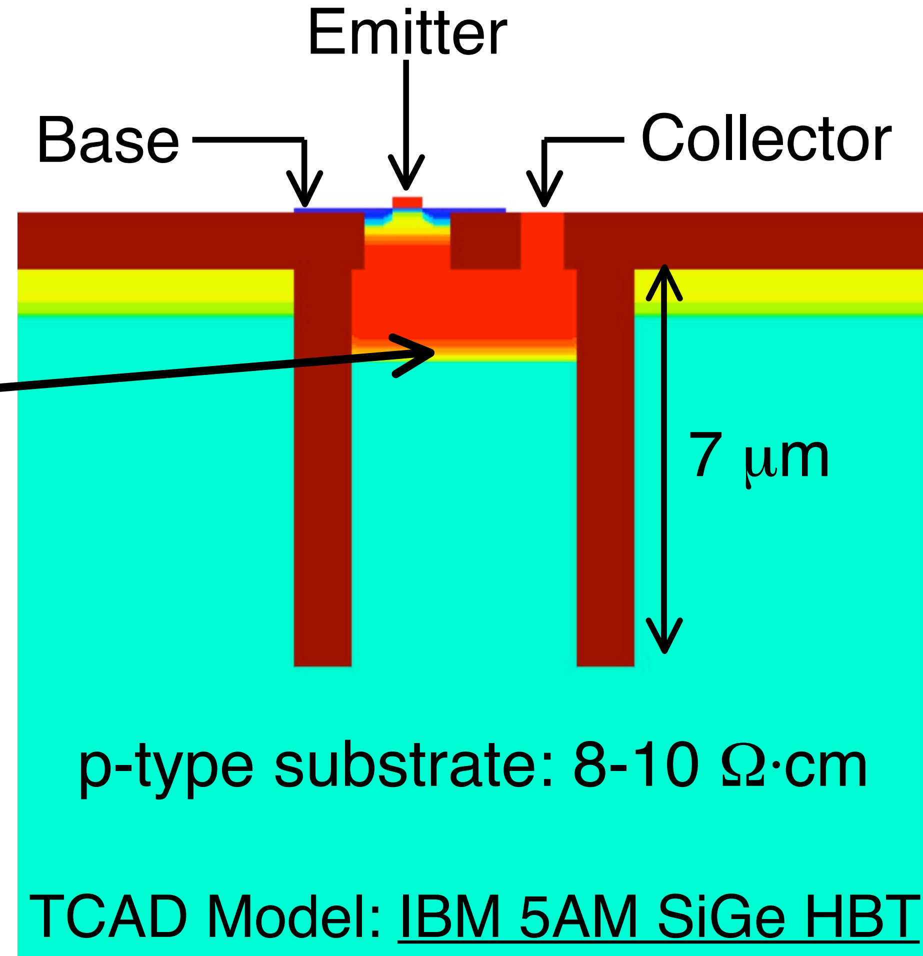
Bit Errors

$$\sigma_{\mathrm{SEU}} = \frac{\#\ \text{Error Intervals}}{\Phi}$$

Error intervals used for SEU cross section calculation

Device and Data Highlights

- Typical bulk SiGe HBT
- SEE-critical features
  - Deep trench isolation
  - Subcollector junction
  - Substrate doping
- Observed non-IRPP response *at low LET*
  - Decreasing σ_{SEU} with increasing LET_{EFF}



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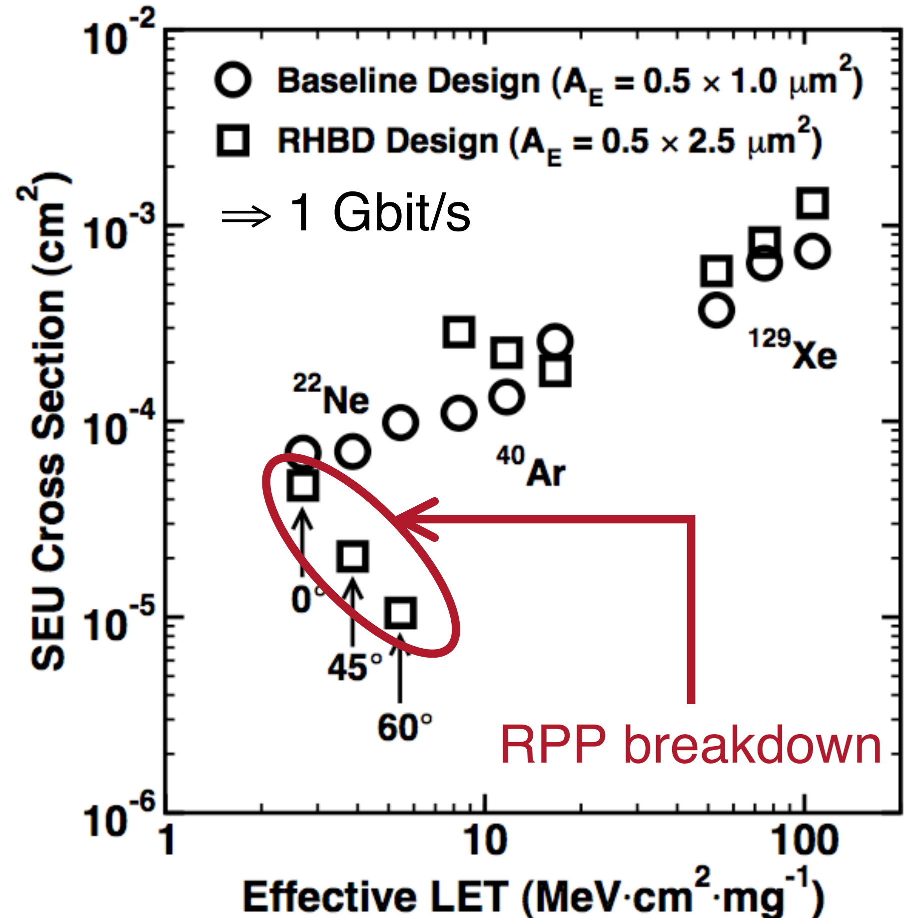
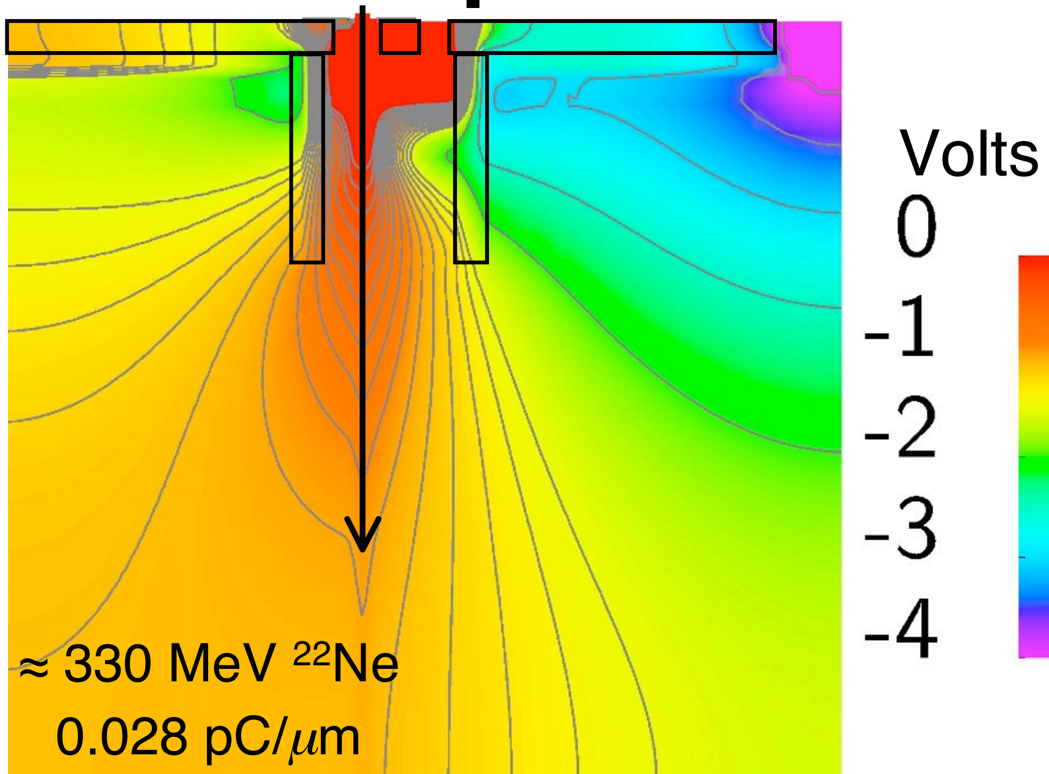


Data after P. W. Marshall, *et al.*, *IEEE Trans. Nucl. Sci.*, vol. 52, p. 2446, Dec. 2005.

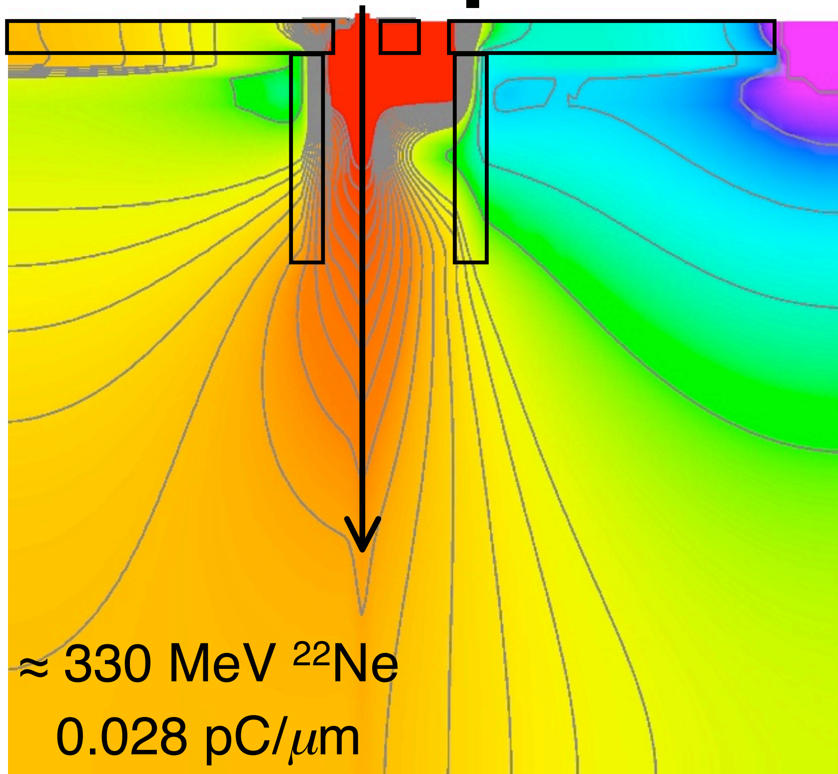
Geometry affects the SEU response of these devices

Ion-Deep-Trench Interaction



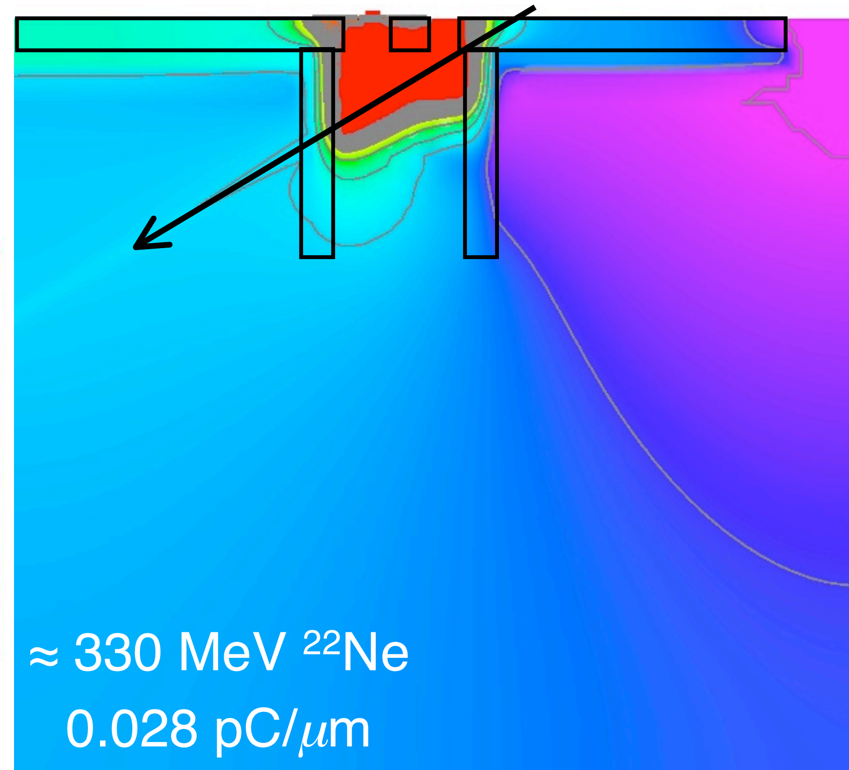
0° strike through emitter

Ion-Deep-Trench Interaction



0° strike through emitter

Volts
0
-1
-2
-3
-4

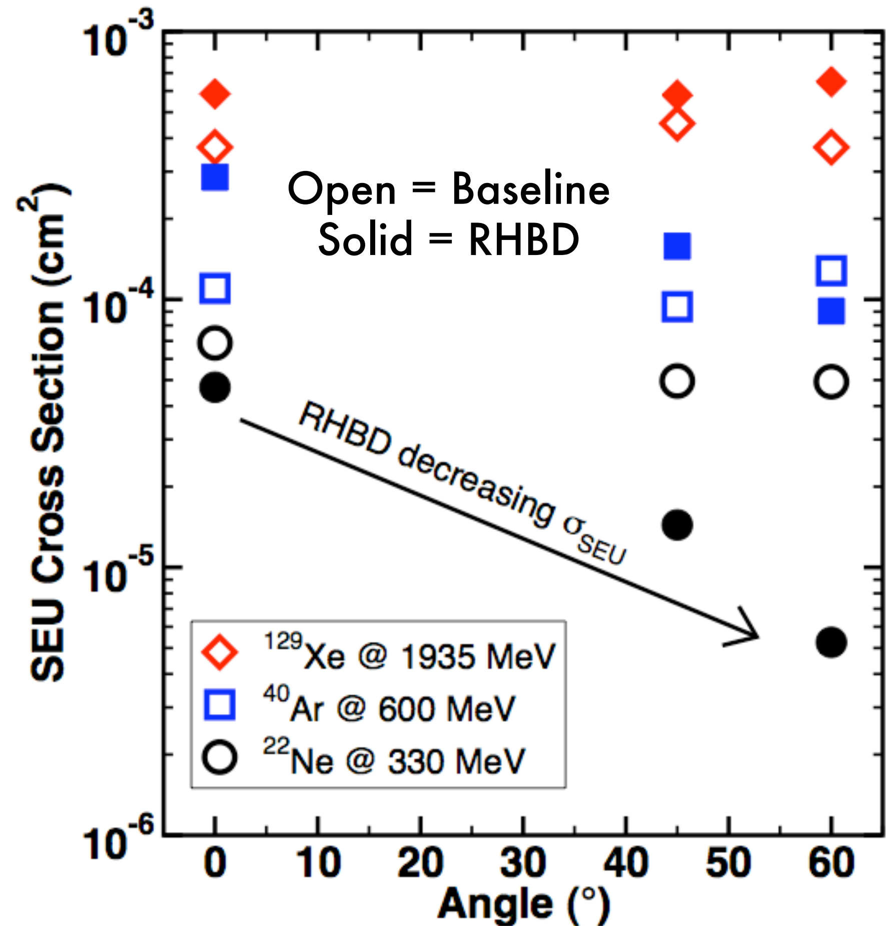


60° strike right-to-left

At grazing angles deep trench mitigates SEU response at larger values of Q_{crit} – important for RHBD devices

SiGe HBT SEU Data – Redefined

- Shift register data
  - Baseline design
    - $A_E = 0.5 \times 1.0\ \mu m^2$
  - RHBD design
    - $A_E = 0.5 \times 2.5\ \mu m^2$
- Removed RPP corrections – $\cos(\theta)$
- Normal-incident LETs of 2.8, 8.3, and 53 MeV·cm²/mg



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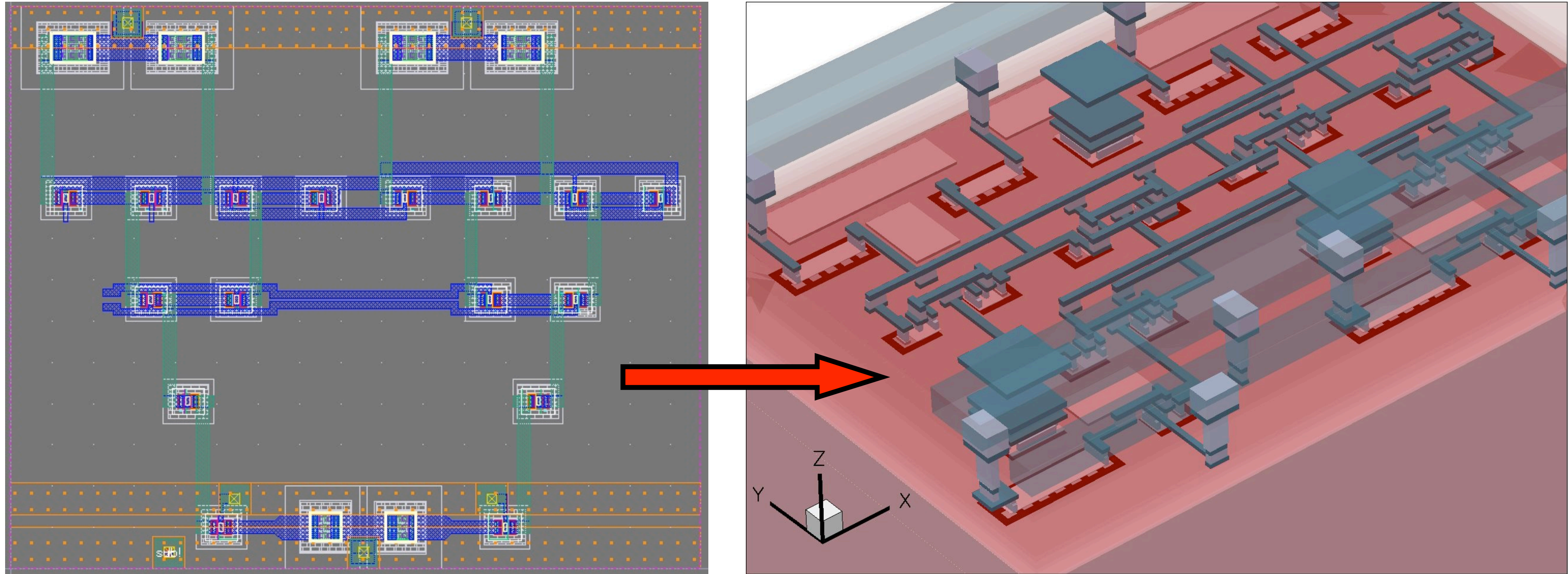
Decreasing trend at low LET not accounted for by IRPP model

Transition from GDSII to 3-D



- Use Synopsys TCAD tool suite to convert layout
- Directly imported into MRED for event generation

All subsequent simulations use real GDSII layout information

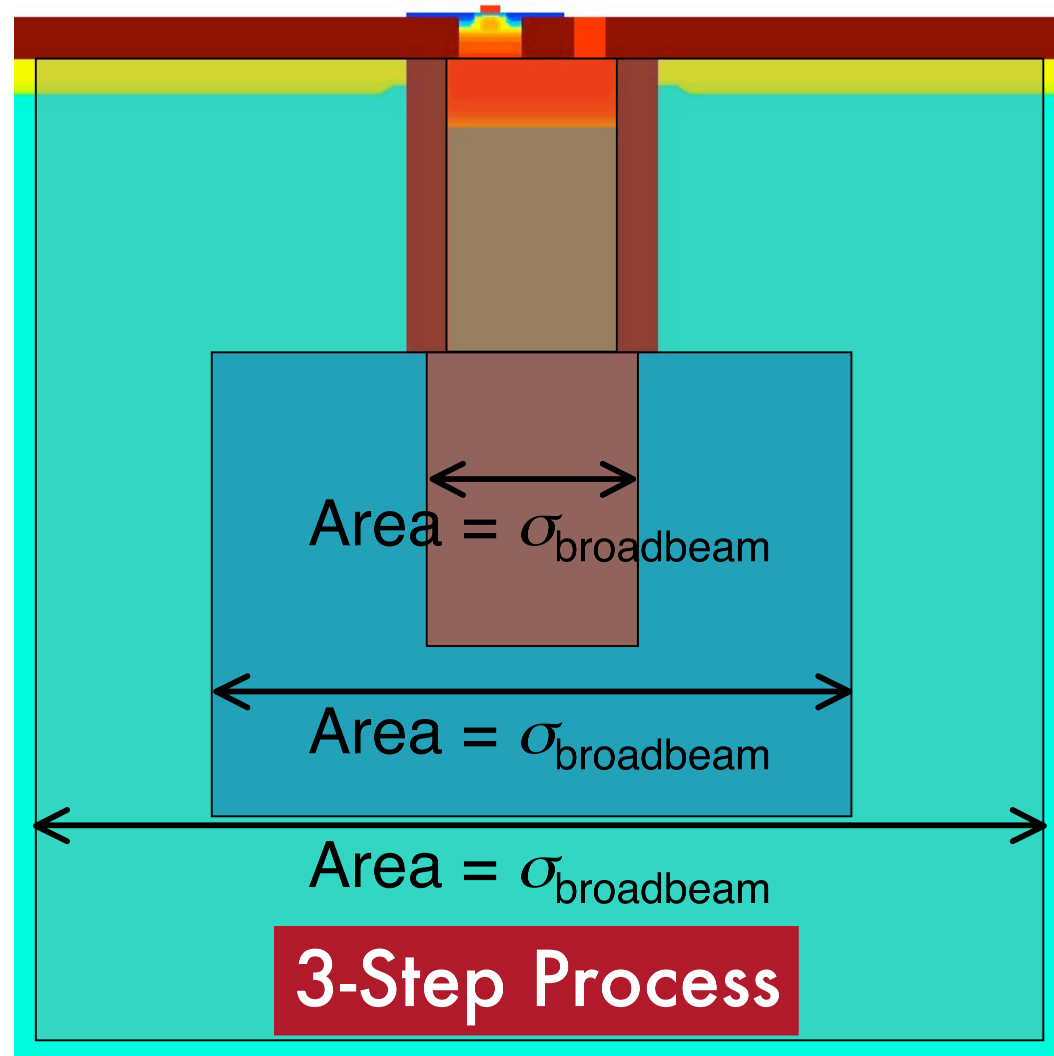
Generalized SiGe HBT Model

- Model provides good approximation to initial conditions, time-evolution
- Total charge collected is weighted sum

$$Q_{\text{coll}} = \sum_i \alpha_i Q_{D_L}$$

- K. M. Warren, *et al.*, *IEEE Electron Device Lett.*, vol. 28, p. 180, Feb. 2007.

Same volume structure works for all SiGe HBT technologies simulated



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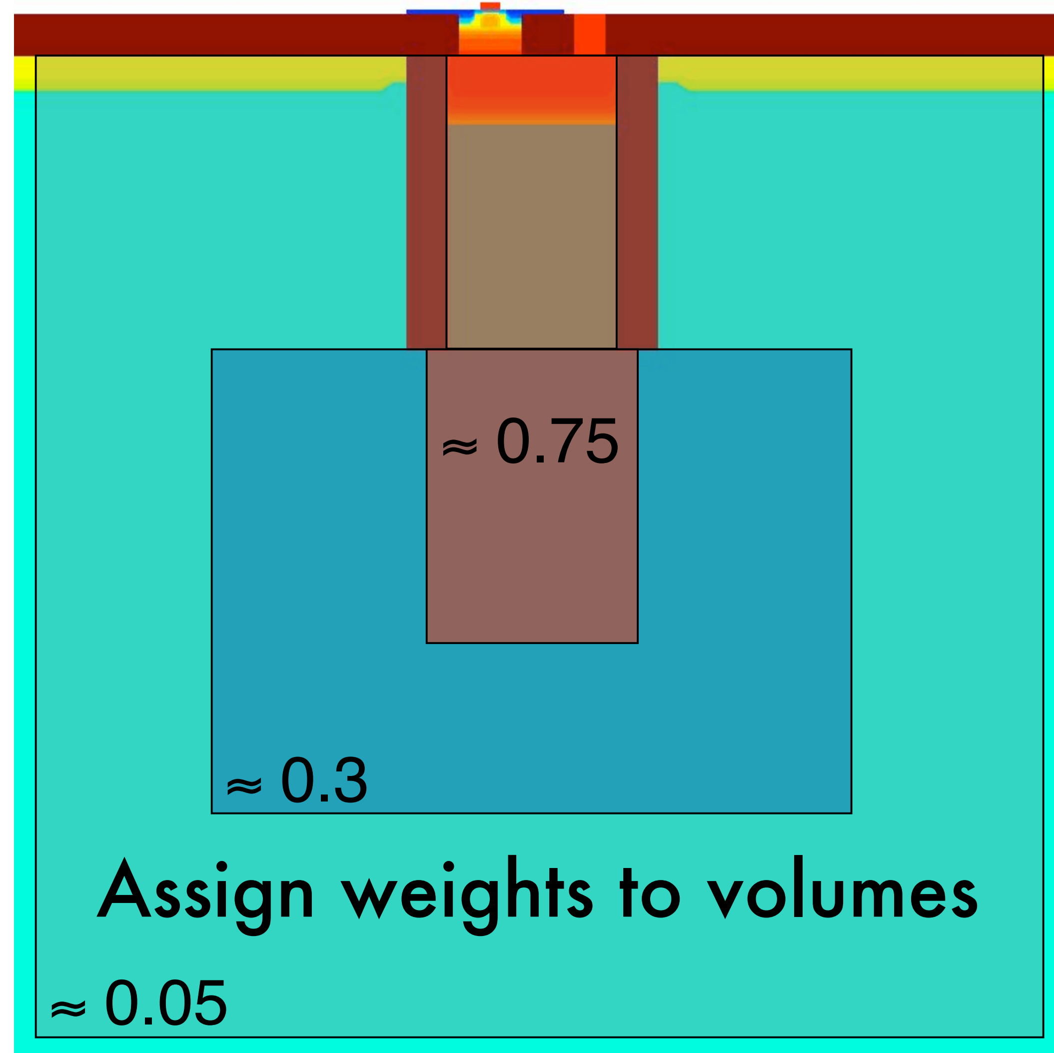

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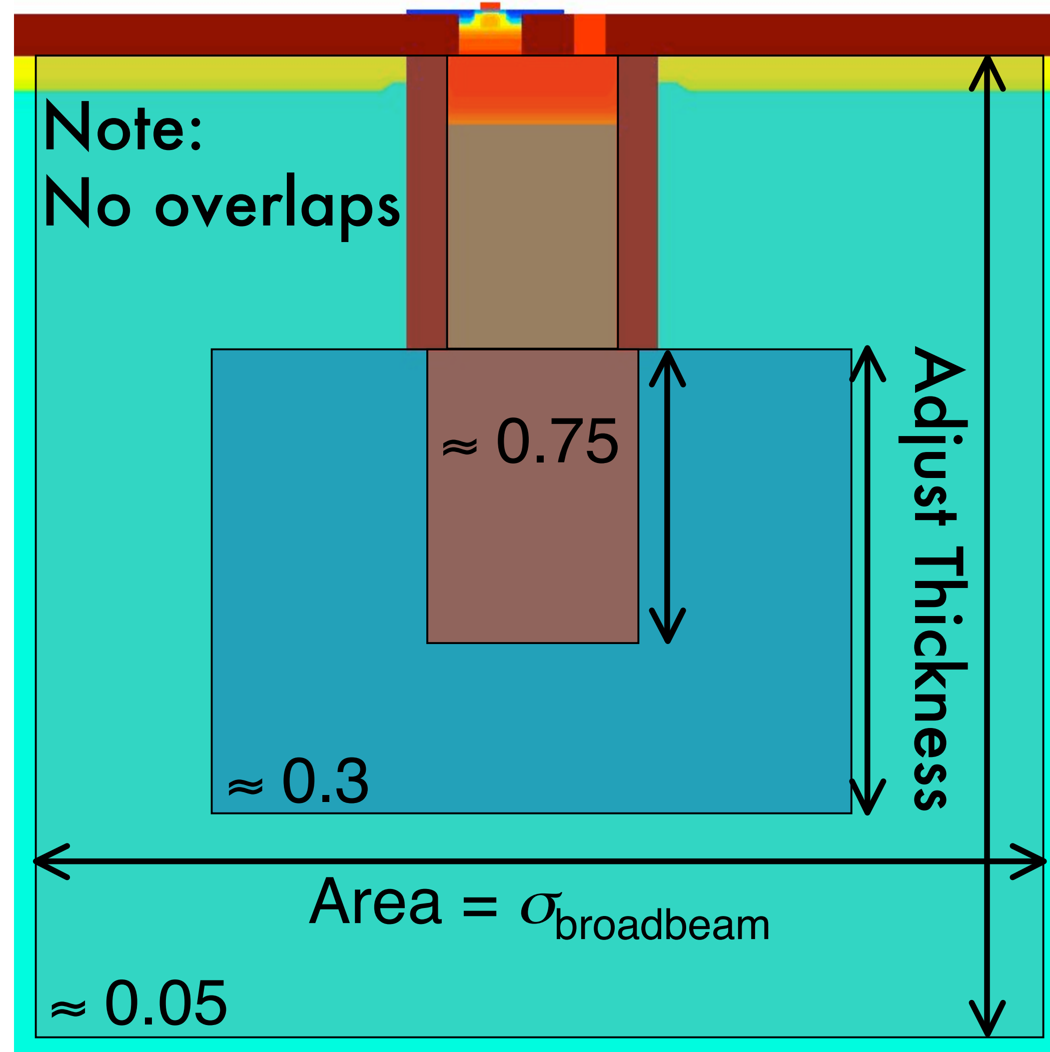
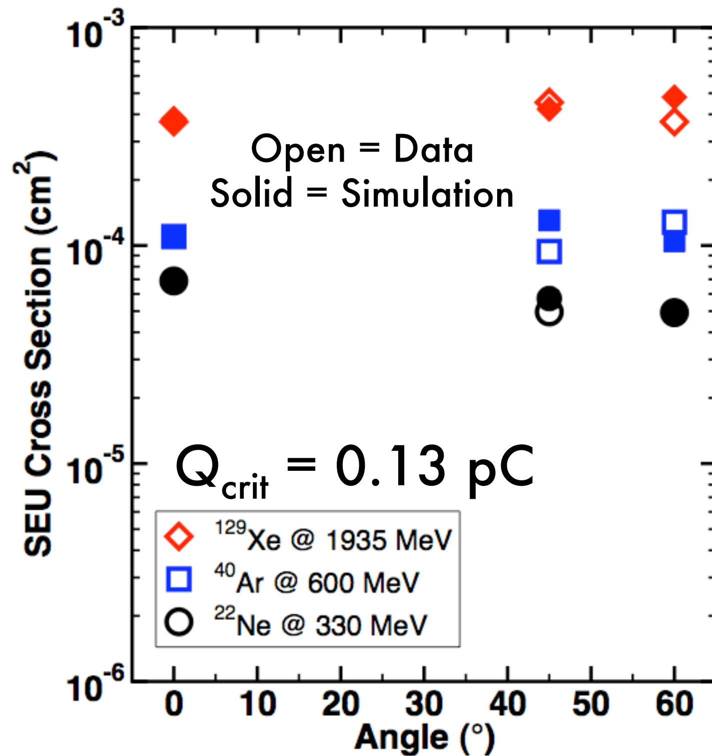


Calibrate to Heavy Ion Data



IBM 5AM SiGe HBT
Baseline Design

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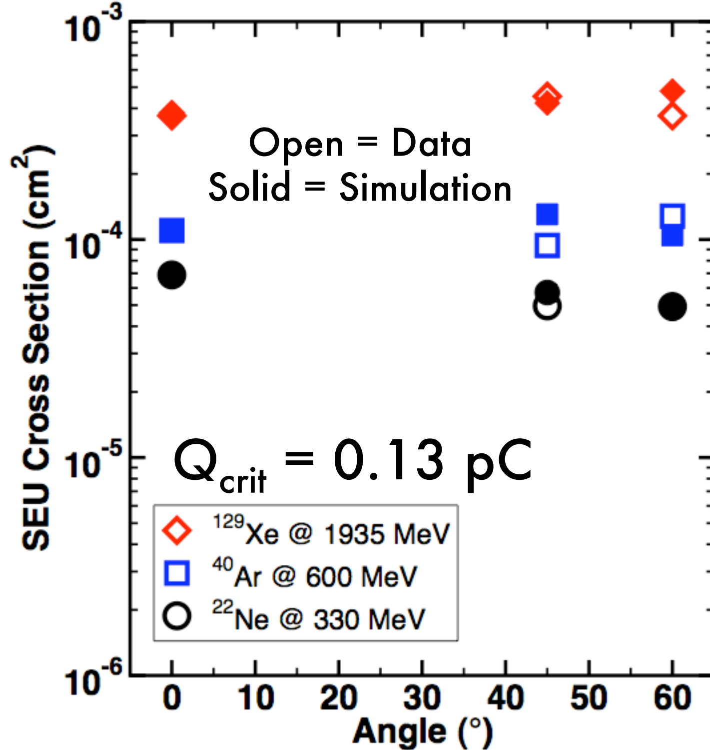

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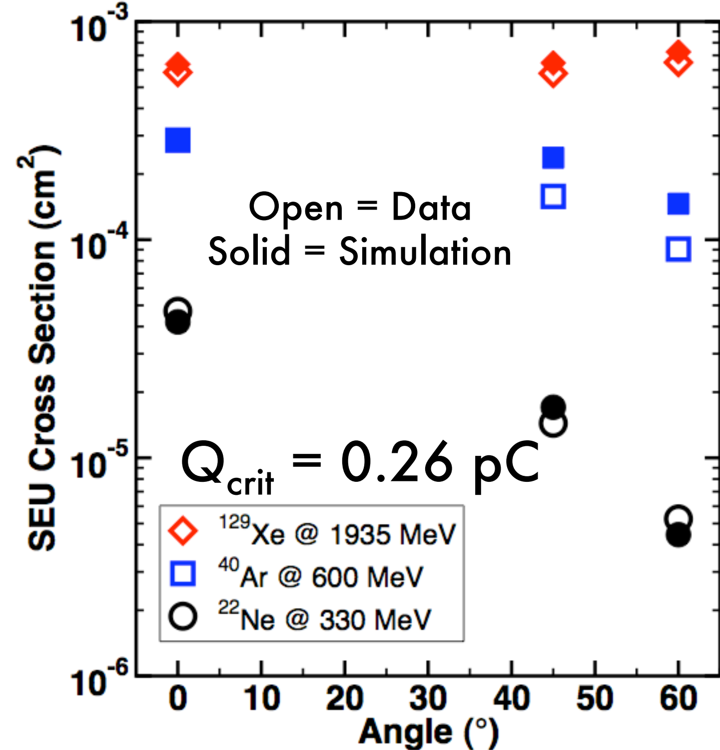


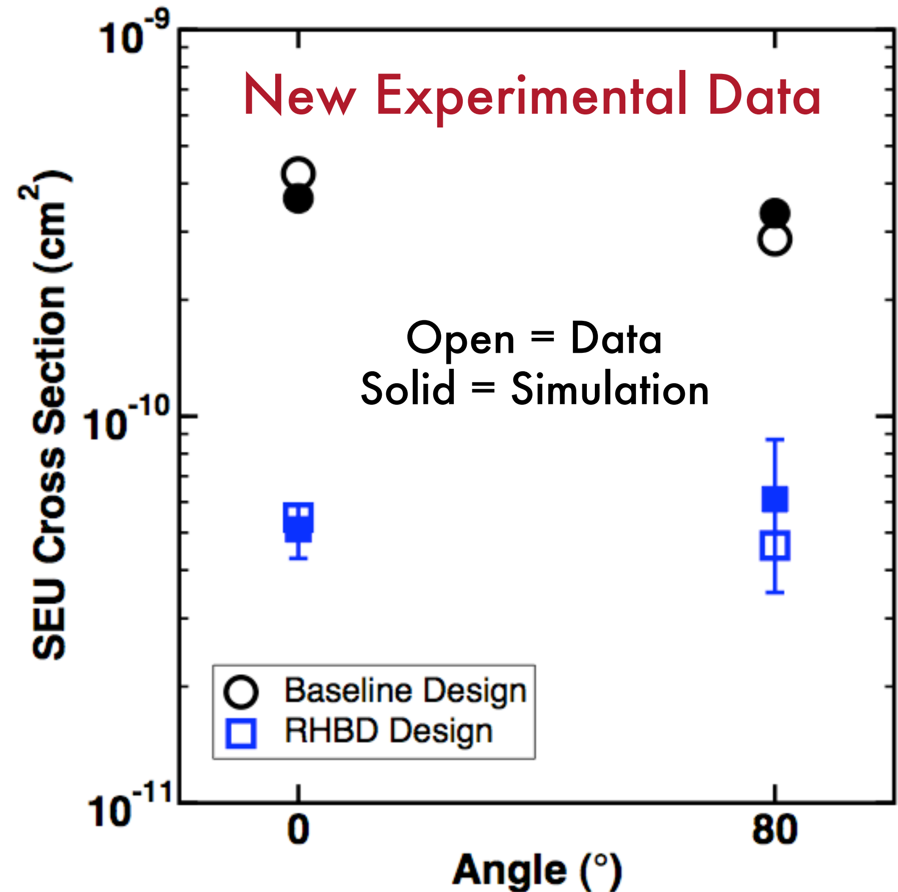
IBM 5AM SiGe HBT
RHBD Design

Data after P. W. Marshall, *et al.*, *IEEE Trans. Nucl. Sci.*, vol. 52, p. 2446, Dec. 2005.

Same sensitive volume model produces required trends

Simulation Compared to Proton Data

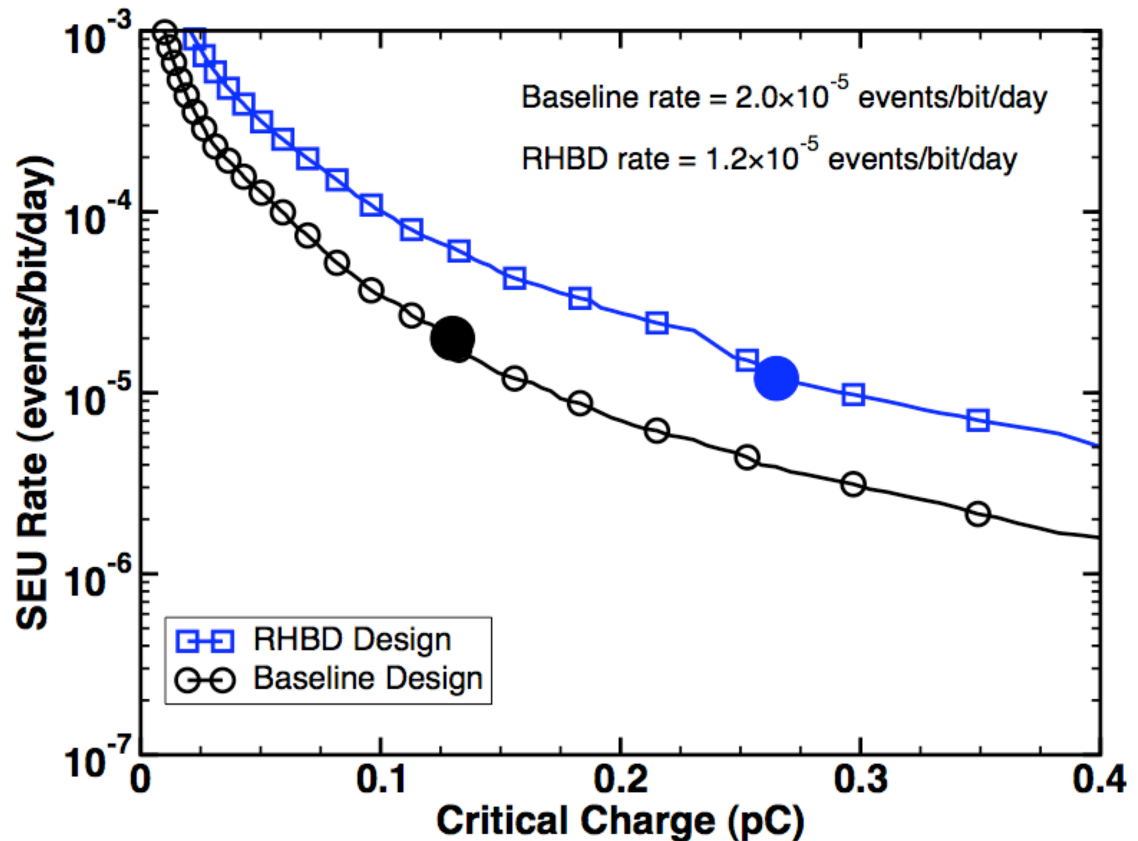
- *No adjustable parameters*
  - *Change particle, energy*
- Different mechanism
  - Direct ionization
  - Nuclear reactions
- Basis for LEO rate calculation in addition to GCR rate calculation
  - Large proton flux component



For protons, no further calibration necessary

Rate Calculations – GCR

- CREME96 spectra
- Reverse-integrated rate curve (≤)
- Evaluated at Q_{crit} from broadbeam calibration
- Baseline = 0.13 pC
- RHBD = 0.26 pC
- Rate curve for RHBD higher than baseline
- Lower evaluated rate due to - Q_{crit}



Larger size of RHBD device defeats hardening in GCR

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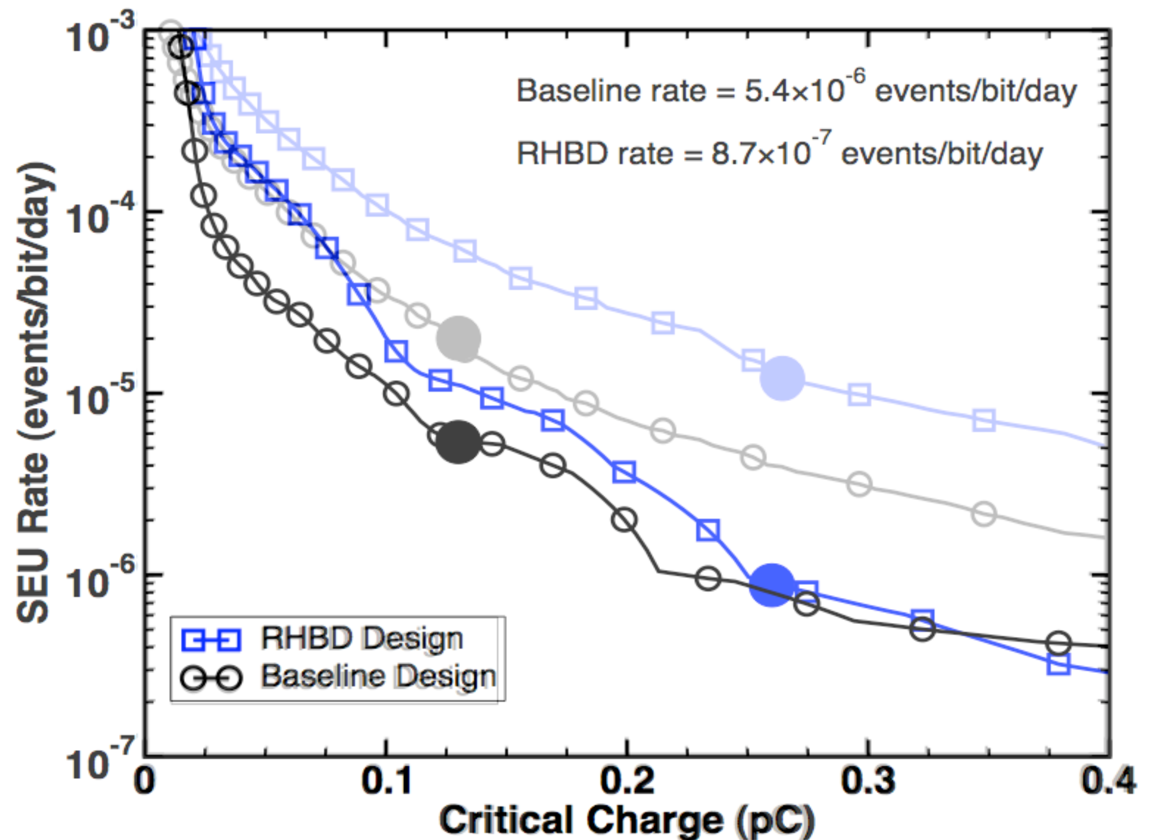

Due to reduced heavy ion flux at LEO, better benefits with RHBD

Conclusions

- Ion interactions with deep trench isolation result in σ_{SEU} rolloff for devices with high Q_{crit}
- Well-studied technology used to develop generalized approach and provide event rates
  - Linear combination of weighted sensitive volumes
  - User-defined orbits
  - No well-behaved data, no Weibull, no CREME96
- Approach works for CMOS too (already done)
- Shortfalls: 1.) model cannot predict burst errors, and 2.) event rates are time-independent

Present Status and Future Work

- This work presented at 2007 NSREC
- SiGe HBT event rate calculations to appear in December 2007 TNS

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- This work presented at 2007 NSREC
- SiGe HBT event rate calculations to appear in December 2007 TNS
- TCAD simulation transient calibration
  - Look for more details in afternoon presentation
    - Moving Single-Event Mechanism Testing and Analysis into the Time-Domain
  - Continued utilization of previous SiGe HBT data
  - IBM Ph.D. Fellowship support
- Complete Ph.D. fall 2008