Single-Event Effects in SiGe Technologies

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Single Event Effects in SiGe HBTs

Key Partners

- University
  - **Robert Reed, Robert Weller, Ron Schrimpf, Mike Alles, Jonny Pellish, Enrique Montes (Vanderbilt),**
  - **John Cressler, and students (Georgia Tech),**
  - Guofu Niu and students (Auburn University),
  - Device and circuit modeling, mitigation approaches, basic mechanisms, fabrication support, testing support, access to emerging SiGe technologies (IBM, TI, Jazz, etc…)
- Naval Research Laboratory (NRL)
  - Dale McMorrow
  - Laser test support
- Sandia National Laboratory (SNL)
  - Gyorgy Vizkelethy, Paul Dodd
  - Microbeam testing
- NASA Goddard Space Flight Center
  - Paul Marshall, Marty Carts, Ray Ladbury, and Hak Kim
  - Radiation testing, modeling support, mitigation approaches support
- Mayo Foundation's Special Purposes Processor Development Group
  - Barb Randall, Pam Riggs, Karl Fritz, Steve Currie, Barry Gilbert
  - Circuit design, fabrication support, device packaging, testing support,

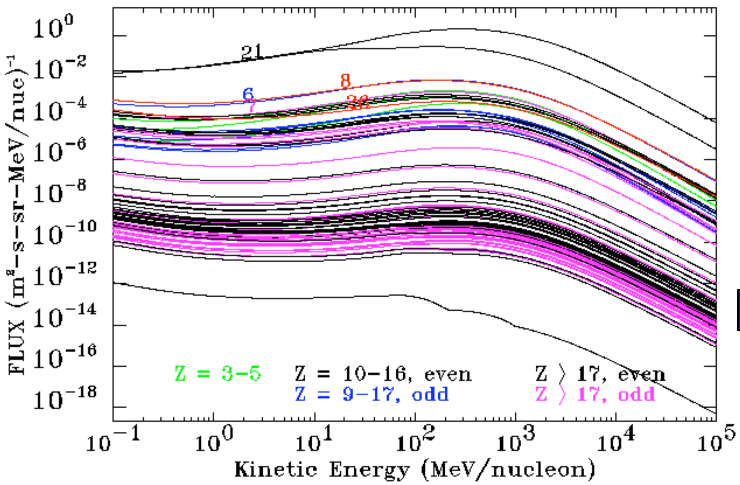
Funding provided MURI, NEPP, DTRA, RHESE

Outline

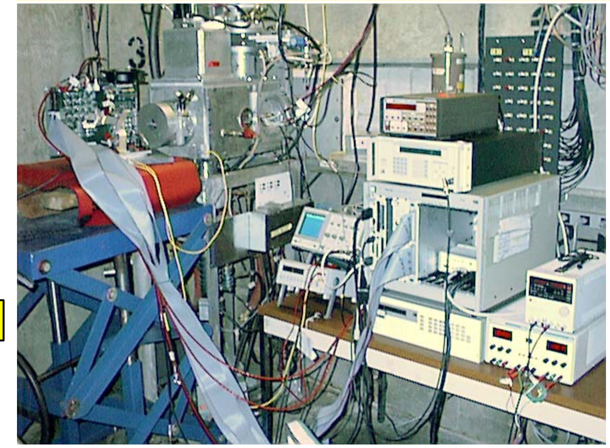
- Single-Event Effects Analysis
- Overview of our approach to improve predictive methods
- Basic mechanisms for charge collection in SiGe HBTs
- Implications for ground testing
- Plans
- DURIP award

Classical On-Orbit SEE Performance Predictions

Space Environment



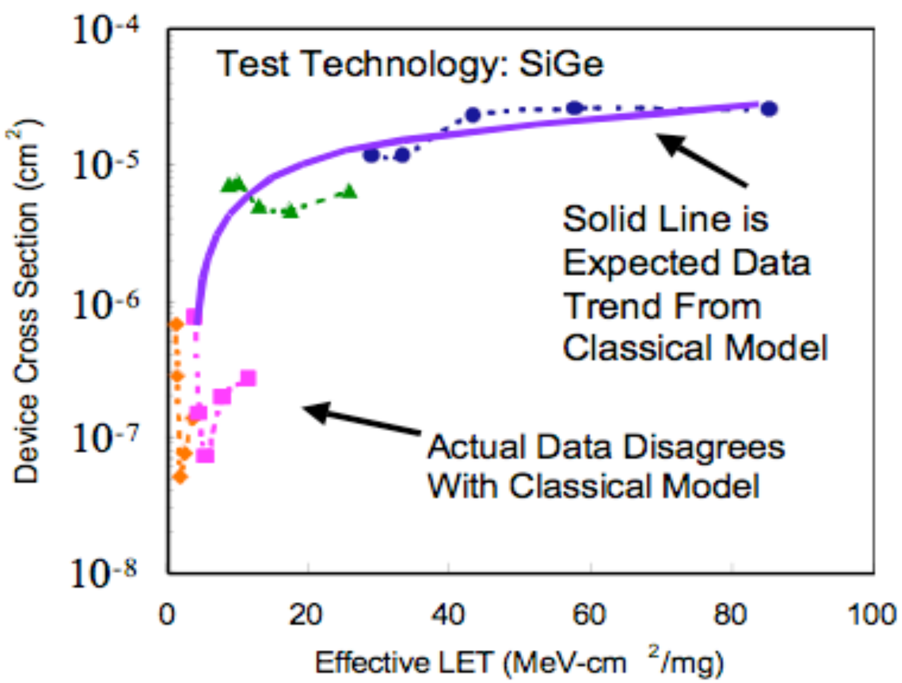
Ground Testing



Integral Rectangular Parallelepiped (RPP) model (circa 1980)
https://creme96.nrl.navy.mil/

On-Orbit SEE Rate

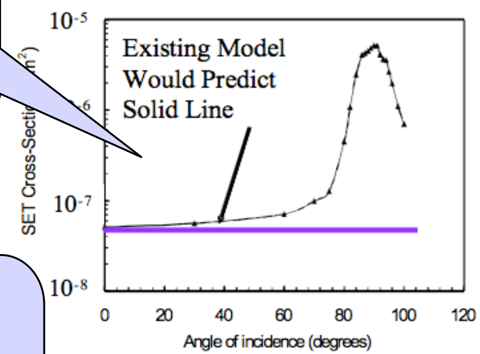
SEE Ground Testing on SiGe HBTs



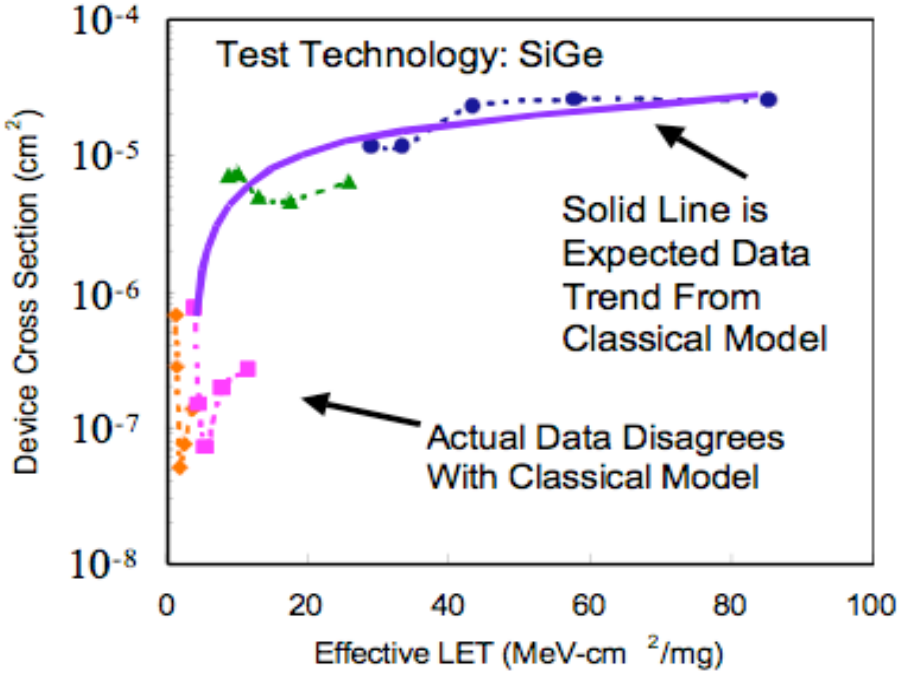
R.A. Reed, et. al IEEE Trans. Nuc. Sci., vol. 50, no. 6, Dec. 2003, pp. 2184 – 2190

Other Examples of Breakdown of Existing SEE Models

Protons effects in Optical Links

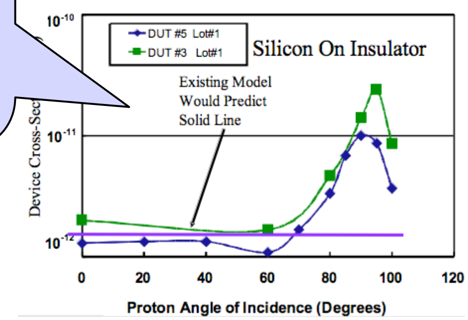


R.A. Reed, et. al IEEE Trans. Nuc. Sci., vol. 48, no. 6, Dec. 2001, pp. 2202 – 2209.



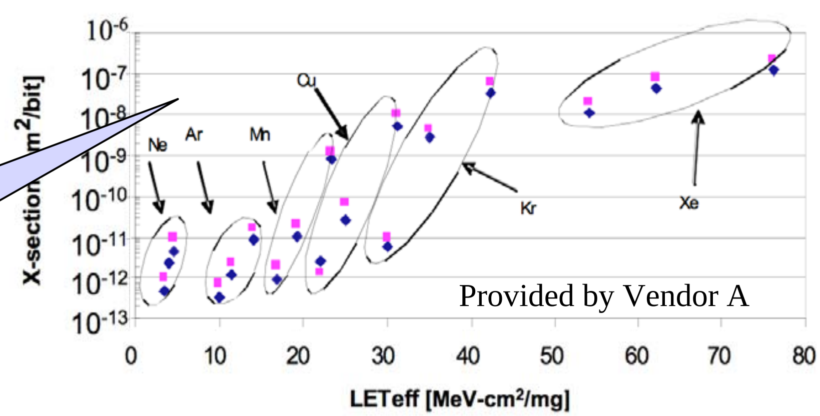
R.A. Reed, et. al IEEE Trans. Nuc. Sci., vol. 50, no. 6, Dec. 2003, pp. 2184 – 2190

Proton effects in SOI based memories

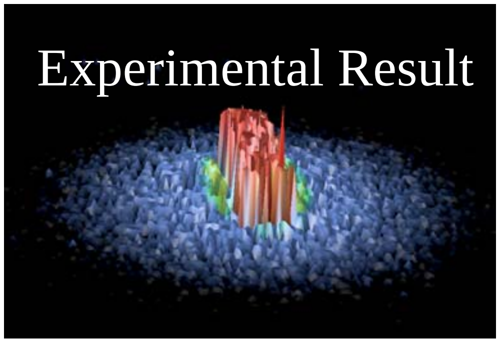


R.A. Reed, et. al, IEEE Trans. Nuc. Sci., vol. 49, no. 6, Dec. 2002, pp. 3038 – 3044.

Heavy Ion effects CMOS SRAM



Plan for Investigation of Single Event Effects in SiGe HBTs circuits



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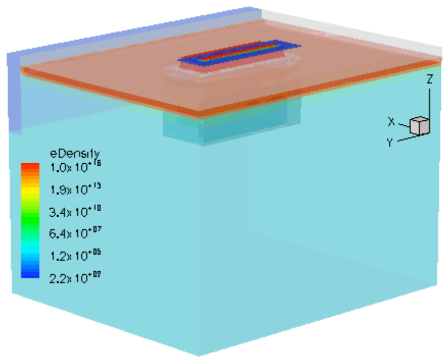
Understanding of basic mechanisms



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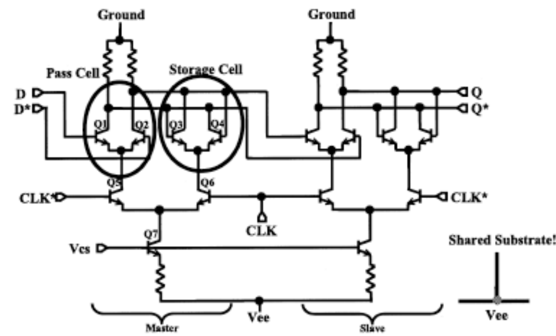
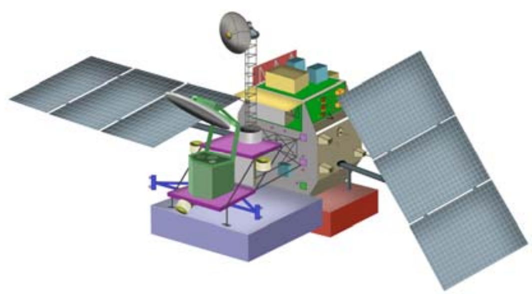
Mixed-Mode TCAD



→ New Predictive Method for On-Orbit Performance



IBM SiGe HBT Technology

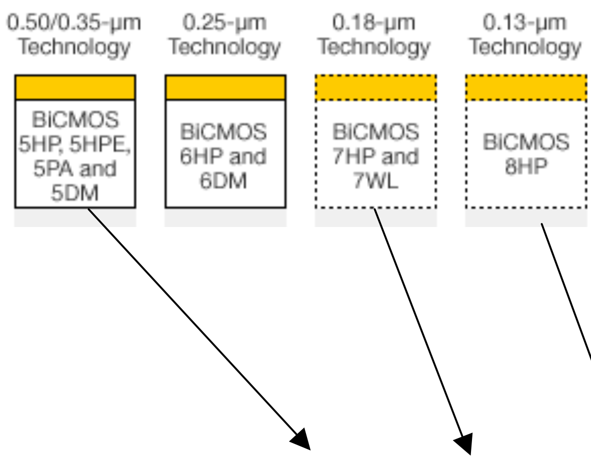
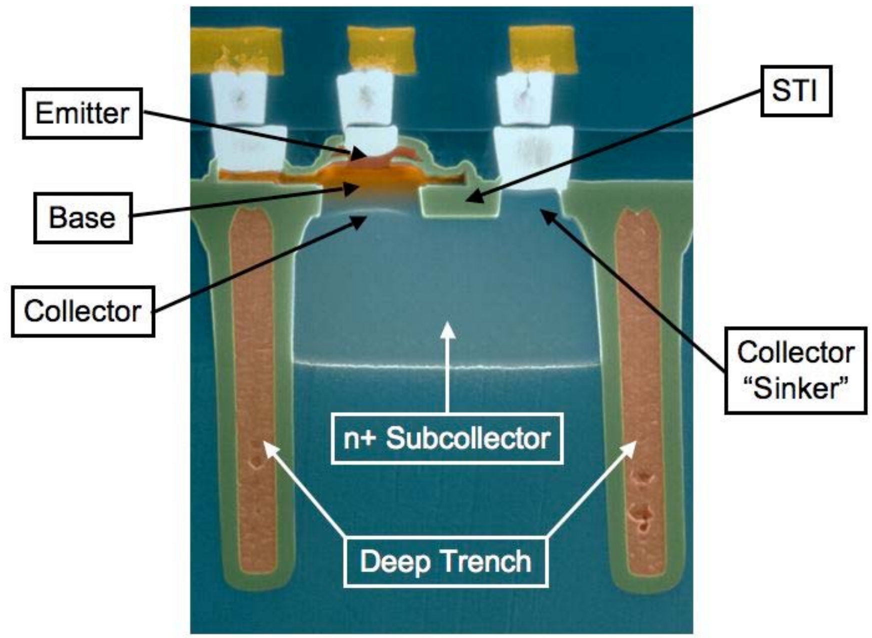


Figure of Merit	1^{st}	2^{nd}	3^{rd}
W_E (μm)	0.42	0.18	0.12
peak f_T (GHz)	50	120	207
peak f_{max} (GHz)	70	100	285

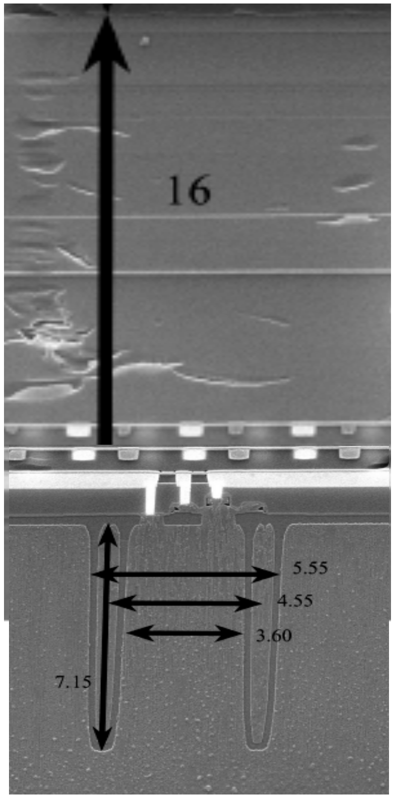
http://www.03.ibm.com/chips/services/foundry/technologies/roadmap.html

Cross Section of IBM's 0.5 Micron UHV/CVD SiGe HBT

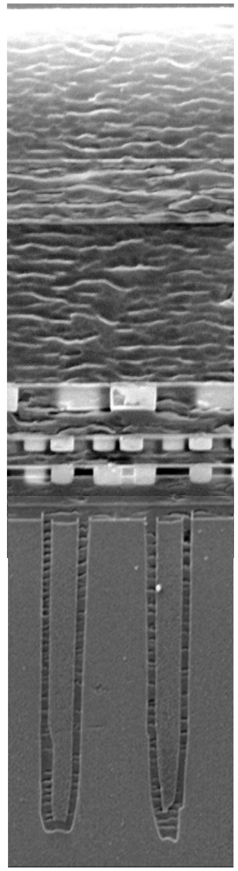


IBM photo from Jan. '00 IEEE Spectrum

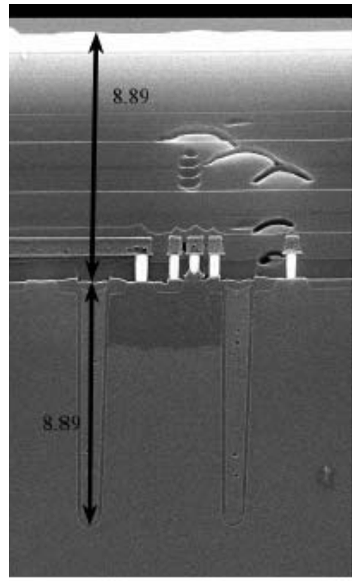
SEMs* of SiGe Technology



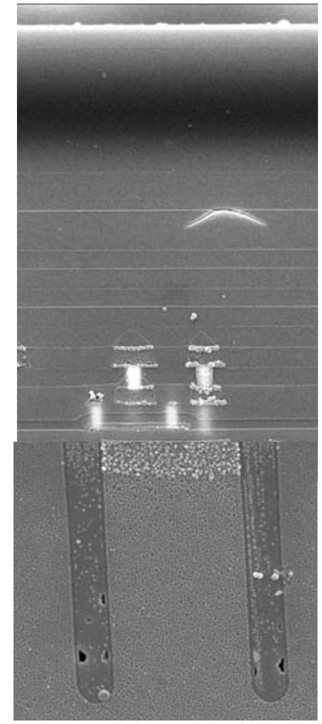
7HP



8HP



Jazz-120

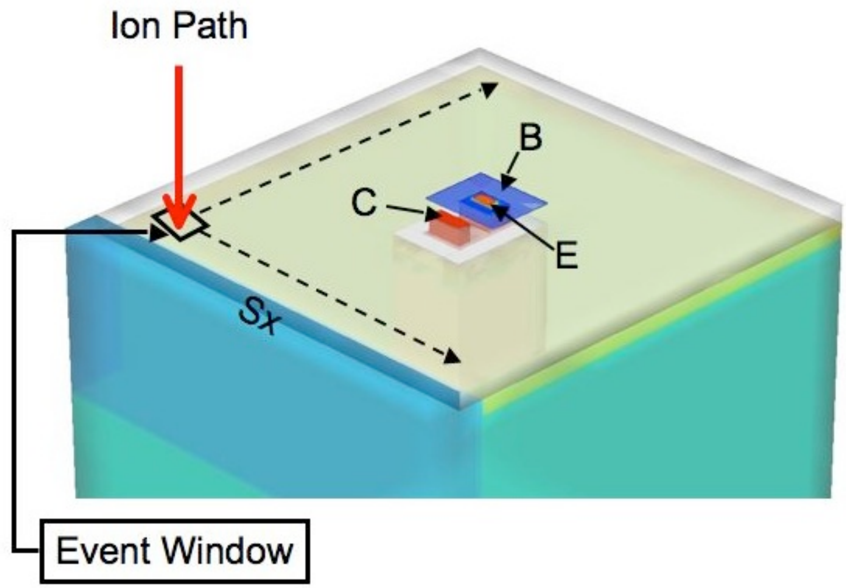


National

* Taken at NASA/GSFC

Ion Beam Induced Charge Collection Measurement

- Sandia National Laboratories
- 36 MeV $^{16}O^{5+}$
  - 26 MeV deposited in Si
- ≈ 600 ions/s = 0.48 fA
- 25.5 μm range in silicon
- Bragg peak @ 7.5 MeV·cm^2/mg
- 1.5 μm^2 spot size; 0.1μm steps



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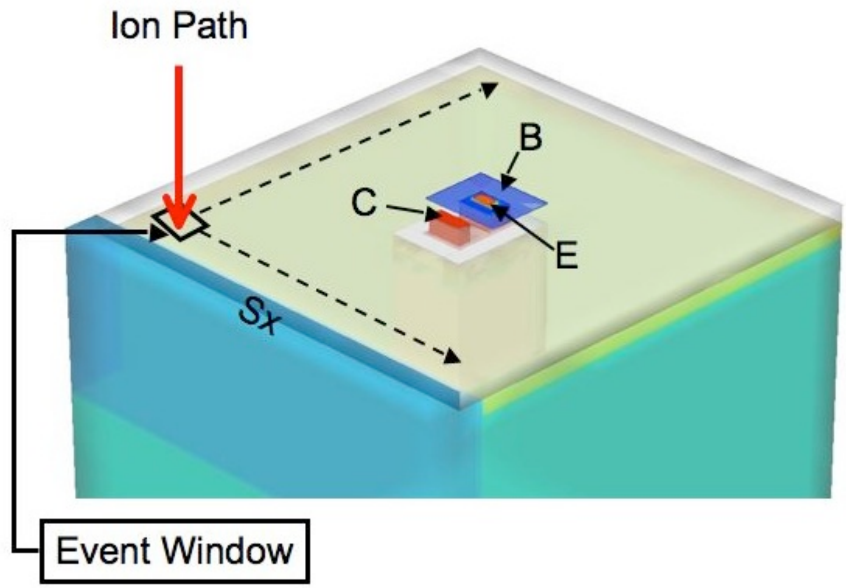

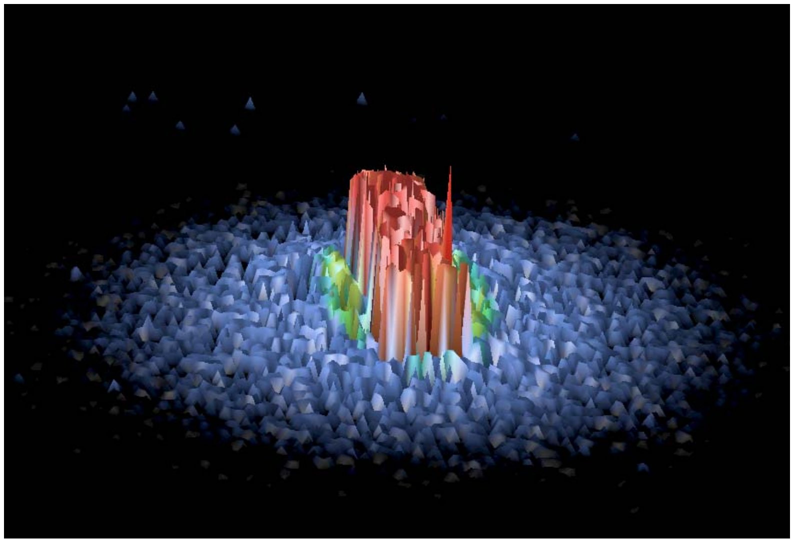

- Peak collection occurs for event inside the deep trench isolation (DTI)
- Lower amount of charge collection for events outside the DTI
- Clear delineation of DTI boundary

Collaboration with Georgia Tech

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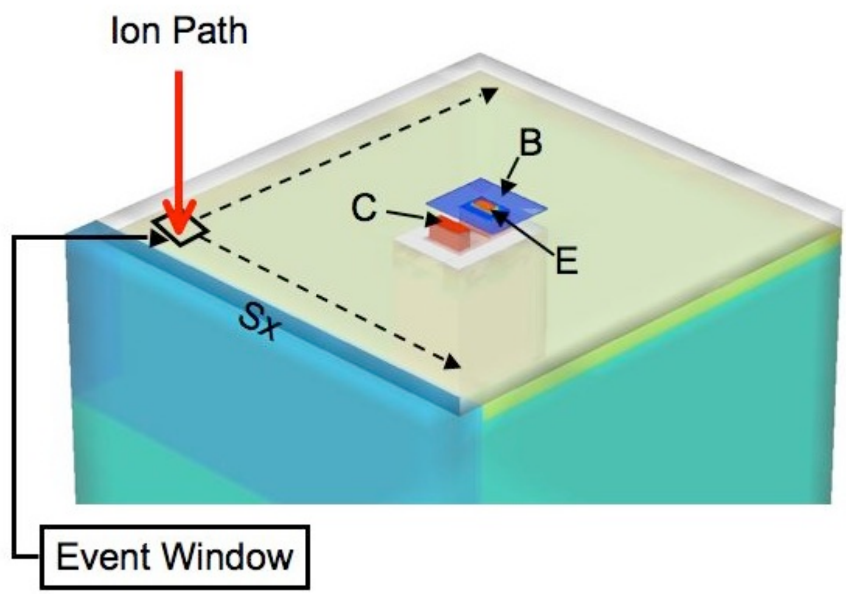
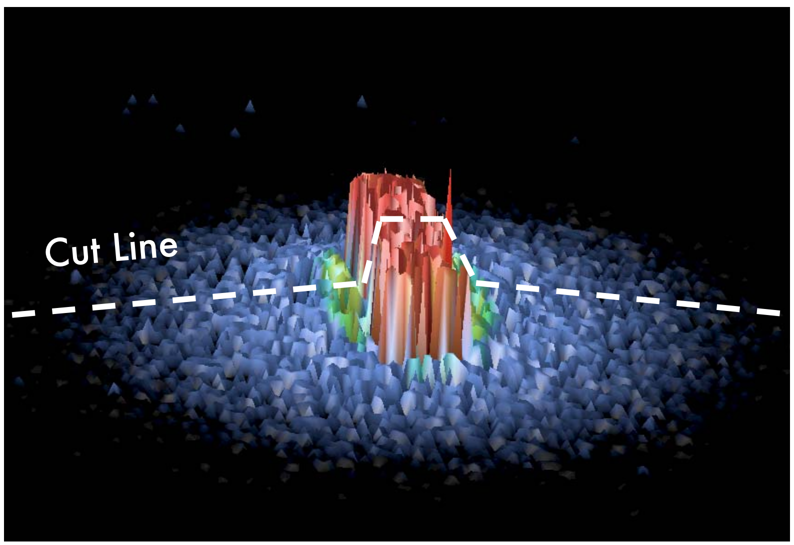
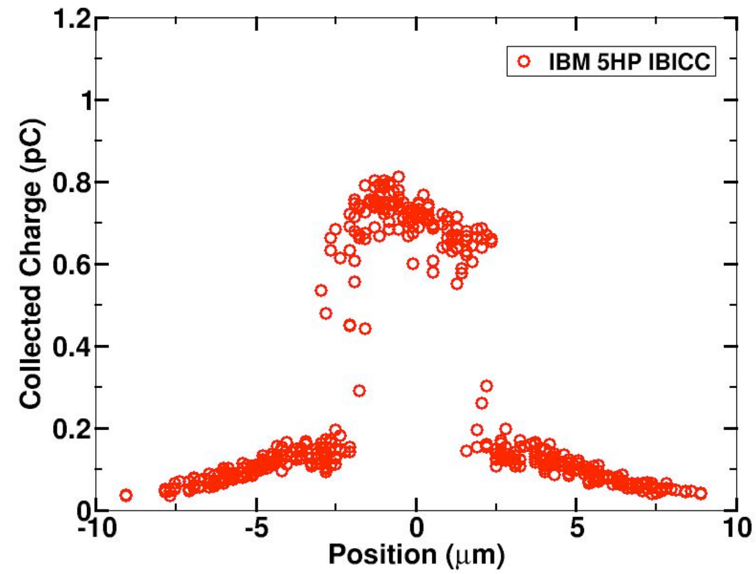
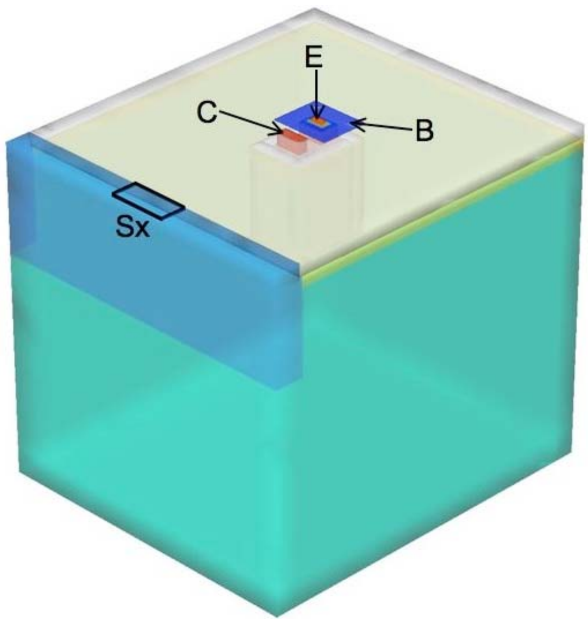
- Bragg peak @ 7.5 MeV·cm^2/mg
- 1.5 μm^2 spot size; 1μm steps

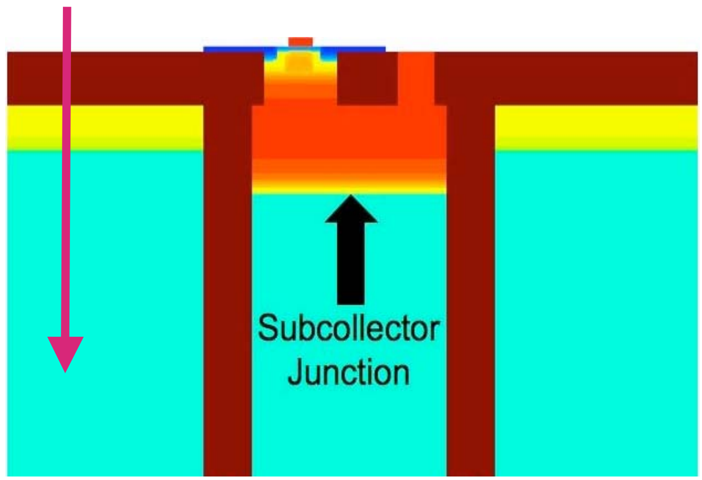


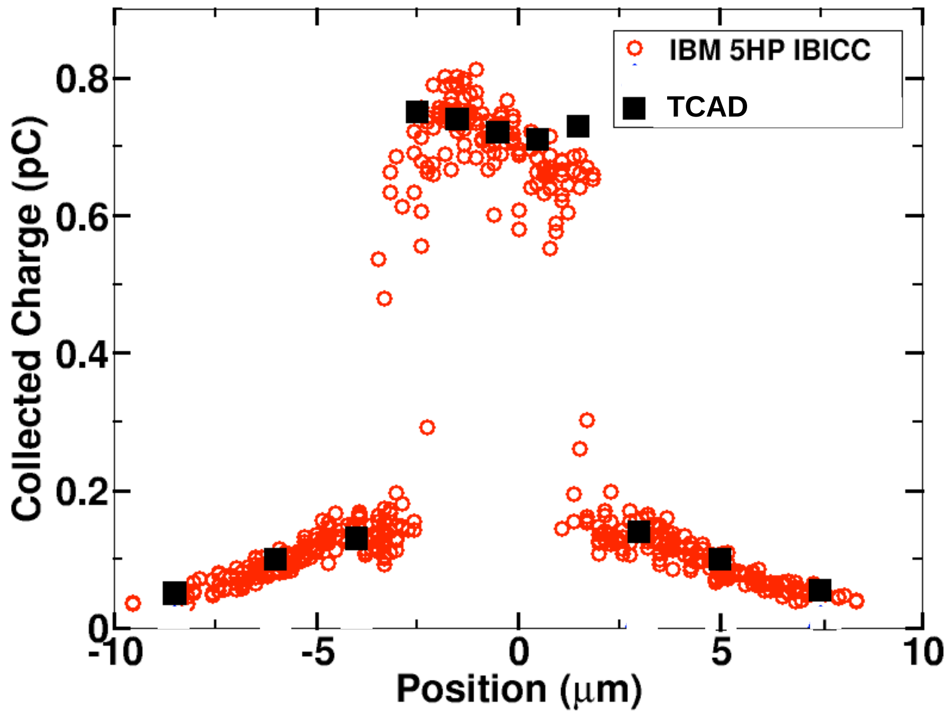




TCAD Modeling of Charge Collection in SiGe HBT

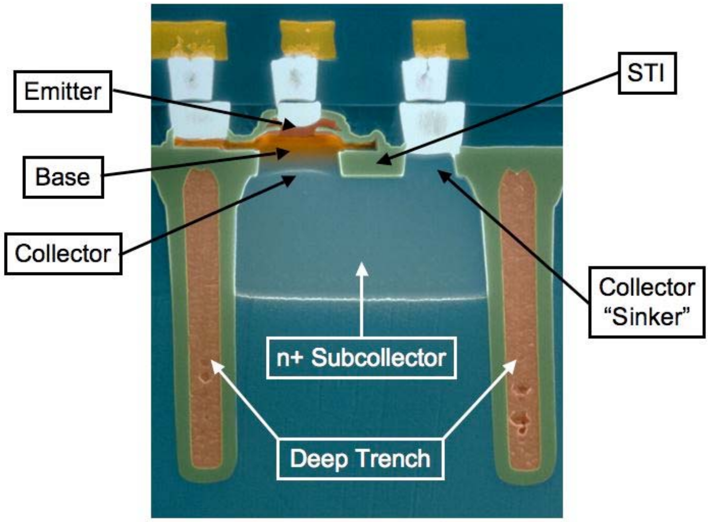


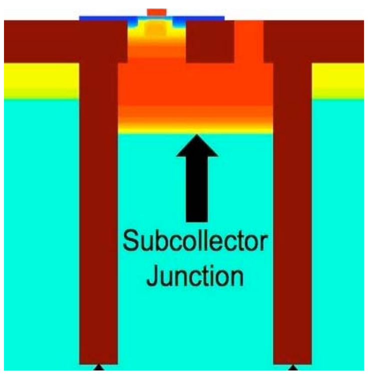


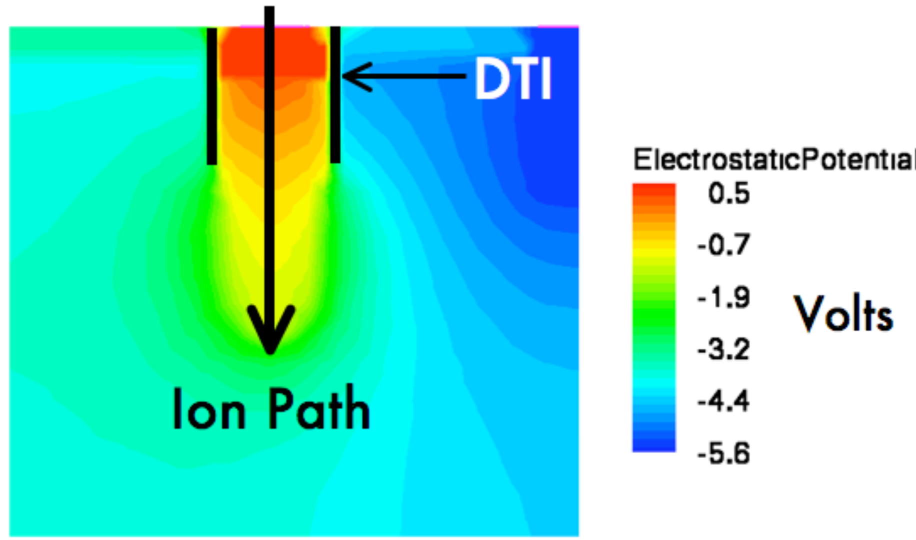


HBT details provided by
John Cressler and Guofu Niu

Ion Event within DTI



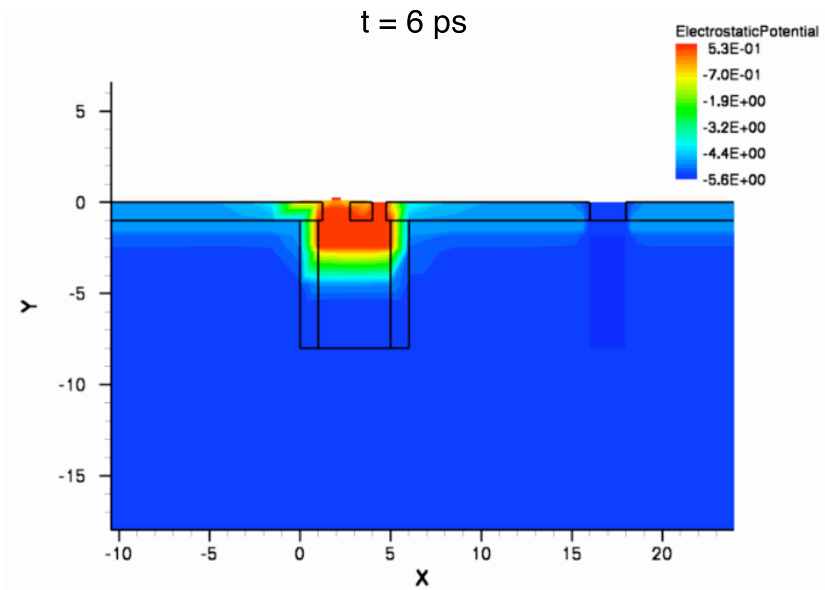


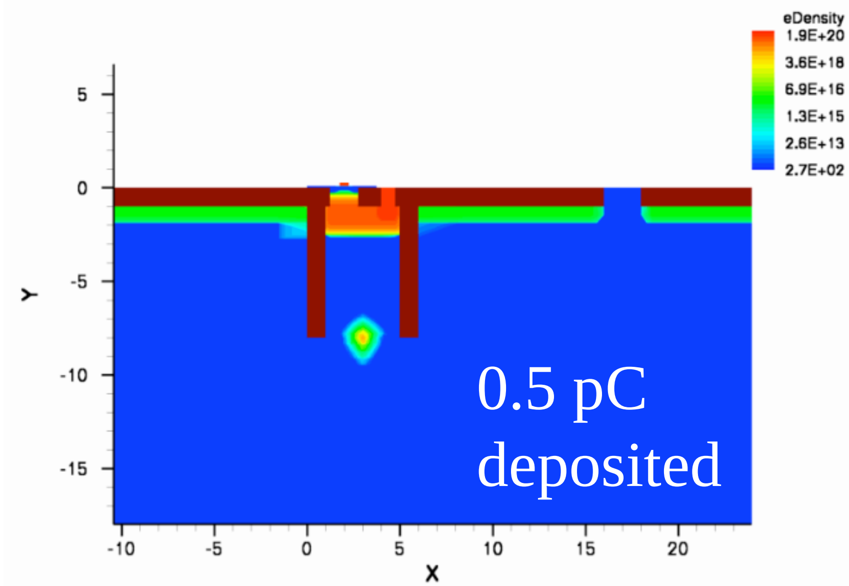


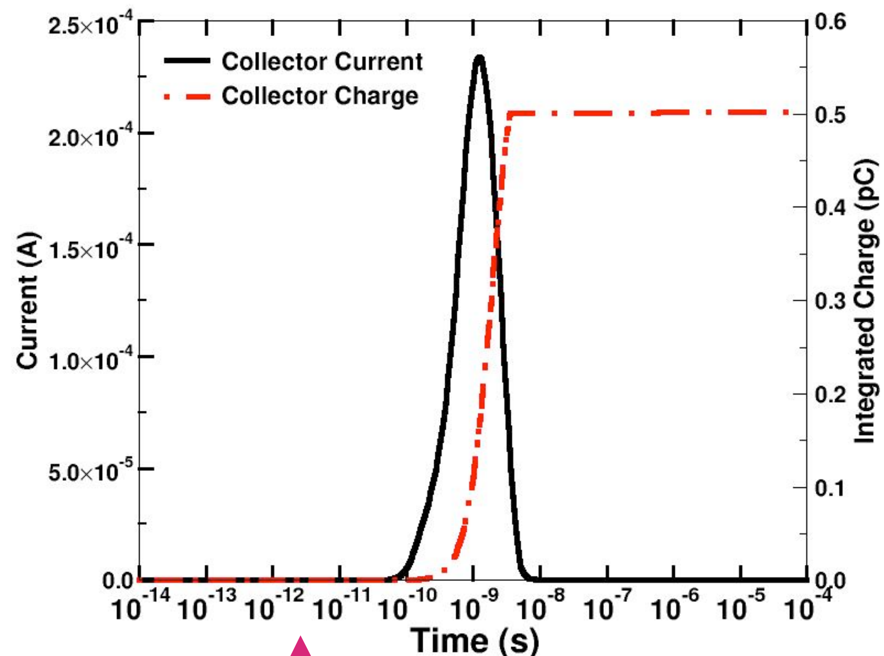
Transient disturbance in the junction electrostatic potential induced by a ion event

C. M. Hsieh, P. C. Murley, and R. R. O'Brien, "A field-funneling effect on the collection of alpha-generated carriers in silicon devices," *IEEE Electron Devices Lett.*, vol. EDL-2, pp. 103-105, Apr. 1981

Collection Collection Mechanisms in SiGe HBTs

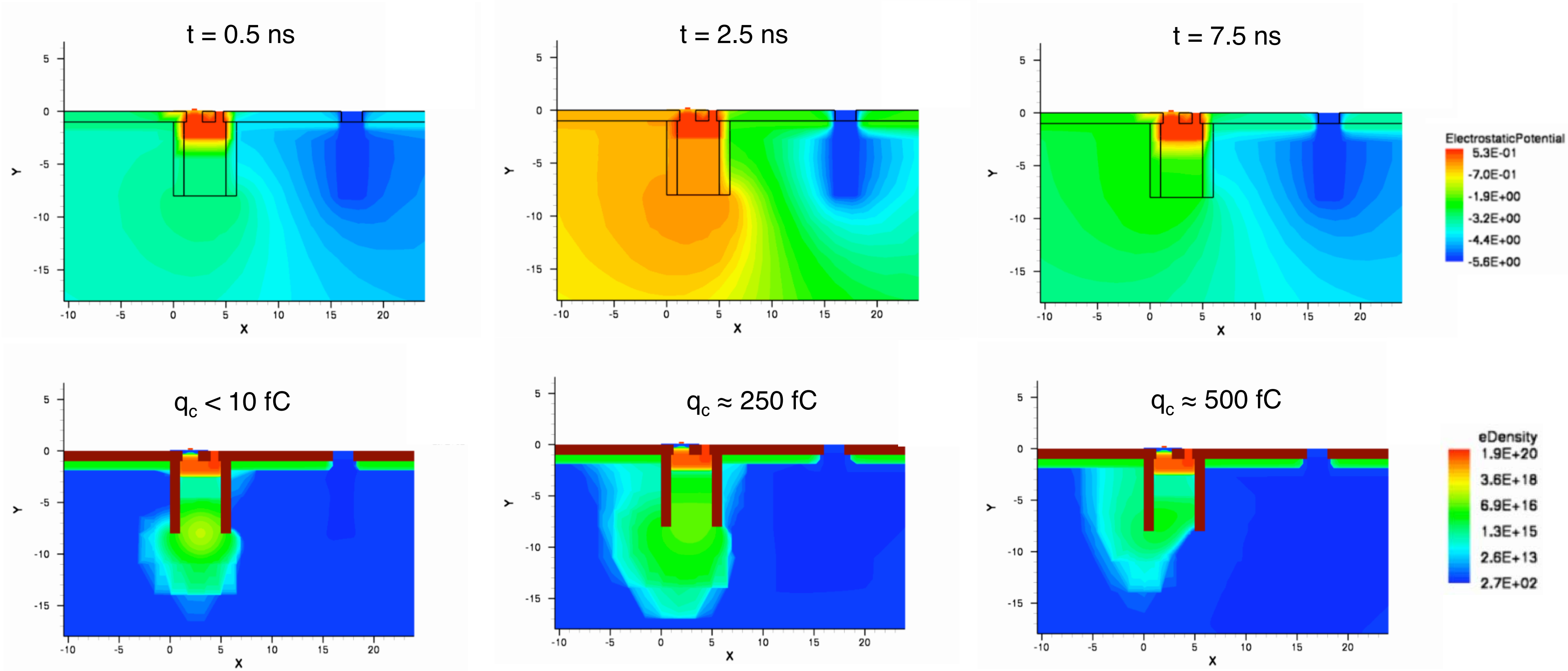




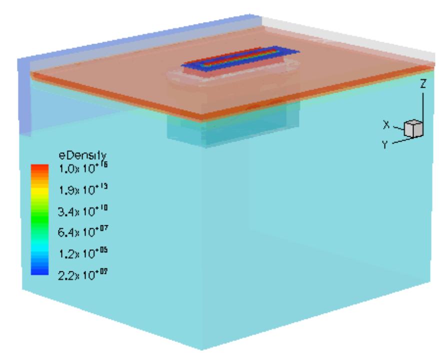


Charge Injection

Collection Collection Mechanisms in SiGe HBTs



Transient disturbance in the junction electrostatic potential induced by carrier diffusion



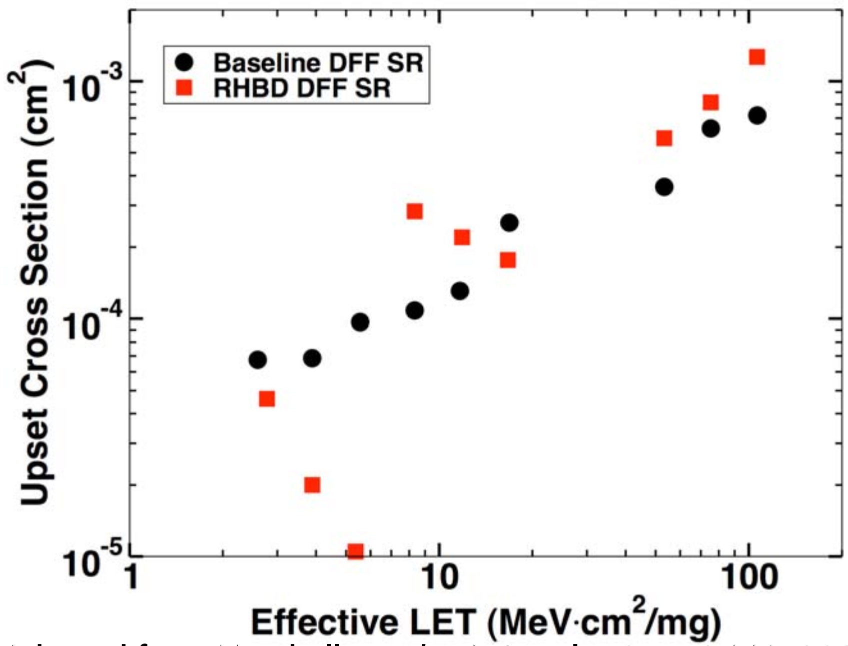
C. M. Hsieh, P. C. Murley, and R. R. O'Brien, "Collection of charge from alpha-particle tracks in silicon devices," IEEE Trans. Electron Devices, vol. 30, no. 6, pp. 686-693, 1983.

Outline

- Single-Event Effects Analysis
- Overview of our approach to improve predictive methods
- Basic mechanisms for charge collection in SiGe HBTs
- Implications for ground testing
- Plans
- DURIP award

SEU Cross Section Measurement of Shift Registers Fabricated in IBMs 5AM SiGe HBT Technology

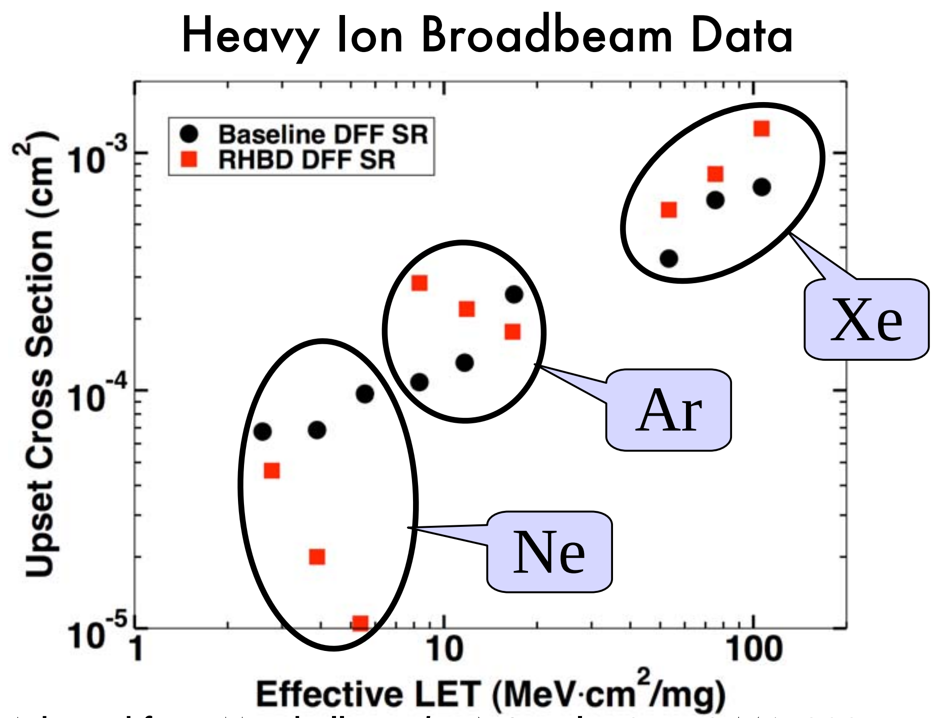
Heavy Ion Broadbeam Data



Adapted from Marshall, *et al.*, TNS, vol. 52, p. 2446, 2005.

Variation of cross section over angle depends on circuit.

SEU Cross Section Measurement of Shift Registers Fabricated in IBMs 5AMHP SiGe HBT Technology



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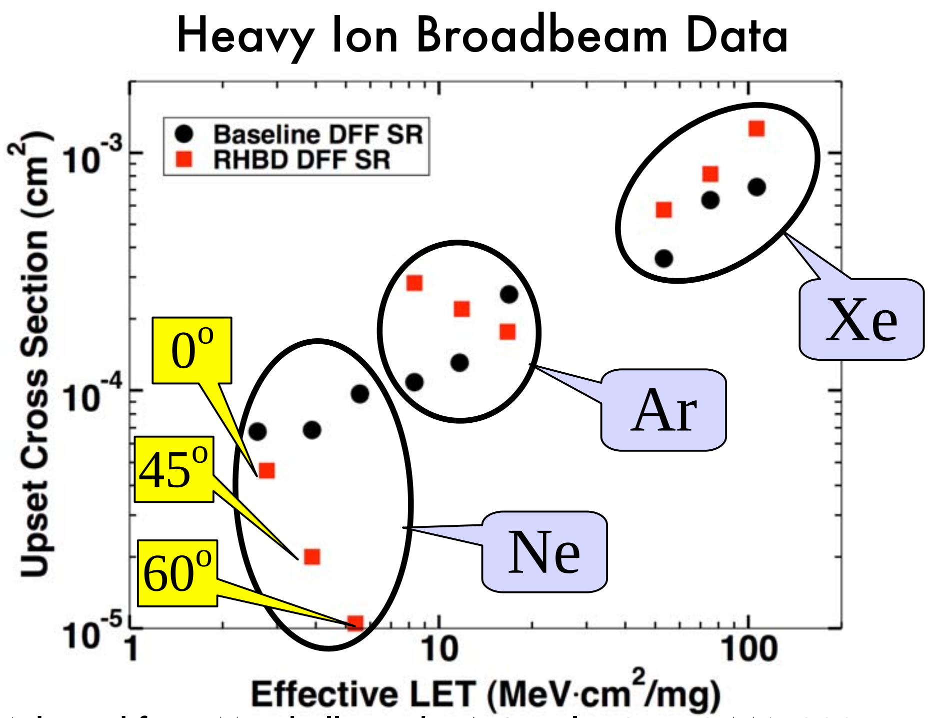
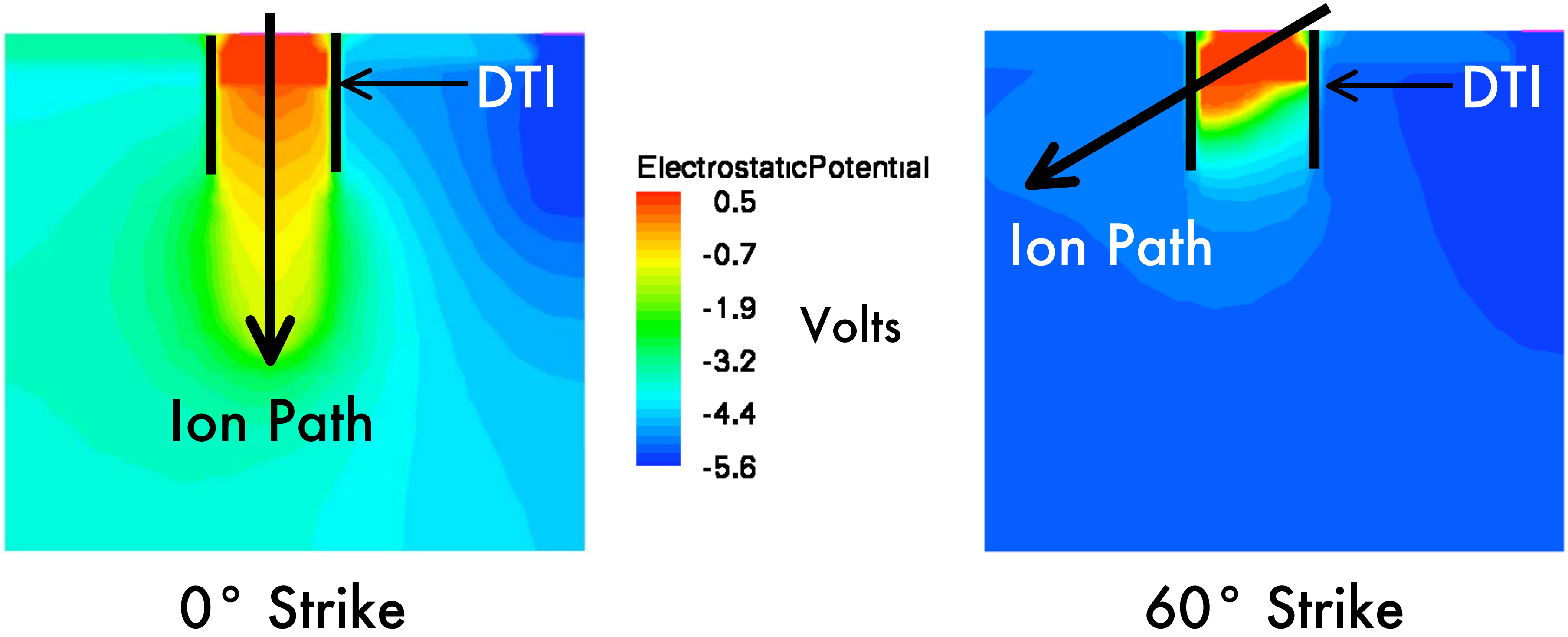


Adapted from Marshall, *et al.*, TNS, vol. 52, p. 2446, 2005.

Variation of cross section over angle depends on circuit.

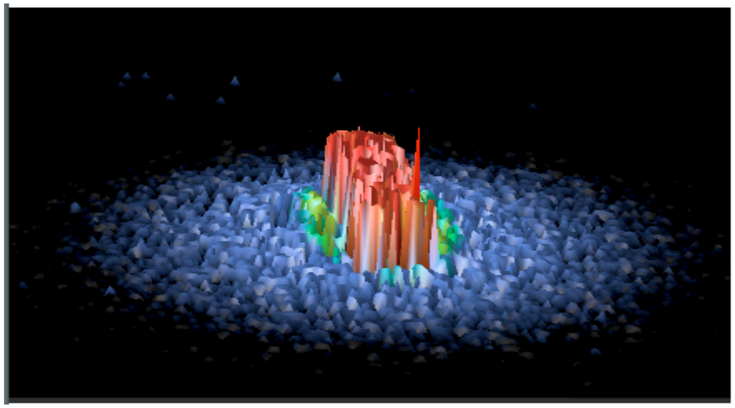
Angle Dependence and Electrostatic Potential



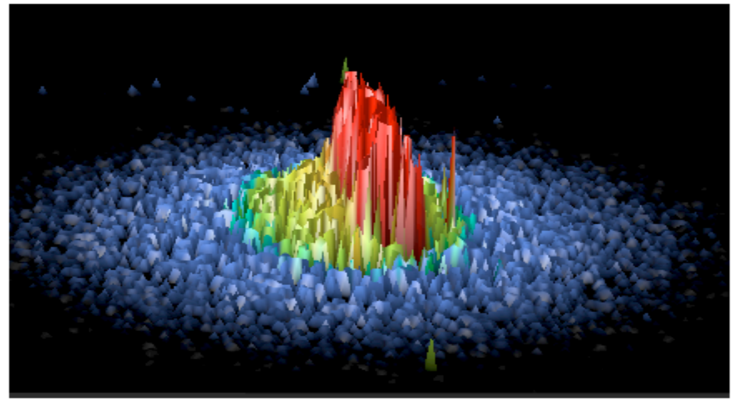
Charge collection and SEU sensitivity driven by interaction of ion path and deep trench isolation

IBICC Data at Angle

0 Degrees



~15 Degrees



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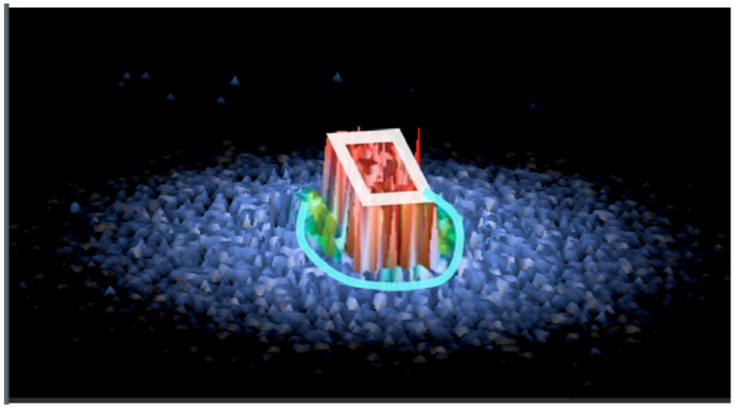
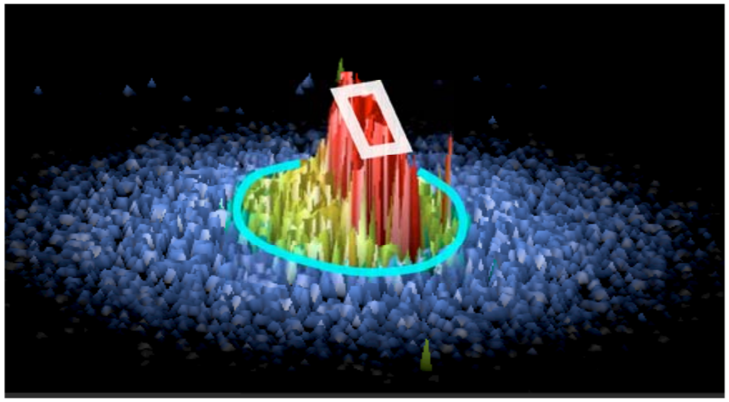
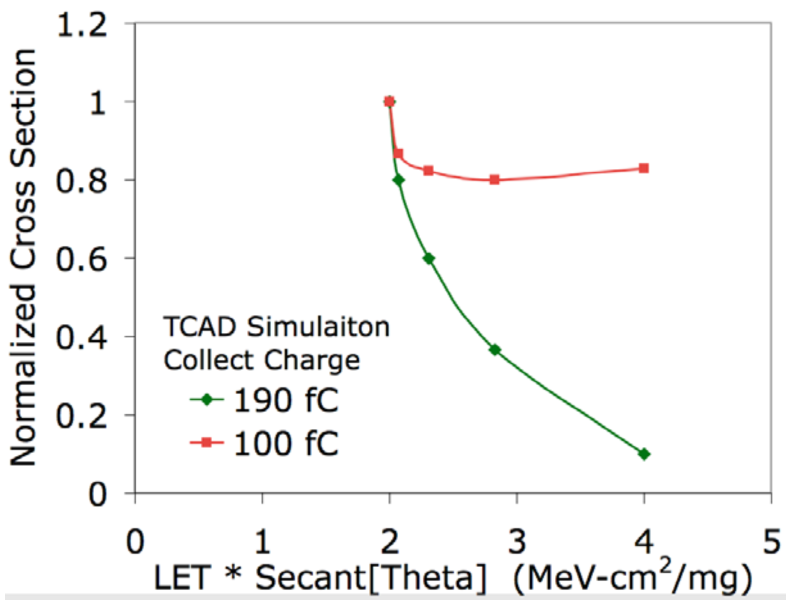


~15 Degrees

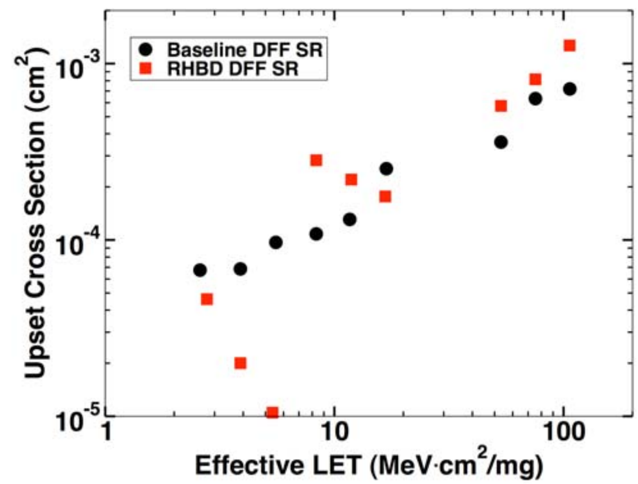


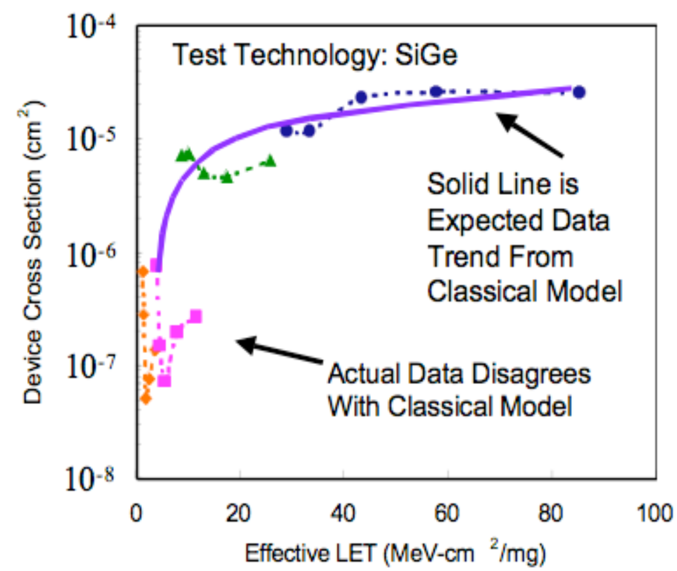
- Larger charge collection events:
  - Classical model would predict 4% reduction in area
  - Data shows 30% reduction in this area
  - Due to truncation of charge collection by DTI
- Small charge collection events:
  - Tends follow classical model more closely
  - Increased charge collection area is due to charge collection by carrier diffusion in the substrate

TCAD Simulation of Angle Response



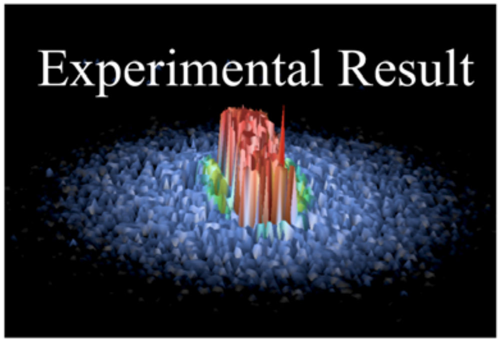
Experiment





- Detailed TCAD simulation support these results
  - Montes, et al., NSREC 2006 : implication of this for SEU cross section

Plan for Investigation of Single Event Effects in SiGe HBTs circuits



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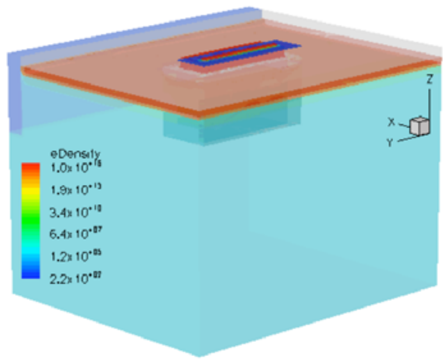
Understanding of basic mechanisms



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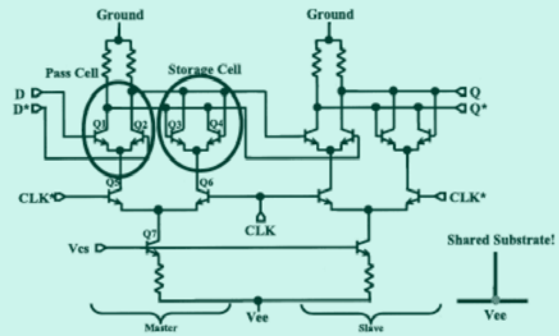
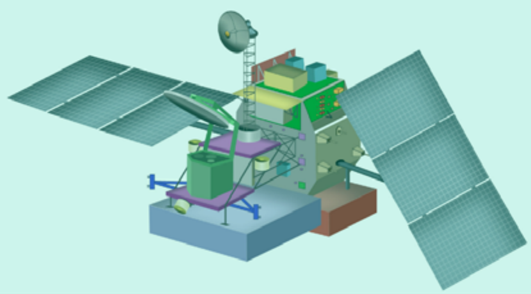
Mixed-Mode TCAD



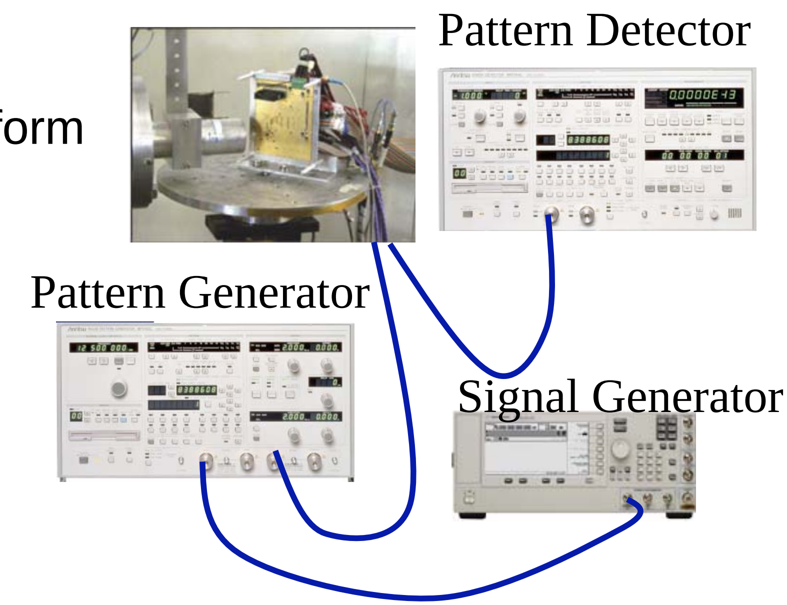
→ New Predictive Method for On-Orbit Performance



Next Few Year!

Defense University Research Instrumentation Program

- Proposal awarded 4/15/2006
  - Associated with the MURI
  - Jerry Witt
  - Kitt Reinhardt (New PM)
- Focused on instrumentation needed to perform high-speed single event effects testing
  - Analog up to 26 GHz
  - Digital up to 12.5 Gbps
- Highlights
  - 0.025 to 12.5 Gbps Anritsu BERT
  - Tektronics 13 GHz single shot, 40 Gsps sampling oscilloscope
  - Agilent 0.250 MHz to 31.2 GHz signal generator
  - Development of a novel method of detecting errors in oscillating circuits(< 26 GHz)
  - High-speed probe station



High-Speed (<13Gbsp) Digital Testing