VANDERBILT UNIVERSITY School of Engineering

High-Speed Single-Event Current Transient Measurements in SiGe HBTs

Jonathan A. Pellish[1], R. A. Reed[2], D. McMorrow[3], G. Vizkelethy[4], V. Ferlet-Cavrois[5], J. Baggio[5], P. Paillet[5], O. Duhamel[5], S. D. Phillips[6], A. K. Sutton[6], R. M. Diestelhorst[6], J. D. Cressler[6], P. E. Dodd[4], N. D. Pate[2], M. L. Alles[2], R. D. Schrimpf[2], P. W. Marshall[7], and K. A. LaBel[1]

1. NASA/GSFC Radiation Effects and Analysis Group, Greenbelt, MD
2. Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN
3. Naval Research Laboratory, Washington, DC
4. Sandia National Laboratories, Albuquerque, NM
5. CEA, DAM, DIF, F-91297 Arpajon, France
6. School of Electrical and Computer Engineering, The Georgia Institute of Technology, Atlanta, GA
7. NASA consultant, Brookneal, VA

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Acknowledgements…

- NASA Electronic Parts and Packaging program
- NASA Advanced Avionics Processor and Systems Project
- DTRA Radiation Hardened Microelectronics program under IACROs #08-4343I and #09-4587I to NASA
- AFOSR MURI program and DURIP award
- SiGe teams at the Georgia Electronic Design Center and IBM
- Naval Research Laboratory
- Sandia National Laboratories
- CEA, DAM, DIF (Arpajon, France)

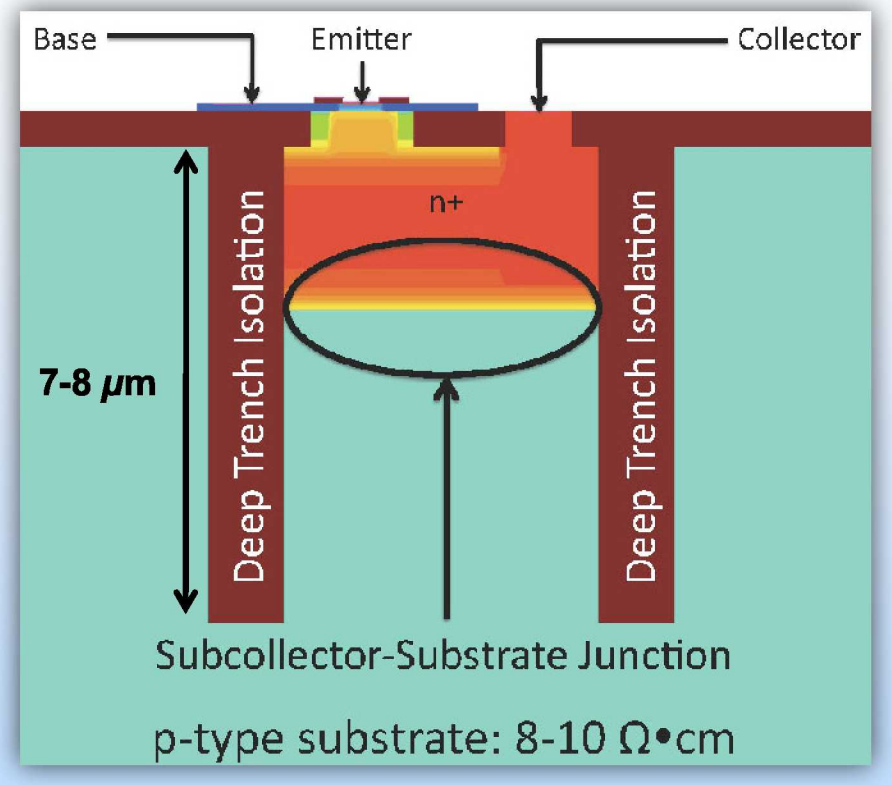
Overview

- IBM 5AM SiGe HBT device background…briefly
- High-speed measurement setup
  - Heavy ion microbeam, heavy ion broadbeam, pulsed laser
  - Advantages/disadvantages
- Low-impedance current transient measurements
- Understanding what the transients represent for single-event effects in SiGe HBTs

Device Background and Introduction

- **Key device characteristics**
  - **Deep trench isolation**
  - **Subcollector junction**
  - **Lightly-doped p-type substrate (large)**
- **Extend state-of-the-art knowledge**

IBM 5AM SiGe HBT (0.5 *μ*m)



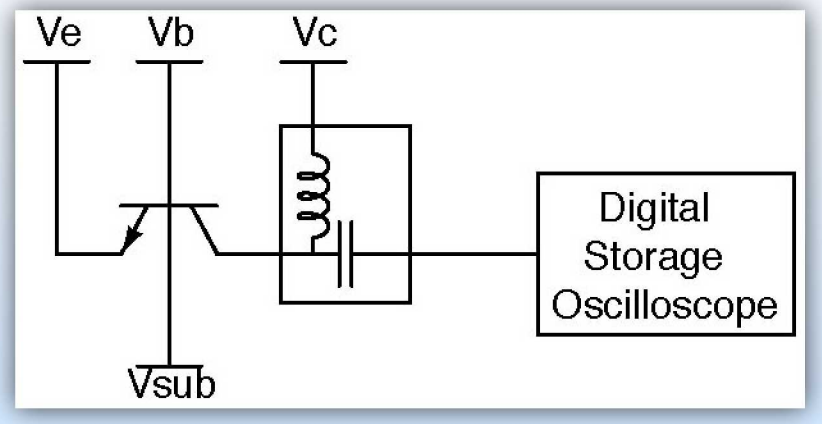
J. A. Pellish *et al.*, *IEEE Trans. Nucl. Sci.*, vol. 55, no. 6, p. 2936, Dec. 2008.

Previous tests focused on pulsed laser carrier generation only

New tests focus on heavy ion carrier generation

Microbeam Experimental Setup

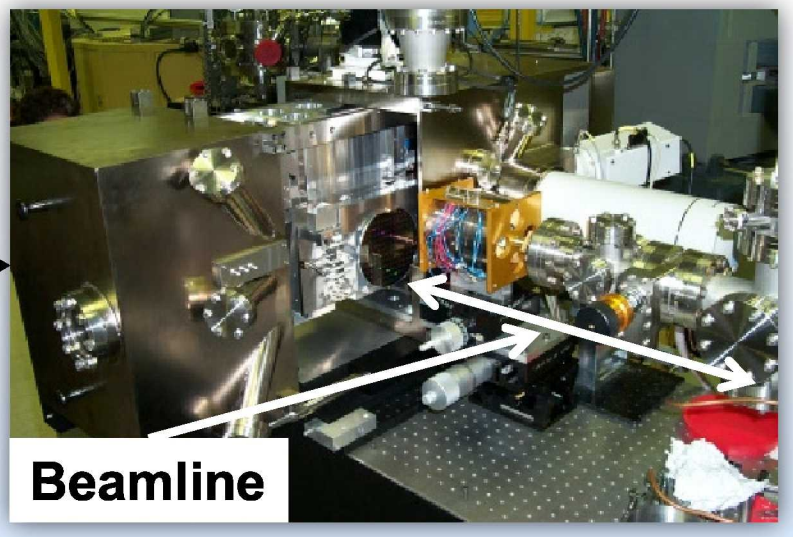
General electrical setup used in all cases

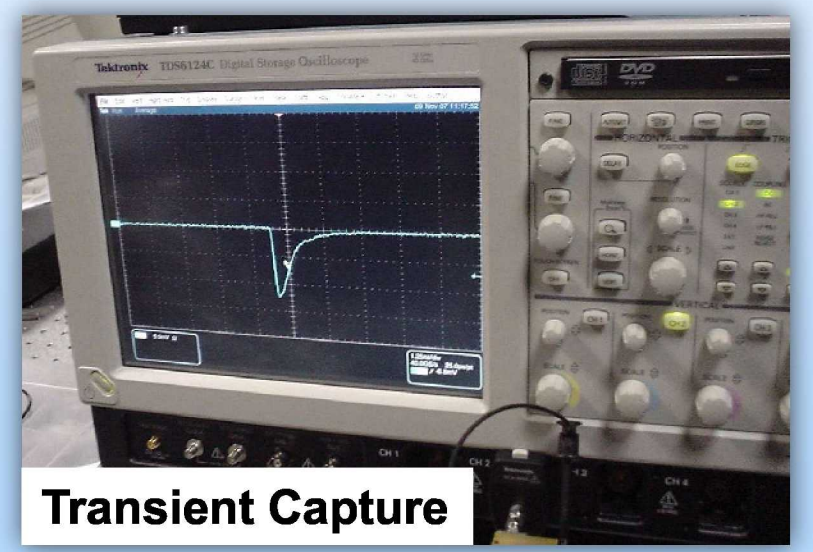


Similar setup for 4-terminal measurements

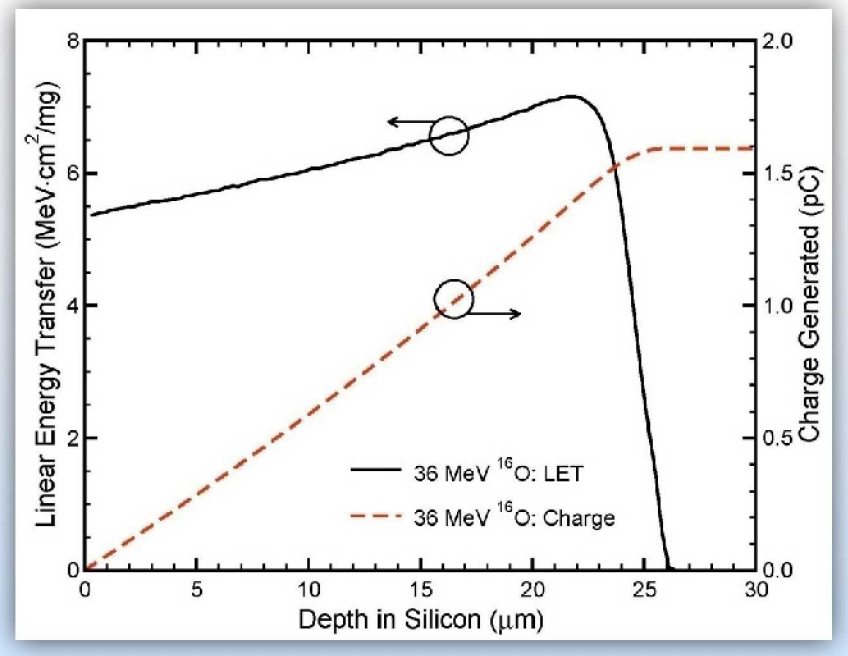
- **PSPL Bias Tees: 5542K**
- **DPO/DSO: Tek 71604A (16 GHz; 50 GS/s), Tek 72004A (20 GHz; 50 GS/s)**
- **2.9 mm coaxial cable assemblies (40 GHz)**

Sandia National Laboratories' Microbeam Chamber





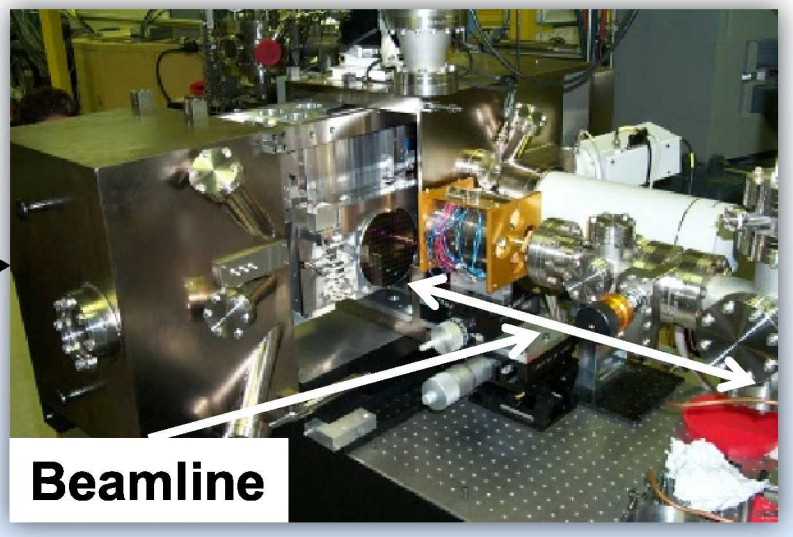
Microbeam Experimental Setup

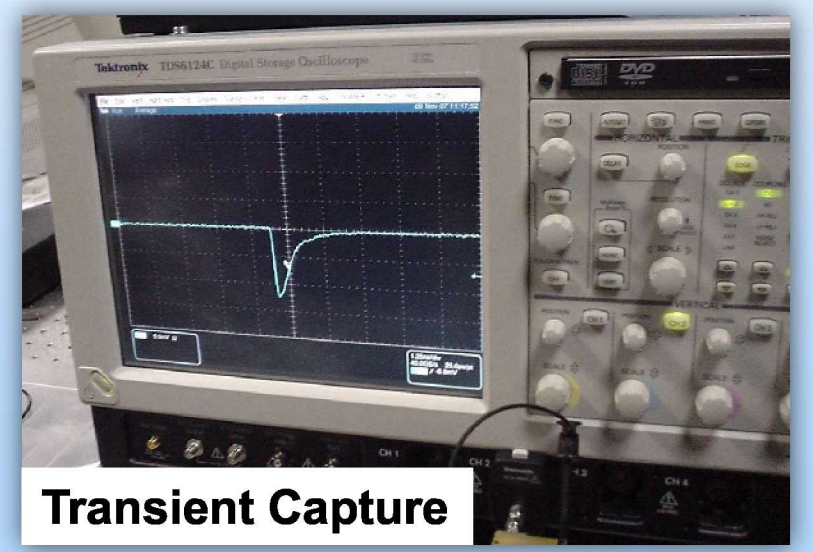


36 MeV ^{16}O d*E*/d*x* profile
[SRIM-2008]

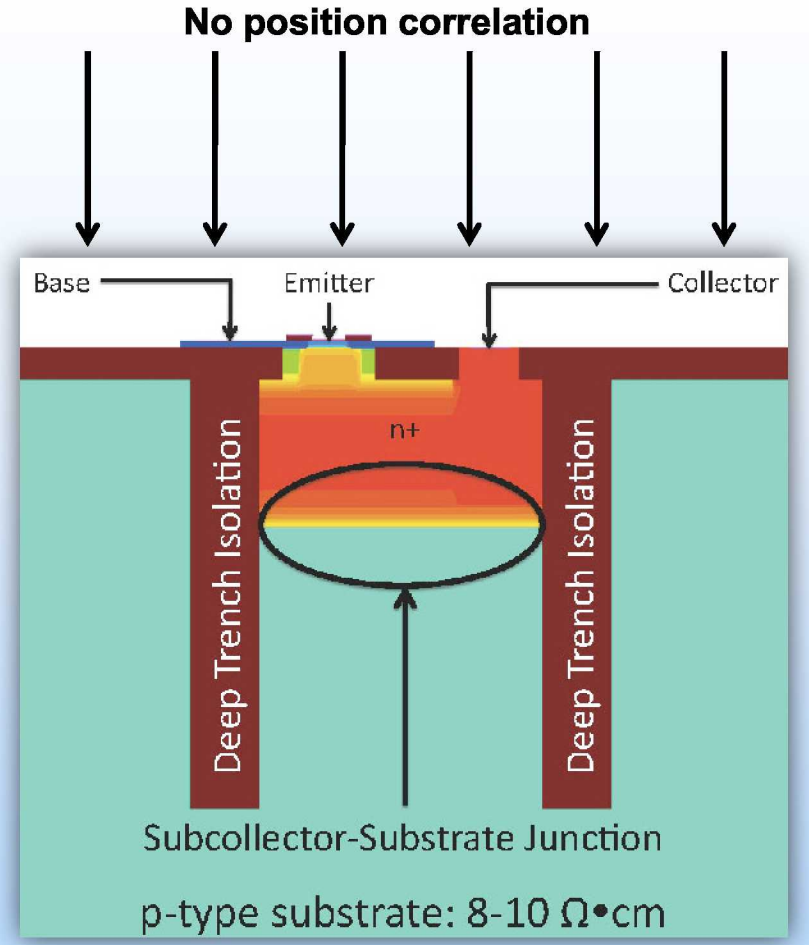
Sandia National Laboratories' Microbeam Chamber

****Advantages/Disadvantages****





Heavy Ion Broadbeam Experiments

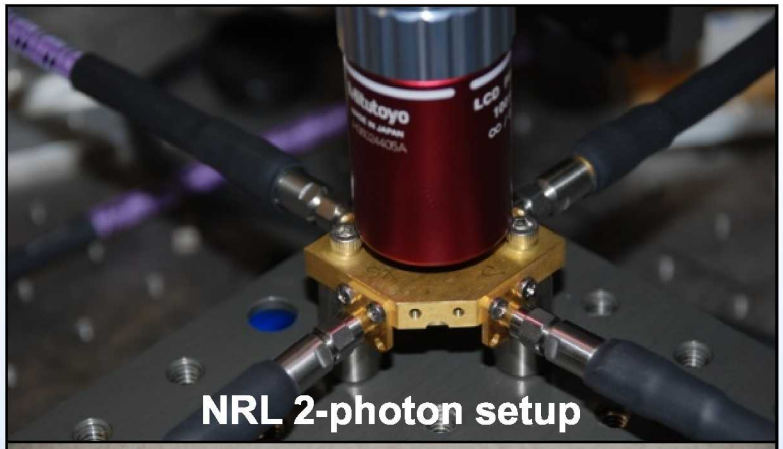


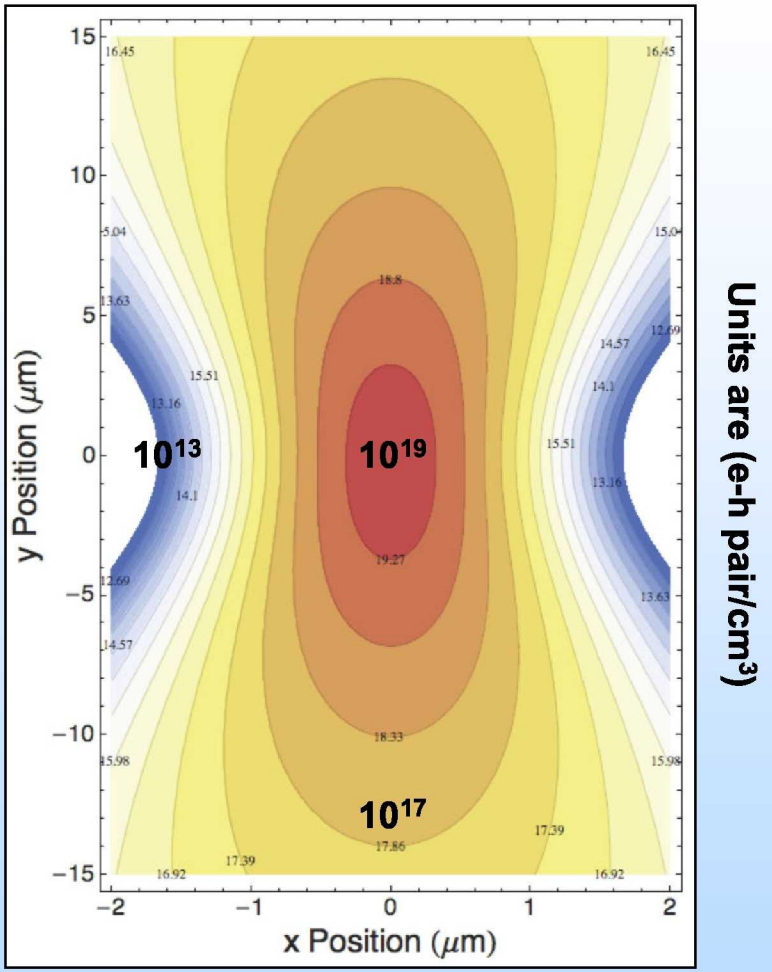
University of Jyväskylä
K-130 Cyclotron

****Advantages/Disadvantages****

- **Data collection at the University of Jyväskylä, Finland and GANIL, France**
- **9.3 MeV/u cocktail including ^{20}Ne, ^{40}Ar, ^{82}Kr, and ^{131}Xe and 45.5 MeV/u ^{136}Xe**

Two-Photon Absorption Testing





1260 nm TPA Electron-hole pair density contour

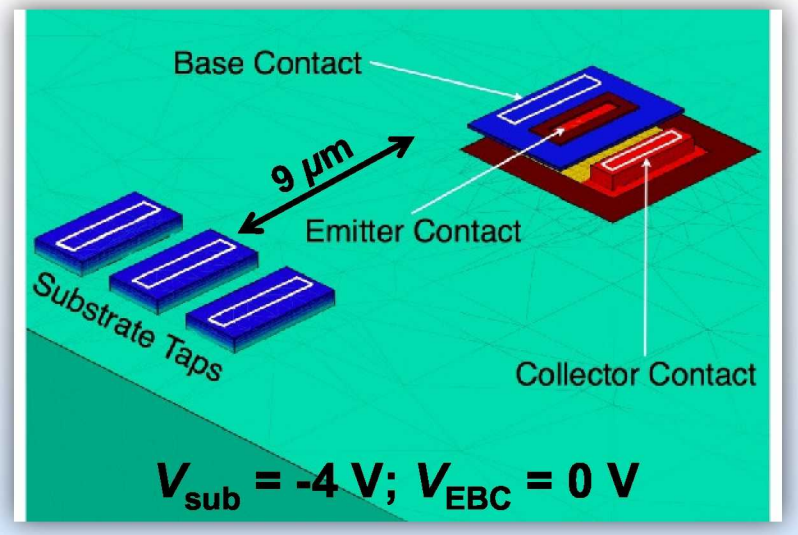
Electron-hole pair charge packet positioned at DUT in all three dimensions

J. A. Pellish *et al.*, *IEEE Trans. Nucl. Sci.*, vol. 55, no. 6, p. 2936, Dec. 2008.

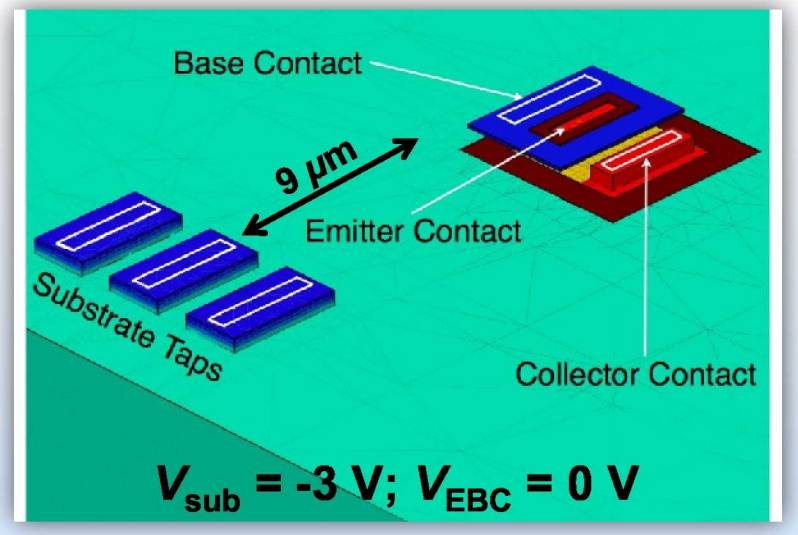
To be presented by Jonathan A. Pellish at the 2009 MURI Review, Vanderbilt University, Nashville, TN on 11/June/2009
and published on http://radhome.gsfc.nasa.gov/, http://www.nepp.gov/, and http://www.isde.vanderbilt.edu/

Bias Conditions of Interest

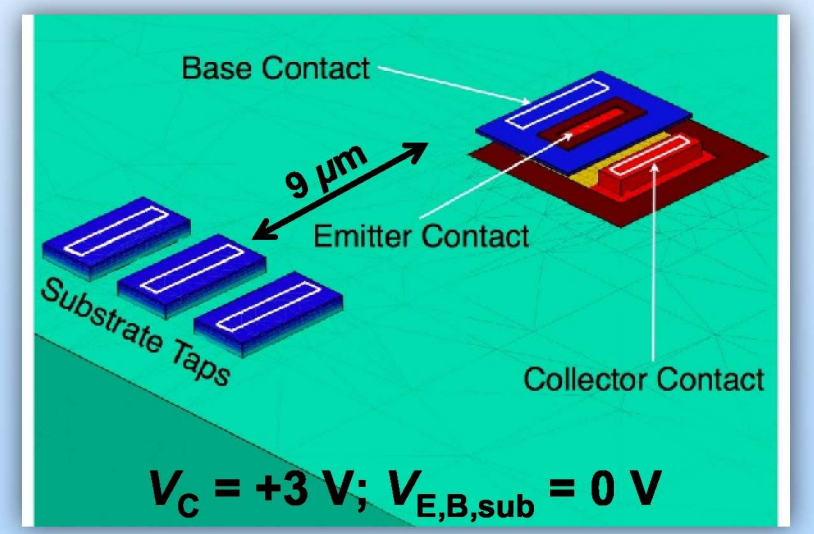
CASE 1



CASE 3



CASE 2

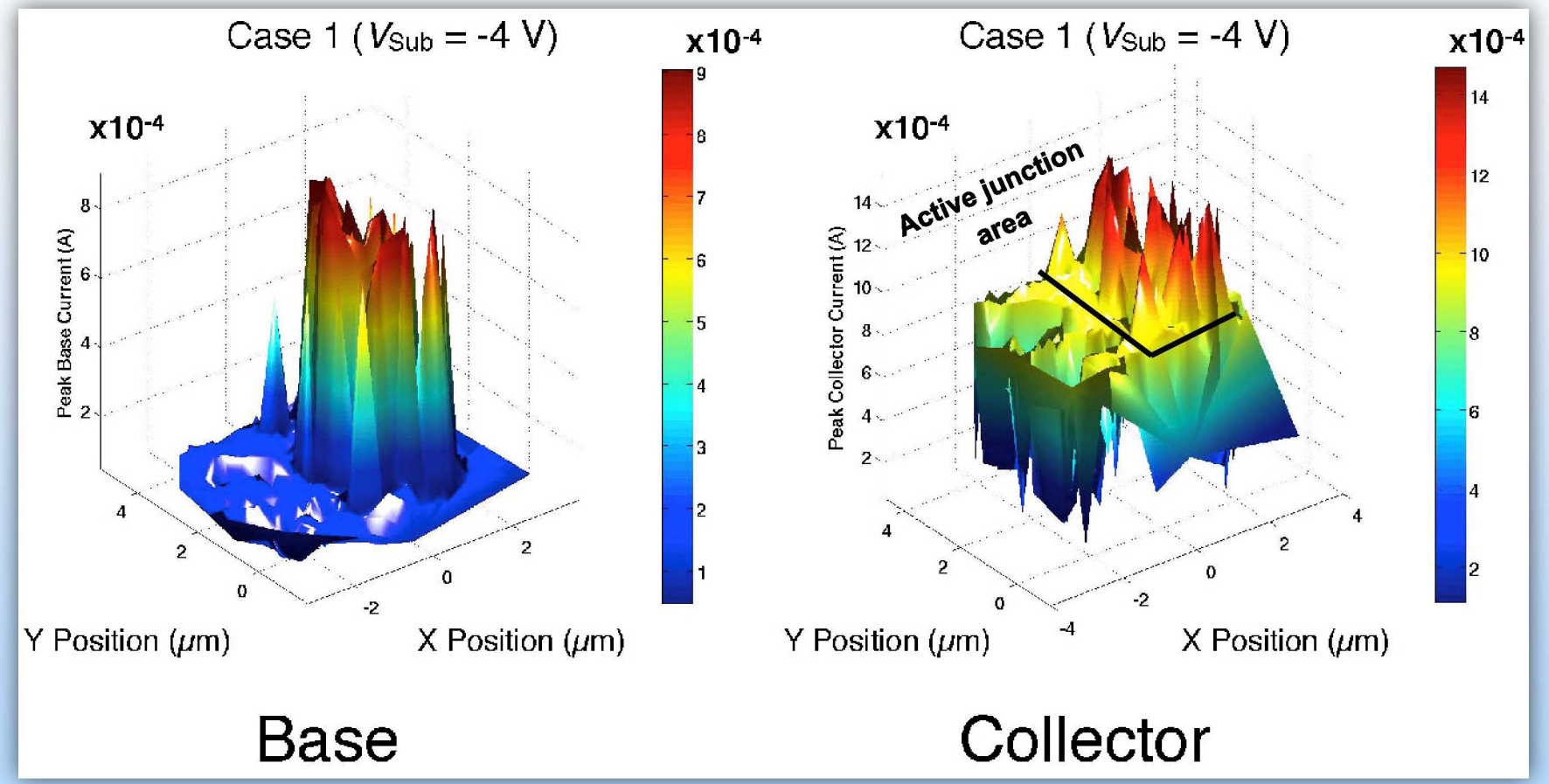


- 3-D TCAD
- Rendering from GDSII of actual DUTs

Heavy Ion Microbeam Transients

36 MeV ^{36}O Microbeam Data: Case 1

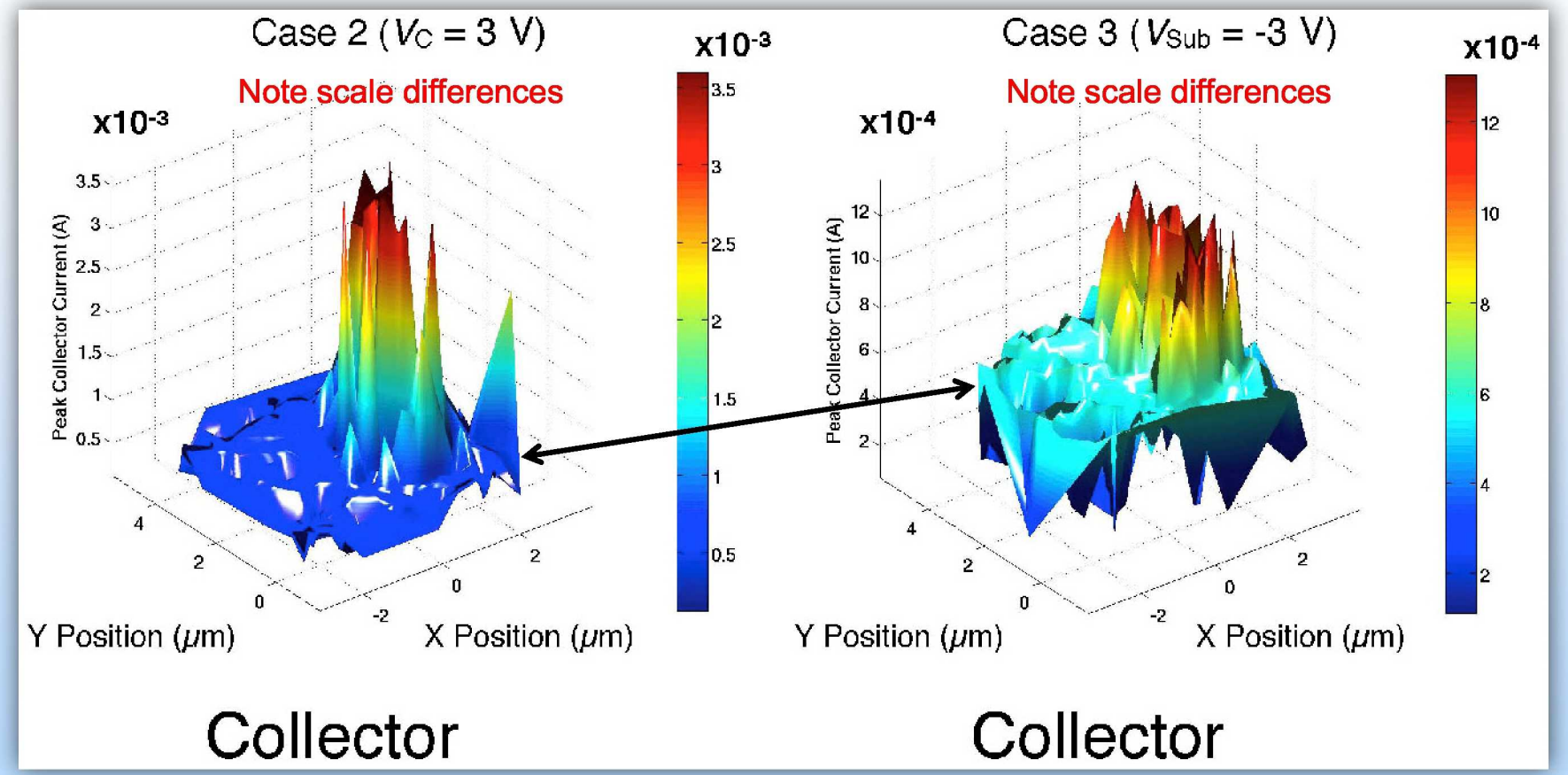
Peak Current Magnitude



- **Base terminal images base-collector junction**
- **Collector terminal images base-collector junction and subcollector**

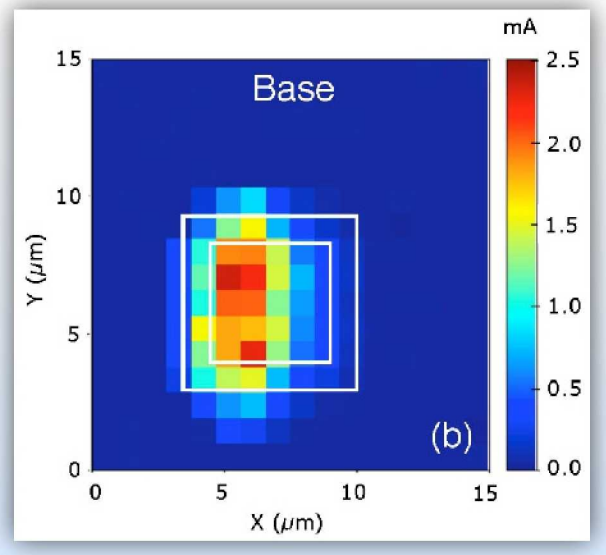
36 MeV ^{36}O Microbeam Data: Cases 2 & 3

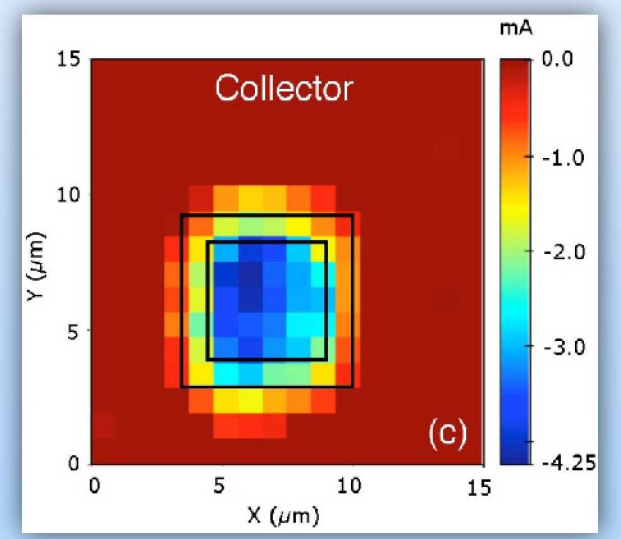
Peak Current Magnitude



- **Significant current magnitude increase for V_C = +3 V**
- **Observed in two-photon pulsed laser testing too**

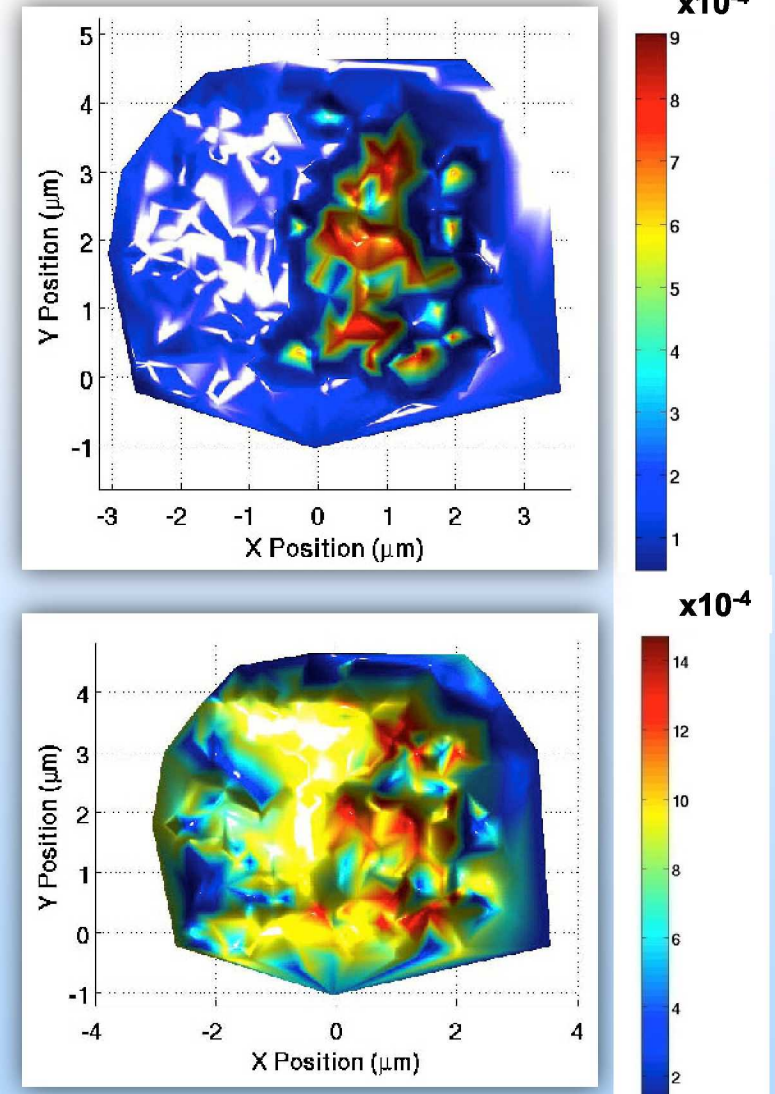
TPA Pulsed Laser *vs.* Microbeam





TPA Pulsed Laser

Both data sets for CASE 1 (V_{sub} = -4 V)

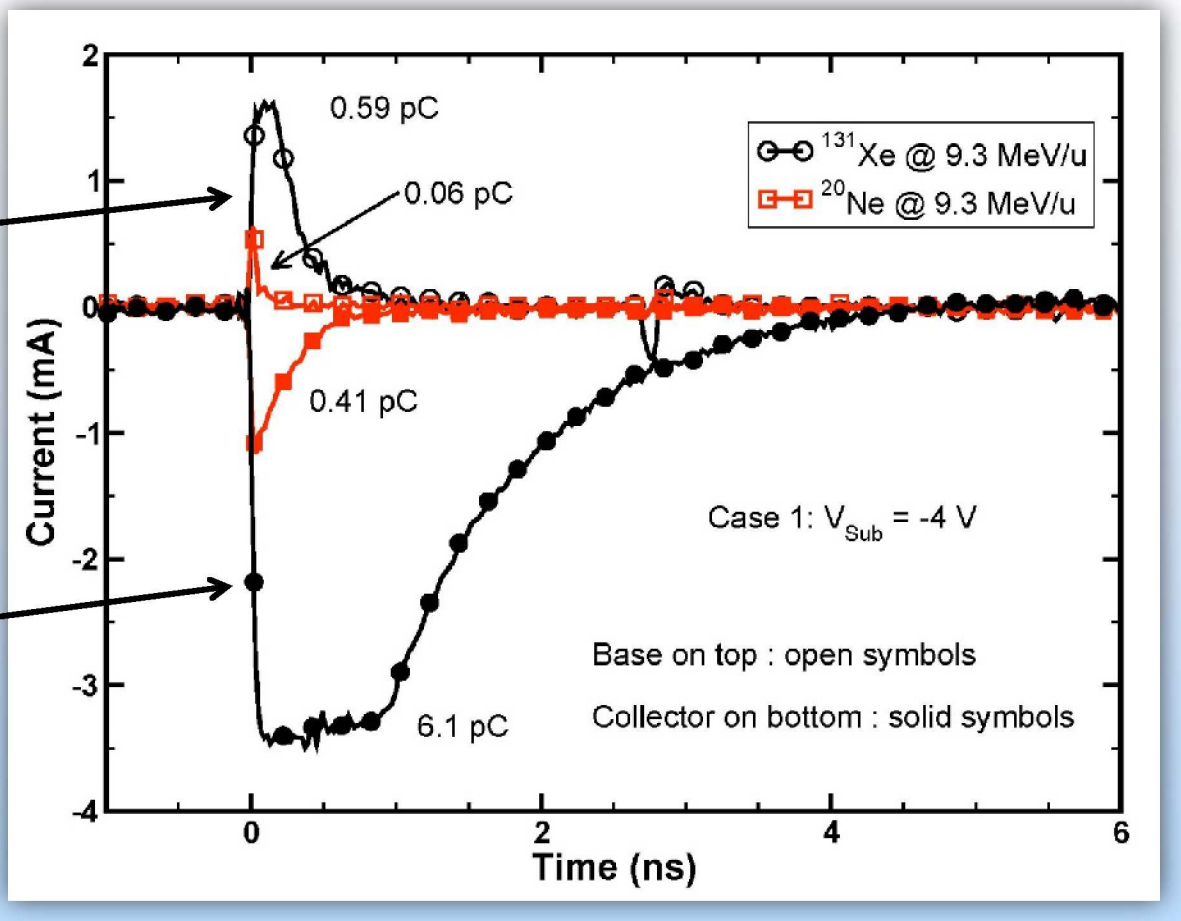


Microbeam

J. A. Pellish *et al.*, *IEEE Trans. Nucl. Sci.*, vol. 55, no. 6, p. 2936, Dec. 2008.

Heavy Ion Broadbeam Transients

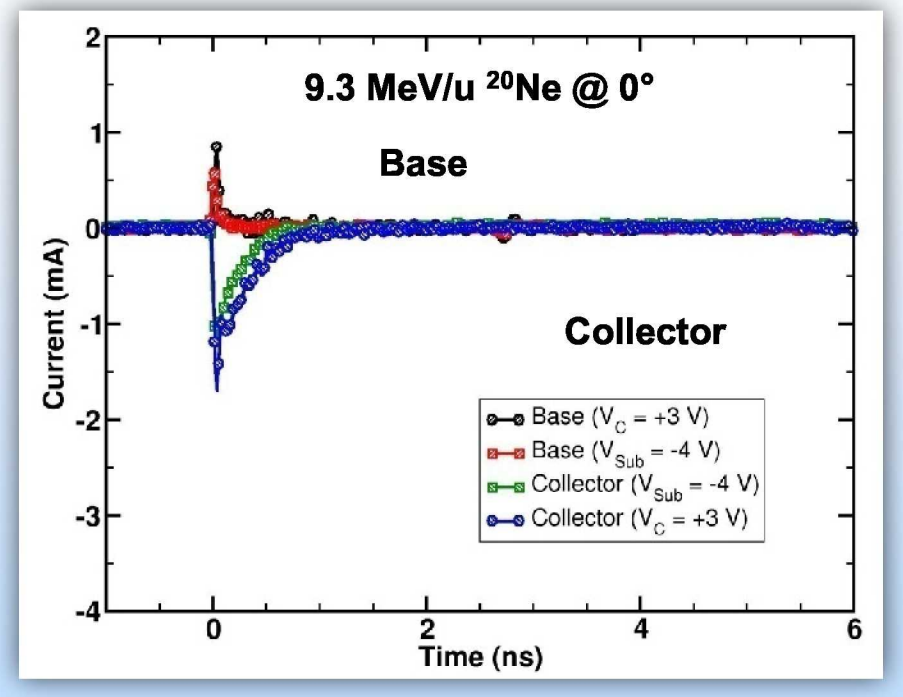
JYFL Broadbeam Transients

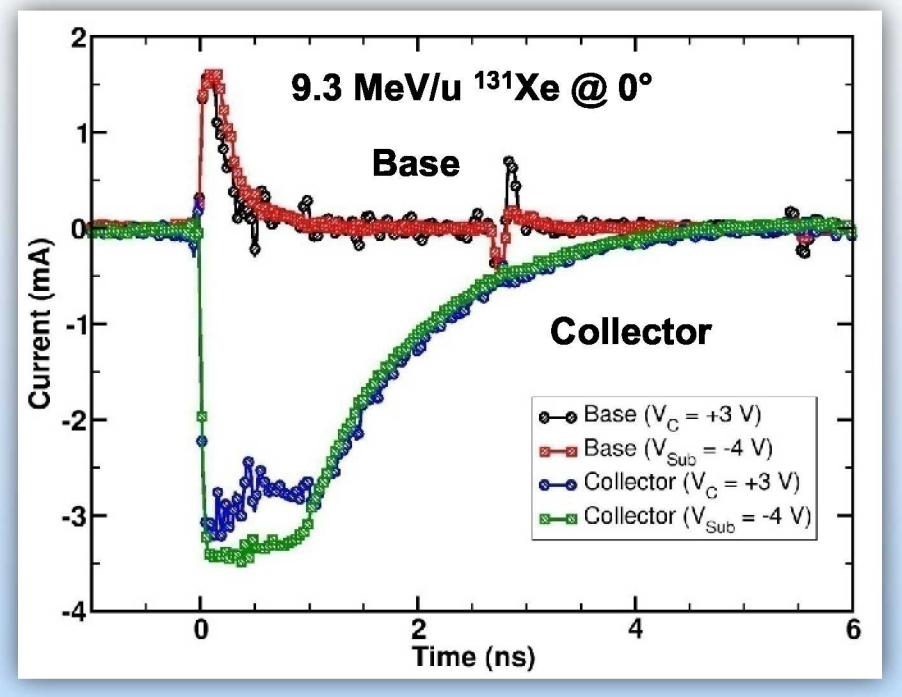


- **Typical events observed from events somewhere within active region**
- **Position inferred using SNL microbeam data**

JYFL Broadbeam Transients

Maximum amplitude transients as a function of bias

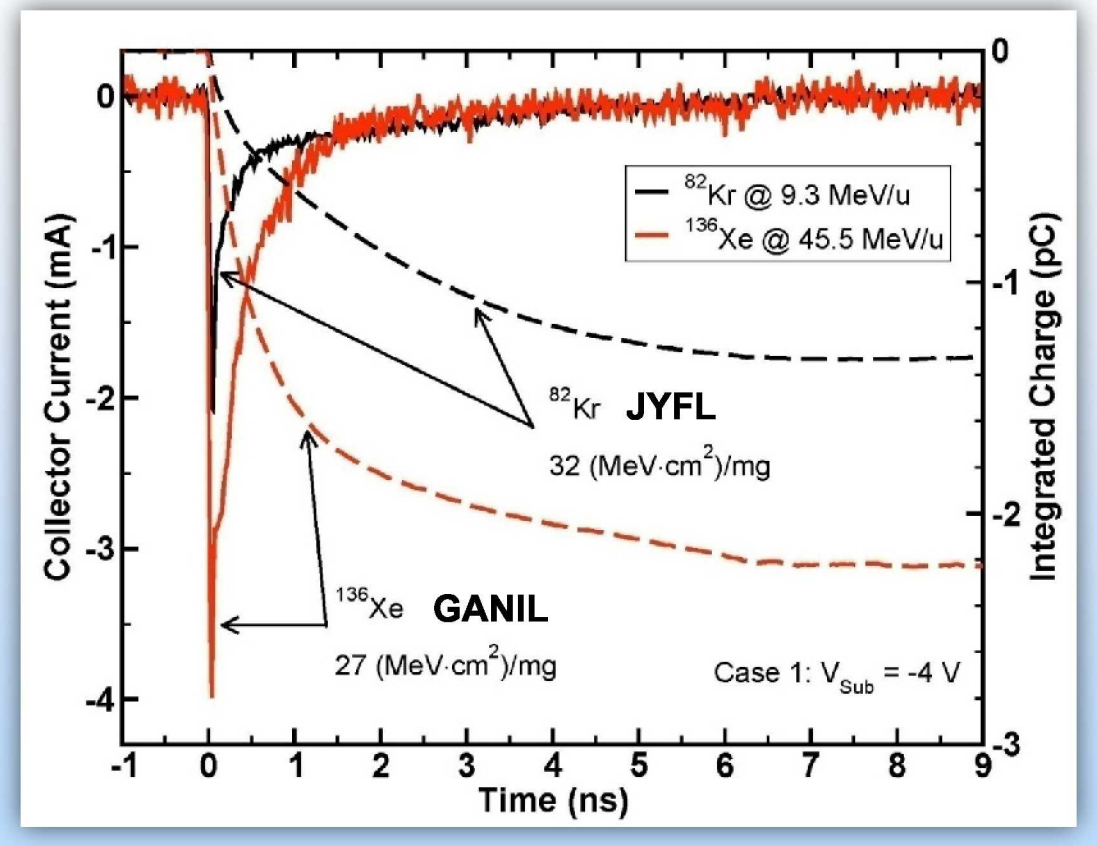




- **Saturation of collector current transient with highly ionizing particle**
- **Some bias dependence, but masked by random hit location**

JYFL *vs.* GANIL Broadbeam Transients

Ion Range



Recombination

- **Similar LET values produce different transient responses**
- **Trend holds for average of all transients for each LET**

Path Forward

- **Attempt to uncover reason for increase in collector current for V_C = +3 V bias condition**
  - **Impact ionization, bias scheme or other positive feedback**
- **Uncover role of ion range and recombination mechanisms in lightly-doped substrates**
  - **GANIL 45.5 MeV/u ^{136}Xe *vs*. JYFL 9.3 MeV/u ^{82}Kr**
- **Build new devices and circuits with matching networks to provide appropriate impedances**
  - **Both "looking in" and "looking out"**

Summary

- **Time-resolved ion beam induced charge reveals heavy ion response of IBM 5AM SiGe HBT**
  - **Position correlation**
  - **Unique response for different bias schemes**
  - **Similarities to TPA pulsed-laser data**
- **Heavy ion broadbeam transients provide more realistic device response**
  - **Feedback using microbeam data**
  - **Overcome existing issues of LET and ion range with microbeam**
- **Both micro- and broadbeam data sets yield valuable input for TCAD simulations**
  - **Uncover detailed mechanisms for SiGe HBTs and other devices fabricated on lightly-doped substrates**
  - **What type of device transient constitutes a circuit effect?**