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

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- Naval Research Laboratory
- Sandia National Laboratories
- CEA, DAM, DIF (Arpajon, France)

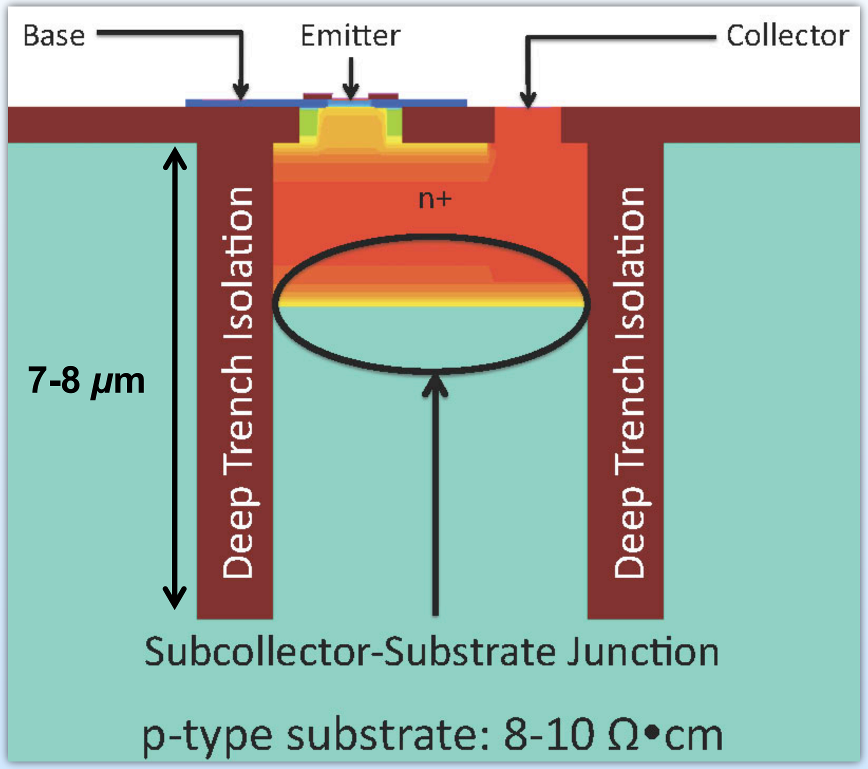
Overview

- **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 μm)



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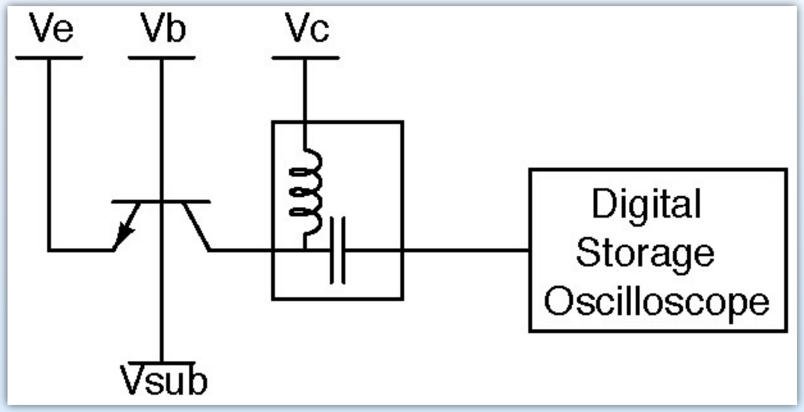
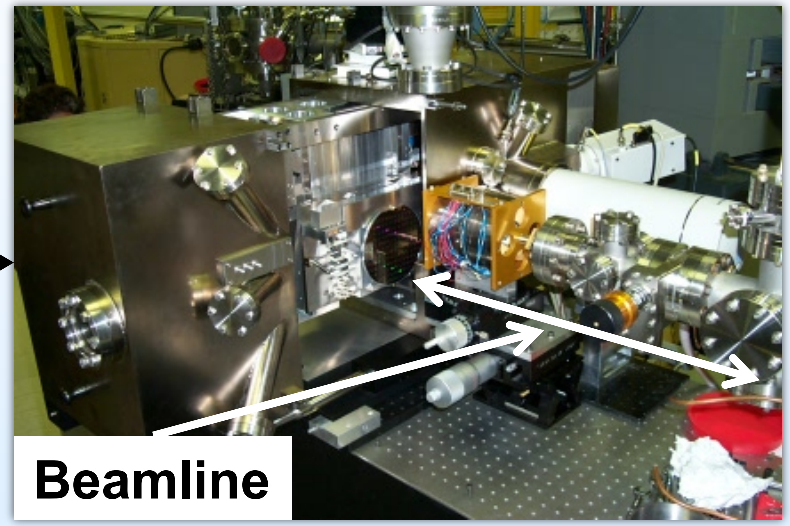
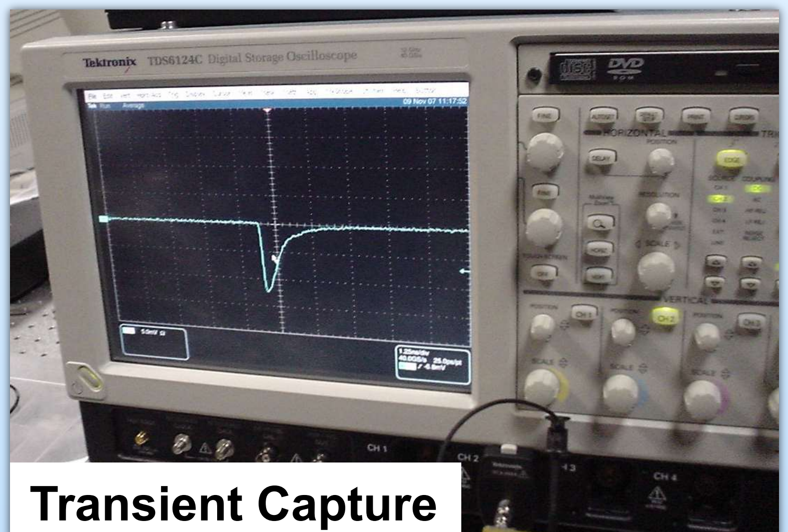
Previous tests focused on pulsed laser carrier generation only
New tests focus on heavy ion carrier generation

Microbeam Experimental Setup

General electrical setup used in all cases





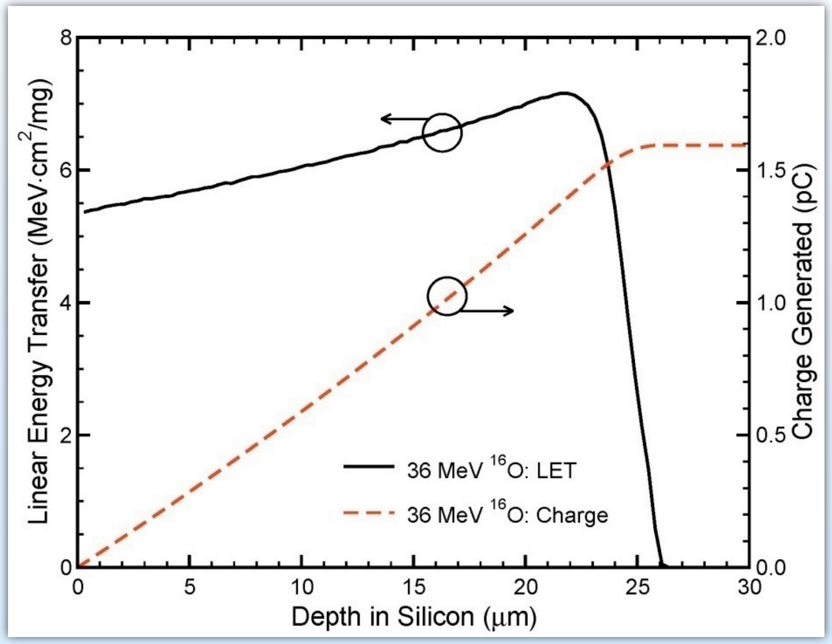


Similar setup for 4-terminal measurements

- **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

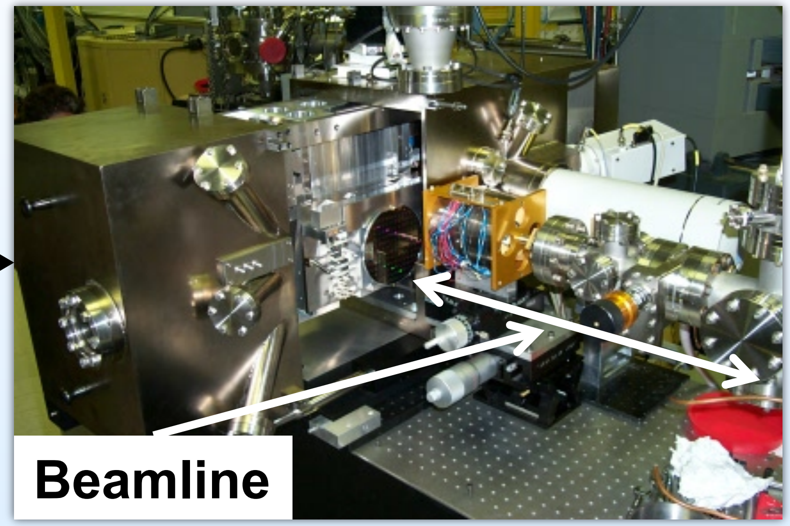
Microbeam Experimental Setup

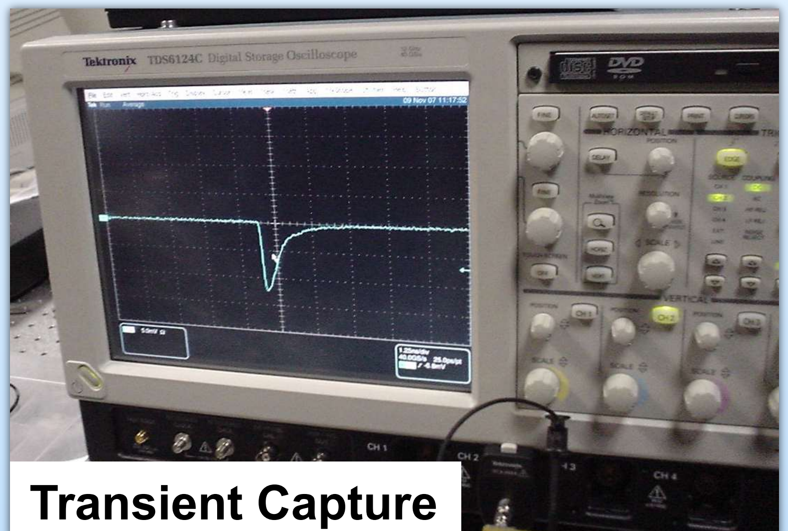


36 MeV ^{16}O d*E*/d*x* profile

[SRIM-2008]

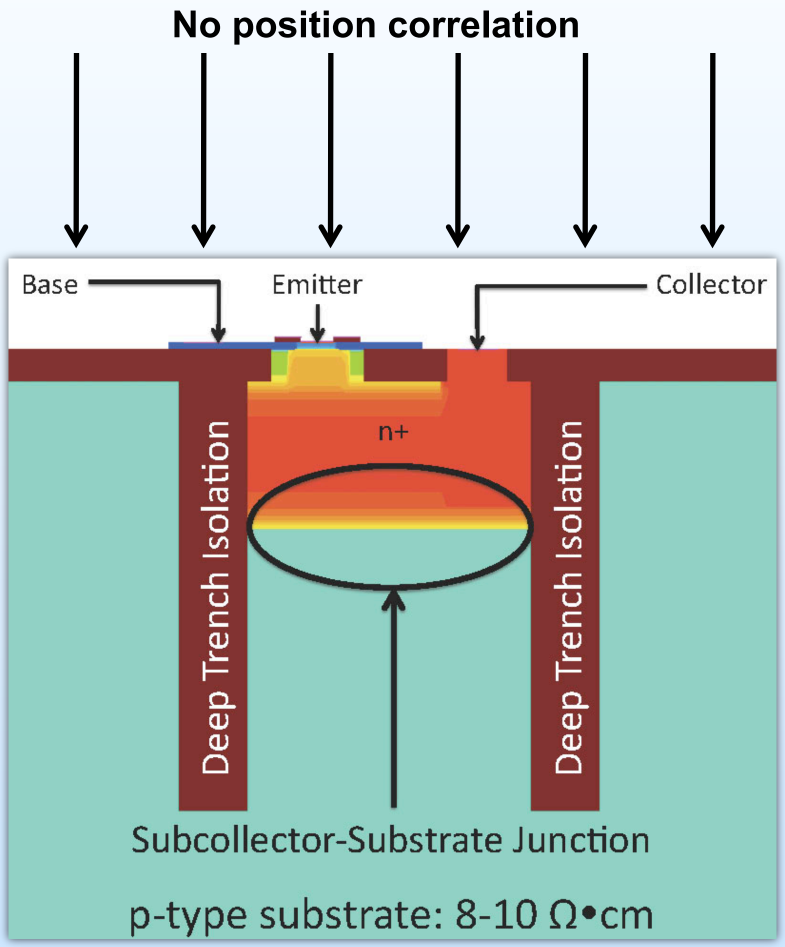
Sandia National Laboratories' Microbeam Chamber





****Advantages/Disadvantages****

Heavy Ion Broadbeam Experiments

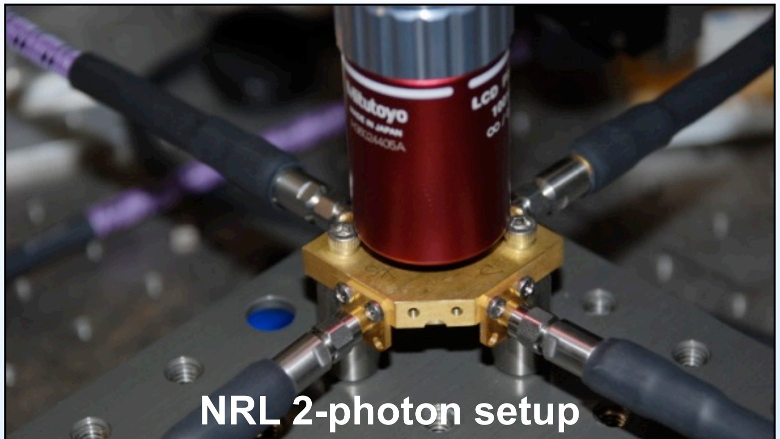


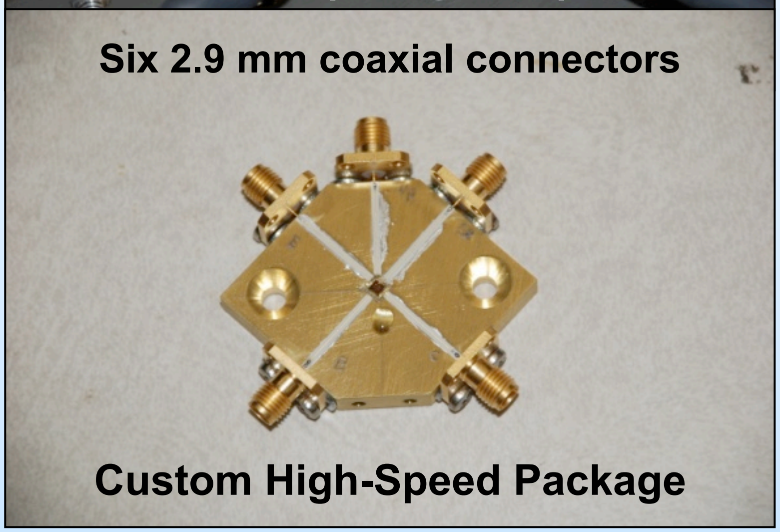
University of Jyväskylä
K-130 Cyclotron

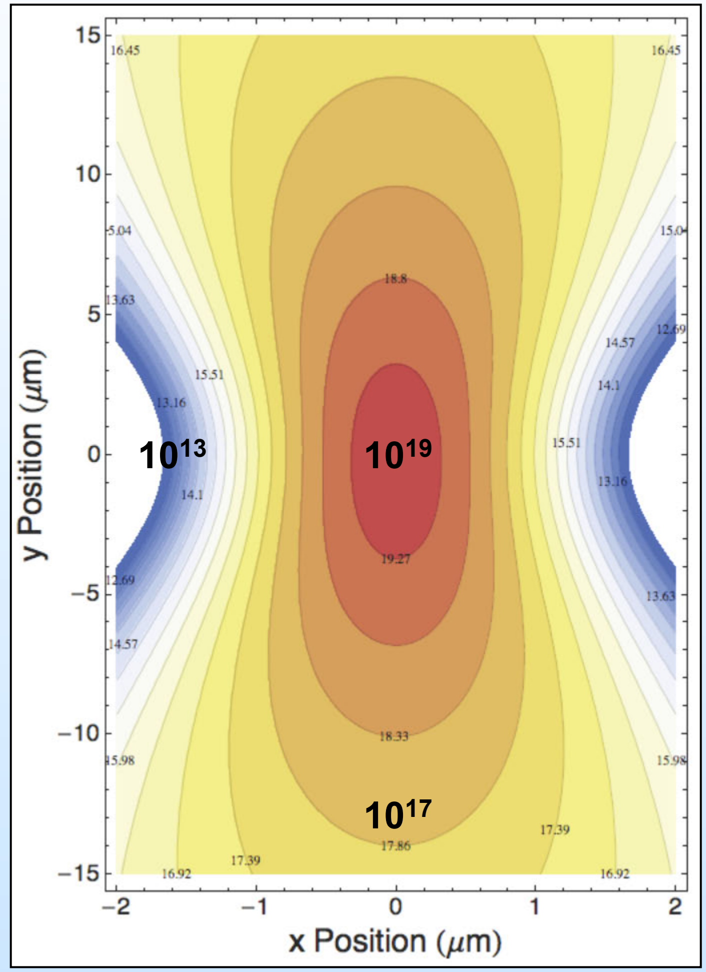
****Advantages/Disadvantages****

- **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

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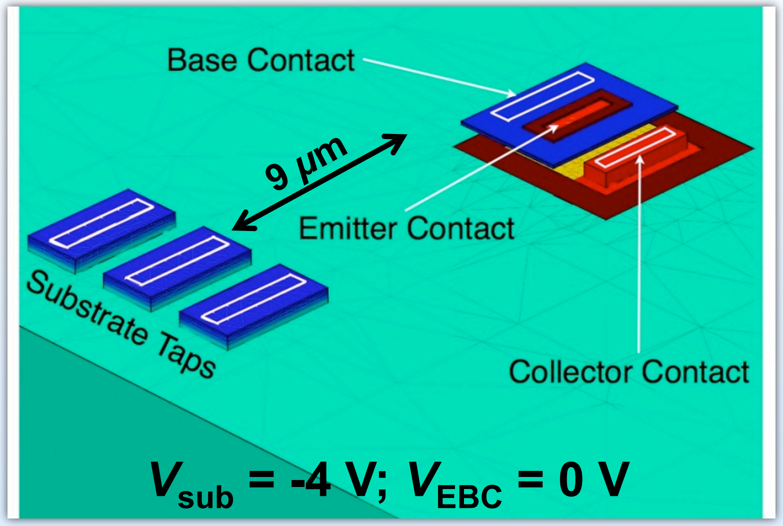
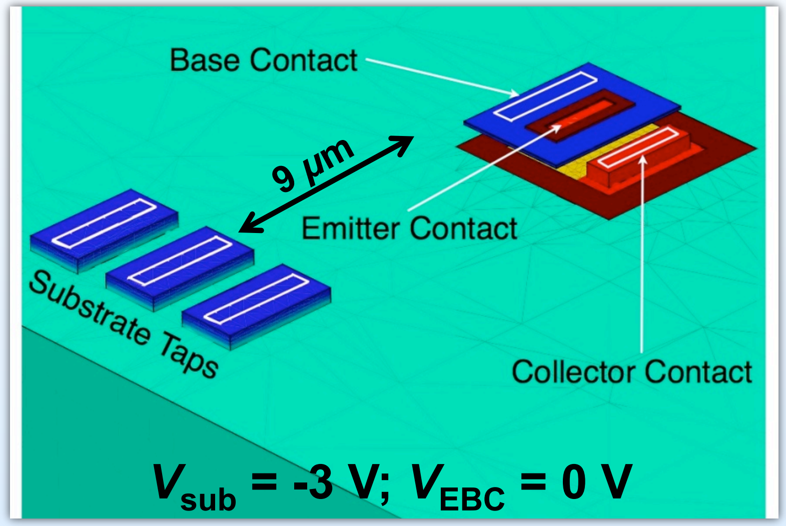
Bias Conditions of Interest

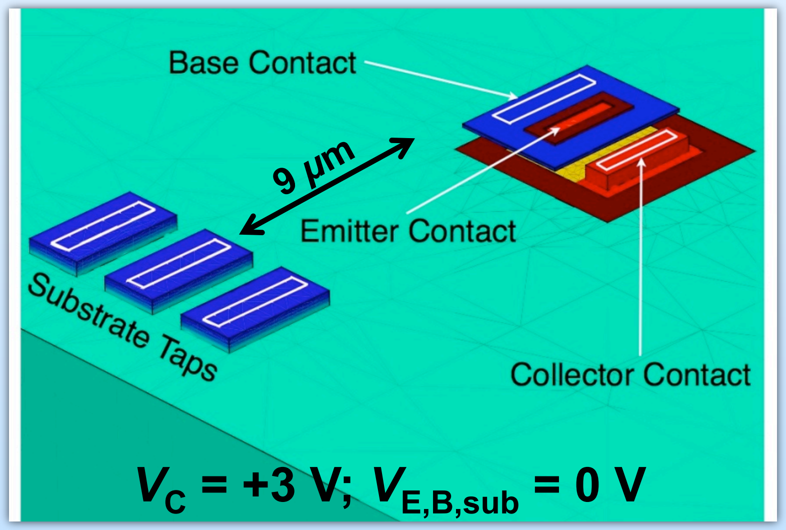
CASE 1



CASE 3



CASE 2

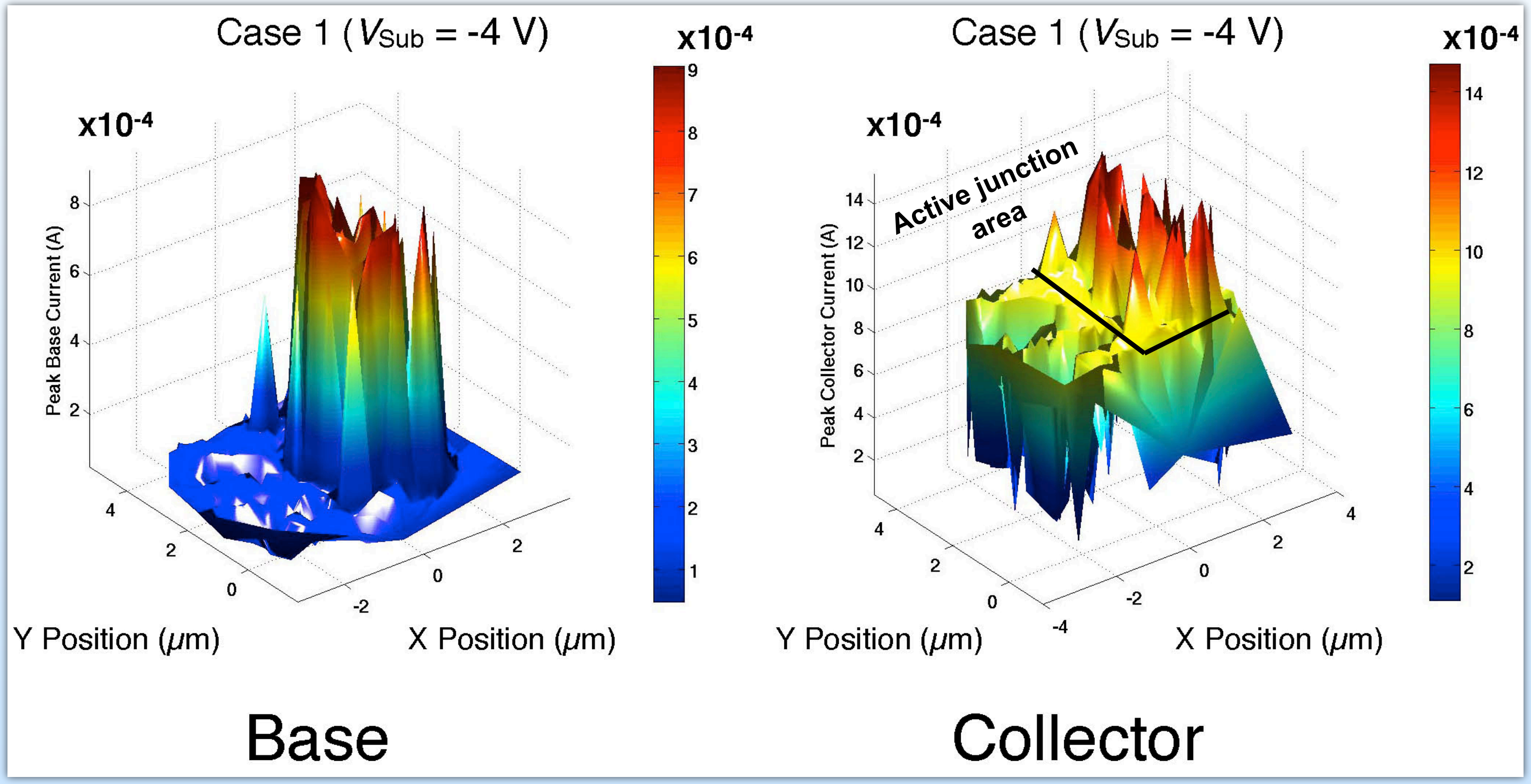


- **3-D TCAD**
- **Rendering from GDSII of actual DUTs**

Heavy Ion Microbeam Transients

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

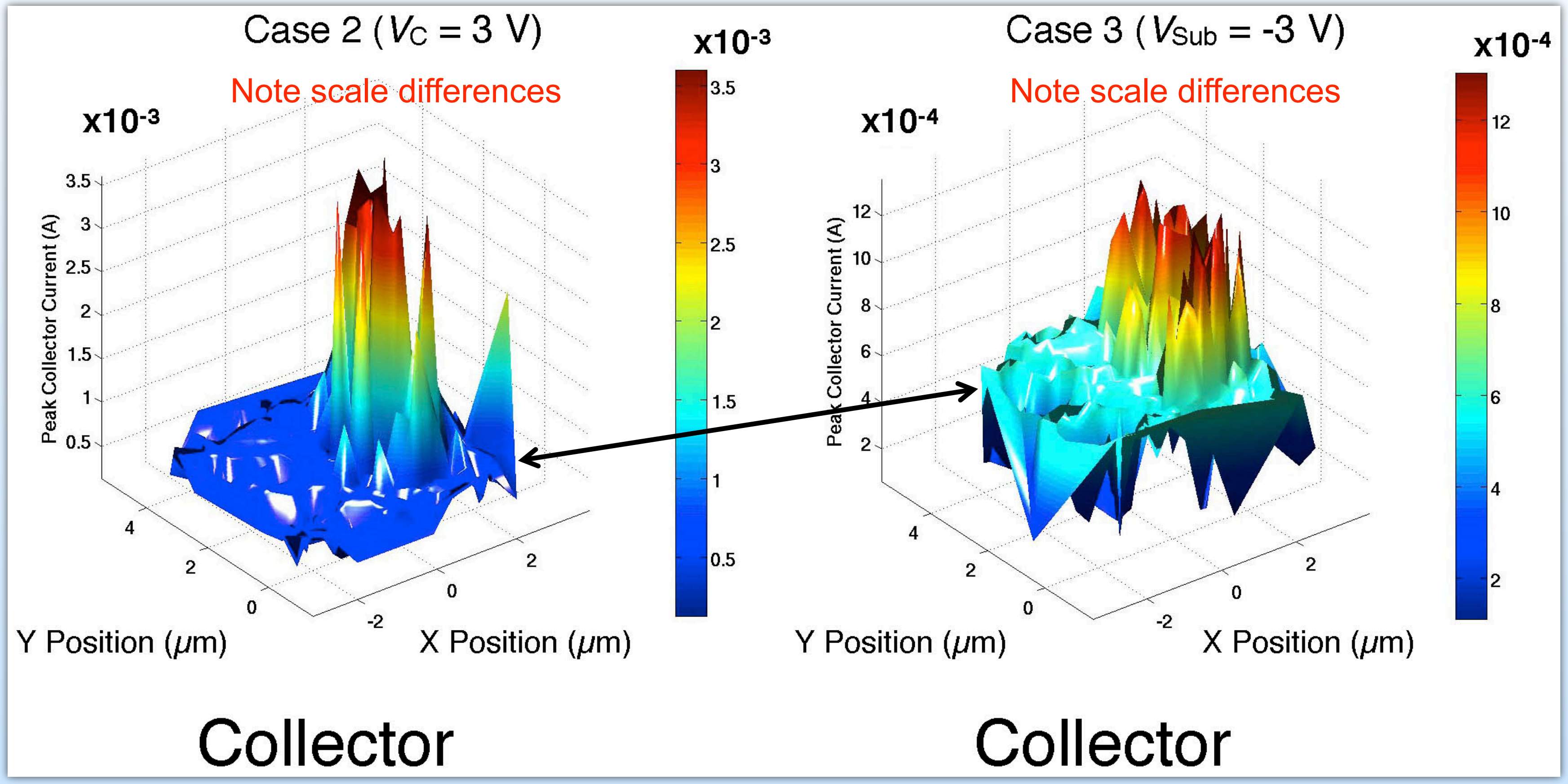
Peak Current Magnitude



- **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

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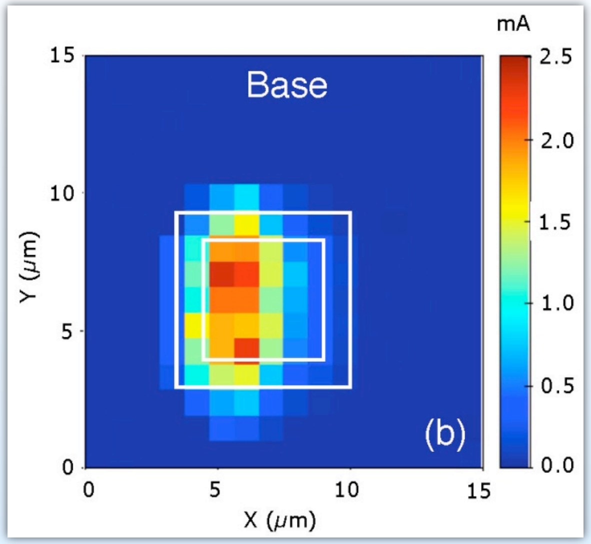
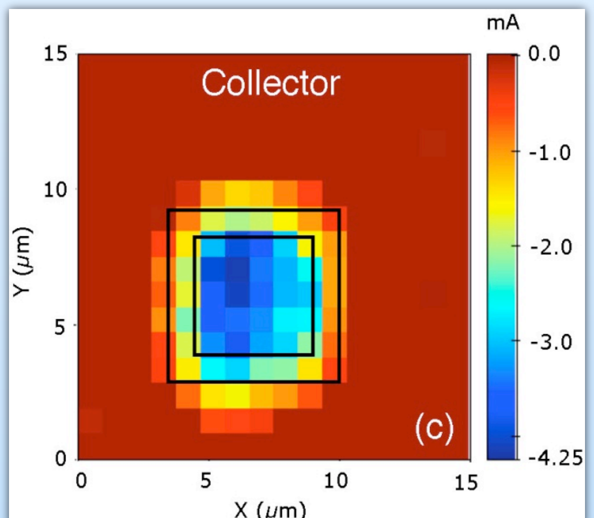
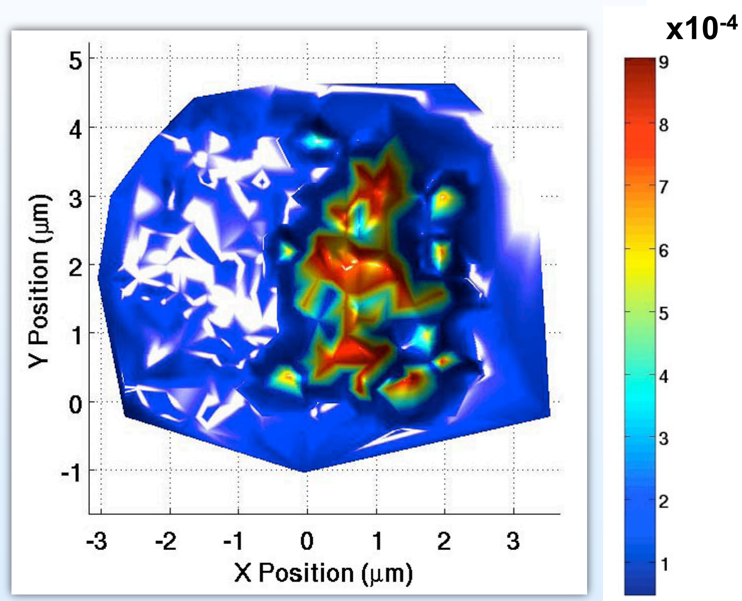
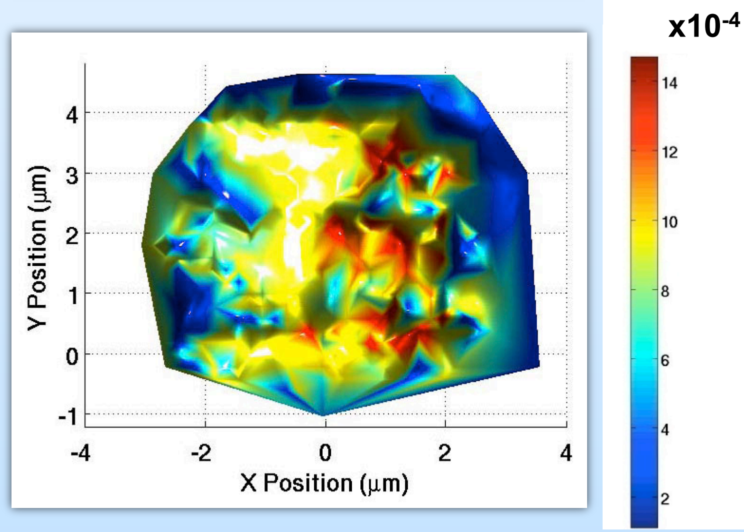




TPA Pulsed Laser

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

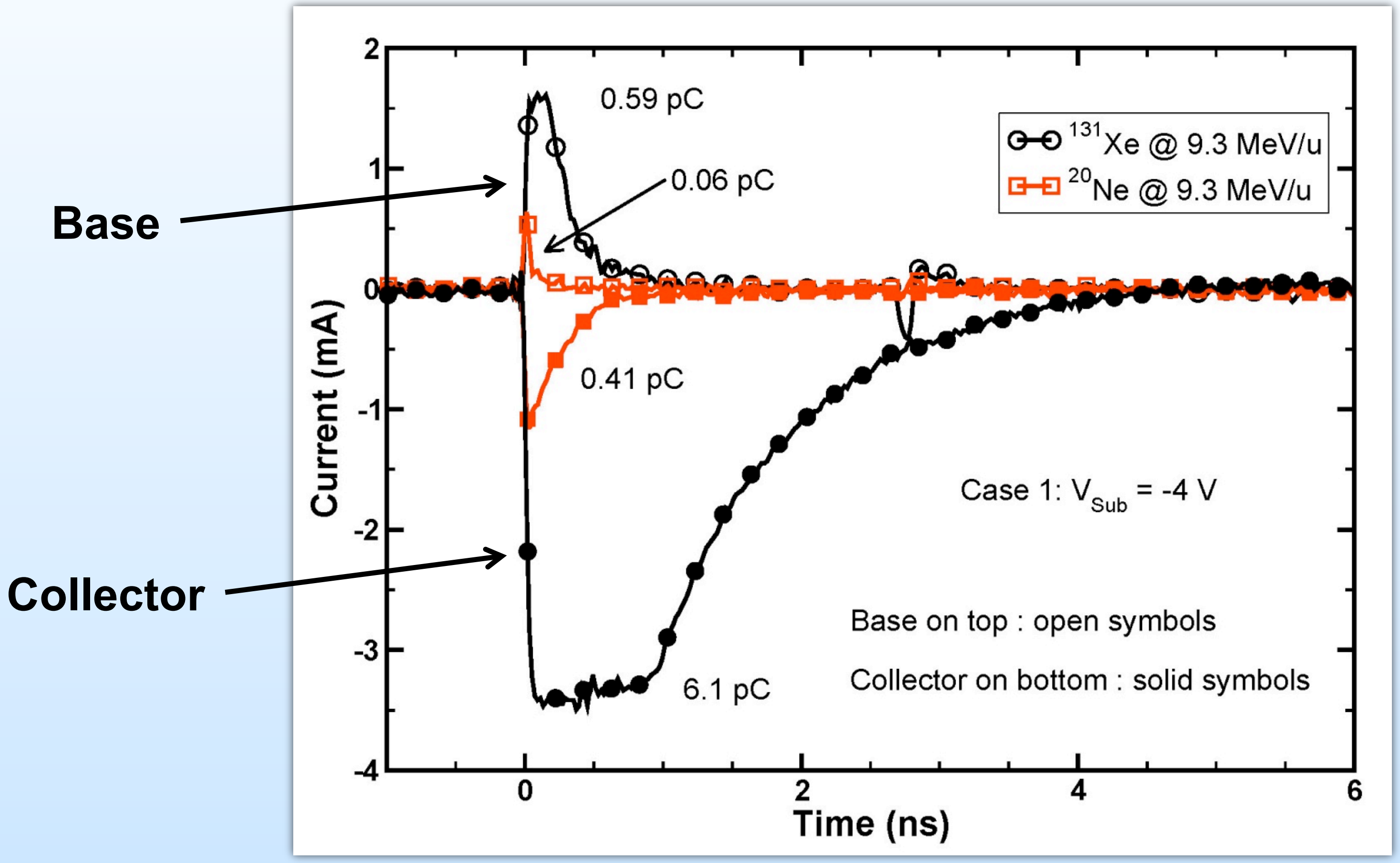




Microbeam

Heavy Ion Broadbeam Transients

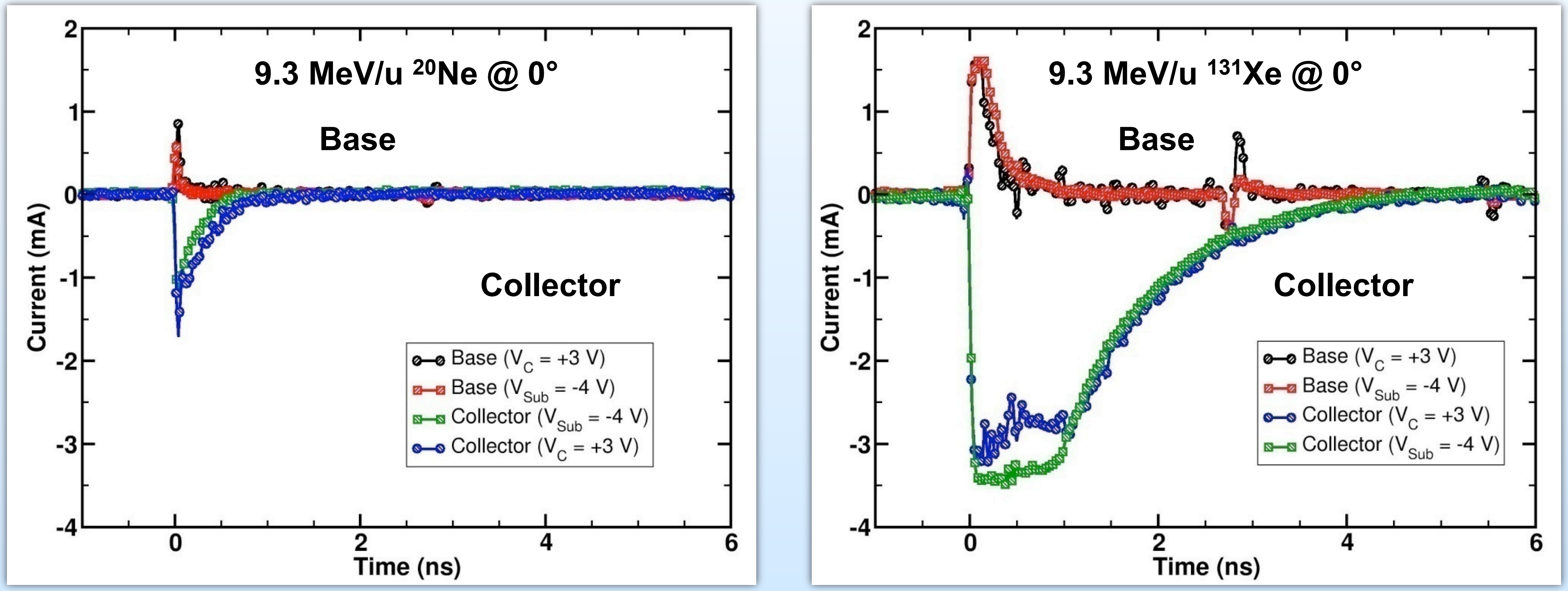
JYFL Broadbeam Transients



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

JYFL Broadbeam Transients

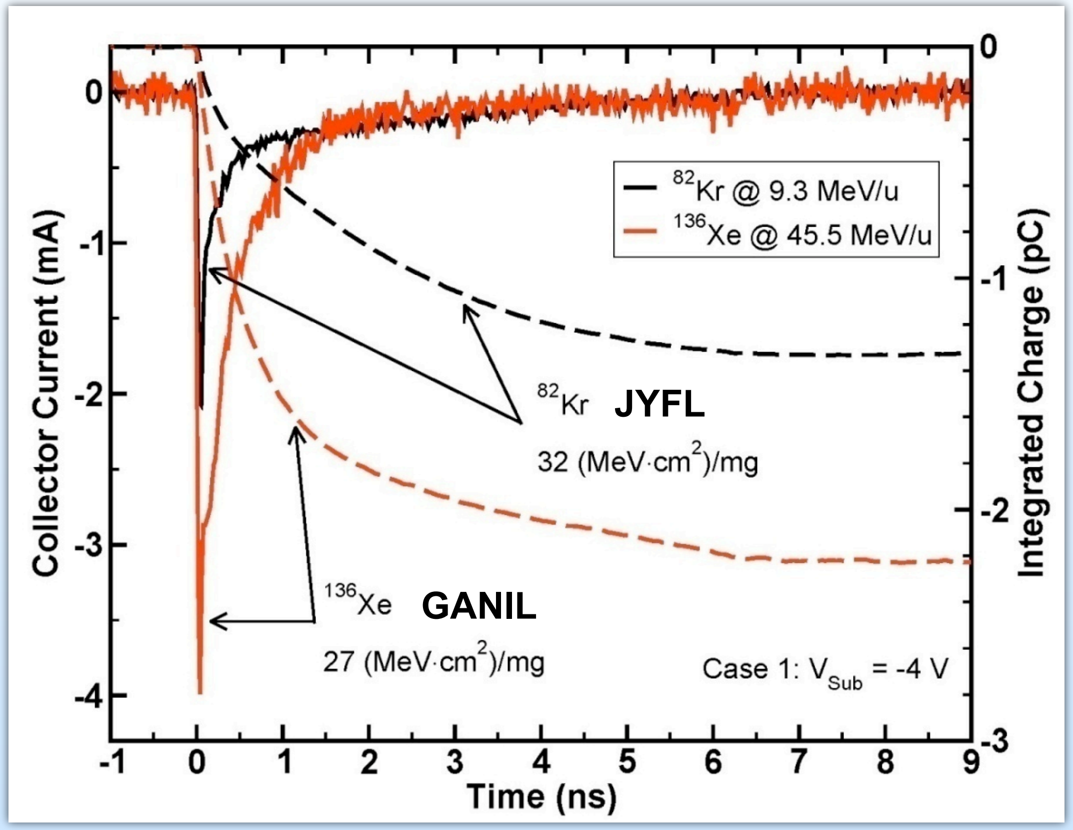
Maximum amplitude transients as a function of bias



- 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 <u>device</u> transient constitutes a <u>circuit</u> effect?