Heavy Ion Current Transients in SiGe HBTs

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Overview

- Look at device under test (IBM 5AM SiGe HBT)
- Review bias conditions of interest
  - Relation to findings of previous experiments
- Heavy ion microbeam data
  - 36 MeV ^{16}O (SNL)
- Heavy ion broadbeam data
  - Low- and high-energy tunes (JYFL and GANIL)
- Path forward and summary

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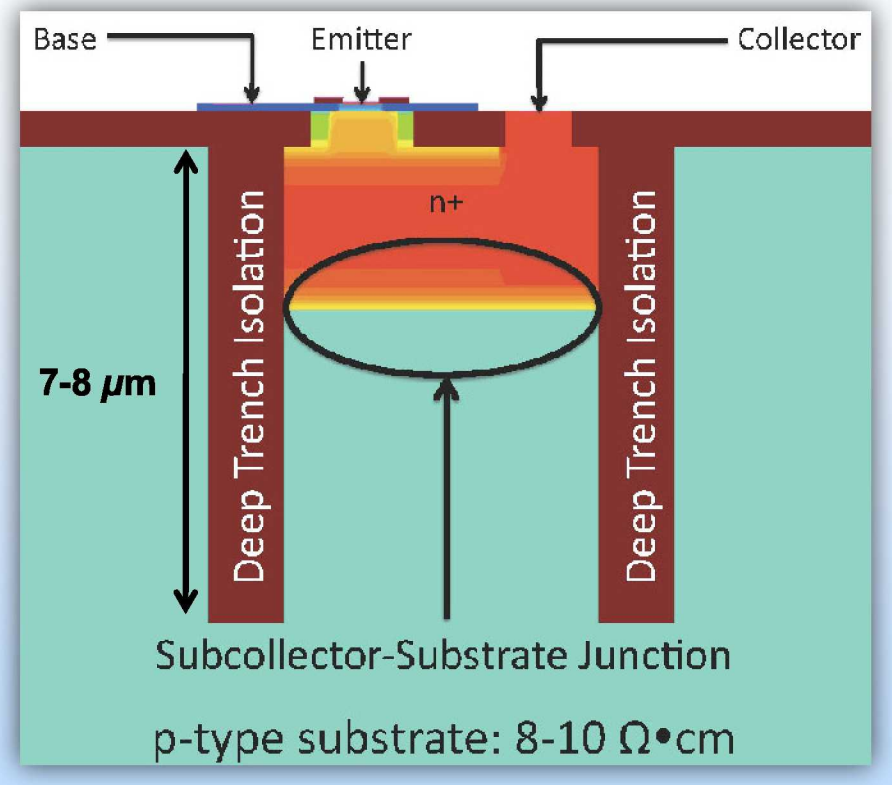
Device Background and Introduction

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

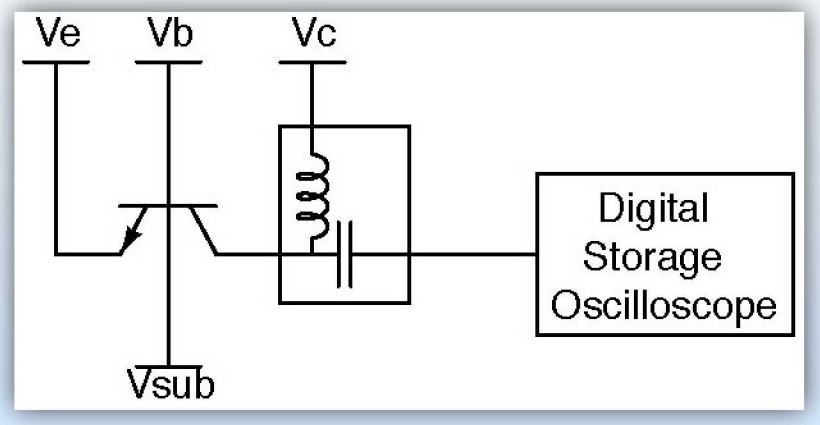
IBM 5AM SiGe HBT (0.5 *μ*m)



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

Previous measurements on SiGe HBTs have only looked at laser-induced transients or heavy ion charge collection.

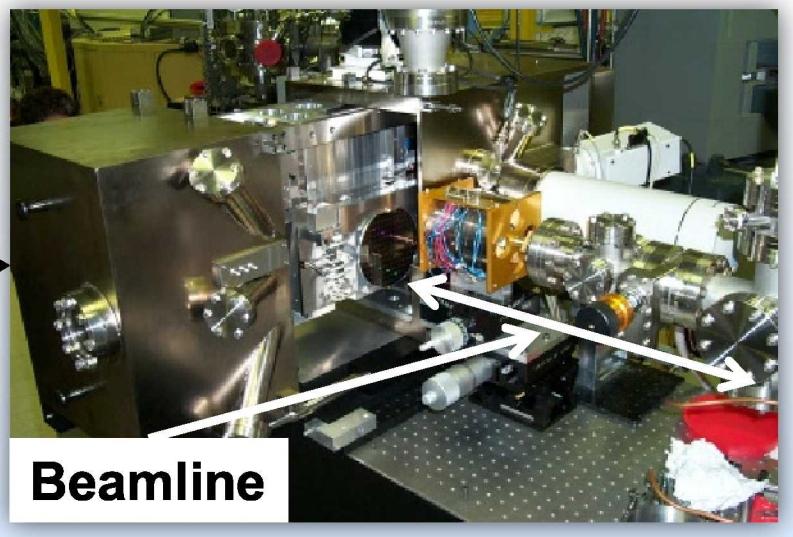
Microbeam Experimental Setup

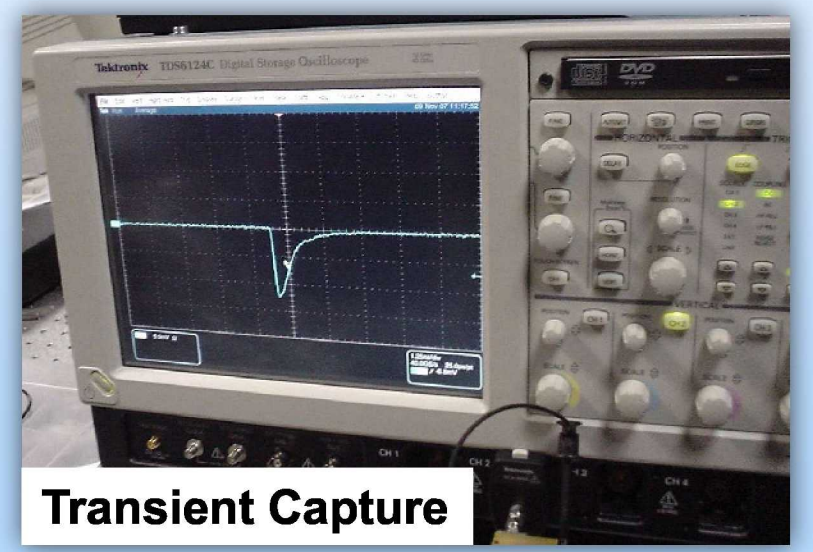


Similar setup for 4-terminal measurements

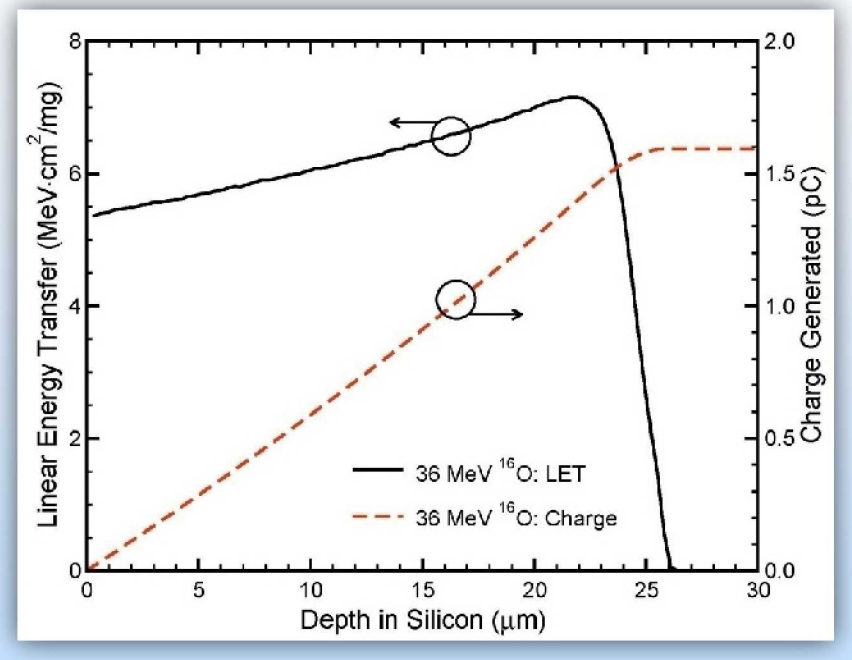
- **PSPL Bias Tees: 5542K**
- **DPO/DSO: Tek 71604A (16 GHz; 50 GS/s), Tek 72004A (20 GHz; 50 GS/s)**
- **2.9 mm coaxial cable assemblies (40 GHz)**

Sandia National Laboratories' Microbeam Chamber



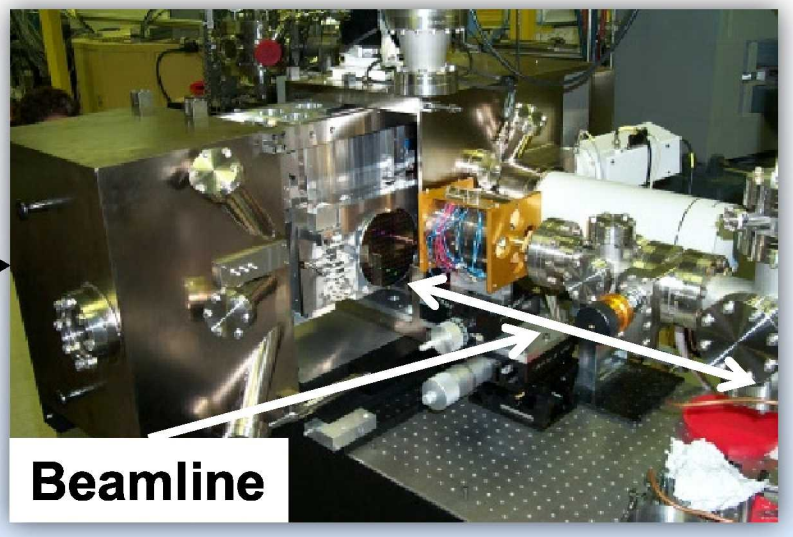


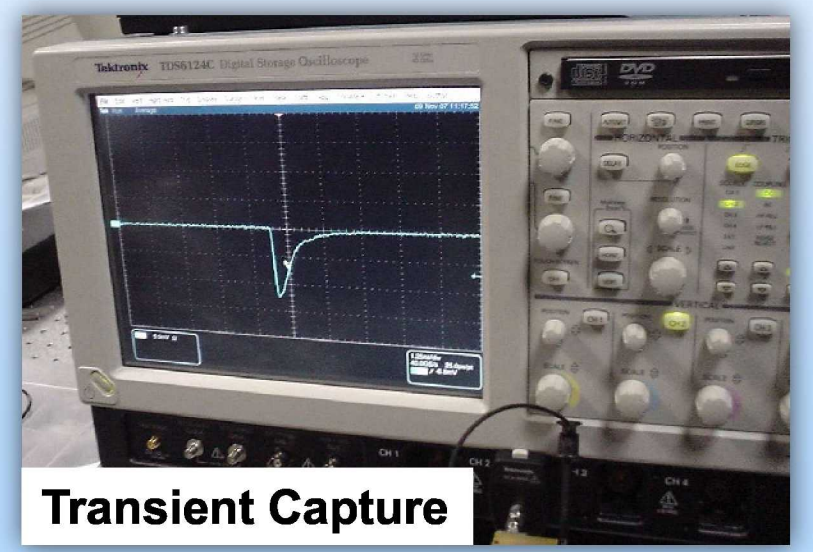
Microbeam Experimental Setup



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

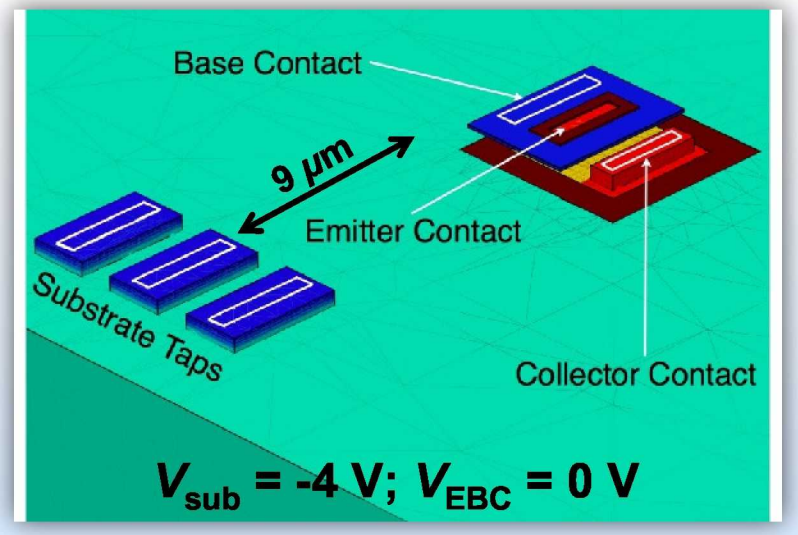
Sandia National Laboratories' Microbeam Chamber



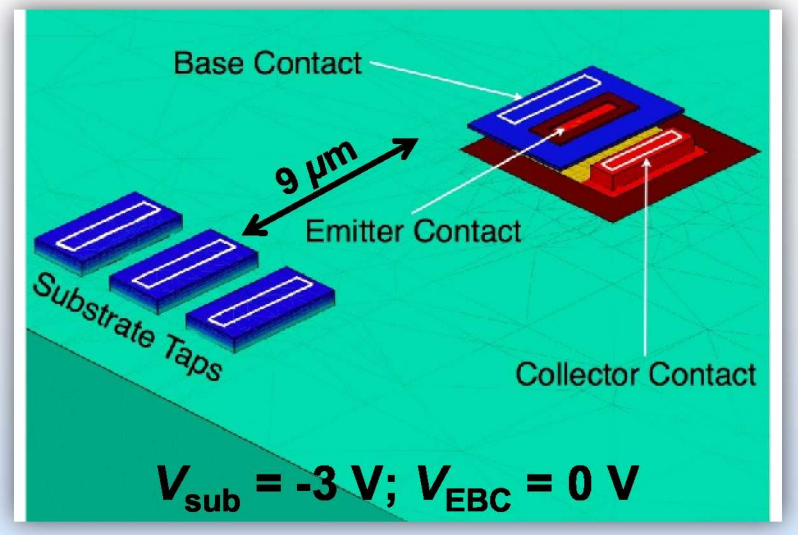


Bias Conditions of Interest

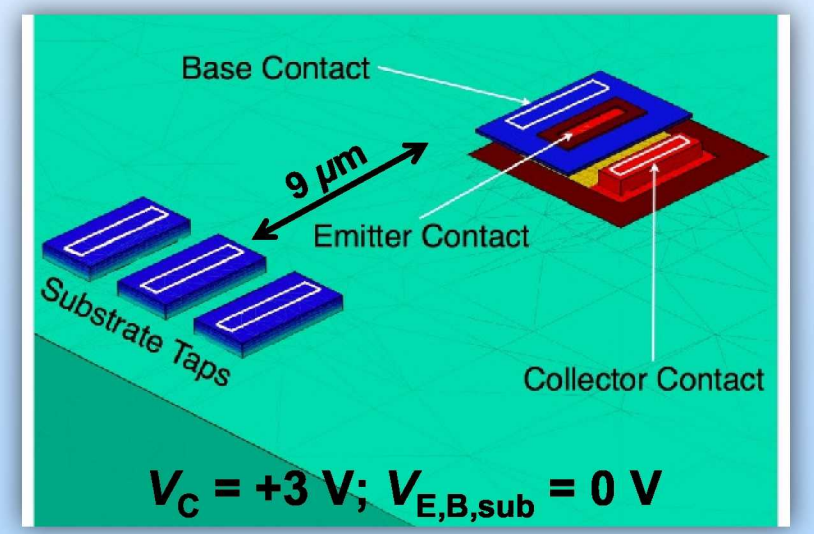
CASE 1



CASE 3



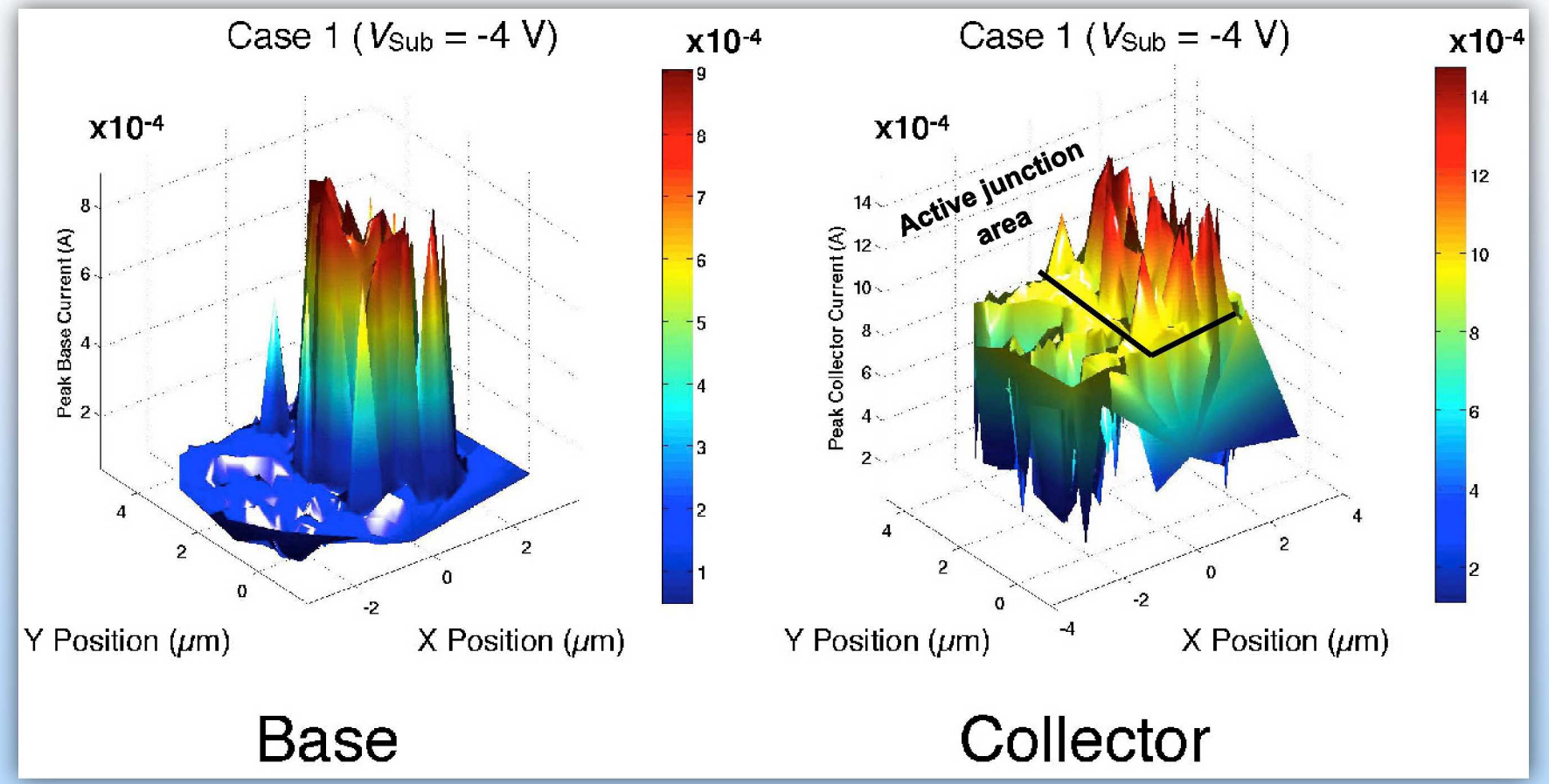
CASE 2



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

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

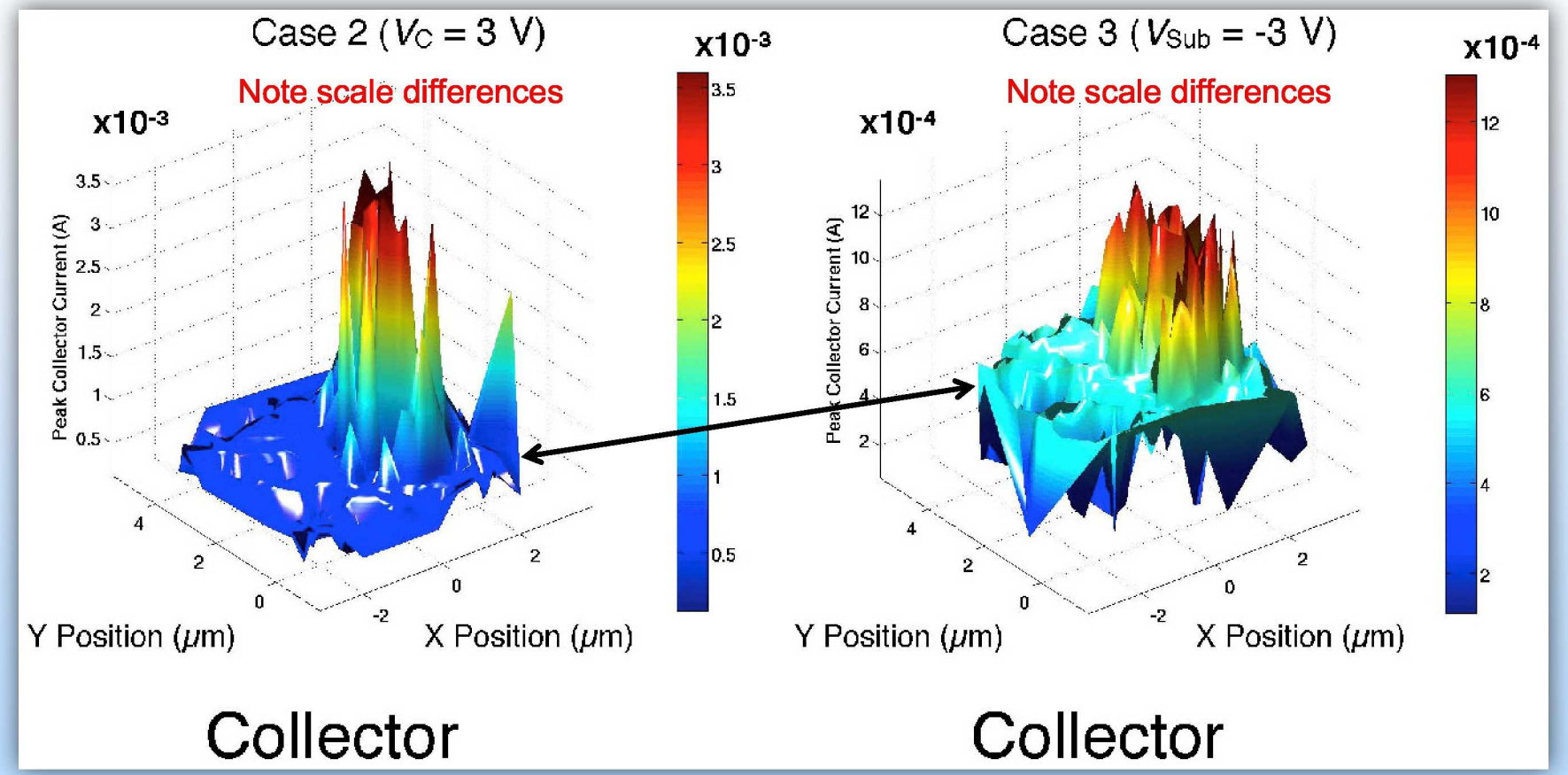
Peak Current Magnitude



- **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**

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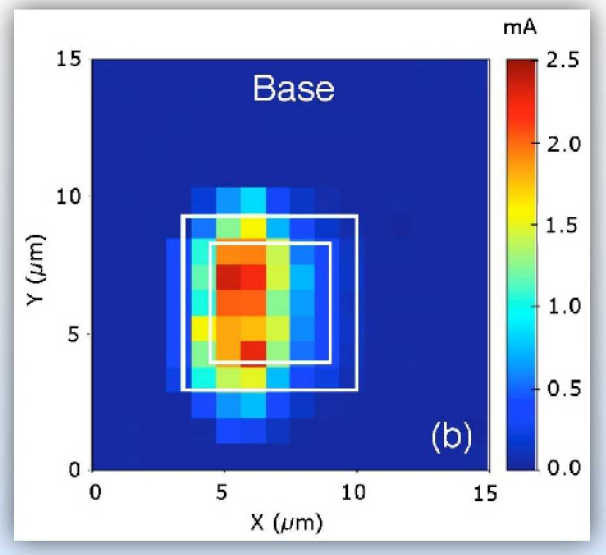
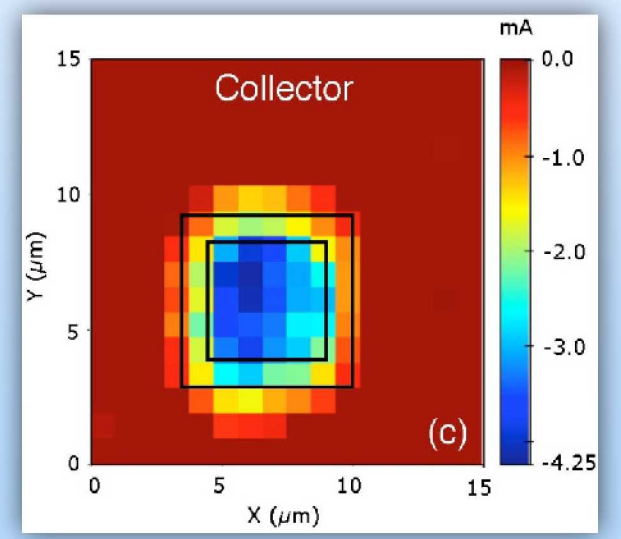
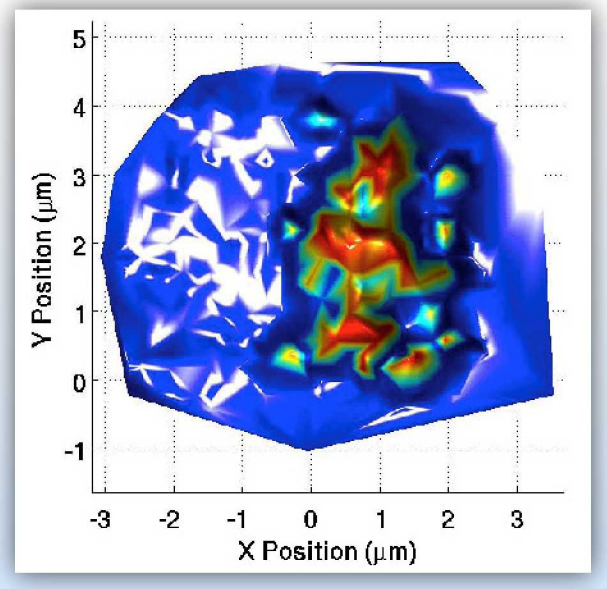
TPA Pulsed Laser *vs.* Microbeam

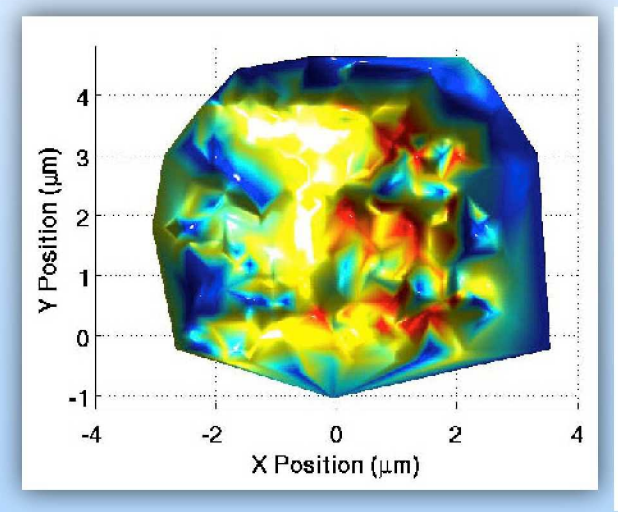




TPA Pulsed Laser

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

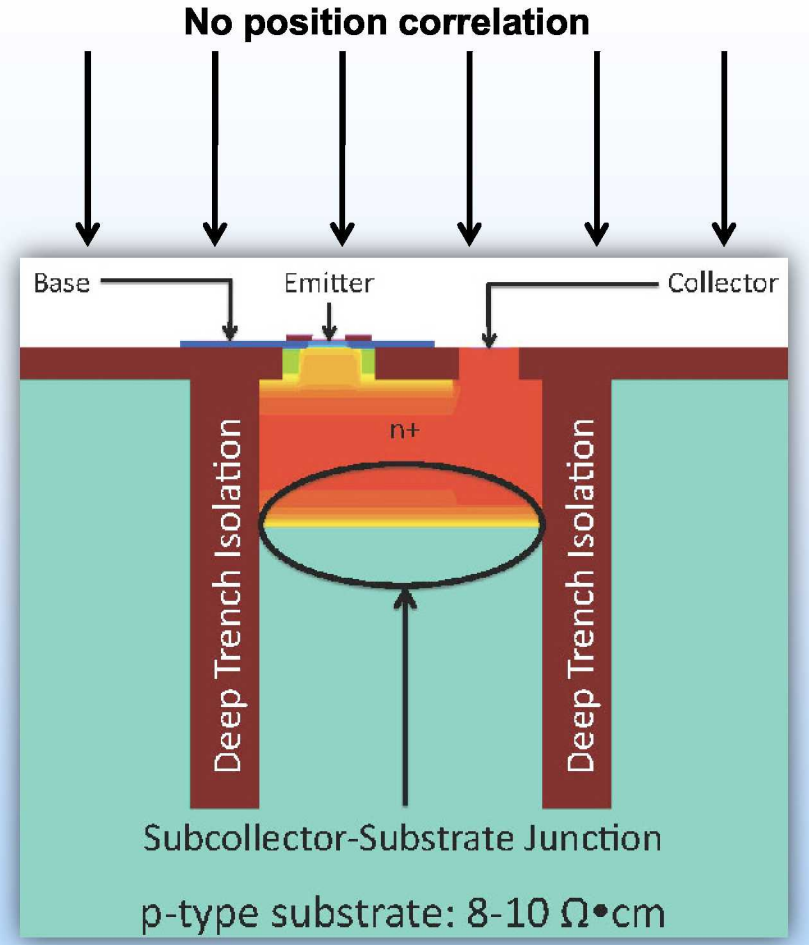




Microbeam

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

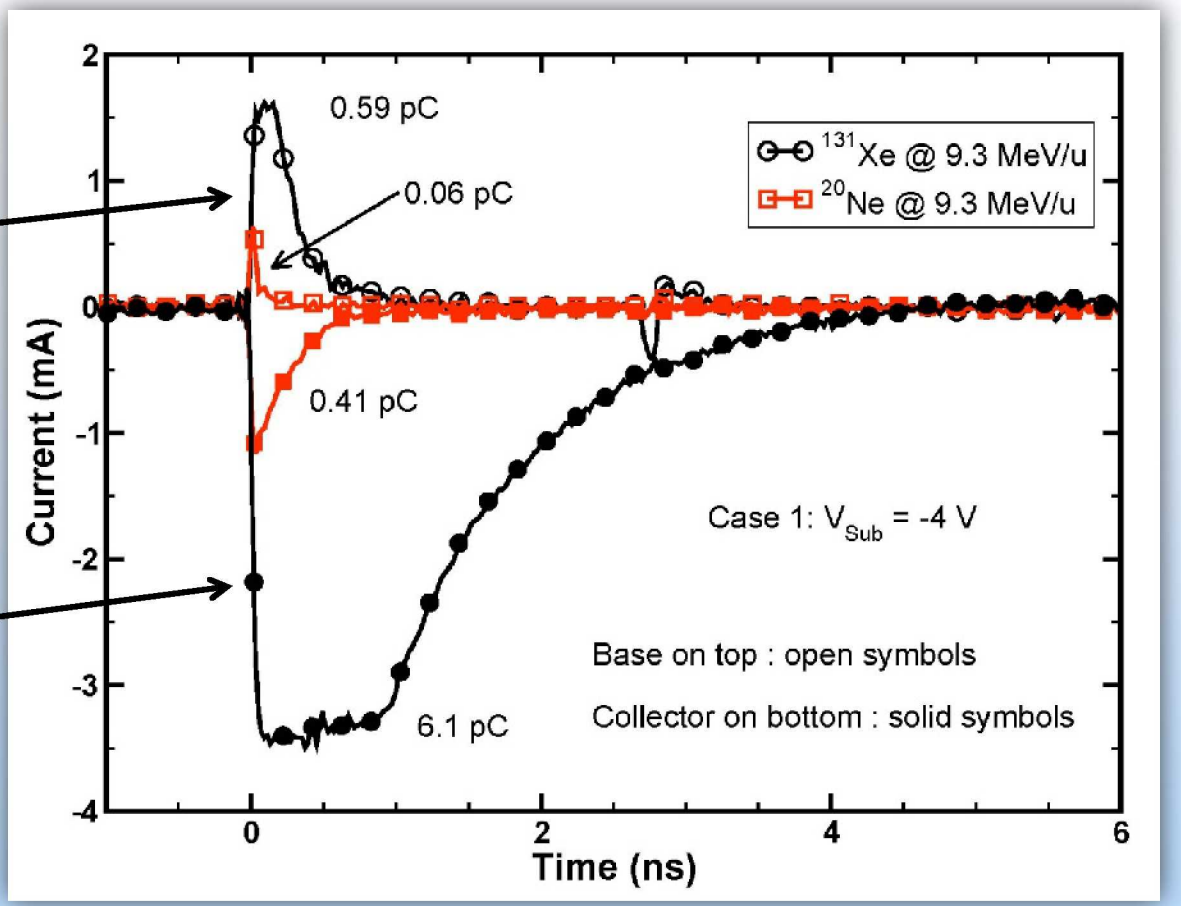
Heavy Ion Broadbeam Transients



University of Jyväskylä
K-130 Cyclotron

- **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**

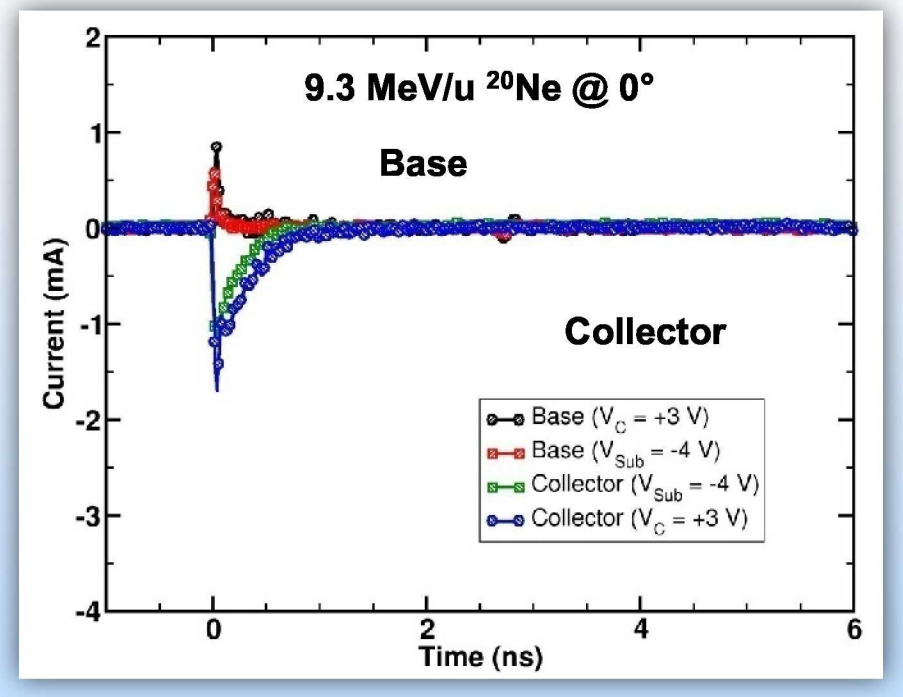
JYFL Broadbeam Transients

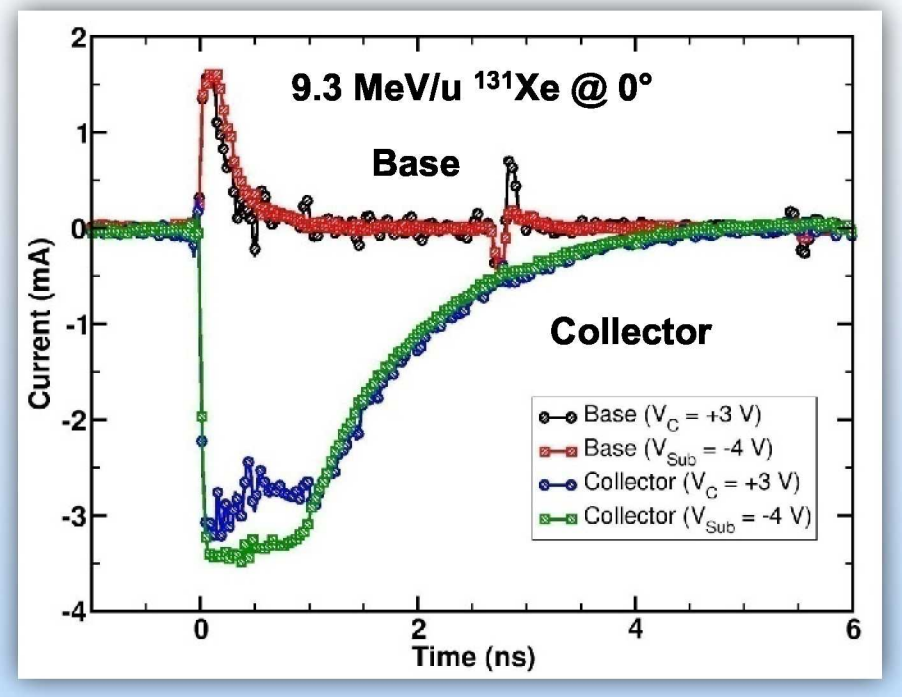


- Typical events observed from events somewhere within active region
- Position inferred using SNL microbeam data

JYFL Broadbeam Transients

Maximum amplitude transients as a function of bias

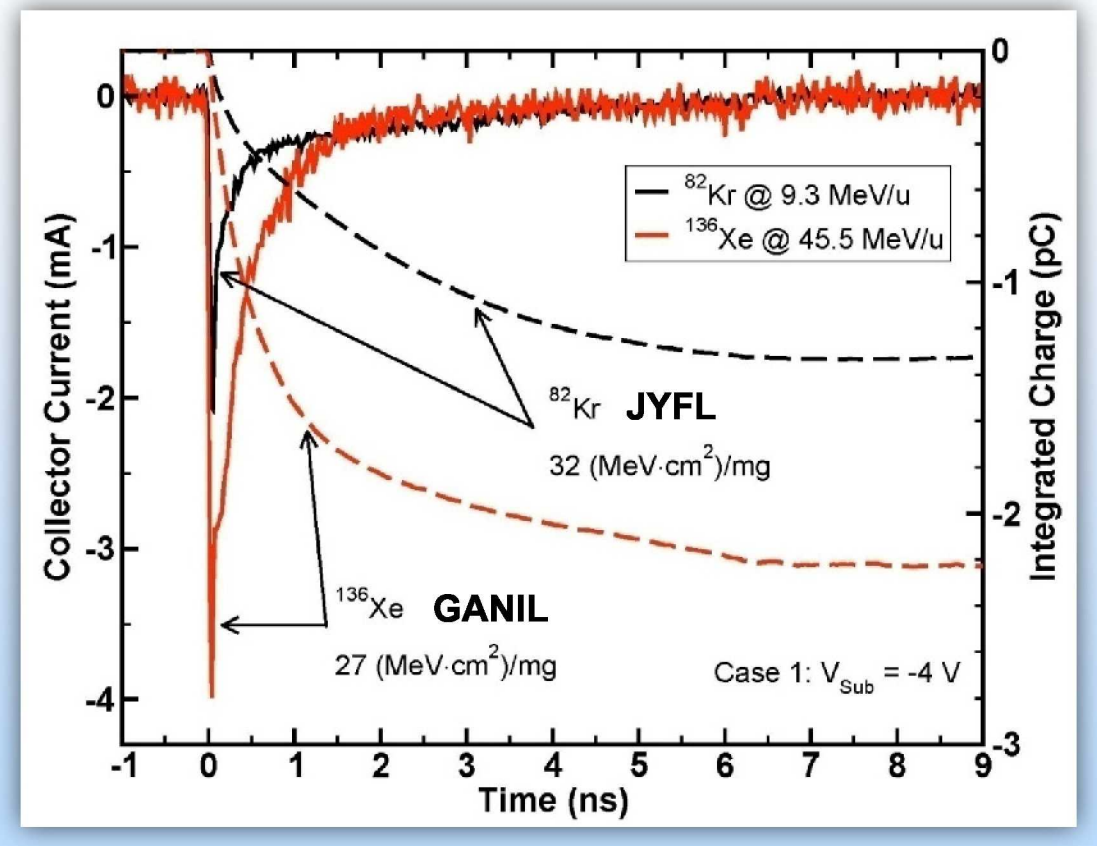




- **Saturation of collector current transient with highly ionizing particle**
- **Some bias dependence, but masked by random hit location**

JYFL *vs.* GANIL Broadbeam Transients

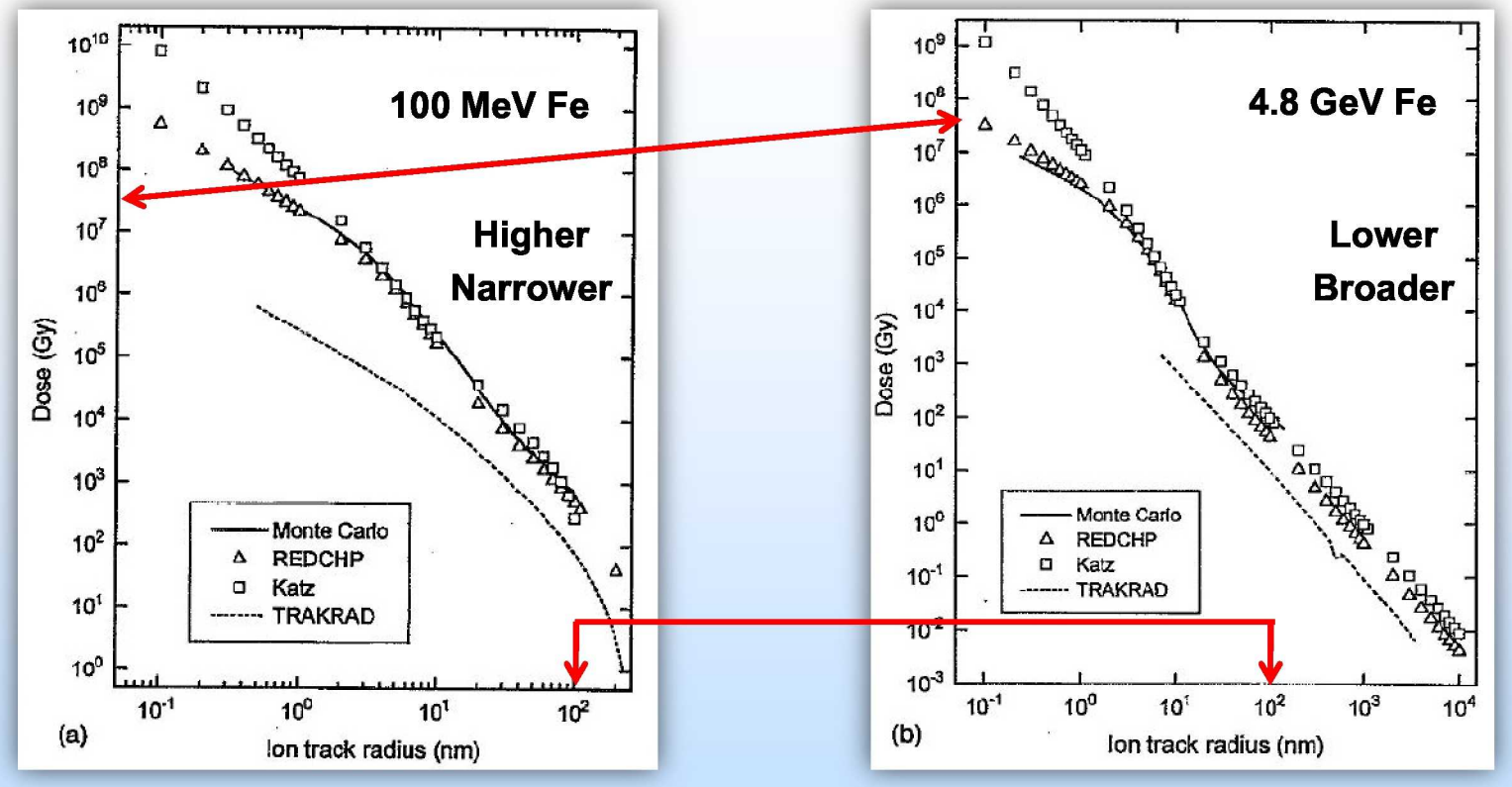
Ion Range



Recombination

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

Influence of Ion Energy



O. Fageeha *et al.*, *J. Appl. Phys.*, vol. 75, no. 5, p. 2317, Mar. 1994.

- **Ion energy determines δ-ray energy**
- **Higher energy ion reduces eh-plasma density**
  - **Ambipolar and bipolar transport affected by carrier density**
  - **Space charge screening effects**

Path Forward

- **Attempt to uncover reason for increase in collector current for V_C = +3 V bias condition**
  - **Impact ionization or other positive feedback mechanism**
- **Conduct simulation study to understand differences between microbeam and broadbeam data**
  - **Alleviates some difficulties with modeling TPA data**
- **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**

Order of Operations

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 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**