Comparison of Single-Event Transients in an Epitaxial Silicon Diode Resulting from Heavy Ion-, Focused X-Ray- and Pulsed Laser-Induced Charge Generation

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Acronyms and Disclaimers

Argonne National Lab	ANL
Lawrence Berkley National Lab	LBNL
Linear Energy Transfer	LET
U.S. Naval Research Lab	NRL
Single Event Effect	SEE
Single Event Transient	SET
Sensitive Volume	SV
Total Ionizing Dose	TID

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Overview

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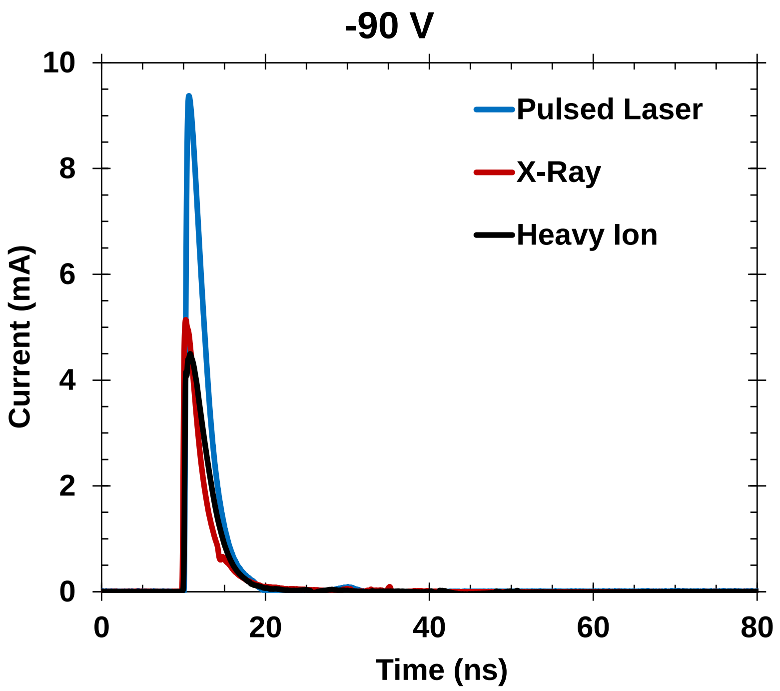
1. A variety of charge generation methods are now used in SEE testing

2. <u>Different SET shape characteristics observed from different sources</u> ★

3. Proposed mechanisms, implications for alternative SEE testing methods



Comparison of Charge Generation Sources for SEE Testing

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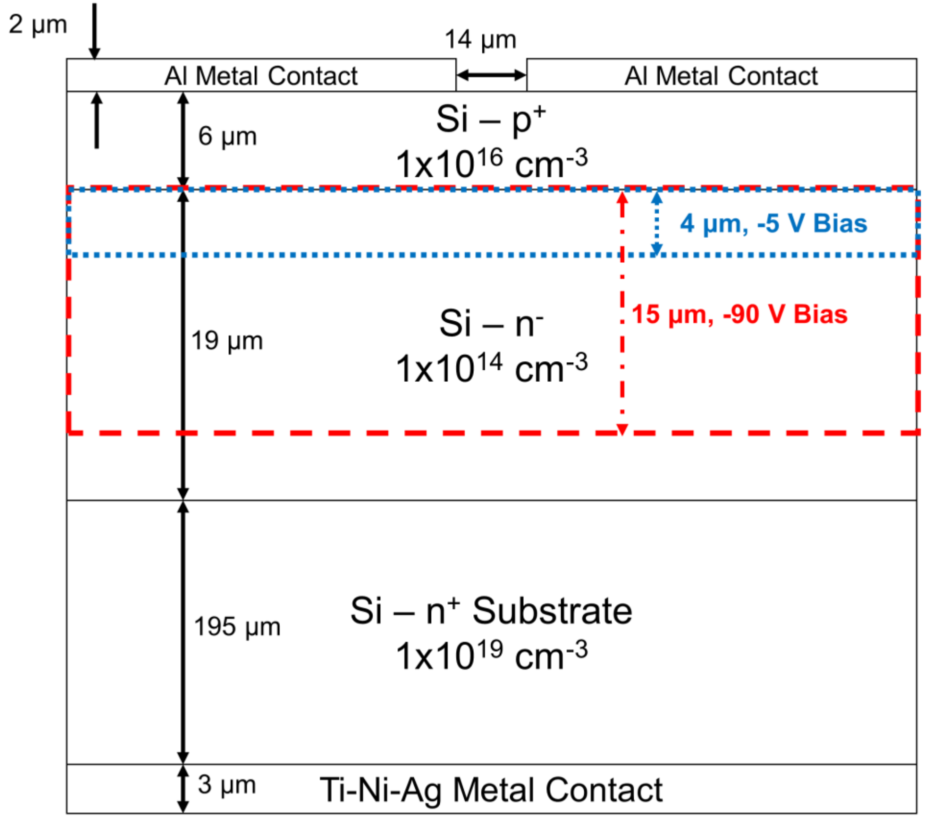
Source	Heavy Ions	Pulses Laser	Focused X-Ray
Known correlation to the space radiation environment	✓	✘	✘
Facility accessibility in U.S.	Few	Many	Few
Spatial, temporal control over charge generation	✘	✓	✓
No accumulation of TID	✘	✓	✘
Penetration of metals	✓	✘	✓

Experimental Conditions

- Heavy Ion SET Testing:
  - LBNL 88” Cyclotron facility
  - 3 LETs from 10 MeV/amu cocktail
- Focused X-Ray SET Testing:
  - ANL Advanced Photon Source
  - 8, 10, and 12 keV photon energies
- TPA Laser SET Testing:
  - NRL Ultrafast Laser Facility
  - 400, 750, and 990 pJ

- **Different electric field strengths, depletion region thicknesses**



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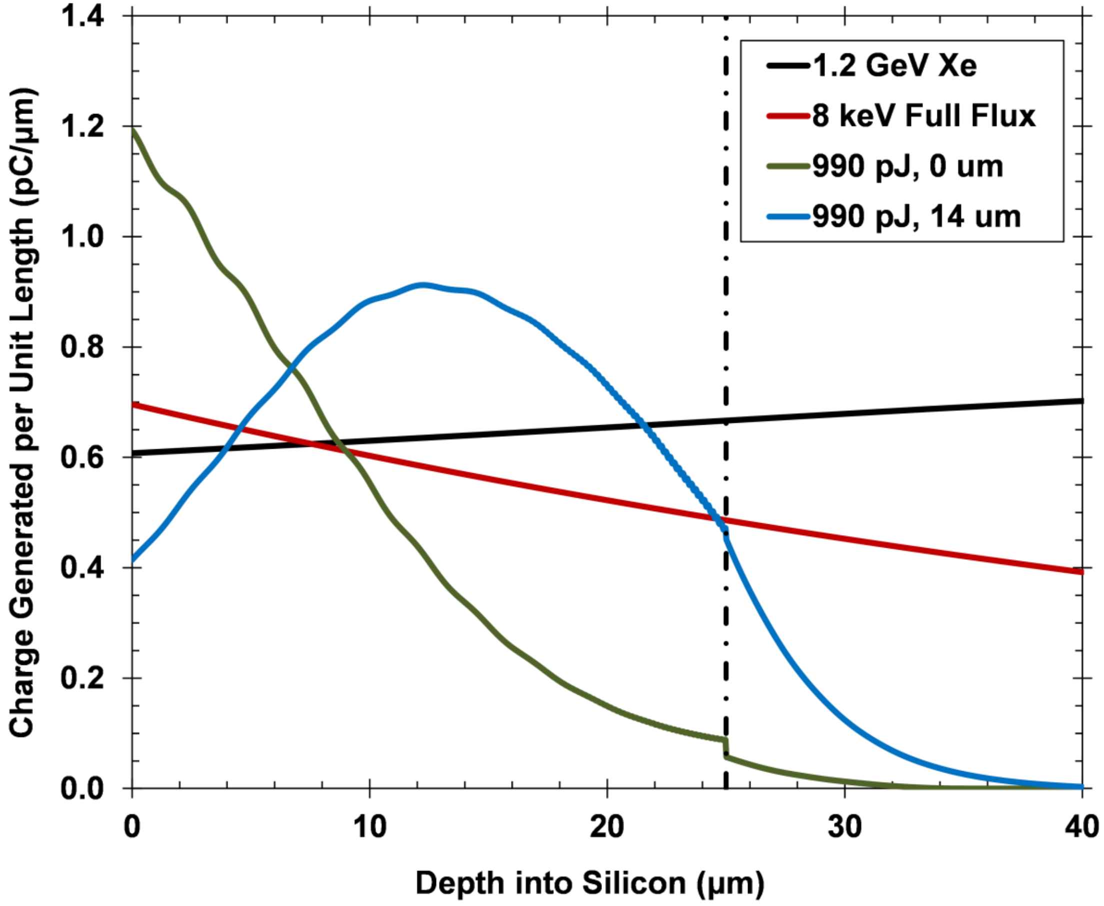
Charge Generation Profiles and Calculations



- **Heavy Ions:**
  - $Q_{gen,ion} = \frac{\rho}{E_{ehp}} \int_l LET(x)dx$
  - <1 µm radial, 10s – 100 µm lateral
- **Picosecond Focused X-Ray:**
  - $Q_{gen,x-ray} = \frac{E_p}{E_{ehp}} \left(1 - e^{-\alpha l}\right)$
  - ~1 µm radial, 10s – 100 µm lateral
- **Femtosecond Pulsed Laser:**
  - Lumerical FDTD Solutions
  - ~1 µm radial, ~10s µm lateral

Transient Shape and Data Analysis

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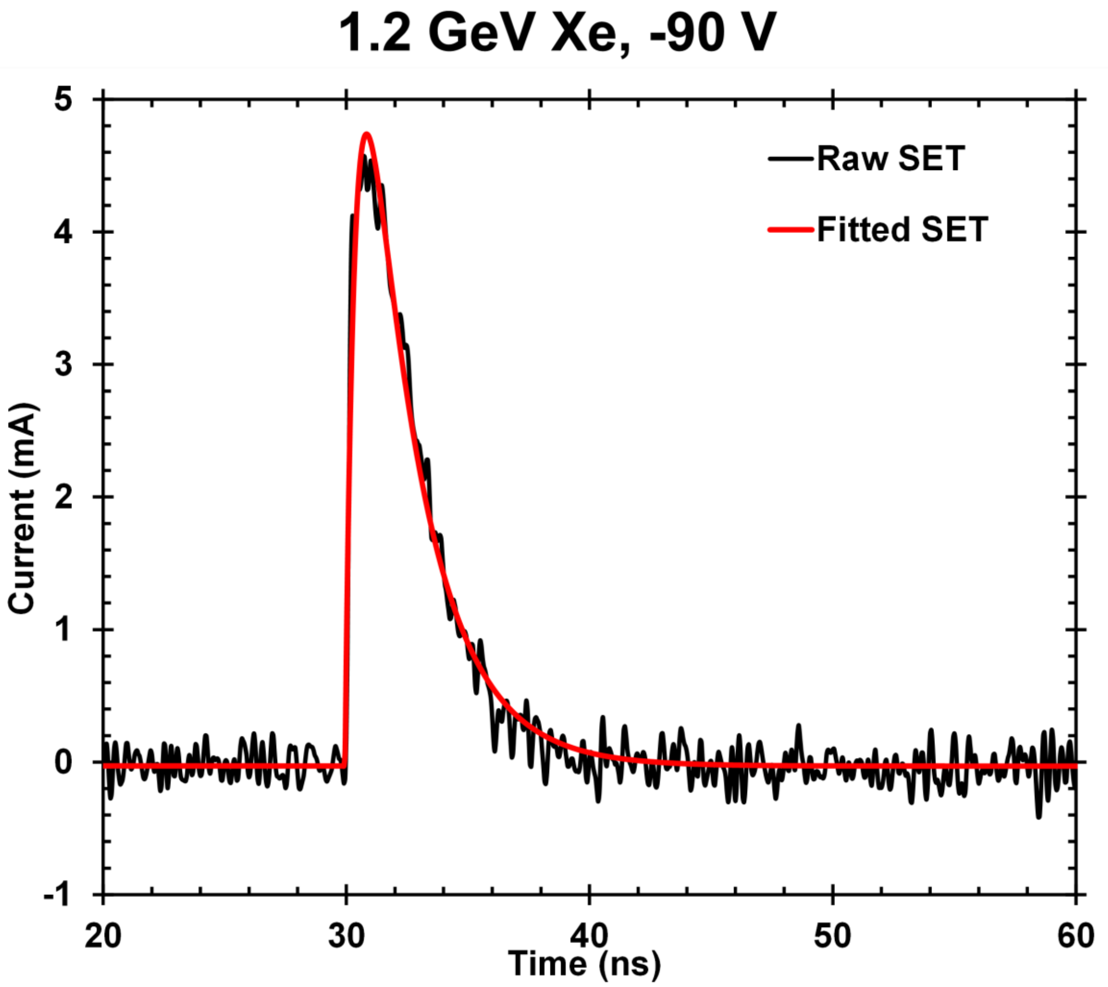
- $$f(t) = \begin{cases} 0, \ t < a \\ I\left(e^{-\tau_1(t-a)} - e^{-\tau_2(t-a)}\right), \ t \geq a \end{cases}$$

- SET characteristics found using fitted SETs

- SET Characteristic Calculations:
  - Collected charge – integral
  - Transient rise time – from 1% to peak
  - *Transient fall time – from peak to 1%*



Collected Charge from -5 V Experiments

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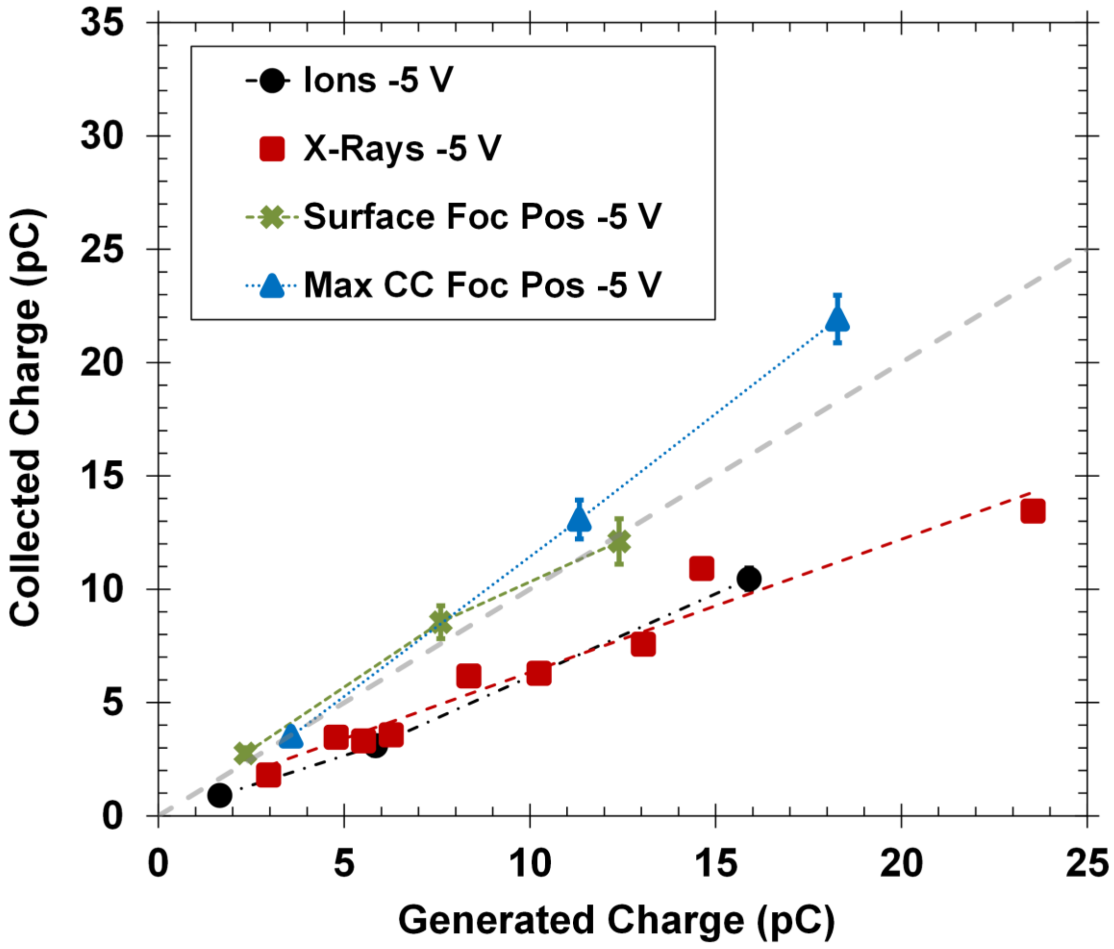

- Collection Efficiency, $Q_{eff} = \frac{Q_{out}}{Q_{in}}$
  - $Q_{eff} \propto$ Sensitive volume (SV)
  - Laser collection efficiencies ~1, 1.2
    - Active region = Laser-induced SV
  - Ion, x-ray collection efficiencies ~0.6
    - Active region > Ion-, x-ray-induced SV
- Larger SV indicates more funneling
  - Laser-induced potential modulation > Ion-, x-ray-induced potential modulation

Collected Charge from -90 V Experiments

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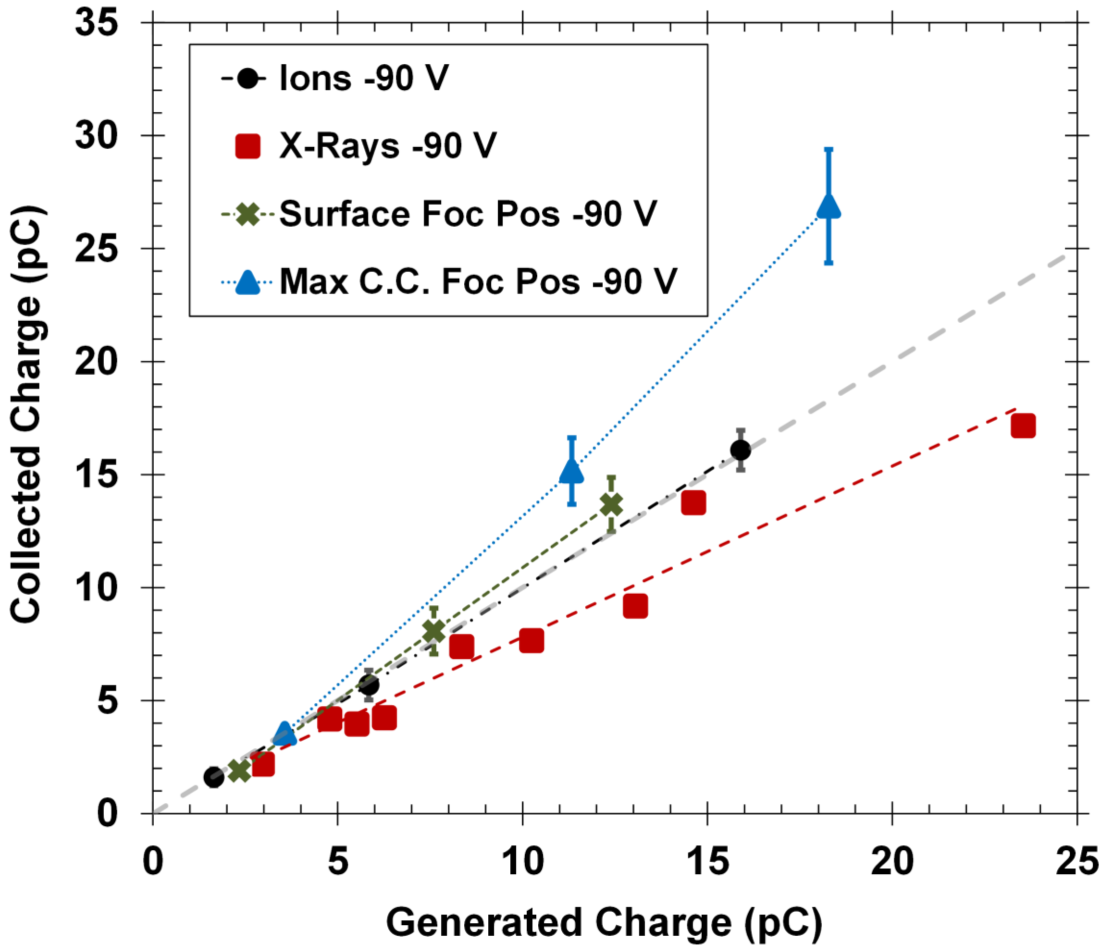

- Collected charge, Q_{eff} increase ∝ Increase in SV over -5 V SVs

	-5 V Q_{eff}	-90 V Q_{eff}	% Increase
Ions	0.6	1.0	67
Lasers	1, 1.2	1.1, 1.4	10, 17
X-Rays	0.6	0.8	33

- Changes in SV relate to funneling
  - Ion SVs – standard funneling
  - Laser SVs – fully depleted device
  - X-ray SVs – less funneling

Transient Rise Time from -5 V Experiments

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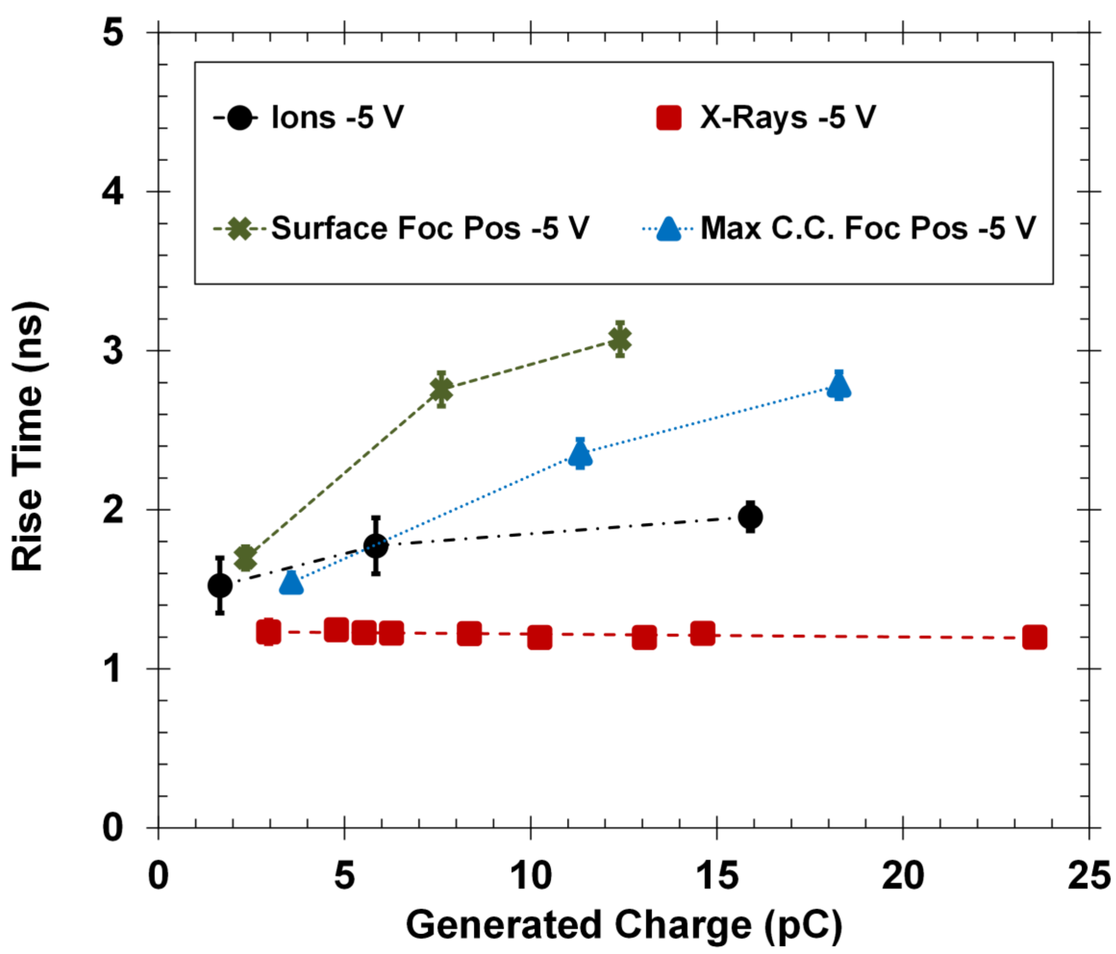
- Dominated by drift ∝ Electric field strength
- Ion, laser rise time increases with generated charge
  - Changes in carrier density cause different perturbations in electric field
- X-ray rise time independent of generated charge
  - X-rays cause less perturbations in electric field compared to ions, lasers



Transient Rise Time from -90 V Experiments

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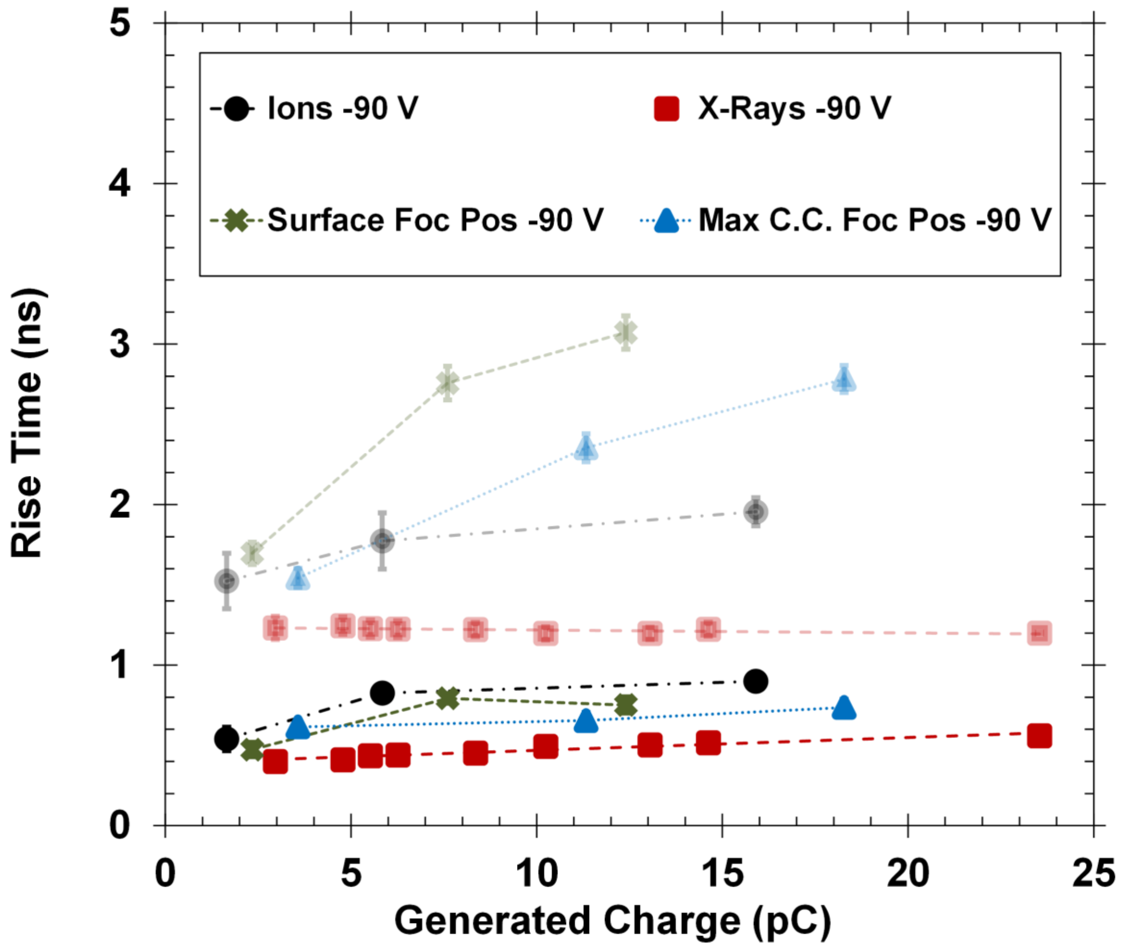
- **More consistency → Stronger electric field dominates response**
  - Faster rise times compared to -5 V
  - Less variation with generated charge

- Transient rise times follow SVs
  - X-ray – smallest SVs, fastest rise times
  - Ion – medium SVs, medium rise times
  - Laser – largest SVs, slowest rise times



Conclusions

SET shape in an epitaxial silicon diode depends on source

Heavy Ions	Q_{eff} increases with increased reverse bias	Transient rise time dependent on charge generated	Medium funneling, perturbations in electric field
Pulsed Laser	Q_{eff} is larger than ions', changes less with bias	Transient rise time dependent on charge generated	Maximum funneling, perturbations in electric field
Focused X-Ray	Q_{eff} is smaller than ions', changes less with bias	Transient rise time independent on charge generated	Minimum funneling, perturbations in electric field