Single-Event Upsets in Substrate-Etched CMOS SOI SRAMs Using Ultraviolet Optical Pulses with Sub-Micrometer Spot Sizes

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Pulsed Laser SEE Testing

MOTIVATION

- Laser SEE testing of highly scaled, high density circuits requires higher spatial resolutions than presently exists

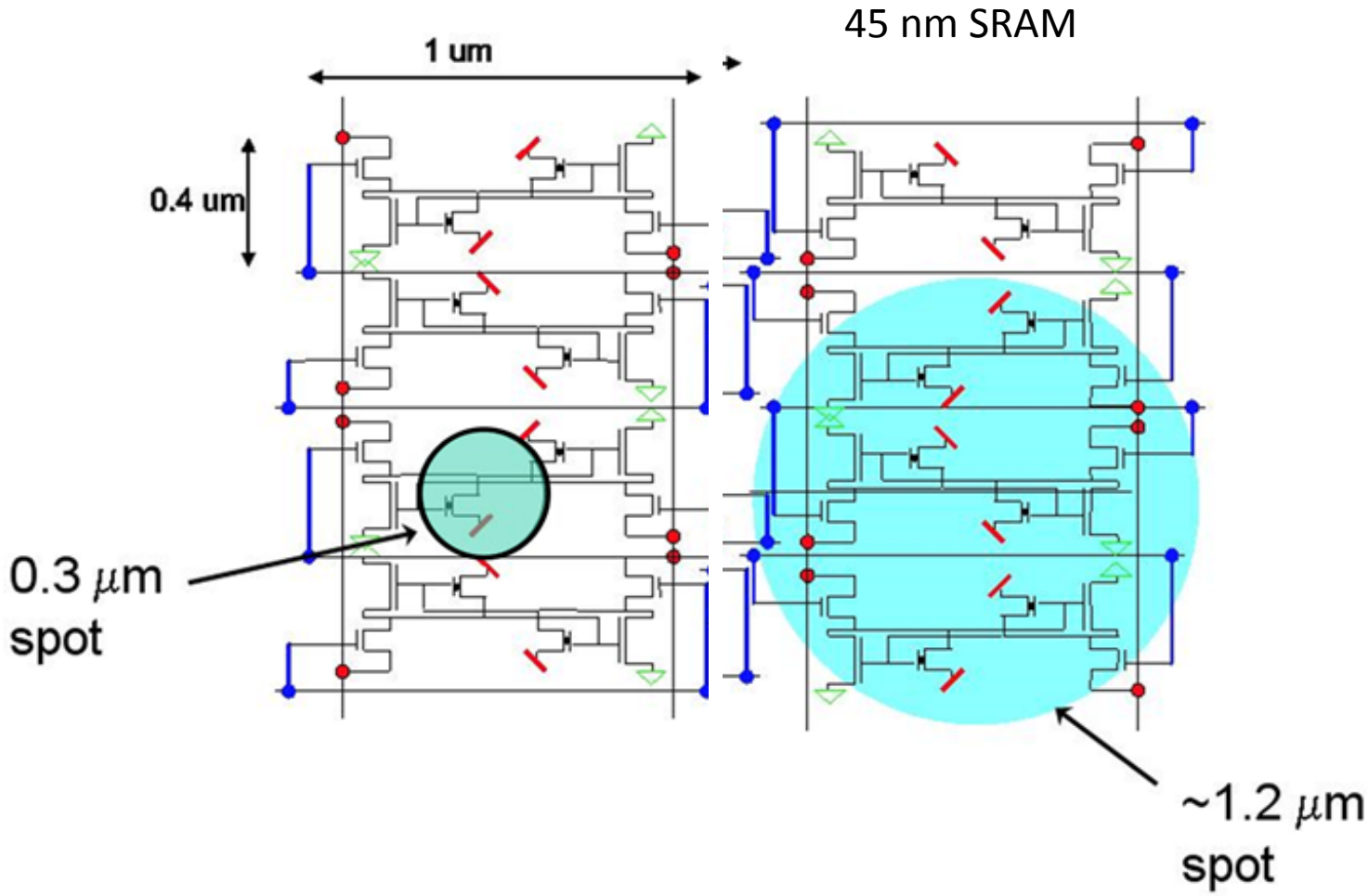
SOLUTION

- Use the shorter wavelength of UV light that can be focused to a smaller spot size

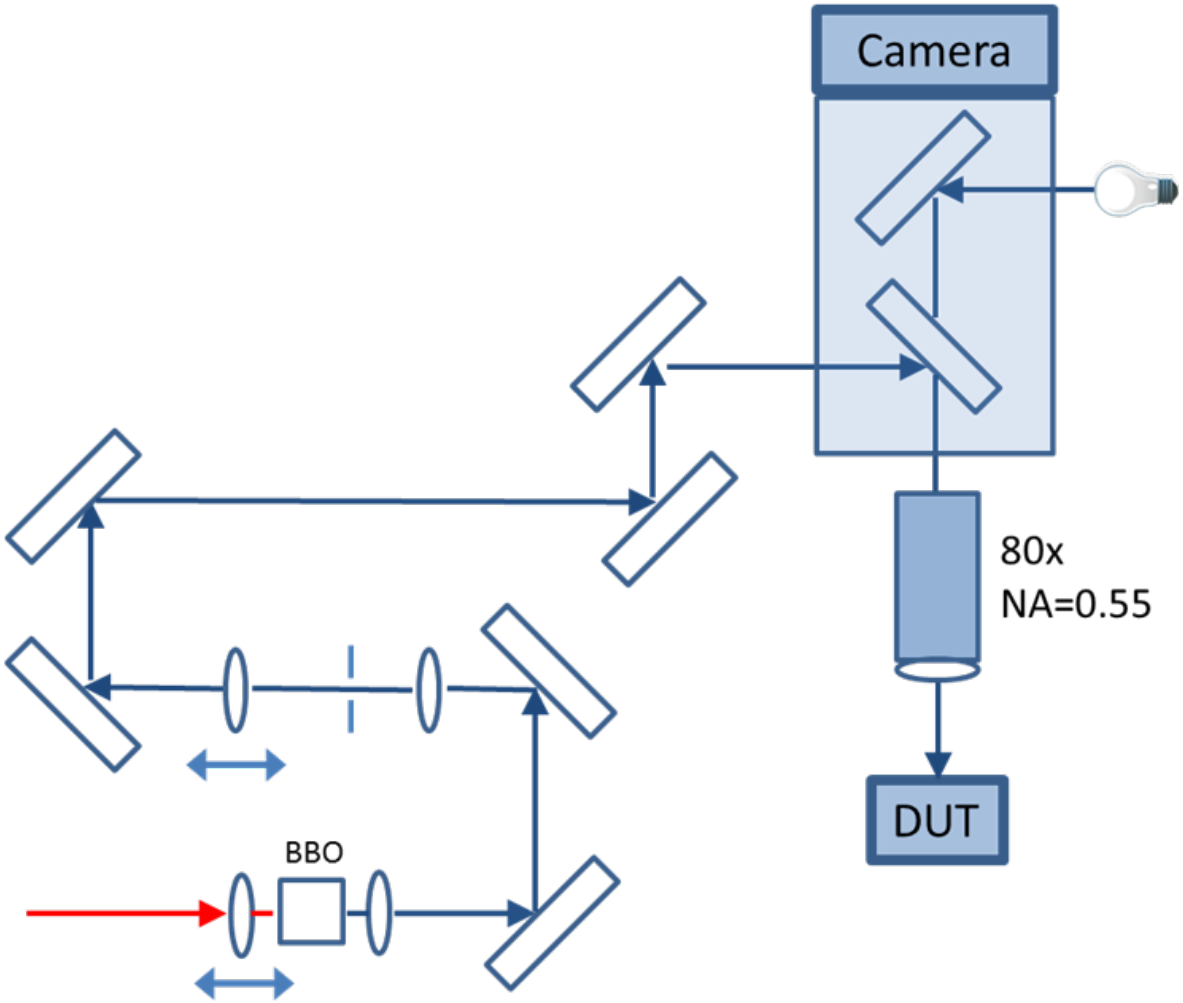
APPROACH

- Demonstrate the validity and advantages of this approach using a densely packed 90 nm SOI SRAM with 0.3 μm diameter UV laser pulses

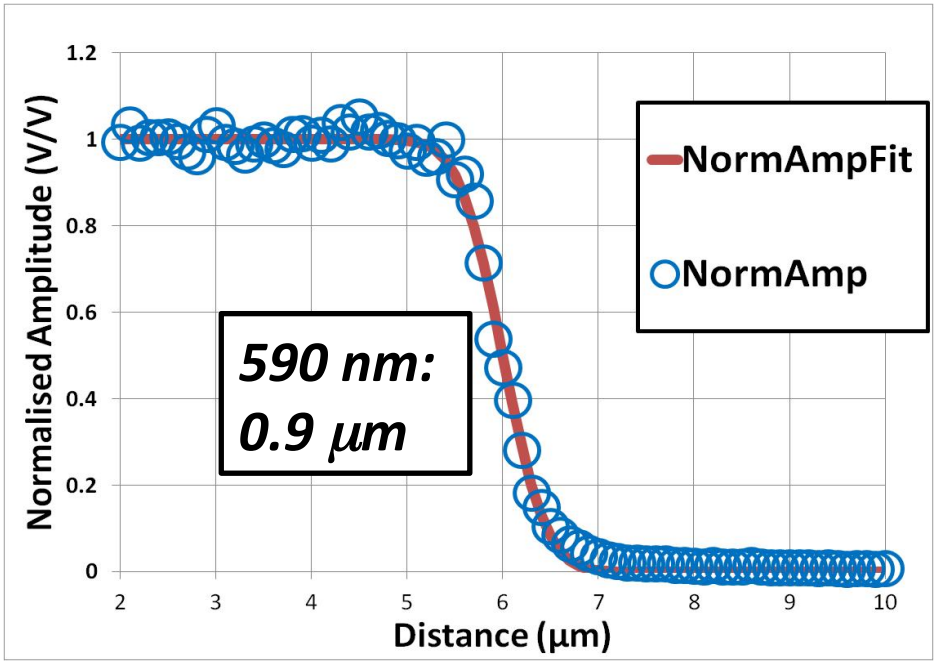
Spot-Size Comparison

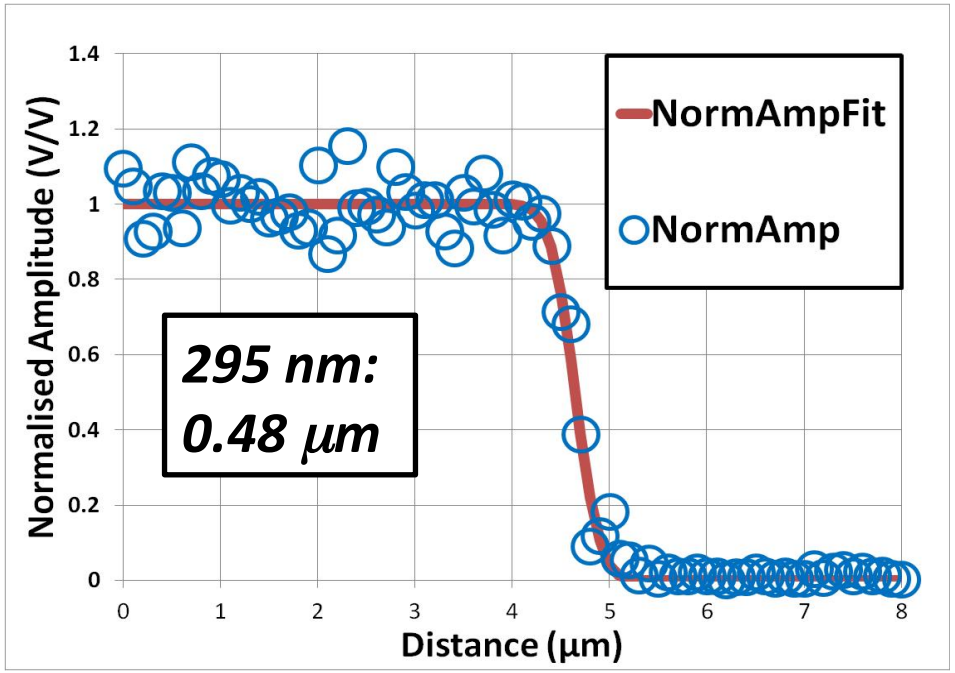


UV SEE Optical Setup

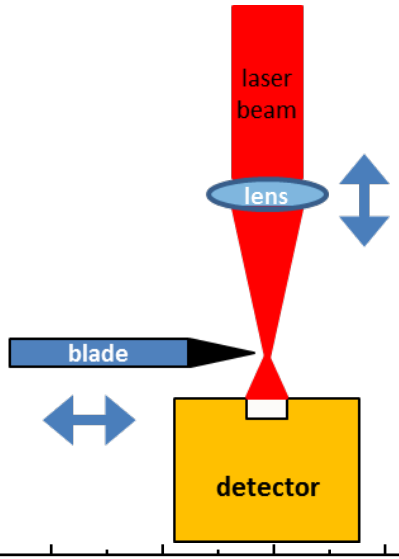


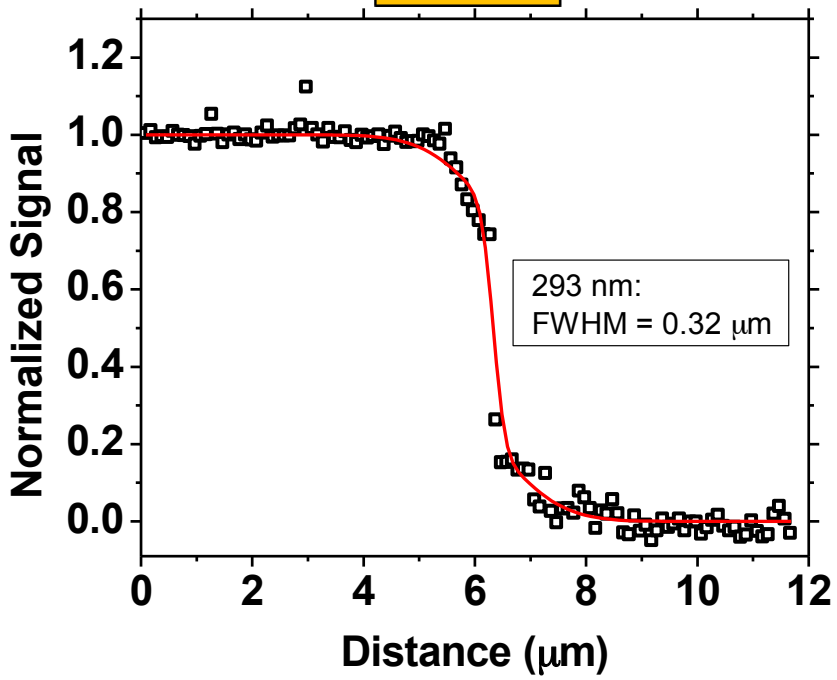
Single-Event Effects in *Substrate-Etched* Devices and Development of a UV Beamline

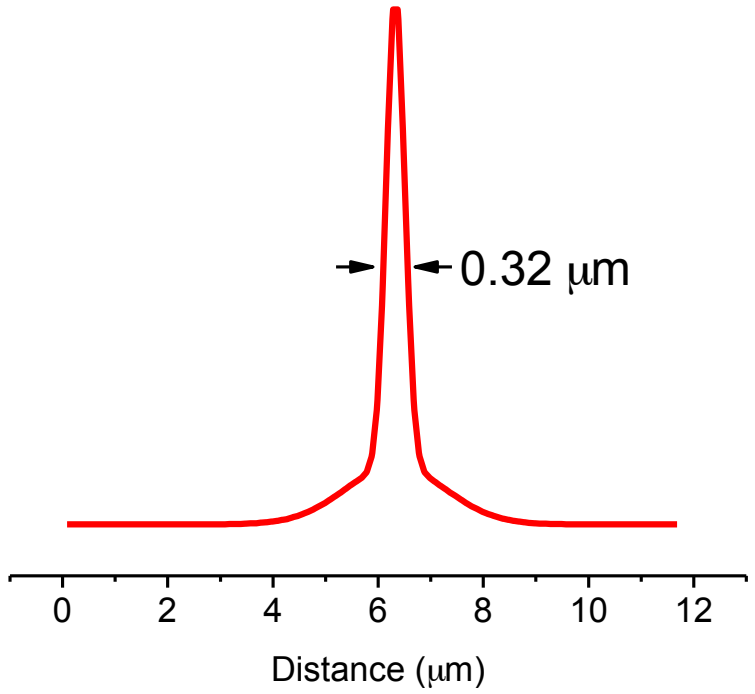




UV Spot Size Measurement

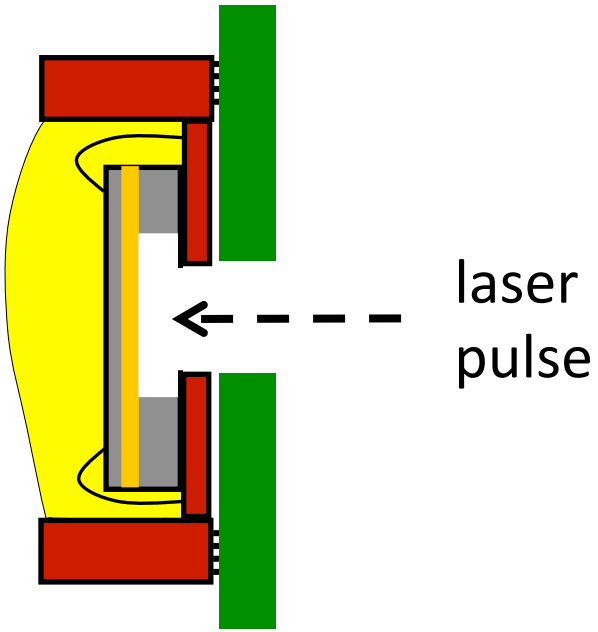






- ***FWHM Spot Size of 293 nm UV optical pulse is 0.32 μm***

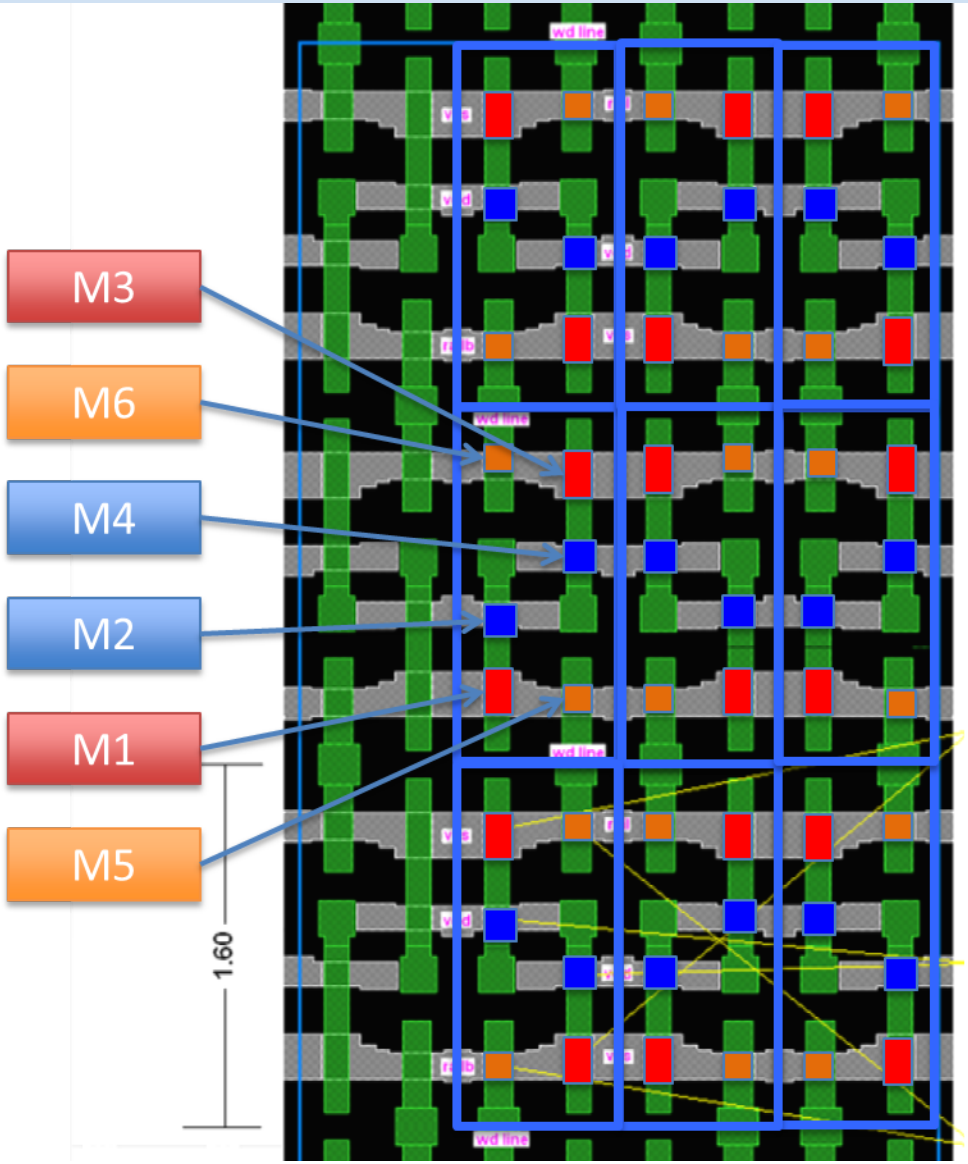
Test Vehicle

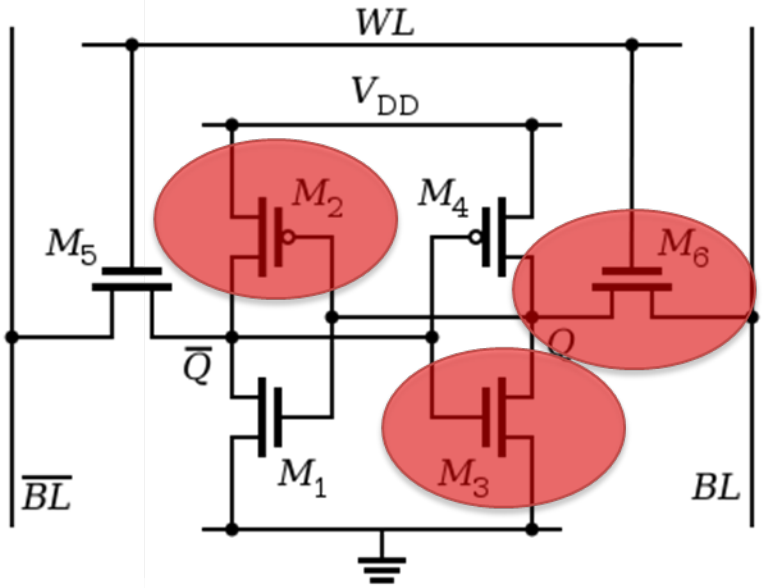


- 90 nm 4-Mbit CMOS/SOI SRAM
- Silicon Substrate removed to BOX using **XeF_2 etch technique developed by NRL***

**N. Kanyogoro et.al., IEEE Trans. Nucl. Sci. Vol. 57, pp. 3414-3418, Dec. 2010*

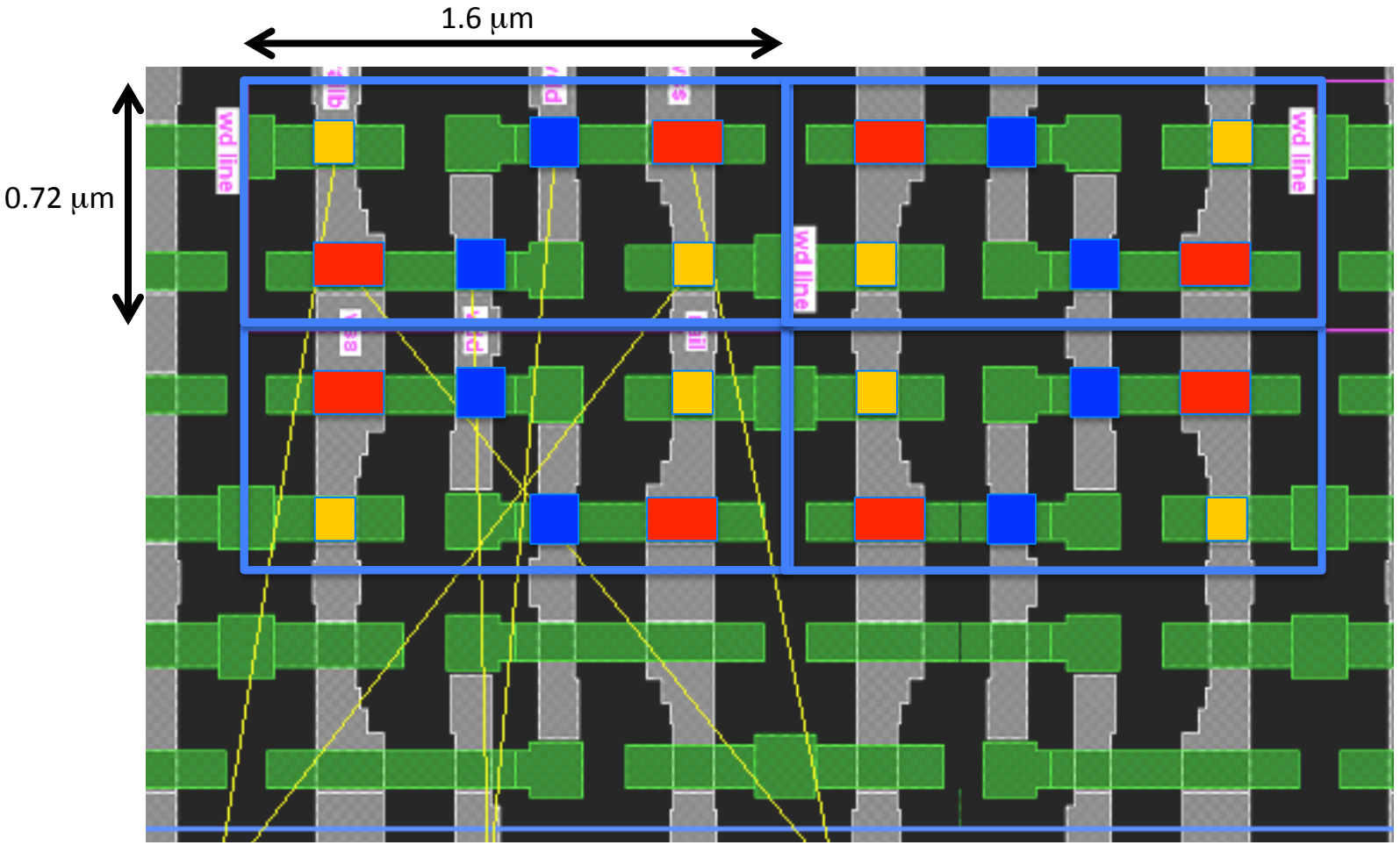
90 nm SRAM Layout



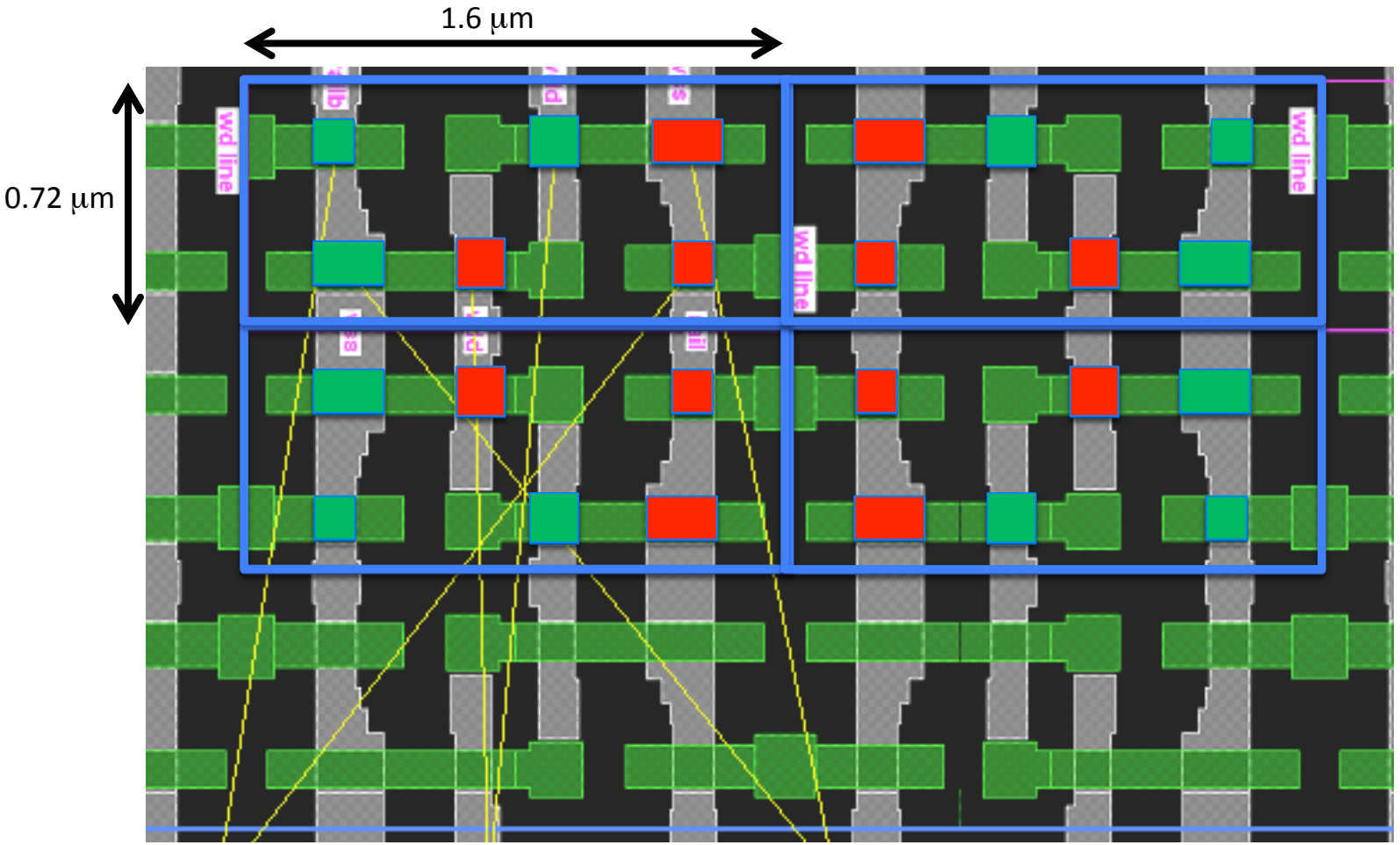


M3 and M1	Latch (N-channel)
M4 and M2	Load (P-channel)
M6 and M5	Access

2D Error Mapping of SOI SRAM

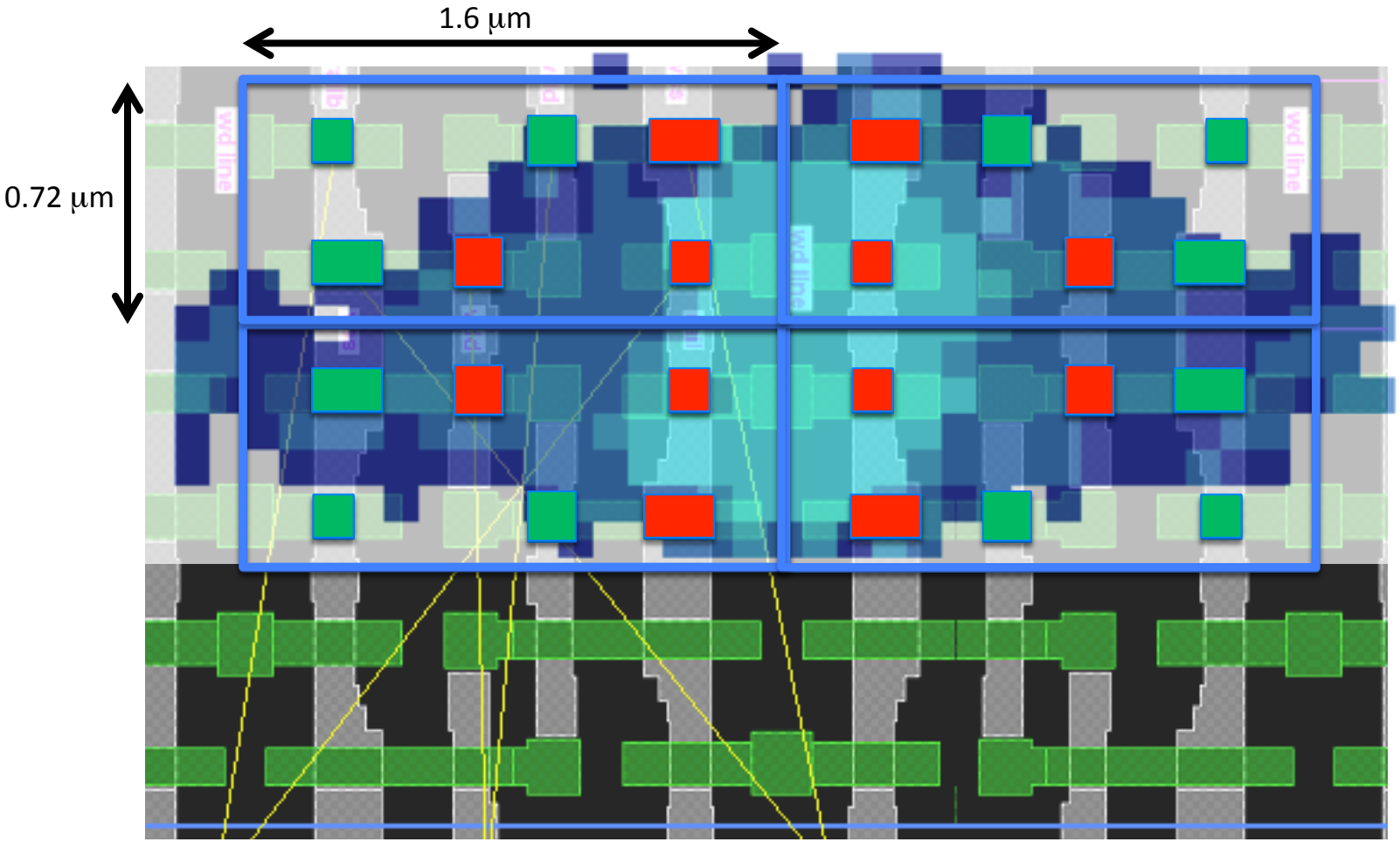


2D Error Mapping of SOI SRAM



Sensitive transistors for all 1's highlighted in RED

2D Error Mapping of SOI SRAM



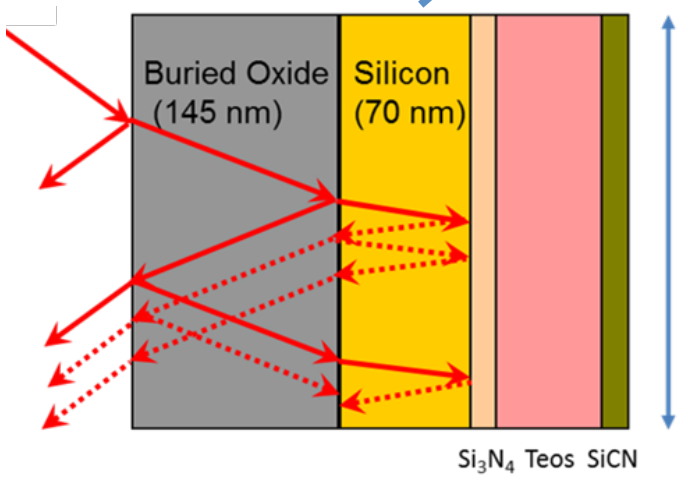
Sensitive transistors for all 1's highlighted in RED

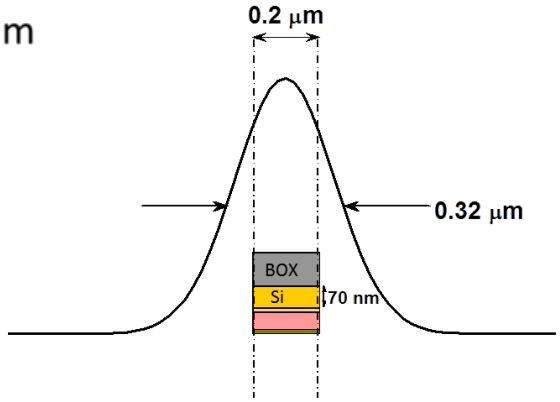
Energy Deposition Determination

$$E_{dep} = E_{threshold} (T \cdot A \cdot F_{overlap})$$

experimentally determined parameter

calculations





Threshold Energy Determination

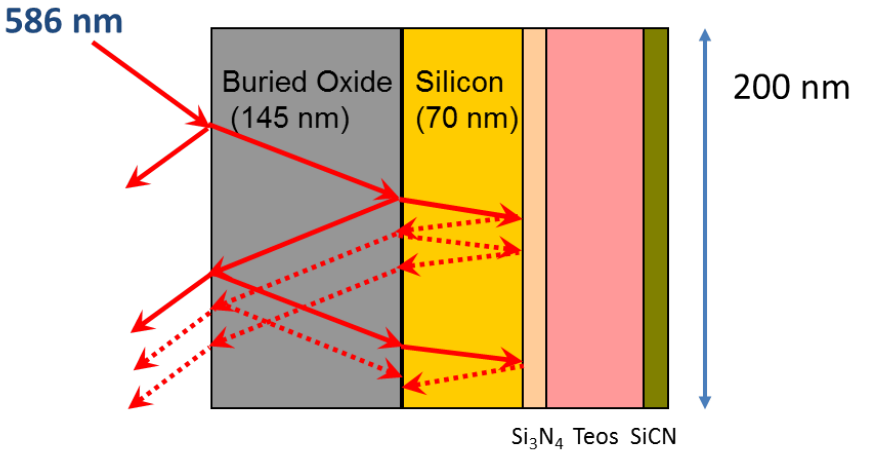
$$E_{dep} = E_{threshold}(T \cdot A \cdot F_{overlap})$$

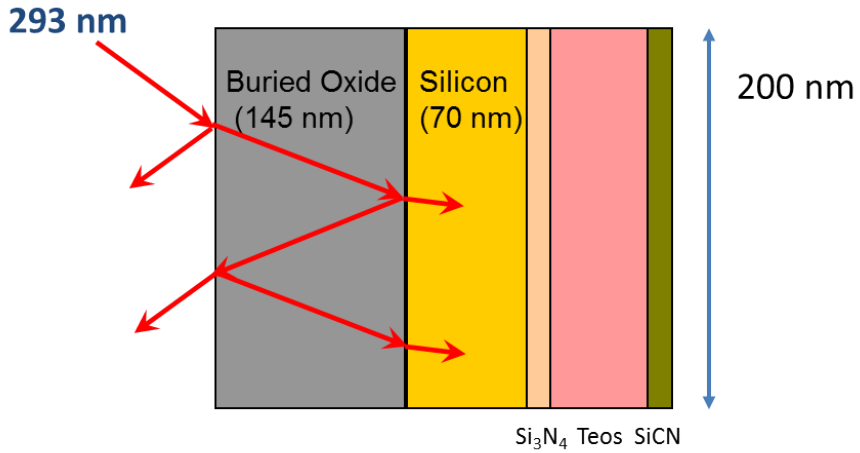
The laser pulse energy threshold, $E_{threshold}$, for SEUs is determined by varying the incident laser pulse energy, focus, and position until the minimum is found

	586 nm	293 nm
$E_{threshold}$ (fJ)	770	45

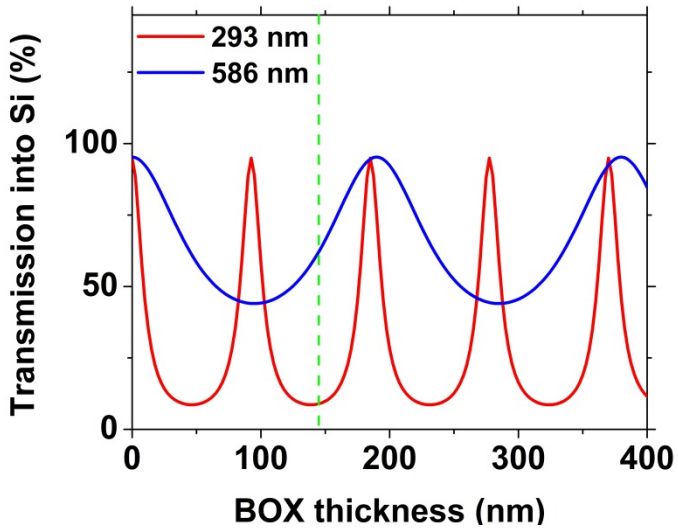
Determination of Transmission and Absorption into Si

$$E_{dep} = E_{threshold}\,(\,T \cdot A \cdot F_{overlap}\,)$$





- Transmission T is **80%**
- Absorption A is **3%**



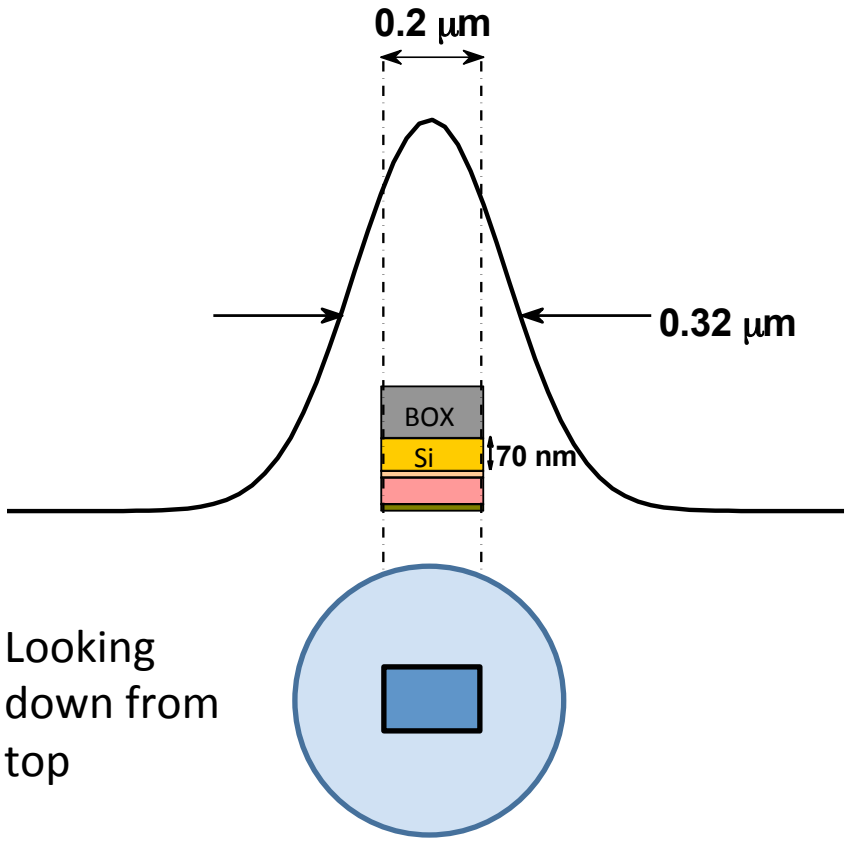
Transmission T is **9%**

Absorption A is **99.99%**

Determination of Overlap Integral

$$E_{dep} = E_{threshold}\,(\,T \cdot A \cdot F_{overlap}\,)$$

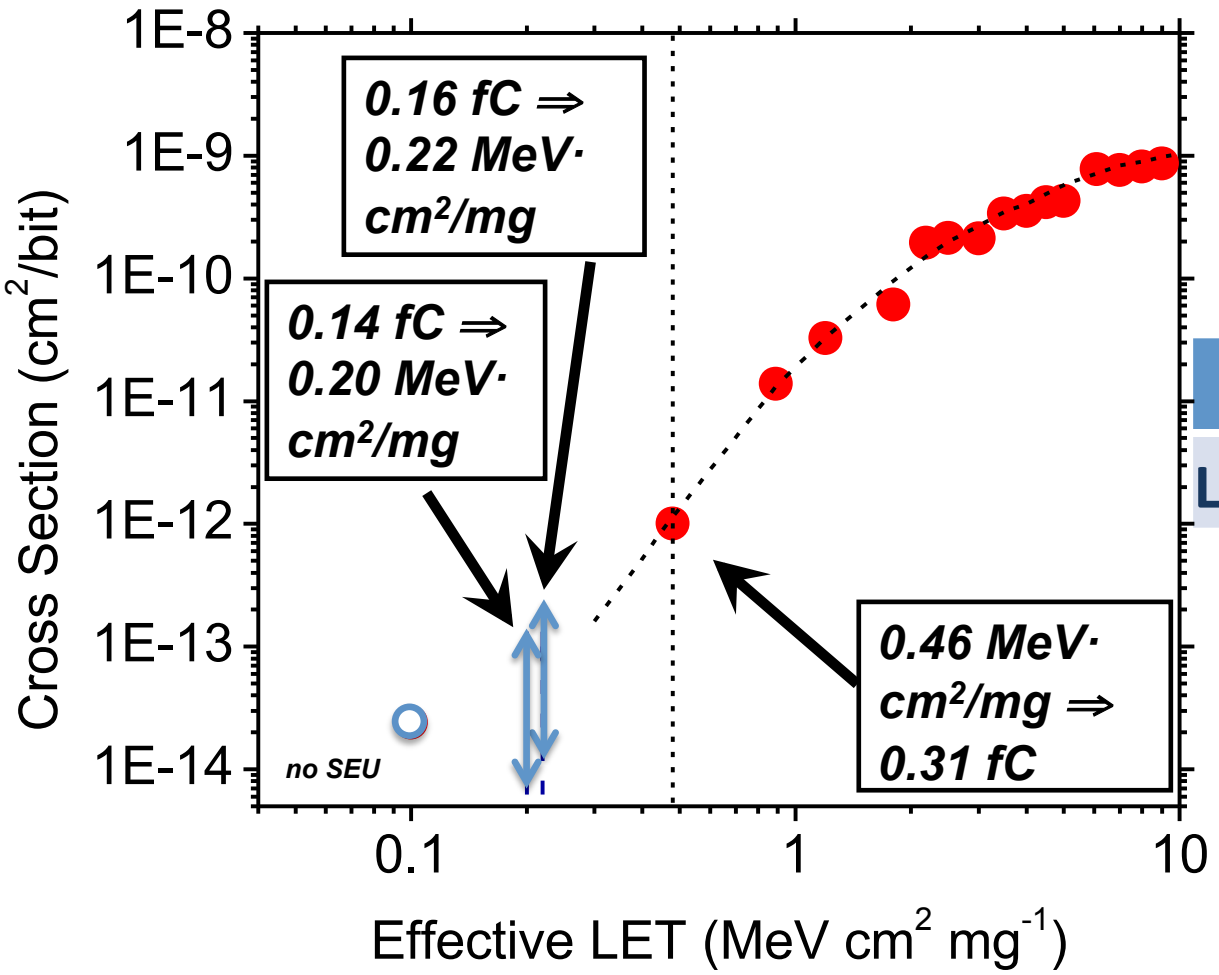
Gaussian pulse overlaps active volume of Si



- at 293 nm $F\downarrow overlap$ = **17%**
- at 586 nm $F\downarrow overlap$ = **2%**

	586 nm	293 nm
E_{dep} (fJ)	0.30	0.68
Q_{dep} (fC)	0.14	0.16

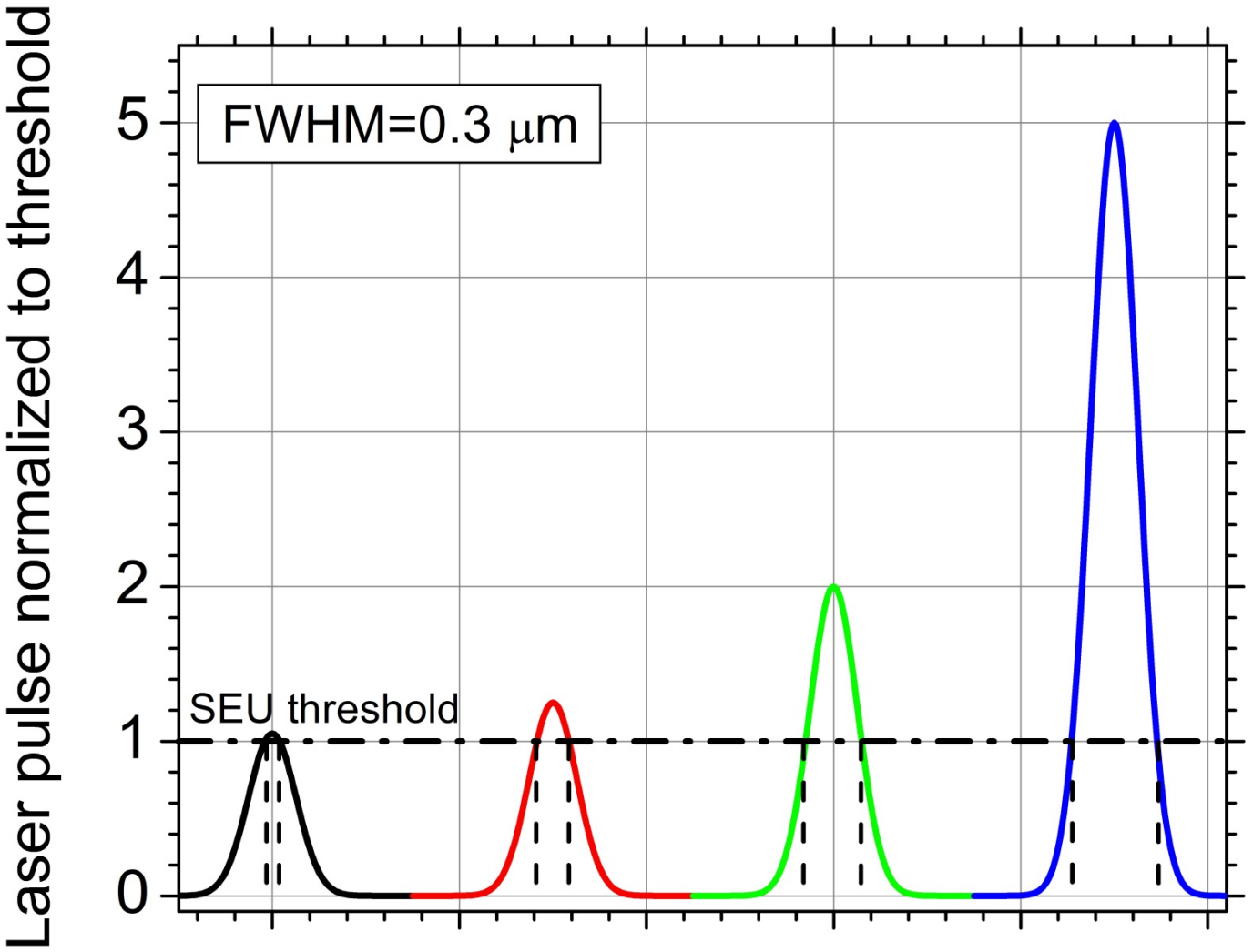
Equivalent LET Determination



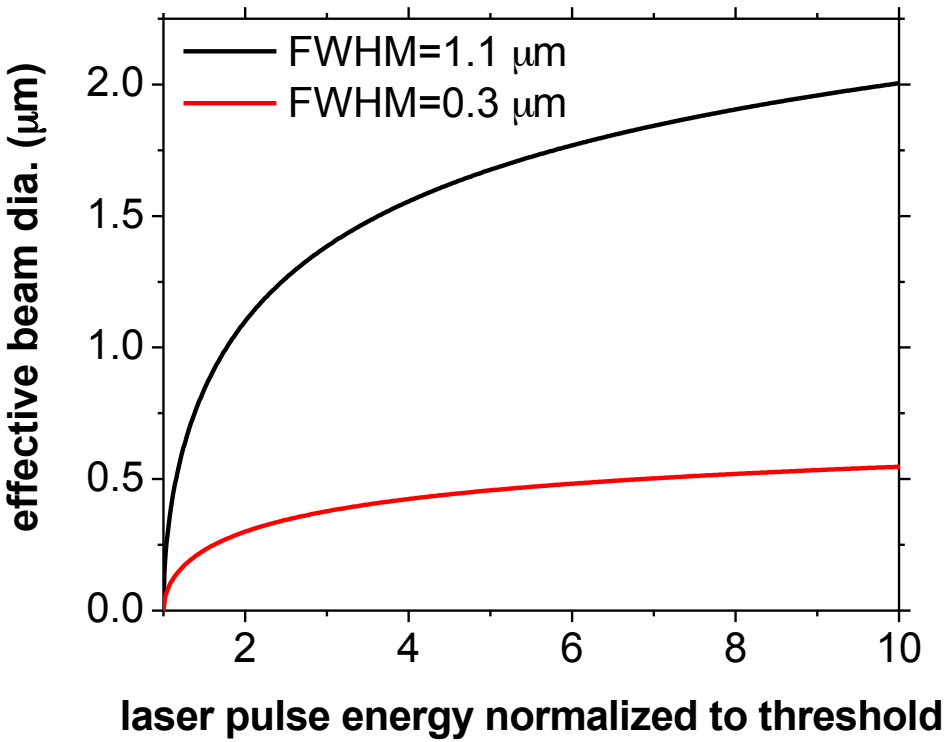
	586 nm	293 nm
LET_{dep}	0.20	0.22

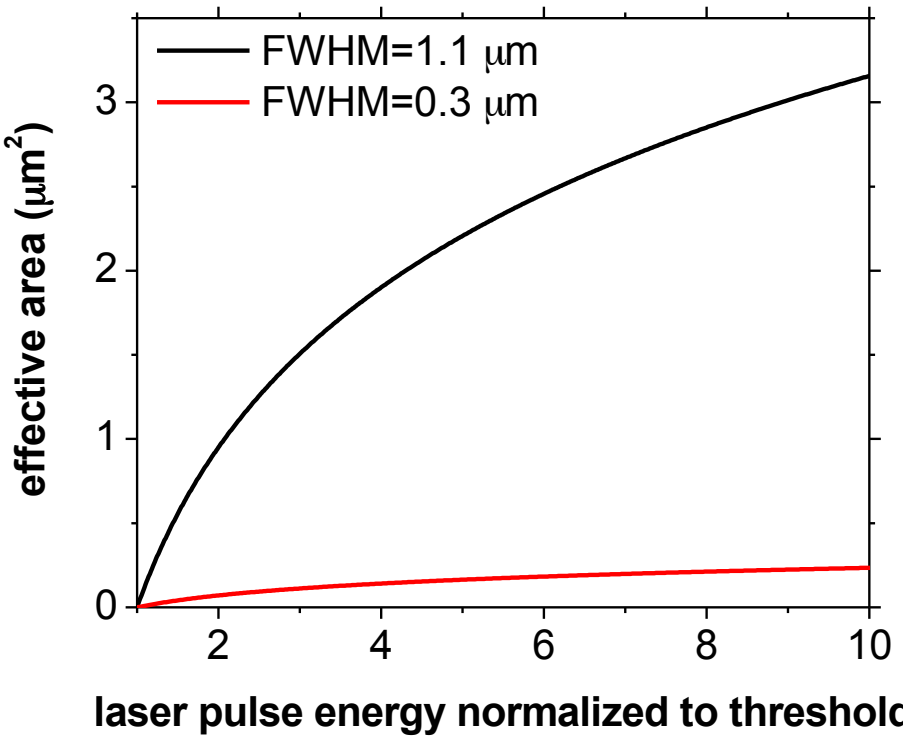
*S. Buchner et.al., IEEE Trans. Nucl. Sci. Vol. 58, pp. 2976 - 2982, Dec. 2011

Effective Beam Diameter



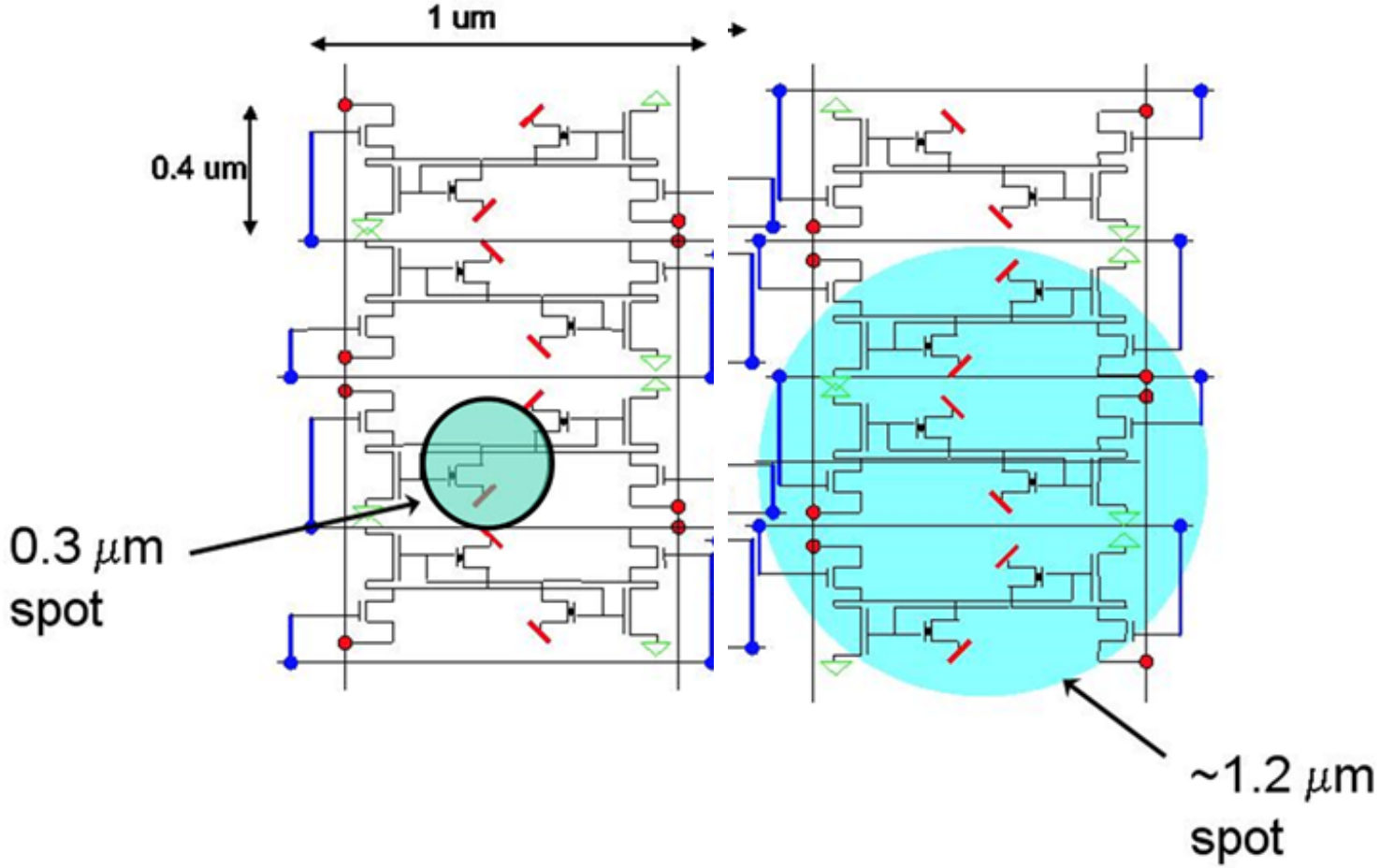
Effective Beam Diameter





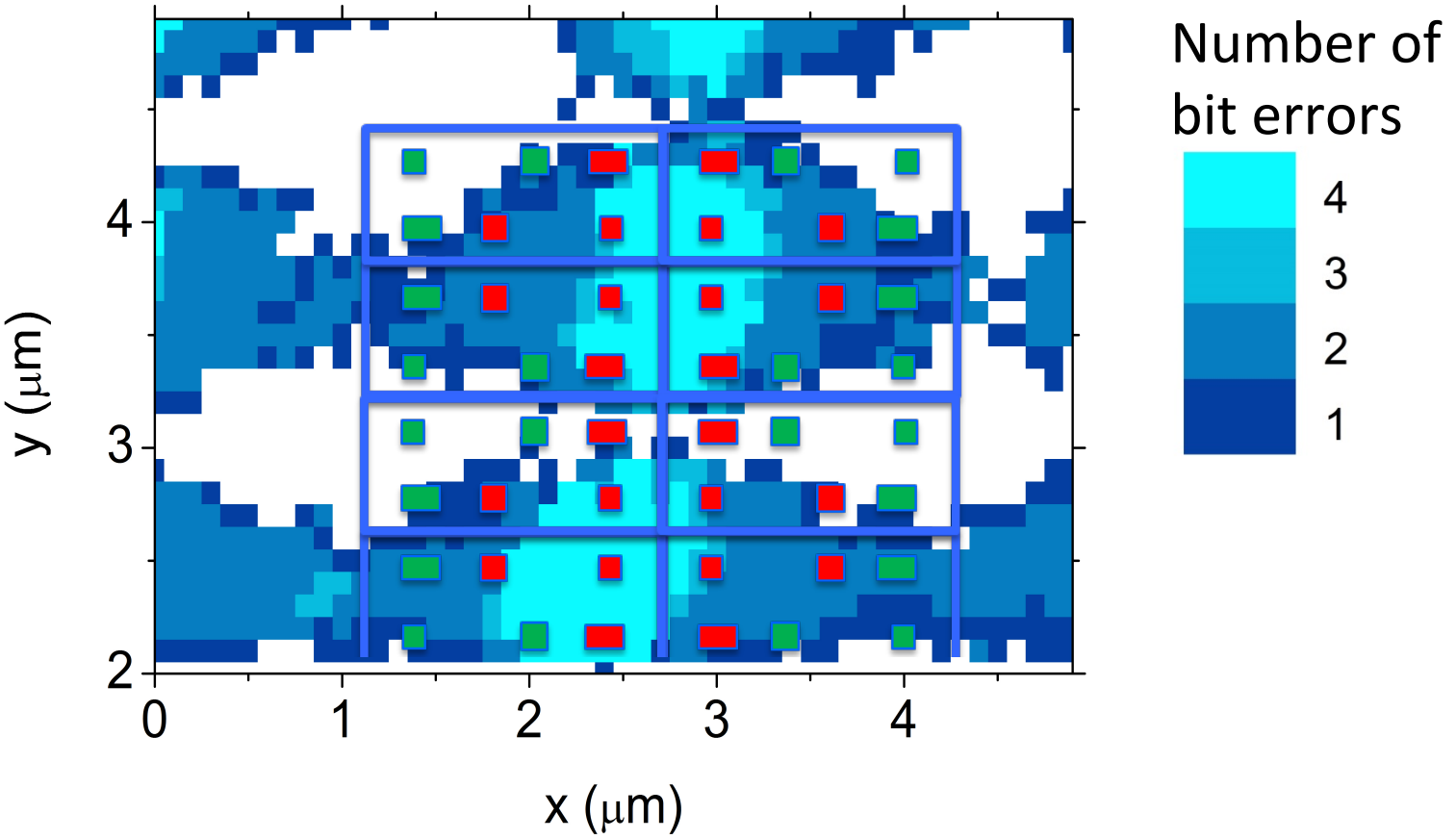
Spot-Size Comparison

45 nm SRAM



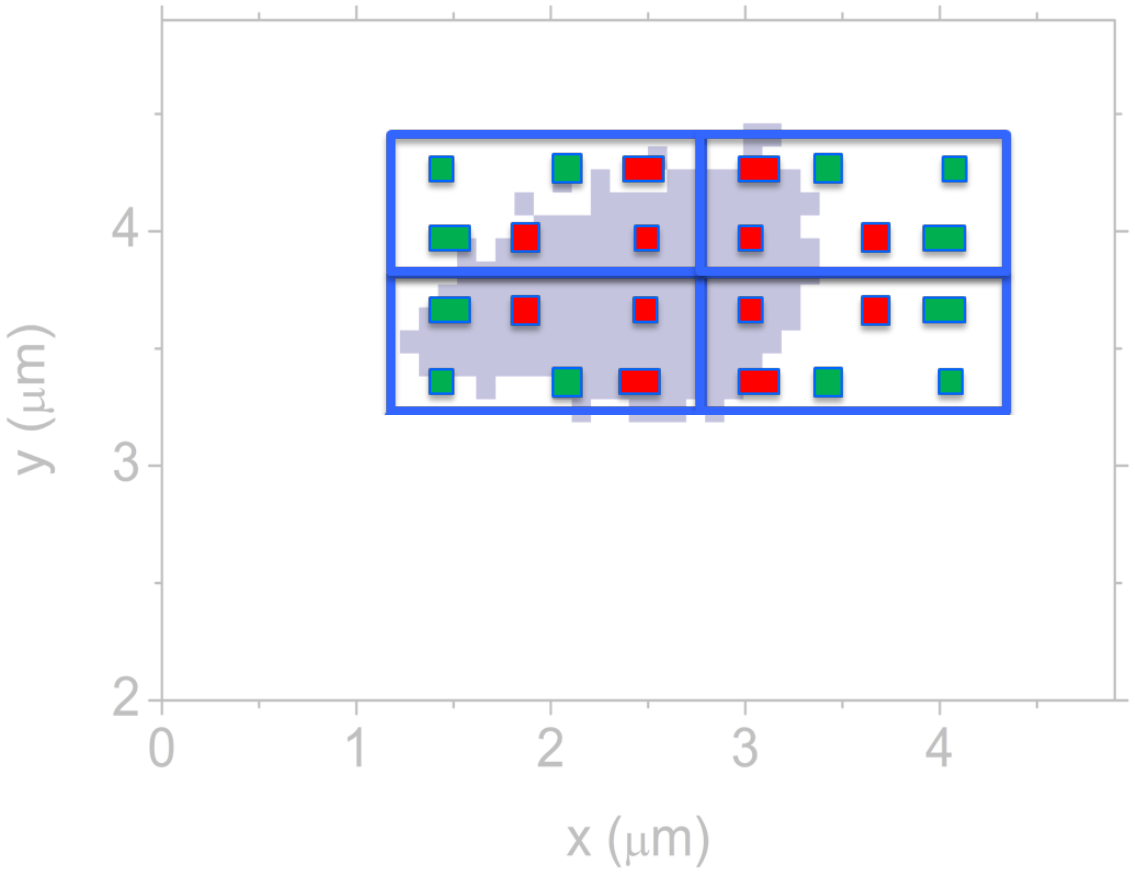
2D Mapping with 293 nm Laser Pulse

Laser pulse energy 25% above threshold:
up to 4-bit errors



2D Mapping with 293 nm Laser Pulse

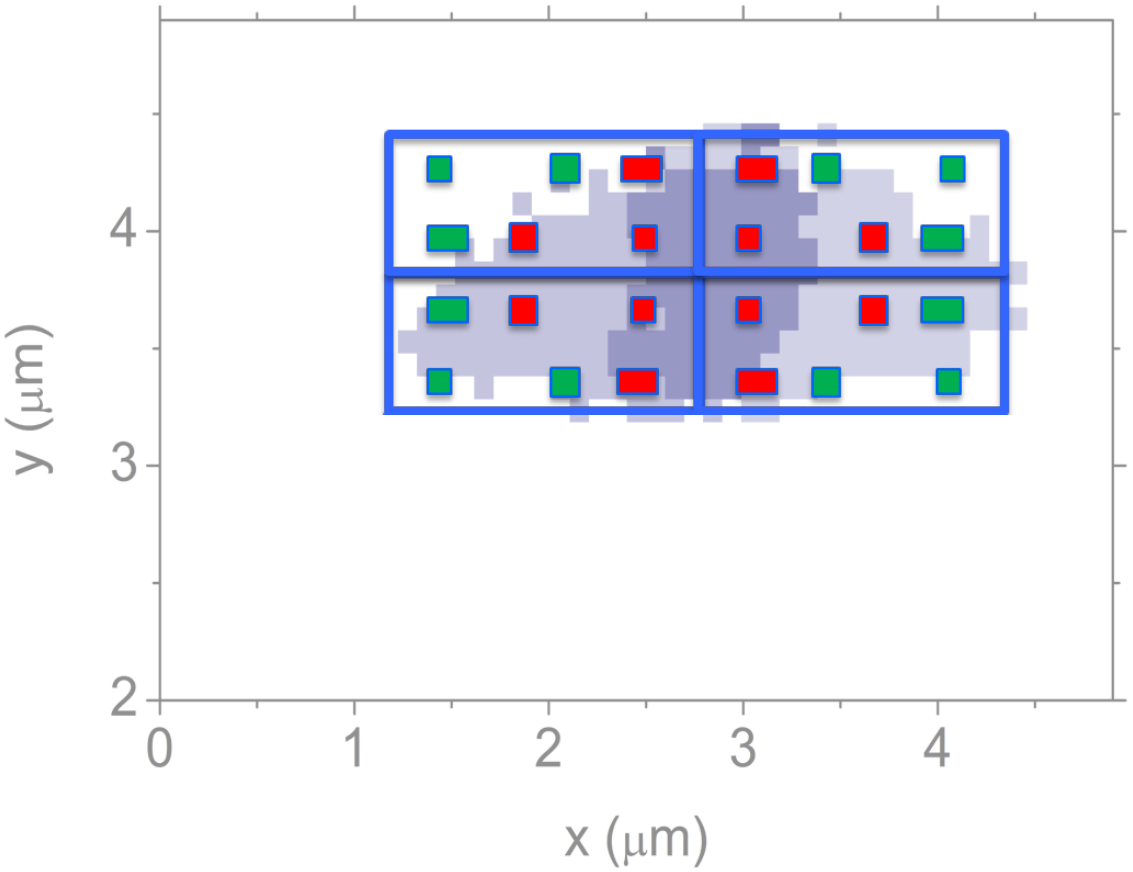
Laser pulse energy 25% above threshold—multiple bit errors



Error Map for Bit #1

2D Mapping with 293 nm Laser Pulse

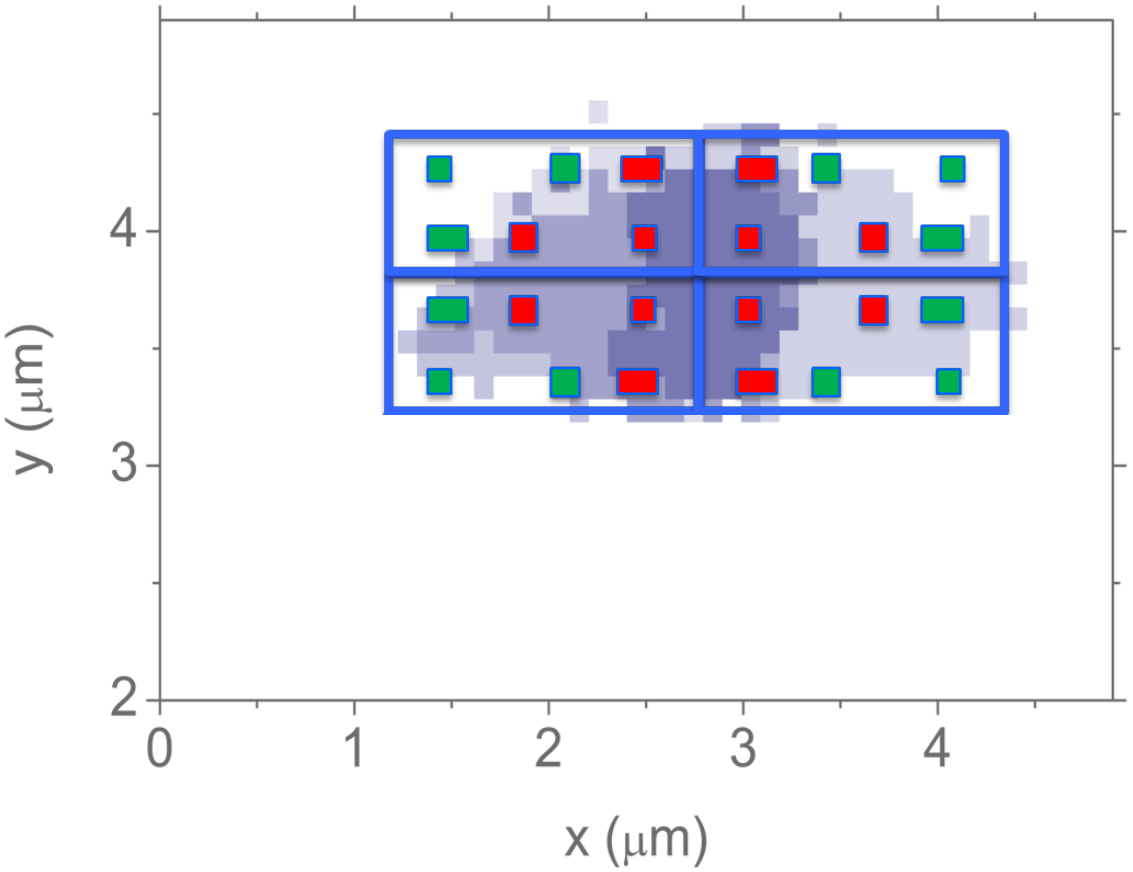
Laser pulse energy 25% above threshold—multiple bit errors



Error Map for Bits 1 and 2

2D Mapping with 293 nm Laser Pulse

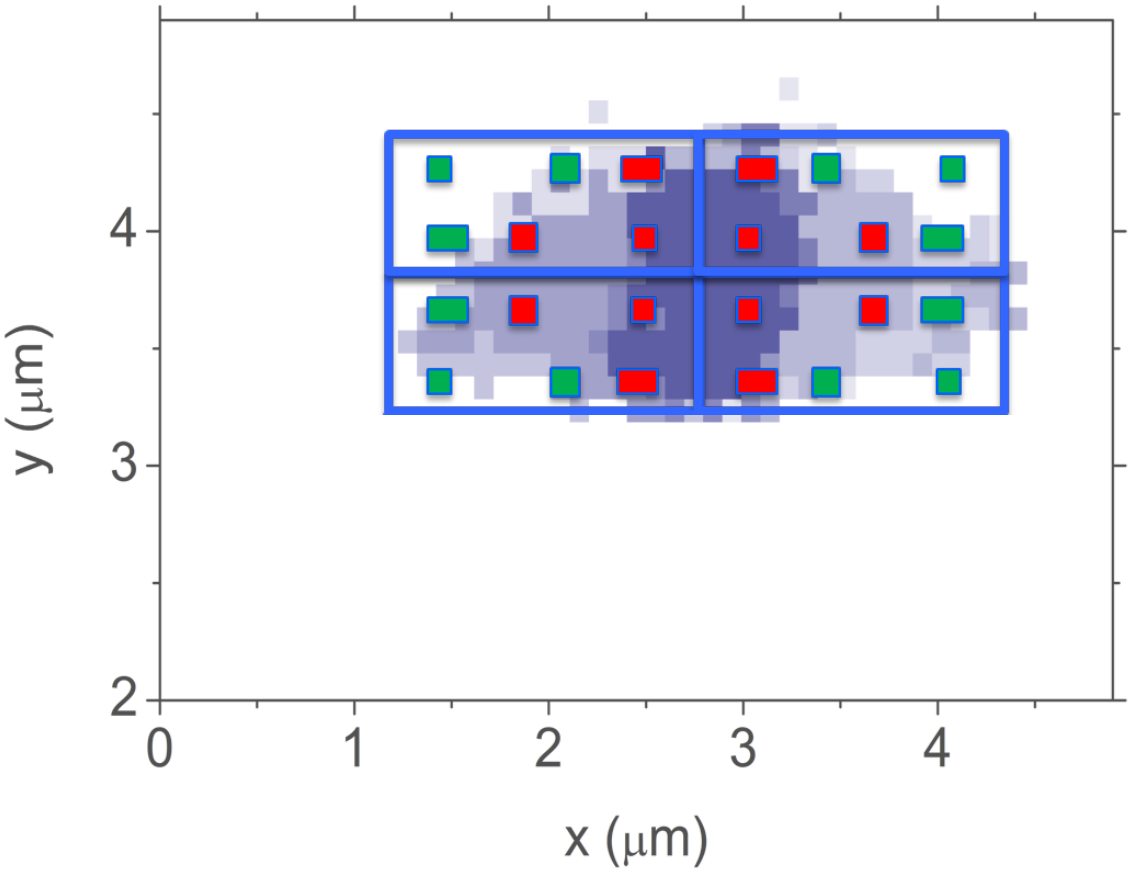
Laser pulse energy 25% above threshold—multiple bit errors



Error Map for Bits 1, 2, and 3

2D Mapping with 293 nm Laser Pulse

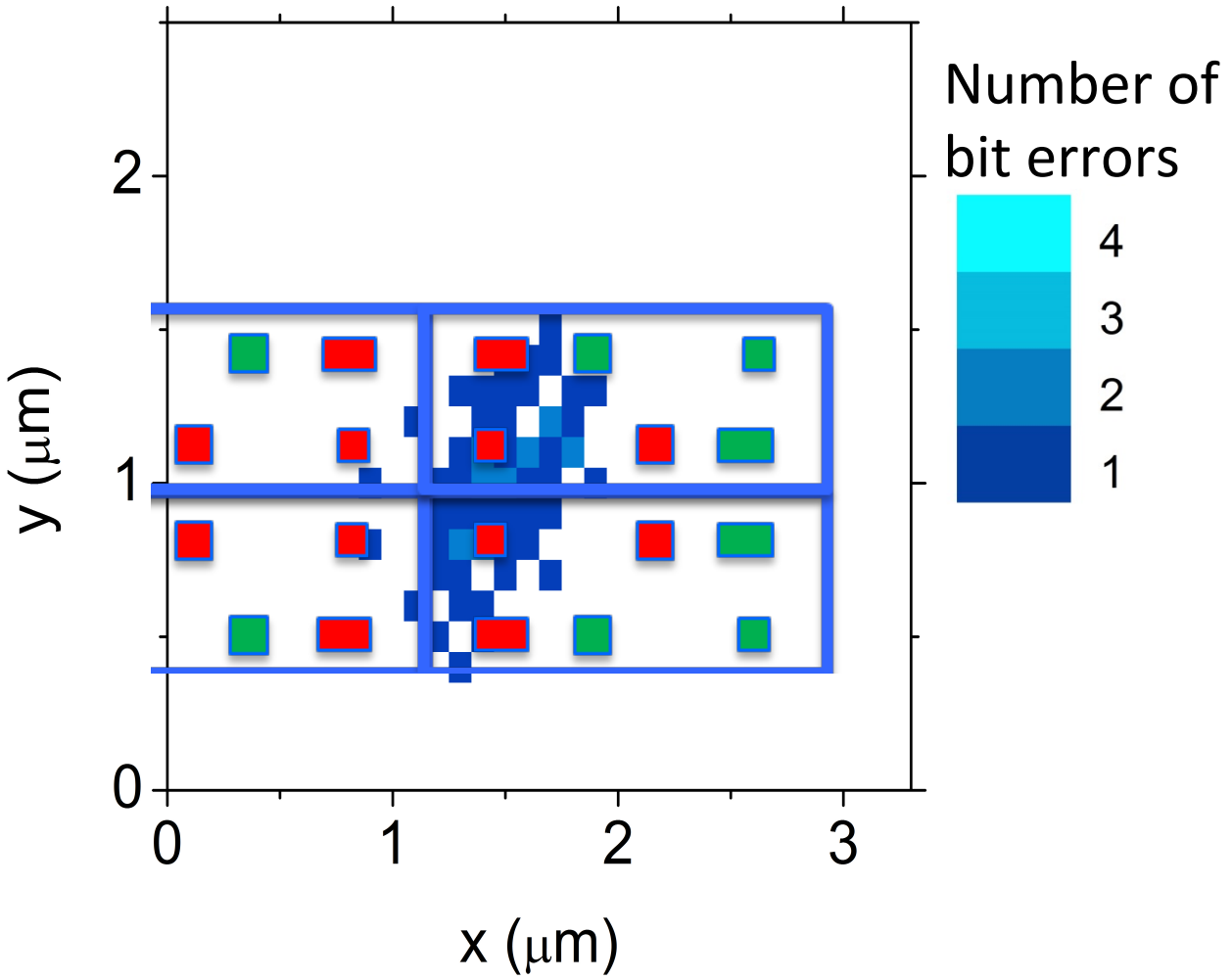
Laser pulse energy 25% above threshold—multiple bit errors



Error Map for Bits 1 thru 4

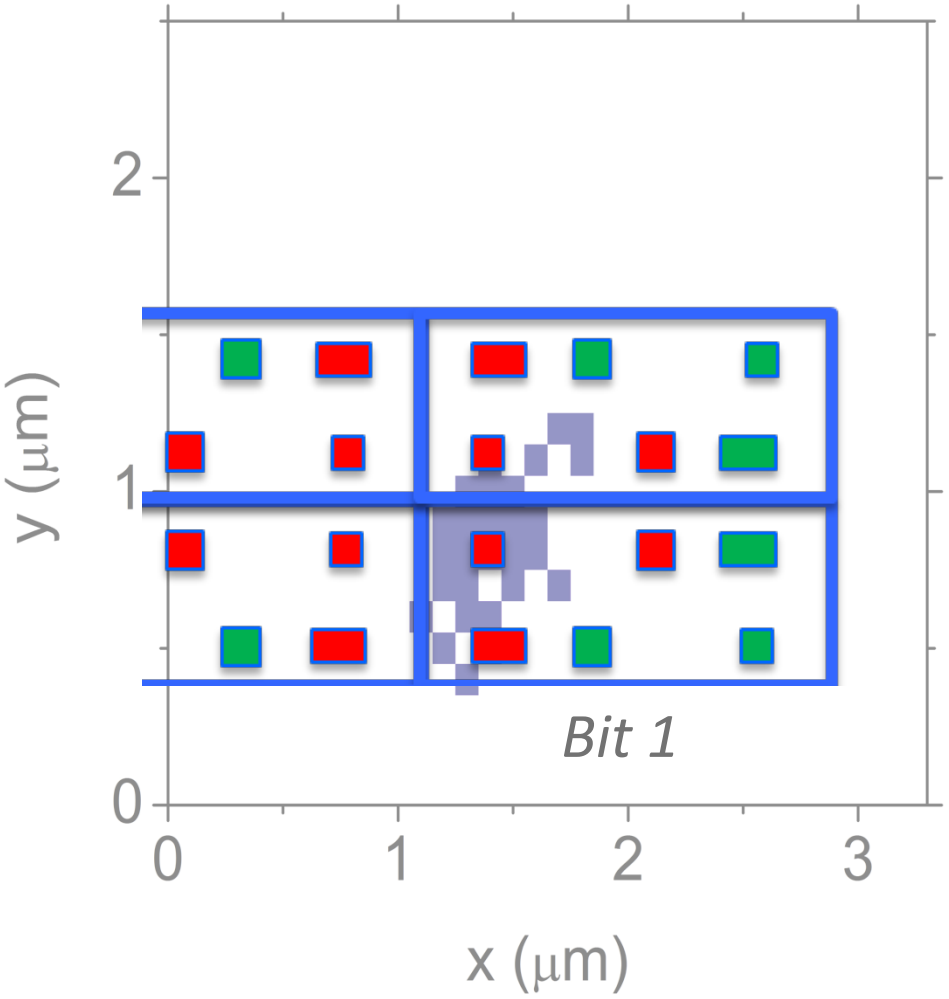
2D Mapping with 293 nm Laser Pulse

Laser pulse energy near threshold: mostly single, and a few double-bit errors



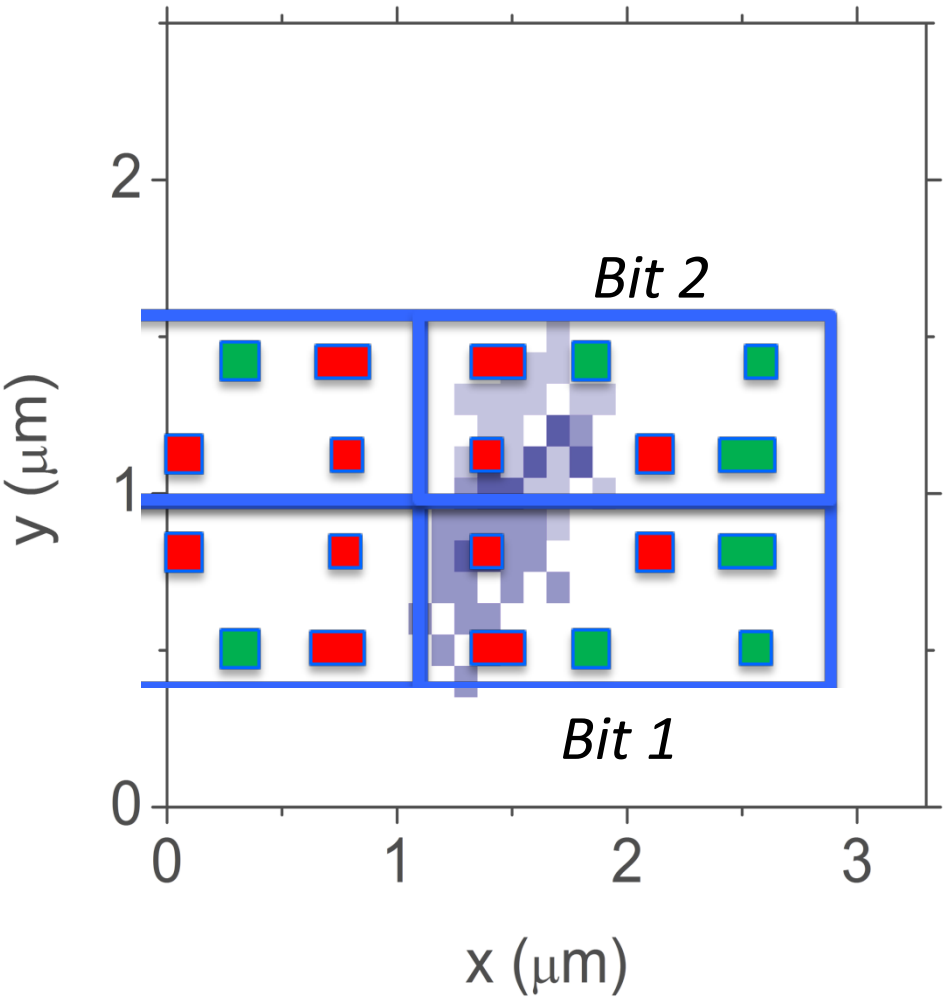
2D Mapping with 293 nm Laser Pulse

Maps for Individual Bit Errors near Threshold



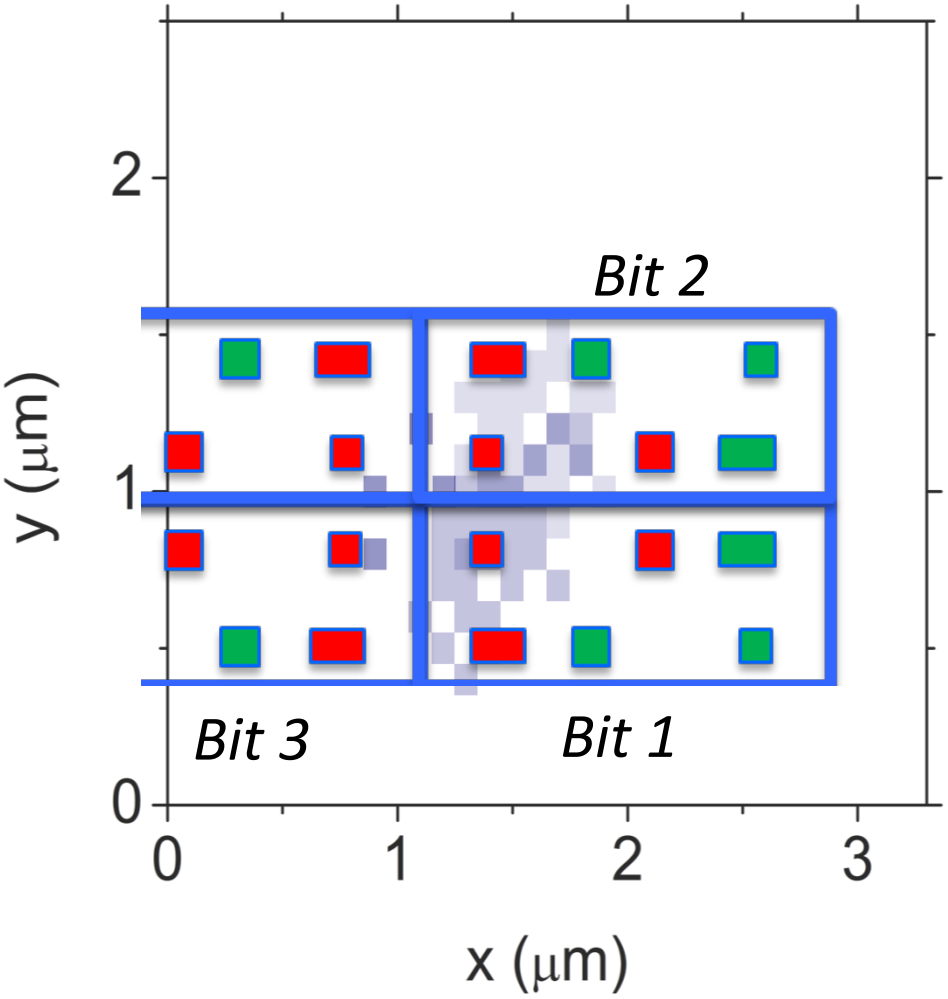
2D Mapping with 293 nm Laser Pulse

Maps for Individual Bit Errors near Threshold



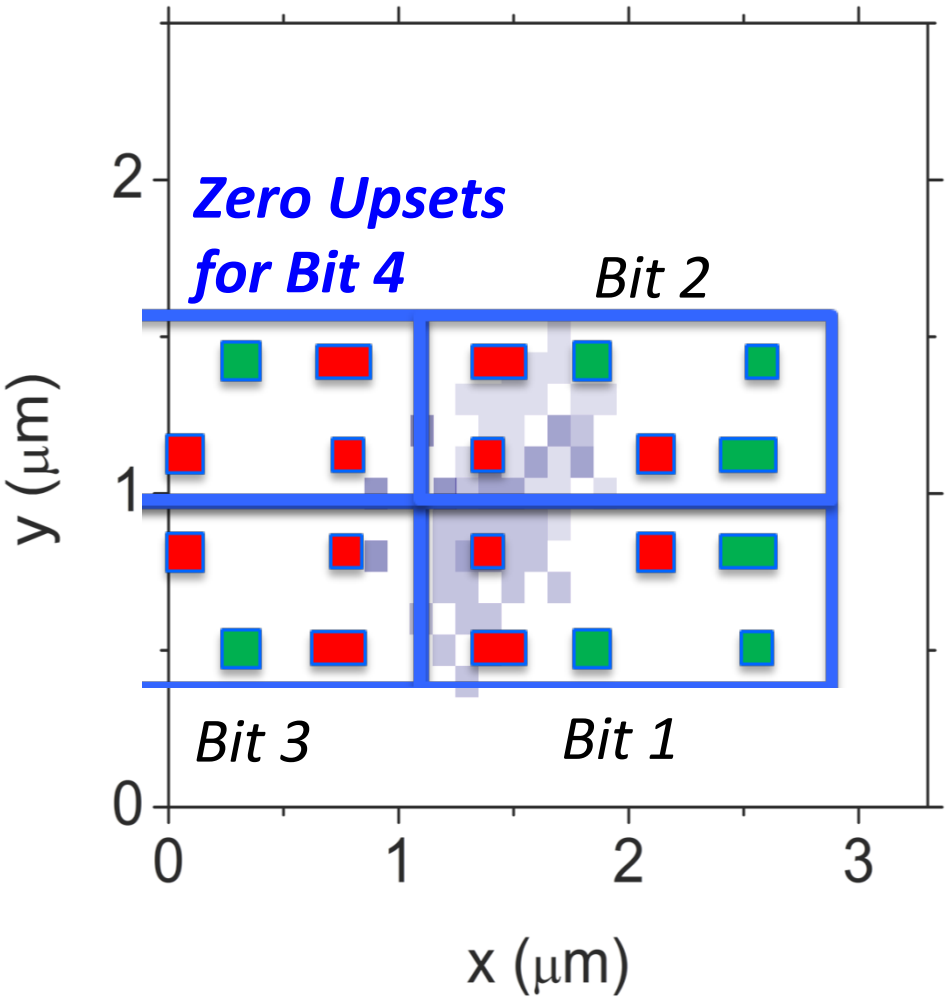
2D Mapping with 293 nm Laser Pulse

Maps for Individual Bit Errors near Threshold



2D Mapping with 293 nm Laser Pulse

Maps for Individual Bit Errors near Threshold



KEY RESULT:

- Direct observation of *cell-to-cell variations in upset sensitivity*
- Consequence of process variations

Conclusions/Summary

- Developed UV Beamline
  - 0.32 um FWHM laser spot
- Applied UV Beamline to investigate SEU in 90-nm SRAM
  - Determined SEU threshold
  - 2D Error maps
    - Identified sensitive areas
  - Revealed asymmetry in sensitivity due to cell-to-cell process variations
- Useful tool for analyzing RHBD designs in highly scaled technologies
- Working to optimize experimental setup to minimize mechanical and optical fluctuations