VANDERBILT UNIVERSITY School of Engineering

Single-Event Transient Pulse-Width Measurements in Advanced Technologies

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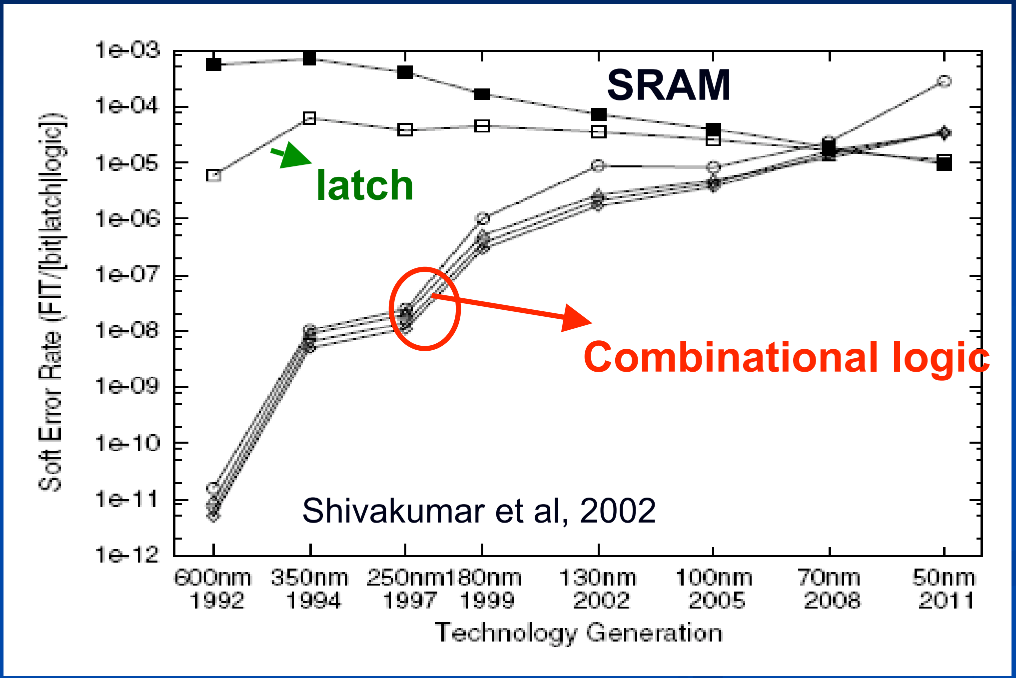
MURI Review Meeting
May 13, 2008

Supported in part by the DTRA Rad-Hard Microelectronics Program

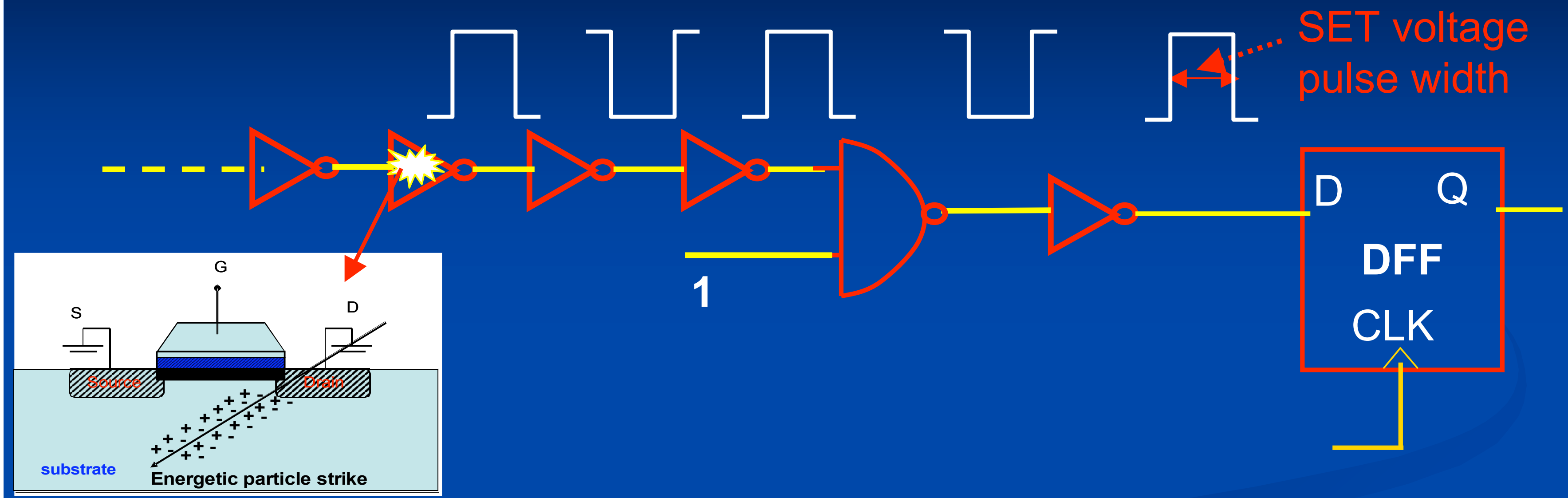
Motivation



- **Combinational logic soft errors – major reliability issue in advanced CMOS processes**
- **Knowledge of SET pulse widths – key to determining error rates**
- **Novel test circuit used for measurements of heavy-ion, neutron, proton and alpha SET widths in 130-nm and 90-nm**
- **Results indicate SET widths increase with scaling and are comparable to legitimate logic signals**

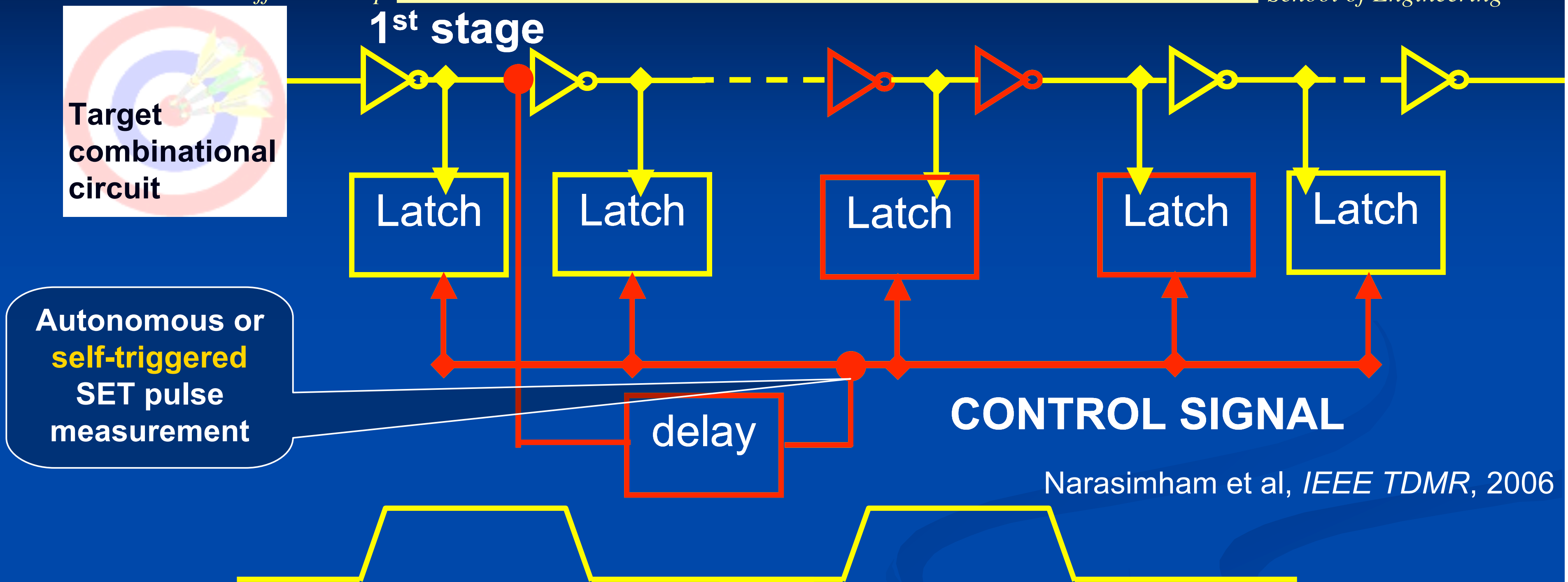
Background

Vanderbilt Radiation Effects Group — *School of Engineering*



- **SET pulse width & clock frequency determine circuit vulnerability**
- **Measurement difficulty**
  - **Pulse width in pico-second time scales – external measurement complex/costly**
  - **Random nature of ion strikes – external trigger signal cannot initiate measurement**
- **Developed on-chip self-triggered pulse measurement**
- **Statistical distribution of SETs measured in 130-nm and 90-nm with heavy-ions, neutrons, protons and alpha particles**

Autonomous SET capture

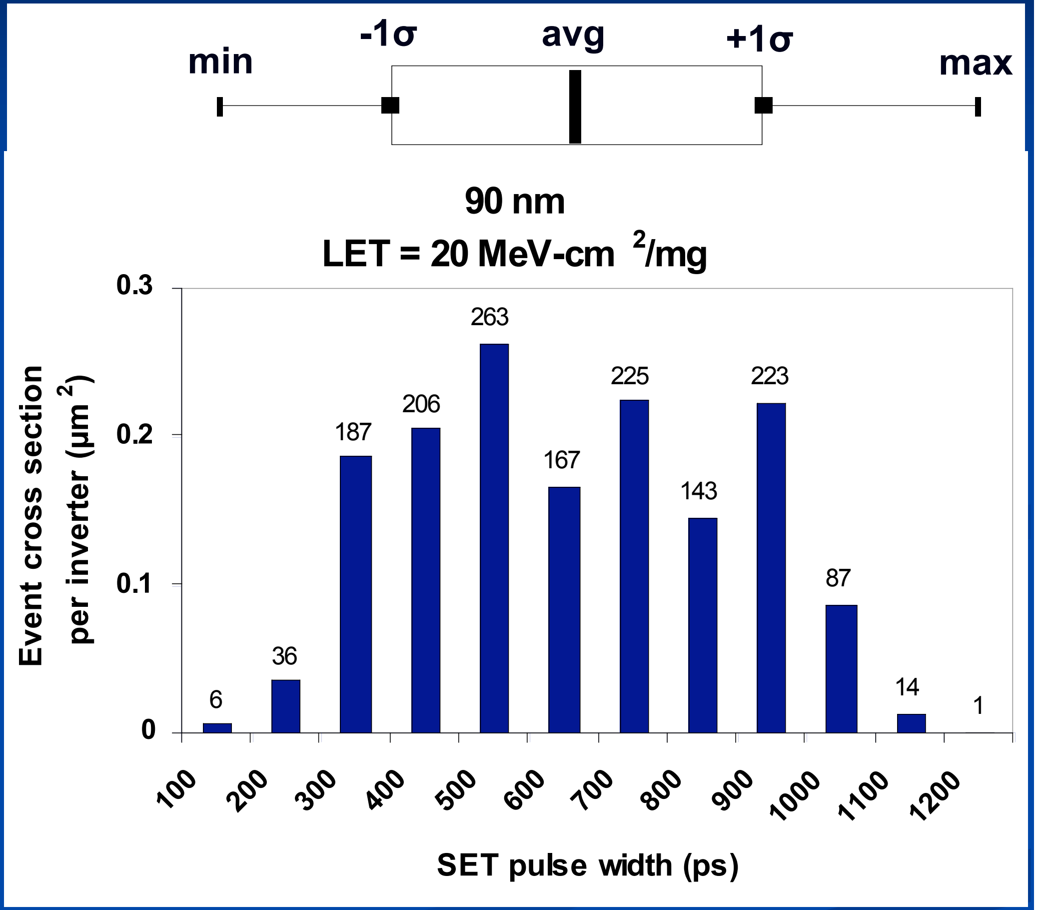


Narasimham et al, *IEEE TDMR*, 2006

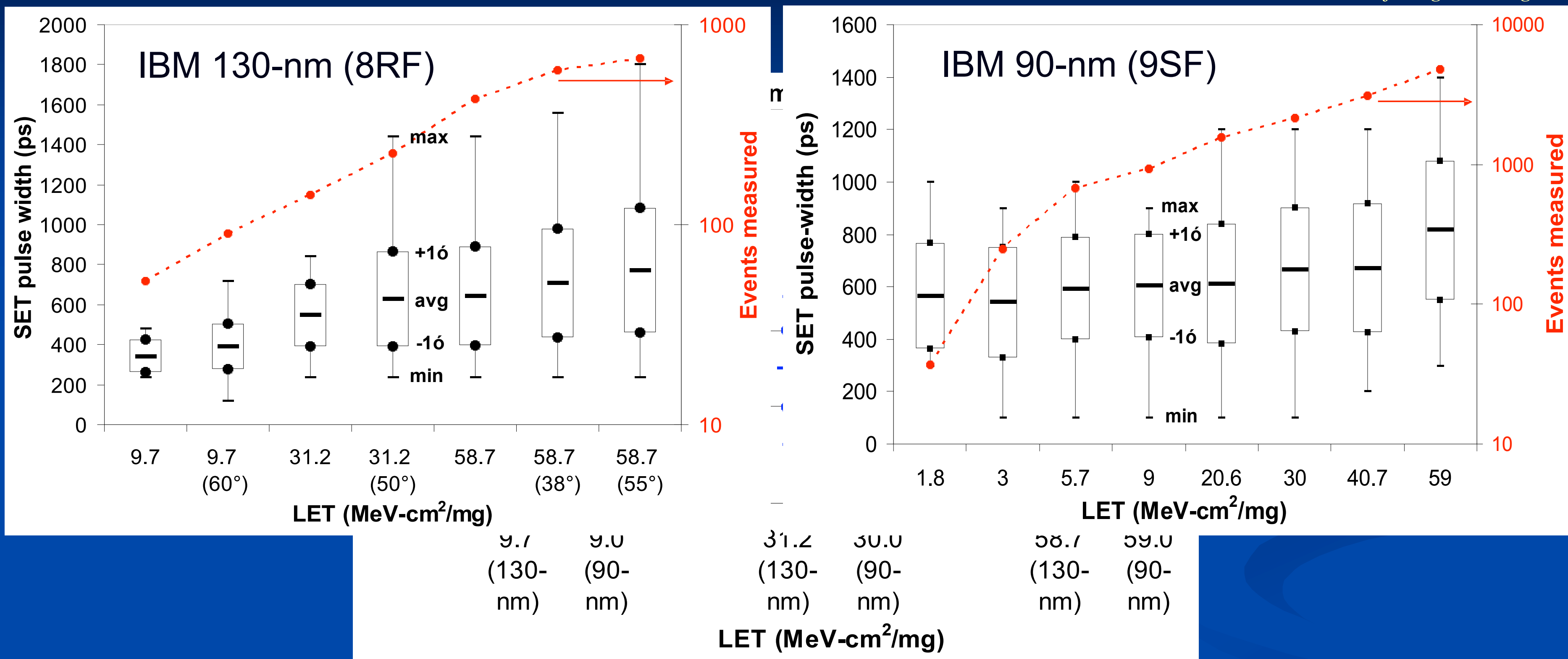
- SET generated in custom inverter target circuitry – propagates and triggers measurement
- Pulse width is proportional to number of switched states (measured in units of inverter delays)
- Upsets after the trigger stage are not measured
- Most single latch upsets (due to direct strikes on the latch) are identifiable and SET width data not affected

Broad Distribution in SET Widths

- Width of SET pulses depend on several factors
  - Energy of incident ion
  - Location of strike with respect to sensitive drain
  - Technology effects of pulse generation (charge collection characteristics)
  - Circuit effects on pulse propagation
- Results in broad distribution of SET pulses for each radiation environment
- Our technique precisely characterizes this statistical distribution of SET pulse widths

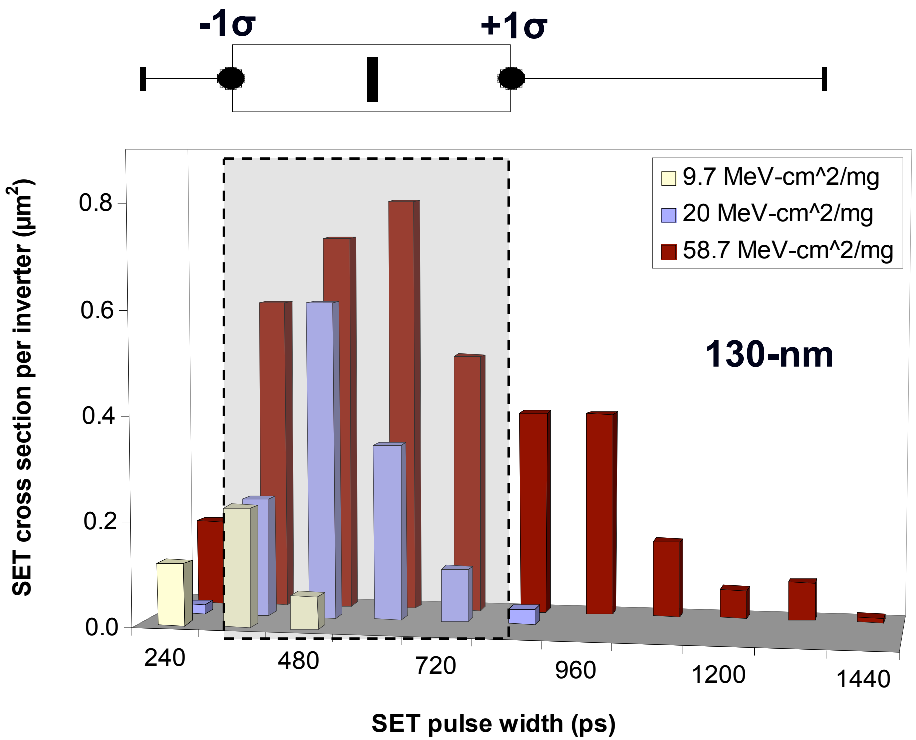


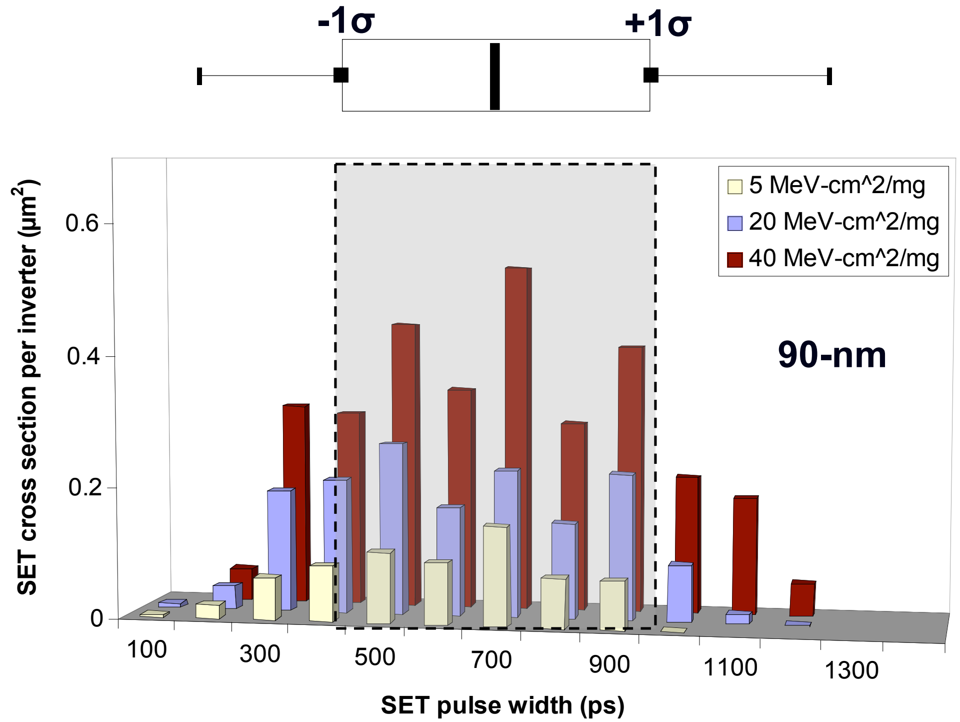
Heavy-Ion – 130-nm & 90-nm



- **Results indicate increasing SET pulse widths with scaling → important as latch setup/hold times decrease with scaling → more SETs latched as error**

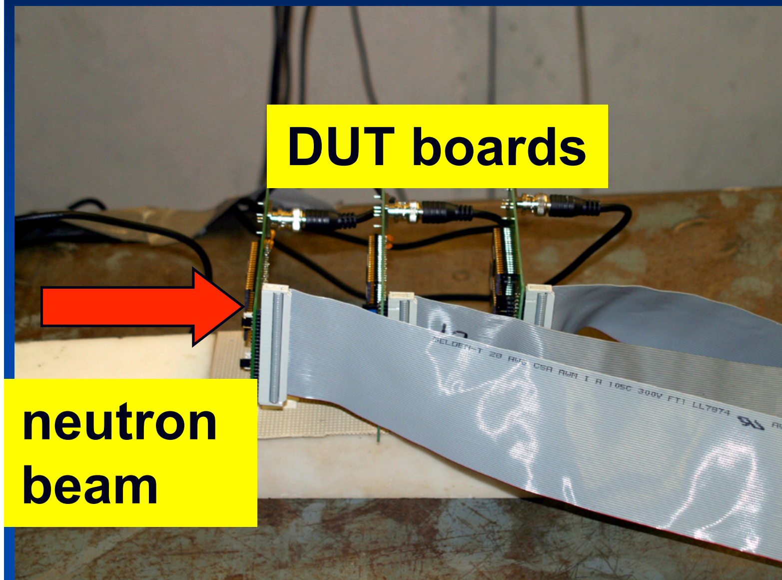
Cross Section Comparison

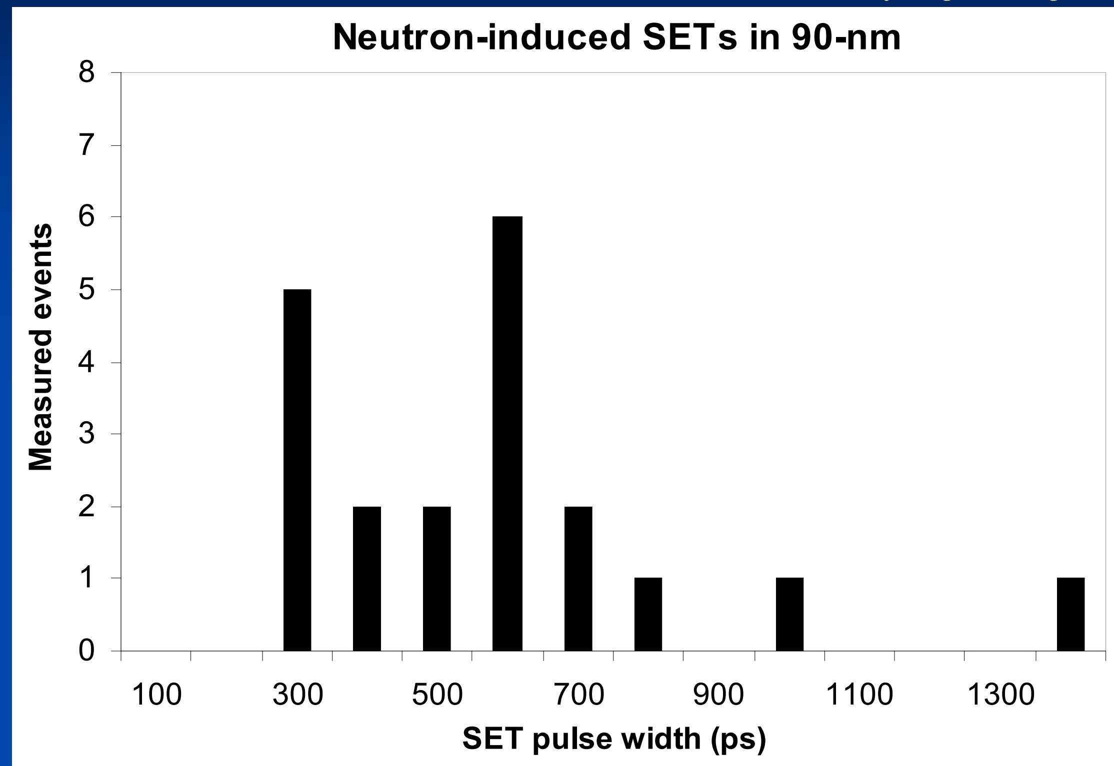




- Event cross section dominated by pulses between
  - 300 ps to 700 ps in 130 nm
  - 400 ps to 900 ps in 90 nm
- Increase in wider transients translates to higher error rates with scaling

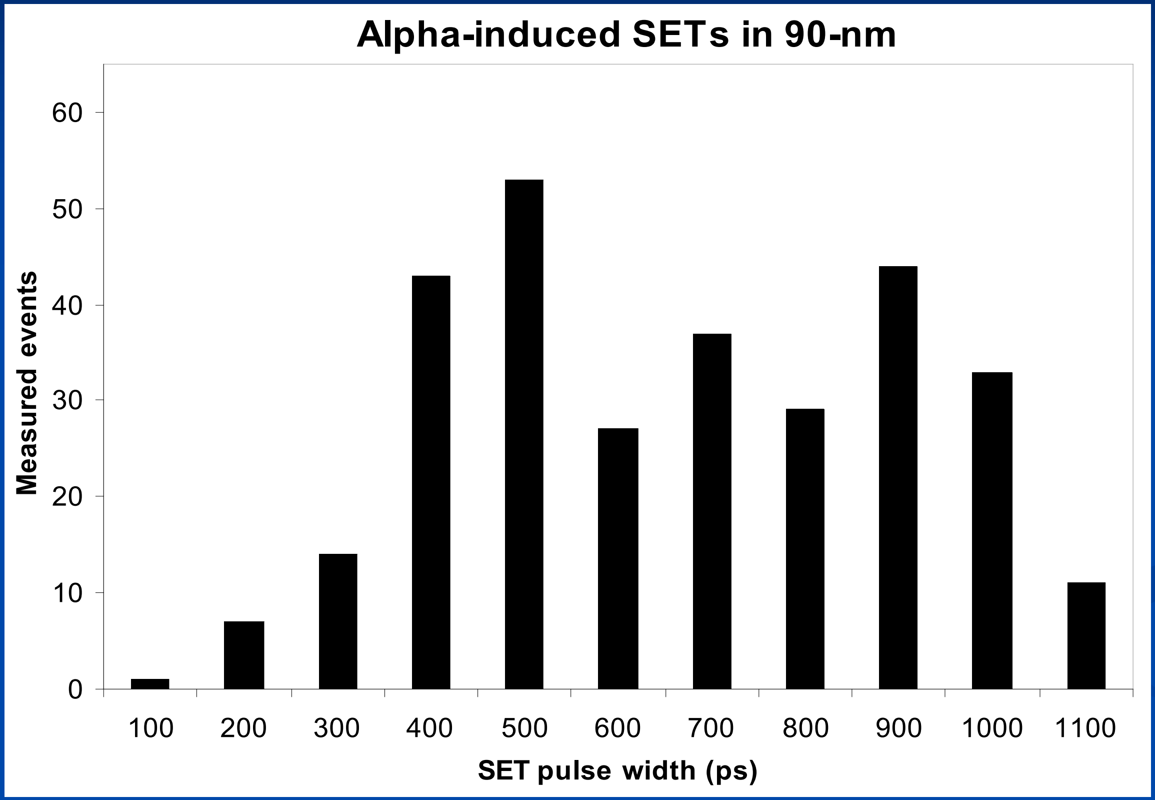
Neutron-Induced SETs





- **Tested six 90-nm ICs at WNR facility at LANL**
- **Energy spectrum matches sea-level spectrum for energies from 10 to 500 MeV**
- **Neutron fluence 1.33×10^{11} neutrons/cm^2**
- **Neutron SET cross-section ~ 2.5×10^{-6} μm^2/inverter**

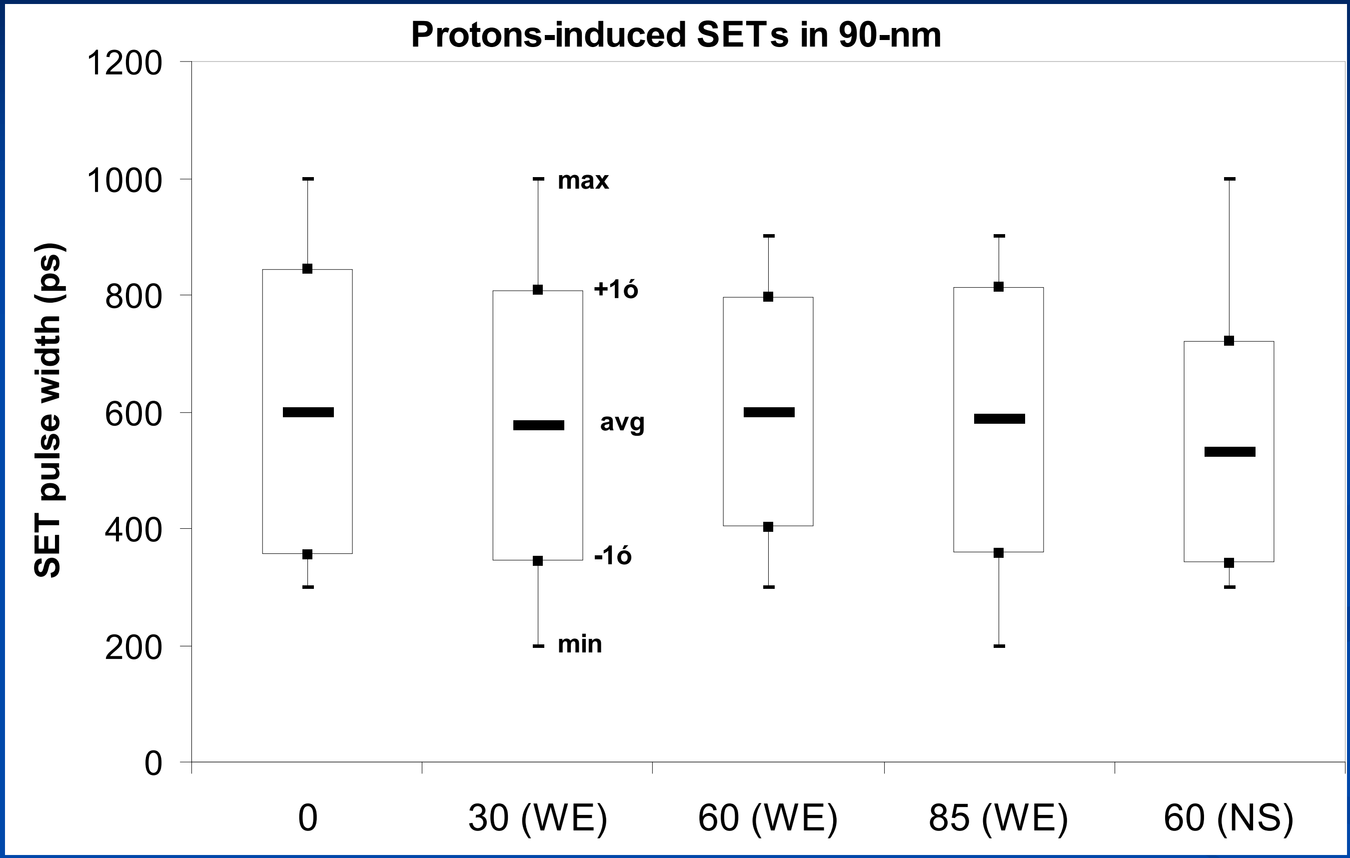
Alpha-Induced SETs



- **Alpha tests at TI using foil of Am^{241}**
- **Energy ~ 5.5 MeV**
- **Fluence ~ 4.45×10^{10} alphas/cm^2**
- **Total events measured ~ 300**

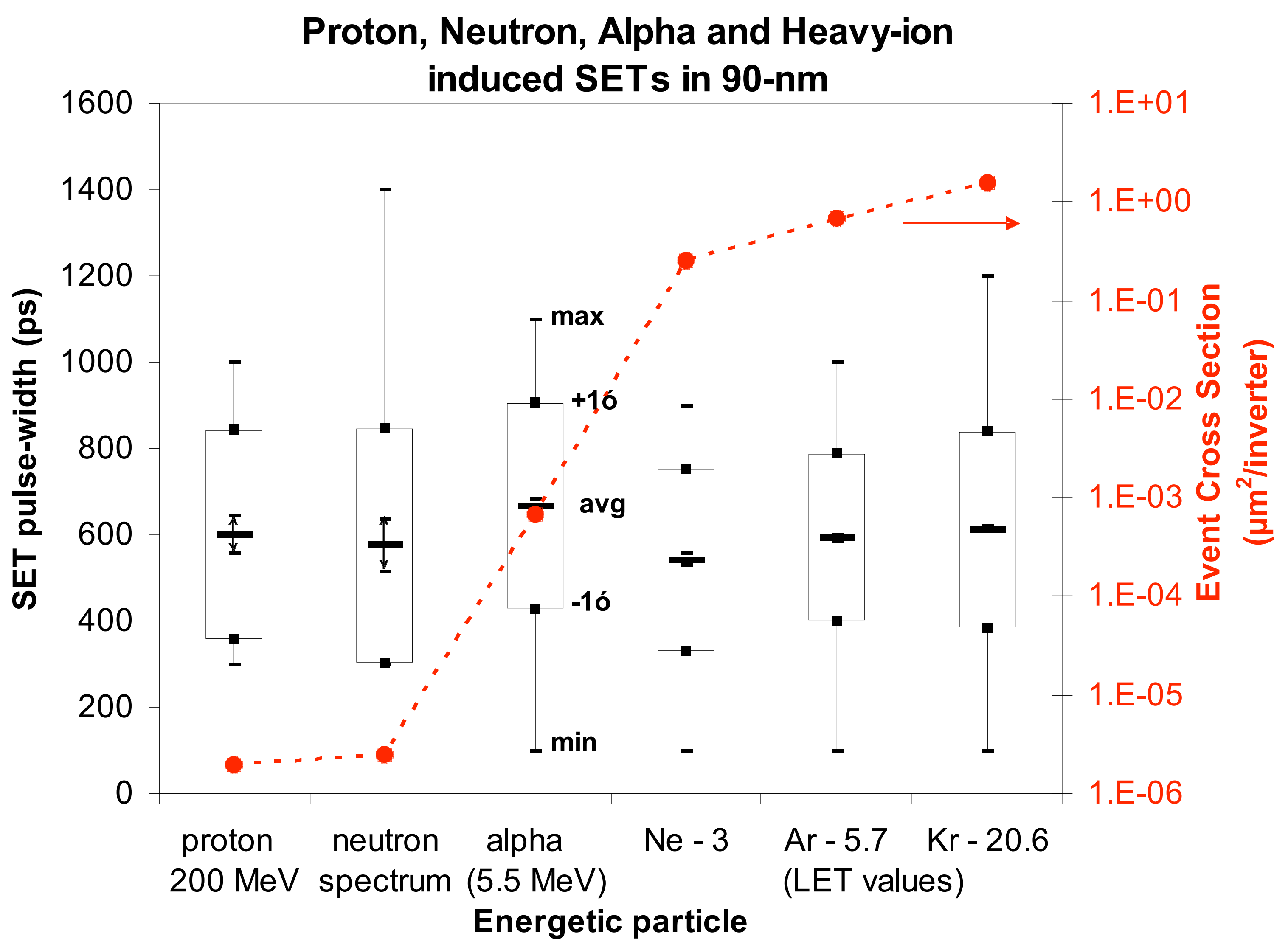
- **Alpha SET cross section ~ 6.74×10^{-4} μm^2/inverter**

Proton-Induced SETs

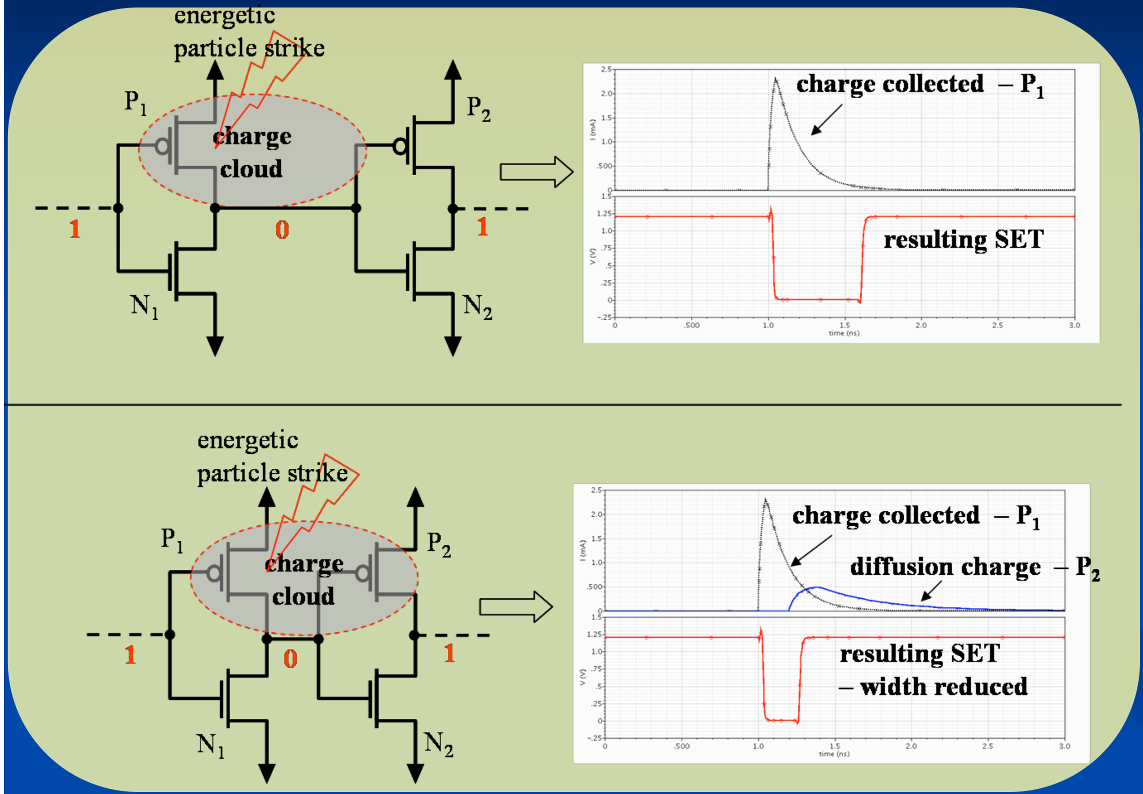


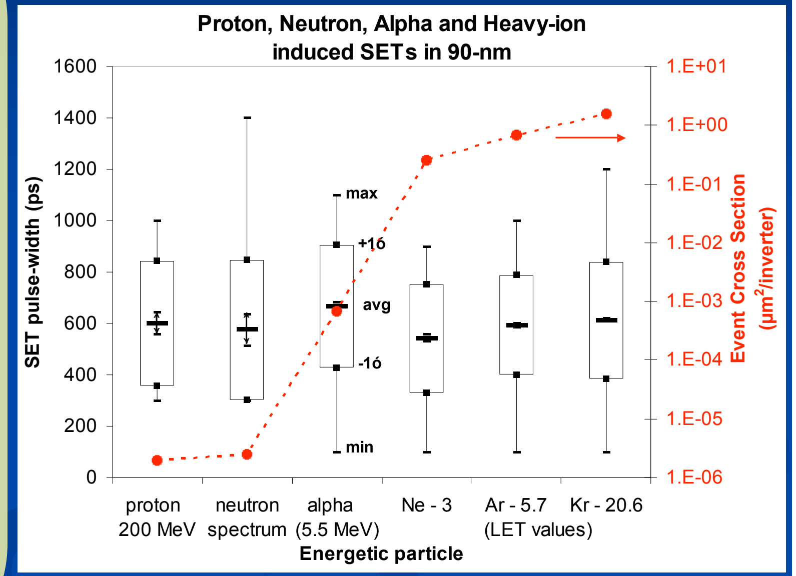
- Tests conducted at Indiana Univ with 200 MeV protons
- Proton SET cross-section ~ 2 × 10^{-6} μm^2/inverter
- Results indicate that proton angle of incidence does not affect SET width distributions

Comparison – Energetic Particles



Similarity in SET Distributions





- **Less variation in SET pulse widths for different particle types – probably due to carrier redistribution and charge sharing effects**
- **Preliminary simulations indicate charge spread and diffusion collection by subsequent gate may limit SET widths**

Other Applications

- Test circuit can help quantify effects of process or layout variations on single events
  - Circuit was used for quantifying effect of guard bands in mitigating long SETs
- Characterization of effect of charge spread on SET width distributions
  - Tested with ions incident from different directions with respect to n-well layout
  - Interleaved inverter chains have been designed to further analyze charge spread effect

Well Contacts and Guard Bands

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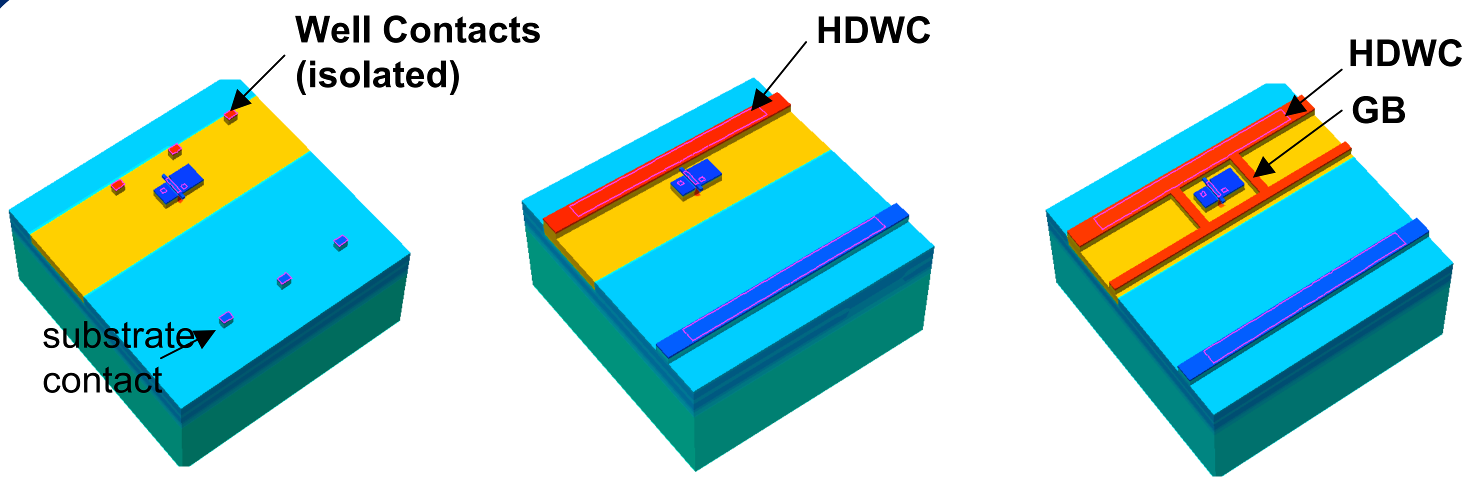
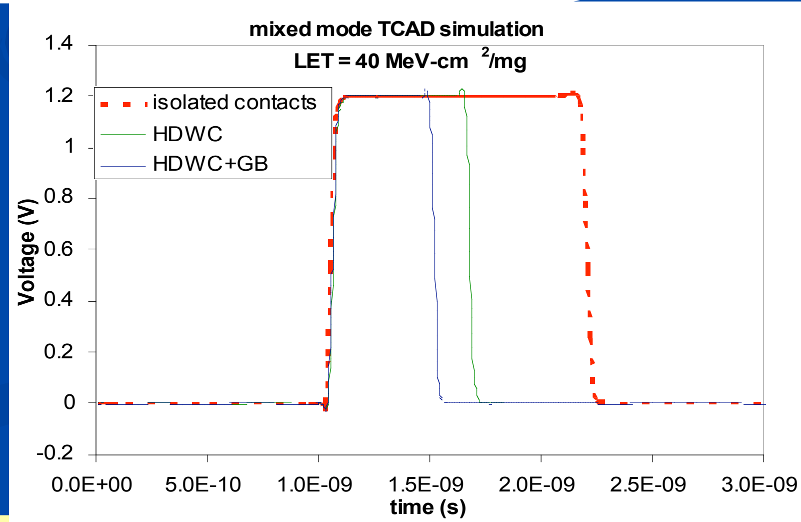


Conventional Layout – Isolated Well Contacts

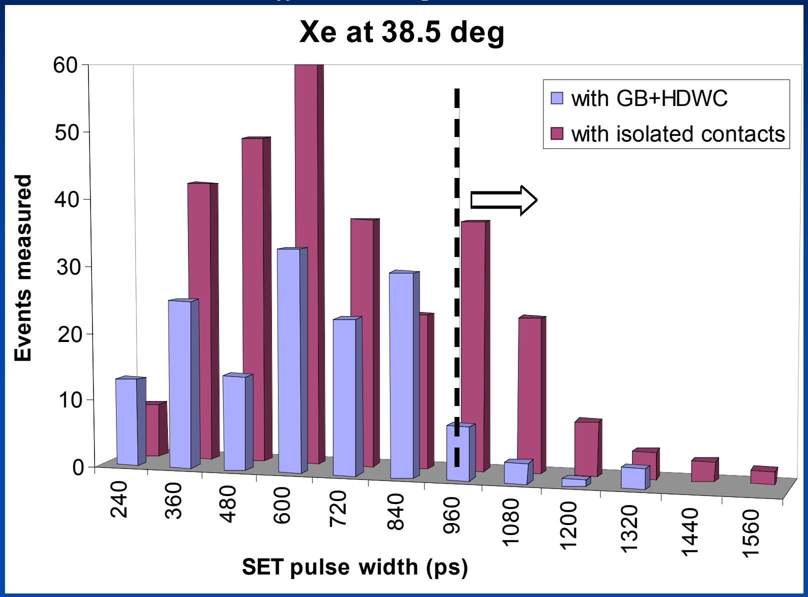
High Density Well Contacts (HDWC)

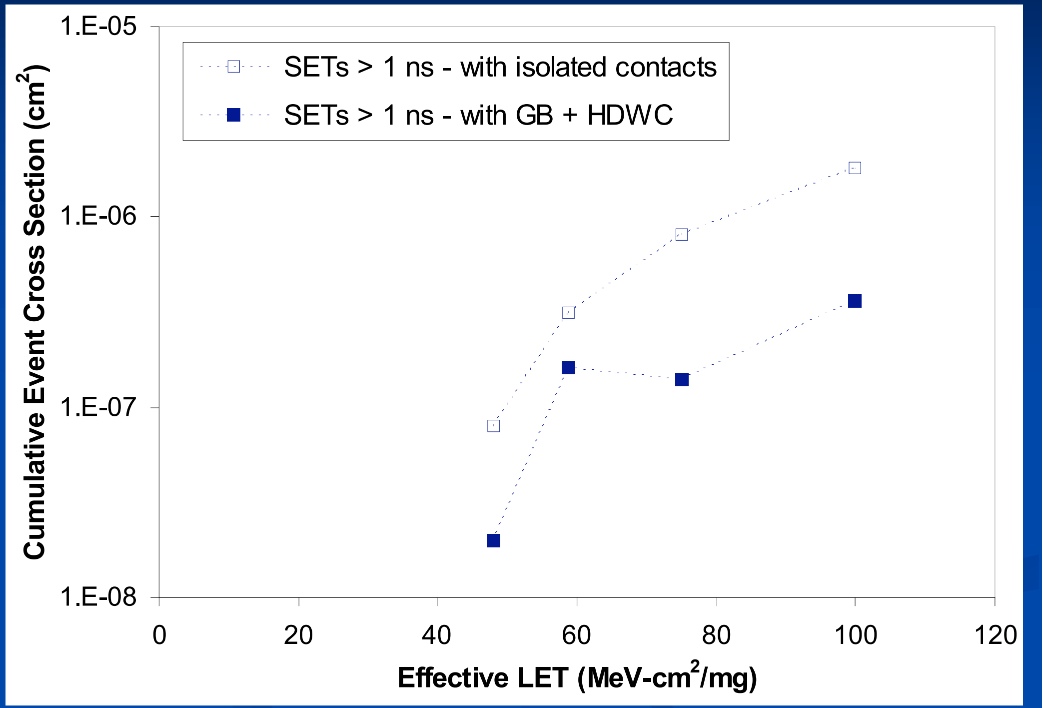
HDWC + Guard Band (GB)

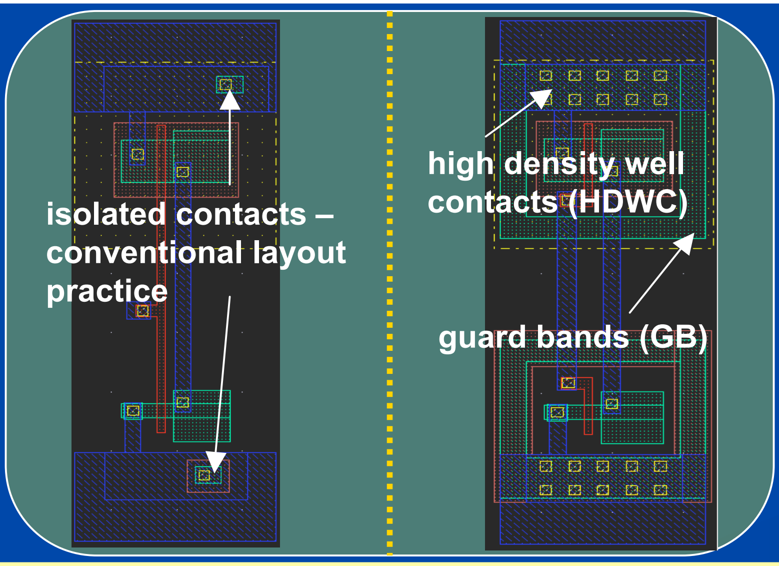
- Strikes within n-well lead to long SETs due to parasitic bipolar effect
- Mixed mode simulations using calibrated 130-nm process – show effect of GB and HDWC in mitigating long SETs



Characterizing Guard Bands







- Events > 1ns reduced by ~72% for circuits with GB + HDWC
- Reduction in frequency and max SET width attributed to reduction in parasitic bipolar effect

Impact

- Resolve controversy on expected pulse widths
- Quantify technology trends in SET pulse widths
- Characterize effect of RHBD structures such as multiple well contacts and guard bands on SET pulse widths
- Determine effect of charge sharing on SETs
- Technique can also be used to measure other spurious signals such as cross-talk pulses

Conclusion

- **Autonomous SET characterization technique developed and implemented to obtain precise distributions of heavy-ion, neutron, proton and alpha induced SET widths in 130-nm/90-nm CMOS**
- **Width and range of dominant SETs increase with scaling**
- **Neutron and alpha particle induced SETs are of order of legitimate logic signals – concern for commercial applications**
- **High density well contacts and guard bands helps reduce more than 70% of SETs longer than 1 ns**