Characterization and Measurement of the SET Pulse Duration of the DARE65T Standard Cells Libraries

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- Measurement results
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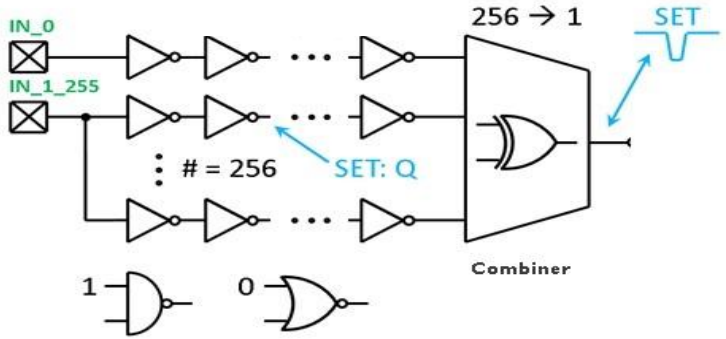
Introduction

- Proper hardening of a digital circuit is related to:
  - An error rate specification
  - Mission profile, orbits...
- Many way to harden a digital circuit
  - Best hardening has an important cost in area, power and speed
- To predict the error rate and to optimize the level of hardening, we need:
  - Cross section versus LET
  - Distribution of the SET duration versus LET
- The goal of this TV is by measuring the cross section and the SET duration on a limited subset of the standard cells, to be able to calculate them for any standard cells of the DARE65T libraries.

SET characterization test structure

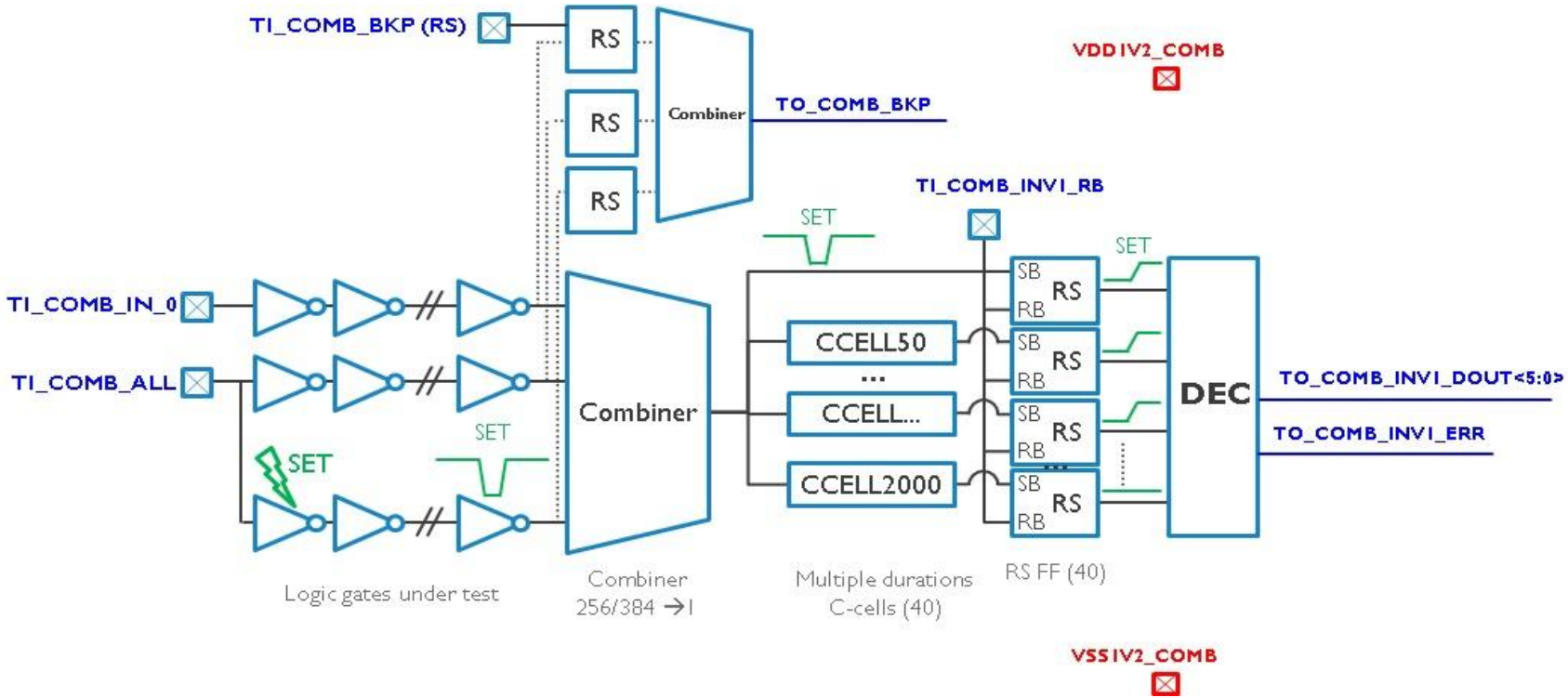
Architecture



- Victims are a limited subset of the std cells libraries:
  - INV D1, D3, D4 & D16
    - Gate length of 60nm and 70nm
    - Threshold flavor: Low, Standard and High
  - CCELL D1, D2 & D4
  - Hardened logic: INVBLx, NAND2BLx & NORD2BLx
- Victim arranged in chains of 16 or 32 cells:
  - Representative of real logic cone
  - Not too long chain to avoid an important pulse broadening (~2ps/gate)
  - Parallelization of the victims is done thanks to a balanced NAND/NOR combiner

SET characterization test structure

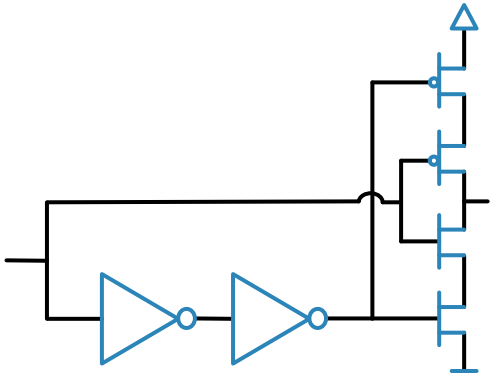
Architecture

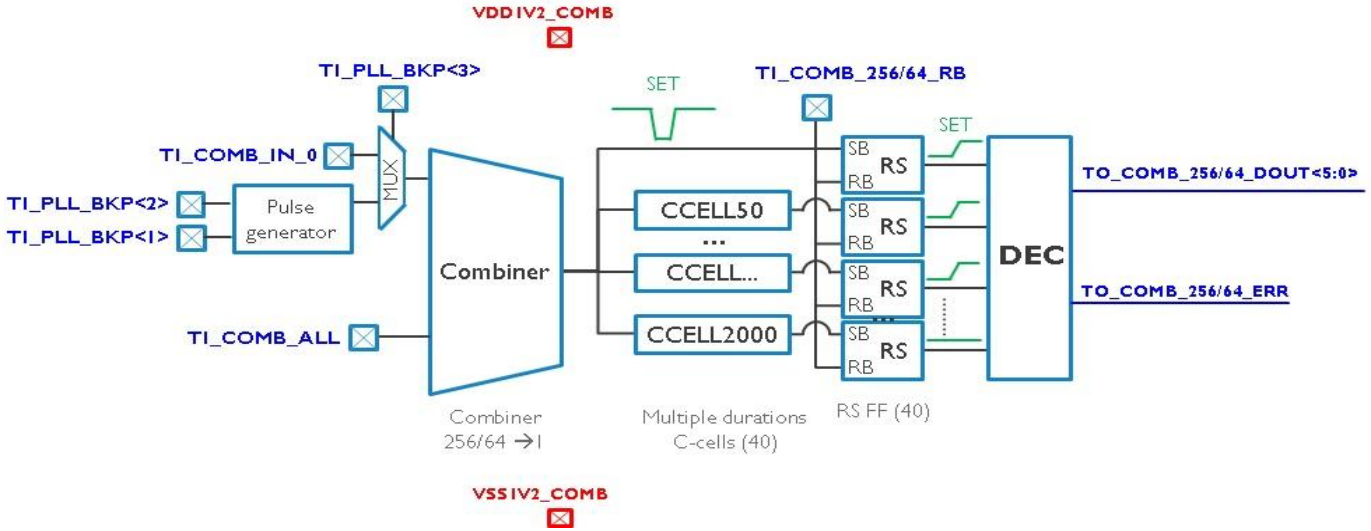


SET characterization test structure

Calibration

- Delay SET filter measurement
  - Ring oscillator using same delay elements
  - Validation of the pulse distortion with the measurement of well-known pulse width





SET characterization test structure

Double hit probability

- Target: 100 hits on the victim chains in 15 minutes under a flux of 10k particles/(s*cm^2)
  - Sensitive area of the victims = 100 / (15 * 60 * 10k) = 1111 µm^2
- Readout frequency of each test structure output: 100Hz
- Each strikes are independent
  - Probability to have a double strike during 10 ms

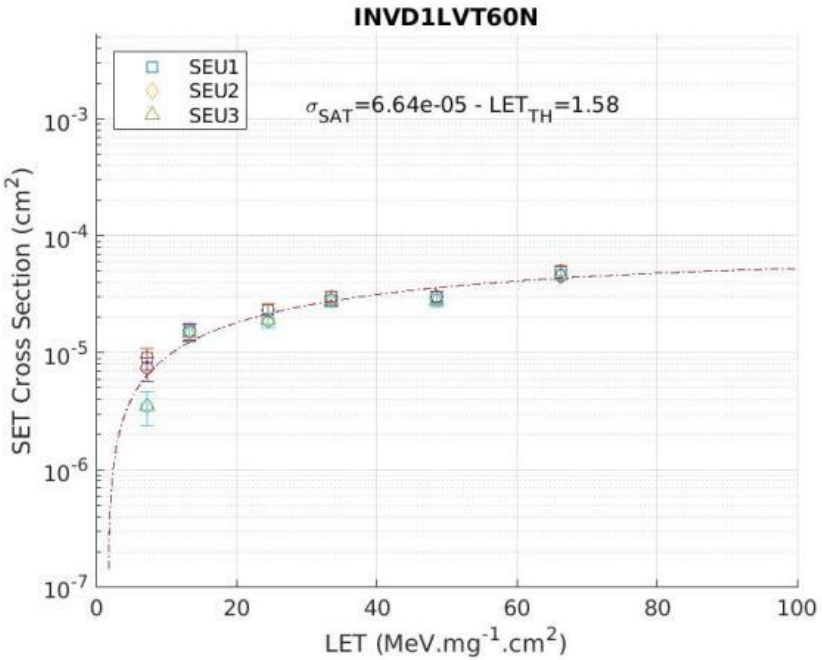
$$P(k = 2, 10ms) = \frac{\lambda^k e^{-\lambda}}{k!} = 6.04 \times 10^{-7}$$

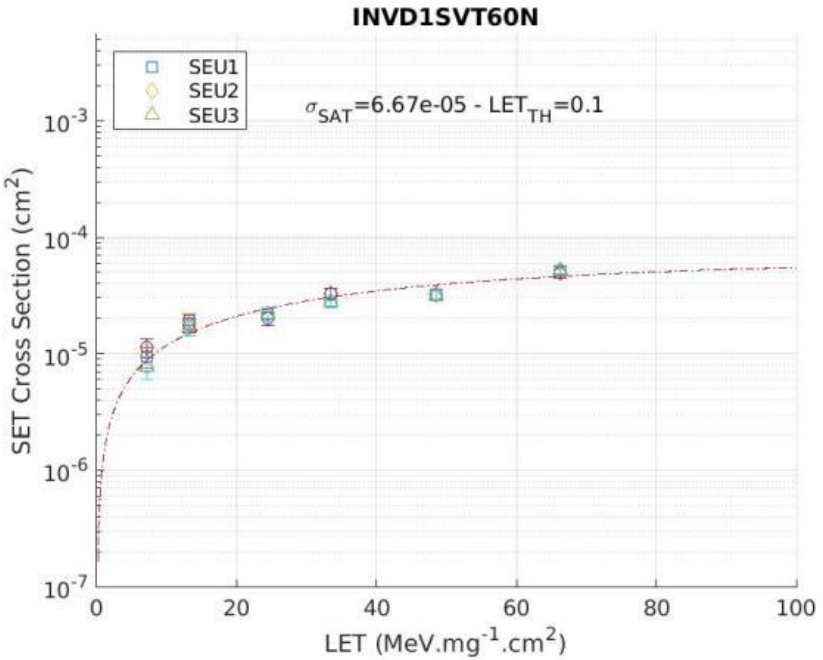
  - Average number of measurement with double strike during a period of 15 minutes

$$6.04 \times 10^{-7} \times \frac{900}{0.01} = 0.054$$

Measurement results

Cross section INVD1 vs flavor





Measurement results

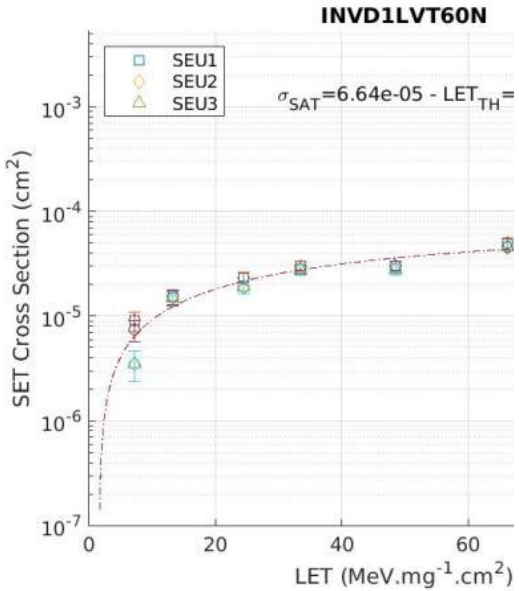
Cross section INVD1 vs flavor

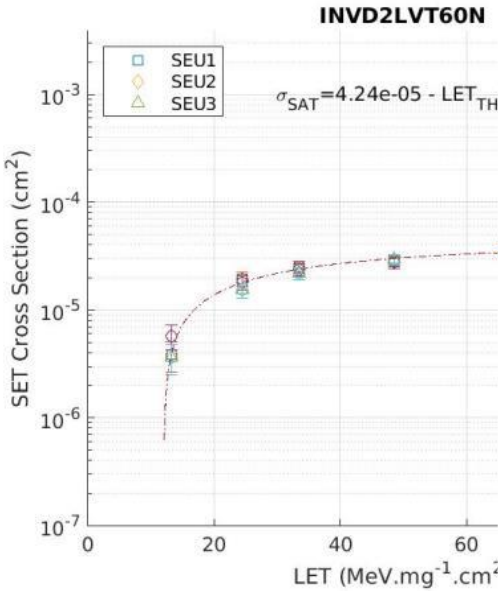
- Without surprise:
  - Saturation cross section similar for the different flavors (Vth and gate length)
  - Low LET cross section strongly impacted by the Vth
    - LVT drive strength > SVT drive strength > HVT drive strength
  - Low LET cross section lightly impacted by the gate length (60 nm vs 70 nm)

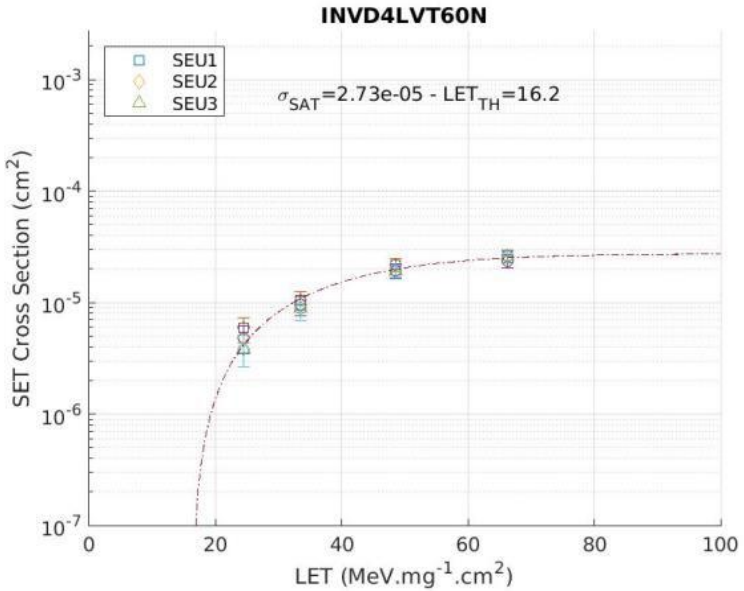
LET ($MeV.mg^{-1}.cm^2$)	Cross section (cm^2)					
	HVT60N	HVT70N	SVT60N	SVT70N	LVT60N	LVT70N
7.2	2.78E-09	2.88E-09	2.32E-09	2.71E-09	1.62E-09	1.92E-09
13.3	4.59E-09	4.39E-09	4.37E-09	4.39E-09	3.69E-09	3.98E-09
24.5	5.86E-09	6.13E-09	5.18E-09	5.44E-09	4.98E-09	5.05E-09
33.5	8.89E-09	8.67E-09	7.62E-09	8.15E-09	7.06E-09	7.81E-09
48.5	8.35E-09	8.64E-09	7.79E-09	7.96E-09	7.20E-09	7.30E-09
66.3	1.34E-08	1.30E-08	1.24E-08	1.23E-08	1.16E-08	1.20E-08

Measurement results

Cross section vs Drive Strength





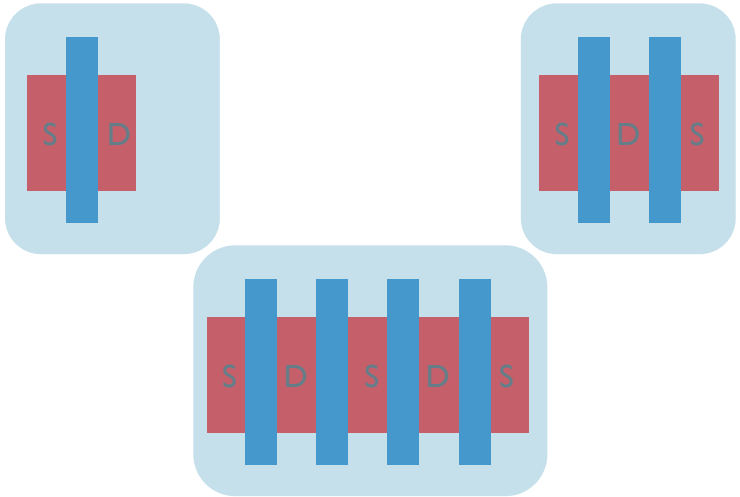


Measurement results

Cross section INVD1 vs Drive Strength

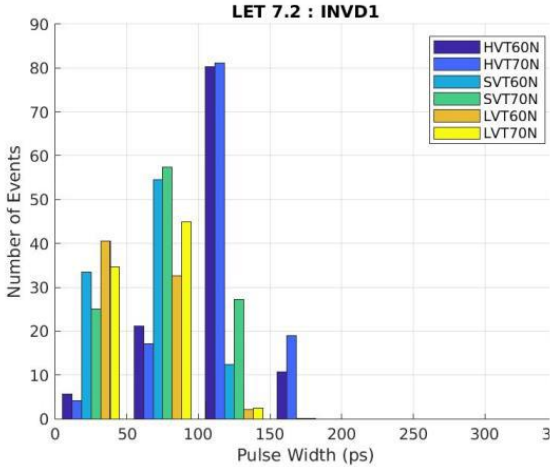
- LET threshold strongly dependent of the drive strength: proportionality observed
- Saturation LET looks similar but... :
  - INVD1 has 1 finger and INVD2 has 2 fingers => same junction area but the higher drive strength decrease a little bit the saturation LET
  - INVD4 has 4 fingers and the 2 drains are close to each other => less than factor 2 with INVD2

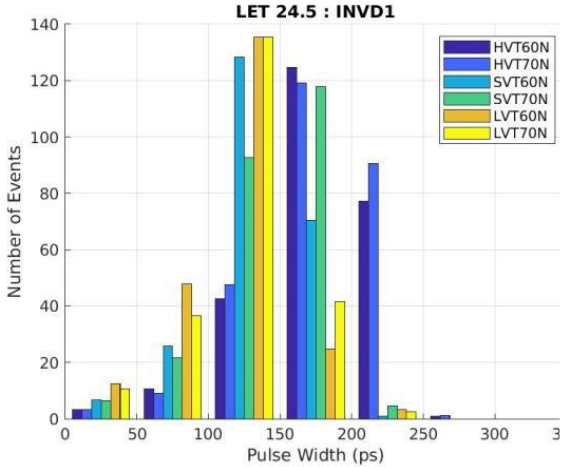
LET ($MeV.mg^{-1}.cm^2$)	Cross section (cm^2)					
	INVD1		INVD2		INVD4	
	SVT60N	LVT60N	SVT60N	LVT60N	SVT60N	LVT60N
7.2	2.32E-09	1.62E-09	1.35E-10	0.00E+00	0.00E+00	0.00E+00
13.3	4.37E-09	3.69E-09	2.37E-09	1.08E-09	2.96E-10	0.00E+00
24.5	5.18E-09	4.98E-09	5.03E-09	4.30E-09	4.27E-09	2.37E-09
33.5	7.62E-09	7.06E-09	6.47E-09	5.74E-09	7.67E-09	4.70E-09
48.5	7.79E-09	7.20E-09	6.88E-09	6.93E-09	1.04E-08	9.81E-09
66.3	1.24E-08	1.16E-08	9.55E-09	8.67E-09	1.22E-08	1.23E-08

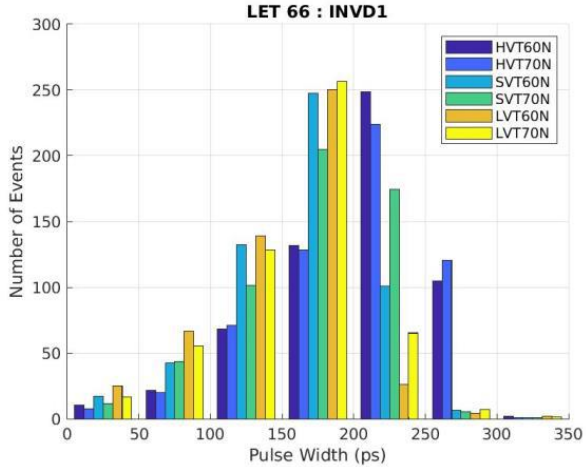


Measurement results

SET pulse width distribution

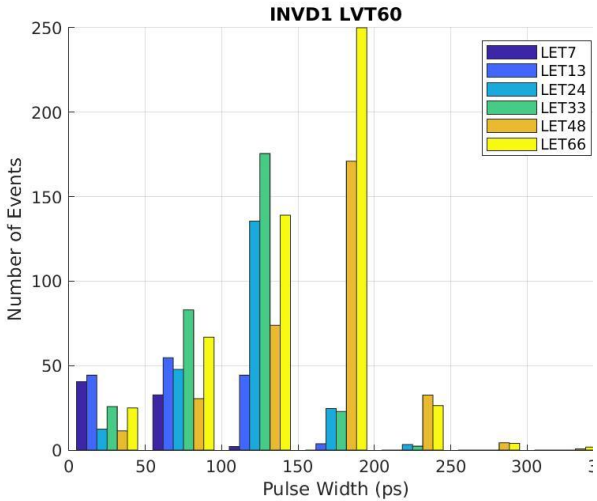


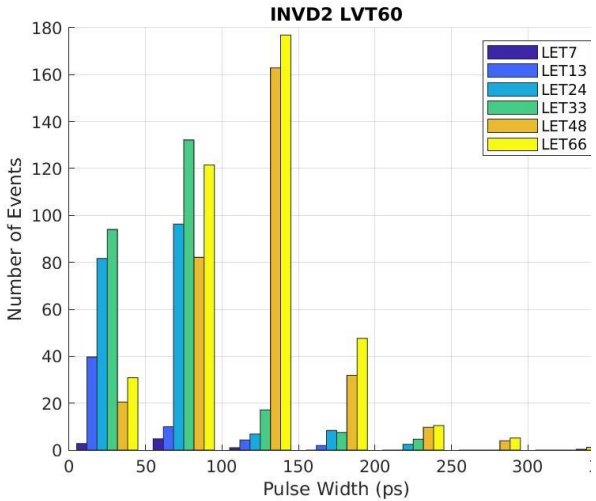


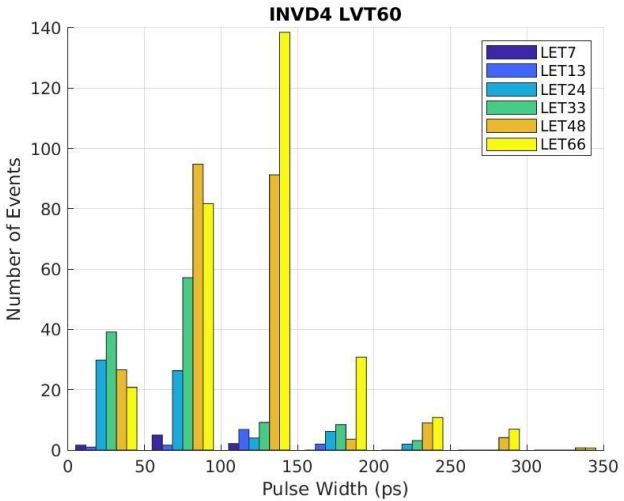


Measurement results

SET pulse width distribution



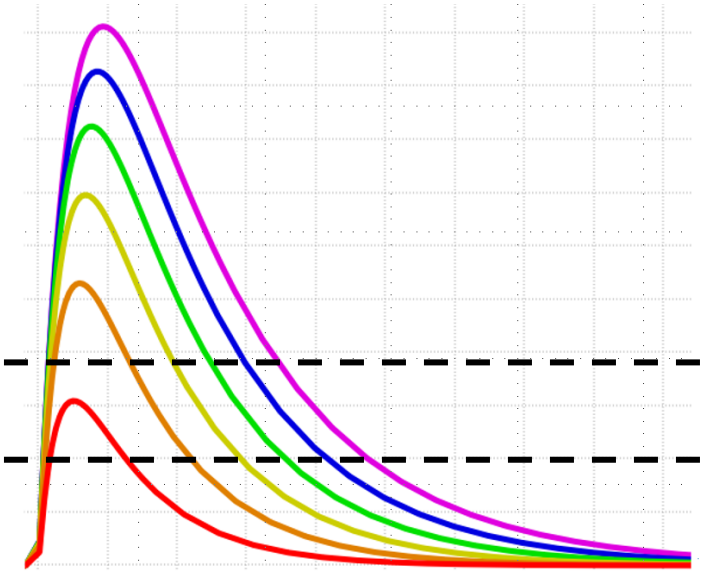




Measurement results

SET pulse width distribution

- SET duration is about 100ps to 250ps
  - Increase with LET
  - Decrease with drive strength



[4] Zheyi Li, Maxim Gorbunov, Henrique Caldas Kessler, Giancarlo Franciscatto, Venkata Sathyajith Kampati, Jinghao Zhao, Jeffrey Prinzie, Laurent Berti; “A Charge-Width Calibration Approach for the Compact Modeling of Single Event Transients”, RADECS 2025

Conclusion

- Cross section of the inverters of the 6 DARE65T standard cells libraries have been measured accurately
- Thanks to the simplicity of the layout of the inverters, these results can be used to calculate the cross section of any other standard cells of these libraries
  - Saturation cross section of any of the standard cell of the DARE65T platform can be directly extracted from the layout
  - The LET threshold is proportional to the drive strength
  - ➢ The cross section versus LET of any standard cell can be calculated
- The SET duration versus LET has been measured for Drive Strength 1 till Drive Strength 16 => DARE65T striker has been updated accordingly (RADECS2025 paper)
- Using these data, it is possible to predict the soft error rate of a given digital circuit.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Backup slides

- [3] Zheyi Li; Laurent Berti; Jan Wouters; Jialei Wang; Paul Leroux, "Characterization of the Total Charge and Time Duration for Single-Event Transient Voltage Pulses in a 65-nm CMOS Technology", IEEE Transactions on Nuclear Science (Volume: 69, Issue: 7, July 2022)