RADLAS 2024

Exploration of the Single Event Effect Sensitivity of a 16nm FinFET System-on-Chip using Single-Photon Absorption Laser Testing

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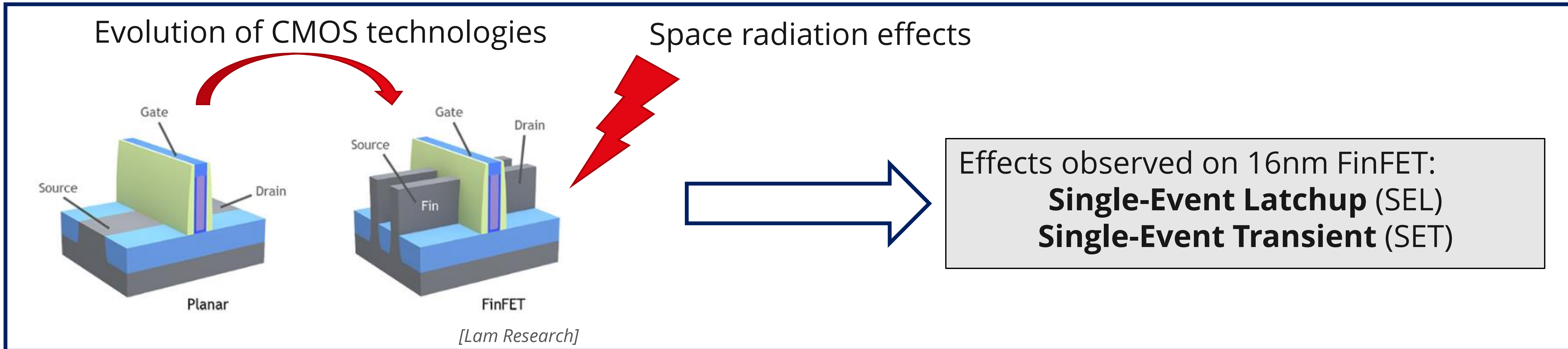
Motivation & objectives



Objectives of this work:

- Observation of the distribution of SEL sensitive regions in a SoC manufactured in a 16nm FinFET process
  - Presented at RADECS 2023
- SET and SEU results using Single Photon Absorption (SPA) laser testing
  - To be presented at RADECS 2024
- Correlation between SPA laser results and heavy ion data from literature

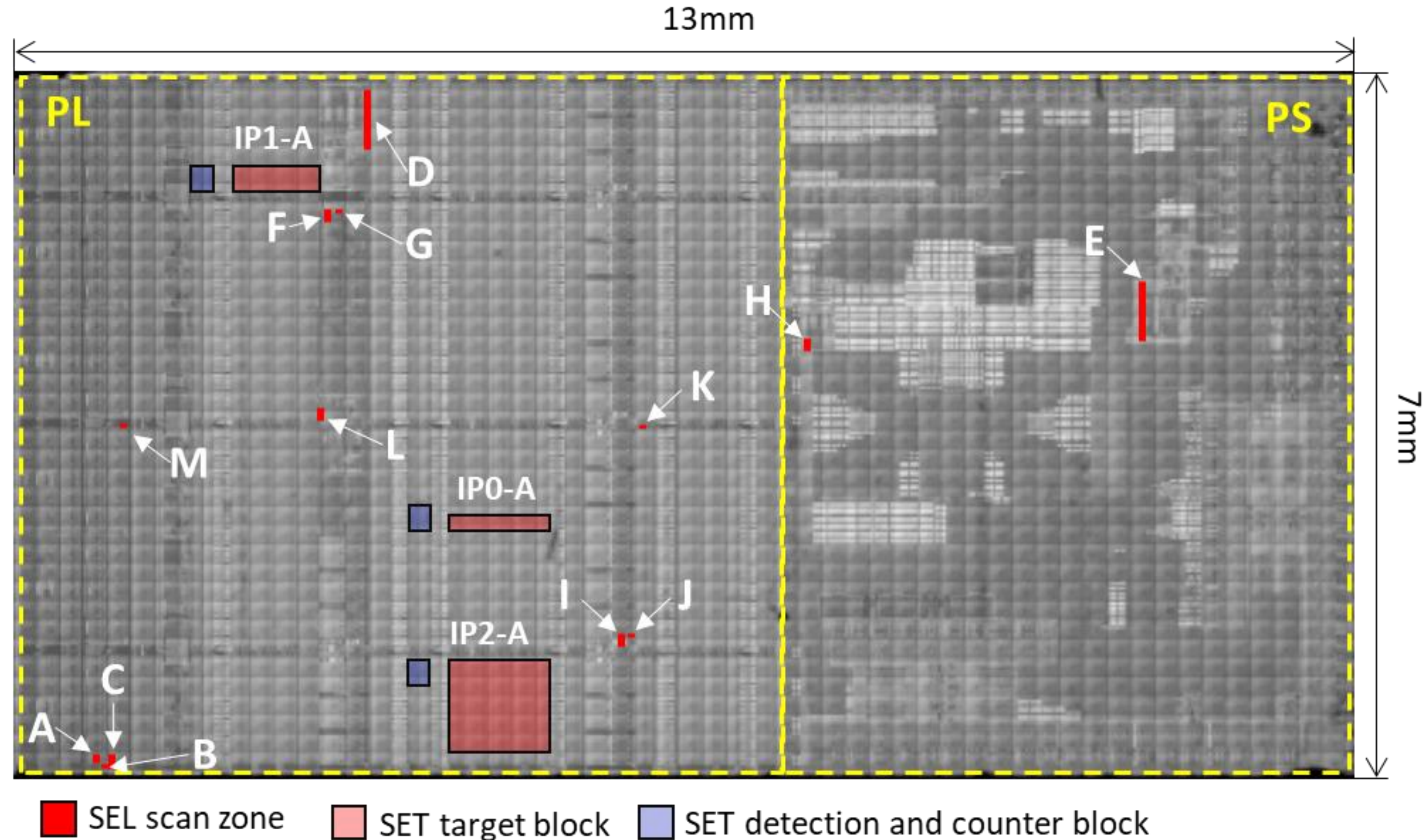
Outline

- Device Under Test
- Experimental setup and method
- Experimental results
- Conclusions

Device Under Test

- Device Under Test (DUT):
  - **Xilinx Zynq Ultrascale+** (XCZU3EG) device in TSMC's 16nm bulk FinFET process
  - Lid-less flip-chip ball-grid array
  - Backside surface polished
- SEL scan zones & SET target blocs superimposed with the infrared picture of the DUT

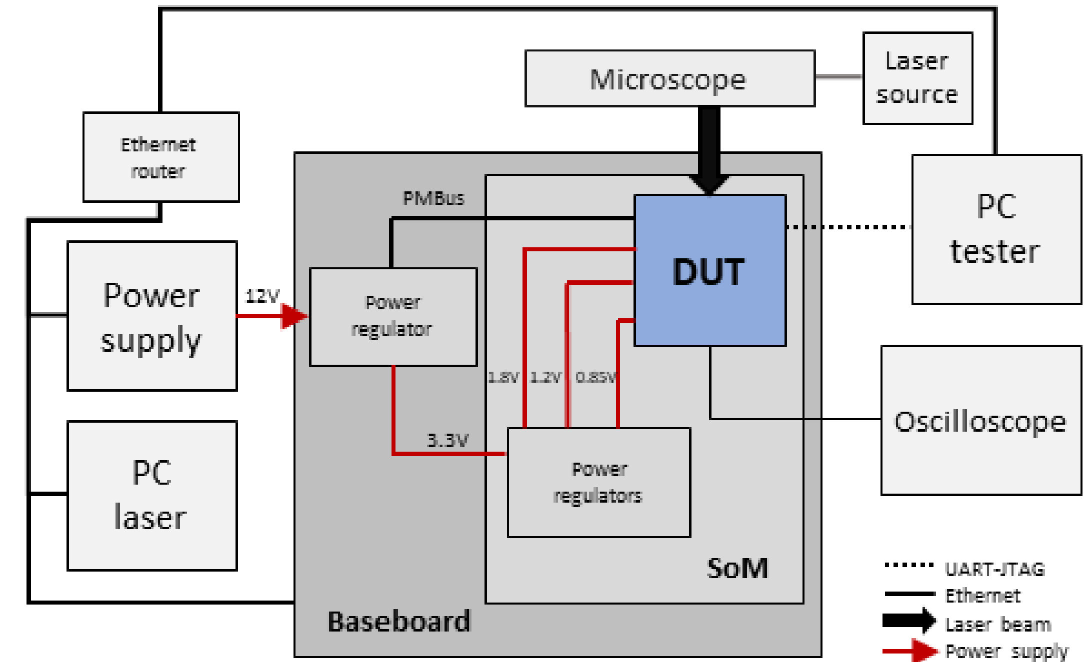
Overview of the zones & resources studied



Experimental setup and method (1/2)

- DUT is part of a System-on-Module (SoM)
  - Provides the environment for operating the device
- SoM mounted on a commercial base-board
  - 3.3V power supply from the 12V power input
- Laser testing :
  - IES Preserve facility
  - 1064nm Single-Photon Absorption (SPA) laser
  - Pulse duration of 30ps
  - Spot size of 1.1µm

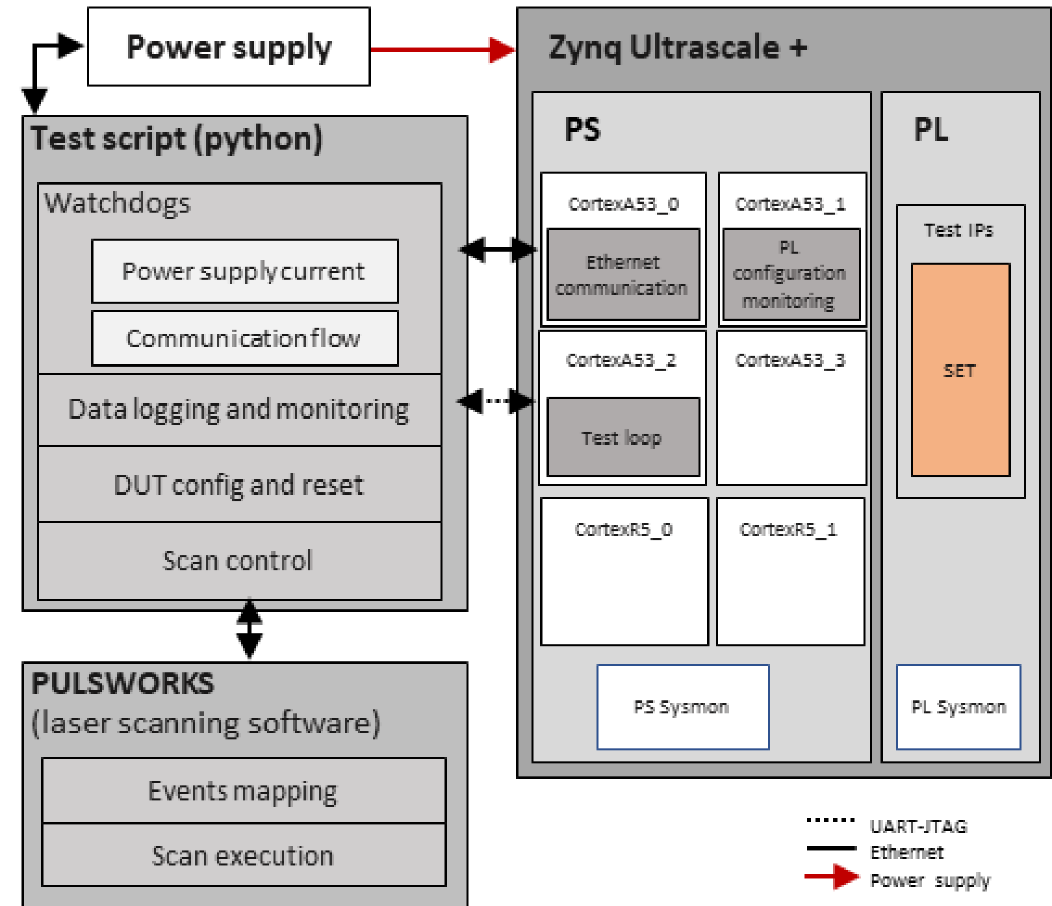
Experimental setup for laser testing



Experimental setup and method (2/2)

- Embedded software and firmware to provide dynamic observability on the device functions
  - APU 0: data output through TCP/ethernet
  - APU 1: monitoring the PL CRAM
  - APU 2: executing the main test loop
- Experiments controlled by a Python script
  - Watchdogs to monitor the supply current and the output data flow

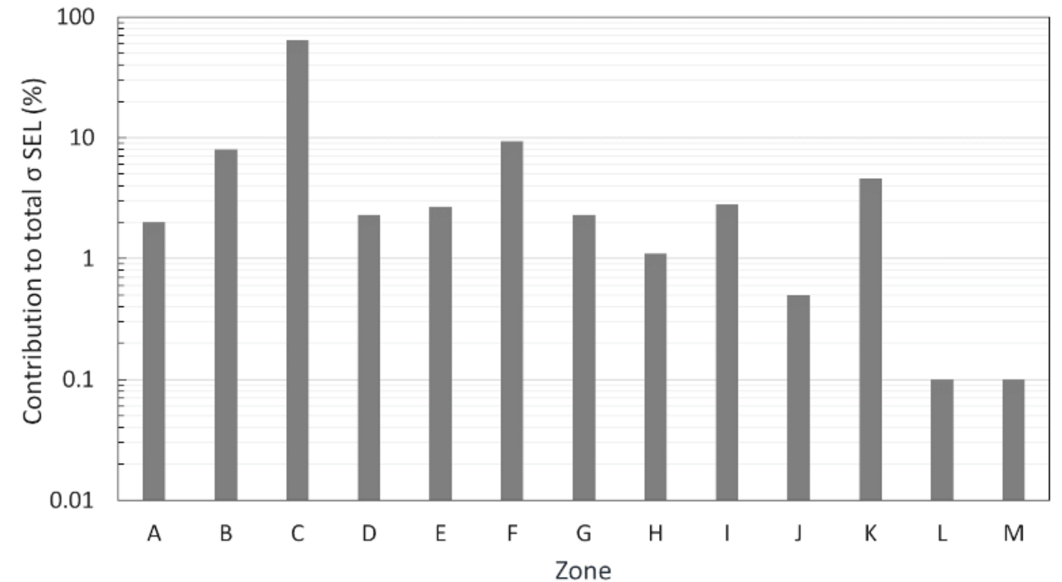
Architecture of the software test bench



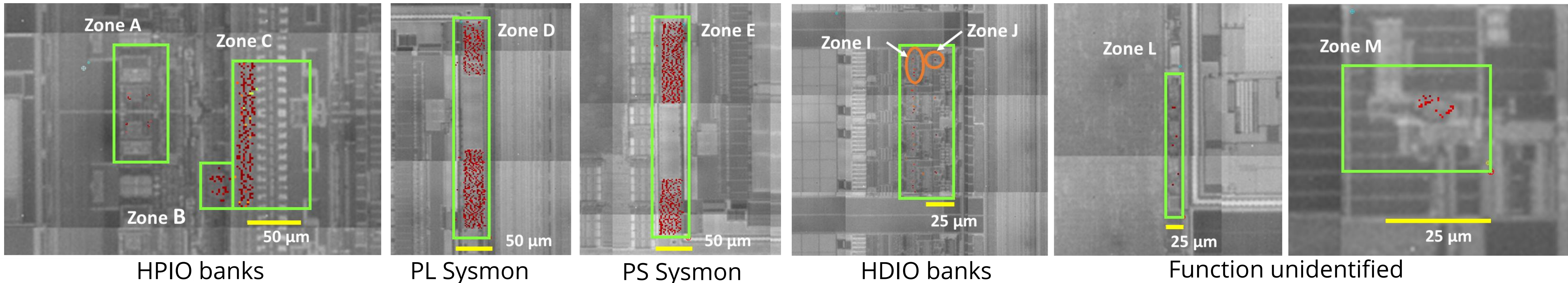
Experimental results – SEL sensitivity

- The full contribution of the sensitive regions identified
- A set of SEL mappings obtained with the same incident pulse energy of 552pJ
- Structures in zones A, B and C are visibly repeated over the full width of the chip

Contribution of the zones to the total SEL laser cross section



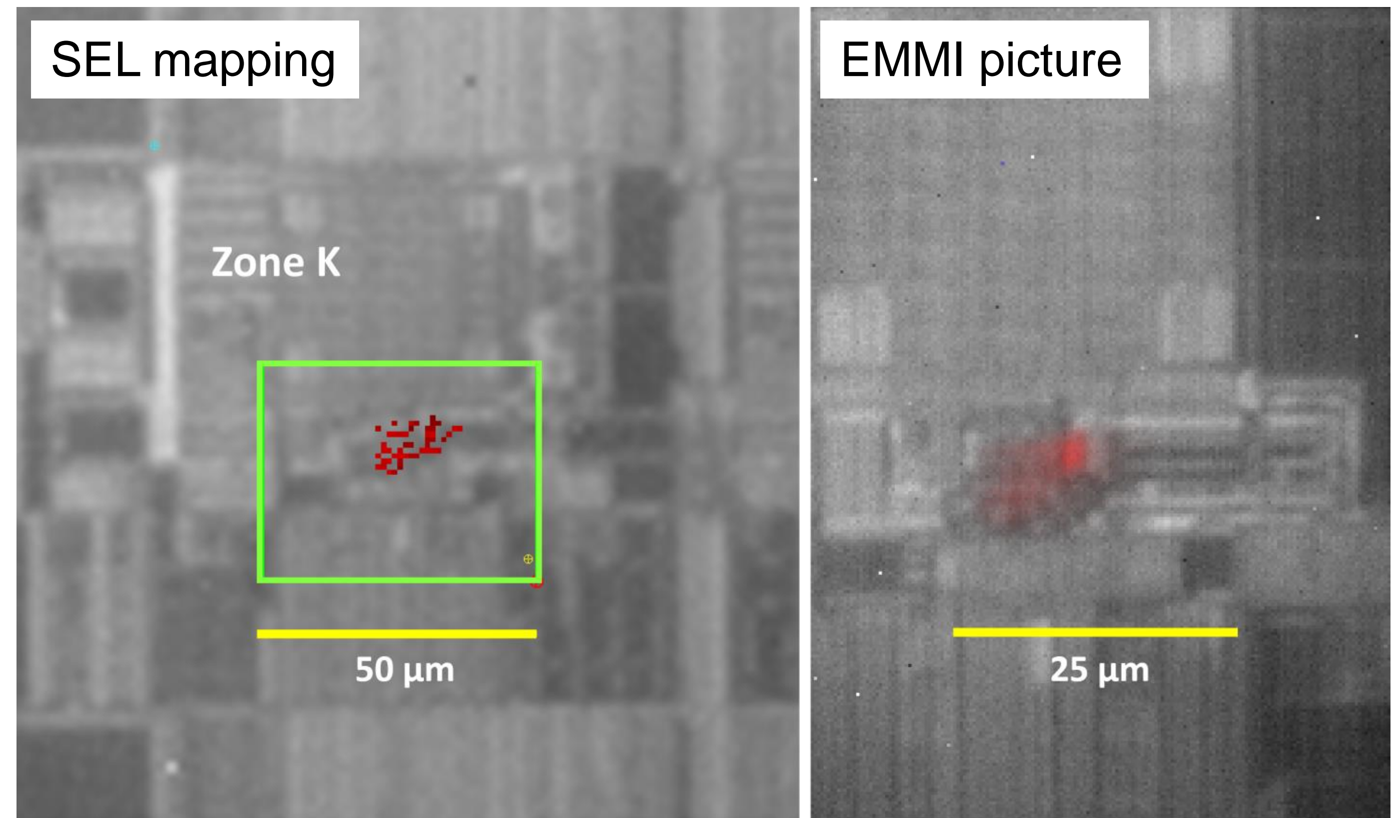
Selection of scanned zones & corresponding SEL mapping



Experimental results – Light Emission Microscopy (EMMI)

- EMMI technique:
  - Capturing the photons produced by the radiative recombination of charge carriers
- Light emission correlated to the apparition of localized high current densities
  - Confirms the SEL nature of the event
  - Provides indications on the current path involved in the SEL
- SEL was confirmed by EMMI observation in all the zones

Correlation between SEL laser mapping and EMMI picture



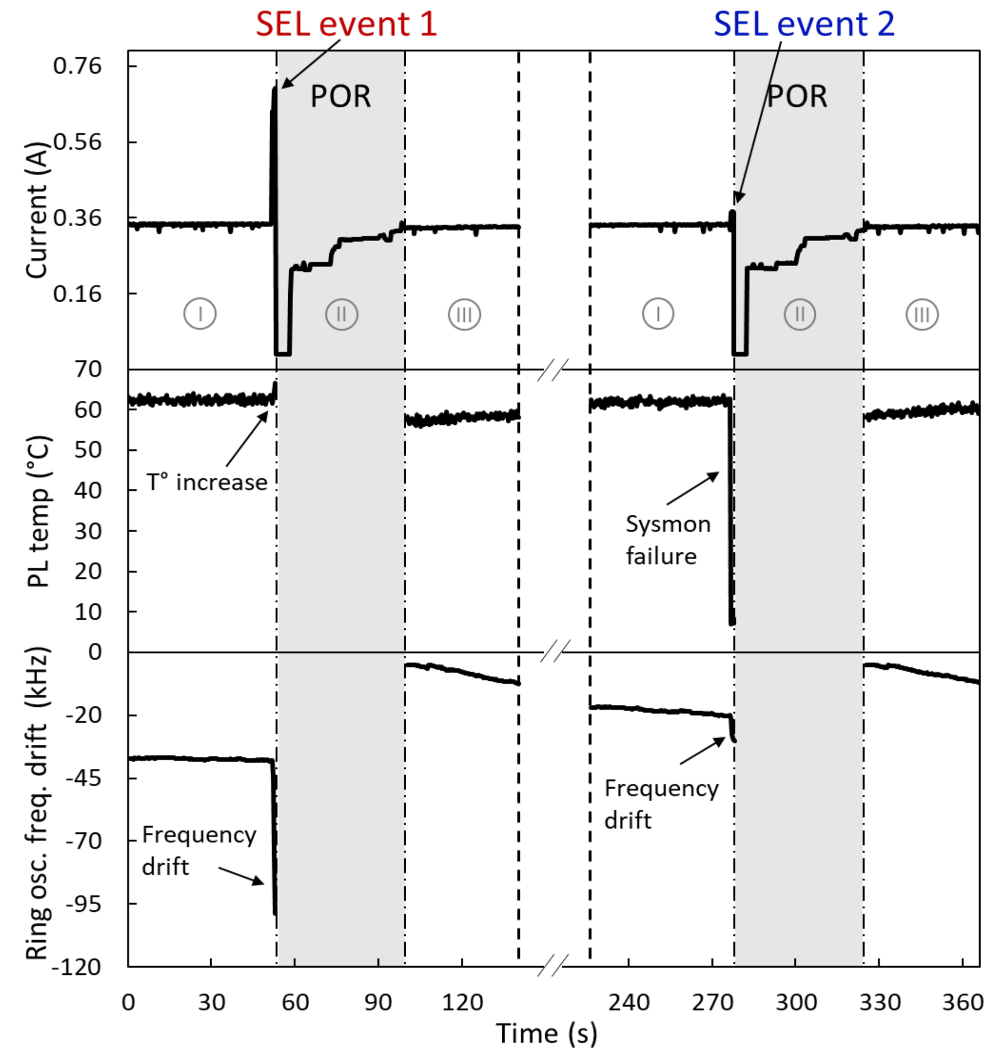
Experimental results – SEL functional impact

- Some SELs were maintained for 1s to observe their functional impact

- Event 1 (HPIO bank):
  - A small temperature increase is observed on the PL Sysmon
  - Drift of a nearby ring oscillator frequency induced by the temperature increase

- Event 2 (PL Sysmon):
  - Temperature reported by the PL Sysmon indicates a failure of this function, while the ring oscillator frequency still allows to diagnose a temperature increase

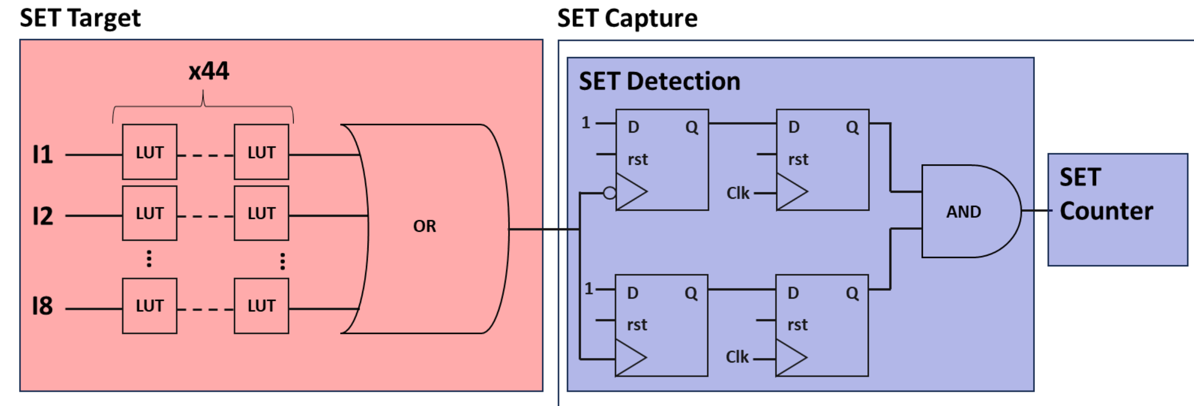
Observation of the SEL functional impact



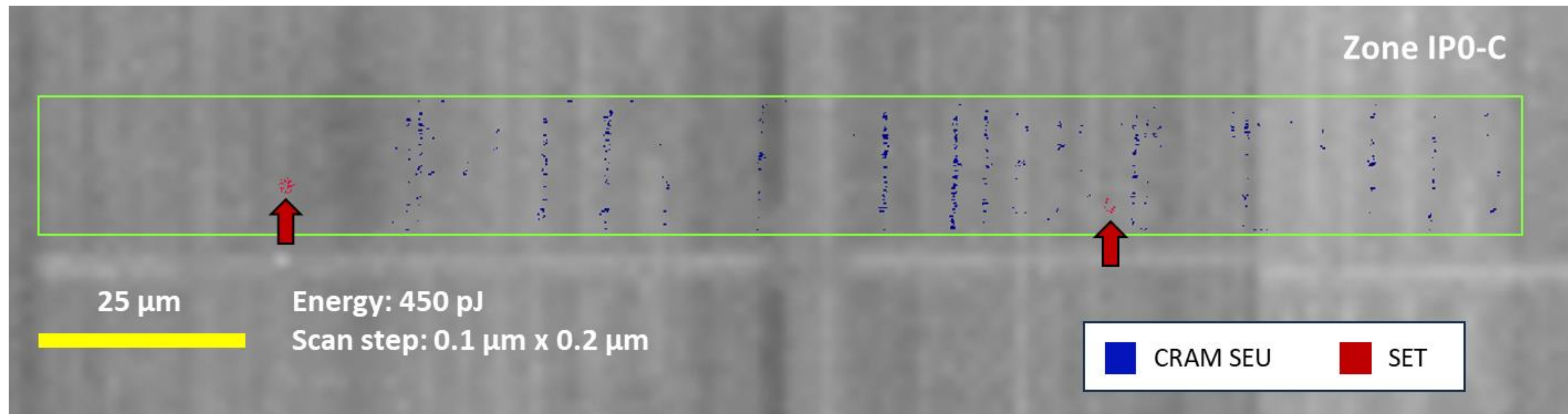
Experimental results – SET

- The test circuit consists in a simple SET target and detection circuit.
- Observation of SEUs in CRAM
  - Most of CRAM errors in this zone were SEUs (73.5 %), MCUs were also observed (26.5 %).
- Capture of SETs
  - SETs not correlated with CRAM errors

Schematic representation of the SET target & capture circuit

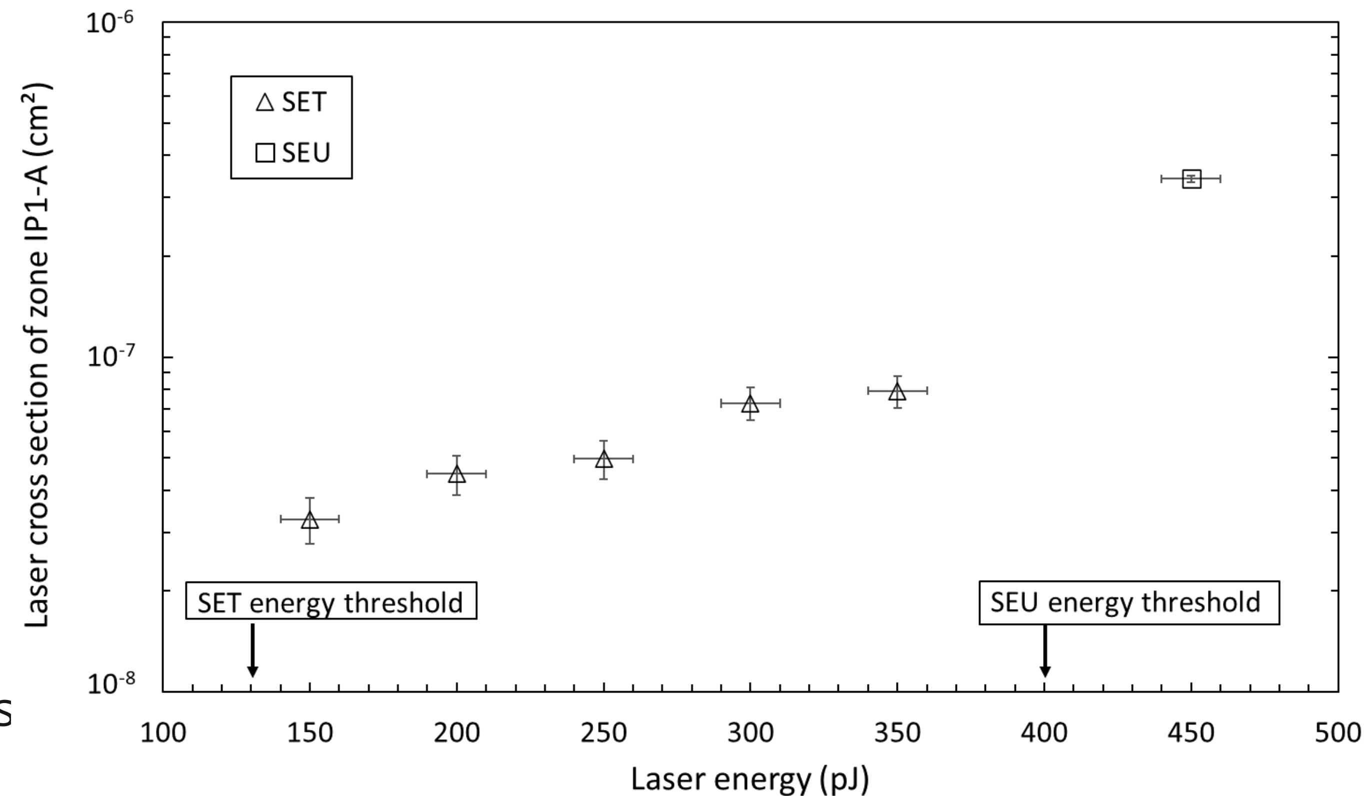


SET & SEU laser mapping



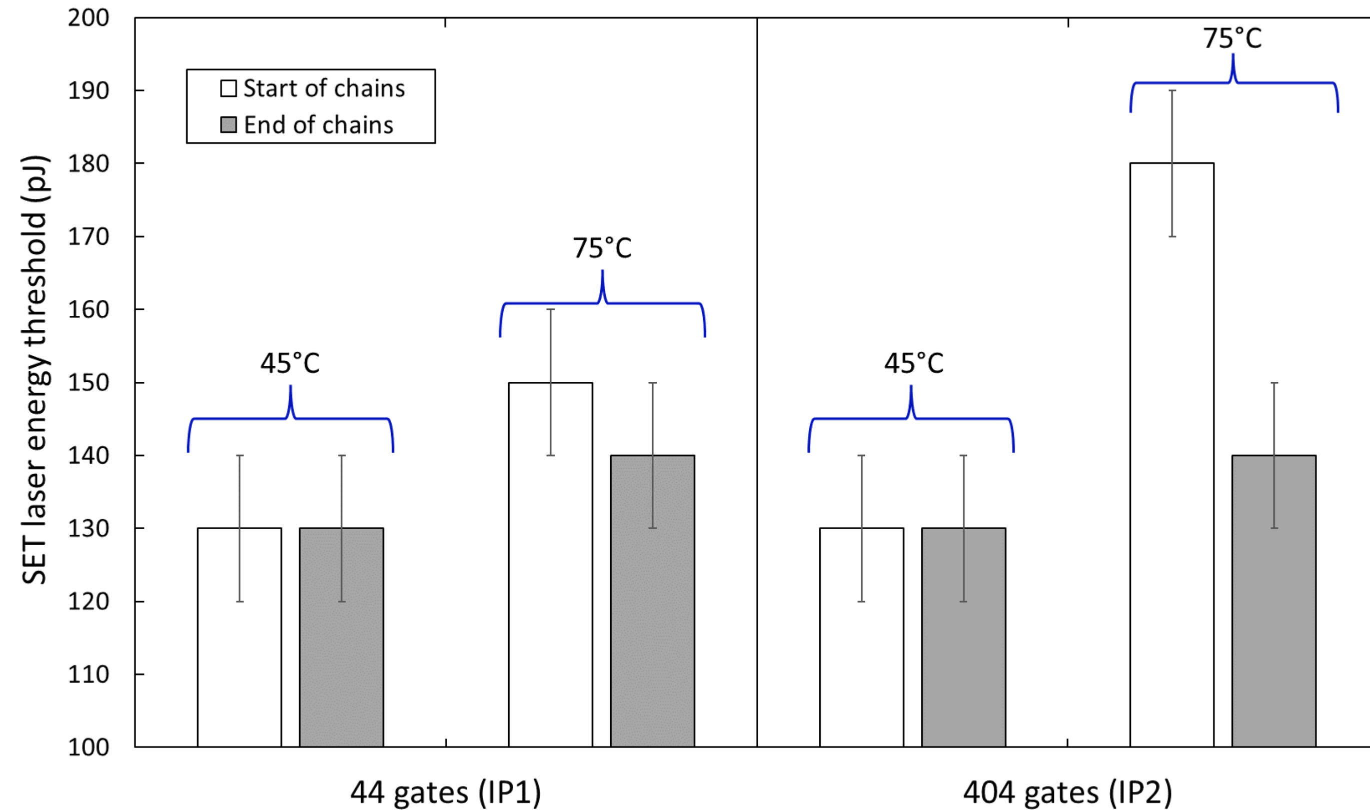
Experimental results – SET & SEU cross sections

- Cross section extracted for a region estimated to include two CLBs and one interconnection matrix
- SET and SEU laser energy thresholds measurements:
  - Z-axis position optimized
  - Error estimation: ±10 pJ
- SET laser energy threshold 3 times smaller than the SEU one
  - Difference not observed under heavy ions *[Harrington, 2018]*
    - → Better resolution with laser testing



Effect of temperature & logic gates chains length

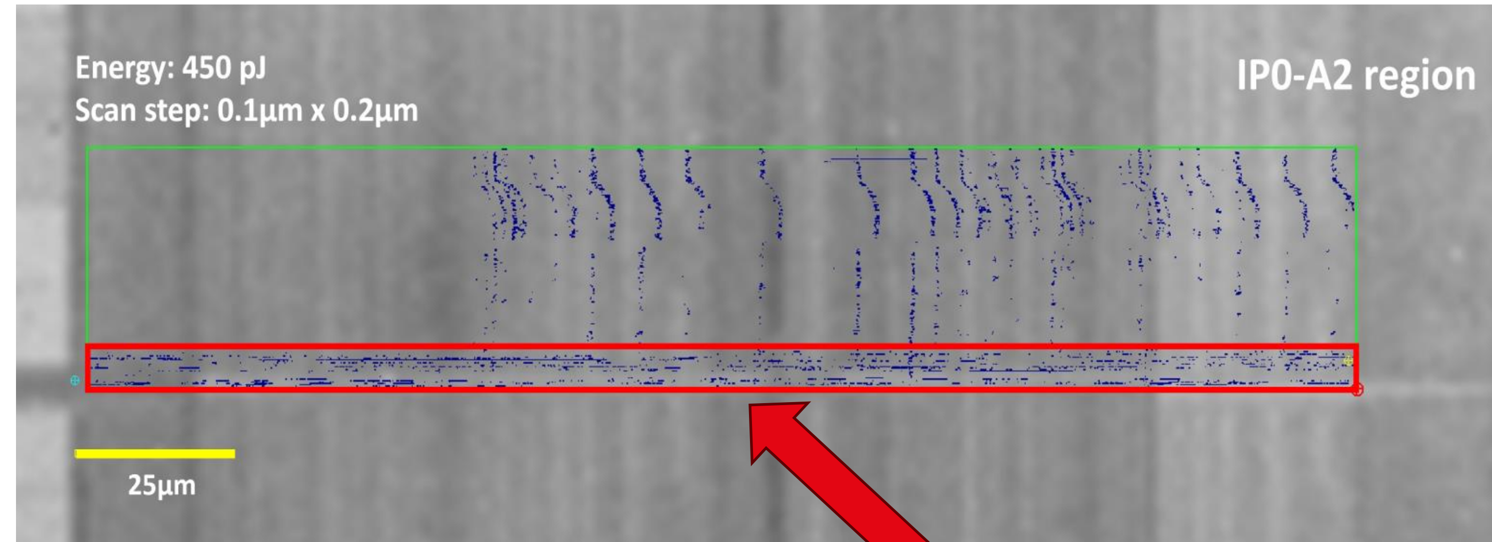
- Effect of SET propagation through the chain
  - Effect only observed at high temperature
- Impact of temperature
  - $E_{th\ SET}$ increases with temperature
  - Observation of an effect of temperature on the SET propagation
- Impact of chains length
  - No effect at 45°C
  - At 75°C:
    - x9.2 chain length ⇒ x1.2 $E_{th\ SET}$
- More details in RADECS 2024 paper next week



Device permanent degradation

- A permanent degradation of the device observed
  - After multiple mapping
  - CRAM errors still present after power cycling, confirming the permanent nature of the degradation
- Up to 200 CRAM addresses identified with an erroneous bit
  - Number depends on temperature
  - Some addresses permanently affected, some others randomly appear and disappear
    - Indications for a degradation of the CRAM addressing and/or read/write logic

Observation of the degradation of the device



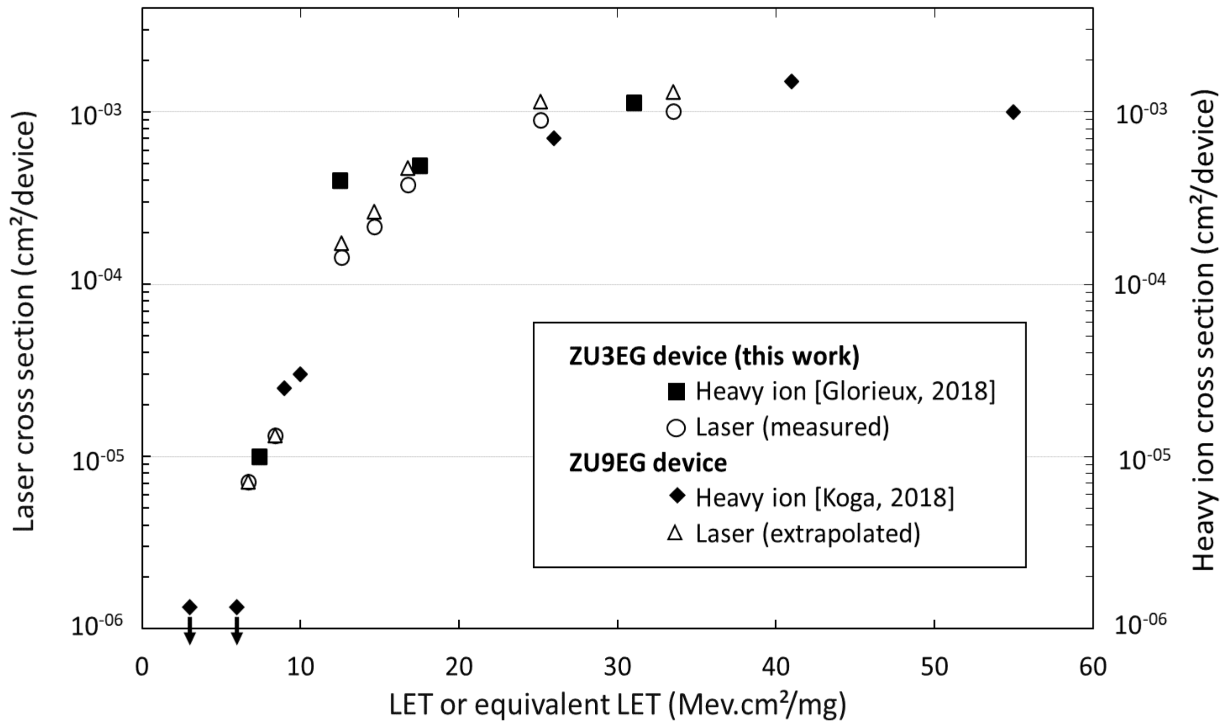
Permanent and random errors reported after the degradation

Correlation with heavy ion data

- Equivalent LET calculated with model-based laser equivalent LET

SEL

SEL laser cross section correlated with heavy ion data



- Good correlation for the SEL cross section

SET, SEU

Equivalent LET threshold calculations

Thresholds	SET	SEU
Eth [pJ]	130	400
$LET_{equ\ th}$ [MeV.cm²/mg] r=∞	7.51	23.1
$LET_{equ\ th}$ [MeV.cm²/mg] r=67nm	1.00	3.06
$LET_{equ\ th}$ [MeV.cm²/mg] r=43nm	0.42	1.30
$LET_{th\ literature}$ [MeV.cm²/mg]	1.00 [1]	1.00 [1] 1.30 [2] 1.50 [3, 4]

[1] Harrington, 2018; [2] Koga, 2018; [3] Glorieux, 2018; [4] Yaqing, 2022

- Adjustment of integration radius required

Conclusions

- Laser testing of SEL, SEU and SET in a commercial 16nm FinFET SoC
- Mapping of SEL sensitivity over the whole chip
  - Confirmed by EMMI
  - Observation of functional impact
  - Good correlation with heavy ion data
- Mapping of SET & SEU in the programmable logic
  - Impact of length of target chain and temperature
  - SET laser energy threshold 3 times smaller than the SEU one
- A permanent degradation of the device was observed

Thank you for your attention!