Pre-screening and classification of sensitivity of COTS parts to Single Event Latchup, based on Pulsed Laser testing

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Outline

I-Presentation of the facility

II-LISA’s calibration and previous works

III-Experimental procedure for DUT’s screening

IV-Activities performed with U SPACE

V-Pros and cons

Conclusion and future work

Context and objectives

- Context
  - Pulsed Laser is a mature alternative facility to heavy ion with +30 years of test results
  - In 2023: test guidelines were published to provide guidance on laser tests
    - “Single-Event Effects Testing with a Laser Beam – Guidelines” published by ESA
    - “Pulsed-Laser Single-Event Effects (PL SEE) Testing – A Practical Desk Reference” published by NRL/NASA/JPL
  - Due to increasing delay associated with Heavy ion tests, the use of PL is beneficial for COTS pre-selection
- Objectives
  - Introduce a method for COTS pre-selection with Laser
  - Present a case application in an industrial context

I-Presentation of the facility

- LISA Pulsed-Laser facility at TRAD-Labège:
  - ➢ Standard installation for Single Photon Absorption (SPA) SEE testing in Silicon devices:

I-Presentation of the facility

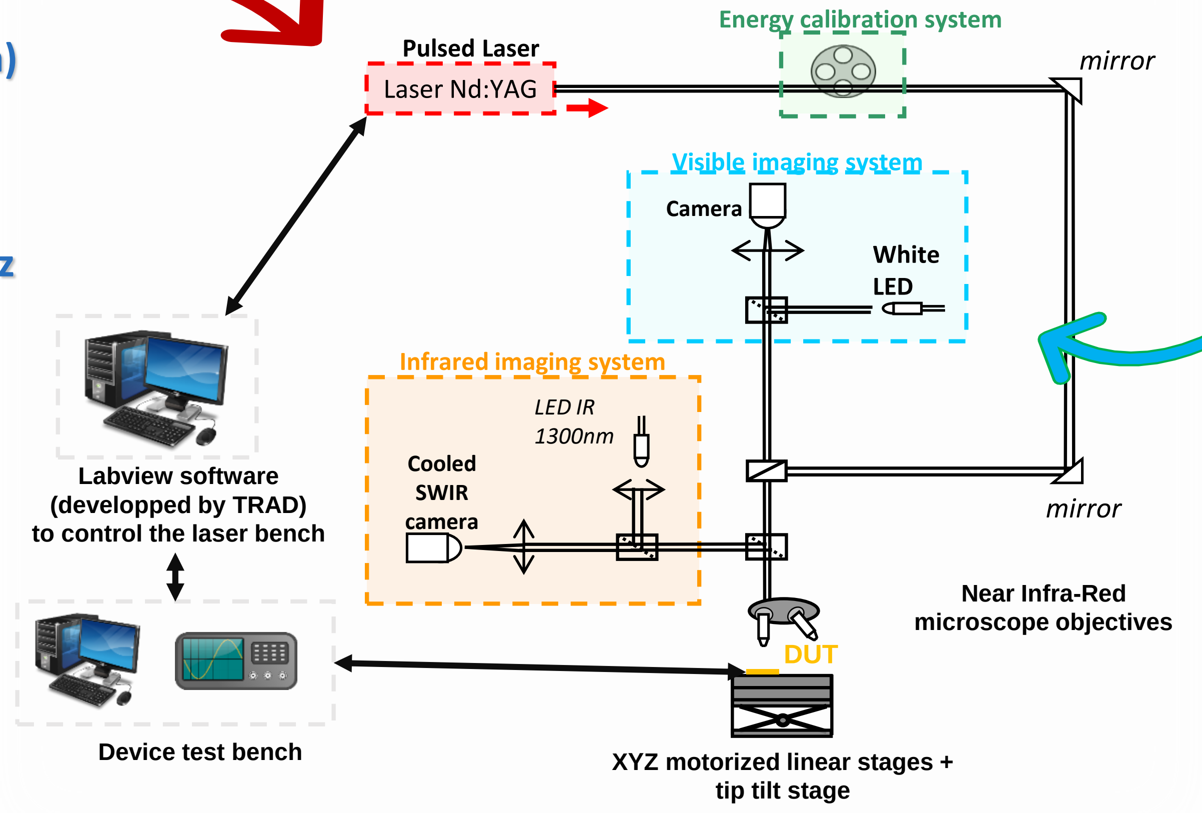
- LISA Pulsed-Laser facility at TRAD-Labège:

Pulsed Laser:

- **Laser Nd:YAG (λ=1064nm)**
- **Pulse duration : 400ps**
- **From single shot to 50kHz**

Objectives and DUT

- **X10, X50 or X100 objectives**
- **Spot size: 8, 2.6 and 1.8µm**

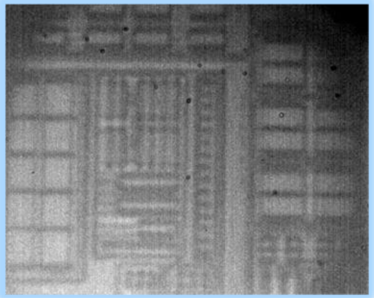


Energy:

- **Tunable from ~0.06 to ~136nJ/pulse**

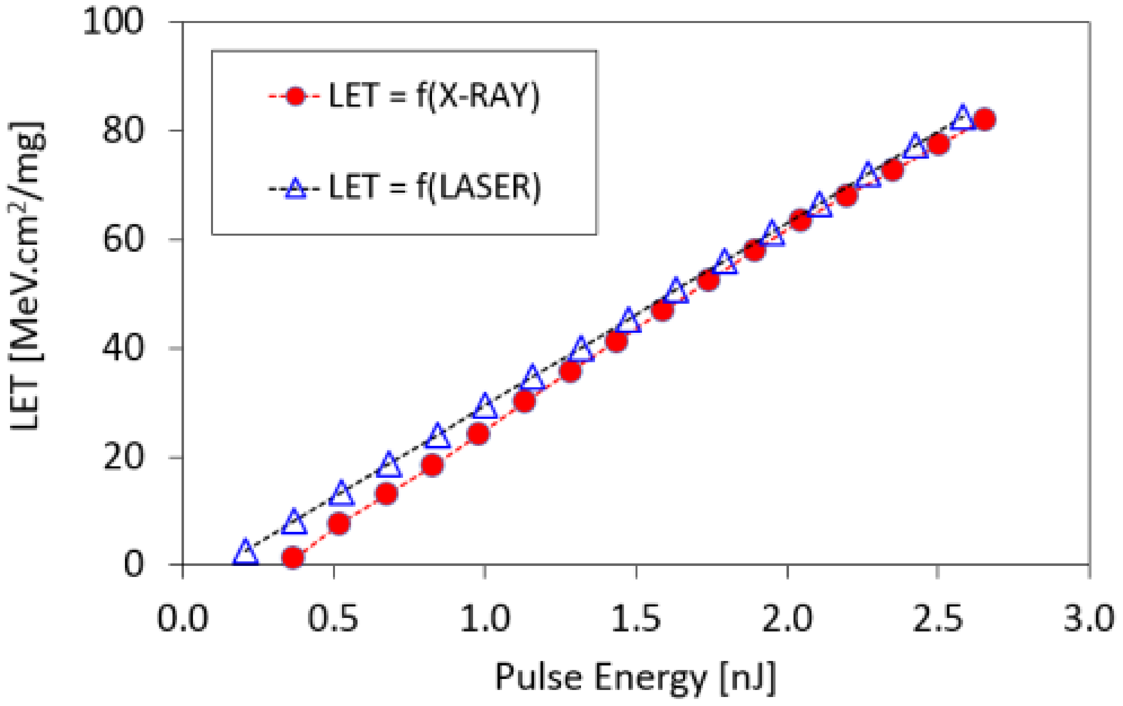
Imaging system:

- **Visible and infrared imaging system**
- **Direct access to active layers in silicon components**



II-LISA’s calibration and previous works

- In 2019: cross-calibration of Pulsed Laser and heavy ions with a photodiode
  - ➢ Estimation of collected charges in a FDS010 silicon photodiode with Laser and Heavy ions (and also pulsed x-rays):



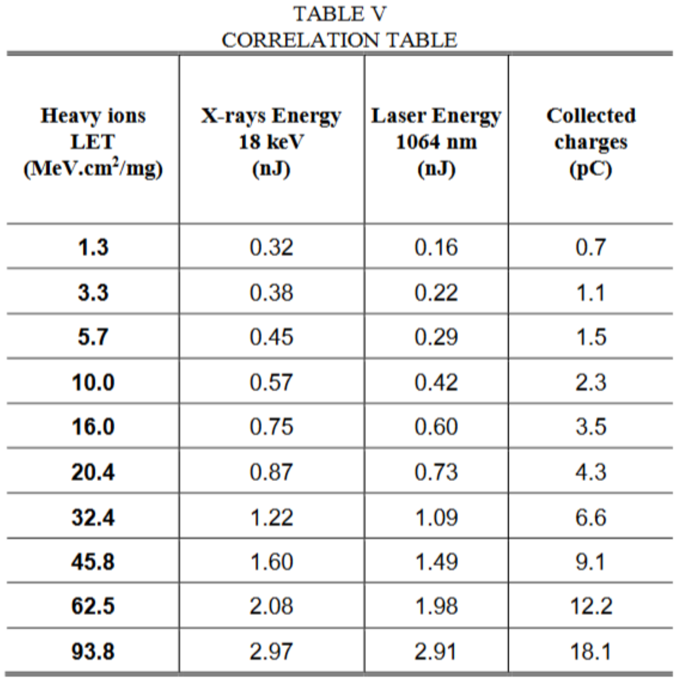


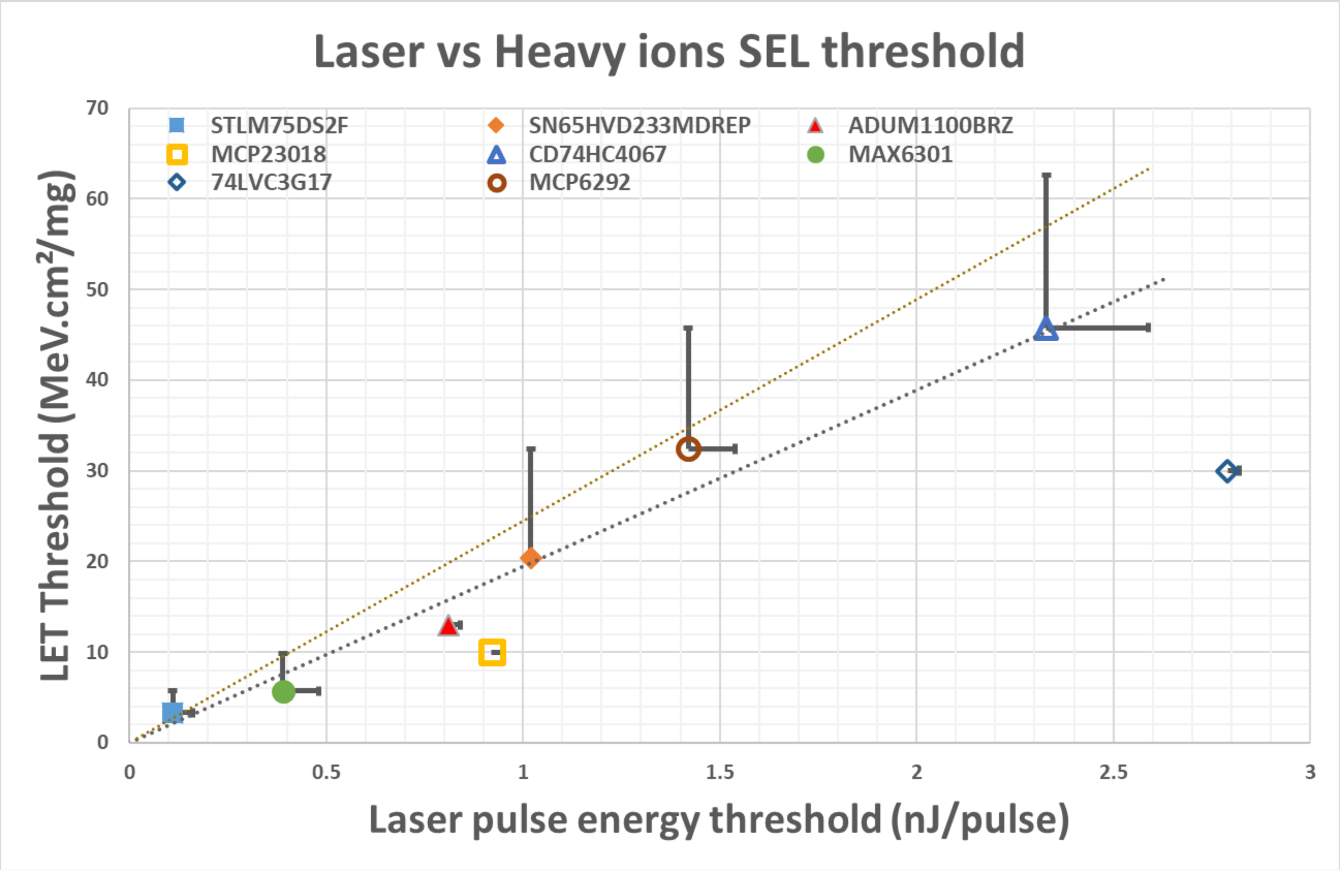
TABLE V
CORRELATION TABLE

Heavy ions LET (MeV.cm²/mg)	X-rays Energy 18 keV (nJ)	Laser Energy 1064 nm (nJ)	Collected charges (pC)
1.3	0.32	0.16	0.7
3.3	0.38	0.22	1.1
5.7	0.45	0.29	1.5
10.0	0.57	0.42	2.3
16.0	0.75	0.60	3.5
20.4	0.87	0.73	4.3
32.4	1.22	1.09	6.6
45.8	1.60	1.49	9.1
62.5	2.08	1.98	12.2
93.8	2.97	2.91	18.1

  - ➢ The range of energy [0;2.5] nJ/pulse (with X50 magnification) seems representative of the range [0;65] MeV.cm²/mg

II-LISA’s calibration and previous works

- In 2023: cross-calibration of Pulsed Laser and heavy ions with multiple devices sensitive to SEL
  - ➢ Several devices sensitive to SEL with a known LET threshold, tested with Laser
  - ➢ An empirical HI/laser comparison was obtained (for X50 mag.):



➢ Large error bars due to unprecise LETth for few parts

➢ « Laser pulse energy » in x axis is recalculated considering backside absorption:

Substrate thickness

$$Ef = Ei(1 - R)e^{-\alpha d}$$

Air/Si reflection

Absorption coefficient in Si

➢ One component is not fitting:
  - ➢ Process variabilities between HI DUT and Laser DUT ?

II-LISA's calibration and previous works

- In 2023: cross-calibration of Pulsed Laser and heavy ions with multiple devices sensitive to SEL

  - Pre-selection of devices vs SEL sensitivity seems possible, using this curve

  - The range of pulse energy (recalculated) [0;3] nJ/pulse seems representative of the range [0;60] of heavy ions LET

  - **However:**
    - These results might be relevant on devices with similar technology nodes only

    - Discrepancies have been observed for destructive behaviour such as burnout events

  - **Overall: a classification methodology have been developed based on these test results**

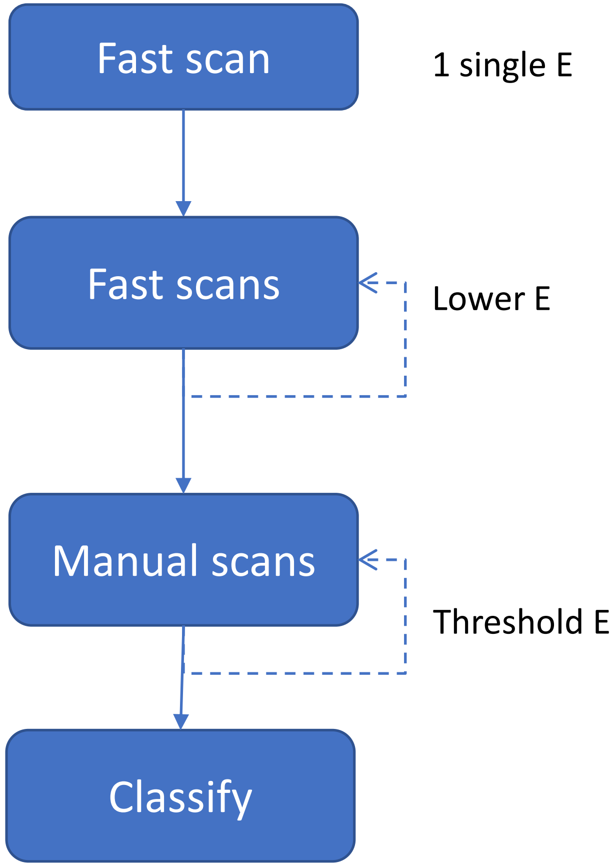
III-Experimental procedure for DUT’s screening

- Test methodology for SEL screening:
  - **First step**:
    - ➢ Fast scan of the die (low magnification, high energy)
    - ➢ Determine if DUT sensitive or not to SEL/DSEE

  Then if sensitive:

  - **Second step**:
    - ➢ Fast scans with higher magnification (X50)
    - ➢ Localize the most sensitive area (i.e. at the lowest energy)
  - **Final step**:
    - ➢ Manual study on this area
    - ➢ Search for the energy threshold E_{th}
    - ➢ Classification with recalculated energy:

Low energy (<1 nJ/pulse)	Medium energy (1-2nJ pulse)	High energy (2-3 nJ/pulse)	Very high energy (>3 nJ/pulse)



Fast scan

1 single E

Fast scans

Lower E

Manual scans

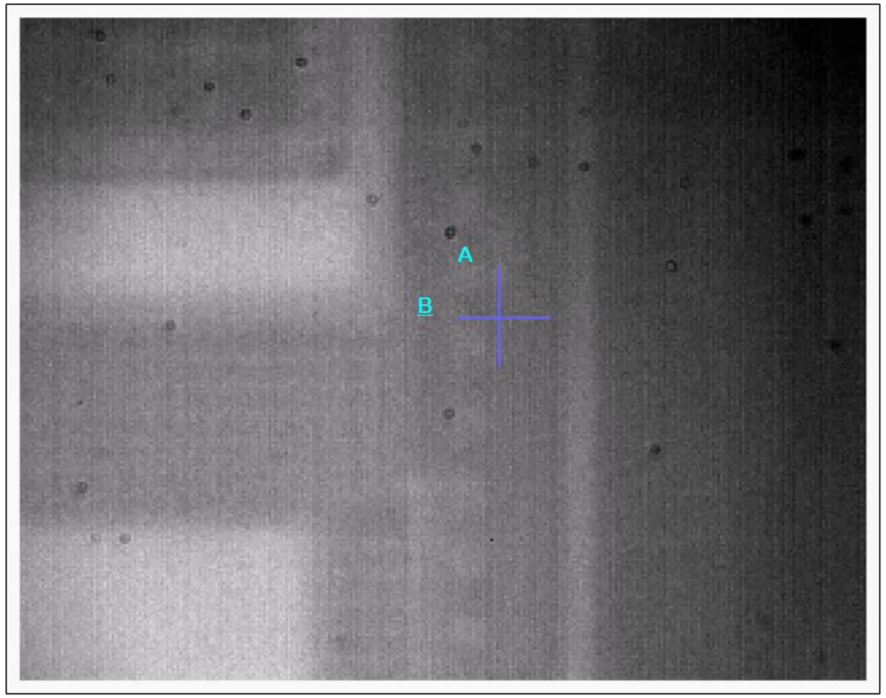
Threshold E

Classify

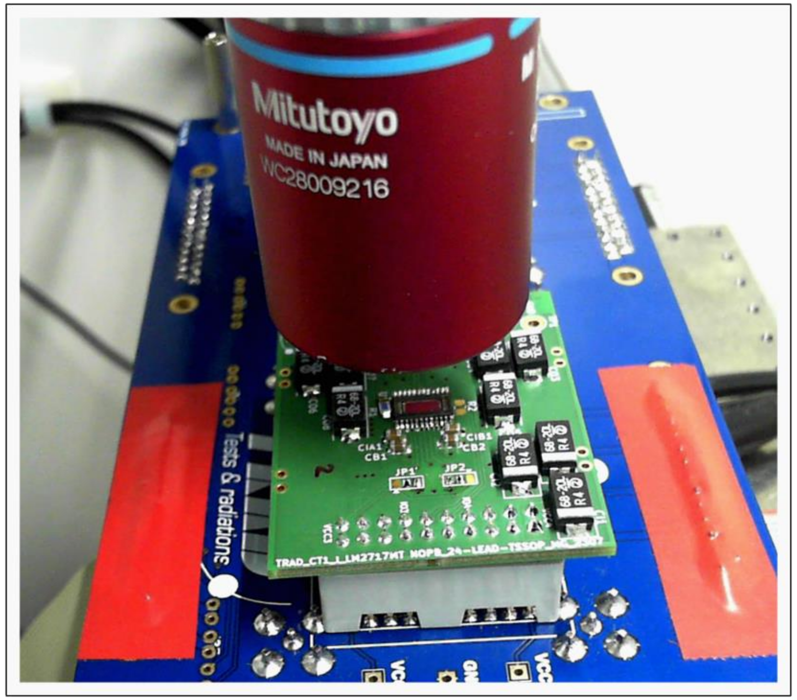
III-Experimental procedure for DUT's screening

- Test methodology for SEL screening:
  - ➢ Fast-scan: maximum speed of 2mm/s

View from the IR camera



View inside the Laser cabin



- ➢ Test time highly depends on DUT size (from 10min to 1 hour)

III-Experimental procedure for DUT's screening

- Test methodology for SEL screening:
  - Finally, DUT sensitivity is classified with the following table:

Sensitivity screening to Single Event Effects			
Low energy (<1 nJ/pulse)	Medium energy (1-2nJ pulse)	High energy (2-3 nJ/pulse)	Very high energy (>3 nJ/pulse)

Corresponds to energy re-calculated in active area

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REF A	**SEL**			
REF B		No SEL/DSEE	**SEL**	

Corresponds to energy re-calculated in active area

Not recommended

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REF A	**SEL**			
REF B		No SEL/DSEE	**SEL**	
REF C			No SEL/DSEE	**SEL**

Corresponds to energy re-calculated in active area

Not recommended

Depends on the RHA considered

III-Experimental procedure for DUT's screening

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REF A	**SEL**			
REF B		No SEL/DSEE	**SEL**	
REF C			No SEL/DSEE	**SEL**
REF D				No SEL/DSEE

Corresponds to energy re-calculated in active area

Not recommended

Depends on the RHA considered

Recommended

- For device with no sensitivity, or a low sensitivity observed (ex. With REF C and D), following actions depends on the RHA considered:
  - A heavy ion might be recommended for confirmation
  - No further action may be considered, and a level of risk may be accepted

IV-Activities performed with

- Objectives:
  - New approach for the evaluation of an equipment with an innovative RHA, considering laser tests only for device’s selection
  - The devices evaluated are part of the board driving the magnetorquer
  - Strategy for U-SPACE equipment validation:

Pre-selection of devices and alternatives, for a given function

Development of test bench and preparation for laser test

Laser testing for destructive events with methodology introduced

Identification of the most robust parts for U-SPACE’s design

Evaluation of soft errors impact on board and rate estimations

IV-Activities performed with U/SPACE

- Objectives:

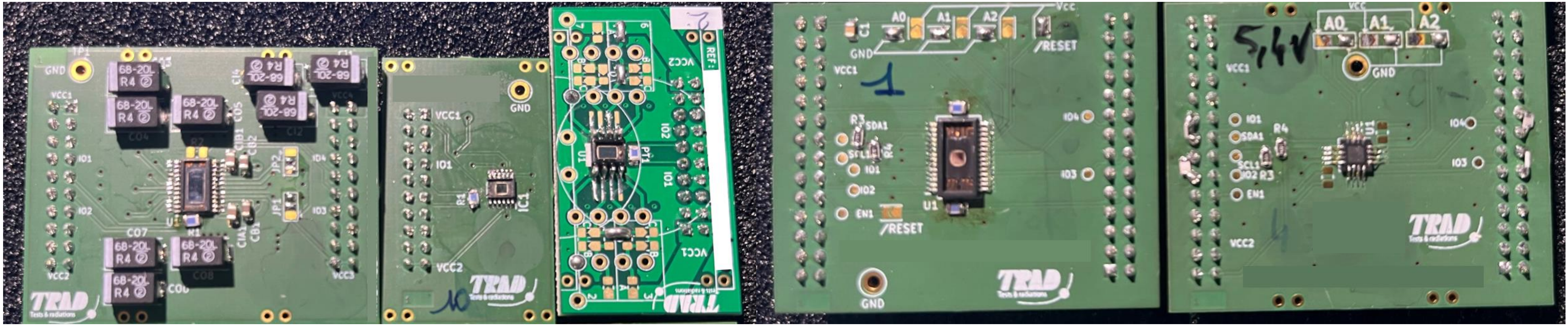
  - ➢ 10 functions with several candidates evaluated:

Function	Number of candidates
Motor driver	5
Voltage regulator	4
Digital potentiometer	3
Timer	2
Interface Ics (I2C extender & I/O expander)	8
Current/voltage measurement Ics	3
Other functions	7

A total of 32 devices evaluated with laser, and classified

IV-Activities performed with U/SPACE

- Test development:
  - Very simple test bench focused on SEL/Destructive events
  - Every parts were prepared successfully in backside for laser tests
    - No problem encountered for backside's preparation
    - Few examples:



IV-Activities performed with U-SPACE

- Test results
  - ➢ All 32 devices successfully classified, for USPACE to select the best references
  - ➢ Few examples of interesting results:
    - ○ For a given function:
      - ○ All references were sensitive to SEL/DSEE at very low pulse energy (<1 nJ/pulse)
      - ○ This function was replaced by U-SPACE

	Sensitivity screening to Single Event Effects			
	Low energy (<1 nJ/pulse)	Medium energy (1-2nJ pulse)	High energy (2-3 nJ/pulse)	Very high energy (>3 nJ/pulse)
REF A	**SEL**			
REF B	**SEL**			
REF C	SEFI/**Destructive events**			

IV-Activities performed with U-SPACE

- Test results

  - But for most functions: differences of sensitivity favours one reference

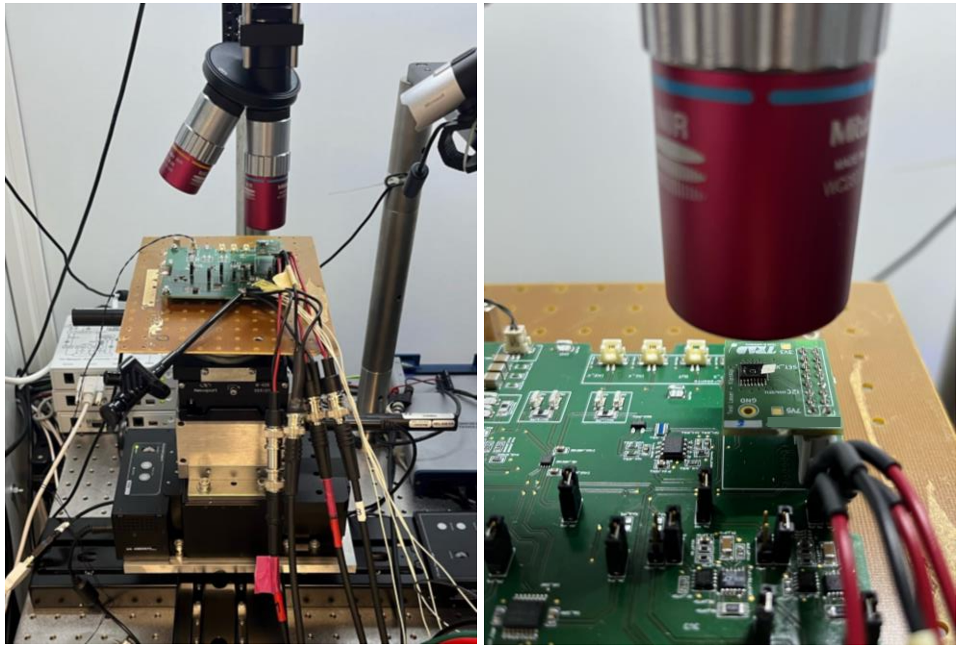
  - Overview of results obtained:

	Sensitivity screening to Single Event Effects				
	Low energy (<1 nJ/pulse)	Medium energy (1-2nJ pulse)	High energy (2-3 nJ/pulse)	Very high energy (>3 nJ/pulse)	Not sensitive
Number of tested devices sensitive to **SEL** or **Destructive events**	**6**	**2**	**5**	**4**	**15**

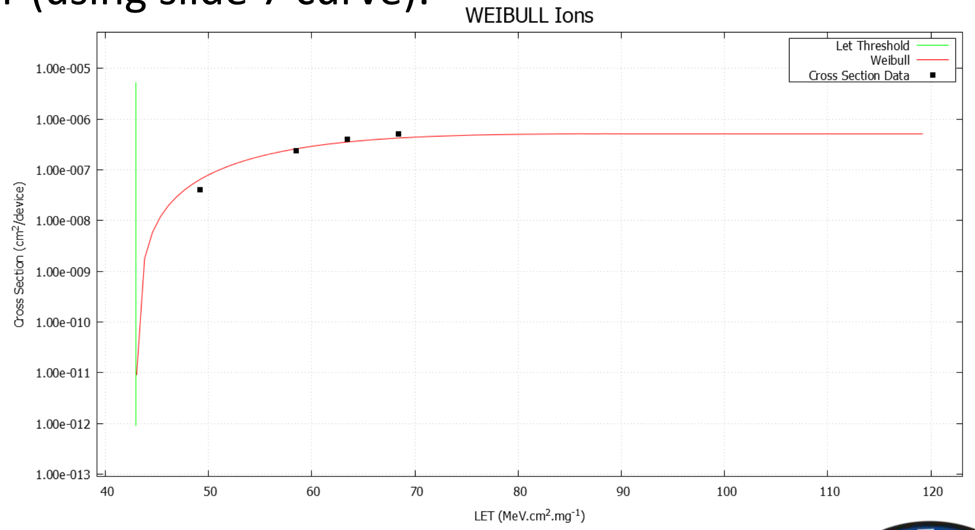
    - ~19% of devices tested are very sensitive to SEL/destructive events
    - ~46% of devices tested showed no sensitivity to SEL/destructive events even at very high pulse energies

IV-Activities performed with U SPACE

- Test results
  - ➢ Additional test: a device was sensitive to SEFIs
  - ➢ The effect of SEFIs were evaluated on the whole board:



➢ A Laser cross section was measured, and pulse energy was converted to LET (using slide 7 curve):



➢ A rate for such events was calculated in OMERE 5.8.1 for a 600km SSO orbit:

SEFI rate (in-flare)	SEFI rate (out of flare)
5.3^{E}-7 /device/day	2^{E}-9 /device/day

V-Pros and cons

- Pros and cons of the proposed methodology and case applications:
  - **Pros:**
    - **As compared to heavy ions:**
      - **Pre-screening of a device for SEL/Destructive events is very quick (few weeks vs few months)**
      - **Test cost reduced by a factor of x2 minimum**
      - **No or few constraints associated with tests (no vacuum, long cables etc.)**
    - **Good success for DUT’s preparation in backside (32/32 devices successfully prepared for U-SPACE project)**
    - **Spatial resolution is useful for the study of soft errors, and their impact on the system**
  - **Cons:**
    - **More « beam time » required as compared to heavy ion test: classification of a device can take few hours, depending on the size of the die, events observed**
    - **No heavy ions confirmation involves accepting a risk level**

Conclusion and future work

- A methodology for pre-screening devices regarding SEL has been presented:
  - ➢ Fast Pulsed Laser scan help identify quickly SEL sensitive devices (or DSEE)
  - ➢ A classification of sensitivity has been introduced
  - ➢ This classification allows to identify, among several candidates, the most robust device for a design
- This laser pre-screening may help reduce overall cost and time for qualification
  - ➢ But a heavy ion test may be required, depending on the RHA considered
- A case application was presented with USPACE
  - ➢ 32 devices were evaluated with Laser
  - ➢ The most sensitive were rejected and the most robust selected
- Future work include:
  - ➢ Collaboration with U-SPACE to work on their New Space RHA to include Laser as a pre-selection method
  - ➢ Additional work on soft errors study and risk estimation with Laser

Thank you for your attention

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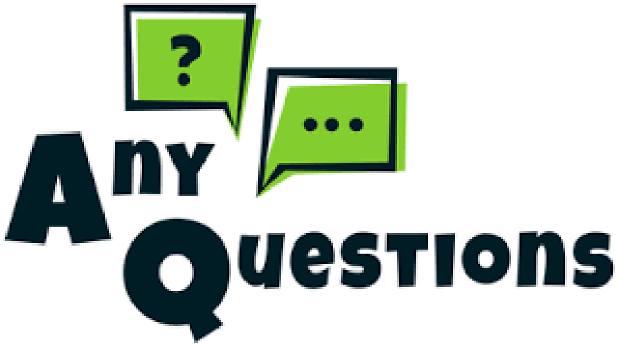

II-LISA’s calibration and previous works

- In 2023: cross-calibration of Pulsed Laser and heavy ions with multiple devices sensitive to SEL

  - ➢ What about equivalent laser LET calculation ?
    - ○ Using ESA’s guidelines formula, and a weighting factor:

Reference	Laser Energy threshold (nJ/pulse)	Laser LET	Heavy Ion LETth (MeV.cm²/mg)
STLM75DS2F	0.3	5.8	3.3<LETth<5.7
MAX6301ESA+	0.96	8.2	5.7<LETth<9.9
MCP23018-E/MJ	1.86	16.2	LETth~12
ADUM1100BRZ	1.56	13.9	LETth~13
74LVC3G17DC	5.09	45.9	LETth~30
SN65HVD233MDREP	3.71	53.6	20.4<LETth<32.4
MCP6292-E/MS	3.11	28.1	32.4<LETth<45.8
CD74HC4067M	5	43.7	45<LETth<62

🟩 Estimation within ±5 MeV.cm²/mg of LETth (or LET range)

🟧 Estimation outside ±5 MeV.cm²/mg