U.S. NAVAL RESEARCH LABORATORY

RADLAS 2024
Noordwijk, Netherlands
September 11, 2024

RADLAS 2024

Enabling Capabilities for Predictive Testing Using Pulsed Lasers

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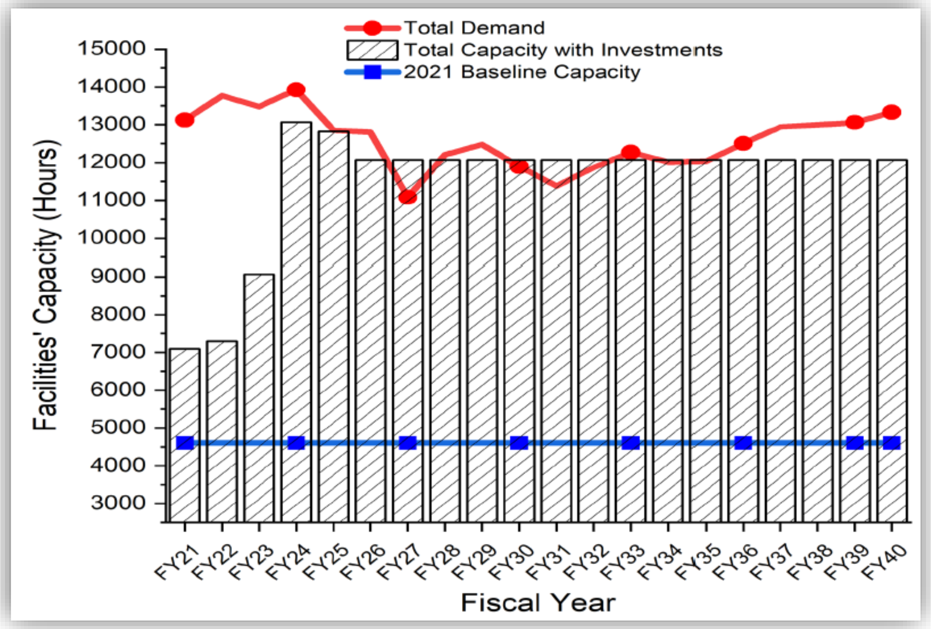
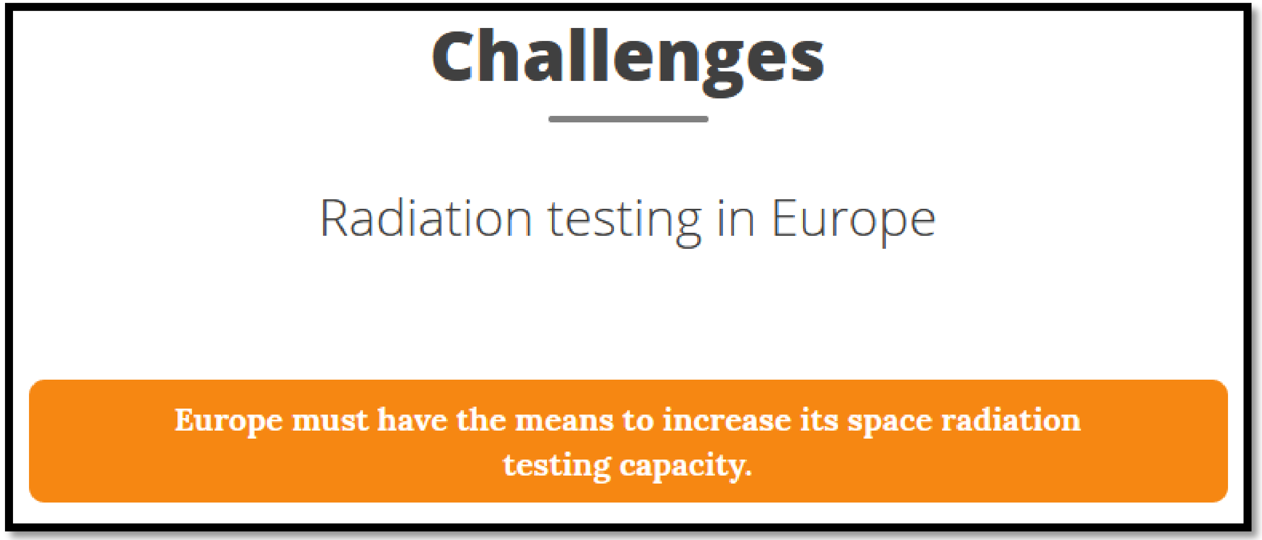
The Need for Surrogate Test Approaches

- **Current SEE Testing Landscape**
  - Increasing demand for testing driven by commercial space and device complexity
  - Total demand far exceeds capacity
  - Surrogate test approaches are an important pathway for narrowing the gap



C. Matzkind, *SEE Symposium,* 2022.



https://hearts-project.eu/challenges/radiation-testing-in-europe/

The Need for Surrogate Test Approaches

- **Role of Pulsed-Laser (PL) SEE Testing**
  - An effective surrogate should be able to predict the heavy-ion SEE response
  - PL SEE testing has matured as a surrogate test approach

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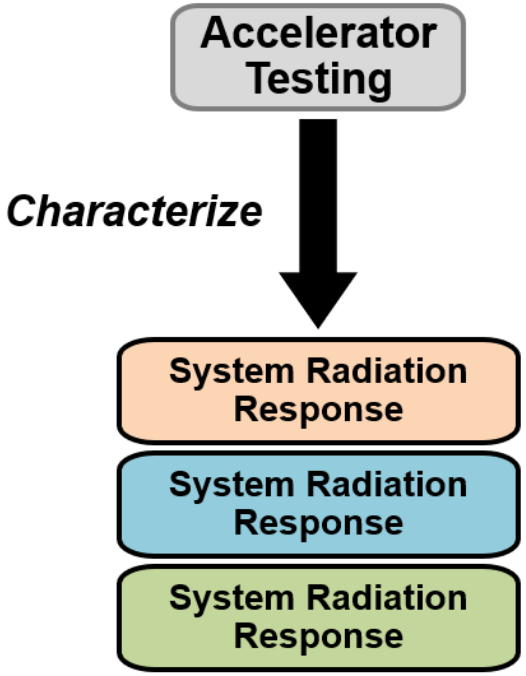
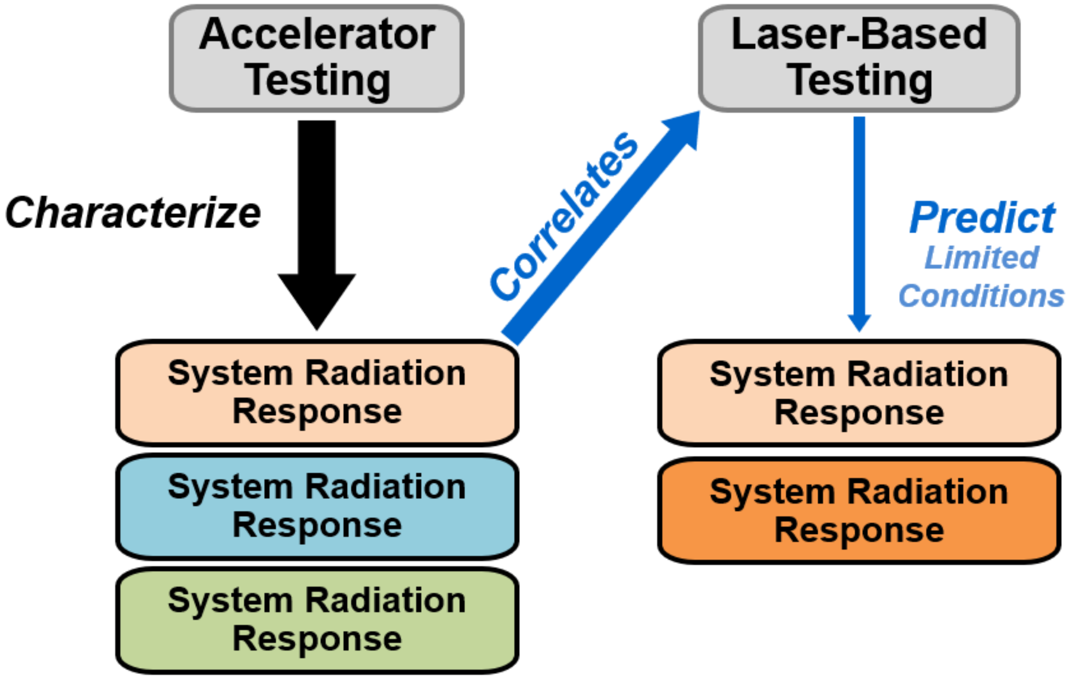


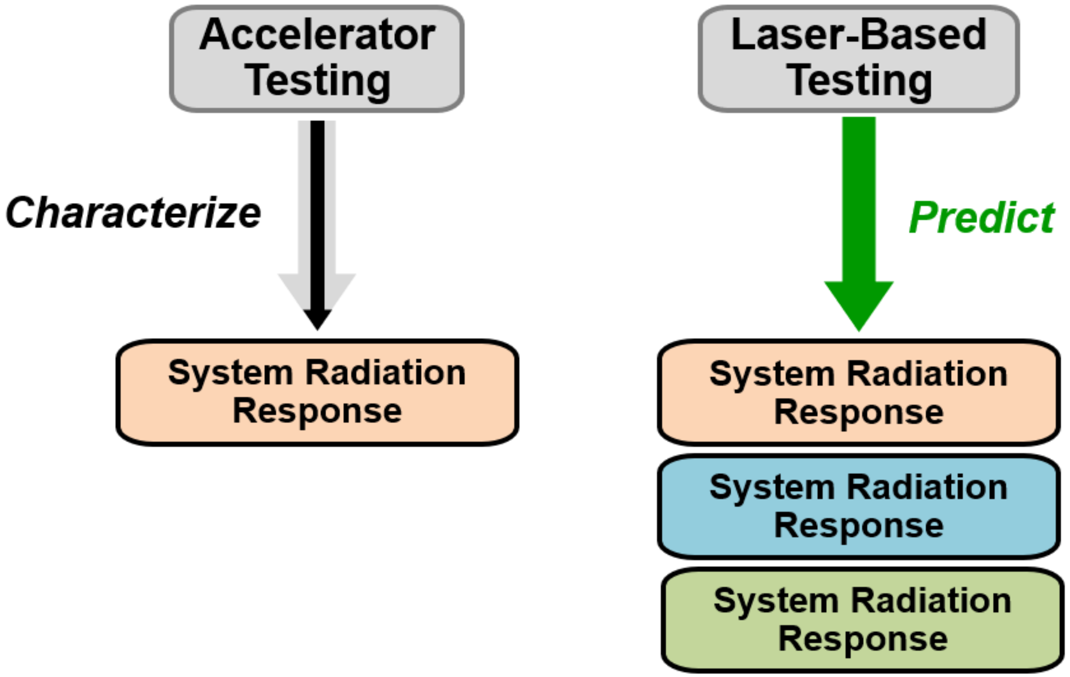
The Need for Surrogate Test Approaches

- **Role of Pulsed-Laser (PL) SEE Testing**
  - Empirical correlation approaches allow for prediction under limited conditions
  - Reliance on existing accelerator data limits ability to narrow the gap



The Need for Surrogate Test Approaches

- **Role of Pulsed-Laser (PL) SEE Testing**
  - Predictive approaches do not rely on pre-existing accelerator data
  - Could significantly narrow the gap but significant challenges exist



Criteria for Predictive Surrogate Testing

Tuning surrogate source to **prescribed heavy-ion LET** and accurately **reproducing SEE response** in the DUT, **without need for existing heavy-ion data**

A. Ildefonso, *et al.*, *TNS,* vol. 71, Apr., 2024.
J. M. Hales, *et al.*, *TNS,* vol. 71, Apr., 2024.

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All Test Conditions

Descriptive Diagnostics

A. Ildefonso, *et al.*, *TNS,* vol. 71, Apr., 2024.
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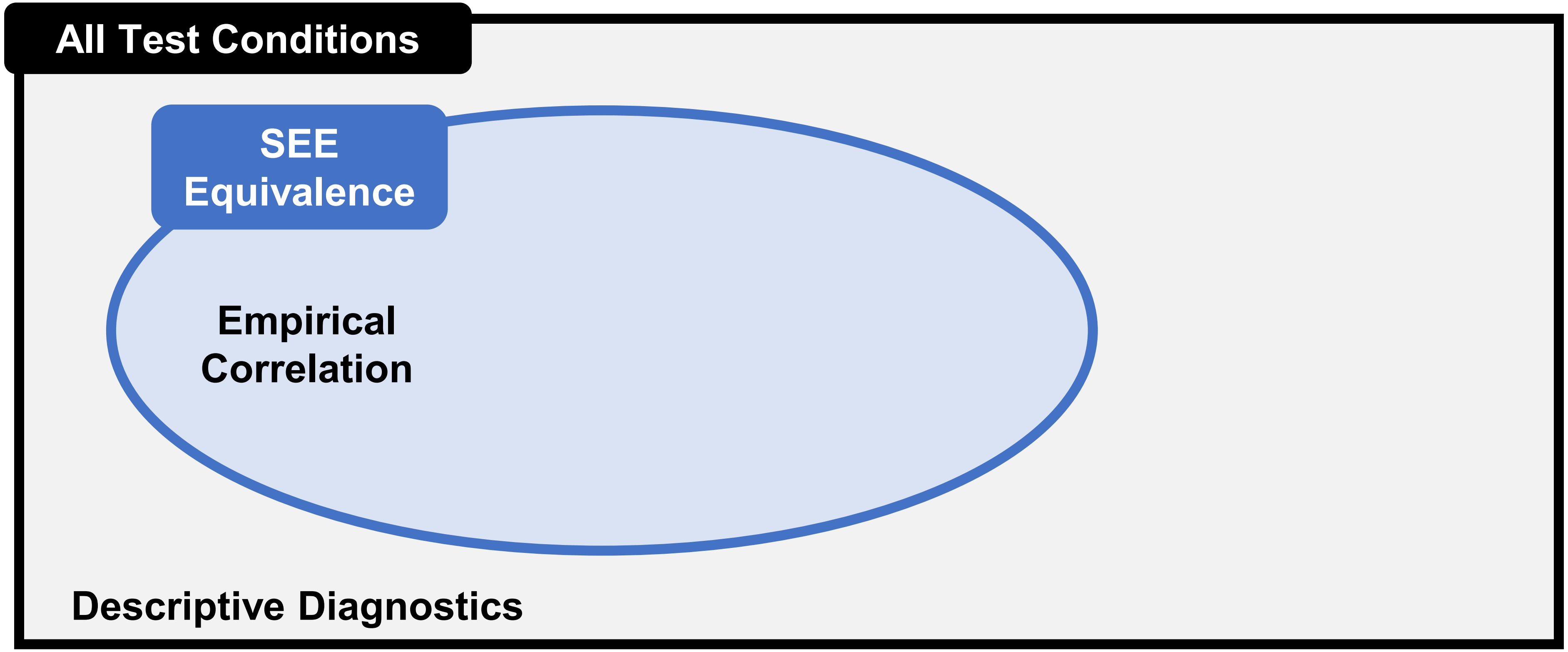

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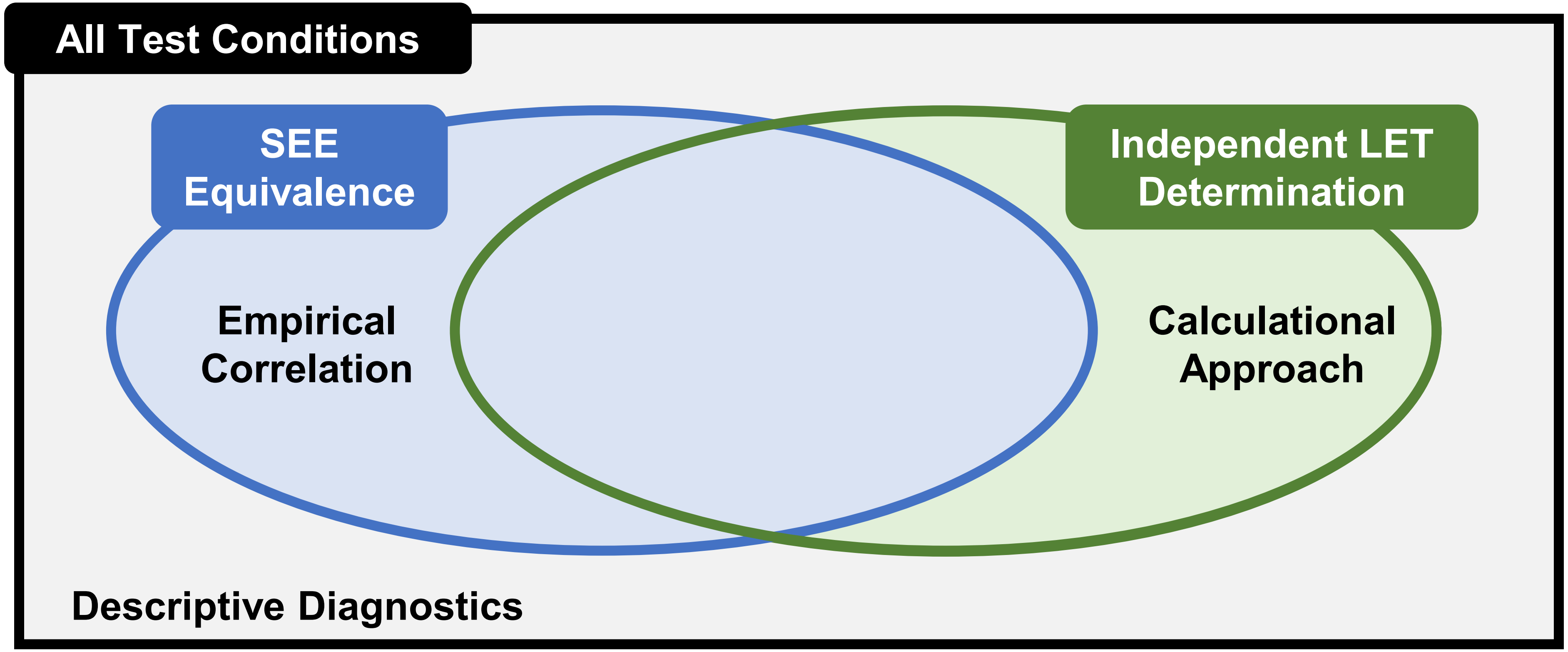

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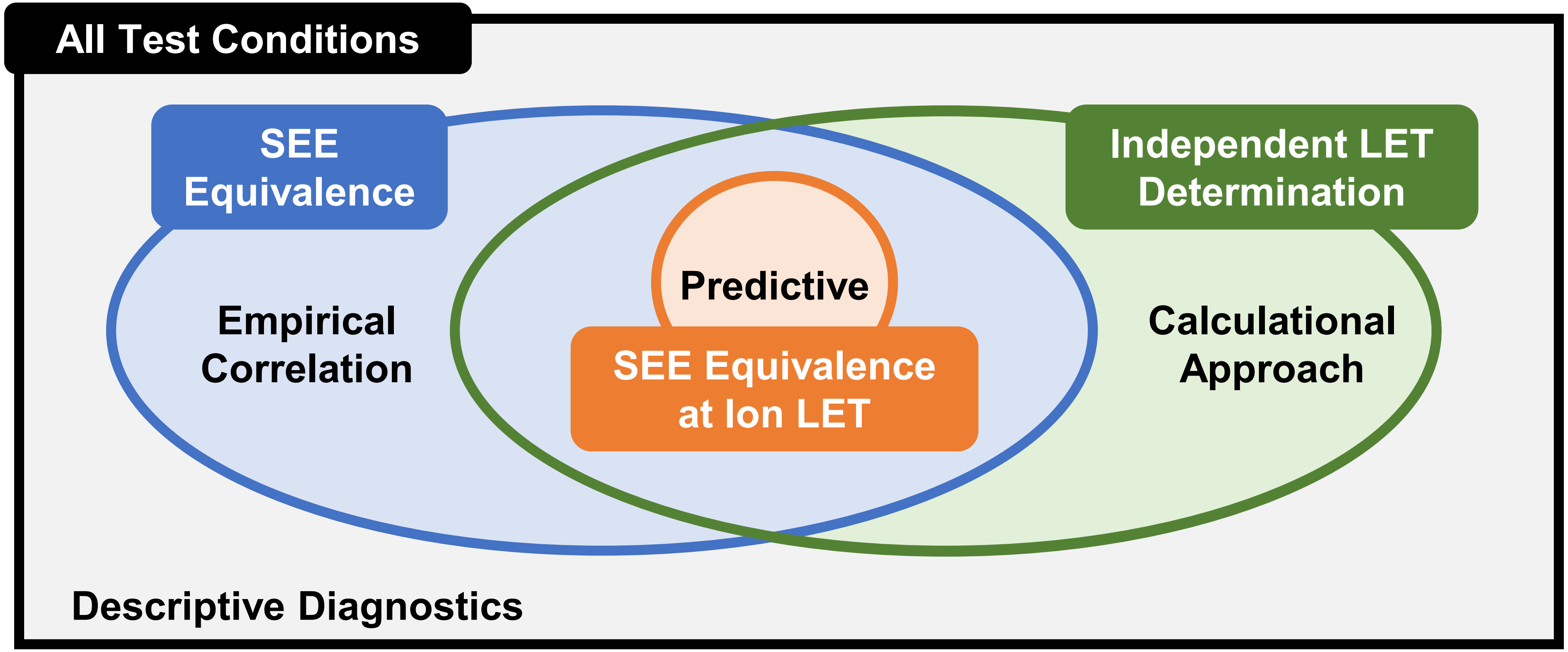

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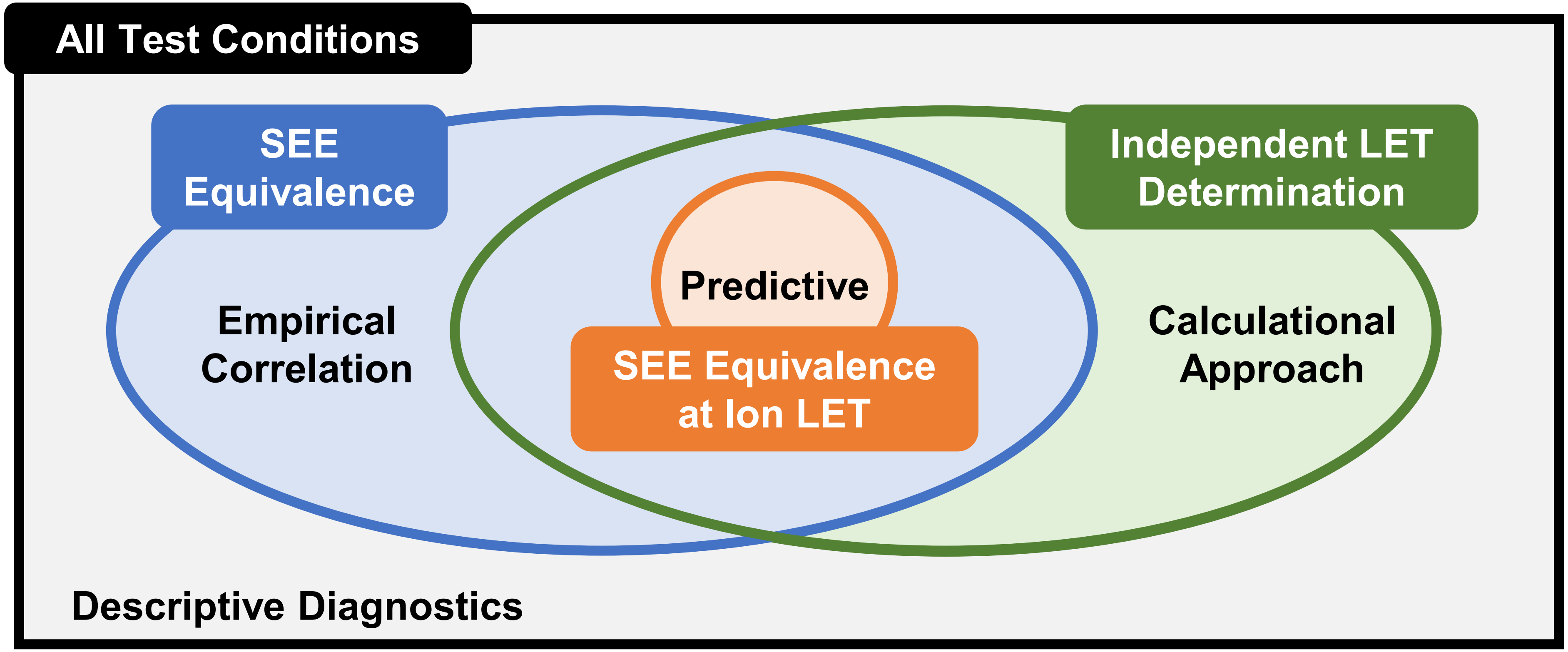
Criteria for Predictive Surrogate Testing

Predictive testing faces many challenges for successful implementation, but various ***capabilities have driven significant progress*** in recent years



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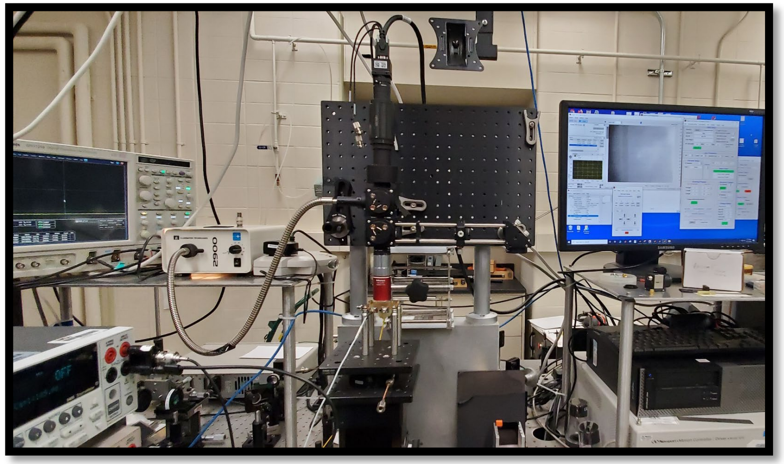
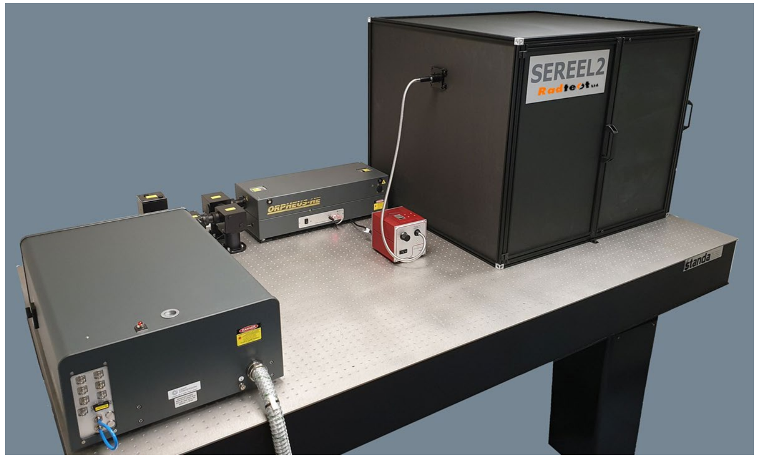
Democratization: Accessibility

- Improvements in laser stability and wavelength tunability have promoted usage
- Introduction of commercial PL SEE systems primary driver for increased accessibility



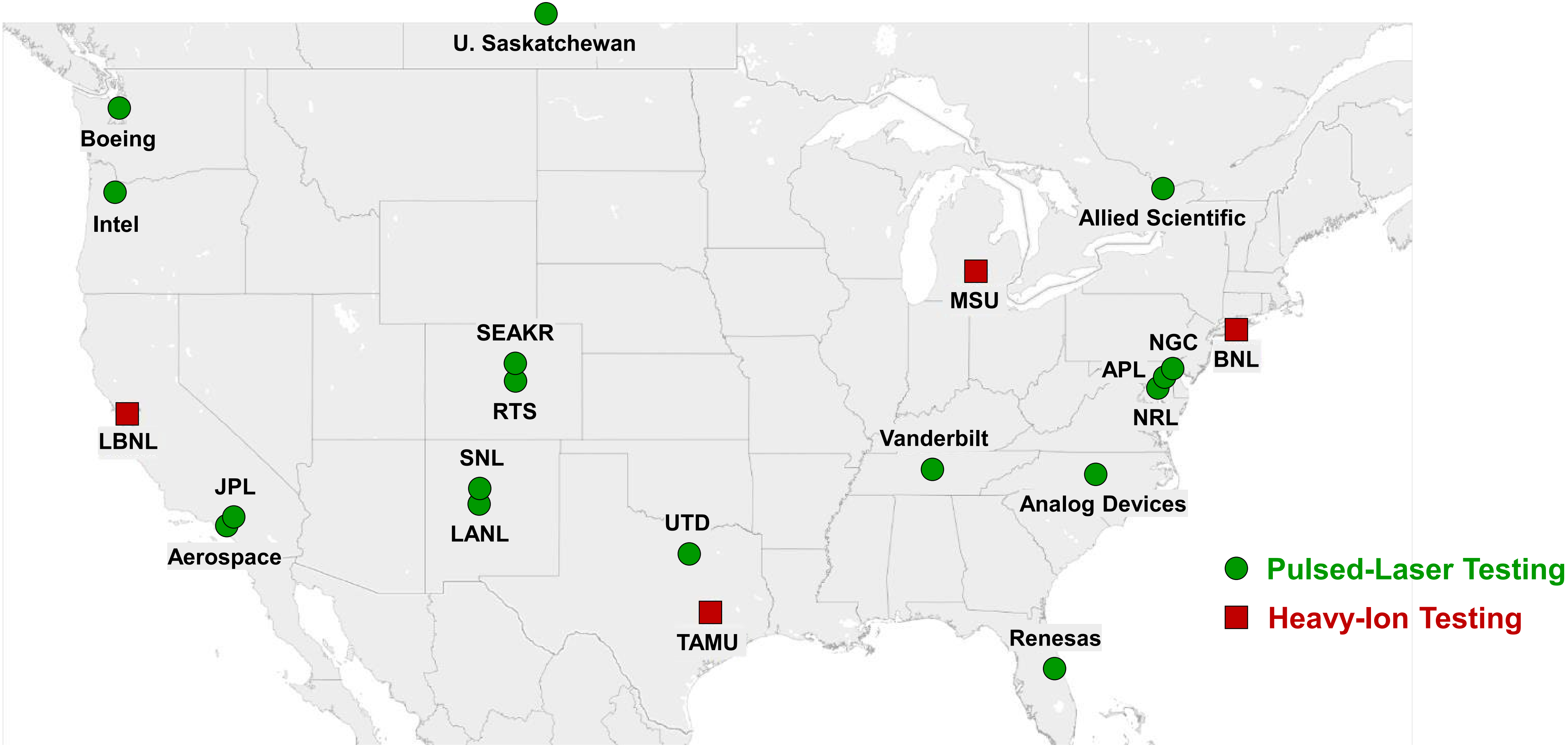
NRL TPA Set-up

PULSCAN PULSYS



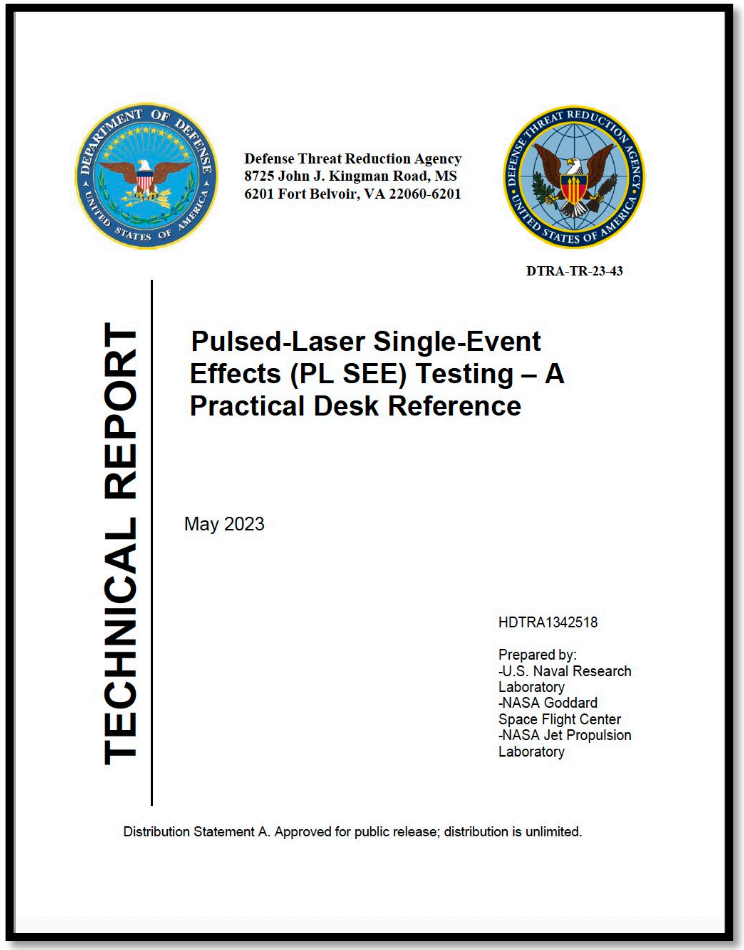
RadTest SEREEL2

Democratization: Accessibility



Democratization: Documentation

- Maturity of PL SEE testing technique has led to valuable reference documents



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DTRA-TR-23-43

TECHNICAL REPORT

Pulsed-Laser Single-Event Effects (PL SEE) Testing – A Practical Desk Reference

May 2023

HDTRA1342518

Prepared by:
-U.S. Naval Research Laboratory
-NASA Goddard Space Flight Center
-NASA Jet Propulsion Laboratory

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esa

Single-Event Effects Testing with a Laser Beam
-
Guidelines

Document information:

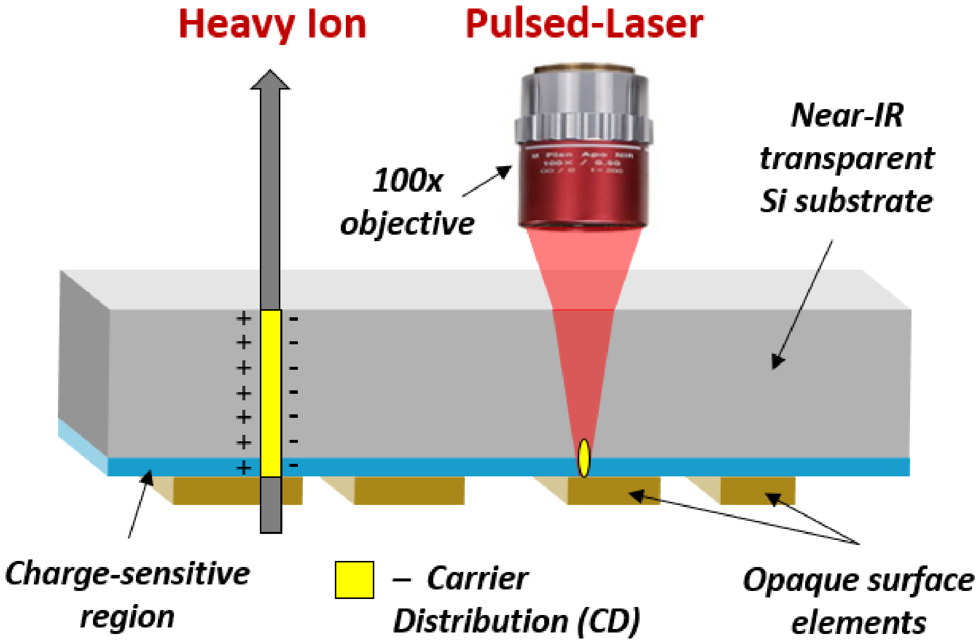
- Reference: ESA-TN2
- Contract No: 4000133635/20/NL/KML/rk
- Version: 2 (final) - date:19/05/2022
- Author: V. Pouget - IES - CNRS (vincent.pouget@umontpellier.fr)
- Technical Officers: Thomas Borel, Christian Poivey - ESA

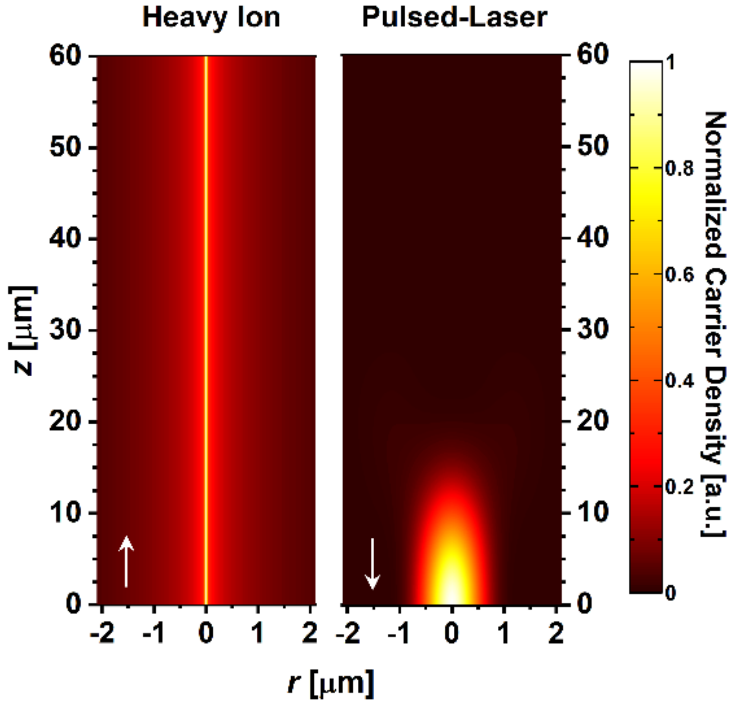
PL SEE Testing – A Practical Desk Reference

SEE Testing with a Laser Beam – Guidelines

Response Agreement: Carrier Distribution (CD)

- CDs generated by a heavy ion and by a pulsed laser are very different
- Overlap of CD and sensitive volume determines SEE response; agreement is difficult

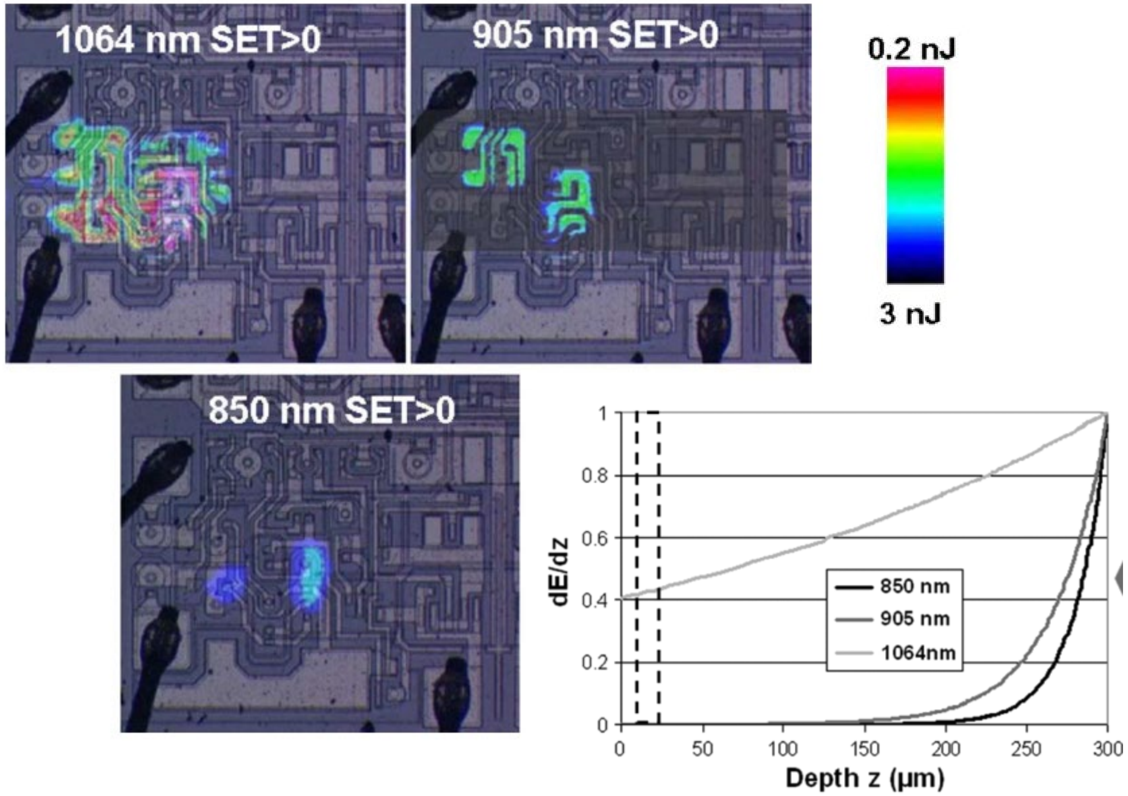




Heavy-Ion CD: lateral: <0.1 μm, depth: 100-200 μm
Pulsed-Laser CD: lateral: ~1 μm, depth: 10-20 μm

Response Agreement: Axial CD

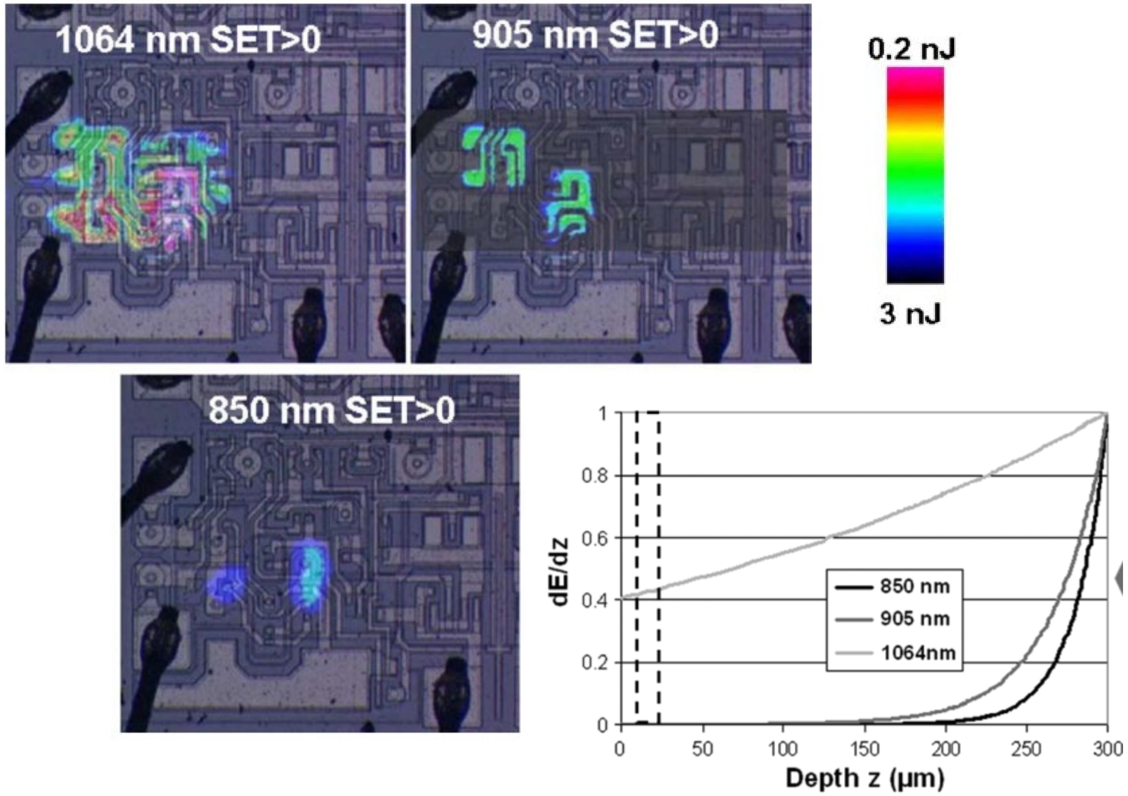
- (Left) NIR excitation allows for backside testing and probing deep sensitive volumes

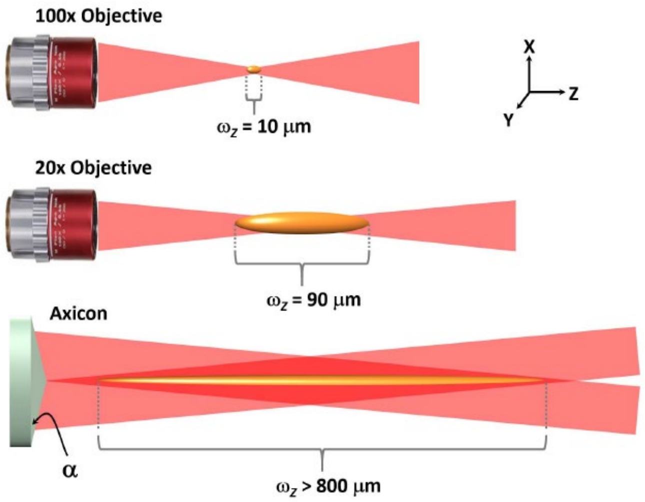


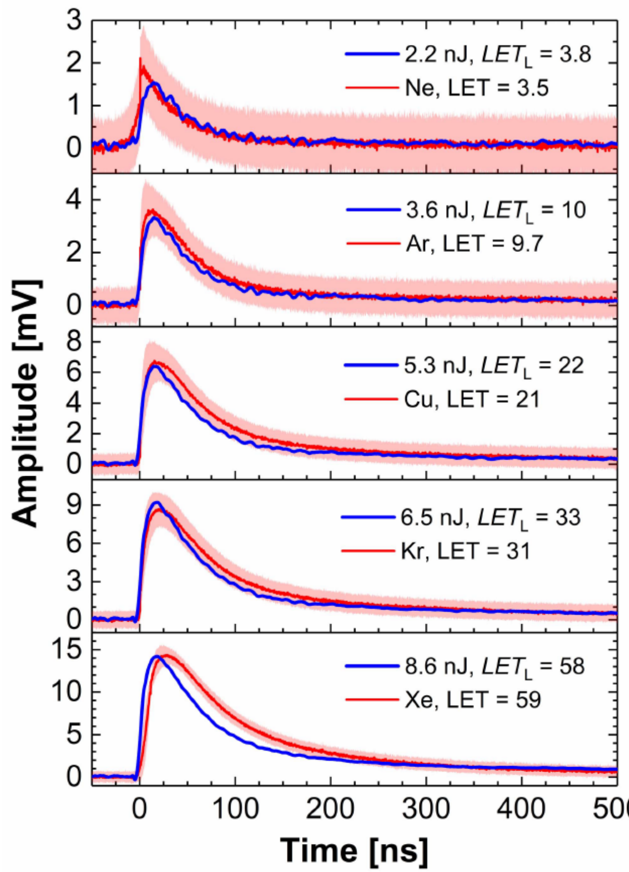
C. Weulersse, *et al.*, *TNS,* vol. 55, Aug., 2008.

Response Agreement: Axial CD

- (Left) NIR excitation allows for backside testing and probing deep sensitive volumes
- (Right) Axicon generates ion-like CD allowing for predicting SET response





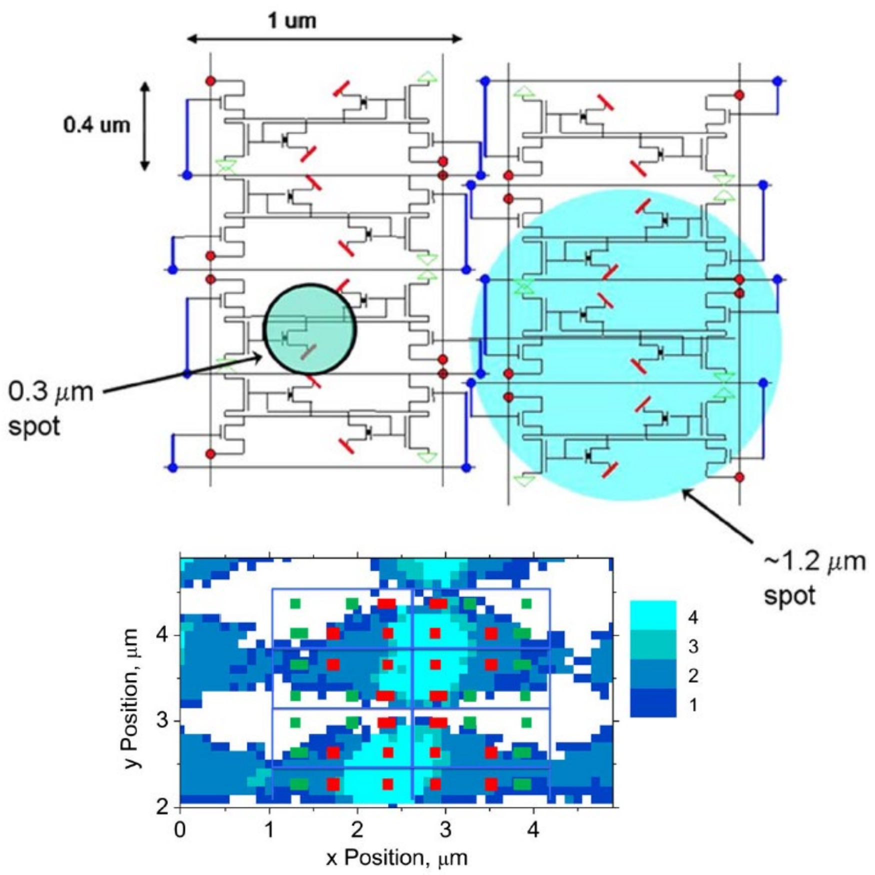


C. Weulersse, *et al.*, *TNS,* vol. 55, Aug., 2008.

J. M. Hales, *et al.*, *TNS,* vol. 67, Jan., 2020.

Response Agreement: Lateral CD

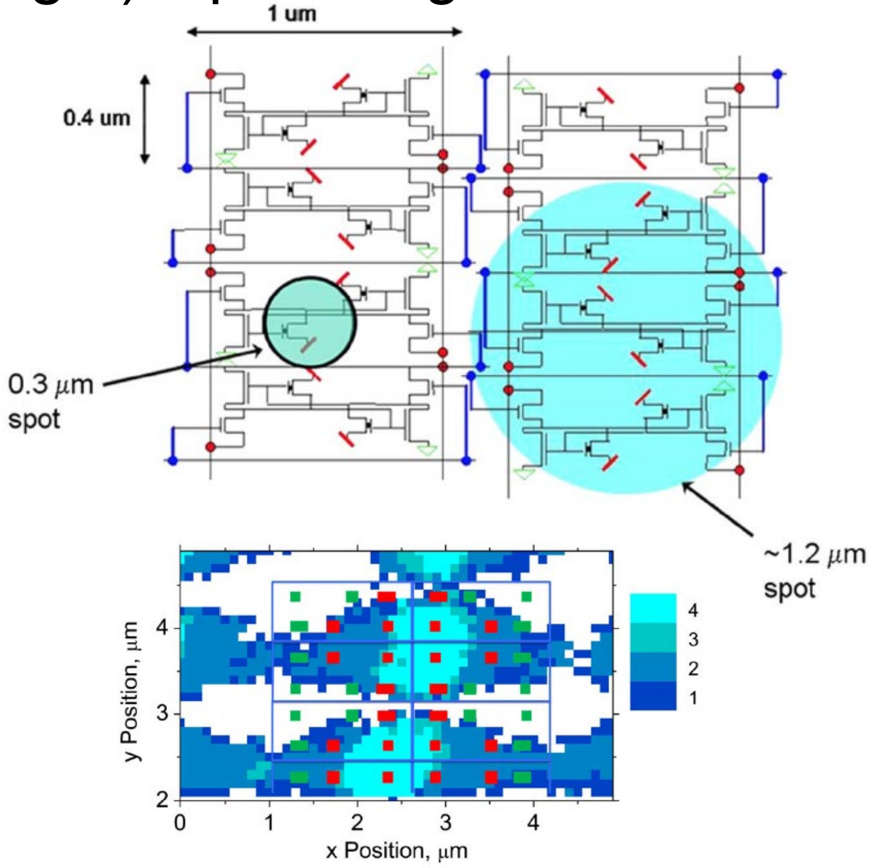
- (Left) UV excitation reduces lateral CD for interrogating single cells in 90-nm SRAM

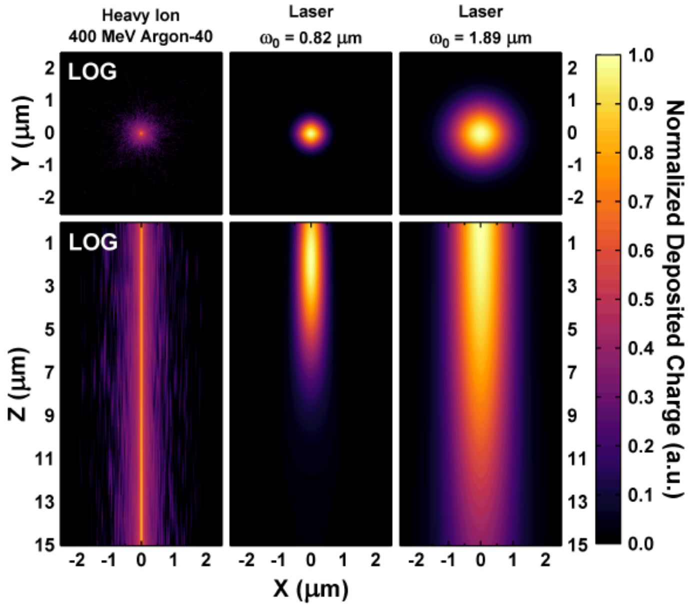


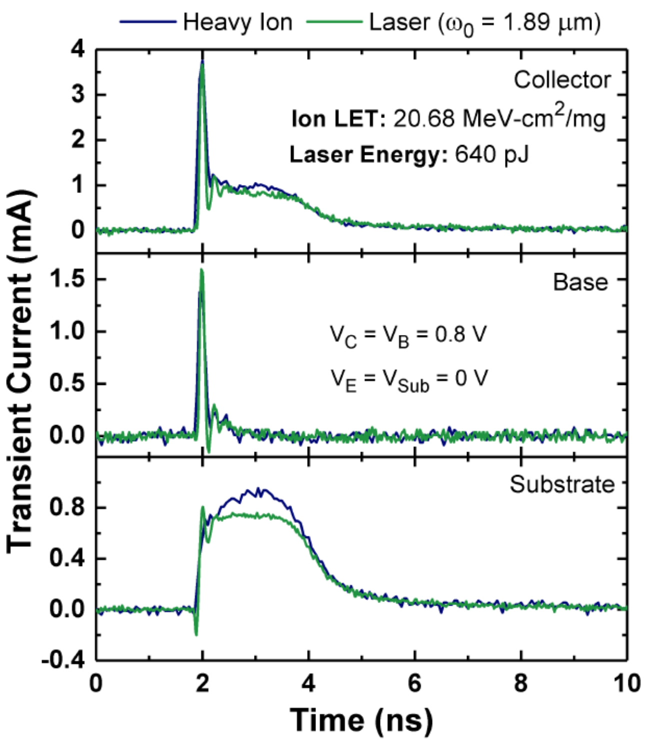
D. McMorrow, *et al.*, *TNS,* vol. 60, Dec., 2013.

Response Agreement: Lateral CD

- (Left) UV excitation reduces lateral CD for interrogating single cells in 90-nm SRAM
- (Right) Optimizing lateral CD results in excellent correlation for SETs in SiGe HBTs





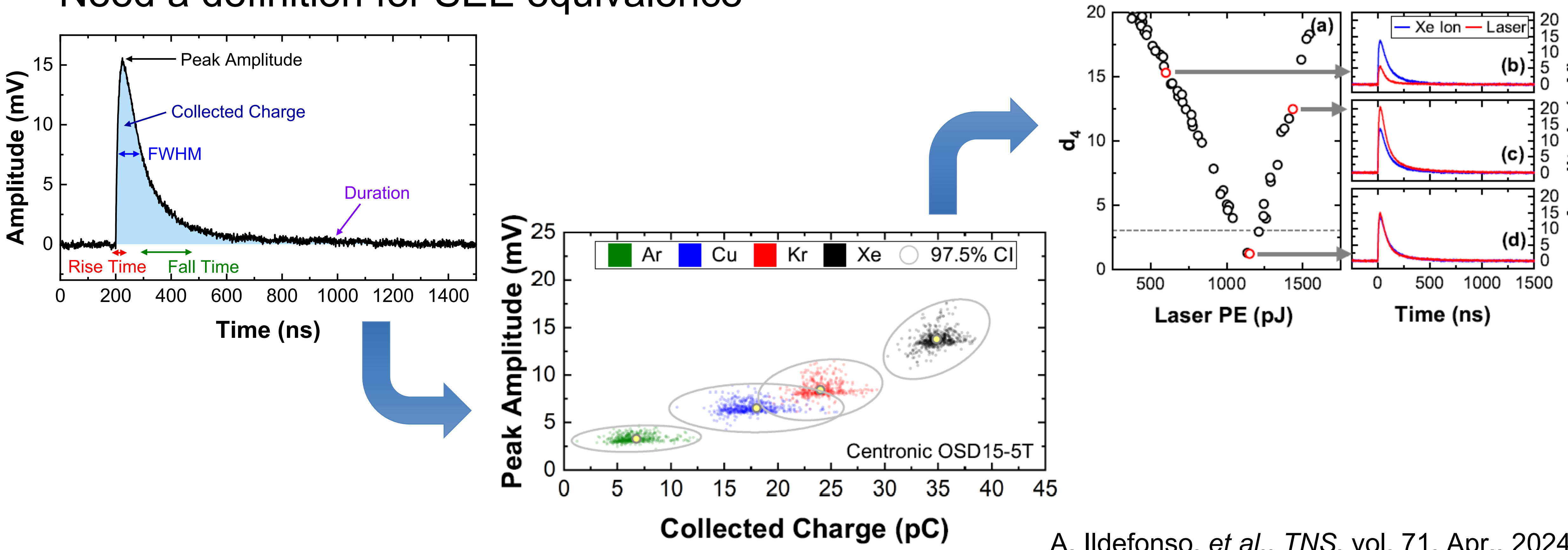


D. McMorrow, *et al.*, *TNS,* vol. 60, Dec., 2013.

A. Ildefonso, *et al.*, *TNS,* vol. 66, Jan., 2018.

Response Agreement: Equivalence

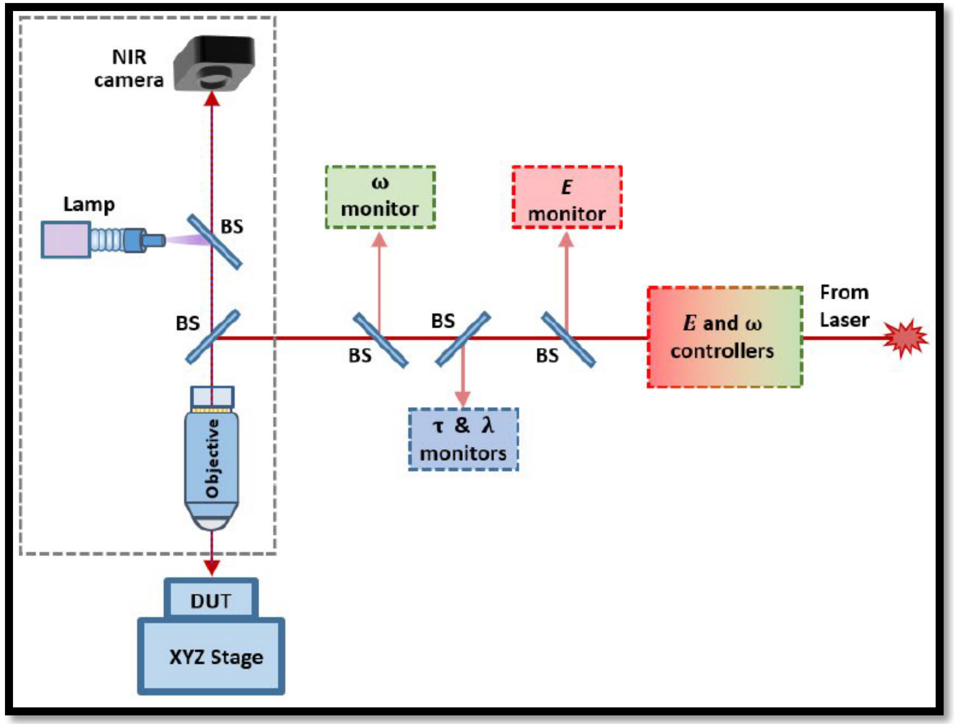
- The quality of the SEE response agreement requires an objective assessment
- Need quantitative metrics to assess SEE similarity for a variety of SEE data
- Need a definition for SEE equivalence



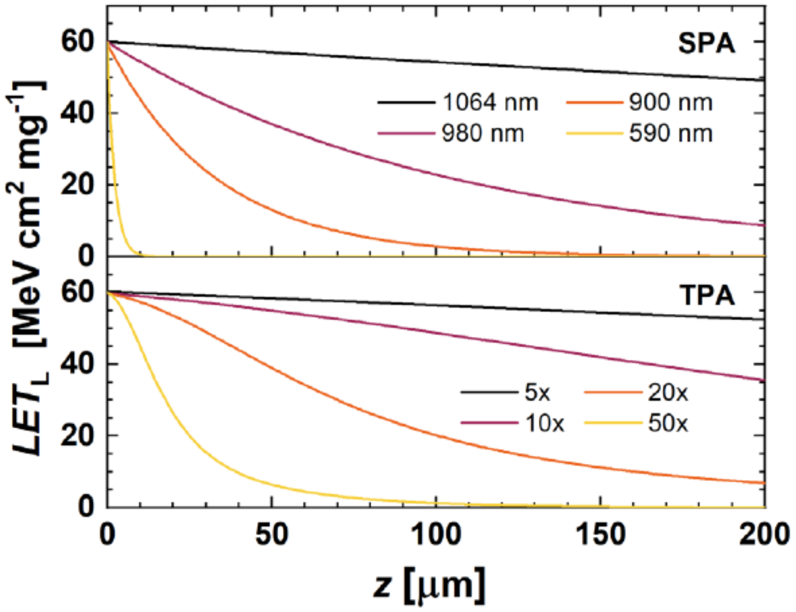
A. Ildefonso, *et al.*, *TNS,* vol. 71, Apr., 2024.

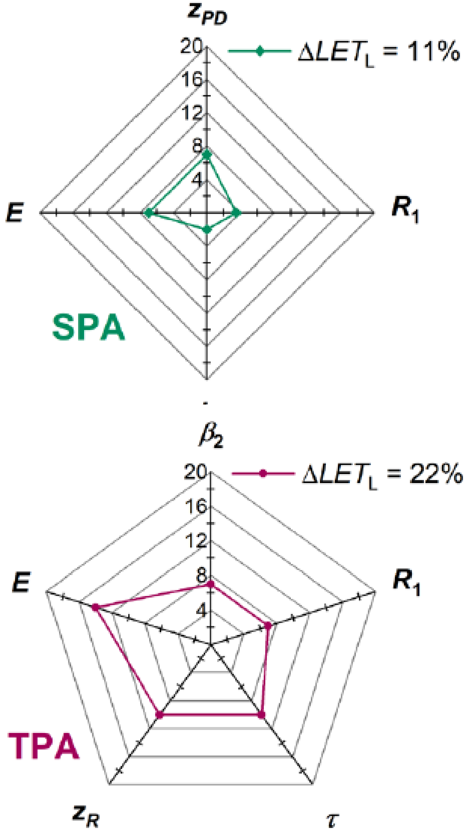
Determining LET: Dosimetry and Calculation

- Dosimetry is key for accurately estimating parameters needed for calculating LET_L
- Method for calculating LET_L over a wide range of conditions developed, validated for accuracy, and uncertainty estimated



PL SEE Testing – A Practical Desk Reference

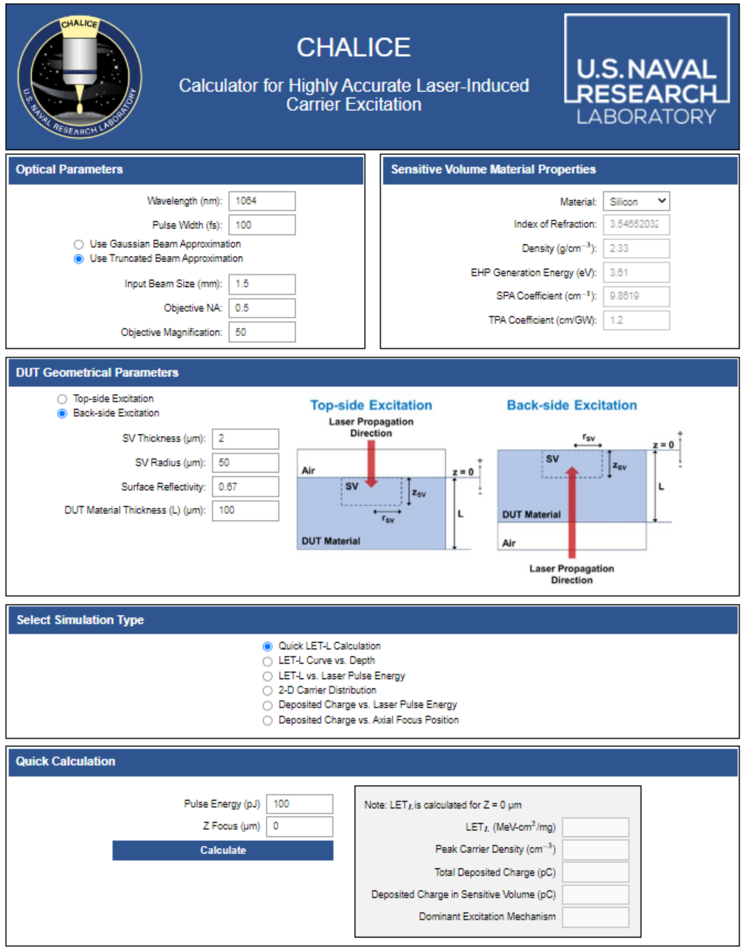


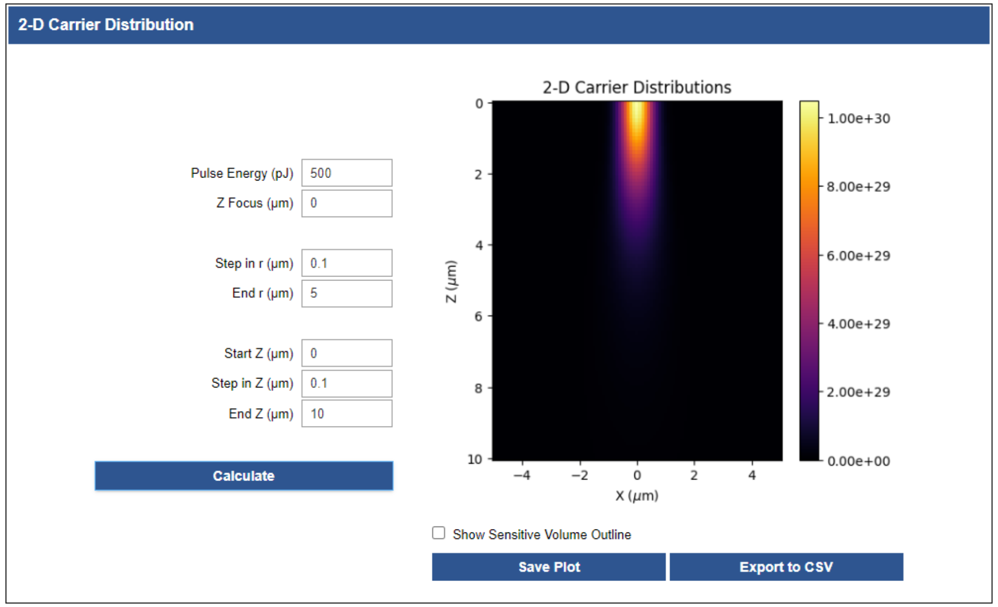


J. M. Hales, *et al.*, *TNS*, vol. 71, Apr., 2024.

Determining LET: CHALICE

- CHALICE – Calculator for Highly Accurate Laser-Induced Carrier Excitation – calculates key quantities for PL SEE testing (e.g., LET_L, CD, deposited charge)



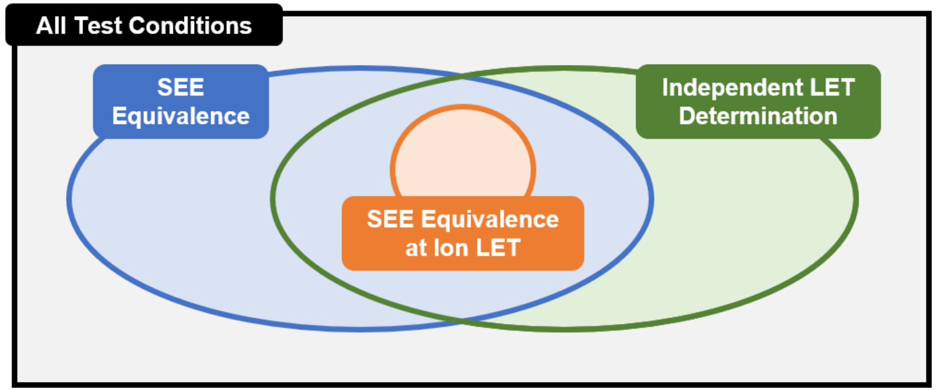


Currently beta testing and tool will be made available to the radiation effects community via nanoHUB in Fall 2024

A. Ildefonso, *SEE Symposium*, 2024.

Predictive PL SEE Case Studies

These capabilities have ***enabled predictive PL SEE testing*** in recent years!



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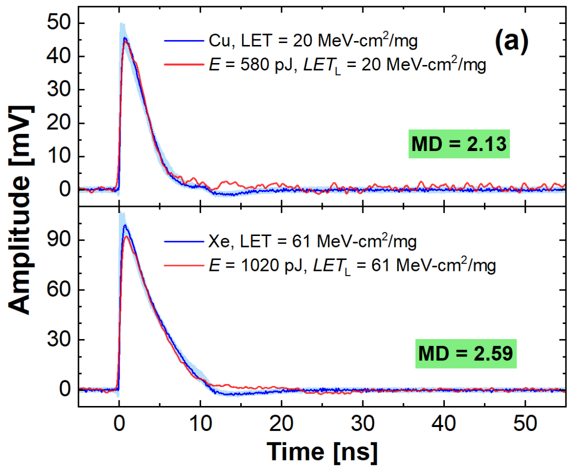
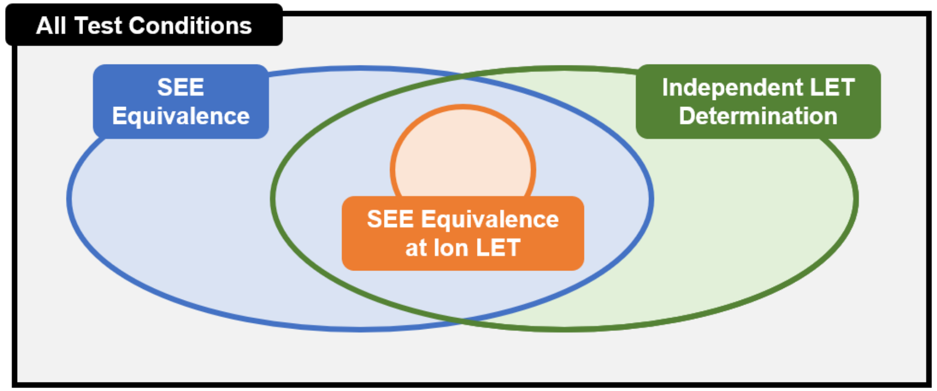


SETs in Si photodiodes [3]



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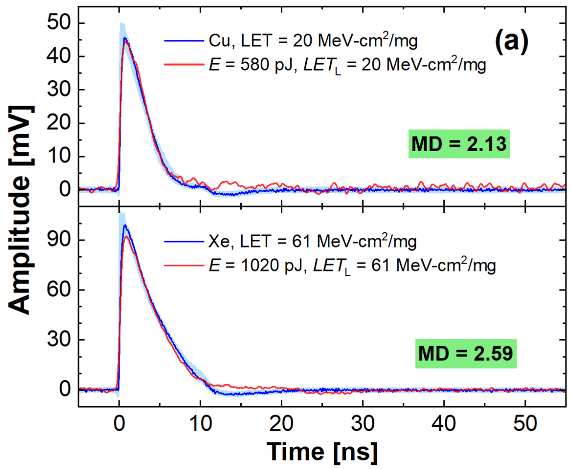

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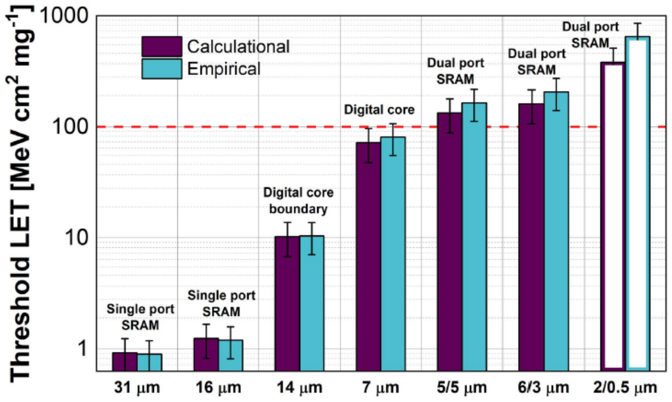
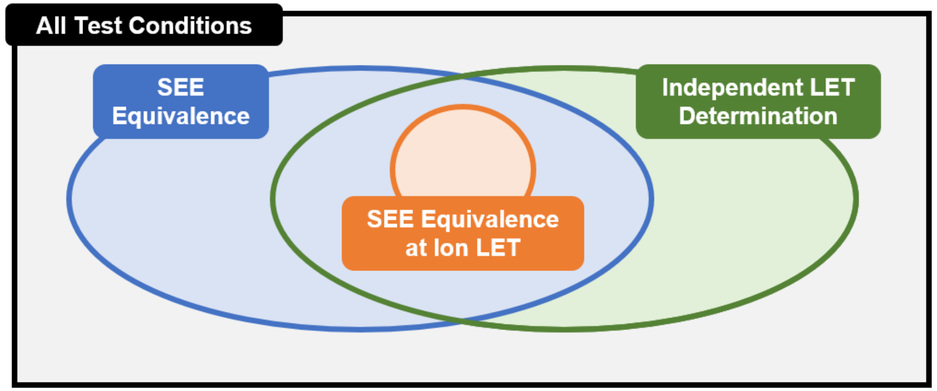


SEL in mixed-signal ASIC [11]



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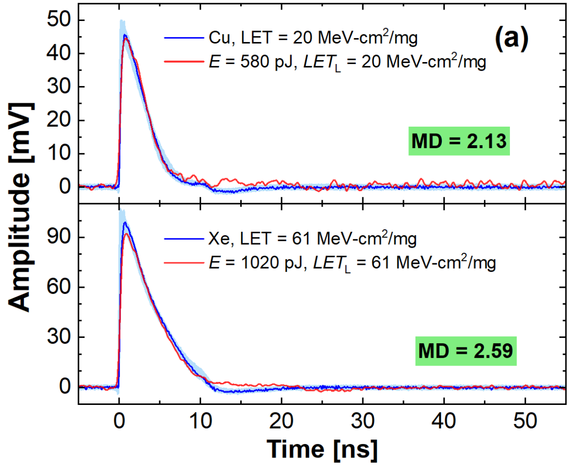

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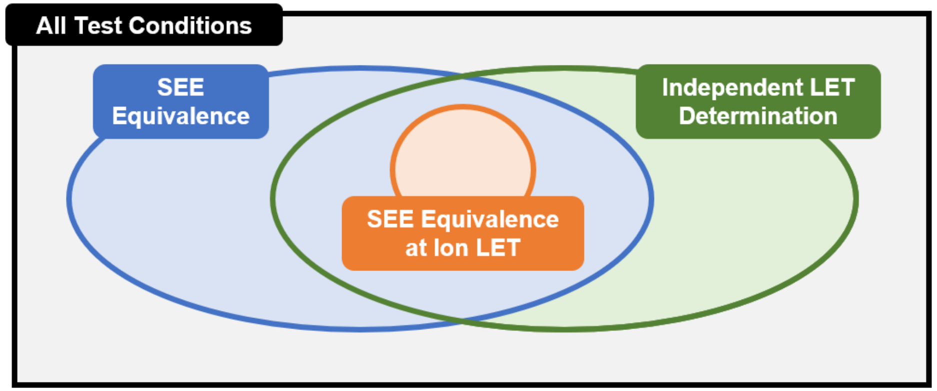

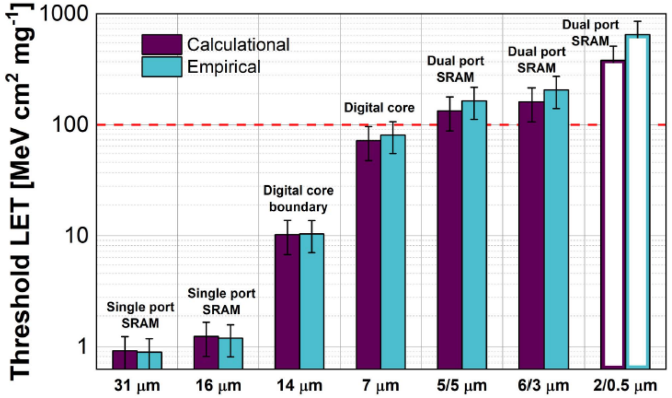

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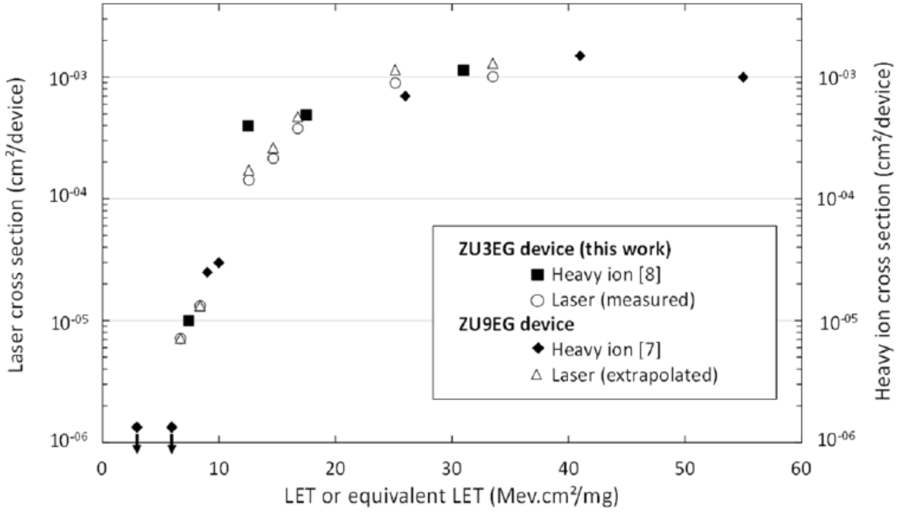

SEL in 16-nm FinFET [12]

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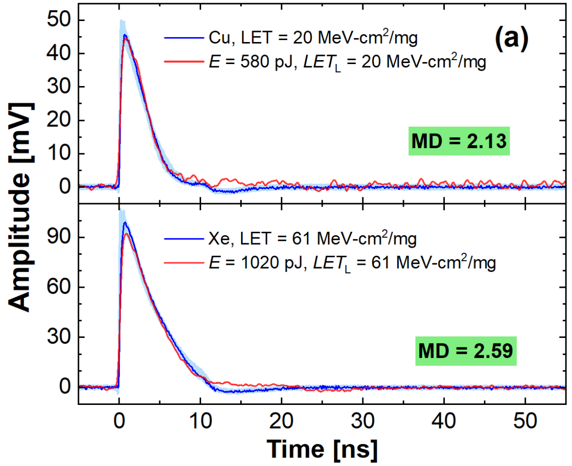

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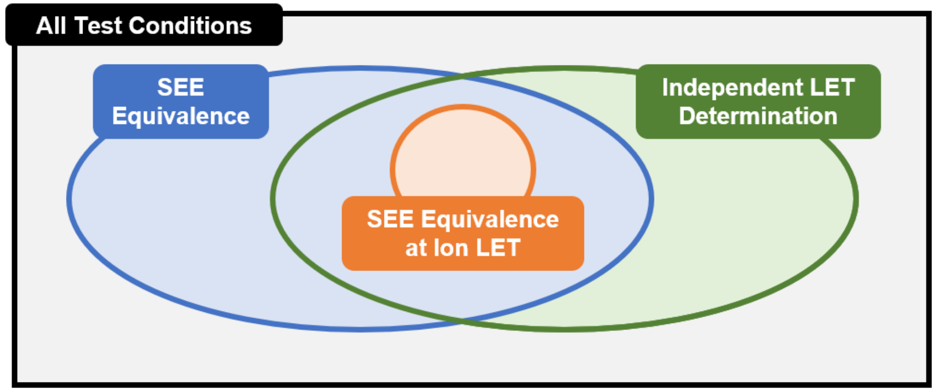

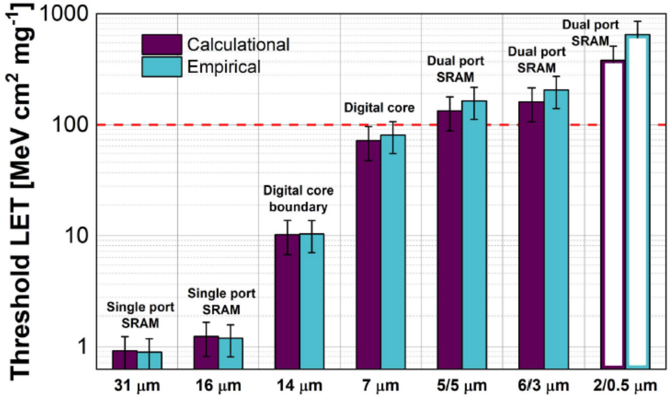

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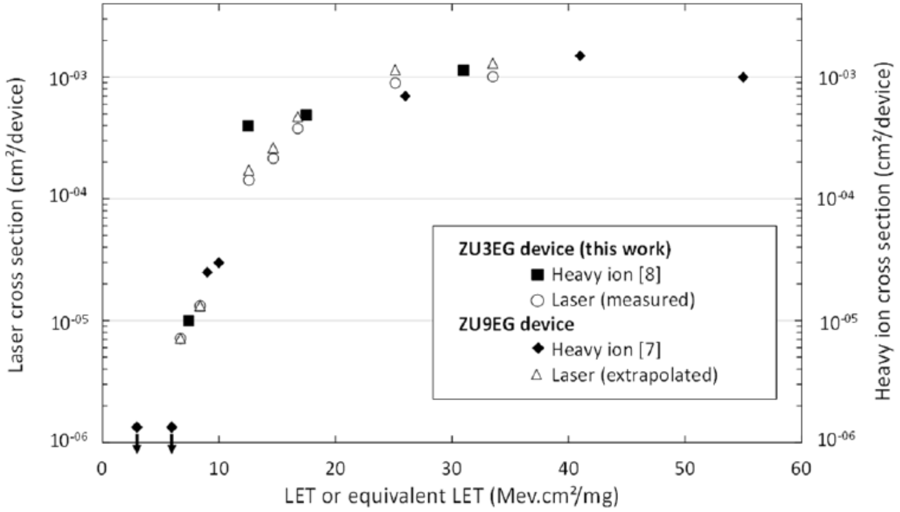

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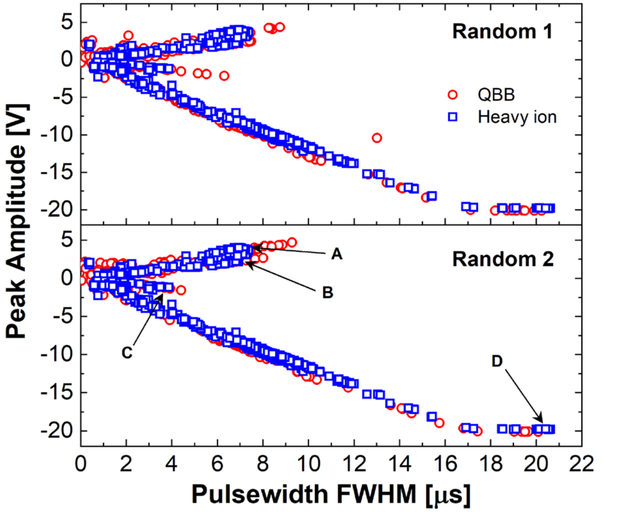

SETs in operational amplifier [13]

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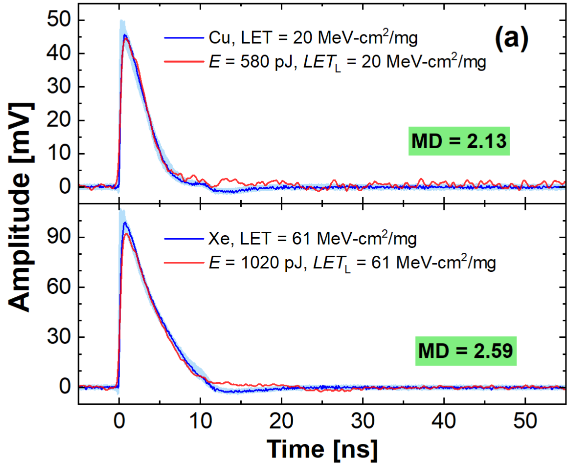

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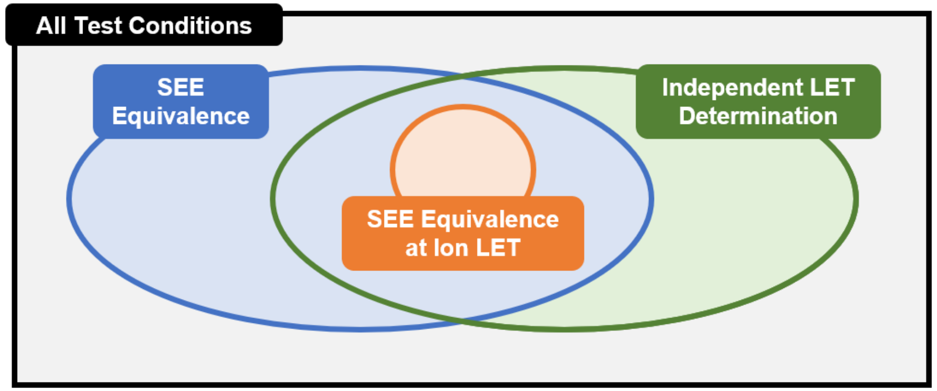
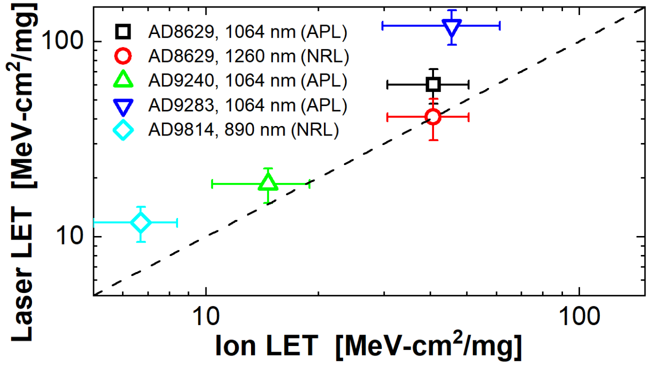
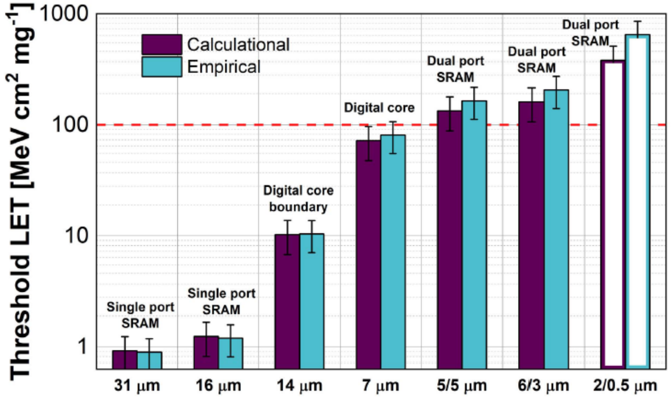




SEL in various COTs [14]



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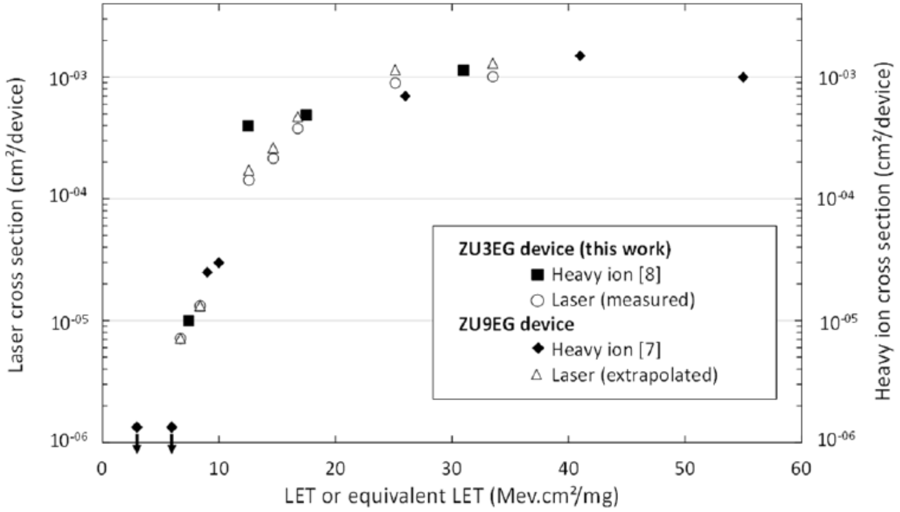

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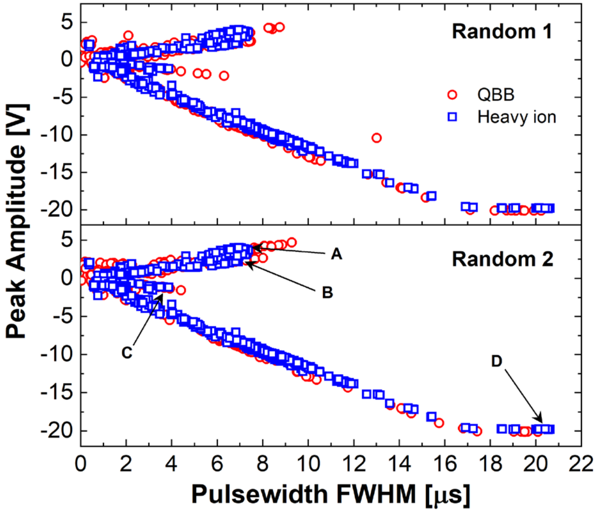

SETs in operational amplifier [13]

Predictive PL SEE Case Studies

- Variety of technologies using different pulsed-laser focusing geometries for testing
- Must validate SEE response agreement using heavy-ion SEE response

Test Condition → Tune to Target LET_L → SEE Response → Validate Agreement

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Predictive PL SEE Case Studies

- Variety of technologies using different pulsed-laser focusing geometries for testing
- Must validate SEE response agreement using heavy-ion SEE response
- Need guidance on choosing, **with reasonable assurance**, that test conditions are predictive

The Need for Surrogate Test Approaches

- DARPA introduces ASSERT program (2024) to accelerate the availability of radiation-qualified, state-of-the-art components
- Goal: develop surrogate sources with deep penetration and high spatial resolution
- Lasers have limited utility for probing 3DHI technologies but used to leverage lessons learned to develop better sources

https://www.darpa.mil/news-events/2023-07-13

Advanced Sources for Single-event Effects Radiation Testing (ASSERT)

Pulsed Electrons

G. Tzintzarov, *SEE Symposium,* 2024.

Pulsed X-rays

D. Monahan, *SEE Symposium,* 2024.

Summary

- **Predictive surrogate testing key to bridging the gap**
  - PL SEE testing has matured as a surrogate test approach
  - Criteria for predictive testing suggest the pathway is challenging
- **Capabilities have driven significant progress in PL SEE testing**
  - **Accessibility** and references have increased testing availability to community
  - **Modifying the CD** has enabled improved correlation with heavy-ion data
  - Quantitative assessment of **SEE equivalence** has been developed
  - Accurately **estimating LET** for all test conditions is feasible
- **Potential and Next Steps**
  - **Predictive PL SEE testing** has been demonstrated
  - Still need rules-of-thumb to ensure a laser test condition is predictive
  - Progress made in PL SEE testing has spurred on other surrogate approaches

References

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