RADLAS 2024 : 6th Workshop on Laser Testing of Radiation Effects on Components and Systems
ESA-ESTEC – September 11, 2024

A Historical Overview of Ion/Laser Correlation Efforts

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Why are we Interested in Ion/Laser Correlation?

THE USE OF LASERS TO SIMULATE RADIATION-INDUCED TRANSIENTS IN SEMICONDUCTOR DEVICES AND CIRCUITS

D. H. Habing
Sandia Laboratory, Albuquerque, New Mexico

ABSTRACT

[•••]

those presently attainable from other sources. It is shown that a pulsed-infrared laser can be used as a relatively simple, inexpensive, and effective means of simulating the effects caused by intense gamma ray sources on semiconductors. Experi-

CONCLUSION

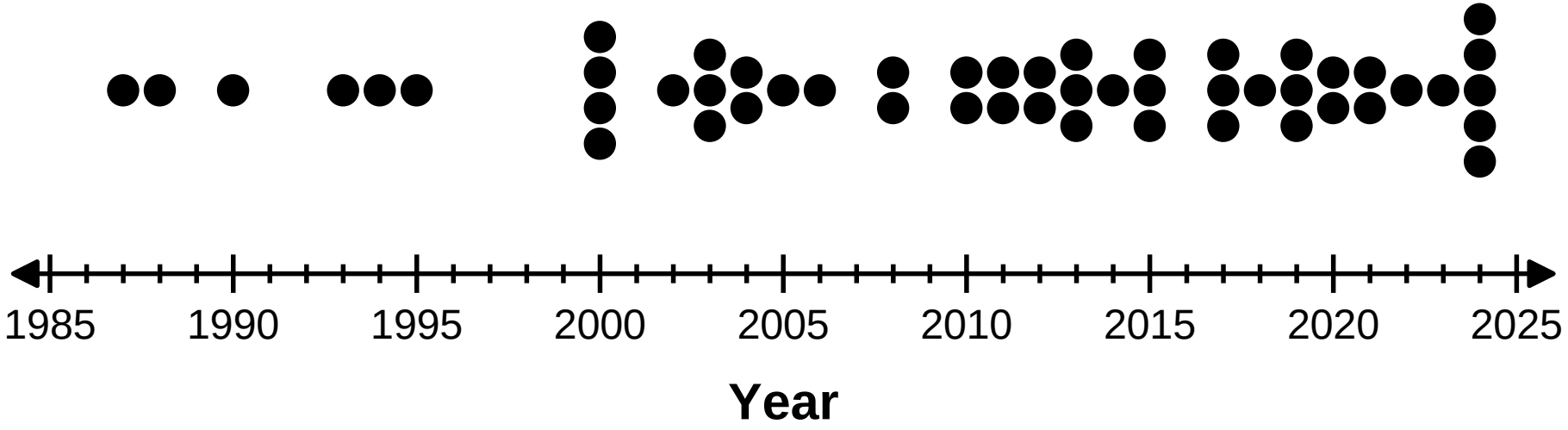
The laser can be a valuable asset to those who must concern themselves with transient effects caused by ionizing radiation and yet have no large testing facility of their own. In addition to being particularly useful during the design phase of a system, a laser can be used for preliminary investigations in order to minimize the time and effort involved in gamma ray testing. If the user

[•••]

D. H. Habing, "The use of lasers to simulate radiation-induced transients in semiconductor devices and circuits," *IEEE Trans. Nucl. Sci.*, vol. 12, no. 5, pp. 91–100, 1965, doi: 10.1109/TNS.1965.4323904.

Goal of This Presentation

- **Goal:** Present a historical overview of ion/laser correlation efforts and the major developments in the field that enabled them based on the published literature
- **Inclusion Criteria:**
  - Any paper published in a journal or conference proceedings that shows laser/ion data on the same plot axes either via empirical correlation or calculation of equivalent LET



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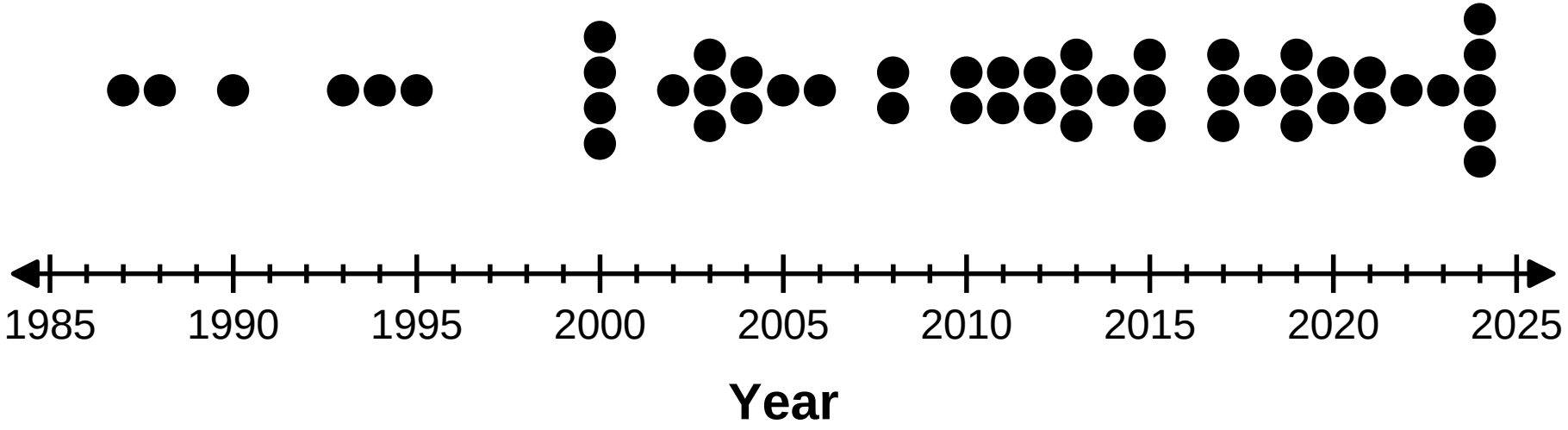

Disclaimer: I conducted an extensive review of the published literature on pulsed-laser studies during the past ~40 years. If I missed your paper… it was not intentional! Please let me know and I will gladly add it to future versions of this talk.

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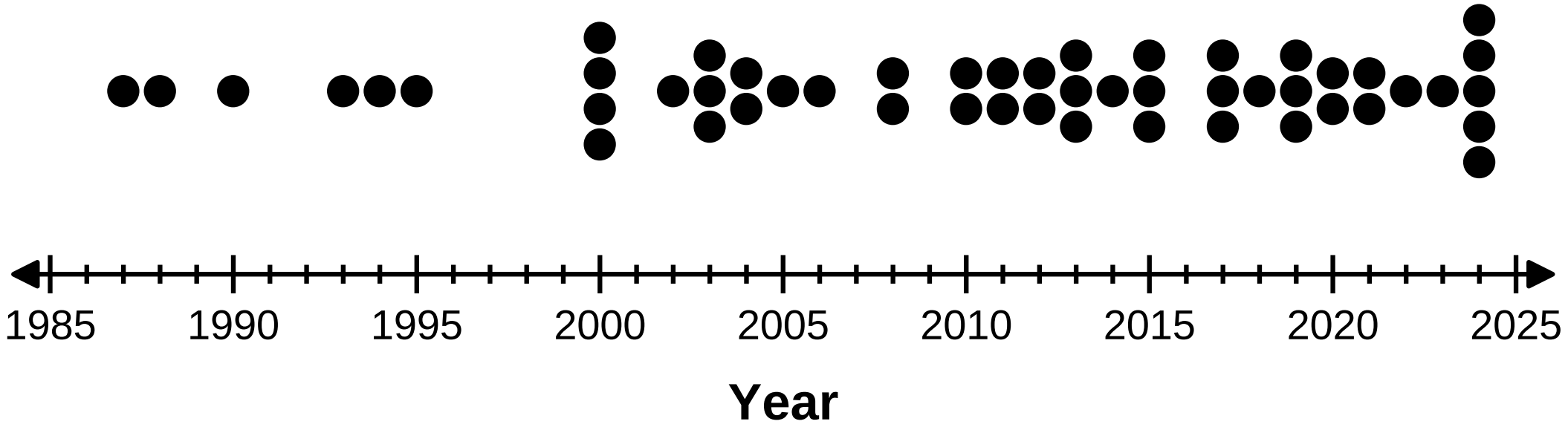
Historical Record of Ion/Laser Correlation Efforts



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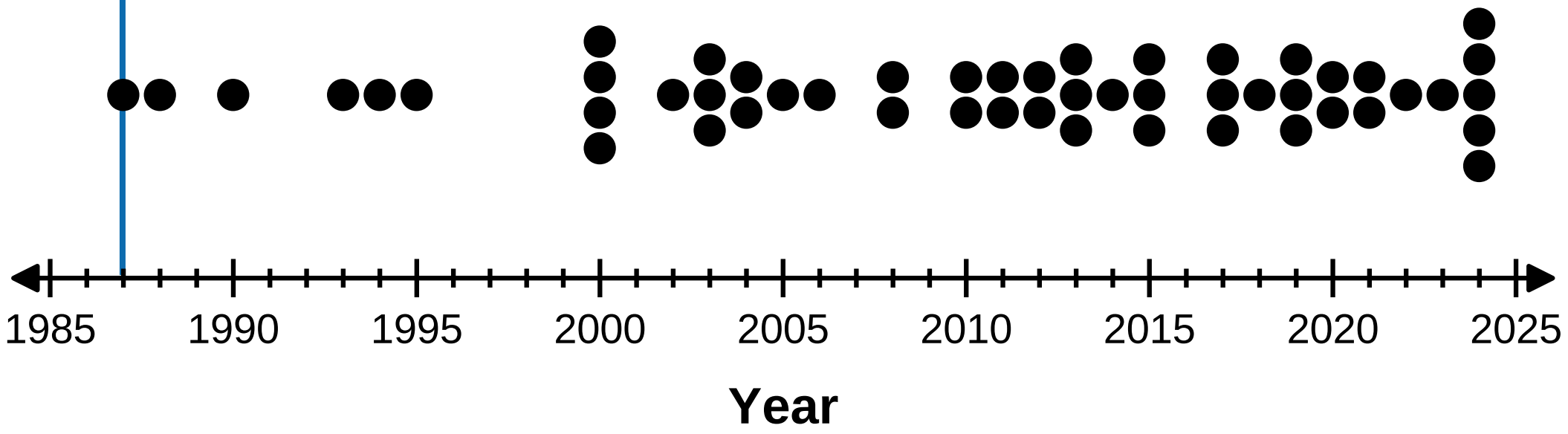
Historical Record of Ion/Laser Correlation Efforts

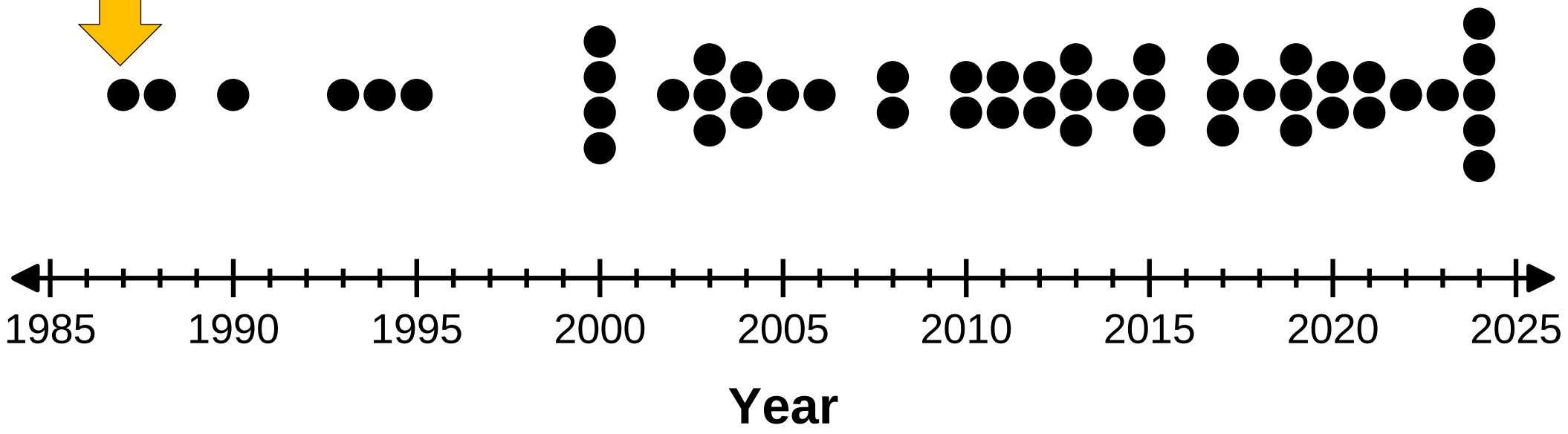
Between 1965 and 1987, there were many laser papers with unfocused and large beams, aimed at emulating effects from ionization at high dose rates.



Historical Record of Ion/Laser Correlation Efforts

In 1987, one of the first publication to use pulsed lasers for SEE testing was an ion/laser correlation paper

A. K. Richter and I. Arimura, “Simulation of Heavy Charged Particle Tracks Using Focused Laser Beams,” *IEEE Trans. Nucl. Sci.*, vol. 34, no. 6, pp. 1234–1239, 1987, doi: 10.1109/TNS.1987.4337458.



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One of the first PL SEE papers studied correlation

Richter introduced the first definition of Laser-equivalent LET

$$LET = \alpha\, T\, e_f\, Q_0\, e^{-\alpha x}$$

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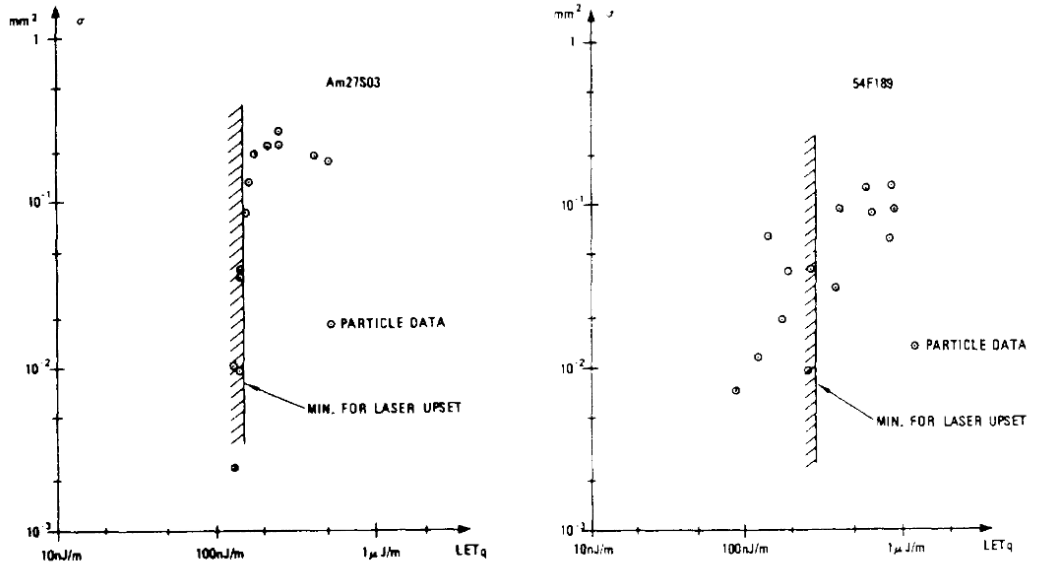

Fig. 5. Comparison of Laser Upset Threshold with Particle SEU Cross Sections for AM27S03 and 54F189.

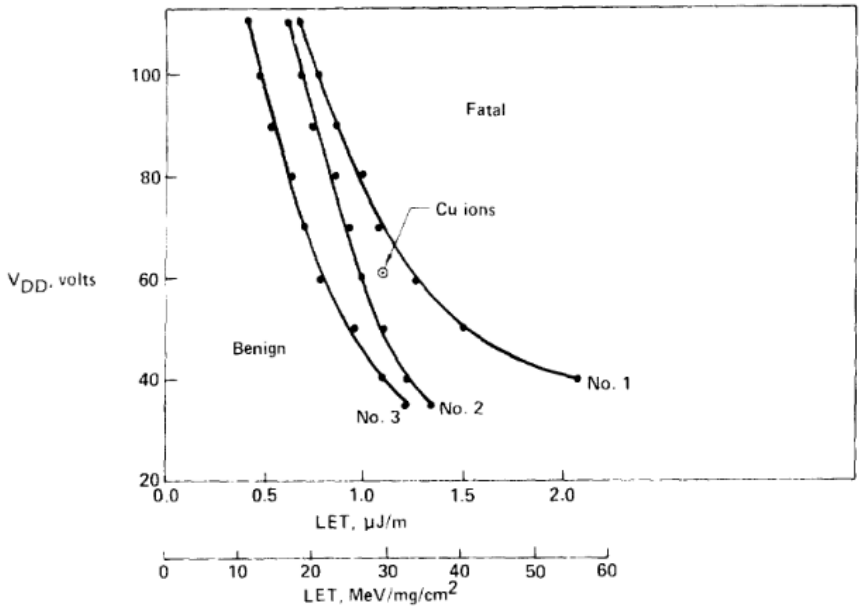

Fig. 9. Comparison of Laser and Particle V_{DS}-LET Burnout Regions for IRF120.

A. K. Richter and I. Arimura, "Simulation of Heavy Charged Particle Tracks Using Focused Laser Beams," *IEEE Trans. Nucl. Sci.*, vol. 34, no. 6, pp. 1234–1239, 1987, doi: 10.1109/TNS.1987.4337458.

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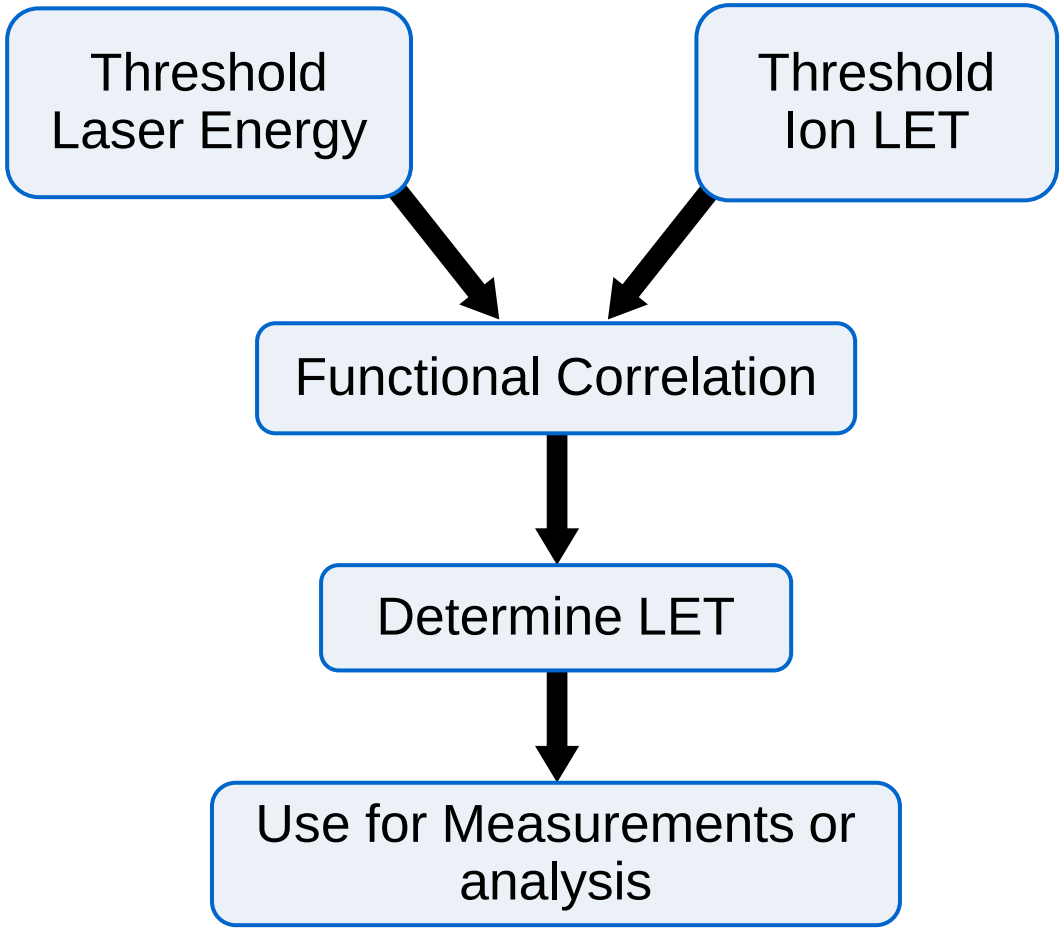
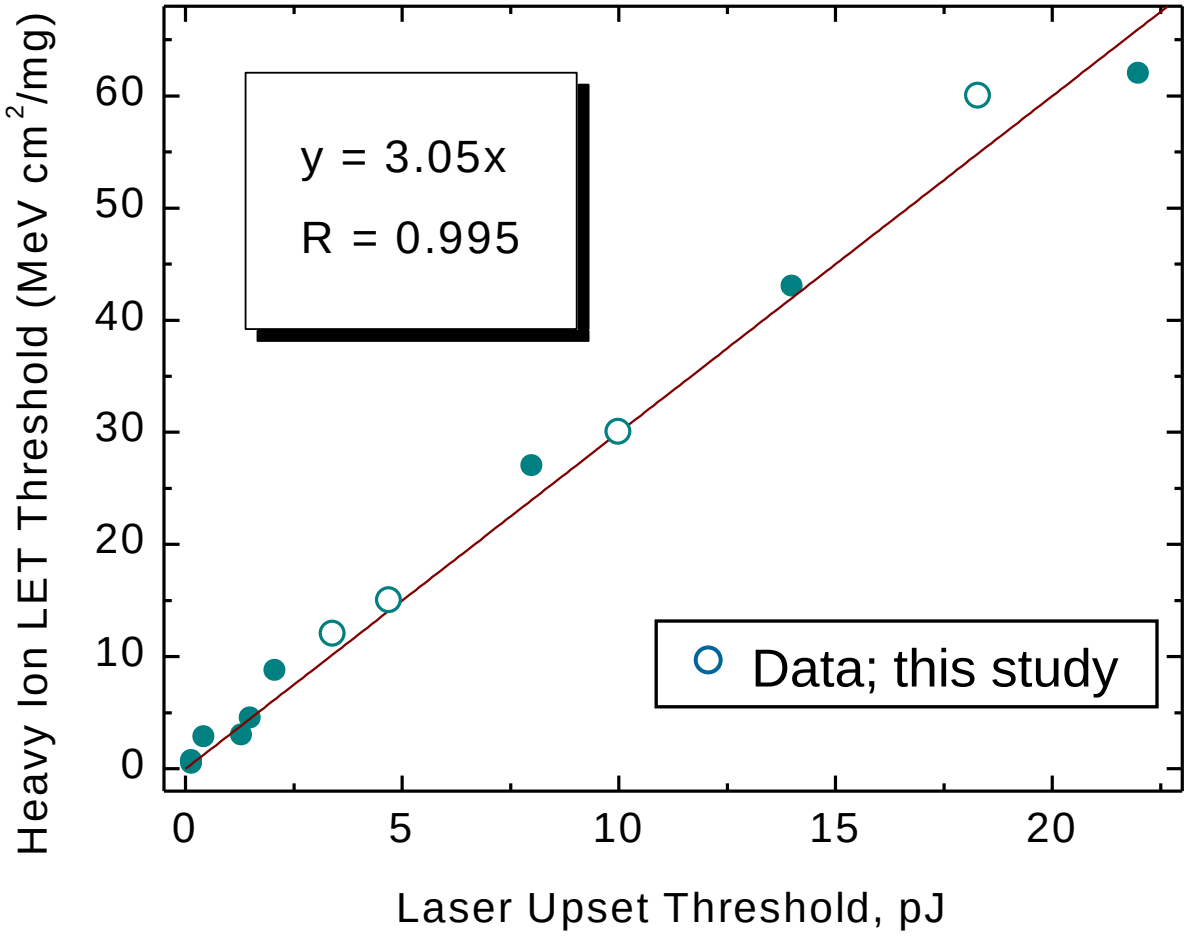
Empirical Correlation Approach





D. McMorrow, *et al.*, *TNS,* vol. 47, Jun, 2000.

Calculational Correlation Approach

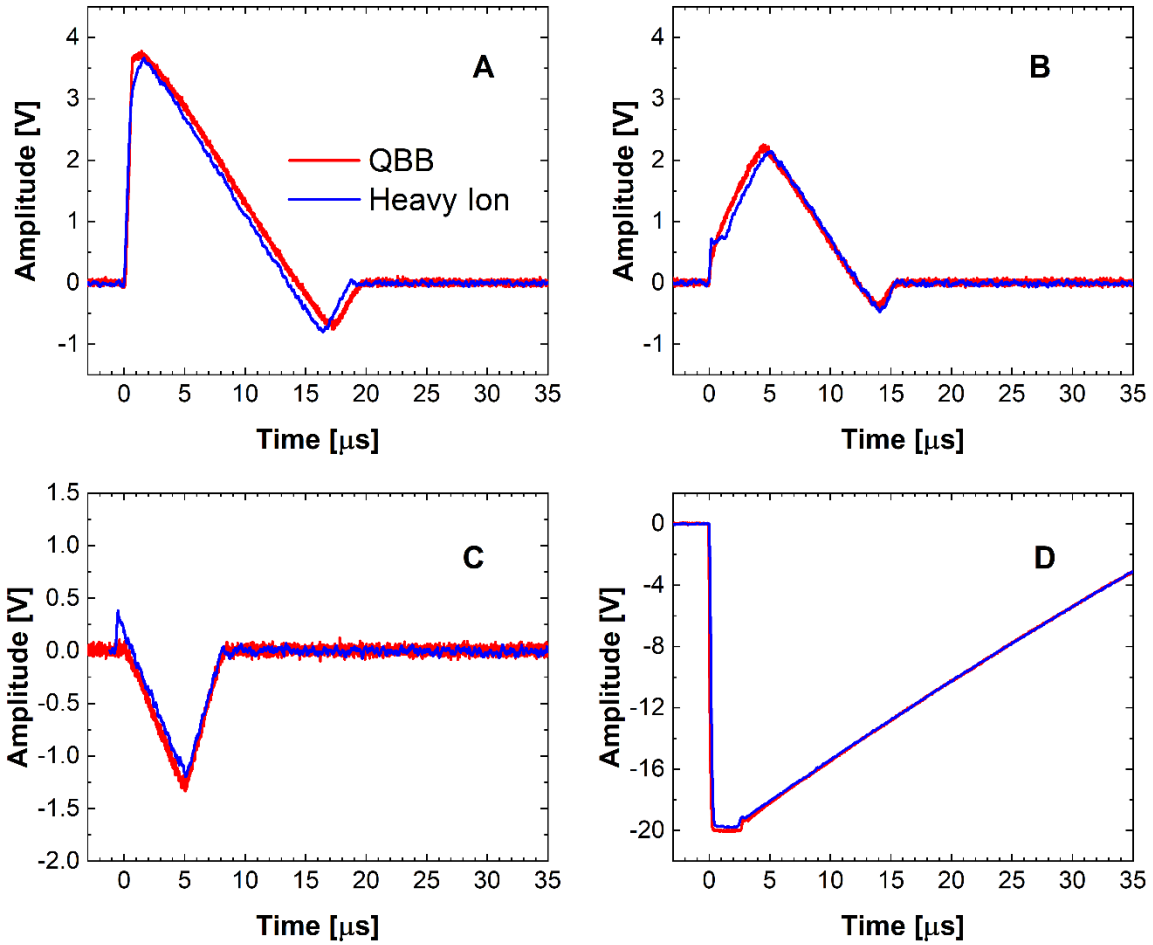
Accurate Characterization of Laser Beam

Calculate LET curve

$$LET(z) = \int_r N(r,z)$$

Use for Measurements or analysis

Measured SETs for LM124

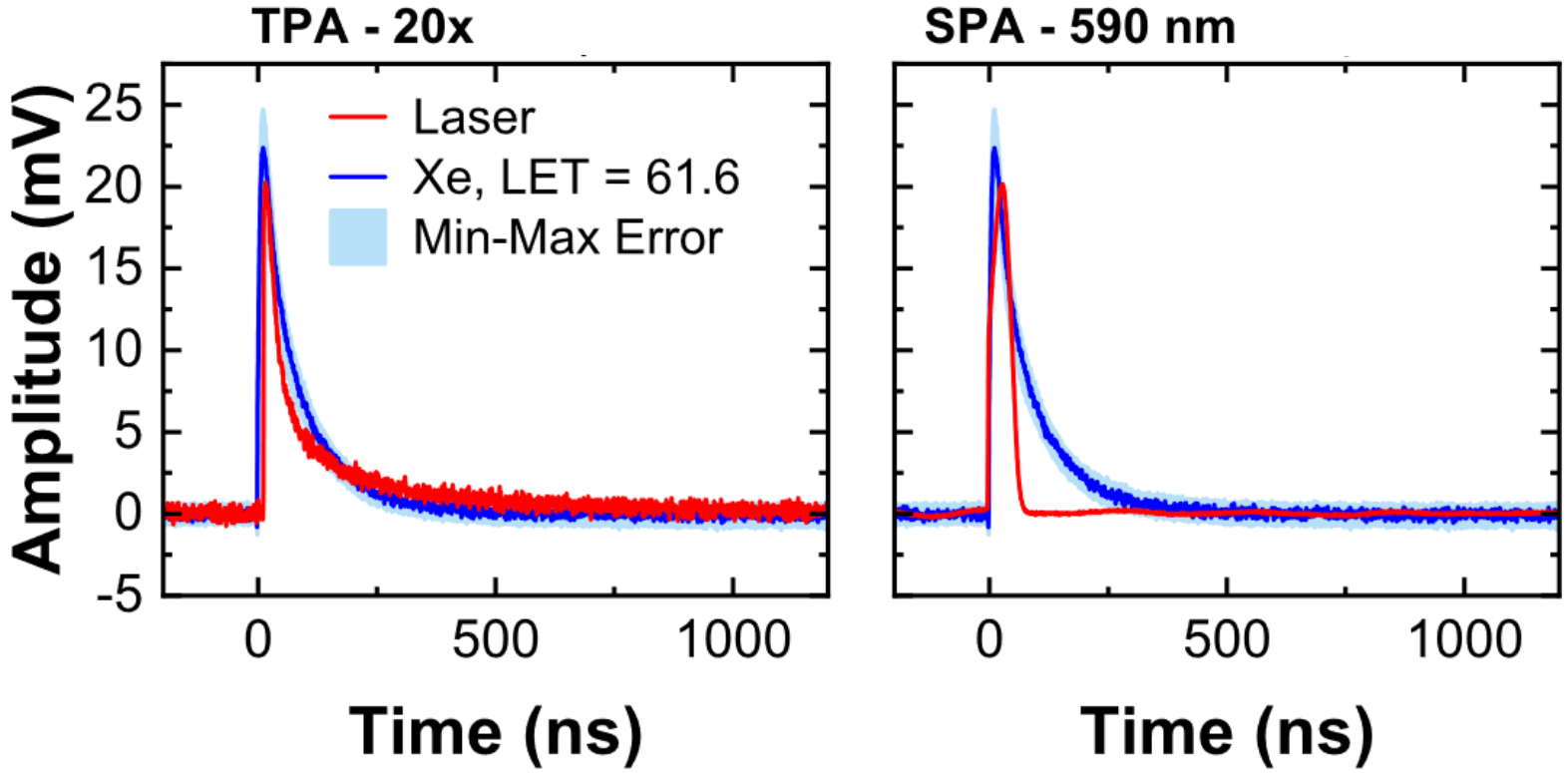


J. M. Hales, *et al.*, *TNS,* vol. 70, Apr, 2023.

Calculational vs. Empirical Approaches

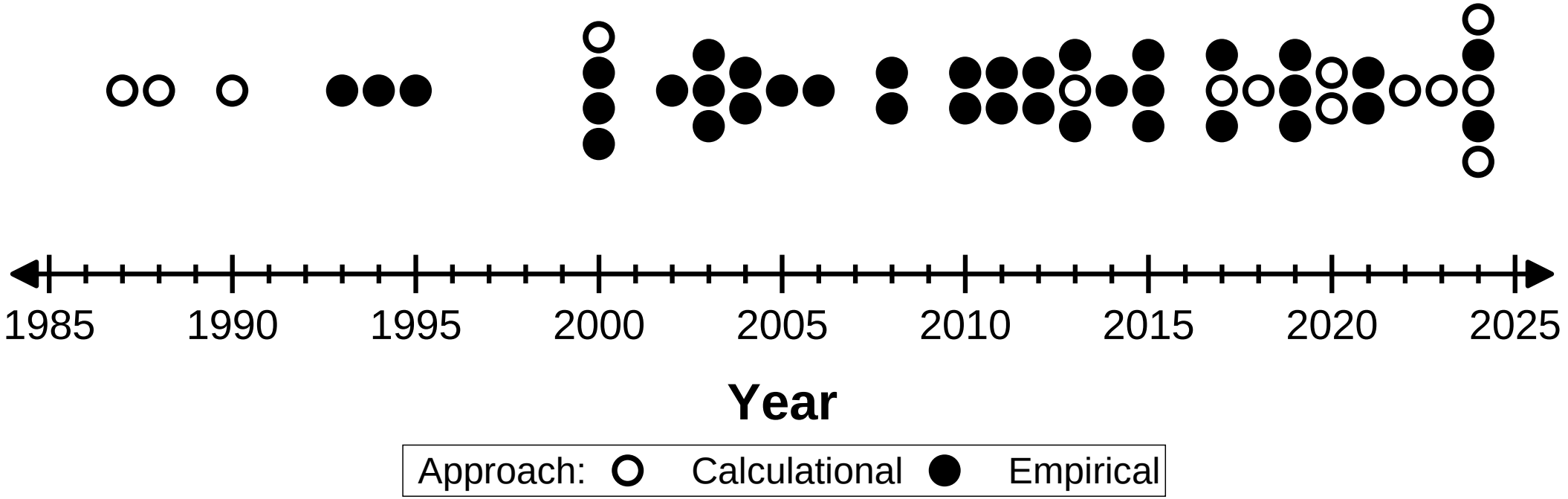
Important Note: Neither of these approaches ensure adequate agreement between the responses. In other words… poor correlation could result from both methods

Empirical Approach: Adjust laser pulse energy to match SET amplitude



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

Historical Record of Ion/Laser Correlation Efforts



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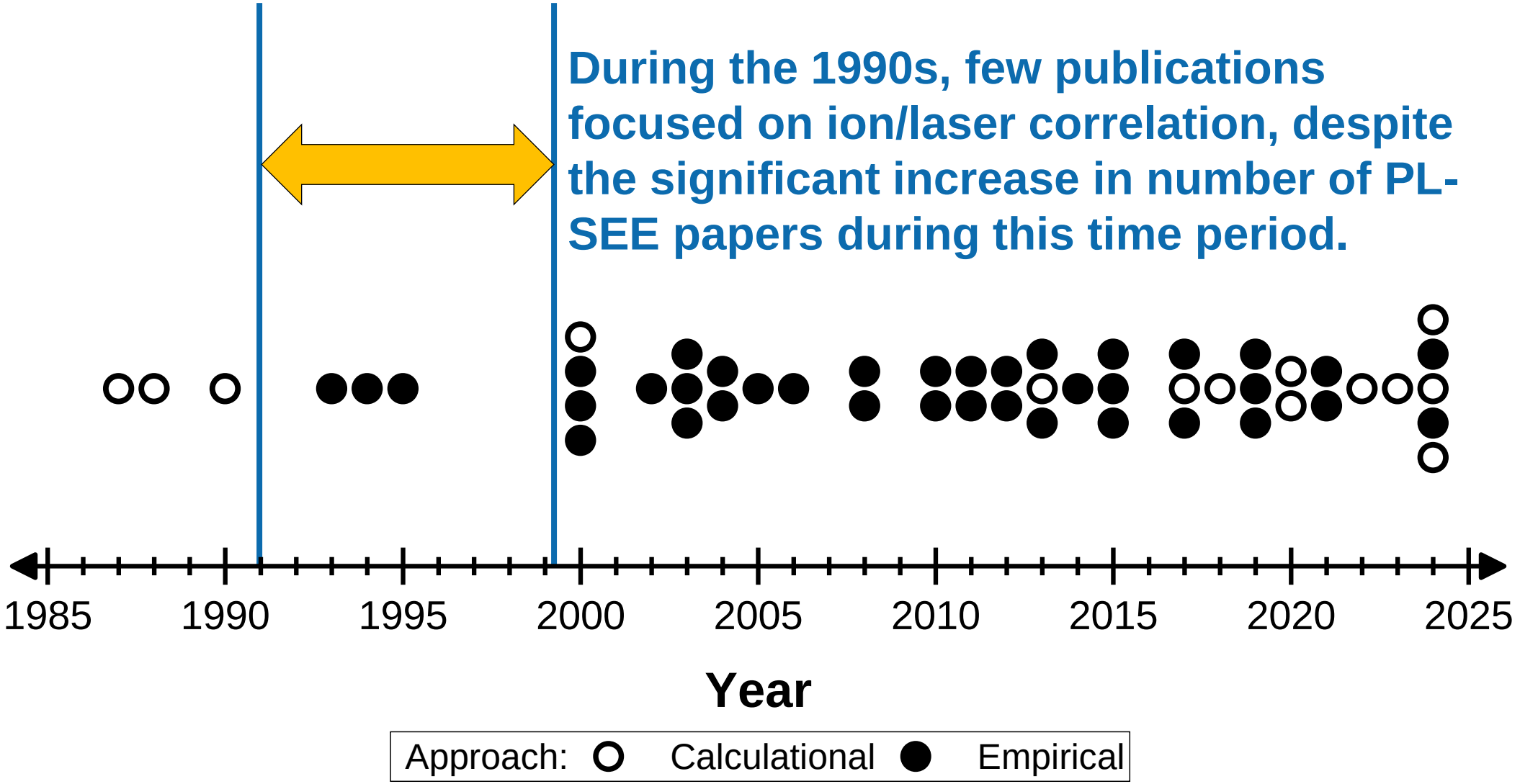
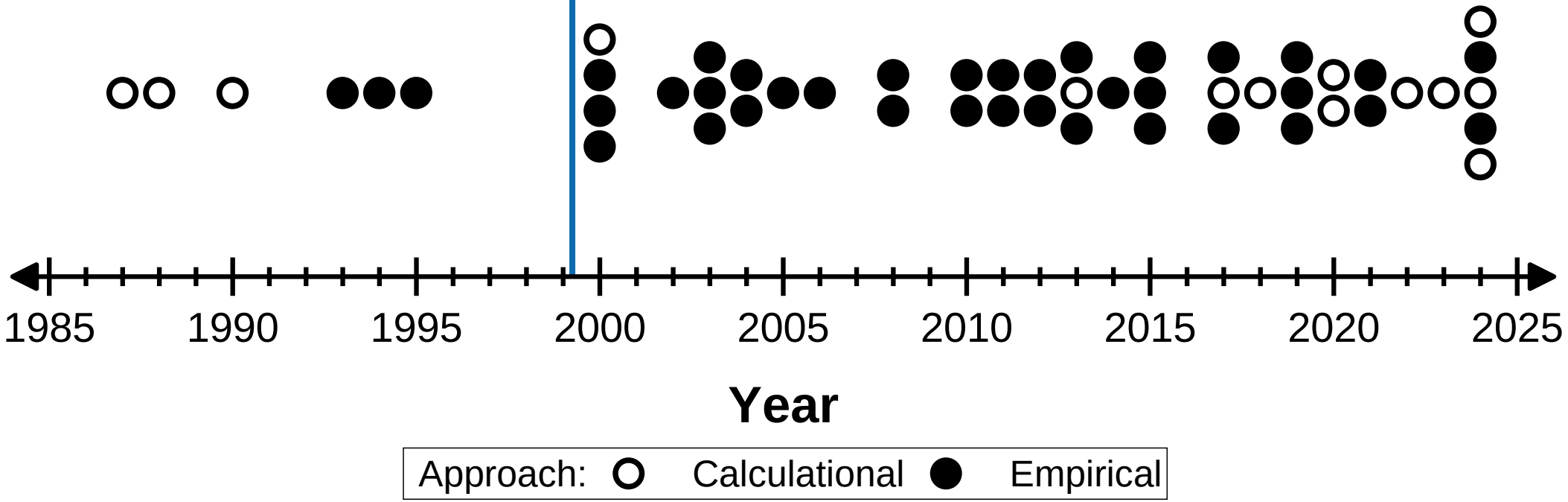


Historical Record of Ion/Laser Correlation Efforts

In the late 1990s, the first PL SEE papers from our European colleagues were published. The ion/laser correlation efforts in the 2000s were dominated by European organizations.



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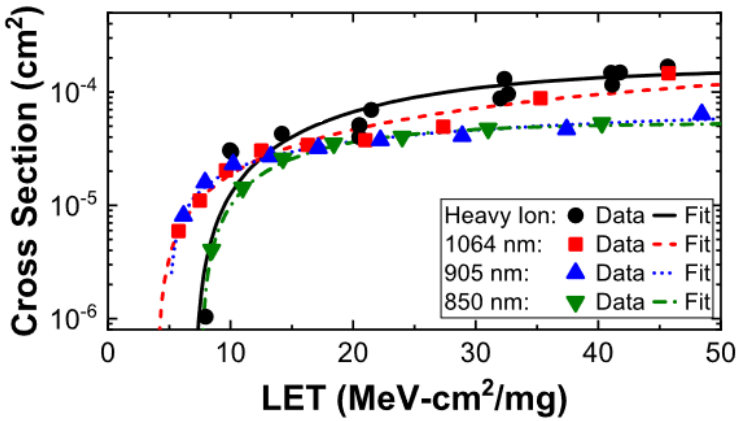
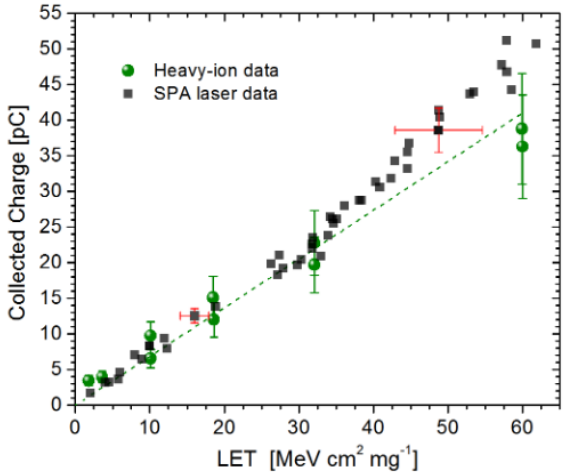
Types of Correlation

SEE Cross Section



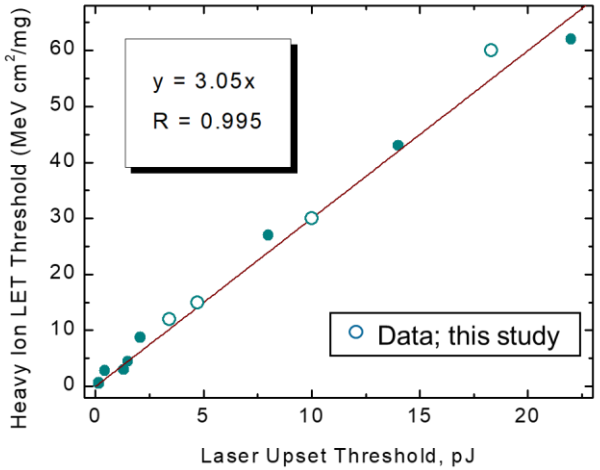
Reproduced from C. Weulersse, *et al.*, *TNS,* vol. 55, Aug, 2008.

Collected Charge



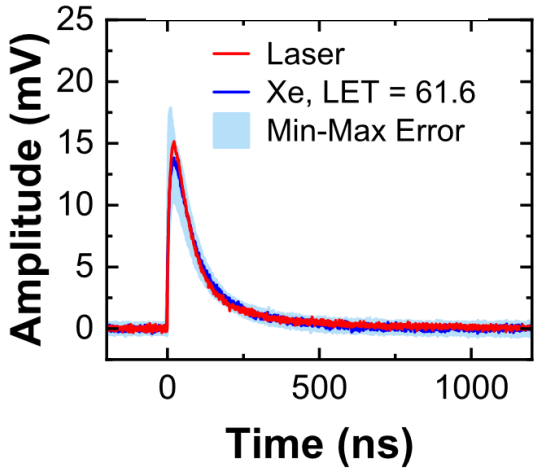
J. M. Hales, et al., TNS, vol. 65, Aug, 2018.

SEE Threshold

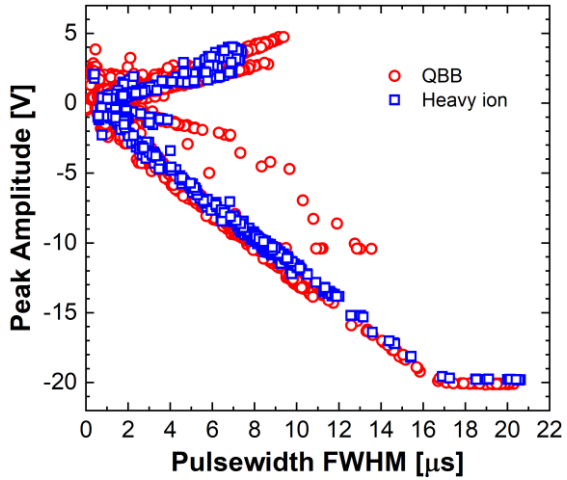


D. McMorrow, *et al.*, *TNS,* vol. 47, Jun, 2000.

Single Event Transients

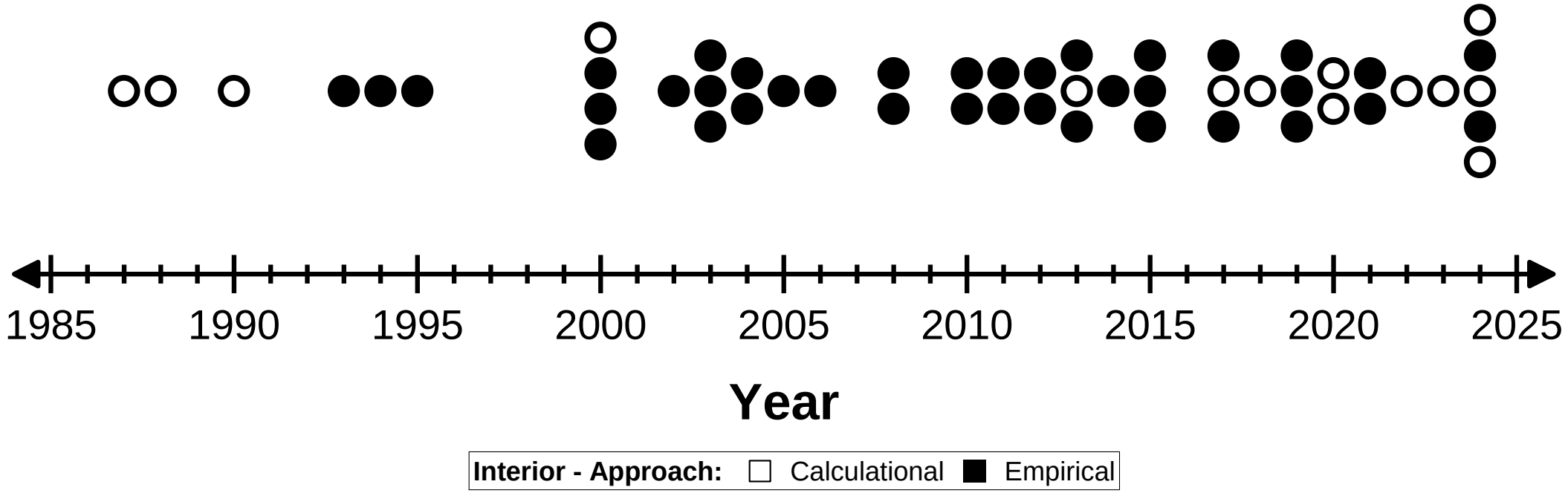


A. Ildefonso, et al., TNS, vol. 71, Apr, 2024.



J. M. Hales, et al., TNS, vol. 70, Apr, 2023.

Historical Record of Ion/Laser Correlation Efforts



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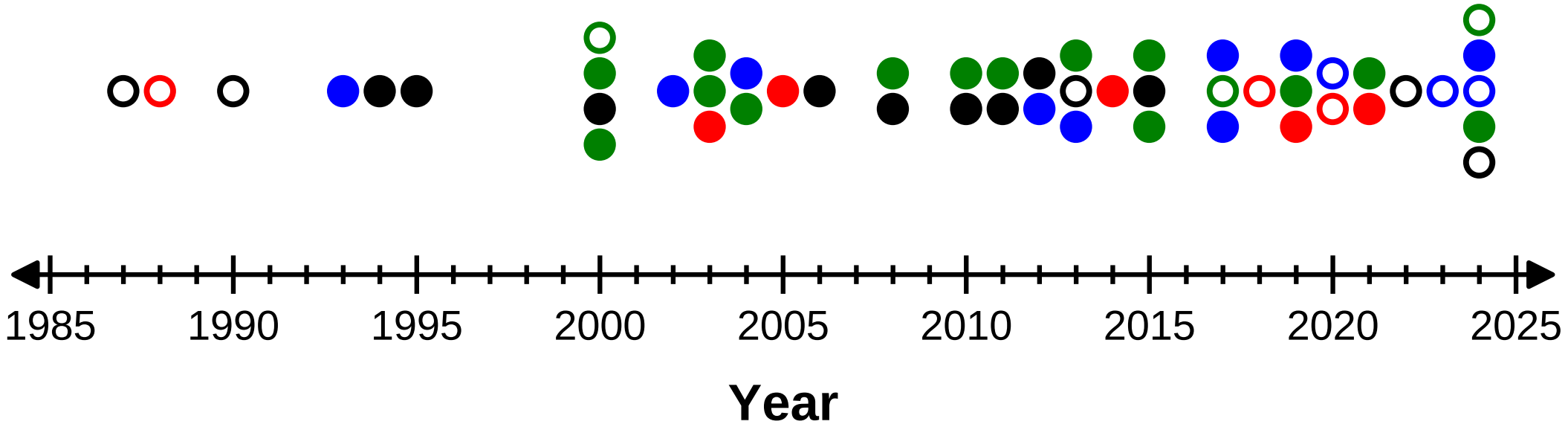
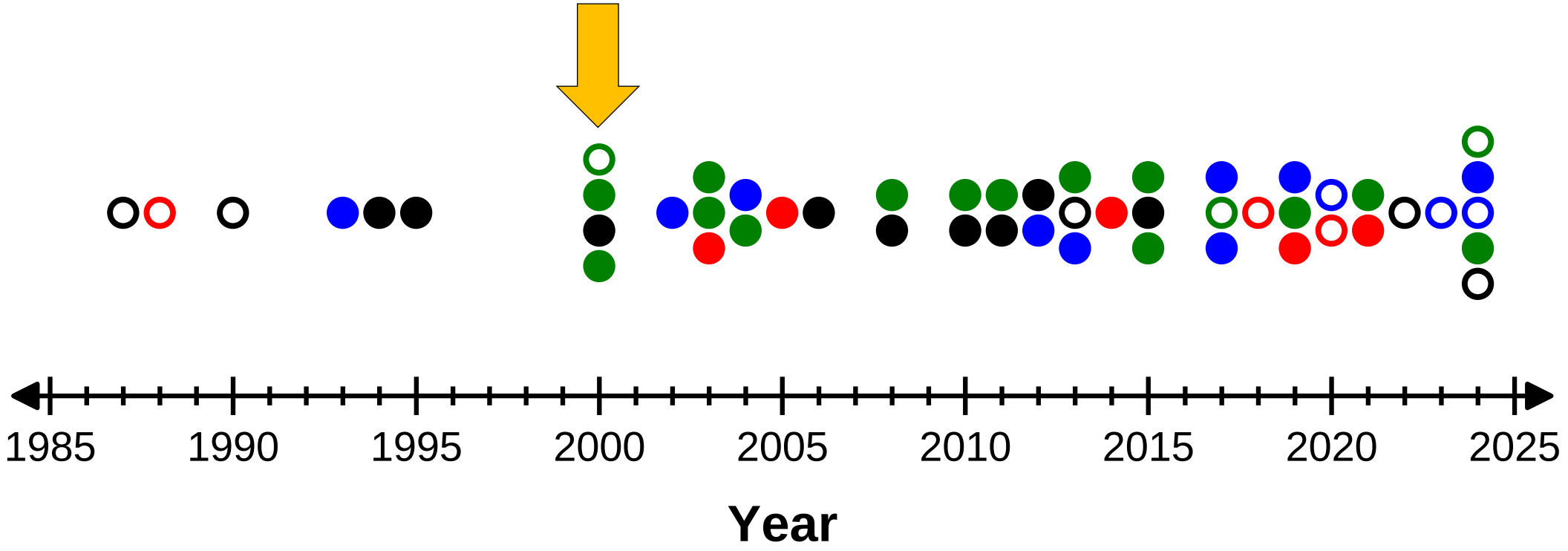


Historical Record of Ion/Laser Correlation Efforts

In 2000, several papers from European organizations introduced the concept of laser-based cross-section measurements.



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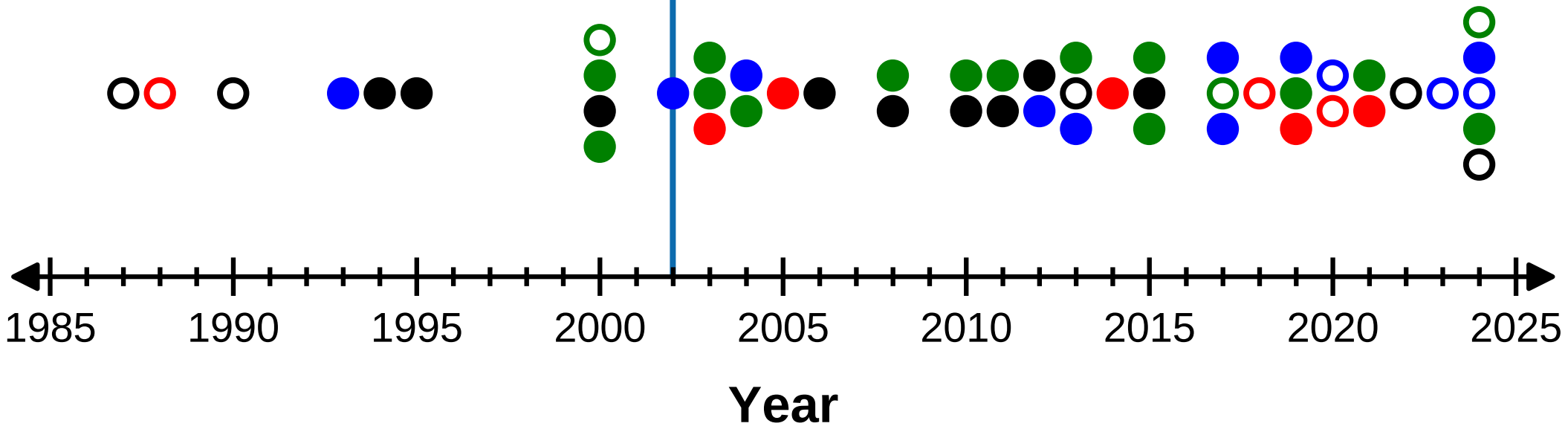
Historical Record of Ion/Laser Correlation Efforts

An important milestone was achieved in 2002: The first demonstration of TPA for PL SEE testing.



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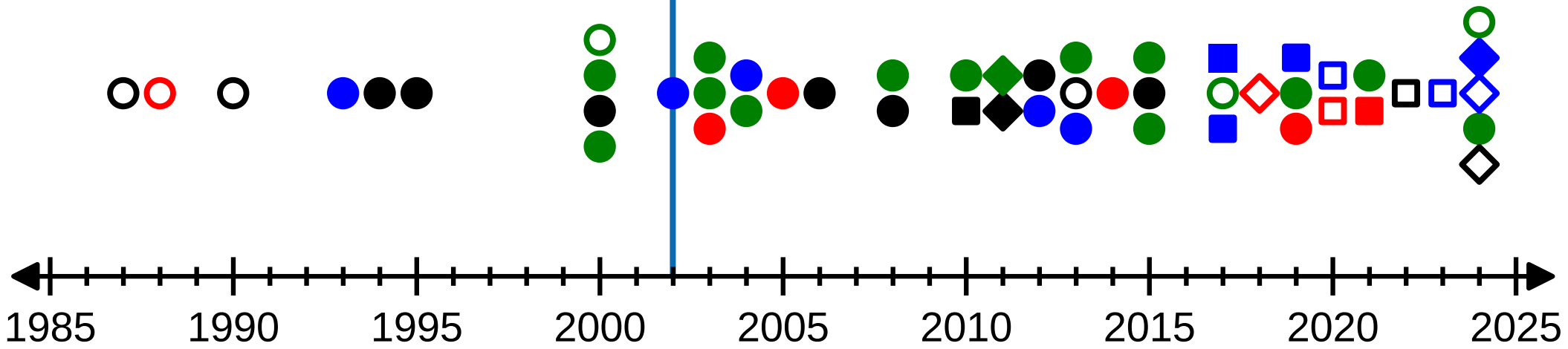

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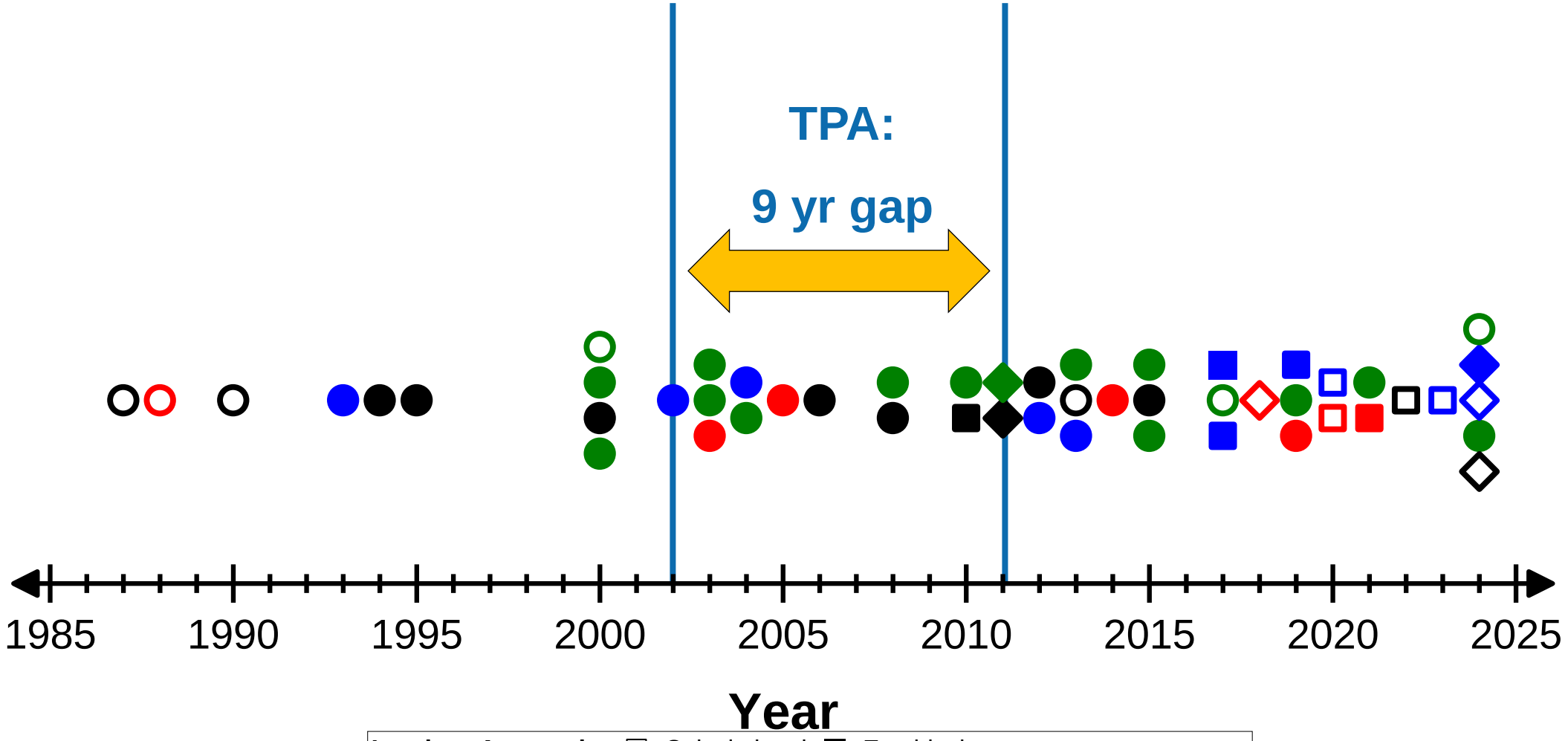

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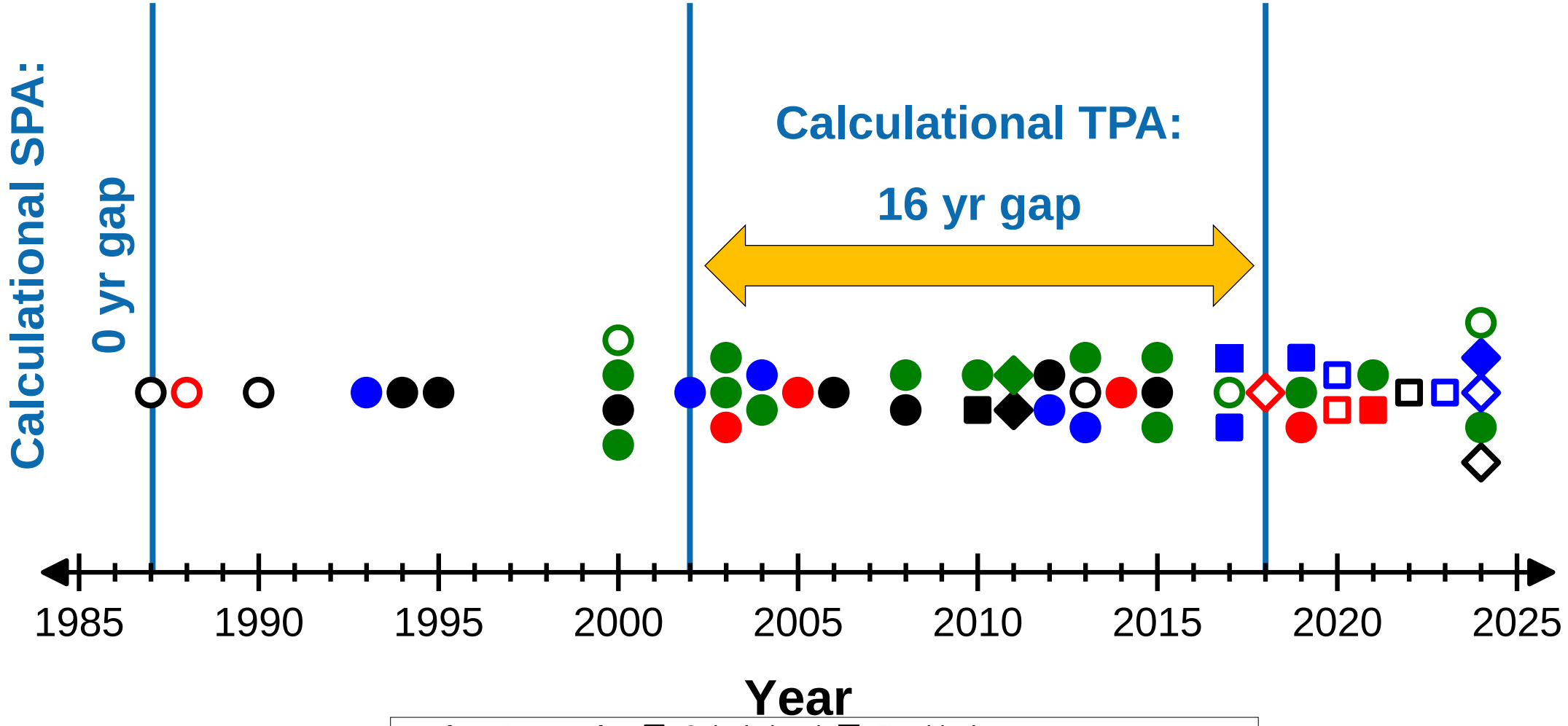
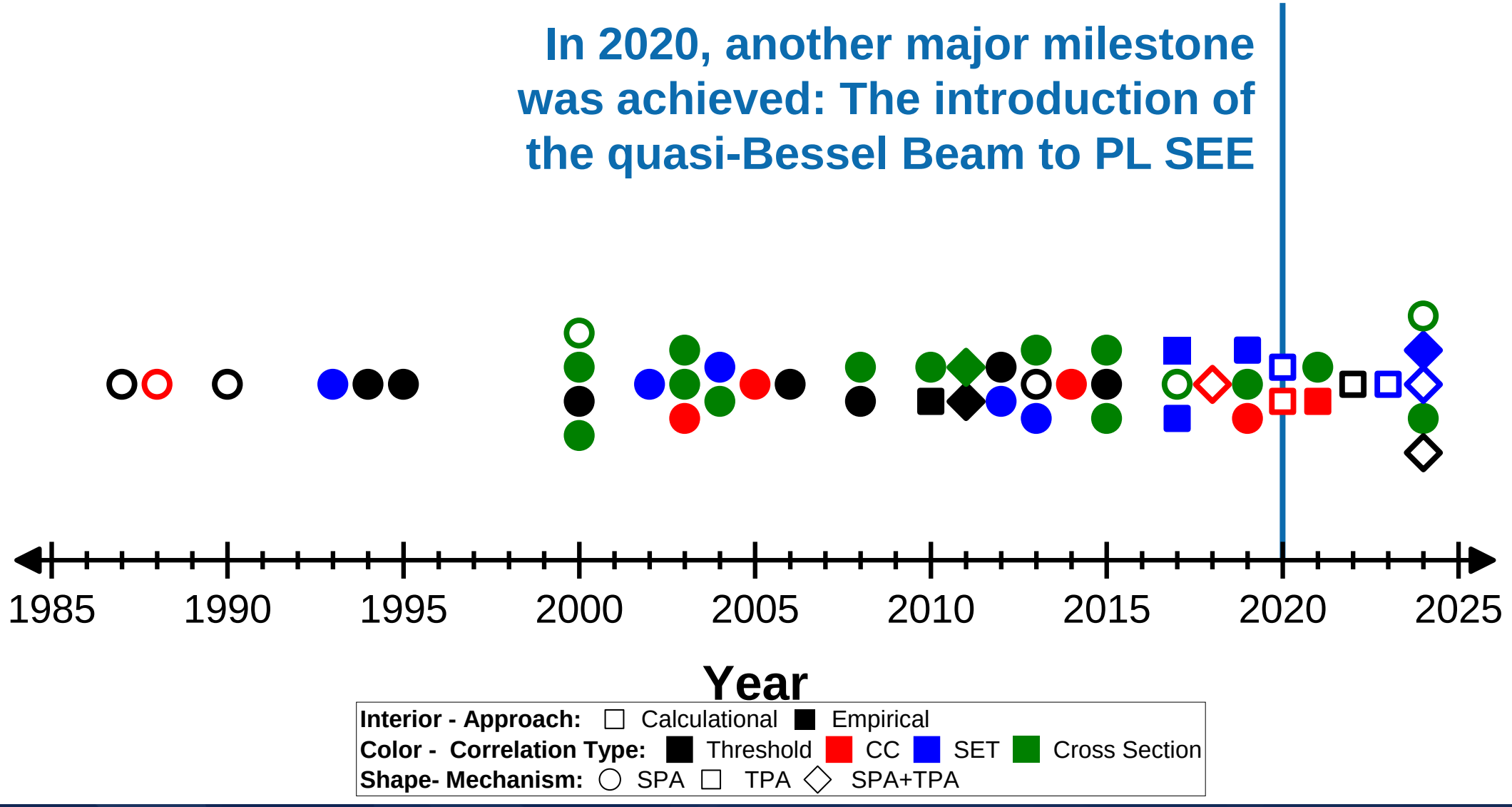


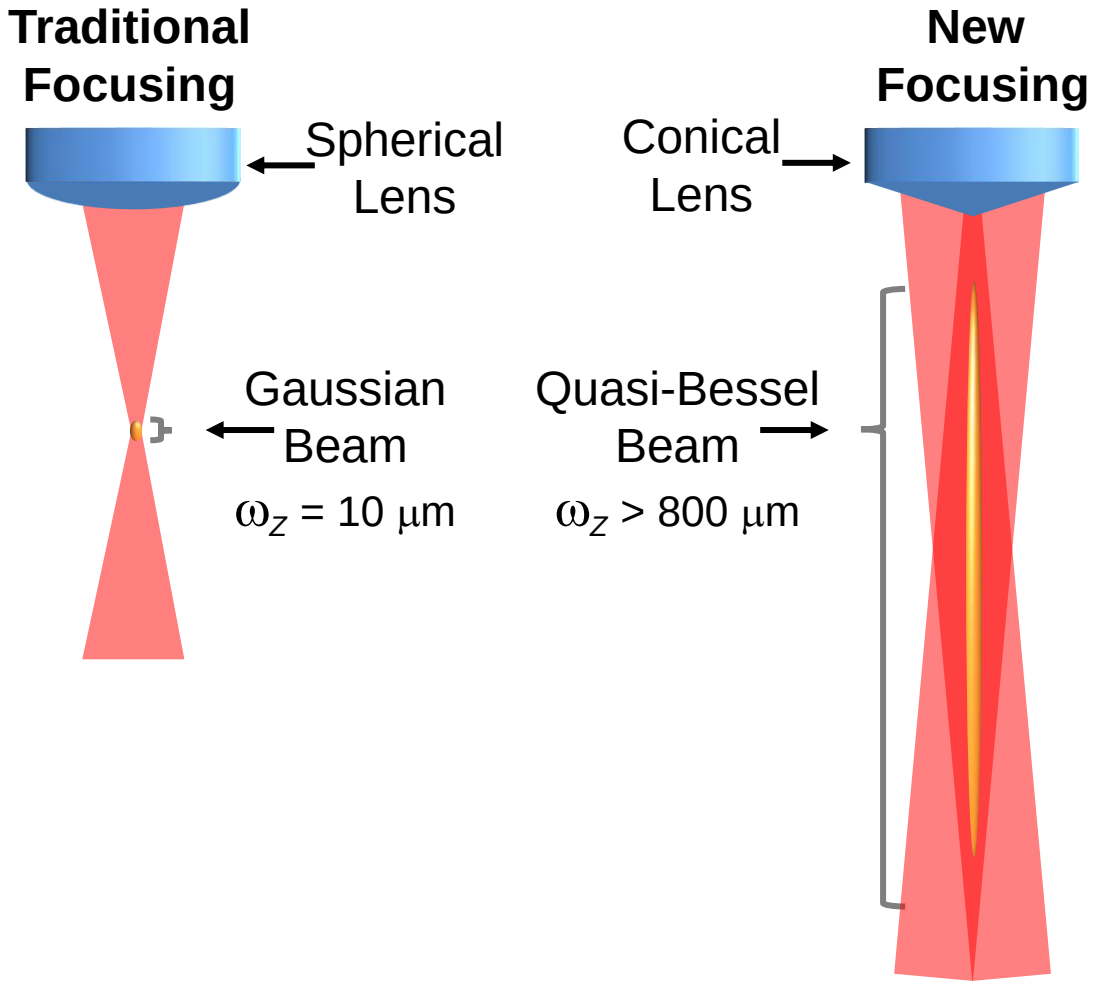
Historical Record of Ion/Laser Correlation Efforts

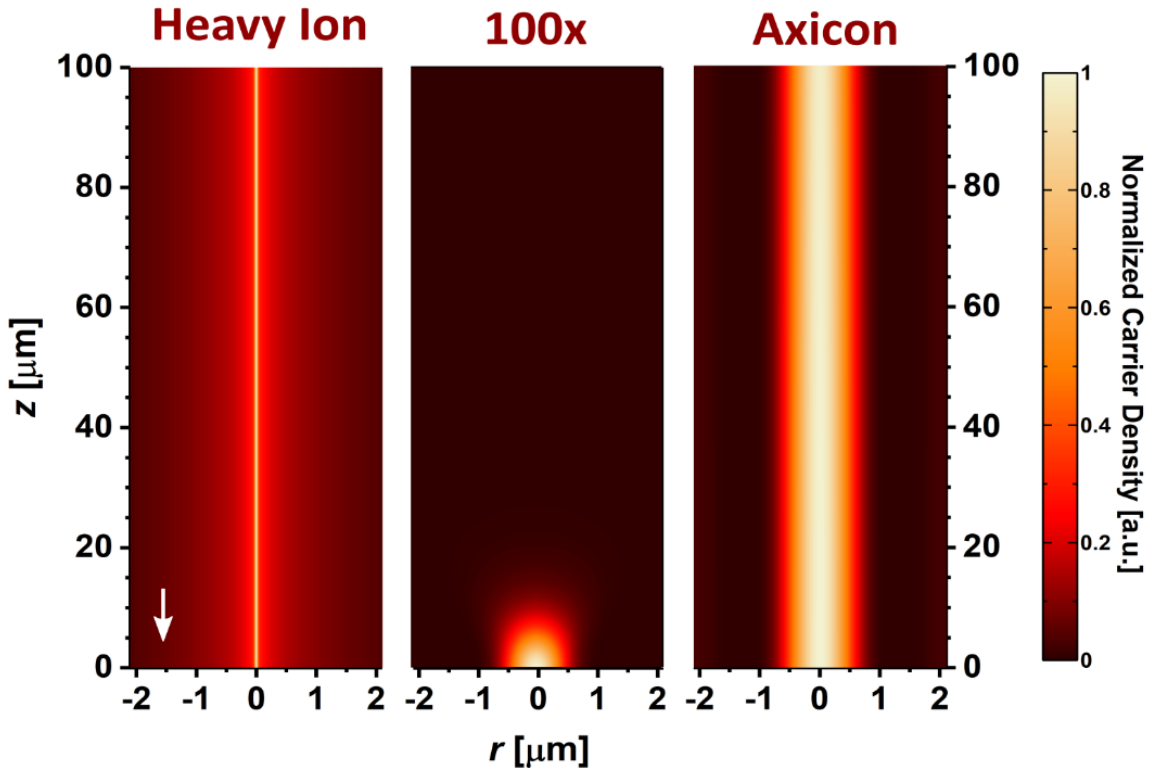
In 2020, another major milestone was achieved: The introduction of the quasi-Bessel Beam to PL SEE



A new approach for PL SEE testing…

QBB PL-SEE approach is a novel focusing technique to better mimic charge profile of heavy ions with TPA





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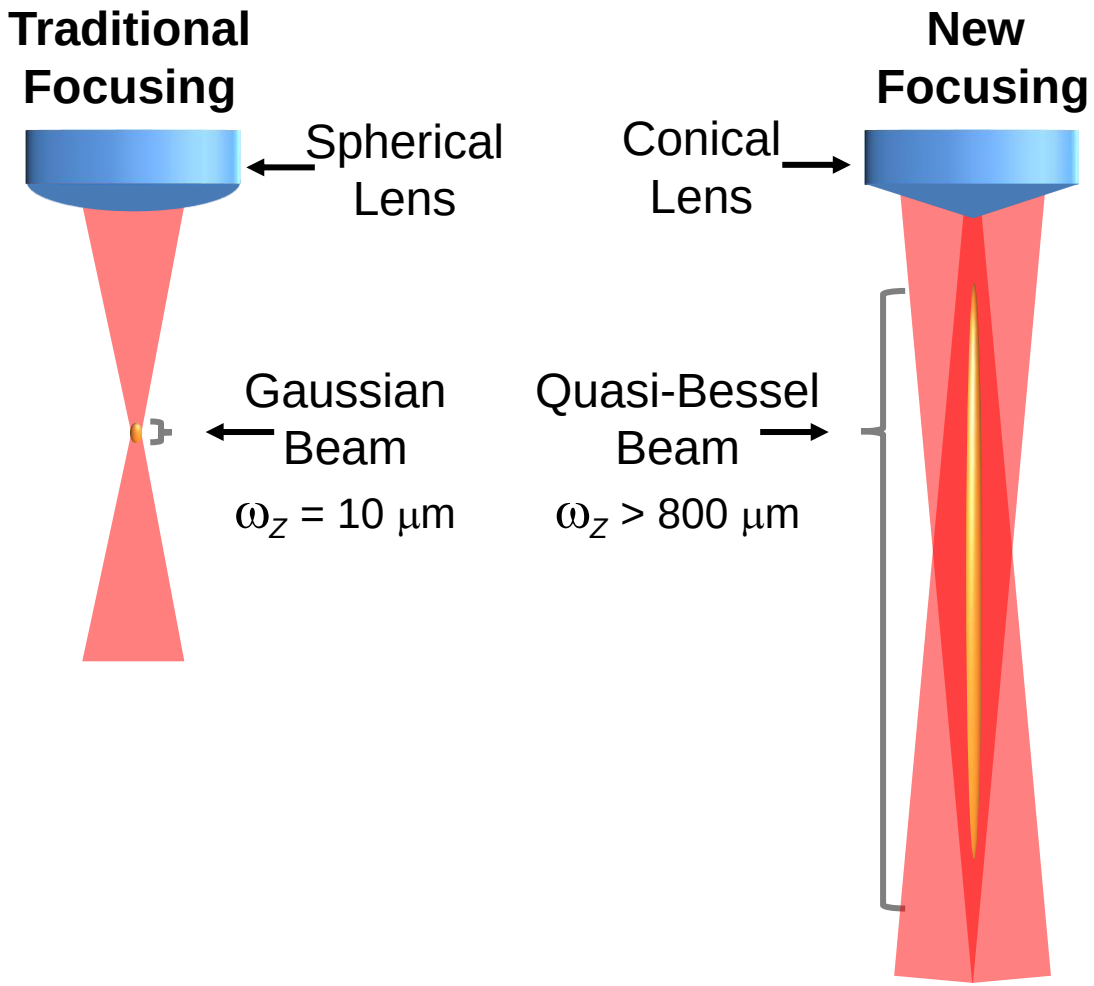

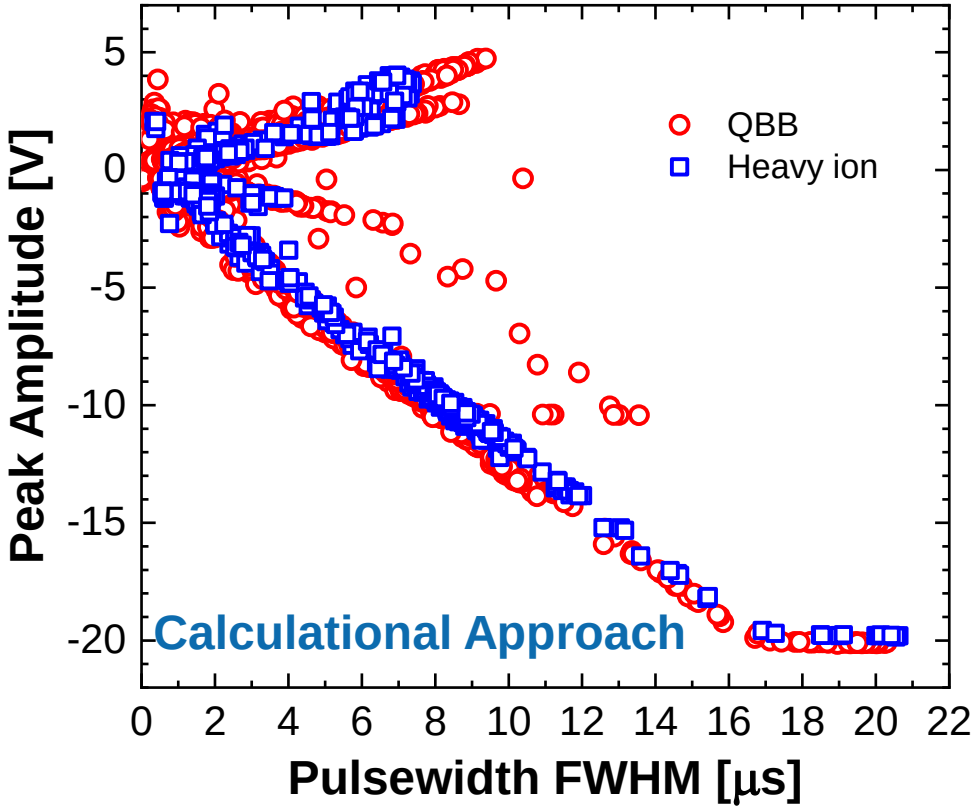

J. M. Hales, *et al.*, *TNS,* vol. 70, Apr, 2023.

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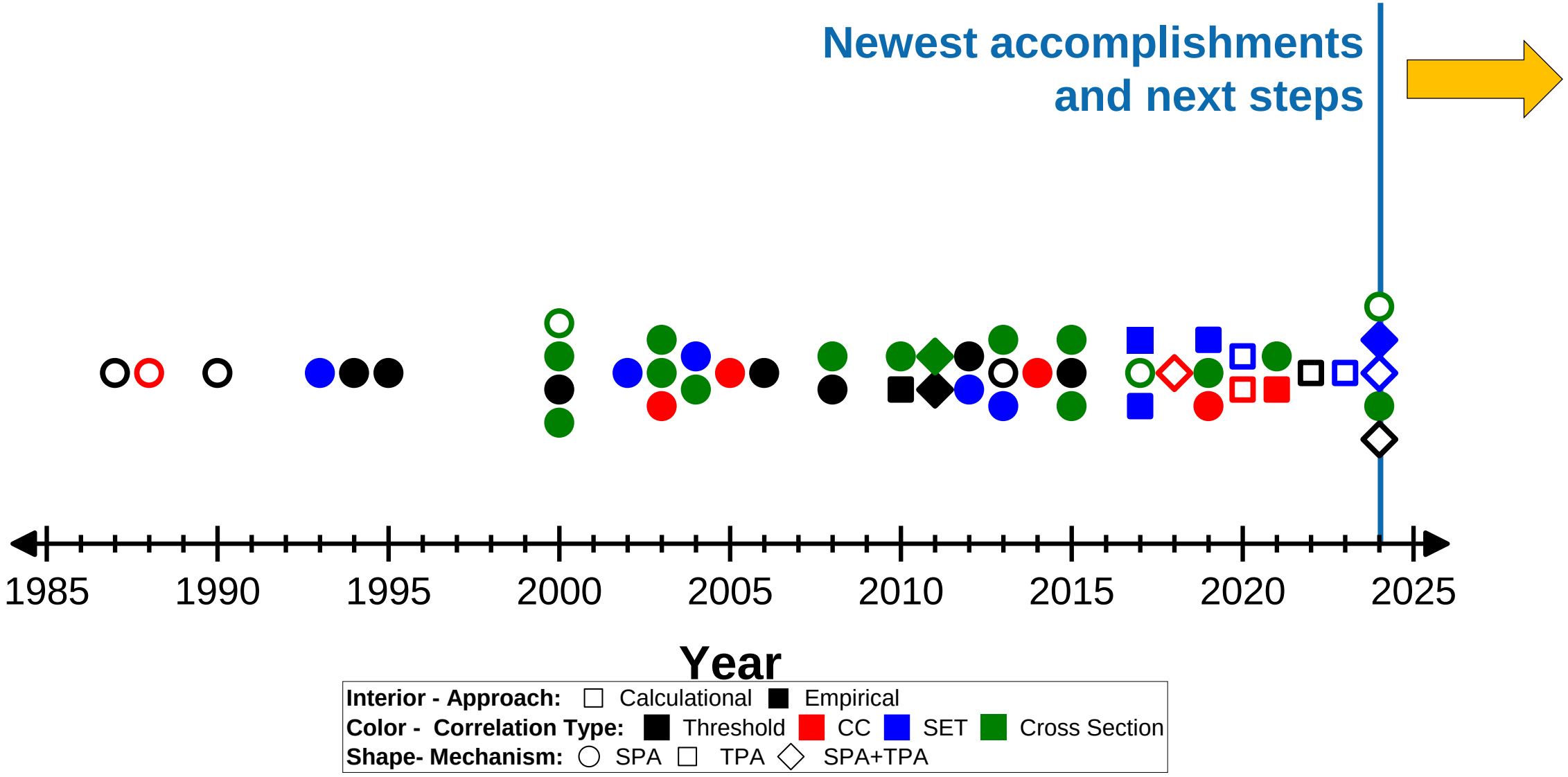
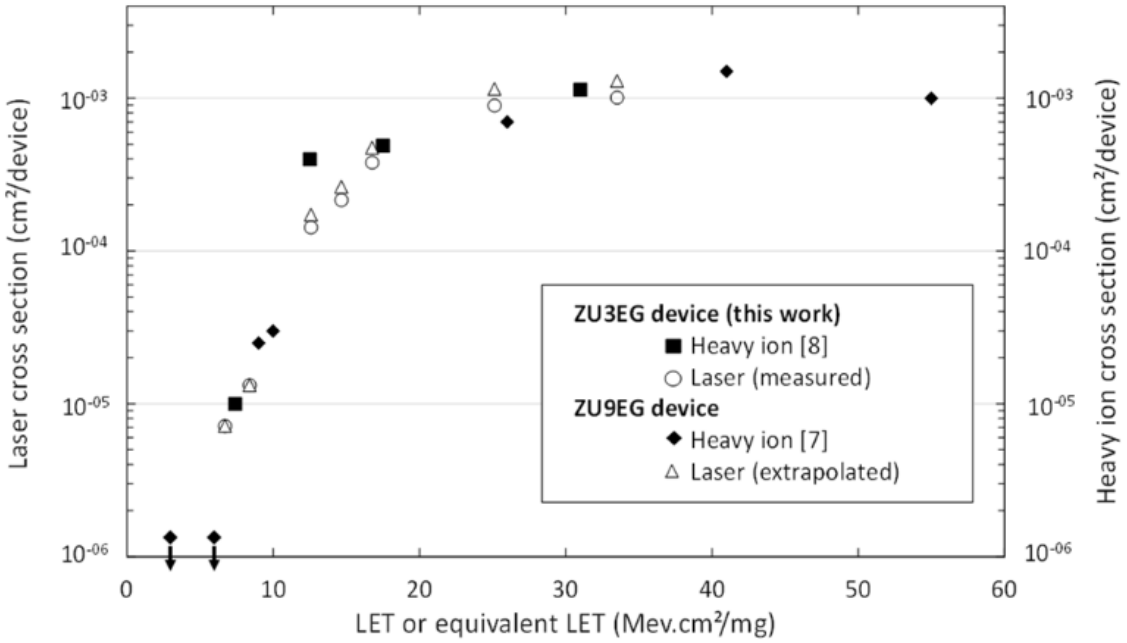


Recent Accomplishment Highlight

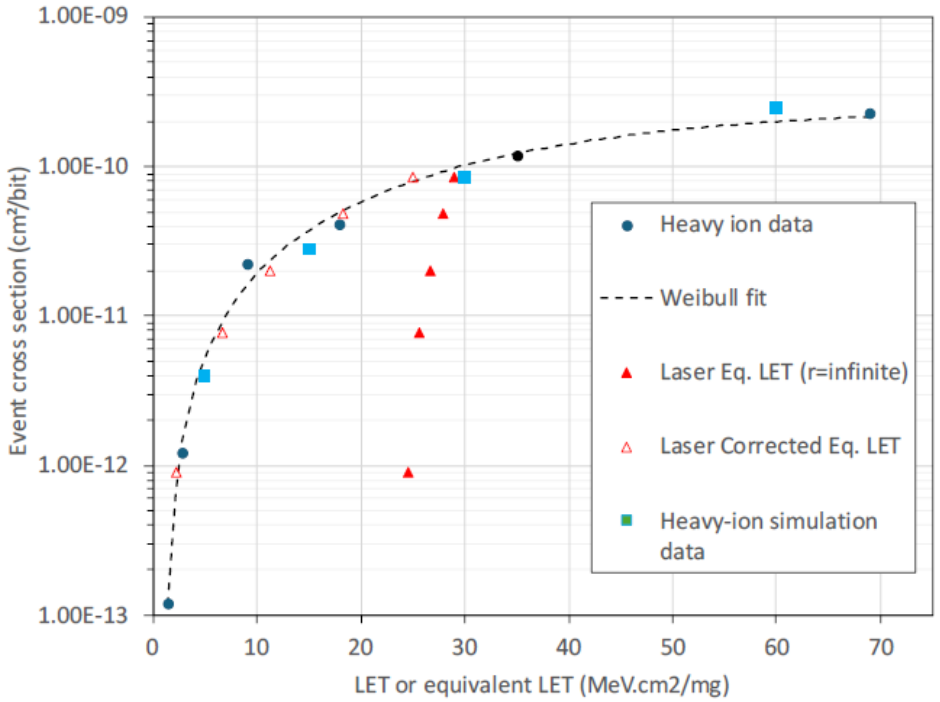
First demonstration of correlation in FinFETs

16 nm FinFETs



M. Fongral, et al., TNS, vol. 71, Aug, 2024.

7 nm FinFETs



S. Achaq, et al., NSREC 2024, Paper I-3.
Submitted to TNS

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Current Trends and Next Steps

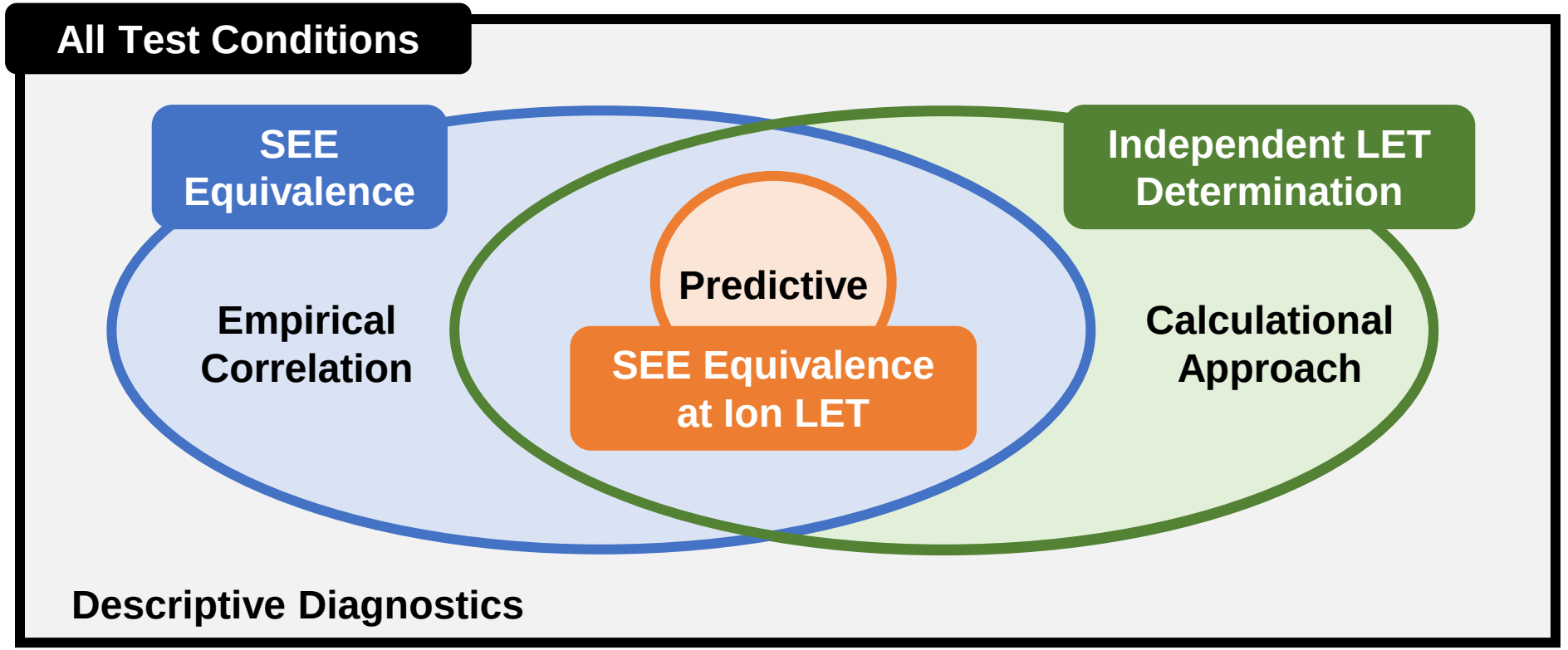
Due to the high demand of particle accelerators, and programmatic delays, a once controversial topic has re-emerged:

Q: Can we use pulsed laser characterization **instead** of accelerator data to qualify parts for a given program or mission?

This question has pushed us to revise our thinking and consider **laser/ion prediction** instead of **ion/laser correlation**.

What are the requirements for prediction?

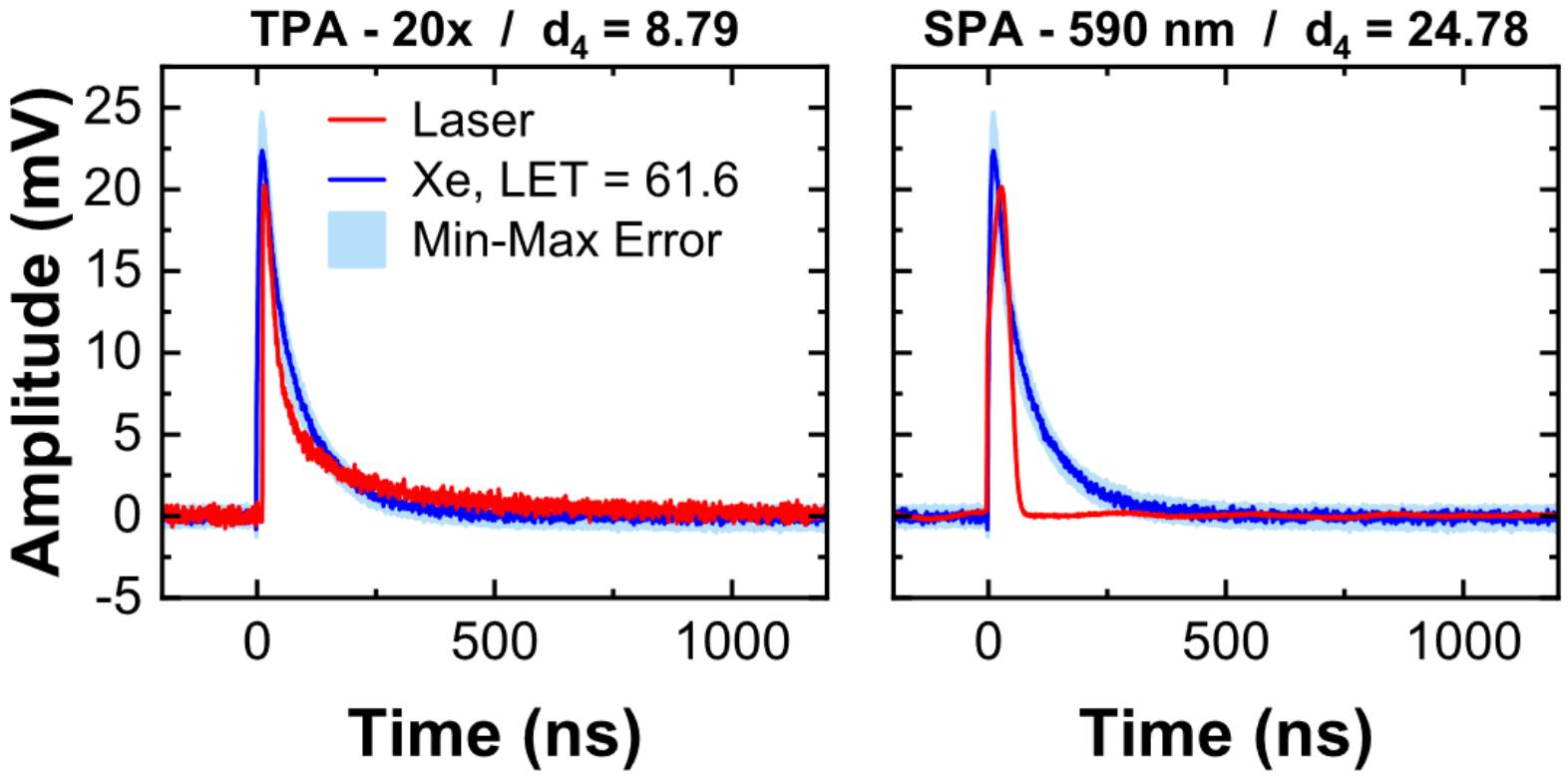
Tuning surrogate source to **prescribed heavy-ion LET** and accurately **reproducing SEE response** in the DUT, **without need for existing heavy-ion data**



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

The Need to Measure Response Agreement

- **Validation of predictive approaches requires quantitative metrics**
  - Developed metrics to assess response agreement for 5 different types of SEE data



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

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Summary

- **Ion/laser correlation is a major topic in the history of PL SEE testing**
  - Interest in the topic has fluctuated, partly due to heavy criticism of PL SEE testing
  - Throughout the years, new developments in PL SEE testing have led to novel correlation approaches both empirical and calculational
  - As more organizations acquire commercially available PL SEE setups, there is no doubt that this history will continue to evolve rapidly.
- **Increased demand for accelerator testing has pushed a once controversial topic to the surface**
  - Can we use lasers instead of ions for programs and missions?
  - The shift from correlation to predictive testing will no-doubt face new challenges

Many more correlation studies are needed to understand the boundaries of applicability for any future predictive testing approaches.

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List of Papers for Ion/Laser Correlation (1/2)

1980s

- A. K. Richter, *et al.*, *TNS,* vol. 34, Dec, 1987.
- S. Buchner, et al., TNS, vol. 35, Dec, 1988.

1990s

- S. Buchner, et al., TNS, vol. 37, Dec, 1990.
- D. McMorrow, et al., TNS, vol. 40, Dec, 1993.
- S. Buchner, et al., TNS, vol. 41, Dec, 1994.
- S. C. Moss, *et al.*, *TNS,* vol. 42, Dec, 1995.

2000s

- D. McMorrow, *et al.*, *TNS,* vol. 47, Jun, 2000.
- O. Musseau, *et al.*, *TNS,* vol. 47, Dec, 2000.
- R. Jones, *et al.*, *TNS,* vol. 47, Jun, 2000.
- V. Pouget, *et al.*, *Micro. Rel.,* vol. 40, Aug, 2000.
- R. L. Pease, *et al.*, *TNS,* vol. 49, Dec, 2002.
- J. S. Laird, *et al.*, *TNS,* vol. 50, Dec, 2003.
- F. Darracq, *et al.*, *RADECS*, 2003.
- F. Miller, *et al.*, *RADECS*, 2003.
- F. Miller, *et al.*, *TNS,* vol. 51, Dec, 2004.
- S. Buchner, *et al.*, *TNS,* vol. 51, Oct, 2004.

2000s

- V. Ferlet-Cavrois, *et al.*, *TNS,* vol. 52, Dec, 2005.
- D. McMorrow, *et al.*, *TNS,* vol. 53, Aug, 2006.
- A. Luu, *et al.*, *TNS,* vol. 55, Aug, 2008.
- C. Weulersse, *et al.*, *TNS,* vol. 55, Aug, 2008.

2010s

- J. R. Schwank, *et al.*, *TNS,* vol. 57, Aug, 2010.
- A. J. Burnell, *et al.*, *TNS,* vol. 57, Aug, 2010.
- J. R. Schwank, *et al.*, *TNS,* vol. 58, Aug, 2011.
- E. Faraud, *et al.*, *TNS,* vol. 58, Dec, 2011.
- S. Buchner, *et al.*, *TNS,* vol. 59, Aug, 2012.
- N. A. Dodds, *et al.*, *TNS,* vol. 59, Dec, 2012.
- A. Zanchi, *et al.*, *TNS,* vol. 60, Dec, 2013.
- D. V. Savchenkov, *et al.*, *RADECS, PE1*, 2013.
- D. McMorrow, *et al.*, *TNS,* vol. 60, Dec, 2013.
- D. Cardoza, et al., TNS, vol. 61, Dec. 2014.
- P. K. Skorobogatov, *et al.*, TNS, vol. 62, *Dec.* 2015.
- D. V. Savchenkov, *et al.*, *RADECS,* 2015.

2010s

- A. A. Pechenkin, *et al.*, *Russ. Micro,* vol. 44, 2015.
- Z. Fleetwood, *et al.*, *TNS,* vol. 64, Jan, 2017.
- H. Itsuji, *et al.*, *Jpn. Appl. J. Phys., vol. 56, Apr. 2017.*
- B. Liang, et al., Sci. China, vol. 60, Jul, 2017.
- J. M. Hales, et al., TNS, vol. 65, Aug, 2018.
- A. Ildefonso, *et al.*, *TNS,* vol. 66, Jan, 2019.
- M. Mauguet, *et al.*, *TNS,* vol. 66, Jul, 2019.
- G. Augustin, et al., RADECS, 2019.

Legend

Empirical Threshold	Calculational Threshold
Empirical SET	Calculational SET
Empirical X-Section	Calculational X-Section
Empirical CC	Calculational CC

List of Papers for Ion/Laser Correlation (2/2)

2020s

- K. L. Ryder, et al., TNS, vol. 67, Jan, 2020.
- J. M. Hales, *et al.*, *TNS,* vol. 67, Jan, 2020.
- A. Y. Borisov, et al., SIBCON, May, 2021.
- K. L. Ryder, et al., TNS, vol. 68, May, 2021.
- J. M. Hales, et al., TNS, vol. 69, Mar. 2022
- J. M. Hales, et al., TNS, vol. 70, Apr, 2023.
- J. M. Hales, et al., TNS, vol. 71, Apr, 2024.
- A. Ildefonso, et al., TNS, vol. 71, Apr, 2024.
- M. Fongral, et al., TNS, vol. 71, Aug, 2024.
- S. Achaq, et al., NSREC 2024 (TNS, Under Review)
- J. Likar, et al., NSREC 2024 (TNS, Under Review)

Legend

Empirical Threshold	Calculational Threshold
Empirical SET	Calculational SET
Empirical X-Section	Calculational X-Section
Empirical CC	Calculational CC