

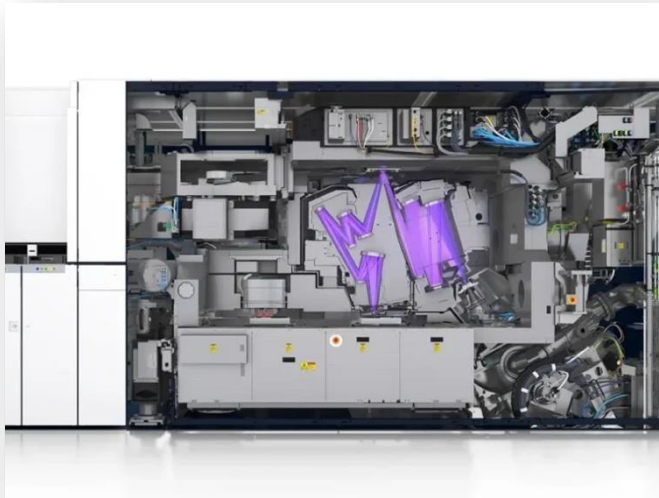
AI/ML Needs for a Commercial EUV Light Source
Christopher M. Pierce

xLight

FEL for EUV Lithography

W h y b u i l d a c o m m e r c i a l p a r t i c l e a c c e l e r a t o r ?

EUV Lithography



<https://www.eenewseurope.com/en/asml-has-started-shipping-second-high-na-euv-litho-machine/>

19nm pitch

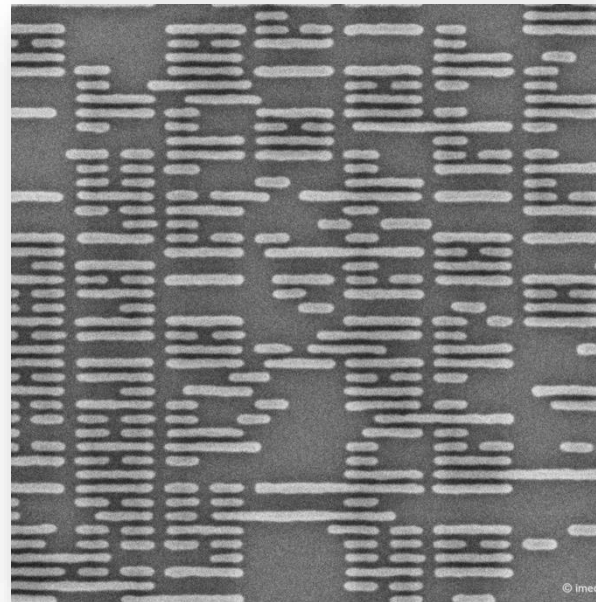


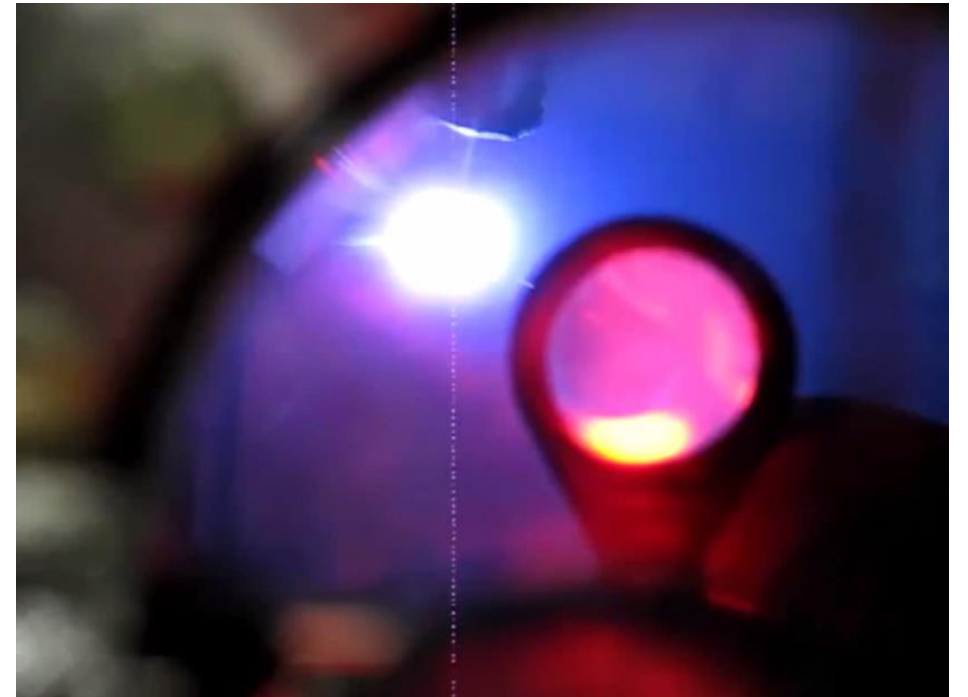
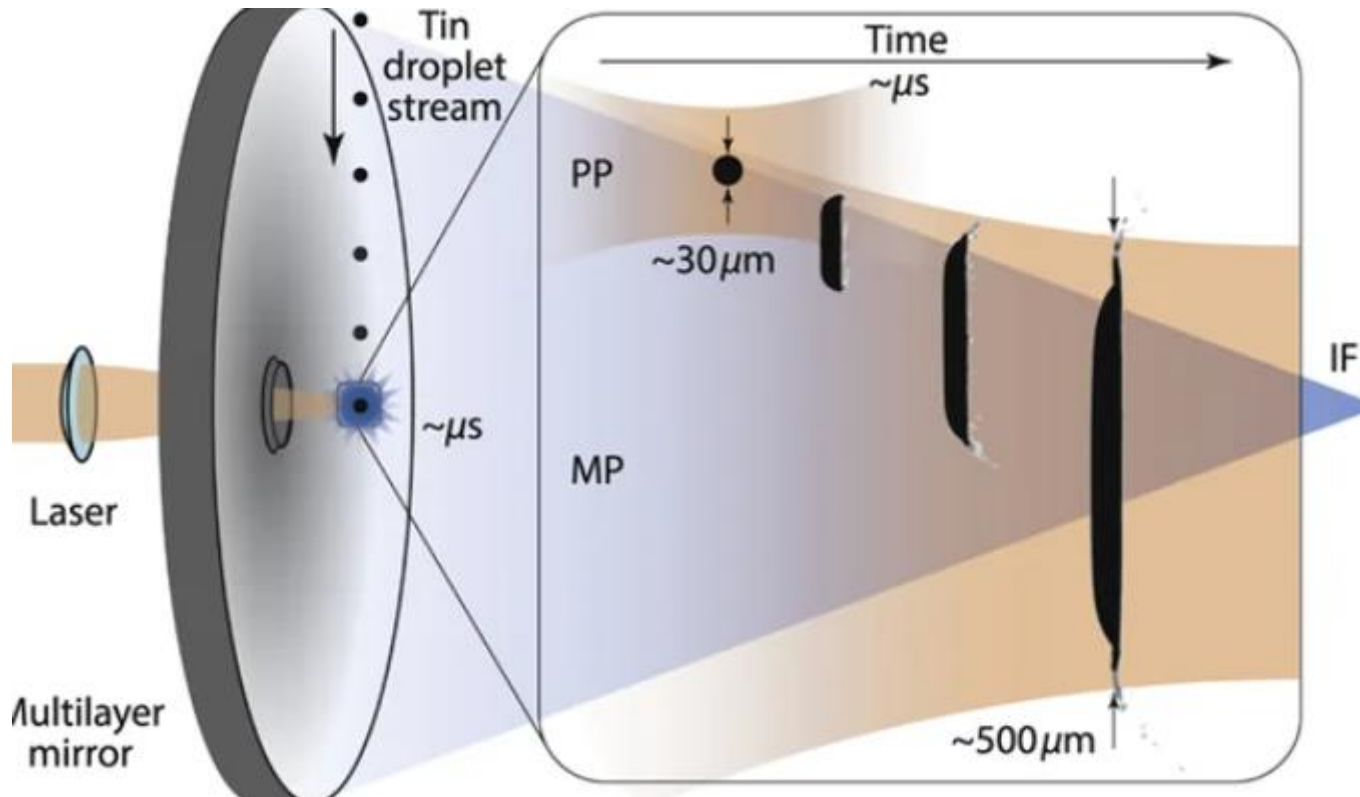
Image from IMEC



Veritasium: "The World's Most Important Machine"
<https://www.youtube.com/watch?v=MtUHjLxm3V0>

Current state-of-art logic and memory chips are made with EUV lithography: feature size and throughput bottleneck

Existing EUV Light Source



C H I P P R O D U C T I O N

LIMITED BY LIGHT

ASML NXE:3400B

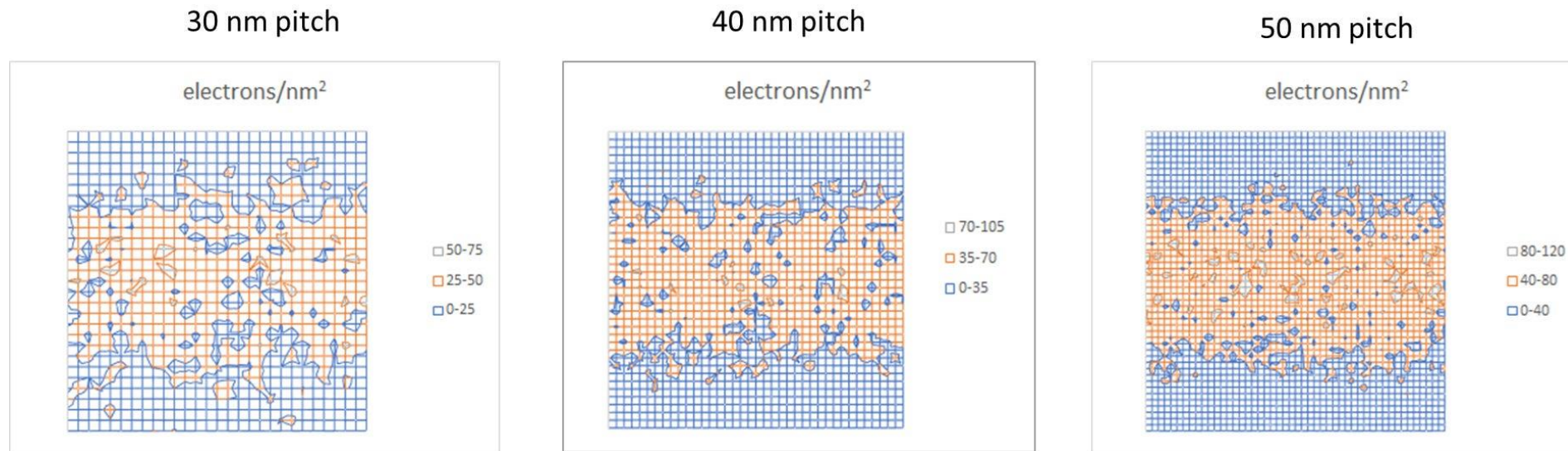


For all advanced chips, a fab's performance, cost, and production volume are determined by the capabilities of ASML's photolithography scanner, which uses extreme ultraviolet (EUV) light.

These scanners are
already capable of
utilizing more light:

- Current scanners are delivered with 600W, but they can operate at 2kW.
- More advanced machines require even more light.

Existing EUV Light Source

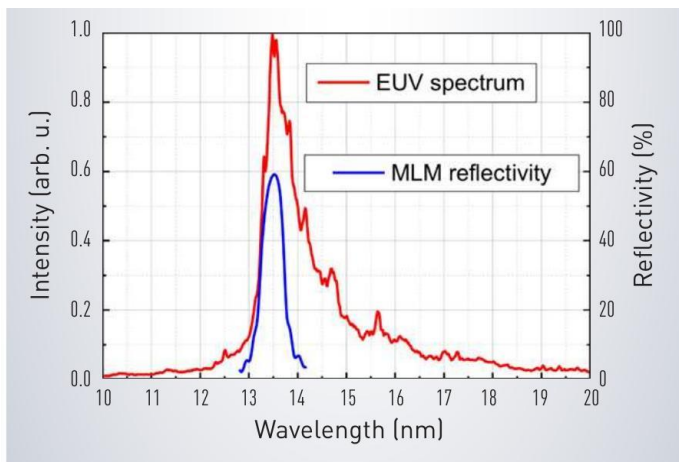


<https://frederickchen.substack.com/p/stochastic-effects-blur-the-resolution>

Stochastics, ie shot noise, matters in feature size: dose helps drive resolution

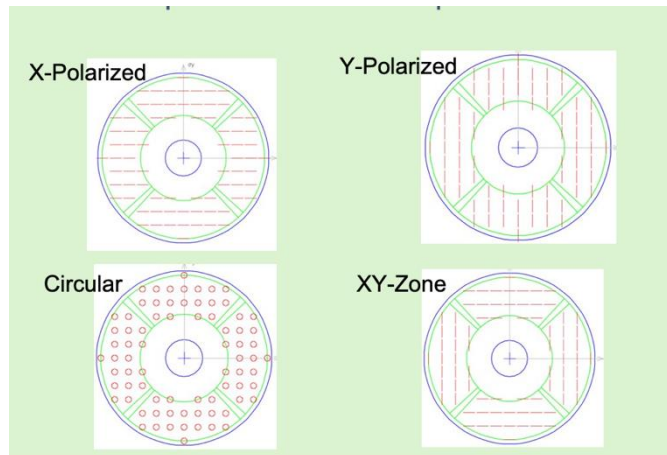
Other Challenges with Existing Source

Mirror Heat Load



Rahman, F. (2018). EUV light sources for next-gen lithography. *Optics and Photonics News*, 29(3), 42-49.

Polarization



Reference: T. Pistor, "Exploring EUV scanner design options enabled by free electron laser sources" in *Optical and EUV Nanolithography* (2024).

Mirror Contamination

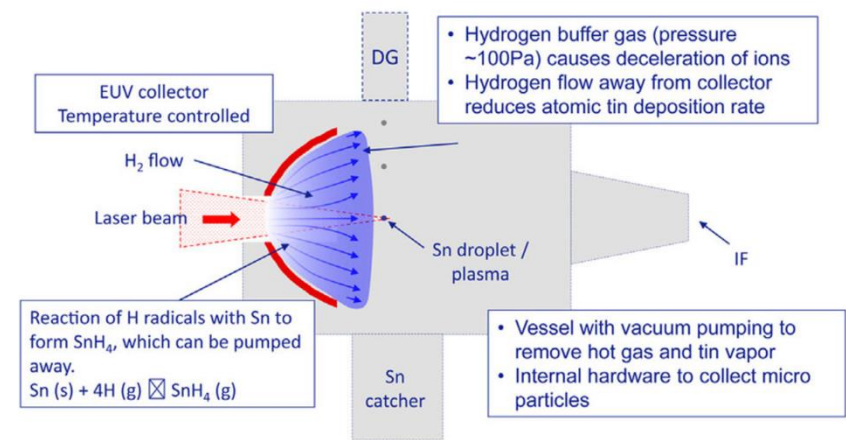
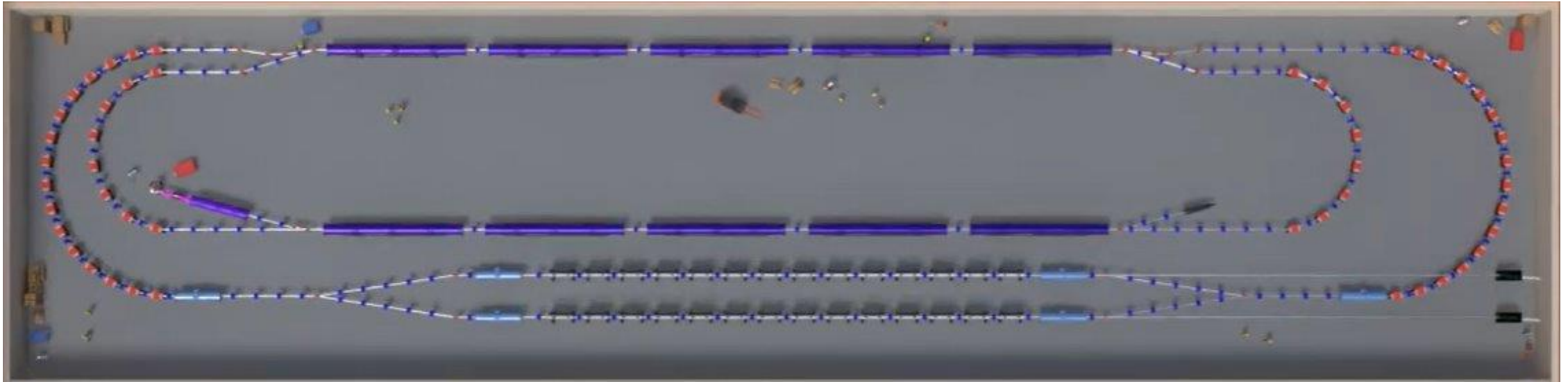


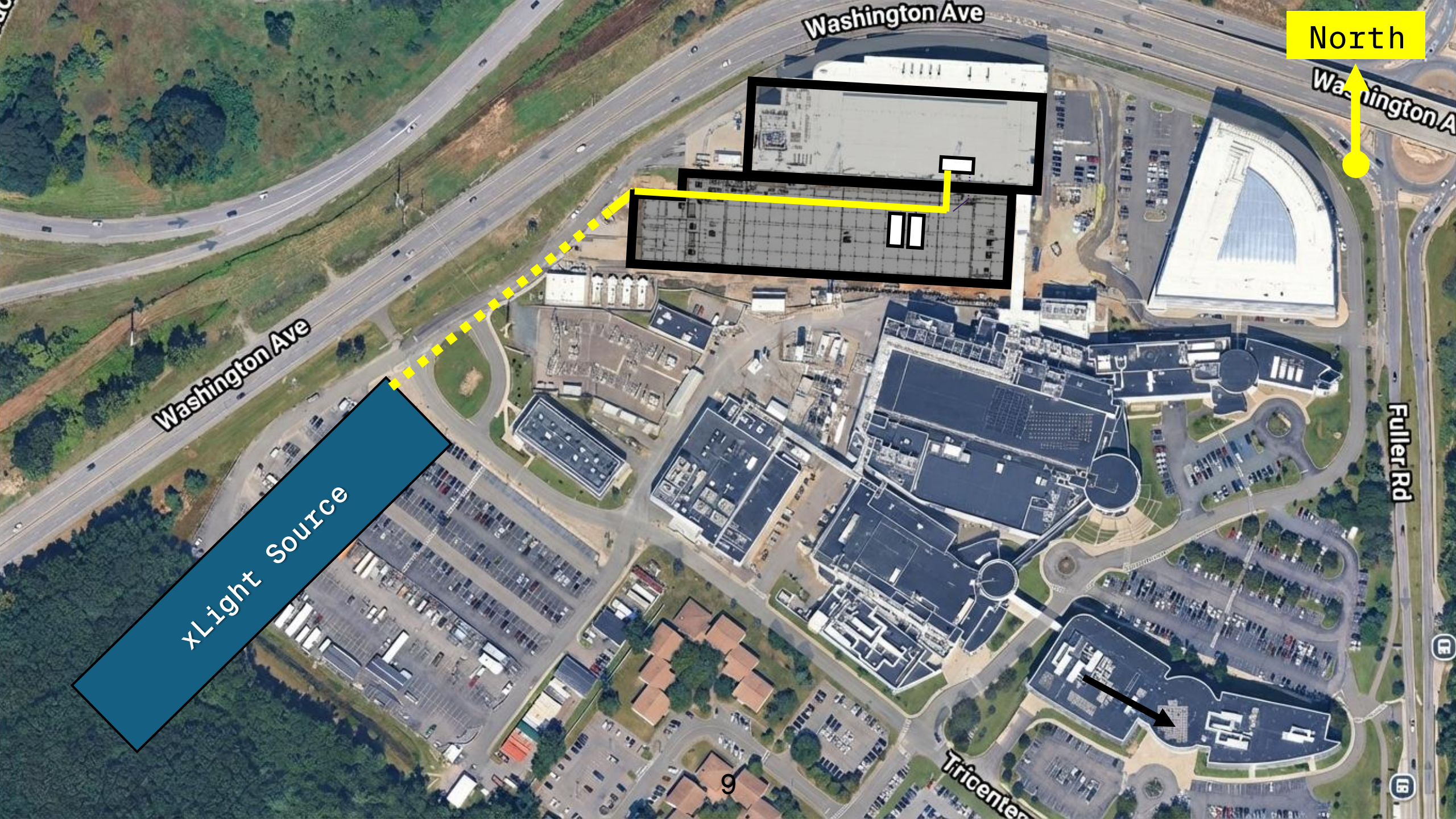
Image Credit: Dekun Yang

Wall-Plug Power

Free Electron Laser Light Source



- EUV power of 1kW at scanners at better efficiency than LPP source
- Drive multiple scanners from one machine with multiplexing technology
- Polarized output, potentially controllable



Unique Aspects of Problem

Uptime

Unplanned downtime costs estimated ~\$1M/hr, need high reliability systems

Autonomy

Fabs will not tolerate team of physicists tweaking machine as it runs. Must turn on and run unaided.

“Photon Factory”

Simpler goal than scientific machines. Only need one wavelength of light. Just a lot of it.

Prospects for AI/ML at xLight

W h y b u i l d a c o m m e r c i a l p a r t i c l e a c c e l e r a t o r ?

Virtual Accelerator Research Paths

Need for fast-to-evaluate models of accelerator for design validation, control system testing, model-predictive control, R&D

Surrogate Model

Replace expensive simulation tools with models, often deep learning.

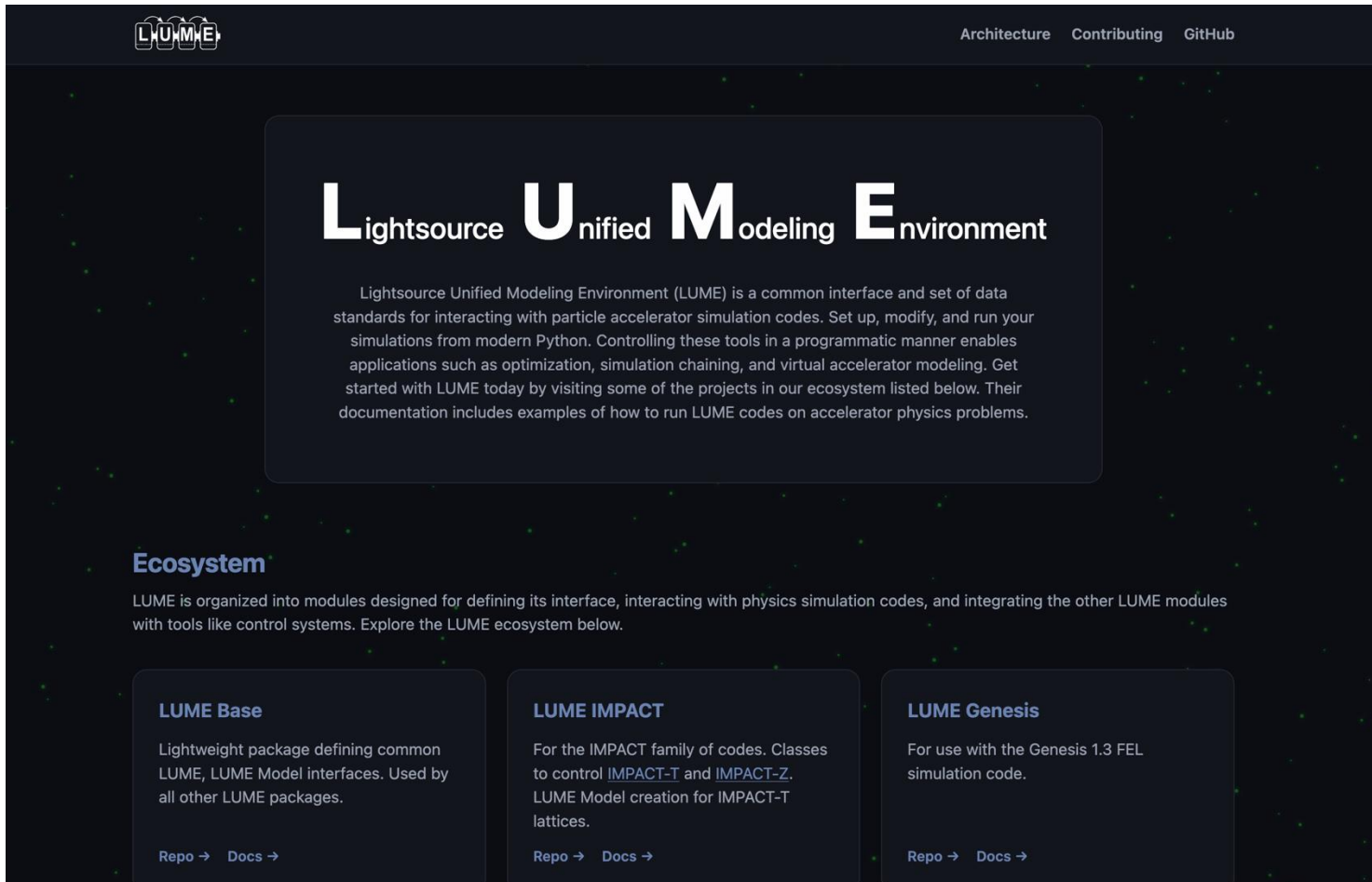
- Data is expensive, how to make more sample efficient? Physics priors? Novel data augmentation?
- Novel label types – Beam distributions, optical fields, ie for chaining
- Uncertainty aware inference.

Digital Twin

Model of the as-built machine, often data-driven, possibly updated in real-time with machine.

- What is the correct way to do simulation data fusion?
- Opportunities for statistically driven model calibration methods.
- Online learning, testing for OOD data
- Standards, best practices for storing accelerator data from running machine.

An Advertisement for LUME Model



Check out at: www.lume.science

LUME Model

Ecosystem and interface for building accelerator virtual machines in python.

Serve existing lattices from EPICS IOC, compatible with ML models. Common layer to expose variables and methods to set / get.

Developed in xLight-SLAC collaboration!

S. Miskovich talk tomorrow.

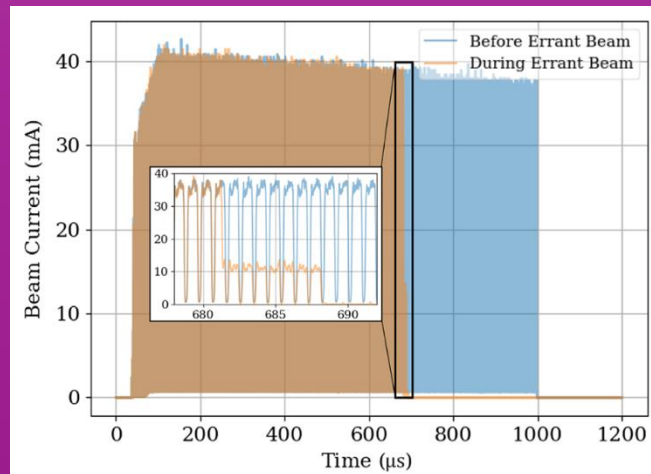
Also see: Roussel, R., Pierce, C. M., Miskovich, S., Lauer, K., Edelen, A., & Mayes, C. (2026). Expanding LUME to Support Virtual Accelerators and Digital Twins. *arXiv preprint*

Machine in Operation – Research Paths

Anomaly Detection

High stored energy beam and high availability requirement requires good fault detection with low false positive rate.

- What diagnostics are best in green field machine
- Which architectures / methods

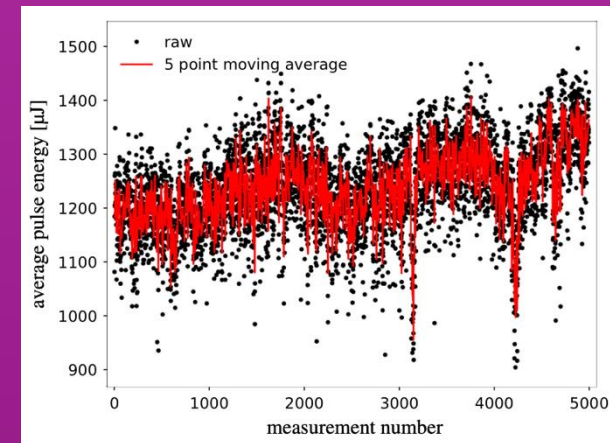


Blokland, W., Rajput, K., Schram, M., Jeske, T., Ramuhalli, P., Peters, C., ... & Zhukov, A. (2022). PRAB, 25(12), 122802.

Automated Startup / Online Tuning

How to keep turn on and keep FEL performance in top shape while running. Unique challenge in that fabs want consistent output. Avoid jittering beam during exposures.

- Use models (including digital twin) as priors for optimization
- Virtual diagnostic crossover for predicting policy from non-destructive beam measurements.



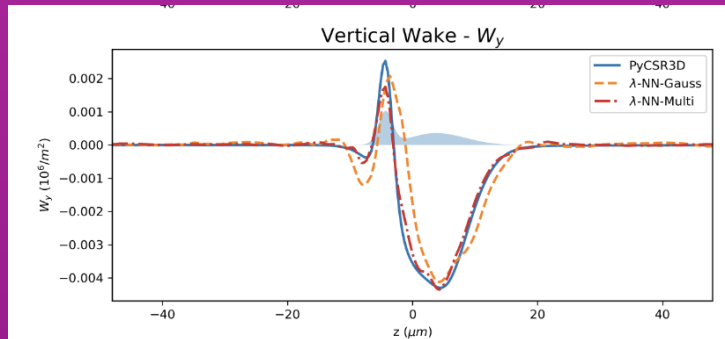
Scheinker, A., Bohler, D., Tomin, S., Kammering, R., Zagorodnov, I., Schlarb, H., ... & Decking, W. (2019). PRAB, 22(8), 082802.

"Blue Sky" Research of Interest

Code Improvements

Accurate simulation of machine is slow. Order of magnitude improvement drastically changes how machines can be designed.

- Surrogate modeling of collective effects.
- Foundation model type work on beam propagation
- Superresolution techniques
- How to interface with and deploy models in existing codes

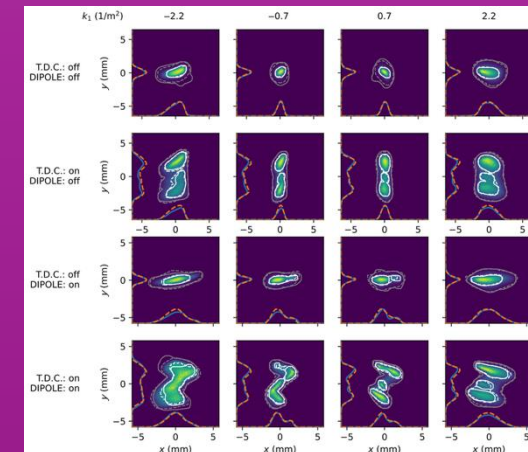


Leon, C., Anisimov, P. M., Yampolsky, N., & Scheinker, A. (2025). *arXiv preprint arXiv:2503.09551*.

Virtual Diagnostics

Nondestructive inference of beam properties of 1MW beam drawn from reliable sources (eg emitted radiation). More information gathered from existing diagnostics.

- Optimal design of experiment for new systems
- How to quantify reliability



Roussel, R., Gonzalez-Aguilera, J. P., Wisniewski, E., Odv, A., Liu, W., Power, J., ... & Edelen, A. (2024). PRAB, 27(9), 094601.

- Open Dataset Creation - Other fields of AI/ML for physical sciences develop and compare algorithms on open datasets and benchmark problems. For most problems mentioned here, non-existent or difficult to find.
 - Data of running machine, simulations of machine, diagnostics scans, etc. shared for community.
- Digital Twin Research - Testing ground for development of data driven digital twin. Quantify accuracy with baseline methods.
- Automated startup - Demonstrate automated startup of beamline from cold state. Particularly injector.
- Online tuning - would be ideal if light source relevant metrics, but development of methods to maintain beam quality metrics in face of changing environment.

