High-average-power ERL FEL for EUV Lithography

Dinh C. Nguyen, for the xLight Team

xLight

xLight is developing a unique light source for High-Volume Semiconductor Manufacturing

Dynamic Output to Each Tool

Customer Scalable

xLight

2 kW at IF
Per Scanner

400 kW Wall Plug
Per Scanner With 20 Connected

98% Availability

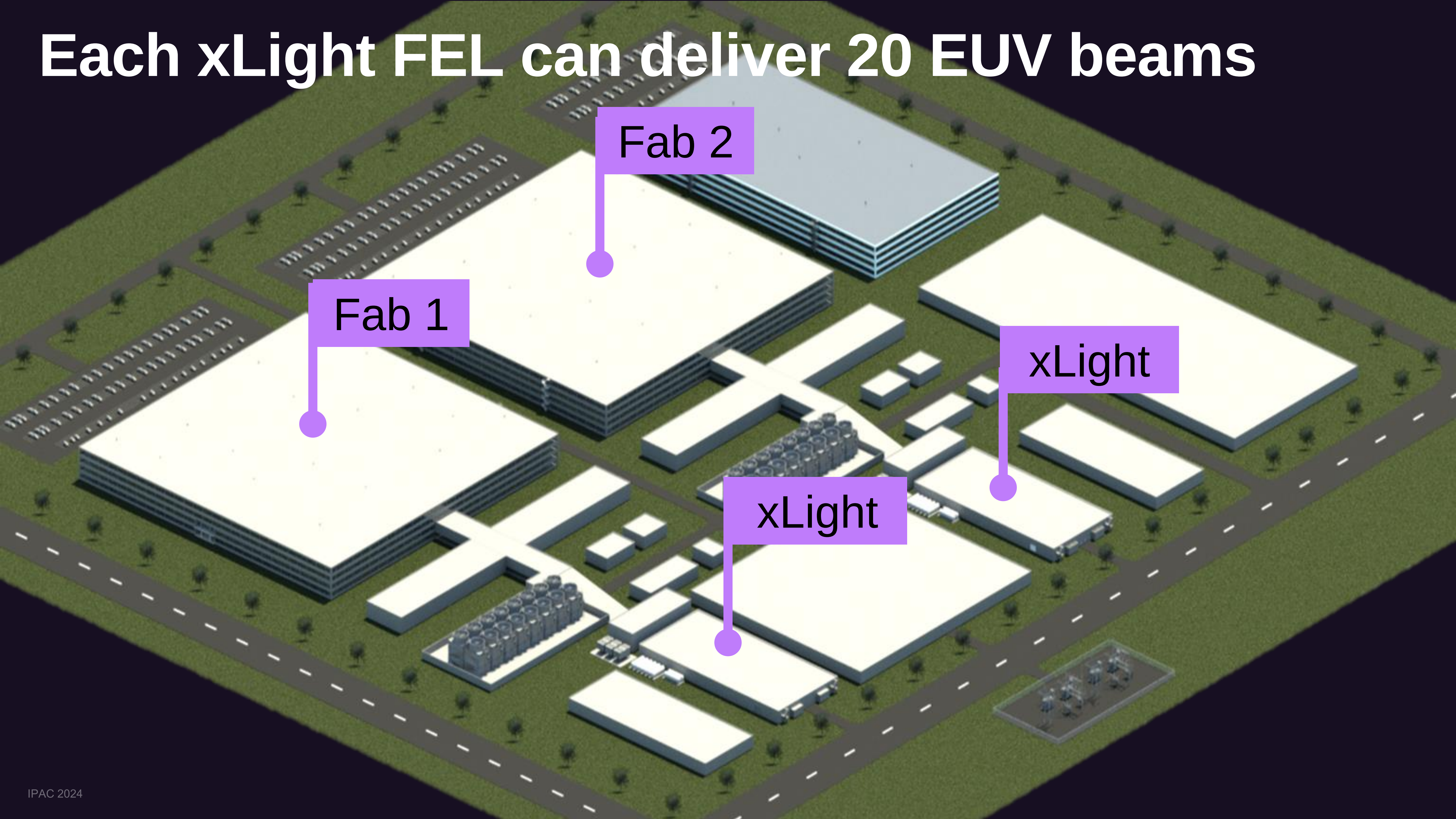
Compatible

Simultaneously Multi-Wavelength

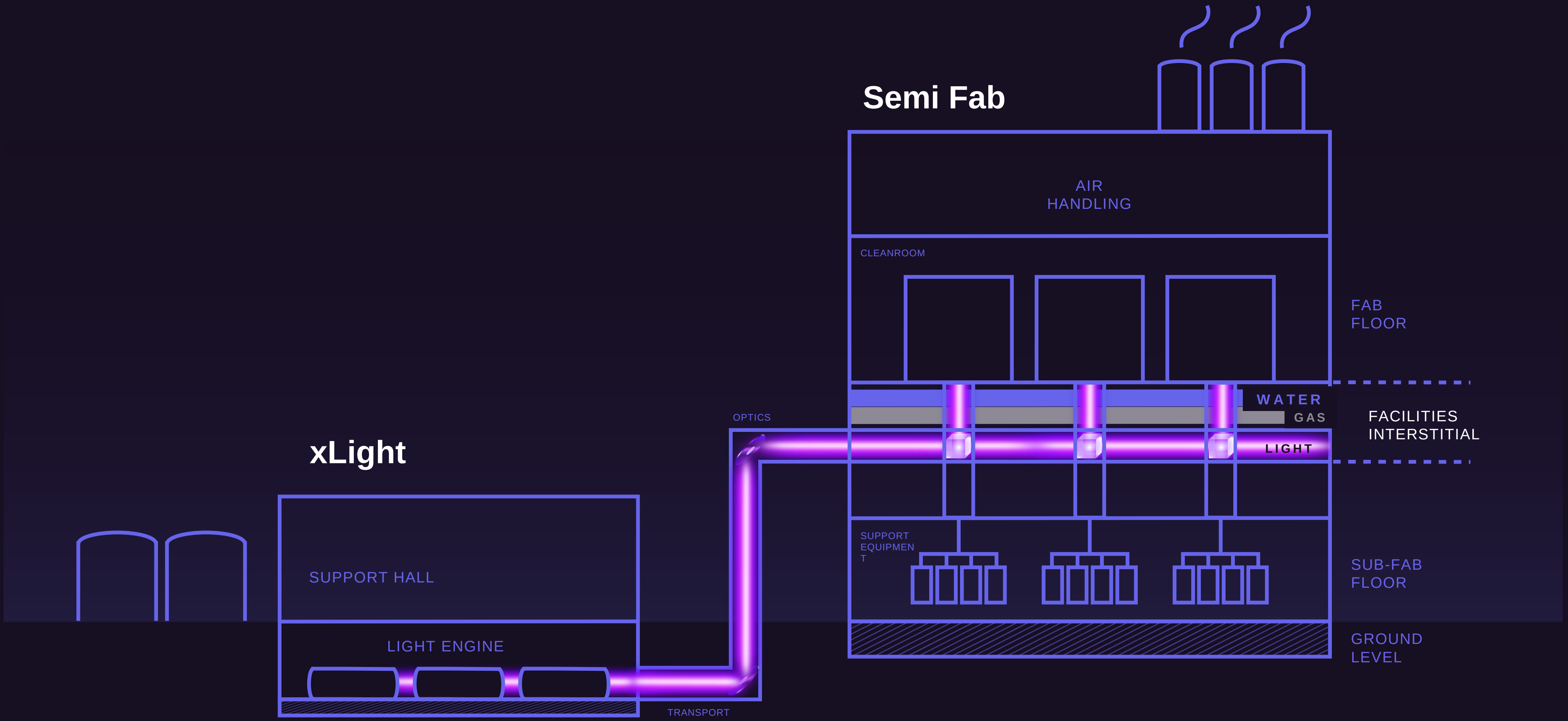
Programmable Polarization

Up To 20 Scanner Connections Per xLight Source

Each xLight FEL can deliver 20 EUV beams

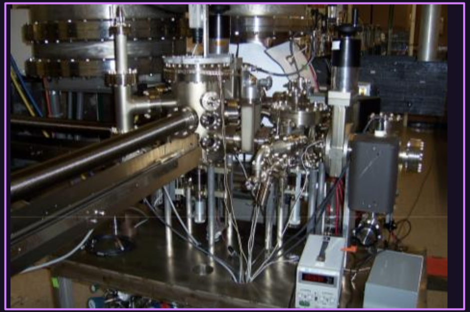


Light as a Utility



Mature Accelerator Technology Foundation

Electron Guns



Berkeley / Cornell / JLAB

SC Accelerator

Fermilab / JLAB / Cornell

Energy Recovery

Cornell / JLAB

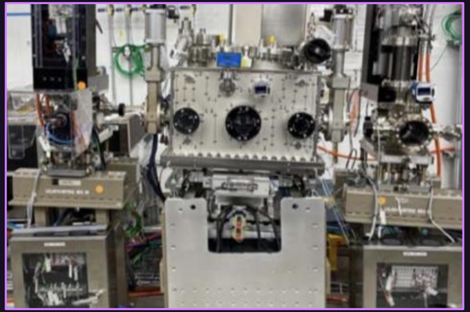
Kicker Cavities

Berkeley / JLAB / Old Dominion University

Undulators

Berkeley / Argonne / Industry

Optical Systems



Berkeley / Argonne / SLAC / Industry

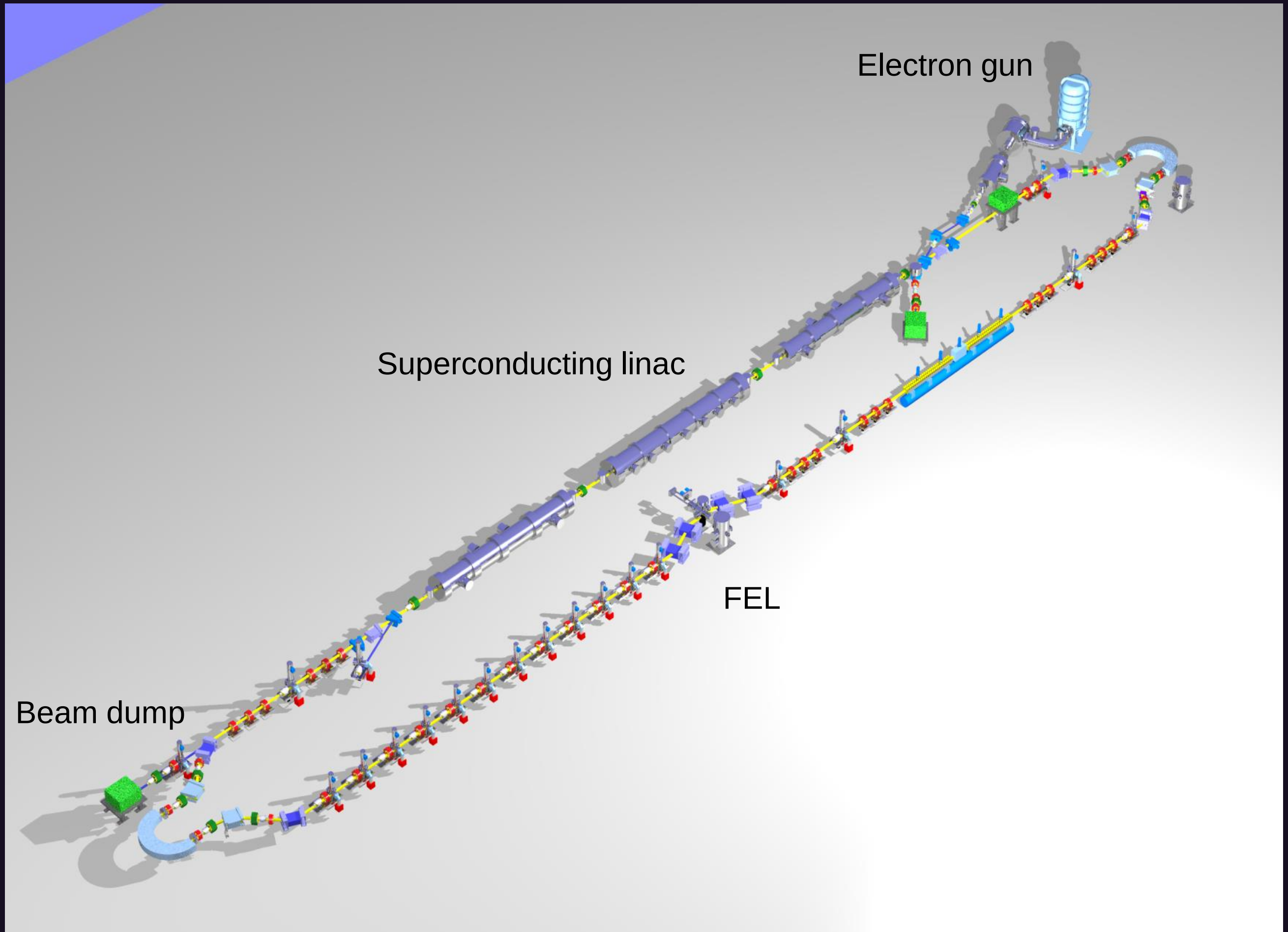
Proven Capability to Expand Upon:

- 10s of kW
- 200 W Wall Plug / W Light
- 90% Availability
  In Lab Settings With “One-Off” Machines
- Supply chain

JLAB ERL FEL has achieved 10 kW average power

The JLAB FEL is the existence proof of a high-average-power (10 kW) FEL based on energy recovery linac (ERL). ERL improves FEL efficiency and greatly reduces material activation.

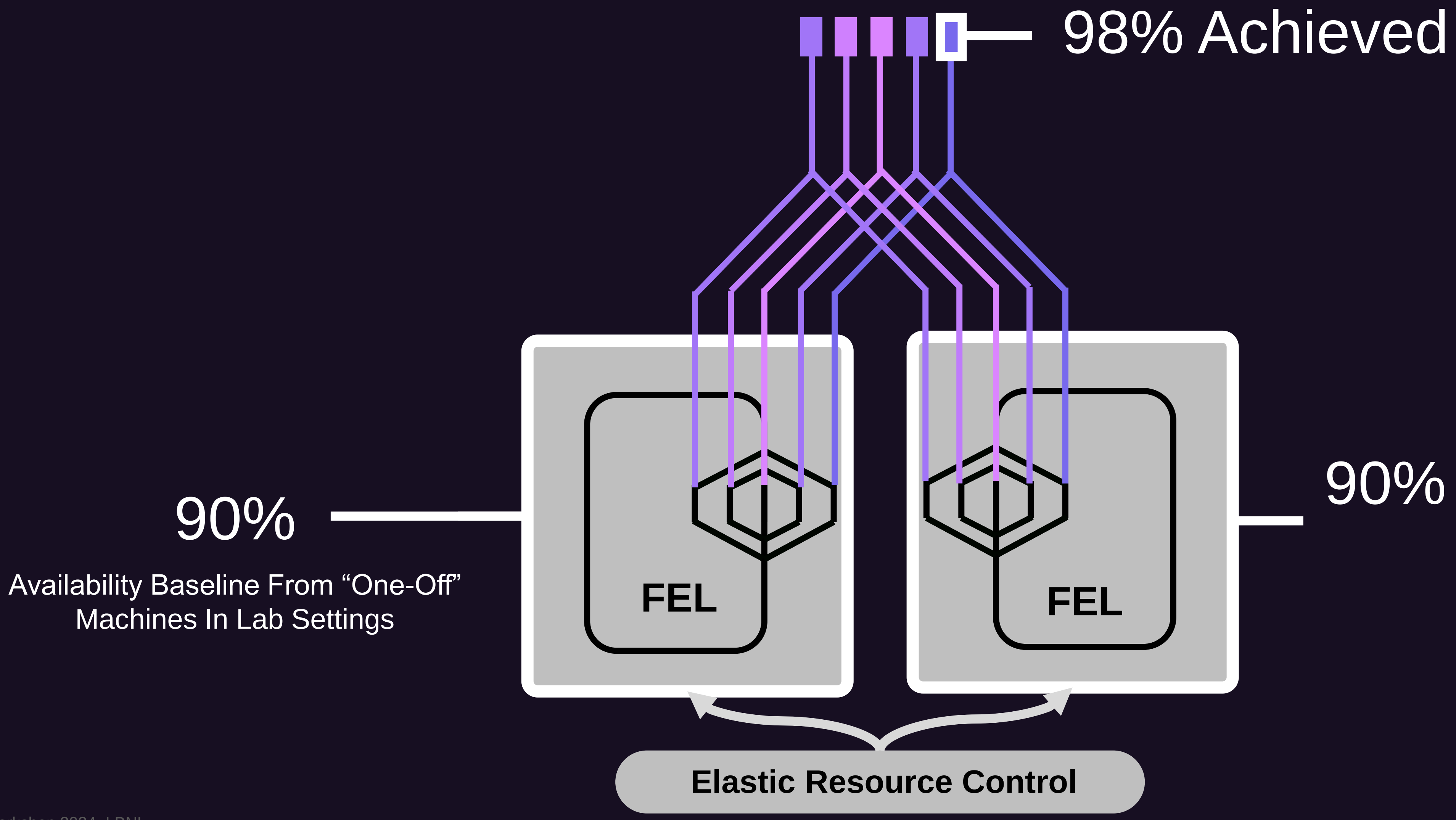
$$\eta_{FEL} = \frac{P_{FEL}}{P_{dump}}$$



Reference: G. Neil et al., “The JLab high-power ERL light source” Nuclear Instruments and Methods in Physics Research, **A 557** (1) pp. 9-15 (2006).

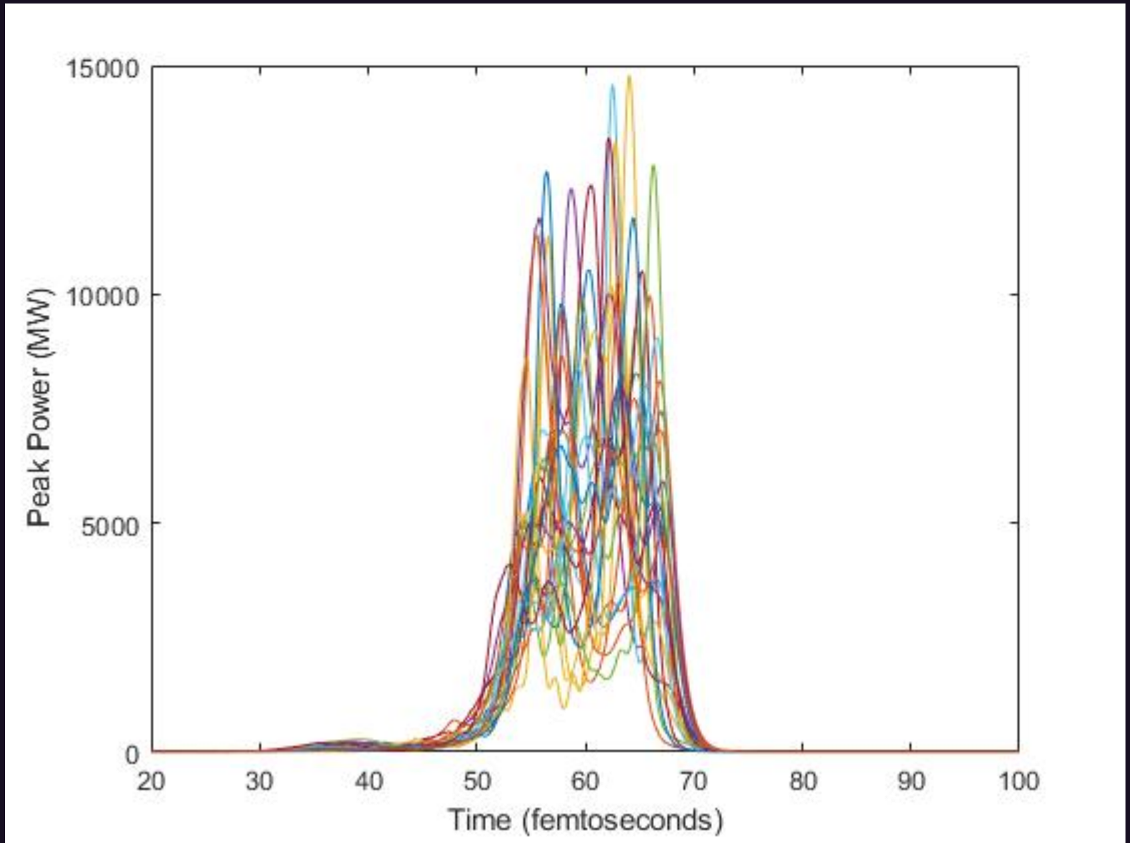
Improved Availability via Redundancy

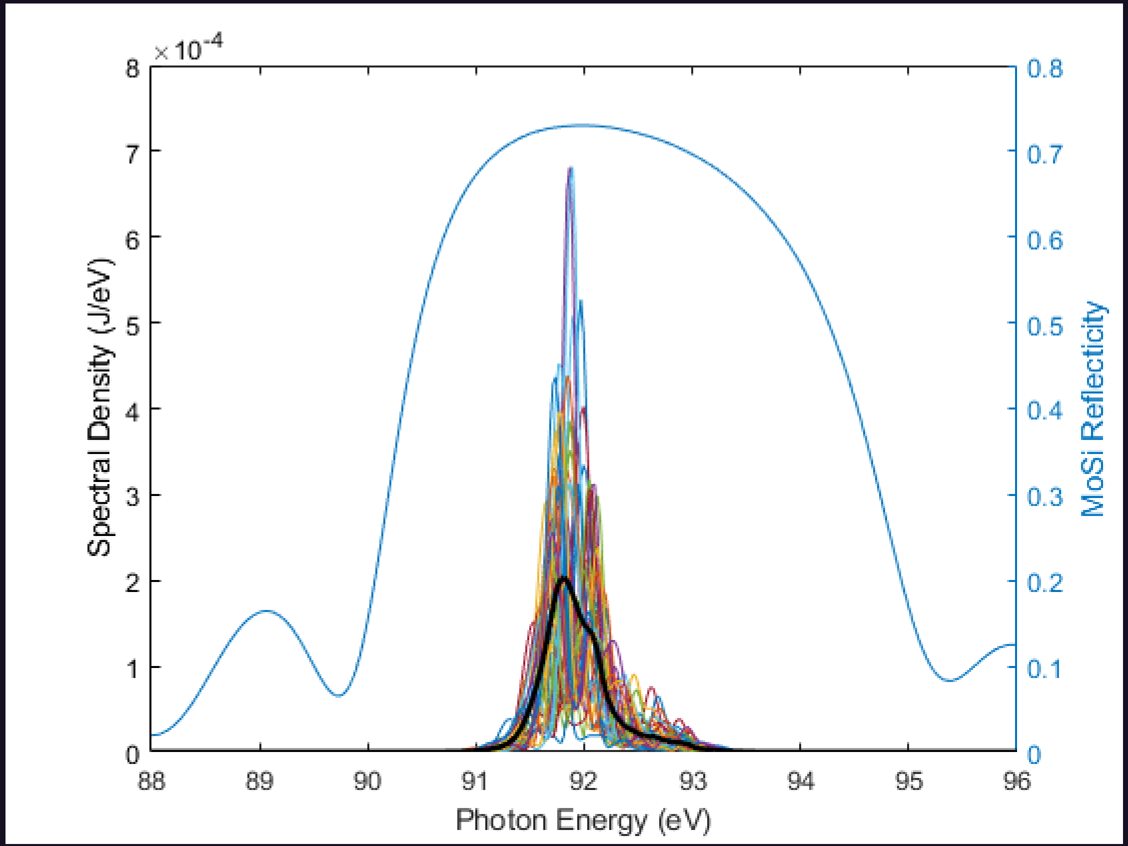
Availability via Redundancy



Reduced Mirror Heating

The SASE FEL Narrow-band Output can be tuned to match the peak reflectivity of Mo-Si mirrors

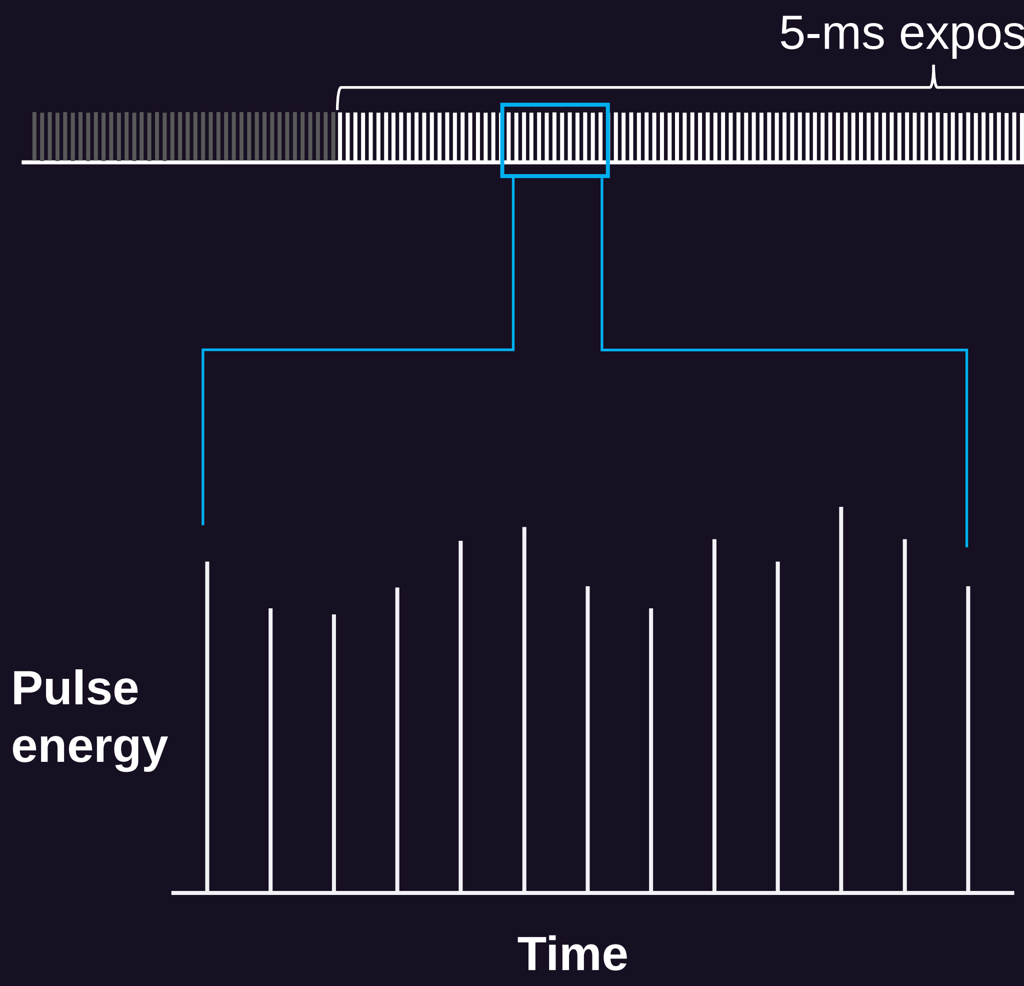




Short interaction length → Few longitudinal modes → Narrower spectral bandwidth

Stable Exposure Dose

xLight FEL delivers Stable Integrated Energy to each scanner during the 5-ms exposure



Pulse rep rate per scanner = 10s of MHz

Each exposure integrates the energy of N pulses

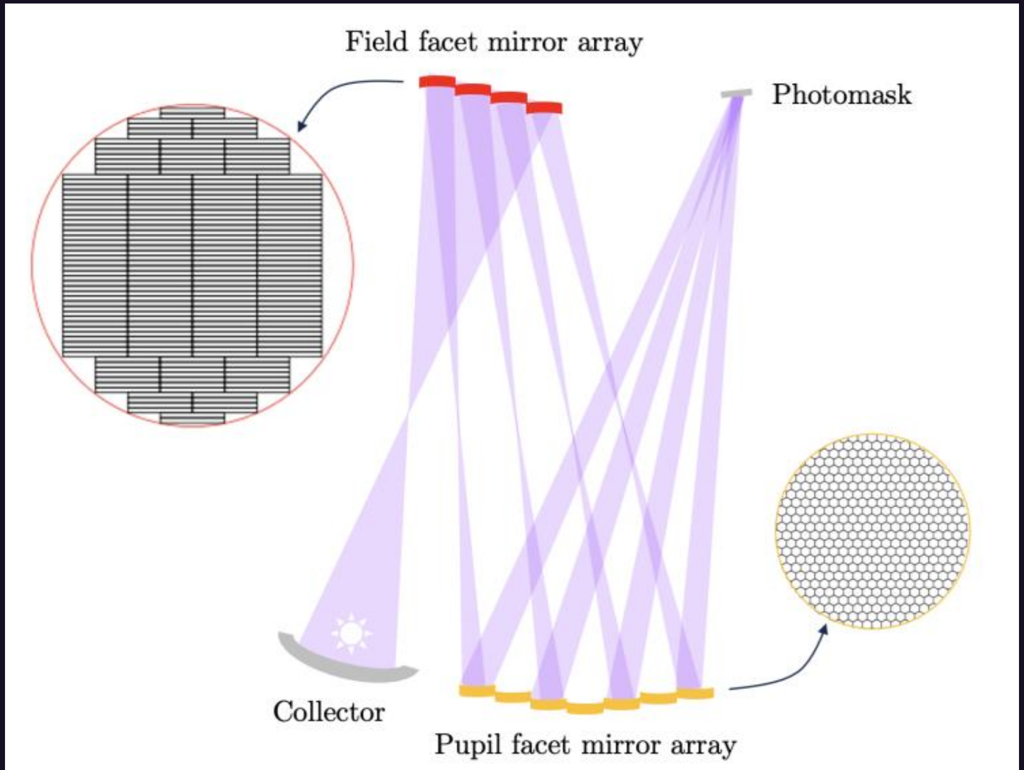
$$N \approx 10^4$$

Exposure energy fluctuation is reduced by $\sqrt{N}$

$$\left(\frac{\sigma_E}{E}\right)_{exposure} = \frac{1}{\sqrt{N}} \left(\frac{\sigma_E}{E}\right)_{FEL}$$

Reduced Speckle Contrast

Field Scan Averaging & Channel Averaging of Femtosecond Pulses Reduce Speckle Contrast



Coherence time ~ 3 fs

Coherence length ~ 1 μm

Facet mirror arrays have built-in delays > 10 μm

Channel averaging of N beamlets reduces the speckle contrast by $\sqrt{N}$

Reduced speckle contrast results in smaller line-width roughness (LWR)

$$LWR \propto \frac{w}{NILS}\left(\frac{dI}{I}\right)_{speckle}$$

Reference: C. Anderson, "On the Compatibility of Free-Electron Lasers with EUV Scanners" in Optical and EUV Nanolithography XXXVII, edited by Martin Burkhardt, Proc. of SPIE Vol. 12953 (2024).

High-average-power EUV FEL Summary

Capability

2 kW per Tool • Programmable Polarization • Adjustable Wavelength

Sustainability

400 kW Wall Plug per Tool

Availability

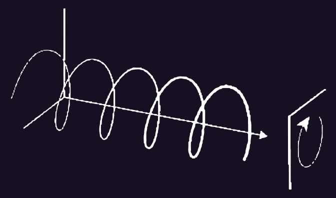
98% Full Redundancy

Compatibility

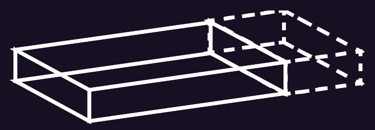
Utilizing Existing Hardware

Future Technology Insertions

Polarization Control → **Superconducting Undulators** → **4K Nb_3Sn SRF Cavities**



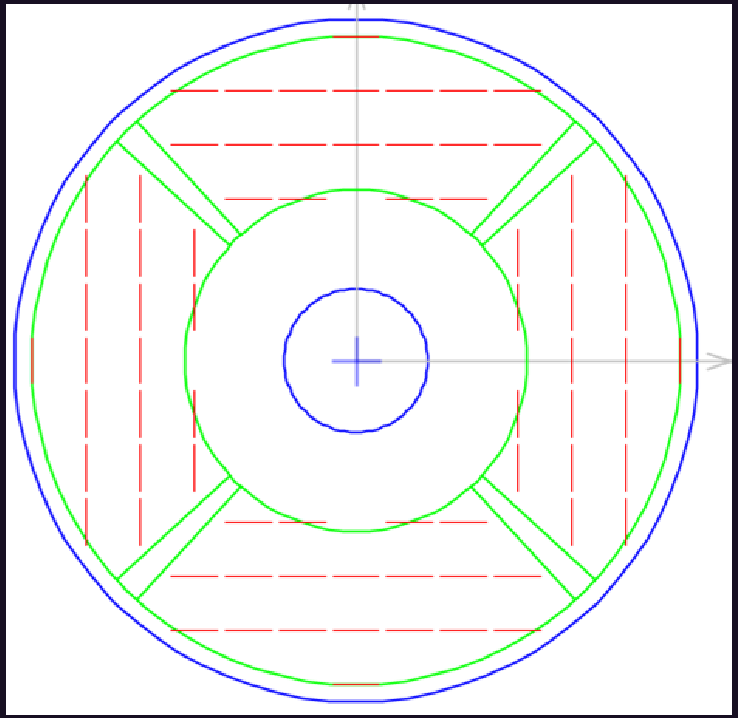
Hyper-NA Process Window

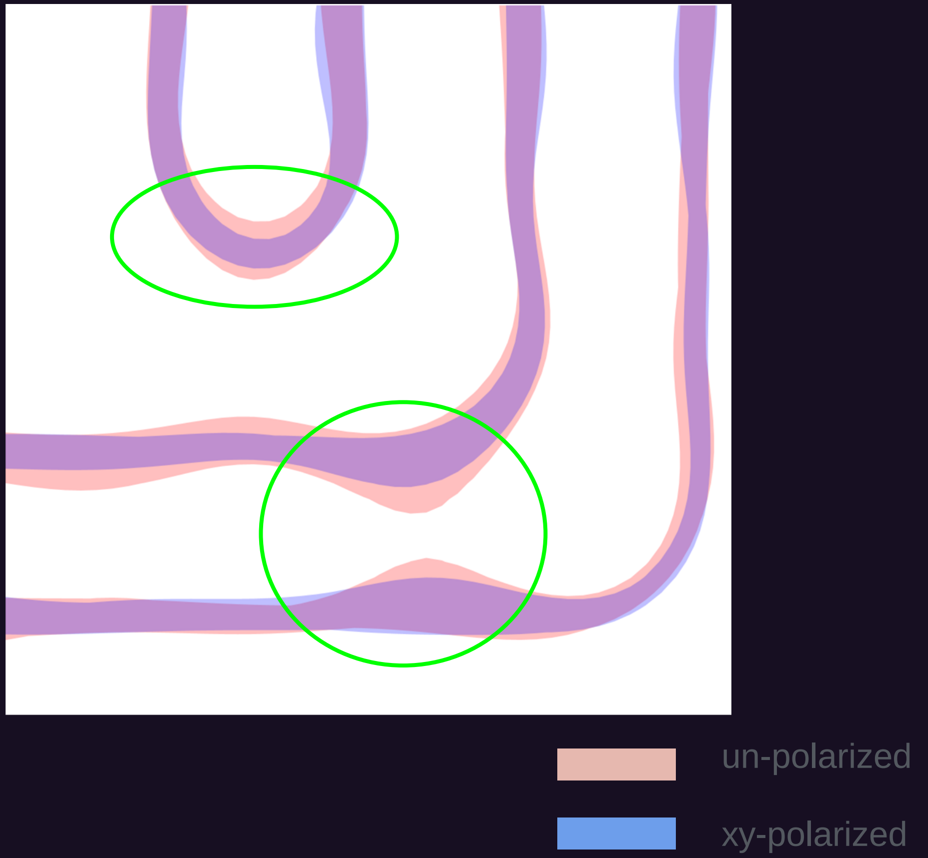


Smaller Footprint & Radiation Damage Resistance

Simpler Cryoplant & 35% Reduction in Energy Consumption

Hyper-NA can benefit from xy-polarized FEL





Reference: T. Pistor, “Exploring EUV scanner design options enabled by free electron laser sources” in Optical and EUV Nanolithography XXXVII, edited by Martin Burkhardt, Proc. of SPIE Vol. 12953 (2024).

Thank you for your attention.