On The Deployment of Free Electron Lasers for EUV High-Volume Manufacturing

Chris Anderson

SPIE Advanced Lithography, Feb. 24, 2026

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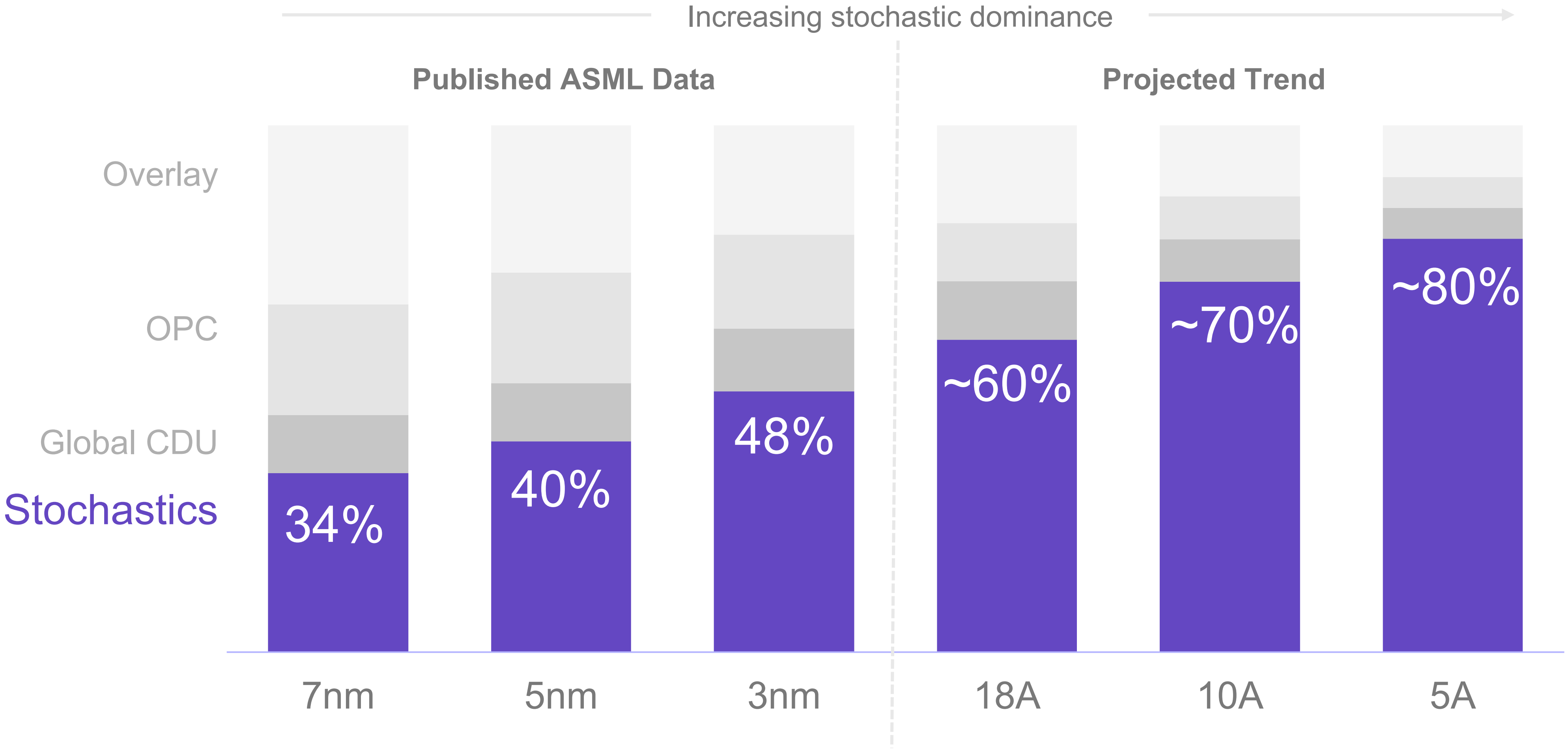
Stochastic Control is Now The Defining Challenge of Advanced Semiconductor Manufacturing.

Stochastics Will Dominate Future EPE Budgets

Published data (7–3nm) and projected stochastic dominance at future nodes



K. Bhattacharyya et. al. "Tough road ahead for device overlay and edge placement error" https://doi.org/10.1117/12.2514820

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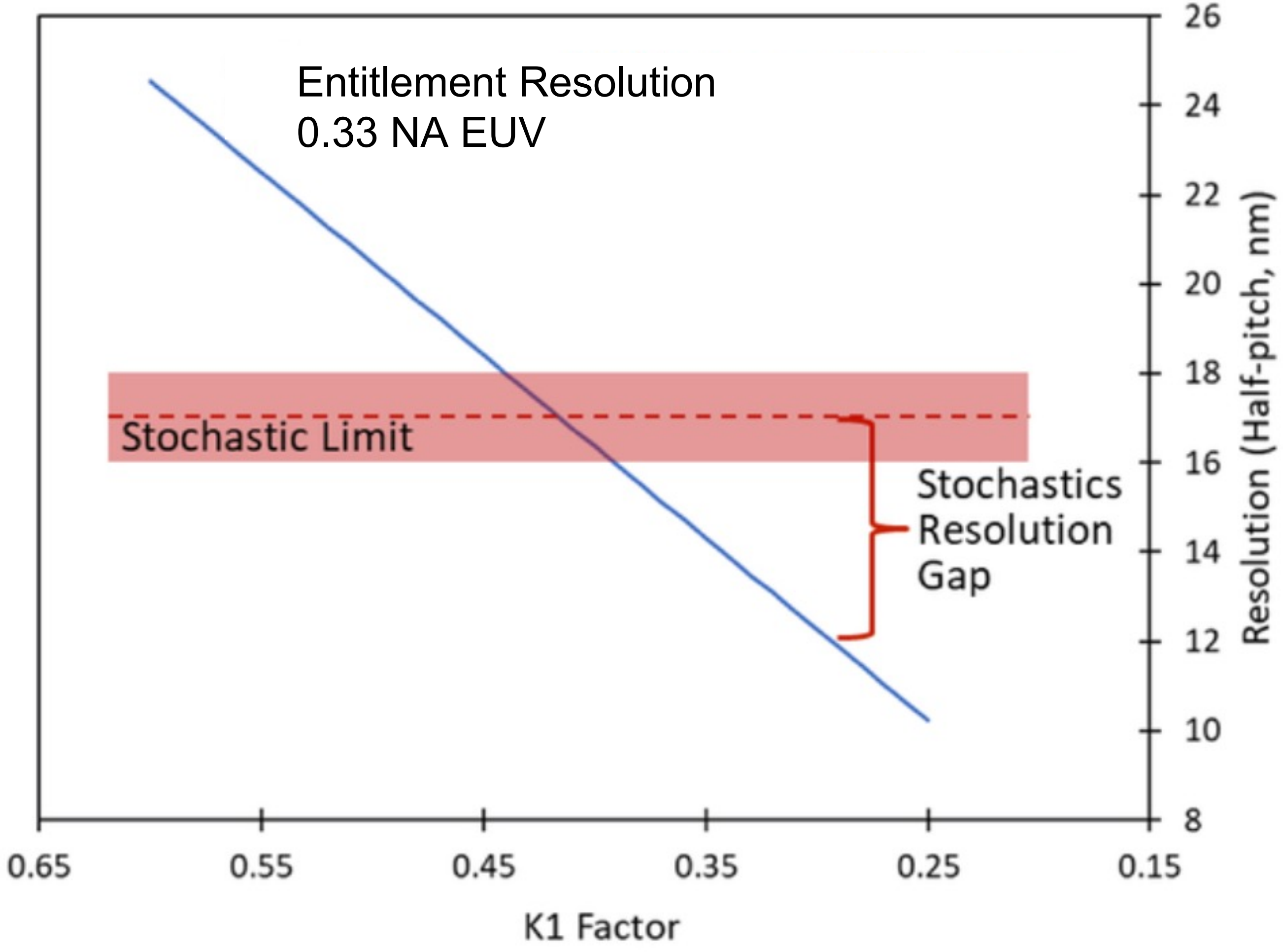
The Stochastics Resolution Gap

Scaling is now defined by dose, materials, and design



Chris A. Mack, Robert L. Bristol, Michael E. Adel https://doi.org/10.1117/12.3072285

Closing the Stochastics Resolution Gap for EUV

- Increase source power (exposure dose)
- Improve resist, etch, and other processing
- Choose integration scheme to provide best resolution/stochastics/cost
- Stochastics-aware design, SMO, and OPC
- Stochastics-aware process control
- More…

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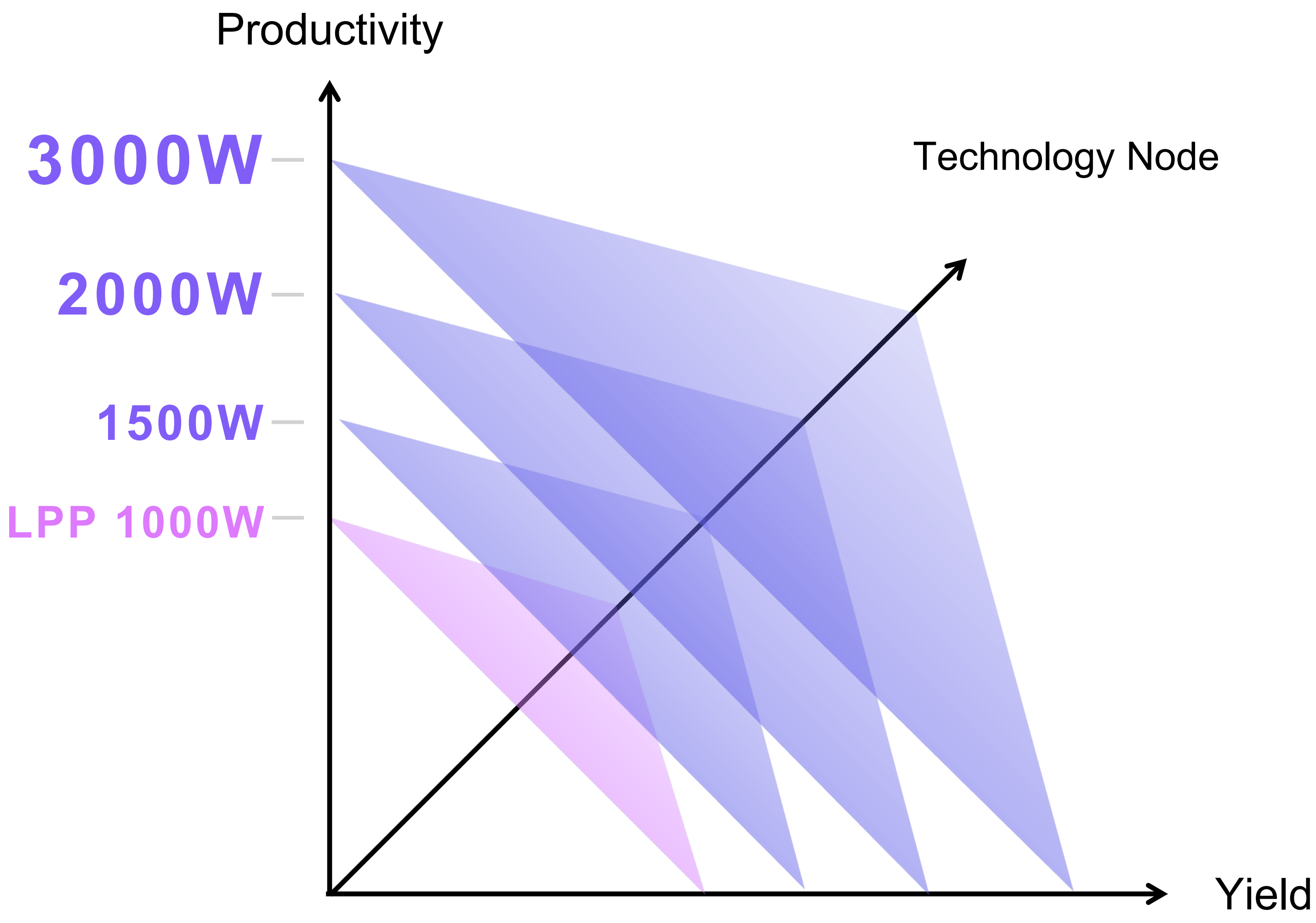
Chris A. Mack, Robert L. Bristol, Michael E. Adel https://doi.org/10.1117/12.3072285

Source Power Unlocks Productivity, Node & Yield



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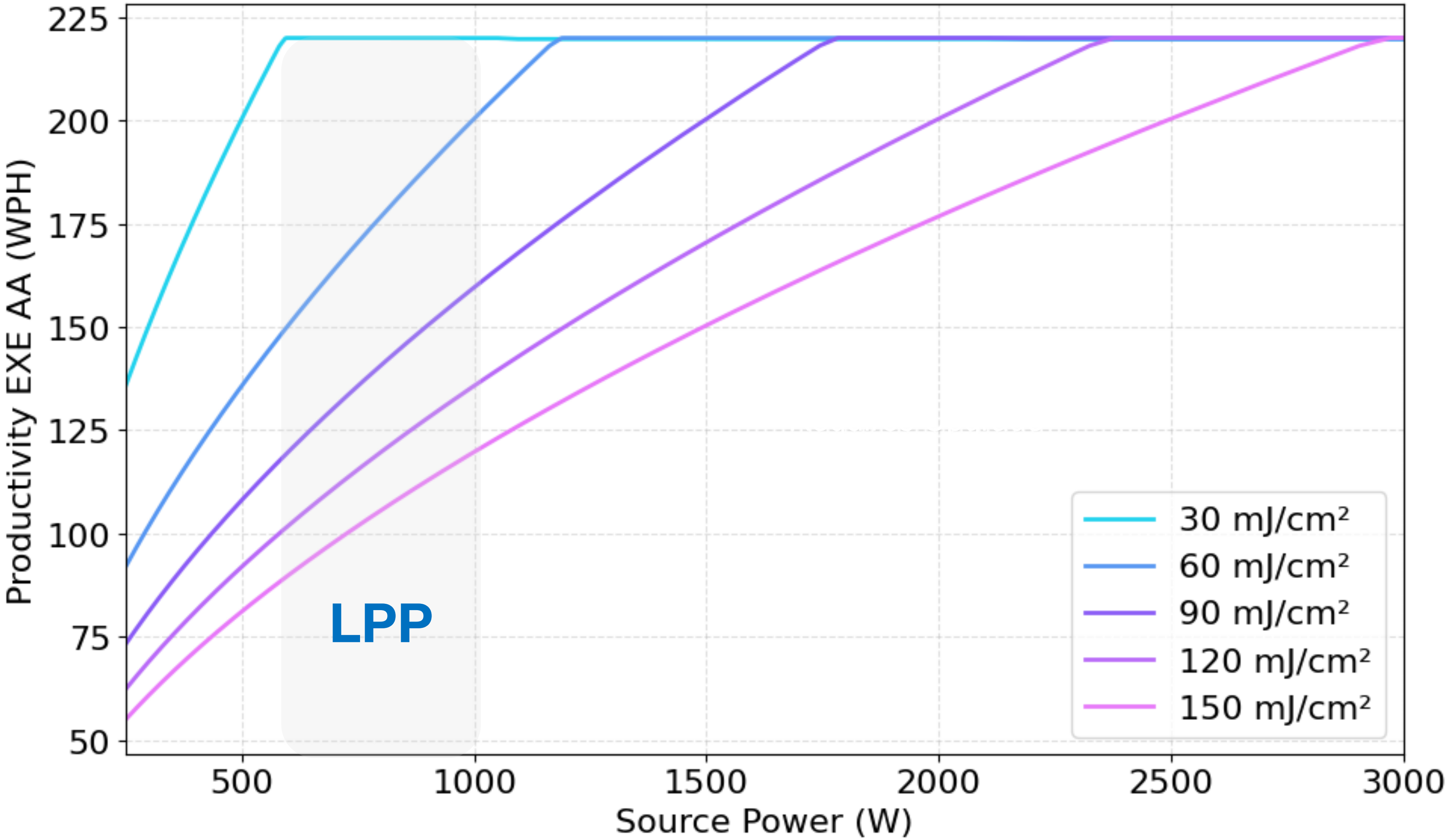
Scanner Productivity vs. Source Power



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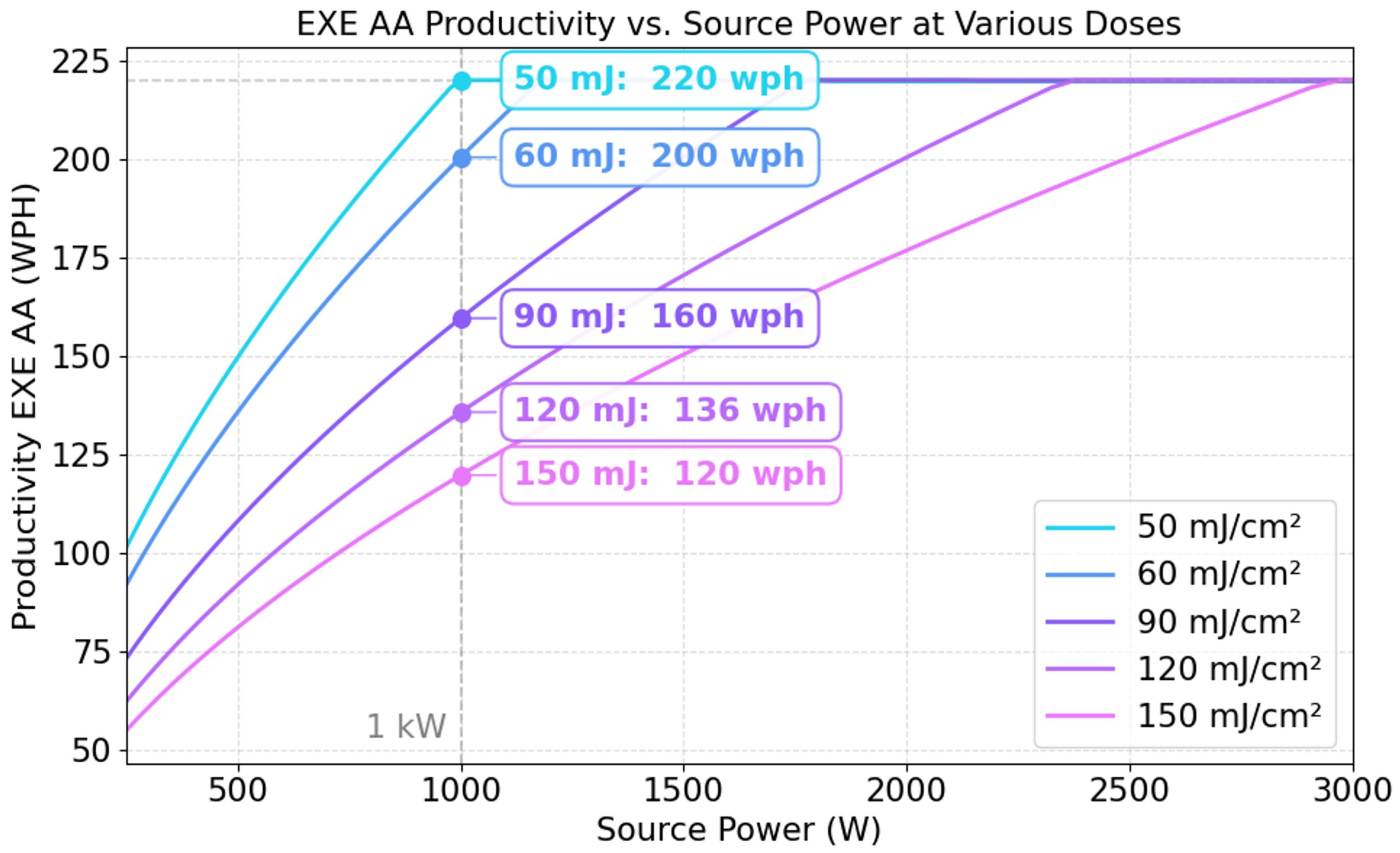
https://euvlitho.com/2024/S1.pdf

Scanner Productivity vs. Dose at 1 kW Source Power



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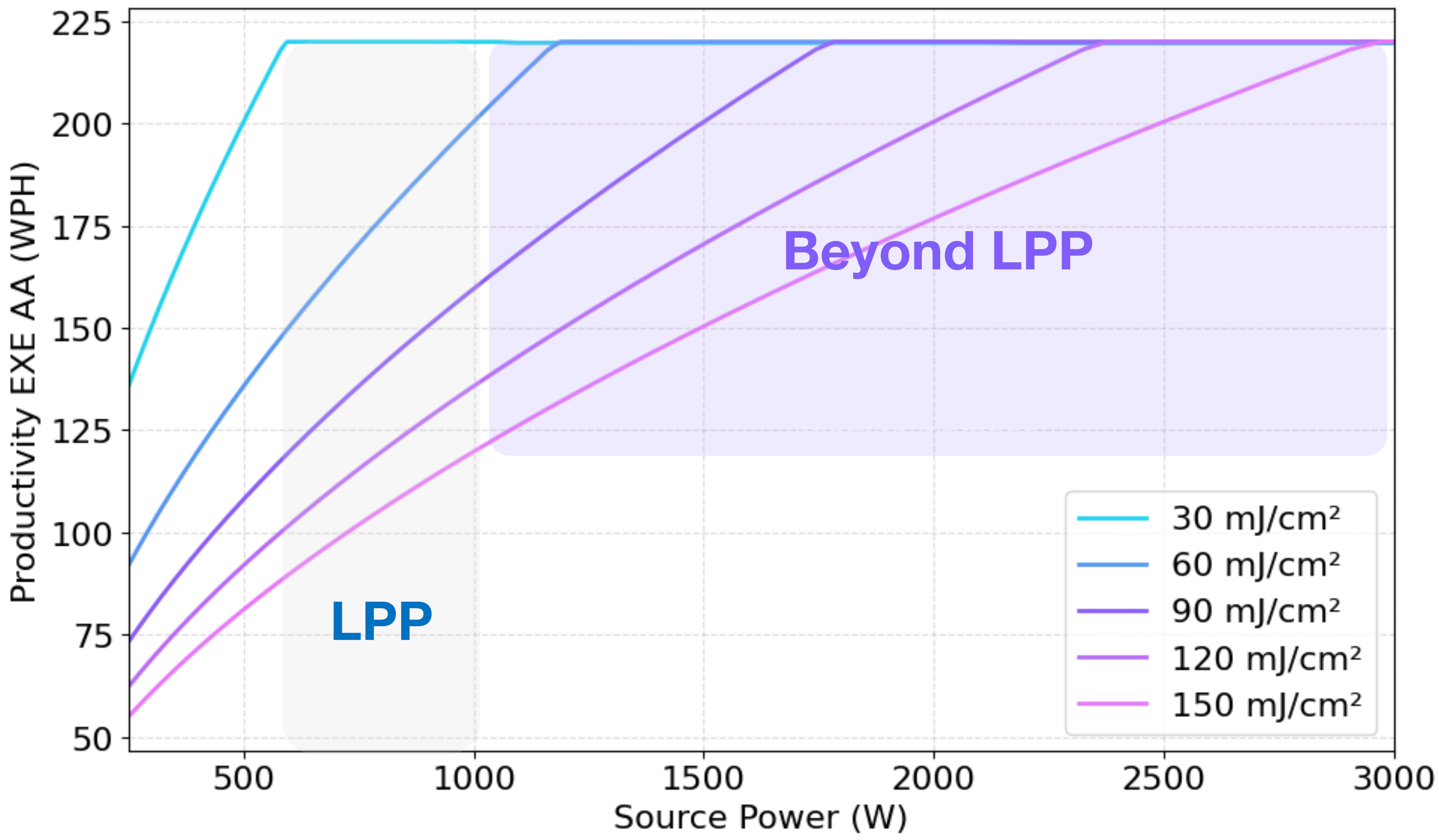
https://euvlitho.com/2024/S1.pdf

Source Power Enables Dose Scaling at Full Productivity



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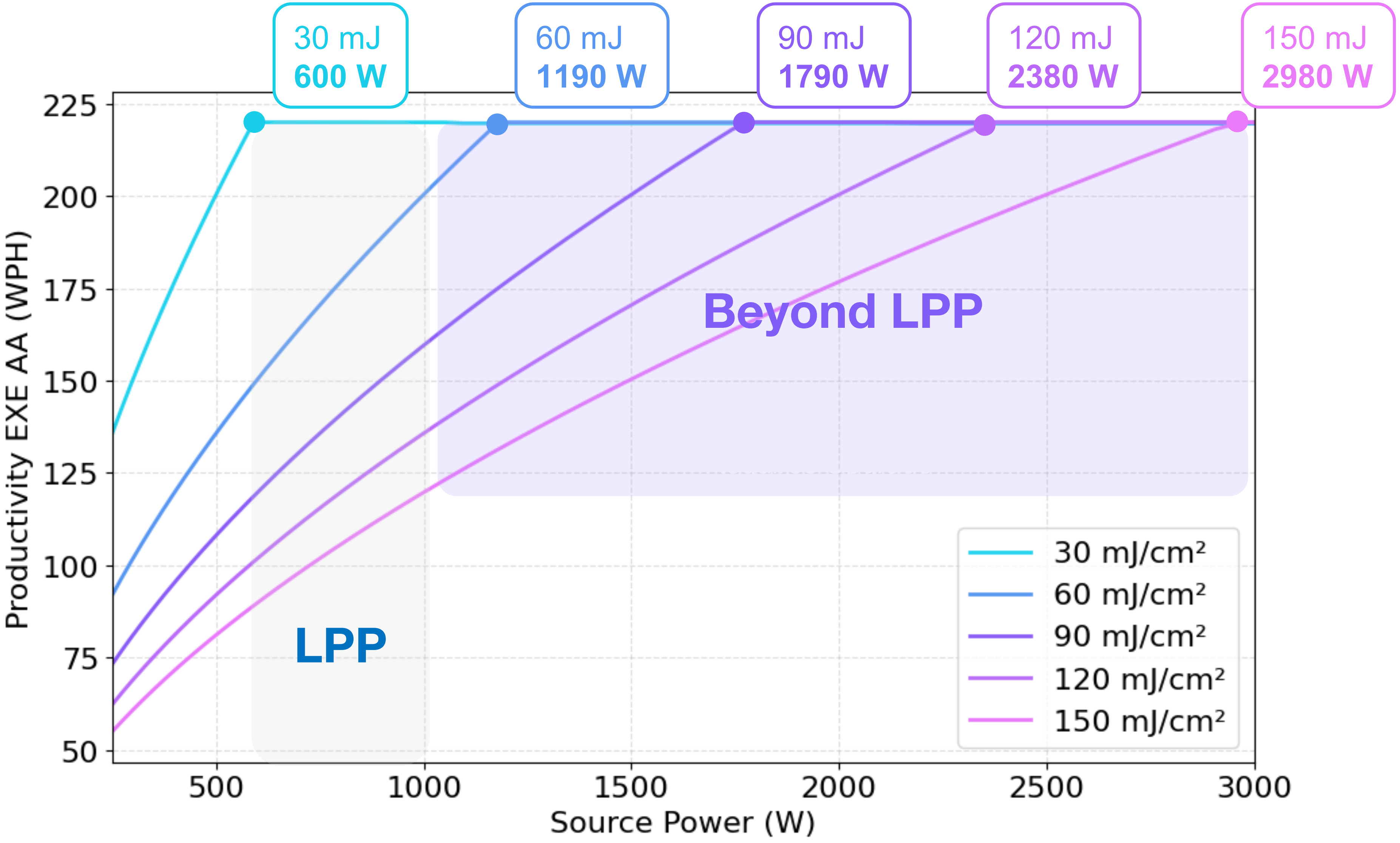
Source Power Enables Dose Scaling at Full Productivity



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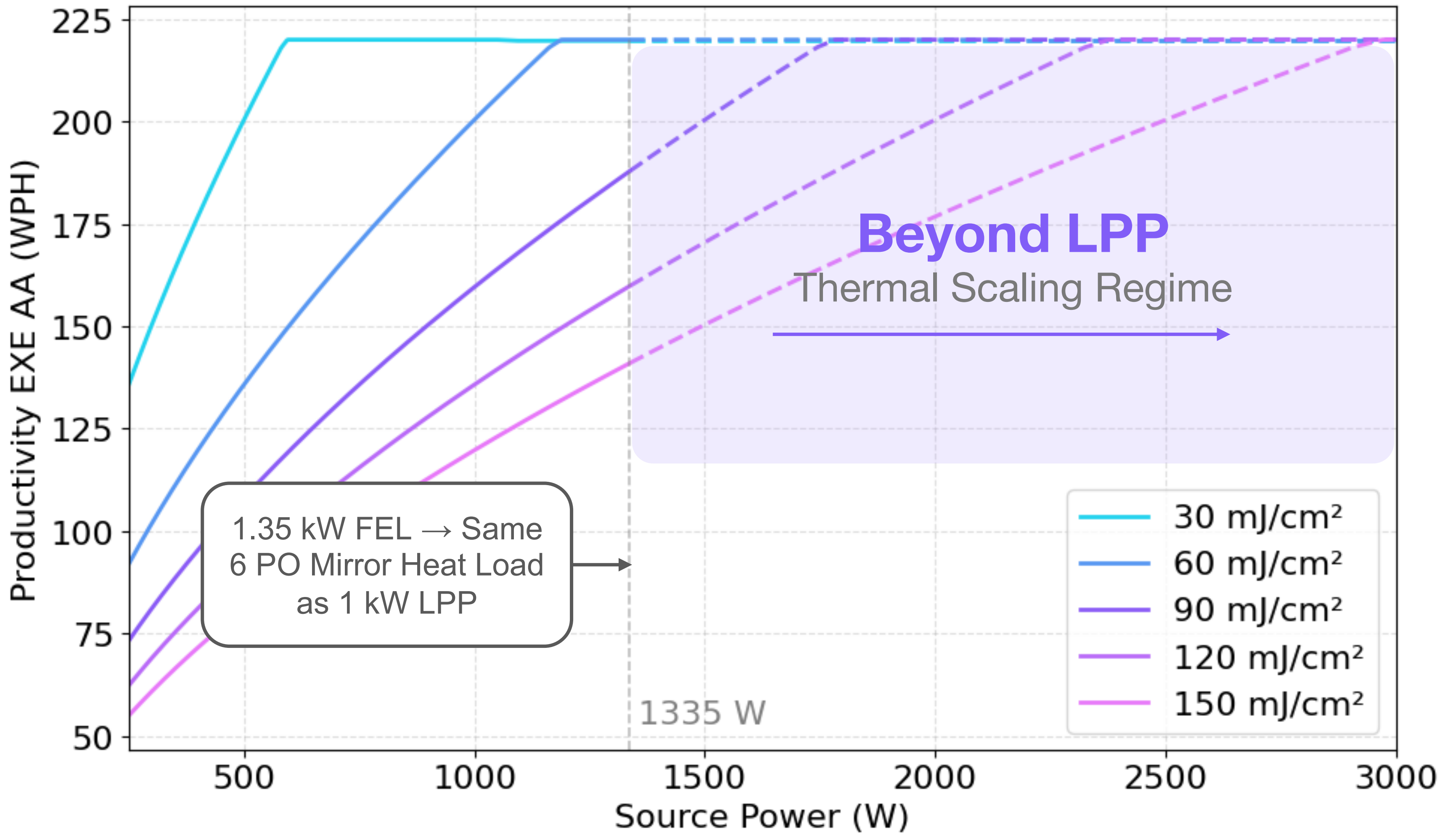
https://euvlitho.com/2024/S1.pdf

FEL Delivers 35% More In-band Power at IF Than LPP For Same PO Heat *Determined by PSDs of Tin, FEL, EUV ML*



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Source Power: In-Band (10-ML reflections) at IF

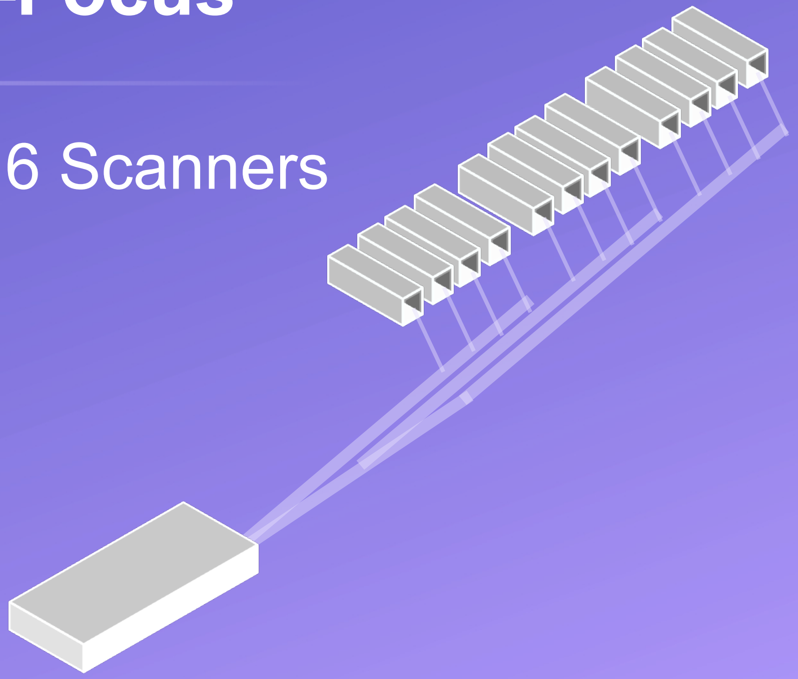
The Next Lever for Stochastic Scaling

Decoupling photon generation from the scanner enables dose breakthroughs

38 kW

Intermediate-Focus

One Source →16 Scanners



99% Availability

Scanner Compatible

9.8 MW
Wall-Plug

2-70 nm
Wavelength

0.5%
Bandwidth

38 kW: 120 kW output, 25% light transmission, 25% gain from bandwidth

99% Availability and 9.8 MW Wall Plug for Dual-Accelerator System

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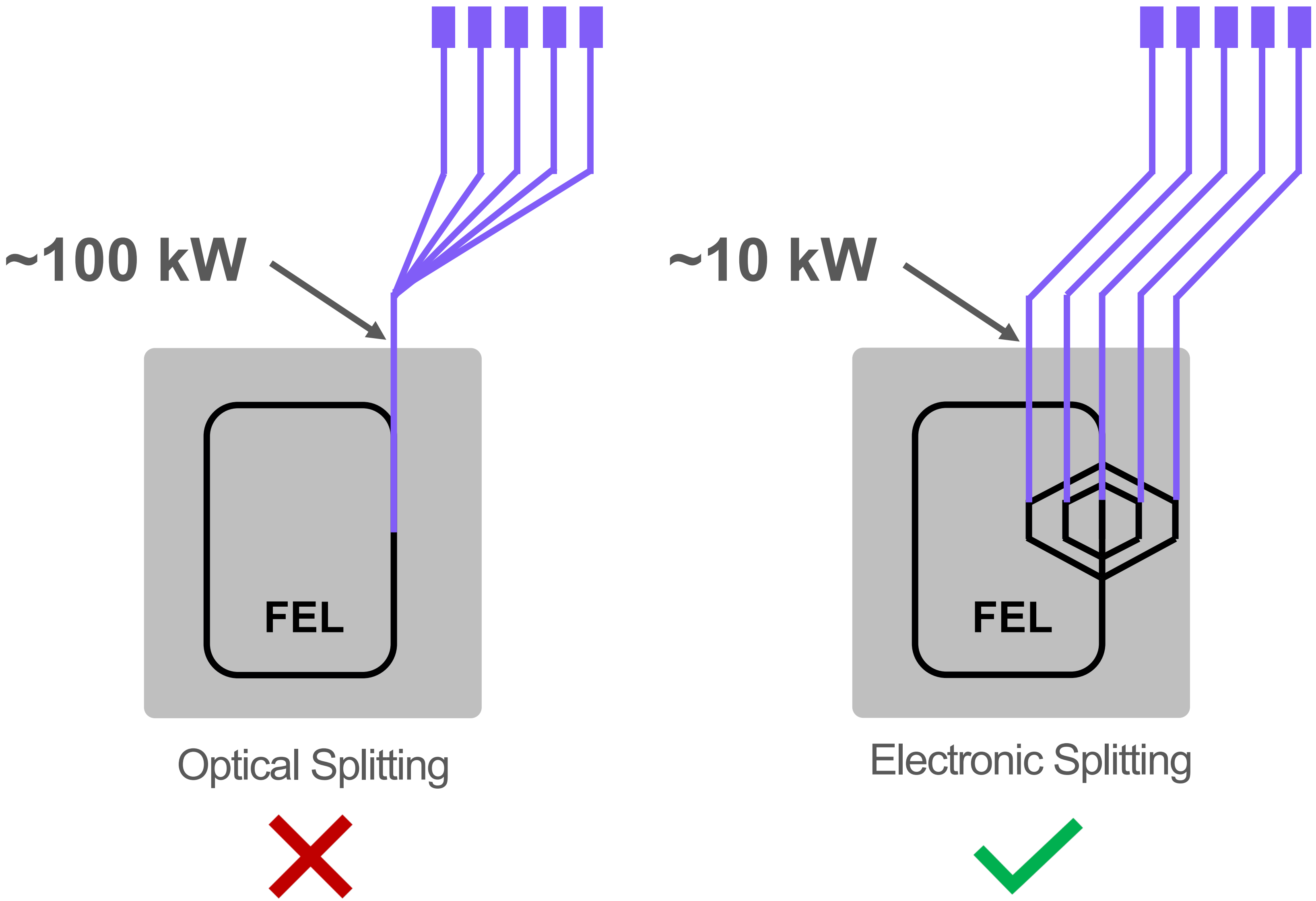
Power Distributed in the Electron Domain — Not the Photon Domain



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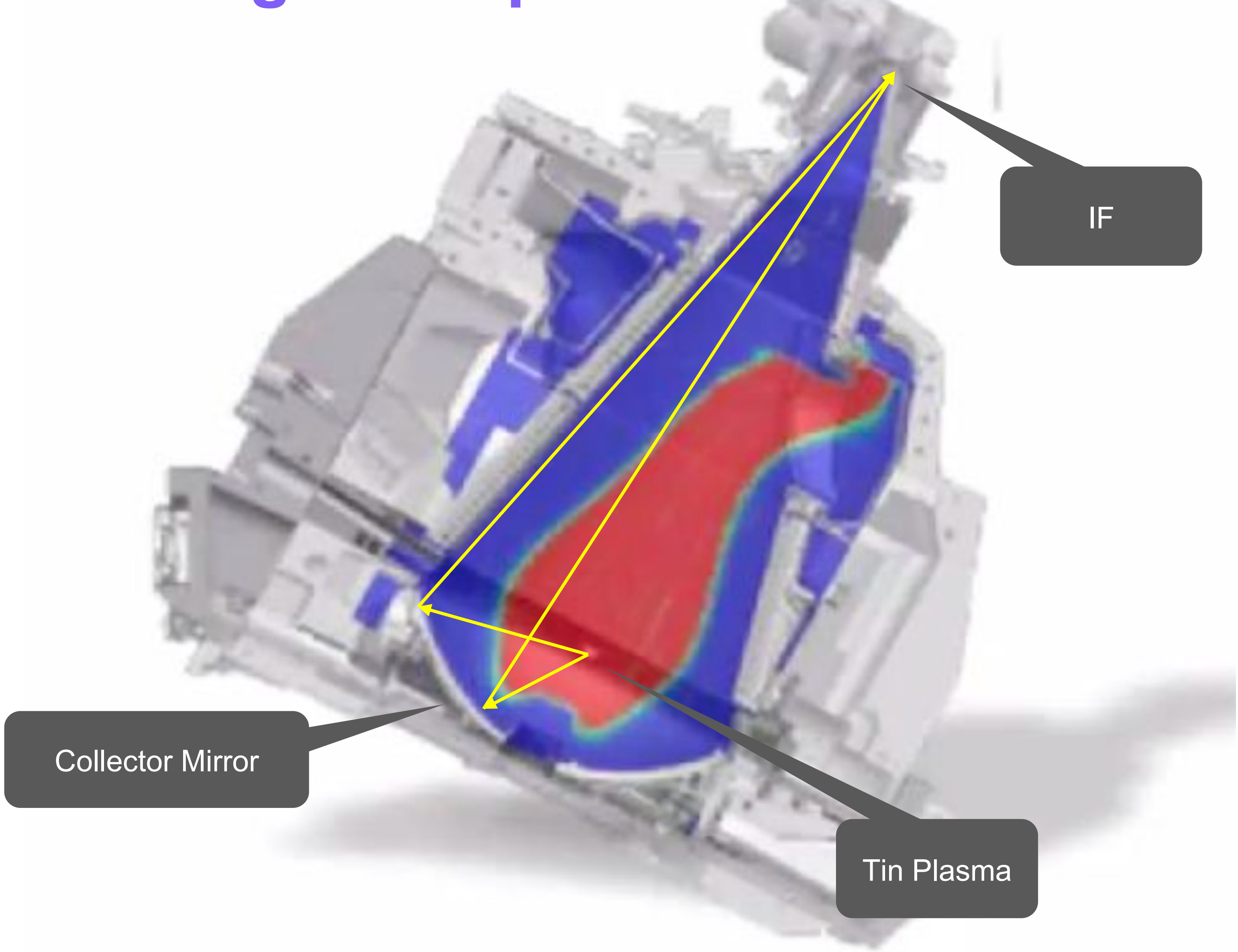
Scanner Integration

Today, LPP collector images Tin plasma to IF



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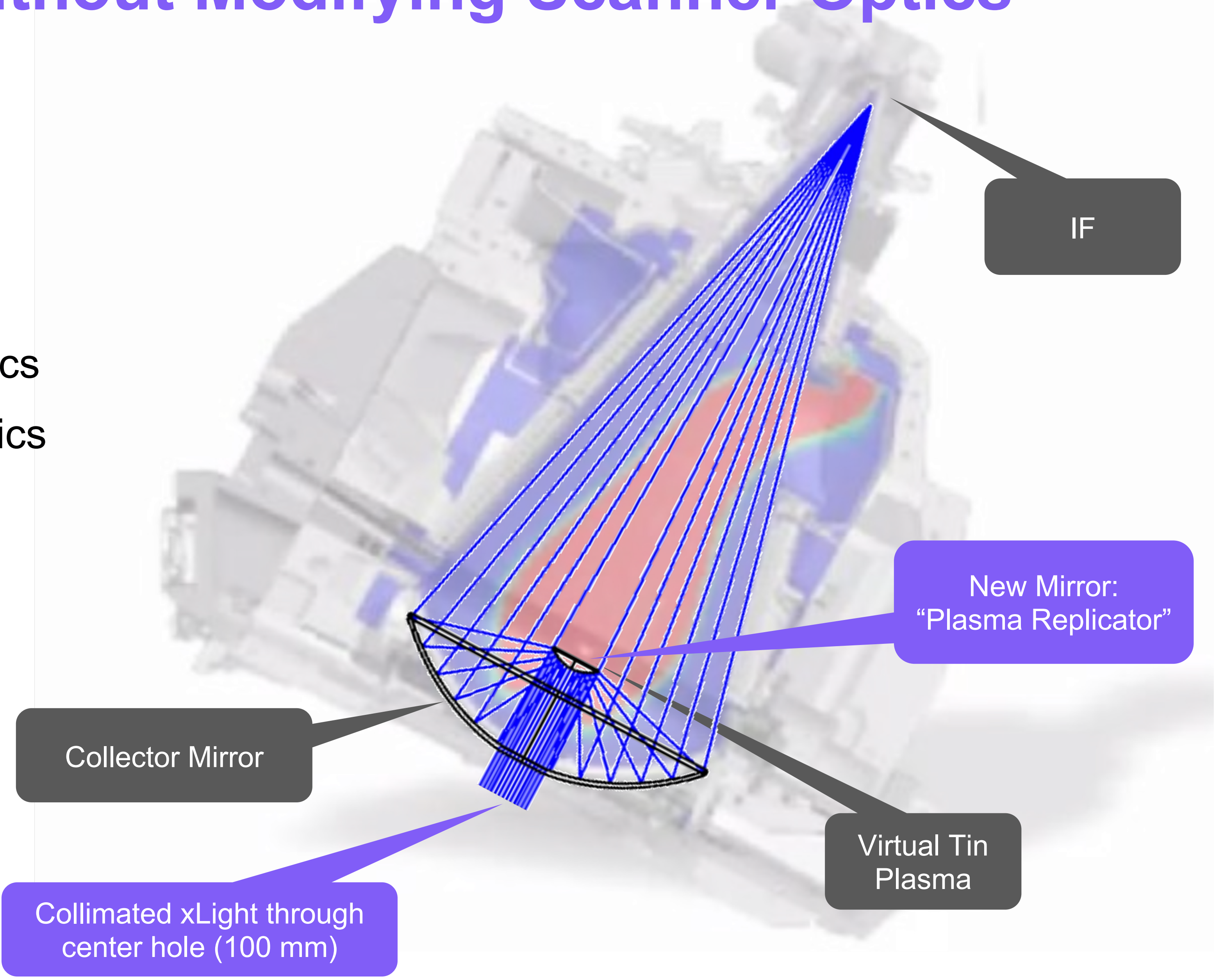
IF Replication Without Modifying Scanner Optics

- Reuses LPP Vessel
- Reuses LPP Collector
- No mod. to Projection Optics
- No mod. to Illuminator Optics



Light Connects Along Same Path, From Sub-Fab

No change from today

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Scanner Architecture Suppresses FEL Speckle to 0.26%

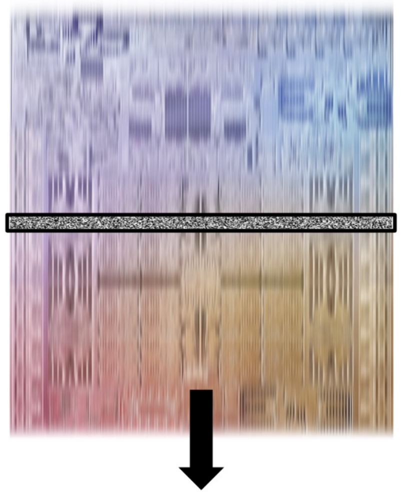
10X Below IDRS 2034 Tolerance (16 nm Pitch, 1.2 nm LWR)

$$100\% \times 1/\sqrt{800} \times 1/\sqrt{180} = 0.26\%$$

Fully developed speckle

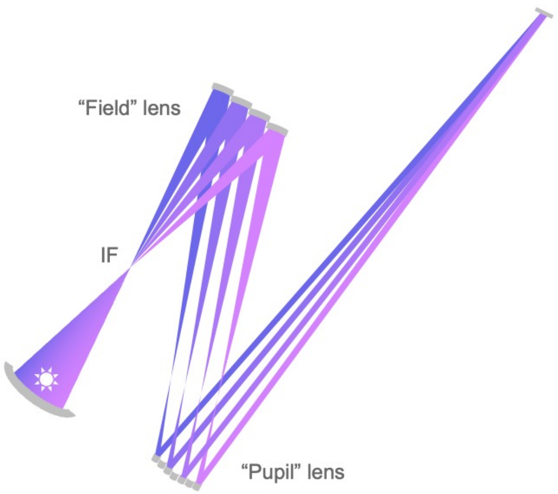
Worst case. Assumes illuminator optics rough enough to fully develop speckle.

Field scan averaging



5 um speckle, 4 mm slit height, 800 speckle grains in scan direction

Channel averaging



Asynchronous arrival of illumination channels changes speckle pattern in time at photomask

0.26% contrast speckle

~10X lower than tolerable level of 2.1% based on IDRS 2034 Pitch 16 nm, 1.2 nm LWR 3σ

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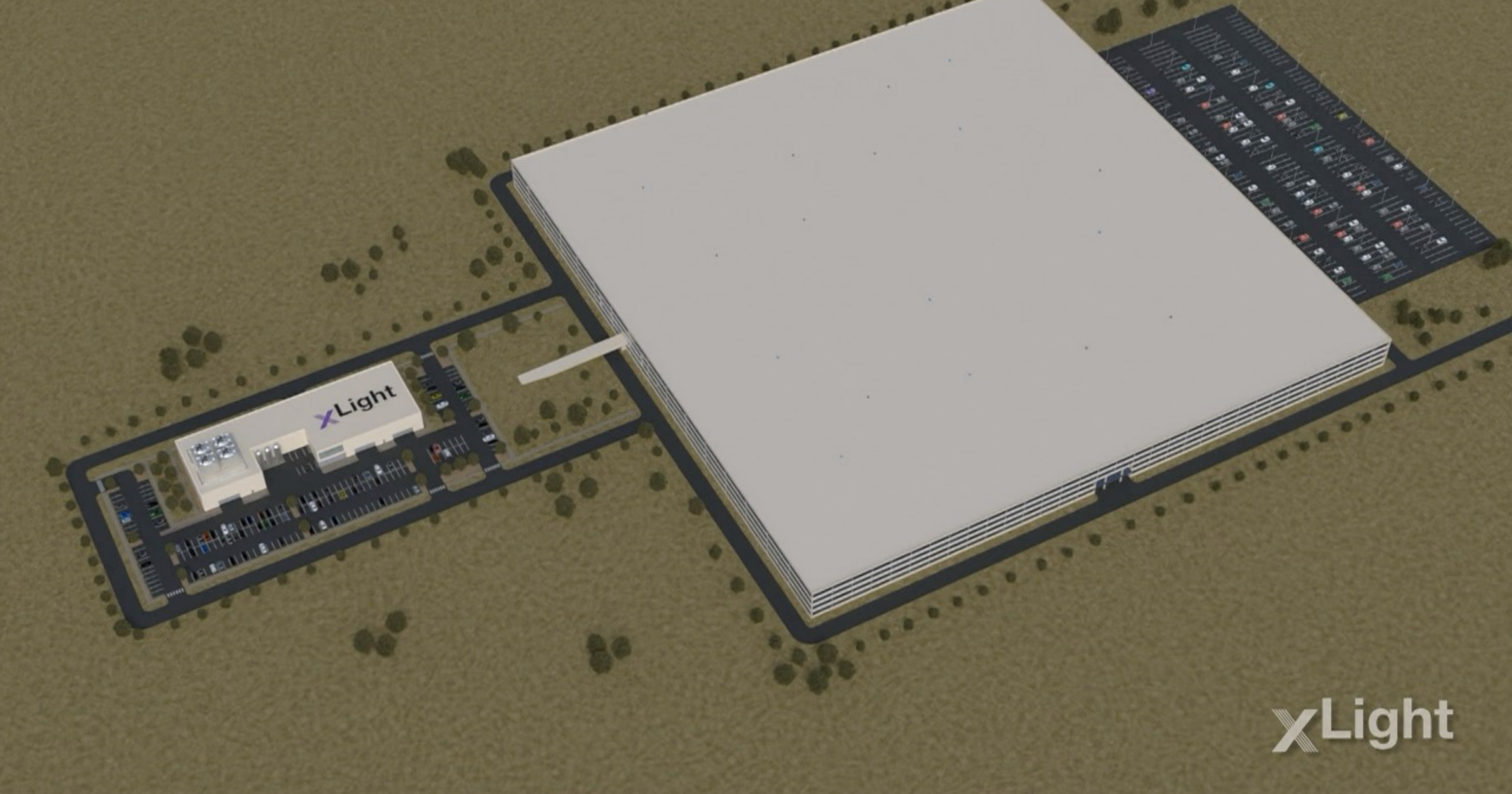
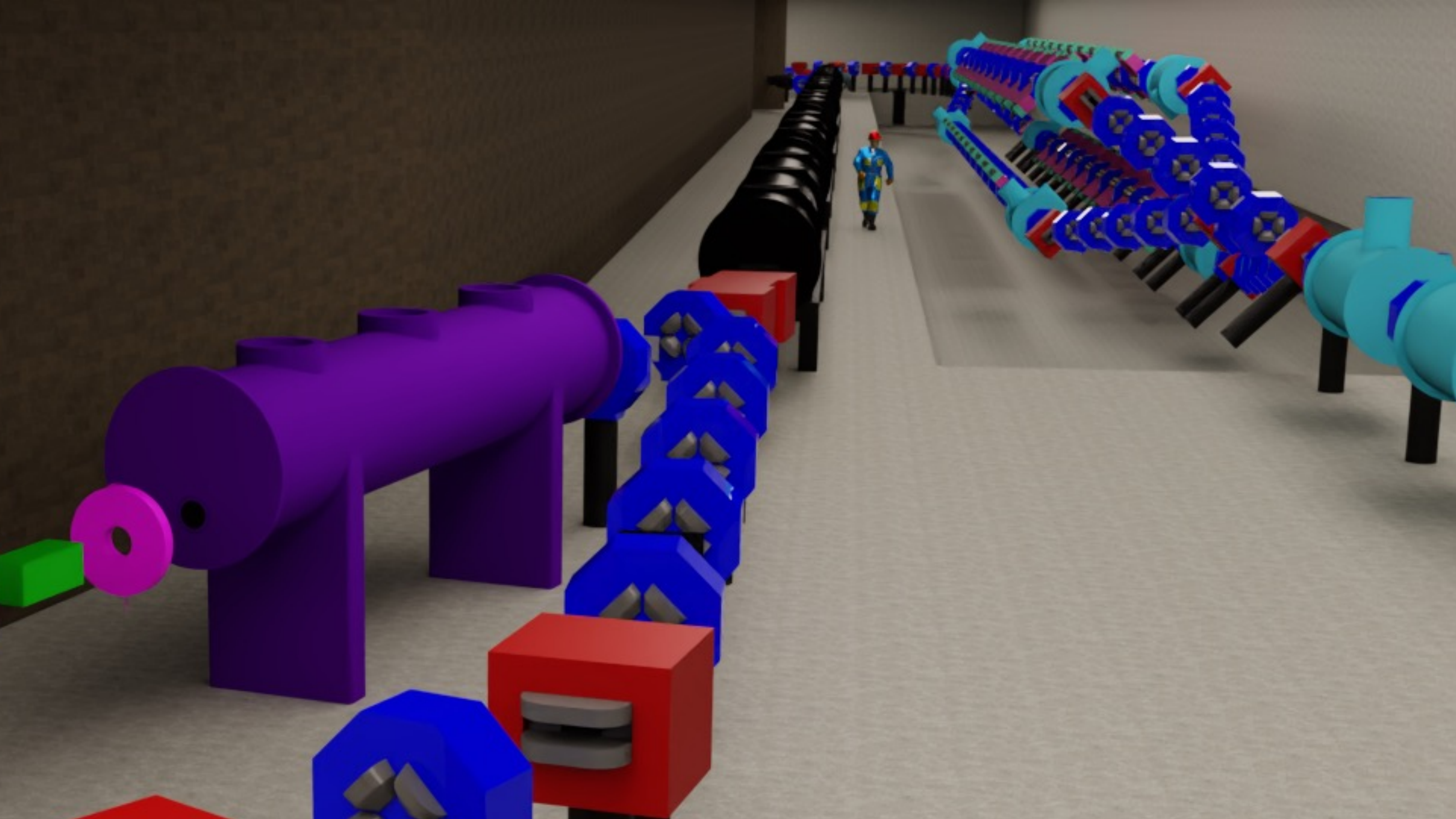
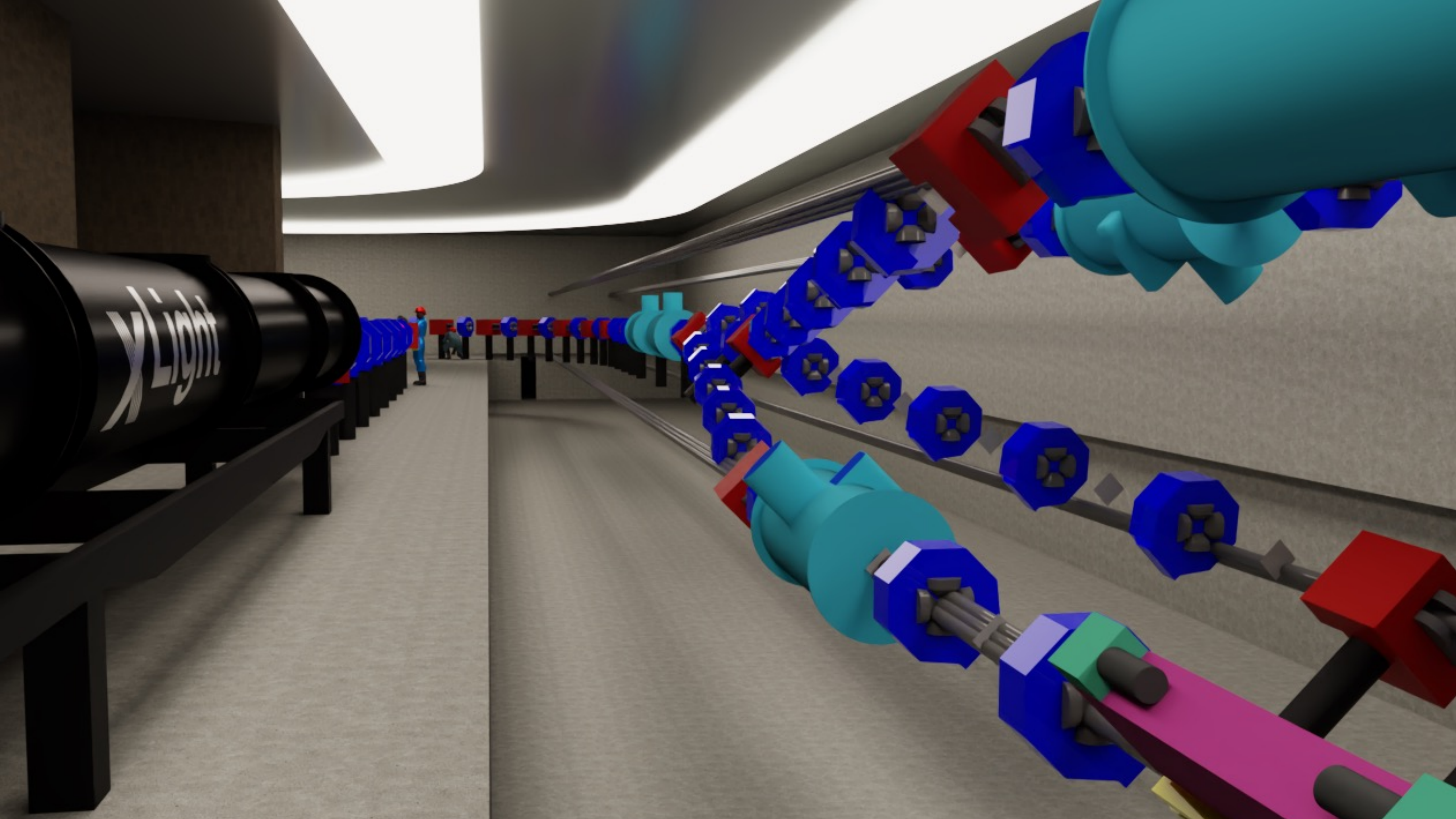
Christopher N. Anderson, "On the compatibility of free-electron lasers with EUV scanners," https://doi.org/10.1117/12.3012412

https://youtu.be/11GAU31LQRs



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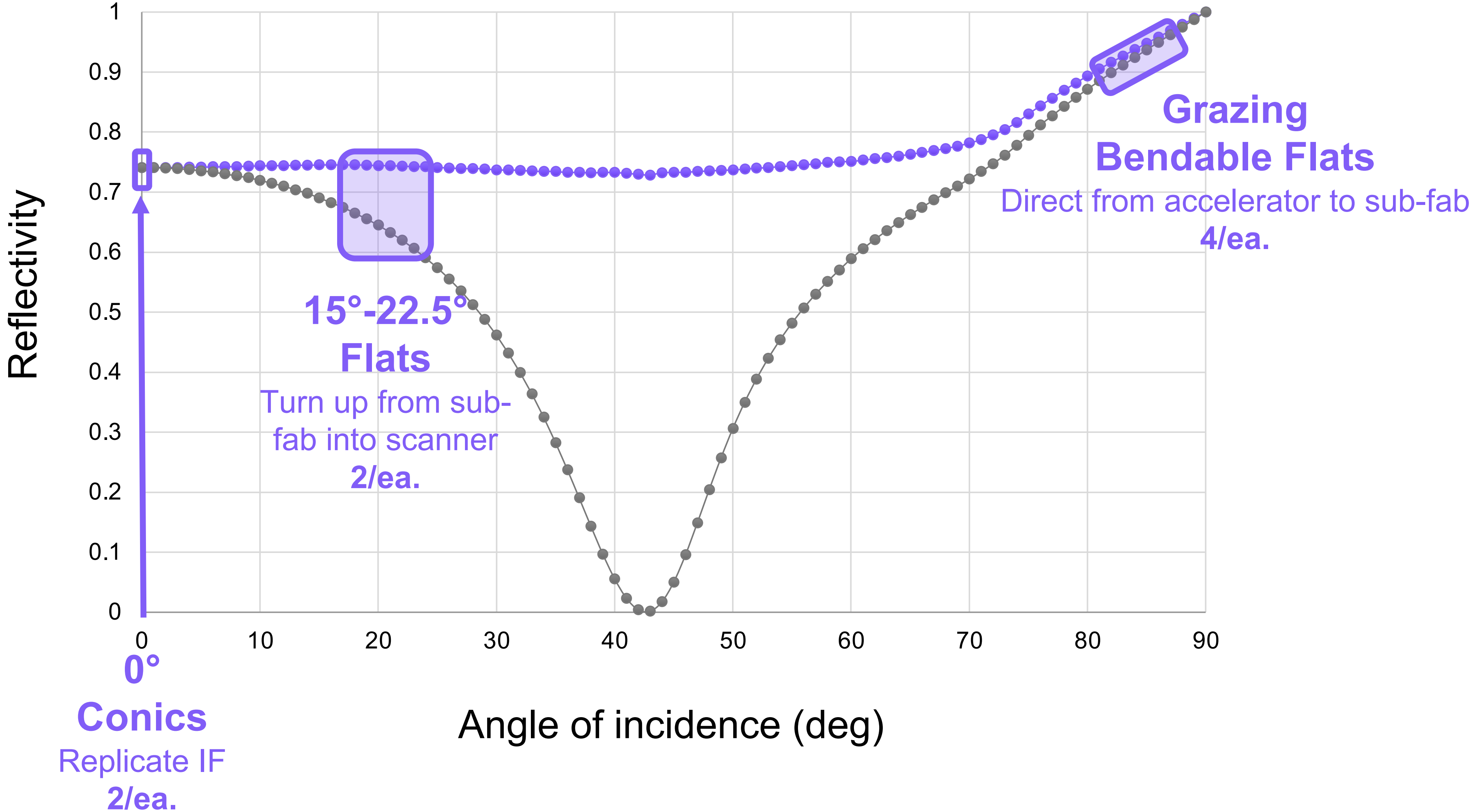
Fab Architecture

Foundational Solutions

xLight Mirrors Operate In Three AOI Regions

Normal incidence; 15°-22.5°; grazing



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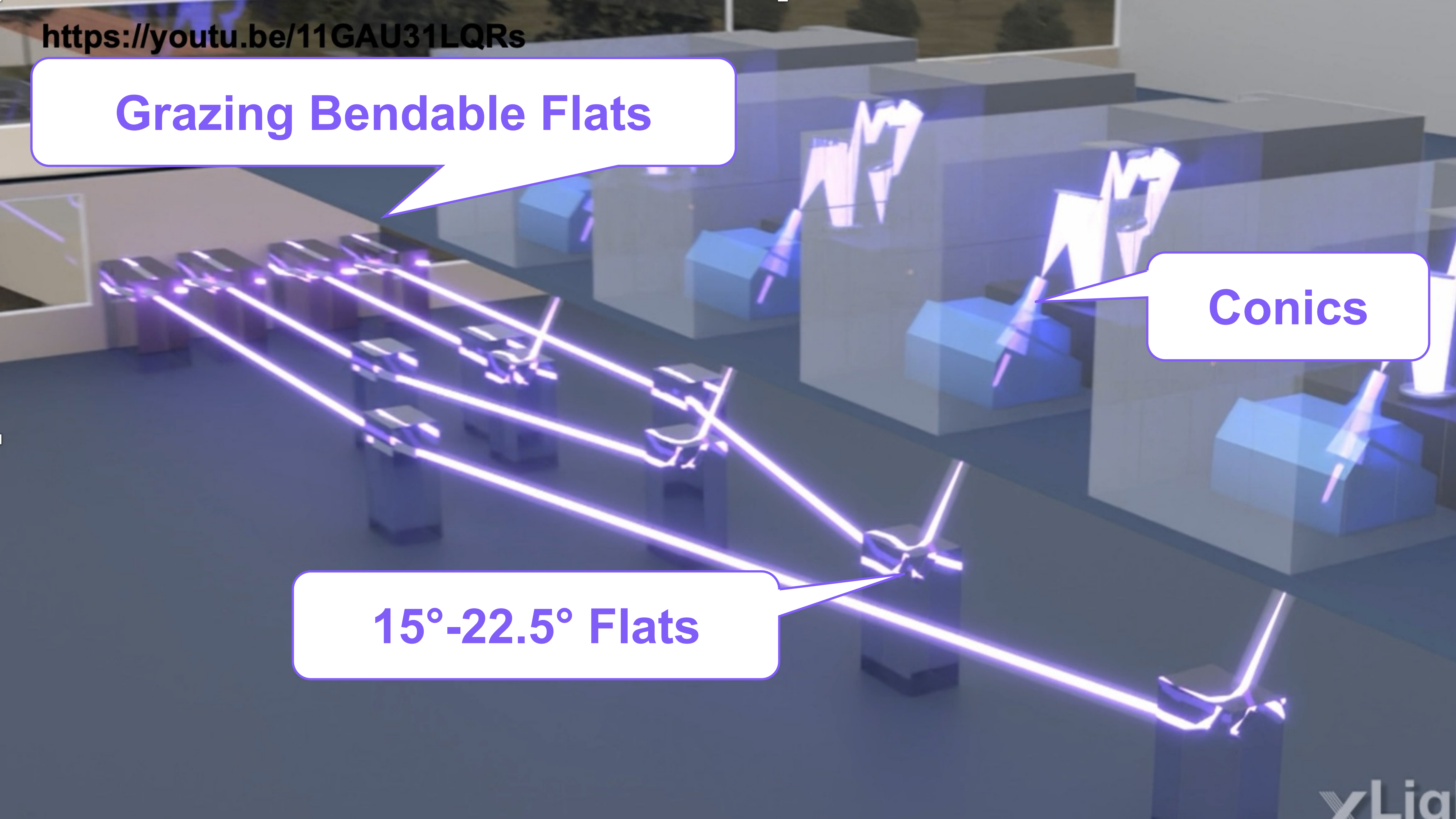

https://youtu.be/11GAU31LQRs
Grazing Bendable Flats
Conics
15°-22.5° Flats

Fab Building Motion Solutions

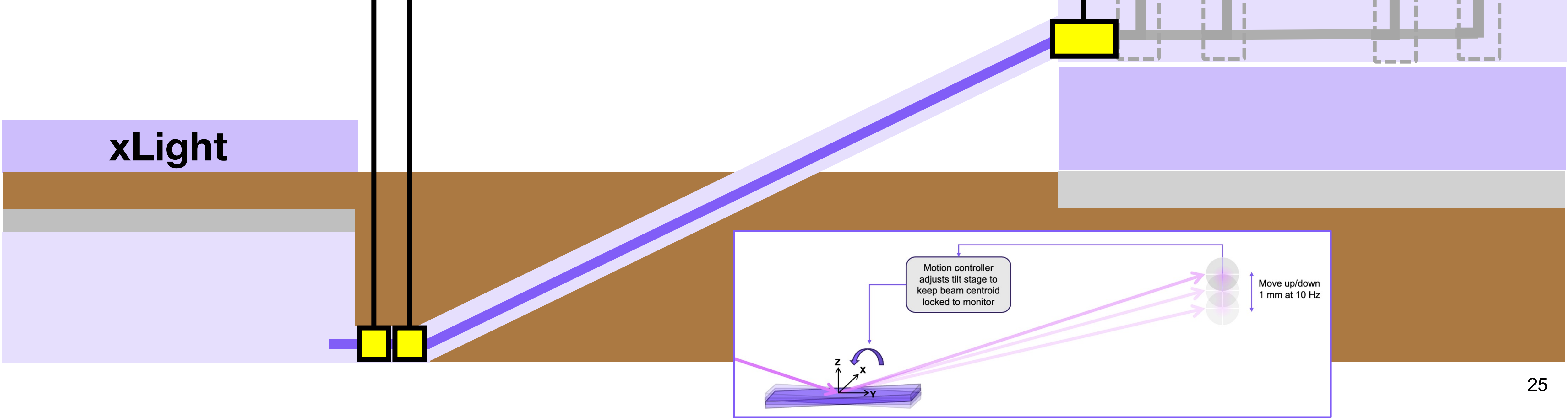
Closed Loop Control Locks Reflected Beam To Next Mirror For > 99.7% Energy Stability

Building Movement

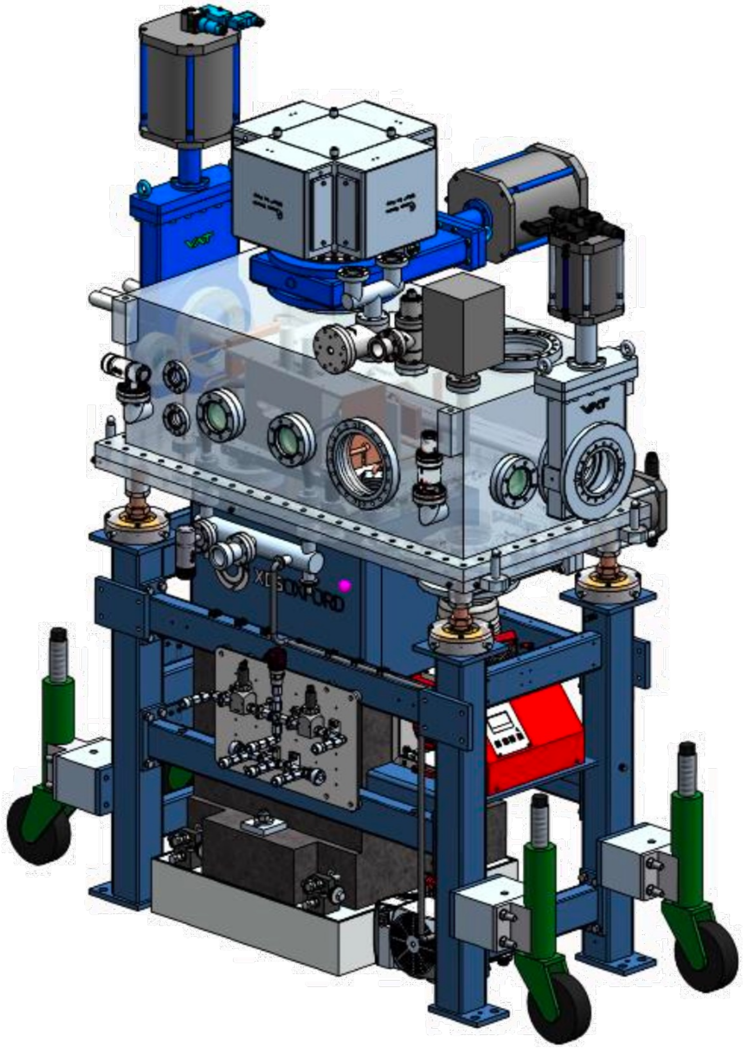
- ±5 mm (X/Y), ±1 mm (Z)
- 0.1-2 Hz

Control

- 10 Hz (> 5× building motion bandwidth)
- Real-time beam position feedback

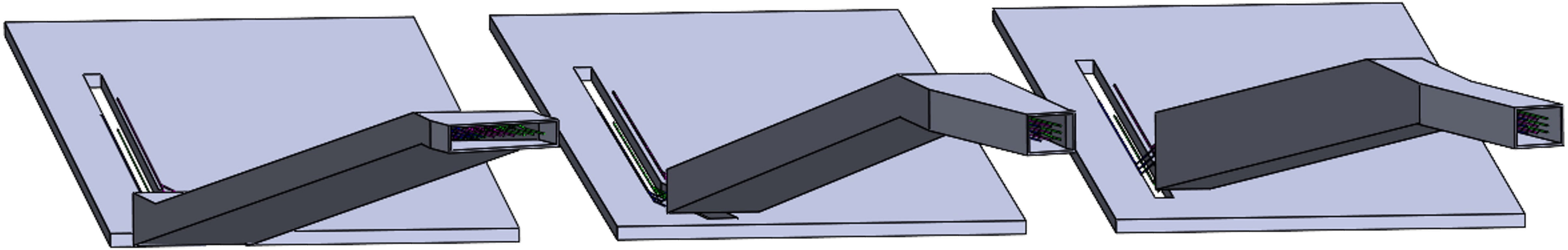


1.5 m x 0.5 m Mirror Modules

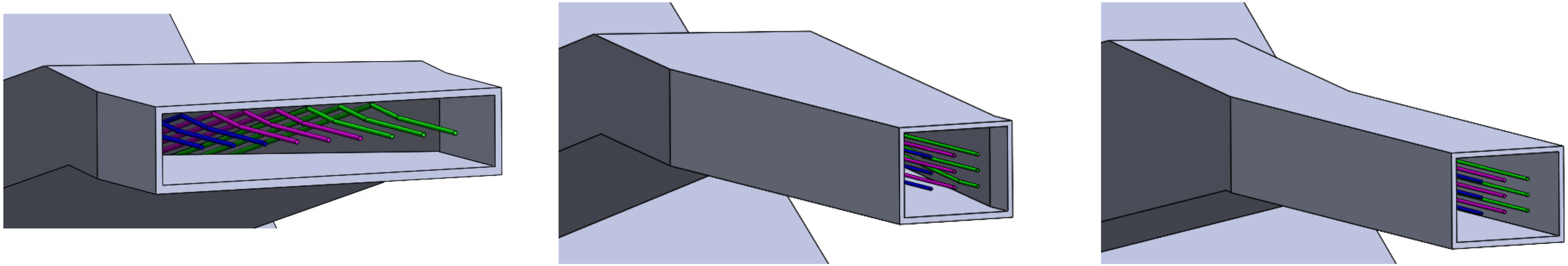


Flexible Routing Supports Horizontal or Gridded Beam Arrays In Fab

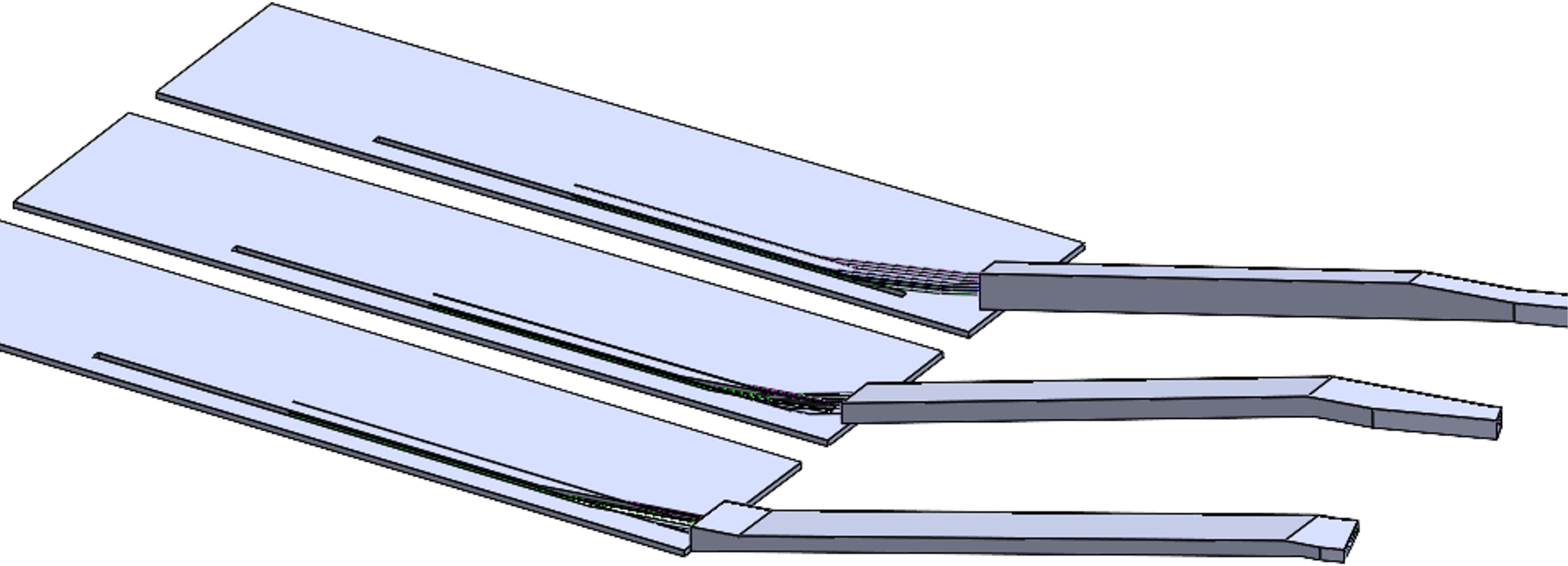
Accommodates different footprints for the transport duct



Horizontal | **Grid Array** | **Grid Array (Alt)**



Transport Duct Perspective View



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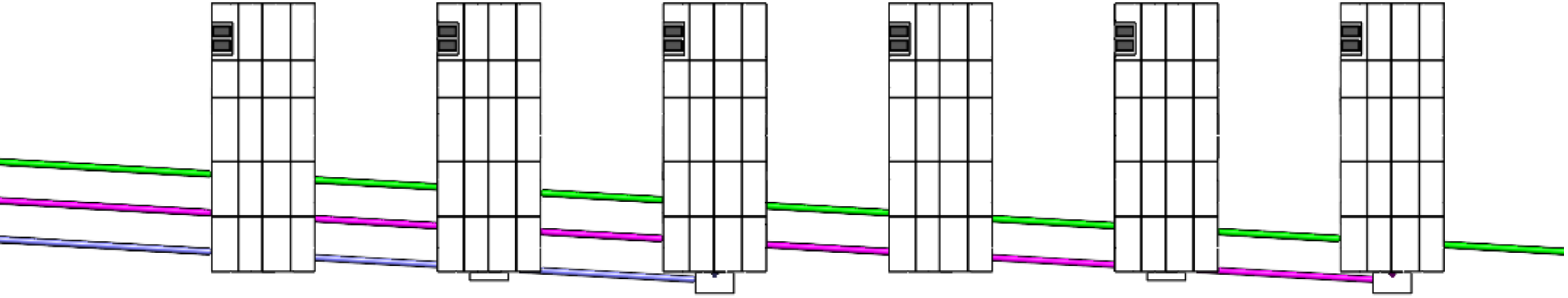
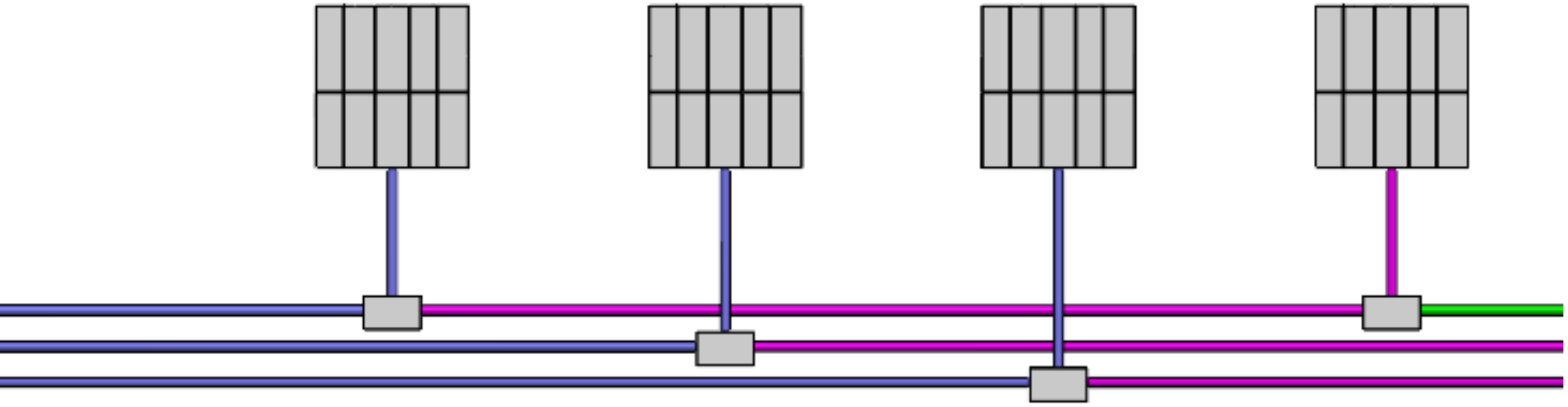
Scanner Clusters In Fab

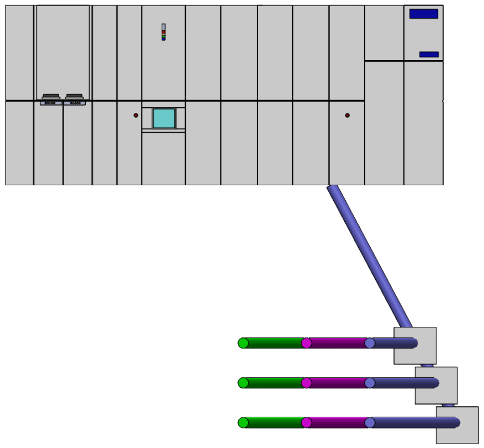
Plan View



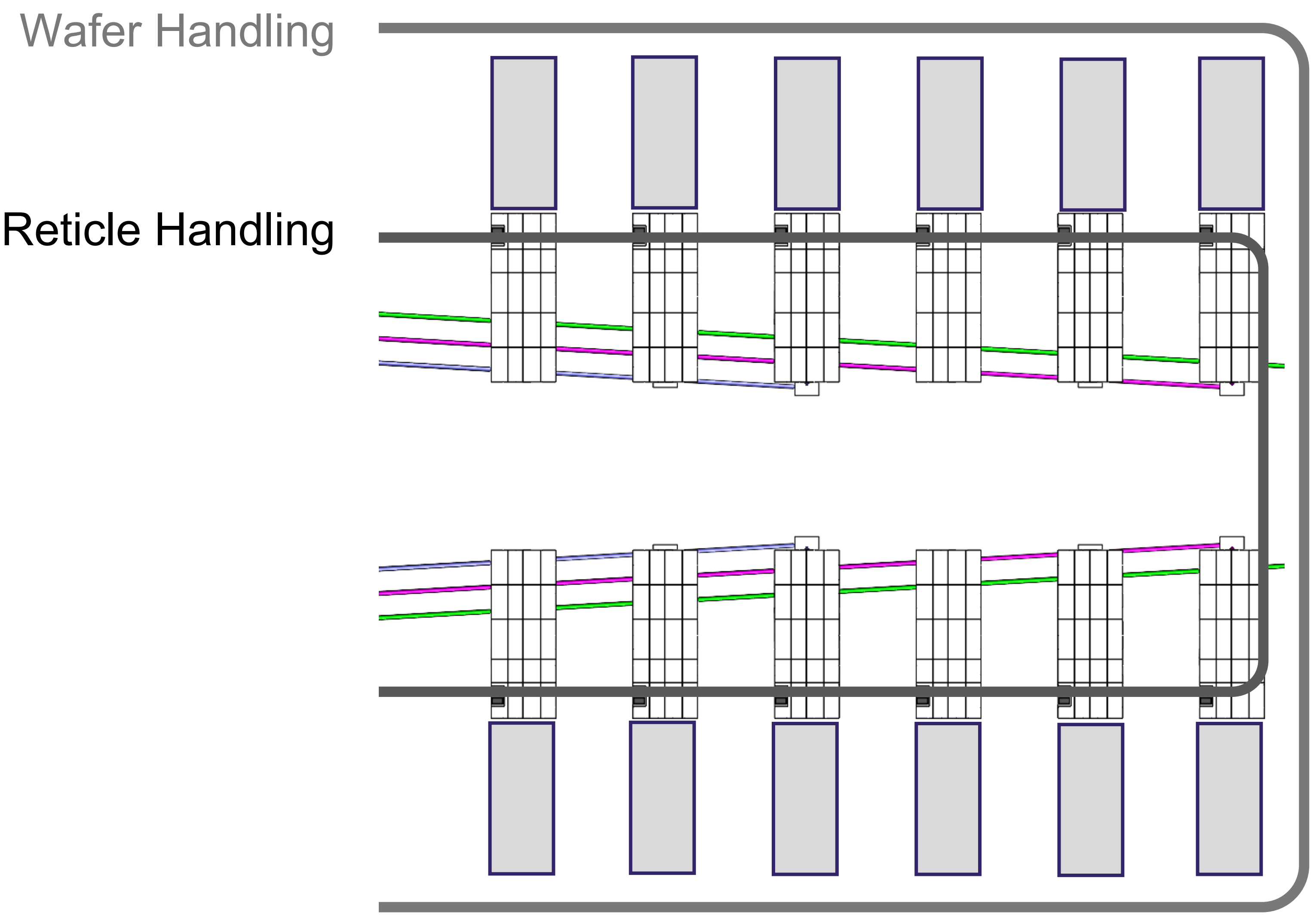
Elevation (End)



Elevation (Side)



Scanner Clusters with OHT



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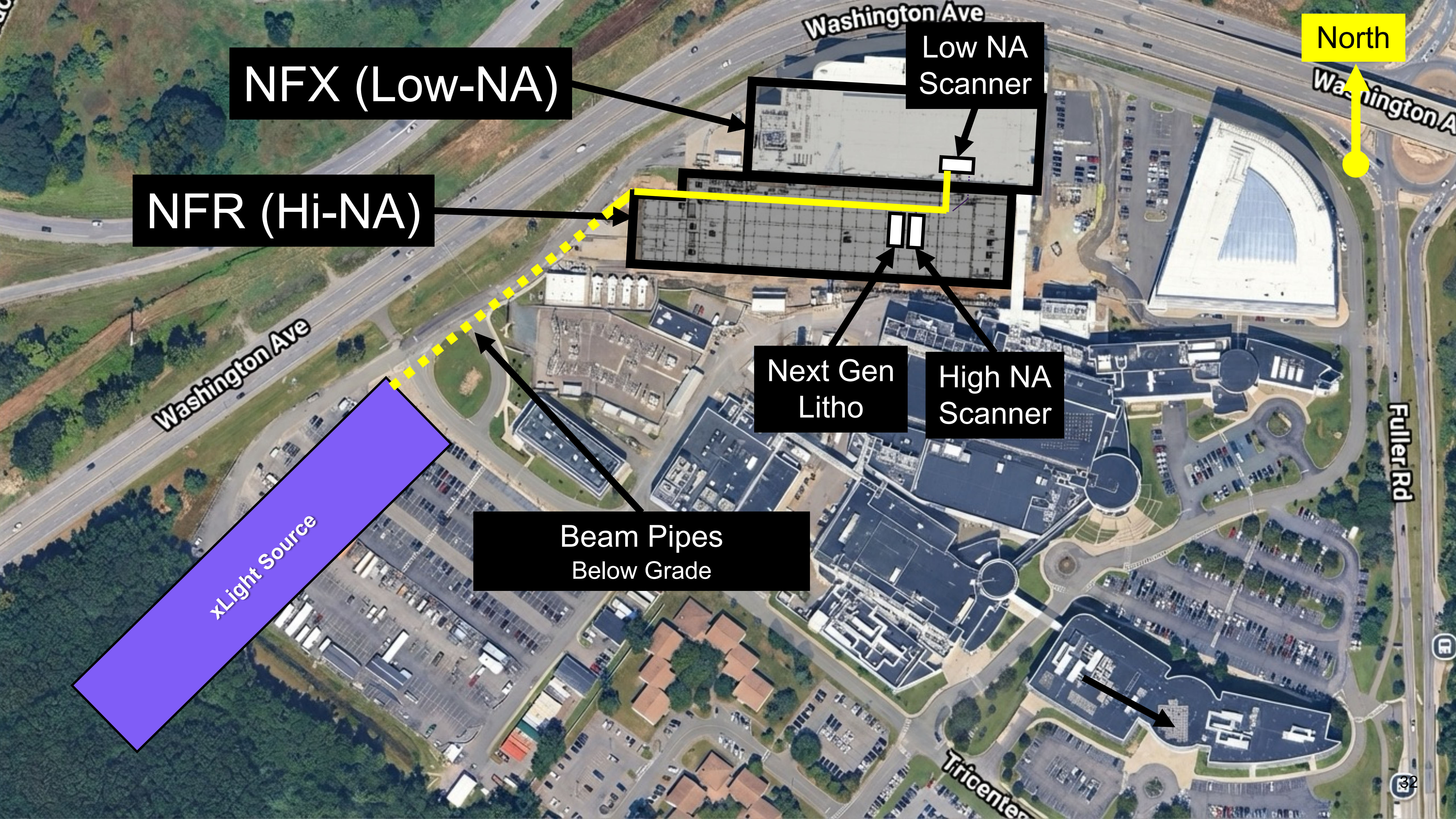
Deploying the Prototype at NY CREATES

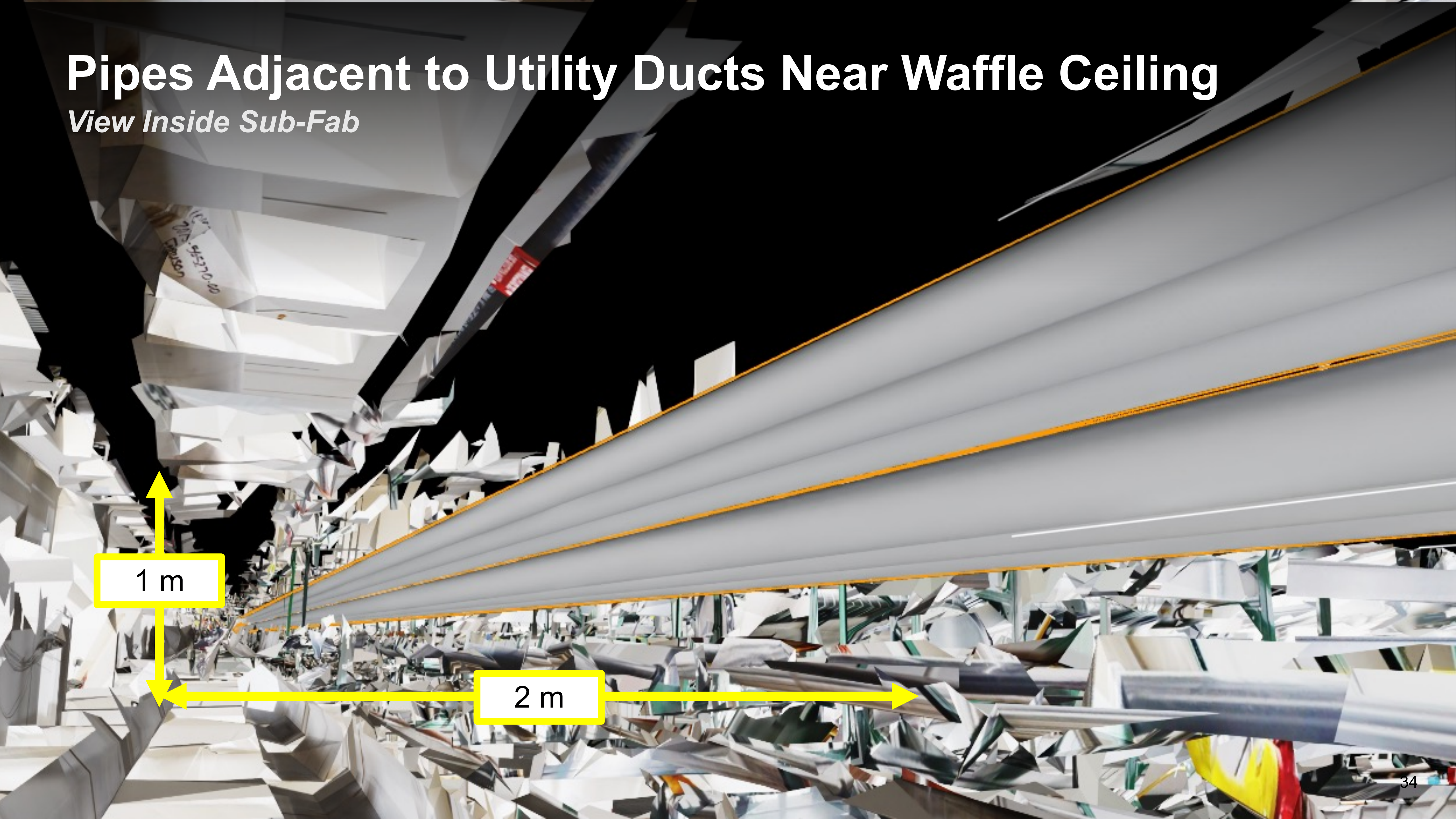
Albany NanoTech Complex


NFX (Low-NA)
NFR (Hi-NA)
Low NA Scanner
North
Washington Ave
Next Gen Litho
High NA Scanner
Beam Pipes
Below Grade
xLight Source
Fuller Rd

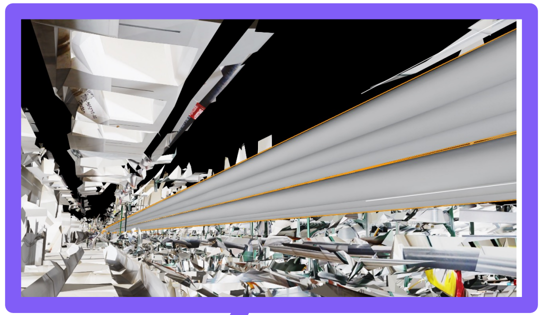
Six Pipes Enter Sub-Fab Above Service Corridor Door

Pipes Adjacent to Utility Ducts Near Waffle Ceiling

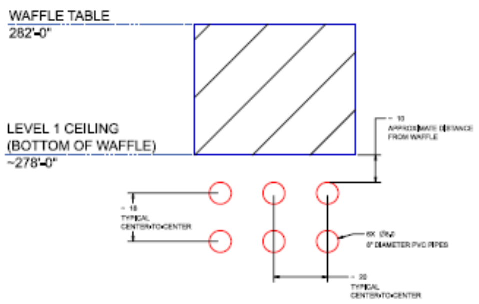
View Inside Sub-Fab

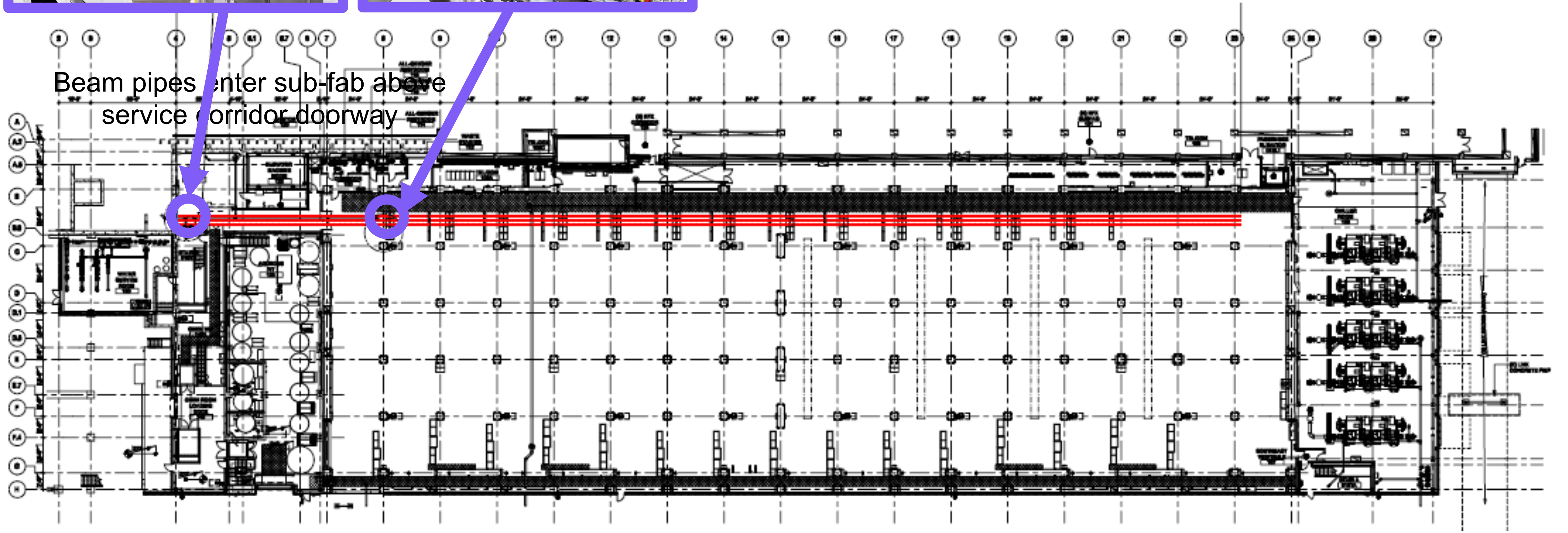


Plan View of NFR Building at NY Creates



FRONTAL ELEVATION VIEW:
VERTICAL POSITION
OF PIPES





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Three of Six Beamlines Committed

Installed Capacity: **6 Beamlines** | Scalable to 9 with Additional Routing

Source
6 Beamlines

Committed (3)

EUV Low-NA

EUV High-NA

BlueX/BEUV

Available (3)

Available
Beamline Port
4

Available
Beamline Port
5

Available
Beamline Port
6

Expansion Enabled: → **9 Total Beams**
With additional routing

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Industrialization

99% Availability With Existing Hardware

Requires redundant, serviceable system architecture

79%

Scientific-Grade

Baseline
Single ERL

85%

Cryoplant Upgraded

For maintenance in service

94%

Spares on site

For hardware that drives unavailability

98%

Dual ERLs

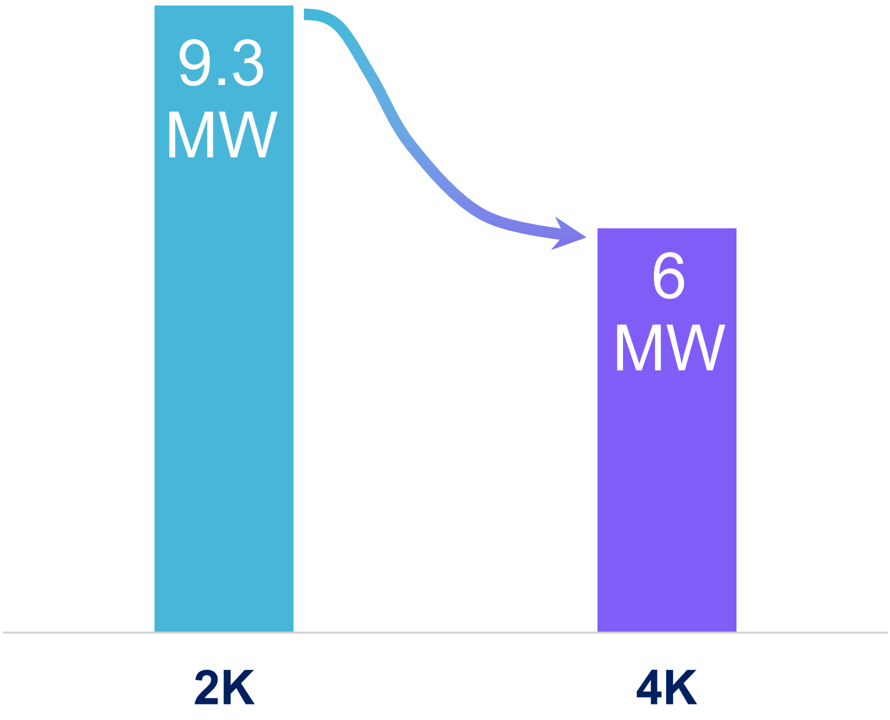
99%

Redundant Utilities

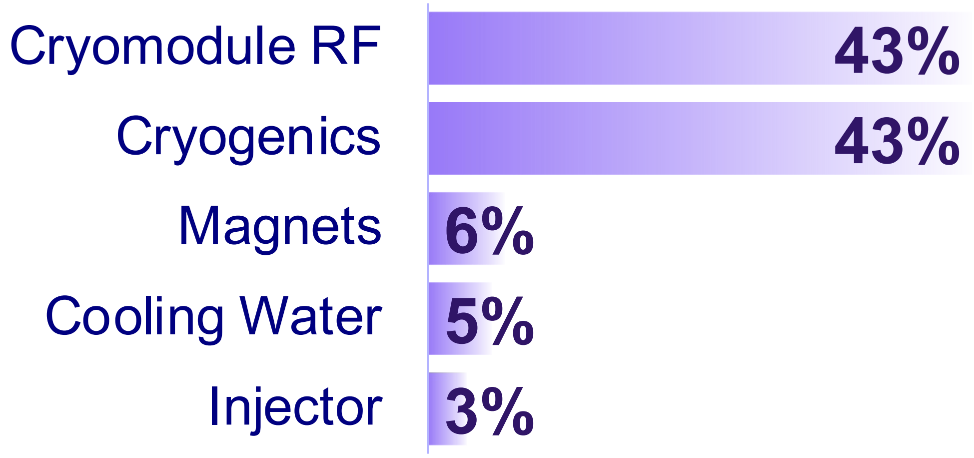
Cryo • Power • Air

6 MW Wall Plug With Transition From 2K to 4K Cavities

For Dual Accelerator System - 35% reduction from 9.3 MW



Power Draw by Component



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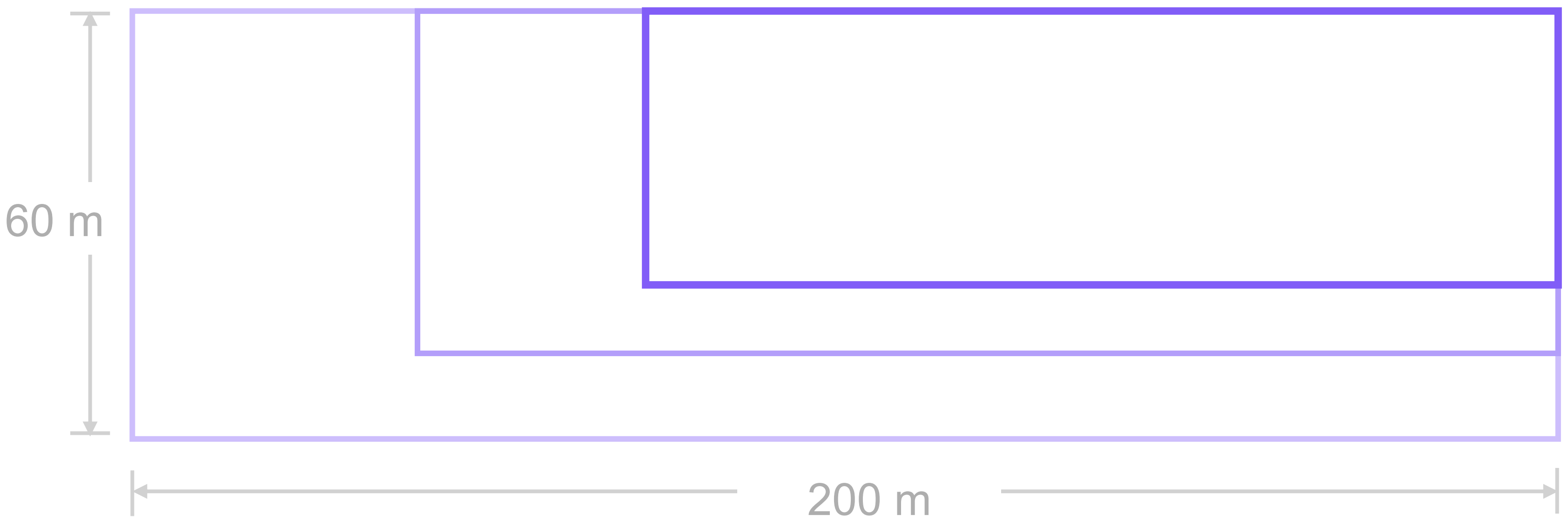
https://proceedings.jacow.org/ipac2024/pdf/FRXD1_talk.pdf

CLASSE Jefferson Lab U.S. DEPARTMENT OF ENERGY

Footprint Reduction Path to 140 m x 40 m

For Dual ERL with 800 MeV Beam Energy and Combined Function Magnets

Gen 1 Dual ERL → 800 MeV Beam Energy → Combined Function Magnets



Light-as-a-Service (LaaS)

30-Year Utility Photon Infrastructure Model

Utility Model

xLight owned & operated

Take-or-pay contracts

Long asset life (30 years)

Scalable Capability

Core Power → Tunable Polarization → Wavelength Extension

Connection fee per system

Breaking the Dose Bottleneck in the Stochastic Era

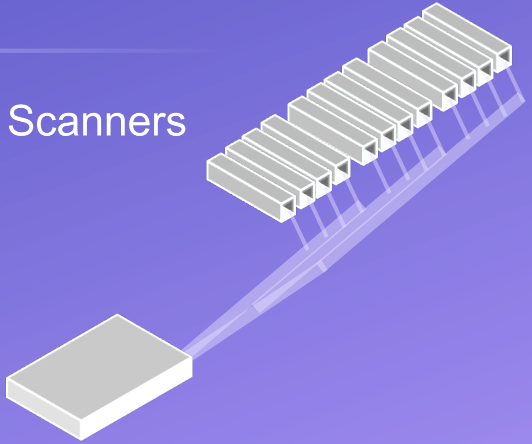
FEL source helps close the stochastic resolution gap — but scaling requires the full lithography stack

38 kW

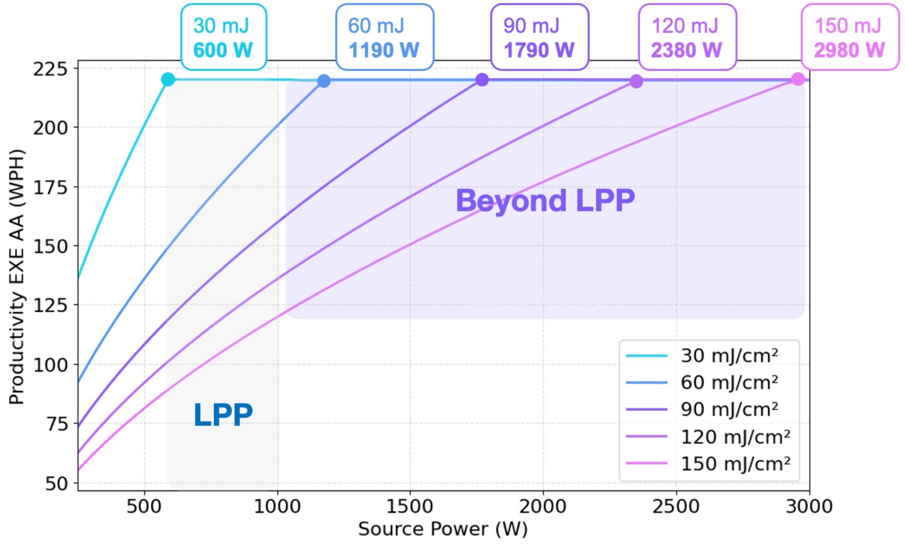
Intermediate-Focus

One Source →16 Scanners

- 99% Availability
- Scanner Compatible
- 9.8 MW Wall Plug
- 2-70 nm Ready



Productivity at Future Doses



Utility-scale photon infrastructure - co-developed with scanner and process roadmaps

Scanner • Materials, etch for stochastics era • Stochastics-aware design, SMO, OPC, process control

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Thank You

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