Current status, challenges, and outlook of EUV Lithography for High Volume Manufacturing

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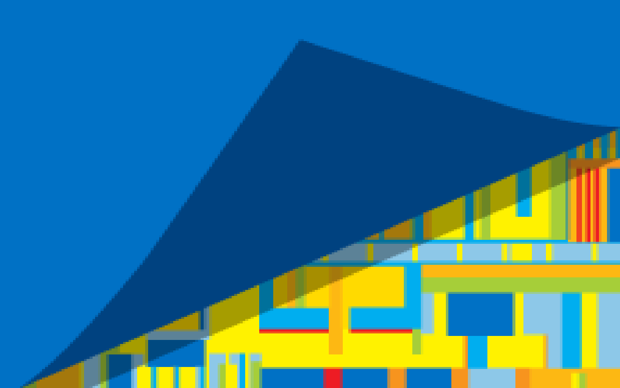
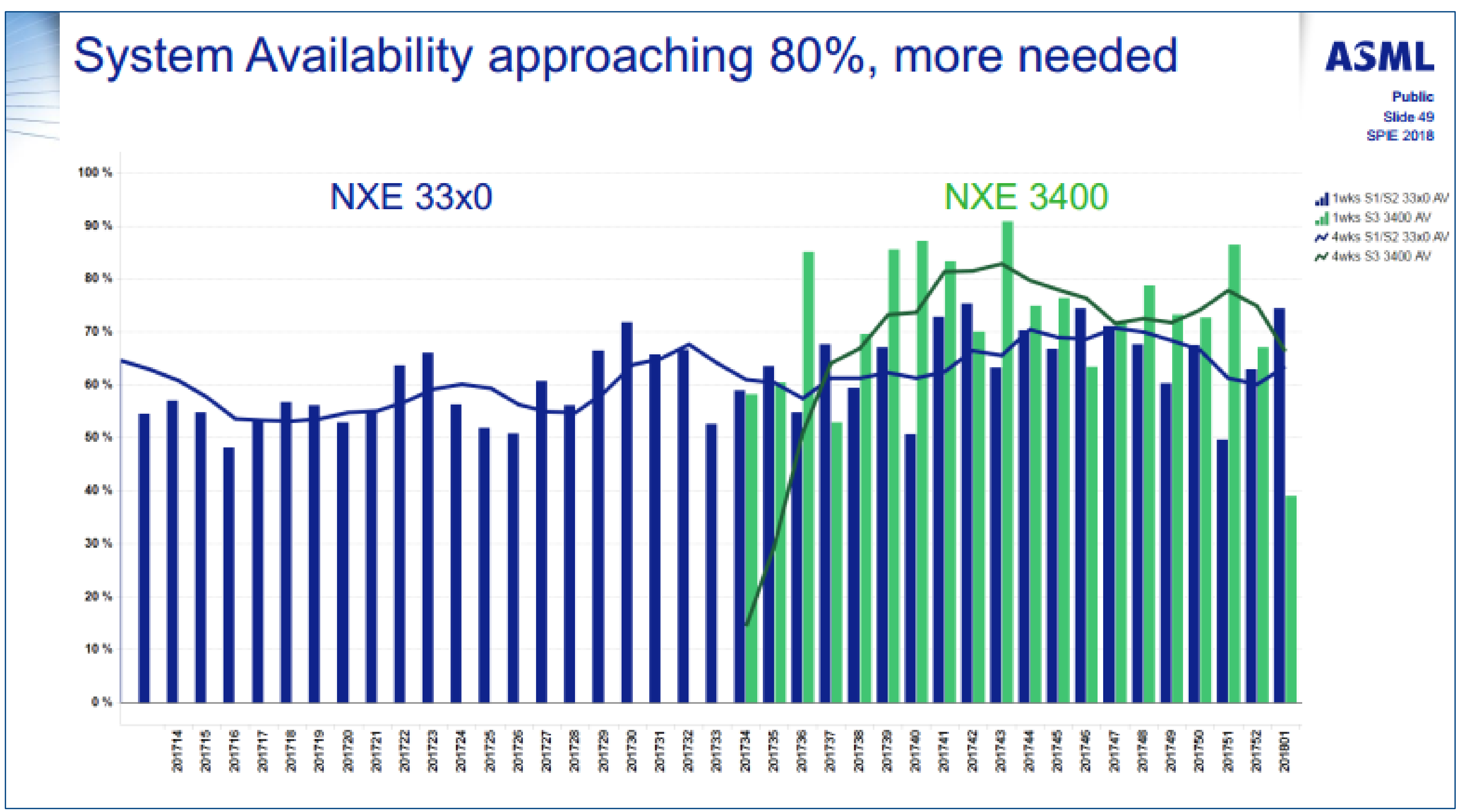


2018 International Workshop on EUV Lithography, 12 June, Berkeley, California

Outline

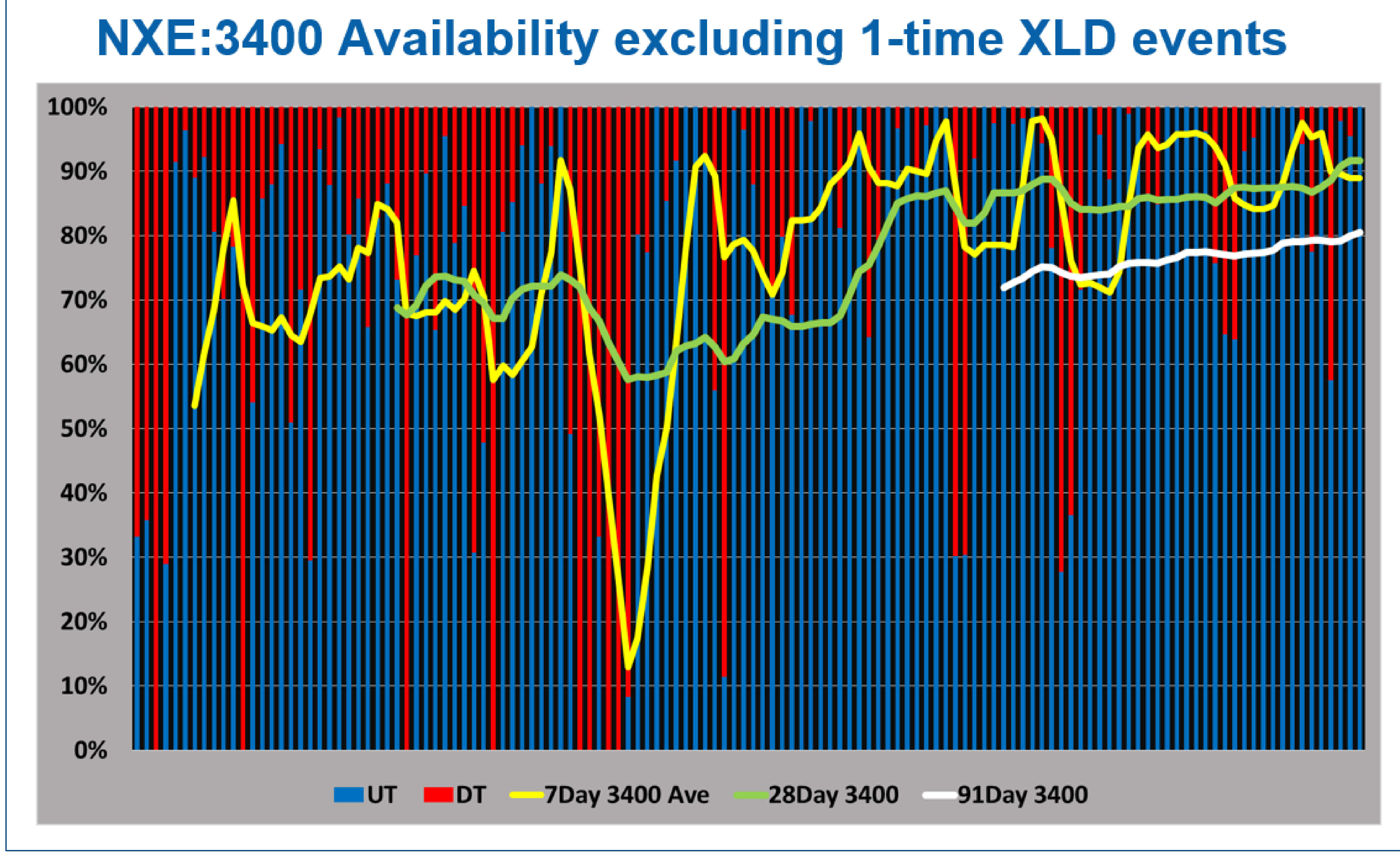
- Milestone Progress
  - Exposure Tool
  - Reticle
  - Pellicle
  - Infrastructure
- HVM Considerations
- Looking Ahead
  - Materials
  - High NA
- Conclusion

NXE:33x0 combined scanner/source availability



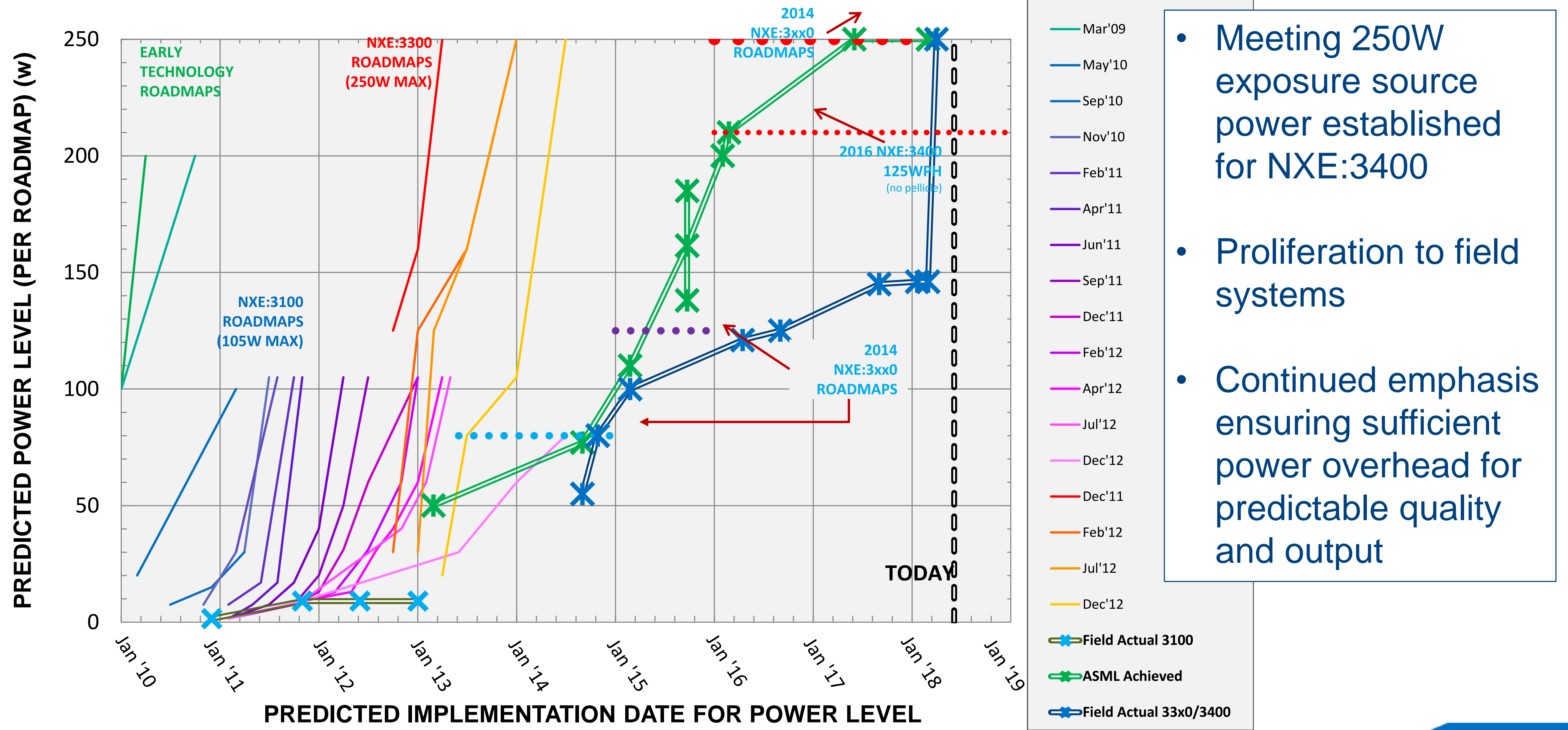
- Improvement from NXE:33X0 to NXE:3400 platform
- Top contributor is exposure source
- Need continued focus on availability

NXE:3400 combined scanner/source availability

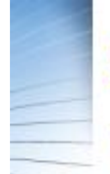


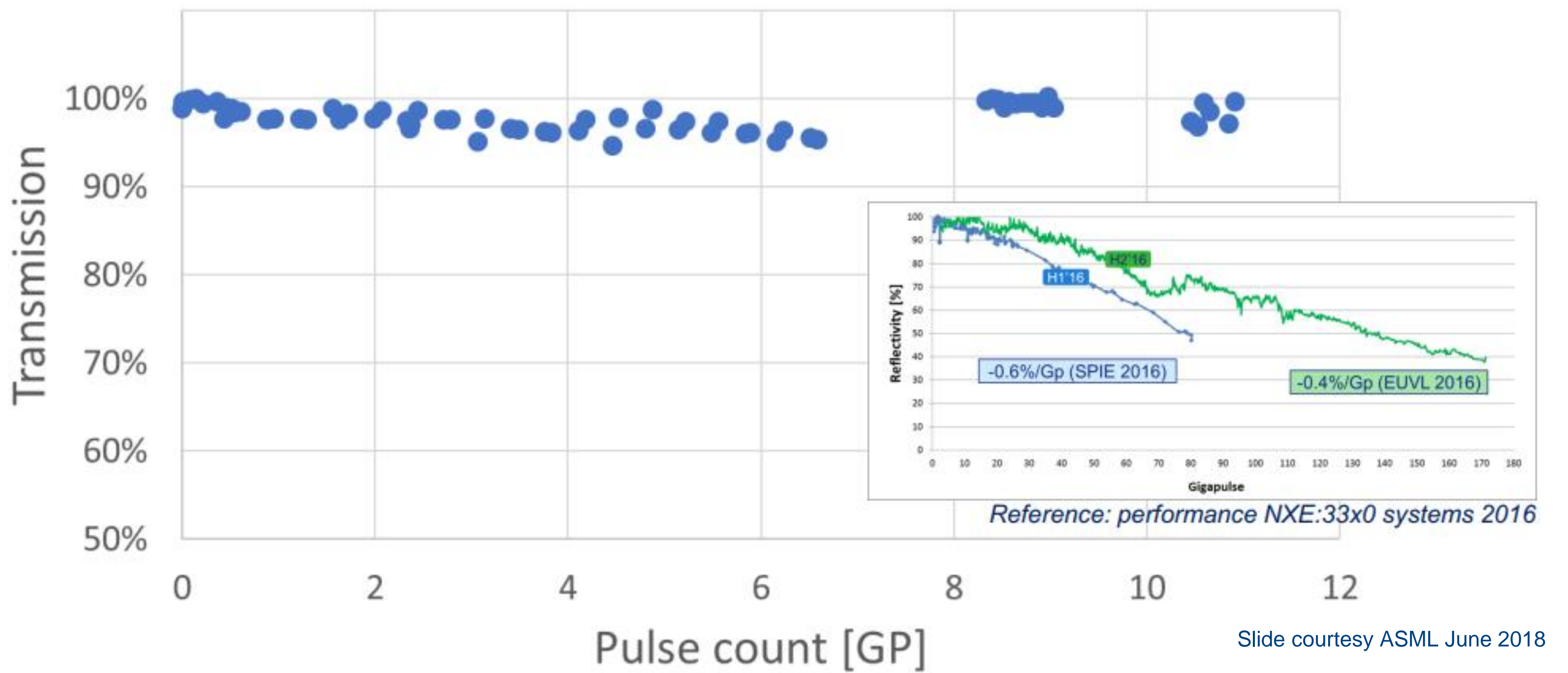
- Best data on 3400 comes from dedicated effort on small number of systems – little bit of luck and lots of focus
- Need to scale to install fleet

Exposure source power meeting roadmap



Collector lifetime improvement continues

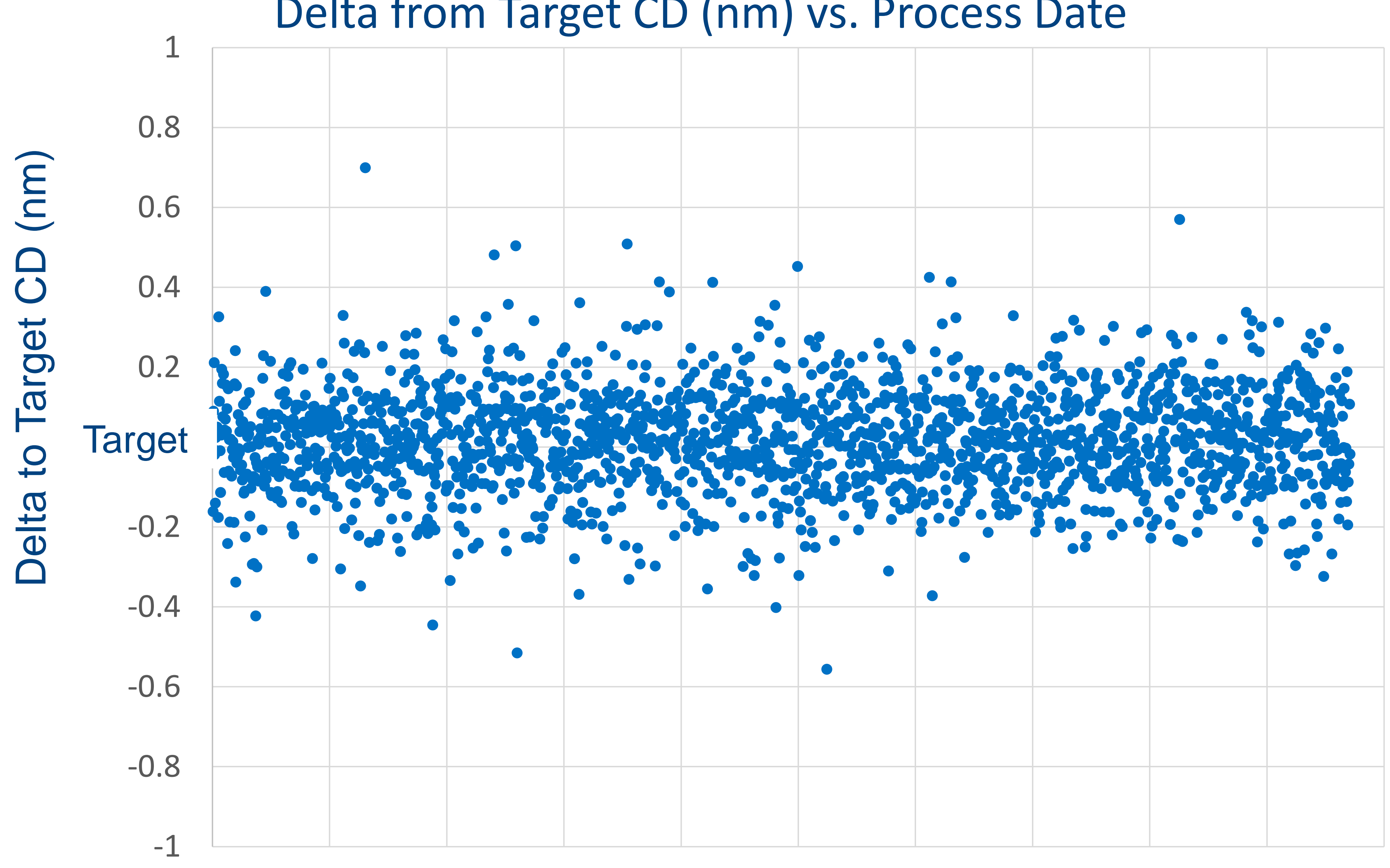




Slide courtesy ASML June 2018

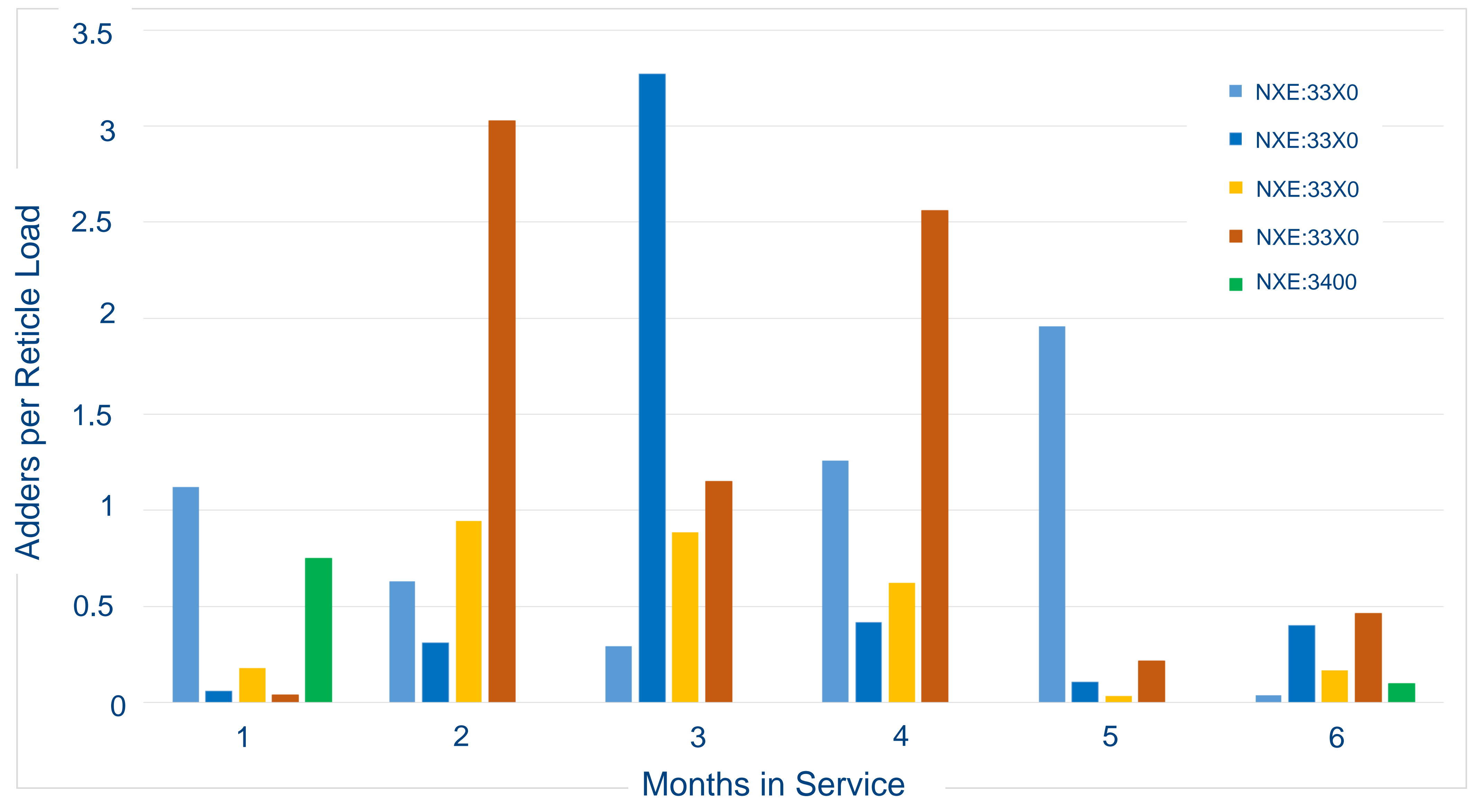
- Collector degradation follows continuous, roughly linear trend – predictable lifetime
- Recent breakthrough advances in reflectivity as f(GP)
- Bottom Line: expect significant correlation to system availability and OpEx

Intel's Pilot Line: CD trend



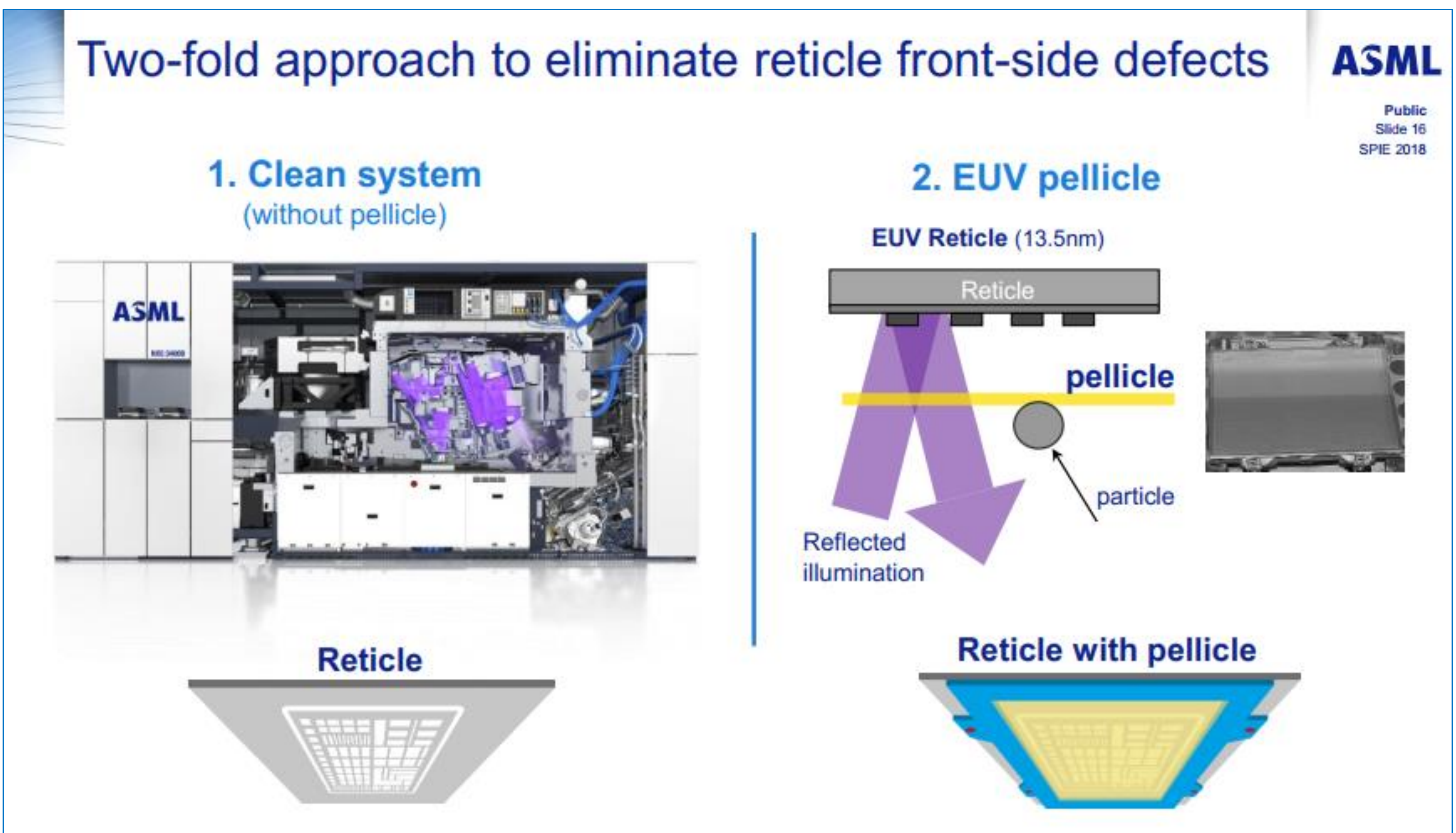
- Unfiltered data
- Timeline > 1 year
- Multiple masks
- Multiple features
- Multiple tools
- CD control within tight distribution
- Stable CD performance trend

Scanner cleanliness: Intel reticle defectivity



- Variability in defect level after ‘burn-in’; many tools showing no adders/reticle load for several weeks
- Every tool has shown adders after many weeks with no adders
- NXE:3400 cleaner overall
- Unpredictability of adder events drives need for pellicle

Scanner cleanliness: reticle defectivity



ASML two-fold approach: one element is to improve cleanliness → avoid particle generation in scanner

- Investigation continues into origin of defects
- Improved understanding of nature of defects introduced by scanner

Pellicle membrane progress and infrastructure

EUV pellicle industrialisation

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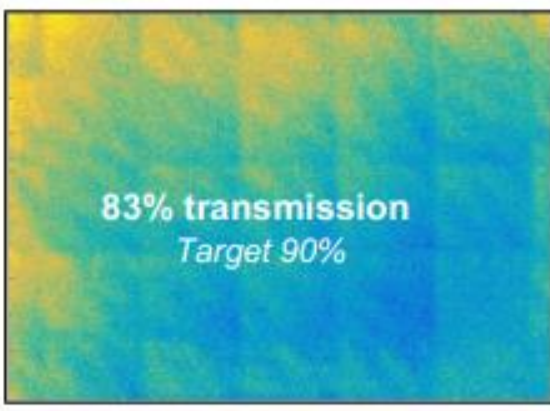
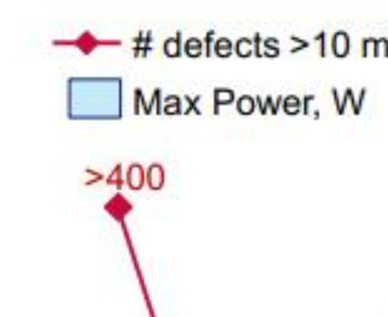
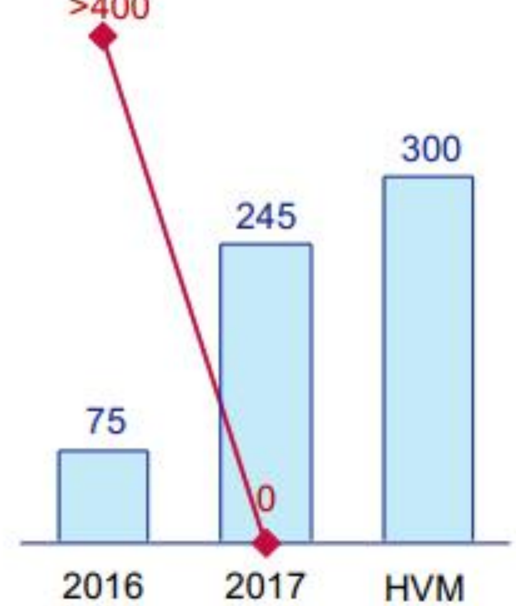
Pellicle Film
EUV Transmission



Pellicle Mounting
Automated Equipment

Pellicle Performance
defects, Max Power





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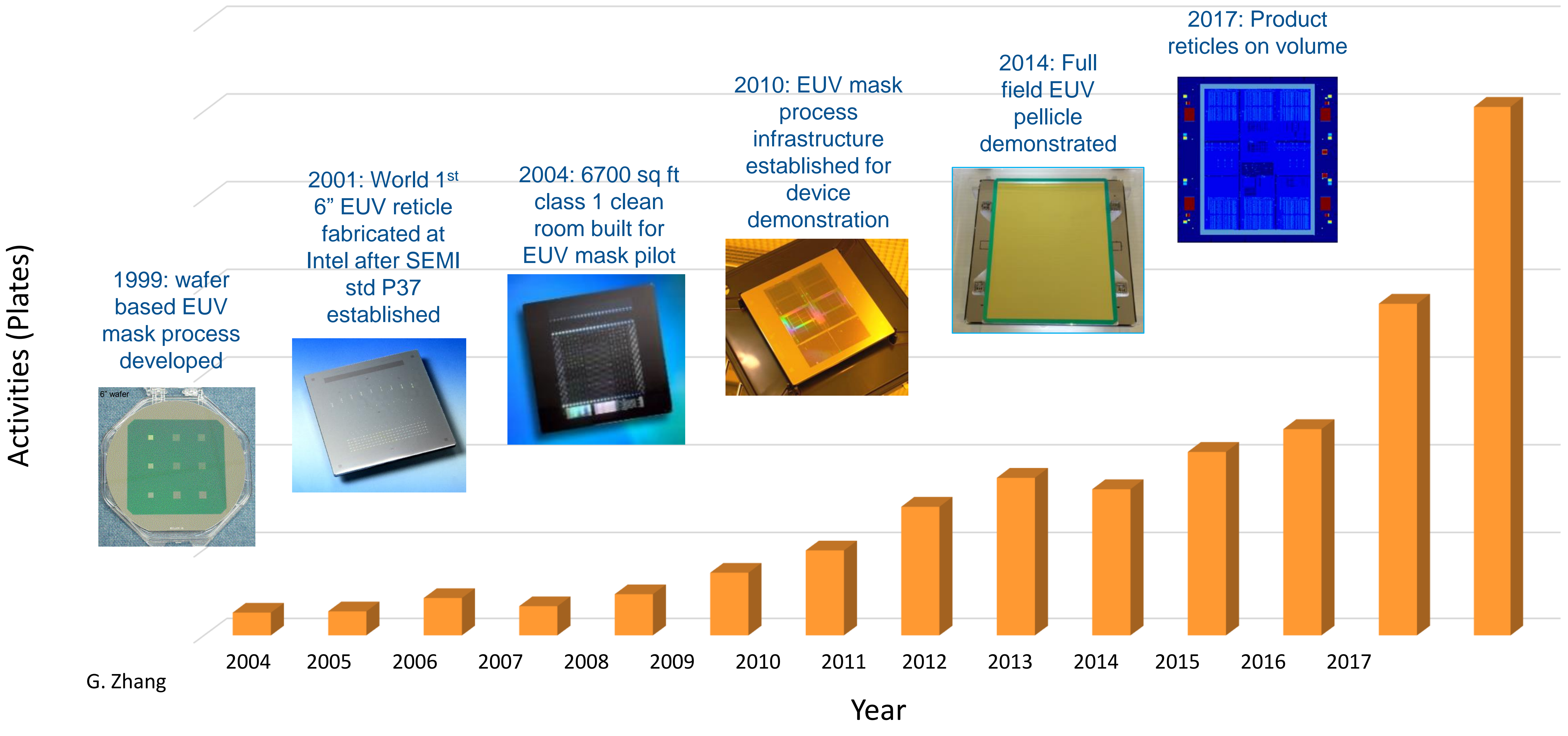
- Steady progress in pellicle membrane defect levels since Q3'16
- Multiple membranes with zero defects >10um
- Continued focus expected to deliver volumes for HVM

EUV mask pilot line activities



Intel EUV mask manufacturing is capable of volume production with full specification product requirements.

Judged as of Today

EUV infrastructure readiness snapshot

EUV infrastructure has 8 key programs

7 are ready or near-ready now; 1 has significant gaps

- **E-beam Mask Inspection:** In use for low volume production. Need TPT increase.
- **Actinic Blank Inspection (ABI):** Ready for qualification of HVM quality blanks
- **AIMS Mask Inspection:** Systems installed in field; NXE:3400 illumination emulation underway
- **Pellicle:** ASML commercializing
- **EUV blank quality:** Process and yield improvements continue
- **Blank multi-layer deposition tool:** Improving defect results
- **EUV resist QC:** RMQC center at IMEC online
- **Actinic Patterned Mask Inspection (APMI):** High resolution PWI for fab. Still need actinic inspection in mask shop.

Overall milestone progress messages

- Combined scanner/source availability improving
  - Exposure source remains largest contributor to tool downtime
  - NXE:3400 availability encouraging; need to scale to install fleet
- Exposure source power meeting 250W roadmap, field upgrades in process
- Scanner defectivity levels improving with introduction of NXE:3400
  - Every tool has shown defects after weeks of clean performance
  - Underscores need for pellicle and associated infrastructure / support
- Significant progress in pellicle program over past year
  - Pellicle membranes manufactured with zero defects >10um; lifetime and power resiliency continue to increase
- Progress has been made in pellicle membrane material development, but continued improvement necessary for increasing transmission, withstanding increased source power, and extending lifetime (OpEx)
  - Pellicle membrane power resiliency needs to keep pace with increasing source power (300W, 500W, …)
- Manufacturing increasing number of defect-free 7nm EUV masks
- Inspection of pelliclized reticles is needed to ensure predictable yield. APMI is not a show-stopper, but without it yield and cost may be an issue – no change

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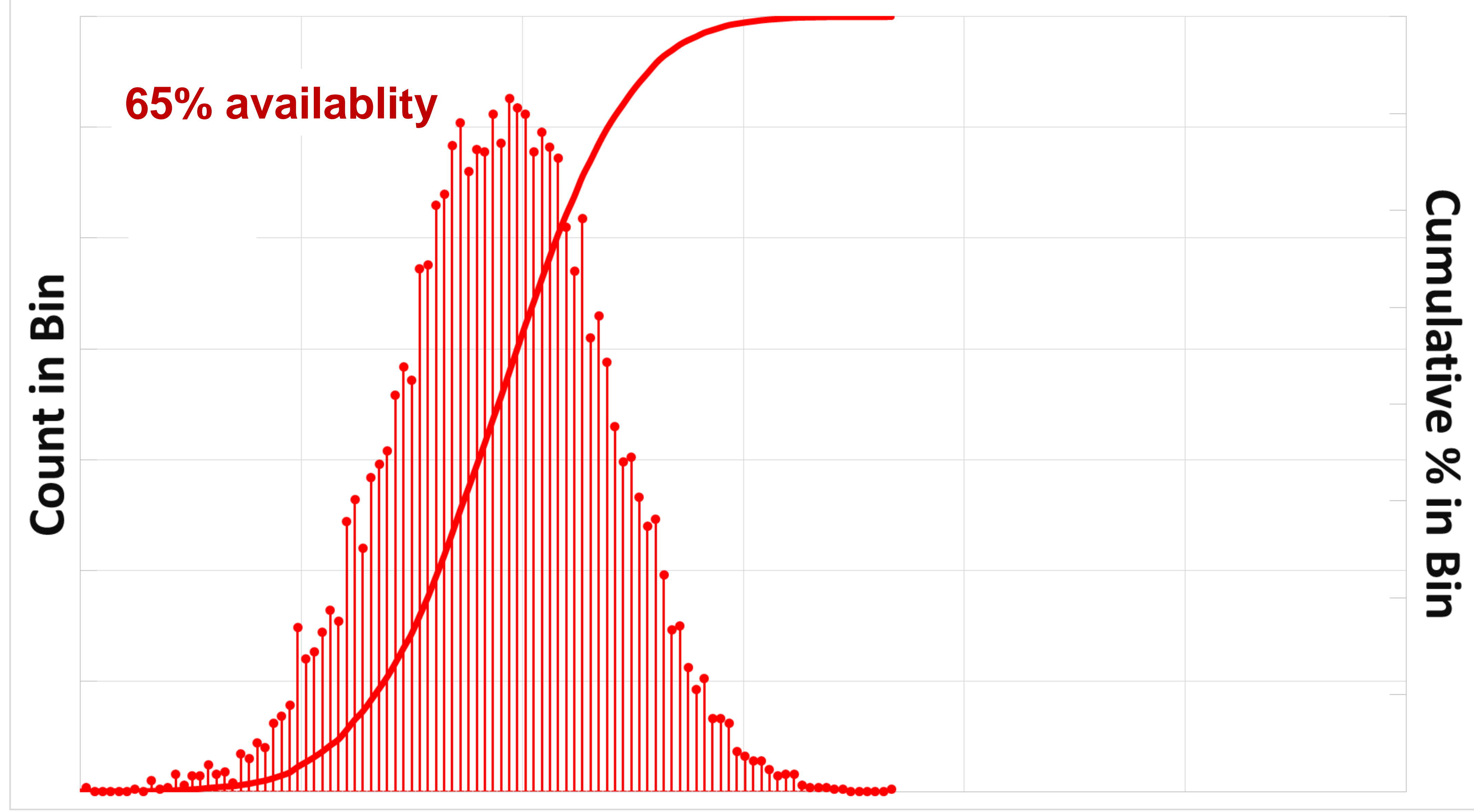
HVM insertion considerations → Predictability

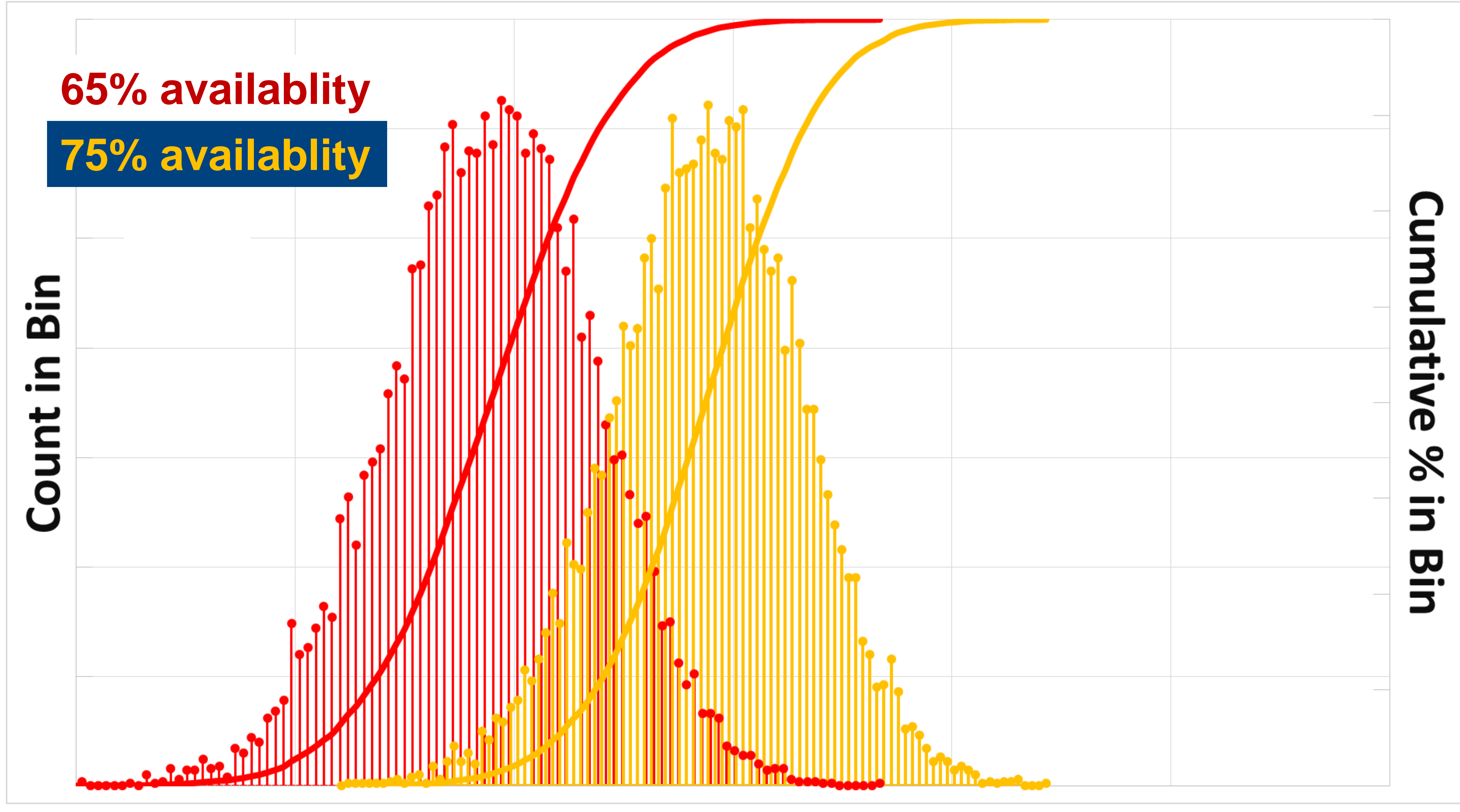
- Capability demonstrated:
  - ✓ Exposure source power meeting HVM roadmap
  - ✓ Pilot line imaging performance
- What is impact on fleet predictability of availability vs. power?
- Simulate HVM conditions – how do these parameters affect reliable TPT?
  - Simulation methodology assumptions:
    - Acceptable level of collector degradation (50%-100% RR)
    - Fixed exposure source power (300W)
    - Vary availability 65%-95%
    - 10,000 runs with comparable results for tool count N=25 and N=100

Impact of Availability is critical



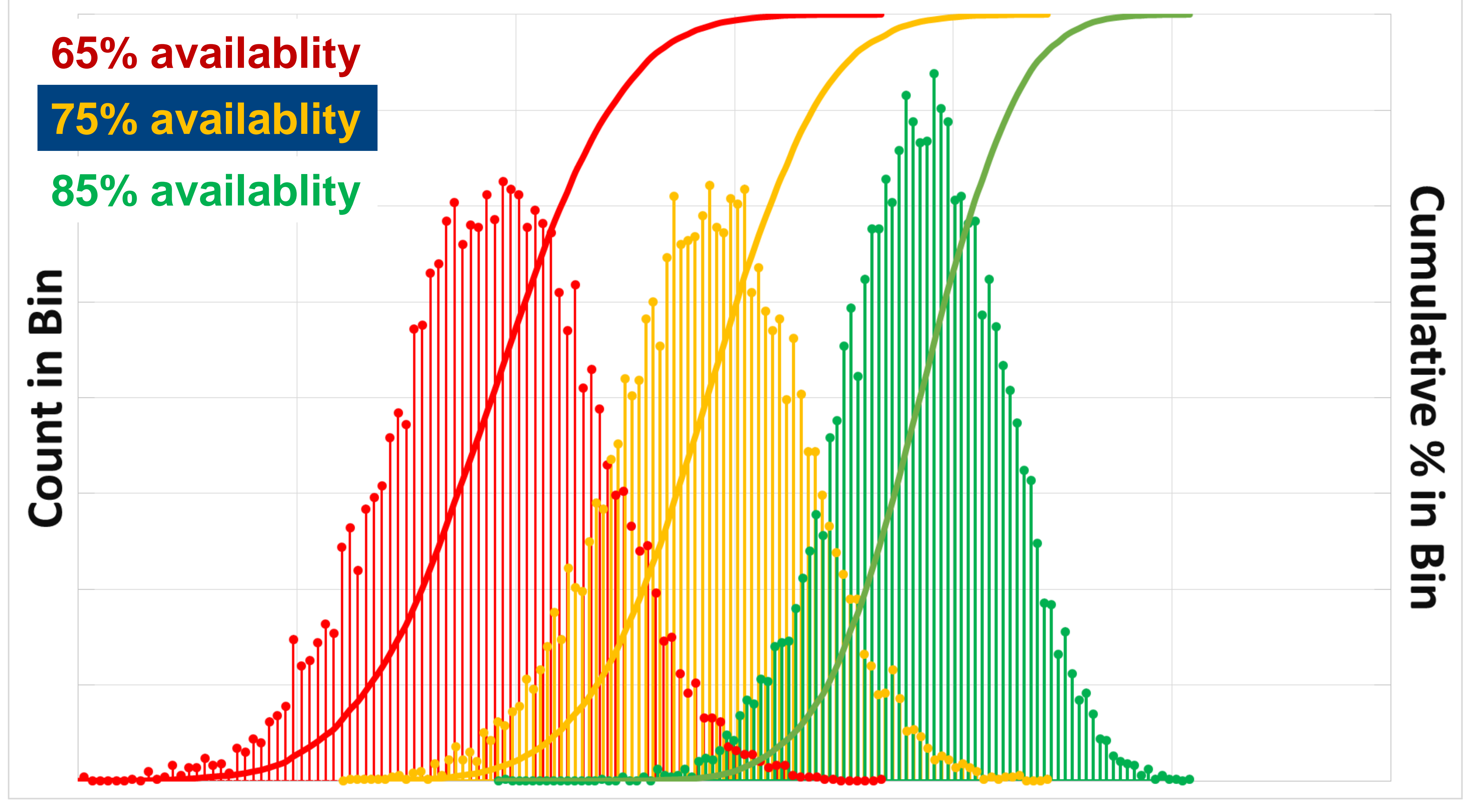
- Wide spread in productivity

Impact of Availability is critical

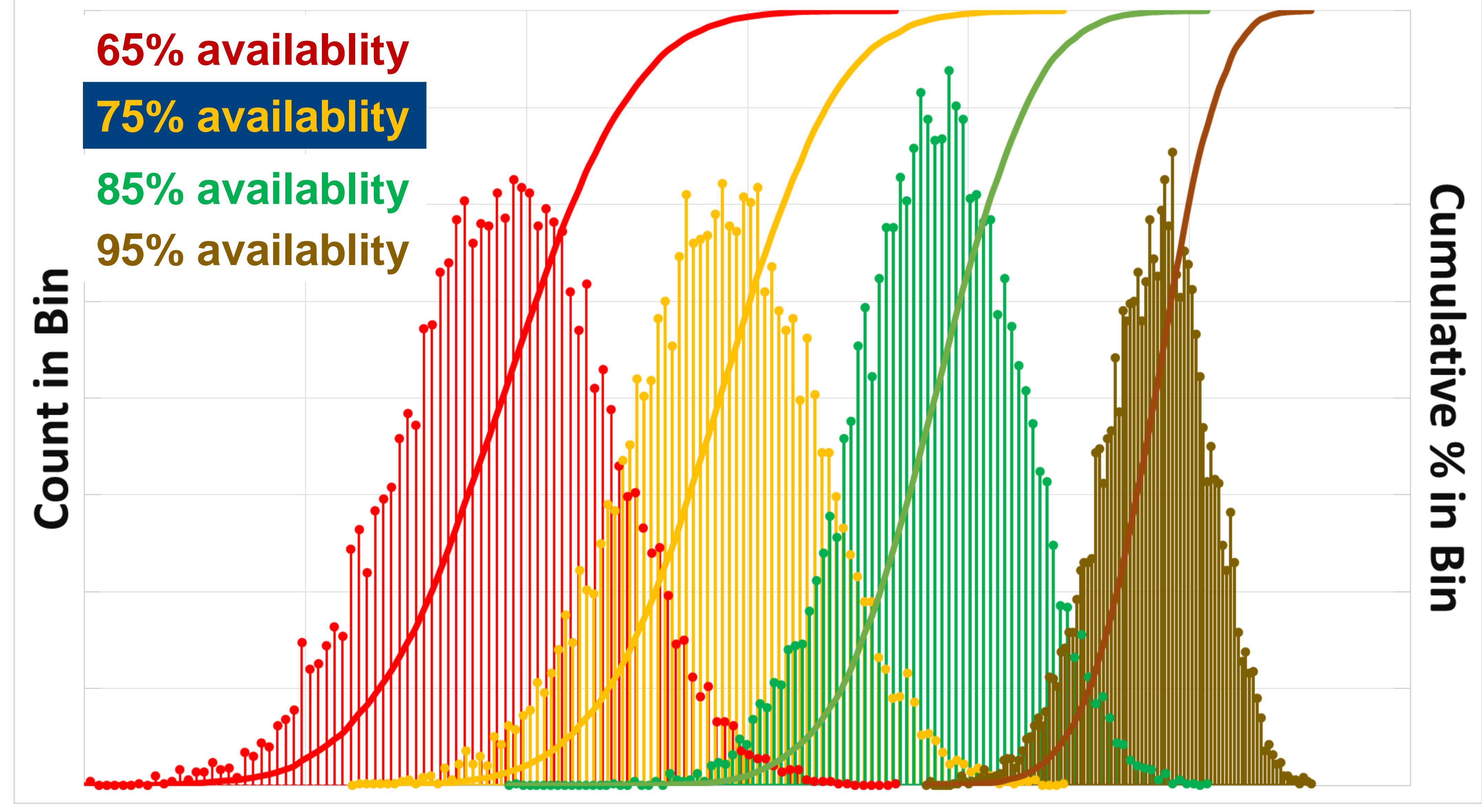


- Fleet productivity distribution improves with increasing availablity

Impact of Availability is critical

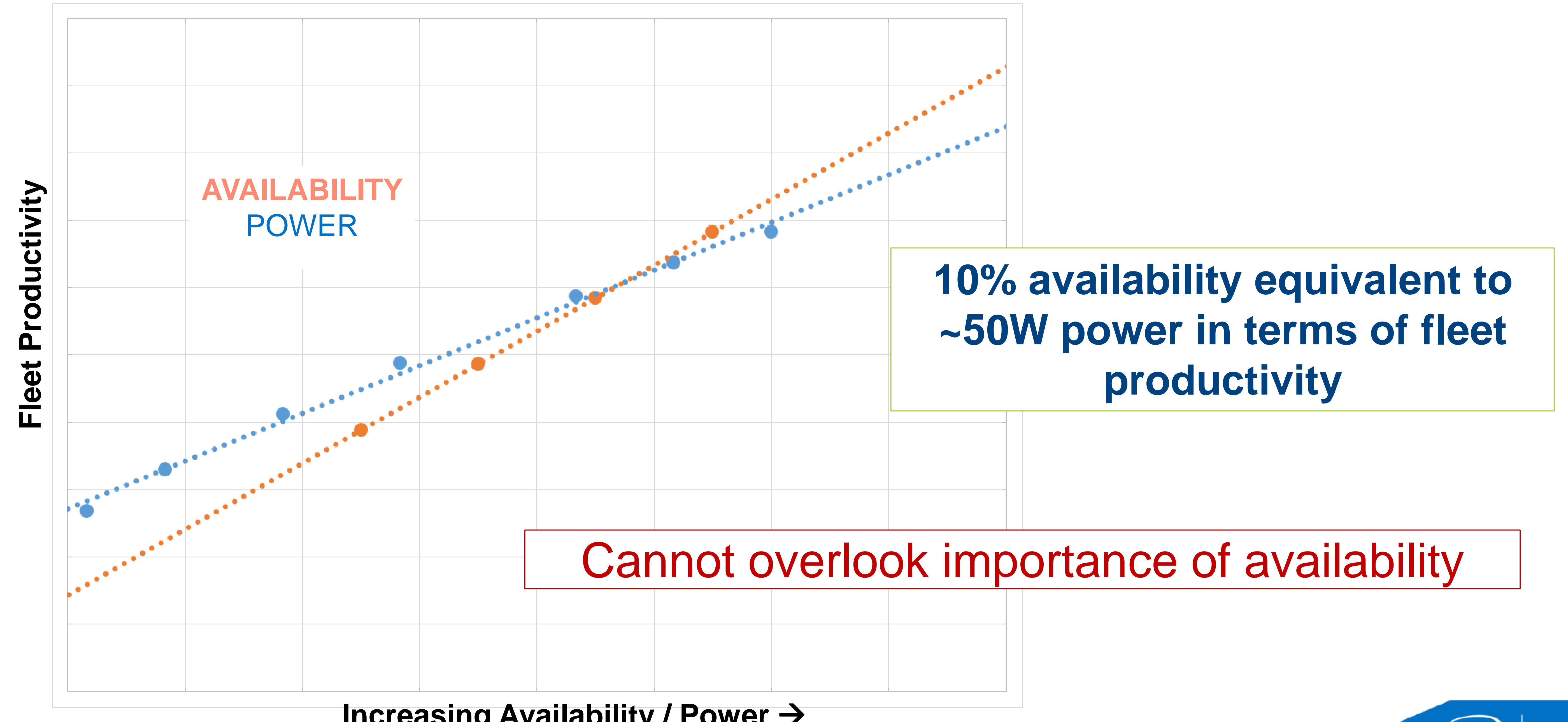


Impact of Availability is critical



→ Best-case productivity of fleet with 65% average system availability is less than the worst-case productivity of a fleet with 95% average availability

Availability vs. Source Power



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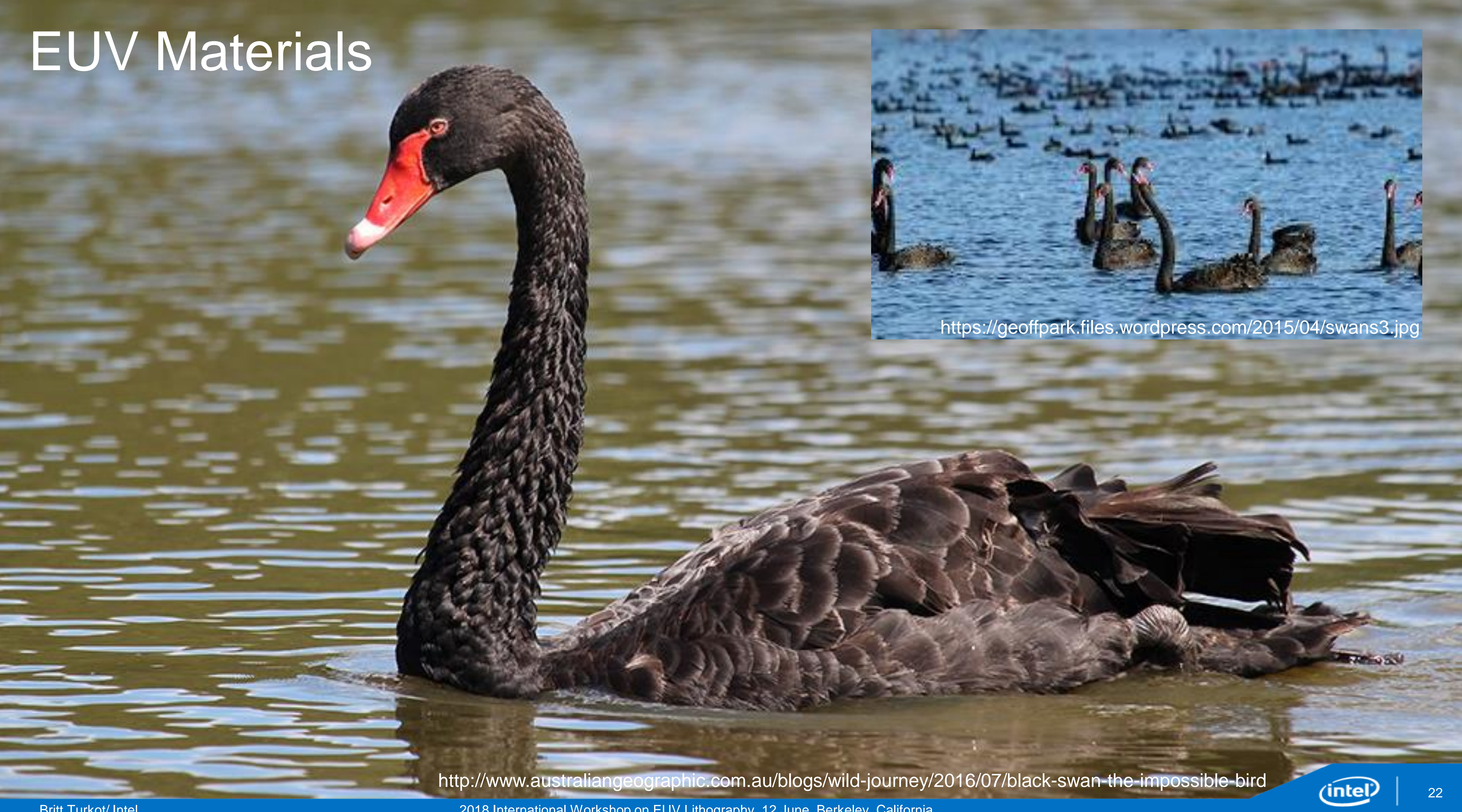
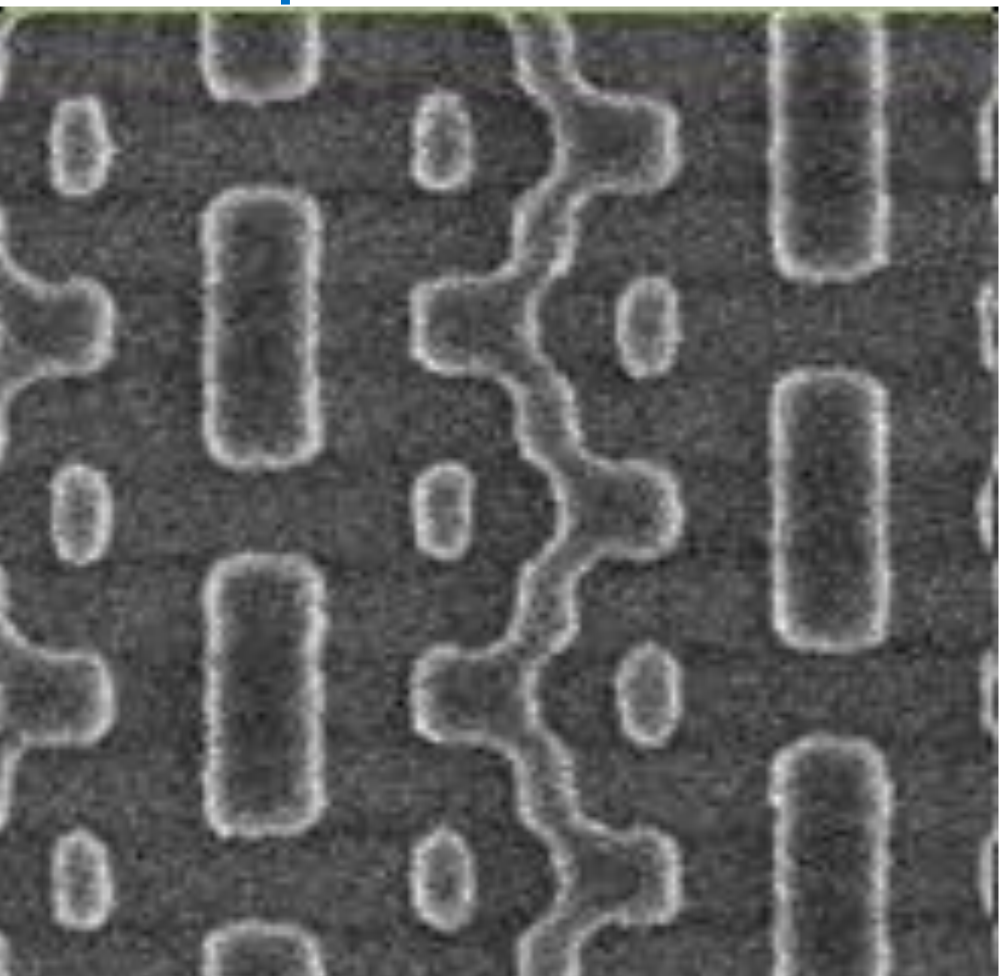
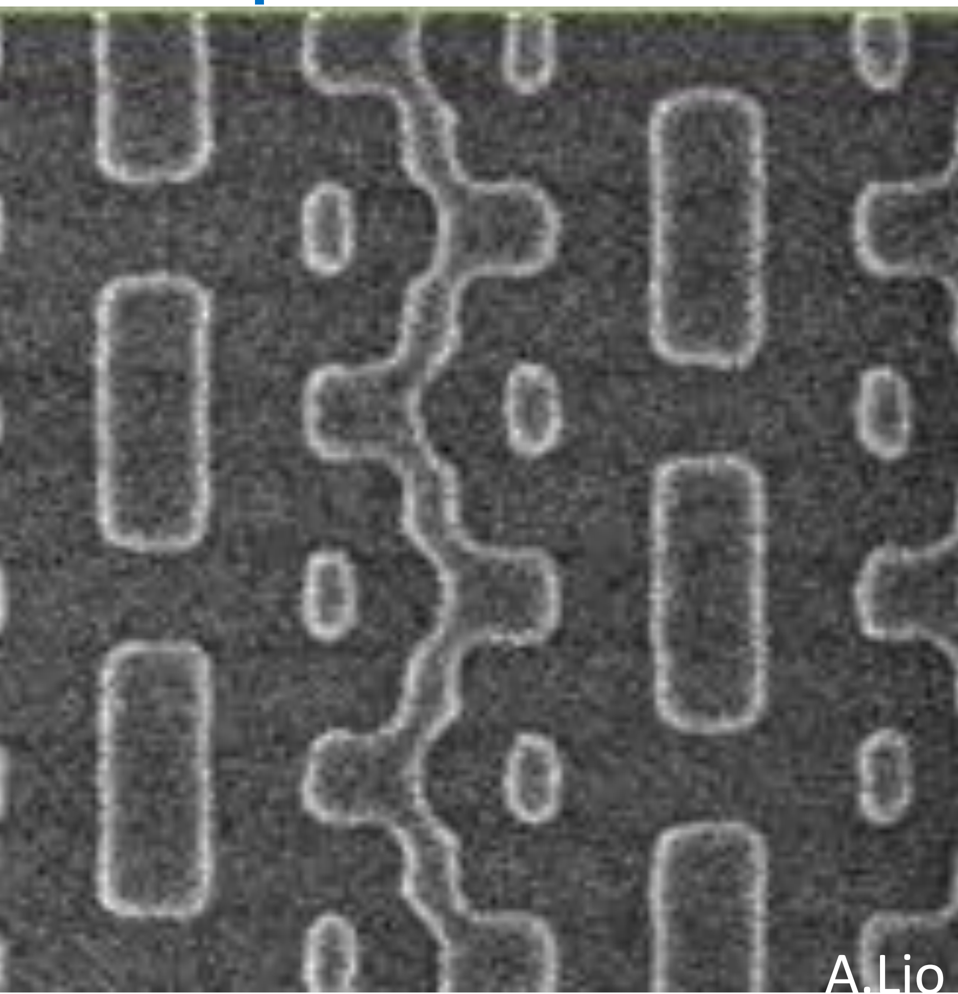
EUV Materials



EUV materials and resolution

Test pattern – Post Litho



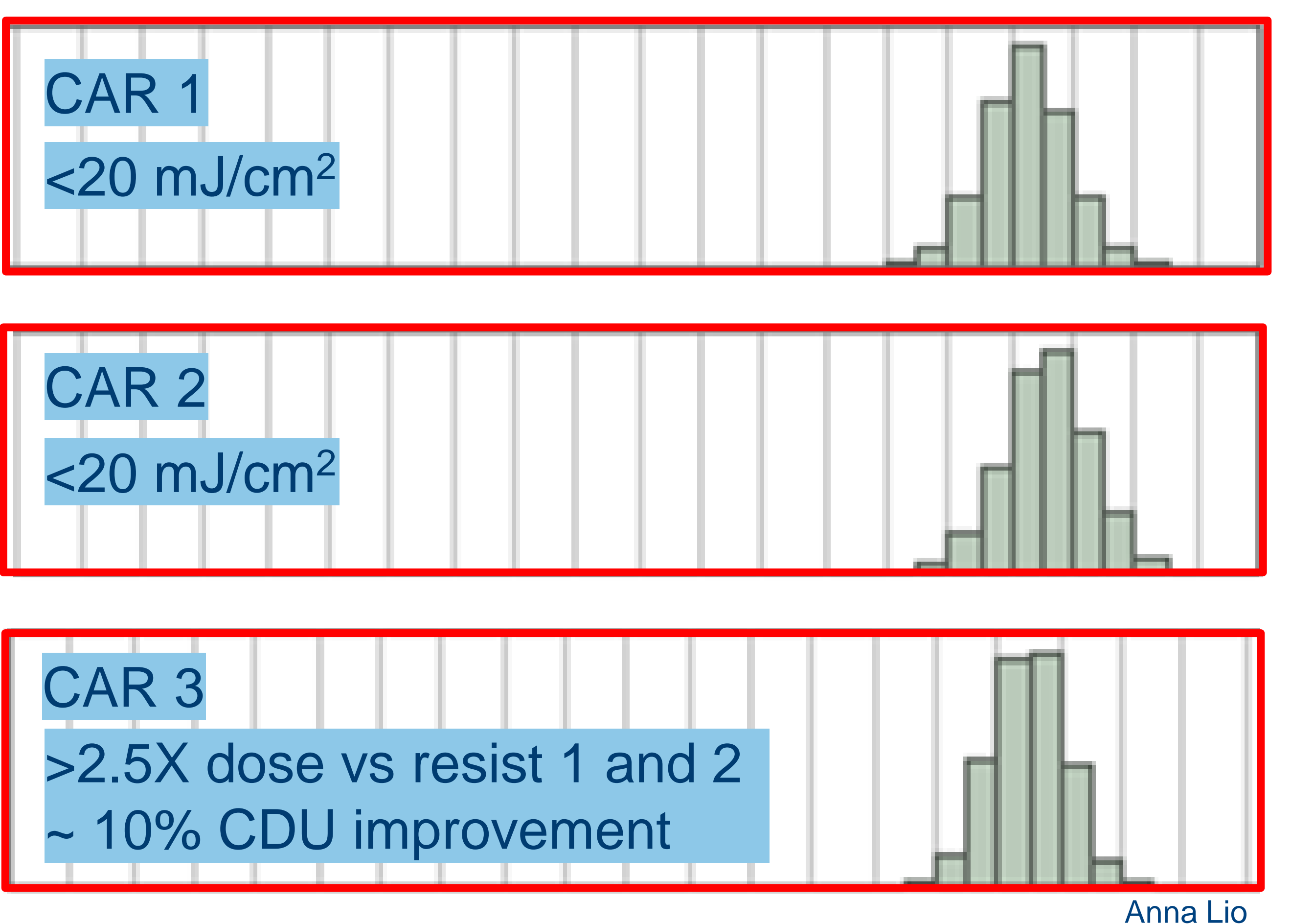


- EUV enables 2D design features, e.g. corner segments
- Need materials that can take advantage of improved EUV resolution
- Adequate for EUV introduction
- Need materials that are tunable for desired properties
- Materials development constrained by photon availability (BL, MET, NXE)

For continued material development, suppliers need an understanding of fundamental properties of materials

Looking ahead: More than photon shot noise

NXE3300, 28 nm hole
72K measurements

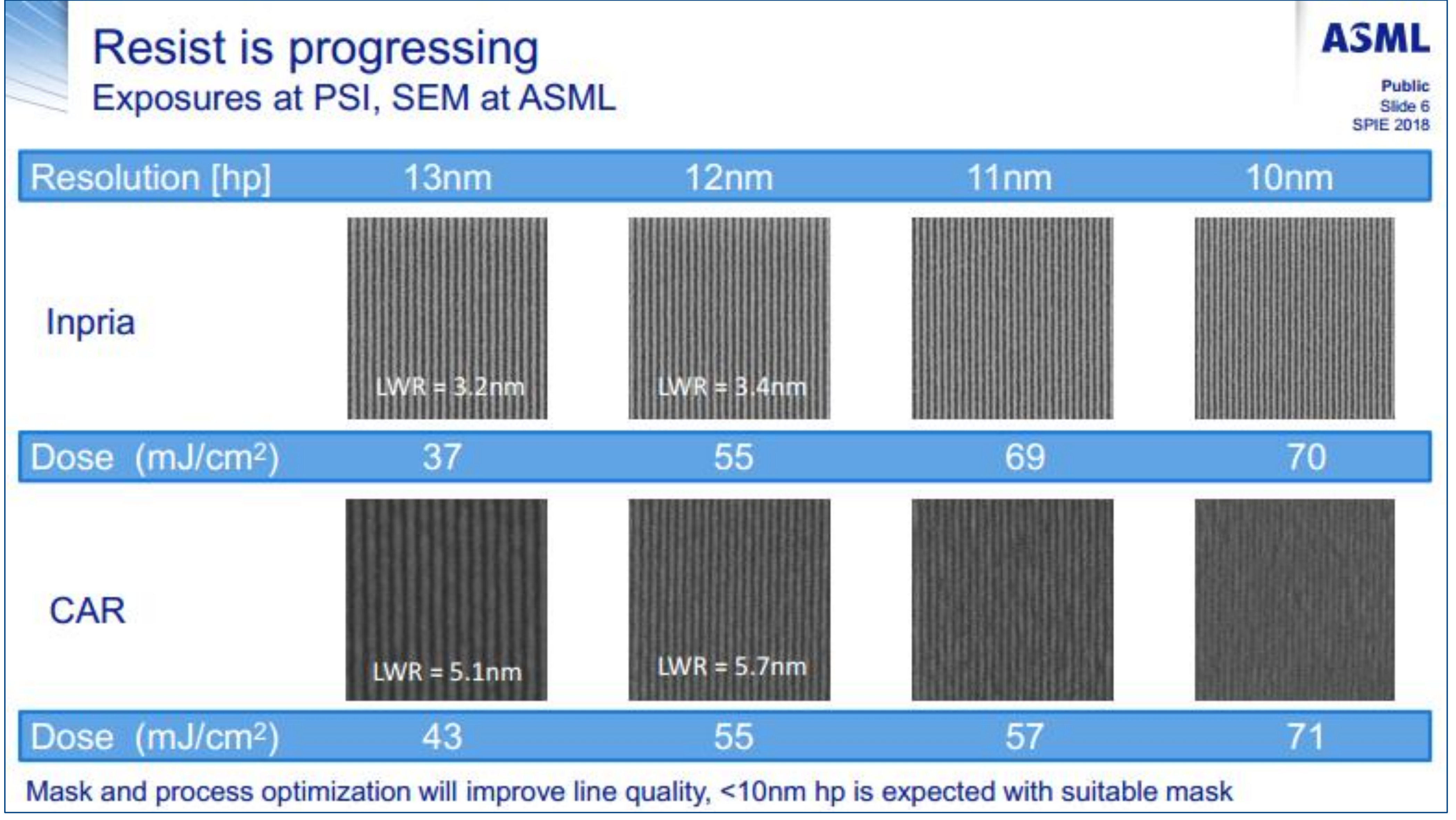


Anna Lio

- 2.5x higher dose provides <10% LCDU improvement
- Not consistent with photon shot noise alone
- There must be a chemical effect
- We must gain a deeper understanding of how EUV radiation interacts with resist and design resist for stochastics
- Next generation EUV requires materials innovation

Materials suppliers must have the means to study fundamental properties of materials

EUV materials



J. Van Schoot, ASML, February 2018

- EUV material interaction processes are complex
  - Photon absorption
  - Photoelectron gen.
  - Secondary electron gen.
  - Radical generation
- Electron-stimulated process induce chemical reactions
- Dissolution mechanism varies for different material systems
- Not one-size-fits-all

Must consider multiple options / material systems

High NA EUV: The next step

Business as usual: increase NA as far as possible

Relative improvement:5X over ArFi, 40% over 0.33 NA EUV

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1.00
0.10
0.01

i-Line 365 nm
KrF 248 nm
ArF 193 nm
ArFi 193 nm
EUV 13.5 nm

Major technology step
(e.g. source, mirror)

Optimization of NA

EUV 0.25
EUV 0.33
EUV 0.55

1990
1995
2000
2005
2010
2015
>2020
Year of introduction

Slide courtesy ASML February 2018

- Next logical step

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Conclusion: Preparation for HVM and beyond

- Exposure source → First field system meeting source power roadmap: power improvements proliferating to install fleet
- Availability → NXE:3400 platform demonstrating improved capability – keep focus
- Pellicle → Needed to ensure EOL yield; pellicle program continues to make significant progress
- Infrastructure → demonstrating increased maturity; single gap remains
- HVM requires predictability
  - Output impact of 1% improvement in availability > 4% improvement in source power
  - OpEx (mostly source consumables) – Collector lifetime improvements encouraging – need to translate to field systems
- Materials
  - Materials performance – Won't gate introduction of EUV, but need to consider stochastics for decreasing feature sizes and high NA: need to understand the interaction of EUV radiation with resist and design resist materials for stochastics

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Backup