Preparing for EUV Lithography in High Volume Manufacturing

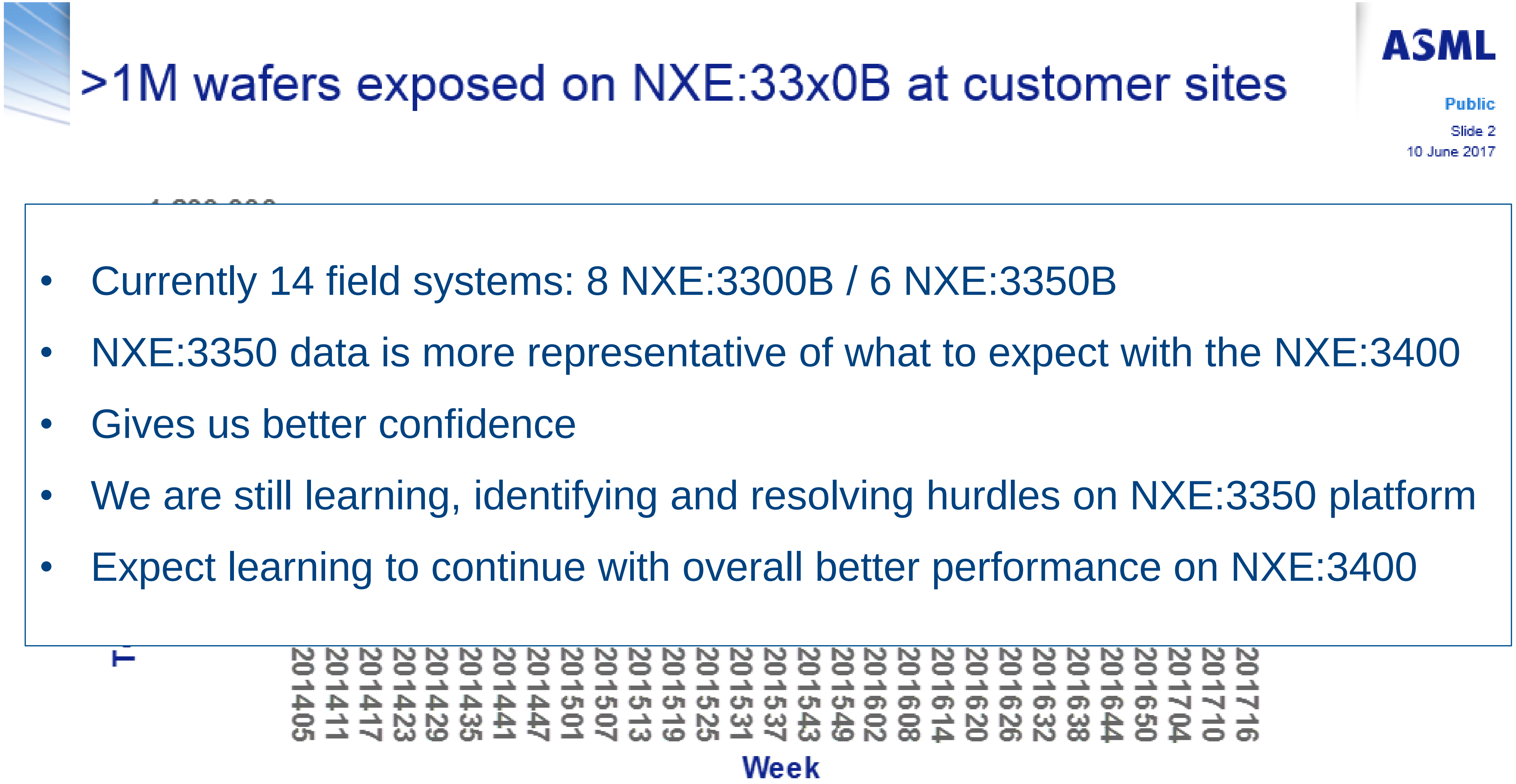
Britt Turkot

Intel Corporation

Outline

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

EUV wafer count continues to grow



>1M wafers exposed on NXE:33x0B at customer sites

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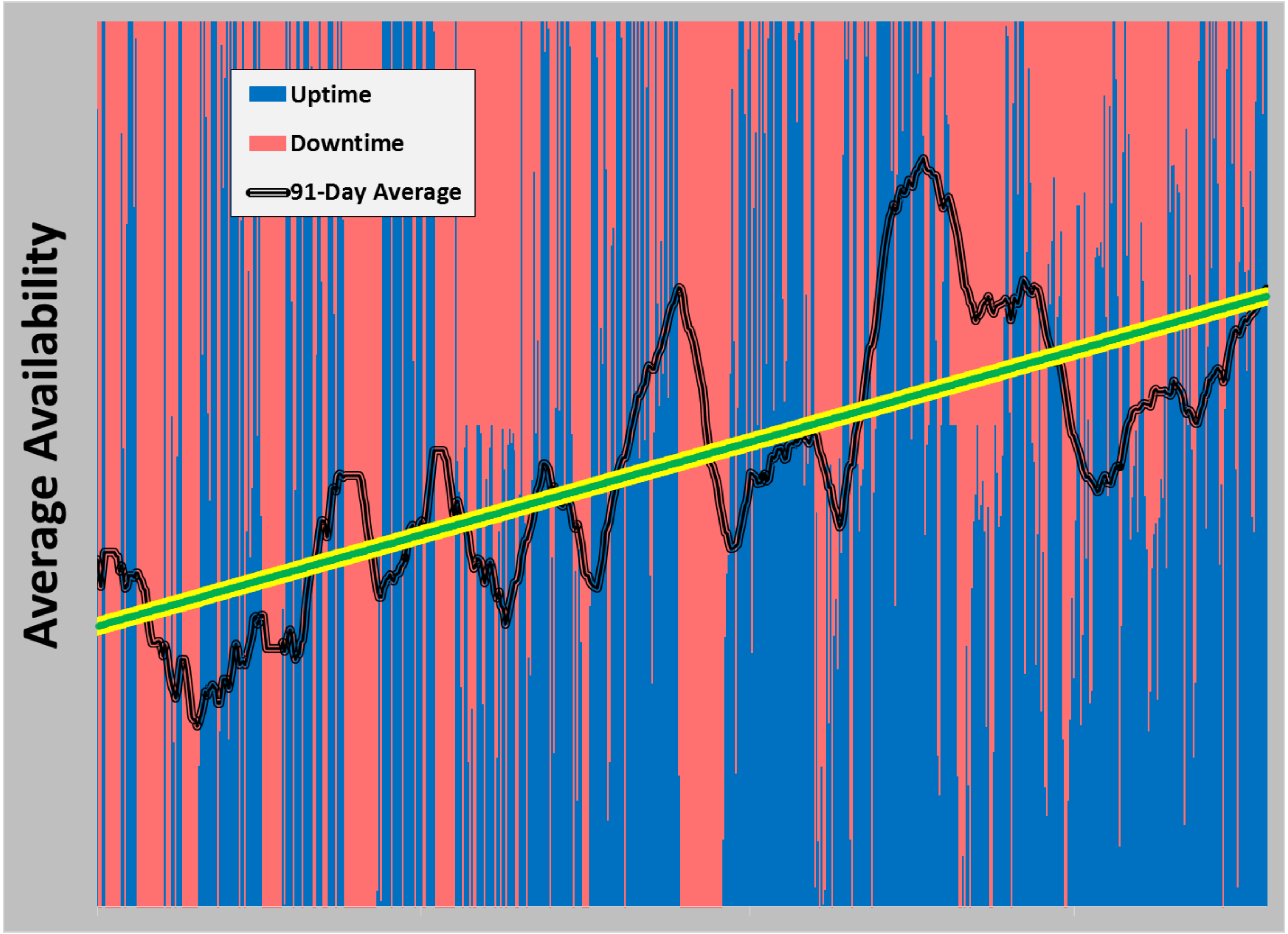
Slide 2
10 June 2017

- Currently 14 field systems: 8 NXE:3300B / 6 NXE:3350B
- NXE:3350 data is more representative of what to expect with the NXE:3400
- Gives us better confidence
- We are still learning, identifying and resolving hurdles on NXE:3350 platform
- Expect learning to continue with overall better performance on NXE:3400

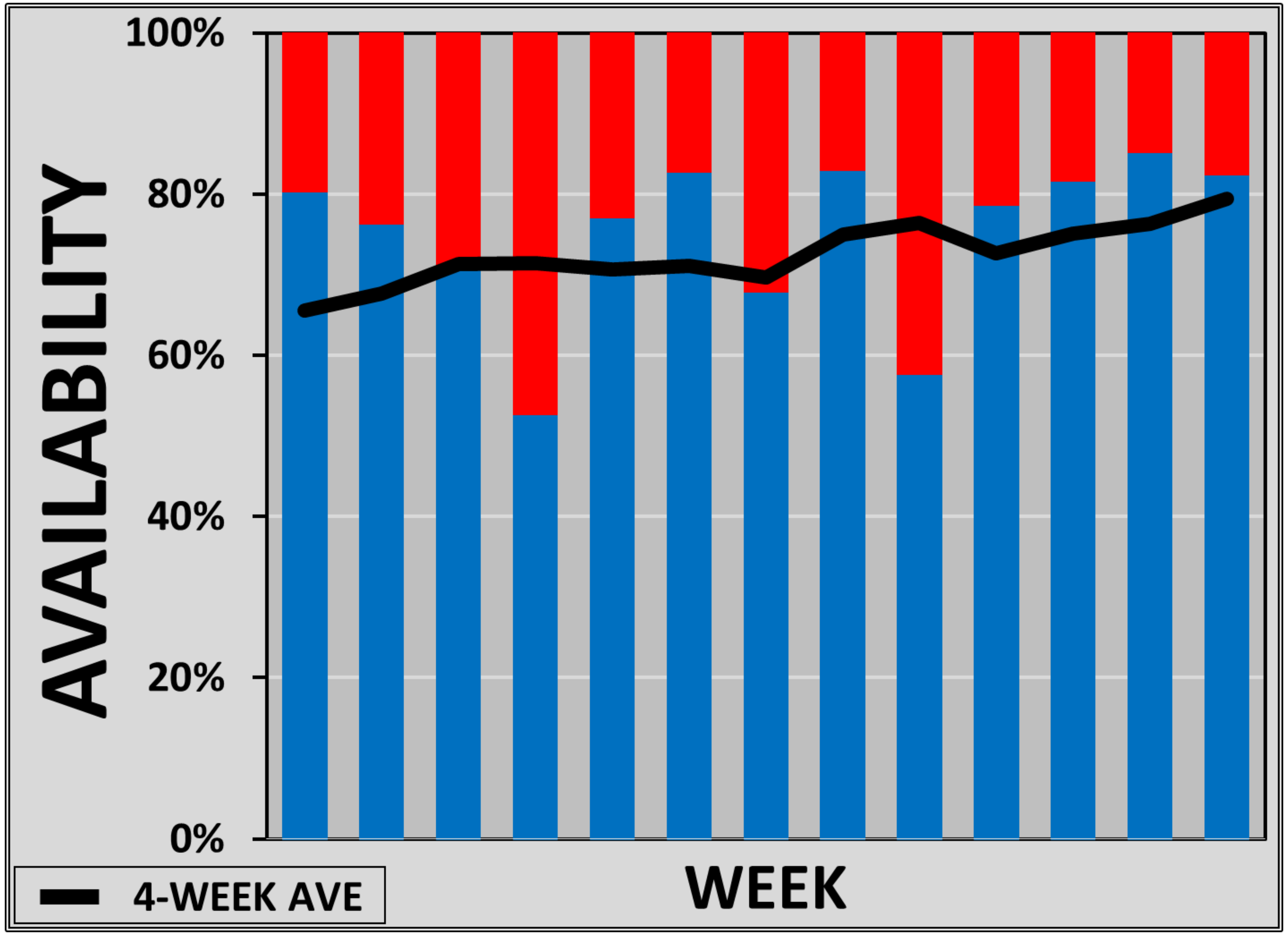
NXE:33x0 combined scanner/source availability



- At daily level, highly variable availability
- Trend in right direction, but needs to be faster
- Much work remains to reach HVM-level availability

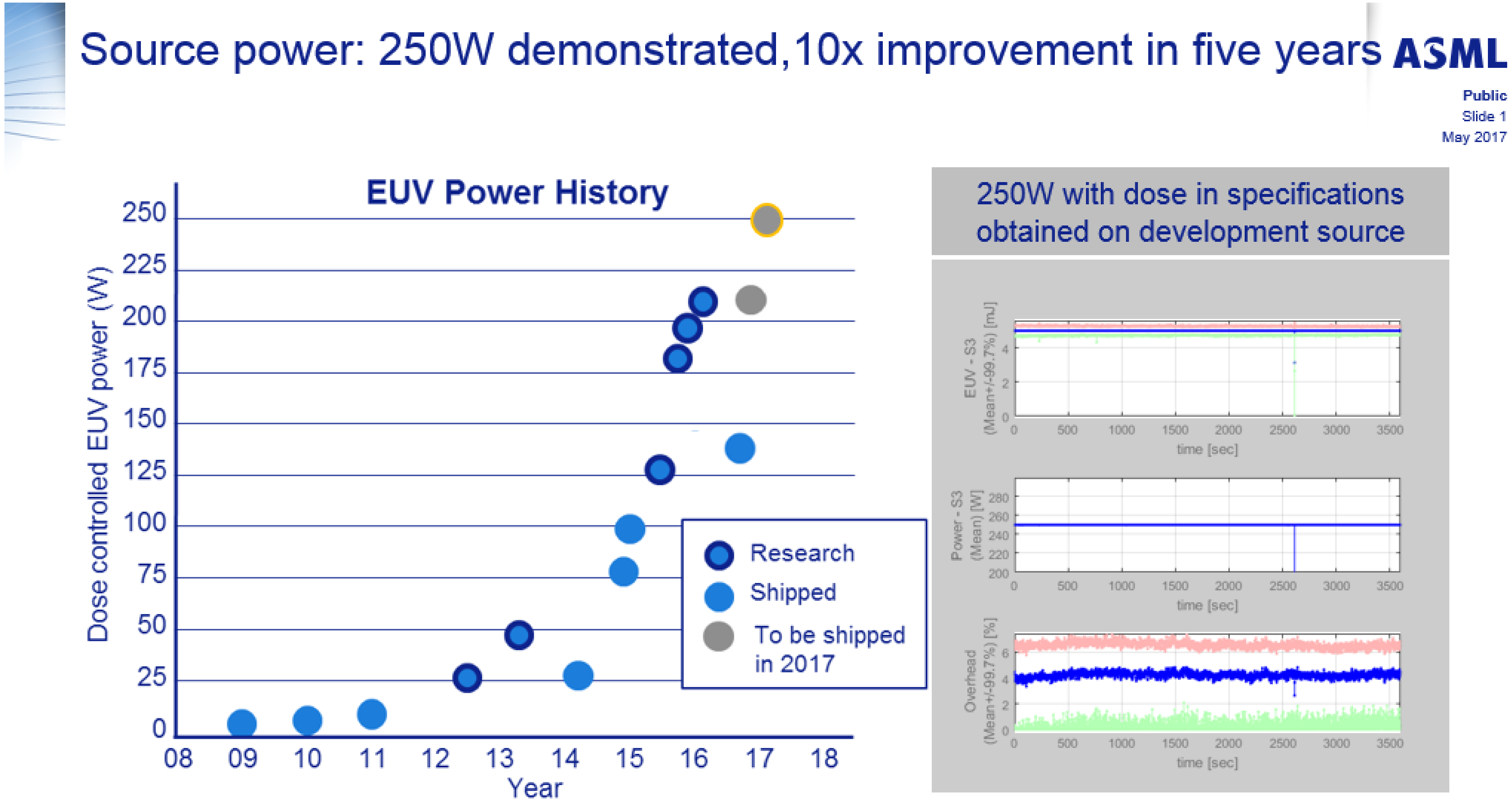
Judged as of Today

Improved combined system availability with NXE:3350



- Introduction of NXE:3350 reduced XLD
- By 2017, NXE:3350 combined availability exceeded 75%
- System availability expectations continue to increase
- NXE:3350 Much work remains to reach HVM-level availability
- Top contributor to tool down time is exposure source

Increased source power with dose control



Source power: 250W demonstrated,10x improvement in five years **ASML**

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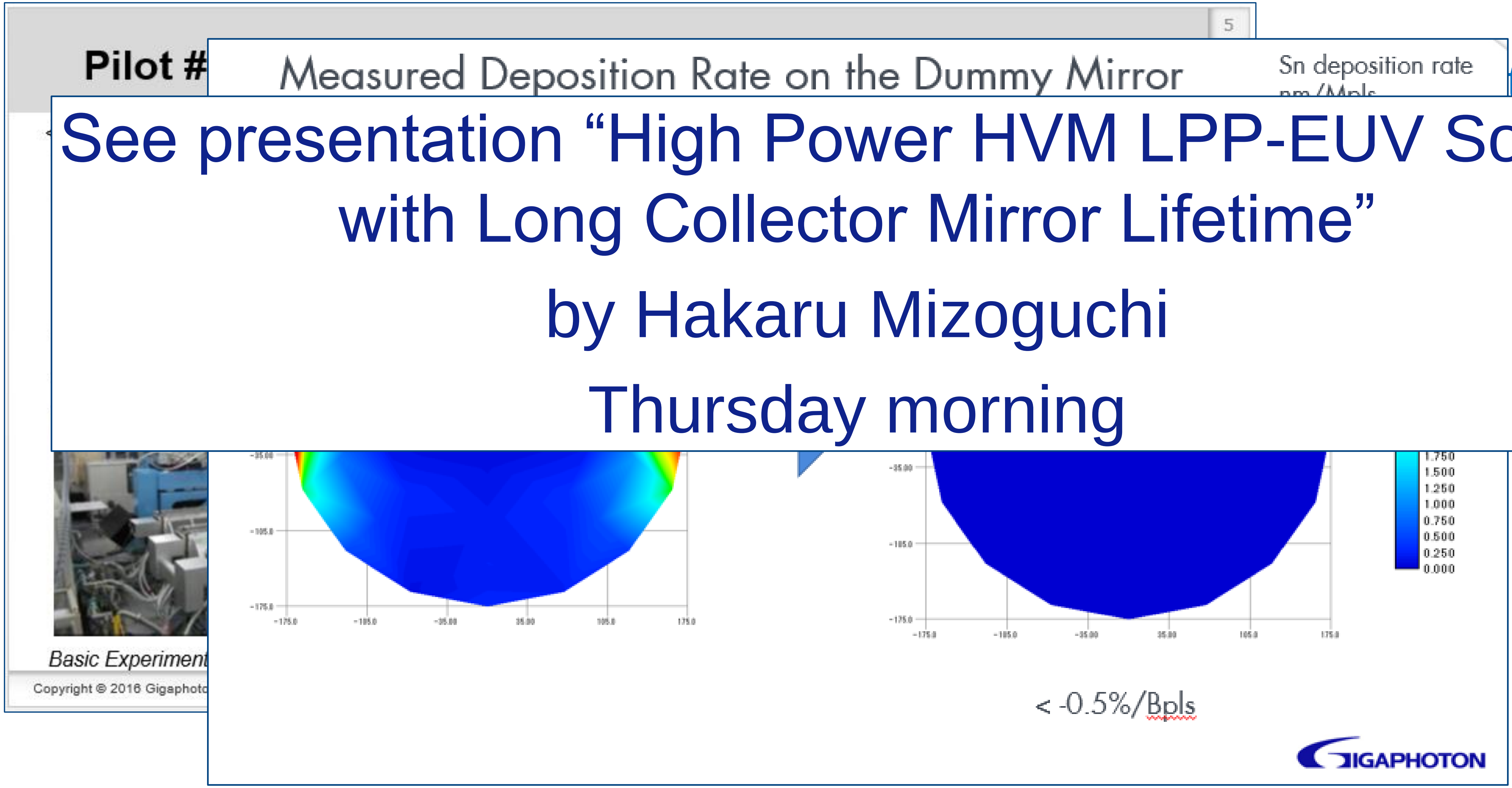
May 2017

250W with dose in specifications obtained on development source

- 250W: key milestone, improvement from 210W just a few months ago
- Must ensure satisfactory dose control at high power
- Power overhead needed for predictable quality and output

2nd Option : Gigaphoton developing LPP source



5

Pilot #

Measured Deposition Rate on the Dummy Mirror

Sn deposition rate

< -0.5%/Bpls

Basic Experiment

Copyright © 2016 Gigaphoto

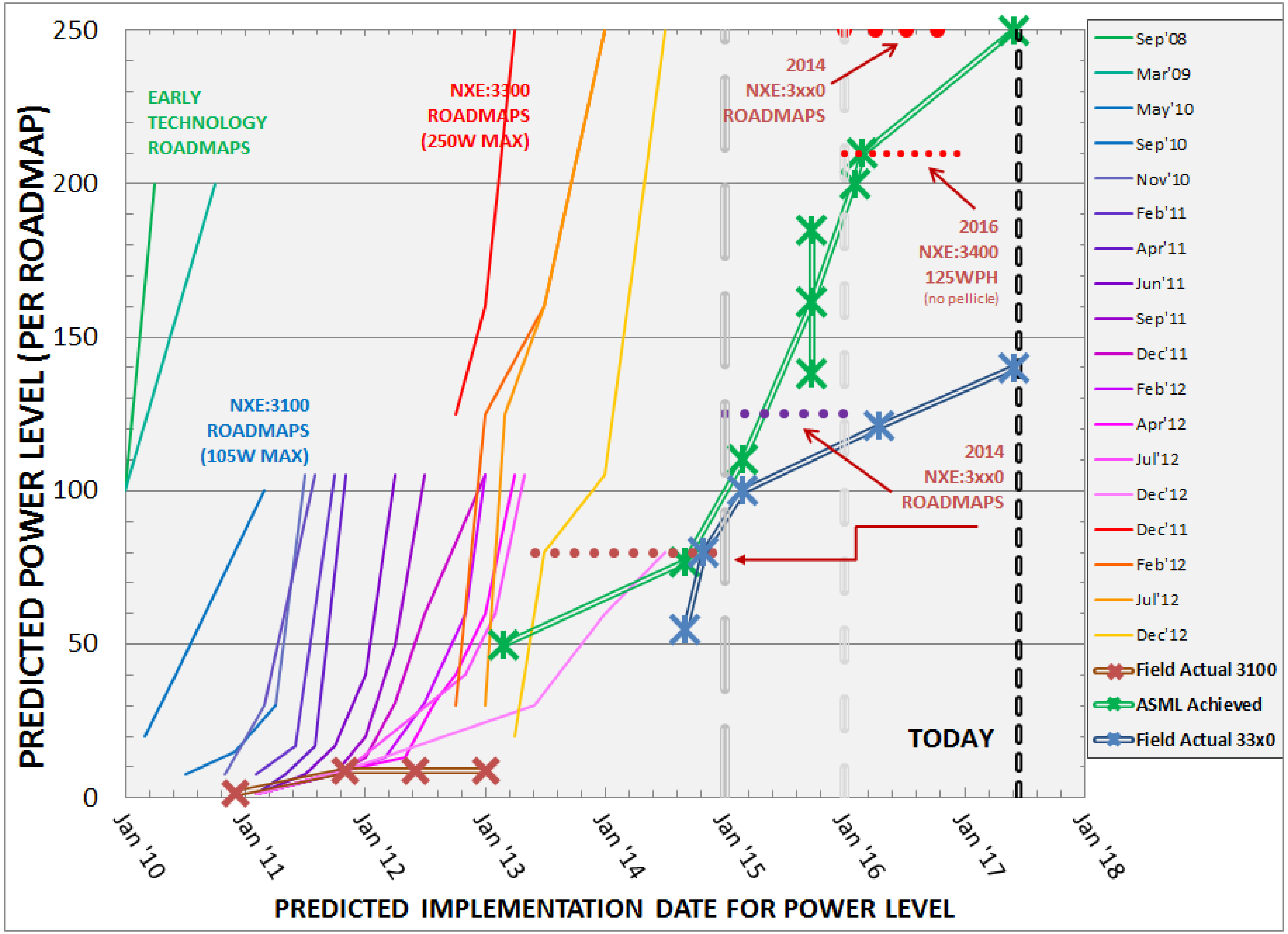
See presentation “High Power HVM LPP-EUV Source with Long Collector Mirror Lifetime”

by Hakaru Mizoguchi

Thursday morning

As of Today

Source power meeting roadmap

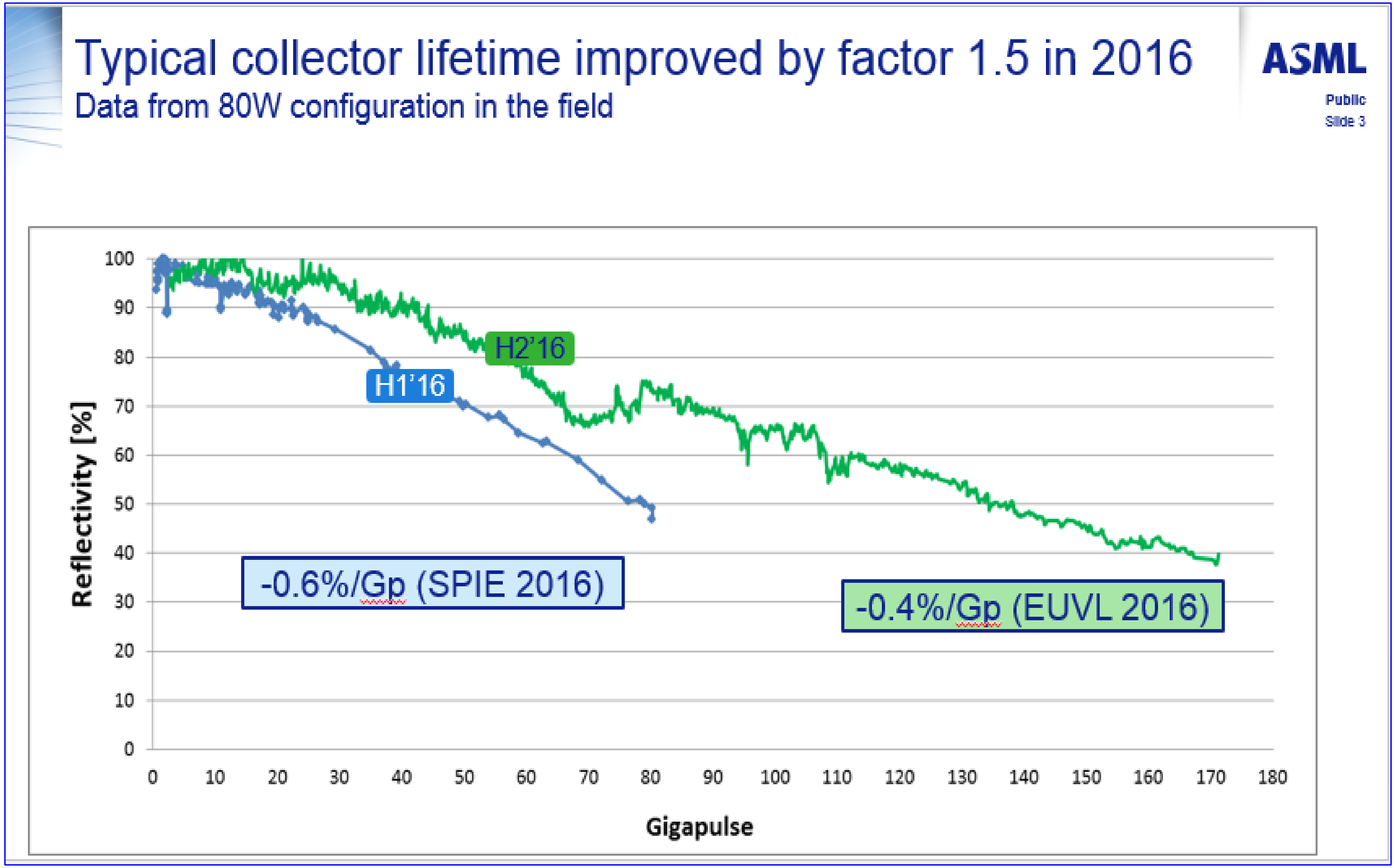


- Meeting 250W exposure source power established for NXE:3300

- Overcome many obstacles

- Continued emphasis ensuring sufficient power overhead for predictable quality and output

Collector lifetime extended with improved reflectivity



Typical collector lifetime improved by factor 1.5 in 2016

Data from 80W configuration in the field

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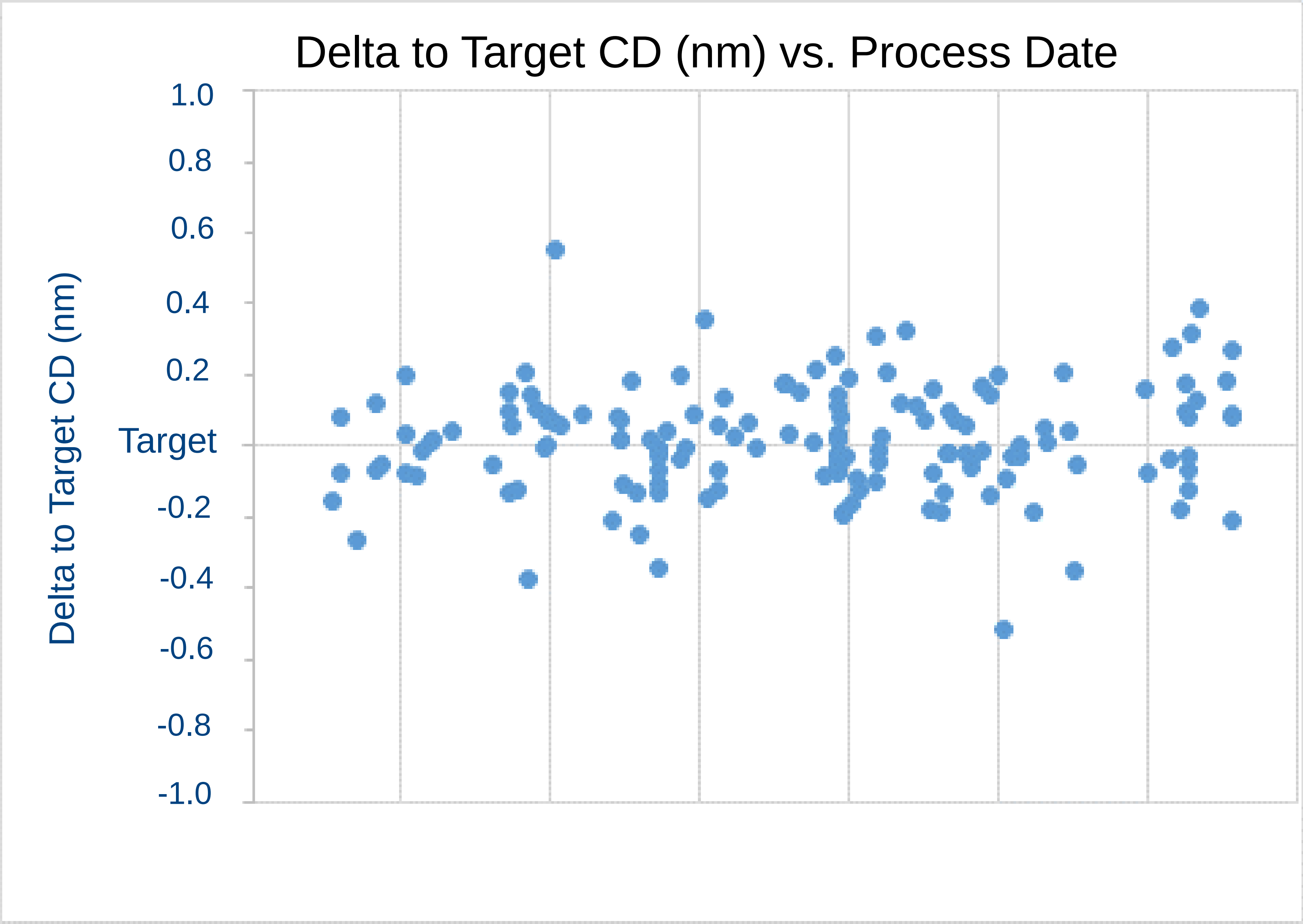
-0.6%/Gp (SPIE 2016)

-0.4%/Gp (EUVL 2016)

- Collector degradation follows roughly linear trend – predictable lifetime
- Degradation rate steeper than desired
- Demonstrated improvement in reflectivity over the course of 2016
- Expect continued improvement
- Bottom Line: expect significant correlation to system availability and OpEx

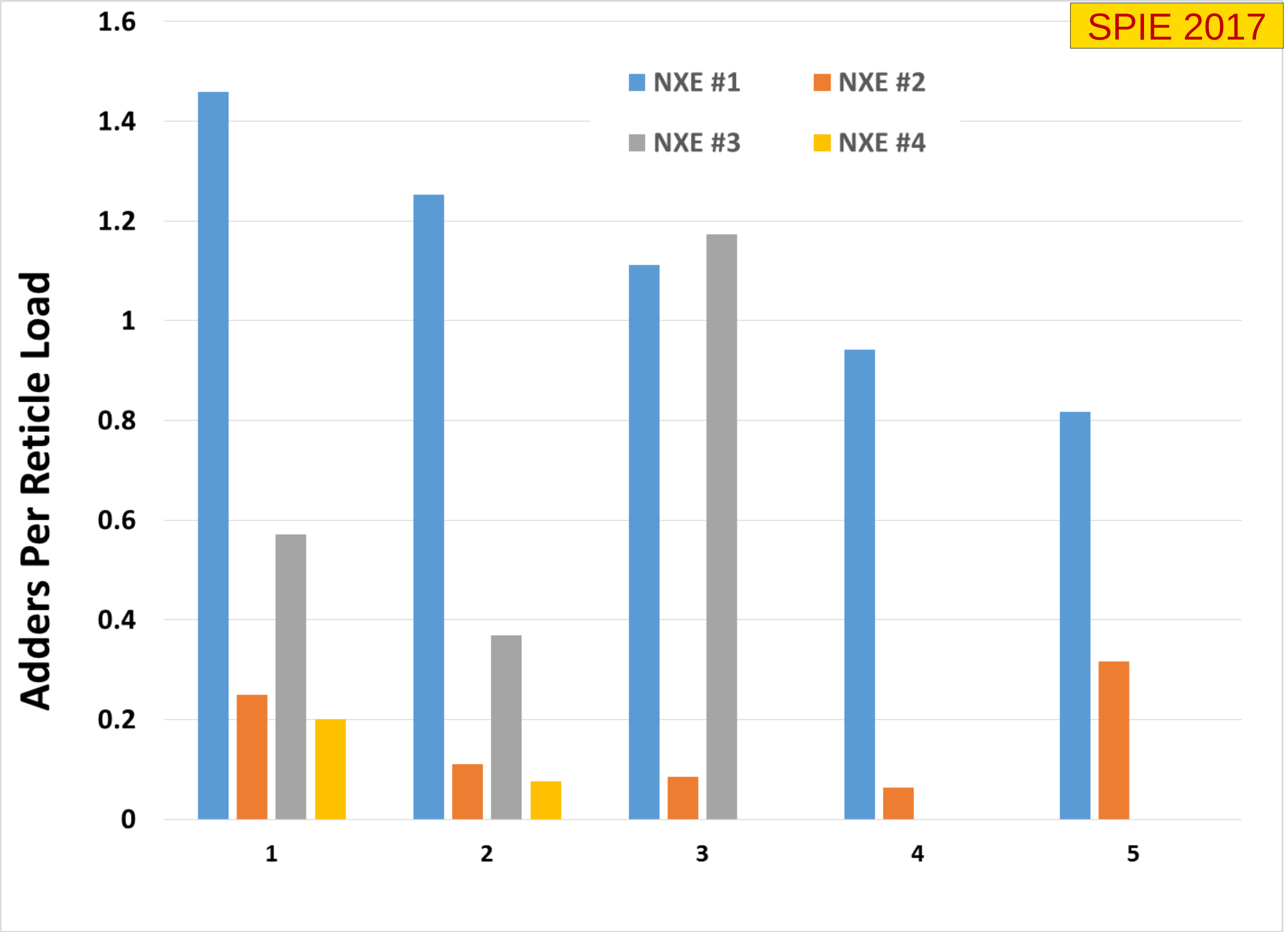
Slide courtesy ASML / Christope Smeets October 2016

Intel’s Pilot Line: CD trend



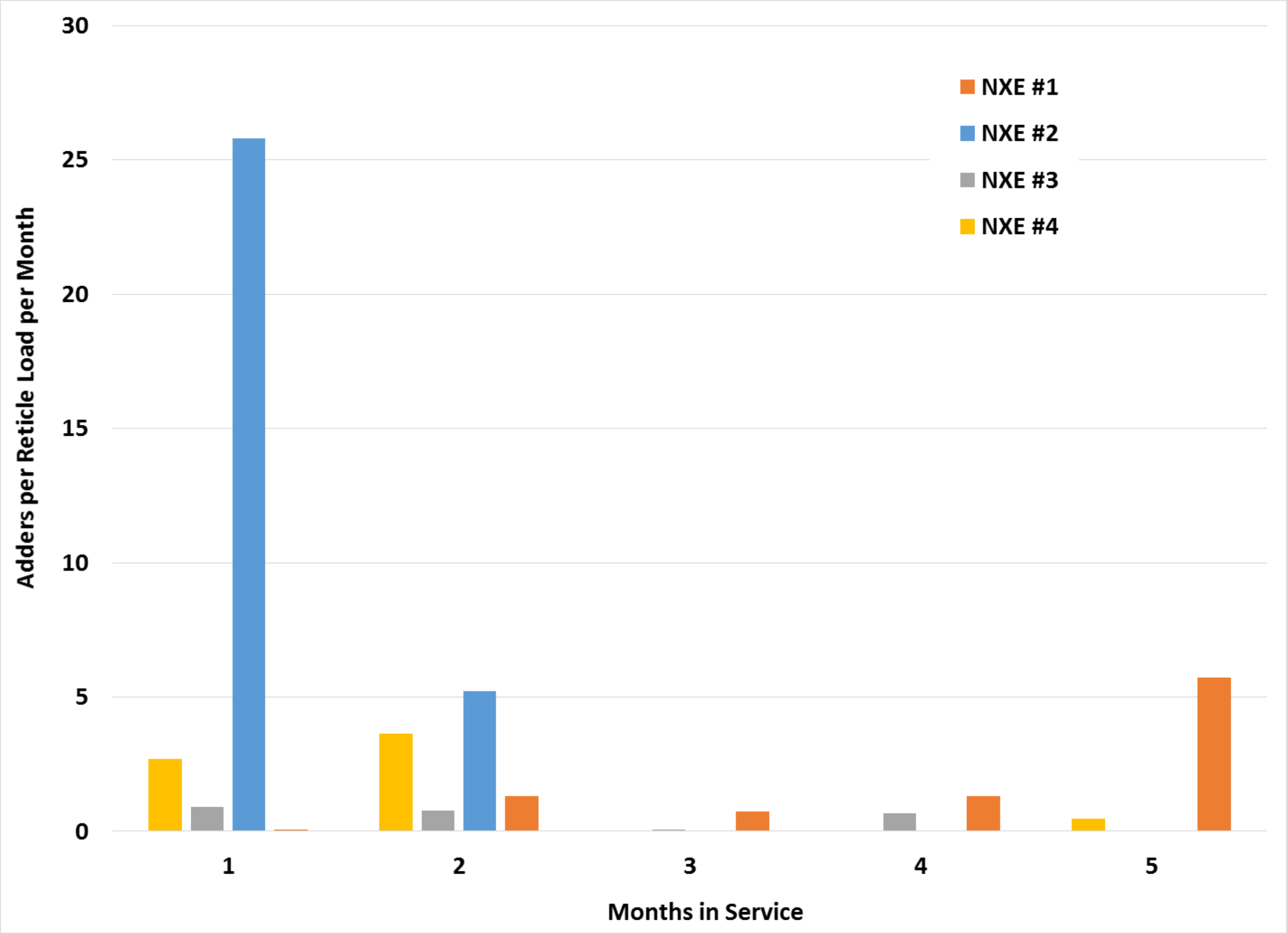
- Multiple tools running pilot line
- CD control within tight distribution
- Stable CD performance trend
- Overlay performance matched between EUV and 193i

Scanner cleanliness: Intel reticle defectivity



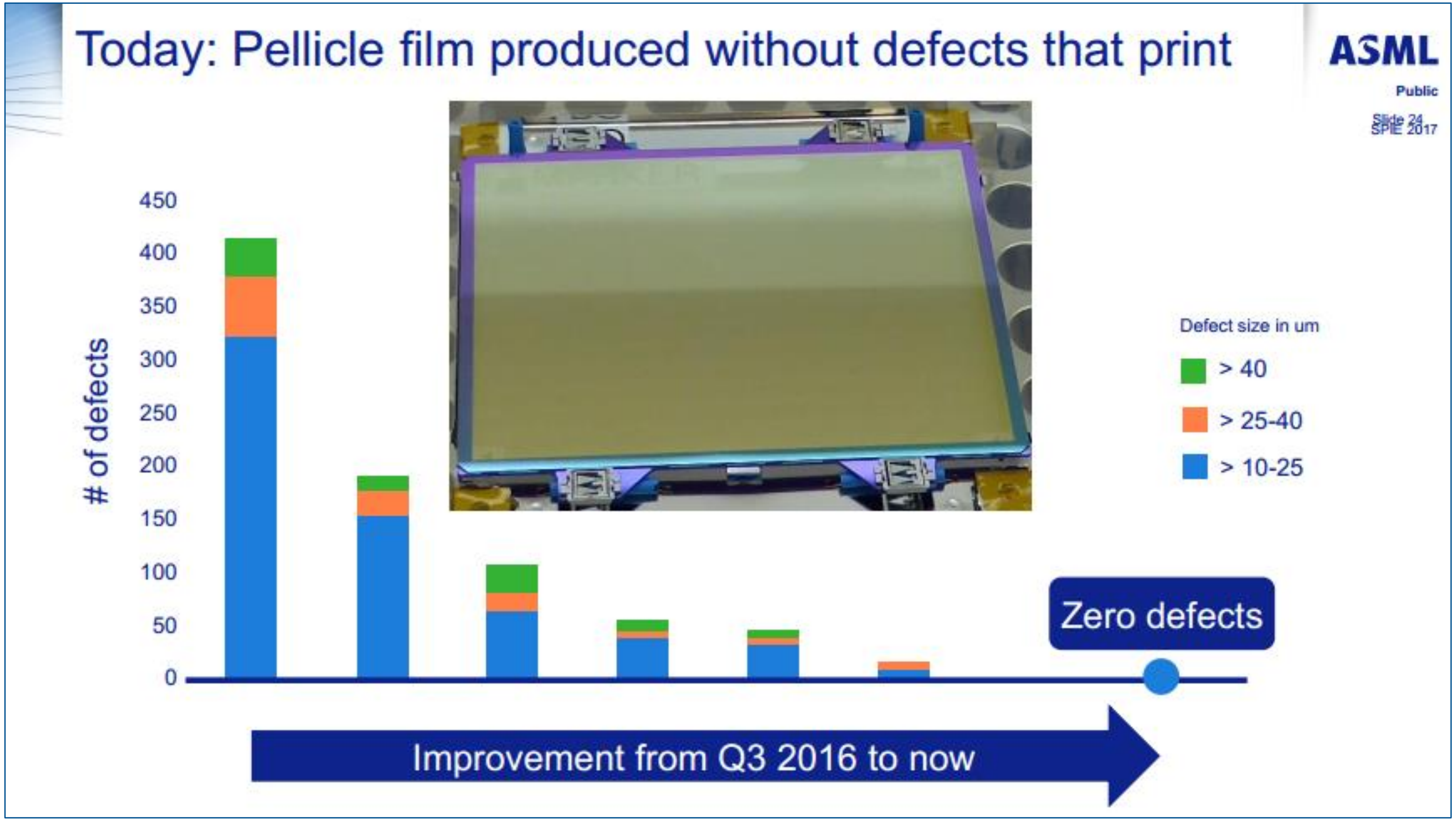
- Patterned wafer defect levels decrease over first few months of scanner service
- Variability in defect level after ‘burn-in’ – source unknown
- PWI defect levels remain similar to 2015

Scanner cleanliness: Intel reticle defectivity



- Many tools showing no adders/reticle load for several weeks
- Every tool has shown adders AFTER many weeks with no adders
- Unpredictability of adder events drives need for pellicle
- 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
- Defect level above acceptable limit → second element of ASML two-fold approach: EUV pellicle

Defect-free EUV pellicle membrane



Today: Pellicle film produced without defects that print

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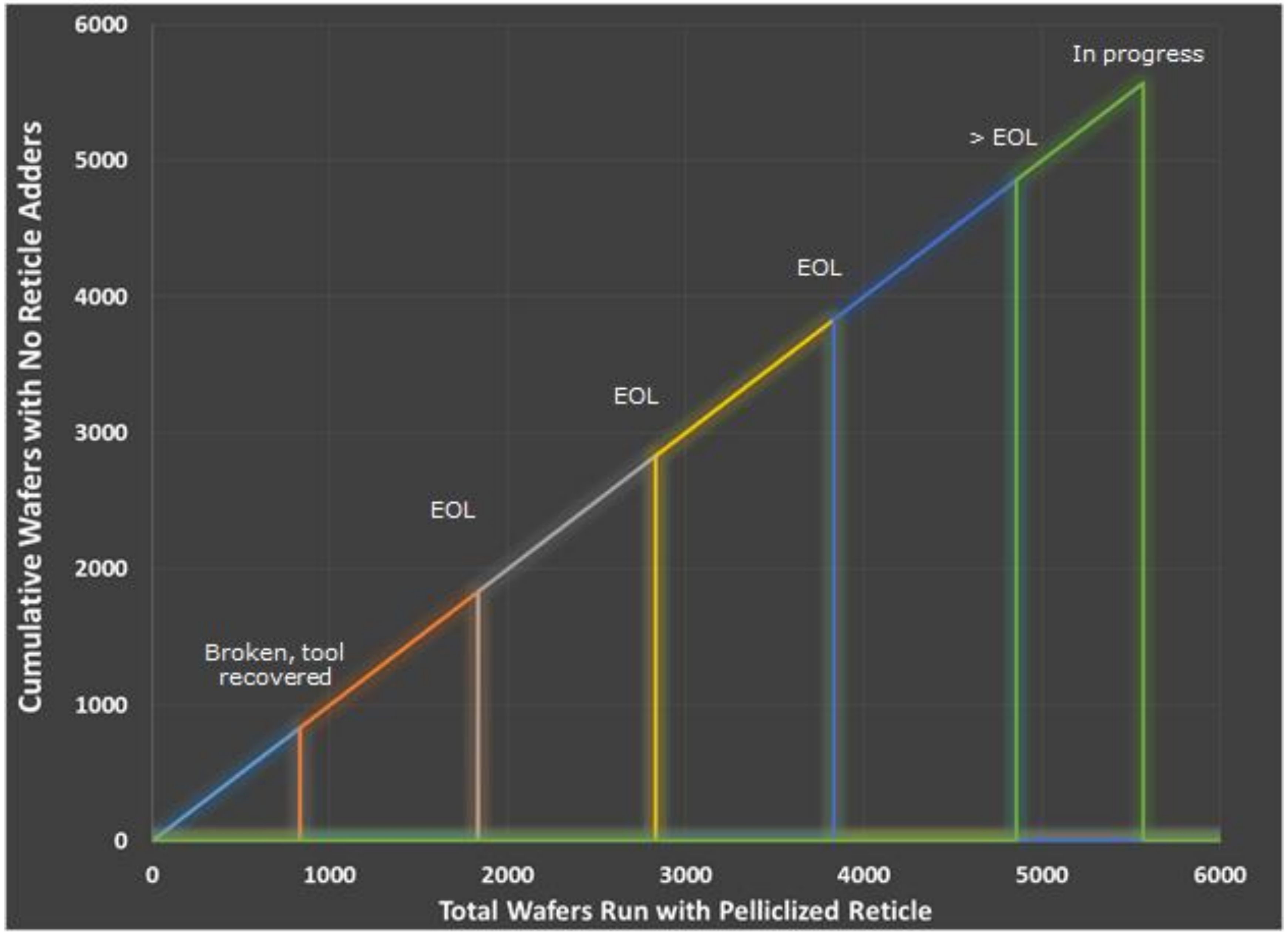
SPIE 2017 ASML / Mark van de Kerkof

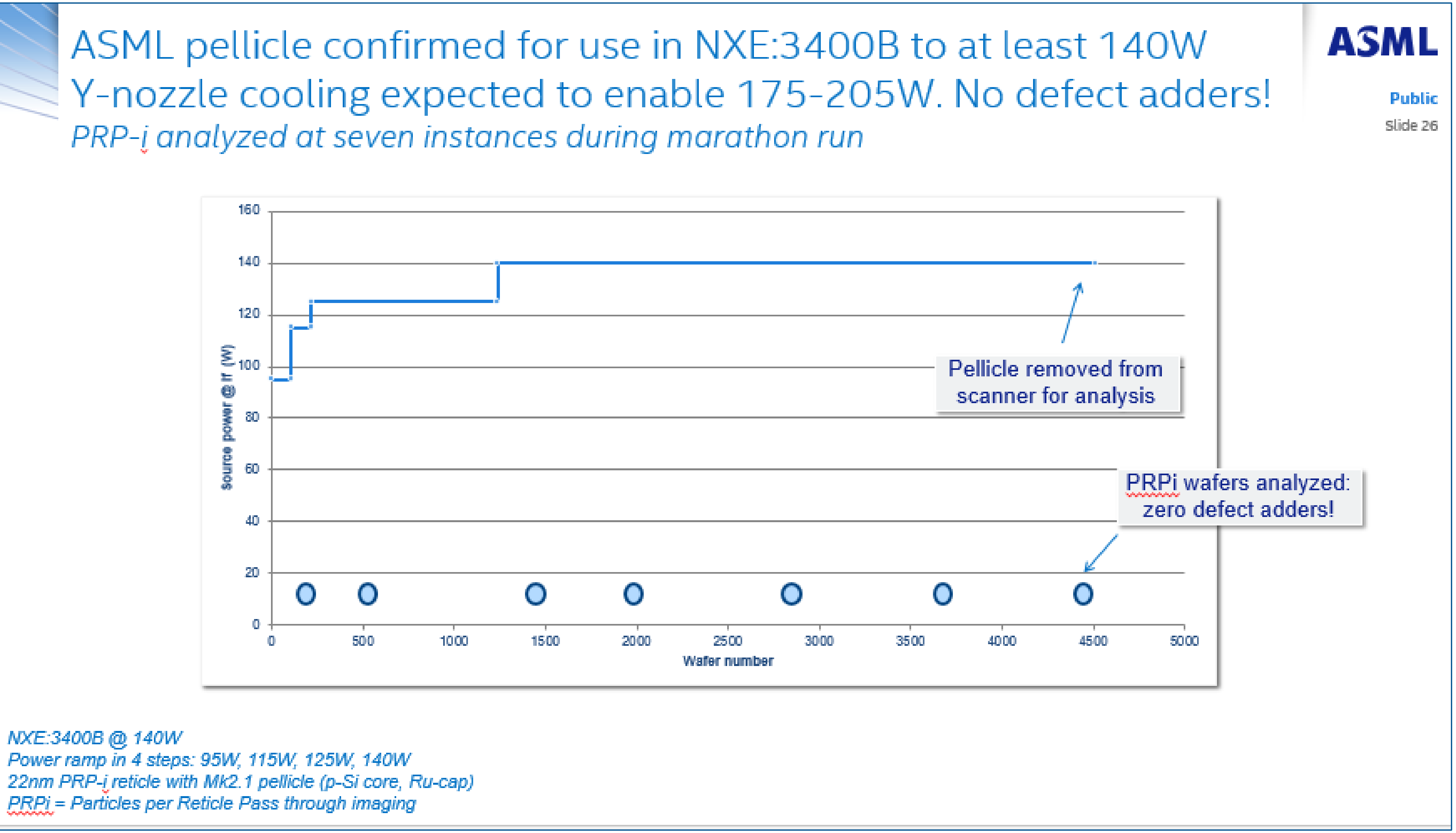
- Significant decrease in pellicle membrane defect levels since Q3’16
- Multiple membranes with zero defects <10um
- Continued focus expected to deliver volumes for HVM

Intel EUV pellicle exposure testing continues



- Multiple pellicles exposed at Intel (represented by various colors)
- >5000 wafer exposures demonstrating effective pellicle and frame design
- Membrane power resiliency not exercised

EUV pellicle power resiliency



ASML pellicle confirmed for use in NXE:3400B to at least 140W
Y-nozzle cooling expected to enable 175-205W. No defect adders!

PRP-i analyzed at seven instances during marathon run

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Pellicle removed from scanner for analysis

PRPi wafers analyzed: zero defect adders!

NXE:3400B @ 140W
Power ramp in 4 steps: 95W, 115W, 125W, 140W
22nm PRP-i reticle with Mk2.1 pellicle (p-Si core, Ru-cap)
PRPi = Particles per Reticle Pass through imaging

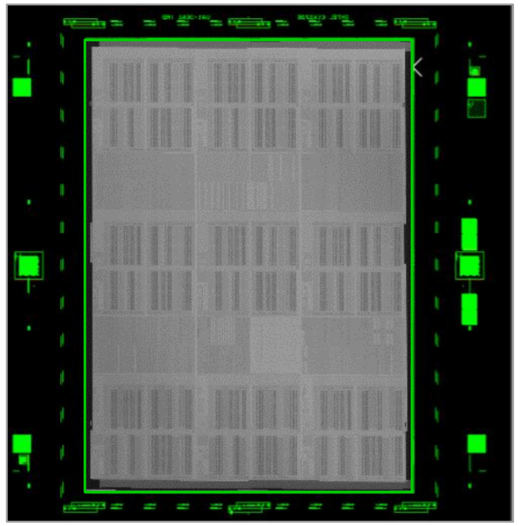
- Single pellicle exposed >4k wafers
- Power at 140W
- No added defects
- Cooling hardware developed; expect to withstand exposure power 205W

Slide courtesy ASML Raymond Maas June 2017

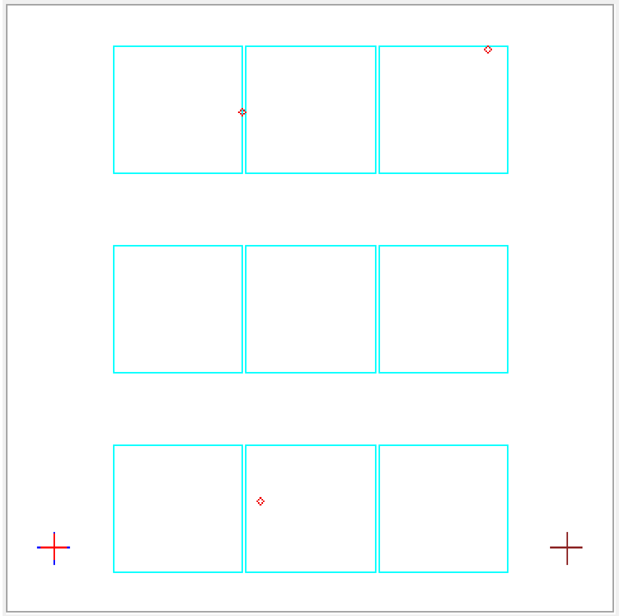
SPIE 2017

Bottom line: No printing defects

N10 Reticle

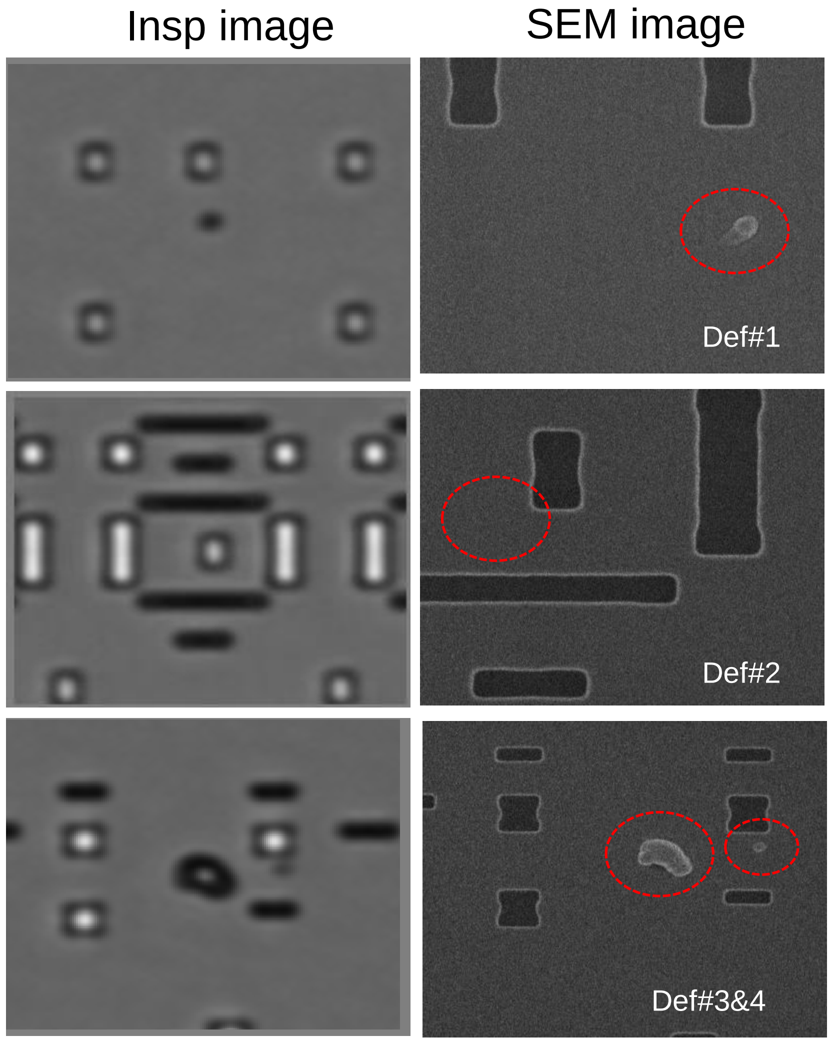


3 Defects found in 9 cells



- 2 of 4 defects hit-back to the blank with no impact to wafer print.

Pattern defects



Guojing Zhang, 2016 BACUS

- Improved metrology
- Defect mitigation by pattern shifting and defect repair
- Also created N7 masks with no printable defects

From 2017 SPIE

EUV infrastructure readiness snapshot

EUV infrastructure has 8 key programs

6 are ready or near-ready now, 1 is in development, 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:** Imaging demonstrated; systems shipping to field
- 🟨 **Pellicle:** ASML commercializing – needs acceleration; production phase in 2H'17 – cannot slip schedule
- ▨ **EUV blank quality:** Process and yield improvements continue
- ▨ **Blank multi-layer deposition tool:** Improving defect results
- ▨ **EUV resist QC:** RMQC center at IMEC expected online in 2017
- 🟥 **Actinic Patterned Mask Inspection (APMI):** High resolution PWI for fab. Still need actinic inspection in mask shop.

★ Two remaining EUVL infrastructure areas of focus pertain to pellicle and mask inspection

Overall milestone progress messages

Judged as of today

- Combined scanner/source availability improving
  - Exposure source remains largest contributor to tool downtime
  - Availability trend going in right direction with insertion of NXE:3350 – trend needs to reach HVM-level
  - Expect continued improvements with NXE:3400
- Exposure source power meeting 250W roadmap, and 2nd supplier (Gigaphoton) with encouraging progress
- Scanner defectivity levels remain similar to 2015
  - Underscores need for pellicle and associated infrastructure / support
- Significant progress in pellicle program over past year
  - Pellicle membranes manufactured with zero defects <10um
  - Continued demonstration of pellicle exposure with pellicle frame design mitigating adder defects
- 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, …)
- Demonstrated capability to manufacture defect-free 7nm EUV masks – need continued blank defect reduction
- 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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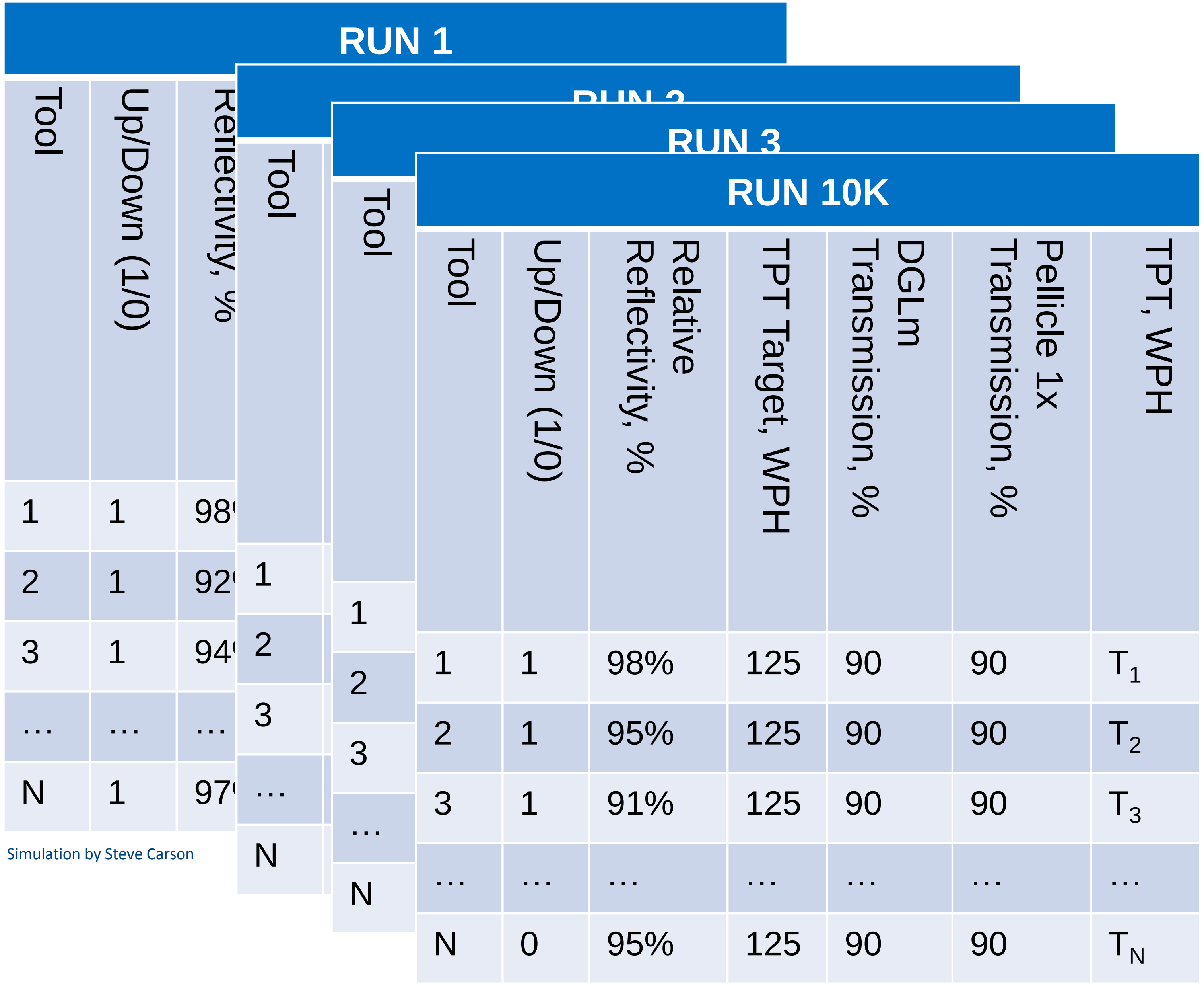
HVM insertion considerations → Predictability

- Capability demonstrated:
  - ✓ Exposure source power
  - ✓ Pellicle efficacy
  - ✓ Material performance
  - ✓ Pilot line CD and overlay performance
- What is impact on fleet predictability?
  - ? Combined scanner / source availability
  - ? Collector reflectivity / lifetime
  - ? Pellicle / DGLm transmission
- Simulate HVM conditions – how do these parameters affect reliable TPT?
  - Simulation methodology assumptions:
    - Average availability across fleet aligned with roadmap
    - Acceptable level of collector degradation
    - Pellicle single-pass transmission; DGL membrane transmission
    - Maximum capable TPT (NXE:3400, 125wph)

Simulation Example



RUN 1

Tool	Up/Down (1/0)	Reflectivity, %
1	1	98
2	1	92
3	1	94
…	…	…
N	1	97

RUN 2

Tool
1
2
3
…
N

RUN 3

Tool
1
2
3
…
N

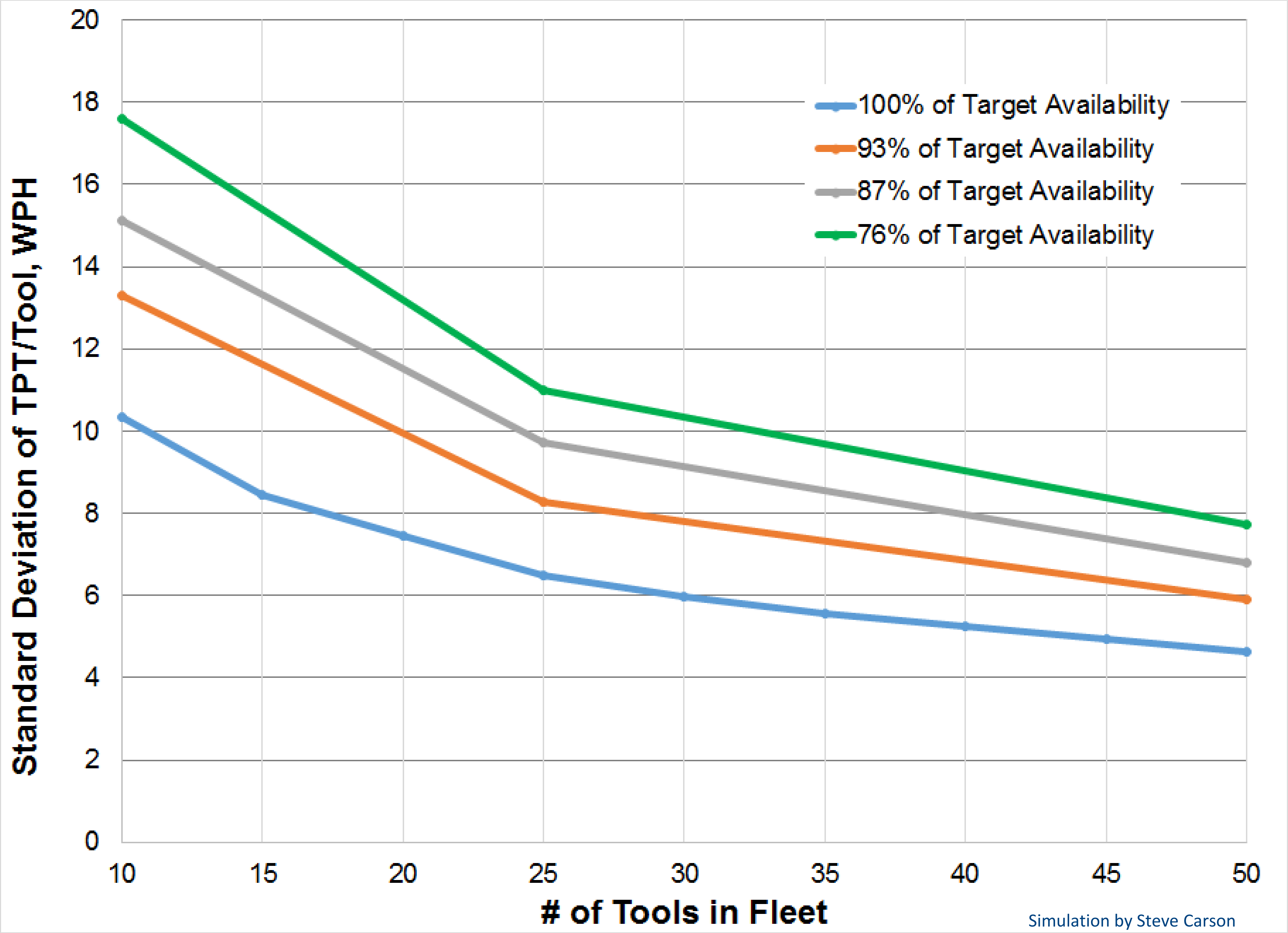
RUN 10K

Tool	Up/Down (1/0)	Relative Reflectivity, %	TPT Target, WPH	DGLm Transmission, %	Pellicle 1x Transmission, %	TPT, WPH
1	1	98%	125	90	90	T_1
2	1	95%	125	90	90	T_2
3	1	91%	125	90	90	T_3
…	…	…	…	…	…	…
N	0	95%	125	90	90	T_N

Simulation by Steve Carson

- At any given point in time, and for each tool in "fleet"
  - Probability of tool being 'Up' = average availability
  - Level of collector degradation = random value between 100% relative reflectivity down to acceptable minimum level
  - Other parameters remain constant
- Single run fleet-wide TPT calculated based on # of tools, availability of each tool, and randomly selected collector relative reflectivity
- Run 10k different fleet-wide TPT's to determine average, max, min, and standard deviation

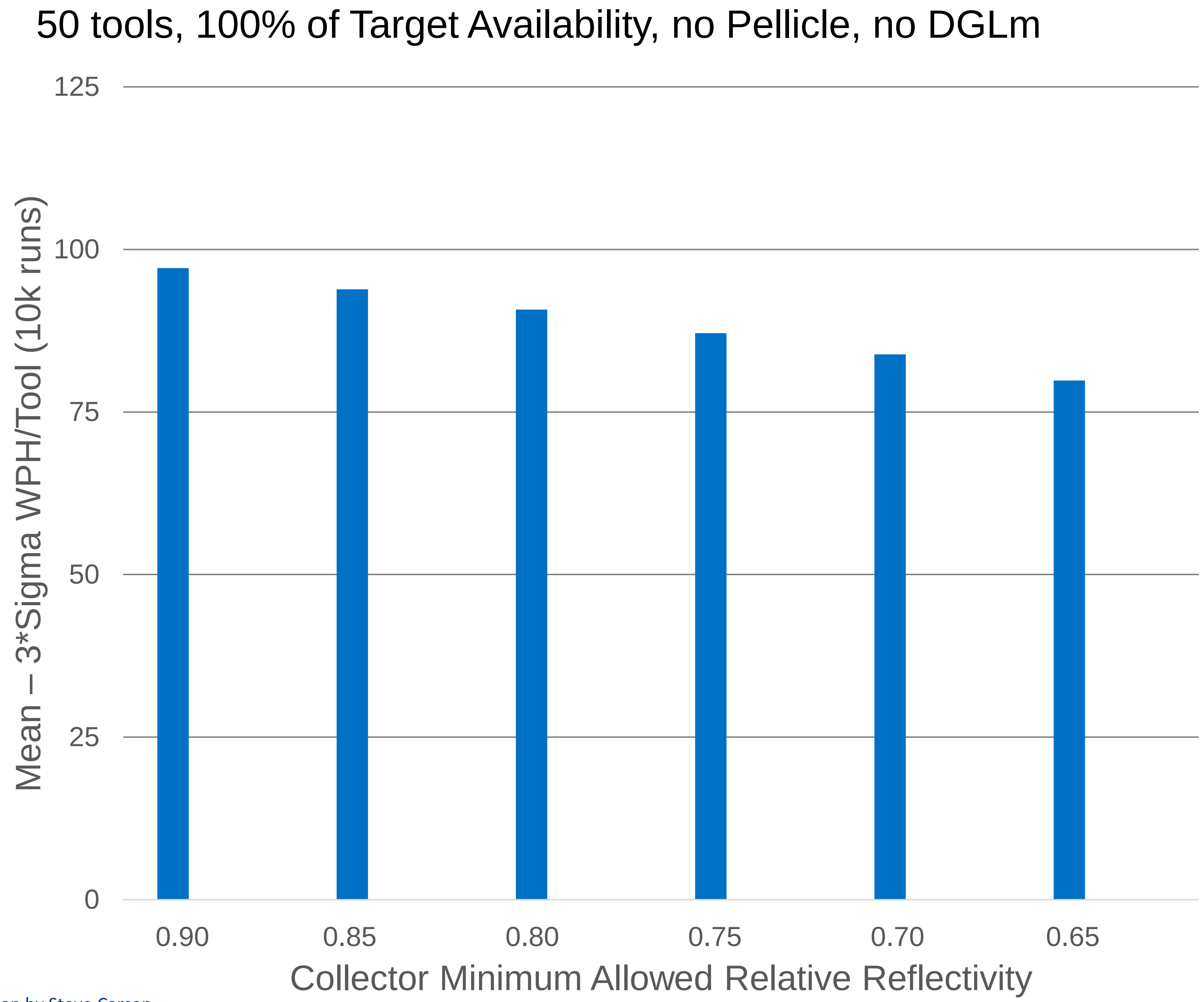
Variability in TPT: # Tools & Availability



Simulation by Steve Carson

- Variability over the lifetime (10k runs) of the fleet
  - will become lower as availability increases
  - Will become lower as fleet size increases
  - Will reach an asymptote (due to collector degradation)
- Subsequent simulations use a fleet size of 50 tools
- Fleet-wide TPT defined by 99.7% confidence interval: **MEAN – 3σ**

Collector Degradation

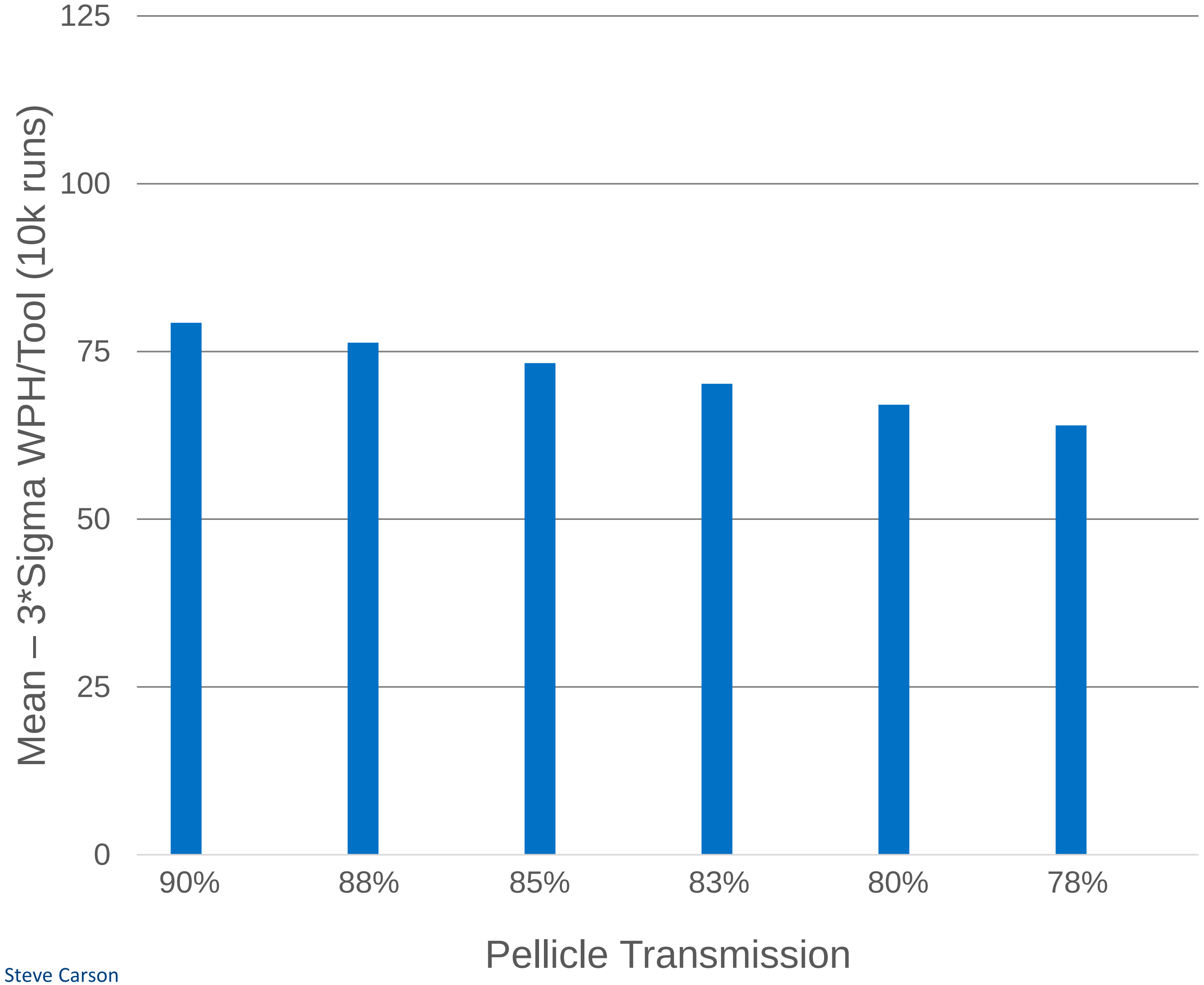


- >20% gap between tool capability and 99.7% confidence in fleet TPT
- Collector degradation must be minimized to reduce impact
- Collector swap is downtime intensive → must minimize # of swaps → must minimize rate of collector degradation

Simulation by Steve Carson

Pellicle transmission

50 tools, 100% of Target Availability, 90% collector RR allowed, 90% transmission DGLm

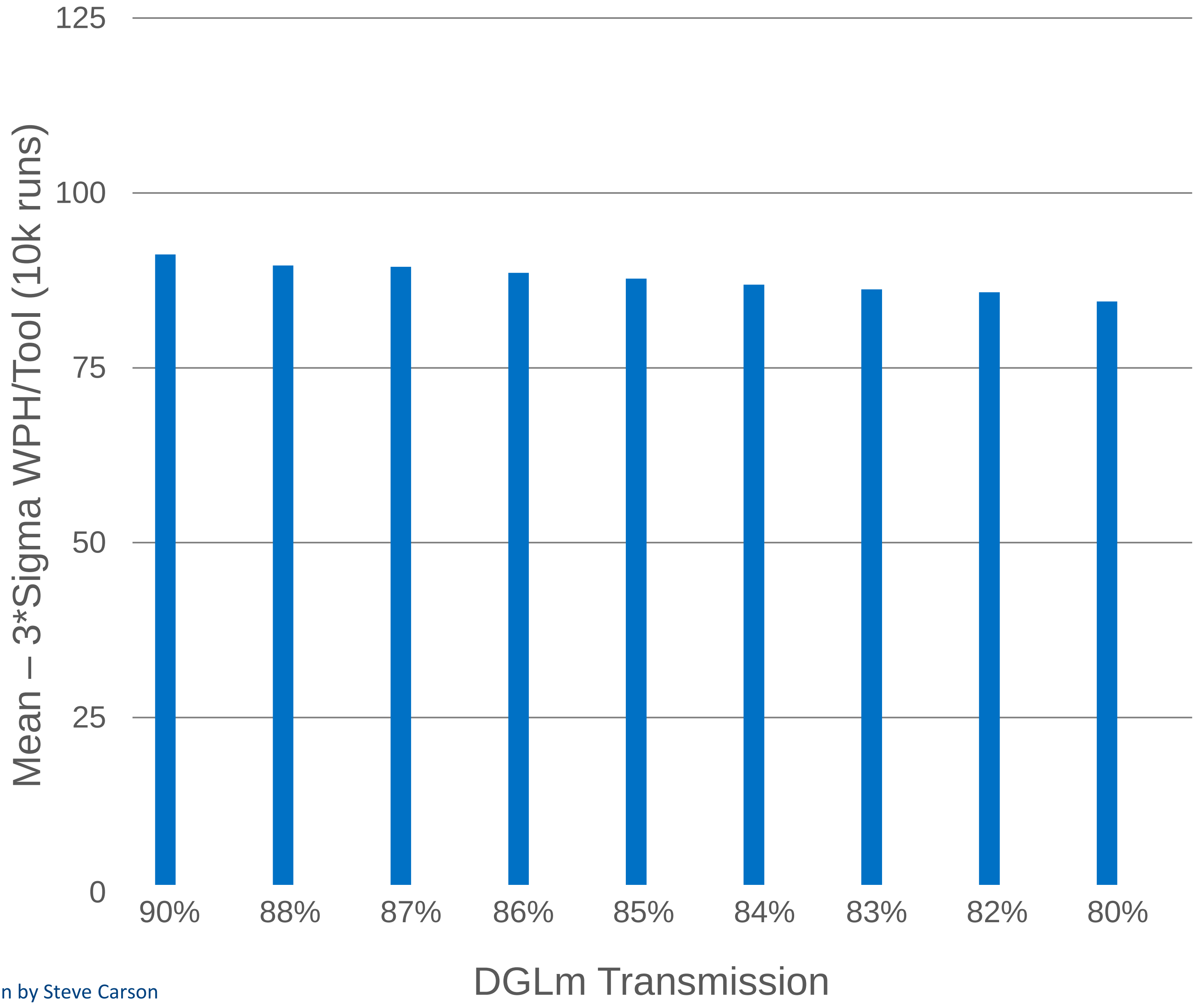


- Pellicle attenuates 99.7% confidence TPT/Tool approximately by transmission squared
- Maximize pellicle transmission for HVM

Simulation by Steve Carson

DGL membrane

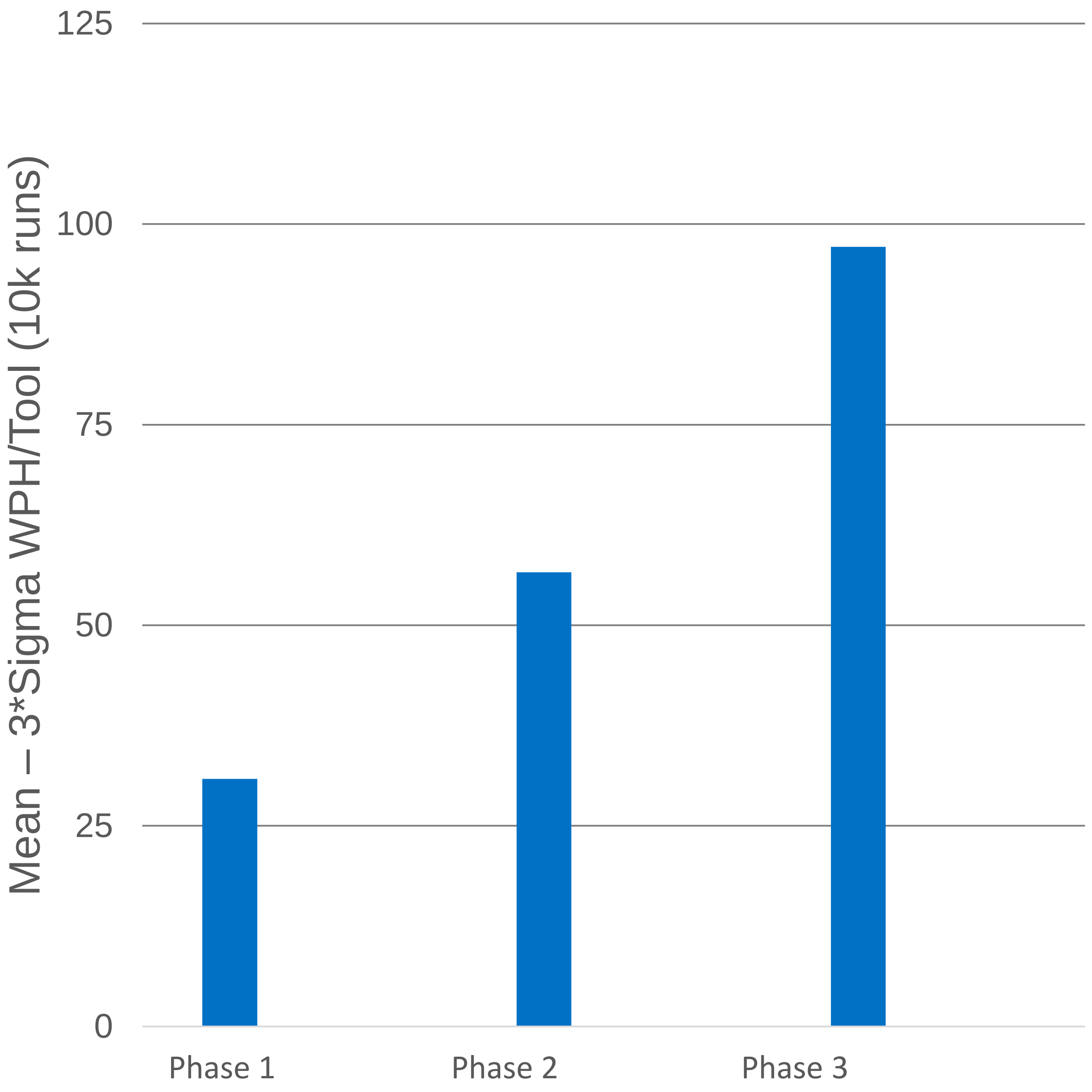
50 tools, 100% of Target Availability, 90% collector RR allowed, no Pellicle



Simulation by Steve Carson

- DGLm attenuates 99.7% confidence TPT/Tool approximately by transmission
- Maximize DGLm transmission for HVM

What does this mean? Across all roadmaps



- Collector relative reflectivity and transmission of pellicle and DGL membranes will improve over time and in concert
- Phases represent arbitrary intercepts of various roadmaps at specific points in time
- ~75% improvement in 99.7% confidence WPH/tool TPT at each phase
- All roadmaps must be met on time in order to reach HVM expectations

Simulation by Steve Carson

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Materials requirements

- Today’s microprocessors have >1B transistors
- If every VIA has to work for a die to yield, for a 99% probability of the die to yield (Y), the probability of a VIA failure (f) is

$$f \sim (1-Y)/Z$$

If number of VIAs $Z= 10^{10}$

$$f \sim E^{-12}$$

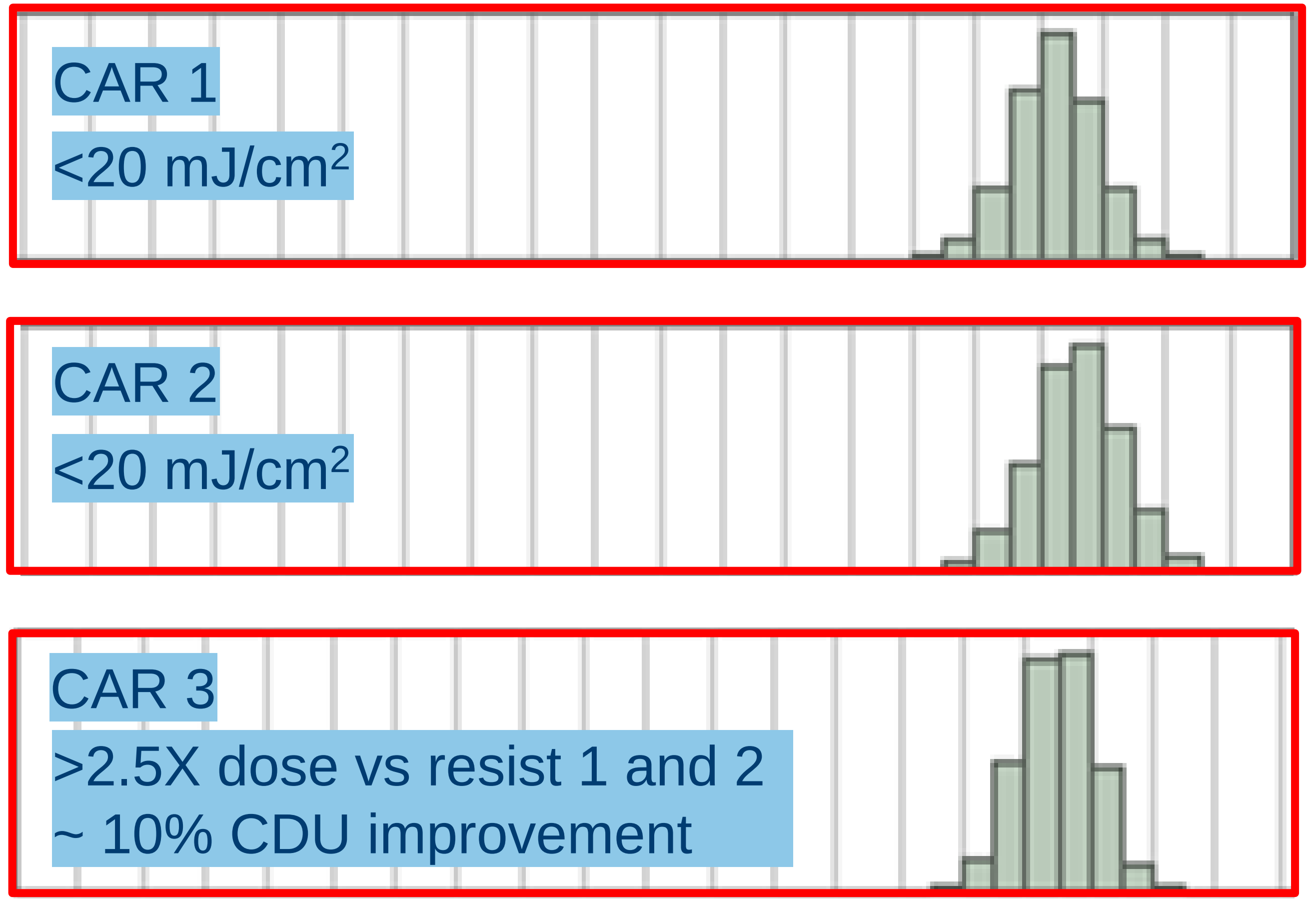
The Failure rate per VIA must be on the order of 1 part per Trillion!!!

We must control variability and stochastics
Resolution is not sufficient

Slide by Anna Lio

More than photon shot noise

NXE3300, 28 nm hole
72K measurements



CAR 1
<20 mJ/cm^2

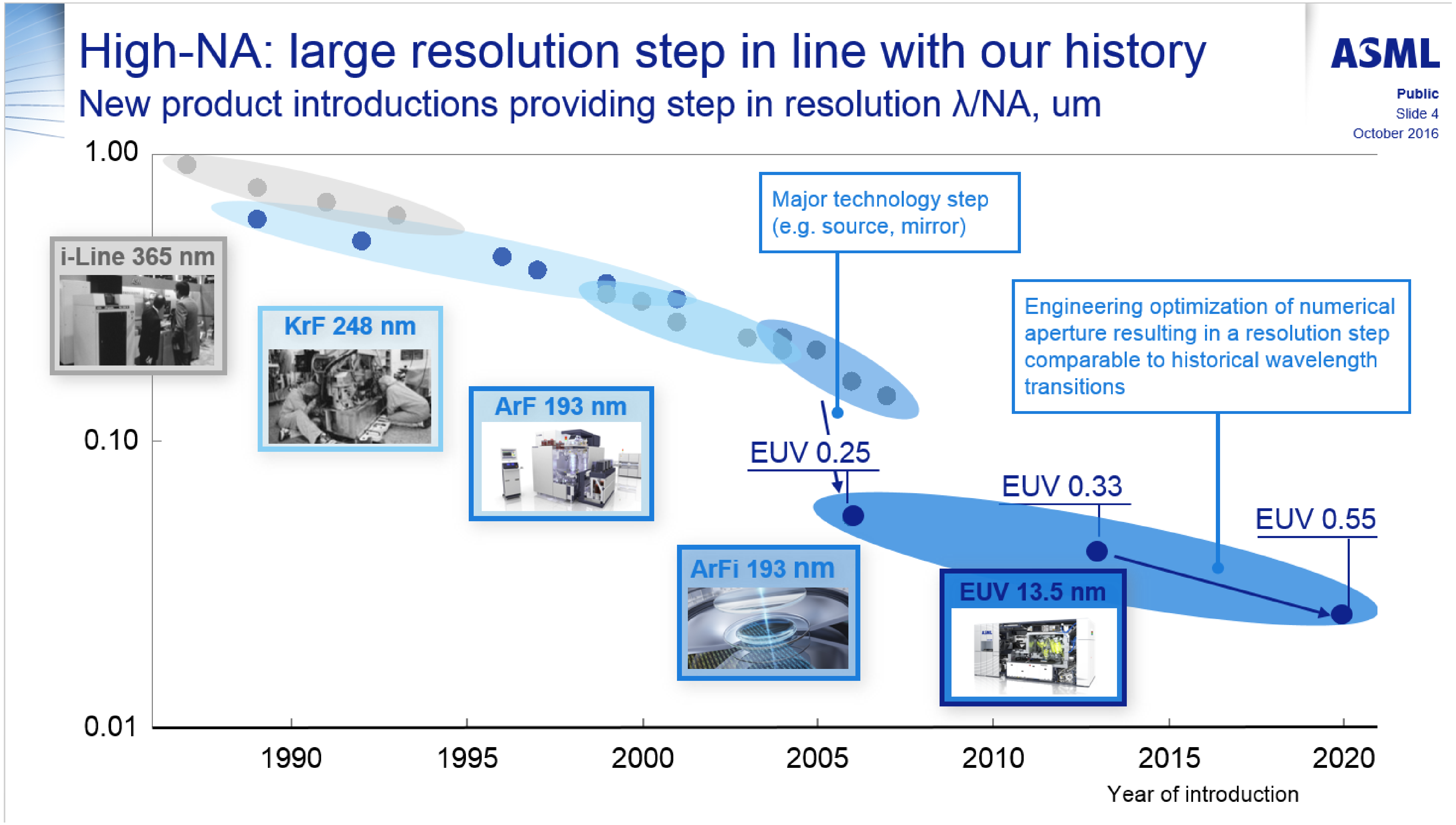
CAR 2
<20 mJ/cm^2

CAR 3
>2.5X dose vs resist 1 and 2
~ 10% CDU improvement

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
- DGL membrane enables accelerated insertion of novel materials
- High NA requires materials innovation

EUV roadmap extension: High NA



High-NA: large resolution step in line with our history

New product introductions providing step in resolution λ/NA, um

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Slide 4
October 2016

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)

Engineering optimization of numerical aperture resulting in a resolution step comparable to historical wavelength transitions

EUV 0.25
EUV 0.33
EUV 0.55

1990
1995
2000
2005
2010
2015
2020

Year of introduction

Slide courtesy ASML February 2017

- HF 0.55NA anamorphic optics, higher transmission, fast stages, offer attractive wafer cost / process simplification proposition

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Conclusion: Preparation for HVM

- Exposure source → Significant progress: improvements in availability & power need to translate to field systems
- Pellicle → Needed to ensure EOL yield; pellicle program continues to make significant progress
- HVM requires predictability
  - Many factors affecting predictability for HVM
    - System availability
    - Pellicle transmission and power resiliency
    - Collector lifetime
  - OpEx (mostly source consumables) – DG lifetime improvement demonstrated in field; Collector lifetime improvements encouraging – need to translate to field systems
- Materials
  - Materials performance – Won’t gate introduction of EUV, but need to emphasize stochastics: need to understand the interaction of EUV radiation with resist and design resist materials for stochastics

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ASML
Gigaphoton

Backup