Progress on Laser Assisted Discharge Produced Plasma (LDP) EUV Light Source Technology

2012 International Symposium on EUV Lithography

Brussels, October 2012

USHIO GROUP

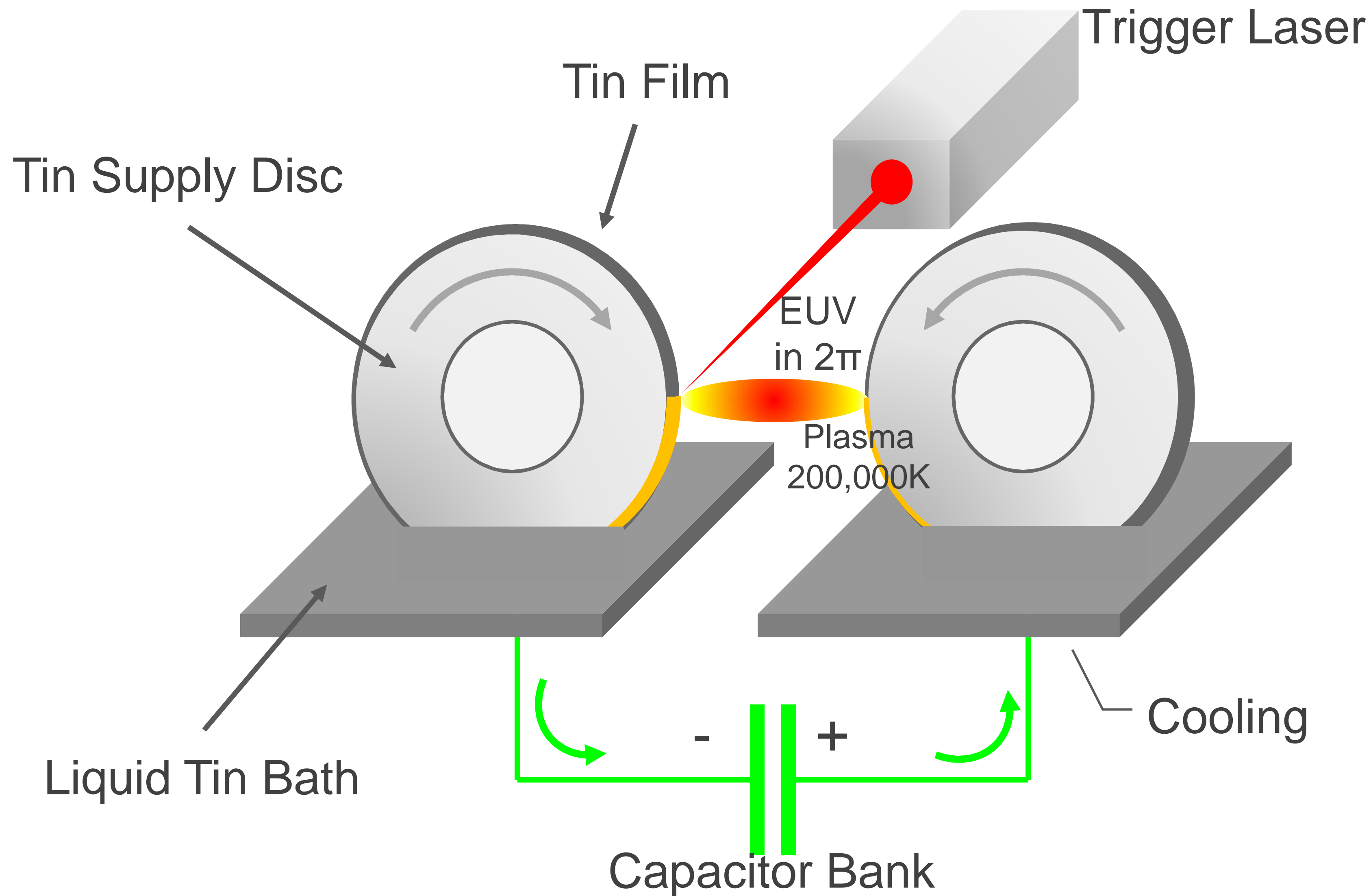
Please visit Poster

P-SO-14

Rolf Apetz, XTREME

XTREME's LDP* Concepts – A Quick Refresher

*Laser assisted Discharge Plasma



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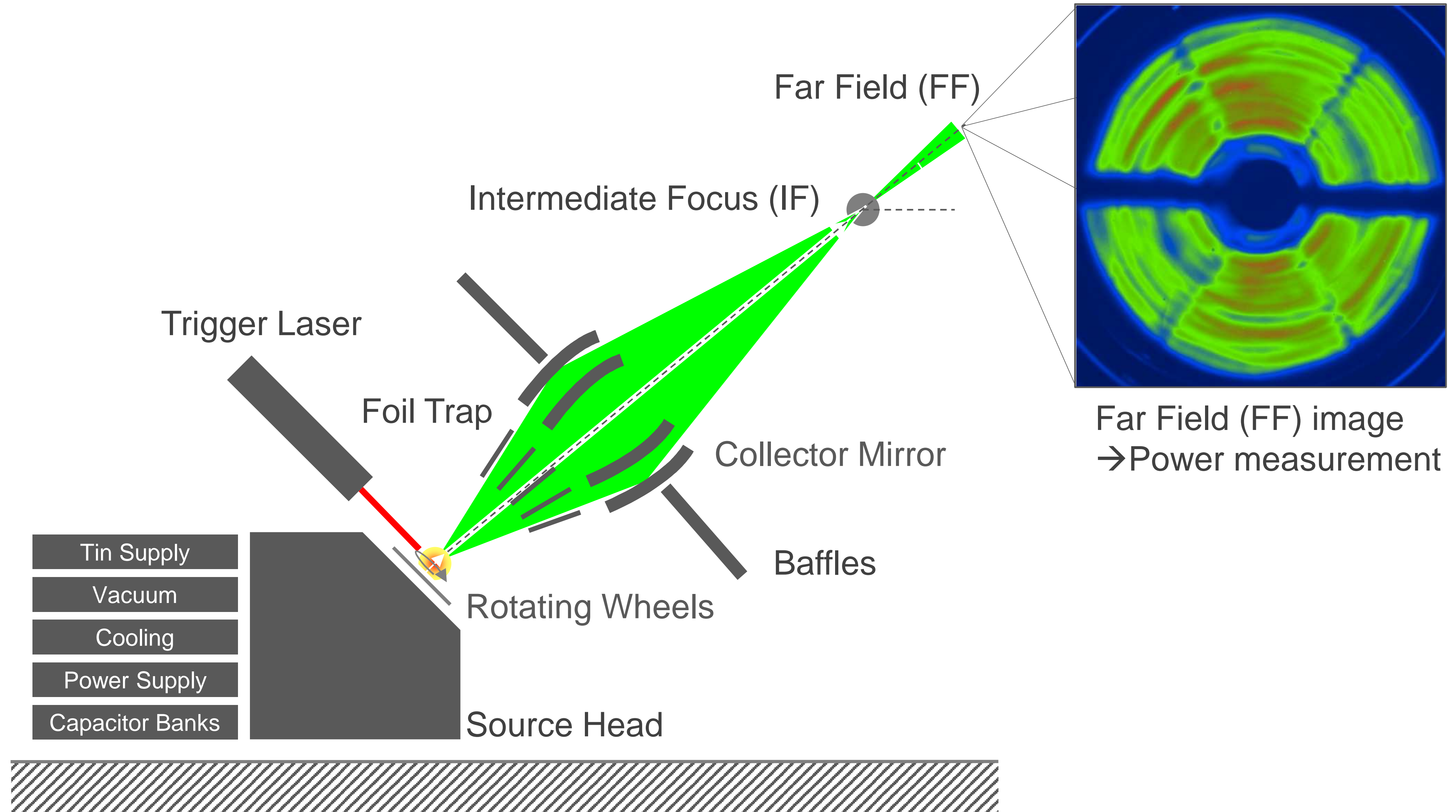
XTREME's LDP* Concepts – A Quick Refresher

***Laser assisted Discharge Plasma**



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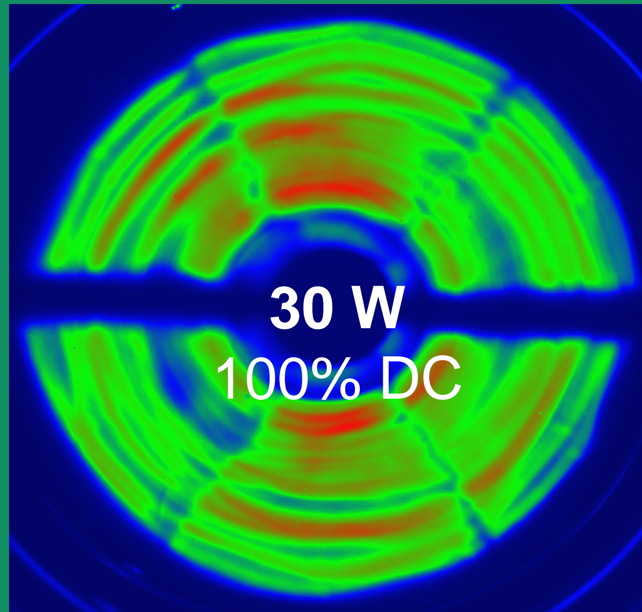
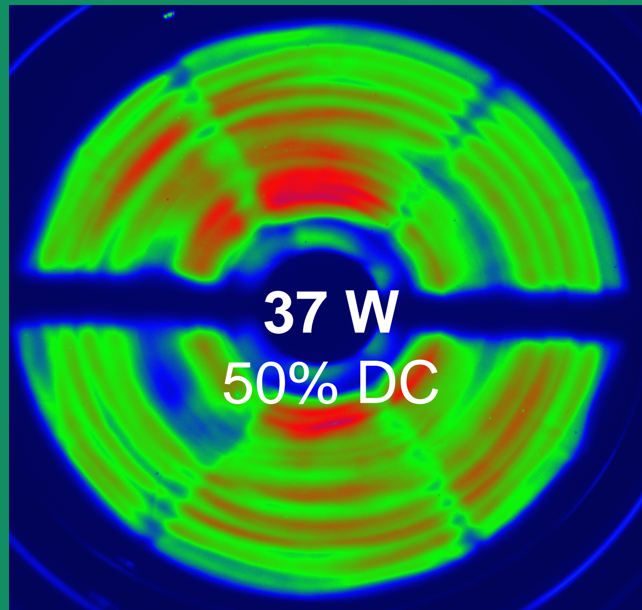
Where Were We Last Year In Miami ?





- Far Field images 35cm after IF
- Power refers to power after IF
- Power was actually measured after IF aperture
  - Not calculated from plasma power

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Will EUVL Ever Be A Reality ?

- Will EUV light sources ever scale ?
- Could EUV light sources be turned into a product ?
- Do we have our priorities right ?
- Conclusions

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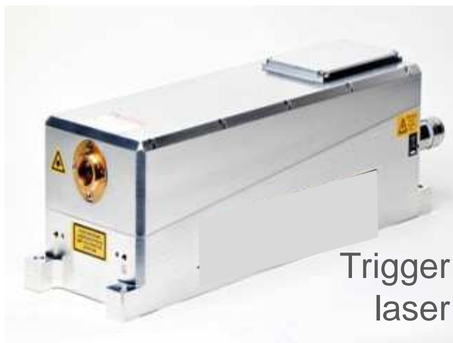
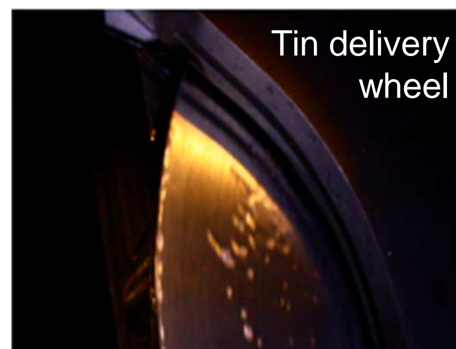
Could Physics Be Integrated Into A Viable Technology ?

- Last July, XTREME has resumed power scaling experiments on Ushio 3 integrated system to investigate short term scalability

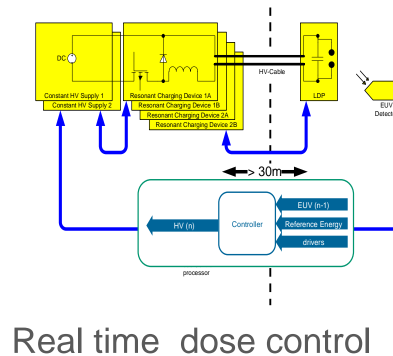
Laser Engineering



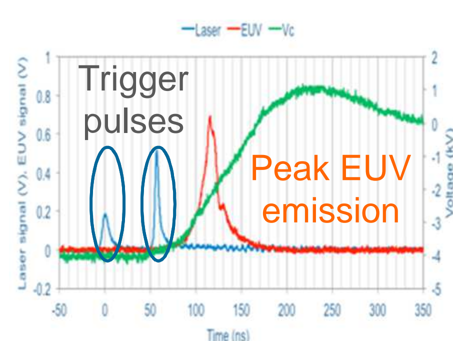
Tin Flow Engineering



Control Engineering

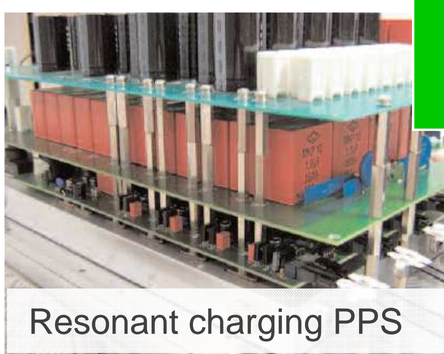


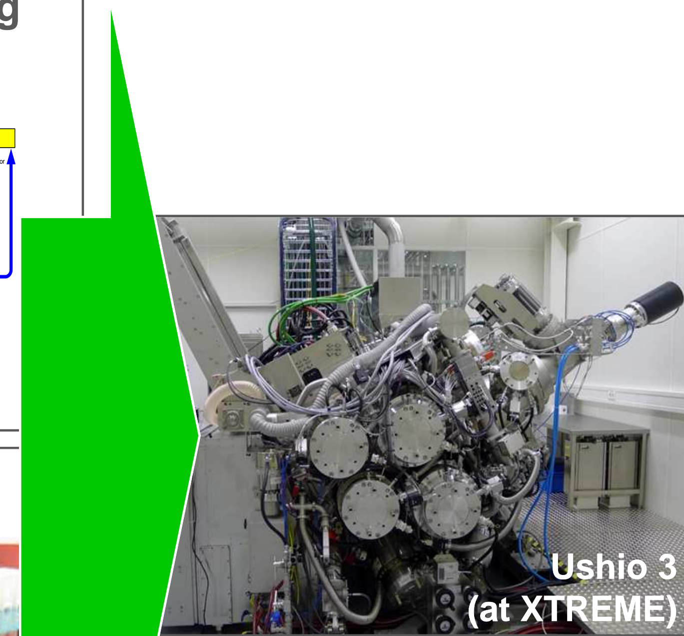
Plasma Engineering



Thermal Engineering

HVPS Engineering





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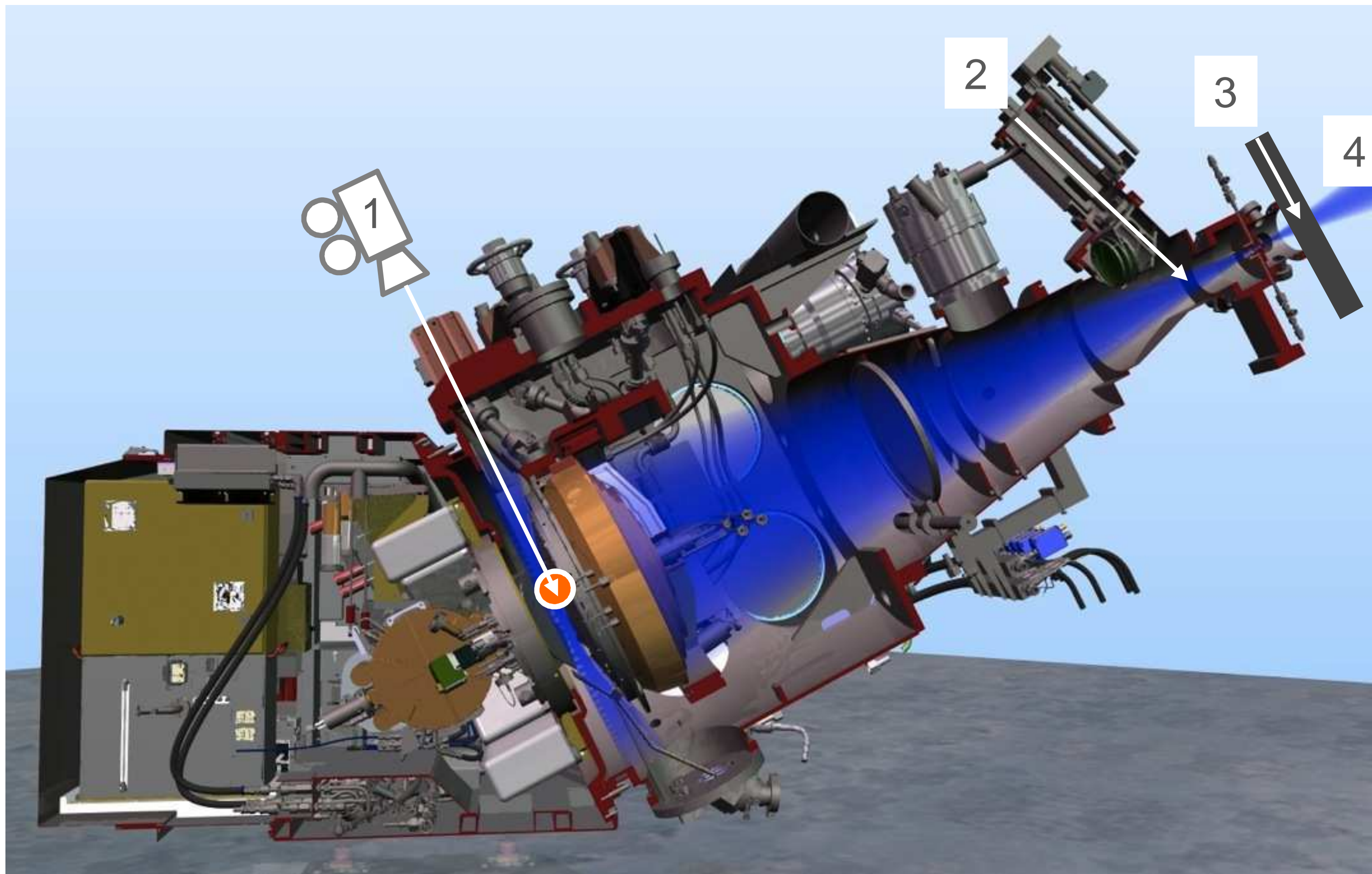
Measuring Collectable EUV Power



1 - At plasma

collectable in-band power with pinch camera calibrated energy monitor

2 - Before IF

NFST camera can be moved in the EUV beam

3 - Behind IF

FFST (external sensor – XTREME only)

4 – Inside scanner

Energy Sensor at reticle level

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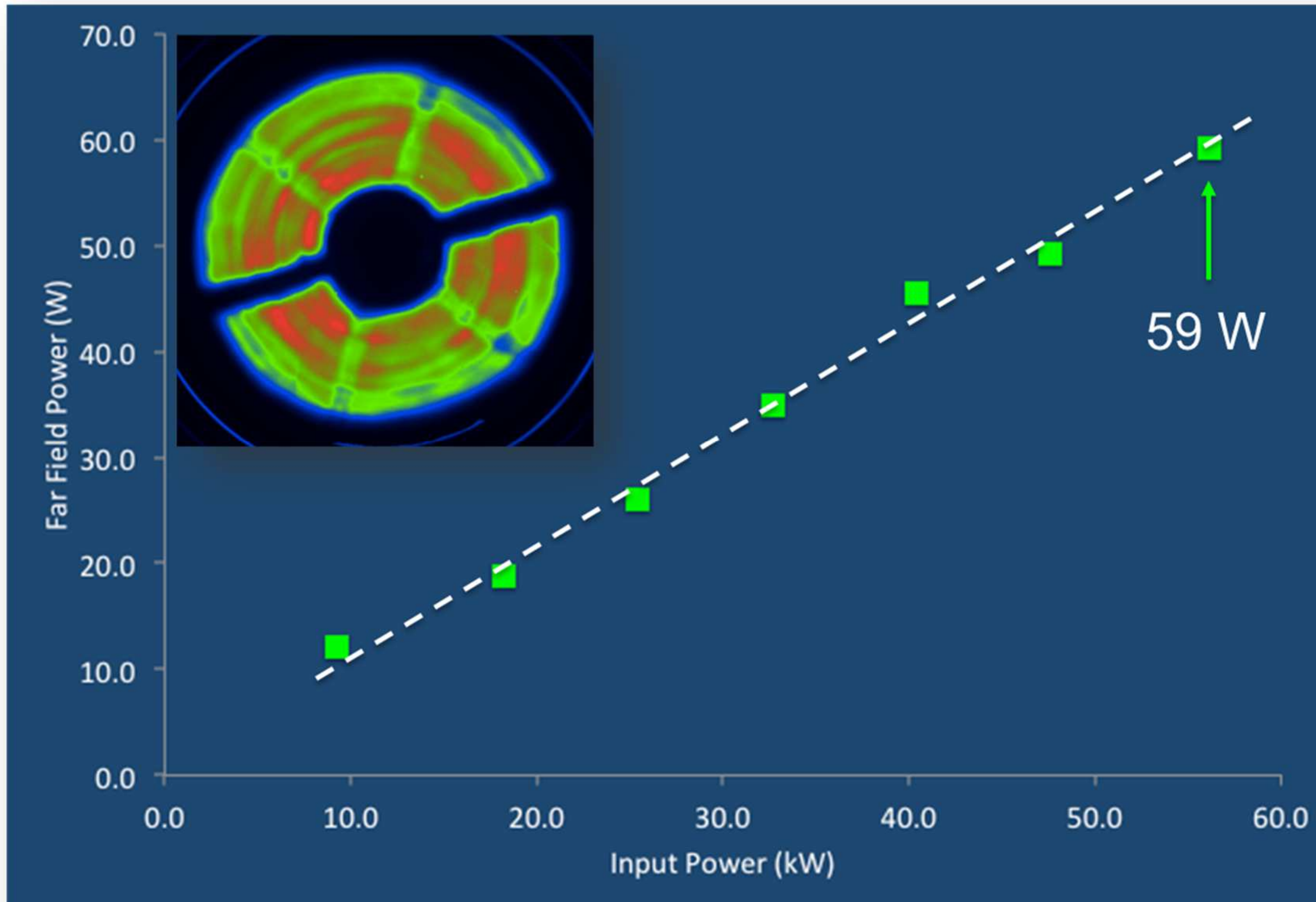
Since Miami …

- In July, 59 W after IF was achieved



Excellent linearity was achieved

Burst mode

200 ms

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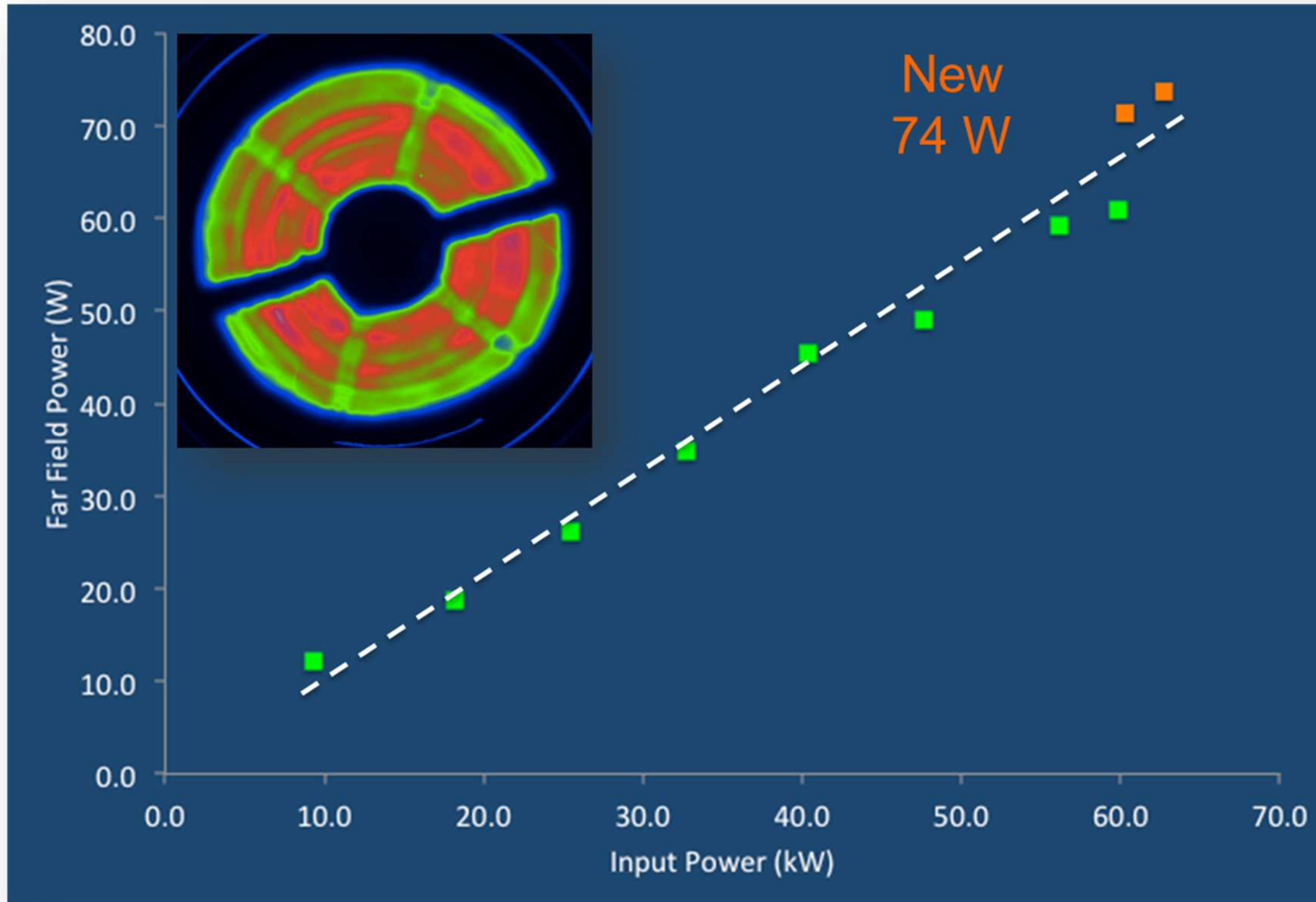
Just In:

New Record 74 W After IF



Burst mode

200 ms / 12% DC

Pulse energy

3-4 J

1 hour run at 74W

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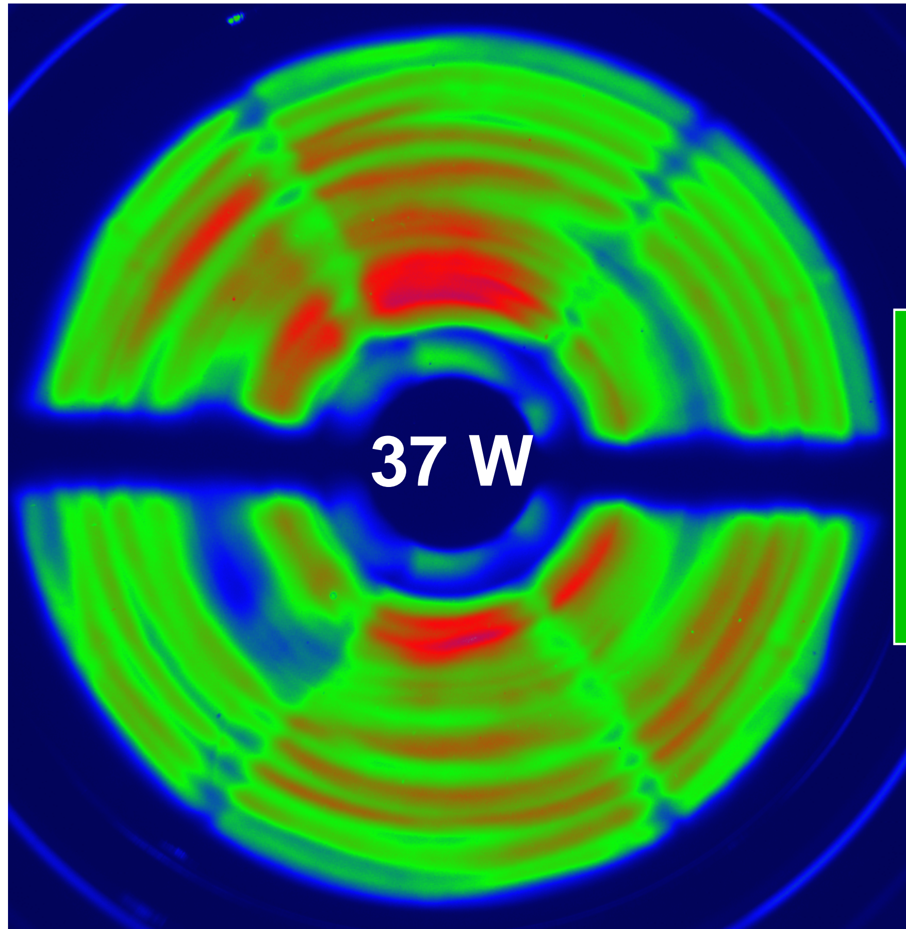
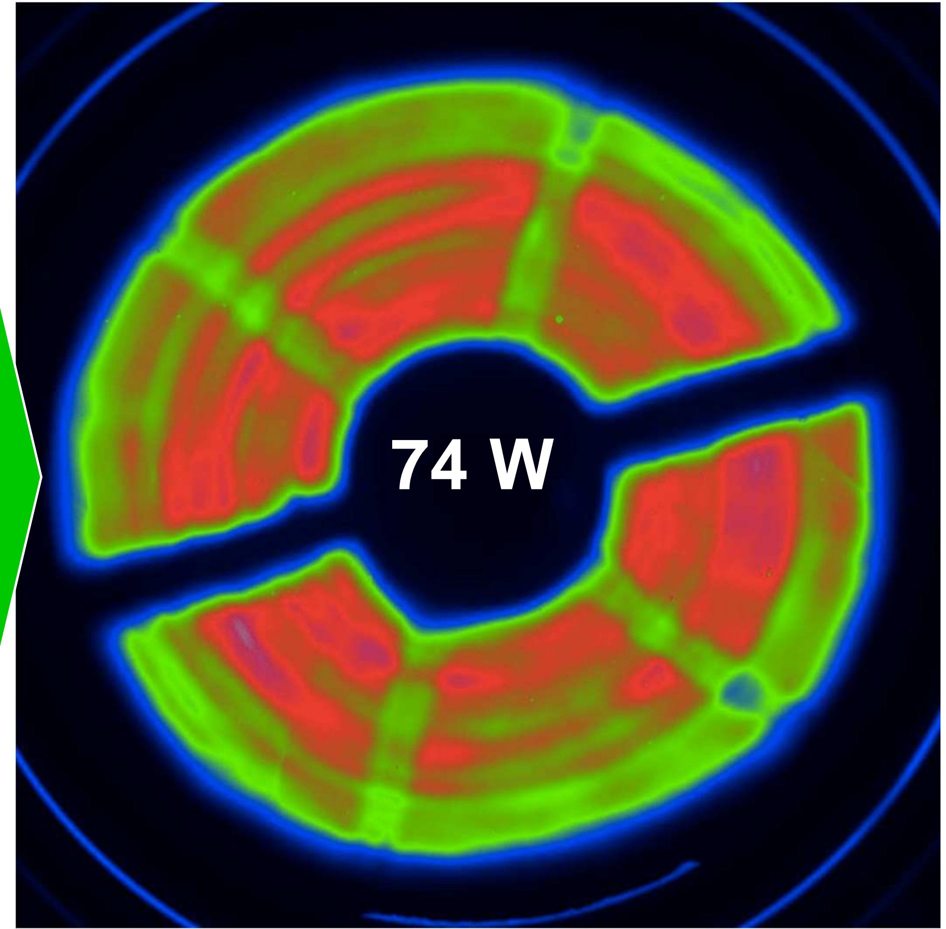
LDP Has Made Steady Progresses

Last year in Miami



This year in Brussels



Integrated source Ushio 3
Burst mode

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Could Physics Be Integrated Into A Viable Technology ?

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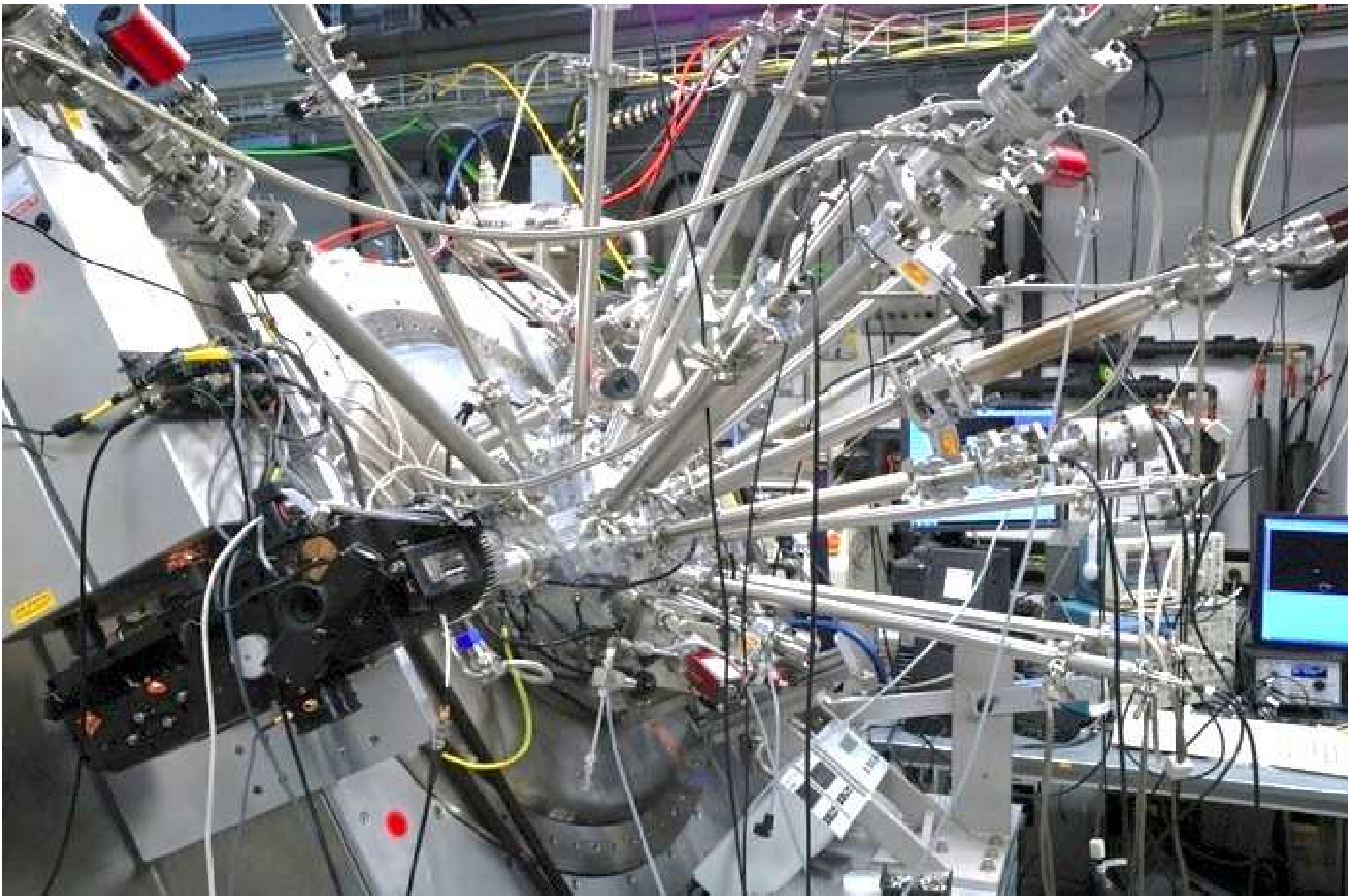
Could LDP Scale Beyond 250 W ?

- Why would anyone pursue a given technological path if it does not scale in the long term ?

→ A test stand (Obelix II) has been specially built to allow XTREME to validate LDP long term scalability



Power scalability:

- Reprate scalability
- Pulse energy scalability
- Conversion efficiency optimization
- Collection efficiency optimization

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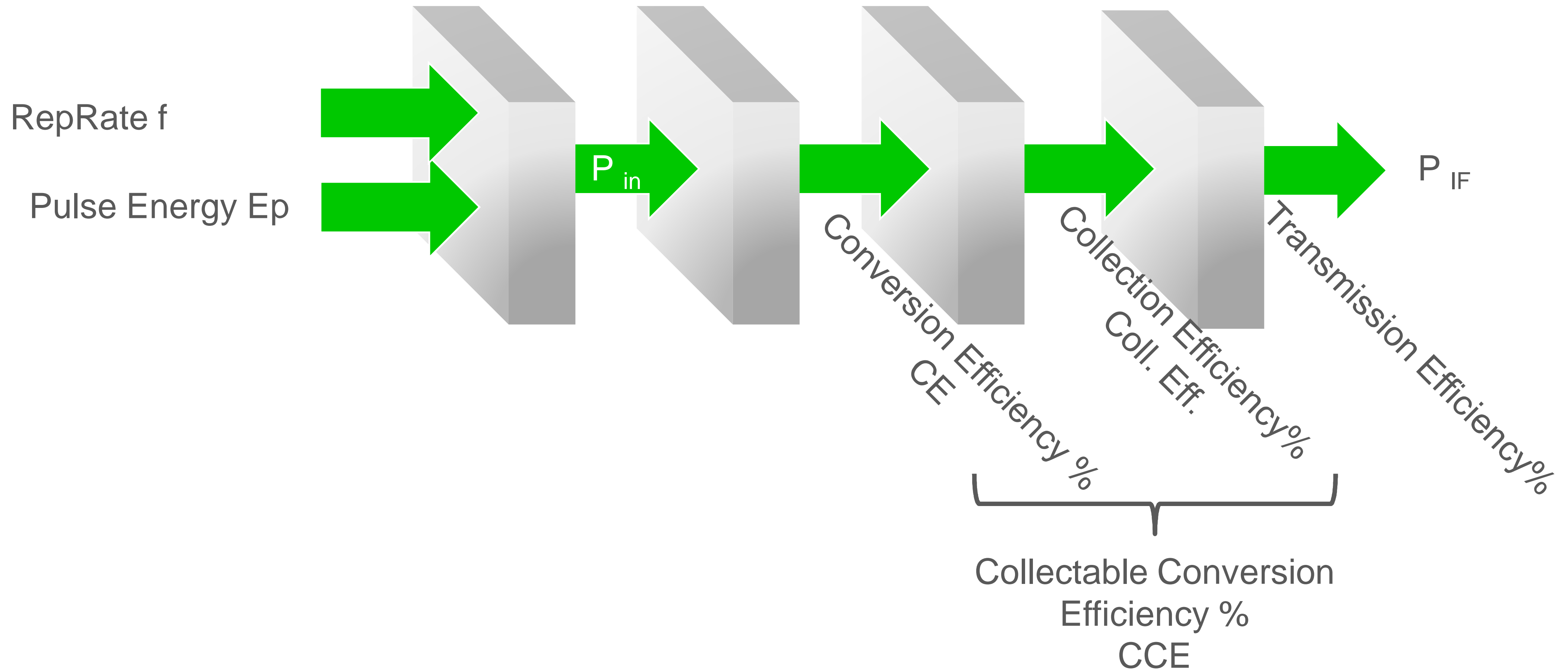
First, What It Means To Scale LDP



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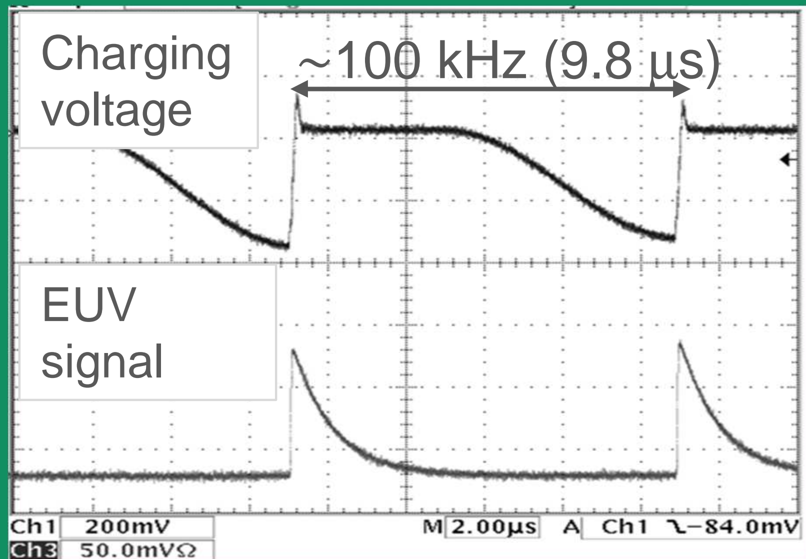
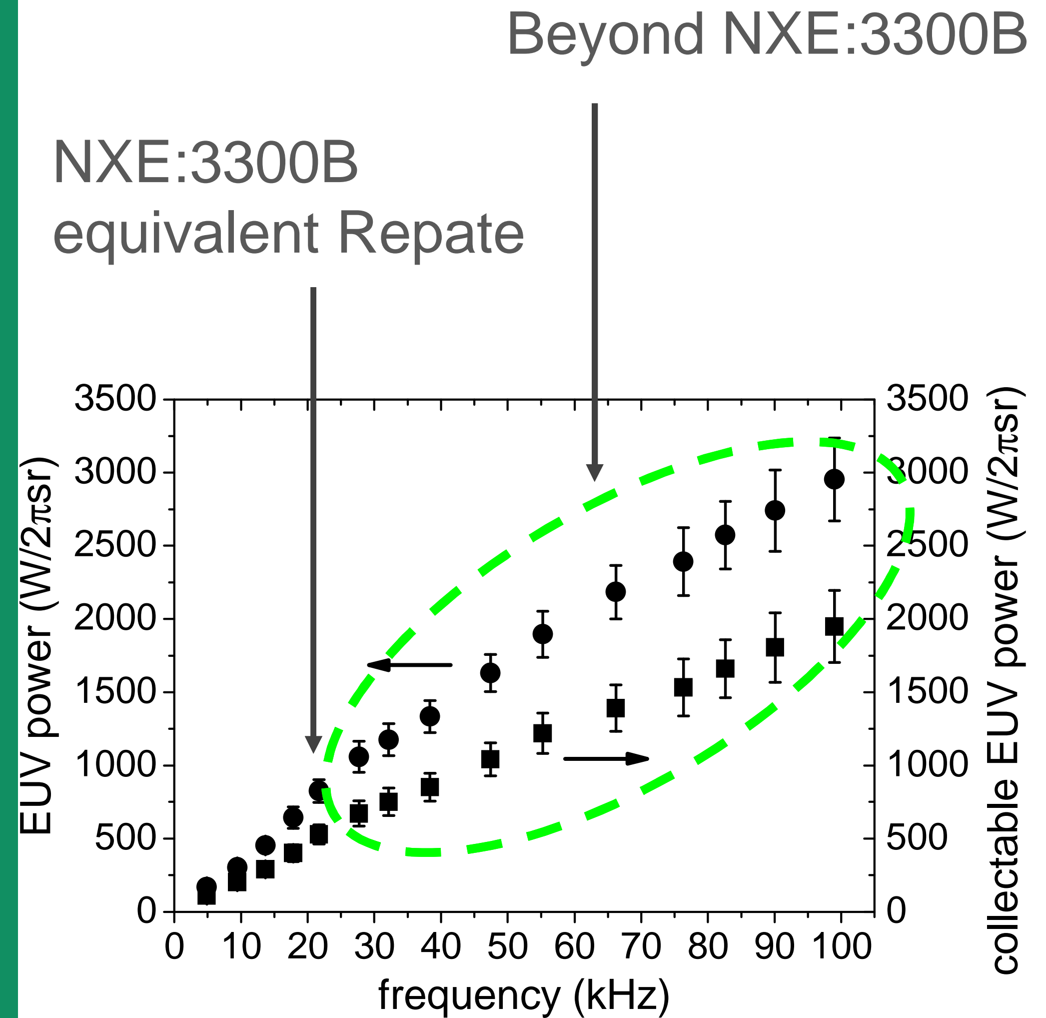
LDP RepRate Scalability

- LDP's reprate long term scalability is proven **BEYOND the requirements for 3300B (250W)**
  - Interlaced low energy pulses experiments





Experiment
Frequency = 1/(ΔT between pulse 1 and 2)

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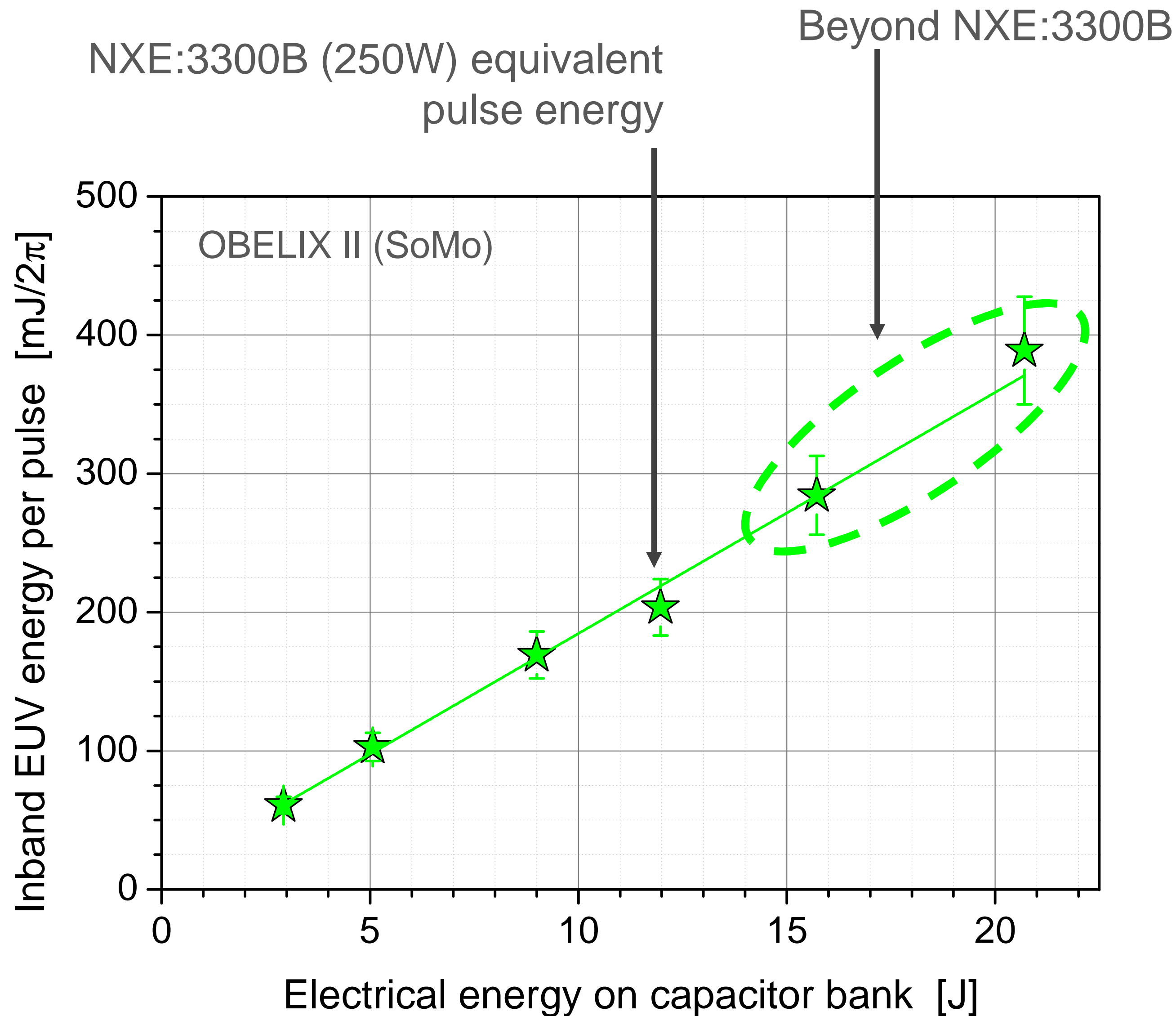
LDP Pulse Energy Scalability

- LDP's long term pulse energy scalability is proven BEYOND the requirements for NXE:3300B (250W)



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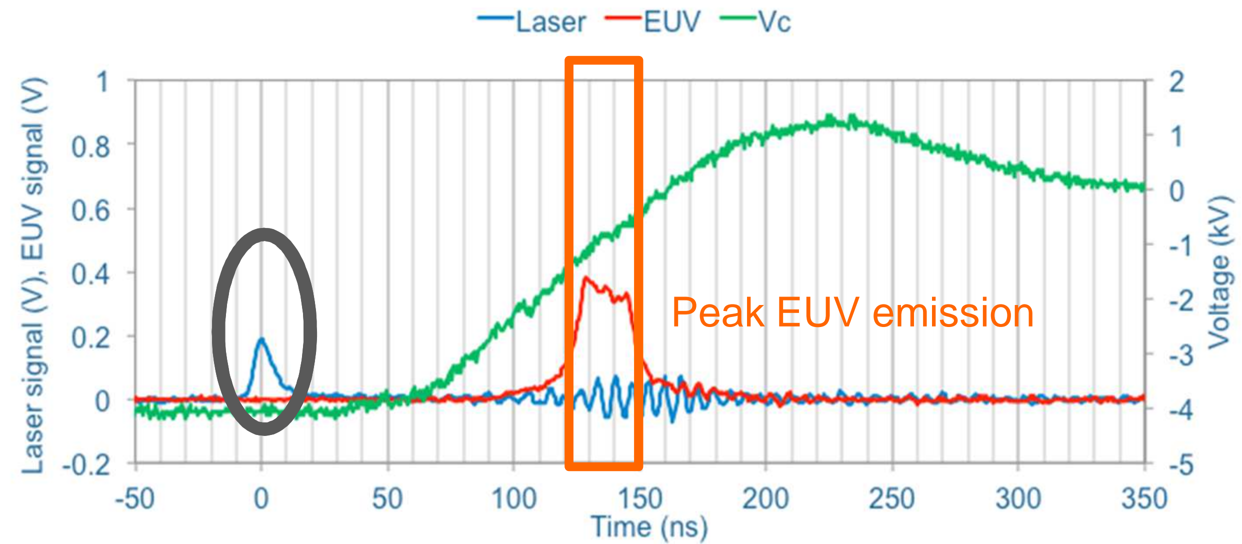
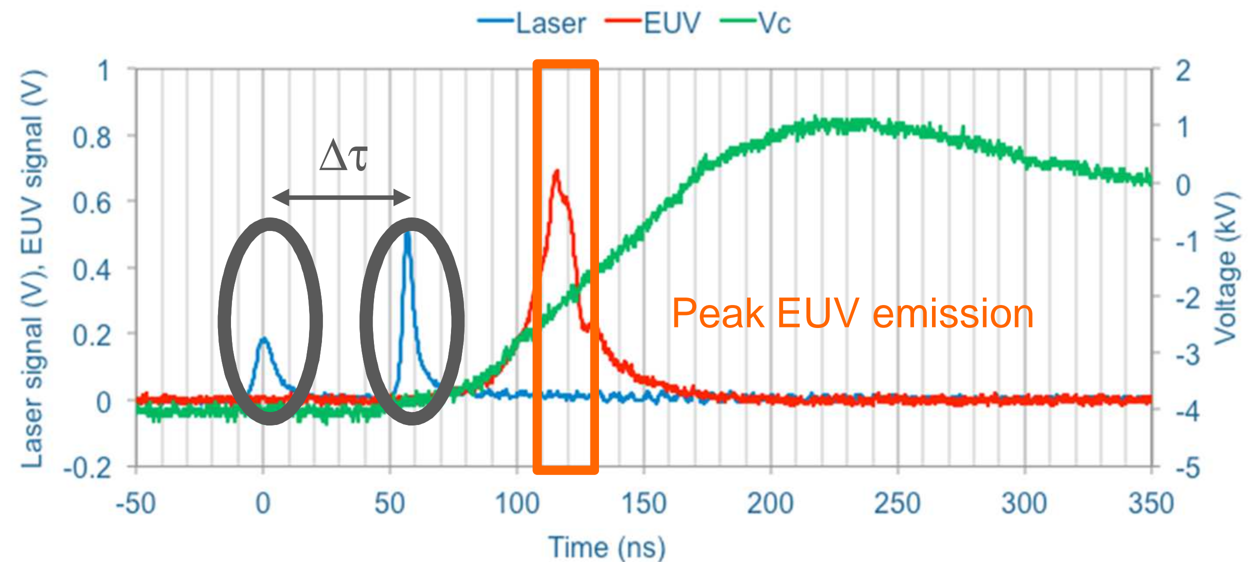
Plasma Engineering

- Tailoring the laser pulse train allows XTREME to engineer the plasma emission

Single trigger laser pulse



Double trigger laser pulse



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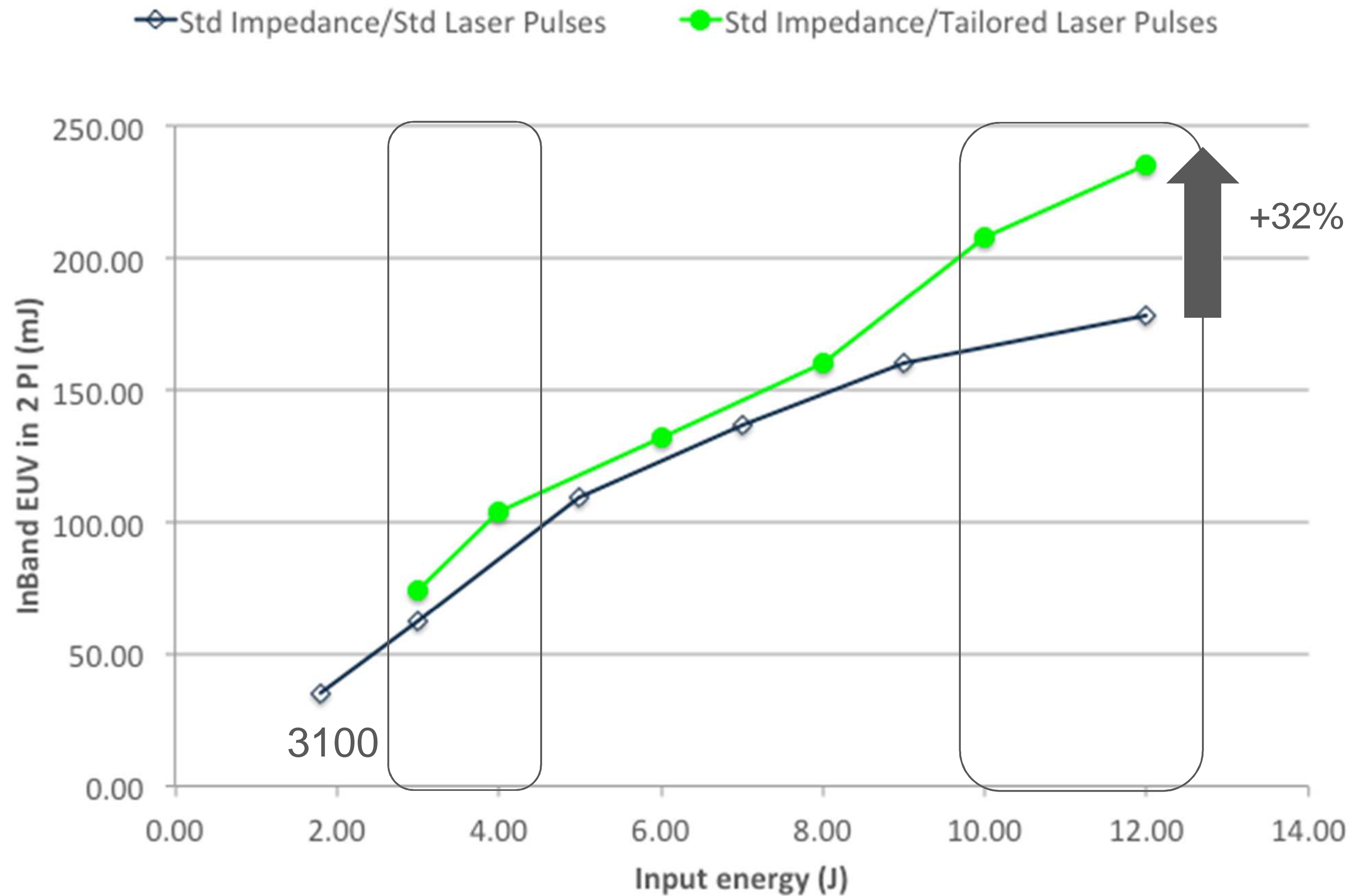
Engineering Pulse Energy With Lasers



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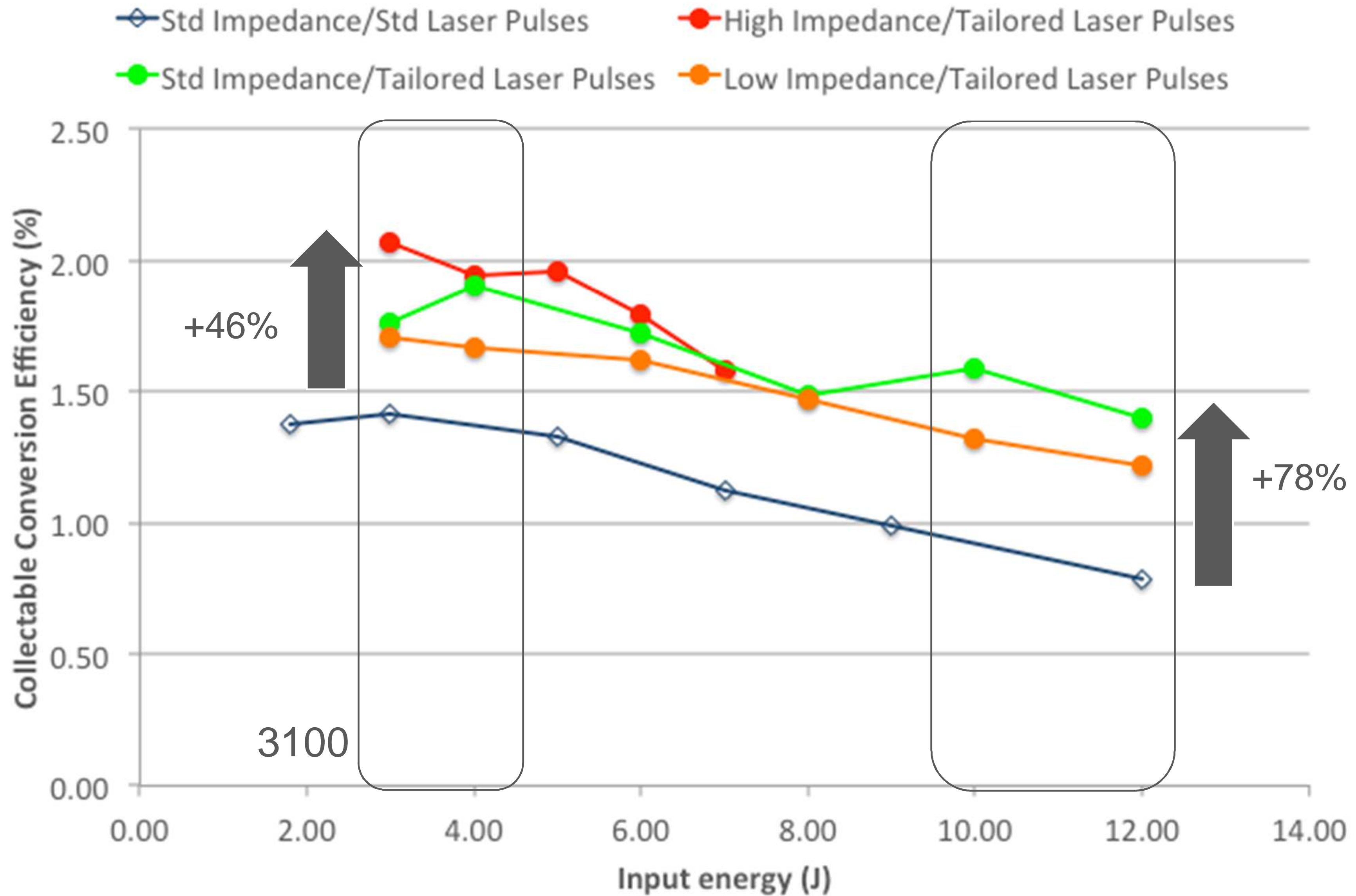
Engineering Collectable Conversion Efficiency

- CCE (Collect. Conv. Eff.) = Conversion Efficiency x Collection Efficiency



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Will EUVL Ever Be A Reality ?

- Will EUV light sources ever scale ?
- Could EUV light sources be turned into a product ?
- Do we have our priorities right ?
- Conclusions

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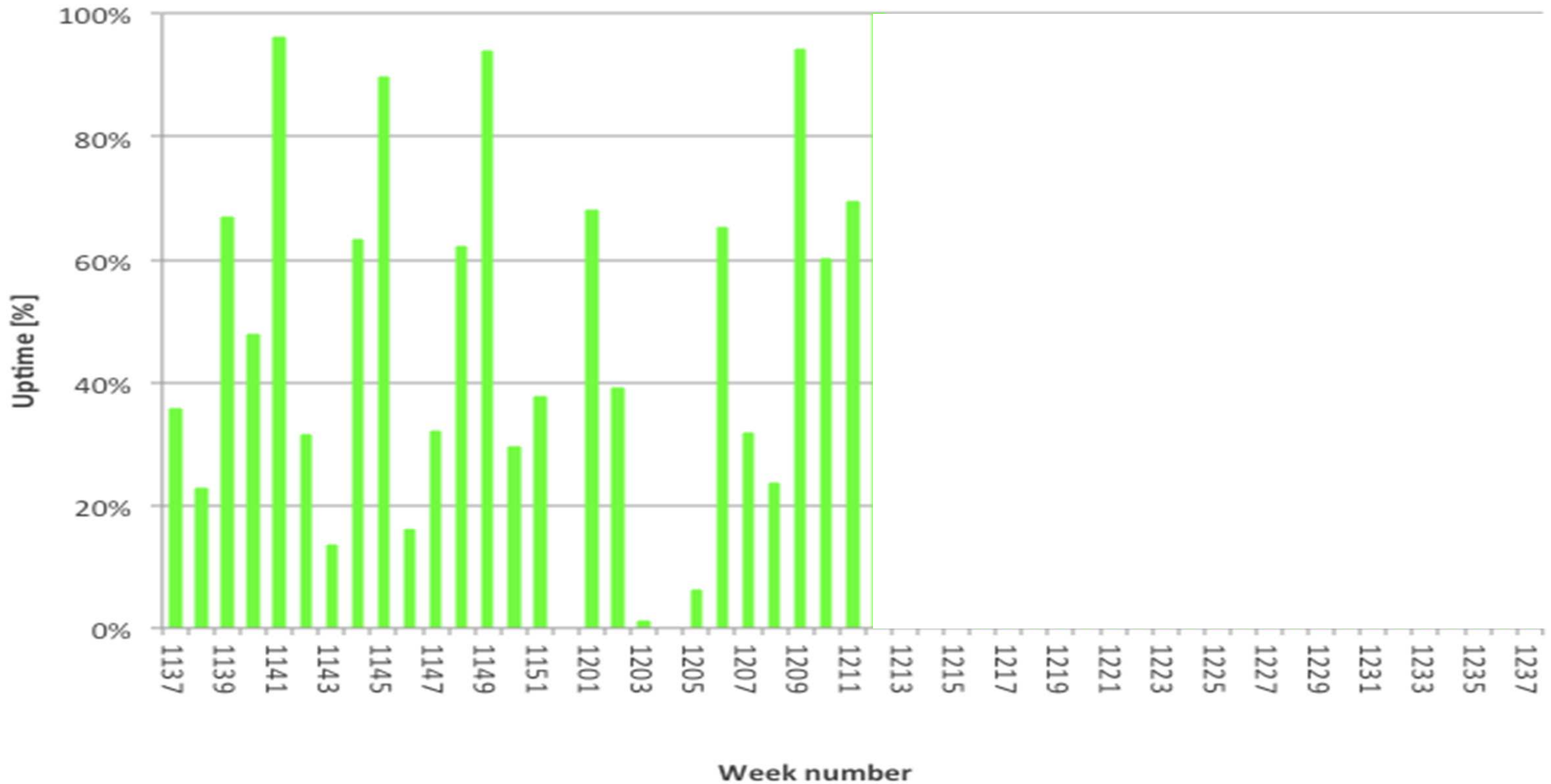
The Not So Long Ago **Early Days Were Painful**

- Ushio 1 source at IMEC initial availability was very disappointing



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Turning Technology Into A Product

- To stabilize the technology, over H1 2012, XTREME reallocated resources, launched a major re-design effort and upgraded Ushio 1

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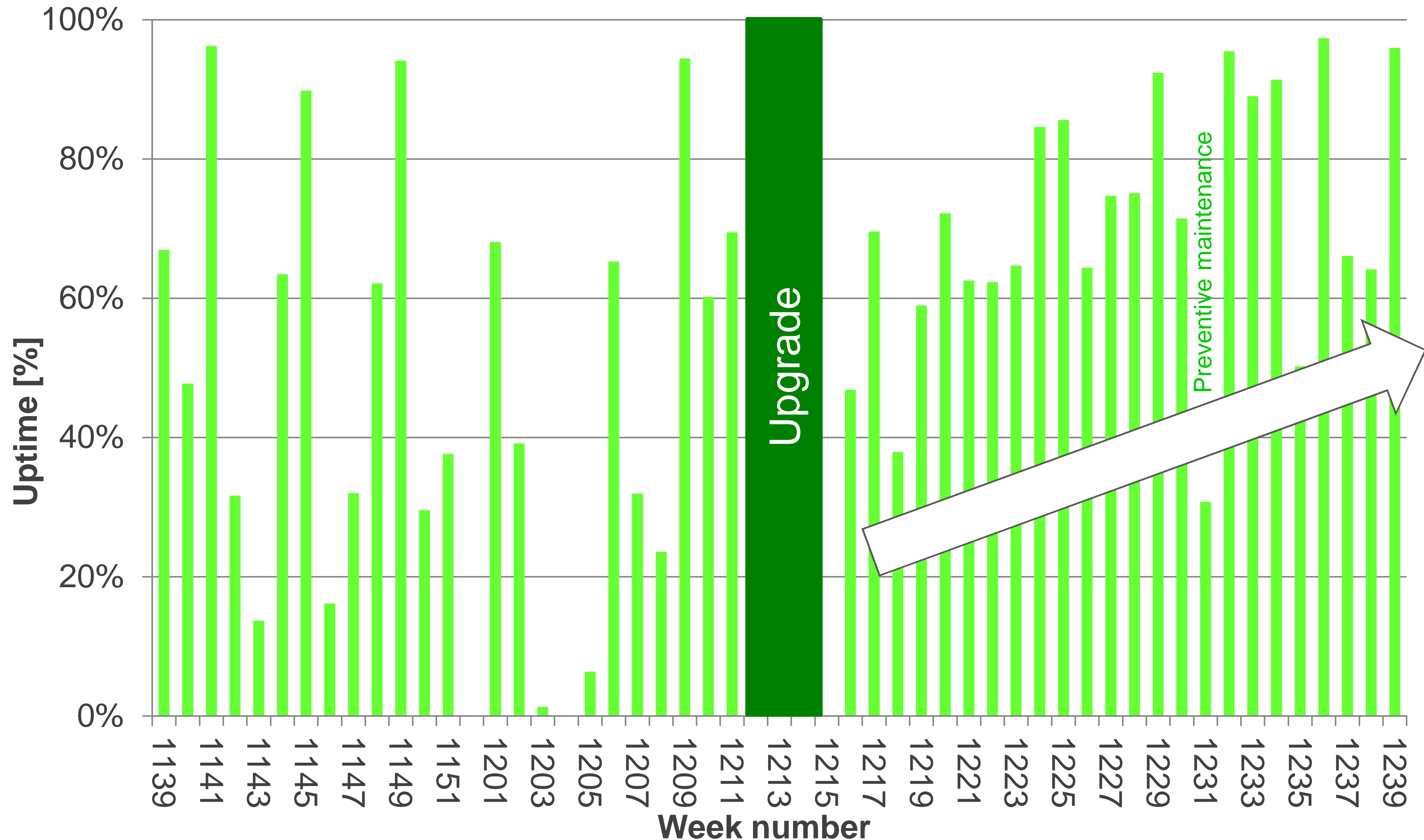
Pictures not for hand out

After Upgrade, Ushio 1 Uptime Has Steadily Increased …

- Recently, uptime exceeds 90% (13 wk average now exceeds 75%)
- Volatility has also drastically decreased



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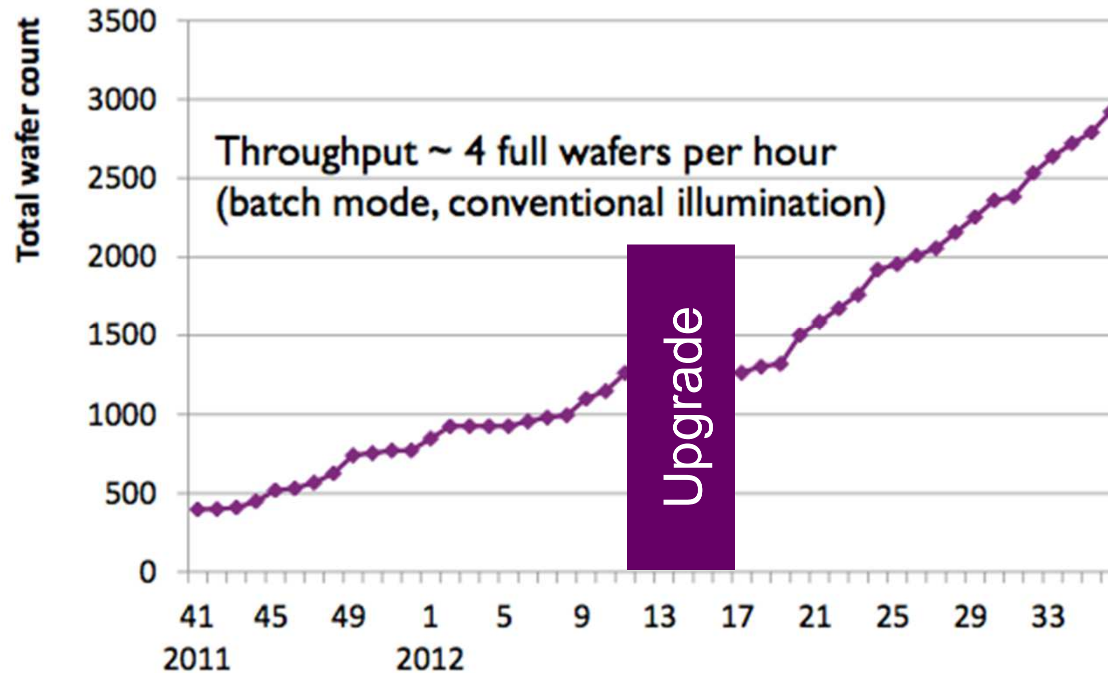
… And Utilization (7x24) Is High

TOTAL NUMBER OF EXPOSED WAFERS NXE:3100
CUMULATIVE WAFERCOUNT



Cumulative wafercount now 3000 exposed wafers since tool installation – clear productivity increase since May 2012

3,000 wafers have been printed so far

Courtesy imec

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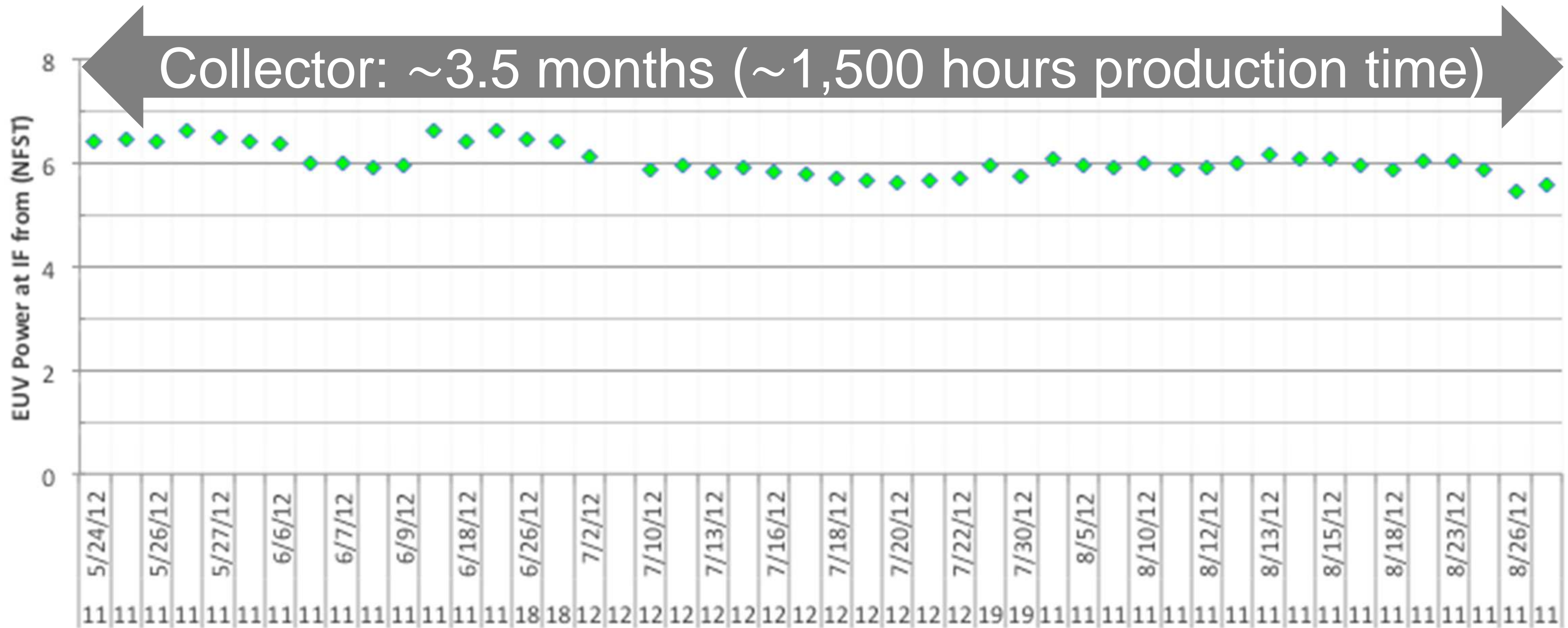
Long Collector Lifetime Is Achieved

- Power at IF is stable over the collector life



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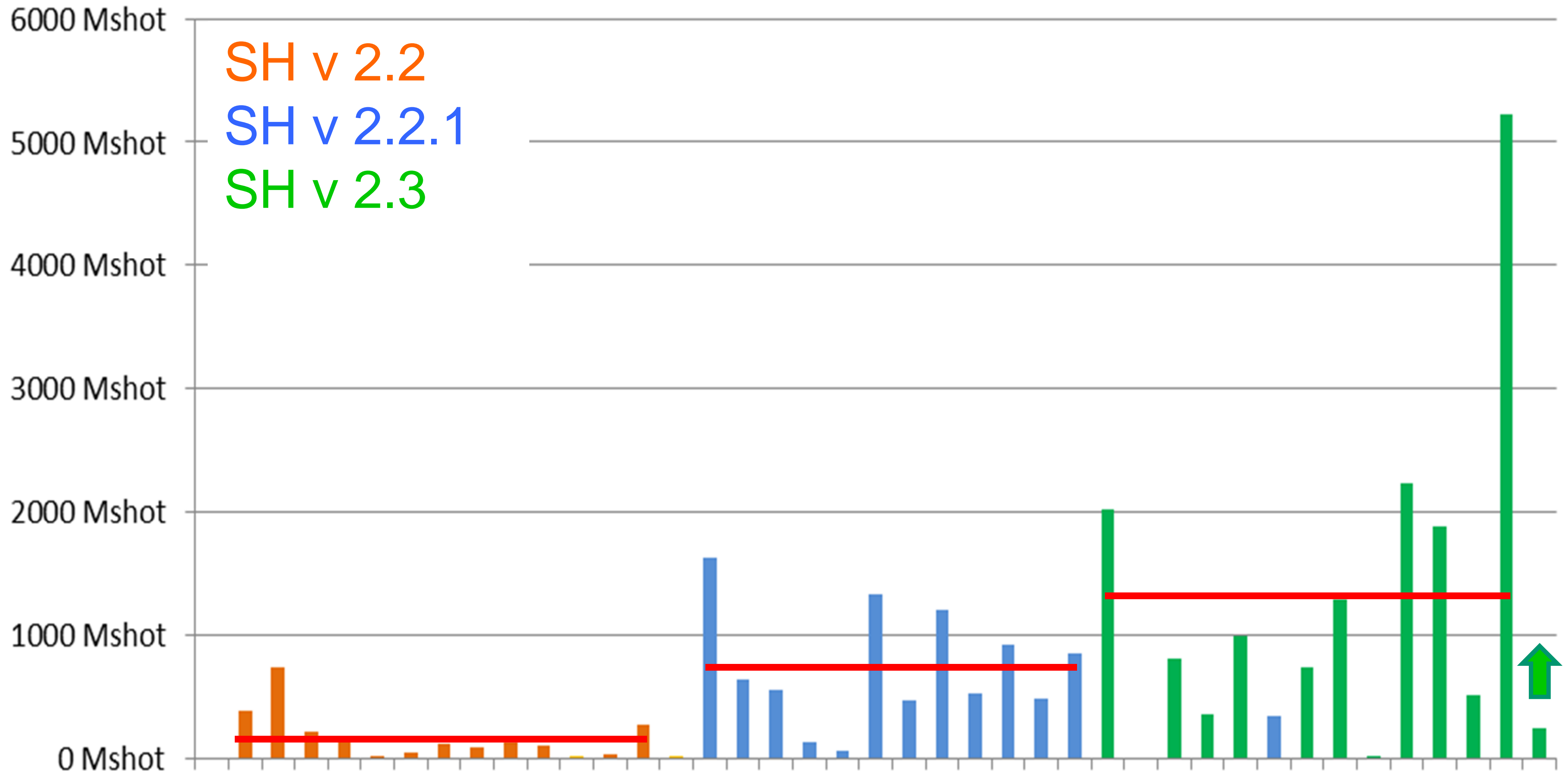
Lifetimes Have Increased

- Source Heads (SH) are no more the primary source of downtime



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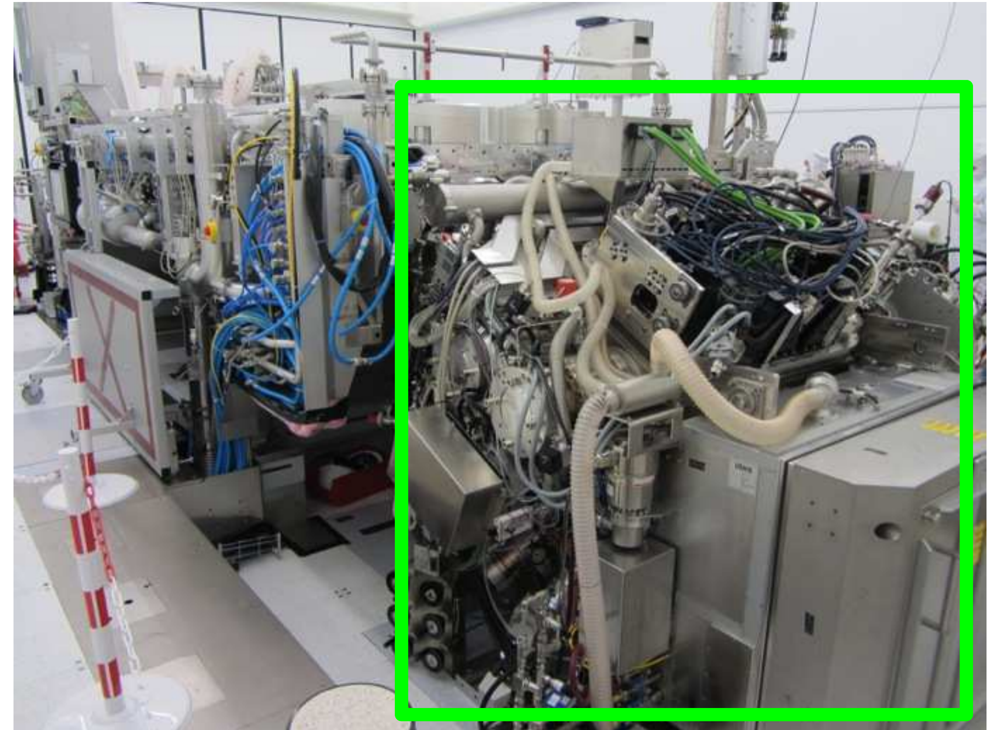
U2 & U4 @ ASML

- Ushio 2 & Ushio 4 light sources (3100) are integrated to NXE:3300B to support scanner development
- U2 (20 kW configuration) & U4 (50 kW configuration) are being upgraded as well
- U2 has now printed its first wafer



Courtesy ASML

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Power, Power, Power !!! …
Simply More Power ?

POWER → THROUGHPUT
&
DOSE STABILITY → YIELD

Can we really talk about power without talking about dose stability

?!?!?

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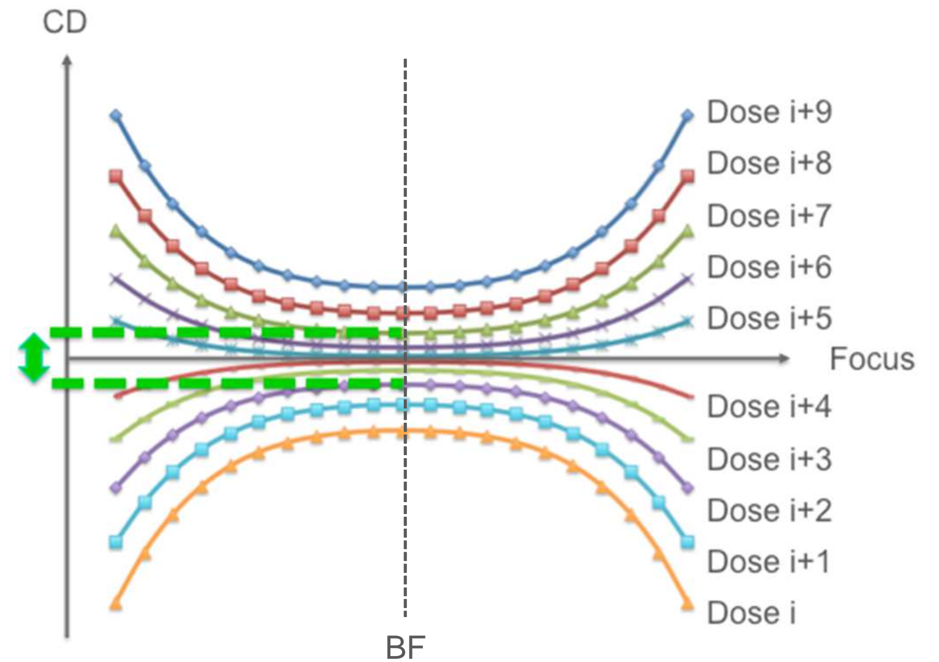
Why Does Dose Stability Matter ?

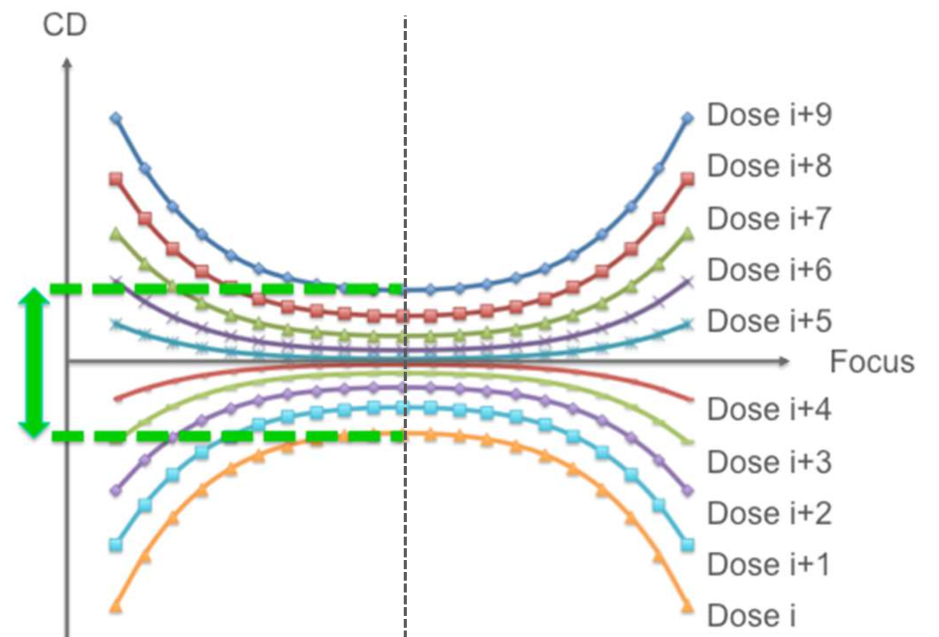
ASML dose specifications for EUV sources:

$3\,\sigma < 0.2\%$

- Small ΔDose → Small ΔCD



- Large ΔDose → Large ΔCD



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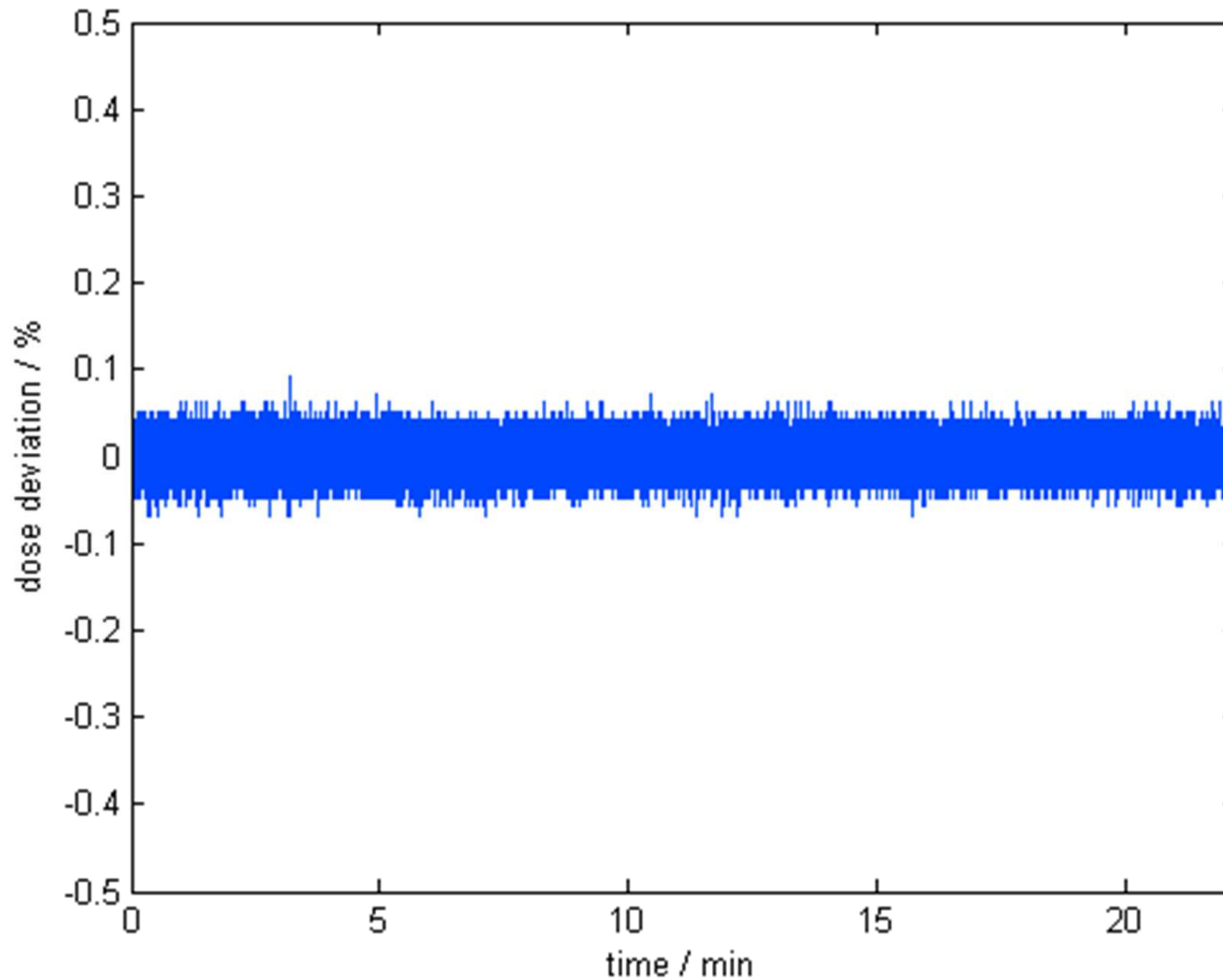
LDP **Dose Stability** at 9kW

- Dose stability is 3 σ < 0.1 %
  - Specification: 3 σ < 0.2%



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How To Ensure Tight Dose Stability ?

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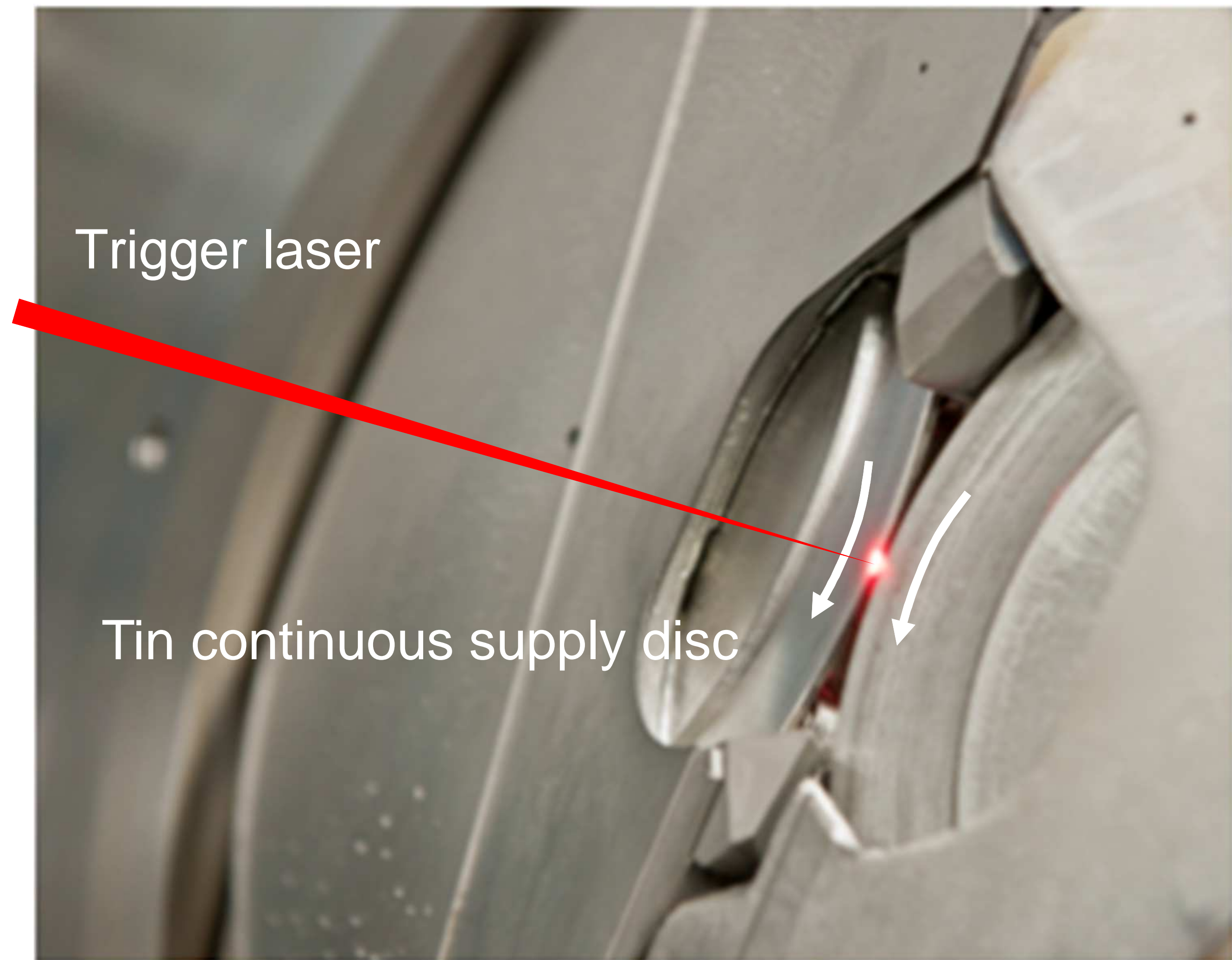
LDP Stability = Continuous Tin Delivery

- o Tin delivery is continuous

→ No temporal discretization

→ No missing target

→ No missed pulse



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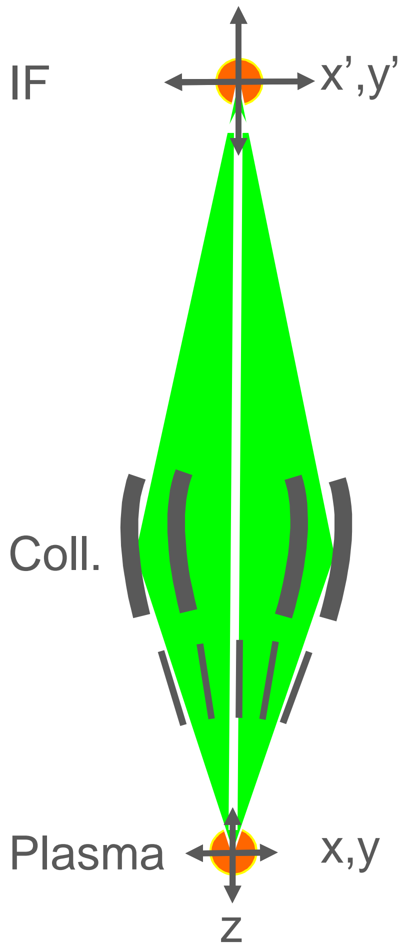
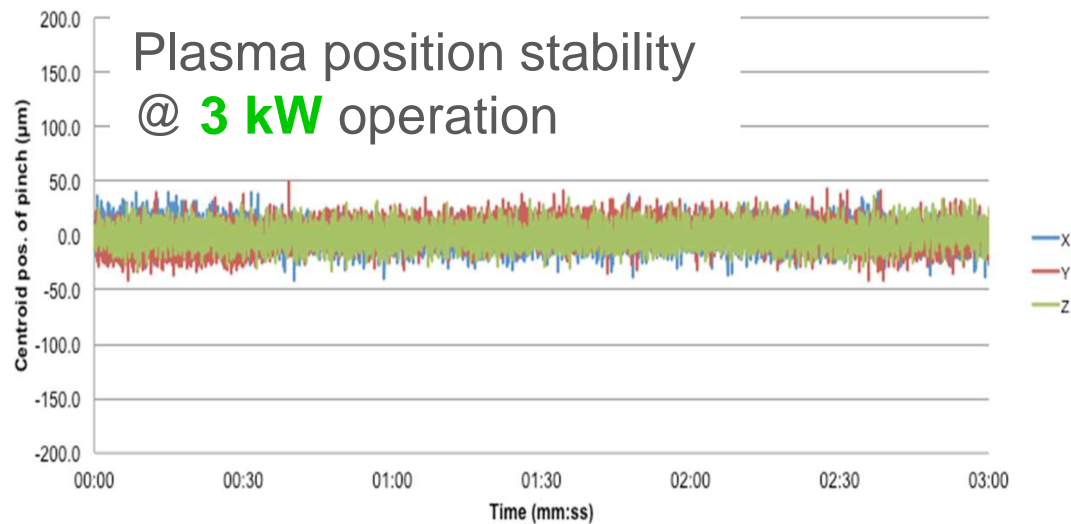
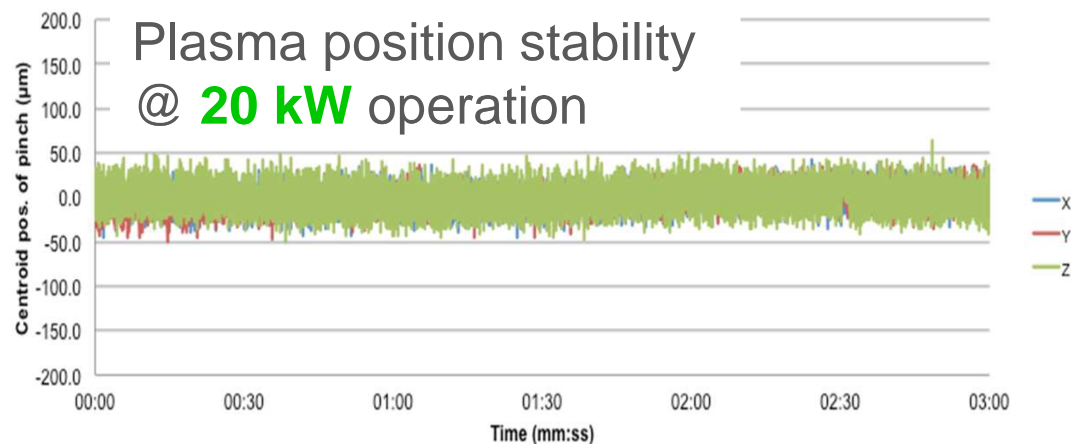
LDP Stability = Plasma Position Stability

- Laser focus, Tin and plasma are always at the surface of the wheel
  - Plasma position remains stable with power scaling







→ Stable laser focus

→ Stable plasma position

→ Stable Far Field image

→ No dose variation caused by plasma position instability

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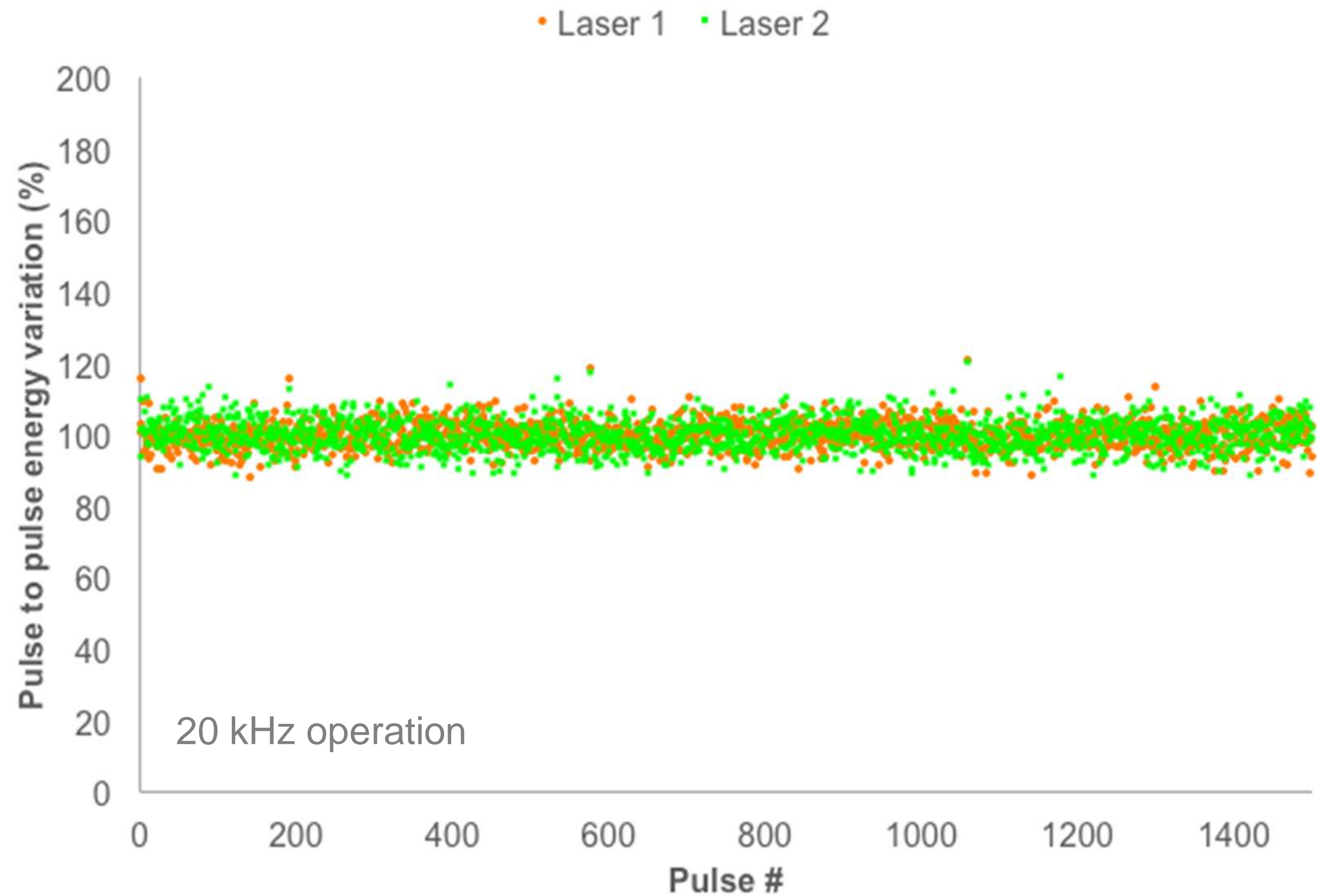
LDP Stability = Trigger Laser Energy Stability

→ Trigger laser intensity stability

→ Tin vaporization repeatability

- Trigger laser stability makes Tin vaporization and plasma production highly reproducible



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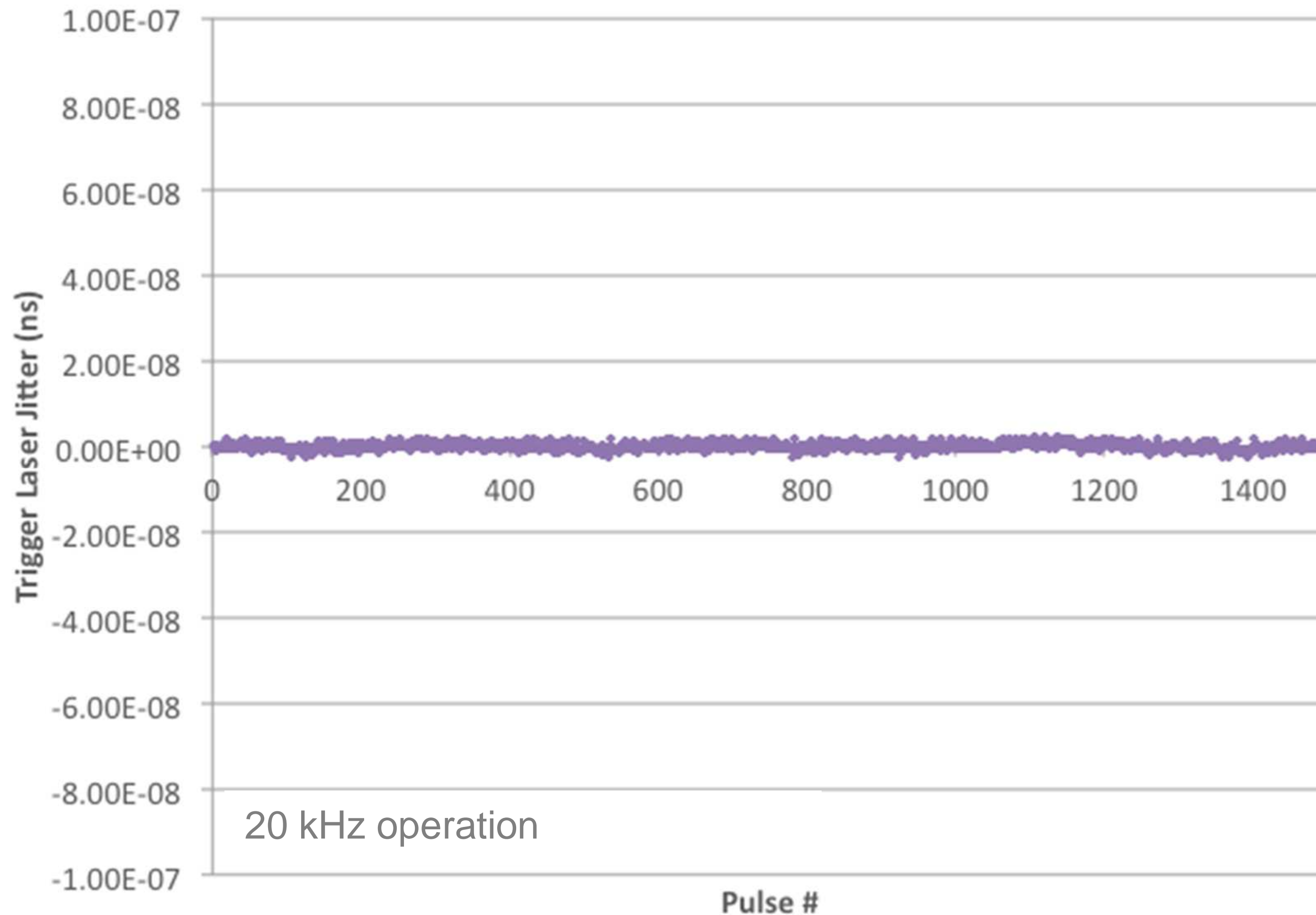
LDP Stability = Trigger Laser Timing Stability

- The jitter between trigger laser pulses is kept << 1 ns



→ No timing instability

→ Tin vaporization is highly reproducible

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LDP Stability = Tin Flow Uniformity

- The amount of Tin vaporized (with each trigger pulse) is highly repeatable

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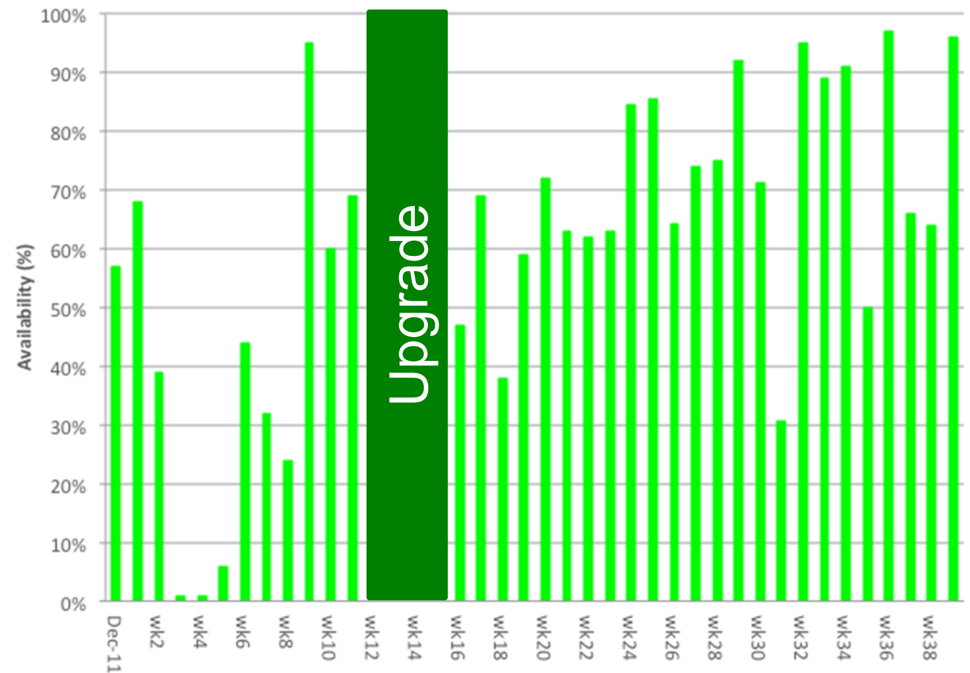
XTREME's 2012 Objectives

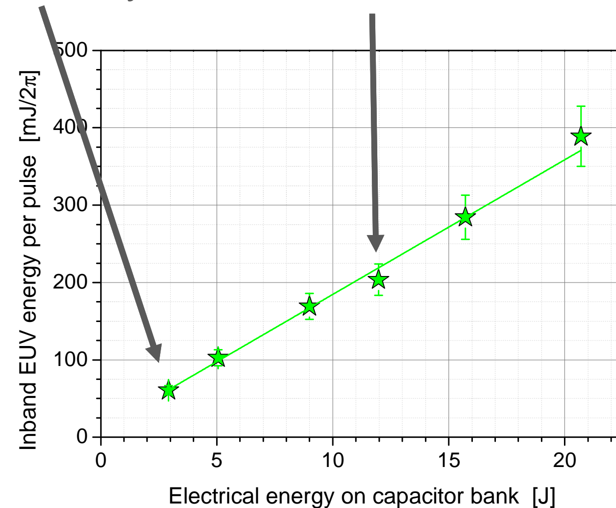
- To drastically improve and stabilize the reliability of XT's 3100 source at IMEC to enable Affiliate Chipmakers to develop their EUV process

☑ Done

- To prove LDP long term scalability

☑ Done





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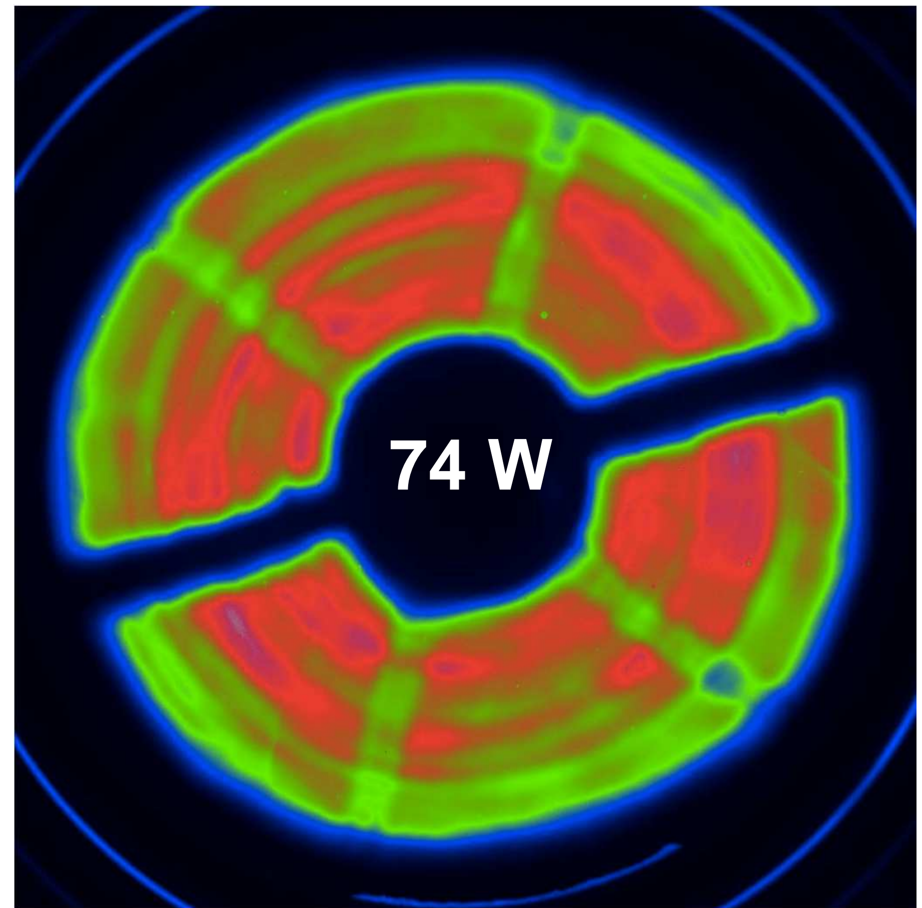
XTREME's 2012 Objectives

- To resume power scaling and demonstrate 50W

☑ Done

- To upgrade XT's 3100 source at IMEC for higher power

☐ Soon



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Conclusions

- EUV is a reality in the making supported by recent progresses of LDP

- No more claims. Results are in:
  - LDP is scalable in the long term
  - 74W power after IF was demonstrated on an integrated source
  - LDP technology is now being turned into a viable product and high uptime is achieved

- The night is always darker before dawn … but the EUV revolution is around the corner

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Acknowledgments

- XTREME would like to acknowledge this work has been possible thanks to a very valuable and fruitful collaboration with Fraunhofer ILT

- XTREME would also like to thank NEDO for their continued support

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