KLA-Tencor

Accelerating Yield

Bright and reliable Xe-based EUV source for metrology and inspection applications

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Outline

- **Introduction**
- **Xe LPP source**
  - **Requirements**
  - **Choice of architecture**
  - **Current status**
    - *Radiance*
    - *Collector lifetime*
    - *Laser optics protection*
    - *Chamber gas management*
    - *Closed loop Xe management system*
    - *Xe droplets subsystem*
- **Conclusions**

Latest reticle inspection solution

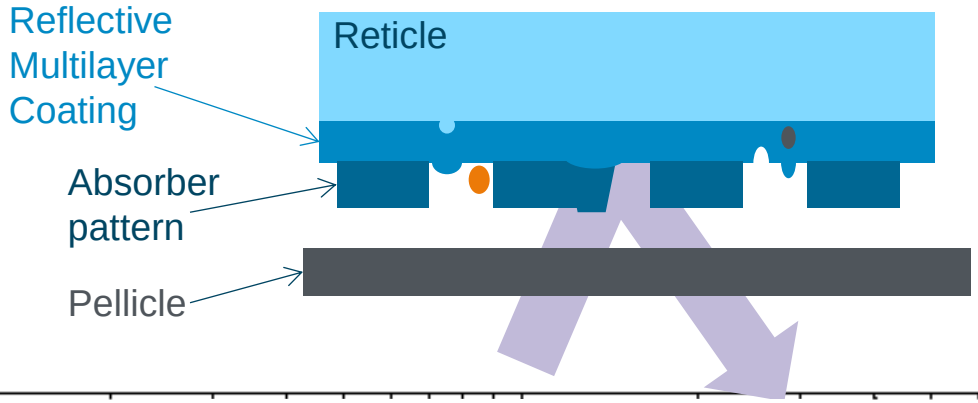
- EUV patterned masks and blanks
- Optical; Complex OPC, Quartz etch reticles
- For ≥ 10nm Generation
- *Practical sensitivity limited by edge roughness*

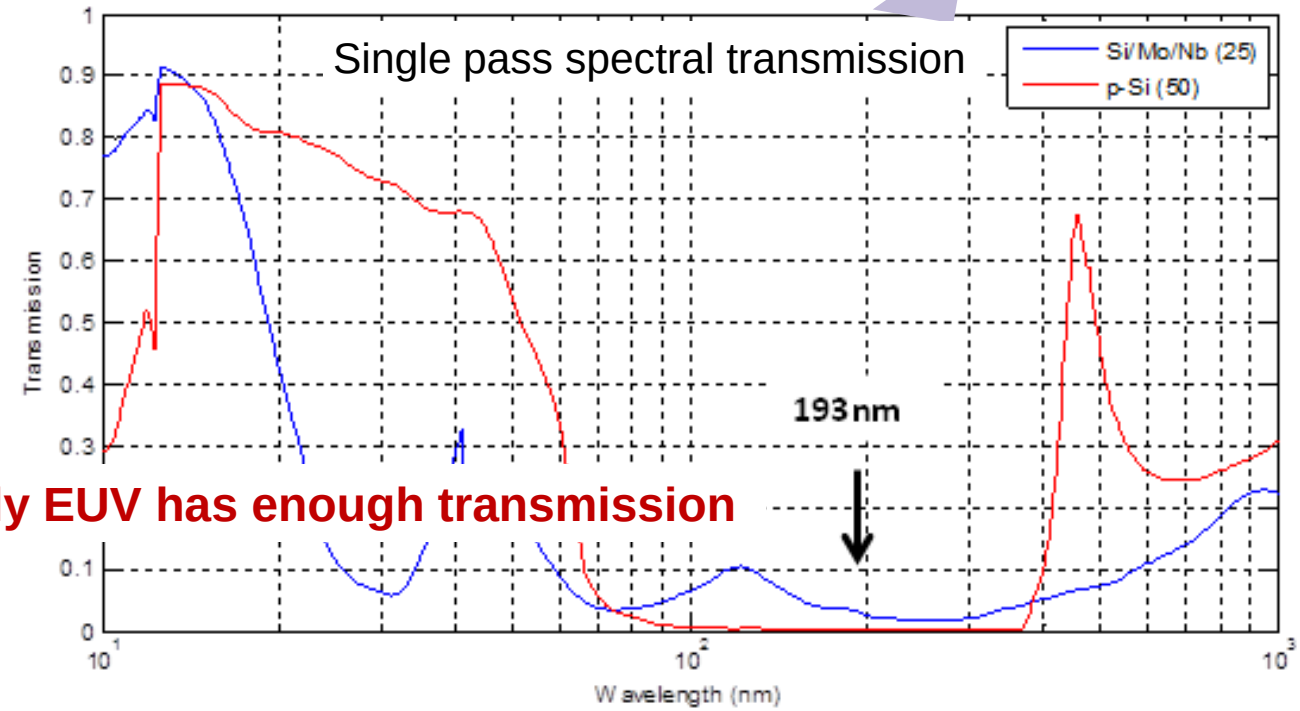
Teron 6xx platform

Industry proven sensitivity for advanced optical and EUV Mask applications

EUV reticle defect and inspection challenges

Pellicle transmission effects will narrow the wavelength choices

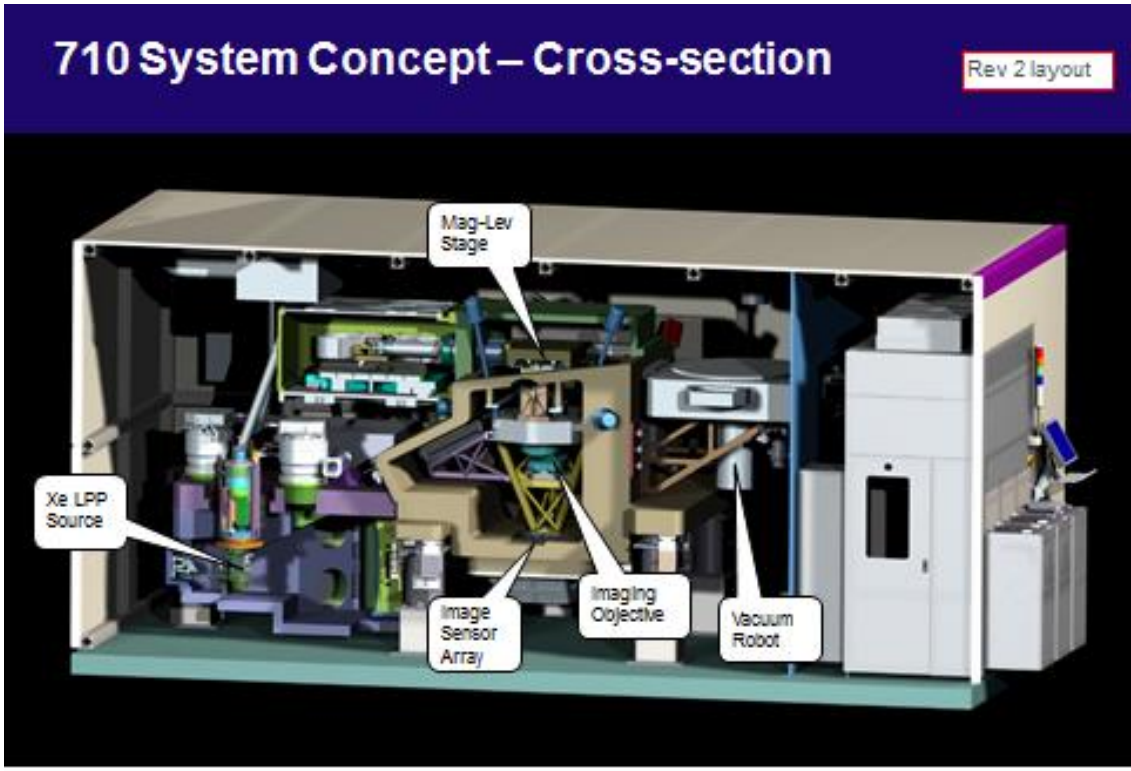




Only EUV has enough transmission

7xx (EUV) program summary

- System Architecture defined
- EUV-specific large format image sensor designed and tested
- Optics concepts provide large field and high transmission
- Xe LPP source prototype shows required lifetime
- Ultra-clean vacuum prototypes tested
- Pilot production facility ready for build-out



Program ready for full-scale development

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Xe –based LPP source as bright and reliable solution

Actinic patterned mask inspection: source requirements

Property/parameter	Target Value	Units
Wavelength	13.5	nm, centroid
Pulse repetition rate	> 10	kHz
Pulse duration	> 10	ns, FWHM
Duty Cycle	> 95%	- minimum burst > 15 sec
Etendue	1.0 x 10^{-2}	mm^2-sr
Radiance at I/F	> 20	W/mm^2-sr
(Averaged over etendue, lifetime)		2.2% band, pre-SPF
Footprint (m)	2.8W x 2.8D x 2.8H	
Availability	> 95%	
Cost of Service (annual)	< 10%	Relative to CoGs / Price
Cost of Operation (annual)	< 5%	

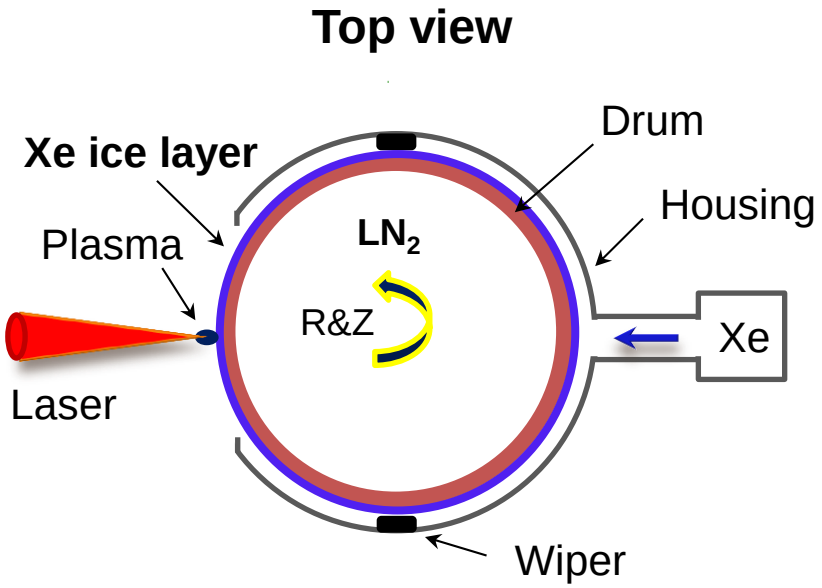
Options – method of plasma generation

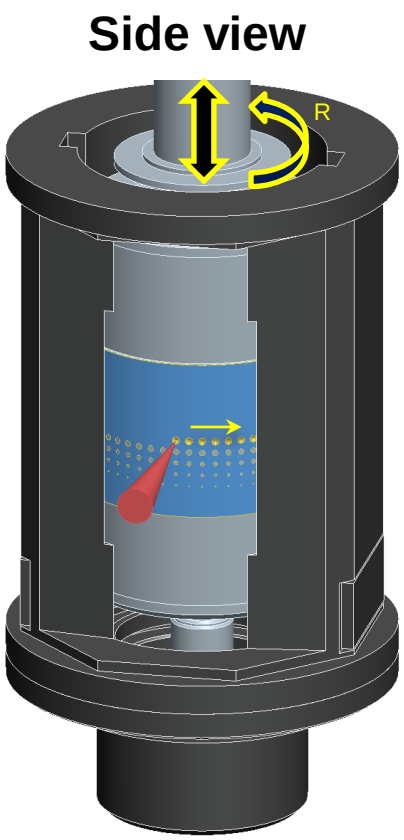
Method	DPP/LDP	LPP
Advantages	Simple for classical z-pinch, advantage quickly disappears with liquid metal delivery schemes and laser trigger/brightness optimization concepts	Clean (mass limited targets) Small plasma size Scaling though repetition rate
Disadvantages	Erosion of near-plasma elements Large plasma volume Long plasma Low repetition rate due to pulse power limitations	

Options – choice of target material

Target	Xe	Sn
Advantages	Noble gas No deposition Can be pumped by off-shell turbo pumps	High CE (>3%)
Disadvantages	Requires closed loop circulation due to high cost of Xe (10-30$/liter)	Deposition (collector lifetime) Messy and dirty (especially in DPP/LDP configuration) Numerous issues with stable and reliable droplet generation Reacts with Ru to form alloys

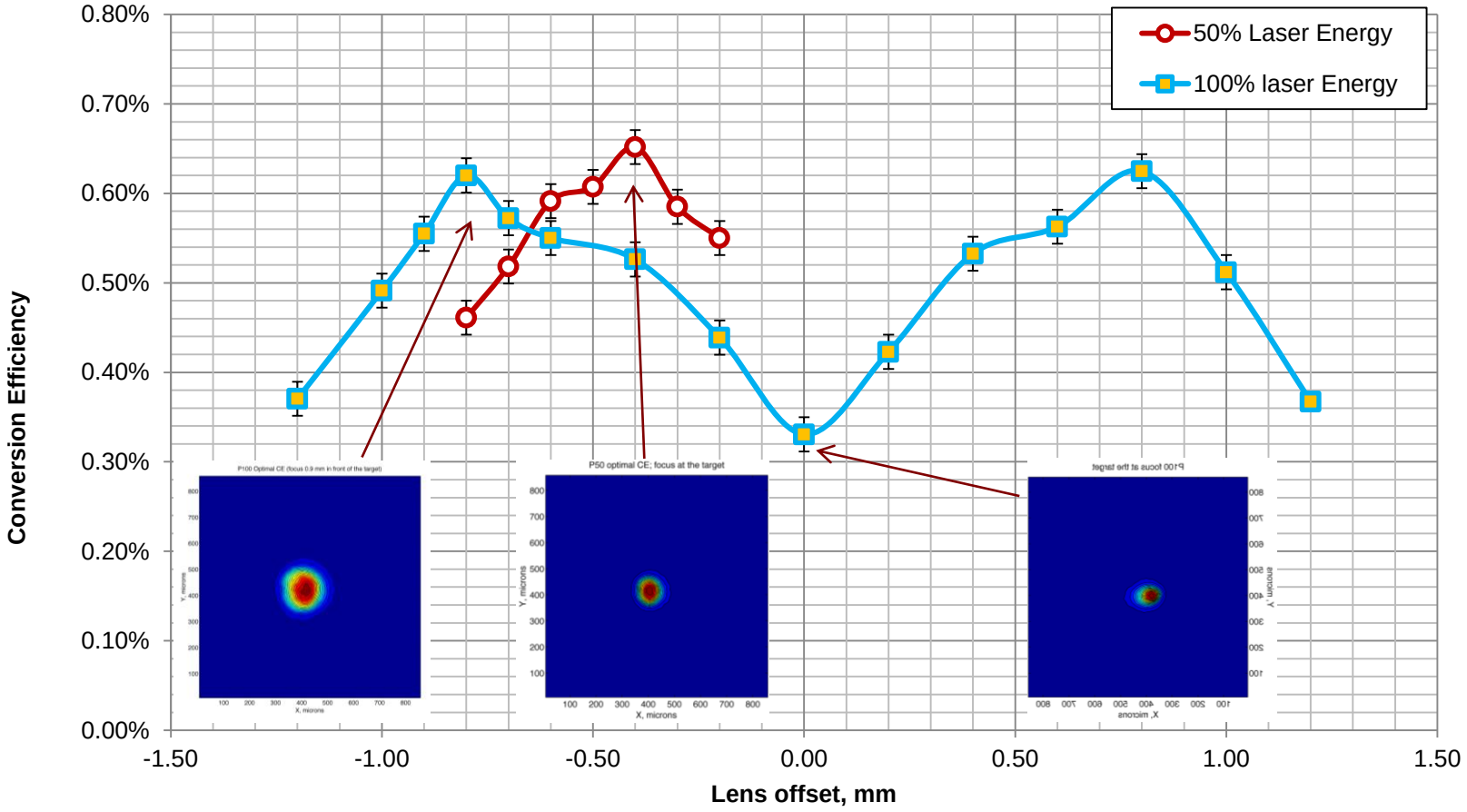
Solid Xenon Drum Target



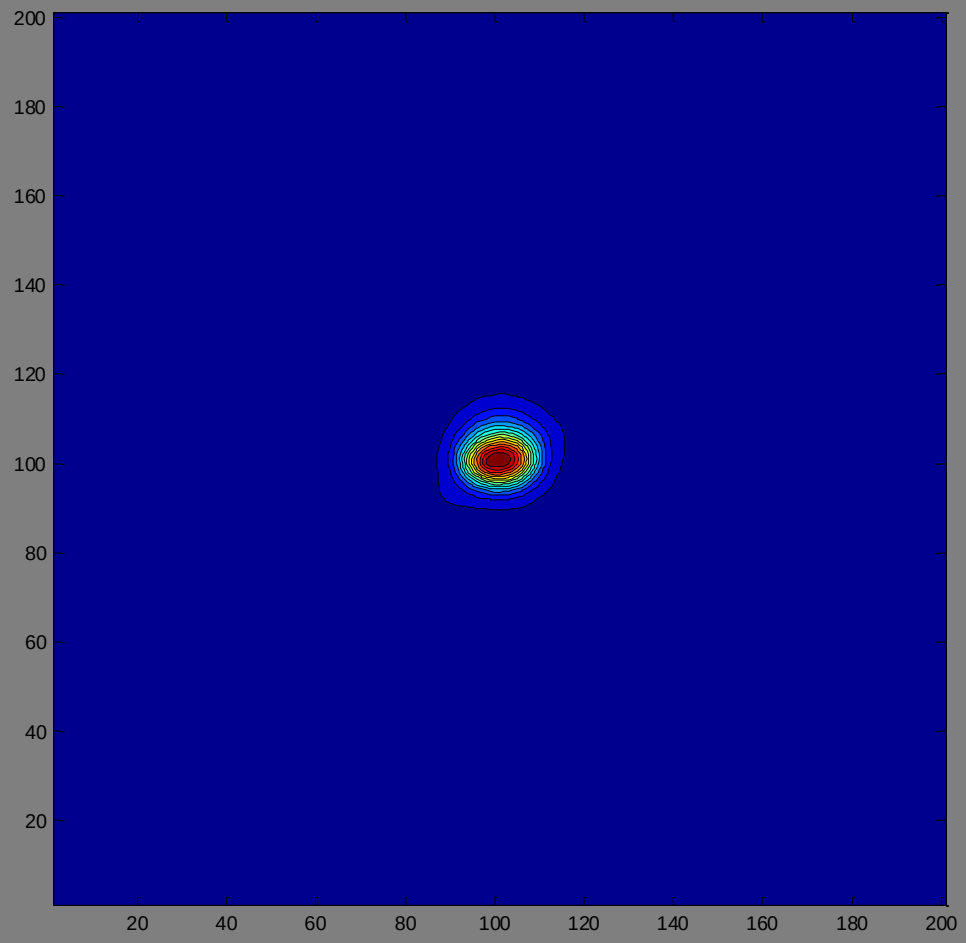


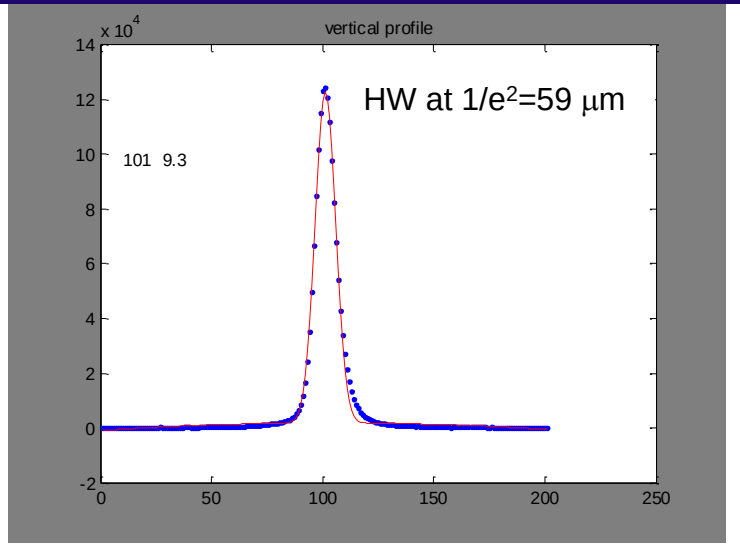
- Key features of the drum target:
  - Cryogenically cooled to form Xenon ice on its surface
  - Rotating and moving up and down → laser hits fresh Xenon ice every time
- Xenon droplets are also in development

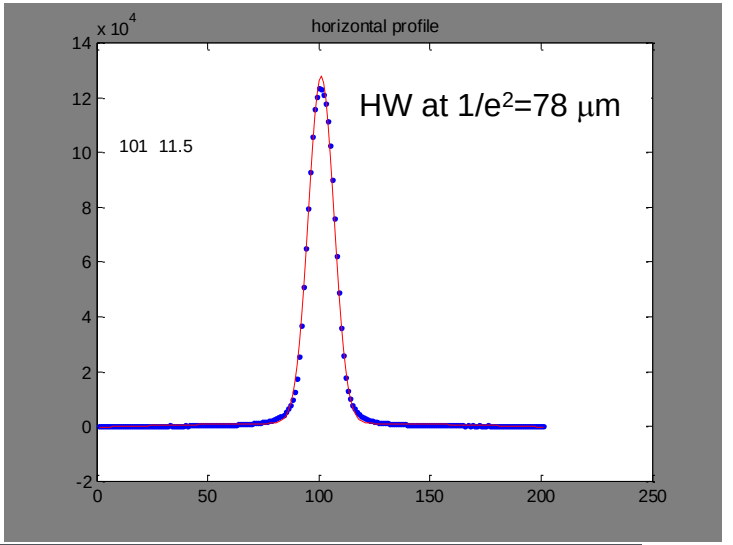
Conversion efficiency and plasma size



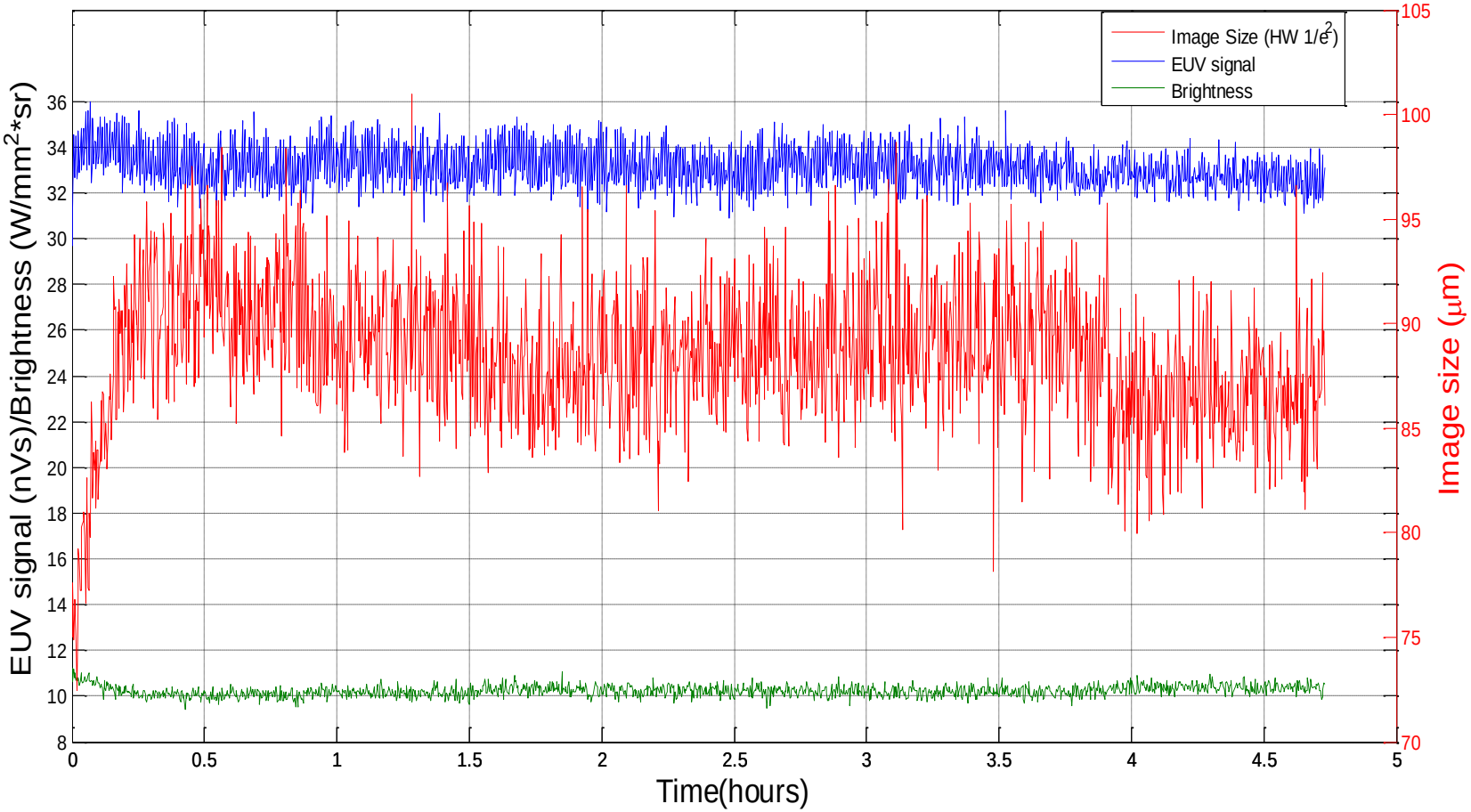
EUV plasma image



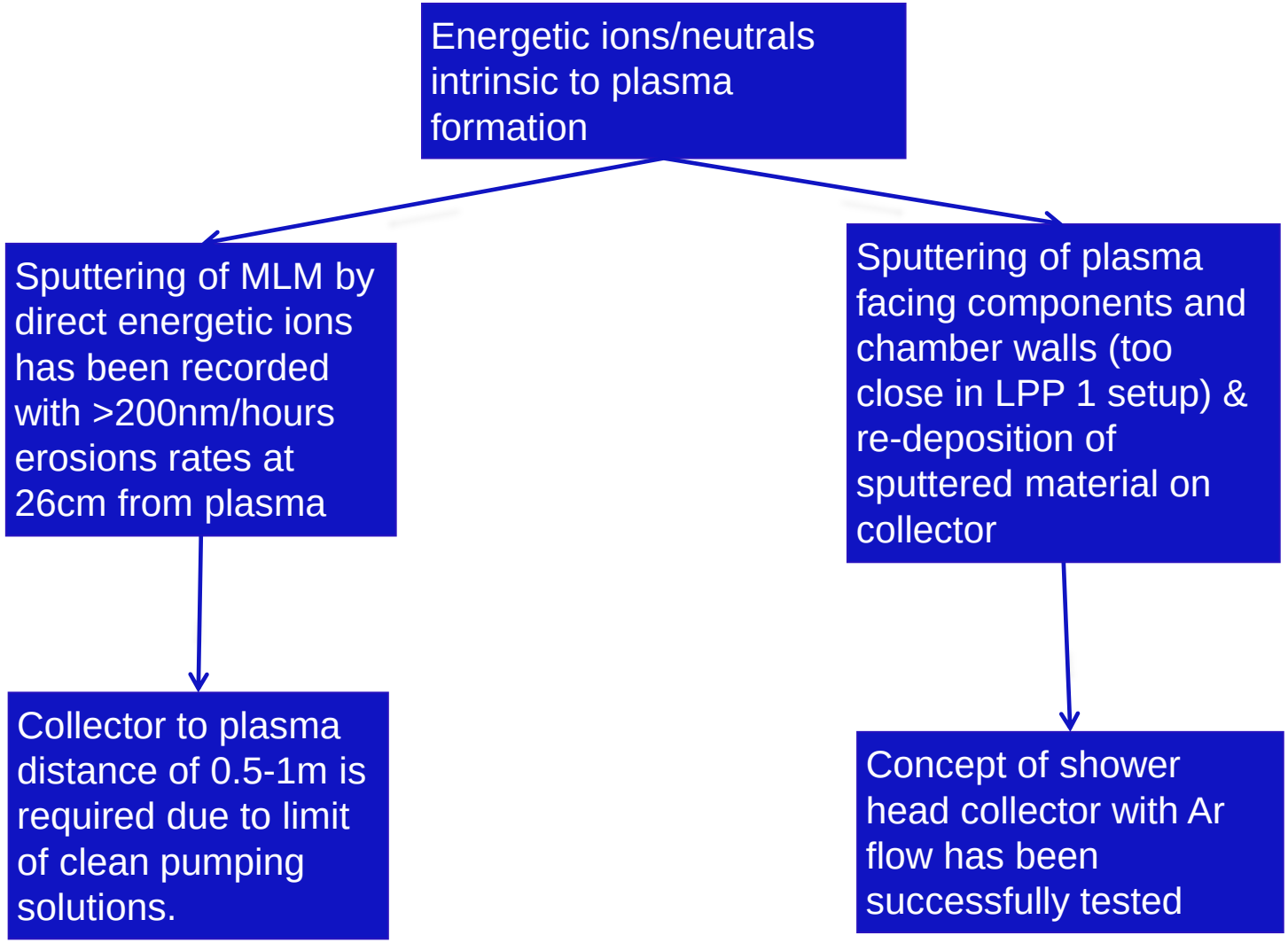




EUV signal, plasma size, and radiance



Primary collector damage mechanisms



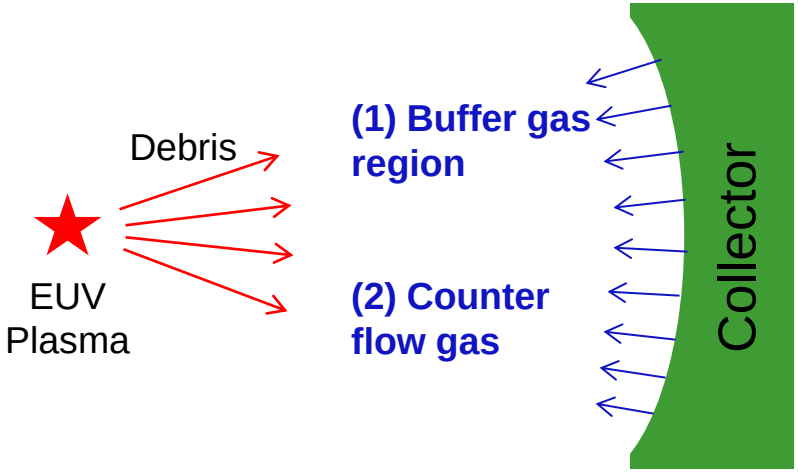
Showerhead collector concept : erosion and deposition mitigation

Collector Damage Mechanisms

Energetic ions intrinsic to plasma formation

Sputtering of plasma facing components & re-deposition on collector

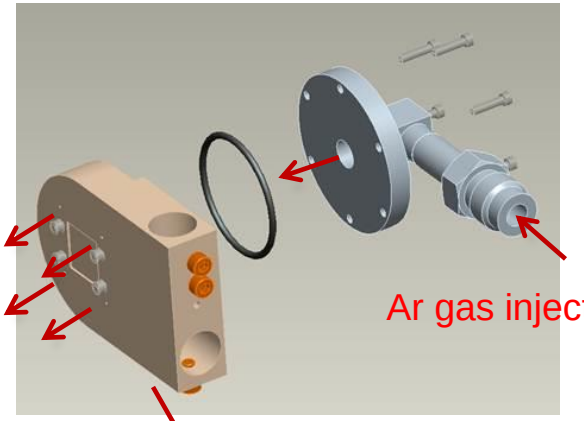
Showerhead collector with counter gas flow

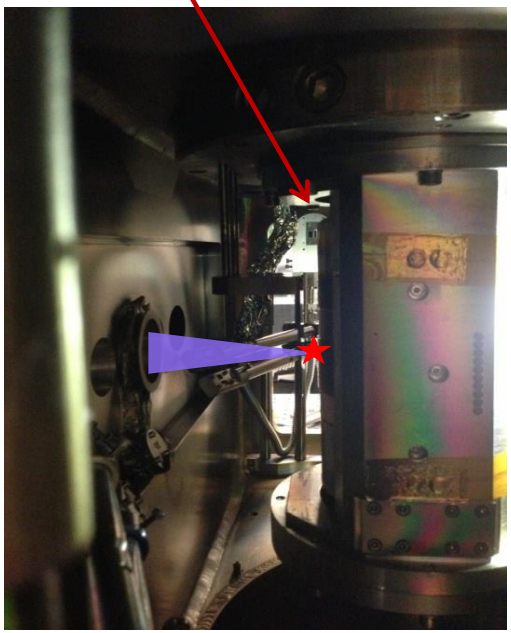


1-2 Torr*cm Argon buffer required to stop energetic Xe ions/neutrals

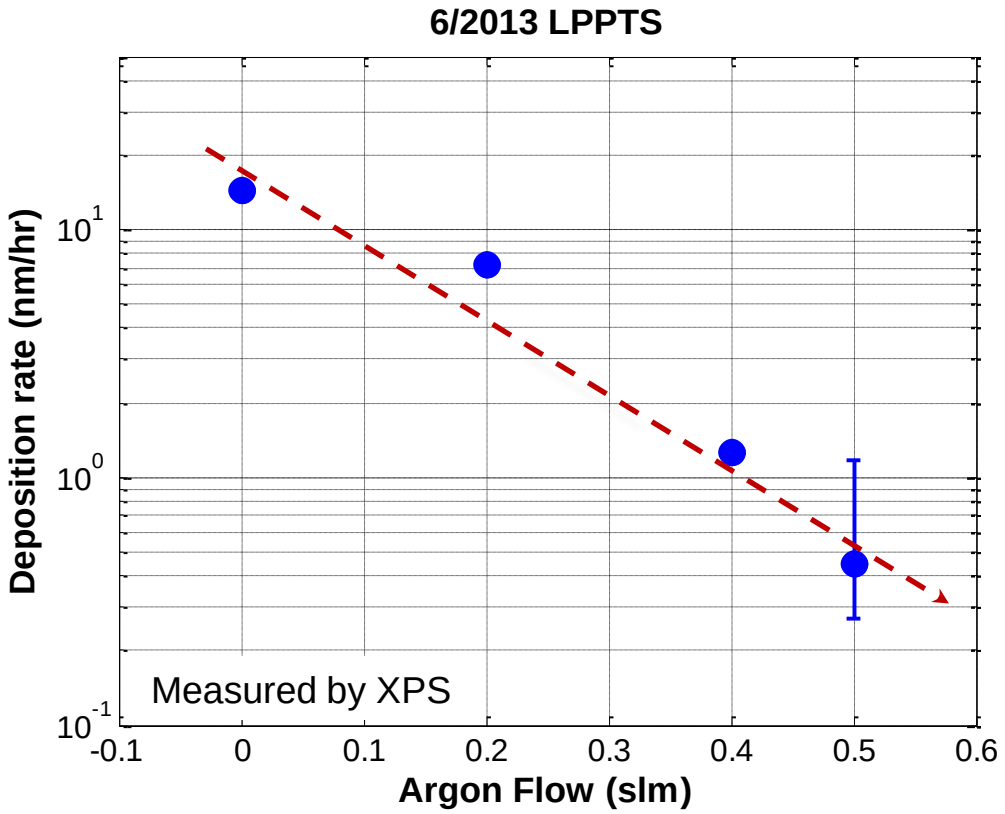
- Provides efficient (>90%) EUV transmission

Showerhead collector: Initial proof-of-concept test

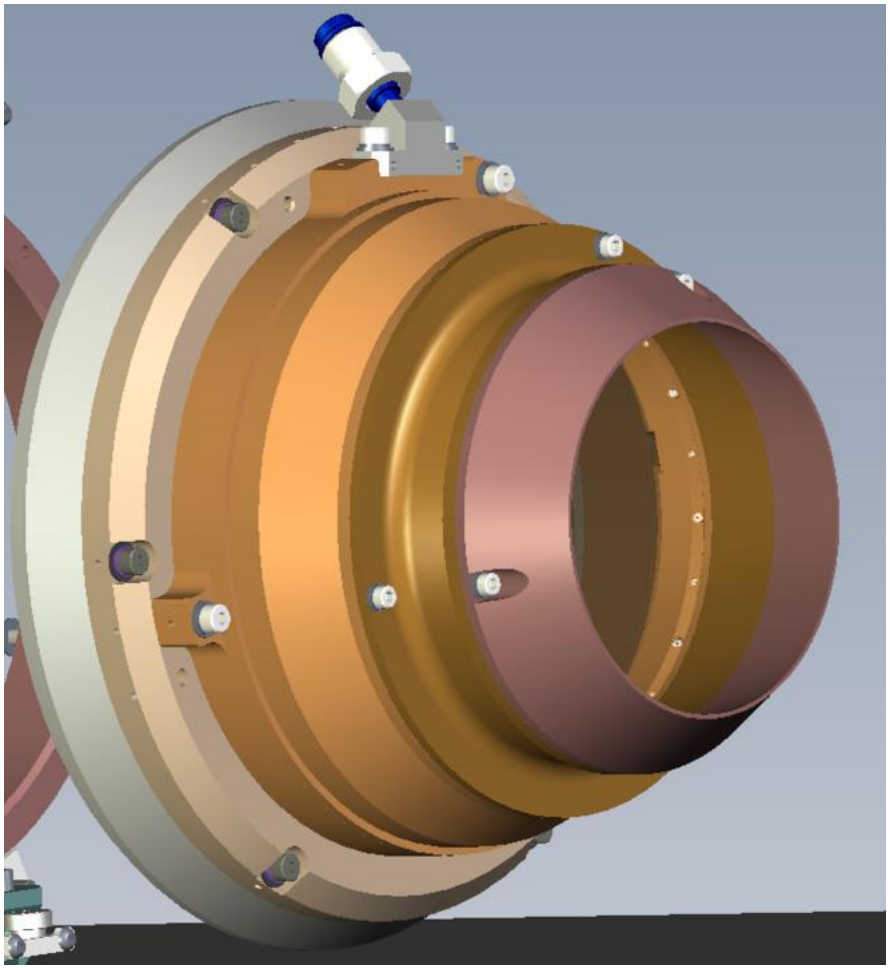


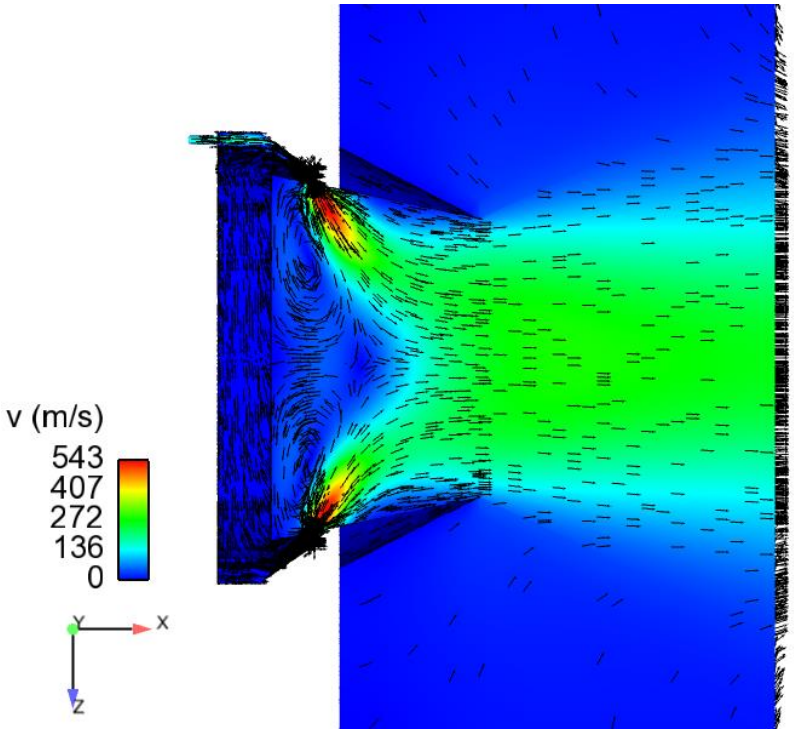


- Flowing Argon gas around the witness sample provides ~40x deposition reduction
- Technique expected to scale to full size collector

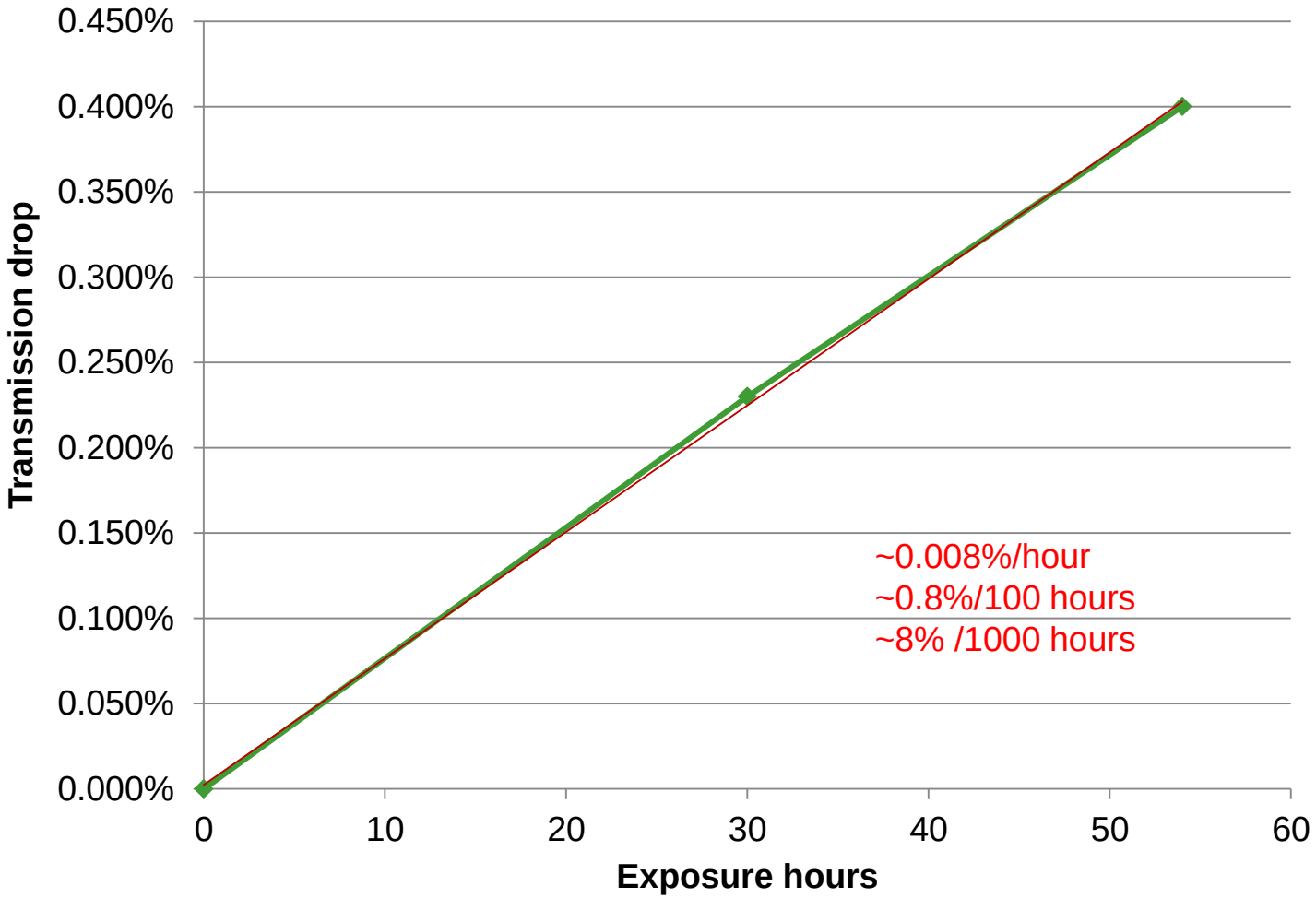


Laser optics protection design and simulation of flow distribution



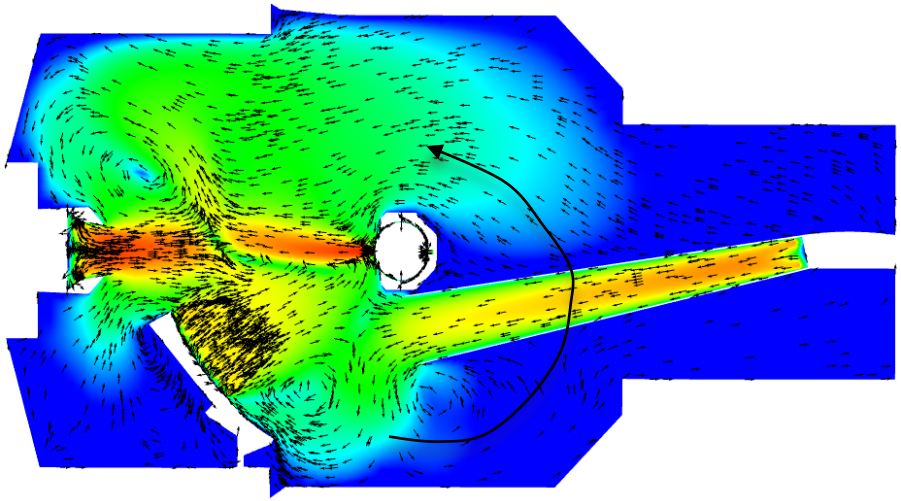


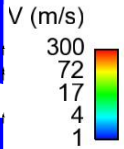
Laser optics protection



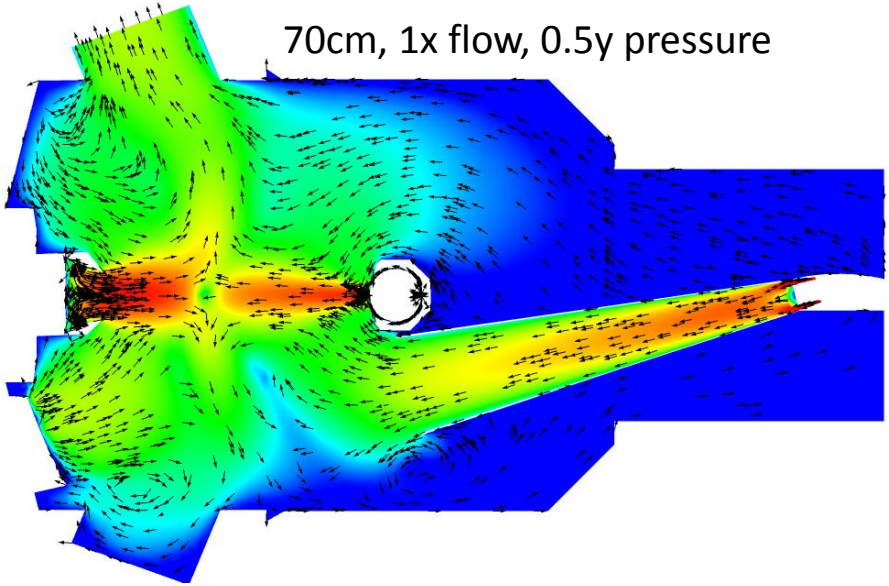
Chamber gas distribution modeling

40cm, 1x flow, 1y pressure

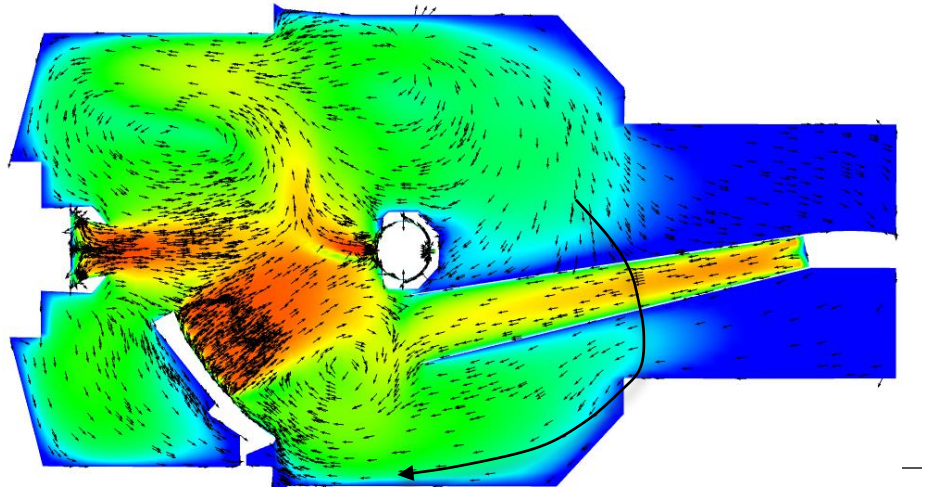


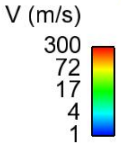


70cm, 1x flow, 0.5y pressure

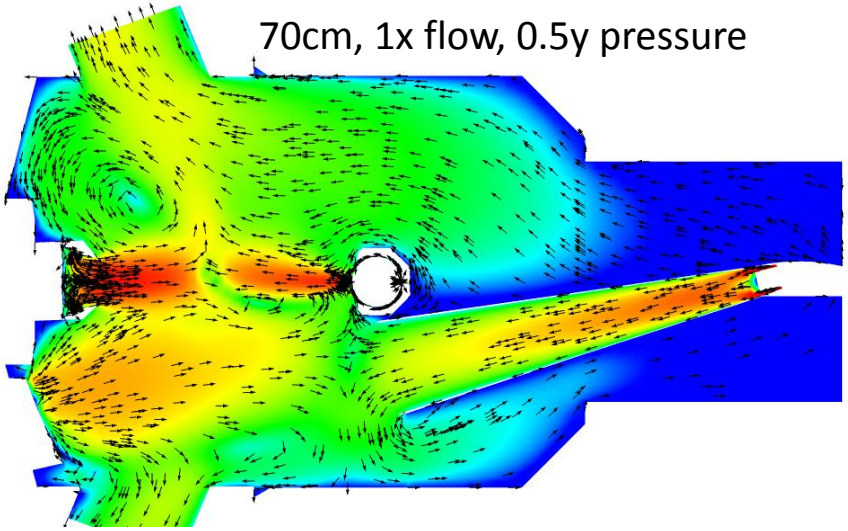


40cm, 2x flow, 1y pressure

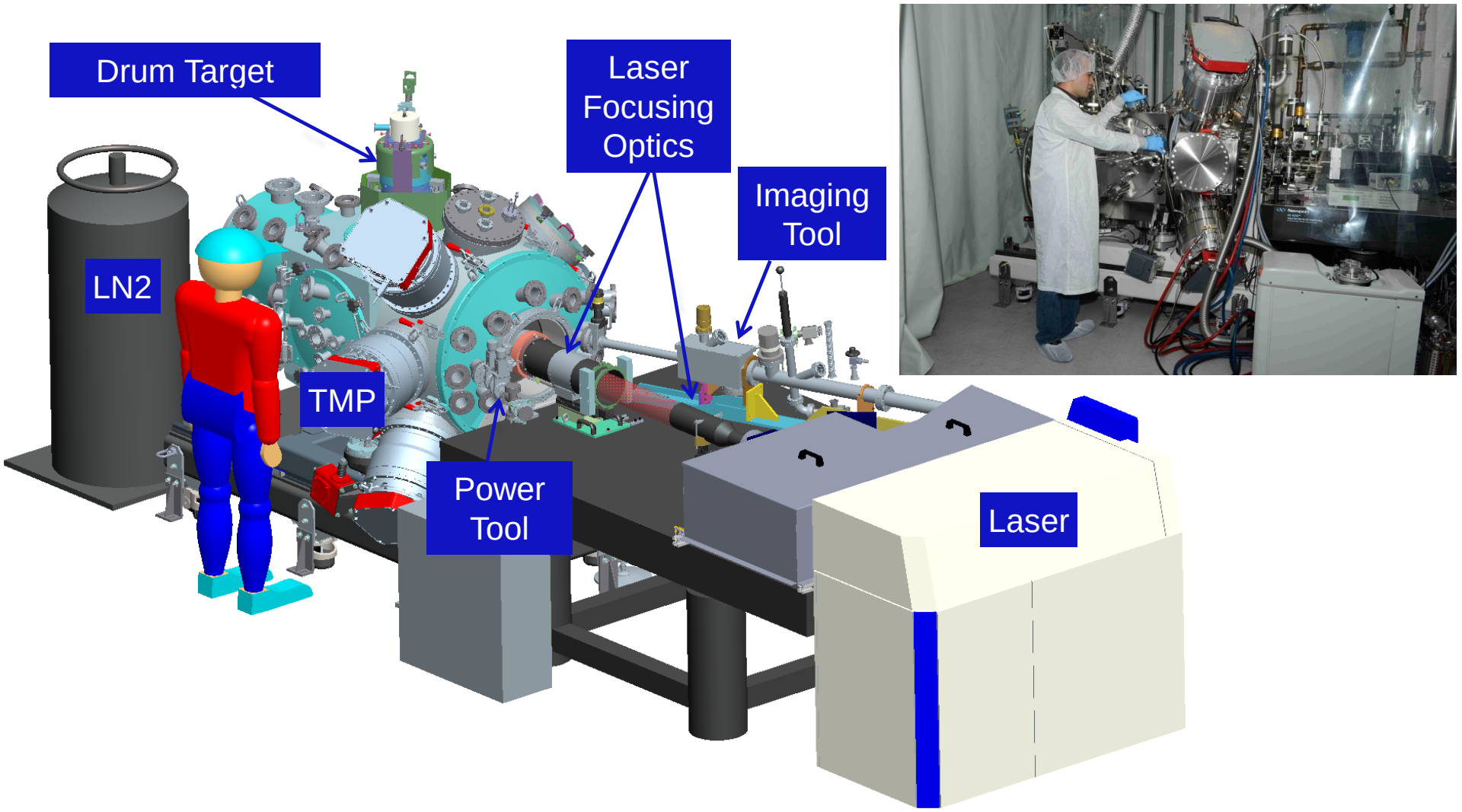




70cm, 1x flow, 0.5y pressure

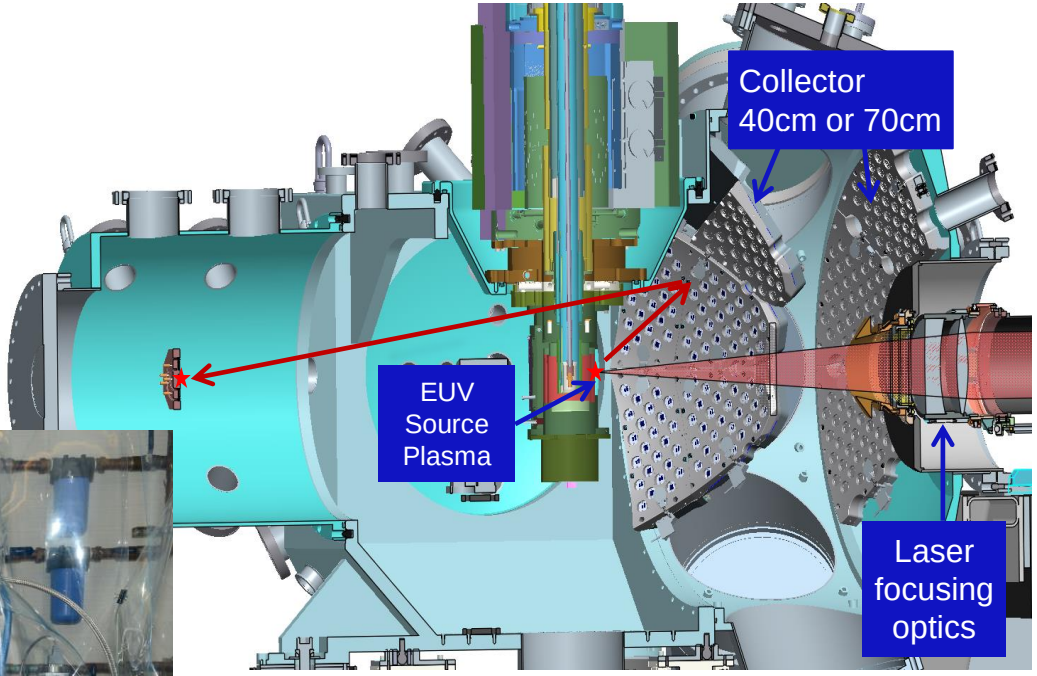


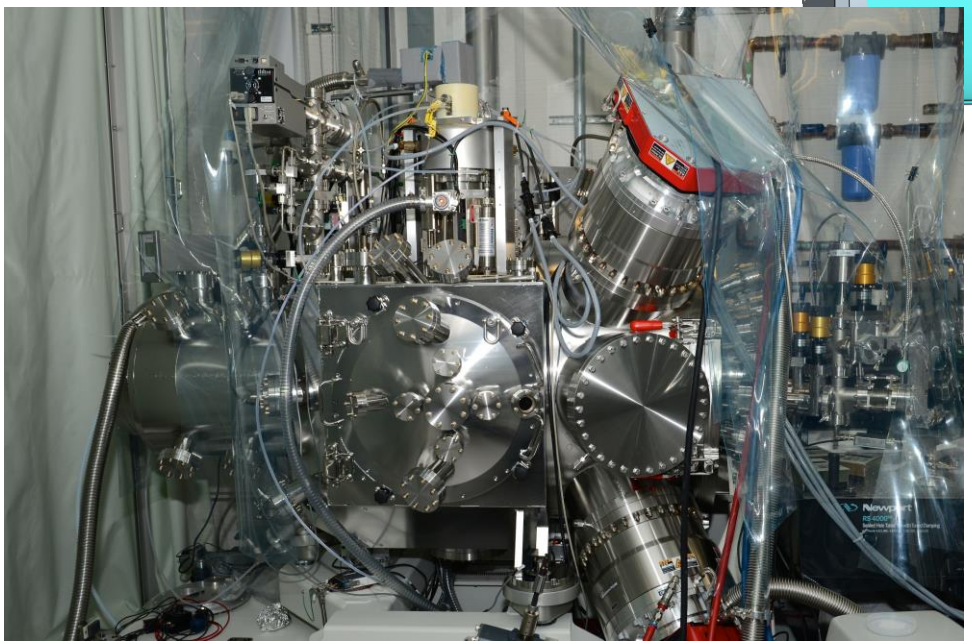
EUV source collector lifetime (CLT) setup



CLT setup details

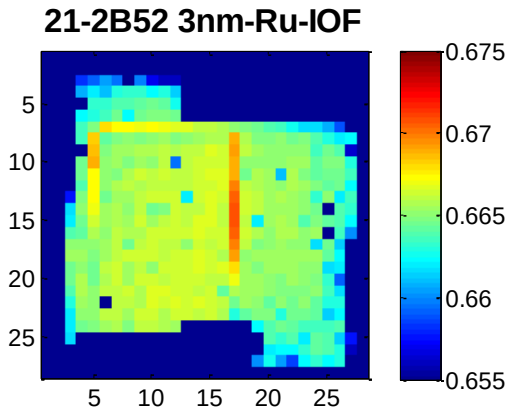
- Support collector 40-80 cm from plasma
- Advanced protection of collector and laser optic with distributed buffer gas flow
- Flexible debris mitigation capabilities

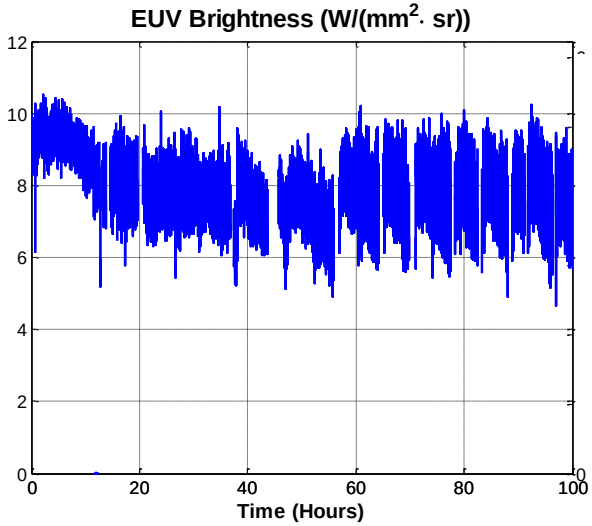


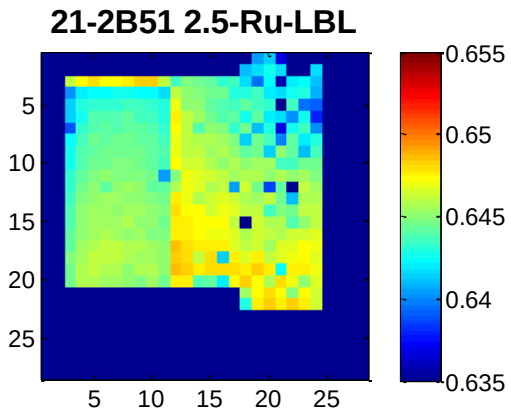


- Plasma –wall distance is > 0.5 m
- Up to 8 turbo-pumps can be installed with total throughput of 16slm
- IF interface ready
- Base pressure is at $2*10^{-8}$torr

Prototype current status







Duration -120 hours

Effective duty cycle - 80% (limit with current target 92%, manual LN2 and Xe bottles replacement)

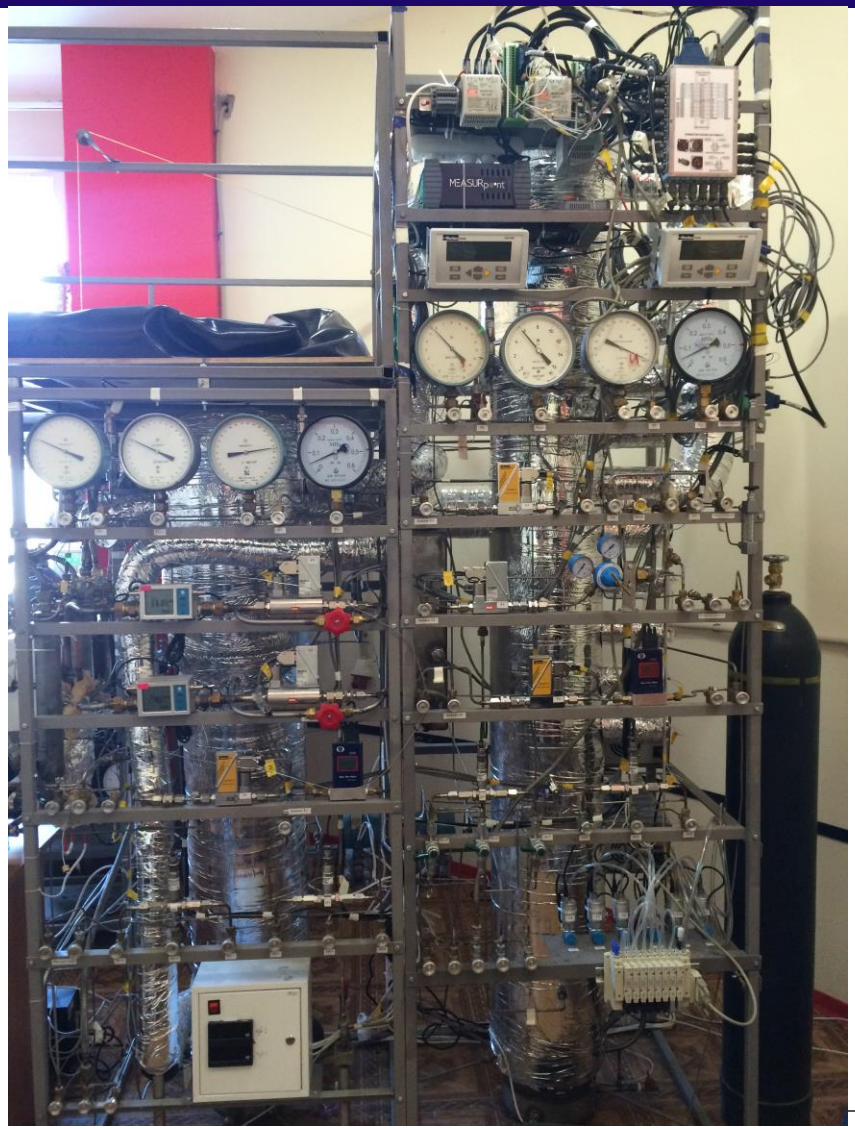
Radiance is at 8W/mm ^{2}sr @5kHz in free run mode

NO reflectivity degradation (within 0.5% accuracy)

Xe recycling – development options

Parameter or Spec	Vendor A	Vendor B	Vendor C
General			
Technology	Distillation and adsorption	Distillation	Multistep adsorption (room temperature, PSA/VSA)
Main products	Rare Gases, Equipment	Rare Gases	Technical Gases
Critical specification parameters			
Recirculation efficiency (RE>98%)	>99%	95%	90%
Xenon Purity (99.999%)	99.999%	>99.999% at 95%RE	>99.9%
Throughput	Demonstrated	Feasible	Up to half of required per system
Contaminations (spec)	Demonstrated	Feasible	TBD
Cost of Recirculation (<$0.6/liter)	<$0.5/liter	>$1.5/liter	TBD
Footprint	<10m^2	50-100m^2	10m^2
Height	<3m	4.5m	2m

Xe recycle unit development: automatic control



Major subsystems operation has been demonstrated.

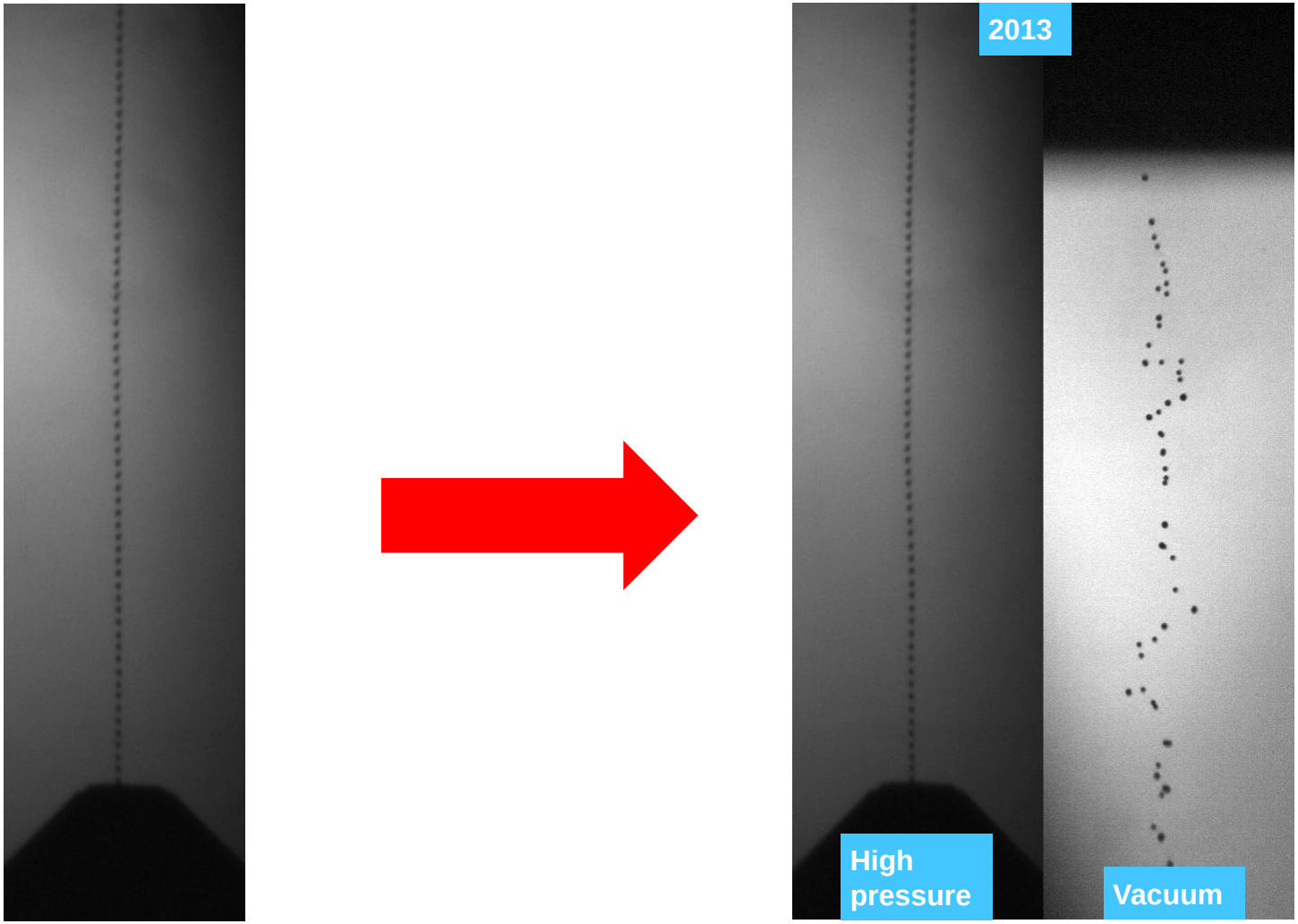
Full scale proto-unit has been built and tested.

Long term (days) operation in steady state regime.

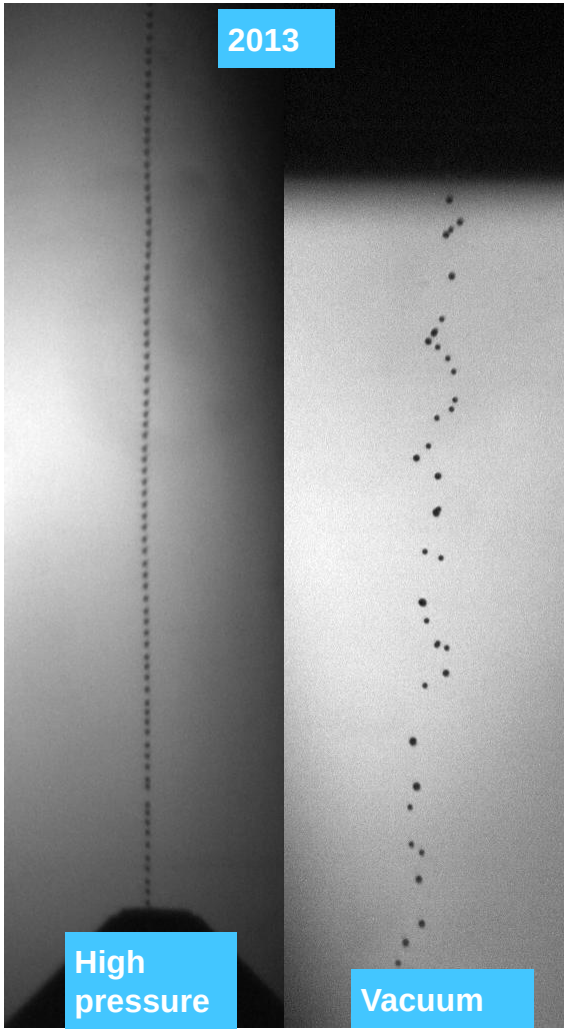
Automated start-up and shut-down proof of principle experiments have been performed.

Full scale automation is in progress.

Xe droplets – not so fast and easy

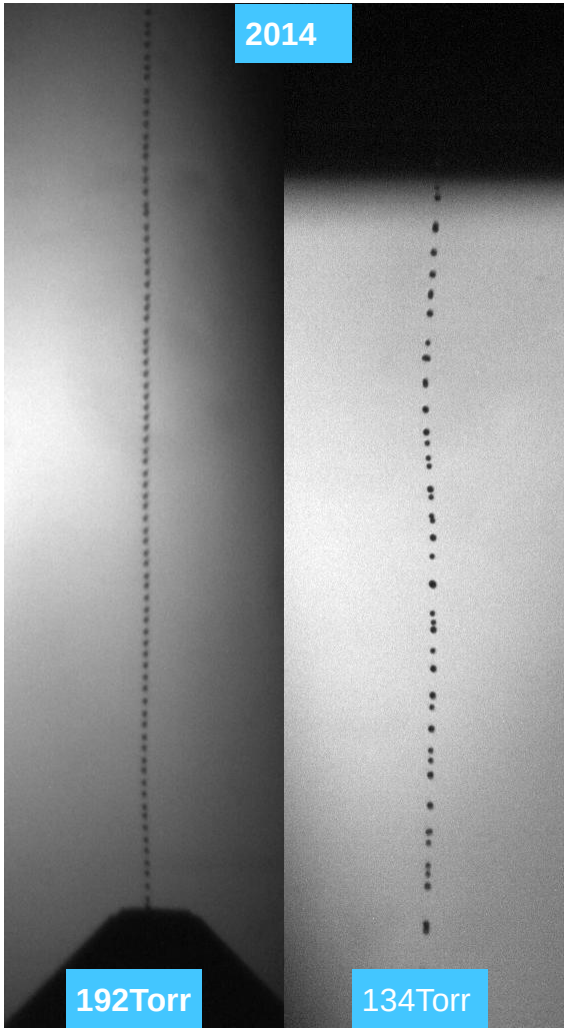


Xe droplets- work in progress



High pressure and vacuum streams were recorded simultaneously.

Evaporation and turbulence (atmosphere to vacuum transition) are main mechanisms of droplet stream disturbance.



Conclusions

- Required radiance has been demonstrated at 10kHz in steady state
- Further radiance scaling is possible through repetition rate.
- Major collector degradation mechanisms have been fully characterized.
- Effective debris mitigation strategies have been developed and tested.
- Full week of operation at 5kHz and 80%DC have been completed with NO collector reflectivity degradation (<0.5%) -> collector lifetime at 10kHz is more than 2000hours.
- Efficient Xe recirculation system has been developed with >99% capture rate Xe and >99.999% Xe purity, which enable cost effective source solution.
- Feasibility of stable Xe droplet delivery has been demonstrated.

Thank You