Laboratory Soft X-ray Tomography with a simple Robust Laser Plasma Light Source

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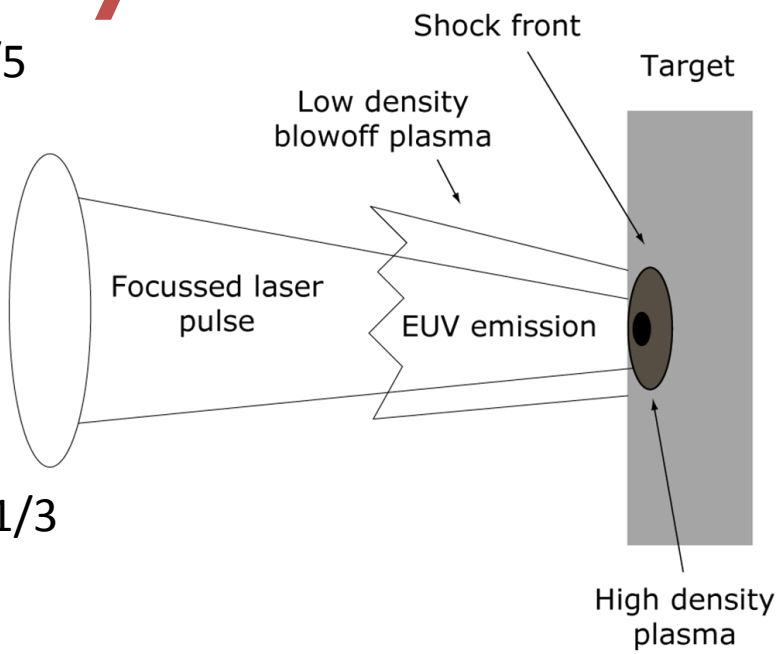
Laser Plasmas & Soft X-rays

$T_e(eV) \approx (\lambda^2\ PowerDensity)^{3/5}$
(Columbant & Tonan, JAP 44 1973)

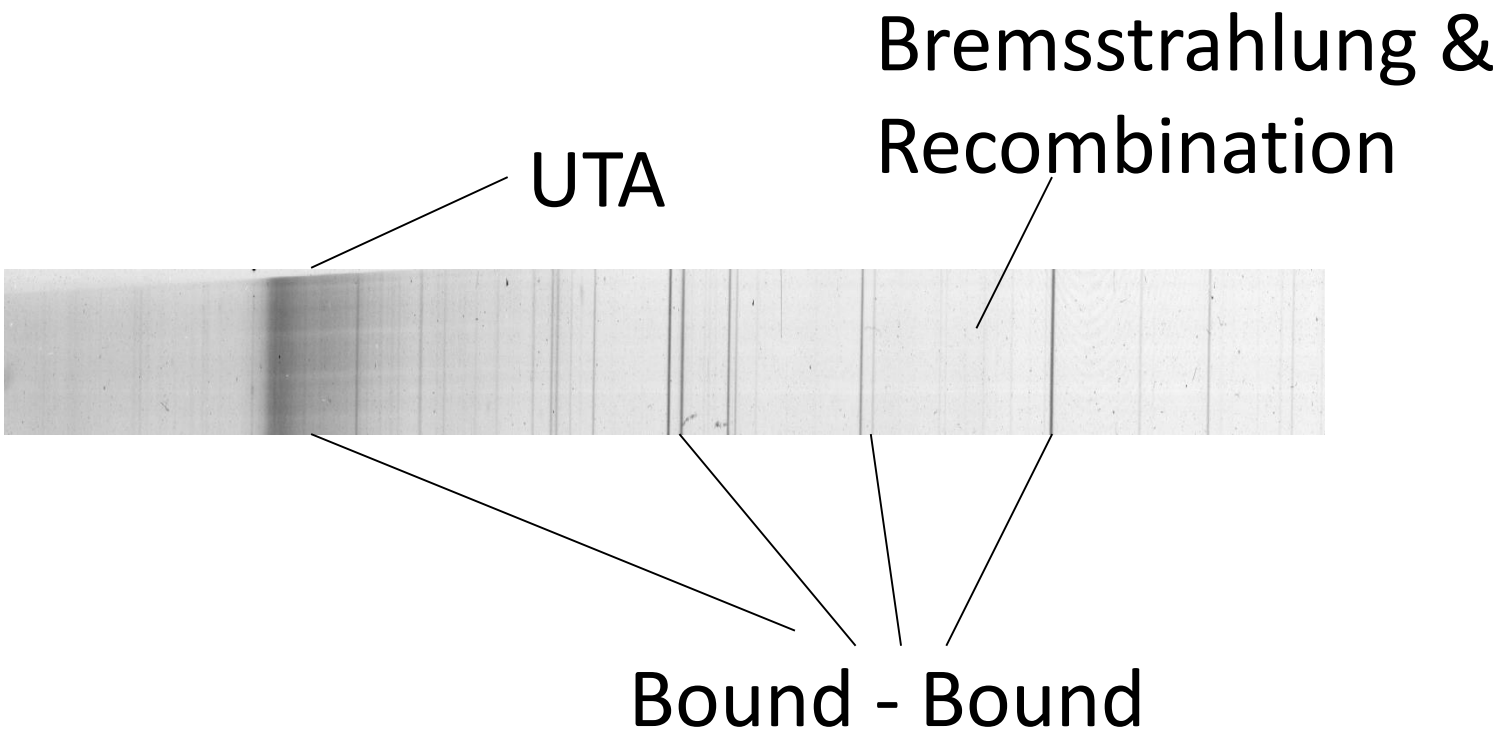


Average charge $\approx 0.67\ (AT_e)^{1/3}$

$n_e \sim 10^{19} - 10^{21}\ cm^{-3}\ (n_{ec} \sim 10^{21}/\lambda^2\ cm^{-3})$

Expansion velocity $\approx 10 - 100\ \mu m/ns$
$(\approx 10^6 - 10^7\ cm/s)$

Soft X-ray/EUV Spectrum



For an optically thin plasma:

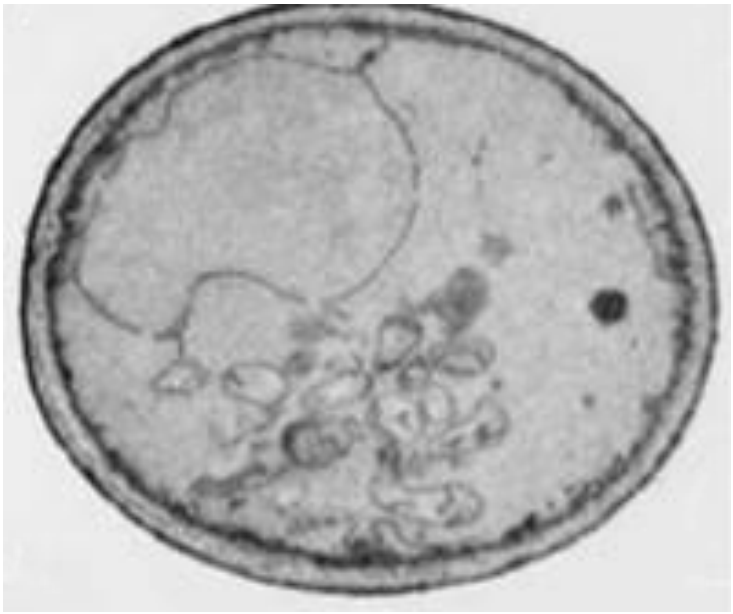
$P_{lines}:P_{recomb}:P_{brem} = 100:10:1$

Biologists' Requirements

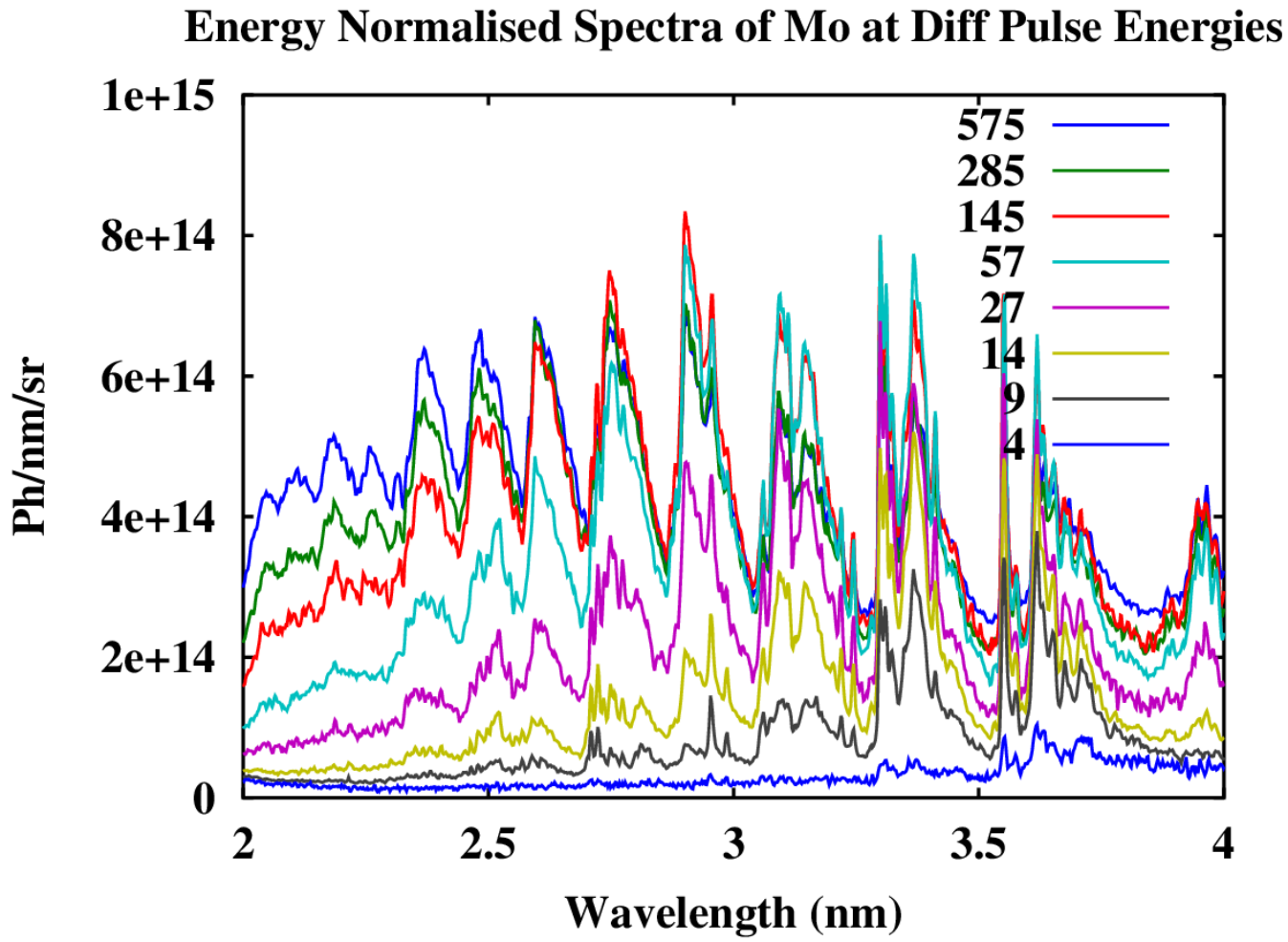
Cell Diameter ~ 10 µm
Organelle size < 200 nm

< 40 nm resolution

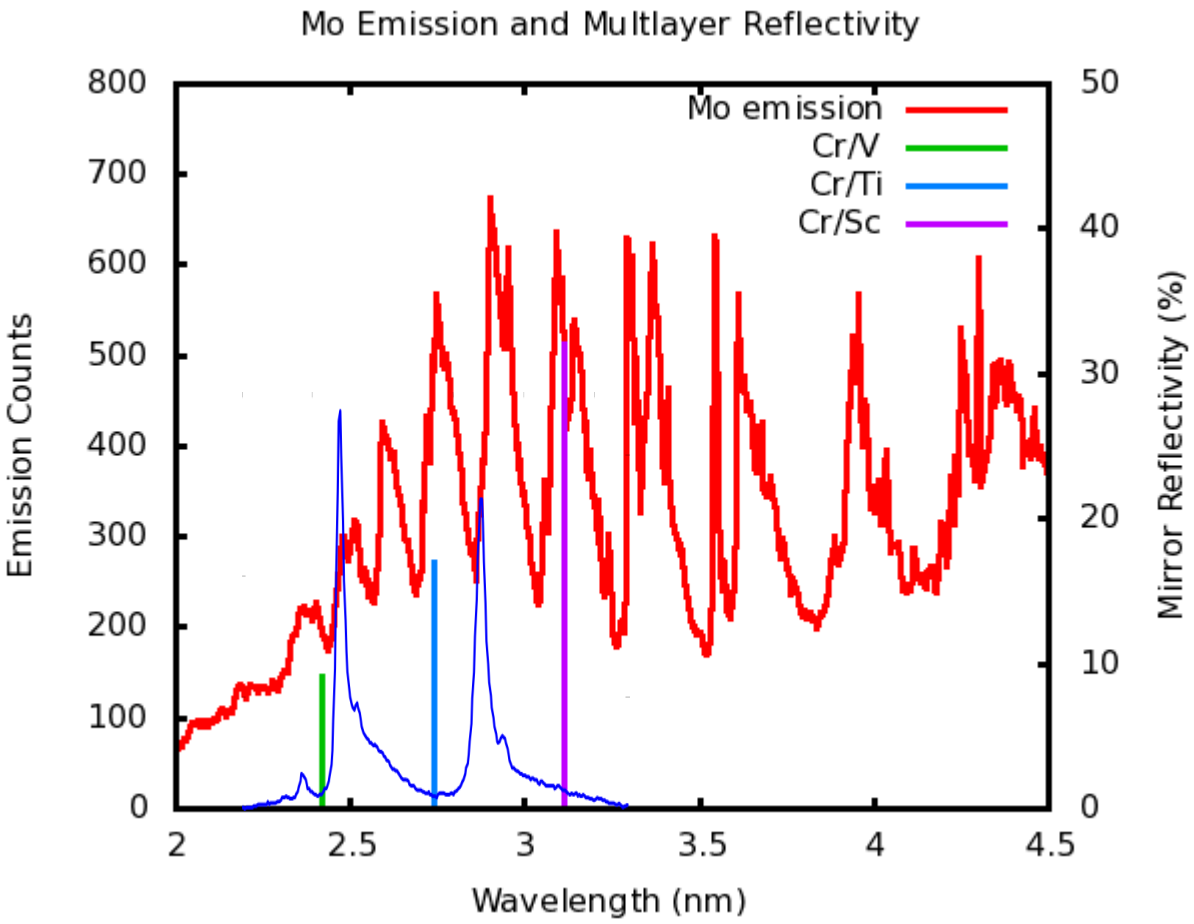
3-D information



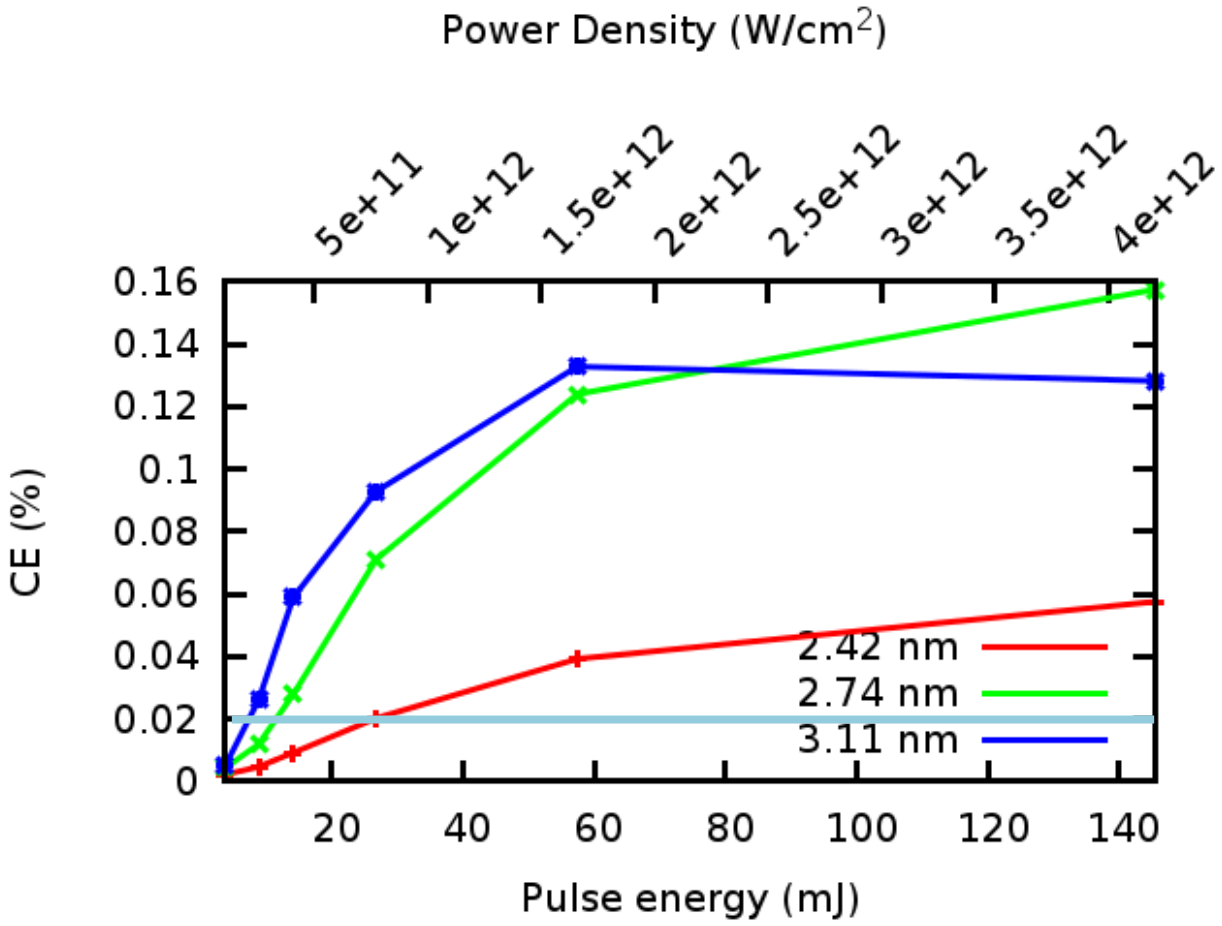
LPP Power Density & Efficiency



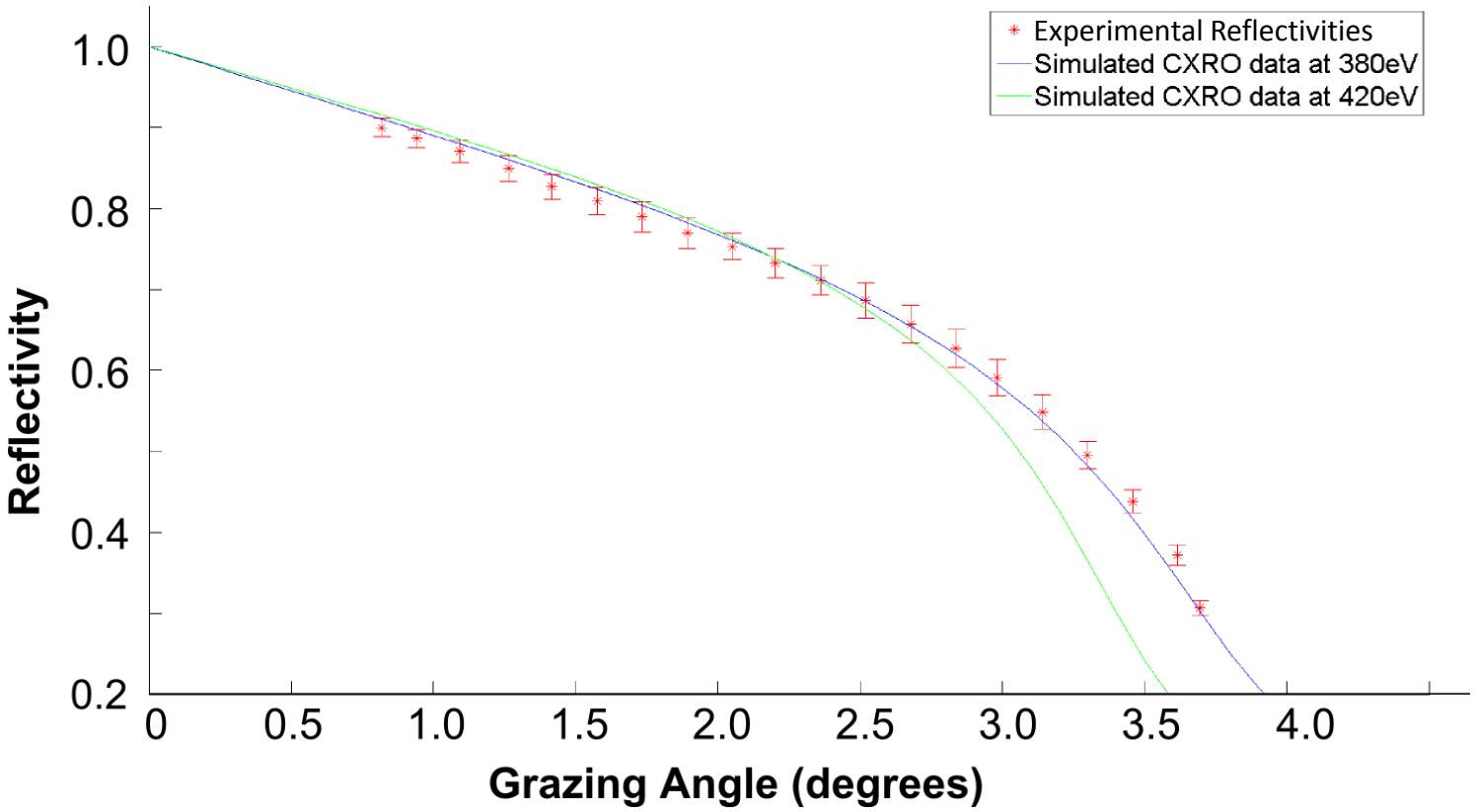
Water Window Sources



Conversion Efficiency Mo



Reflectivity of Liquid in WW

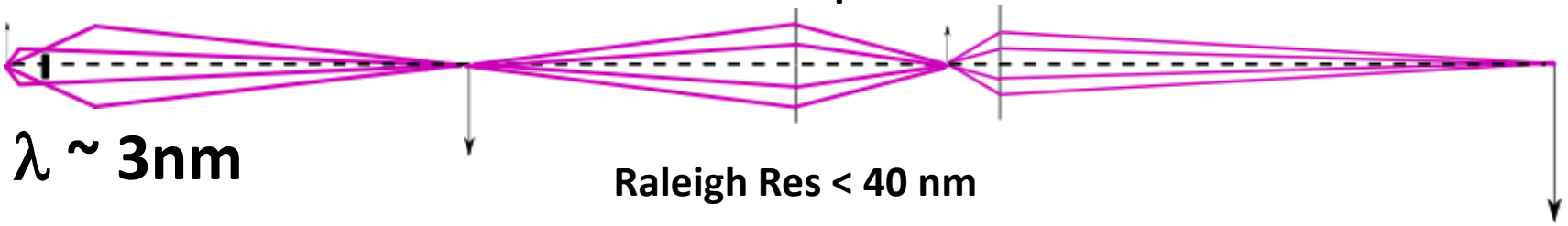


Microscope Requirements

Nyquist Res < 40 nm

Sample pixel size ~ 15 nm ← **Mag ~ 1000** ← CCD pixel size ~ 15 µm

FOV ~ 15 µm ← CCD ~ 1000X1000 Pixels



λ ~ 3nm

Raleigh Res < 40 nm

Objective NA > 0.03 ~ (0.61λ/Resolution)

DOF ~ a few microns

From Etendue Considerations

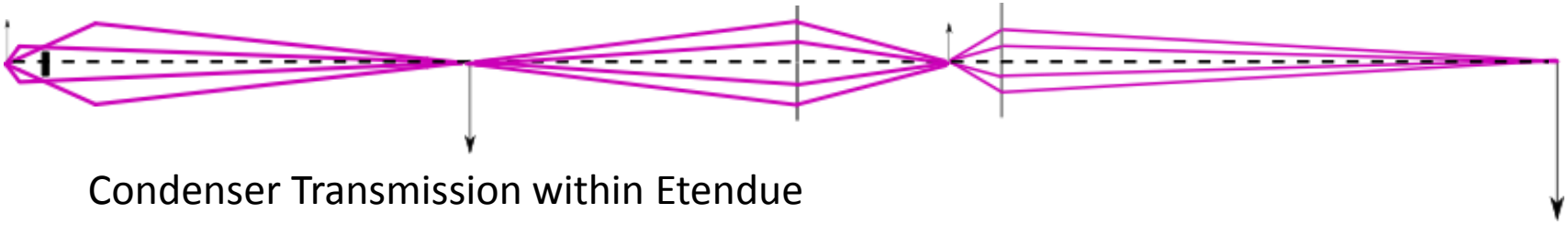
10 µm Source → 0.3% Photons to FOV

400 µm Source → 0.0002% Photons to FOV

100 W into 10 µm Source gives more **usable photons at sample** than 150 kW 400 µm Source

Photon Budget

Need > 5E4 photons/pixel at Sample
Total 5E10 photons in 30% Uniformity



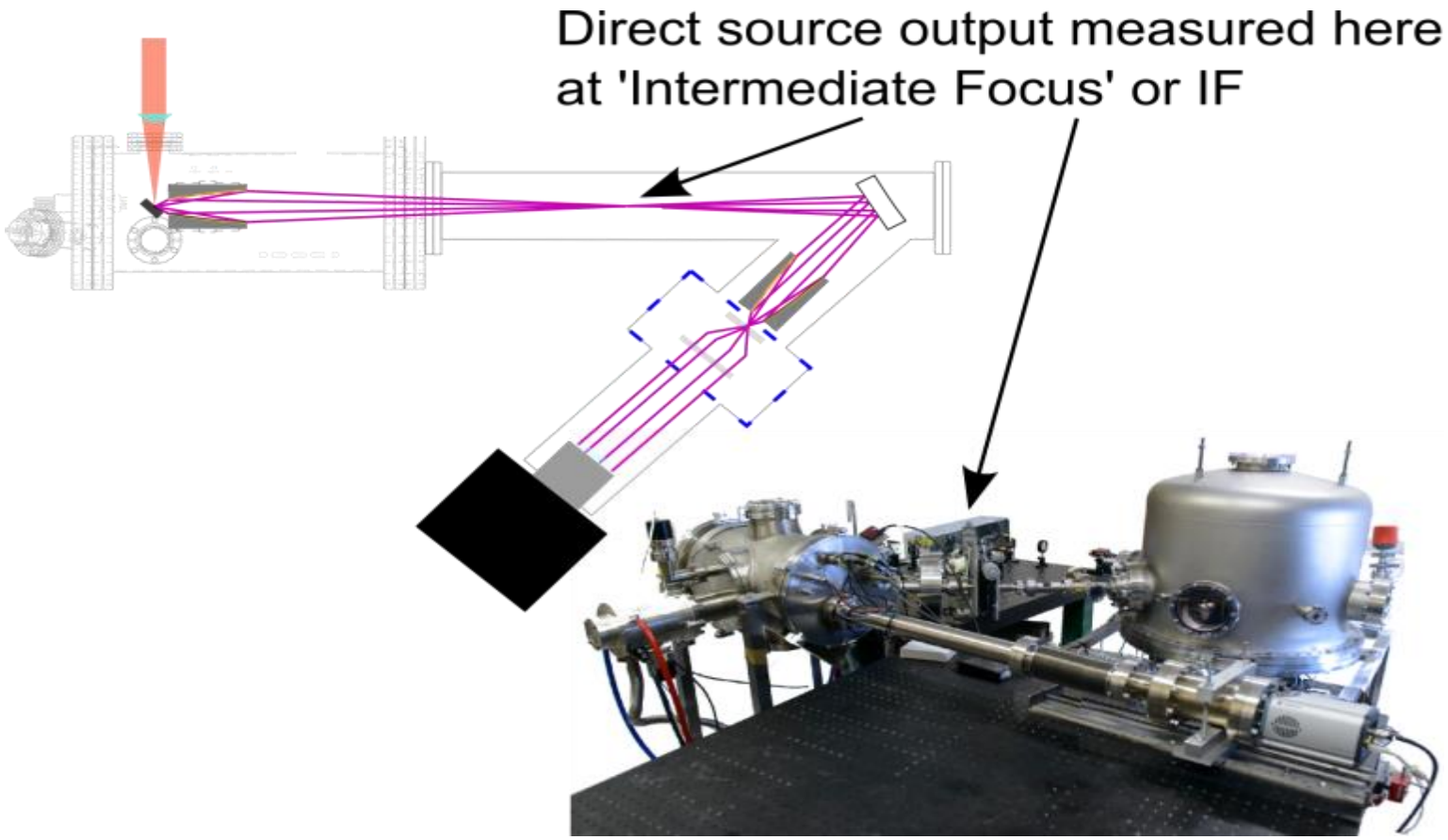
Condenser Transmission within Etendue
~ 0.1% of Total Photons from Source
Total 5E14 Photons/0.2% Bandwidth

Need > **1000 photons/pixel at CCD**

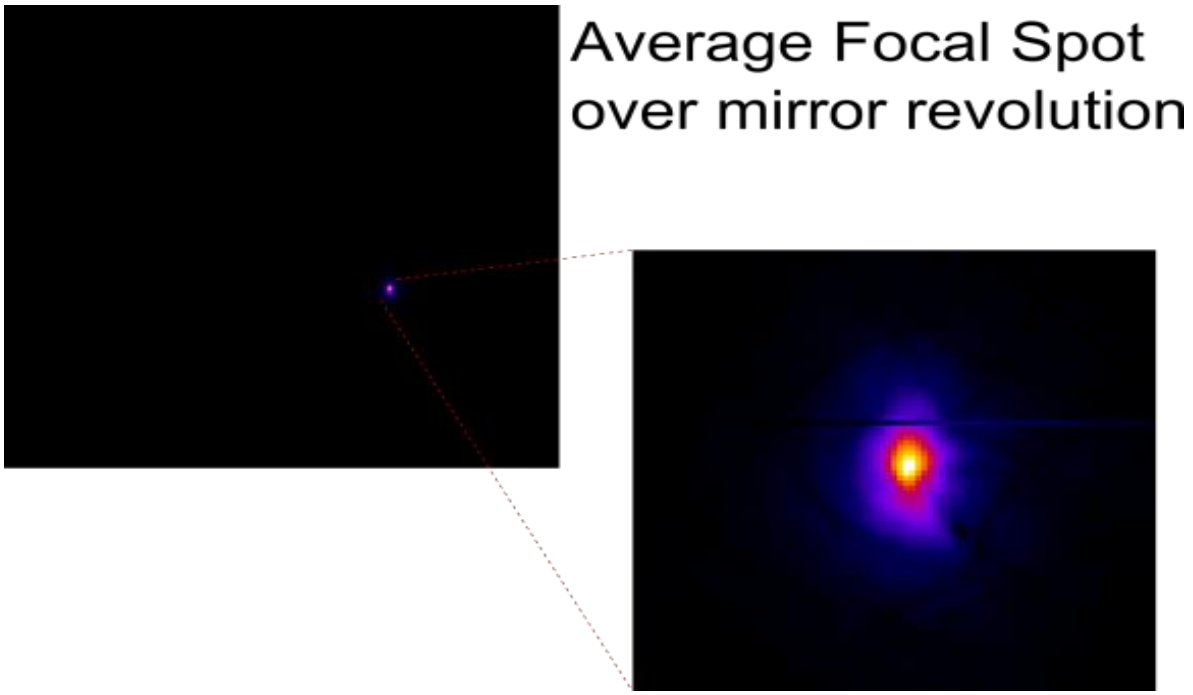
100W 10µm laser plasma with 0.05% CE will provide these photons in a few seconds

"Compact x-ray microscope for the water window based on a high brightness laser plasma source", Opt Expr. 30, 18362-18369 (2012)

Output After Collector

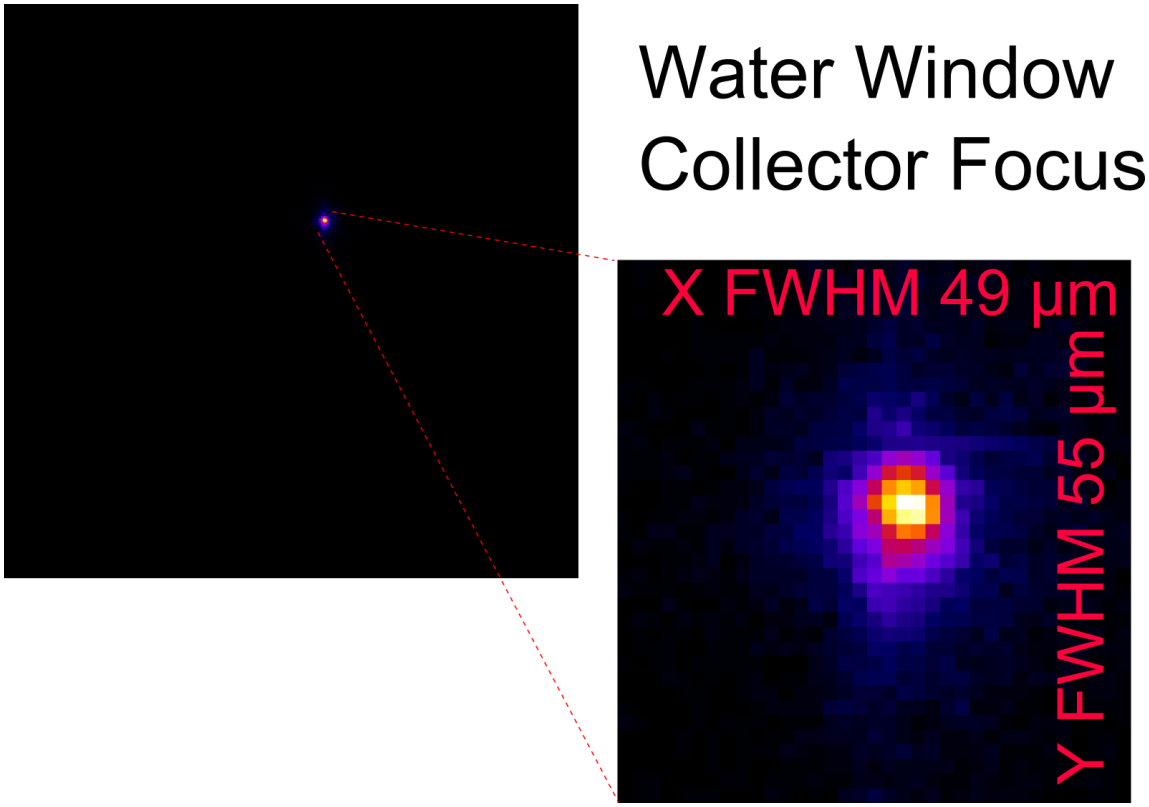


Focused WW Photons



Soft X-ray source spot is 70 µm x 70 µm FWHM on average at collector intermediate focus.
Corresponds to an average 17.5 µm diameter emission area at plasma

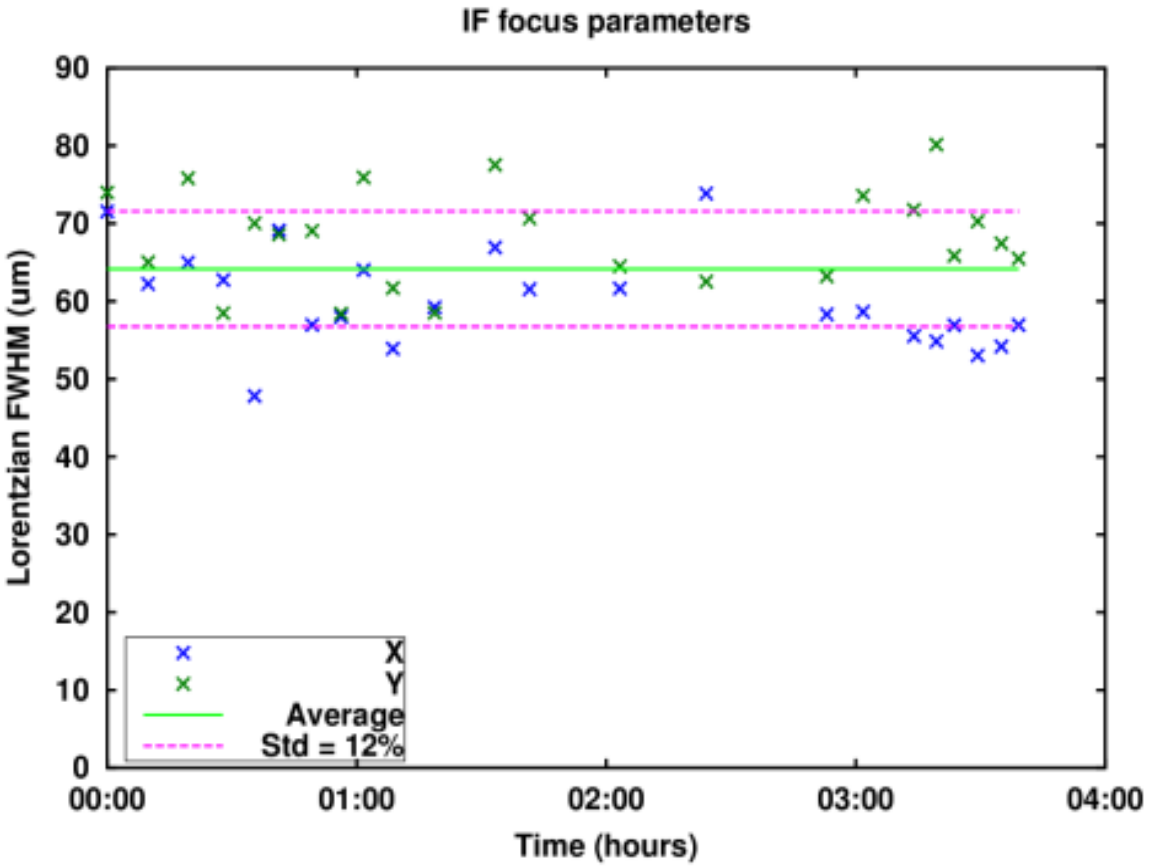
Best Plasma Size



~ 50 shots - best focus. Suggests a plasma volume of ~ 12.5 µm × 14 µm, FWHM.

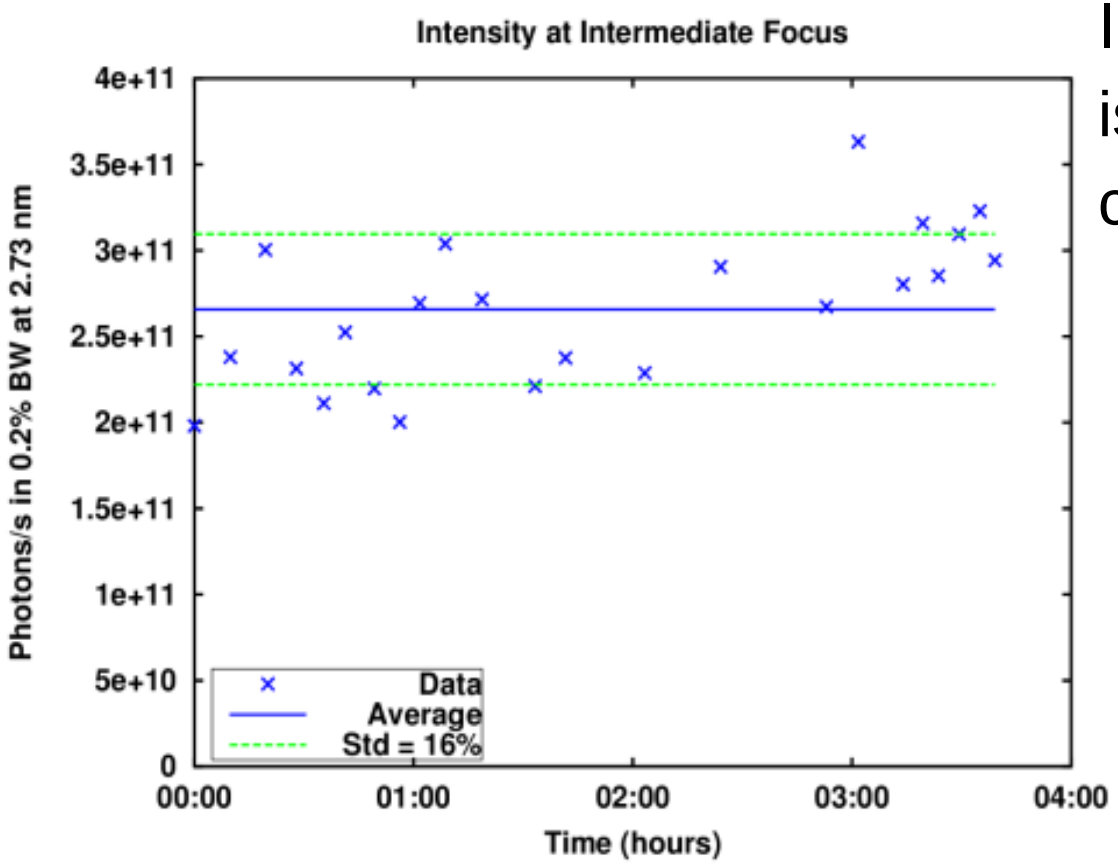
Working towards sub 10 µm WW emission diameter.

Focused WW Photons



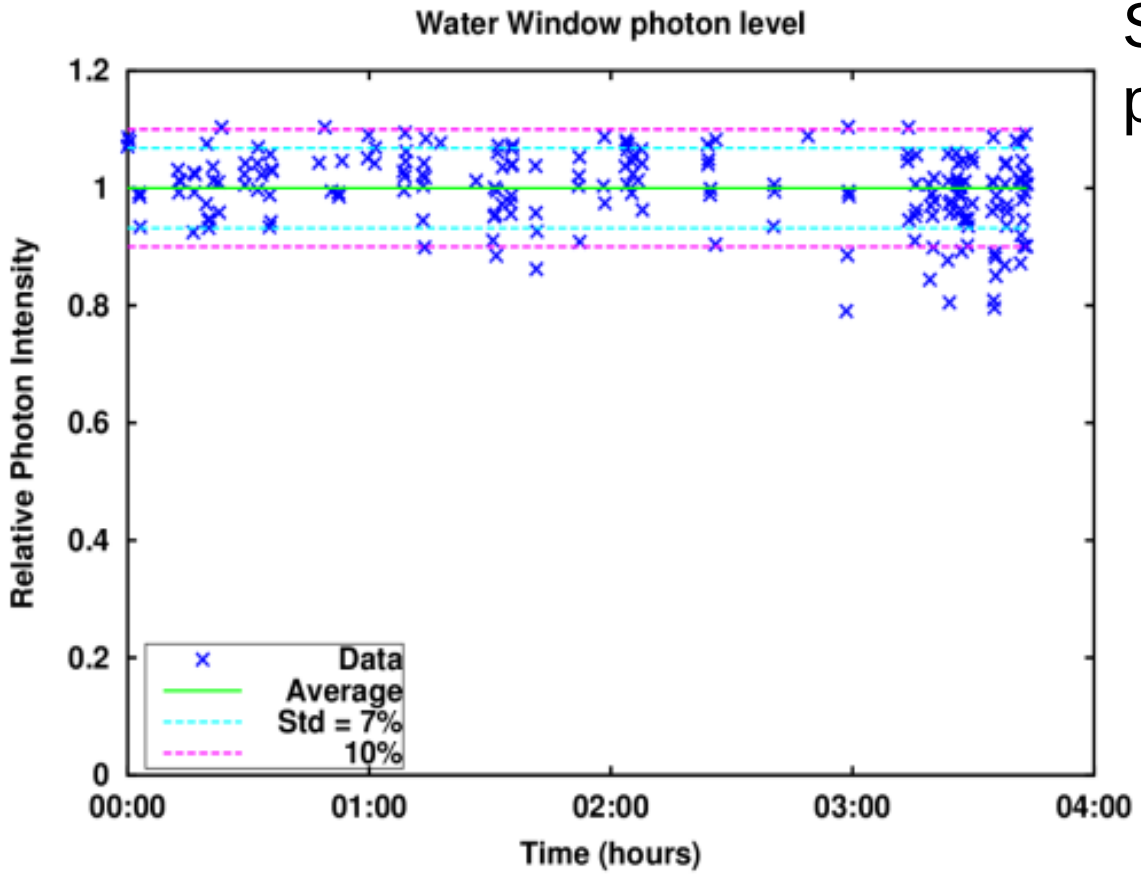
IF focal spot less than 70μm x 70μm FWHM

Focused WW Photons



Intensity at focus is ± 16% with current optic mount

Focused WW Photons

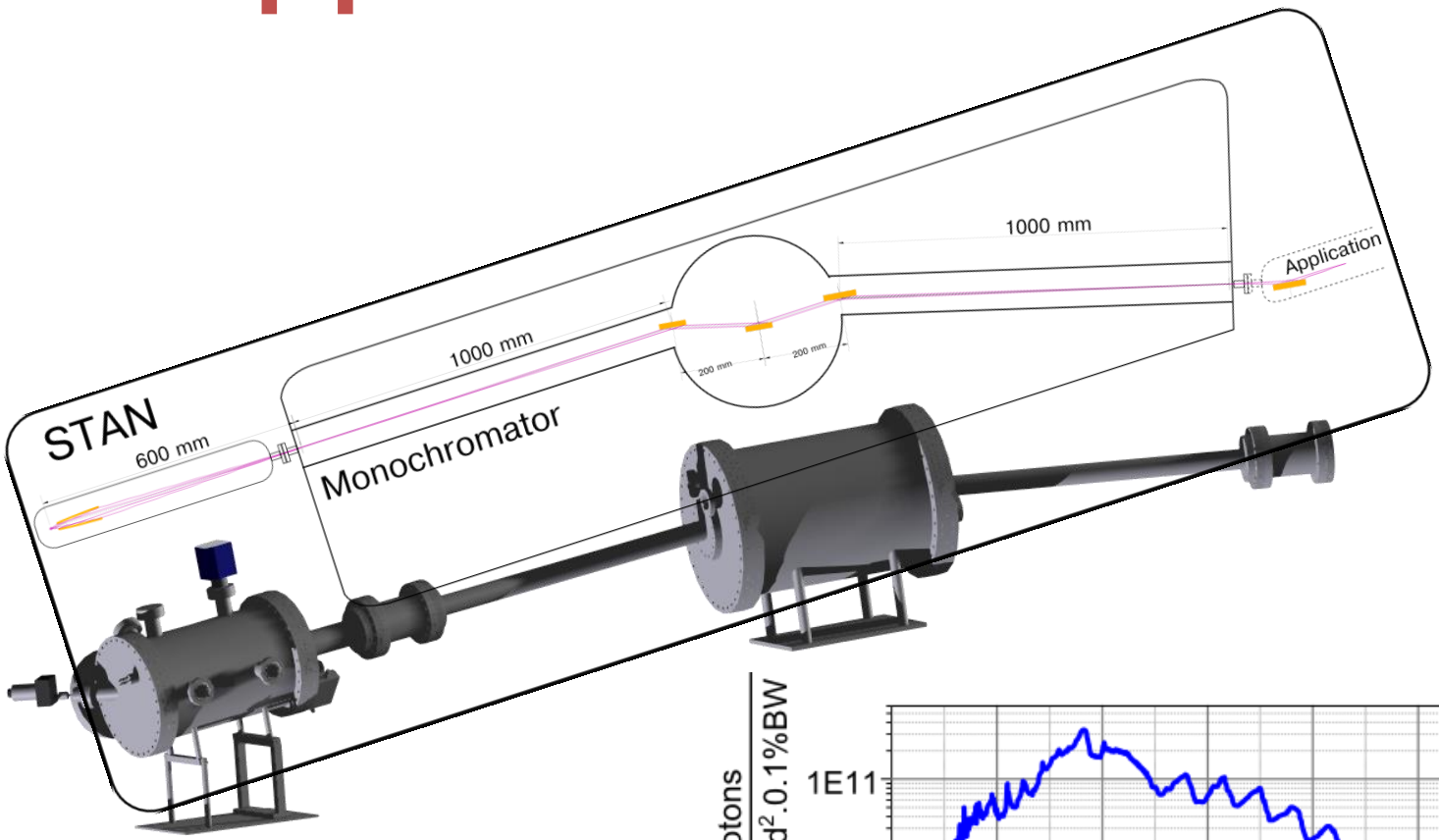


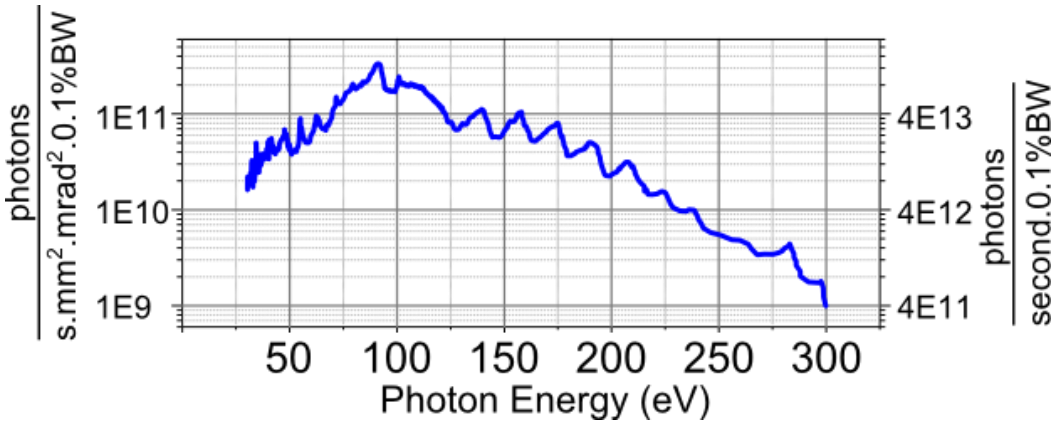
Source Intensity at plasma is ± 10%

An EUV Source @13.5 nm?

- Galinstan Target
- Galinstan Collector
- Clean Output Photons
- Similar or Superior Brightness to WW
- Low Etendue

Application -EUV Beamline





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Thank you!