LLNL Laser-Compton X-ray Characterization

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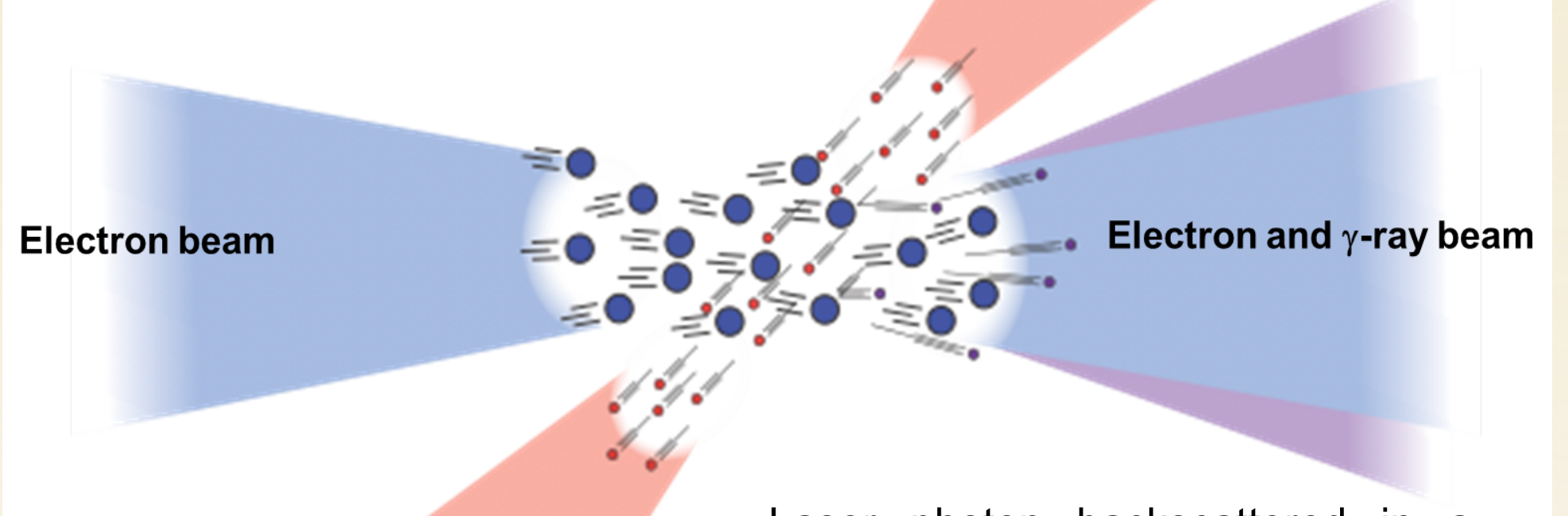
Abstract

Laser-Compton X rays have been produced at LLNL, and results agree very well with modeling predictions. An X-ray CCD camera was calibrated for flux and resolution for characterization of the 30 keV X-ray beam. A resolution test pattern was imaged to measure the source size. K-edge absorption images using thin foils confirm narrow bandwidth and offer electron beam diagnostics.

Laser-Compton X-rays

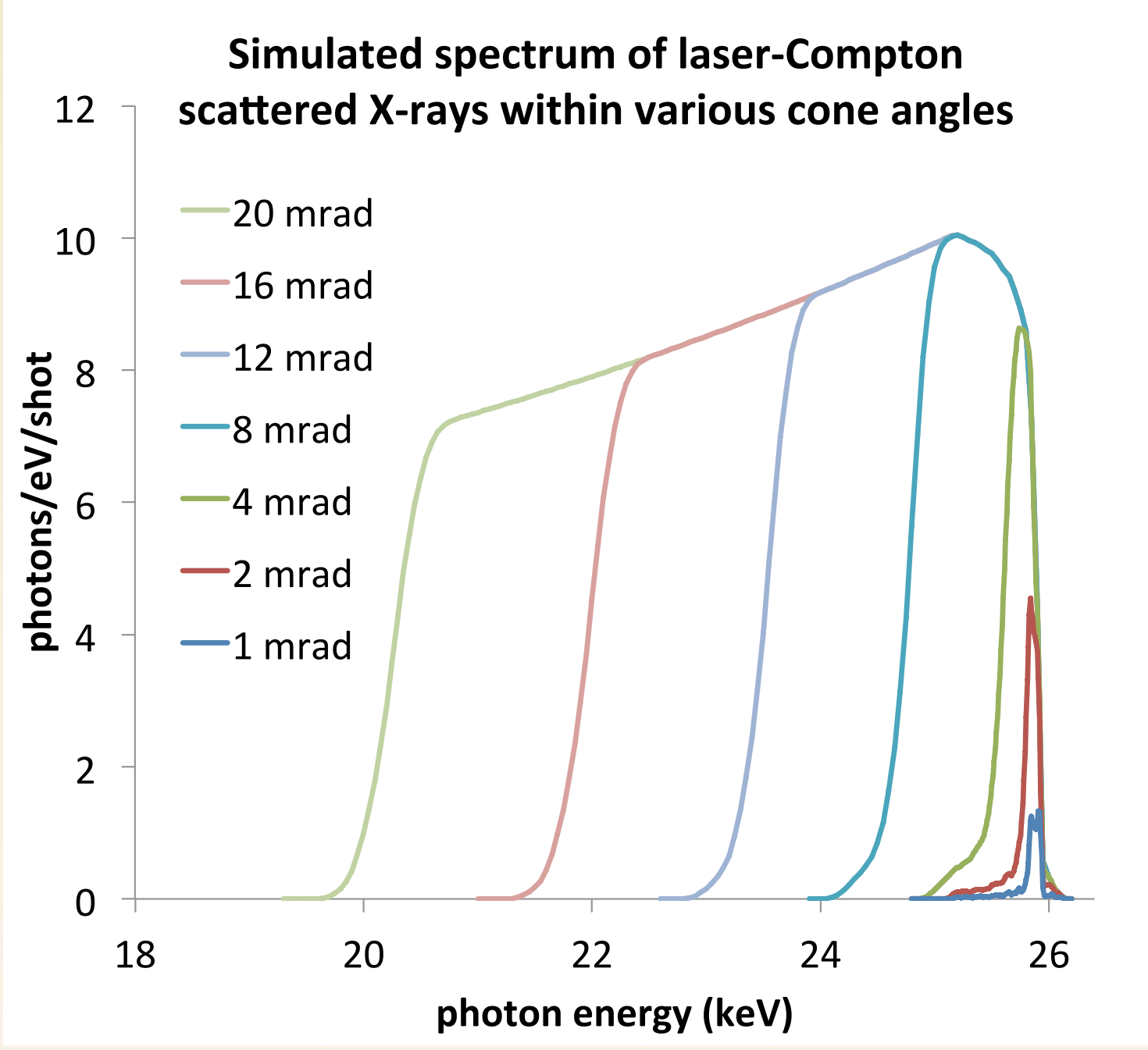
$$E_{scattered} \approx \frac{4\gamma^2}{1+\gamma^2\theta^2+4\gamma k_0 \lambda\!\!\!^{-}_c} E_{laser}$$

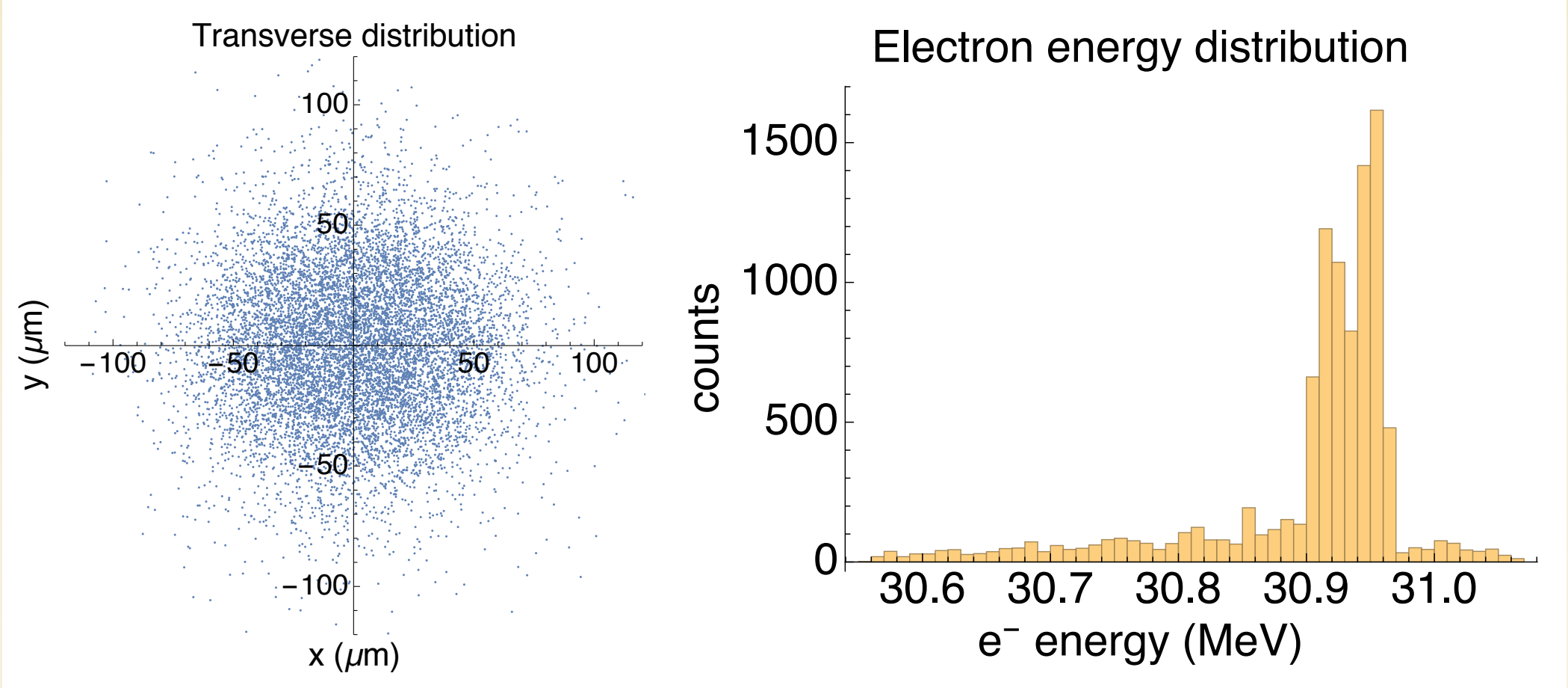


- Laser photon backscattered in a head-on collision with an electron is Doppler-boosted by a factor of $4\gamma^2$
- Undulator wavelength on the order of laser wavelength enables a compact source compared to synchrotrons

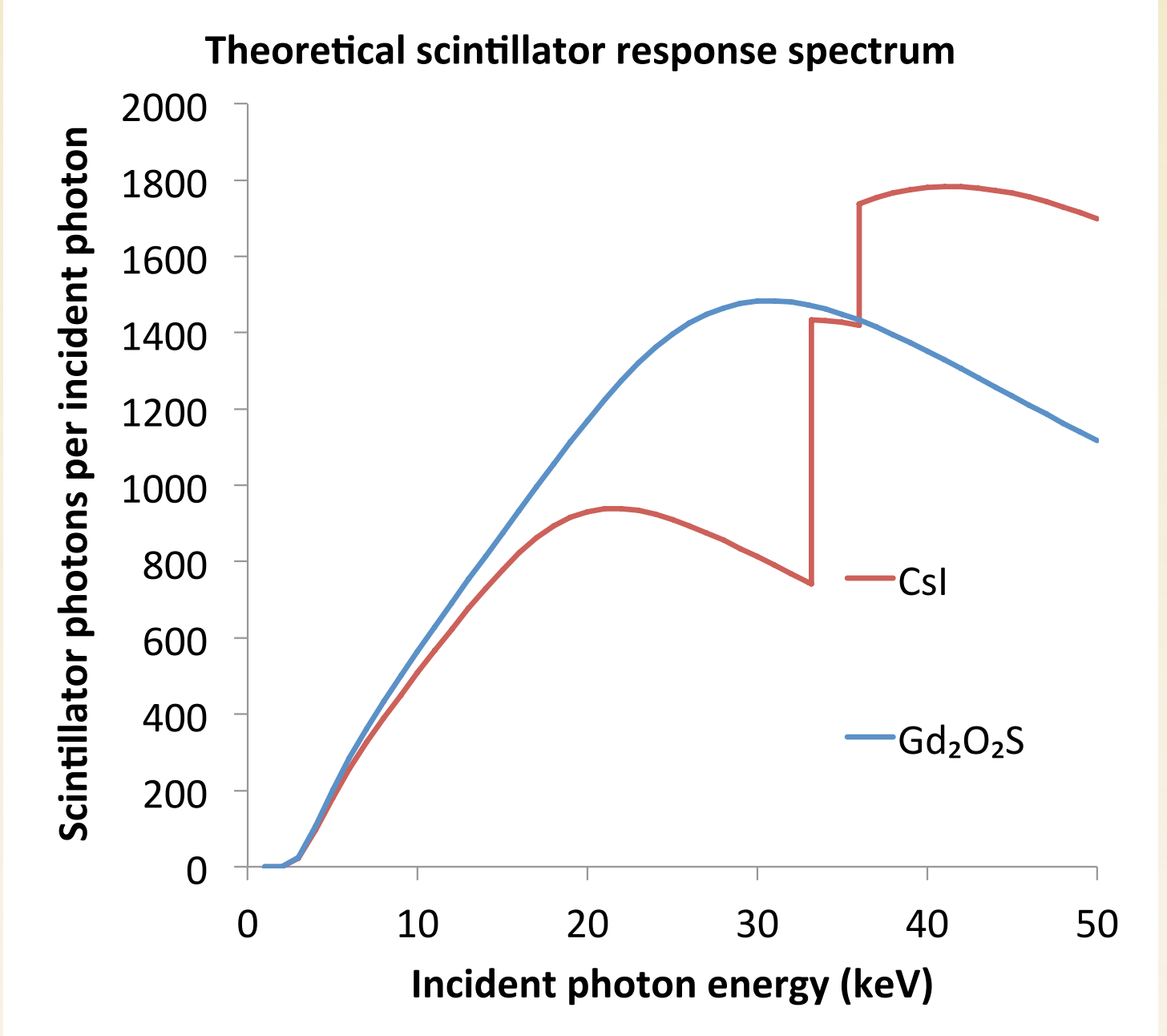
	Current Parameter	Upgrade Parameter	Upgrade Method	Capability
Pulse length	6ns	2ps	Install diode-pumped multi-Joule laser as ILS	>350x flux increase
Laser energy	750mJ	1J		
Repetition rate	10Hz	120Hz		
Bunches per pulse	1 to 4	1000	Install GHz PDL and ILS recirculation	>60x flux increase
Charge per bunch	100pC	25pC		
e^- emittance	0.3µm	0.3µm		
e^- energy **γ energy**	30MeV **34keV**	90MeV **290keV**	Install second section, RF pulse compressor	Dense material radiography
		250MeV **2MeV**	Procure additional RF power and sections	Nuclear Resonance Fluorescence

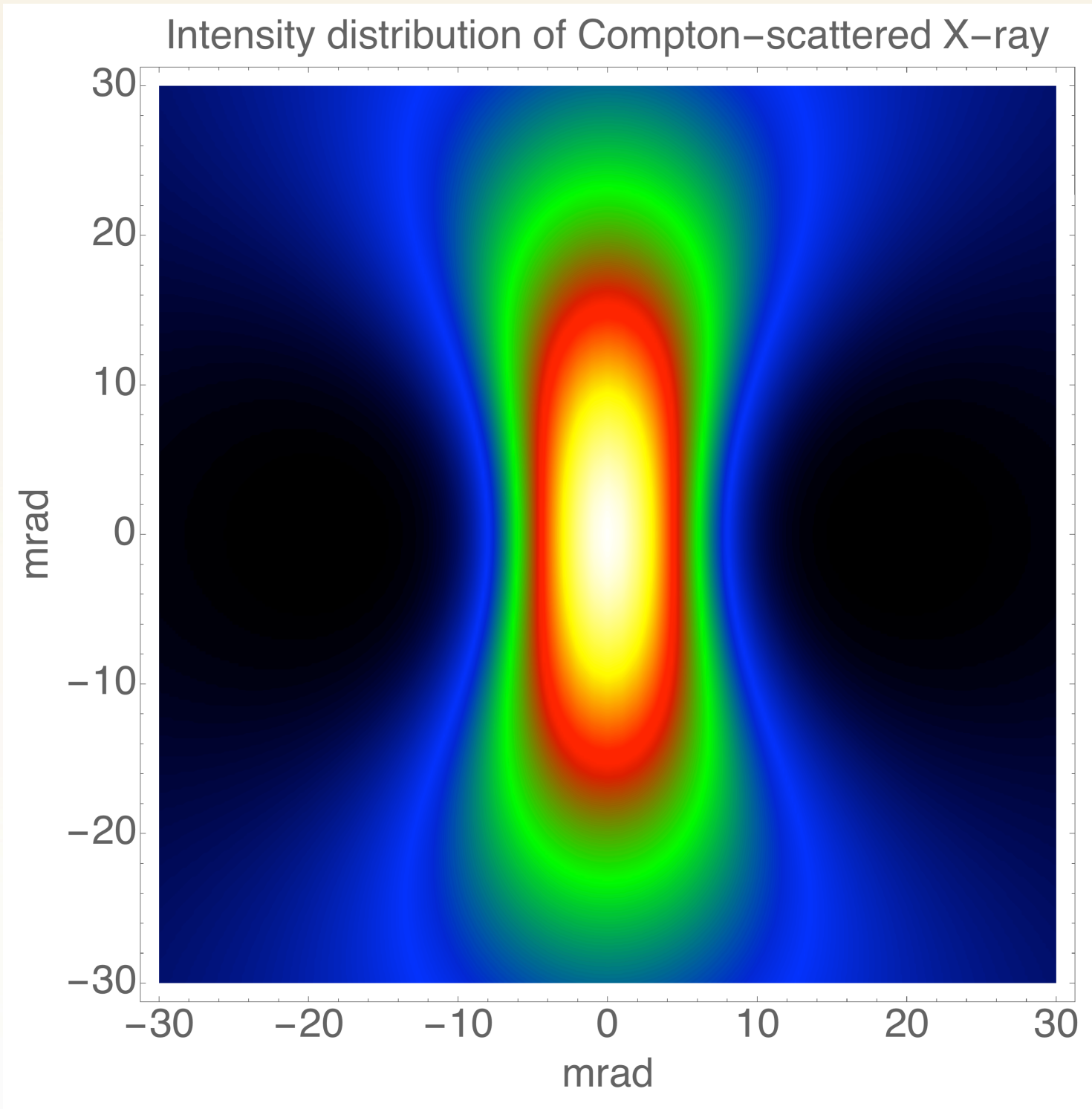
Spectral & spatial modeling of electron beam, X-rays and detection system

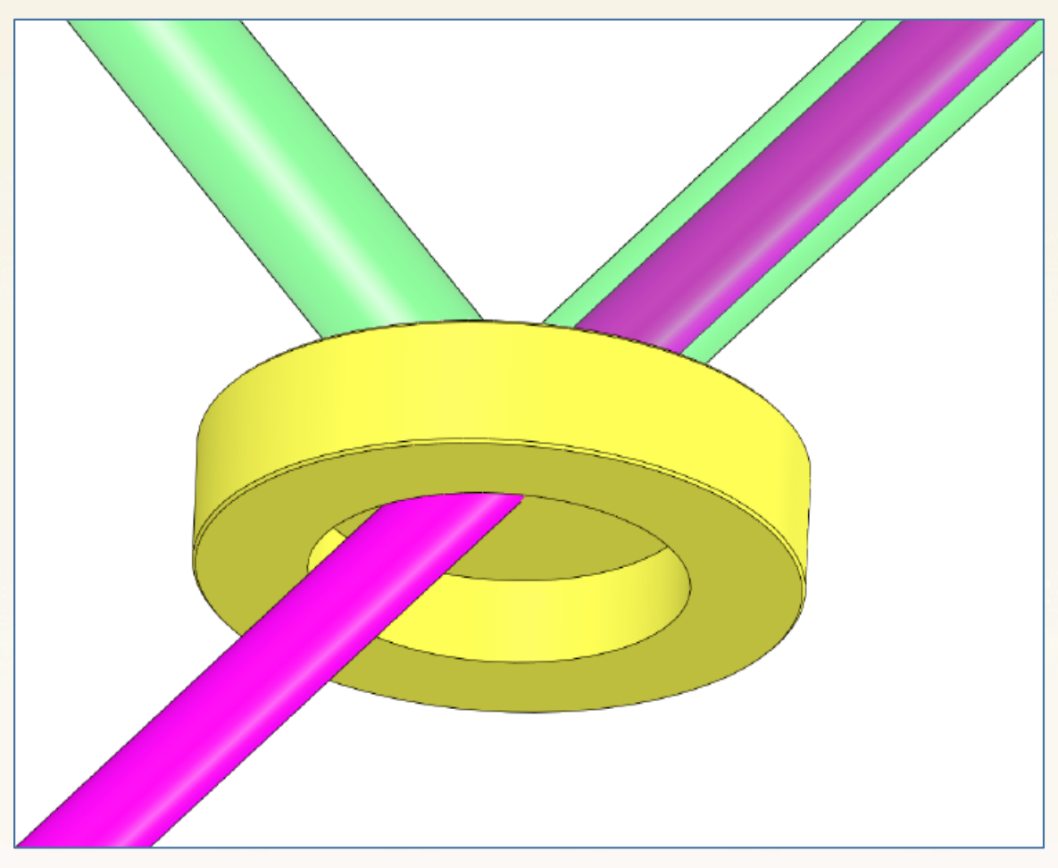




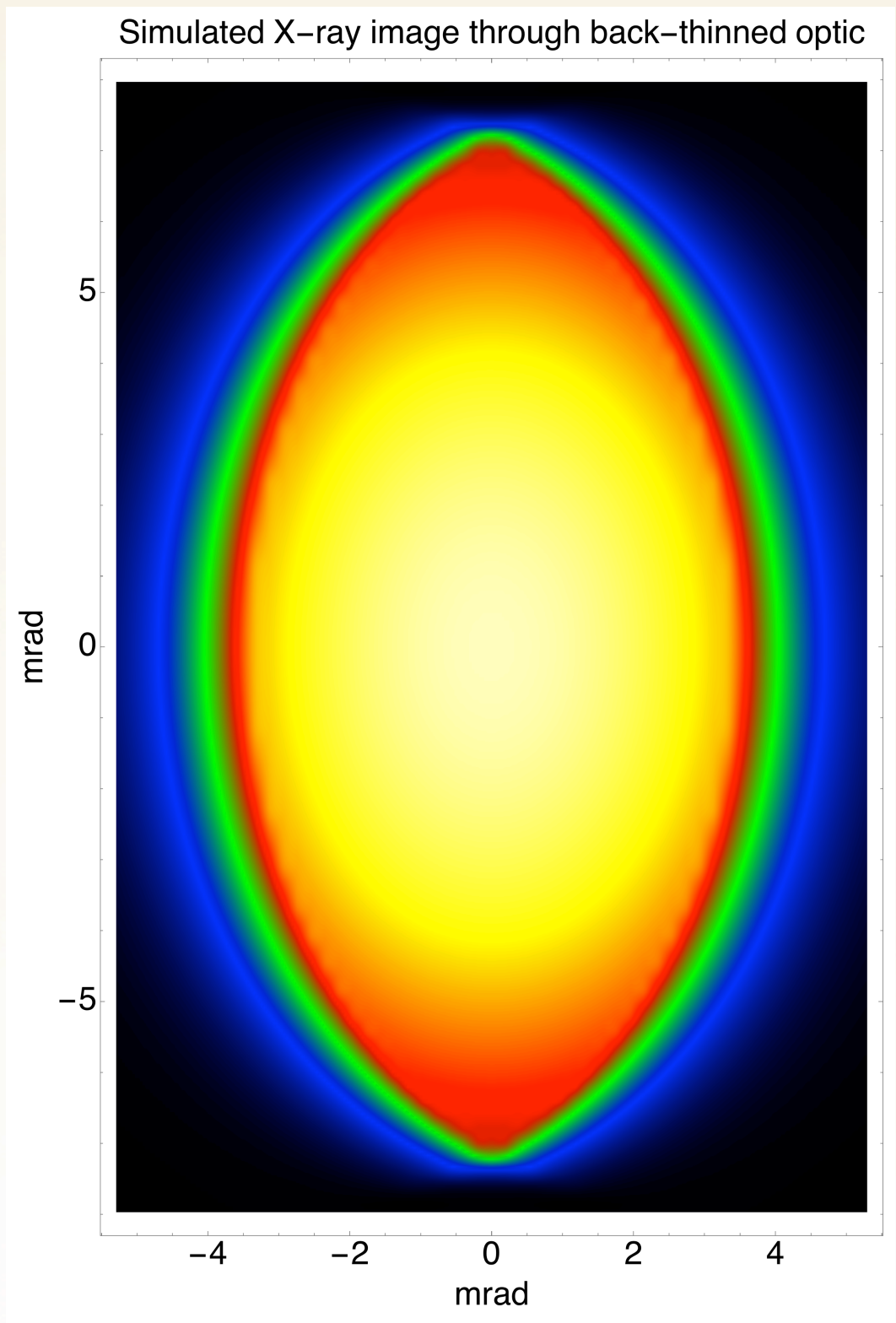
Electron beam was simulated with PARMELA using 10,001 particles. Each particle's Compton scattering cross section with a head-on photon is calculated. Overlap of PARMELA particle and laser is calculated assuming ballistic trajectory and Gaussian beam profile. X-ray spectrum within a cone angle centered on the laser axis can be generated by an analytic code.

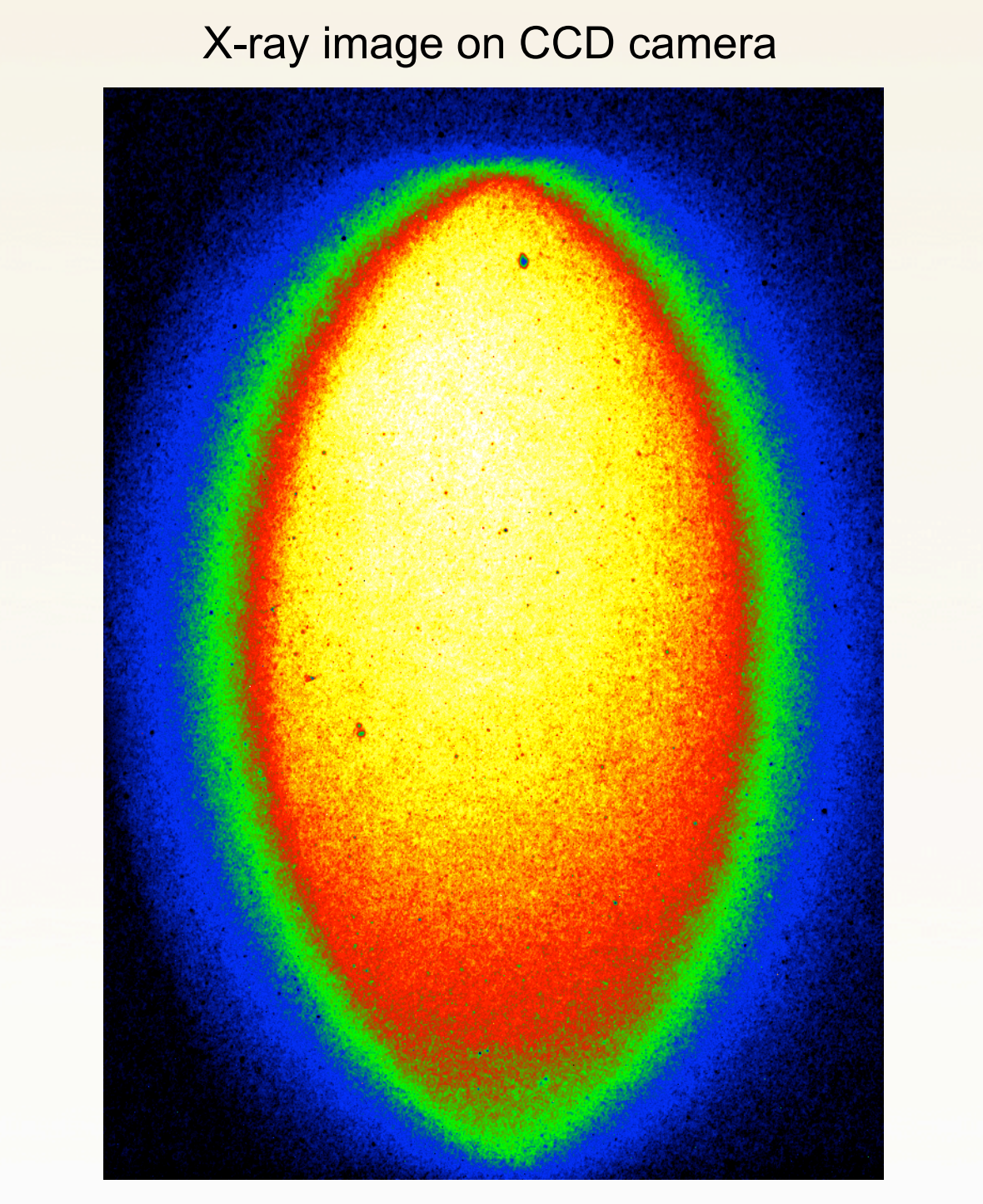




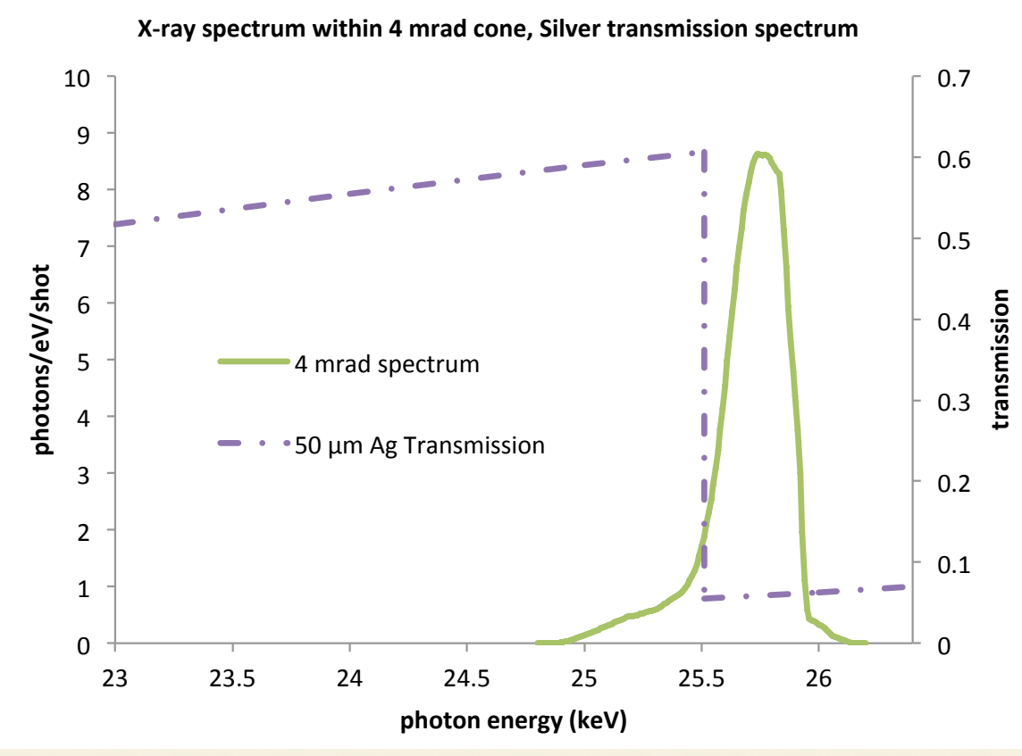


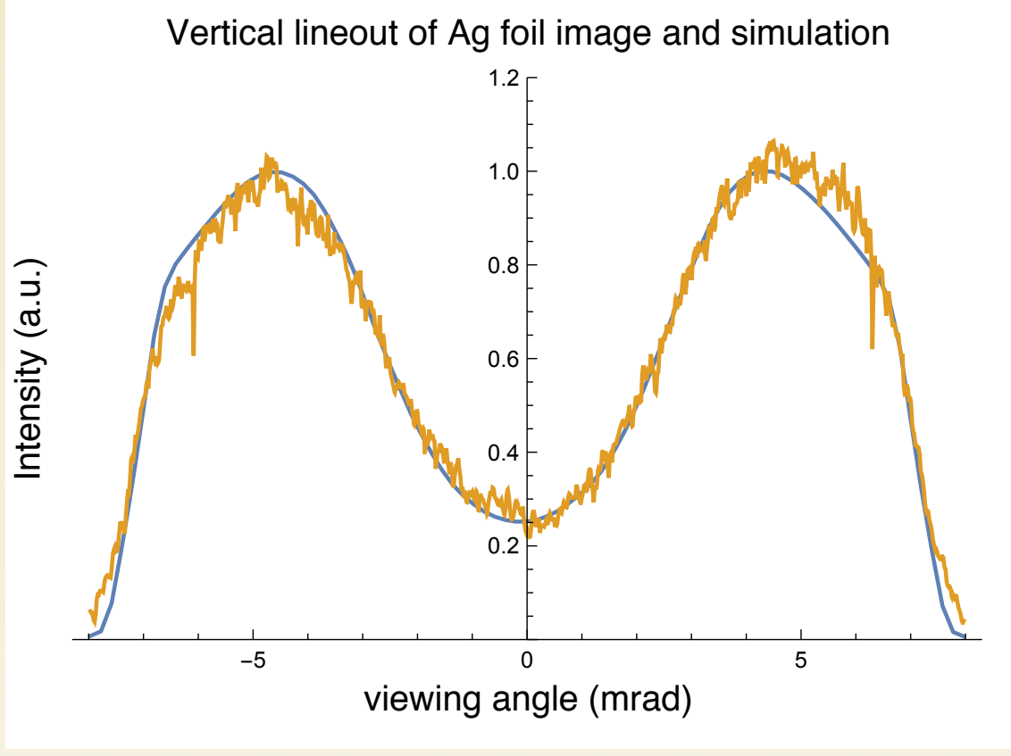
The mirror (yellow) reflecting the laser (green) for head-on collision with electron beam is thinned in the central region to let X-rays (purple) through. Since the mirror is at 45˚ with the X-ray beam, the thinned region creates a football-shaped X-ray window.



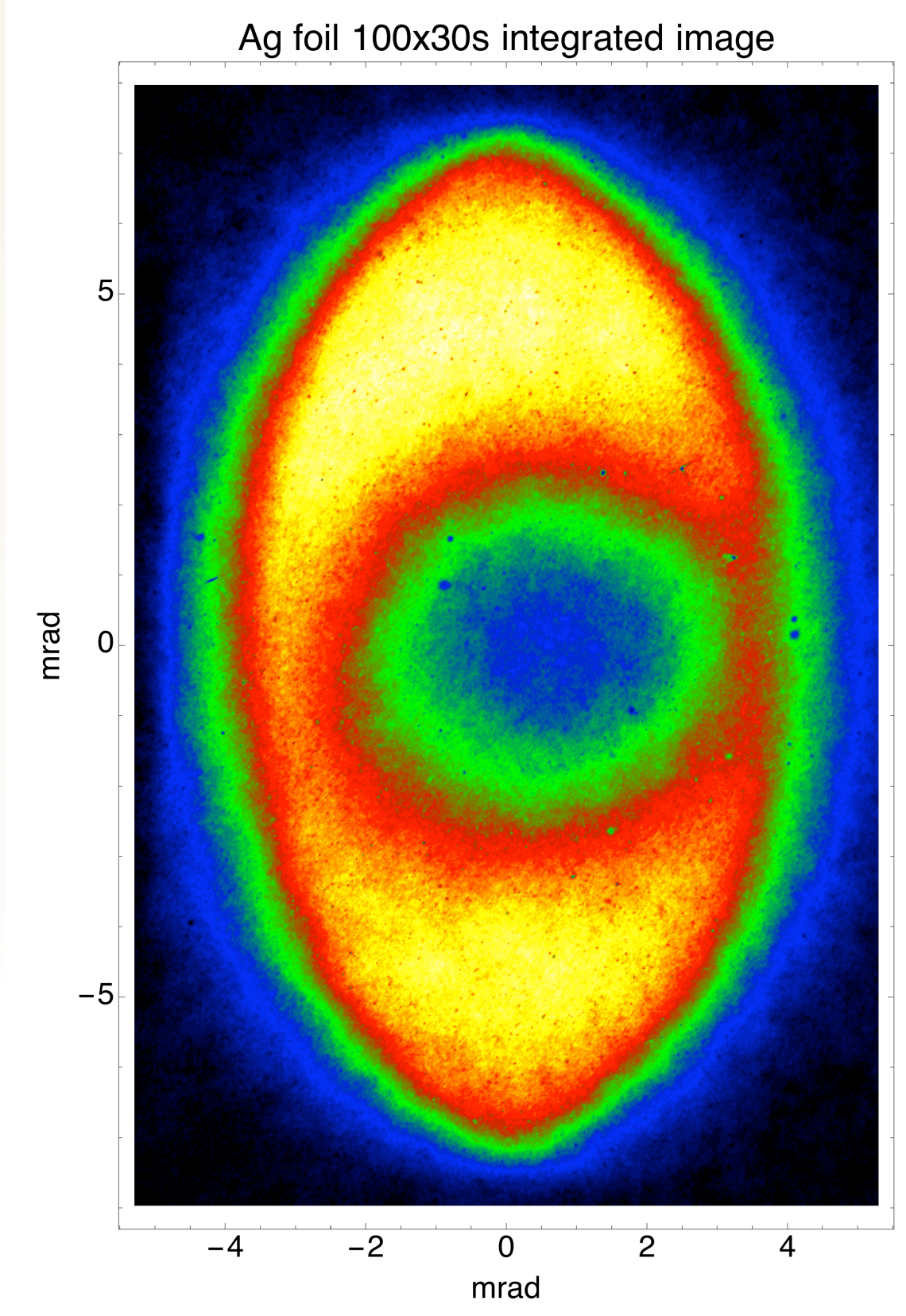


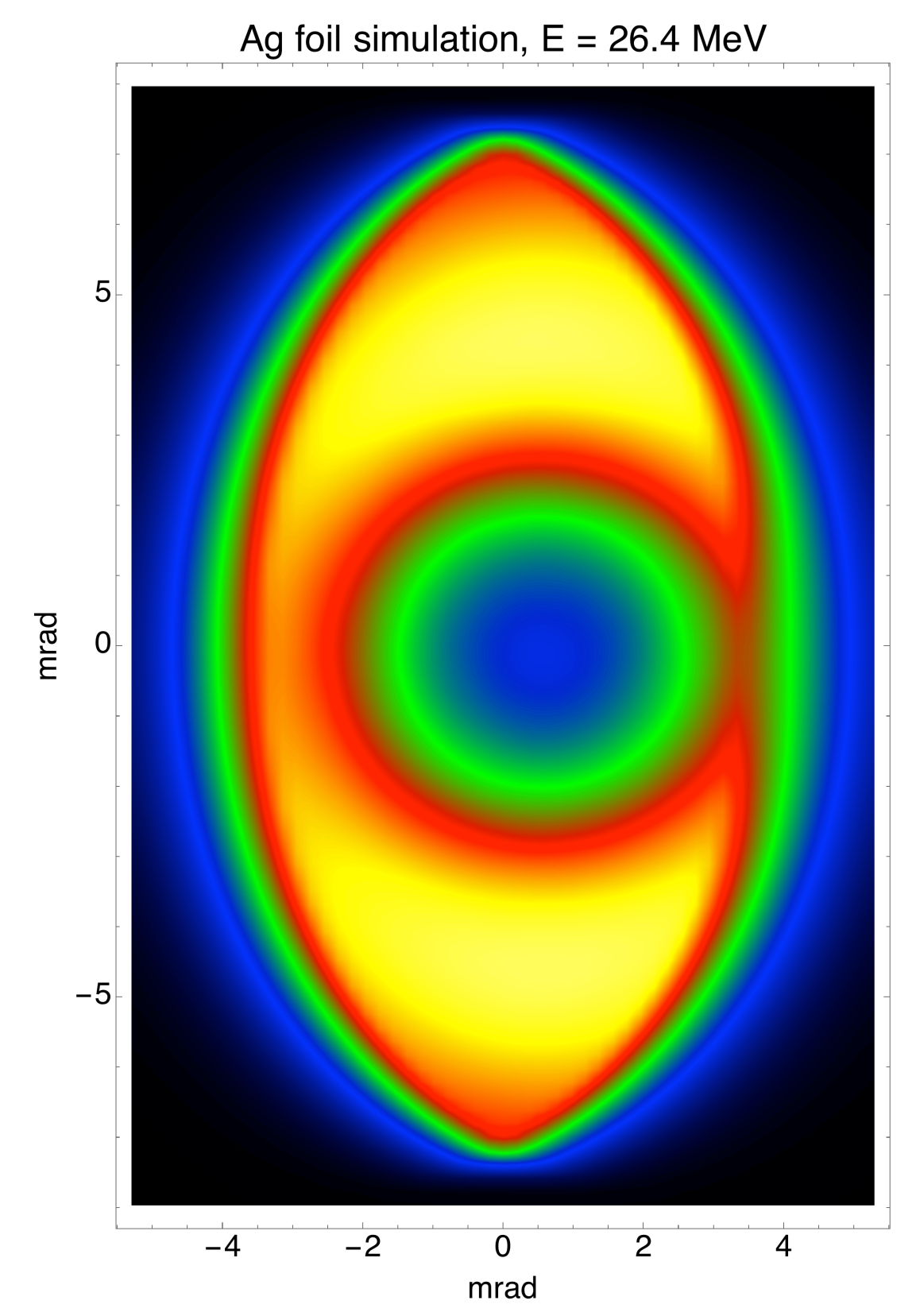
Narrow-bandwidth K-edge absorption



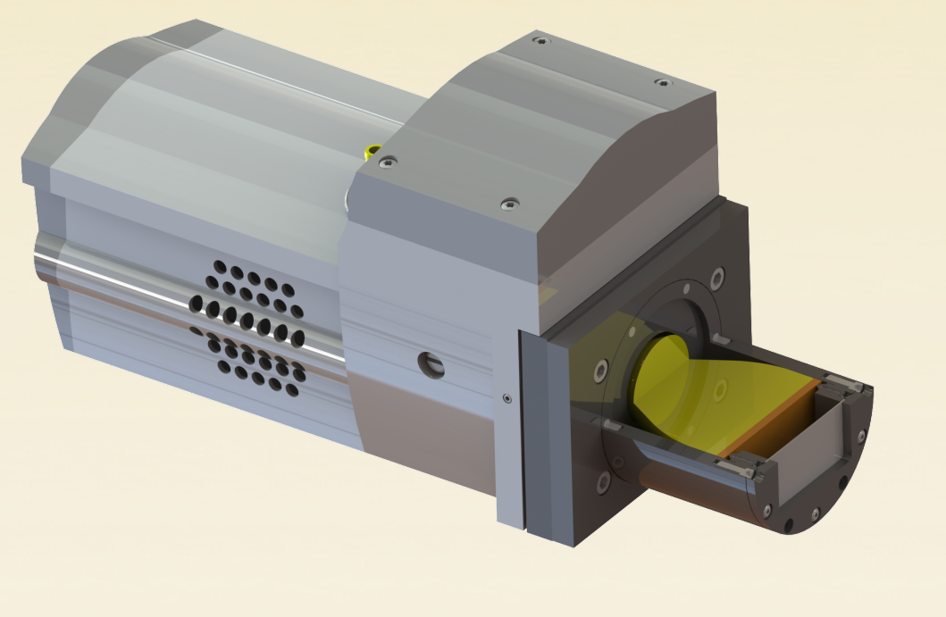


Due to the Doppler shift, photon energy is correlated with scattered angle, with maximum energy in the direction of the electron beam (180˚ backscattering) and decreasing to half of maximum at θ = 1/γ, which also corresponds to the half-angle of the cone within which half of the flux is contained. A thin foil with a K-edge slightly lower than the peak energy can be put in front of the beam to create an absorption hole in the center where the spectrum is strongly attenuated. According to simulations, X-rays from a 26.4 MeV electron beam creates a 4 mrad diameter hole. The hole profile (top right) is highly sensitive to X-ray bandwidth, which in turn is mostly determined by electron beam parameters including energy distribution and angular distribution. Therefore, the shape of the K-edge hole profile is an efficient beam diagnostic.



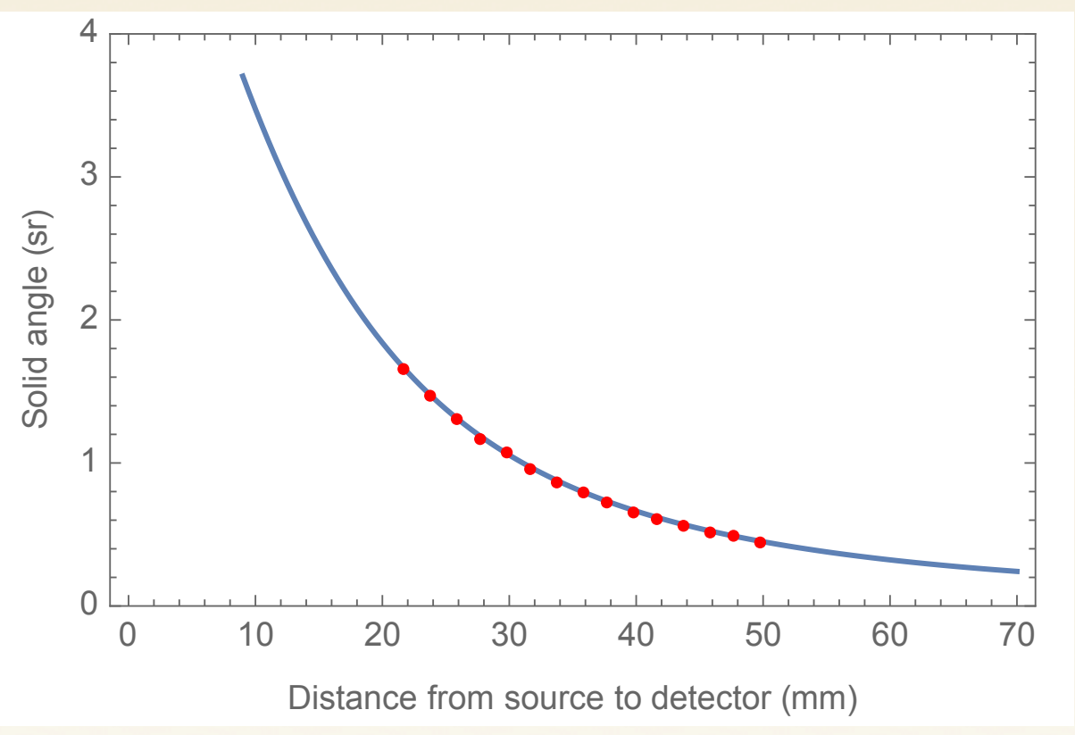


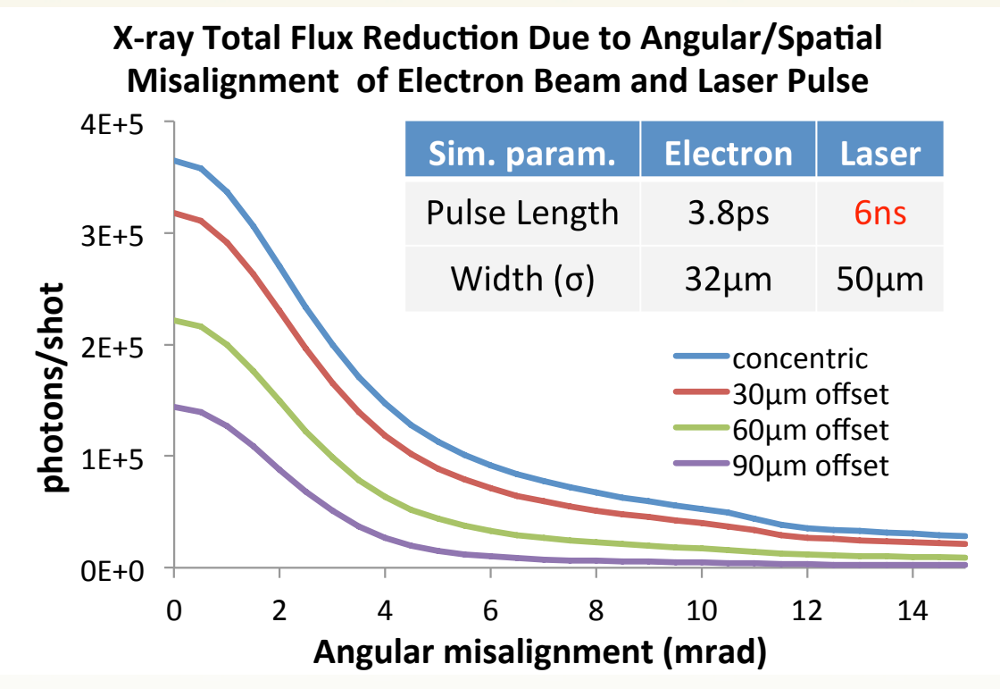
Camera calibration & flux measurement



The Andor X-ray camera is a 1024x1024 pixel 16-bit image intensified CCD camera coupled with a scintillator screen either directly or via a 3:1 de-magnifying fiber taper. We have used CsI(Tl) grown on a fiber plate and a Gd_2O_2S:Tb (P43) phosphor screen as scintillating materials. The front is covered with a Beryllium window to block low energy photons. CCD is thermoelectrically cooled to -20˚C and the imaging area is 40x40 mm.

Both scintillator configurations have been calibrated using a ^{129}I sealed source, chosen for having most of its emission spectra in the 30-40 keV range. Due to the Be window, it is difficult to accurately measure the distance between the scintillator and the source when they are very close. The source was mounted on a translation stage and its intensity as a function of distance was recorded to make a fit to solid angle curve (blue) with offset distance as the free parameter.

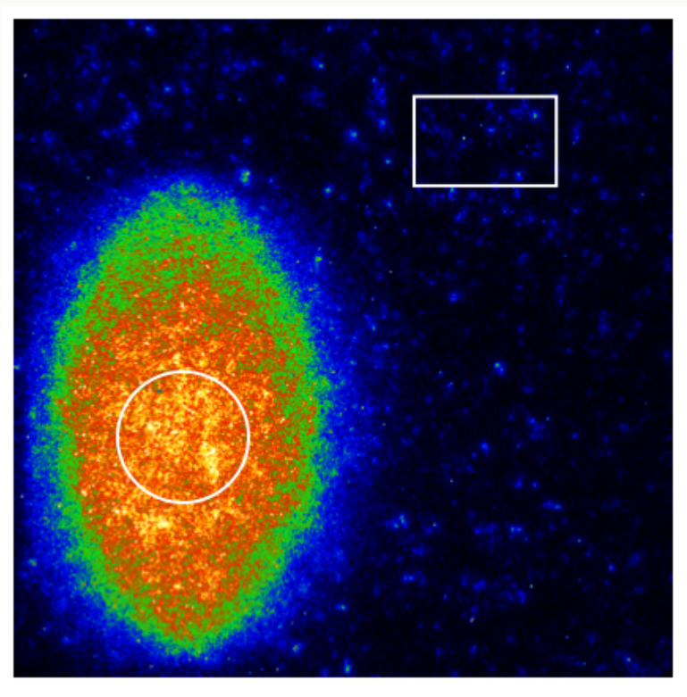




Sim. param.	Electron	Laser
Pulse Length	3.8ps	6ns
Width (σ)	32µm	50µm

Misalignment of the interaction laser with the electron beam is one of the critical factors affecting the flux in the current setup, largely due to the very long laser pulse interacting with a short electron bunch. If a picosecond laser is used, the angular misalignment has negligible effect on the overlap. Spatial misalignment can decrease the flux by half when the two beams are a full beam width apart.

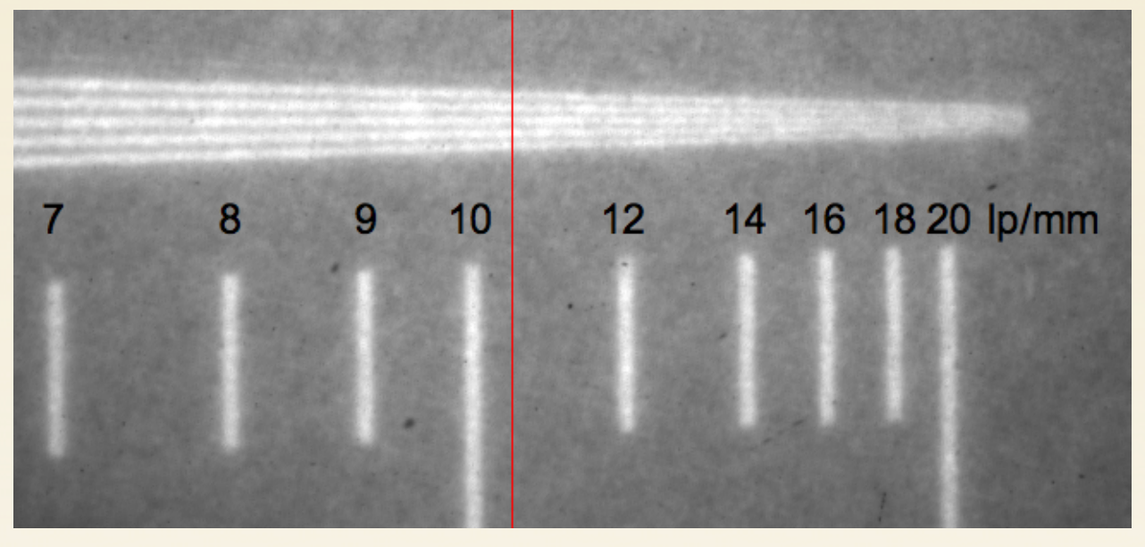
Flux was determined by counting the background-subtracted CCD counts in the central 4 mrad cone region of the beam (white circle) and comparing it to the simulated spectrum taking into account the attenuation by the back-thinned optic, Be windows, absorption spectrum of the scintillator and the calibration factor. Electron bunch charge data for calculating theoretical flux is directly supplied from daily logs. With good alignment, flux matches the theoretical value for the best shots, but low frequency jitter seems to affect the average performance. Shown to the right is a 1 second exposure (10 shot integration) taken with Gd_2O_2S.



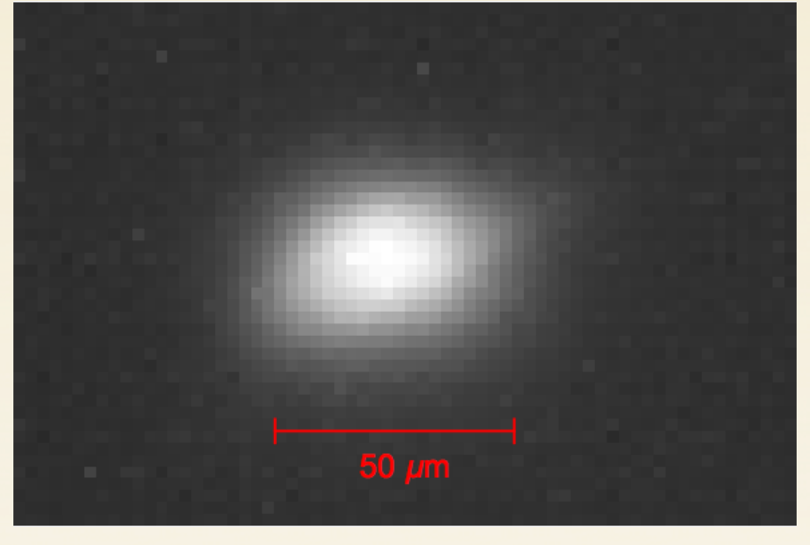
Resolution & source size measurement

Since the source size is estimated to be about the size of the electron beam (13 µm rms), high resolution is critical, and blur in the imaging system must be small and well characterized. A 30 µm thick Pb resolution test pattern with up to 20 line pairs per mm was used to measure the spatial resolution of the imaging system and the source size.

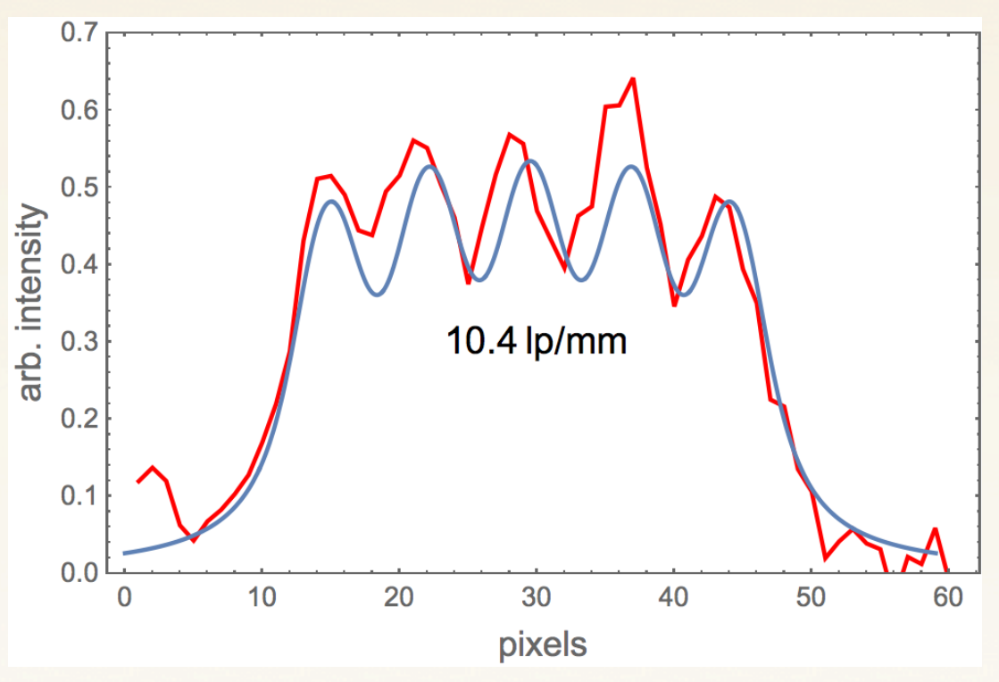
Radiograph of resolution test, no magnification



OTR image of 1,000 e^- beam shots

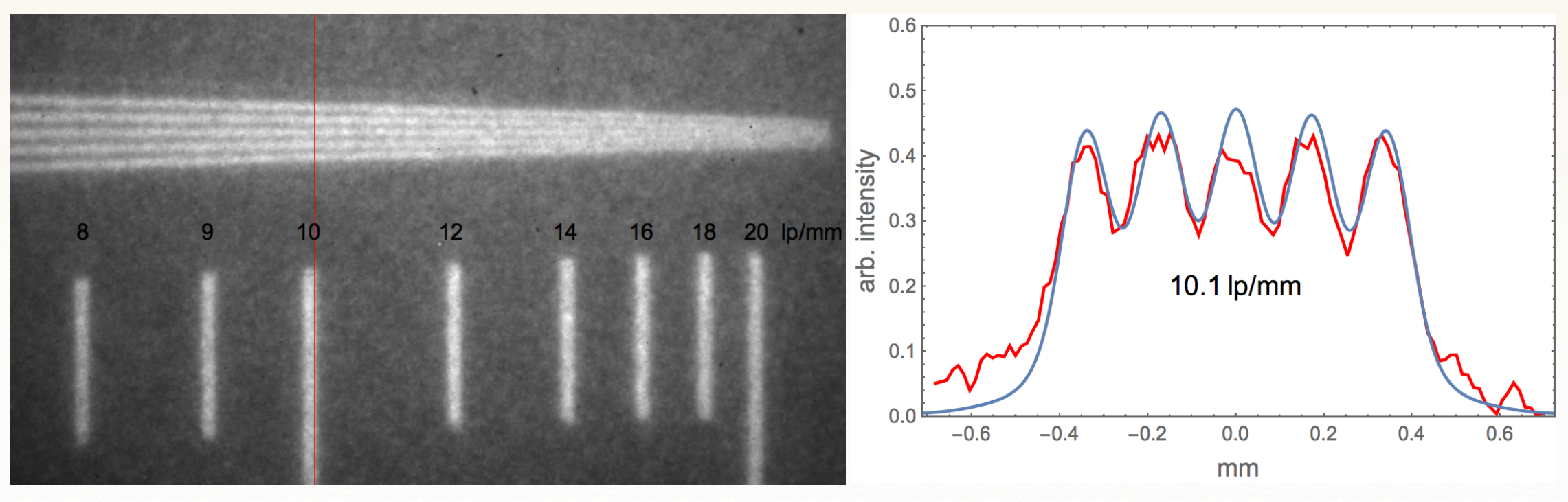


Lineout of test pattern and Cauchy fit



To measure the spatial resolution of the Andor camera, the resolution test pattern was placed as close to the scintillator to give unity magnification and eliminate blur from the source. Scintillator blur pattern has higher kurtosis than Gaussian distribution, so a Cauchy distribution was used to fit the lineouts. The spatial resolution is about 65 µm FWHM. Radiograph shows the resolving limit around 12 lp/mm.

Radiograph of resolution test, 1.7x magnification



For the source size measurement, the test pattern was placed as close as possible to the interaction point so that the pattern image was magnified 1.7x. Blur pattern due to finite source size was found to be very close to Gaussian, so the fit to the magnified image was a Gaussian distribution further blurred by convolution with 65 µm FWHM Cauchy distribution, representing the imaging system blur. Source size is confirmed to be smaller than 100 µm FWHM, and measurement is limited by the imaging system resolution and signal-to-noise ratio.

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