Development of a High-Throughput, High-Resolution, Streaked Kirkpatrick–Baez Microscope for Planar Direct-Drive Experiments on OMEGA

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A High-Throughput, High-Resolution, Streaked Kirkpatrick-Baez Microscope for Planar Direct-Drive Experiments on OMEGA

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A streaked Kirkpatrick-Baez (KB) microscope is being developed for OMEGA to increase the sensitivity and spatial resolution in planar hydrodynamic stability experiments. A four-mirror, metal-coated KB optic is designed to couple to the high-current, PJX streak tube. This design provides up to 3-orders-of-magnitude-higher throughput than a pinhole array/framing camera, mainly due to the mono-layer Ir coating and a grazing angle of 2.1°. This angle has been optimized with respect to the U backlighter spectrum and choice of coating. The spectral window is peaked at 1.5 keV with a FWHM of about 700 eV, thus eliminating the contrast impairment due to U *M*-band emission. It has been shown numerically that the device is capable of registering 2 μm spatial features over a 120-μm field of view. Detailed ray tracing has been used to characterize and optimize the optical parameters, including diffraction response. This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460.

Summary

An advanced Kirkpatrick–Baez x-ray optic has been designed for the next-generation streak camera

UR LLE

- Future planar-foil Rayleigh–Taylor (RT) experiments require high-spatial-resolution diagnostics.
- A new, high-resolution, streaked imager, utilizing the high-current PJx streak camera, is being developed.
- The imager is a Kirkpatrick–Baez (KB) x-ray microscope with better-than-5-μm resolution over a 200-μm field of view and a 2.1° working angle for increased throughput.
- The iridium coating on the KB optic takes advantage of the PJx's large dynamic range.
- The KB optic has been optimized for planar-target hydrodynamic experiments.

Hydrodynamic instabilities in laser-driven targets are seeded by both mass and intensity perturbations

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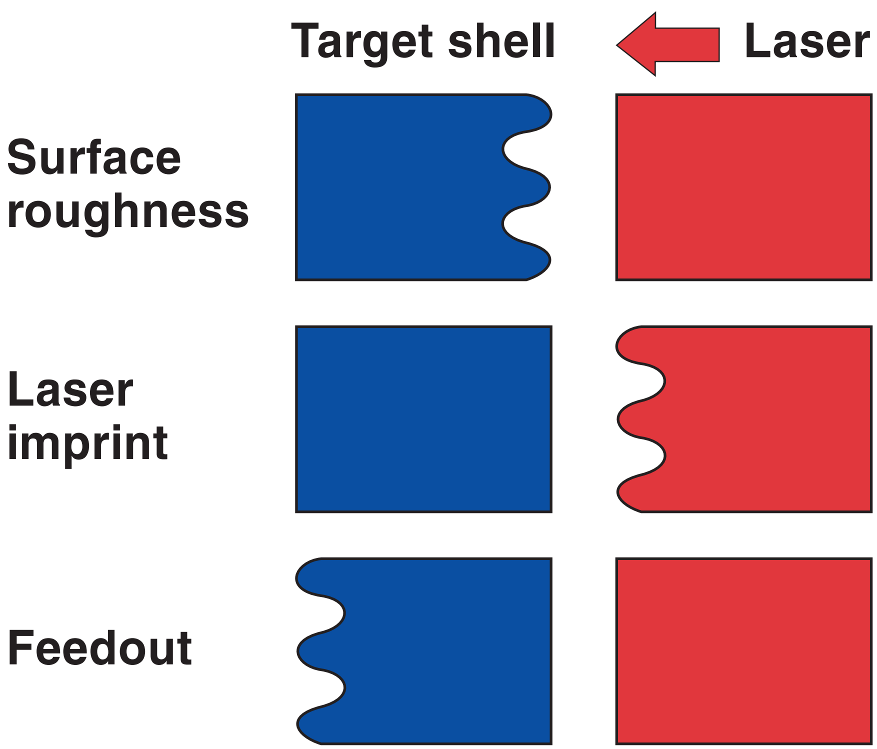
- Perturbations on the shell surface, seeded by different factors, are amplified by hydrodynamic instabilities and disrupt the shell integrity.



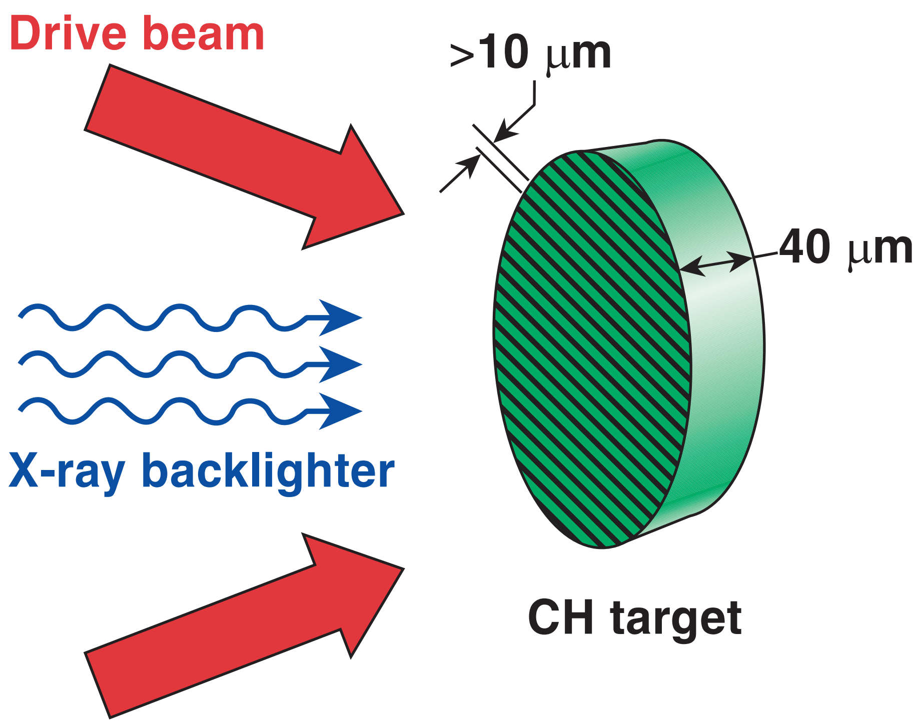
Seed mechanisms

- Target-surface roughness (preimposed perturbations)
- Laser imprint
- Feedout—effective at shock breakout

E10558

The observation of short-wavelength (down to 10 μm) modes is an experimental challenge that demands high resolution

- The evolution of short-wavelength mass perturbations in planar ICF targets is studied through face-on, x-ray radiography.



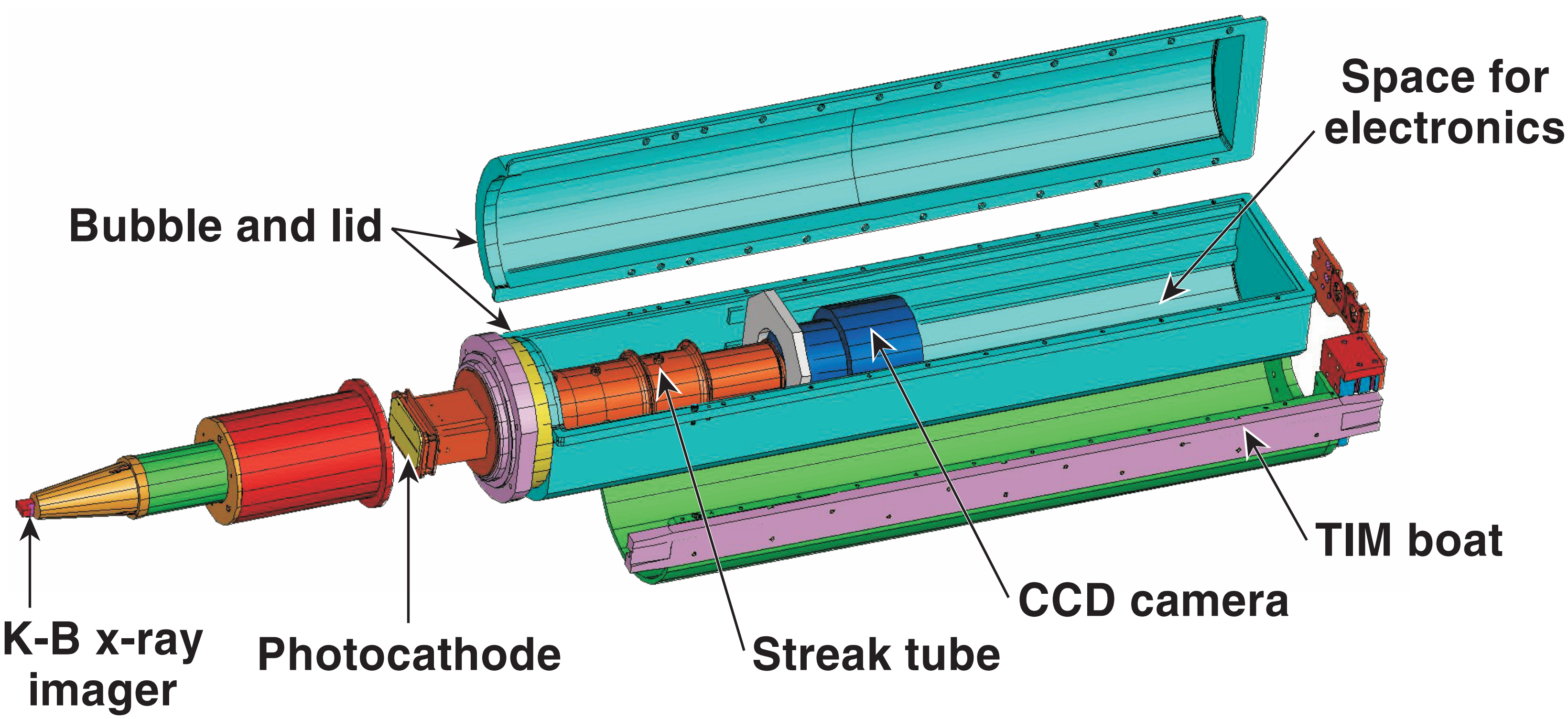
- Uranium source produces the backlighting x-rays.
- Surface corrugations on the front surface of as much as 40-μm-thick planar CH target.
- Spatial features with less-than-10-μm size must be resolved.

E10559

Grazing-incidence x-ray optics with a large collecting angle will be coupled to a high-dynamic-range streak camera

- Current x-ray pinhole framing cameras provide insufficient throughput to diagnose mass perturbations on 40-μm (or more) -thick CH foil.
- The front-end of the apparatus is a Kirkpatrick-Baez microscope with metal-coated mirrors.
- The detector is a high-current streak tube (PJx), coupled directly to a high-resolution CCD.
- KB resolution is ~3 μm on axis (6$\times$ magnification).
- The PJx has a PSF with a FWHM of 18 μm. A magnified image will be registered at the PJx photocathode.

The PJx streak tube mounted in a hermetically sealed air bubble is the prototype of a new style of TIM-based x-ray diagnostic



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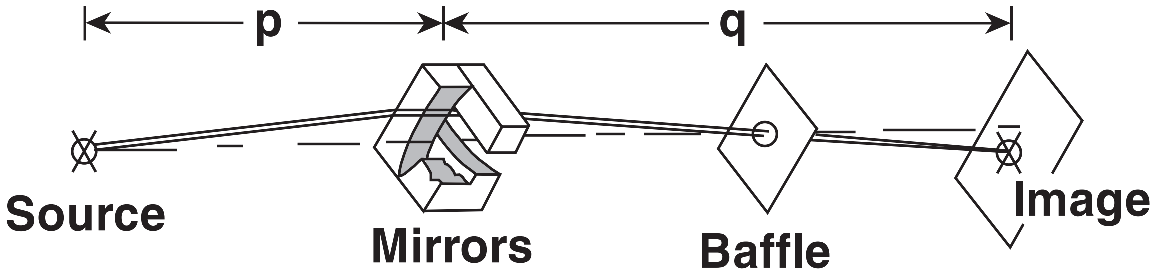
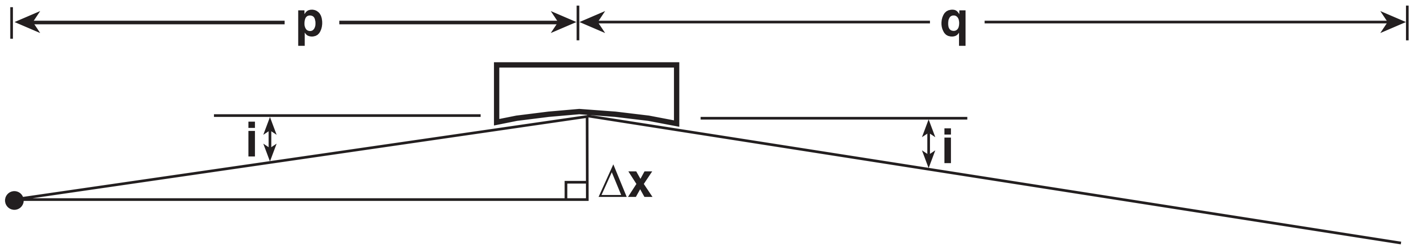
X rays undergo grazing incidence from two perpendicular mirrors to form a 2-D image



p = source distance
q = image distance
i = angle of incidence
$\Re$ = mirror radius

$M = \frac{q}{p}$ = magnification

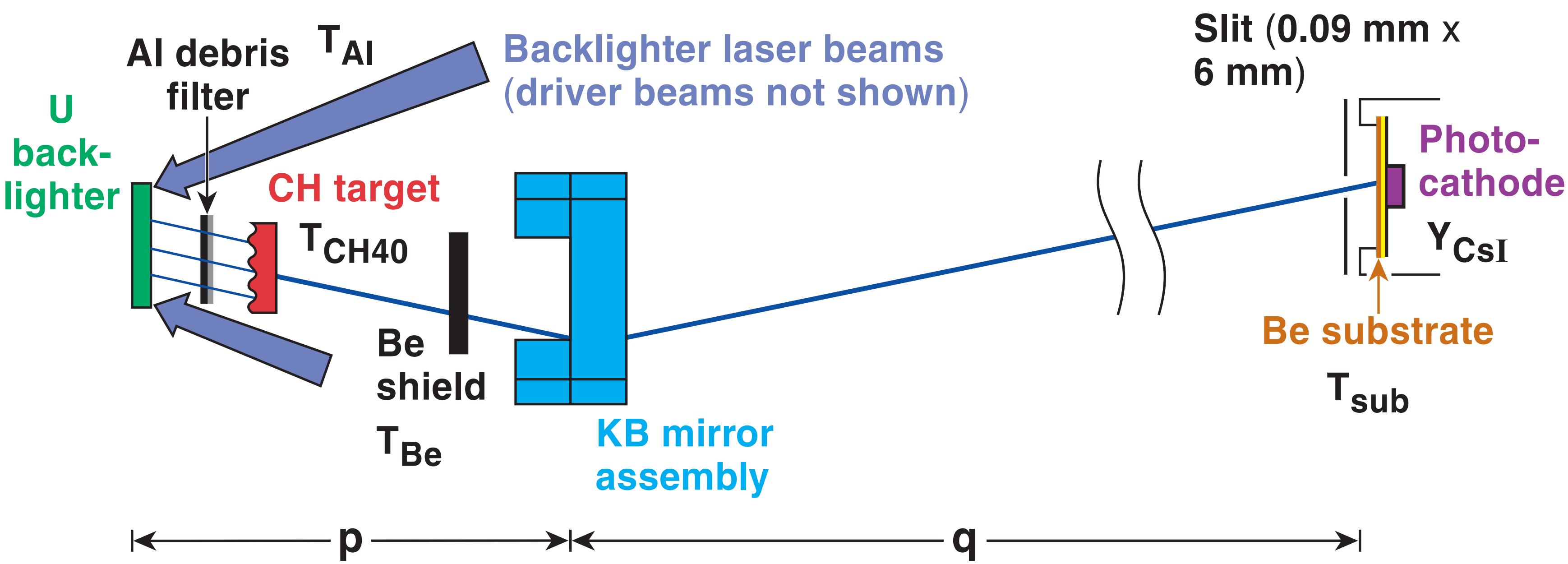


- The mirror foci (for the tangential rays) are matched at the image plane by a slight variation of the mirror spacing Δx (grazing angle).
- The optimal resolution at a certain x-ray energy depends on the working distance and incidence angle.

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} = \frac{2}{\Re \sin i} \cong \frac{2p}{\Re \Delta x}$$

$$R_{opt} \sim \left(\frac{p\lambda^2}{i}\right)^{1/3}$$

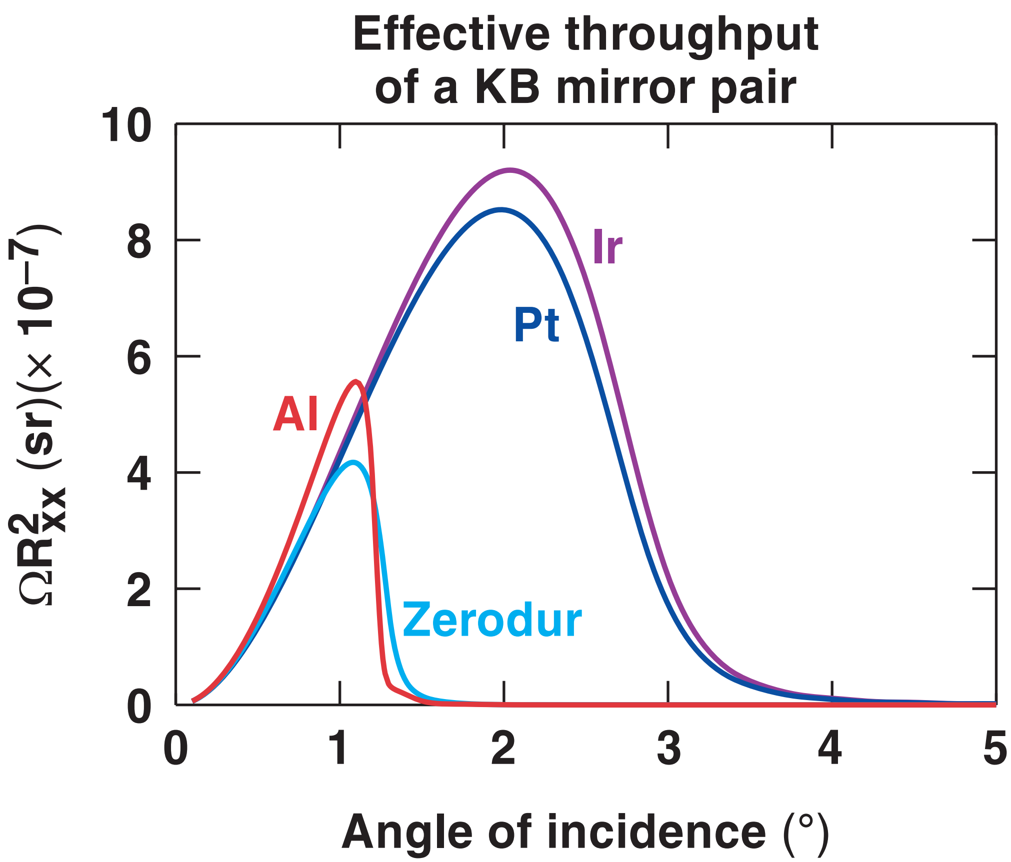
An optimal magnification that accommodates the resolution requirements and the size of the CCD detector is provided by the chosen geometry



- 6× magnification at current configuration
- Projected resolution of better than 5 μm over a 200-μm field of view.
- The radius of curvature for each concave mirror is $\mathfrak{R}$ = 4250 mm.
- f = 77.5 mm, p = 90 mm, q = 560 mm

E10562

Optimal throughput depends on the grazing angle and the coating material



Ω = solid angle (sr)

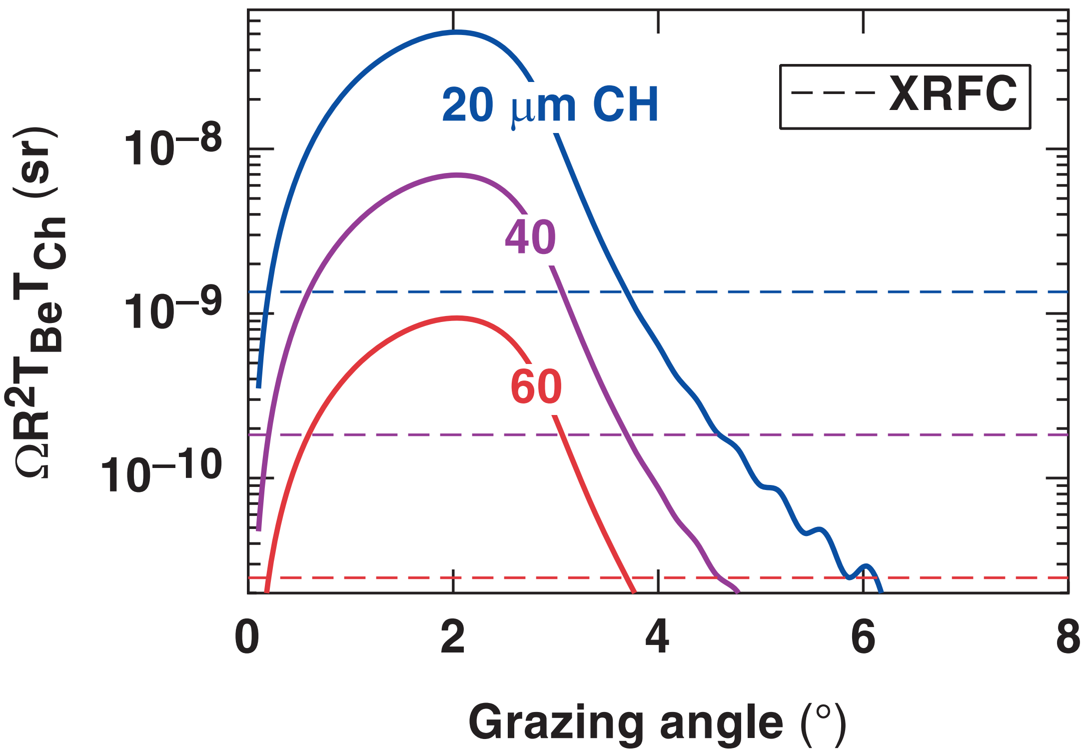
R_{xx} = material reflectivity at 1.4 keV

- Optimal:
  - Zerodur glass substrates with surface roughness < 2 Å rms, coated with 500 Å Ir.
  - Angle of incidence i = 2.1°.

E10563

Improvements in throughput over the current diagnostics are due to the higher collection angle

Throughput characteristics of KB optics at 1.4 keV-x-ray energy



- Comparison of the microscope with a gated pinhole array (XRFC) shows a solid angle improvement of two orders of magnitude at the optimal angle of incidence.

Ω = solid angle (sr)

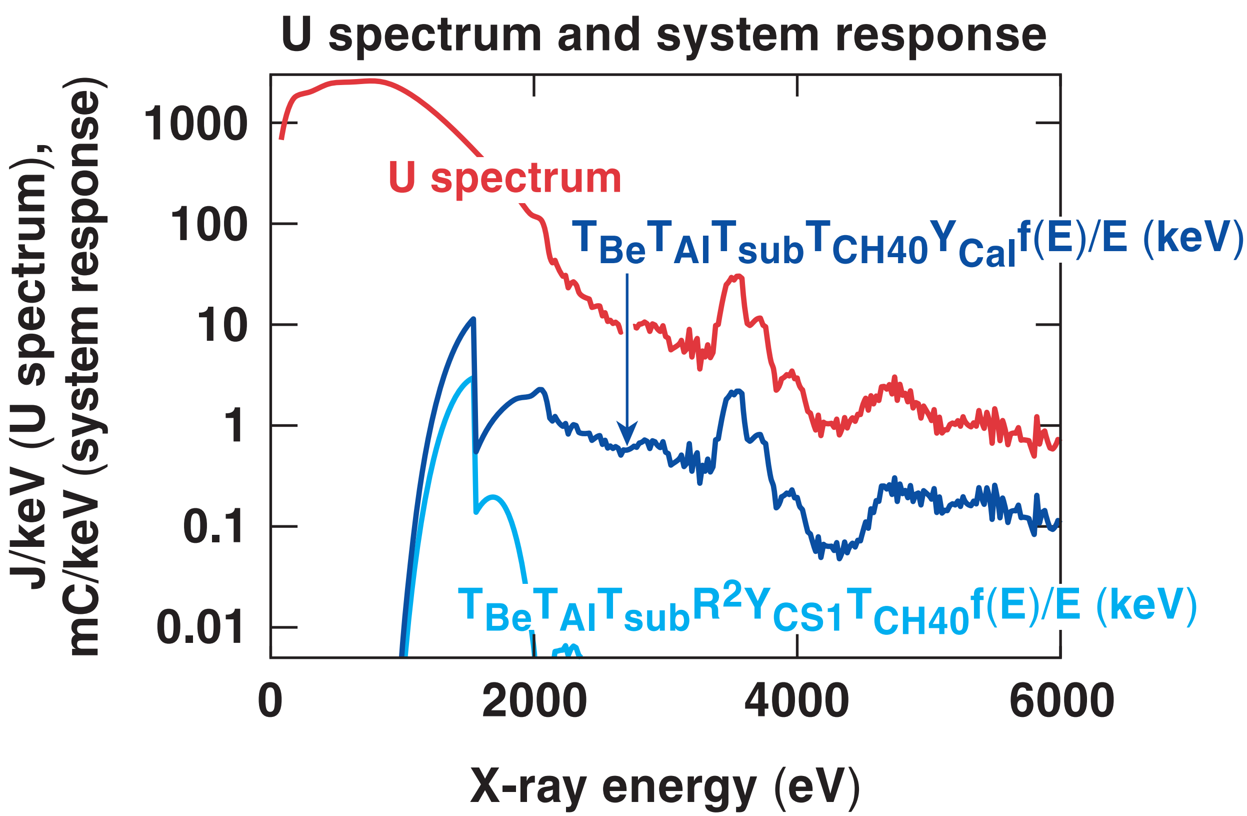
R = Ir reflectivity at 1.4 keV

T_{CH} = Ch target transmission

T_{Be} = Be filter transmission

E10564

The high-energy cutoff in the Ir reflectivity prevents the uranium M-band from being detected



$f(E) =$ U spectrum (J/keV)

$R =$ Ir reflectivity

$T_{CH} =$ CH target transmission

$T_{Be} =$ Be filter transmission

$T_{Al} =$ Al filter transmission

$T_{sub} =$ substrate transmission

- The coupling of the spectral responses of all the components results in a 700-eV FWHM spectral window.
- A high energy cutoff at ~2.4 keV exists for the Ir reflectivity:

$$E_c = \frac{eh}{i}\left(\frac{\pi m_e}{n_e}\right)^{-1/2}$$

E10565

The current induced by hard x rays is limited by the mirror cutoff at high energy

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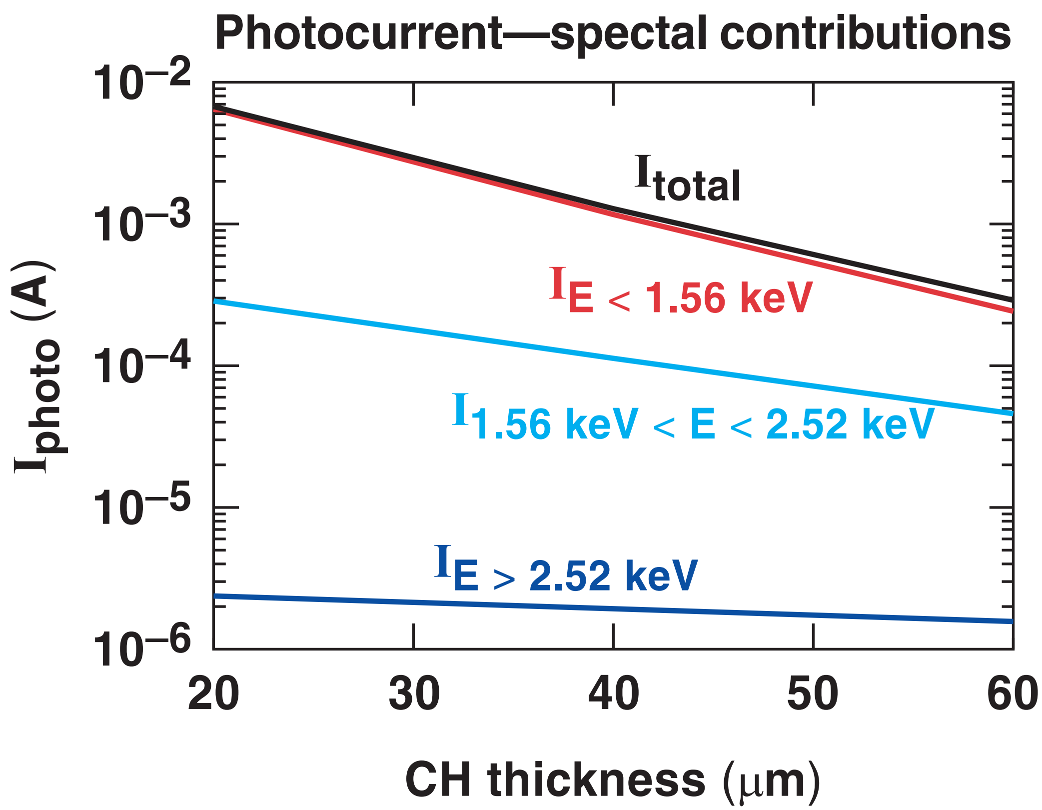
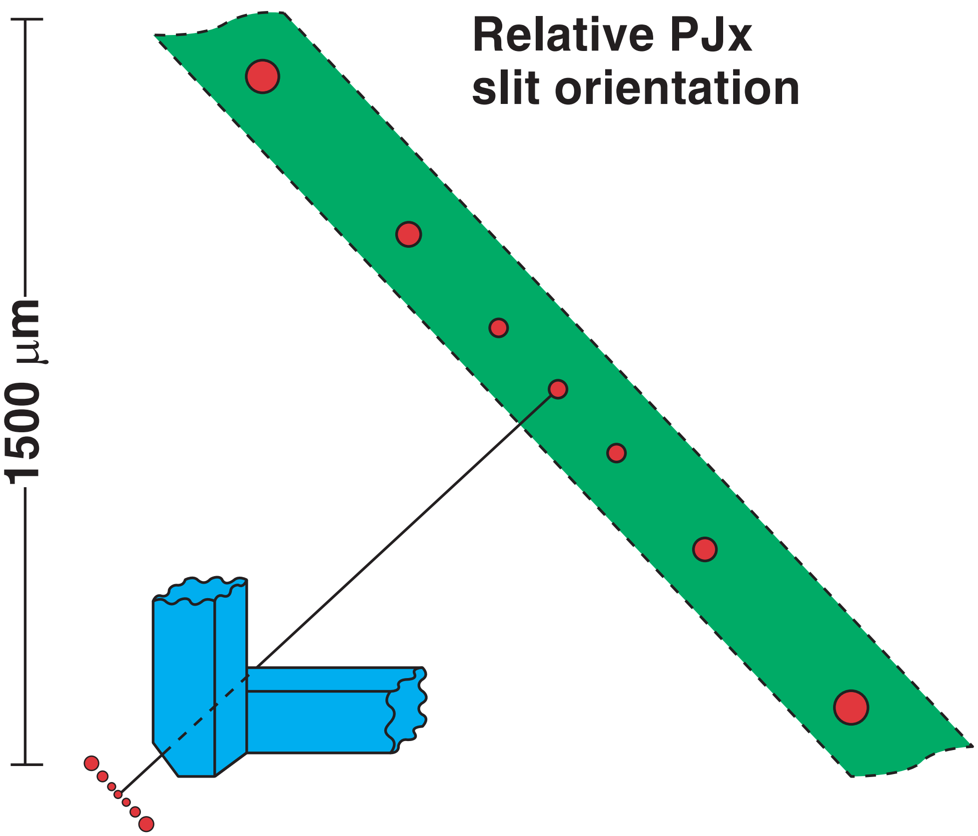


- **Spectral partitioning of the PJx current shows no contrast impairment due to hard-x-ray-induced photocurrent.**

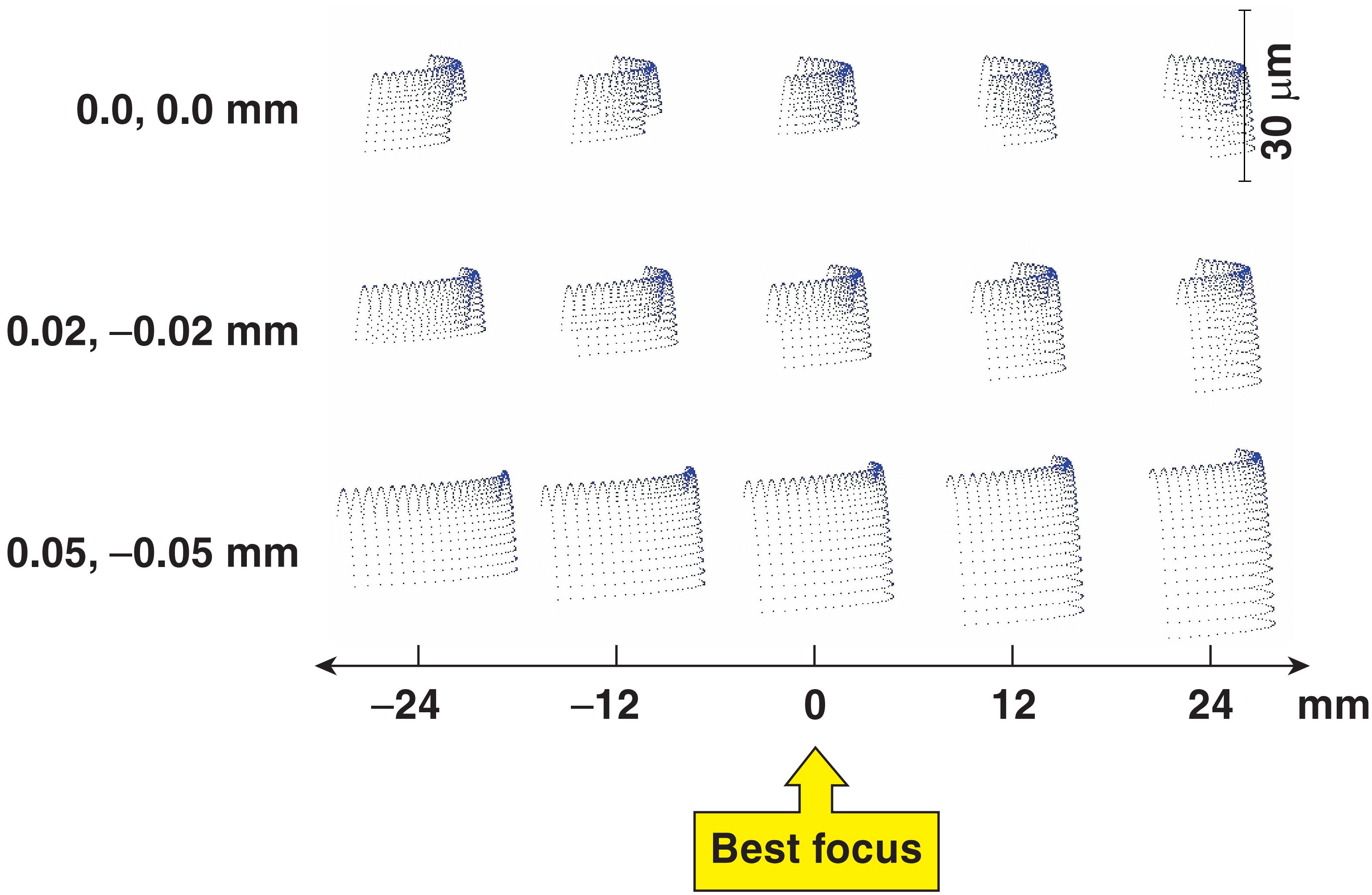
E10566

The required optical parameters are validated through numerical ray tracing



- Point objects from a field of view of 200 μm were imaged, resulting in the spot diagram shown.

Spot diagrams of point objects with different field positions show a weak image distance dependence



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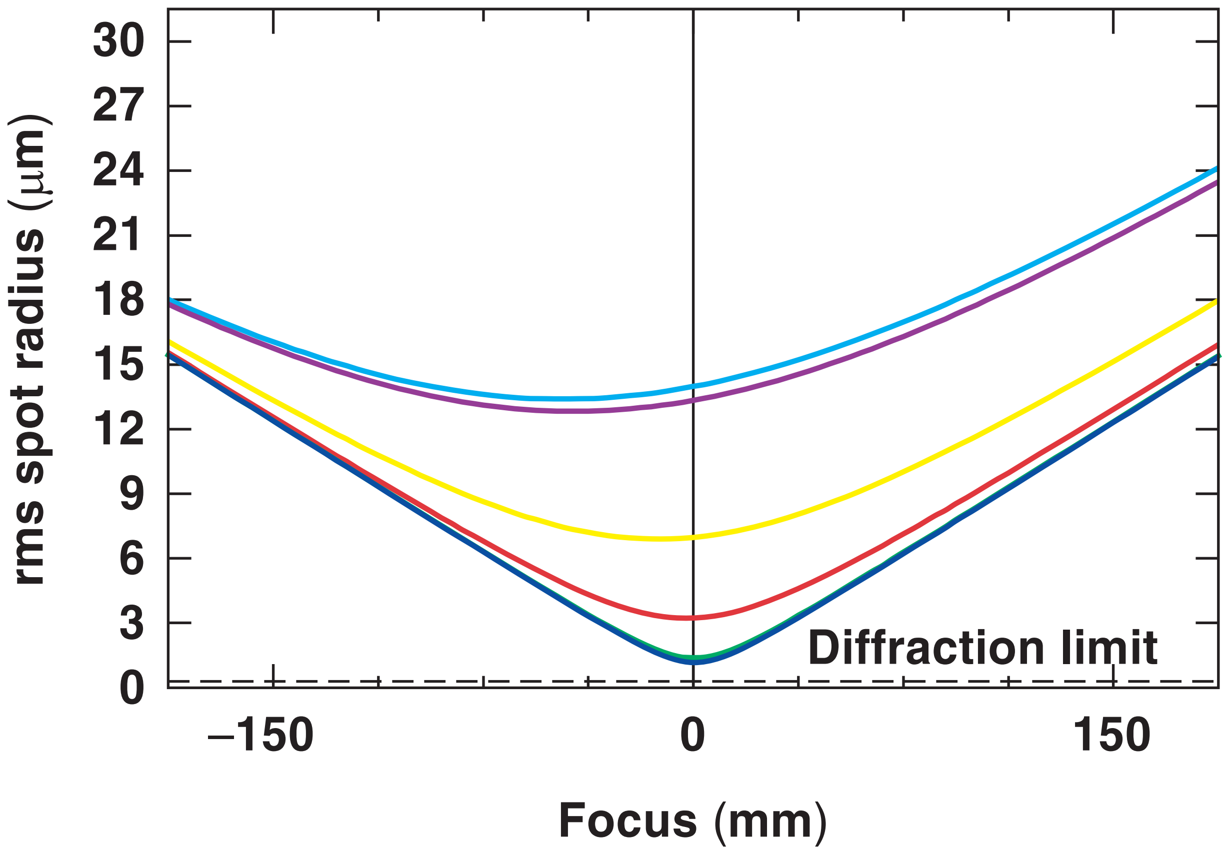
The image spot size is sensitive to the source field position and grows almost linearly with image distance

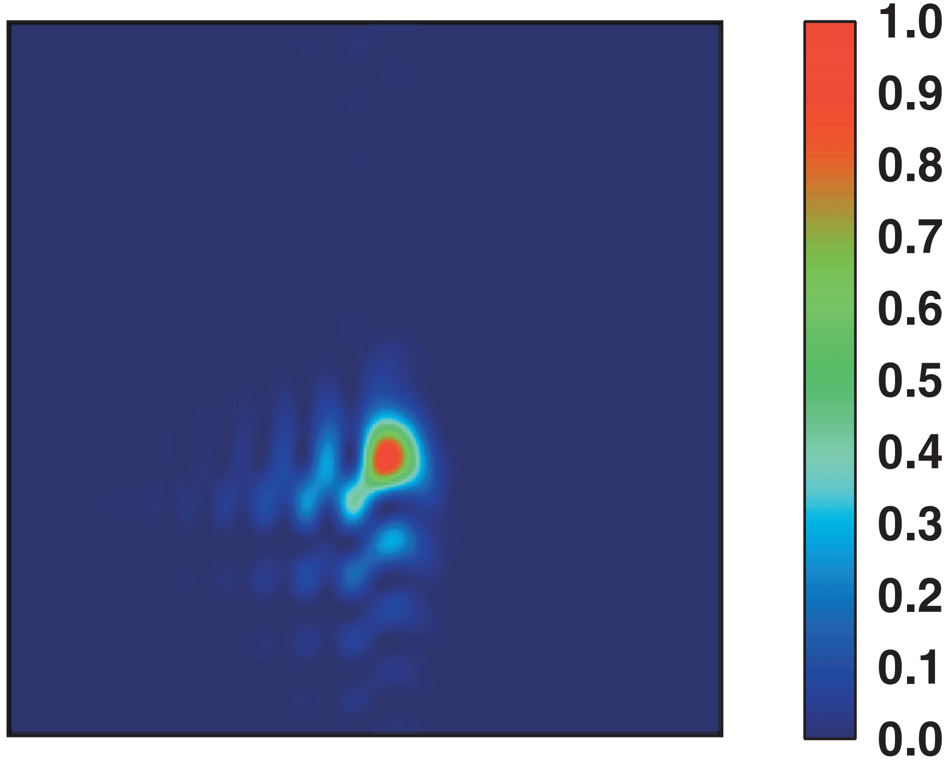


Field coordinates

1. (0,0) μm
2. (3,3) μm
3. (20,20) μm
4. (50,50) μm
5. (200,200) μm
6. (–200,–200) μm

E10569

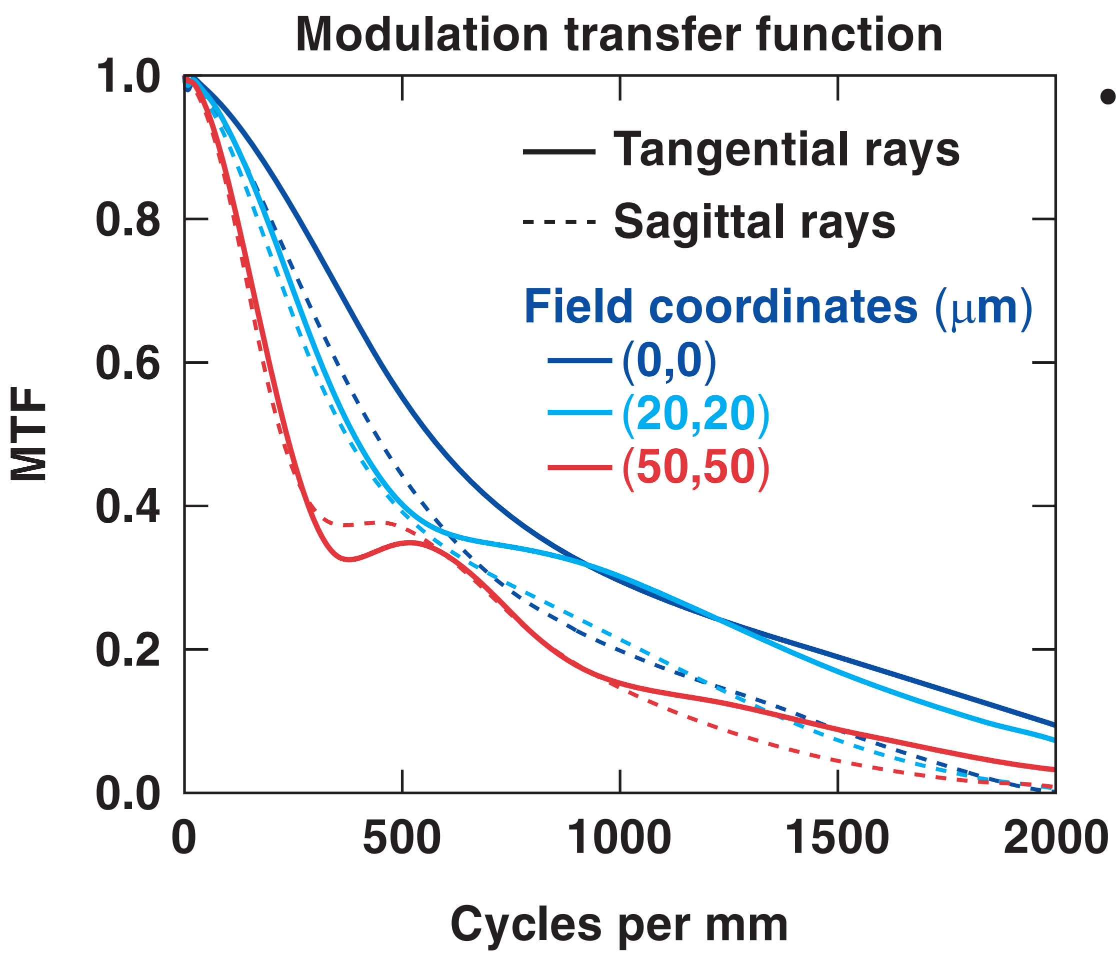
The point-spread function (PSF) for an object on axis shows better-than-5-μm spatial resolution



- **The image spot size at the 10% level is less than 15 μm (box size is 30 μm). A division by the magnification M = 6 yields 2.5 μm resolution in the object plane.**

E10570

Calculation of the modulation transfer function (MTF) confirms the resolving capabilities of the system

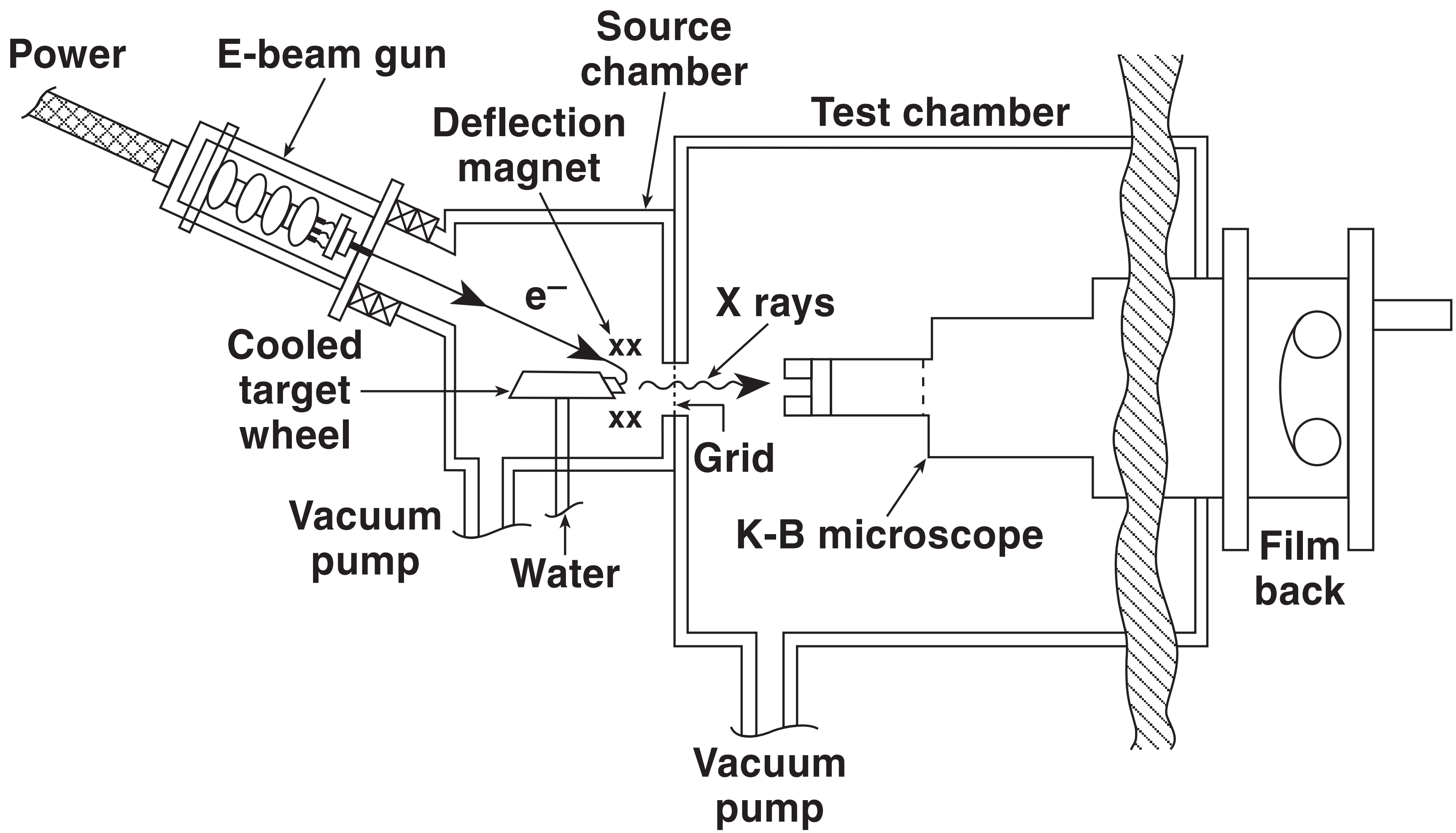


- For 5-μm wavelength (200 cycles per mm) the MTF is greater than 0.6 at all three fields and for both tangential* and sagittal rays.

*Defined parallel to the plane of the front mirror, while the sagittal rays are perpendicular to the mirror.

E10687

Currently, the new KB front end is being tested at the OMEGA x-ray microscope test facility



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