X-ray optics on the Z-Accelerator backlit with the Z-Beamlet Laser & Z-Petawatt Laser systems

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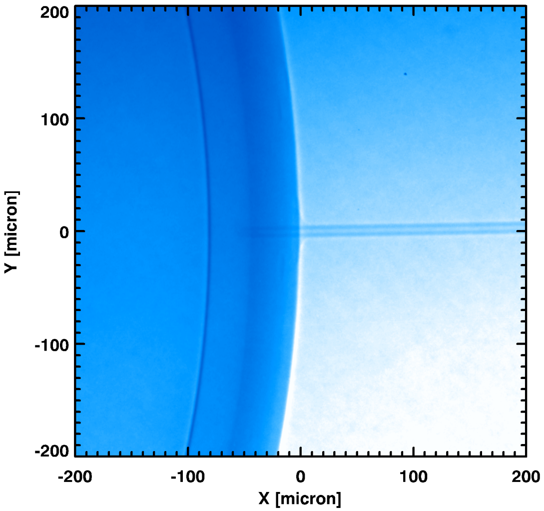

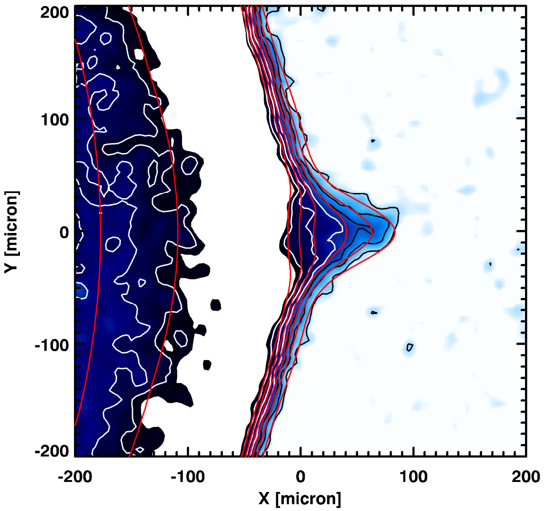

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Abstract

6.151-keV curved-bragg-crystal x-ray optics are routinely used to image inertial-confinement-fusion capsules, wire-array z-pinches, and other ultrafast experiments on Sandia National Laboratories' Z-Accelerator [M. K. Matzen *et al*., Phys. Plasmas 12, 055503 (2005)]. Two temporally and spatially separated 6.151-keV x-rays sources are created by the terawatt-class, multikilojoule Z-Beamlet Laser (ZBL) [P. K. Rambo *et al*., Appl. Opt. 44, 2421 (2004)], allowing a two-frame history of an event to be recorded. Despite the size of Z, the world's most powerful pulsed soft x-ray source, the imaging system allows, for example, μg mass measurements to be made on a 1-mg capsule, with ns time resolution, 20+/-5 μm spatial resolution, and 4-8 ns between the frames. Z's imaging capabilities will soon be enhanced with the addition of a second laser; the 2-kJ, 0.5-1 ps Z-Petawatt Laser (ZPW). ZPW will permit higher energy x-ray imaging capabilities - for example, possibly 25-keV curved-bragg-crystal imaging in Laue mode - at higher temporal resolutions, which are required to diagnose the details of extremely dense, fast moving plasmas. Maximizing x-ray source brightness, optic collection efficiency, and detector sensitivity, as well as optimizing the spatial resolution and the number of frames, is a constant, ongoing activity. ZBL, ZPW, and the x-ray optics represent a large portion of the Z infrastructure; a diagnostic capability that allows the maximum scientific return to be obtained from physics performed on Z. This talk will cover, for the nonexpert, aspects of our ultrafast x-ray optics

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The Z-Accelerator [1], the World's most powerful and energetic x-ray source, is used in various areas of high-energy-density-physics

An enhancement to the Z-Accelerator will soon provide a 26-MA peak current, nearly doubling the previously available energy

This enormous current can be used to either create soft x-rays, or drive a planar flyerplate for shockwave physics experiments

The soft x-ray flux can be used, for example, to uniformly compress inertial-confinement-fusion capsules

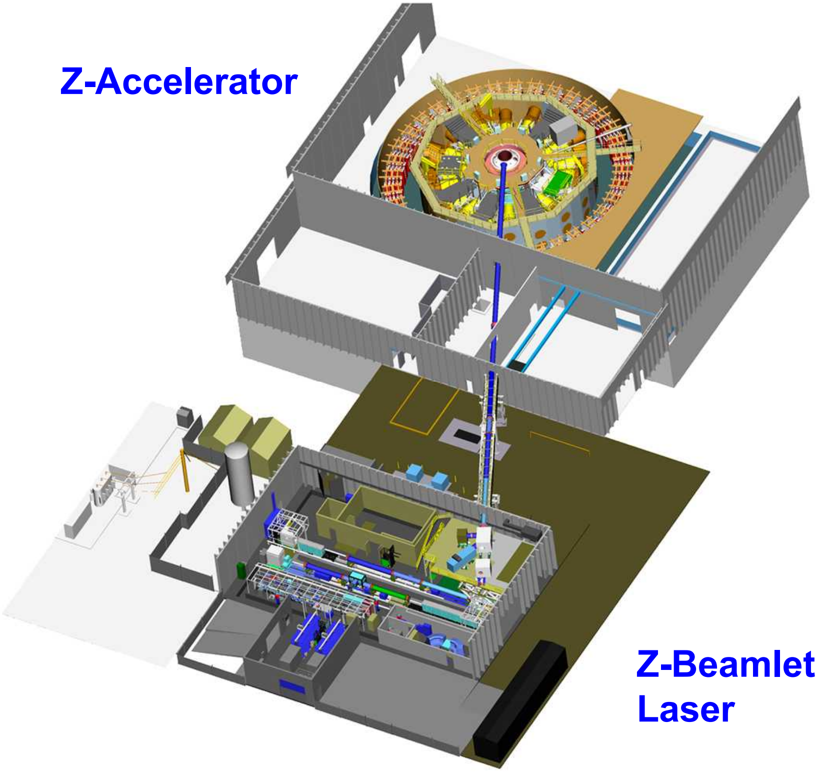
[1] M. K. Matzen *et al*. Phys. Plasmas. **12,** 055503 (2005)

Imaging certain experiments with ultrafast x-ray optics is often a critical requirement on Z

In 2001, the addition of the Z-Beamlet Laser (ZBL) [2] allowed an optic to be backlit with a bright, fast x-ray source on Z

ZBL is a TW-class, multi-kJ, 526.57 nm Nd:glass laser capable of generating four 0.2-1.8 ns pulses anywhere within a 20 ns window

The first Z/ZBL experiments used, in fact, ~6.7 keV point-projection imaging (the dental radiograph scheme), to study ICF capsule implosions [3,4]



[2] P. K. Rambo *et al*. Appl. Opt. **44,** 2421 (2005)
[3] G. R Bennett *et al*. Phys. Rev. Lett. **89,** 245002 (2002)
[4] R. A. Vesey *et al*. Phys. Rev. Lett. **90,** 035005 (2003)

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More recently, 6.151 keV curved-crystal (α-Quartz 22$\underline{4}$3) imaging [5,6] has replaced 6.7 keV point-projection

6.151-keV curved-crystal imaging advantages:

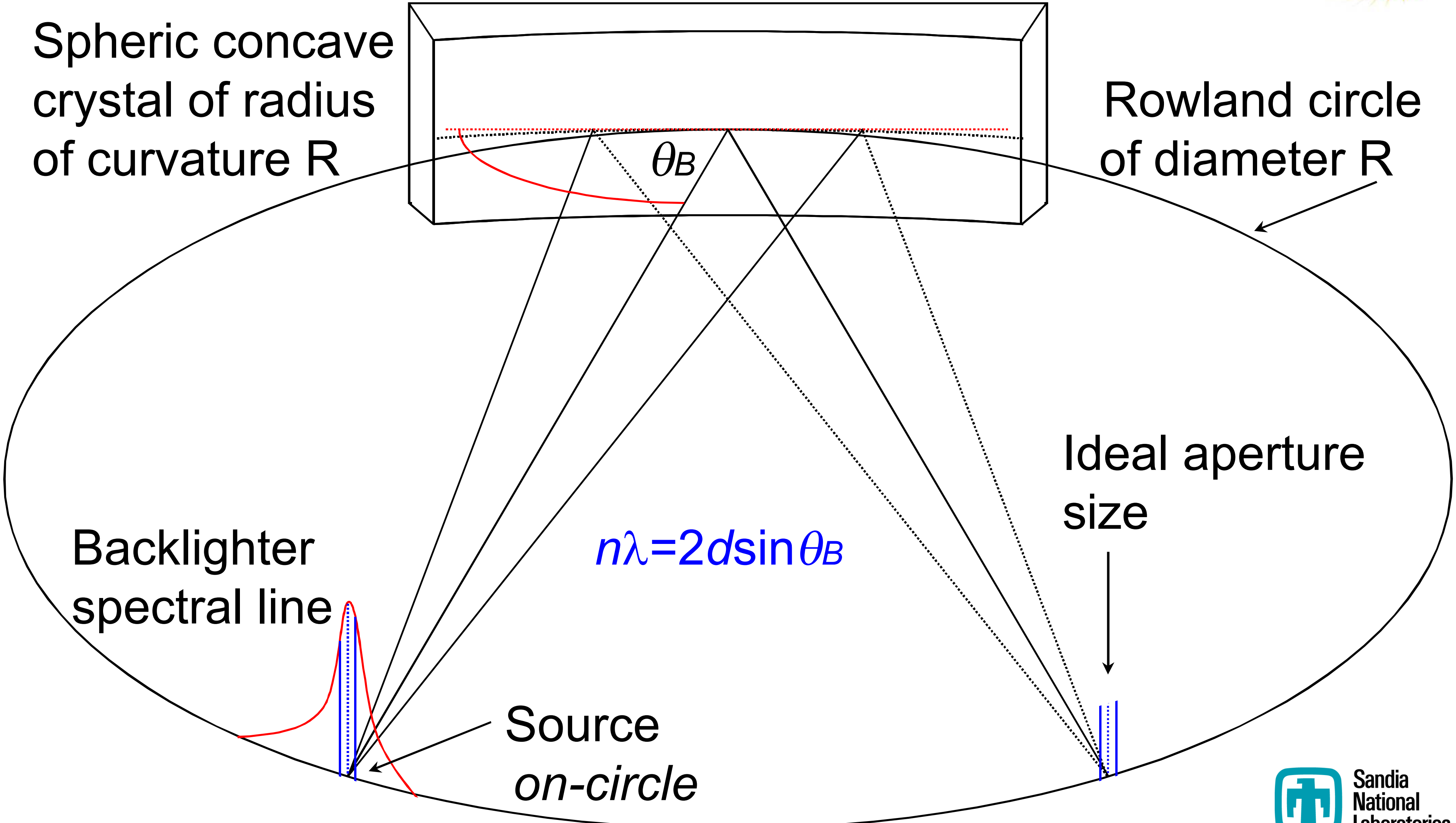
(1) **Higher spatial resolution for a given ZBL spot size**
(2) **Highly monochromatic: The Bragg diffraction condition is satisfied**
(3) **Larger field of view**
(4) **Higher dynamic range: Image plate and other advanced detectors can be fielded**

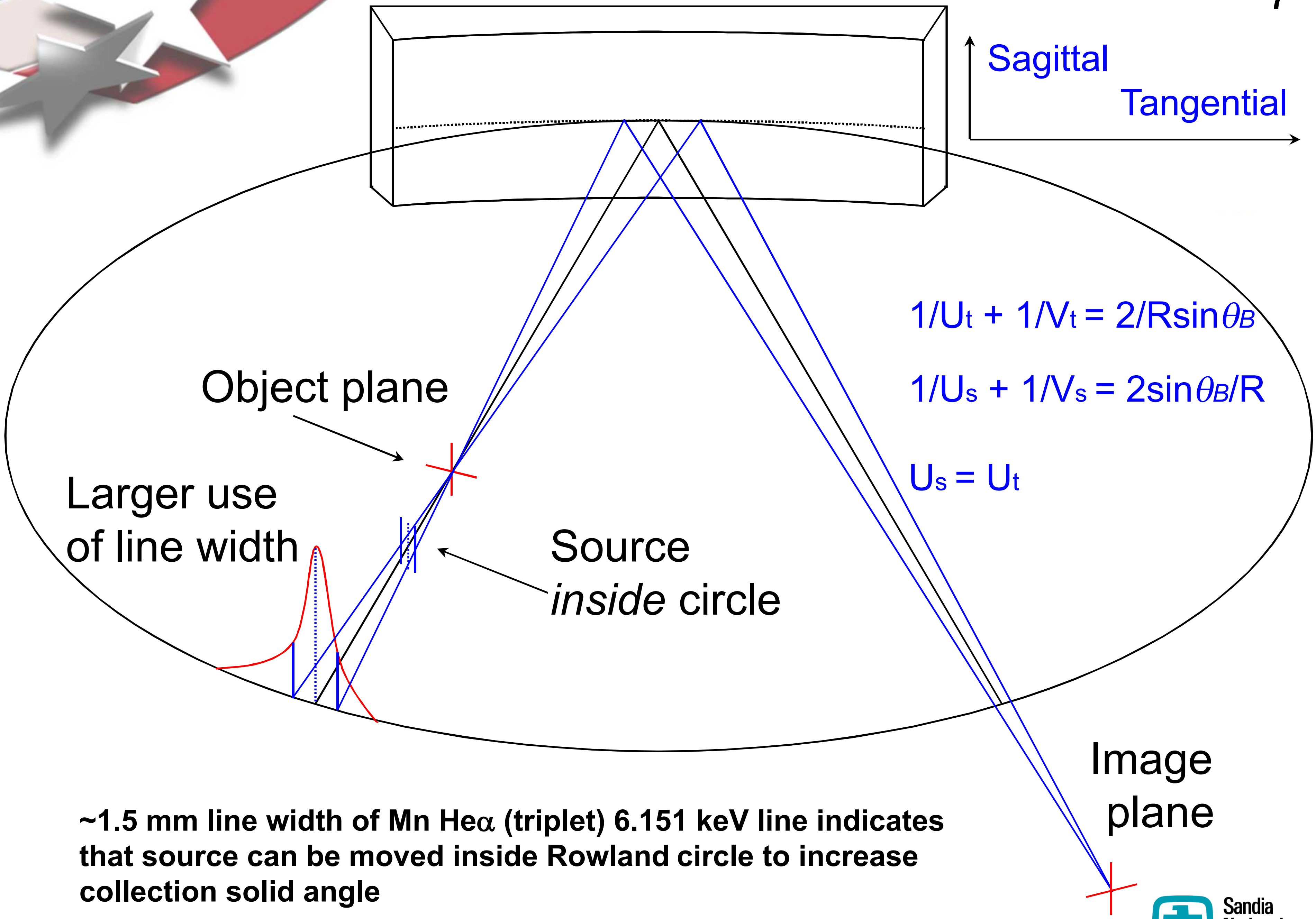
Point-projection imaging advantage:

(1) **Simpler**

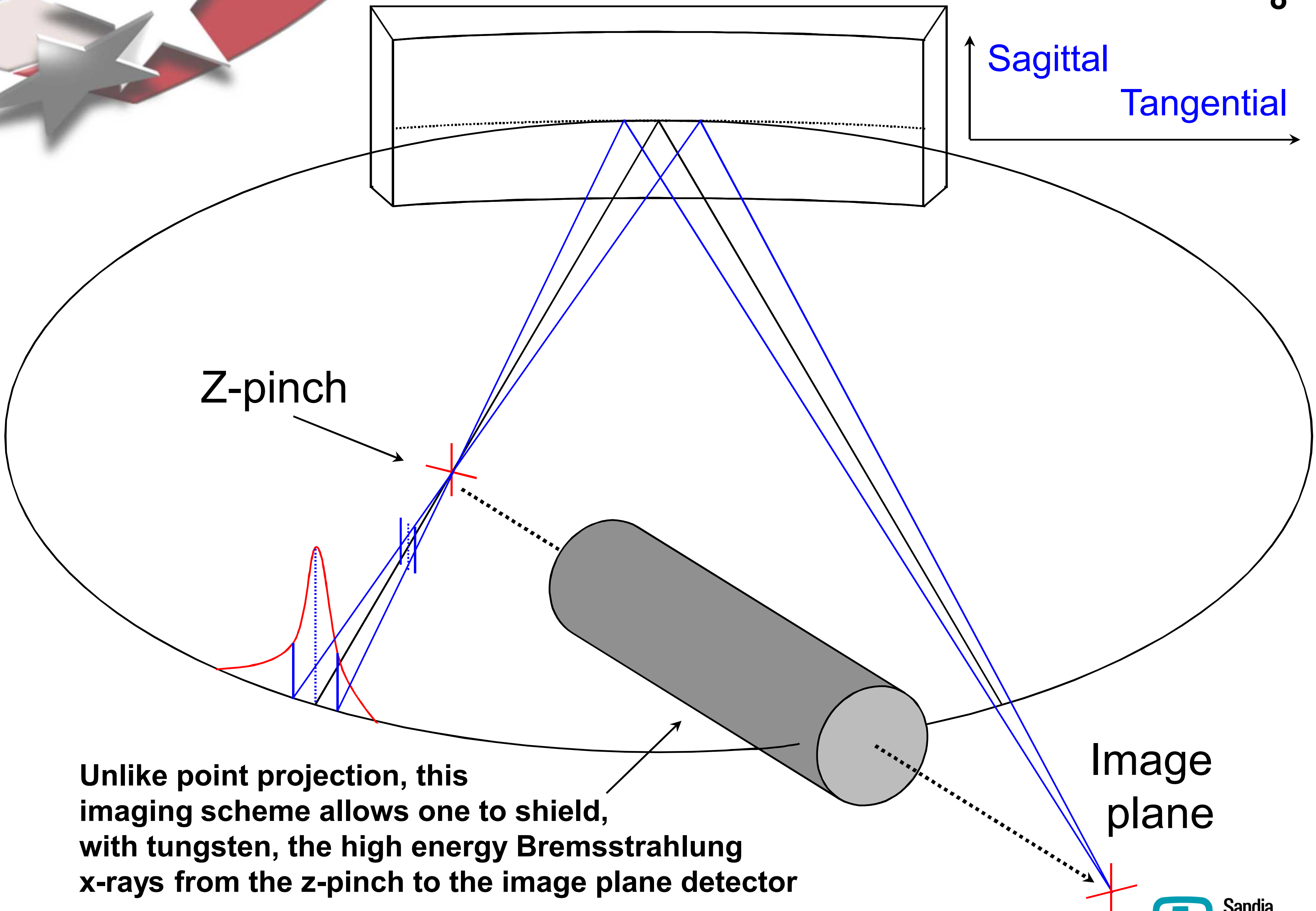
[5] D. B. Sinars *et al*. Rev. Sci. Instrum. **75,** 3672 (2004)
[6] G. R. Bennett *et al*. Rev. Sci. Instrum. **77,** 10E322 (2006)

Bragg diffraction & Rowland circle are key to backlit monochromatic operation and approximate non-imaging of near-Planckian (T<300 eV) z-pinch-emitted x-rays





~1.5 mm line width of Mn Heα (triplet) 6.151 keV line indicates that source can be moved inside Rowland circle to increase collection solid angle



Unlike point projection, this imaging scheme allows one to shield, with tungsten, the high energy Bremsstrahlung x-rays from the z-pinch to the image plane detector

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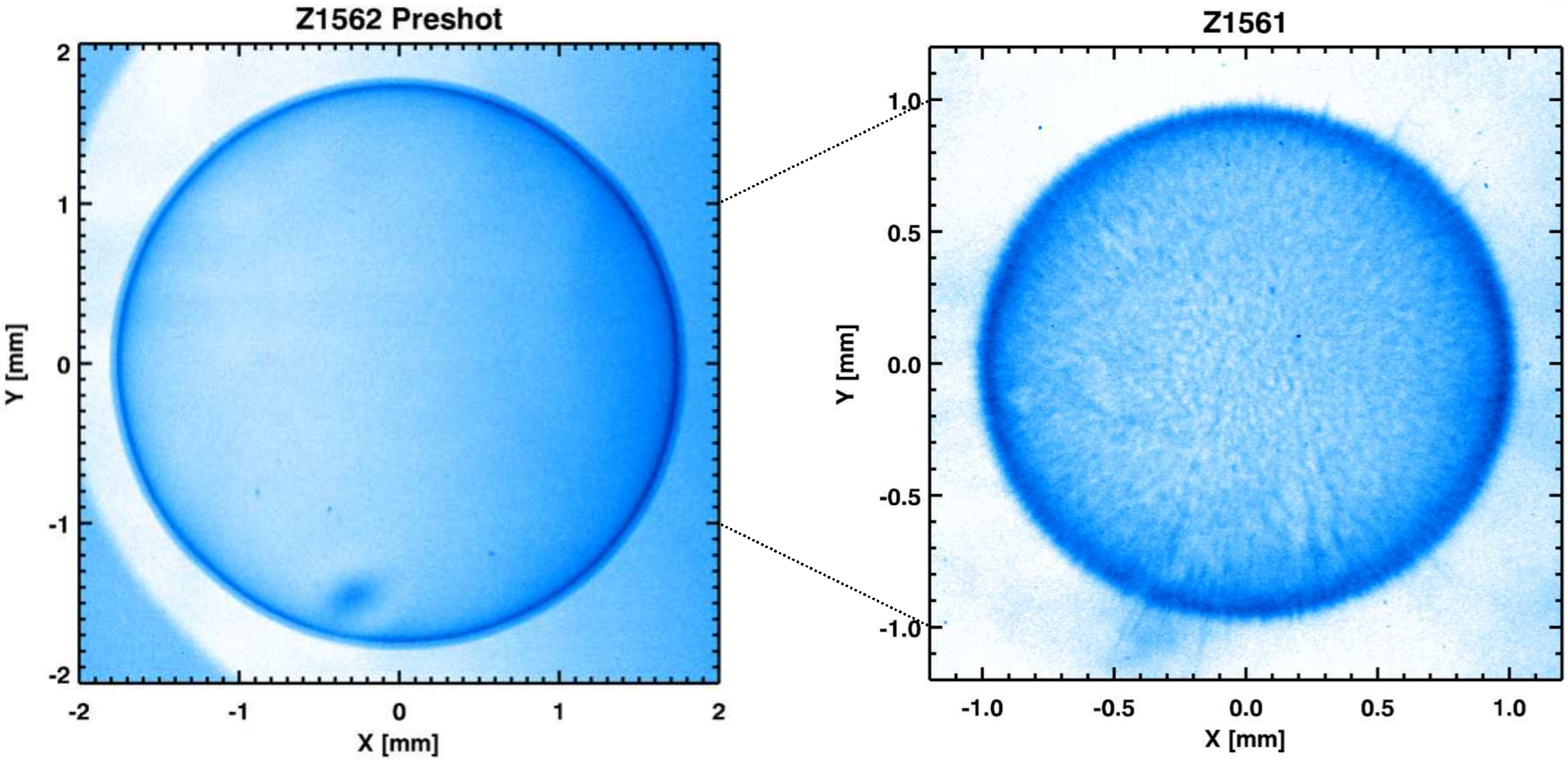
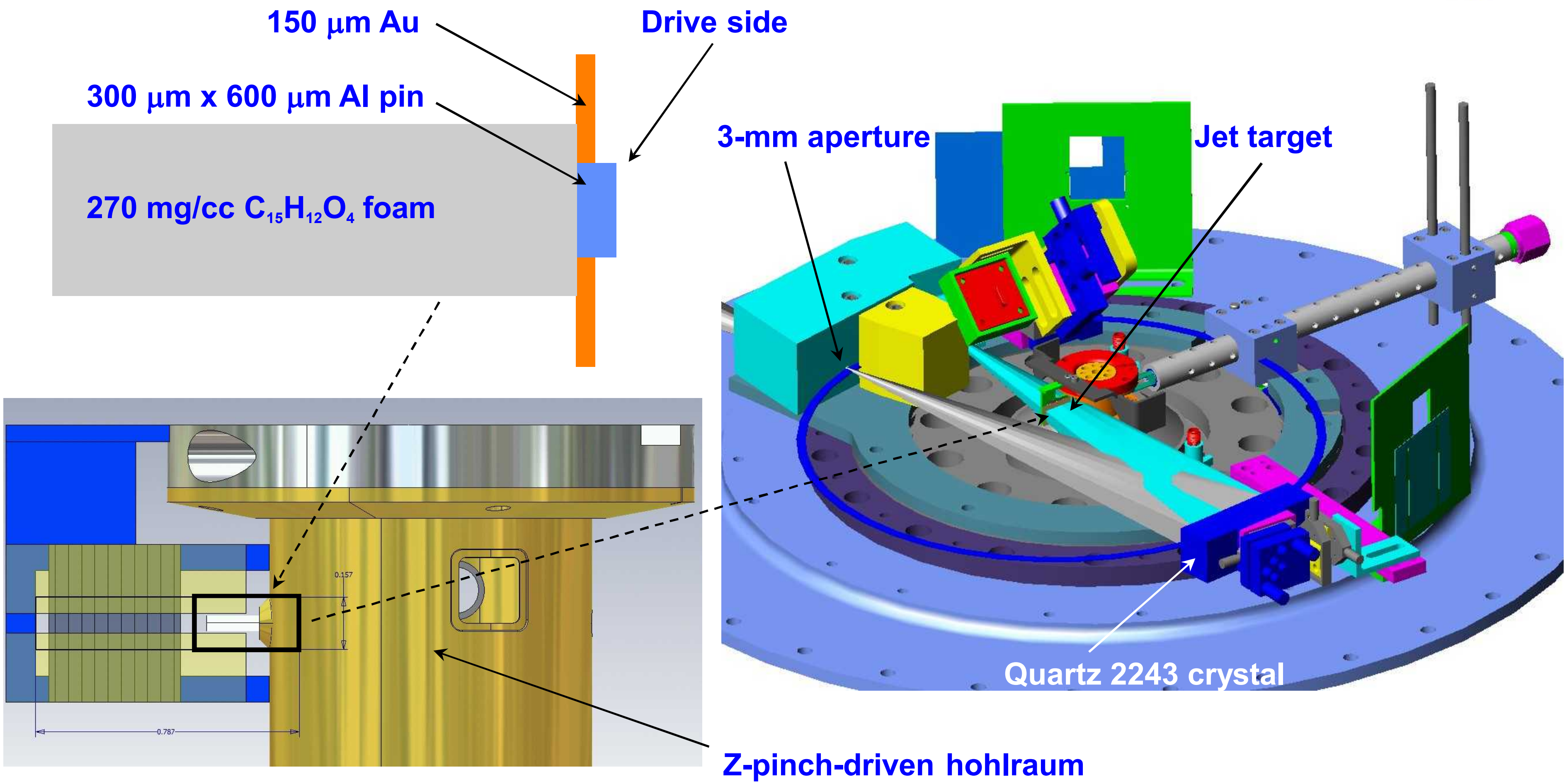
A curved-bragg-crystal x-ray optic backlit by ZBL has revealed good scientific images [5,6] on Z experiments



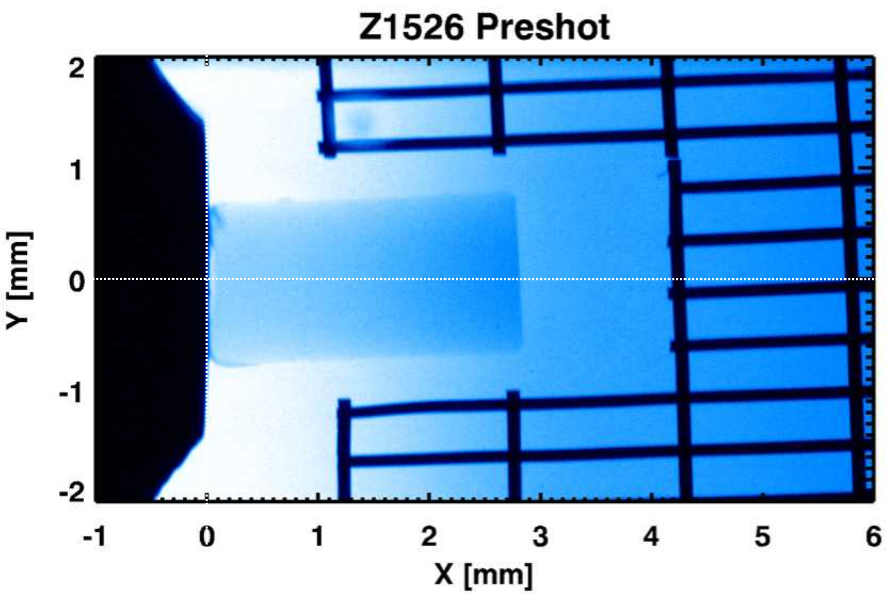
ICF capsule implosion in Sandia's Double-Ended Hohlraum

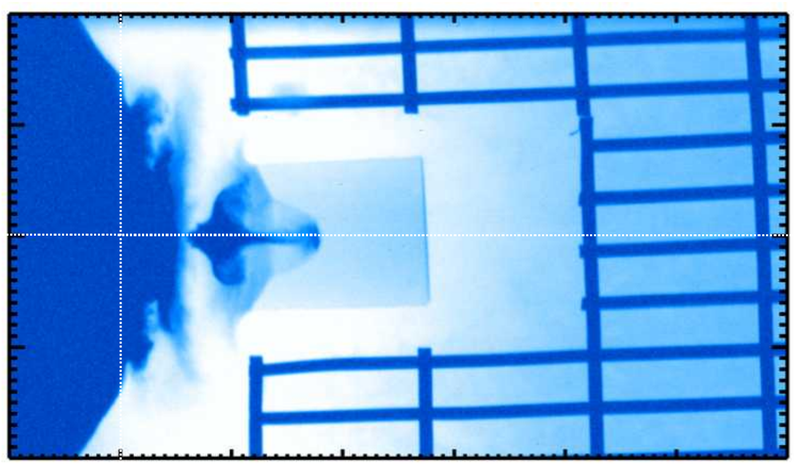
[5] D. B. Sinars *et al.* Rev. Sci. Instrum. **75,** 3672 (2004)
[6] G. R. Bennett *et al.* Rev. Sci. Instrum. **77,** 10E322 (2006)

Supersonic jet examples

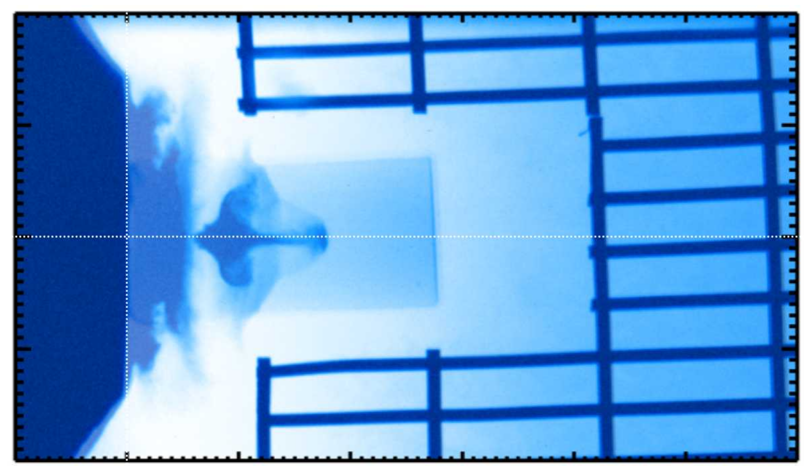


In-situ pre-shot radiograph allows one to determine exact x=y=0 ref point and correct rotation



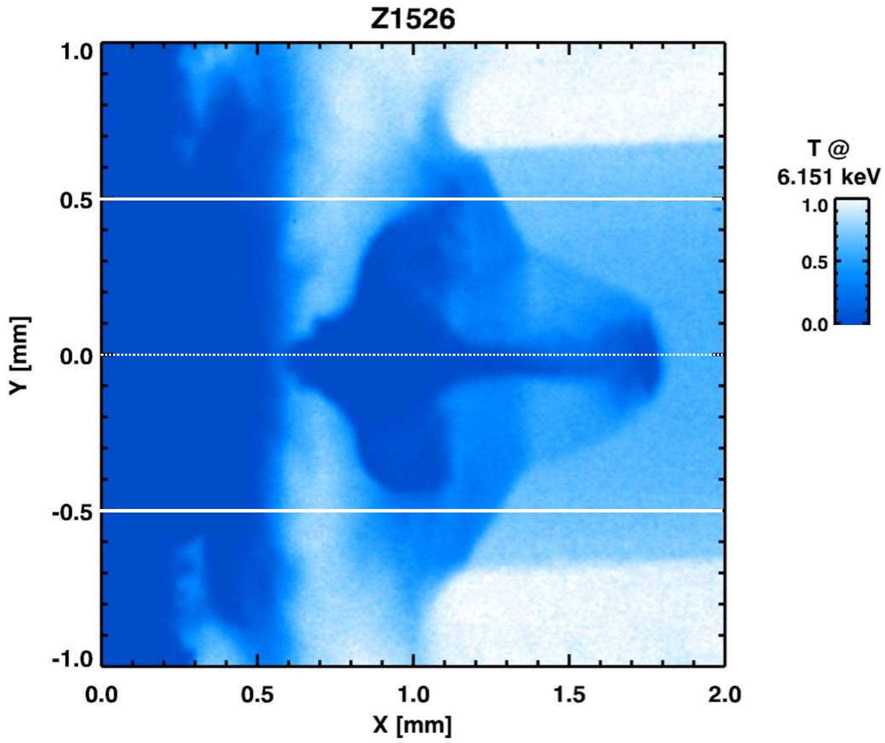


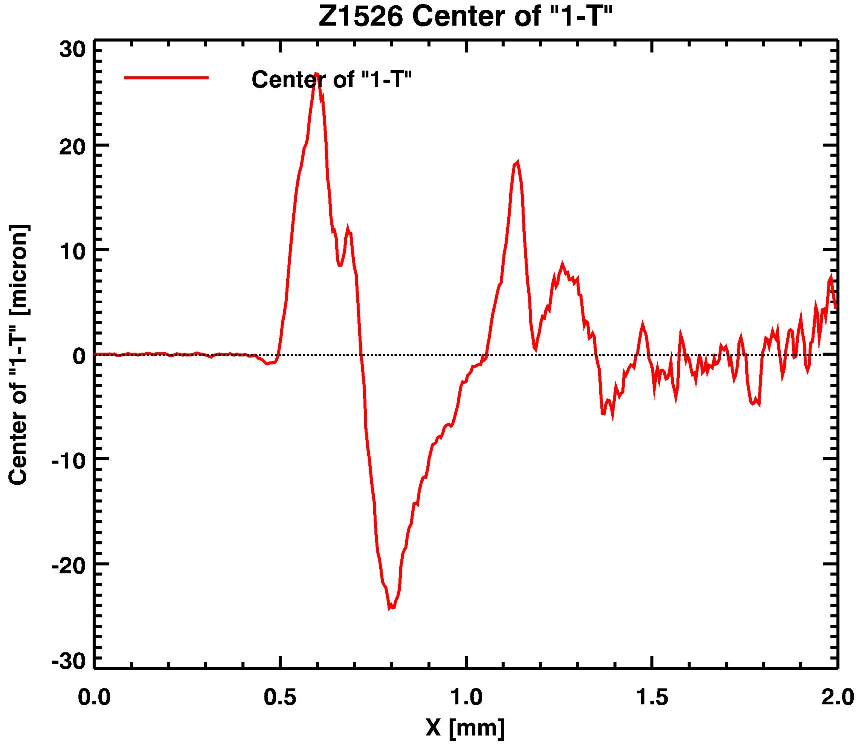
Z1526 pre-shot and down-line images overlaid



Analysis of "1-T" center for Z1526 between y=-0.5 and +0.5 mm indicates a very symmetric jet

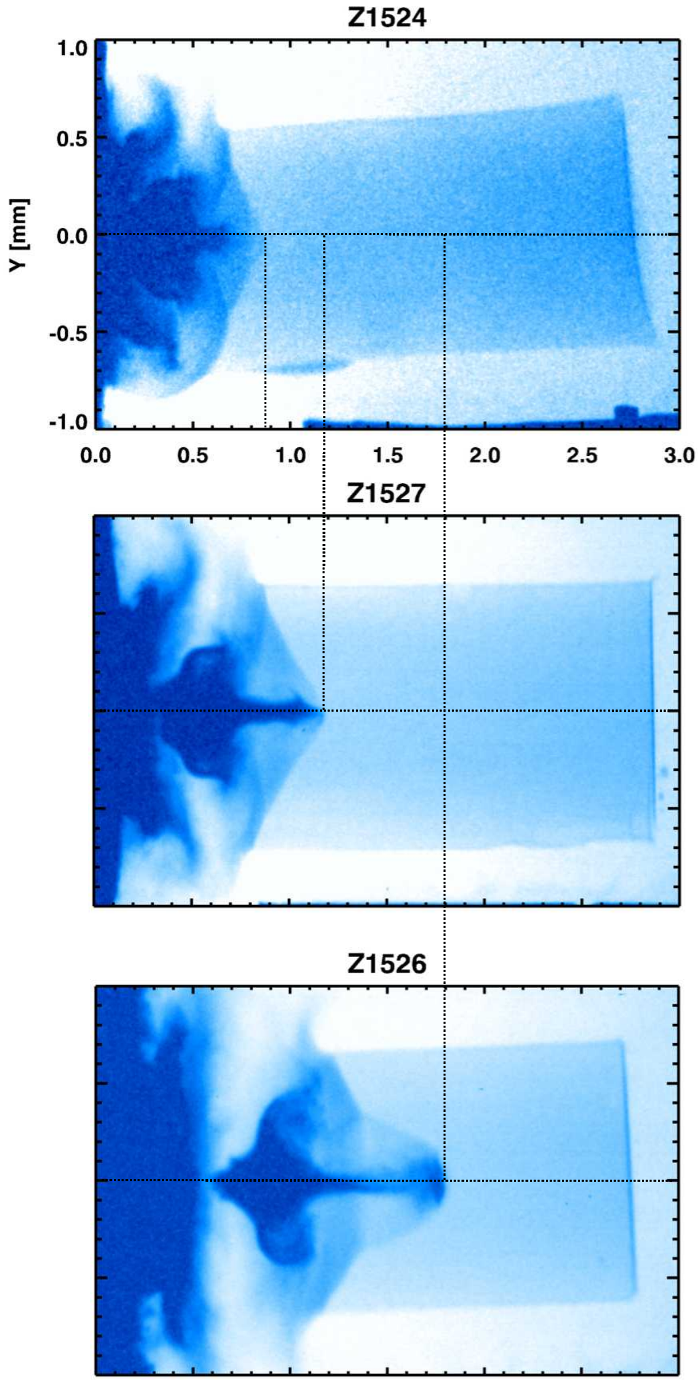
T=T(x,y)=transmission at 6.151 keV. Center of "1-T" is a metric that allows one to quantify a jet's symmetry





In this case, the Center of "1-T" deviates by <+/-30 micron over a 2 mm extent

Time sequence of most symmetric jets



t=31 ns
328.1 mg/cc

t=40 ns
285.2 mg/cc

t=73 ns
270.1 mg/cc

Each image requires one Z shot (presently one a day)

Intent was to study early time jet evolution (before symmetry was broken) under reproducible conditions

Slight differences in drive and foam densities, shot-to-shot, makes such a study difficult

Developing a Multiframe Ultrafast Digital X-ray Cameras (MUDXC) to obtain 4 images per shot at 6.151 keV with ZBL….

….and two 25.2713 keV frames per shot with ZPW

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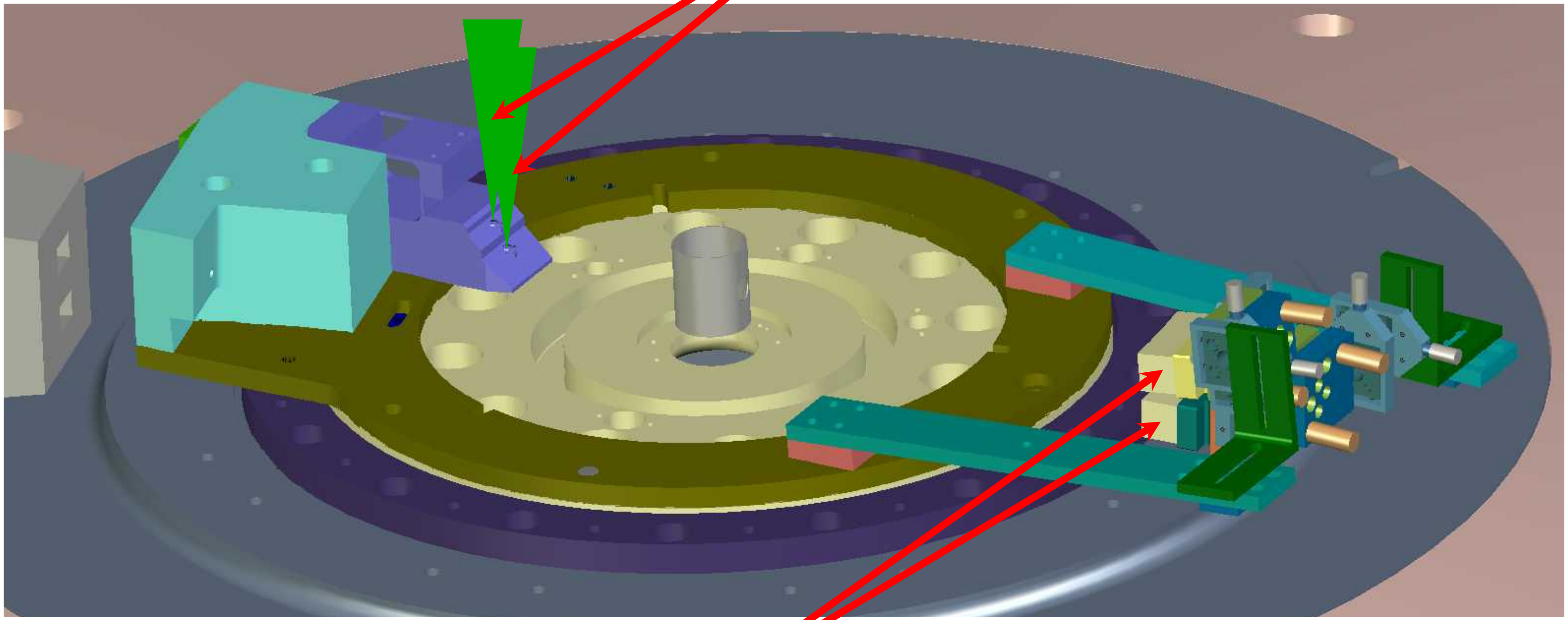
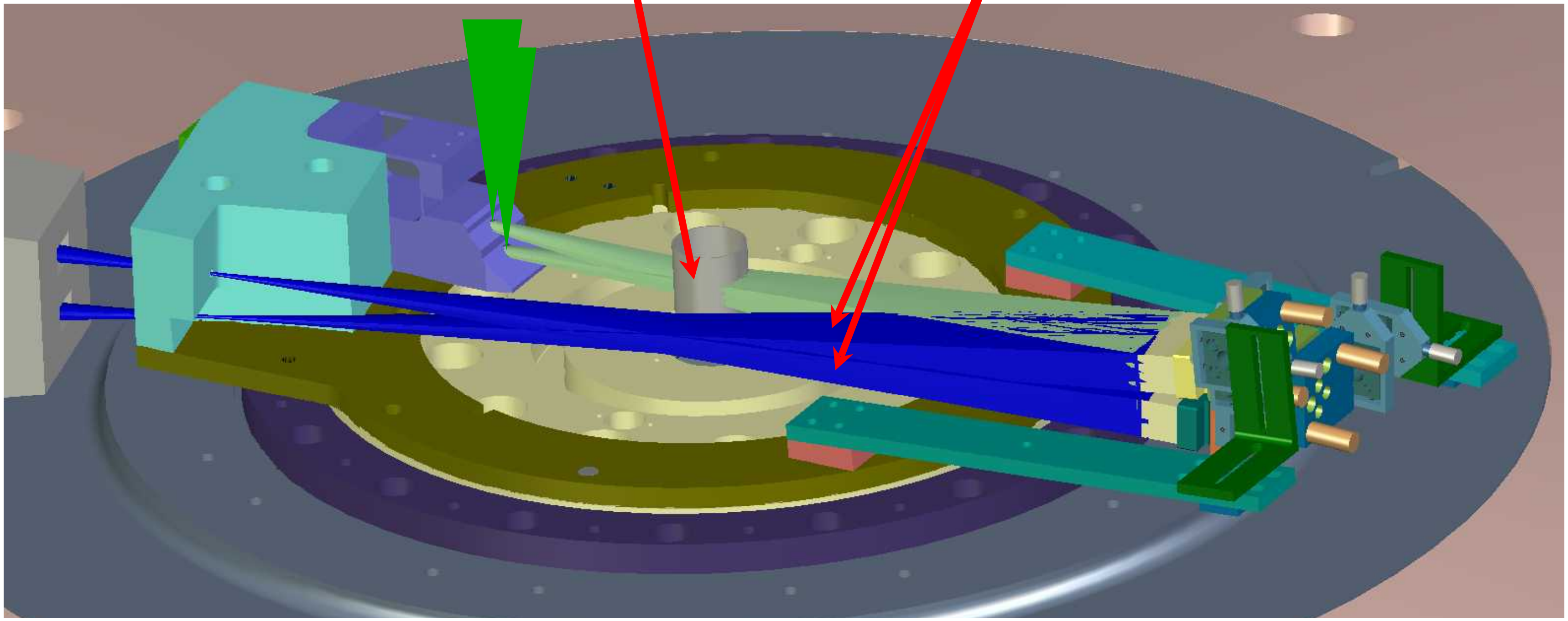
ZBL has recently being modified to provide a "2-Frame" capability for experiments on Z

Two temporally and spatially separated ZBL beams irradiating Mn foils

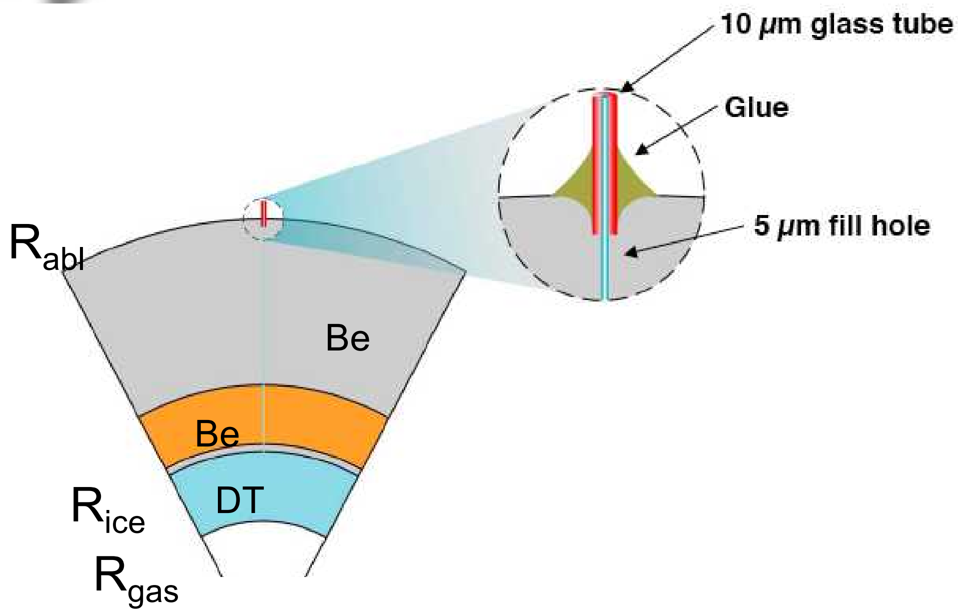


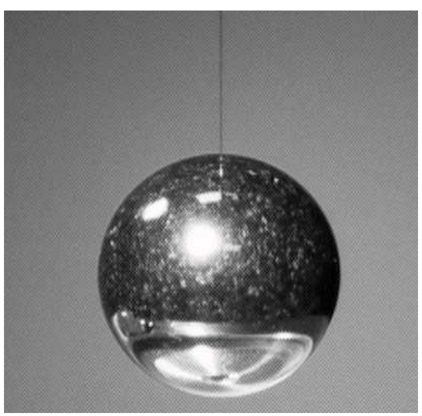
Two independent 6.151-keV systems

Z-pinch Double-Ended-Hohlraum
Focused 6.151-keV x-ray beams

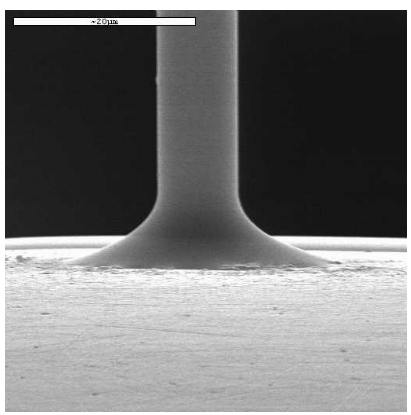


First ignition capsules on NIF will be filled using 10 micron diameter fill tubes





Be capsule with 10 micron tube



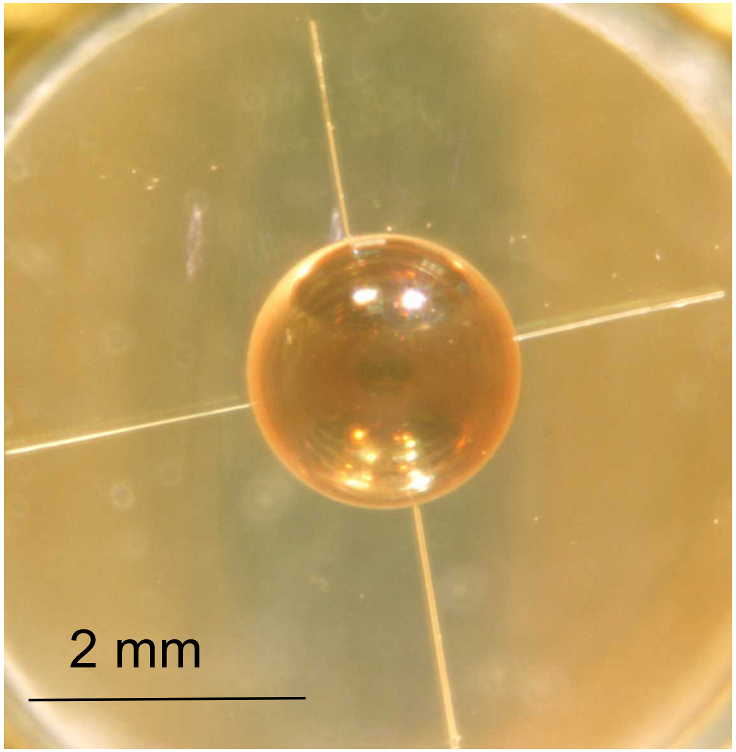
SEM image of tube and glue fillet

Using fill tubes significantly reduces complexity and expense of cryogenics system compared with diffusion fill and cryo transport

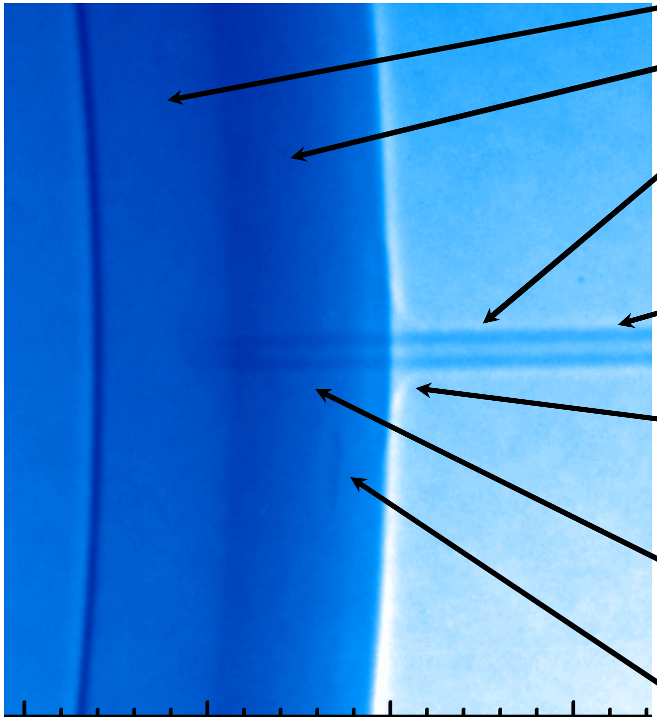
Target fabrication has demonstrated that fill tubes and holes can be made at the NIF specifications

Calculating the perturbations arising from fill tubes is a computational challenge

State of the art targets were fabricated by General Atomics



Optical image of CH capsule with 4 fill tubes (12-45 micron OD) attached around an equator



High resolution Xradia image of as built configuration gives important details for simulation

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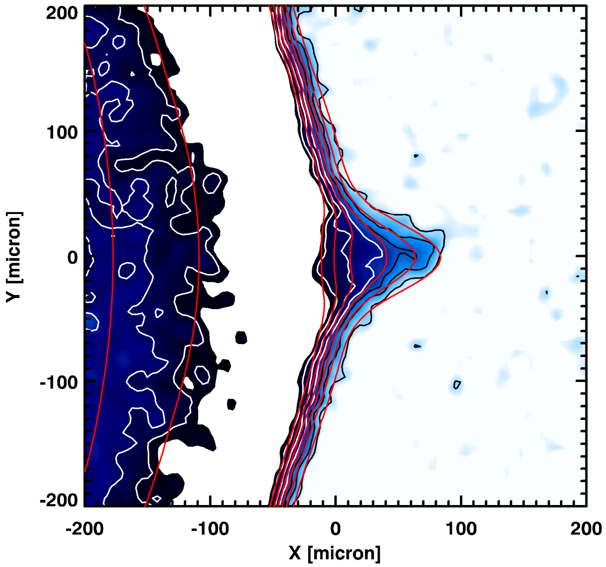
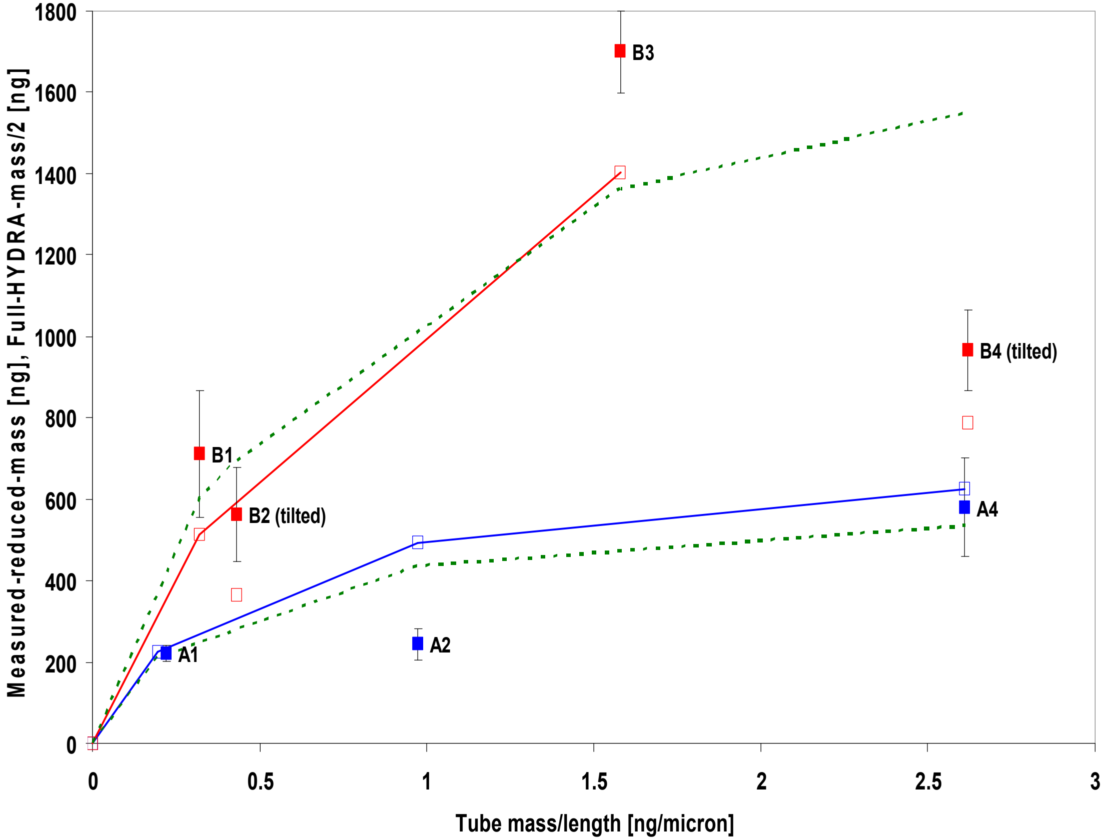
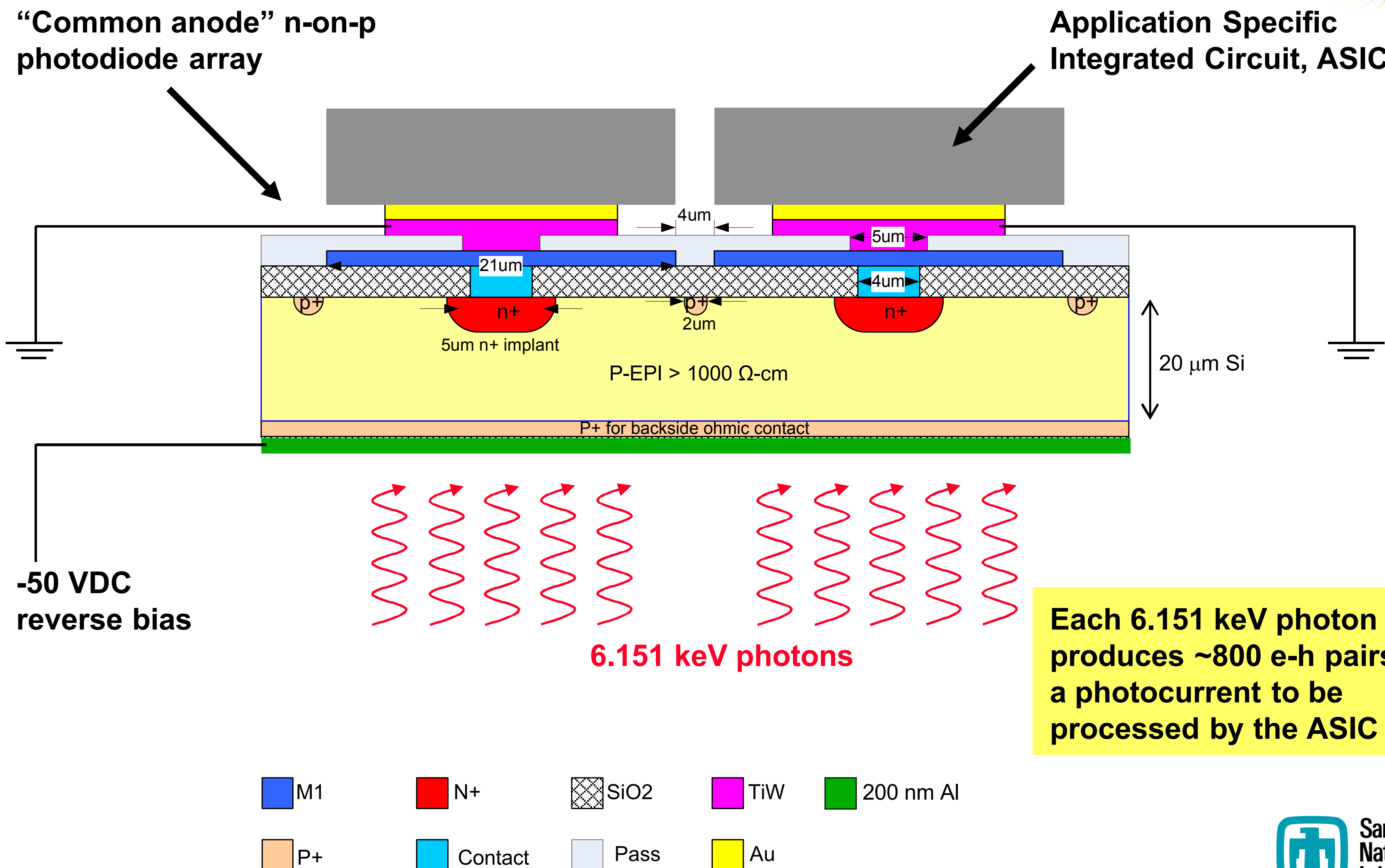
μg mass perturbation measurements have recently been performed on NIF-scale, 1-mg capsules; using 6.151-keV x-ray imaging [7]





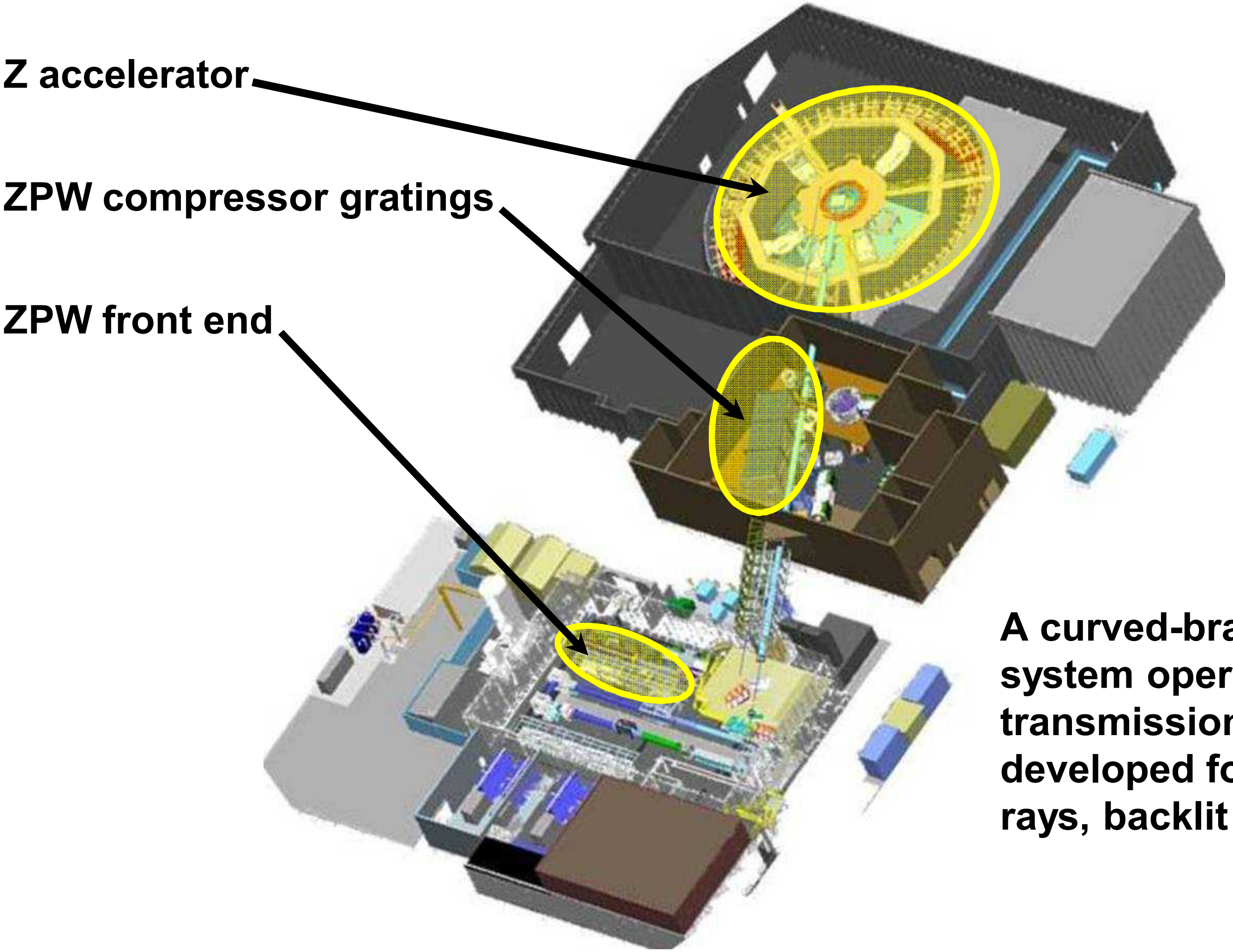
[7] G. R. Bennett *et al.* Submitted

To provide >2 frames, with a gated capability, we are developing a Multiframe Ultrafast Digital X-ray Camera



Each 6.151 keV photon produces ~800 e-h pairs, a photocurrent to be processed by the ASIC

Bright, ultrafast Kα_1 sources will be produced by the Z-Petawatt Laser (ZPW), a second laser to ZBL providing 2 kJ of 1053 nm light in 0.5-10 ps pulses



A curved-bragg-crystal imaging system operating in transmission mode is being developed for 25.2713-keV x-rays, backlit by ZPW

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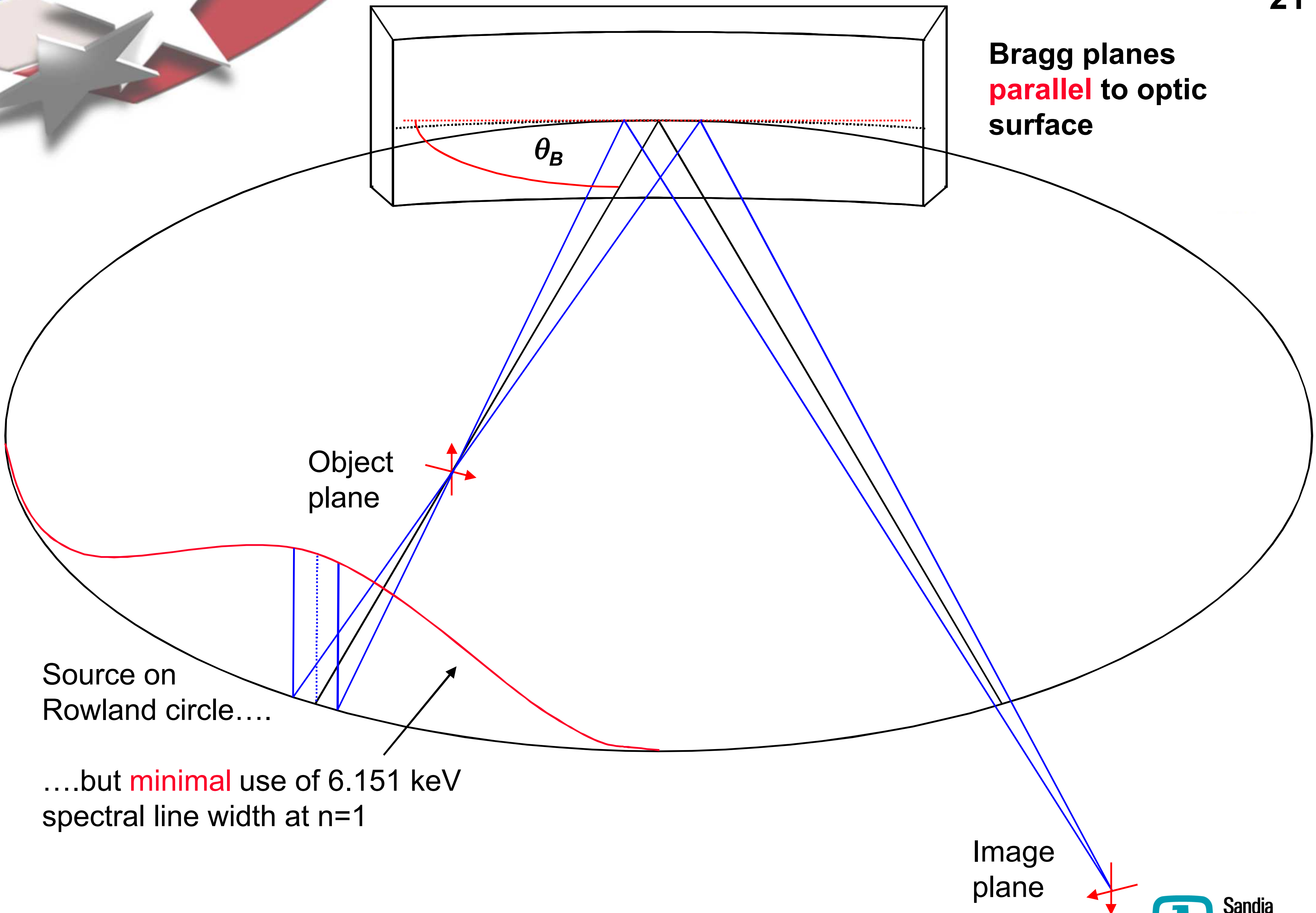
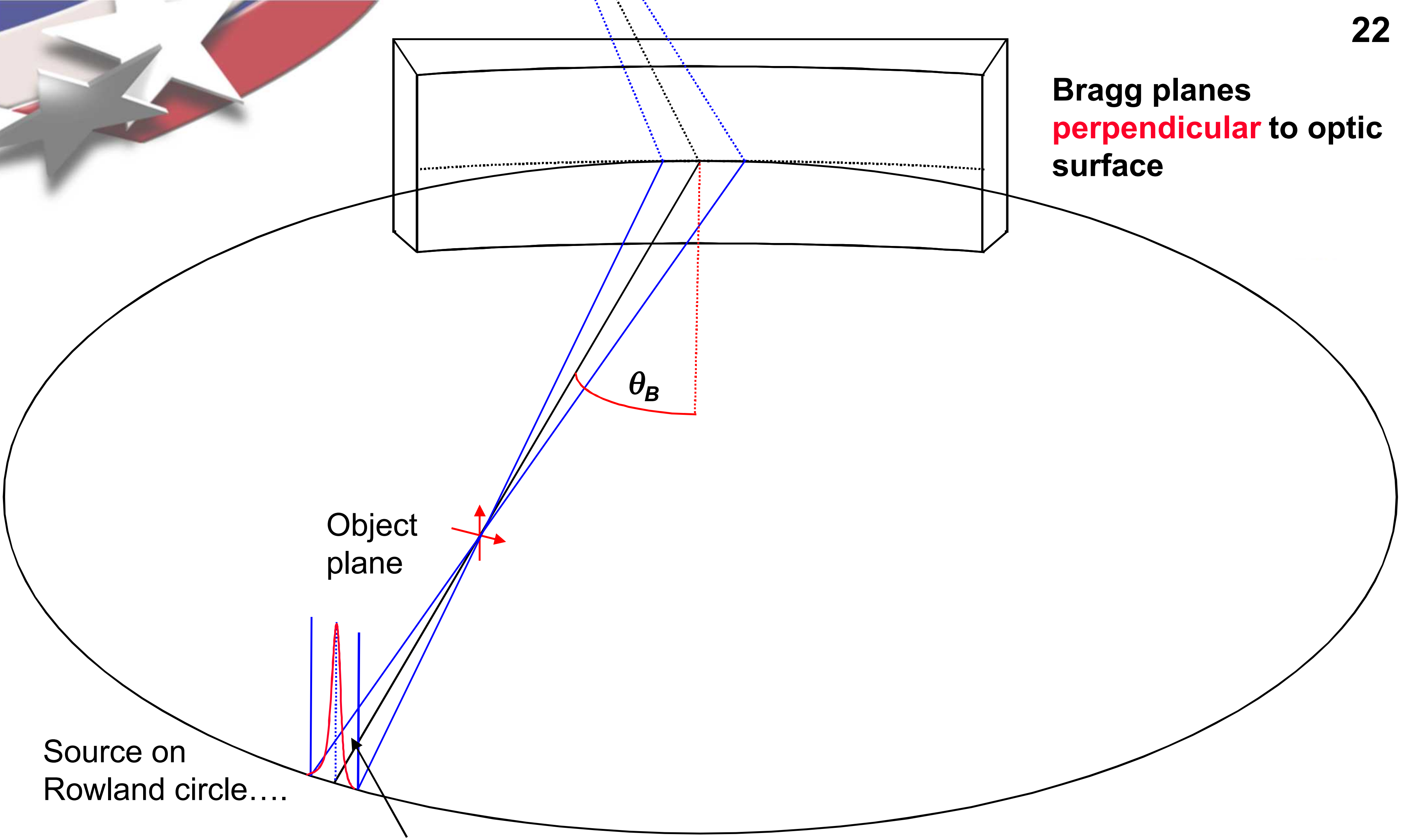

Bragg planes
parallel to optic
surface
θB
Object
plane
Source on
Rowland circle….
….but minimal use of 6.151 keV
spectral line width at n=1
Image
plane

Bragg planes perpendicular to optic surface



….with maximum use of 25.2713 keV spectral line width at n=1

Large photon energy results in small Bragg angle (at n=1), leads to extreme line width reduction on Rowland circle

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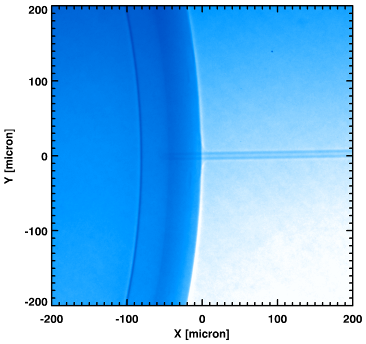

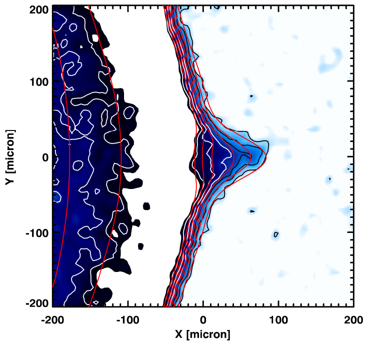

Summary

Ultrafast x-ray optics are a key requirement for many Z-Accelerator experiments

The ZBL and ZPW lasers backlight our optic with ns and ps x-ray bursts

Maximizing source brightness, optic collection efficiency and detector sensitivity are constant areas of effort

Optimizing a multiframe capability is also a key effort

To date, x-ray imaging has allowed μg mass perturbation measurements to be performed on a NIF-scale, 1-mg capsule [7]

More scientific advances of this kind are expected in the future

[7] G. R. Bennett *et al.* Submitted