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Ultra-Intense-laser produced high-Z backlighters for Compton Radiography

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Ultra-Intense-laser produced High-Z backlighters for a Compton Radiography ignition diagnostic for NIF

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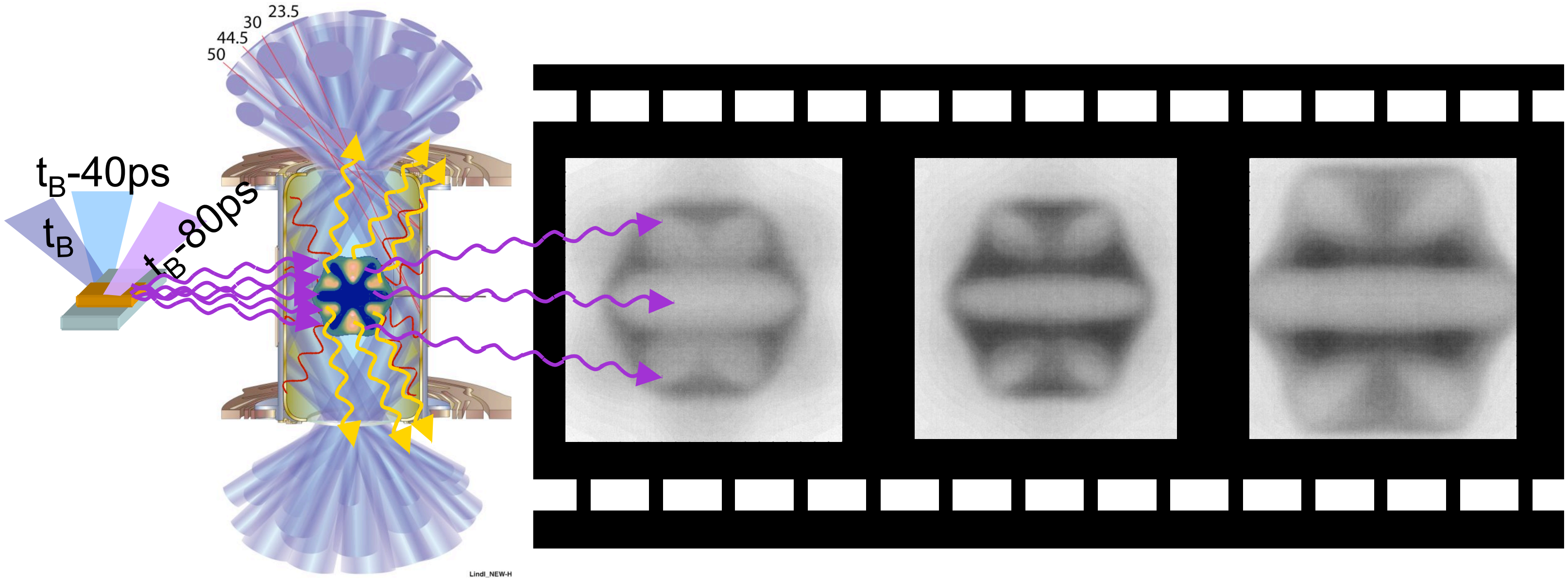
John Seely and Glenn Holland - Naval Research Laboratory, Washington DC

Larry Hudson, Csilla Szabo - National Institute of Standards and Technology, Gaithersburg MD



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Imaging the implosion of dense cold fuel surrounding core is fundamental to understand possible failures

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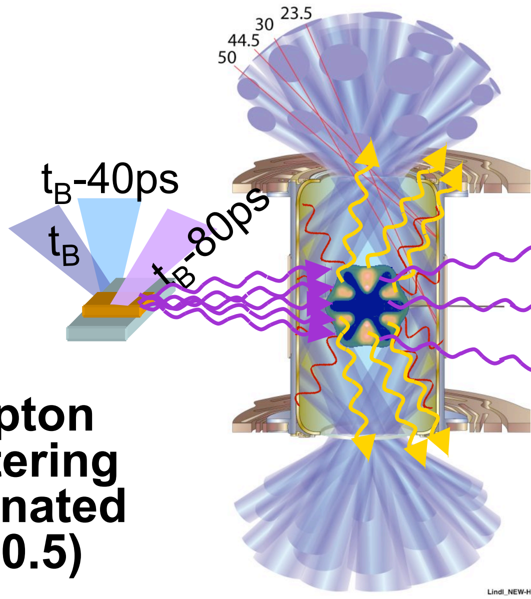
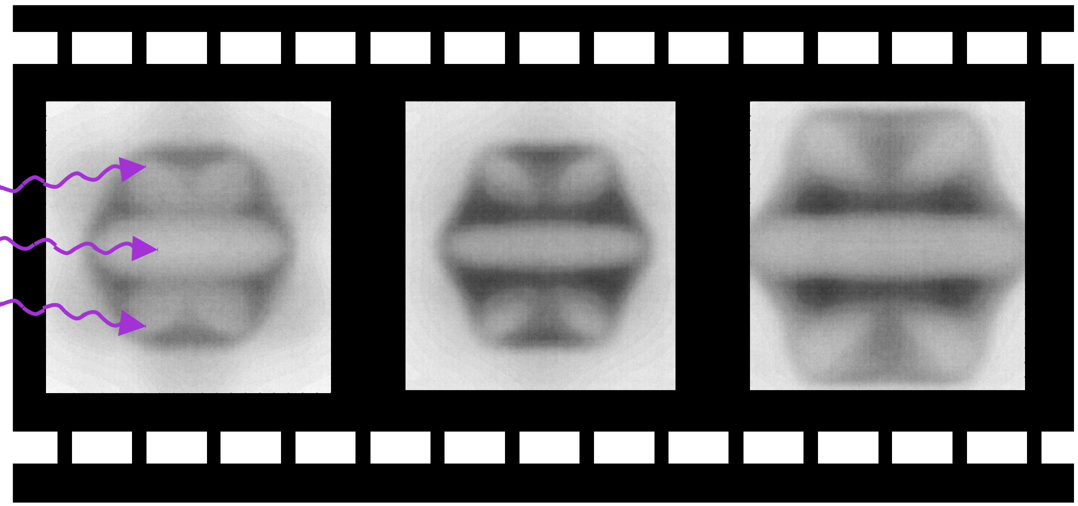


Compton Scattering dominated (OD~0.5)



Record the implosion evolution through bang time with 10um resolution

We want to record the time history of implosions using multiple radiographs produced by x-ray backlights.

The main opacity for 30-200keV x-rays traversing the core is Compton scattering: Compton radiography

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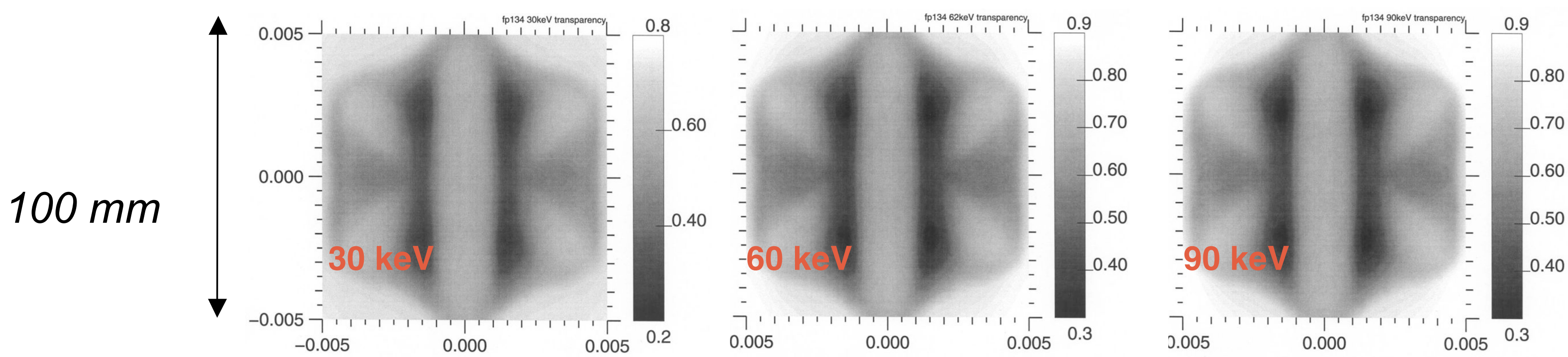
- Largely independent of probing energy between 50 keV and 200keV
- In our case: optical depth ~0.5 for ρR~3 g cm^{-2}, nearly ideal



[Simulated images, S. Hatchett, 2006]

ARC integrates multiple short-pulses into NIF: possibility to produce multiple backlighters

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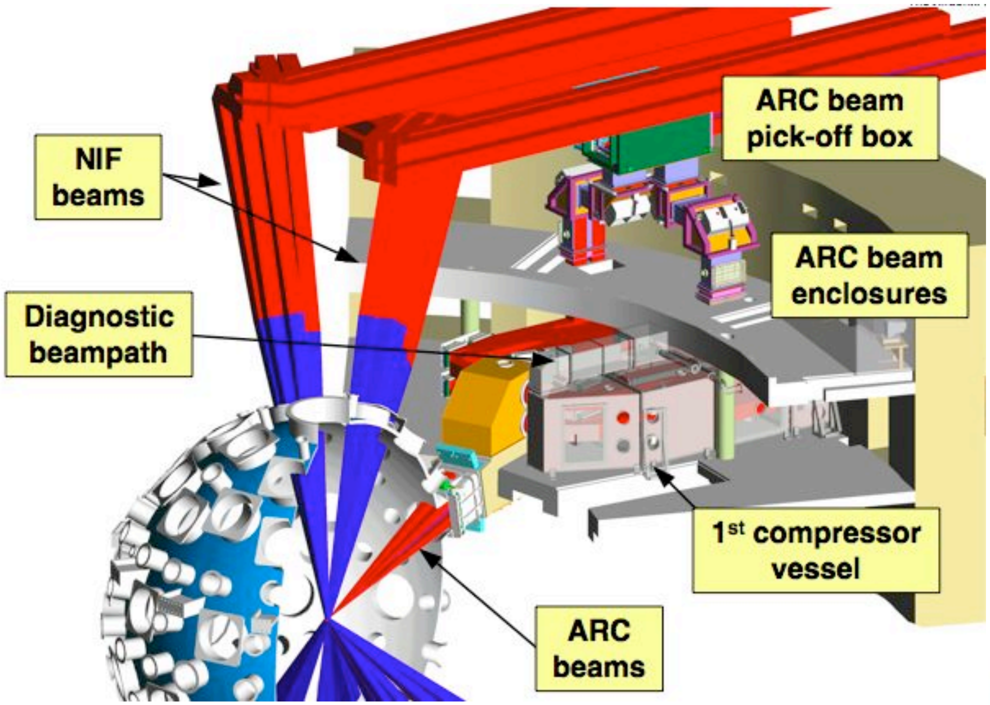

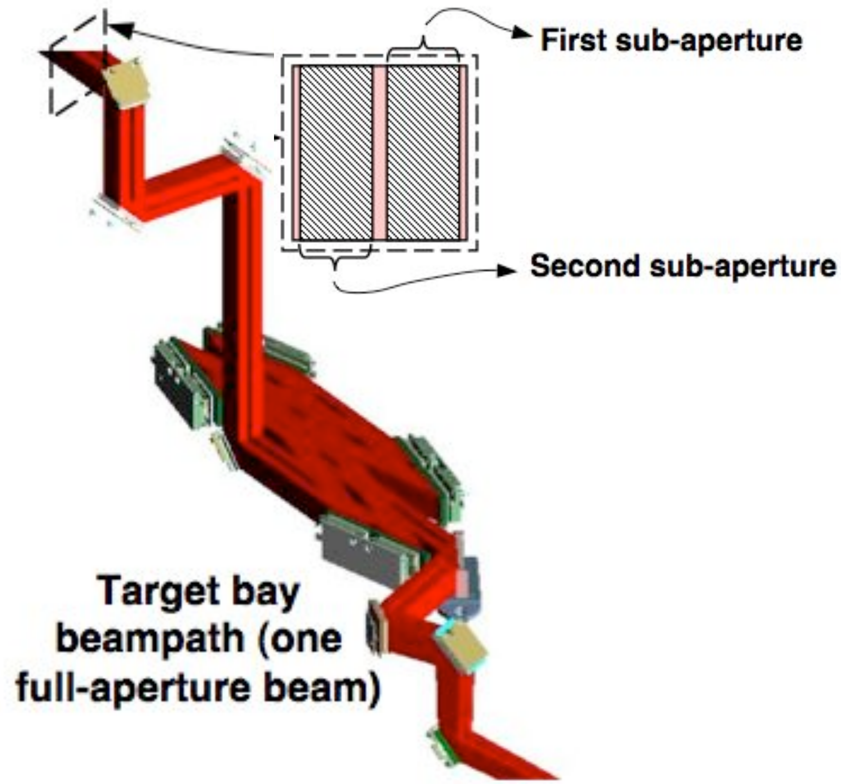

Each ARC beam is divided into two split-beams using sub-apertures

ARC will have

- **up to 8 split beams that can be independently focused on target, separated in time**
- **0.5-1.6 kJ in 0.7-50 ps / split beam: intensities up to 10^{19} W/cm^2**

We will develop multipulse ARC backlighting for NIF to record the implosion time history

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Multipulse, up to 8, backlighters for Compton radiographs of ignition capsules as they evolve through peak compression will be an extremely powerful tool to make science.

We are aiming at:

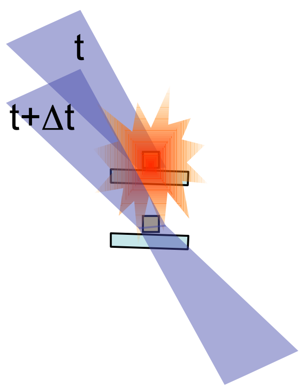
- **X-ray photon energy between 75 keV and 200 keV (for adequate S/B)**
- **2D spatial resolution of ~ 10 μm (to resolve the important features)**
- **Temporal resolution of ~ 10 ps (< implosion velocity)**
- **Interframe of ~ 50ps (to bracket peak compression)**

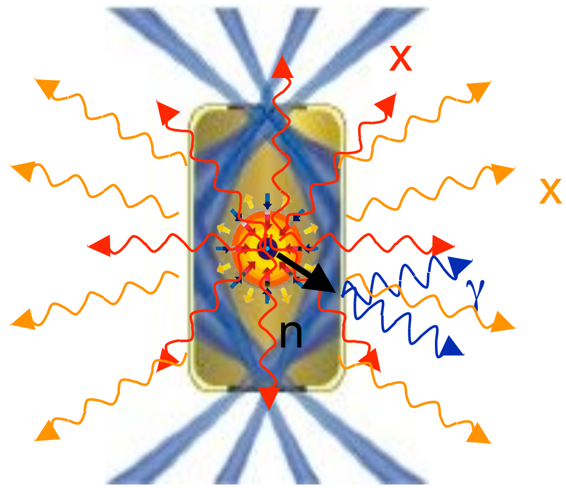
This will allow:

- **Better symmetry tuning during the ignition campaign**
- **Better science: multiple images at same shot eliminates shot to shot variations**
- **Better facility usage: Reduce damage and number of shots**

Major challenges: background and backlighters destroying each other

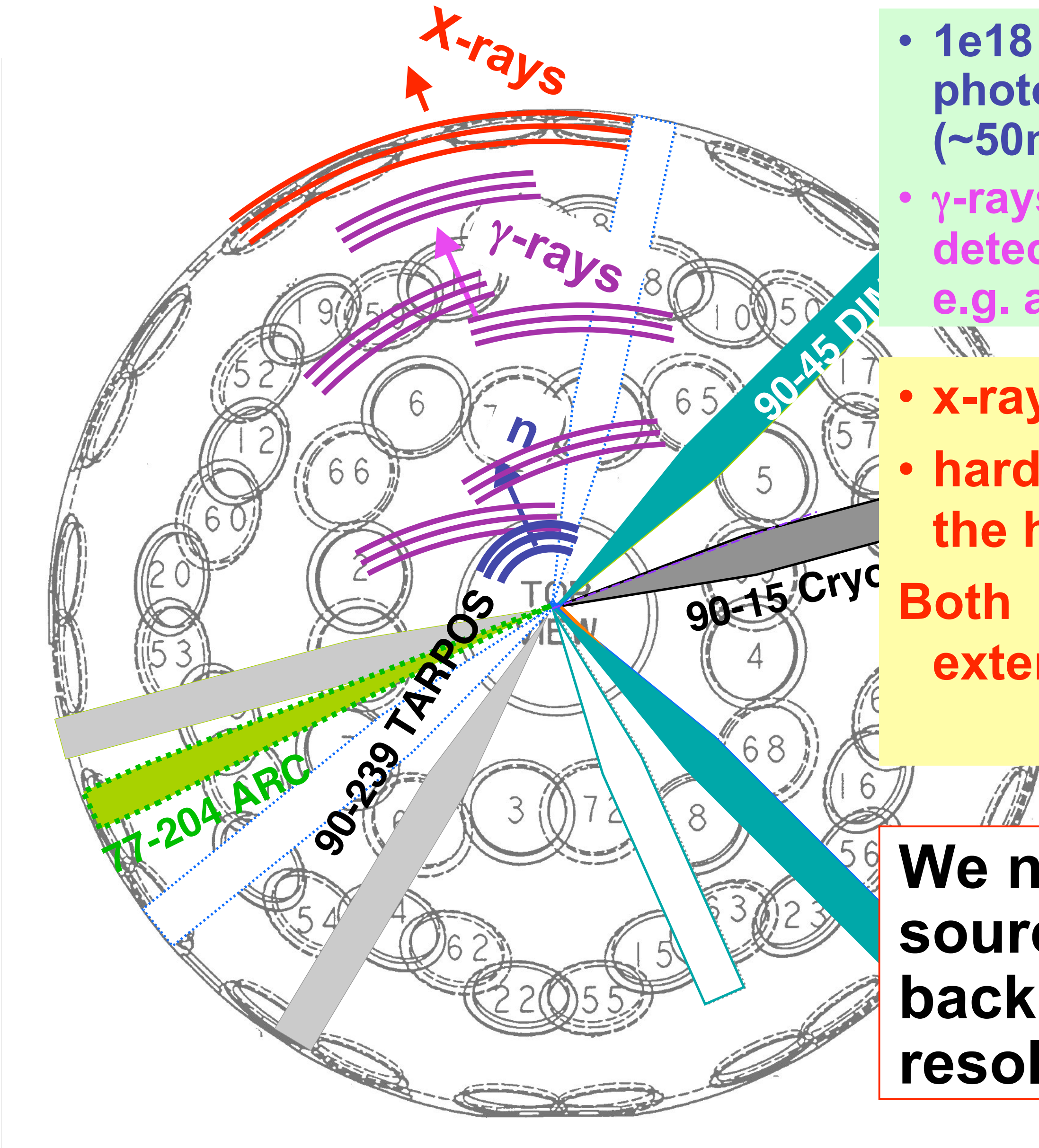
In order to record the time history of implosions through bangtime we will need to address the background: x-ray self-emission from core, hard x-rays from hohlraum, neutrons from fusion reactions, gamma rays from n-g reactions.





An ARC irradiated backlighter may destroy the next one, therefore preventing the next frame to be recorded.

Our main concern has been assessing the backlighter performance vs background



- 1e18 14MeV n's are slower than photons (~1/6 c): use a gated detector (~50ns)
- γ-rays from n- γ reactions: use a detector less sensitive in the MeV's, e.g. a thin scintillator.

- x-rays from hot core self emission
- hard x-rays from hot electrons in the hohlraum walls

Both are strong and with spectrum extended to the region of interest.

We need to know what flux and source size to expect from our back-lights to evaluate resolution, S/B and S/N.

We need to know how the backlighter signal compares to x-ray background

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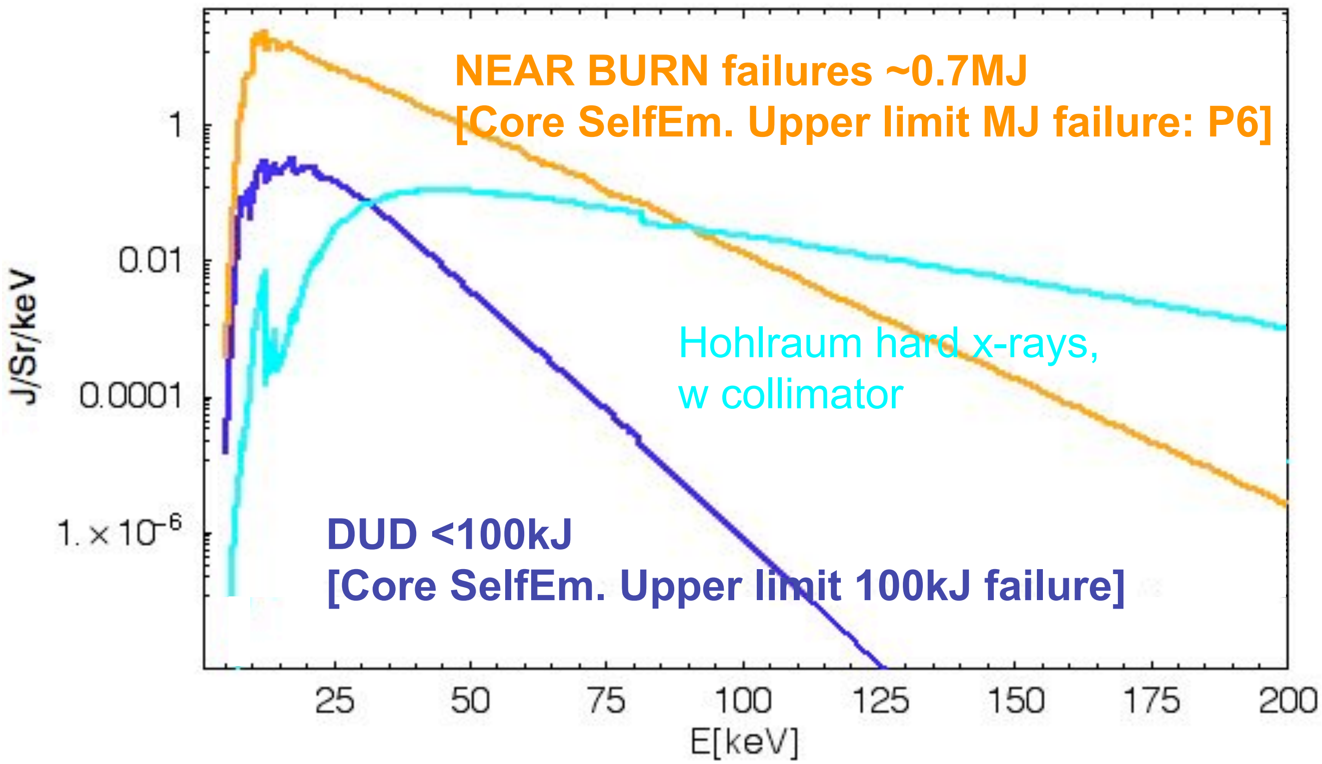

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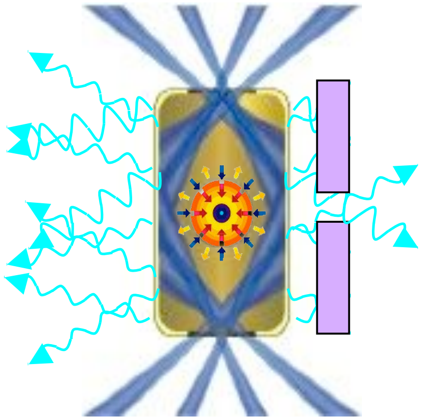

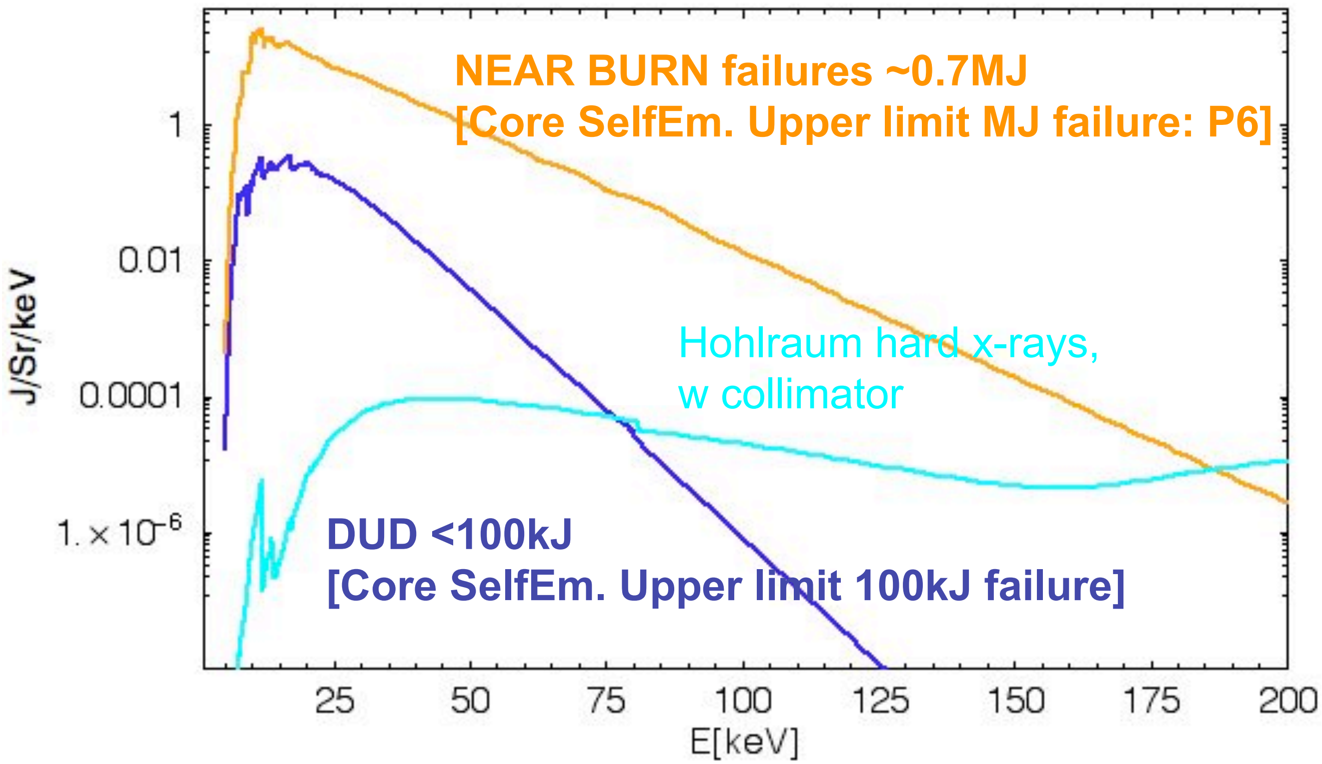

The hohlraum hard x-rays can be shielded using a collimator. The core self emission cannot, since it is generated entirely within the FOV.

We measured conversion efficiency, CE, to hard x-rays on TITAN to predict backlighter performance

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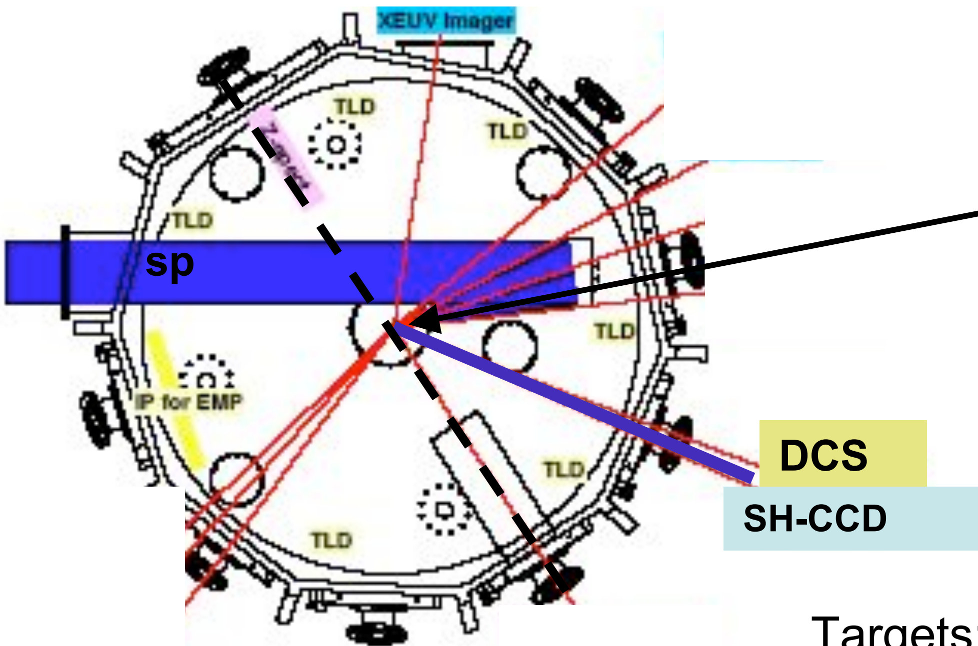

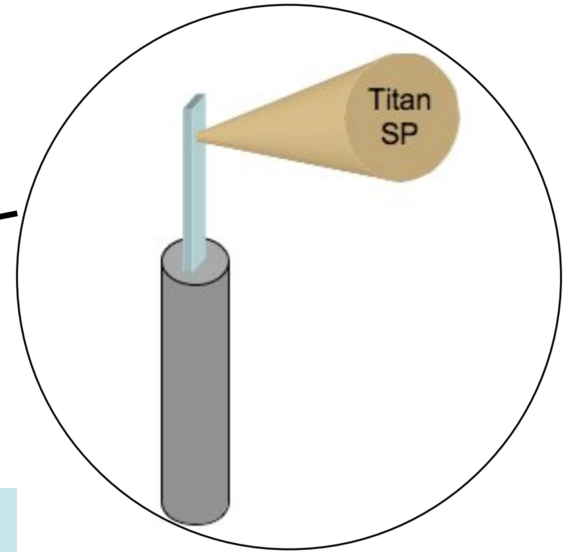

Titan parameters were maintained constant:

- Spot Size ~ 50μm diameter
- Energy ~ 250J; Intensity ~ 2E17 W/cm^2
- Pulse Duration ~ 40ps;

Targets:

- Mo, Ag, Sn, Sm,Ta, Au, Pb; foils, 25μm thick, 500 μm wide

Diagnostics:

- Dual Crystal Spectrometer, DCS [NIST-NRL]
- Single-hit CCD, providing calibration points (@ Mo, Ag and Sn Kα energies)
- Grid projection for source size.

DCS recorded the hard x-ray spectra on TITAN

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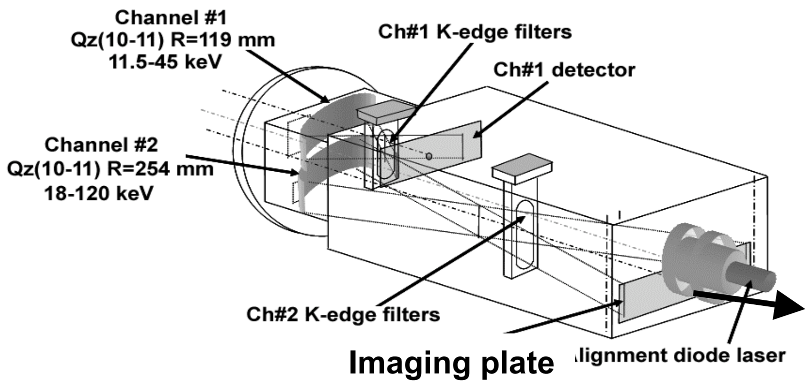

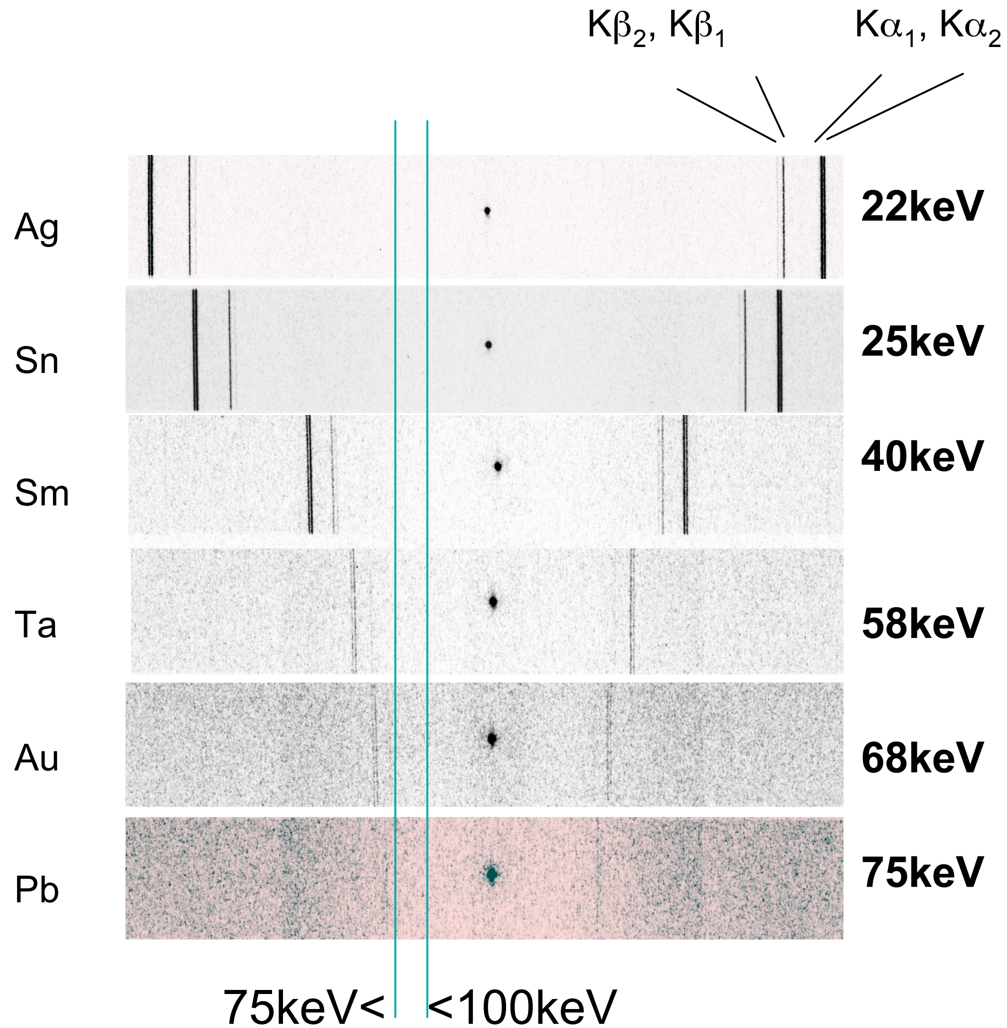

Lines are bright and distinct

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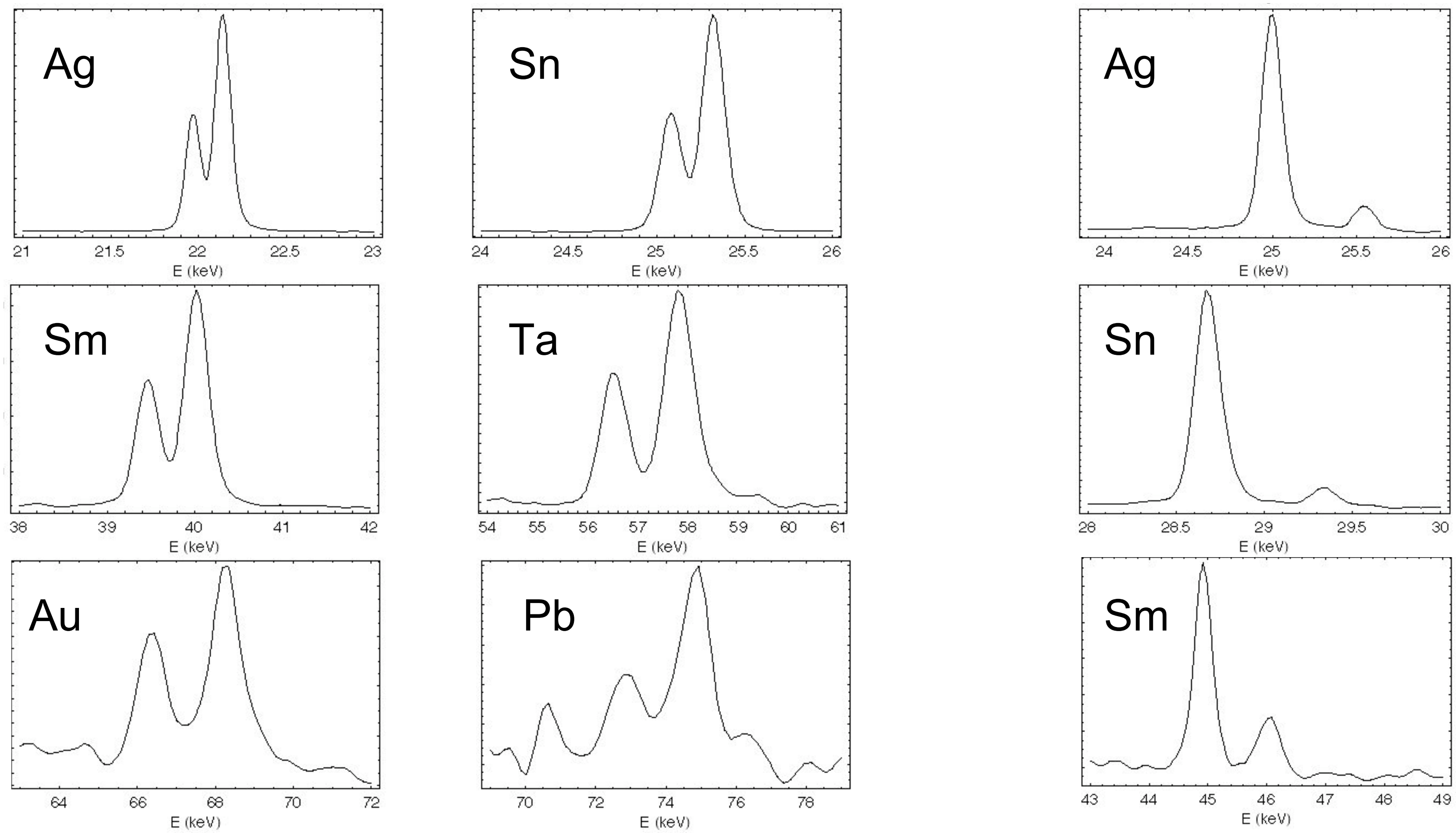
Kα lines	Kβ lines



DCS: Energy Calibrated Spectra

Spectra were deconvolved from IP and crystal calculated efficiencies.

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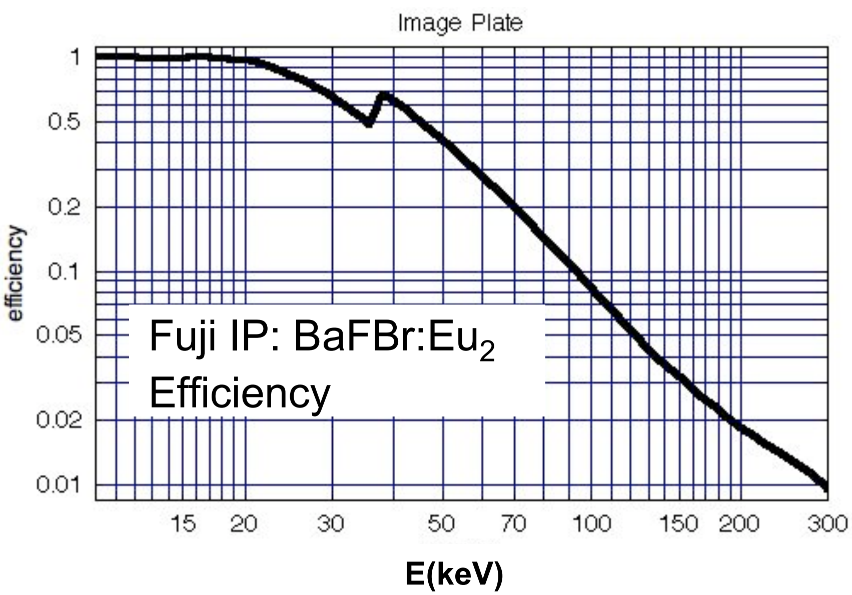

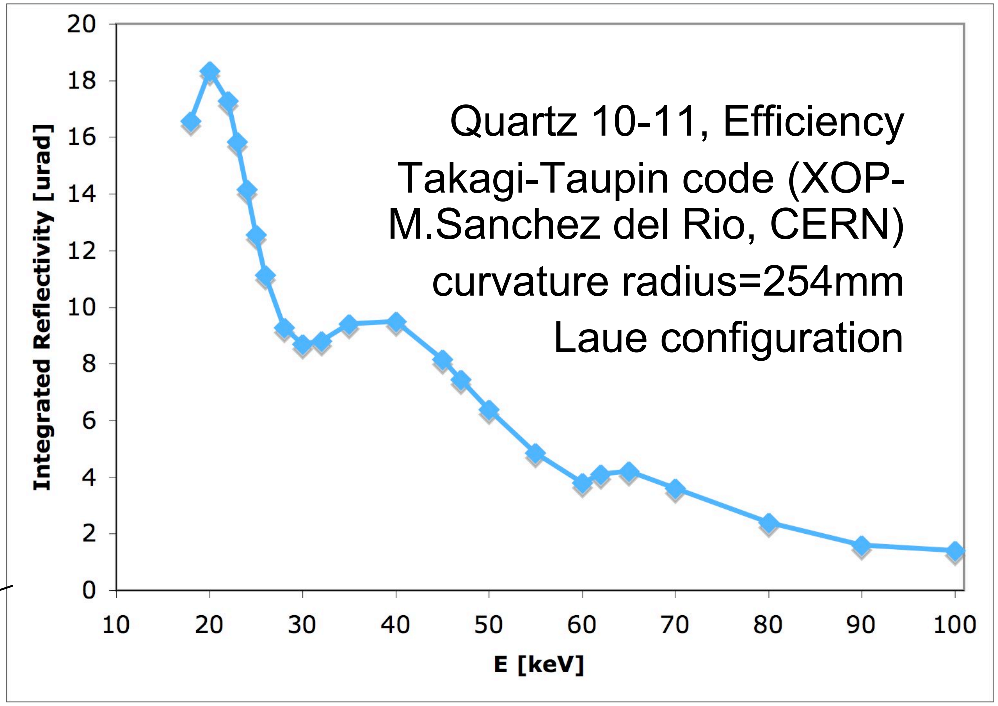

We are planning experimental measurements of the crystal efficiency [NRL-NIST]

CE to line emission: nearly independent of energy

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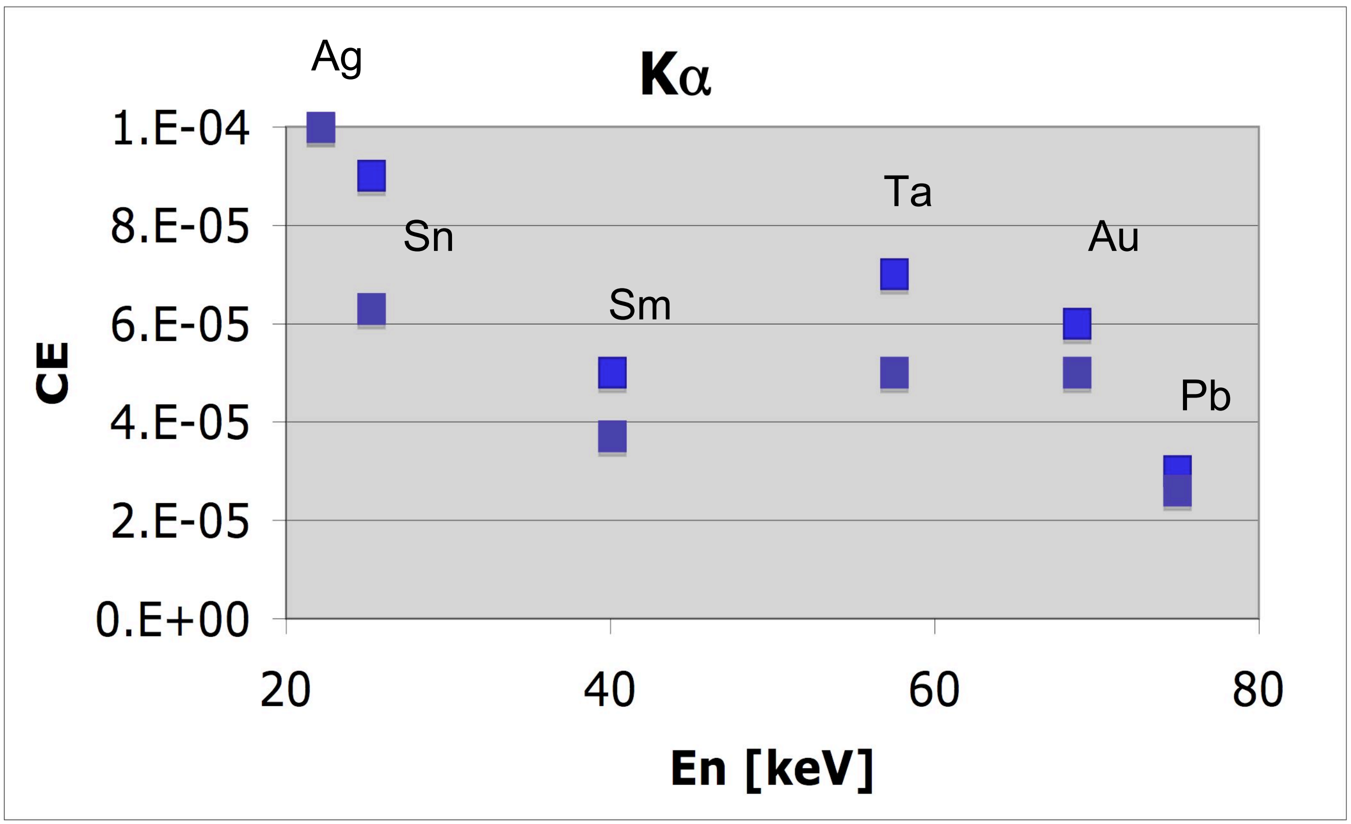
- DCS data, corrected for <u>calculated</u> instrument and detector response, give the relative CE
- Absolute CE for Ag and Sn: from single hit CCD spectra



CE to 75-100keV continuum: nearly independent of Z

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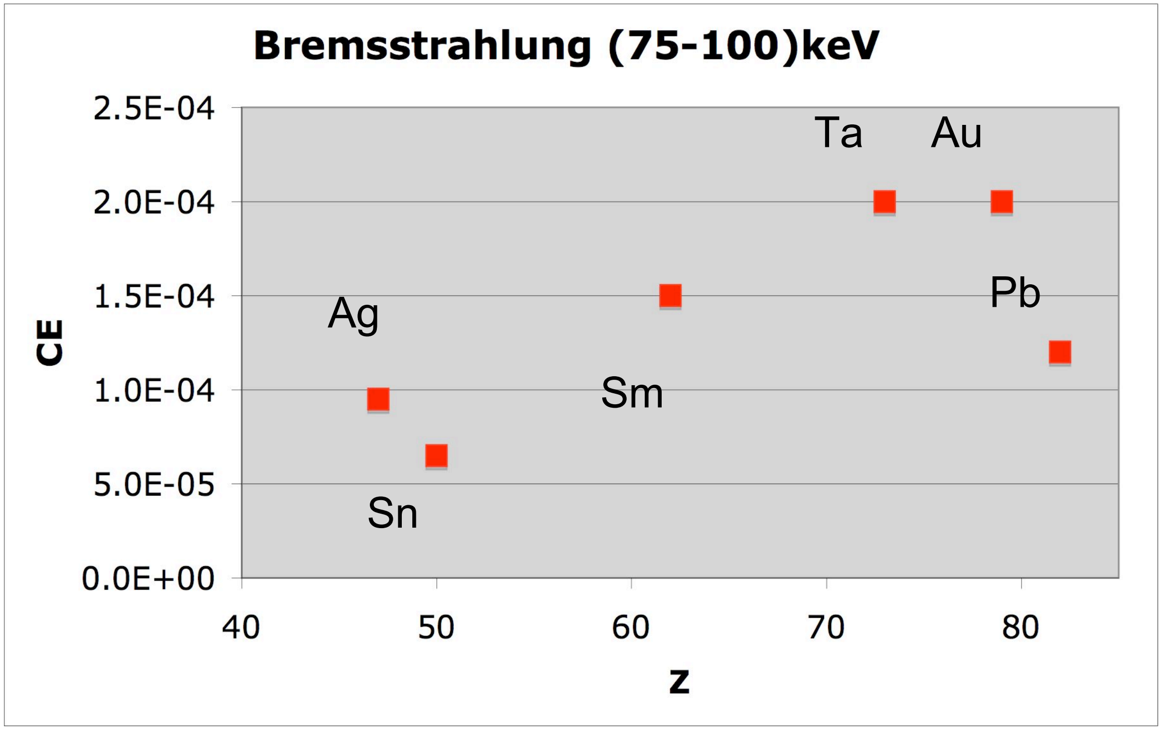

Broadband detection is easier to implement: these efficient bremsstrahlung backlighters represent big progress.

We will investigate CE at intensities > 2E17 W/cm^2 and at higher photon energies.

CR is expected to produce useful images for x-ray energies > 75 keV at sub-ignition yield levels

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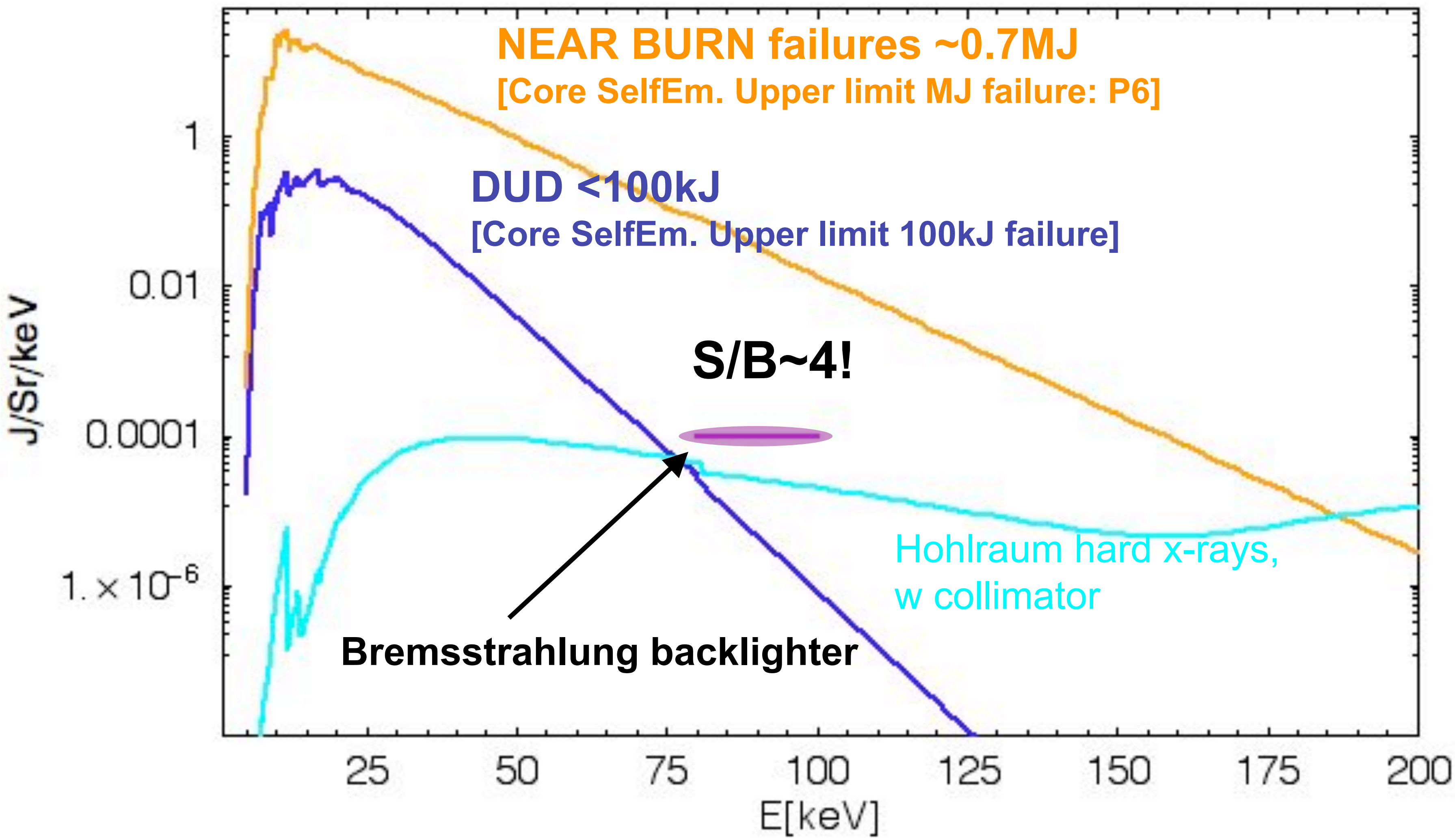

We need a 150-200keV backlighter for high-yield failures

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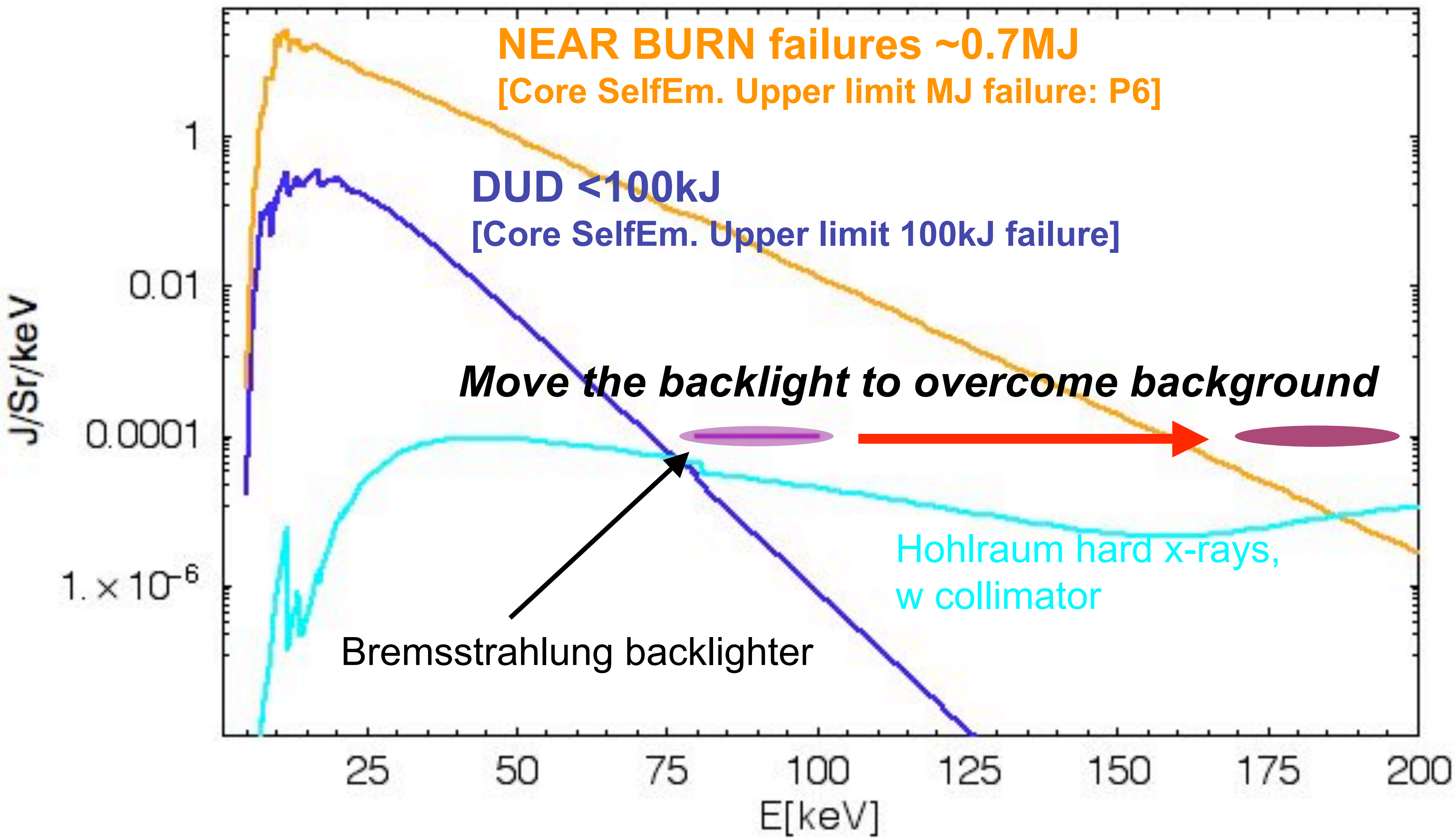

<10 μm resolution 2D radiography is achieved at 22 keV using embedded wire targets, viewed end-on

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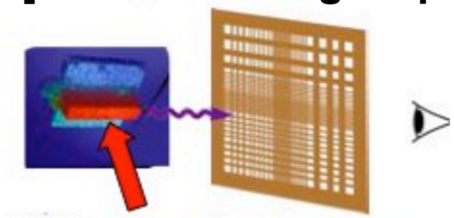
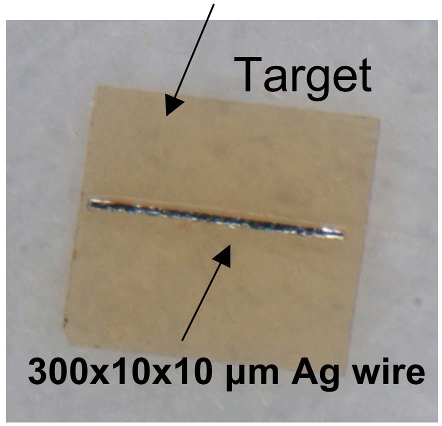
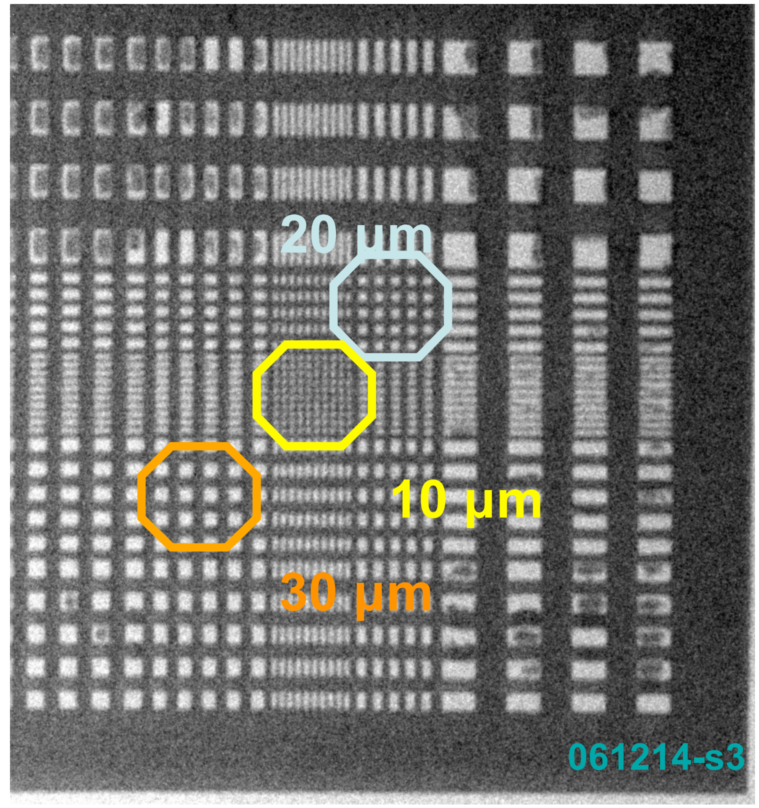
[micro-wire targets provided by GA]



300x300x4 μm CH substrate



(H-S Park et al., Dec 2006)



Effective source size = 8.5 μm: essentially limited by the wire cross section. Similar results have been obtained at 40keV. This is good enough for NIC! We expect the same at higher x-ray energies.

Implosion images of dense fuel are vital for NIC - Simulations show the great value of CR images vs downscattered neutron images

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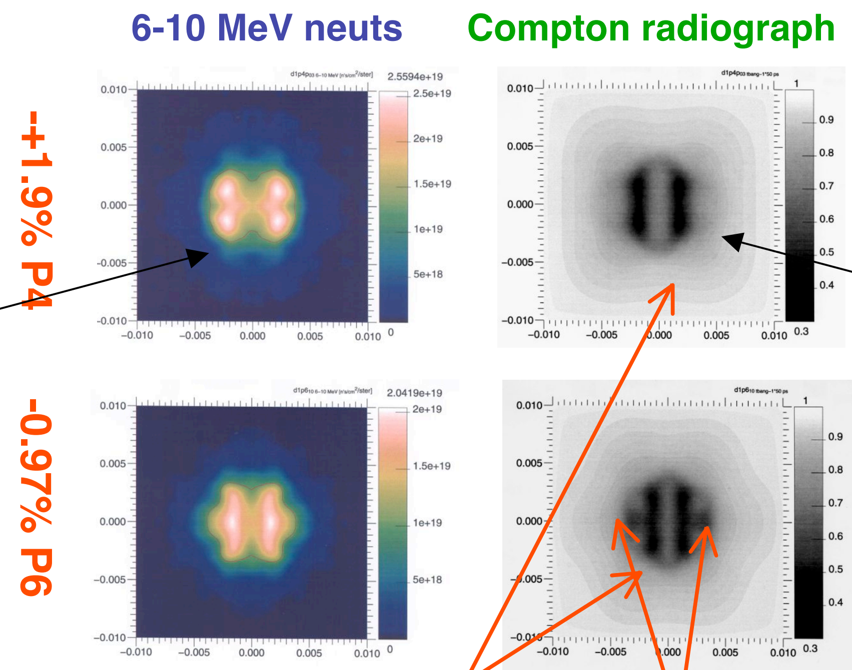
[S. Hatchett]



These are low signal regions (low S/N)

These are high signal regions (high S/N)

Compare *high* transmission contours. (*Low* contours of primary neut. image give no info)

Shadows of polar blobs

Compton radiographs distinguish the very subtle differences between a +P_4 and -P_6 drive asymmetry, at the same yield (1 MJ). Compton radiography is the only time resolved imaging diagnostic.

CR requirements are being defined by studying simulated radiographs

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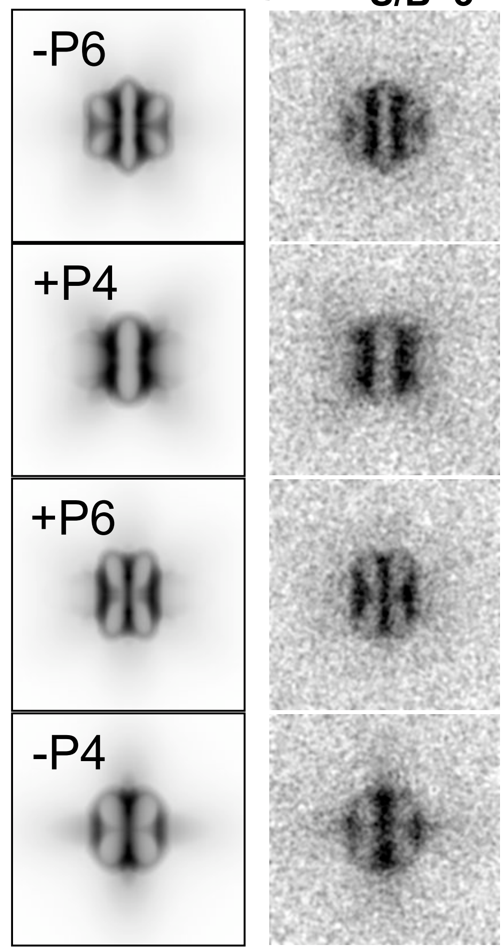
Rough cut

- **Resolution: 10 µm**
- **S/N ≥ 25**
- **S/B ≥ 1**
- **Field of view: 200 µm**
- **Temporal resolution: 10ps**
- **4 frames**
- **Interframe: 50ps (NIC); (10-20 ns, HED)**

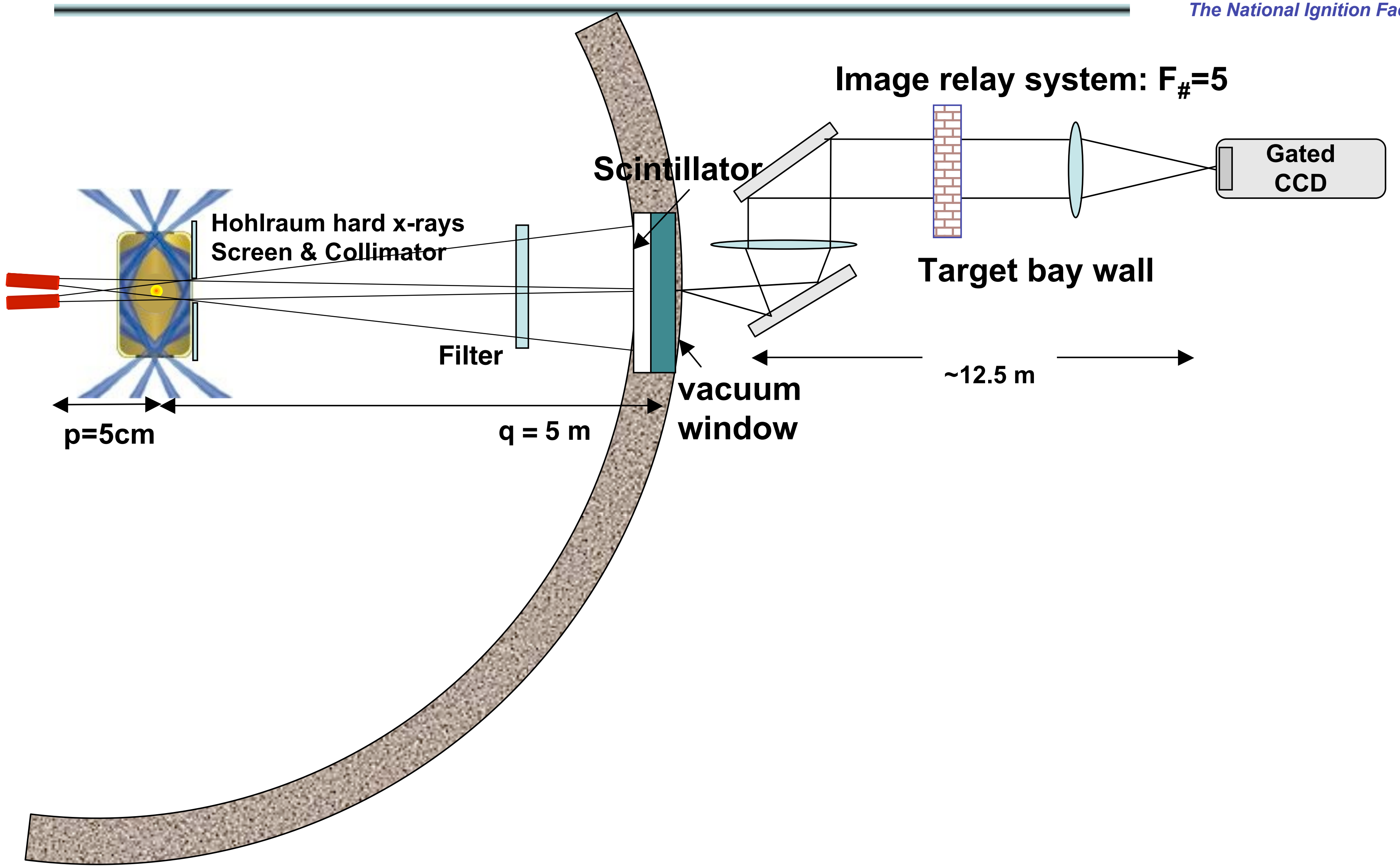
Perfect images

Simulated radiographs scaling TITAN results to ARC:

Res.=10µm
2000ph/res.el
S/B=3



We are working on the actual setup of a Bremsstrahlung backlighter for CR on NIF



A possible setup for Compton Radiography uses two orthogonal LoS (HEXRI) - 4 micro-embedded-wire BLs provide 4 snapshots of the implosion with ~40ps delay

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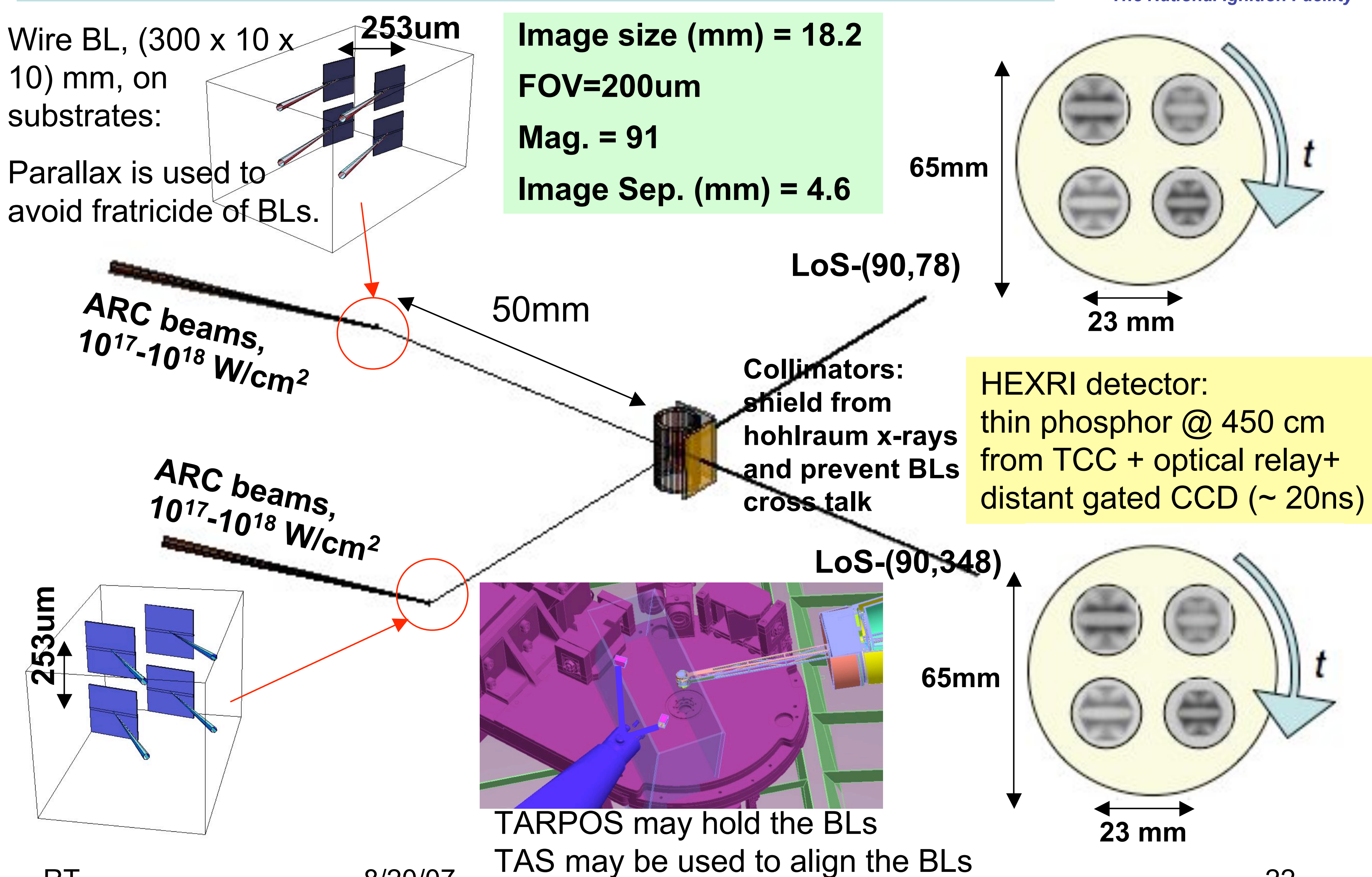

Conclusions: we have brightness and resolution to realize a powerful diagnostic of implosions on NIF

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Compton Radiography using ARC on NIF

- Probes the full core.
- Provides the time history of the compressed fuel shape leading up to peak-compression, in a single NIF shot.
- Experiments indicate that, using 75+ keV x-rays, we will have adequate source brightness and size to diagnose sub-ignition implosions.
- To diagnose high yield failures (~MJ) we need a backlighter in the $h\nu$~150-200keV region.

NEXT:

- **Extend CE measurements to U Ka (92keV) and above 100keV for continuum. Check CE to Bremsstrahlung at relevant end-on wire view.**
- **Measure the DCS efficiency.**
- **Demonstrate resolution maintained at > 75keV.**
- **Check CE to Bremsstrahlung at slightly higher intensity.**
- **Timely integration on NIF-ARC for the National Ignition Campaign.**