Opacity Spectrometer development for the National Ignition Faciltiy

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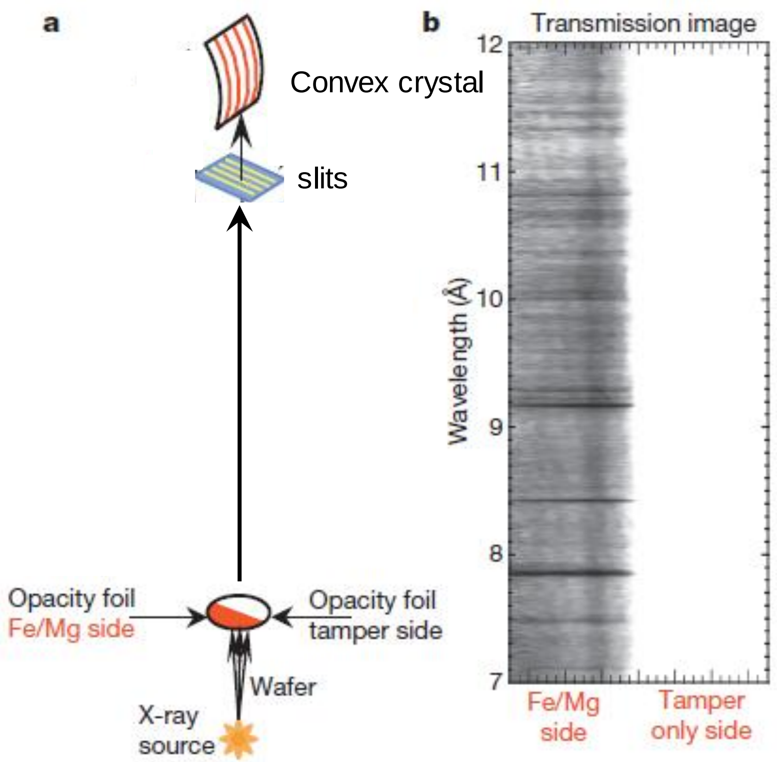
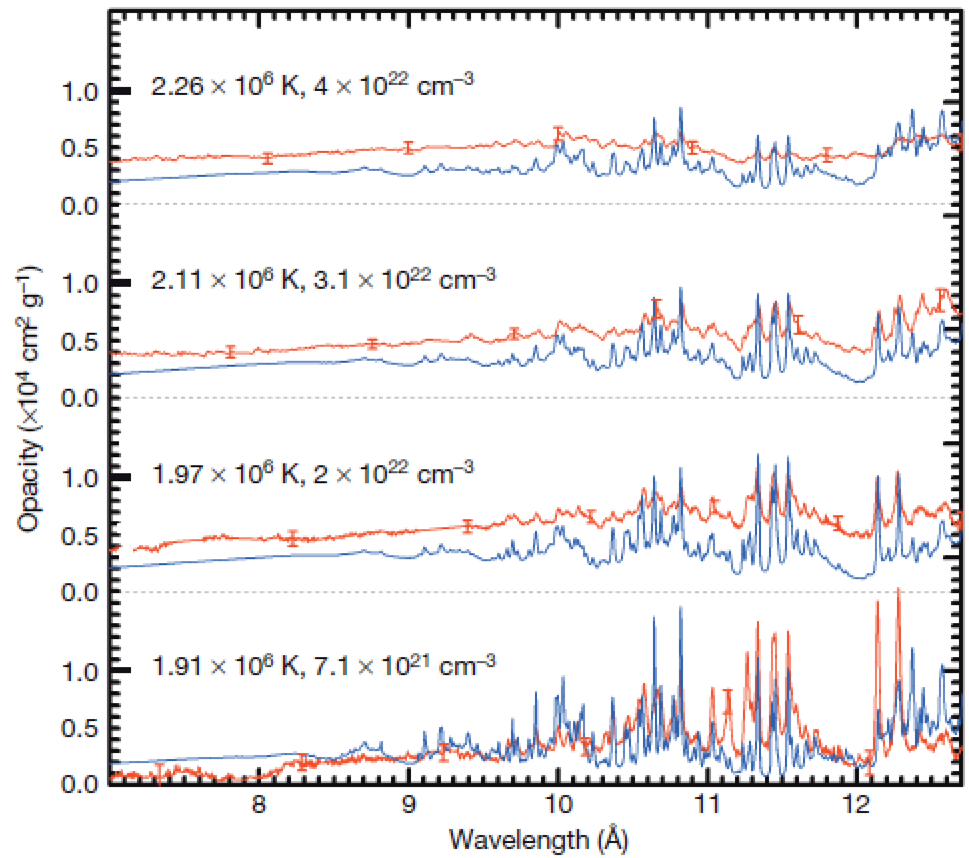
Outline

- Background – Opacity Experiments at Z
- Physics design of the Opacity Spectrometer
- Resolving Power and Photometrics of OpSpec
- Calibration of the Opacity Spectrometer
- Future Upgrades to OpSpec

Opacity Experiments at Z disagree with models

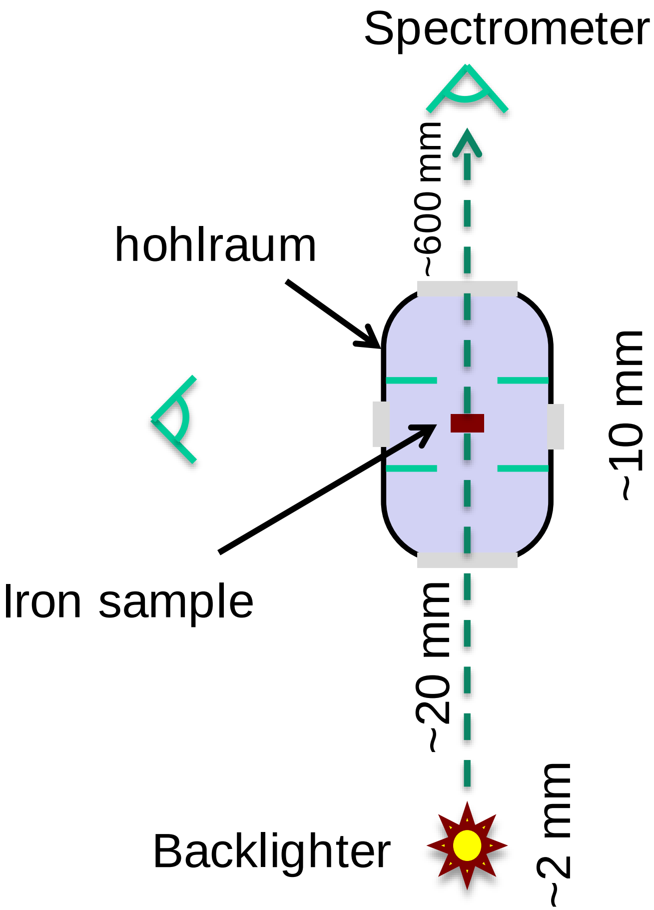


Z- data in red. Model in blue



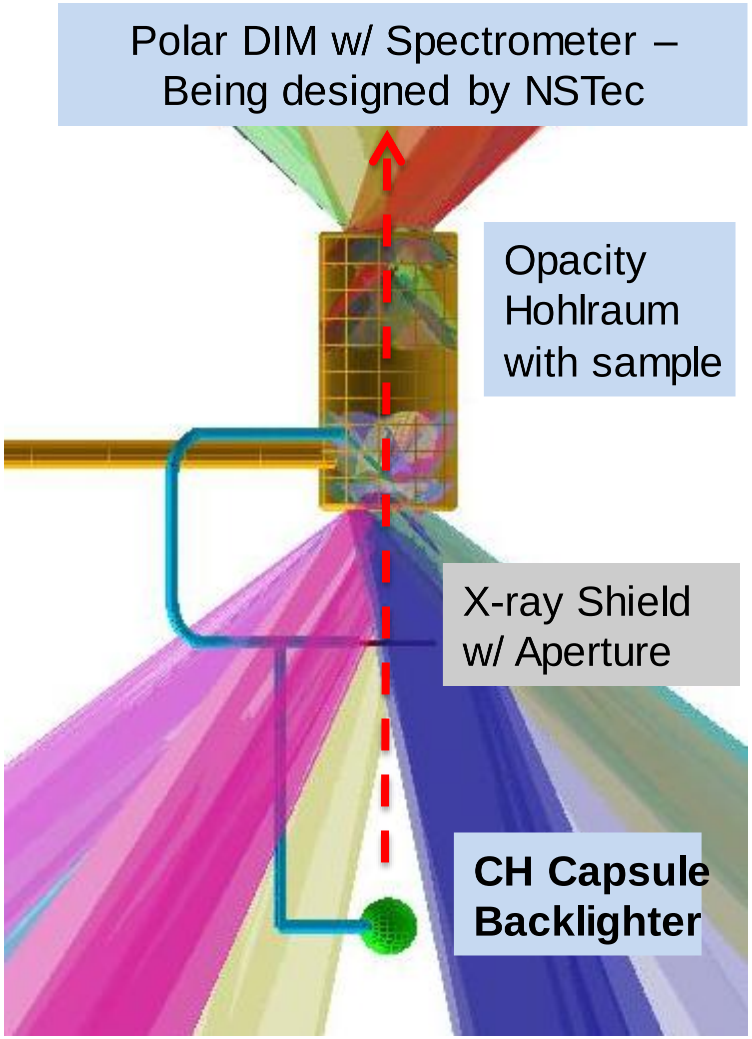
As the sample increases in temperature and pressure, the discrepancy with the model increases (Bailey, et al., *Nature* 2015.)

NIF Opacity Platform – Confirm Z opacity measurements on an independent platform

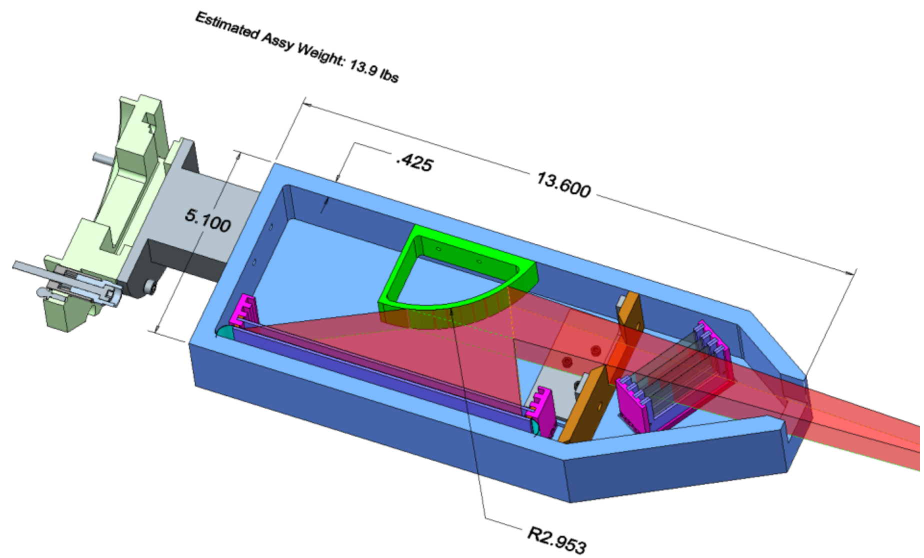


- Iron target is heated using a laser-driven hohlraum (can achieve temperatures > 200 eV)
- When the target is heated to a plasma, the backlighter is imploded, creating a broadband X-ray flash
- Simultaneously measure density with an orthogonal view of the target
- Spectrometer must cover desired spectral range
  - Spectral range determined by crystal choice
  - Minimum range dictated by Cr lines (L lines), oxygen absorption
  - Maximum range dictated by necessary spectral range (Al K-shell through Ly-beta at 2048 eV, for temperature diagnostic)

NSTec Spectrometer to be used in a 5-lab collaboration (LANL, LLNL, SNL, NSTec, LLE) for a stewardship Opacity Platform using NIF



- **NIF is only place to replicate the Z experiment.**
  - **Temperatures: 150-250 eV, 10^{21}-10^{22} cm^{-3}**

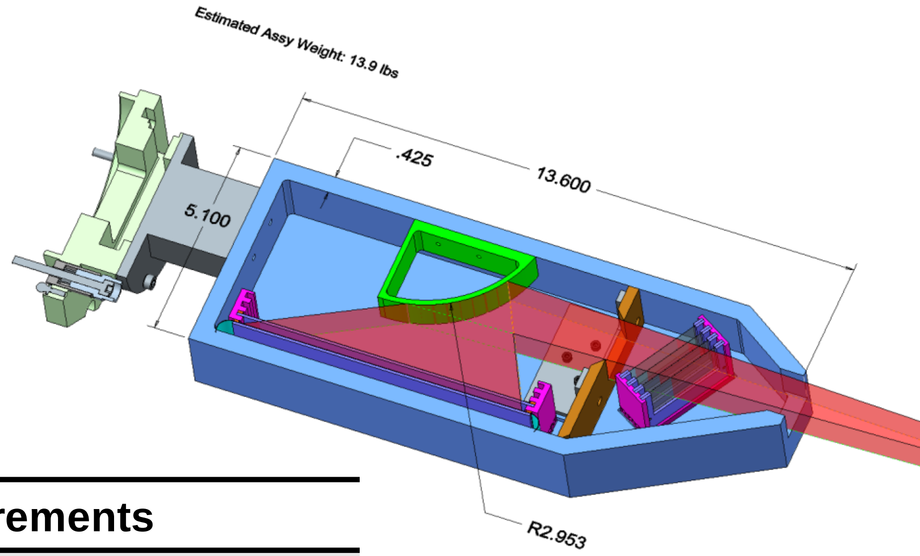


NSTec Opacity Spectrometer

Description of the NIF Opacity X-Ray Spectrometer (OpSpec)

The OpSpec is a crystal spectrometer snout designed to be fielded on a DIM in NIF. (Self-contained snout)

Time-integrated X-ray spectroscopy will be performed on NIF with OpSpec. (Time-resolved opacity measurements using a pulsed backlighter X-ray flash of ~500 ps)

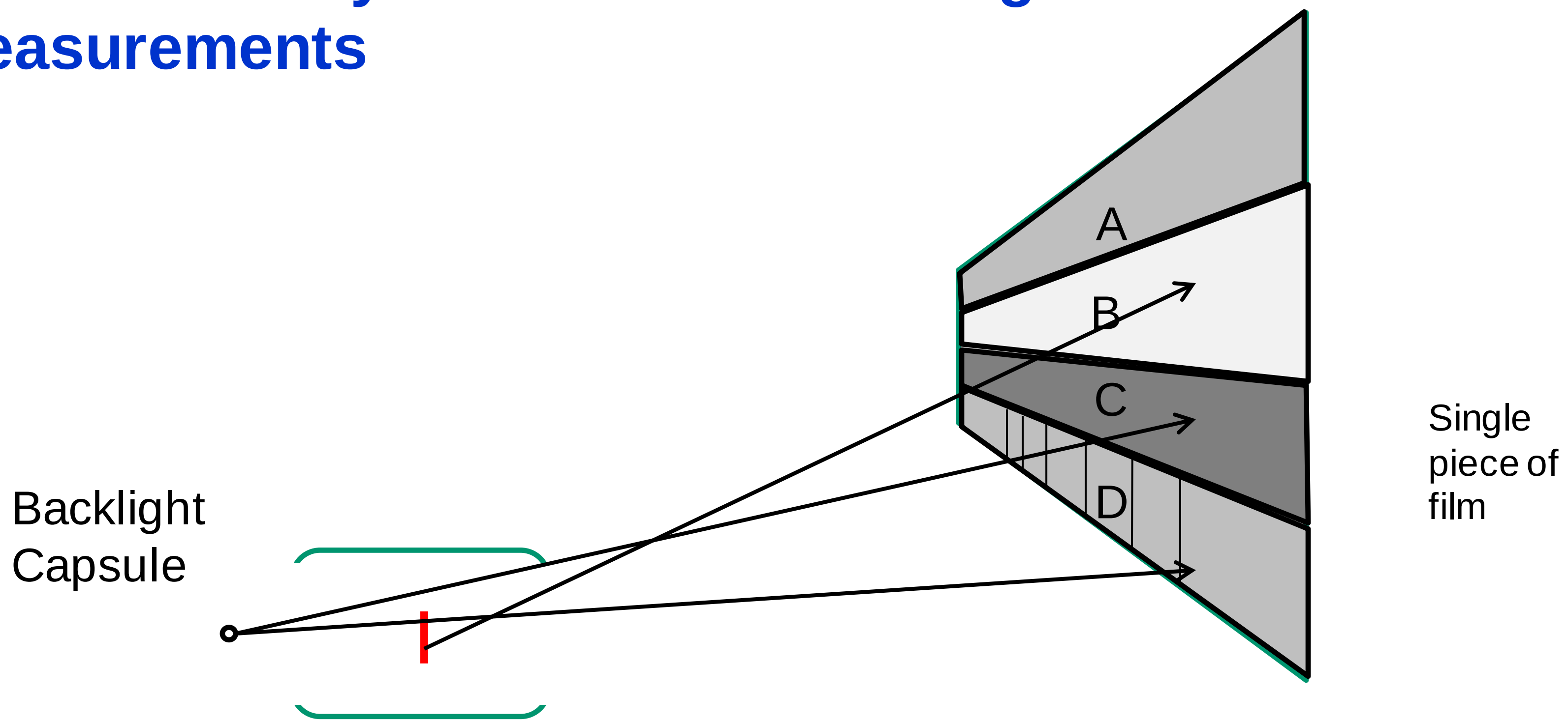


Preliminary OpSpec Design

OpSpec Design Specifications/Requirements	
Dispersion Element	2 Curved Bragg Crystals
Spectral Coverage	0.54 – 2.1 keV photon energy (extendable using other dispersion elements e.g. PET vs. KAP crystal)
Resolving Power	E /ΔE > 500 (>700 from 0.8 to 1.5 keV)
Data Collection	Time-integrated X-ray film or Image Plate (Solid State detector in future)
NIF Usage	All DIMs (initially on Polar DIM). Weight <15lbs

OpSpec requieres ~170 mm film

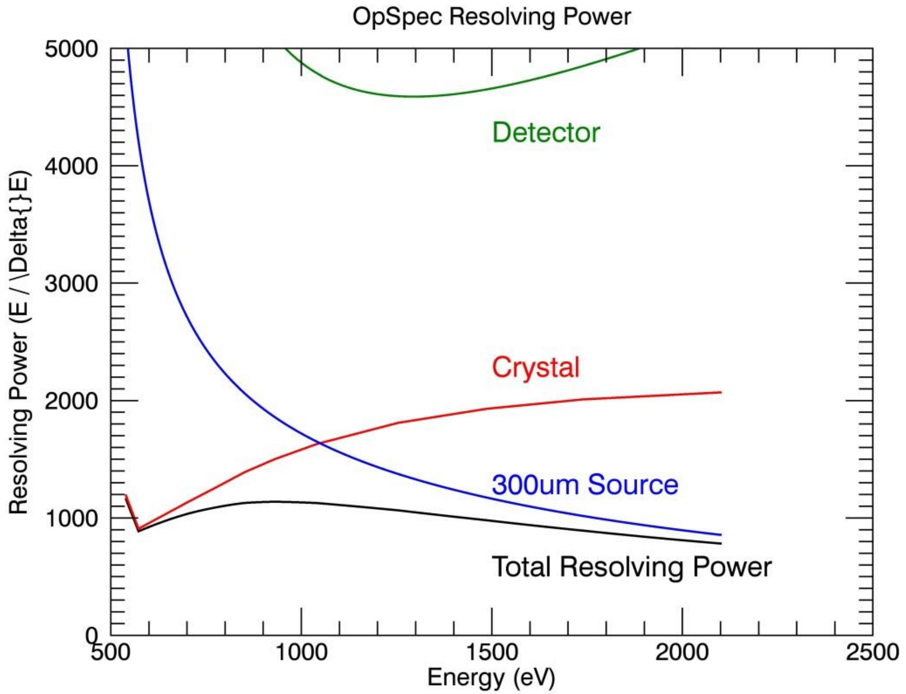
Ray tracing the NIF Opacity platform allows us to simultaneously make data and background measurements



A. Background
B. Self Emission
C. Source (unattenuated)
D. Opacity region (data of interest)

Data mirrored about Line of sight on 2nd piece of film.

OpSpec Resolving power meets design parameters of > 800 over the energy range 540 eV to 2100 eV



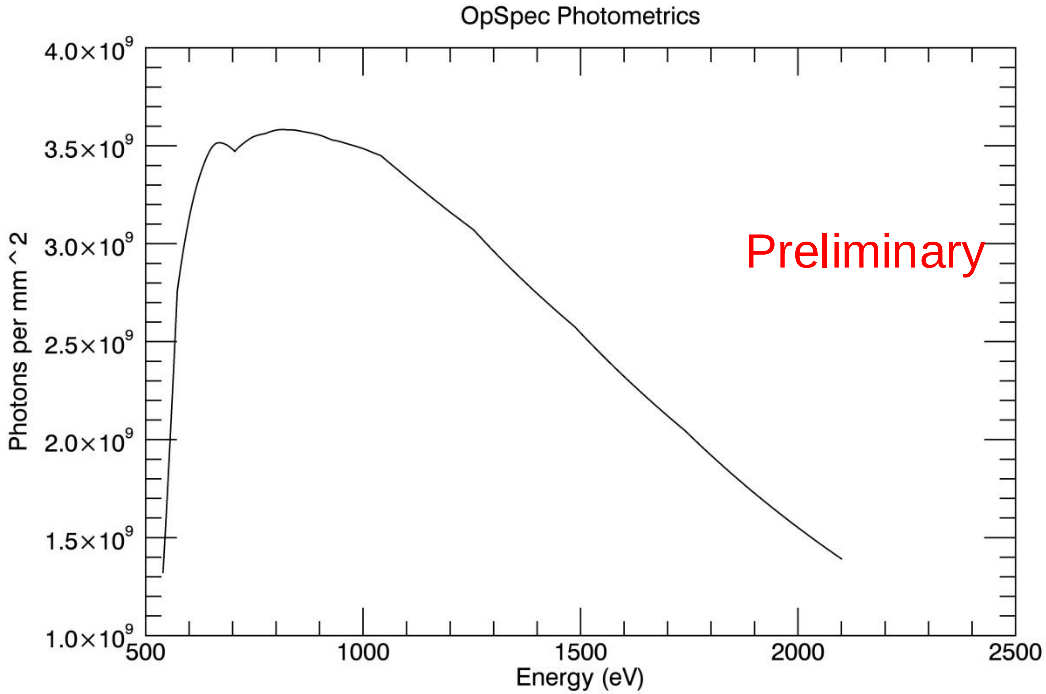
OpSpec Design Parameters

Film Length	173 mm
Resolving Power	>800
Crystal	KAP
Crystal Radius	75 mm

- Calculations assume a source size of 300 µm and a source-to-crystal distance of 600 mm.
- Detector resolution is assumed to be 20 µm.
- Crystal resolving power is from Henke’s tables.

Preliminary OpSpec photometrics calculations indicate sufficient number of photons for good statistics

- Expected resolution of film: ~20 μm
- Expected number of photons: ~10^6 photons per resolution element
- Since this is a point-projection geometry, we can use averaging over the entire data region to increase photon statistics
  — ~5×10^7 photons per spectral resolution element



Calibration of the Opacity Spectrometer

- Offline calibration
  - — Use a Manson source with Fe, Cu, Mg, Al lines to cover the desired spectral range

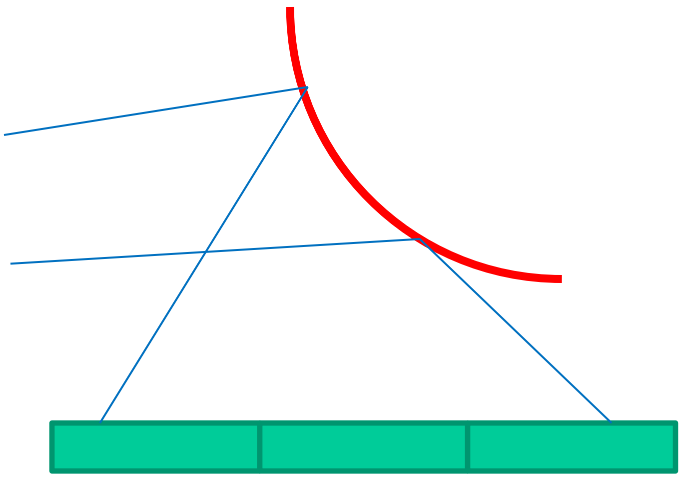
- Optical characterization of the crystals between shots

- In situ calibration
  - — Spectral range to include O and Al absorption lines
    - – Filter material will be aluminized polyimide. (includes O and Al)
  - — OpSpec designed to simultaneously measure:
    - – Background level
    - – Self emission of the sample
    - – Unattenuated source emission
    - – Sample absorption
- 2^{nd} order X-ray contamination to be measured by using different filters on each crystal to cut out the low energy x-rays

Future Upgrade: OpSpec II, Gated Solid-State detector

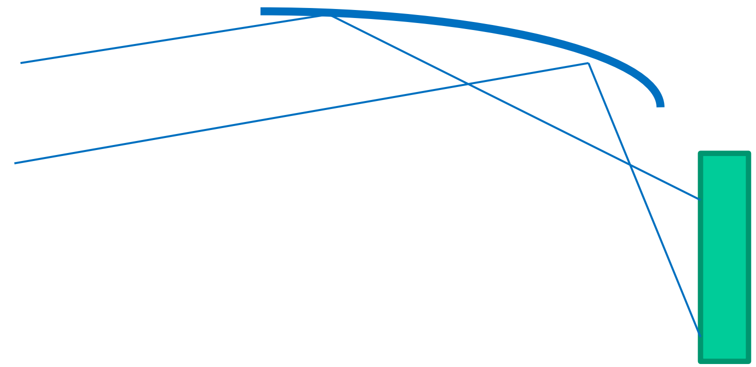
- Current detector: Kodak 2492 film
  - Need 7” of film, 2 pieces per NIF shot
  - Supply is limited
  - Time integrated
- Future Instrument with solid-state sensor
  - Looking into Sandia sensor development
  - 1 ns gating
  - Multi-frame, allows for temporal resolution
    - (multiple backlighters? Self-emission?)

OpSpec II: Convex vs. Concave crystal



Advantages:
- Minimal Re-design
- Small Crystal Size
- Lots of detector pixels

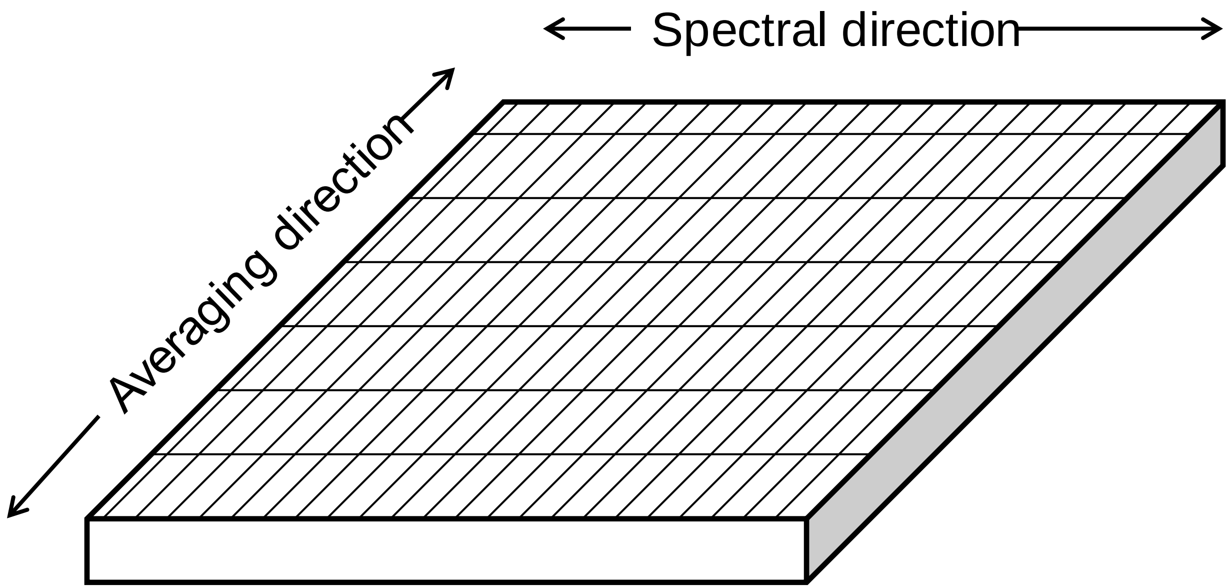
Disadvantages:
- Multiple, tiled CCD's
- Custom CCD (tiling, etc.)
- Lose spectrum at tiling?



Advantages:
- Single CCD
- Commercial detector
- Do not need to co-time cameras

Disadvantages:
- Tiled crystal (possible 250 mm)
- Significant hardware re-design
- Lose spectrum at tiling?

Sensor Solution: Asymmetric pixels?



OpSpec could use a chip with pixels that are significantly larger in the For the OpSpec, having asymmetric pixels may reduce the complexity of the detector, allowing more chip-space for necessary architecture.

Timeline for the OpSpec

- 1 October – Preliminary design complete
- 5 October - 30 October – NIF reviews (TaLIS, D&S, etc.)
- 30 October – NIF final design review
- 1 October – begin purchasing long-lead items
- 5 December - 14 February – Hardware fabrication and cleaning
- Mid-March –Deliver to NIF
- Mid-April – First shots on NIF
- Post-shot calibrations

- FY16-17 begin process for developing the sensor to replace the film
  - (OpSpec II)