Spatially-resolved $T_{ion}$ for NIF

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The neutron imaging system is operating at NIF and has been providing hot-spot and cold fuel shape information since 2011.
Nic experience shows us that neutron and x-ray imaging are not the same. Recent 3D simulations have provided insight into this difference.

A comparison of neutron images to x-ray images shows significant differences due to uneven distribution of mix in the simulations.

Currently there is no x-ray imager with the same view of the target as NIS, so we can’t compare directly for asymmetric (3D) sources.
Multi-frame neutron imaging

- Burn width is short compared to time of flight spread due to neutron energy variation
- Current NIS records images of two energy bins: 14-17 MeV (primary) and 6-12 MeV (downscattered)
- Neutron imaging with multiple frames could provide images with finer energy resolution and allow determination of ion temperature profile at bangtime
- This is not a new concept, but it was not previously considered feasible. Higher yields, faster cameras, and better analysis may have changed that
Measurement concept

Separate images

Reconstructions

Coregistration

Time series for each pixel
Notional recording system

Replacing one of the 1-frame cameras on the NIS with a 1 GHz multiframe camera could provide the required data - cameras are or soon will be available.

Sandia Hybrid multiframe sensor  Specialised Imaging 1 GHz framing camera
Modeling – Information content

- Modeling with an ideal pinhole shows that the information exists to reconstruct ion temperature profile
- Reconstruction depends on pixel size, time resolution, and signal level
- Model uses neutron counting statistics
At $Y_n=3\times10^{15}$, 10% error in $T_{ion}$ at brightest pixel

![Graph showing Tion error for 25um P0, 4um pixel, 100% contour, $dt=1$ns](image)
At $Y_n=2 \times 10^{16}$, 10% error in $T_{ion}$ at a 4$\mu$m pixel on the 17% contour.
Larger pixels (worse spatial resolution) allow more accuracy at lower yield

8µm pixels $\rightarrow$ 10% error at 17% contour at $Y_n=1e15$
Some information can be obtained with fewer frames

dI/dT @ 3 keV

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Challenges

- Current reconstruction algorithms are optimized for shape, not pixel accuracy
- QE of split-intensified framing cameras is poor
- 1 GHz hybrid CMOS camera not yet available to field
- 3D to 2D spatial averaging – each pixel in an image averages ion temperature along a line integral through the source, reducing the signature
- Coregistration and cross-calibration challenging
Path forward for 2D imaging

- Work underway to determine yield required for Tion reconstruction with a real system
- New aperture may be needed to capture lower-signal outer time bins
- Reconstruction algorithms could be adjusted
Potential alternative: 1D imaging

- Spatially integrating along one dimension increases signal to noise ratio, and allows use of more sensitive streak cameras
1D imaging

- Forward model has been developed, studying signal levels
- Downside: spatial averaging problem is significantly worsened
- Localized hotspot may only change diagnostic signature a few %

Simulated streak image for 200x magnification rolled edge, 1D simulated source plasma with $T_{ion} = 4$ keV (avg)
Combining with other data

- Temperature profile can be combined with neutron image to extract DT ion density
- Ion density and temperature can be used to calculate expected x-ray emission (from DT alone)
- This can be combined with measured x-ray emission to determine amount of carbon mix
- 3D time (energy)-integrated neutron imaging may be combined with a Tion measurement to better understand 3D structure of hotspots, etc