3D Burn Imaging with Neutrons and Photons

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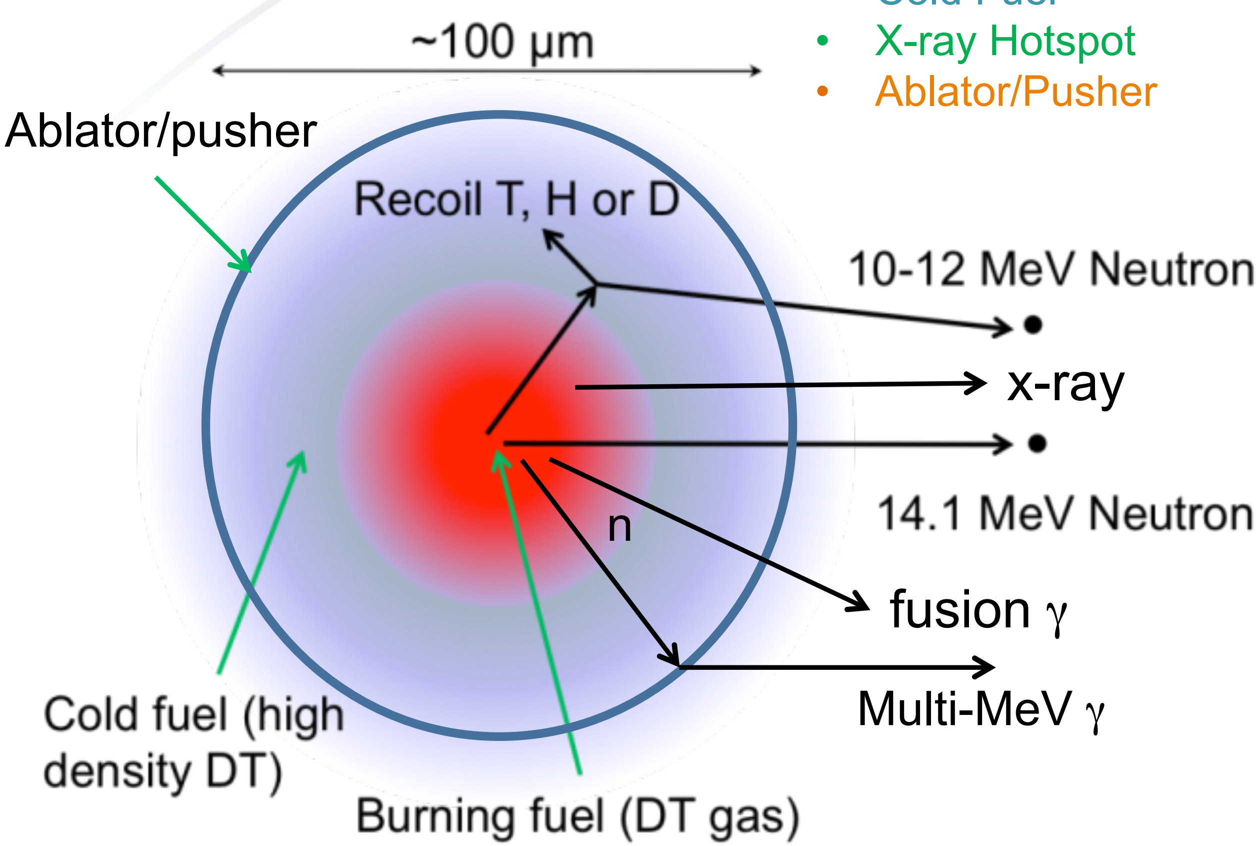
Our goal is to fully measure and characterize the 3D fuel assembly at stagnation.



- Neutron Hot spot
- Cold Fuel
- X-ray Hotspot
- Ablator/Pusher

- 3D down scattered image provides location of dense, but non-burning fuel.
- Combining neutron emission with x-ray emission, provides information on mix.
- (n, γ) in ablator/pusher provides location of ablator.
- Energy resolved neutron imaging provides spatially resolved temperature and possibly rotation velocity.
- Fusion γ imaging has potential to provide a measure of time resolved burn.

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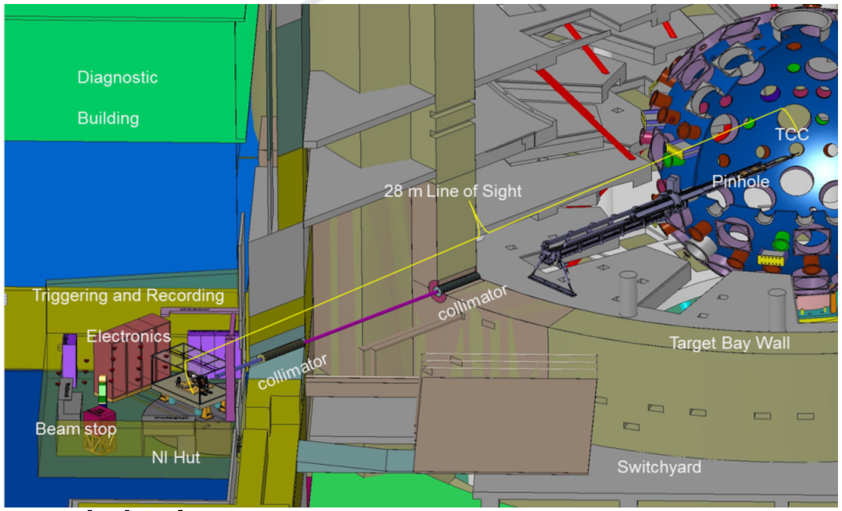
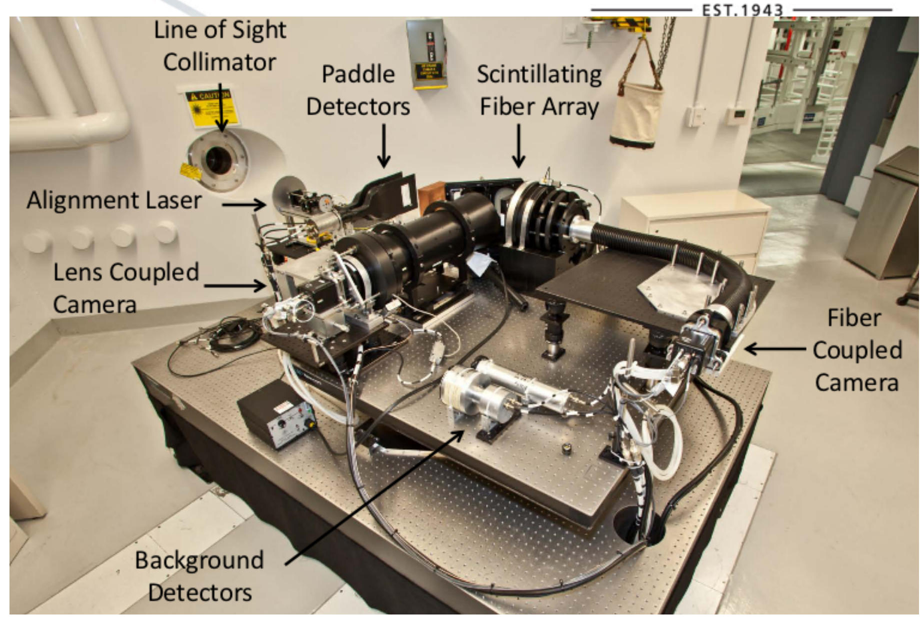
We are investigating a wide range of diagnostics to achieve this goal.

1. Neutron Imaging System (NIS on 90-315)
2. Co-Neutron and X-ray Imaging (CNXI)
3. Multi-View Neutron Source Imaging
4. 3D x-ray and Neutron emission reconstructions
5. Gamma, Neutron and X-ray Imaging (GNXI, 90-315)
6. Spatially Resolved Temperature Measurements (SRT, 90-315).
7. Fusion Gamma Imaging (FGI, 90-315)

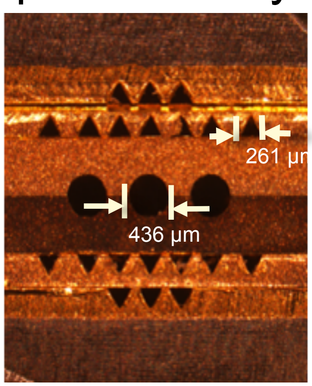
Done
Actively working on
Determining Feasibility
Need Technology Development

The existing neutron imaging system continues to provide the backbone for these measurements.



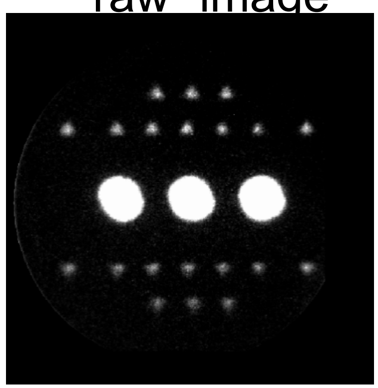


pinhole array

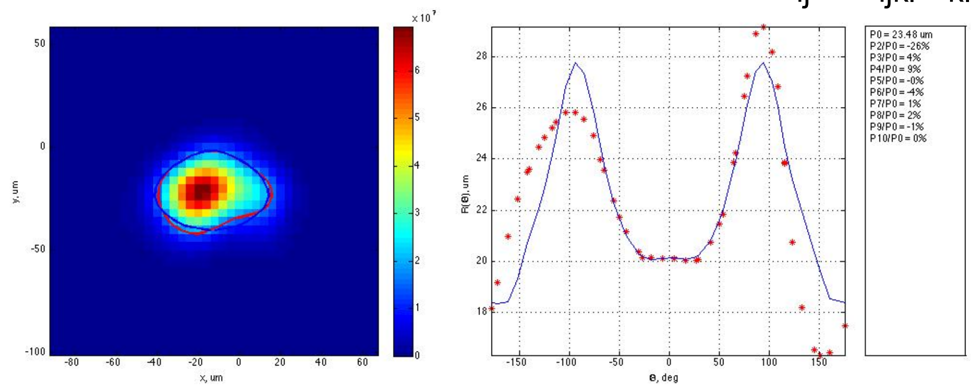


20 cm of gold

“raw” image

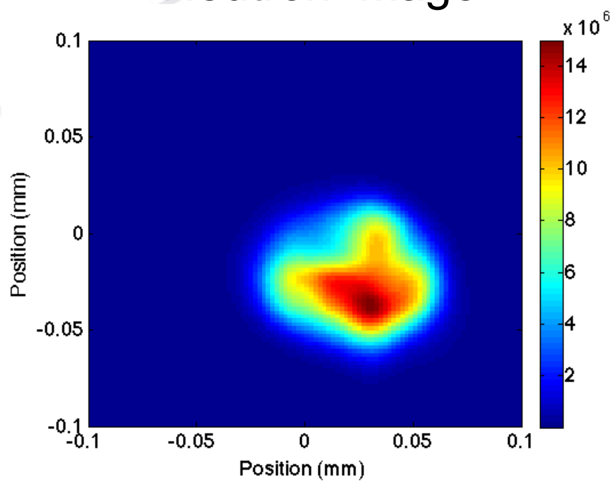


Source reconstruction (solve $I_{ij}=M_{ijkl}S_{kl}$)

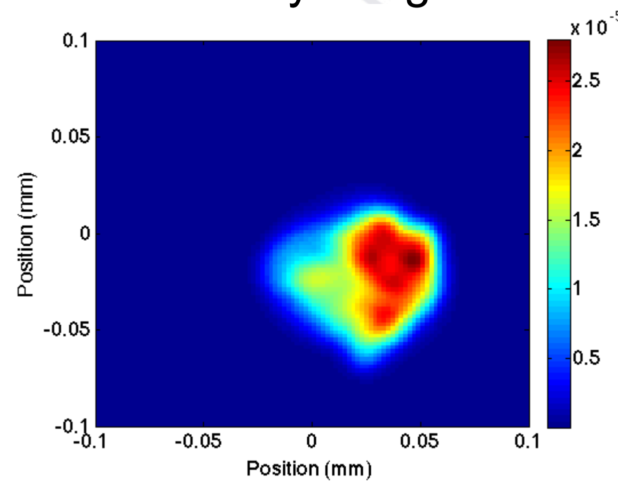


Mix and areal mass variation can result in differences in x-ray and neutron emission.

Neutron Image

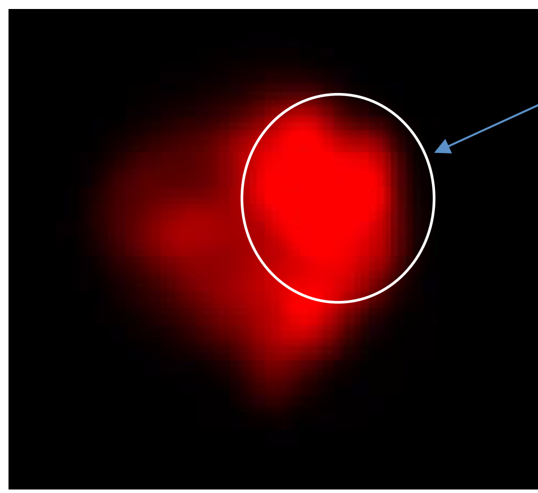


X-ray Image



Spears et al. 3D simulations provides a neutron and x-ray image on the same line of sight.

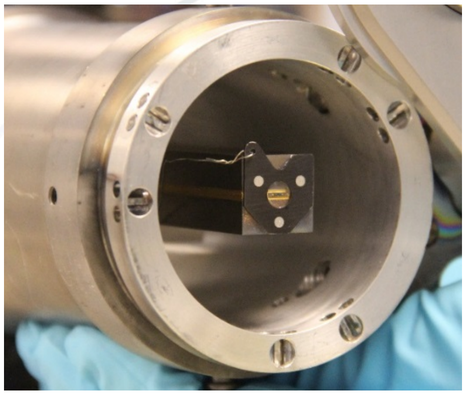
Regions "bright" with x-rays and "dim" with neutrons is an indicator of non-uniform mix.

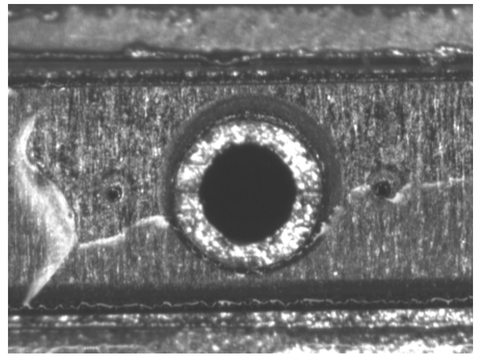


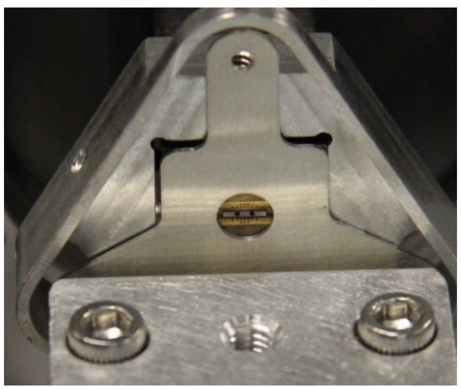
High mix region

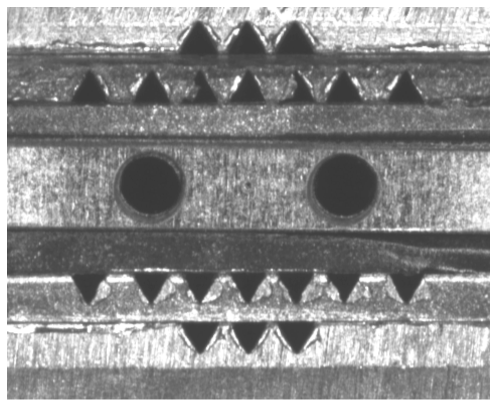
Fading back and forth from neutrons (red) to x-rays (cyan).

X-ray Pinholes Were Installed in July. First Data in August.

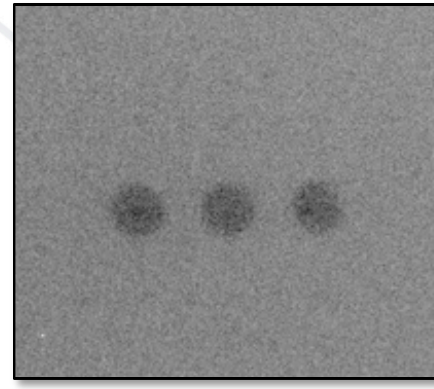


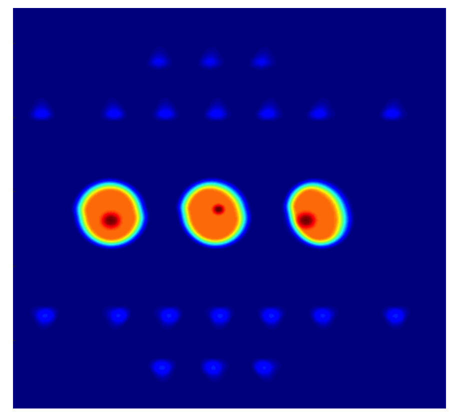




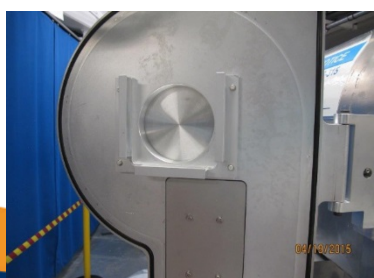


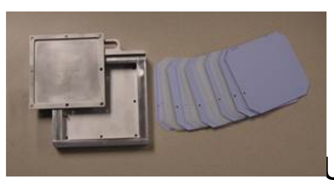
Data N150820-003



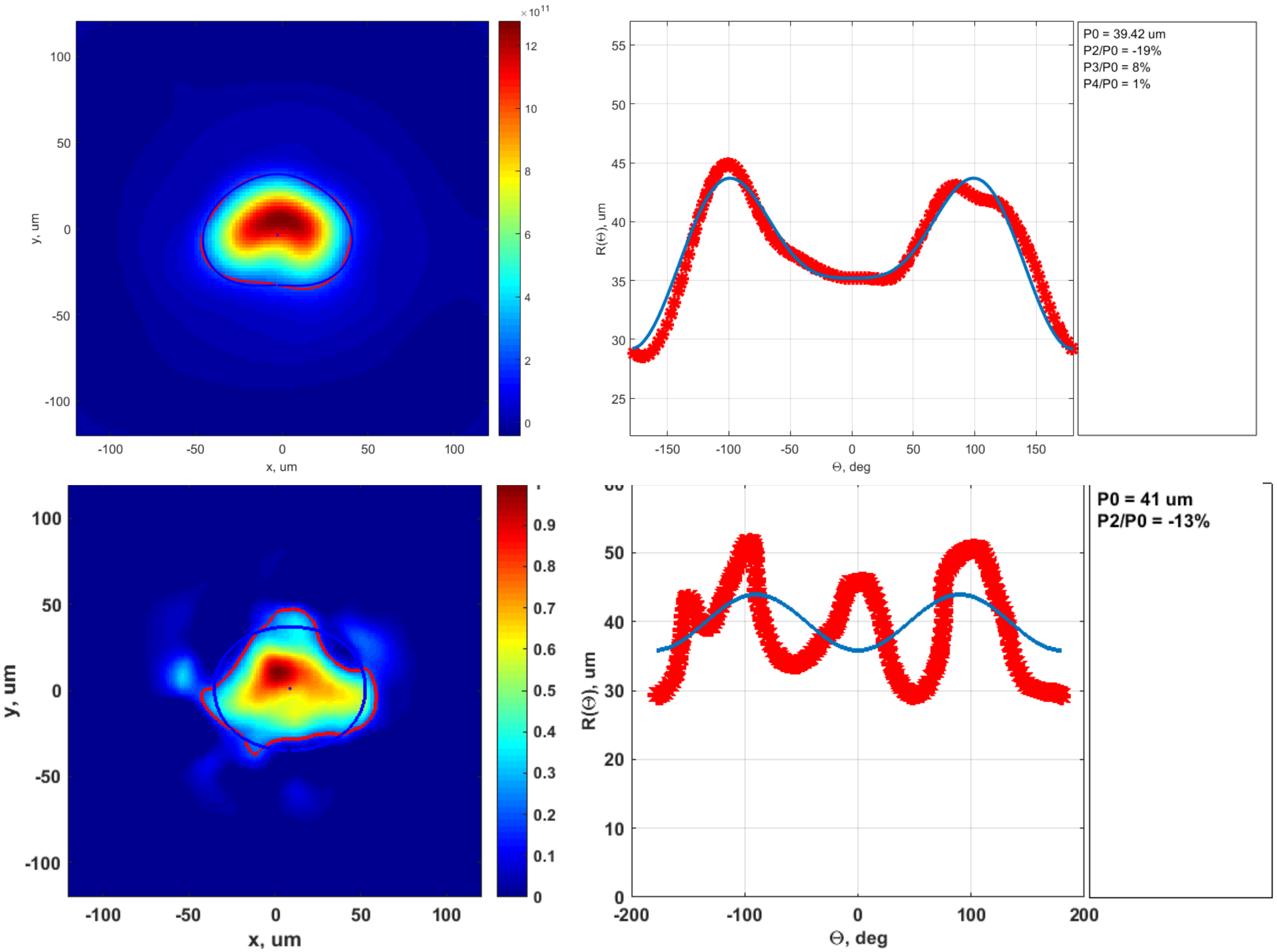


Simulation N150820-003





CNXI is now installed on 90-315 at NIF and was performance qualified on a sub-scale CSym shot (N150820-003)



Neutron Source

39.4 um

x-ray source

41 um

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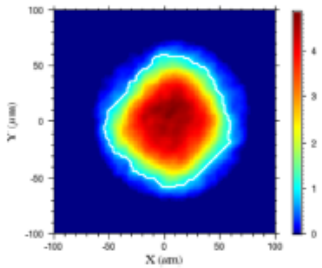
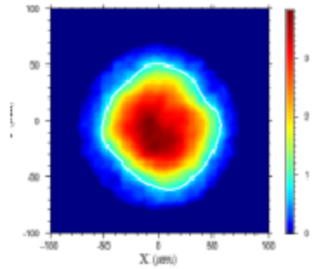
X-ray images from the pole do not show imprint of any windows.

Los Alamos NATIONAL LABORATORY EST. 1943

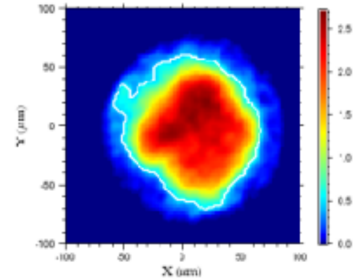
N141202-002



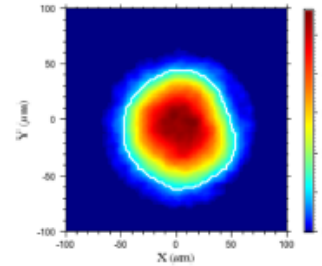
N141207-001



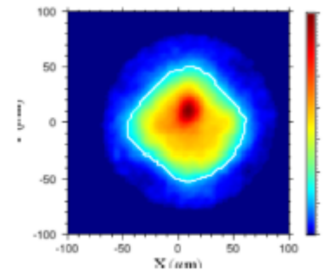
N150108-002



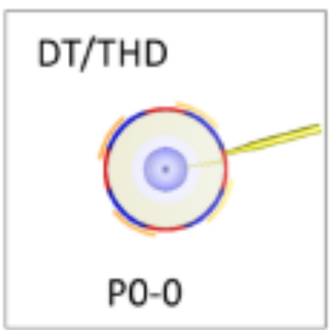
N150518-001

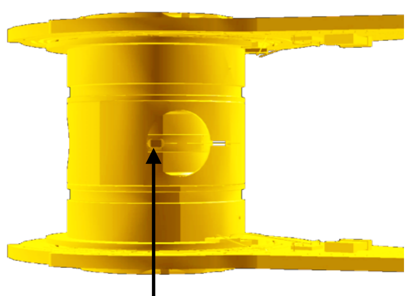


N150820-003



shot		x-ray M0 (um)	x-ray M2/M0 (%)
N141202-002	control	52	3.4
N141207-001	imposed drive +P2 w/ CF	52	3.9
N150108-002	imposed downwards P1	57	5.6
N150518-001	Imposed p1/p2 drive asymetries	49	3.8
N150820-003	CNXI PQ	47	3.4





90-315 window

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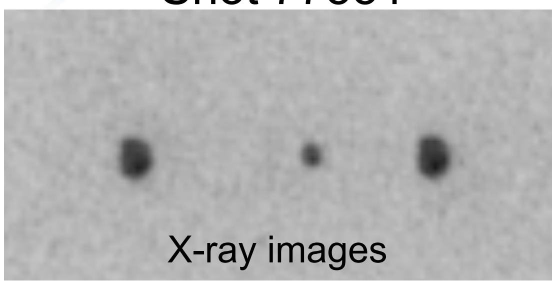
N.Izumi, S.Khan, T.Ma
and the Shape Working Group
and Charles Kelsey, shot RI.

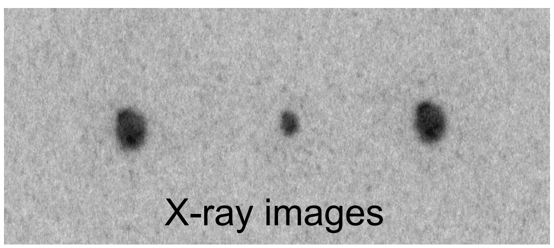
Relative x-ray image positions provide source position information. Similar information can be extracted from neutron images, allowing the relative comparison of x-ray and neutron images.

Front pinhole provides higher magnification than back pinhole.

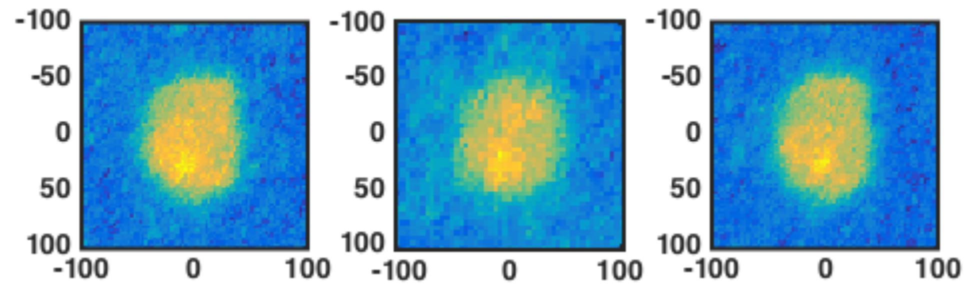
Shot 77551

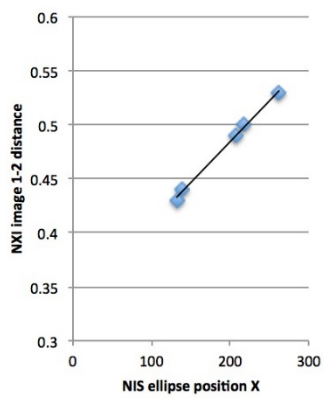


Shot 77553

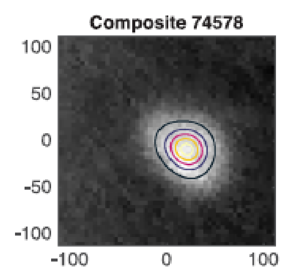


Three x-ray images scaled





X-ray image position relative to neutron source position for three pointing solutions. Strong correlation is demonstration of co-registration capabilities.



Using this technique we can co-register neutrons to x-rays within 12 μm.

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3D Simulations and measurement experience has shown that one view is insufficient to characterize the hot spot shape.

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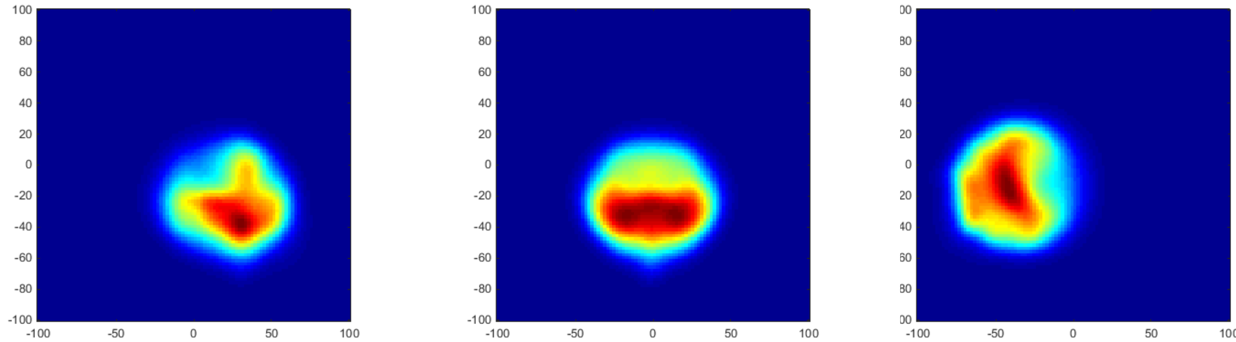
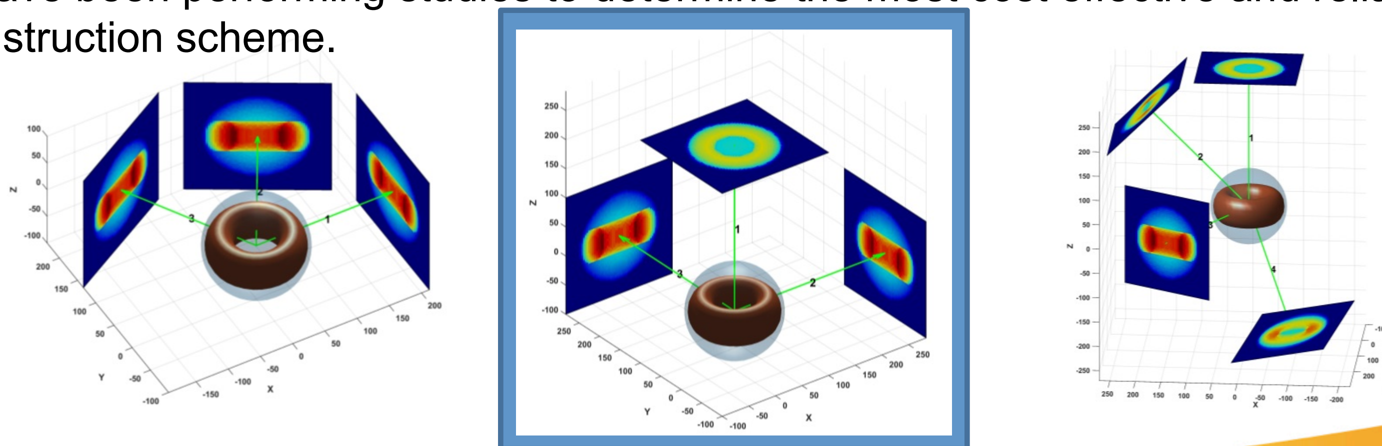
3D simulation of an implosion with a large asymmetry in the drive



Spears et al.

Simulated neutron images along three views shows the resulting structure at stagnation.

We have been performing studies to determine the most cost effective and reliable 3D reconstruction scheme.



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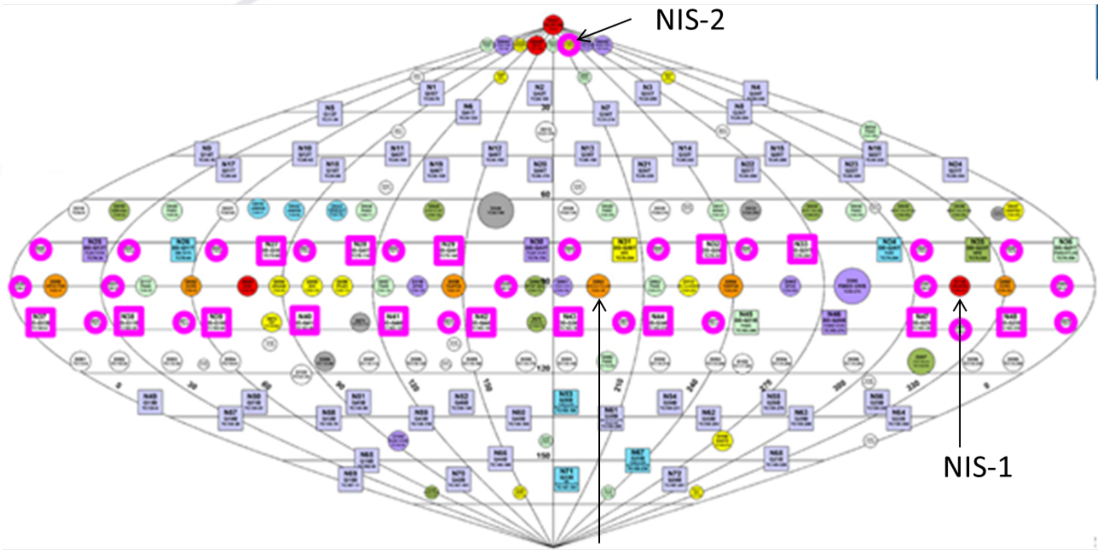
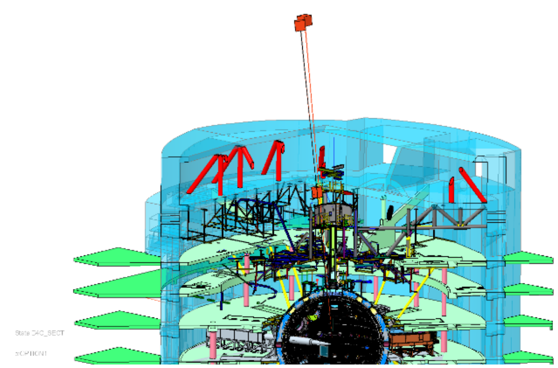
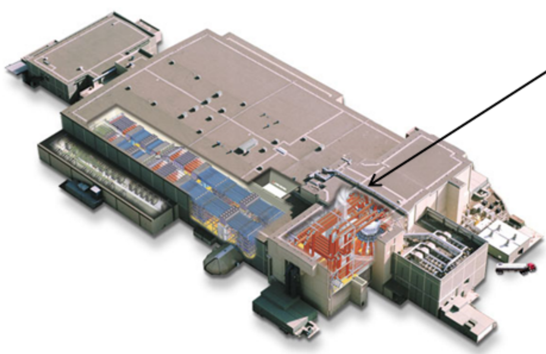
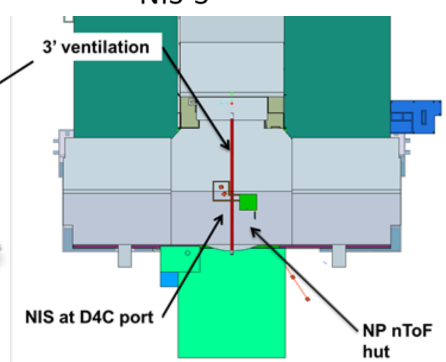
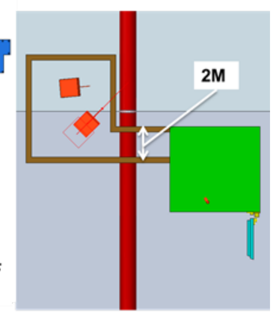
One year ago we proposed a short line of sight system, risk drove us to consider a 28 m line of sight system and cost drove us back to consider a short line of sight system.

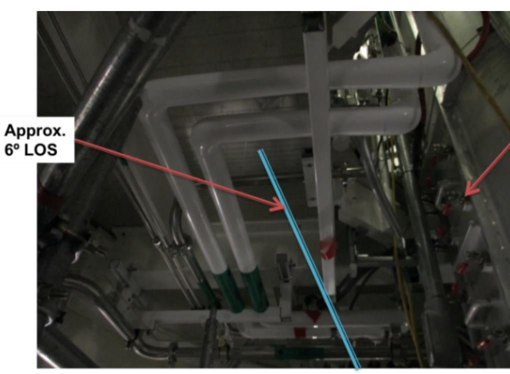




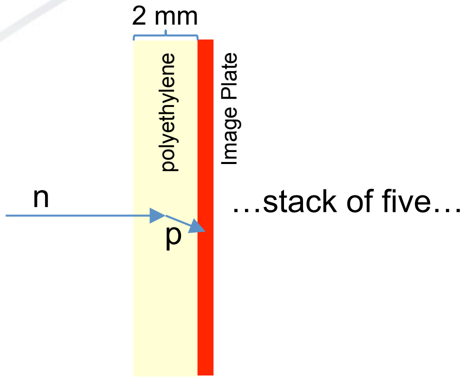




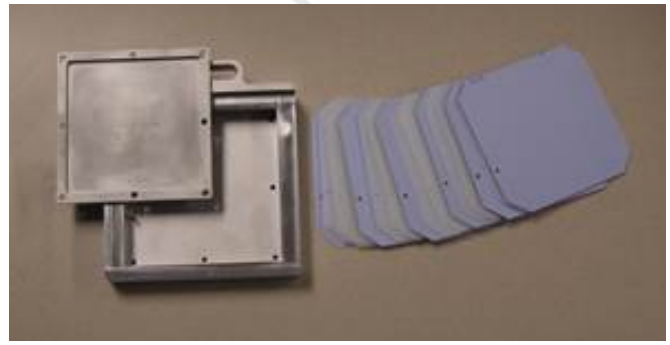




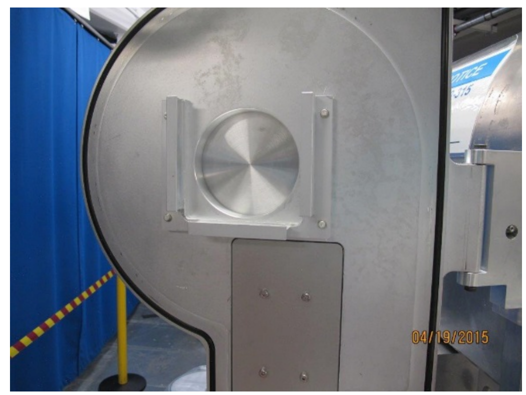
We have been using the image plate based detector system, developed for CNXI, to study the possibility of a short line of sight, energy integrated imaging system.



Detector box mounted on back of DIM



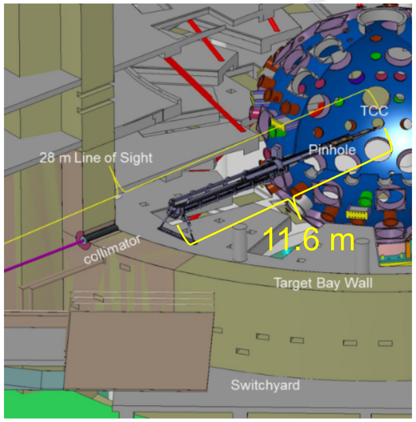
“P” Door at back of 90-215 DIM

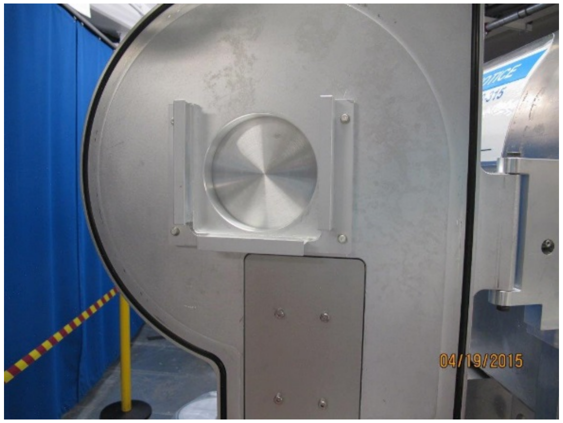


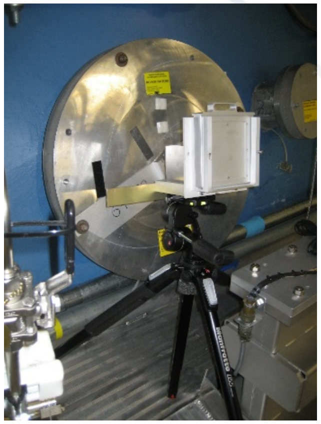
An inexpensive neutron detector, consists of a stack of polyethylene converter in front of an image plate. We have been looking at the performance of this system for imaging of high yield experiments.

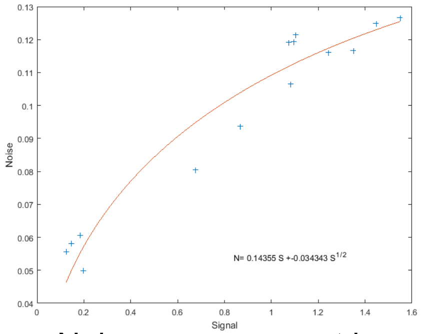
90-315 neutron imaging system has been modified to provide image plate based measurements at the back of the DIM.

Kim Christensen is the reason that we have made this level of progress!

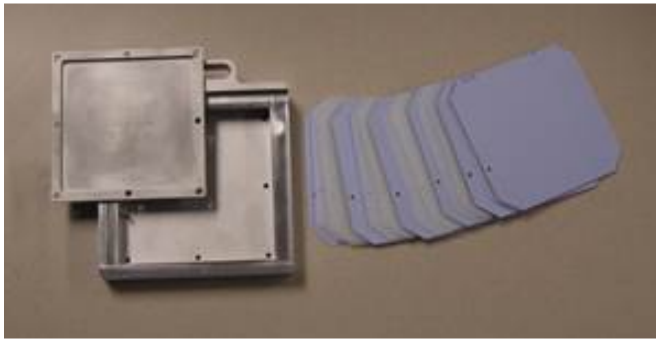


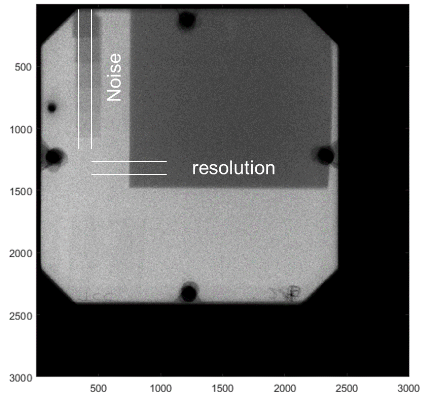




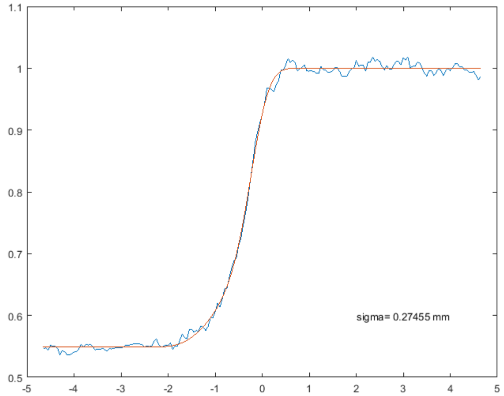


Noise measurement is consistent with 3% effective QE.





Measured and fit Transmission



Gaussian blur with σ=275 µm

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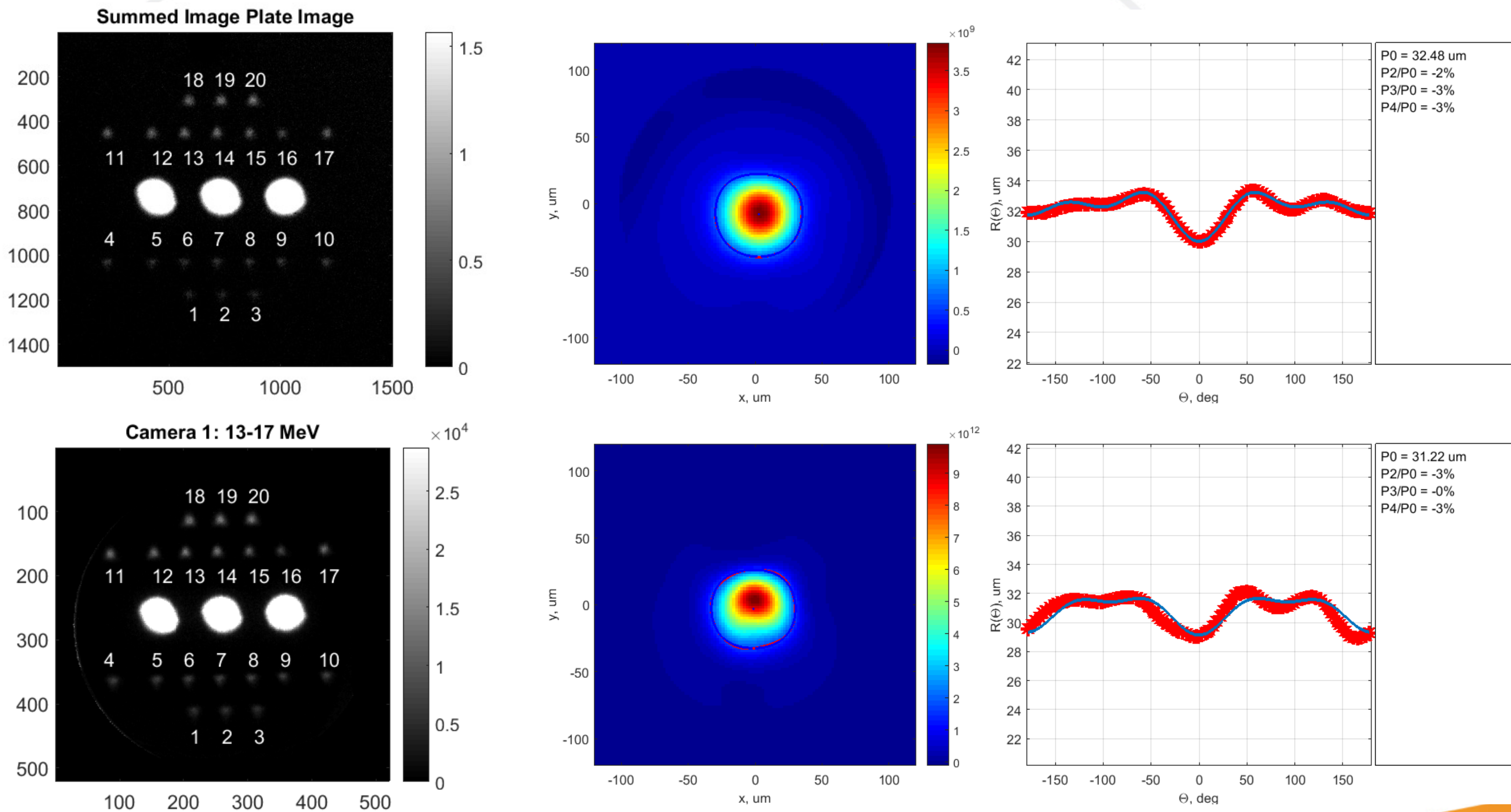
Performance of the short line of sight imaging system has been very promising, enabling consideration of a short line of sight system on the polar axis.

N150528, 5.7x10^{15} neutrons



5 pinhole reconstructions

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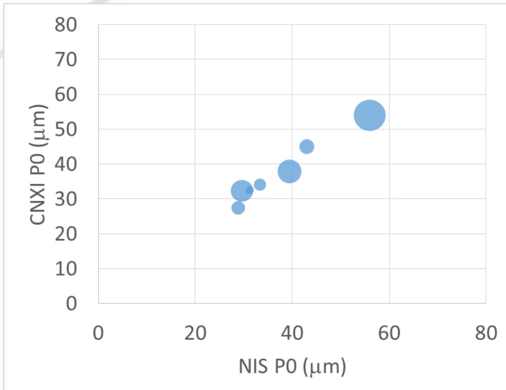
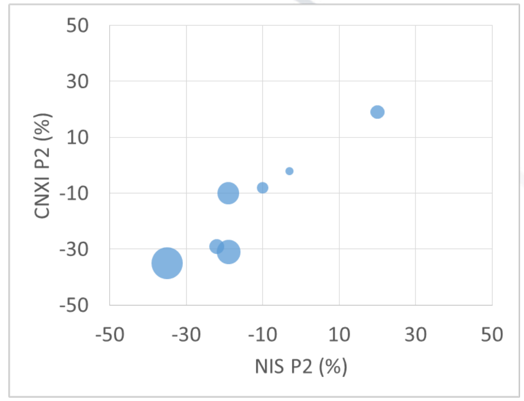
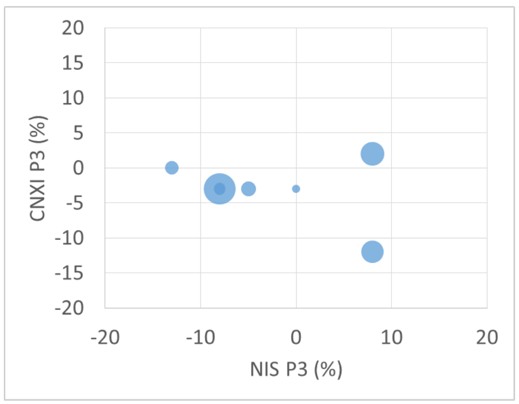
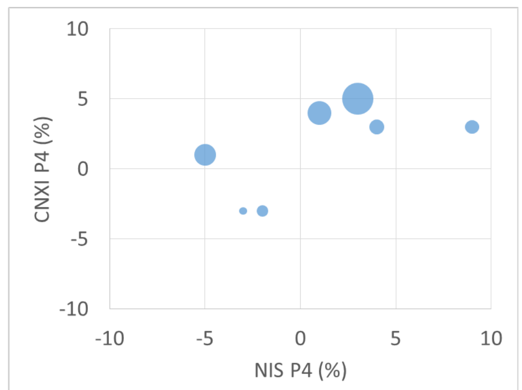
Agreement between CNXI and NIS reconstructed neutron emission gives us high confidence in a short line of sight energy integrated measurement..



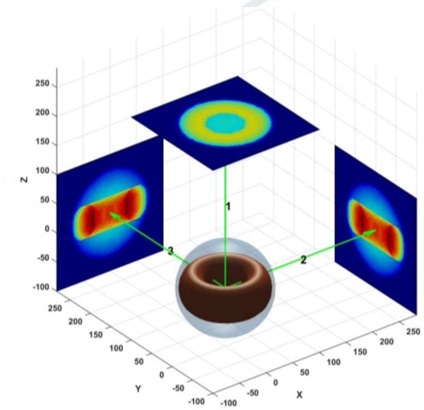


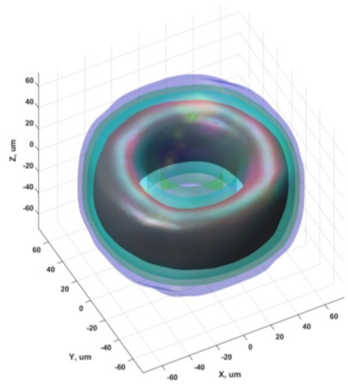


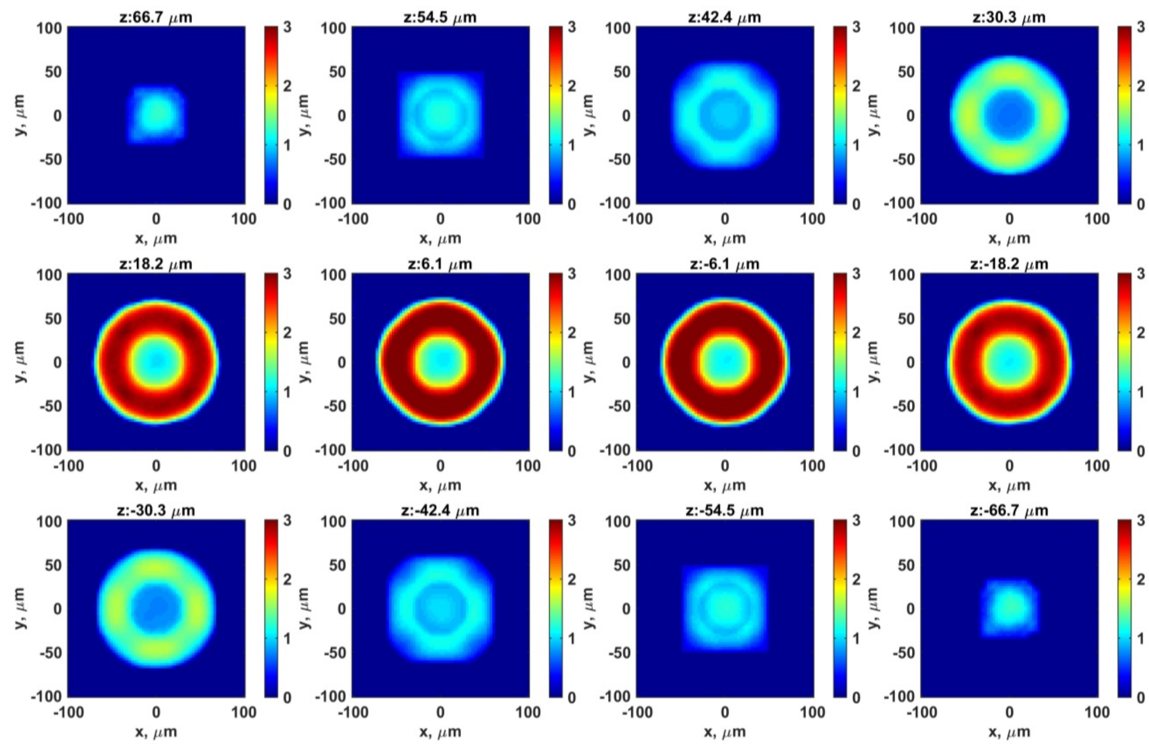


The development of CNXI has provided the opportunity to test and characterize this new, simple and inexpensive measurement scheme, providing the confidence to field this for other neutron imaging systems

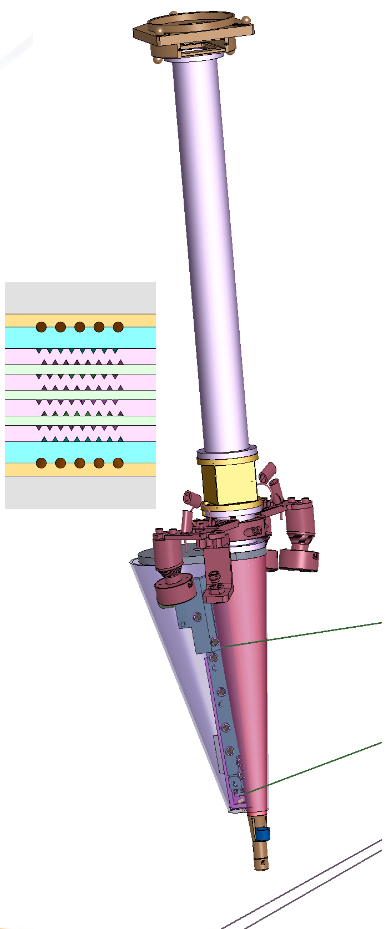
A third short line of sight neutron imaging system on the equator, ideally orthogonal to 90-315 and the polar line of sight, is the minimal required for 3D reconstructions.

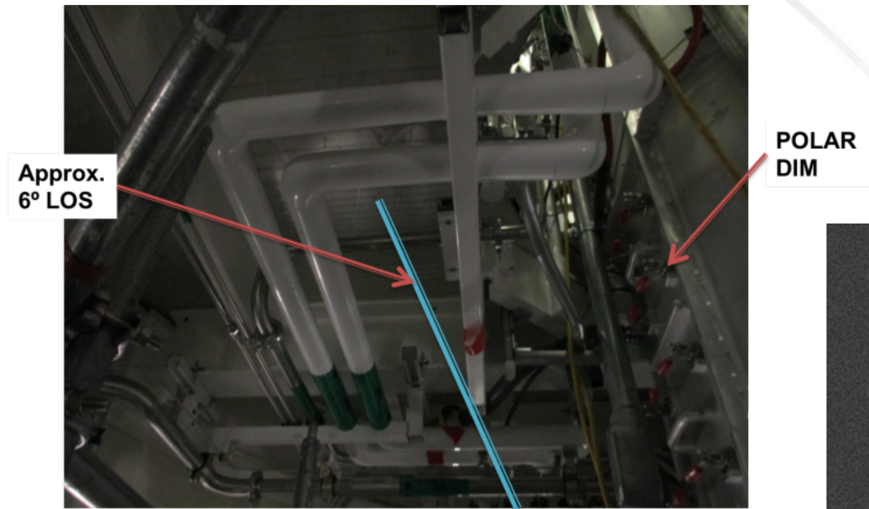


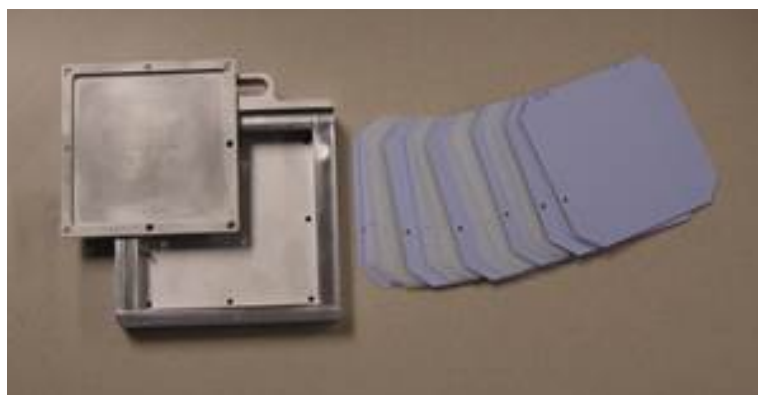


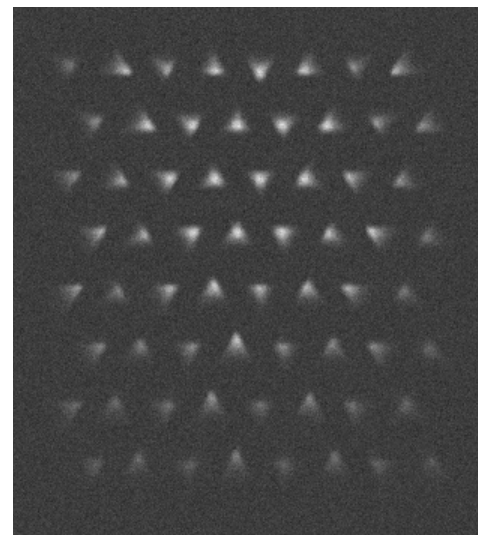


Phase 1A is a bare-bones system to install a pinhole and form an image on an image plate based detector located in the rotunda of the existing NIF building.



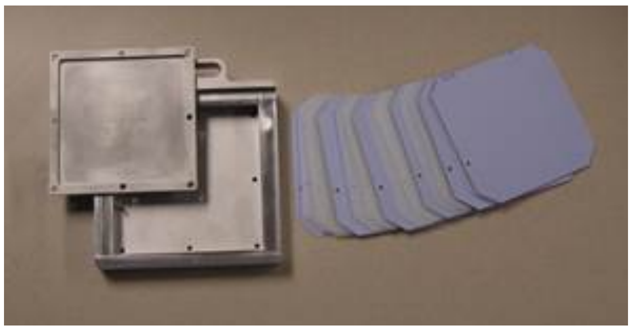




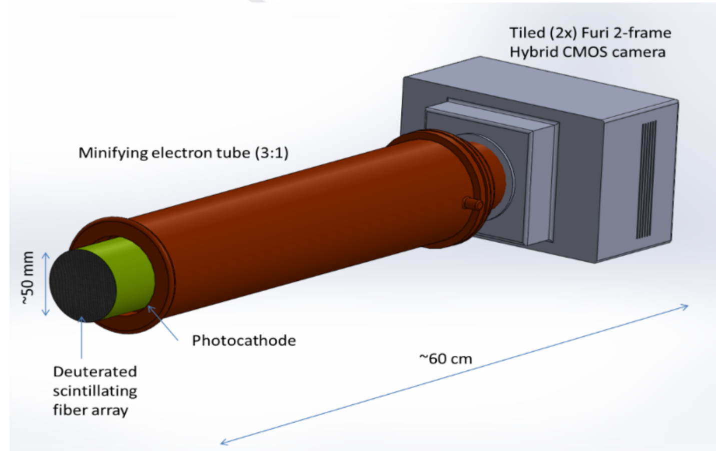


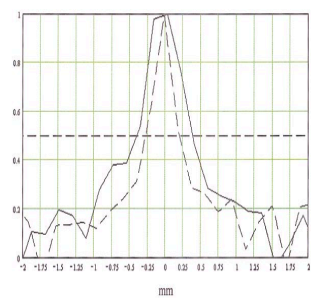
Phase 1B replaces the passive polar detector with a high-resolution, energy-resolved measurement system.

“Yugo”

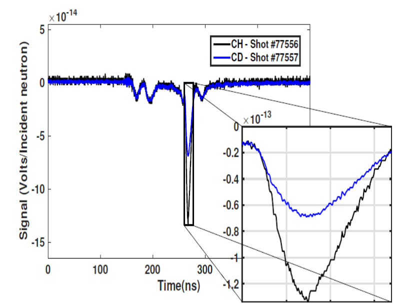


“Cadillac”





Measured PSF for liquid scintillator filled capillaries *Disdier et. al RSI 75 – 2134 (2004)*

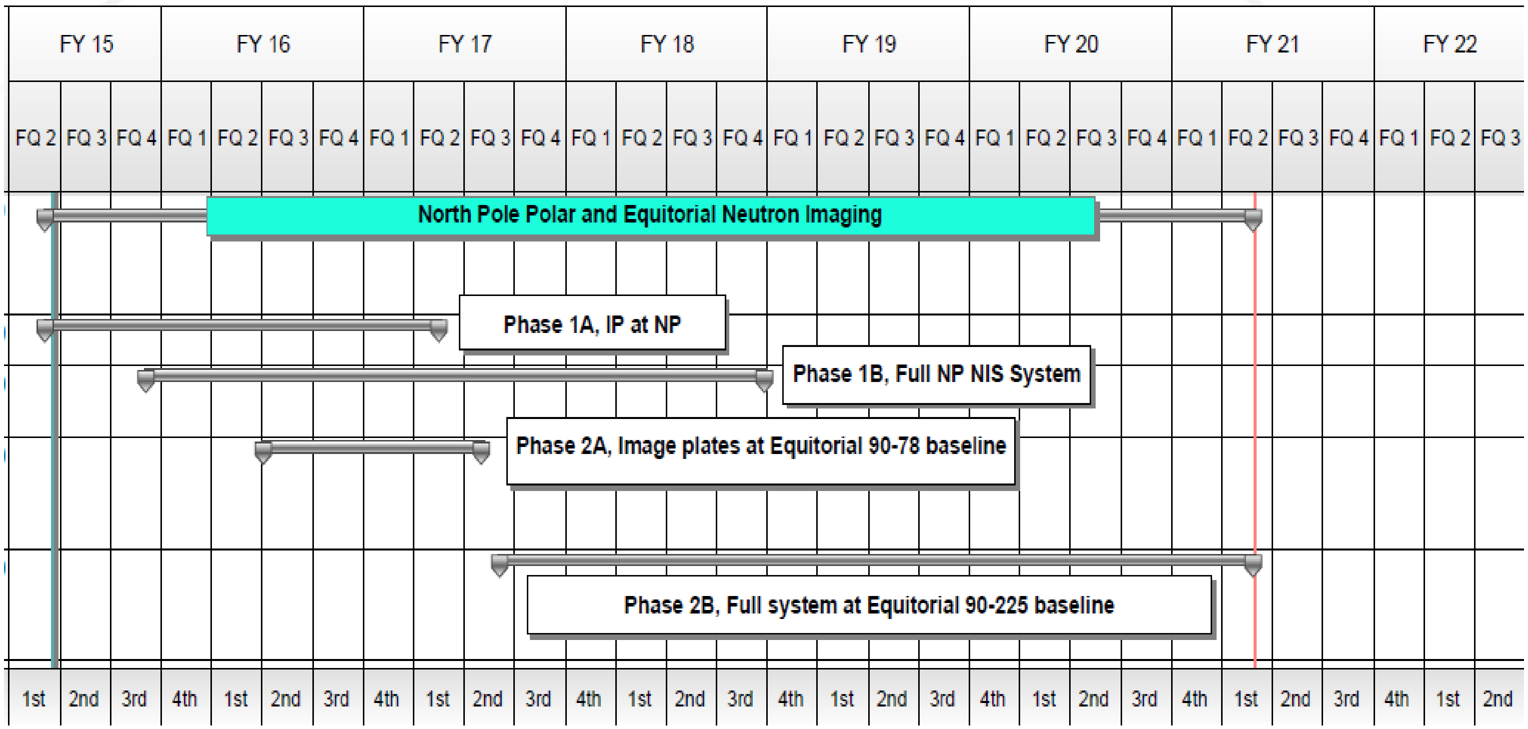


Solid polystyrene and deuterated polystyrene light output response to fast Neutrons *Simpson et. al Submitted to NIM A*

40% improvement in resolution

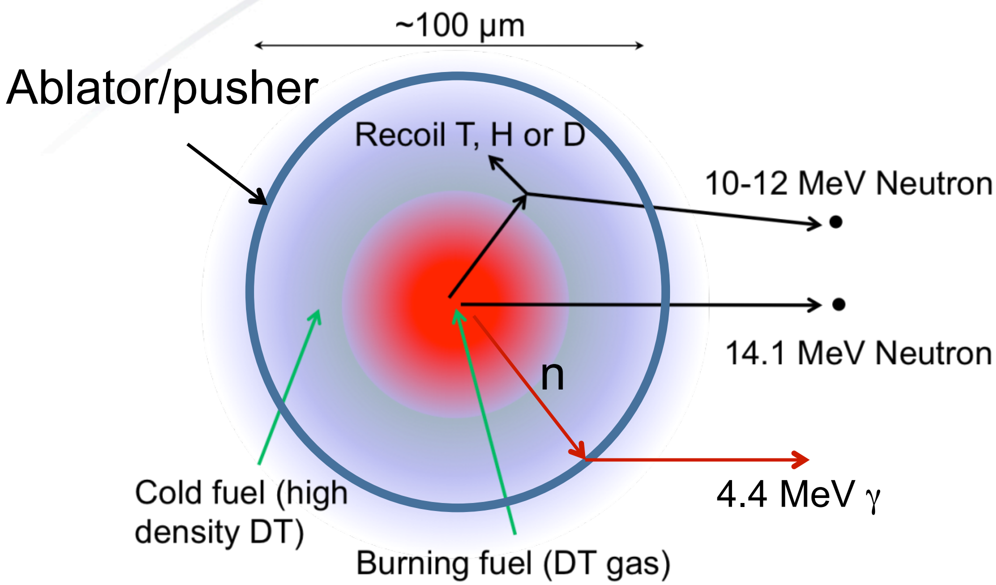
60% of the light

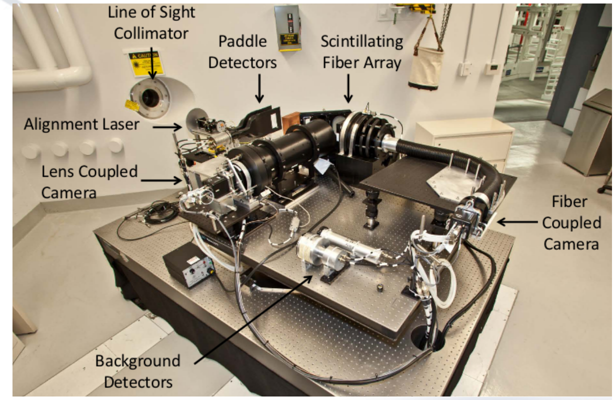
We have a four-stage, four-year plan to get energy resolved 3D neutron source measurements*

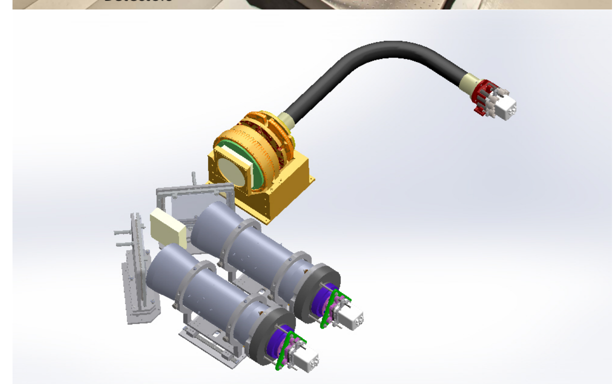


* Assuming a near ideal funding availability.

Slight modifications to the existing and future systems could allow measurements of $^{12}C(n,n'\gamma)^{12}C$ gammas or location of gold pusher in double shell experiments.



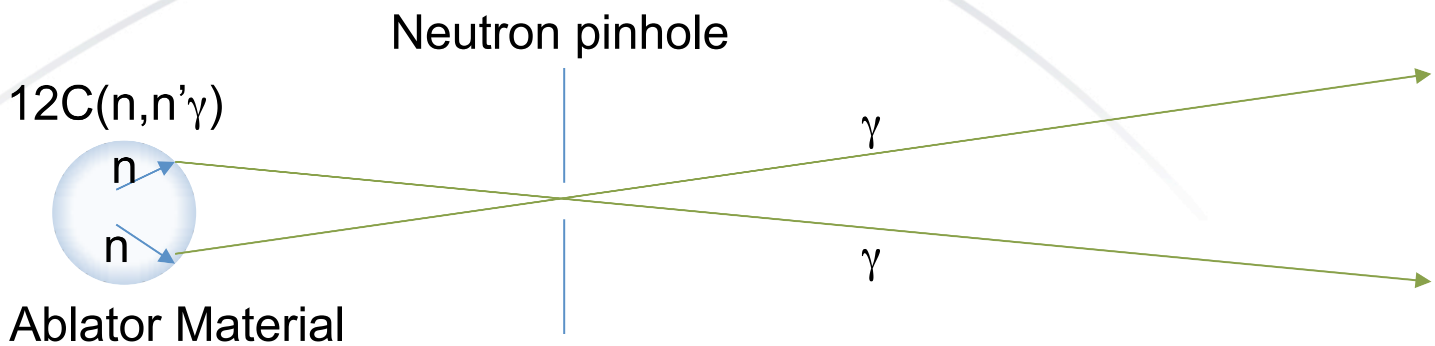




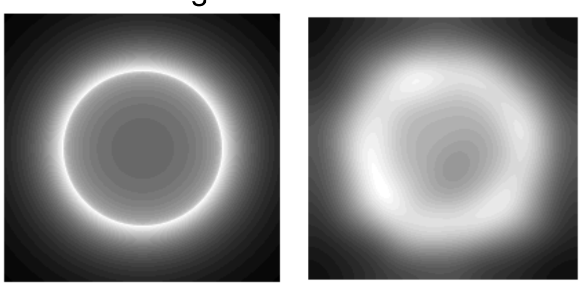
Small modifications would allow new capabilities. Replacement of the fiber coupled system with a lens coupled imager would allow for a gamma ray imaging system located behind the neutron imaging detector.

(n,γ) interactions on carbon or gold in the ablator/pusher would allow a 2D measure of the location of this material.

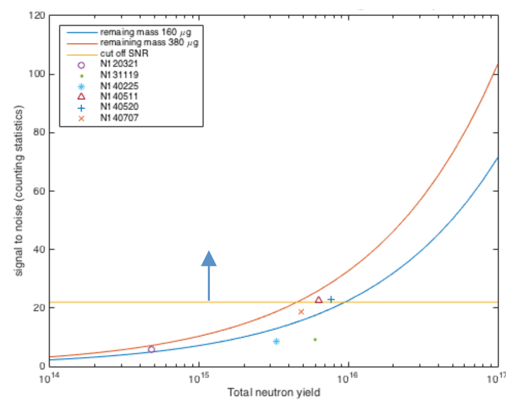
Ablator and double shell gold pusher measurements make sense at present yields (~10^{16}).

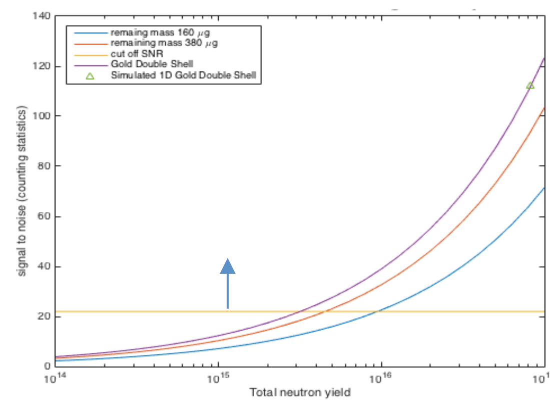


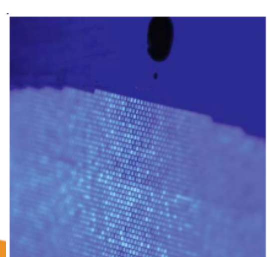
Simulated image from Izumi and Tomassini

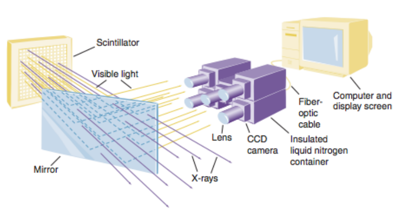


Neutron yield of ~10^{16}









If LSO is the right material we may have an opportunity to leverage DARHT detector development work.

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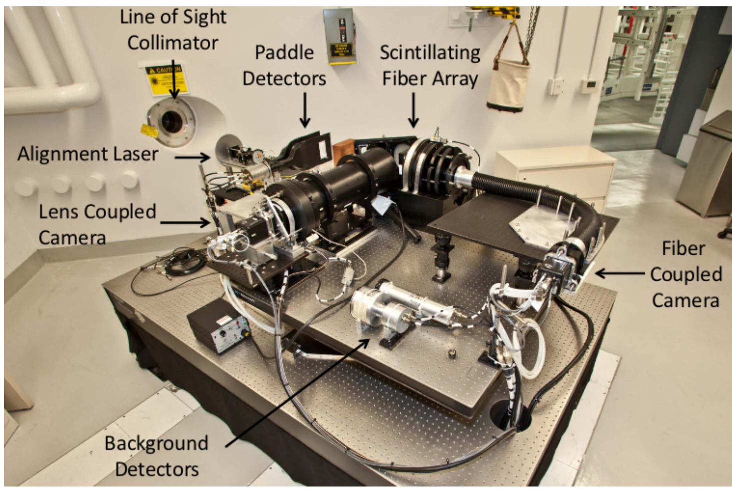
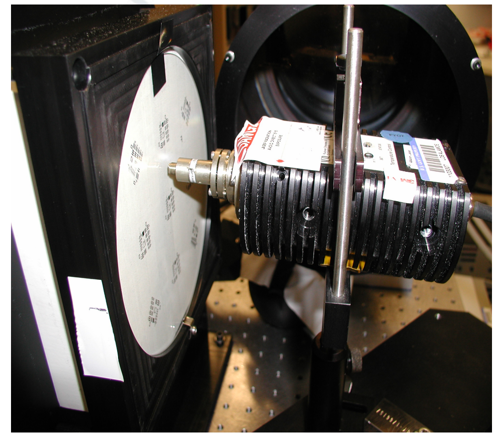
Can we use the existing two-frame system to measure spatially resolved temperature or Doppler shift from bulk motion?

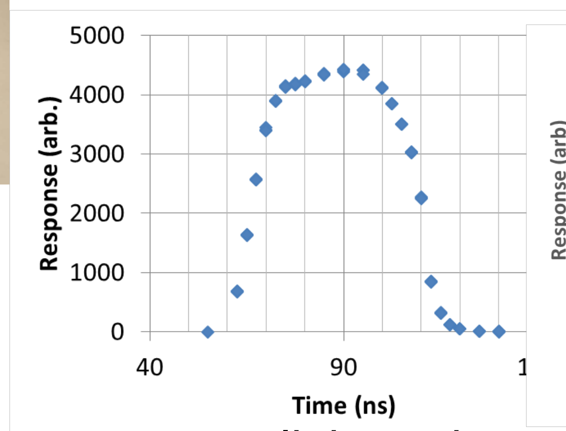
Two imaging systems independently gated.



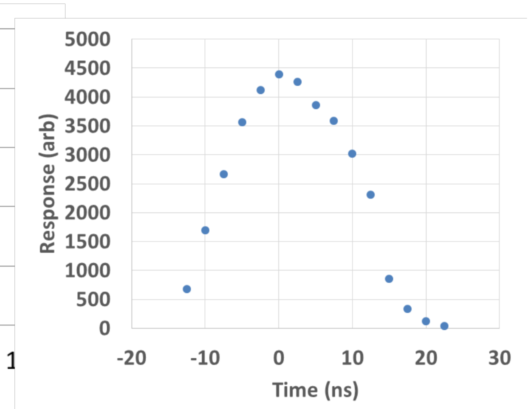


At 28 m the neutron arrival time difference is ~10 ns per 1 MeV.

Detector FWHM is ~2 MeV, making this measurement challenging.



walkthrough



22 ns FWHM

We have been forward modeling a simple source with a large signal to understand the potential for this type of measurement.

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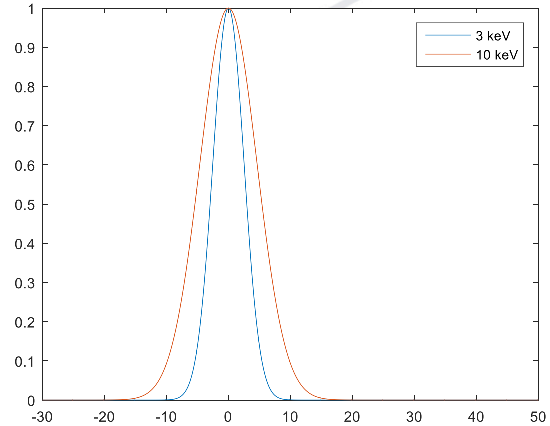
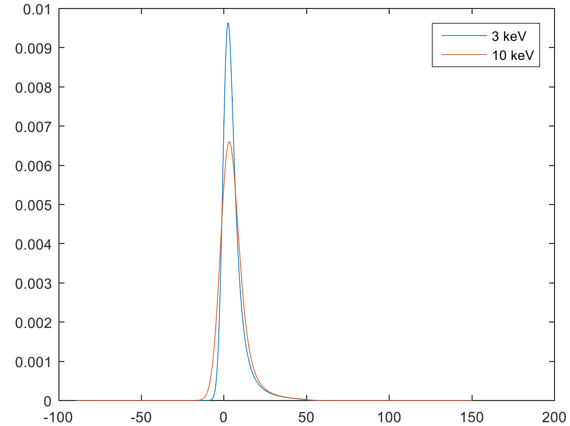
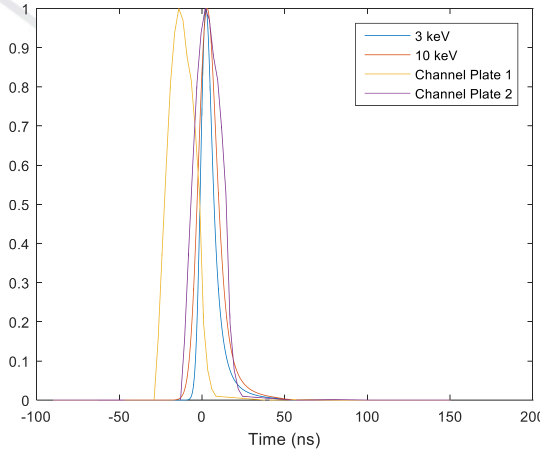
Neutron arrival time



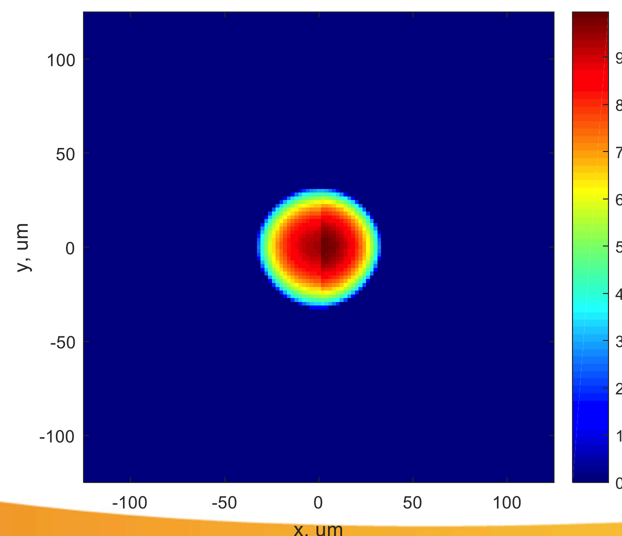
Neutron arrival time convolved with scintillator response and transit time



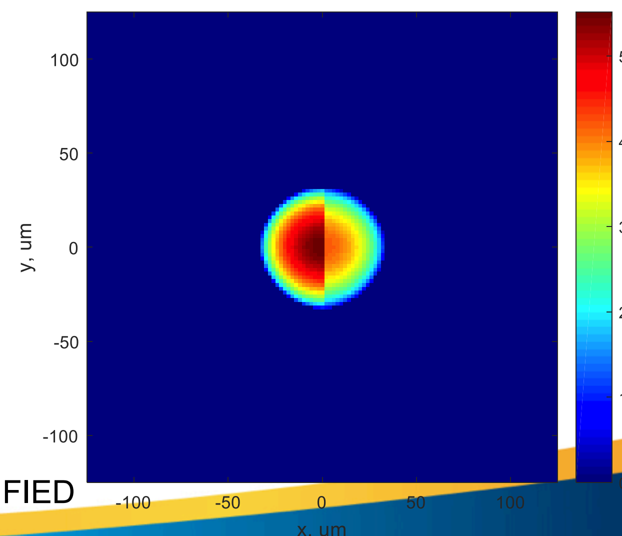
Optimized for contrast to noise ratio



Low Energy

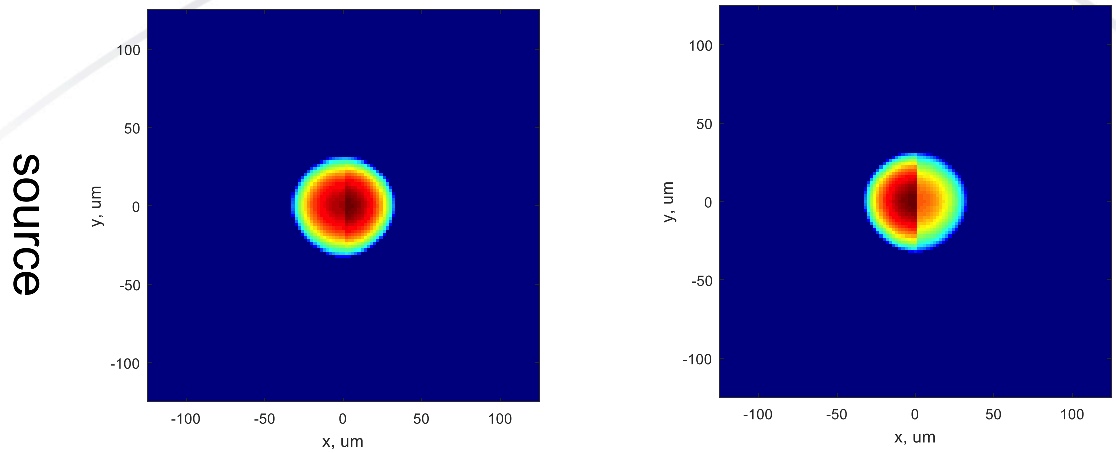


High Energy

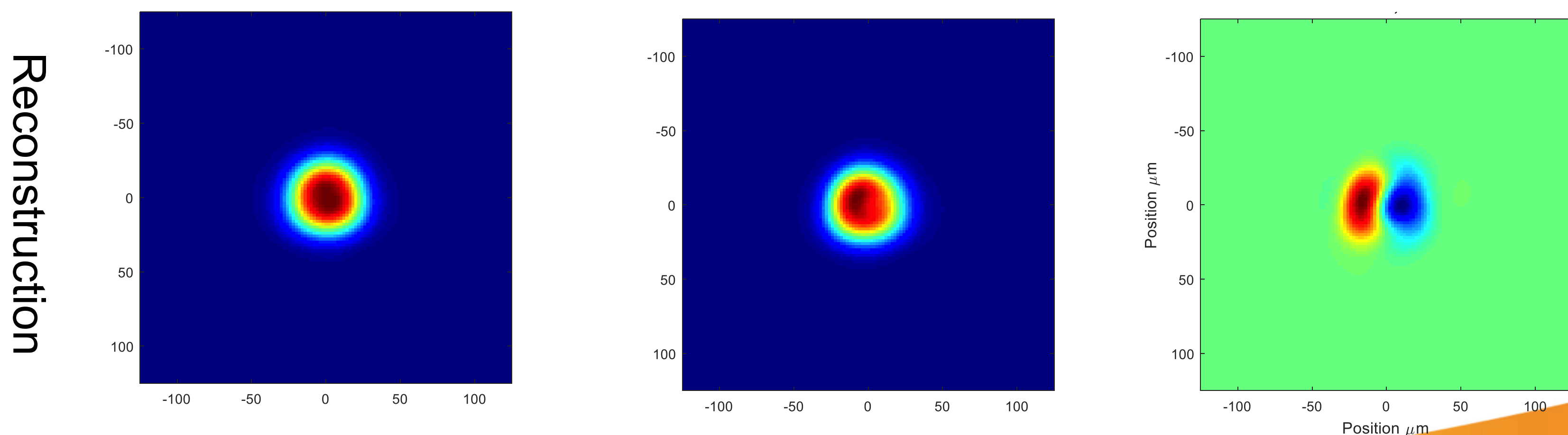


Reconstruction of this forward model source shows the technique is viable for this large signal…

Low Energy High Energy



The limiting case:
This technique is viable for $5x10^{16}$ neutrons with a temperature difference of 3 to 10 keV.



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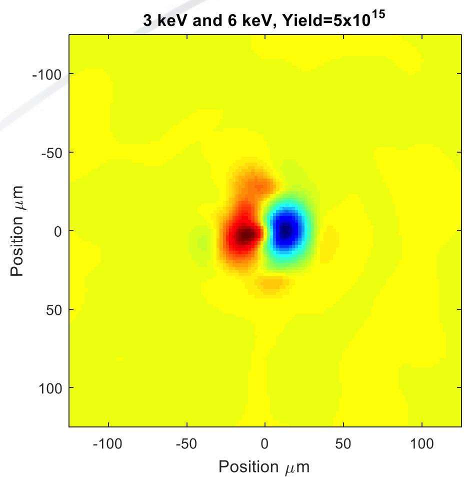
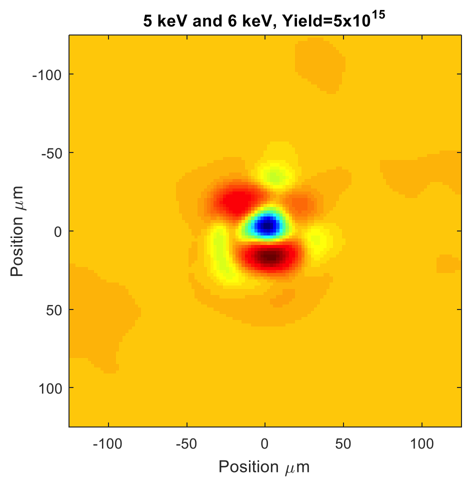
There is limited measurement possibilities at ~10^{16} neutrons with the existing system, but this requires studying the potential interesting temperature distributions. Blurring effects can make noise look like signal!

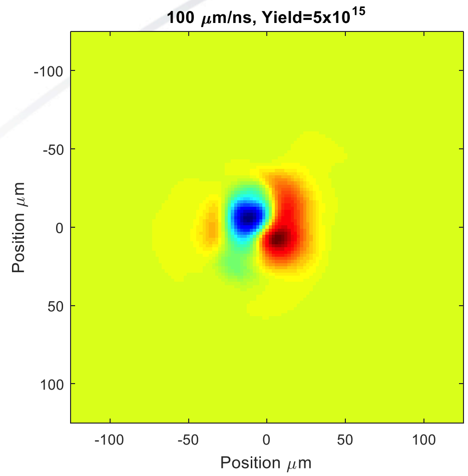


Signal persists with a 3 keV energy range and 5×10^{15} neutrons.

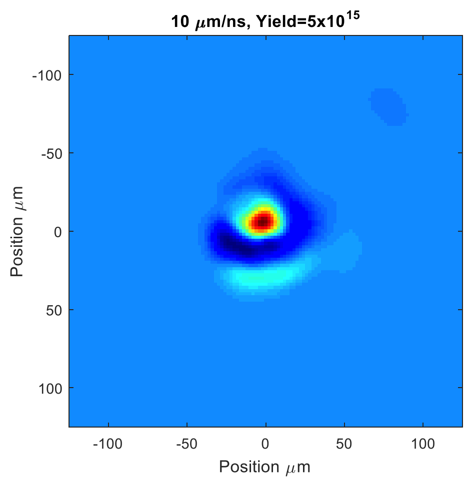


Noise dominates the measurement with a 1 keV energy difference at 5×10^{15} neutrons

We looked at diagnosing Doppler shifting of the neutron energy and see similar results.



100 μm/ns velocity difference between left and right at $5x10^{15}$ neutrons provides an observable signal.



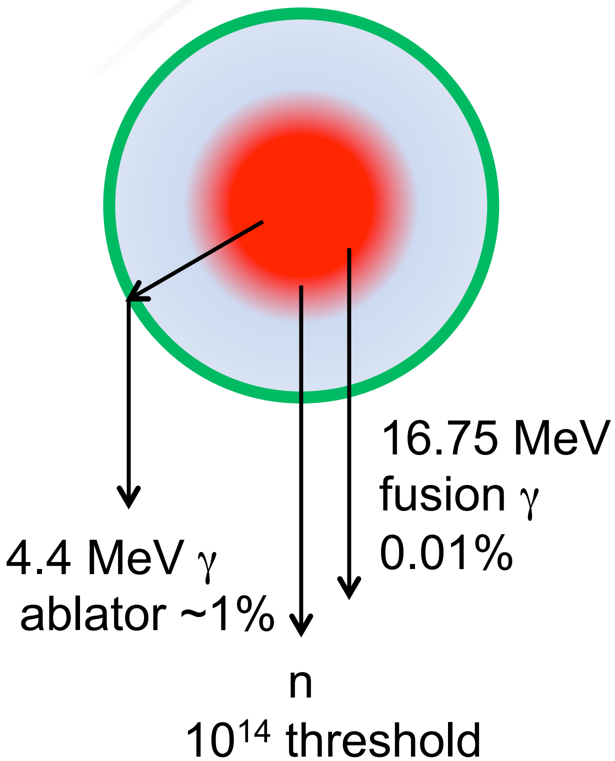
The signal from 10 μm/ns velocity difference between left and right at $5x10^{15}$ neutrons is lost in the noise.

More work is required to determine if this measurement would be useful

- Determine what temperature variation and/or fuel velocity is physically possible and interesting to measure.
- Perform hydro simulations to provide the neutron images expected from these configurations.
- Use our forward model of this system to determine if useful signal exists at the expected yields.
- If useful signal is predicted, need to more carefully characterize the time response of our imaging system.
- Need to carefully time the two imaging systems relative to each other.
- Fully develop the analysis and interpretation tools for this type of measurement.

Chris Danly will present a new diagnostic design, which builds on the existing system to make these measurements with a faster imaging detector.

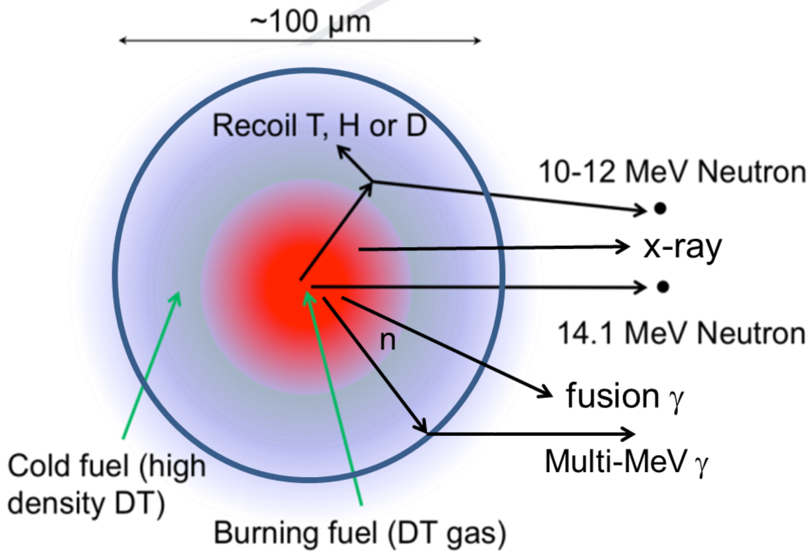
At the moment it is too difficult to extract the 16 MeV gammas in 100 4 MeV gammas to perform a time resolved hot spot measurement.



Unlike neutrons, where energy is mapped to arrival time, gammas would allow for time resolved imaging.

Yield	Opportunity
10^{16}	Time integrated gamma ray imaging of ablator location.
10^{17}	Time resolved gamma ray imaging of ablator location (fast scintillator or Cerenkov converter).
$>10^{18}$	Time-resolved imaging of fusion hot-spot with fusion gammas. (Thresholded, Cerenkov converter and time expansion system)

Conclusions



The plan is:

- Use the existing system for primary and down scatter measurements.
- Use CNXI measurement for 3D x-ray source reconstructions.
- Compare x-ray emission with neutron sources.
- Energy integrated polar neutron imaging system.
- Energy resolved polar neutron imaging system.
- Energy integrated third neutron imaging system on equatorial axis
- Energy resolved polar neutron imaging system on equatorial axis.
- Continue working on GRI for gold pusher and ablator remaining mass measurements.
- Is it useful to push on temperature measurements with existing system or do we need a faster imaging system.
- Delay development of an imaging system with fusion gammas.

We are investigating a wide range of diagnostics to achieve this goal.

1. Neutron Imaging System (NIS on 90-315)
2. Co-Neutron and X-ray Imaging (CNXI)
3. Multi-View Neutron Source Imaging
   I. Short Line of Sight, Energy-Integrated Neutron Source Measurements
   II. Polar Neutron Imaging System (NISP, 7-225)
      a. Phase 1A
      b. Phase 1B
   III. Second Equatorial Neutron Imaging System (NIS3, 90-225?)
      a. Phase 2A
      b. Phase 2B
4. 3D x-ray and Neutron emission reconstructions
5. Gamma, Neutron and X-ray Imaging (GNXI, 90-315)
6. Spatially Resolved Temperature Measurements (SRIT, 90-315).
7. Fusion Gamma Imaging (FGI, 90-315)
   I. Low flux, energy discrimination, fast detectors – <u>too difficult!</u>

Done
Actively working on
Determining Feasibility
Need Technology Development