Gamma Component of AI on 90-315 LOS at NIF (or GNXI)

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Building on the work of many (Gary Grim, Daniel Lemieux, Nobuhiko Izumi….)

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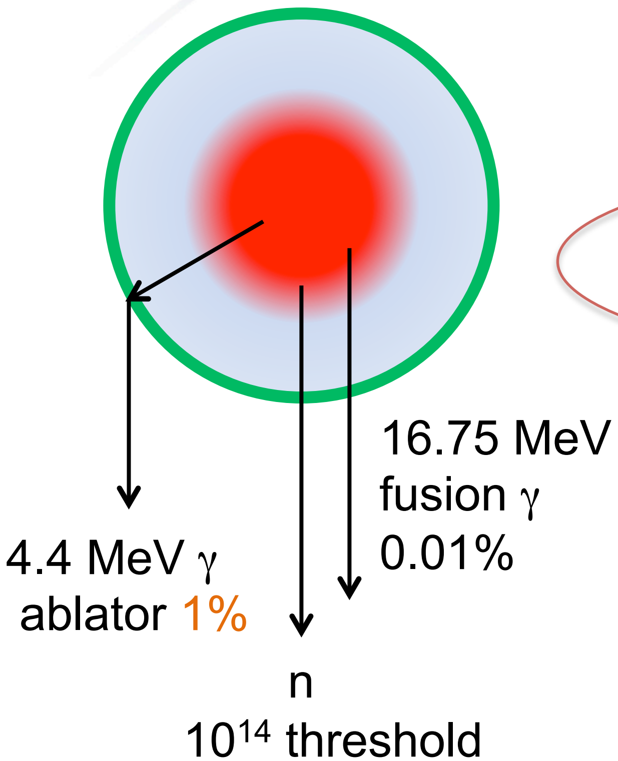
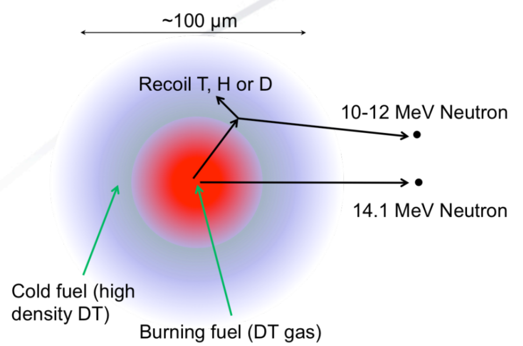
Possibilities for gamma ray imaging



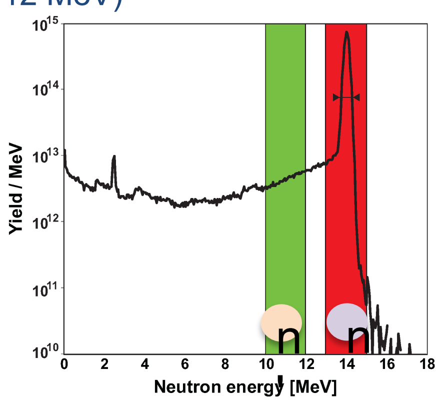
Unlike neutrons, where energy is mapped to arrival time, gammas would allow for time resolved imaging.

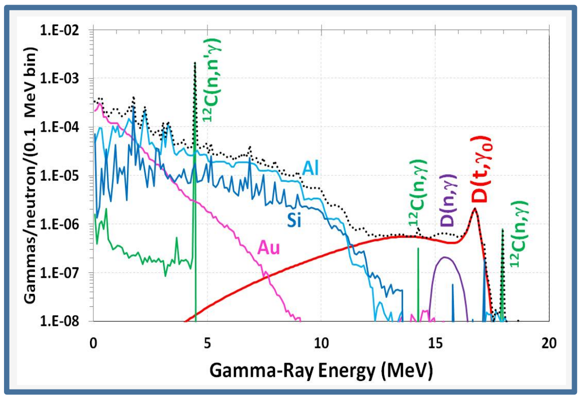
Yield	Opportunity
10^{16}	Time integrated gamma ray imaging of ablator location.
10^{17}	Time resolved gamma ray imaging of ablator location (fast scintillator or Cerenkov converter).
$>10^{18}$	Time-resolved imaging of fusion hot-spot with fusion gammas. (Thresholded, Cerenkov converter and time expansion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

Neutron images provide the shape and size of the imploded fuel at stagnation. Gamma imaging can measure the ablator location.

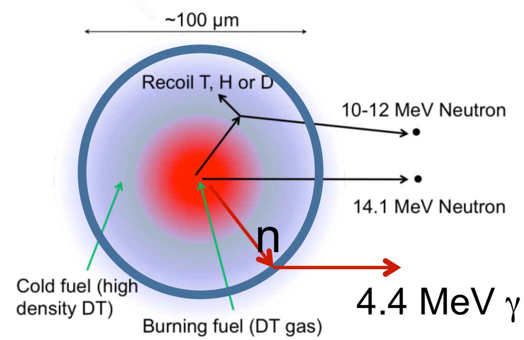


Neutron images are used to diagnose NIF implosions. Temporal separation of neutrons after 28 m drift results in ability to collect two neutron images: Primary (13-17 MeV), Down-Scattered (10-12 MeV)





Courtesy of H. Herrmann et.al.



Gamma Ray Imaging

At yields >10^{16} neutrons and sufficient remaining ablator mass there should be enough (n,γ) reactions to form images of the ablator location.

GRH provides spatially integrated measurement of Carbon gamma production

- Cerjan et.al. use GRH measurement of $^{12}C(n,n'\gamma)^{12}C$ gamma production to infer rho-r

TABLE II. Experimental characteristics of the selected shot series including laser drive energy and hohlraum lining, capsule thickness, and peak implosion velocity. Spherically averaged peak densities, matching radii, and the e^{-1} ablator width (α^{-1}) are derived from fitting the three-dimensional static model using the experimental GRH hydrocarbon areal densities and estimated remaining ablator mass. These averaged fit values are designated as *3DFit*. Error ranges for the experimental constraint values and the resultant fit quantities are indicated.

Shot	N120321	N131119	N140225	N140511	N140520	N140707
Drive energy (MJ)	1.573 U(Au)	1.908 Au	1.568 Au	1.859 U(Au)	1.764 U(Au)	1.570 Au
CH thickness (μm)	195	194	177	191	178	164
Peak velocity ($\frac{\mu m}{ns}$)	321	352	333	372	389	350
ρr_{CH} ($\frac{mg}{cm^2}$)	450 ± 90	229 ± 46	262 ± 52	295 ± 59	306 ± 61	374 ± 75
m_{CH} (μg)	319 ± 42	244 ± 41	279 ± 37	155 ± 40	140 ± 38	233 ± 34
3DFit r_0 (μm)	53 ± 5	57 ± 2	63 ± 3	54 ± 3	50 ± 5	55 ± 4
3DFit ρ_0 ($\frac{g}{cm^3}$)	293 ± 108	99 ± 42	126 ± 54	328 ± 106	310 ± 75	311 ± 78
3DFit width (μm)	27 ± 13	57 ± 19	43 ± 18	13 ± 7	15 ± 4	19 ± 6

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Simulated $^{12}C(n,n'\gamma)^{12}C$ production with MCNP

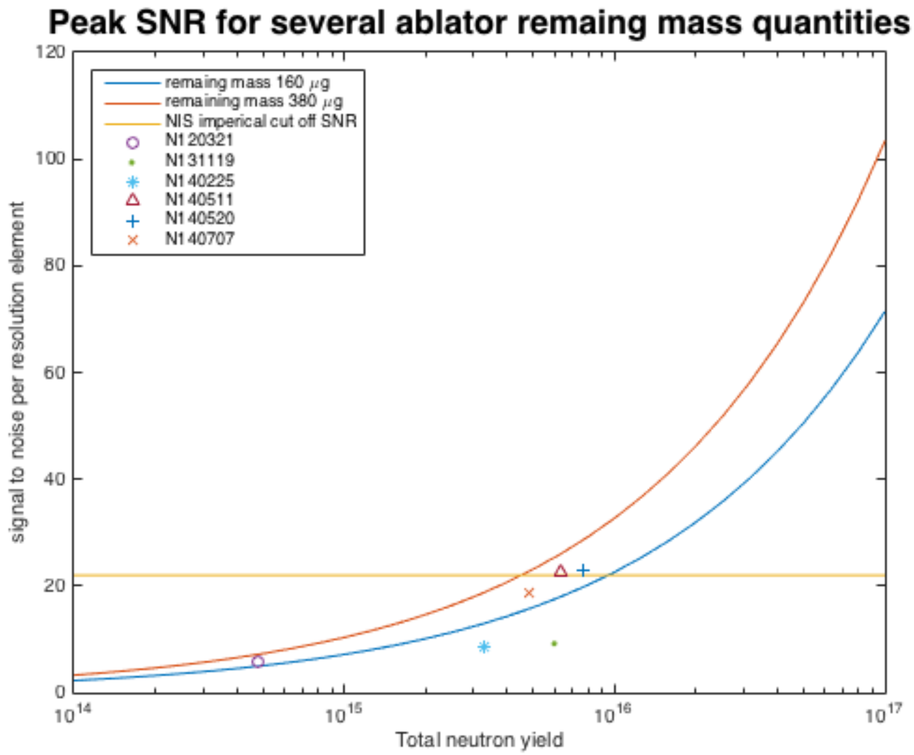
- Uniformly distributed 14 MeV neutron source (hot spot)
- Uniform density plastic shell
- “perfect” 20 micron pinhole for imaging detector tally
- MCNP gives total C-12 gamma production and appropriate gamma flux at detector location

Current NIF implosion conditions are approaching feasibility for GRI

- C-12 gamma production for carbon ablator ICF experiments has (~)linear dependence on on both neutron yield and remaining ablator mass at peak neutron production

$$Y_{\gamma,C} = \frac{\sigma}{m} Y_n \langle \rho R \rangle_C$$

- Parameters used for the two simulated curves yield ~0.3% and ~0.7% C-12 gammas per neutron



Consistent with previous scoping study by Izumi and Tommasini

LLNL-TR-639123

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Gamma ray imaging of the imploding shell using NIS hardware

N. Izumi, R. Tommasini

June 14, 2013

(3) Summary

Imaging of the 4.433 MeV gamma ray from 12C(n, n' γ) is doable with using existing NIS when Yn >1E15 and rhoR_CH > 300mg/cm2 with the detection statistics of ~84 events/resolution element. The image quality can be significantly improved (to 285 count/resolution element) by replacing existing plastic scintillator array (thickness 5cm) with new Lu2SiO5 (LSO) scintillator array (thickness 2.5cm).

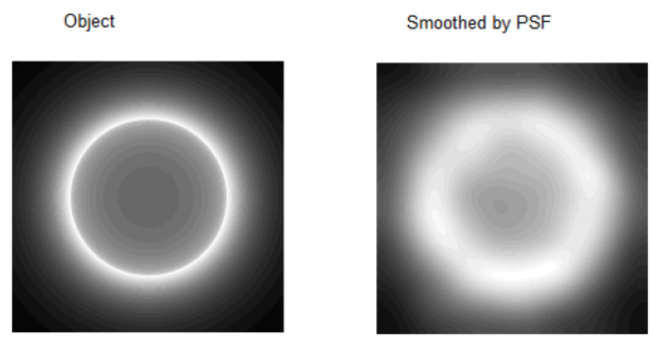

Fig. 6. Expected gamma ray image with LSO scintillator array (Yn = 1E15,ρΔR = 300 mg/cm^2)

- Izumi's study had assumed the ability to add 20 of the current pinhole signals, which is not possible given current NIS alignment tolerances
  - For 4 pinholes (used in this study) Izumi's simulations would represent Yn≈5E15

Simulations indicate that NIF double shell experiments can be imaged with GRI

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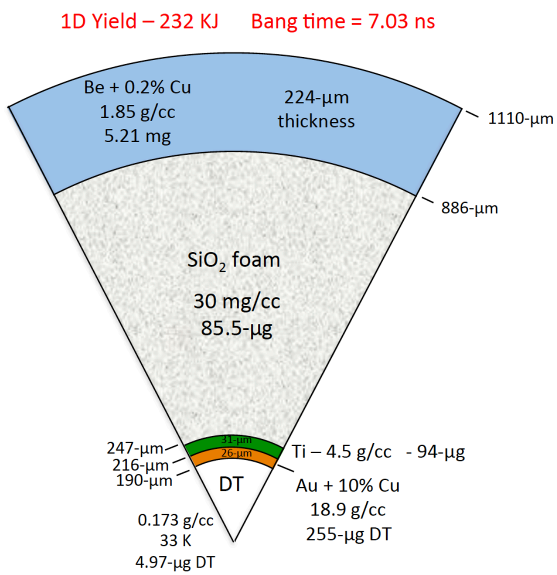
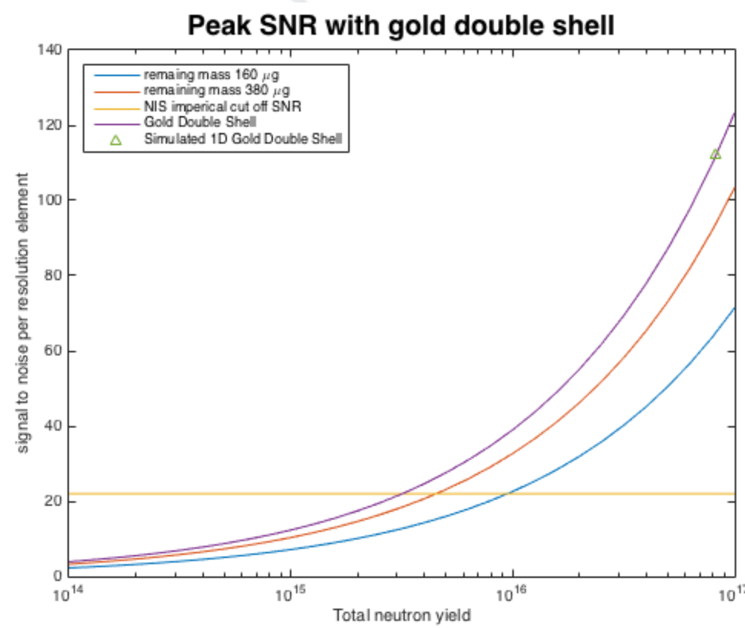
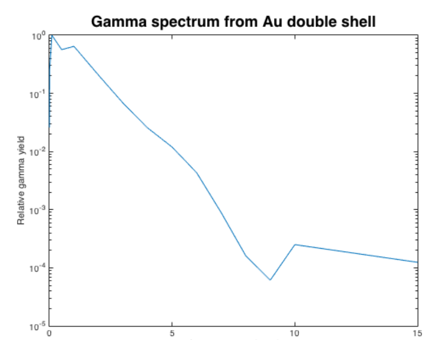
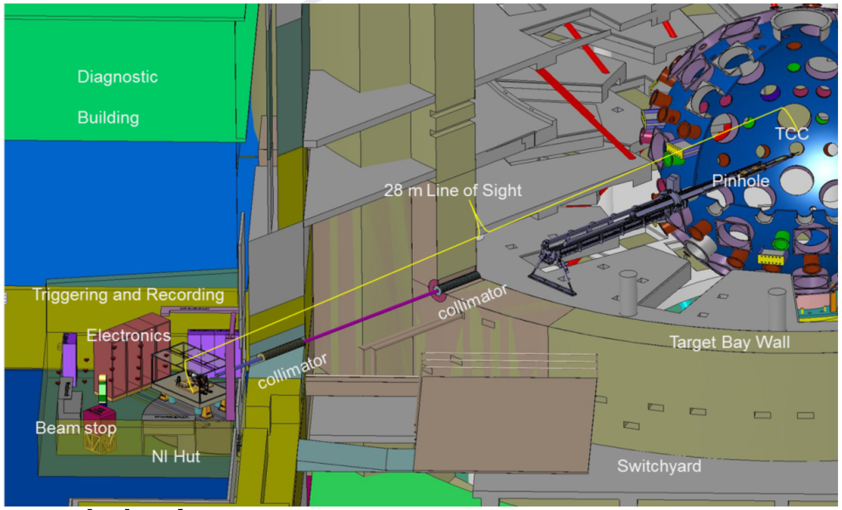


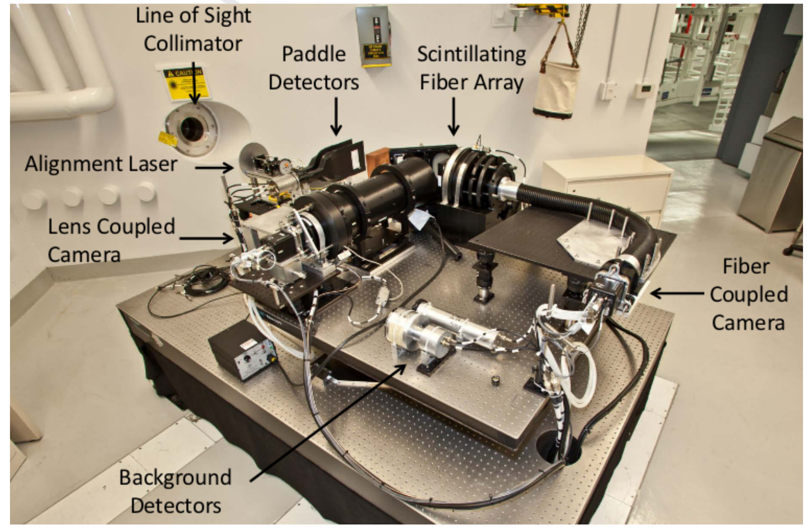




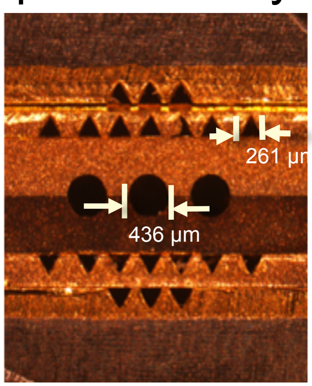
Stagnation Conditions:
Neutron Yield: 8E16
Inner gold shell radius: 20 microns
Gold shell thickness: 35 microns
Mass averaged gold density: 2200 g/cc

90-315 neutron imaging system provides most of the needed components of a gamma ray imaging system



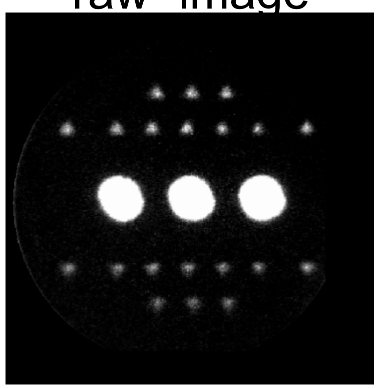


pinhole array

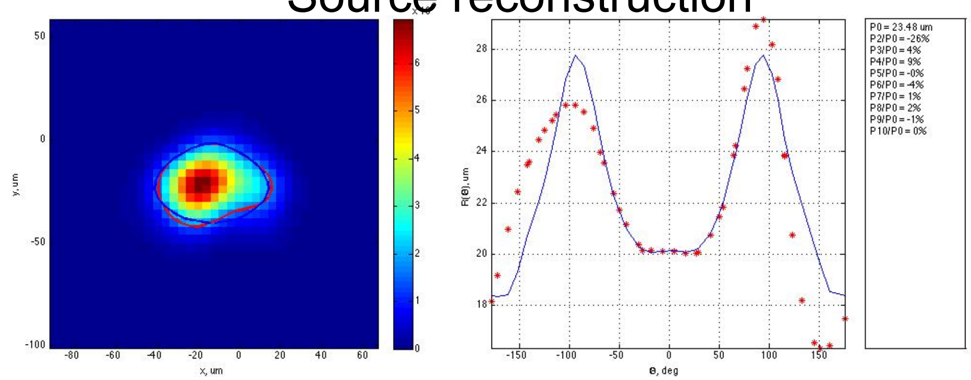


20 cm of gold

“raw” image



Source reconstruction



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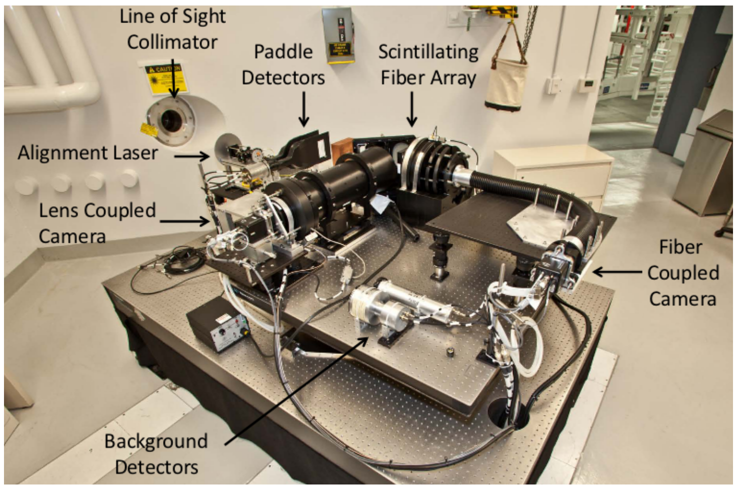
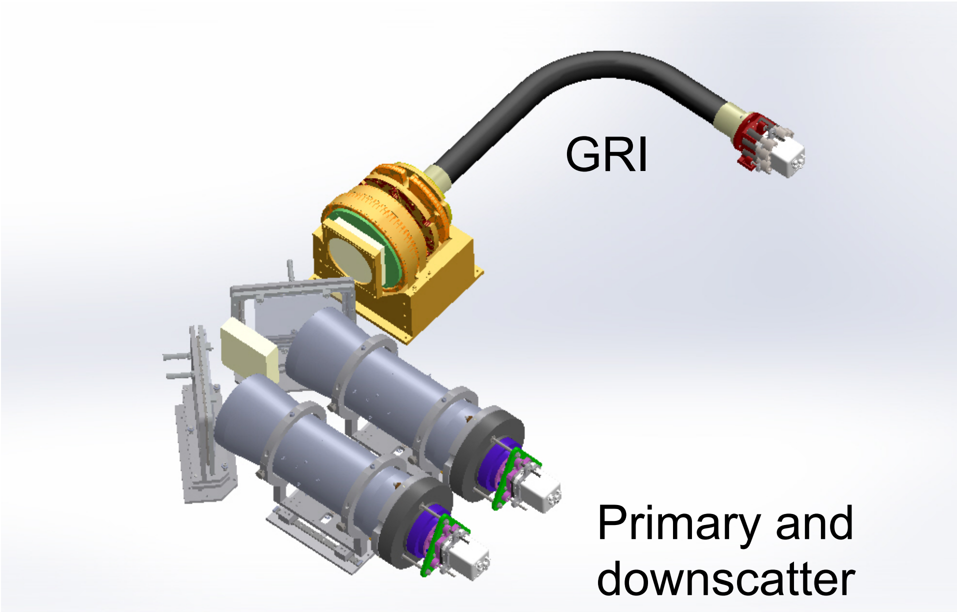
Relatively straight forward addition to 90-315 LOS

- Replace downscatter arm with a copy of the lens system used for the primary imaging
- Use existing fiber coupled system for GRI





LYSO is an obvious choice for ~4 MeV gamma detection

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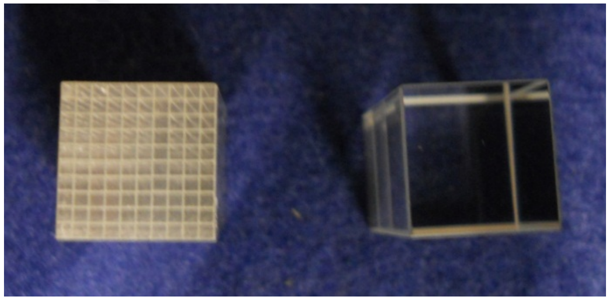
Daniel Lemieux and Gary Grim investigated options for detectors

Scintillator	Formula	Density (g/cm^3)	Light Yield (ph/Mev)	Decays (ns)	Emission Max(nm)	Refractive Index	Atten. @ 4.44MeV (cm^{-1})	%Int of 4.44MeV in (2cm)	Light Yield In 100ns (ph/MeV)
BGO	$Bi_4Ge_3O_{12}$	7.13	8,200	300	480	2.15	0.276	42	2,300
LSO	Lu_2SiO_5:Ce	7.4	27,000	40	420	1.82	0.278	43	24,900
YSO	Y_2SiO_5:Ce	4.45	9,200	42	420	1.8	0.144	25	21,500
LYSO	$Lu_{1.8}Y_{0.2}SiO_5$:Ce	7.11	32,000	41	420	1.81	0.264	41	29,200



BGO
- Slow Decay
- FWHM = 1.1 mm
- Low light Output

YSO
- Low Density
- FWHM = 1.7mm
- Low light output

LYSO
- Fast
- High light output
- FWHM = 1.2mm
- Lutetium decay negligible

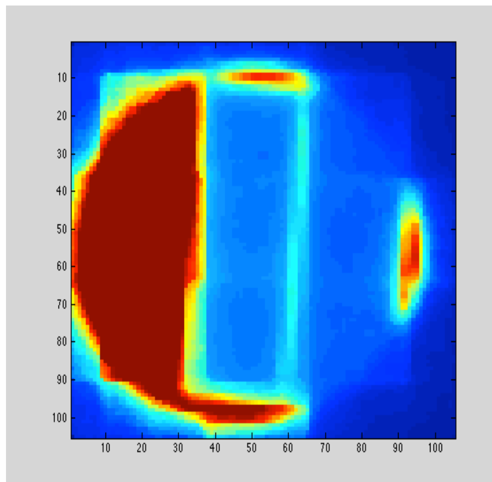
LA-UR-15-27702

LYSO scintillator detector

- LANL / University of Arizona collaboration to develop prototype detector

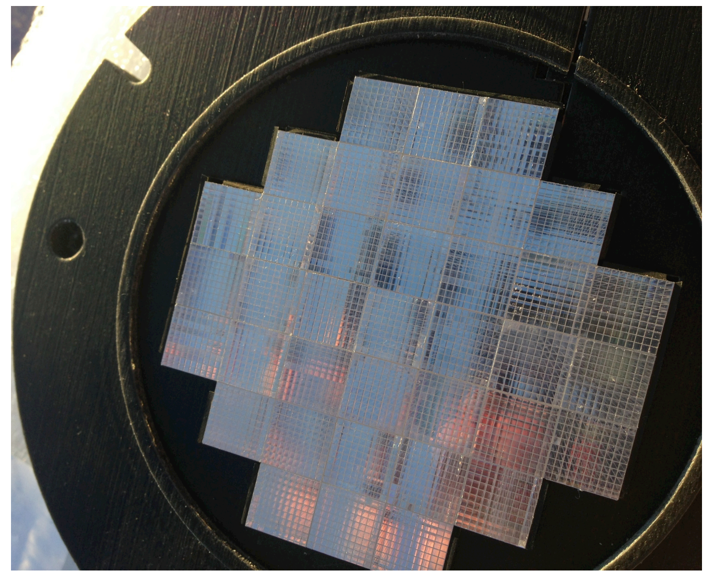
LYSO Array

- 37 crystals
  - 1 cm x 1cm x 2 cm
  - 10 x 10 pixels
    - 1 mm x 1mm
- Total of 3700 pixels
- ESR coating on sides of pixel and back end.
- Produce 420 nm light



Resolution slit

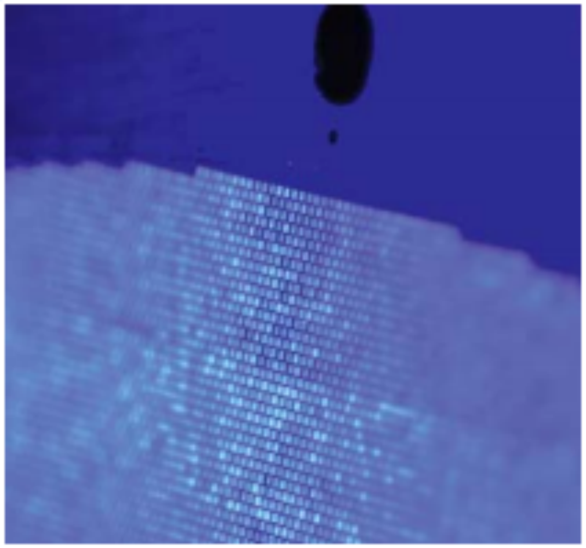
- ~1.7 mm

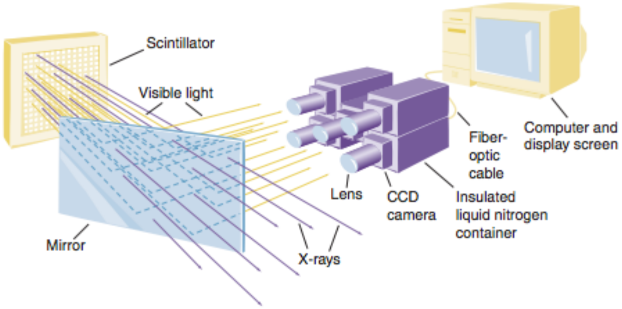


Courtesy of Daniel Lemieux and Gary Grim et.al.

Opportunity to leverage DARHT scintillator replacement project

- Dual-Axis Radiographic Hydrodynamics Test (DARHT) facility at LANL detector is designed for detection of ~4 MeV gammas
  - LSO
  - ~1 mm pixels
  - ~40 cm square





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Conclusions / future work

- Imaging of $^{12}C(n,n'\gamma)^{12}C$ gamma rays is possible with neutron yields O(1E16)
- GRI of gold double shell experiments should be even easier
- Modest modifications to the 90-315 NIS can enable this
- Need to design and measure noise in detector
- Can apply NIS full system model to study effect of aperture on features of interest etc.

Possibilities exist for gamma ray imaging in current NIF implosions as well as future double shell implosions

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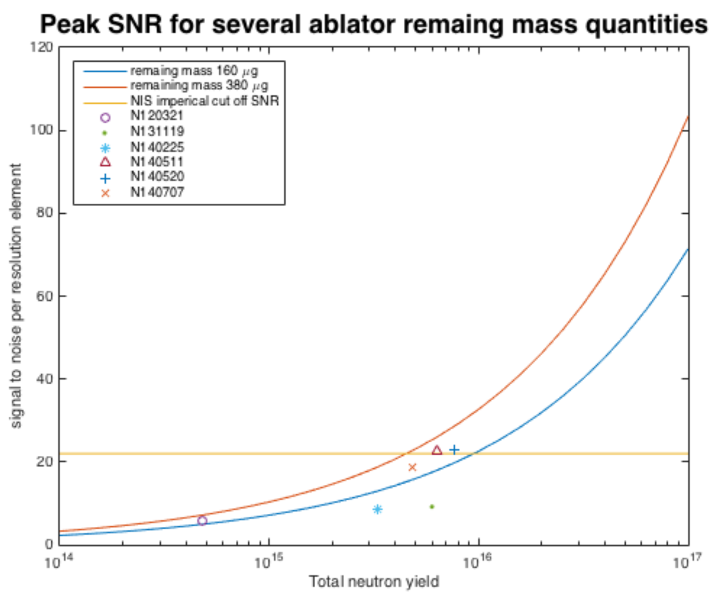
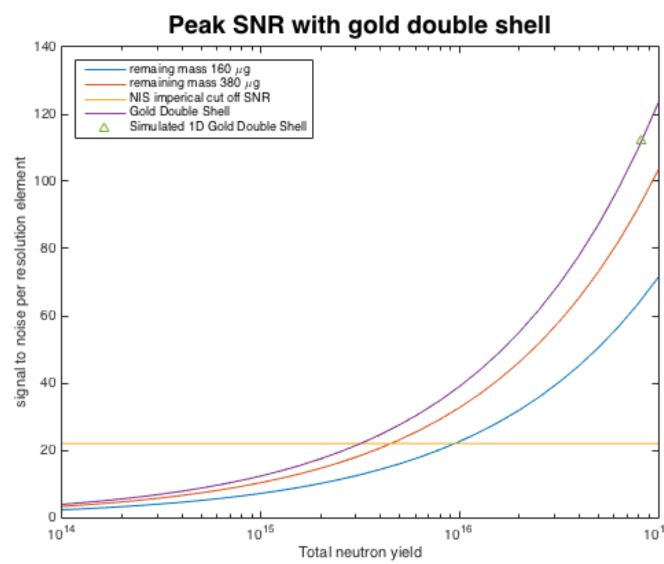
- GRI of gold double shell experiments should be even easier





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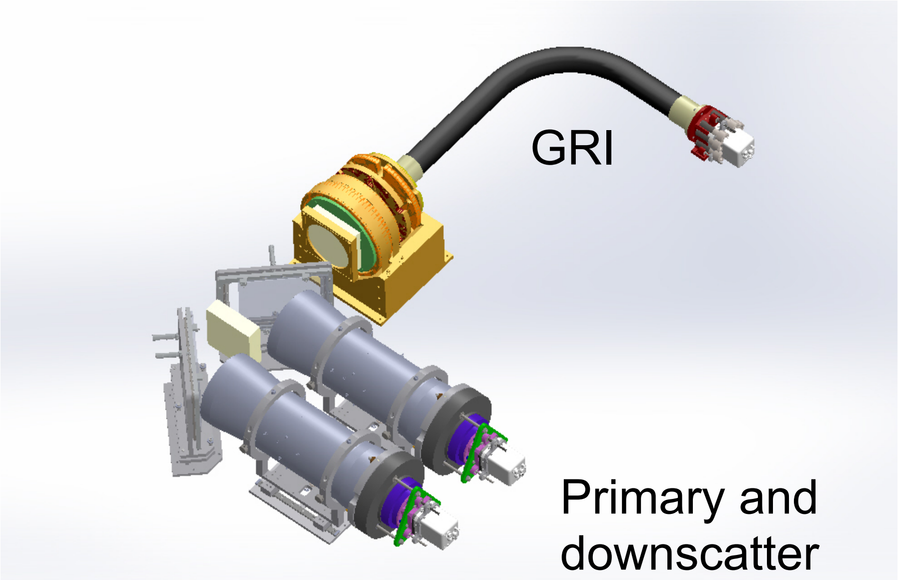
Opportunities to leverage current NIS as well as DARHT detector development

- Utilize current NIS aperture and LOS
- Replace downscatter imager with copy of lens used for primary and use existing fiber optic system for GRI



- DARHT is currently investigating replacing its LSO detector made of 1 mm diameter by 4 cm long pixels
- This system is nominally what GRI at NIF would require