Imaging γ-ray's at the NIF

CEA-DOE Diagnostics Workshop

29-30 June 2016, LLE, Univ. of Rochester,
Rochester, NY

LLNL-PRES-XXXXXX
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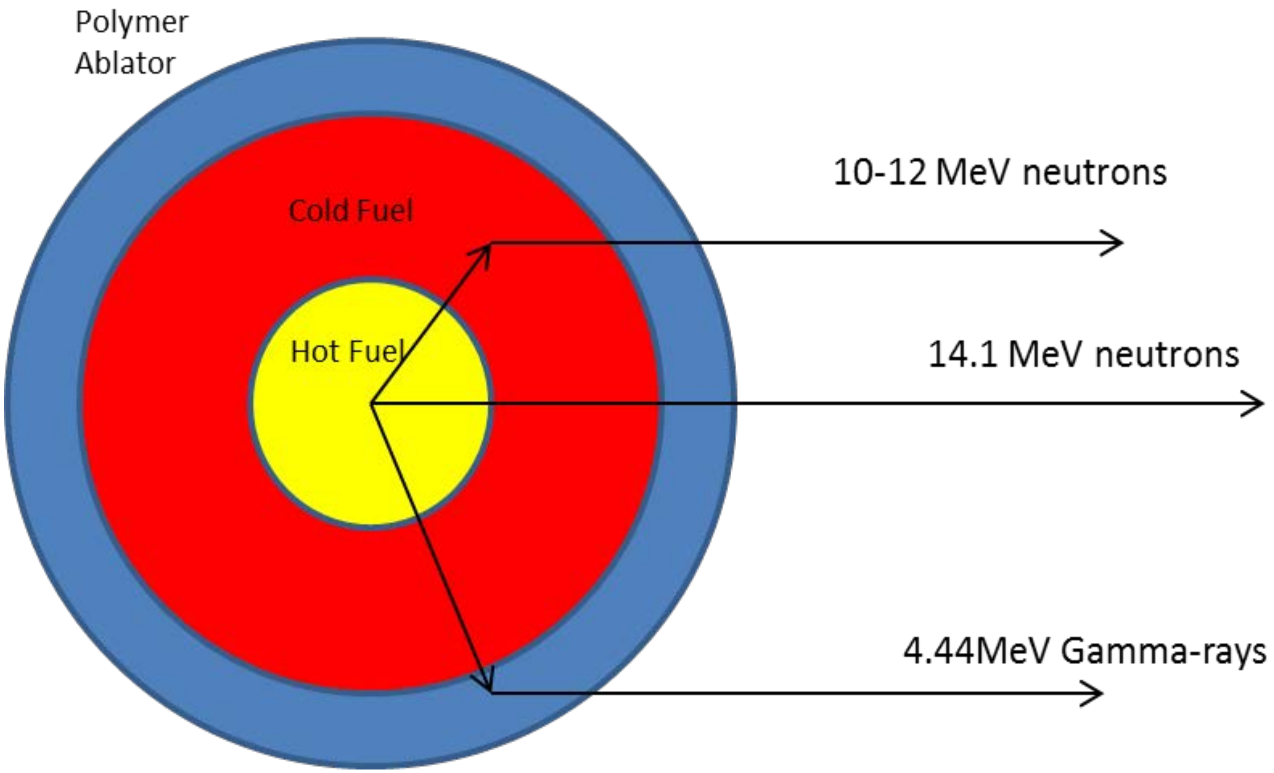
Summary

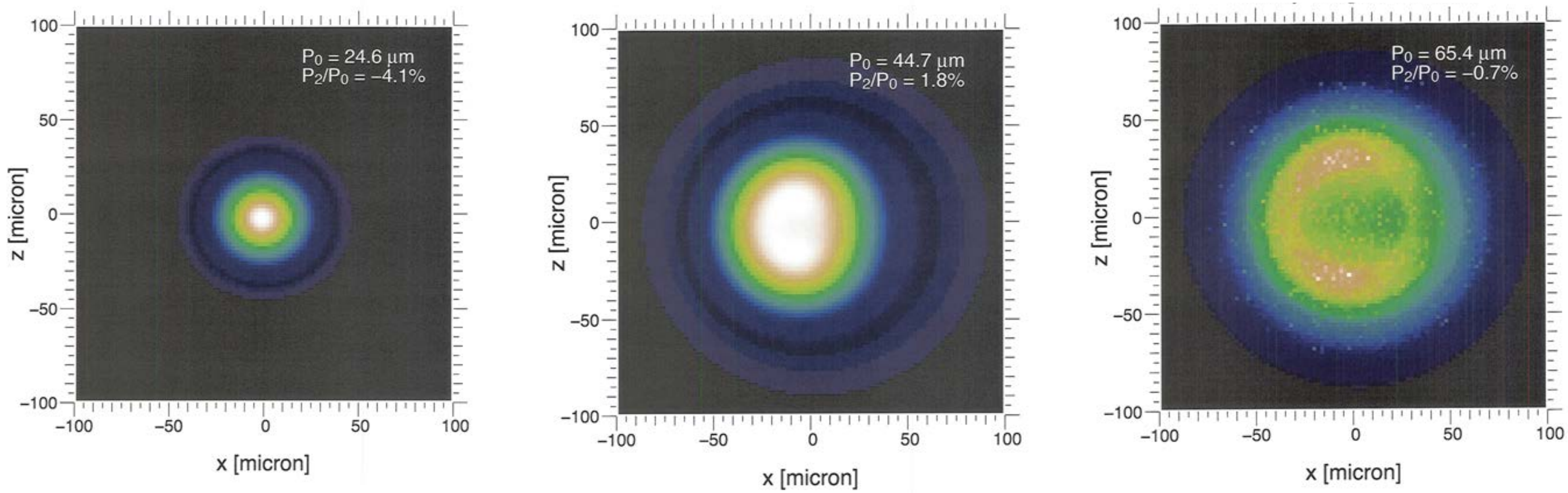
- NIF plans to implement imaging of gammas along the (90,315) line-of-sight in FY-17.
- Gammas from ^{12}C (n,n'g) reactions provide quantitative information on the distribution of carbon in layered implosions using CH and HDC ablator materials.
- Scoping activities have taken place and initial indications are that imaging carbon is viable on layered shots with DT yields in the low 10^{15}'s.
- A concept for implementation is almost complete and Implementation will principally involve reconfiguring the NI camera table by adding a gamma scintillator and extra imaging channels.

γ-ray imaging uses neutrons from the source to probe the carbon ablator



This complements the primary and down-scattered neutron data.

γ-ray images should be larger than the down-scattered image.

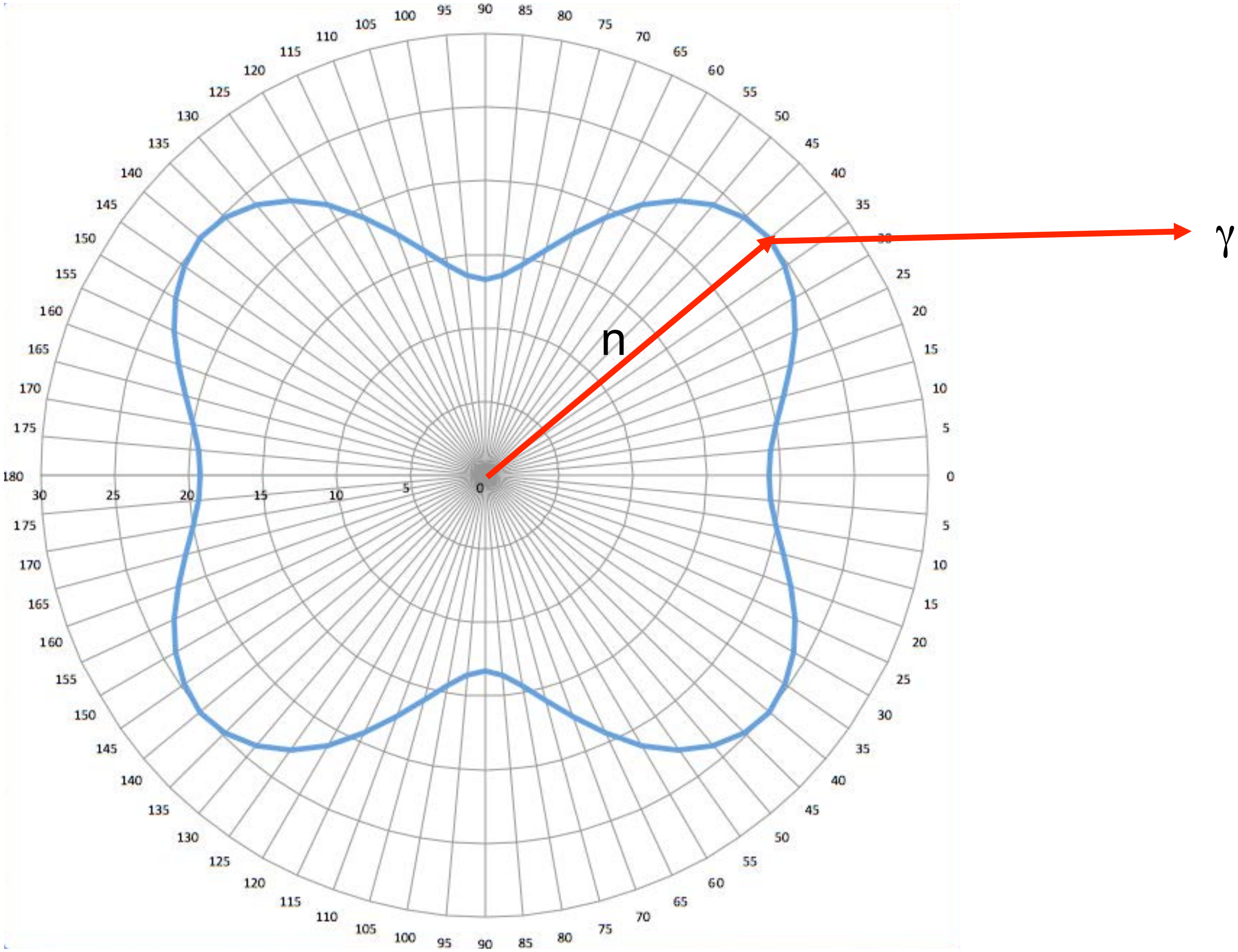


Primary NI | Scattered NI | Gamma Image

Simulated images

Courtesy: Charlie Cerjan

Symmetric dipole excitation — equal emission in the forward and backward directions

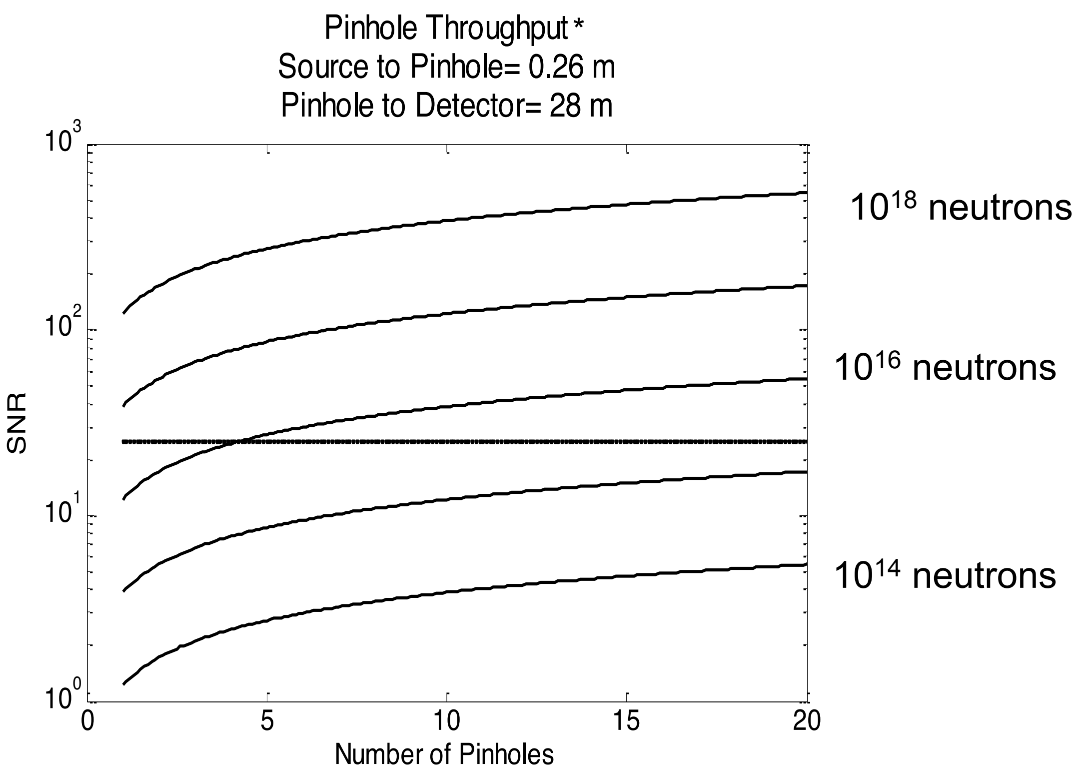


The full shell assembly will contribute to the image, unlike in downscattered images.

Penumbral apertures are needed at current yields…

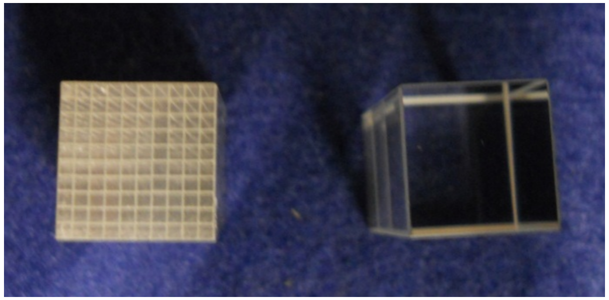
- For 26 cm TCC pinholes at least 5 are needed for decent images at 10^{15} neutrons. Even worse as pinhole is moved away from TCC.

- Penumbras are needed to improve SNR



To ensure DQE, pixelated LYSO was selected* as the converter…

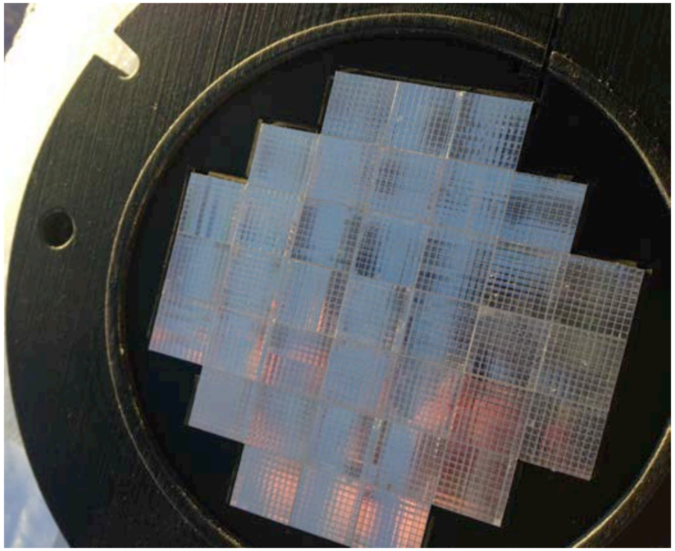
Scintillator	Formula	Density (g/cm³)	Light Yield (ph/Mev)	Decays (ns)	Emission Max(nm)	Refractive Index	Atten. @ 4.44MeV (cm⁻¹)	%Int of 4.44MeV in (2cm)	Light Yield In 100ns (ph/MeV)
BGO	$Bi_4Ge_3O_{12}$	7.13	8,200	300	480	2.15	0.276	42	2,300
LSO	Lu_2SiO_5:Ce	7.4	27,000	40	420	1.82	0.278	43	24,900
YSO	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

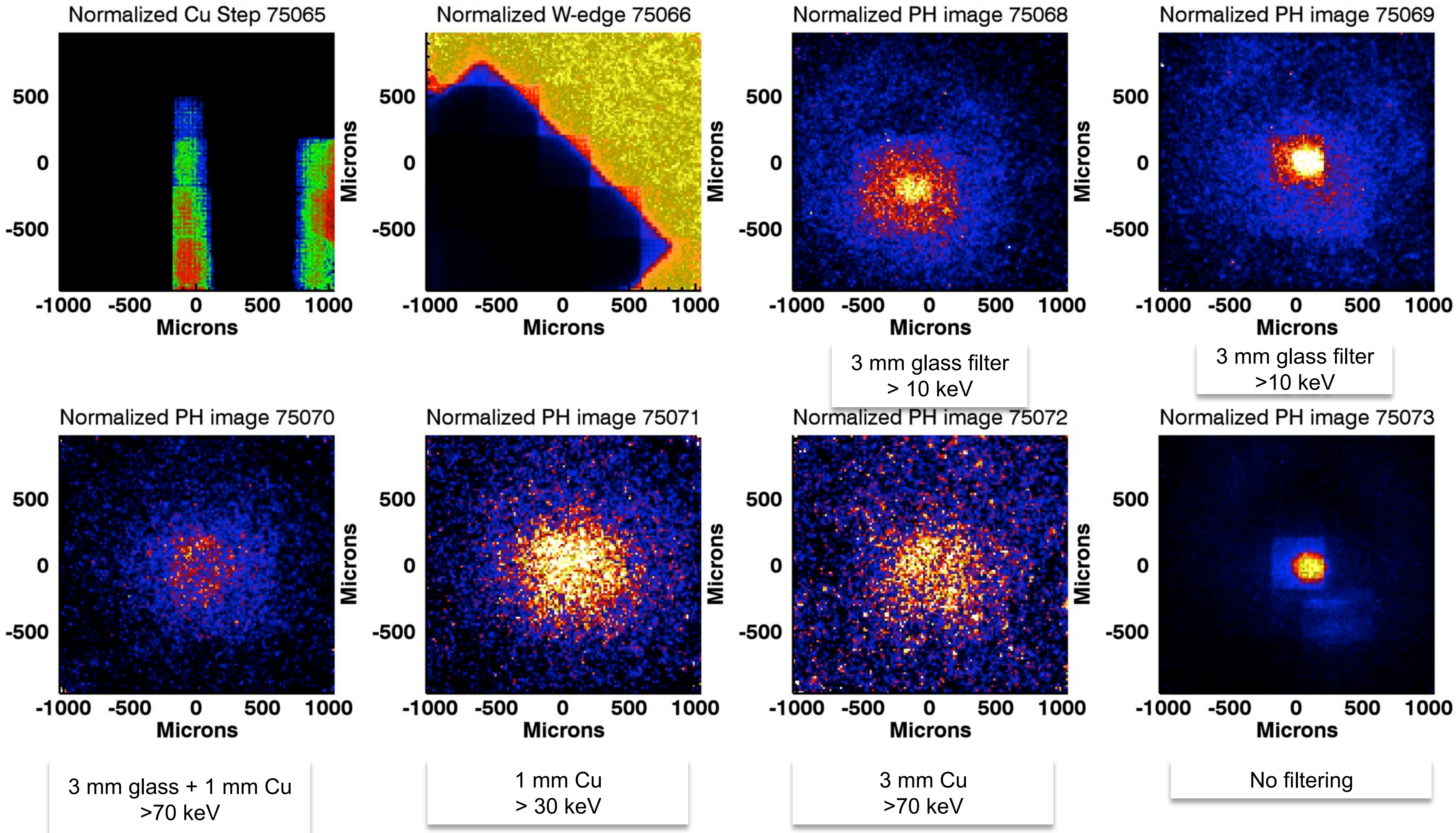
YSO
- Low Density
- FWHM = 1.7mm
- Low light output

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



*D. Lemieux, University of Arizona

A proto-type was fielded* at Omega, collecting images of hot-e bremsstrauhlung in CH implosions…



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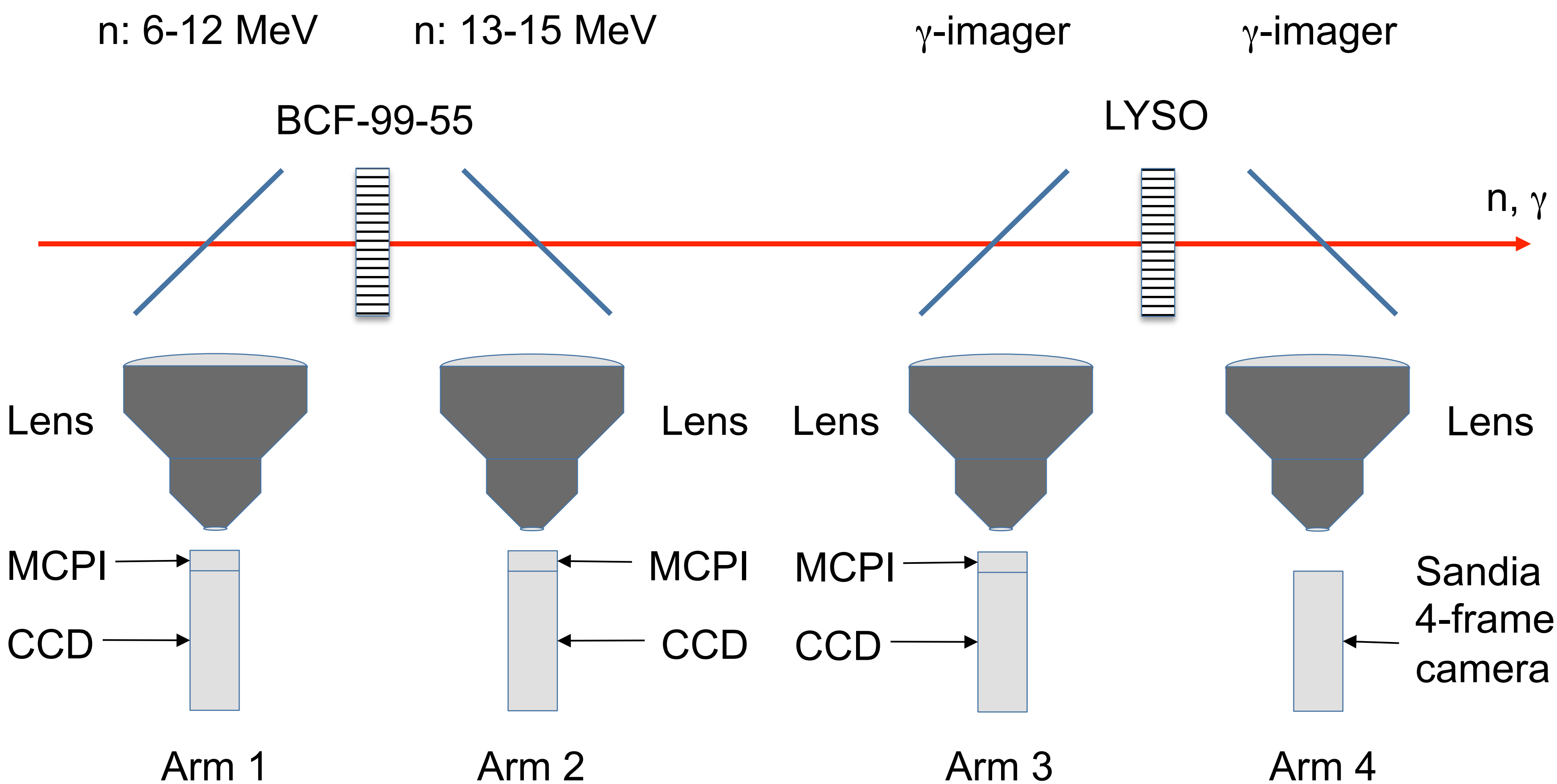
Concept for upgrading the (90,315) camera table to allow γ-ray imaging…



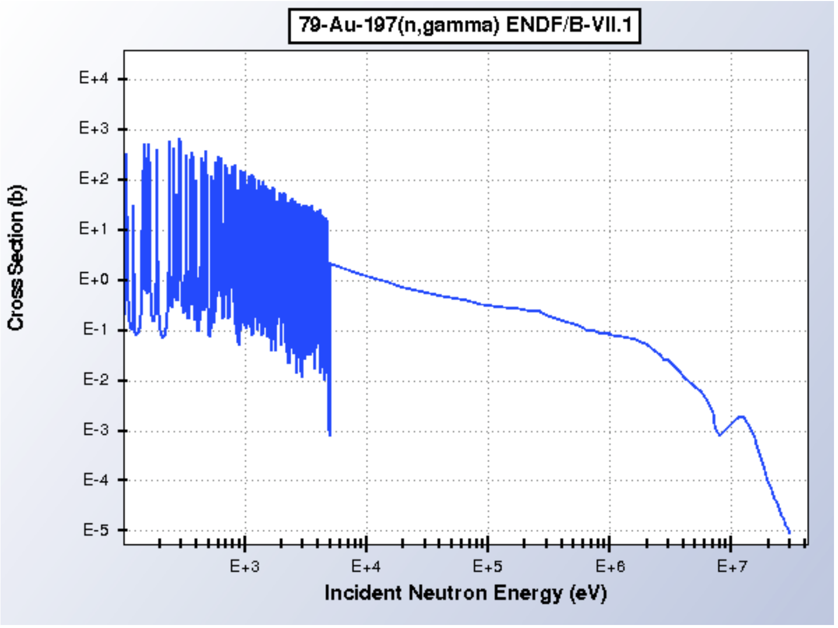
At this point we are costing out the project and developing requirements

- Image Resolution — 10 μm
- FOV at Source—?
- Minimum Gate Width—10 ns
- Gate Rise Time—1 ns
- Gate Fall Time—1 ns
- # Frames—2?

Possible issues that still need to be addressed

- γ production in the Au of the Hohlraum or NIS pinhole array
  — Some MCNP modeling may be useful.

- Possible need for new pinhole array
  — Either for reconstruction, field of view, etc.



Images of gammas were first collected in 2015 using sub-scale Symcaps and the NIF NI system

13-17 MeV neutron image

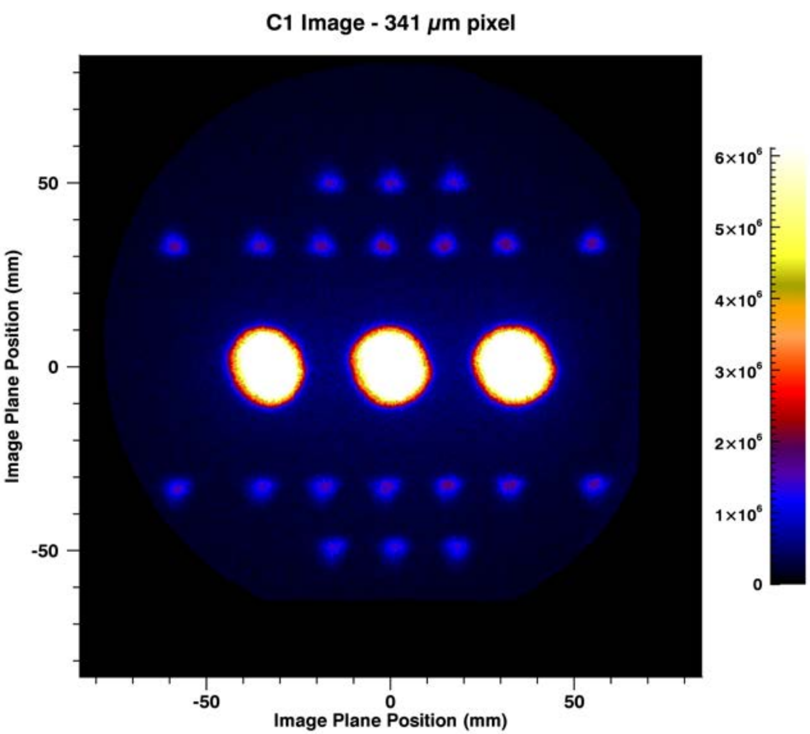


Image gated ±38 ns around γ flight time

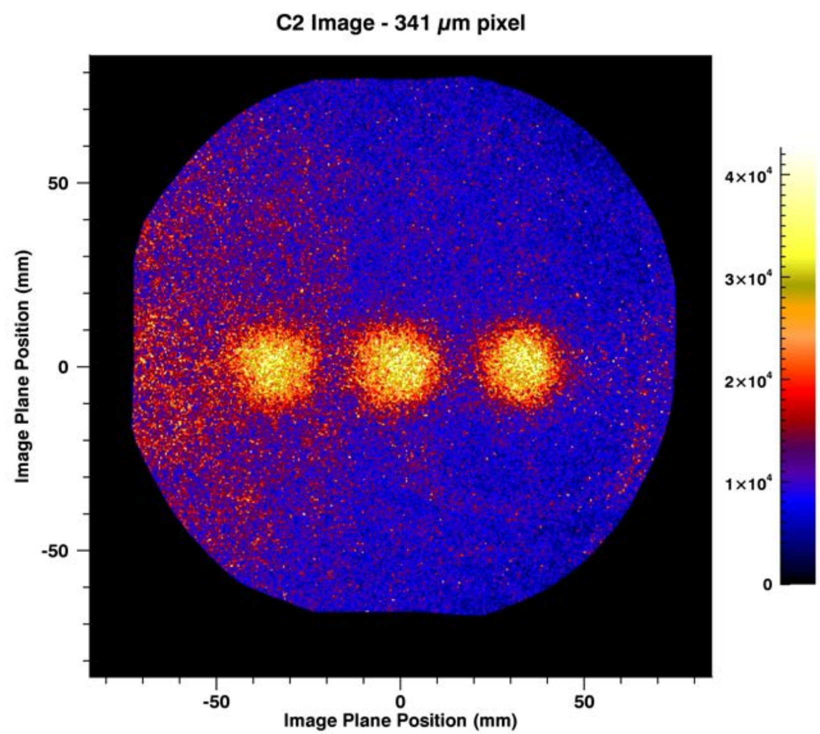


Image strength challenged reconstruction, but demonstrated viability…

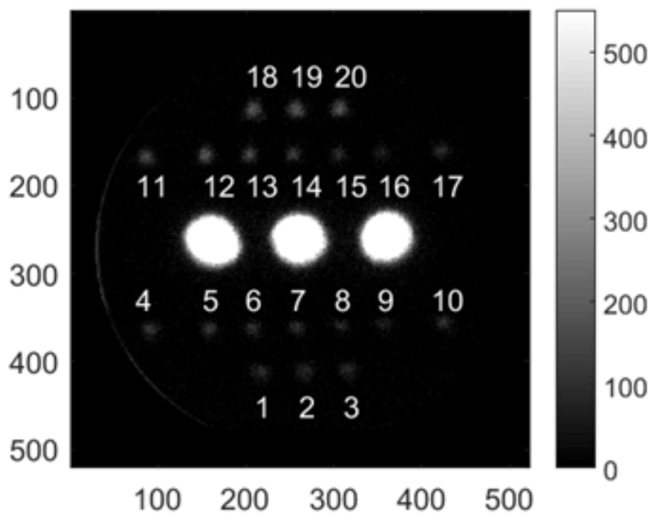
Possible sources of the radiation include

1. $^{12}C(n,n')^{12}C^{*}$ - 4.4 MeV. – Primary signal
2. T+D ➔ $^{5}He^{*}$ - 16.7 MeV – 100 x weaker
3. $(n,n'\gamma)$ – 1 - 2 MeV? – Background scattering sources
   1. Within penumbral images:
      1. TMP, Blast shield, aperture walls
   2. Outside penumbral images:
      1. NIS blast shield, snout etc…
4. Hot-electron bremsstrahlung in TMP and CH shell < 1 MeV
   1. Likely very weak.

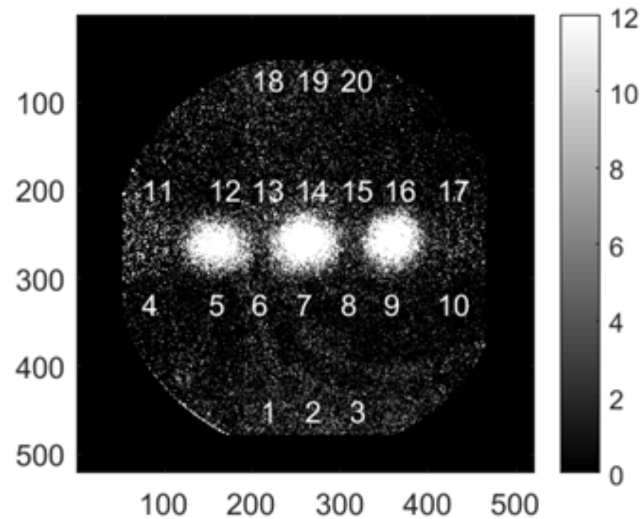
All, but source 1 seems unlikely to contribute much signal in the penumbral regions.

First gamma image from a layered CH implosion N160602…

Camera 1: 6-12 MeV



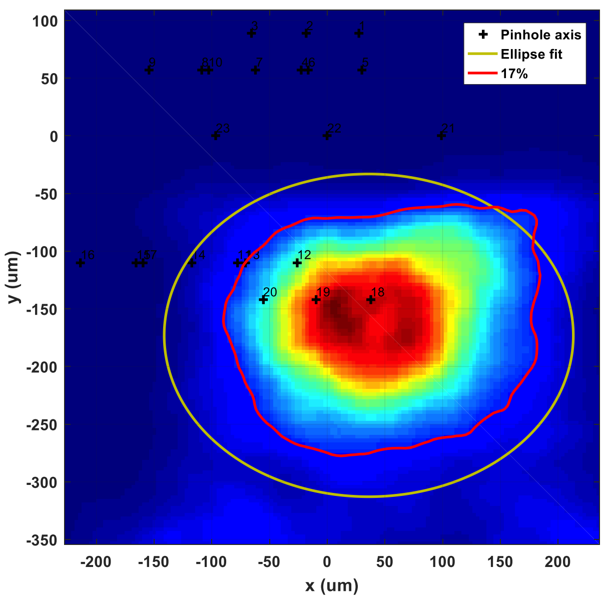
Camera 2: γ-image



Au-lined DU hohl (sc672), T-1 (175 um) CH capsule
0.6 mg/cc 4He hohlraum fill
3-shock high-foot drive, 1.54 MJ, 425 TW

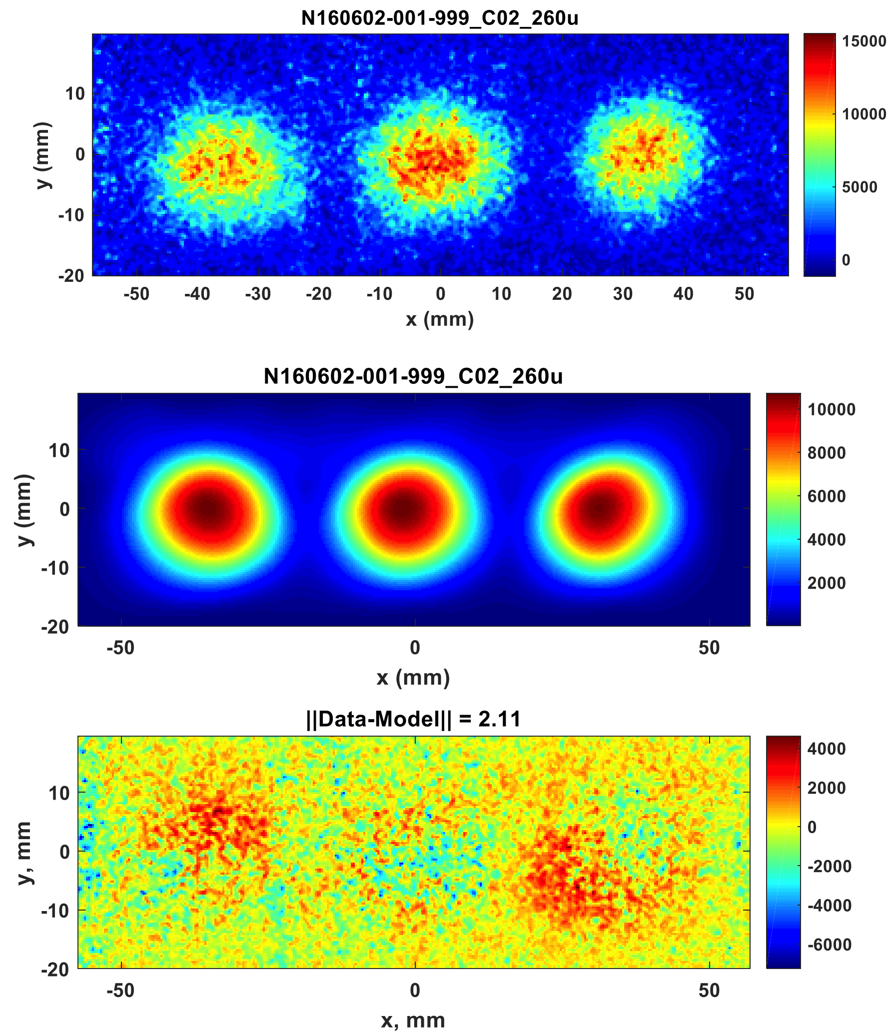
Y (13-15) :	1.65e+15
T_ion:	3.45 keV
dsr:	3.9%

N160602: Expectation Maximization Recon by LANL (Volegov, Wilde and Wilson)

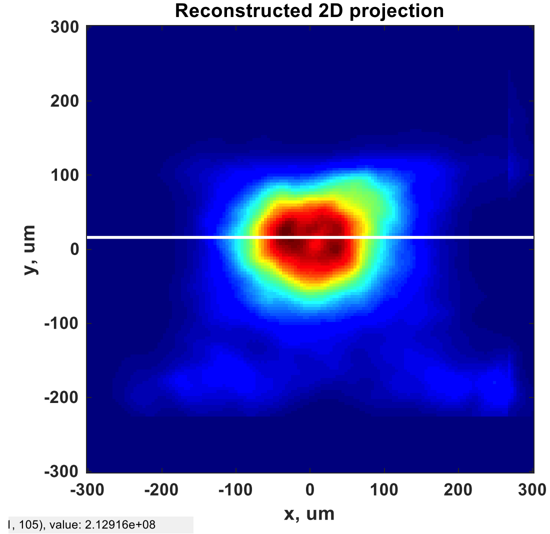


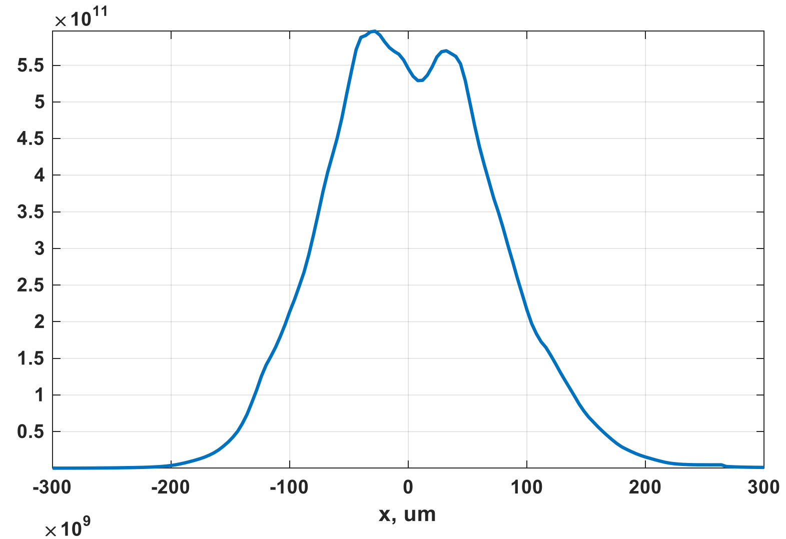
Position: (52, -163)
Size @17%: (278,217)
P0 = 129
P2/P0 = -16%

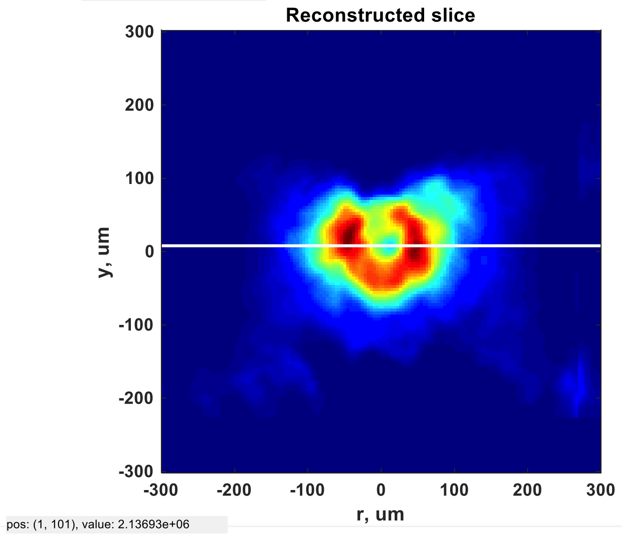
EMML, stop @ $\Delta\chi2/\chi2 < 10^{-4}$

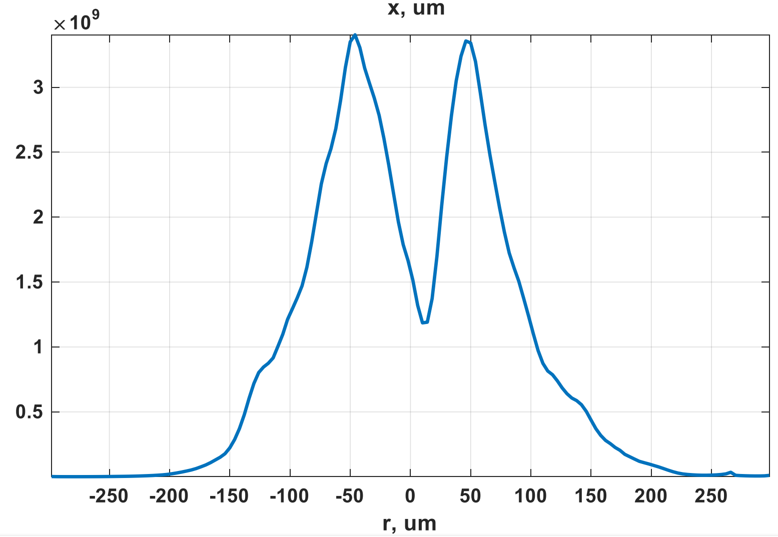


Abel inversion: $S(\rho,\phi,z) = S_{left}(\rho,z)\dfrac{1-sin\phi}{2} + S_{right}(\rho,z)\dfrac{1+sin\phi}{2}$

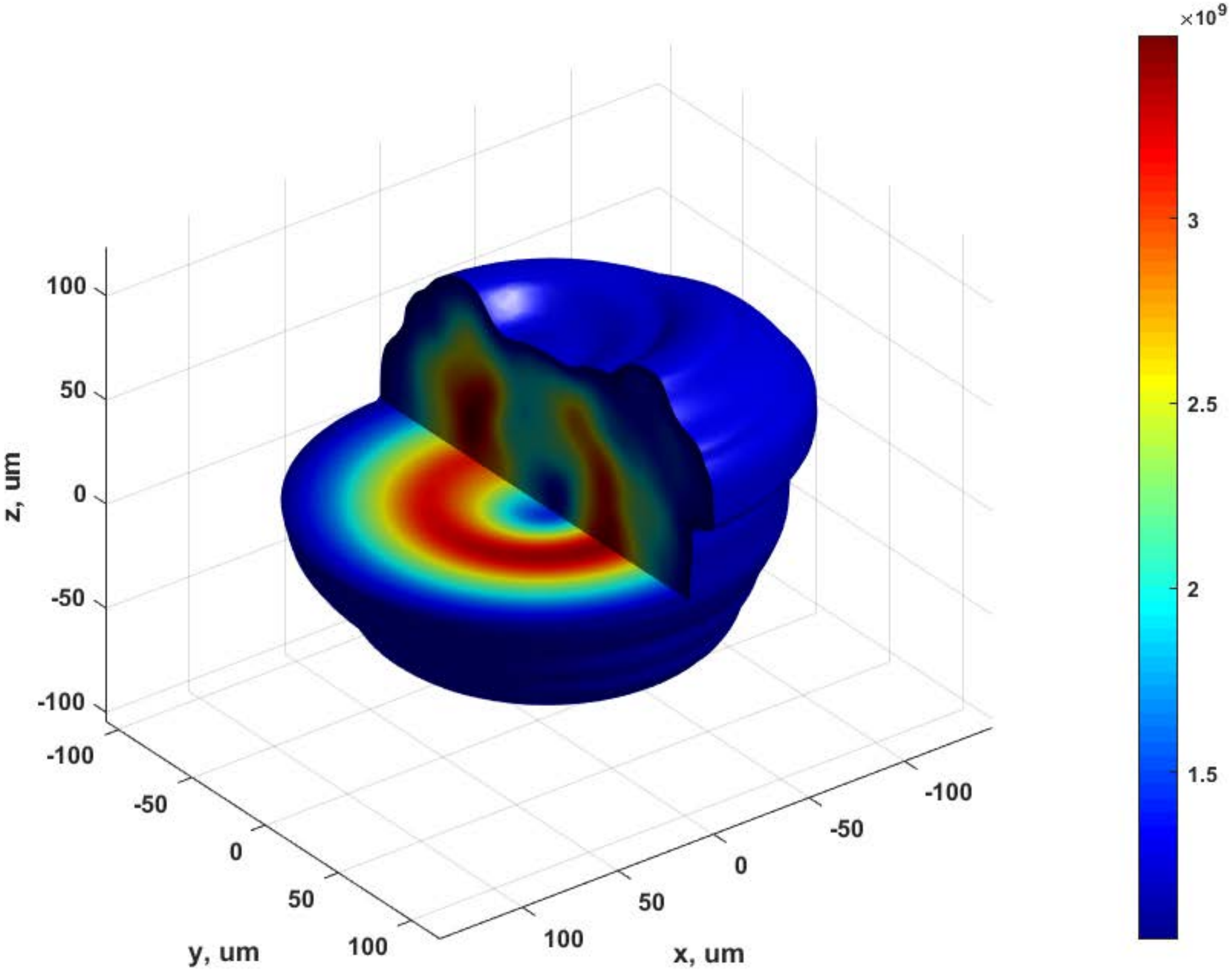








N160602: 3D rendering of reconstructed gamma source



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The scattering is more strongly directed forward and backward.

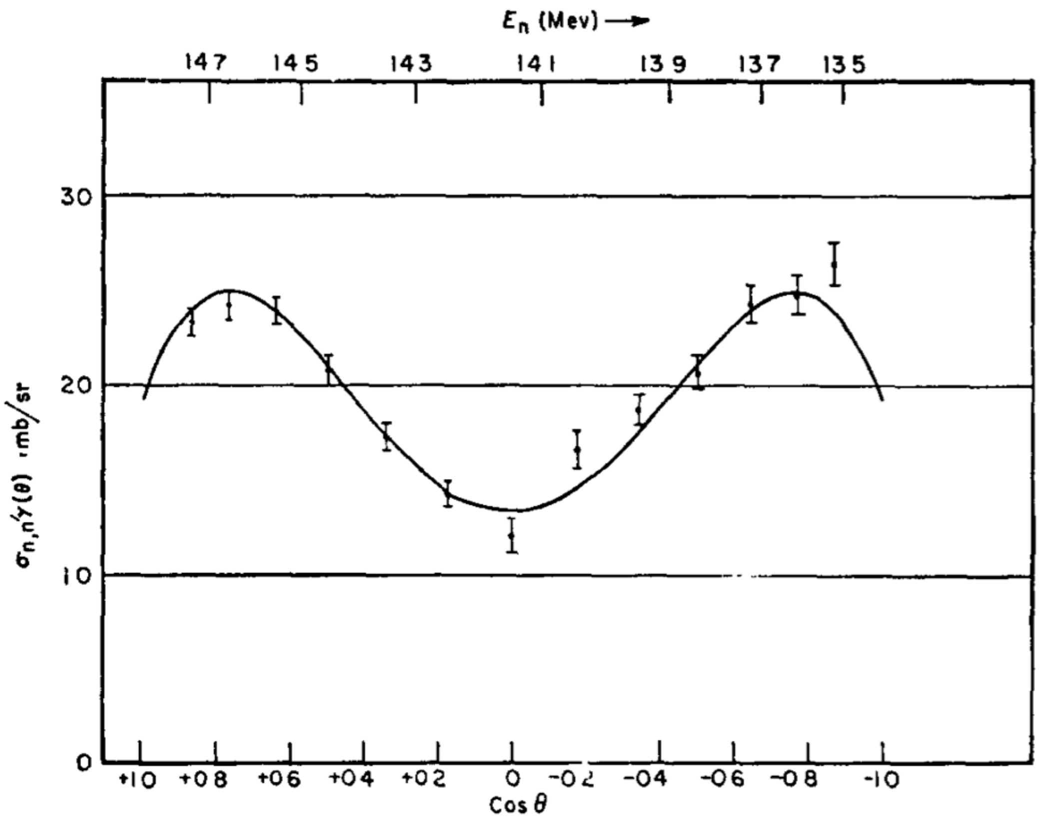


Fig. 4. Differential cross section for production of 4.43-MeV gamma rays by 14.1-MeV neutrons.

Images will receive contributions from the entire shell!

J. Benveniste, et al., Nuclear Physics **19**, 448-452 (1960).

Interpreting the images will depend on our understanding of the (n,n'γ) scattering.

- Reaction

$$C^{12}\left(n,n'\right)C^{12*} \rightarrow C^{12} + \gamma\left(4.43\ \mathrm{MeV}\right)$$

- Angular Distribution Fit Function (θ wrt neutron direction)

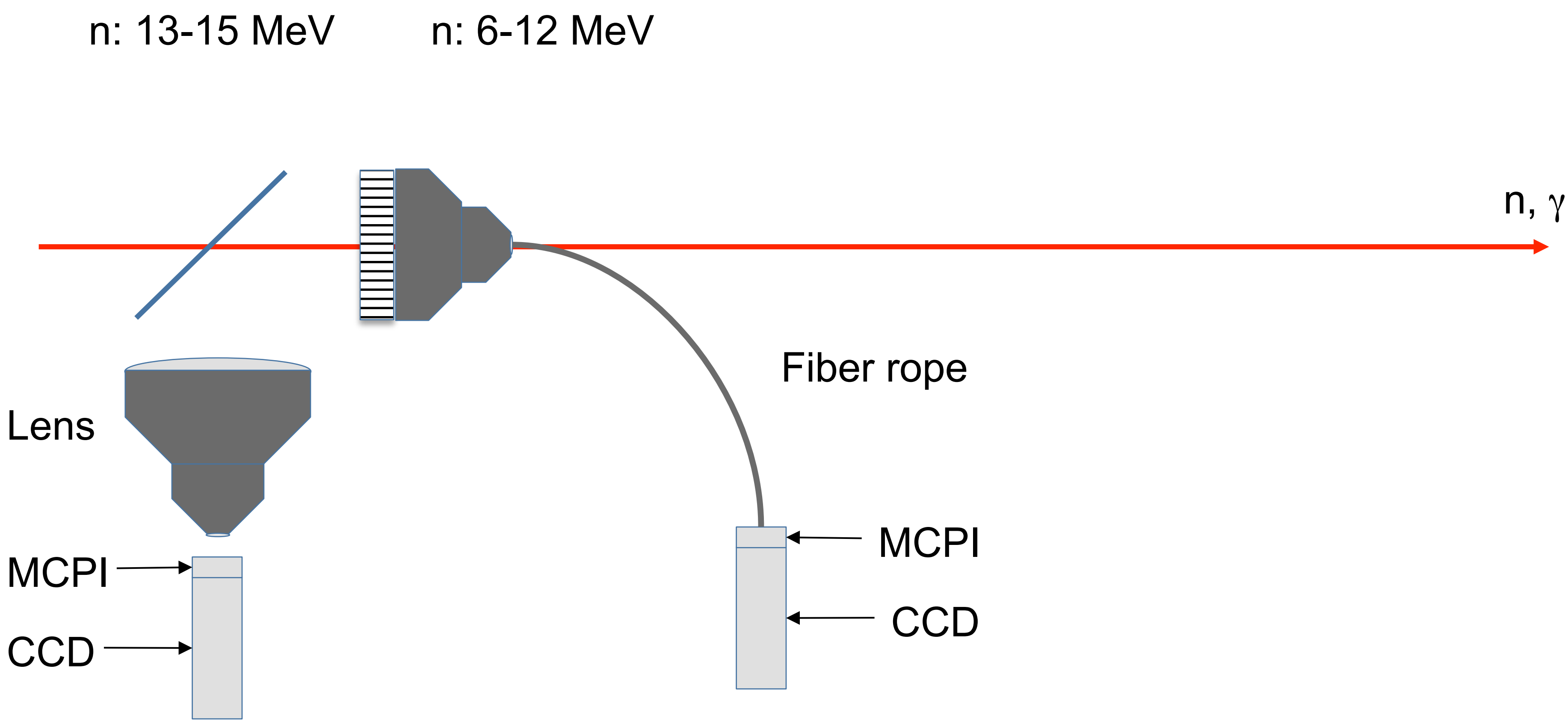
$$\sigma\left(\theta\right) = \left(13.3 \pm 0.6\right) + \left(40.0 \pm 4.7\right)\cos^2\theta - \left(34.1 \pm 5.1\right)\cos^4\theta \quad \text{in mb/sr}$$

- Integrated Cross-section

$$\sigma_{n,n'\gamma}\left(4.43\ \mathrm{MeV}\right) = 249 \pm 28\ \mathrm{mb}$$

J. Benveniste, et al., Nuclear Physics **19**, 448-452 (1960).

We are looking at upgrading the existing NIS to allow γ-ray imaging without sacrificing images.



Can the different image regions inform the spectrum?