Single line-of-sight Multimodal Radiography with the Titan laser

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Experimental PI | APT HED

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Thank you to the large team that contributed to the success of this experiment!

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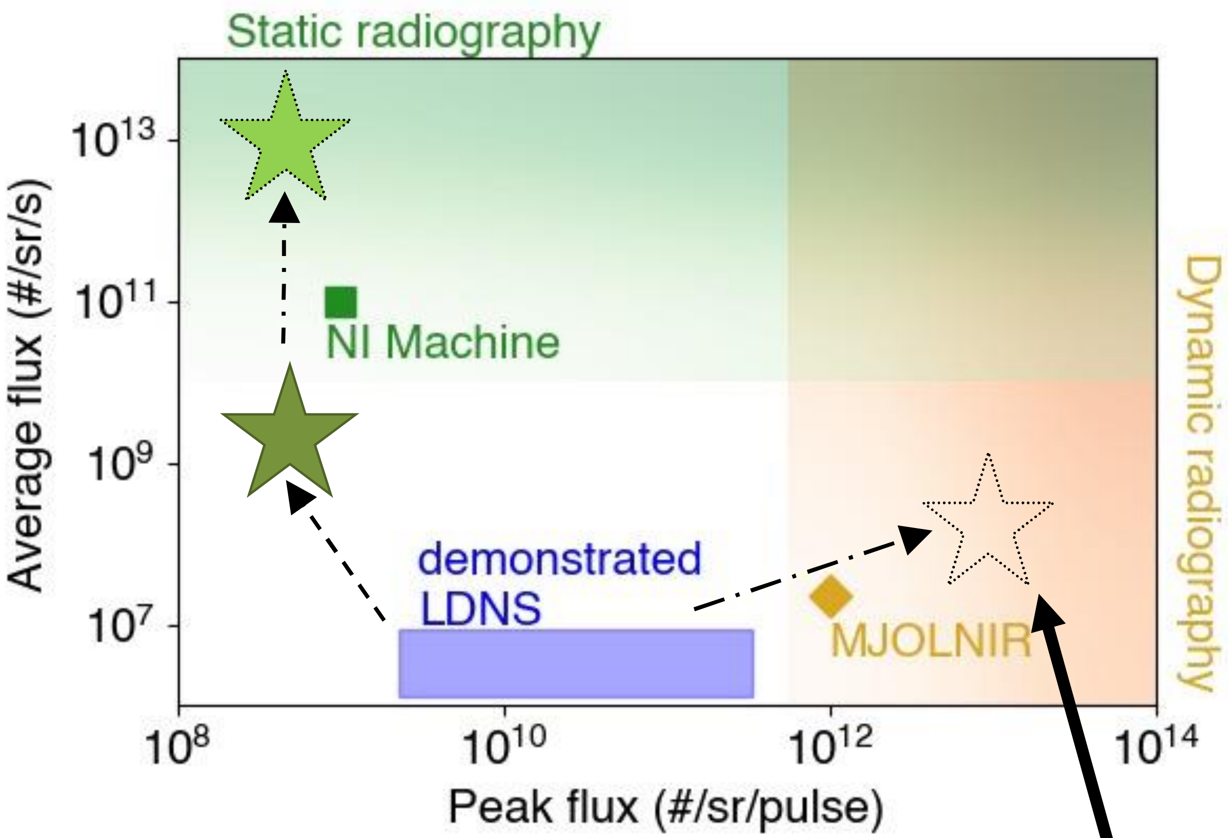
Laser development may allow for laser-driven neutron sources to be leveraged for non-destructive evaluation

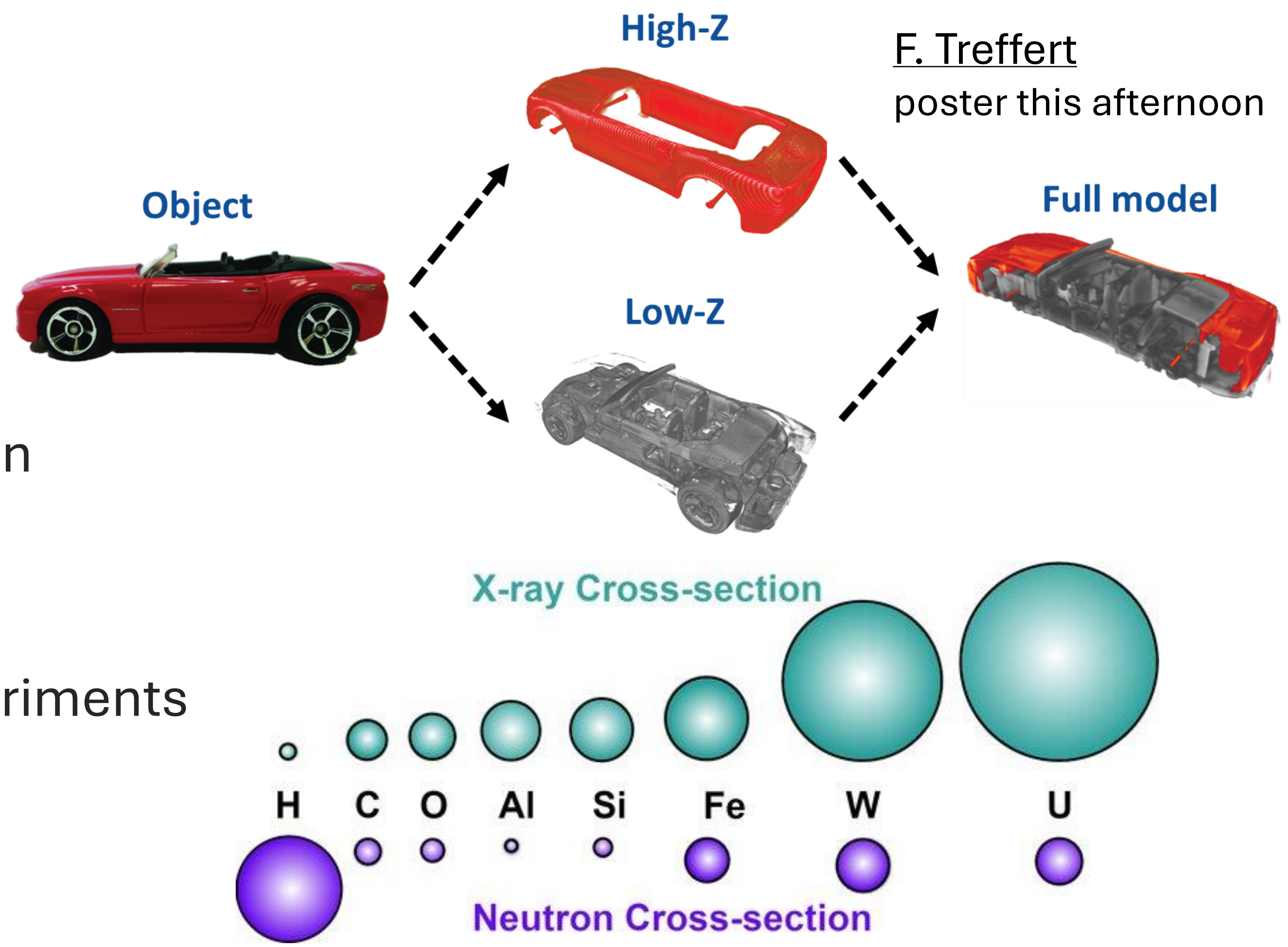
- Laser-driven neutron sources (LDNS) scale in neutron flux by the drive laser characteristics:
  - Energy - Peak flux
  - Repetition rate – Average flux
- Next-generation lasers are moving towards high energy and rep-rate
  - BAT, USA (30 J, 10 kHz)
  - ZEUS, USA (75 J, 1Hz)
  - ELI-Beamlines, Czech Republic (150J, 1/min)
- Can we use current laser systems to benchmark expected performance of future ones?



Stretch goal for LDRD Williams ERD #20-02-06

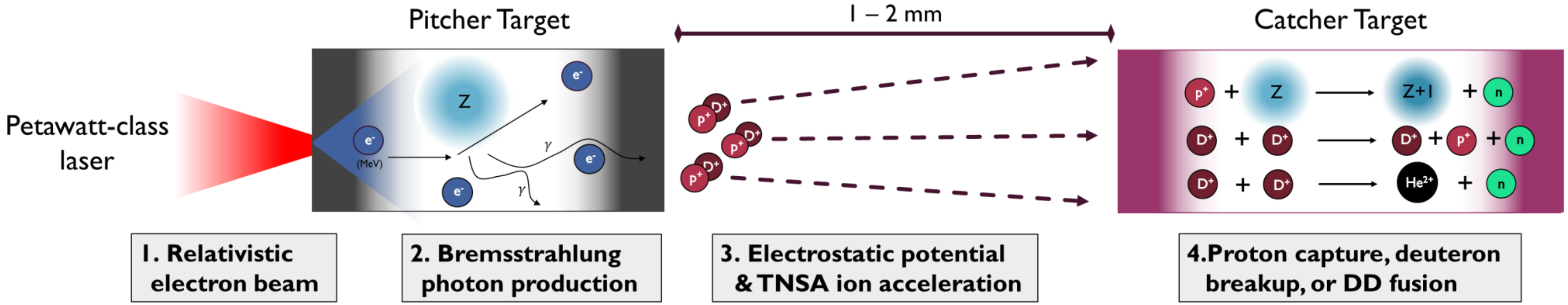
X-rays and neutrons have contrasting cross-sections that can generate complimentary radiographs

- Single-species radiographs are not suited to composite objects
- Combining x-ray and neutron radiographs can give more NDE information on an object
- Same line-of-sight make comparison and combination easier
- Same time (± 10’s ns) desirable for evolving systems such as HED experiments

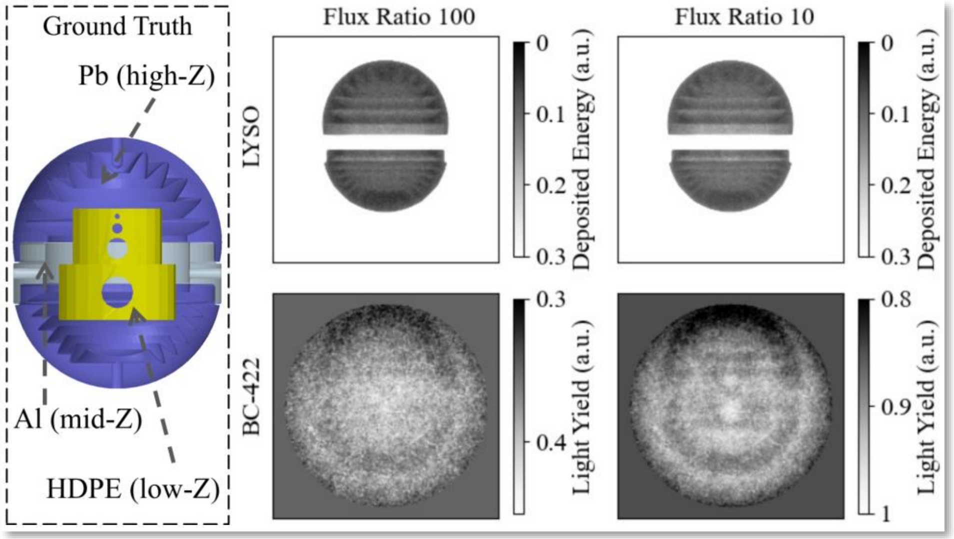


F. Treffert
poster this afternoon

TNSA ion beams can be used to generate fast neutrons with a directional component for NDE

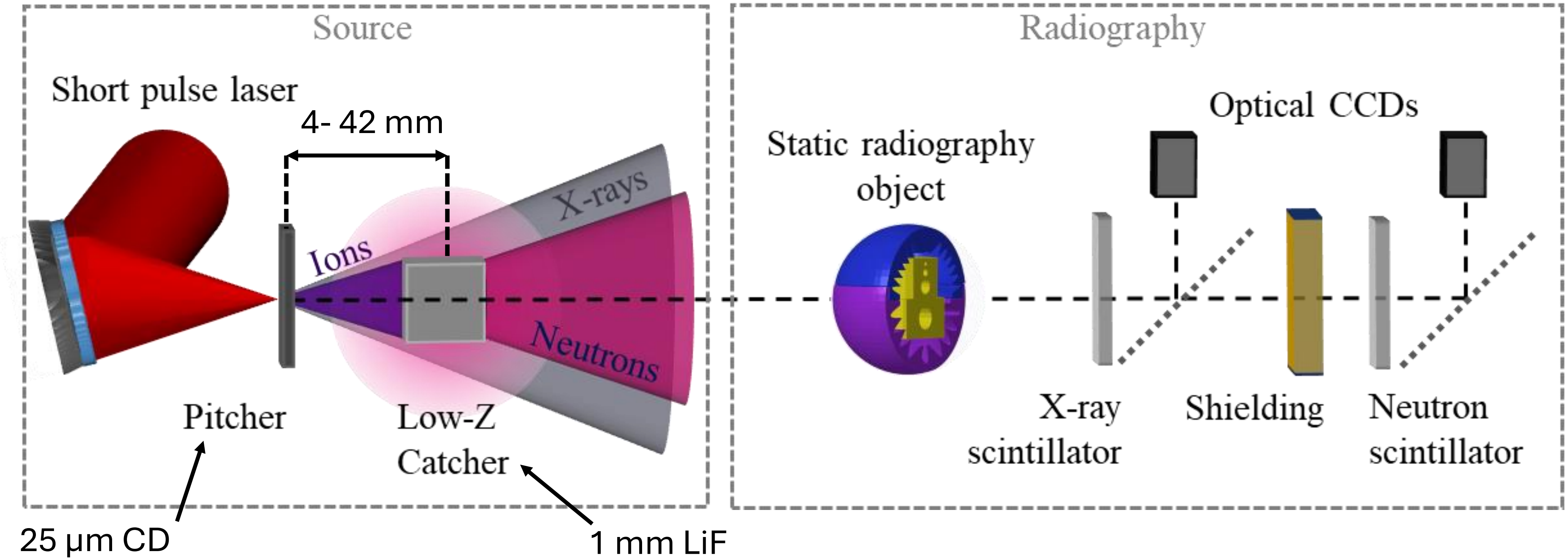


- Combined target normal sheath acceleration (TNSA) ions into catcher (neutrons) and bremsstrahlung (x-ray)
- Proton capture and D,D break-up neutrons have a directional component, generating a neutron beam
- Neutron radiography can be used to non-destructively evaluate(NDE) objects with plastic components
    - Desired neutron yield scales linearly with ion yield
    - Energy range of radiography interest is 0.5 – 25 MeV



F. Treffert *et al.*, *Rev. Sci. Instrum.* 95, 123305 (2024)

Titan 2024 investigated neutron yields for different catchers and attempted multi-modal radiography



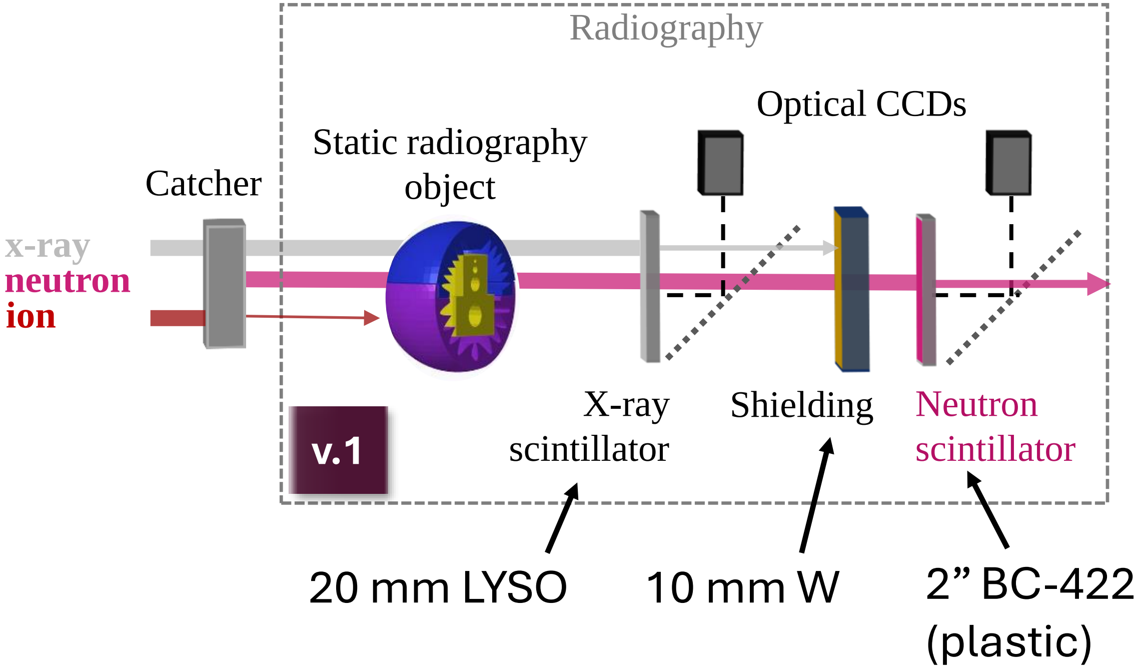
Data scans
1. Pitcher-catcher separations 2. Catcher material comparisons 3. Multi-modal radiography statistical repeats

Can we reach sufficient yields and design a radiography imaging system that achieves both x-ray and neutron images?

F. Treffert *et al.*, *Rev. Sci. Instrum.* 95, 123305 (2024)

X-rays attenuated post-imaging to prevent it generating a high background on the neutron scintillator

- X-ray scintillators are rarely neutron efficient
  - High-Z and thin
- Neutron scintillators are often x-ray efficient
  - Thick
- X-ray attenuation more achievable than neutron attenuation, so x-ray scintillator should be closer to the source

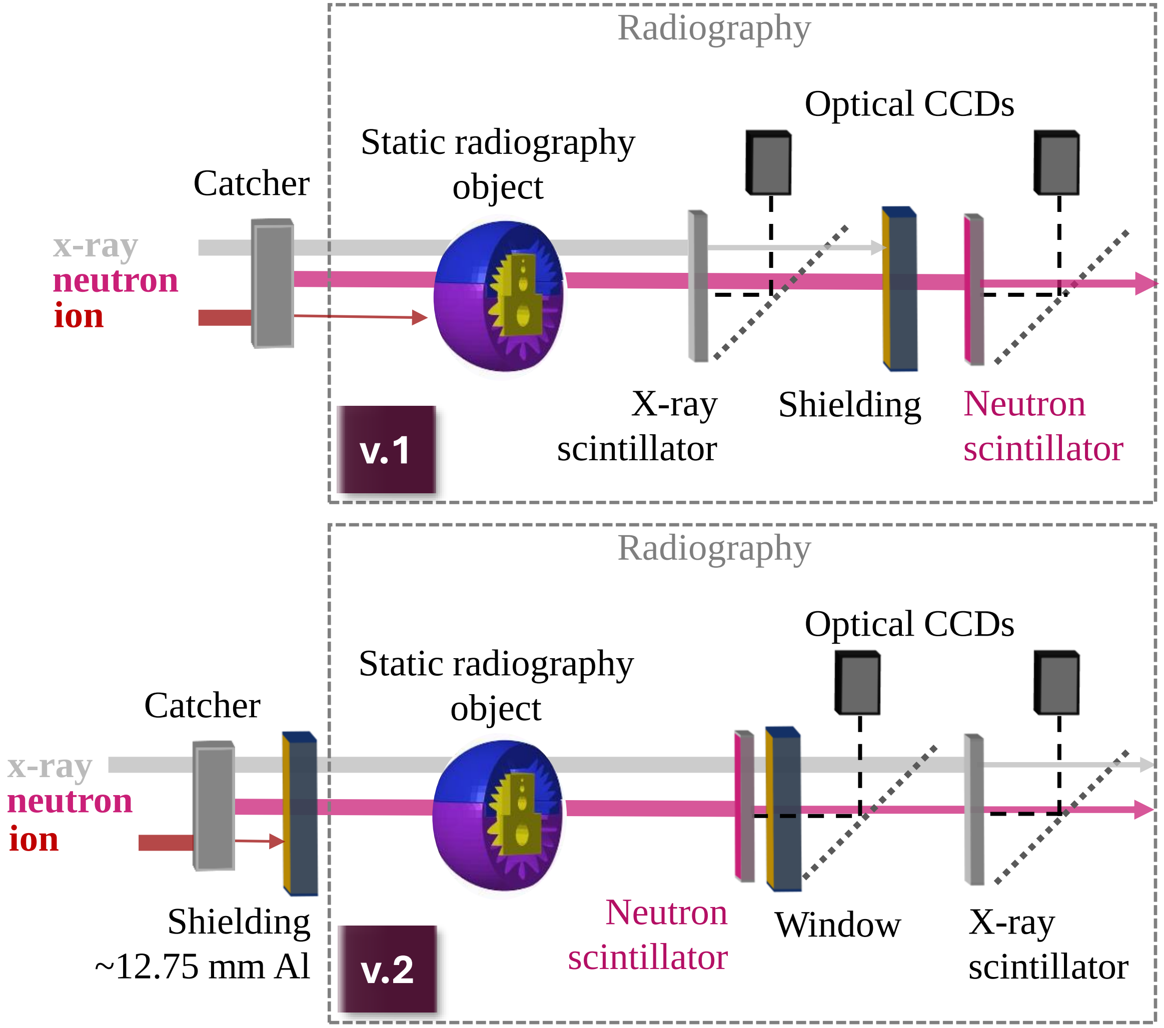


More details in afternoon poster session: Franzi Treffert (LLNL)

Radiography setup and pitcher target changes were required to increase neutron signal levels

No plan survives first contact with the laser
- Helmuth von Moltke (probably)

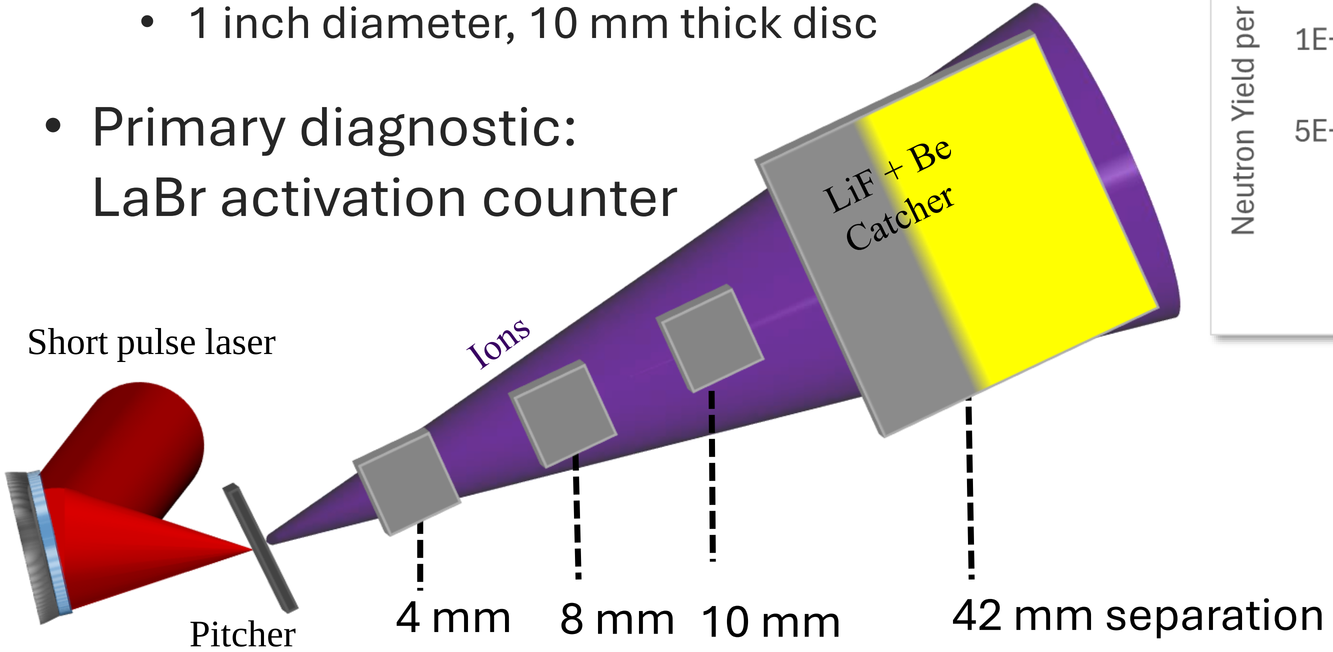
- 25 µm Cu replaced CD pitcher target
  - More pre-pulse resistant
  - Higher x-ray generation
  - Lower neutron generation
- Neutron scintillator brought closer to the source, with added shielding pre-object
  - Increase signal levels
  - X-ray contribution lower than anticipated

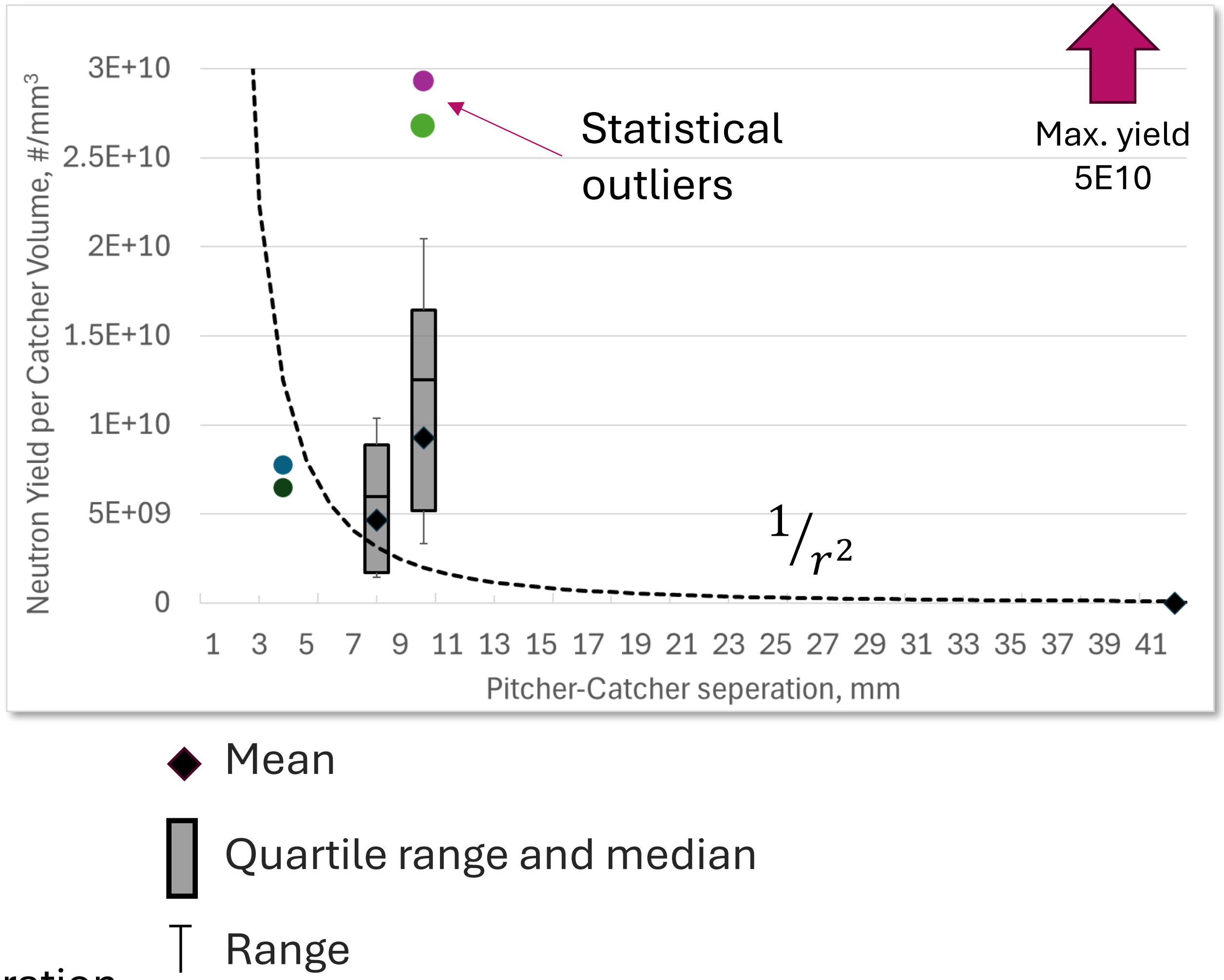


Increased yield at higher pitcher-catcher separation

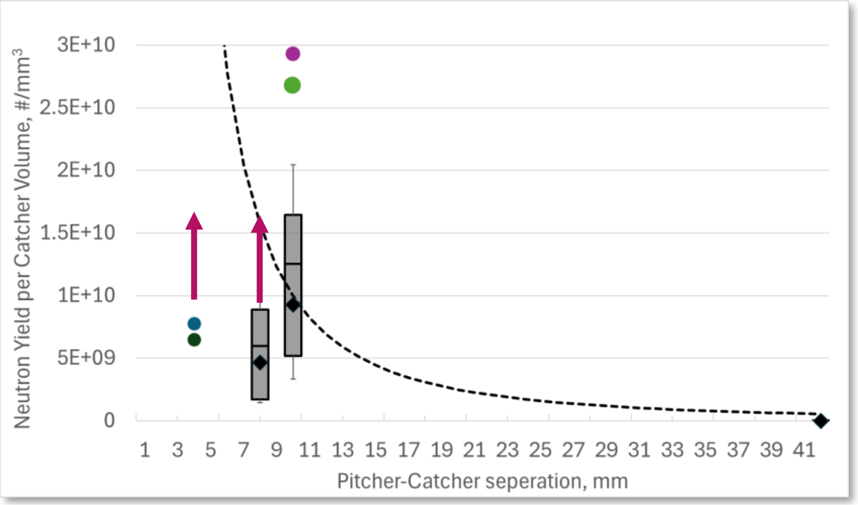
Despite fewer ions interacting with catcher in geometric expansion

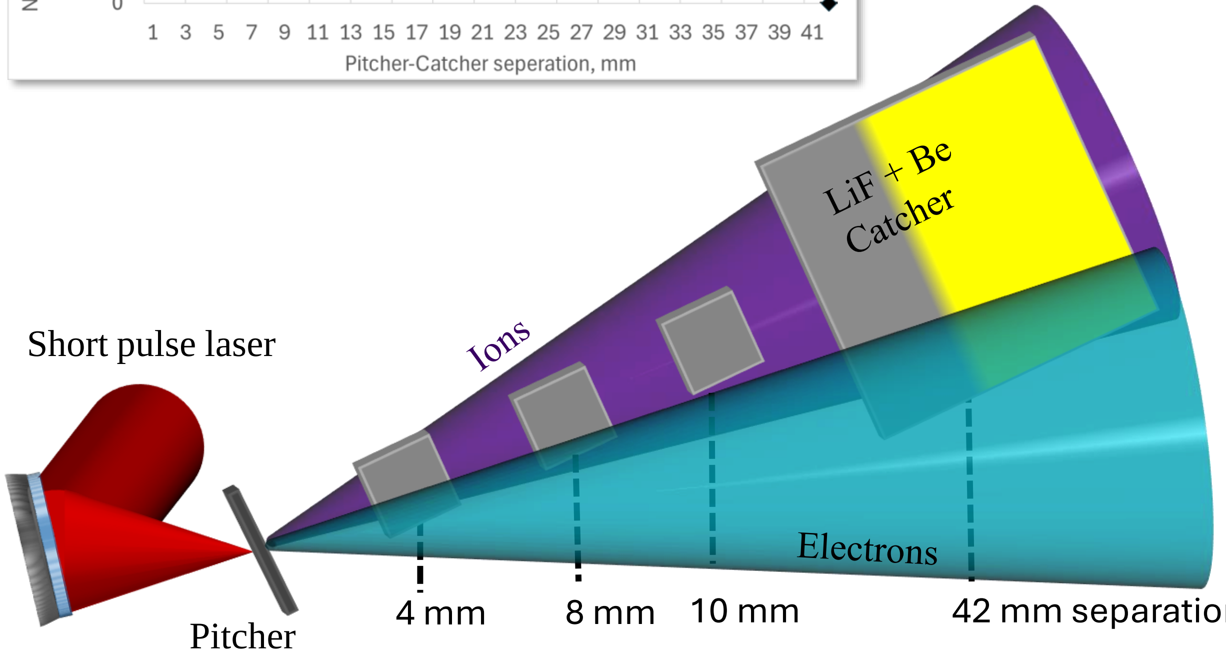
- Neutron yield was scaled by catcher volume to normalize results across varying cross-sectional area and thickness
  - 1×1×1 mm cube
  - 1 inch diameter, 1 mm thick disc
  - 1 inch diameter, 10 mm thick disc
- Primary diagnostic: LaBr activation counter





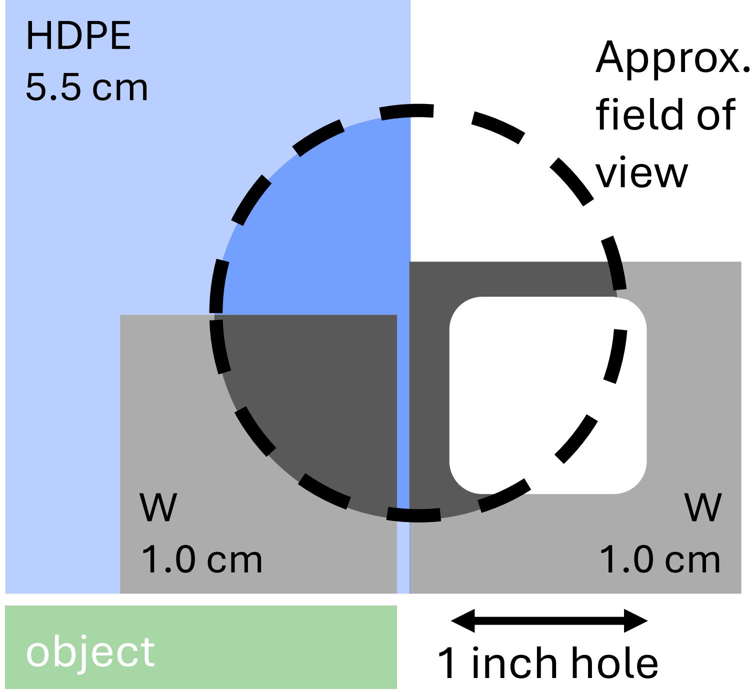
Diminished neutron yields at lower separations require further study to diagnose





- Ion profile was comparable for all separations
- Plasma expansion from the pitcher could interact with the 4 mm separation target
  - Could be diagnosed with shadowgraphy
  - D. R. Rusby Titan-24 campaign
- 4 mm, 8 mm, and 42 mm catchers all extend across laser beam axis
  - Electron beam may have an effect
  - Laser leak-through may also play a factor

The radiography object has large features of high contrast between x-ray and neutron signal

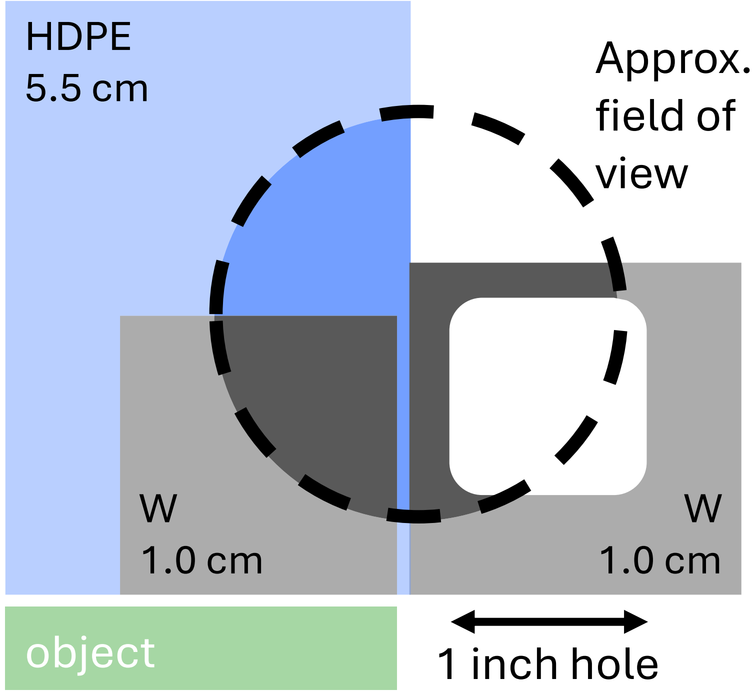


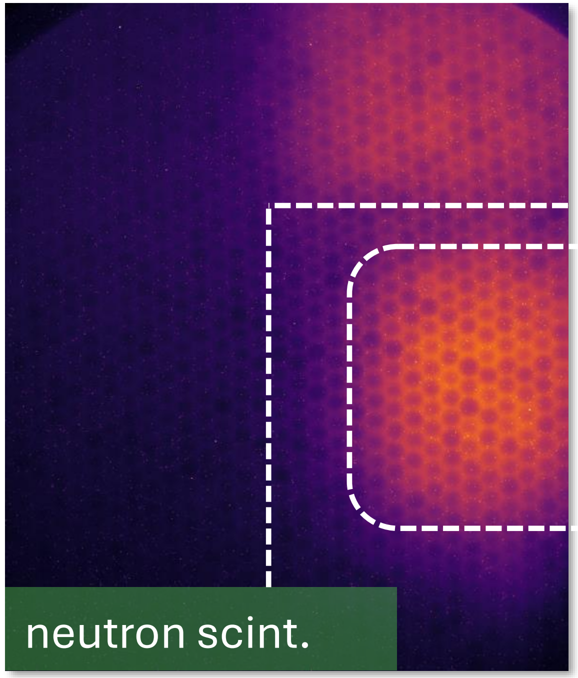
- Planned redundancy for large features
  - Low signal would be compensated with large source, and reducing resolution
- The object design will generate different neutron and x-ray radiographs due to the cross-sections:

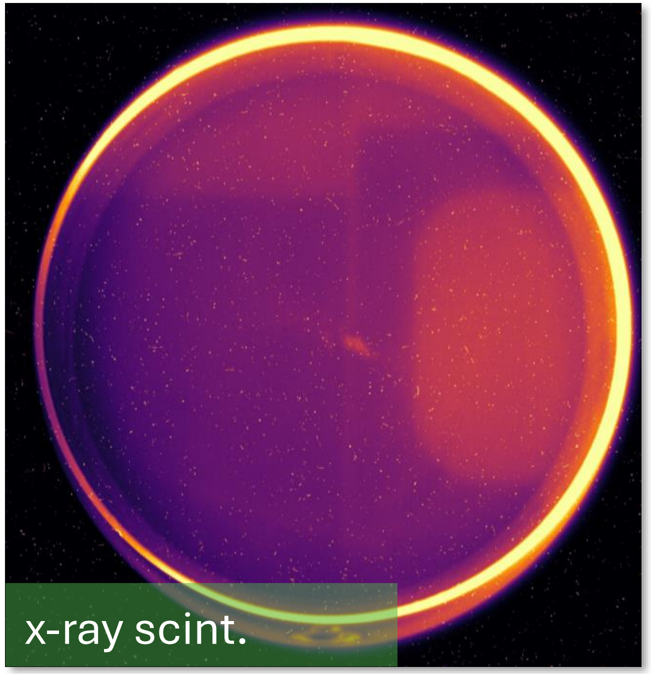
Filter	X-ray contrast	Neutron contrast
Plastic		
Tungsten		
Tungsten behind Plastic		
None		

Results are indicative of multi-modal radiography

but other particle contributions need to be fully discounted





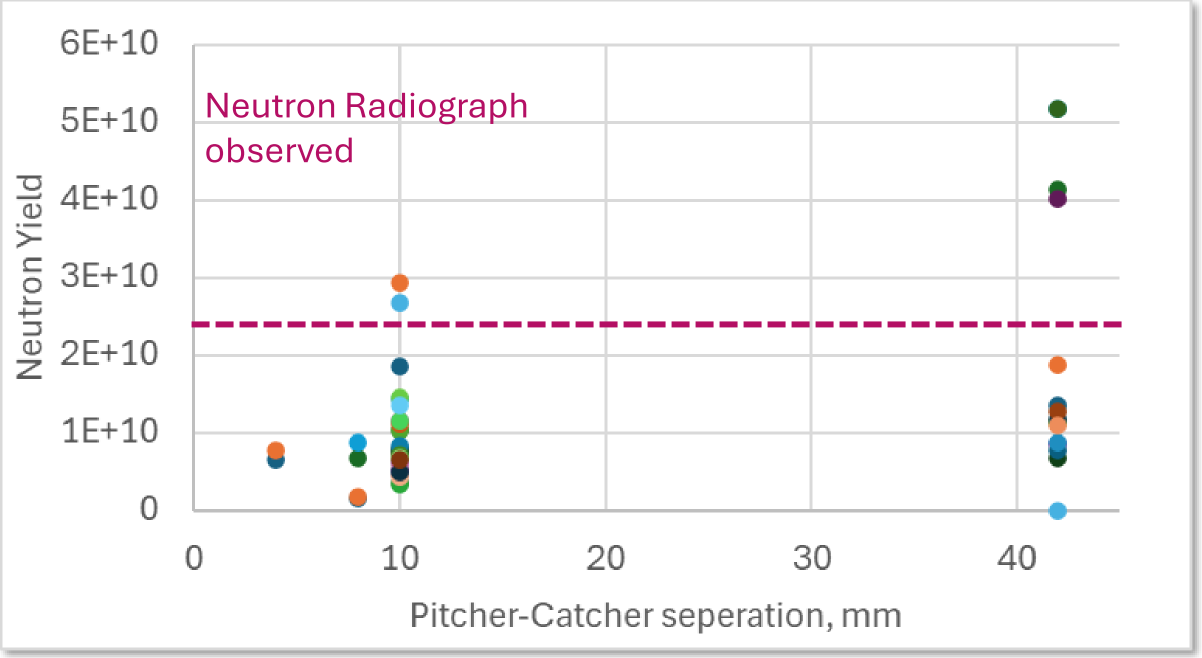


- ✓ X-ray scintillator shows little contrast through plastic
- ✓ Neutron scintillator shows contrast through plastic and less through metal
- ? Could neutron scintillator signal be from electron / proton / soft x-ray?

Results are a key milestone for multimodal LDRD
Williams ERD #20-02-06

Further study into laser-driven neutron sources will be aided by high-repetition-rate

- 4 radiographs were observed over the run
  - A 5th high yield shot was with no object
- 52 shots taken overall
- Key metrics were stable across all shots:
  - Laser energy
  - Ion spectrum
  - X-ray spectrum and yield
  - Electron spectrum
- A higher repetition rate facility will enable further statistical study into the high-yield outliers



We believe multi-modal radiography has been demonstrated using the Titan laser

- Contrasting x-ray and neutron images were generated from a single line-of-sight
    - Requires more analysis to disprove other particles
- Proof-of-principal shown for next-generation lasers
- Electron beam or laser light incident on catcher target reduces neutron yield
- Mechanism for highest neutron yields requires further investigation with rep-rate statistics