CVT-ORNL Collaboration

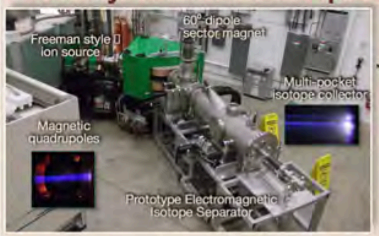
Paul Hausladen

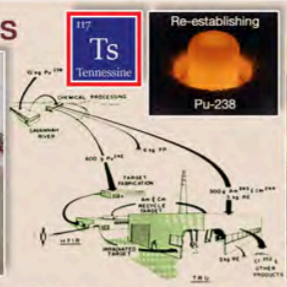
Oak Ridge National Laboratory

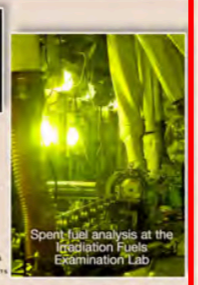
30 November 2017

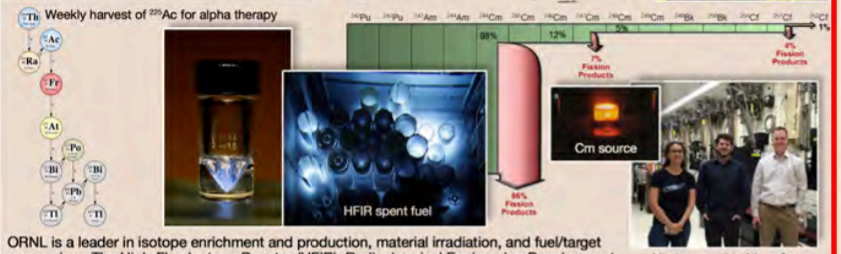
Relevant ORNL Capabilities

Fuel Cycle and Isotopes







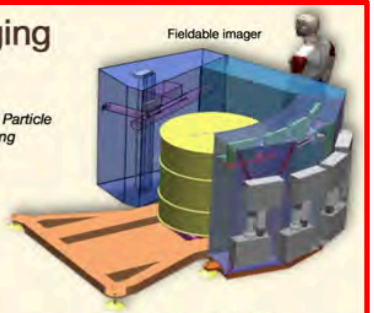


ORNL is a leader in isotope enrichment and production, material irradiation, and fuel/target processing. The High-Flux Isotope Reactor (HFIR), Radiochemical Engineering Development Center (REDC), and Enriched Stable Isotope Pilot Facility (ESIPF) are flagship U.S. facilities.

Next generation ideas for heavy element production

Radiation Detection and Imaging

Associated Particle Imaging



Passive Gamma and Neutron Coded Aperture Imaging

Fast Neutron Imager: automated mask rotation, variable mask thickness, and mask-detector distance

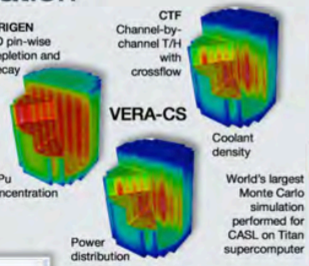
HPGe coded aperture imager: mechanically cooled, 3X gamma zoom. Coaligned stereo video. Allows projection of gamma images onto optical images.

Versatile Array of Neutron Detectors at Low Energy

ORNL is pioneering advancements in imaging and radiation detection technology for nuclear security applications.

Modeling and Simulation

Consortium for Advanced Simulation of LWRs Provides leading-edge modeling and simulation (M&S) to improve the performance of currently operating light water reactors (LWRs)



World's largest Monte Carlo simulation performed for CASL on Titan supercomputer

Radiation Search and Emergency Response Modeling for Urban Environments

ORNL develops advanced computational tools for nuclear R&D, nuclear power, isotope production, and nuclear security applications.

Advanced Materials

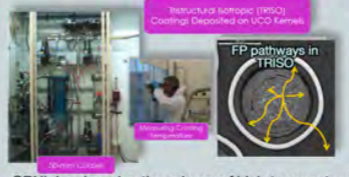
Additive Manufacturing

Titanium robotic hand holding sphere fabricated using additive manufacturing at ORNL

High-Temperature Materials

Secretary Perry, Senator Alexander in printed utility vehicle at the MDF/ORNL

The Center for Nanophase Materials Sciences (CNMS) integrates nanoscale science with neutron science using state-of-the-art methods for material modeling and simulation, synthesis, and analysis.

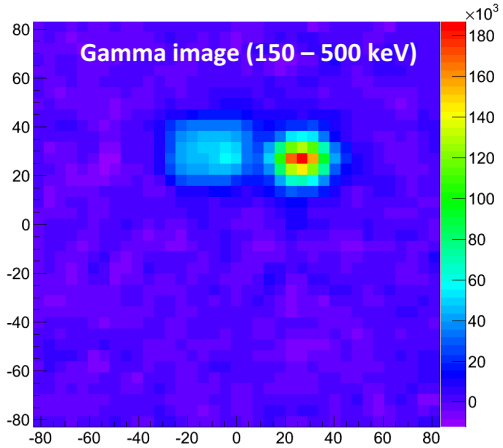


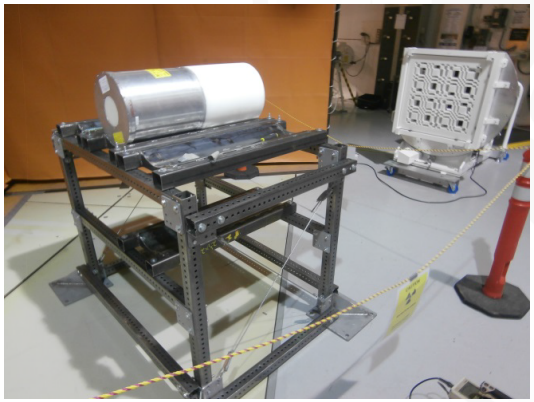
ORNL is advancing the science of high-temperature fuel manufacture and behavior. ORNL fabricated the record-setting reliable fuel in the recent Advanced Gas Reactor (AGR-1) capsules.

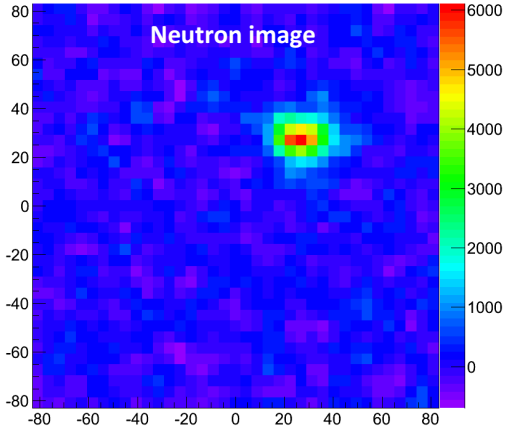
CVT Students

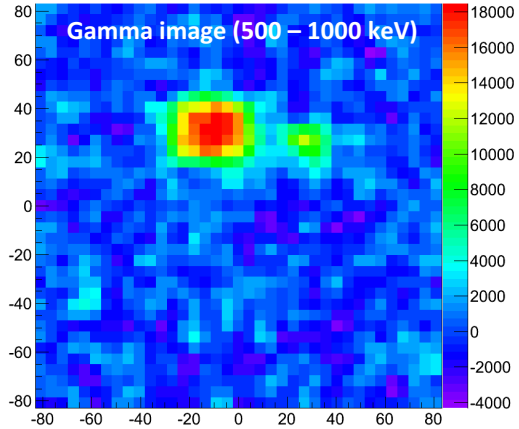
Year	Student	Institution	Role
2015	Jack Linkous	NCSU	Student intern (DAQ for Neutron Coded Aperture Imager)
2016	Peter Chapman	NCSU	Experiment – measurements of multiplying material at DAF using NCA *(PhD thesis)*
2017	Rob Weldon	NCSU	Student intern
2017	Mark Walker	Princeton	Student intern
2017	Mark Norsworthy	UM	Experiment – measurements of EJ-309 light yield for carbon recoils at ORNL *(part of PhD thesis, submitted for publication)*
2017	Marc Ruch	UM	
2017	Mike Hamel	UM	

Fast Neutron Imaging Capability: Coded Aperture Imaging







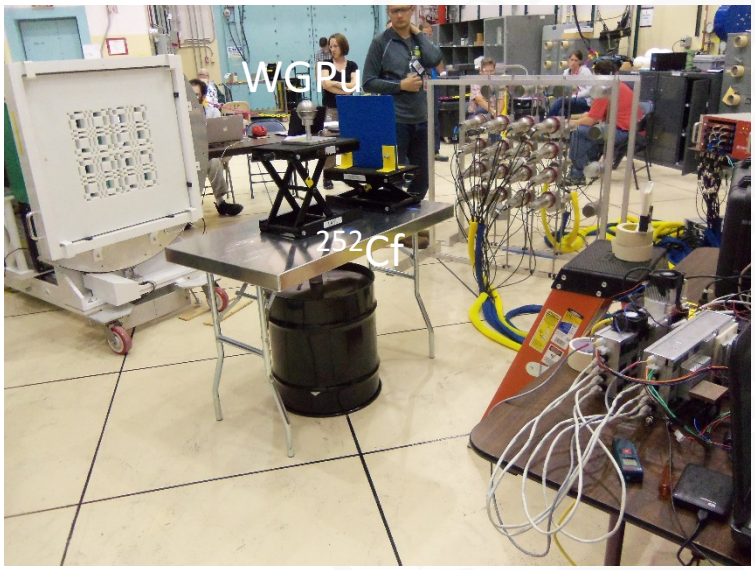


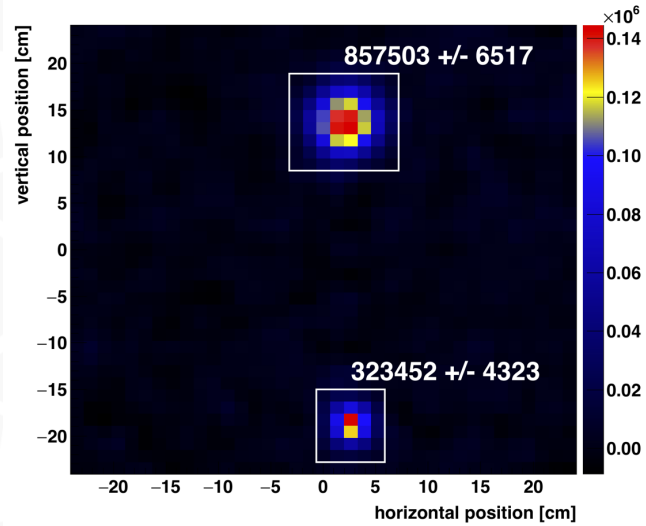
- The coded aperture imager and example images

This Work: Fast Neutron Imaging of Multiplying Media

- Passive image can confirm the configuration of a prolific neutron emitter such as plutonium
- Can imager perform simultaneous measurement of multiplication?
  - Use neutron pulse height and gamma-neutron coincidence timing in passive measurements (plutonium)
  - Use pulse height discrimination or time dependence with respect to interrogation pulse in active measurements (uranium)
  - Use fast-neutron coincidence with external detectors to get pixel-by-pixel Feynman variance
- With an imaging measurement, not confused by (potentially) other sources nearby in the same or adjacent rooms

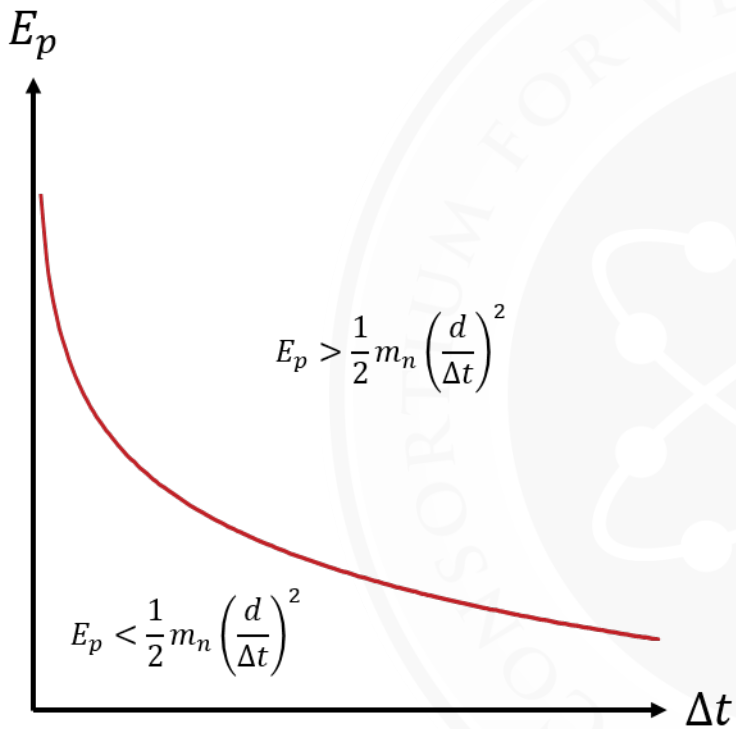
Distinguishing Multiplying and Non-Multiplying Sources (2015)

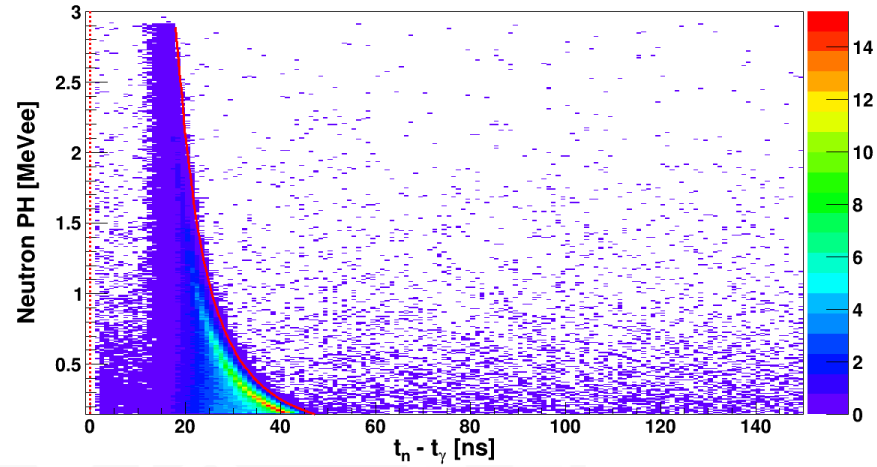




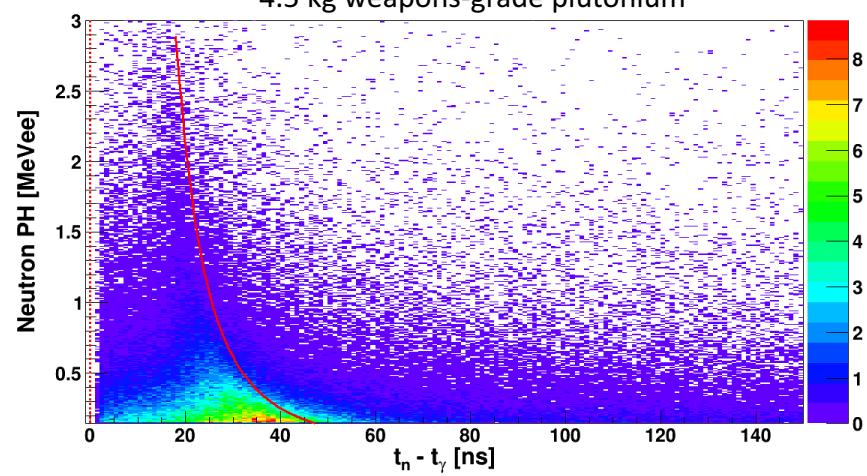
- Imager records time, pulse height (energy deposited), and pulse shape (particle type) of each detection event
- Use this data to distinguish single fissions from fission chains

Single Fissions vs. Fission Chains



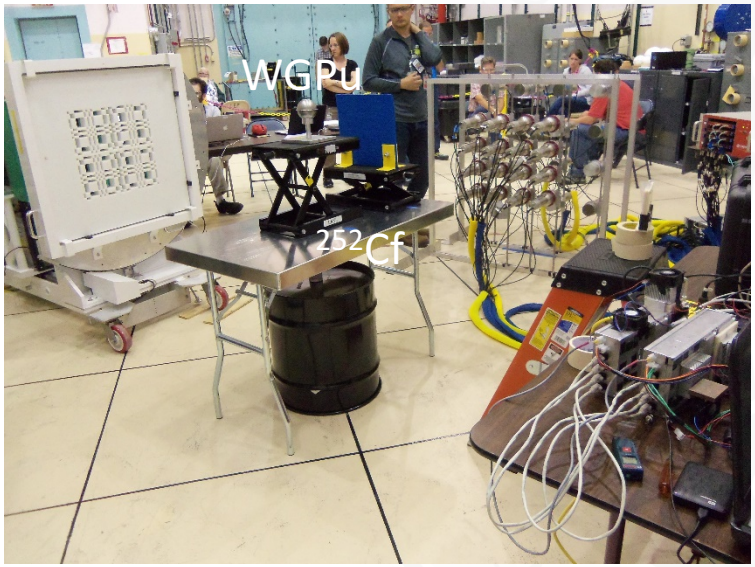


4.5 kg weapons-grade plutonium

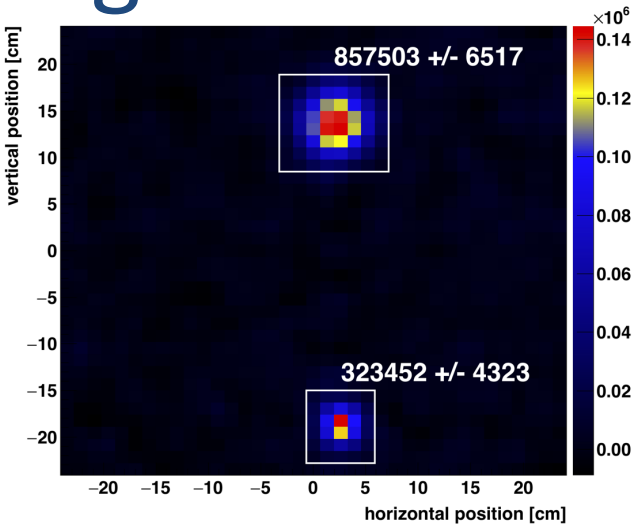


- stuff

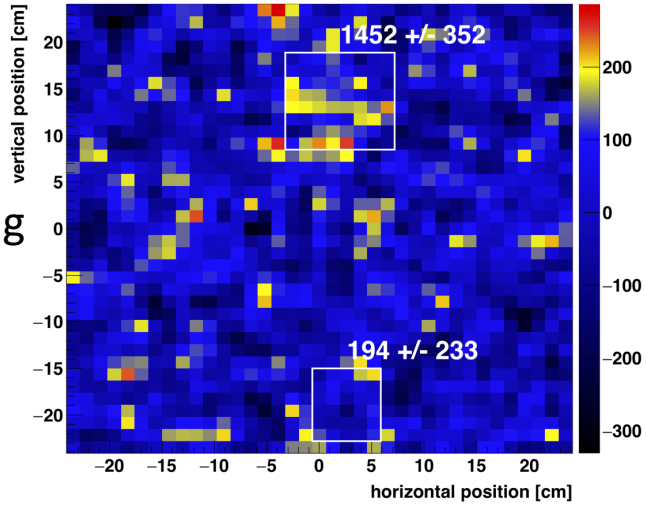
Distinguishing Multiplying Sources



All events

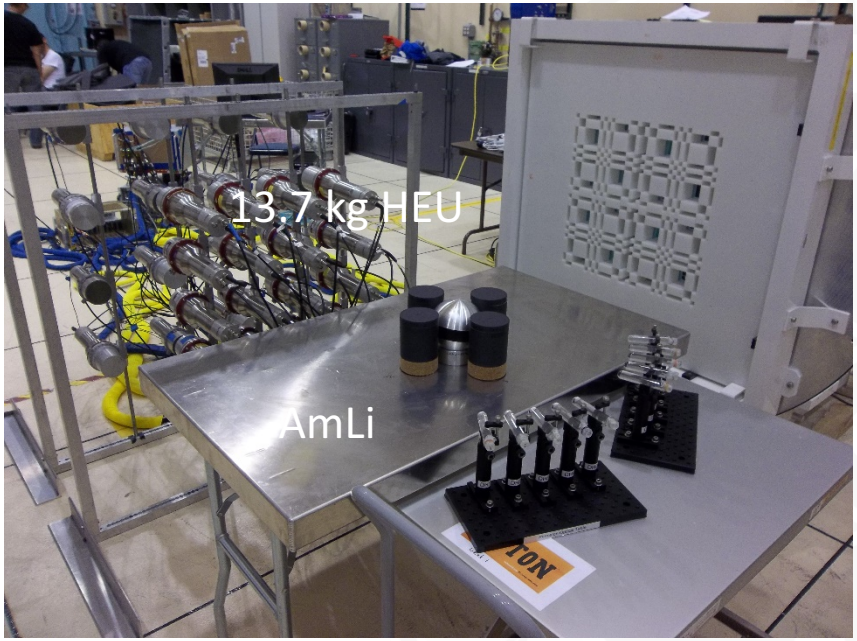


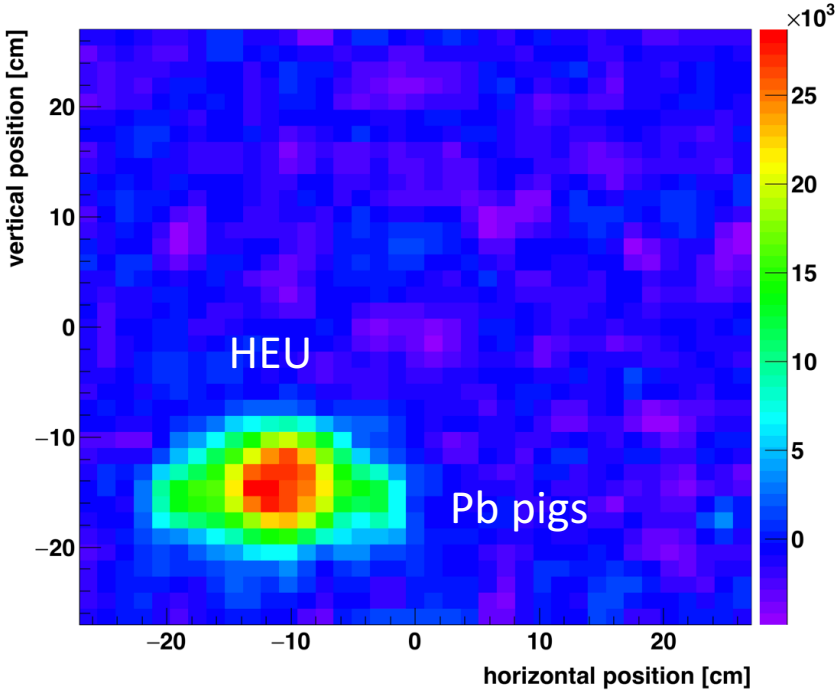
Exceeding cut



- Works for “good” data; can it work with higher efficiency?

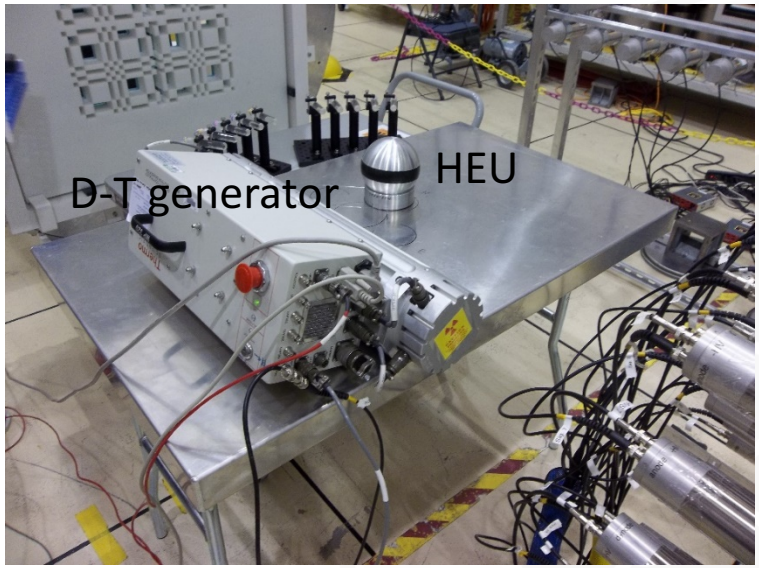
Active Measurements (2016)

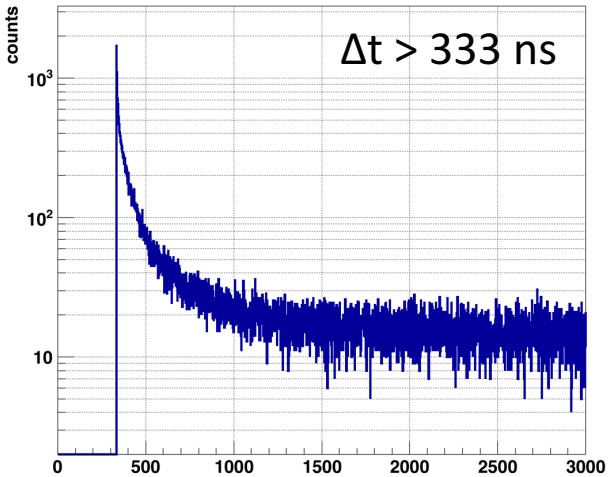


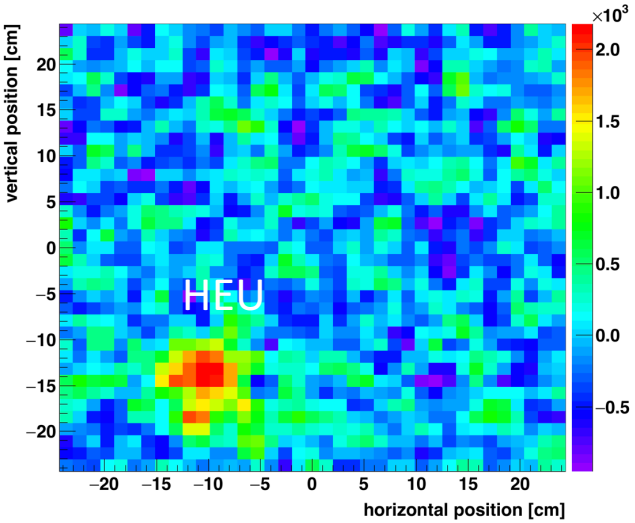


- Stimulate fission using neutrons from an AmLi source
- Emitted neutrons below threshold in detectors
- Emitted neutrons have energy below the fission barrier in U-238, so can only initiate fission in U-235

Active Measurements (Cont.)





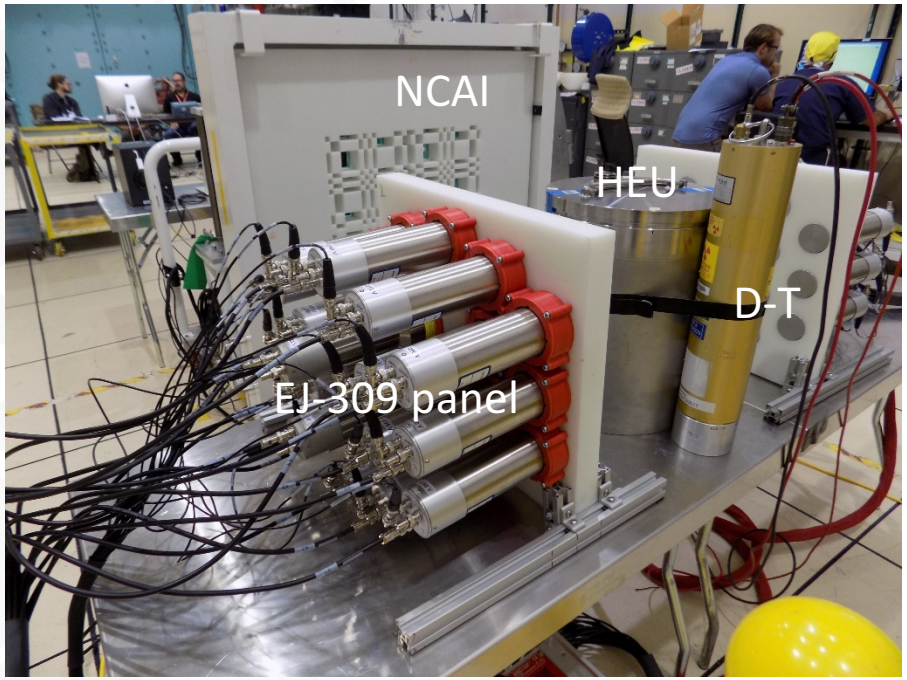


- 14 MeV D-T neutrons stimulate fission in uranium
- Beta-delayed neutrons at delayed times re-interrogate the material similarly to AmLi neutrons (below detection threshold and U-238 fission barrier)

Coincidence Imaging Measurements (2017)

~30 kg HEU metal

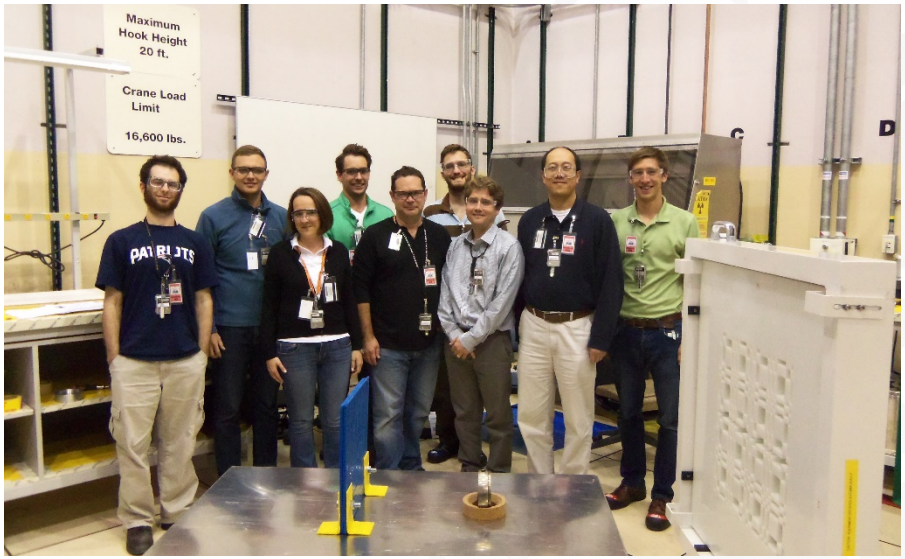
Coincidence-triggered imaging



- Awaiting results…

CVT DAF experiment team 2015 and 2016

2015

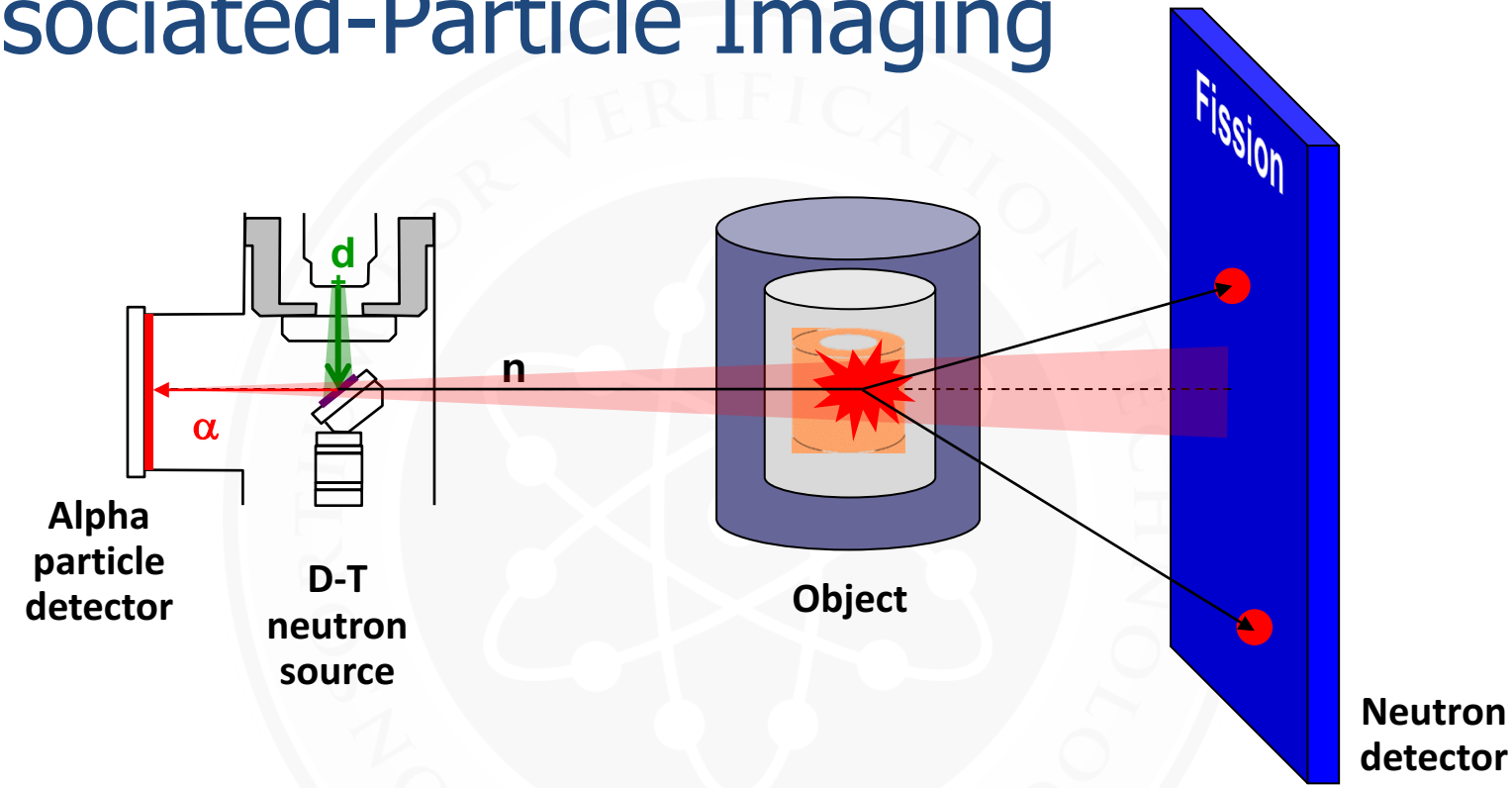


Jonathan Mueller (NCSU), Mike Hamel (UM), Sara Pozzi (UM), Kyle Polack (UM), John Mattingly (NCSU), David Goodman (UM), Jason Newby (ORNL), Zhong He (UM), Michael Streicher (UM)

2016

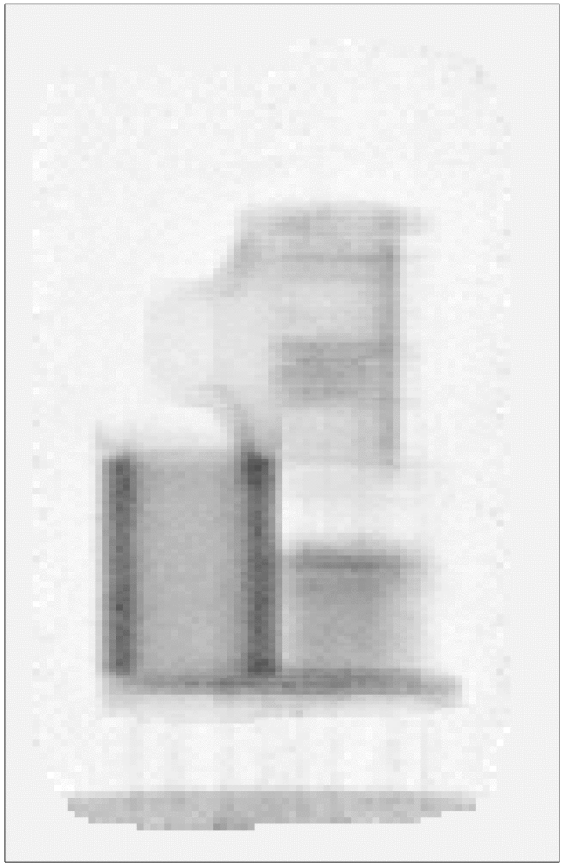
Ben Reimold (Princeton), Sebastien Phillipe (Princeton), Pete Champman (NCSU), Jason Newby (ORNL), John Mattingly (NCSU), Lazar Supic (UM), Mike Hamel (UM), Jason Nattress (UM), Igor Jovanovic (UM)

Fast Neutron Imaging Capability: Associated-Particle Imaging



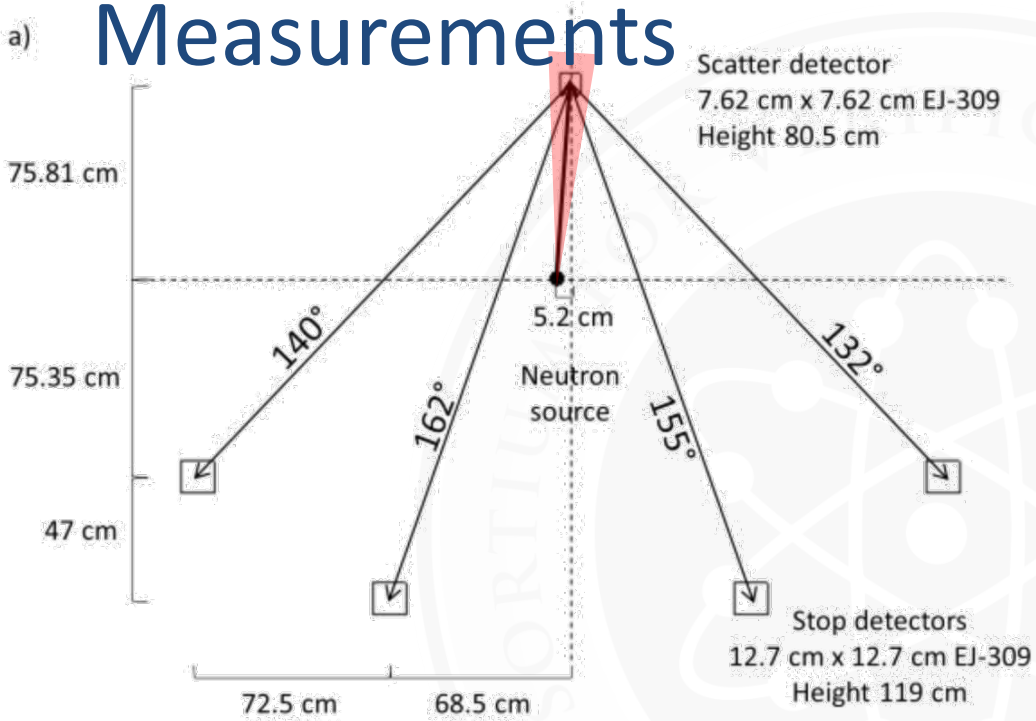
- Identify neutron direction via alpha coincidence (up to uncertainty from "spot size," detector resolution)
- Identify transmission, stimulated fission via number, position, and arrival times of neutrons

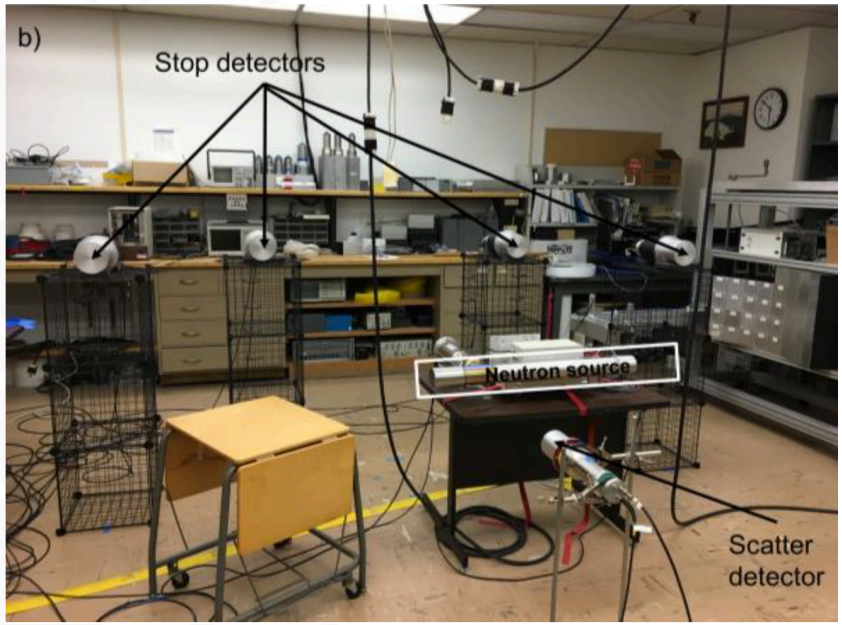
Example Experimental Data



- Photographs and projection data where transmission is shown in grayscale, induced neutron doubles are shown in red, and hydrogen scatter is shown in blue

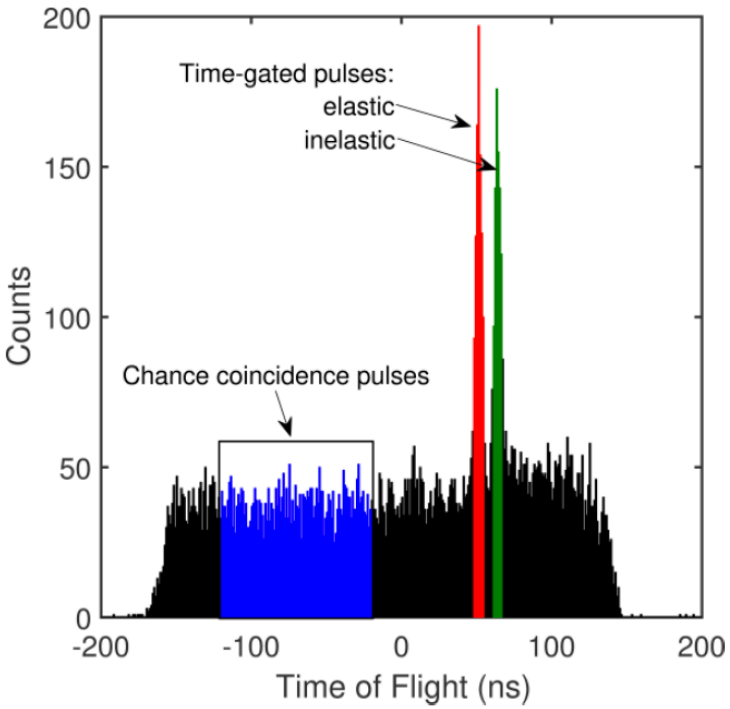
Experimental Setup– EJ309 Scintillator Measurements

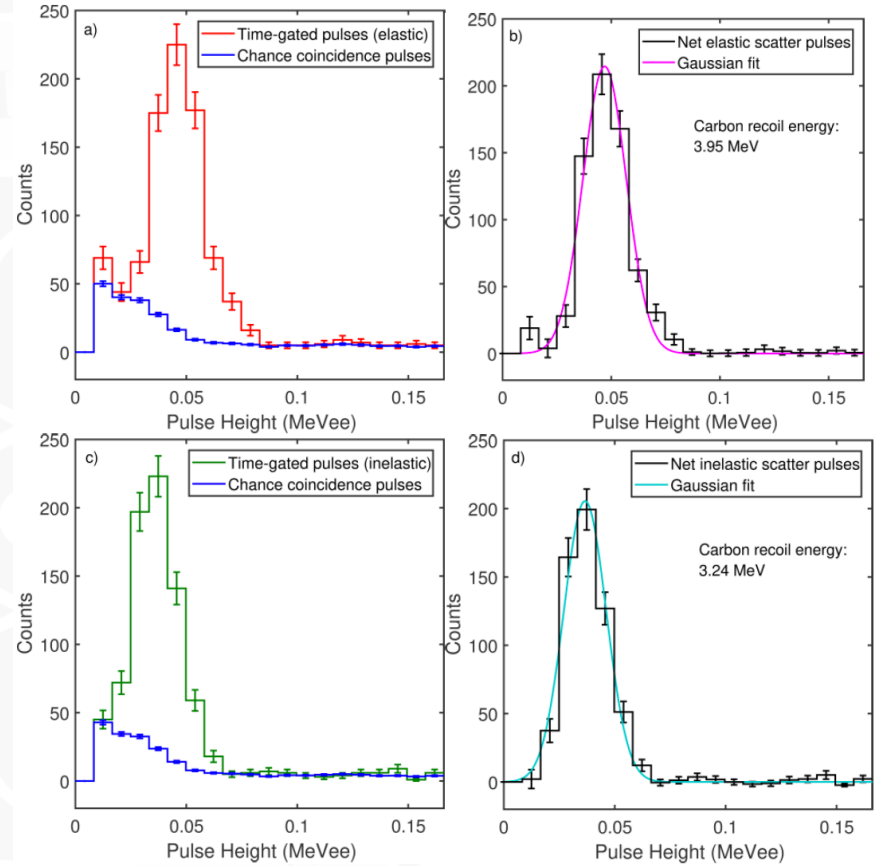




- Setup included associated-particle D-T neutron source, scatter detector containing EJ-309, and stop detectors at back angles
- Carbon recoils in scatter detector selected via alpha-scatter-stop coincidence at appropriate time of flight (TOF)

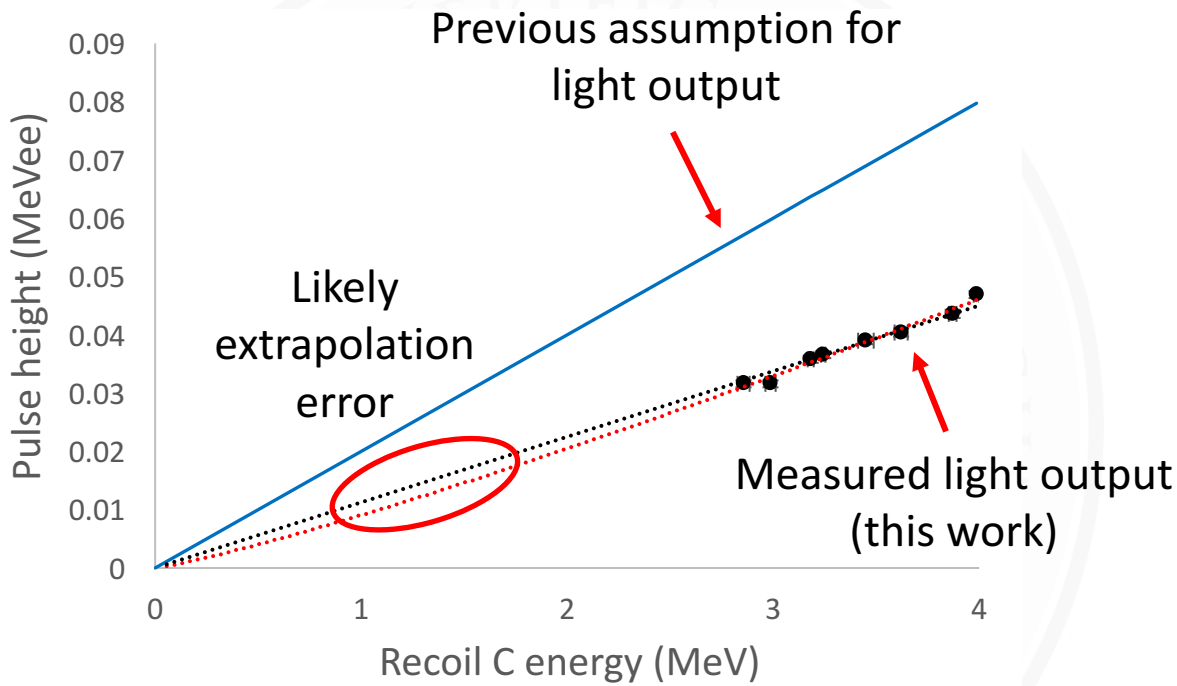
Pulse Heights for Carbon Recoils





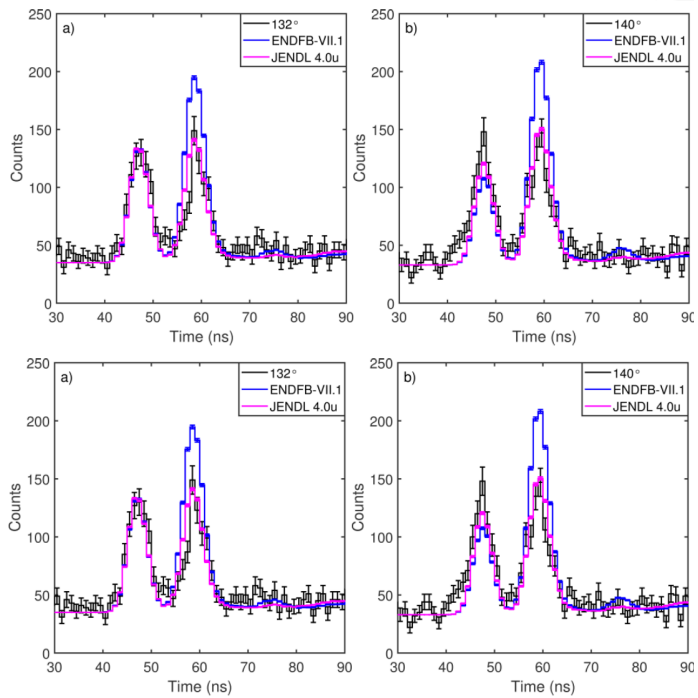
- For stop detector positioned at 162 degrees, example TOF spectrum with elastic and inelastic scattering peaks highlighted
- Example extracted pulse height spectrum shown for each

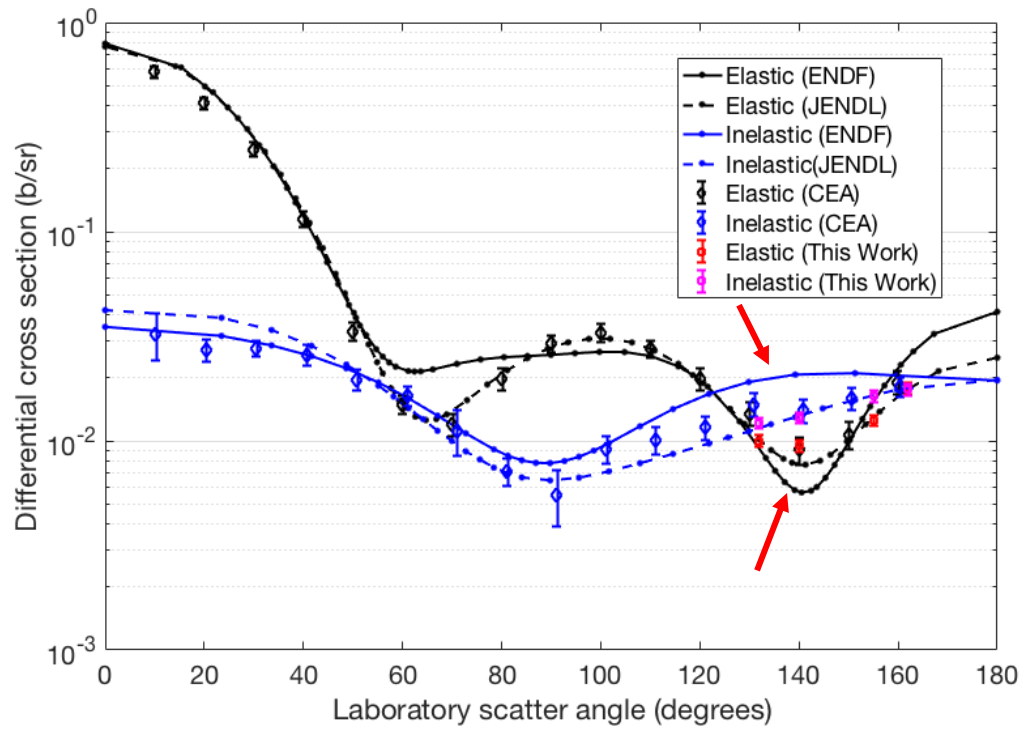
Liquid Scintillator EJ-309 Light Curve For Carbon Recoils



- These measurements extracted first measurement of EJ-309 light output from carbon recoils
- Change compared to original assumption nearly a factor of 2
- Same methodology could be used to extend curve to lower energies

Can Extract Differential Cross Sections





- Normalization of careful simulation can be used to extract value of differential cross section for elastic and inelastic scattering
- Disagrees with Evaluated Nuclear Data File (ENDF) for carbon at back angles but agrees with Japanese Evaluated Nuclear Data Library (JENDL)

Consortia-Relevant Projects in DNN R&D

- Radiation Imaging:
  - Fast Time-of-Flight Correlation (with LLNL)
    - ORNL PI: Jason Newby, newbyrj@ornl.gov, 865-241-2164
  - Single Volume Scatter Camera (with SNL-L)
    - ORNL PI: Paul Hausladen, hausladenpa@ornl.gov, 865-574-0284
  - 3D Tomography and Image Processing Using Fast Neutrons
    - PI: Paul Hausladen, hausladenpa@ornl.gov, 865-574-0284
  - Detection of Fuel Pin Diversion Via Fast Neutron Emission Tomography:
    - PI: Paul Hausladen , hausladenpa@ornl.gov, 865-574-0284
- Radiation Transport and related Modeling:
  - Predictive Modeling and Uncertainty Quantification with Application to Emergency Response (with LANL)
    - PI: Keith Bledsoe, bledsoekc@ornl.gov, 865-574-8602
  - Modeling Urban Scenarios & Experiments:
    - PI: Dan Archer, archerde@ornl.gov, 865-574-1356
- Data Analytics
  - Multi-Informatics for Nuclear Operations Scenarios
    - PI: Bryan Broadhead, broadheadbl@ornl.gov, 865-574-7644