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Title: LANSCE Science Overview

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LANSCE Science Overview

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June 27, 2024

LAMP
LANSCE Modernization Project

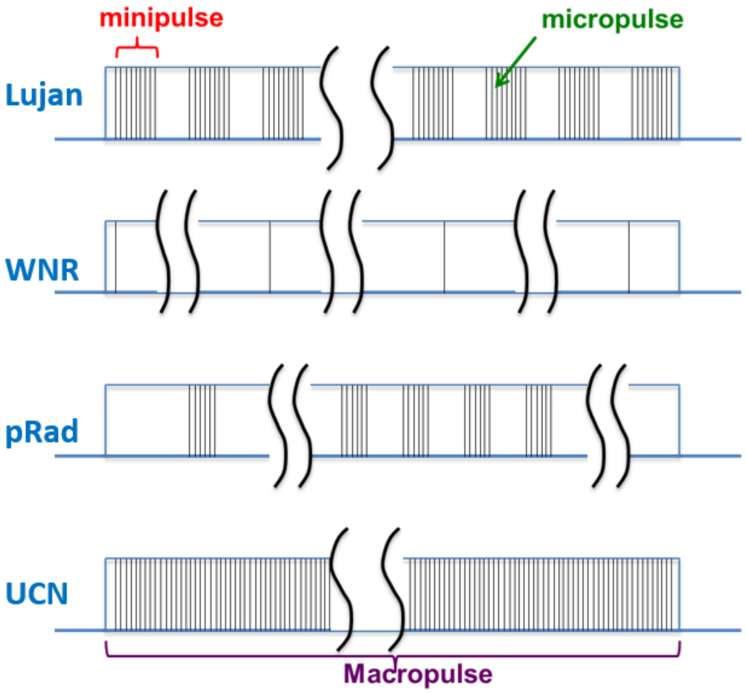
Agenda

- LANSCE is primarily focused on three science questions for NNSA and contributes to several other programs.
- We will primarily consider the NNSA questions:
  1. How can we advance our understanding of dynamic material behavior using focused experiments?
  2. What tools are needed to address Advanced Manufacturing and Aging?
  3. How do we constrain the nuclear reaction networks involved in weapons?

- Other missions we will consider today:
  1. The Isotope Production Facility as an enabler for future nuclear reaction studies.
  2. Existing and potential use of LANSCE beams for radiation effects studies.

LANSCE brings a flexible, high-power, 800 MeV proton accelerator *and the ability to do hard things* to the table

- H^+ and H^- simultaneously accelerated in 120 macropulses/second.
  - Each macropulse contains many micropulses
  - Micropulses can be accepted, rejected, bunched.
  - Total (possible) current of 1 mA / 800 kW.
- Two beams + micropulse/macropulse structure offers significant flexibility for experiments.
- **Result: beam delivery can be (and is) tailored to the science being addressed.**
- LANSCE authorization basis allows measurements on **hazardous, classified, and/or radioactive samples** – this allows work that cannot be done anywhere else.



Schematic of LANSCE beam delivery schemes

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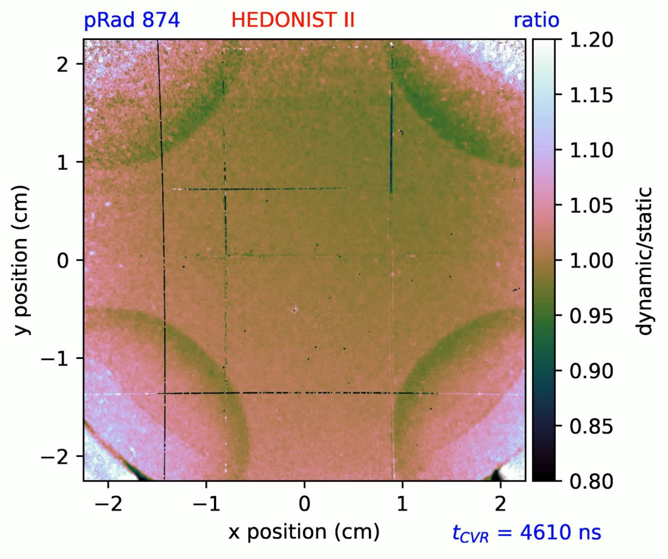
1. **How can we advance our understanding of dynamic material behavior using focused experiments?**
    - High-level experiment requirements
    - How LANSCE beam delivery enables pRad
    - Looking forward, how pRad could be improved

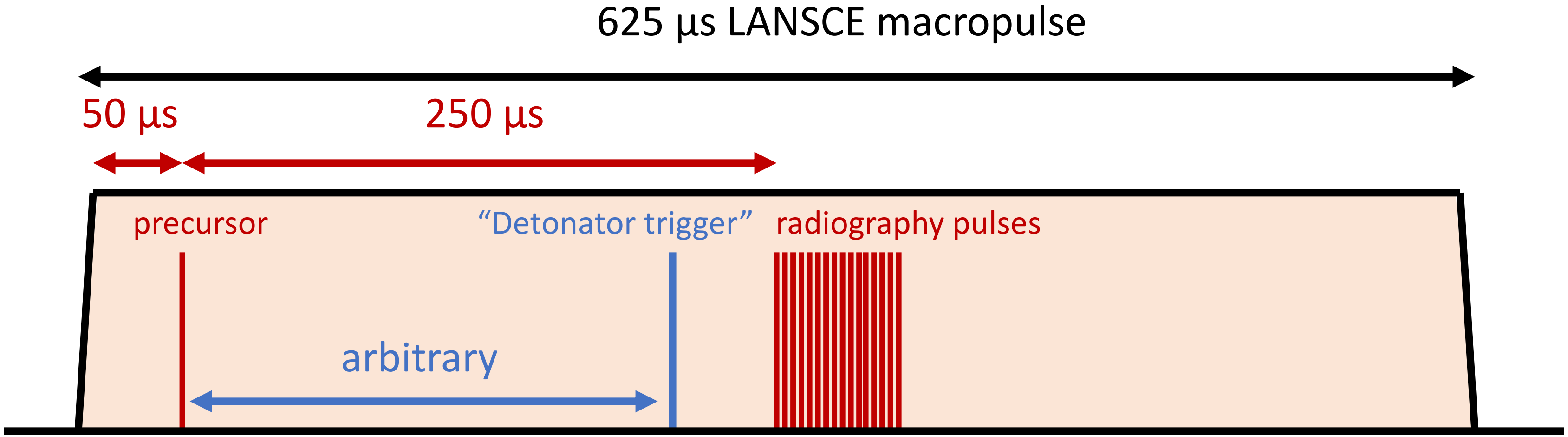
Proton radiography is uniquely suited for focused experiments addressing dynamic material behavior

- We desire the ability to study the behavior of high explosives (HE) and other materials to understand quantities such as Equations of State.
  - This can be done by detonating HE and shocking other materials in question.
- Studying the time evolution of shocked materials demands multi-frame radiography (movies) tailored to the experiment in question.
  - Experiments naturally require a flexible facility.
- pRad provides a flexible radiographic platform capable of imaging HE



Burn behavior of octol

pRad exploits the LANSCE accelerator's macro/micropulse structure for tailored image timing



- The LANSCE macropulse length is longer than a typical pRad experiment (~20 frames with 120 – 500 ns between frames)
- LANSCE's micropulse structure means that frames can be placed arbitrarily with 5 ns time increments between each frame.
- …so the particular physics of each experiment gets to drive the timing.

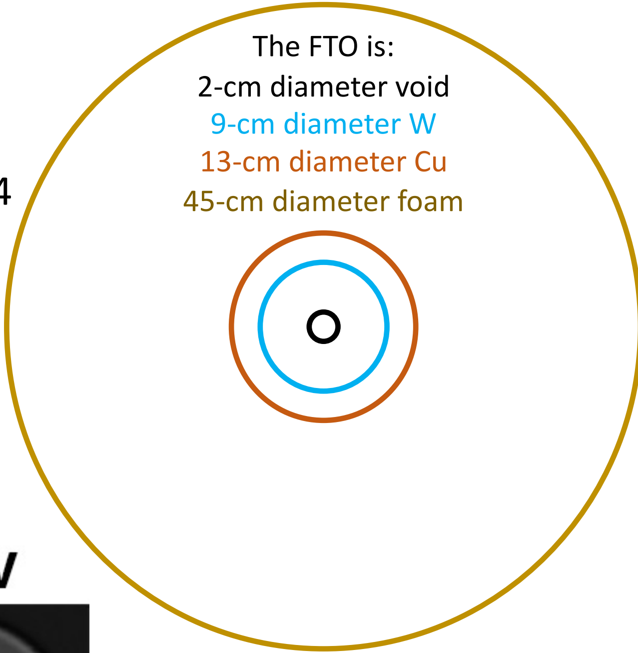
3 to 5 GeV pRad would increase image quality and depth penetration

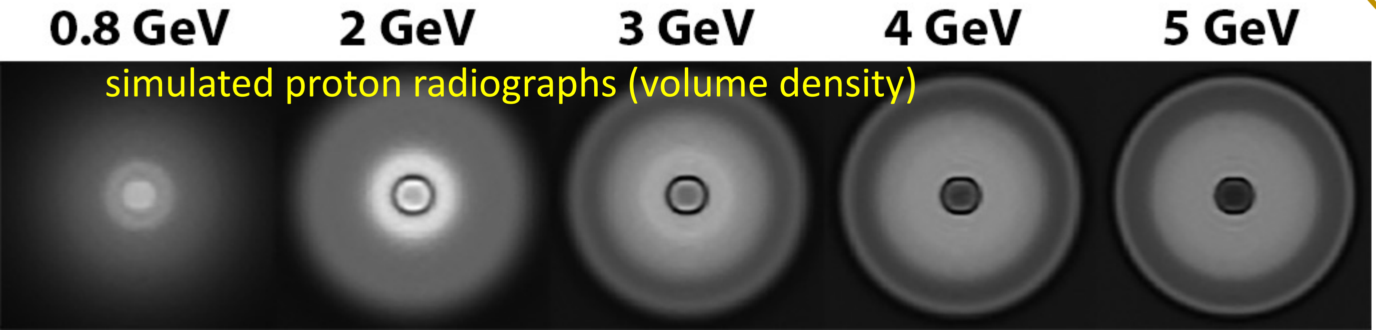
At 3 GeV, compared to 0.8 GeV:

- Loss in spatial resolution with increasing object thickness (chromatic effects) is decreased by βp^2, an improvement of ×7.9
- Depth penetration improves with βp, an improvement factor of ×3.0
- Approaching the ability to visualize something as thick as the FTO (214 g cm^{-2})

3-GeV pRad can be used for:

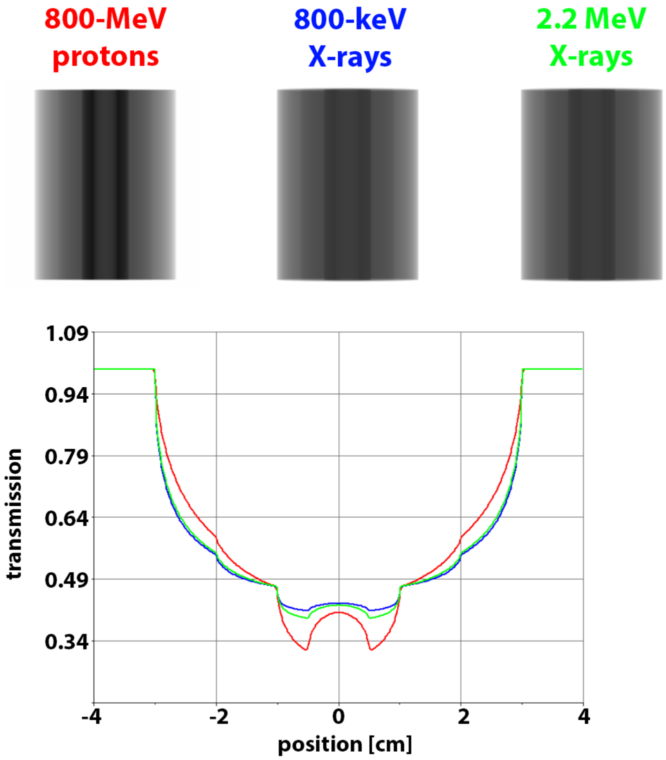
- small-scale plutonium experiments with thick aluminum windows
- ~cm-thick targets @ 10-µm spatial resolution
- studying ejecta formation, transport and breakup
- material damage: void formation, coalescence and failure





M. Freeman and K. Prestridge

A complementary light source would increase dynamic range, improve systematics and data quality



- Example: complementary x-rays provide unique attenuation profile to emphasize different parts of the experiment.
- Overlap in dynamic range for each probe permits cross-examination for improved systematics
- Placing the two probes on different axes allows overt tests of symmetry assumptions

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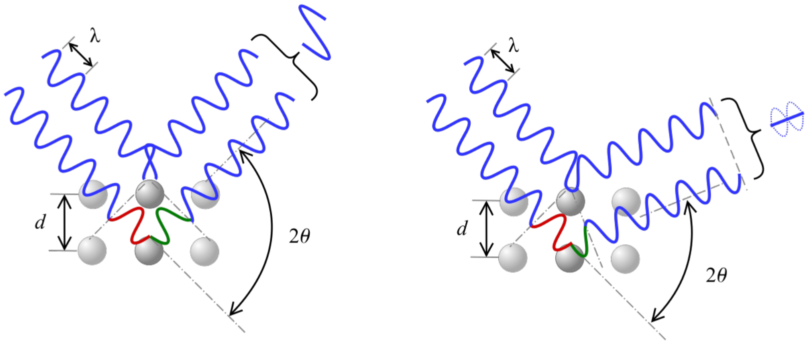
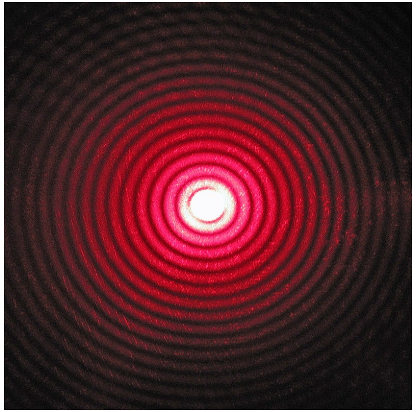
1. How can we advance our understanding of dynamic material behavior using focused experiments?
2. **What tools are needed to address Advanced Manufacturing and Aging?**
    - How neutron ‘white sources’ work
    - What the Lujan Center provides for materials characterization
    - Future directions for materials characterization

Neutrons are a powerful way to characterize material microstructure

- Understanding material properties enables credible responses to questions such as “what if we have to make this part a new way?” or “what happens when this part gets old?”
- Slow neutrons have wavelengths close to the typical distance between atoms in a solid material.
  - Neutron diffraction can be used to study microstructure
- Neutrons interact with nuclei, not atoms.
  - They penetrate very differently than x-rays

Schematic rendering of Bragg’s Law

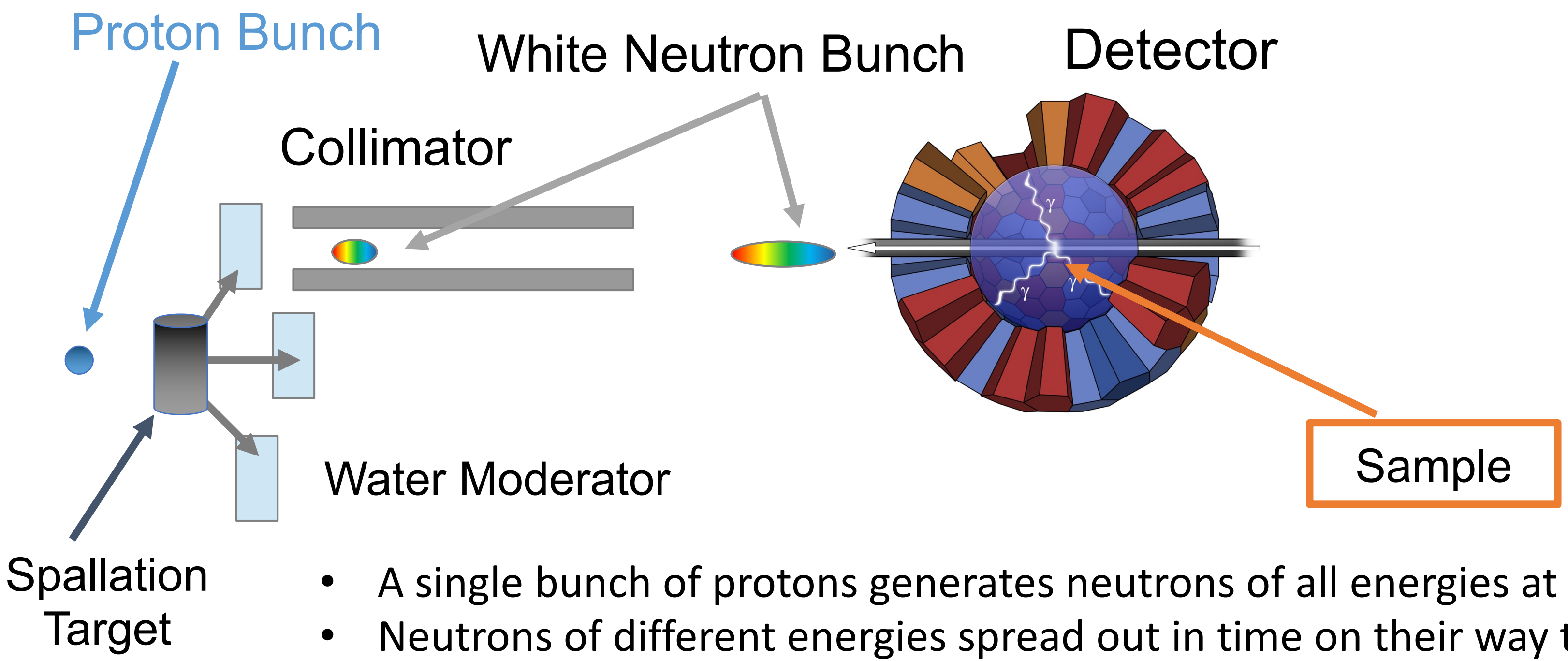




Wikipedia.org

Diffraction pattern from a red laser. Neutron diffraction can be used to understand microstructure

Neutron 'white sources' allow precise selection of the desired neutron energy via time of flight

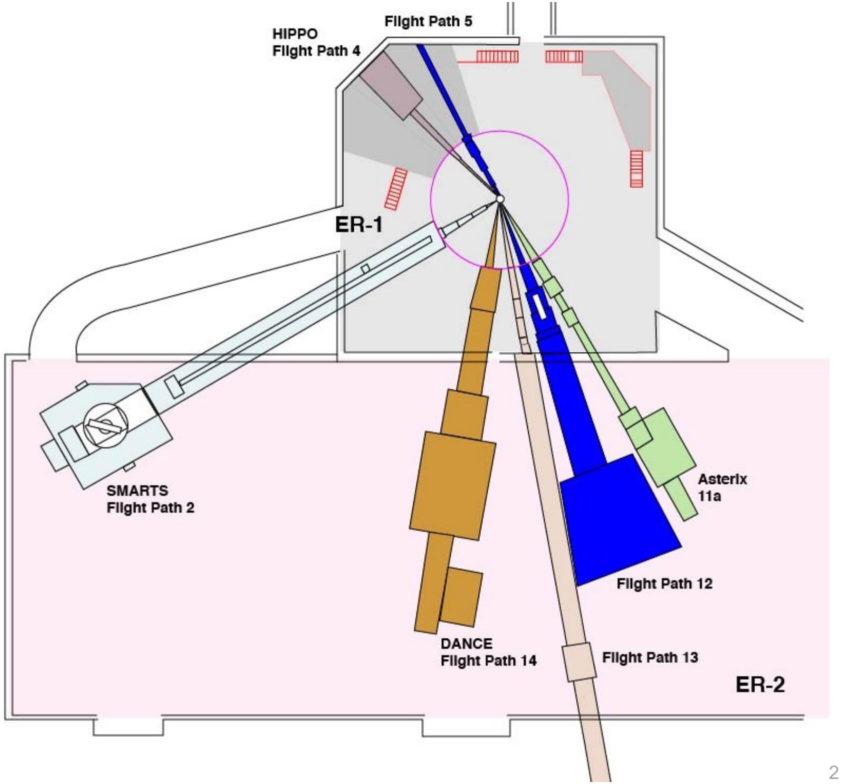


- A single bunch of protons generates neutrons of all energies at once.
- Neutrons of different energies spread out in time on their way to the experiment.
- The longer the distance, the better the energy resolution.

Materials end-stations at Lujan are optimized for measurements on NNSA-relevant materials

- Materials such as beryllium, uranium, U6Nb, plutonium have large lattice dimensions.
  - Requires long time-of-flight windows to access longer neutron wavelengths
- SMARTS is positioned at 31 meters to obtain high resolution.
- Lujan Center receives beam at 20 Hz to meet the time window requirement.
- **Authorization basis to work with hazardous, radioactive, or classified components**

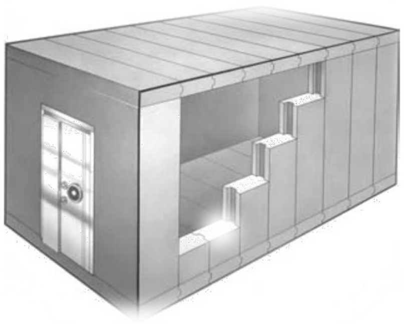
Floor plan of the Lujan Center



Looking forward: neutrons and x-rays, with the right authorization basis, enable unique measurements

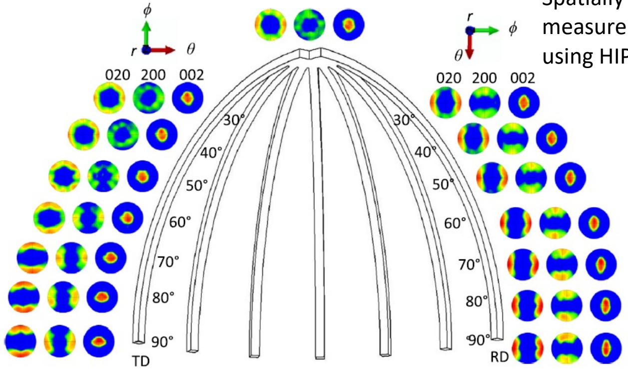
Vault-type Room

- Dedicated flight path for classified experiments @ Lujan
- Improve classified experiment operations
- Maximize flexibility for mission-relevant experiments



Upgrade Lujan Flight Paths to Optimize for Current and Future Mission

- SMARTS / HIPPO upgrades
- Evaluate optimal mix of capabilities, and stand up or restart flight paths as appropriate
- One early contender - new multi-probe flight path to provide energy-resolved imaging/bulk characterization

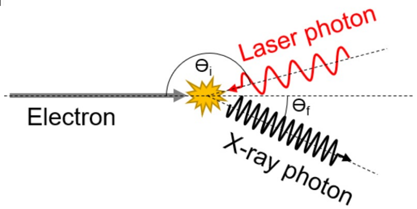


Spatially-resolved texture measurement of uranium using HIPPO

Timeline

Advanced Scattering Science

- Compact x-ray light source
  - Complement neutron measurements
  - Complementary attenuation profile
  - High-res, small scale experiments
  - Expands capability to experiments w/ hazardous, classified components



Notional parameters:

- 100 MeV
- 1 µm optical cavity wavelength
- 60-100 keV X-ray energy range

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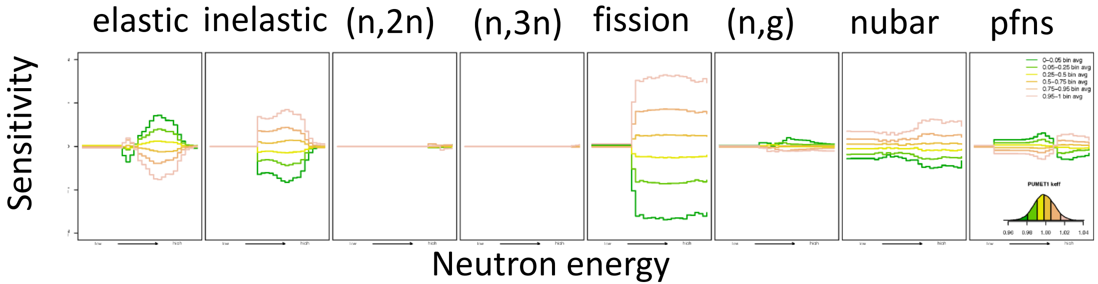
    2. What tools are needed to address Advanced Manufacturing and Aging?
    3. **How do we constrain the nuclear reaction networks involved in weapons?**
        - A brief look at the types of measurements required
        - Co-location of nuclear physics and Isotope Production Facility enables globally unique science
        - Future directions for nuclear physics
- Other missions we will consider today:
    1. **The Isotope Production Facility as an enabler for future nuclear reaction studies.**

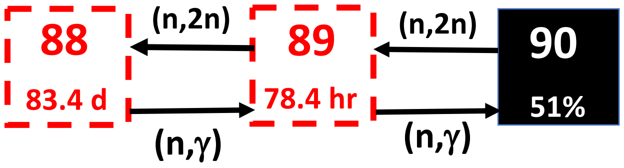
Fission properties and nuclear cross sections inform neutron reactivity and radiochemical diagnostics

Science of reactivity: nuclear reactivity has relevance for understanding performance, and sensitivity studies (example below) guide the measurements.



Results of sensitivity study for a critical assembly spanning various reactions and fission properties on ^{239}Pu. Larger deflection from the middle is more sensitive. (LA-UR-18-22053)

Science of diagnostics: fission product yields and transmutation of stable elements by e.g. (n,2n), (n,p), (n,a), (n,g) can provide diagnostic information, and our understanding of the relevant physics is incomplete



Example: simplified Zr reaction network, where many reactions are on unstable nuclei (few to no measurements)

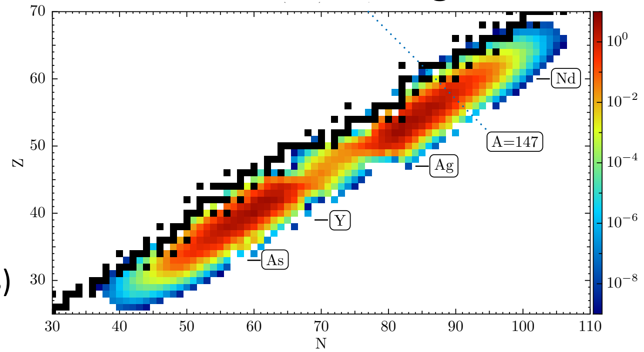
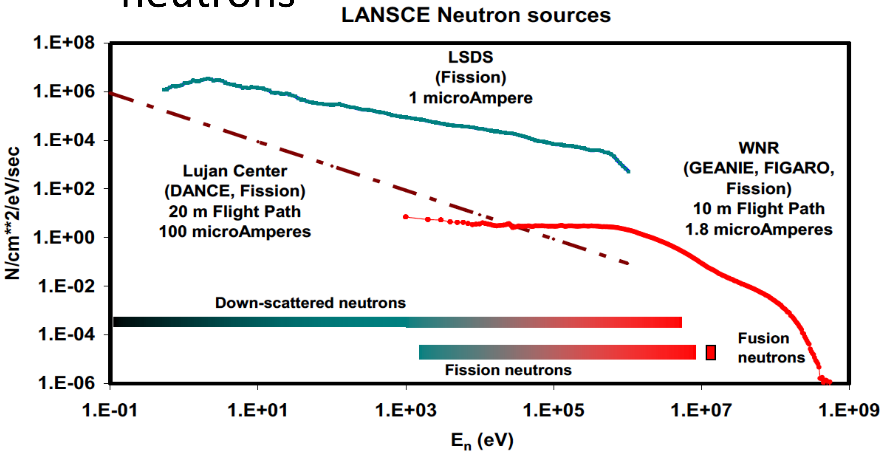
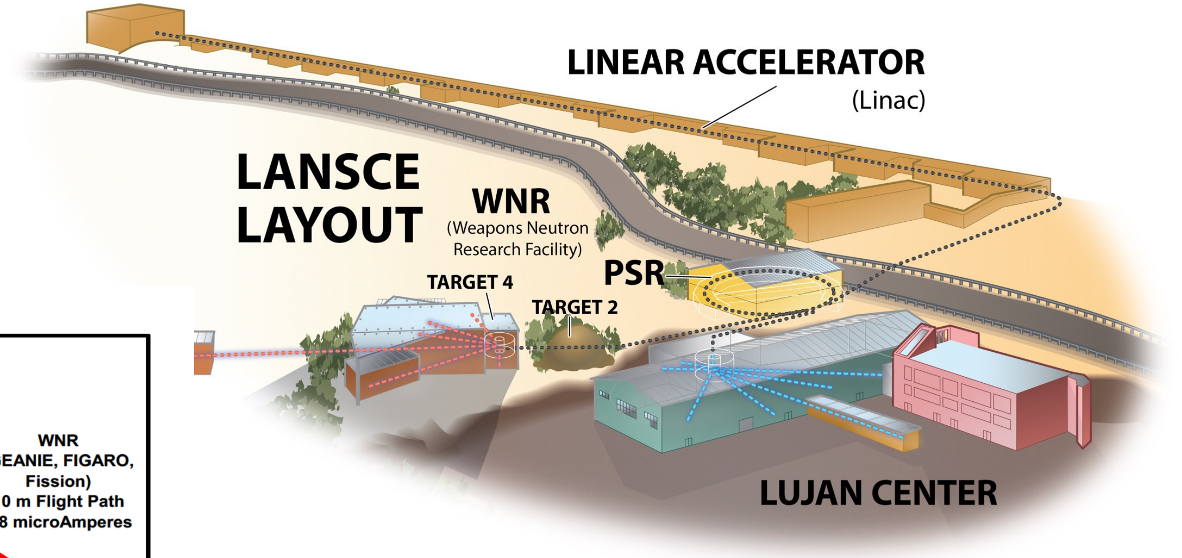


Chart of nuclides where black squares are stable isotopes, and color contours represent our best estimate of how ^{239}Pu breaks up during fission. The contours are a function of both neutron energy and fissioning isotope, and many holes exist in the data.

LANSCE drives the world's brightest neutron time-of-flight neutron sources for nuclear physics

- Lujan uses a moderated neutron spectrum to access slow reactions
- WNR is not moderated - fast neutrons

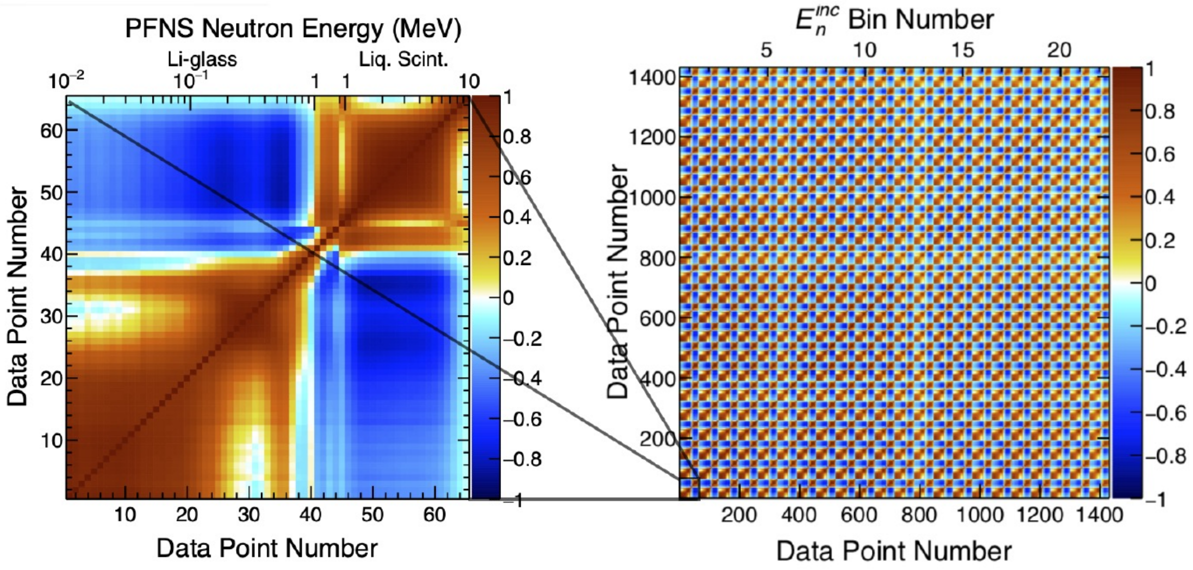




- Each WNR flight path is optimized for the physics in question – angle relative to beam, space, collimation, instrumentation.

Neutron white sources are naturally suited to measure the shape of nuclear cross sections

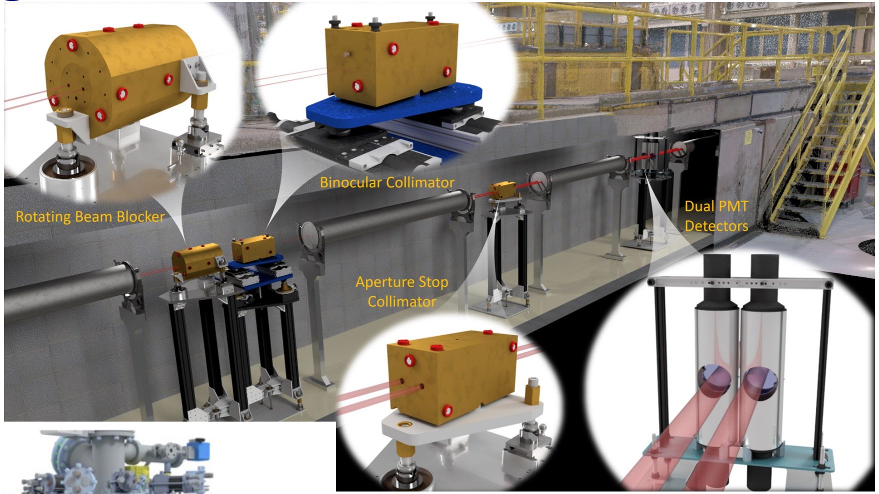
- Each experiment at WNR or Lujan measures all neutron energies simultaneously.
- Good shape information improves the constraints provided by nuclear physics benchmarks (e.g. critical assemblies).

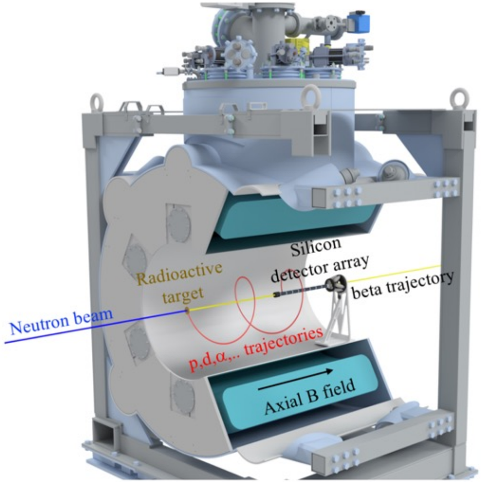


Example correlation plot from the Chi-Nu project. A vast array of energy-correlated information is providing nuclear data evaluators with an unprecedented view of the Prompt Fission Neutron Spectrum

WNR/Lujan + IPF is enabling a new generation of measurements on radioisotopes

- Having both radioisotope production and measurement capabilities at one facility enables measurements that have been **impossible worldwide**.
- Several instruments in development to push the limits of this new field.
- Recent work includes measurements on ^{56}Ni (6 day half life)
- The nearest technical neighbor was a measurement on ^{237}U (6.7 day half life) using an underground nuclear explosion (PRC 9, 717 (1974)).

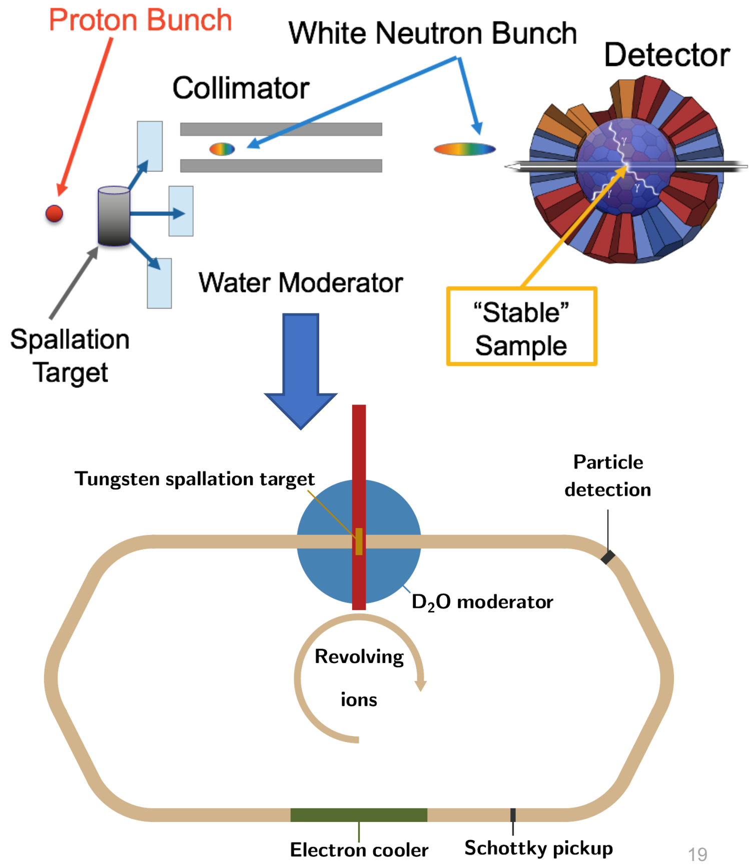




Schematic rendering of DICER for slow neutron reaction (top) and proposed solenoidal spectrometer for fast neutron reaction studies (left)

Facility optimizations and potential upgrades can push LANSCE nuclear physics beyond the state of the art

- Neutron beam experiments on radionuclides are ultimately limited by intrinsic backgrounds or short half-lives.
- Currently IPF can perform chemical separations but not isotopic separation.
  - Backgrounds are higher than optimal – limits what we can measure.
- A radionuclide isotope separator providing purified samples would expand LANSCE's experimental reach.
- Ultimately short half-lives will limit what can be done
  - We are developing a concept to address this issue (ongoing LDRD project)
  - Interact beam of radioactive ions with standing field of neutrons.



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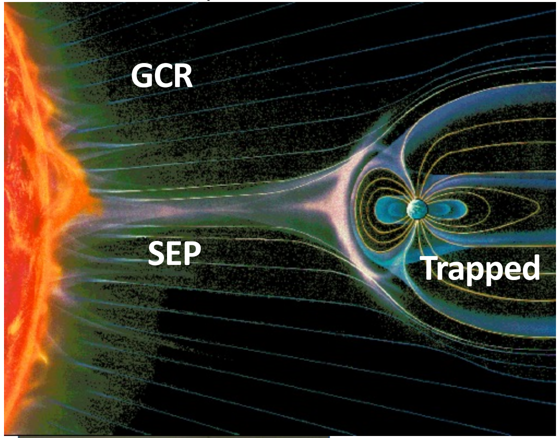
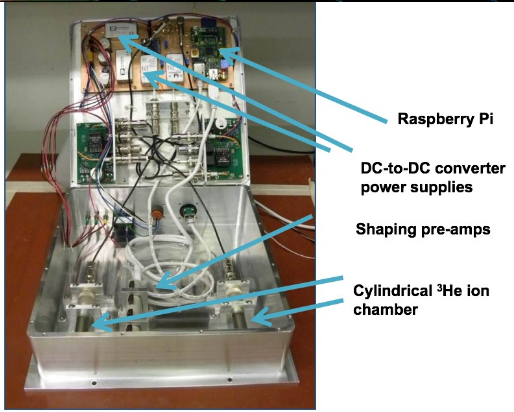
Community demand is building the case for radiation effects testing with protons and thermal neutrons

- Galactic cosmic rays (GCR), solar energetic particles (SEP), and trapped particles contribute to space radiation environment, and can damage electronics. Much of the concern is with energetic protons.
- Cosmic rays hitting atmosphere create neutrons. Fast neutrons are prevalent in the atmosphere. Thermal neutrons can induce $^{10}B(n,\alpha)$ and cause electronics failures.
- Demand for component testing for both cases outstrips supply in the U.S.
- Concepts being generated to use LANSCE protons, thermal neutrons to address.

Illustration of space radiation environment





Tinman instrument to measure thermal neutrons in aircraft

Key takeaways

- LANSCE's combination of beam power, flexibility, and authorization basis uniquely positions it to address a broad set of NNSA (and beyond) science.
- We have a programmatically motivated science vision for the facility that extends through the next several decades.