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Title: Nuclear data activities at LANSCE

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Issued: 2024-08-14

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PHYSICS SINCE 1943

Experiendo cognoscitur

Nuclear data activities at LANSCE*

Th. Stamatopoulos
on behalf of the Low Energy Nuclear Physics Team

A. Cooper, A. Couture, M. Devlin, P. Gastis, K. Kelly, S. Kuvin,
E. Leal-Cidoncha, H.Y. Lee, C. Prokop, R. Reifarth, Th. Stamatopoulos, J. Winkelbauer

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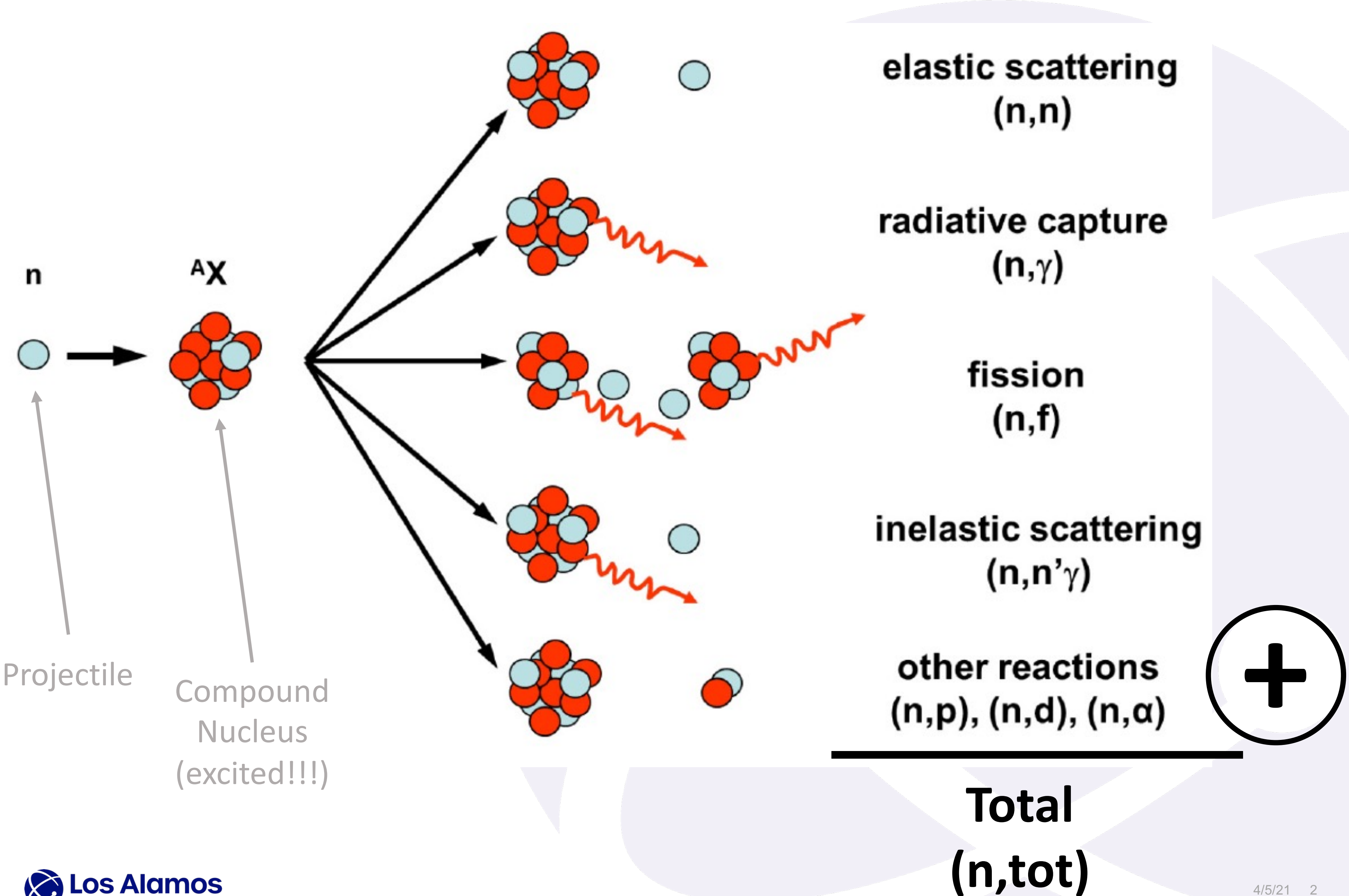
*Funded by LANL/LDRD-ECR, LANL/LDRD-DR, OES-SAT, OES-PAT, NCSP

4th Annual MCNP User Symposium
August 19th – 22nd, 2024
Los Alamos, NM

LA-UR-24-xxxxx

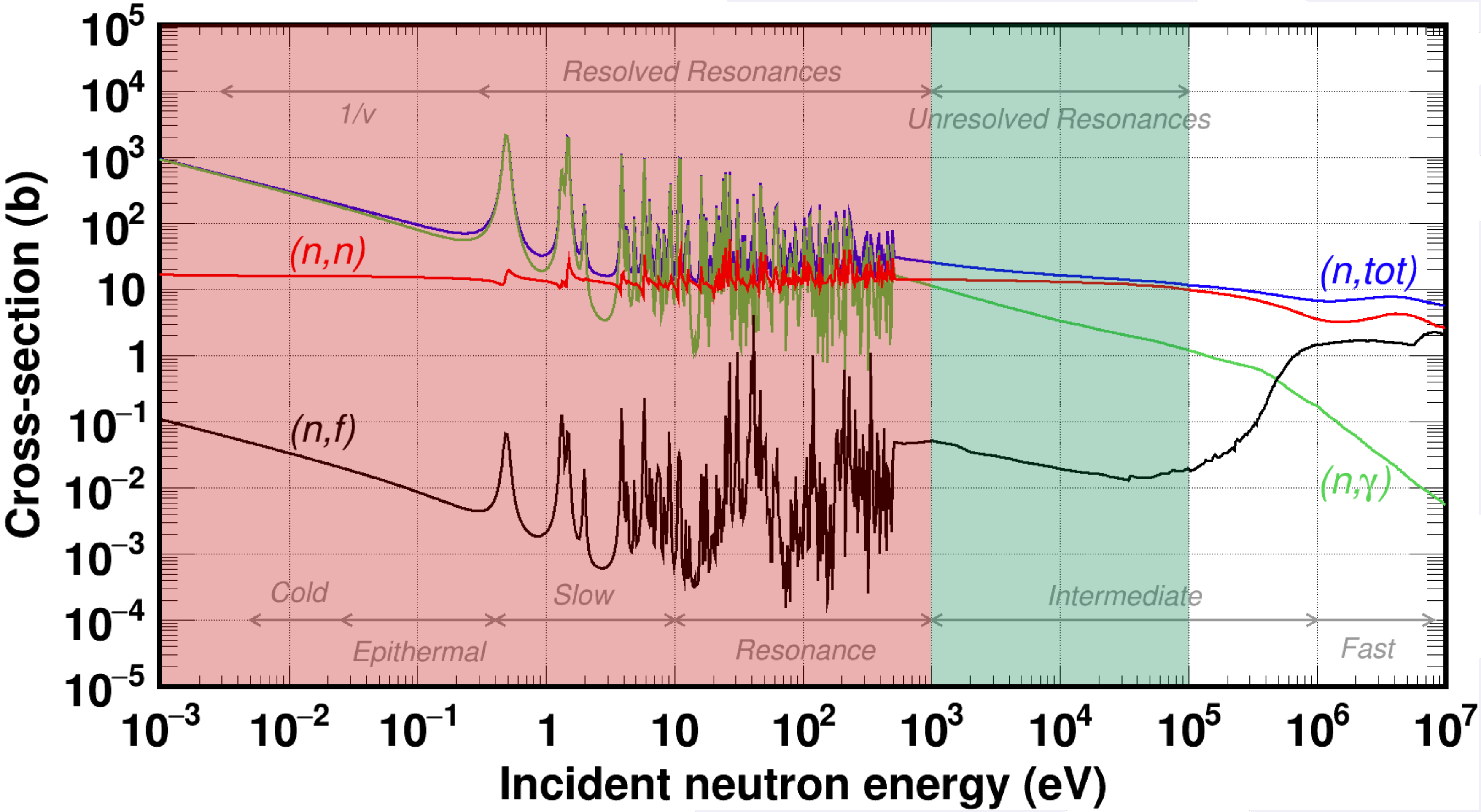
Neutron-induced reactions

De-excitation channels



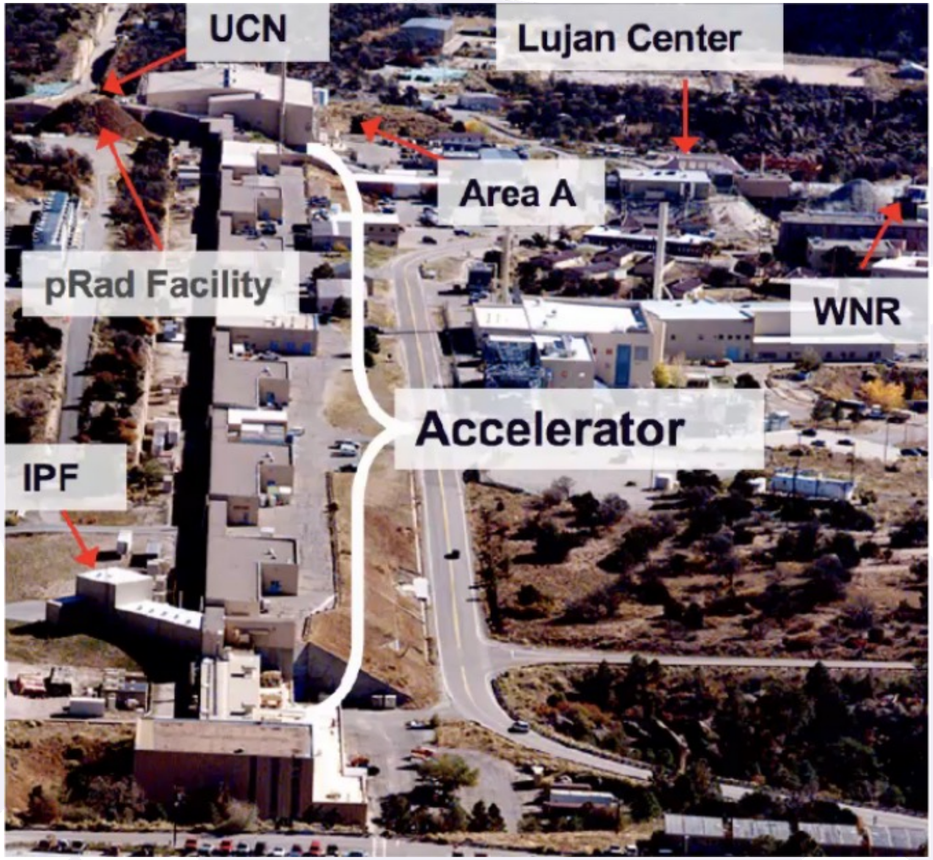
Neutron-induced cross sections

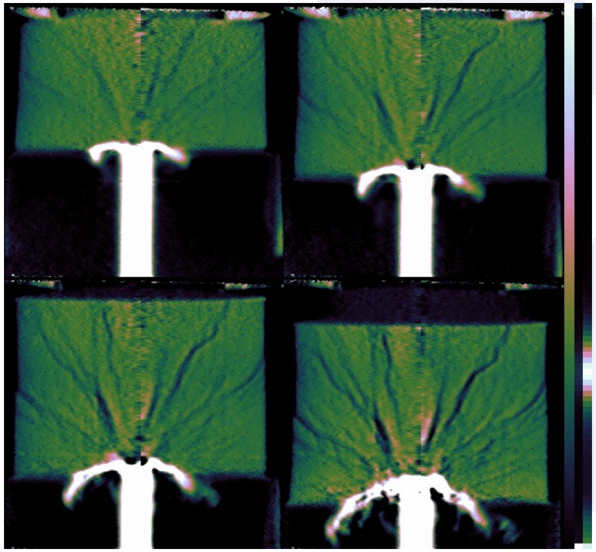
- **Cross section (σ_i)** : The probability/area for the reaction *i* to occur (1 barn = 10^{-24} cm^2
- Experimental cross sections are needed in evaluations
- Evaluated data are used in MCNP

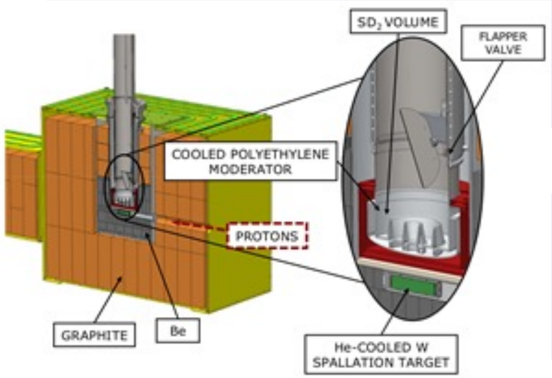


LANSCE: The Los Alamos Neutron Science Center

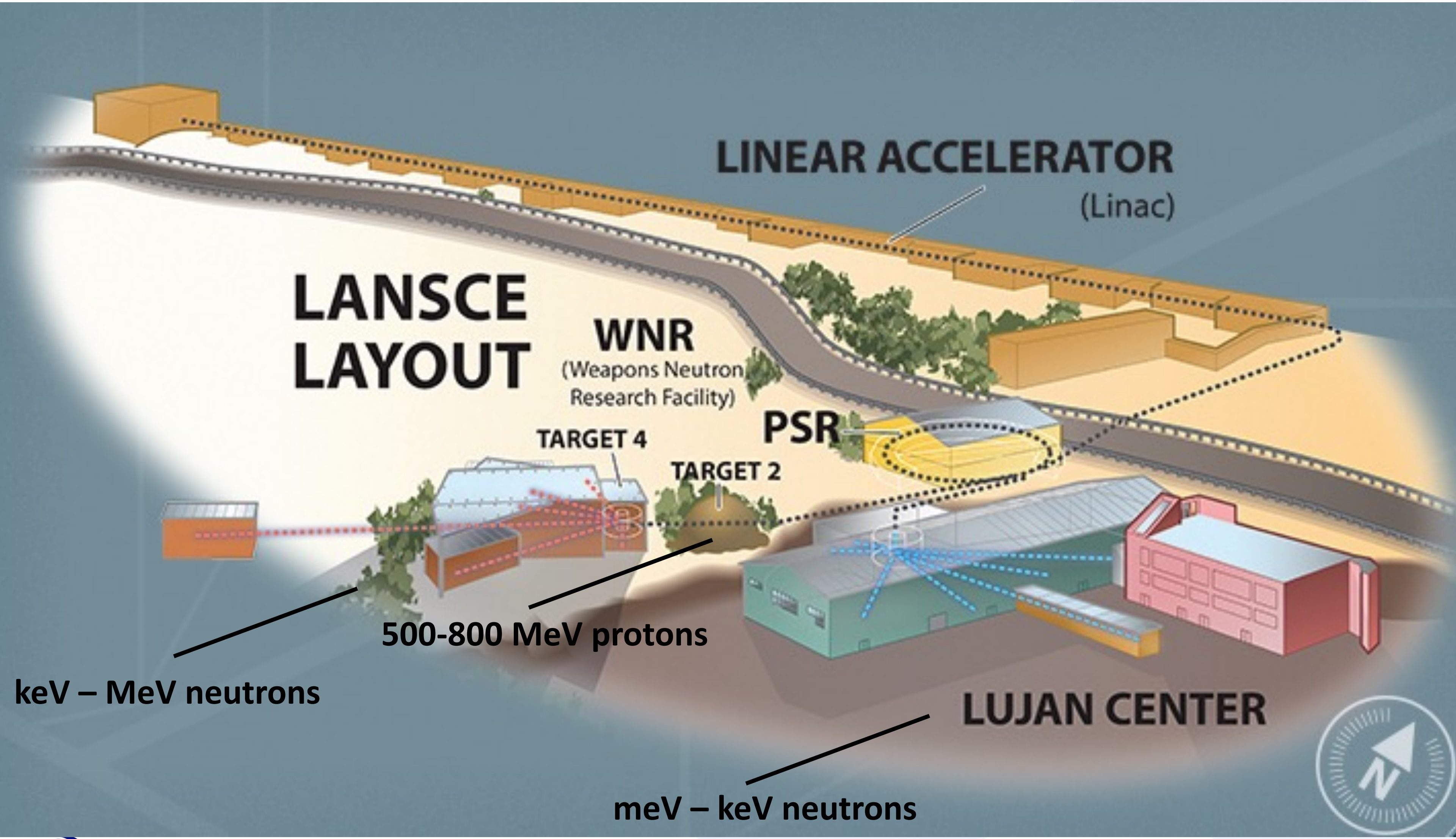
- 1 km long **LIN**ear **AC**celerator
- Up to 800 MeV protons
- Multi-user proton (p) and neutron (n) facility
  - Isotope Production Facility (IPF) (100 MeV p)
  - Proton irradiation (pRad) (800 MeV p)
  - Ultra Cold Neutrons (UCN) (<300 neV n)
  - **Lujan Center (meV – keV n)**
  - **WNR (keV – MeV n)**
  - Target 4 (500 - 800 MeV p)



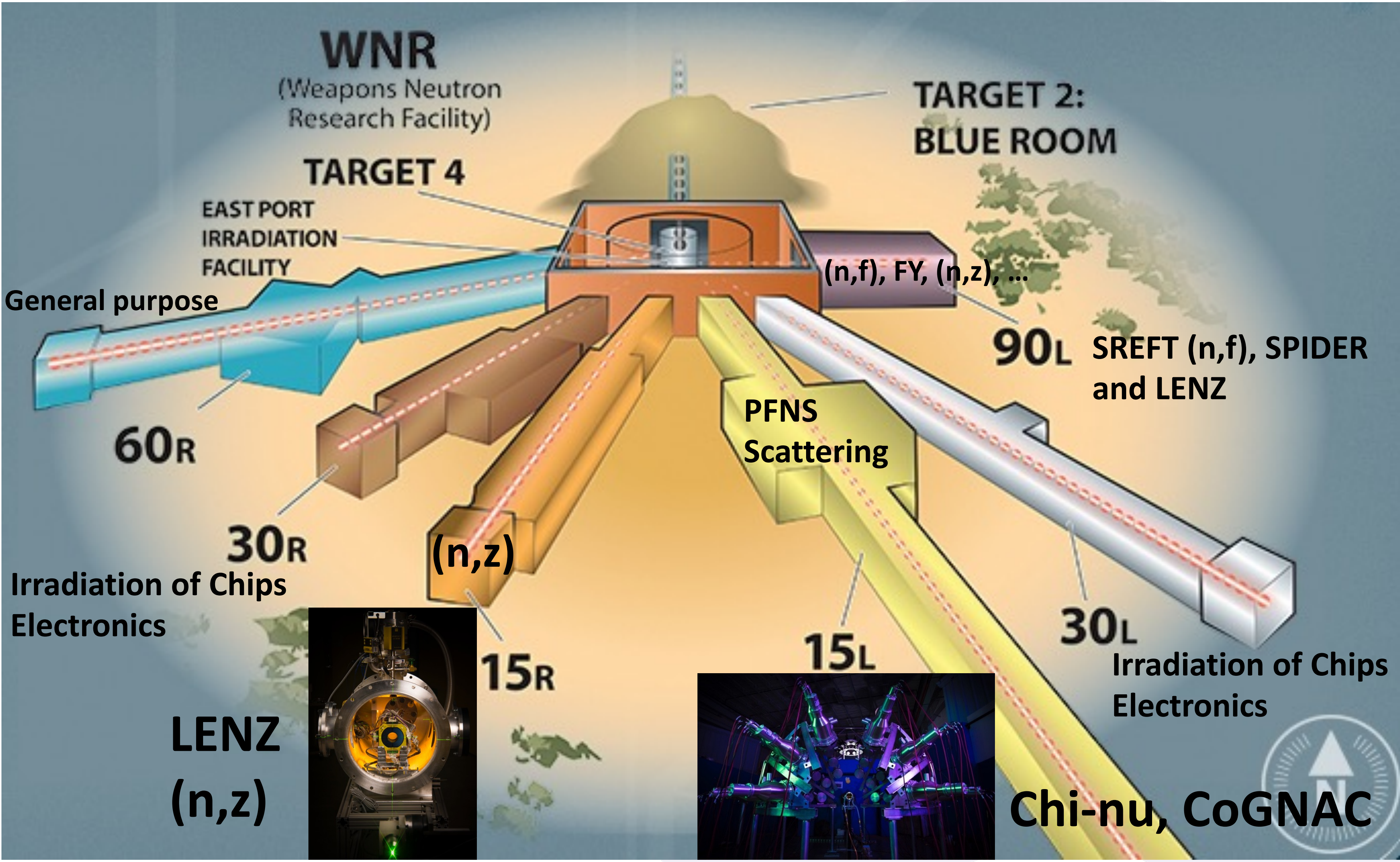




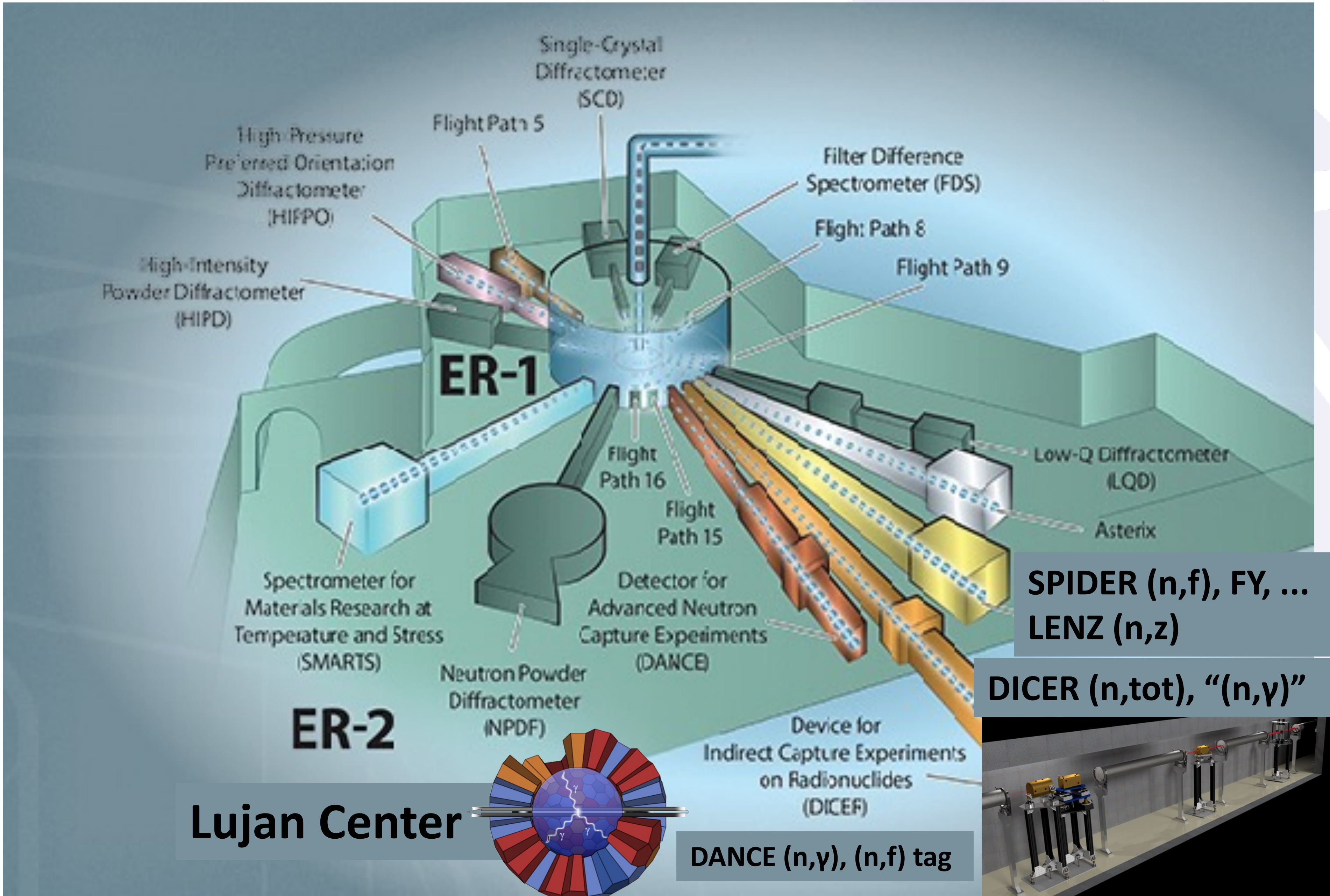
The Los Alamos Neutron Science Center - LANSCE



WNR – High energy neutrons

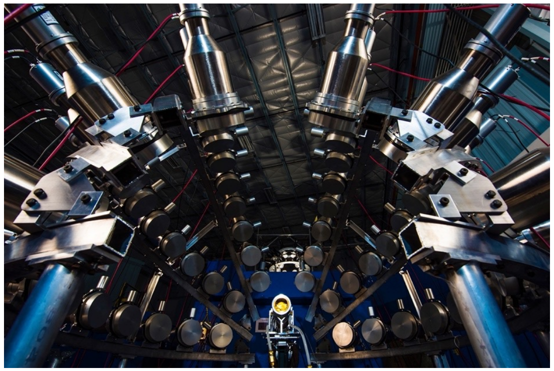


Lujan Center – Low energy neutrons

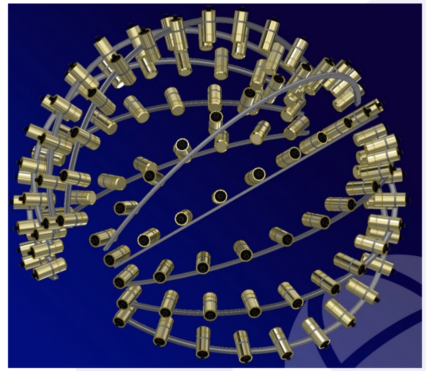


LANSCE nuclear physics is focused on n-induced reactions

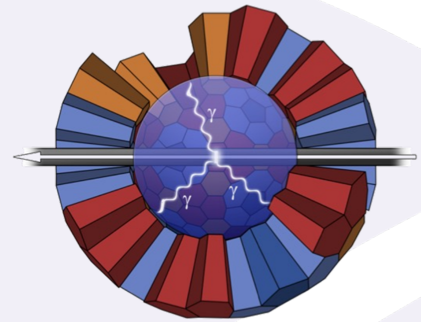
Chi-Nu
PFNS



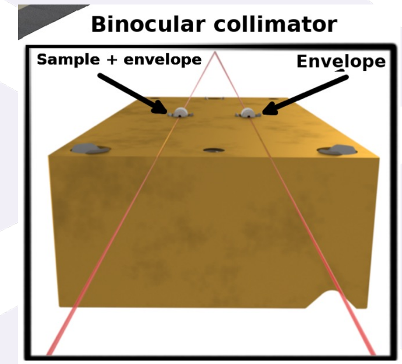
CoGNAC
Scattering



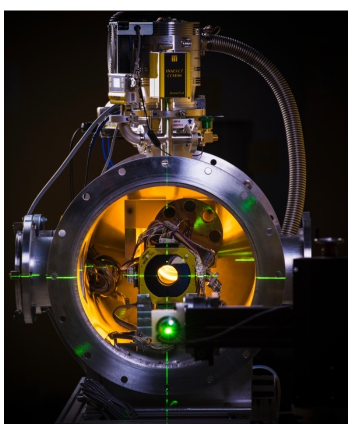
DANCE
(n,γ), (n,f)/(n,γ)



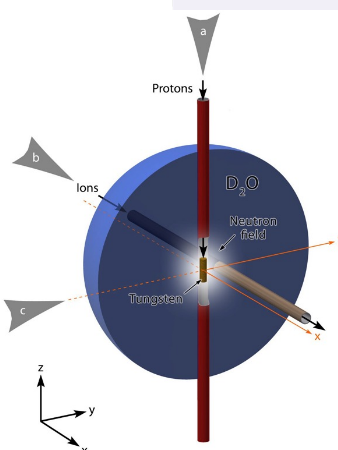
DICER
(n,γ), (n,tot)



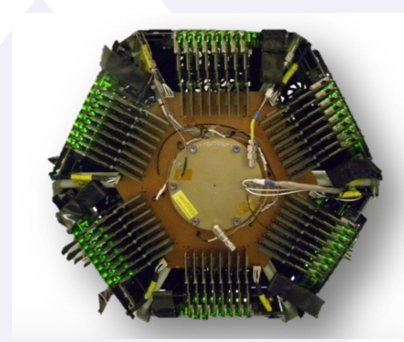
LENZ
(n,z)



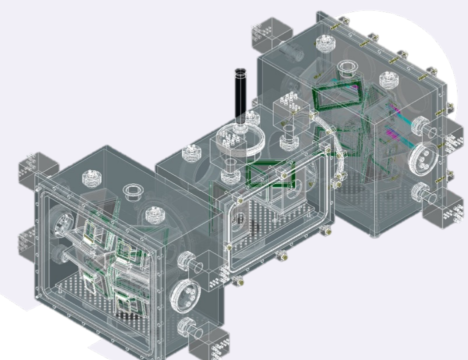
NTD
(n,γ)



TPC/SREFT
(n,f)

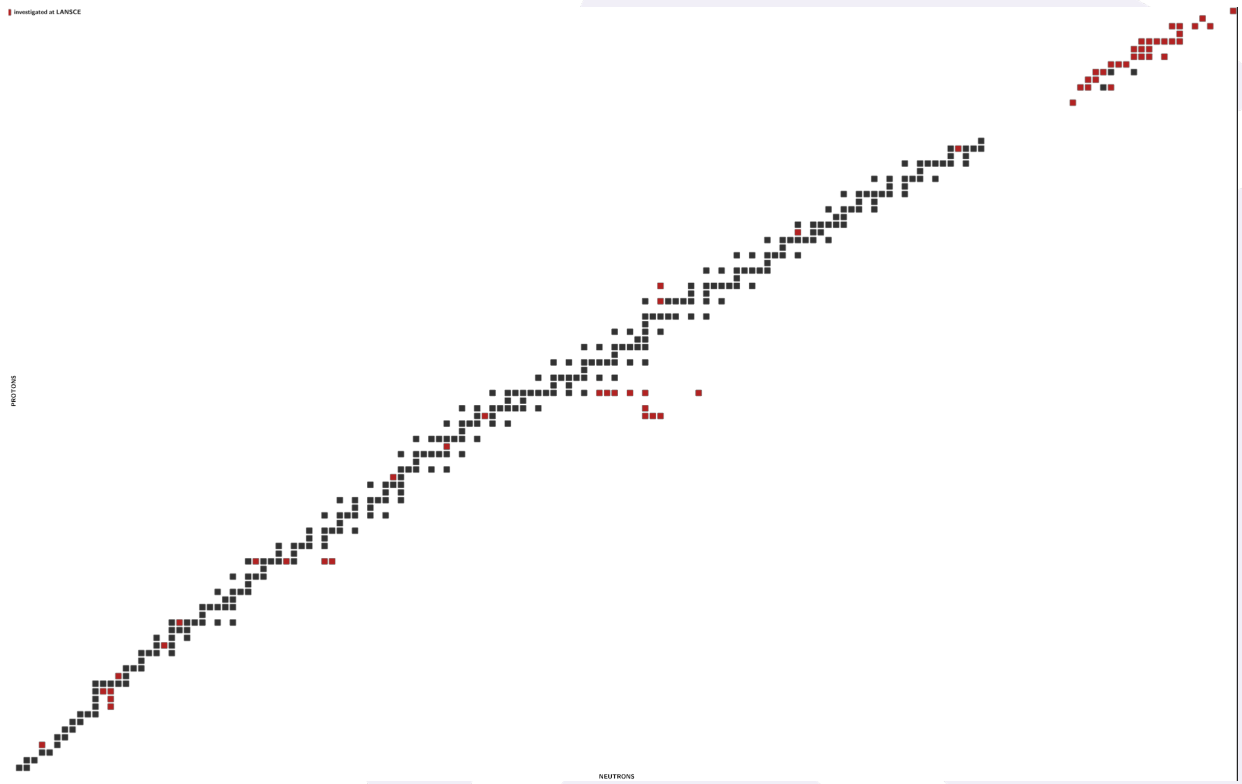


SPIDER
Fission products



LANSCE nuclear physics is focused on n-induced reactions

- **EXFOR: Database of experimental data managed by the IAEA**
- **1297 datasets from Los Alamos**
- **230 nuclides, that span all the way across the chart of nuclides**



Request #16195 www-nds.iaea.org 2024-08-09,15:15:43
Found: Entries:1297 Subentries:10458 Datasets:8892 Targets:404

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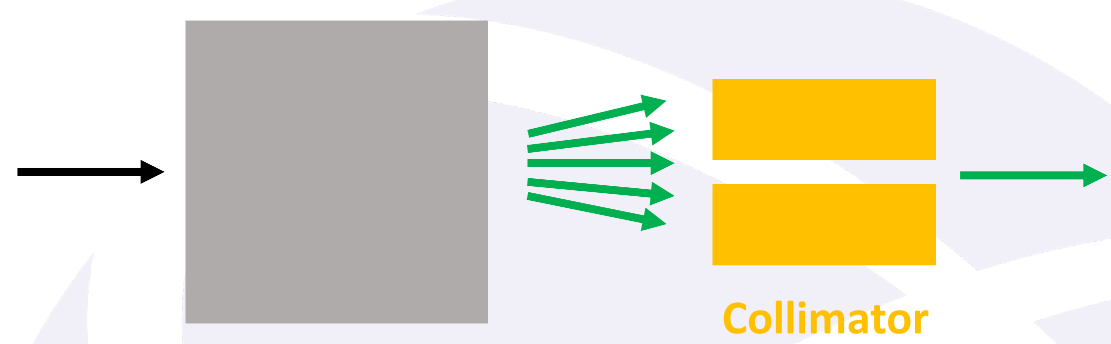
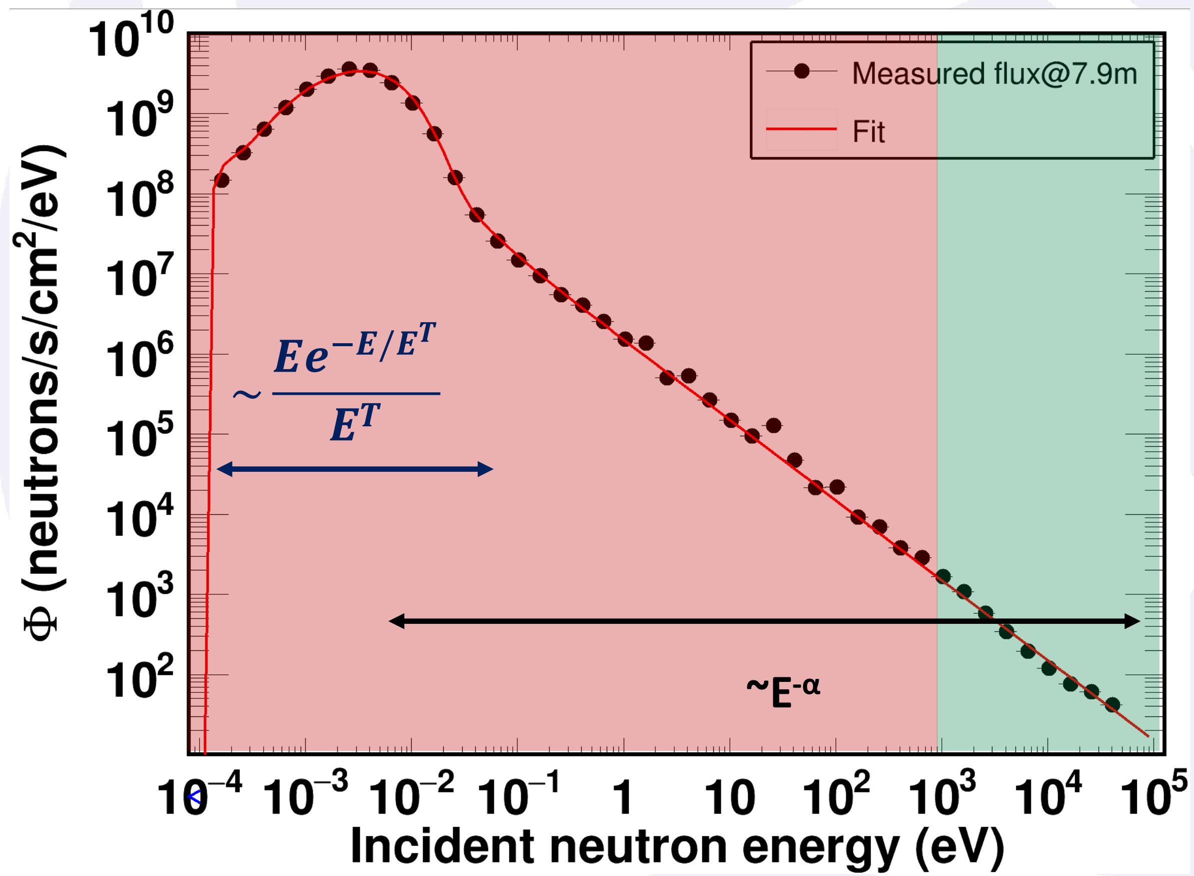
Neutron production

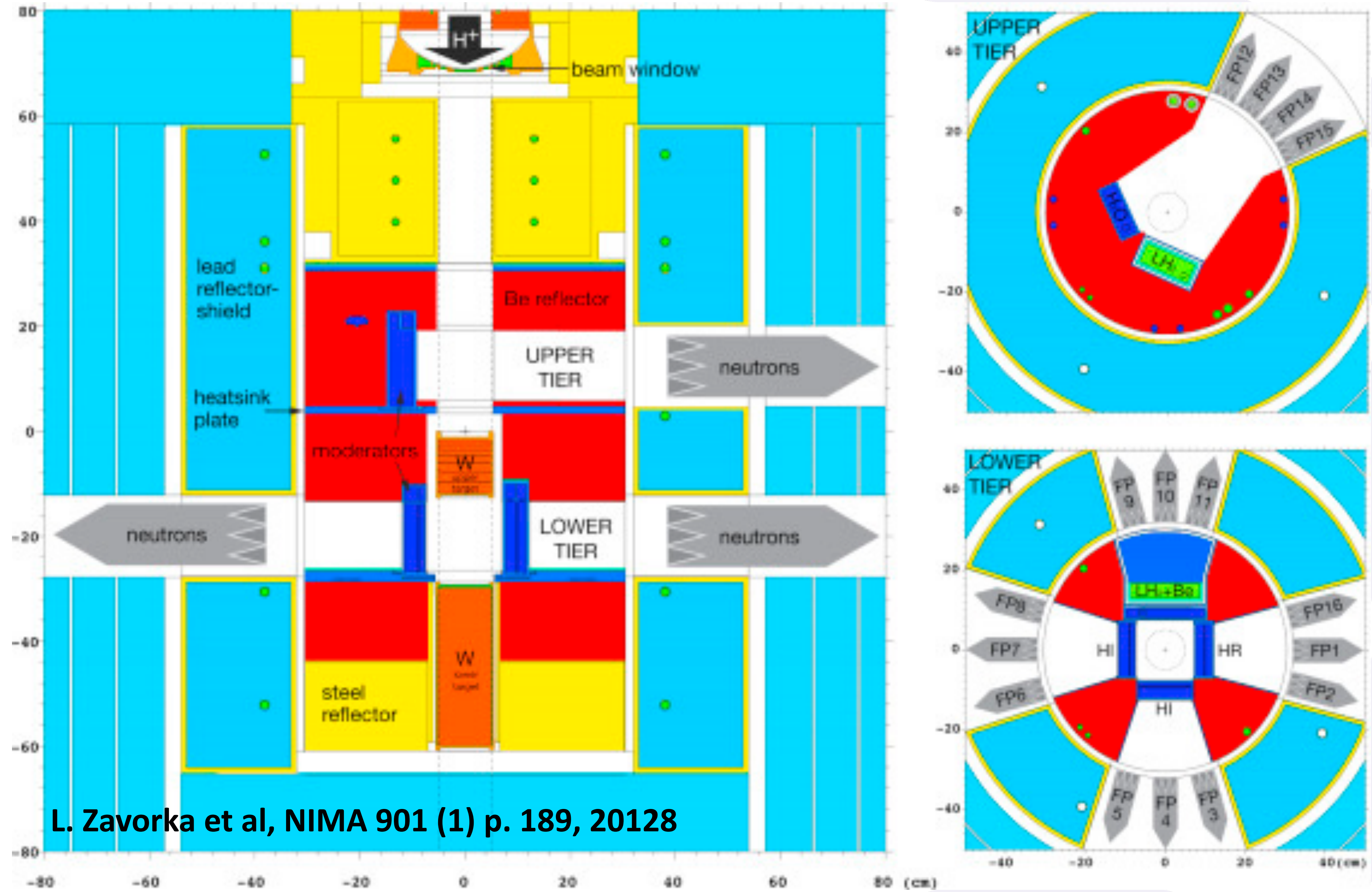
- High energy particle beams (i.e. **p** or **e**) impinge on heavy elements (i.e. Pb, W, U)
- All sorts of charged and uncharged particles are produced
- Neutrons are uncharged and go all over the place
- Collimators: blocks with holes to guide them to your experiment
- Continuous spectrum (white beam)





Neutron production

- MCNP is used to design the neutron production target

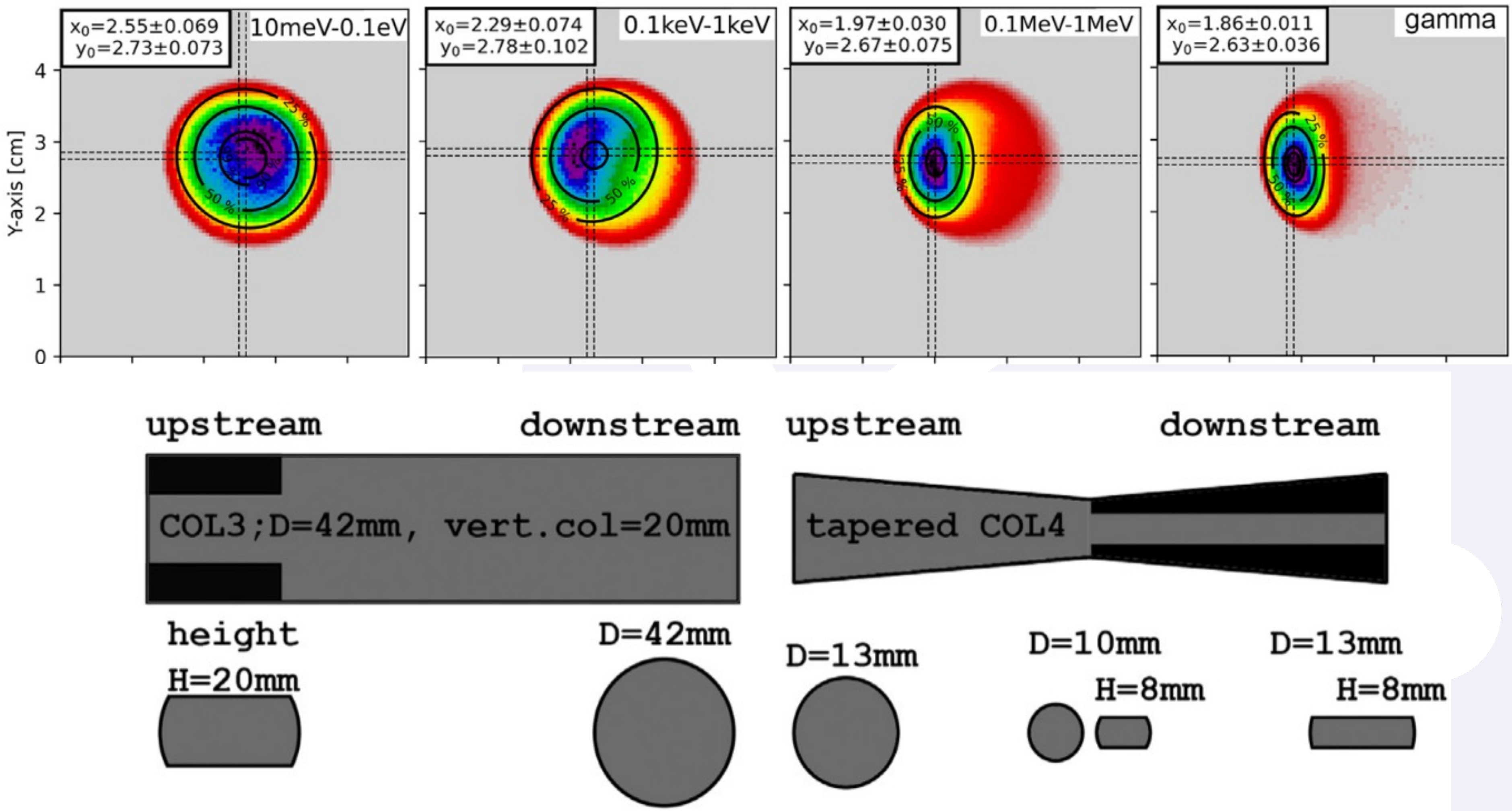


L. Zavorka et al, NIMA 901 (1) p. 189, 20128

Neutron production

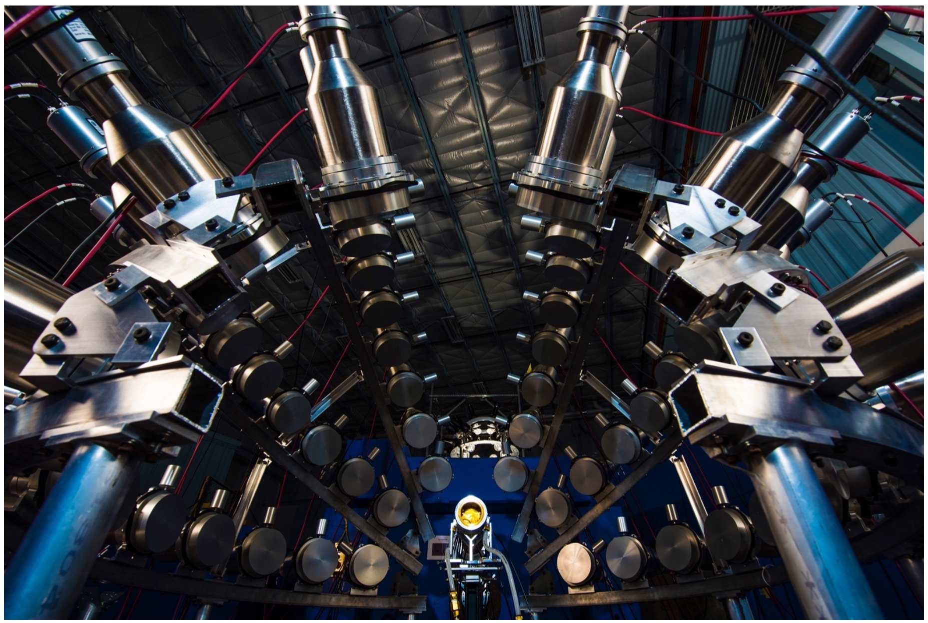
- MCNP is used to design/understand performance of neutron collimation downstream of the neutron production target

J. Svoboda et al, NIMA 1062 (2024) 169167

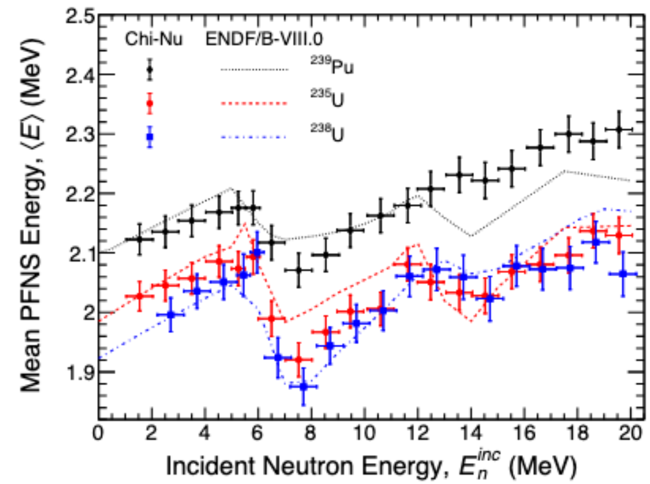


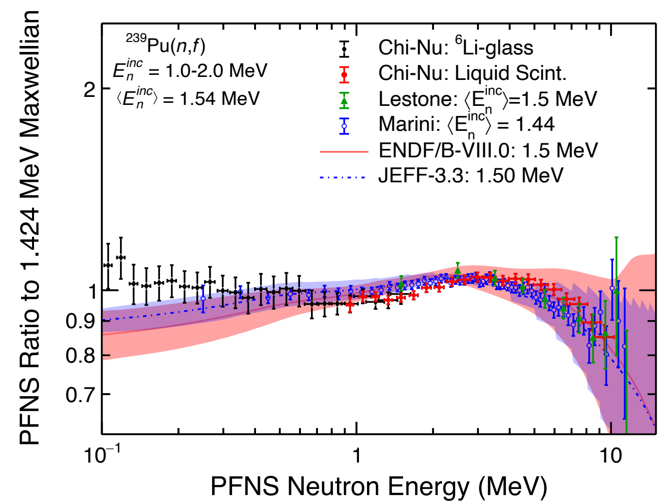
Chi-Nu: Measurements of neutron-induced fission Prompt Fission Neutron Spectra (PFNS) measurement

Improved nuclear data for criticality are NNSA and LANL priorities, including the output fission neutron spectra. Chi-Nu has measured PFNS for neutron-induced fission on ^{235,238}U and ^{239,240}Pu for incident neutron energies from below 1 MeV to 20 MeV.



The χ-ν array of 54 liquid scintillators with a LLNL PPAC fission detector





^{239}Pu(n,f) – *PRC* **102,** 034615 (2020)
^{235}U(n,f) – *PRC* **105,** 044615 (2022)
^{238}U(n,f) – *PRC* **108,** 024603 (2023)
^{240}Pu(n,f), Pu(sf) – *PRC* **109,** 064611 (2024)

Contact: Matt Devlin, devlin@lanl.gov
Keegan Kelly, kkelly@lanl.gov

Chi-Nu: Current and planned PFNS measurements

Spontaneous fission PFNS measurements of ^{240}Pu and ^{242}Pu have been completed, and an improved ^{240}Pu(sf) measurement is in progress for NA-22. A ^{233}U(n,f) PFNS measurement for NCSP is planned for FY25, and a ^{237}Np(n,f) is being planned for later.

Recent publication highlighted in PRC

Featured in Physics

Measurement of the prompt fission neutron spectrum from 800 keV to 10 MeV for ^{240}Pu(sf) and for the ^{240}Pu(n, f) reaction induced by neutrons of energy from 1–20 MeV

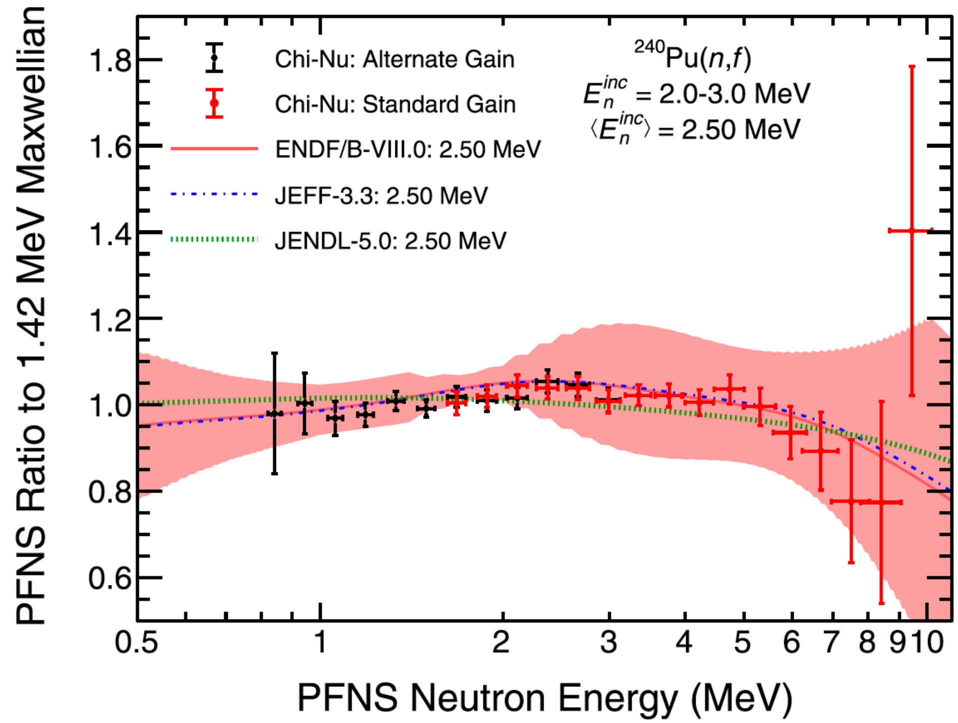
K. J. Kelly, M. Devlin, J. M. O'Donnell, D. Neudecker, C. Y. Wu, R. Henderson, A. E. Lovell, R. C. Haight, E. A. Bennett, J. L. Ullmann, N. Fotiades, and P. A. Copp

Phys. Rev. C **109**, 064611 (2024) – Published 13 June 2024

Physics Synopsis: Adding Certainty to Plutonium's Fission Yield

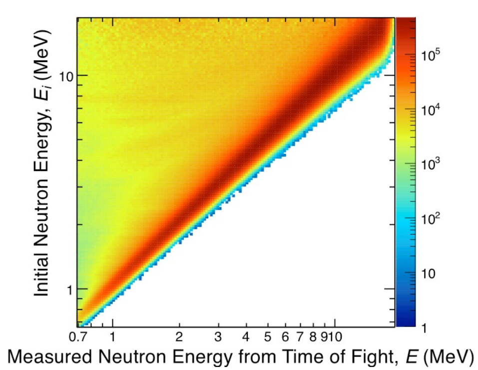
A first-of-its-kind measurement reveals the energy spectrum of the neutrons produced during the fission of plutonium, a common nuclear fuel component.

Show Abstract +



Funding from OES/PAT and SAT, NCSP, and NA-221

Work done at LANSCE by P-3, P-2,T-2 at LANL and LLNL



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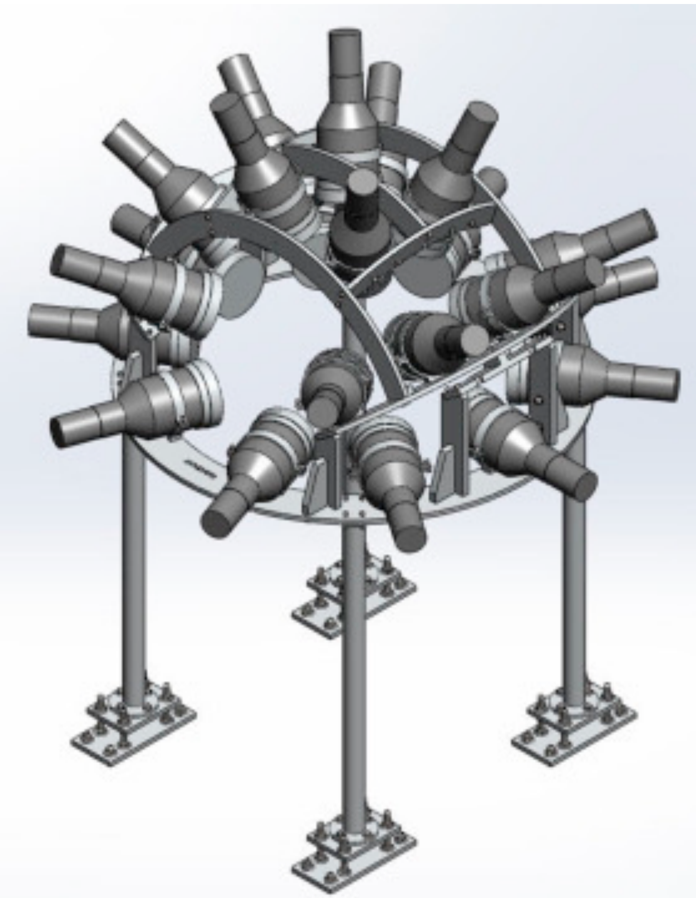
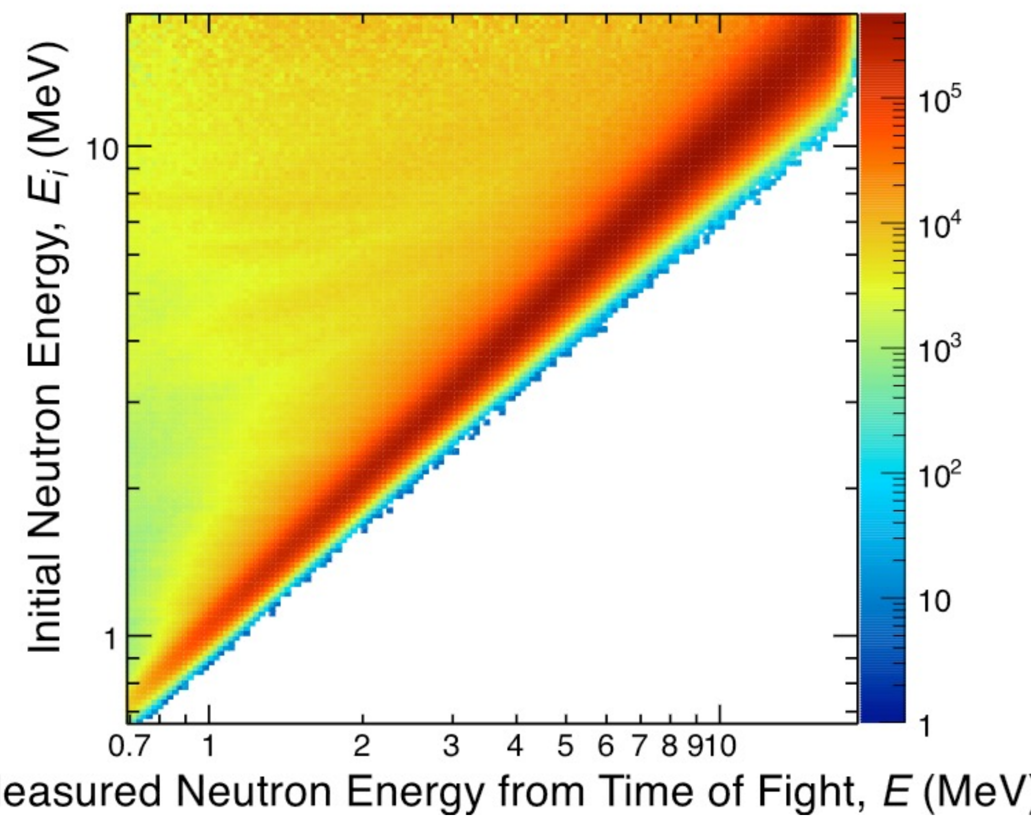
Chi-Nu: Highlight of MCNP-related work

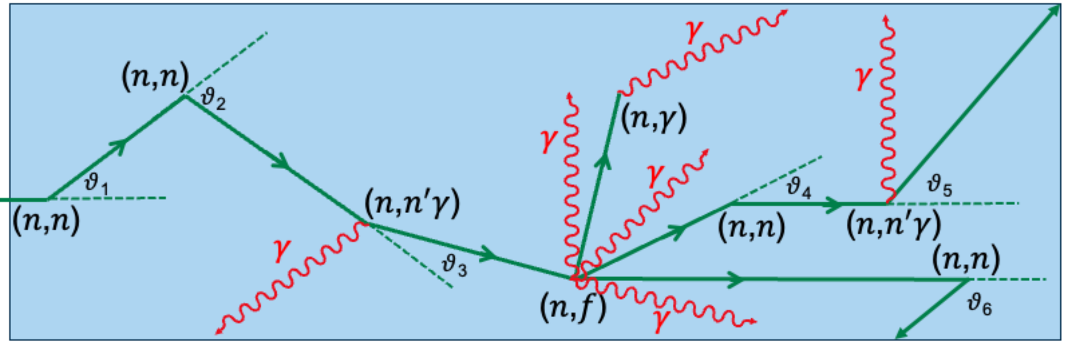
- Response function of the array
- Scattering causes an excess in counts at low neutron energies and a deficiency at high energies
- Detector efficiency needs to be corrected

K. Kelly et al., NIMA 886 (2017) p. 182
K. Kelly et al., NIMA 1010 (2021) 165552

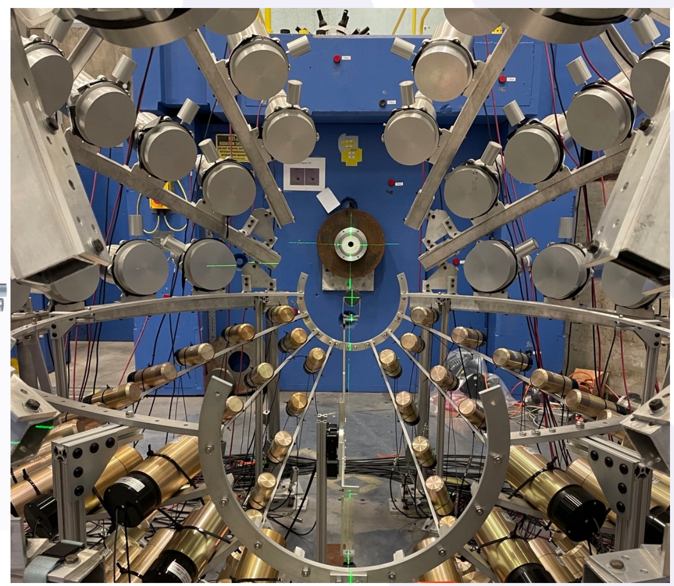




CoGNAC: The Correlated Gamma-Neutron Array for sCattering, Helps Guide MCNP Neutron Transport



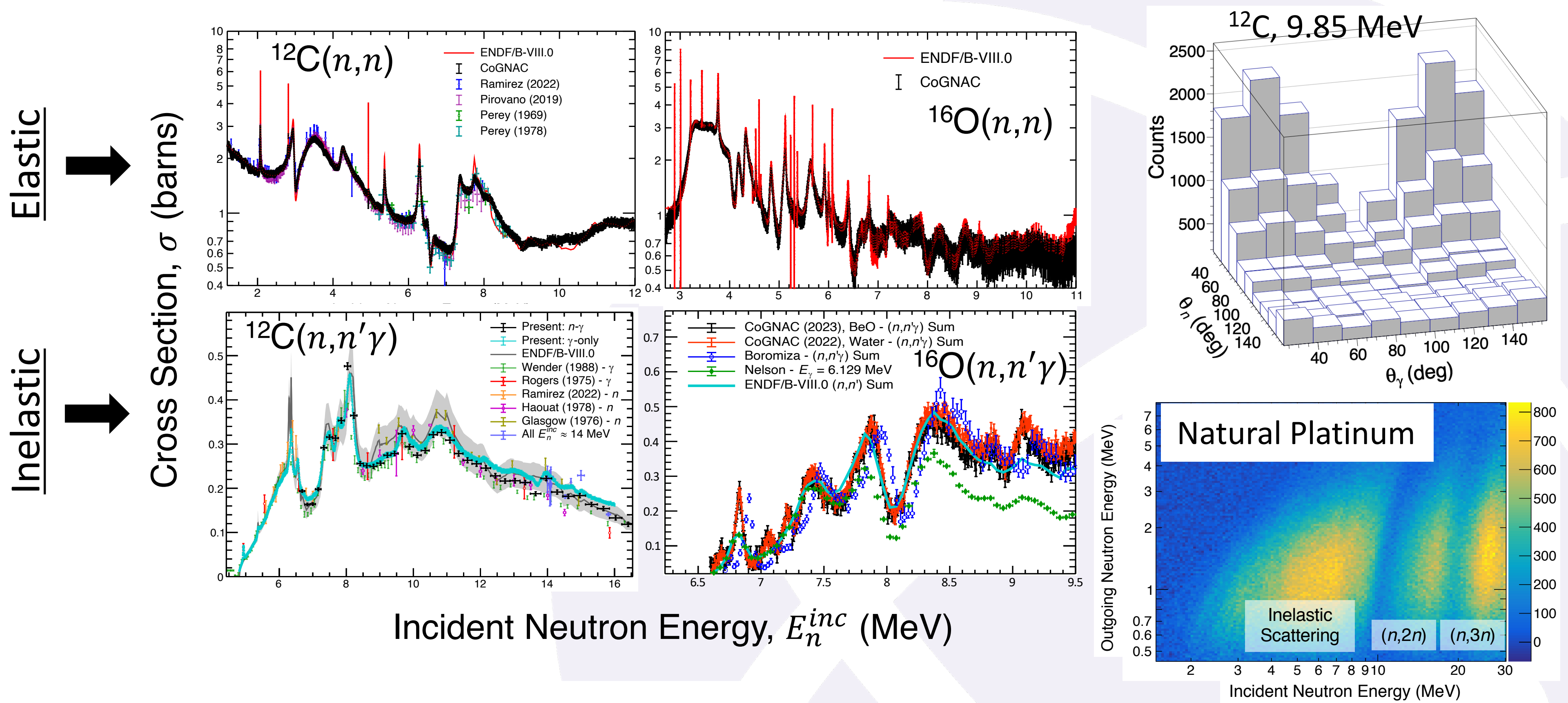
- Neutron elastic (n,n) and inelastic $(n,n'\gamma)$ reactions dominate the total cross section
- Scattering angular distributions define the energy and angular neutronic flow



- 54 Liquid Scintillators (upper)
- 72 CLYC detectors (lower)
- Recent results on ^{12}C, ^{16}O, and ^{28}Si neutron scattering
  - Kelly, et al., PRC 104 (2021) 064614
  - Kelly, et al., PRC 108 (2023) 014603
  - Kelly, et al., EPJ WoC 284 (2023) 01004

Contact: Keegan Kelly, kkelly@lanl.gov
Matt Devlin, devlin@lanl.gov

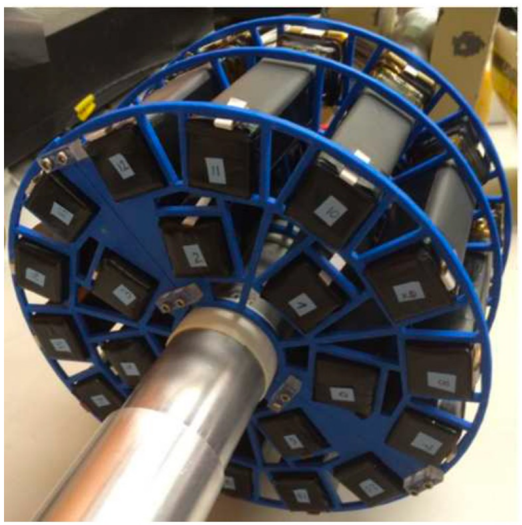
Correlated White-Source Elastic-Inelastic Scattering; Expansion to $(n,2n)$, $(n,3n)$, and (n,xn) Measurements

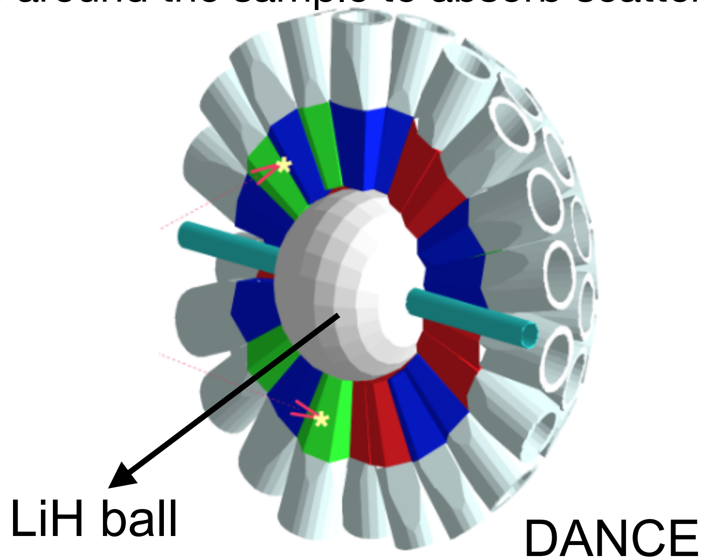


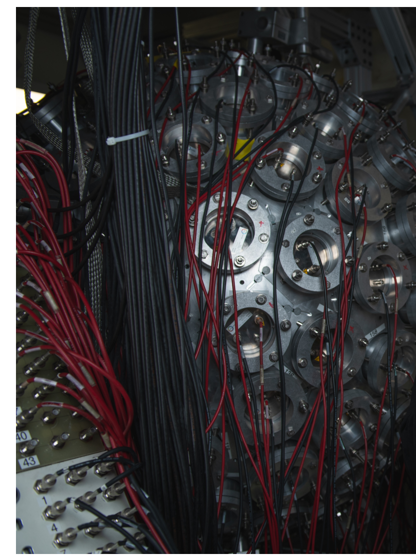
- First-ever white-source (n,n) and (n,n') measurements provide continuous results to high precision with constancy check against total cross section.
- Rarely-observed correlated n-γ angular distributions inform nuclear models.
- n-n and higher-order coincidences being explored for (n,xn) measurements.

DANCE: Detector for Advanced Neutron Capture Experiments

- $4\pi BaF_2$ γ-ray calorimeter composed by 160 crystals with an inner cavity of 17 cm radius [1].
- Used to measure neutron capture cross section data on small quantities of radioactive isotopes. Single γ-ray detection efficiency of 85%.
- We can measure En, Esum, Ecl, and Mcl, providing more information than with C6D6 detectors.
- A LiH ball is placed inside around the sample to absorb scattered neutrons.







[1] M. Heil et al., Nucl. Instrum. Methods Phys. Res. A **459**, 229 (2001).

Contact: Aaron Couture, acouture@lanl.gov
Esther Leal-Cidoncha, elealcid@lanl.gov

DANCE: Detector for Advanced Neutron Capture Experiments

- **Capture-to-fission ratio** measurements:
  - For some isotopes, the fission rate is considerable compared to capture.
  - Good discrimination between γ-rays coming from capture and fission.
  - Advantages: It is much simpler and more reliable to determine experimentally as many of the systematic questions cancel out:
    - Sample mass
    - Self-shielding
    - Neutron exposure
- Successfully measured ratios combining a fission detector and DANCE:
  - ^{235}U:

    [4] M. Jandel et al., Phys. Rev. Letters **109**, 202506 (2012).
  - ^{239}Pu:

    [5] S. Mosby et al. Phys. Rev. C **89**, 304610 (2014).

    [6] S. Mosby et al. Phys. Rev. C **97**, 041601 (2018).

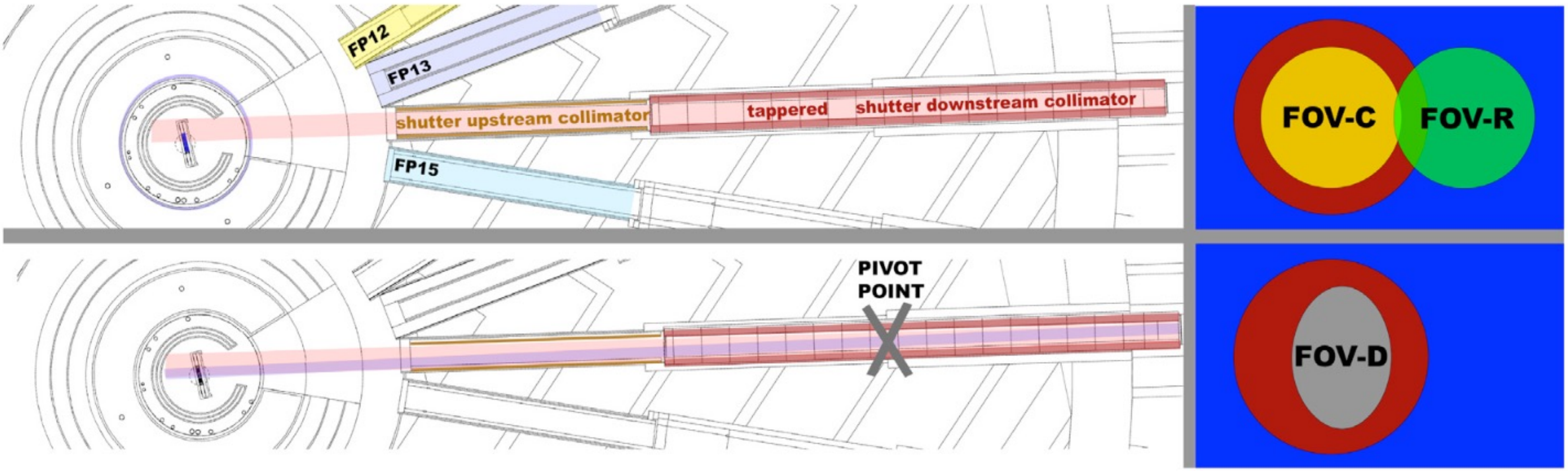
    [7] S. Mosby et al. Nucl. Data Sheets **148**, (2018) 312-321.
  - ^{233}U:

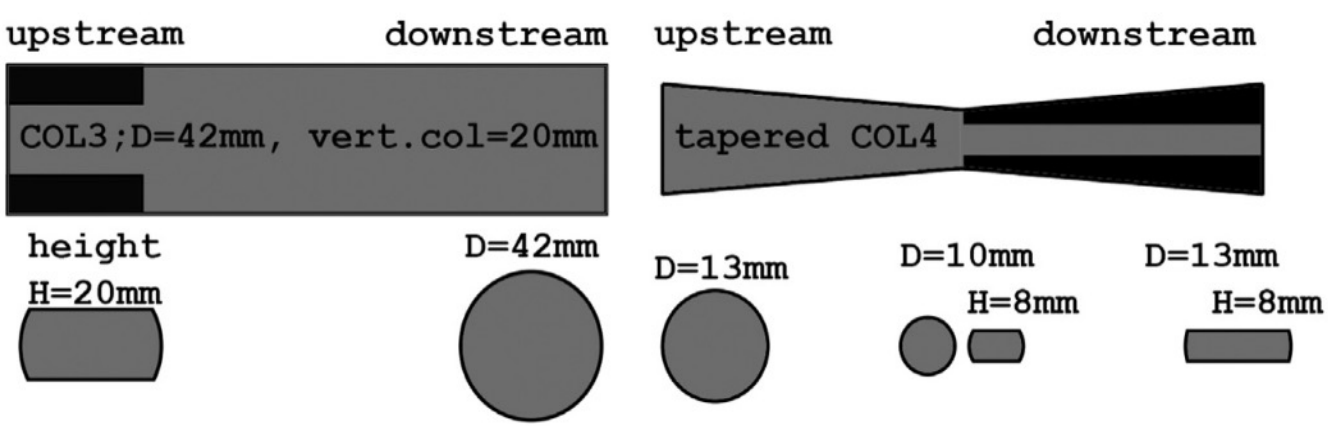
    [8] E. Leal-Cidoncha et al., Phys. Rev. C **108** 014608 (2023)

DANCE: Detector for Advanced Neutron Capture Experiments

- MCNP is used to change the configuration of the instrument after the installation of a new neutron production target

J. Svoboda et al, NIMA 1062 (2024) 169167





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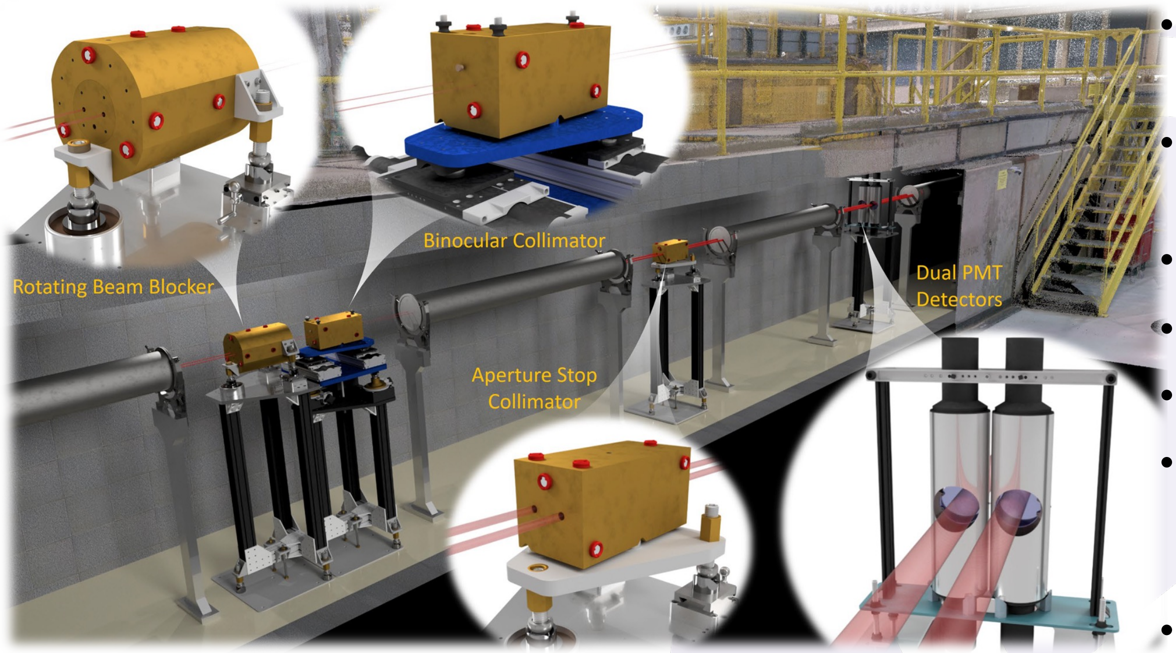
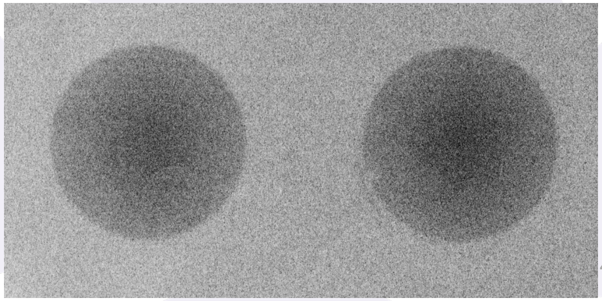
DICER: Device for Indirect Capture Experiments on Radionuclides (n,γ), (n,tot)



- Indirect (n,γ) measurements on radionuclides
- (n,tot) measurements on tiny samples
- Developed couple years ago
- 1mm diameter
- 66ng – a few mg
- Typical samples in other facilities:
  - cm in diameter
  - g in mass
- First ever binocular collimator
- Two beam spots of equal flux
  - One for the sample
  - The other for background
  - Simultaneous measurement of the two
  - Typically people cycle between the two

A. Stamatopoulos et al., NIMA (1025) 166166, 2022
A. Stamatopoulos et al., IEEE Trans. Nucl. Science 70, (2023)
A. Stamatopoulos et al., Neutron News 33, 12 – 14 (2022)

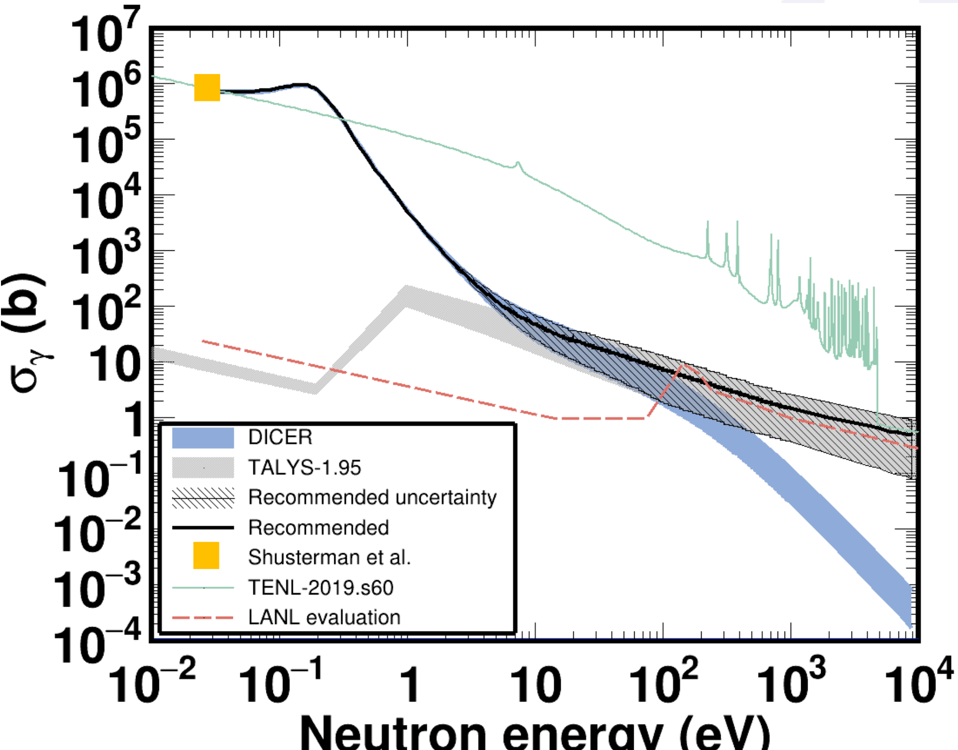


Contacts: Thanos Stamatopoulos, thanos@lanl.gov
Andrew Cooper, alcooper@lanl.gov

DICER: Selected highlights

^{88}Zr

- Compatible cross section:
  σ^{th}_{DICER} = 771(31) kb vs σ^{th}_{LLNL} = 861(69) kb
- Incompatible resonance integral:
  I_{DICER} = 15.21(67) kb vs I_{LLNL} = 2530.0(280) kb
- 1 keV MACS in agreement with LANL evaluation
  $MACS_{DICER}$ = 1.6(12) b. vs $MACS_{LANL}$ = 1.1 b

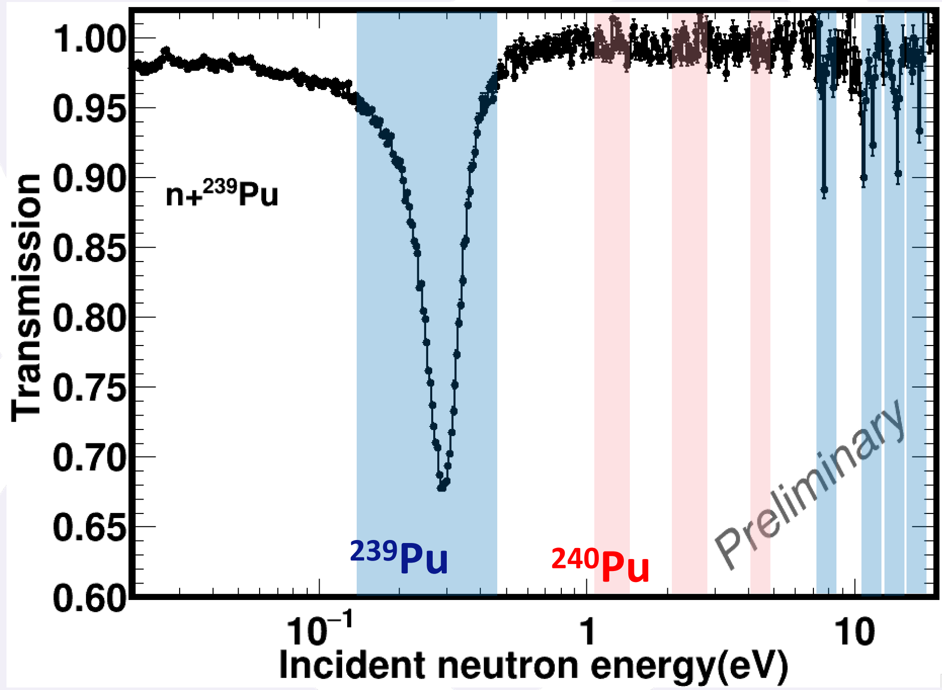


Submitted to Phys. Rev. Lett.

Pre-print: https://doi.org/10.21203/rs.3.rs-3331910/v1

^{239}Pu

- ^{239}Pu(n,tot) measurement sponsored by the Nuclear Criticality Safety Program.
- Need for an isotopically pure sample (even 1% of ^{240}Pu can make the measurement problematic)
- Probably the purest ^{239}Pu sample in the world: 99.96% but only ~100 mg available.
- DICER only needed ~1 mg



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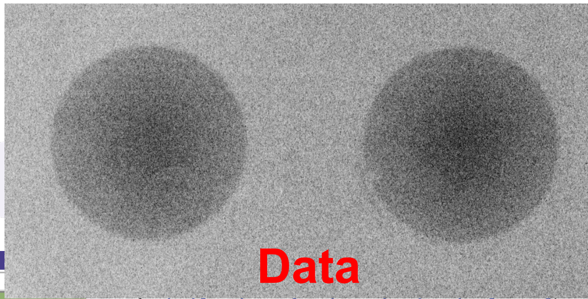
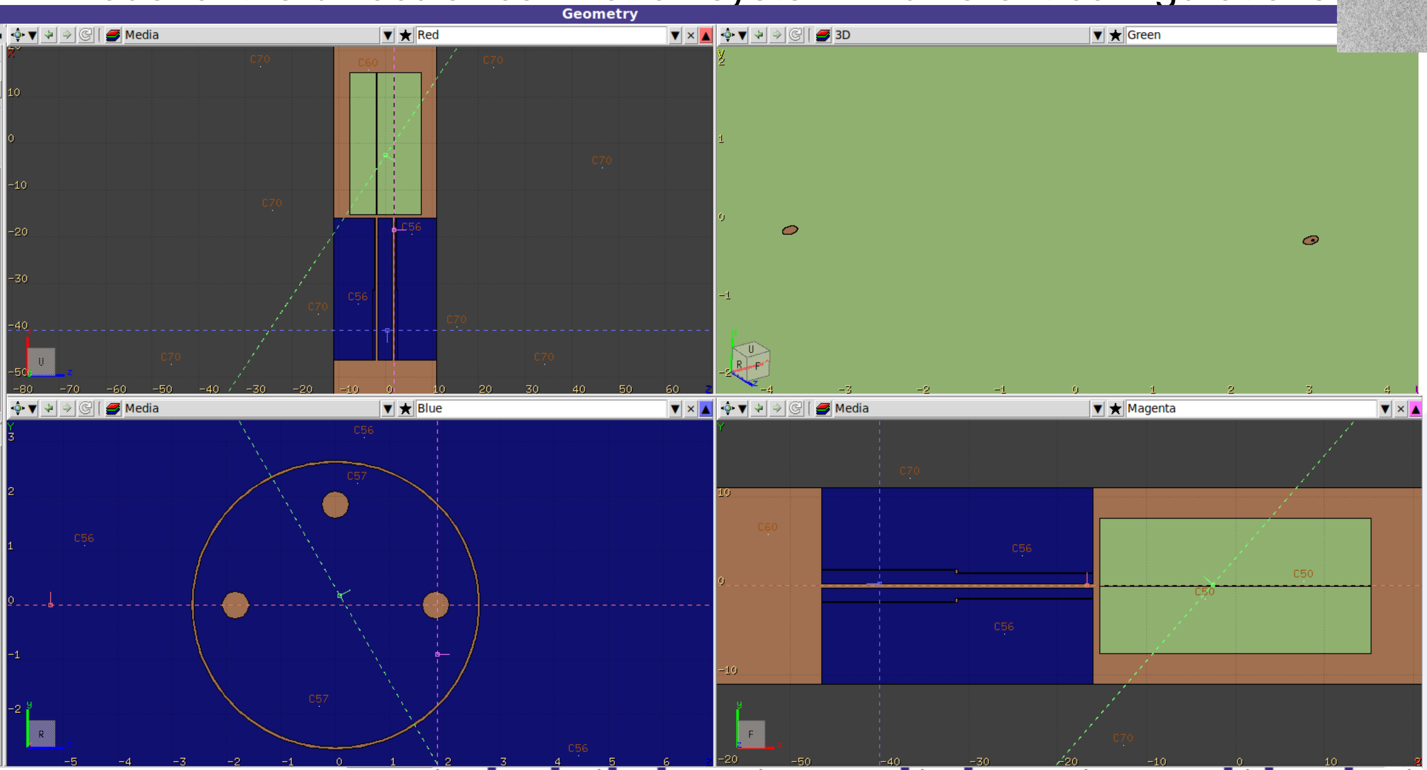
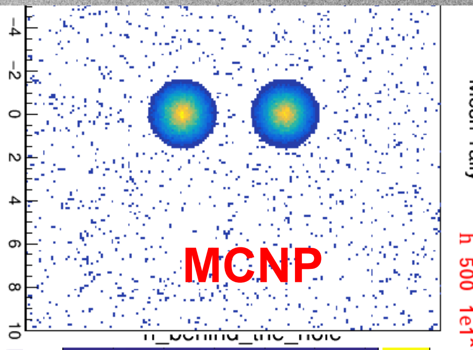
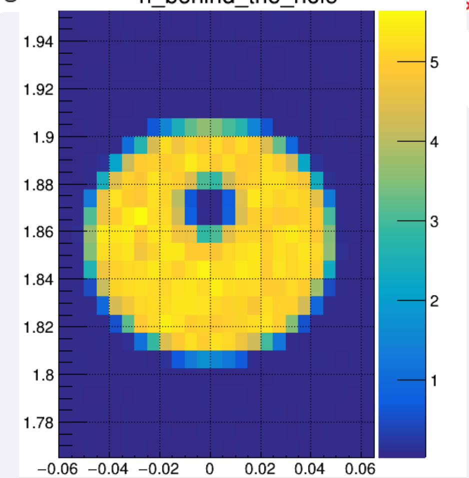
DICER: MCNP-related work

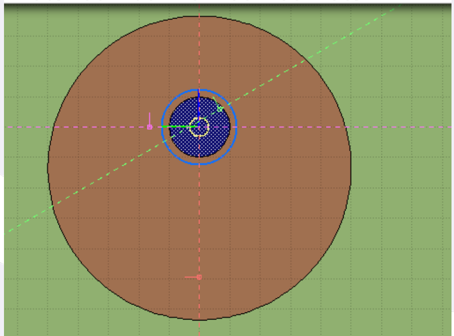
- Not intuitive neutron transport
- Model of the binocular collimation system in different configurations

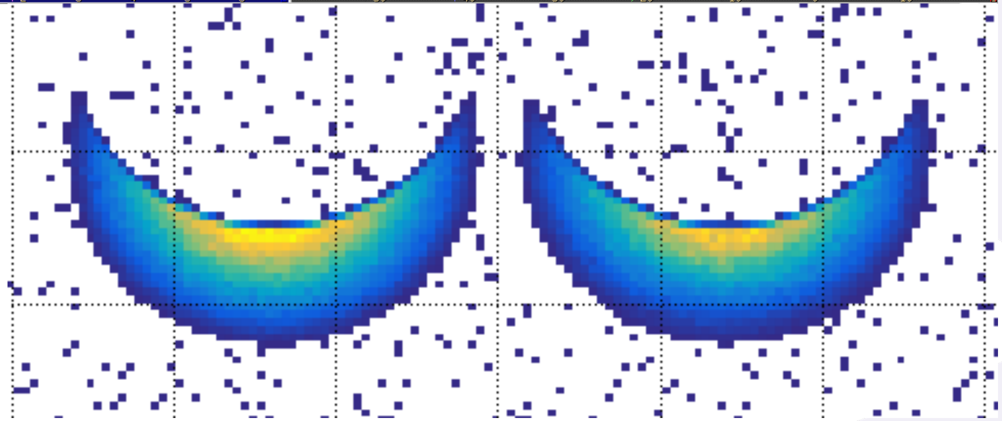






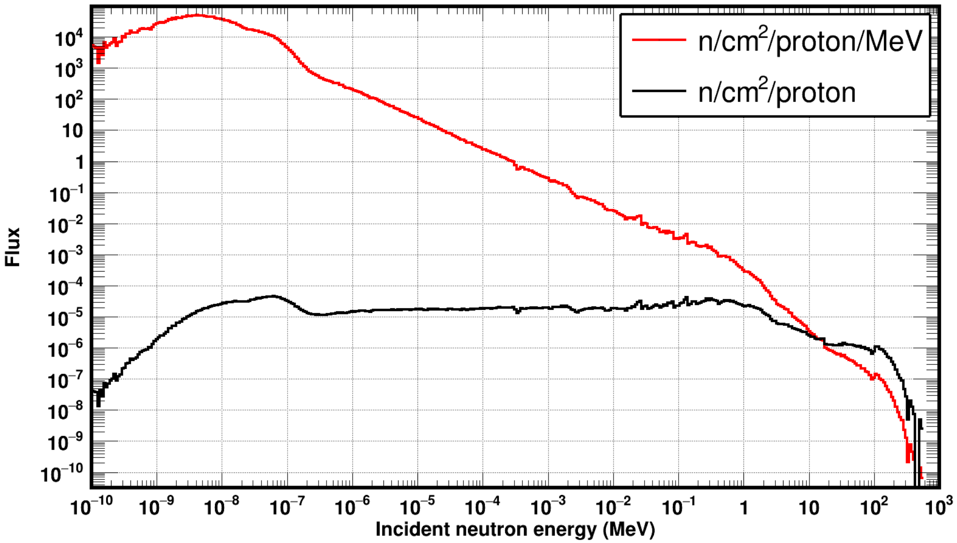




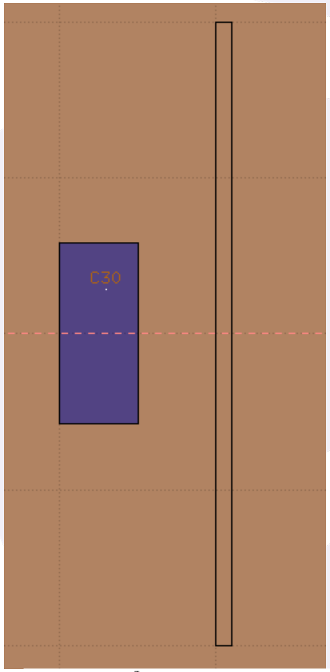


DICER: MCNP-related work

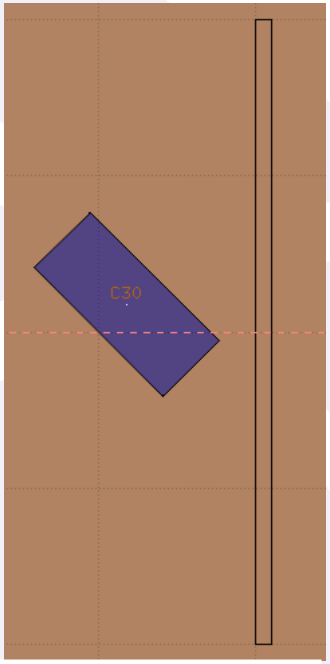
- Estimation of neutron flux; covid days

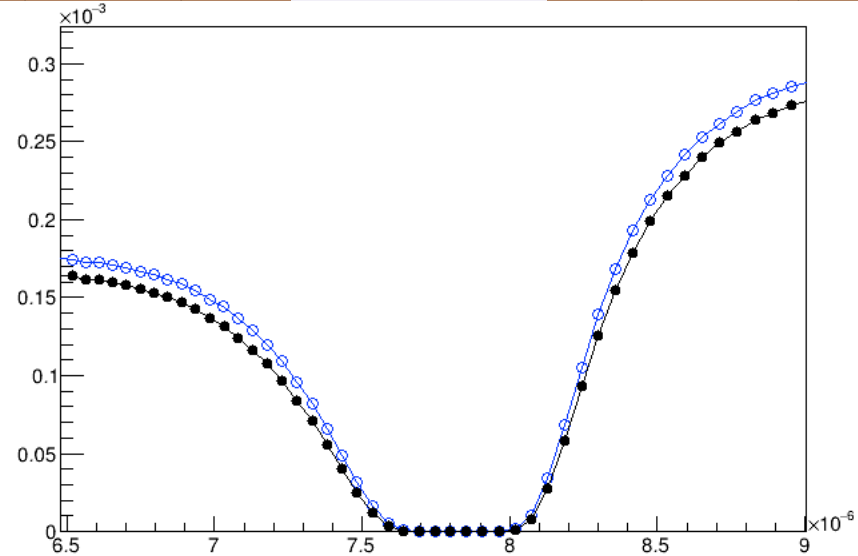


- Sample positioning, non-uniformities, etc



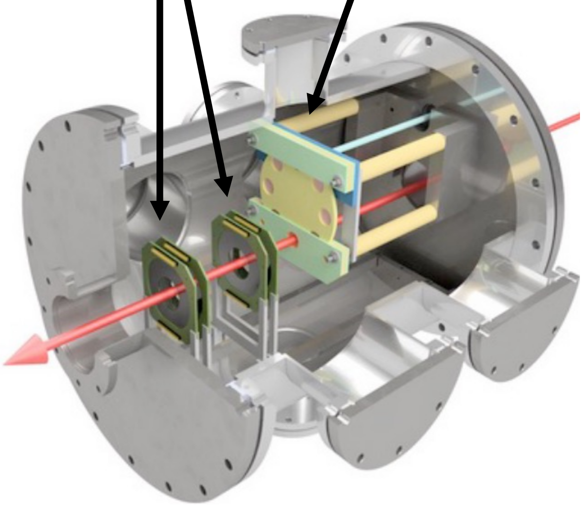
VS

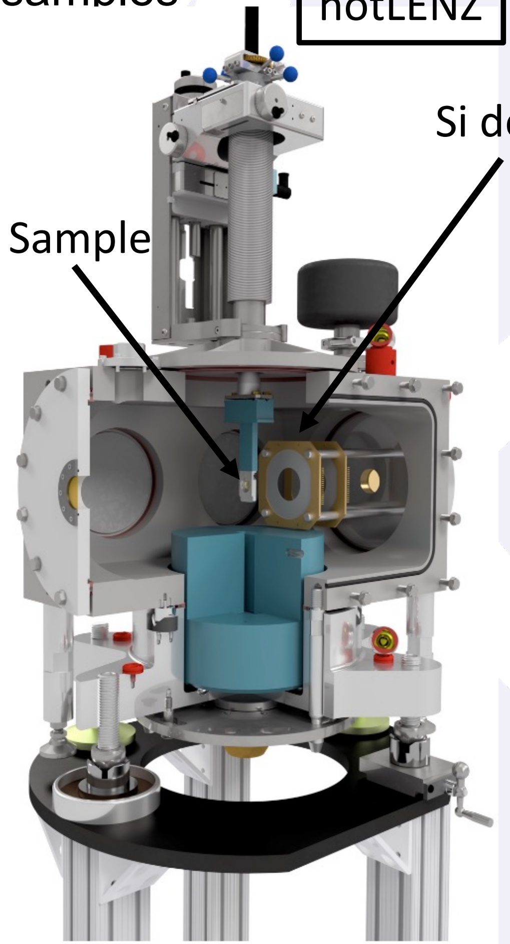




LENZ: Low Energy (n,z) instrument

- **L**ow **E**nergy **N**eutron-induced charged particle (**Z**)
- Annular Double-sided Silicon Strip detectors close to the sample
- Coverage angle: 45°-65° and 15°-30°
- Hot-LENZ for radioactive samples





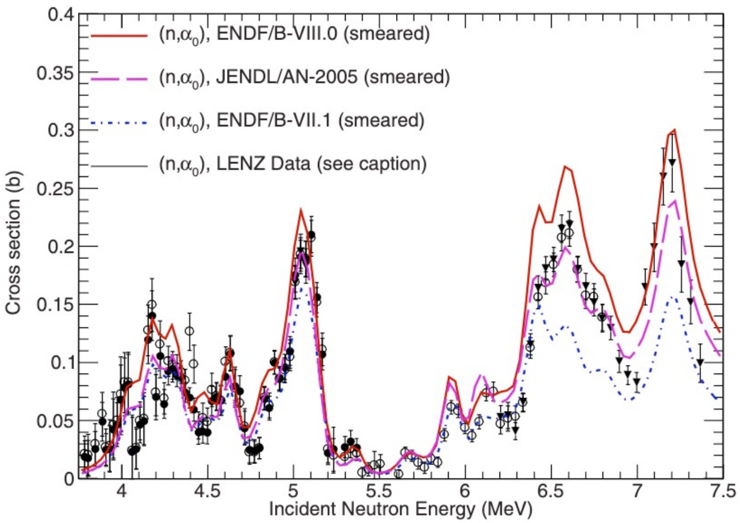
S. Kuvin et al., Phys. Rev. C 105 (4), 044608 2022
H-Y Lee et al., Phys. Rev. C 109 (1), 014601 2024
S. Kuvin et al., Phys. Rev. C 102 (2), 024623 2020

Contacts

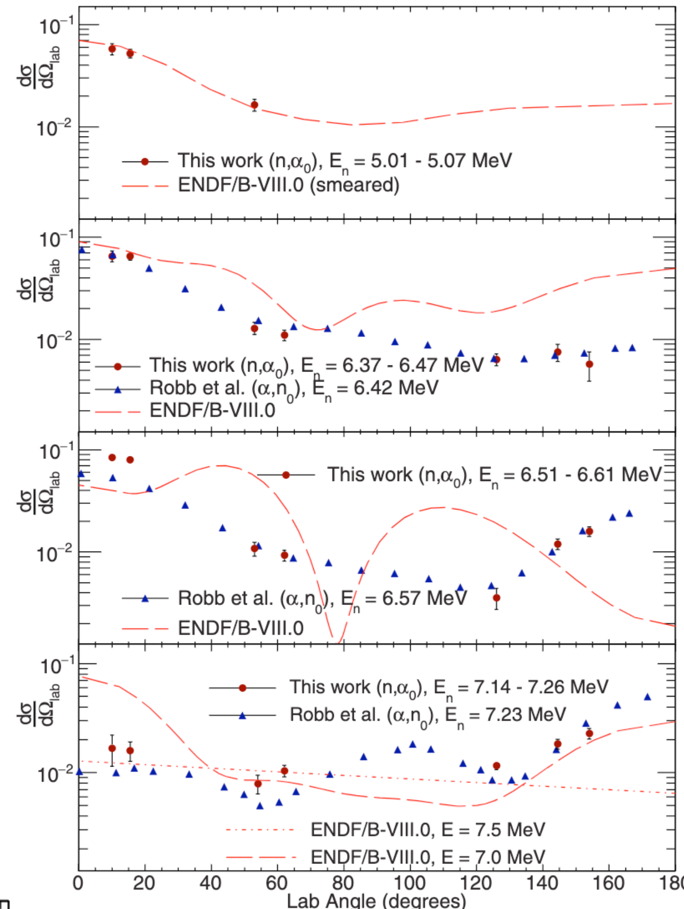
Sean Kuvin : kuvin@lanl.gov
Hye-Young Lee: hylee@lanl.gov

LENZ: Highlights

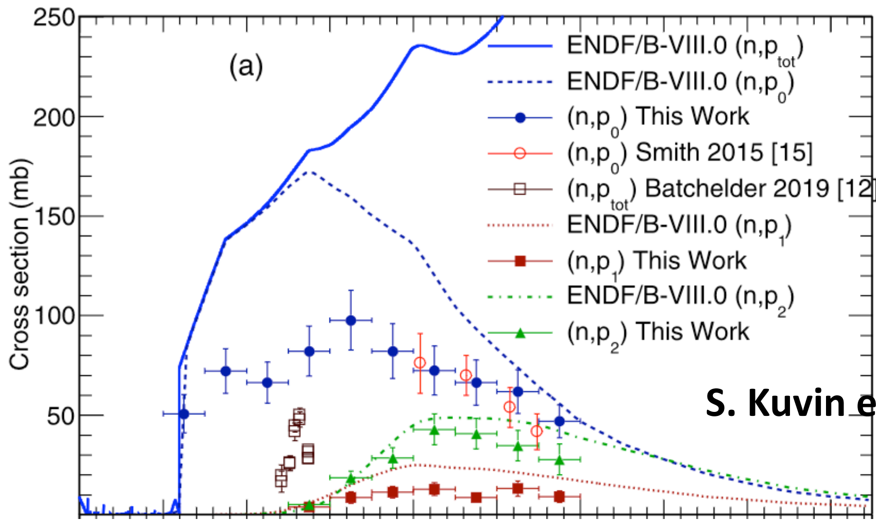
- $^{16}O(n,\alpha)$: cross section and angular distributions



H-Y Lee et al., Phys. Rev. C 109 (1), 014601 2024



- 35Cl(n,p)



S. Kuvin et al., Phys. Rev. C 102 (2), 024623 2020

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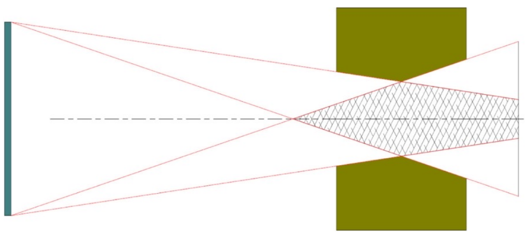
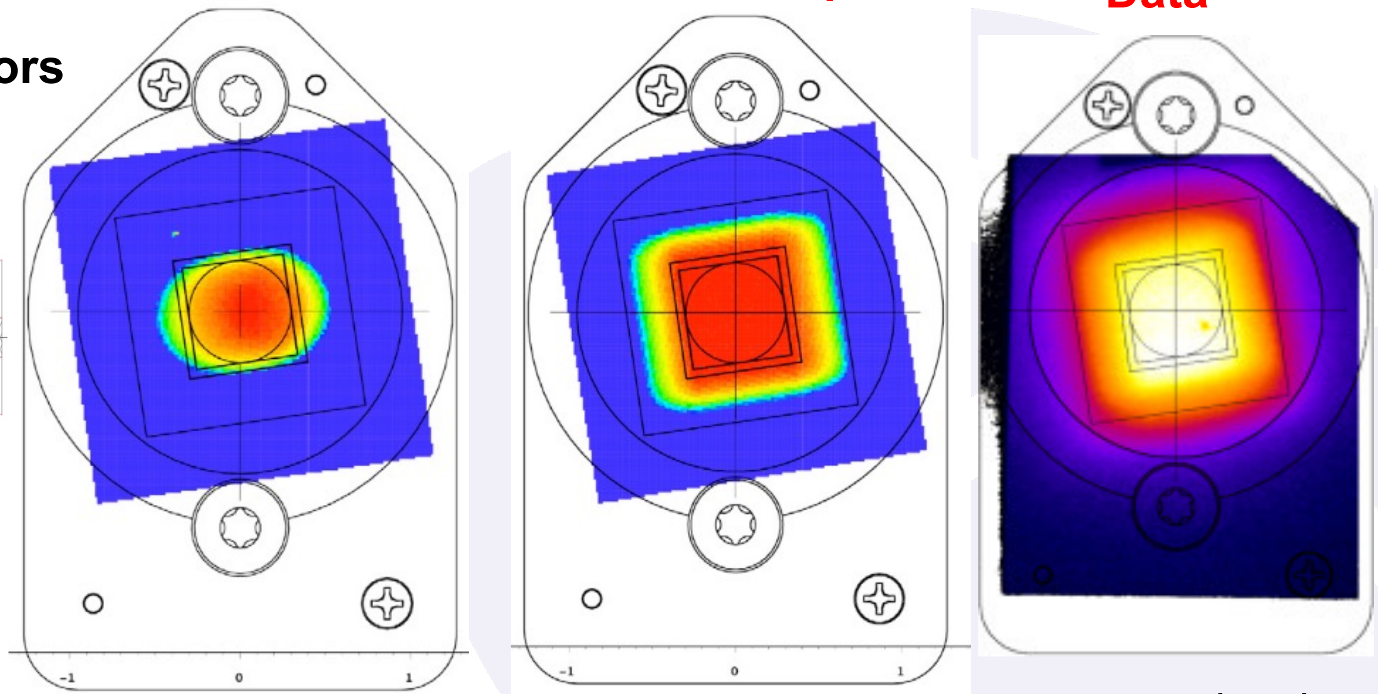
LENZ: MCNP-related work

- **Designing collimators**

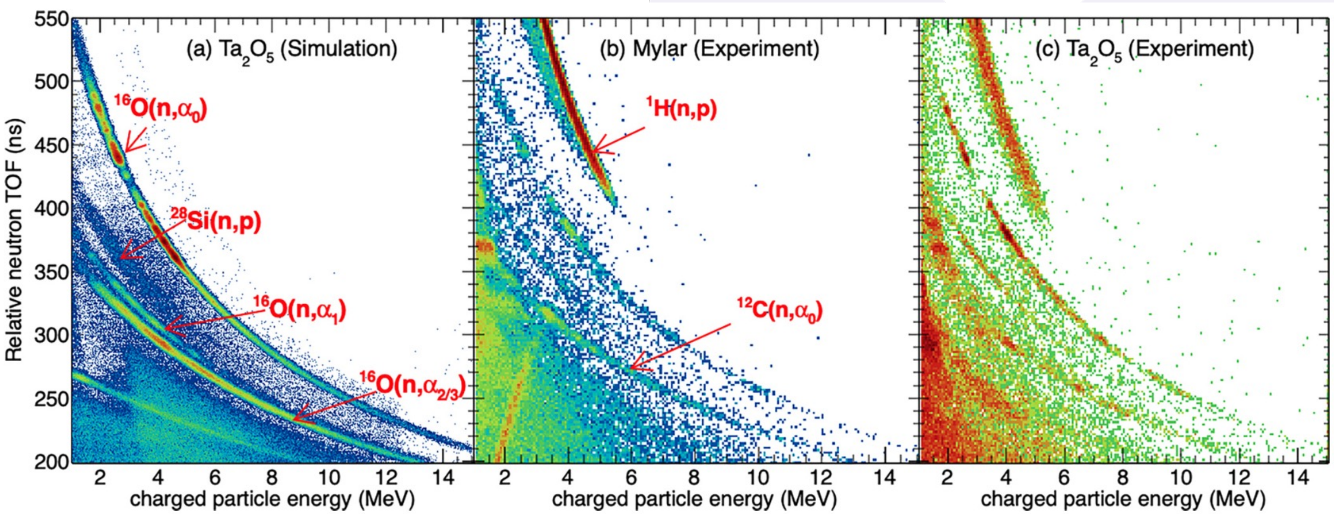


Old beam spot **New beam spot** **Data**



B. DiGiovine et al., NIMA 1013, 165631 (2021)

- **Estimating experimental spectra**



NTD: Neutron Target Demonstrator
(n,γ) in inverse kinematics

Data for the weapons physics and radiochemical diagnostics communities on daughter nuclei from fission neutron reactions:

- Higher fission neutron energies: (n,2n), (n,Z)
- Lower fission neutron energies: (n,g)

NGC 6888: The Crescent Nebula

Contacts: Andrew Cooper, alcooper@lanl.gov
Shea Mosby, smosby@lanl.gov
Aaron Couture, acouture@lanl.gov
Rene Reifarth, rreifarth@lanl.gov

Heavy-element nucleosynthesis:

- s-process (10^8-10^{11} n/cm^3, $t_{1/2} \sim$ yrs-days)
- i-process (10^{12}-10^{15} n/cm^3, $t_{1/2} \sim$ hrs-sec)
- r-process (10^{20}-10^{22} n/cm^3, $t_{1/2} \sim$ subsec)

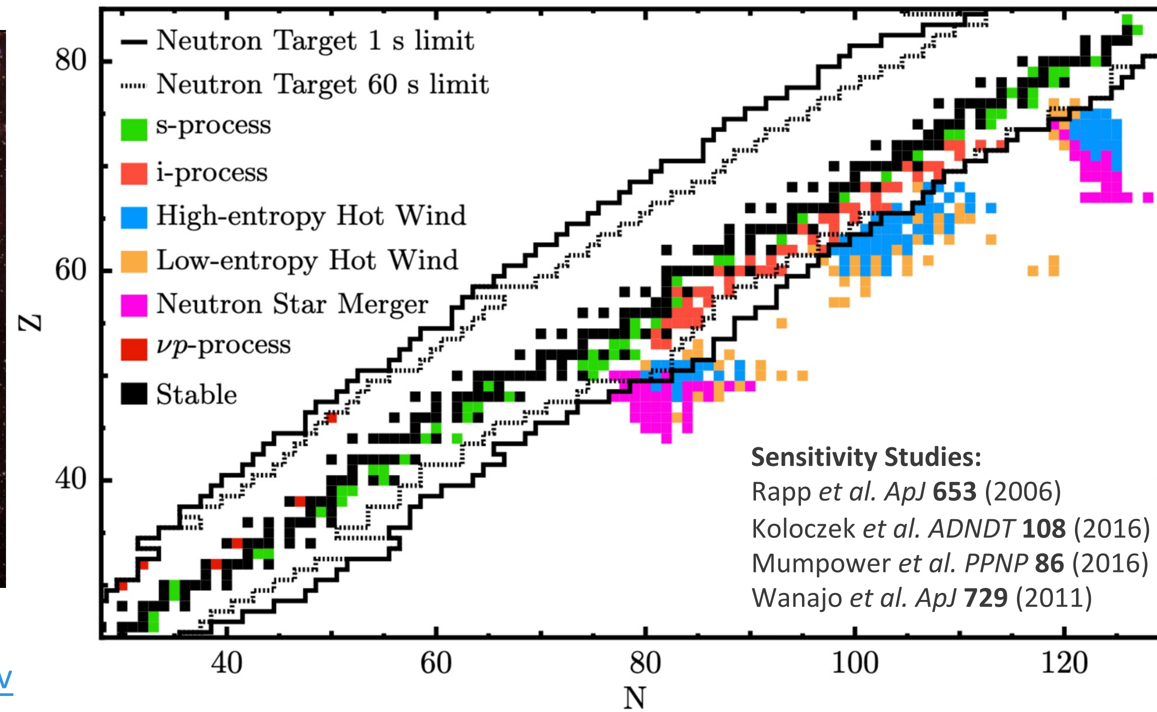
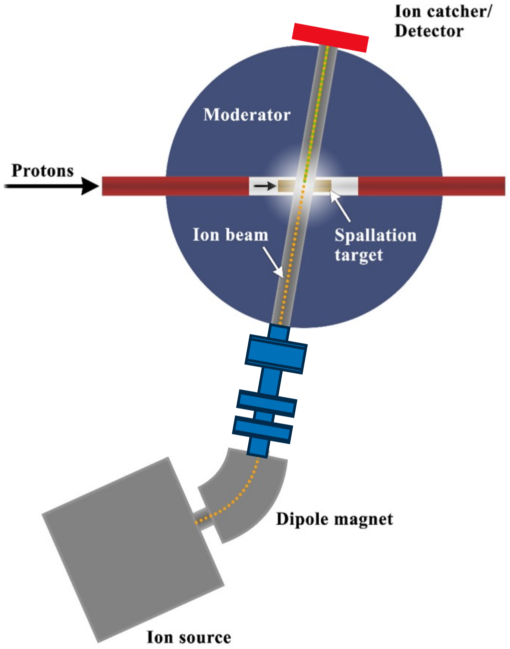


Fig. credit: S. Mosby + A. Couture

The Neutron Target Demonstrator at LANSCE: Overview



Testing and measurement objectives:

- **Tech. mat.** → Validate the neutron target concept and reveal future challenges.
- **n density in moderator** → Validate design and simulation capability.

A single-pass neutron target proof-of-principle experiment at Target 2:

1. **Construct a simple, cost-effective target and moderator, and characterize ion pipe neutron field density with Au samples during operation with LANSCE proton beam.**

2. **Transport heavy ions through the neutron target assembly to induce neutron captures in inverse kinematics using strong, well-known resonances and collect ions for offline analysis.**

3. **Measure the number of transmuted beam ions collected via decay gamma-ray counting setup to obtain the effective neutron density within the moderator.**

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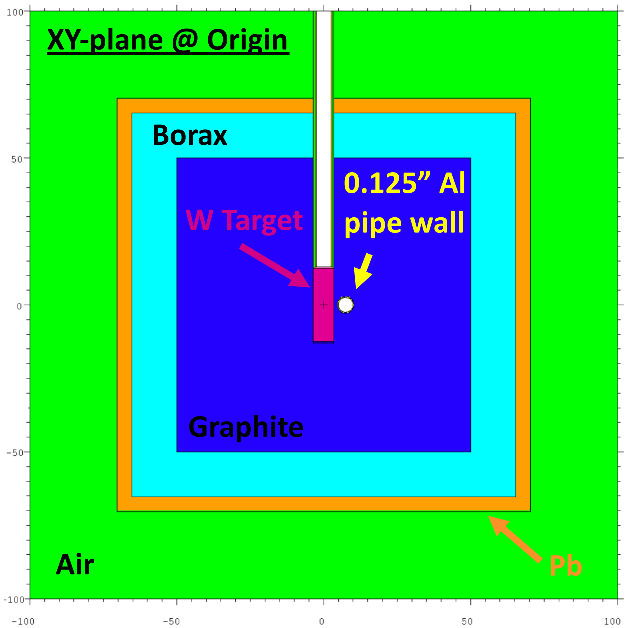
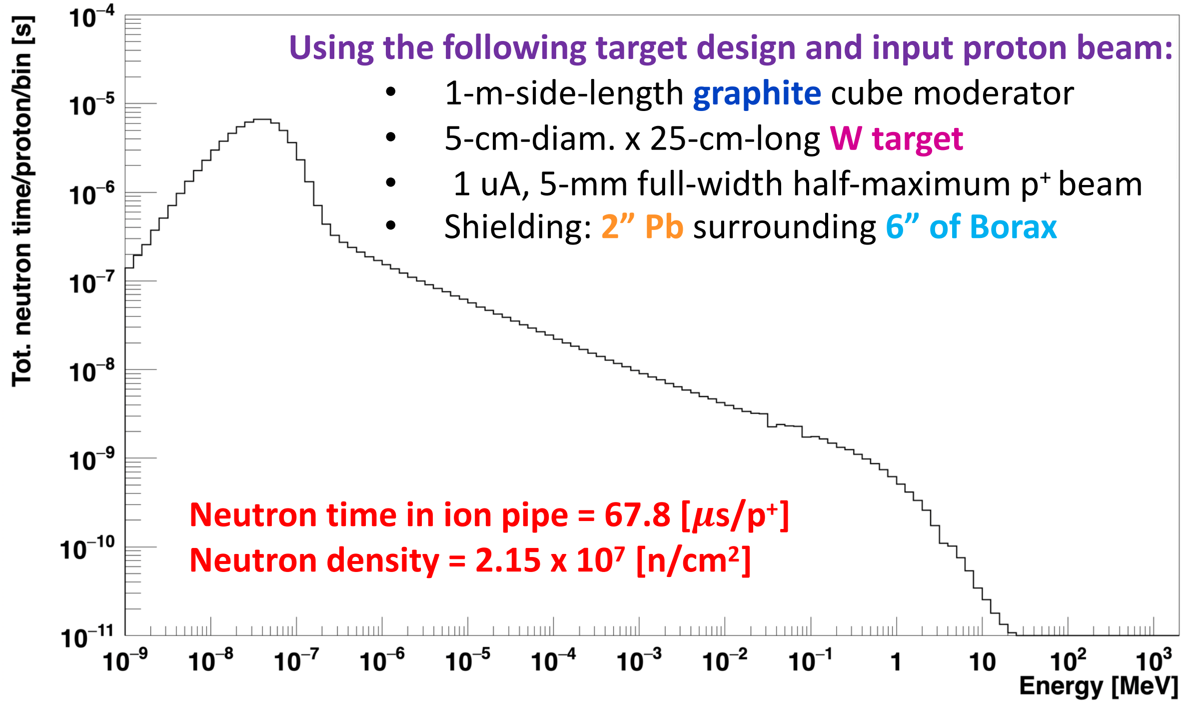
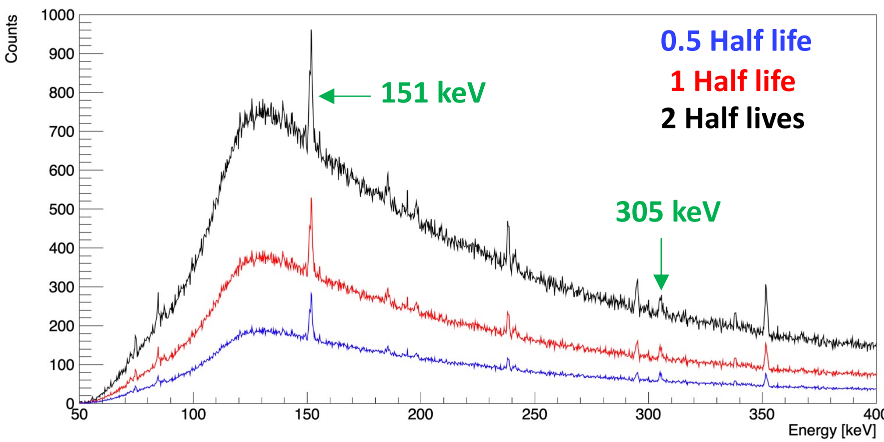
The NTD at LANSCE: MCNP6 and GEANT4 simulations







Counting five, 20 cm² targets after a 0.5-half-life delay

Target 2/Blue Room experiment:

^{84}Kr(n,γ)^{85}Kr measurement using E^{CM}_r = 513 eV, σ_r = 363 b:

- **1 mA of of E^{LAB}_r = 43.2 keV $^{84}Kr^+$** passing through moderator.
- Roughly 80% of reaction products β decay from **$t_{1/2}$ = 4.5 hr, 305-keV isomer state in ^{85m}Kr.**
- **Very simple γ-decay structure.**
- **^{84}Kr has highest isotopic abundance in nat. Kr.**

N = 1.75 x 10⁵ rxns/hr of beam

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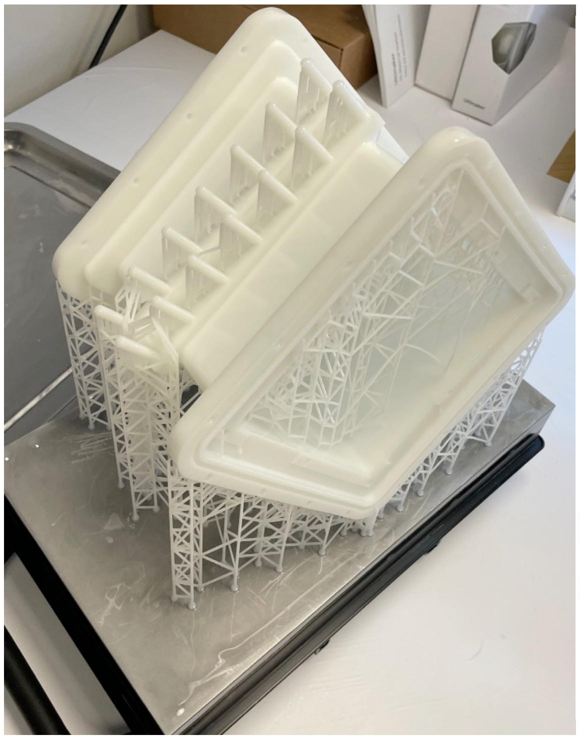
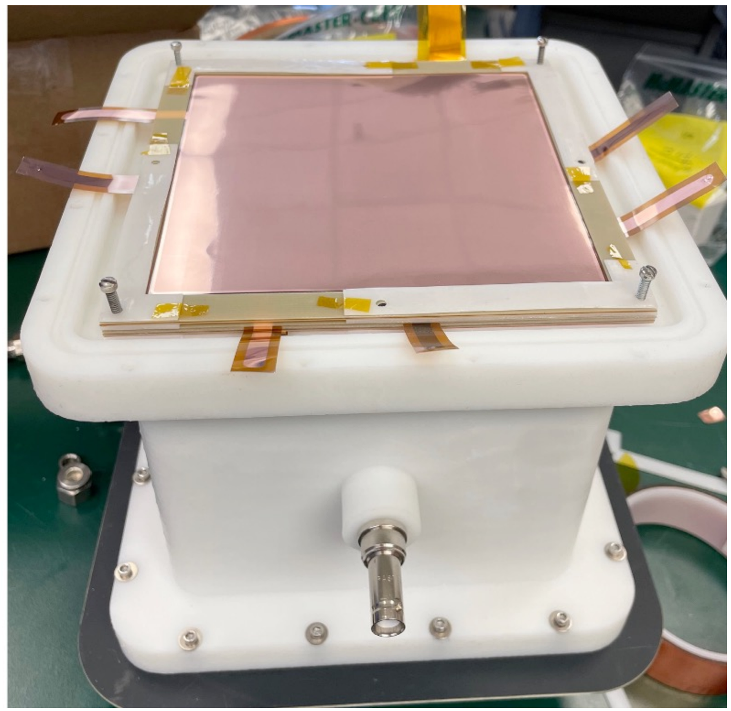
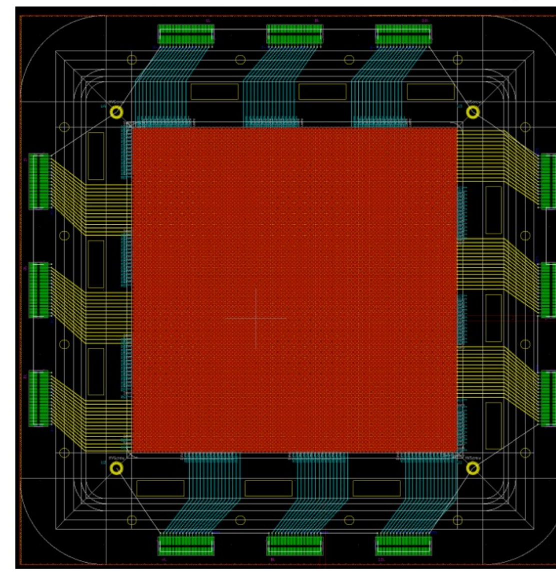
SREFT: Spatially REsolved Fission Tracker (n,f)

- **Gaseous detector based on Gaseous Electron Multipliers (GEM)**
- **High gain robust detectors**
- **Tracking capability**
- **Under development**







Contacts: Chris Prokop, cprokop@lanl.gov

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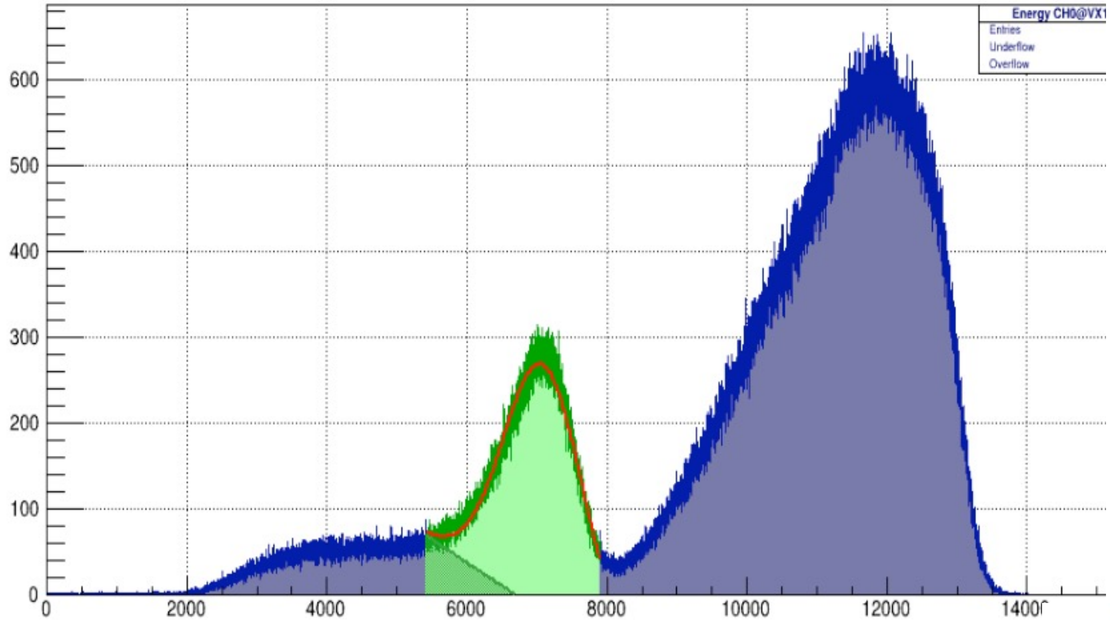
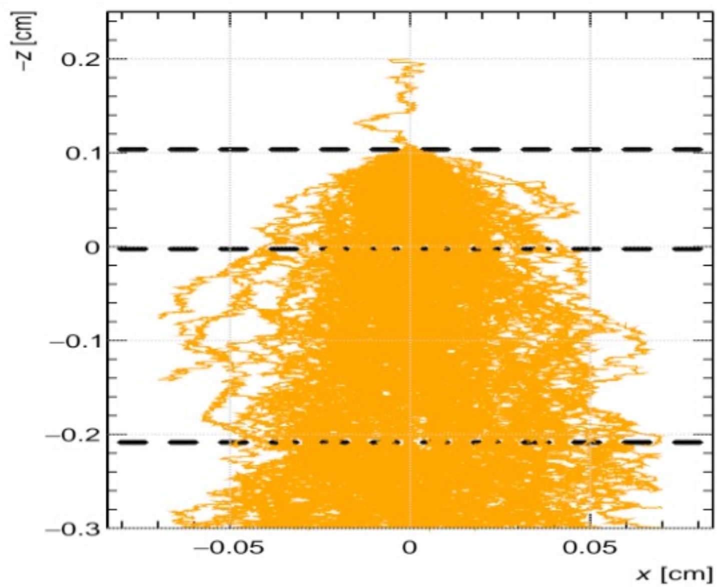
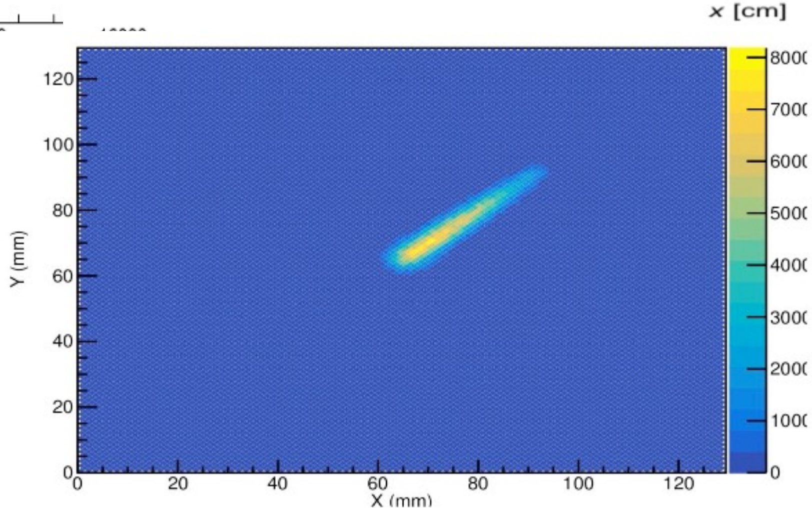
SREFT: Spatially REsolved Fission Tracker (n,f)

- **Test with sources**
- **Will see beam in the next months**







Contacts: Chris Prokop, cprokop@lanl.gov

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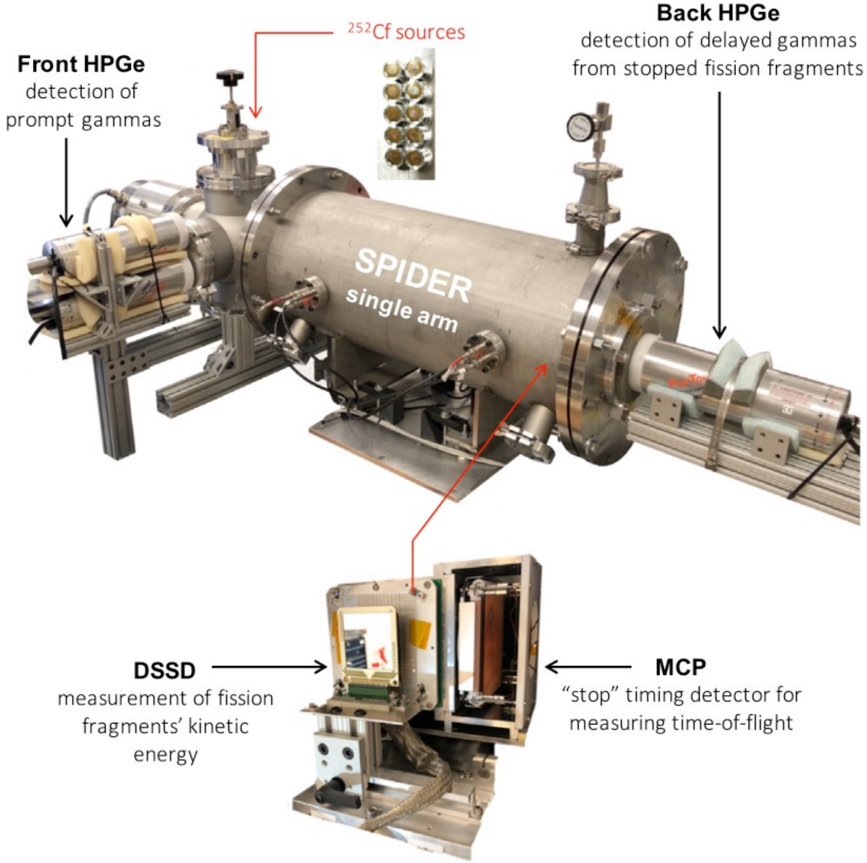
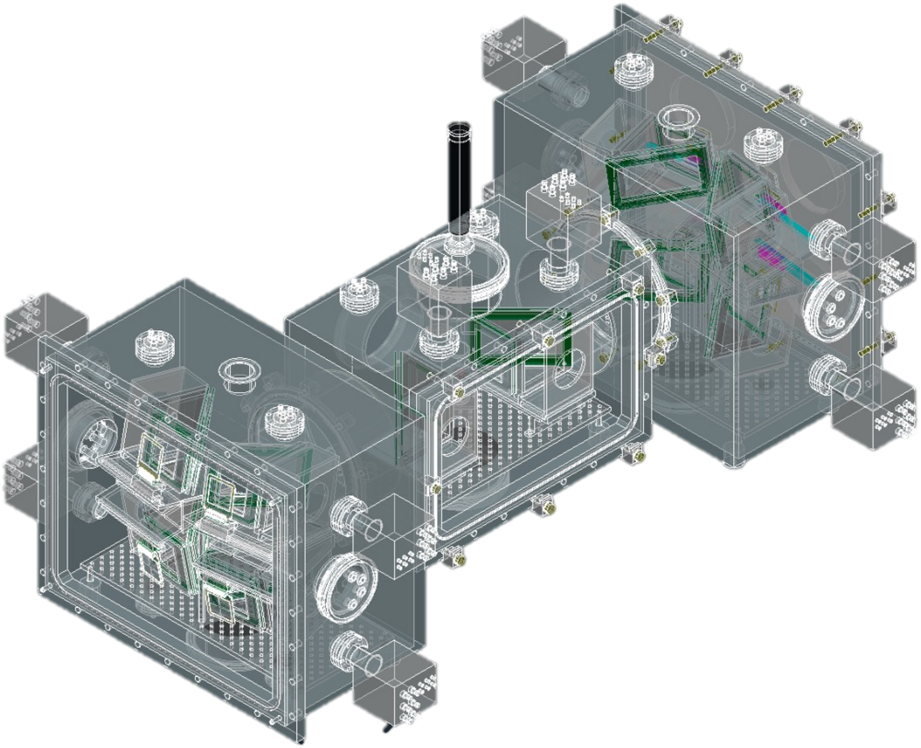
SPIDER: SPectrometer for Ion DEtermination in fission Research , Fission Products

- **Multi-arm detector**
- **Detects fission products using the 2E-2v technique**



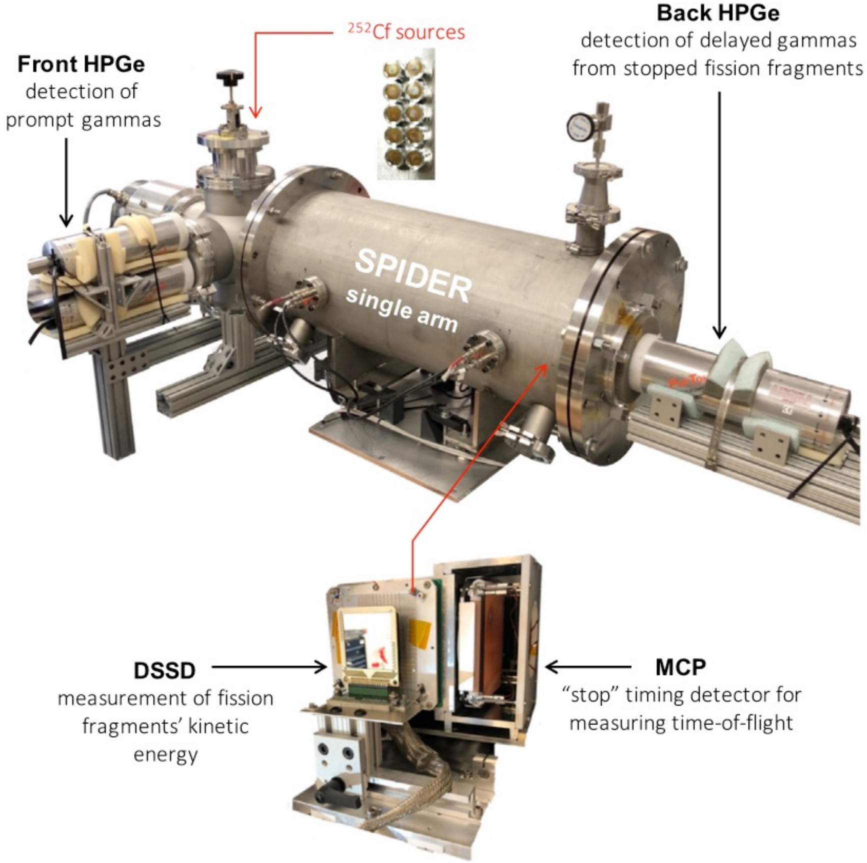


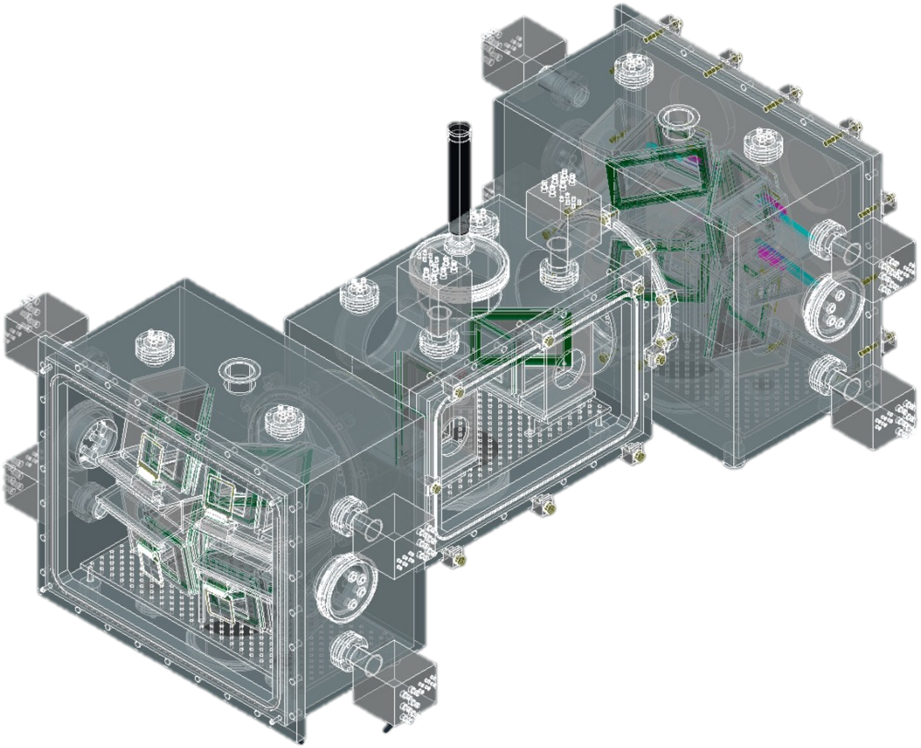
Contacts: Jack Winkelbauer, winkelba@lanl.gov

P. Gastis et al., NIMA 1037 (2022) 166853

SPIDER: SPectrometer for Ion DEtermination in fission Research , Fission Products

- **Multi-arm detector**
- **Detects fission products using the 2E-2v technique**



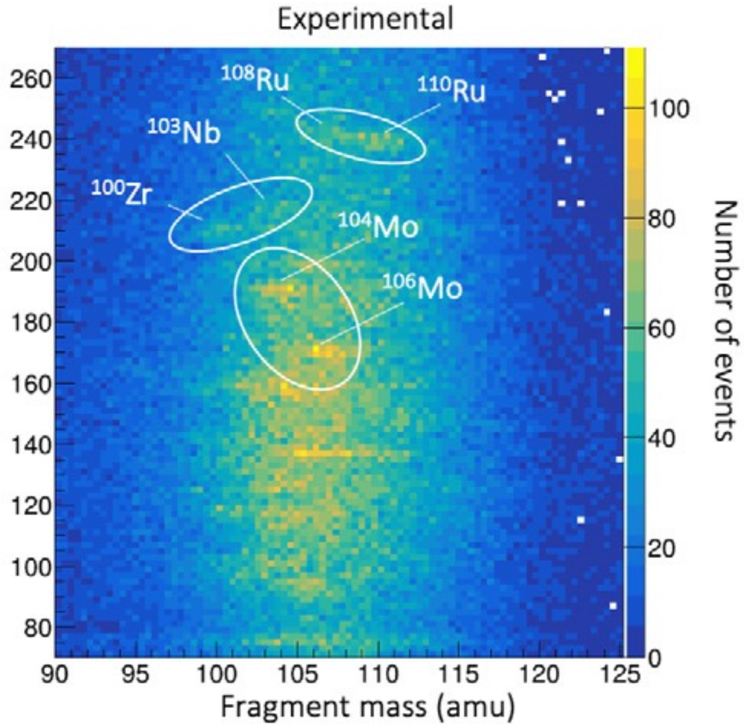


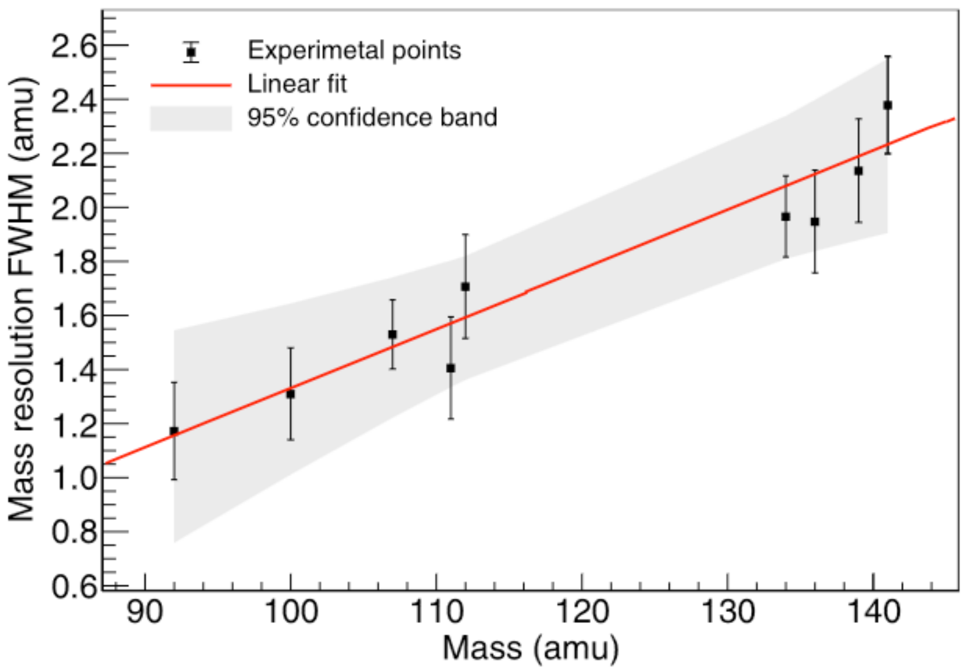
Contacts: Jack Winkelbauer, winkelba@lanl.gov

P. Gastis et al., NIMA 1037 (2022) 166853

SPIDER: SPectrometer for Ion DEtermination in fission Research , Fission Products

- **Successful in-beam observation of fission fragments**
- **Great mass resolution**
- **Development of more arms**





P. Gastis et al., NIMA 1037 (2022) 166853

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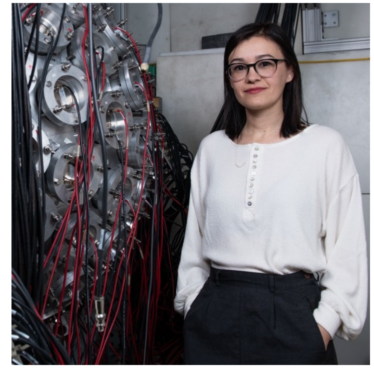
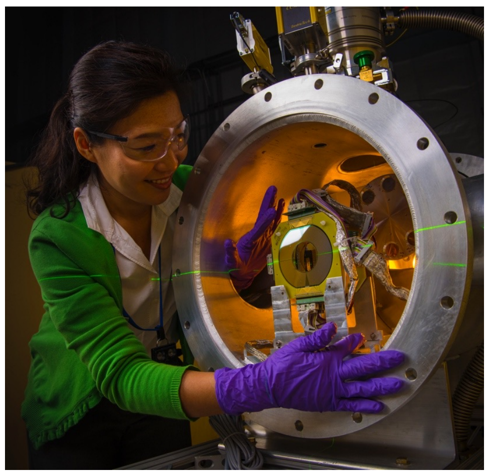
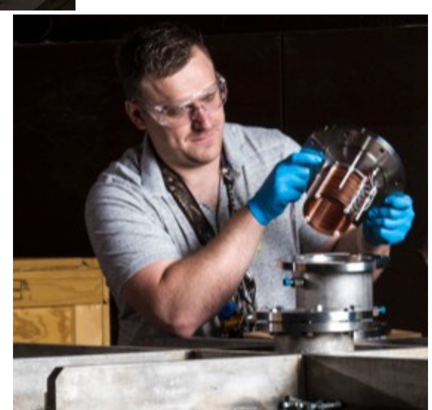
Thank you for your attention!





Can be one of you


Thank you for your attention!

Back-up slides

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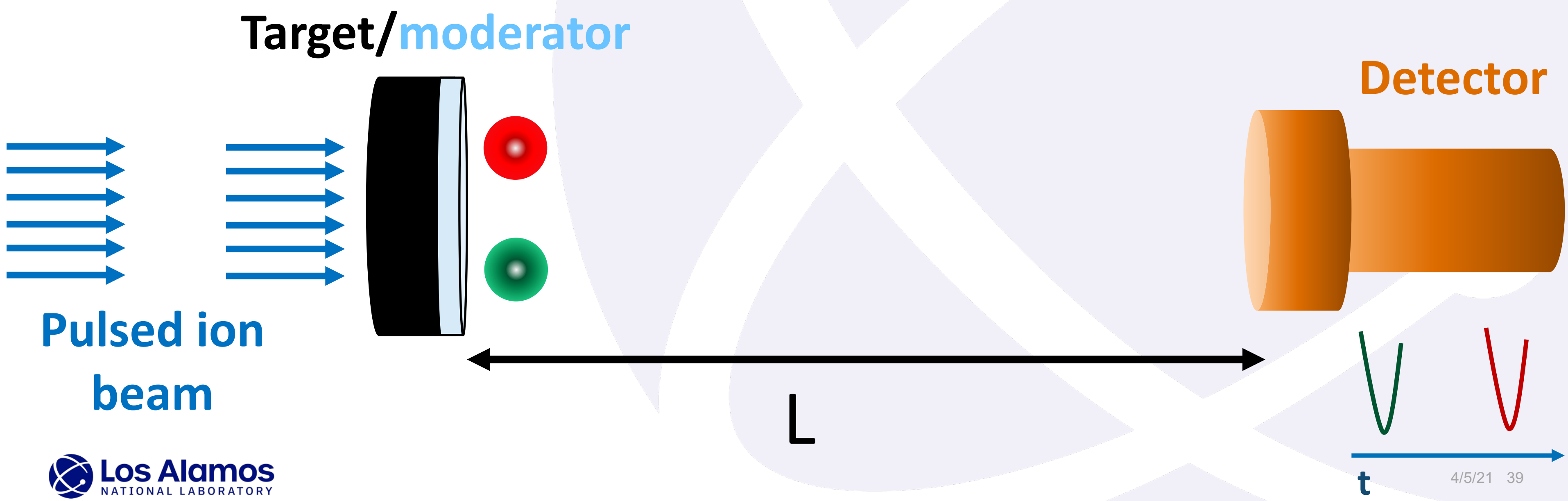
The time of flight (tof) technique

- The neutron velocity *v* is related to its energy *E*

$$E = \frac{1}{2} m\, v^2 = \frac{m}{2}\left(\frac{L}{t}\right)^2 \cong \left(72.3\,\frac{L[m]}{t[\mu s]}\right)^2$$

- **Fast** neutrons need less time than **slow** ones, to travel a given distance *L*

- Measuring the travel time or **time of flight** *t*, we reconstruct the incident energy *E*



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