Nuclear Science and Security Consortium
Virtual Scholar Showcase 2020

Indirect Neutron-Capture Constraints for Basic Research and Applications

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NUCLEAR SCIENCE and SECURITY CONSORTIUM

Introduction

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Academic Advisor:
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National Superconducting Cyclotron Laboratory
Department of Chemistry

Laboratory Mentor:
Dr. Aaron Couture
(P-27: Nuclear Astrophysics and Structure)

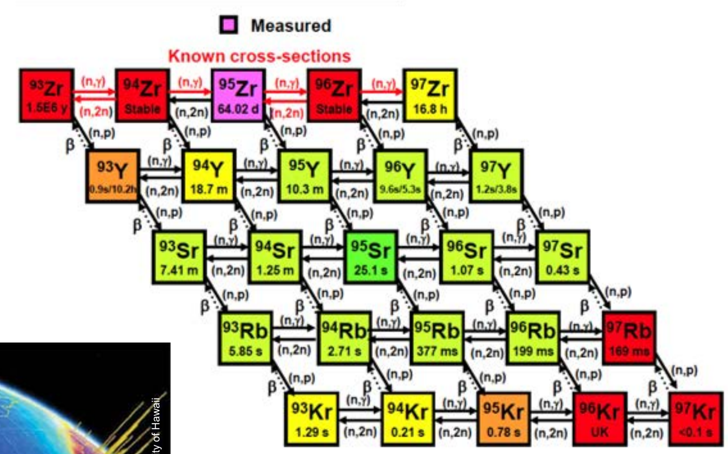
Indirect neutron-capture constraints on short-lived nuclei for basic research and applications

Focus Area: Nuclear & Particle Physics

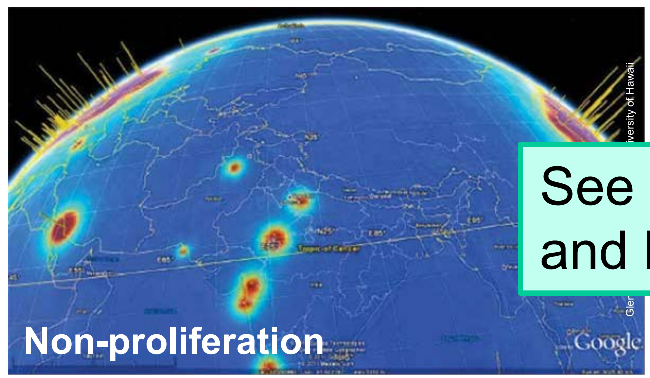
Crosscutting Areas: Radiation Detection & Instrumentation/ Nuclear Data

Relevance to the NNSA Mission

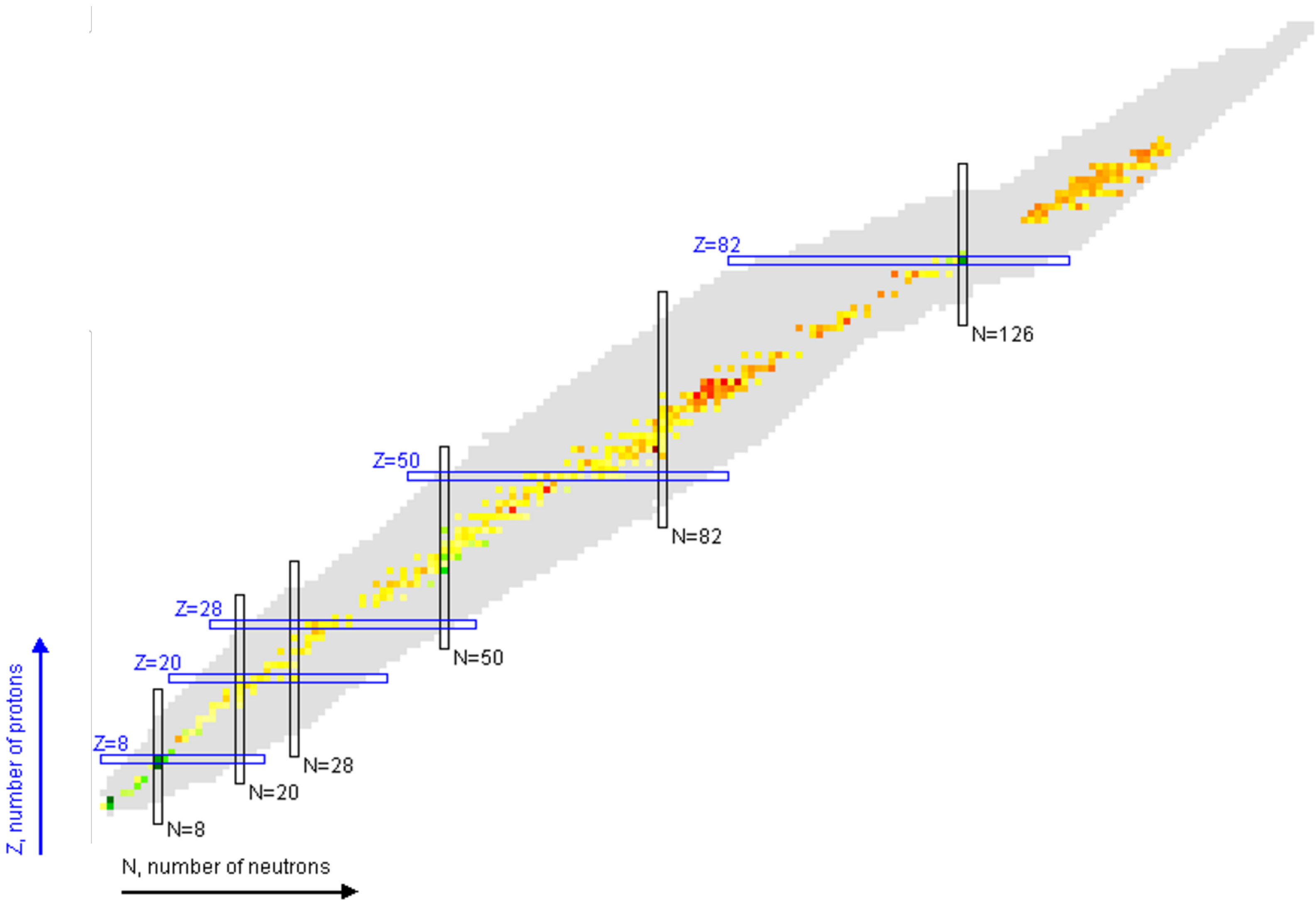
- ✓ Reaction networks
- ✓ Nuclear Energy
- ✓ Basic Nuclear Science
- ✓ Astrophysics



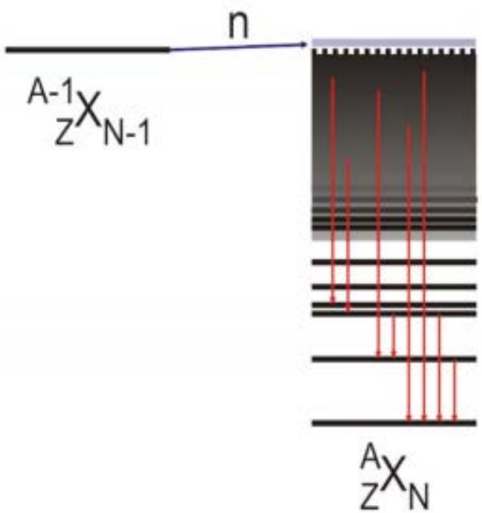
See talks by Adriana Sweet and Katherine Childers!



Constraining (n,γ) rates on short-lived nuclei

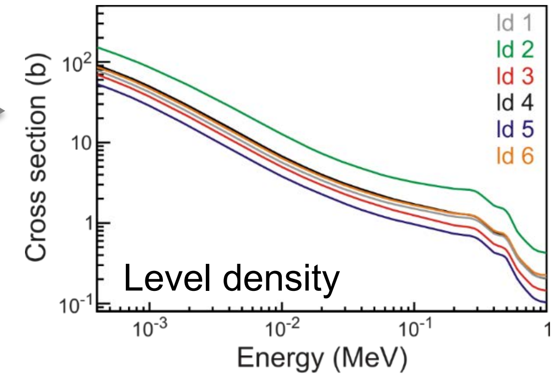


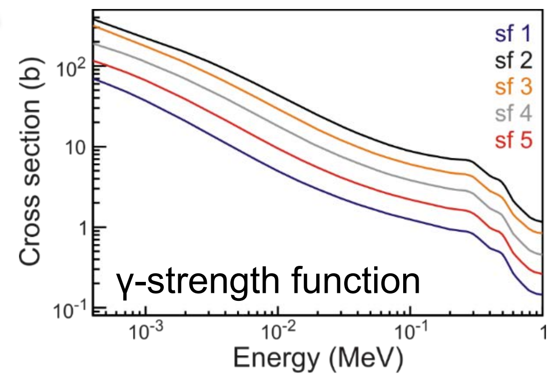
Nuclear level densities and γ-ray strength functions dominate uncertainties in (n,γ) calculations

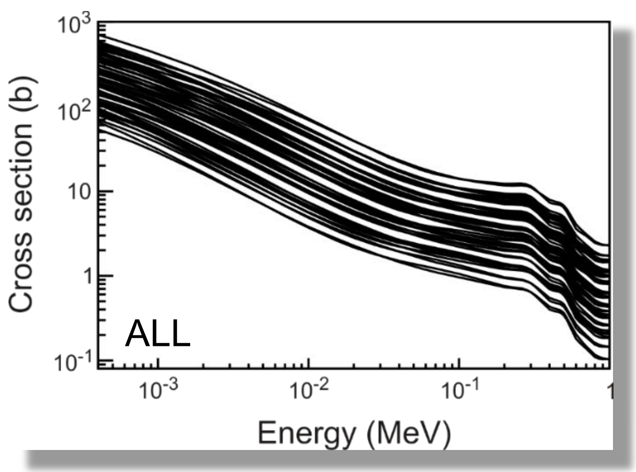


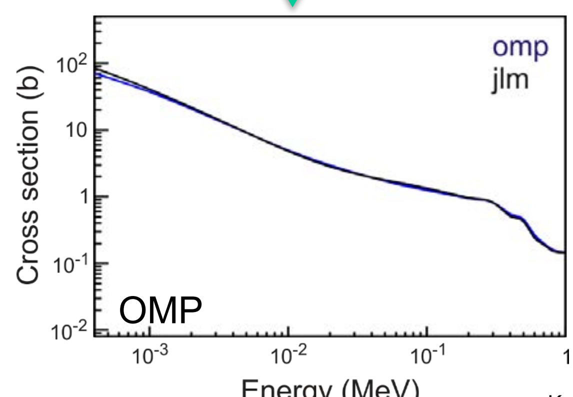
Hauser – Feshbach

- Nuclear Level Density
  Constant T + Fermi gas, back-shifted Fermi gas, super-fluid, microscopic
- γ-ray strength function
  Generalized Lorentzian, Brink-Axel, various tables
- Optical model potential
  Phenomenological, Semi-microscopic







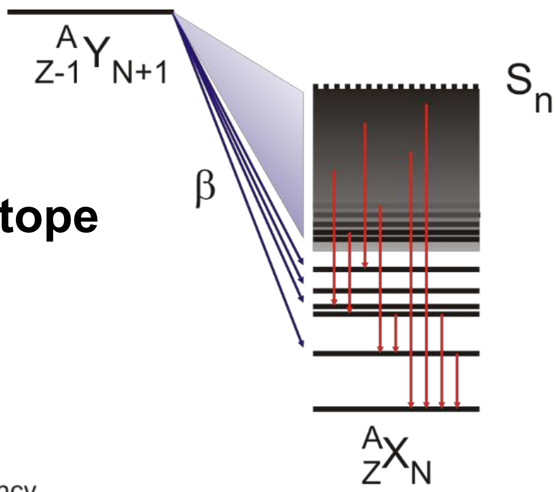


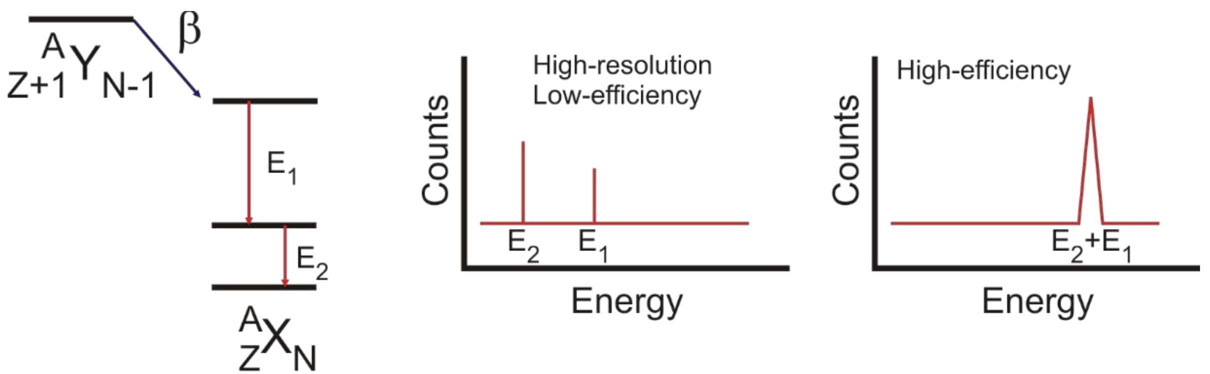
$^{95}Sr(n,\gamma)^{96}Sr$

Koning and Rochman, Nucl. Data Sheets **113**, 2841 (2012)
Hauser and Feshbach, Phys. Rev. **87**, 366 (1952)

Using β-decay total absorption spectroscopy to infer neutron capture cross sections

- **Measure β-decay of nucleus**
  - Extract level densities and γ-ray strength function
- **Need total excitation energy of the daughter isotope**
  - Cannot use β-decay electron
  - Measure total emitted photon energy instead!

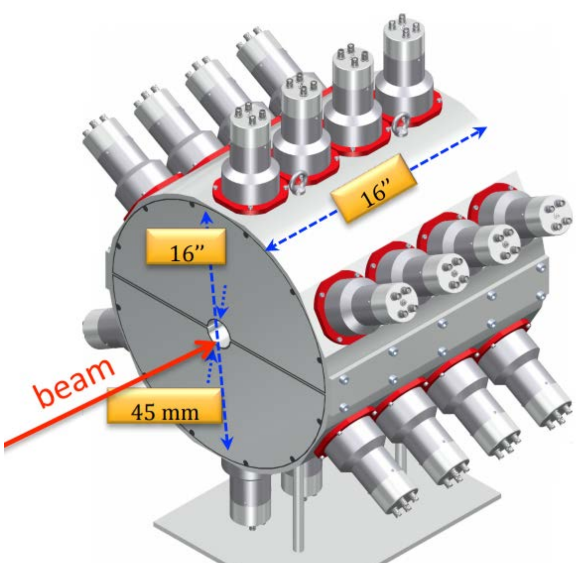


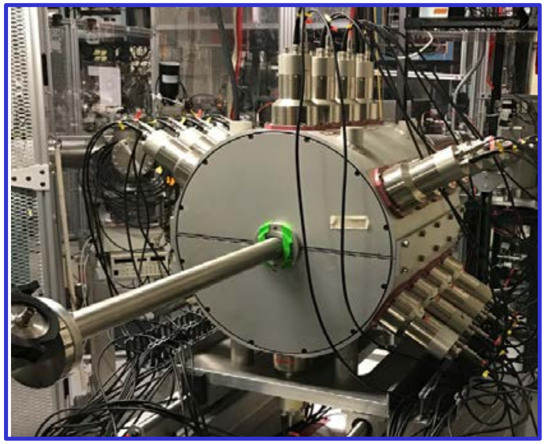


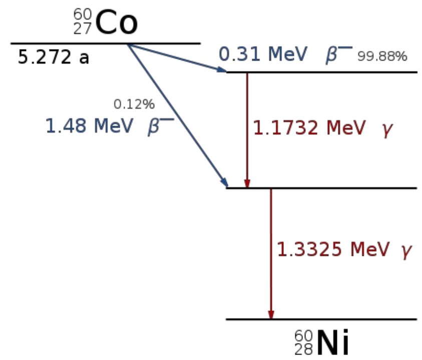
- **Technique requires a high detection efficiency**
  - Extract nuclear level density and γ-ray strength function
  - Insert both quantities into a statistical reaction model to constrain (n,γ) rates

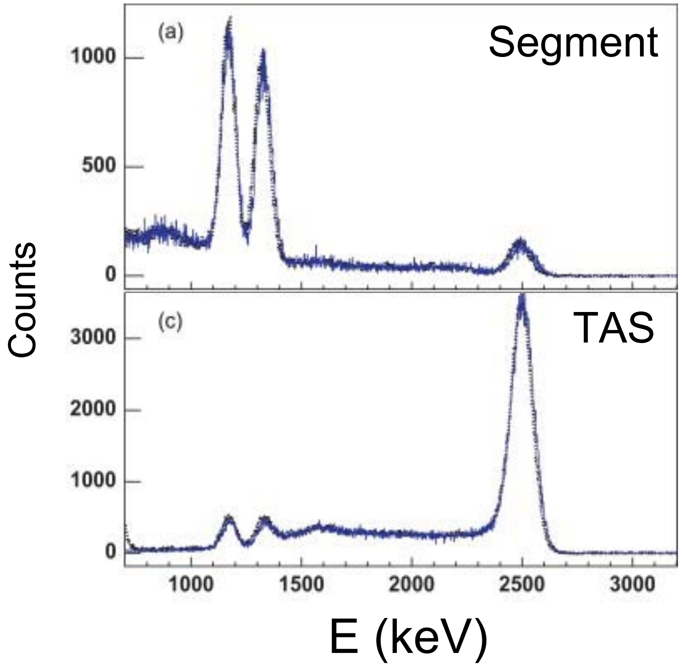
Total absorption spectroscopy with the Summing NaI (SuN) detector

- Large size, high efficiency γ-ray detector
- Summing of all γ-rays gives the excitation energy
- Segmentation provides information about individual γ-rays
- Resolution at 1 MeV – 6%
- Efficiency at 1 MeV – 85%





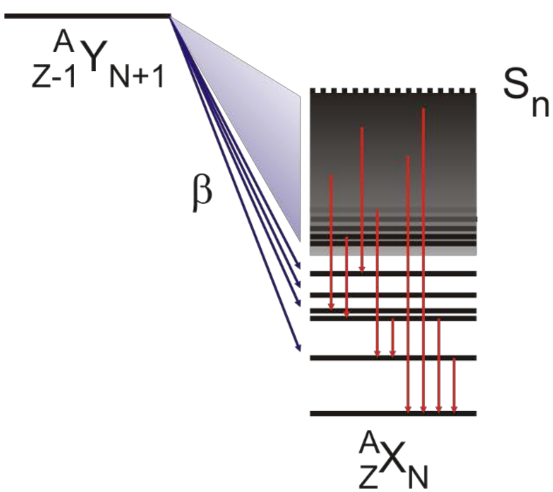


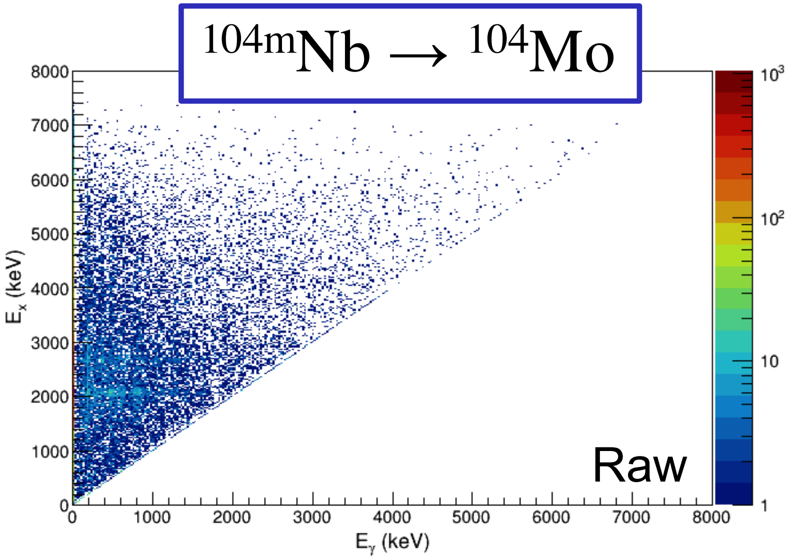


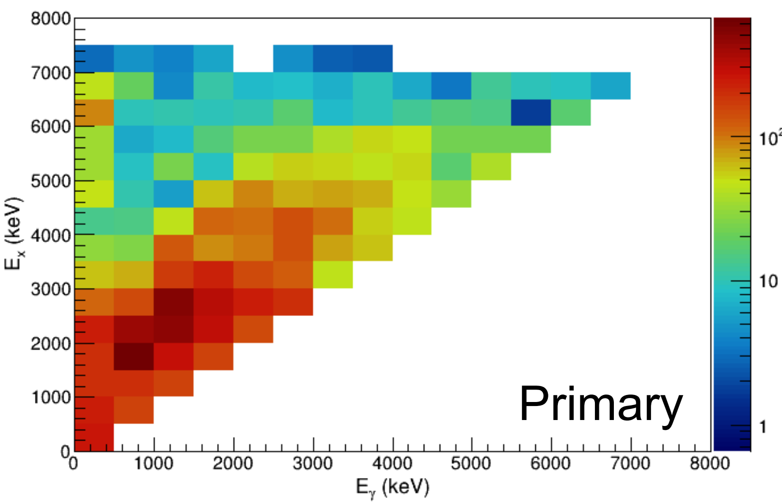
Simon, A., et al. *NIM A* 703 (2013): 16-21

The β-Oslo method for inferring neutron-capture rates

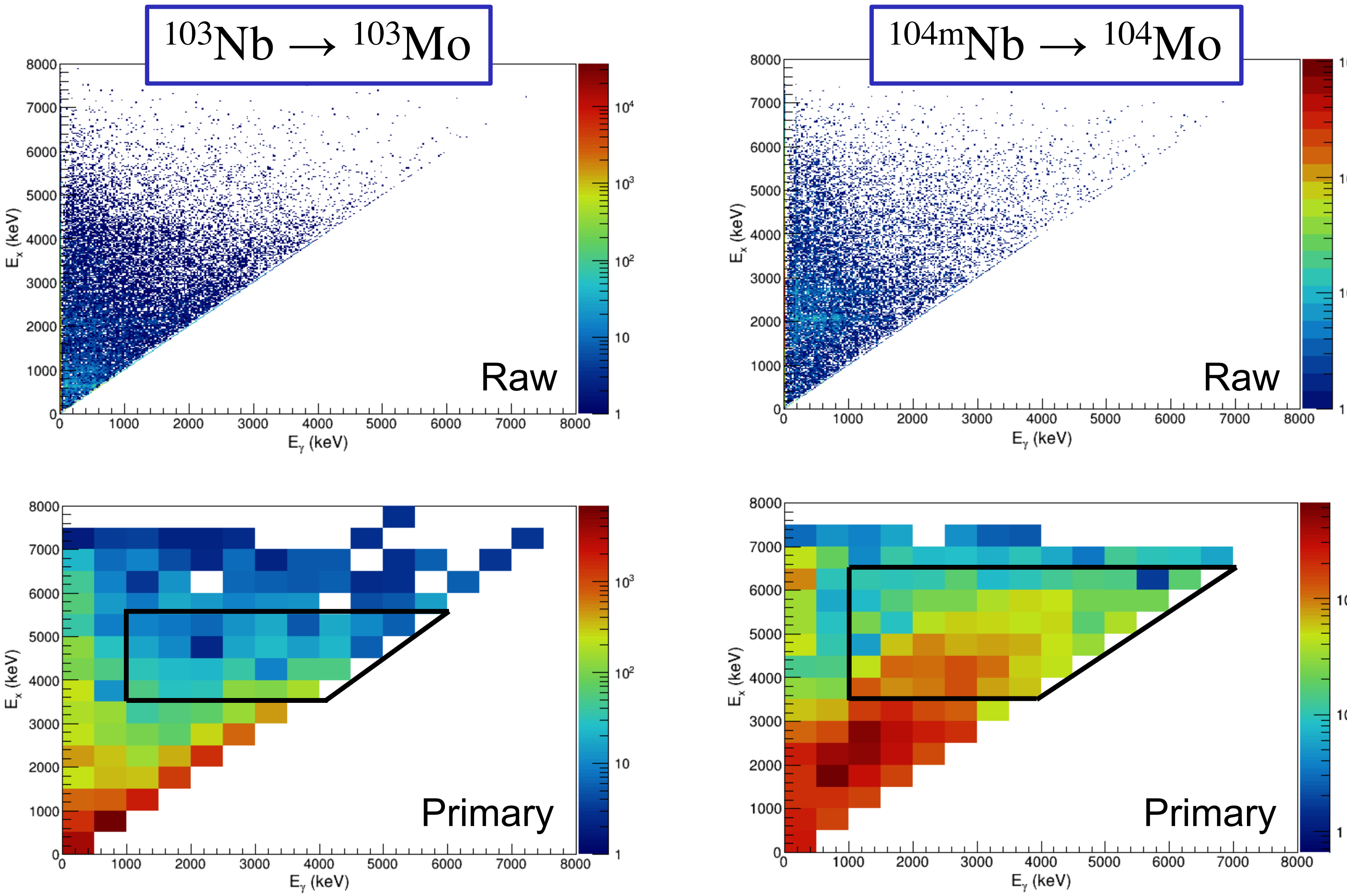
- **Extract the first generation γ-ray in the cascade from the experimental spectrum**
- **Use primary γ-rays to extract nuclear level density and γ-ray strength function using the Oslo Method**
- **Three normalization points:**
  - Low-energy level density
  - Level density at S_n
  - Average radiative width at S_n





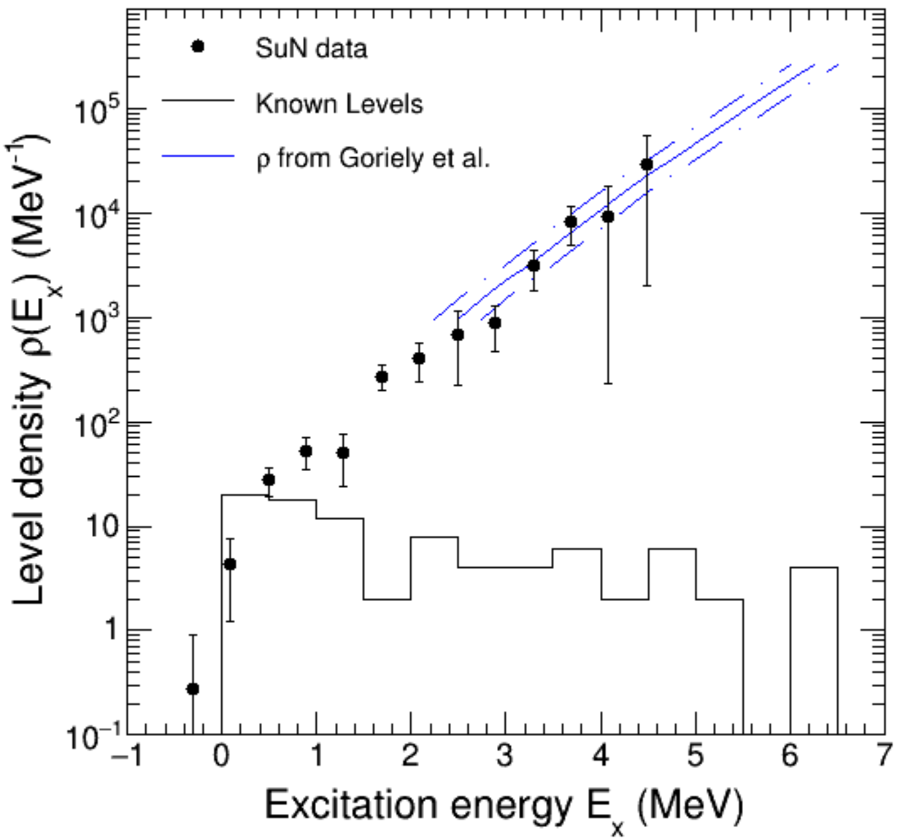


Primary γ-rays are extracted from the raw matrices to obtain the observables needed for (n,γ) calculations

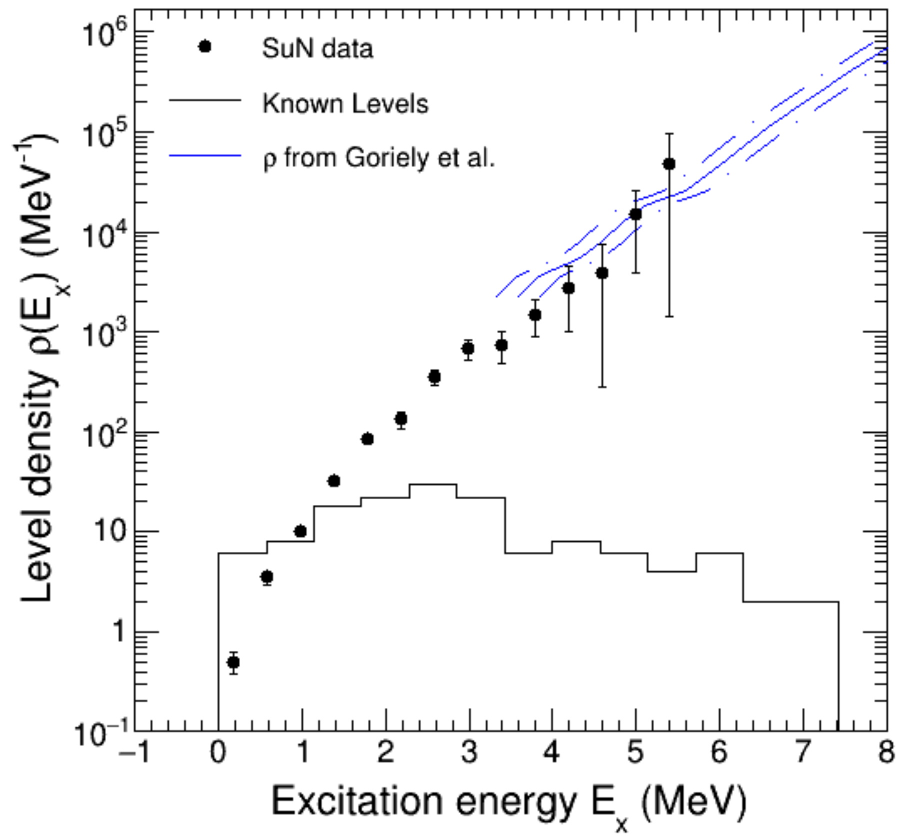


Nuclear level densities for ^{103,104}Mo are extracted and normalized

^{103}Mo

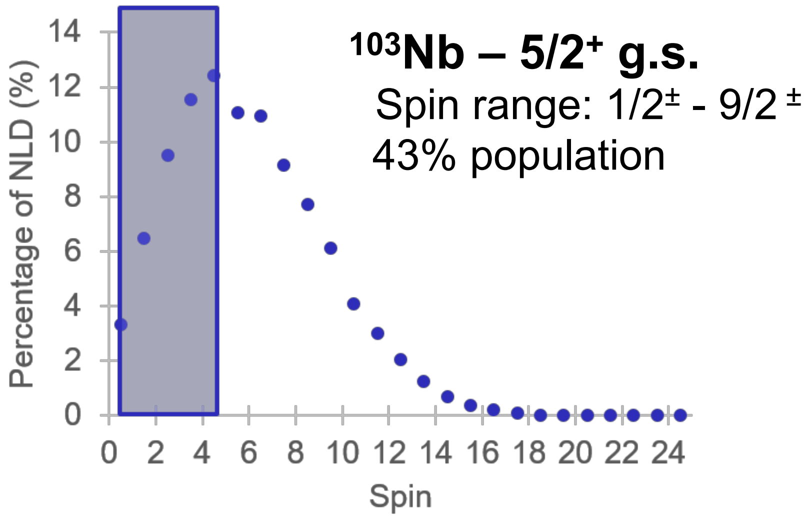


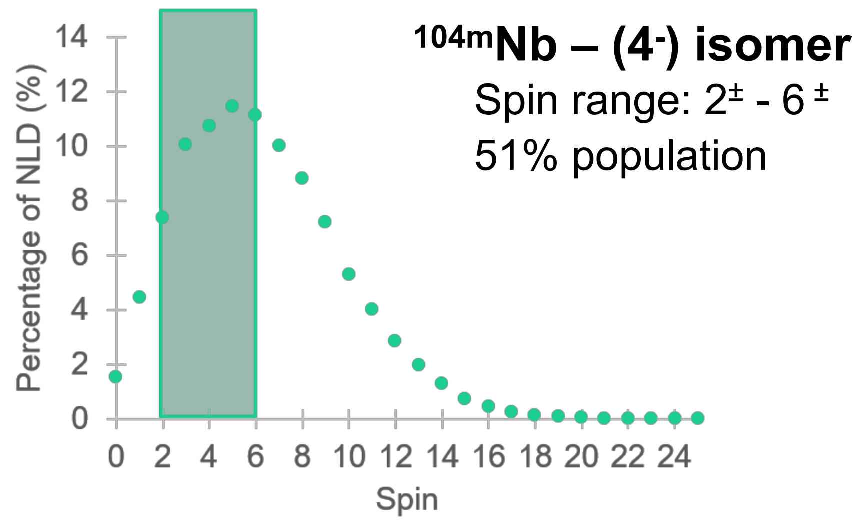
^{104}Mo

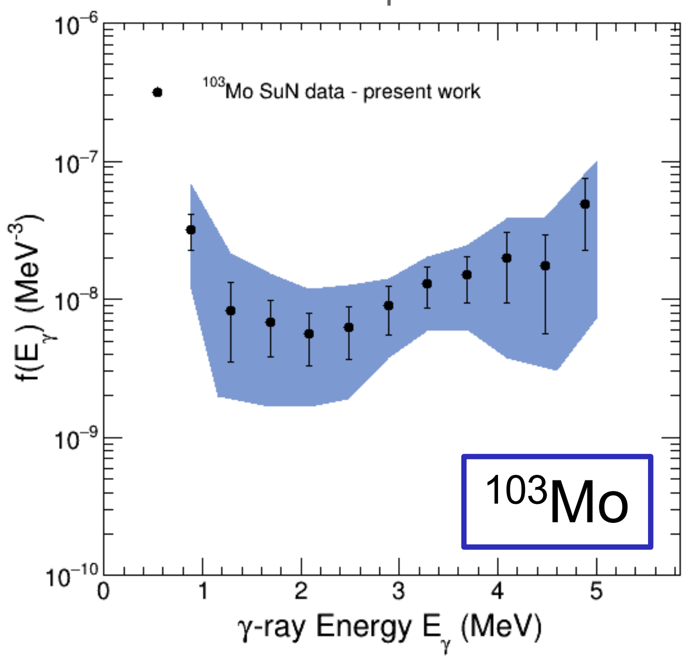


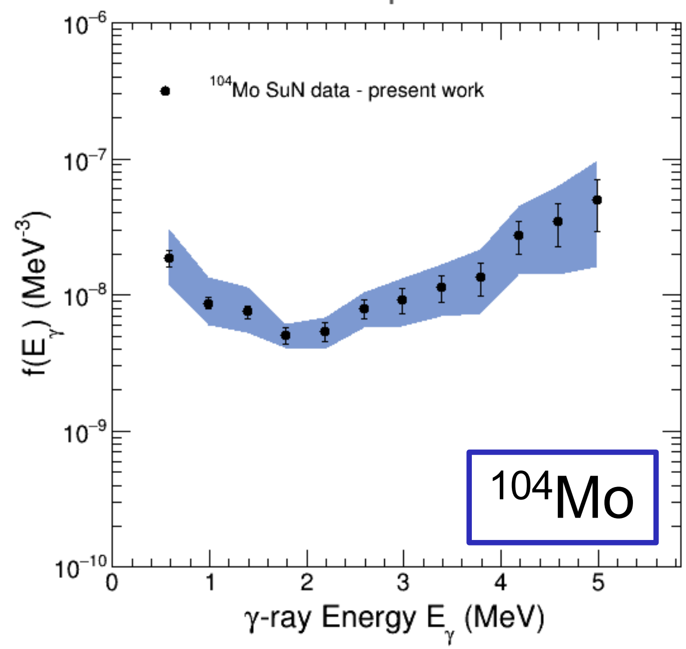
Goriely, Hilaire, and Koning, PRC **78**, 064307 (2008)

The γ-ray strength functions are extracted and normalized using β-decay selection rules

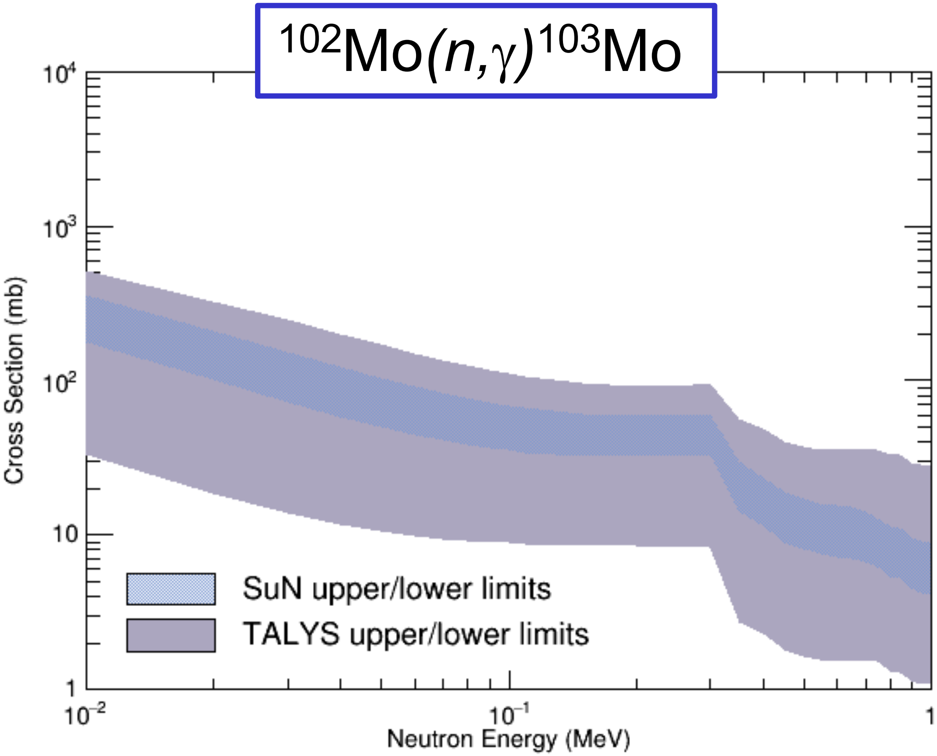


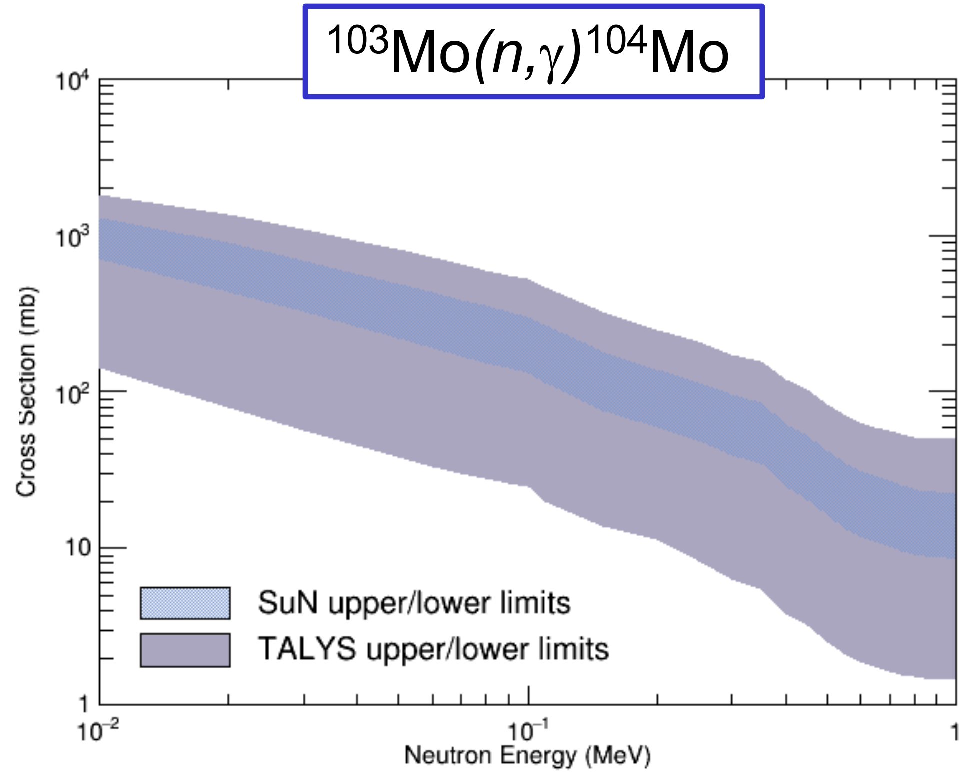






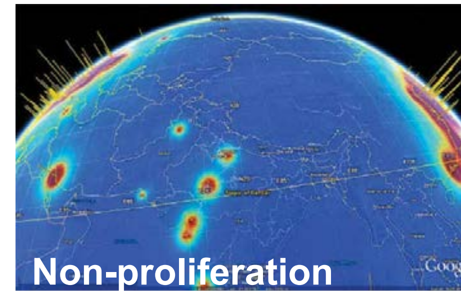
Experimentally constrained cross sections for $^{102}Mo(n,\gamma)^{103}Mo$ and $^{103}Mo(n,\gamma)^{104}Mo$

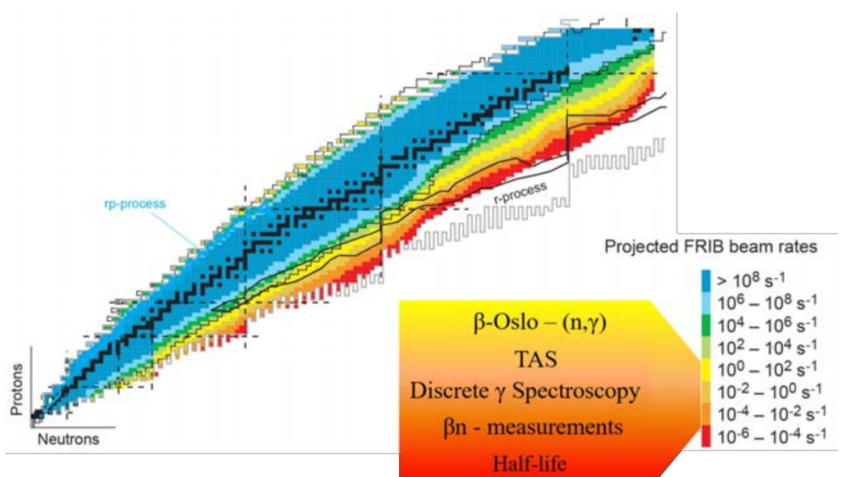




Summary and Outlook

- Neutron-capture cross sections are important for basic science and applications
- Indirect techniques are required to constrain neutron-capture for short-lived nuclei
- Neutron-capture cross section calculations for ^{102}Mo(n,γ)^{103}Mo and ^{103}Mo(n,γ)^{104}Mo are complete
- Expanded experimental reach with upcoming Facility for Rare Isotope Beams (FRIB)





Collaborators

S. N. Liddick, A. Spyrou, T. Baumann, K. Childers, T. N. Ginter, C. Harris, E. Kwan, R. Lewis, S. Lyons, F. Naqvi, W.J.- Ong, A. Palmisano, J. Pereira, S. J. Quinn, M. K Smith, C. Sumithrarachchi

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D. L. Bleuel, N. D. Scielzo, A. Sweet

P. A. DeYoung. J. Brett, J. P. Gombas, D. P. Scriven

A. Simon, A. C. Dombos

B. P. Crider

NSSC Experience

Graduate work at Ohio University

M.S. - 2014 - neutron time-of-flight spectroscopy

Ph.D. - 2018 - nuclear structure – β–decay and γ-ray spectroscopy

NSSC Postdoctoral Fellow at the NSCL

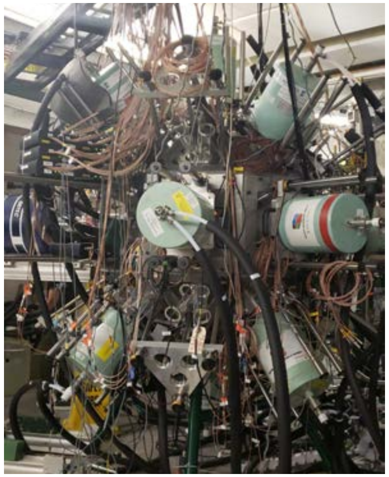
2018 - 2019 NSSC Fall Advisory Board Meeting

2019 University Program Review

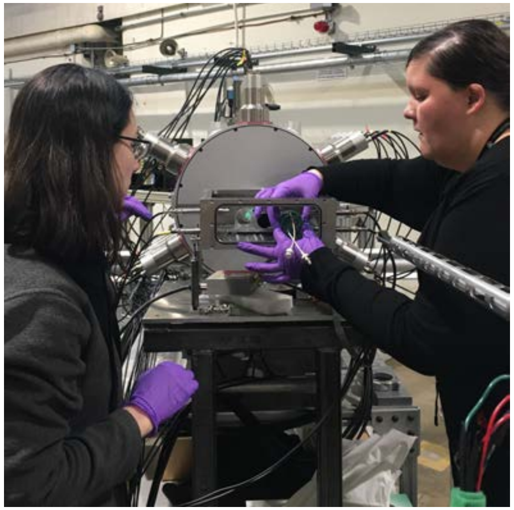
Collaboration with CVT consortium at the University of Michigan

Future proposal at LANSCE in collaboration with lab mentor

Clover campaign completed at NSCL (2019-2020)



SuN + Tape Station Campaign at ANL (ongoing)



Acknowledgements

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