Neutron capture cross sections constrained in β-decay experiments

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Introduction

Some of the SuN group at
Argonne National Laboratory

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Department and School: Facility for Rare Isotope Beams, Michigan State University

Academic Advisor: Artemis Spyrou

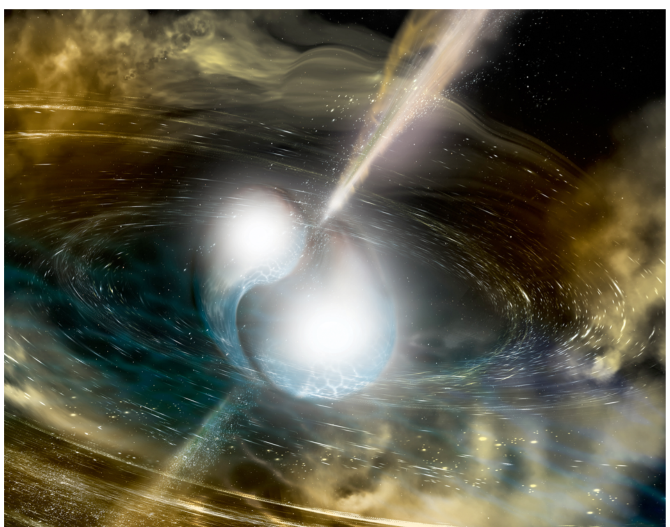
Lab Mentor: Nicholas Scielzo, LLNL

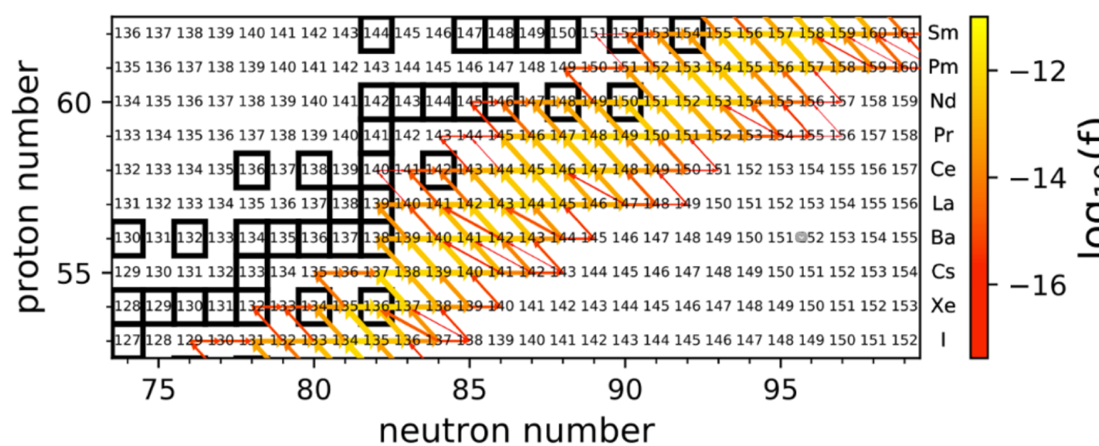
Research Focus Areas: Nuclear and particle physics, radiation detection and instrumentation, nuclear data

Mission Relevance of Research: Providing neutron capture cross sections of interest for nuclear astrophysics, stockpile stewardship, and nuclear energy

NNSA Connections

- Basic Science
  - Neutron capture cross sections
  - Nuclear statistical properties
- Nuclear Astrophysics
  - Nuclear reaction network inputs
- Nuclear Power
  - Reactor monitoring

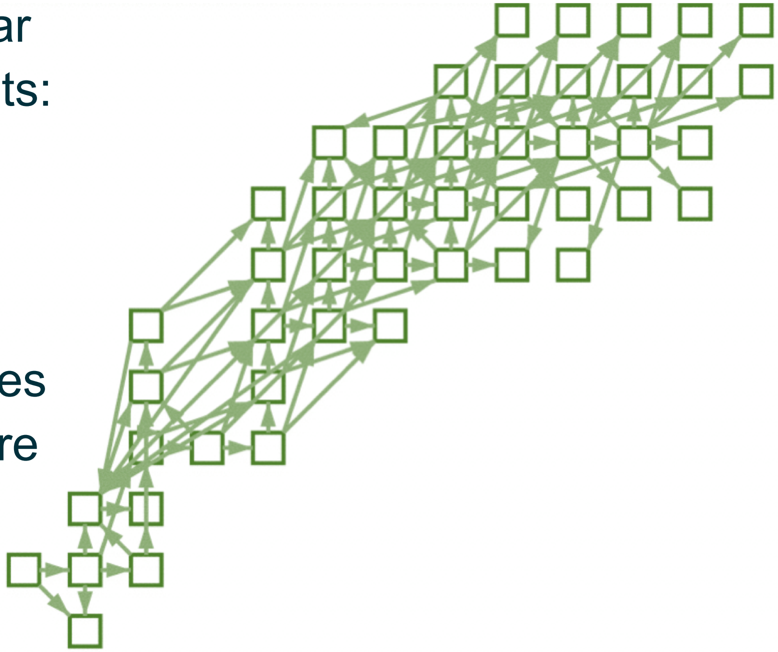




Astronomy Magazine, npr.org via Exelon, P.A. Denissenkov *et al* (2020)

Where are the elements made?

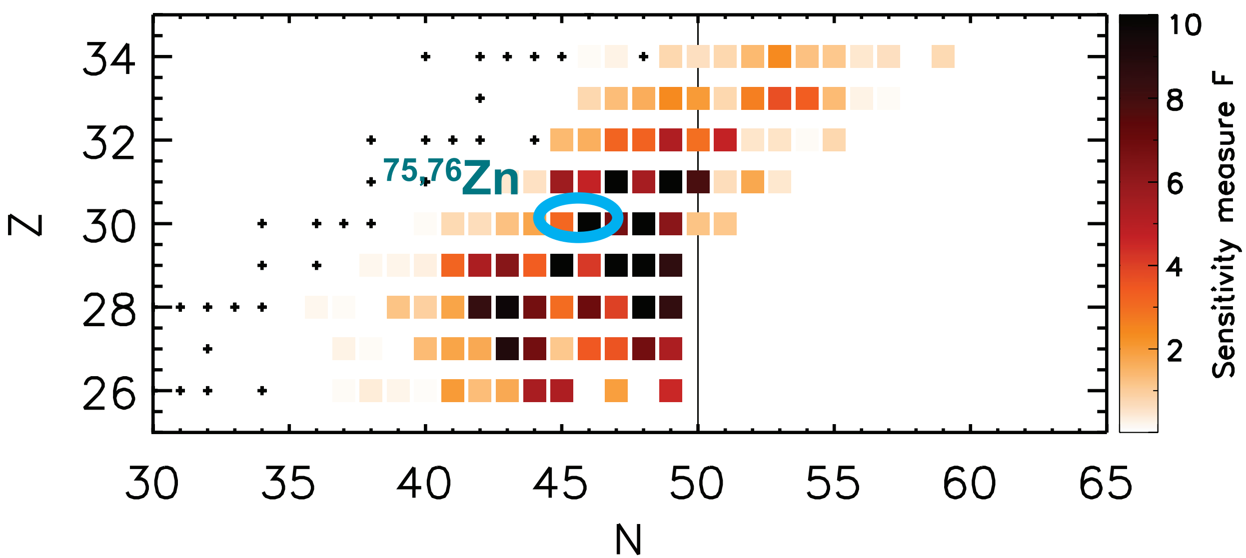
- Most neutron-rich nuclei are made in the r- and i-processes
  - Weak r-process, main r-process, and i-process
- These processes can be modeled with nuclear network calculations that require precise inputs:
  - Masses
  - Beta-decay rates
  - Neutron capture cross sections
- Surman *et al* have identified which abundances are most sensitive to changing neutron capture cross sections in the weak r-process
  - ^{75,76}Zn neutron capture cross sections



M.A. Famiano *et al, Astrophysical Journal* (2002), R. Surman *et al, AIP Advances* (2014)

Measuring reaction network inputs

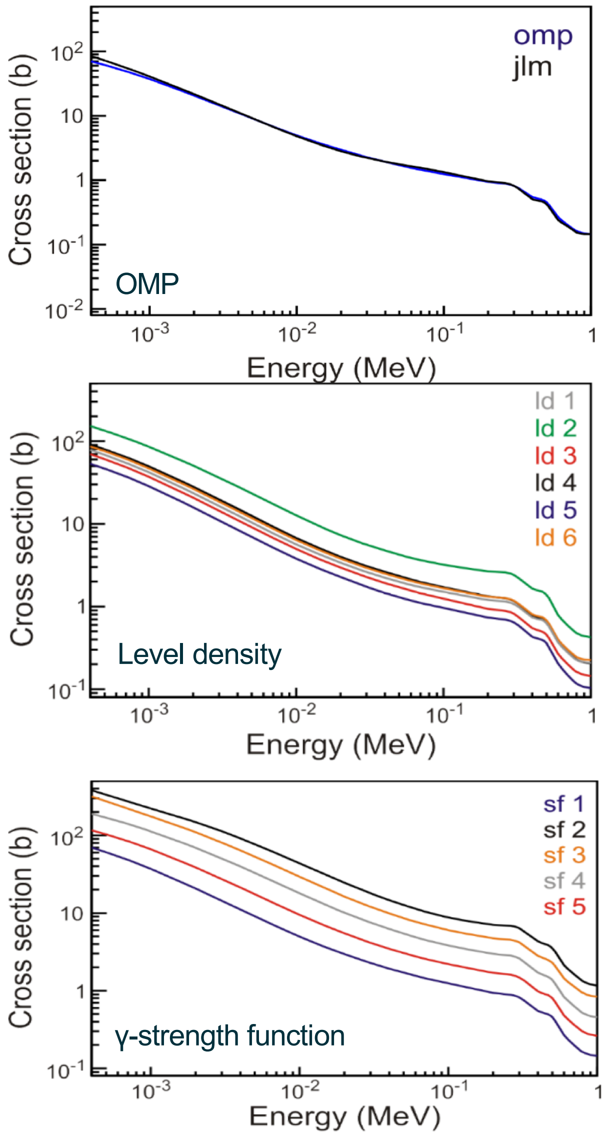
- Direct measurements are ideal, but difficult
  - Neutron and short-lived isotope targets aren't practical due to short half-lives
  - Neutron-rich nuclei are difficult to create as isotope beams with high enough intensity
- Indirect techniques can avoid these pitfalls: one of these is the β-Oslo method



- β-Oslo method uses the decay of these isotopes as a tool
- β-Oslo method does not require high rates of radioactive beams

R. Surman *et al, AIP Advances* (2014)

Indirect calculations of neutron capture cross sections



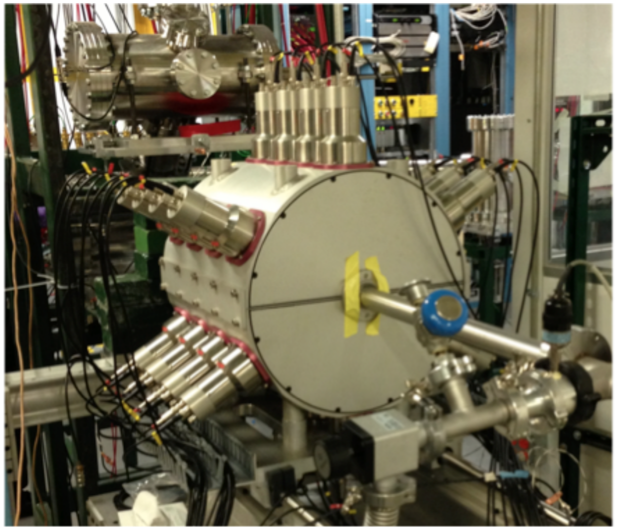
TALYS inputs for ^{95}Sr(n,γ)^{96}Sr

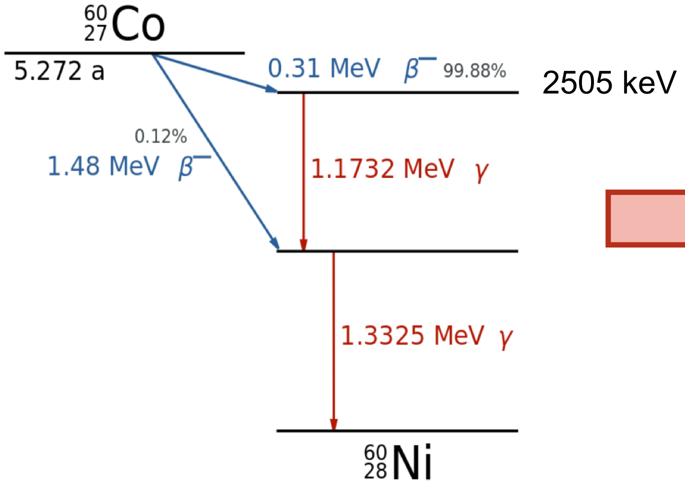
- Hauser-Feshbach statistical model codes like TALYS can be used to calculate neutron-capture cross sections using these inputs:
  - Neutron-nucleus optical model potential (nOMP)
  - Nuclear level density (NLD)
  - γ-ray strength function (γSF)

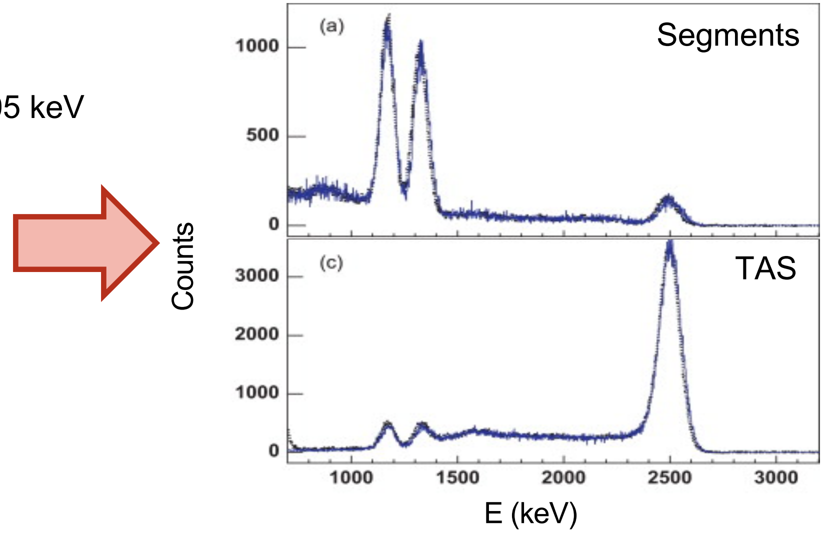
- Main uncertainties in these calculations come from NLD and γSF
- Experimental determination of the NLD and γSF can greatly reduce uncertainties

SuN: Segmented NaI detector

- Segmented, high-efficiency NaI detector
  - γ-ray resolution at 1 MeV: 6%
  - γ-ray efficiency at 1 MeV: 85%
- Capabilities:
  - Total absorption γ spectroscopy: gives excitation energy of nuclei
  - Segmentation provides individual γ-ray energies







Wikipedia; A. Simon *et al*, *NIM A* 713 (2013).

Experimental quantities determined in SuN measurements

Beta decay properties

- Beta feeding intensities
- B(GT) values

Uses:

- Average gamma, electron, and neutrino calculations

Applications:

- Reactor decay heat calculations
- Anti-neutrino reactor anomaly

Statistical properties

- Nuclear level densities
- Gamma ray strength functions

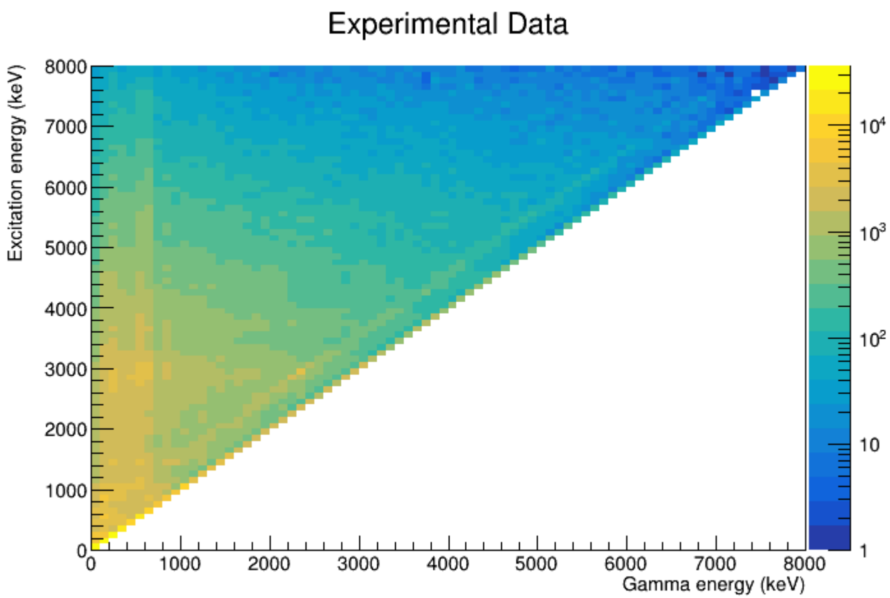
Uses:

- Neutron capture cross section calculations

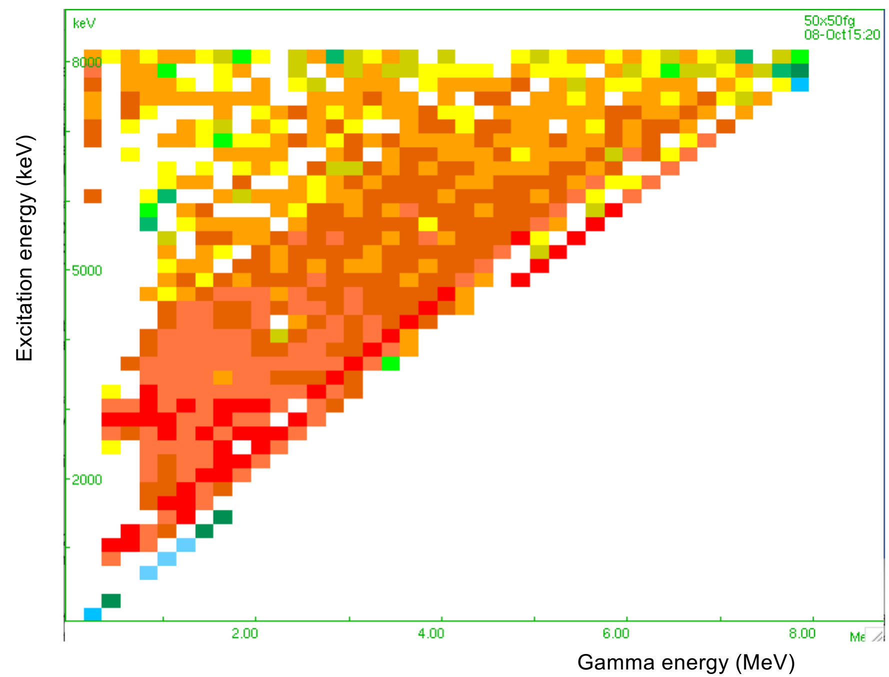
Applications:

- Nuclear astrophysics models
- Stockpile stewardship

The β-Oslo Method: matrices from β-decay of ^{77}Cu

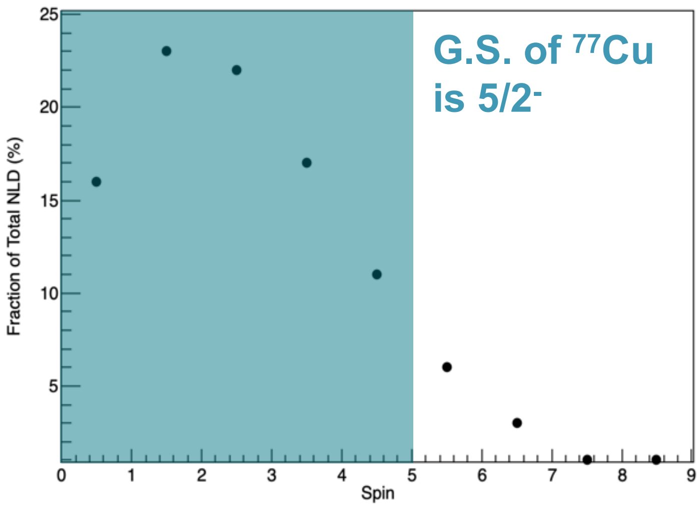


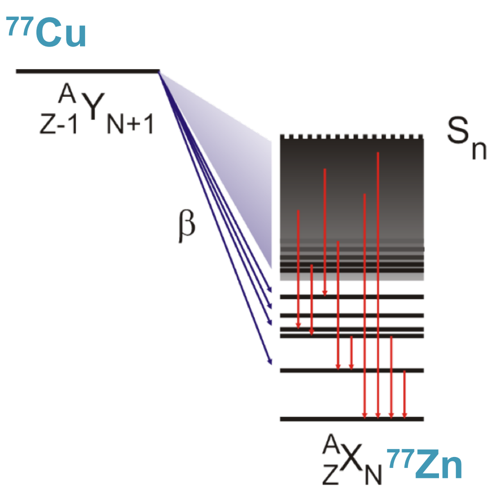
1. Create E_γ v E_x matrix from experimental data



2. Extract first generation γ-ray from each γ-cascade to create primary matrix

The β-Oslo Method: statistical properties and normalization



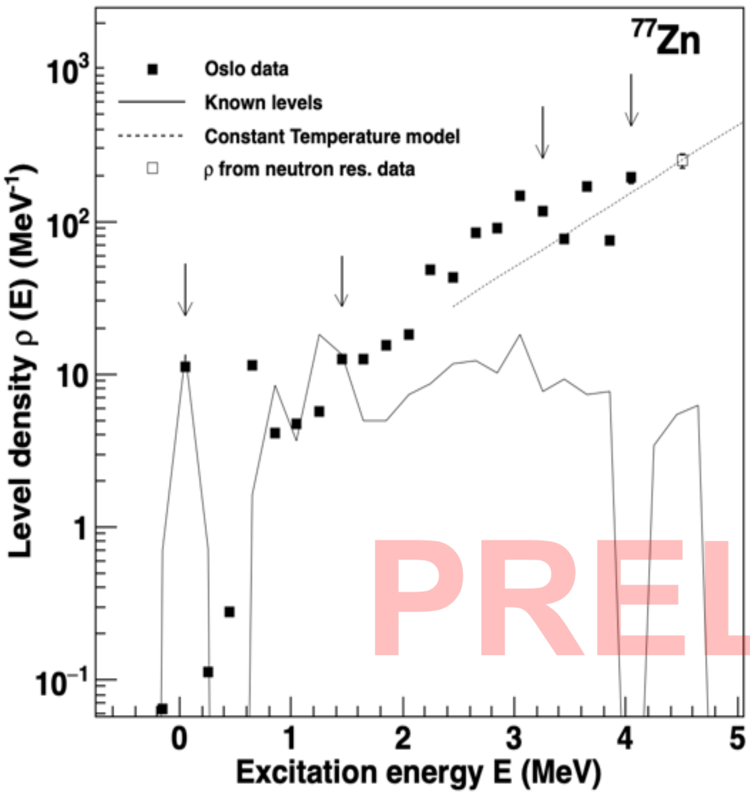


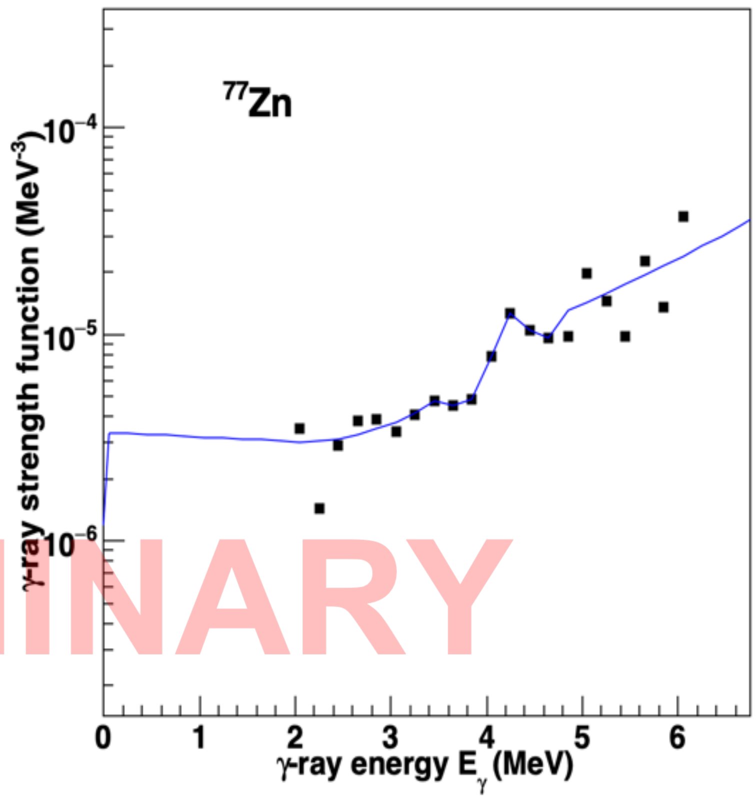
3. Use the Oslo method to extract statistical properties from the primary γ-ray matrix:
   - Nuclear level density (NLD)
   - γ-ray strength function (γSF)

4. Normalize statistical properties with three normalization points:
   - Level density of low-energy discrete states
   - Level density at neutron separation energy $\rho(S_n)$, which can be found from neutron resonance spacings D_0
   - Average radiative width (Γ_γ) at S_n

- Must take selective spin population of beta decay into account

First results for $^{76}Zn(n,\gamma)$

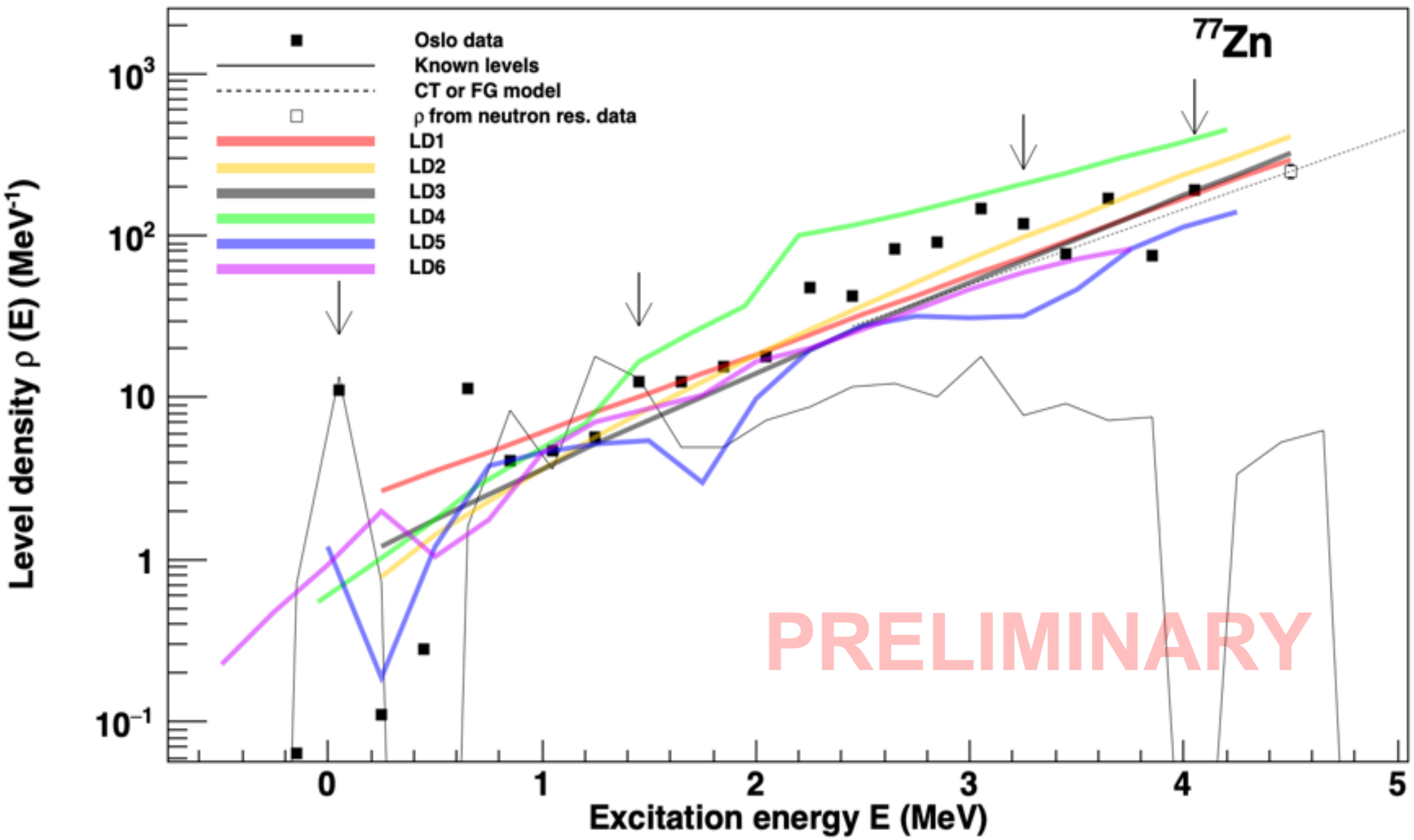




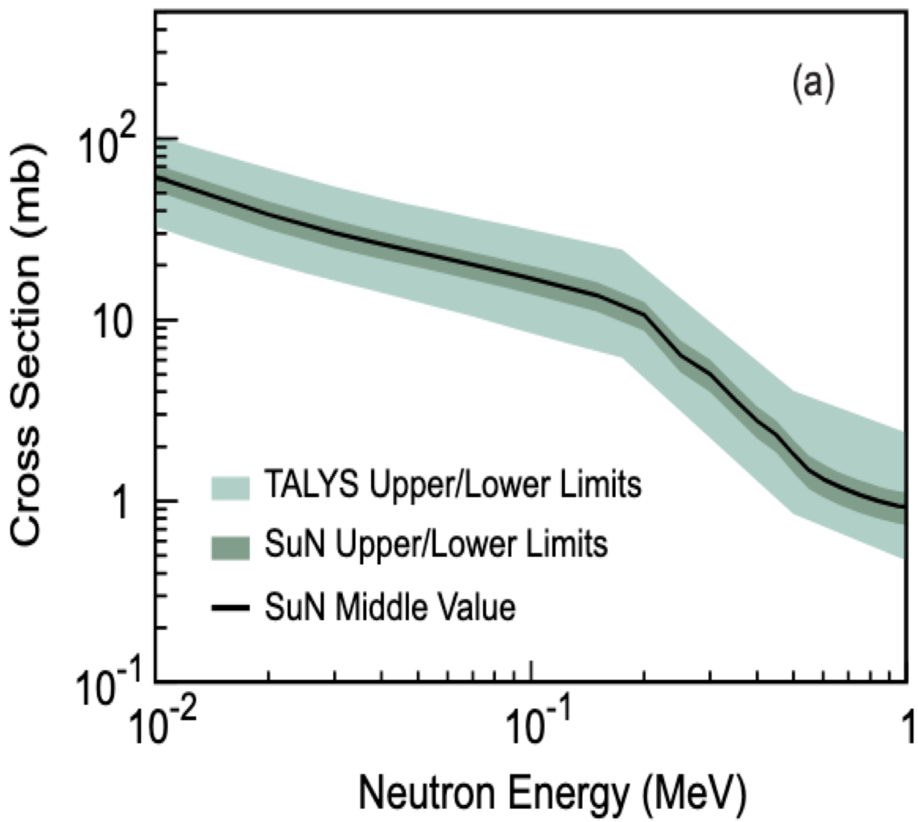
The Olso method has been used to extract the nuclear level density and gamma ray strength function for ^{77}Zn, which is used to calculate $^{76}Zn(n,\gamma)$

Comparison with theory: TALYS

Experimentally determined NLD of ^{77}Zn has been compared with TALYS's six standard NLD models



Future work:



^{74}Zn(n,γ) from Lewis et al. Phys Rev C (2019)

- Use these experimentally determined NLD and γSF to reduce uncertainties in theoretical (n, γ) cross sections
- Also working on total absorption spectroscopy (TAS) for both isotopes to determine their beta decay feeding intensities
- More β-Oslo measurements planned at FRIB and ANL!

My NSSC Experience

- University Program Review, September 2021
- Various NSSC-hosted online talks and workshops during COVID
- Collaborations with national laboratory partners:
  - Lawrence Livermore National Laboratory
  - Pacific Northwest National Laboratory
- Ongoing experimental campaign at Argonne National Laboratory

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