Nuclear Science and Security Consortium
Virtual Scholar Showcase 2020

Validation of an Indirect Method for Constraining Neutron-Capture Cross Sections

June 2, 2020

Katherine Childers
Michigan State University

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NUCLEAR SCIENCE and SECURITY CONSORTIUM

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Introduction

Graduate Student

Department of Chemistry, Michigan State University

National Superconducting Cyclotron Laboratory

Academic Advisor:
Sean Liddick
Department of Chemistry
National Superconducting Cyclotron Laboratory

Lab Mentor:
Aaron Couture
P-27: Nuclear Astrophysics and Structure

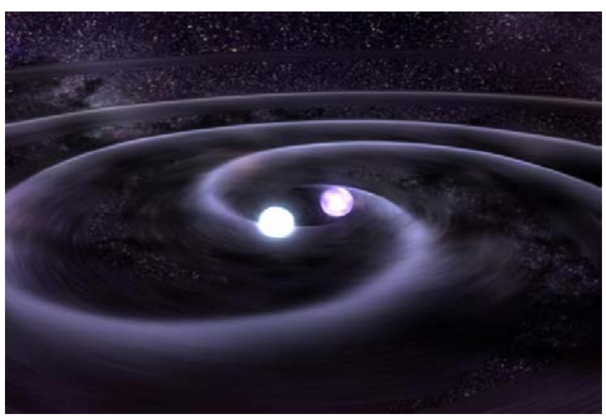
Focus Area: Nuclear and Particle Physics

Crosscutting Area: Nuclear Data

Application and Measurement of (n,γ) Cross Sections

Neutron-capture cross sections are valuable for various nuclear data applications.

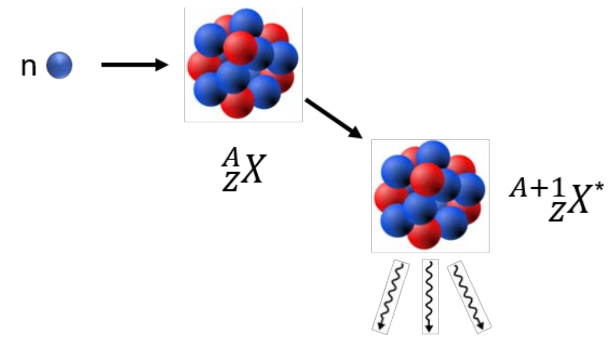
- Nuclear energy
- Reaction networks and astrophysics
- Non-proliferation



Artist rendering of neutron star merger from NASA website

Direct measurement on short-lived nuclei are challenging

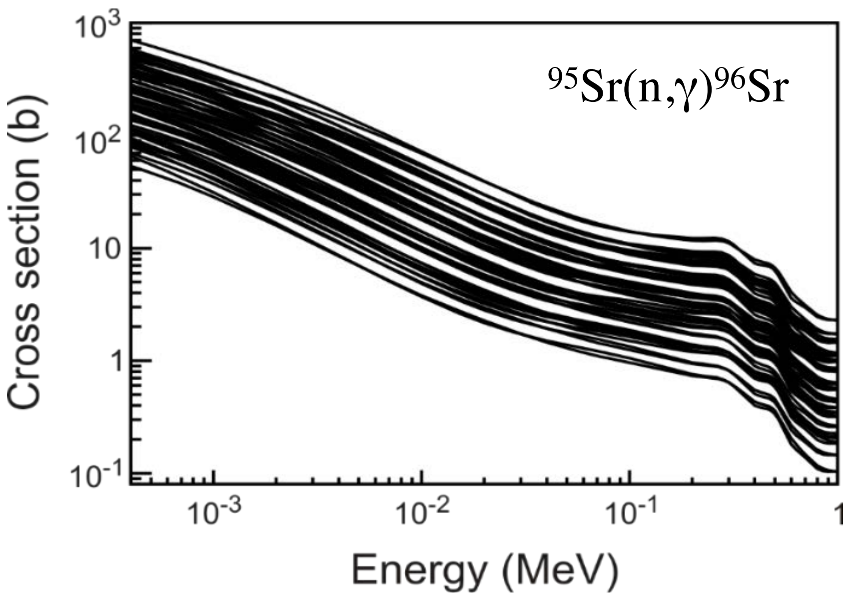
- Radioactive targets or neutron targets are not feasible
- Many cross-sections are not well known



Indirect technique

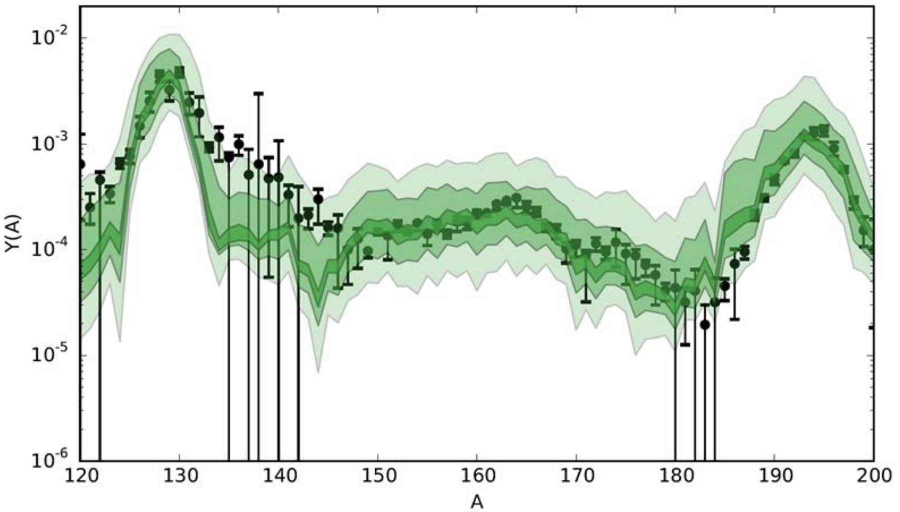
- Statistical model – Hauser-Feshbach
- Use theoretically calculated nuclear properties to determine cross sections

Uncertainties of nuclear properties



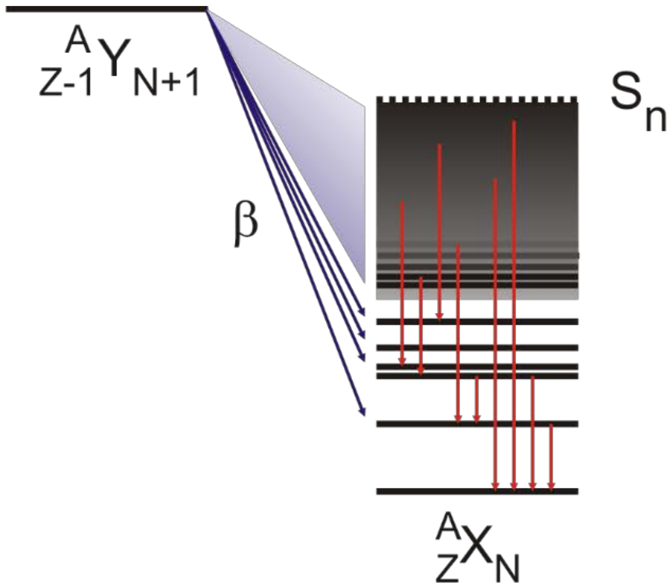
- Many theoretical models to choose from
- Large range of possible cross sections introduces a large uncertainty

Example: Impact on astrophysical calculation of abundance patterns



Liddick *et. al.*, PRL **116**, 242502 (2016).

Experimentally constraining inputs with β-decay

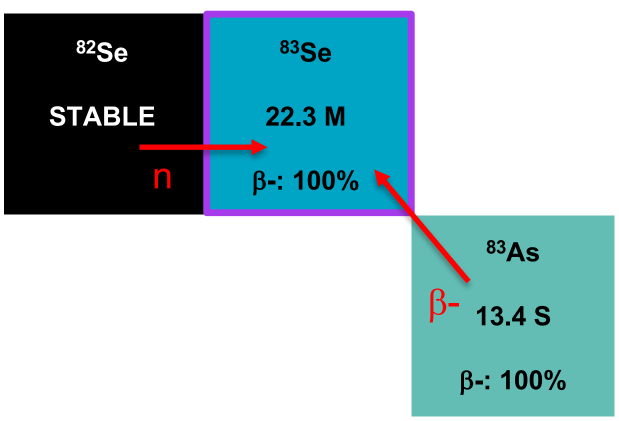


- **Measure γ–decay – β-Oslo Method**
  - Need individual γ-ray energy and total excitation energy of nucleus
  - Extract nuclear level density (NLD) and γ-ray strength function (γSF)

- **Extracted NLD and γSF inserted into statistical reaction model to constrain cross section**

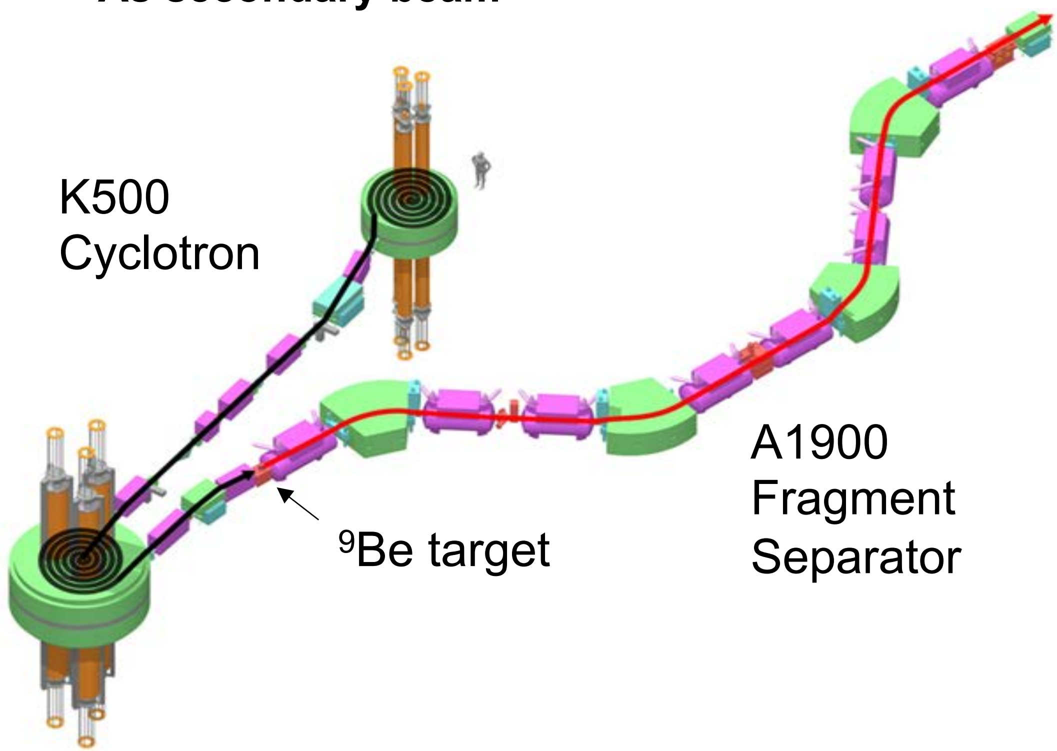
- **Need a high efficiency detector**

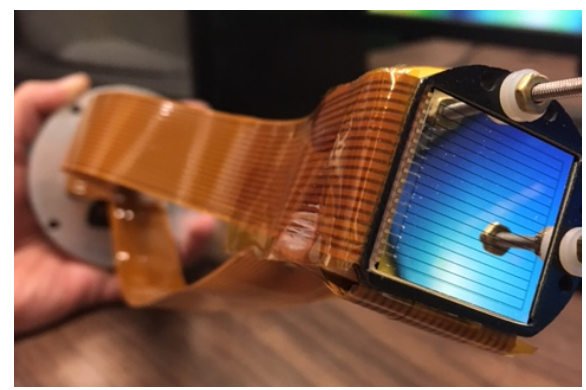
Need a validation in a higher mass region!



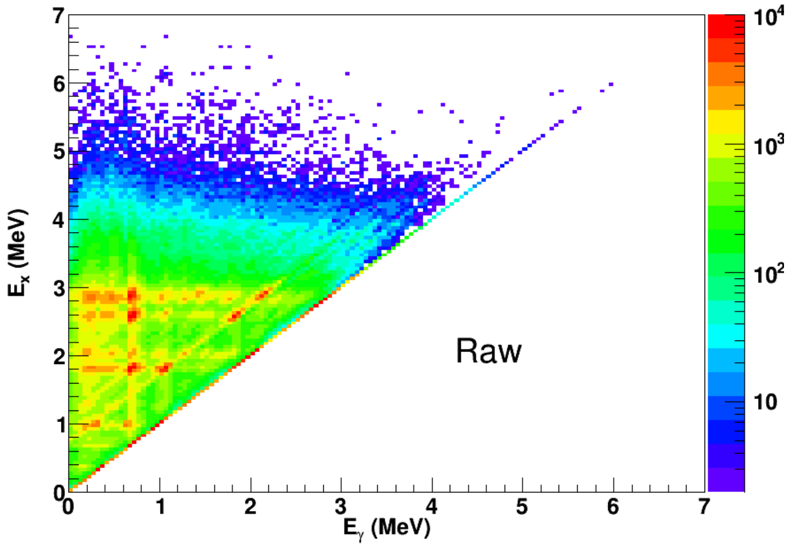
NSCL Experiment Studying the Decay of ^{83}As

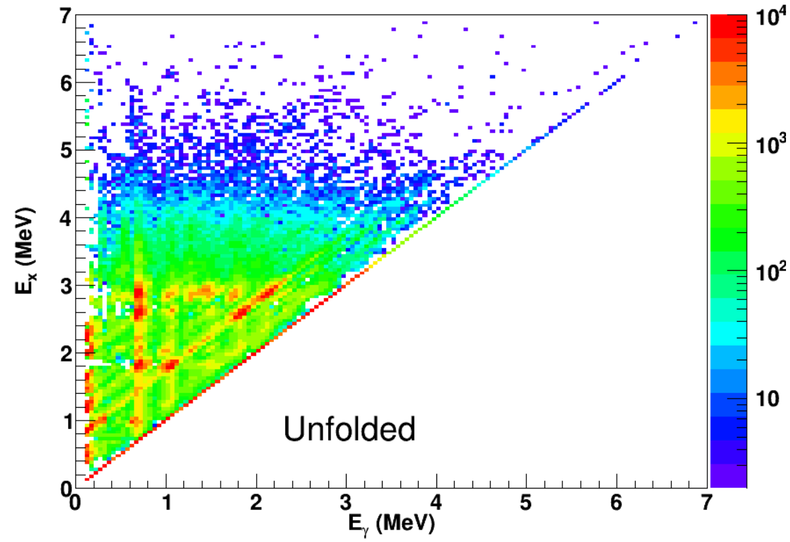
- ^{86}Kr primary beam – 140 MeV/u
- ^{9}Be target
- ^{83}As secondary beam

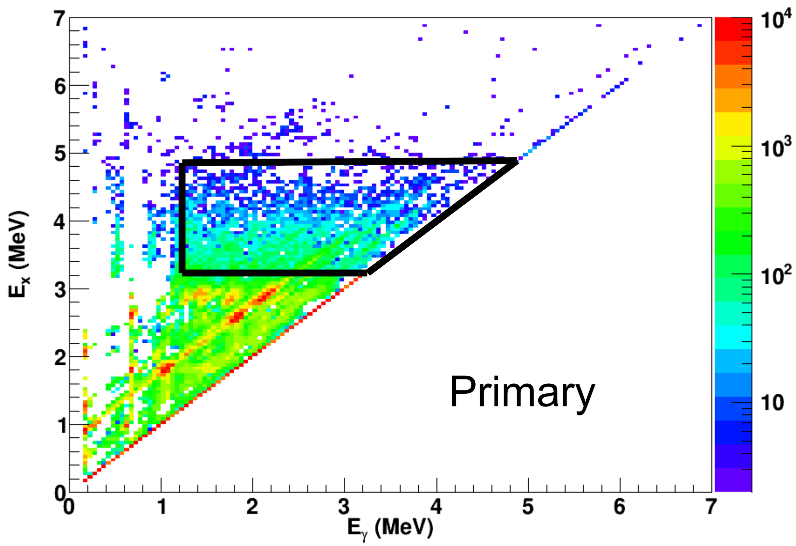




β-Oslo Method





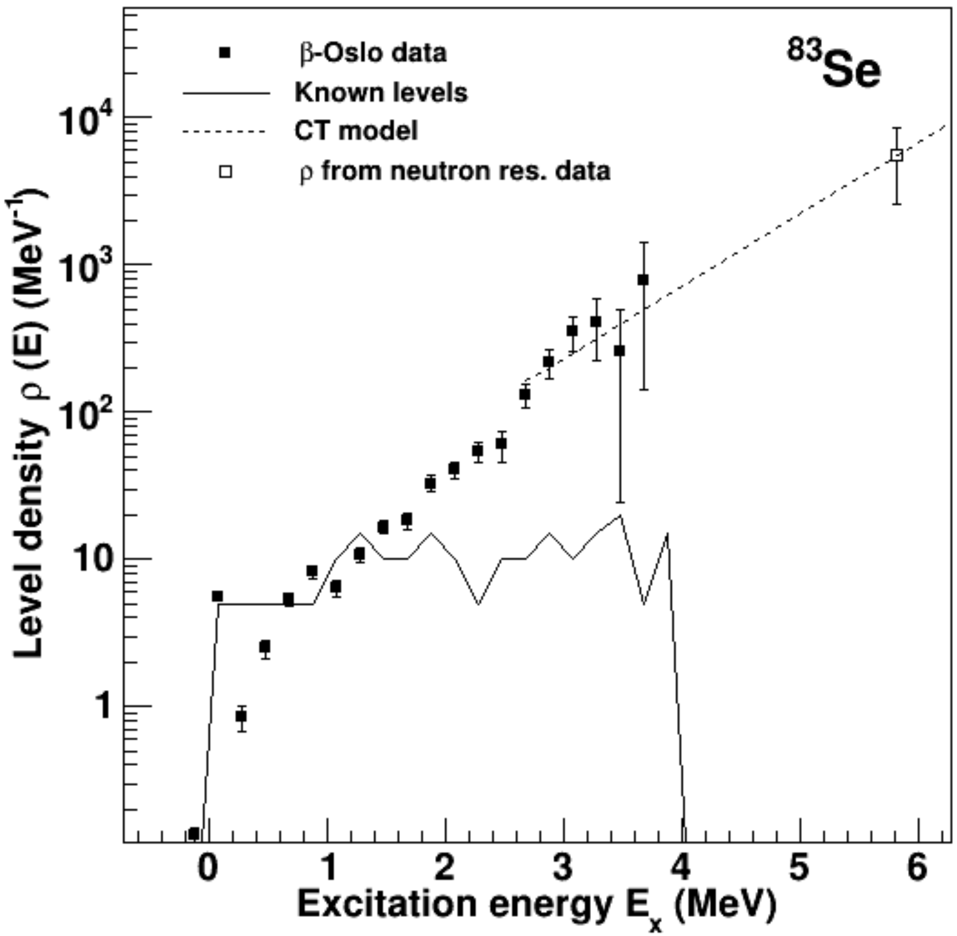


Nuclear Level Density (NLD)

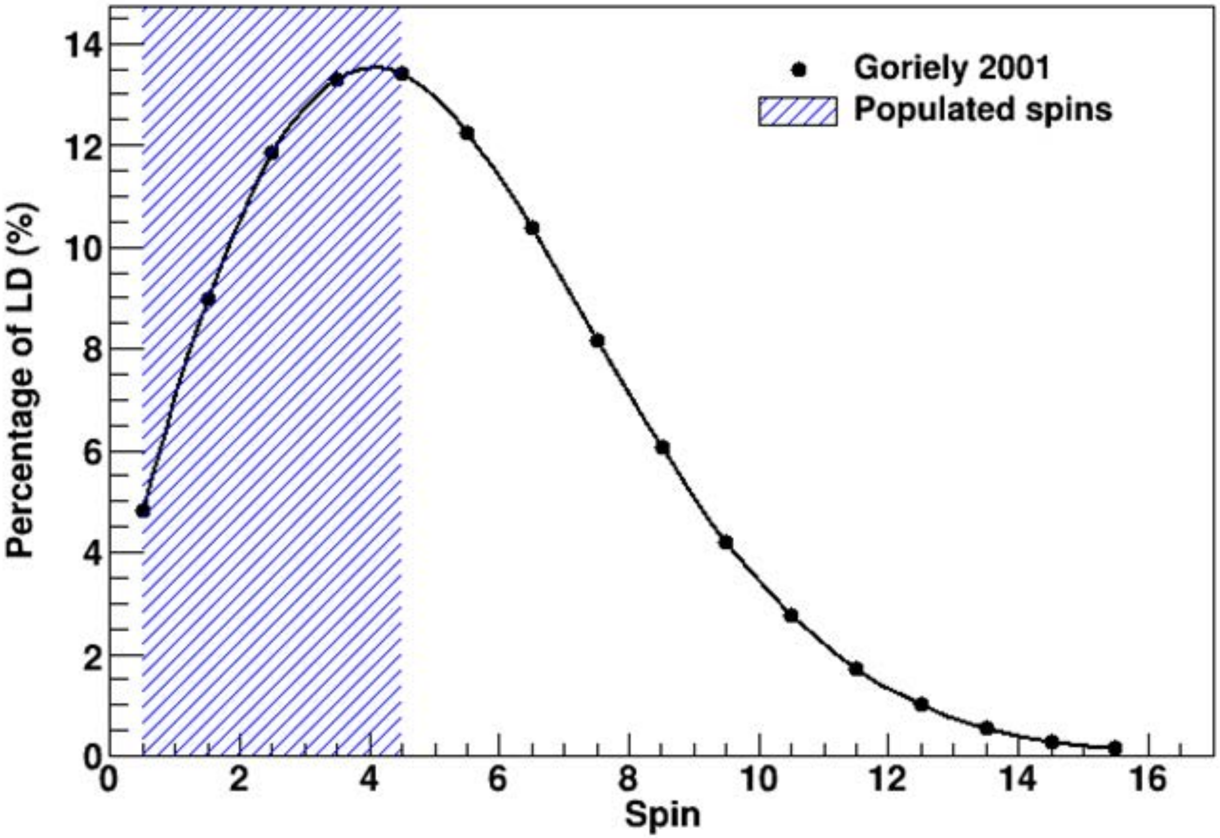
γ-ray Strength Function

M. Guttormsen, *et al.,* NIM A 374, 371 (1996).
M. Guttormsen, T. Ramsoy, and J. Rekstad, NIM 255, 518 (1987).
A. Schiller, *et al.,* NIM A 447, 498 (2000).

Nuclear Level Density Normalization

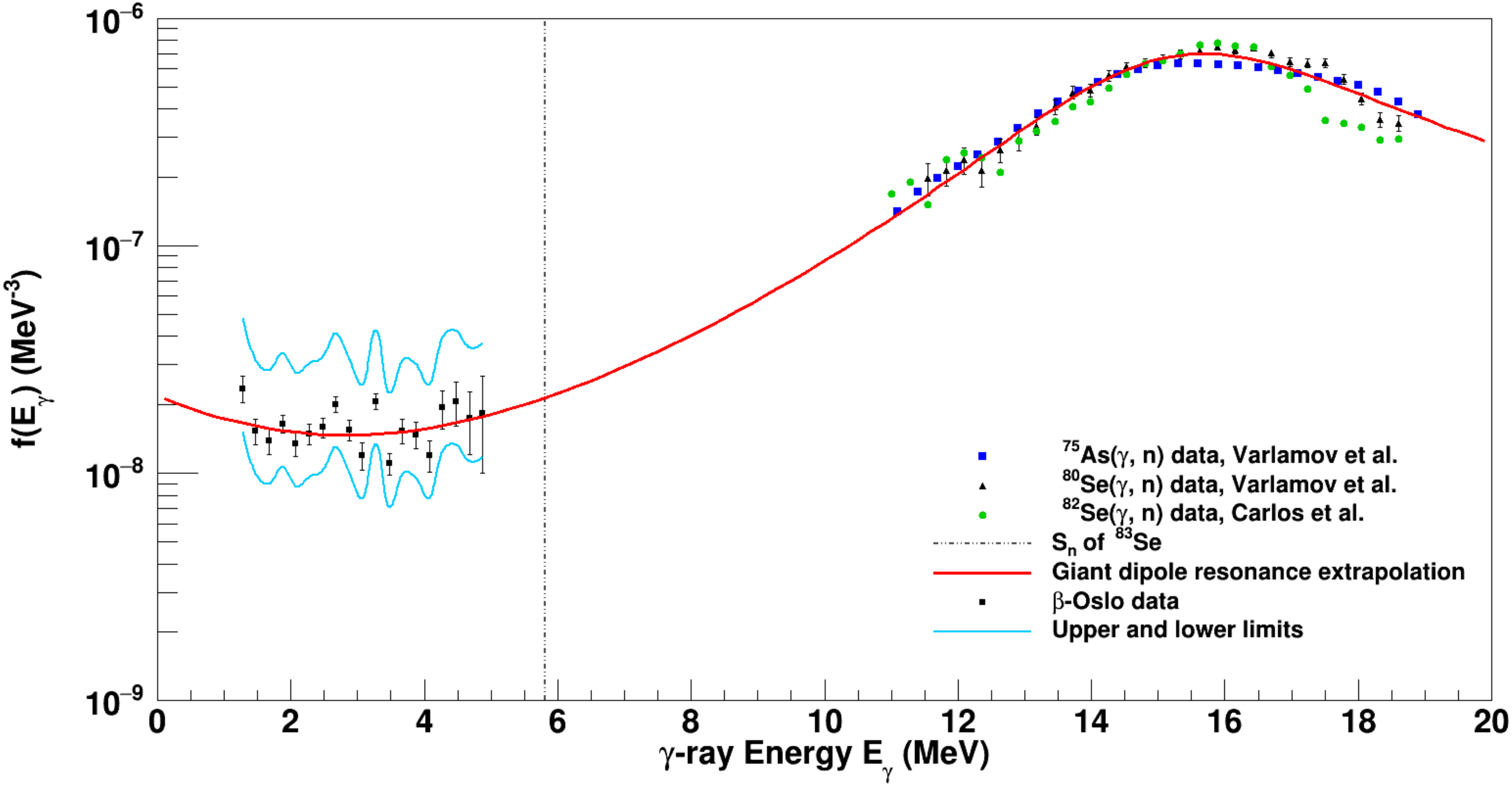


Reduction of Level Density

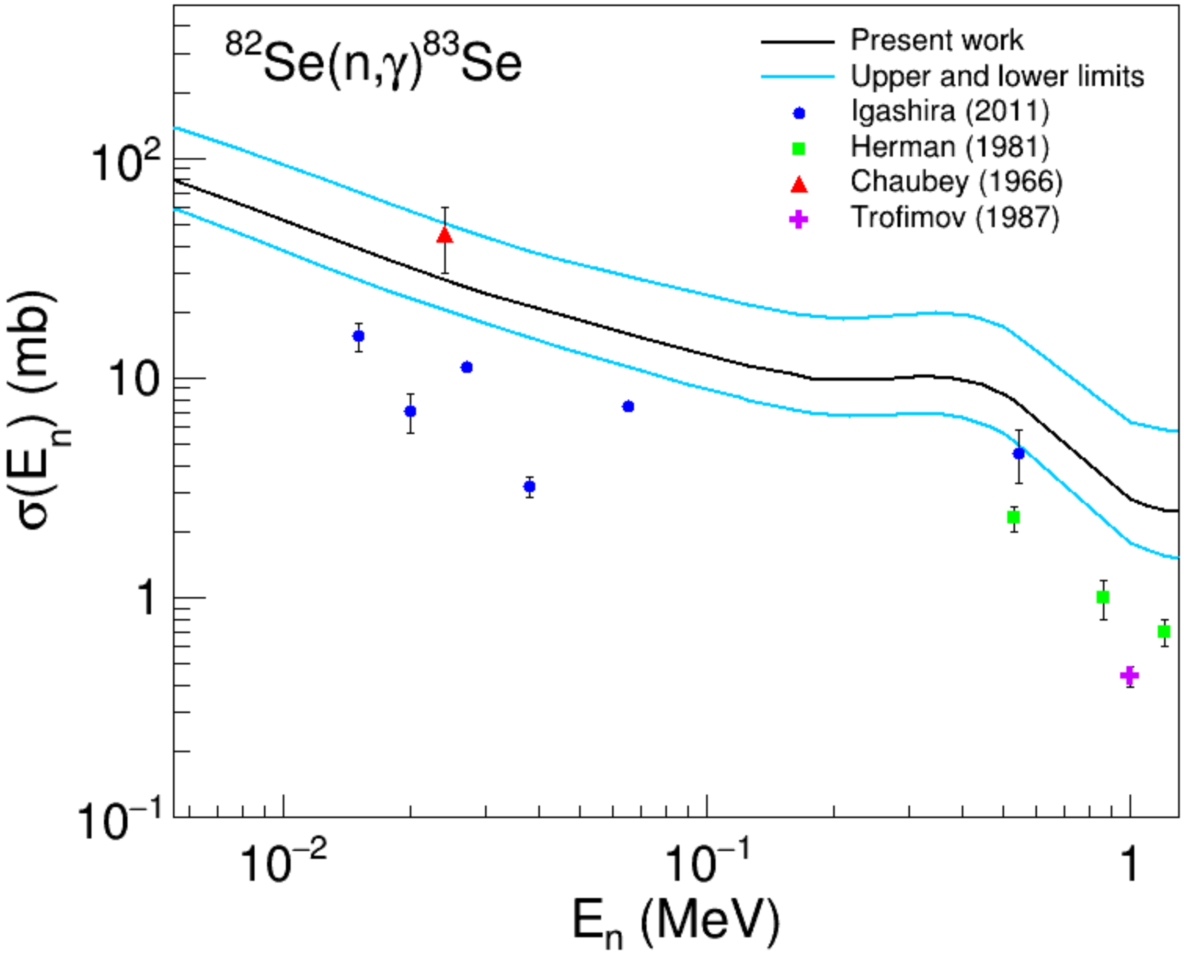


S. Goriely, F. Tondeur, and J. Pearson, Atomic Data and Nuclear Data Tables 77, 311 (2001).

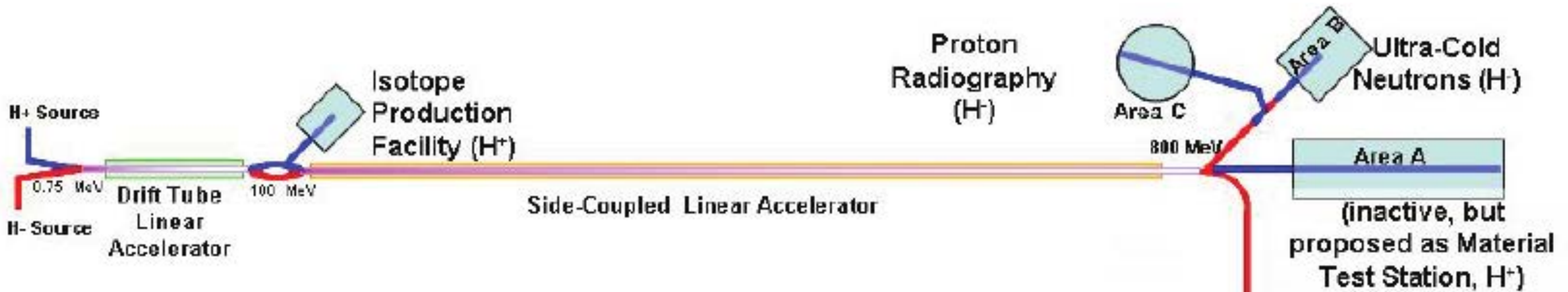
γ-ray Strength Function Normalization



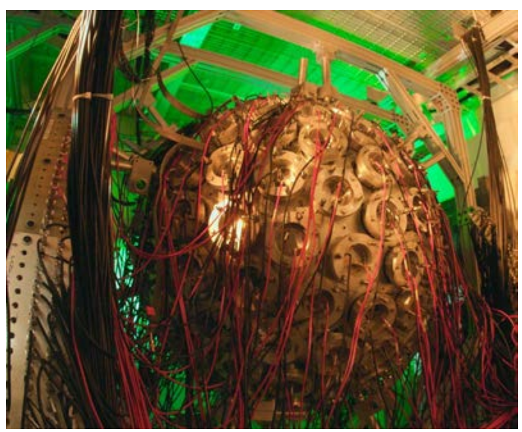
TALYS calculation

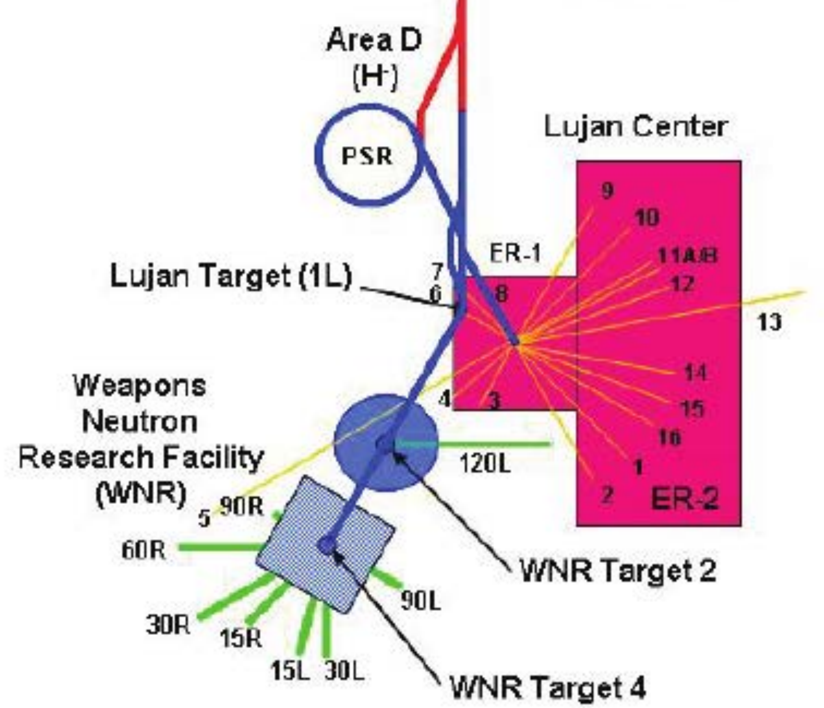


Direct Measurements at LANSCE

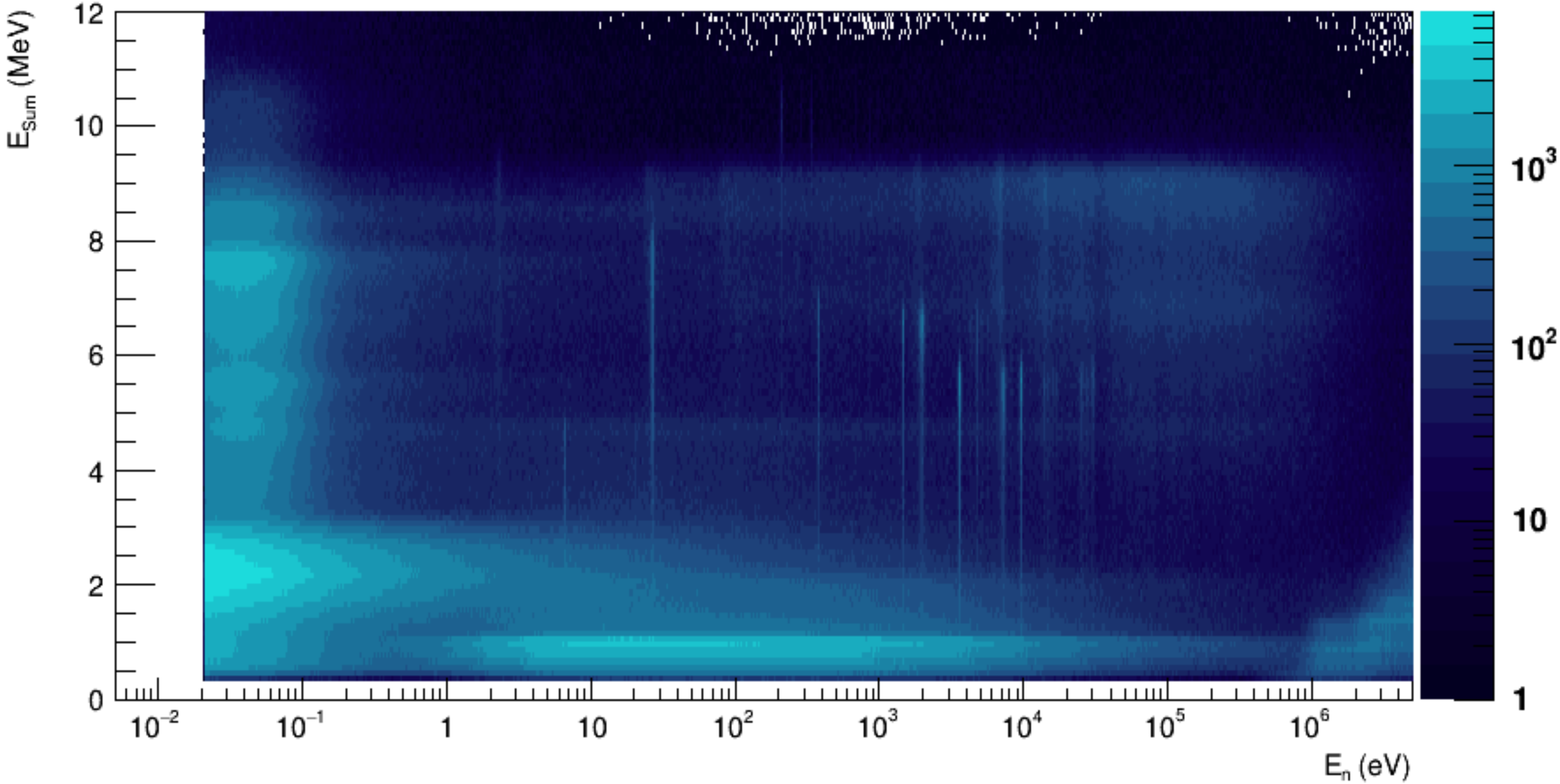


- Detector for Advanced Neutron Capture Experiments (DANCE) – γ-ray calorimeter
- 160 BaF_2 crystals
- 3.5π coverage

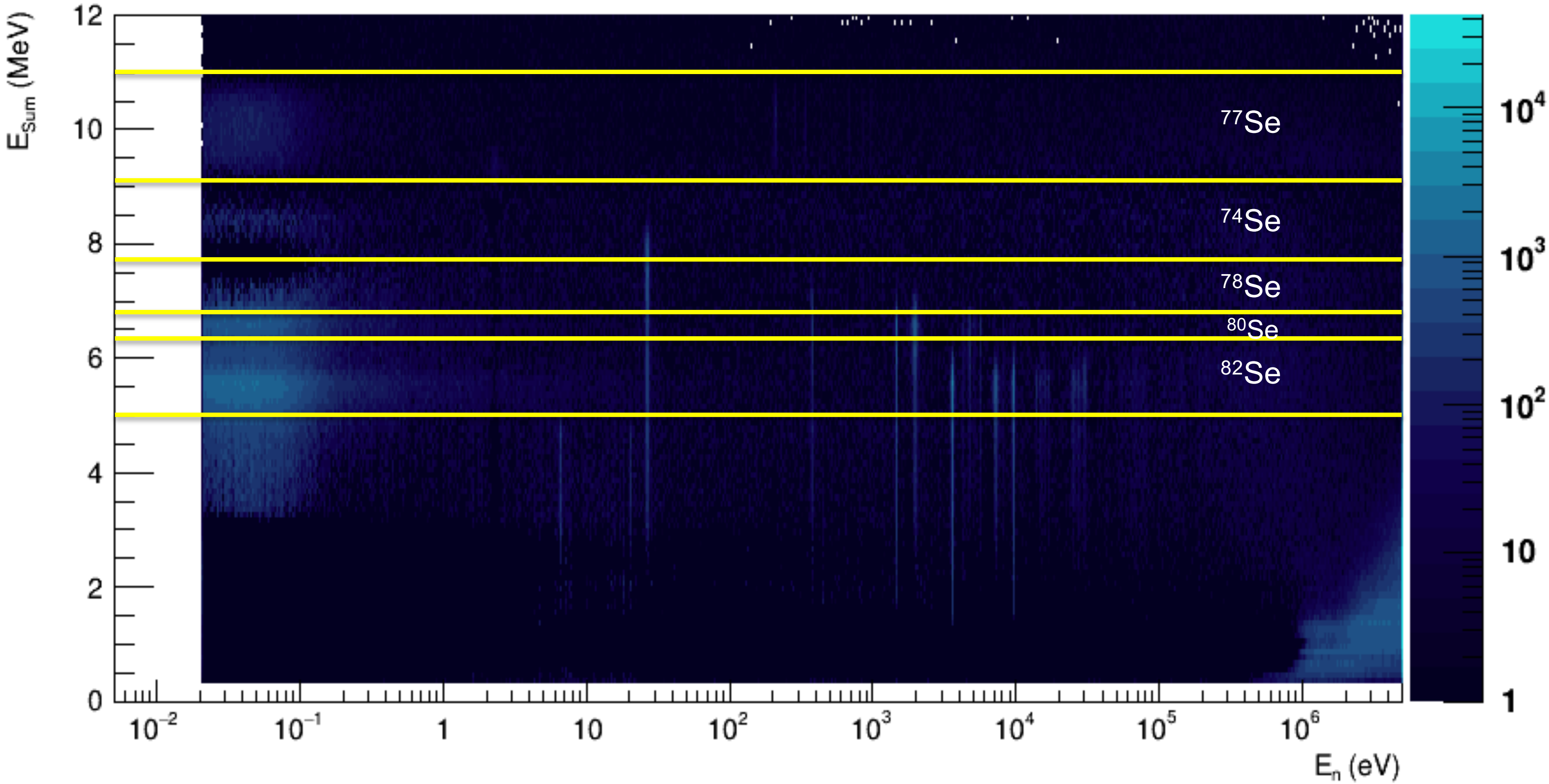




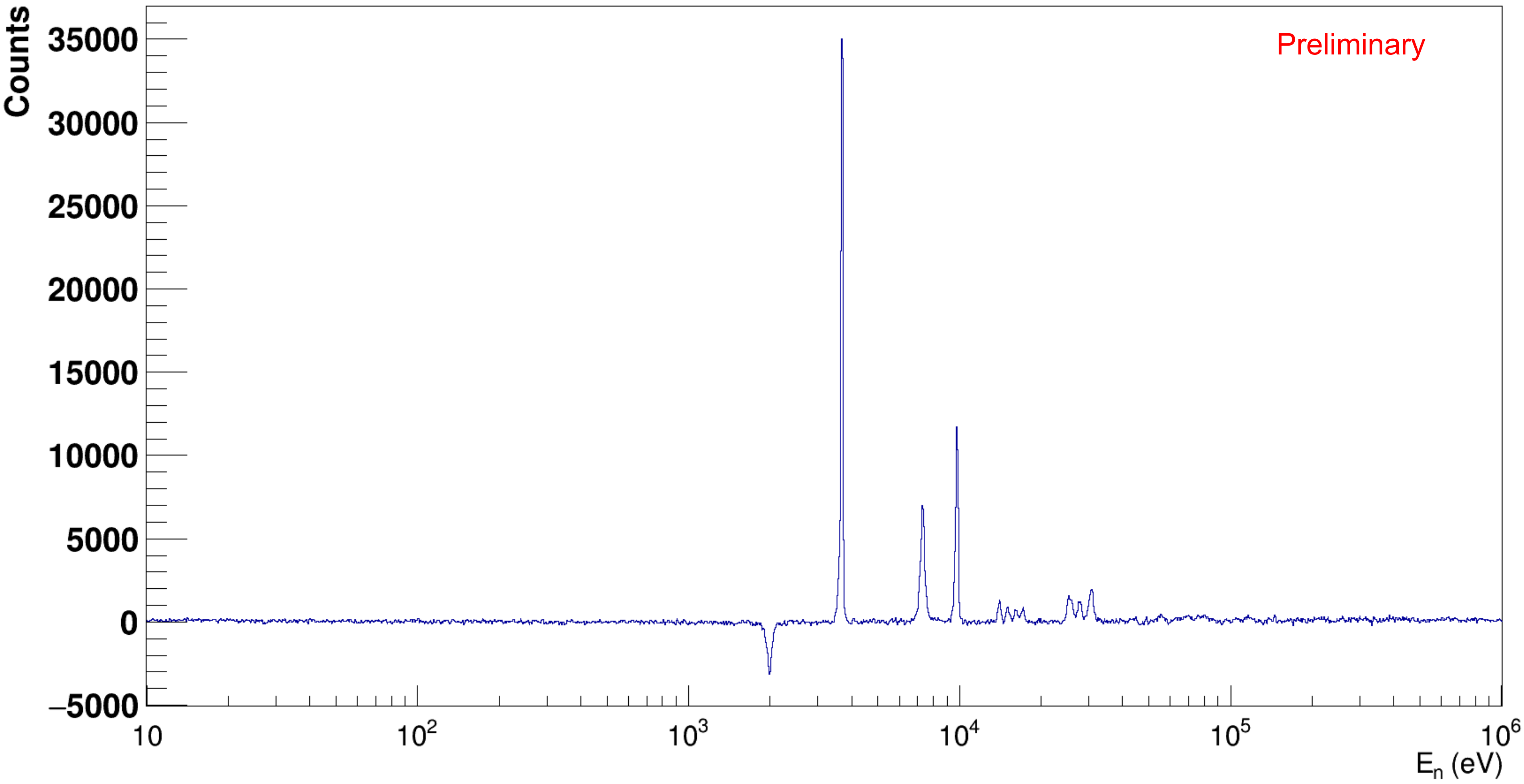
Neutron Energy vs. Total Energy



Subtraction of Contaminants

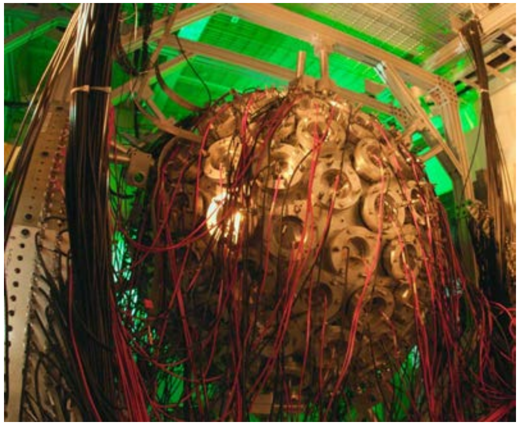


Yield of neutron capture on ^{82}Se



Summary

- β-Oslo method needs to be validated against a directly measured neutron capture cross section
- The NLD and γSF have been constrained for ^{83}Se using the β-Oslo method
- The neutron capture cross section of ^{82}Se(n,γ)^{83}Se has been calculated using the constrained NLD and γSF
- Analysis of directly measured cross section with DANCE is ongoing



Collaborators

S.N. Liddick, B.P. Crider, R. Lewis, S. Lyons, A. Spyrou, A.C. Dombos, F. Naqvi, A. Richard

A.C. Larsen, M. Guttormsen, L.C. Campo, T. Renstrom, S. Siem

A. Couture, S. Mosby, C.J. Prokop, J. Ullmann, C. Fry

D.L. Bleuel

S. Quinn

G. Perdikakis

NSSC Experience

- PNNL Radiation Detection for Nuclear Security Summer School, June 2019

- Nuclear Science and Security Consortium Fall Workshop and Advisory Board Meeting, October 2019

    - APS Division of Nuclear Physics Fall Meeting, October 2019

Many trips out to Los Alamos National Laboratory!

Acknowledgements

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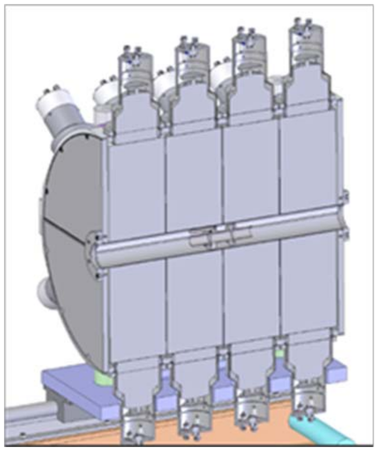
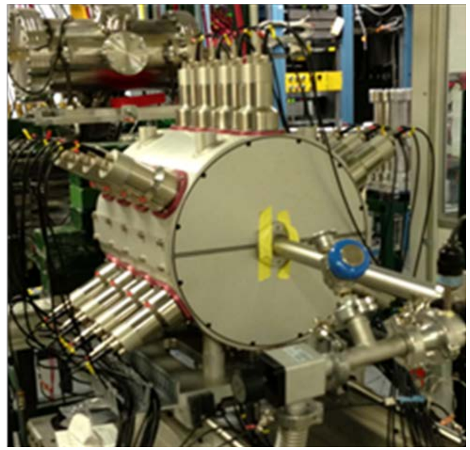
Backup Slides

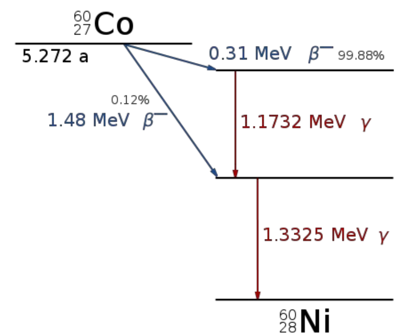
SuN - Total Absorption Spectrometer

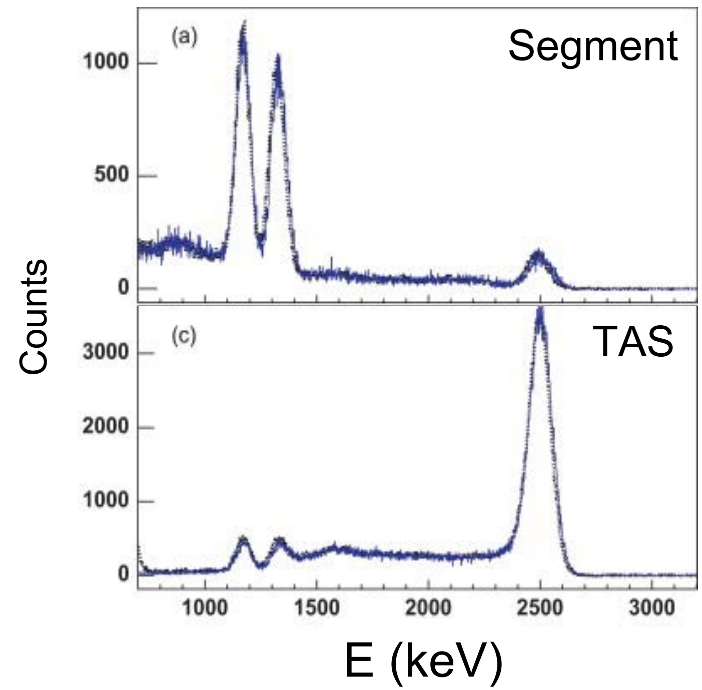




- **High efficiency, lower resolution**
  - Resolution at 1 MeV - 6%
  - Efficiency at 1 MeV - 85%

- **Segments give individual γ-ray energies**
- **Summing of all γ-rays give initial excitation energy**





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

Validation of the β–Oslo Method

- β-Oslo method has already been used to constrain the neutron capture cross section of ^{75}Ge, ^{68}Ni, ^{69}Ni, ^{73}Zn, and ^{50}Ti

1. Target nucleus must be able to be produced by neutron capture and β-decay
2. β-decay parent must have $Q_{\beta-}$ large enough to populate high energies
3. Ability to produce parent nucleus and study its β-decay

^{82}Br 35.282 H β-: 100%	^{83}Br 2.40 H β-: 100%	^{84}Br 31.76 M β-: 100%	^{85}Br 2.90 M β-: 100%
^{81}Se 18.45 M β-: 100%	^{82}Se STABLE	^{83}Se 22.3 M β-: 100%	^{84}Se 3.26 M β-: 100%
^{80}As 15.2 S β-: 100%	^{81}As 33.3 S β-: 100%	^{82}As 19.1 S β-: 100%	^{83}As 13.4 S β-: 100%

n

β-

Liddick *et al*. (accepted).
Spyrou *et al.* PRL **113**, 232502 (2014).
Spyrou *et al.* J. Phys. G: Nucl. Part. Phys. **44** 044002 (2017).
Liddick *et al.* PRL **116**, 242502 (2016).
Lewis *et al.* PRC **99**, 34601 (2019).