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Title: Using neutron resonance parameters from advanced experiments and analyses to improve photon strength functions and nuclear level densities

Author(s): Koehler, Paul E.

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Using neutron resonance parameters from advanced experiments and analyses to improve photon strength functions and nuclear level densities

Paul Koehler

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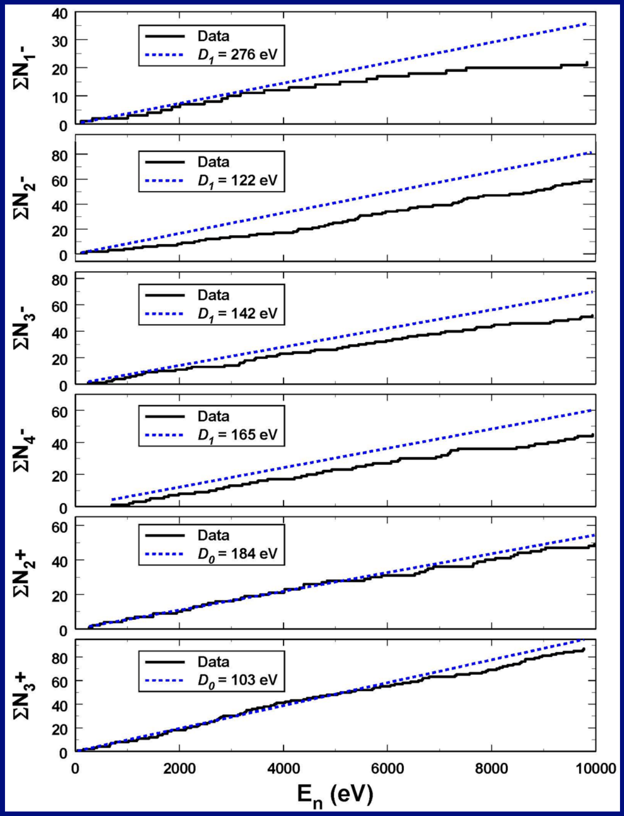
Connections Between Neutron Resonance Parameters and Nuclear Level Densities (NLD) and Photon Strength Functions (PSF)

- Traditional: Average resonance spacing, D_0, and average radiation width, $<\Gamma_\gamma>$, used to calibrate NLDs and PSFs measured using, for example, the Oslo technique[1]
- More recent: Γ_γ distribution data can be used to test/constrain assumptions behind both the nuclear statistical model (NSM) and the Oslo technique and to obtain better NLDs and PSFs[2]
- Even more recent: Determining average resonance spacings, $D_{l,J}$, for several spins[3] can be used to test/constrain spin/parity assumptions in NLD models

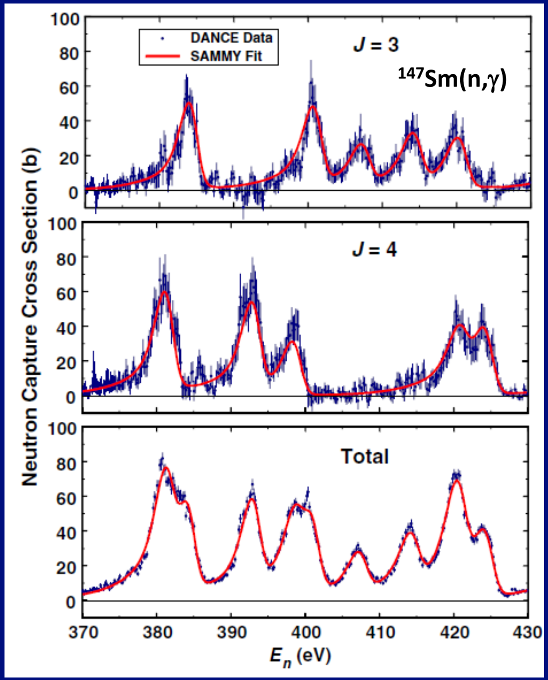
^{95}Mo+n

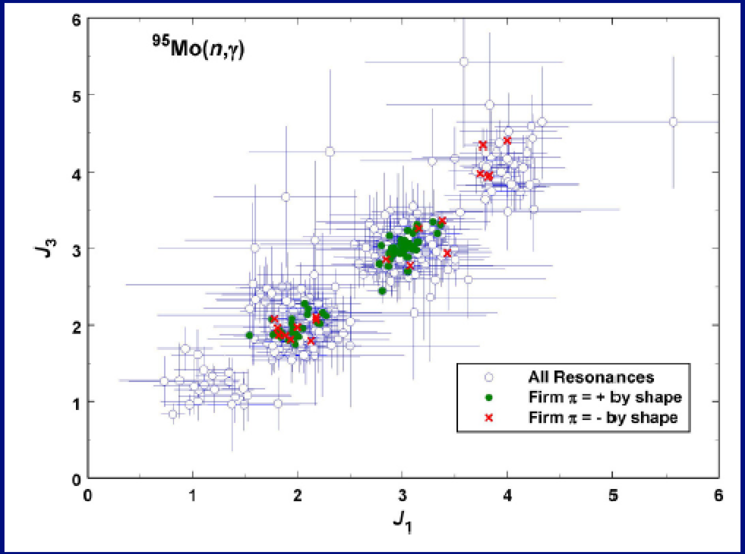


$$\Delta D = \frac{0.52D}{\sqrt{N}}$$

Neutron Resonance Measurement and Analysis Requirements

- **It takes substantial effort to obtain a resonance parameter set of the required size and quality to test model assumptions and obtain improved NLDs and PSFs**
- Need to measure and do simultaneous *R*-matrix analysis of both neutron capture and transmission
- Determining J^{π} values requires measuring and analyzing gamma cascade data[2,4]





DICER Plus DANCE Can Provide the Needed Data

- DICER[5] – Device for Indirect Capture Experiments on Radionuclides

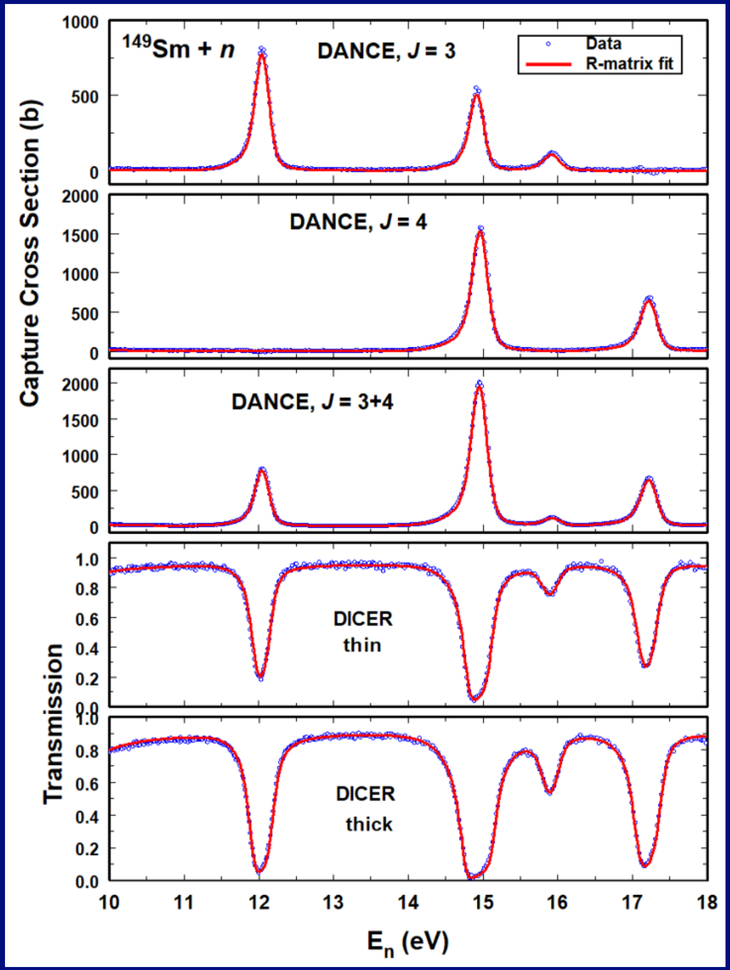
  Neutron transmission measurements on samples as small as 1 μg

- DANCE[6] – Detector for Advanced Neutron Capture Experiments

  Neutron capture cross section and resonance spin measurements on samples as small as 10 μg[7]

- Same data used to test and improve NLD and PSF models is directly valuable for applications such as criticality safety[3,8]

  For example, new transmission and capture data needed for a range of fission products for burnup credit applications[9]



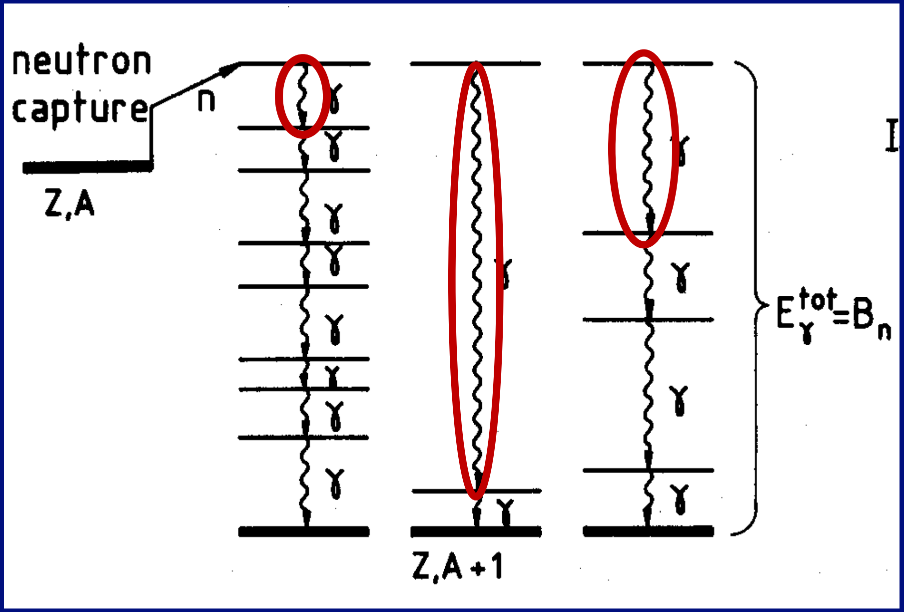
Using Γ_γ Distributions to Test and Constrain Models

- $\langle\Gamma_\gamma\rangle$ used to normalize the PSF obtained from the Oslo method[1]
- Γ_γ distributions can be used to constrain assumptions involved in that normalization[2,10]
  Assumptions are a model of the spin distribution as a function of excitation energy and that the nuclear statistical model (NSM) is valid
- Γ_γ "samples" NLD and PSF over wide range of energies

  Γ_γ is the sum of partial radiation widths, $\Gamma_{\gamma i}$, for primary transitions from the capturing resonance

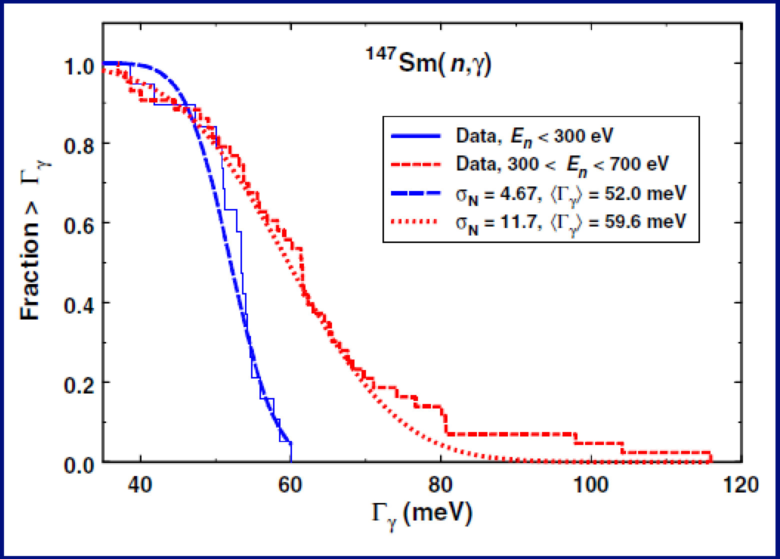
$$\Gamma_\gamma = \sum_{i=1}^{N} \Gamma_{\gamma i}$$

- Γ_γ distributions are calculated using measured NLD and PSF via a NSM simulation

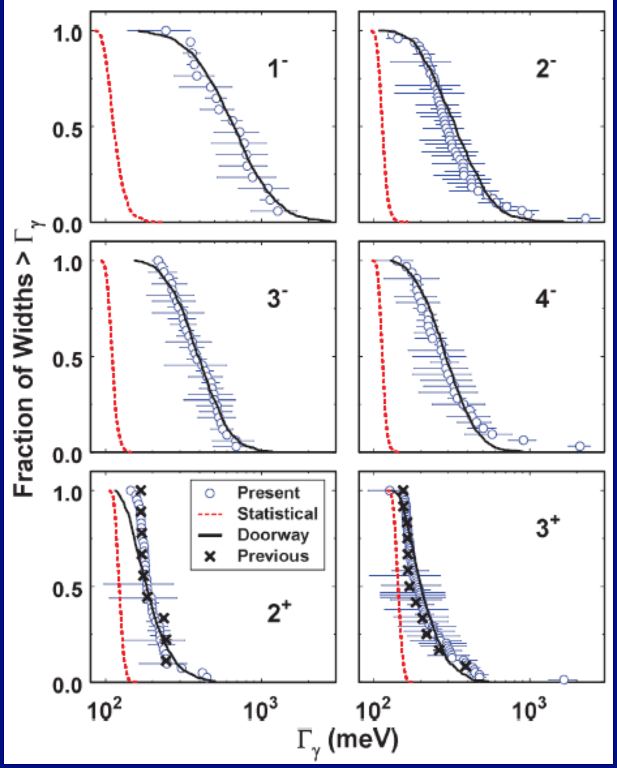


Using Γ_γ Distributions to Test the Statistical Model Assumption

- ^{148}Sm – abrupt change with neutron energy in both the mean and the width of the distribution in disagreement with known physics and remains unexplained[10]



- ^{96}Mo – disagreement (between measured and NSM-simulated distributions) revealed large non-statistical effects[2]



- All cases tested so far revealed substantial disagreements with the assumption that the NSM is applicable

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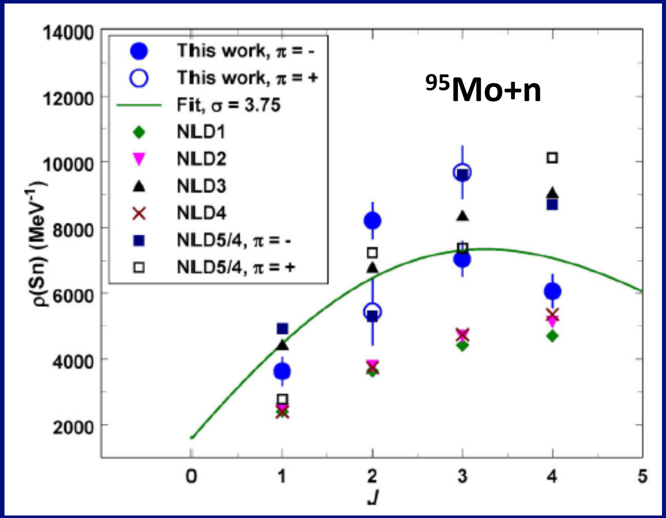
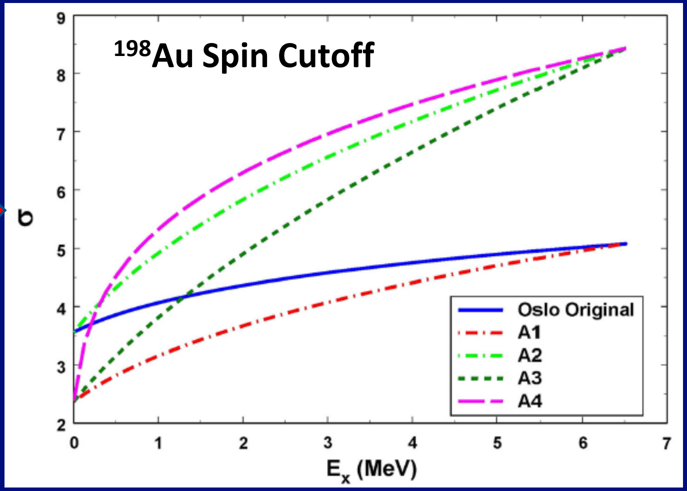
Using Neutron Resonance Data to Test and Constrain Spin-Distribution Models

- In many cases, the only constraints on NLD models at high excitation are from neutron resonance data
- Normalization to the total NLD requires a spin distribution model
- Normalization factor typically is quite large because the single spin constrained by the neutron resonance data usually is the least likely spin in the distribution
- With tools now available, it is possible to do much better
- Average neutron resonance spacings can be measured[3] for several J^{π}'s
- Γ_{γ} distributions for several J^{π}'s can be measured and used to constrain the spin distribution across a range of excitation energies[11]
- Two cases tested so far[3,11] disagree with standard spin-distribution models





Summary

- Neutron resonance data play many roles in improving NLDs and PSFs
- Traditional and continuing role of calibrating NLDs and PSFs measured via Oslo techniques
- State-of-the-art neutron resonance data provided by instruments like DICER and DANCE allow more stringent tests of assumptions inherent in extracting NLDs and PSFs
- All these new neutron resonance data have revealed problems with these assumptions
  Gamma decay in ^{96}Mo is not statistical as assumed[2]
  ^{148}Sm Γ_γ distribution undergoes an abrupt change in disagreement with model[10]
  ^{198}Au Γ_γ distribution is inconsistent with the assumed spin distribution[11]
  ^{95}Mo average resonance spacings differ from current models[3]
- In addition to testing and improving models needed for applications, these neutron resonance data can have direct impact on applications such as criticality safety

References

1. A. C. Larsen *et al*., Phys. Rev. C **83**, 034315 (2011)
2. P. E. Koeher *et al*., Phys. Rev. C **88**, 041305(R) (2013)
3. P. E. Koehler, Phys. Rev. C **105**, 054306 (2022)
4. P. E. Koehler *et al*., Phys. Rev. C **76**, 025804 (2007)
5. A. Stamatopoulos *et al*., Nucl. Inst. and Methods in Physics Research A **1025**, 166166 (2022)
6. R. Reifarth *et al*., Nucl. Inst. and Methods in Physics Research A **531**, 530 (2004)
7. A. Ebran *et al*., Phys. Rev. C **99**, 064603 (2019)
8. A. Chambers, Five year execution plan for mission and vision of the United States Department of Energy Nuclear Criticality Safety Program, March 2022
9. L. C. Leal *et al*., Assessment of Fission Product Cross Section Data for Burnup Credit Applications, ORNL/TM-2005/65 (2007)
10. P. E. Koehler *et al*., Phys. Rev. Lett. **108**, 142502 (2012)
11. P. E. Koehler *et al*., Eur. Phys. J. A 58:195 (2022)