Recent Experiments at ORELA and LANSCE, and Their Impact on Compound Nuclear Models

(Main motivation: Nuclear Astrophysics)

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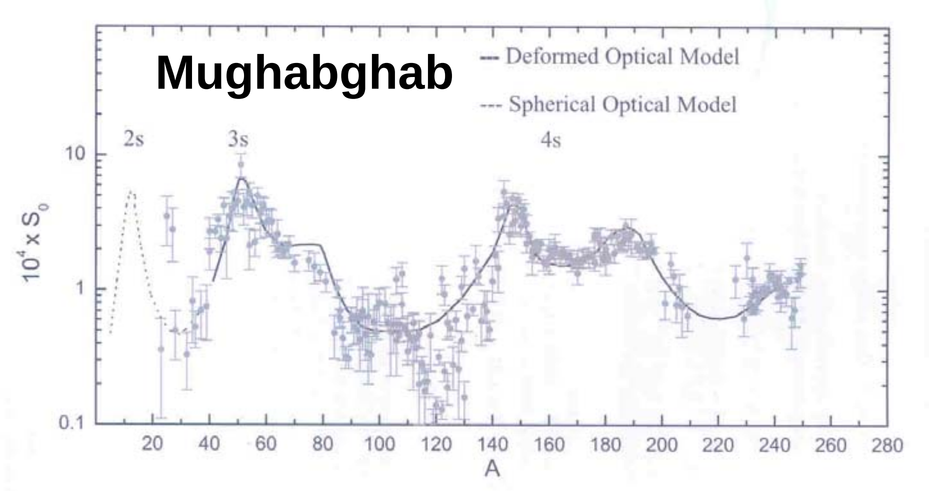
Close Connection Between Neutron Measurements in the Resonance Region and Compound Nuclear Models

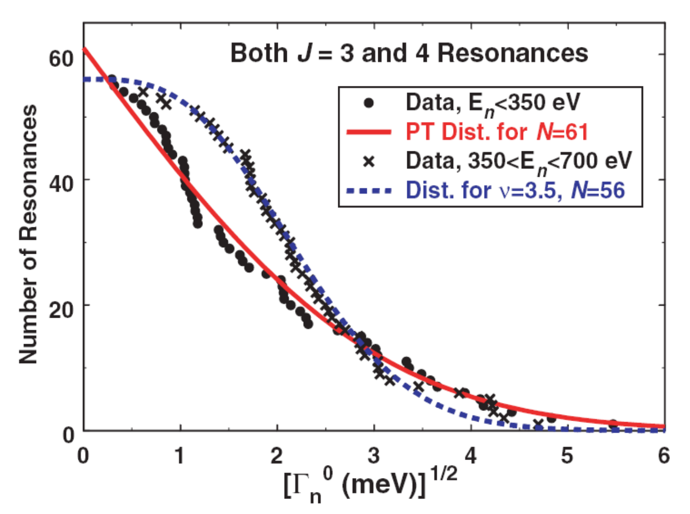
- Model parameters tested and improved via experiments.

  Level Spacings. Neutron and γ-ray Strength Functions.

- Basic assumptions of models tested.

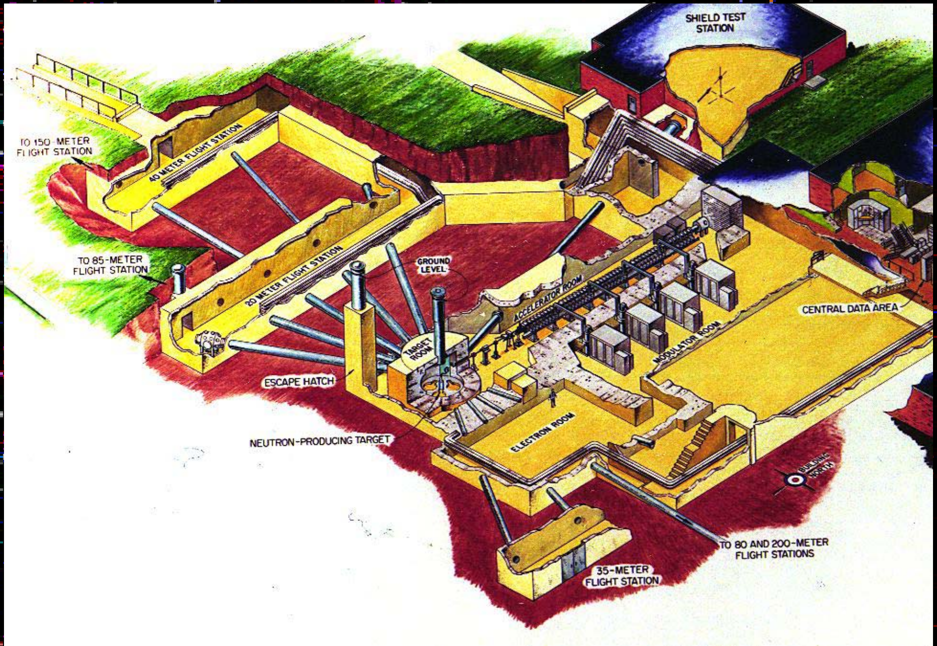
  Distributions of Widths and Spacings.





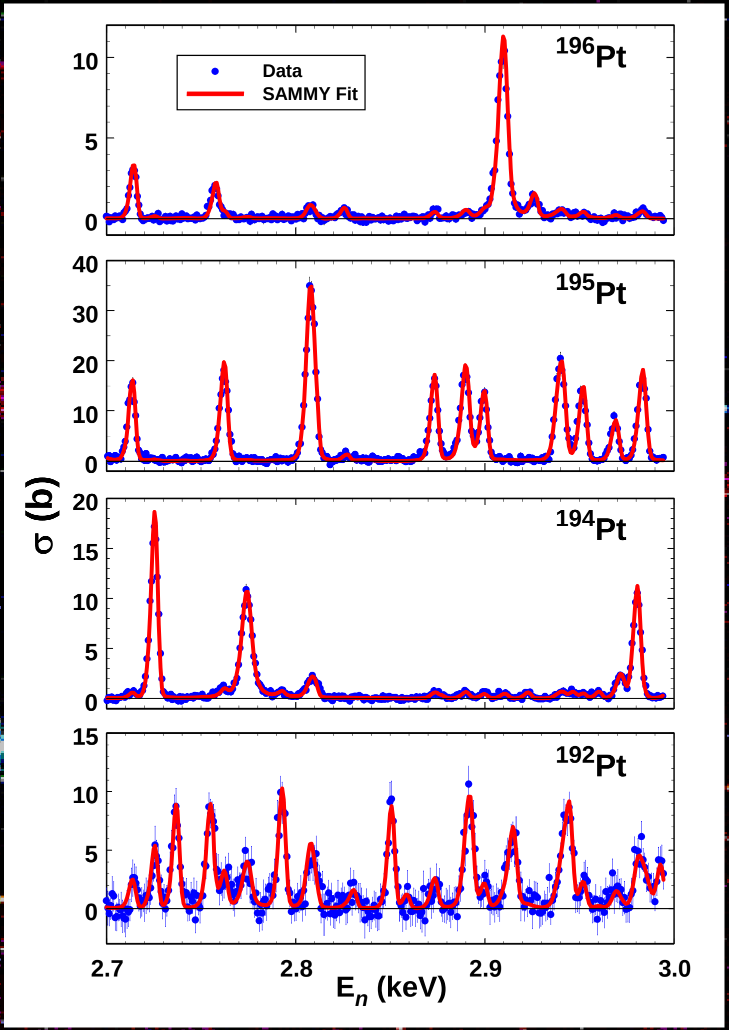
Example 1: $^{192,194,195,196}Pt$ Measurements at ORELA

- Measured (n,γ) and total cross sections using isotopically-enriched samples.
  (n,γ) using C_6D_6 at 40 m on FP7 at ORELA.
  σ_t using ^6Li-glass detector at 80 m on FP1 at ORELA.



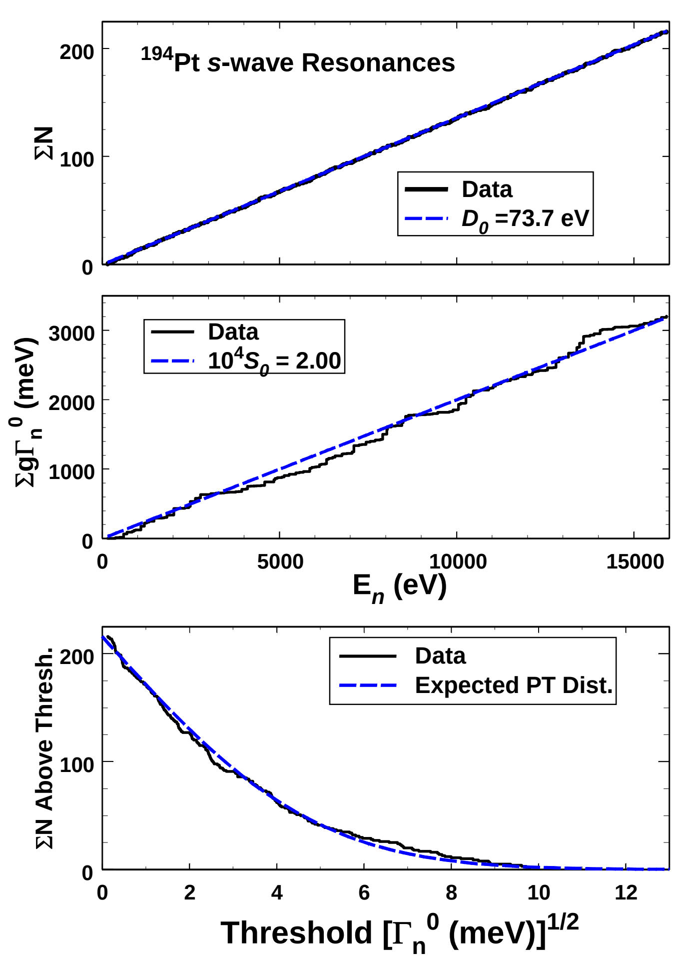
Example 1: $^{192,194,195,196}Pt$ Measurements at ORELA

- R-matrix analysis using SAMMY.
  "Simultaneous" fits to all 9 data sets.
  1262 resonances (70 before).



Example 1: $^{192,194,195,196}Pt$ Measurements at ORELA

- Determined S_0, D_0, $\langle\Gamma_{\gamma 0}\rangle$, and neutron- and γ-width distributions for all four isotopes.
  Separate values for 0^- and 1^- resonances in ^{195}Pt.
- Determined S_1, D_1, and neutron-width distributions for $^{194,196}Pt$.
  Corrected for missing resonances.

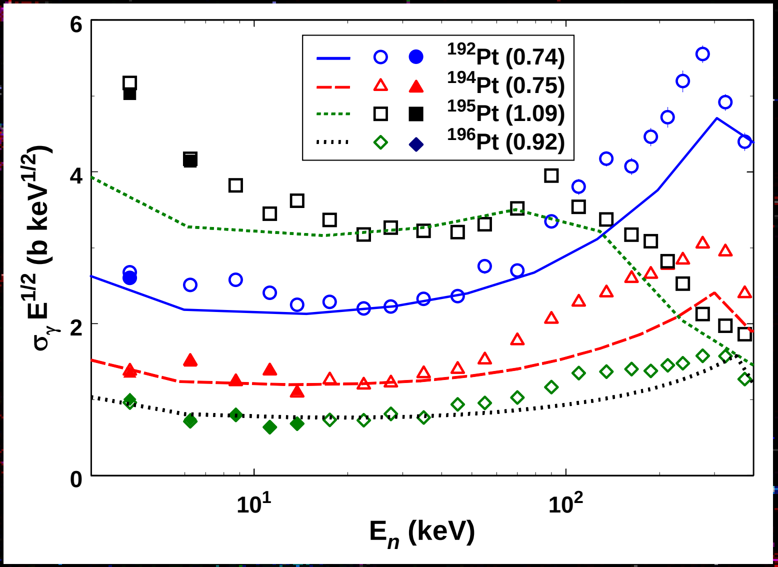


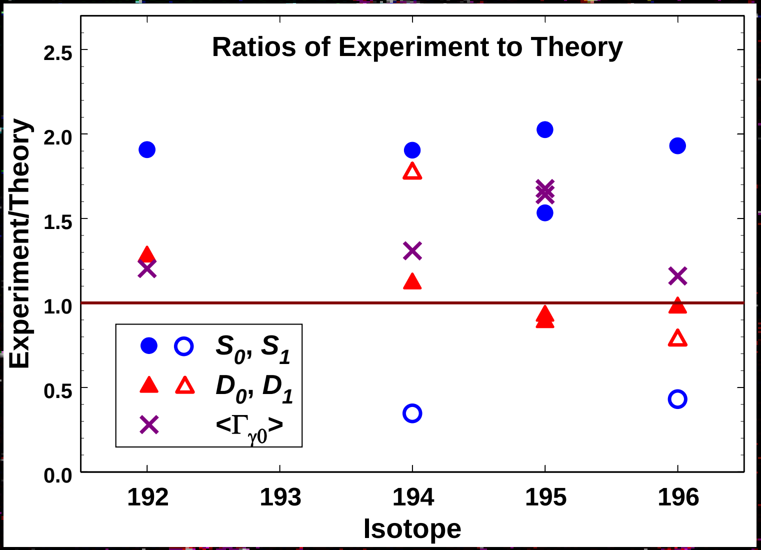
Example 1: ^{192,194,195,196}Pt Measurements at ORELA

- Comparison to statistical model (NON-SMOKER).

  Cross sections.
  Theory cross-section shapes flatter than measured (normalized to data near 30 keV).

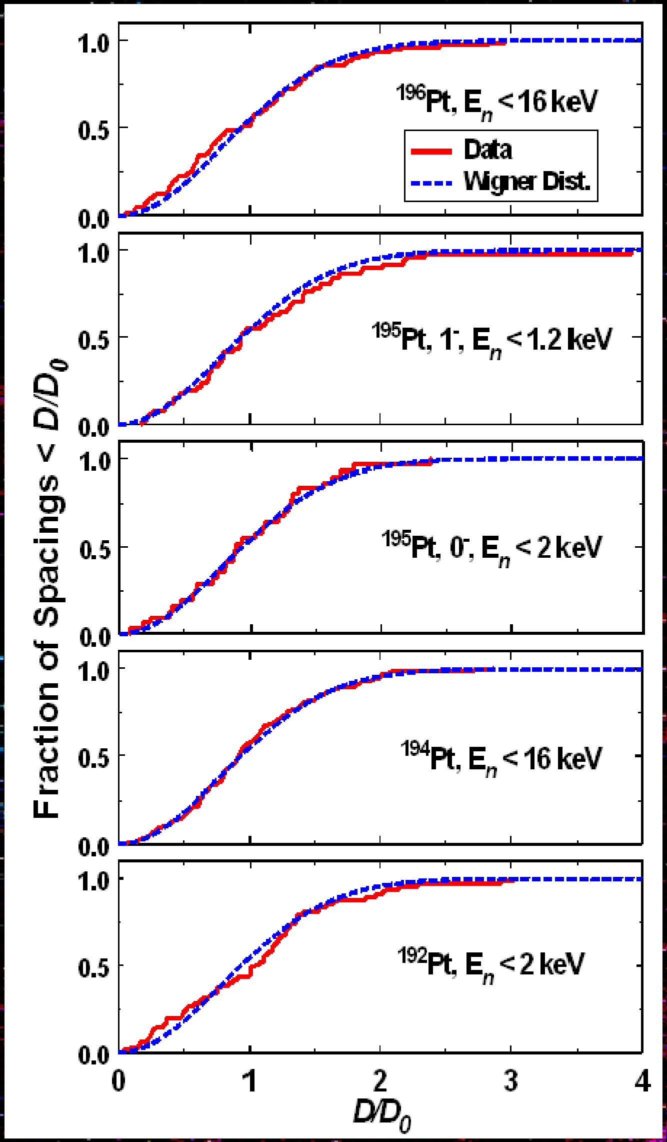
  Average resonance parameters.
  More direct comparison $T = 2\pi S$.
  Minimizes confounding uncertainties.
  Results mixed.





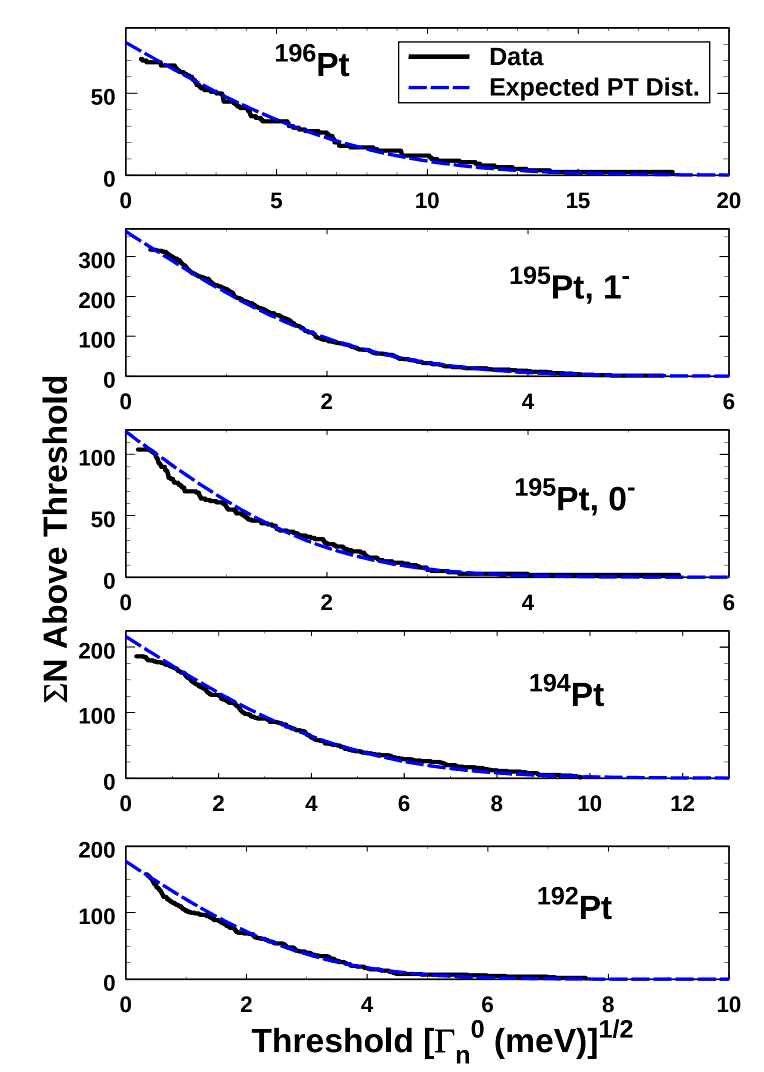
Example 1: $^{192,194,195,196}Pt$ Measurements at ORELA

- Distributions.
  Level spacings.
  Agree with expected
  Wigner distributions.



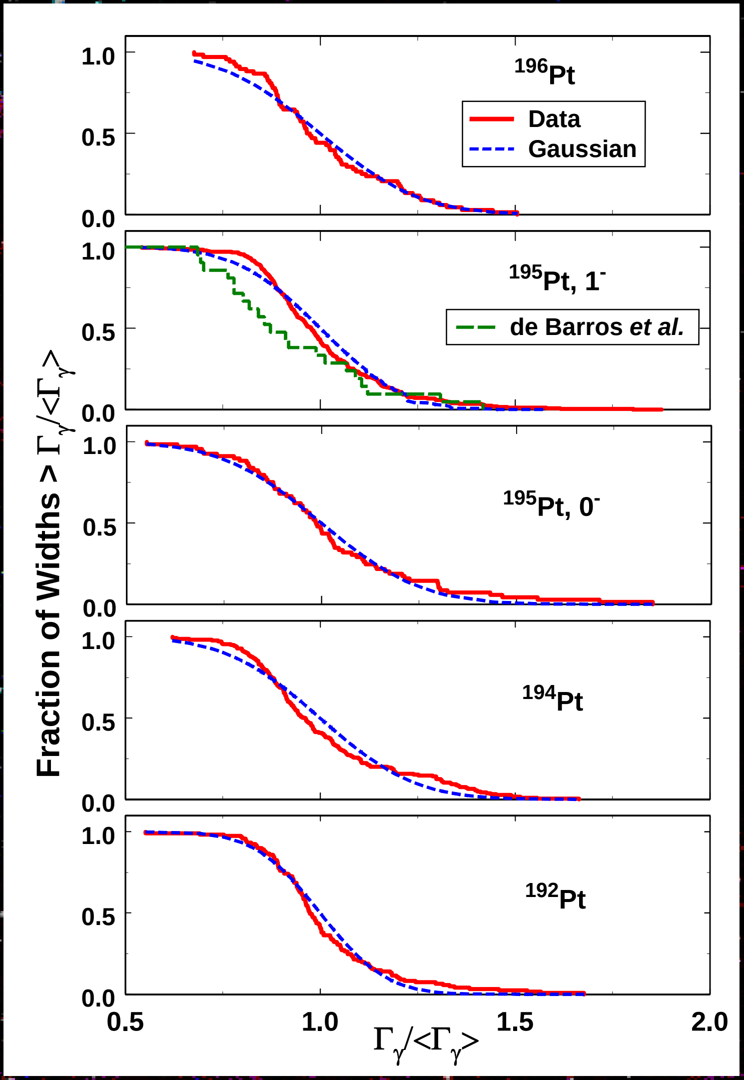
Example 1: $^{192,194,195,196}Pt$ Measurements at ORELA

- Distributions.
  Neutron widths.
  In agreement with expected Porter-Thomas distribution.



Example 1: ^{192,194,195,196}Pt Measurements at ORELA

- Distributions.
  Radiation widths.
  Narrow as expected.
  Some appear to be "double".

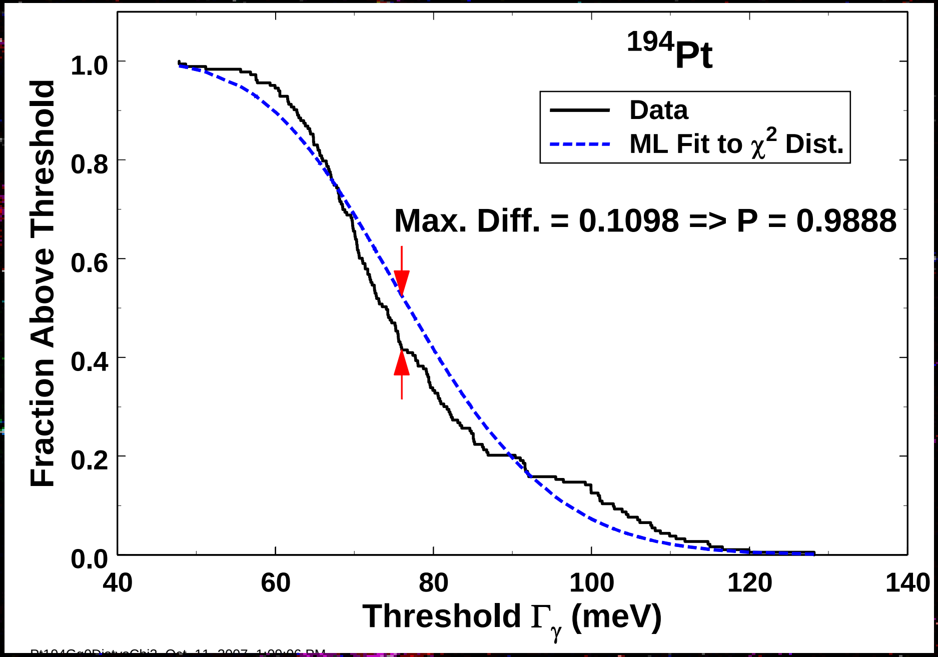


Is There New Information in Γ_γ Distributions?

- Two components real?
  Determined ν and $\langle\Gamma_\gamma\rangle$ using maximum-likelihood technique.

  Used Kolmogorov-Smirnov (KS) test to determine if data consistent with this χ^2 distribution.
  Rejected at 98.88% CL.

  Correlations?
  Broken symmetries?
  Isomers?



Is There New Information in Γ_γ Distributions?

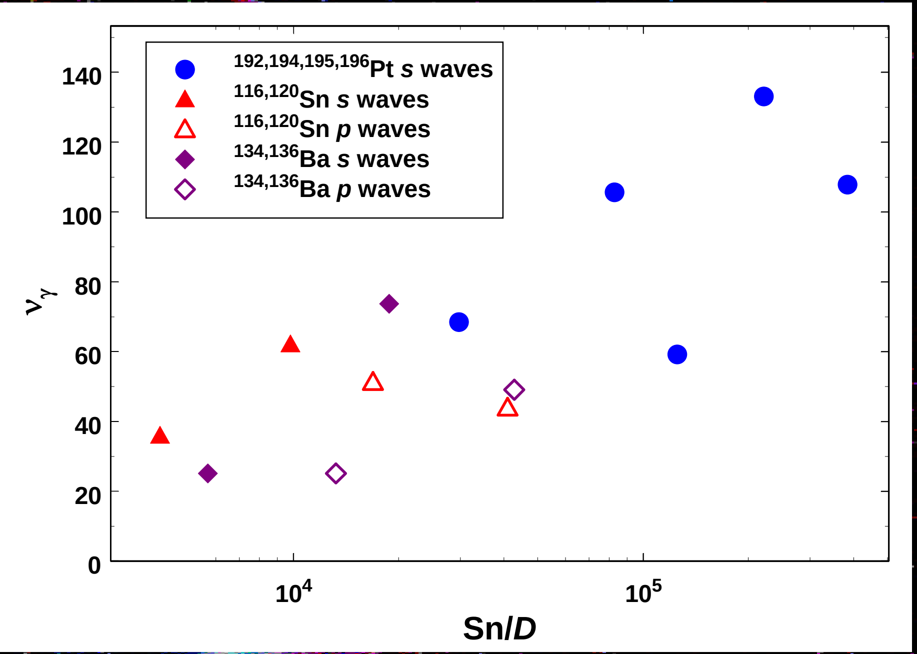
- Can ν values constrain model parameters?

$$P(x,\nu) = \frac{\nu}{2G(\nu/2)}\left(\frac{\nu x}{2}\right)^{\nu/2-1}\exp\left(-\frac{\nu x}{2}\right)$$

$x=\Gamma/\langle\Gamma\rangle$

ν proportional to number of independently contributing partial widths (number of channels, N).

$Sn/D \approx N$.



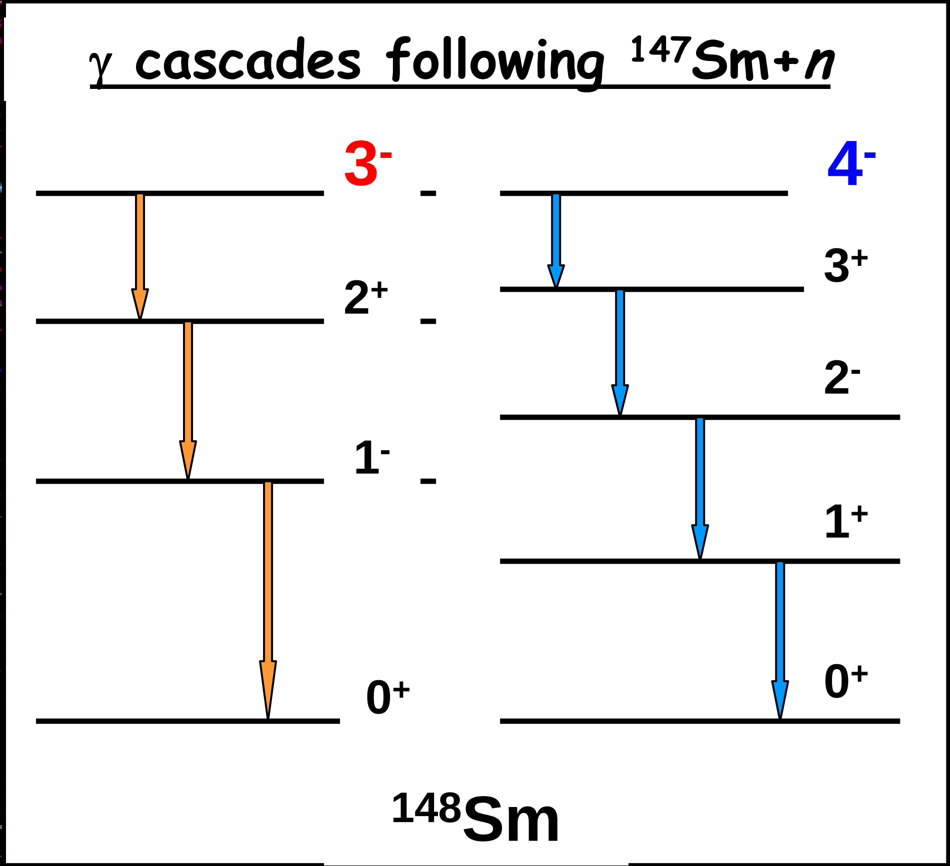
Correlated!

Can this information be used to test and improve models?

Example 2: ^{147}Sm(n,γ) at LANSCE

Determining Resonance Spins in Odd-A Nuclides

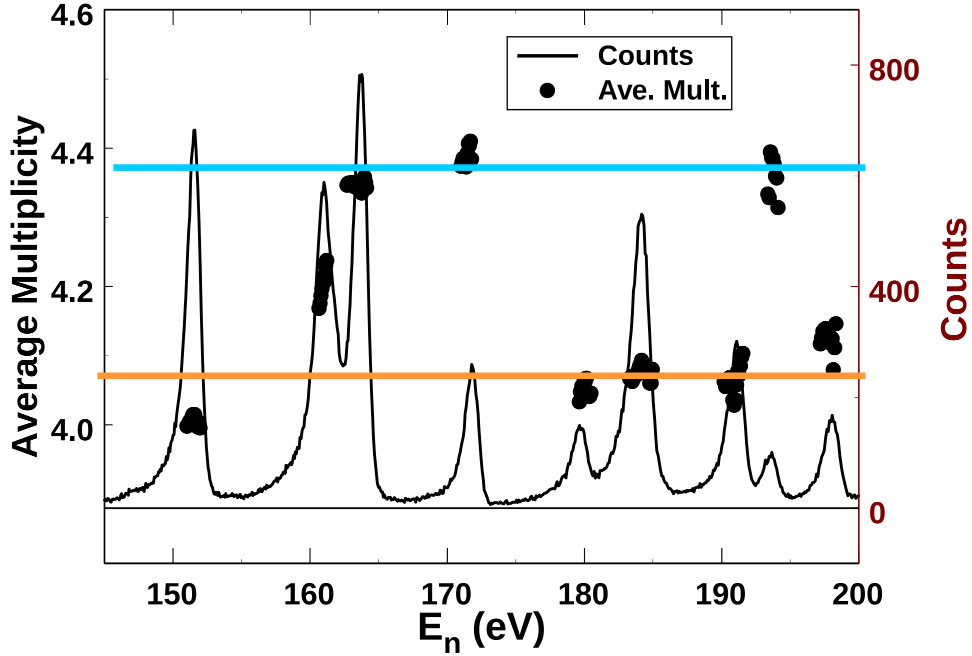
- $J^{\pi}=3^{-}$ and 4^{-} states in ^{148}Sm formed at high E_x by *s*-wave neutron capture on ^{147}Sm ($I^{\pi}=7/2^{-}$).
- ^{148}Sm decays to ground state by emitting M γ-rays.
  Simple dipole model predicts $M_{J=3}=3$ and $M_{J=4}=4$.
  Other multipolarities and decay statistics result in M distributions with different <M> for J=3 and 4.
- <u>Measure <M> to determine J</u>



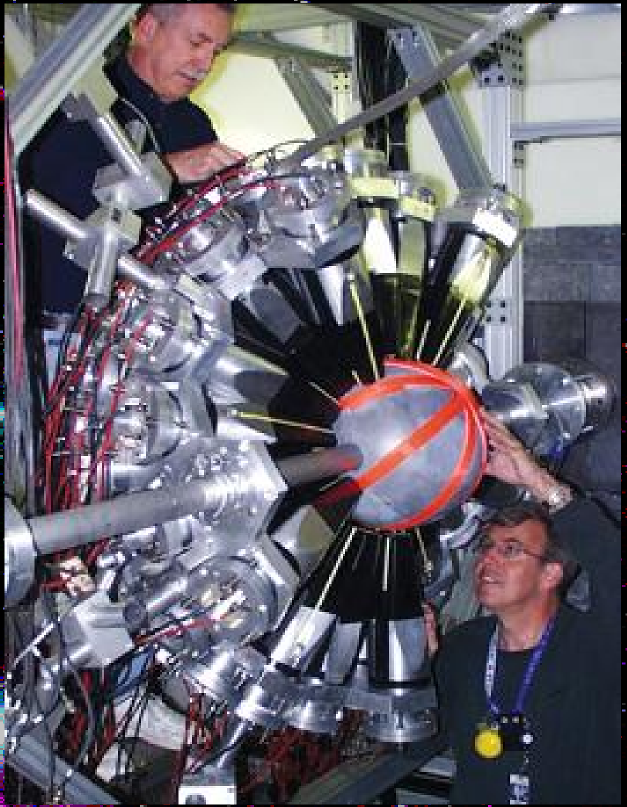
The Experiment at LANSCE

- 10-mg enriched ^{147}Sm sample.
- E_n, E_γ, and M measured for each event.
- Background measured using blank sample holder.

Results: <M> and Yield vs. E_n



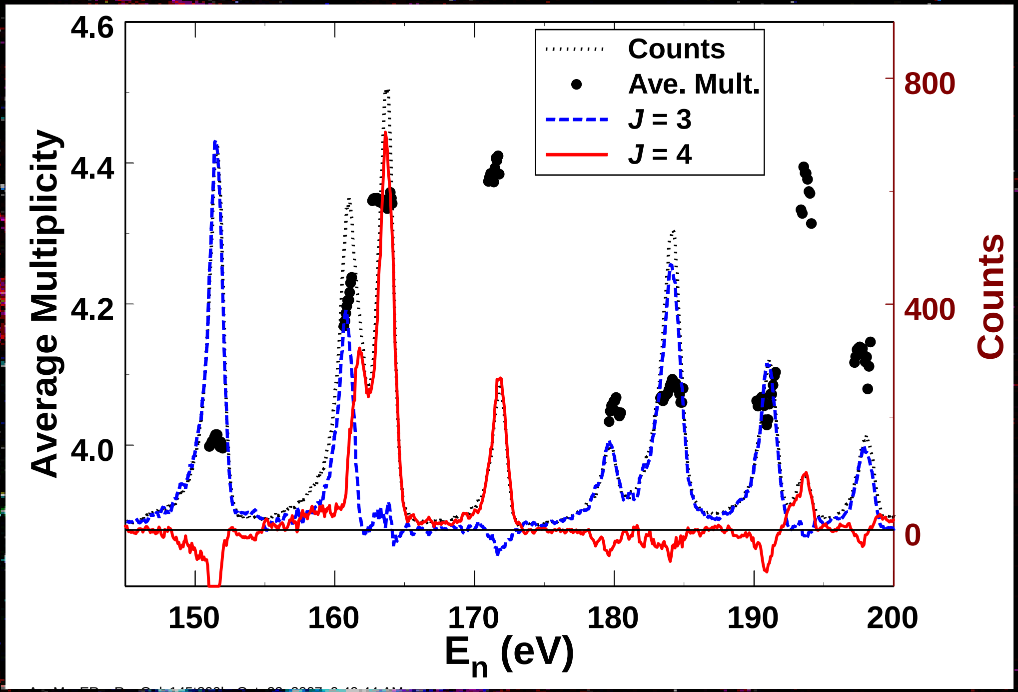
The DANCE Detector



160-element BaF_2 ball

New Technique for Determining Spins from Multiplicities

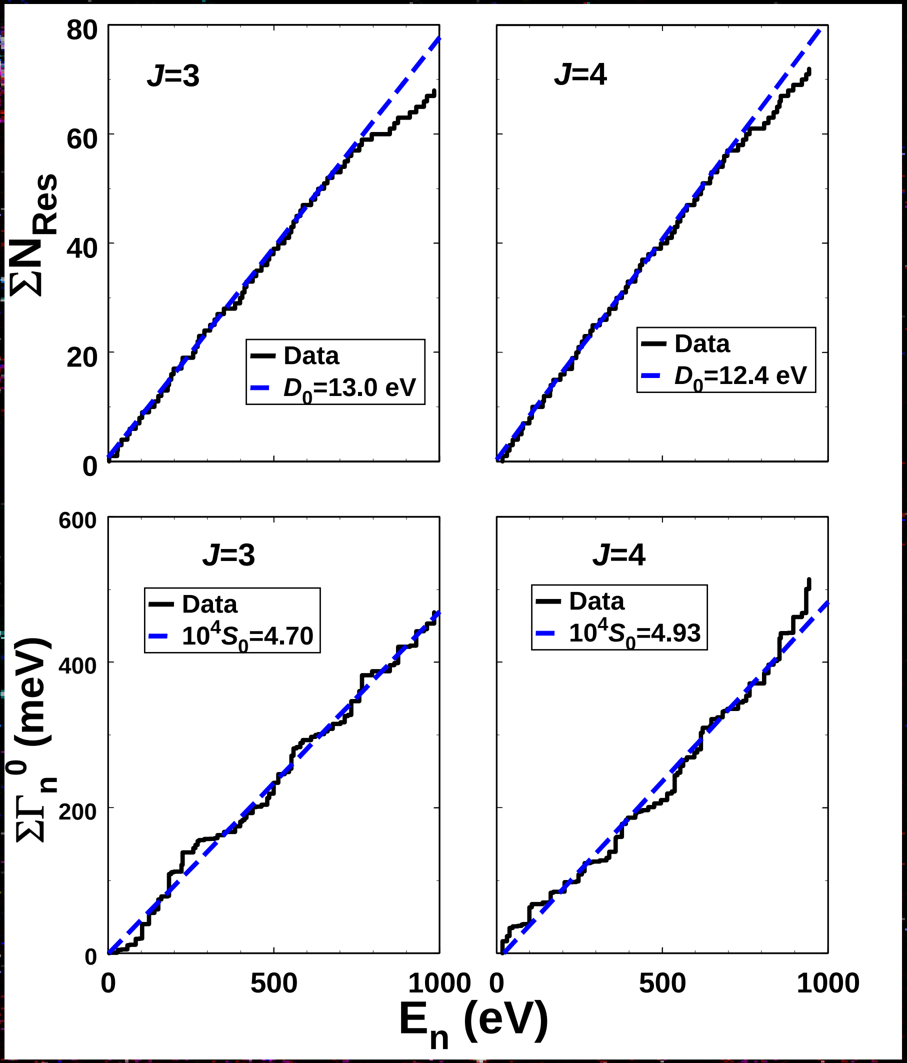
- $\langle M \rangle = \Sigma i C_i / \Sigma C_i$
  Problematical when resonances not well resolved.
  Noisy.
- Used "Judicious Linear Combinations" of M's to determine J's.
  JLC's measure difference between data and prototypical J=3 and 4 M distributions.
  Revealed 6 previously unknown doublets.



P. E. Koehler *et al.*, Phys. Rev. C 76, 025804 (2007).

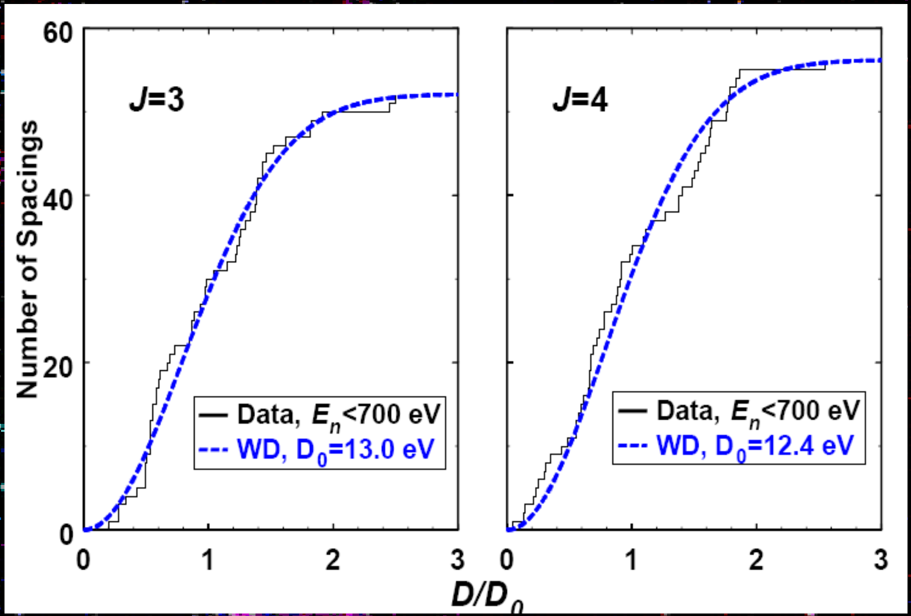
Results: Spins, Level Spacings, and Strength Functions

- 42 new J values for resonances with previously unknown (34) or tentative (8) J.
- Extracted D_0's and S_0's for each J (Γ_n^0 from Mizumoto). Results consistent with theory (spin cutoff parameter, statistical model S_0 ratio).



Results: Spins, Level Spacings, and Strength Functions

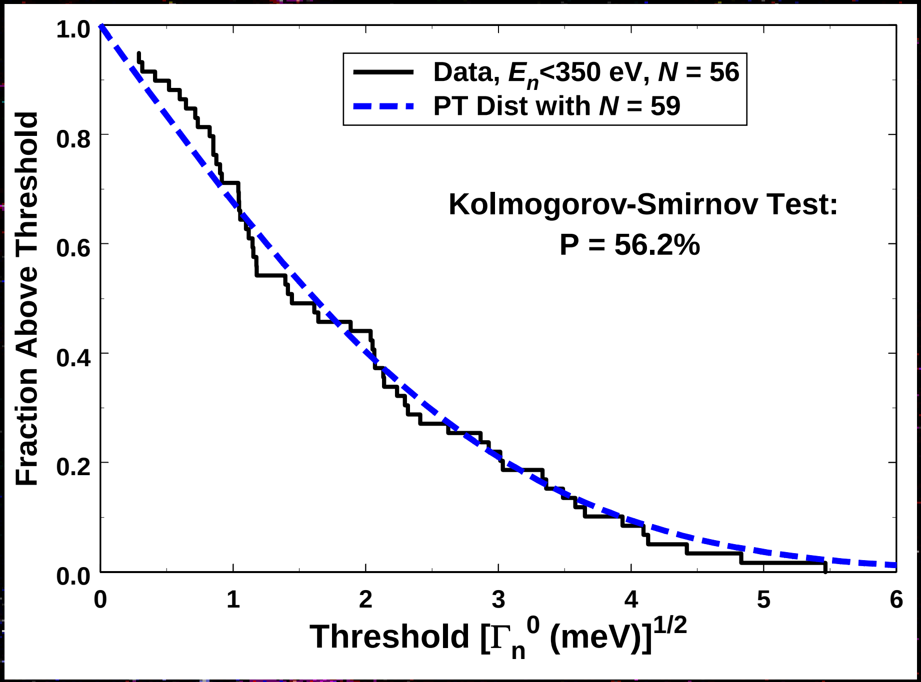
- Very few resonances missed below 700 eV.
  Spacings agree with Wigner and Δ_3.
  Two techniques used to correct for missed res.



Results: Neutron Width Distributions

- Divided data into two regions: 0-350 eV and 350-700 eV.
  Previous ^{147}Sm(n,α) data revealed unexplained abrupt change in S_α ratio at 350 eV.
- Examined Γ_n^0 distributions above and below this energy.
- Γ_n^0's should follow a Porter-Thomas (PT) distribution (χ^2 distribution with ν=1).
- <u>E_n<350 eV data agree with PT.</u> Used standard technique (Fuketa and Harvey) to calculate that only 3 small resonances missed by 350 eV (8 by 700 eV).

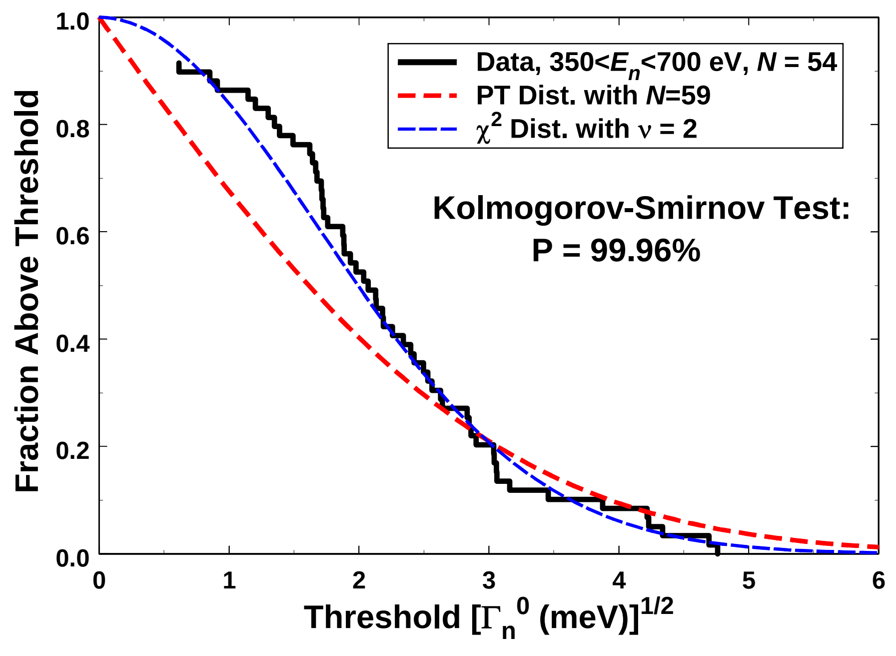
Γ_n^0 Distribution, E_n<350 eV

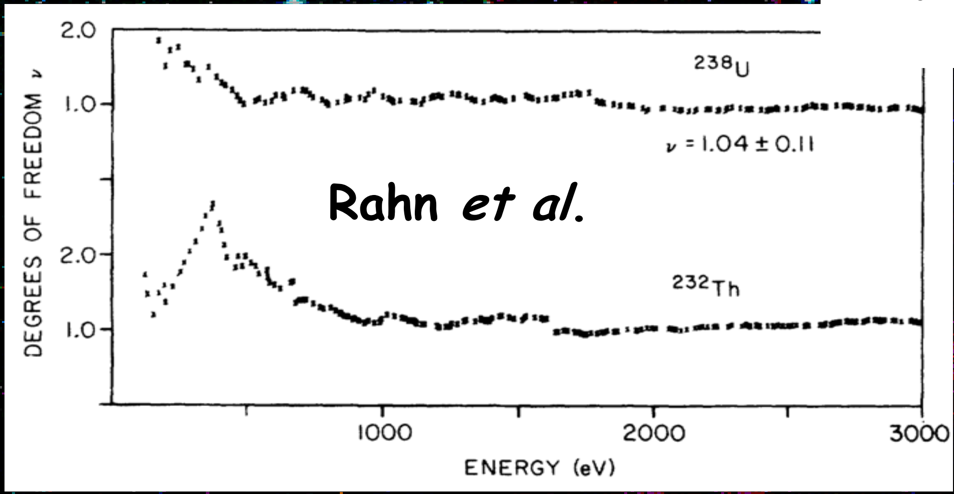


Results: Non-statistical Effect

- Neutron Width Data for $350<E_n<700$ eV do not agree with expected PT dist.
- Data in good agreement with $\nu \geq 2$ (ML, $\nu=3.19\pm0.83$).
- Similar effects reported for ^{232}Th, ^{151}Sm, ^{163}Dy, ^{167}Er, ^{175}Lu, and ^{177}Hf.
- No Known explanation.
- TRIV implies $\nu = 2$.

Γ_n^0 Distribution, 350<En<700 eV





Conclusions

- State-of-the-art neutron experiments can provide valuable new information for improving compound-nuclear models.

- Γ_γ distributions may be valuable source of new (overlooked) data with which to test and improve models.

- Determining resonance spins for odd-A nuclides now routine using DANCE.

- Surprises so far:

  Γ_γ distributions for Pt may have two components.
  Γ_n^0 distribution for ^{147}Sm disagrees with PT.