Simulating Γ_γ Distributions

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Outline

- Why simulate Γ_γ distributions?
- What is Γ_γ?
- How are Γ_γ's measured?
- Simulating Γ_γ distributions with the statistical model.
- Results and physics issues.
  Testing level-densities and photon-strength-functions.
  Constraining the Porter-Thomas distribution in Pt.
  Failure of the statistical model in ^{96}Mo?

Motivation: Can the Loop be Closed?

- **Measured $\rho(E_x)$ and $f_{XL}(E_\gamma)$ calibrated using part of the neutron data.**
  D_0 and $\langle\Gamma_{\gamma 0}\rangle$.

- **Can statistical-model simulations reproduce $\langle\Gamma_\gamma\rangle$ as well as Γ_γ distributions (for all J^π)?**

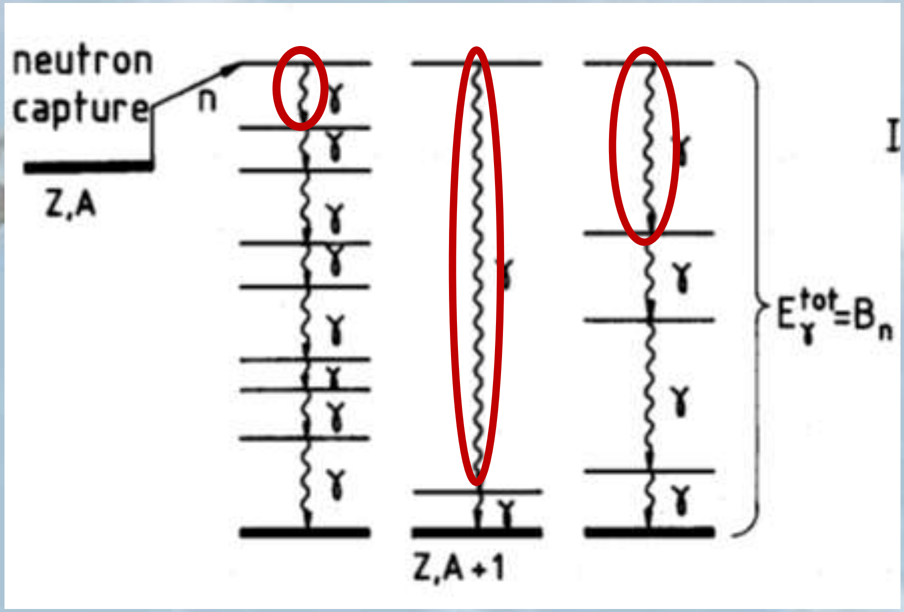
- **Tests:**
  $\rho(E_x)$ and $f_{XL}(E_\gamma)$.
  Statistical-model assumptions.
  J^π distribution model.

What is Γ_γ?

- Γ_γ is the total radiation width.

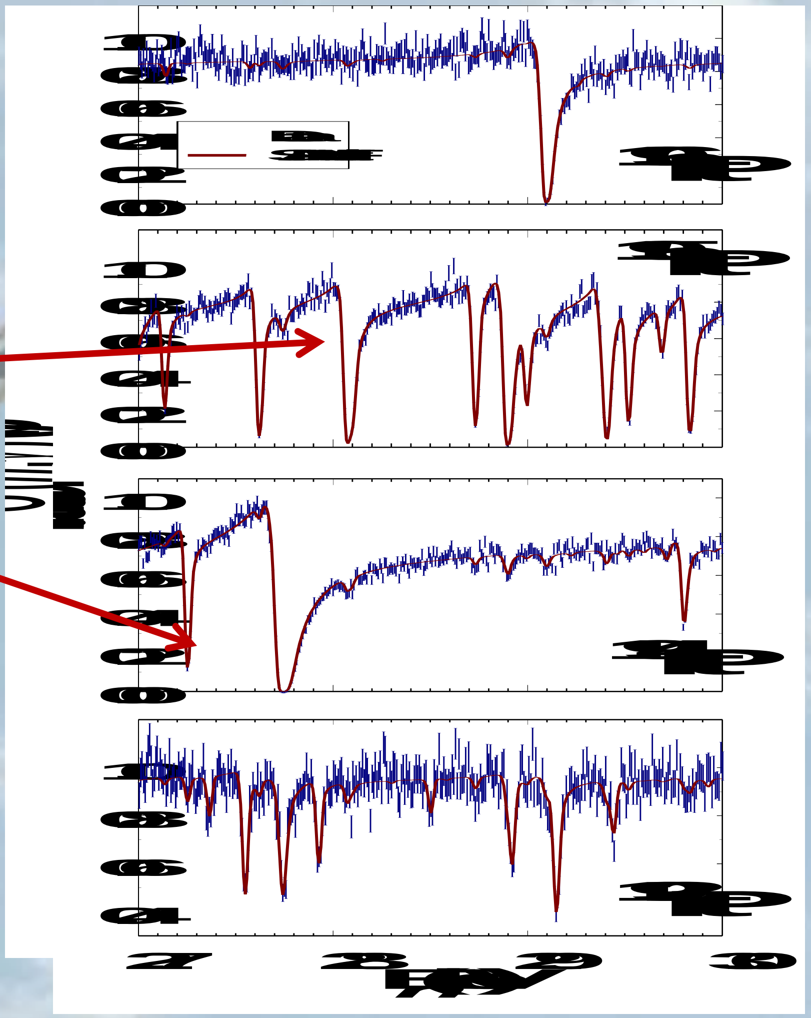
  Sum of partial radiation widths, $\Gamma_{\gamma i}$, for primary transitions from the capturing state (resonance).

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



How are Γ_γ's Measured?

- ***R*-matrix analysis of neutron-resonance data.**
- **Need both capture and total (transmission) data.**
- **Capture area. $A_\gamma = g_J \Gamma_n \Gamma_\gamma / (\Gamma_n + \Gamma_\gamma)$.**
- **Transmission → Γ_n.**
- **Get Γ_γ only for subset of *s*-wave resonances.**
- **Much better and larger sets of Γ_γ data due to recent improvements.**



What Does the Statistical Model Predict?

- $\Gamma_{\gamma i}$'s follow the Porter-Thomas distribution (PTD).
  Same distribution as Γ_n^0
  Follows from assumption of compound nucleus model and central limit theorem of statistics.
  The PTD is a χ^2 distribution with 1 degree of freedom (ν=1).

$$P(x;\rho)dx = \frac{\rho(\rho x)^{\rho-1}e^{-\rho x}}{\Gamma(\rho)}dx$$

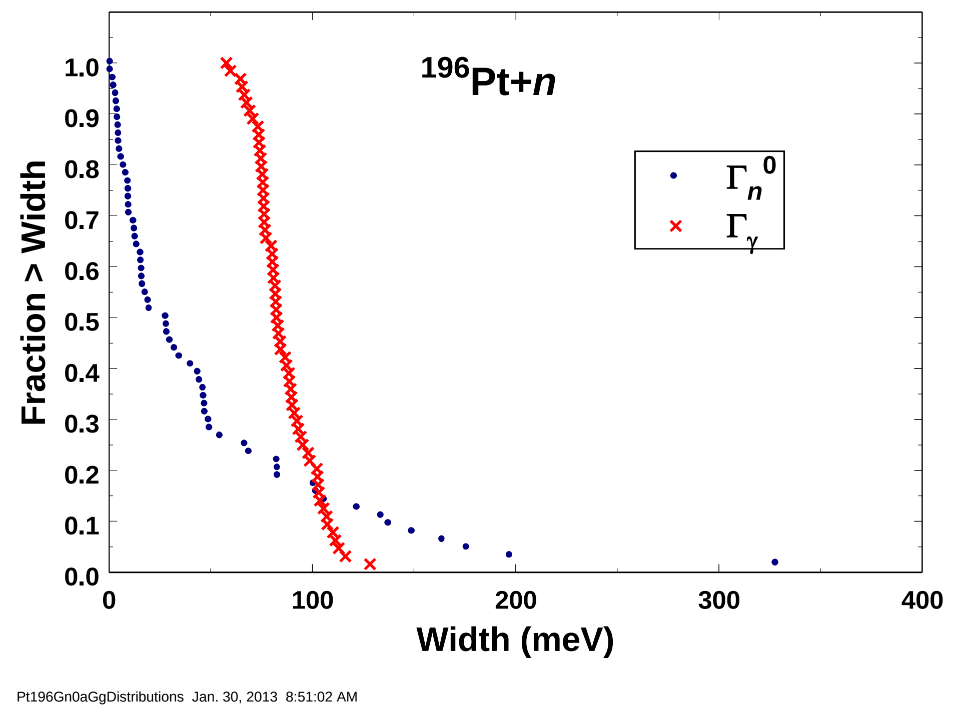
$$\nu = 2\rho, x = \frac{\Gamma}{\langle\Gamma\rangle}$$

- Sum of samples from N χ^2 distributions having ν = 1 is a χ^2 distribution with N degrees of freedom.
  Expect Γ_γ to follow a χ^2 distribution with ν equal to the number of independently-contributing channels, ν≈100.

Comparison of Γ_n^0 and Γ_γ Distributions

- **Neutrons, Γ_n^0.**
  Single channel, ν=1.
  PTD.
  Very broad.

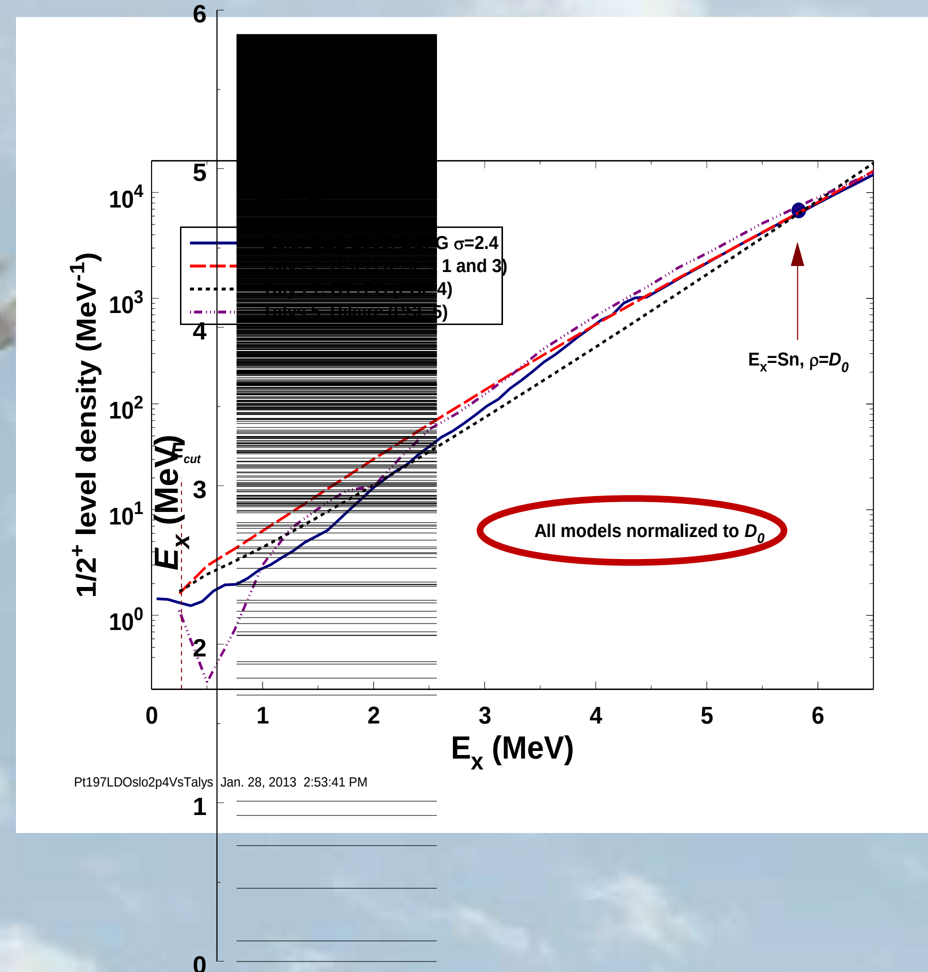
- **Gammas, Γ_γ.**
  ν~100 channels.
  Very narrow.



Simulating Γ_γ Distributions: Step 1

Generating a Level Scheme

- Use $\rho(E_x)$ and random number generator to get set of E_{xi}'s.
- Throw away those below E_{cut}.
- Add in known levels below E_{cut}.



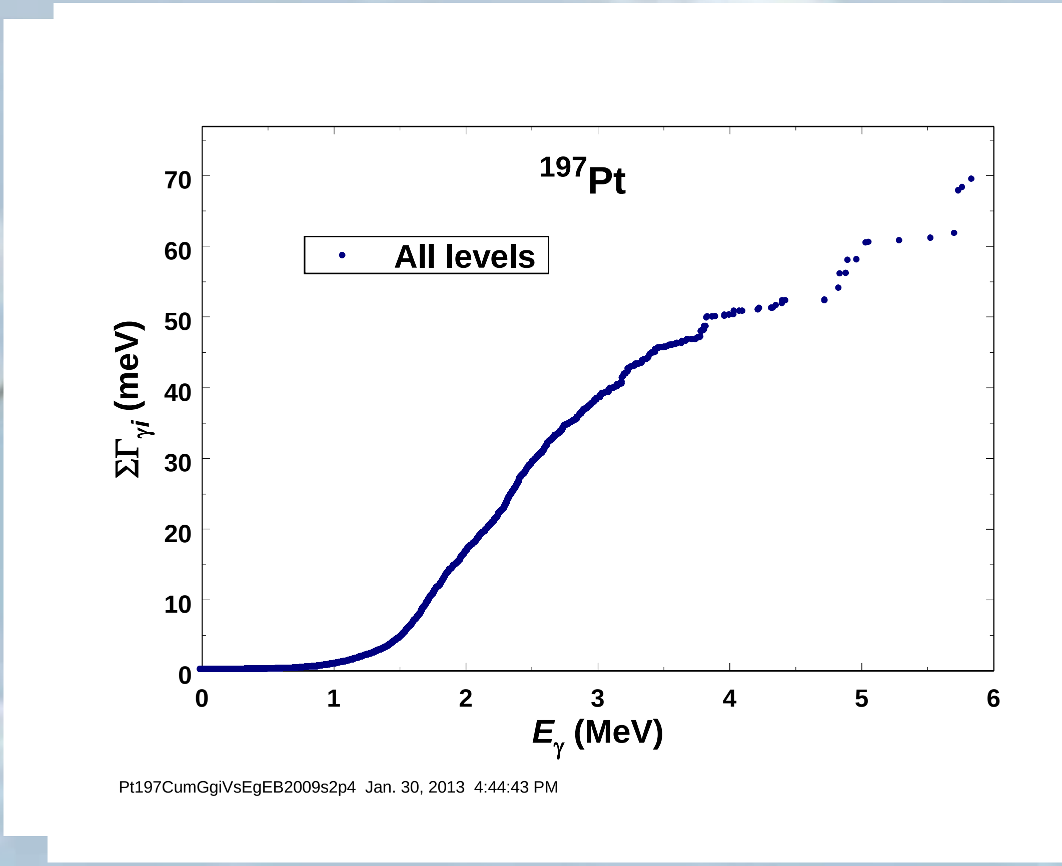
Simulating Γ_γ Distributions: Step 2
Calculating the $\Gamma_{\gamma i}$'s

- $E_{\gamma i} = S_n - E_{xi}$.
- Calculate $f_{X1}(E_{\gamma i})$'s.
- Calculate "PTD" factor ξ_i^2.

  Generalize to allow $\nu \neq 1$.

- $\Gamma_{\gamma i} = D_0 \, \xi_i^2 \, f_{X1}(E_{\gamma i}) \, E_{\gamma i}^3$.

  Calculate $\Gamma_{\gamma i}$'s for each J^π reached by dipole decay.

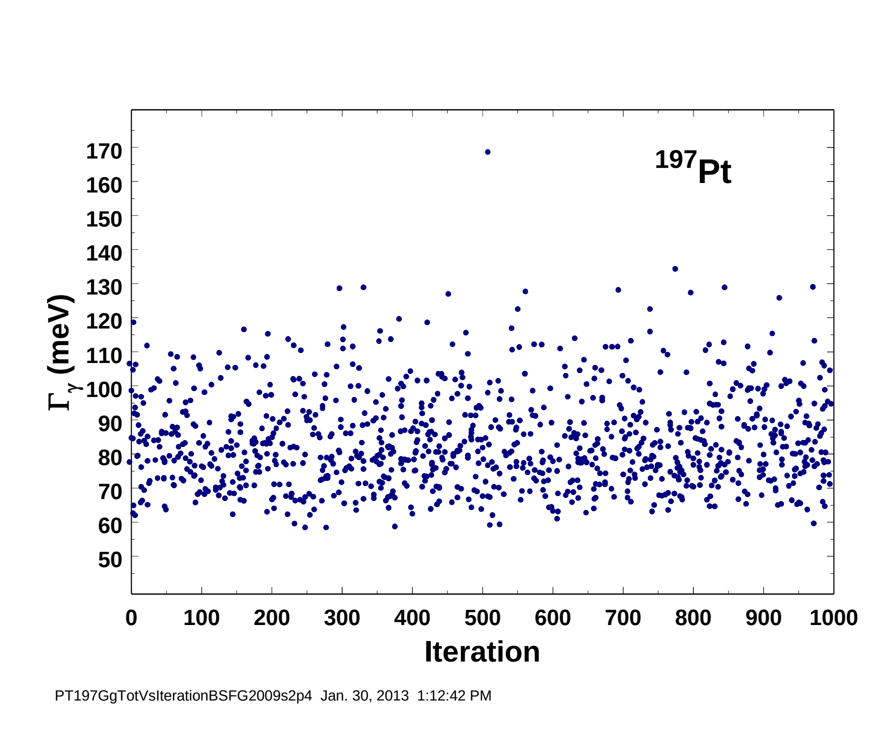


Simulating Γ_γ Distributions: Steps 3 and 4
Calculating Total Widths and Iterating

- Sum $\Gamma_{\gamma i}$'s to get total width.

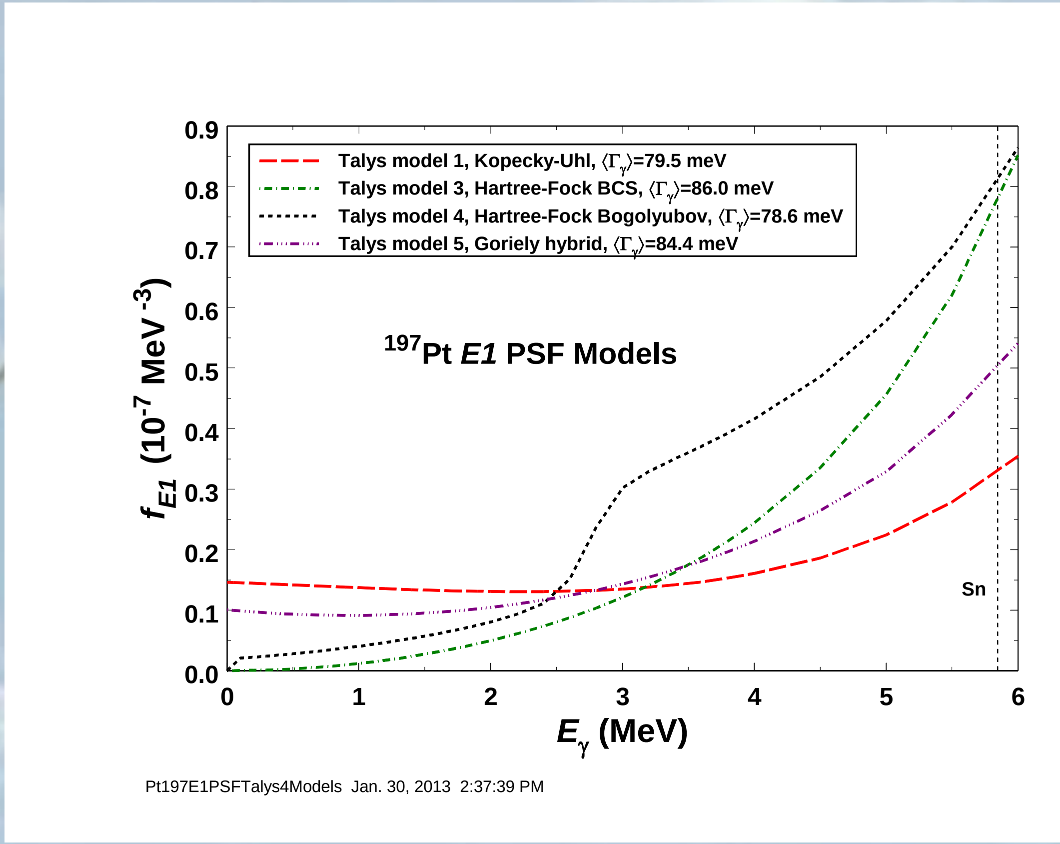
$$\Gamma_\gamma = \sum_{i,X,J} \Gamma_{\gamma i}$$

- Iterate.
  Use same level schemes, etc.
  New $\Gamma_{\gamma i}$'s by varying ξ_i^2 only.
  Yields distribution of Γ_γ's.
- Shape of Γ_γ distribution due to:
  Shapes of LD and PSF models.
  "PTD" fluctuations.



Examples: ^{197}Pt LD and PSF Models in Talys

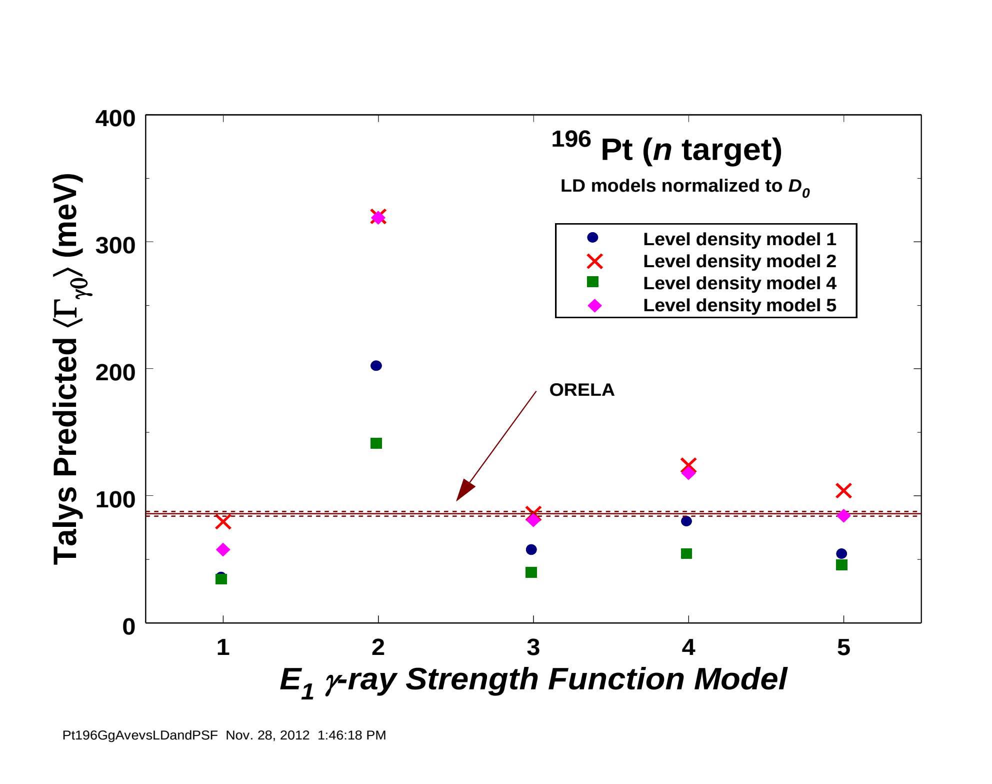
- Five LD models.
  1 – Const. T + Fermi Gas.
  2 – Back-shifted Fermi Gas.
  3 – Generalized Superfluid.*
  4 – Goriely.
  5 – Hilaire.
- Five PSF models.
  1 – Kopecky-Uhl Lorentzian.
  2 – Brink-Axel Lorentzian.
  3 – Hartree-Fock BCS.
  4 – Hartree-Fock Bogolyubov.
  5 – Goriely's Hybrid.



*Didn't use. Couldn't normalize.

^{197}Pt Talys Results for $\langle\Gamma_\gamma\rangle$

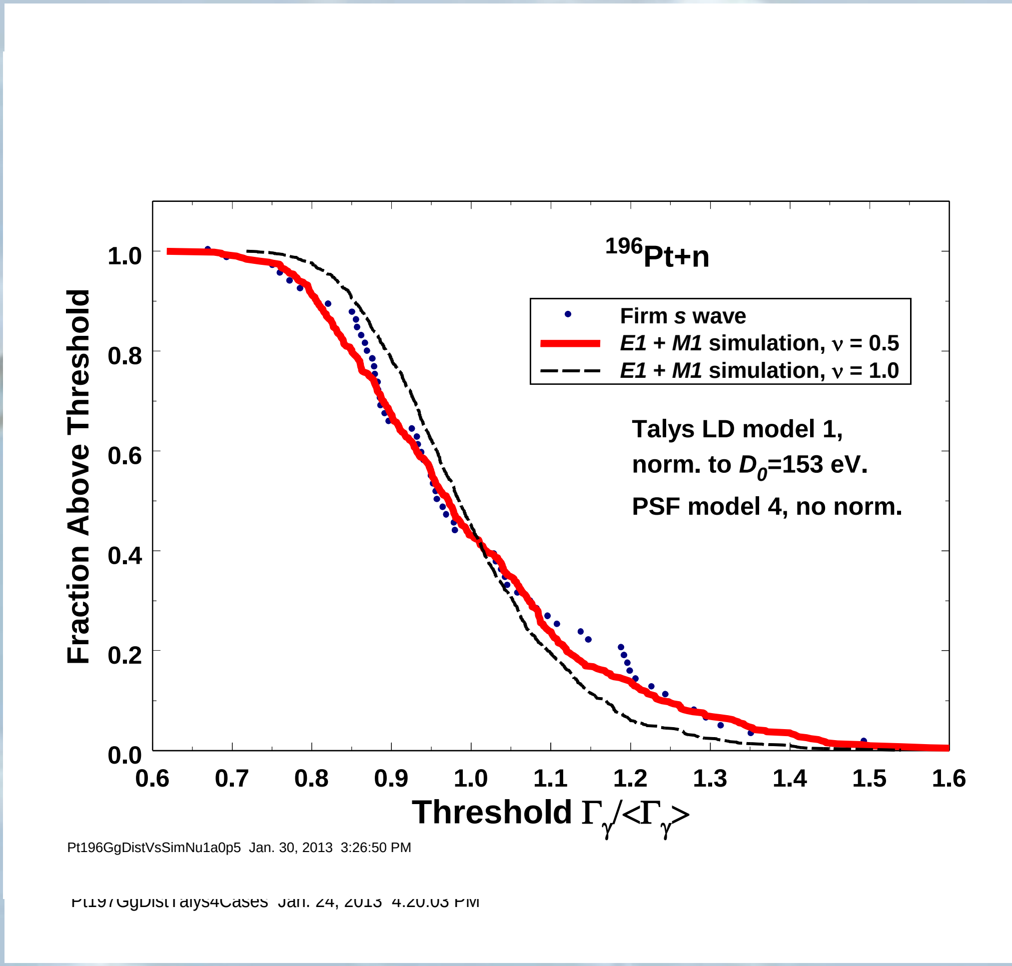
- Talys calculation with 4 LD and 5 PSF models.
- Normalized LD models to ORELA D_0 = 153 eV.
  LD models 1 and 2 normalized using "*a*", models 4 and 5 using "*c*" and "δ".
- PSF models un-normalized.
- Chose LD/PSF combinations which gave closest to ORELA value, $\langle\Gamma_\gamma\rangle$ = 85.9±1.8 meV, for simulations.



^{197}Pt Simulation Results with Talys Models

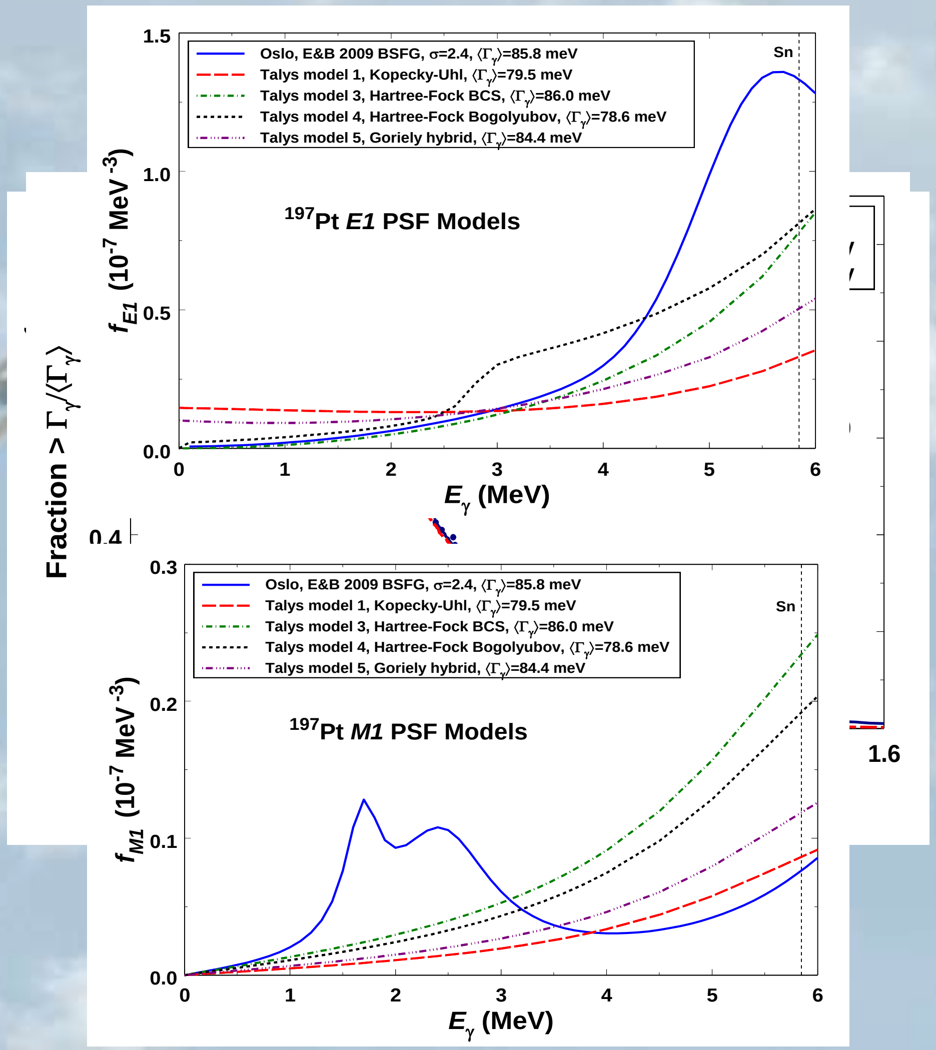
- All simulations using Talys models yielded Γ_γ distributions significantly narrower than measured.
- Decreasing ν results in much better agreement between simulation and data.

Another sign of violation of the PTD?



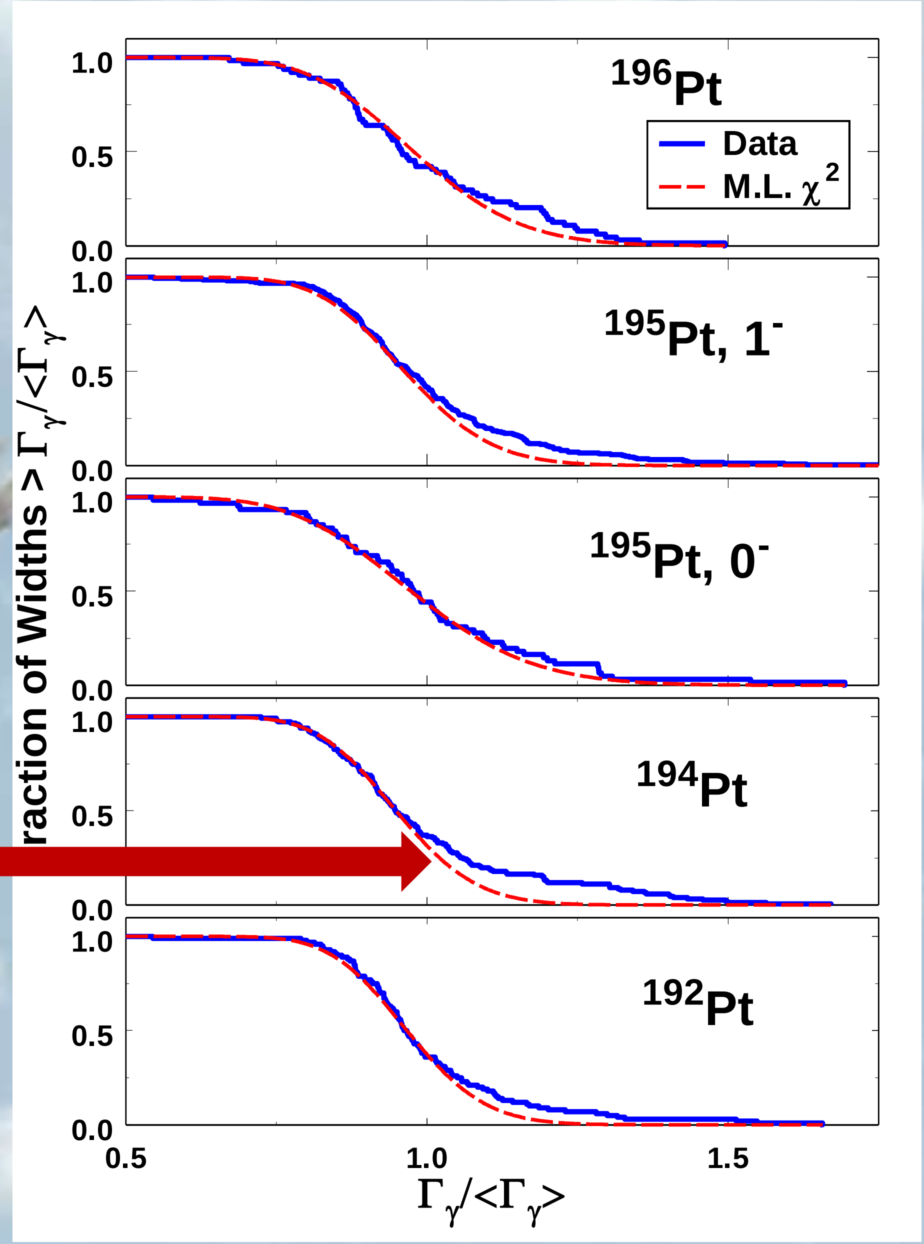
^{197}Pt Simulation Results with LD and PSF from Oslo

- Oslo LD is somewhat different than TALYS.
- Oslo PSF's are significantly different from TALYS.
- Simulations with Oslo LD and PSF in very good agreement with the data.
- Open questions affecting simulated shape.
  What is spin distribution?
  How to partition PSF between *M*1 and *E*1?
  How important is lack of information about J^{π}'s at low E_x?



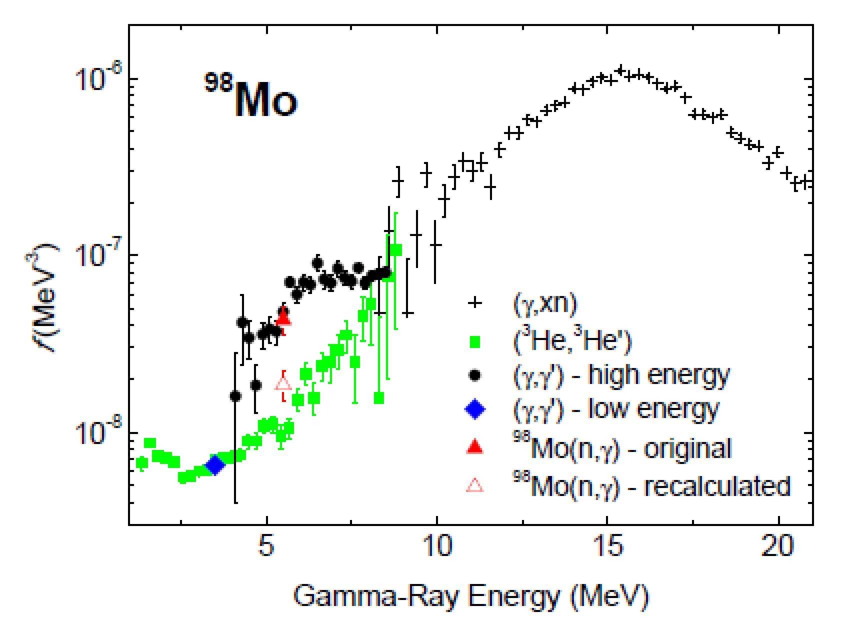
Lessons Learned from ^{196,197}Pt Simulations

- Shape of PSF and division into E1 vs. M1 important.
  Affects shape of Γ_γ distribution.
  Steeper PSF results in broader Γ_γ distribution, and vice versa.
- Spin distribution of LD important.
  Experiment σ affects PSF shape.
  Odd-even *J* staggering gives results in disagreement with data.
- ^{195}Pt may be more interesting case.
  Better statistics than ^{197}Pt.
  Most visible “tail”.



The Strange Case of Mo

- Disagreements about shape of PSF just below B_n.
- Disagreements about existence of low-energy enhancement in PSF.
- Disagreements about whether γ decay is statistical.
  Sheets *et al.*, PRC 024301 (2009): "…extreme statistical model works very well..”
  Musgrove *et al.*, NP A270, 108 (1976): “…presence of non-statistical γ-decay mechanisms.” “…theory needs to be extended to include doorway state contributions to the radiative widths.”



Milan Krtička[1,a] and František Bečvář[1]
EPJ Web of Conferences **2**, 03002 (2010)

Large Improvement in ^{95}Mo+n Resonance Parameters

- **ORELA measurements resulted in large increases in:**

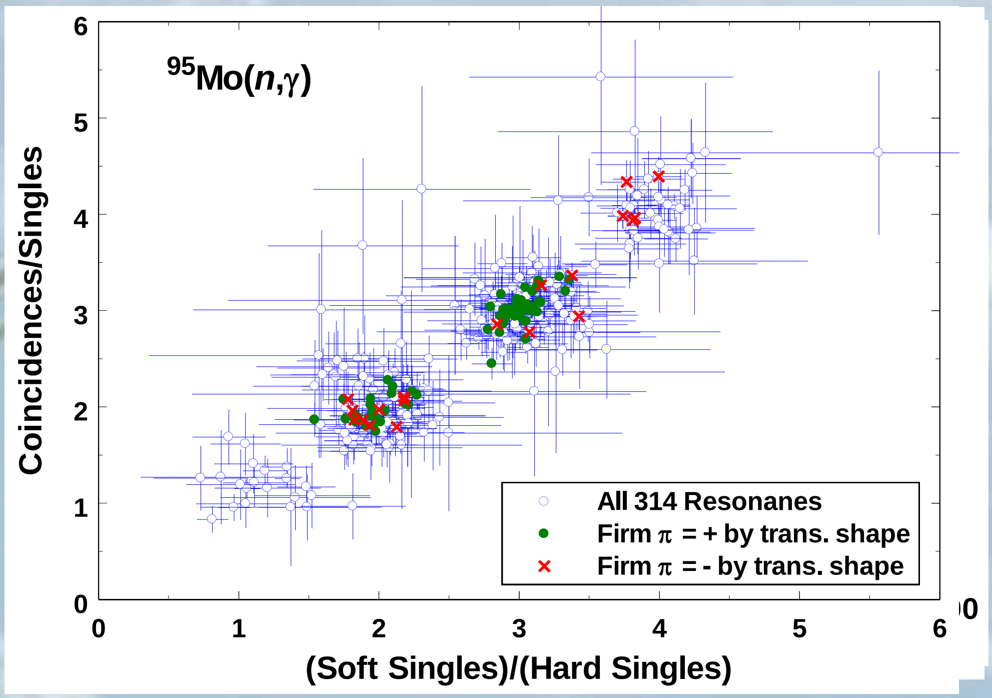
Resonances: 108 → 314.

Firm *J*: 33 → 274.

Firm π: 38 → 253.

Firm J^{π}: 32 → 253.

P.E. Koehler *et al.*, J. Korean Phys. Soc. 59, 2088 (2011).

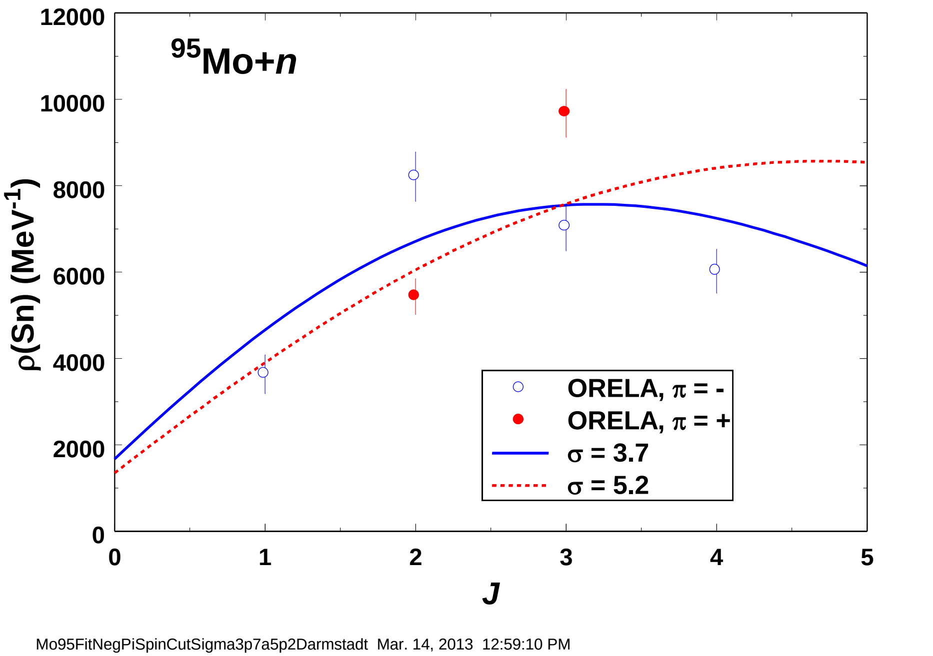


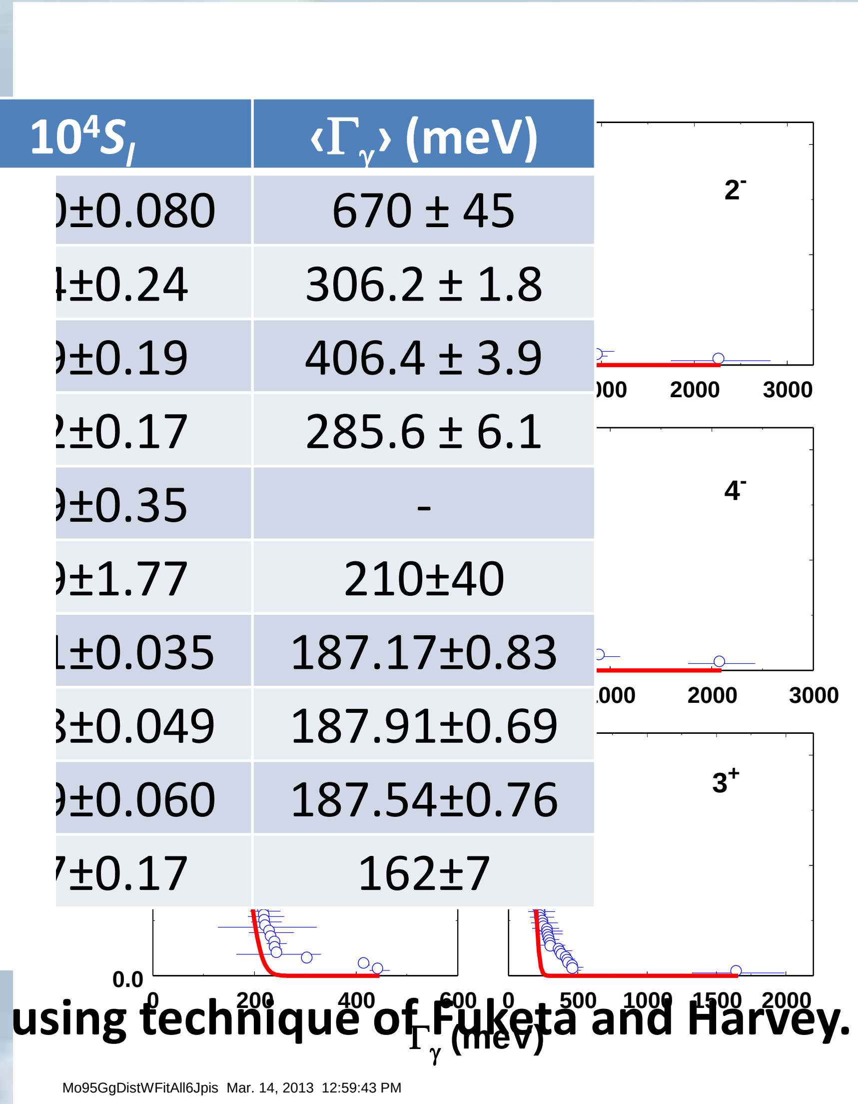
s- and *p*-wave: 2^+, 3^+, 1^-, 2^-, 3^-, and 4^-.

Firm J^{π} and Γ_{γ}: 11 → 251

^{95}Mo+*n* ORELA Results

J^{π}	D_l (eV)	$10^4 S_l$	$\langle\Gamma_\gamma\rangle$ (meV)
		±0.080	670 ± 45
		±0.24	306.2 ± 1.8
		±0.19	406.4 ± 3.9
		±0.17	285.6 ± 6.1
		±0.35	-
		±1.77	210±40
		±0.035	187.17±0.83
		±0.049	187.91±0.69
		±0.060	187.54±0.76
		±0.17	162±7





***D_l* and *S_l* corrected for missed resonances using technique of Fuketa and Harvey.**

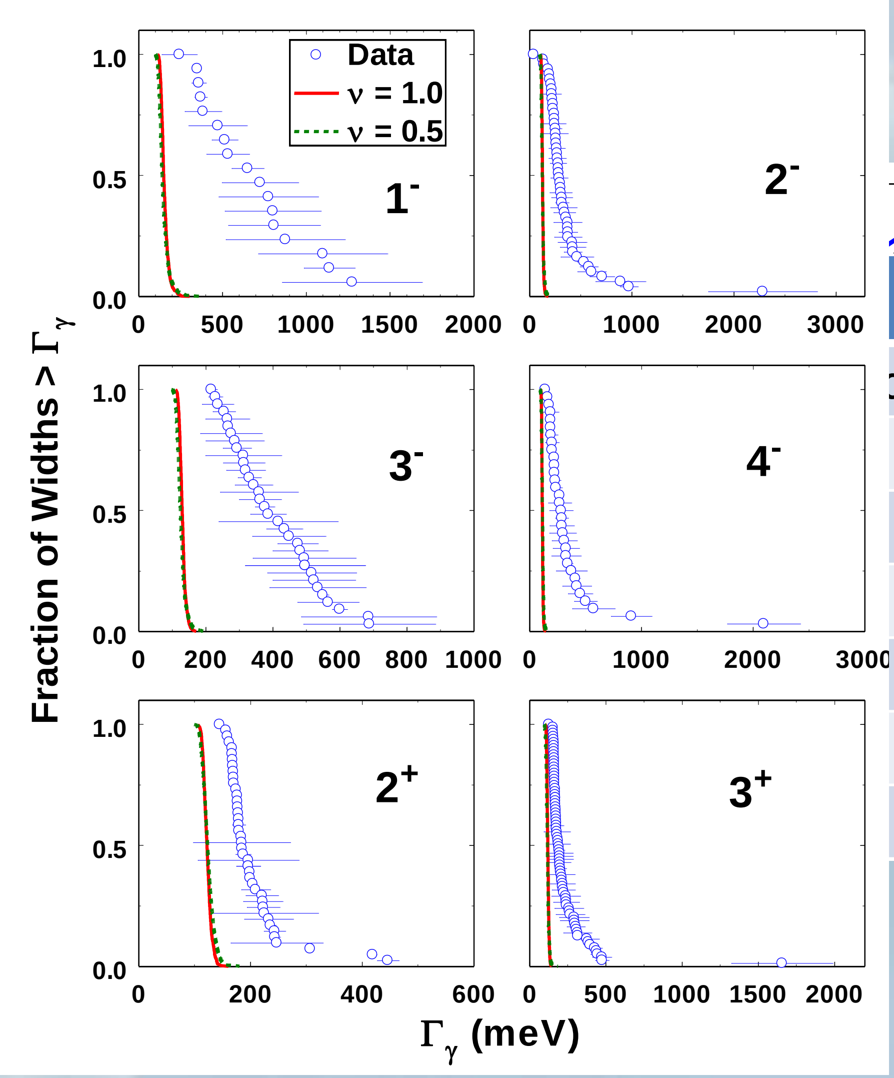
^{96}Mo Simulations

- Used Oslo LD and PSF.
  LD π independent.
  PSF upbend in *E1* or *M1*.

- Simulations much narrower than measurements.
  Including simulations with ν=0.5, and with TALYS LD's and PSF's.

- Simulated ‹Γ_γ›'s much smaller than measured.

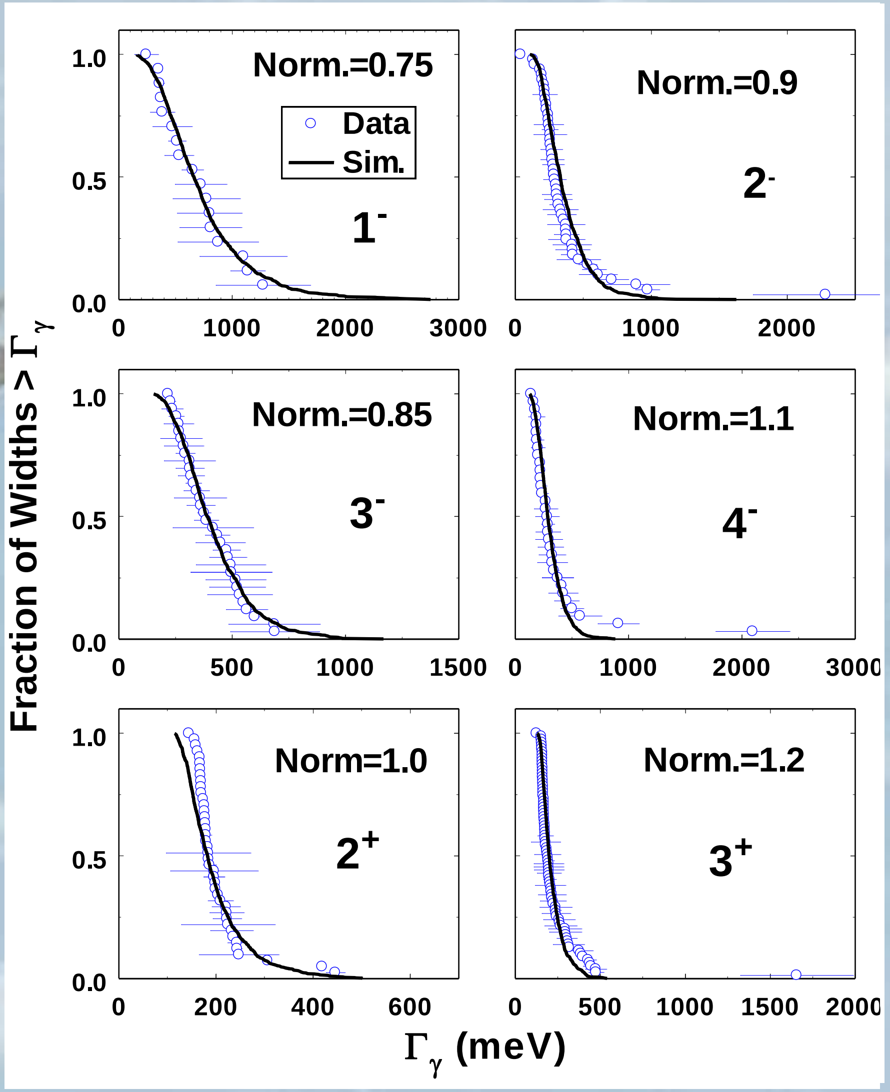
- Simulated ‹Γ_γ› difference for the two parities much smaller than measured.
  Need π dependent LD?



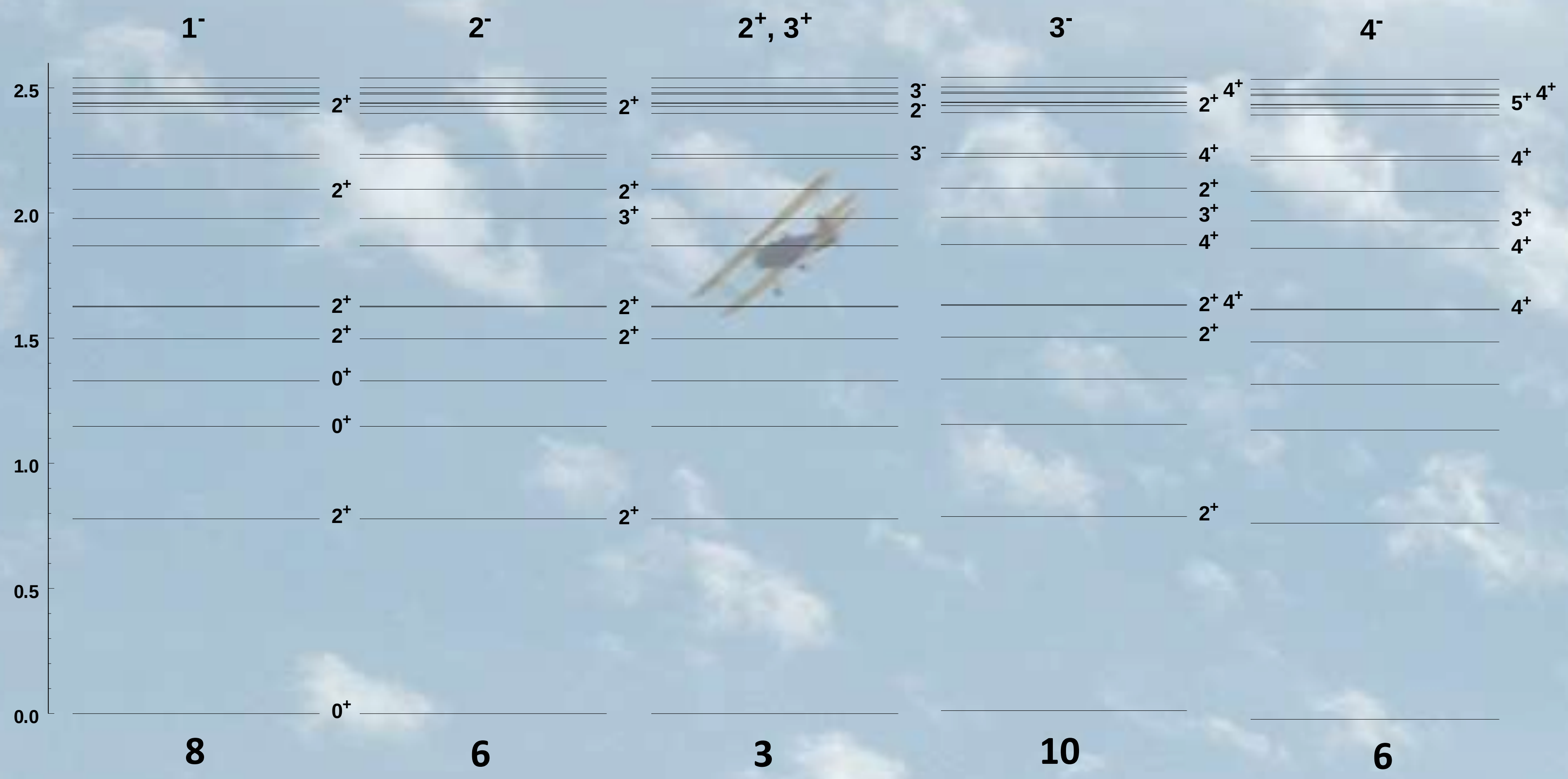
Two (Very Non-statistical) Ways to Fix ^{96}Mo

1. All transitions to levels below ≈B_n/2 totally correlated (same Porter-Thomas factor).
   Γ_γ distribution shapes in much better agreement with data.
   ‹Γ_γ› still much smaller than data.
   Parity problem persists.

2. *E*1 transitions to levels below ≈E_{cut} enhanced by ≈25.
   Each transition still has its own Porter-Thomas factor.
   Both shapes and averages in much better agreement with the data.



^{96}Mo *E*1 Transitions to Levels Below E_{cut}



Some Questions, Problems, and Recommendations

- Can Pt PSF's be determined accurately enough to use Γ_γ simulations to test random matrix theory?
- What is the basis for the even-odd *J* LD staggering?
  It appears to be incorrect for ^{196}Pt.
  Parity dependent LD may be needed for ^{96}Mo.
- Can the large non-statistical signatures in the Γ_γ data for ^{96}Mo be reconciled with the good agreement between DICEBOX simulations and data (DANCE and two-step cascades)?
  Are DICEBOX simulations valid in this case?
- Apply new J^π technique(s) "retroactively" to n_TOF and GELINA data.

Some Questions, Problems, and Recommendations

- **Develop a quantitative doorway model for γ decay.**
- **Better *J* distribution data needed.**
- **Measure γ spectra for ^{95}Mo+*n* resonances.**
  Ge at GELINA?
  TAC at n_TOF?
  Reexamine DANCE data?

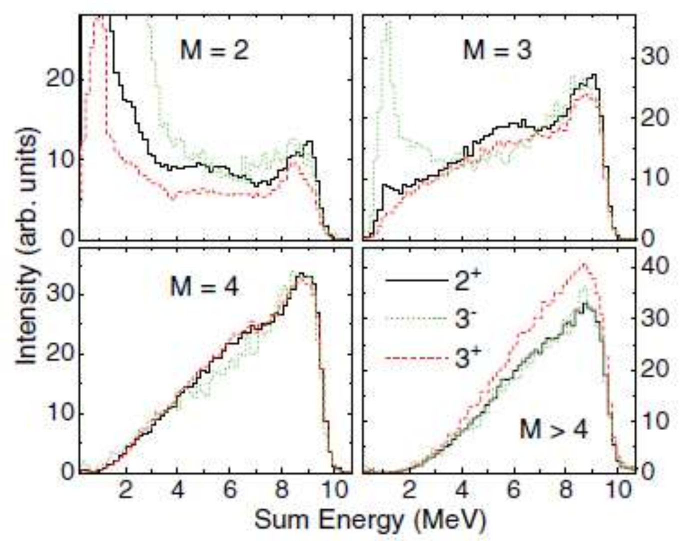
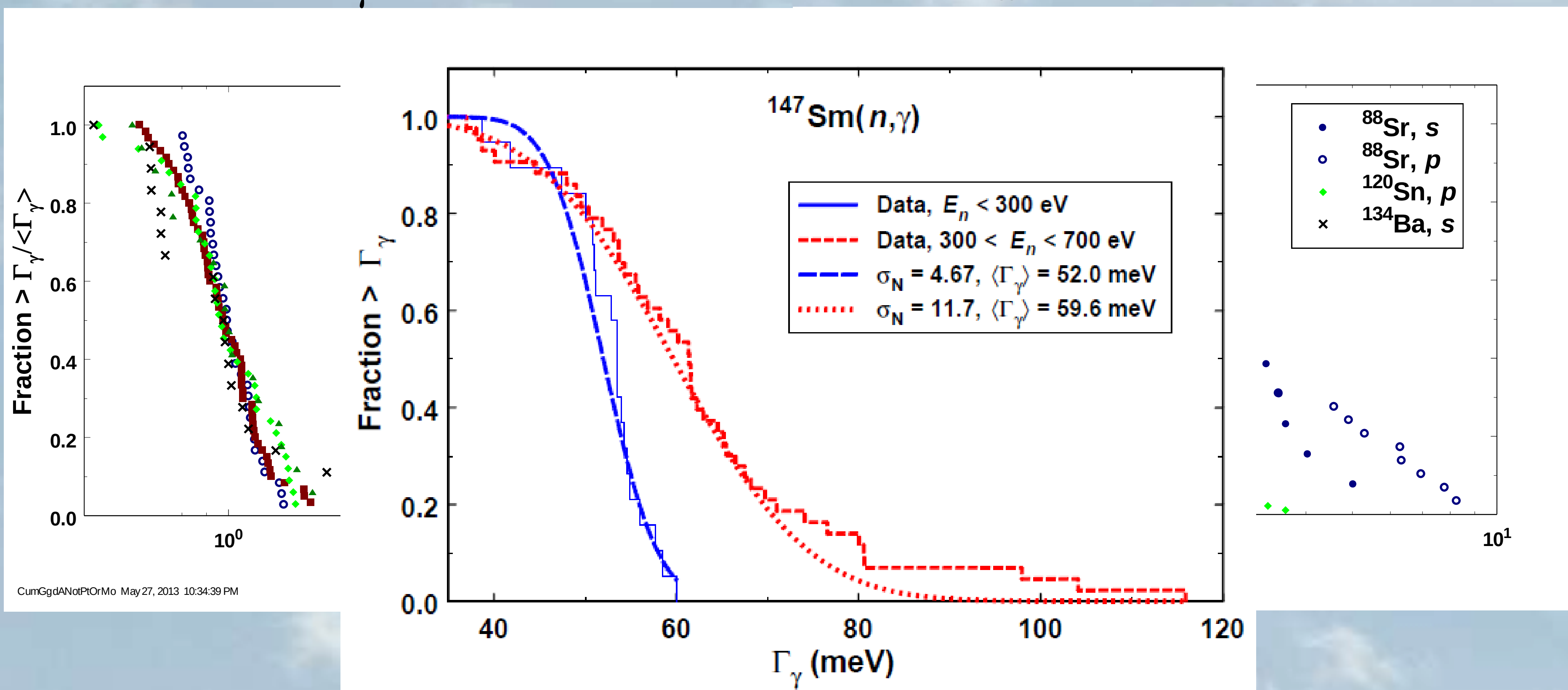


FIG. 1. (Color online) Examples of sum-energy spectra for resonances at energies of 160, 554, and 1361 eV with J^{π} assignments 3^+, 2^+, and 3^-, respectively. The multiplicities of the γ cascades, M, are indicated. The spectra are normalized to the intensity in the E_{total} peak for multiplicities $M = 2$–7.

Simulating Γ_γ distributions is potentially a very valuable way to test and constrain theory.

Nine More Γ_γ Distributions from ORELA

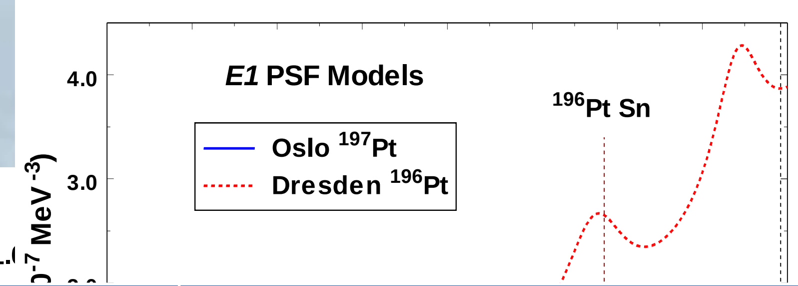
Γ_γ Distribution Changes with E_n in ^{147}Sm+n



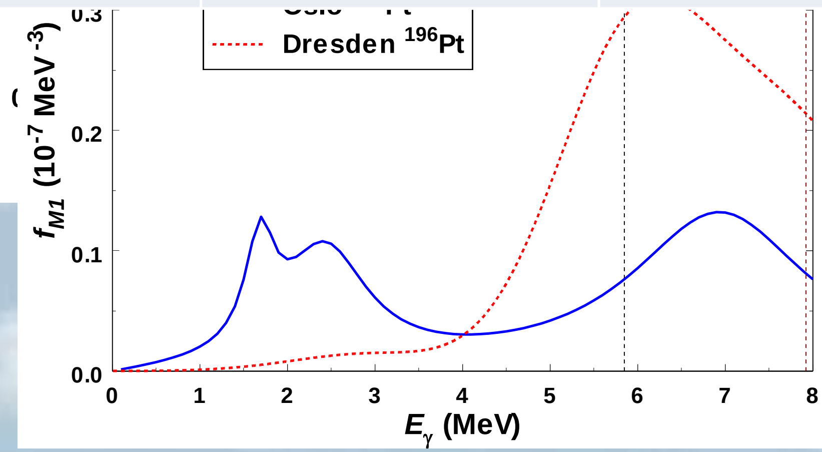
P.E. Koehler *et al*., Phys. Rev. Lett. 108, 142502 (2012)

^{196}Pt Simulation Results with LD and PSF from Dresden

- Dresden ^{196}Pt PSF substantially different from Oslo ^{197}Pt PSF.
- Dresden LD has odd-even *J* staggering.
- Simulated $\langle\Gamma_\gamma\rangle$'s are substantially different from ORELA data.
- Simulated $1^-/0^-$ $\langle\Gamma_\gamma\rangle$ ratio is very different from ORELA data.
- Simulated distributions are much narrower than ORELA data.



J^π	$\langle\Gamma_\gamma\rangle$ (mev)	
	Simulated	Measured
0^-	67.3	110
1^-	283	127
$1^-/0^-$	4.2	1.15

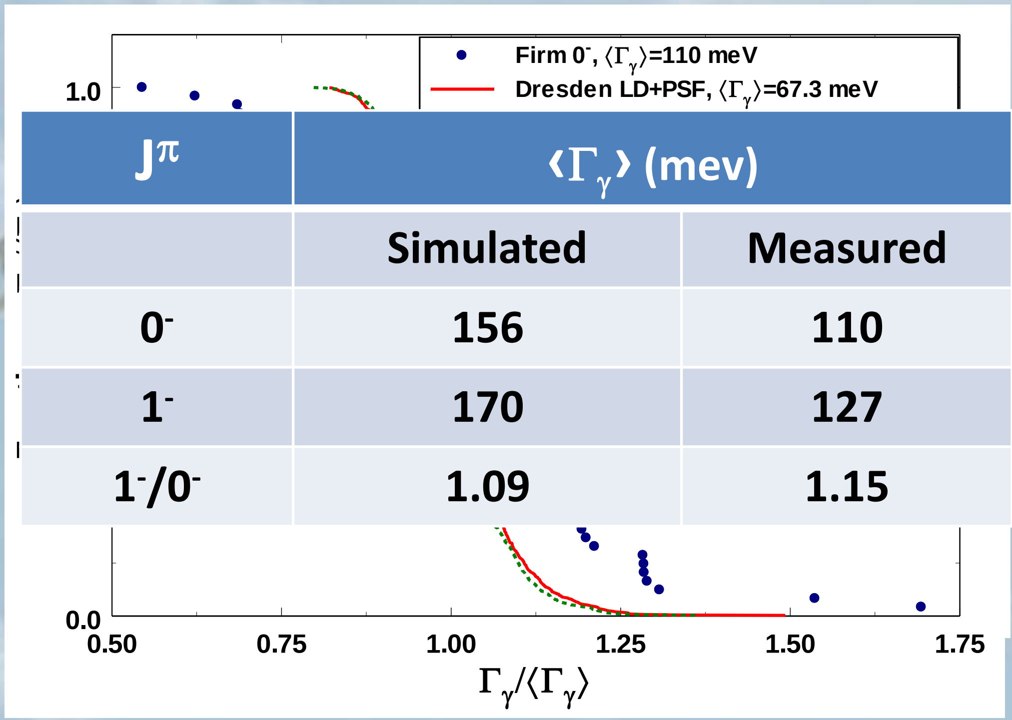


^{196}Pt Simulation Results with TALYS LD and Dresden PSF

- TALYS LD does not have odd-even *J* staggering. Normalized to measured D_0=16 eV.

- Simulated ‹Γ_γ›'s are closer to ORELA data.
- Simulated $1^-/0^-$ ‹Γ_γ› ratio is close to ORELA data.

- Simulated distributions are still much narrower than ORELA data.



J^π	‹Γ_γ› (mev)	
	Simulated	Measured
0^-	156	110
1^-	170	127
$1^-/0^-$	1.09	1.15

^{196}Pt Simulation Results with TALYS LD and Modified Dresden PSF

- *E*1 PSF modified to follow shape of Oslo ^{197}Pt PSF below 5 MeV.
- Simulated $\langle\Gamma_\gamma\rangle$'s are closer to ORELA data.
- Simulated $1^-/0^-$ $\langle\Gamma_\gamma\rangle$ ratio is close to ORELA data.
- Simulated distributions are much closer to ORELA data.
- Simulations with ν=0.5 in even better agreement with data.