Testing of level density models with new data from particle evaporation technique

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Plan for the talk

- Most popular level density models
- Problems with current experimental data to constrain models
- Particle evaporation technique and its advantage and limitations
- Test of level density models against particle evaporation data for ^{92,94,96}Nb isotopes

MODEL LANDSCAPE

TALYS 2.2 recommends empirical and microscopic level-density prescriptions

Talys keywords

ldmodel 1	**Gilbert-Cameron** Composite constant-temperature plus Fermi-gas description	Phenomenological models
ldmodel 2	**Fermi-gas model** Fermi-gas model with an energy dependent parameter	
ldmodel 5	**HFB combinatorial** Microscopic Skyrme-Hartree-Fock-Bogolyubov tables from S. Goriely et al., Phys. Rev. C 78 (2008).	Microscopical models
ldmodel 7	**BSKG3 triaxial HFB** Updated triaxial combinatorial tables from S. Goriely et al., Phys. Rev. C 113, 014320 (2026).	

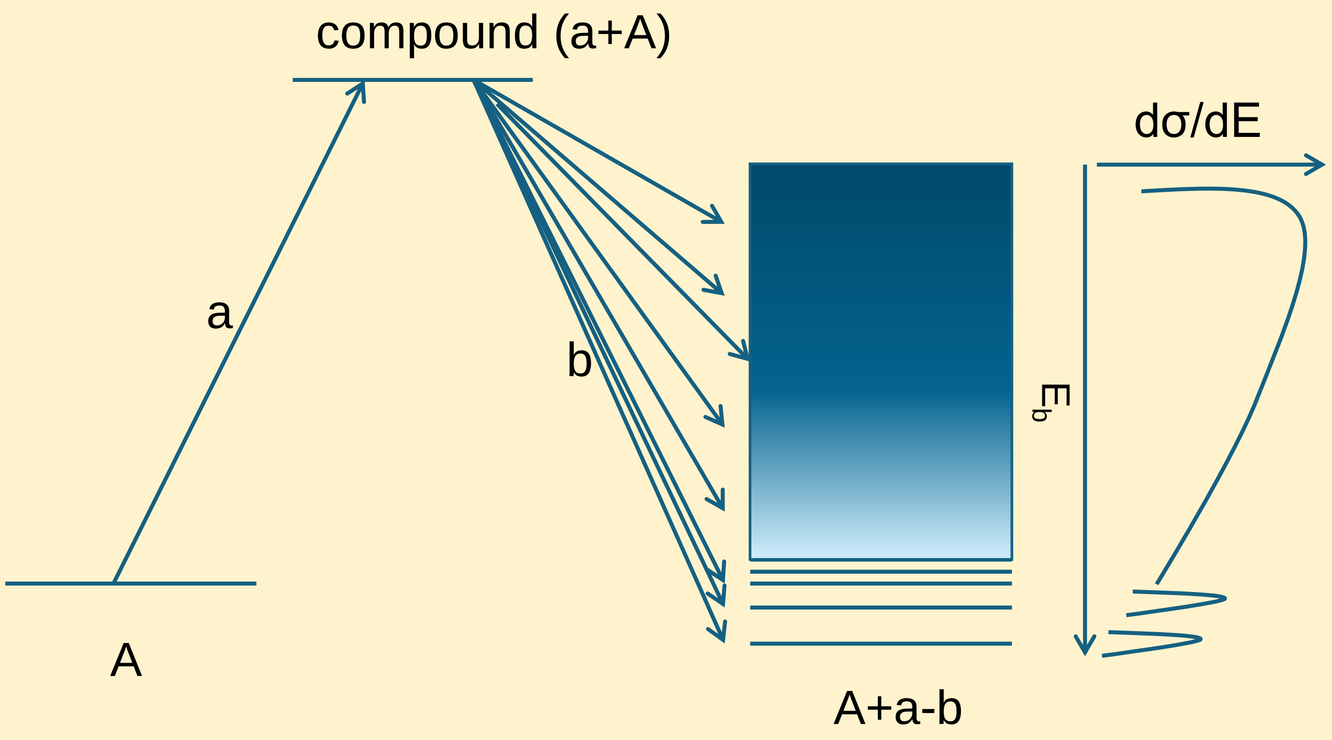
Both phenomenological (GG and FG) and microscopical models use neutron resonance spacings (D_0) to constrain parameters

Main uncertainties for model predictions are due to the small fraction of levels associated with D_0 (about 10-20% of all levels at S_n) , and very limited ranges of spins and excitation energy

- Shape of LD model function ρ(E)
- Spin distribution at S_n (spin cutoff factor),
- parity distribution
- Are neutron resonance spacings data accurate ?
  potential problem: systematics uncertainties, related missing resonances, distinguishing between s and p wave resonances etc. RIPL-3 and Mughabhab compilations often give different results

Data in broader spin and energy intervals are needed to improve models !!!

Particle evaporation technique



$$\boxed{\frac{d\sigma(E)}{dE} \sim \sigma_C(E)\frac{T_{out}(E')\rho_f(E^*)}{\sum_i T_{out\ i}}}$$

$$\frac{d\sigma_{exp}(E)/dE}{d\sigma_{cal}(E)/dE} \propto \frac{\rho_{exp}(E_x)}{\rho_{cal}(E_x)}$$

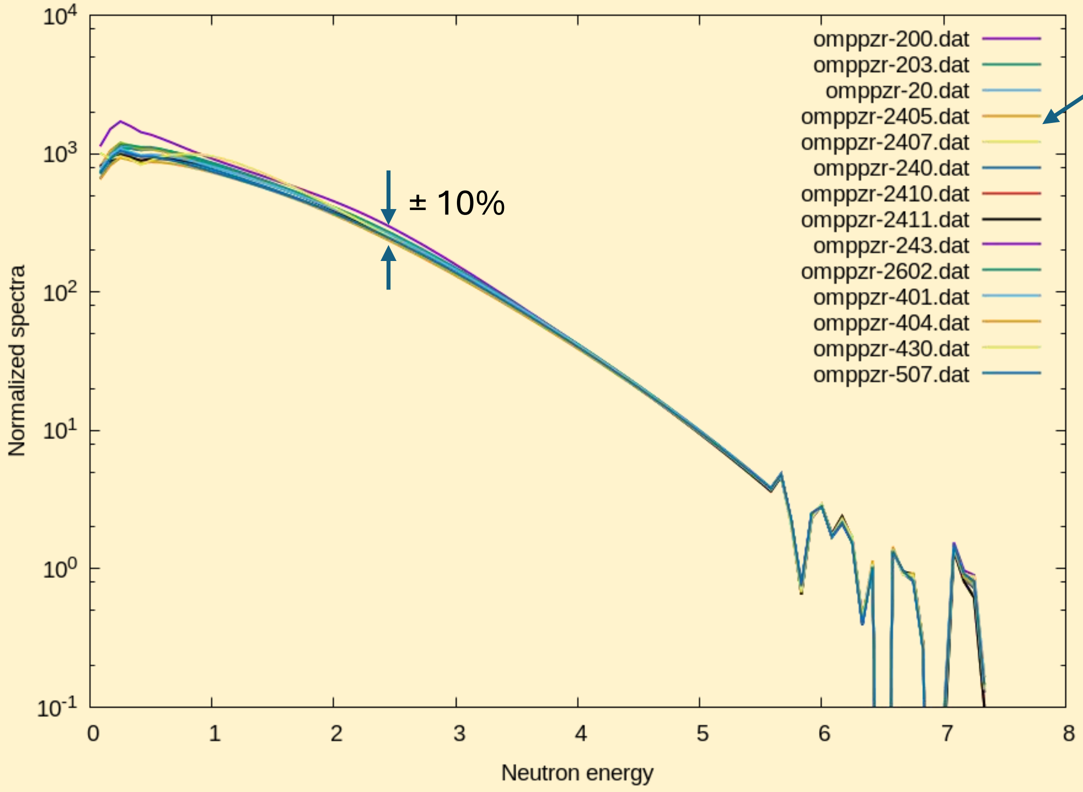
$$\rho(E)^{exp} \propto \frac{d\sigma}{dE}^{exp} / \frac{d\sigma}{dE}^{cal} \times \rho(E)^{cal}$$

Discrete levels are used for absolute Normalization !!!

- Select appropriate reactions (beam species, energies, targets).
- Measure the outgoing particles at backward angles

Sensitivity test of neutron spectra to optical model parameter sets

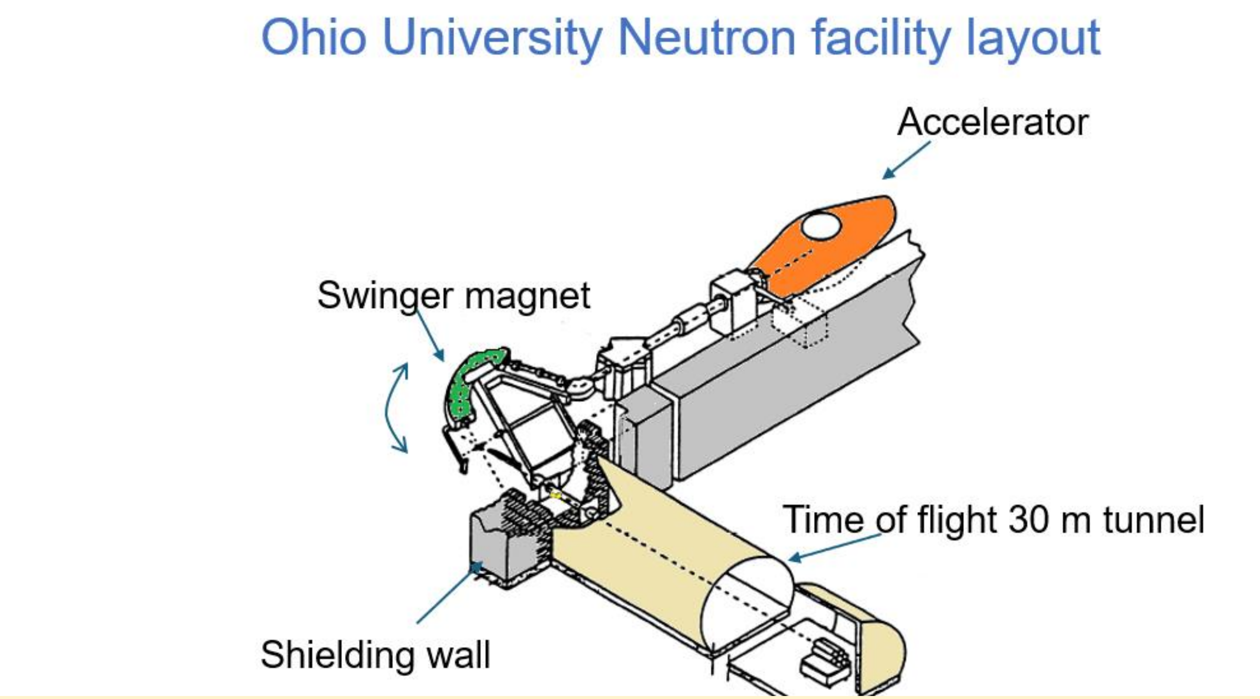
^{96}Zr(p,n) ^{96}Nb



± 10%

RIPL3 OMP index

The Swinger facility couples a long underground flight path to neutron TOF spectroscopy.



Experimental details

FACILITY

Edwards Accelerator Laboratory, Ohio University

TECHNIQUE

Underground neutron time-of-flight measurement

REACTION SET

92Zr(p,n)92Nb, 94Zr(p,n)94Nb, 96Zr(p,n)96Nb

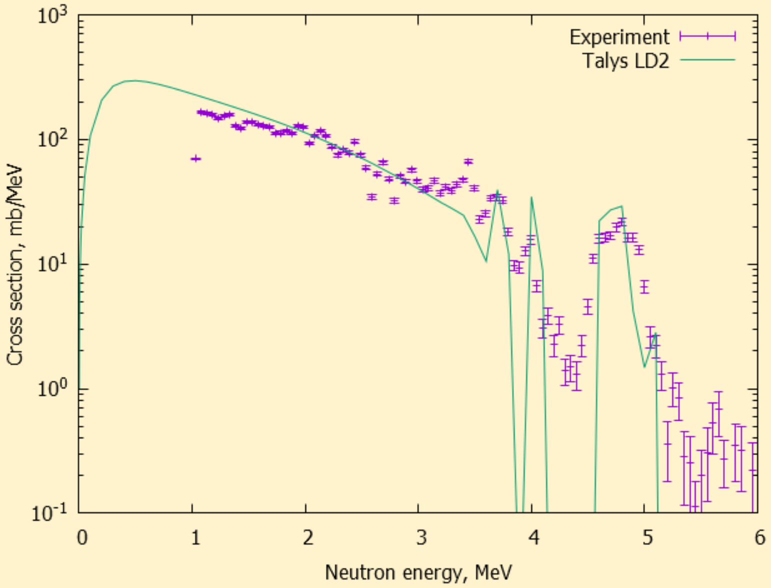
BEAM ENERGY

Ep = 8 MeV

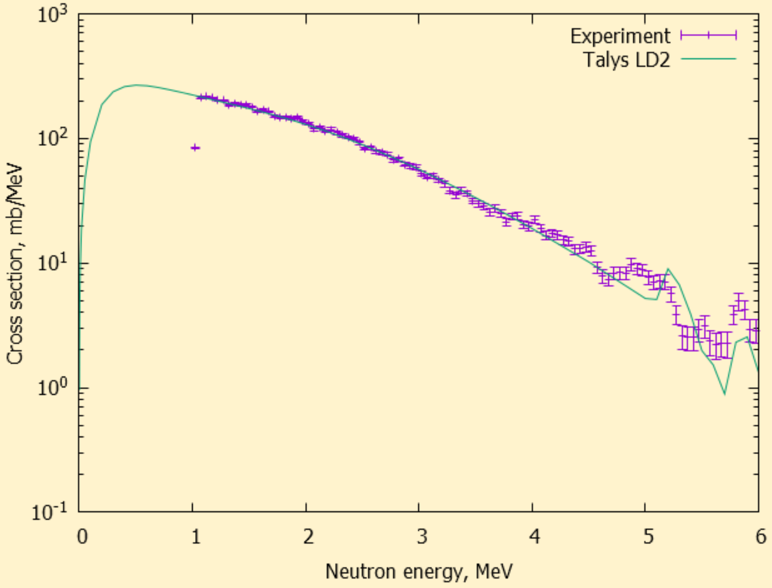
Neutron TOF **Swinger** **8 MeV**

Experimental double differential spectra from ^{92,94,96}Zr(p,n) ^{92,94,96}Nb reactions. E_{beam}=8 MeV

^{92}Zr(p,n) ^{92}Nb

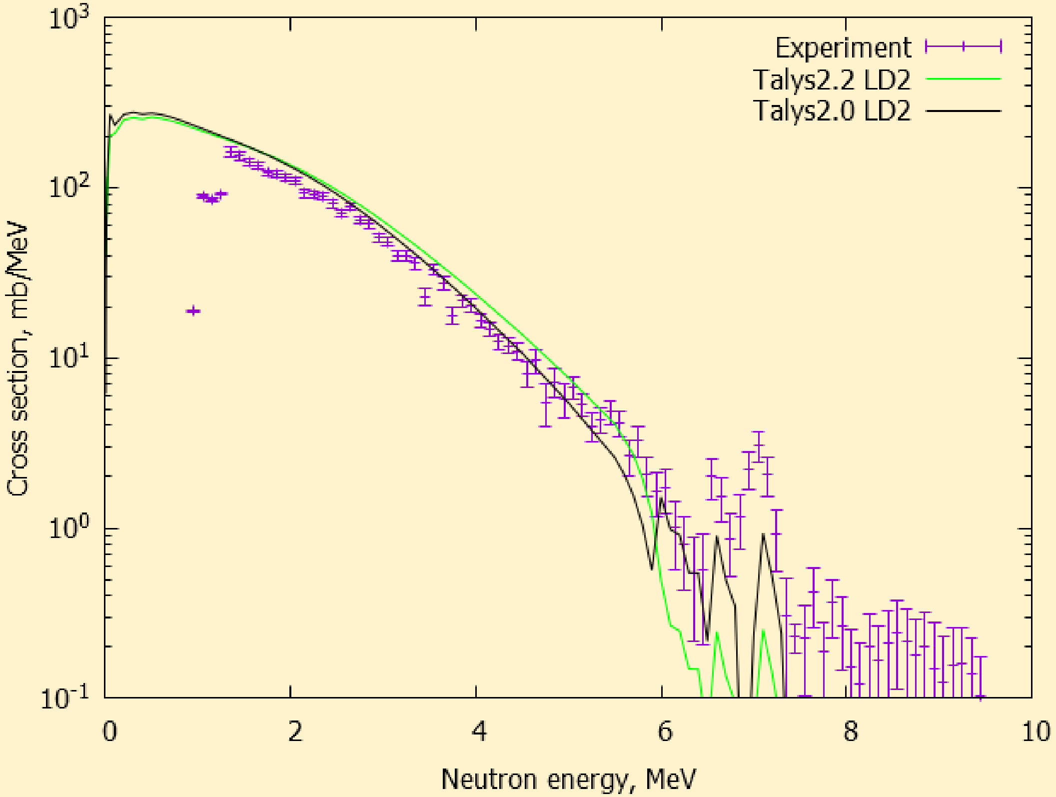


^{94}Zr(p,n) ^{94}Nb

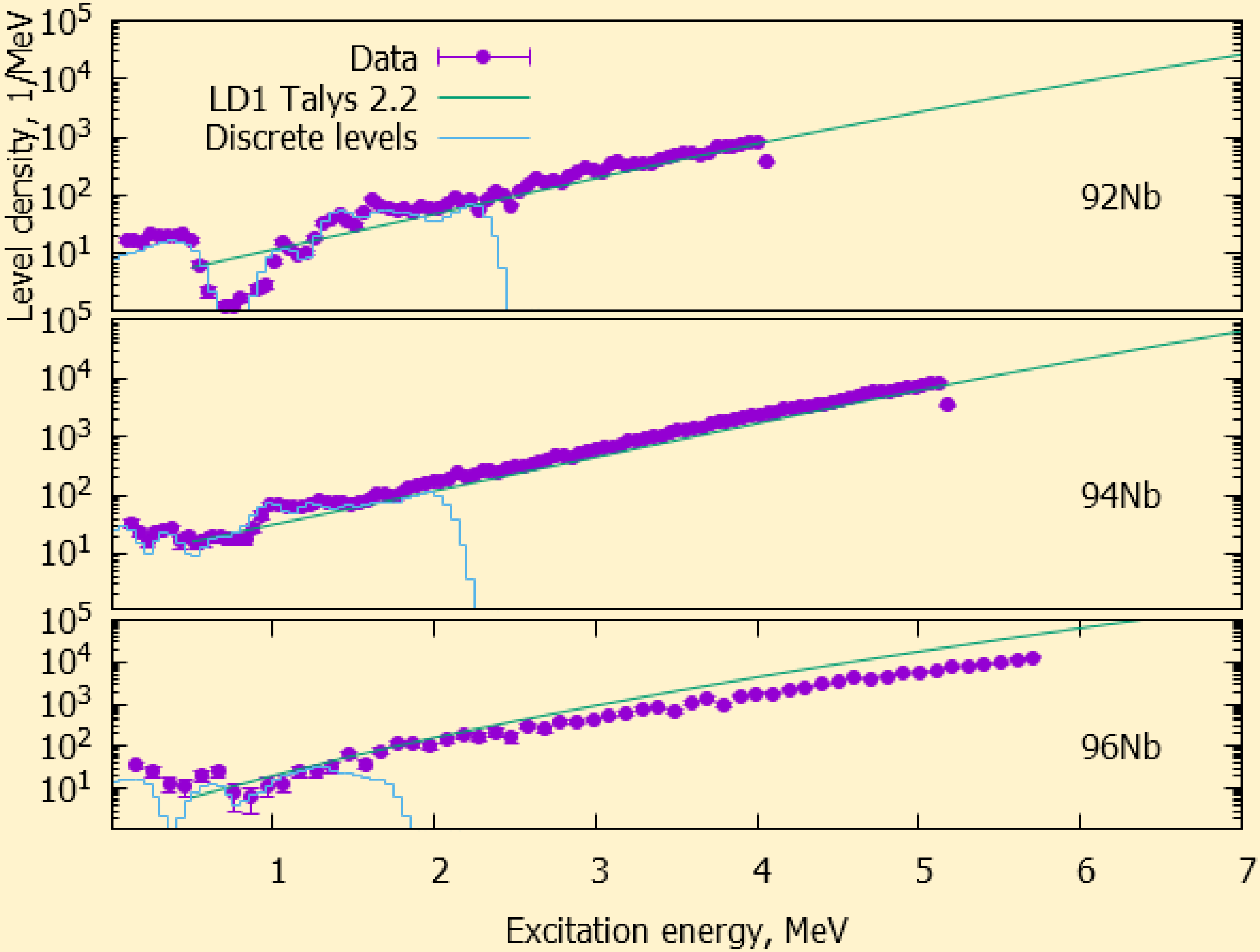


Experimental double differential spectra from ^{92,94,96}Zr(p,n) ^{92,94,96}Nb reactions. E_{beam}=8 MeV

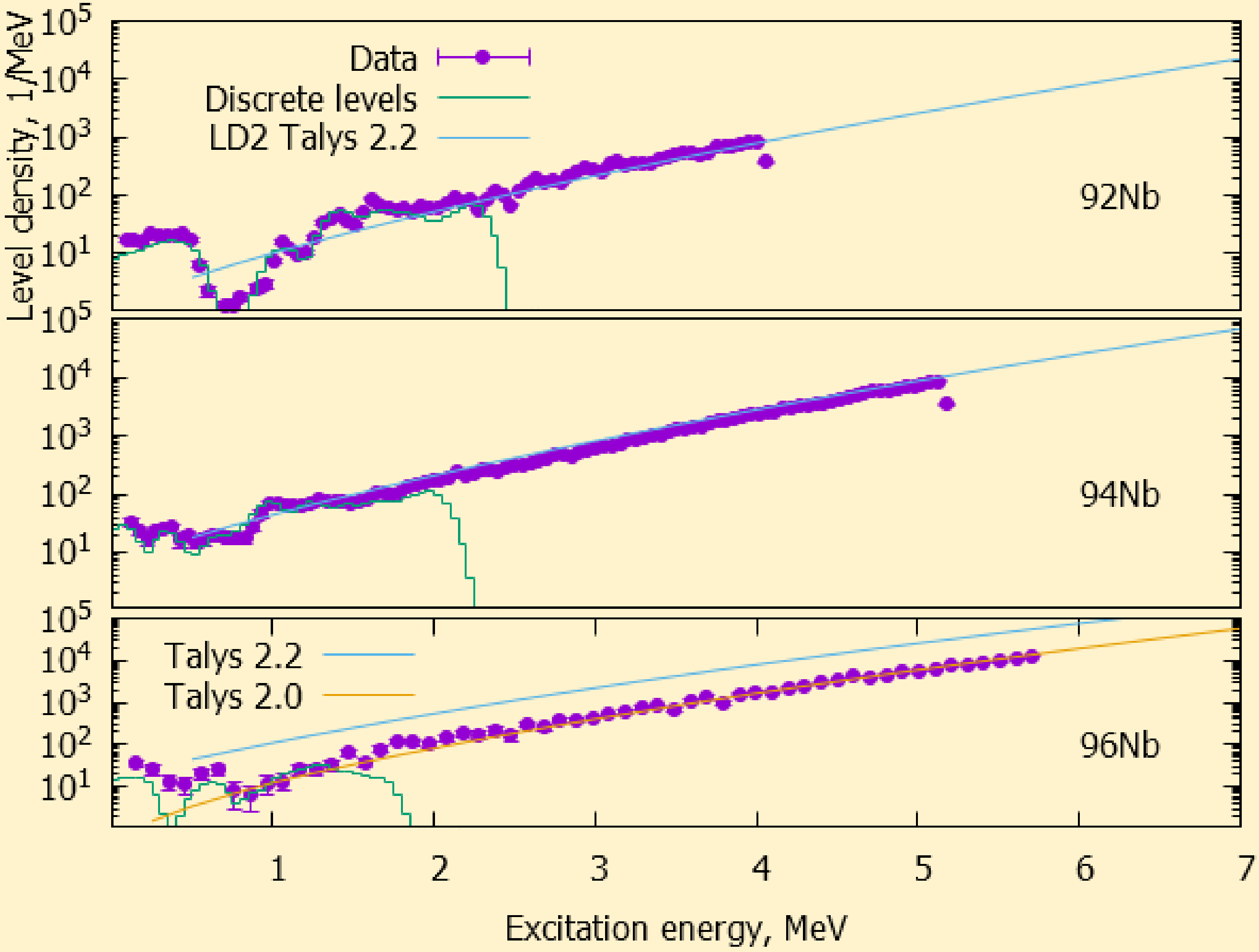
^{96}Zr(p,n) ^{96}Nb



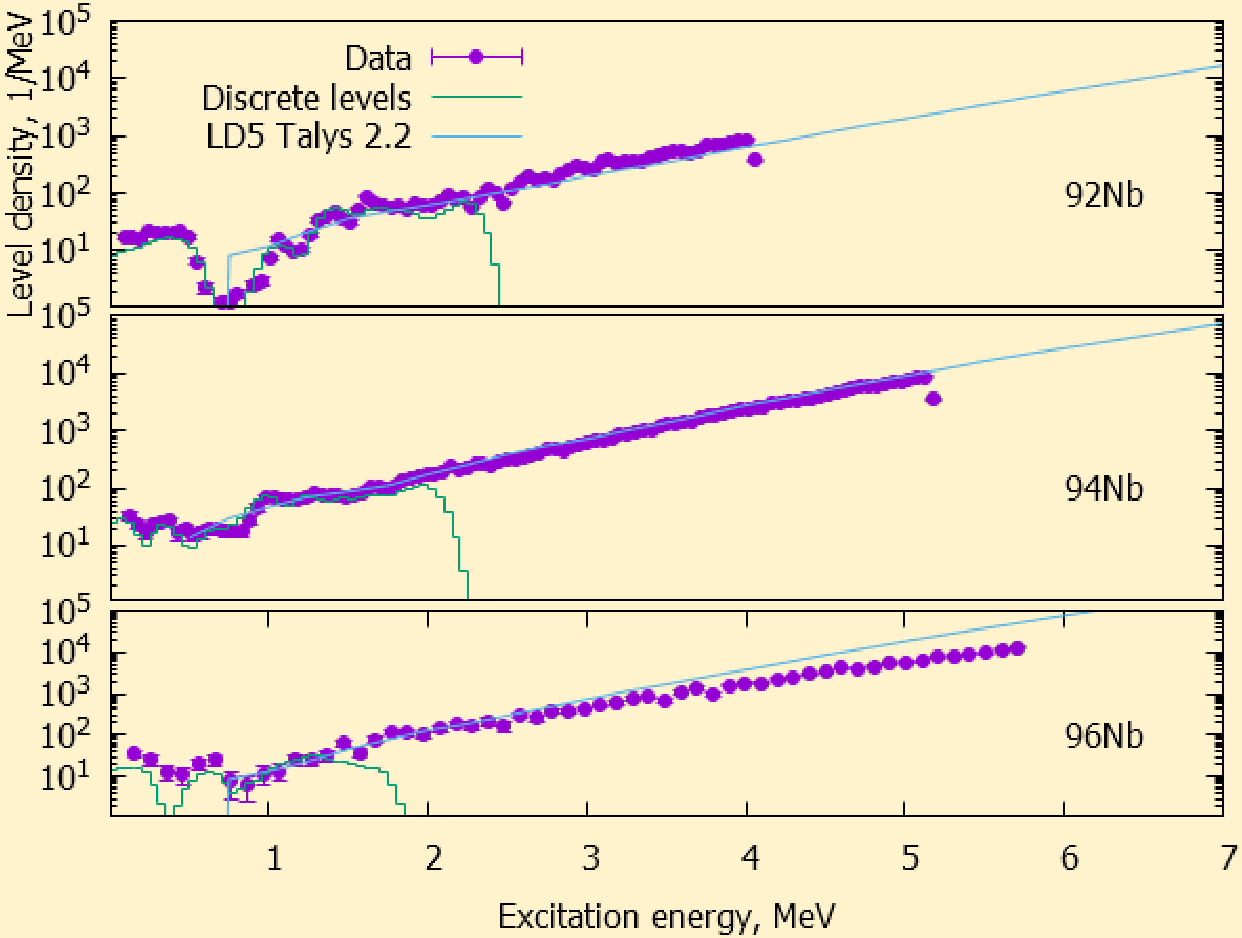
Experimental data vs Talys GC, ldmodel 1



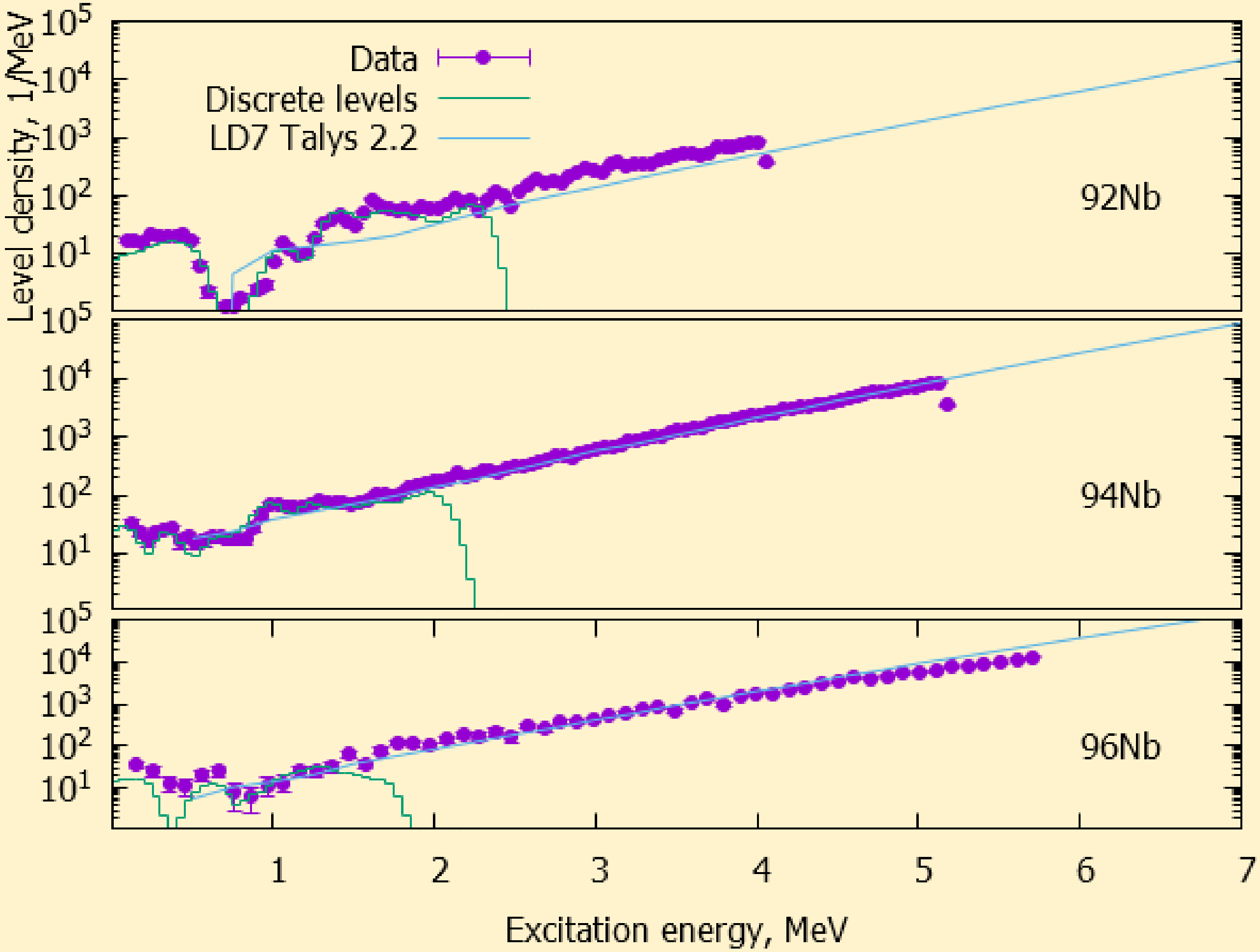
Experimental data vs Talys FG, ldmodel 2



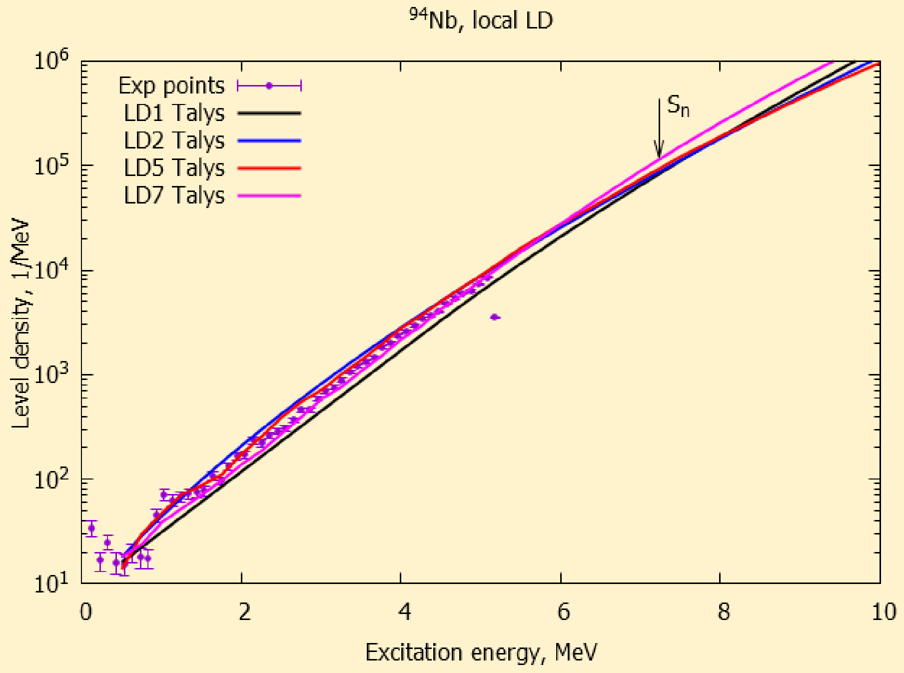
Experimental data vs Talys, lmodel 5

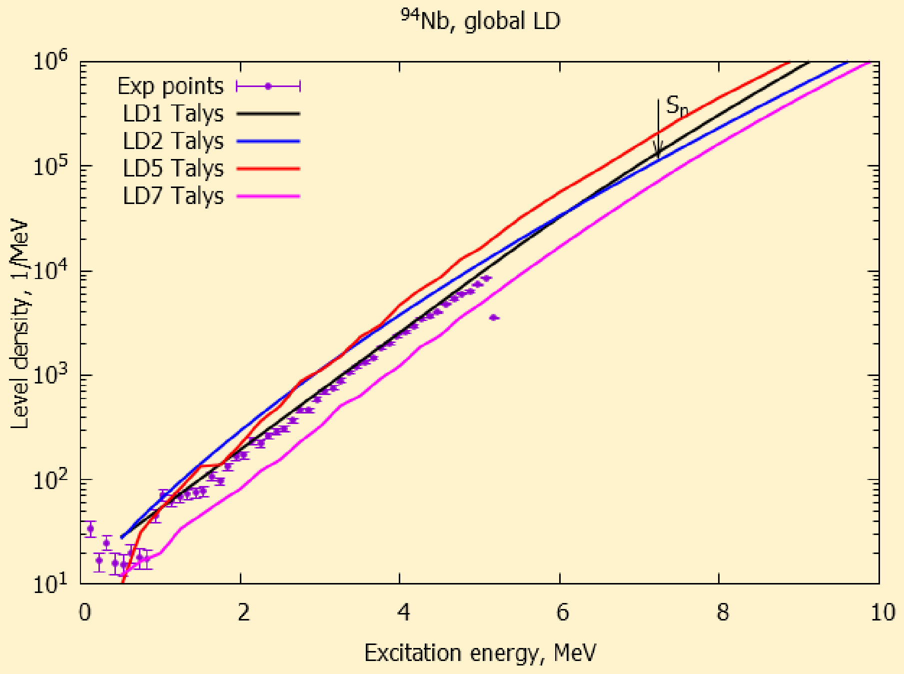


Experimental data vs Talys, model 7



Local vs global level density models

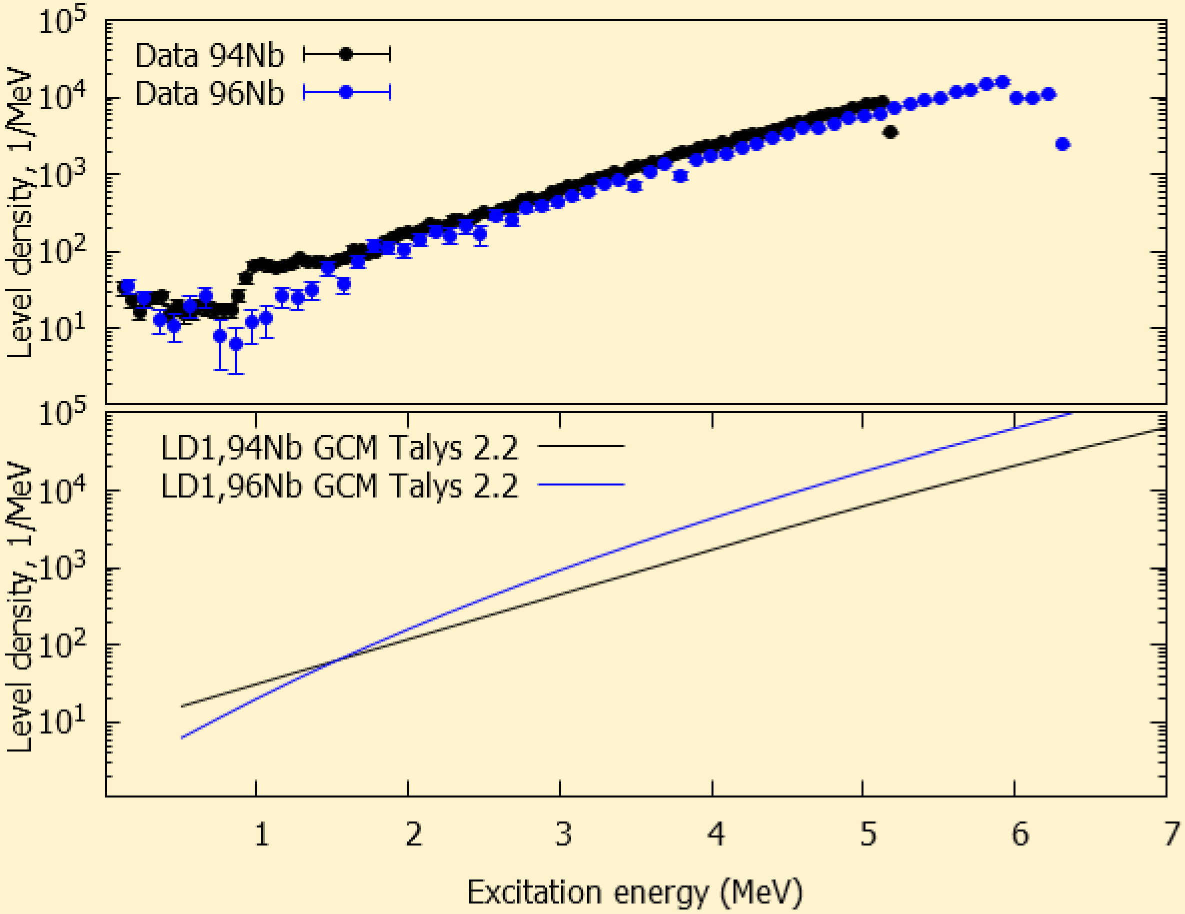




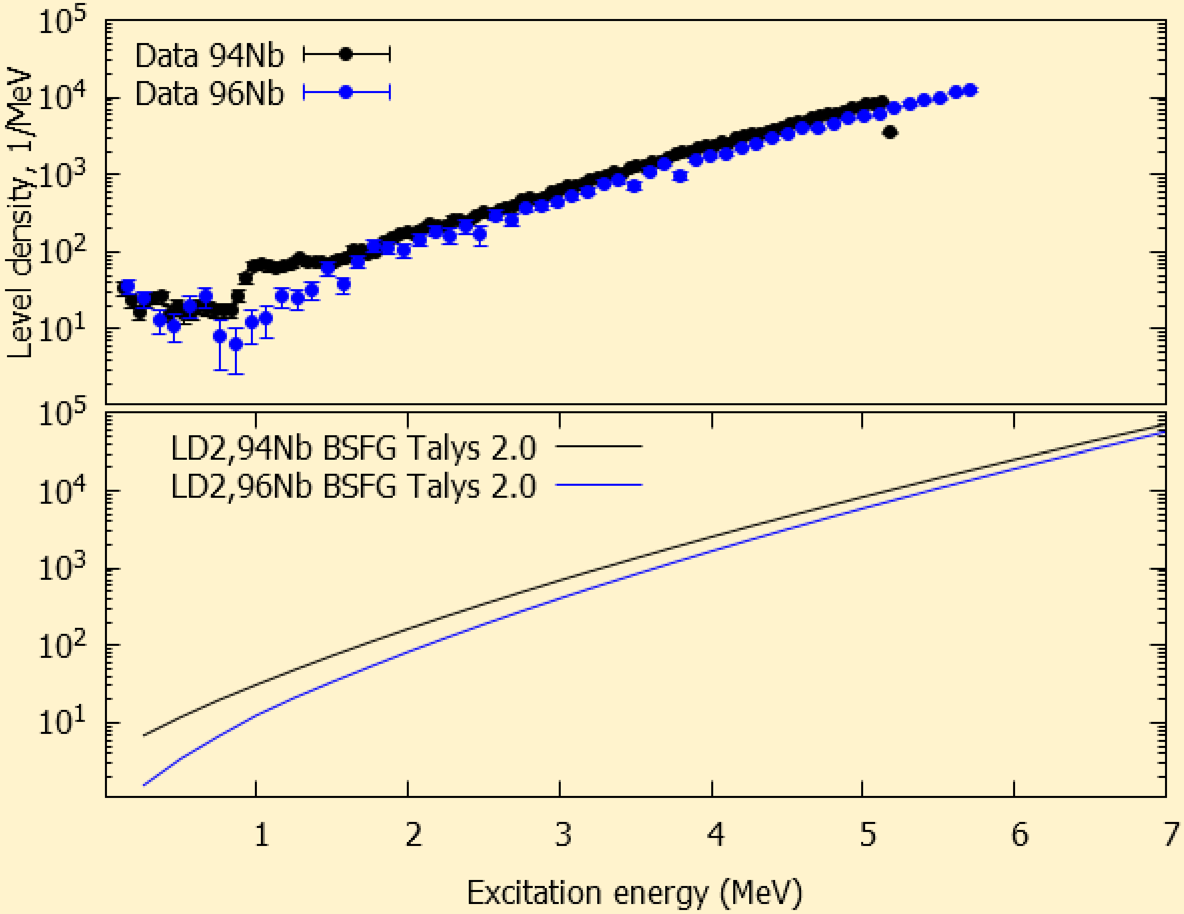
Microscopic Talys models (5 and 7) are best among local models

GC, (1) is best among global models

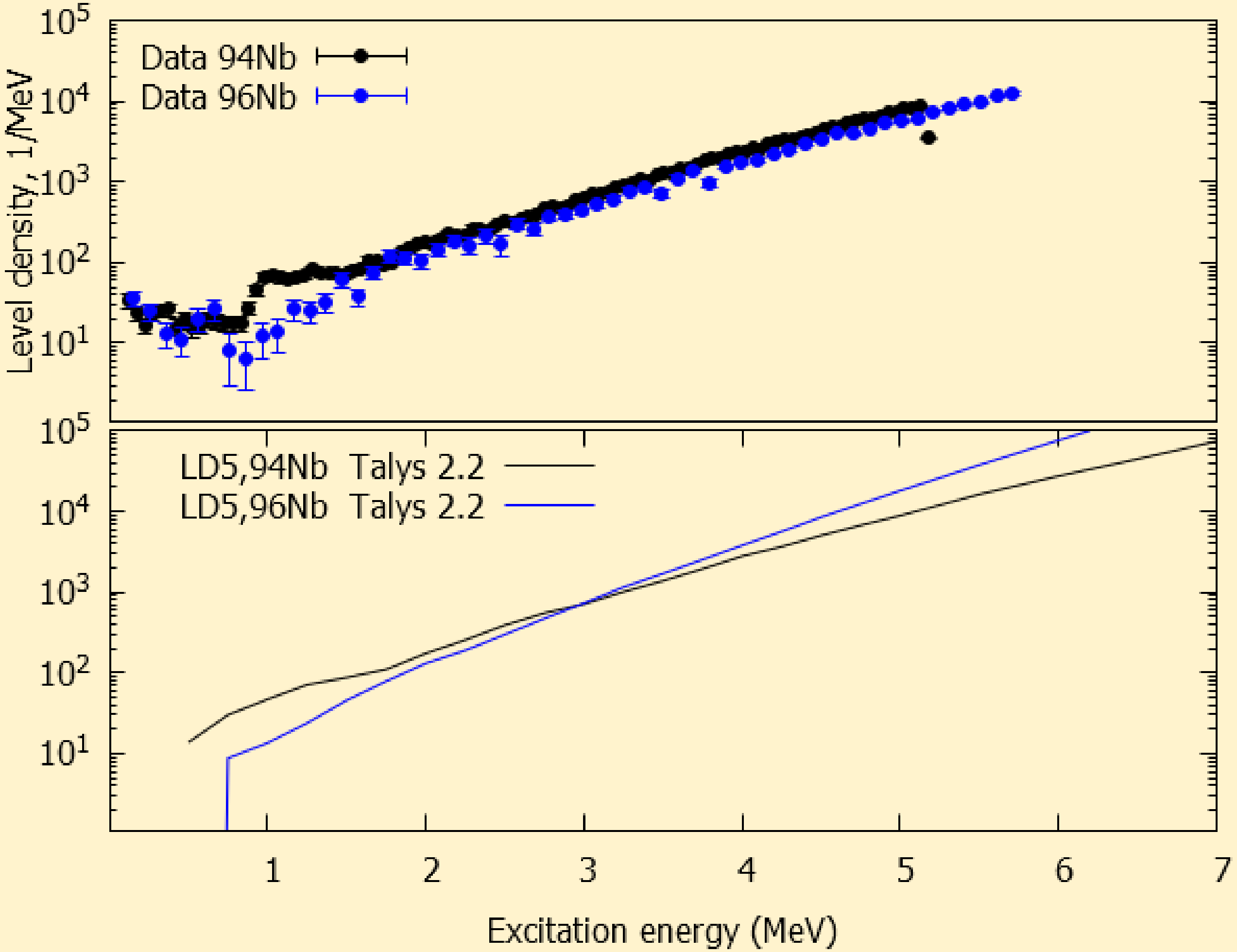
Comparative plots for ^{94}Nb and ^{96}Nb, Level density model 1 (GCM)



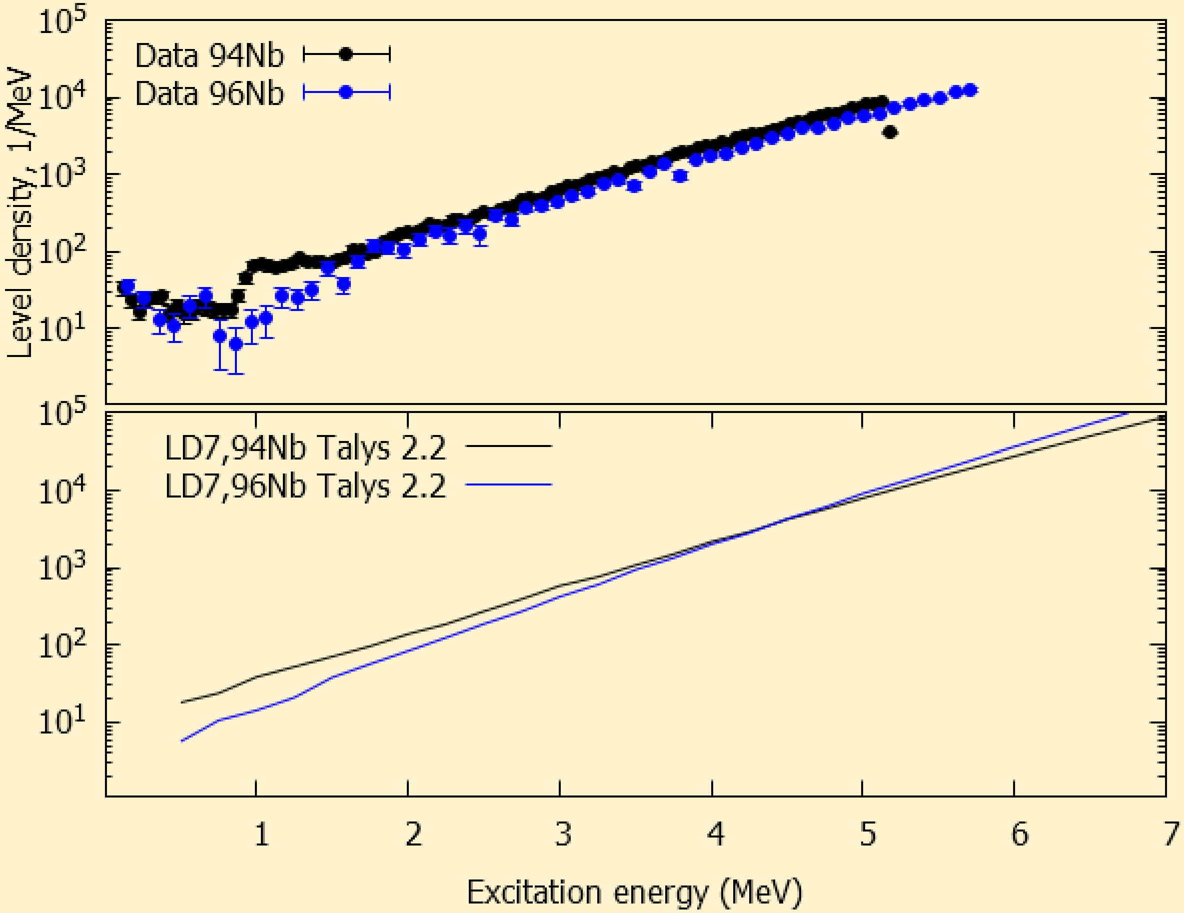
Comparative plots for ^{94}Nb and ^{96}Nb, Level density model 2 (FGM)



Comparative plots for ^{94}Nb and ^{96}Nb, Level density model 5 (HFB)



Comparative plots for ^{94}Nb and ^{96}Nb, Level density model 7 (BSKG3 triaxial HFB)



Phenomenological models (both GG and FG) are based on Fermi-gas prescription

$$\rho(U) = \frac{\exp\left(2\sqrt{aU}\right)}{12\sqrt{2}\,\sigma\, a^{1/4} U^{5/4}}$$

$$\sigma = 0.0138 A^{5/3} \frac{\sqrt{aU}}{\tilde{a}}$$

$$a(U) = \tilde{a}\left[1 + \delta W \frac{1 - e^{-\gamma U}}{U}\right]$$

$$U = E - \Delta$$

A. V. Ignatyuk, G. N. Smirenkin, and A. S. Tishin, *"Phenomenological description of the energy dependence of the level density parameter"*, Sov. J. Nucl. Phys. **21**, 255 (1975).

$$\left.\begin{aligned} \tilde{a}(A) &= 0.072A + 0.195A^{2/3} \\ \delta W &= M_{exp} - M_{LDM} \end{aligned}\right\} \text{RIPL systematics}$$

We will fit parameters $\tilde{a}$ and Δ to ^{92,94,96}Nb LD data and compare $a(4)_{exp}$ $a(4)_{sys}$

Fermi-gas model parameter study

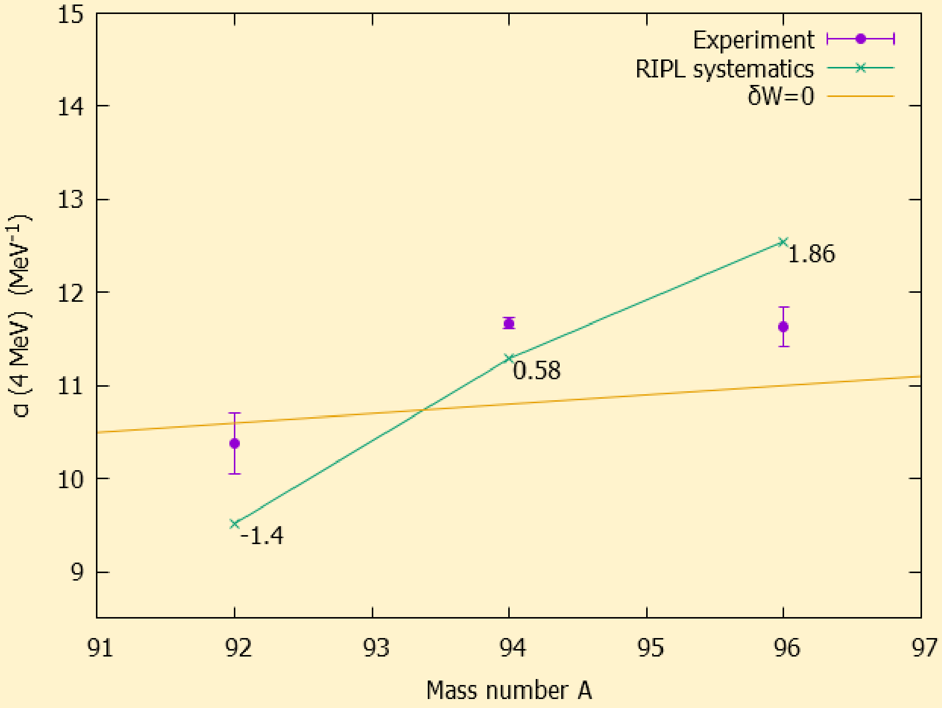
very preliminary !!!

$$a(U) = \tilde{a}\left[1 + \delta W \frac{1 - e^{-\gamma U}}{U}\right]$$

$$\tilde{a}(A) = 0.072A + 0.195A^{2/3}$$

$$\delta W = M_{exp} - M_{LDM}$$

RIPL systematics



	N	δW	$a(4)_{exp}$	$a(4)_{sys}$
^{92}Nb	51	-1.4	10.4(3)	9.5
^{94}Nb	53	0.58	11.7(1)	11.3
^{96}Nb	55	1.86	11.6(2)	12.6

Data might not support a strong dependence on shell corrections δW !!!

Dependence of the Fermi-gas parameter “a” on the mass number of Ni isotopes

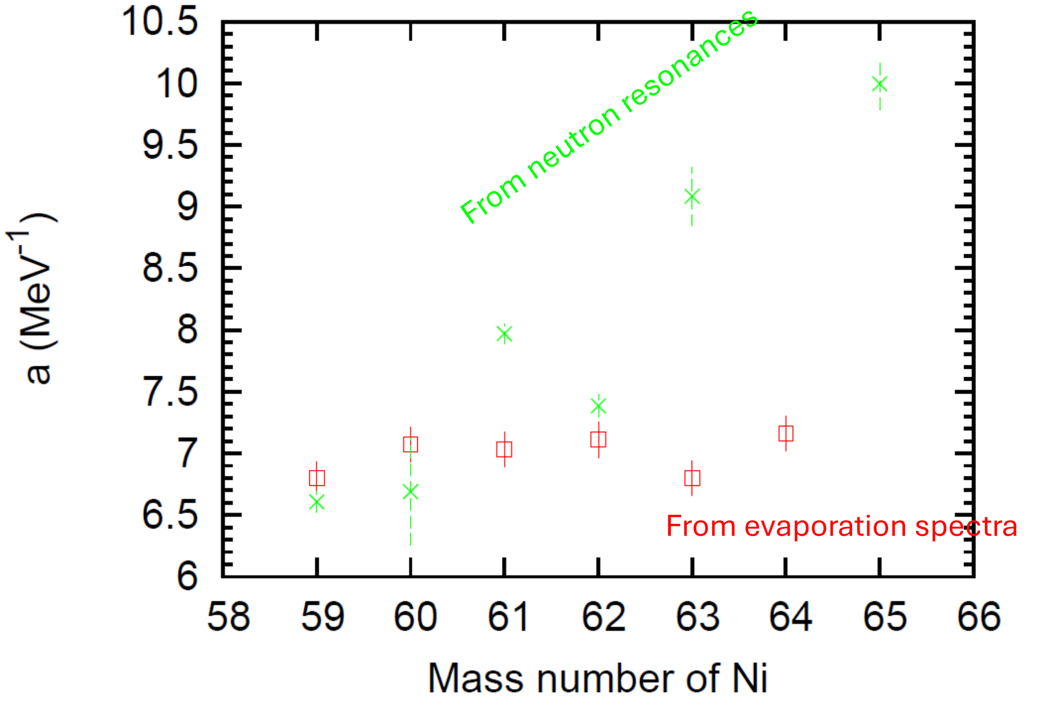


Fig. 4. Level density parameter *a* obtained from both neutron resonance data (stars) and from proton evaporation spectra (squares)

A.V. Voinov et al, EPJ Web of Conferences 21, 05001(2012)

Conclusions

- Analysis of Nb data from the particle evaporation technique showed a good agreement between models and data for ^{92,94}Nb, while models predict a steeper LD slope for ^{96}Nb.
- Data do not support a strong level density dependence on shell corrections for the Fermi-gas phenomenological model for ^{92,94,96}Nb
- Neutron resonance data are no longer sufficient to serve as the sole basis for model improvements because of their limitations. They need to be complemented by other types of data obtained using different experimental techniques.

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