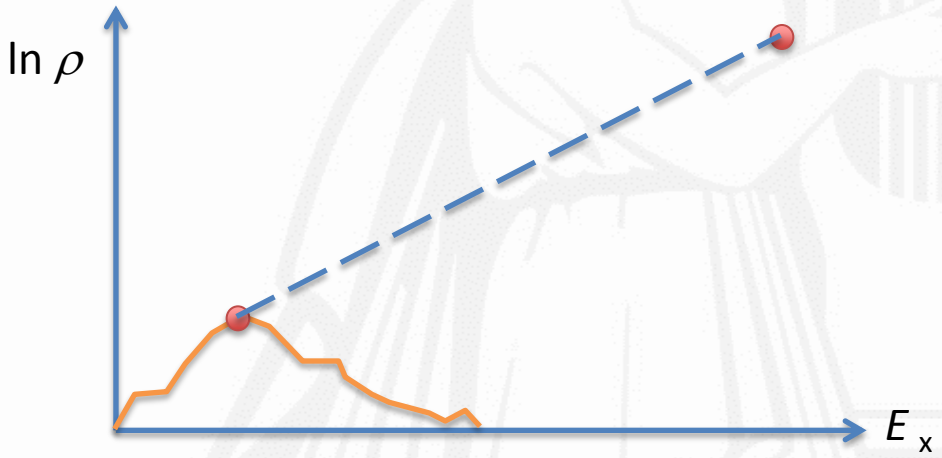
Nuclear Level Densities from an Experimental Point of View

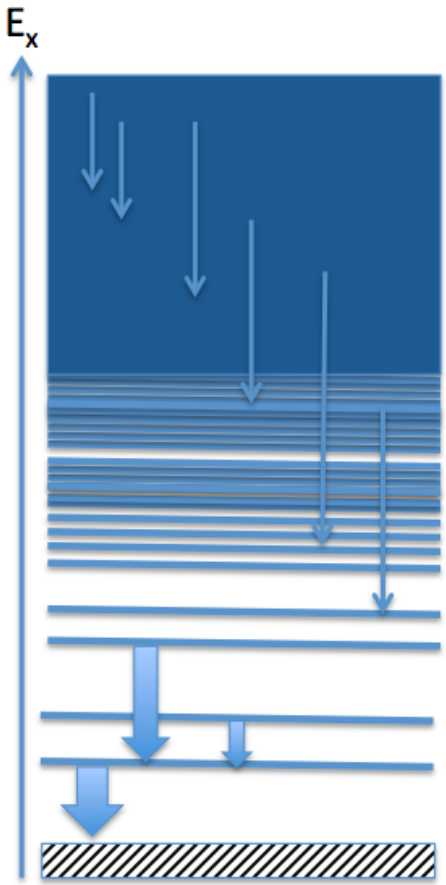


Magne Guttormsen
Department of Physics
University of Oslo, Norway

Energy regimes of the nucleus

Level spacing *D* and width Γ

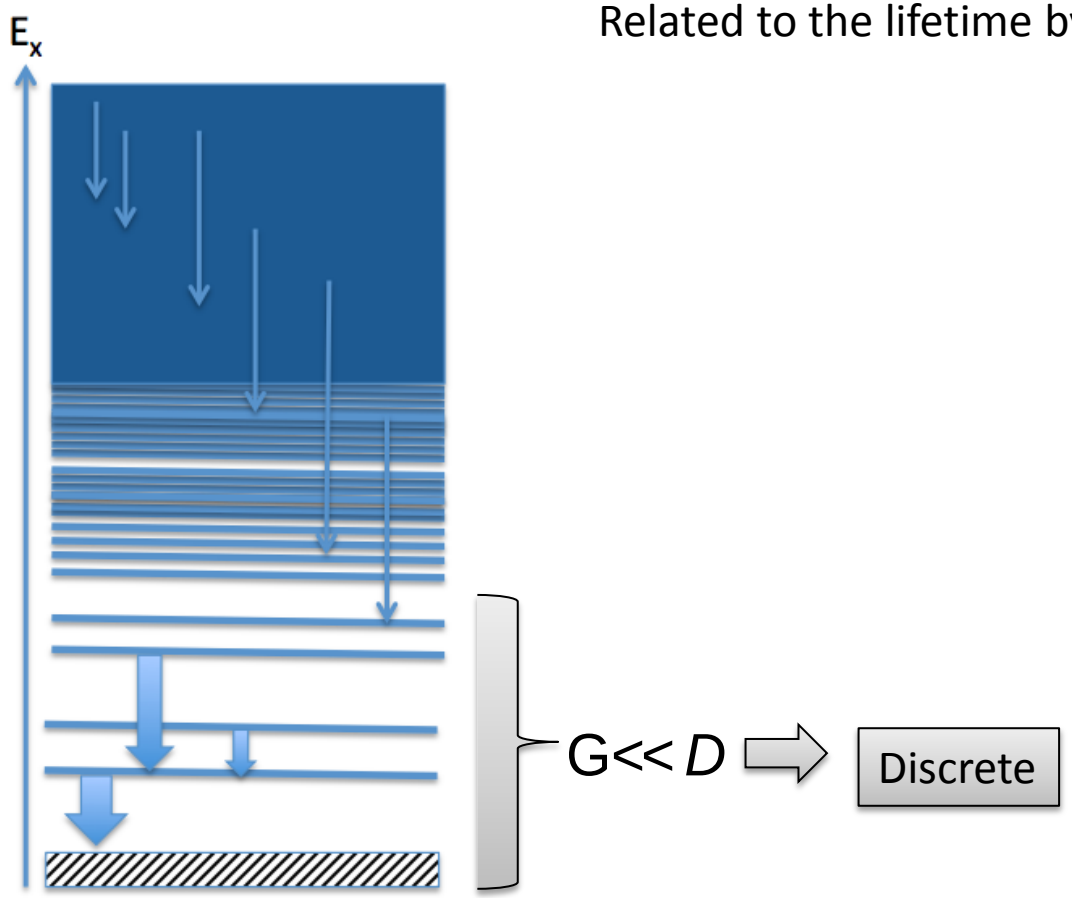
Related to the lifetime by $G\mu \frac{1}{t}$



Energy regimes of the nucleus

Level spacing *D* and width Γ

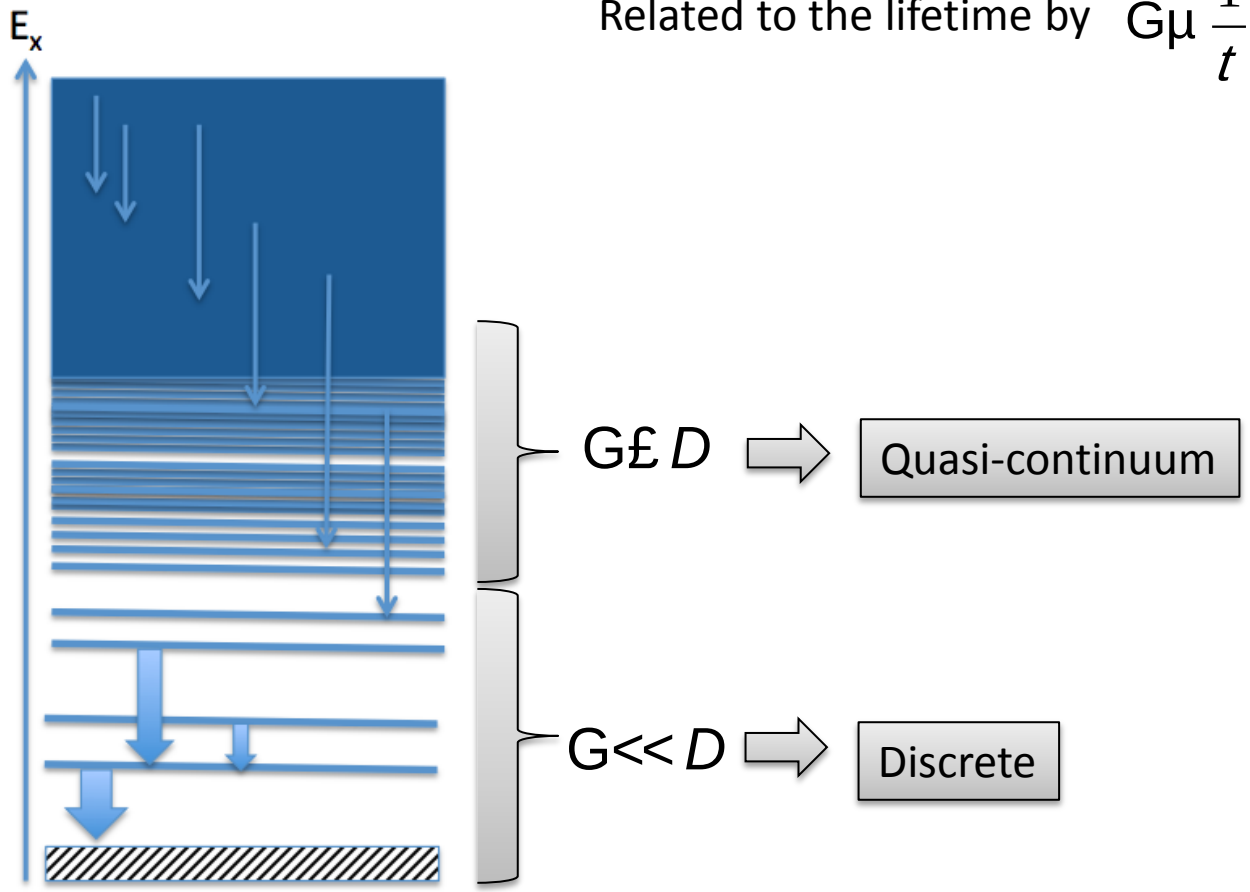
Related to the lifetime by $G\mu \frac{1}{t}$



Energy regimes of the nucleus

Level spacing *D* and width Γ

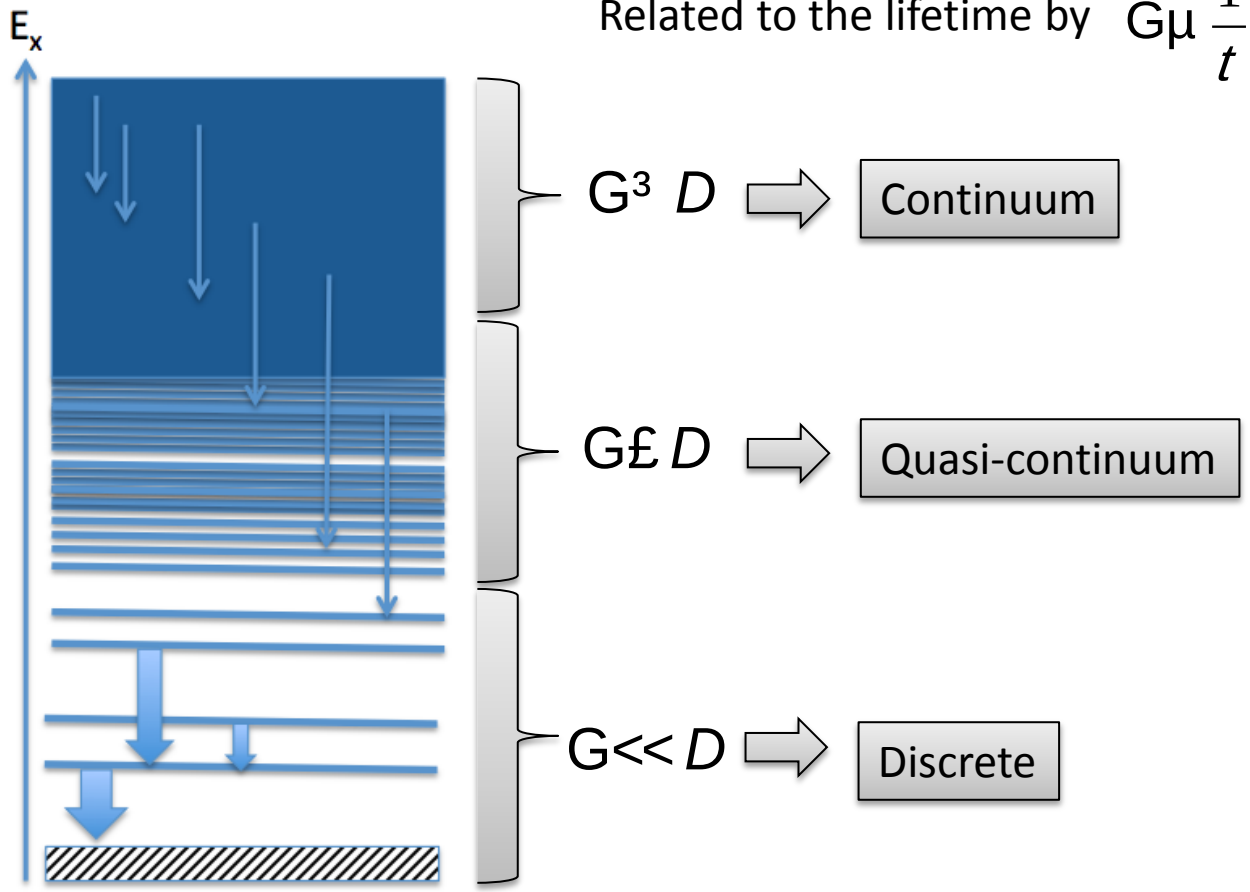
Related to the lifetime by $\Gamma \mu \frac{1}{t}$



Energy regimes of the nucleus

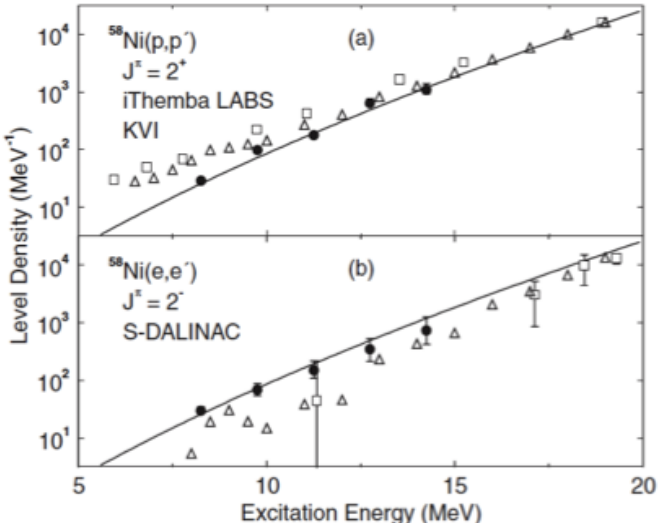
Level spacing D and width Γ

Related to the lifetime by $G\mu \frac{1}{t}$

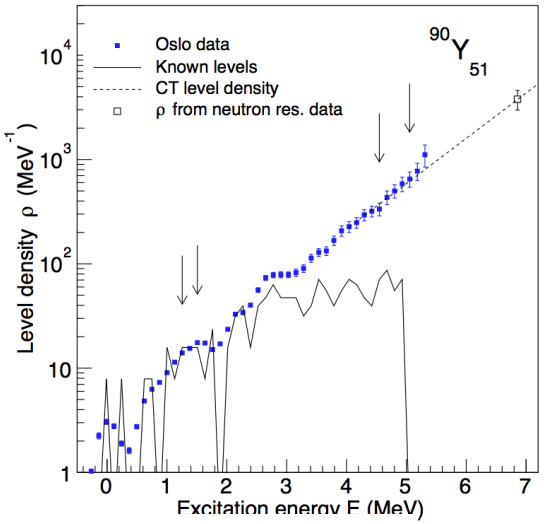


Techniques to measure level density

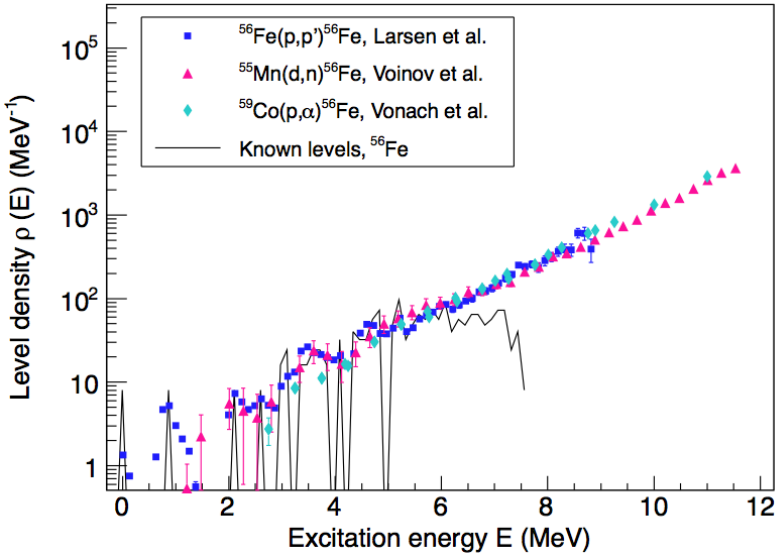
- Discrete levels (Ex < 2 - 3 MeV or < 50 - 100 levels/MeV)
- Neutron/proton resonances (Ex = Sn or Sp)
- Particle evaporation spectra (Ex = 4 - 15 MeV)
- Spin/parity resolved level densities from (p,p´) or (e,e´)
- Ericsson fluctuations (Ex ~ 15 MeV)
- Primary γ spectra with the Oslo method (Ex < Sn)



Kalmykov et al.,
PRL **99**,
202502 (2007)



M. Guttormsen et al.,
PRC, (2014), in press

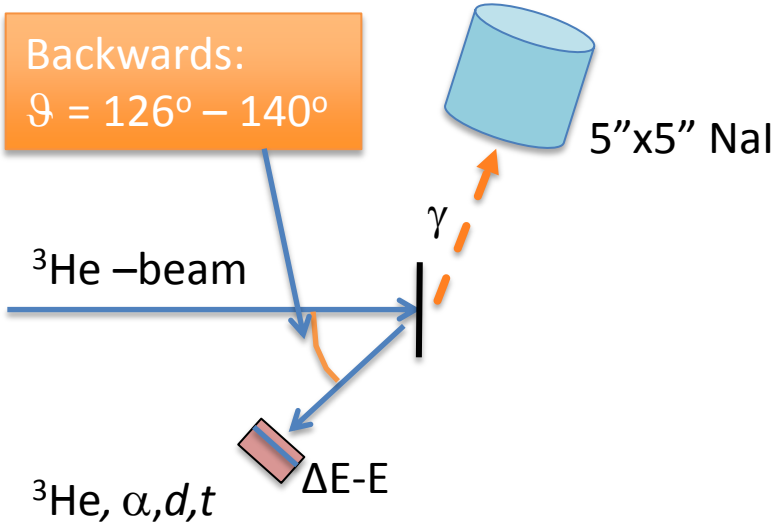


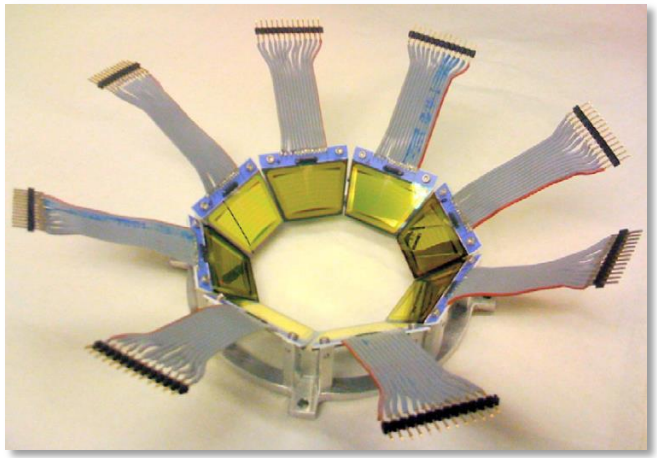
A.C. Larsen et al.,
PRL **111**,
242504 (2013)

Th and U experiments at OCL

12 MeV d on ^{232}Th
24 MeV ^{3}He on ^{232}Th
15 MeV d on ^{238}U

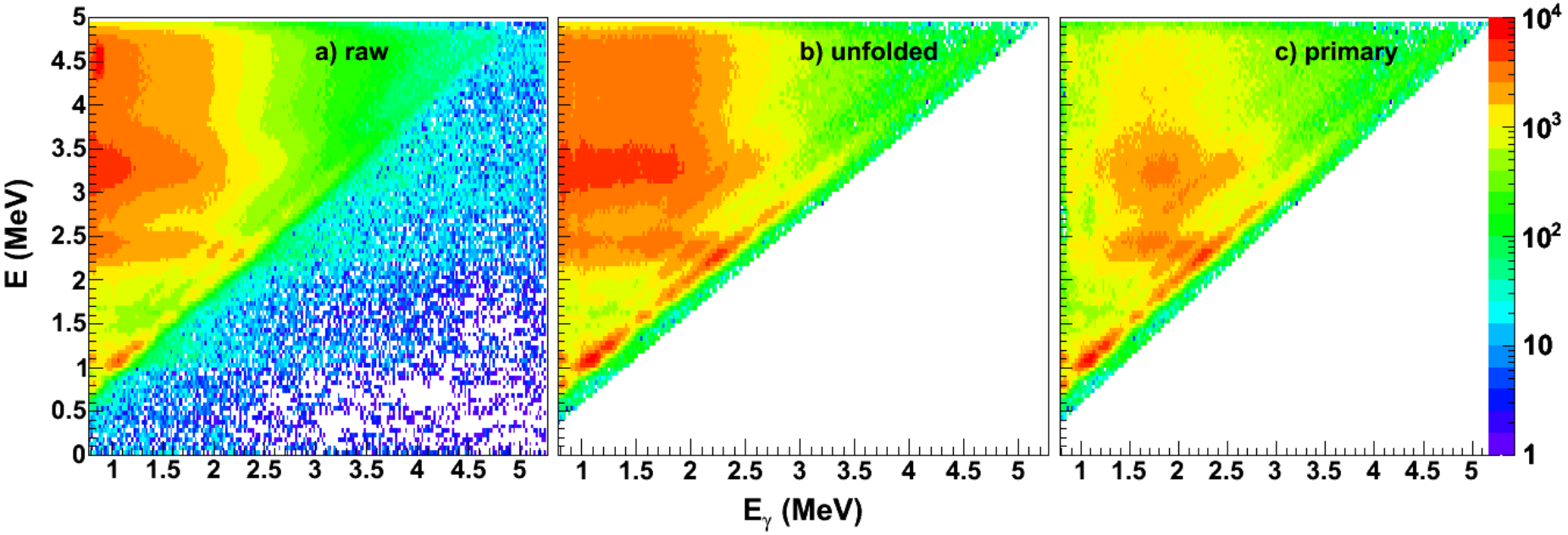
Backwards:
ϑ = 126° – 140°





M.Guttormsen, A.Bürger, T.E.Hansen, N.Lietaer,
NIM A648(2011)168

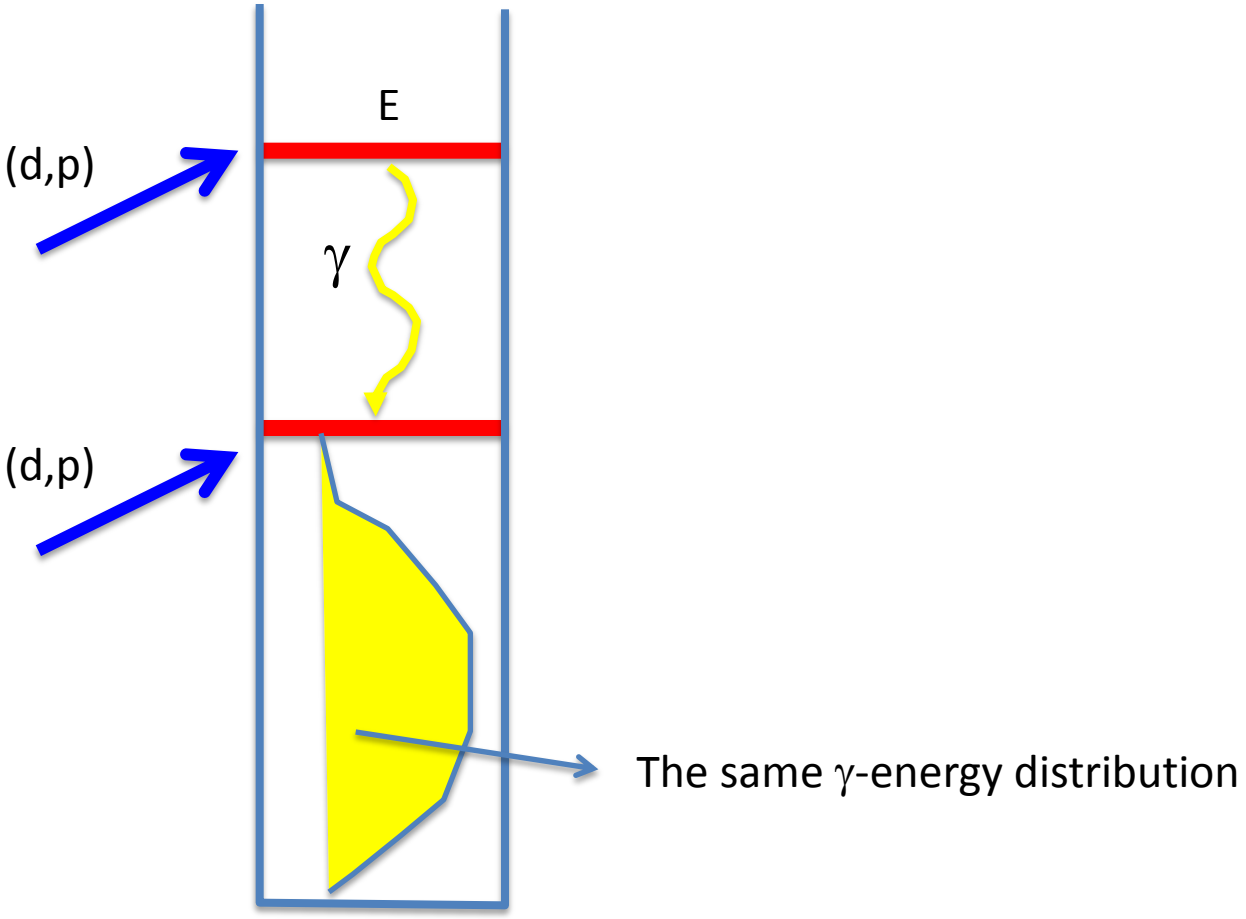
The Oslo method
Simultaneous extraction of NLD and γSF



T.G. Tornyi et al., PRC **89**, 044323, (2014)

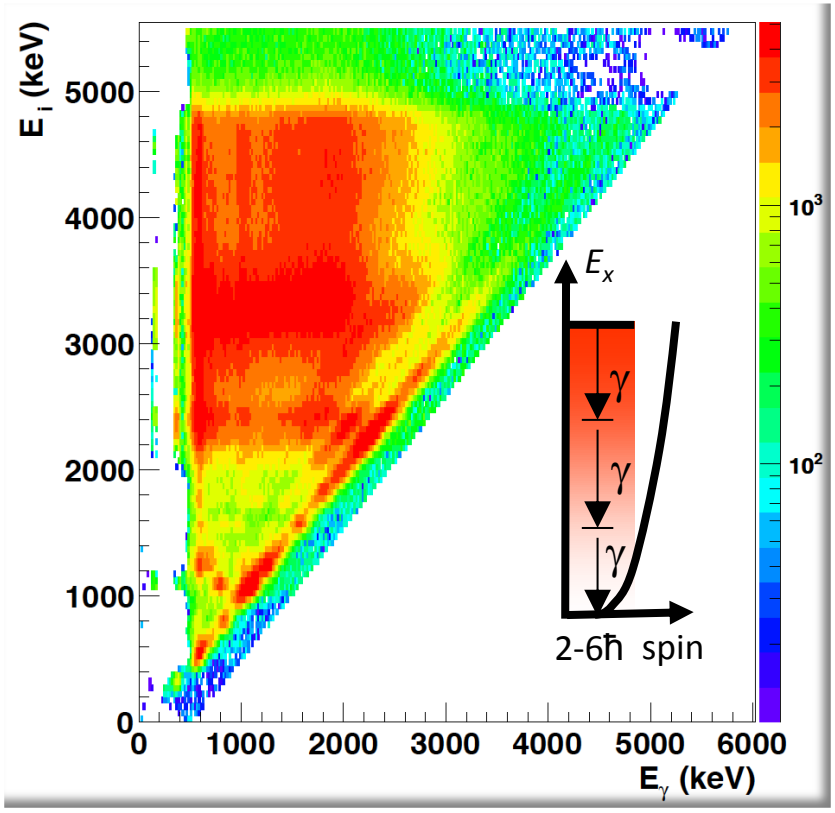
Oslo method:
M. Guttormsen et al., NIM A374 (1996) 371
M. Guttormsen et al., NIM A255 (1987) 518
A. Schiller et al., NIM A447 (2000) 498
A.C. Larsen et al., PRC **83**, 034315 (2011)

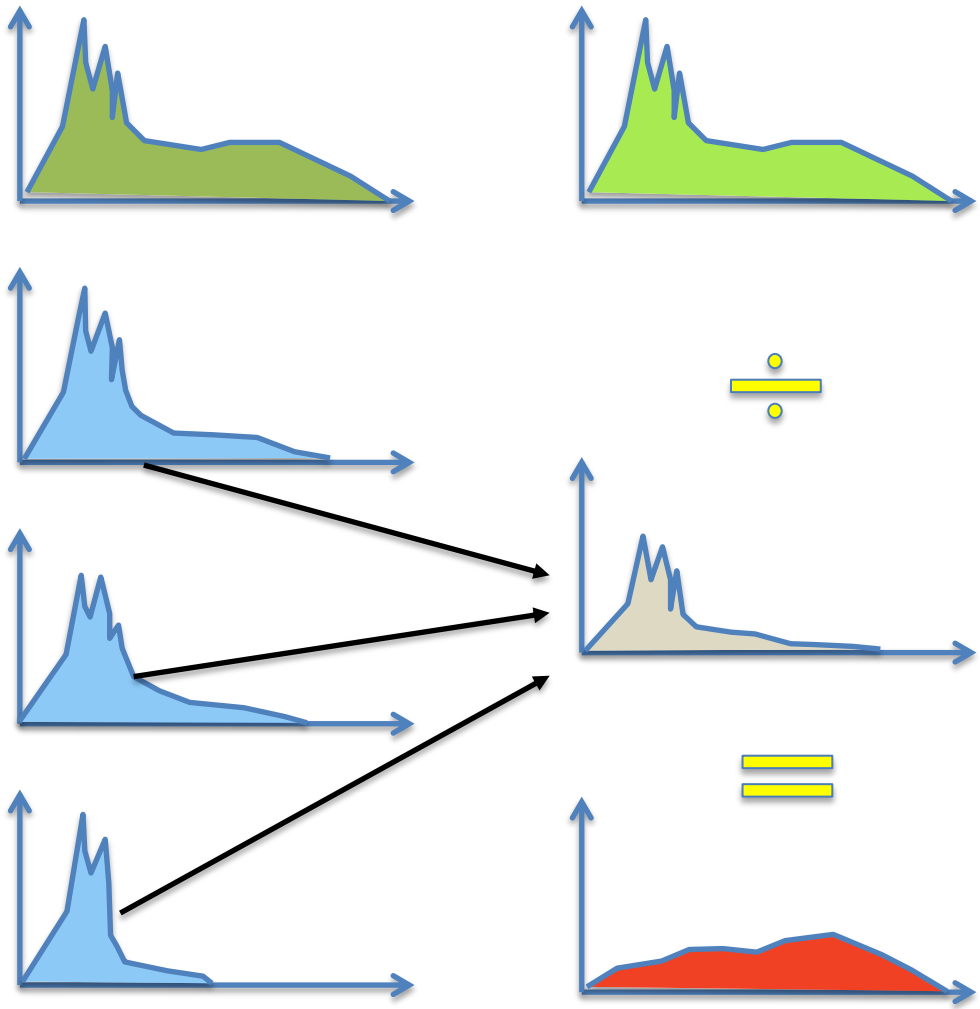
Assumption for the extraction of primary γ-spectra



From total to primary γ-ray matrix

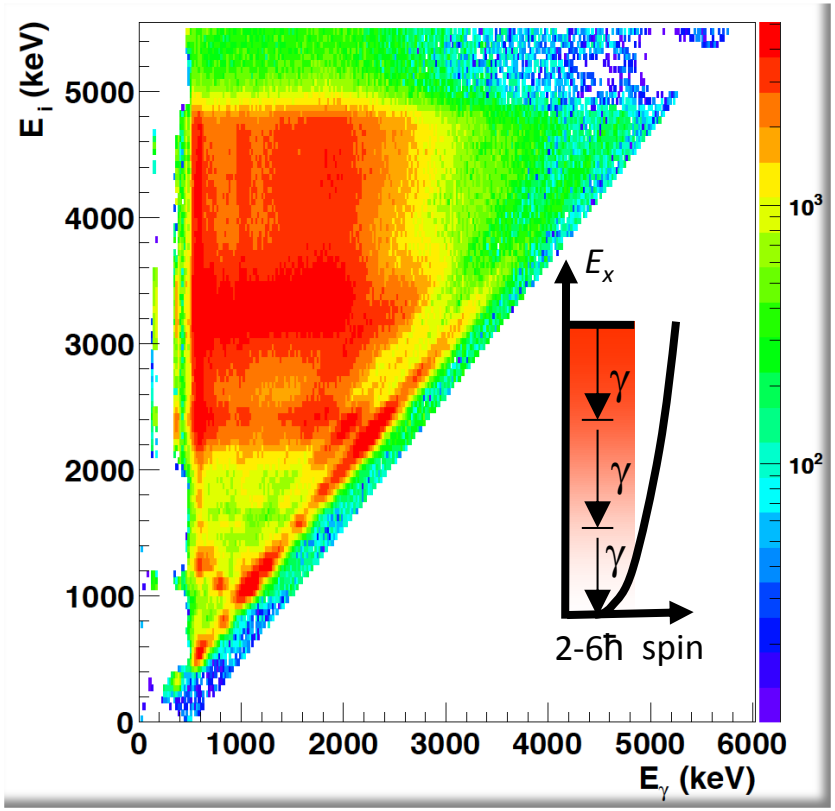
^{232}Th(d,p) ^{233}Th

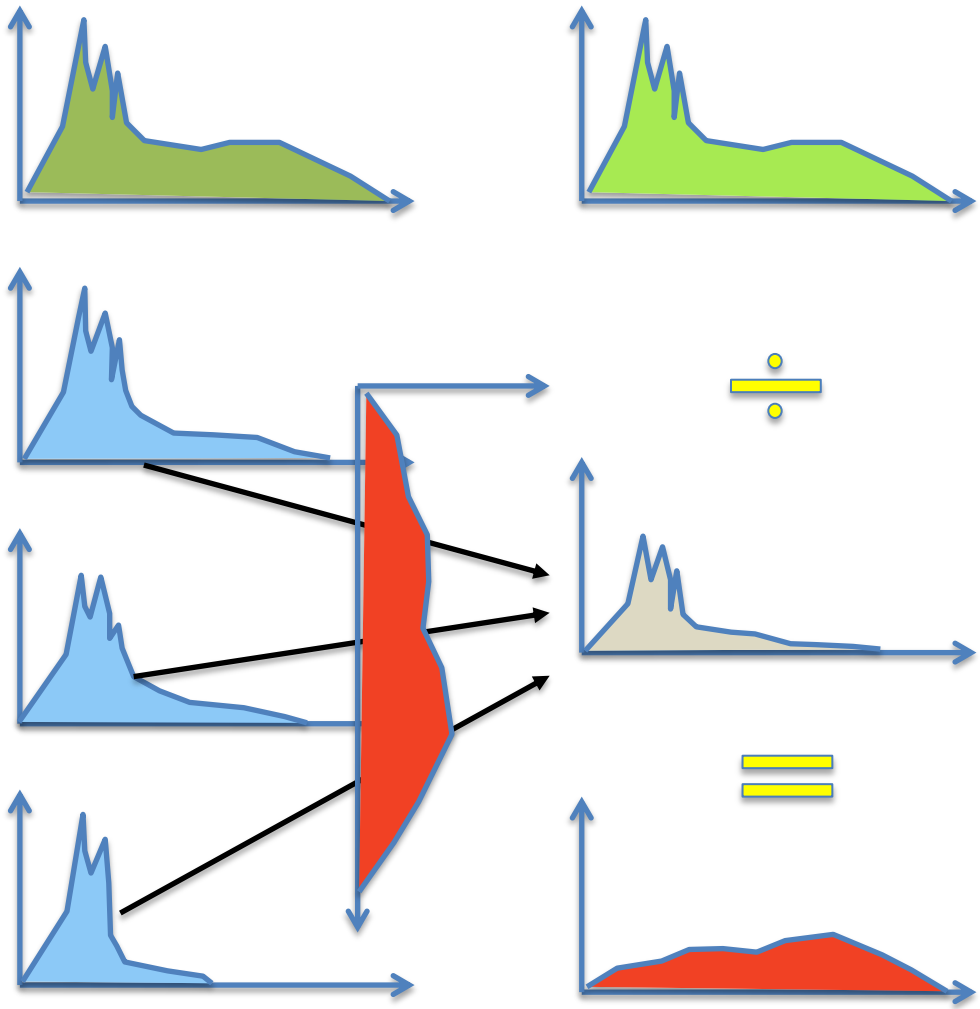




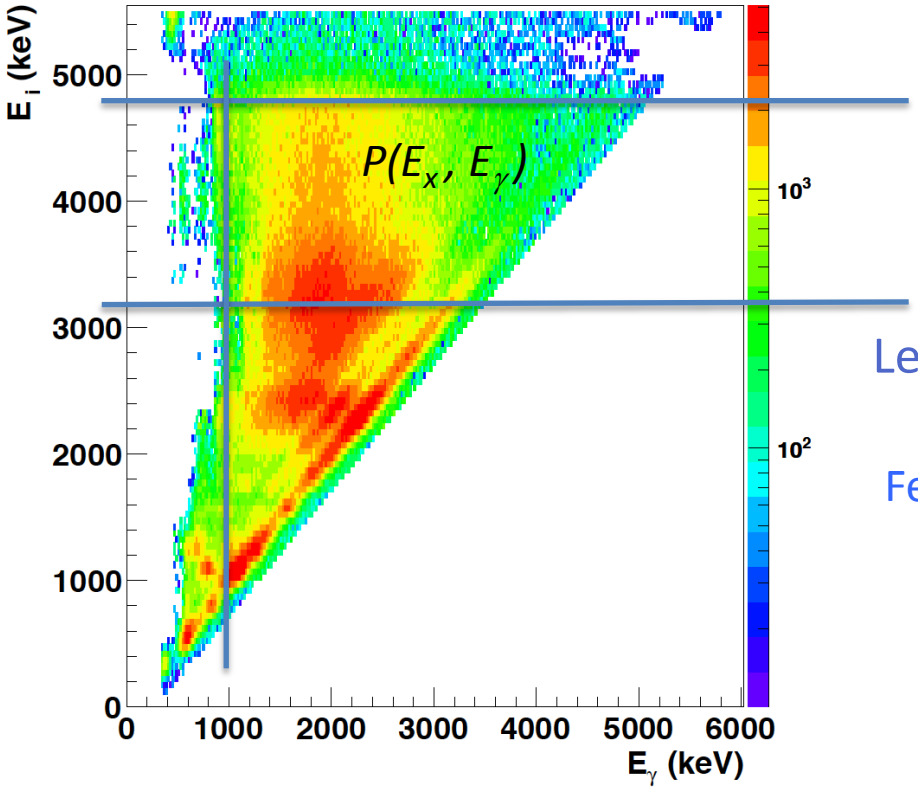
From total to primary γ-ray matrix

^{232}Th(d,p) ^{233}Th





Primary γ-ray matrix



$P(E_x, E_\gamma)$

Level density

$\rho(E_f)$

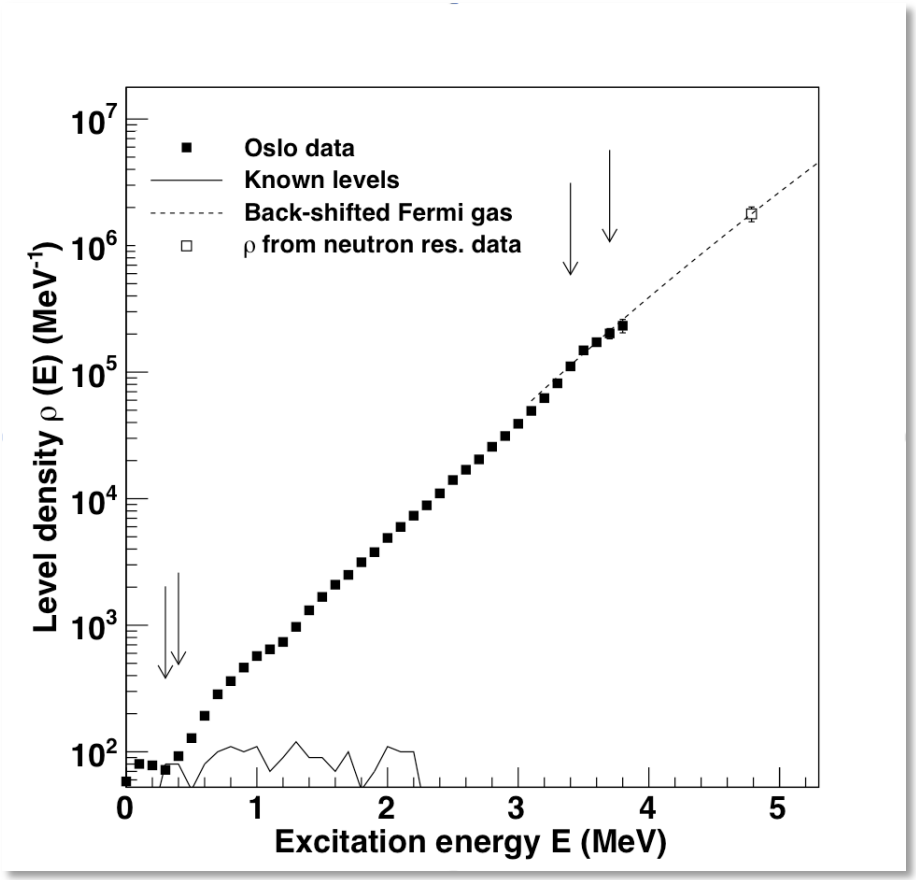
Fermi's golden rule

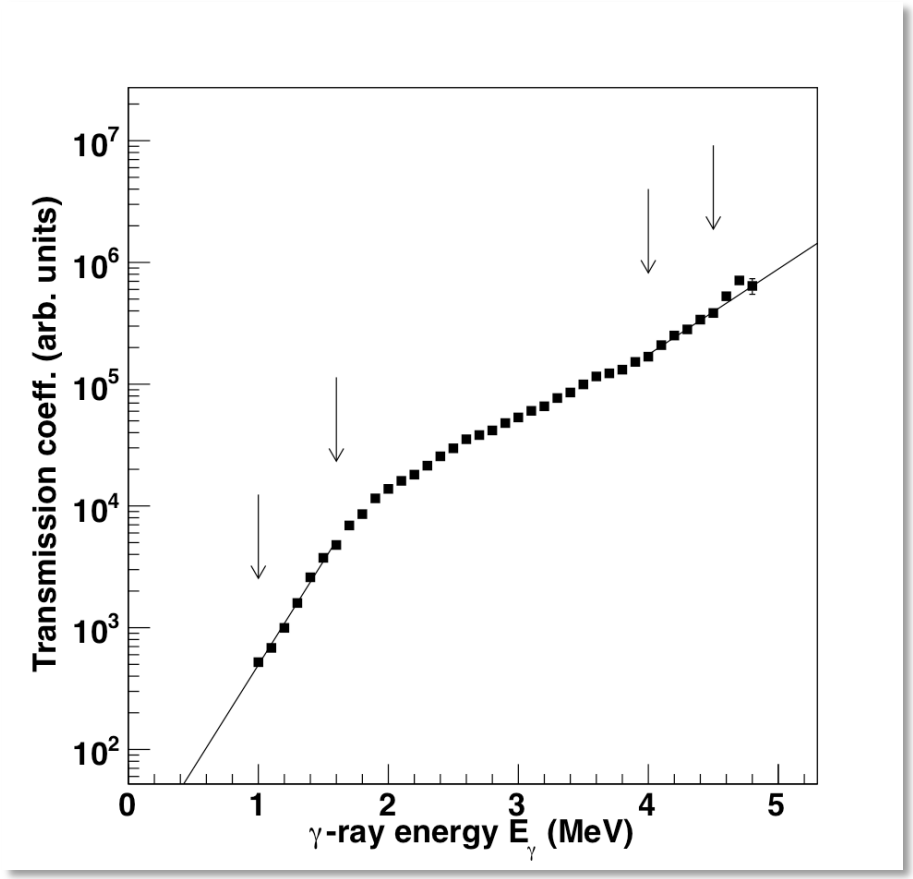
Trans. coeff.

$T(E_\gamma)$

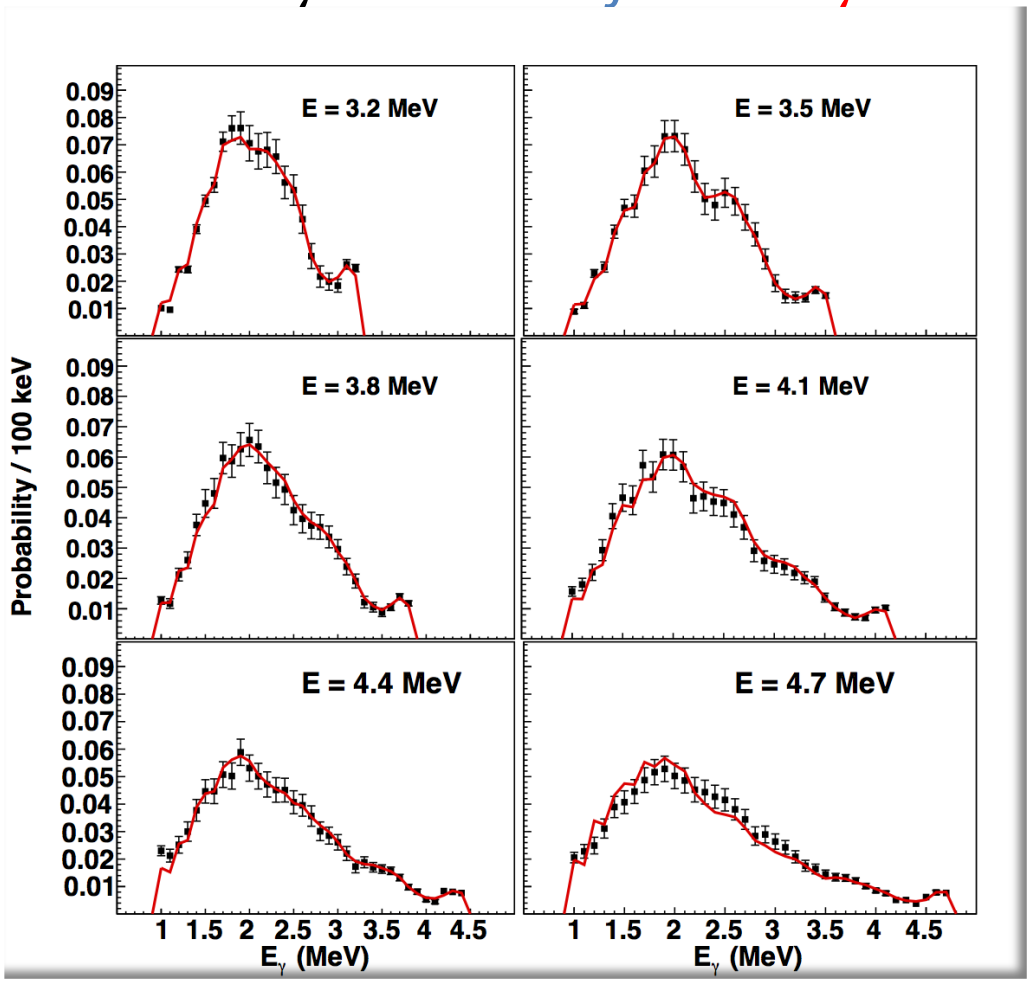
Brink hypothesis

$\rho(E_f)$ and $T(E_\gamma)$



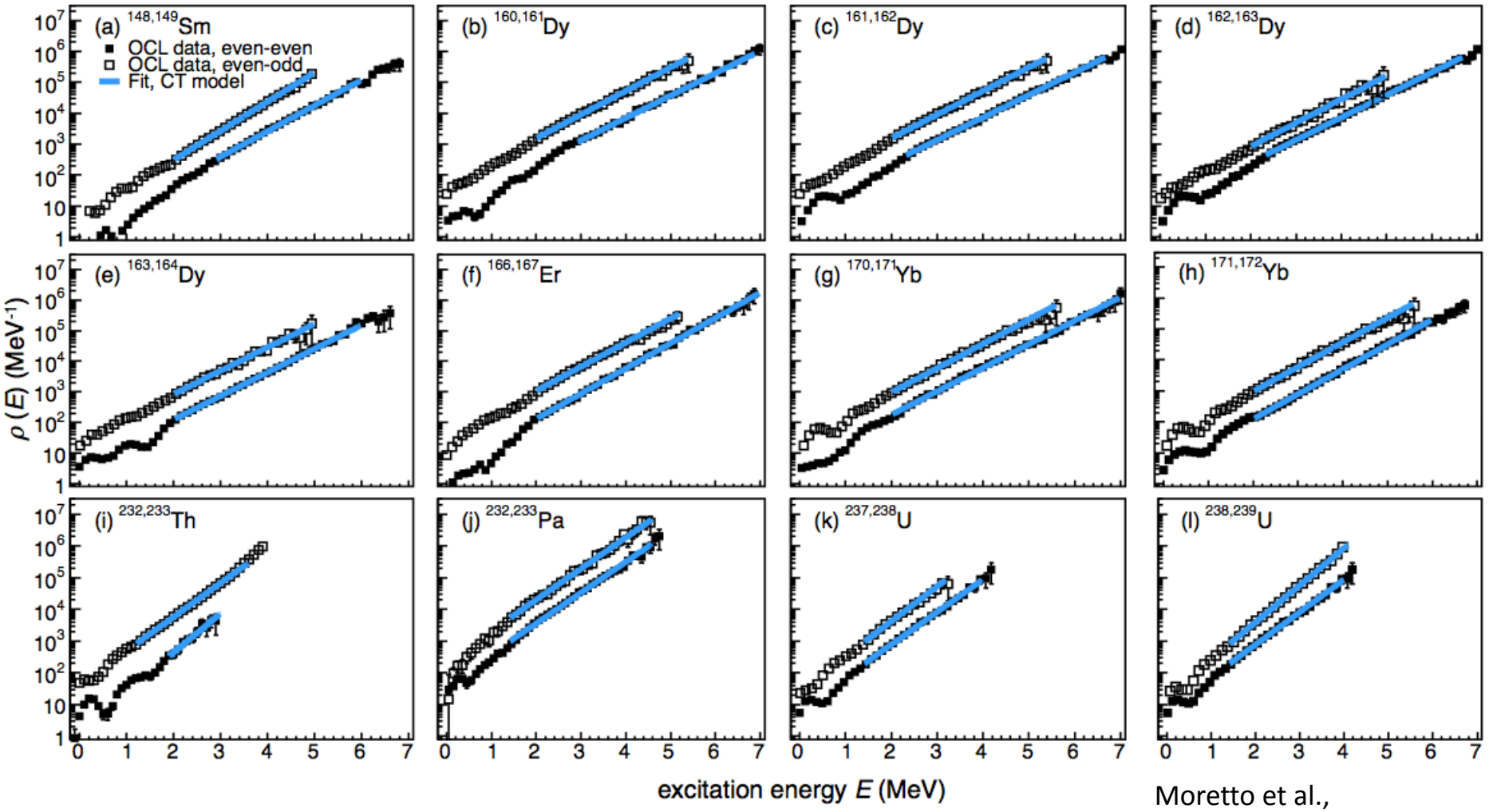


$$P(E,E_\gamma) = \rho(E_f) \cdot T(E_\gamma)\ ?$$



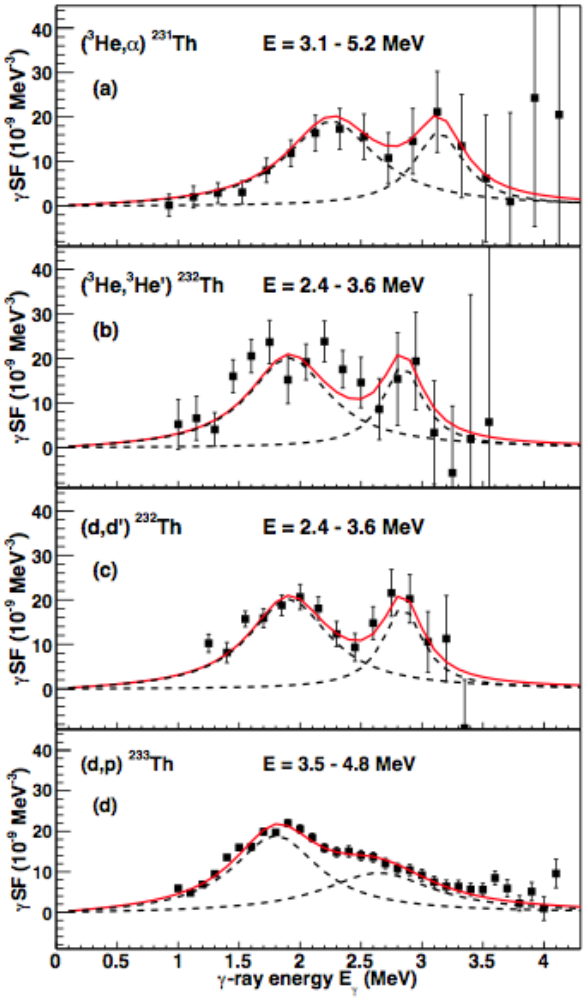
M. Guttormsen et al.,
PRL **109**, 162503, (2012)

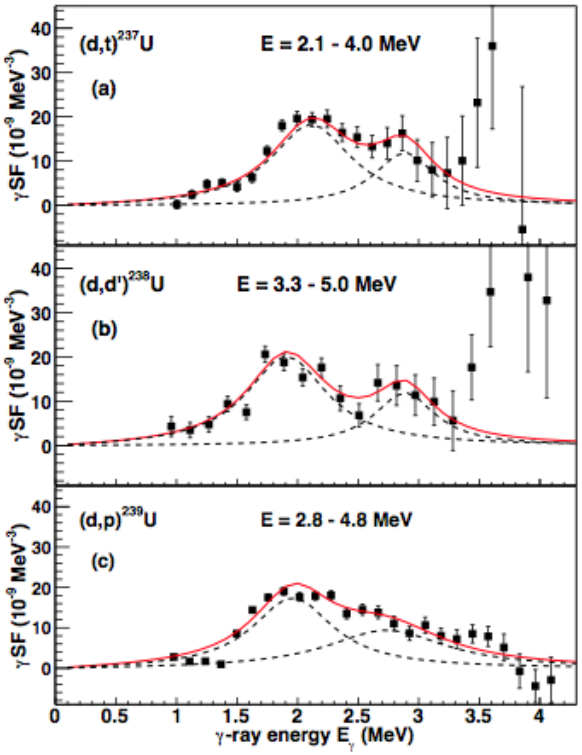
Constant-temperature level densities

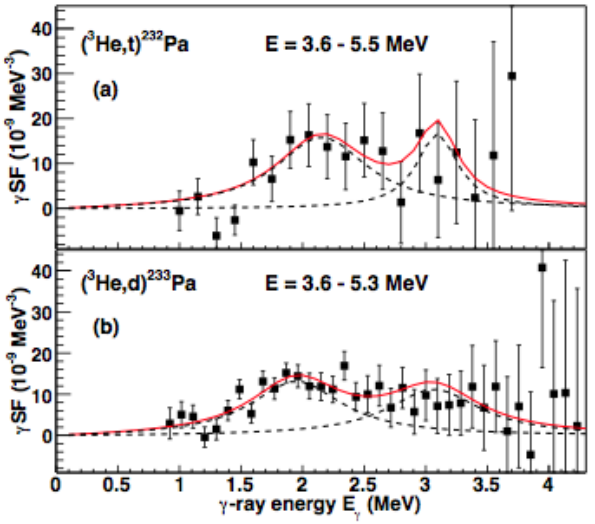


Moretto et al.,
arXiv:1406.2642 (2014)
$T = \Delta / 1.77 = 12A^{-1/2} / 1.77$

Scissors mode



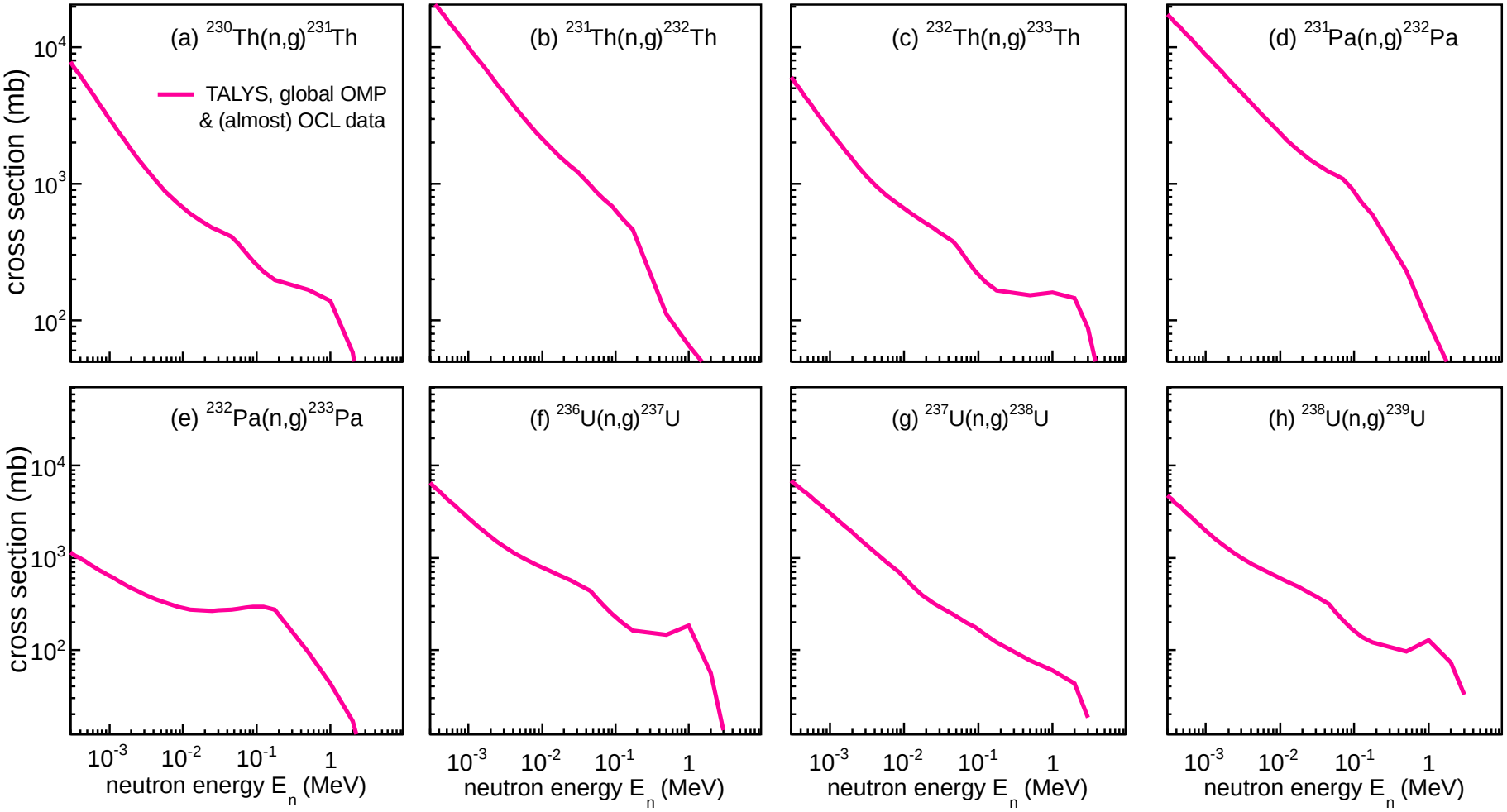




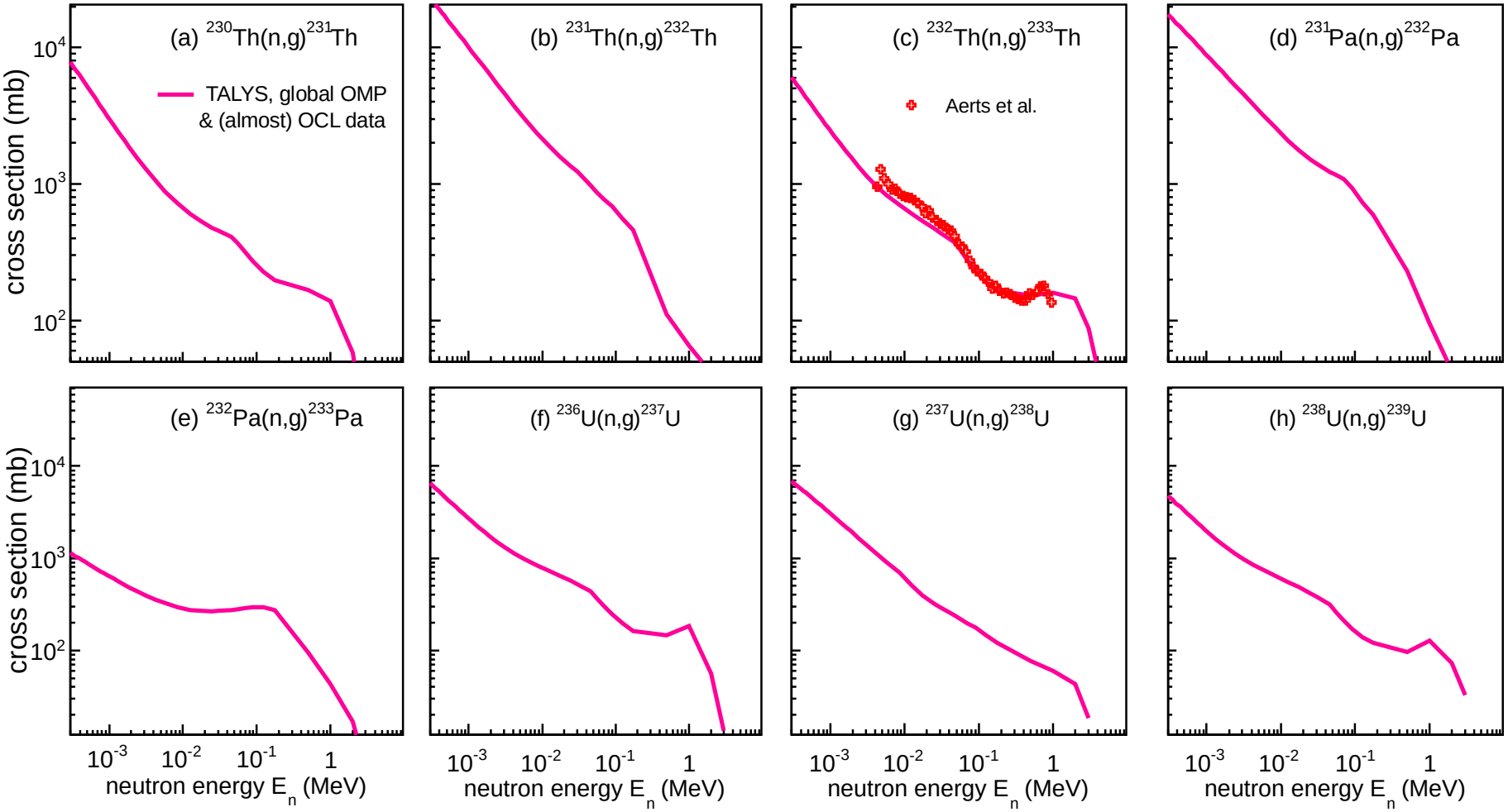
E_γ ≈ 2.4 MeV

B(M1) ≈ 9 -11 μ_N^2

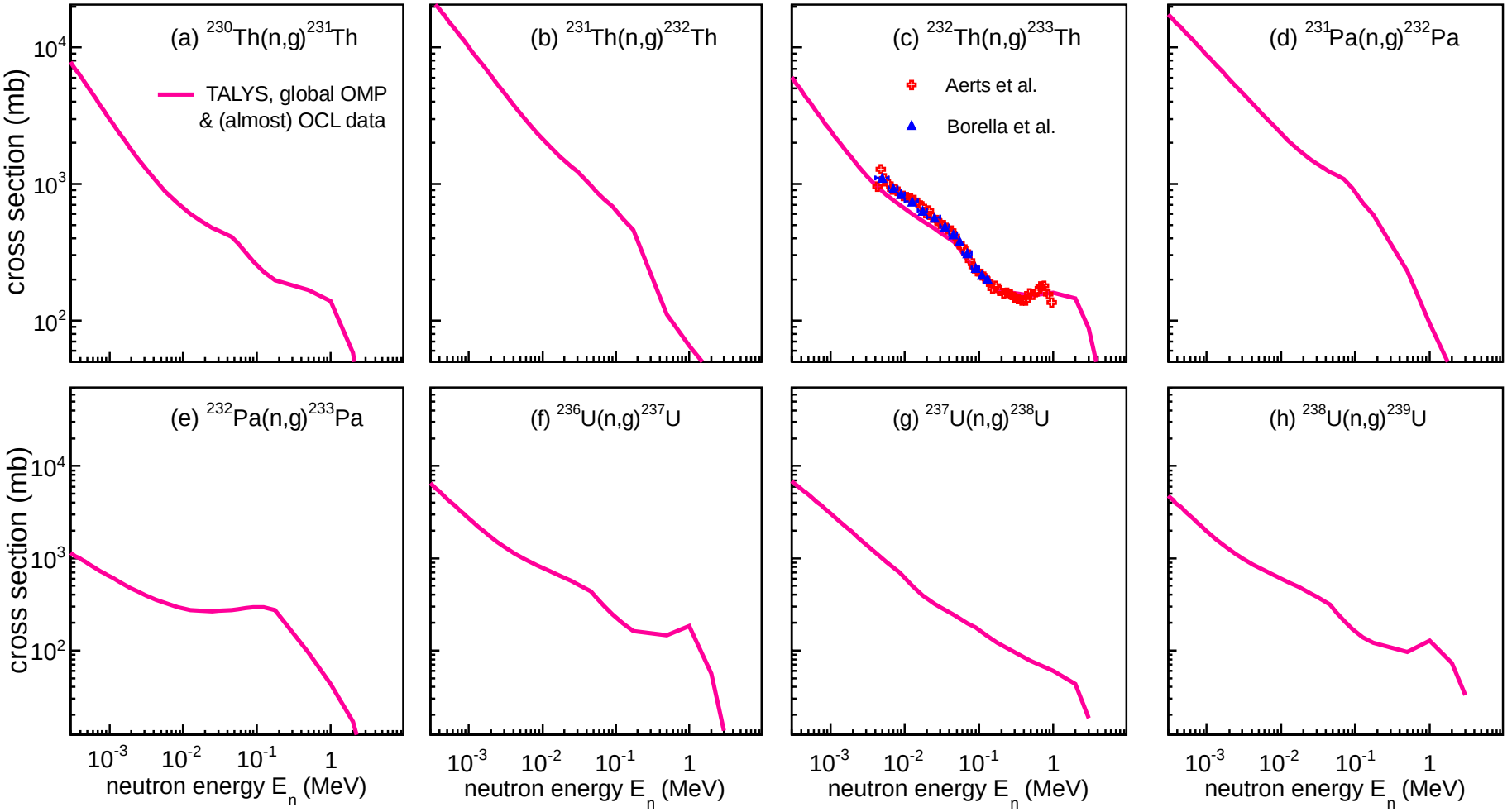
NLD + γSF + OMP = true



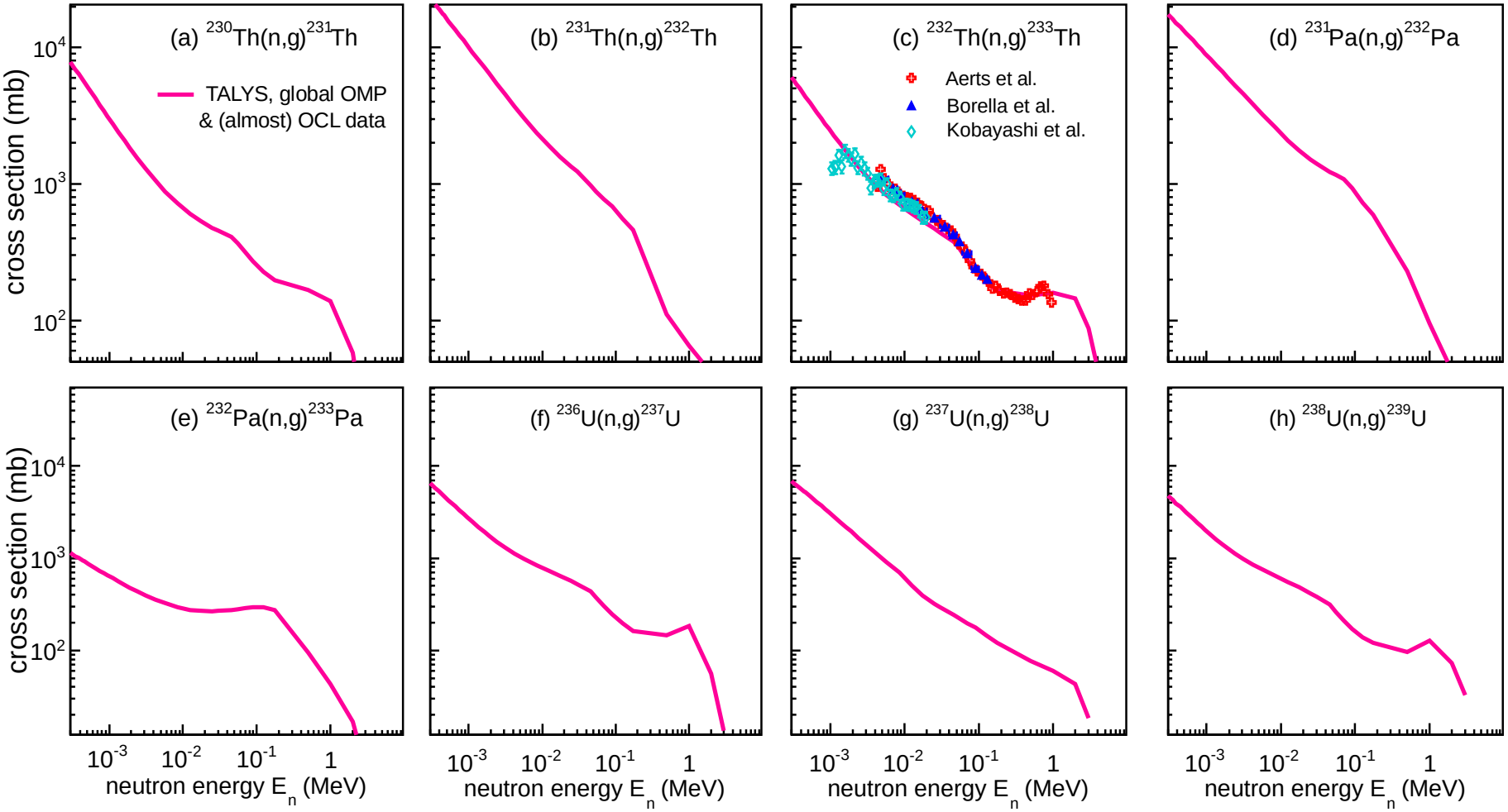
NLD + γSF + OMP = true



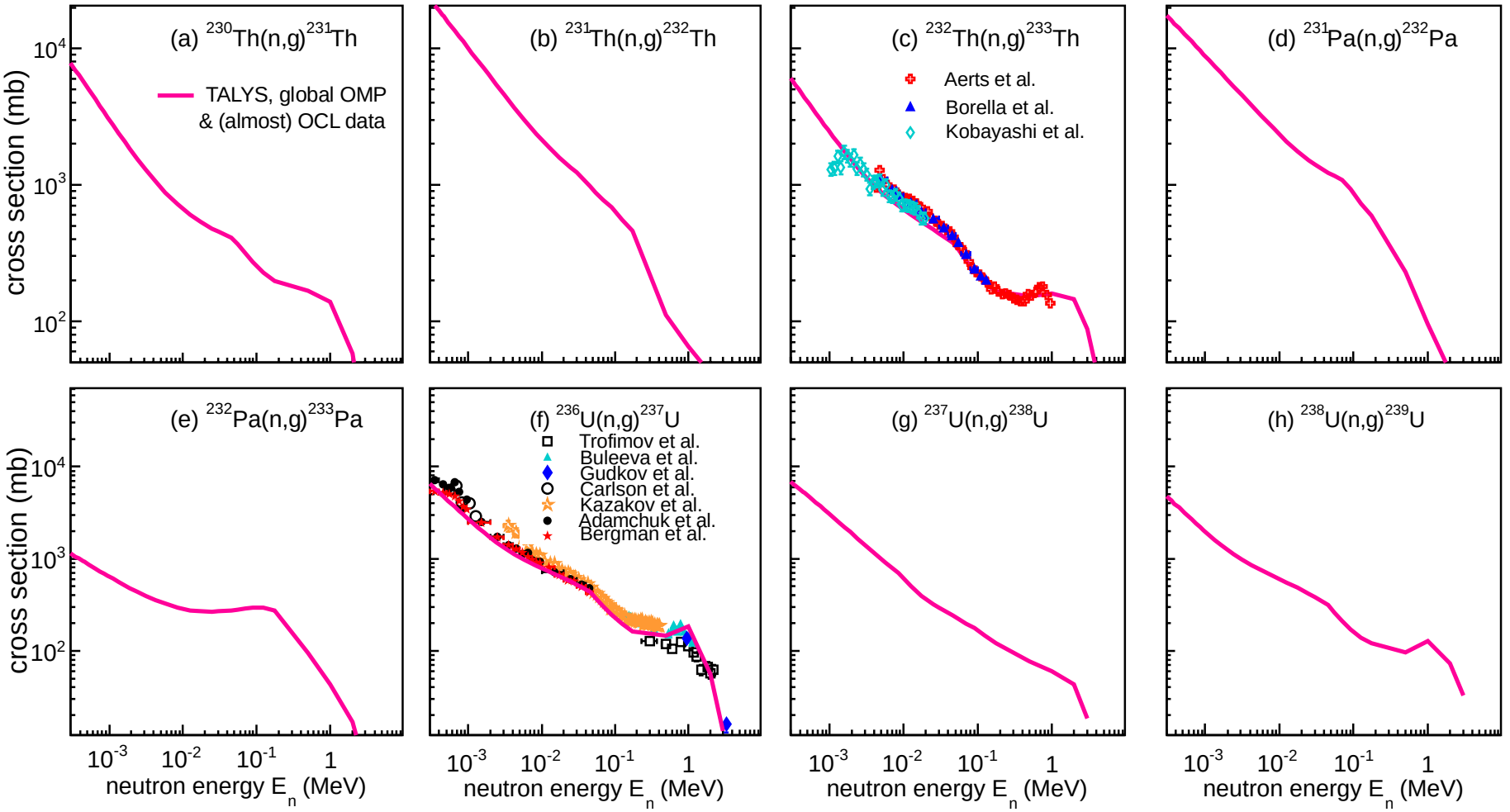
NLD + γSF + OMP = true



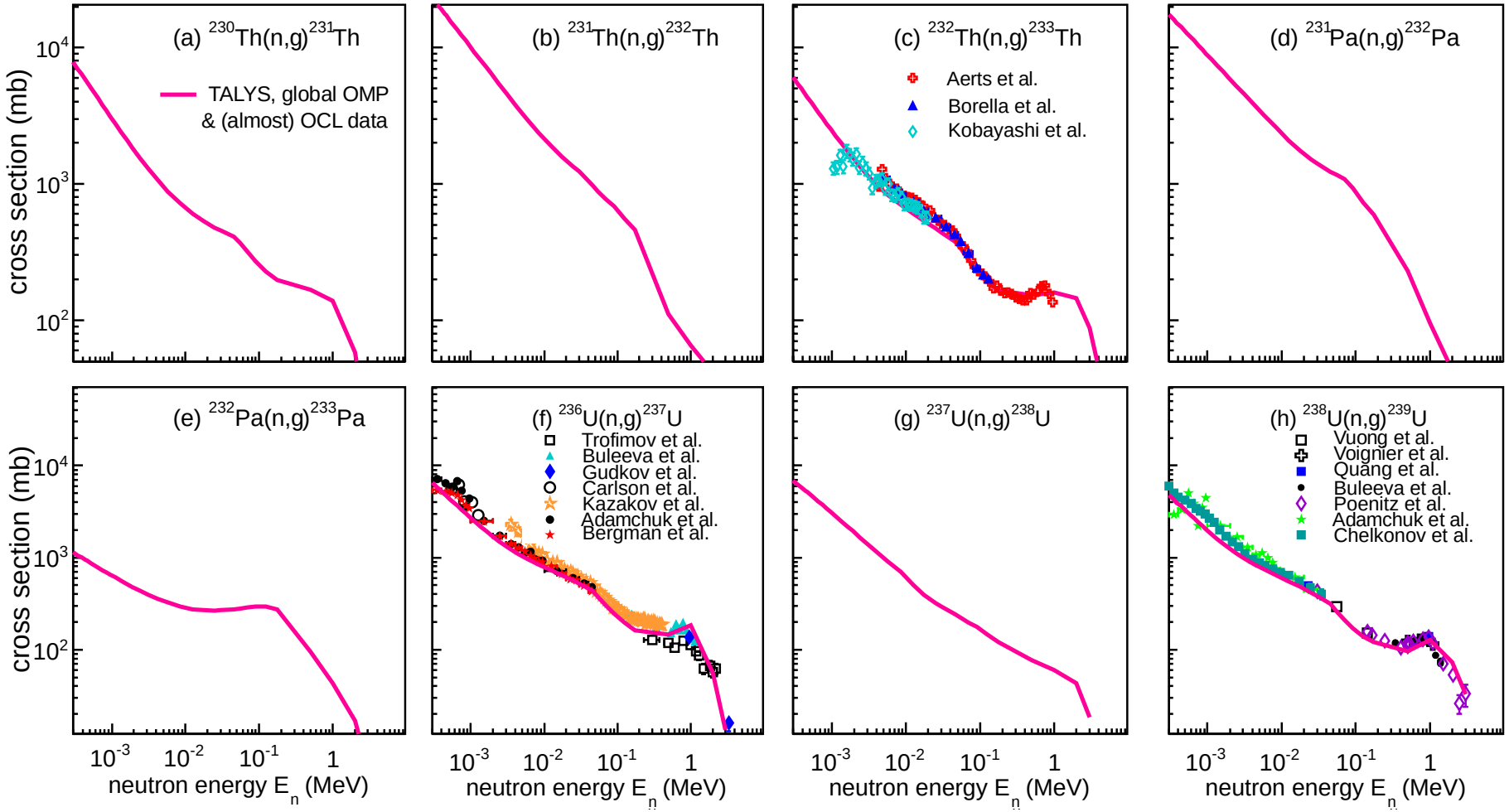
NLD + γSF + OMP = true



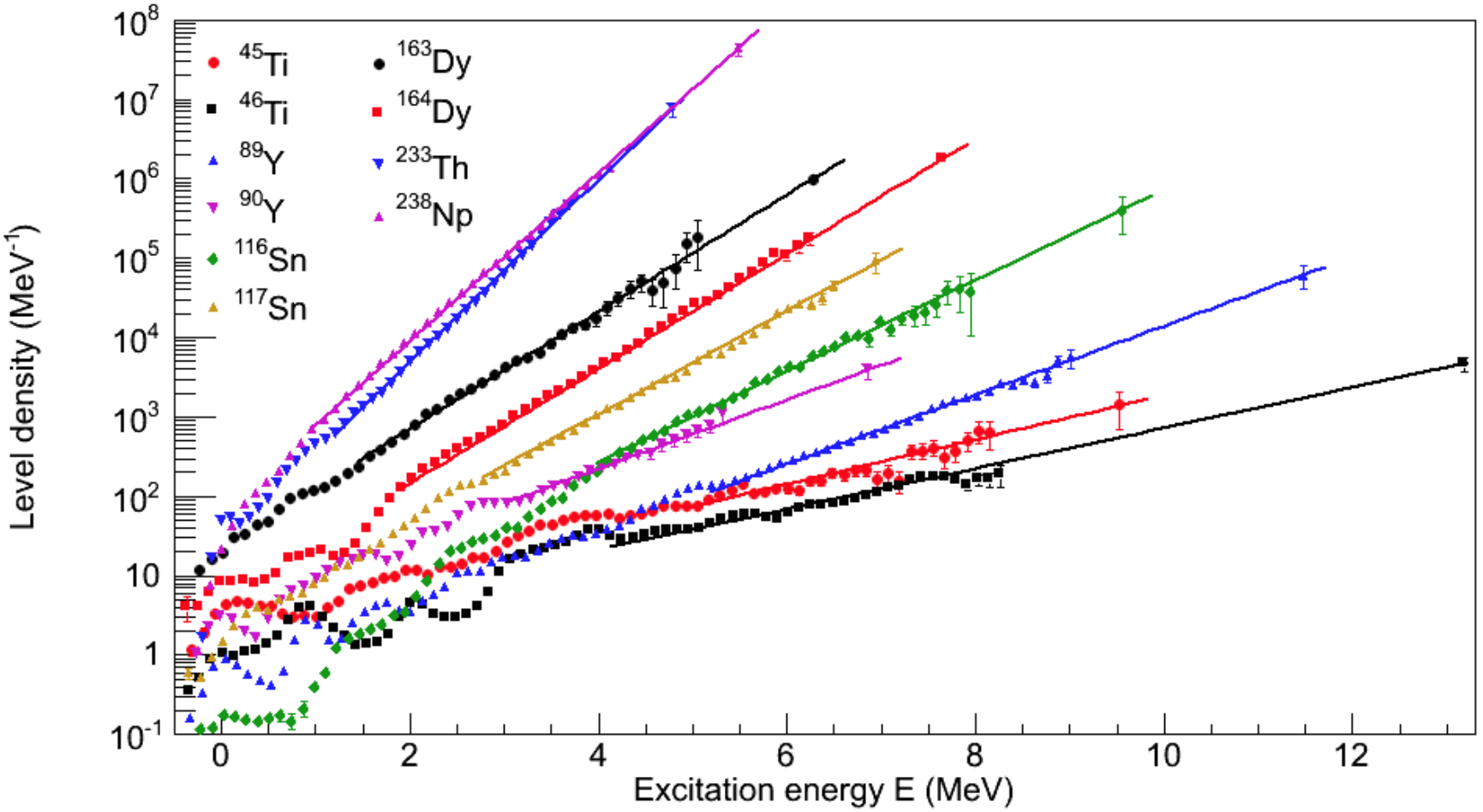
NLD + γSF + OMP = true



NLD + γSF + OMP = true



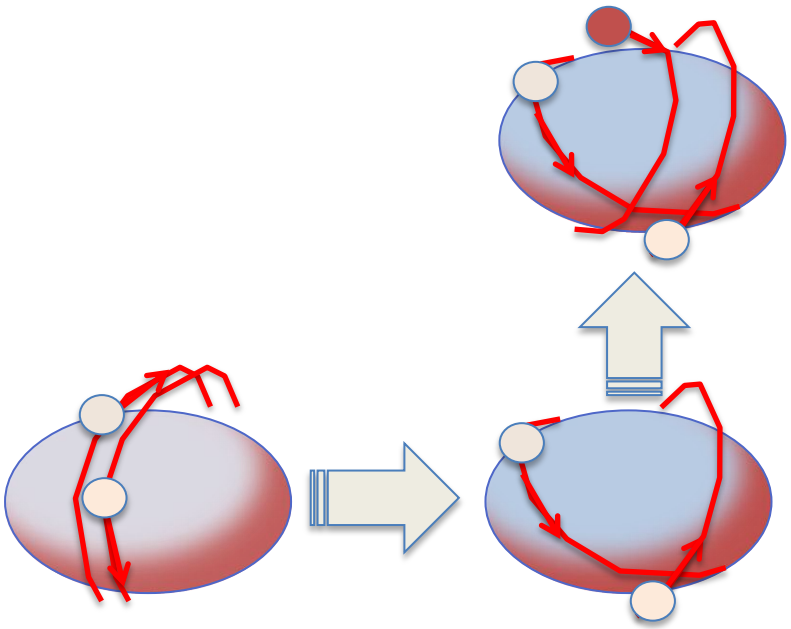
Experimental level densities with the Oslo method



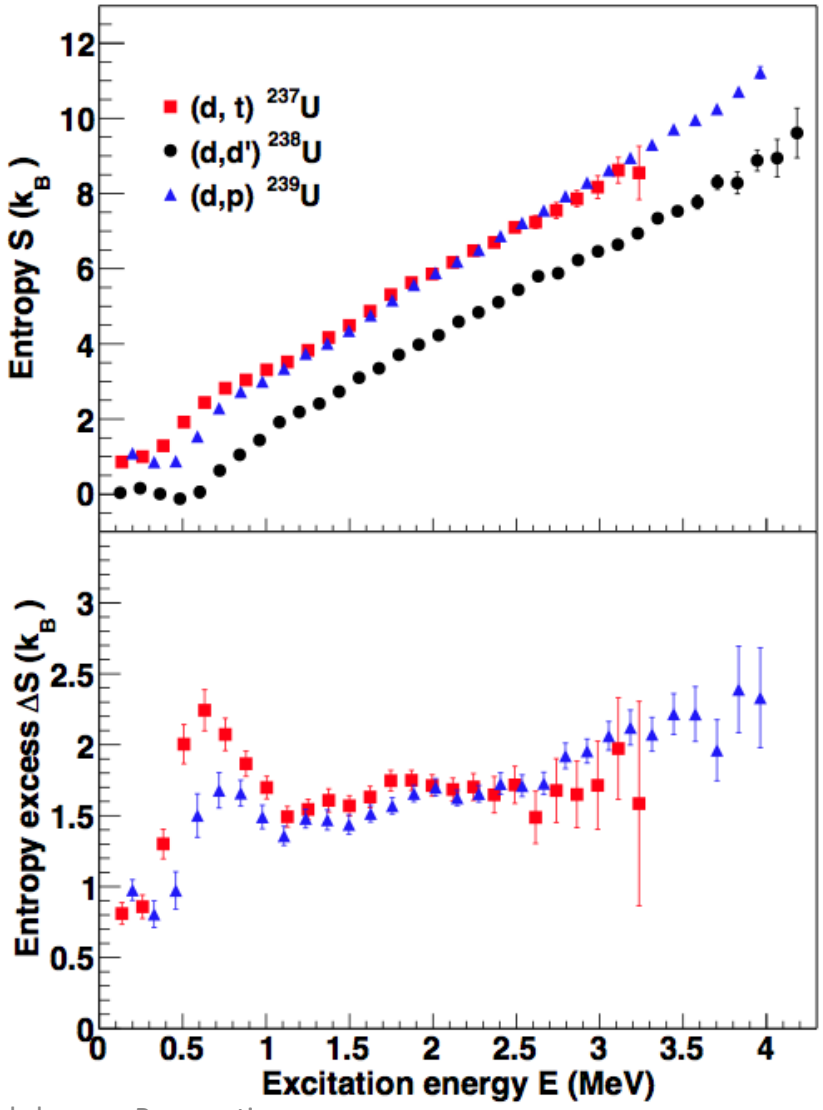
Level densities and entropy

$$S(E) = k_B \ln W(E) \propto k_B \ln r(E)$$

$$S(E) \xrightarrow[E \to 0]{} 0$$

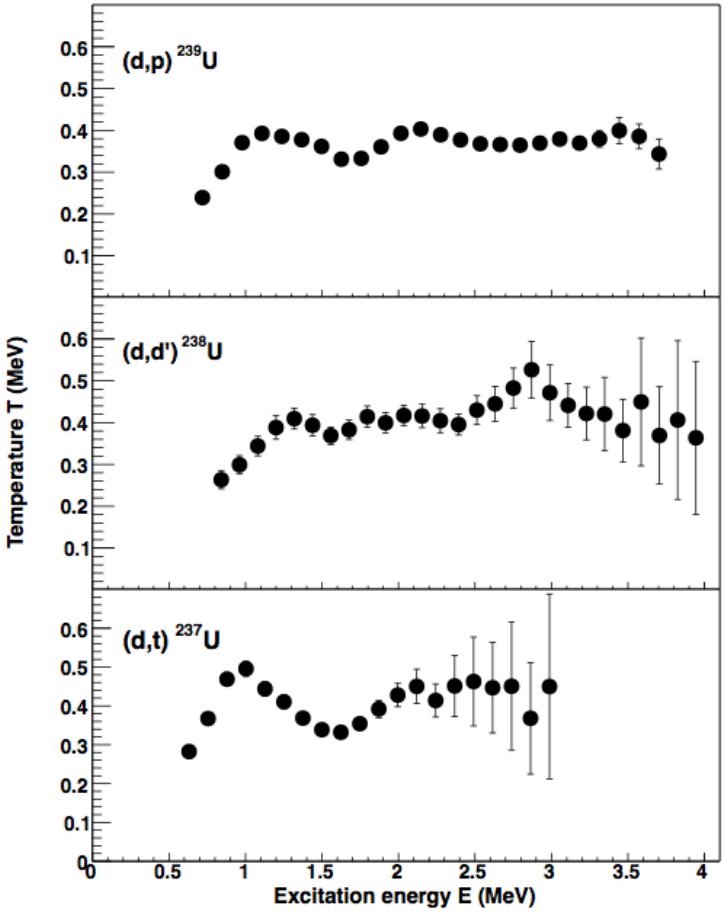


M. Guttormsen et al., PRC **88**, 024307 (2014)

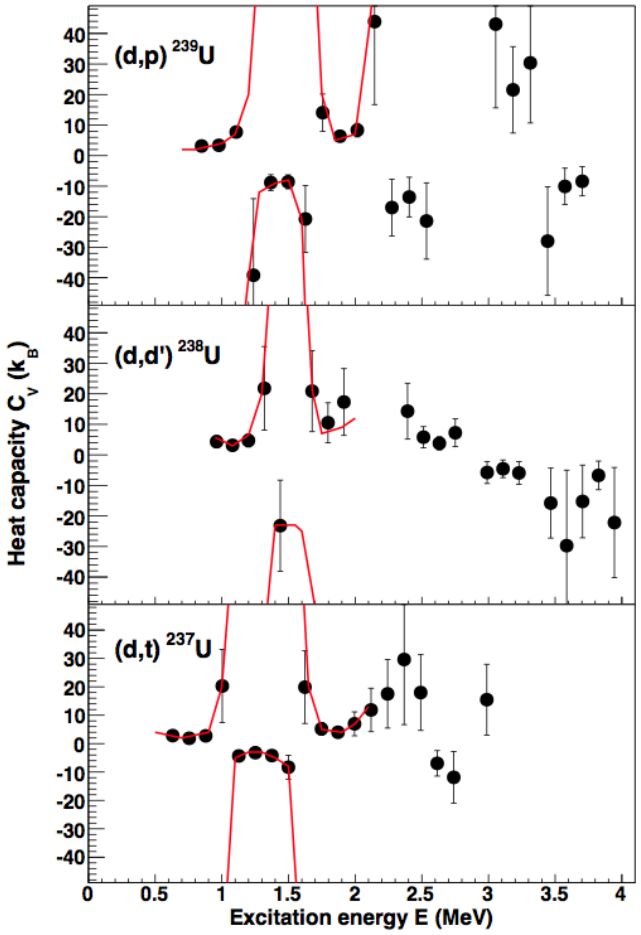


Temperature and heat capacity

$$T(E) = (\partial S / \partial E)^{-1}$$



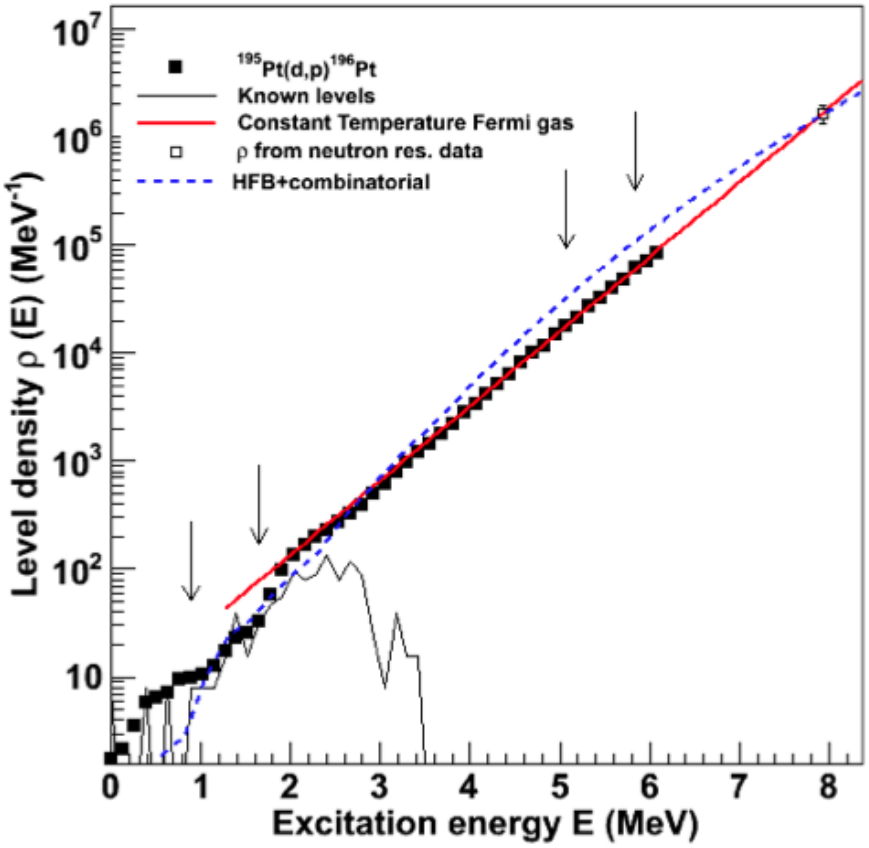
$$C_V(E) = (\partial T / \partial E)^{-1}$$



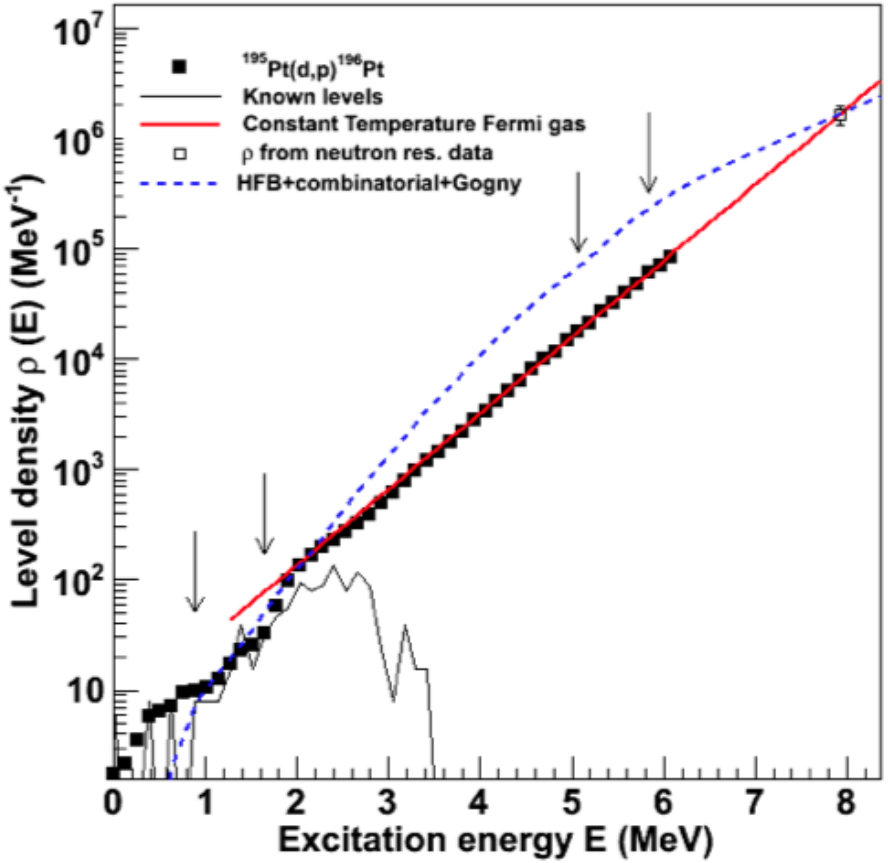
M. Guttormsen et al.,
PRC **88**, 024307 (2014)

Modeling level density in ^{196}Pt

F. Giacoppo et al., arXiv:1408.6173 (2014) and private communication

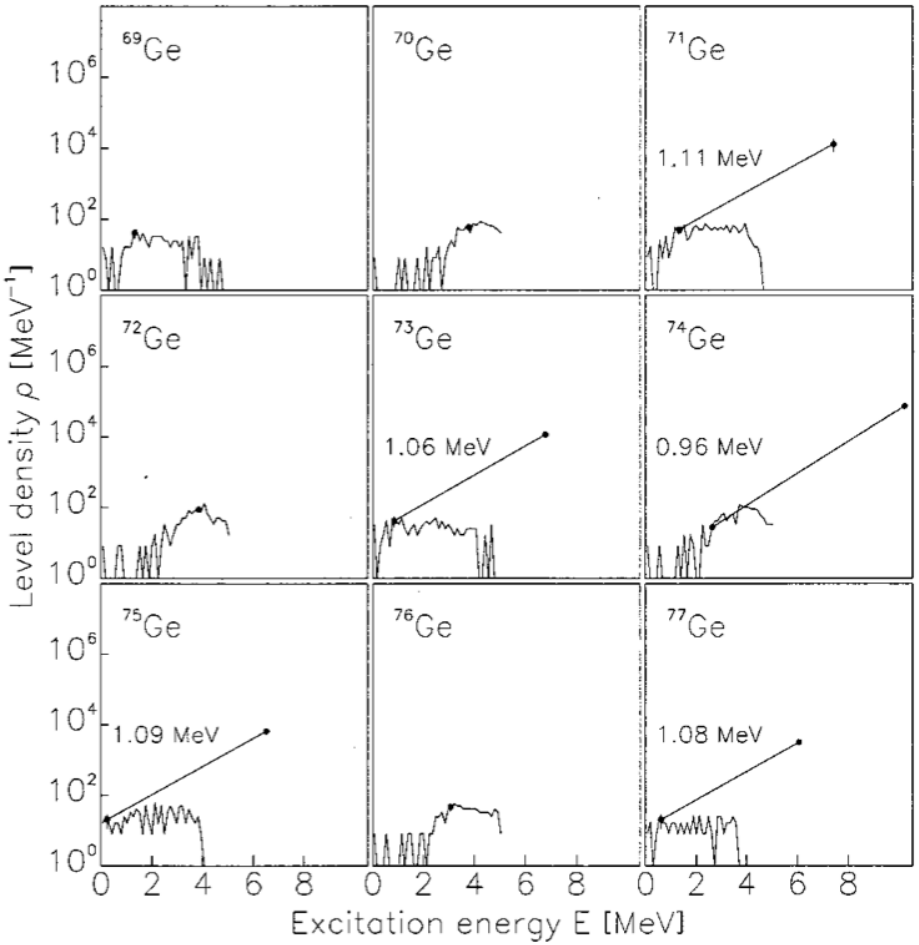


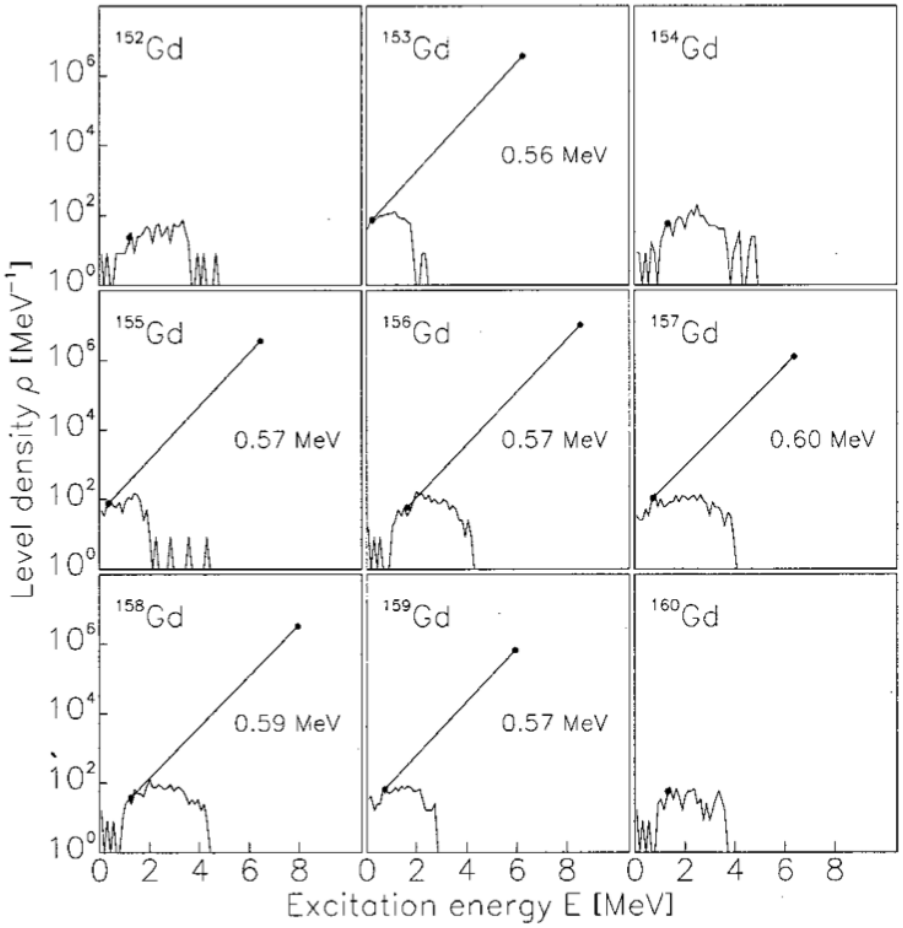
S. Goriely et al., PRC **78**, 064307 (2008)



S. Hilaire et al., PRC **86**, 064317 (2012)

Predictions



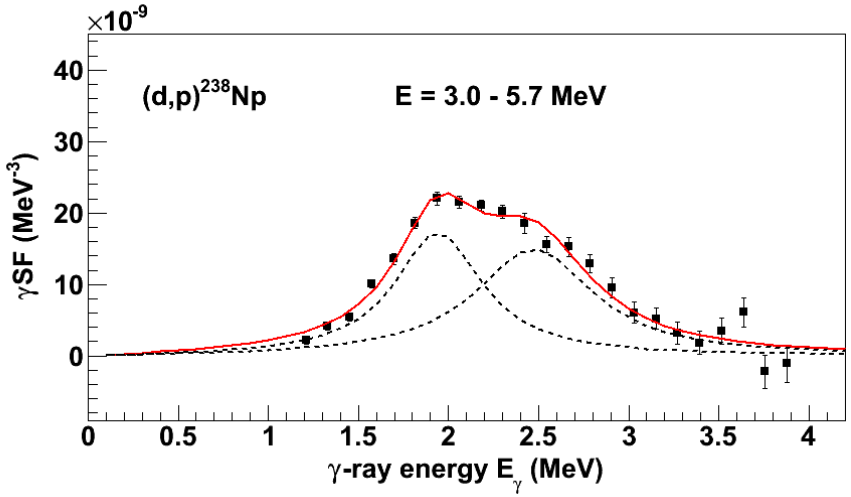


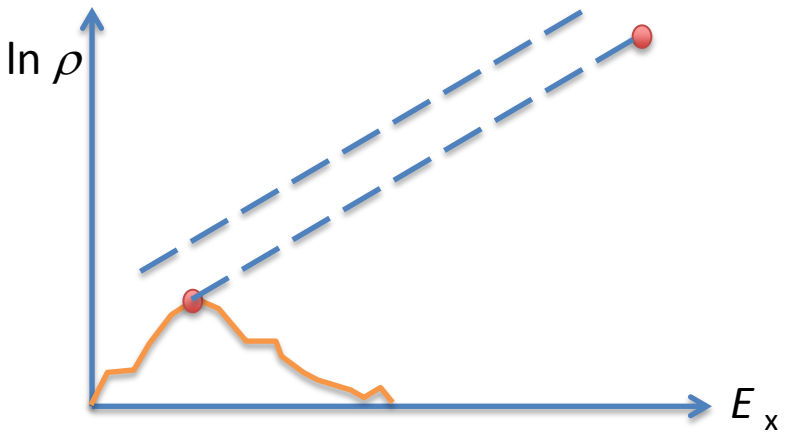
M. Guttormsen et al.,

PRC **63**, 044301 (2001)

Summary

- Scissors mode in rare earth and actinide region
- Experimental data support the CT level density model
- Neighboring nuclei have the same temperature
- Single quasiparticle entropy of S_1 = 1.5 - 2.0 k_B
- Two anchor points for predictions:
  - discrete levels at low excitation energy
  - neutron/proton resonance spacings at Sn/Sp





Thanks to all coworkers

M. Aiche, F.L. Bello Garrote, L.A. Bernstein, D. Bleuel, Y. Byun, Q. Ducasse, T.K. Eriksen, F. Giacoppo, A. Görgen, F. Gunsing, T.W. Hagen, B. Jurado, M. Klintefjord, A.C. Larsen, L. Lebois, H.T. Nyhus, T. Renstrøm, S.J. Rose, E. Sahin, S. Siem, T. Tornyi, G.M. Tveten, A. Voinov, M. Wiedeking and J.N. Wilson

University of Oslo, CENBG Gradignan, LLNL, Ohio University, IPN Orsay, CEA Saclay, iThemba LABS

http://tid.uio.no/workshop2015/

5th Workshop on Nuclear Level Density and Gamma Strength

Oslo, May 18 - 23, 2015

We thank our sponsors:

The Research Council of Norway

SAFE
Senter for Akseleratorbasert Forskning og Energifysikk

UiO : Department of Physics
University of Oslo

Scientific Program

The scientific program will include invited talks, selected oral contributions from submitted abstracts, and poster presentations, covering the following topics:

- Nuclear level density
- Gamma-strength function
- Phase transitions in mesoscopic systems
- Applications in astrophysics and reactor physics
- Other related topics

As in previous Oslo Workshops, the program will allow ample time for discussions.

Abstracts

Abstracts should be less than one page long and must be submitted in PDF format. The deadline for the submission of abstracts is **March 1, 2015**.

Venue

The workshop will be held at the Department of Physics on the Blindern Campus of the University of Oslo. The scientific sessions will be held at Helga Engs Hus, opposite from the Department of Physics.