UiO : Department of Physics
University of Oslo

Scissors resonances in the quasi-continuum of heavy nuclei

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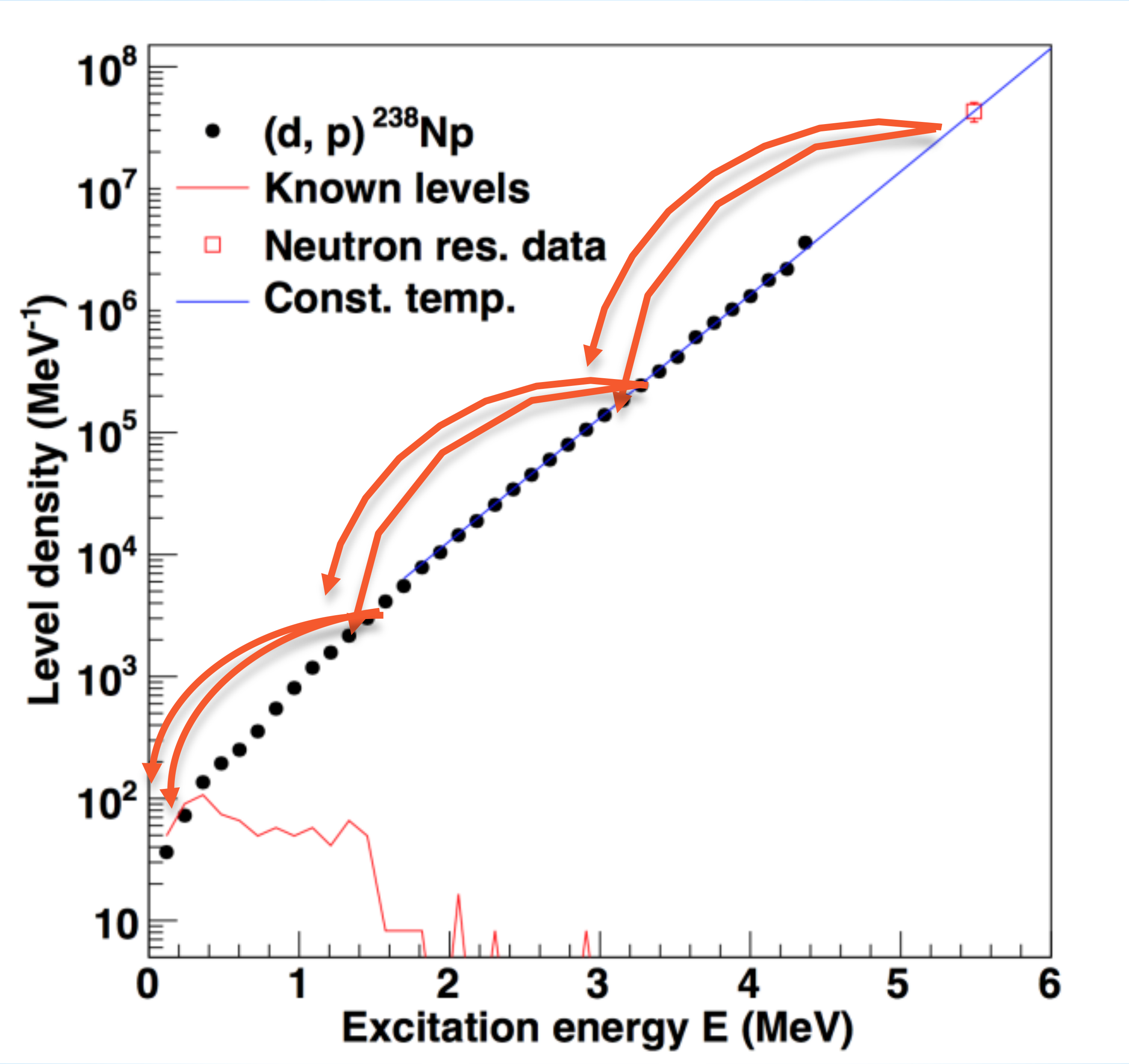


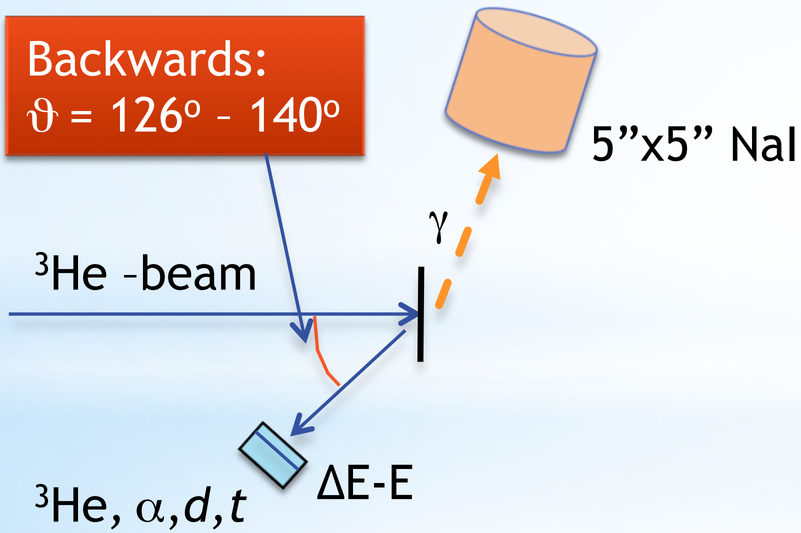
(d, p) 238Np
Known levels
Neutron res. data
Const. temp.
Level density (MeV-1)
Excitation energy E (MeV)
10
10^2
10^3
10^4
10^5
10^6
10^7
10^8
0
1
2
3
4
5
6

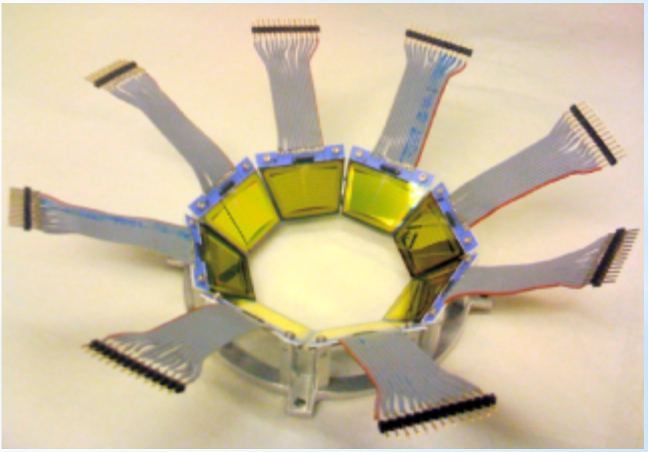
The Oslo method

Th and U experiment at OCL

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

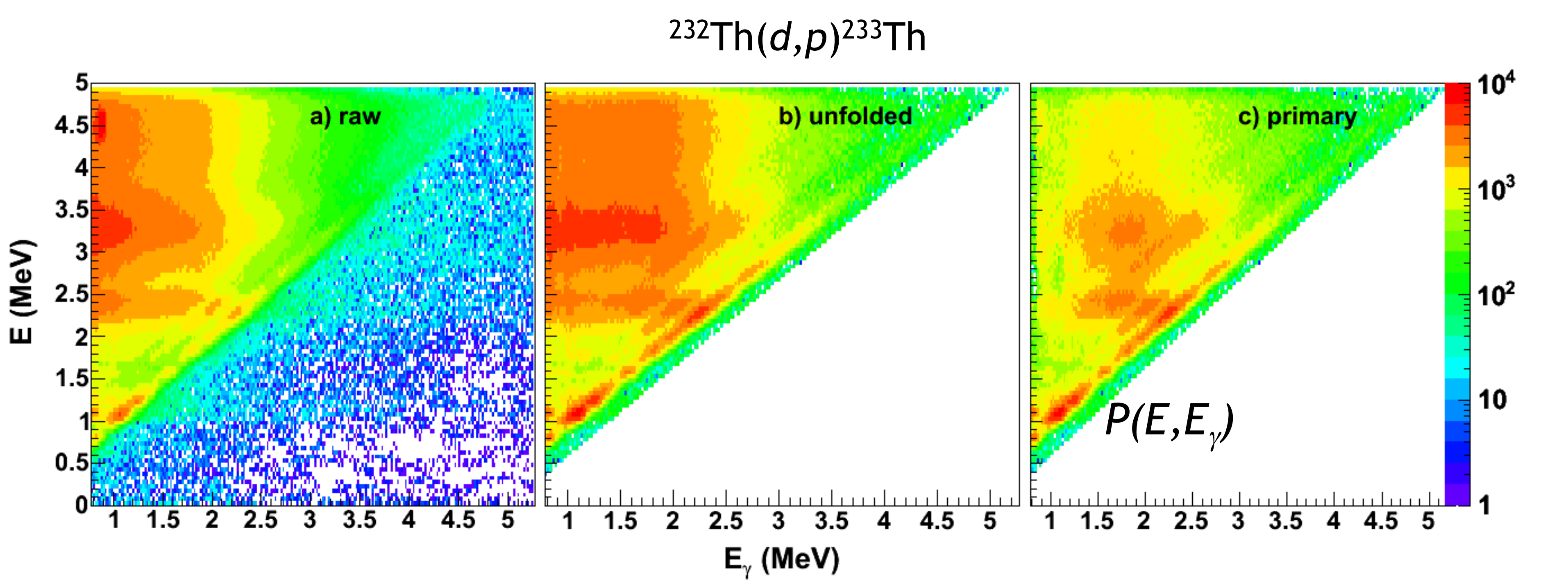
Backwards:
ϑ = 126° – 140°





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

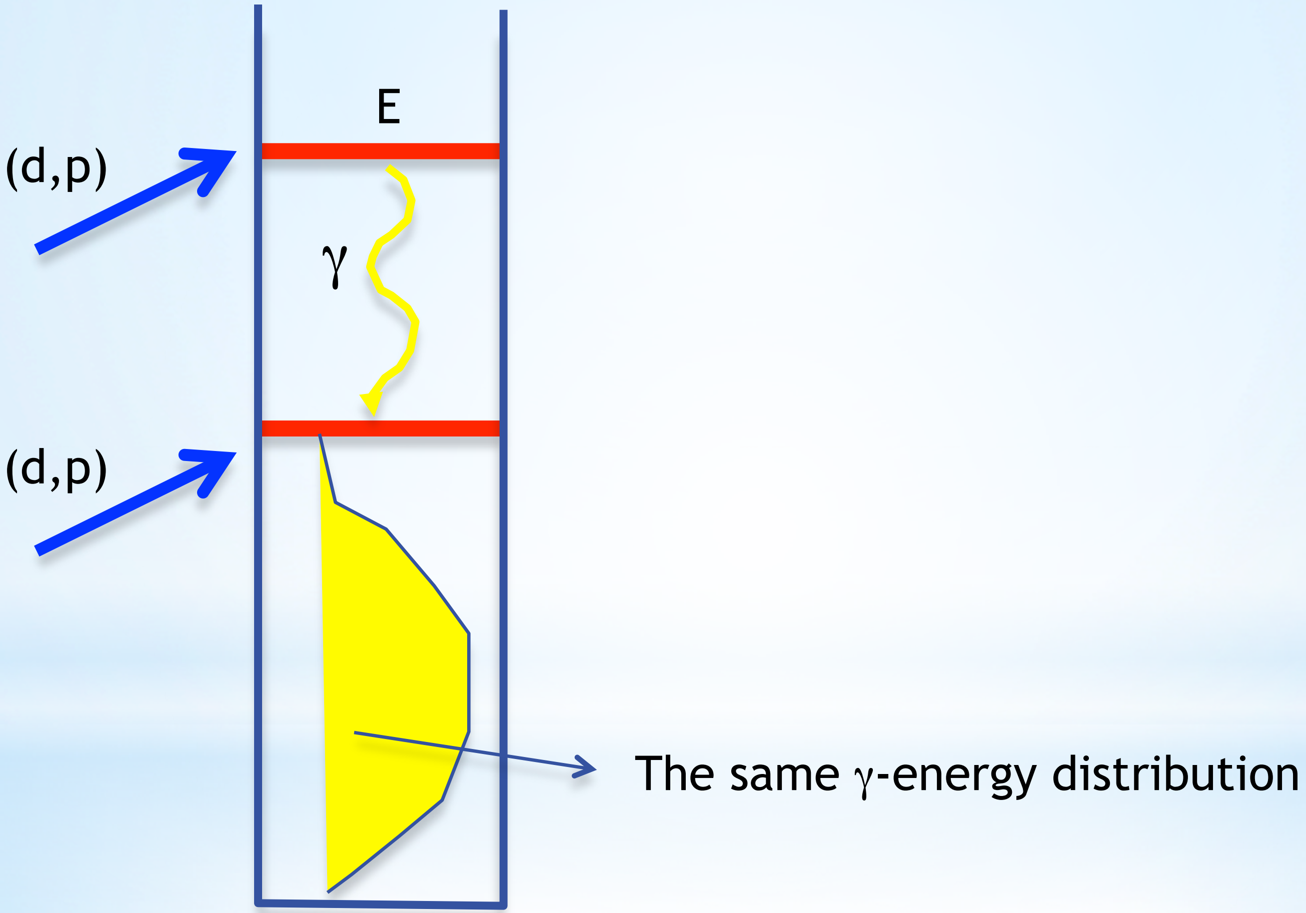
Simultaneous extraction of NLD and γSF



Oslo method:

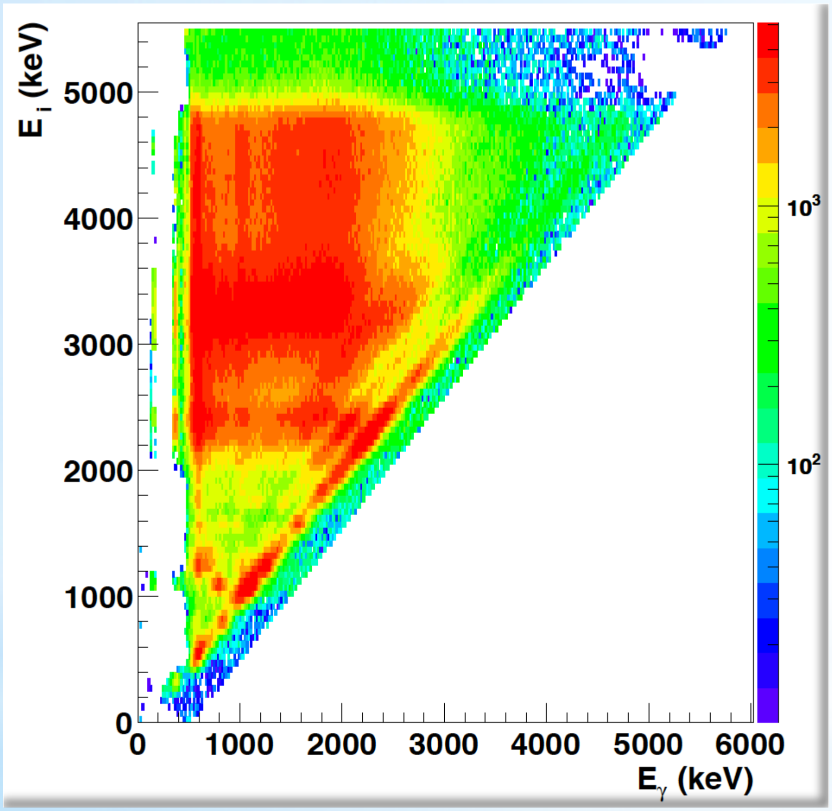
M. Guttormsen et al., NIM A374 (1996) 371
M. Guttormsen et al., NIM A255 (1987) 518
A. Schiller et al., NIM A447 (2000) 498
A.C. Larsen et al., Phys. Rev. C 83, 034315 (2011)

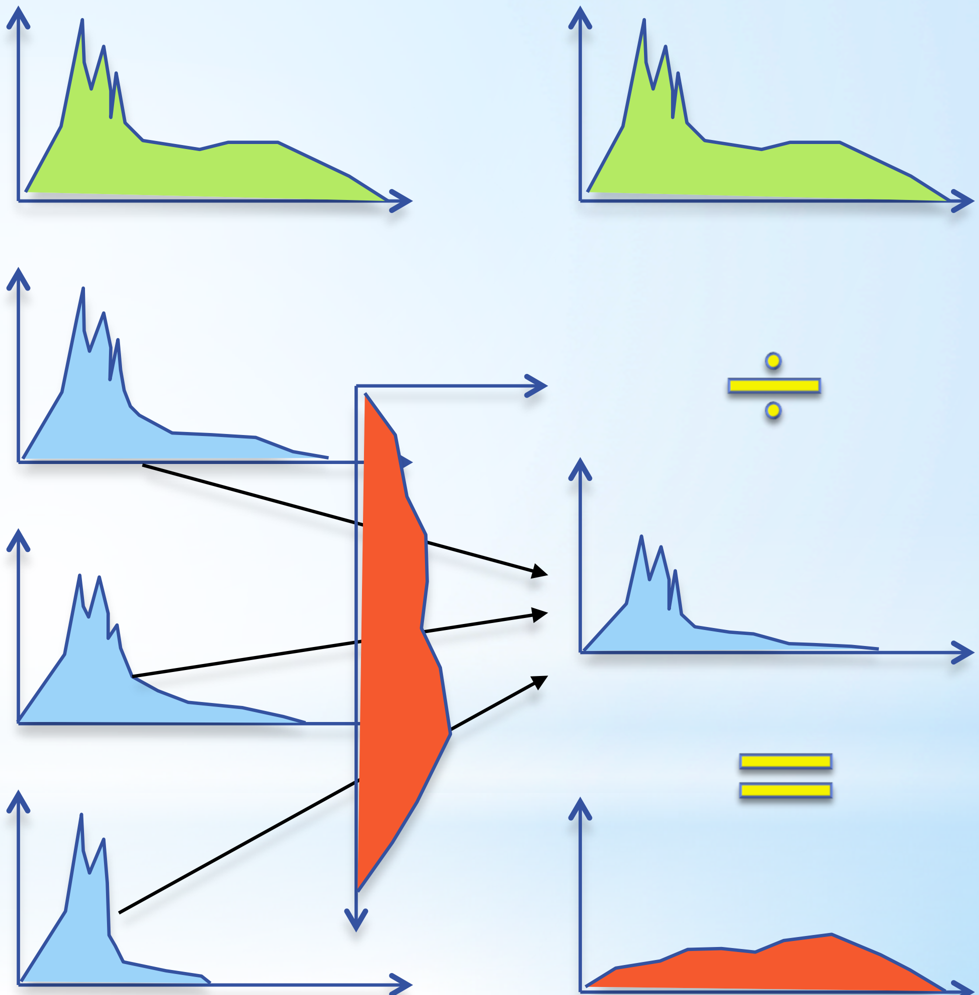
Assumption for the extraction of primary γ-spectra



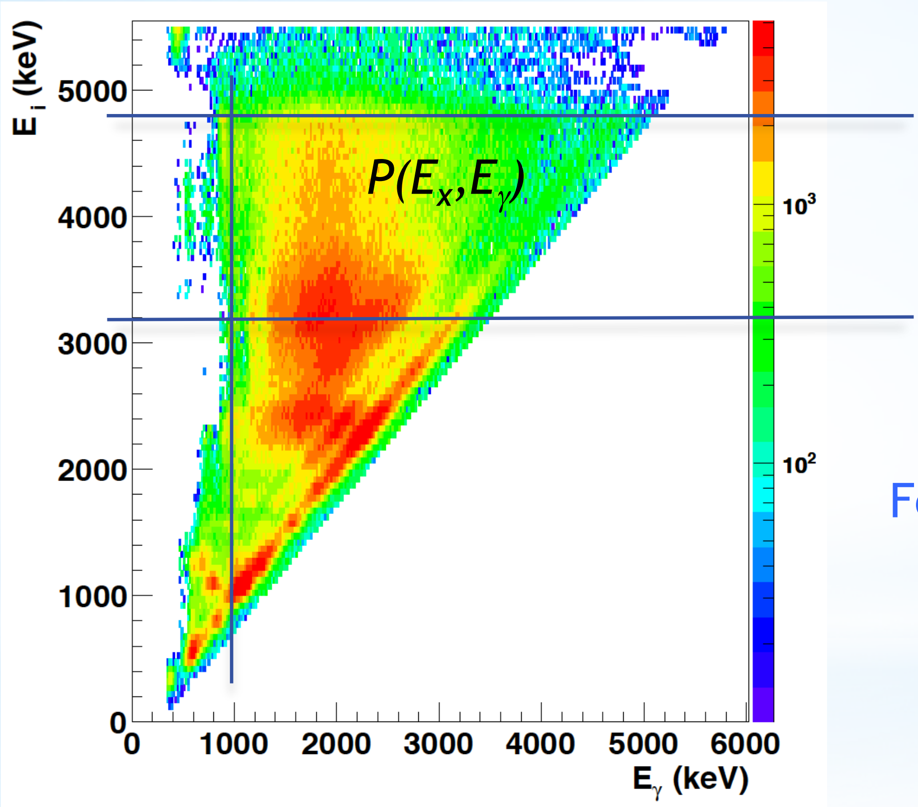
From total to primary γ-ray matrix

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





Primary γ-ray matrix

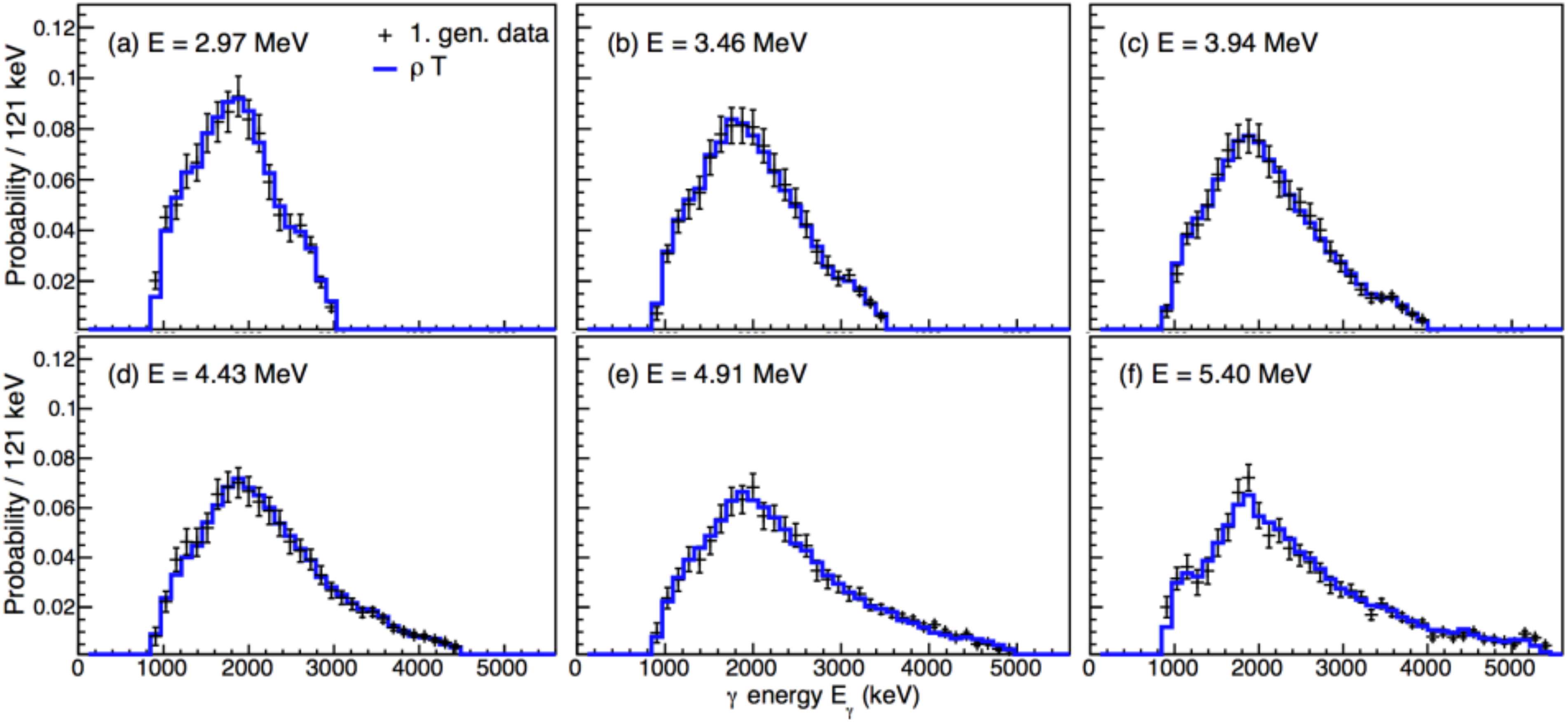


$P(E_x,E_\gamma)$

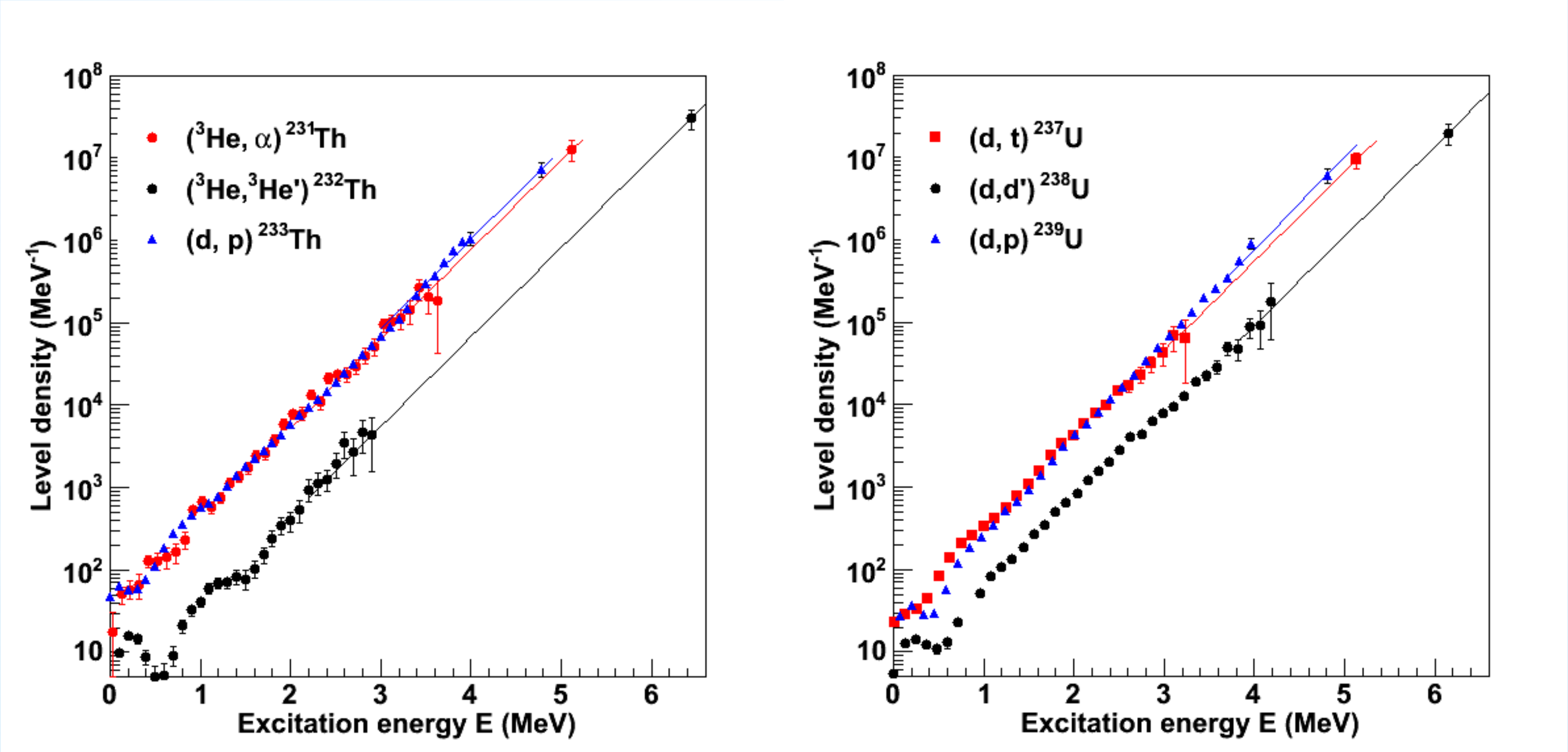
Level density
$\rho(E_f)$
Fermi's golden rule

Trans. coeff.
$T(E_\gamma)$
Brink hypothesis

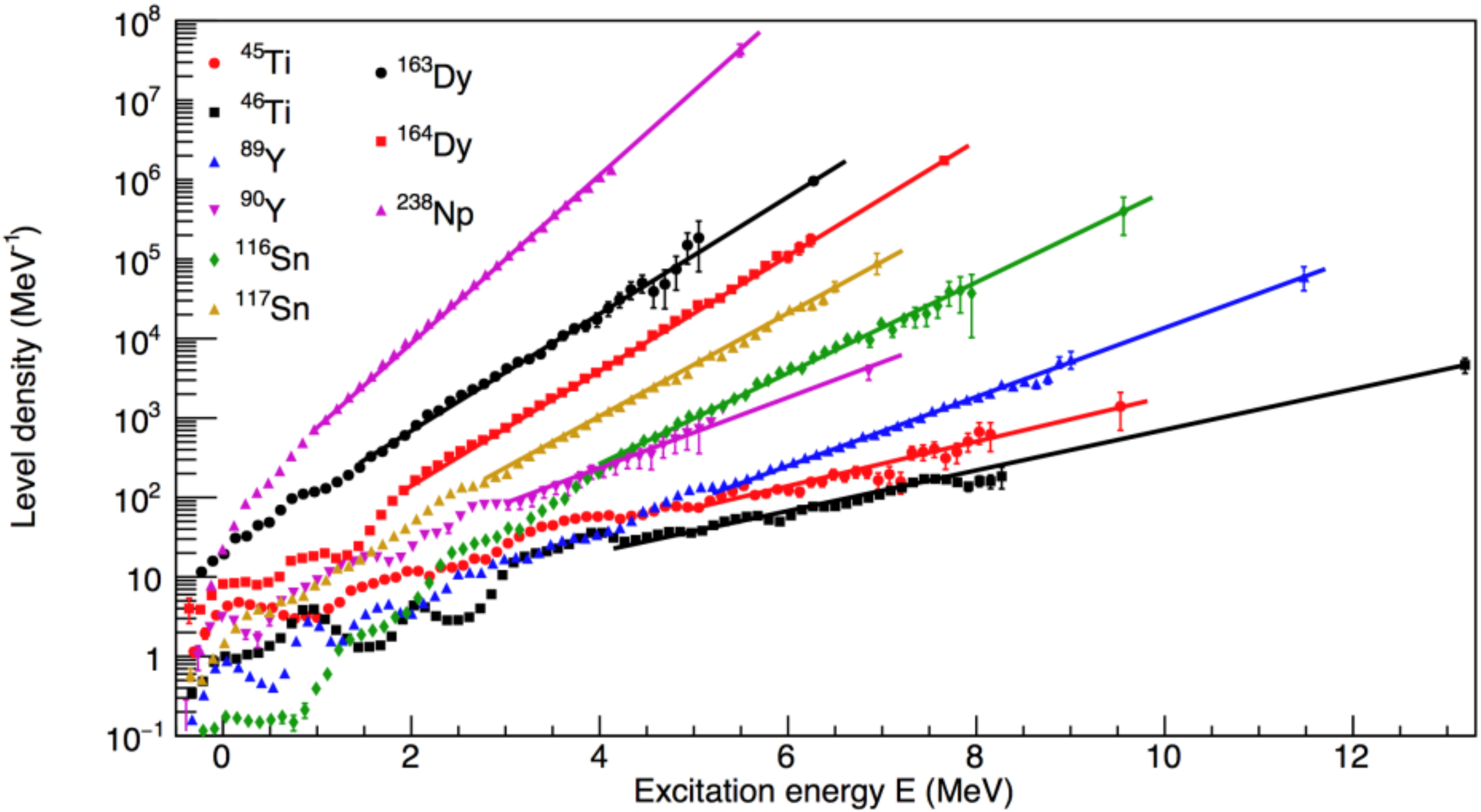
$$P(E, E_\gamma) = \rho(E_f) \cdot T(E_\gamma) ?$$



Constant-temperature level densities



Constant-temperature level densities

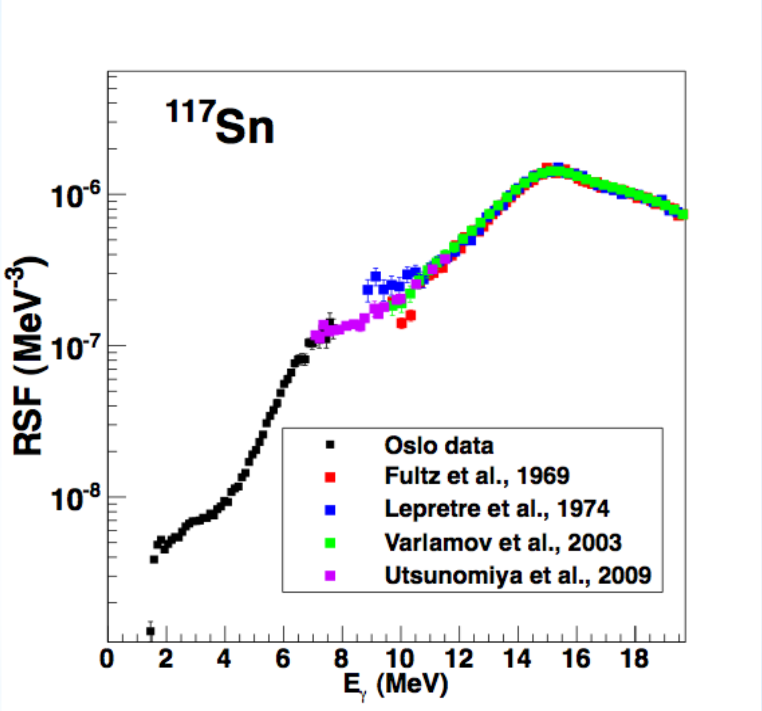


γ-ray strength functions

Dear child, many names:

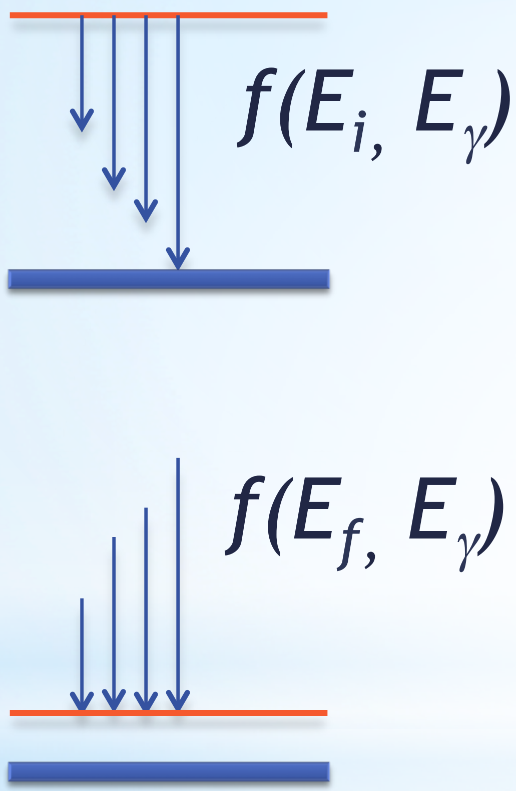
- γ-ray strength function (γSF)
- radiative strength function (RSF)
- photon strength function (PSF)

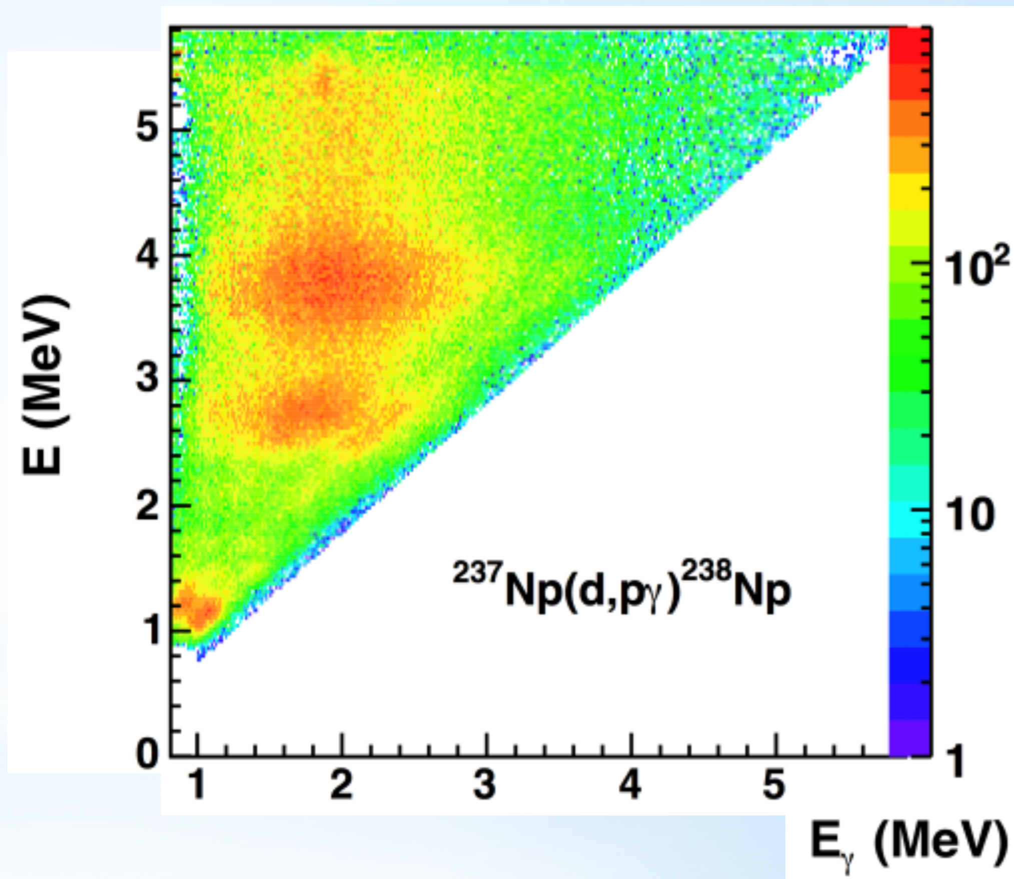
$$f(E_\gamma) = \frac{1}{2\pi}\frac{T(E_\gamma)}{E_\gamma^3}$$



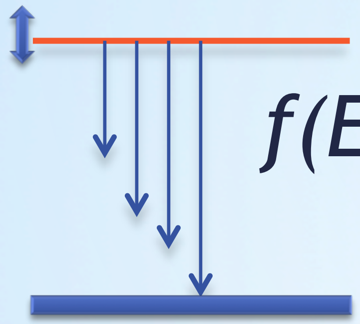
Utsunomiya et al., PRC 80, 055806 (2009)
Agvaanluvsan et al., PRL 102, 162504 (2009)

Generalized Brink-Axel hypothesis

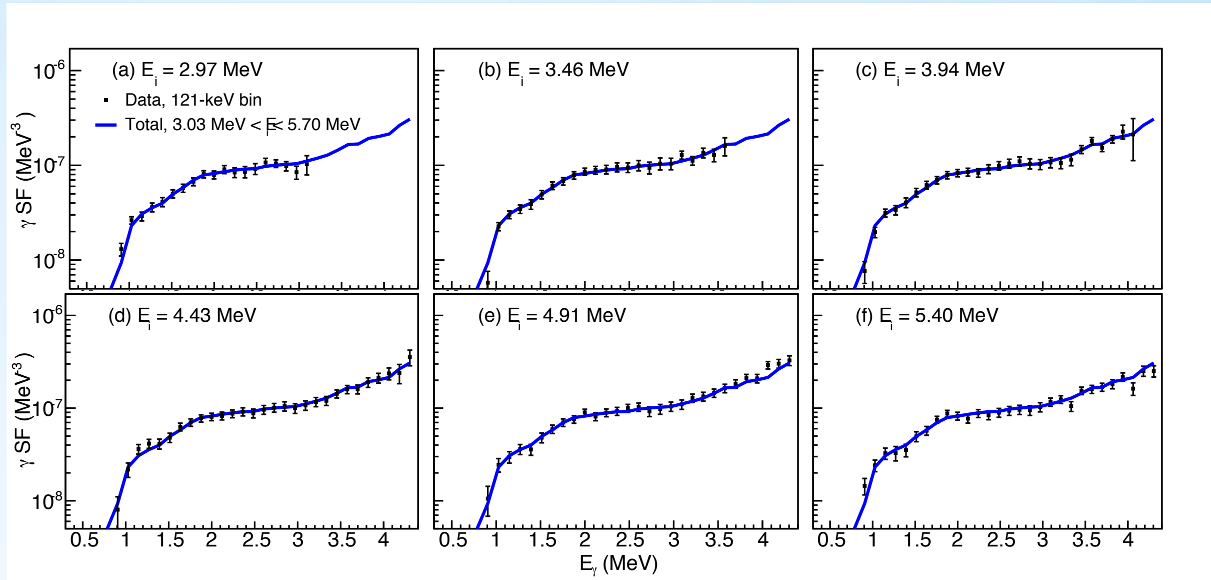


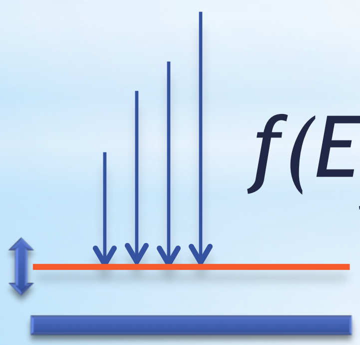


It works!

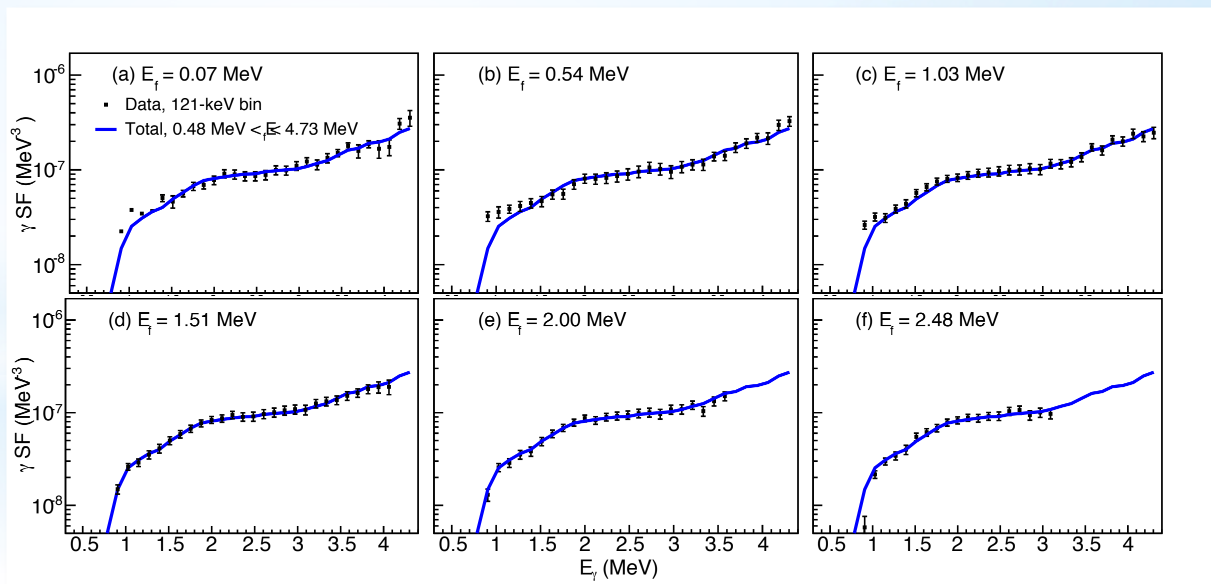


$f(E_i, E_\gamma)$

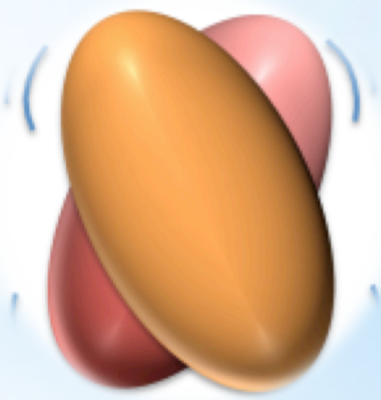




$f(E_f, E_\gamma)$

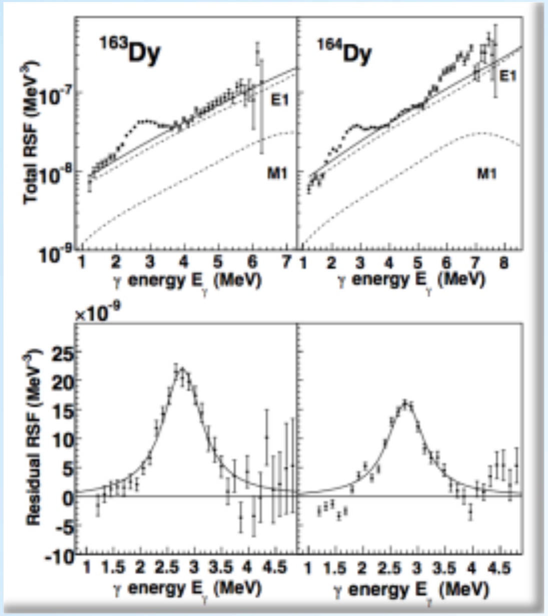


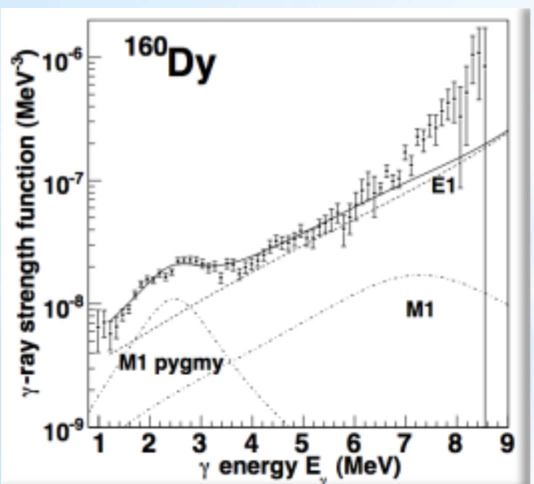
The scissors resonance

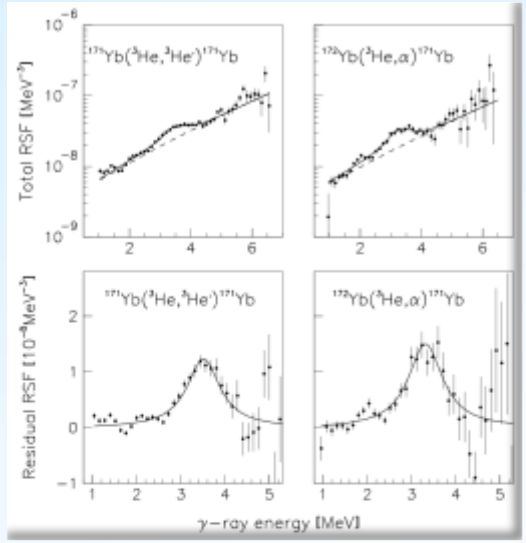


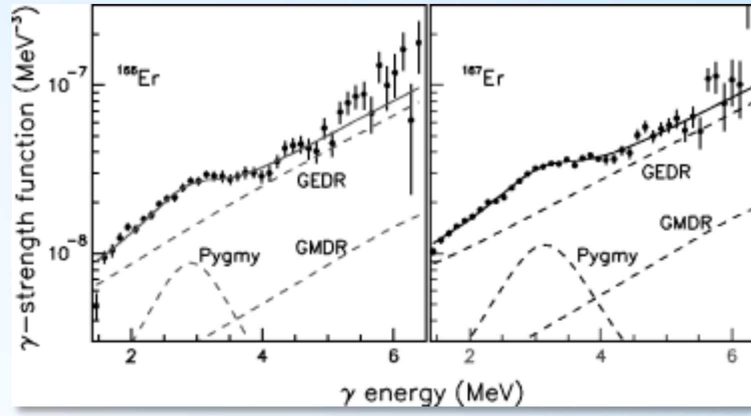
K. Heyde et al., Rev. Mod. Phys. **82**, 2365 (2010)

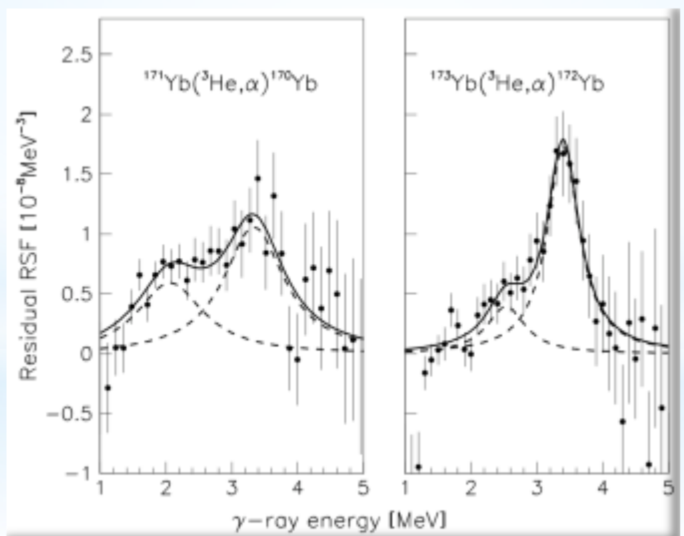
Scissors resonances, rare earth region









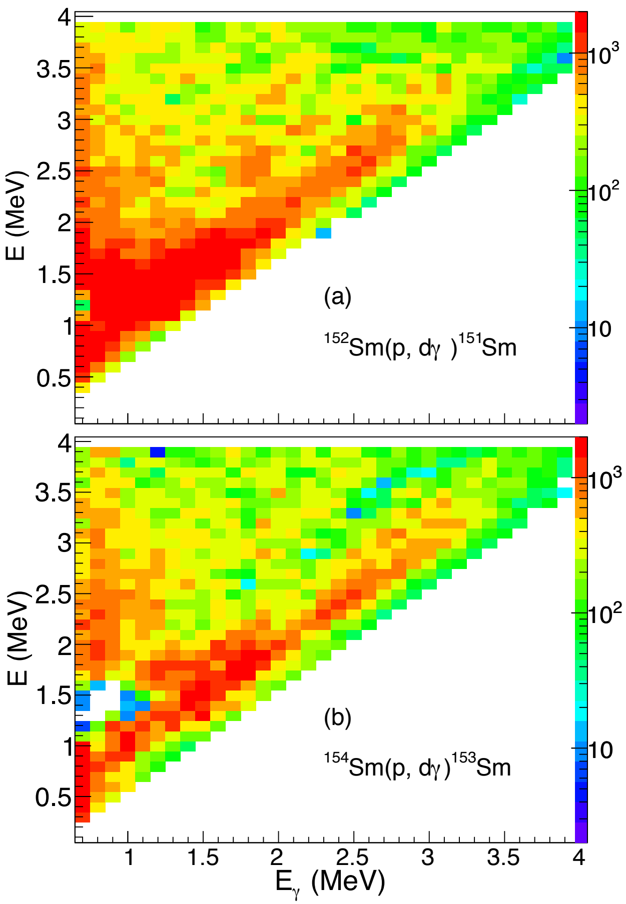


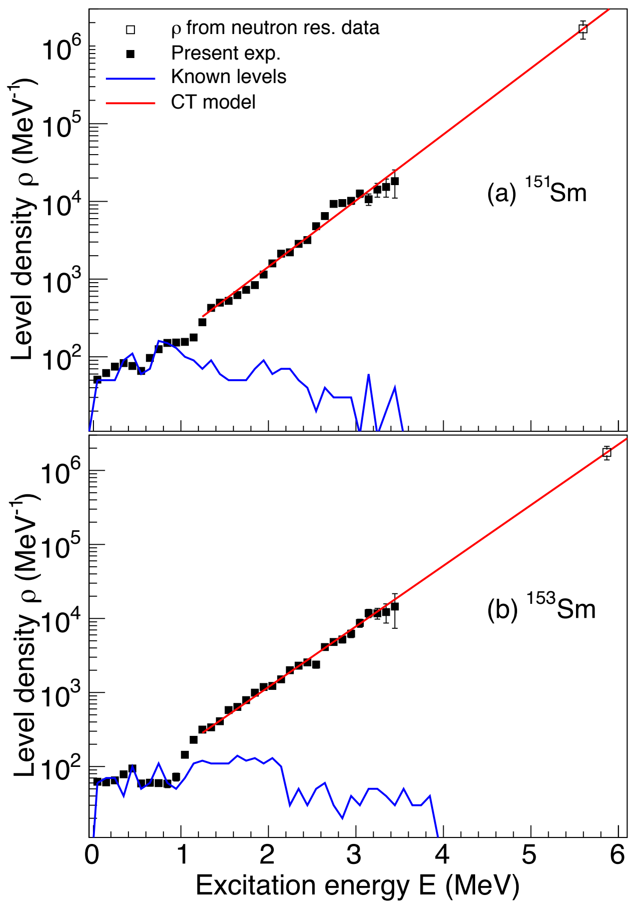
M. Guttormsen et al., PRC **68**, 064306 (2003)
H.T. Nyhus et al., PRC **81**, 024325 (2010)
U. Agvaanluvsan et al., PRC **70**, 054611 (2004)
E. Melby et al., PRC **63**, 044309 (2001)

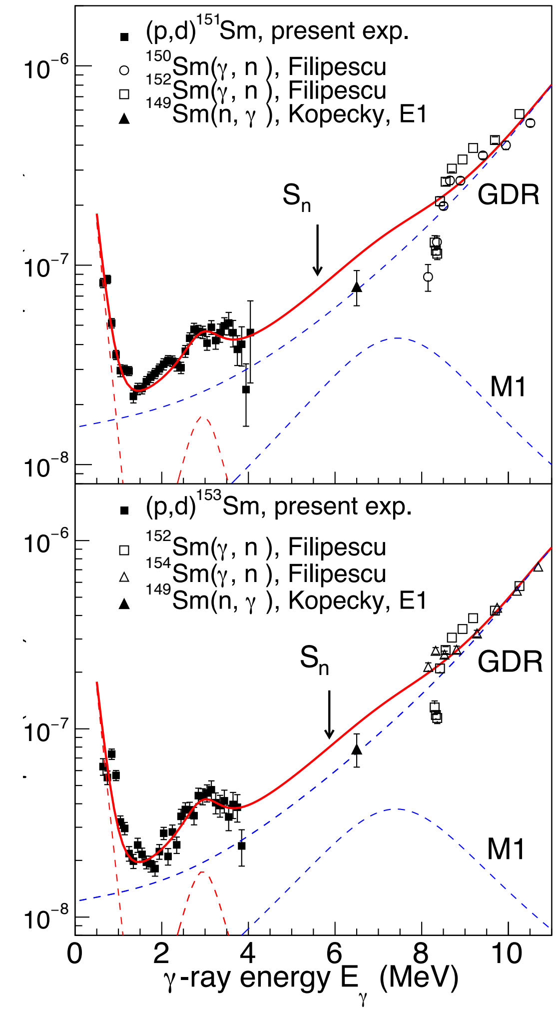
Low-energy γ-enhancement in rare-earth nuclei

A. Simon et al.,
STARLiTER Clover detectors,
25 MeV (p, d) reaction, Cyclotron Institute of Texas A&M University

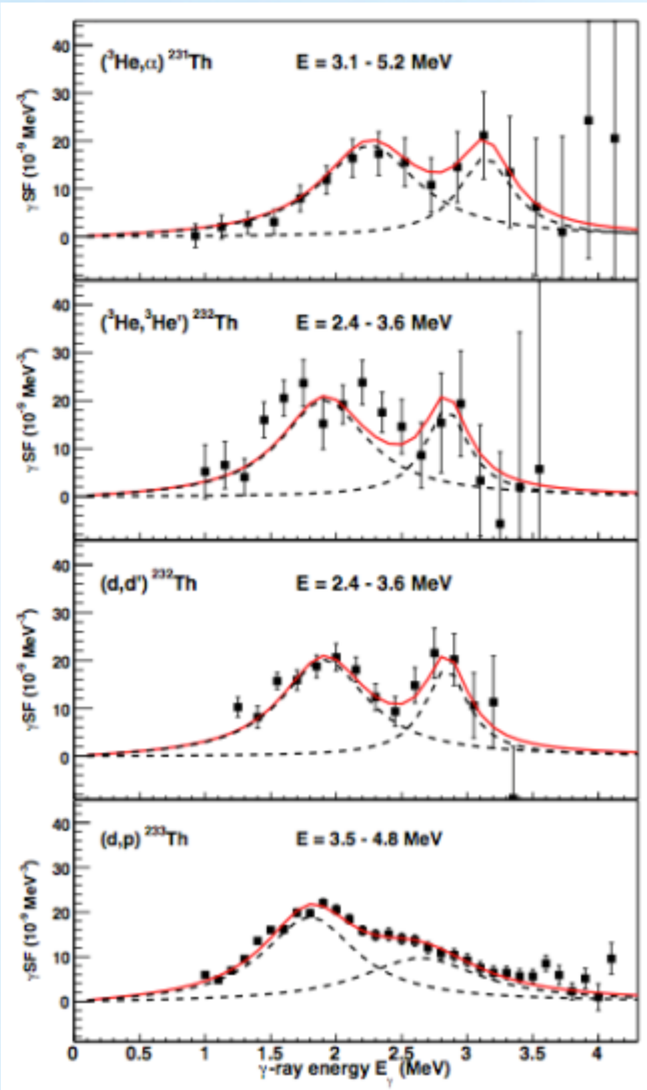
PRELIMINARY!!!

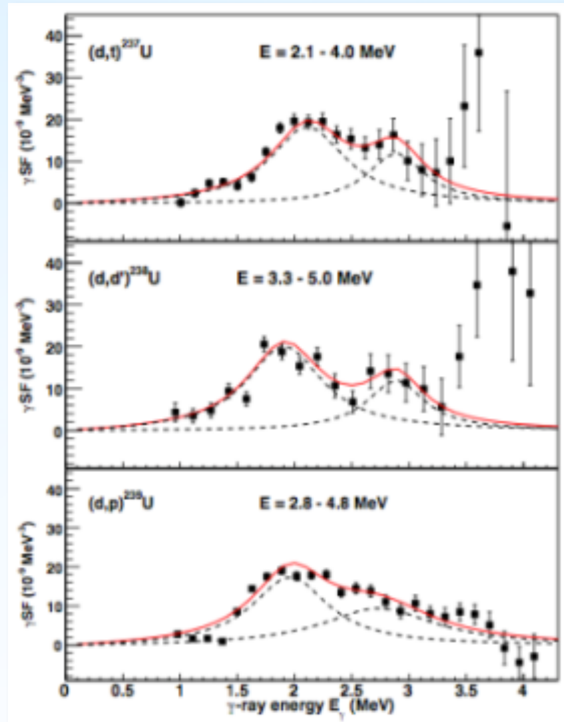


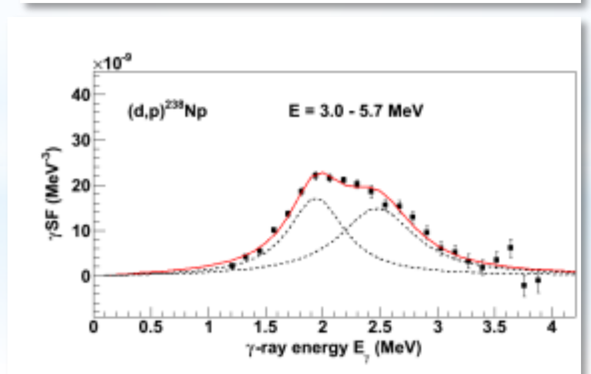


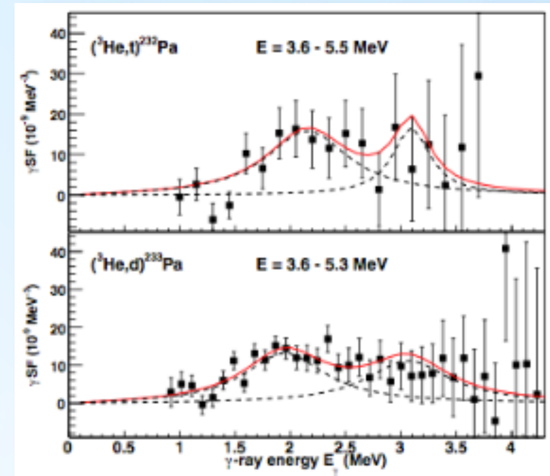


Scissors resonance, actinides









Data:
M. Guttormsen et al., PRC **89**, 014302 (2014)
T.G. Tornyi et al., PRC **89**, 044323 (2014)

Theory on two-bumps:
Orbital and spin scissors
E. B. Balbutsev, I.V. Molodtsova, and P. Schuck,
Phys. Rev. C **91**, 064312 (2015)

Scissors resonance systematics

Inversely and linearly energy-weighted sum rules

J. Enders, P. von Neumann-Cosel, C. Rangacharyulu, and A. Richter, Phys. Rev. C **71**, 014306 (2005).

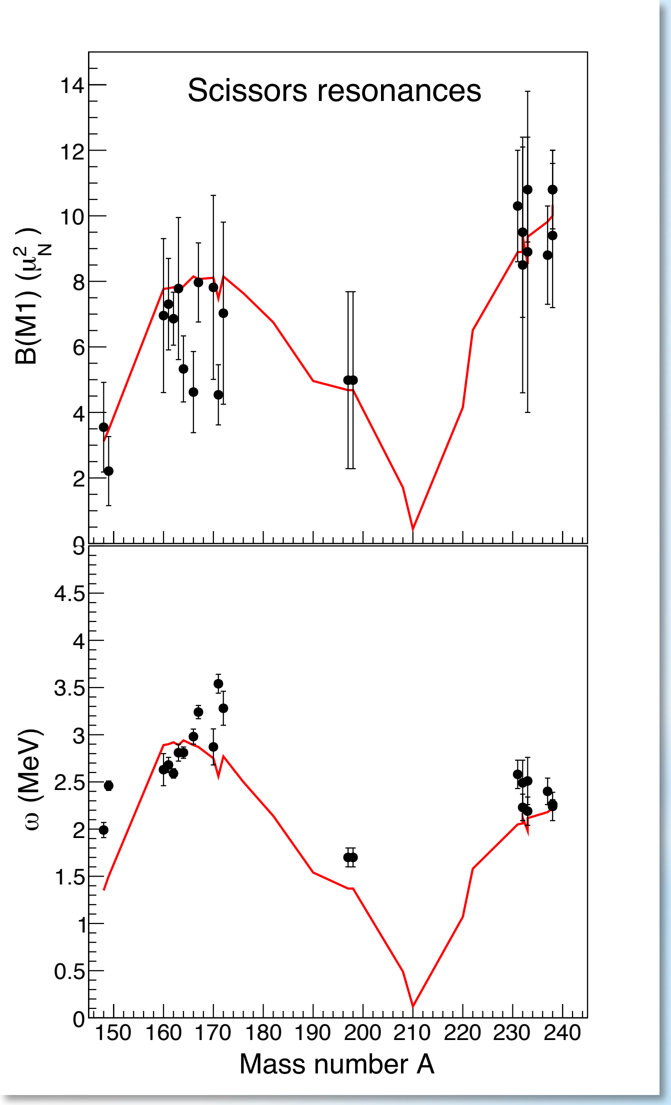
$$\begin{aligned} \omega_{SR} &= \sqrt{S_{+1}/S_{-1}} \\ &= \delta\omega_D\sqrt{2\xi}, \\ B_{SR} &= \sqrt{S_{+1}S_{-1}} \\ &= \frac{3}{4\pi}\left(\frac{Z}{A}\right)^2 \Theta_{\text{rigid}}\delta\omega_D\sqrt{2\xi} \\ &= \frac{3}{4\pi}\left(\frac{Z}{A}\right)^2 \Theta_{\text{rigid}}\omega_{SR}. \end{aligned}$$

$$\Theta_{\text{rigid}} = \frac{2}{5} m_N r_0^2 A^{5/3}(1+0.31\delta)$$

$$\xi = \frac{\omega_Q^2}{\omega_Q^2 + 2\omega_D^2}$$

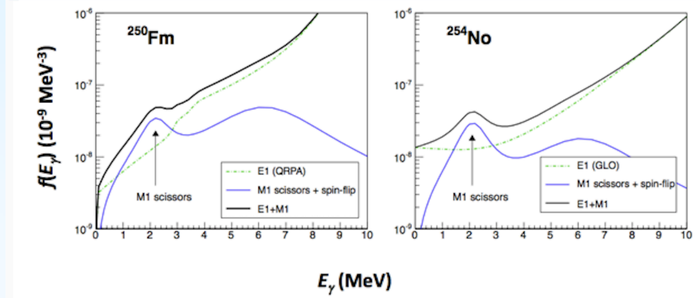
depends on the IVGDR and ISGQR frequencies of

$$\begin{aligned} \omega_D &\approx (31.2A^{-1/3} + 20.6A^{-1/6})(1-0.61\delta)\text{MeV}, \\ \omega_Q &\approx 64.7A^{-1/3}(1-0.3\delta)\text{MeV}. \end{aligned}$$



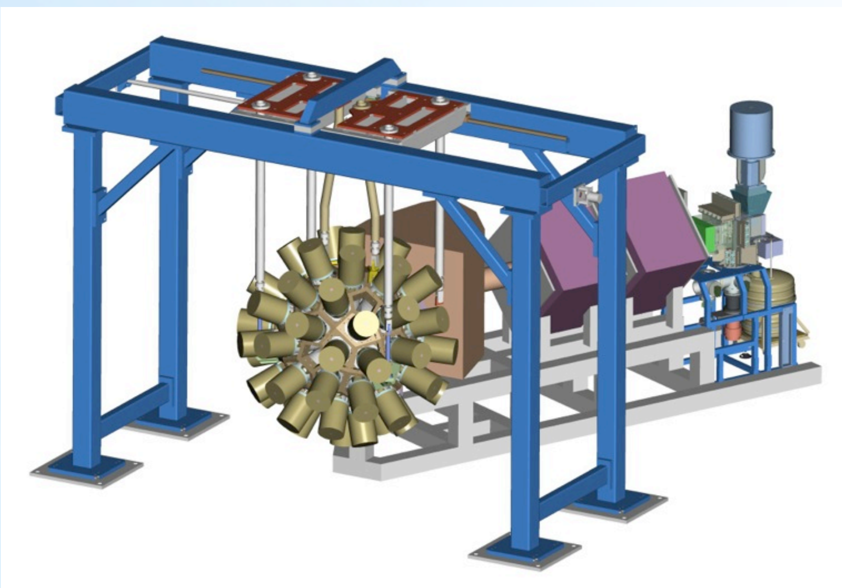
Scissors resonance in superheavy nuclei?

Nucleus	Deformation β_2	ω_{SR} (MeV)	$B_{SR}(M1)$ (μ_N^2)
^{250}Fm	0.30	2.28	13.0
^{252}No	0.29	2.20	13.1
^{254}No	0.29	2.20	13.0

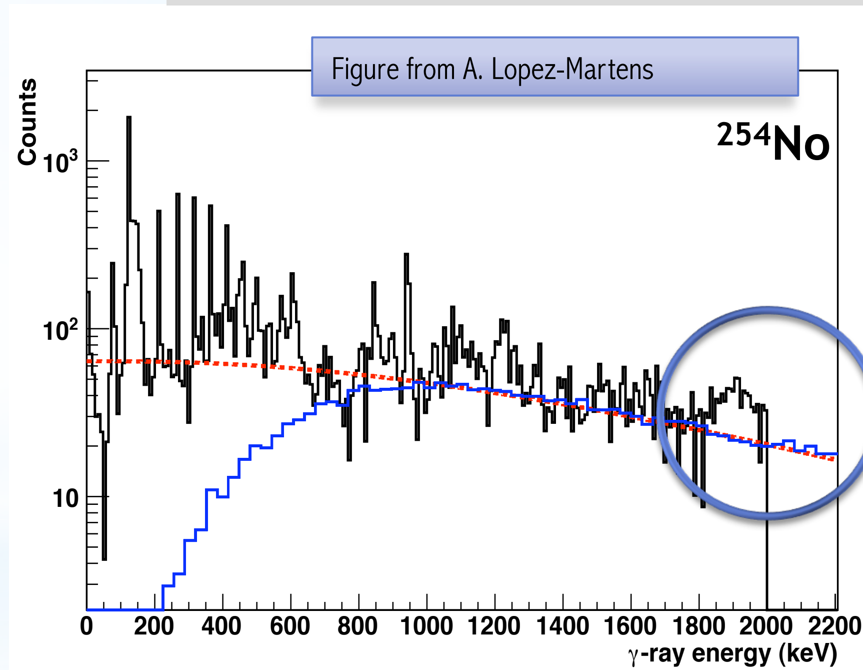


Now running JYFL – JR137:
"Search for the M1 Scissors Mode in ^{254}No"

Fusion-evaporation reaction
^{208}Pb(^{48}Ca,2n)^{254}No $\Rightarrow$ Tag recoils (^{254}No)



JUROGAM2-RITU-GREAT
spectrometers @ JYFL



Blue: statistical E1, simulations [T. Lauritsen, private comm.]
Red: statistical E1, fit [S. Leoni et al., PLB **409**, 71 (1997)]

Applications

Astrophysics, nuclear energy and radioactive waste

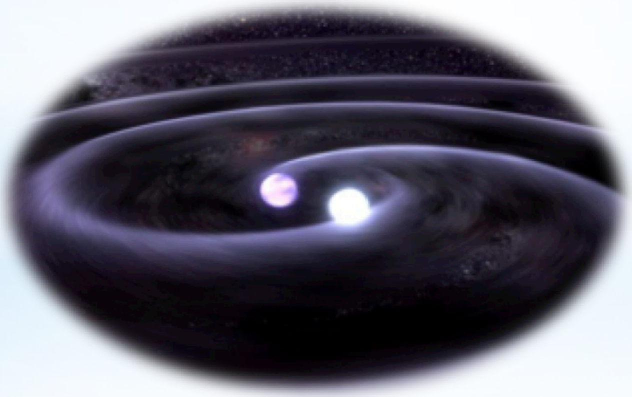
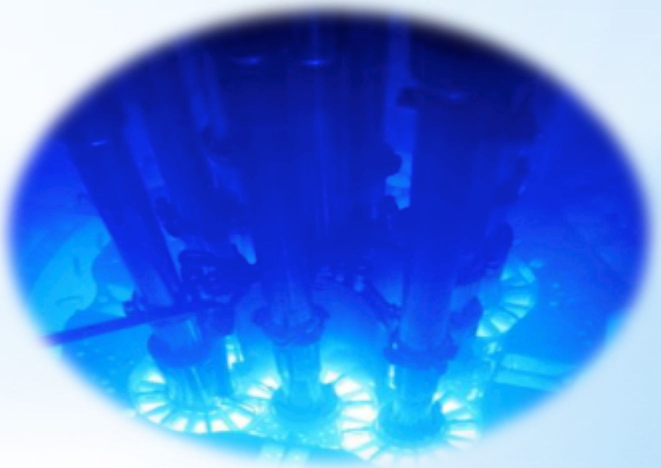
Oslo
NLD
γSF

→

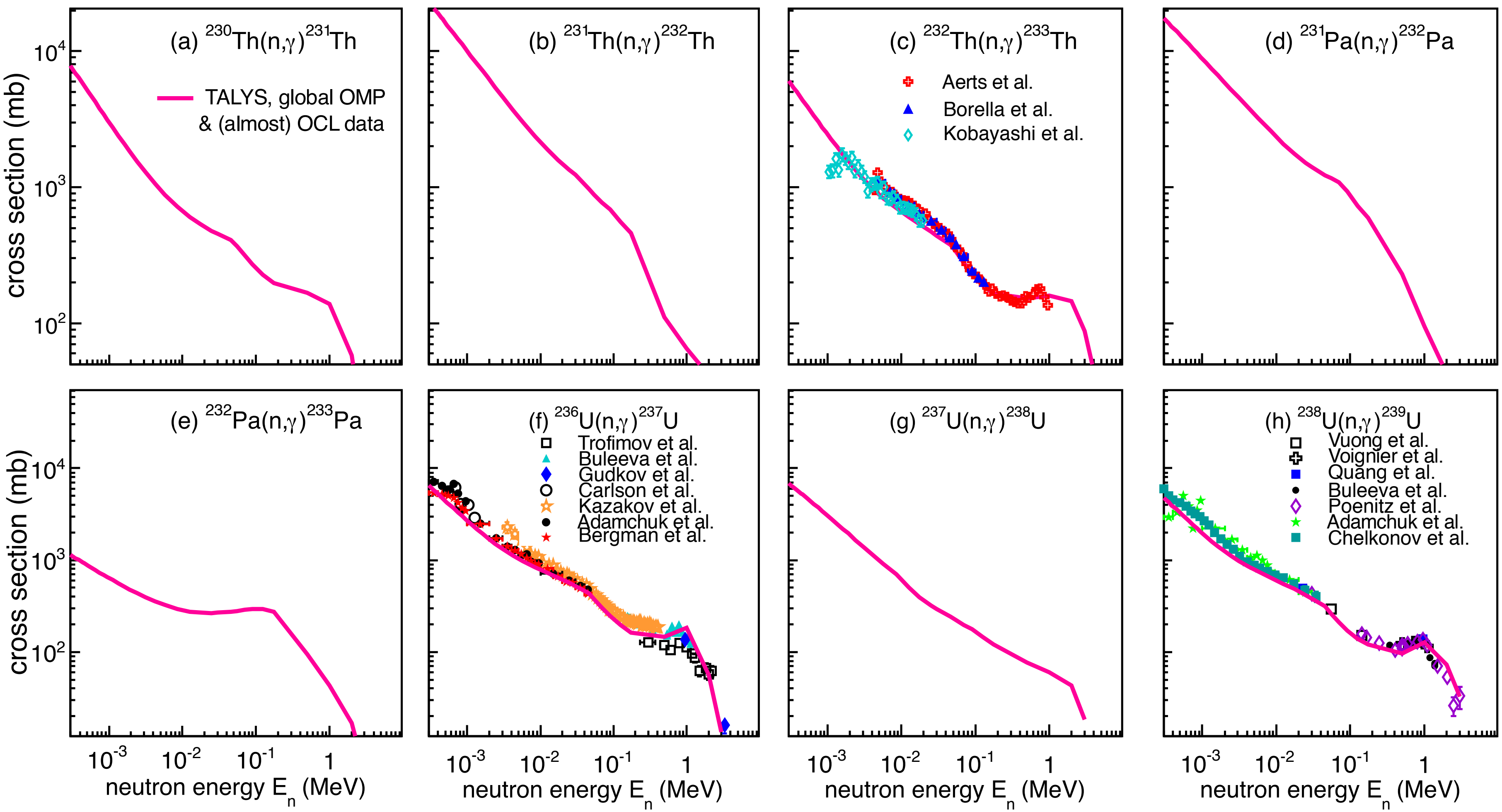
TALYS
with
global OMP

→

(n, γ)
cross
sections

(*n*, γ) cross sections



Summary

NLD
- Constant-temperature level densities

Scissors
- Rare earth $B(M1) \approx 5 - 7\ \mu_N^2$ at $E_\gamma \approx 3$ MeV
- Actinides $B(M1) \approx 8 - 11\ \mu_N^2$ at $E_\gamma \approx 2$ MeV
- Splits into two components

Applications
- γSF + NLD predict accurate (n,γ) cross sections

Outlook
- Funding for 30 3.5x8" $LaBr_3$ CACTUS -> OSCAR
- Far from stability, new β-Oslo methods at MSU

Listen to Artemis Spyrou on Friday!

The scissors digging team!

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, S.N. Liddick, M. Klintefjord, A.C. Larsen, L. Lebois, F. Naqvi, H.T. Nyhus, G. Perdikakis, T. Renstrøm, S.J. Rose, E. Sahin, A. Simon, A. Spyrou, S. Siem, T.G. 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, NSCL/MSU, University of Notre Dame