Level density and γ strength – achievements and challenges

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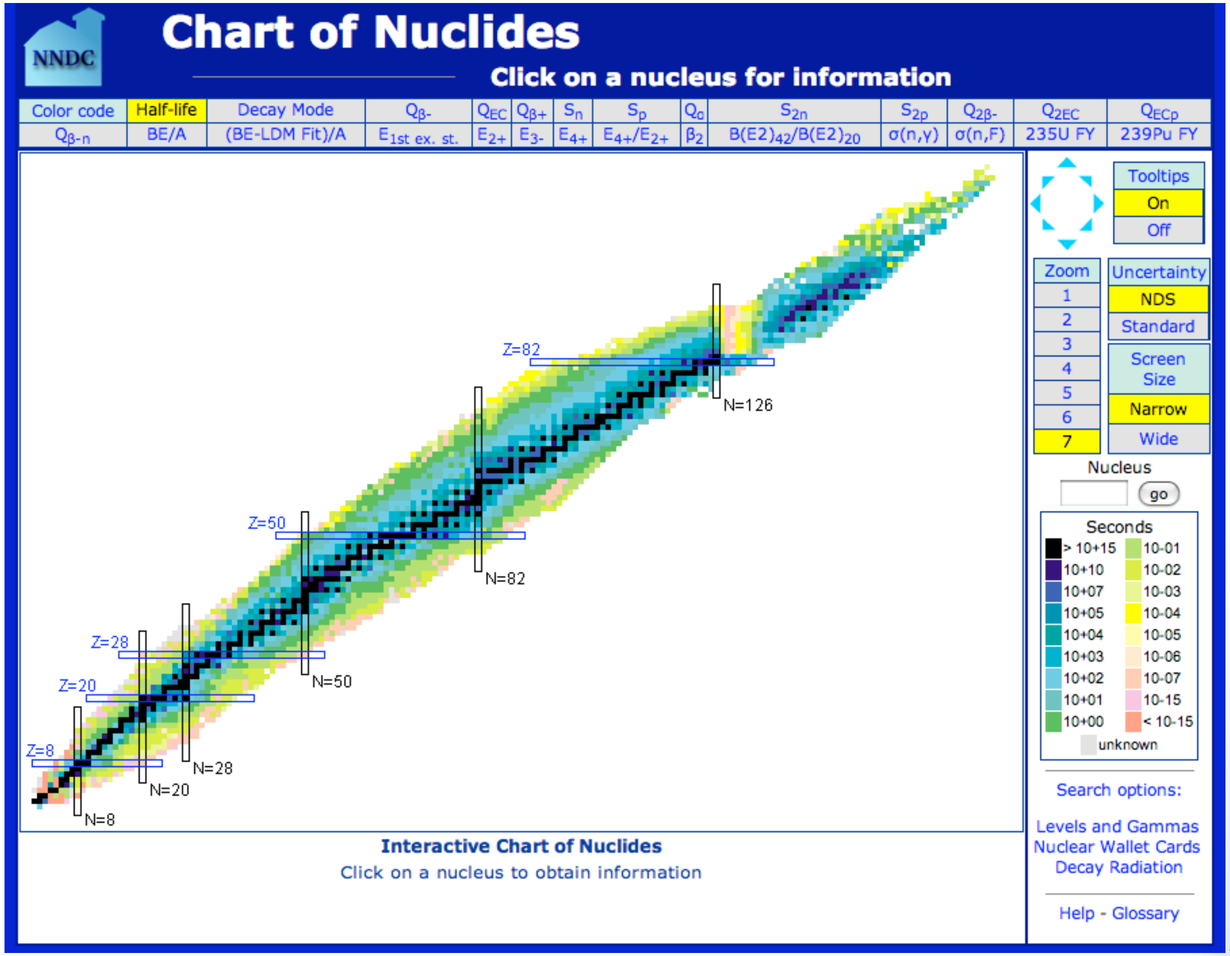
SAFE
Senter for Akseleratorbasert Forskning og Energifysikk

To-do list

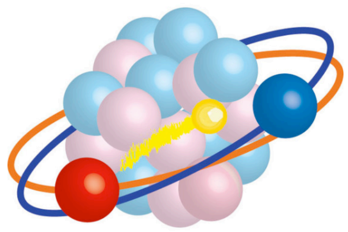
- Level densities
- Strength functions


"Mr. Osborne, may I be excused? My brain is full."

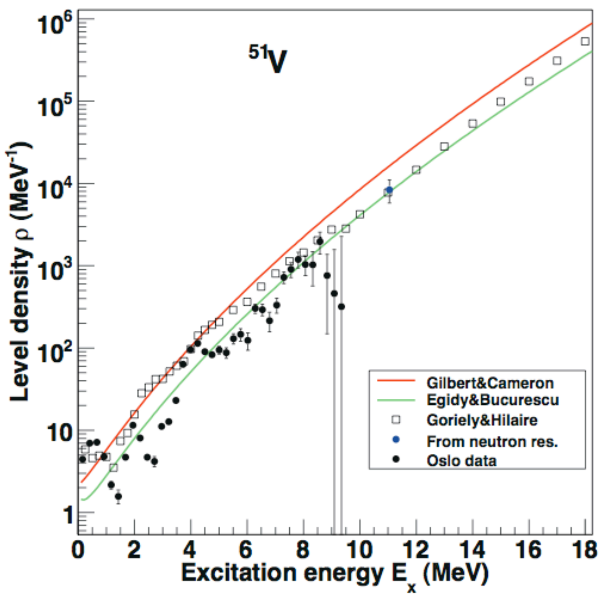


Level density – what and why?

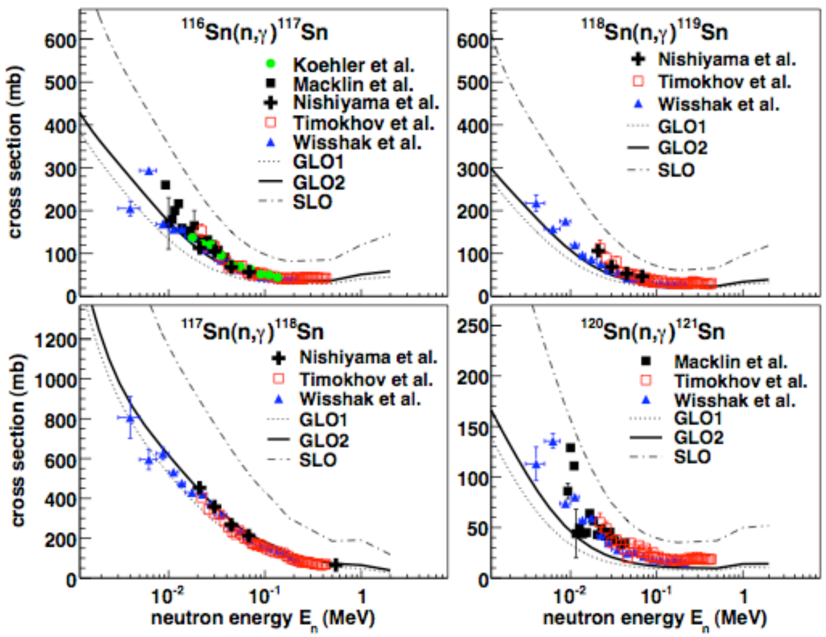
- Number of nuclear levels per energy unit
- Average quantity
- Sensitive to gross structural changes
- Input for cross-section calculations



[Larsen, PhD thesis (2008)]



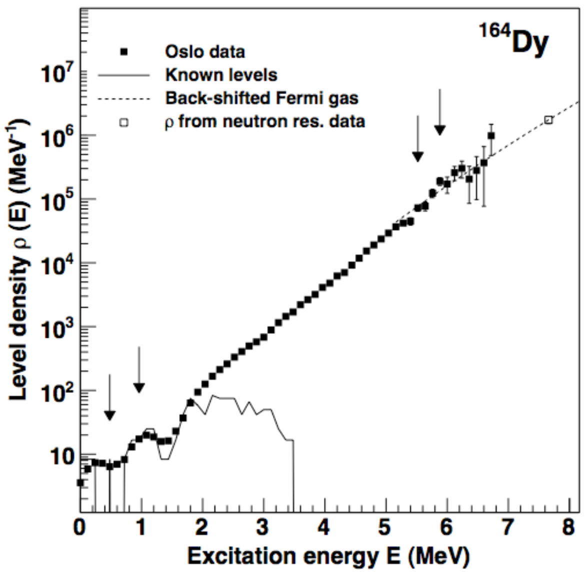
[Toft et al., PRC 83, 044320 (2011)]



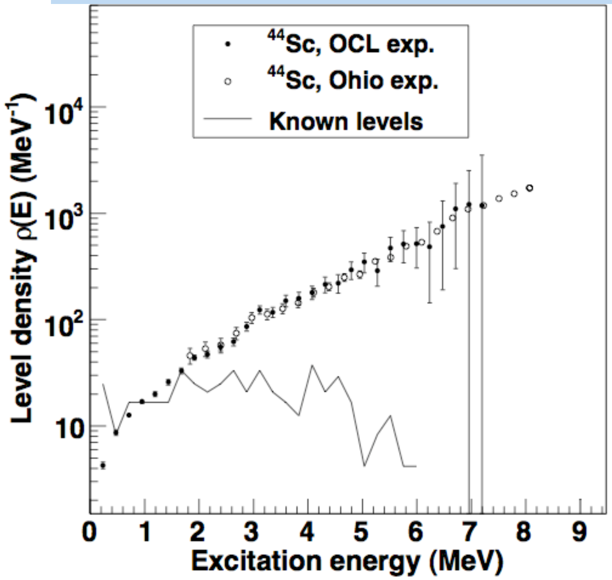
Level density – what do we know from experiments?

- Discrete levels (up to E_x ~ 2–3 MeV)
- Neutron/proton resonances (@ B_n/B_p)
- Particle evaporation spectra ($E_x \approx$ 4–15 MeV)
- Ericsson fluctuations ($E_x \approx$ 15 MeV)
- Primary γ spectra (up to $\approx B_n$)

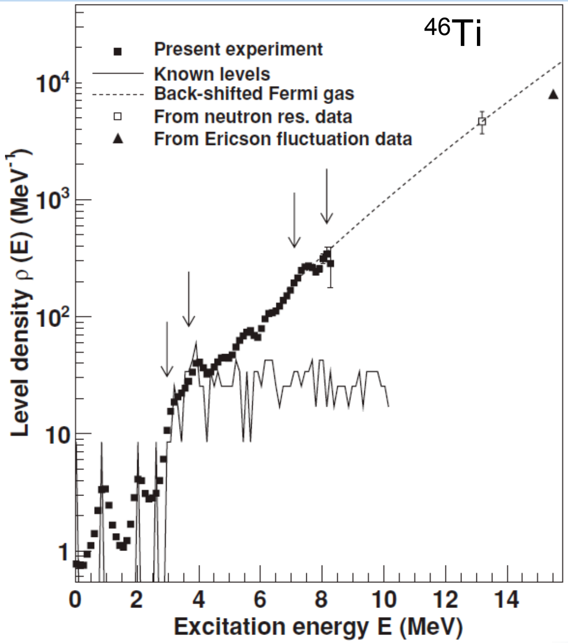
[Nyhus et al., PRC 81,024325 (2010)]



[Larsen et al., PRC 76,044303 (2007)
Voinov et al., PRC 77, 034613 (2008)]



[Guttormsen et al., PRC 83,014312 (2011)
Salas-Bacci et al., PRC 70, 024311 (2004)]



Spin/parity resolved level density

- $J^\pi = 2^+$ and 2^- for ^{58}Ni and ^{90}Zr
  [Kalmykov et al., PRL 99, 202502 (2007)]
- $E_x \approx 10$ MeV, $J^\pi = 1/2^+$ and $1/2^-$ for ^{45}Sc
  [Agvaanluvsan et al., PRC 67, 064608 (2003)]

$\Rightarrow \approx$ equally many +/- states

... but what about $\pi(E_x)$ and $J(E_x)$?

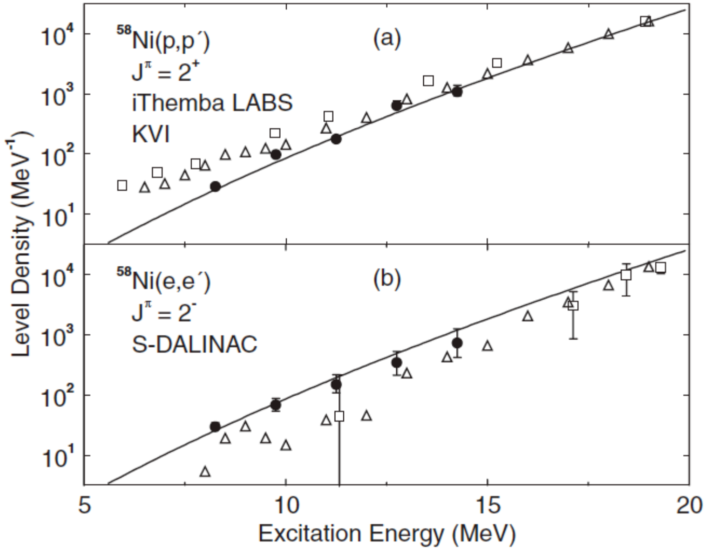
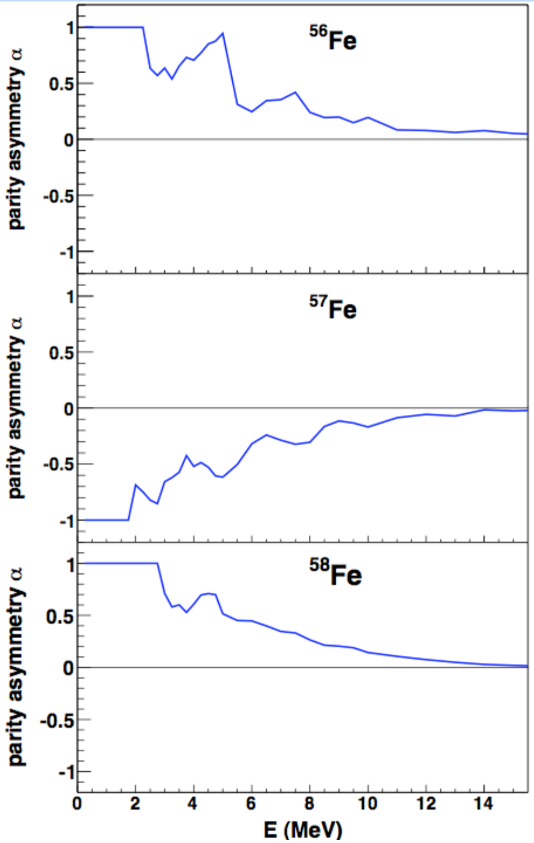


FIG. 2. Experimental (solid circles) level densities of (a) 2^+ and (b) 2^- states in ^{58}Ni compared to BSFG (solid lines), HFB (open triangles), and SMMC (open squares) predictions.

Level density – experimental challenges

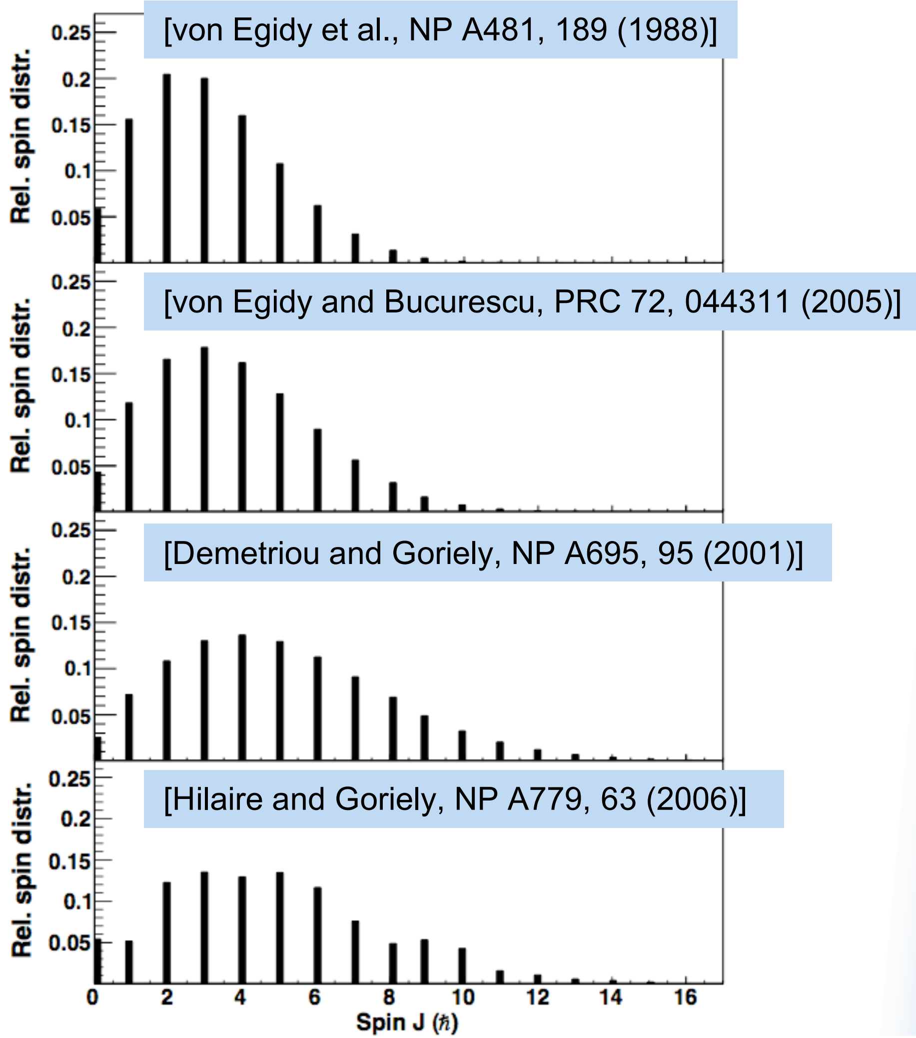
Parity dependence

[Goriely et al., PRC 78, 064307 (2008)]



Exp. data usually for low E_x only

Spin distribution



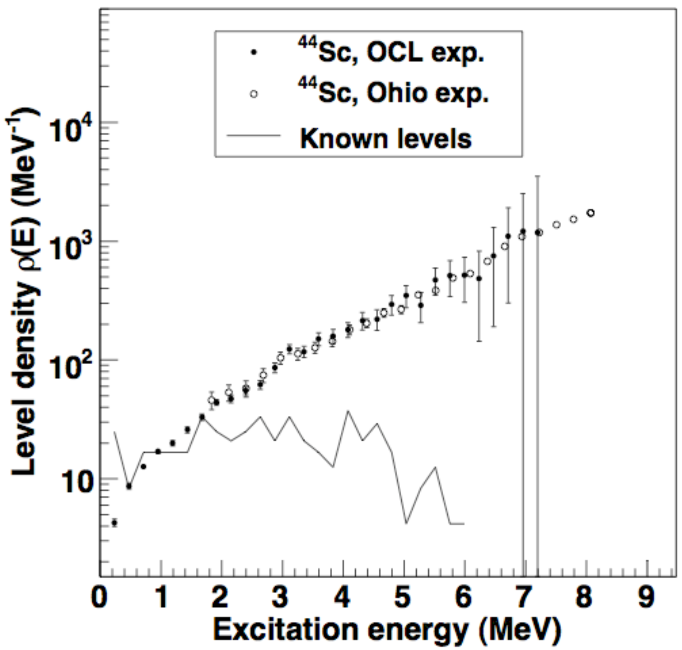
Spin distribution and normalization

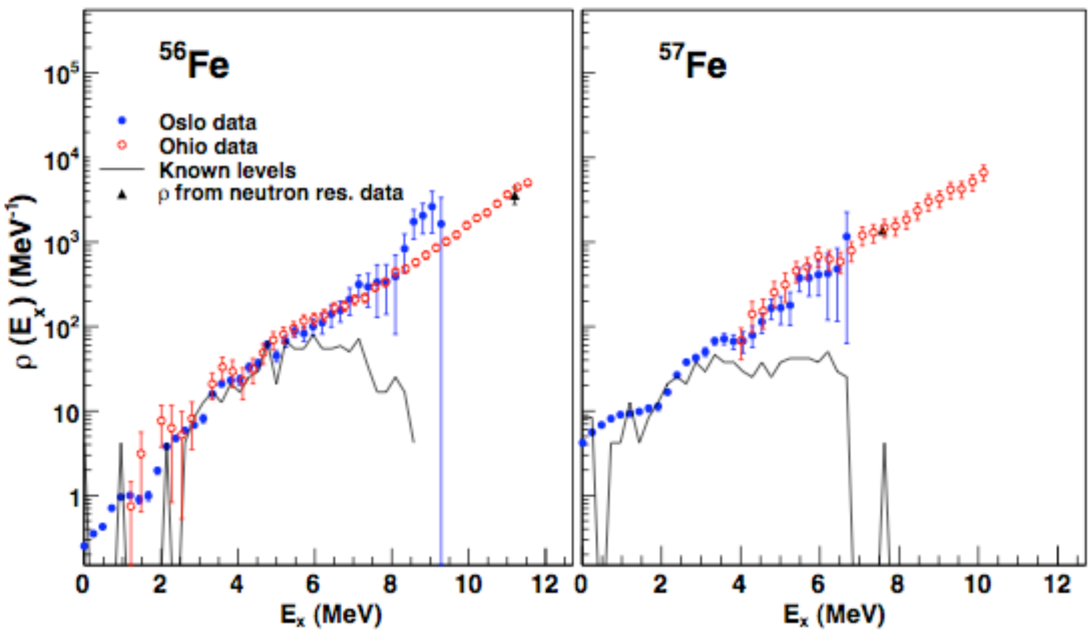
TABLE I: Variation of the calculated $\rho(S_n)$ using different spin cutoff parameters. The target spin in the (n,γ) reaction is denoted by I_t^π, and E_1 is the total backshift for the back-shifted Fermi-gas model while a is the level-density parameter. All level spacings (D_0) are taken from [33]. The parameter η is the ratio $\rho_{EB}(S_n)/\rho_{GC}(S_n)$.

				[von Egidy et al., NP A481, 189 (1988)]				[von Egidy and Bucurescu, PRC 72, 044311 (2005)]				
Nucleus	I_t^π	S_n (MeV)	D_0 (keV)	a (MeV^{-1})	E_1 (MeV)	σ	$\rho_{GC}(Sn)$ (MeV^{-1})	a (MeV^{-1})	E_1 (MeV)	σ	$\rho_{EB}(Sn)$ (MeV^{-1})	η
^{51}V	6^+	11.05	2.3(6)	6.42	−0.511	3.24	5.18×10^3	6.17	−0.153	3.83	4.15×10^3	0.80
^{57}Fe	0^+	7.646	25.4(22)	7.08	−0.910	3.20	8.46×10^2	6.58	−0.523	3.83	1.20×10^3	1.41
^{96}Mo	$5/2^+$	9.154	0.105(10)	11.14	1.016	4.21	7.38×10^4	11.39	0.779	5.15	1.01×10^5	1.37
^{117}Sn	0^+	6.944	0.380(130)	13.23	0.197	4.48	1.08×10^5	13.62	−0.210	5.58	1.67×10^5	1.54
^{164}Dy	$5/2^+$	7.658	0.0068(6)	17.75	0.416	5.49	1.74×10^6	18.12	0.310	6.91	2.59×10^6	1.49

[Larsen et al., PRC 83, 034315 (2011)]

Complementary experiments



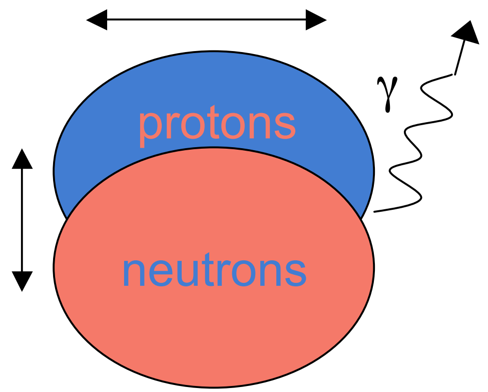


[Larsen et al., PRC 76,044303 (2007)
Voinov et al., PRC 77, 034613 (2008)]

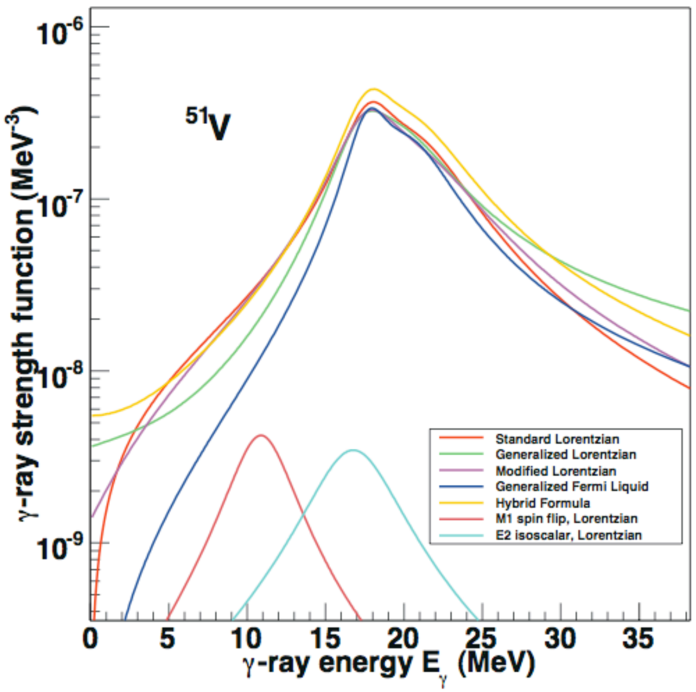
[Algin et al., PRC 78,054321 (2008)
Voinov et al., PRC 74, 014314 (2006)]

Gamma strength – what and why?

- Average electromagnetic decay properties
- Sensitive to collective resonances
- Input for cross-section calculations

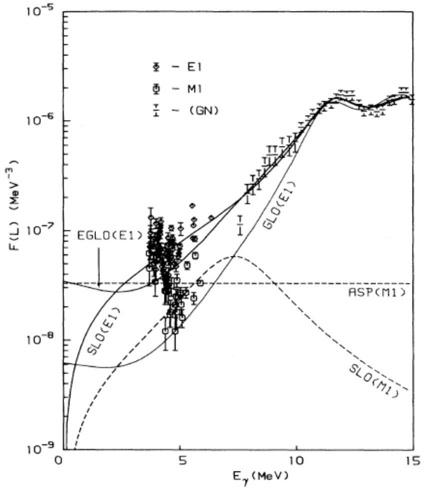


Giant Electric Dipole Resonance

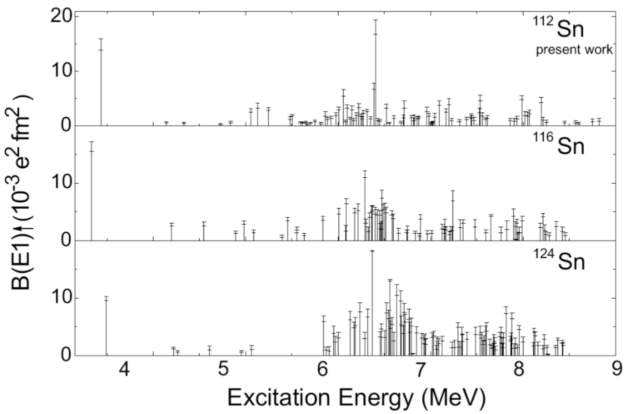


Gamma strength – experiments

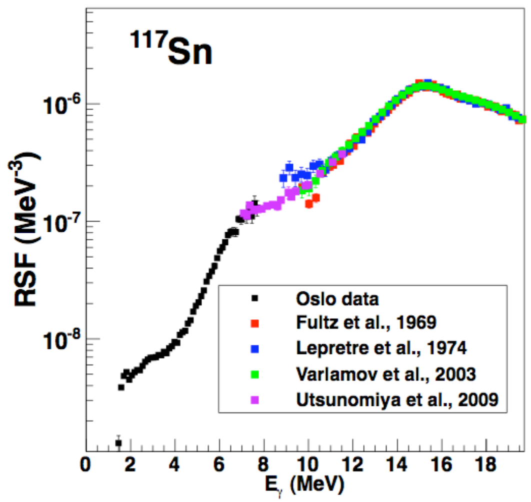
- Photonuclear reactions (above B_n)
- Primary transitions following neutron capture (around B_n)
- Nuclear resonance fluorescence (γ,γ'), electron scattering, proton scattering, ... (below B_n)
- Two-step cascade spectra following neutron/proton capture (below B_n)
- Primary γ spectra (below B_n)



[Kopecky et al, PRC 47, 312 (1993)]



[Özel et al., NP A788, 385c (2007); Govaert et al, PRC 57, 2229 (1998)]

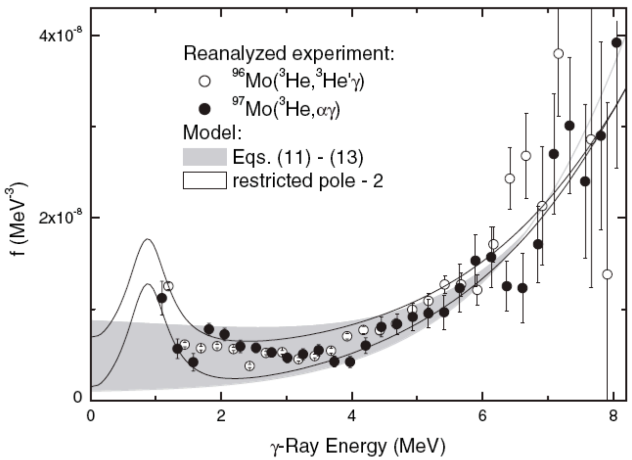


[Utsunomiya et al., PRC 80, 055806 (2009); Agvaanluvsan et al, PRL 102, 162504 (2009)]

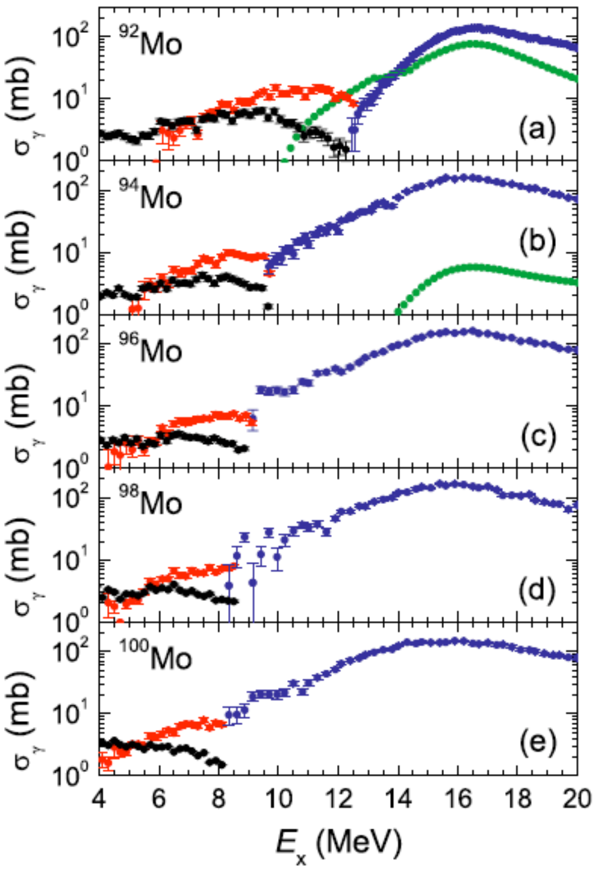
Gamma strength – challenges

- Independence of E_x (Brink hypothesis)?
- Independence of spin?
- Sufficient averaging?
- What about parity?
- ... When is γ strength a fruitful concept?

Different experiments may disagree!



Krticka et al., PRC 77, 054319 (2008)]

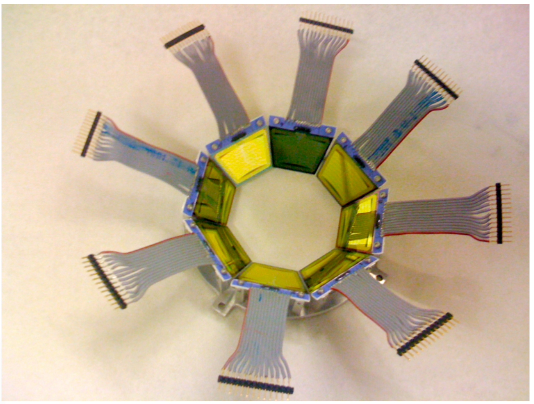


Rusev et al., PRC 79, 061302(R) (2009)]

OCL experiments and methods

- Charged-particle induced reactions
- Particle-γ coincidence data with SiRi and CACTUS
- Separation of primary γ rays $\Rightarrow$ extraction of level density and γ strength

[Guttormsen et al., NIM A 374,371 (1996); Guttormsen et al., NIM A 255, 518 (1987); Schiller et al., NIM A 447, 498 (2000)]



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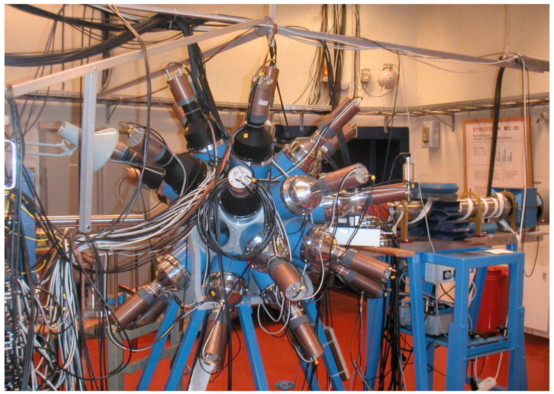

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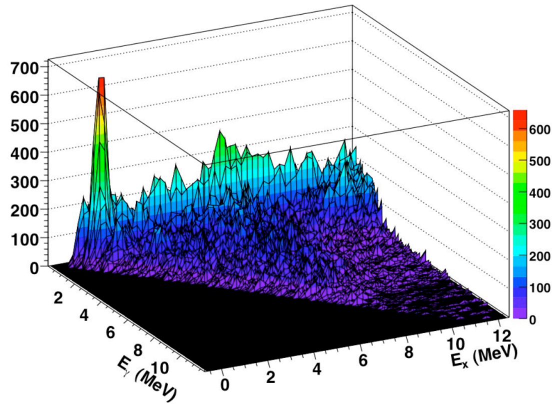
^{44}Sc

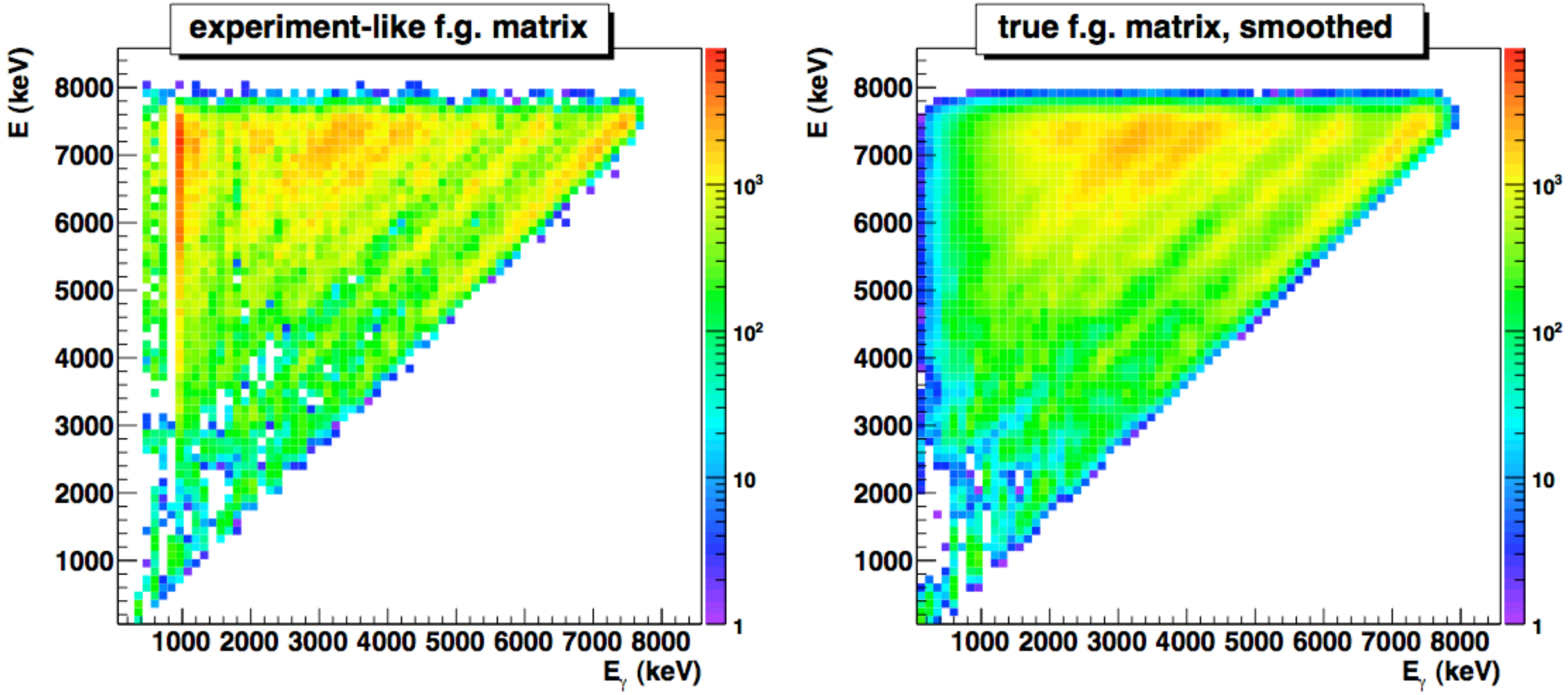


Talk of Hilde T. Nyhus on Thursday

Testing the Oslo method – separation of primary gammas

- Simulations using the DICEBOX code [Bečvář, NIM A 417, 434 (1998)] performed by M. Krtička

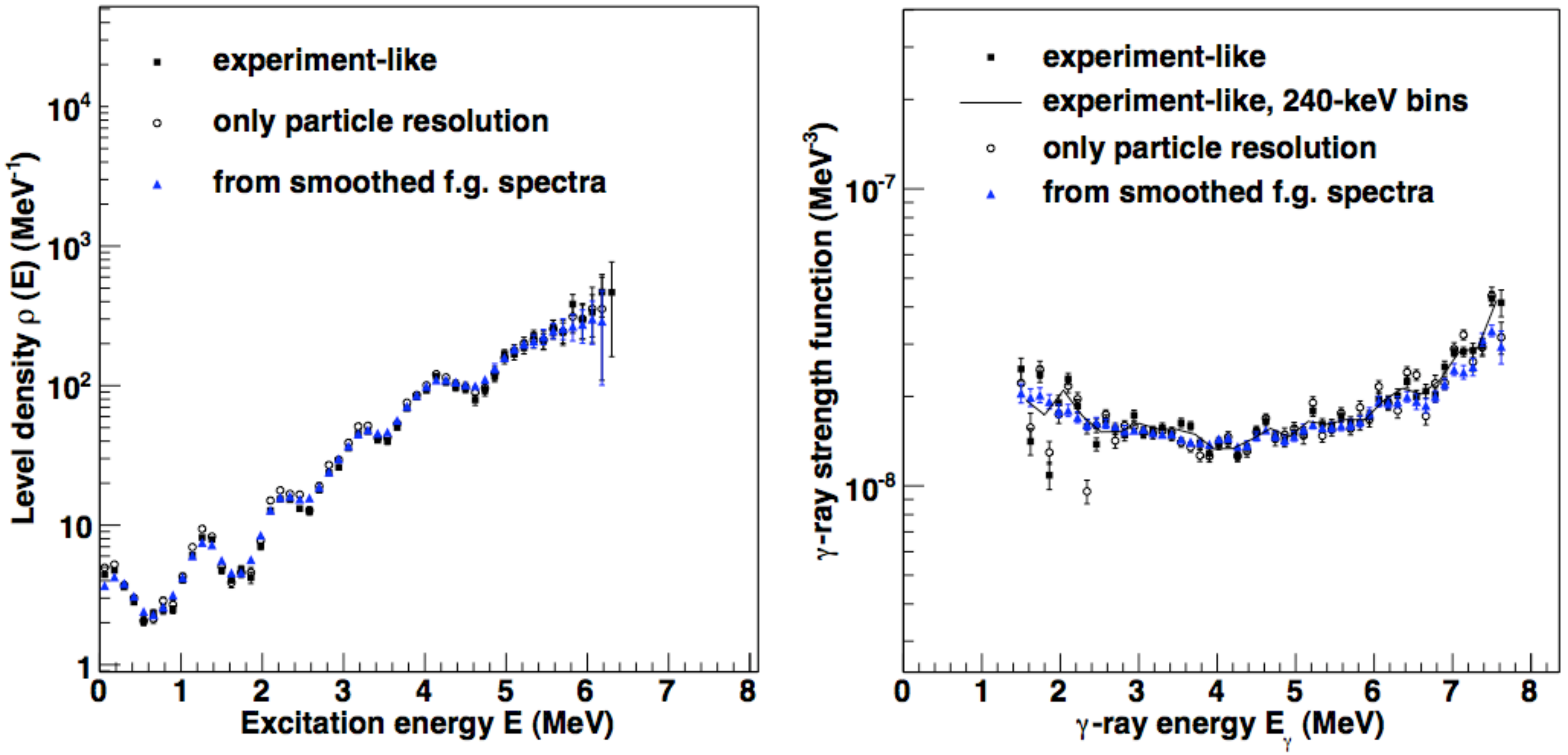
Artificial ^{57}Fe



[Larsen et al., PRC 83, 034315 (2011)]

Comparison of extracted level density and γ strength

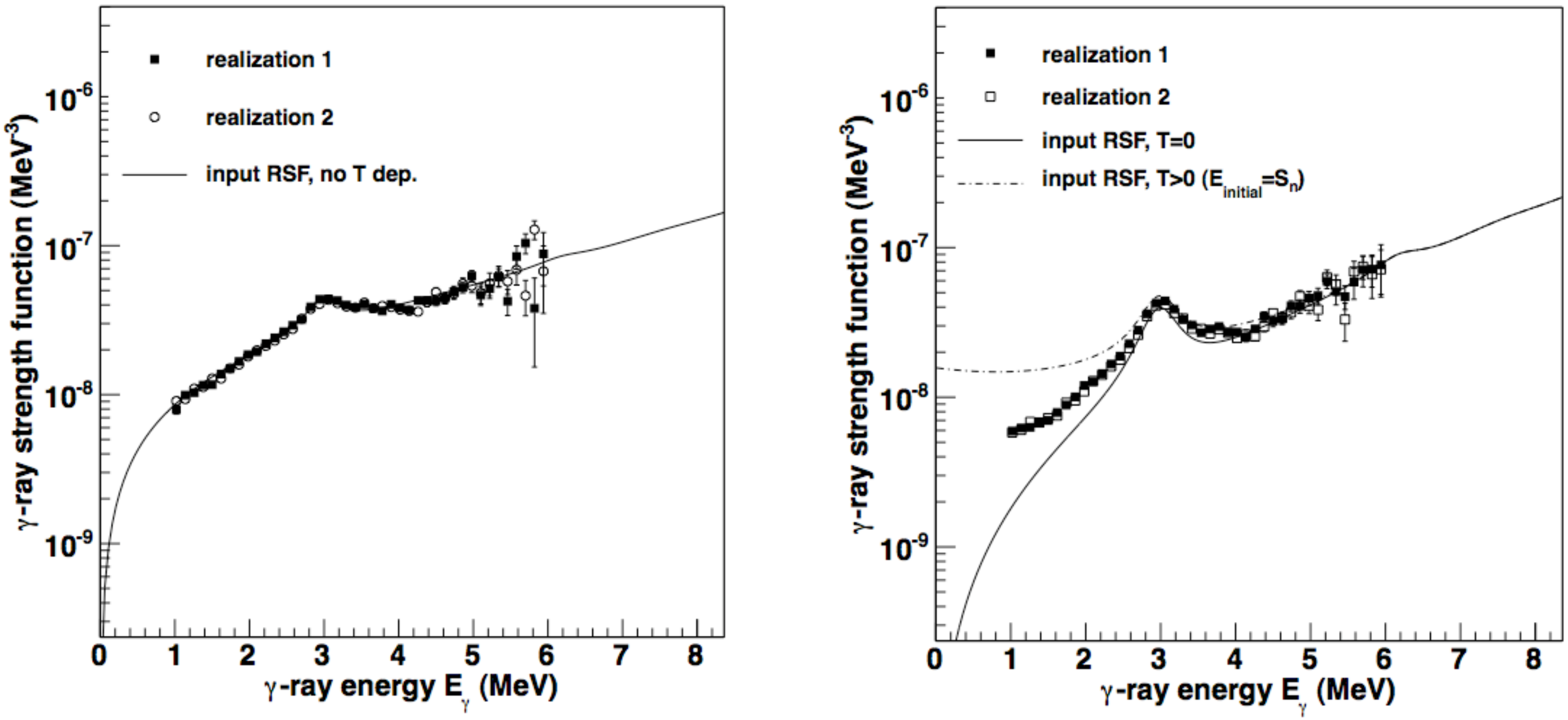
Artificial ^{57}Fe



[Larsen et al., PRC 83, 034315 (2011)]

Testing the Oslo method – extraction of γ strength in heavy nuclei

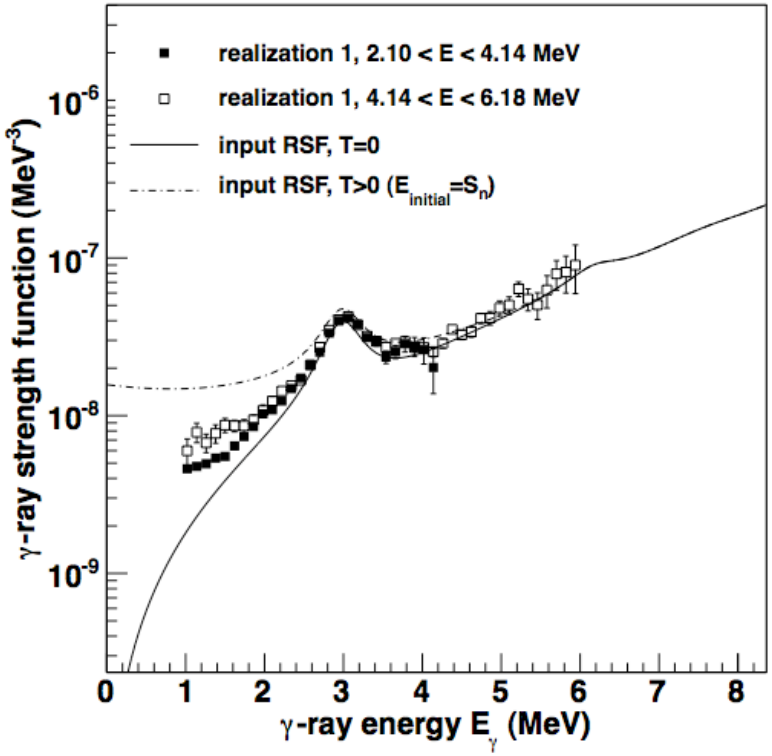
Artificial ^{163}Dy



[Larsen et al., PRC 83, 034315 (2011)]

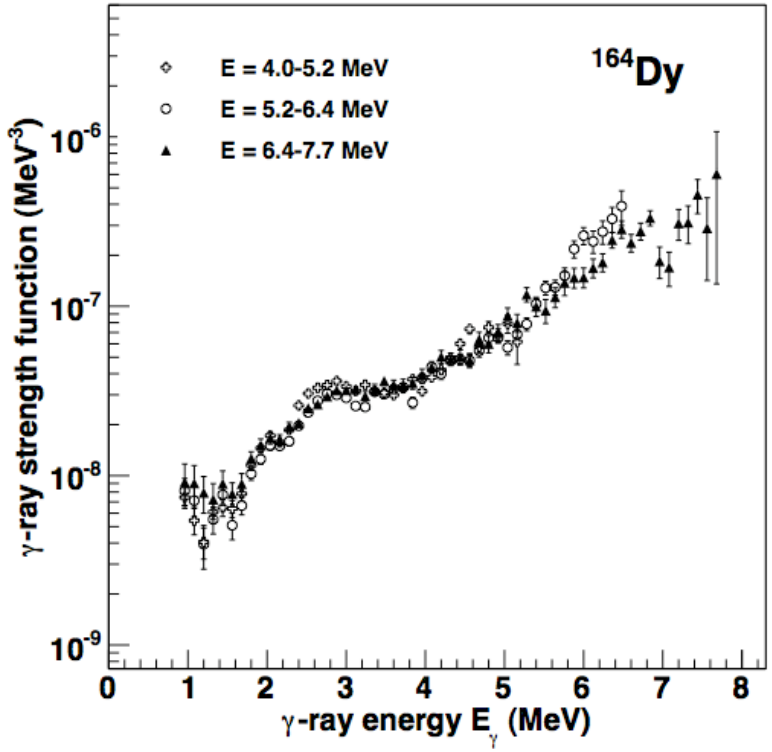
Tests of the Oslo method – extraction of γ strength in heavy nuclei

Artificial ^{163}Dy



Experiment

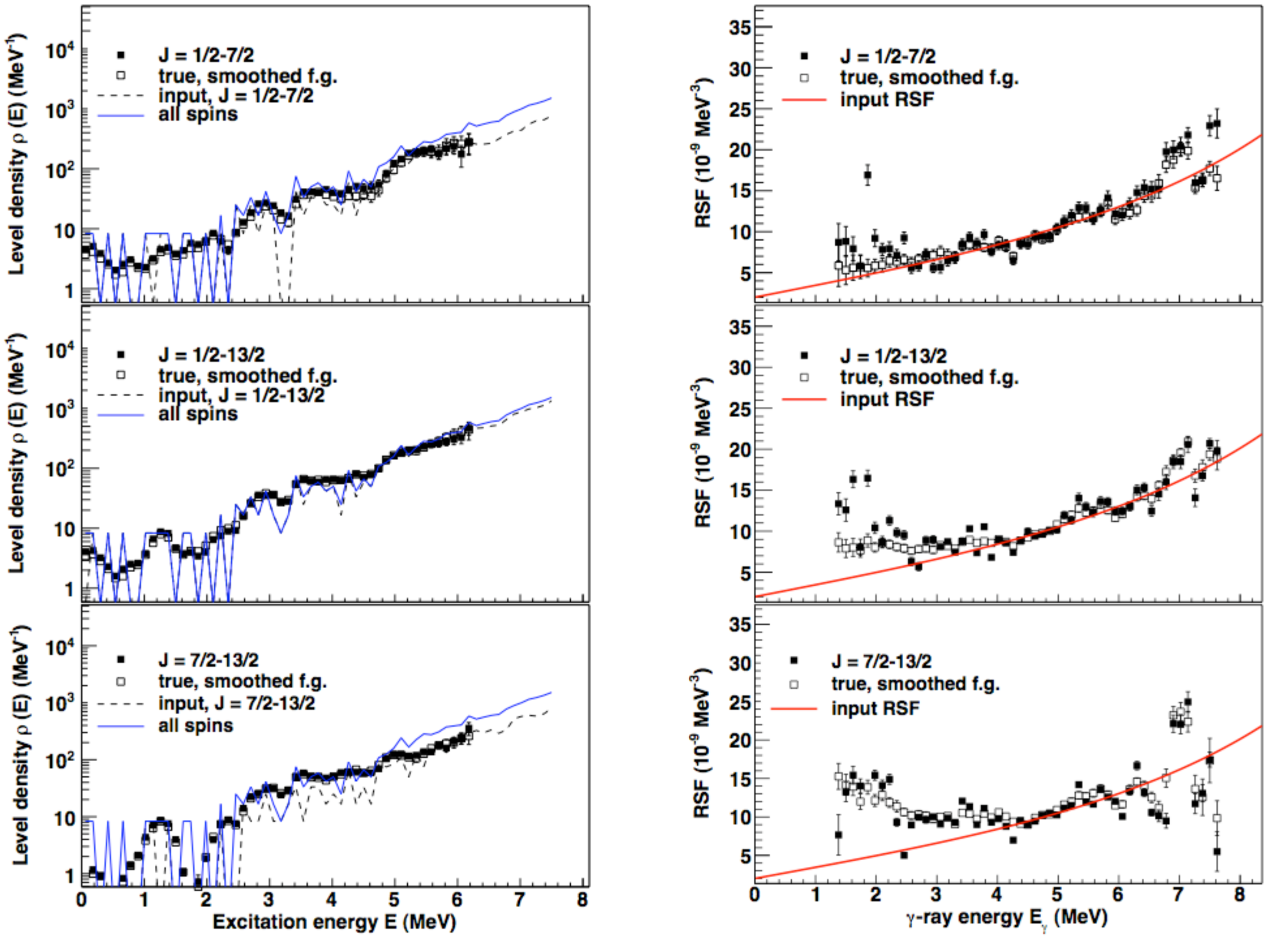
[Nyhus et al., PRC 81,024325 (2010)]



[Larsen et al., PRC 83, 034315 (2011)]

Tests of the Oslo method – extraction of γ strength in lighter nuclei

Artificial ^{57}Fe, various spin ranges on initially populated levels

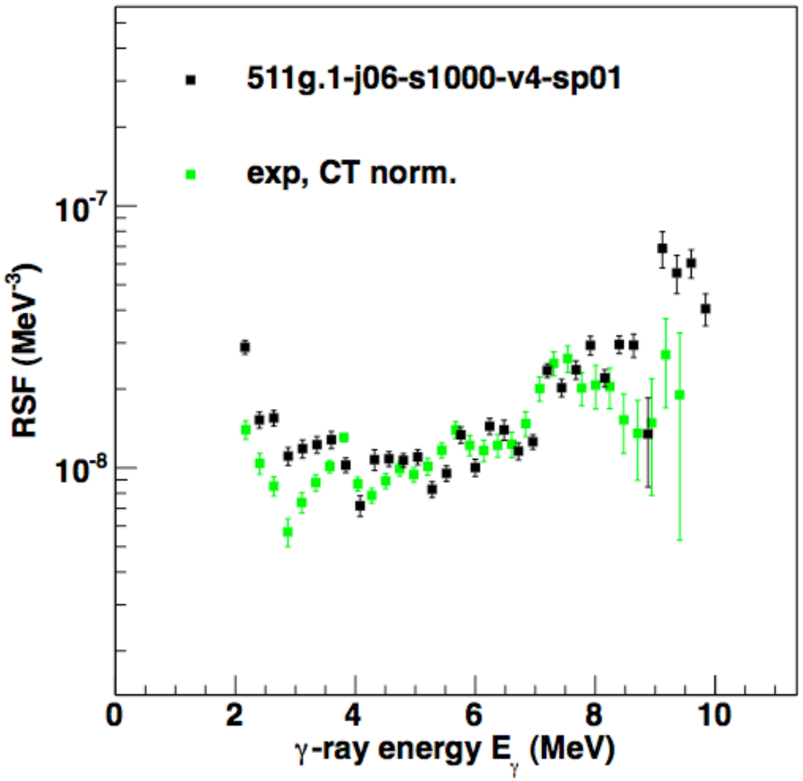


- -low level density
- -dipole radiation
- -spin restriction

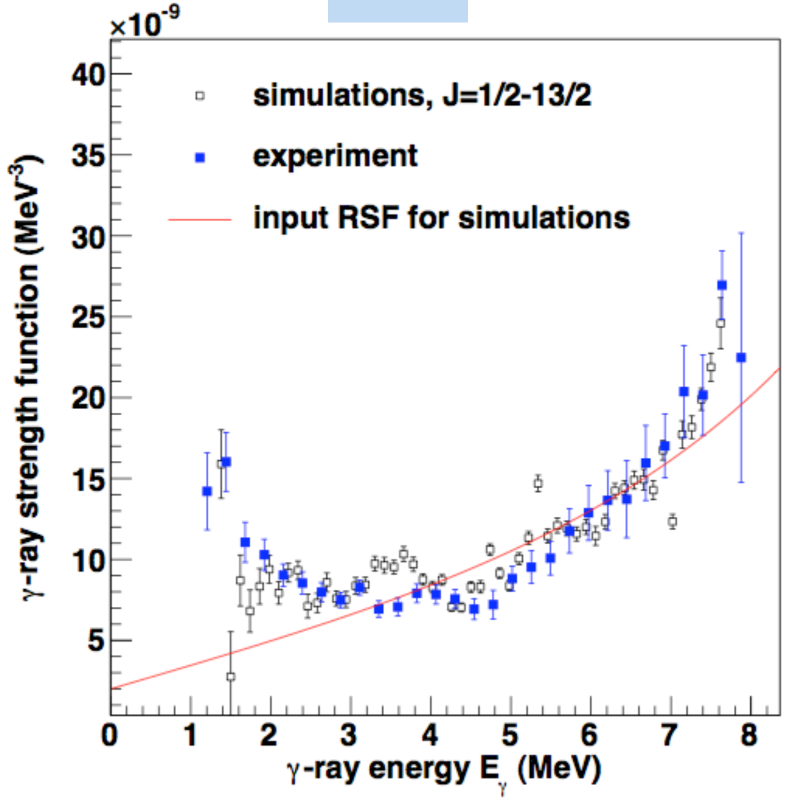
[Larsen et al., PRC 83, 034315 (2011)]

Comparison of experiment and simulations, light nuclei

^{44}Ti



^{57}Fe

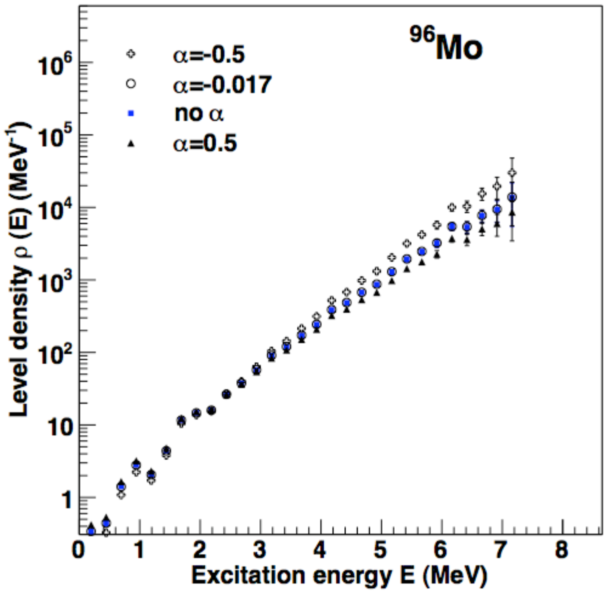


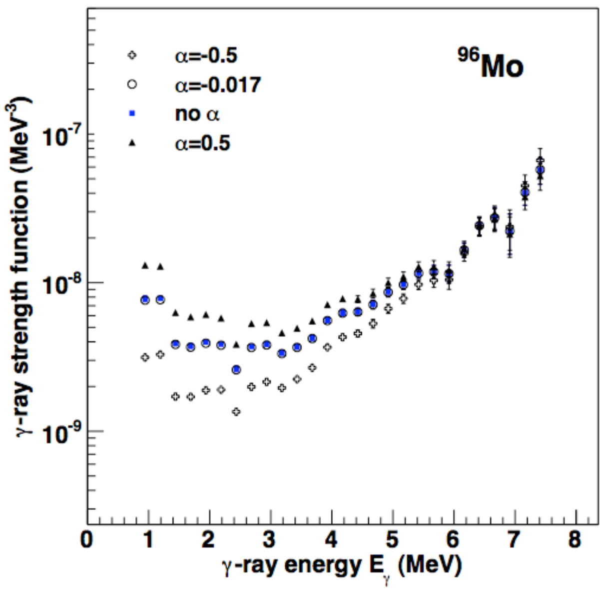
Talk of Milan Krticka on Thursday

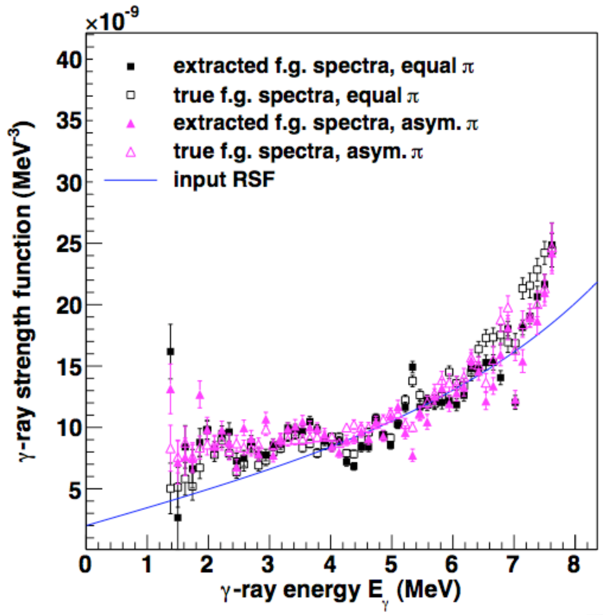
Tests of the Oslo method – effects of parity distribution

Experiment
[Guttormsen et al., PRC 71,044307 (2005)]

Artificial ^{57}Fe

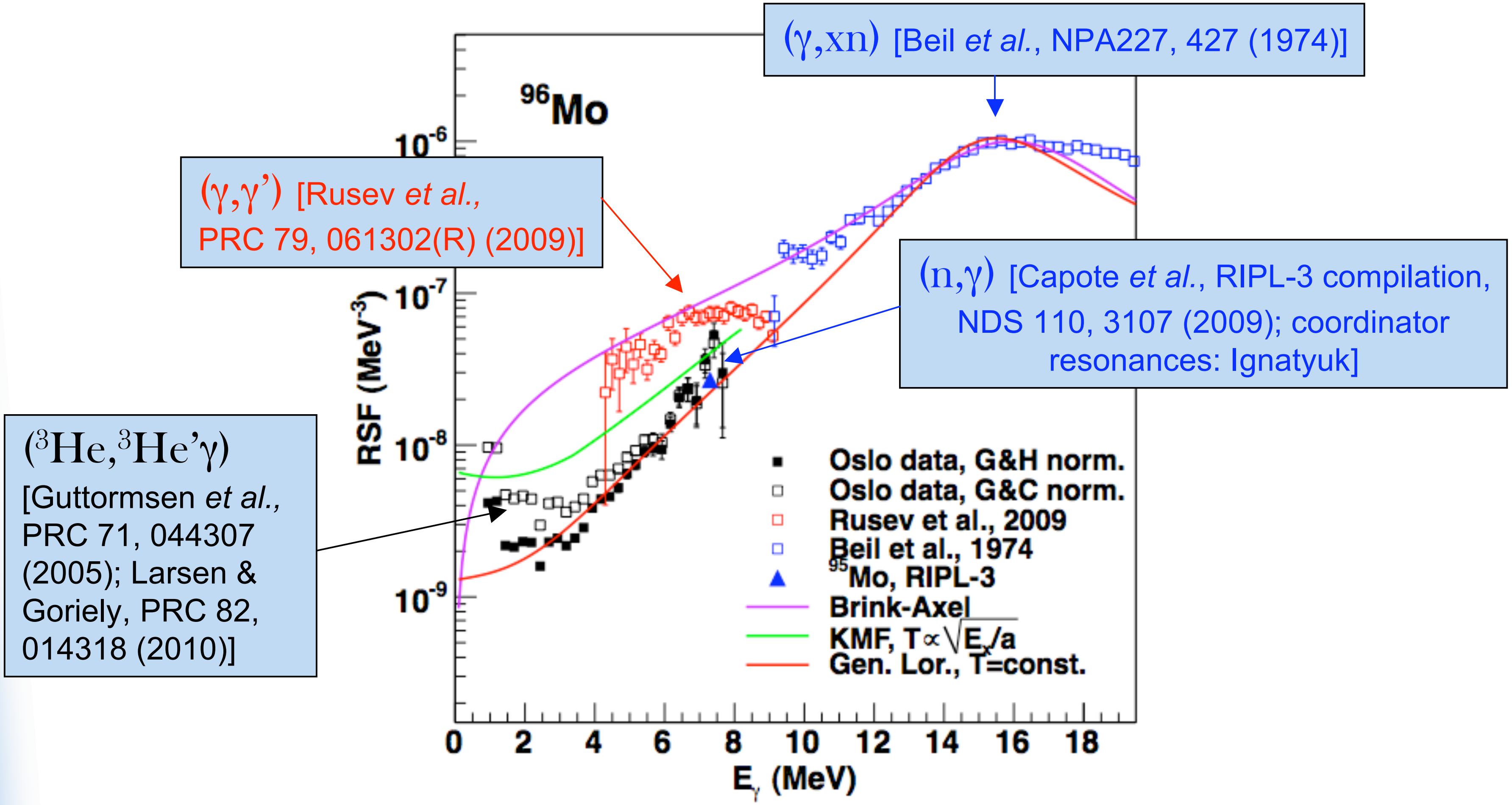






[Larsen et al., PRC 83, 034315 (2011)]

Gamma strength – why do some experiments disagree?

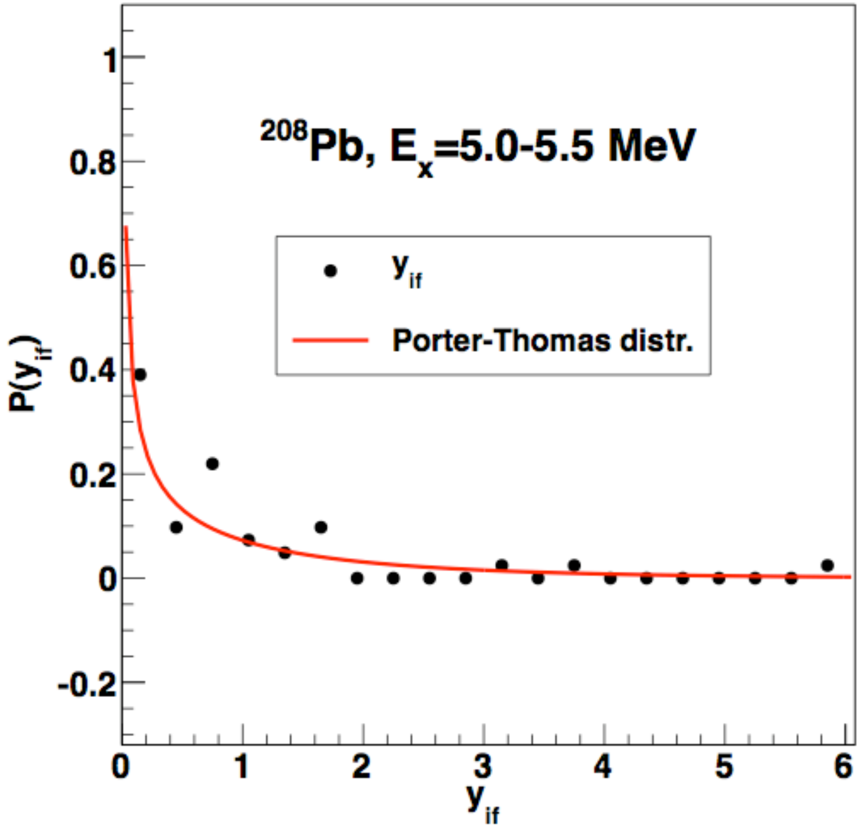


Porter–Thomas distribution of partial widths

$$P(\Gamma_{if},\langle\Gamma_{if}\rangle,\nu) = K\Gamma_{if}^{(\nu/2-1)}\exp(-\nu\Gamma_{if}/2\langle\Gamma_{if}\rangle)d\Gamma_{if}$$

Porter-Thomas: $\nu=1$

$y_{if} = \Gamma_{if}/\langle\Gamma_{if}\rangle$



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- Andreas Schiller and Alexander Voinov, Ohio University
- Milan Krticka, Charles University
- Emil Betak, Institute of Physics SAS
- Sotirios Harrisopulos, NCSR “Demokritos”
- Lee Bernstein and Darren Bleuel, Livermore National Lab
- Mathis Wiedeking, iThemba Lab
- Undraa Agvaanluvsan, Stanford University/MonAme Scientific Research Center
- Gary Mitchell, North Carolina State University/Triangle Universities Nuclear Laboratory
- Emel Algin, Eskisehir Osmangazi University
- Tom Lönnroth, Åbo Akademi

… and many thanks to you for your attention!