Photon Strength Functions at the low-energy tail of GDR

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(Problems with) Photon Strength Functions at the low-energy tail of GDR (from experimentalists point of view)

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Photon Strength Functions

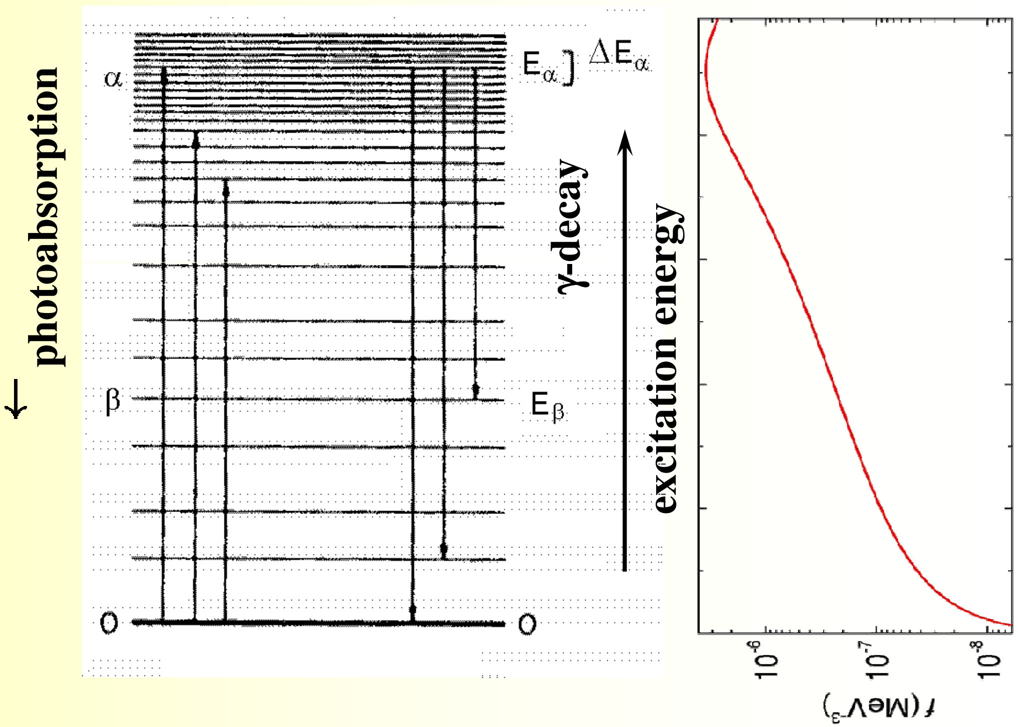
- PSFs describe the (average) energy distribution of photon emission from “highly-excited” states or cross section for photon absorption (detailed balance principle)

$$\overline{\Gamma}^{(XL)}_{\alpha\gamma\beta} = \frac{1}{(\pi\hbar c)^2}\,\frac{E_\gamma^2}{2L+1}\,\frac{\overline{\sigma}^{(XL)}_{\text{tot}}(\beta\to\alpha)}{\rho(E_\alpha, J_\alpha, \pi_\alpha)}$$

$$\overline{\Gamma}^{(XL)}_{\alpha\gamma\beta} = \frac{f^{(XL)}E_\gamma^{2L+1}}{\rho(E_\alpha, J_\alpha, \pi_\alpha)}$$

$$= \frac{8\pi(L+1)}{L[(2L+1)!!]^2}\left(\frac{E_\gamma}{\hbar c}\right)^{2L+1} B(XL)\downarrow$$

$$f^{(XL)} = \frac{1}{(\pi\hbar c)^2}\,\frac{\overline{\sigma}^{(XL)}_{\text{tot}}(\beta\to\alpha)}{(2L+1)E_\gamma^{2L-1}}$$



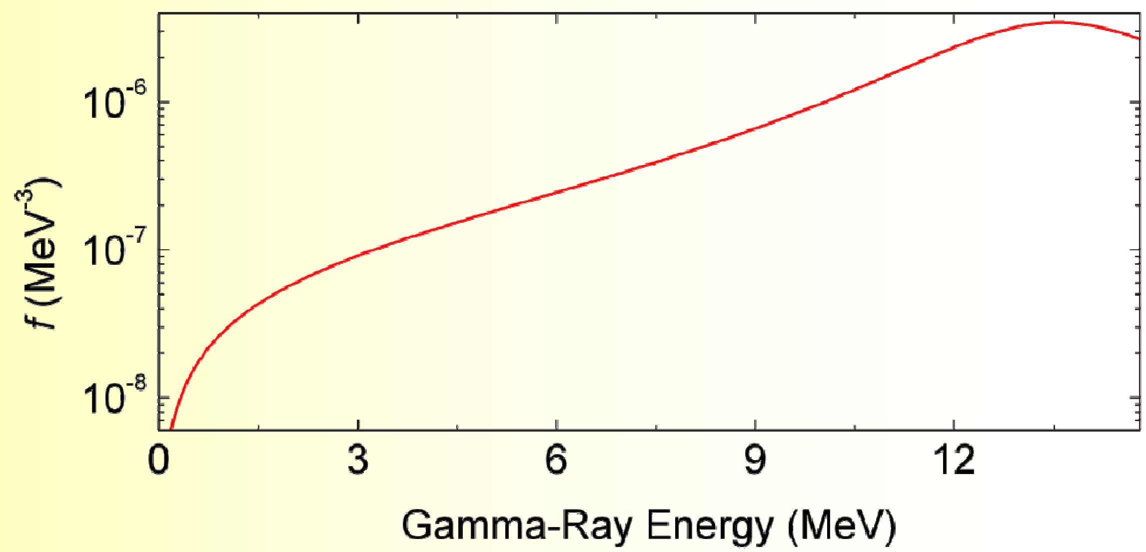
- Individual intensities fluctuate (according to Porter-Thomas distribution)
see also talk of Paul Koehler

Photon Strength Functions

Quantities which PSFs can dependent on:

- type of transitions (E1, M1, E2, …) ✓
- gamma-ray energy ✓
- microscopic properties of the level (energy, J^{π}) **?**

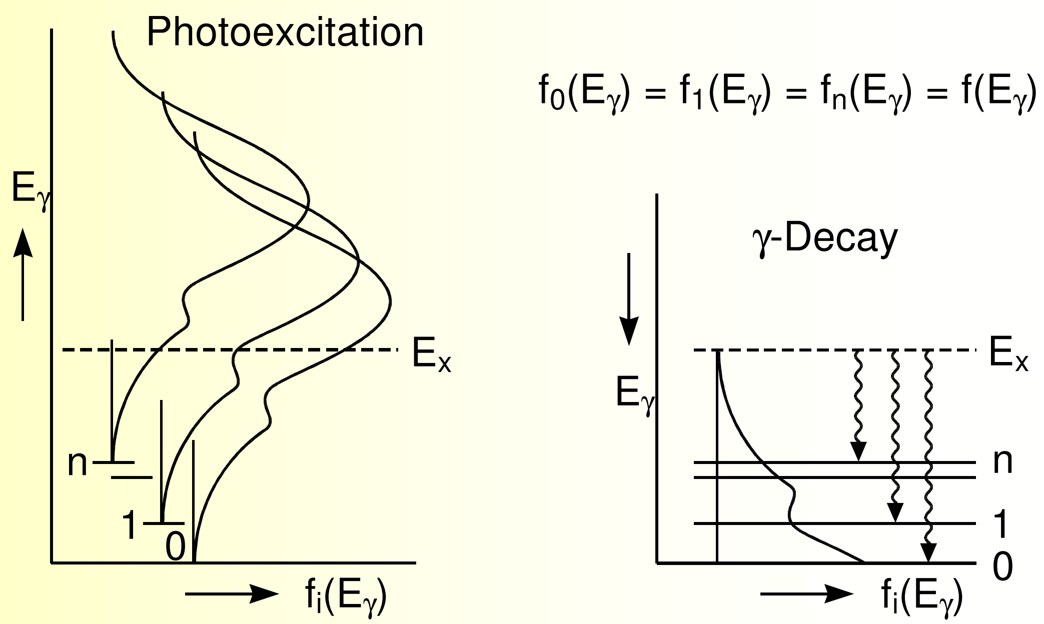
  $\Rightarrow$ Brink hypothesis



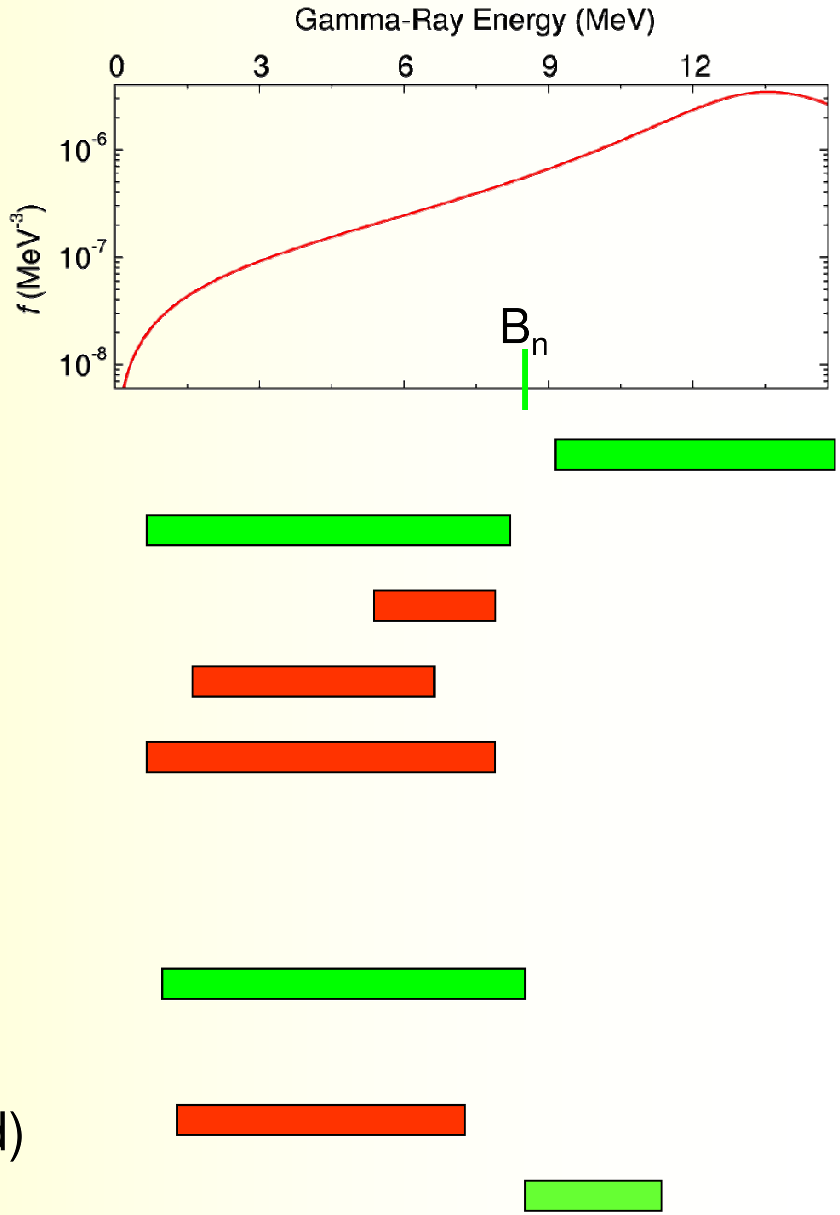
Brink hypothesis

- The energy dependence of the photoeffect is independent of the detailed structure of the initial state
  $\Rightarrow$ dependence on γ-ray but not on excitation energy (T), J^{π},…

- validity of the hypothesis?
- at least approximately - from (n,γ) reaction, hot nuclei, Oslo method
- some signs for temperature dependence

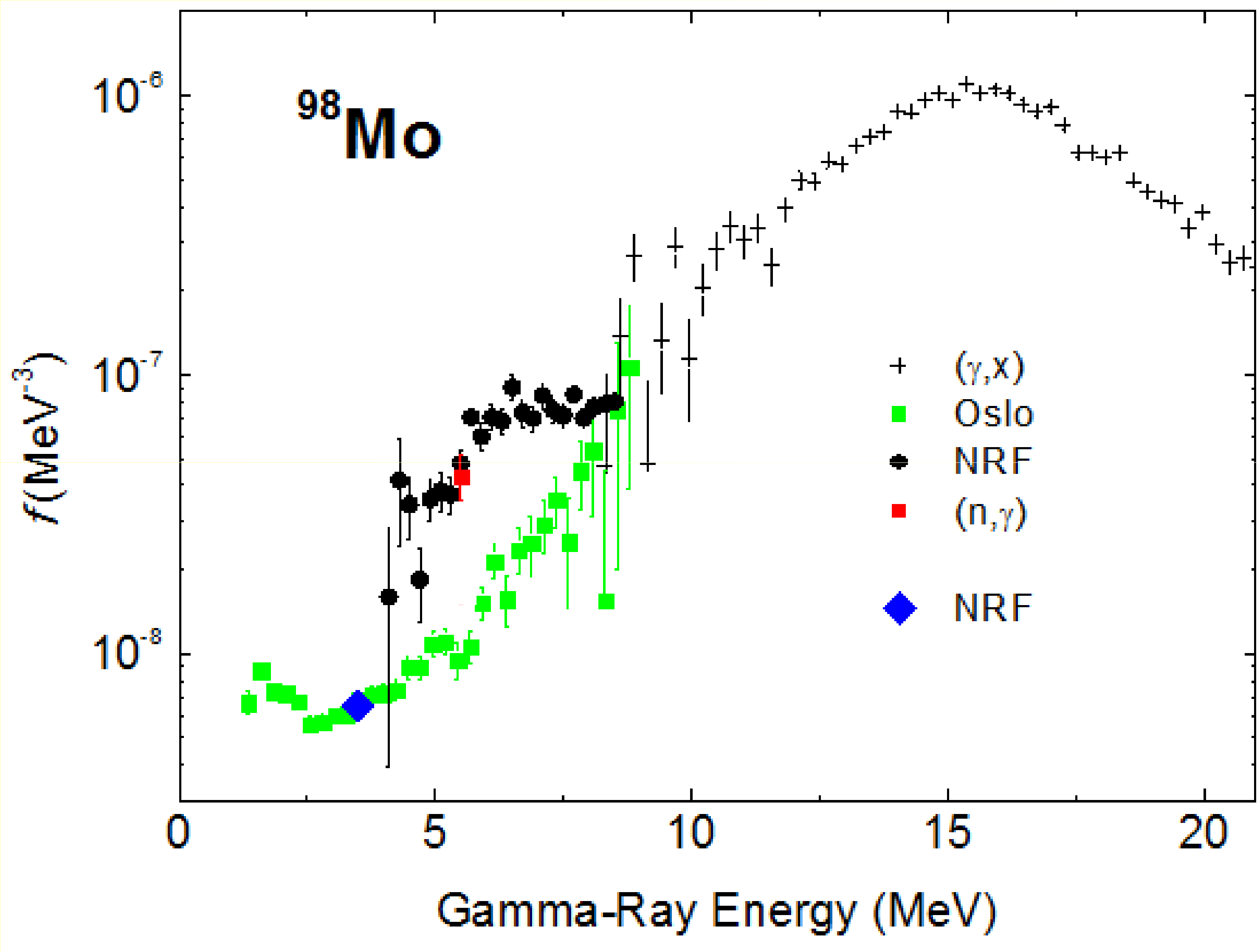


Where could we learn about PSFs from?



- photoexcitation techniques
  - $(\gamma,$particle$)$
  - NRF experiments
- primaries from (n,γ) reaction
- two-step cascades spectra - (n,γ)
- spectrum fitting method
  - single spectra
  - coincidence spectra
- inelastic scattering of charged particles (e,e'), (p,p'), …
- sequential extraction (Oslo, ^{3}He-induced)
- RA beams – Coulomb dissociation
- …

Are results consistent?



G. Rusev et al., PRC77, 064321 (2008)

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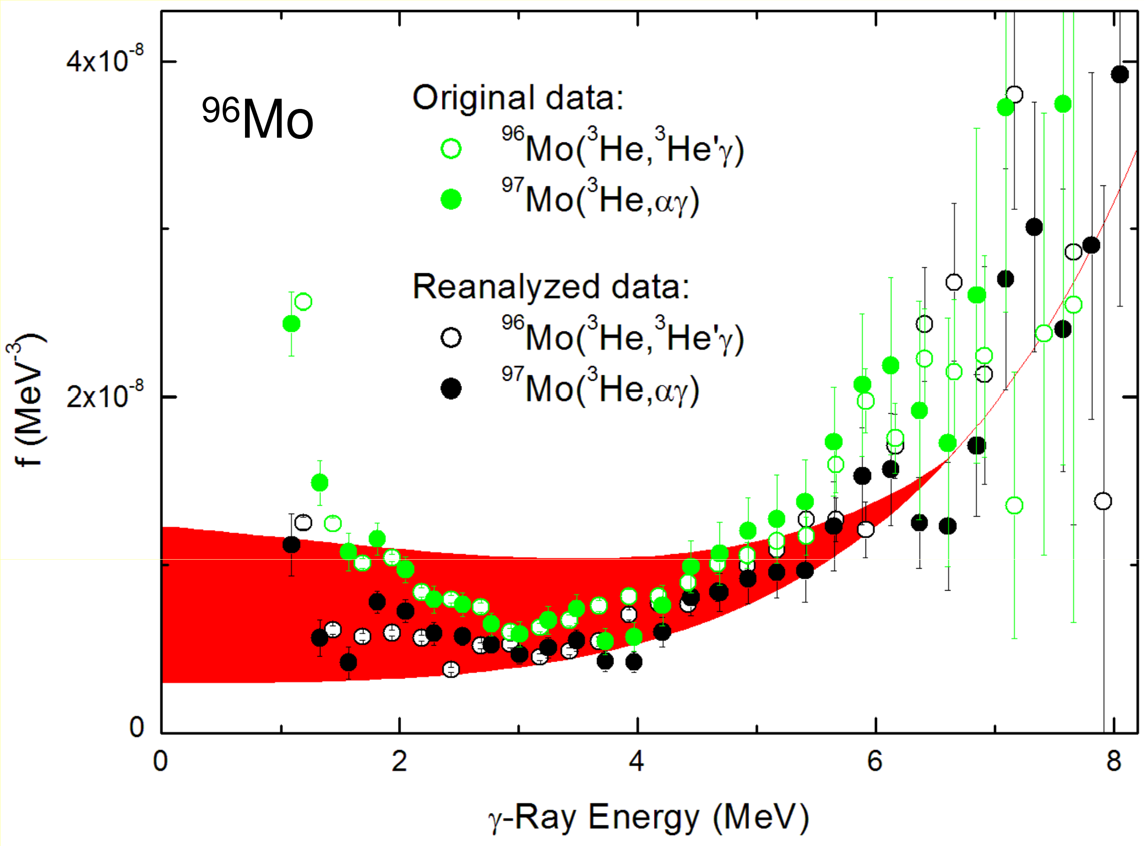


PSF (T-dependent) which is consistent spectra from (n,γ) experiments - TSC and multistep spectra from DANCE experiment – simulations performed with the DICEBOX code

Krticka et al., PRC 77 054319 (2008), Sheets et al., PRC 79 024301 (2009)

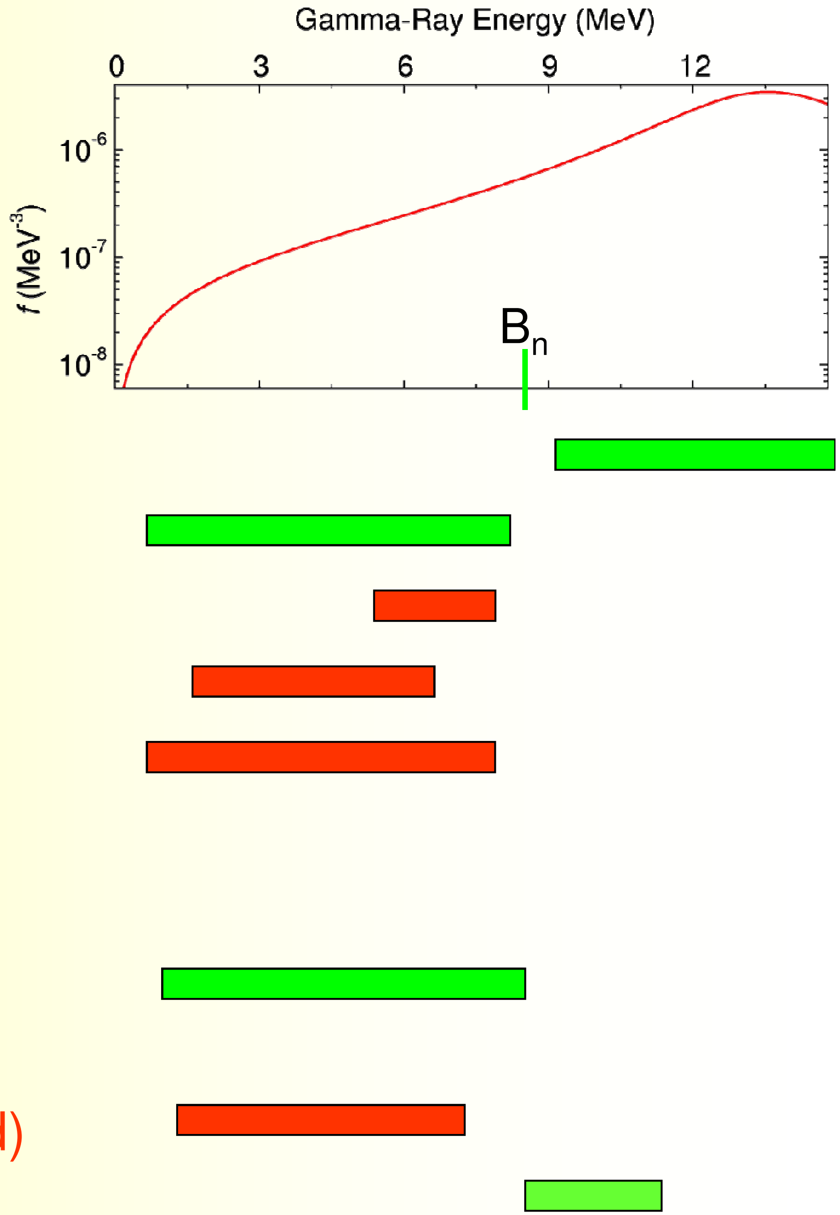
Why are there different results?

- Concept of photon strength function and/or Brink hypothesis is not valid
- Quantities deduced from different experiments are not the same
- The same quantities are deduced but interpretation is not correct

Why are there different results?

- Concept of photon strength function and/or Brink hypothesis is not valid
- Quantities deduced from different experiments are not the same
- The same quantities are deduced but interpretation is not correct
  - The methods are usually “not direct”
  - Measured spectra must be often deconvoluted and interpreted
  - Spectra often comes from an interplay of PSF and level density
  - Additional information, often about level density, is required to produce final results

Where could we learn about PSFs from?



- photoexcitation techniques
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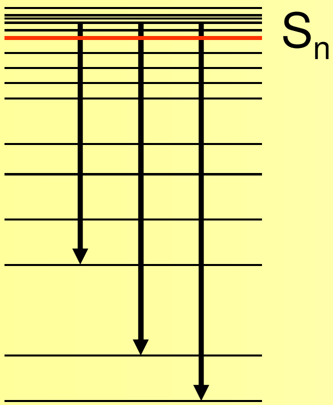
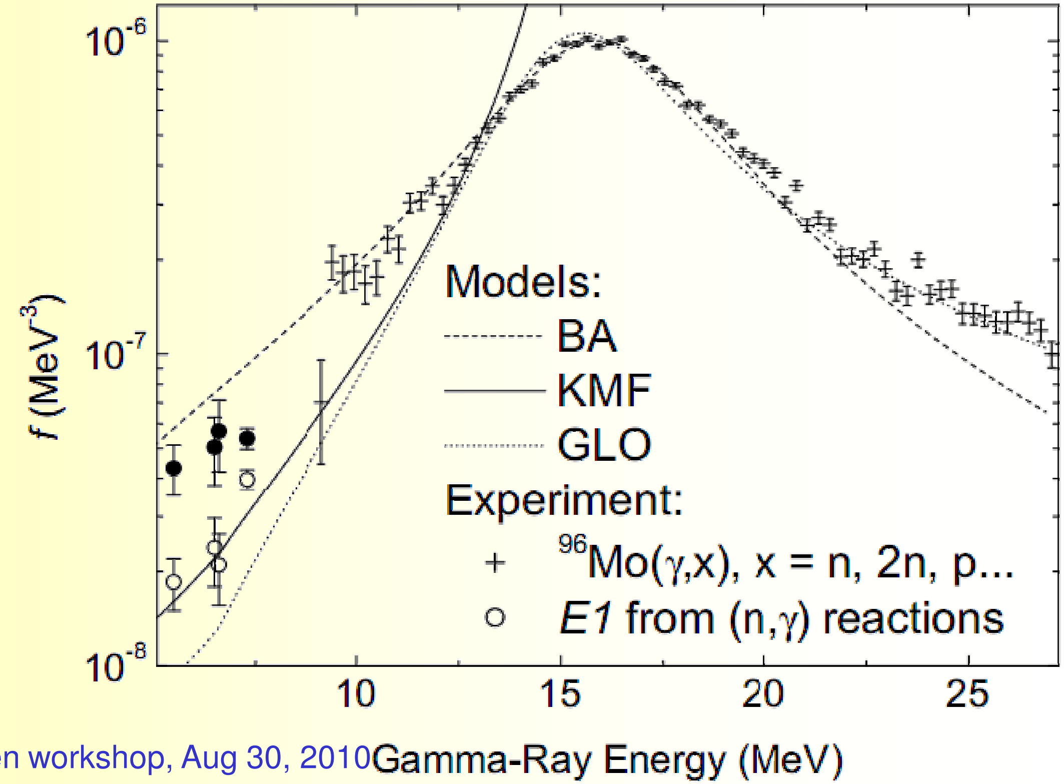
(n,γ) reactions – part 1

- PSF from intensities of primary transitions (Kopecky values in RIPL)

$$\overline{\Gamma}^{(XL)}_{\alpha\gamma\beta} = \frac{f^{(XL)} E_\gamma^{2L+1}}{\rho(E_\alpha, J_\alpha, \pi_\alpha)}$$



Nucleus	XL	E_γ (MeV)	original (Kopecky) $\langle D \rangle$ (eV)	original (Kopecky) $f_{XL} \times 10^{-8}$ (MeV^{-3})	recalculated (RIPL) $\langle D \rangle$ (eV)	recalculated (RIPL) $f_{XL} \times 10^{-8}$ (MeV^{-3})
^{93}Mo	$E1$	6.6	1000	5.67(147)	2700(500)	2.10(54)
	$M1$	6.2		1.46(42)		0.54(16)
^{95}Mo	$E1$	7.3	975	5.38(41)	1320(180)	3.97(30)
^{99}Mo	$E1$	5.5	429	4.32(81)	1000(200)	1.85(35)
	$M1$	5.5		0.59(18)		0.25(7)
^{94}Nb	$E1$	6.5	37.8	5.04(124)	80(10)	2.38(59)
	$M1$	6.5		1.20(44)		0.57(21)



- Values from RIPL must be taken with care

(n,γ) reactions – part 2

Data from "spectrum fitting method", TSC spectra,…

– decay simulated using the DICEBOX code (see also talk of Jiri Kroll)

- Try and error method
  - agreement of simulated spectra with experiment is checked
  - "standard" PSFs are usually tested
- There is a sensitivity to energy dependence of PSFs and sometimes (TSC spectra) to ratios of PSFs of different types (E1, M1, E2)
- There is no sensitivity to absolute values of PSFs in simulation of decay
- The only "absolute" quantity in simulations of decay is the total radiation width

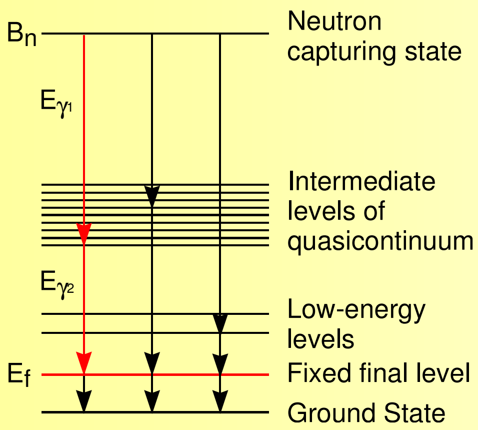
$$\Gamma_{\lambda\gamma} = \sum_f \Gamma_{\lambda\gamma f} \approx \sum_{XL} \int_0^{B_n} \frac{\rho(B_n - E_\gamma, J_f)}{\rho(B_n, J_{B_n})} f^{(XL)} E_\gamma^{2L+1}\, dE_\gamma$$

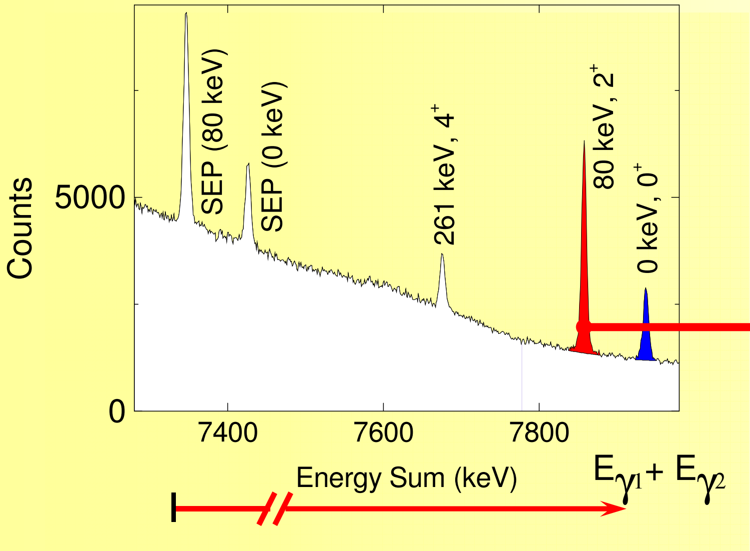
- Often photoabsorption data are matched above S_n and comparison of PSF from primaries is done

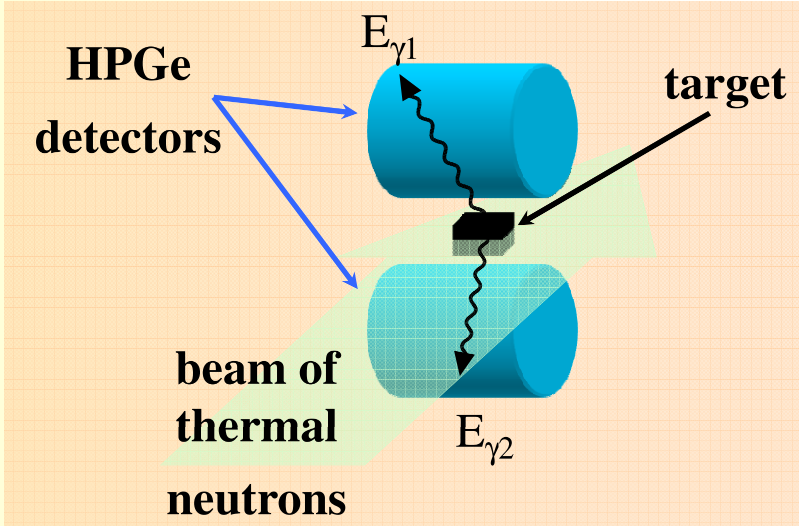
TSC spektra

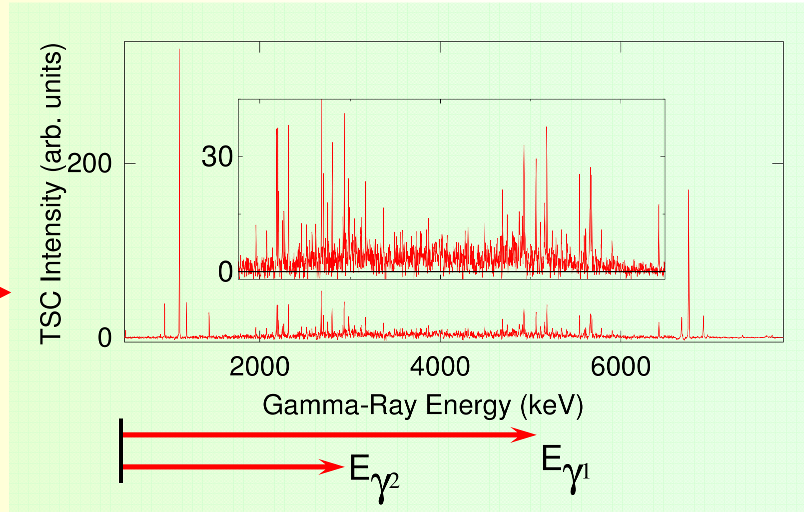
(see also talk of Jiri Kroll)

capture of thermal neutrons

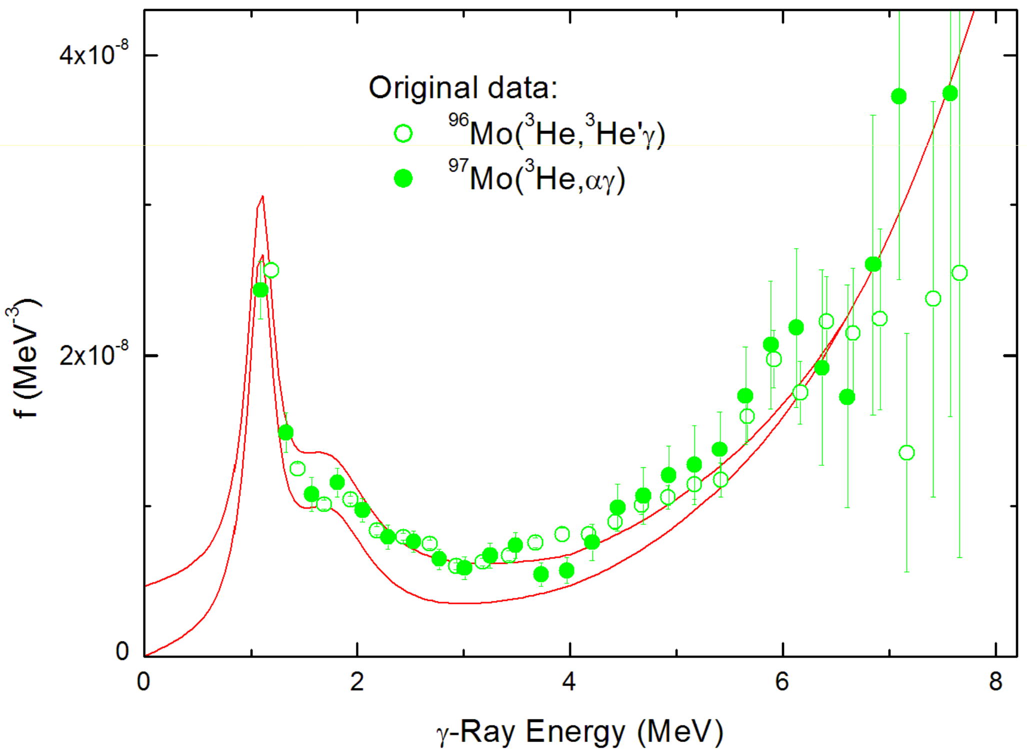


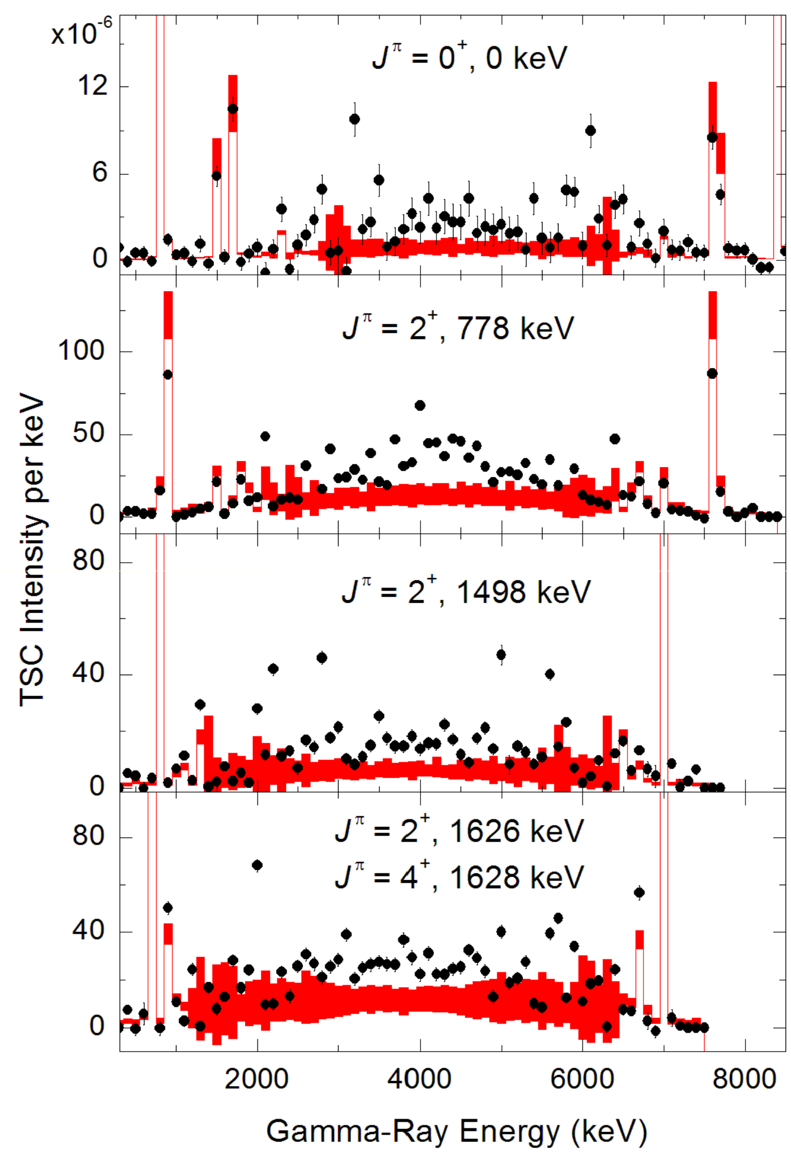




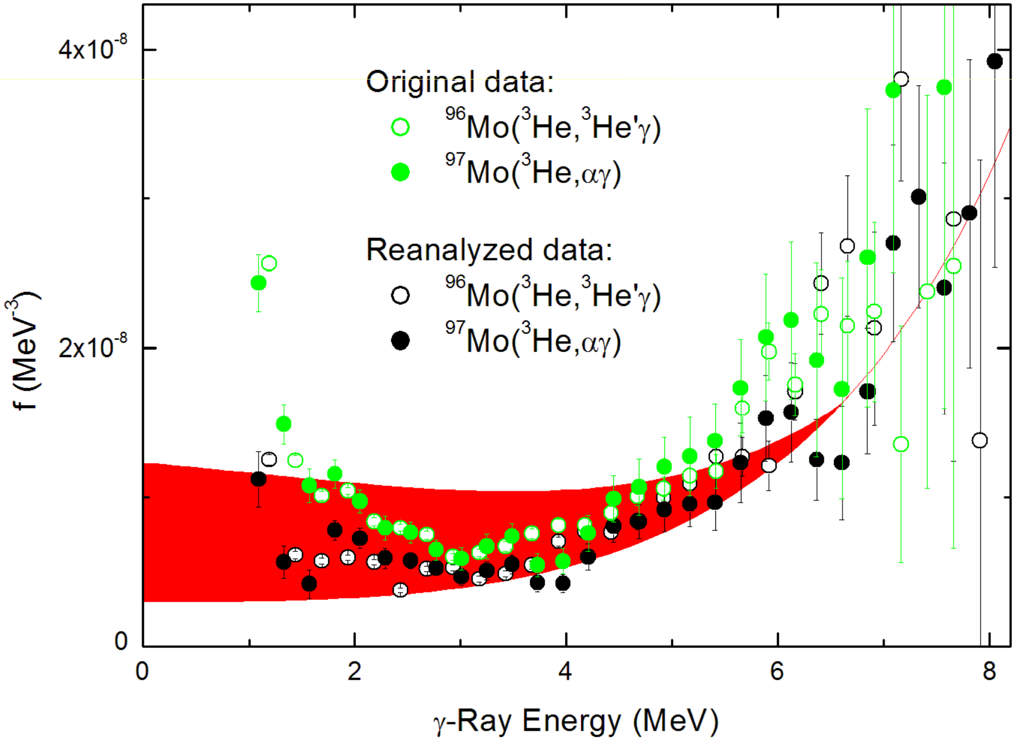


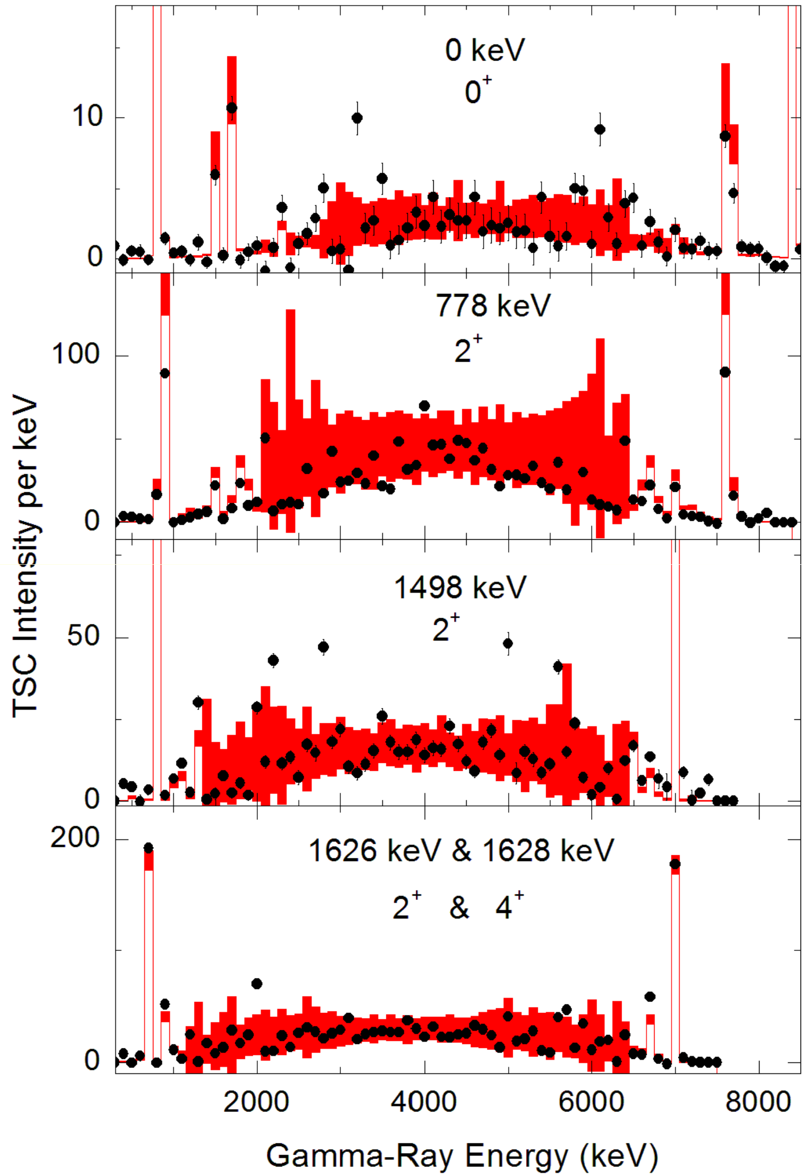
TSC spectra in ^{96}Mo





TSC spectra in ^{96}Mo





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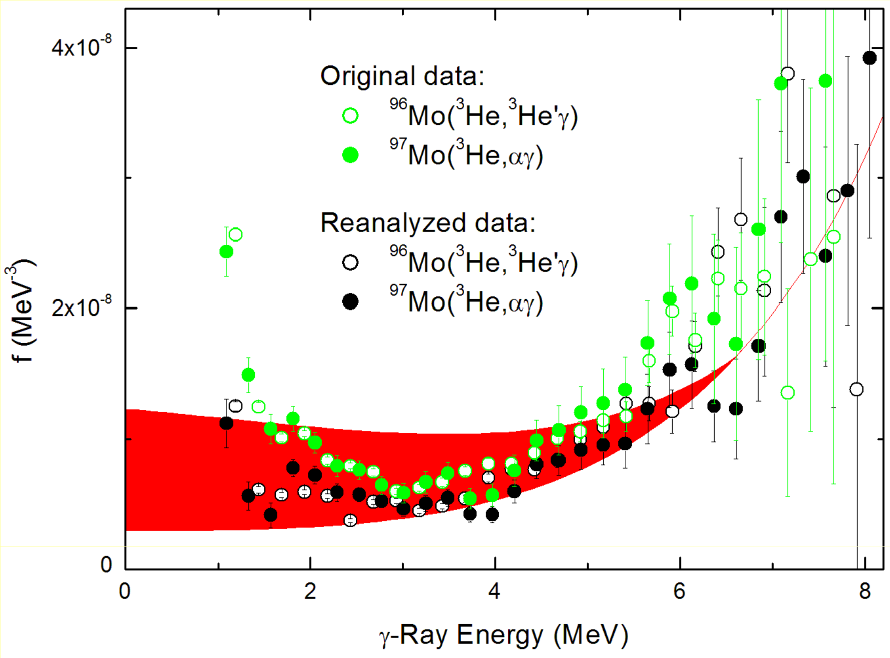
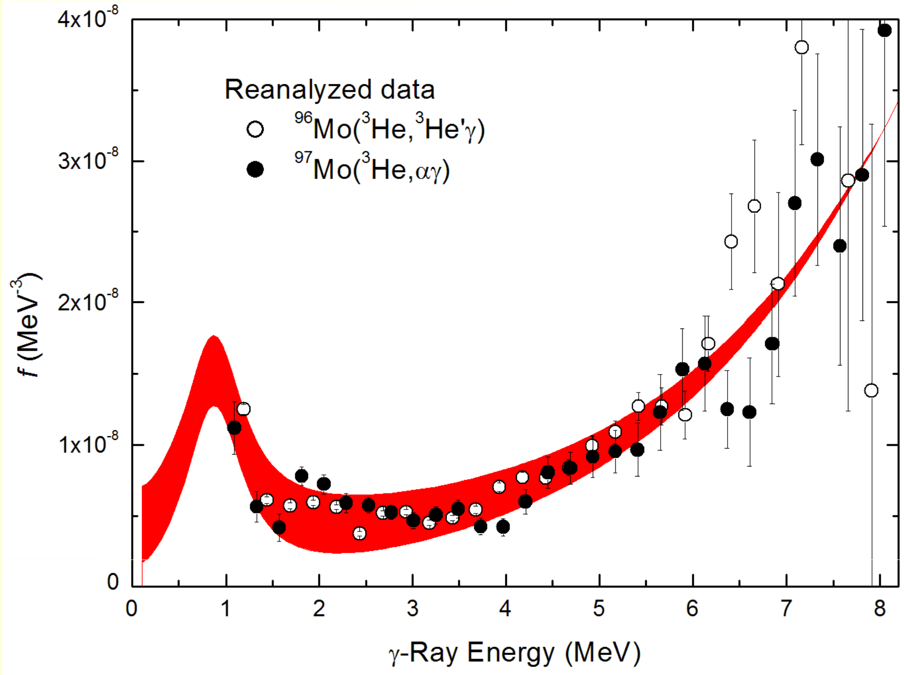


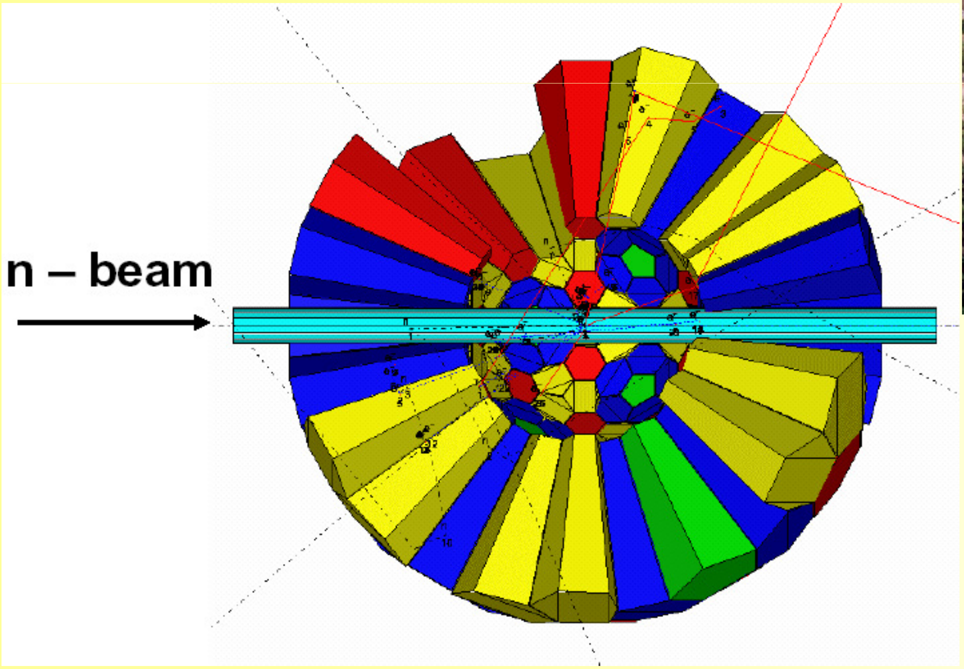


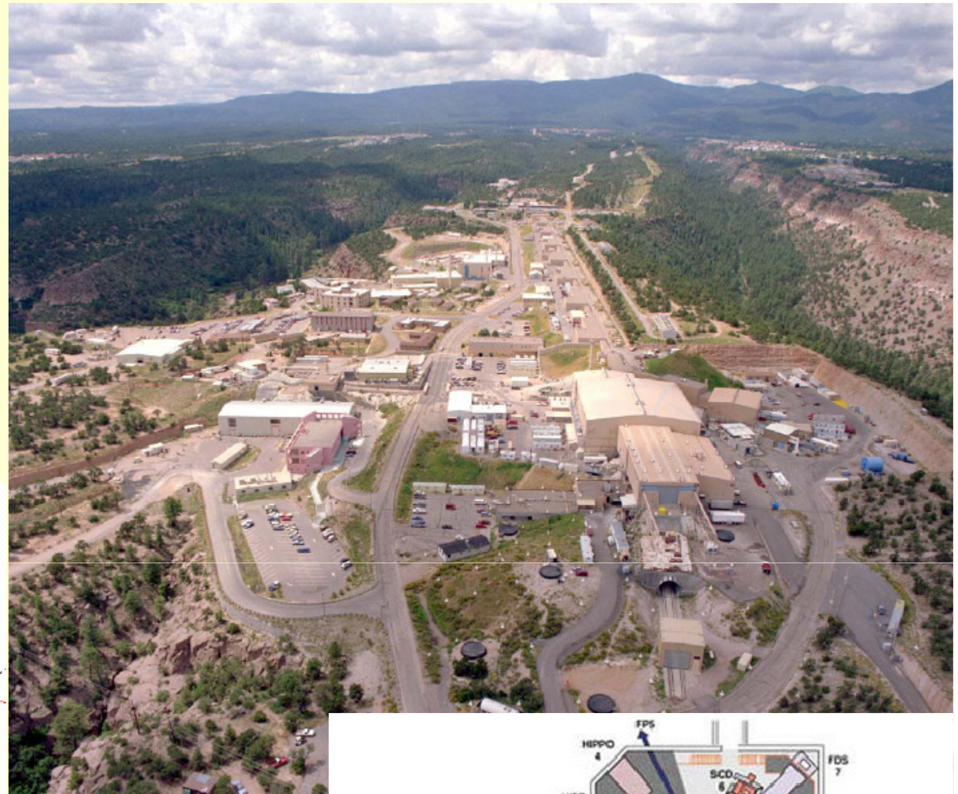
Pictures with comparison similar but correct statistical analysis excludes also this model at 99.8 % confidence level
Krticka et al., PRC 77 054319 (2008)

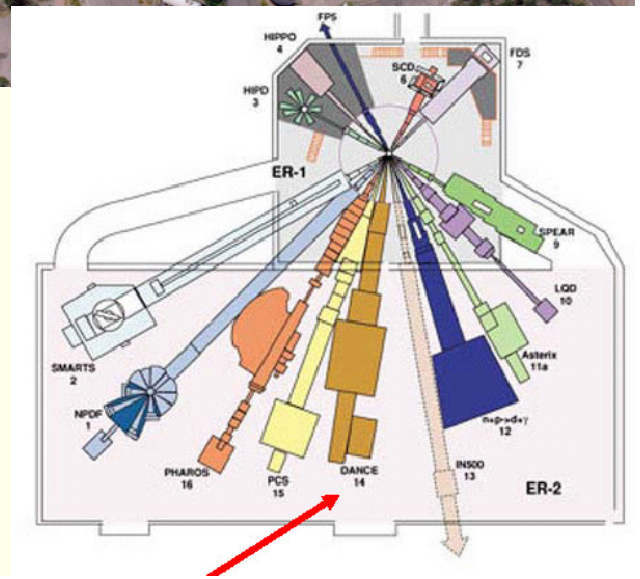
$\Rightarrow$ the enhancement is very weak if any analysis of data from DANCE confirm this

DANCE @ LANSCE

- Moderated W target gives “white” neutron spectrum, ~14 n’s/proton
- DANCE is on a 20 m flight path / ~1 cm @ beam after collimation
- repetition rate 20 Hz
- pulse width ≈ 125 ns
- DANCE consists of 160 BaF_2 crystals

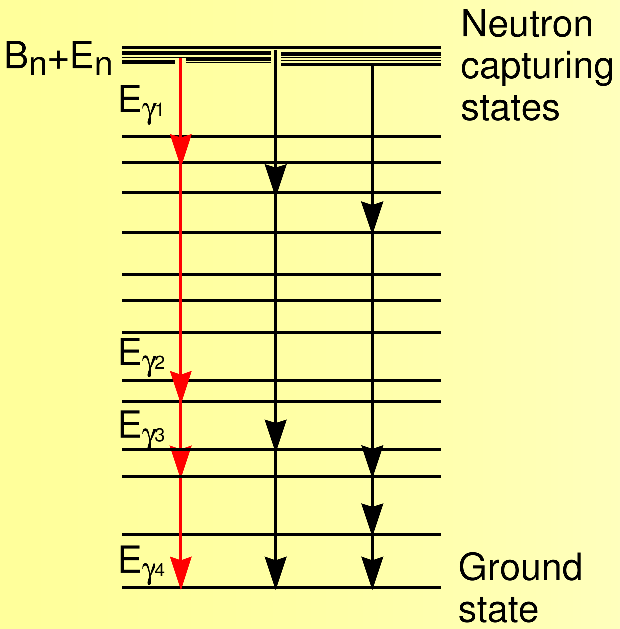


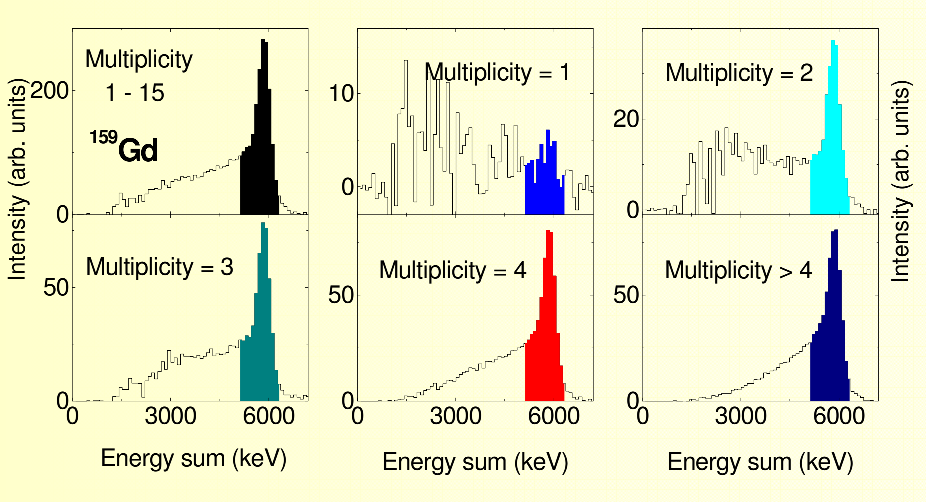


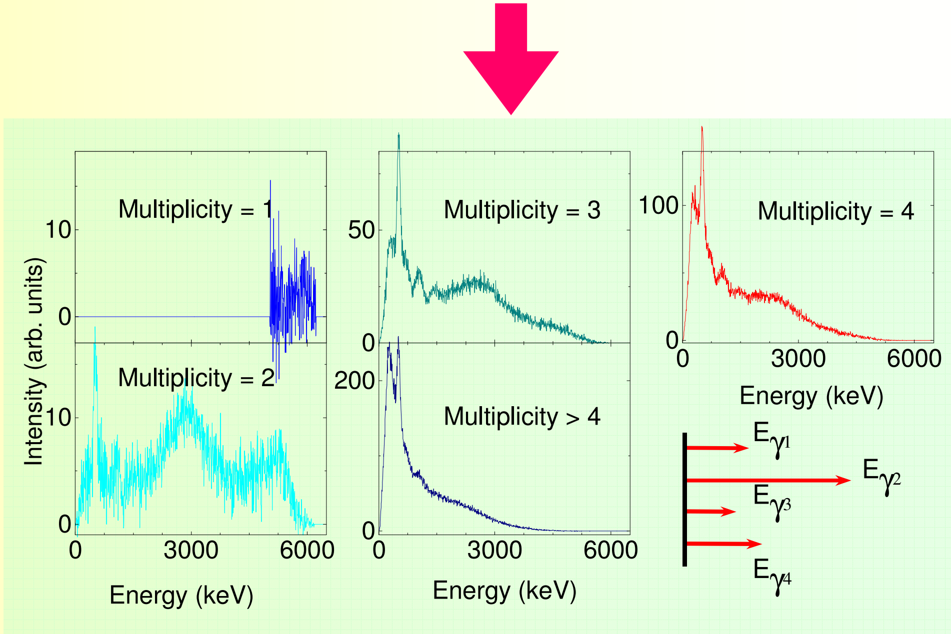


see also talk of John Ullmann

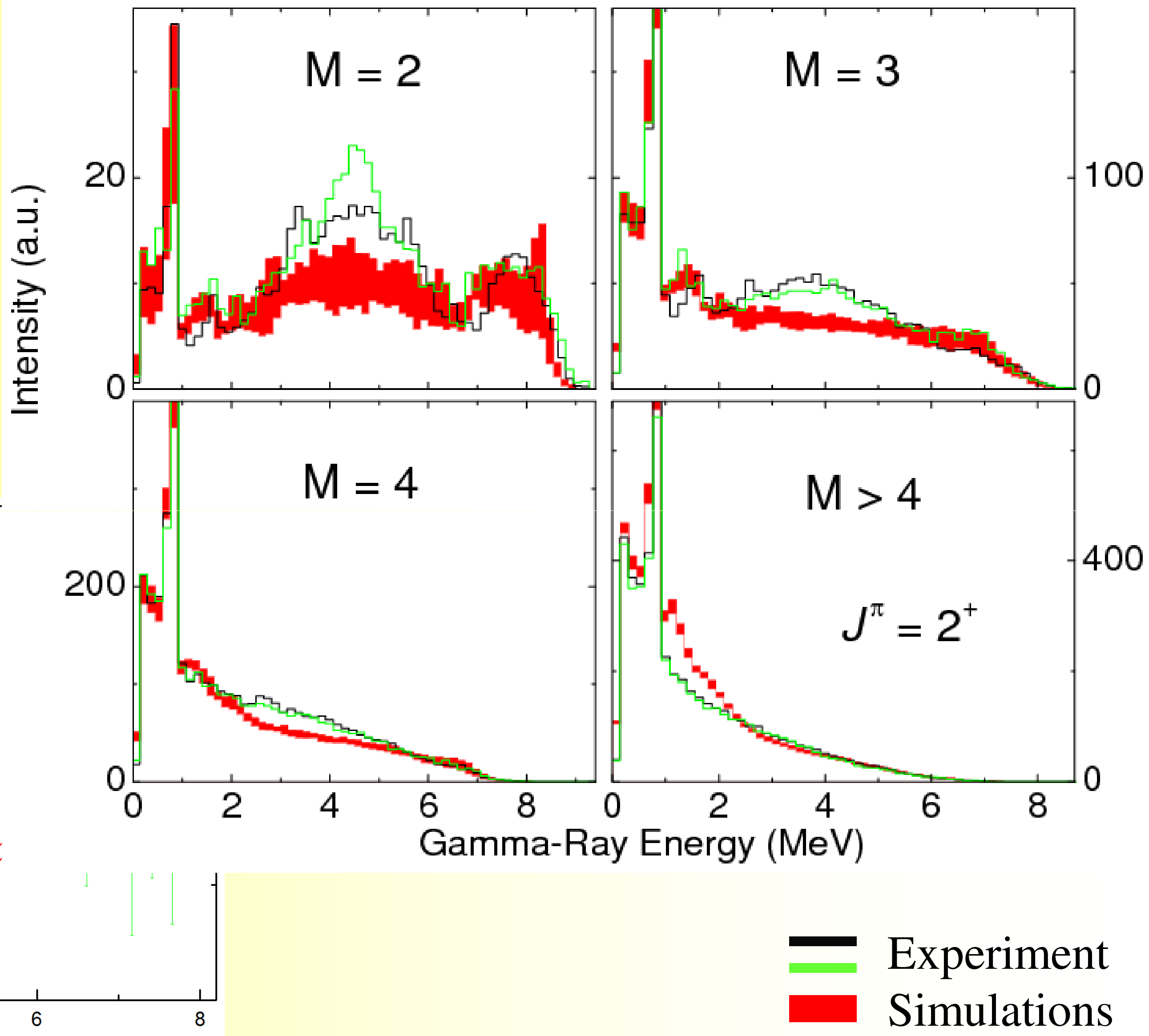
What can be checked?

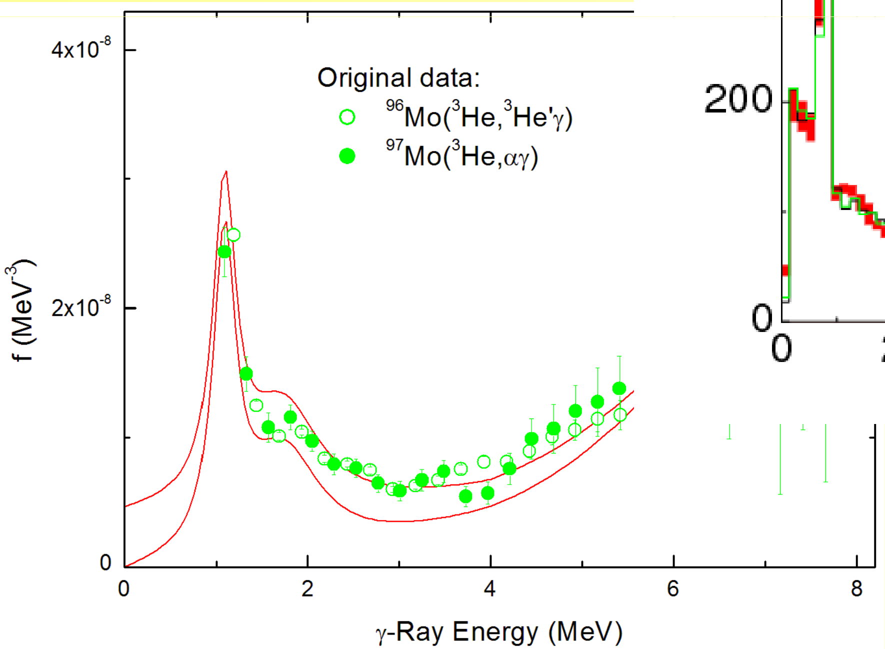






MSC spectra in ^{96}Mo





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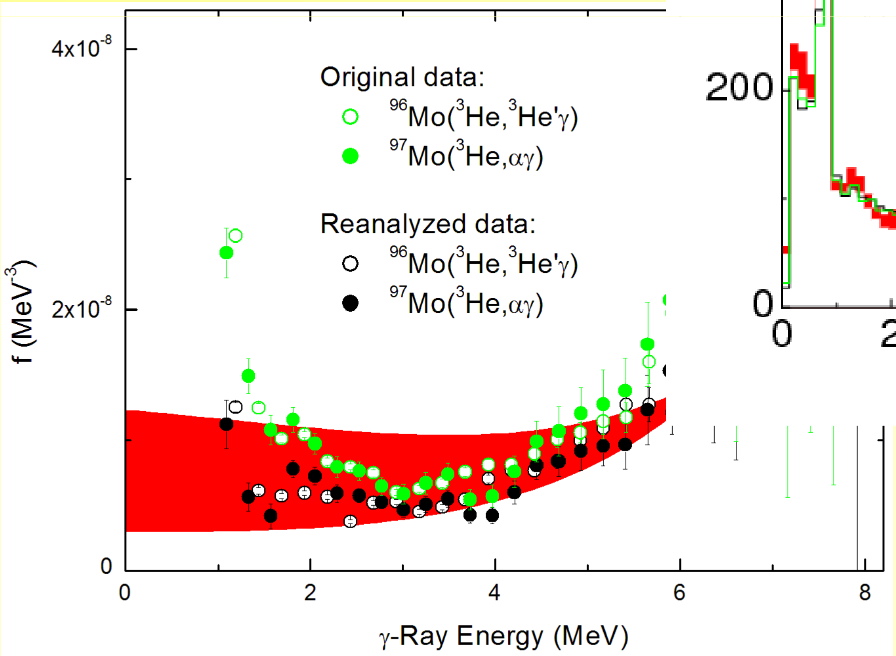
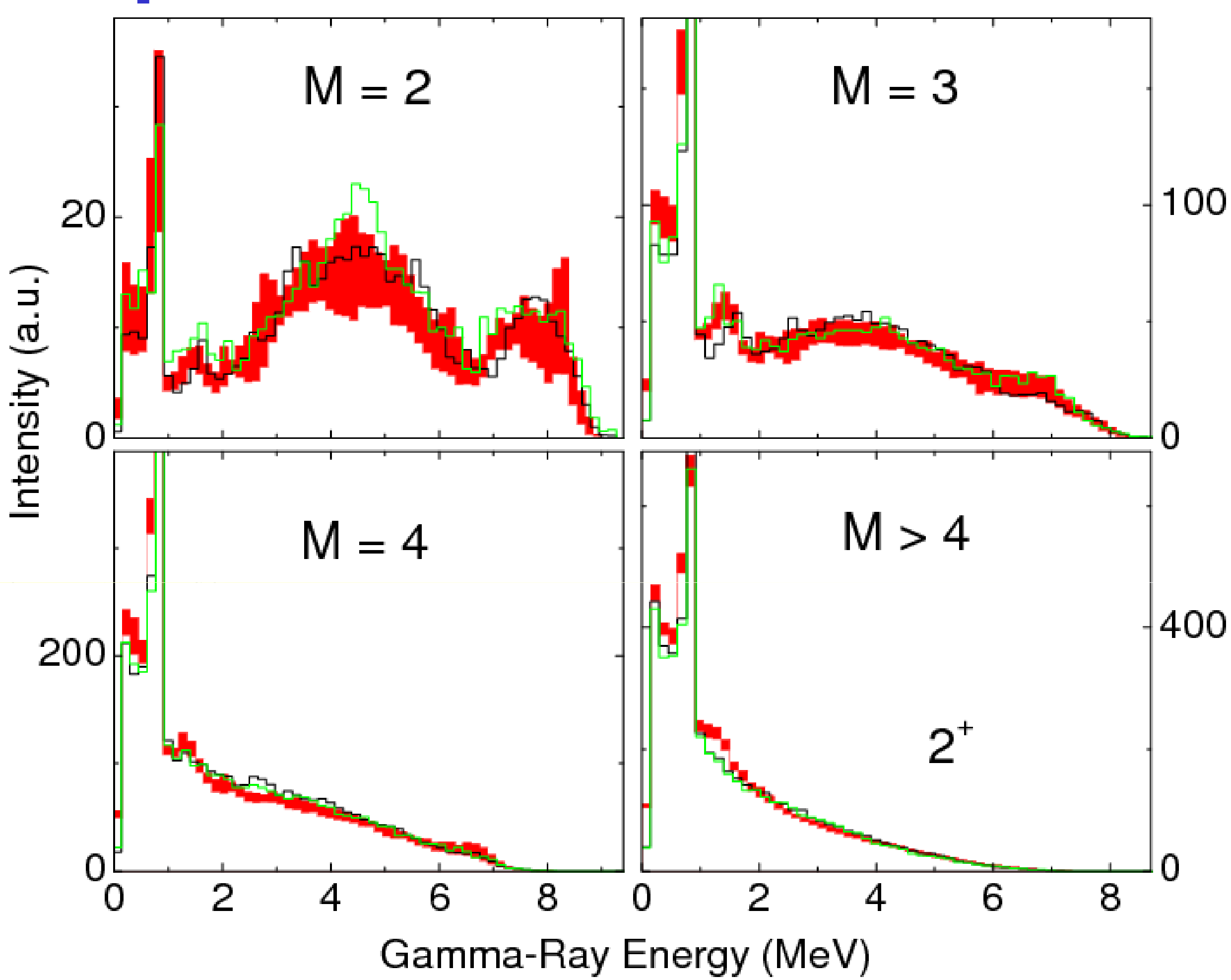


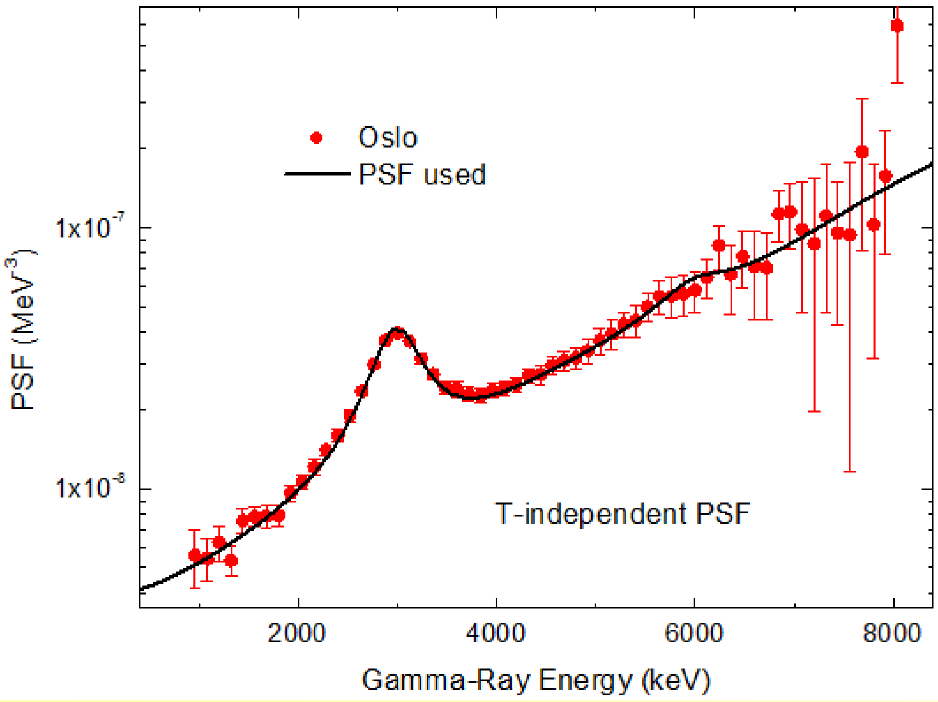


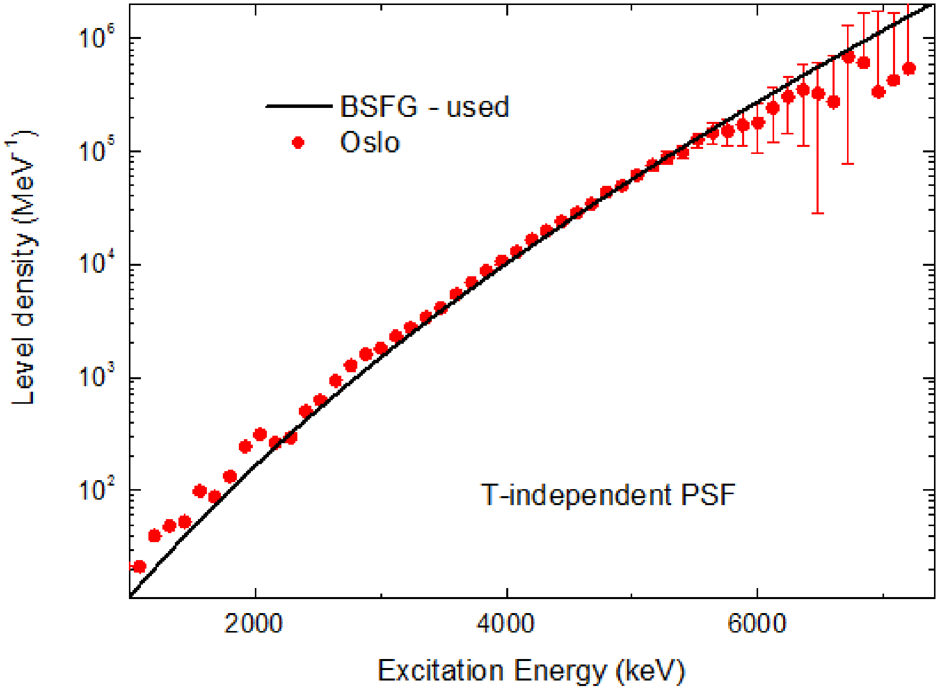
S. Sheets et al., Phys. Rev. C **79**, 024301 (2009)

Oslo method

(see also talk of Ann-Cecilie Larsen)

- Spectra of primaries are extracted from measured spectra (unfolding of detector response)
- Iterative procedure applied to spectra of primaries - two functions can be obtained
  - one dependent only on excitation energy (level density)
  - the other one only on gamma-ray energy (PSF)





Oslo method

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- Iterative procedure applied to spectra of primaries - two functions can be obtained
  - one dependent only on excitation energy (level density)
  - the other one only on gamma-ray energy (PSF)
- The procedure works very well but there are no unique results – infinite number of solutions connected via relations

$$f(E_\gamma) = N_f \ e^{-\alpha E_\gamma} \ \tilde{f}(E_\gamma)$$

$$\rho(E_{\rm exc}) = N_\rho \ e^{\alpha E_{\rm exc}} \ \tilde{\rho}(E_{\rm exc})$$

- What does happen if the PSF depends on excitation energy? Not discussed here …

Oslo method

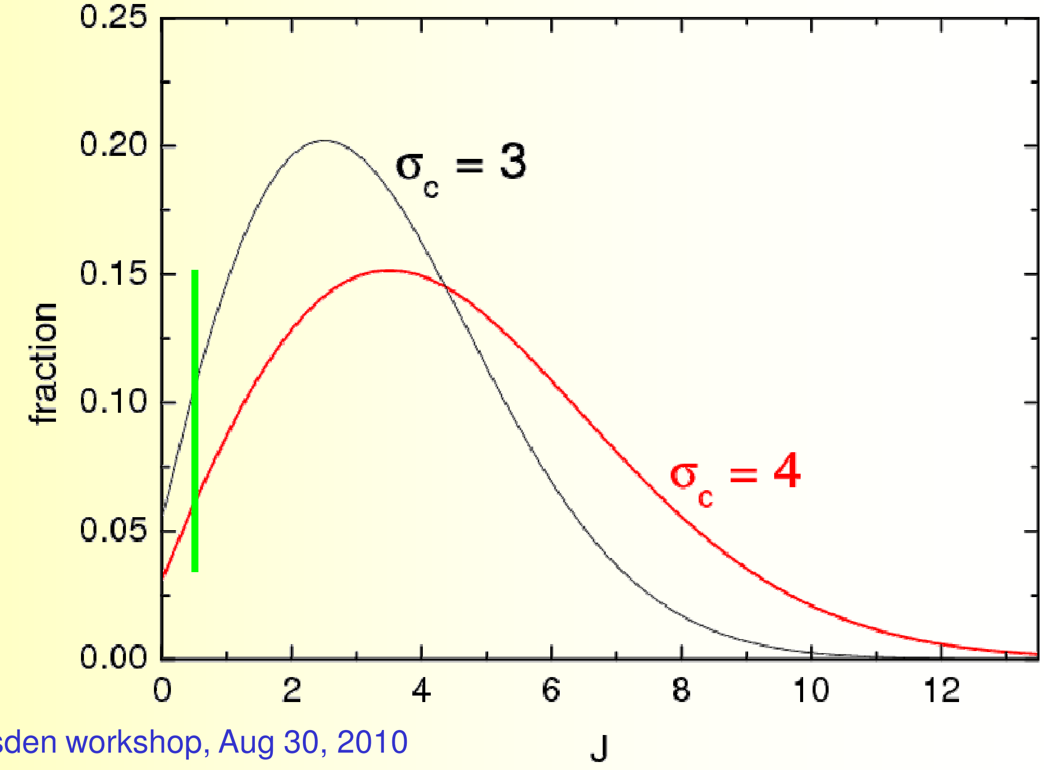
- Slope (coef α) and absolute value of level density are fixed using levels near the ground state and neutron resonances

- Problem – spin dependence of level density, especially in the resonance region

$$\rho(J) = \frac{2J+1}{2\sigma_c^2}\ \exp\left(-\frac{(J+1/2)^2}{2\sigma_c^2}\right)$$

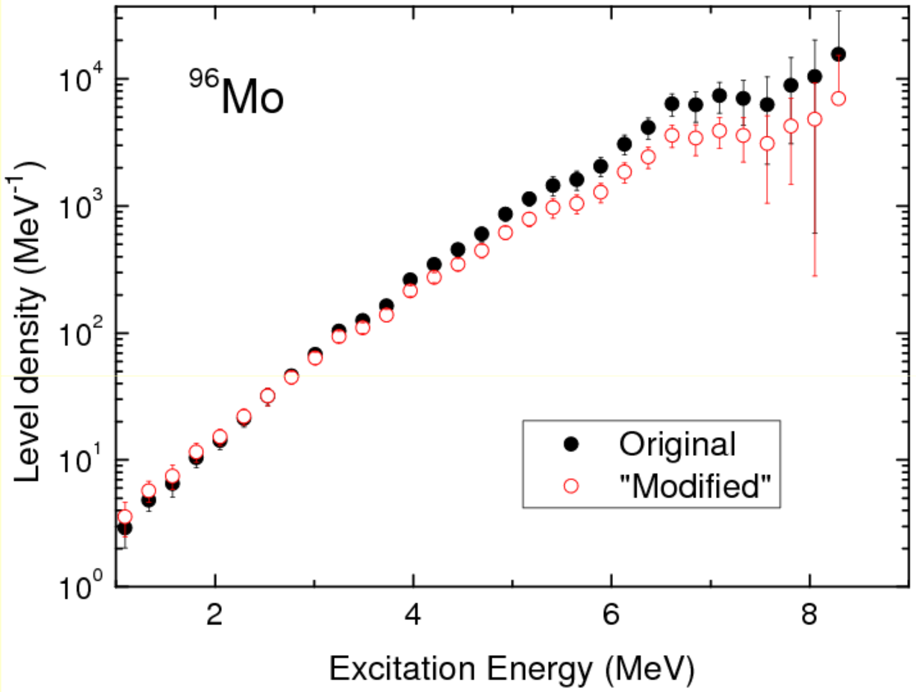
$$f(E_\gamma) = N_f\ e^{-\alpha E_\gamma}\ \tilde{f}(E_\gamma)$$

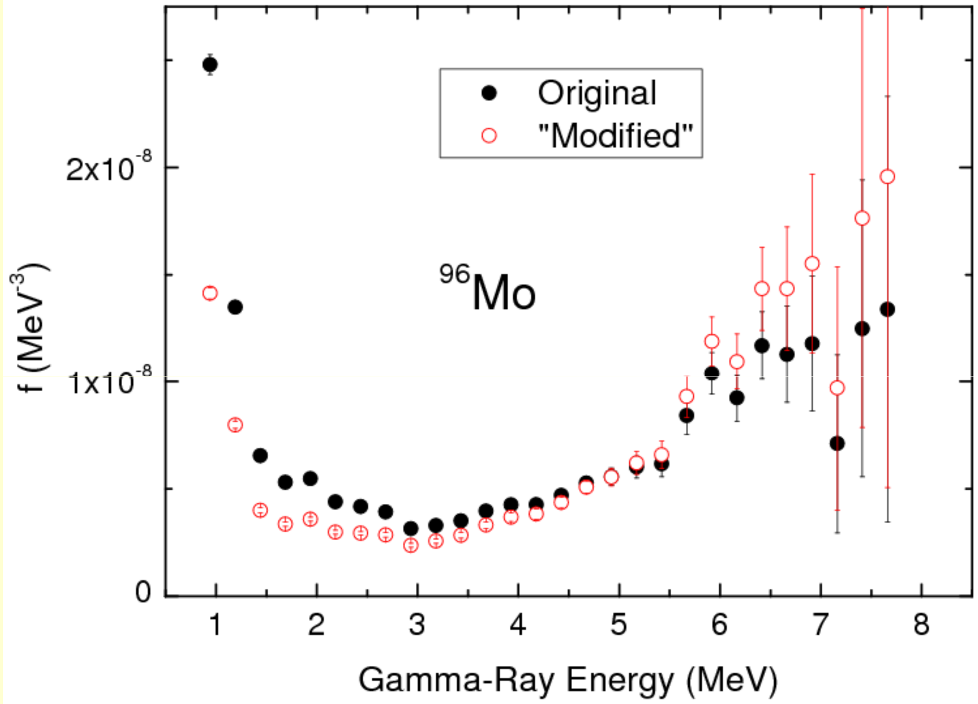
$$\rho(E_{\rm exc}) = N_\rho\ e^{\alpha E_{\rm exc}}\ \tilde{\rho}(E_{\rm exc})$$



Oslo method

- This might lead to very different value of coef α and shape of PSF





- Additional problem with absolute value (normalization) of PSF
  - usually done with help of total radiation width

Oslo method

Spin dependence of level density may be much more complicated than that given by closed-form expression

$$\rho(J) = \frac{2J+1}{2\sigma_c^2} \ \exp\left(-\frac{(J+1/2)^2}{2\sigma_c^2}\right)$$

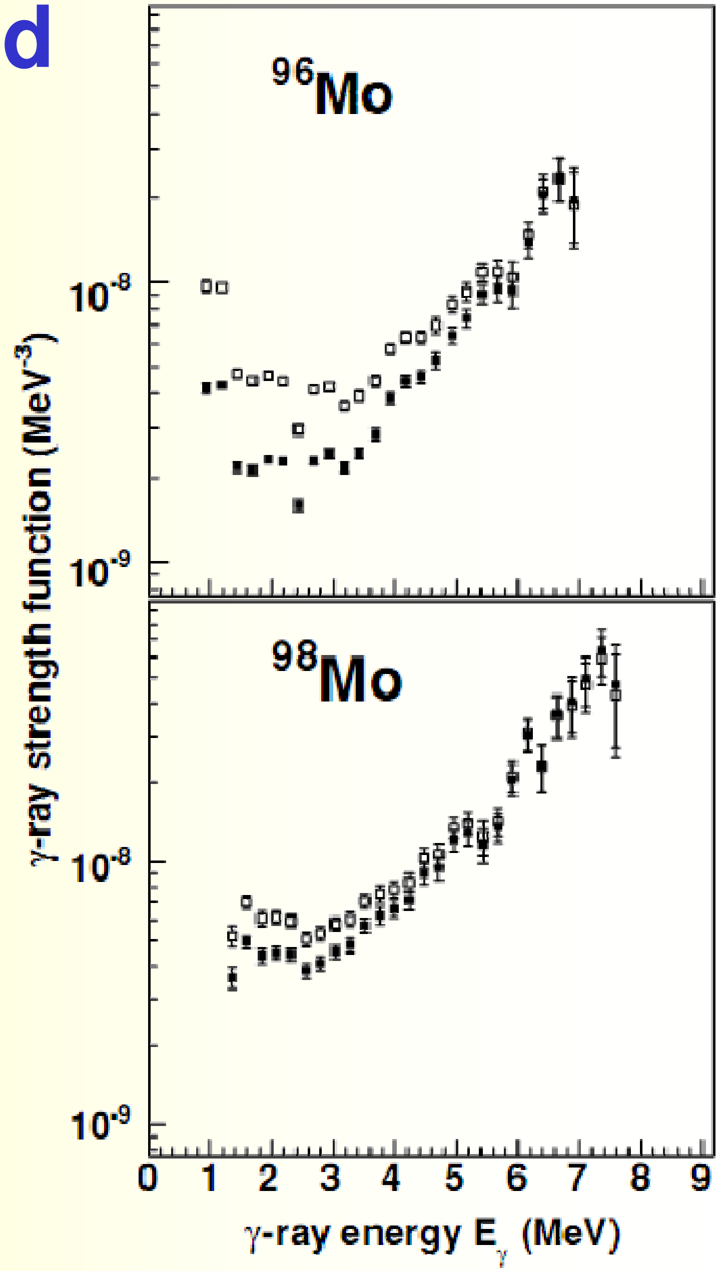
A published example:

Recalculation of RSF based on calculated level density from

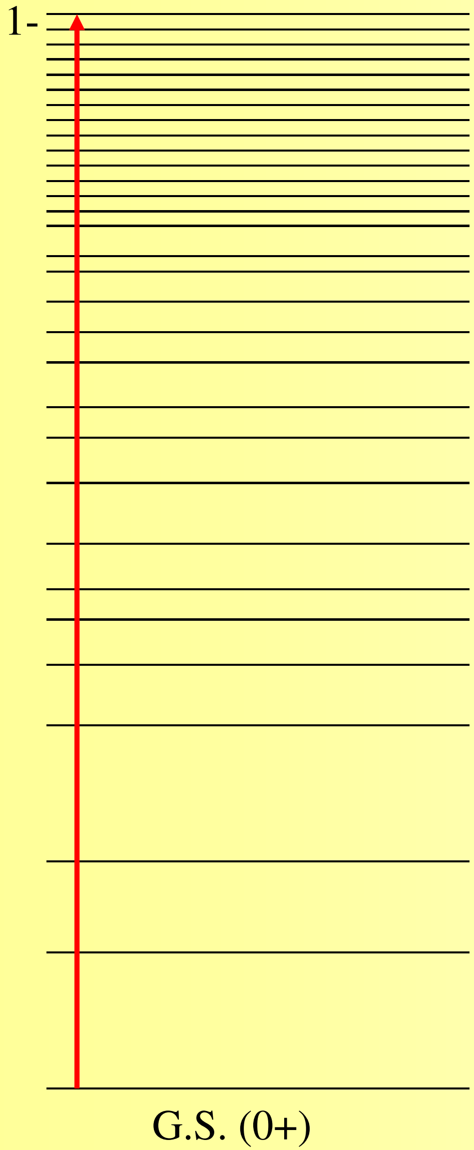
Goriely, Hilaire, and Koning, Phys.Rev.C 78, 064307(2008)

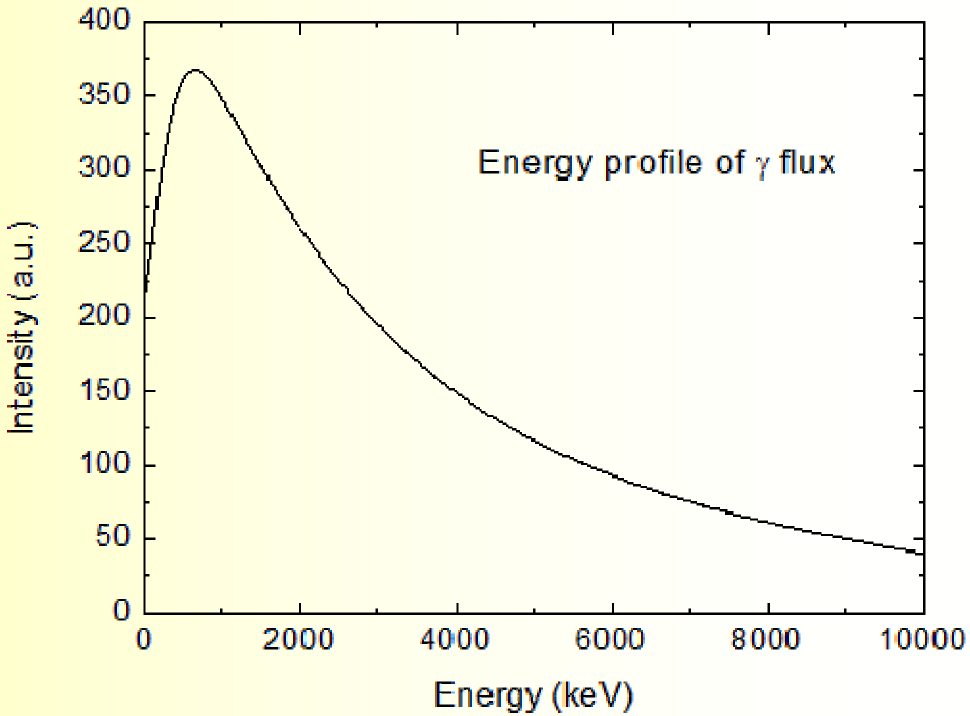
were published recently in

Larsen and Goriely, PRC 82 014318 (2010)



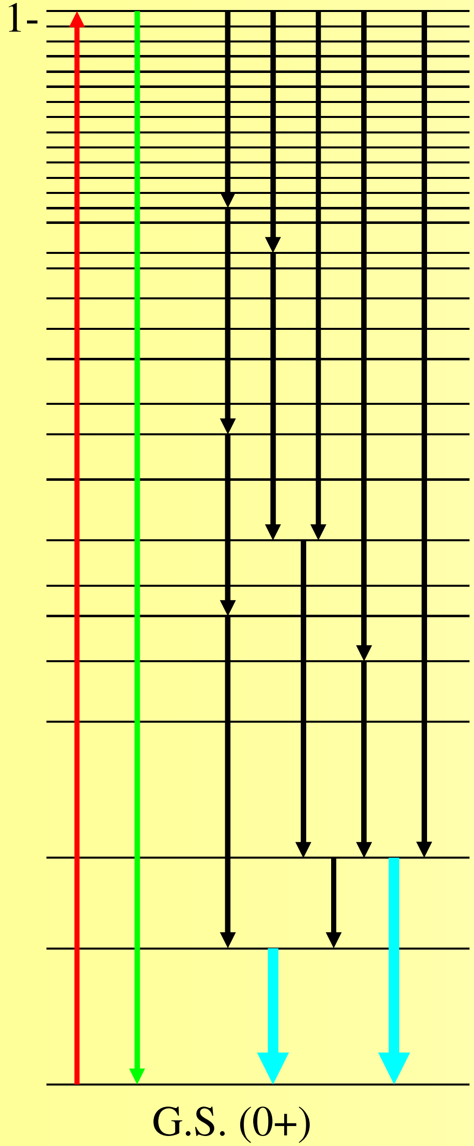
NRF with beam from “bremsstrahlung”





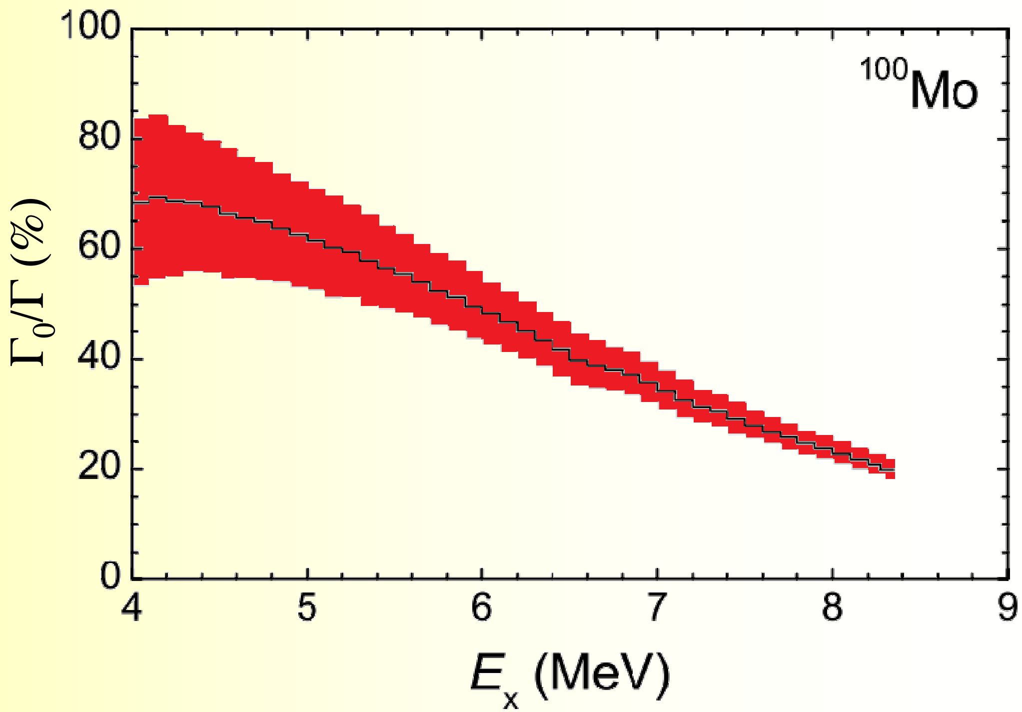
(see also talks of members of Rossendorf group)

NRF with beam from “bremsstrahlung”



Many transitions to excited states – correction for them is needed

$$I_s = \int_0^\infty \sigma_{\gamma f}(E)dE = \frac{2J_R+1}{2J_0+1}\left(\frac{\pi\hbar c}{E_R}\right)^2 \Gamma_0 \frac{\Gamma_f}{\Gamma}$$



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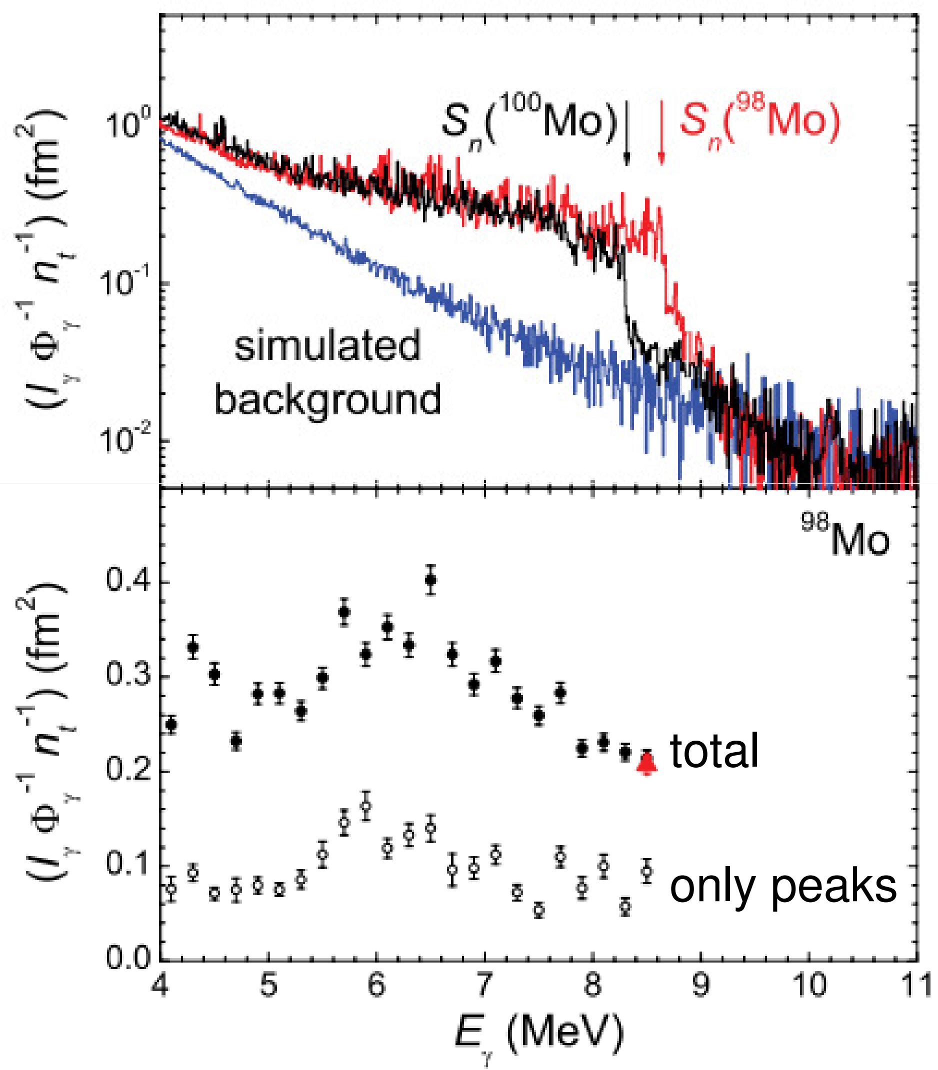
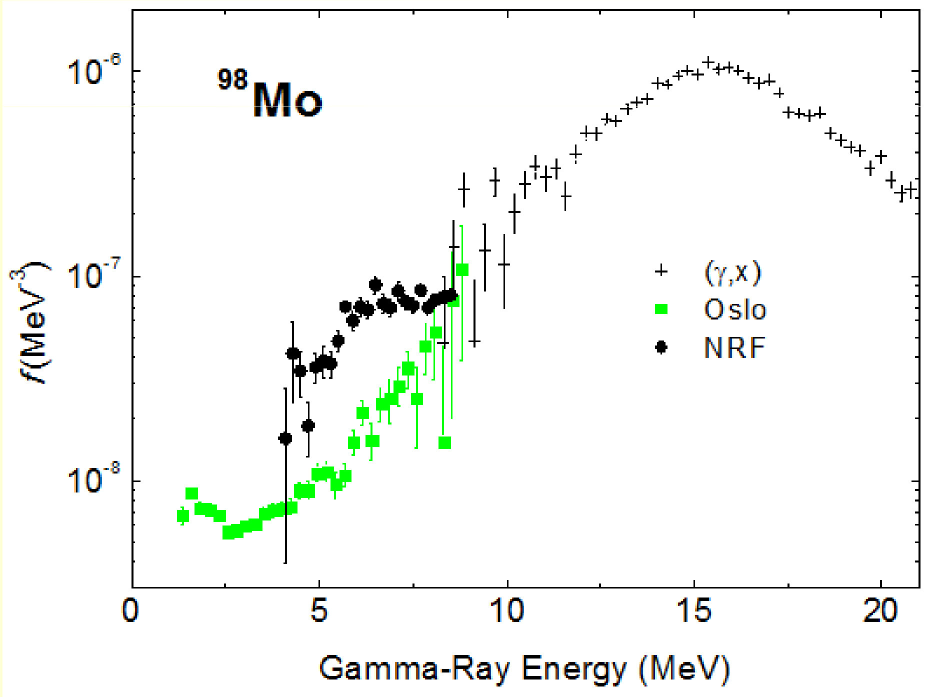
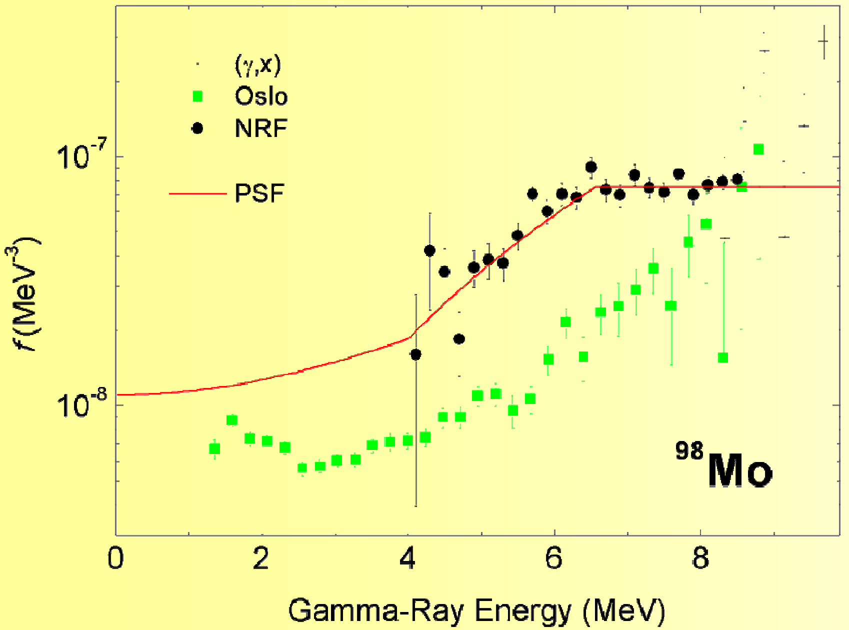


G. Rusev et al., PRC77, 064321 (2008)

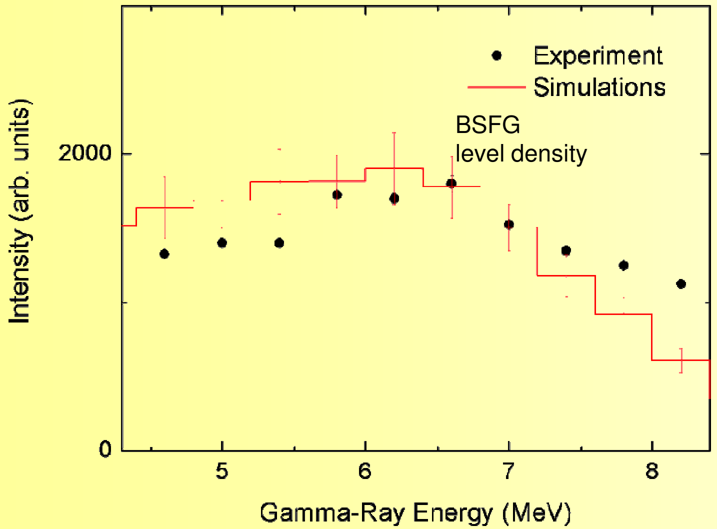
- An "iterative" procedure is applied and PSF to the GS is obtained



NRF with beam from "bremsstrahlung"



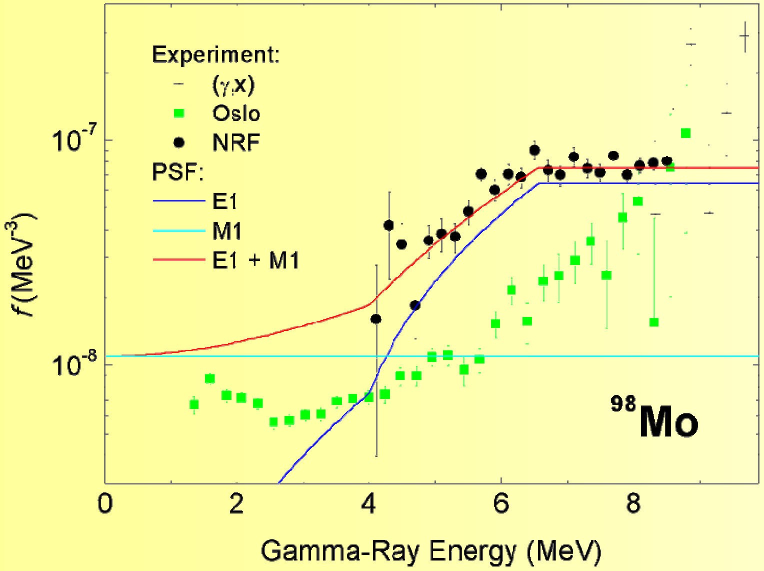
- Simulations of gamma decay with DICEBOX code can produce spectra comparable to measured ones.

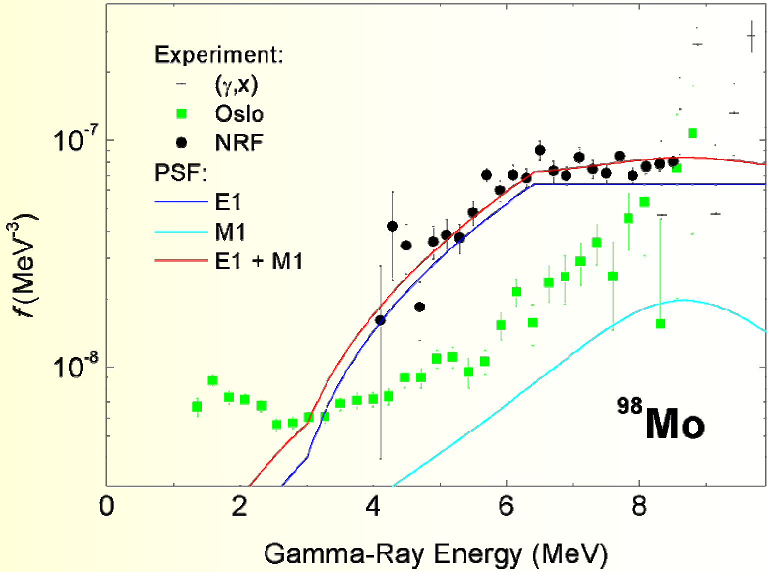


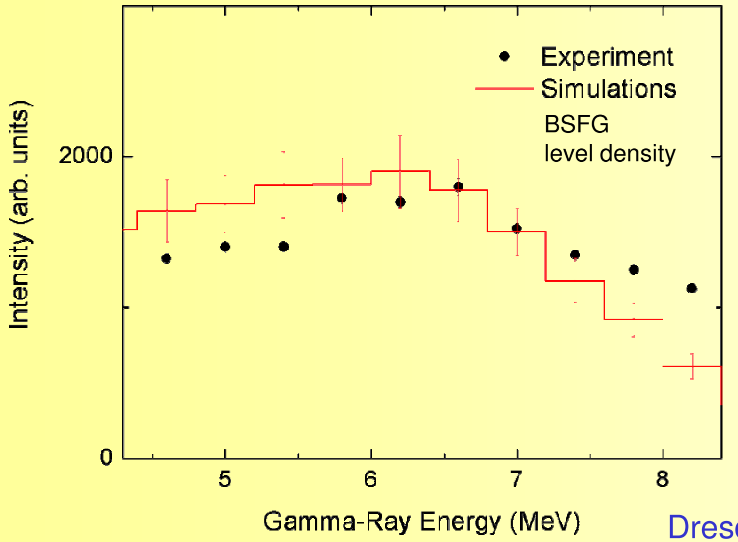
- The PSF reproducing NRF dat seems not to reproduce the spectrum

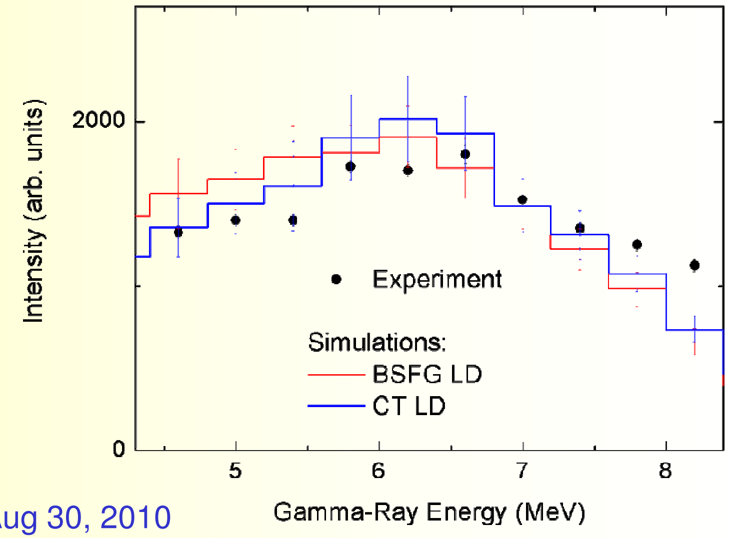
The results are preliminary

NRF with beam from "bremsstrahlung"

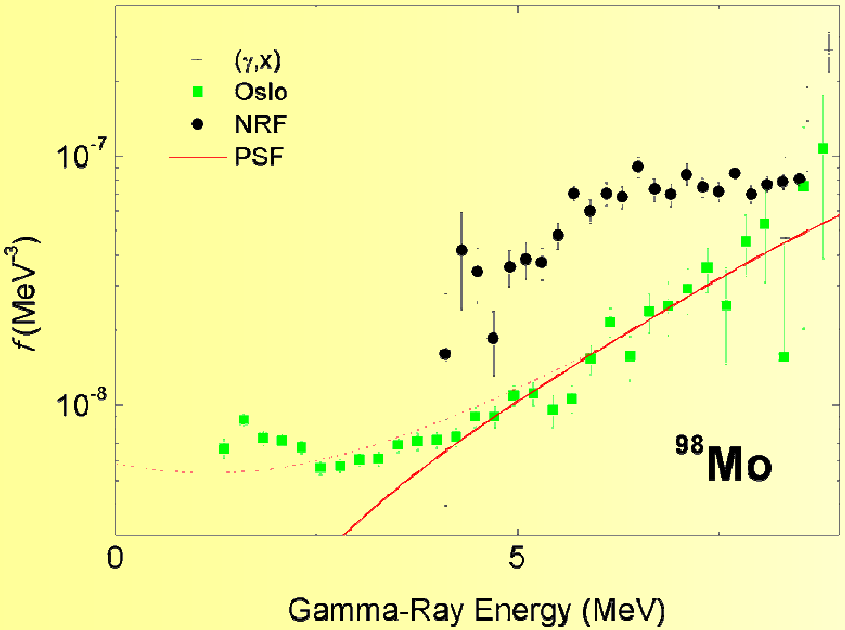


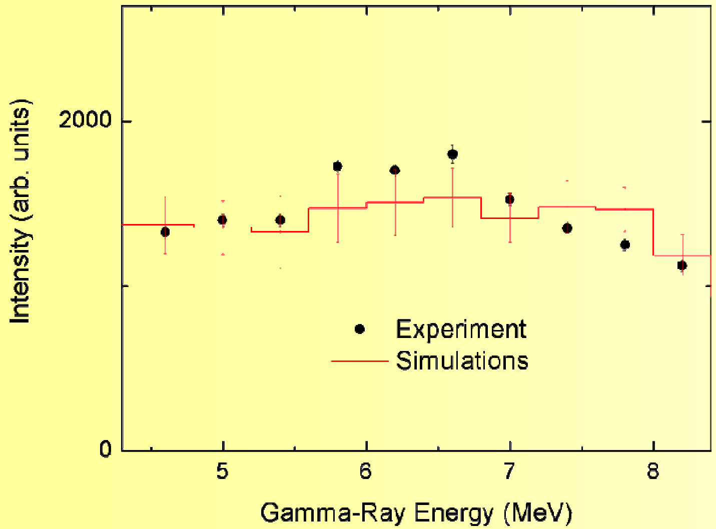






NRF with beam from “bremsstrahlung”



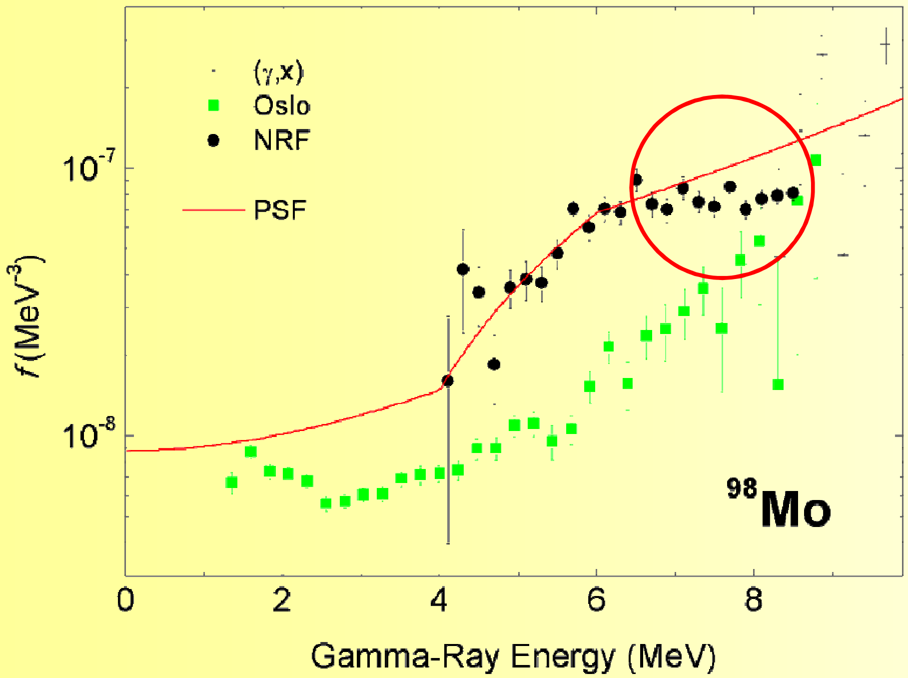


- Spectra cannot be reproduced also using PSF from Oslo measurement

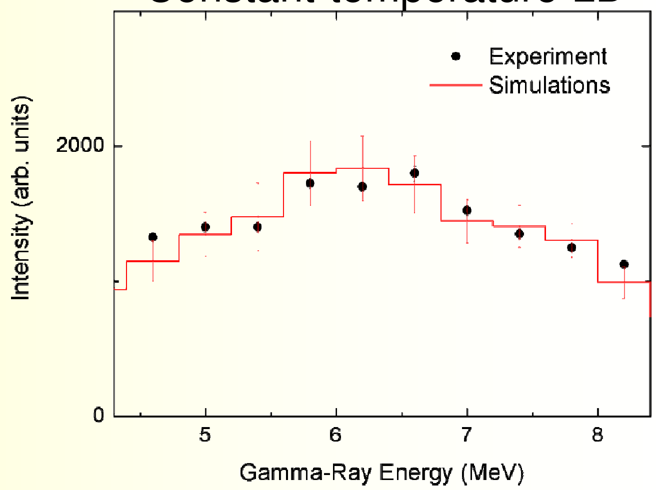
NRF with beam from "bremsstrahlung"

- Better agreement between experimental data and simulations can be achieved

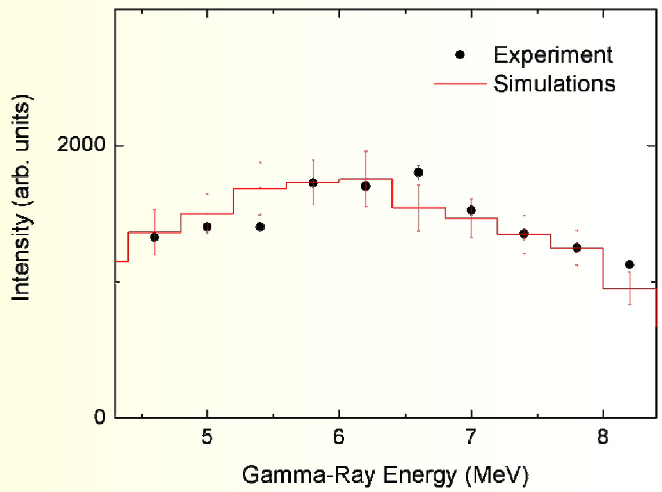
PSF used in simulations



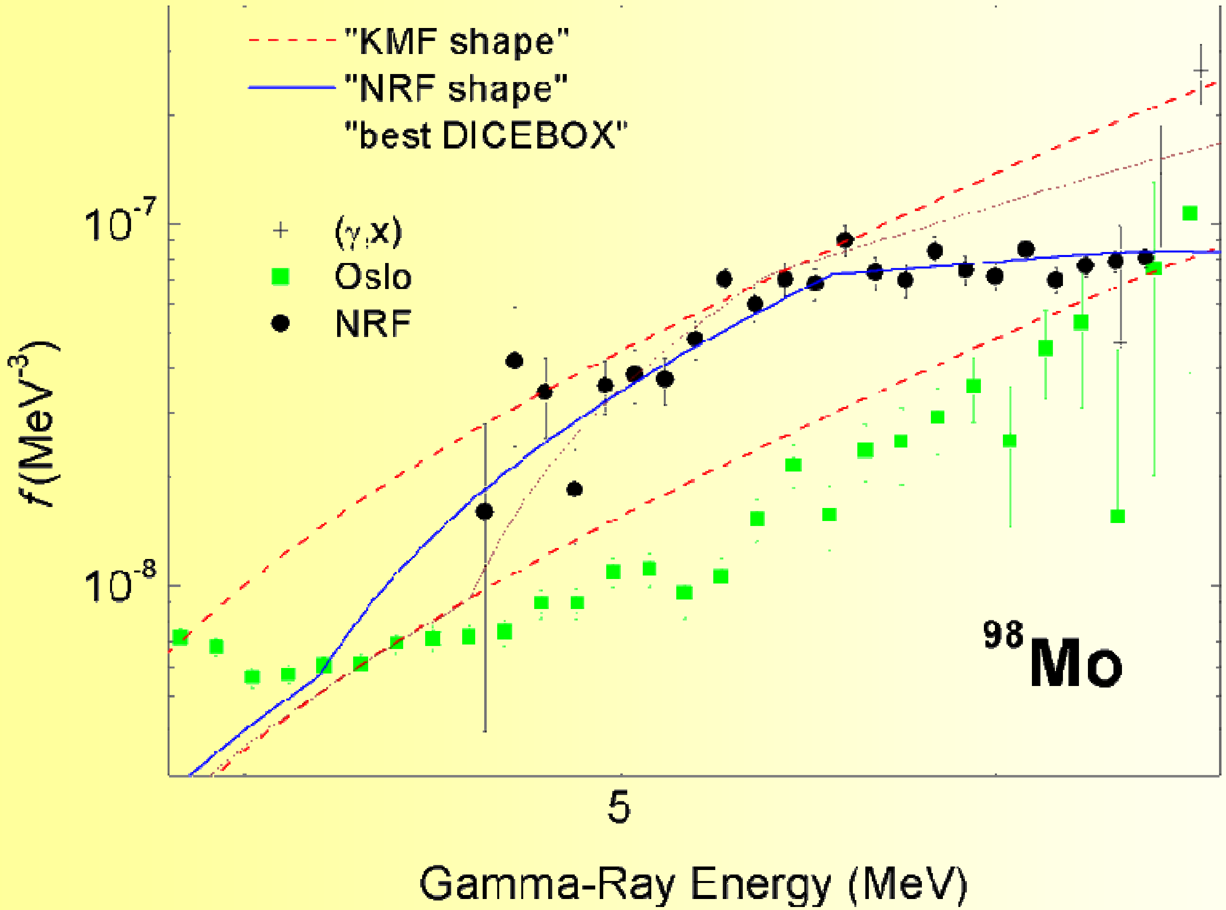
Constant-temperature LD



Back Shifted Fermi Gas LD



NRF with beam from "bremsstrahlung"

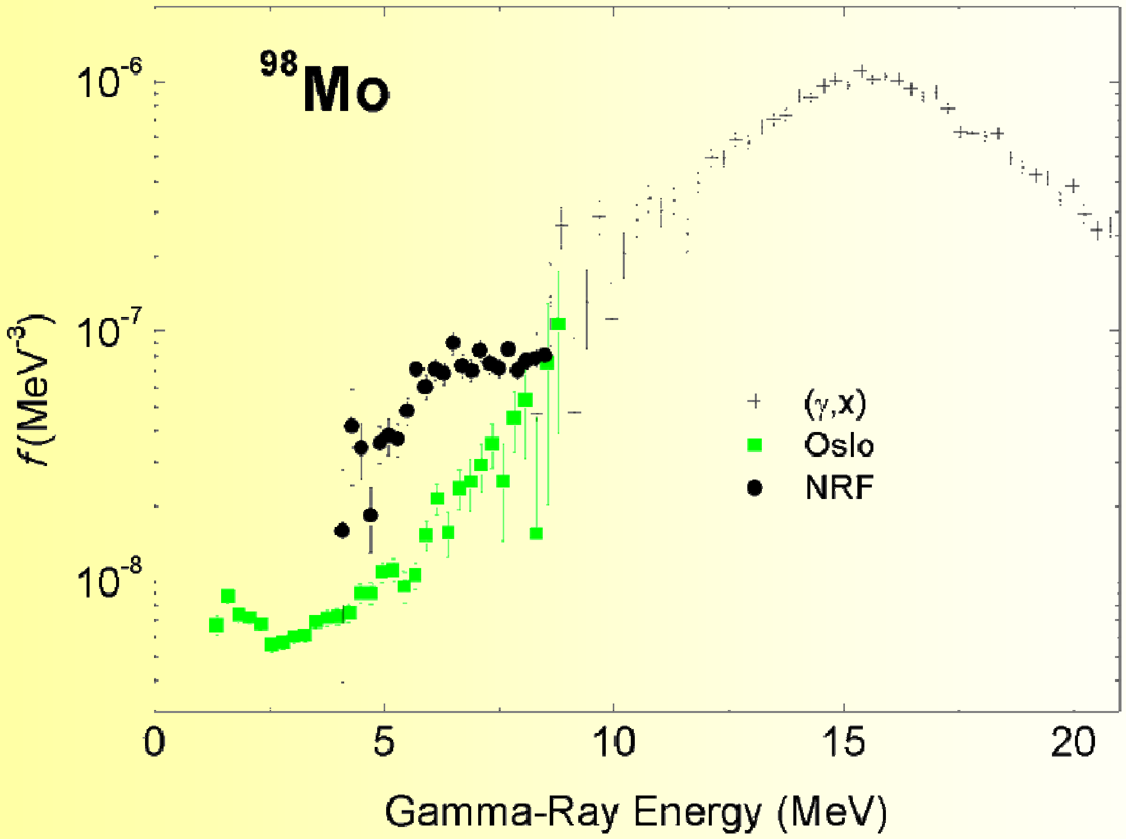


"no bump"

"too strong bump"

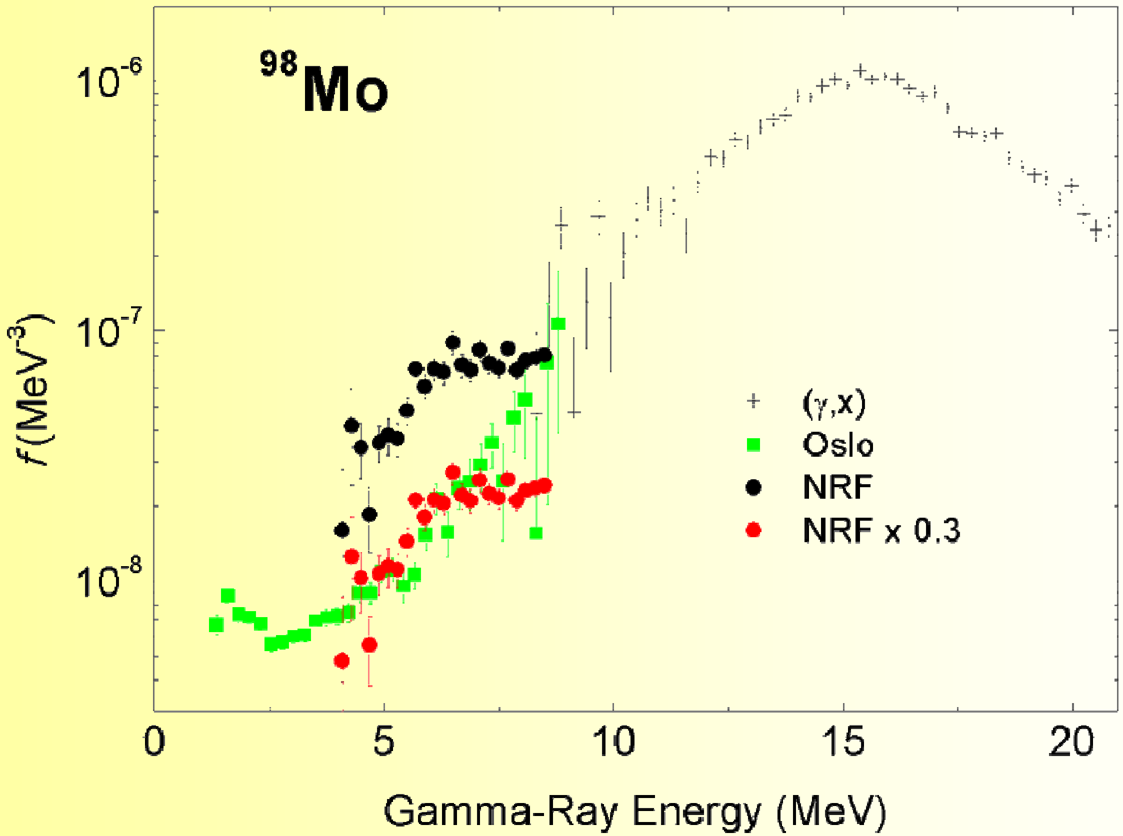
May such a difference occur due to non-validity of Brink hypothesis for the pygmy resonance?

And a “wild” speculation



Are the data really that different?

And a "wild" speculation

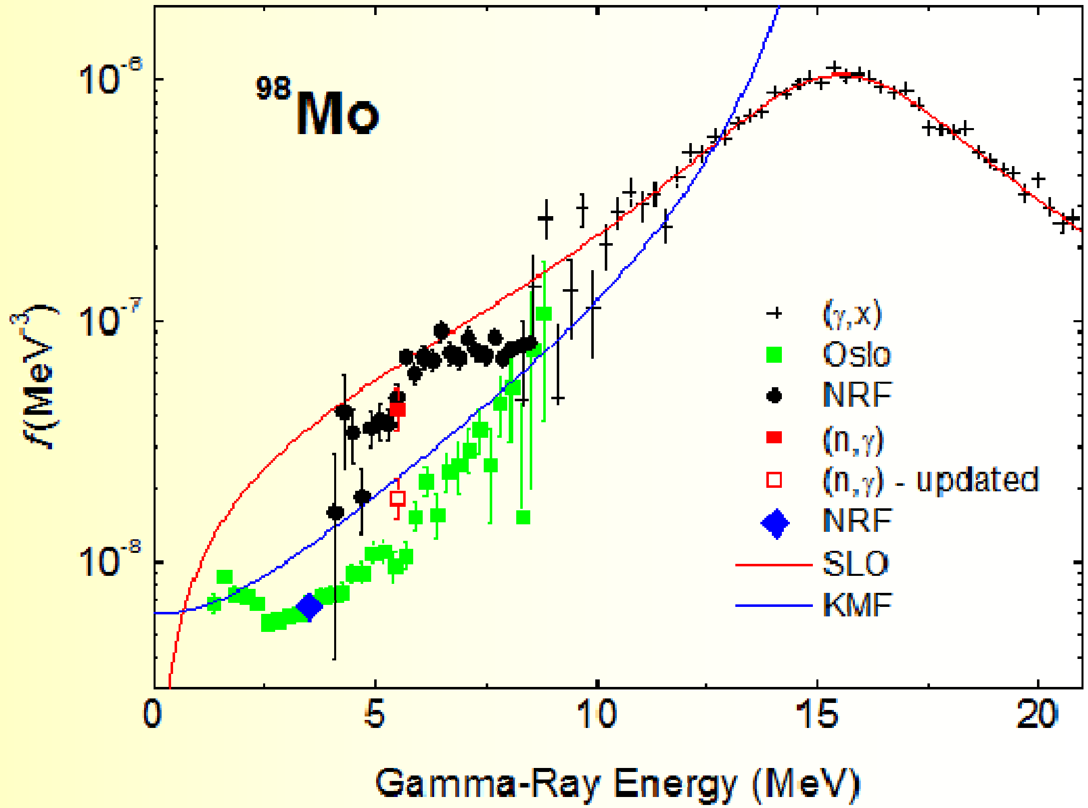


But this would induce other problems

- total radiation width of neutron resonances
- absolute value of PSF near S_n from (γ,γ')

Conclusions

- Our understanding of PSF is far from desired
- Each of the discussed methods may be “incorrect”
- Additional information on PSFs and validity of Brink hypothesis is needed




Invitation
Compound Nuclear Reactions (CNR*11)
Prague, September 19-23, 2011