What Do We Really Know About Photon Strength Functions?

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Biased View on Experimental Information on Photon Strength Functions in Mo isotopes?

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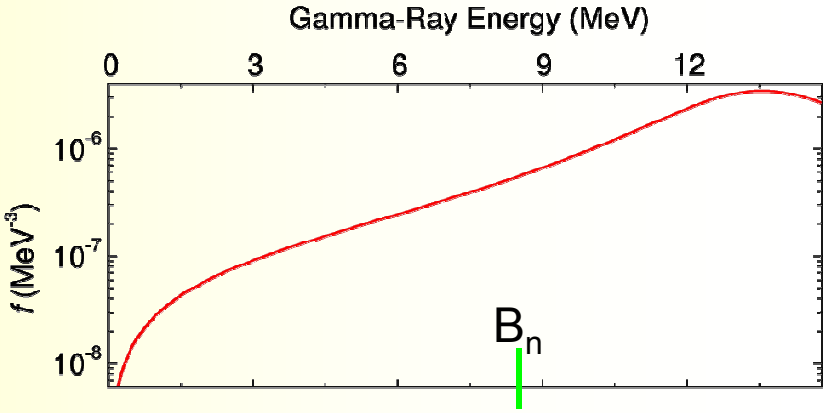
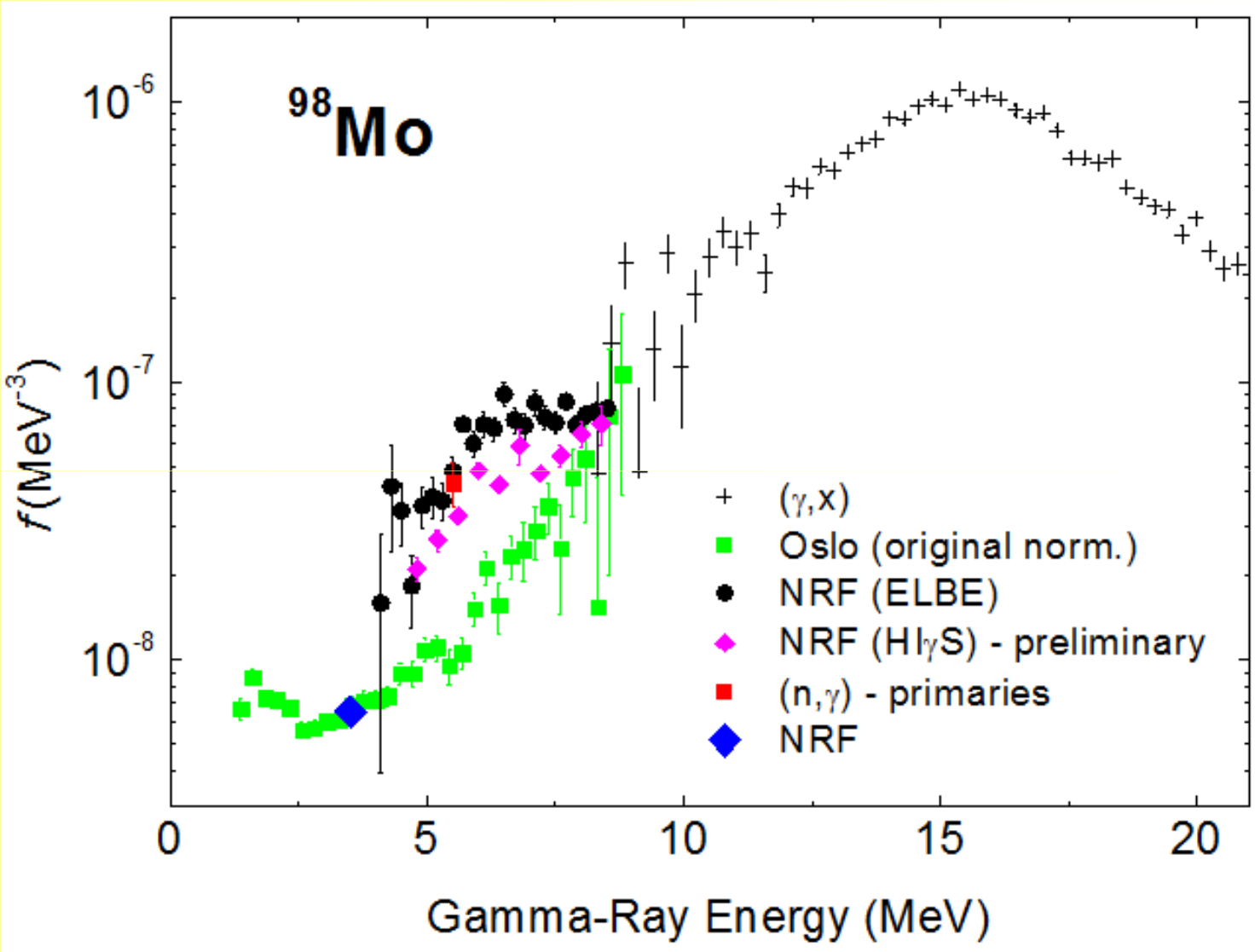
Where could we learn about PSFs from?



- photoexcitation techniques
  - (γ,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
- … (d,p) …

Are results consistent?



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

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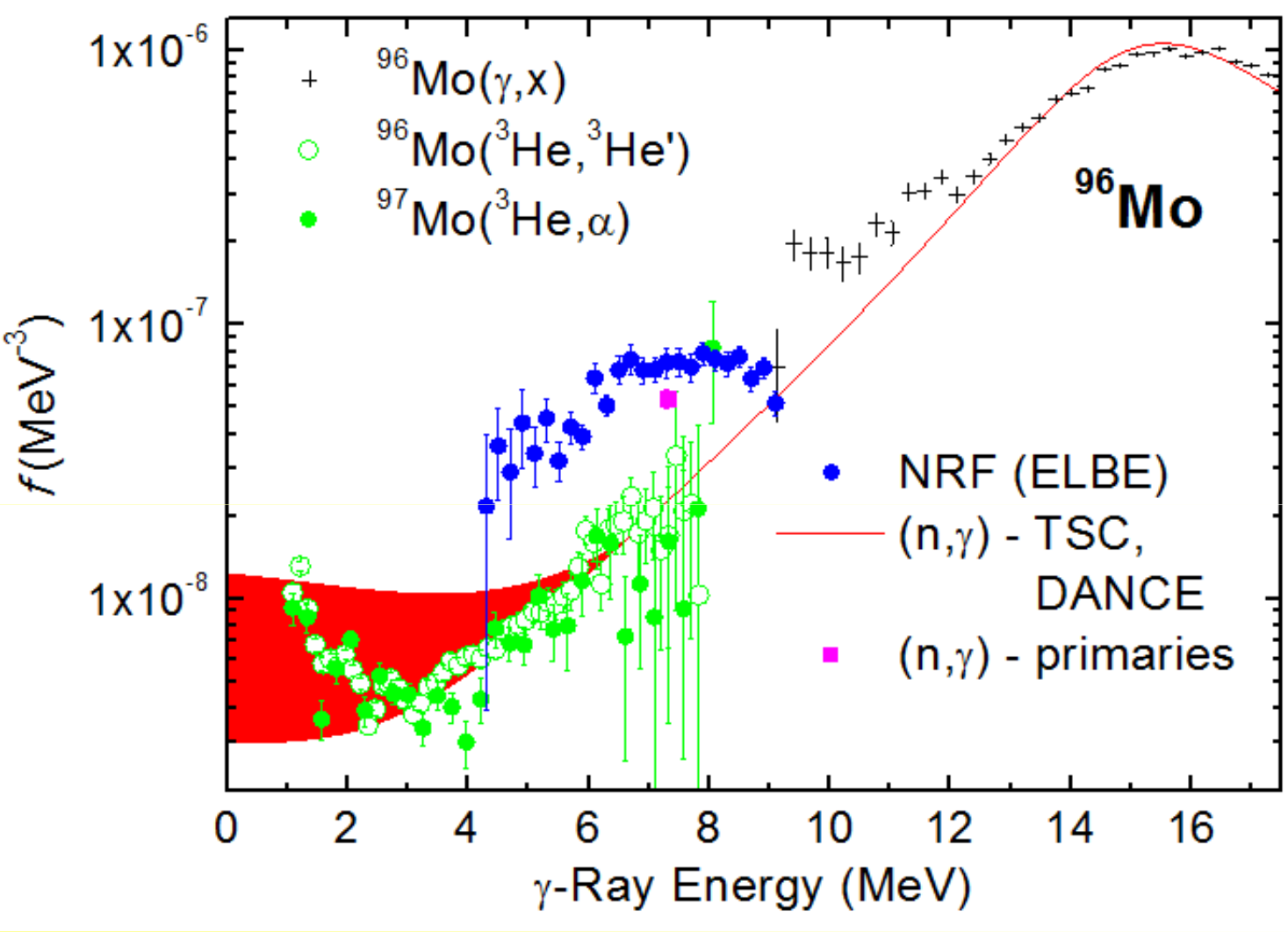


Krticka et al., PRC 77 054319 (2008), Sheets et al., PRC 79 024301 (2009),
Erhard et al., PRC 81 034319 (2010), Guttormsen et al., Phys. Rev. C 71, 044307 (2005)

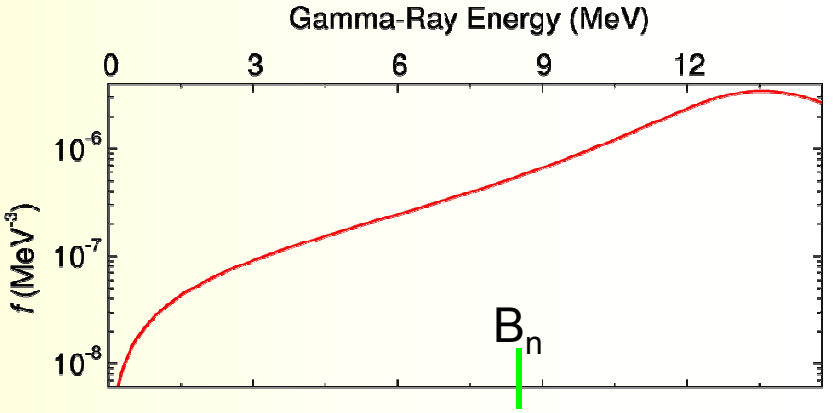
Why, oh why do results differ?

- 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, oh why do results differ?

- 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 “indirect”
  - Measured spectra must be often deconvoluted and interpreted
  - Spectra often come from an interplay of PSFs and level density
  - Additional information, often about level density, is required to produce final results

Where could we learn about PSFs from?



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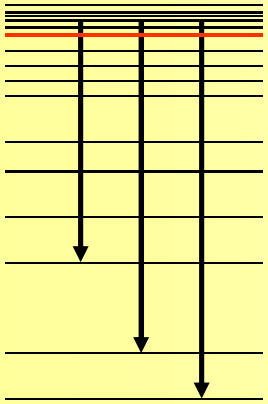
(n,γ) reactions – part 1

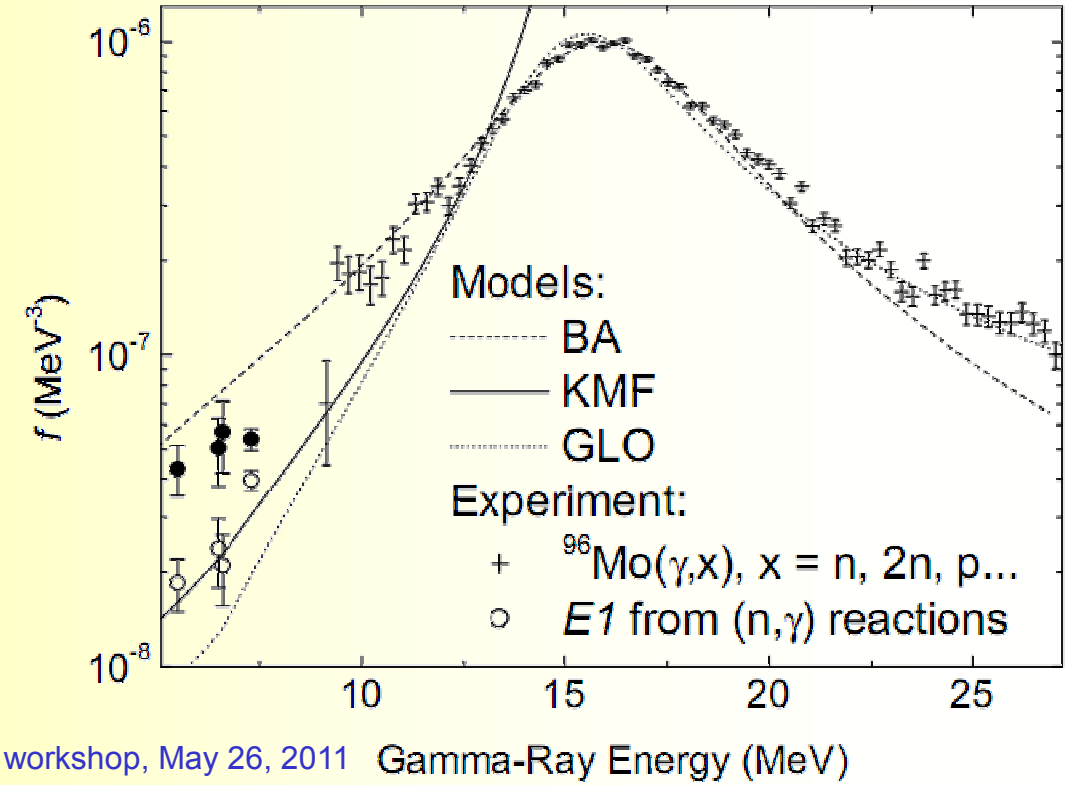
- PSF from intensities of primary transitions (Kopecky values in RIPL)

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



- Values from RIPL must be taken with care

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)



(n,γ) reactions – part 2

Data from "spectrum fitting method", TSC spectra,…
– decay simulated using the DICEBOX code

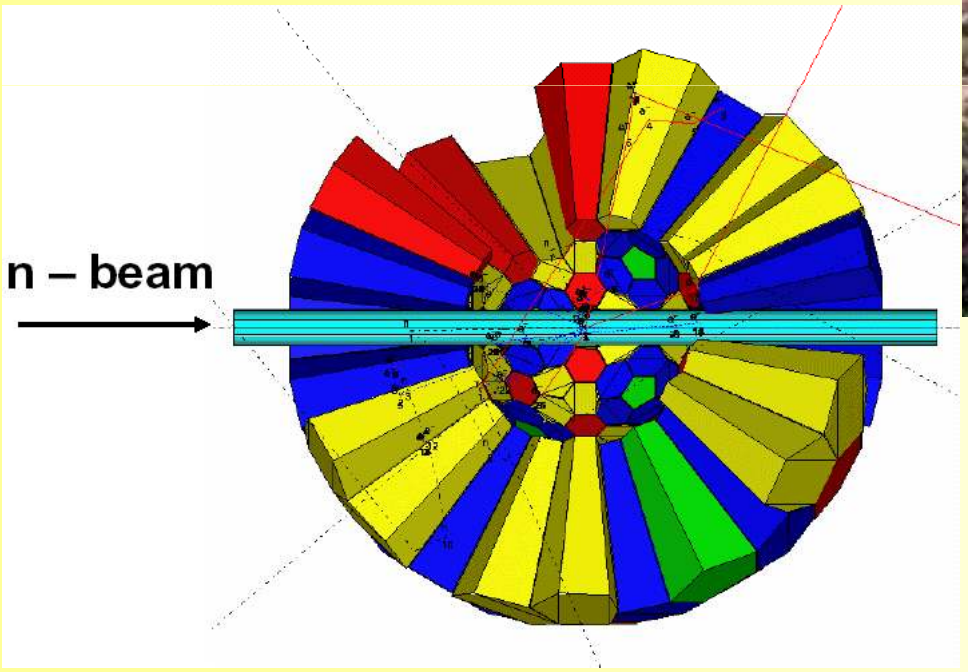
- Try and error method
  - agreement of simulated spectra with experiment is checked
  - "standard" PSFs are usually tested
- There is a sensitivity to energy dependence of PSFs and sometimes (TSC spectra) to ratios of PSFs of different types (E1, M1, E2)
- There is no sensitivity to absolute values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

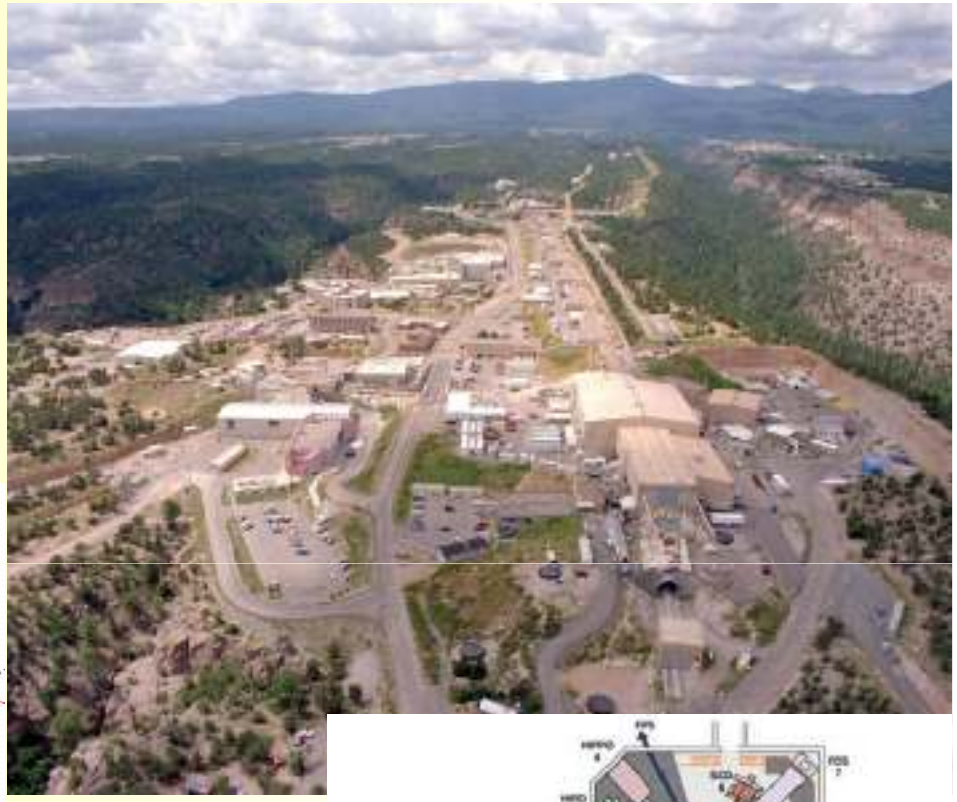
$$\Gamma_{\lambda\gamma} = \sum_f \Gamma_{\lambda\gamma f} \approx \sum_{XL} \int_0^{B_n} \frac{\rho(B_n - E_\gamma, J_f)}{\rho(B_n, J_{B_n})} f^{(XL)} E_\gamma^{2L+1} \, dE_\gamma$$

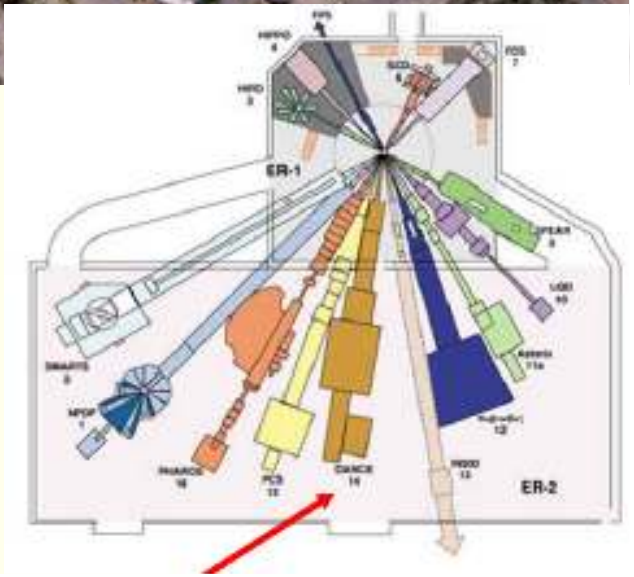
- Often photoabsorption data are matched above S_n and comparison of PSF from primaries is done

DANCE @ LANSCE

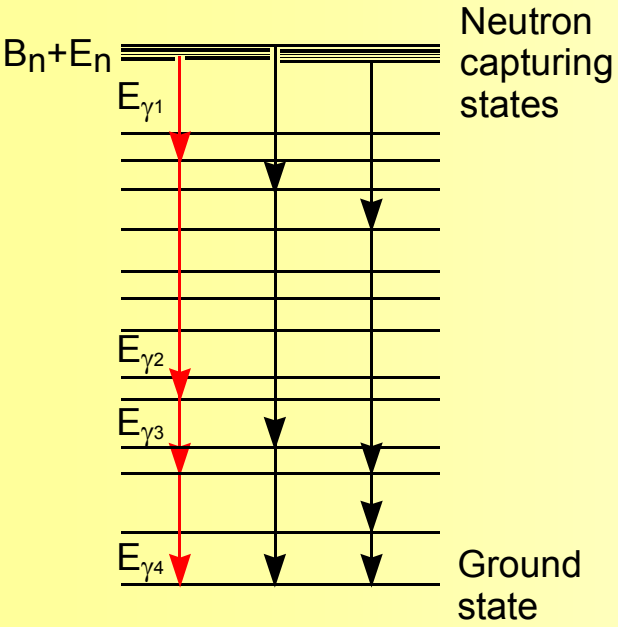
- Moderated W target gives “white” neutron spectrum, ~14 n’s/proton
- DANCE is on a 20 m flight path / ~1 cm @ beam after collimation
- repetition rate 20 Hz
- pulse width ≈ 125 ns
- DANCE consists of 160 BaF_2 crystals

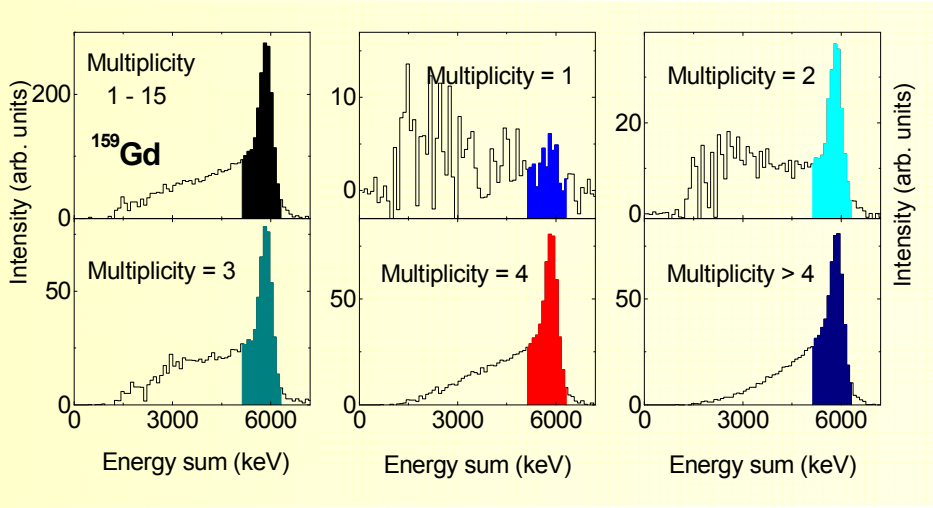


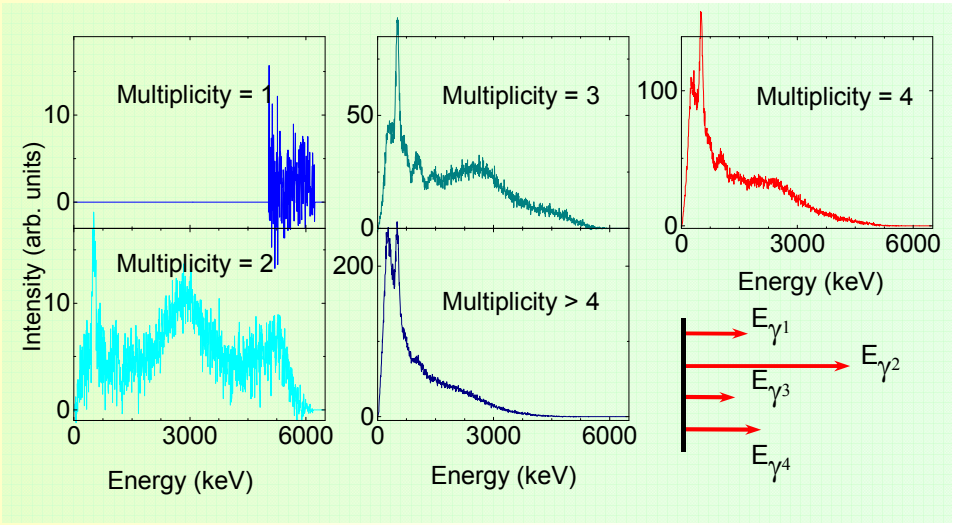




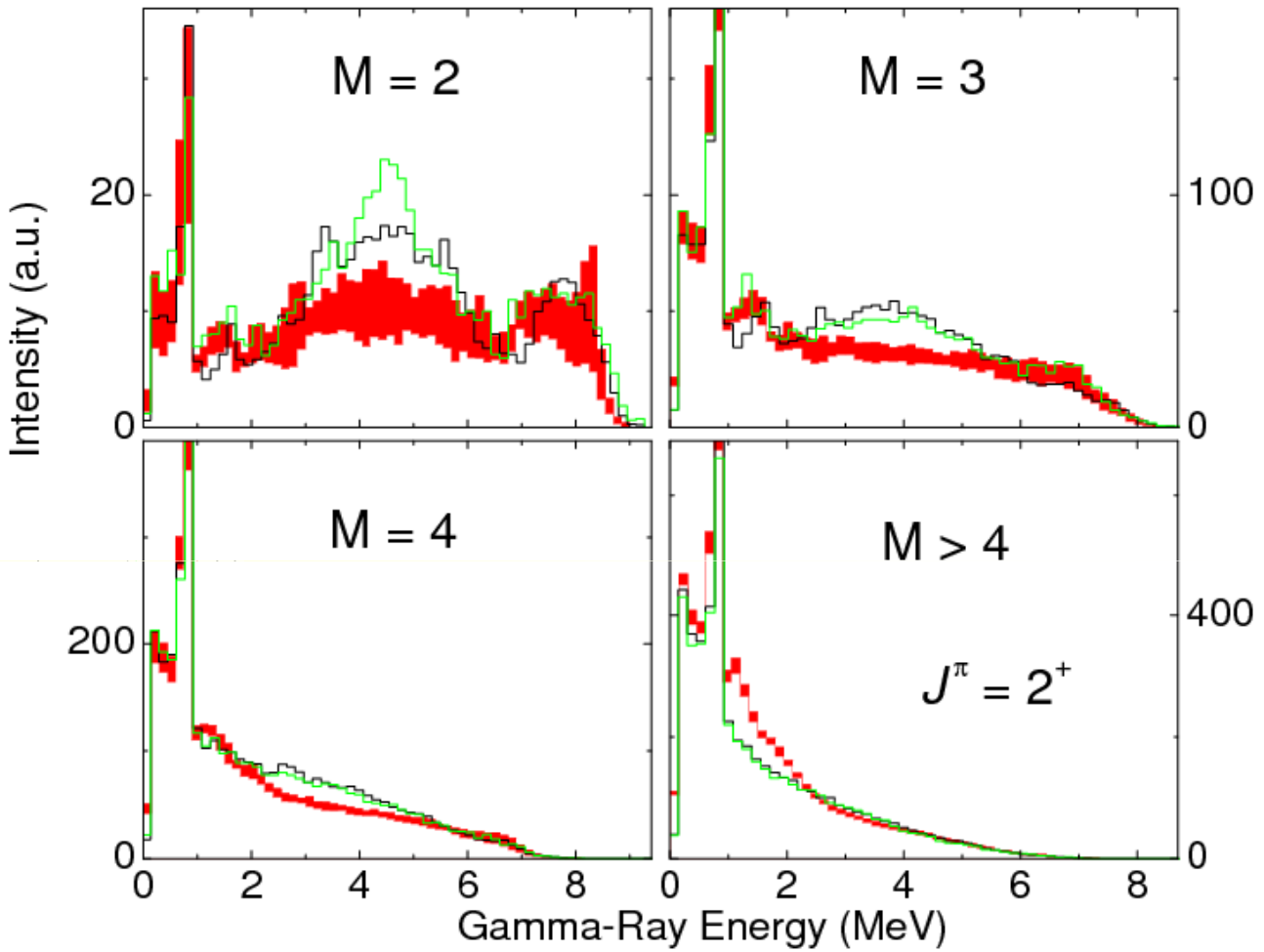
What can be checked?

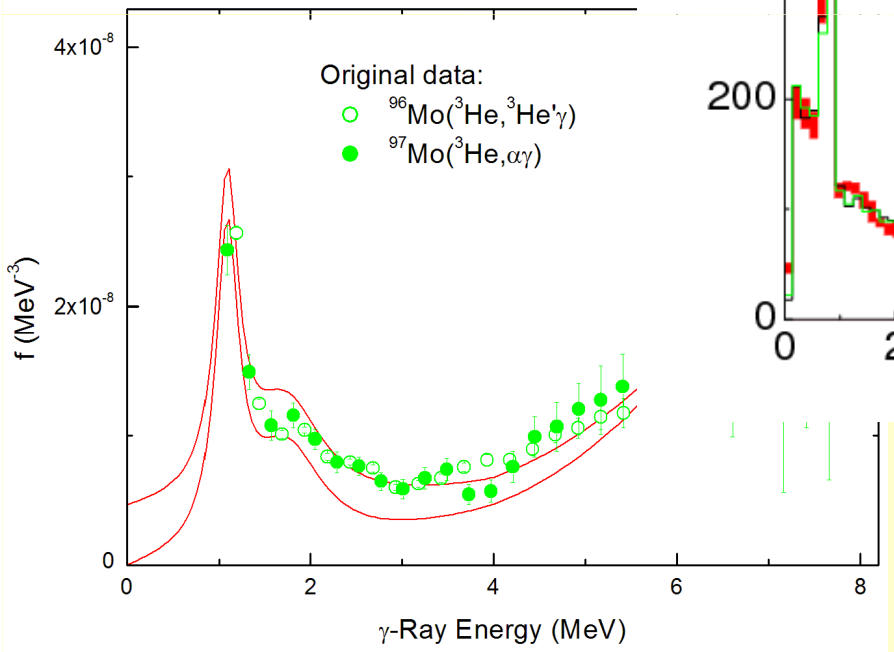






MSC spectra in ^{96}Mo





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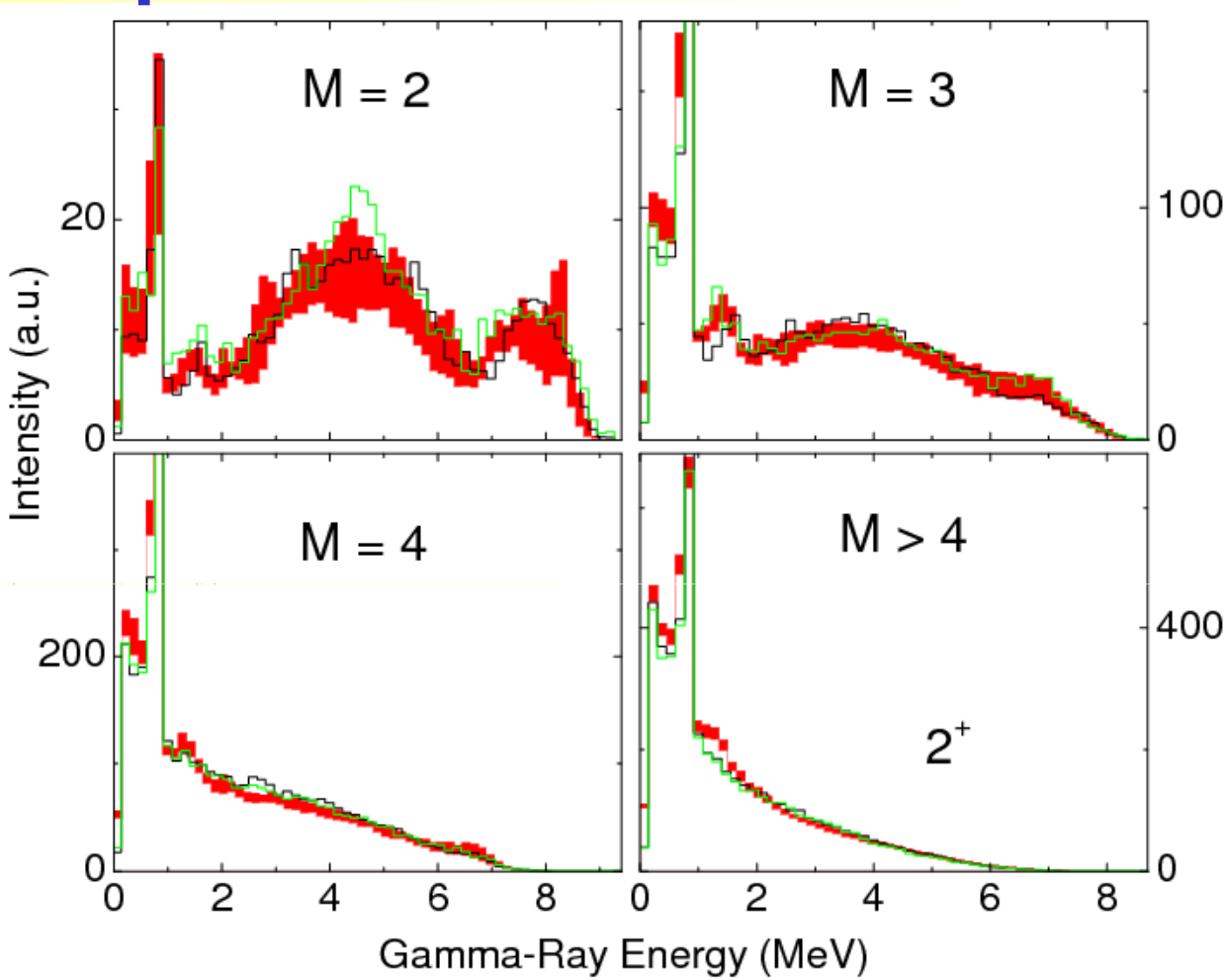
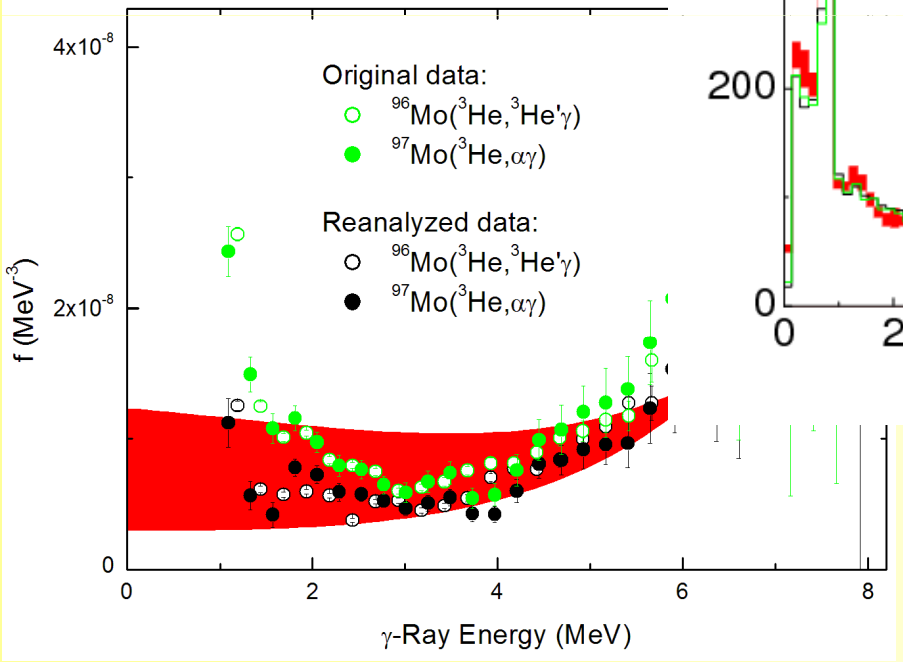
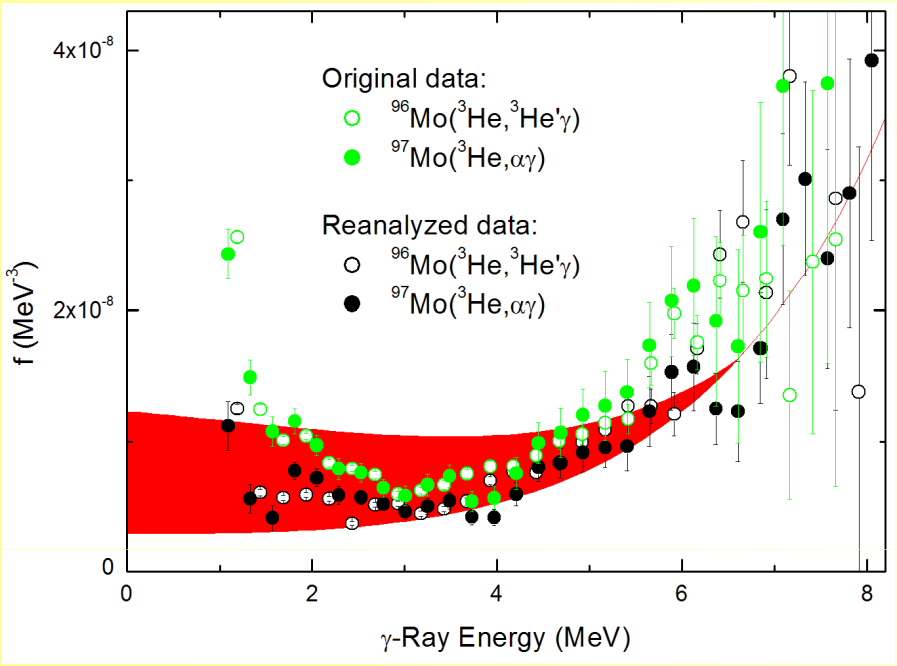
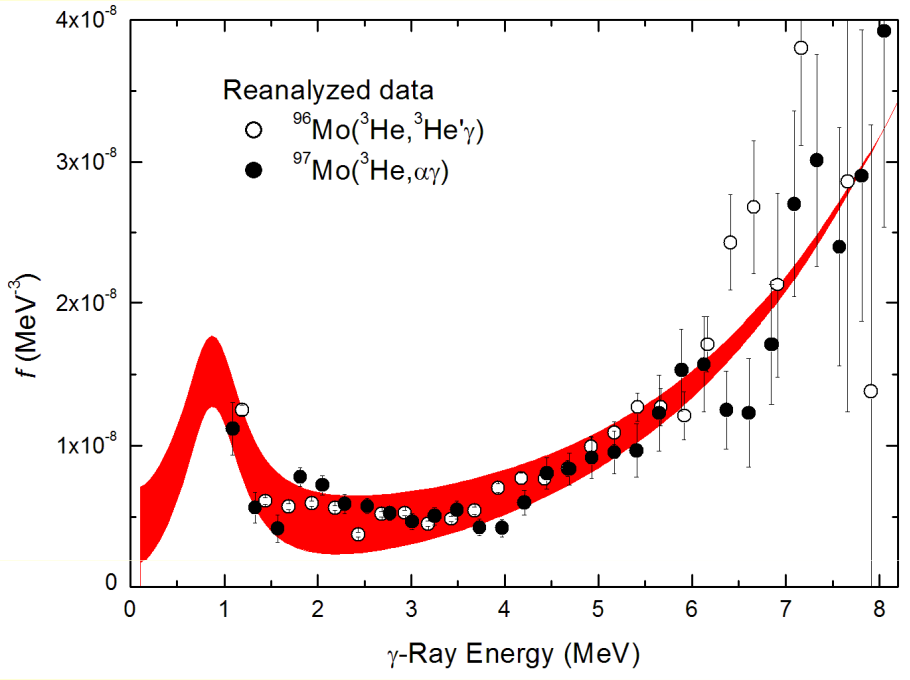




S. Sheets et al., Phys. Rev. C **79**, 024301 (2009)

MSC & TSC spectra in ^{96}Mo





Pictures with comparison similar for these two options from MSC and TSC experiment but correct statistical analysis of TSC data excludes “Oslo” model (upbend) at 99.8 % confidence level

Krticka et al., PRC 77 054319 (2008)

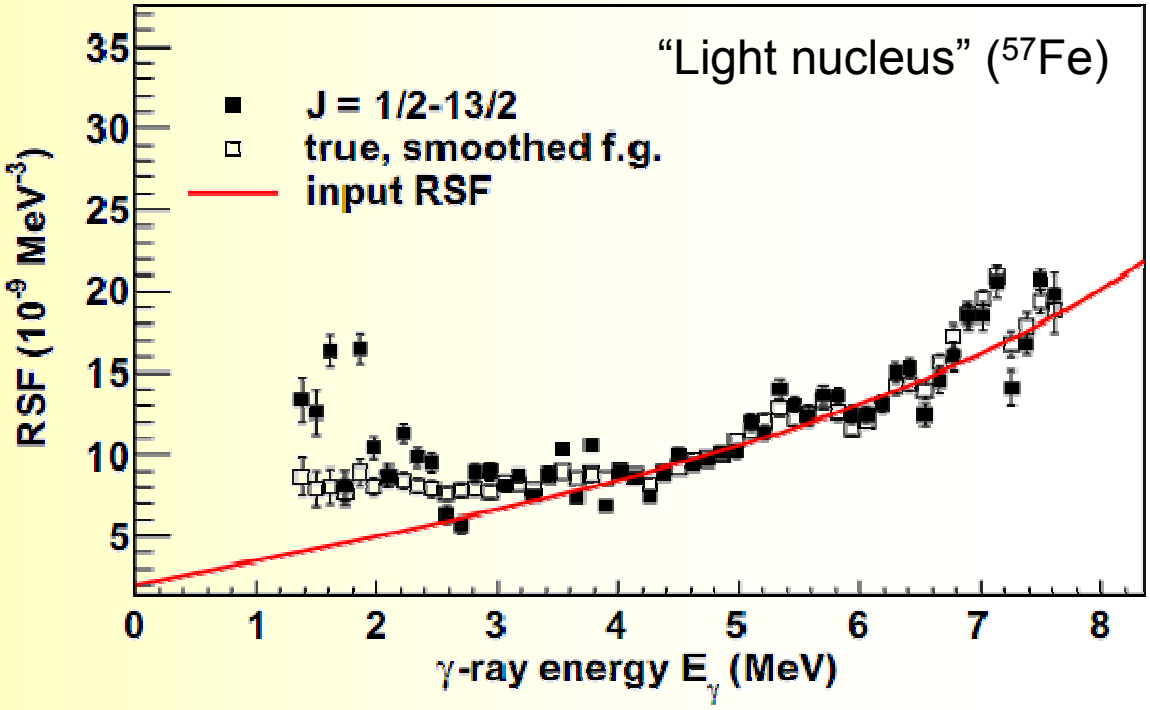
$\Rightarrow$ the enhancement is very weak if any

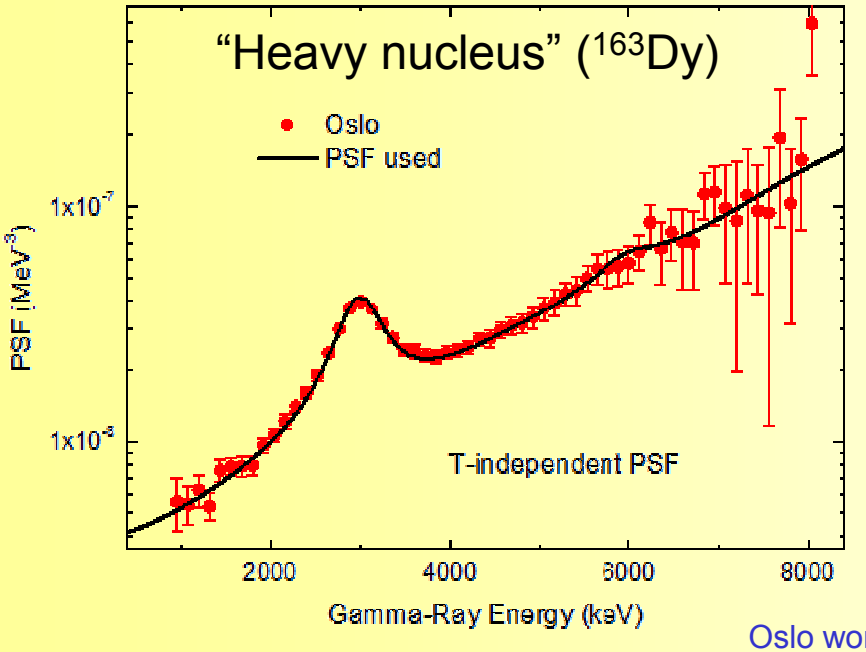
Oslo method

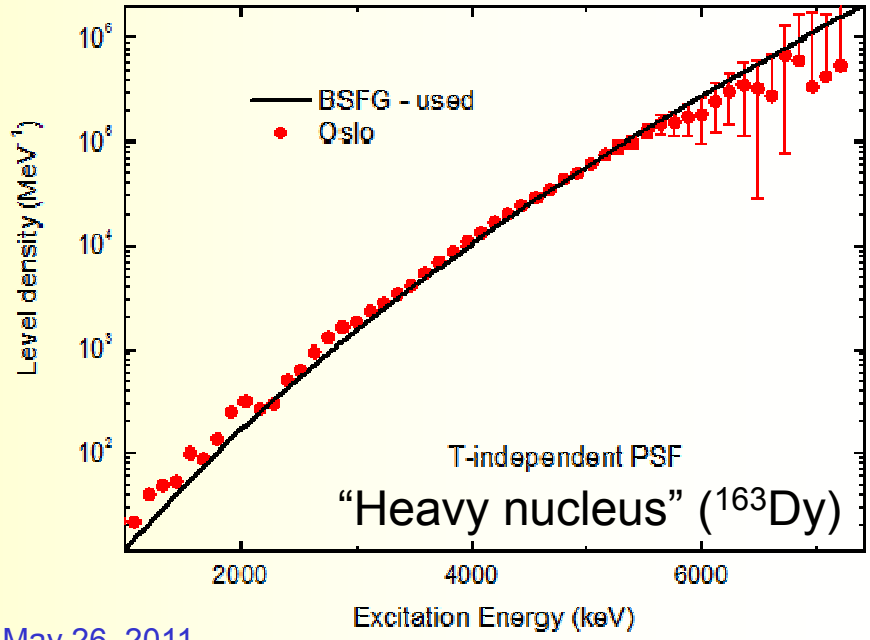
- Spectra of primaries are extracted from measured spectra (unfolding of detector response)
- Iterative procedure applied to spectra of primaries - two functions can be obtained
  - one depends only on excitation energy (level density)
  - the other one only on gamma-ray energy (PSF)

Oslo method

Check for Mo isotopes is planned …







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- The procedure works very well but there are no unique results – infinite number of solutions connected via relations

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

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

Oslo method

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

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

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

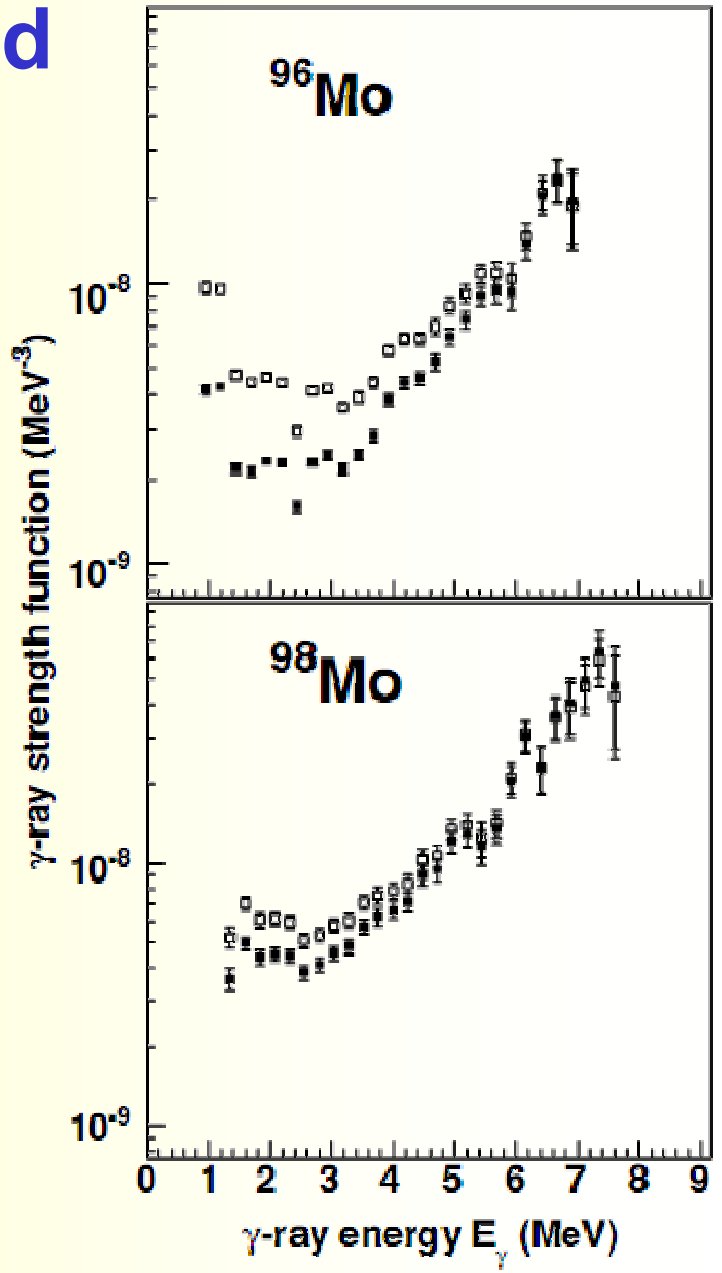
A published example:

Recalculation of RSF based on calculated level density from

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

were published in

Larsen and Goriely, PRC 82 014318 (2010)



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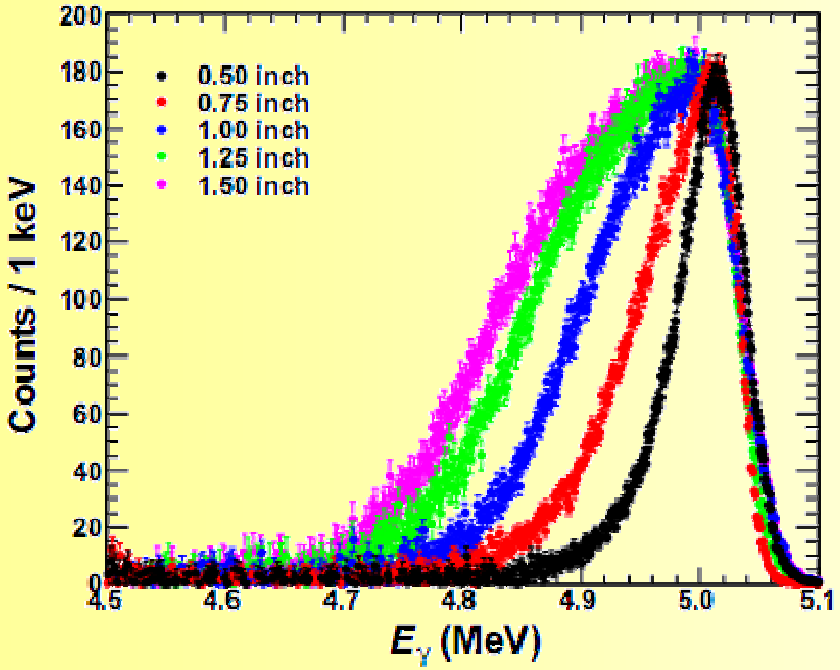
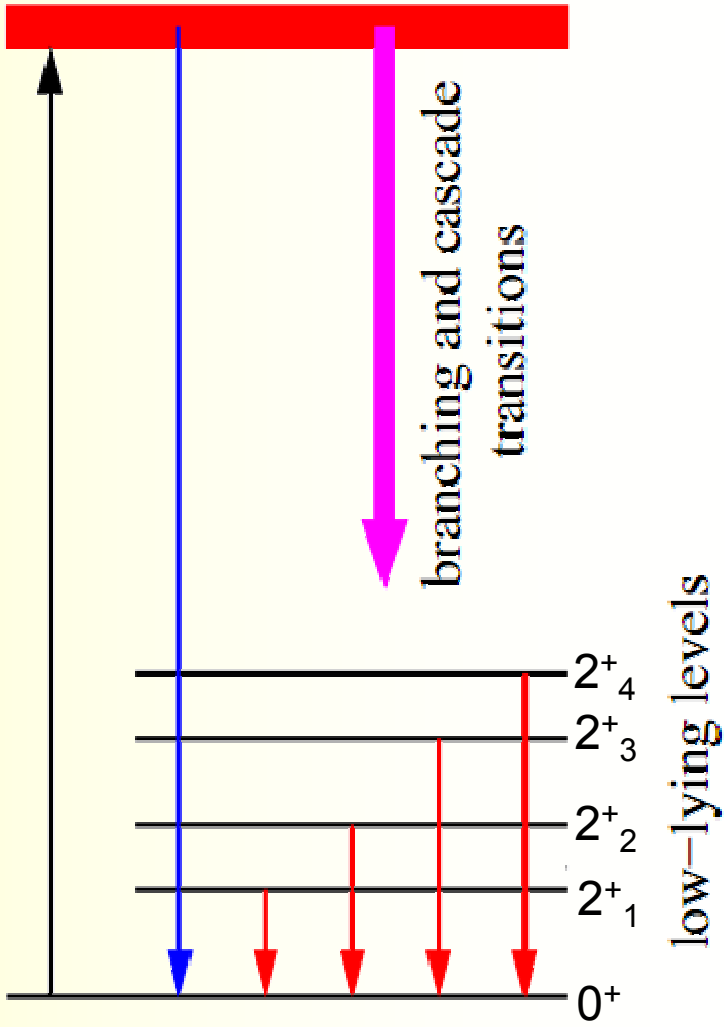
- What does happen if the PSF depends on excitation energy? Not discussed here …

NRF from HIγS (monoenergetic beam)

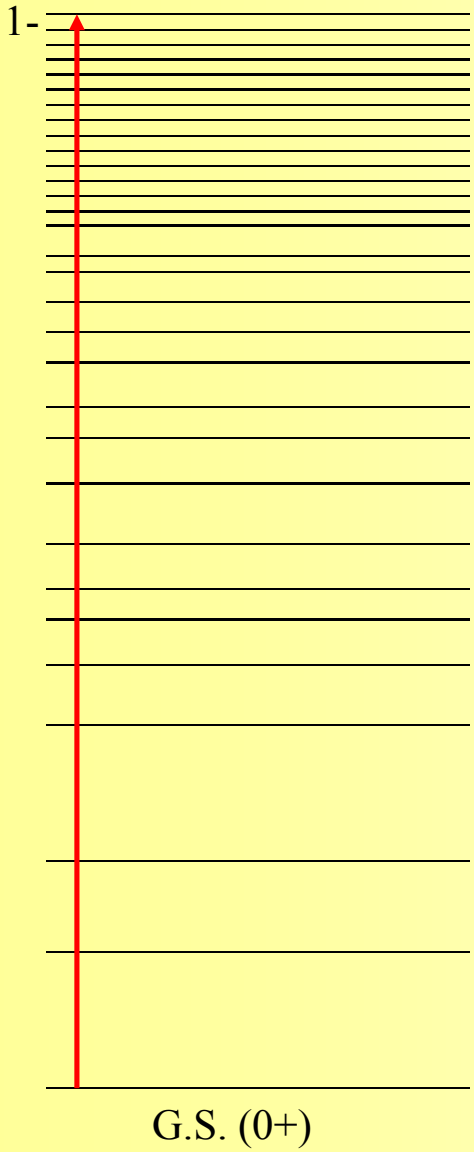


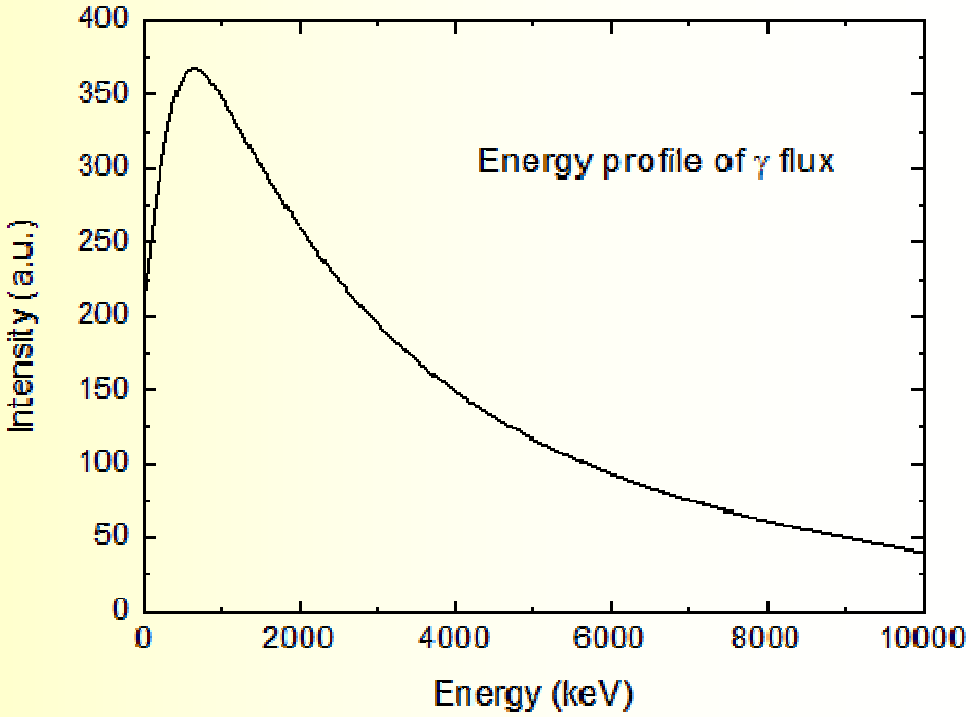
from Gencho Rusev's talk



- If GS feeding from higher levels small (often the case) then the sum of direct GS feeding and intensity depopulating low-lying levels gives the x-section (PSF)

NRF with beam from “bremsstrahlung”





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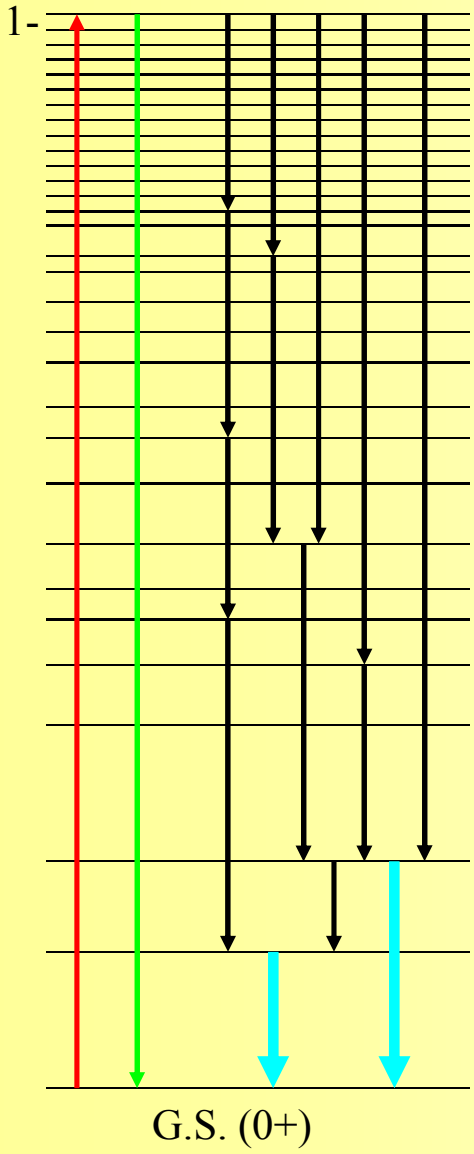
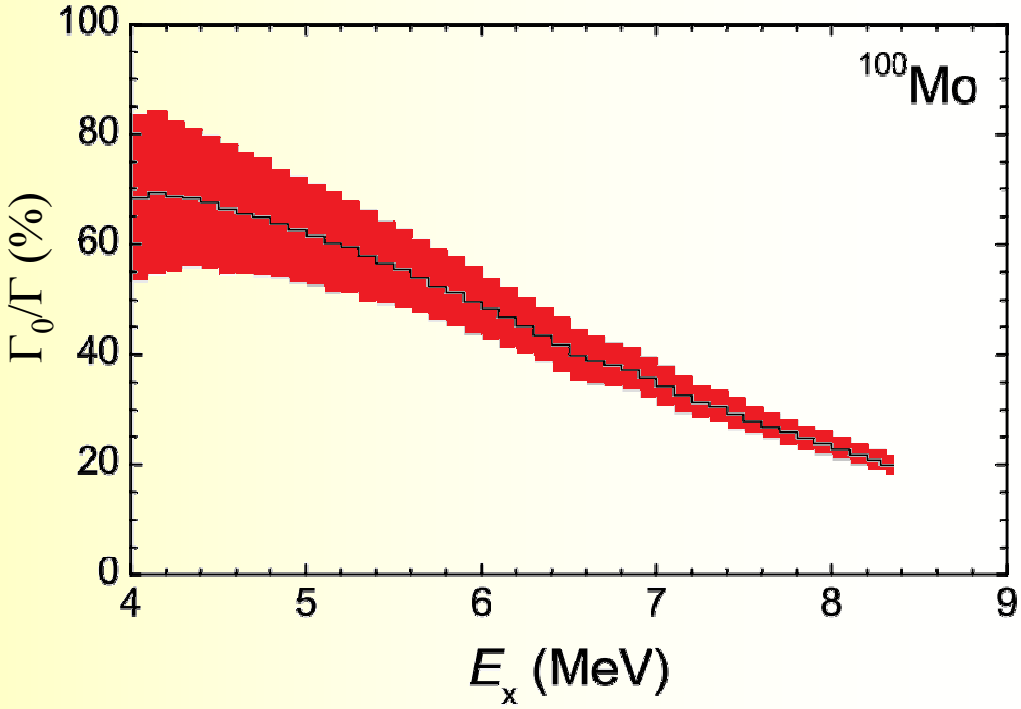


Many transitions to excited states – correction for them is needed

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



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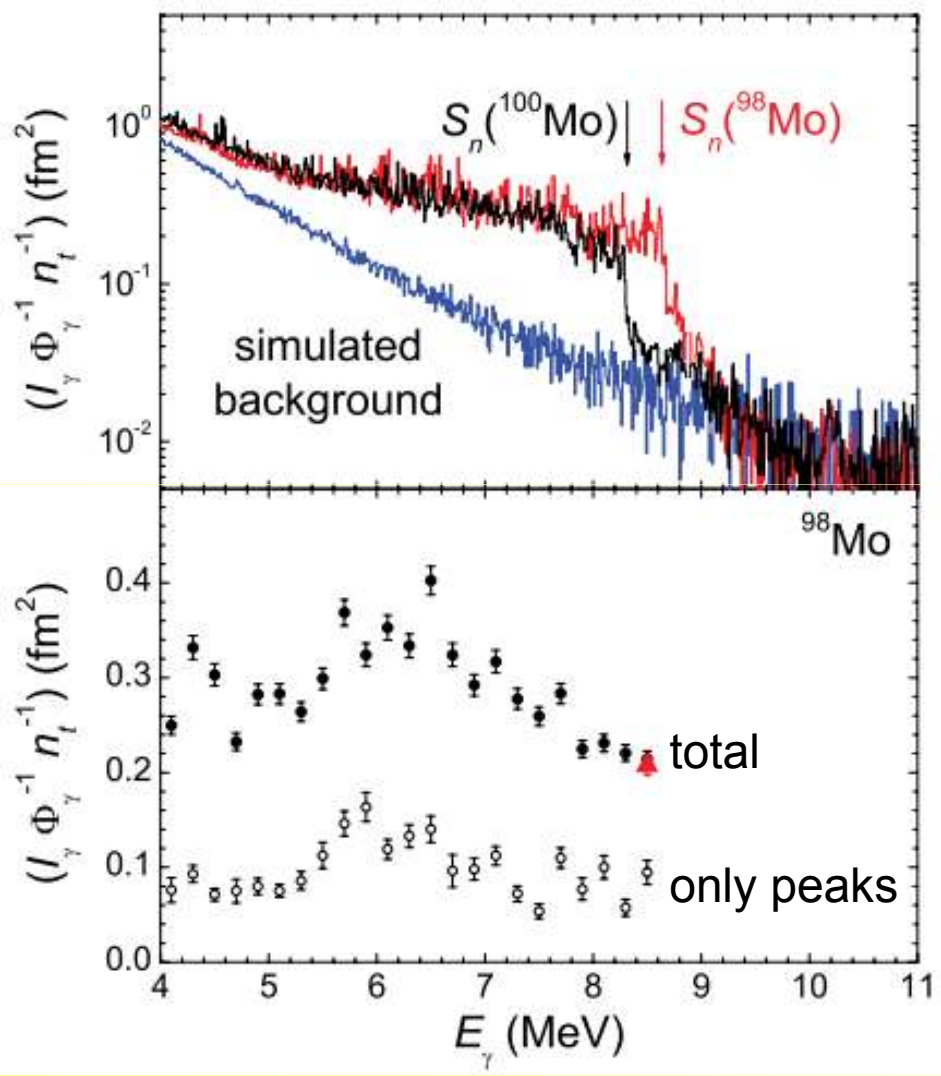
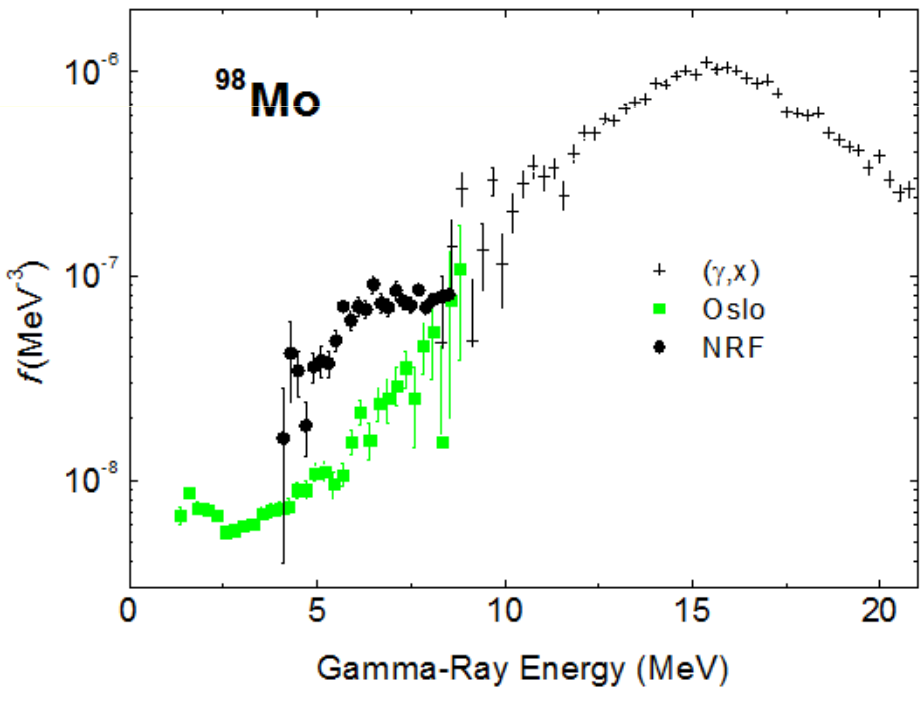


- An “iterative” procedure is applied and PSF to the GS is obtained



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

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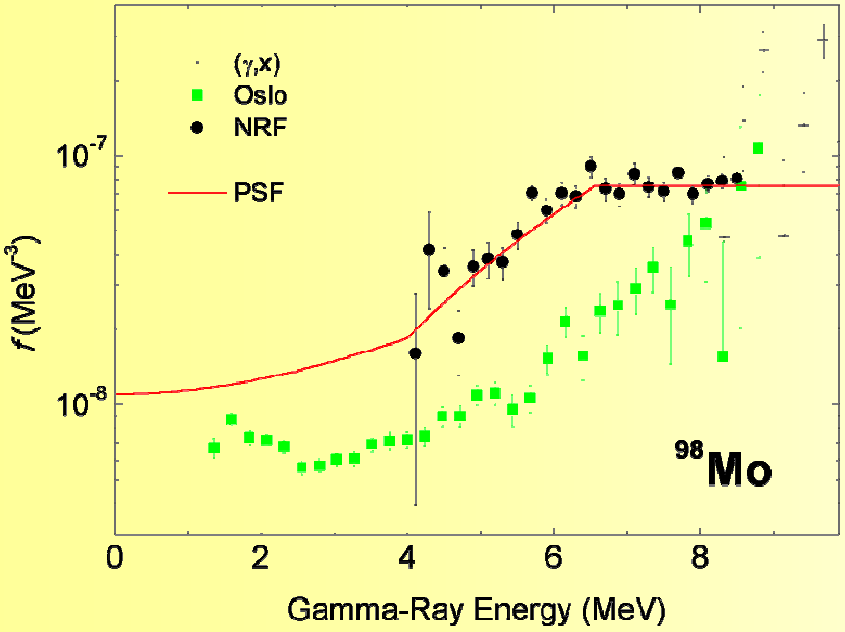
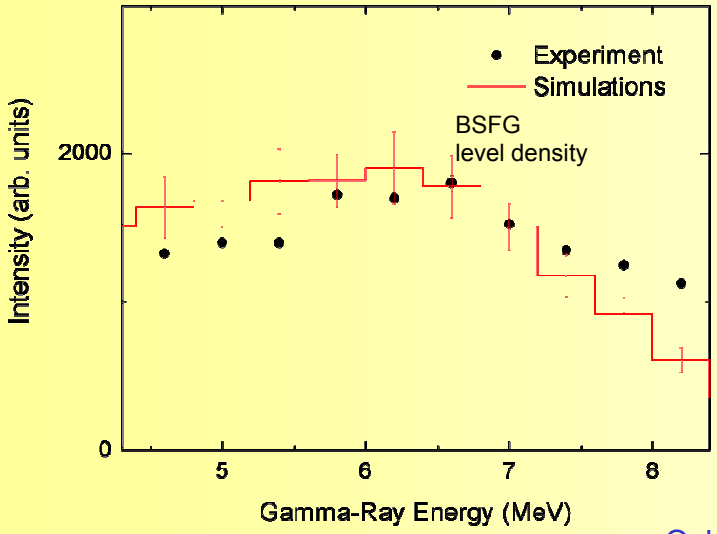


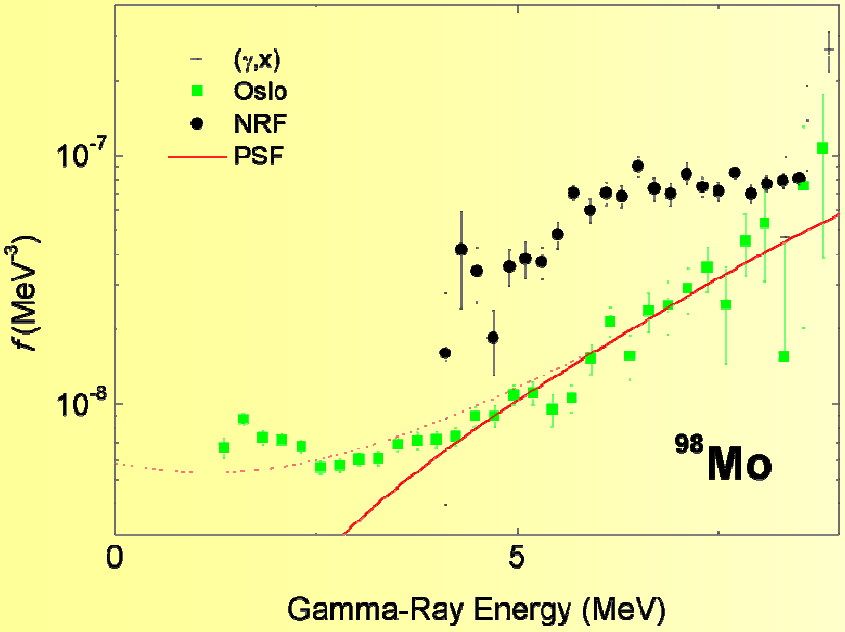
- Simulations of gamma decay with DICEBOX code can produce spectra comparable to measured ones

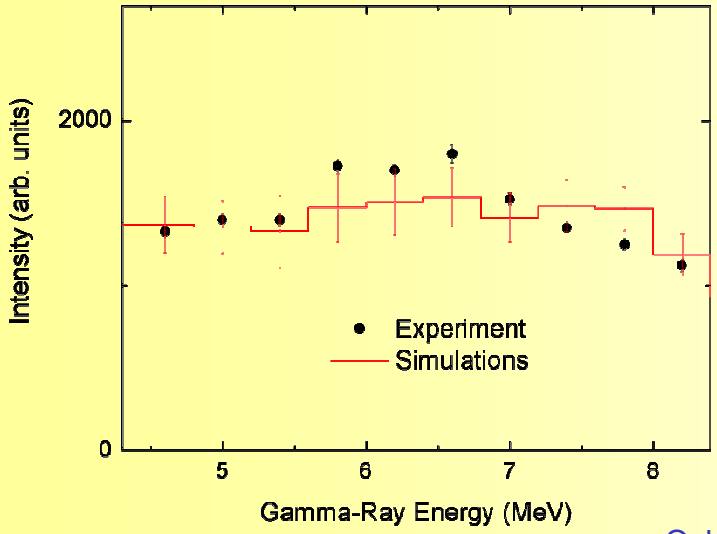


- The PSF reproducing NRF data seems not to reproduce the spectrum

The results are preliminary

NRF with beam from “bremsstrahlung”



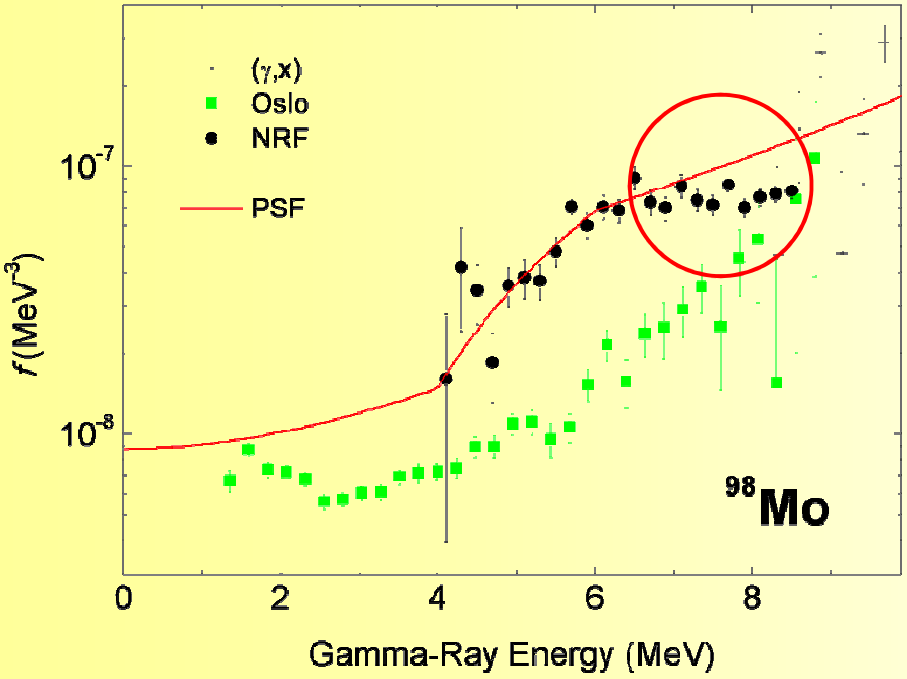


- Spectra cannot be reproduced also using PSF from Oslo measurement

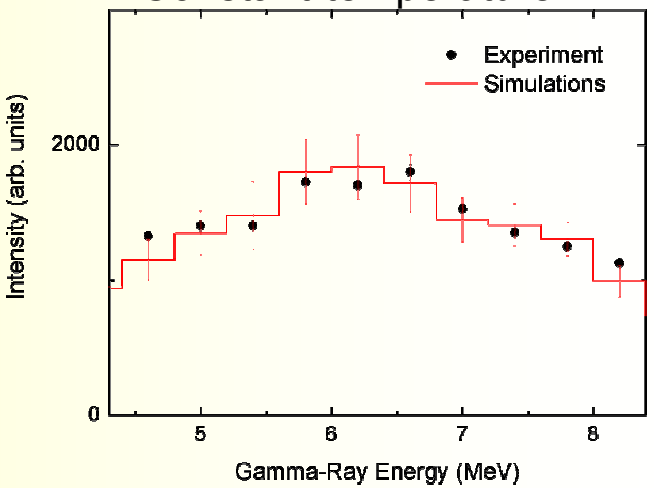
NRF with beam from “bremsstrahlung”

- Better agreement between experimental data and simulations can be achieved

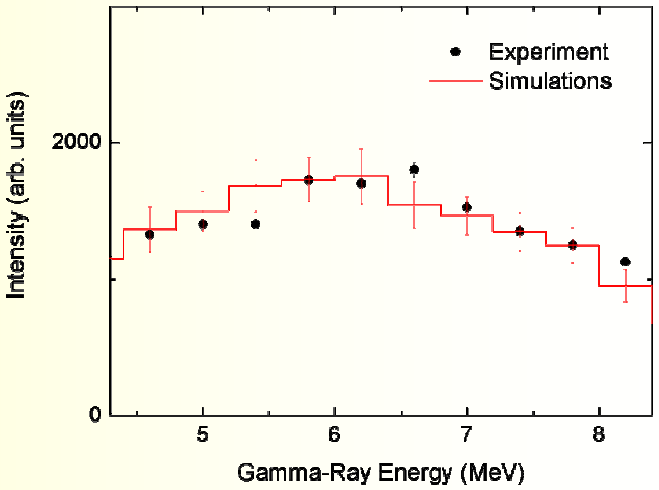
PSF used in simulations



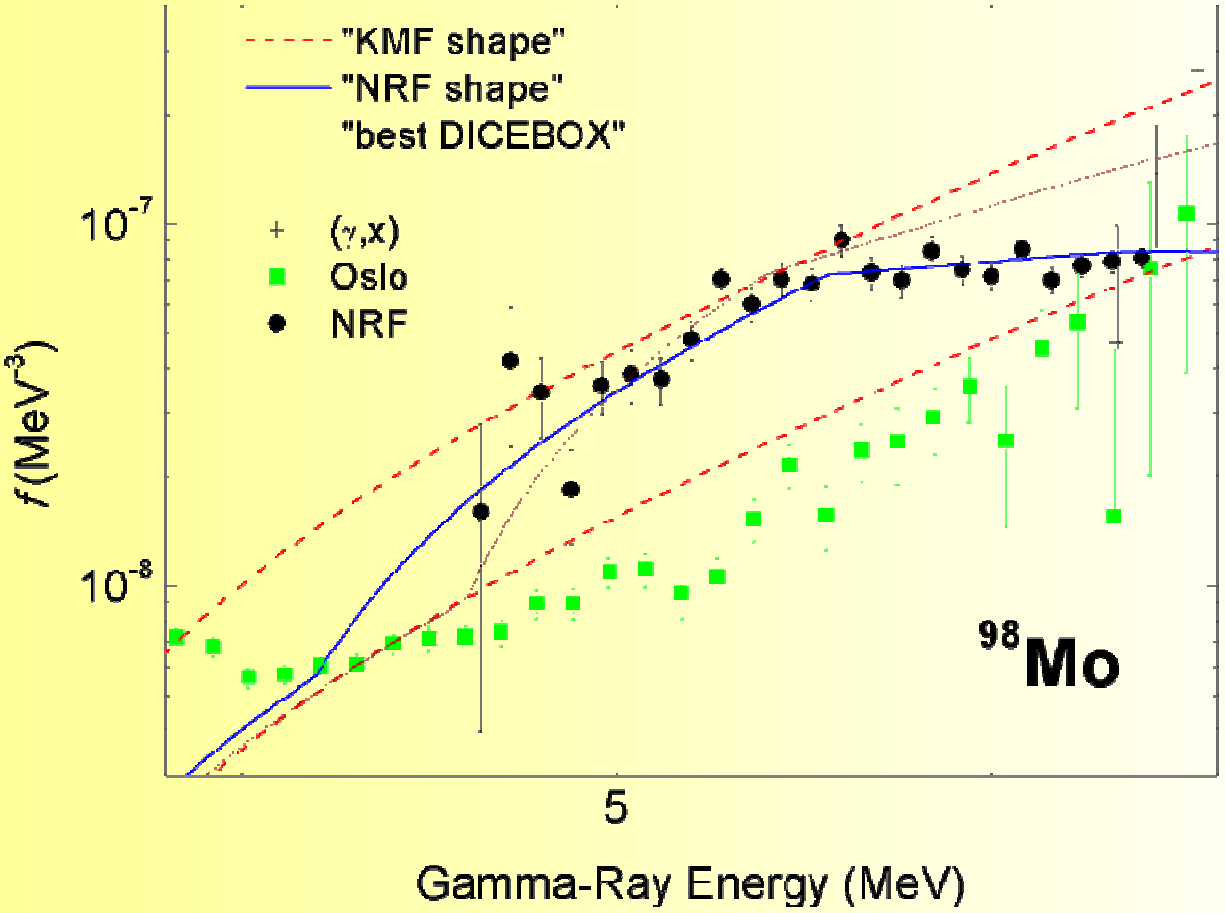
Constant-temperature LD



Back Shifted Fermi Gas LD



NRF with beam from “bremsstrahlung”

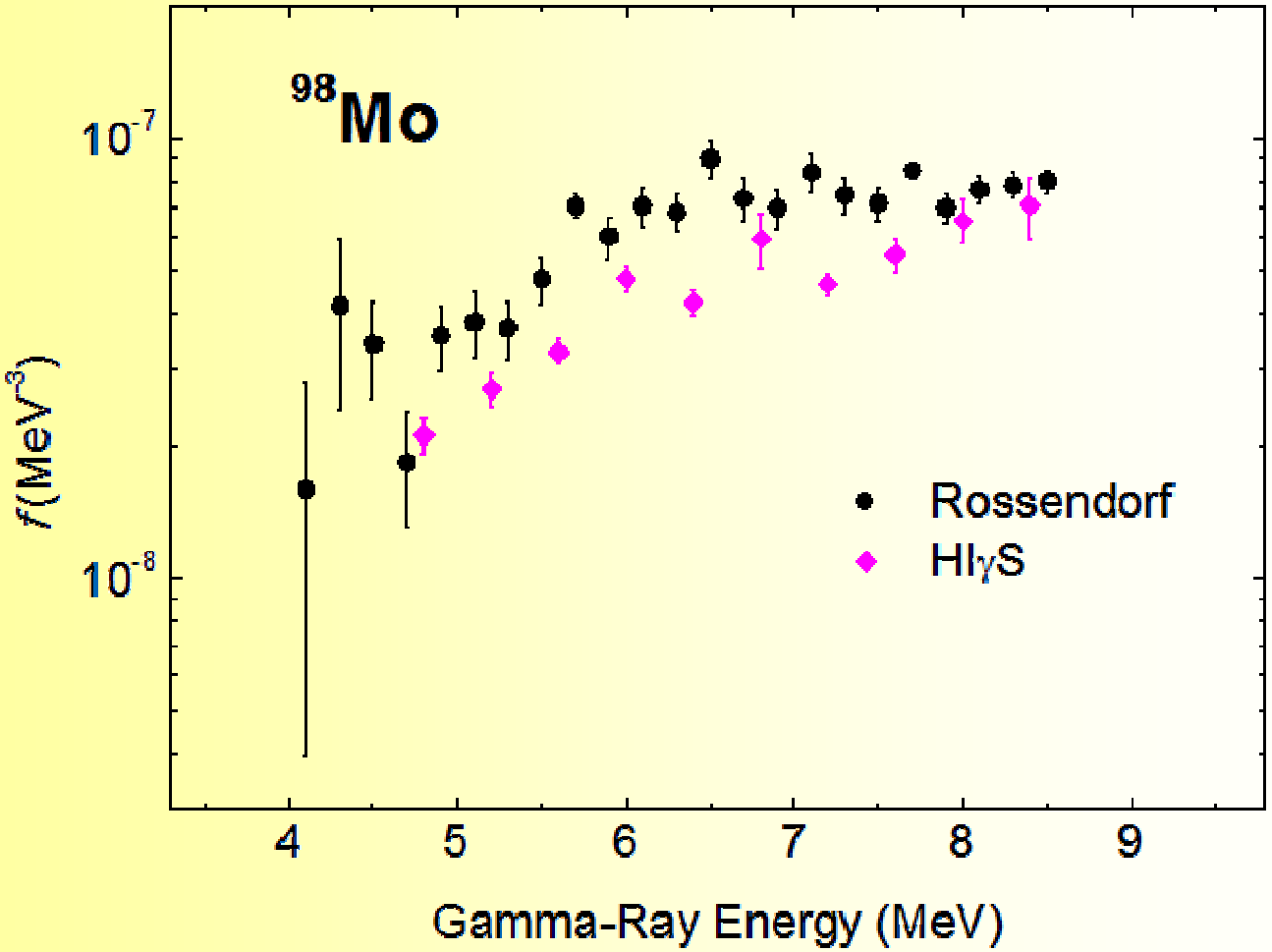


“no bump”

“too strong bump”

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

Consistency of NRF data?



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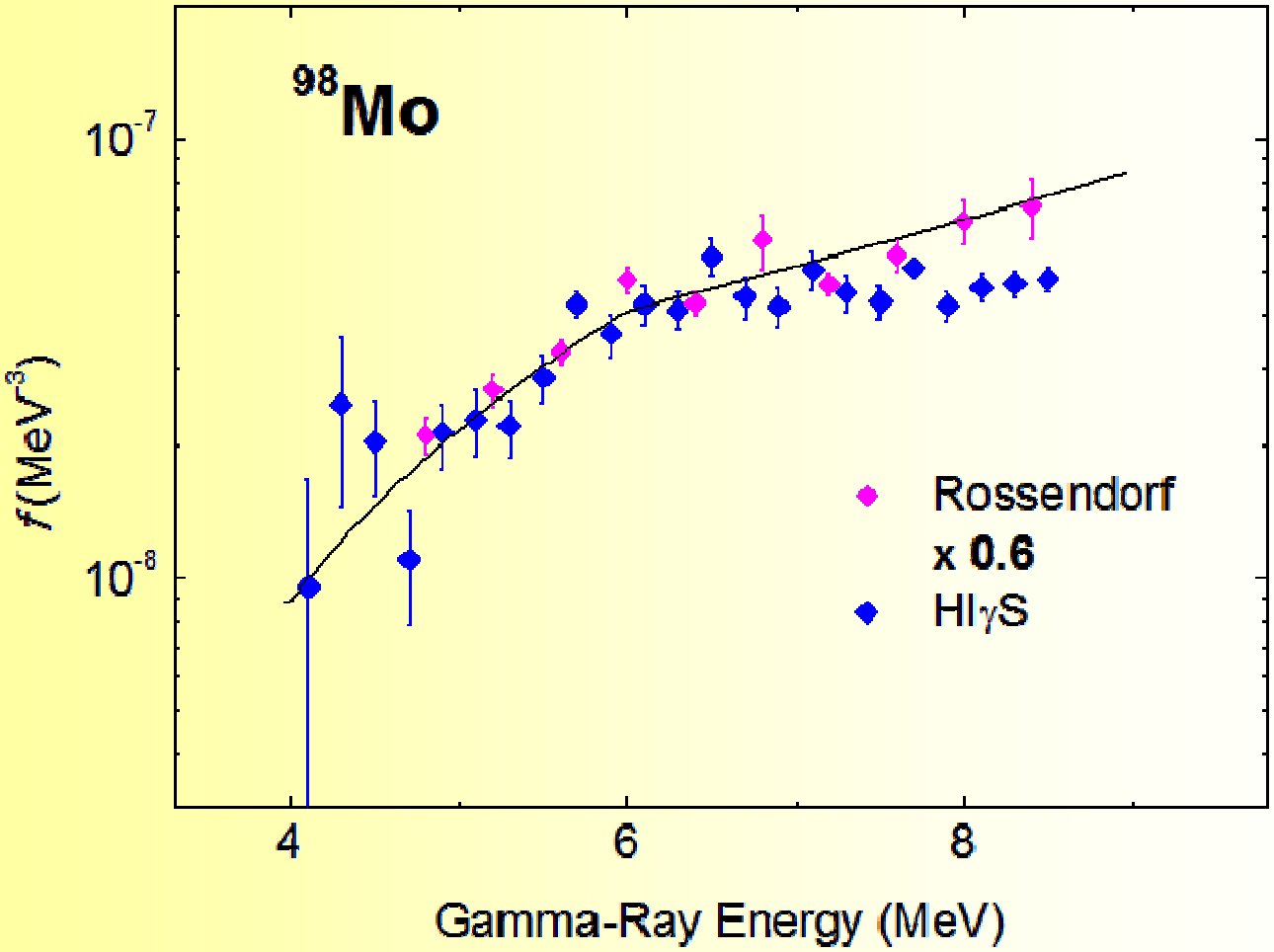
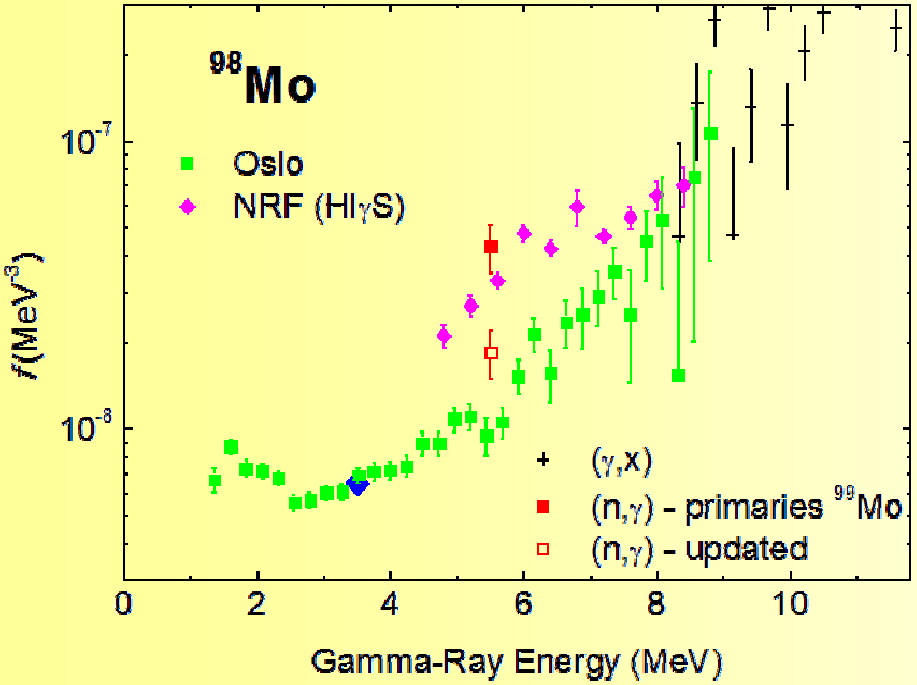
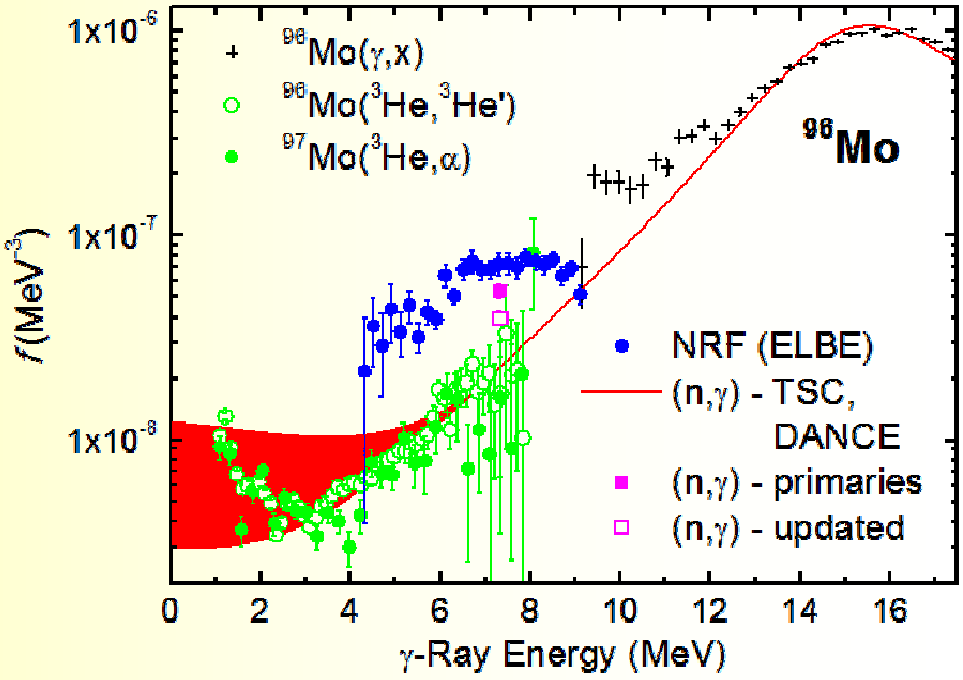


Consistency of all data?

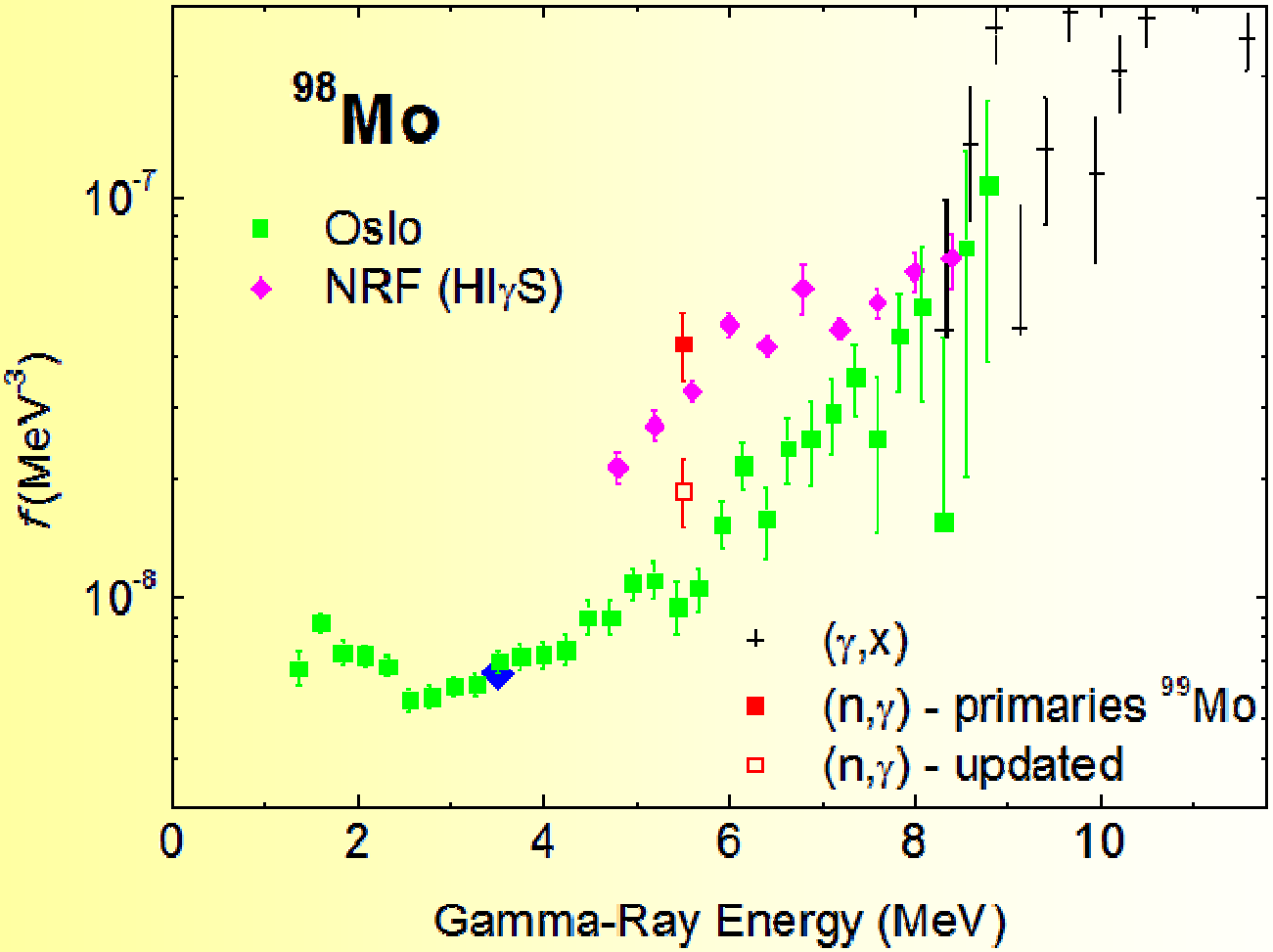




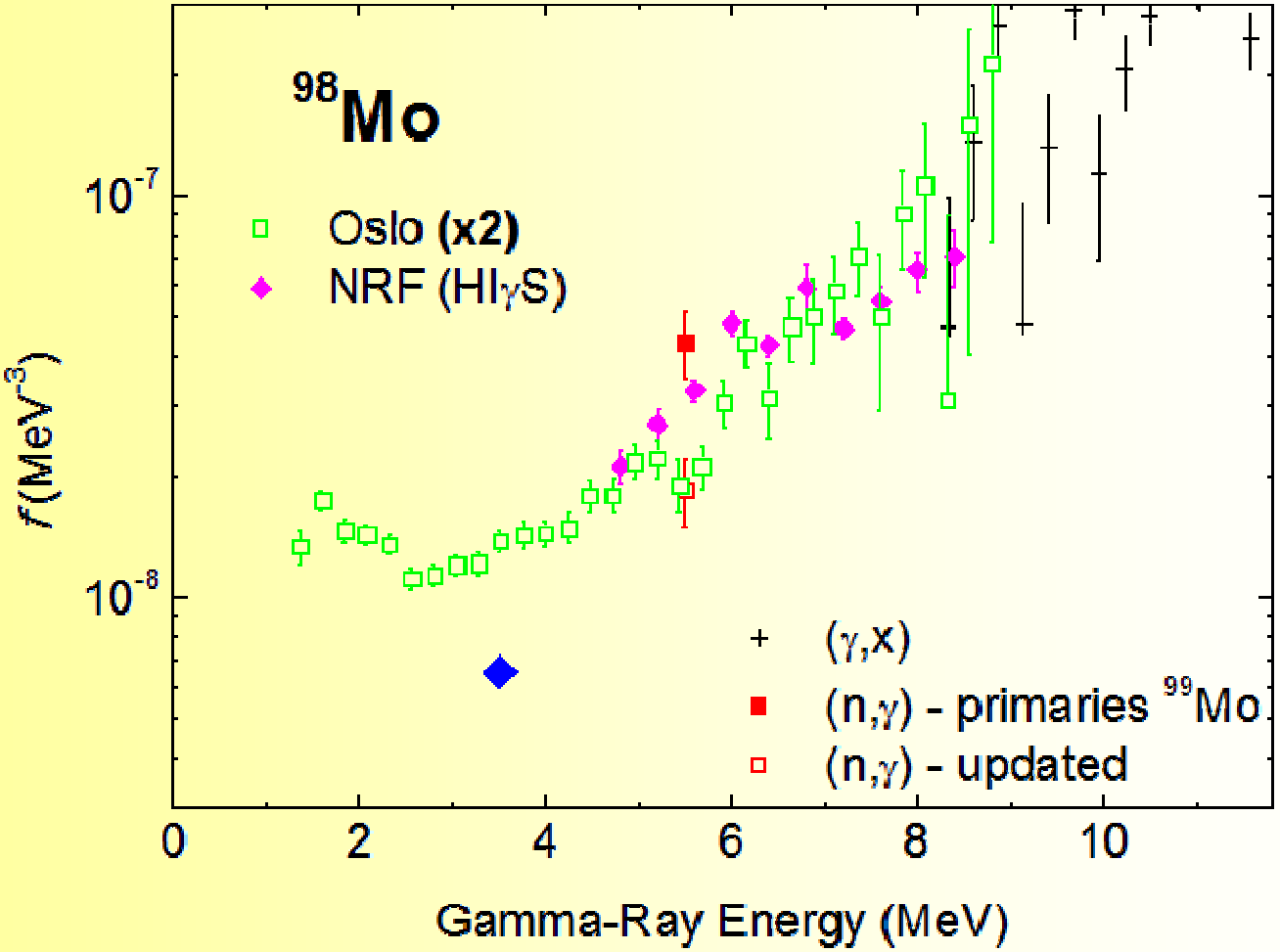
How to explain the difference?

- strong violation of Brink hypothesis
- or … (“wild” speculation)

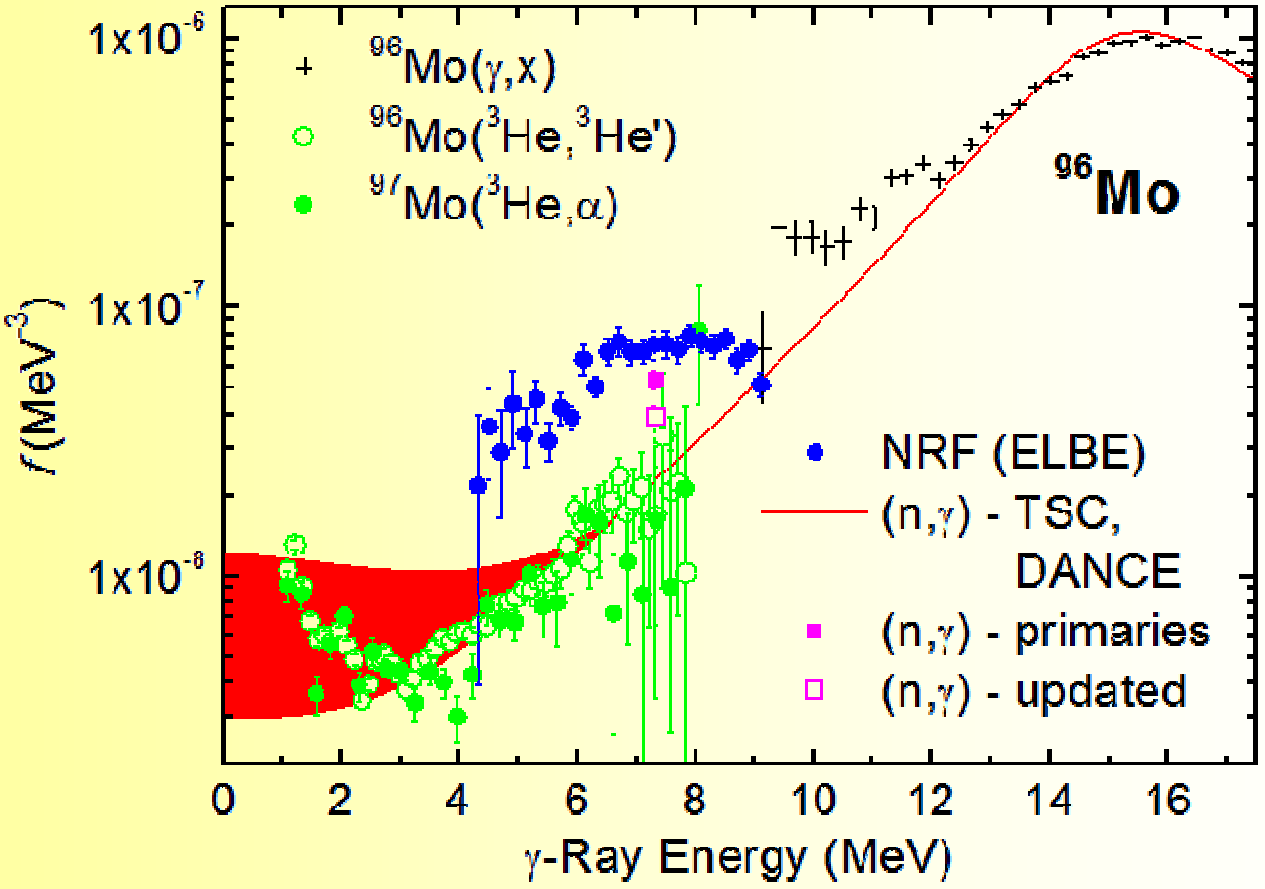
And a “wild” speculation



And a “wild” speculation

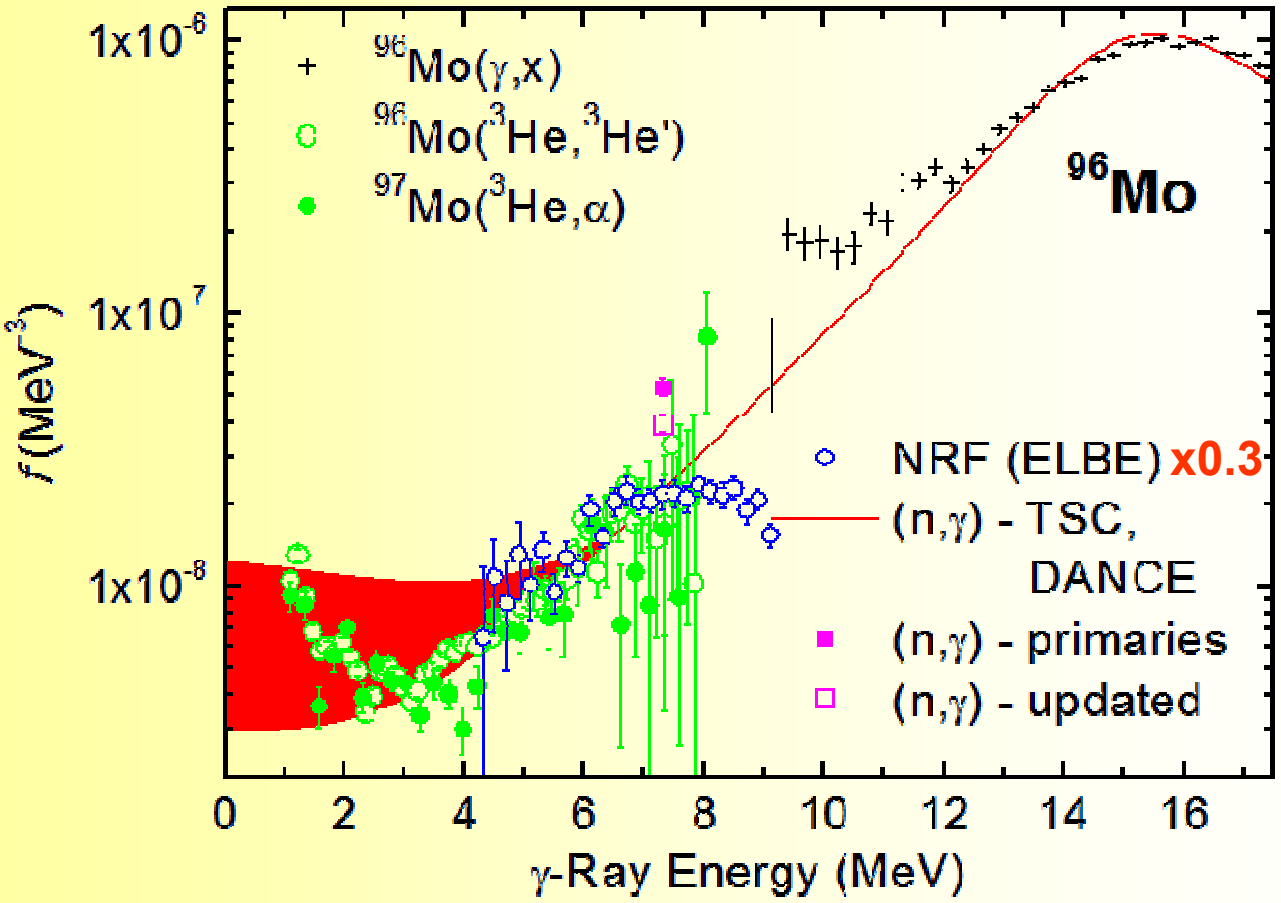


And a “wild” speculation



Krticka et al., PRC 77 054319 (2008), Sheets et al., PRC 79 024301 (2009),
Erhard et al., PRC 81 034319 (2010), Guttormsen et al., Phys. Rev. C 71, 044307 (2005)

And a “wild” speculation

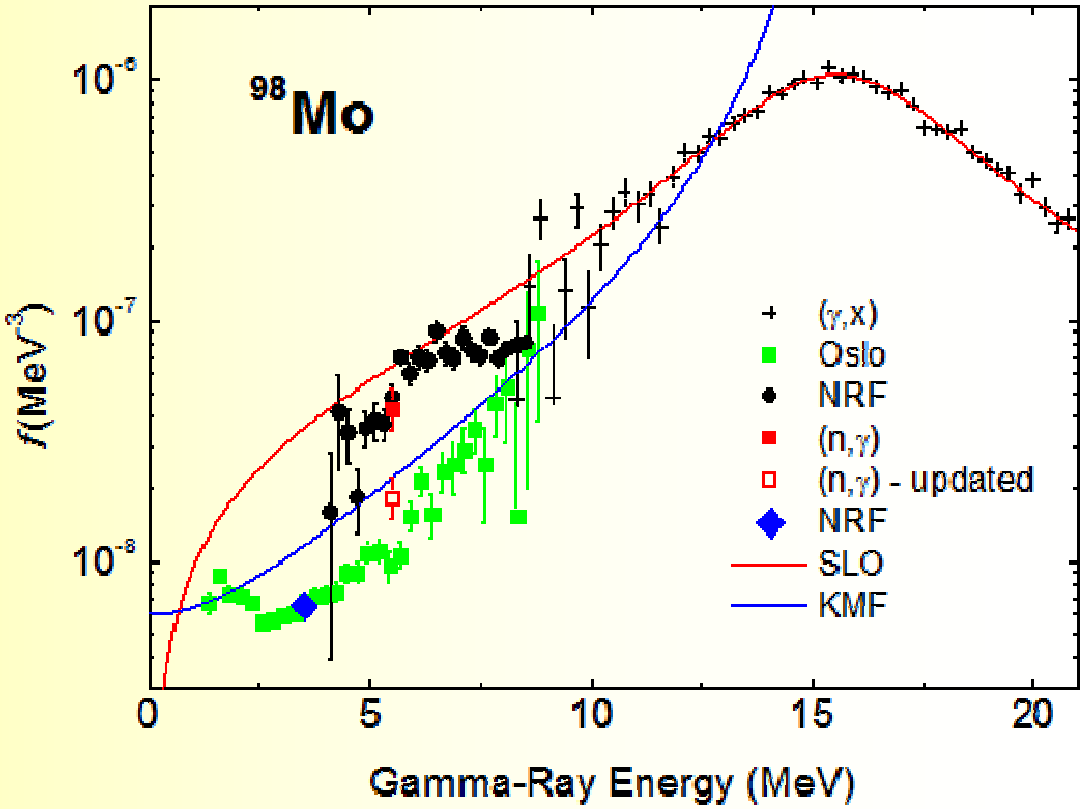


But this would probably cause a problem

- total radiation width of neutron resonances (must be checked)

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



Thank you very much
for your attention ...

Third International Workshop on

Compound Nuclear Reactions and Related Topics

September 19 - 23, 2011

Prague, Czech Republic

Organized by Charles University in Prague, Faculty of Mathematics and Physics

CNR*11

Topics of interest to CNR*11 include:

- Nuclear reaction mechanisms,
- Optical model,
- Direct reactions and compound nucleus,
- Pre-equilibrium reactions,
- Neutron-induced cross section measurements,
- Surrogate reactions;
- Decay of the compound nucleus,
- Hauser-Feshbach statistical model,
- Fission,
- Particle and gamma ray emission,
- Level densities,
- Strength functions,
- Nuclear structure for compound-nuclear reactions,
- Statistical properties of nuclear reactions,
- Applications,
- Nuclear energy,
- Astrophysics,
- Nuclear fusion,

...

www-ucjf.troja.mff.cuni.cz/cnr11

Abstract submission: June 15

Photon Strength Functions

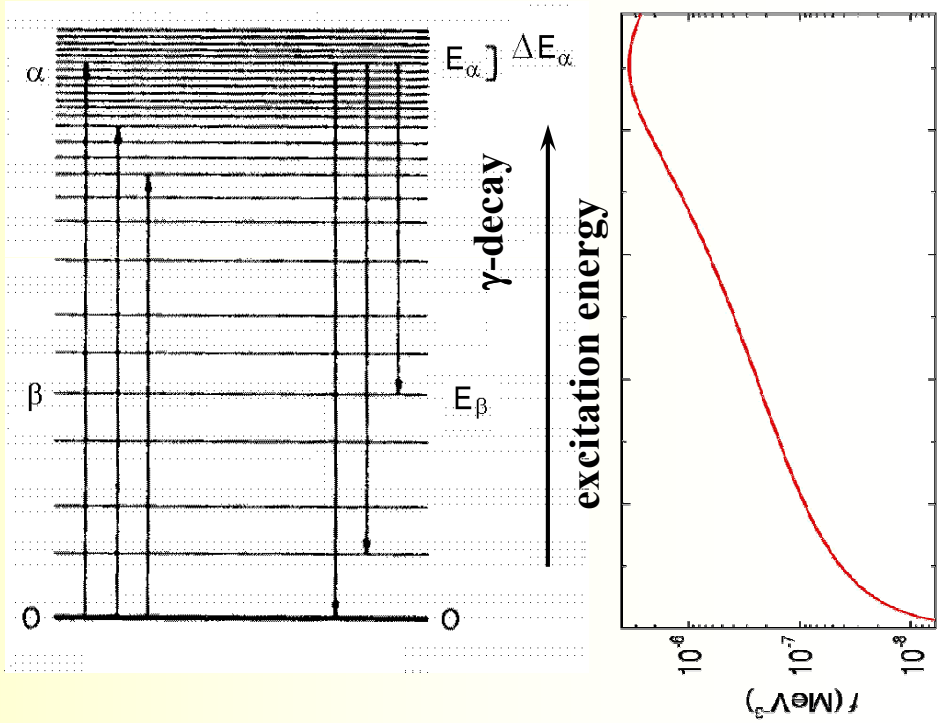
- PSFs describe the (average) energy distribution of photon emission from “highly-excited” states or cross section for photon absorption (detailed balance principle)

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

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

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

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



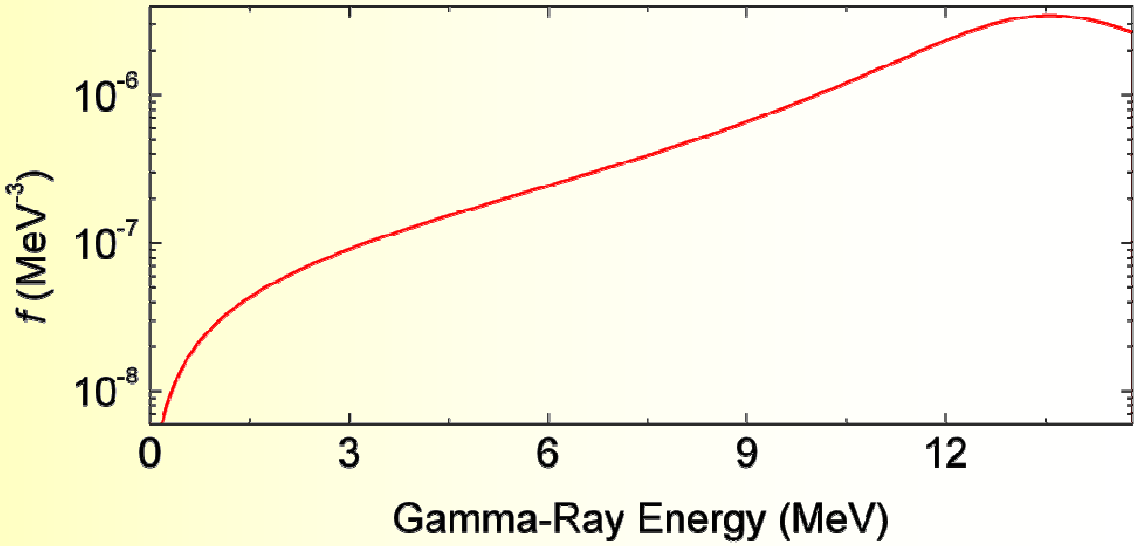
- Individual intensities fluctuate (according to Porter-Thomas distribution)

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}) ?

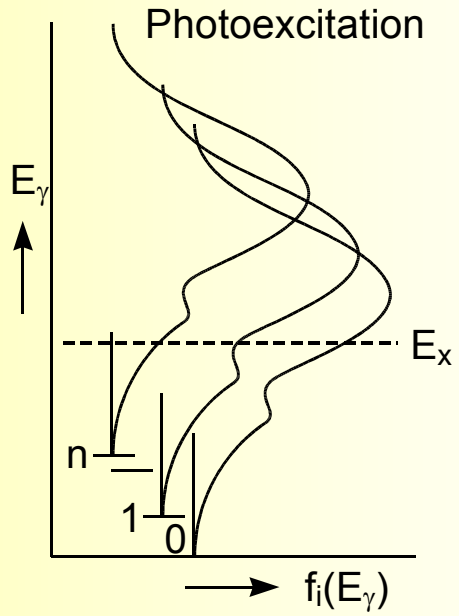
  $\Rightarrow$ Brink hypothesis



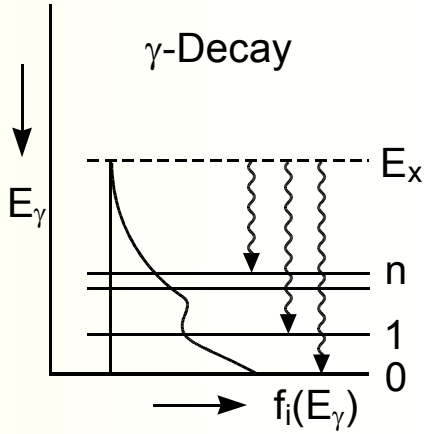
Brink hypothesis

- 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},…

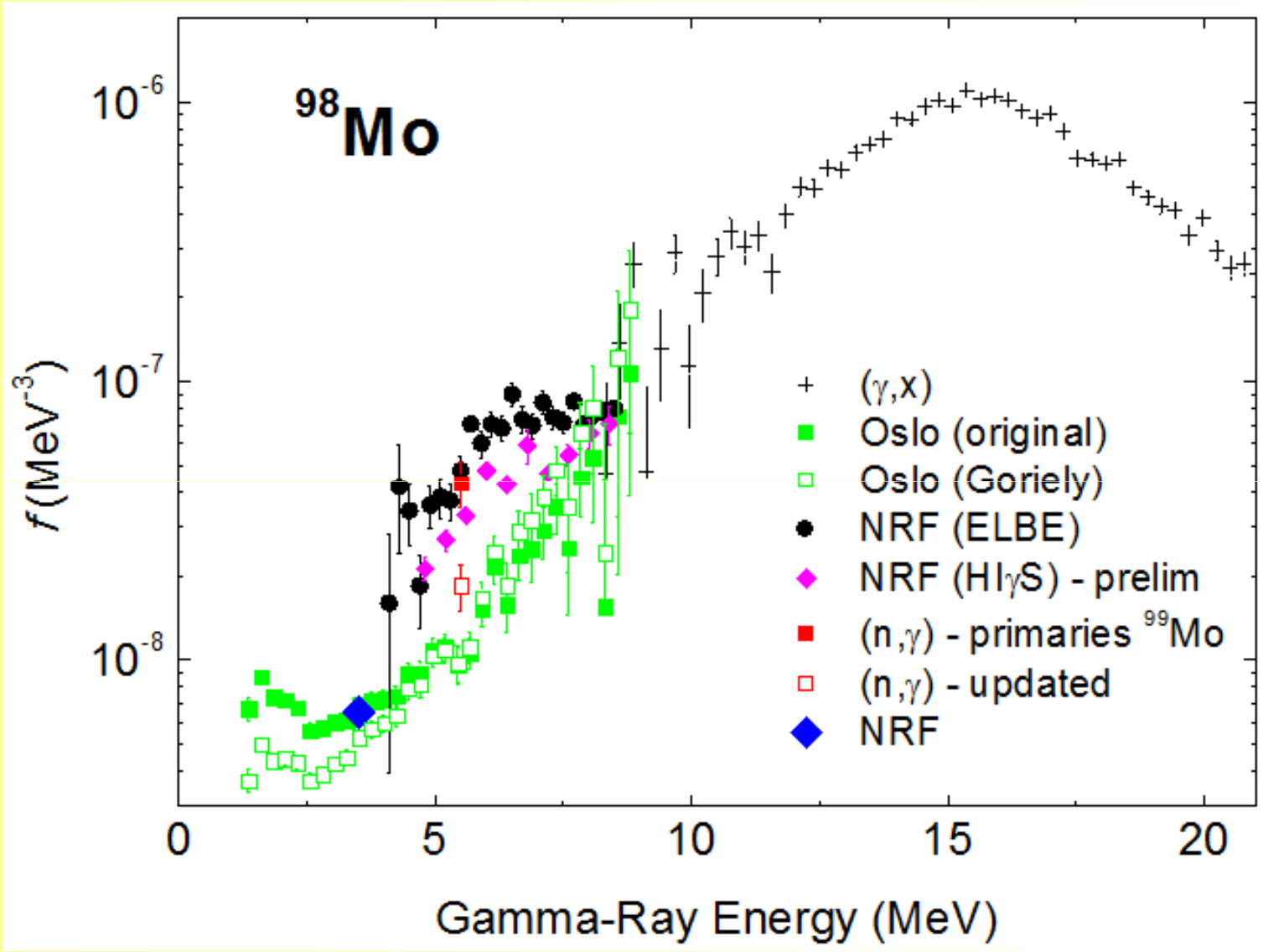
- validity of the hypothesis?
- at least approximately - from (n,γ) reaction, hot nuclei, Oslo method
- some signs for temperature dependence



$$f_0(E_\gamma) = f_1(E_\gamma) = f_n(E_\gamma) = f(E_\gamma)$$



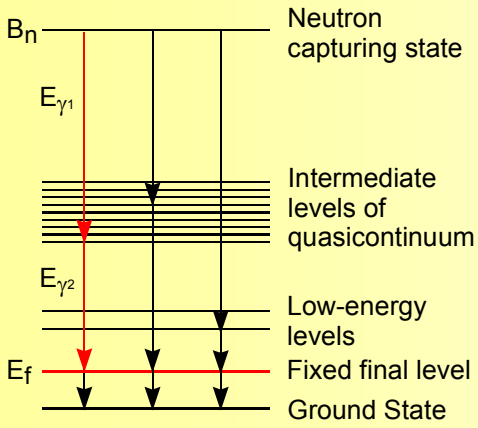
Are results consistent?

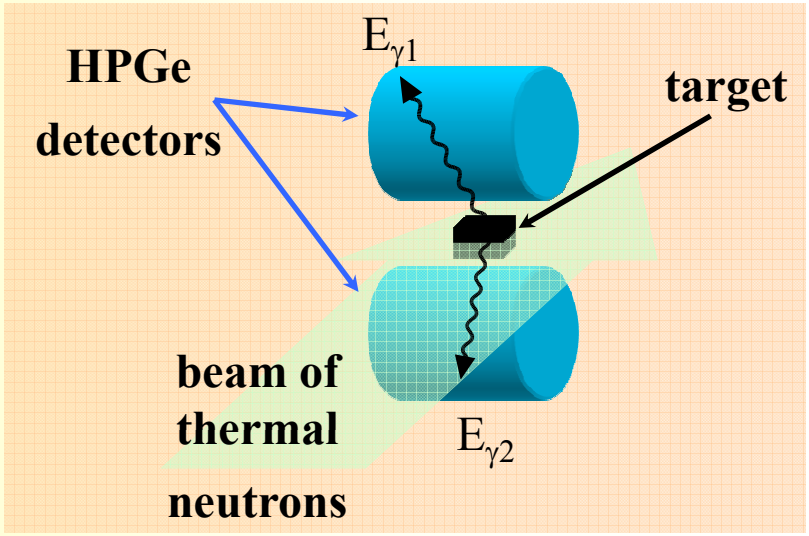


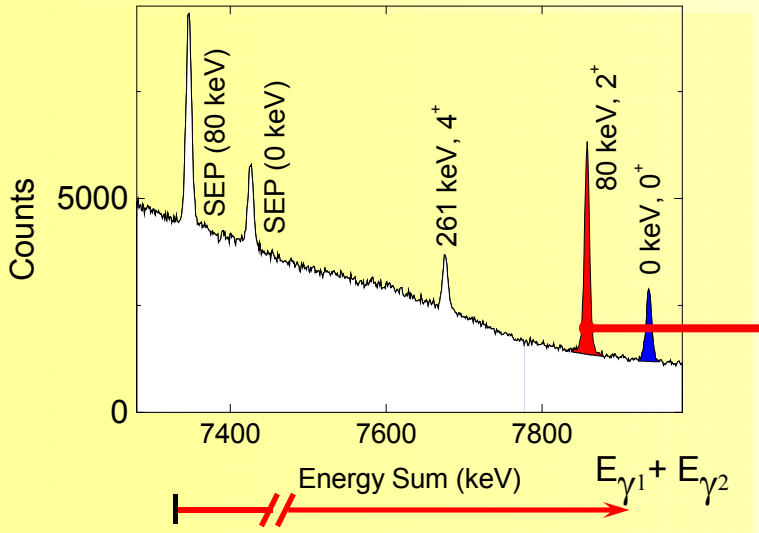
based on G. Rusev et al., PRC77, 064321 (2008)

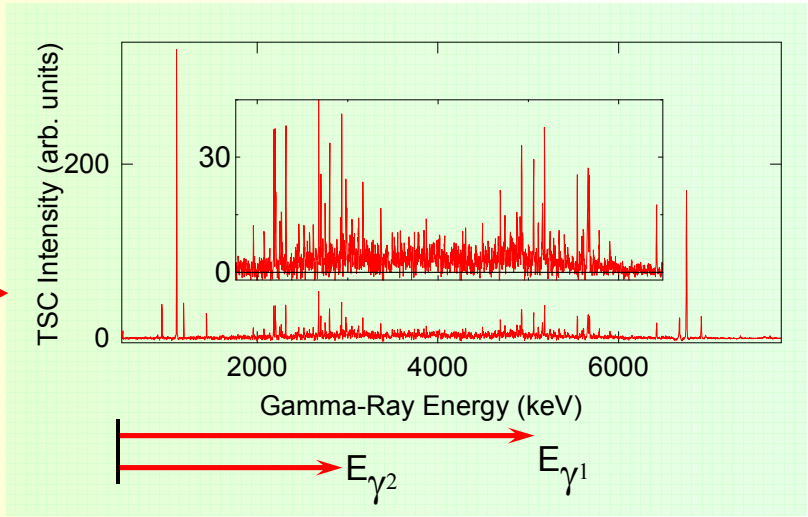
TSC spektra

capture of thermal neutrons

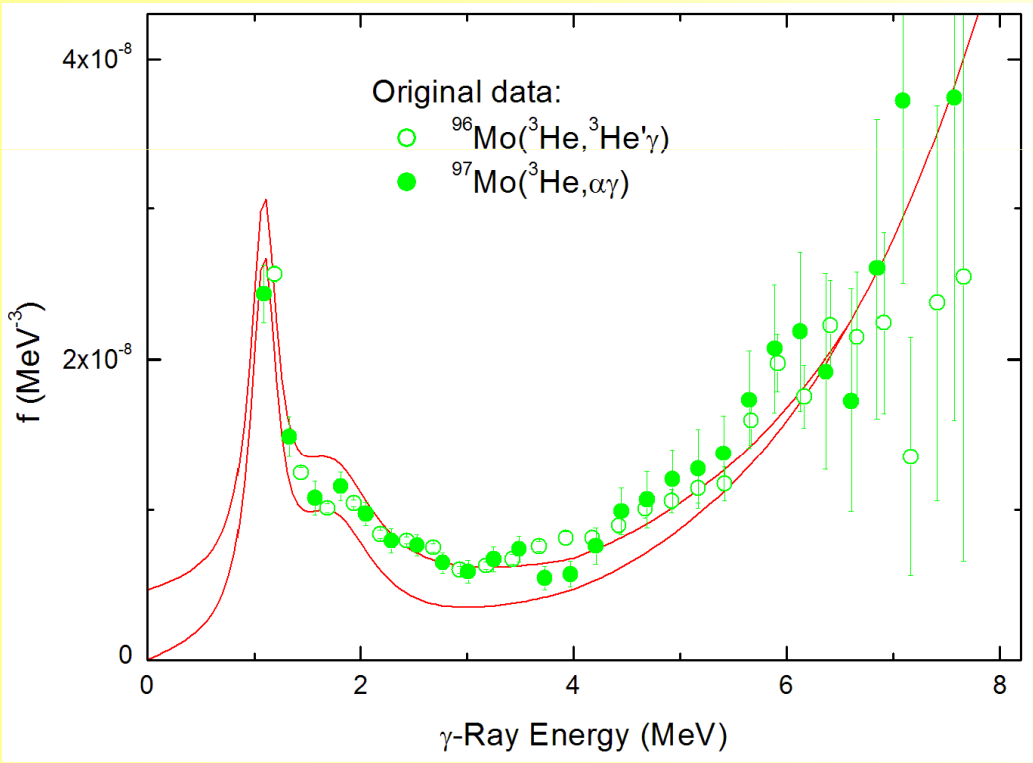


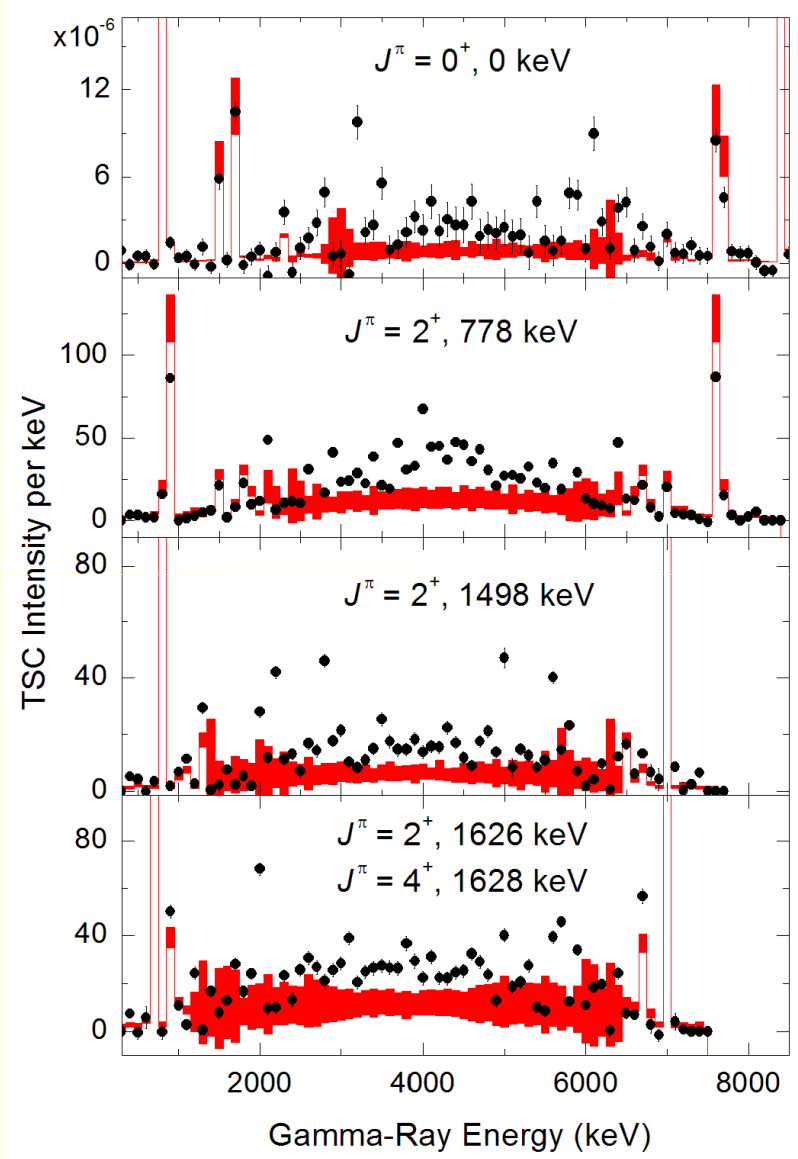




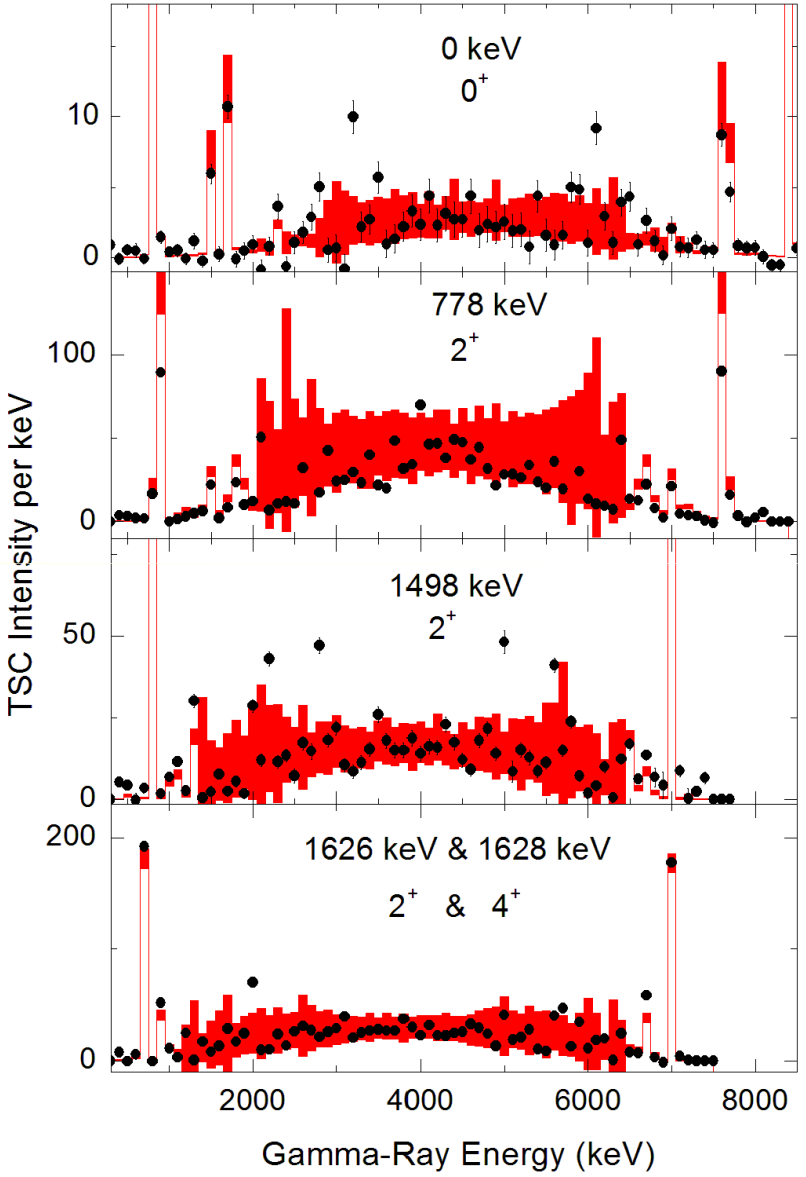


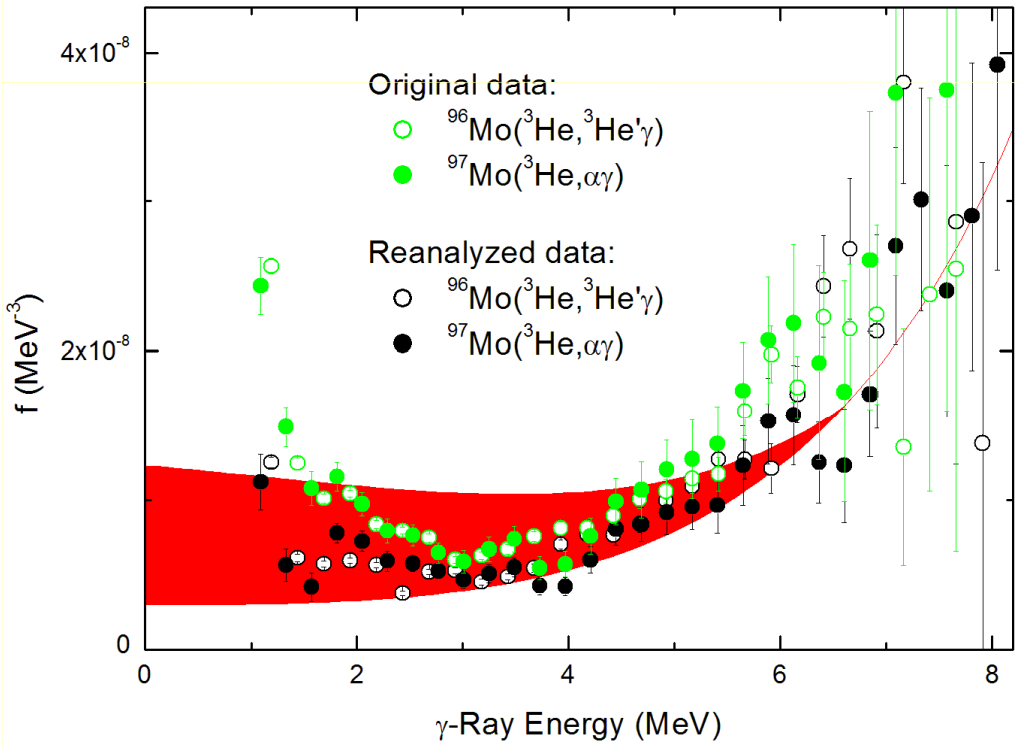
TSC spectra in ^{96}Mo



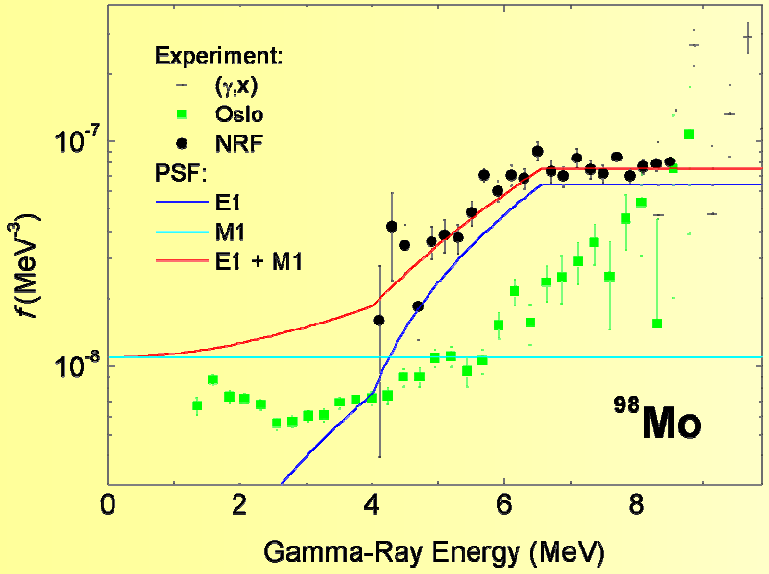


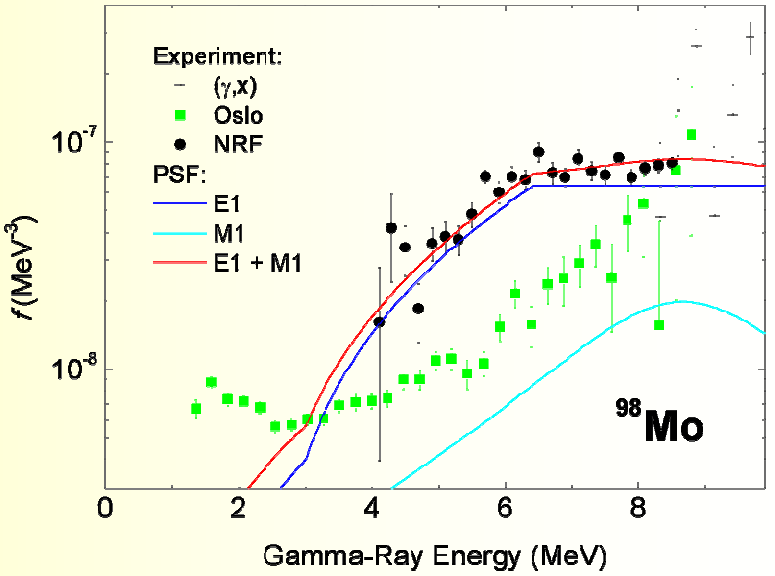
TSC spectra in ^{96}Mo

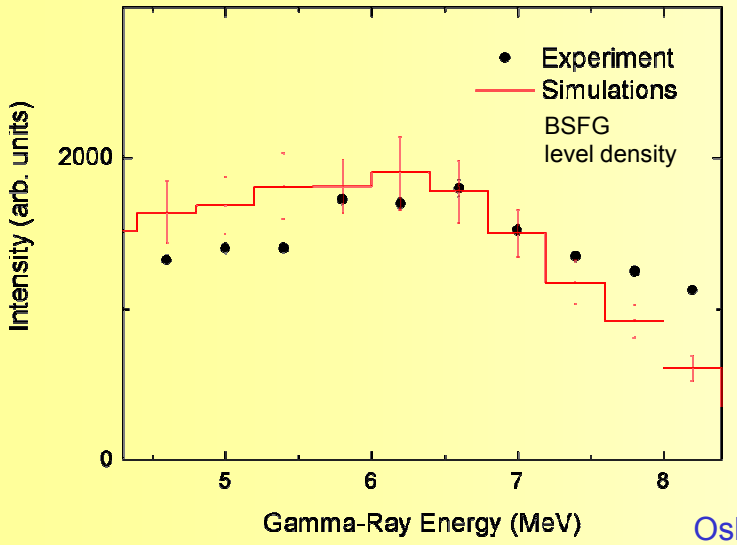


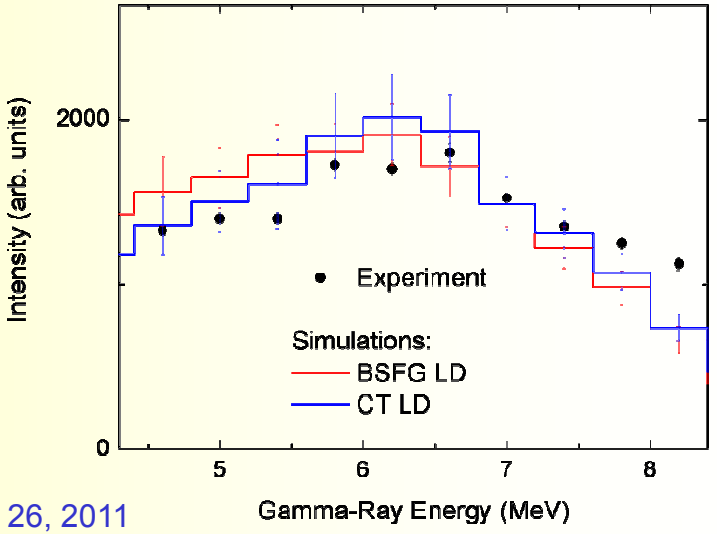


NRF with beam from “bremsstrahlung”

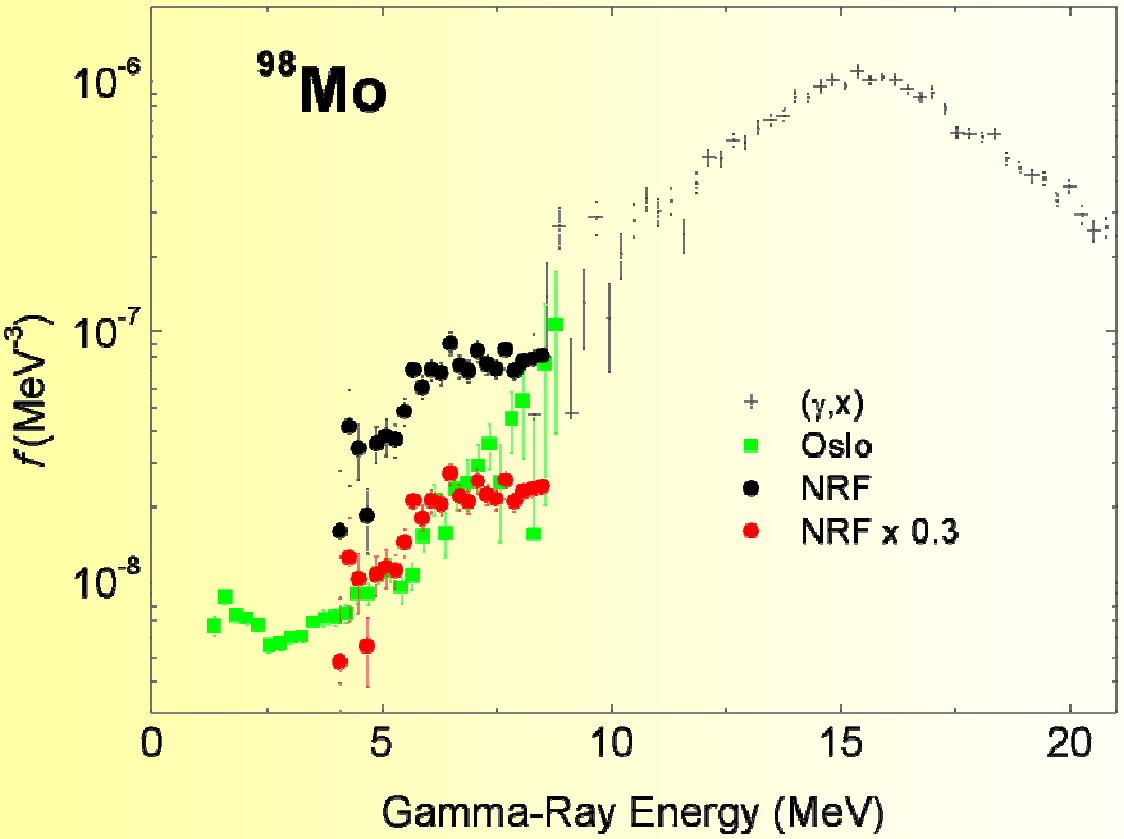








And a “wild” speculation



But this would induce other problems

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