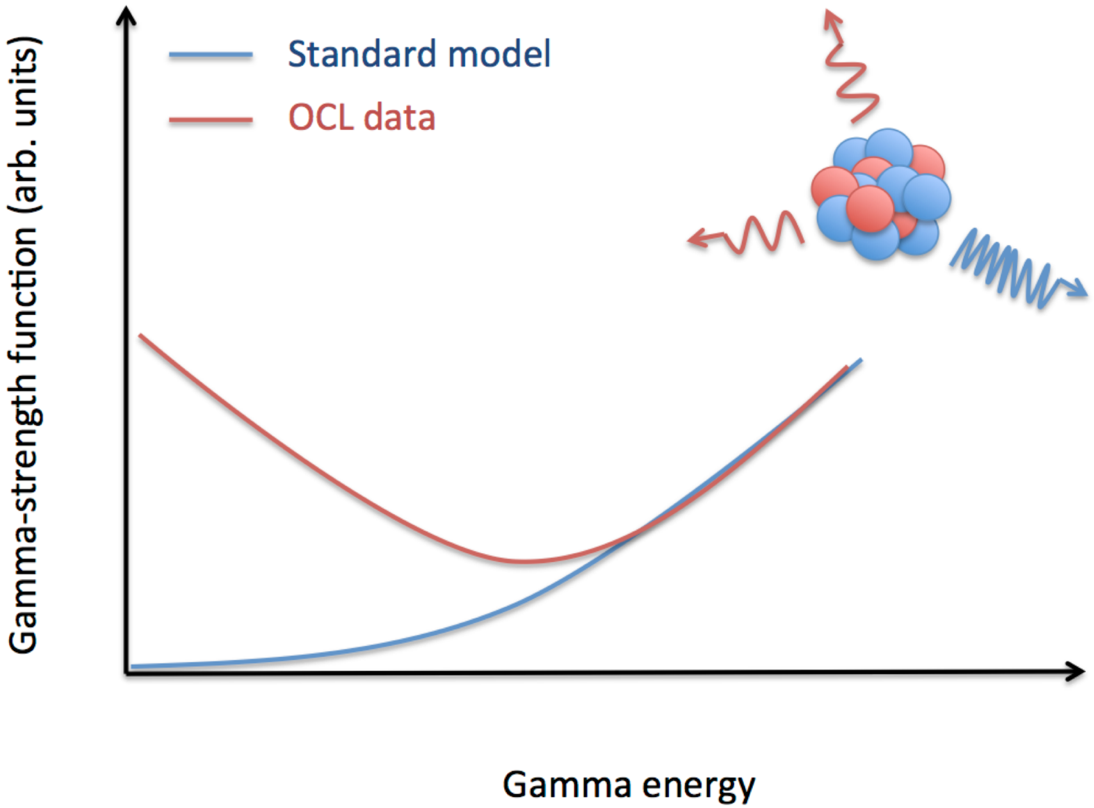
Demystifying the γ-strength function ⚡



Lecture FYS4515, Friday 4 October, 2019

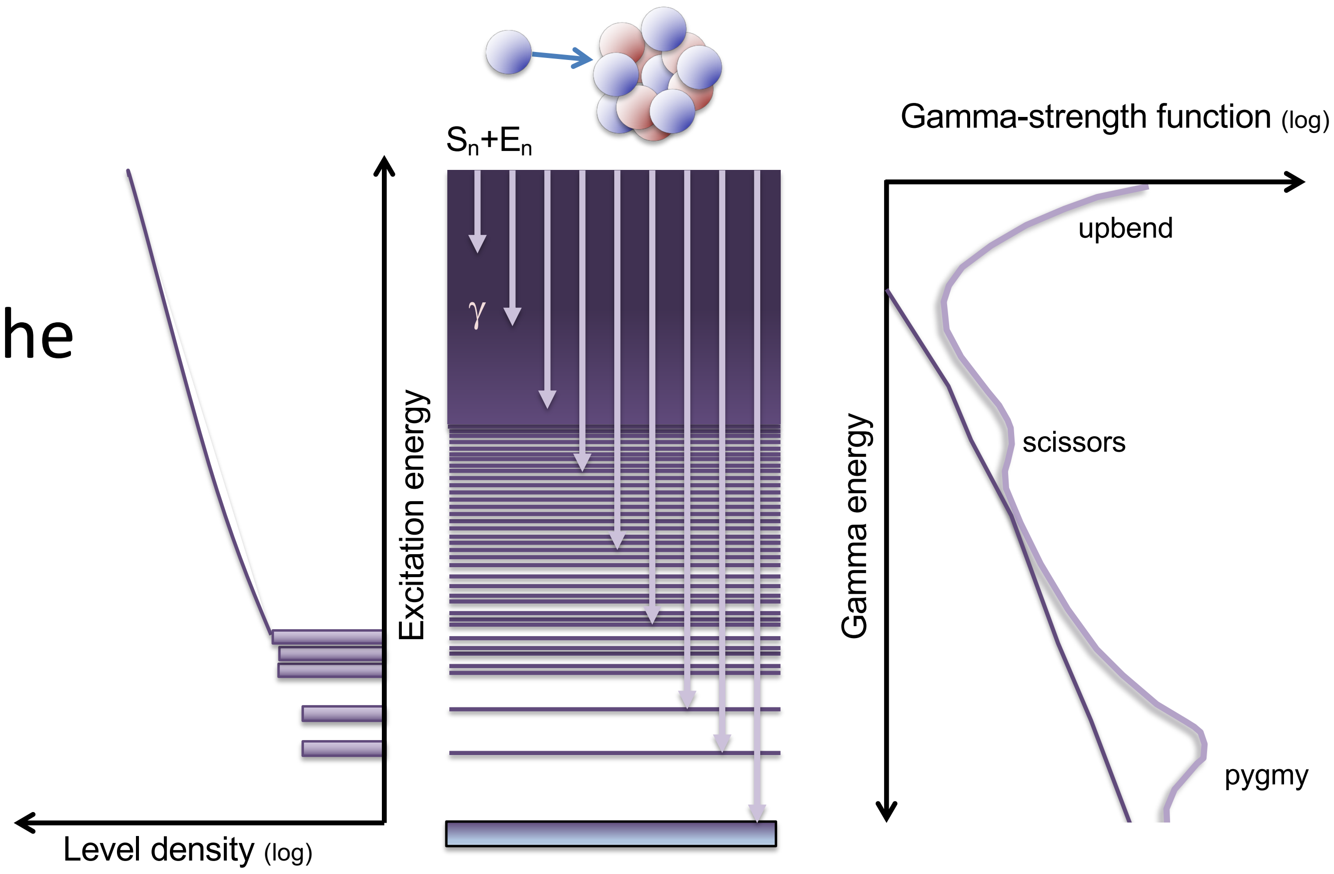
Ann-Cecilie Larsen a.c.larsen@fys.uio.no

What do you think the γ-strength function is? 🤔

- Discuss ~2-3 minutes

Suggestions after discussing:

- Function relating energy of the gamma with respect to the excitation energy?
- Angle of the gamma ray?
- Cross section?



Definition of the γ-strength function 🤓

Bartholomew et al., Advances in Nuclear Physics 7, 229 (1973):

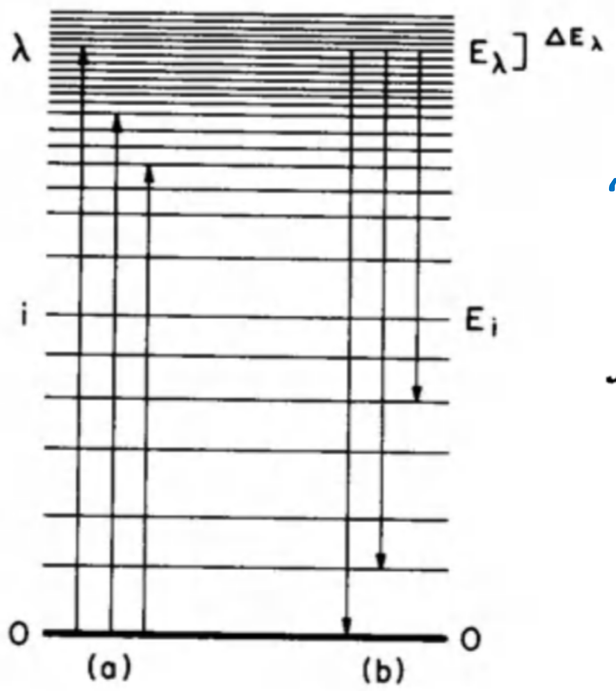
[Provided in Canvas under Part 3: Reading Material – Gamma-Strength Function]

"The γ-ray strength function as used herein is the distribution, as a function of γ-ray energy, of the average reduced width for transitions of a particular multipole type."

"Upward" strength

$$\vec{f}^{J}_{0\lambda XL}(E_\gamma) = \frac{\bar{\Gamma}^{J}_{\gamma 0\lambda XL}\,\varrho_J(E_\lambda)}{E_\gamma^{2L+1}}$$

NOTE: *partial* width, not *total* width



"Downward" strength

$$\overleftarrow{f}^{J}_{i\lambda XL}(E_\gamma) = \frac{\bar{\Gamma}^{J}_{\gamma i\lambda XL}\,\varrho_J(E_\lambda)}{E_\gamma^{2L+1}}$$

Connecting the γ-strength function with reduced transition strength

Let us recapitulate from Andreas' lectures:

Reduced transition strength:
$$B(XL, J_i \rightarrow J_f) = \frac{1}{2J_i+1} \sum_{M_i, M_f} |\langle f|\mathcal{O}_{LM_L}|i\rangle|^2,$$

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

where (2L+1)!! = 1 x 3 x 5 x … x (2L+1).

Using $\Gamma = \hbar\lambda$,
$$\Gamma(X1) = \frac{16\pi}{9}\left(\frac{E_\gamma}{\hbar c}\right)^3 B\!\downarrow(X1)$$

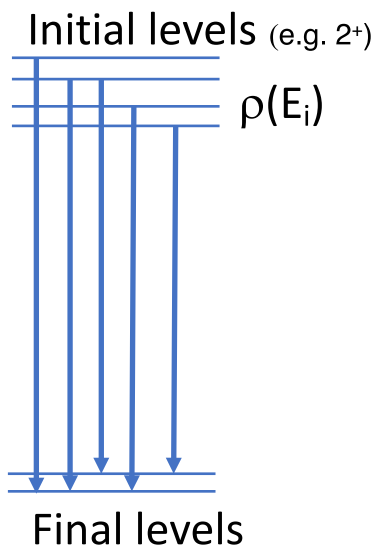
$$\Gamma(X2) = \frac{4\pi}{75}\left(\frac{E_\gamma}{\hbar c}\right)^5 B\!\downarrow(X2),$$

Connecting the γ-strength function with reduced transition strength (II)

Now we use the definition of the γ-strength function [using a more "modern" notation]:

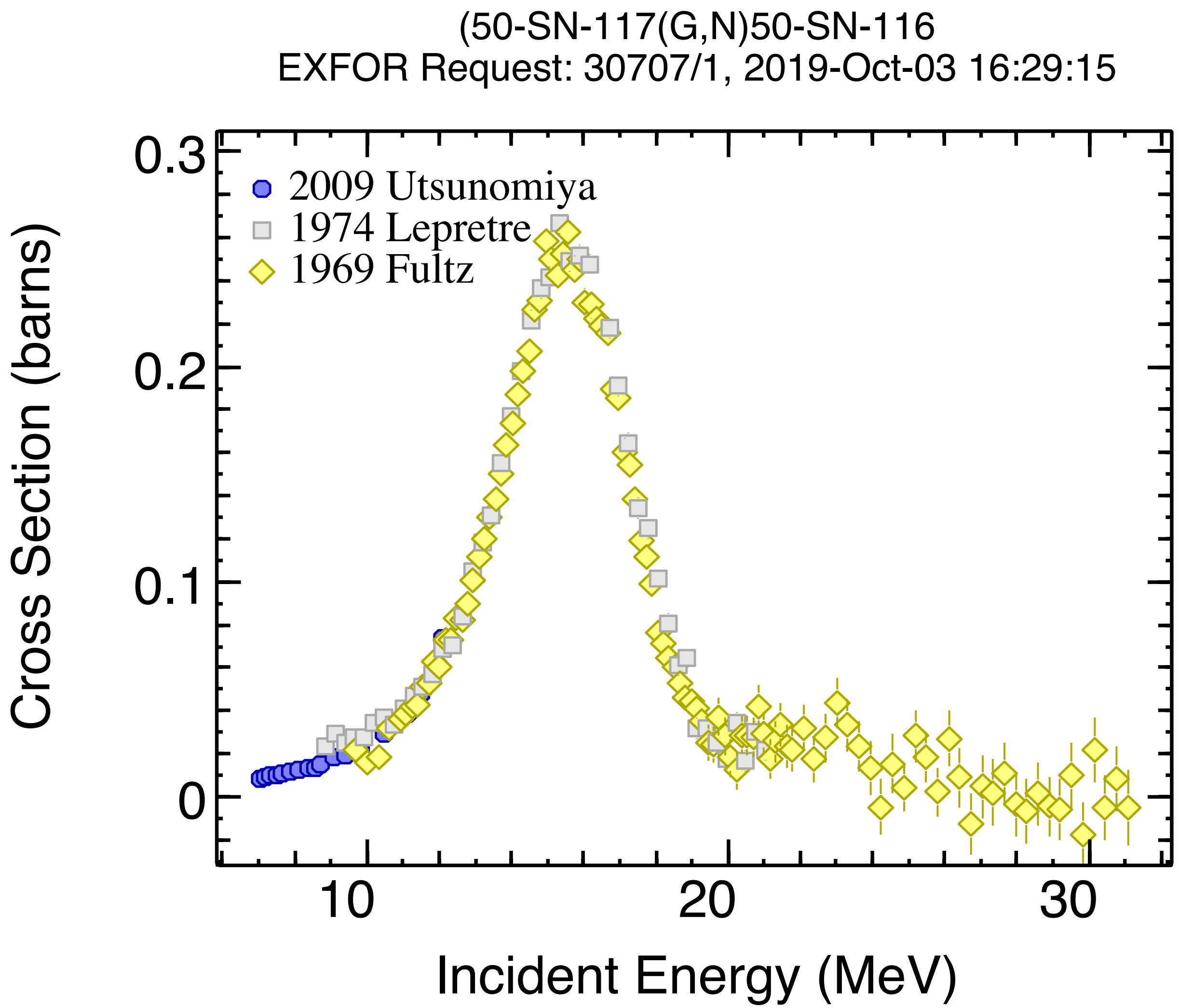
$$f_{XL}(E_\gamma, E_i, J_i, \pi_i) = \frac{\langle \Gamma_\gamma^{XL} \rangle (E_\gamma, E_i, J_i, \pi_i)}{E_\gamma^{2L+1}} \rho(E_i, J_i, \pi_i)$$

$$= \frac{16\pi}{9\hbar^3 c^3} \langle B(XL) \rangle (E_\gamma, E_i, J_i, \pi_i) \rho(E_i, J_i, \pi_i)$$



Photoabsorption/photonuclear experiments

- Shoot photons on the nucleus, measure neutrons that come out (above the neutron separation energy)



https://www-nds.iaea.org/exfor/

Photoabsorption/photonuclear experiments

From (γ,n) cross section to upward strength function
[Bartholomew 1973, from Axel 1968]:

$$\vec{f}^{J}_{0\lambda XL}(E_\gamma) = 26 \cdot 10^{-8} \frac{\bar{\sigma}^{J}_{\gamma a XL}(E_\gamma)}{g_J E_\gamma^{2L-1}} (\mathrm{MeV})^{-(2L+1)}$$

The g_J is the statistical factor $(2J+1)/(2J_0+1)$ taking into account the magnetic substates

Generally:

$$f_{XL}(E_\gamma) = \frac{1}{(2L+1)(\pi\hbar c)^2} \frac{\langle \sigma_{XL}(E_\gamma) \rangle}{E_\gamma^{(2L-1)}}$$

For all practical applications, E1 dominates:

$$f(E_\gamma) = \frac{1}{3\pi^2\hbar^2c^2} \frac{\sigma_{\gamma n}(E_\gamma)}{E_\gamma}$$

$$1/3\pi^2\hbar^2c^2 = 8.674 \times 10^{-8}\,\mathrm{mb}^{-1}\,\mathrm{MeV}^{-2}$$

… but what about the region below S_n? 🤔

- Traditionally: primary γ rays from neutron capture experiments discrete resonance and resonance-averaged γ rays
- (γ,γ') experiments, also called Nuclear Resonance Fluorescence (peak analysis)
- (e,e') experiments

More recently:

- (p,p') at very high energies and forward angles (~0 degrees)
- Coulomb dissociation experiments
- (γ,γ') including the unresolved part of the spectrum & (α,α'γ)
- Spectrum fitting (total spectra or two-step cascade spectra)
- Oslo method
- Beta-Oslo method
- Ratio & shape method

$$\overleftarrow{f}^{J}_{i\lambda XL}(E_\gamma) = \frac{\overline{\Gamma}^{J}_{\gamma i\lambda XL}\,\varrho_J(E_\lambda)}{E_\gamma^{2L+1}}$$

See also A.C. Larsen, A. Spyrou, S.N. Liddick, M. Guttormsen, Prog.Part. Nucl. Phys. **107**, 69 (2019)
https://doi.org/10.1016/j.ppnp.2019.04.002
- also on Canvas: Part 3: Reading Material – Gamma-Strength Function

… but what about the region below S_n? 🤔

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Dipole radiative strength functions from resonance neutron capture

Carol M. McCullagh,* Marion L. Stelts,† and Robert E. Chrien
Brookhaven National Laboratory, Physics Department, Upton, New York 11973
(Received 22 October 1980)

Photon strength functions have been derived from discrete neutron resonance data for electric and magnetic dipole radiation using the methods of slow neutron time-of-flight spectroscopy. The data cluster reasonably well around strengths of $b(E1) \cong 0.04$ Weisskopf units/MeV and $b(M1) = 1.4$ Weisskopf units/MeV, respectively.

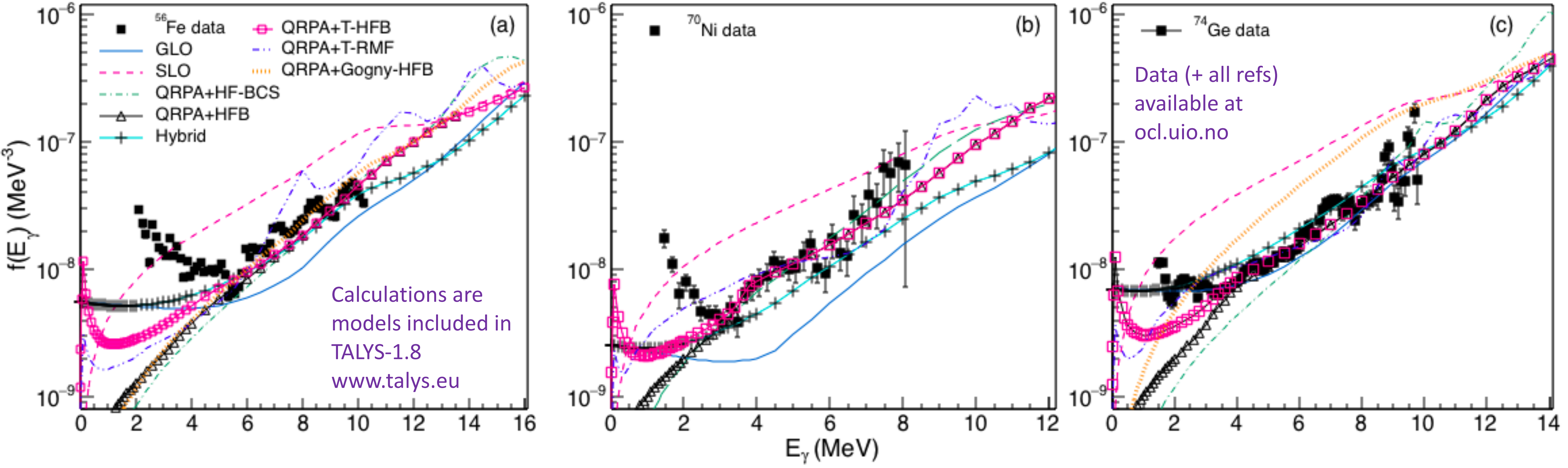
[NUCLEAR REACTIONS Measured $\Gamma_{\gamma if}$, J, π, $\sigma(n,\gamma)$; derived $\langle \Gamma_{\gamma if} \rangle$, $\Gamma/D(E1)$, $\Gamma/D(M1)$.]

$$\overleftarrow{f}^{J}_{i\lambda XL}(E_\gamma) = \frac{\overline{\Gamma}^{J}_{\gamma i\lambda XL}\,\varrho_J(E_\lambda)}{E_\gamma^{2L+1}}$$

See also A.C. Larsen, A. Spyrou, S.N. Liddick, M. Guttormsen, Prog.Part. Nucl. Phys. **107**, 69 (2019)
https://doi.org/10.1016/j.ppnp.2019.04.002

On the theoretical side 🤓

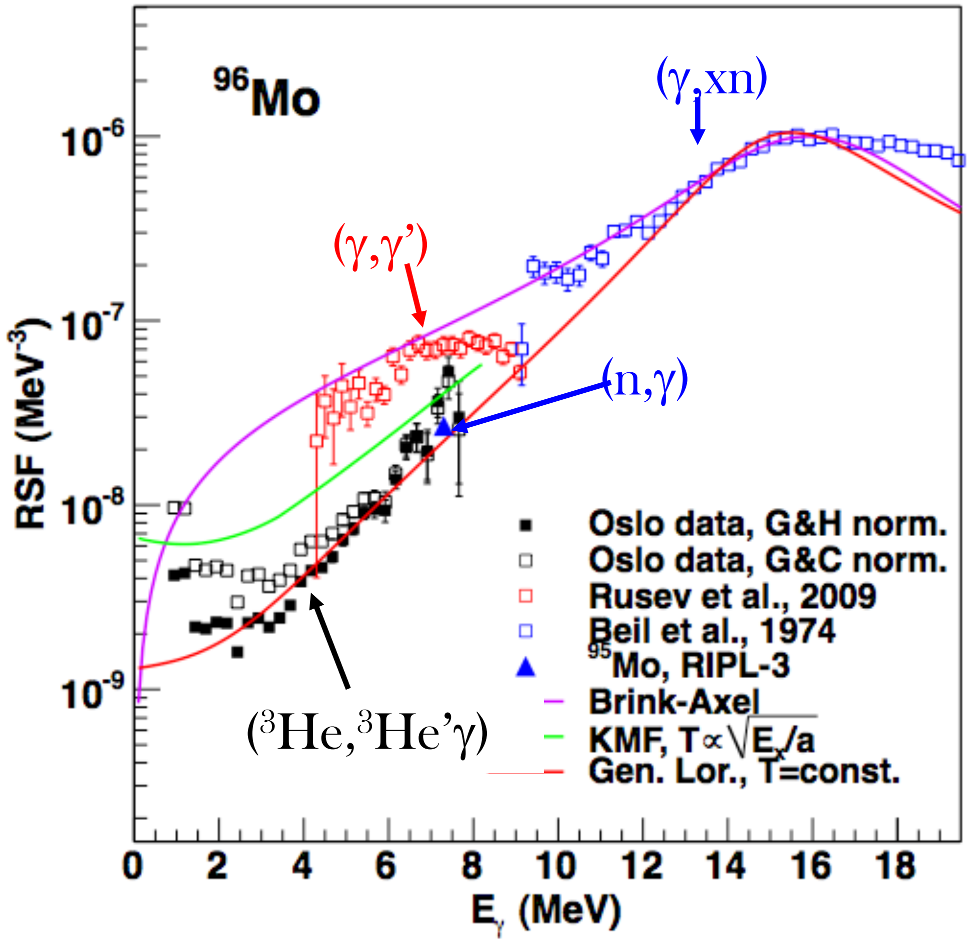
Standard Lorentzian, Generalized Lorentzian, Kadmenskii-Markushev-Furman, various more or less microscopic models (quasi-particle random-phase approximation combined with Hartree-Fock(Bogoliubov), multi-phonon model, …)



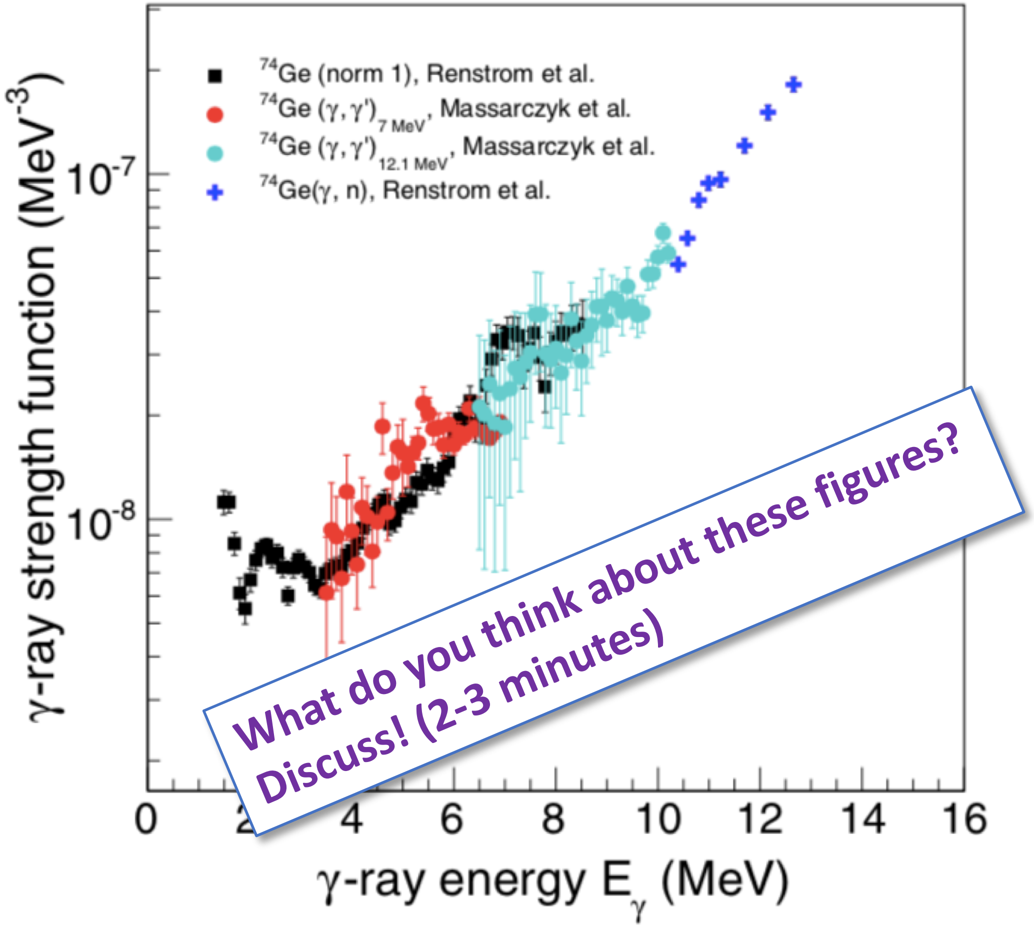
… but no universal description for all mass regions and resonance-like phenomena

Do experiments agree with each other? 🤔

From my talk at the Dresden conference, 2010



From Therese Renstrøm et al., Phys. Rev. C (2016)



Let us now go back to the basics: Interpretation of D and Γ, and getting the γ-ray transmission coefficient

From Blatt & Weisskopf (1952), pages 386-389:

- Semi-classical approach (correspondence principle)
- Linear combinations of wave functions of neighboring, stationary states, corresponding to a group of particles [generalize to decay]
- Motion of particles (nucleons) for highly excited states
- Periodic motion with period *P*

[I will add a little note showing what I did on the black board on Canvas: Part 3: Reading Material – Gamma-Strength Function]

Coming lectures

Detailed balance – is the upward and downward strength function the same?

The Brink hypothesis (From Brink's doctoral thesis, Oxford, 1955):

In the above paragraphs we have considered the nuclear photo effect from the ground state of the nucleus. Now we assume that the energy dependence of the photo effect is independent of the detailed structure of the initial state so that, if it were possible to perform the photo effect on an excited state, the cross section for absorbtion of a photon of energy E would still have an energy dependence given by (15). In the following paragraphs a calculation of the radiative widths of neutron resonances will be made on the basis of this assumption.

The final project

- Master students work in pairs
- PhD students will use OMpy in addition to the usual Oslo-method software
- Fabio will tell about & show OMpy on Tuesday 8 Oct
- Hand in on Canvas
- Deadline Nov 8, 17:00 (5PM)