Slow-Neutron Capture: *Present Status and Outlook*

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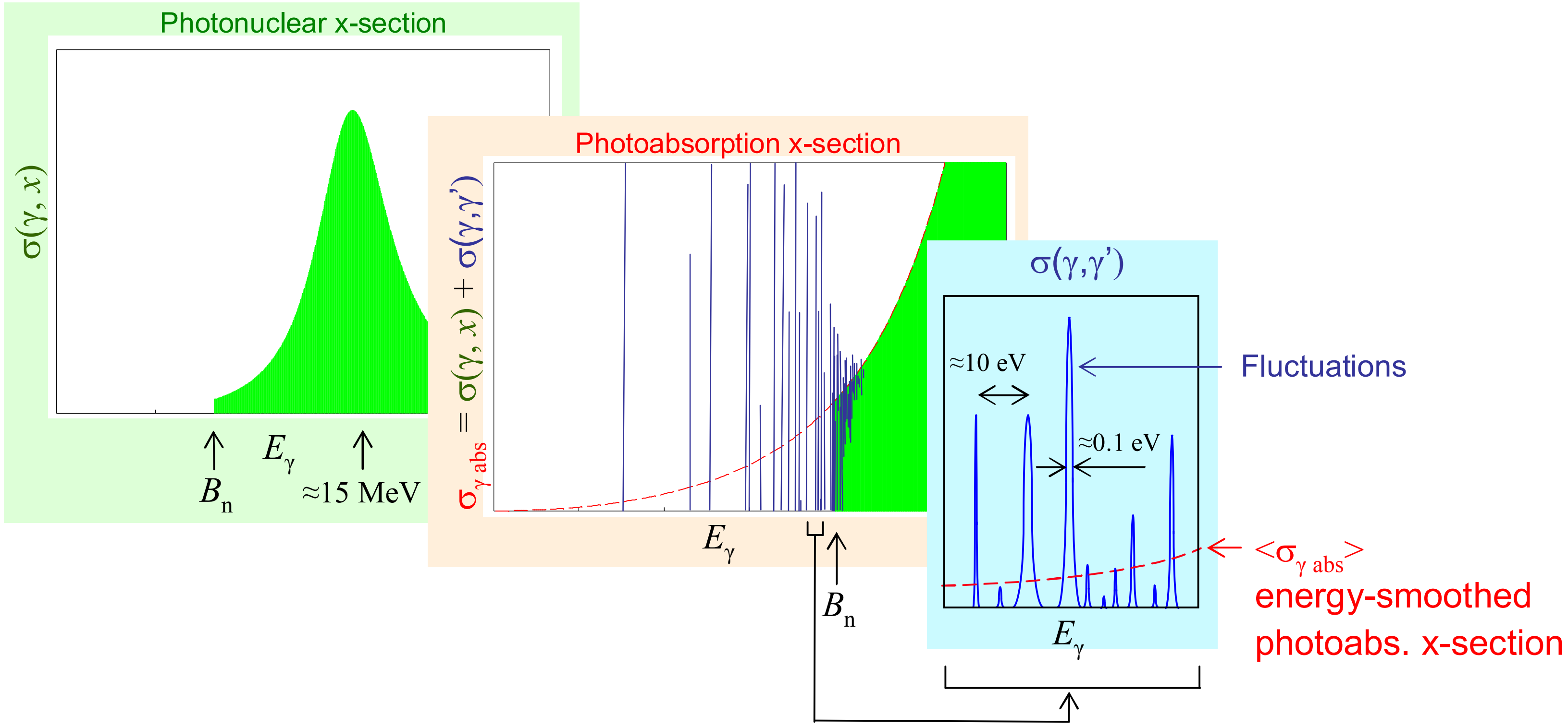
faculty of mathematics and physics

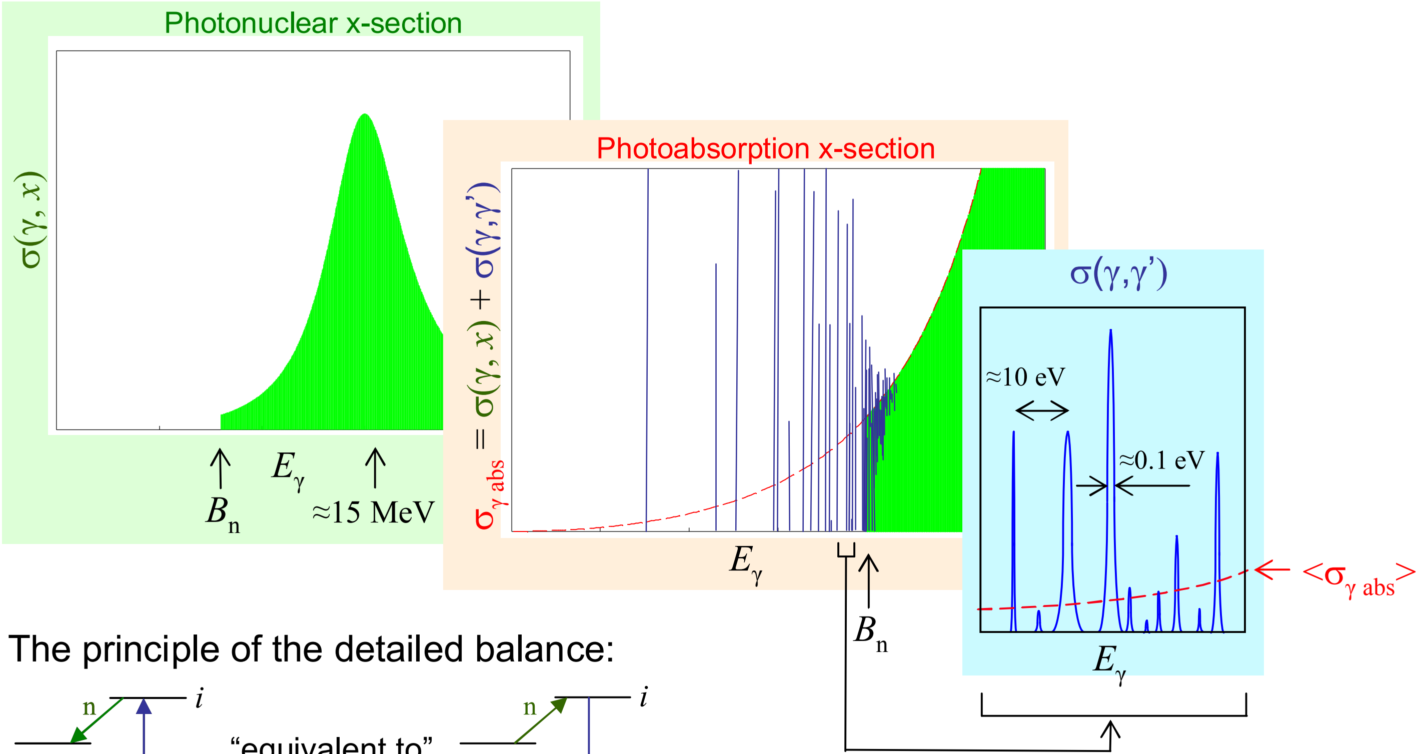
Cornerstones of the *extreme* statistical model of γ decay

- Porter-Thomas distribution of partial radiation widths
- A notion of strength function
  (fragmentation of strength of simple nuclear states)
- The principle of the detailed balance
- Brink hypothesis
- … and rather problematic absence of width correlation

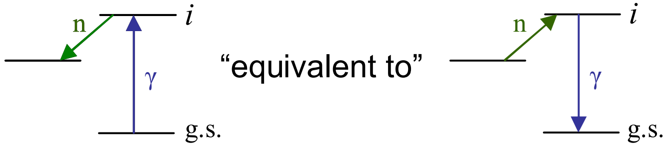
Fragmentation of the GDR and the paradigm of the photon strength function



Fragmentation of the GDR
and the paradigm of the photon strength function

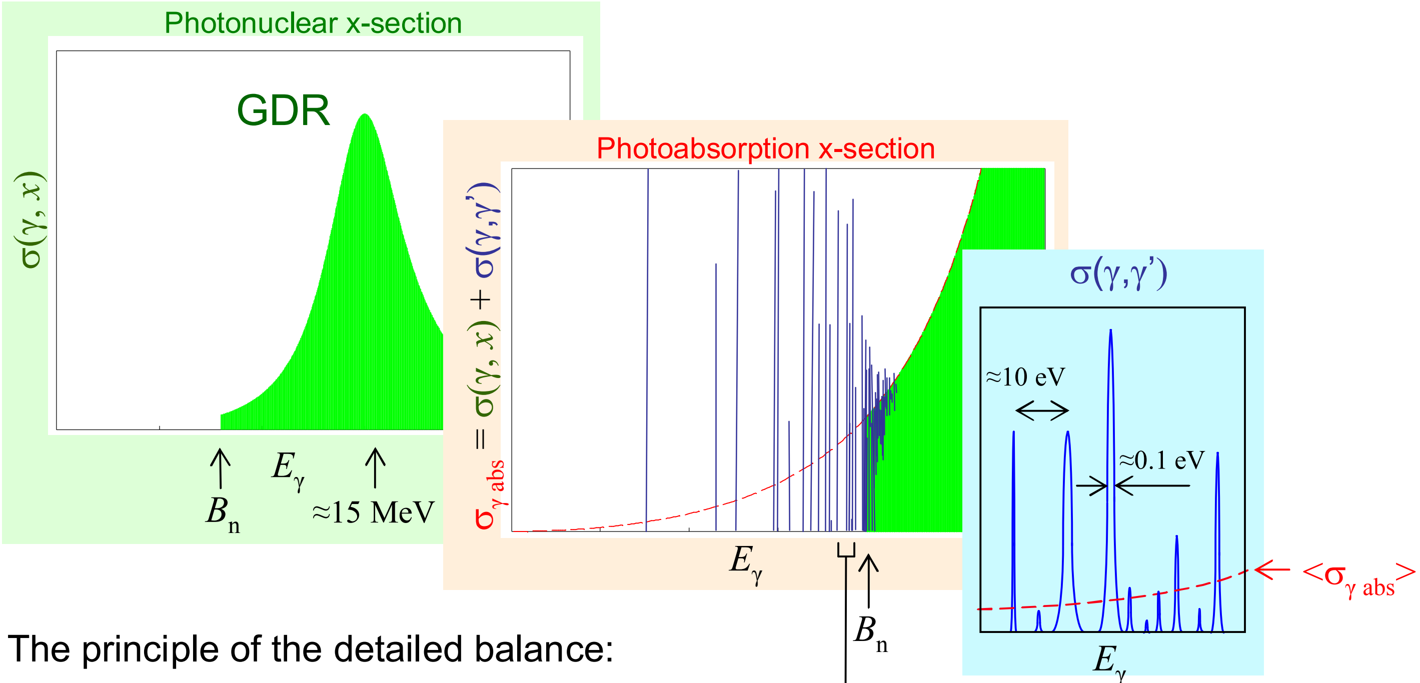


The principle of the detailed balance:



Quantitatively: $k_\gamma^2\,\sigma_{\gamma n} = k_n^2\,\sigma_{n\gamma}$

Fragmentation of the GDR
and the paradigm of the photon strength function



The principle of the detailed balance:

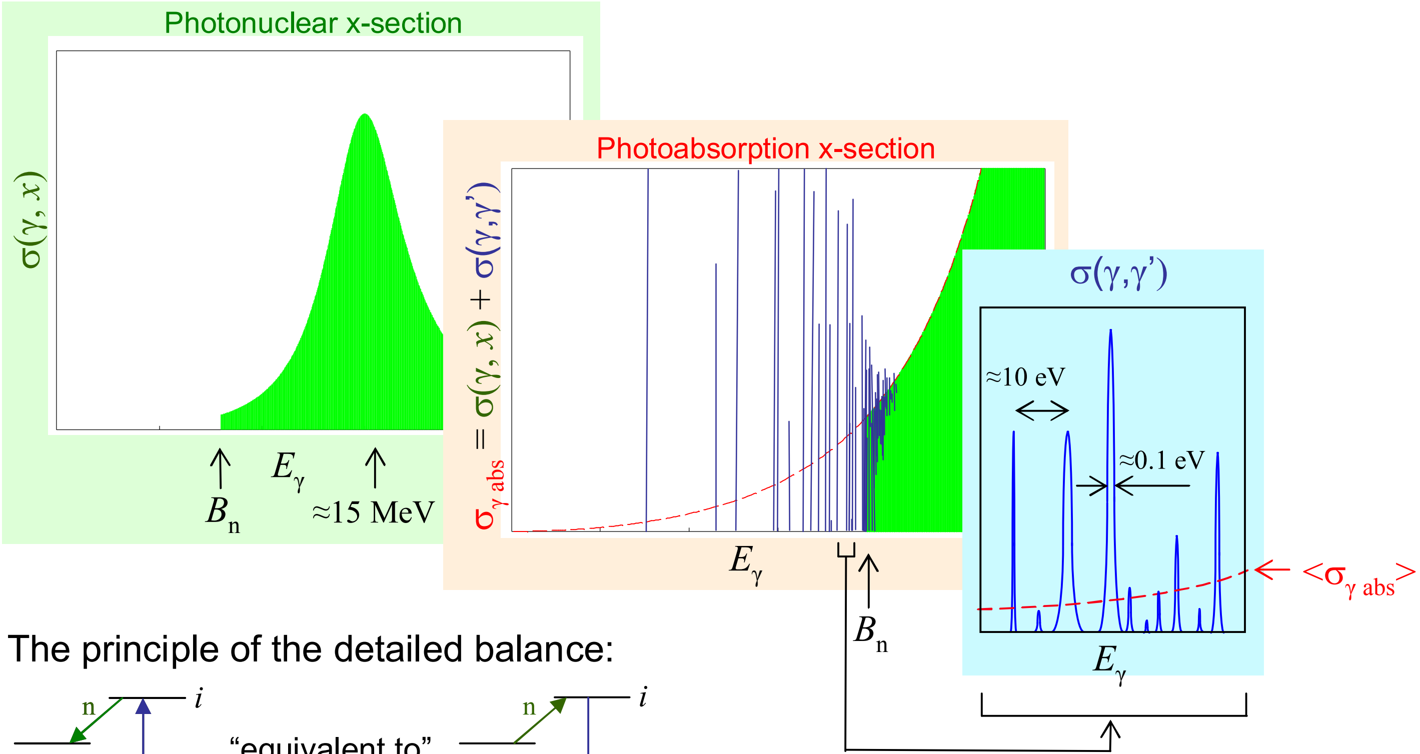
If *E*1 transitions dominate and the non-resonance process is negligible

$$\langle \Gamma_{i\gamma \mathrm{g.s.}} \rangle = f^{(E1)}(E_\gamma)\, E_\gamma^{3} / \rho(E_i)$$

$$f^{(E1)}(E_\gamma) = \langle \sigma_{\gamma\, \mathrm{abs}}(E_\gamma) \rangle / (3\, \pi^2 \hbar^2 c^2 E_\gamma)$$

— **Photon strength function**

Fragmentation of the GDR and the paradigm of the photon strength function



The principle of the detailed balance:

The paradigm of PSF: $f^{(XL)}$ and ρ are <u>generic</u>, not derived quantities

In a general case

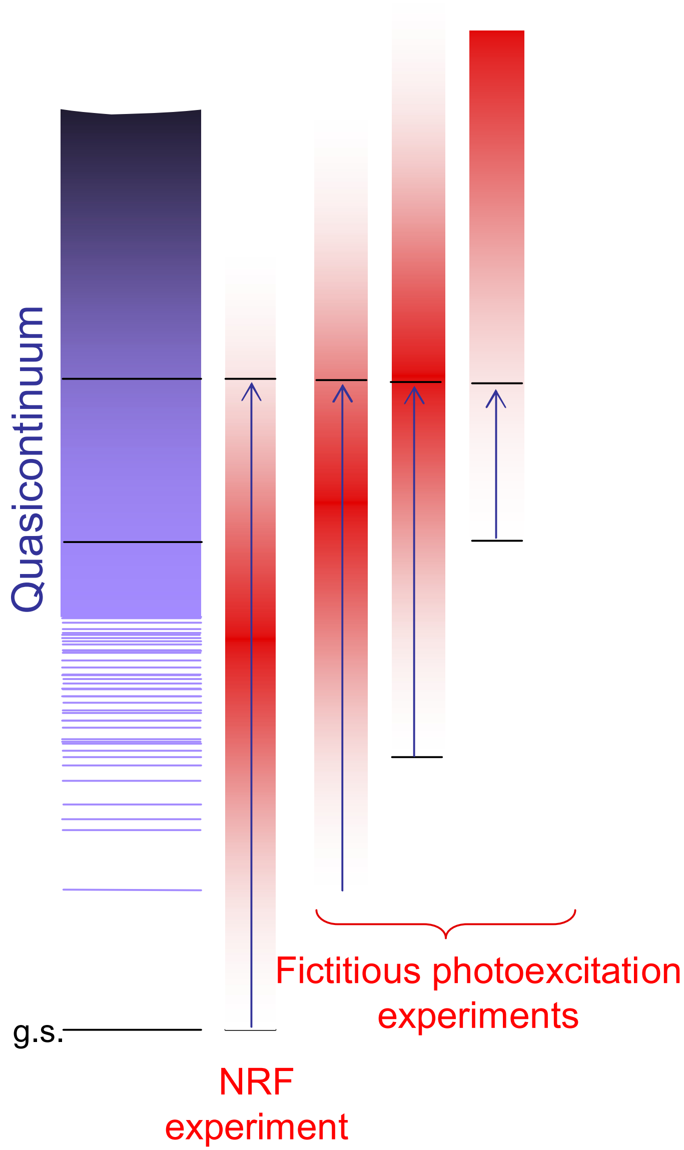
$$\langle \Gamma_{i\gamma g.s.}^{(XL)} \rangle = f^{(XL)}(E_\gamma)\, E_\gamma^{2L+1} / \rho(E_i)$$

$$f^{(XL)}(E_\gamma) \equiv \langle \sigma_{\gamma\,abs}^{(XL)}(E_\gamma) \rangle / [(2L+1)\pi^2 \hbar^2 c^2 E_\gamma]$$

$$\langle \sigma_{\gamma\,abs}(E_\gamma) \rangle = \Sigma_{XL} \langle \sigma_{\gamma\,abs}^{(XL)}(E_\gamma) \rangle$$

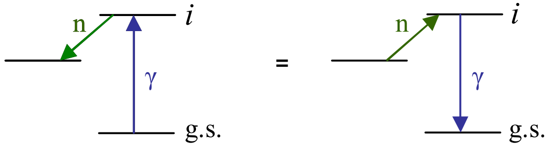
Brink hypothesis

Photoexcitation pattern does not depend on initial excitation energy of a target nucleus



Brink hypothesis

A target in photonuclear/photoabsorption experiment is in the ground state



$$<\Gamma_{i\gamma g.s.}^{(XL)}> = f^{(XL)}(E_\gamma)\, E_\gamma^{2L+1}/\rho(E_i)$$

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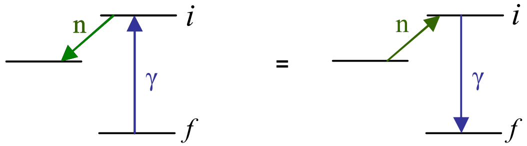
$$<\sigma_{\gamma\, abs}(E_\gamma)> = \Sigma_{XL} <\sigma_{\gamma\, abs}^{(XL)}(E_\gamma)>$$

Identical !

Brink: generalization "g.s." → "*f* "



$$<\Gamma_{i\gamma f}^{(XL)}> = f^{(XL)}(E_\gamma)\, E_\gamma^{2L+1}/\rho(E_i)$$

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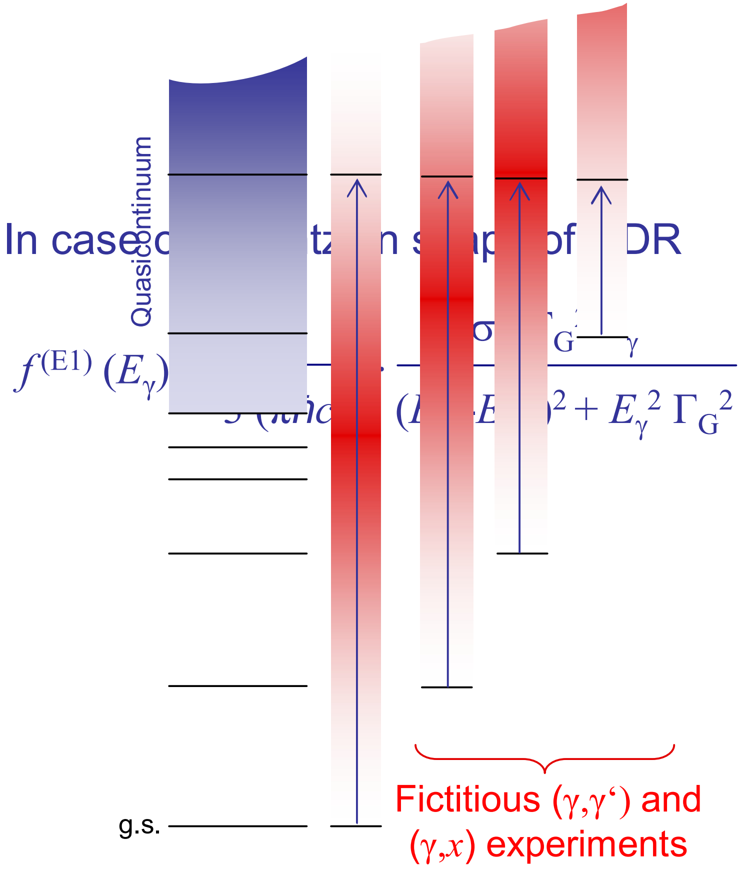
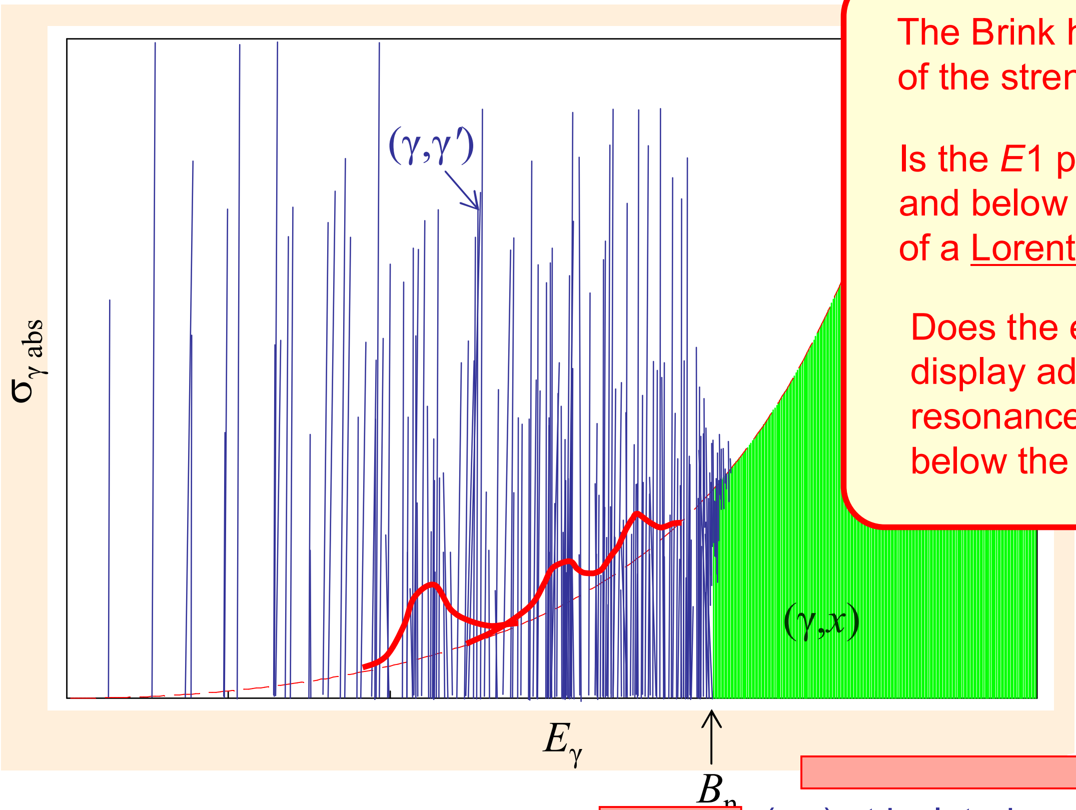


Photoexcitation pattern

Photon strength functions: problems



The Brink hypothesis and the paradigm of the strength function: do they hold?

Is the $E1$ part of $<\sigma_{\gamma\ abs}(E_\gamma)>$ for energies near and below neutron threshold an extrapolation of a Lorentzian GDR?

Does the energy dependence of $<\sigma_{\gamma\ abs}(E_\gamma)>$ display additional, statistically significant resonance-like structures in the region near or below the neutron threshold?

Obstacles in studying PSFs:

- strong Porter-Thomas fluctuations
- limited knowledge of other quantities

(γ,x) – g.s. only

(n,γ) at isolated neutron resonances, ARC

(γ,γ') – NRF, g.s. only

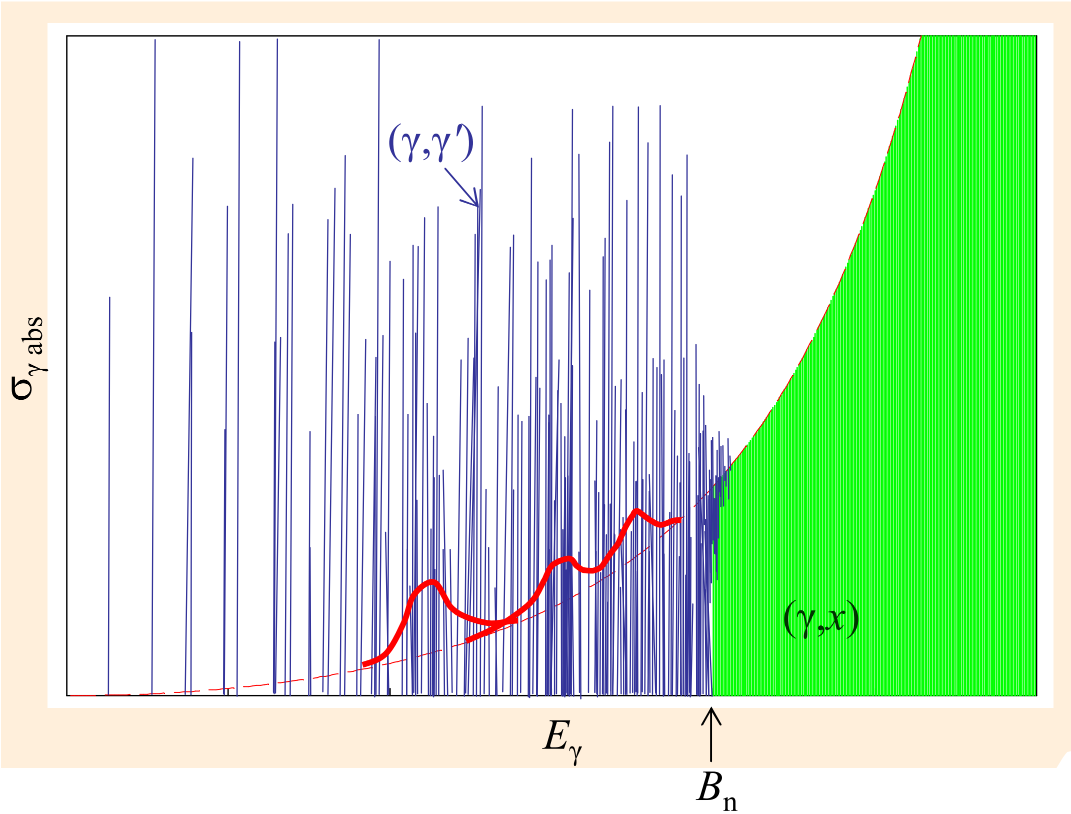
(n,γ) – two-step & n-step cascades (thermal and keV neutrons)

$(^3He,^3He'\gamma)$, $(^3He,\alpha\gamma)$ reactions

$(p,p'\gamma)$ at small angles of scattering

Singles γ-ray spectra from (n,γ), total radiation widths $\Gamma_{\gamma\ tot}$

Photon strength functions: problems



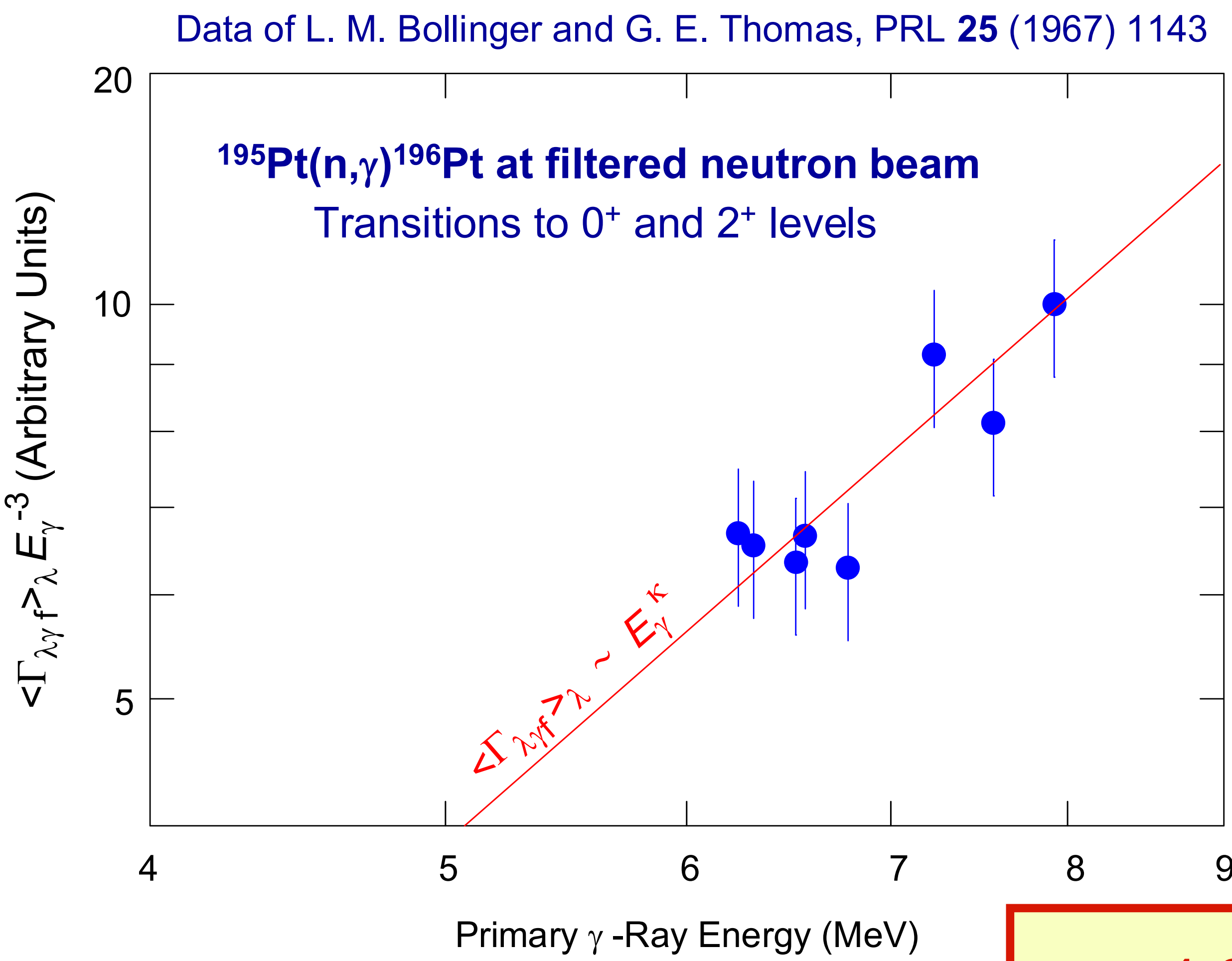
- **No deconvolution**
- **Trial-and-error approach**
- **Need for γ-cascade simulation**

(n,γ) – two-step & *n*-step cascades (thermal and keV neutrons)

(^{3}He,^{3}He'γ), (^{3}He,αγ) reactions

- **Deconvolution needed**
- **Direct extraction of PSF (no simulations)**

First hint for validity of Brink hypothesis



$\kappa = 4.9 \pm 0.5$

First hint for validity of Brink hypothesis

L. M. Bollinger and G. E. Thomas, Phys. Rev. Lett. **18** (1967) 1143:

"*There is no adequate, theoretically based explanation of the E_γ^5 dependence of the experimental widths, although an idea introduced by Brink and developed by Axel may be relevant*."

For **Lorentzian** *E*1 GDR

$$f^{(E1)}(E_\gamma) = \frac{1}{3\,(\pi\hbar c)^2} \cdot \frac{\sigma_G\,\Gamma_G^2\,E_\gamma}{(E_\gamma^2 - E_G^2)^2 + E_\gamma^2\,\Gamma_G^2}$$

then for heavy nuclei

$$\frac{d}{d E\gamma} \ln f^{(E1)}(E_\gamma) \approx 2 \quad \text{at} \quad E_\gamma \approx 7\ \text{MeV}$$

$$\langle I_{\lambda\gamma f}\rangle_\lambda \propto E_\gamma^5$$

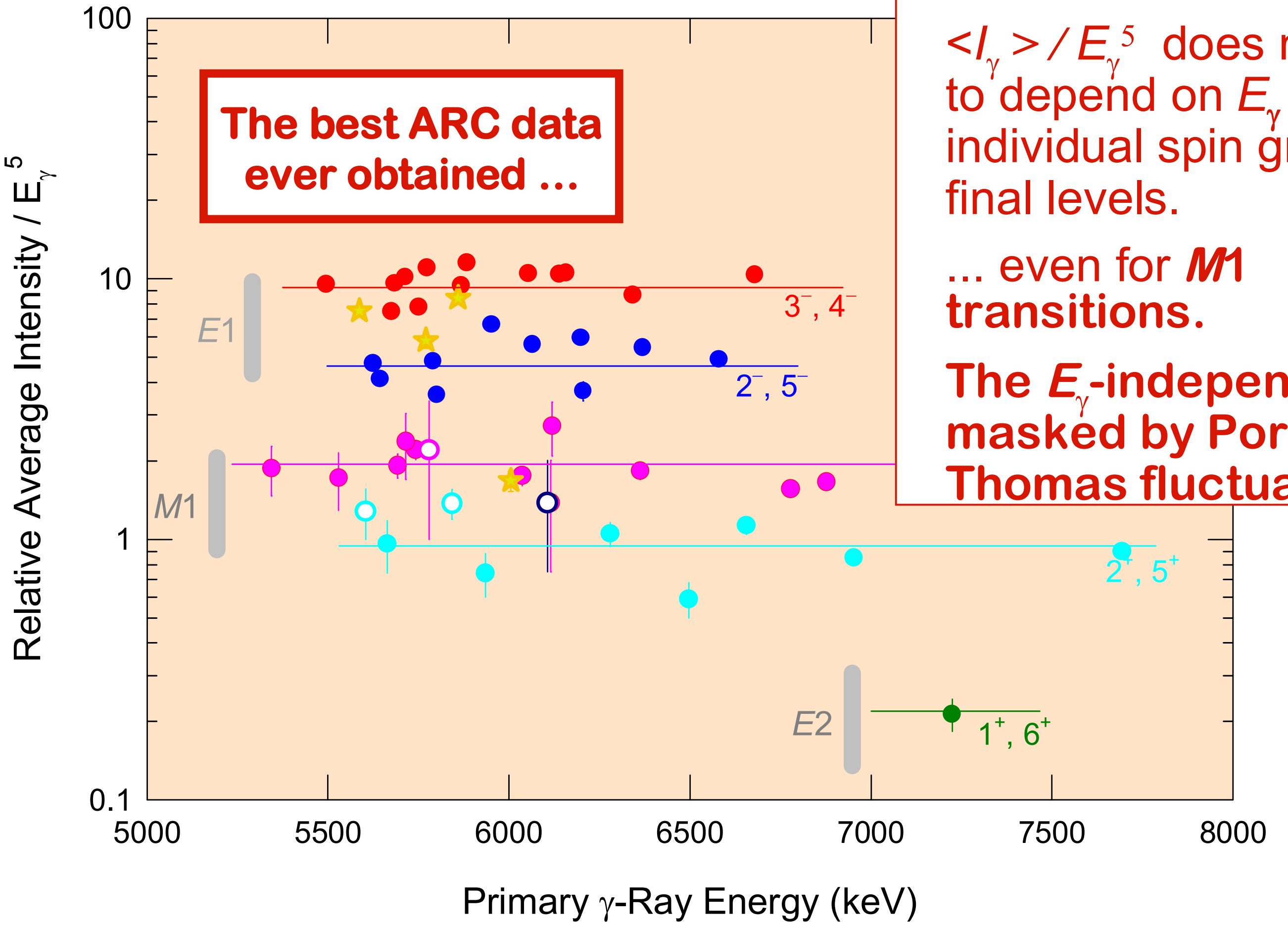
… a statistical model for γ decay of neutron capturing states
implications for *complete spectroscopy* of low-lying levels (ARC method)

Taken for granted for last 40 years

Widely accepted arguments in favor of Brink hypothesis

ARC data from ^{167}Er(n,γ)^{168}Er reaction: ***detailed analysis***

W. F. Davidson *et al.*, J. Phys. G **7** (1981) 455



$<I_\gamma>/E_\gamma^5$ does not seem to depend on E_γ for individual spin groups of final levels.

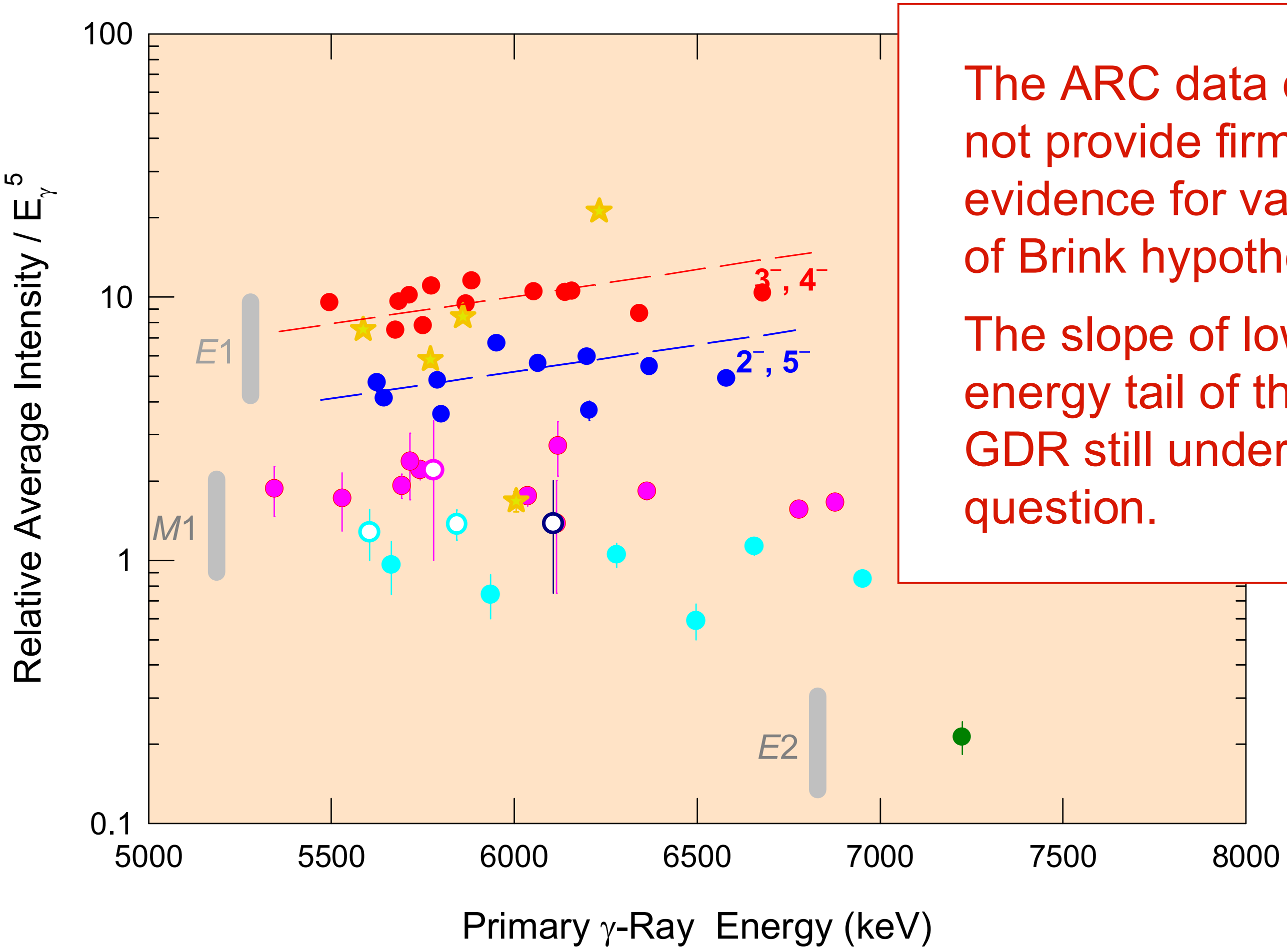
... even for ***M*1 transitions.**

The E_γ-independence masked by Porter-Thomas fluctuations.

Reality

ARC data from $^{167}Er(n,\gamma)^{168}Er$ reaction

W. F. Davidson *et al*., J. Phys. G **7** (1981) 455



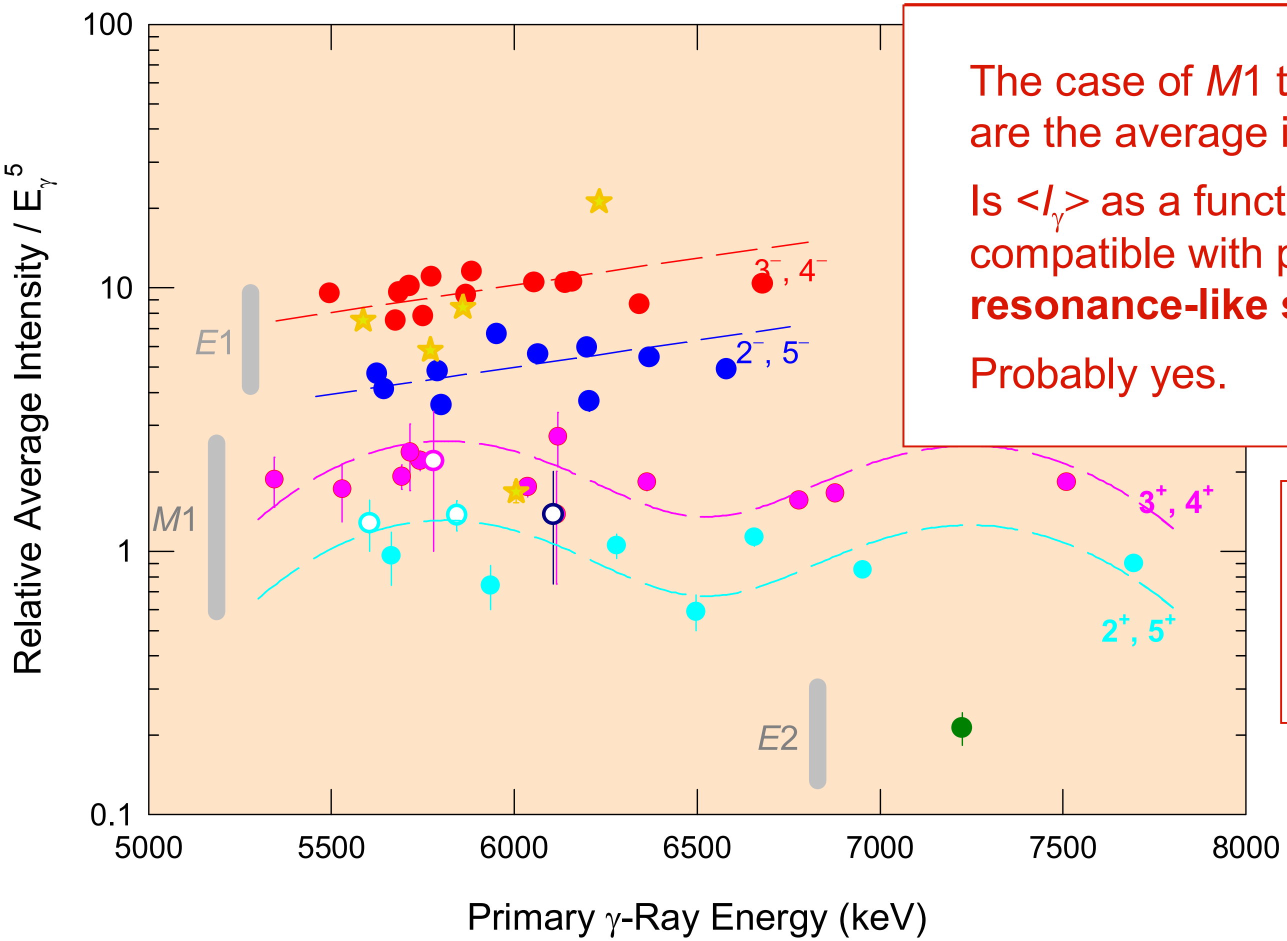
The ARC data do not provide firm evidence for validity of Brink hypothesis.

The slope of low-energy tail of the GDR still under question.

Behavior of primary *M*1 transitions in ARC experiments

ARC data from $^{167}Er(n,\gamma)^{168}Er$ reaction

W. F. Davidson *et al.*, J. Phys. G **7** (1981) 455



The case of *M*1 transitions:
are the average intensities:

Is $<I_\gamma>$ as a function of E_γ compatible with presence of **resonance-like structures?**

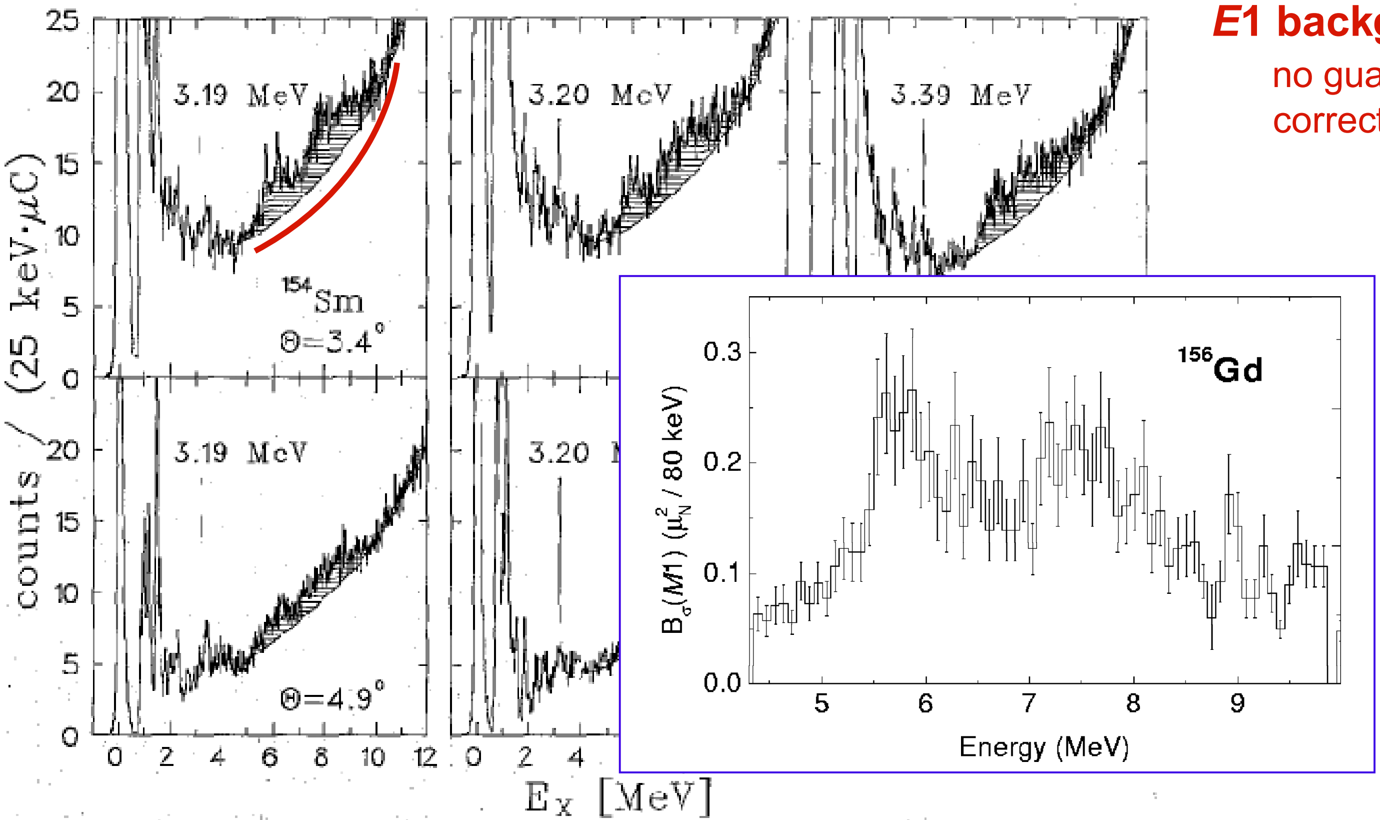
Probably yes.

Masking effects due to Porter-Thomas fluctuations

*M*1 transitions below neutron threshold in another experiment

(p,p') reactions at intermediate energies (E_p ≈200 MeV) at forward angles

– provide information on *M*1 spin-flip transitions



E1 background:

no guarantee for its correct elimination

– These transitions display marked resonant behavior

– Problems with determination of a full *M*1 strength

– **So far, no serious comparison between (p,p') and (n,γ) data has been made**

Models used for E1 PSF

1. Axel-Brink model:

$$f_{\mathrm{AB}}^{(E1)}(E_\gamma) = \frac{1}{3(\pi\hbar c)^2} \frac{\sigma_{\mathrm{G}}\,\Gamma_{\mathrm{G}}^2\,E_\gamma}{(E_\gamma^2 + E_{\mathrm{G}}^2)^2 + E_\gamma^2\,\Gamma_{\mathrm{G}}^2}$$

SLO model

2. Model of Kadmenskij, Markushev and Furman:

The damping width due to strongly interacting quasiparticles

Kadmenskij, Matkushev, Furman (1982)

$$f_{\mathrm{KMF}}^{(E1)}(E_\gamma, T_f) = \frac{1}{3(\pi\hbar c)^2} \underbrace{\left(\frac{1+2f_1'/3}{1+2f_0'}\right)}^{1/2} \frac{\sigma_{\mathrm{G}}\,E_{\mathrm{G}}\,\tilde{\Gamma}_{\mathrm{G}}(E_\gamma, T_f)}{(E_\gamma^2 + E_{\mathrm{G}}^2)^2}$$

Landau-Migdal parameters

$$\tilde{\Gamma}_{\mathrm{G}}(E_\gamma, T_f) = \frac{\Gamma_{\mathrm{G}}}{E_{\mathrm{G}}^2}\,(E_\gamma^2 + 4\pi^2 T_f^2)$$

… energy and temperature dependence

- **An approximation for low γ-ray energies**
- **Not justified for deformed nuclei**
- **At *T*>0 it gives a non-zero limit for $E_\gamma \to 0$**
- **Diverges for $E_\gamma \to E_G$**

Models used for E1 PSF

Important ingredience

3. Model GLO:

$$f^{(E1)}_{\mathrm{GLO}}(E_\gamma, T_f) = \frac{1}{3(\pi\hbar c)^2} \frac{\sigma_{\mathrm{G}}\, \tilde{\Gamma}^2_{\mathrm{G}}\, E_\gamma}{(E^2_\gamma + E^2_{\mathrm{G}})^2 + E^2_\gamma\, \tilde{\Gamma}^2_{\mathrm{G}}} + f^{(E1)}_{\mathrm{KMF}}(0, T_f)$$

$$\tilde{\Gamma}_{\mathrm{G}}(E_\gamma, T_f) = \frac{\Gamma_{\mathrm{G}}}{E^2_{\mathrm{G}}}\,(E^2_\gamma + 4\pi^2 T^2_f)$$

Energy dependendent of damping width

Divergence for $E_\gamma \rightarrow E_{\mathrm{G}}$ removed

R. E. Chrien, Dubna Report No. D3, 4, 17-86-747 (1987)

4. Semi-empirical model EGLO:

$$f^{(E1)}_{\mathrm{EGLO}}(E_\gamma, T_f) = \frac{1}{3(\pi\hbar c)^2} \frac{\sigma_{\mathrm{G}}\, \tilde{\tilde{\Gamma}}^2_{\mathrm{G}}\, E_\gamma}{(E^2_\gamma + E^2_{\mathrm{G}})^2 + E^2_\gamma\, \tilde{\tilde{\Gamma}}^2_{\mathrm{G}}} + f^{(E1)}_{\mathrm{KMF}}(0, T_f)$$

$$\tilde{\tilde{\Gamma}}_{\mathrm{G}}(E_\gamma, T_f) = \left[k_0 + \frac{E_\gamma - E_{\gamma 0}}{E_{\mathrm{G}} - E_{\gamma 0}}(1 - k_0)\right] \frac{\Gamma_{\mathrm{G}}}{E^2_{\mathrm{G}}}\,(E^2_\gamma + 4\pi^2 T^2_f)$$

k_0 , $E_{\gamma 0}$ adjustable parameters

J. Kopecky, M. Uhl and R. E. Chrien, PRC 47 (1993) 312

A good description for spherical, transitional and deformed nuclei achieved at energies E_γ > 6 MeV

Models for M1 PSF

1. **The single-particle model**
   A constant PSF

2. **The spin-flip model**
   Analogous to AB model for E1 PSF
   Parameters deduced from the (p,p'γ) data

3. **The scissors-resonance temperature-independent model**
   Photon strength assumed not to depend on nuclear temperature

$$f^{(M1,\mathrm{SR})}(E_\gamma) = \frac{16\pi}{27(\hbar c)^3} \frac{E_0}{\arctan(2E_0/\Gamma_{\mathrm{SR}})} \frac{\Gamma_{\mathrm{SR}}\; E_\gamma}{(E_\gamma^2 + E_{\mathrm{SR}}^2)^2 + E_\gamma^2\; \Gamma_{\mathrm{SR}}^2} \sum B(M1)\uparrow$$

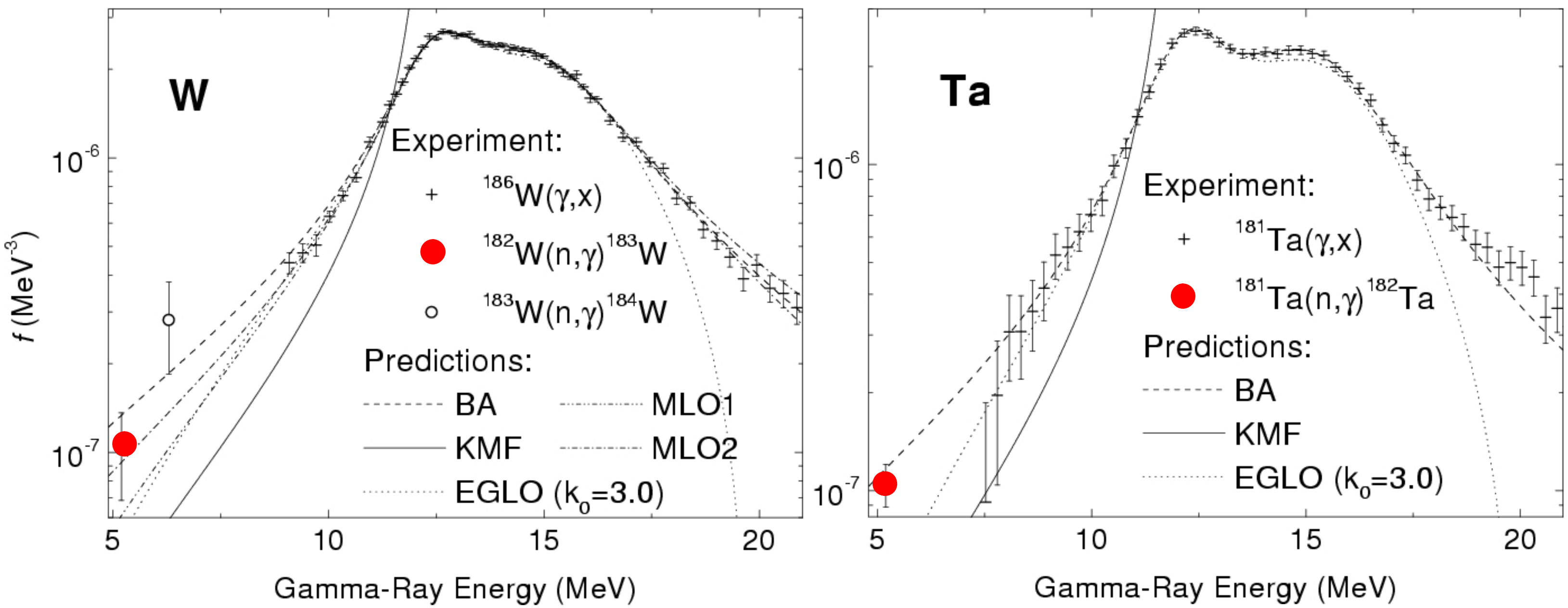
$$E_0 = \sqrt{E_{\mathrm{SR}}^2 - \Gamma_{\mathrm{SR}}^2/4}$$

F. Becvar et al., PRC52 (1995) 1278

Comparison between photonuclear and (n,γ) data

Lorentzian/Axel-Brink/GLO model

Typical deformed nuclei:
an excellent agreement between (n,γ) and photonuclear data

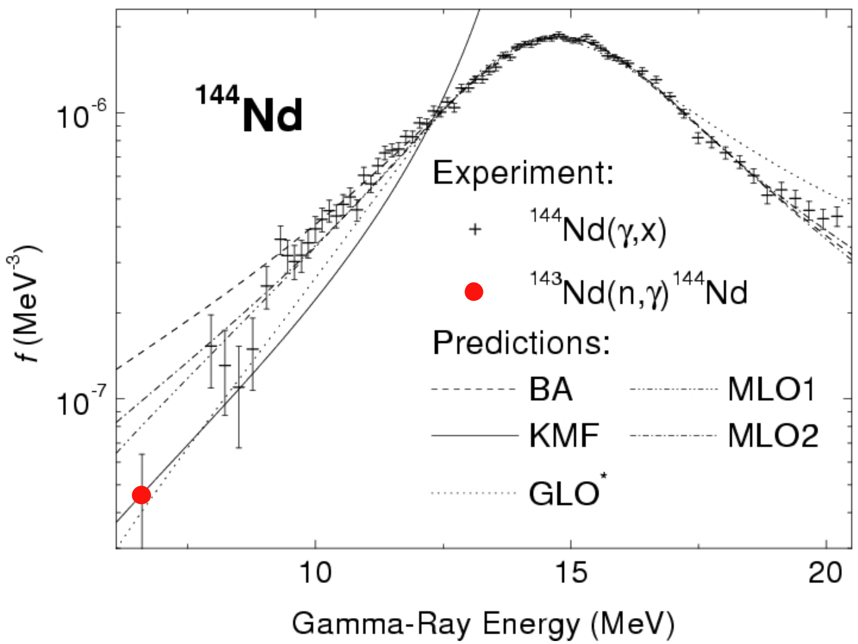


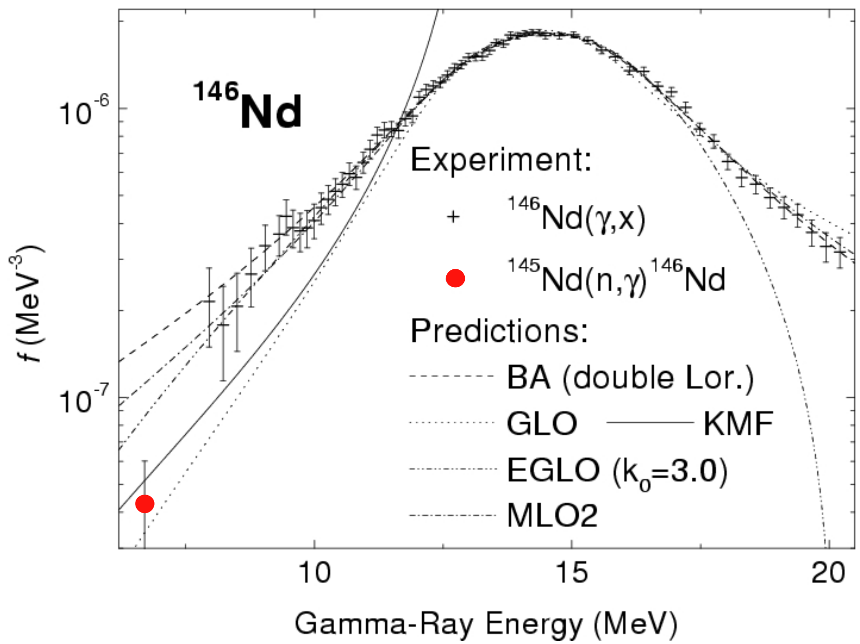
(n,γ) data: intensities of primary transitions from isolated neutron resonances

Comparison between photonuclear and (n,γ) data

Lorentzian/Axel-Brink/GLO model

Transitional or spherical nuclei: a not satisfactory agreement



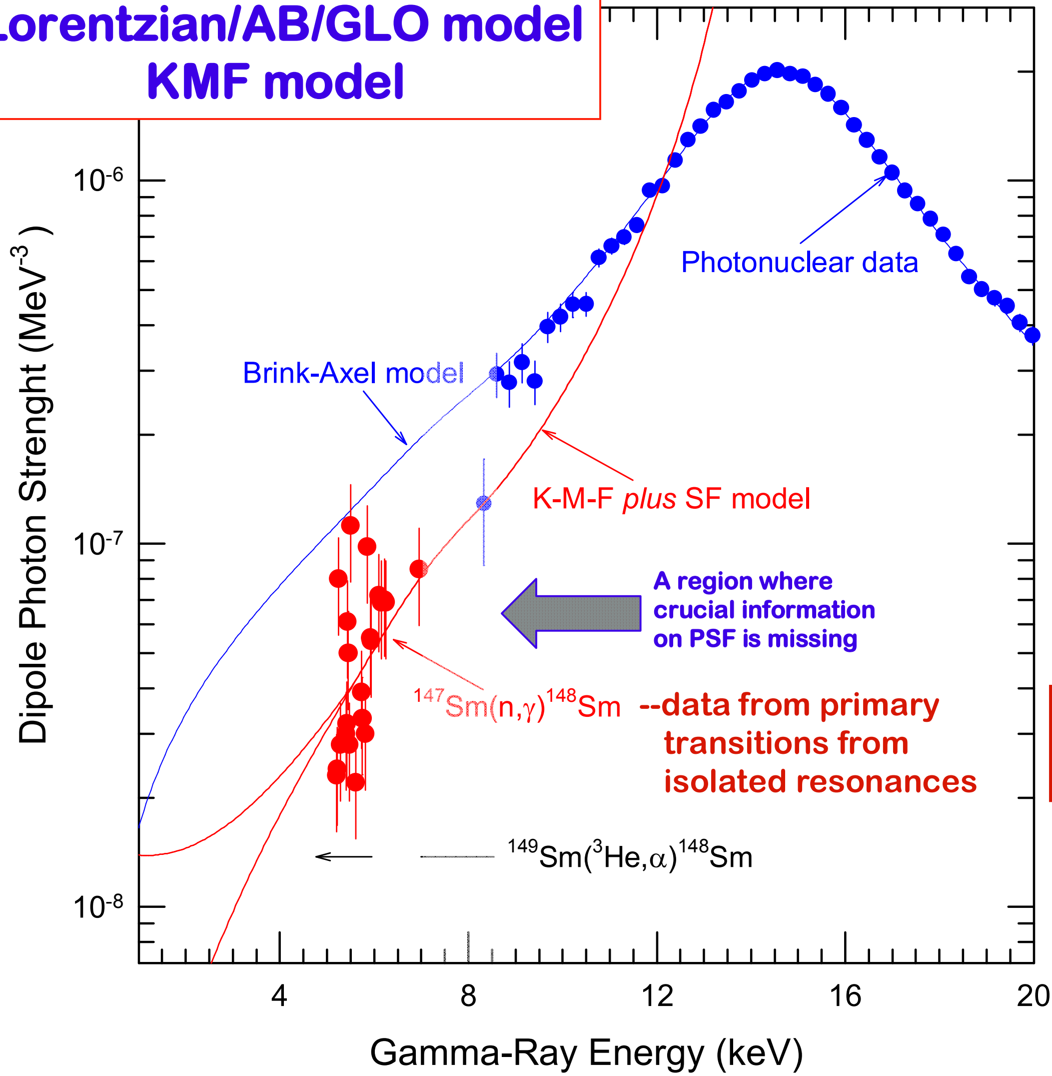


(n,γ) data: intensities of primary transitions from isolated neutron resonances

Comparison between photonuclear, (n,γ) and (^{3}He,$\alpha\gamma$) data

Another transitional nucleus: ^{148}Sm

Lorentzian/AB/GLO model
KMF model



A region where crucial information on PSF is missing

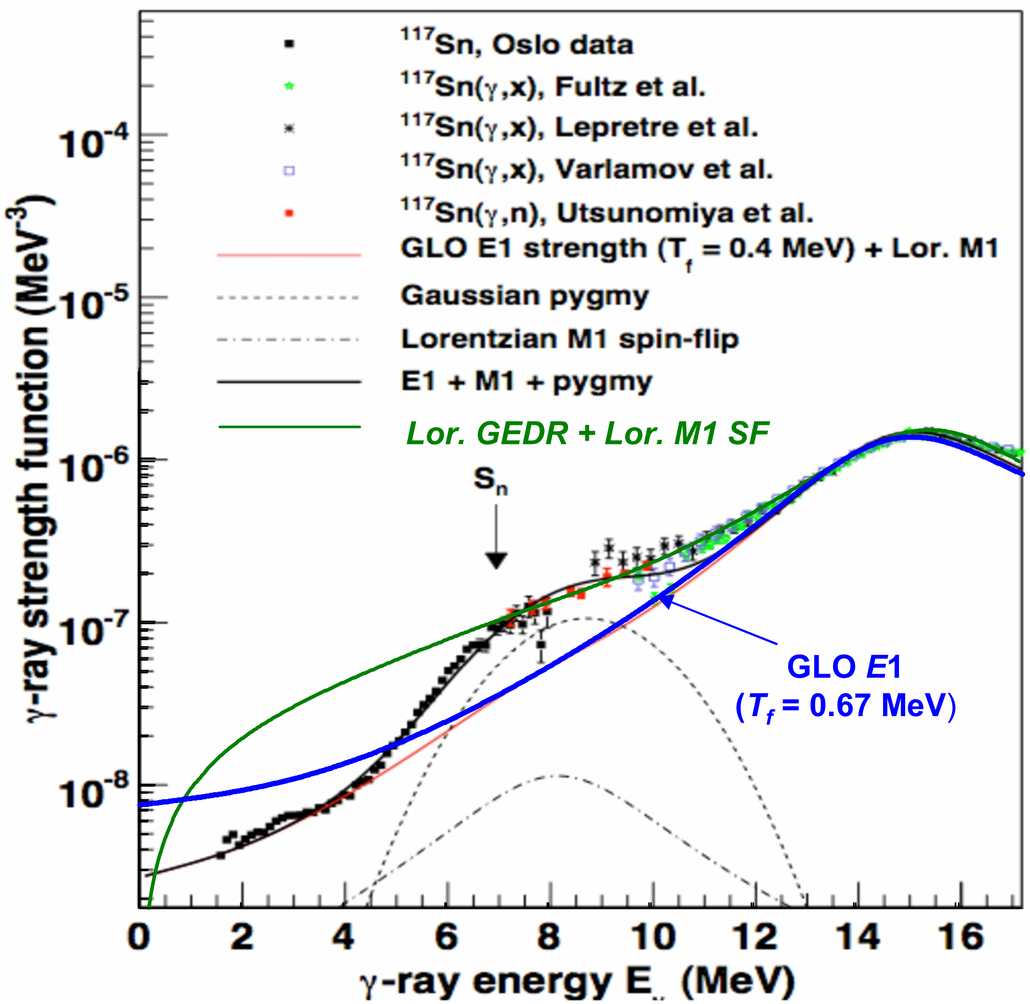
--data from primary transitions from isolated resonances

A limited energy range

Suppression of Lorentzian below 8 MeV?

^{117}Sn: photonuclear reaction and ^{3}He-induced emission

Agvaanluvsan *et al*. Phys. Rev. Lett. **102**, 162504 (2009)



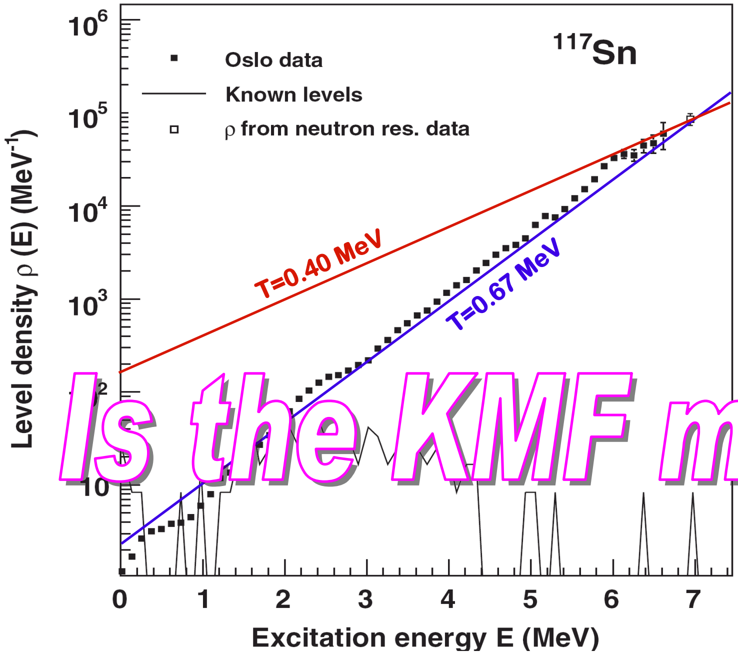
Anomalous 7 MeV *M*1 resonance superimposed on GLO *E*1 GDR?

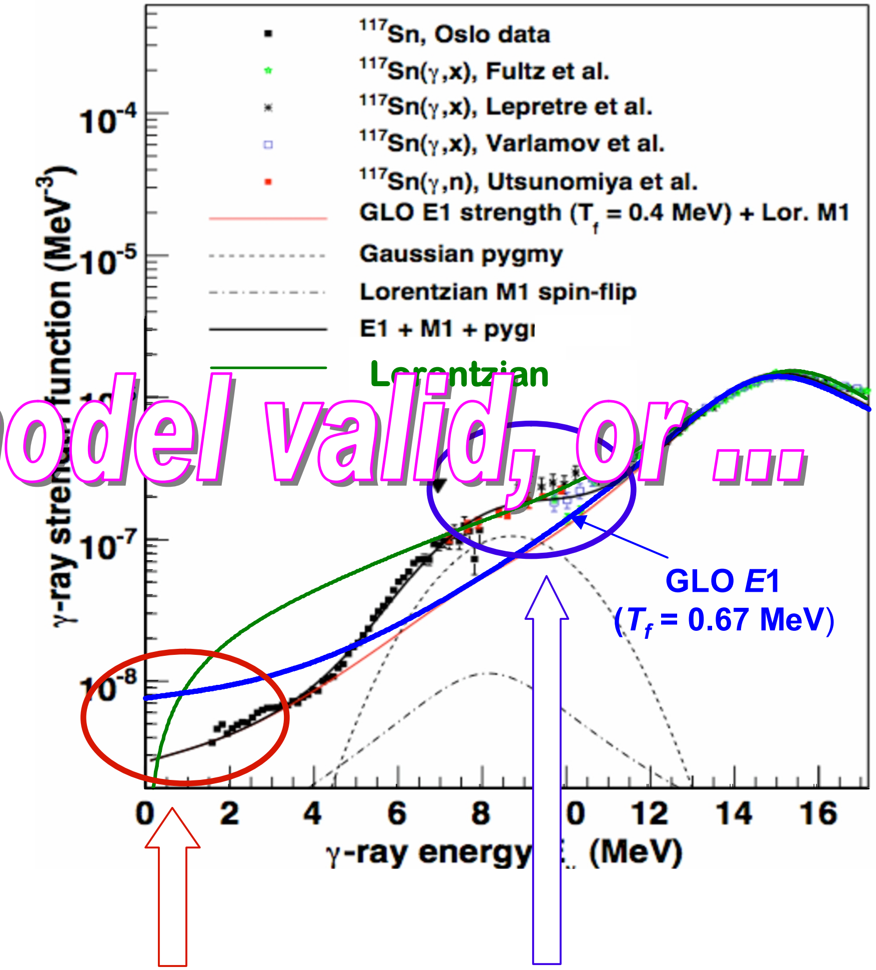
or

Suppression of the Lorentzian GDR?

Conflict between the ^{3}He-induced γ-emission and the KMF model

Agvaanluvsan *et al*. Phys. Rev. Lett. **102**, 162504 (2009)





Is the KMF model valid, or ...

Fit of level-density function: T = 0.67 MeV
... photon strength function: T = 0.40 MeV

Reasons for the difference between between the Lorentzian and GLO models:

(1) KMF T-dependent term

(2) Proportionality of Γ to E_γ^2

Simulation of γ cascades by means of DICEBOX algorithm

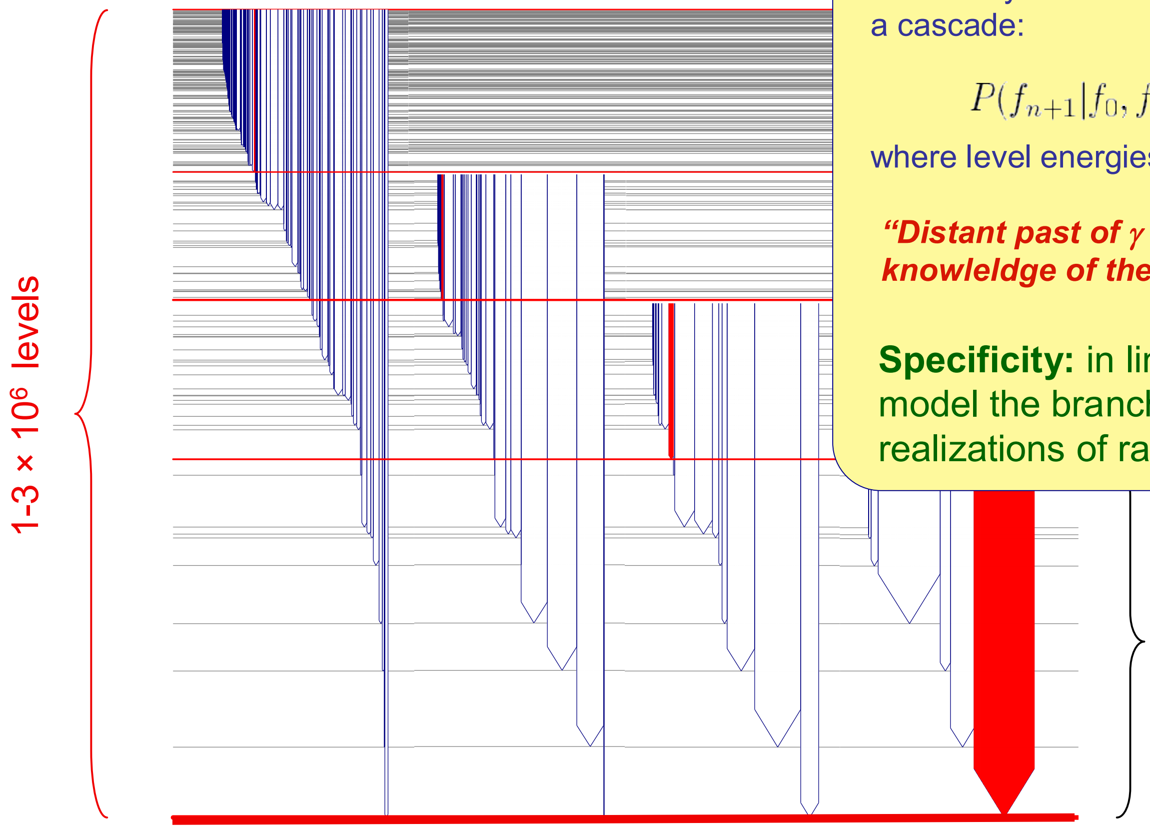
Assumptions:

- For nuclear levels below certain “critical energy” spin, parity and decay properties are known from experiments
- Energies, spins and parities of the remaining levels are assumed to be a discretization of an *a priori* known level-density formula – a random discretization with the Wigner-type long-range level-spacing correlations
- A partial radiation width $\Gamma_{i\gamma f}^{(XL)}$, characterizing a decay of a level *i* to a level *f*, is a random realization of a chi-square-distributed quantity the expectation value of which is equal to

$$f^{(XL)}(E_\gamma)\, E_\gamma^{2L+1}/\rho(E_i),$$

  where the PSFs $f^{(XL)}$ and the density ρ are also *a priori* known
- Selection rules governing the γ decay are fully observed
- Any pair of partial radiation widths $\Gamma_{i\gamma f}^{(XL)}$ is statistically uncorrelated
- Depopulating intensities are given by $I_{if} = [\Sigma_{XLf}\, \Gamma_{i\gamma f}^{(XL)}] / [\Sigma_{X'L'f'}\, \Gamma_{i\gamma f'}^{(X'L')}]$

Siimulation of γ cascades by DICEBOX



Probability of reaching a level f_{n+1} after *n*-th step of a cascade:

$$P(f_{n+1}|f_0, f_1, f_2, \ldots, f_n) = \tilde{P}(f_{n+1}|f_n),$$

where level energies $E_{f_0} > E_{f_1} > E_{f_2} > \cdots > E_{f_N}$:

"Distant past of γ cascading is irrelevant given knowleldge of the recent past"

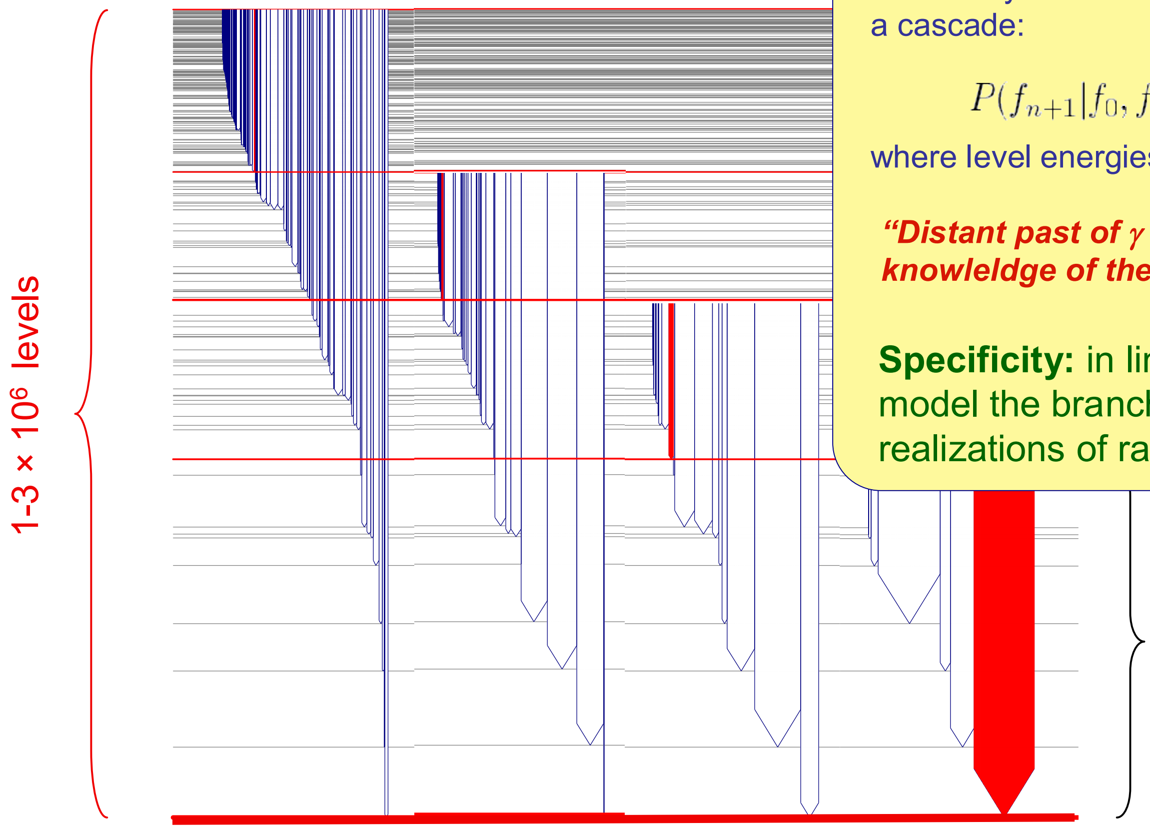
… Markovian process

Specificity: in line with the extreme statistical model the branching intensities $I_{if} = P(f\,|\,i)$ are realizations of random variables

A complete decay scheme is known for at most 100 levels, i.e. for a 10^{-2} % fraction

Necessity to generate the rest part of the decay scheme

A straightforward approach to simulating γ cascades



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Necessity to generate the rest part of the decay scheme

This problem is overcome by introduction of the so-called precursors

A notion of a nuclear realization

A set of realizations $\{I_{fi}\}$ for all possible i,f and a set of realizations $\{E_f, J_f, \pi_f\}$ for all levels f ≡ **A nuclear realization**

- An infinite number of NRs exist for a given level-density ρ and a set of photon strength functions $f^{(XL)}$
- Of these NRs only one of characterizes the behavior of a given nucleus
- Simulations of γ cascades based on the use of various NRs lead to mutually different predictions of the cascade-related quantities
- Simulations of γ cascades based on the use of various NRs lead to different predictions of the cascade-related quantities
- To assess uncertainties of these predictions simulations of γ cascades are to performed for a large number of NRs

The outcome of γ-cascading

- The number of steps of a given cascade is known

- So also the energies of the individual transitions and the intermediate levels involved

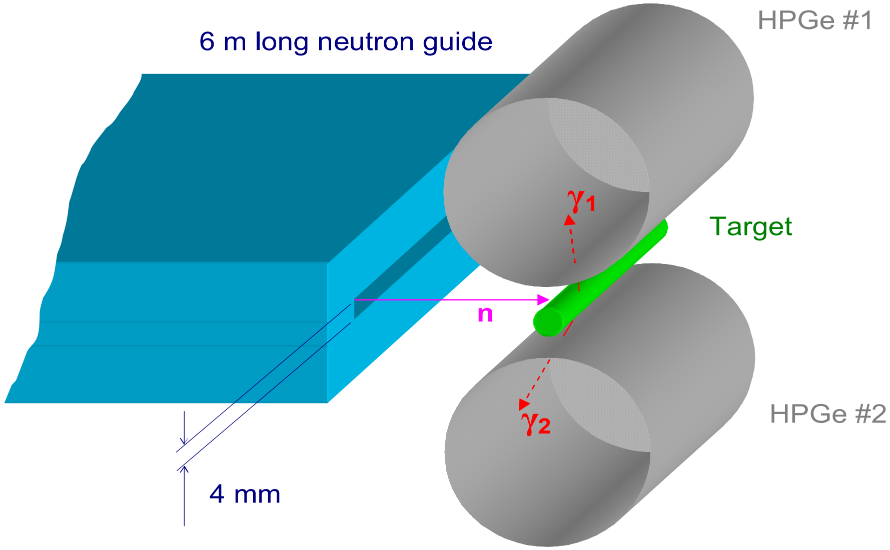
- The procedure described is reiterated many times. Typically a set of 100 000 cascades are obtained for a given nuclear realization

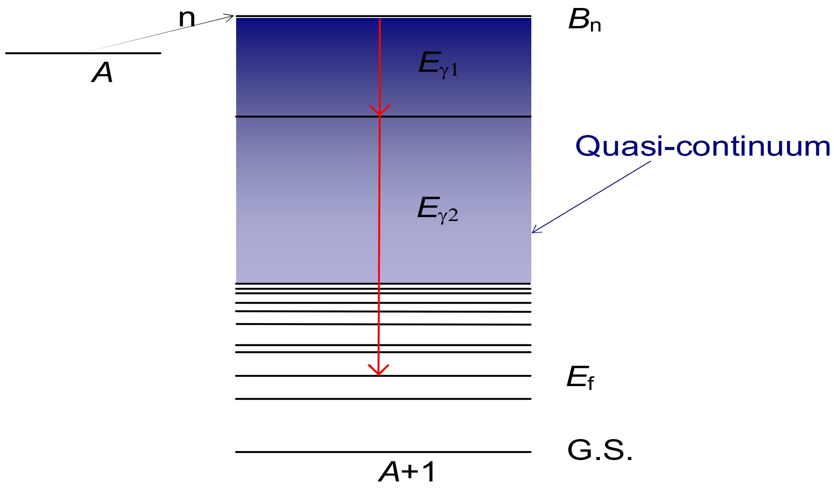
-The whole this process in repeated for an enough large number of other nuclear realizations

- Various *cascade-related quantities* can be deduced and their residual Porter-Thomas r.m.s. uncertainties estimated

Two-step γ-cascades following the thermal neutron capture

Geometry:





Data acquisition:

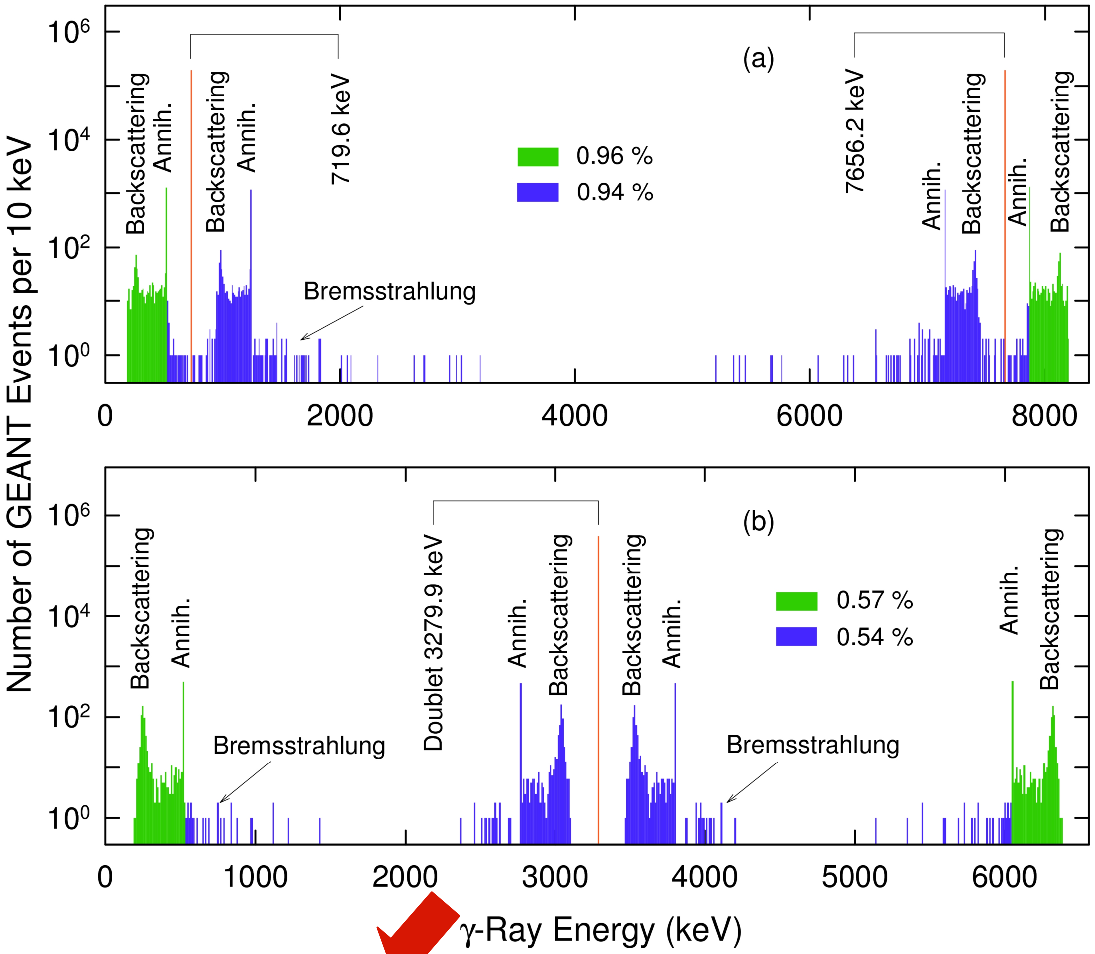
Three-parametric, list-mode

- Energy $E_{\gamma 1}$
- Energy $E_{\gamma 2}$
- Detection-time difference

Off-line analysis:

background-free spectra of two-step cascades terminating at preselected final levels

Response function of the TSC HPGe spectrometer



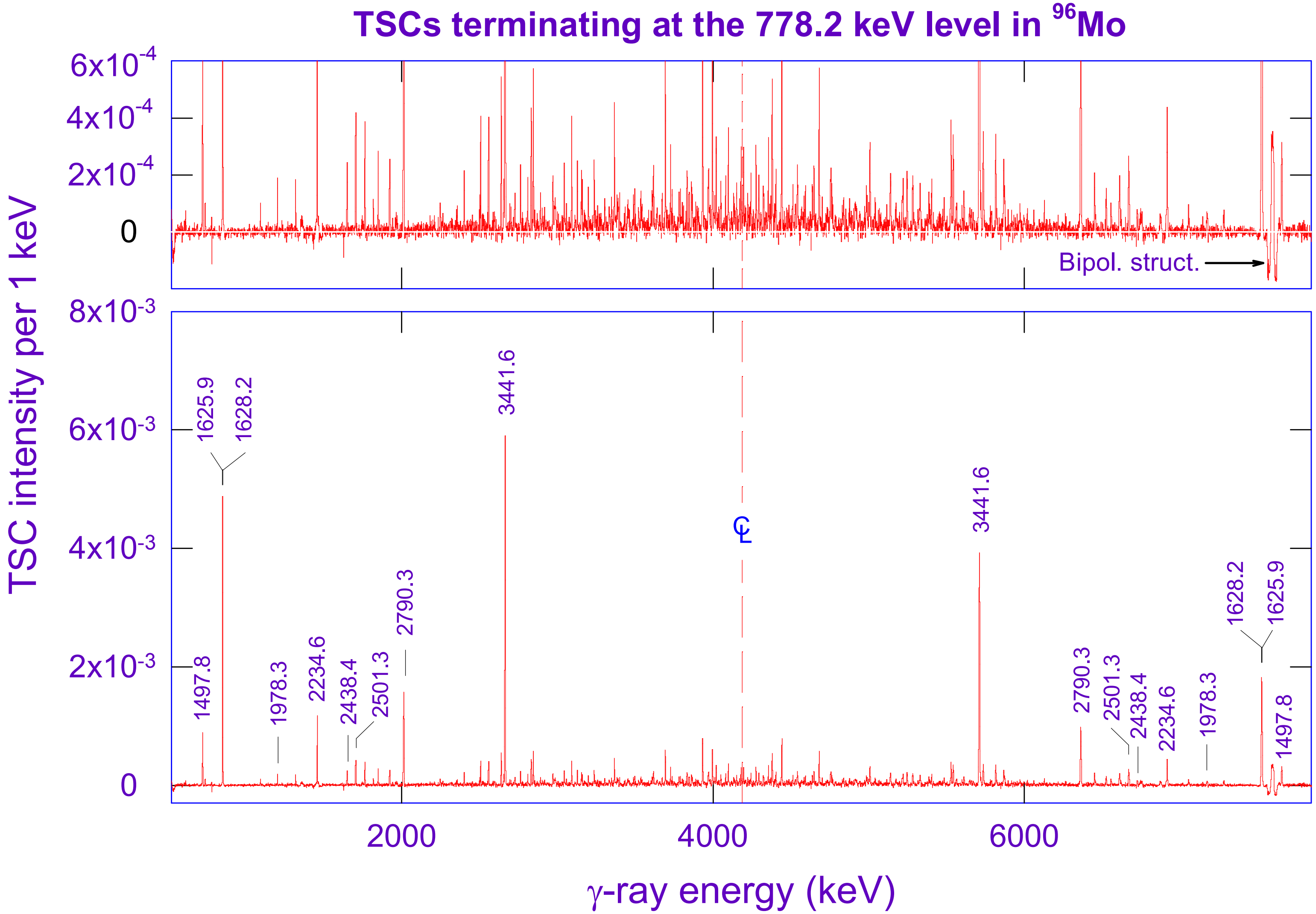
A pair of TSC γ lines carries > 98 % of the detected events

GEANT3 simulation

- Virtually free of background
- γ-cross-talk negligible
- no need for deconvolution

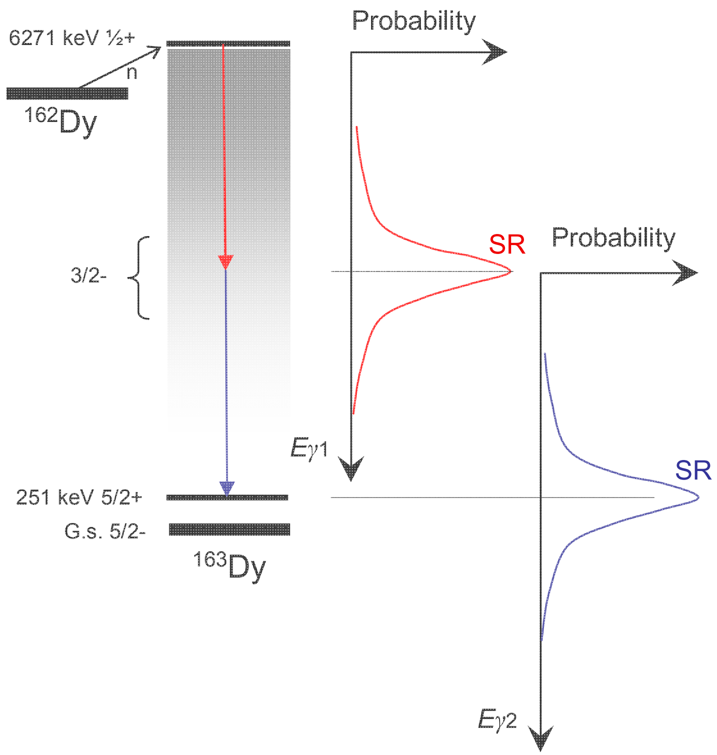
Courtesy of Gencho Rusev

An example of aTSC spectrum



TSCs in the $^{162}Dy(n,\gamma)^{163}Dy$ reaction

Specifity of TSCs terminating at 251 keV level



Role of scissors mode built on excited levels?

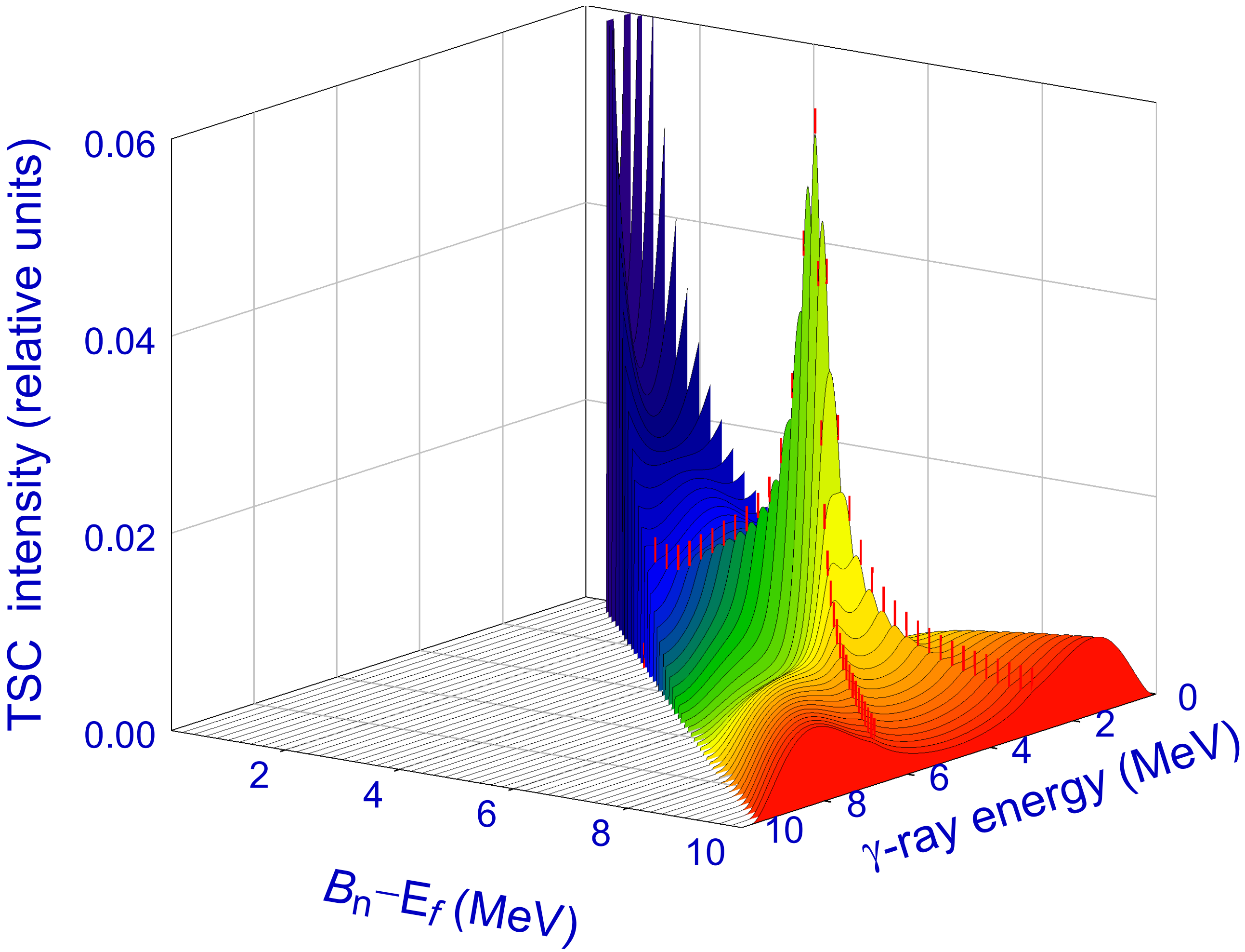
Allowed transitions *E*1 – *E*1 & *M*1 – *M*1 favourable energy span $B_n - E_f \approx 2E_{SR}$

… effect of *co-operative* enhacement of primary and secondary transitions?

A unique possibility of a sensitive test for presence of SRs built on the levels in the quasicontinuum

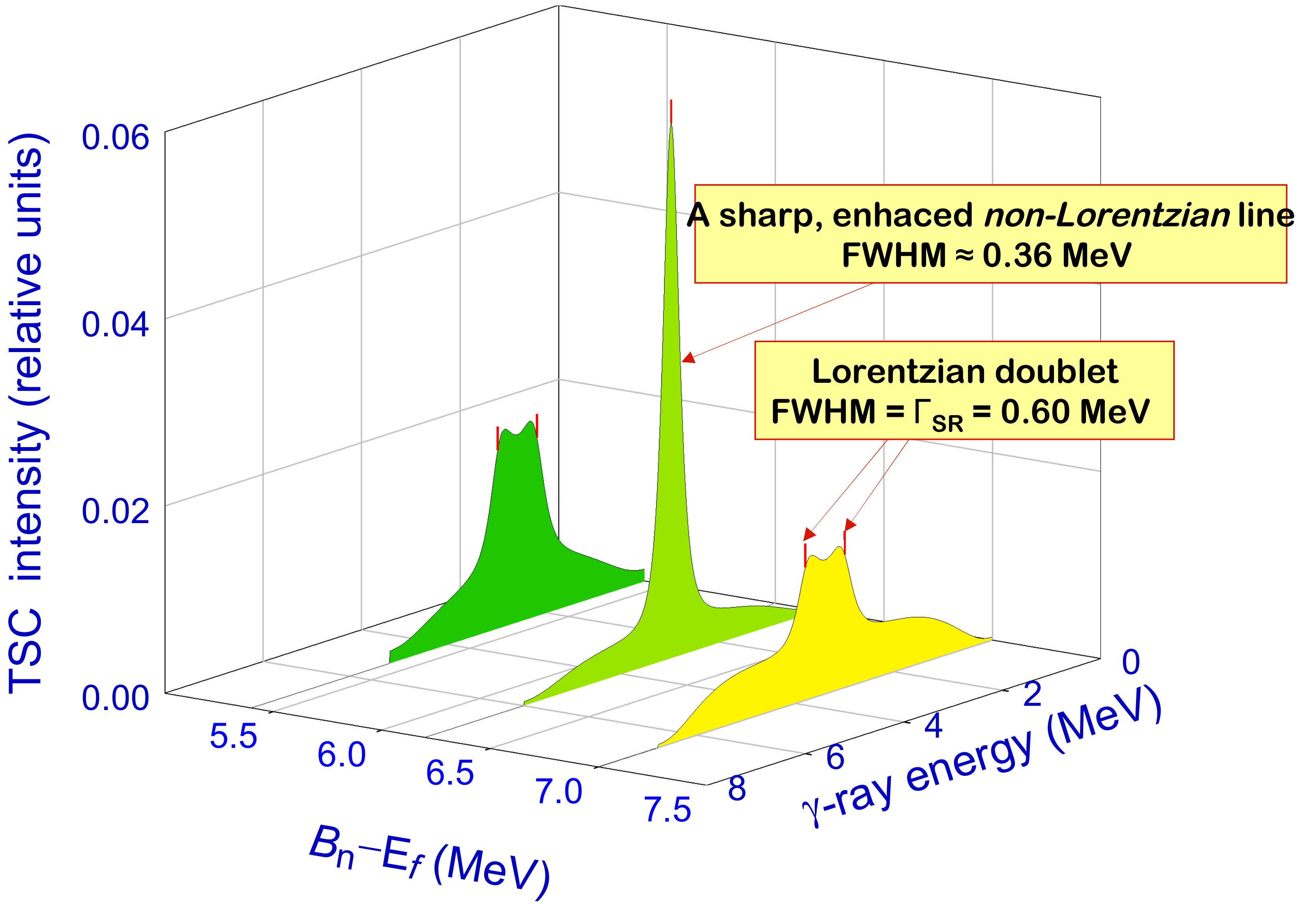
Co-operative enhancement of primary and secondary transitions

Co-operativness -- what does it mean?

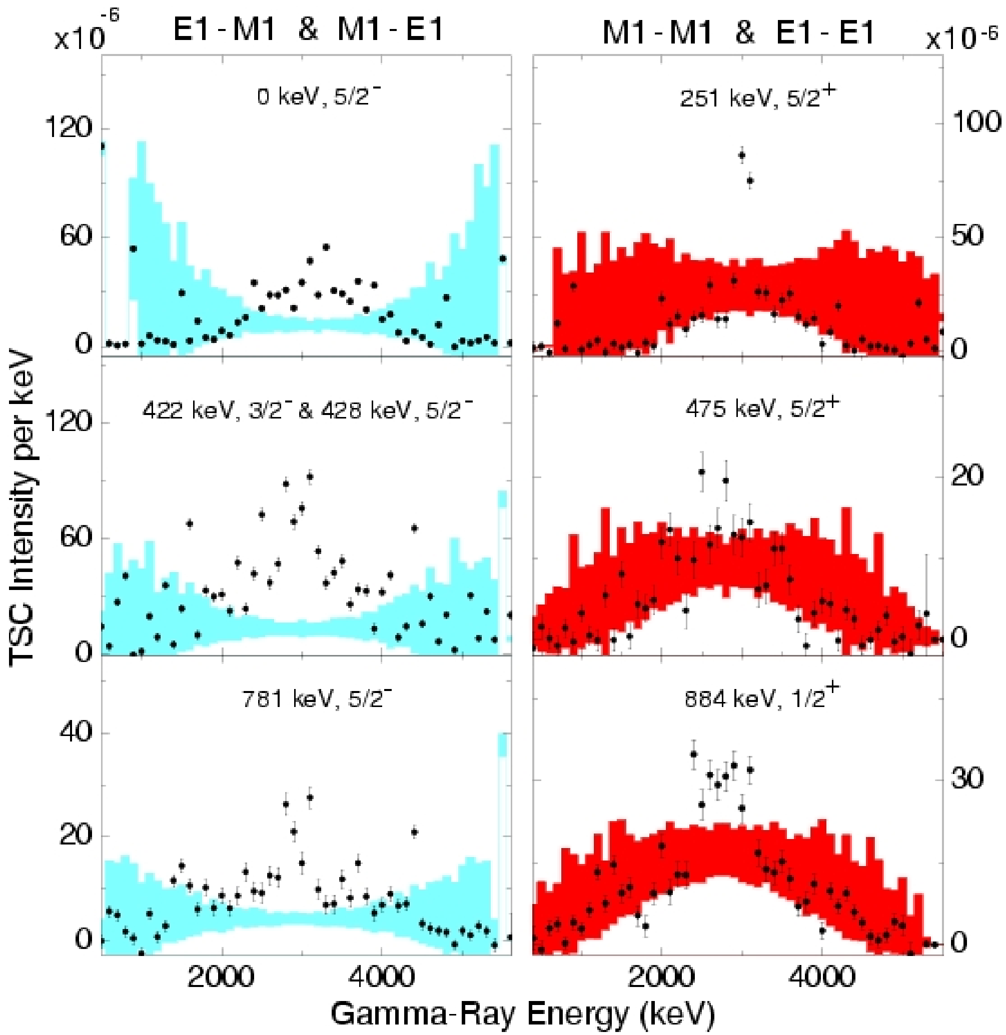


$E_{SR} \approx 3.0$ MeV
$\Gamma_{SR} \approx$ **0.6 MeV**

Co-operative enhancement of primary and secondary transitions

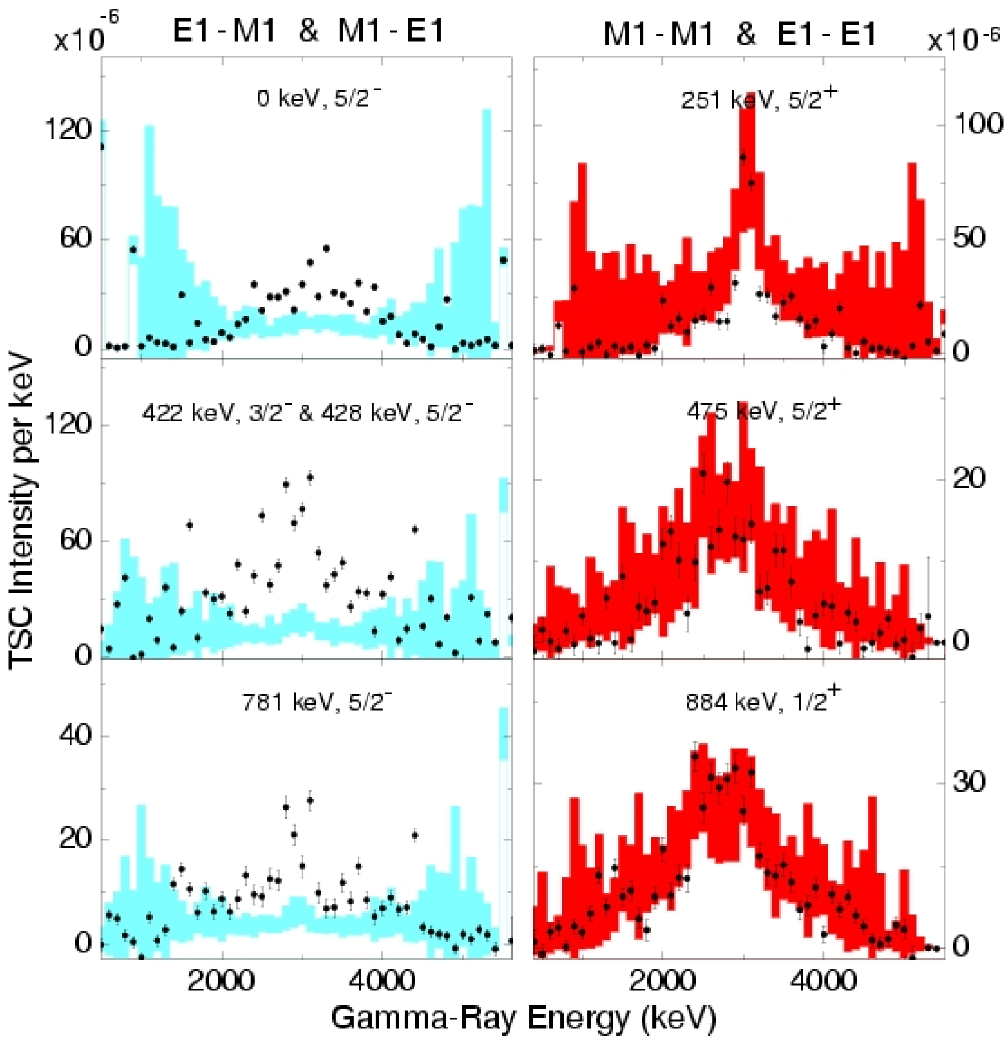


TSCs in the $^{162}Dy(n,\gamma)^{163}Dy$ reaction



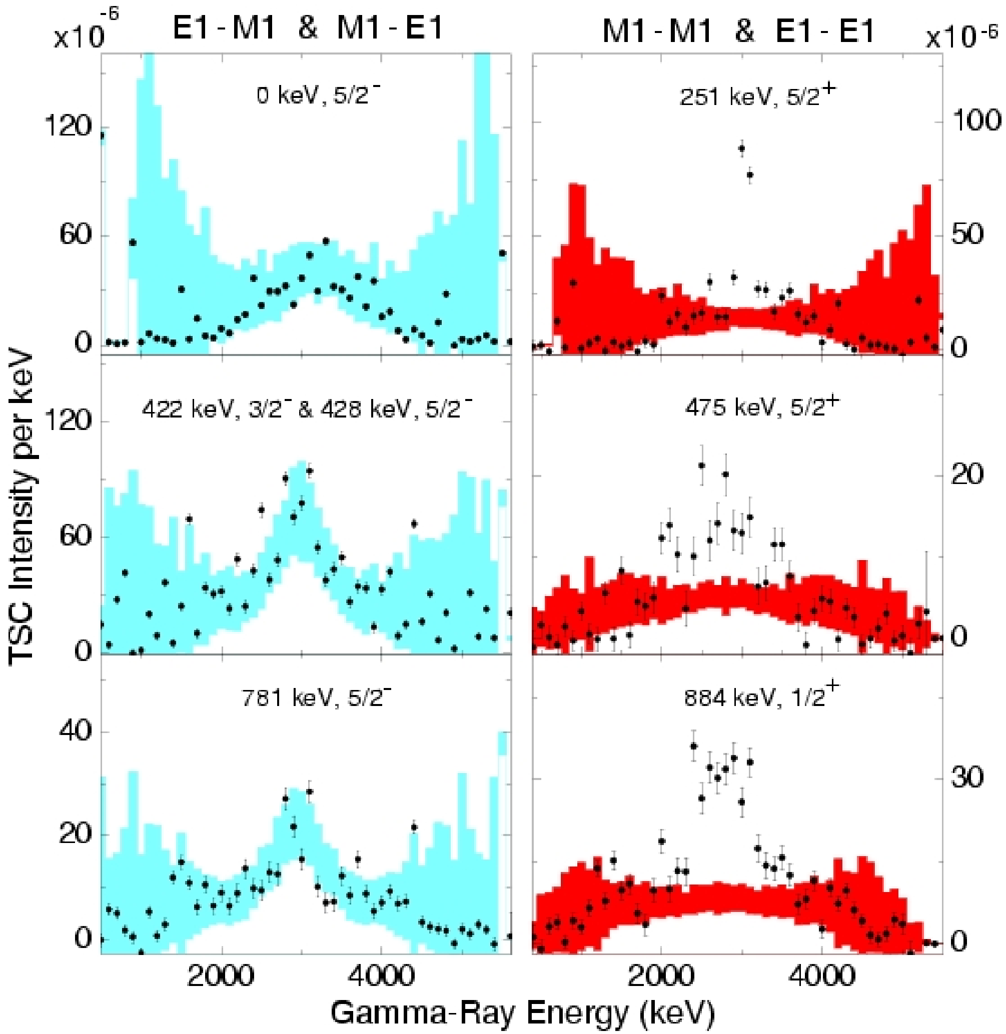
Entire absence of SRs is assumed

TSCs in the $^{162}Dy(n,\gamma)^{163}Dy$ reaction



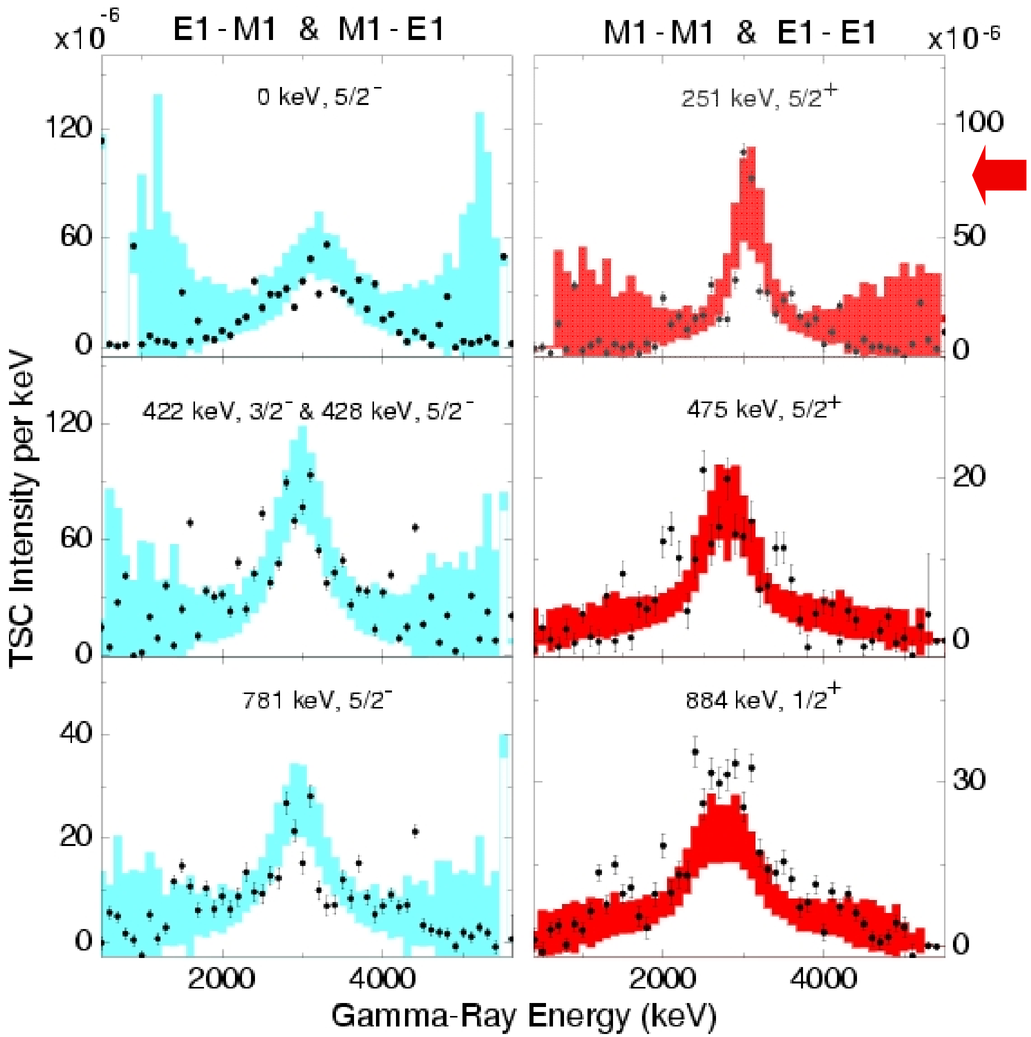
A "pygmy E1 resonance" with energy of 3 MeV assumed to be built on **all** levels

TSCs in the $^{162}Dy(n,\gamma)^{163}Dy$ reaction



SRs assumed to be built only on all levels below 2.5 MeV

TSCs in the $^{162}Dy(n,\gamma)^{163}Dy$ reaction



Sharpening the 3 MeV peak well reproduced

plus

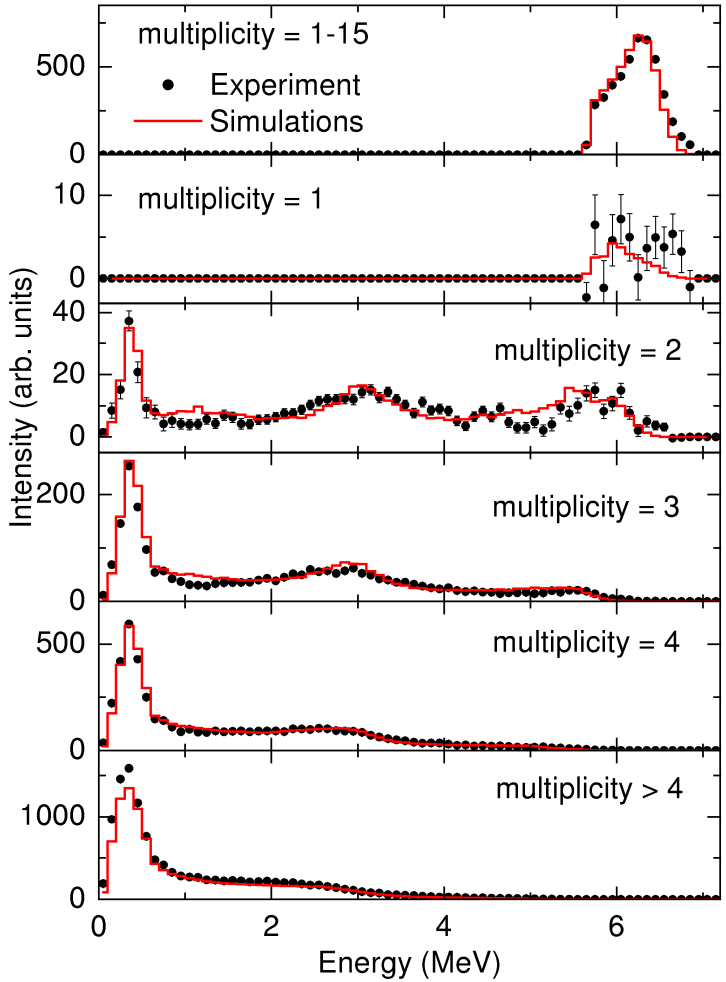
a quantitative agreement between the predicted and simulated TSC spectra

Scissors resonances assumed to be built on **all** ^{163}Dy levels

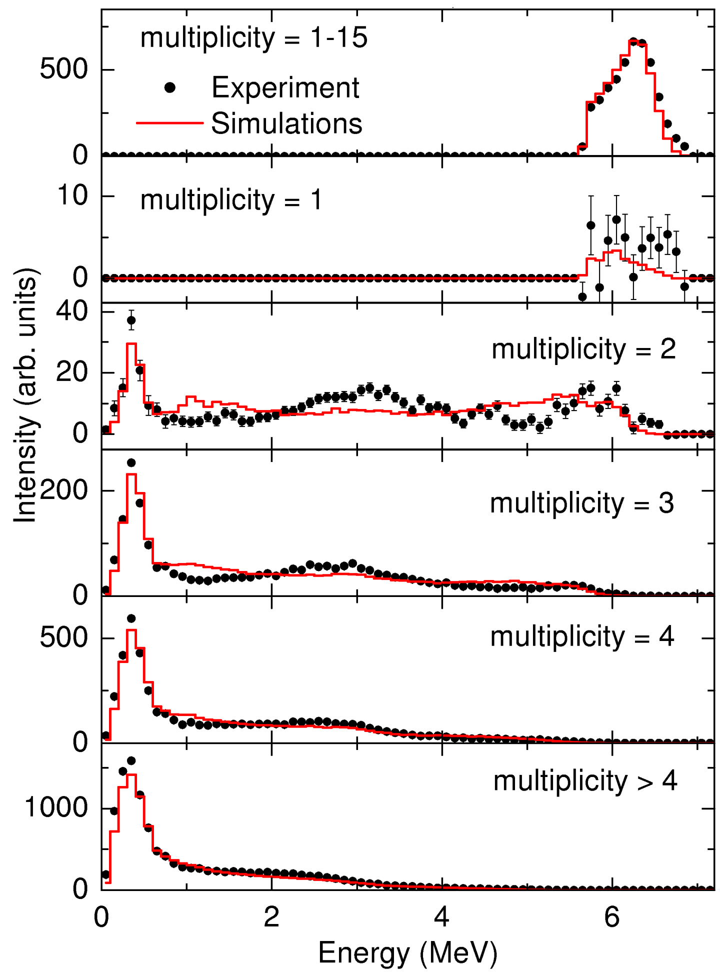
n-step cascades following the capture of keV neutrons in ^{162}Dy

E_n = 90-100 keV

SRs built on **all** ^{163}Dy levels



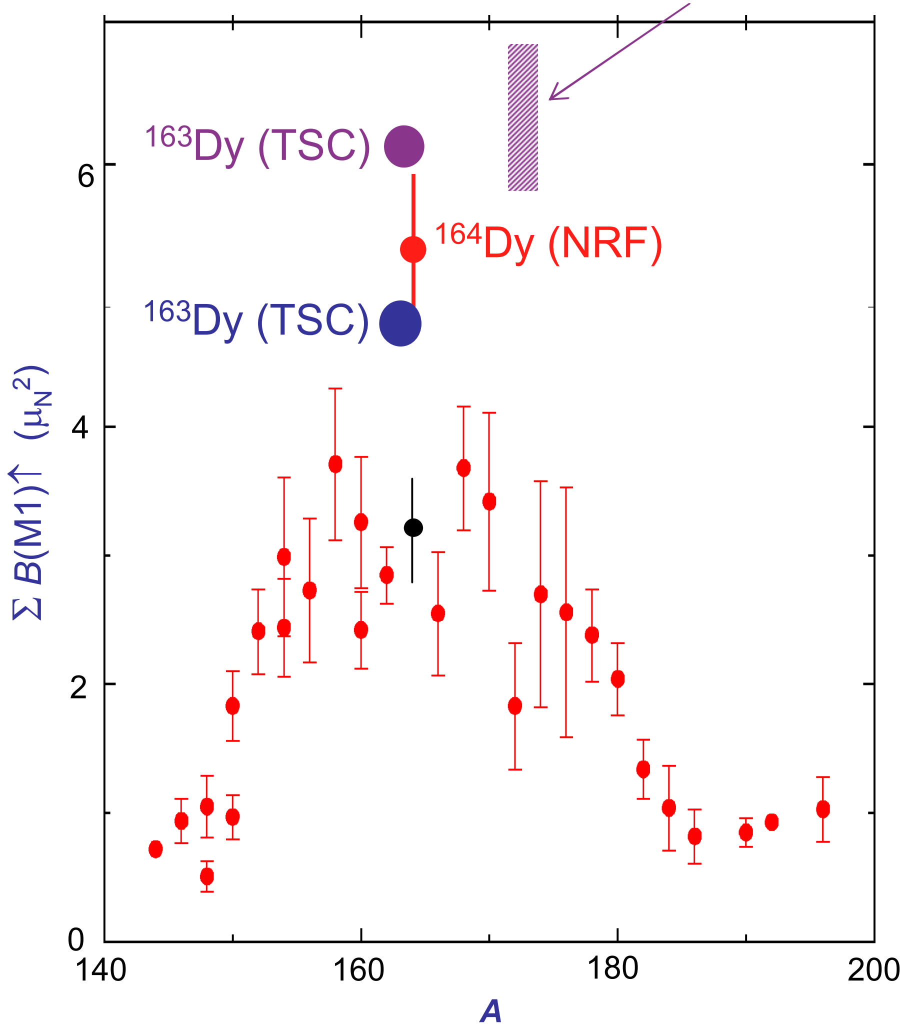
…only on levels with E_f <2.5 MeV



Comparison between the TSC and NRF data

I. NRF data for 29 even-even nuclei

Theory of E. Lipparini and S. Stringari, Phys. Rep. 175 (1989) 103



Redrawn from J. Enders *et al.*, PRC 59 R1851 (1999)

- Summing interval for $\Sigma\, B(M1)\uparrow$: **2.5 - 4.0 MeV**
- Summing interval for $\Sigma\, B(M1)\uparrow$: **2.7- 3.7 MeV**
- Summing interval for $\Sigma\, B(M1)\uparrow$: **2.5 - 4.0 MeV**
  - deduced from data in original paper of J. Margraf *et al.*, PRC 52, 2429 (1995)
- **Value from TSCs in ^{163}Dy;** summing interval for $\Sigma\, B(M1)\uparrow$: **2.5 - 4.0 MeV**
- **Value from TSCs in ^{163}Dy:** total sum $\Sigma\, B(M1)\uparrow$

Scissors-mode strength $\Sigma\, B(M1)\uparrow$:

A considerable loss due to a finite summing energy interval

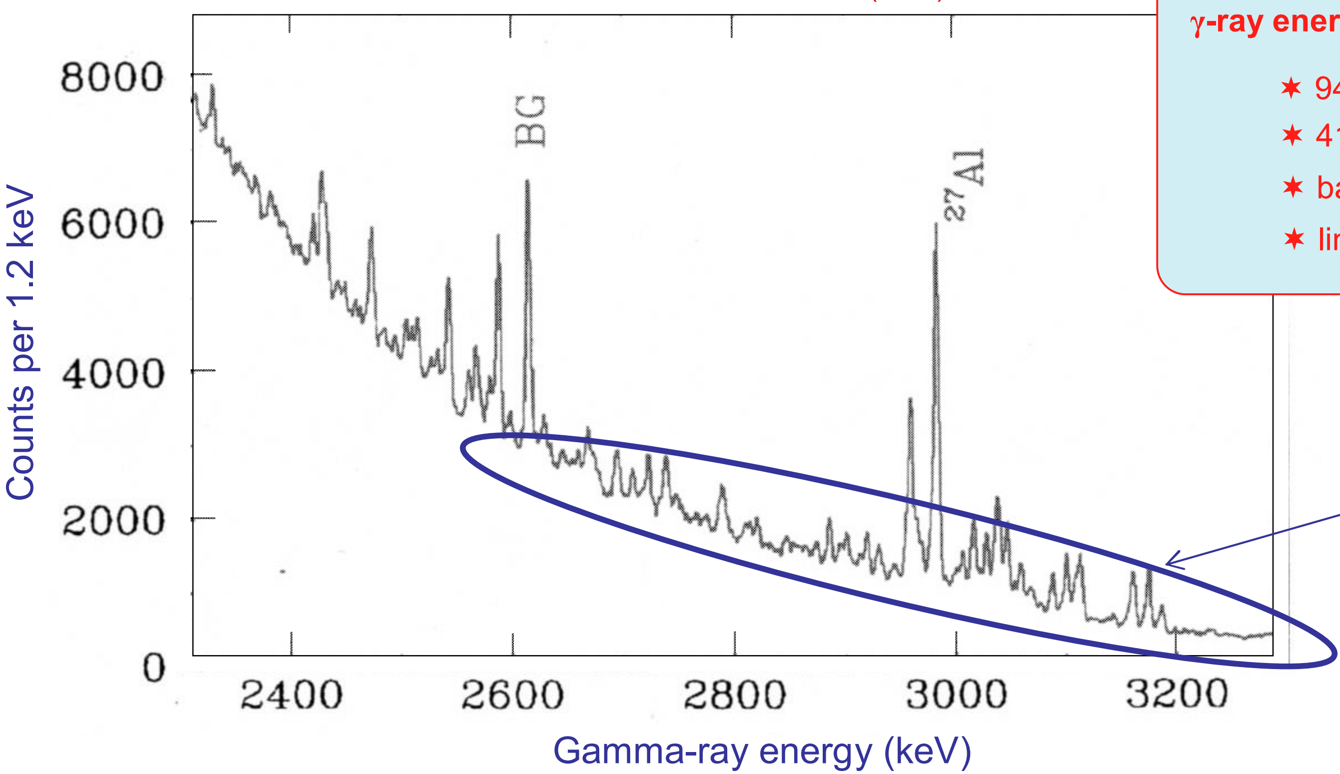
The data from TSCs in odd ^{163}Dy agree well with the NRF data at least for even-even ^{164}Dy …

Comparison between the TSC and NRF data

II. NRF data for ^{163}Dy

Spectrum of γ-rays scattered off ^{163}Dy

A. Nord *et al.*, PRC 67, 034307 (2003)



γ-ray energies 2.3-3.3 MeV:

- 94 lines from ^{163}Dy
- 41 lines from ^{164}Dy
- background lines
- line spacing of 7 keV

Probably a large number of unresolved lines here ...

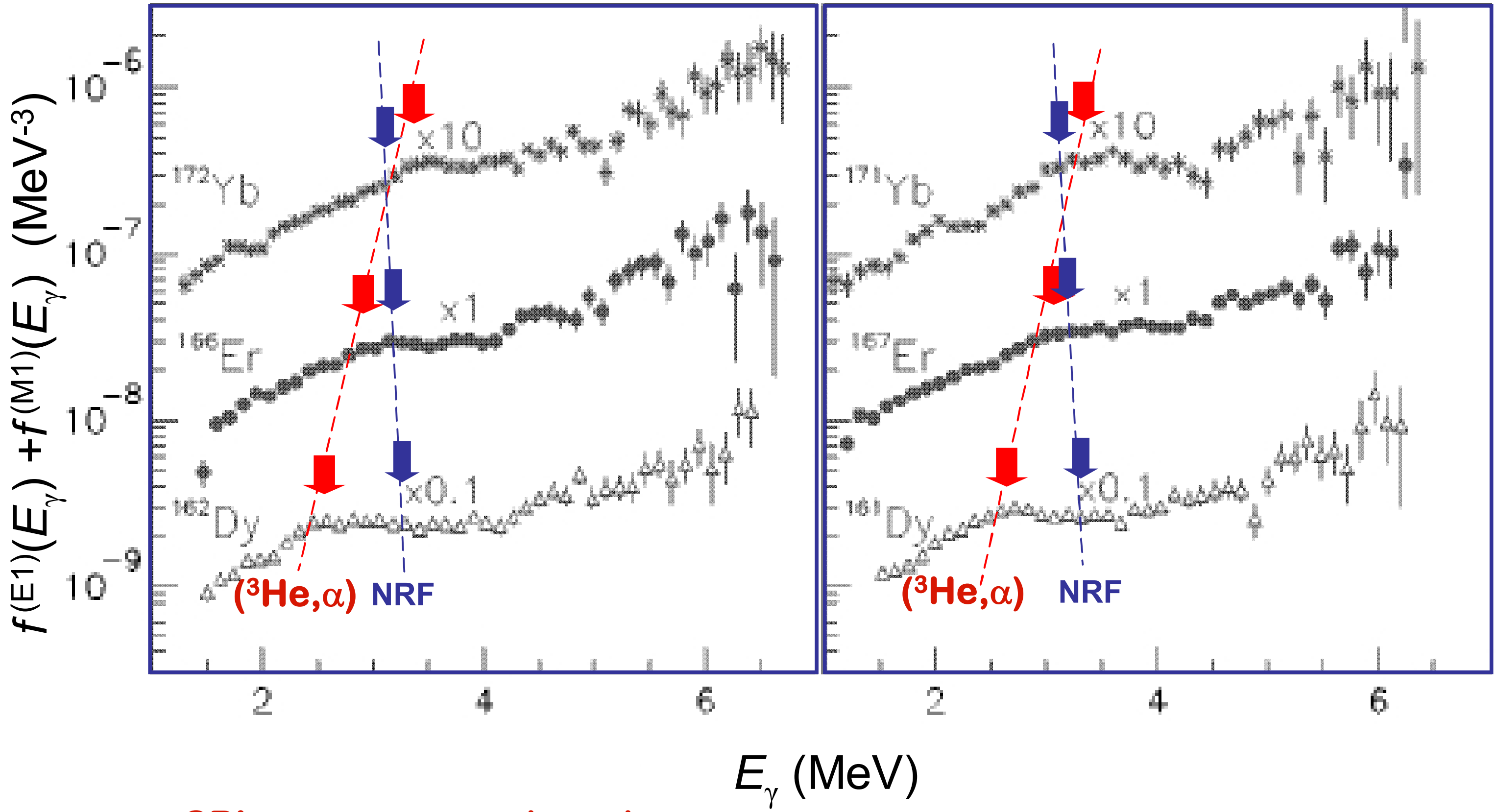
Limits of NRF?

Even if **all** ^{163}Dy transitions observed are *M*1 we get only **Σ *B*(*M*1)↑ = 1.53 μ_N^2**

… while TSC ^{163}Dy data yield <u>total</u> **Σ *B*(*M*1)↑ = 6.2 μ_N^2**

A 3 MeV resonance seen from (^{3}He,α) reactions in deformed nuclei

Data taken from a paper of E. Melby *et al.*, PRC **63** (2001) 044309



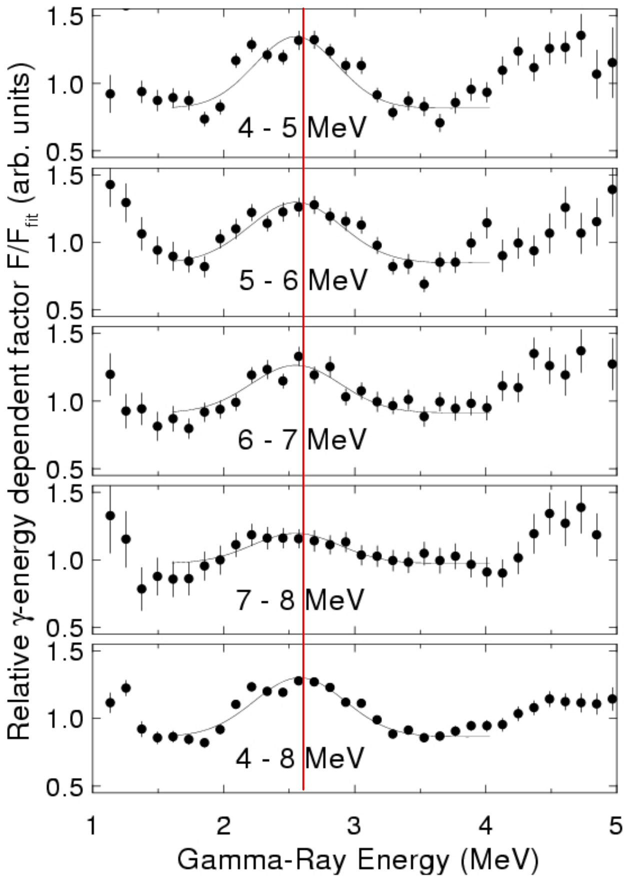
- **SR's seen are very broad**
- ***A*-dependence of SR energy differs differs from that observed from NRF data**

- a "pygmy resonance" of an unknown multipolarity or the SR resonance?

- dependence of SR energy on energy of the level on which the SR resides?

The 3 MeV resonance-like structure in the $^{172}Yb(^{3}He,^{3}He'\gamma)^{172}Yb$ data

Dependence of SR energy on energy of the level on which the SR resides?



It does not seem to be the case:

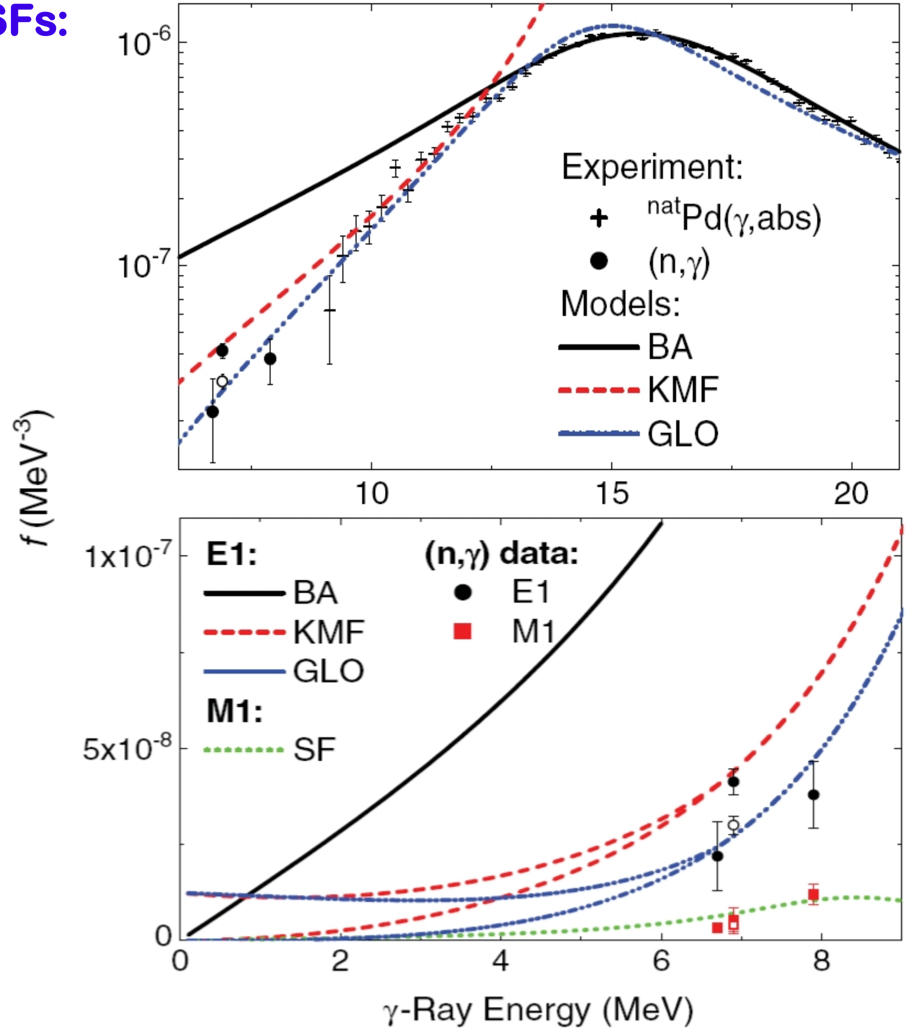
- **the position of the 3 MeV peak is remarkably stable with changing the initial excitation**

Data taken from A. Schiller *et al.*, Physics of Atomic Nuclei 62 (2001) 1186

Populations of ^{106}Pd low-lying levels from thermal neutron capture in ^{105}Pd

Krtička *et al.*, Phys. Rev. C **77**, 054615 (2008) & D. De Frenne and E. Jacobs, Nucl. Data Sheets **72**, 1 (1994)

Postulated PSFs:

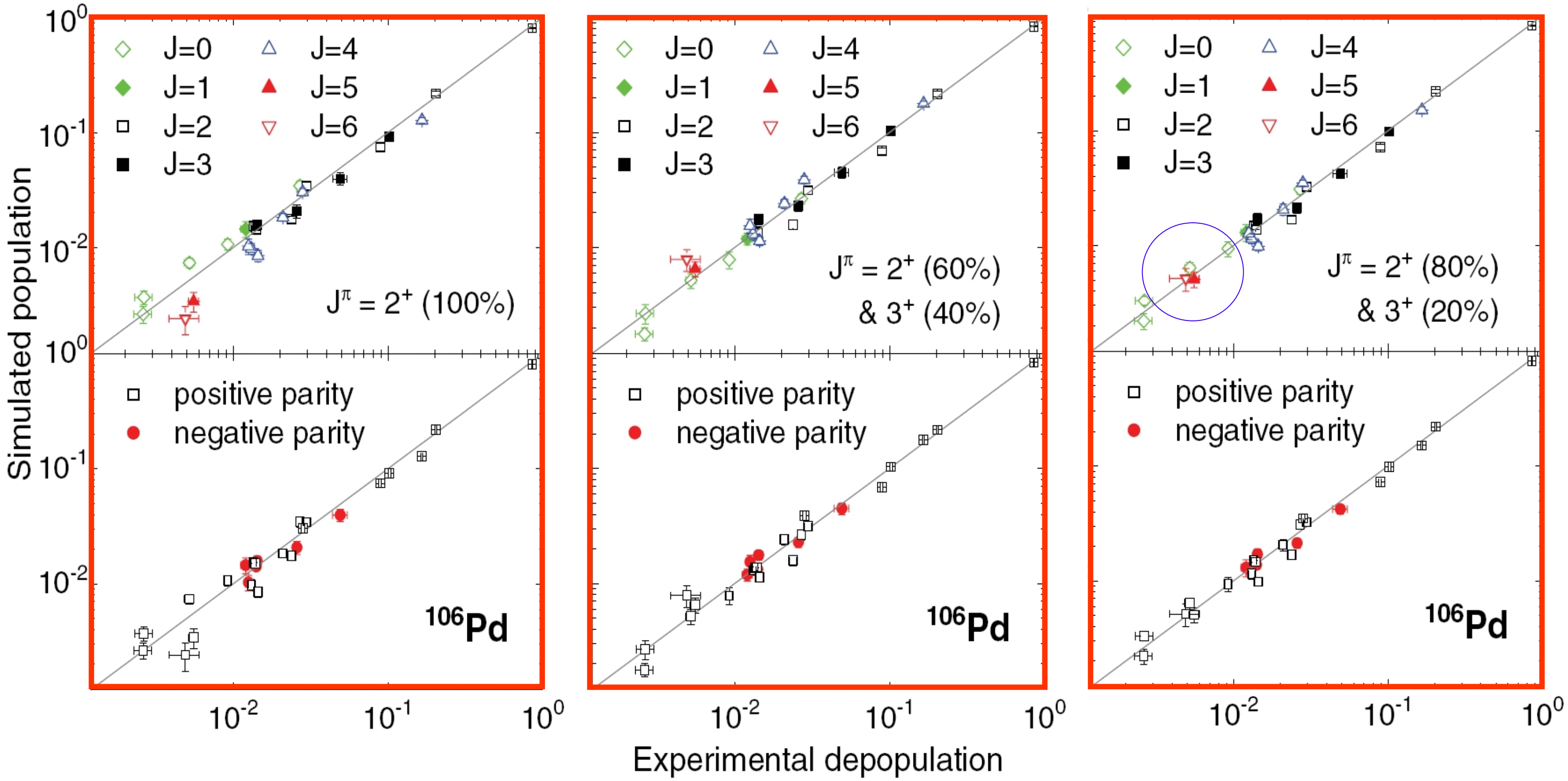


A triaxiality of ^{106}Pd ignored

Sensitivity of populations of low-lying levels to a spin makeup of the (thermal) neutron capturing state

^{105}Pd(n,γ)^{106}Pd reaction

Krtička *et al.*, Phys. Rev. C **77**, 054615 (2008) & D. De Frenne and E. Jacobs, Nucl. Data Sheets **72**, 1 (1994)

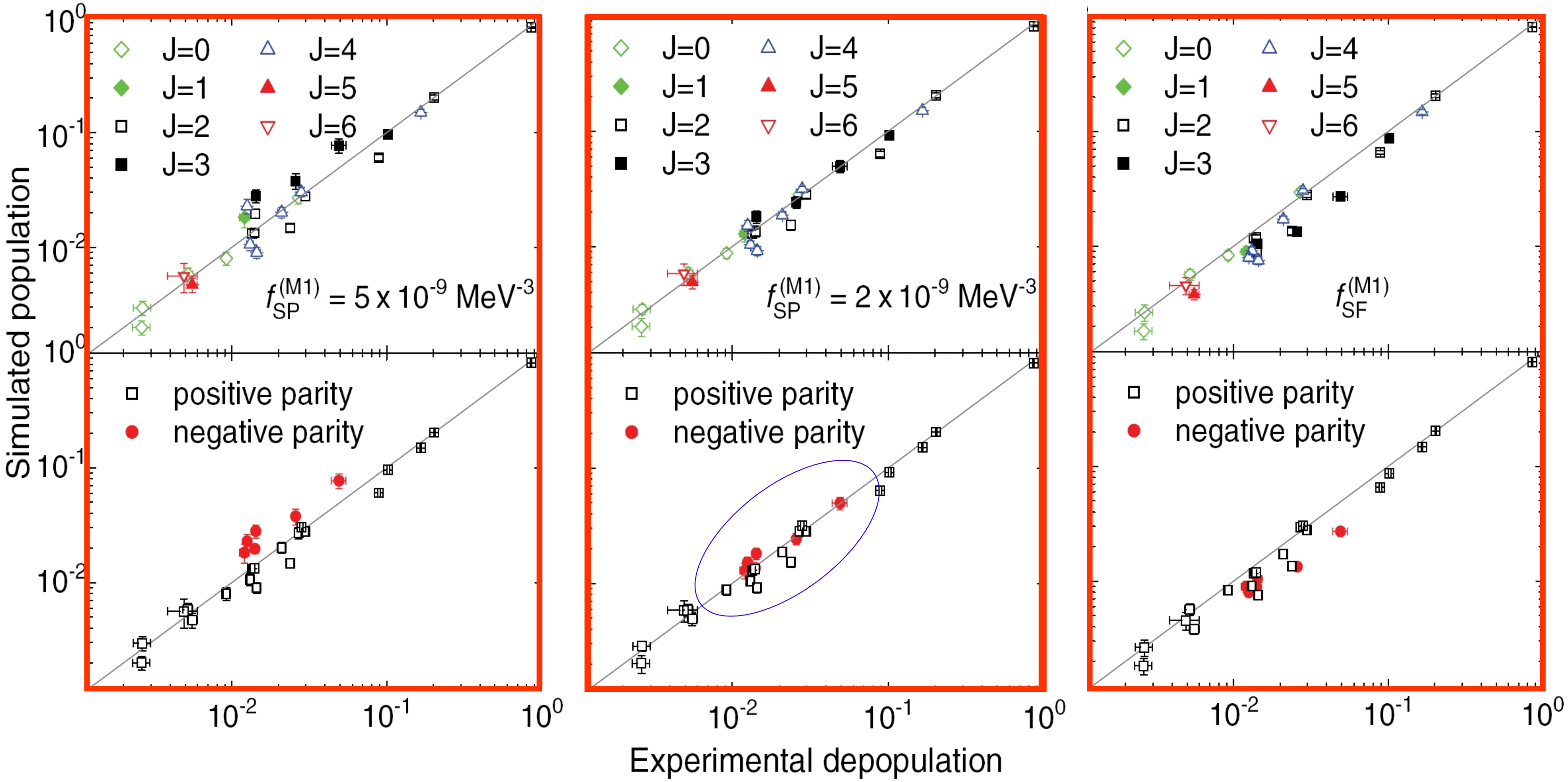


Dynamic range: almost 3 orders !

Sensitivity of populations of low-lying levels to $E1$-to-$M1$ ratio of PSFs

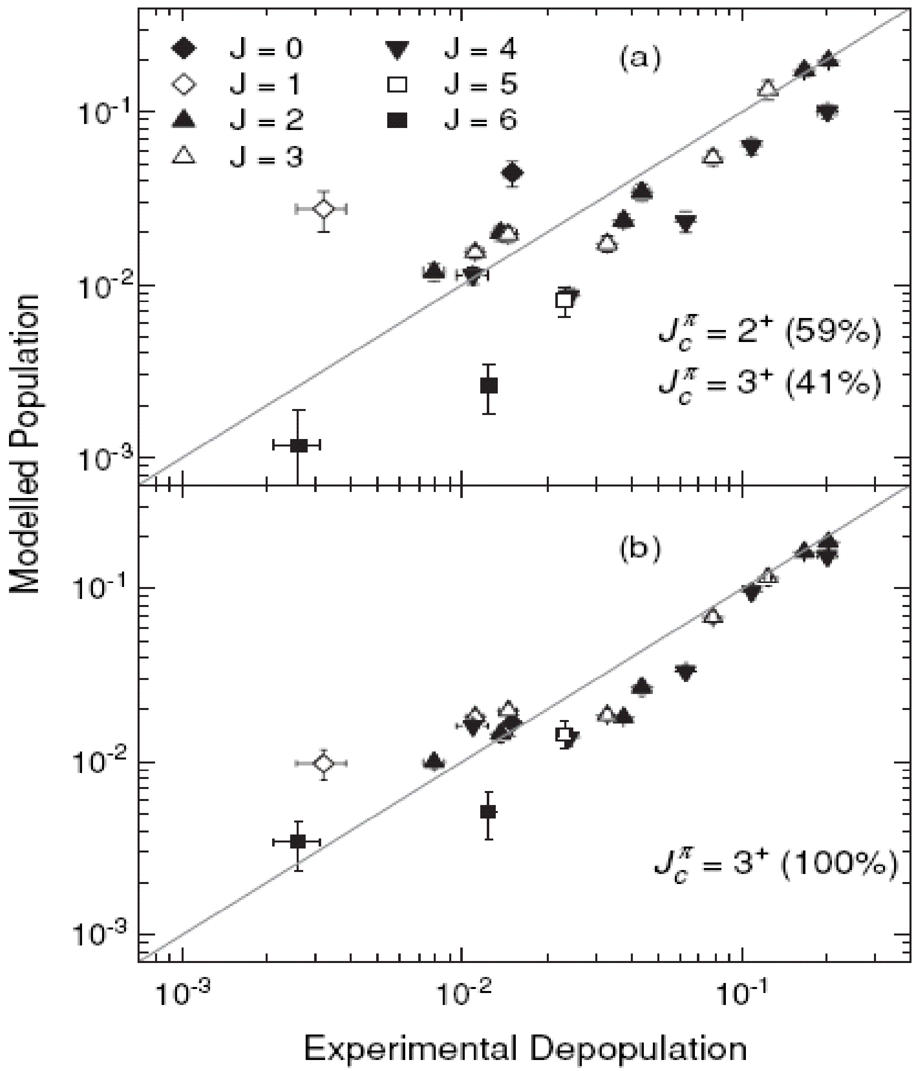
^{105}Pd(n,γ)^{106}Pd reaction

Krtička *et al.*, Phys. Rev. C **77**, 054615 (2008) & D. De Frenne and E. Jacobs, Nucl. Data Sheets **72**, 1 (1994)



A constant M1 PSF seems to be better ...

Populations of ^{96}Mo low-lying levels from thermal neutron capture in ^{95}Mo

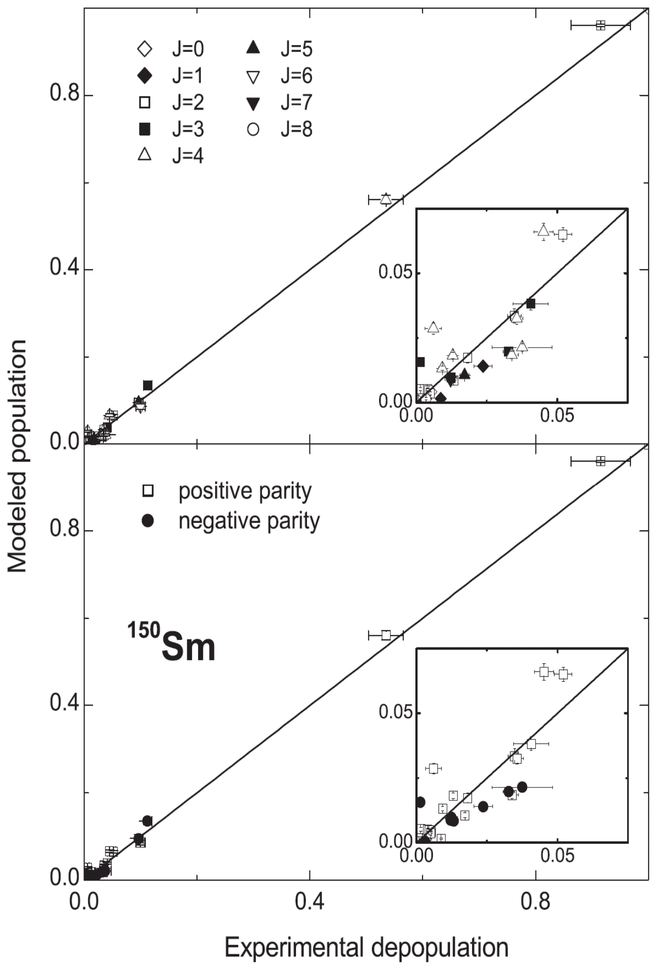


Krtička et al., Phys. Rev. C 77, 054319 (2008) & Nuclear Data Sheets

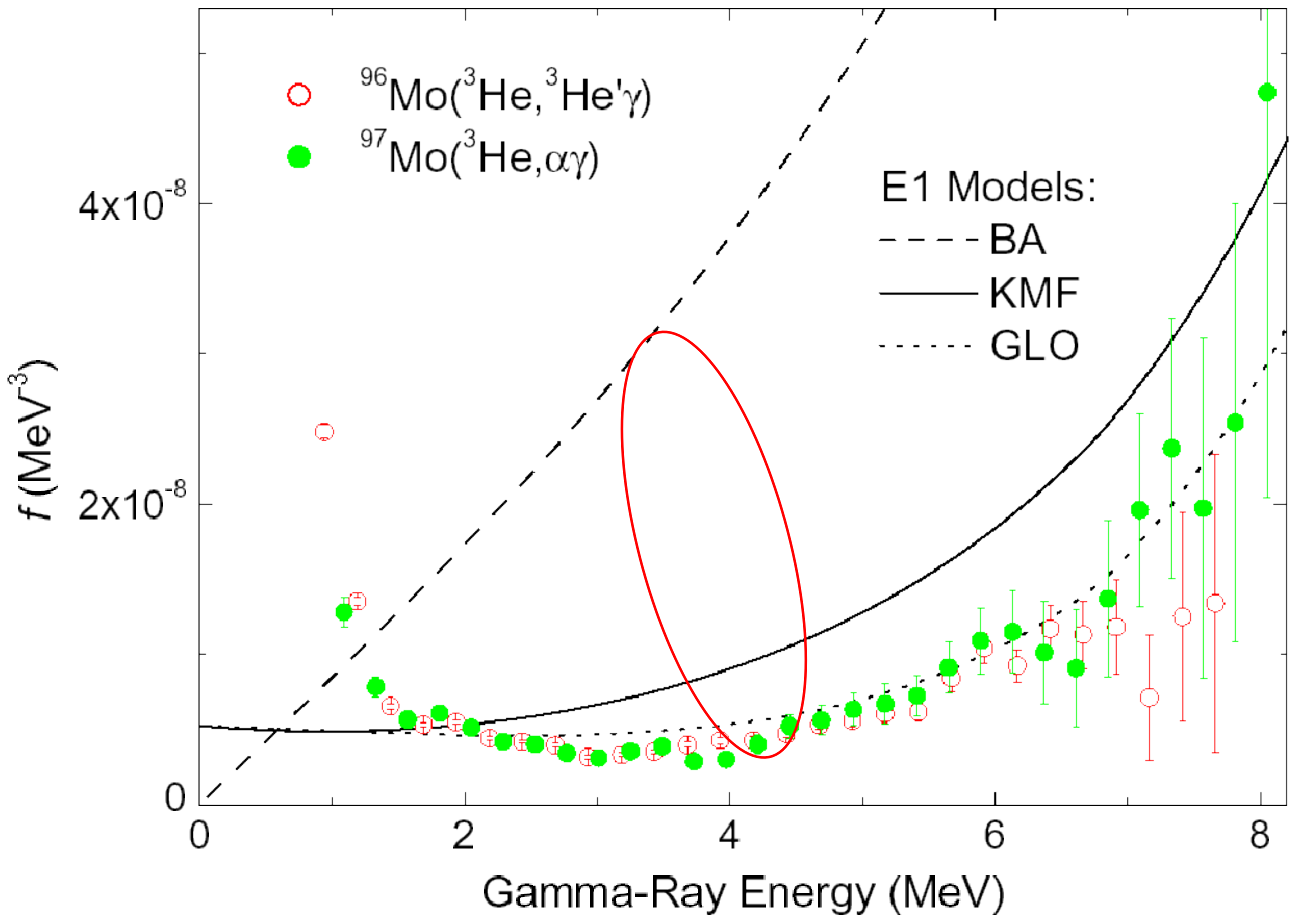
- **The spin makeup of neutron capturing state differs from that listed in BNL-325**
- **The agreement still far from being ideal – misplaced levels?**

Populations of ^{150}Sm low-lying levels from thermal neutron capture in ^{147}Sm

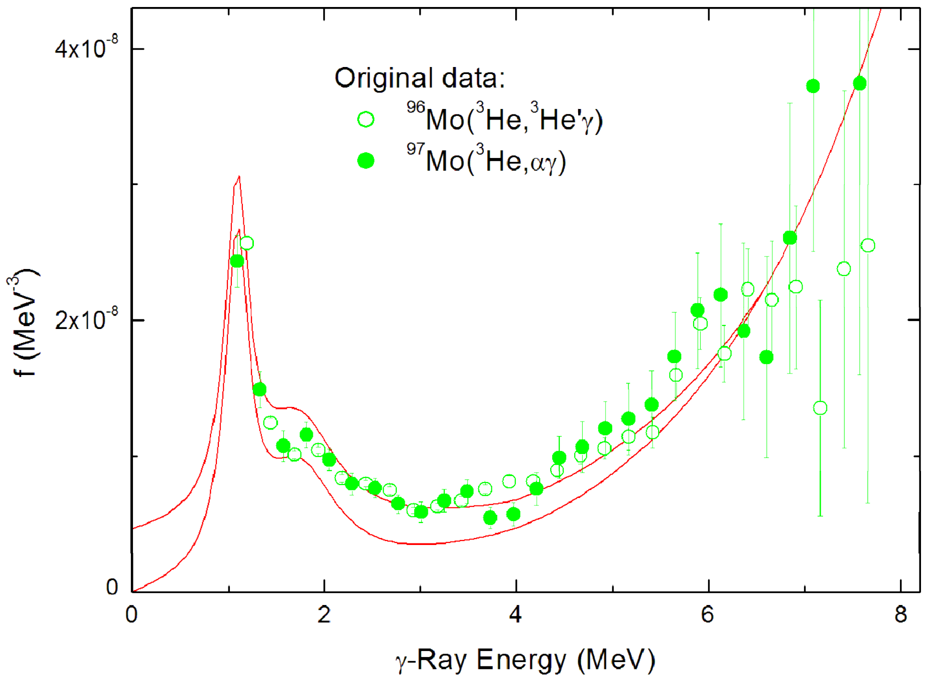
Shangwu Wang, et al., Nucl.Instr. Methods A 513, 585 (2003)

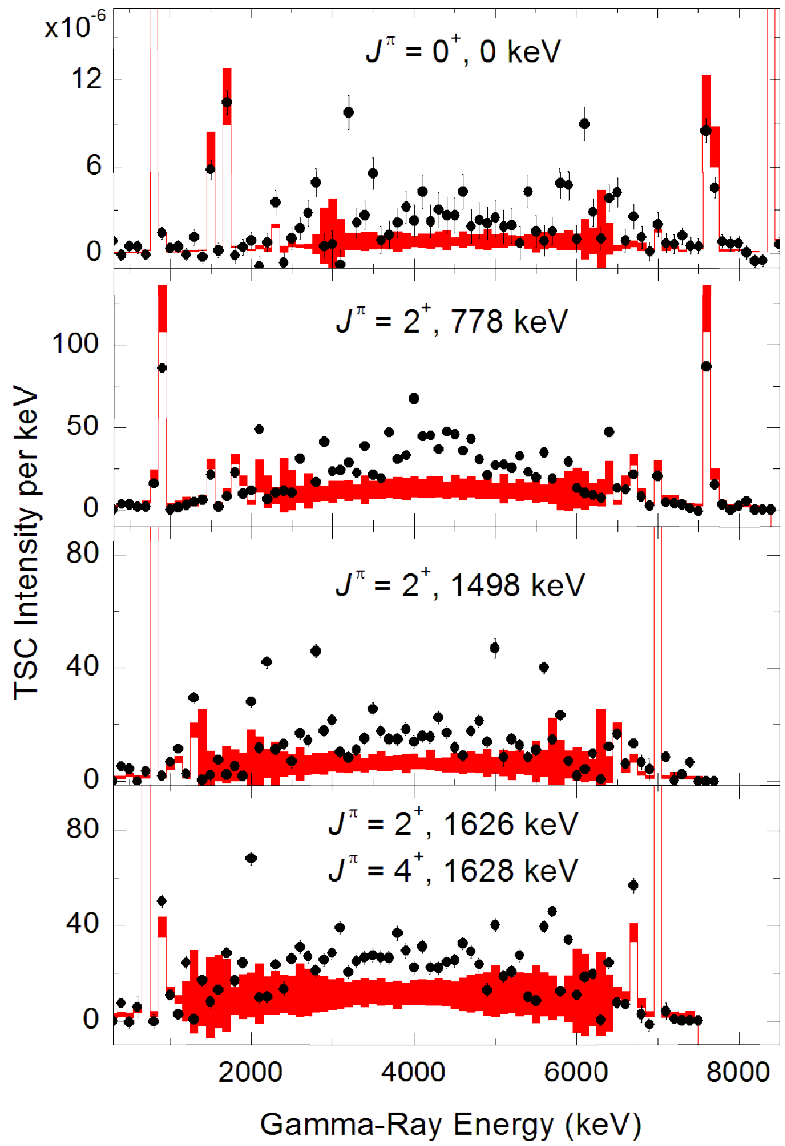


Problem of strong enhancement of strength of ^{96}Mo at low γ energies



Problem of strong enhancement of strength of ^{96}Mo at low γ energies



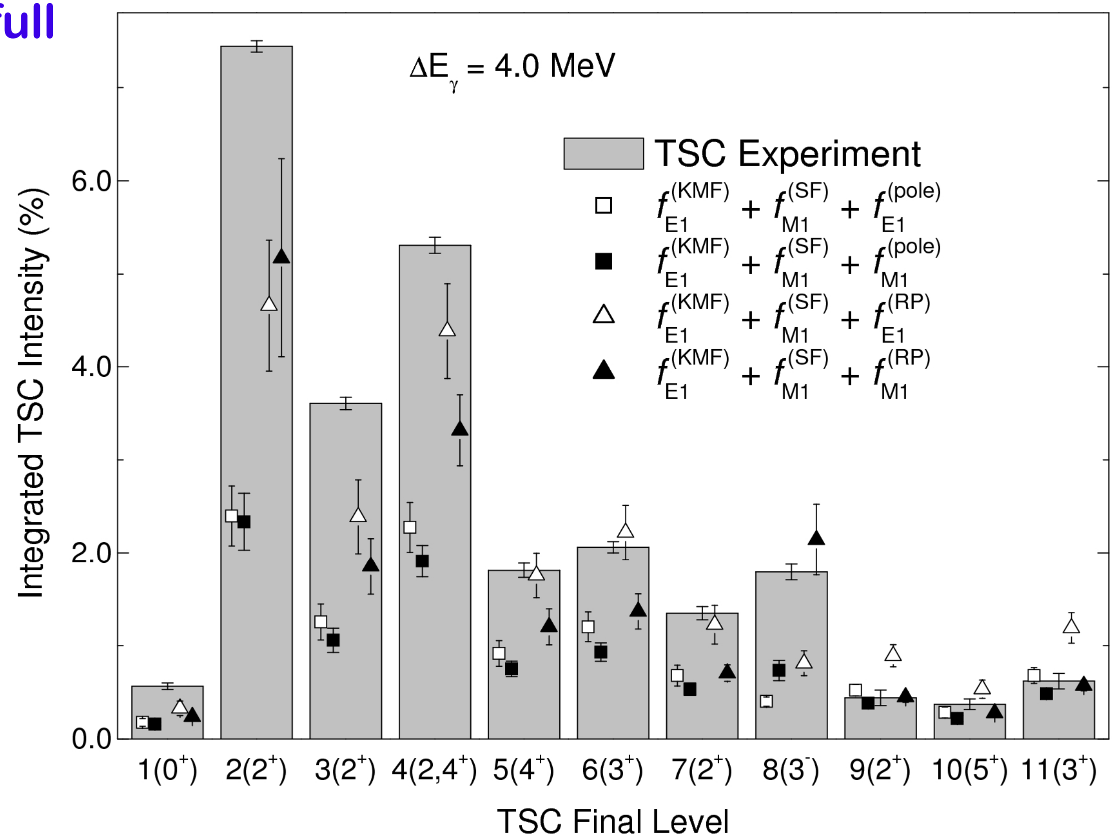


Problem of strong enhancement of strength of ^{96}Mo at low γ energies

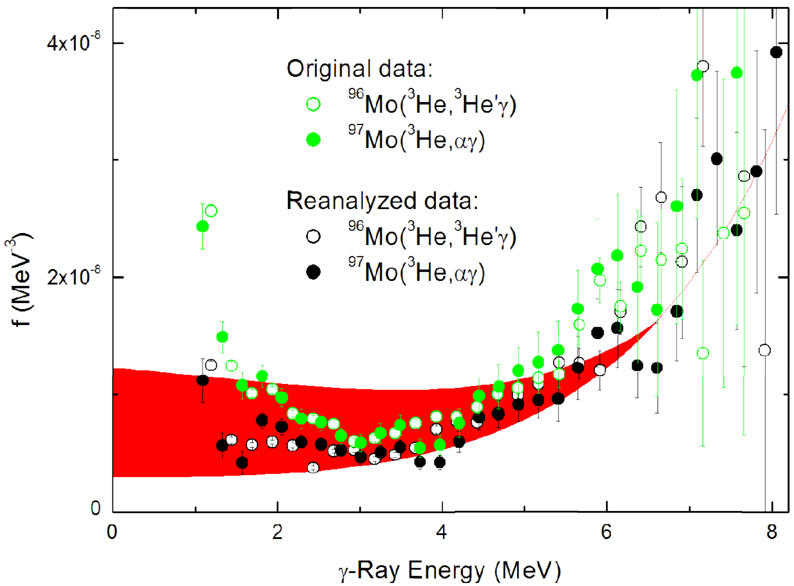
Integrated TSC intensities

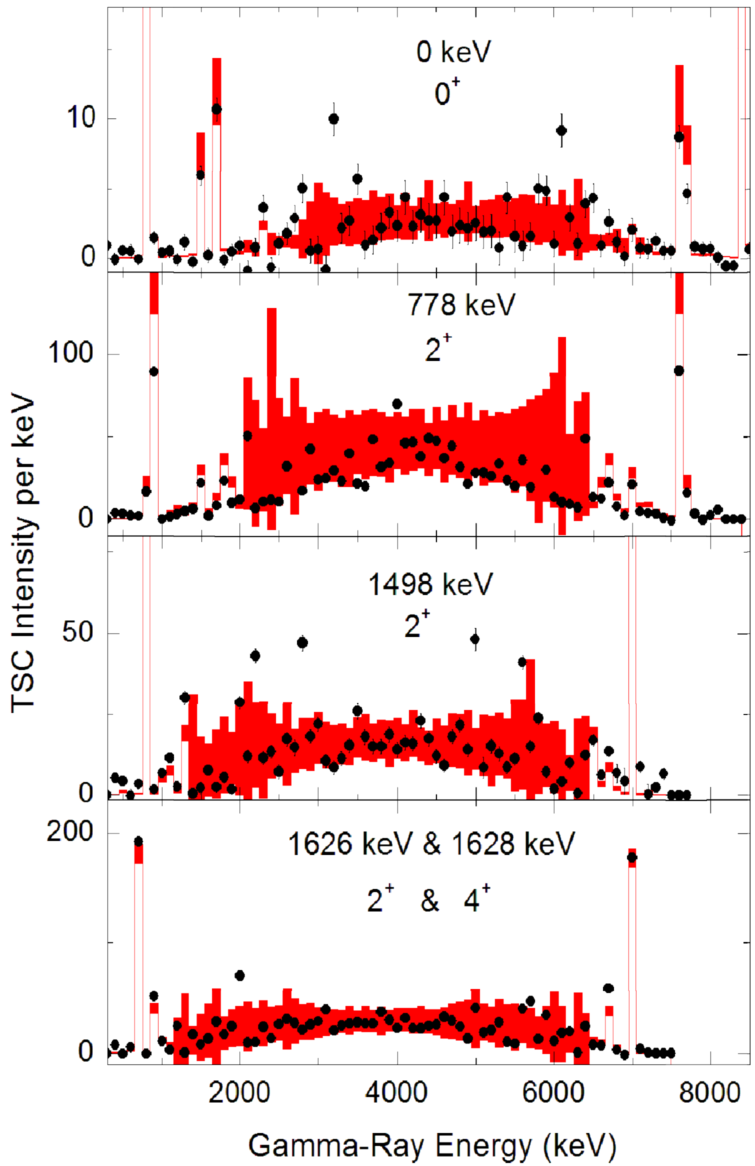
Simulations:
Dipole PSF models with a full or restricted divergence at zero energies

Data:
TSC experiment at Rez



Problem of strong enhancement of strength of ^{96}Mo at low γ energies





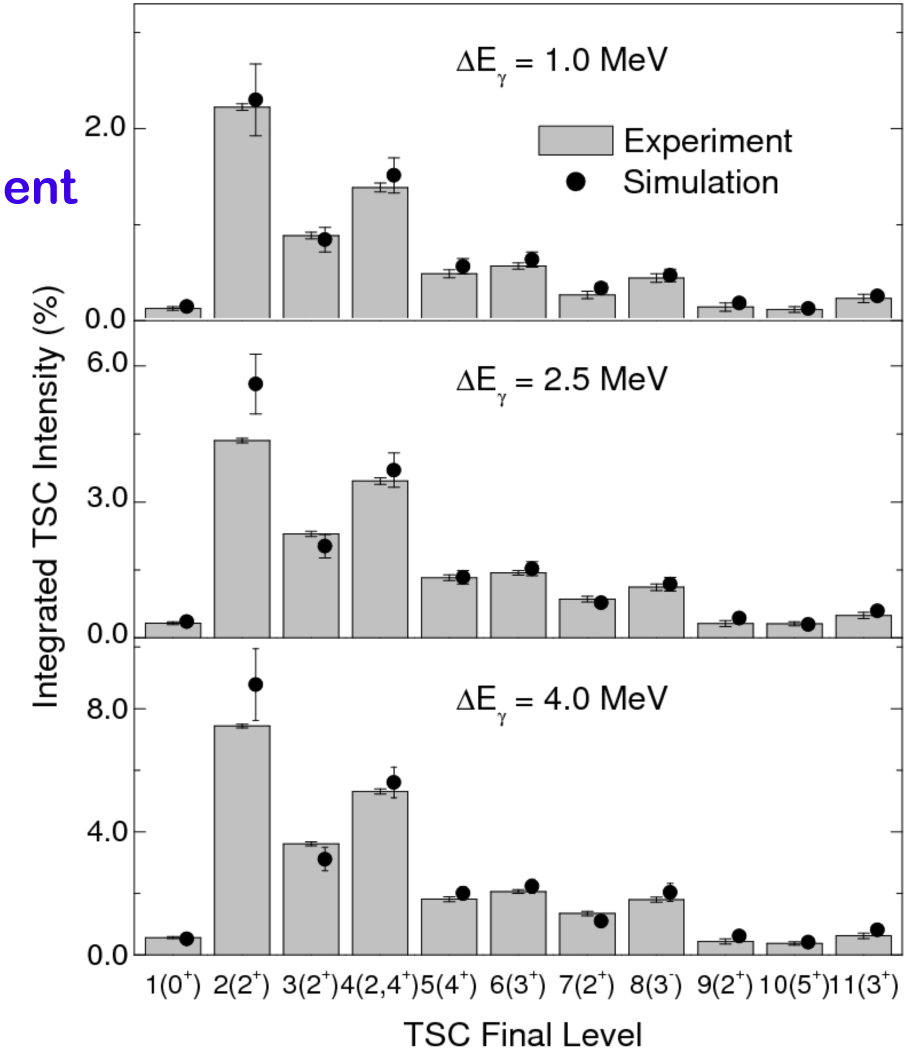
GLO model successful ...

Problem of strong enhancement of strength of ^{96}Mo at low γ energies

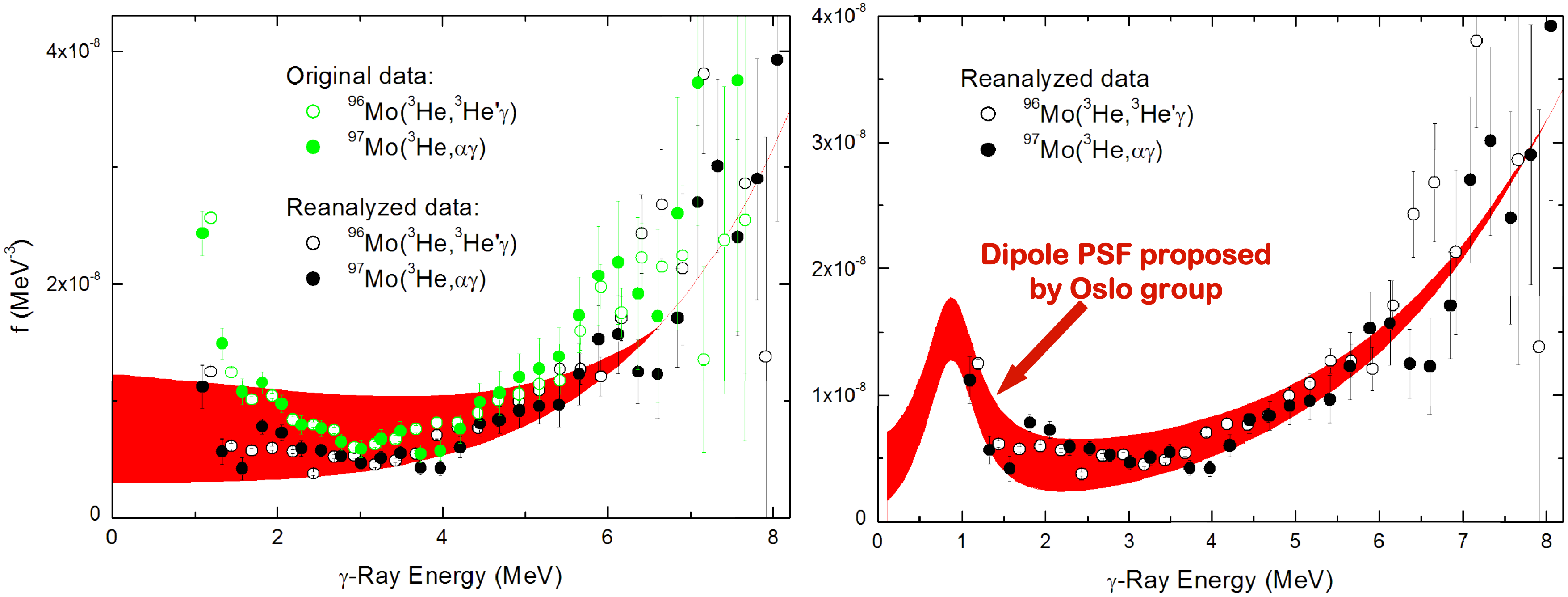
Integrated TSC intensities

Simulations:
GLO PSF models without enhancement
At low energies

Data:
TSC experiment at Rez



Problem of strong enhancement of strength of ^{96}Mo at low γ energies



1. Rigorous analysis excludes the proposed Oslo PSFs at 99.8% confidence level.

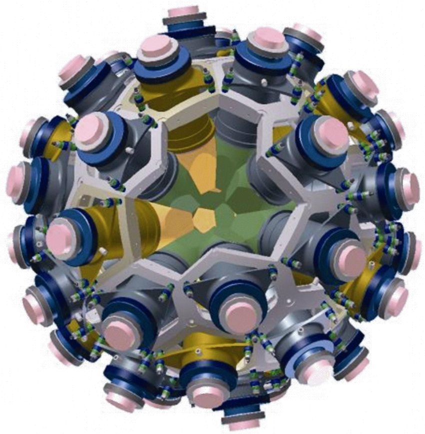
Krticka *et al.*, Phys. Rev. C 77, 054319 (2008)

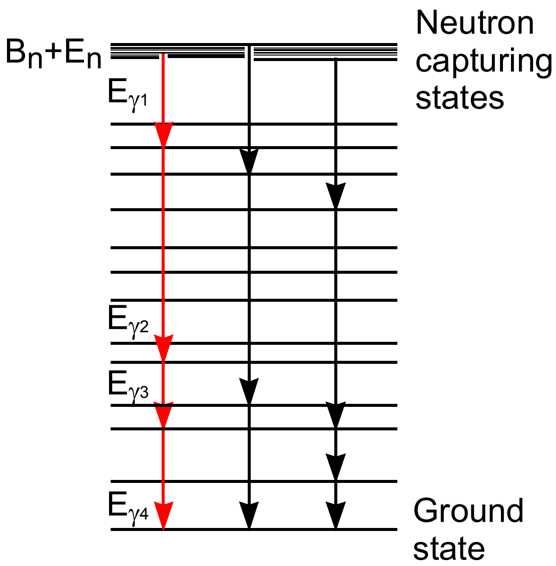
2. The enhancement is very weak, if any.

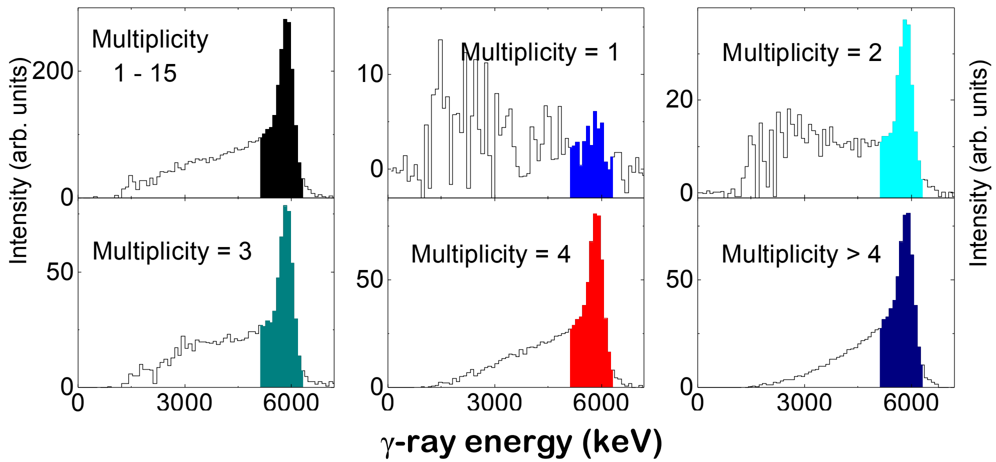
3. Data from DANCE at isolated *s*- and *p*-wave resonances confirm this conclusion

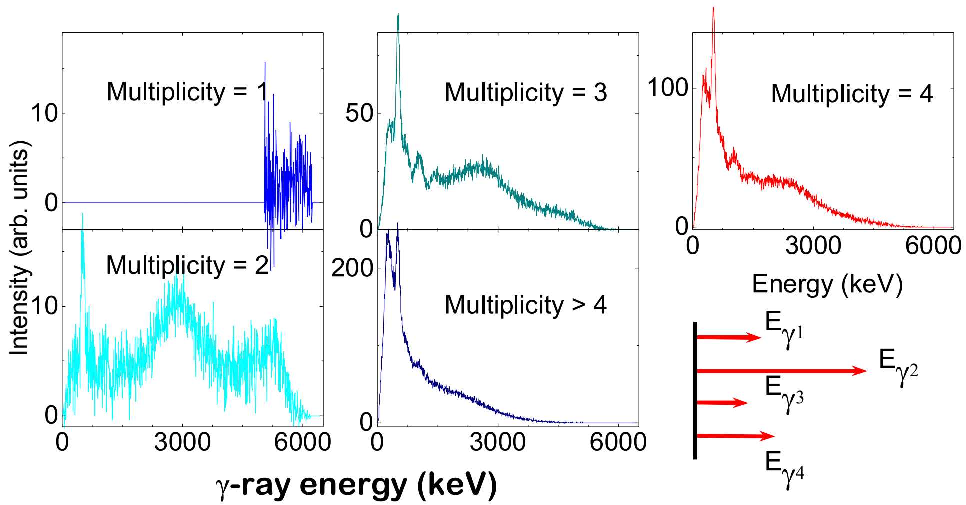
Essentials of γ-calorimetric studies of γ cascades

4π BaF_2 detector array







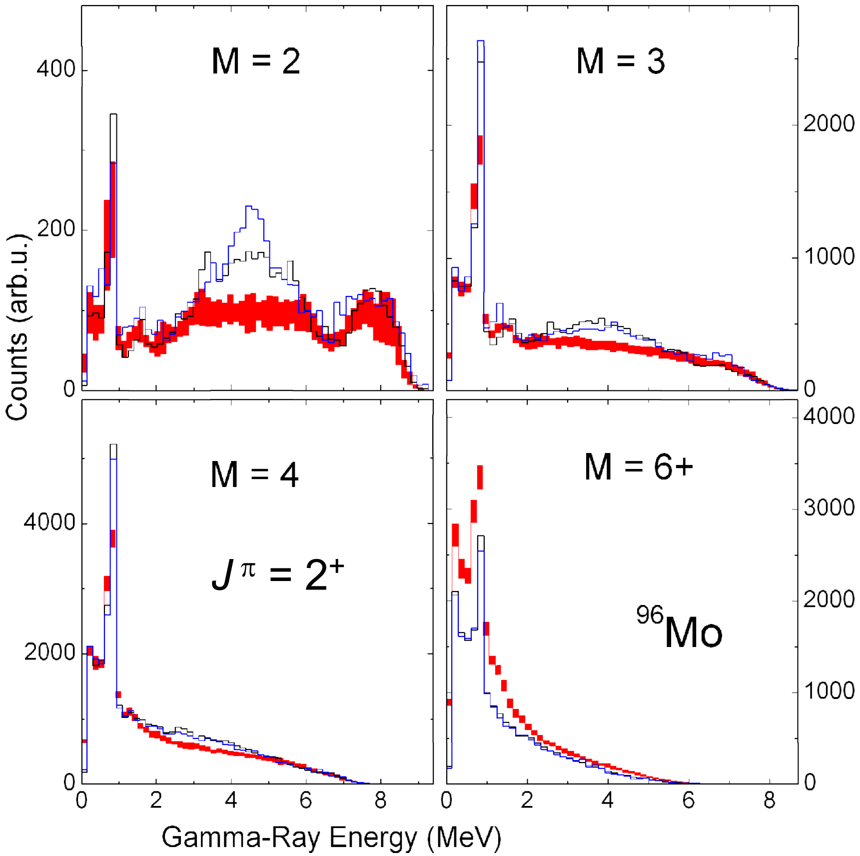


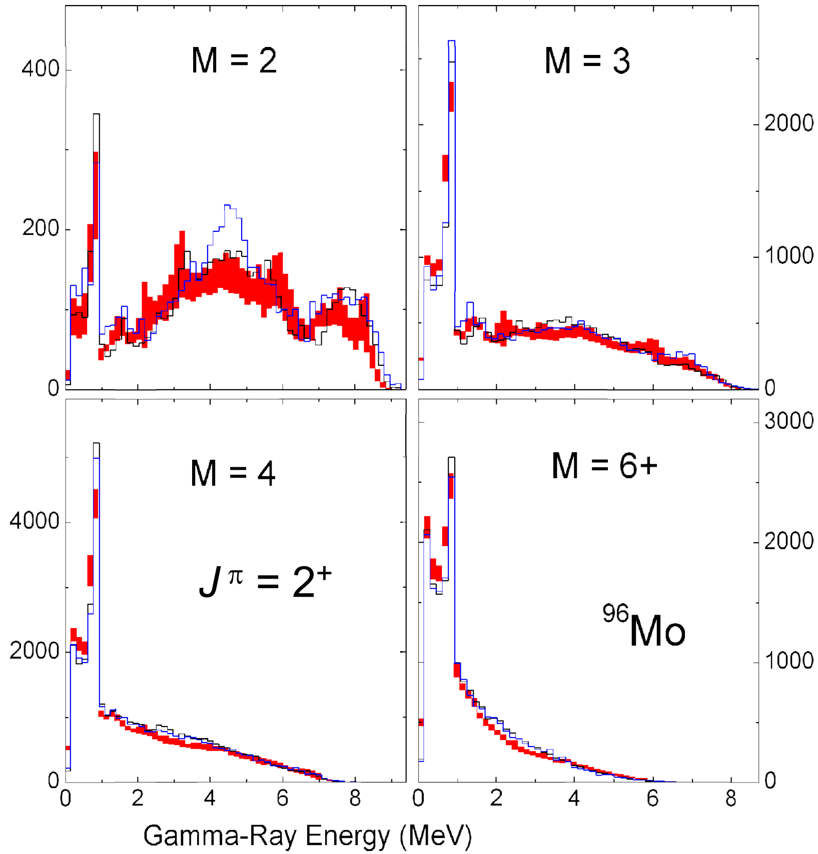
Problem of strong enhancement of strength of ^{96}Mo at low γ energies

Data from the DANCE array v.s. simulations

Postulated PSFs used identical to those obtained by Oslo group from ^{3}He-induced γ emission

Postulated PSFs used identical to the "best PSFs" obtained by *trial-and-error method* from TSC data



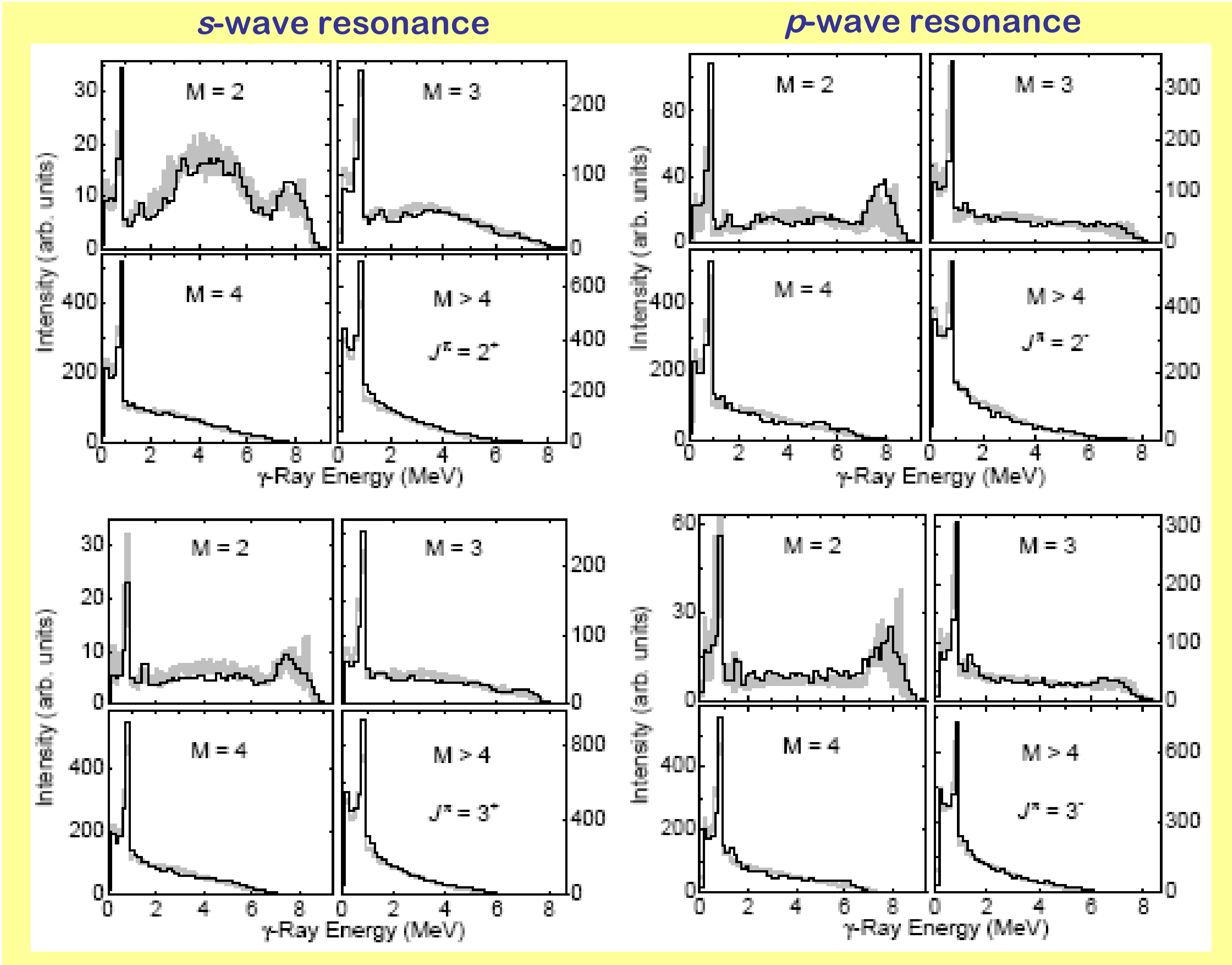


Problem of strong enhancement of strength of ^{96}Mo at low γ energies

Data from the DANCE array v.s. simulations

Simulations:

the postulated PSFs used were identical to the "best PSFs" obtained by *trial-and-error method* from analysis of Řež TSC data



SUMMARY

A deficit of photon strength in spherical and transitional nuclei at γ-ray energies of 6-8 MeV

Methods of TSCs and the *n*-step cascades (following the capture of keV neutrons or capture at isolated resonances) proved to be efficient tools for studying PSFs at intermediate γ-ray energies of 2 – 4 MeV

A strong evidence for scissors-like vibrations of *excited* deformed nuclei. The scissors M1 mode *per se* displays, indeed, resonance-like behavior

Very large values of the reduced *B*(M1)↑ strength found; a deeper revision of the NRF data would be welcome

No meaningful enhancement of photon strength at low energies in ^{96}Mo has been found

With present knowledge of PSFs the populations of low-lying levels are predicted with success

Discrepancy between the data from the ^{3}He-induced γ emission and the KMF model

OUTLOOK

The role of nuclear temperature still not fully established. Measurements on a TSC setup with highly efficient multi-detector system installed on pure thermal neutron beam could shed more light on this key problem.

Future γ-calorimetric data from DANCE, n_TOF and J-Parc facilities may reveal possible presence of scissors mode in very heavy nuclei or even radioactive nucle

Co-operative efforts of NRF, (n,γ) and photonuclear communities may solve still open problems related to existence of pygmy resonances

Attention of theorists is needed for understanding the physics behind the suppression of the low-energy tail of the GDR

The very existence of the scissors resonances built on each excited level is a great challenge for microscopic nuclear theory. *The intuition of D. M. Brink is fascinating.* Finding the nature of this phenomenon may lead to prediction and discovery of new, so far, not known phenomena in behavior of medium-weight and heavy nuclei.

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M. Jandel – *LANL Los Alamos*
F. Kaeppeler – *FzK Karlsruhe*
G. Mitchell – *TUNL Raleigh*
R. Reifarth – *LANL Los Alamos*
S. A. Sheets – ***TUNL Raleigh***
I. Tomandl – *NPI Řež*
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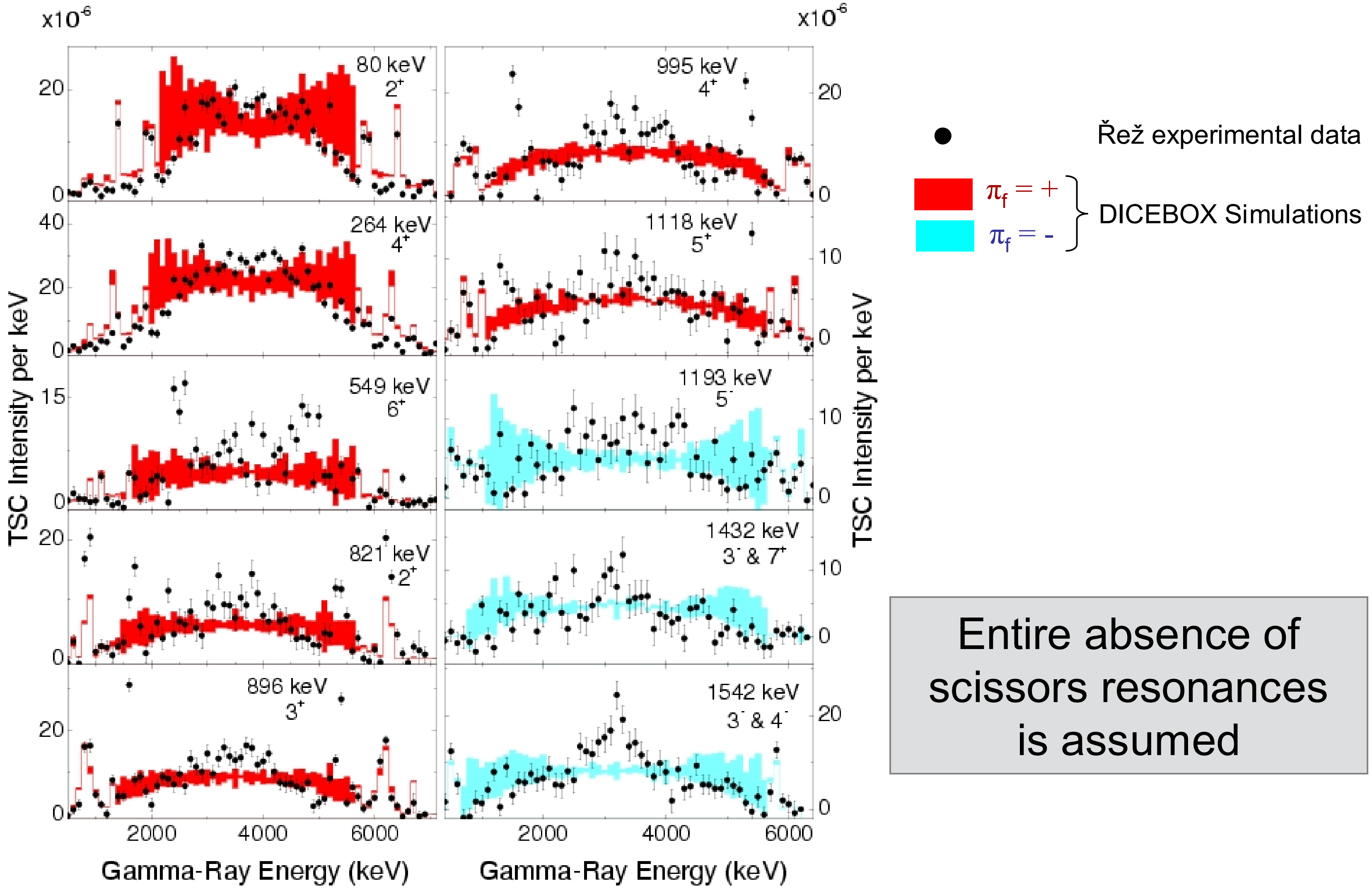
D. J. Vieira – ***LANL Los Alamos***
F. Voss – *FzK Karlsruhe*
K. Wisshak – *FzK Karlsruhe*

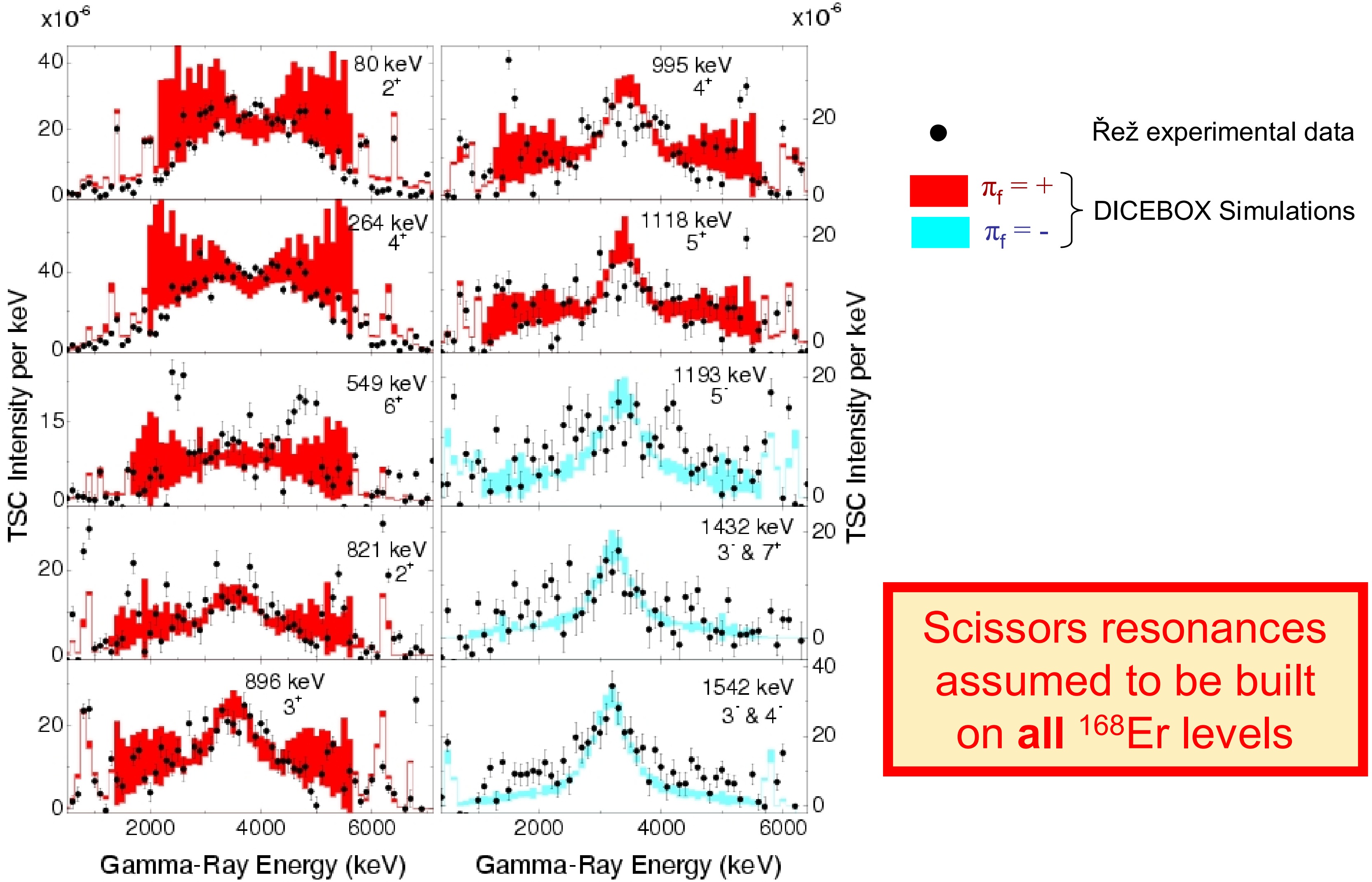
Thank you

TSCs in the $^{167}Er(n,\gamma)^{168}Er$ reaction



Entire absence of scissors resonances is assumed

TSCs in the $^{167}Er(n,\gamma)^{168}Er$ reaction



Scissors resonances assumed to be built on **all** ^{168}Er levels