Slow-neutron capture

in the context of experimental research at Dubna

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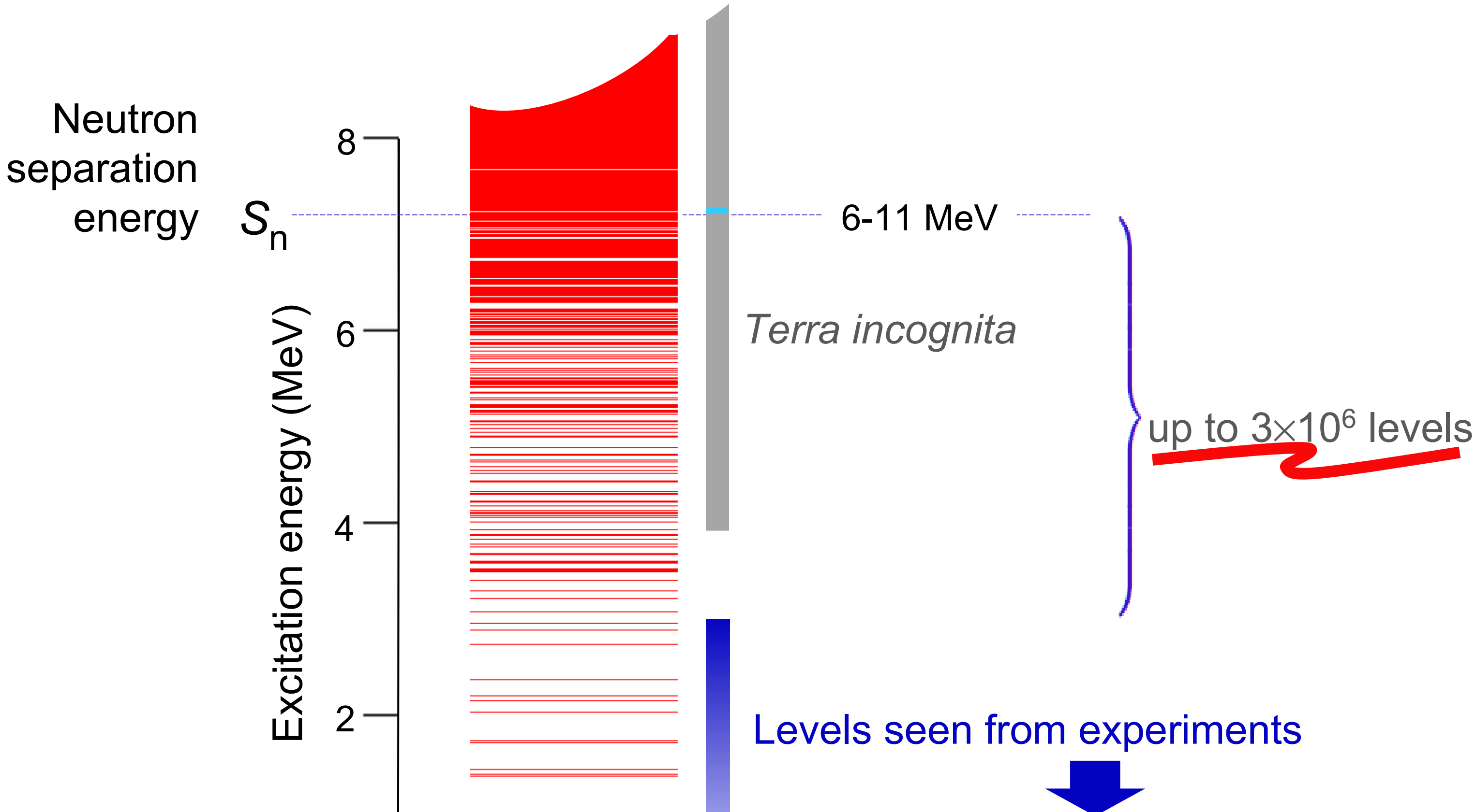
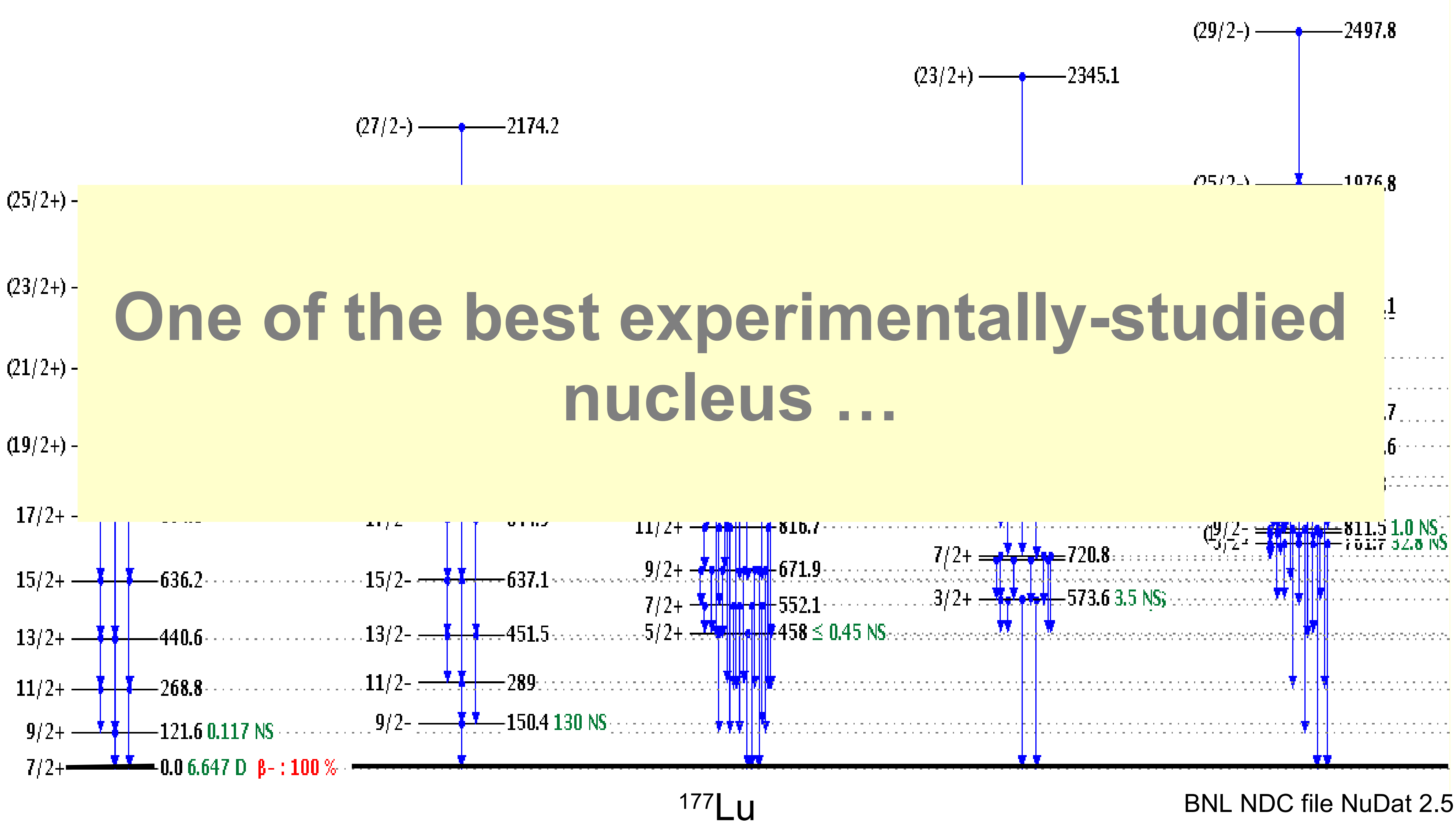
Levels in heavy nuclei



- Knowledge of their energies, spin and π
- Energies and intensities of the depopulating γ-transitions
- Multipolarity makeup of these transitions
- Assignment of the levels to rotational bands , *etc.*

An example of energy levels in a heavy nucleus: ^{177}Lu

band 1 band 2 band 3 band 4 band 5



One of the best experimentally-studied nucleus …

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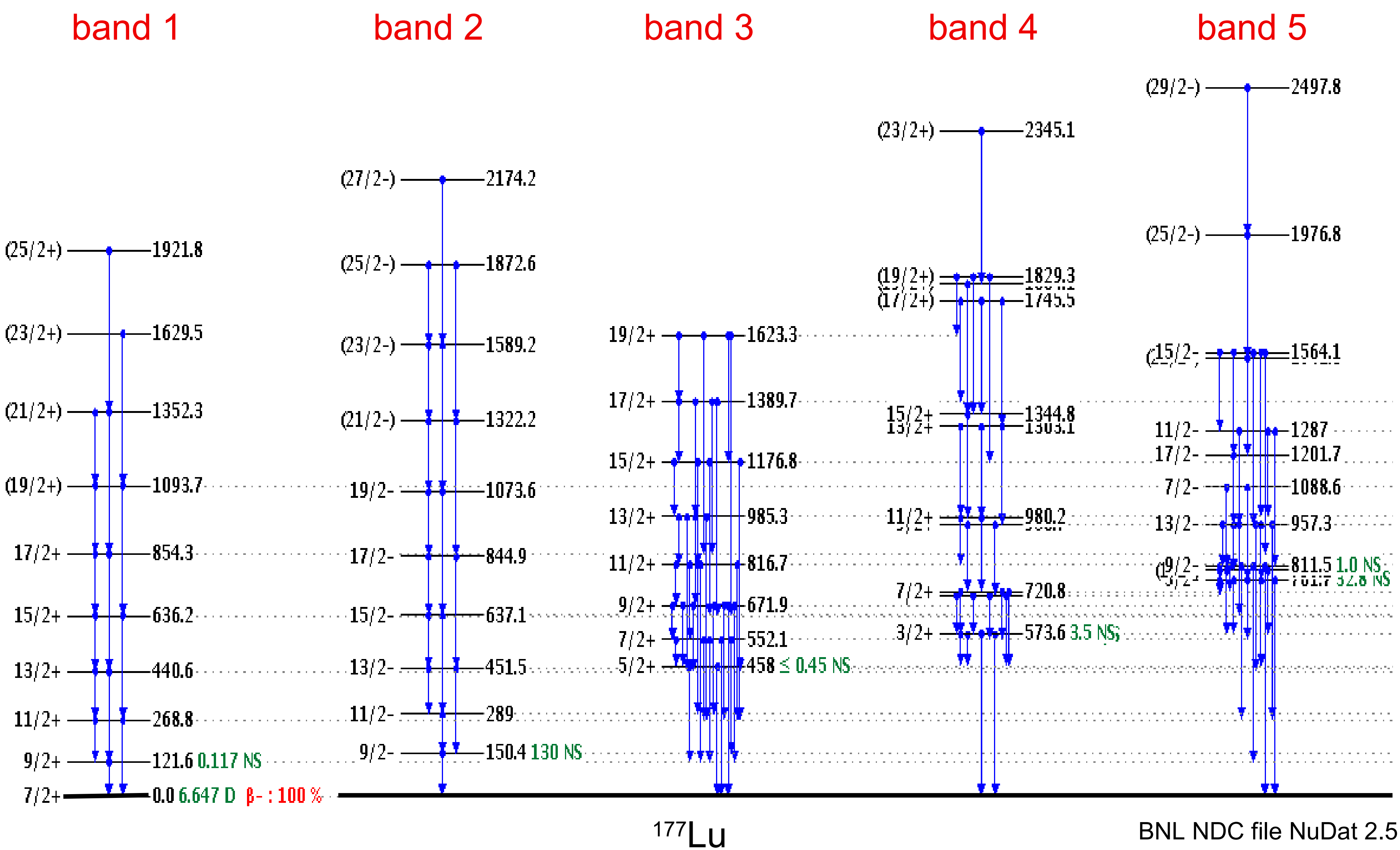
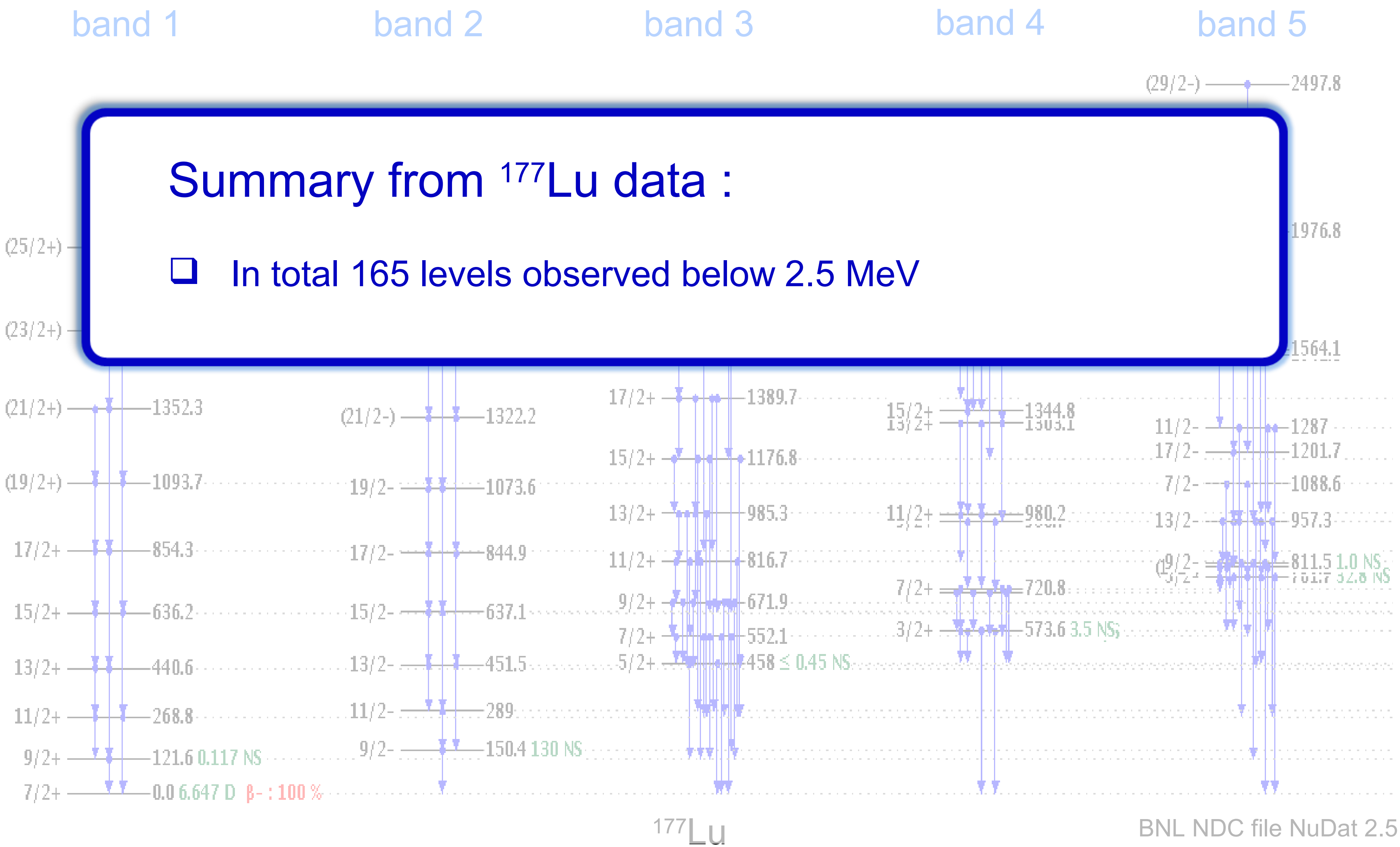


BNL NDC file NuDat 2.5

An example of energy levels in a heavy nucleus (contn'd)

Summary from ^{177}Lu data :

- ❑ In total 165 levels observed below 2.5 MeV



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An example of energy levels in a heavy nucleus (contn'd)

Summary from ^{177}Lu data :

- ❑ In total 165 levels observed below 2.5 MeV
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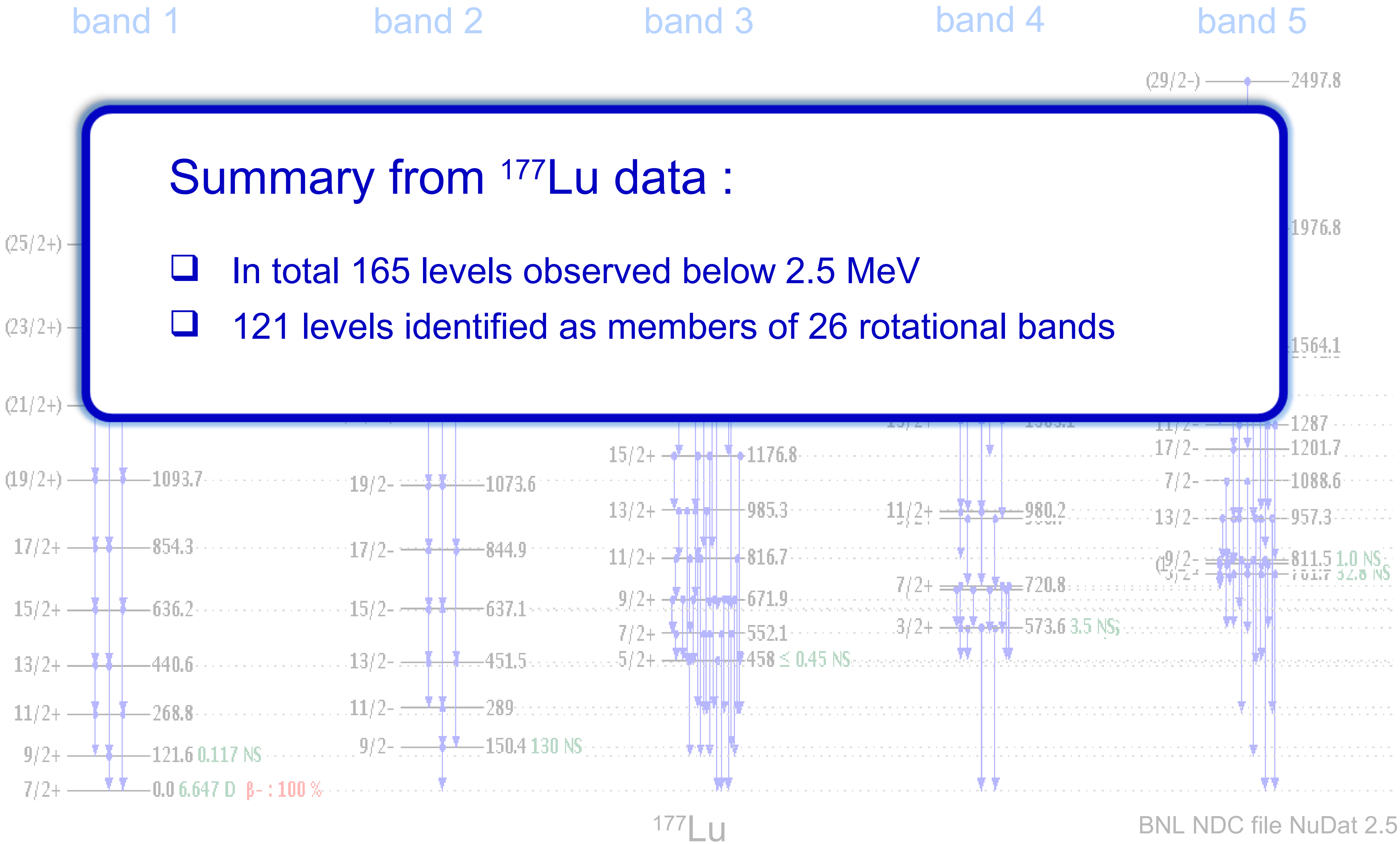

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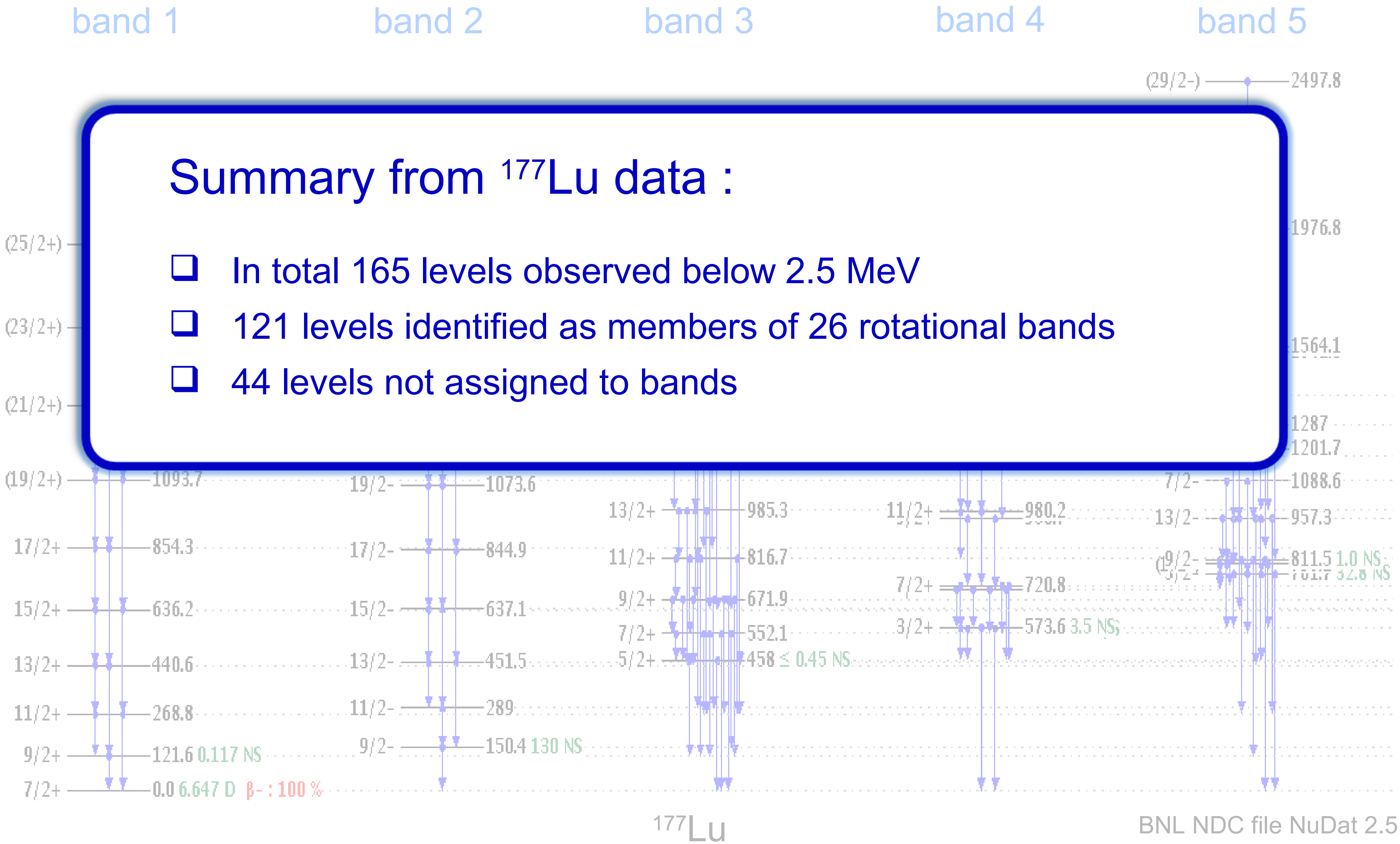

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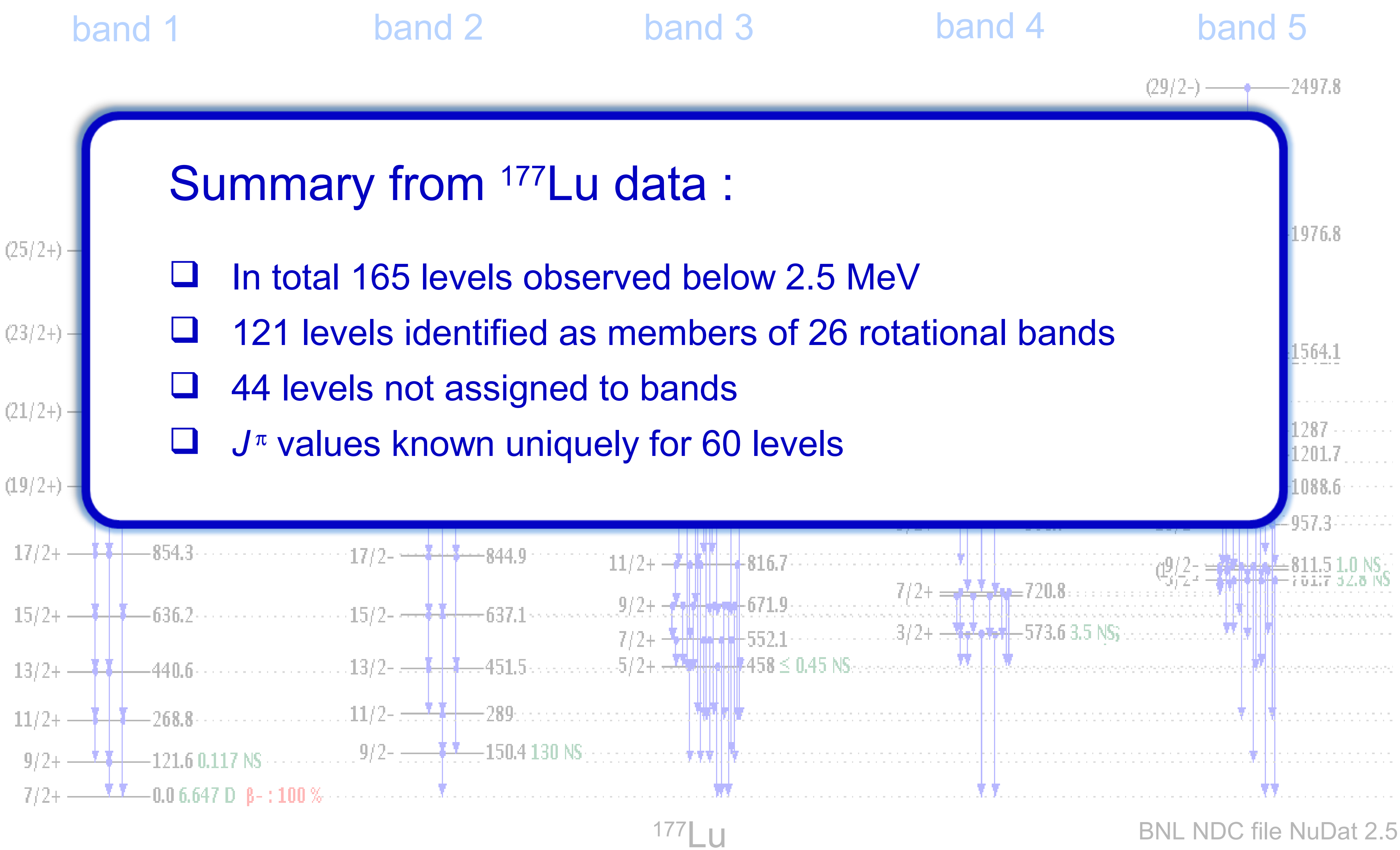

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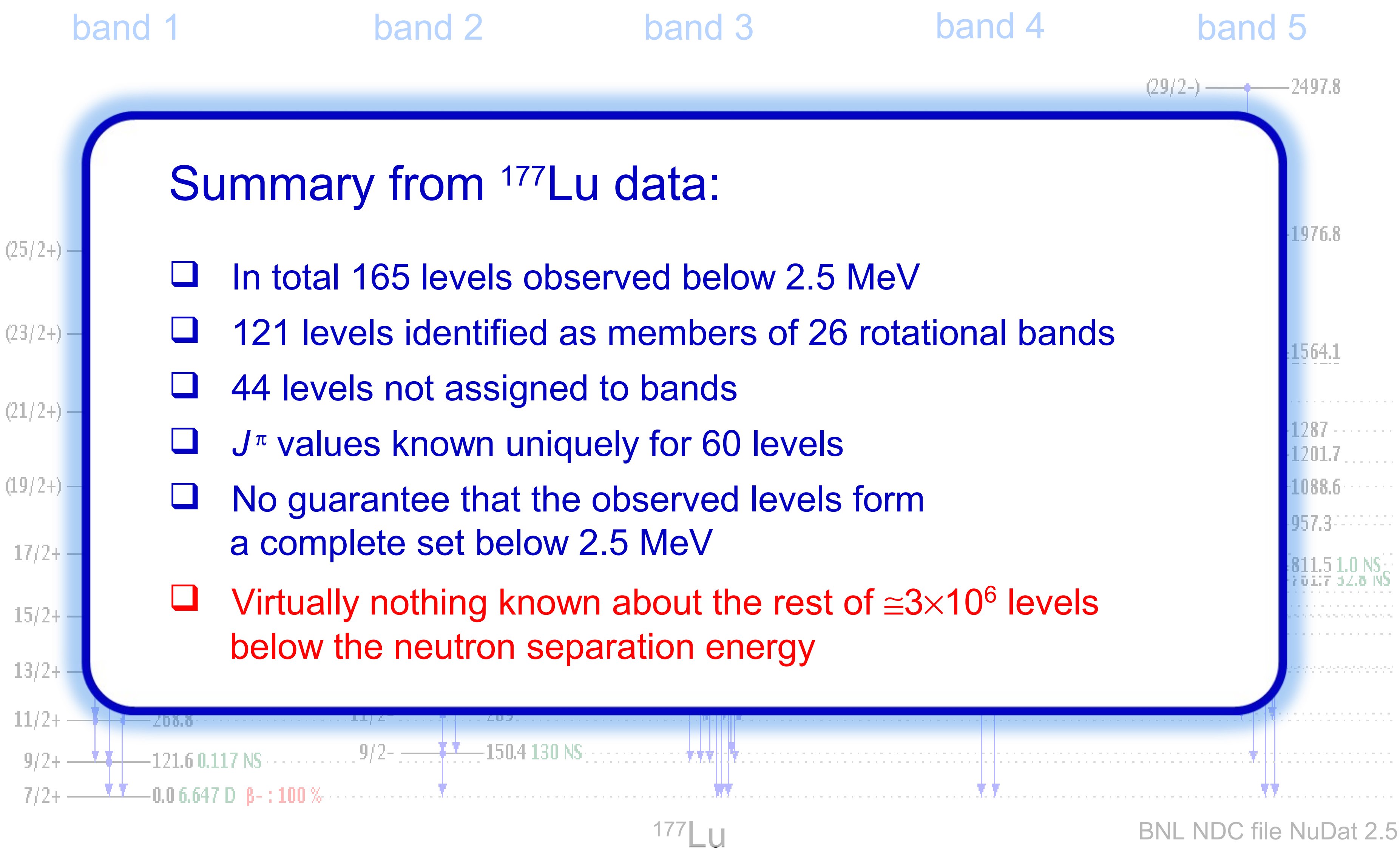
- ❑ In total 165 levels observed below 2.5 MeV
- ❑ 121 levels identified as members of 26 rotational bands
- ❑ 44 levels not assigned to bands
- ❑ J^{π} values known uniquely for 60 levels
- ❑ No guarantee that the observed levels form a complete set below 2.5 MeV
- ❑ Virtually nothing known about the rest of $\cong 3\times10^{6}$ levels below the neutron separation energy



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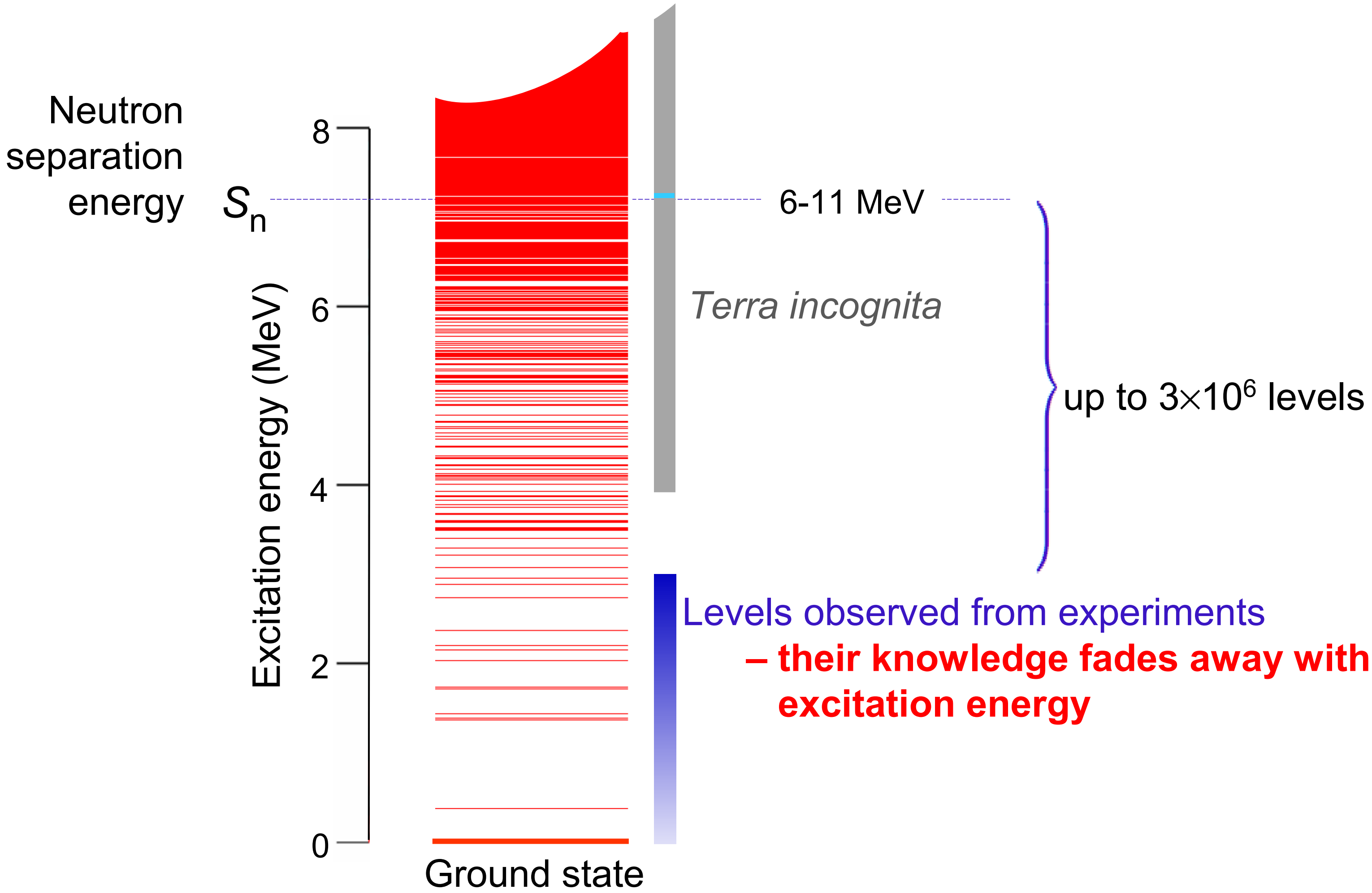
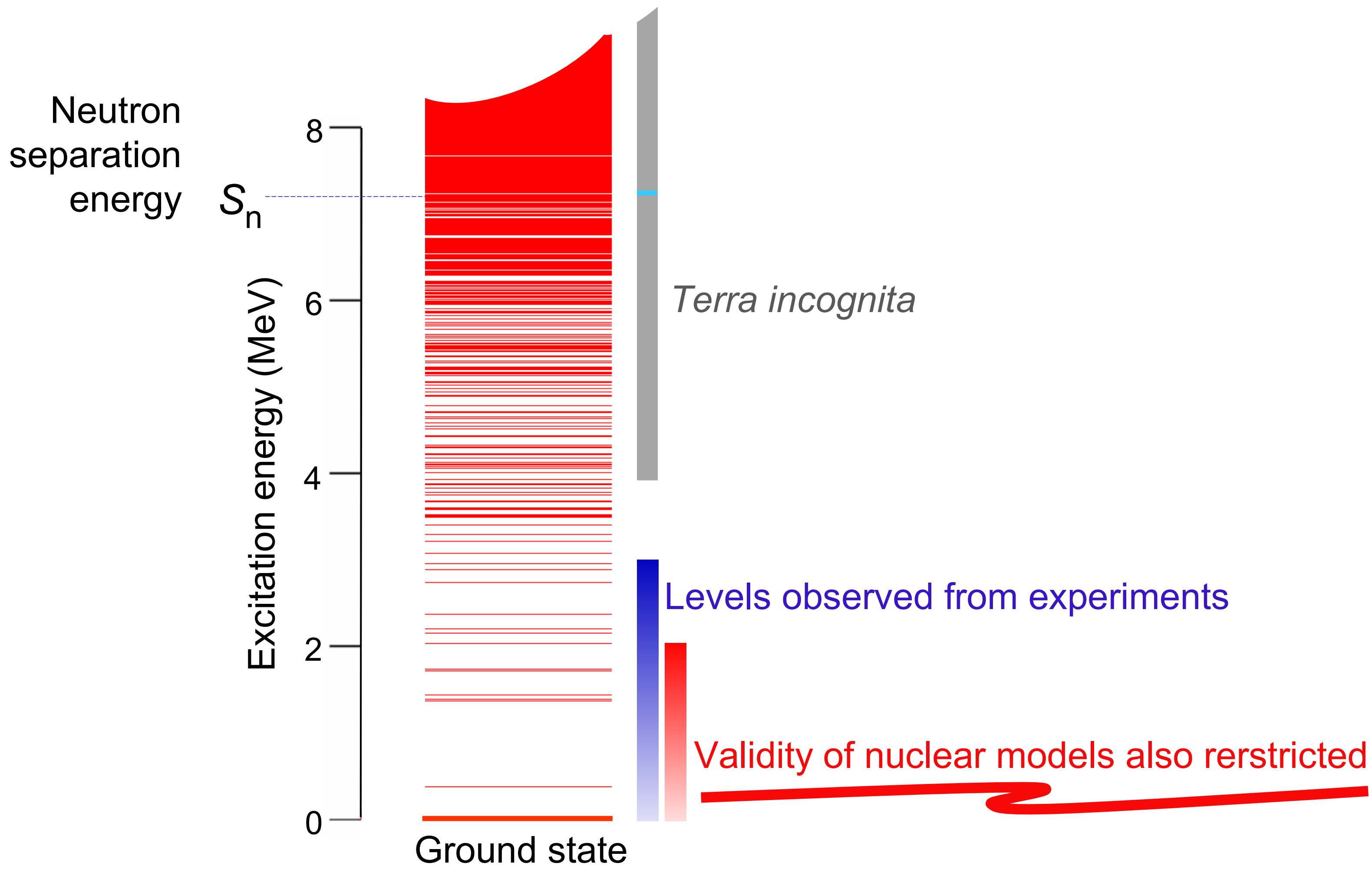
Levels in heavy nuclei



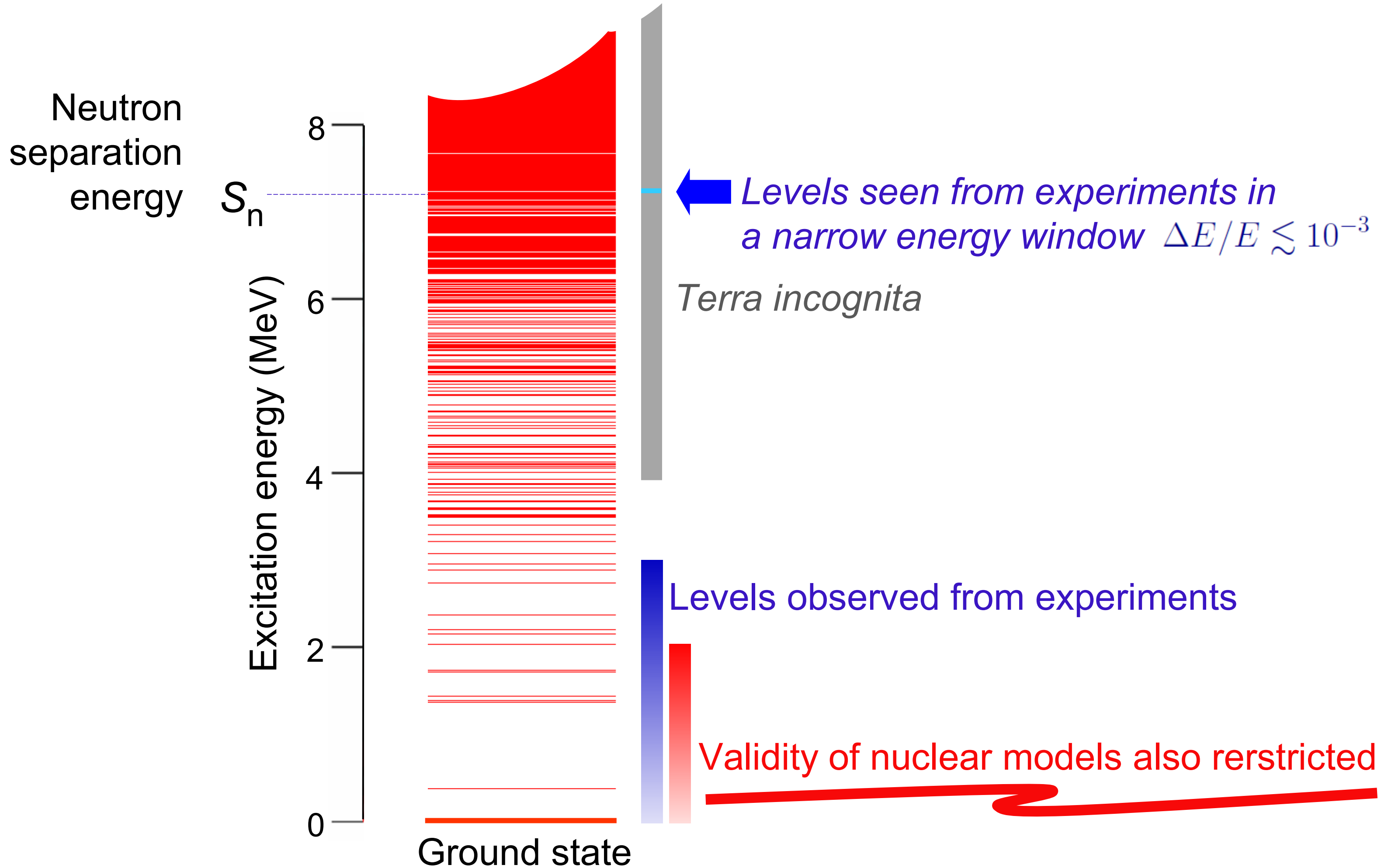
Levels observed from experiments

– their knowledge fades away with excitation energy

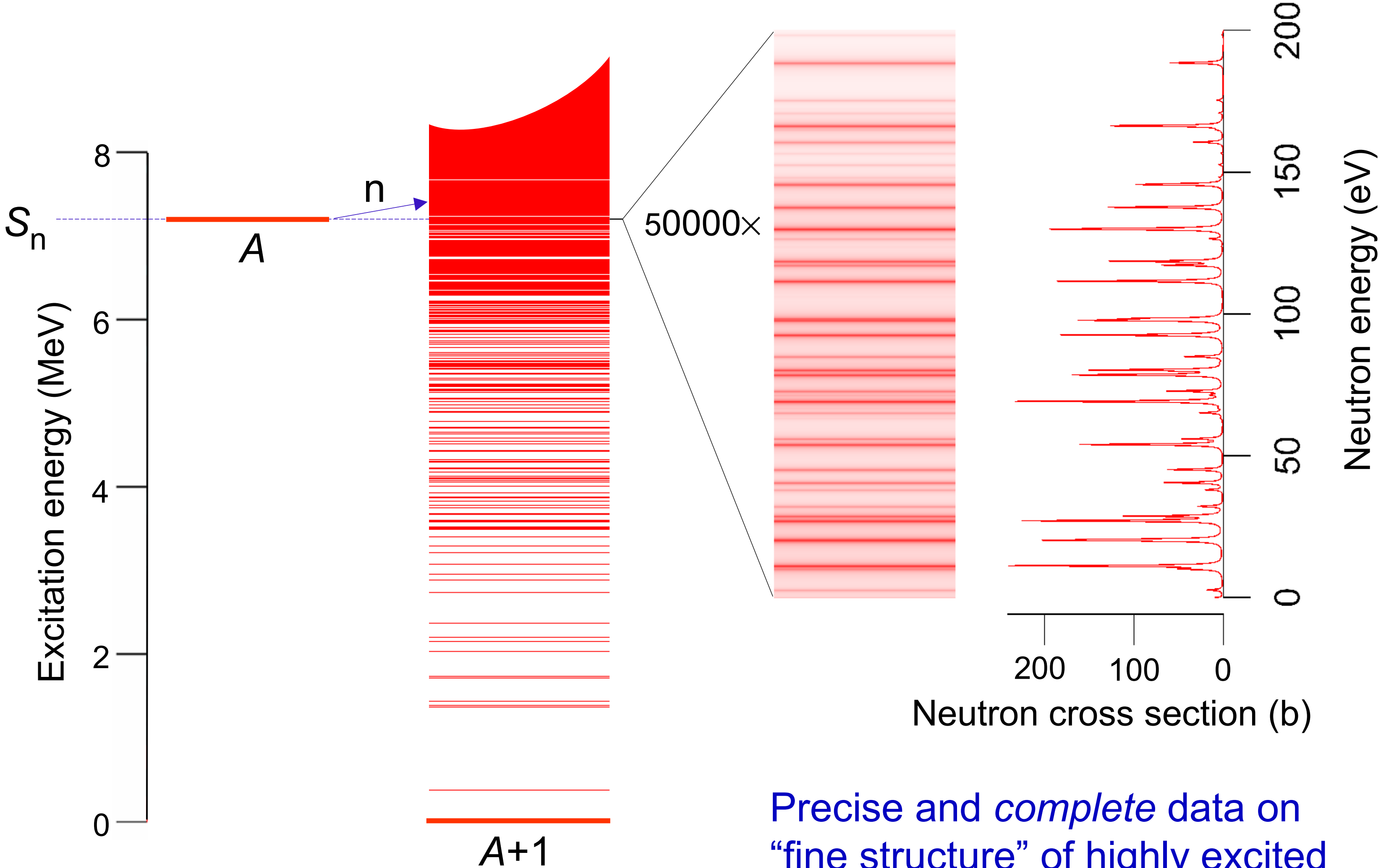
Levels in heavy nuclei



Levels in heavy nuclei: additional information at high eneries

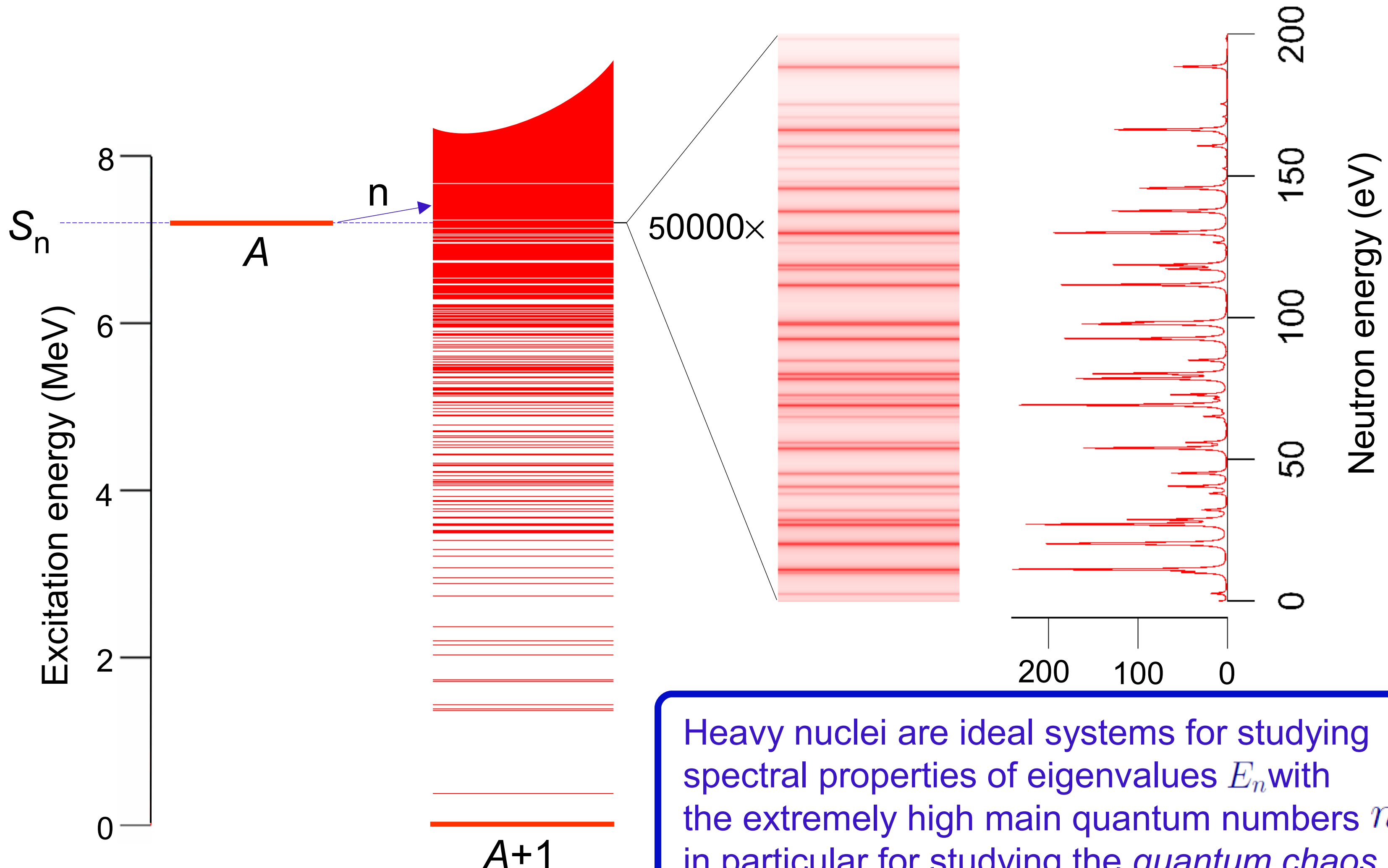


Neutron resonances of heavy nuclei



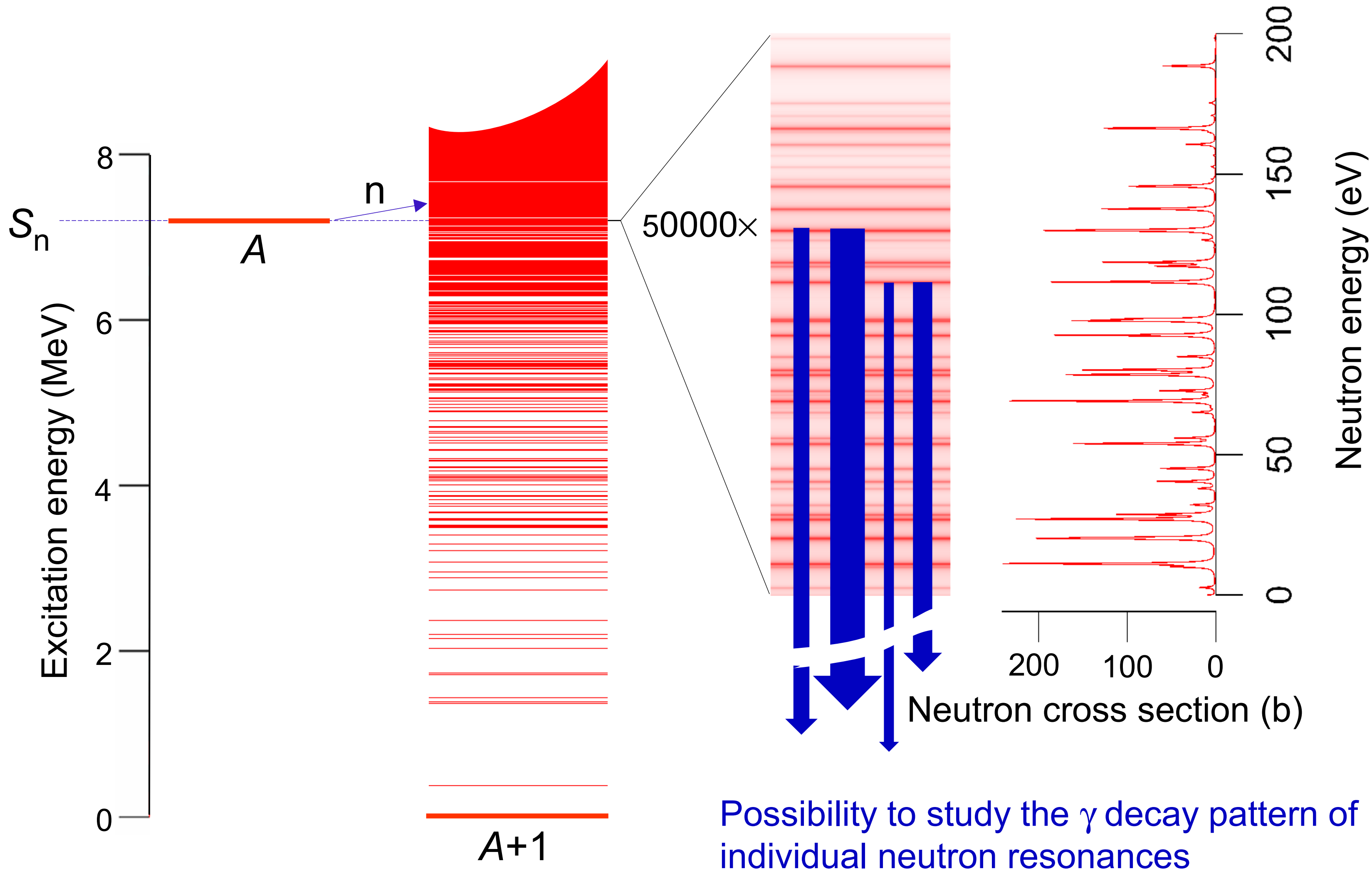
Precise and *complete* data on "fine structure" of highly excited nuclear levels (energies, J^{π}, *XL*)

Neutron resonances of heavy nuclei



Heavy nuclei are ideal systems for studying spectral properties of eigenvalues E_n with the extremely high main quantum numbers n, in particular for studying the *quantum chaos*

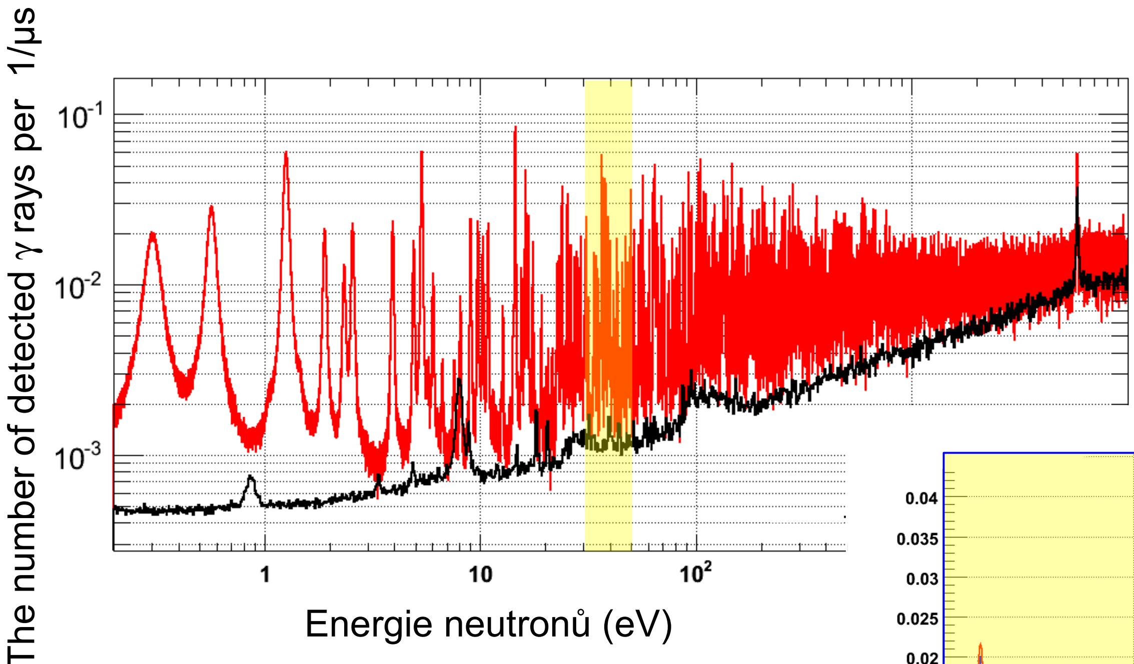
Neutron resonances of heavy nuclei

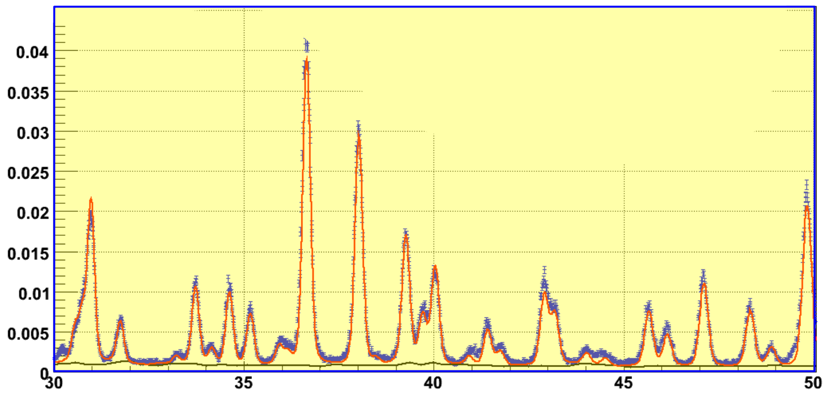


Possibility to study the γ decay pattern of individual neutron resonances

Neutron resonances of heavy nuclei

With the present state-of-the-art even neutron resonances of *radioactive* isotopes can be studied – an example of ^{241}Am resonances:





Precision of resonance energies: up to 1 meV

Almost an ideal „microscop“

Project n_TOF, CERN

Levels in heavy nuclei

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- However, as far as global or average properties are concerned, there is still a lot of physics to be accessed and understood from this large set of levels.
- During last two decades several new possibilities appeared to follow this path:
  - (i) the technique of the ^{3}He-induced γ emission (Oslo)
  - (ii) the use of fast γ calorimeters installed at pulsed spallation sources (CERN, Los Alamos, J-Parc in Tokai-Mura)
  - (iii) novel facilities for studying ($\gamma\,\gamma'$) reactions (Dresden, TUNL),
  - (iv) the method of two-step cascades, *etc.*

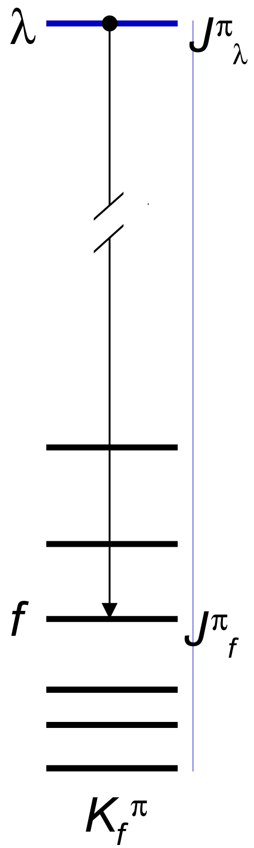
Is K a good quantum number at high nuclear excitations?

<u>A legitimate question</u>

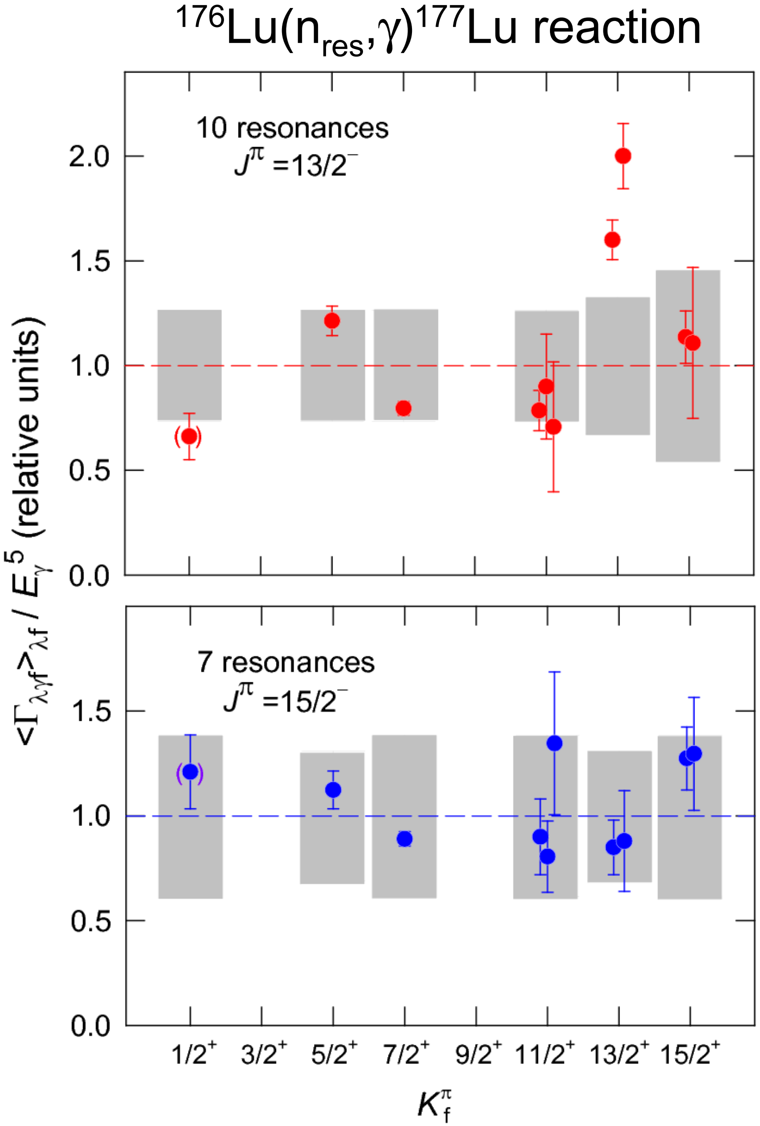
There is no guarantee that wave functions of neutron resonances λ do not contain components belonging to some relicts of collective motion.

If they do, the primary intensities of transitions from neutron resonances to low-lying levels f will be (at average) sensitive to quantum number K_f

An experiment for clarifying this issue was proposed by V. G. Soloviev



Is quantum number *K* good at high nuclear excitations?

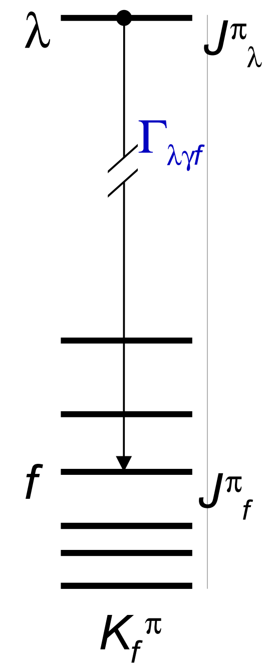


Plotted quantity:

$$<\Gamma_{\lambda\gamma f}>_{\lambda f} E_\gamma^{-5}$$

GDR correcting factor

partial radiative width for transition $\lambda \rightarrow f$ averaged over λ, f



^{176}Lu(n,γ)^{177}Lu reaction is unique:

- J^π values of s-wave ^{176}Lu resonaces are 13/2$^-$ and 15/2$^-$
- Existence of a number of bands with wide range of K^π_f – bands which are formed by levels accessible by *E*1 transitions from *s*-wave resonances

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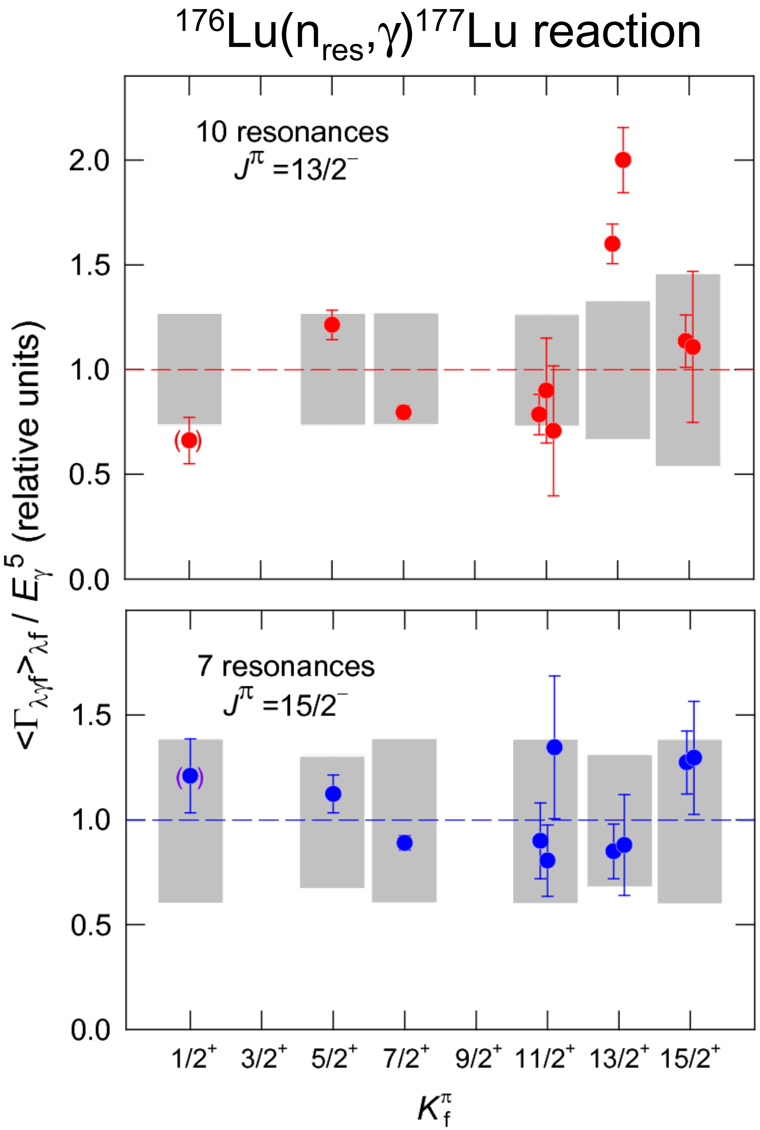

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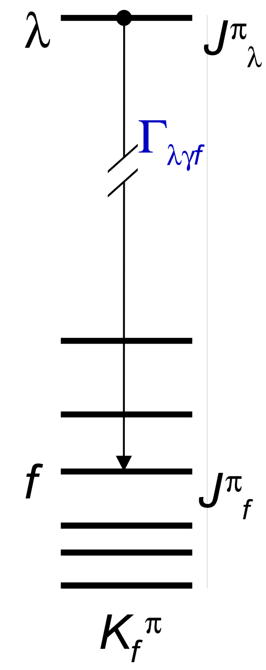

Global χ^2 test:

statistically significant dependence of $\Gamma_{\lambda\gamma f}$ on K_f *not found.*

The expected, but not well tested artifact of a strong Coriolis mixing

L. Aldea *et al.*, in Proc. Int'l Conf. on Nuclear Physics, Munich (North Holland, N.Y., 1973), p. 660

F. Becvar, *in* II School on Neutron Physics, Alushta 1974 (JINR, Dubna, 1974), p. 294

Correlation between reduced neutron and partial radiation widths of neutron resonances

Following the extreme statistical model of the nucleus, partial radiation widths $\Gamma_{\lambda\gamma f}$ and the reduced neutron widths $\Gamma_{\lambda n}{}^{0}$ can be, in general, correlated

According to Soloviev's quasiparticle-phonon model, in case of s-wave resonances in deformed nuclei and *E*1 multipolarity, this correlation is expected for transitions from the resonances to the levels of the rotational bands with band heads having a specific QP structure

The so-called *R* correlation is determined from the data on $\Gamma_{\lambda\gamma f}$ and $\Gamma^{0}_{\lambda \mathrm{n}}$

$$R = \sum_{f} \omega_f r_f$$

summation goes over levels *f* of a fixed rotational and where

$$r_f = \mathrm{Corr}[\Gamma_{\lambda\gamma f}, \Gamma^{0}_{\lambda \mathrm{n}}]$$

ω_f – statistical weighting factor

Results of *R*-correlation analysis

Target	band QP structure in product nucleus	number of partial widths $\Gamma_{\lambda\gamma f}$	R_{exp}	$P\,(R<R_{exp})$
^{152}Gd	*n*[521]↓, *n*[521]↓, *n*[530]↑	20	-0.107	0.361
^{154}Gd	*n*[521]↑	11	0.086	0.68
	n[532]↓	11	-0.290	0.19
	n[532]↓	11	0.664	0.9980
^{173}Yb	*n*[512]↑-*n*[510]↑	60	0.302	0.9880
^{167}Er	*n*[633]↑-*n*[521]↓	25	0.407	0.94
	n[633]↑+*n*[521]↓	25	0.246	0.90
^{176}Lu	*p*[404]↓+n[514]↓±*n*[510]↓	36	0.599	0.9994
	p[404]↓+n[514]↓-*n*[521]↓	36	-0.034	0.43
	p[404]↓+n[514]↓+*n*[521]↓	36	0.021	0.53
	p[404]↓+n[514]↓+*n*[512]↓	18	0.042	0.56
^{185}Re	*p*[402]↑-*n*[510]↑	48	0.054	0.689
	p[402]↑+*n*[510]↑	38	0.502	0.9970
	p[402]↑-*n*[512]↓	72	0.074	0.722
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Very high values

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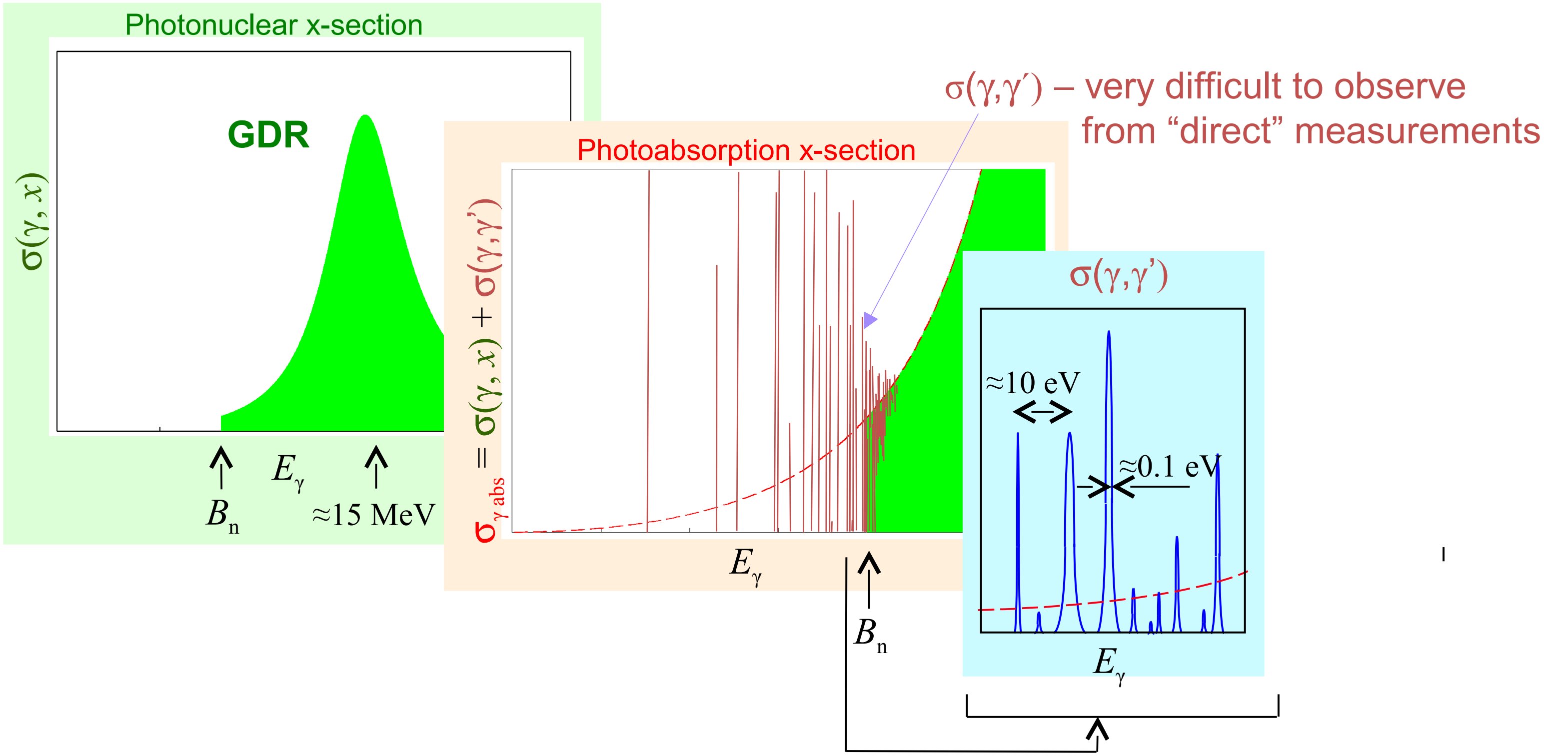
Conclusion: The correlation between the partial radiation widths $\Gamma_{\lambda\gamma f}$ and the reduced neutron widths $\Gamma_{\lambda n}$ does exist, as expected from predictions of Soloviev's QP-phonon model

Photonuclear and photoabsorption reactions



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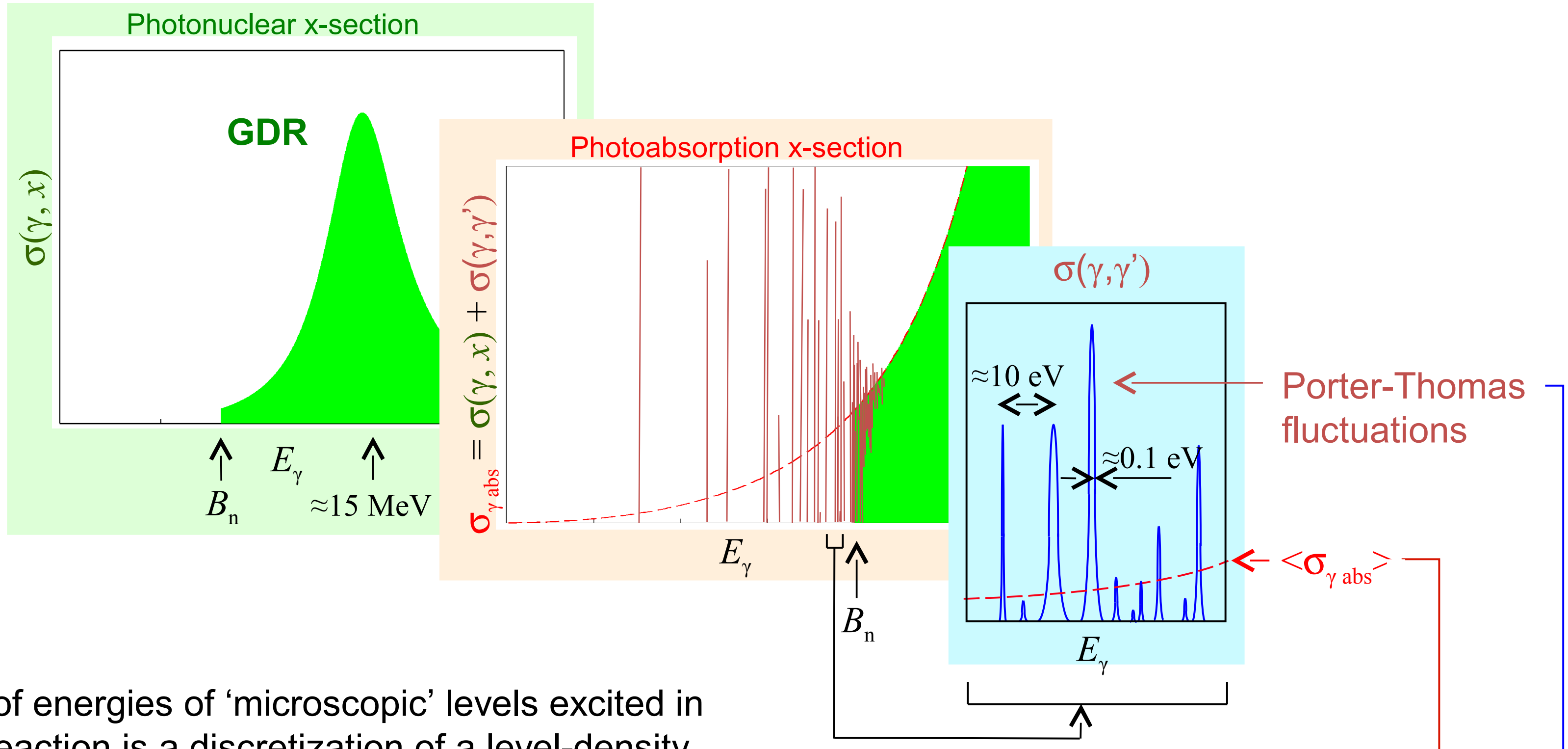
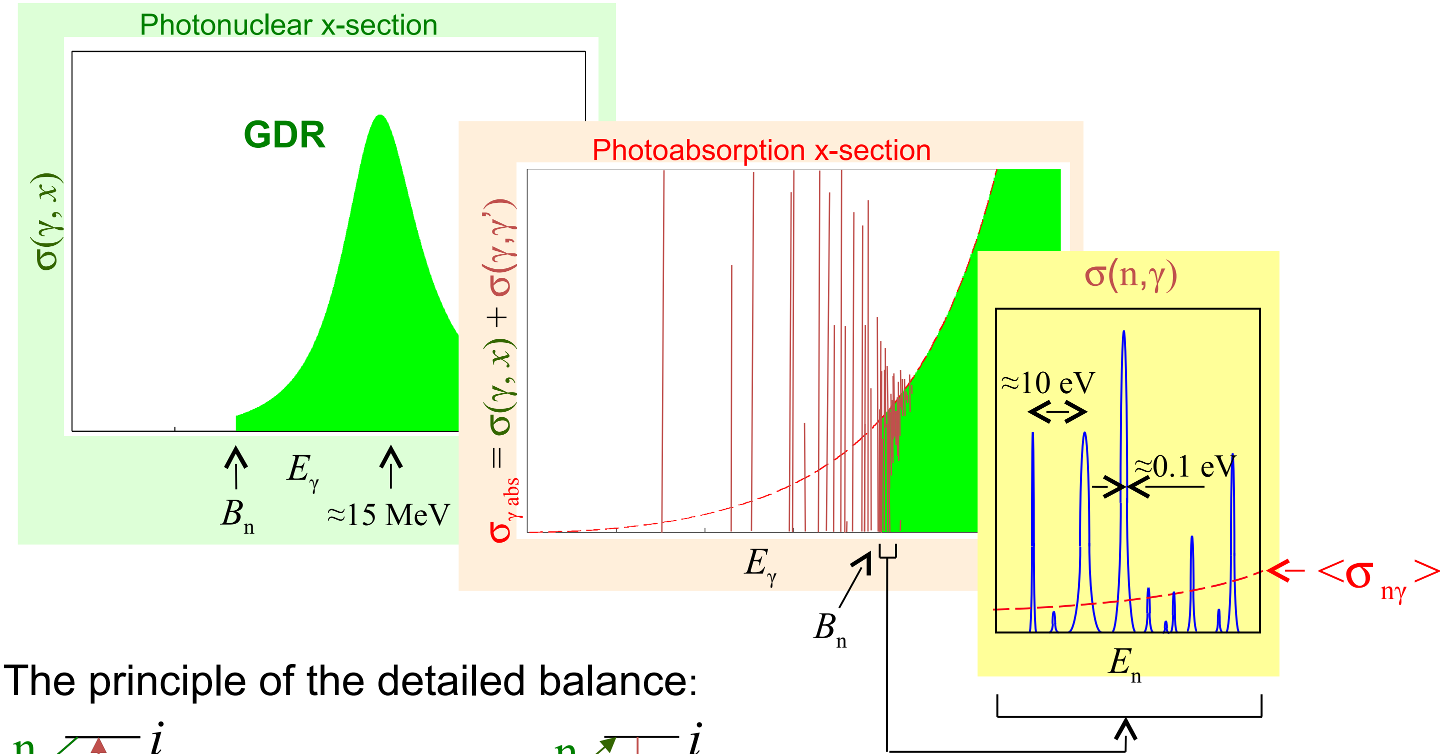


A set of energies of 'microscopic' levels excited in (γ,γ') reaction is a discretization of a level-density function

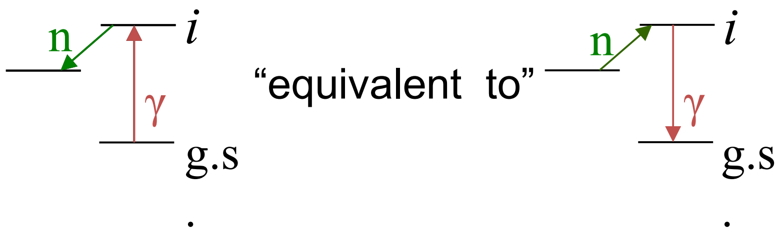
Existence of **expectation value** of photoabsorption x-section as a function of energy E_γ. It is not an uninteresting quantity resulting from **a mere averaging**, but an entity inherent to collective nuclear motion

Line intensities are random quantities fluctuating according to **Porter-Thomas distribution** around this expectation value

Relation between (γ,n) and (n,γ) reactions



The principle of the detailed balance:



Quantitatively: $k_γ^2\,σ_{γn} = k_n^2\,σ_{nγ}$

Photon strength function for the ground state *E1* transitions

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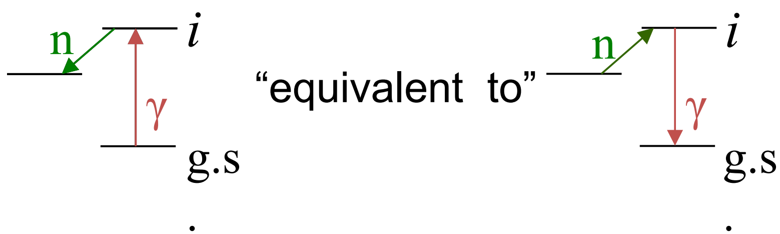

Quantitatively: $k_\gamma^{\,2}\,\sigma_{\gamma n} = k_n^{\,2}\,\sigma_{n\gamma}$

From this equation it follows the link between the *local average* of partial radiative widths $\langle \Gamma^{(E1)}_{i\gamma \mathrm{g.s.}} \rangle_{\mathrm{local}}$ and the *smoothed* photoabsorption cross section $\langle \sigma^{(E1)}_{\gamma\ \mathrm{abs}}(E_\gamma) \rangle_{\mathrm{local}}$:

$$\langle \Gamma^{(E1)}_{i\gamma \mathrm{g.s.}} \rangle_{\mathrm{local}} = f^{(E1)}(E_\gamma)\,\frac{E_\gamma^3}{\rho(E_i)}$$

$$f^{(E1)}(E_\gamma) = \frac{1}{3\pi^2\hbar^2c^2}\frac{1}{E_\gamma}\langle \sigma^{(E1)}_{\gamma\ \mathrm{abs}}(E_\gamma) \rangle_{\mathrm{local}}$$

Photon strength function (PSF) for *E*1 radiation

According to classical electrodynamics the *E*1 PSF is of Lorentzian shape.
As a consequence, at low γ-ray energies $f^{(E1)}(E_\gamma) \propto E_\gamma$

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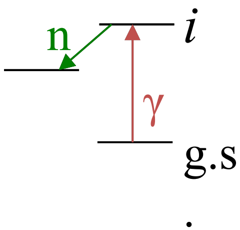
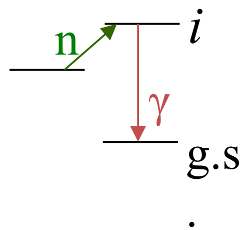


"equivalent to"



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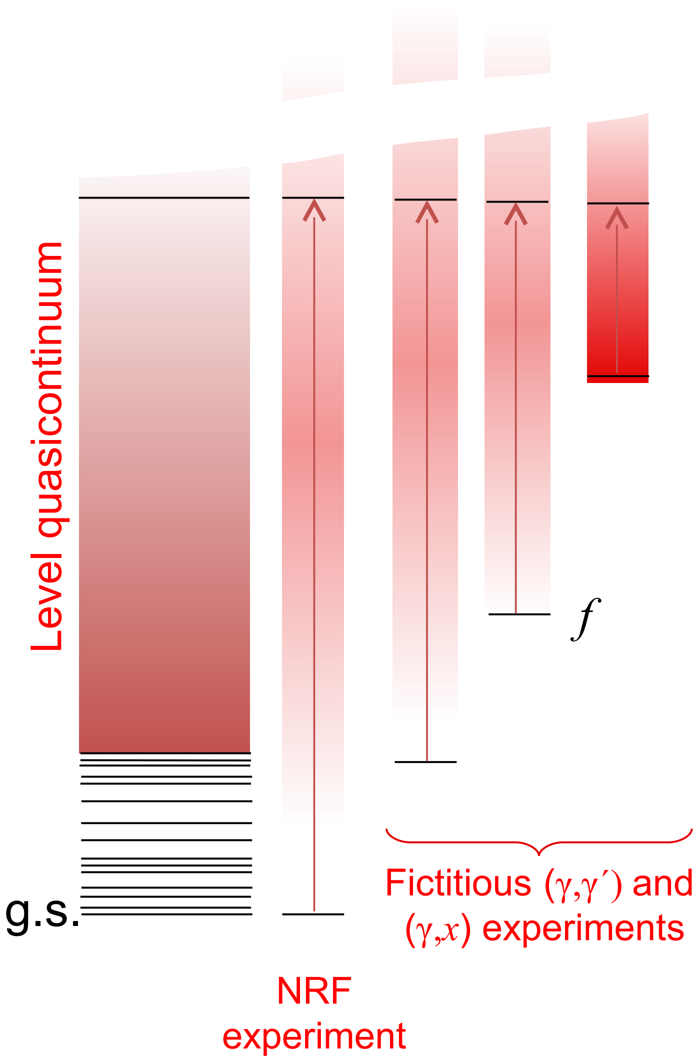
$$f^{(E1)}(E_\gamma) = \frac{1}{3\pi^2\hbar^2c^2}\,\frac{1}{E_\gamma}\,\langle \sigma^{(E1)}_{\gamma\ \mathrm{abs}}(E_\gamma) \rangle_{\mathrm{local}}$$

Average properties of the E1 γ decay of highly-excited levels to the *ground state* are thus governed by $f^{(E1)}(E_\gamma)$

Brink hypothesis



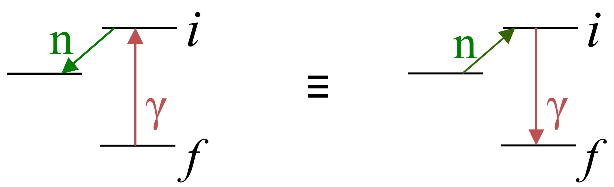
- Photoexcitation pattern does not depend on excitation of the target
- PSF does not depend on f

In case of E1 transitions it implies that the GDR is built not only on the ground state, but also on *each* excited level.

There exist no first principles which would guarantee the validity of Brink hypothesis

Photon strength function for the ground state *E1* transitions

Consider now the validity of Brink hypothesis and the equivalence



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

The link between the *local average* of partial radiative width $\langle \Gamma_{i\gamma f}^{(E1)} \rangle_{\rm local}$ and the *smoothed* photoabsorption cross section will be :

$$\langle \Gamma_{i\gamma f}^{(E1)} \rangle_{\rm local} = f^{(E1)}(E_\gamma) \frac{E_\gamma^3}{\rho(E_i)}$$

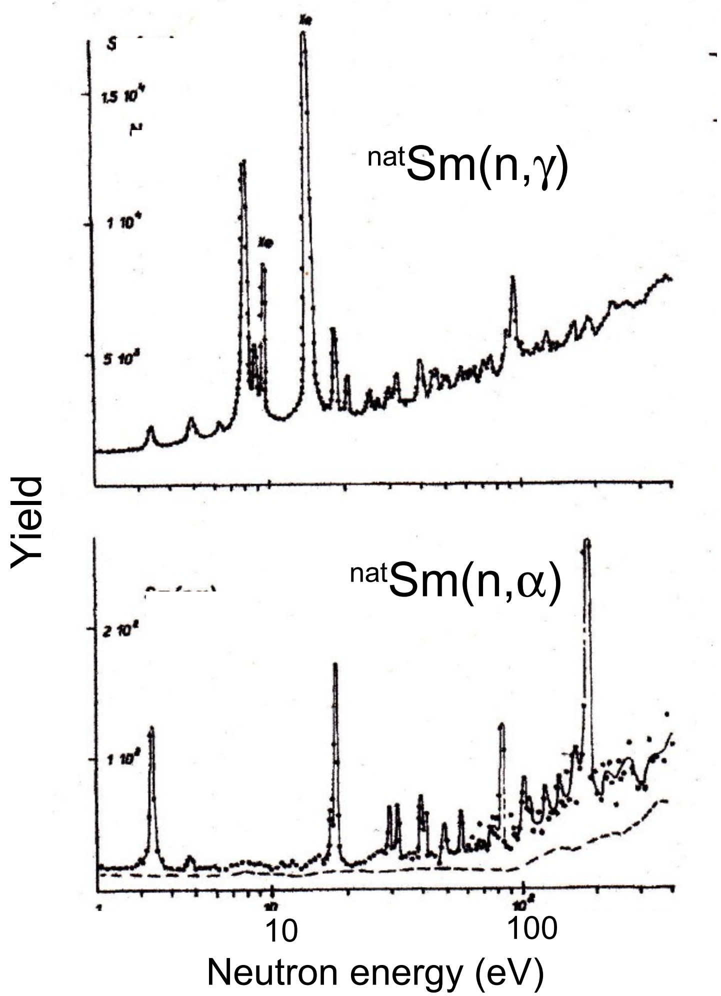
$$f^{(E1)}(E_\gamma) = \frac{1}{3\pi^2\hbar^2c^2} \frac{1}{E_\gamma} \langle \sigma_{\gamma\ {\rm abs}}^{(E1)}(E_\gamma) \rangle_{\rm local}$$

Again, the cross section for the target in the ground state

Average properties of the E1 γ decay of highly-excited levels to any level are thus governed by the same $f^{(E1)}(E_\gamma)$

Systematic studies of α decay of neutron resonances

Example of the data



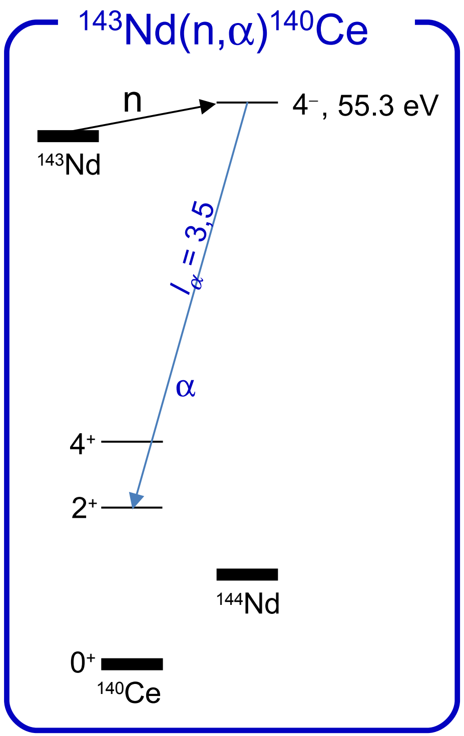
J. Kvítek and Yu. P. Popov, Phys. Lett. **22**, 186 (1966)

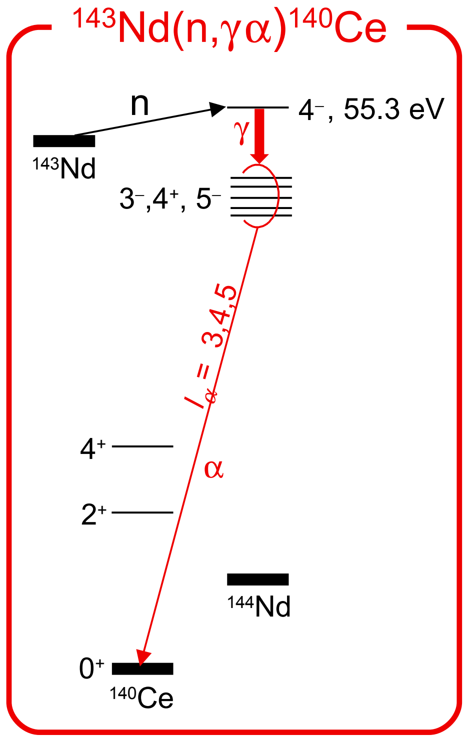
Main results achieved by the group of Yu. P. Popov at FLNP:

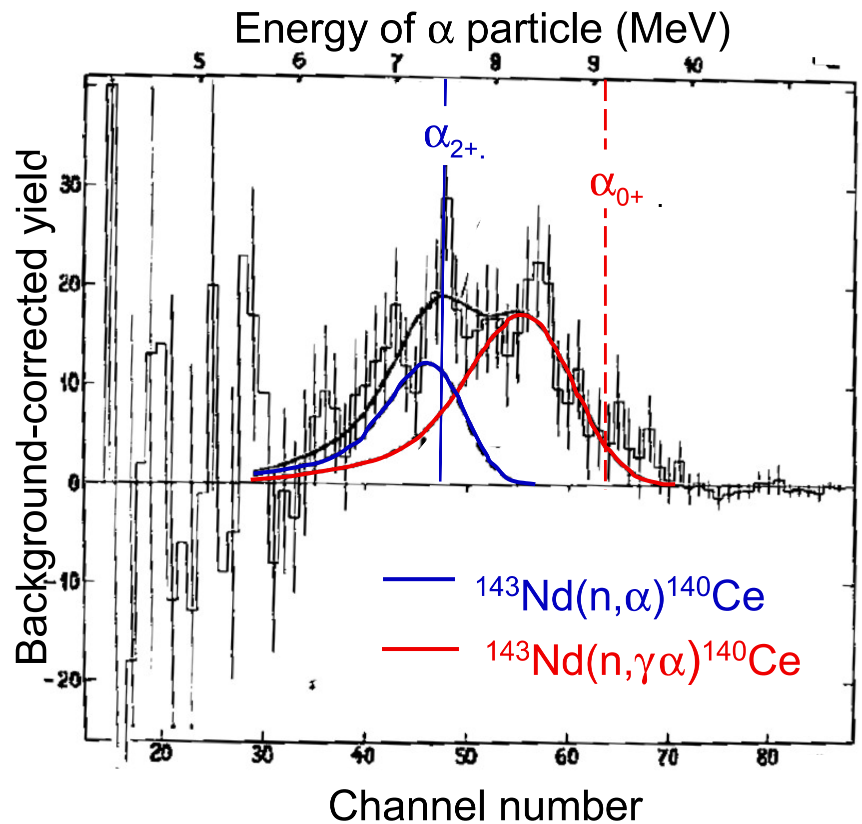
- Understanding the role of Coulomb barrier
- Invoking the optical model
- Systematics of α partial widths across a wide range of mass number *A*

^{143}Nd(n,γα)^{140}Ce reaction and behavior of soft γ transitions

Measurements with a ionization chamber at the pulsed n-beam of IBR-30 [1]





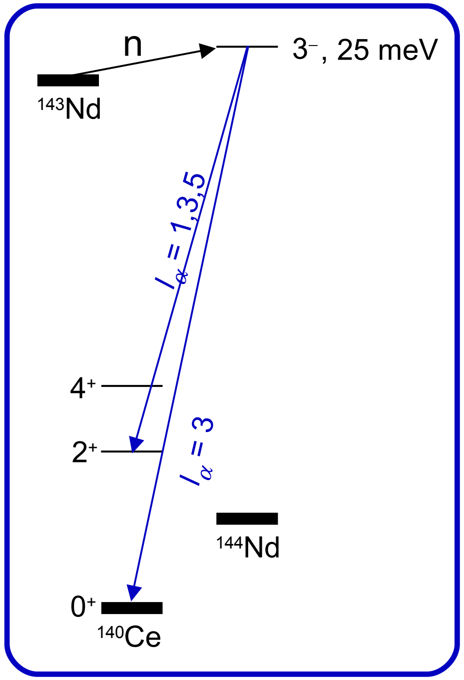


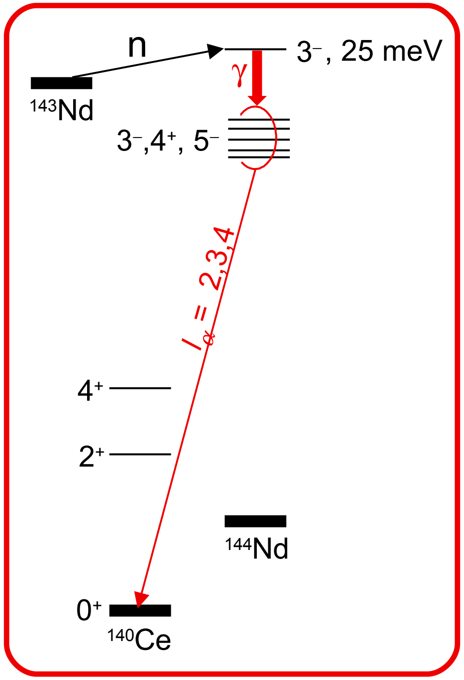
The detailed analysis made by Furman *et al.* [2]:

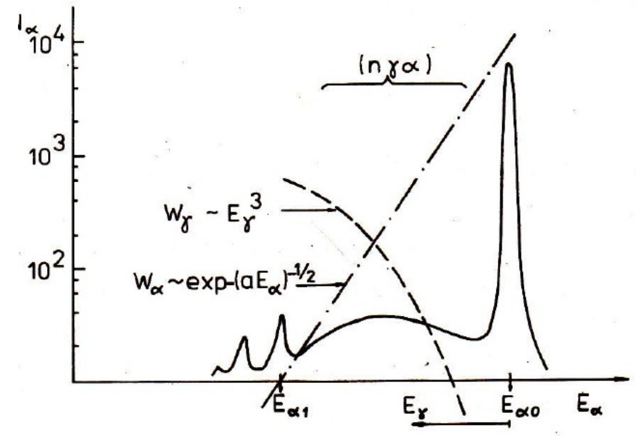
- the data can be interpreted within the Weisskopf single-particle model (with suitably adjusted hindrance factors for *E*1 and *M*1 transitions), using the optical model for description of α-particle widths
- the partial widths for the soft primary γ transitions ($E_\gamma \approx$ 1 MeV) are thus to be proportional to E_γ^3

[1] P. Winiwarter *et al.*, JINR Report P-36754 (1972)
[2] W. Furman *et al.*, Phys. Lett. B **44**, 465 (1973)

^{143}Nd(n,γα)^{140}Ce reaction at thermal neutron energies





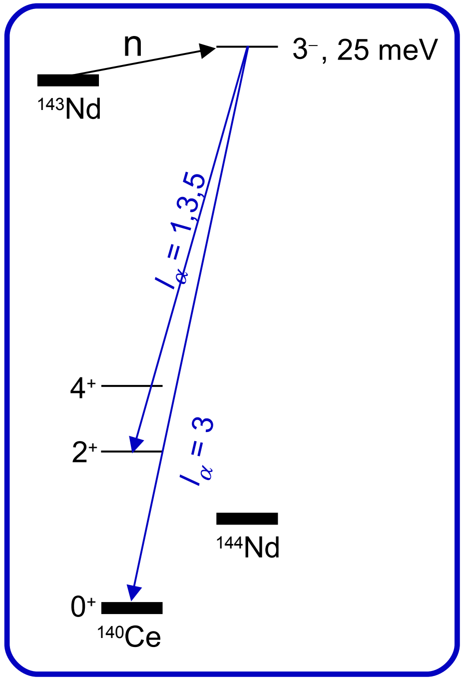


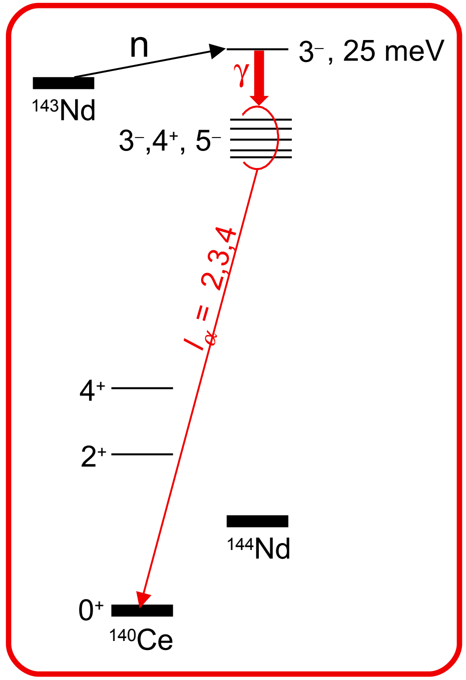
A schematic picture

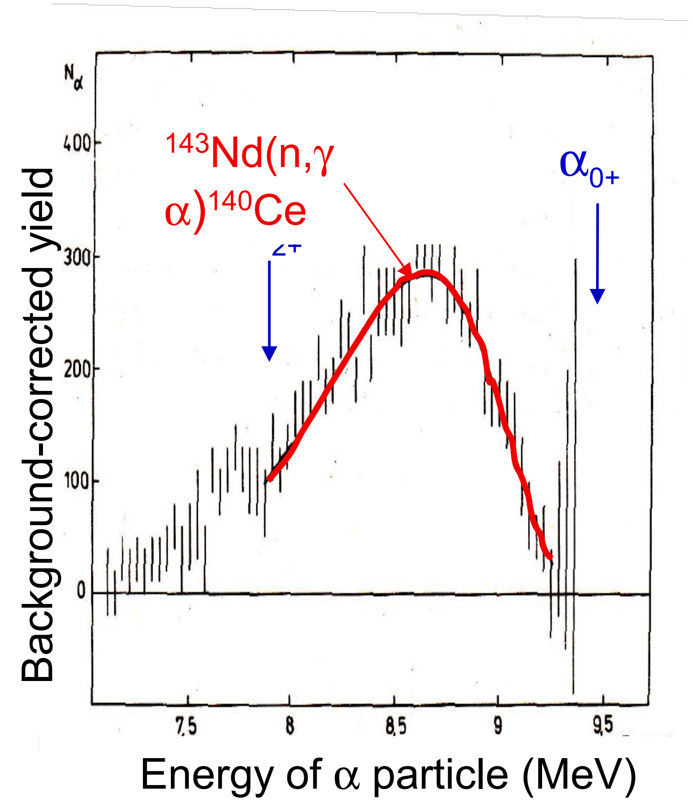
To isolate the effect from the ^{143}Nd(n,γα)^{140}Ce reaction at thermal neutron energies, where the capturing state spin and parity of ^{144}Nd is 3 $^{-}$, a high-resolution semiconductor spectrometer is need

Yu. P. Popov, in Neutron Induced Reactions (Institute of Physics, Slovak Aademy of Sciences, Bratislava, 1982), p. 121

^{143}Nd(n,γα)^{140}Ce reaction at thermal neutron energies







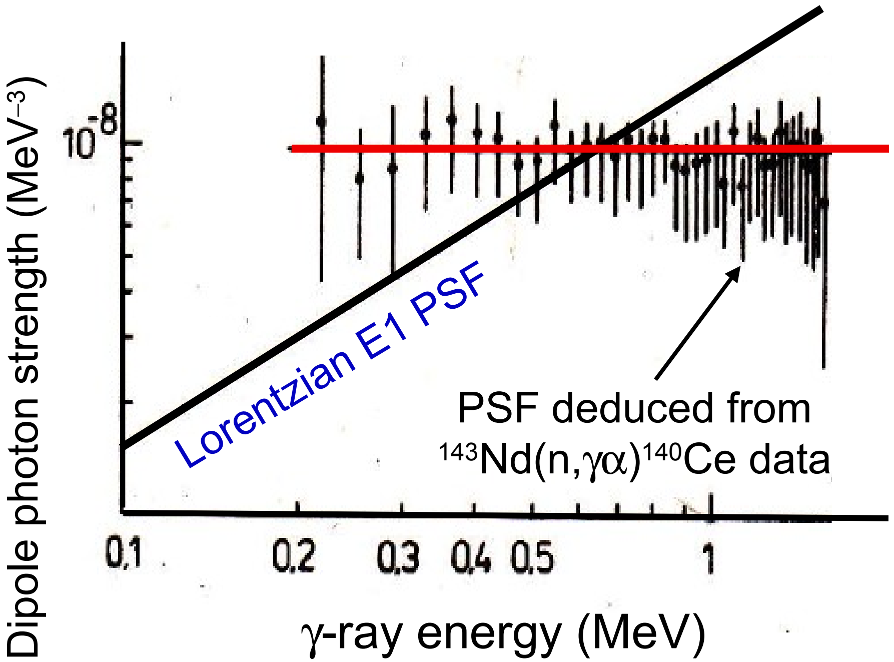
Results from Julich measurements [1] and their their interpretation by the Dubna group [2]

[1] L. Aldea and H. Seyfarth, *in* Neutron Capture Gamma-Ray Spectroscopy , Ed. by R. E. Chrien and W. R. Kane (Plenum Press, N.Y., 1979), p.

[2] Yu. P. Popov, *in* Neutron Induced Reactions (Institute of Physics, Slovak Aademy of Sciences, Bratislava, 1982), p. 121

$^{143}Nd(n,\gamma\alpha)^{140}Ce$ reaction at thermal neutron energies

Dipole photon strength function deduced
Validity of Brink hypothesis implicitly assumed



An impetus for development of a new model for PSF by Kadmenskij, Markushev and Furman

S, G. Kadmenskij, V. P. Markushev and V. I. Furman, Sov. J. Nucl. Phys. **37**, 165 (1983)

Model of Kadmenskij-Markushev-Furman (KMF)

KMF approximation of the *E*1 PSF:

GDR damping width — nuclear temperature

$$f_{\gamma \mathrm{KMF}}^{(E1)}(E_\gamma, T_f) = \frac{F_\mathrm{K}}{3\pi^2\hbar^2c^2} \frac{\sigma_{\gamma\,\mathrm{abs}}^{\max}\,\Gamma_\mathrm{G}^2(E_\gamma^2 - 4\pi^2T_f^2)}{E_\mathrm{G}(E_\gamma^2 - E_\mathrm{G}^2)^2}$$

energy of the GDR

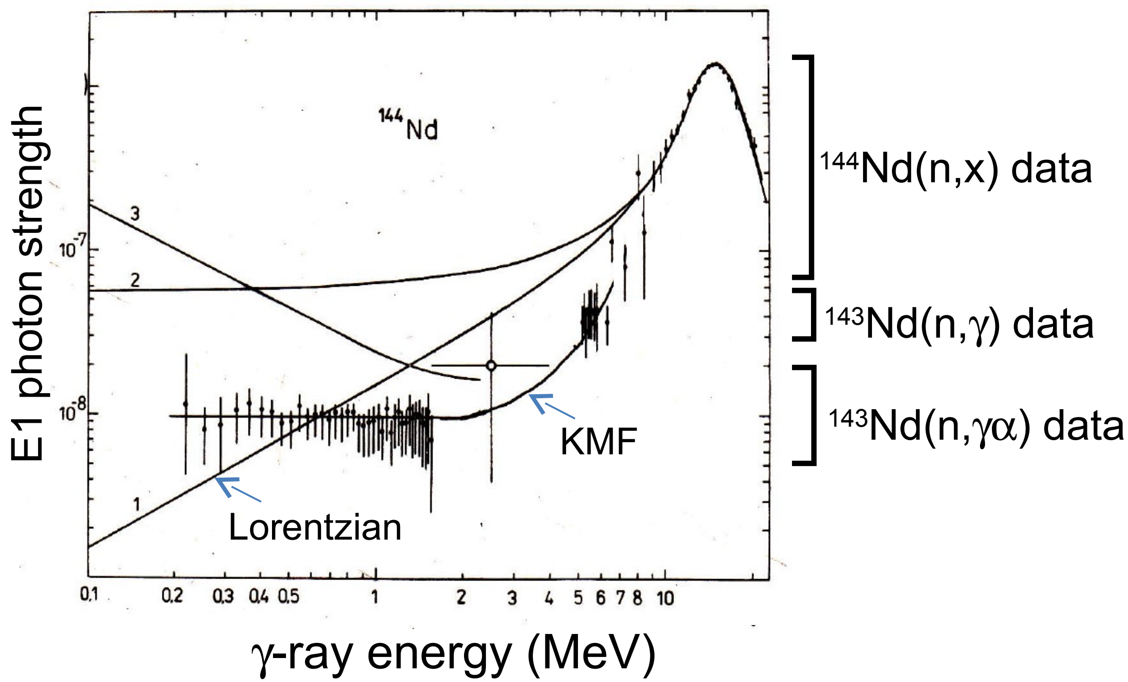
Model of Kadmenskij-Markushev-Furman (KMF)

KMF approximation of the *E*1 PSF:

GDR damping width — nuclear temperature

$$f^{(E1)}_{\gamma\mathrm{KMF}}(E_\gamma, T_f) = \frac{F_\mathrm{K}}{3\pi^2\hbar^2c^2}\,\frac{\sigma^{\max}_{\gamma\,\mathrm{abs}}\,\Gamma^2_\mathrm{G}(E^2_\gamma - 4\pi^2T^2_f)}{E_\mathrm{G}(E^2_\gamma - E^2_\mathrm{G})^2}$$

energy of the GDR



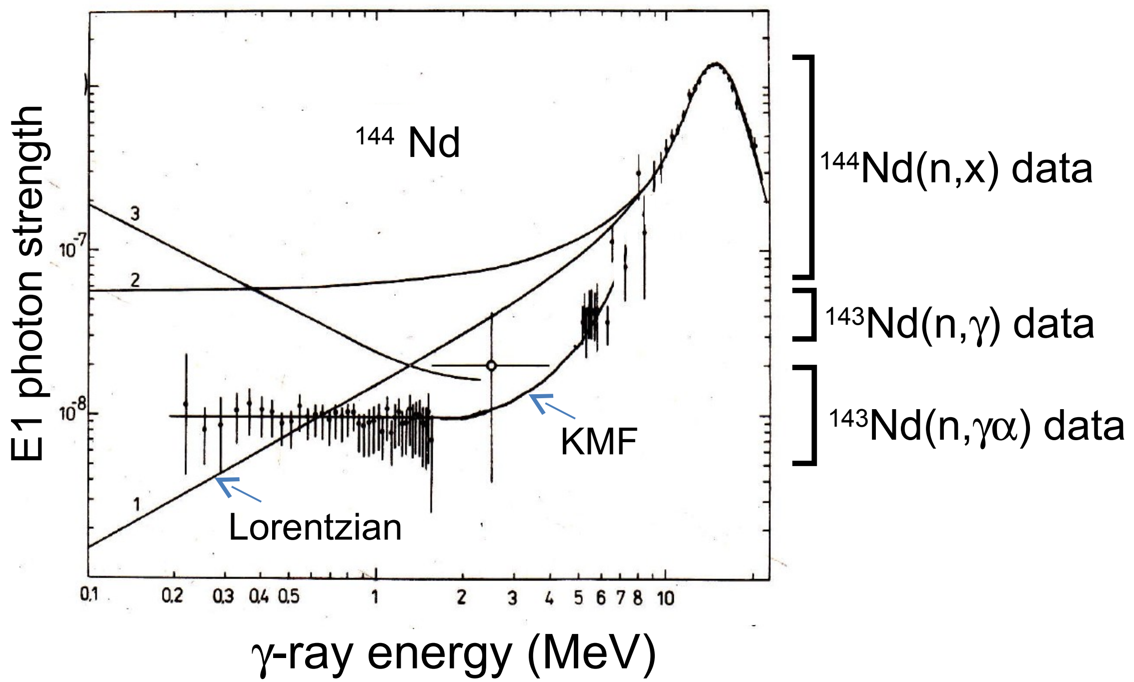
Model of Kadmenskij-Markushev-Furman (KMF)

KMF approximation of the $E1$ PSF:

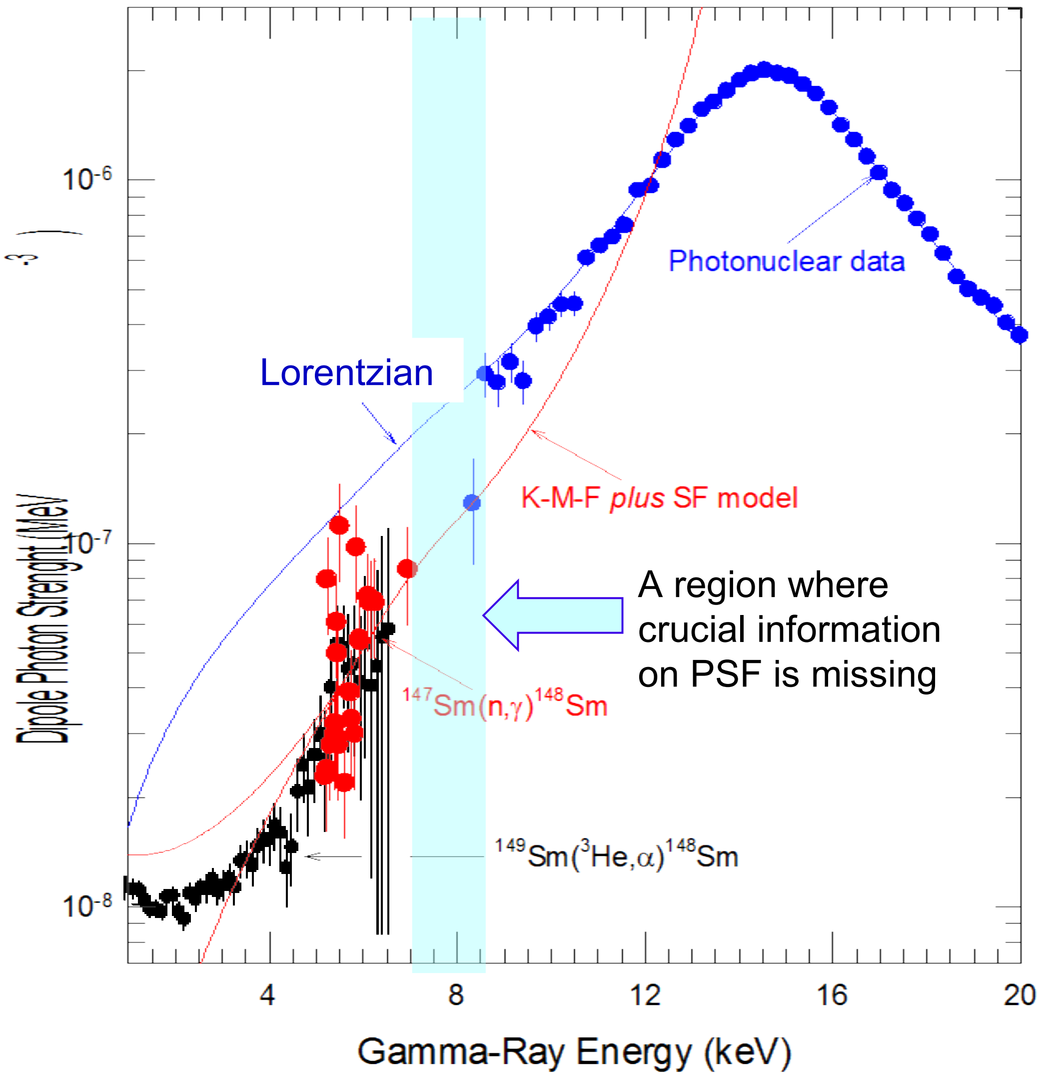
$$f^{(E1)}_{\gamma \mathrm{KMF}}(E_\gamma, T_f) = \frac{F_\mathrm{K}}{3\pi^2\hbar^2c^2}\,\frac{\sigma^{\max}_{\gamma\,\mathrm{abs}}\,\Gamma^2_\mathrm{G}(E^2_\gamma - 4\pi^2T^2_f)}{E_\mathrm{G}(E^2_\gamma - E^2_\mathrm{G})^2}$$

GDR damping width (Γ_G), nuclear temperature (T_f), energy of the GDR (E_G)

The KMF model and its various modifications are so far the most successful for description of the decay of highly-excited nuclear levels



Further evidence for validity of KMF approximation



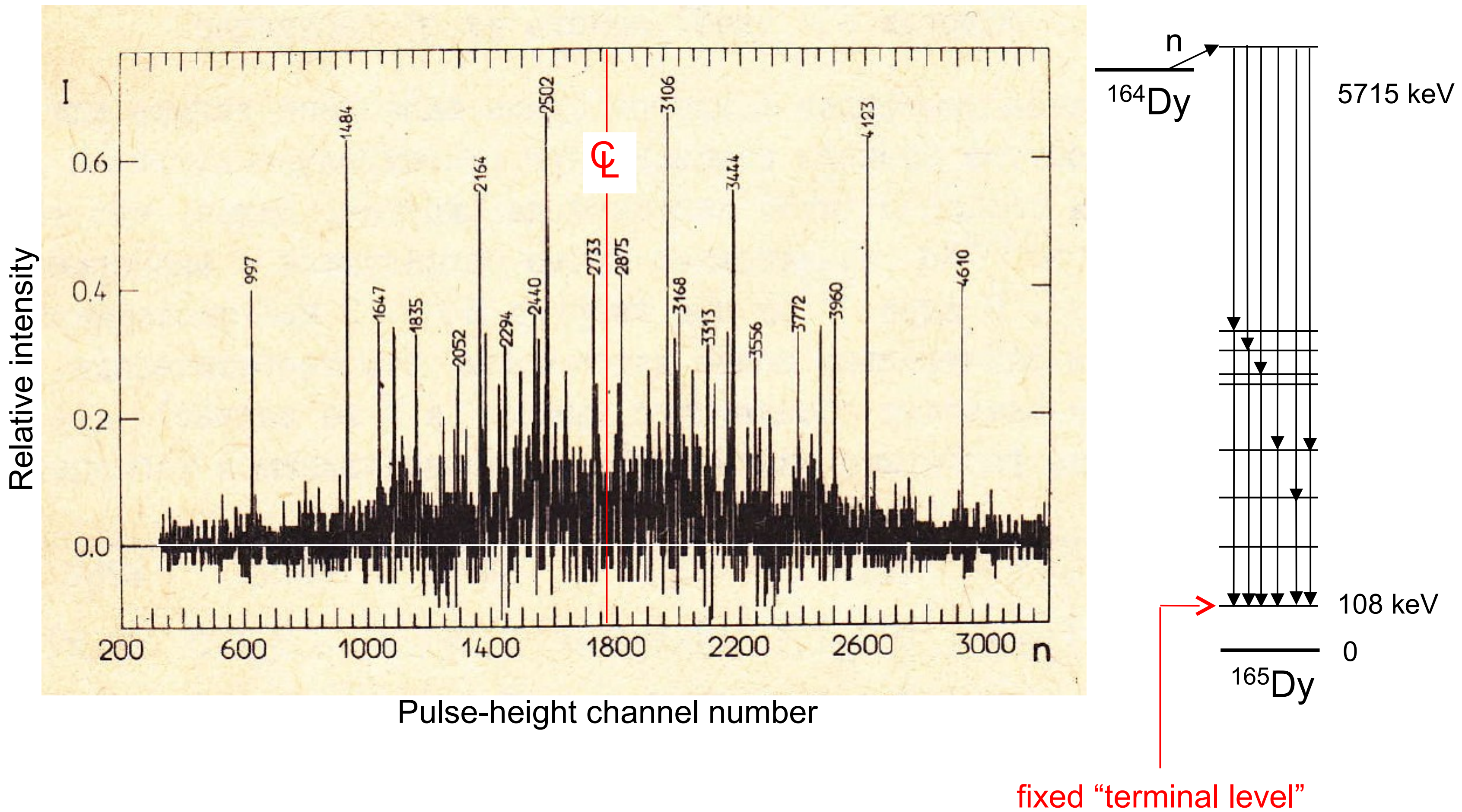
Phonuclear reactions

(n,γ) reaction
- γ spectra from isolated neutron resonances measured at IBR-30

^{3}He-induced γ emission
- Oslo method of direct extraction of photon strength

Invention and implementation of the TSC method

Two-step cascades (TSCs) in $^{164}Dy(n,\gamma)^{165}Dy$ reaction

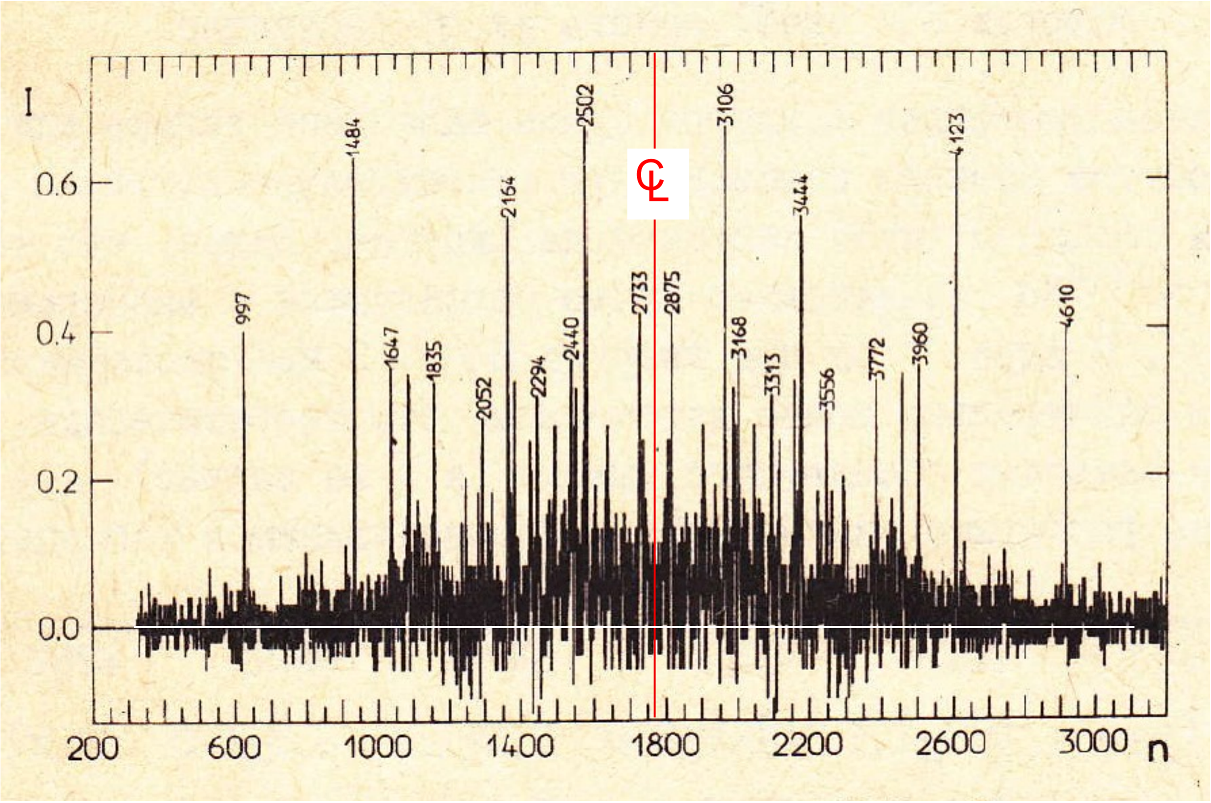


Ю. П. Попов, А. М. Суховой. В. А. Хитров, Ю. С. Язвицкий, Нейтронная физика, том III (АН СССР, Москва, 1984), стр. 3

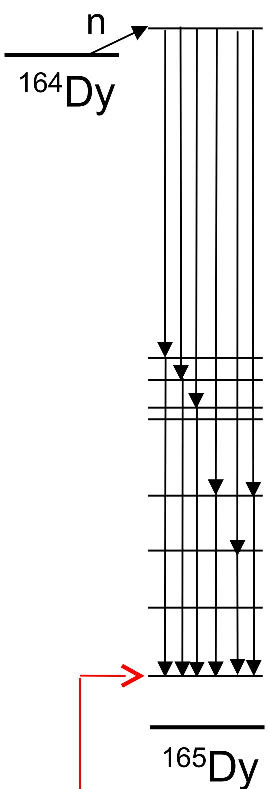
Invention and implementation of the TSC method

Two-step cascades (TSCs) in $^{164}Dy(n_{th},\gamma)^{165}Dy$ reaction

Relative intensity



Pulse-height channel number



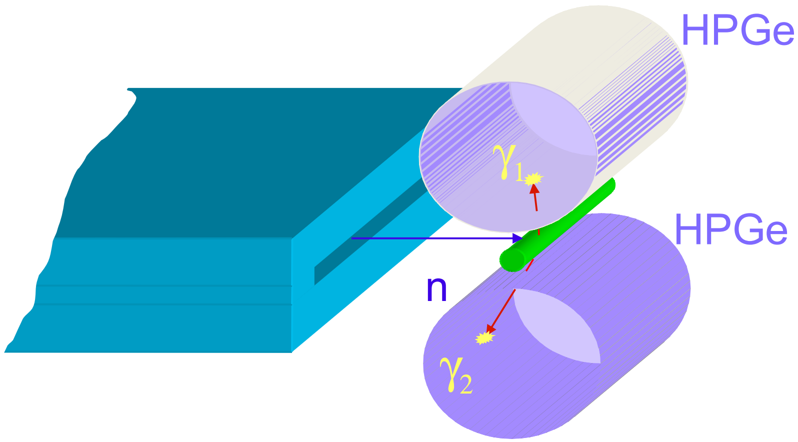
A unique tool for studying photon strength functions

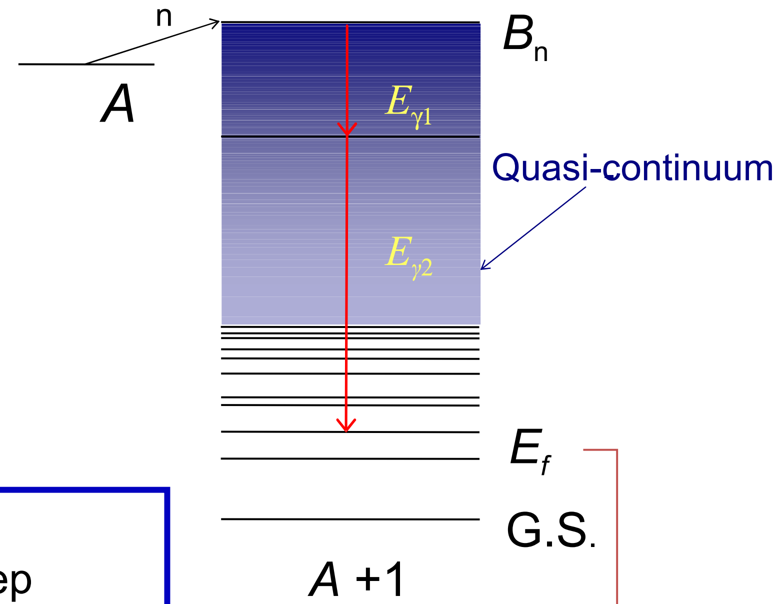
fixed “terminal level”

Ю. П. Попов, А. М. Суховой. В. А. Хитров, Ю. С. Язвицкий, Нейтронная физика, том III (АН СССР, Москва, 1984), стр. 3

A method of two-step γ cascades

A powerful tool invented by Sukhovoj and Khitrov *et al.* at FLNP in 1982





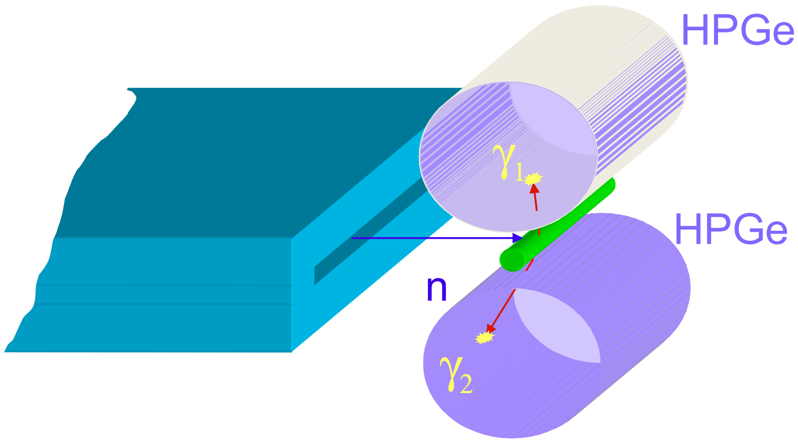
Two-step cascade (TSC) γ-ray spectrum:
Energy spectrum of transitions forming **all** two-step cascades that initiate at the neutron capturing state and terminate at a prefixed 'terminal level' *f*

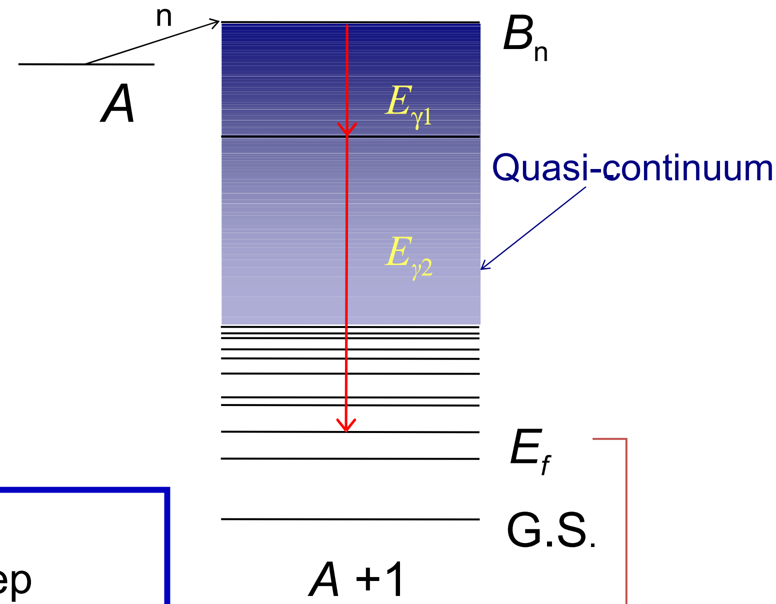
Using the *sum-coincidence method*, TSC spectra for *many levels f* can be accumulated

A major contribution of FLNP to the neutron capture γ-ray spectroscopy

A method of two-step γ cascades

A powerful tool invented by Sukhovoj and Khitrov *et al.* at FLNP in 1982



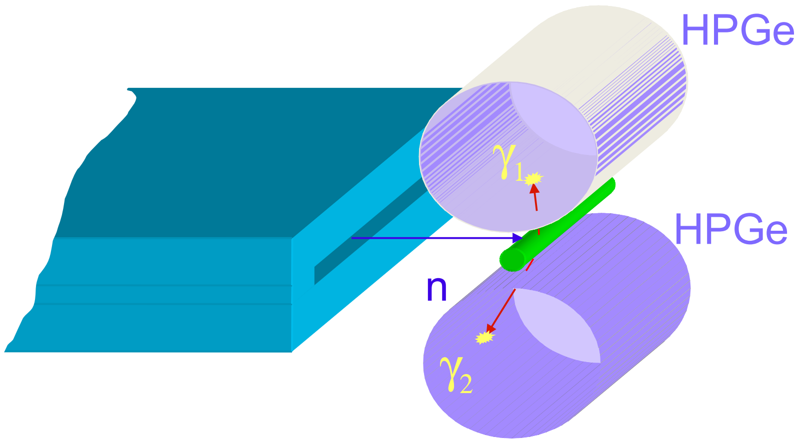


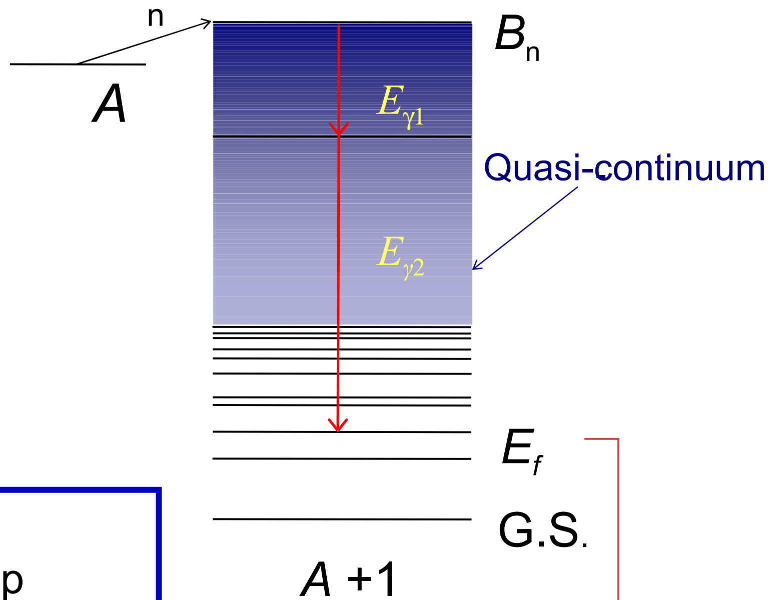
Two-step cascade (TSC) γ-ray spectrum:
Energy spectrum of transitions forming **all** two-step cascades that initiate at the neutron capturing state and terminate at a prefixed 'terminal level' *f*

Using the sum-coincidence method, TSC spectra for *many levels f* can be accumulated

Shape, size and fluctuation properties of TSC spectra depend in a complicated way on the PSF for the transitions to the terminal level and PSFs for transitions to an enormously large number of the levels in the quasi-continuum, typically 10^5-10^6.

A method of two-step γ cascades





Two-step cascade (TSC) γ-ray spectrum:
Energy spectrum of transitions forming **all** two-step cascades that initiate at the neutron capturing state and terminate at a prefixed 'terminal level' *f*

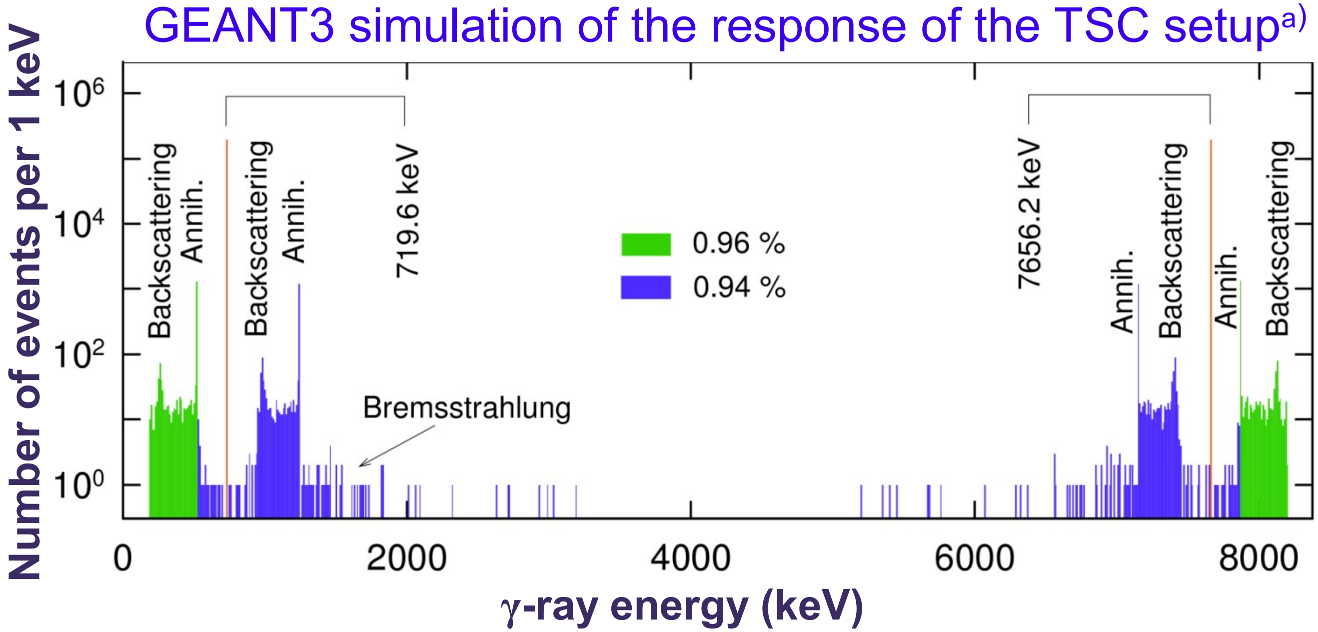
Using the sum-coincidence method, TSC spectra for *many levels f* can be accumulated

To extract information on PSFs, γ-cascades have to be simulated under various assumtions about PSFs. Then TSC spectra are predicted and subsequently compared with experimental TSC spectra. The **trial-and-error approach** is to be adopted

Response function of the TSC detector setup

γ cascade

GEANT3 simulation of the response of the TSC setup[a)]



A pair of TSC γ lines 7656 and 720 keV carries > 98 % of the detected events

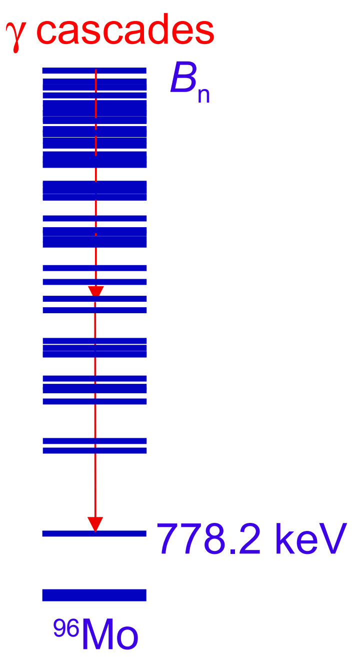
An almost ideal spectrometer

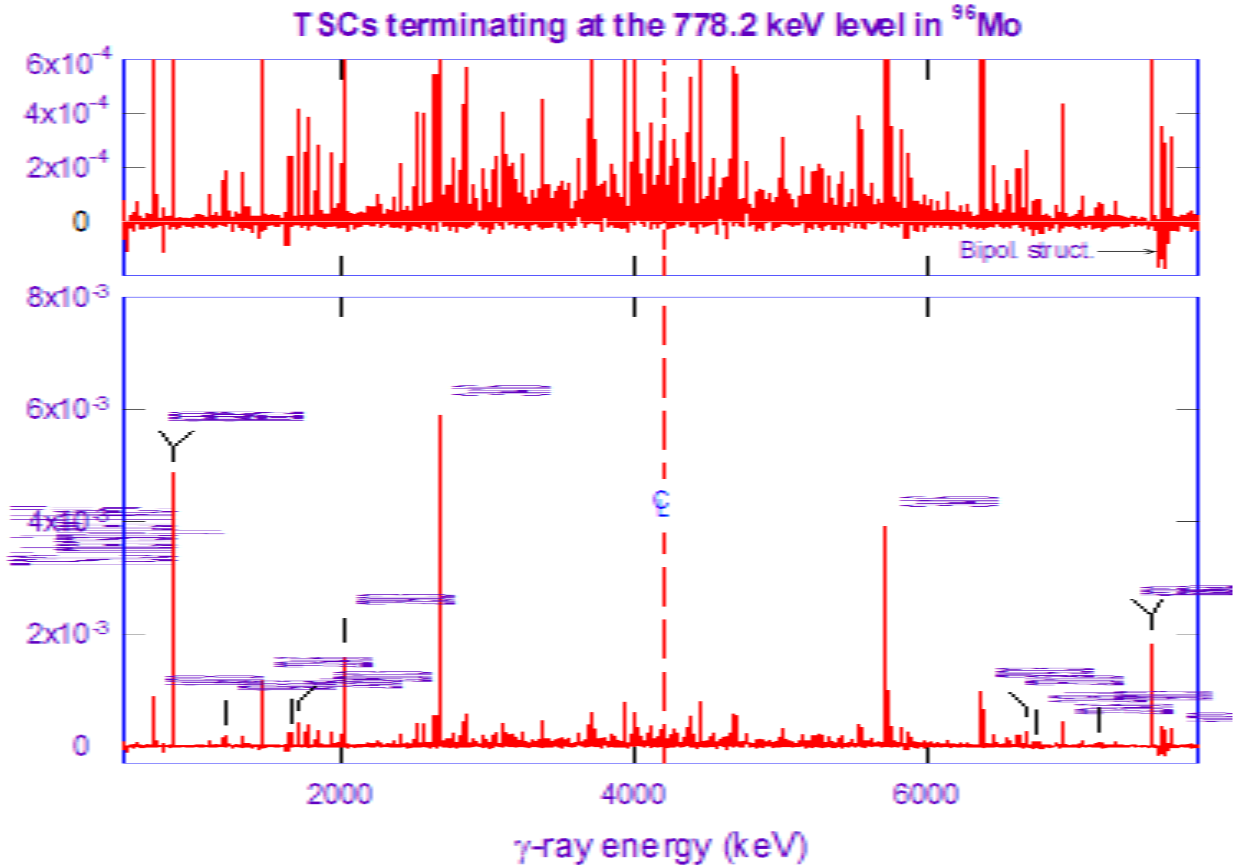
- **Virtually free of background**
- **γ-cross-talk negligible**
- **no need for deconvolution**

---

a)Simulated by G. Rusev at Triangle Universities Nuclear Laboratory (TUNL), Raleigh, NC, USA

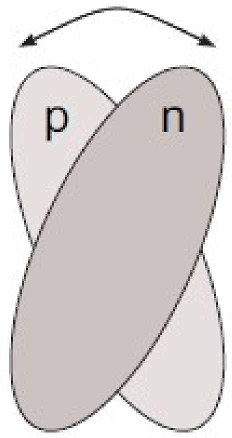
Another example of a TSC spectrum





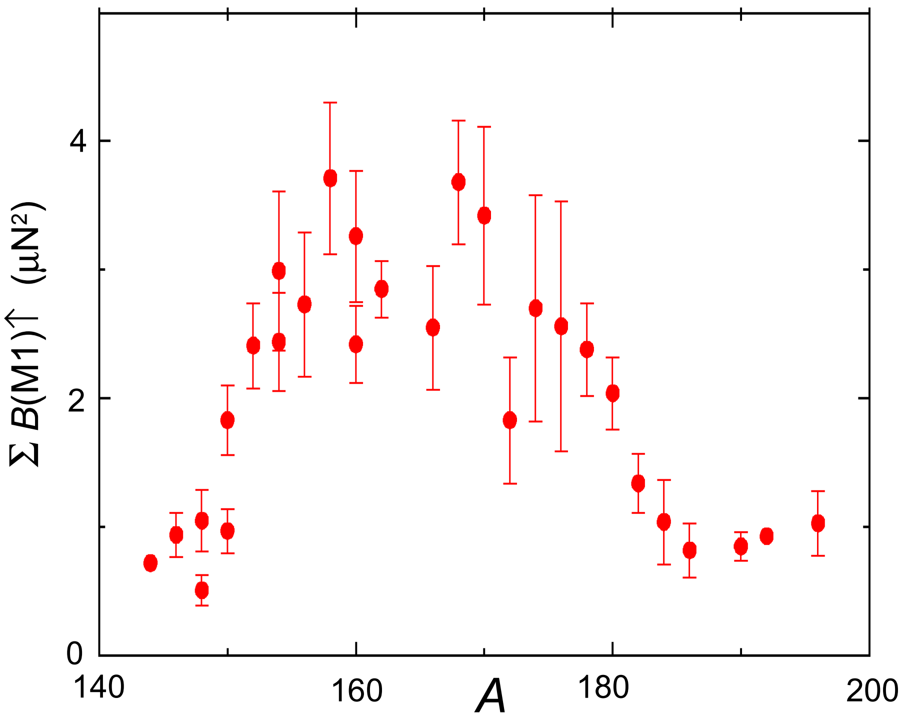
Dynamic range 10^3

Scissors $M1$ vibrational mode



Centroid of energy of the mode ≈3.0 MeV

Data from (γ,γ′) measurements at Darmstadt



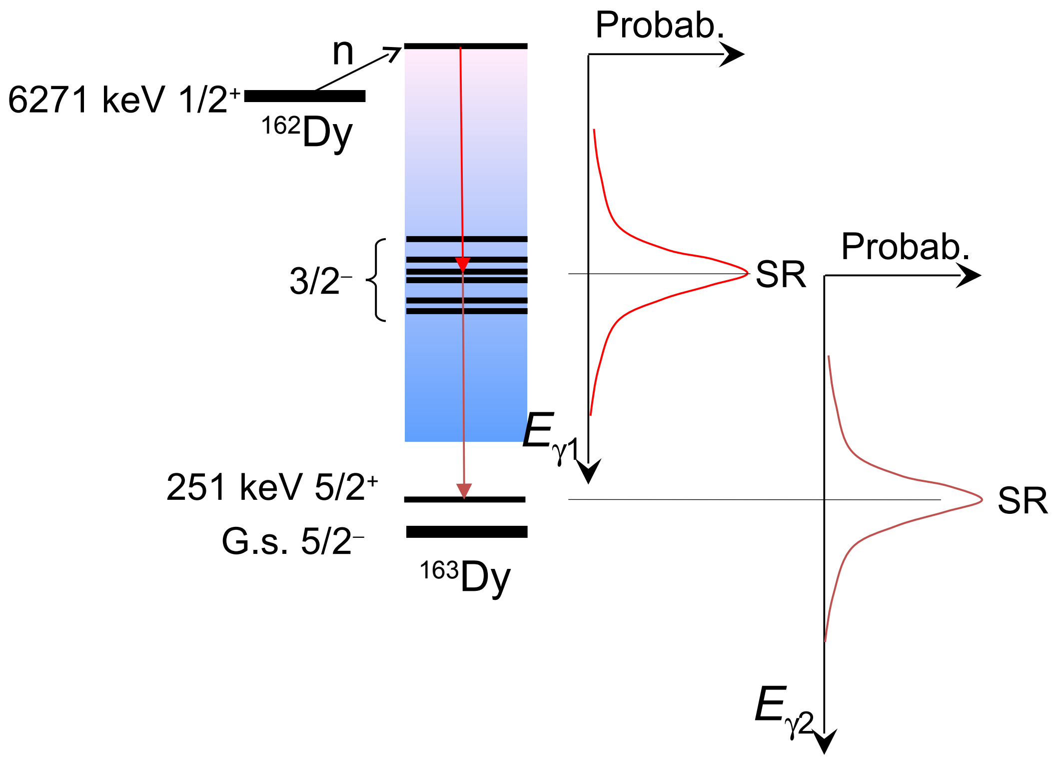
J. Enders *et al.*, PRC 59 R1851 (1999)

[1] R. R. Hilton, in Proceedings of the International Conference on Nuclear Structure, Dubna, 1976 (unpublished)
[2] N. Lo Iudice and F. Palumbo, Phys. Rev. Lett. **41,** 1532 (1978)

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

A search for the scissors-mode *M*1 resonances built on excited levels

Specifity of TSCs terminating at the 251 keV level



Allowed transitions *E*1 – *E*1 and *M*1 – *M*1

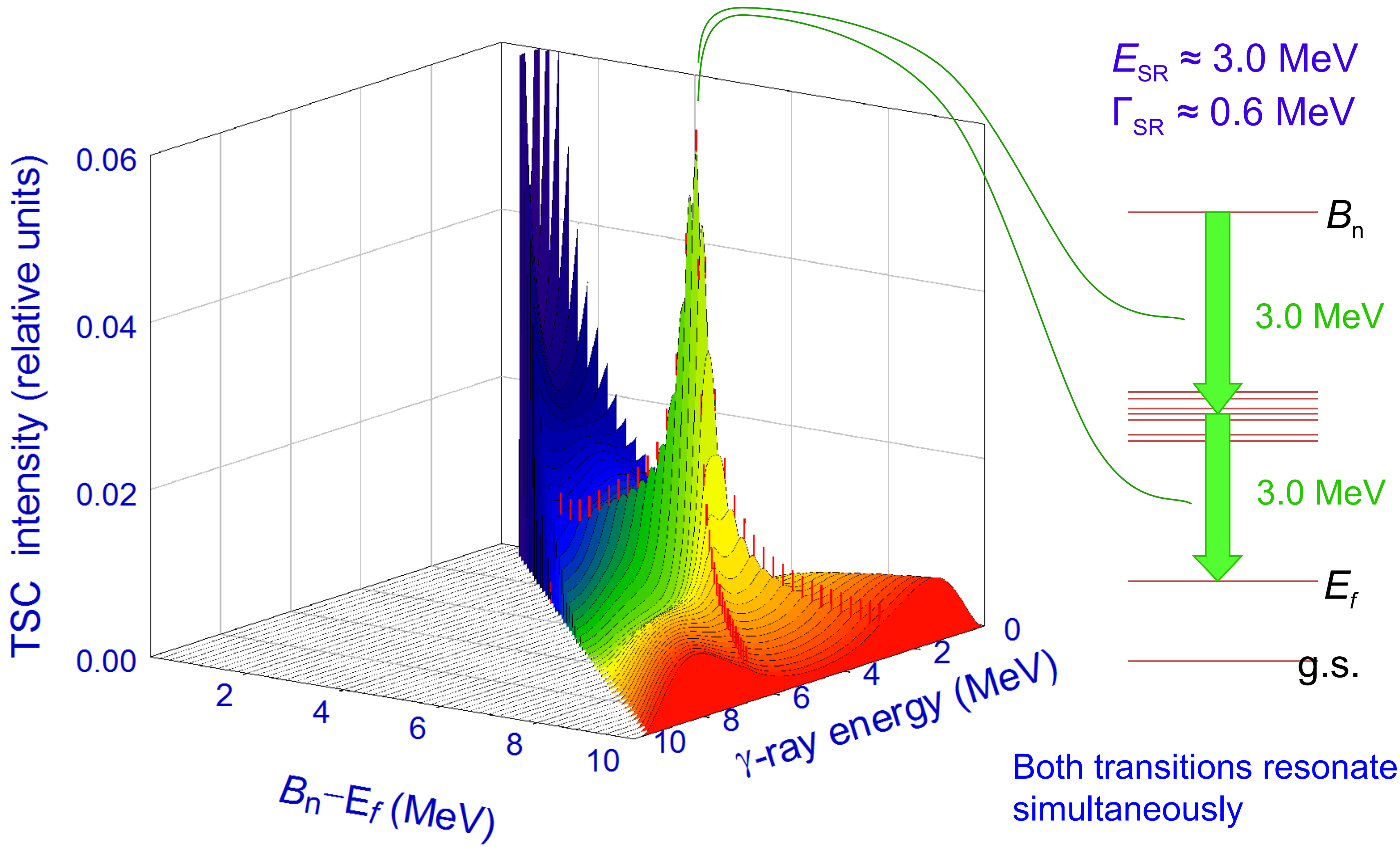
Favorable energy span

$B_n - E_f \approx 2E_{SR}$

Effect of *co-operative* enhancement
of primary and secondary transitions

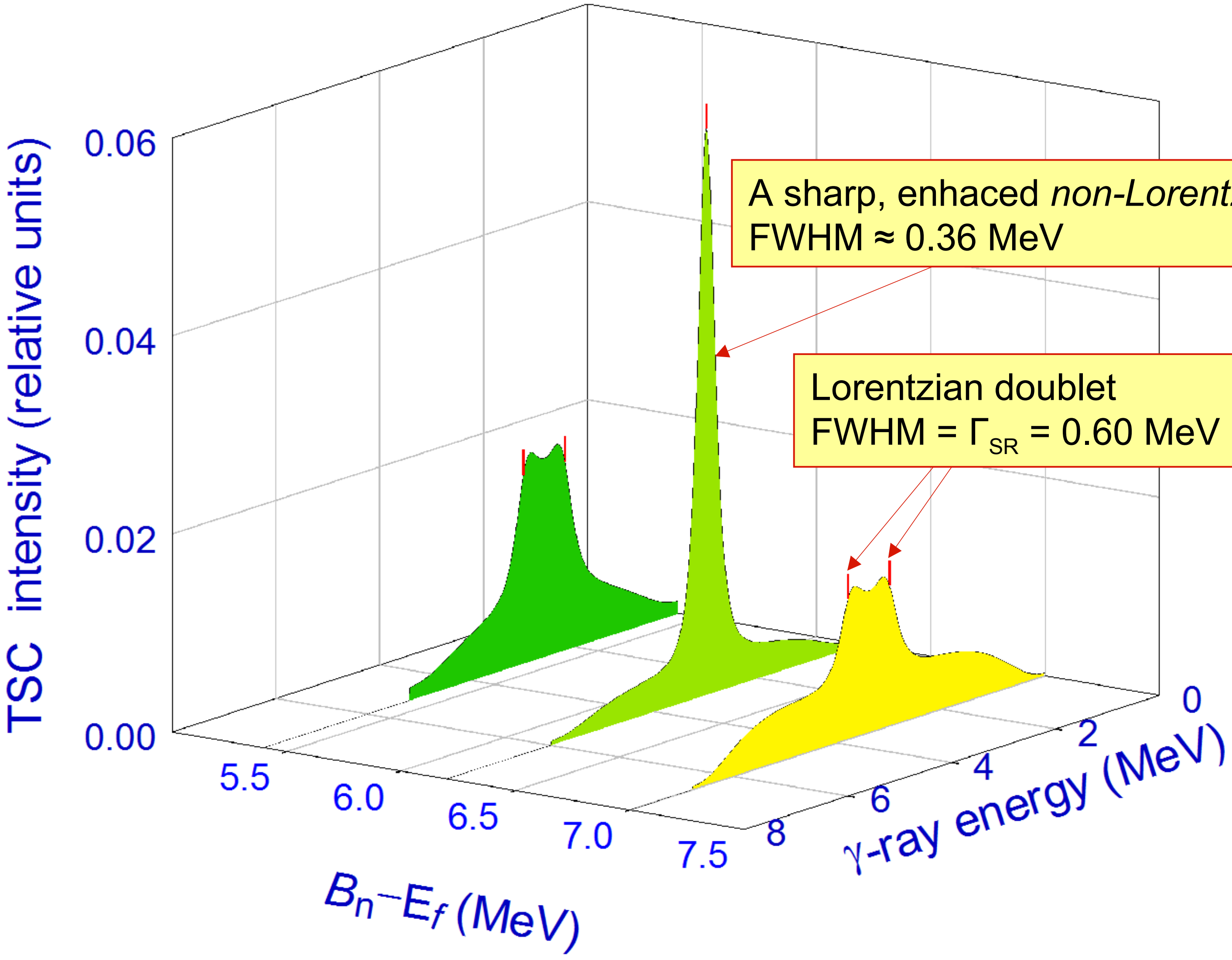
A unique possibility of
a sensitive test for presence
of SRs built on the levels
in the quasicontinuum

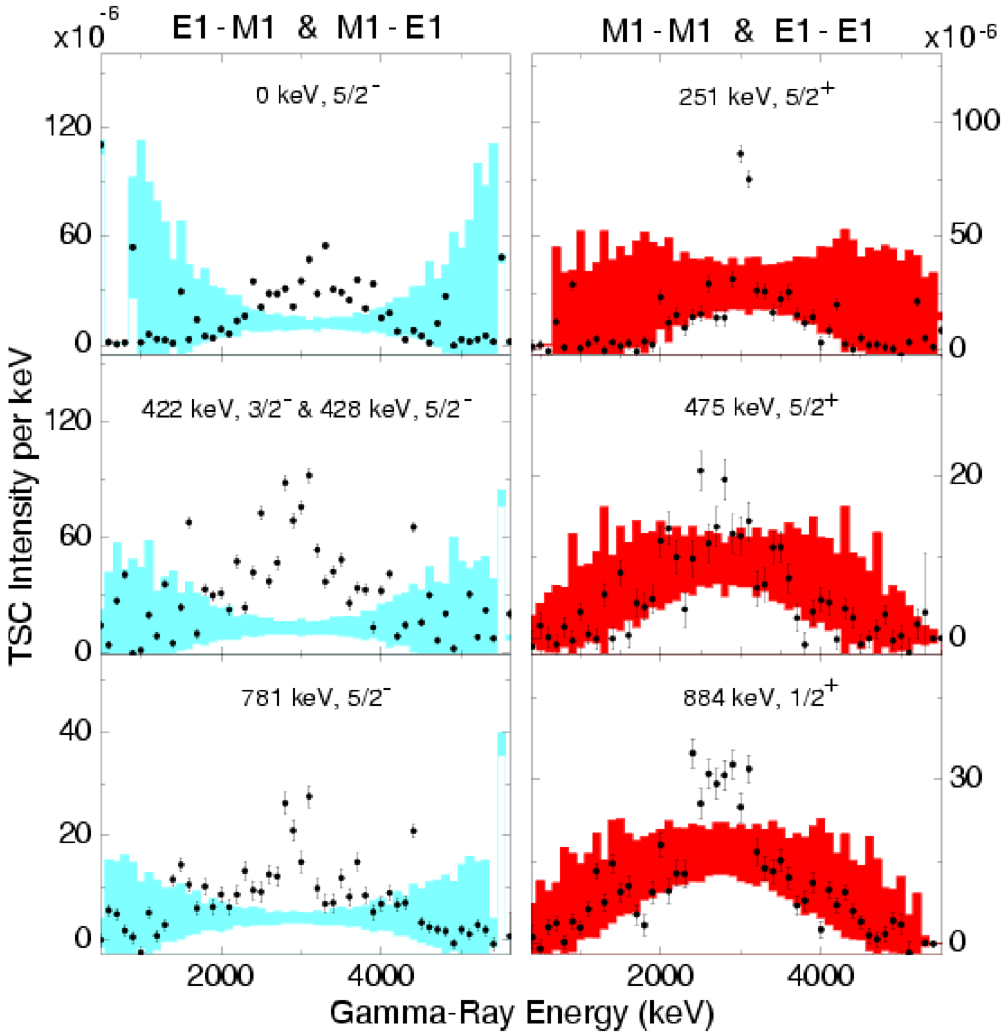
Cooperativness of primary and secondary transitions



Both transitions resonate simultaneously

Cooperativness of primary and secondary transitions

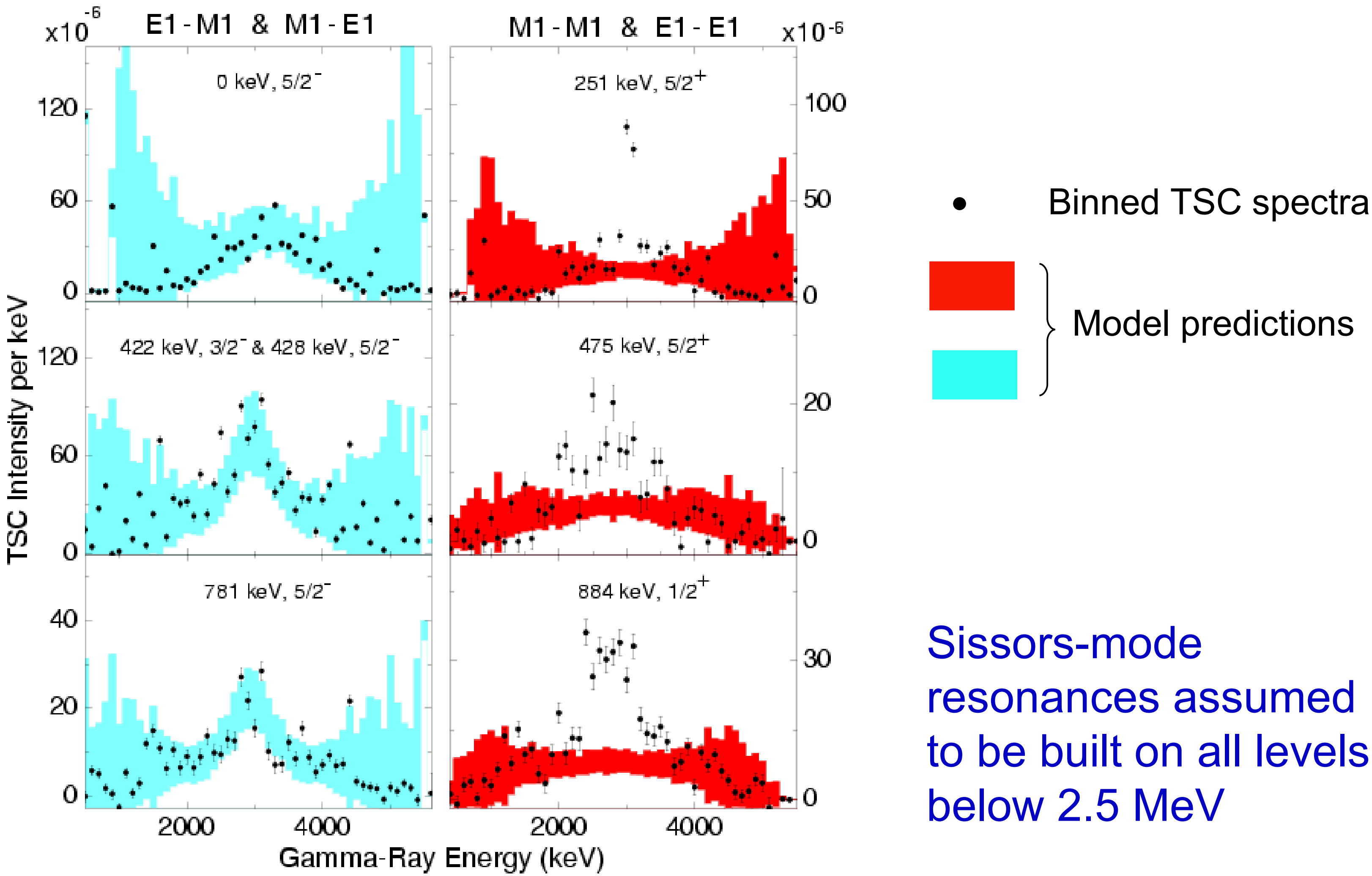




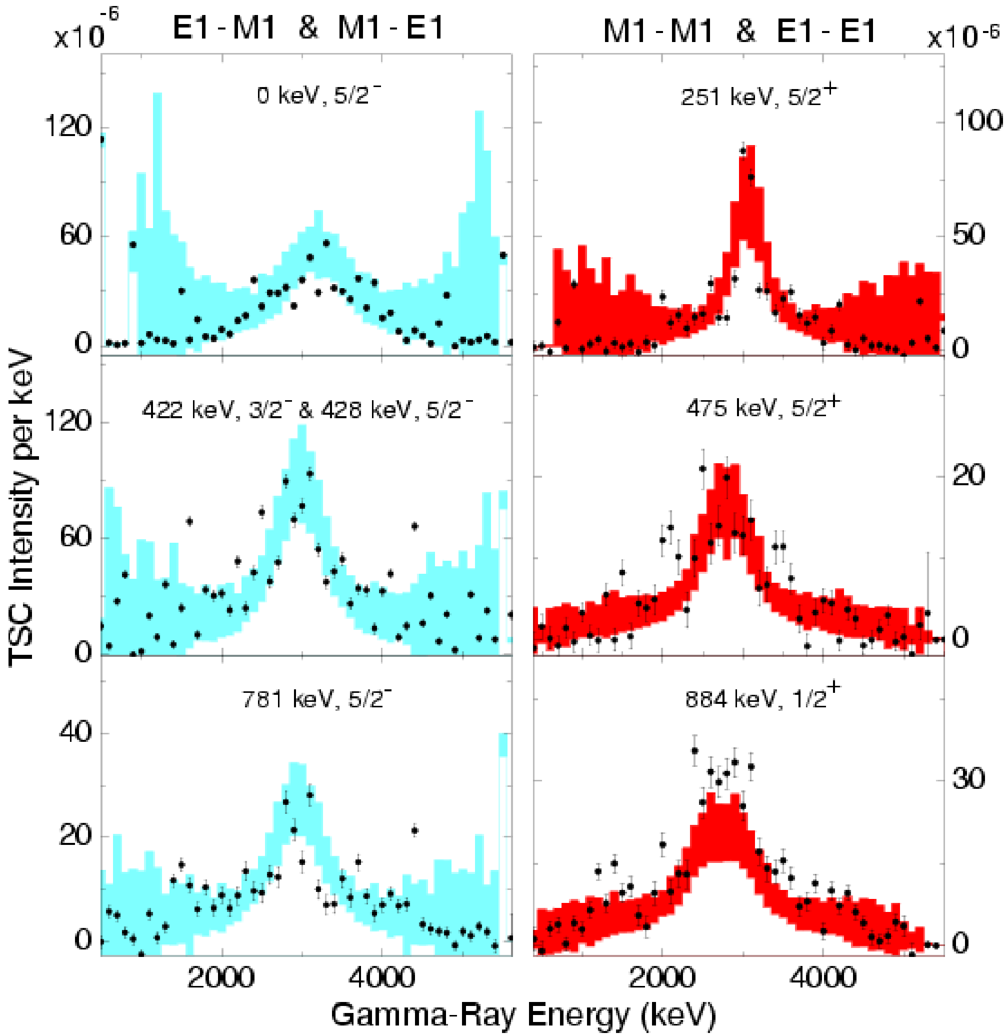
• Binned TSC spectra

Model predictions

Entire absence
of scissors-mode
resonances is assumed



Sissors-mode resonances assumed to be built on all levels below 2.5 MeV



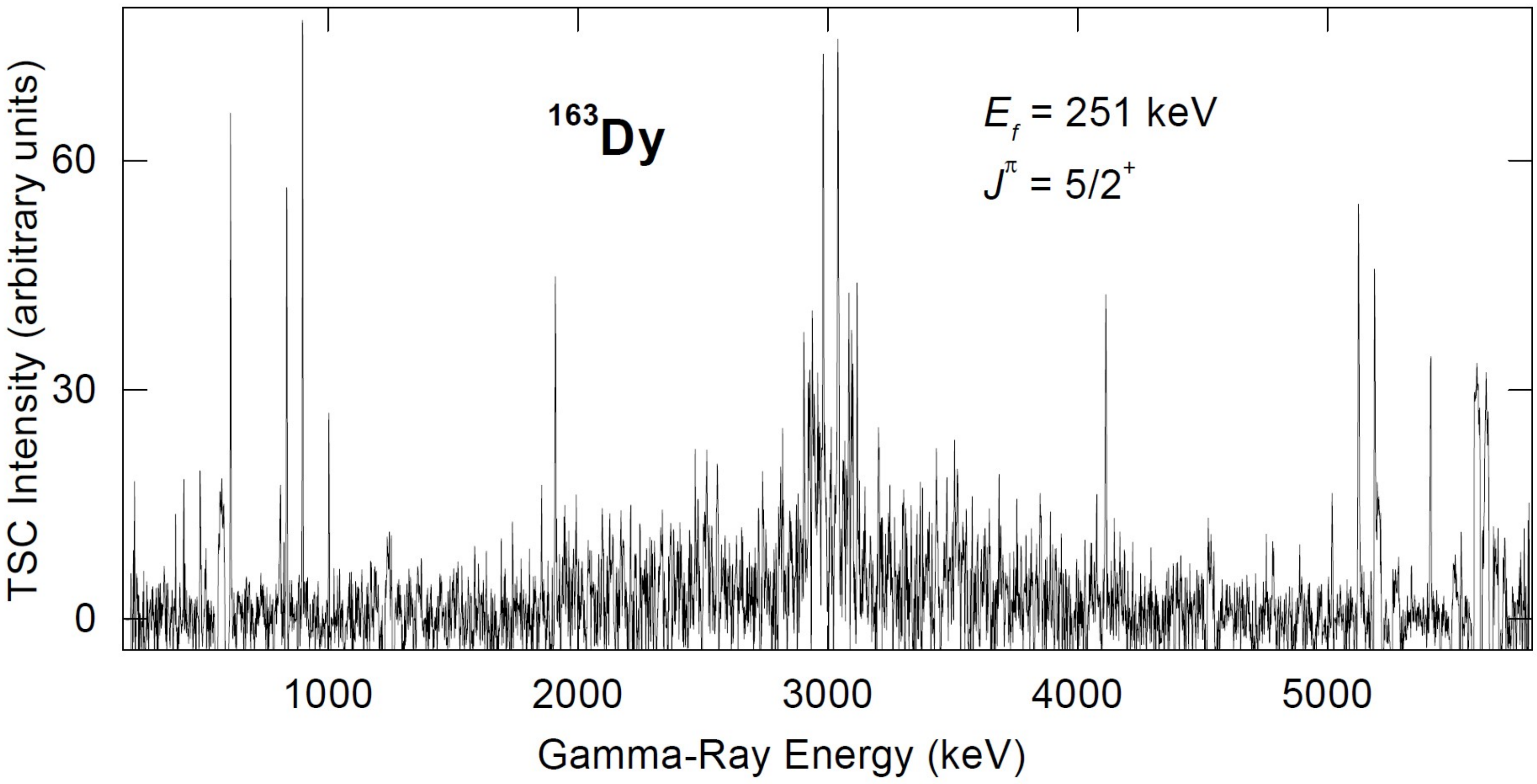
Sharpening the 3 MeV peak due to cooperativness well reproduced

plus

a quantitative agreement between the predicted and simulated TSC spectra

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

M. Krtička et al., Phys. Rev. Lett. **92**, 172501 (2004)

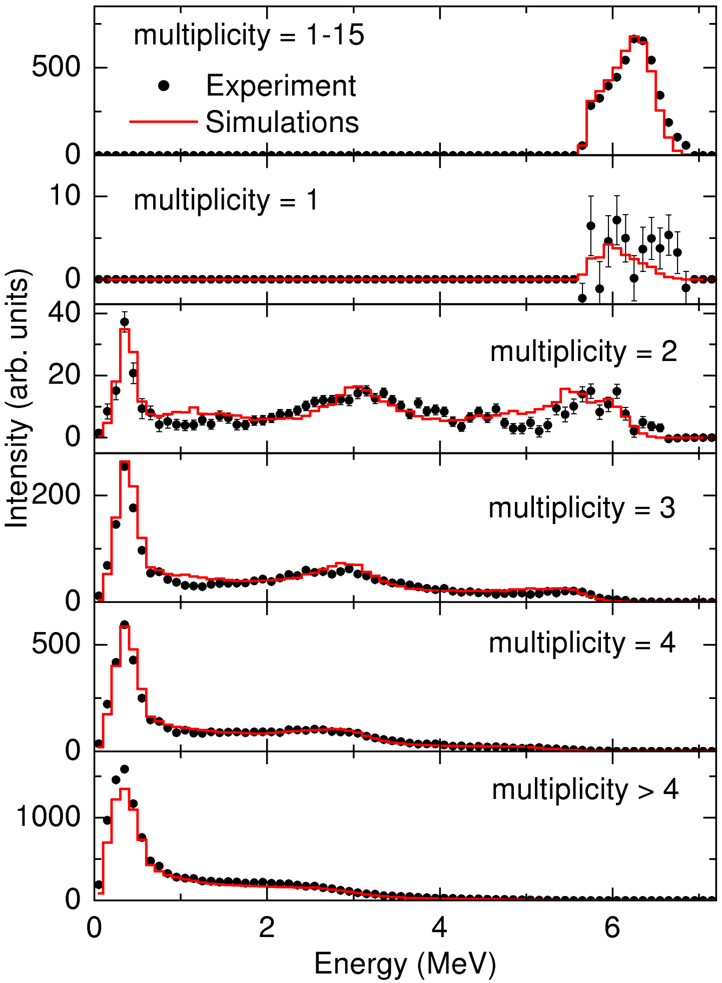


^{163}Dy
E_f = 251 keV
J^{π} = 5/2^{+}
TSC Intensity (arbitrary units)
0
30
60
1000
2000
3000
4000
5000
Gamma-Ray Energy (keV)

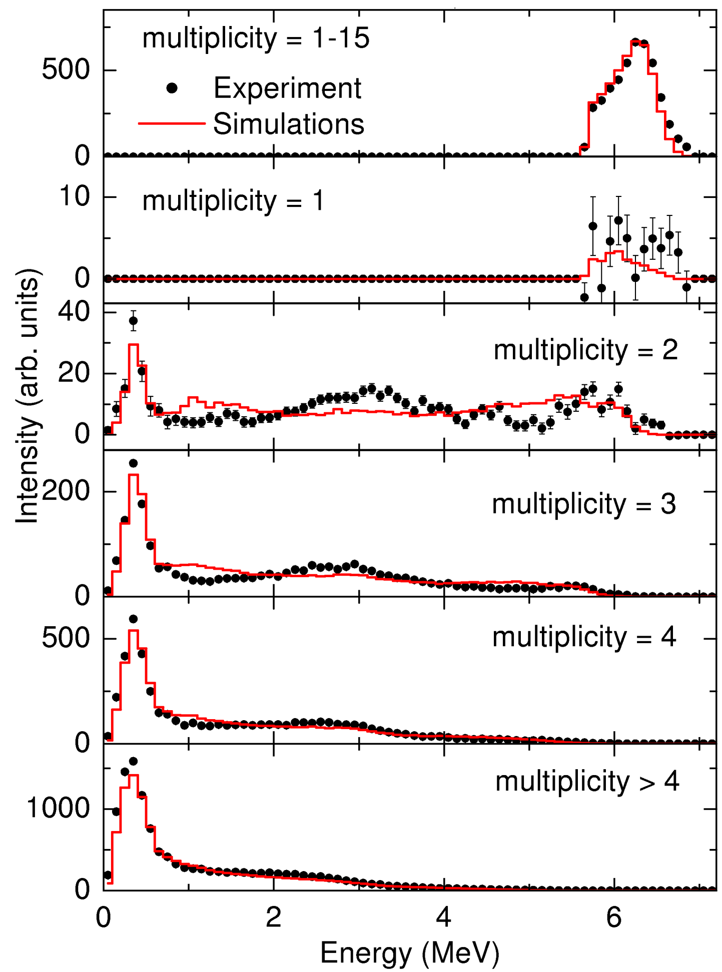
n-step cascades following the capture of keV neutrons in ^{162}Dy

E_n = 90-100 keV, measured with the Karlsruhe 4π BaF2 crystal ball

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

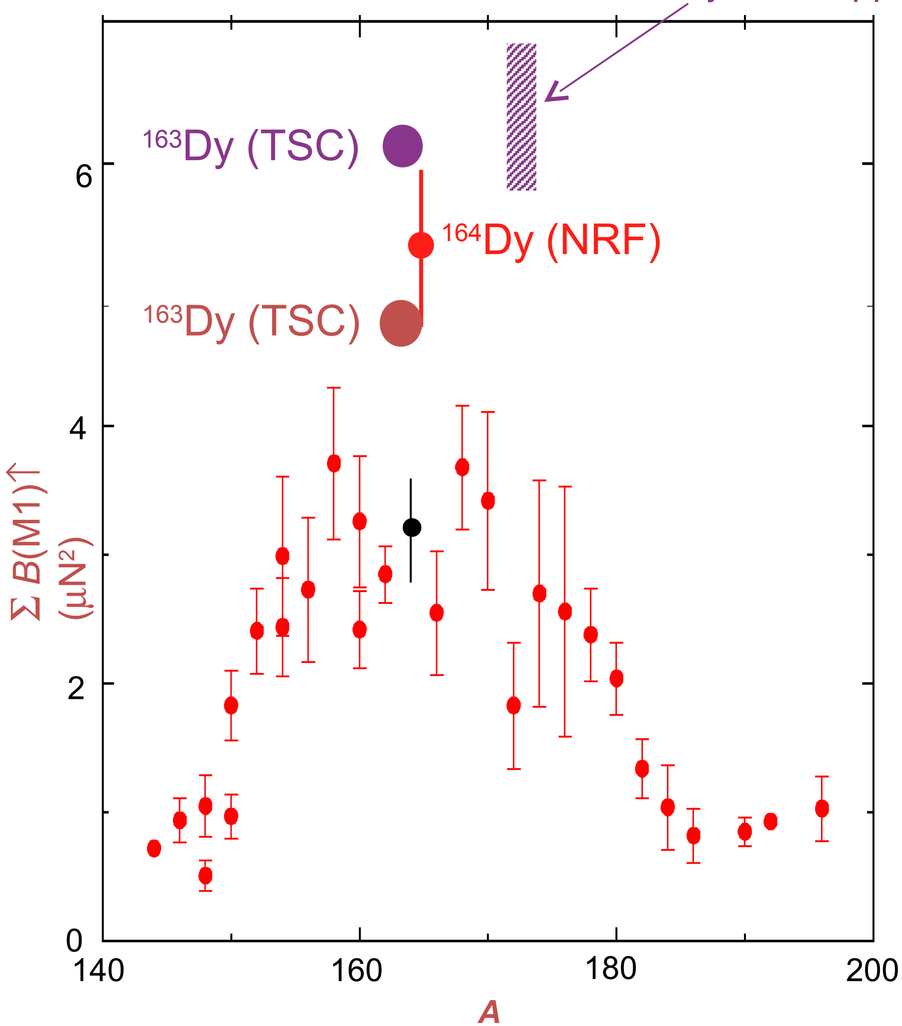


…only on levels with E_f <2.5 MeV



Comparison between the TSC and NRF data

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 $\Sigma B(M1)\uparrow$:

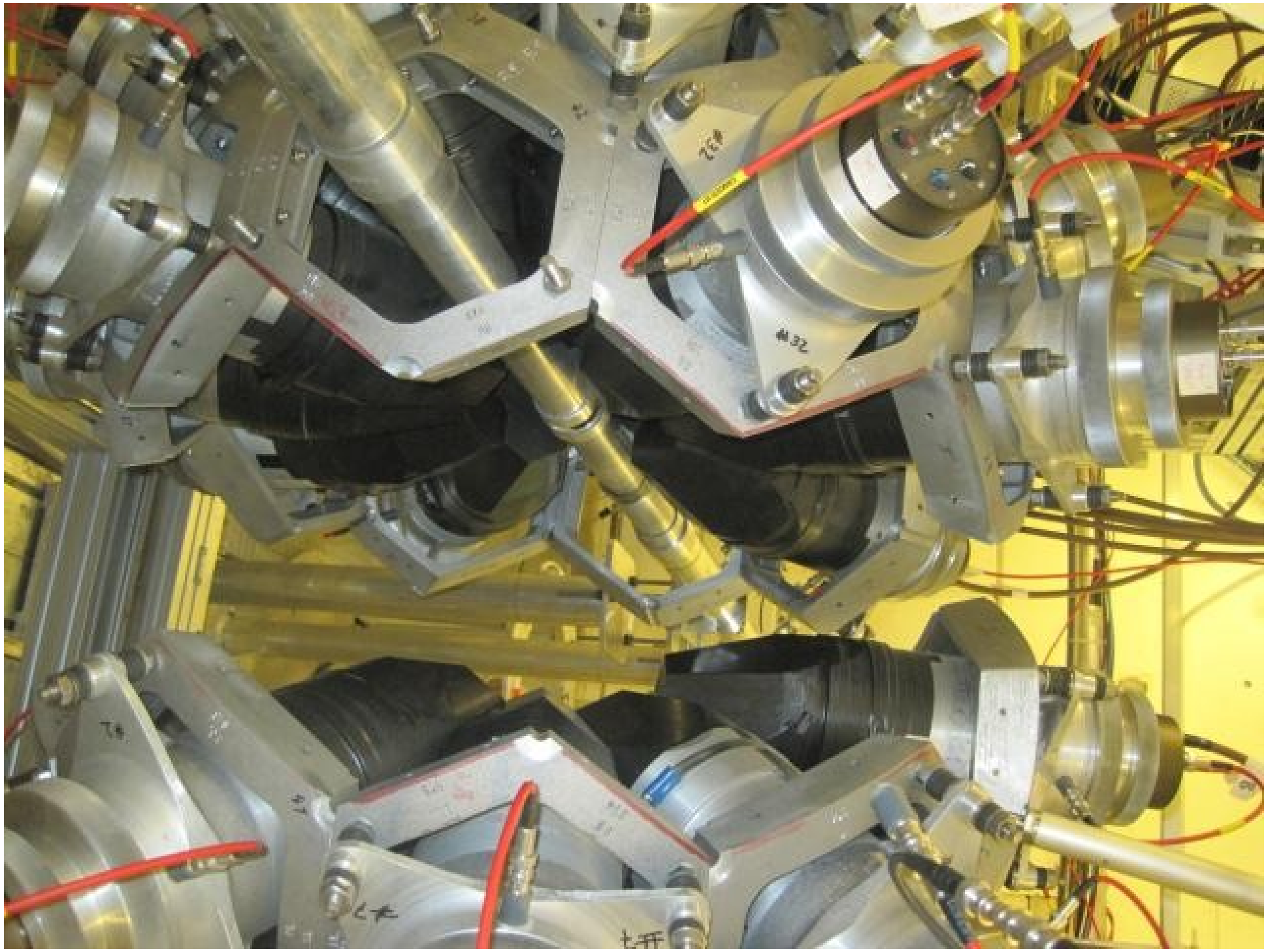
A considerable loss due to a finite summing energy interval

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

The CERN n_TOF 4π BaF_2 γ-calorimeter

Installed at a pulsed neutron beam of the CERN spallation source

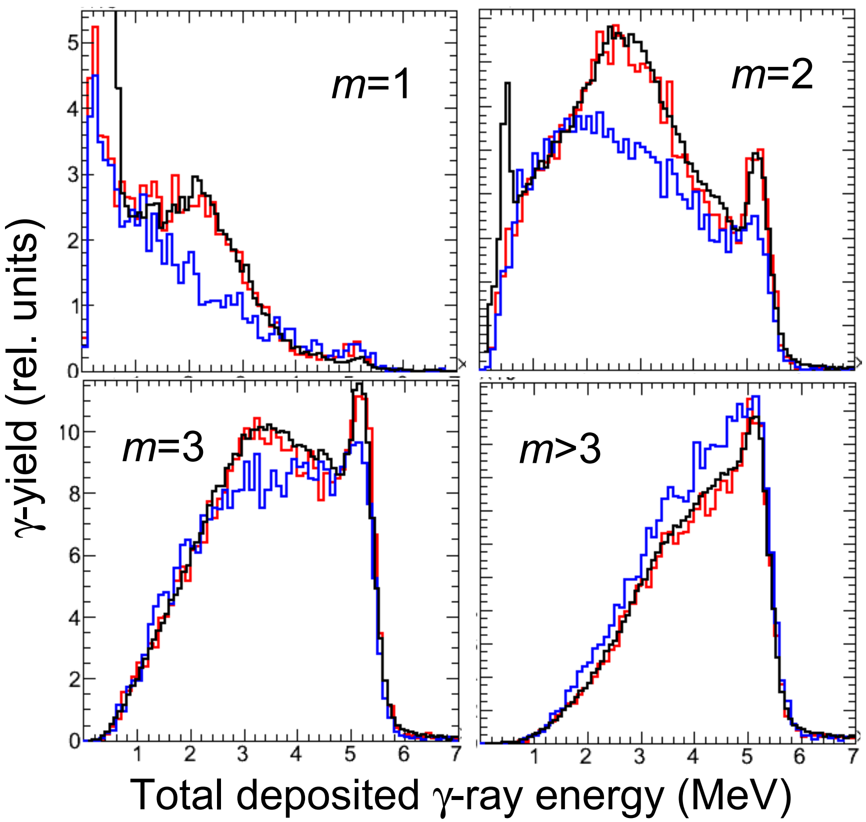
24 GeV protons are used to induce spallation



Multi-step γ cascades in the $^{240}Pu(n_{res},\gamma)^{241}Pu$ reaction

γ-calorimetric measurements at the CERN n_TOF facility

Comparison between the data and combined DICEBOX/GEANT4 *simulations*



- Data: spectra of deposited energy from γ cascades with various multiplicities *m*
- Simulations according to photon strength functions recommended by the IAEA RIPL Library
- Simulations with added photon strength from *M*1 scissors resonances built on *each level* of ^{242}Pu

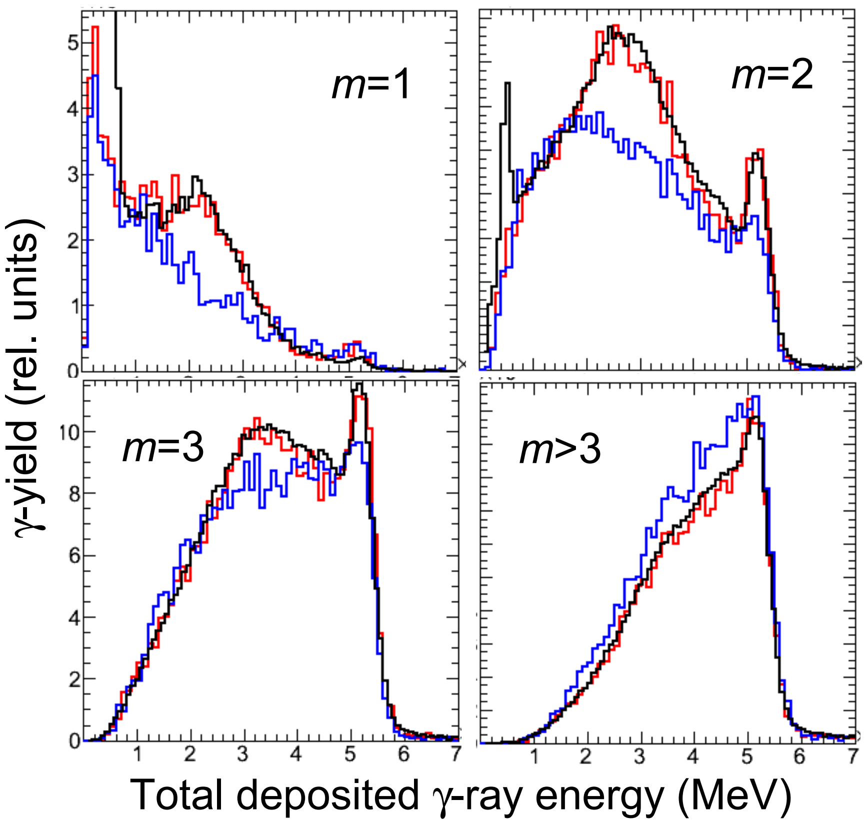
Trial-and-error method

C. Guerrero *et al.*, in Int'l Conf. on Nuclear Data and Applications 2010 (Jeju, Korea, 2010)

Multi-step γ cascades in the $^{240}Pu(n_{res},\gamma)^{241}Pu$ reaction

γ-calorimetric measurements at the CERN n_TOF facility

Comparison between the data and combined DICEBOX/GEANT4 simulations



- Data
- Simulations according to photon strength functions recommended By the IAEA RIPL Library
- Simulations with added photon strength from *M*1 scissors resonances built on *each level* of ^{242}Pu

A strict validity of Brink hypothesis is assumed while performing simulations

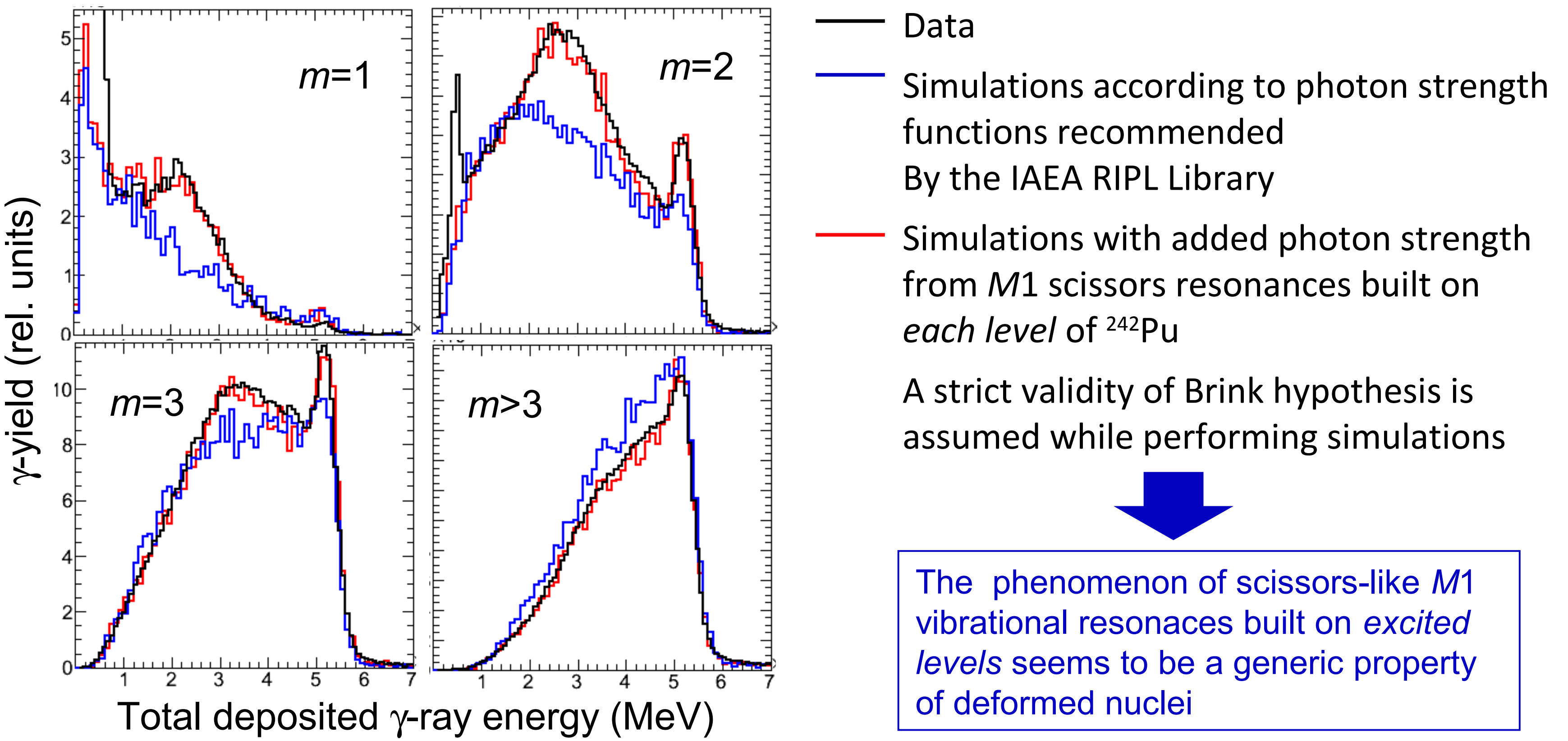
Trial-and-error method

C. Guerrero *et al.*, in Int'l Conf. on Nuclear Data and Applications 2010 (Jeju, Korea, 2010)

Multi-step γ cascades in the $^{240}Pu(n_{res},\gamma)^{241}Pu$ reaction

γ-calorimetric measurements at the CERN n_TOF facility

Comparison between the data and combined DICEBOX/GEANT4 simulations



A strict validity of Brink hypothesis is assumed while performing simulations

The phenomenon of scissors-like *M*1 vibrational resonaces built on *excited levels* seems to be a generic property of deformed nuclei

C. Guerrero *et al.*, in Int'l Conf. on Nuclear Data and Applications 2010 (Jeju, Korea, 2010)

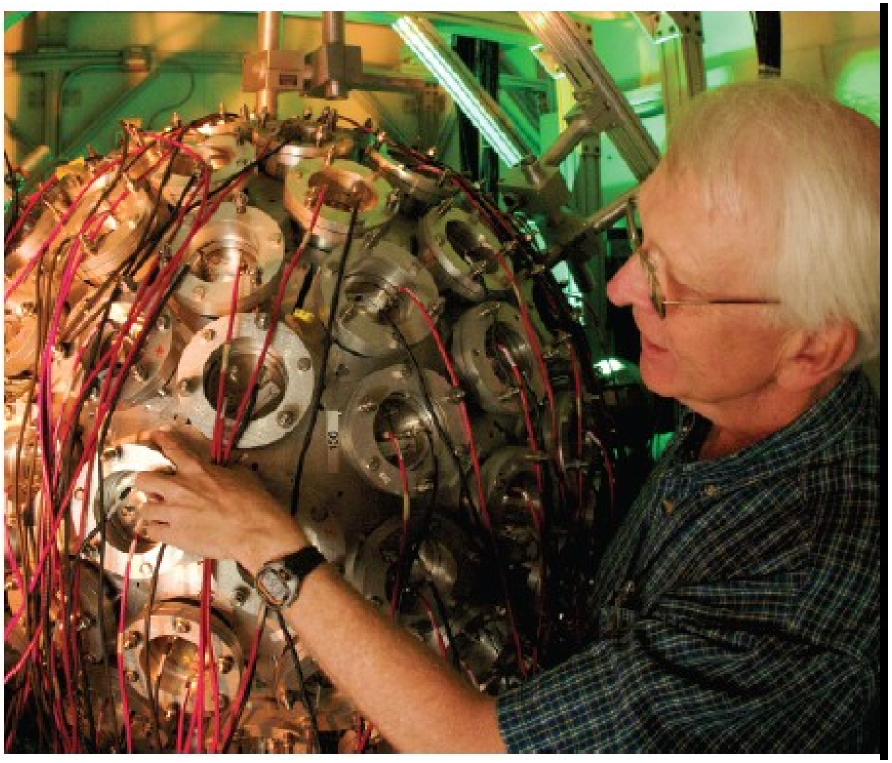
The DANCE 4π BaF_2 γ-calorimeter at Los Alamos

Detector for Advanced Neutron Experiments (DANCE) at Los Alamos

Installed at one of the pulsed neutron beams of Los Alamos Scattering Center (LANSCE)

Neutrons are produced by neutron spallation source driven by an 800 MeV proton linac

- 160 BaF_2 scintillation detectors in a compact 4π geometry
- 20 m flight path
- State-of-the-art, fully digitized electronics
- Possibility to study neutron resonances using samples as small as 0.1 mg.

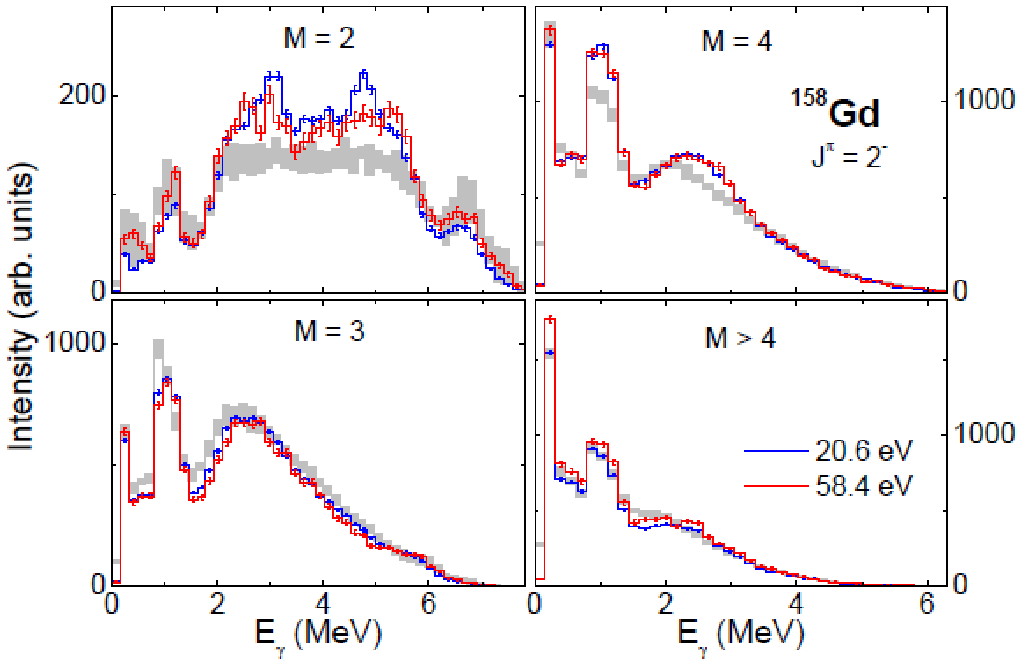


Neutron beams at LANSCE

Multi-step γ cascades in the $^{157}Gd(n_{res},\gamma)^{158}Gd$ reaction

Trial-and-error method

DANCE measurements



Data: spectra of deposited energy for various multiplicities *M*

Simulations according to the *E*1 KMF photon strength functions and the *M*1 SP+SF PSFs.

Multi-step γ cascades in the $^{157}Gd(n_{res},\gamma)^{158}Gd$ reaction

Trial-and-error method

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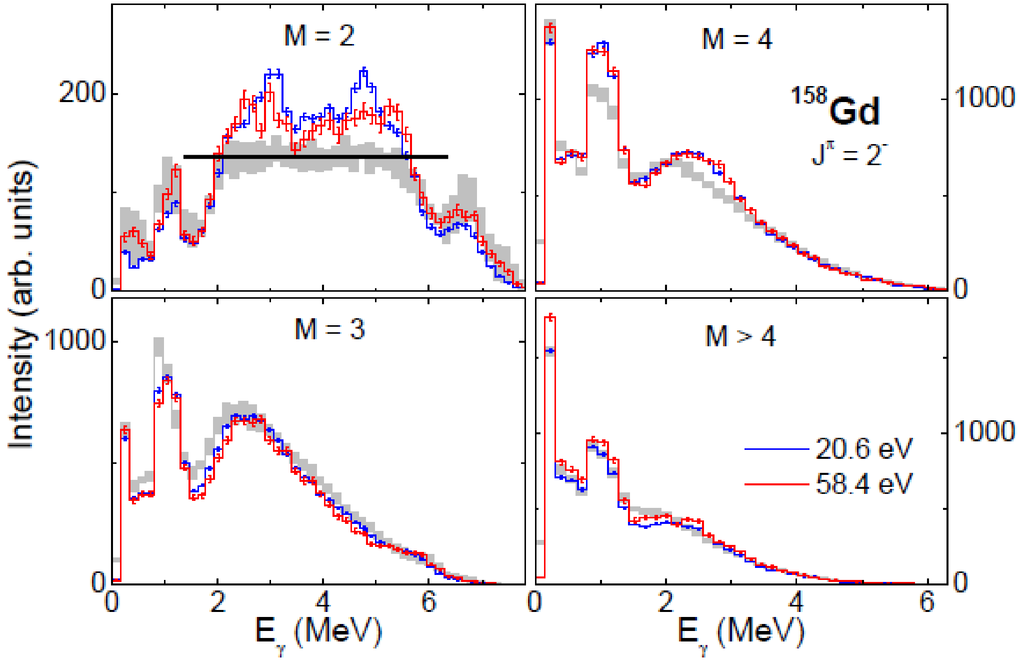
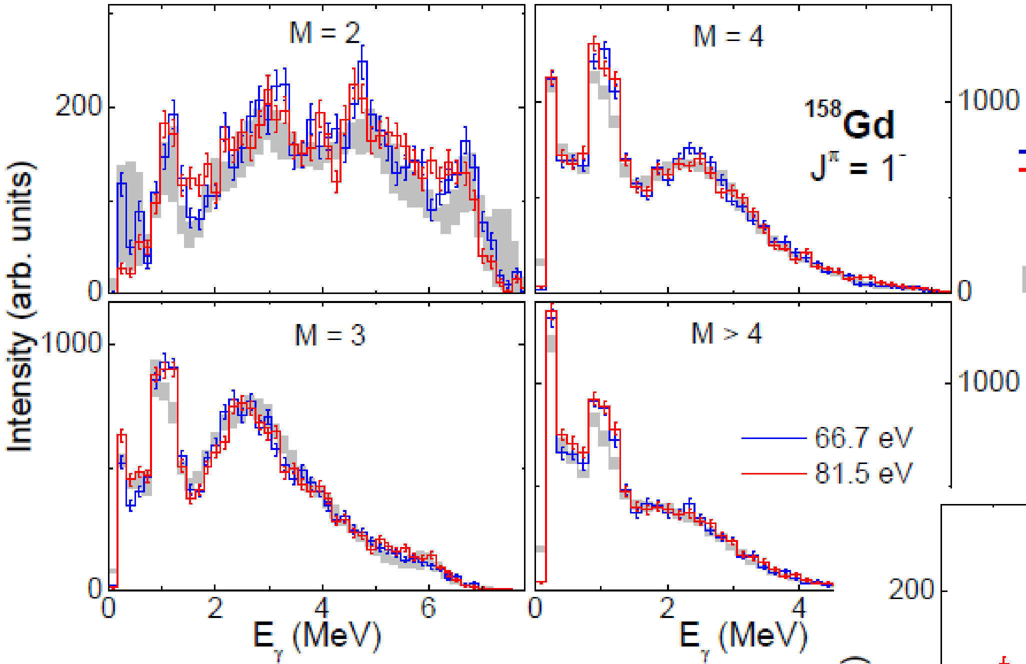
DANCE measurements



Unacceptable disagreement

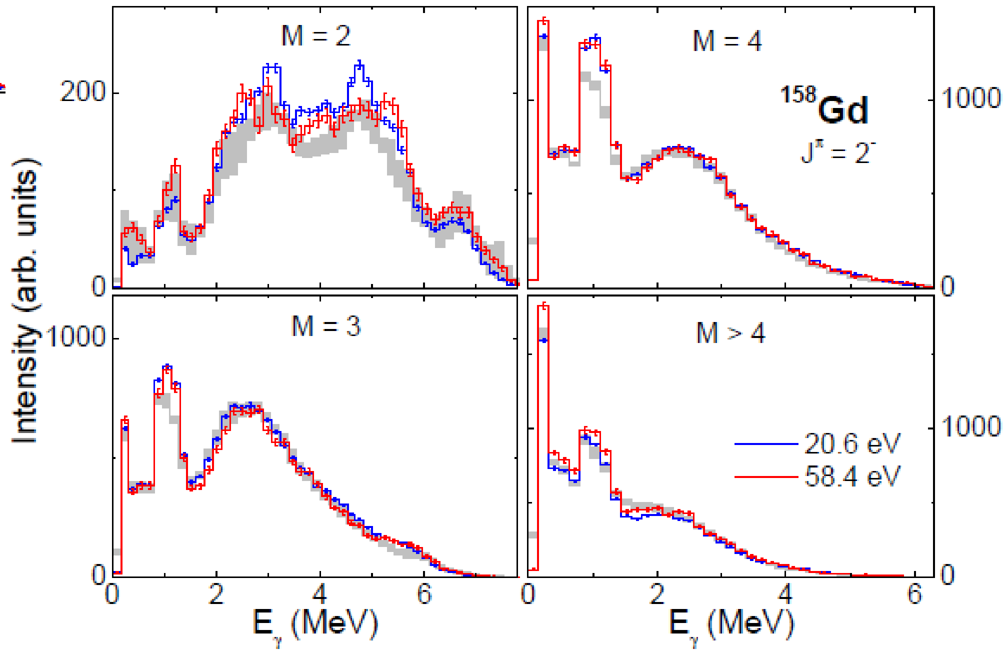
Multi-step γ cascades in the $^{157}Gd(n_{res},\gamma)^{158}Gd$ reaction



DANCE measurements

Data: spectra of deposited energy for various multiplicities *M*

Simulations according to the *E*1 KMF photon strength functions and the *M*1 SP+SF+SM PSFs.

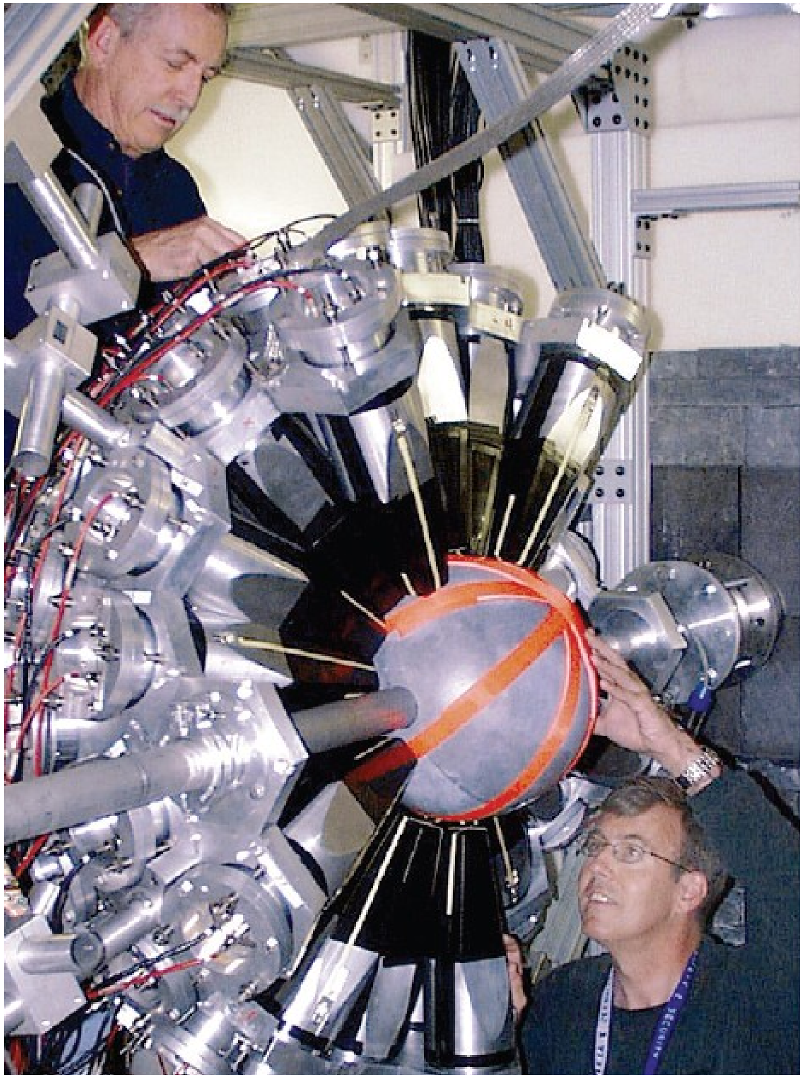


The agreement is achieved only by

- postulating the *E*1 photon strength function according to predictions of Kadmenskij-Markushev-Furman,
- together with postulating the scissors *M*1 resonances residing on each level in ^{158}Gd

Thank you for attention

The DANCE 4π BaF_2 γ-calorimeter at Los Alamos



DANCE detector system at LANSCE
is a part of Weapons Neutron Facility at Los Alamos

Let Us Beat Swords Into Plowshares
(Евгений Викторович Вучетич (1908-1984)