Evidence for the Scissors Mode in ^{160}Tb from the Two-Step Gamma Cascades measurement

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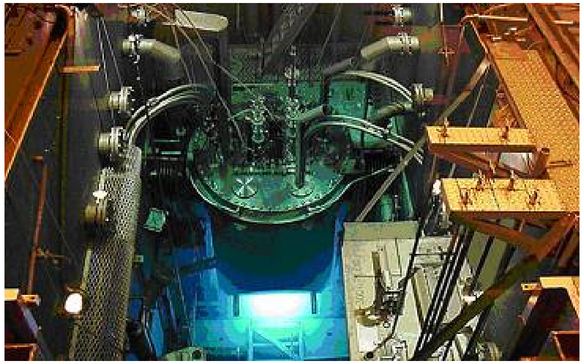
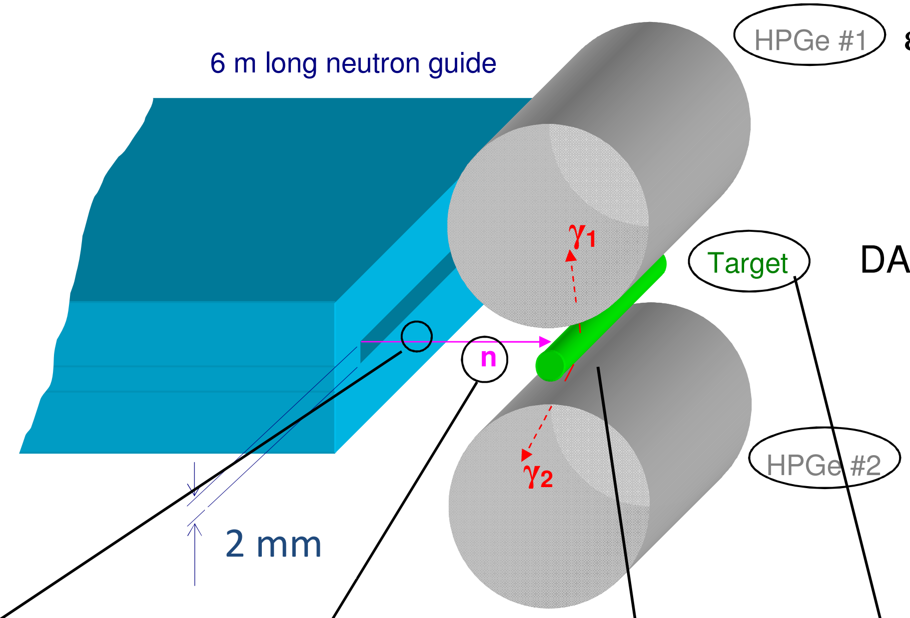
Outline

- Experimental setup for the TSCs measurement
- Simulations of gamma decay
- Main results
- Conclusions

Experimental setup for the TSCs measurement

LWR-15 reactor





ε_R = 25%

DAQ time: 800 h

ε_R = 28%

3.0×10^6 n cm^{-2} s^{-1}

$E_n = 0.025$ eV

Tb_4O_7 (m = 0.88g)

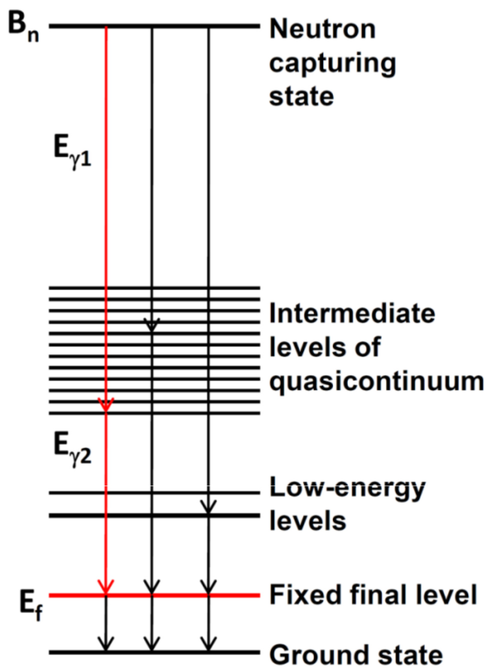
Neutron shielding: $^6Li_2CO_3$

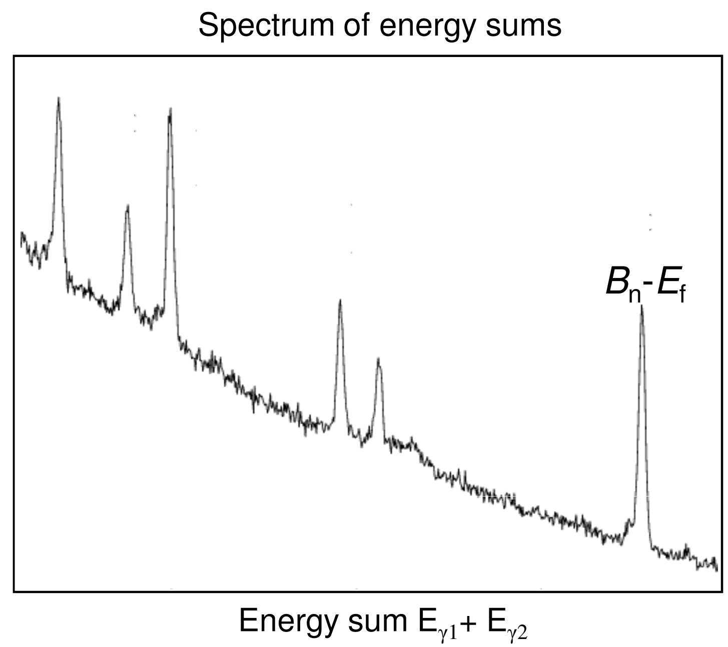
Low energy γ-ray shielding: Lead

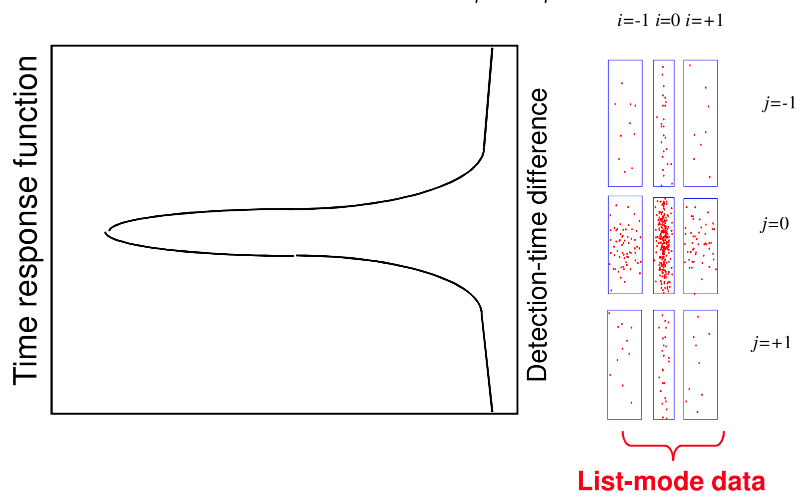
DAQ conditions for the TSCs:

- energies $E_{\gamma 1}$ *and* $E_{\gamma 2}$
- time difference

Data processing



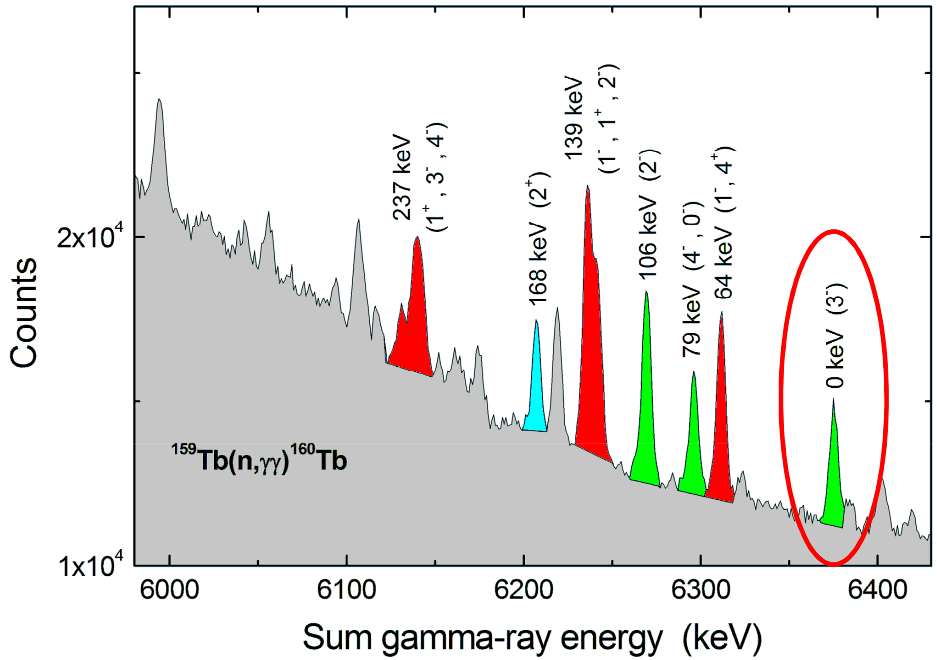




From information about $E_{\gamma 1}$ and $E_{\gamma 2}$ and **detection time difference**, one can retrieve virtually background-free TSC spectra.

Experimental setup for the TSCs measurement (3)

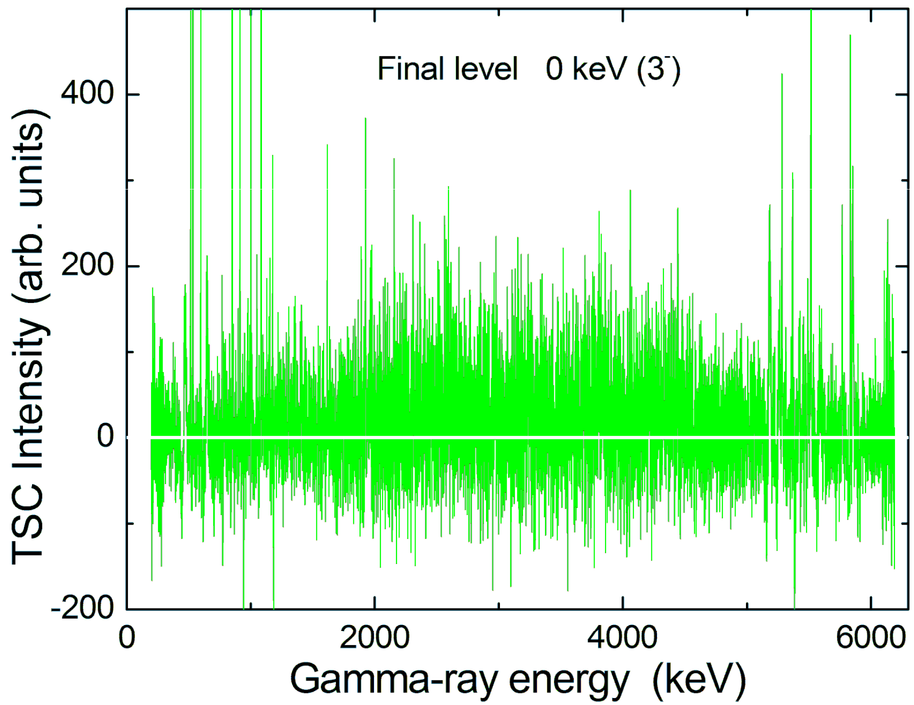
Spectrum of energy sums

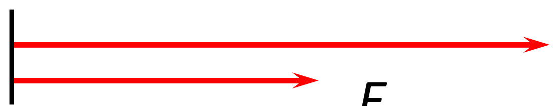


$E_{\gamma1} + E_{\gamma2}$

S_n = 6.375 MeV

Spectrum of Two-Step Cascades





$E_{\gamma2}$

$E_{\gamma1}$

Simulations of gamma decay – DICEBOX (1)

1. Below a **critical energy *E_{crit}*** the energies *E*, spins *J*, parities π and the decay properties of all levels are taken from known data

2. Above the critical energy E_{crit} the energies *E*, spins *J* and parities π of levels are obtained by random discretization of an *a priory* known level density

$$\rho(E, J, \pi)$$

3. **Partial radiation widths $\Gamma_{i\gamma f}$** for transitions between initial (i) and final (f) levels are generated according to the formula:

$$\Gamma_{i\gamma f} = \sum_{XJ} y^2_{ifXJ}(E_i - E_f)^{2J+1} \frac{f^{(XJ)}(E_i - E_f)}{\rho(E_i, J_i, \pi_i)}$$

4. Partial radiation widths $\Gamma_{i\gamma f}$ for different initial and/or final levels are statistically independent.

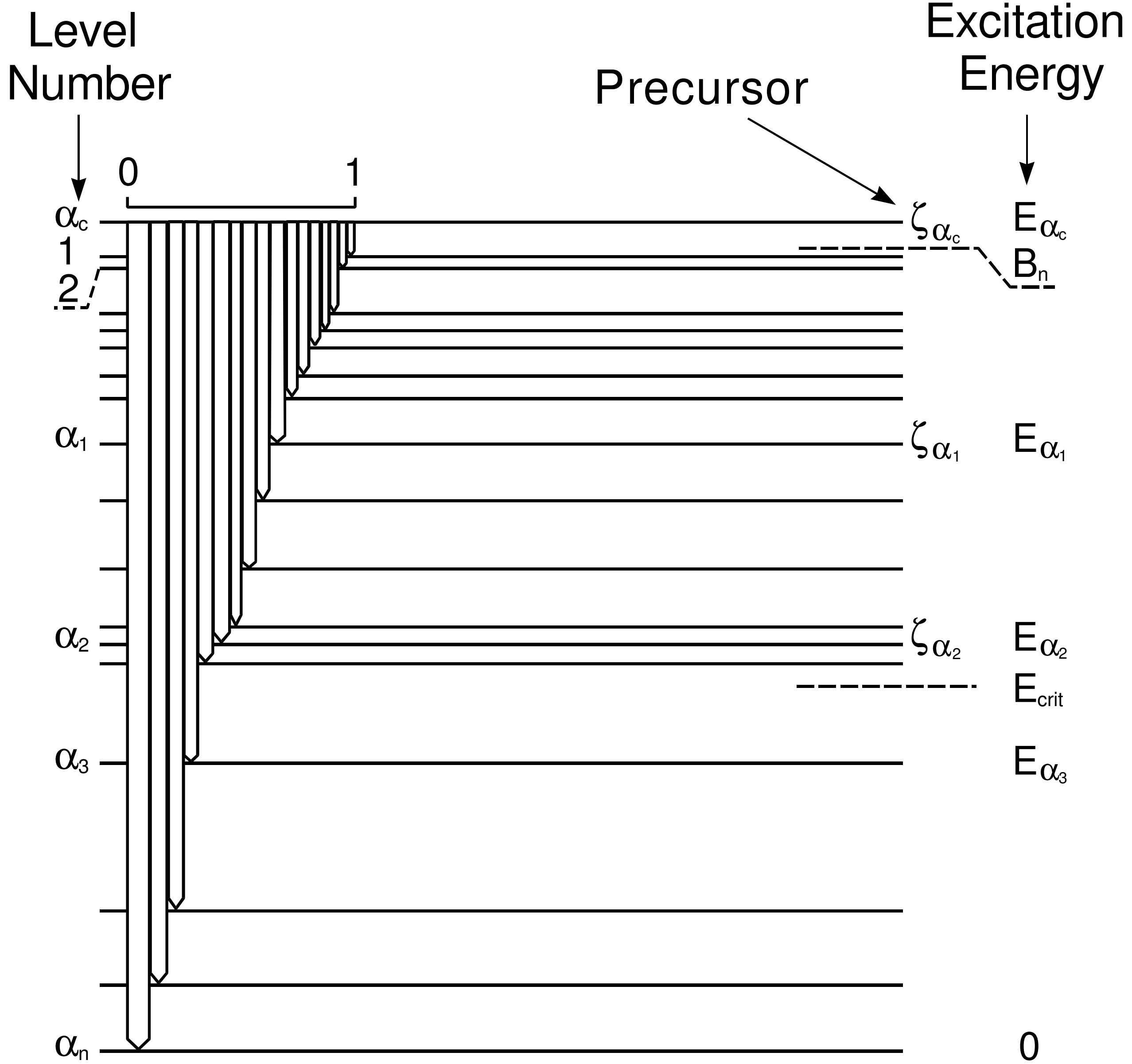
Simulations of gamma decay – DICEBOX (2)

Nuclear Realization:

10^6 energy leves

$10^{12}\ \Gamma_{i\gamma f}$

System of precursors



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P-T fluctuations

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Simulations of gamma decay – DICEBOX (4)

Nuclear Realization:

10^6 energy leves

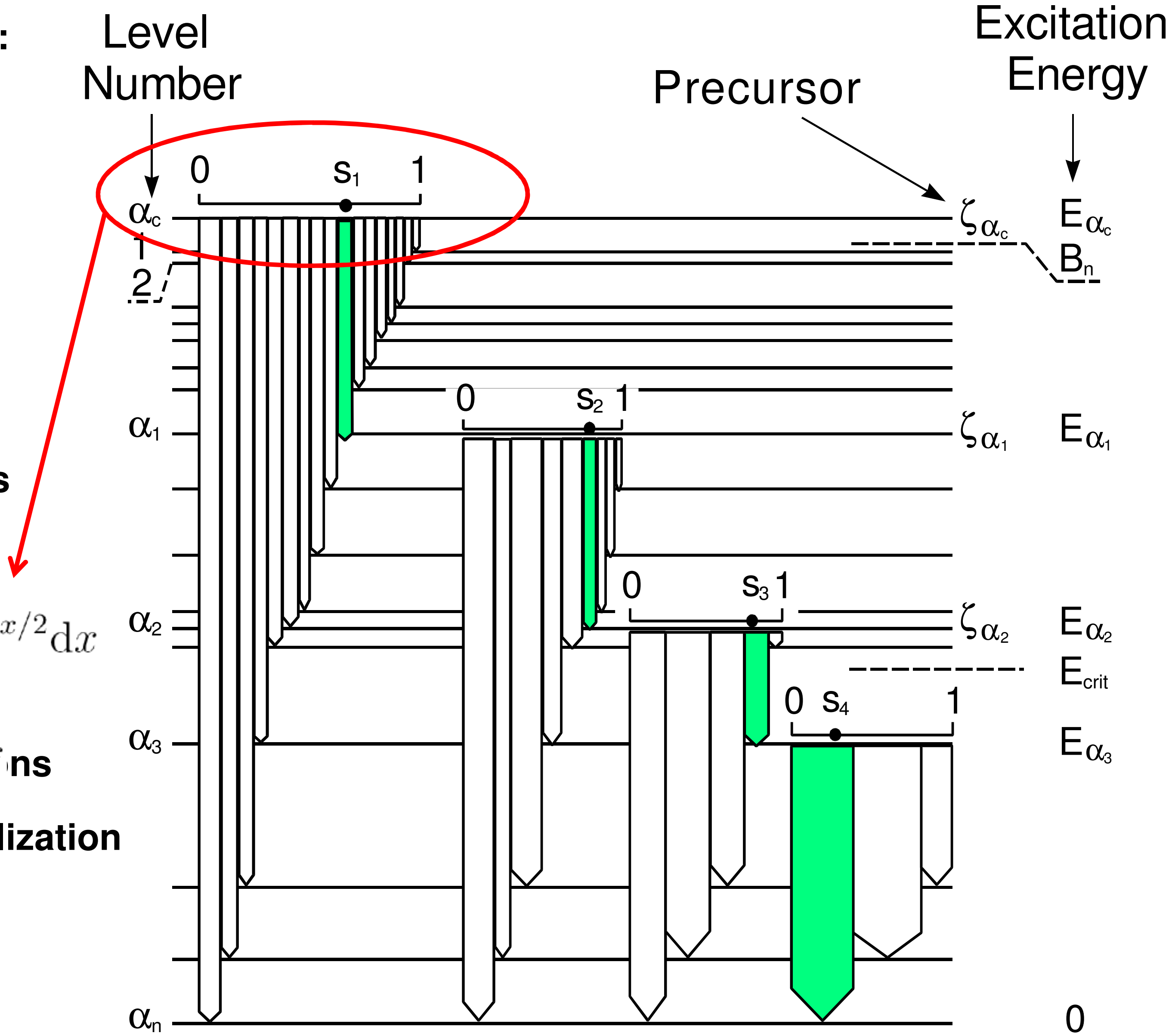
$10^{12}\ \Gamma_{i\gamma f}$

System of precursors

$$P(x)dx = \frac{1}{\sqrt{2\pi x}} e^{-x/2} \mathrm{d}x$$

50 $x = \Gamma_{i\gamma f}/\overline{\Gamma}_{i\gamma f}$ **ns**

10^5 dacays in one realization



Simulations of gamma decay – LD (1)

1. Below a **critical energy E_{crit}** the energies *E*, spins *J*, parities π and the decay properties of all levels are taken from known data

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$$\rho(E, J, \pi)$$

Level density

3. **Partial radiation widths $\Gamma_{i\gamma f}$** for transitions between initial (i) and final (f) levels are generated according to the formula:

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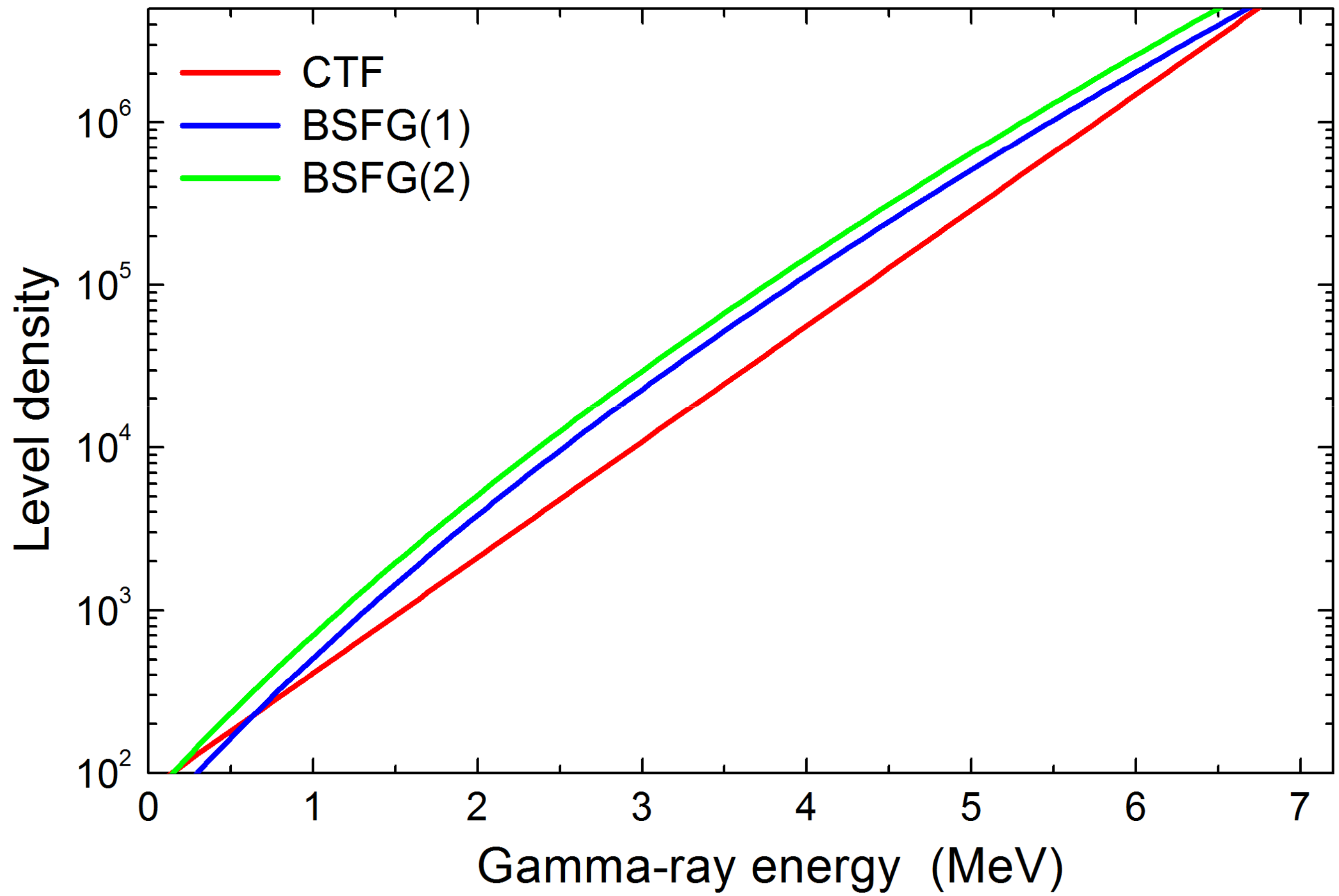
4. Partial radiation widths $\Gamma_{i\gamma f}$ for different initial and/or final levels are statistically independent.

Simulations of gamma decay – LD (2)

Tested models of LD (total)



(1) T. von Egidy, H.H. Schmidt and A.N. Behkami, Nucl. Phys., **A481** (1988) 189
(2) T. von Egidy and D. Bucurescu, Phys. Rev. **C72**, (2005) 044311

Simulations of gamma decay – PSFs (1)

1. Below a **critical energy E_{crit}** the energies E, spins J, parities π and the decay properties of all levels are taken from known data

2. Above the critical energy E_{crit} the energies E, spins J and parities π of levels are obtained by random discretization of an *a priory* known level density

$$\rho(E, J, \pi)$$

Level density

3. **Partial radiation widths $\Gamma_{i\gamma f}$** for transitions between initial (i) and final (f) levels are generated according to the formula:

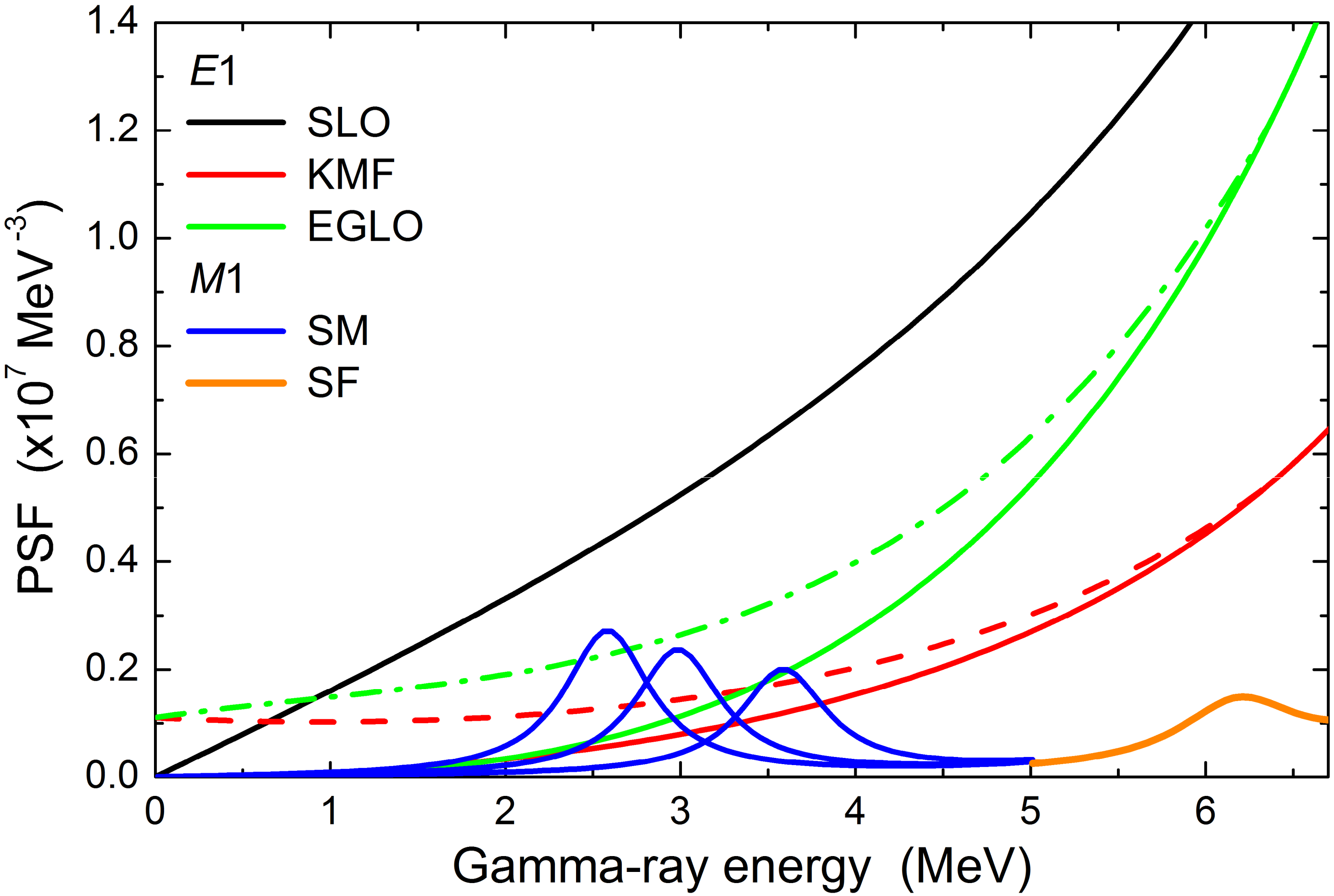
PSFs

P-T fluctuations

$$\Gamma_{i\gamma f} = \sum_{XJ} y^2_{ifXJ} (E_i - E_f)^{2J+1} \frac{f^{(XJ)}(E_i - E_f)}{\rho(E_i, J_i, \pi_i)}$$

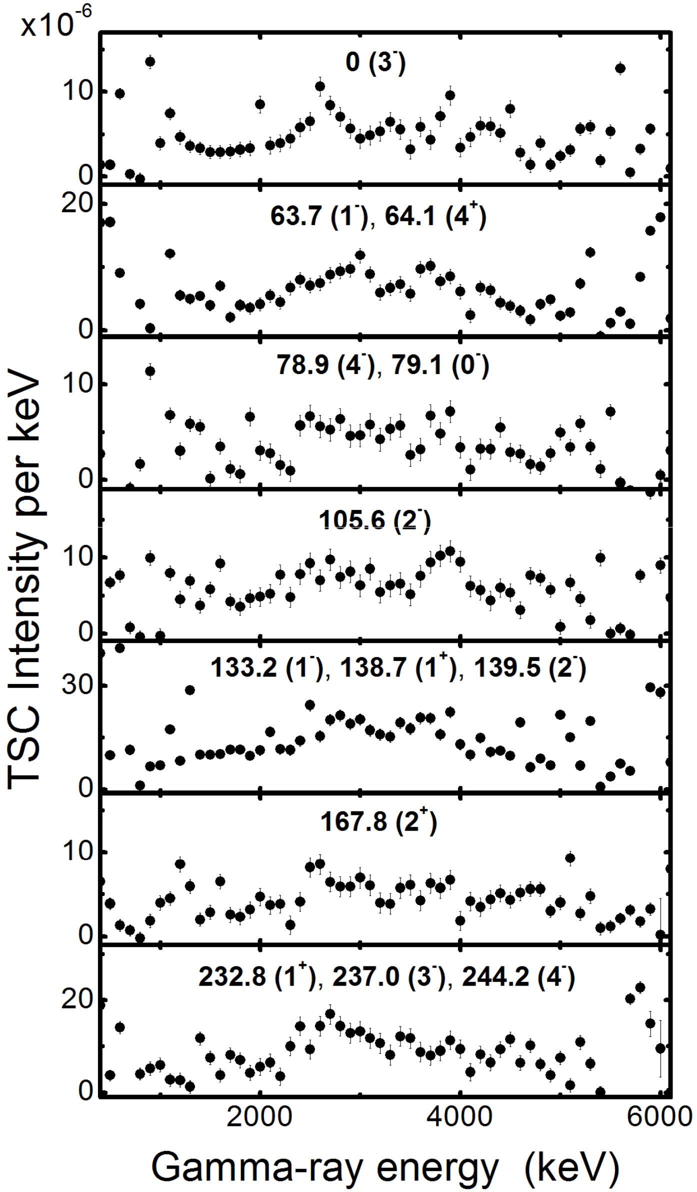
4. Partial radiation widths $\Gamma_{i\gamma f}$ for different initial and/or final levels are statistically independent.

Simulations of gamma decay – PSFs (2)



The energy of the SM is 2.6, 3.0 and 3.6 MeV, damping width is 0.6 MeV and the total $\Sigma B(M1)\uparrow \approx 5\ \mu_N^2$.

Results (1)

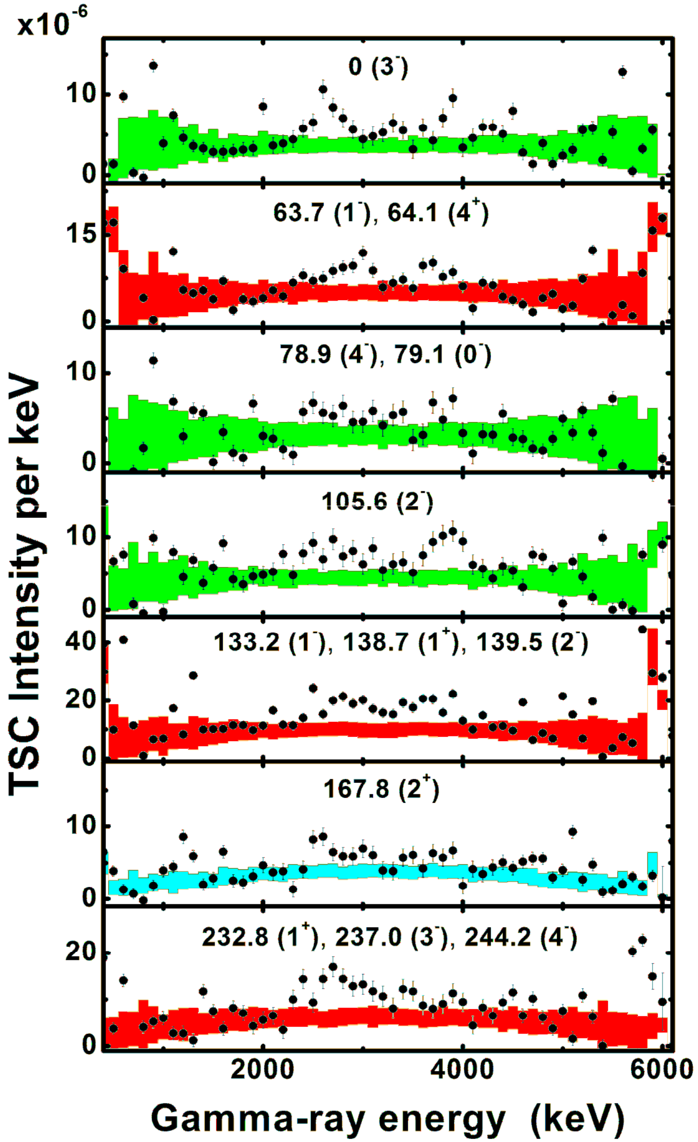


Experimental binned TSC spectra.

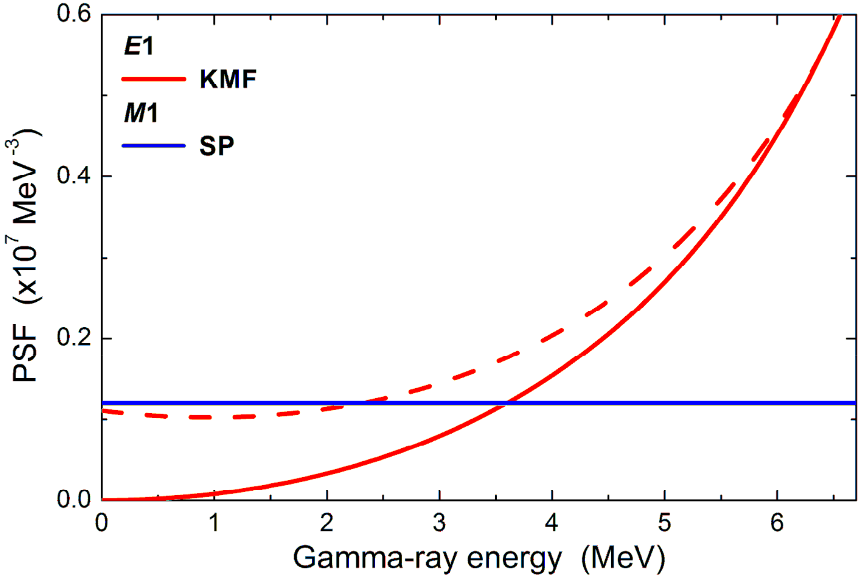
The bin width is 100 keV.

Individual experimental TSC spectra display distinct **resonance-like structures at 2.6 MeV and 3.6 MeV**.

Results (2)

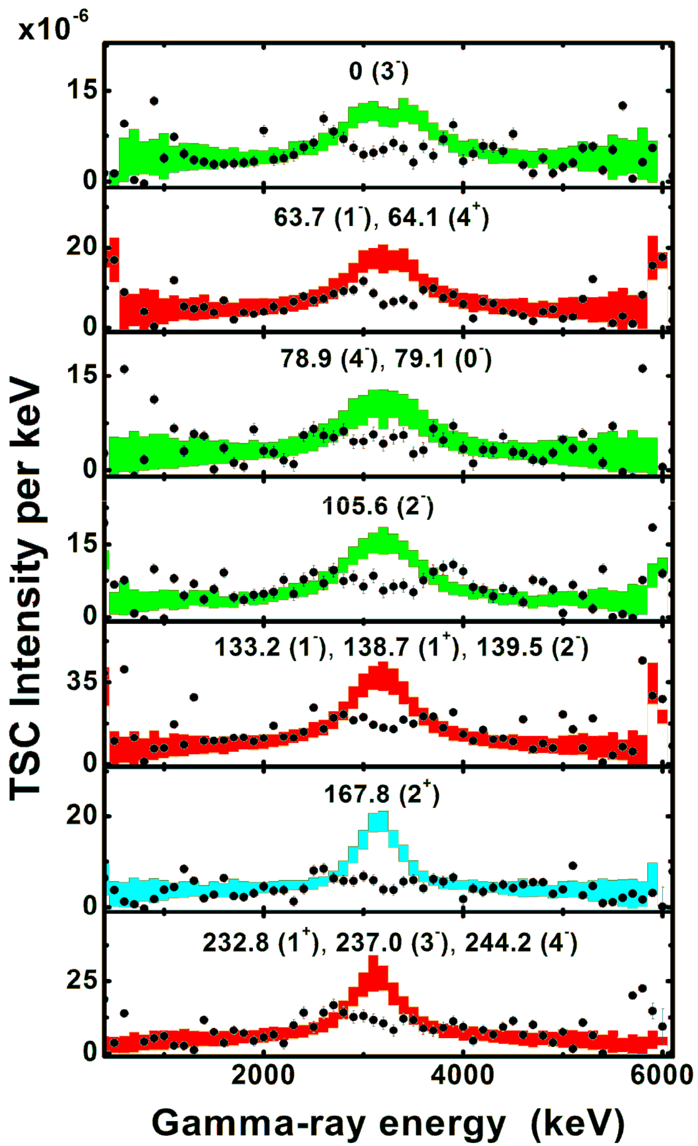


No resonance structure in ***M*1**.

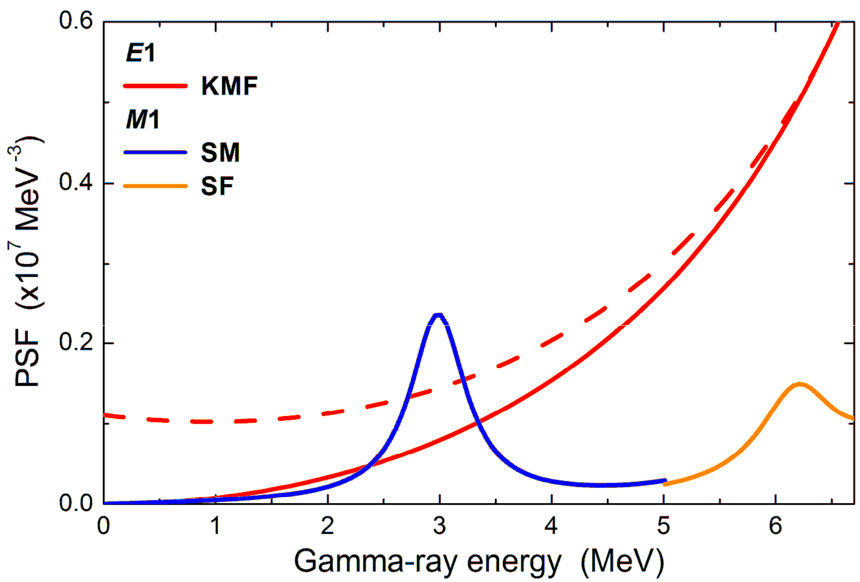


Evident disagreement !

Results (3)

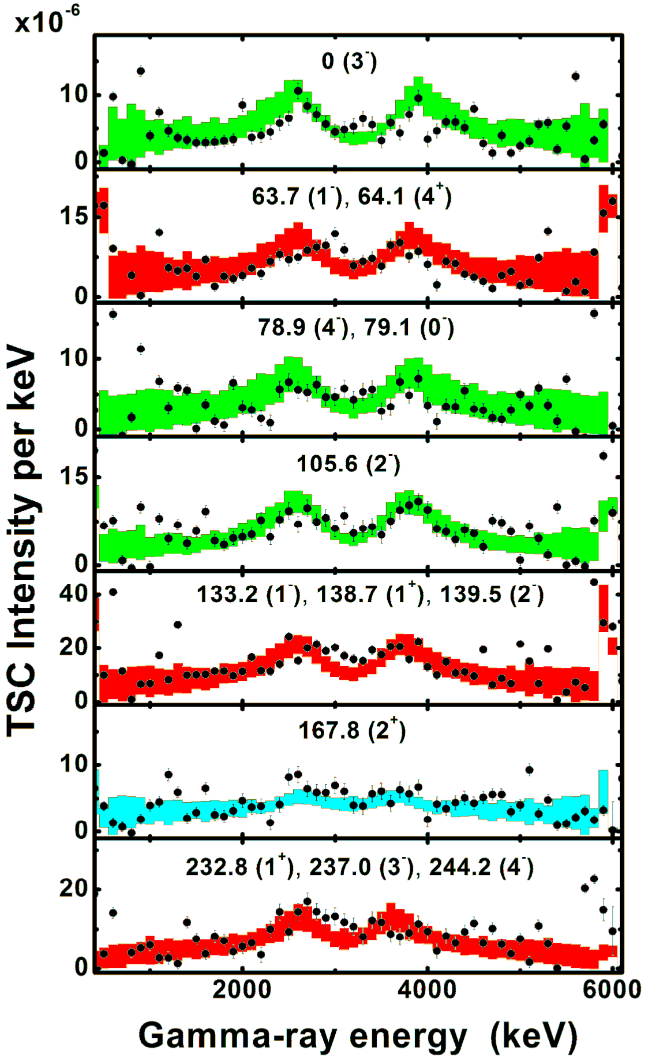


SM used for ***M*1** PSF on the energy
$\boldsymbol{E_{SM}}$ **= 3.0 MeV**, Γ_{SM} = 0.6 MeV and σ_{SM} = 1.0 mb.

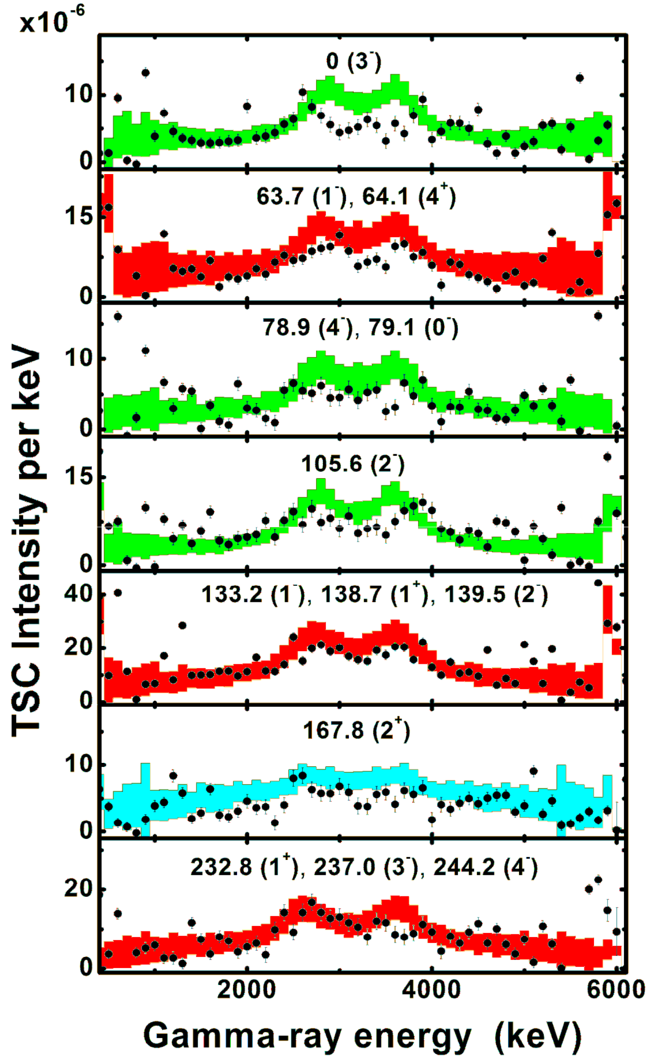


The double-humped structure still not reproduced !

Results (4)

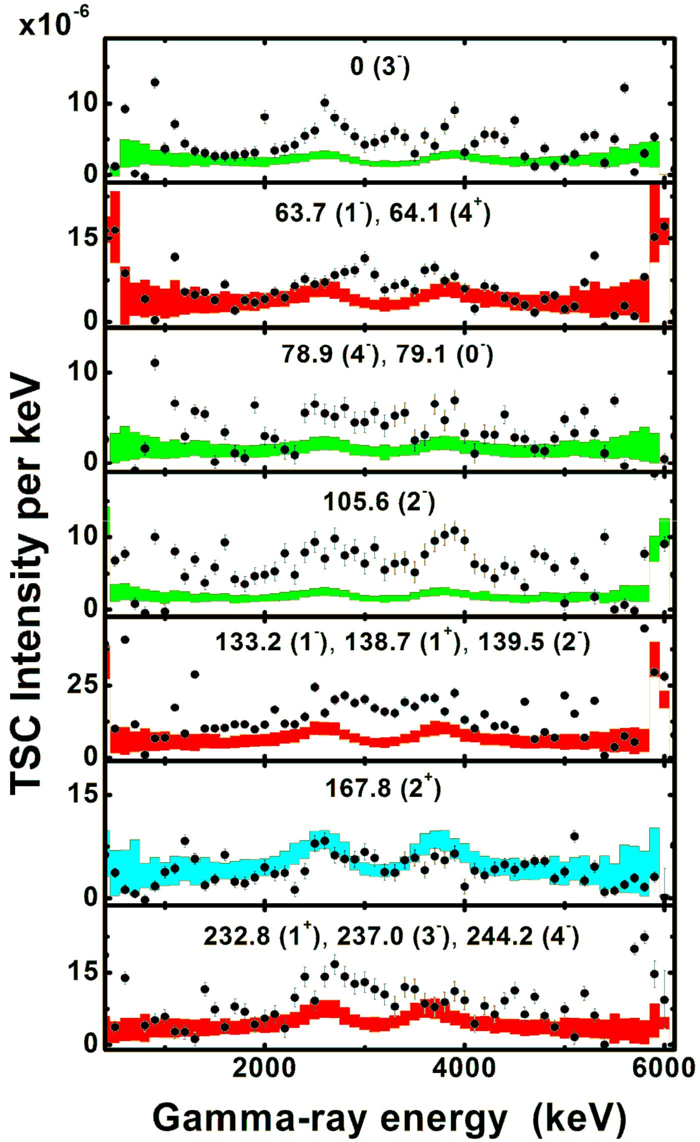


SM in $M1$ PSF: $\boldsymbol{E_{SM}}$ **= 2.6 MeV**, Γ_{SM} = 0.6 MeV and σ_{SM} = 1.0 MeV



SM in $M1$ PSF: $\boldsymbol{E_{SM}}$ **= 3.6 MeV**, Γ_{SM} = 0.6 MeV and σ_{SM} = 1.0 MeV

Results (5)



Lorentz-shape resonance structure with E_R = 2.6 MeV, Γ_R = 0.6 MeV and σ_{SM} = 1.0 mb is postulated in *E*1 PSF. For *M*1 it is supposed non-resonance shape.

The observed structures cannot be reproduced by the presence of local maximum of *E*1 PSF neither at 2.6 nor at 3.6 MeV !

Results (6)

Reaction	(γ, γ')	$(^3He, x\gamma)$	$(^3He, x\gamma)$	$(n, \gamma\gamma)$	$(n, \gamma\gamma)$
Nuclei	e-e[1]	$^{160,161,162}Dy$[2]	$^{163,164}Dy$[3]	^{163}Dy[4]	^{160}Tb
E_{SM} (MeV)	~3.0	2.6 – 2.8	~2.8	~3.0	2.6 – 2.8 (3.6 – 3.8)
Γ_{SM} (MeV)	-----	1.2 – 1.6	0.8 - 0.9	0.6 (0.5 – 0.7)	0.4 – 0.9
σ_{SM} (mb)	-----	0.3 – 0.4	0.5 – 0.7	0.9 (0.8 – 1.0)	0.4 – 0.9
$\Sigma B(M1)$ (μ_N^2)	~3	~7	5 - 8	~6	~6 (3 – 9)

[1] Kneissl, Pitz and Zilges, Prog. Part. Nucl. Phys. 37 (1996) 349

[2] Guttormsen et al. Phys. Rev. C 68, 064306 (2003)

[3] Nyhus et al., Phys. Rev. C 81, 024325 (2010)

[4] Krticka, et al., Phys. Rev. Lett. 92, 172501 (2004)

Conclusions

- Double-humped structure in experimental TSC spectra clearly indicates that the *M*1 SM plays an important role in gamma deexcitation of ^{160}Tb.

- The *E*1 origin of the resonance-like structures in the TSC spectra is unambiguously excluded.

- The energy of the SM is very likely $E_{SM} = 2.6 \pm 0.1$ MeV but the value $E_{SM} = 3.6 \pm 0.1$ MeV cannot be completely excluded. The damping width of the SM has to be $\Gamma_{SM} = 0.5 – 0.9$ MeV. The best agreement is obtained with the strength of the mode $\Sigma B(M1)\uparrow = 6 \pm 1\ \mu_N^2$.

Thank you for your attention !