Systematics of Scissors Mode in Gd Isotopes from experiment with DANCE Detector

Jiří Kroll

for DANCE collaboration

Faculty of Mathematics and Physics, Charles University, Prague

Outline

- Motivation
- SM observed in (n,γ) reaction
- DANCE experiment at LANSCE
- DICEBOX simulations of gamma decay
- Main results
- Conclusions

Scissors mode (SM) in *M*1 PSF

SM proposed in deformed nuclei by theorists in late 70’s:

N. Lo Iudice and F. Palumbo, Phys. Rev. Lett. **53,** 1532 (1978).
R. R. Hilton, in *Proceedings of the International Conference on Nuclear Structure*, Dubna, 1976.

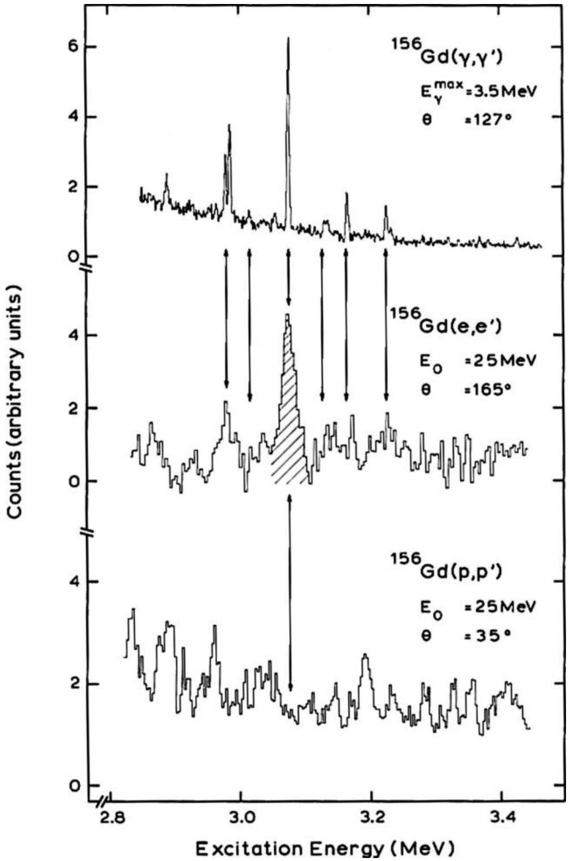
Scissors mode (SM) in $M1$ PSF

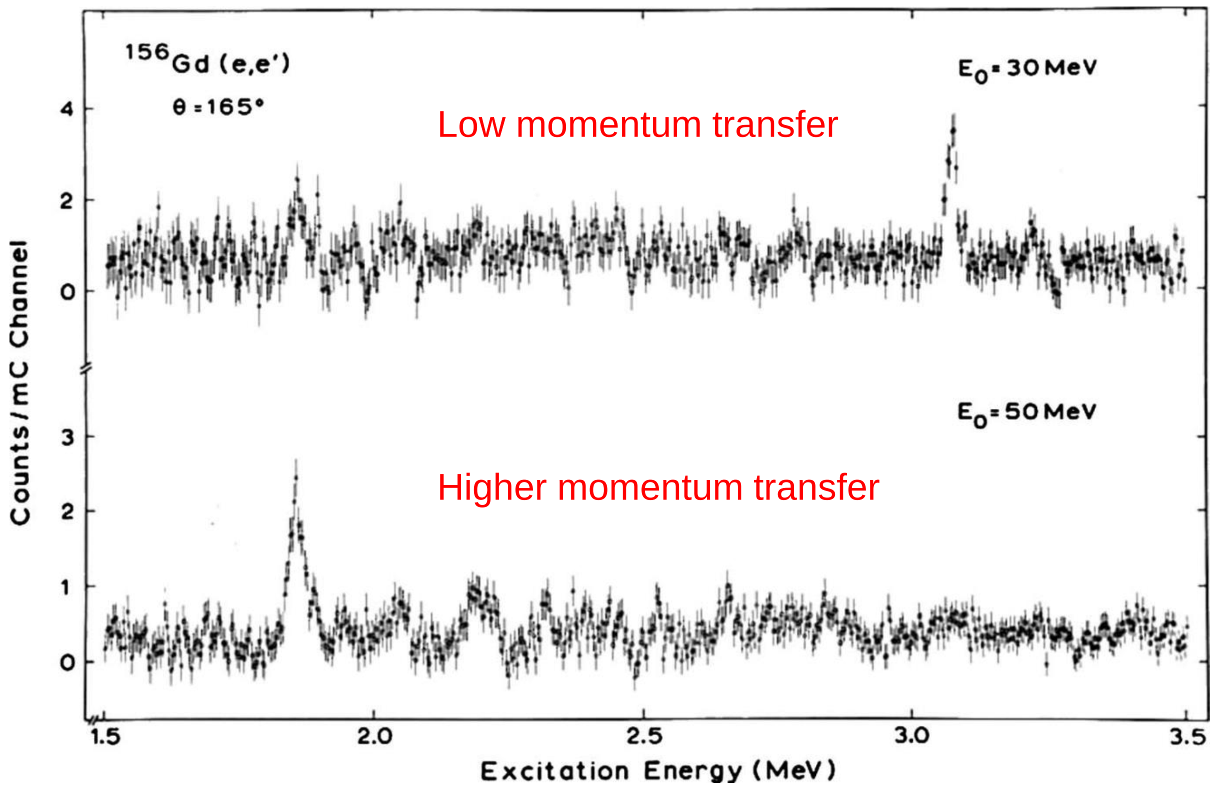
SM proposed in deformed nuclei by theorists in late 70's:

N. Lo Iudice and F. Palumbo, Phys. Rev. Lett. **53,** 1532 (1978).
R. R. Hilton, in *Proceedings of the International Conference on Nuclear Structure*, Dubna, 1976.

SM experimentally confirmed in high-resolution (e,e') experiments on rare-earth nuclei

D. Bohle *et al*., Phys. Lett. B **137,** 27 (1984).





Scissors mode (SM) in *M*1 PSF

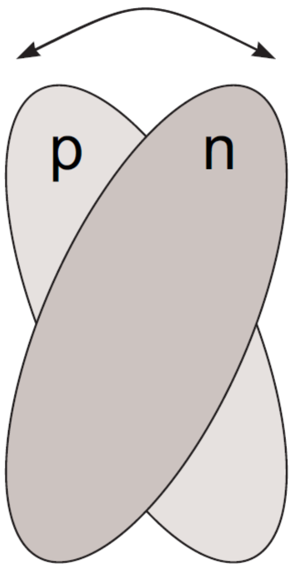
SM proposed in deformed nuclei by theorists in late 70's:

N. Lo Iudice and F. Palumbo, Phys. Rev. Lett. **53,** 1532 (1978).
R. R. Hilton, in *Proceedings of the International Conference on Nuclear Structure*, Dubna, 1976.

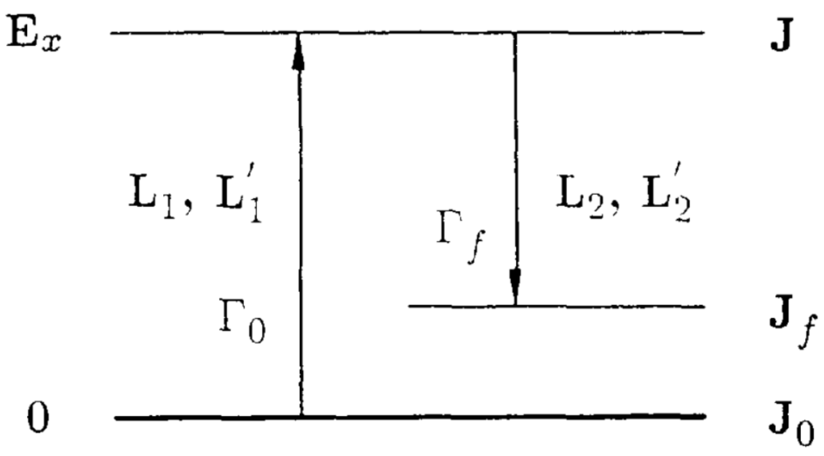
SM experimentally confirmed in high-resolution (e,e') experiments on rare-earth nuclei

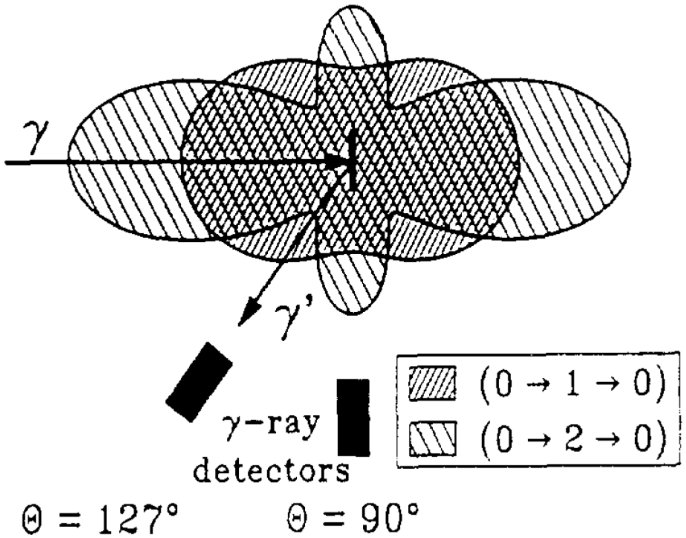
D. Bohle *et al*., Phys. Lett. B **137,** 27 (1984).

SM for the GS transitions in even-even nuclei studied in detail in the 80's and 90's mainly using the (γ,γ') experiments



SM in Nuclear Resonance Fluorescence technique





$$I_s = \frac{2J+1}{2J_0+1}\left(\frac{\pi\hbar c}{E_\gamma}\right)^2 \frac{\Gamma_0\Gamma_f}{\Gamma}\frac{W(\theta)}{4\pi}$$

$$\Gamma_0 = 8\pi \sum_{XL=1}^{\infty} \frac{(L+1)}{L[(2L+1)!!]^2}\left(\frac{E_\gamma}{\hbar c}\right)^{2L+1}\frac{2J_0+1}{2J+1}B(XL,E_\gamma)\uparrow$$

$$B(E1)\uparrow = 2.866\times 10^{-3}\frac{\Gamma_0}{E_\gamma^3}[\mathrm{e^2fm^2}]$$

$$B(M1)\uparrow = 0.2598\frac{\Gamma_0}{E_\gamma^3}[\mu_N^2]$$

$$W(\theta)_{\mathrm{Dipole}} = \frac{3}{4}\left(1+\cos^2(\theta)\right)$$

$$W(\theta)_{\mathrm{Quadrupole}} = \frac{5}{4}\left(1-3\cos^2(\theta)+4\cos^4(\theta)\right)$$

$W(90^\circ)/W(127^\circ) = 0.734$ dipole

$W(90^\circ)/W(127^\circ) = 2.28$ quadrupole

SM in Nuclear Resonance Fluorescence technique

SM proposed in deformed nuclei by theorists in late 70's:

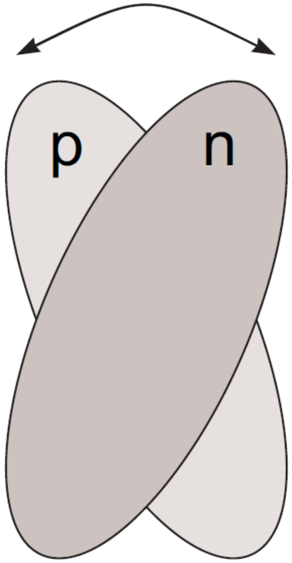
N. Lo Iudice and F. Palumbo, Phys. Rev. Lett. **53,** 1532 (1978).
R. R. Hilton, in *Proceedings of the International Conference on Nuclear Structure*, Dubna, 1976.

SM experimentally confirmed in high-resolution (e,e') experiments on rare-earth nuclei

D. Bohle *et al*., Phys. Lett. B **137,** 27 (1984).

SM for the GS transitions in even-even nuclei studied in detail in the 80's and 90's mainly using the (γ,γ') experiments

In well-deformed even-even nuclei
$E_{SM} \approx 3$ MeV and $\Sigma B(M1) \approx 3 - 3.5\ \mu_N^2$.



SM in Nuclear Resonance Fluorescence technique

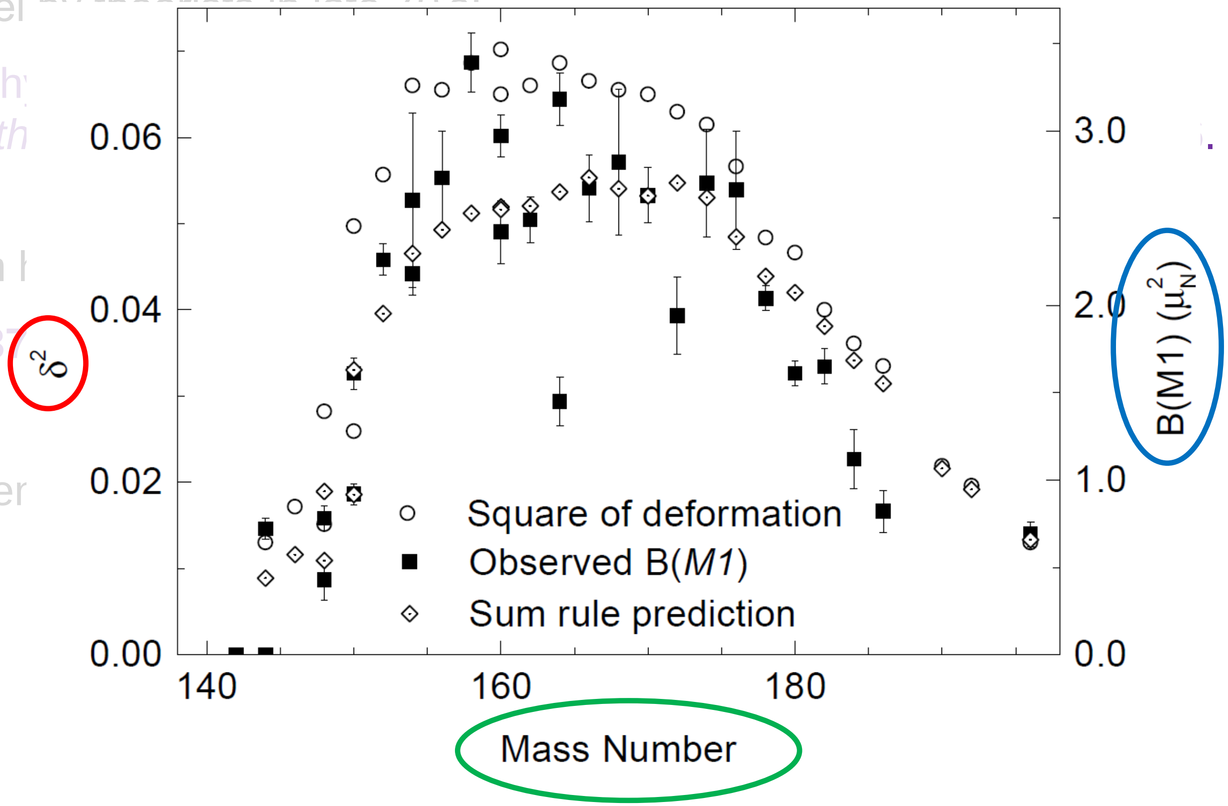
SM proposed in deformed nuclei

N. Lo Iudice and F. Palumbo, Ph
R. R. Hilton, in *Proceedings of th*

SM experimentally confirmed in

D. Bohle *et al*., Phys. Lett. B **13**

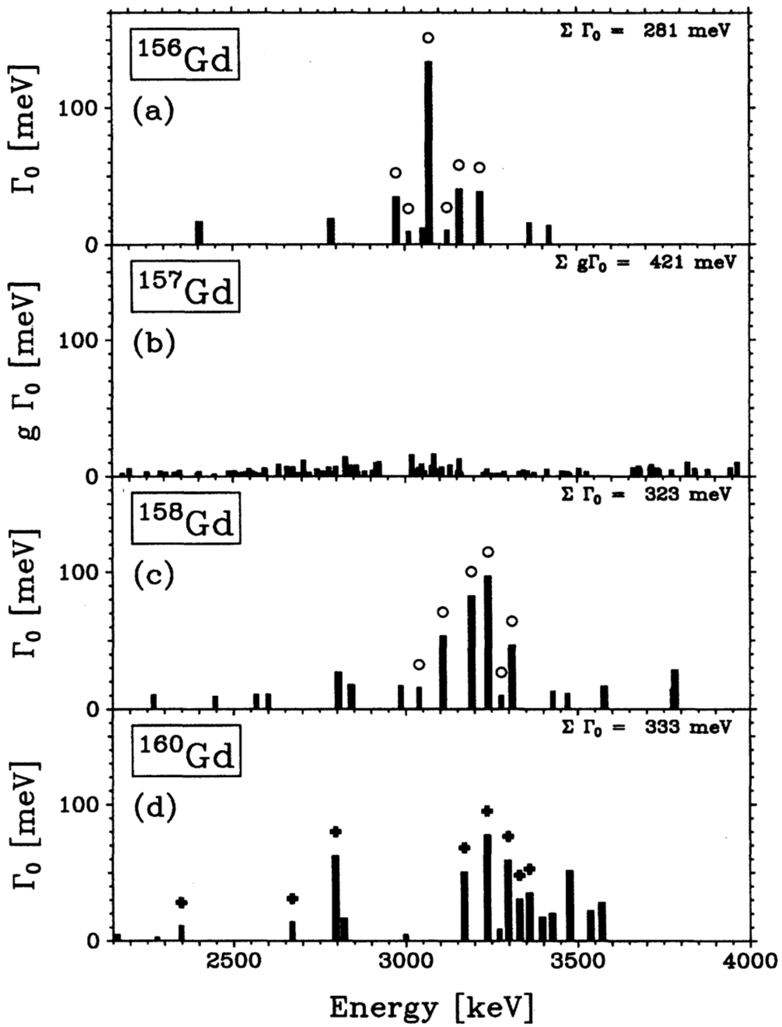
SM for the GS transitions in ever
using the (γ,γ') experiments

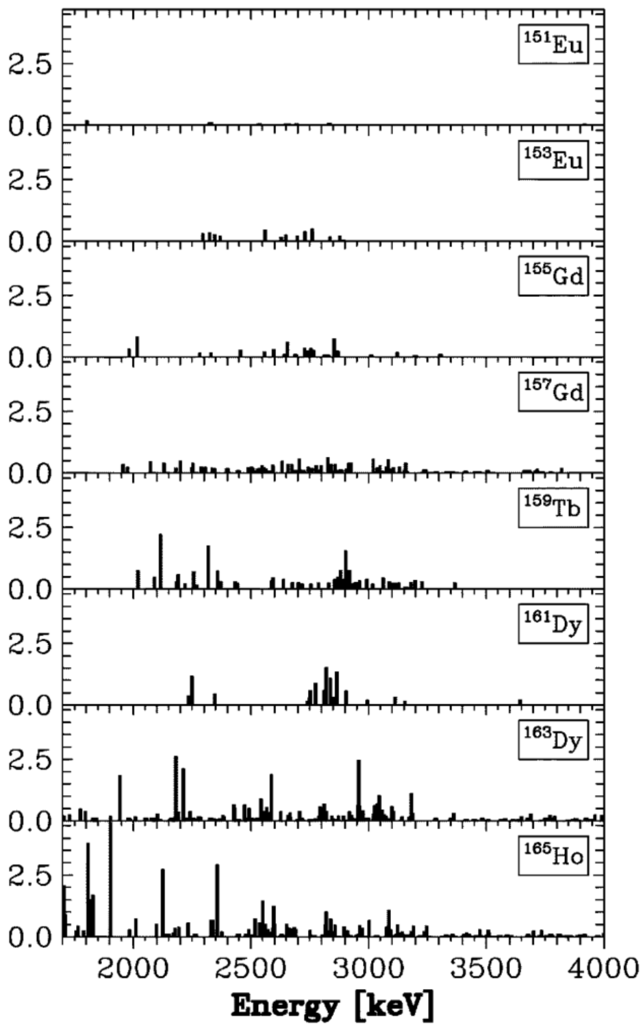


Exploiting data from (γ,γ') – a sum rule was derived
by N. Lo Iudice and A. Richter, Phys. Lett. B **304,** 193 (1993).

$$\sum B(M1)\uparrow \approx 0.0042\frac{4NZ}{A^2}E_{SC}A^{5/3}(g_p-g_n)^2\delta^2\,[\mu_N^2]$$

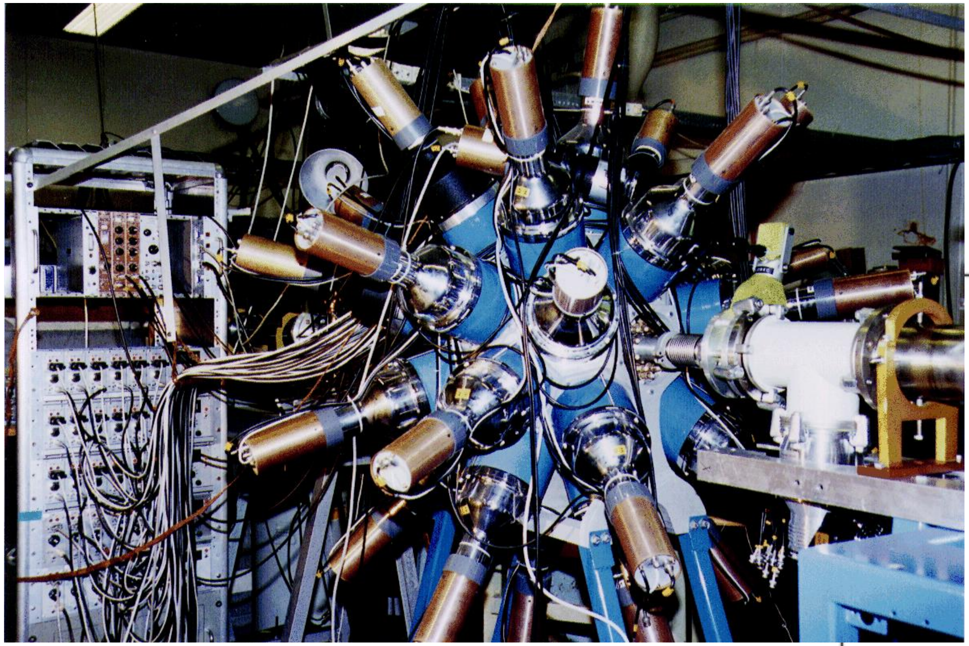
SM in Nuclear Resonance Fluorescence technique



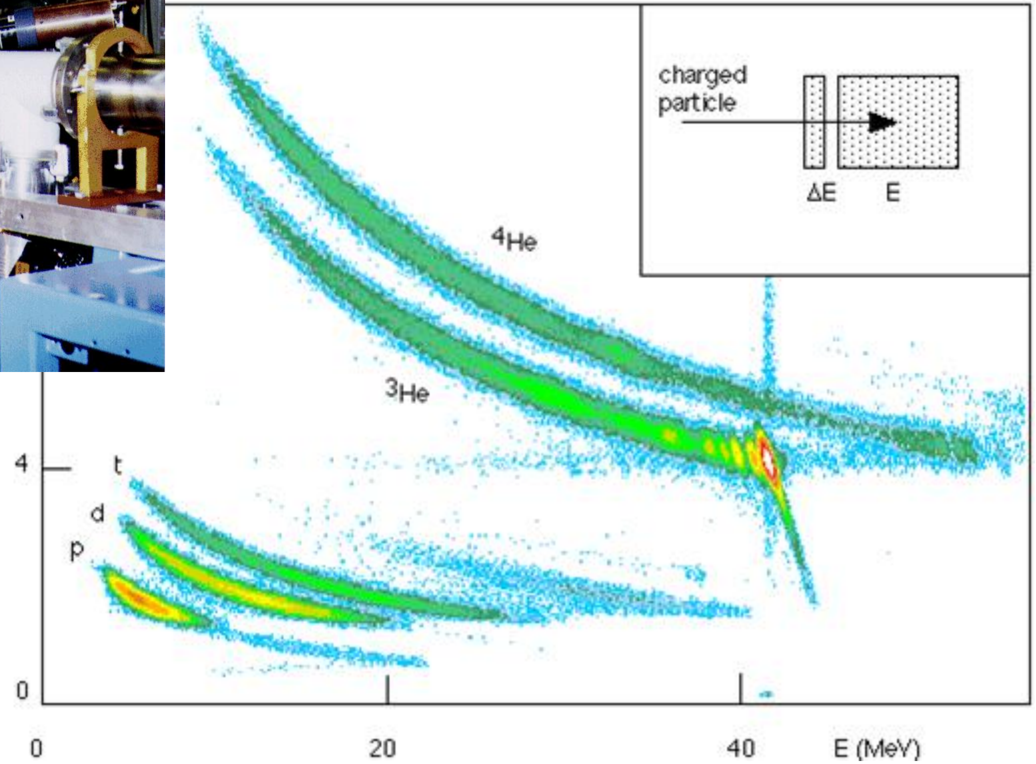


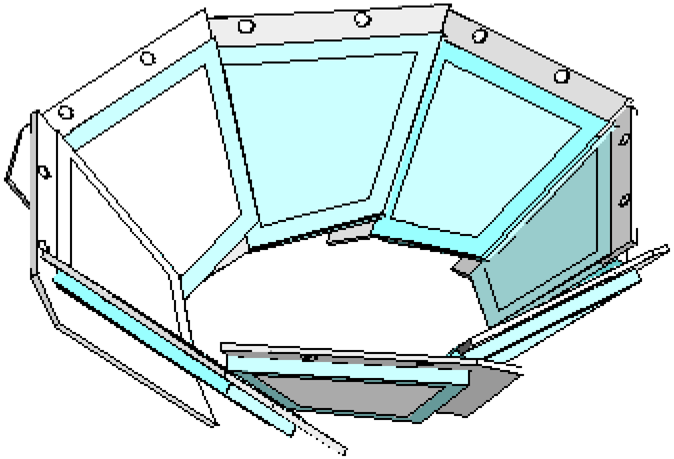
In odd nuclei $\Sigma B(M1,\text{odd}) \approx 1/3\ \Sigma B(M1,\text{e-e})$ from (γ,γ') ← problems with high NLD

SM in Oslo method (^{3}He-induced reactions)



CACTUS 28 NaI(Tl) 5” x 5”

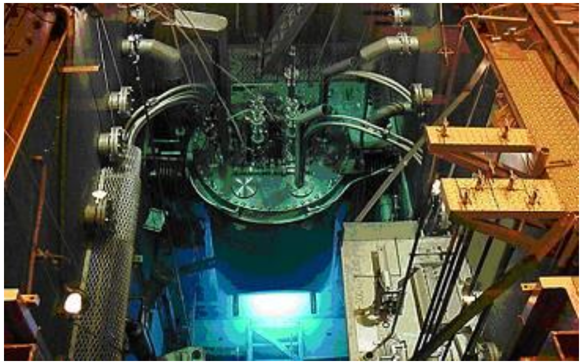


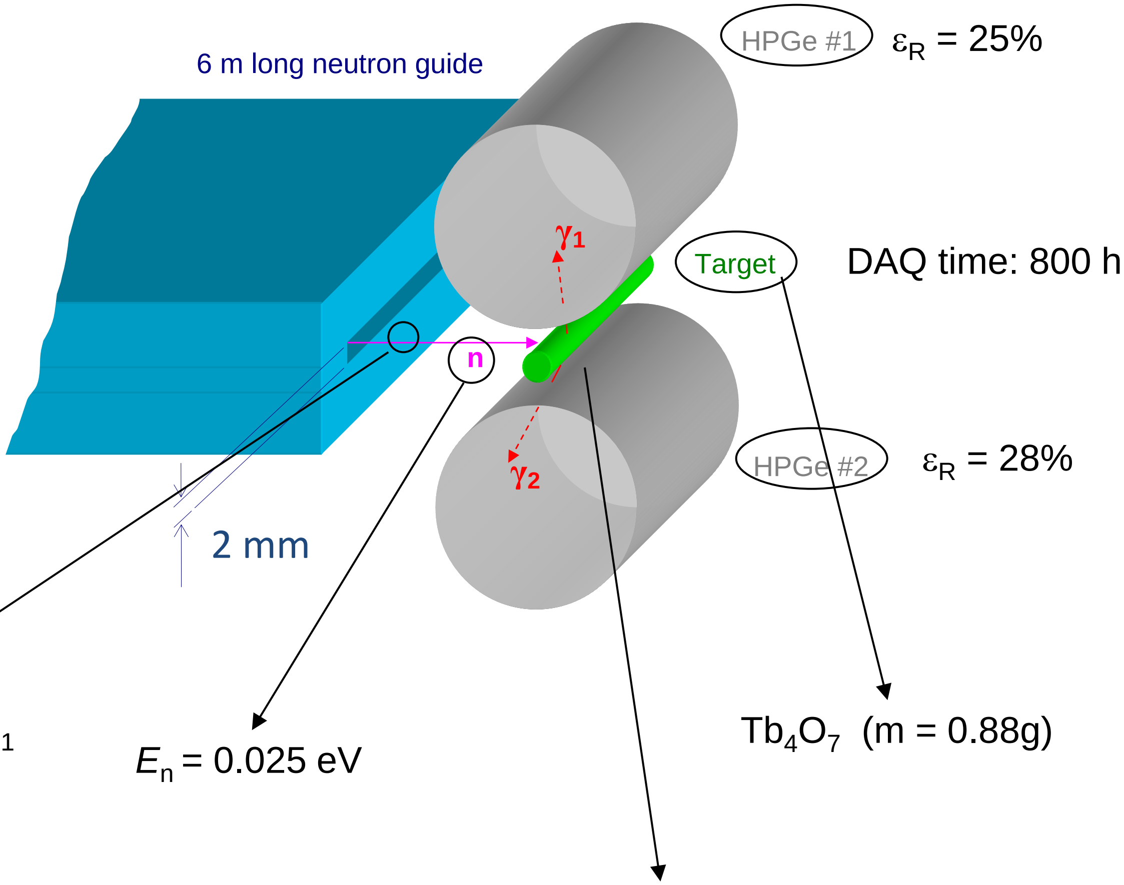


8 Si charged particle telescopes

SM observed in (n,γ) reactions - TSC

LWR-15 reactor

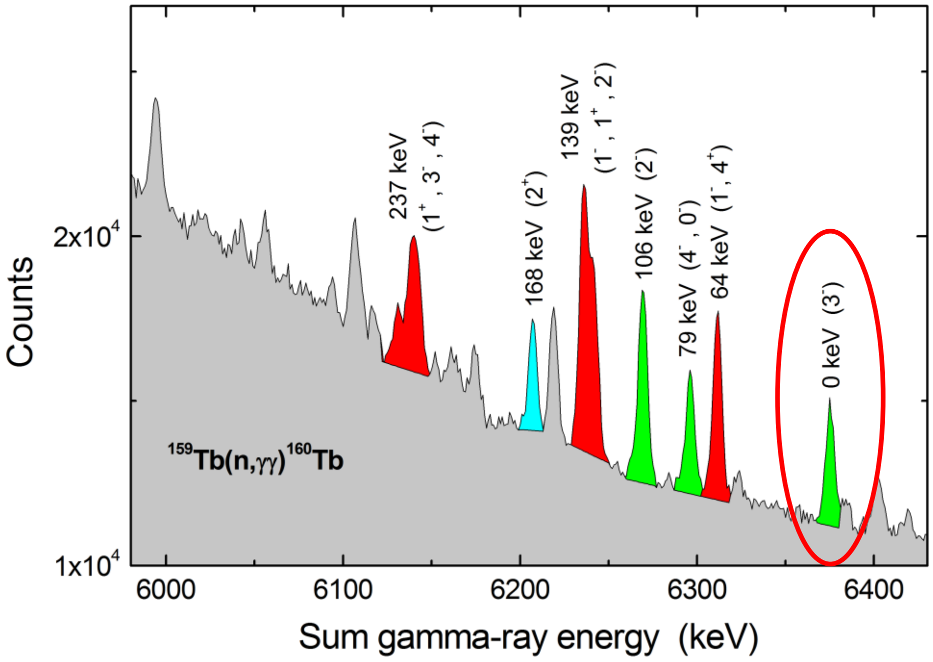


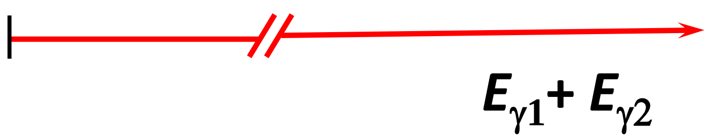


DAQ conditions for the TSCs:

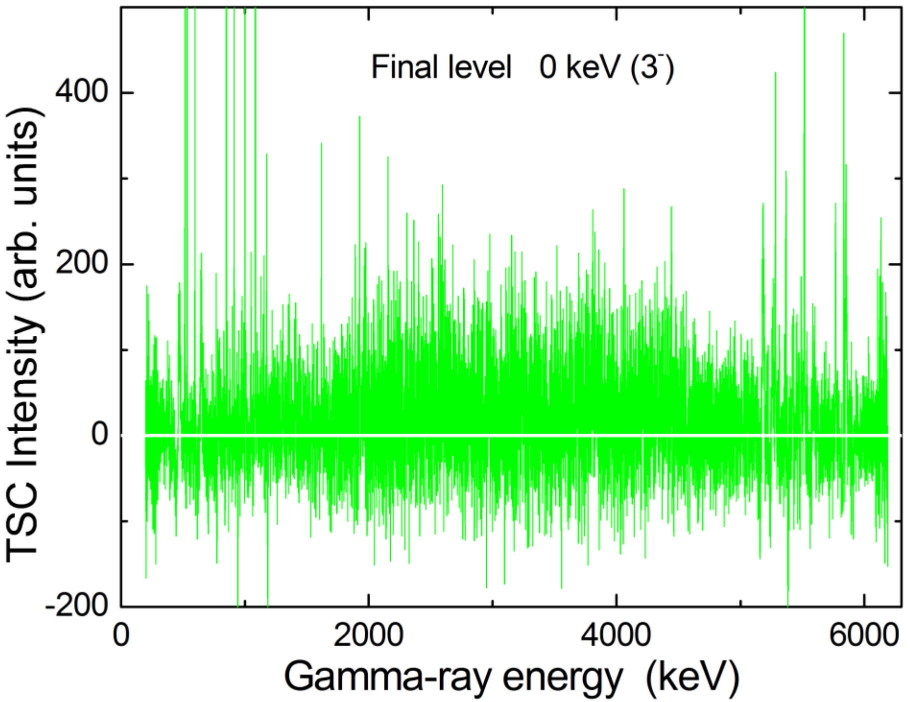
- energies $E_{\gamma 1}$ and $E_{\gamma 2}$
- time difference

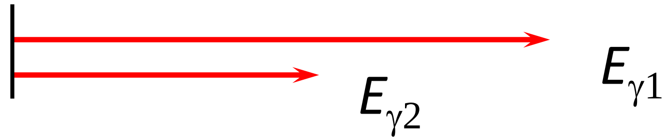
SM observed in (n,γ) reactions – TSC





J. Kroll *et al*., Int. Jour. Mod. Phys. E **20**, No. 2, 526 (2011).

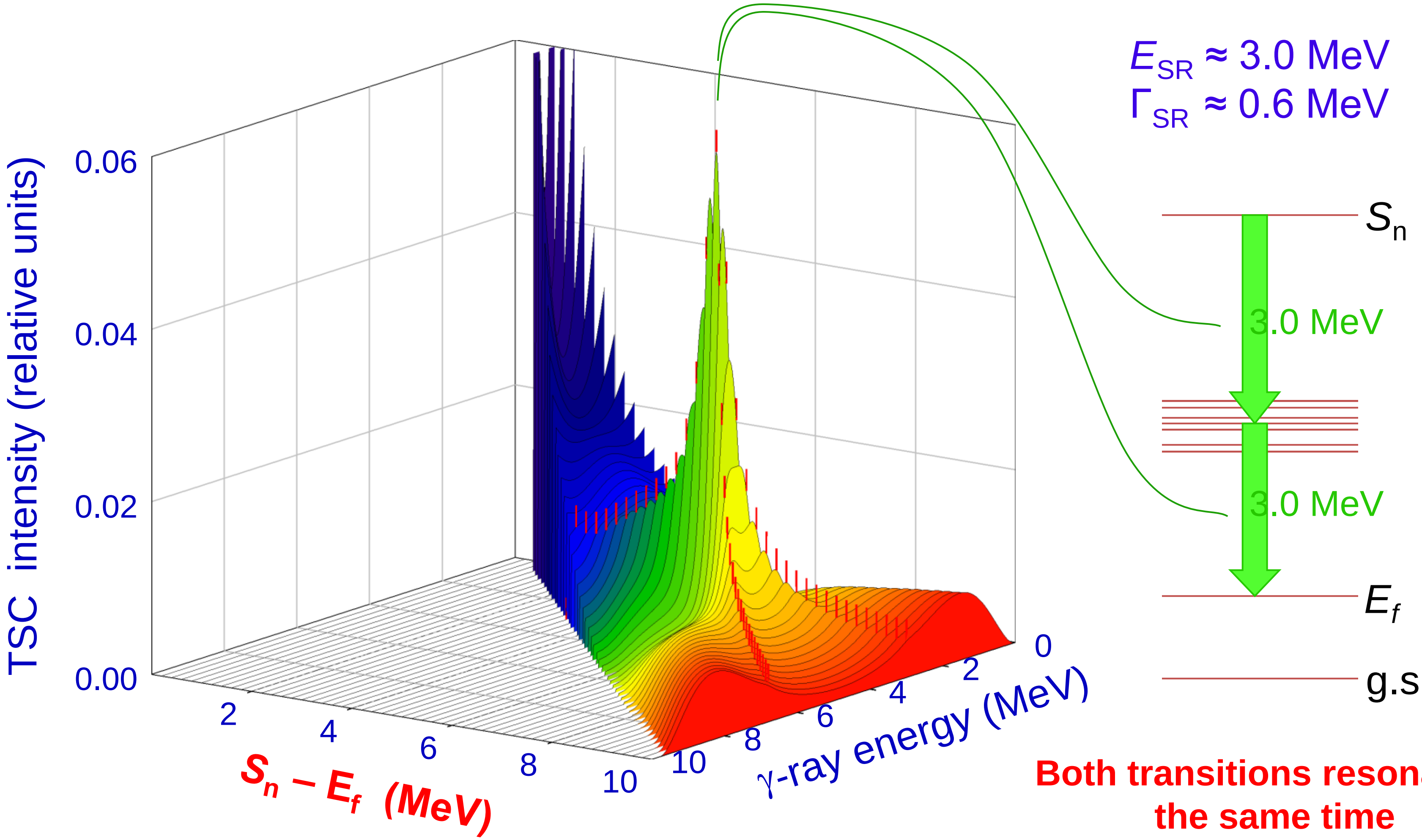




To get TSC spectra for separate final levels, the sum coincidence method was used

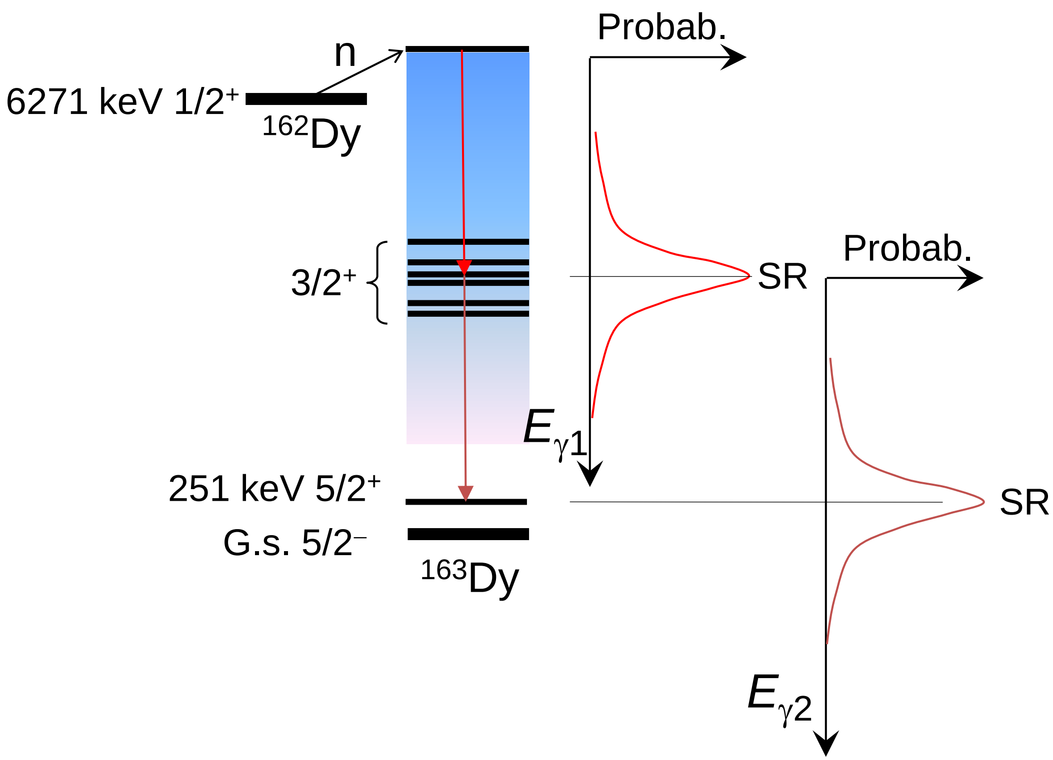
J. Honzátko *et al*., Nucl. Instr. Meth. A **376**, 434 (1996).

SM observed in (n,γ) reactions - TSC

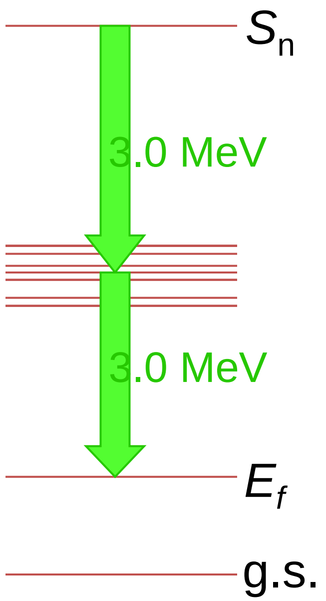


Both transitions resonate at the same time

SM observed in (n,γ) reactions – TSC



$E_{SM} \approx 3.0$ MeV
$\Gamma_{SM} \approx 0.6$ MeV

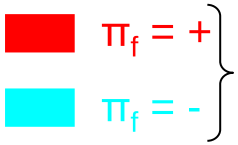


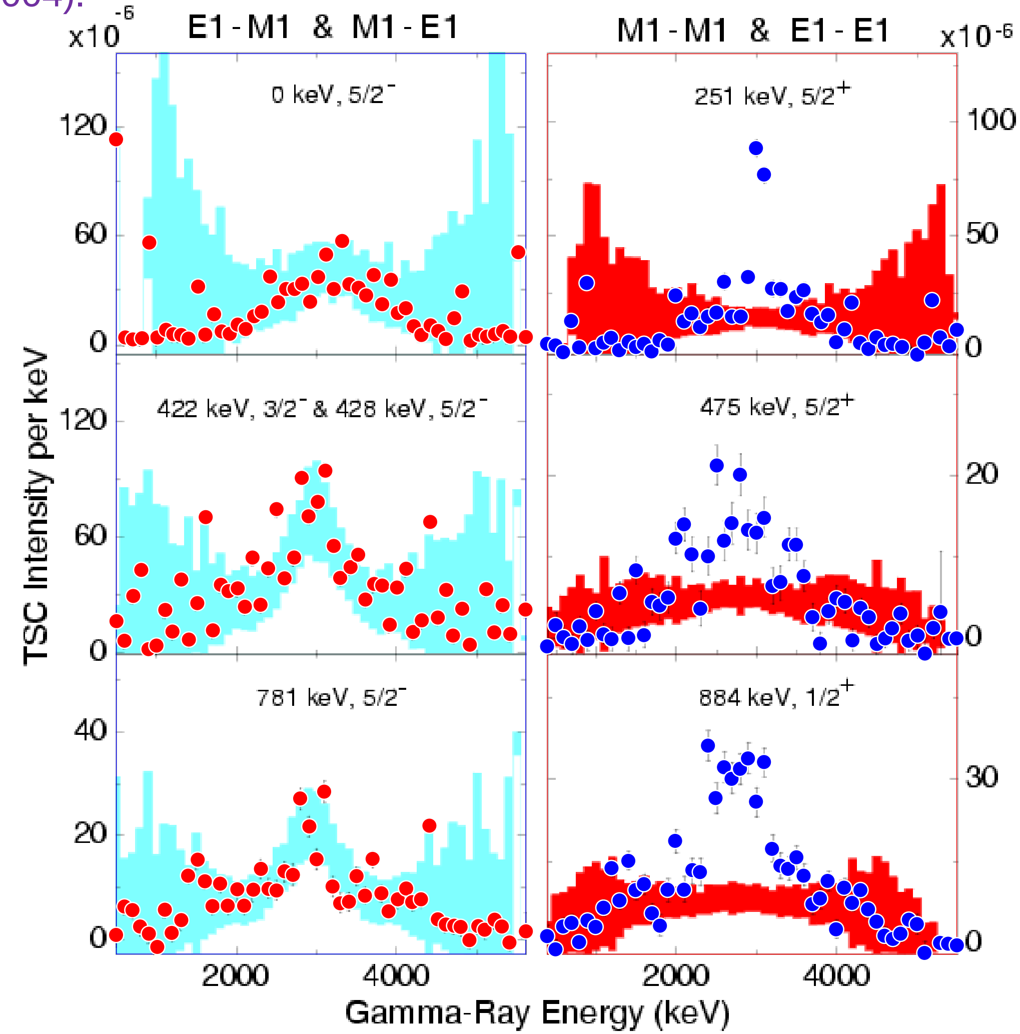
Both transitions resonate at the same time

SM observed in (n,γ) reactions - TSC

SM on the excited states was observed for the first time in TSC experiment with ^{163}Dy

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





Simulation assumption:

SM is built only on the states below the energy of 2.5 MeV

Corridors represent the region of residual Porter-Thomas fluctuations.

SM observed in (n,γ) reactions - TSC

SM on the excited states was observed for the first time in TSC experiment with ^{163}Dy

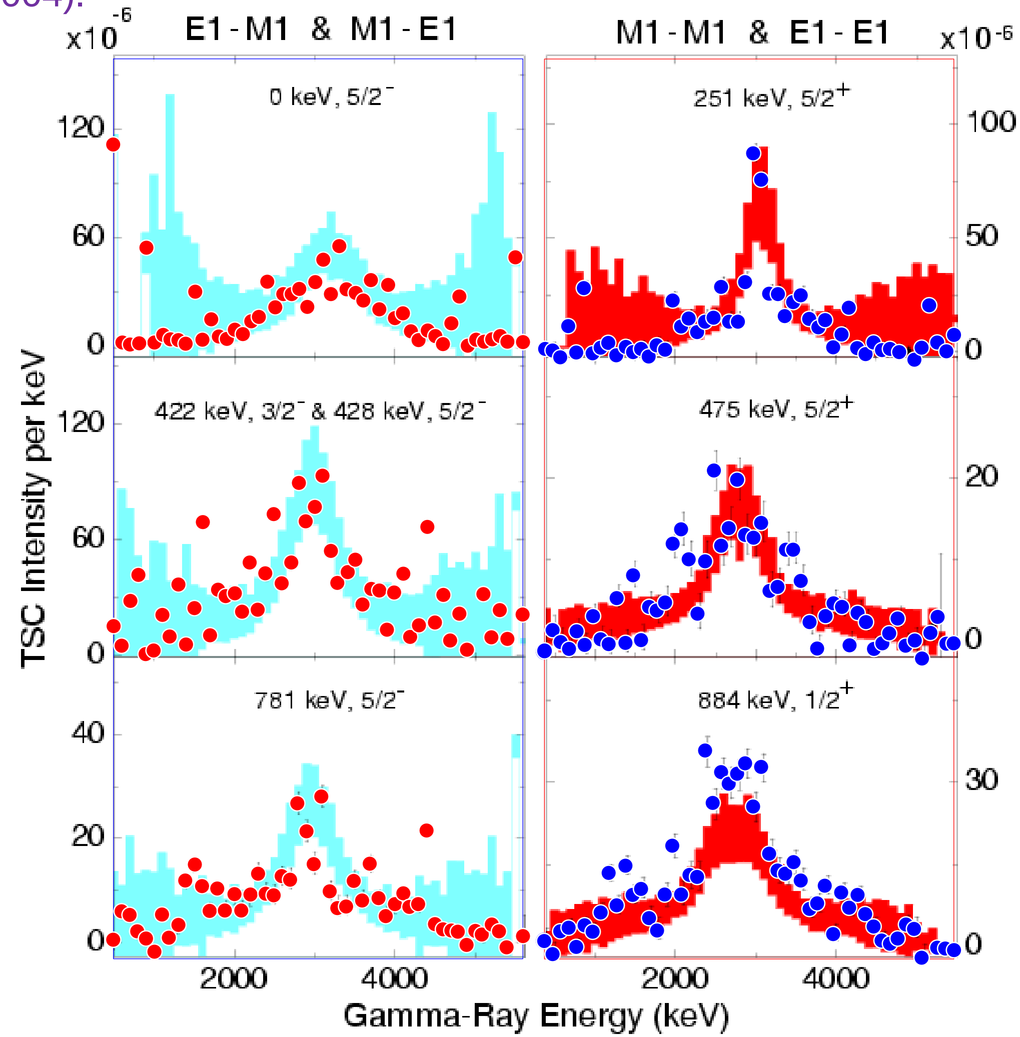
M. Krtička *et al*., Phys. Rev. Lett. **92,** 172501 (2004).

$\pi_f = +$ } DICEBOX Simulations
$\pi_f = -$

$E_{SM} = 3.0$ MeV, $\Gamma_{SM} = 0.6$ MeV and $\Sigma B(M1)\uparrow \approx 6\ \mu_N^2$

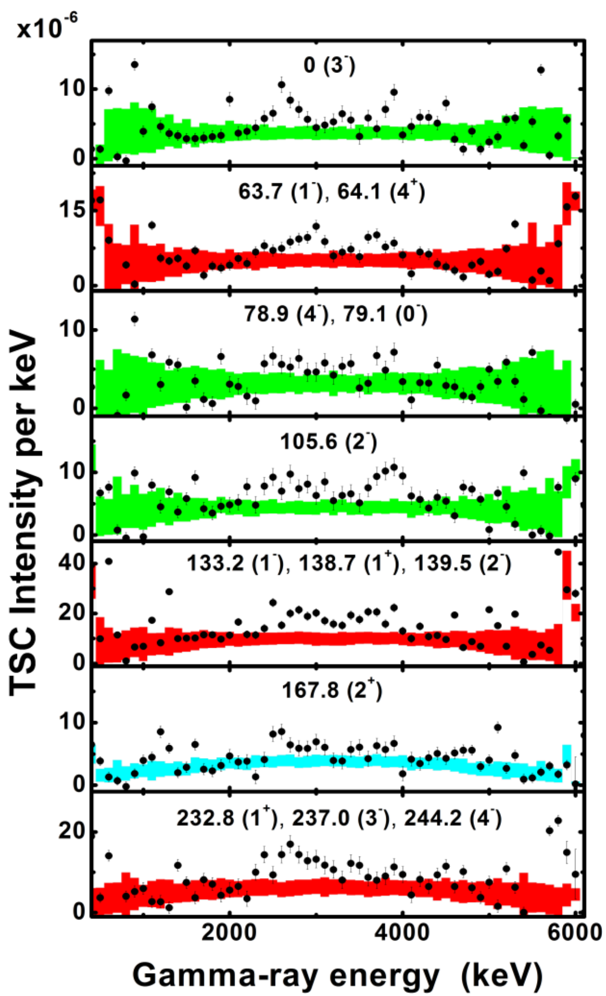
Simulation assumption:

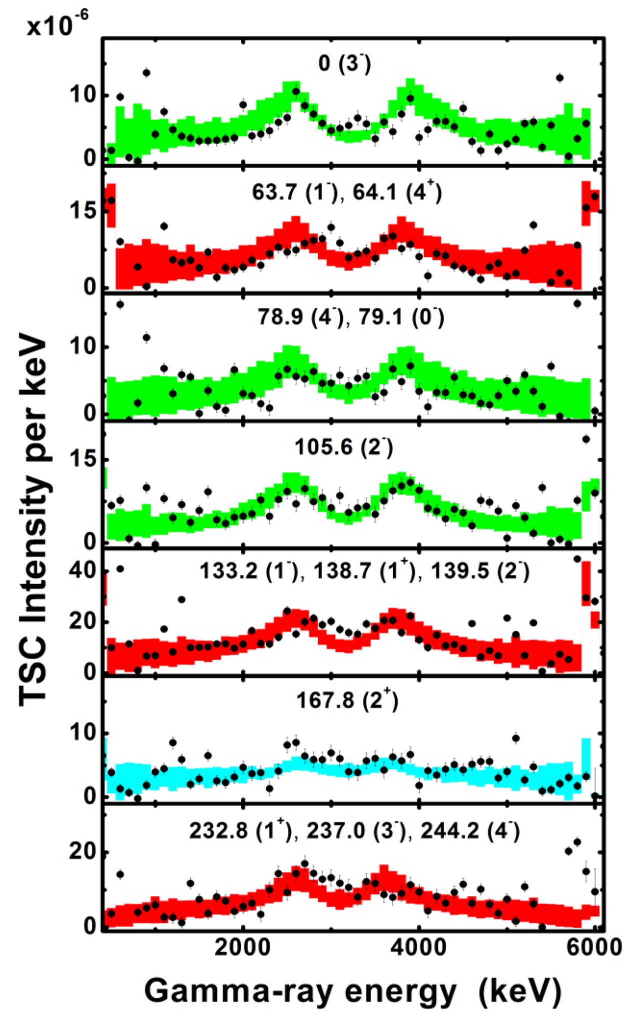
SM is built on all ^{163}Dy levels



Corridors represent the region of residual Porter-Thomas fluctuations.

SM observed in (n,γ) reactions - TSC

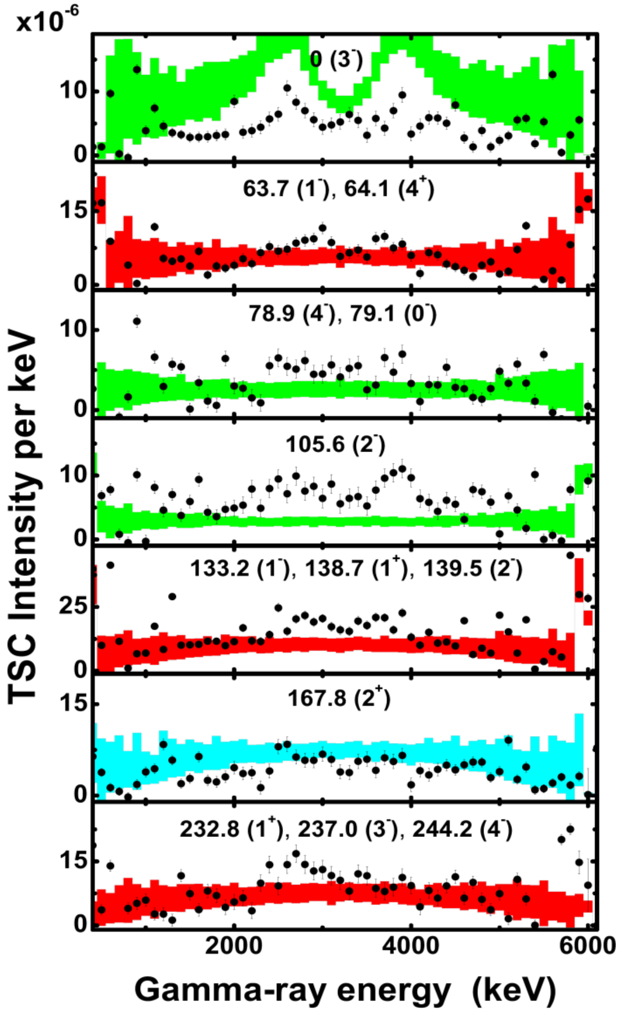


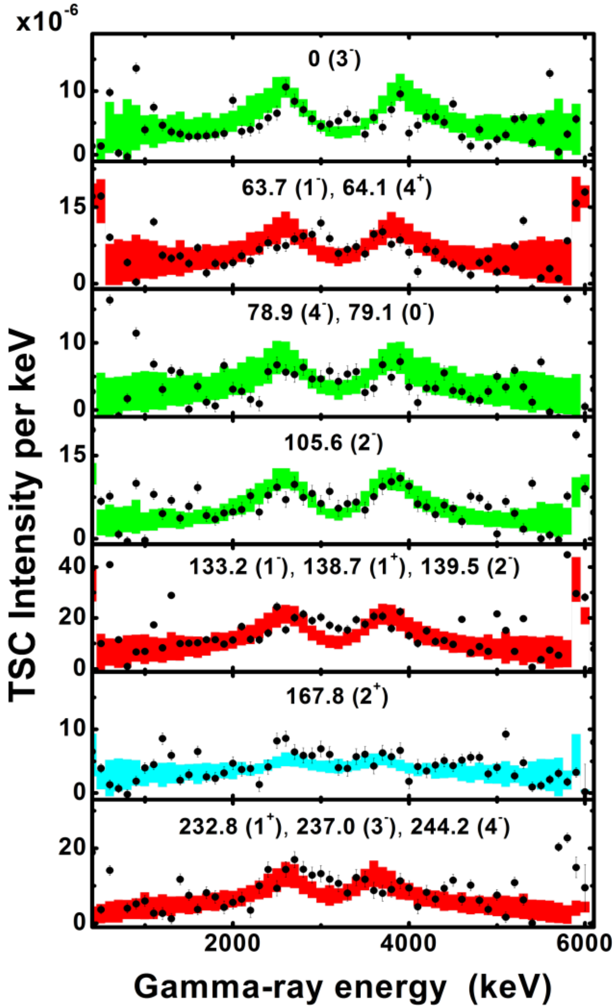


No resonance structure postulated near 3 MeV in PSF

SM in *M*1 PSF: E_{SM} = 2.6 MeV, Γ_{SM} = 0.6 MeV, σ_{SM} = 1.0 MeV

SM observed in (n,γ) reactions - TSC



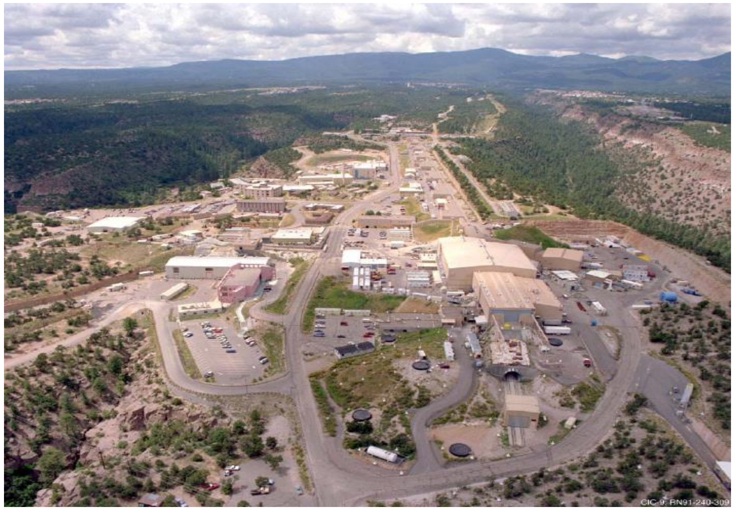


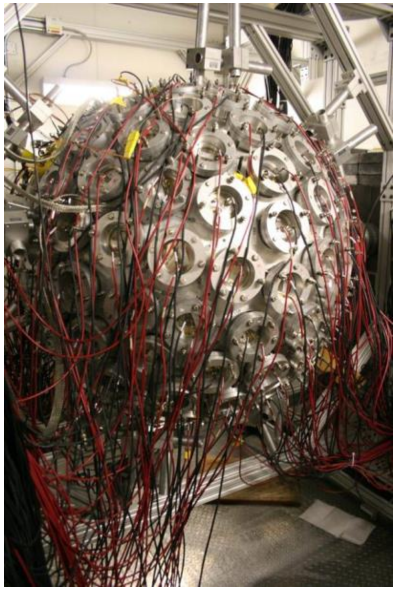
SM in $M1$ PSF only on the GS:
E_{SM} = 2.6 MeV, Γ_{SM} = 0.6 MeV and σ_{SM} = 1.0 MeV

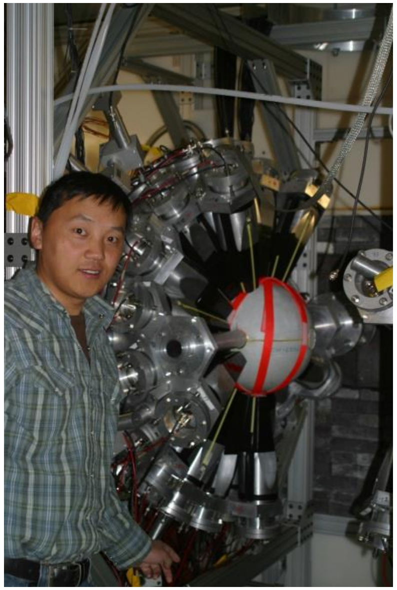
SM in $M1$ PSF: E_{SM} = 2.6 MeV,
Γ_{SM} = 0.6 MeV and σ_{SM} = 1.0 MeV

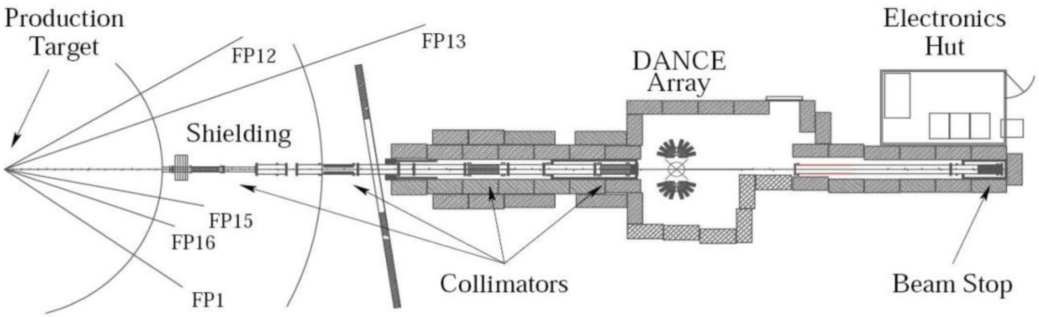
DANCE experiment at LANSCE

- Moderated W target gives “white” neutron spectrum ≈ 14 n’s / proton
- Repetition rate 20 Hz
- Pulse width ≈ 125 ns
- DANCE (**D**etector for **A**dvanced **N**eutron **C**apture **E**xperiments) detector is placed on a 20m long flight path / ≈ 1 cm beam after collimation





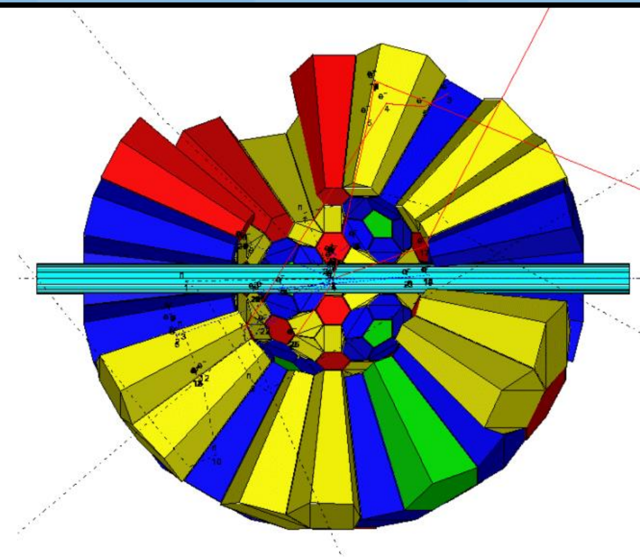


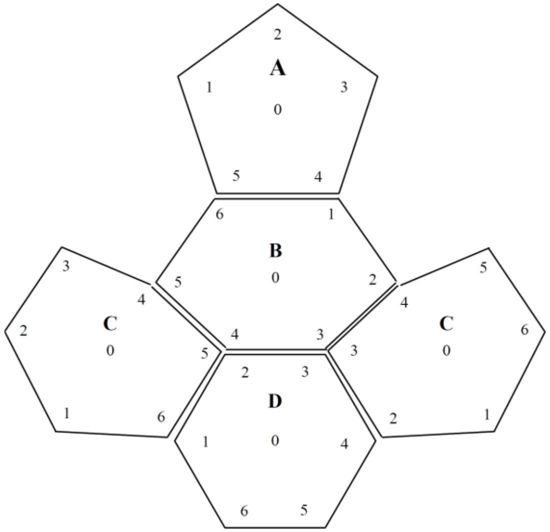


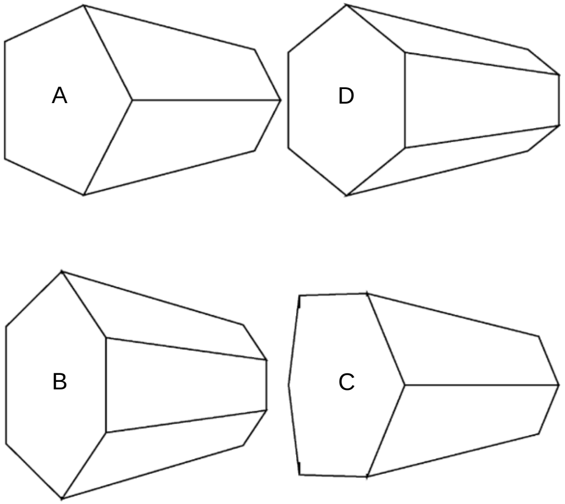
Average proton current ≈ 100 μA

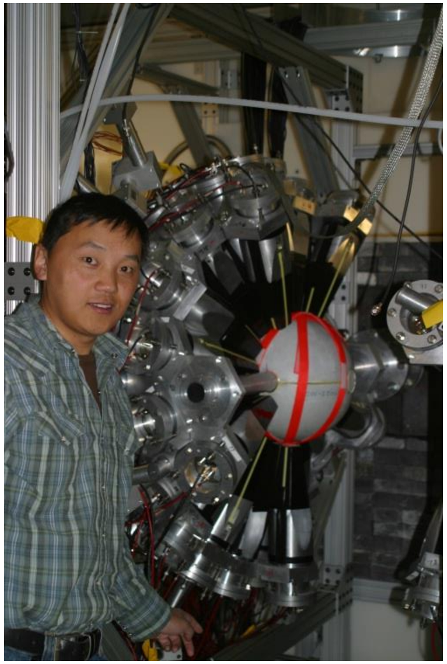
DANCE experiment at LANSCE – BaF_2 crystals

- **DANCE** consists of 160 BaF2 crystals (fullerene-type structure)
- total efficiency of detecting o photon from cascade > 90%
- efficiency for 1 MeV photon ≈ 86%
- energy resolution: dE/E = 1.089e-2 + 0.146/sqrt(E)
  - 1 MeV γ-ray ≈ 16%
  - 6 MeV γ-ray ≈ 7%
- timing resolution ≈ 2 ns



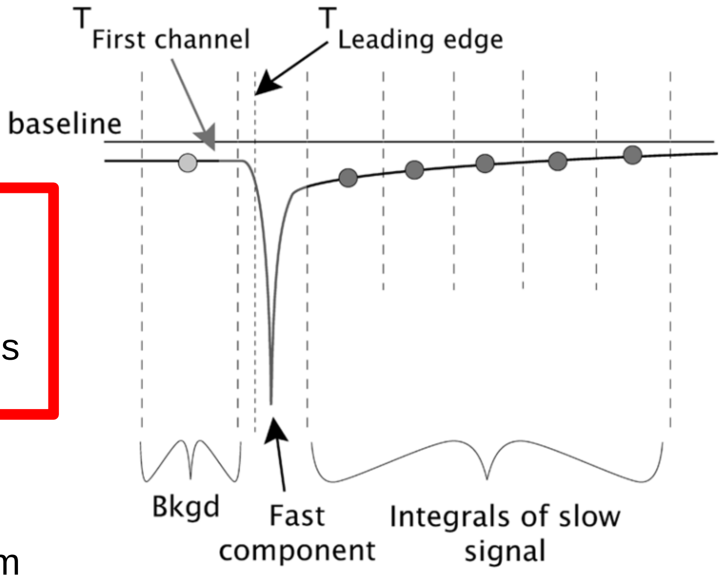






DANCE experiment at LANSCE - signal

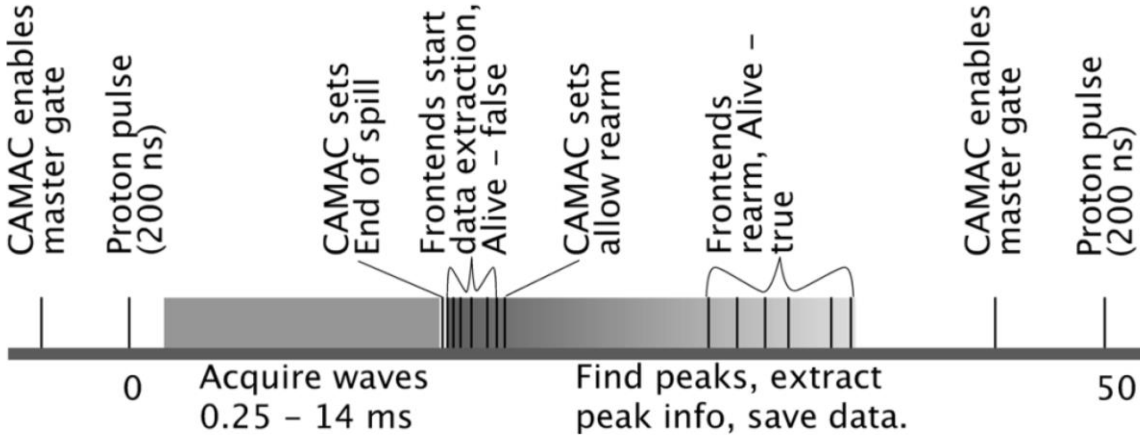
- ➢ Data Acquisition System
- Each crystal is connected to a chanel in two different digitizers
- Acqiris 4-channel DC256 difitizers (500 MHz, 8 bit resolution)



- ➢ BaF_2 light output consits of
- Fast component (0.6 ns, 220 nm) – 1 integral / 32pts = 64ns
- Slow component (630 ns, 310 nm) – 5 integrals / 100pts = 200ns

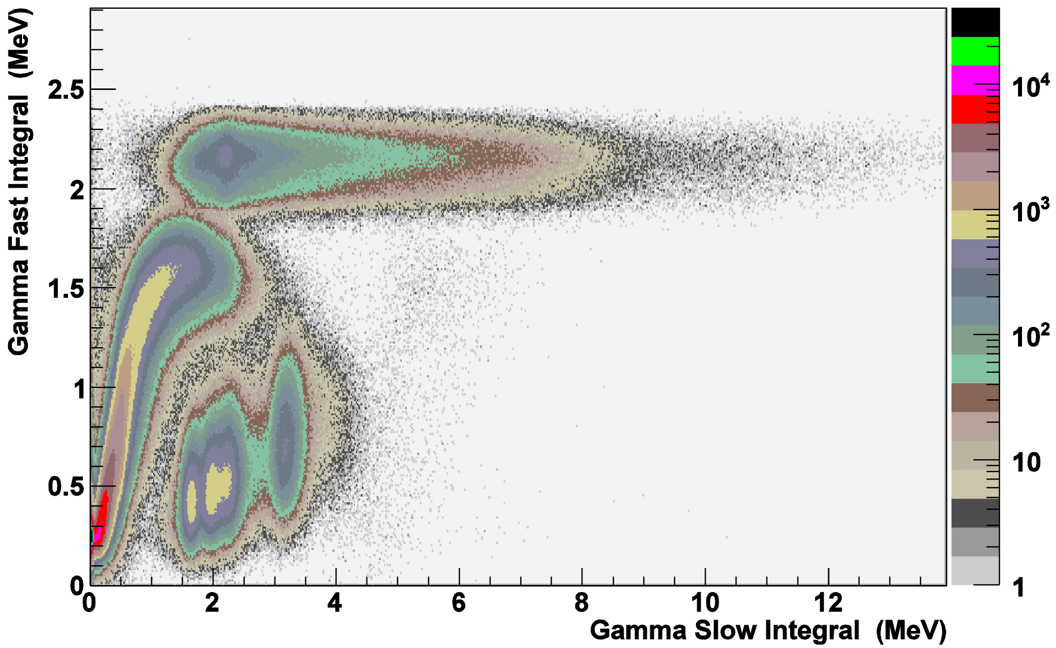
- ➢ Data rate reduced to ≈ 1 Mbyte/s
- ➢ DAQ has ≈ 40 ms to read out the digitizers, extract the waveform information and send data to the Midas served

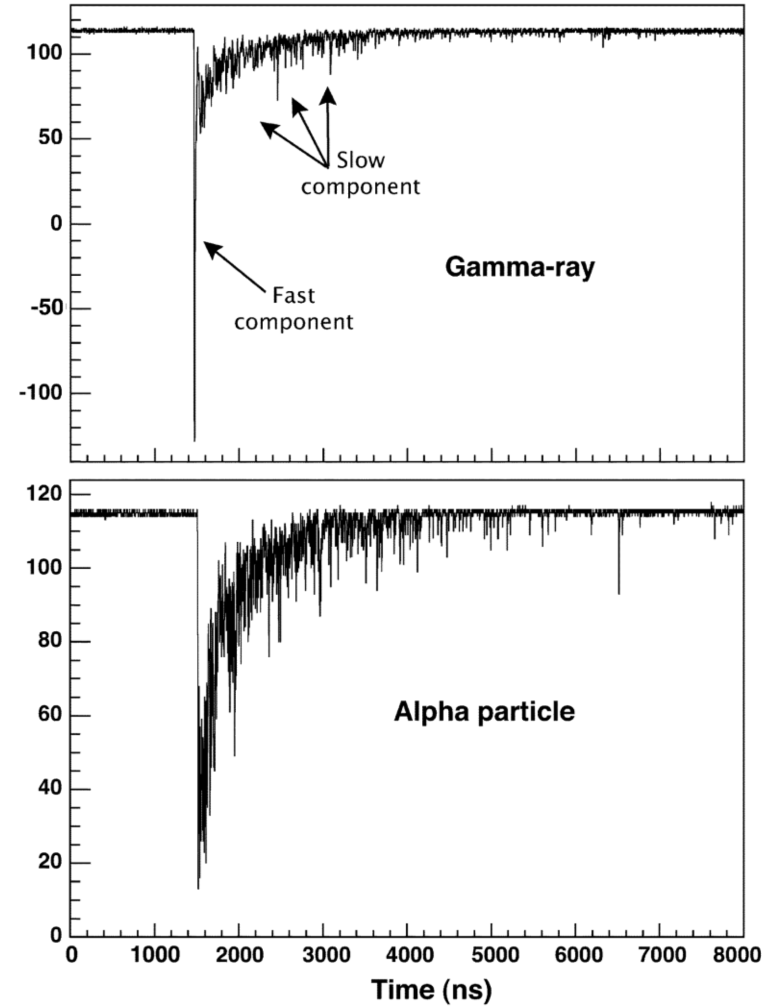
TIME LINE FOR ONE BEAM SPILL



DANCE experiment at LANSCE - calibration

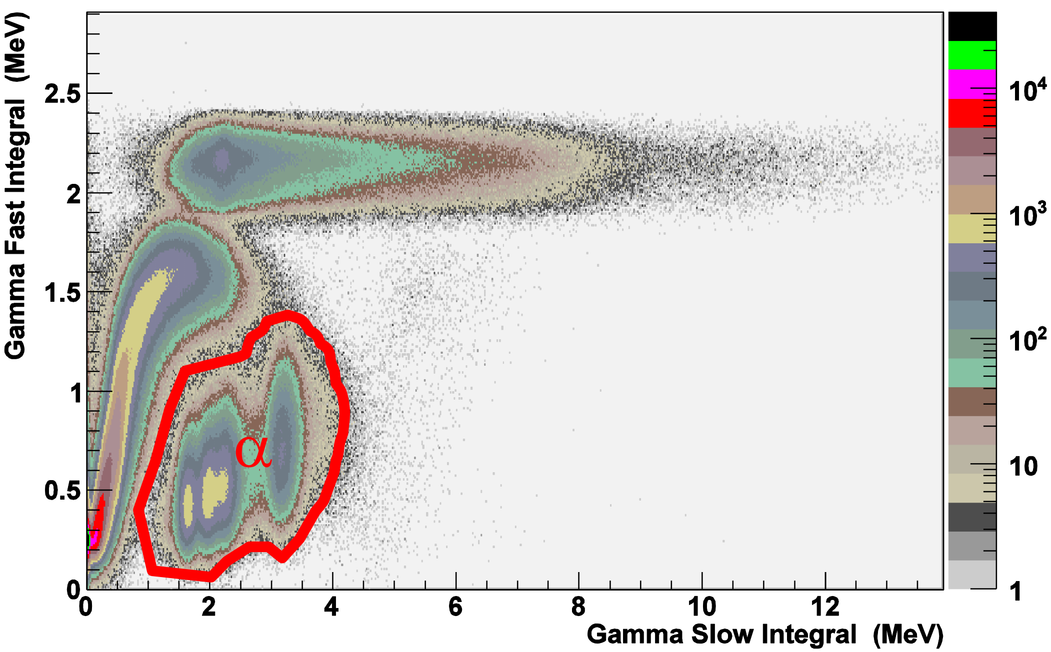
- Primary energy calibration (^{88}Y, ^{60}Co, ^{22}Na)
- Gain for each crystal updated run-by-run by the α-particles from Ra isotopes present in BaF_2 crystals
- Signal from α-particles is easily identified

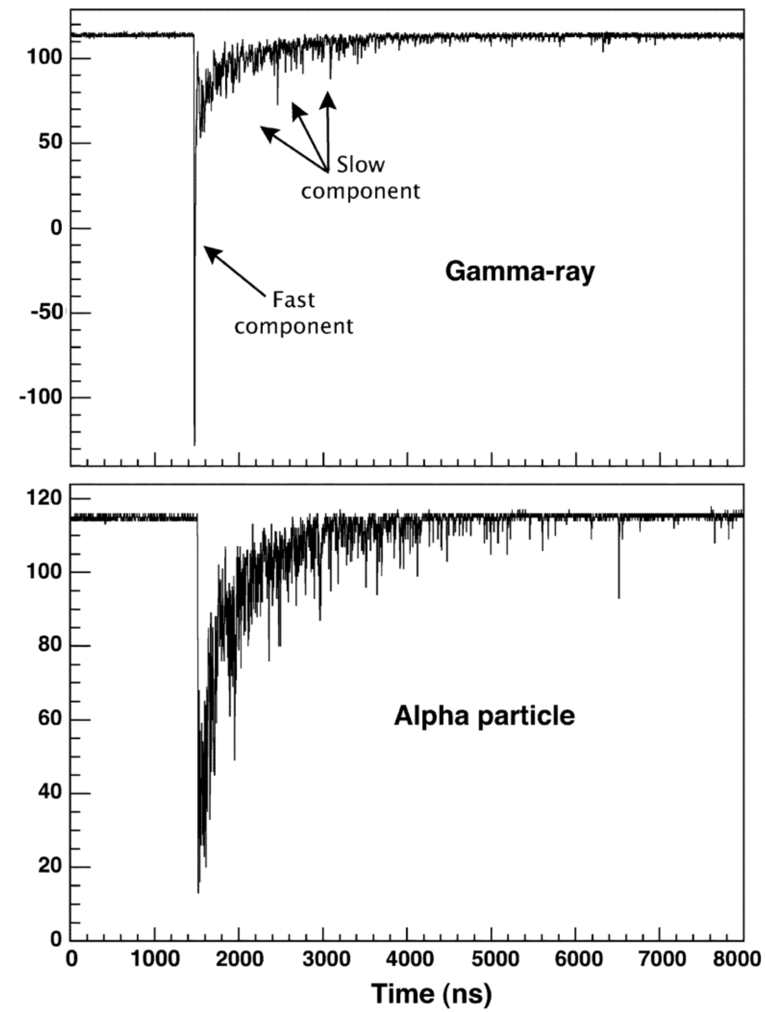




DANCE experiment at LANSCE - calibration

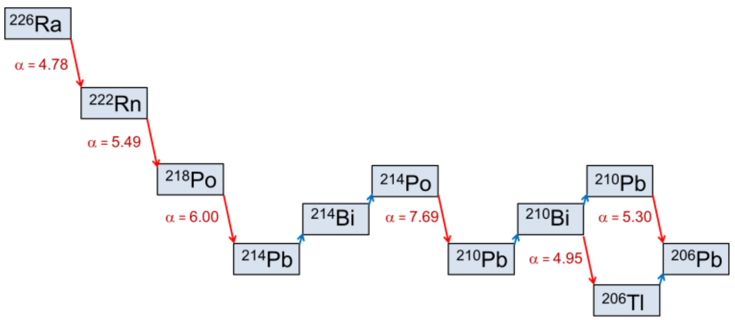
- Primary energy calibration (^{88}Y, ^{60}Co, ^{22}Na)
- Gain for each crystal updated run-by-run by the α-particles from Ra isotopes present in BaF_2 crystals
- Signal from α-particles is easily identified

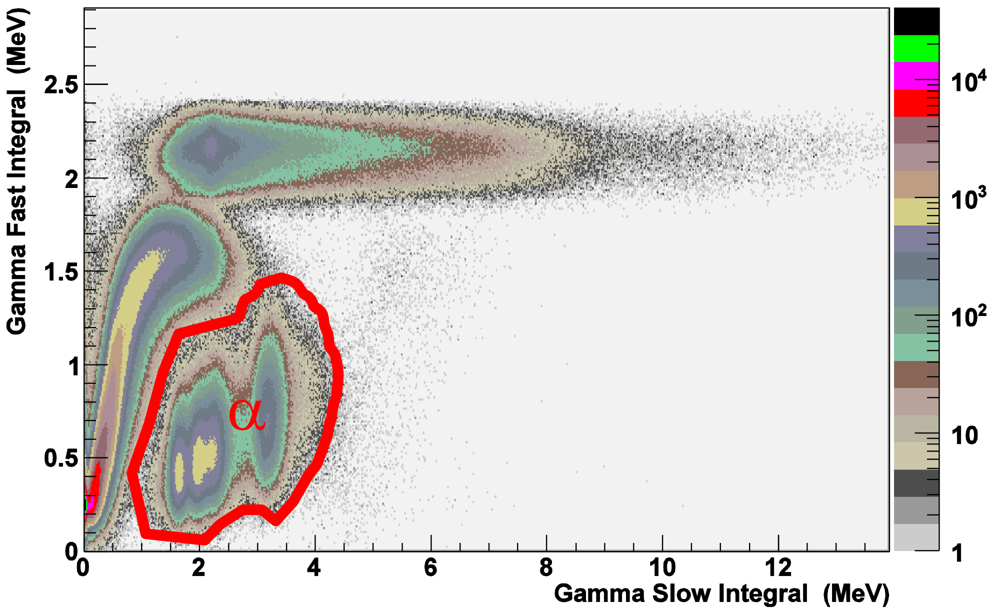


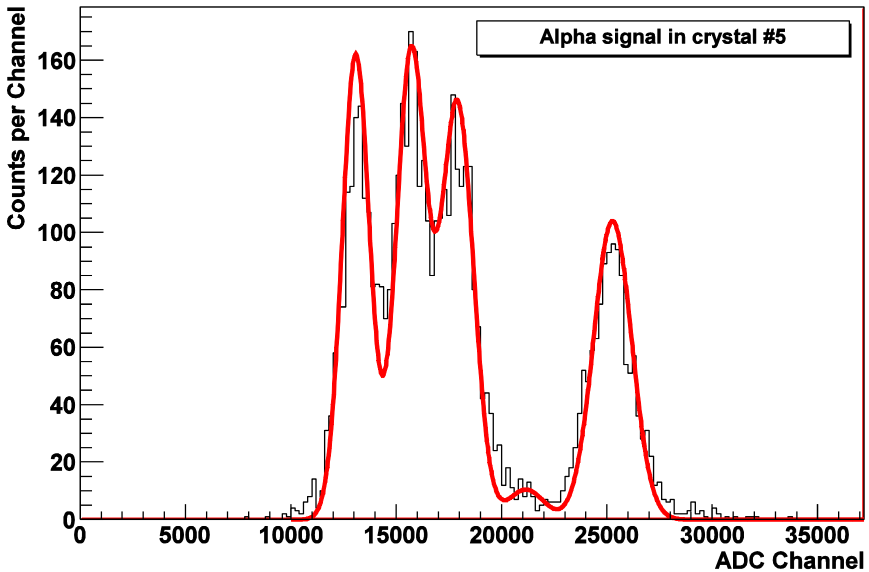


DANCE experiment at LANSCE - calibration

- Primary energy calibration (^{88}Y, ^{60}Co, ^{22}Na)
- Gain for each crystal updated run-by-run by the α-particles from Ra isotopes present in BaF_2 crystals
- Signal from α-particles is easily identified





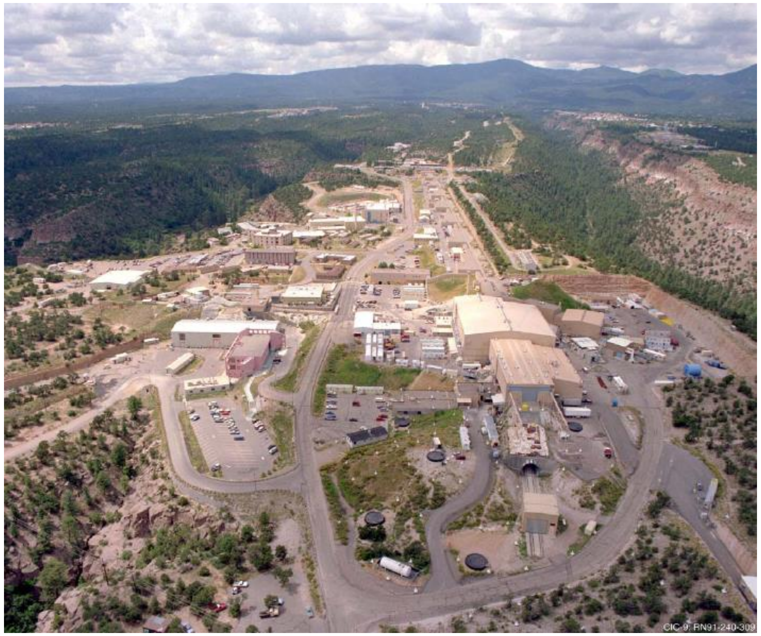


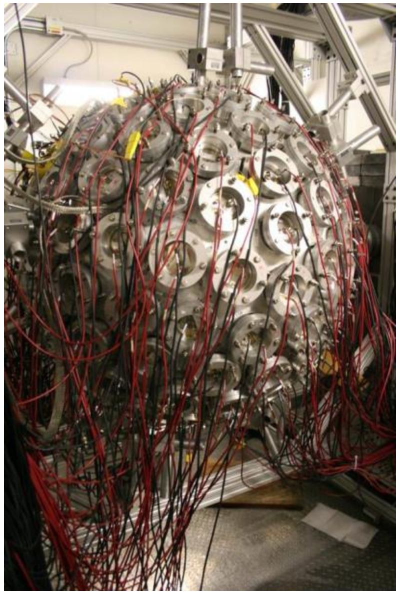
DANCE experiment – Gd isotopes

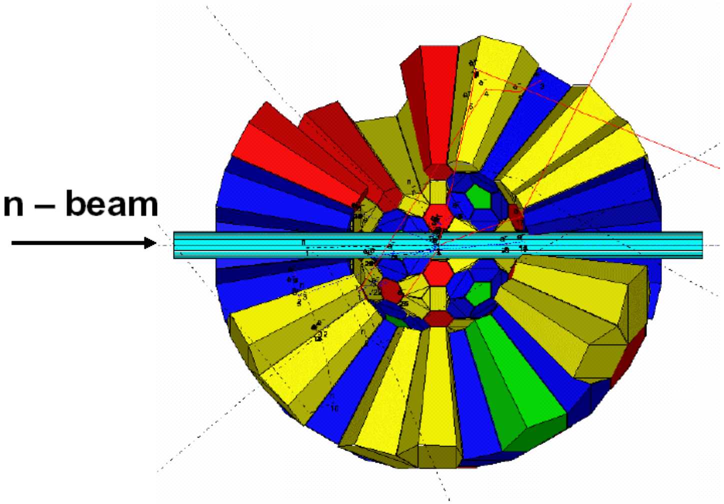
With a DANCE detector we have measured stable Gd isotopes

^{153}Gd, ^{155}Gd, ^{156}Gd, ^{157}Gd, ^{158}Gd, ^{159}Gd

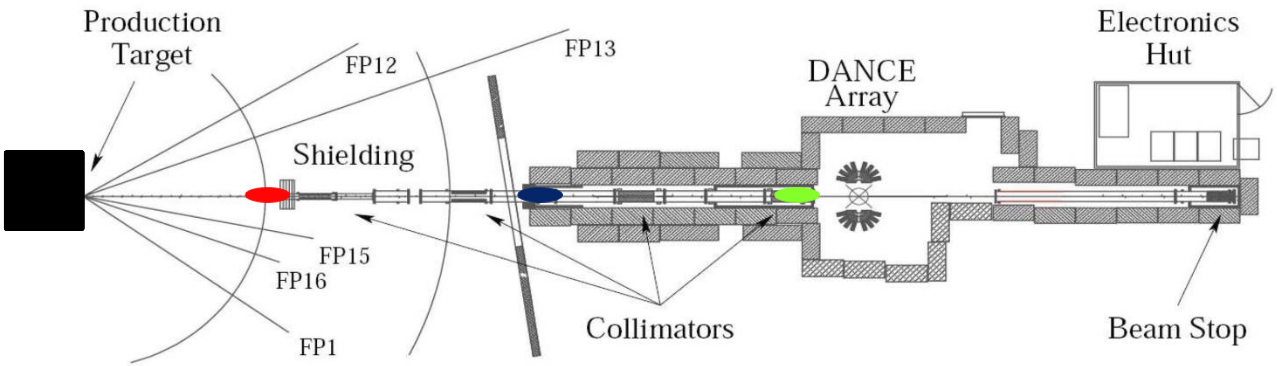
mainly to get information about the Photon Strength Functions (PSFs)



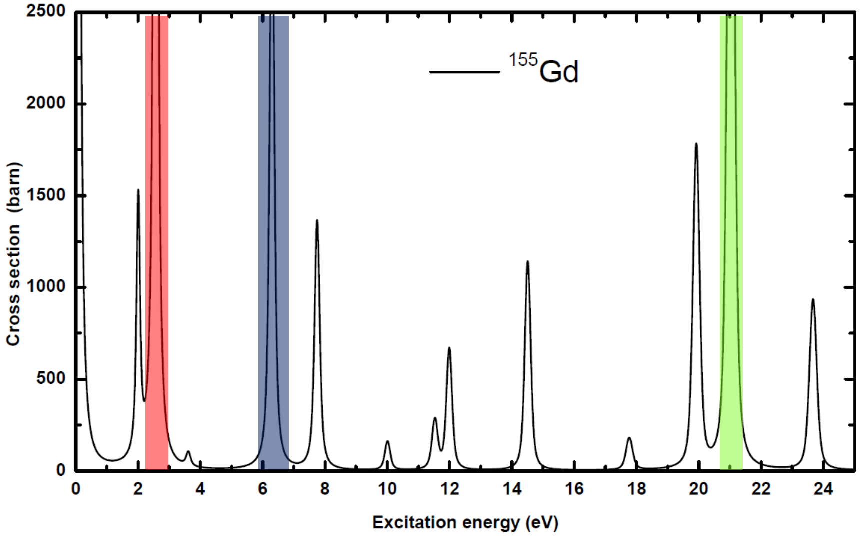




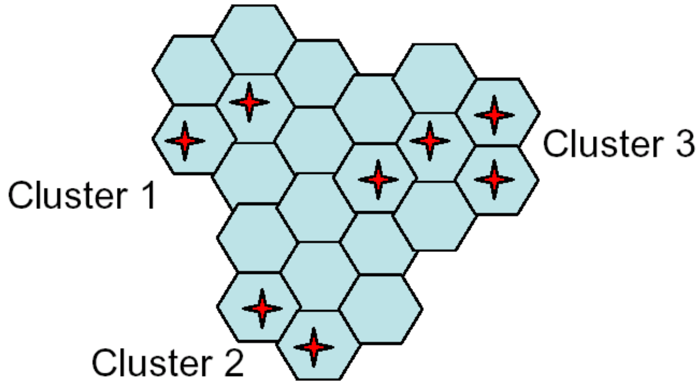
DANCE experiment – TOF method

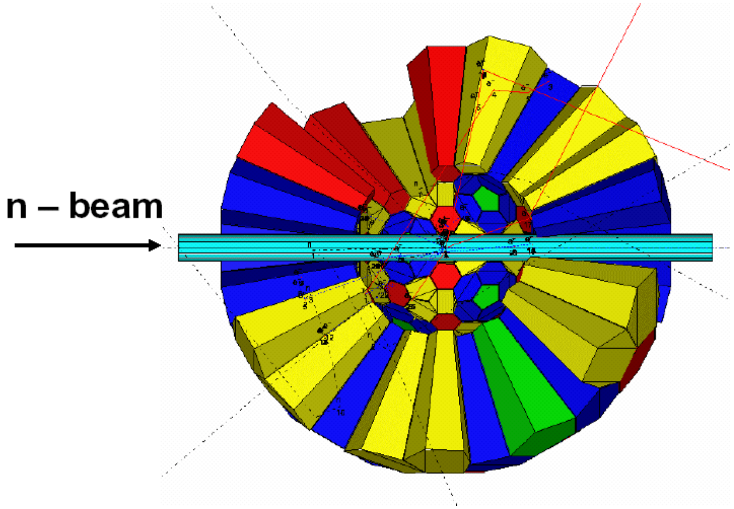


- **TOF method** → we are interested only in the strong and well-isolated resonances
- The background for these strong resonances is small and can be subtracted

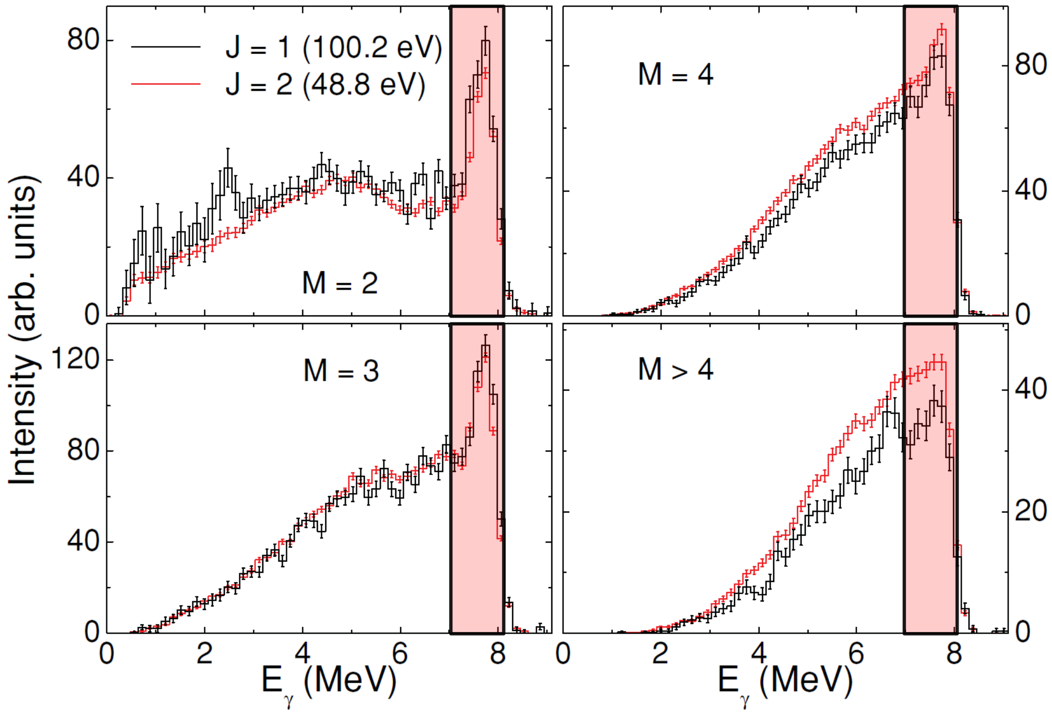


DANCE experiment – data processing

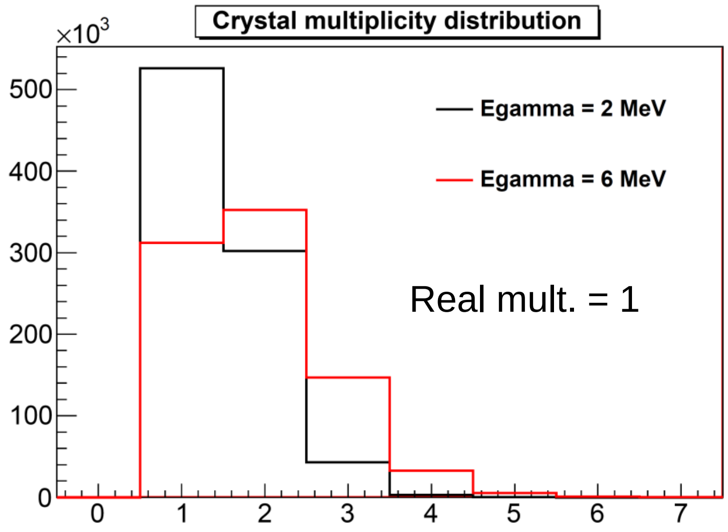


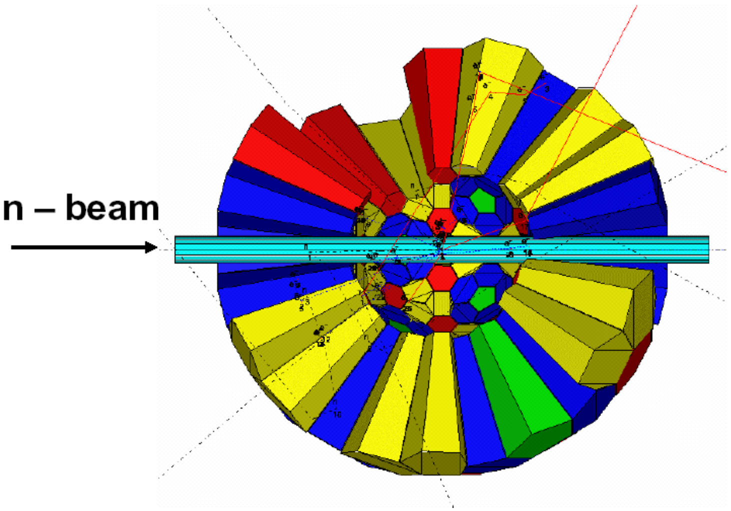


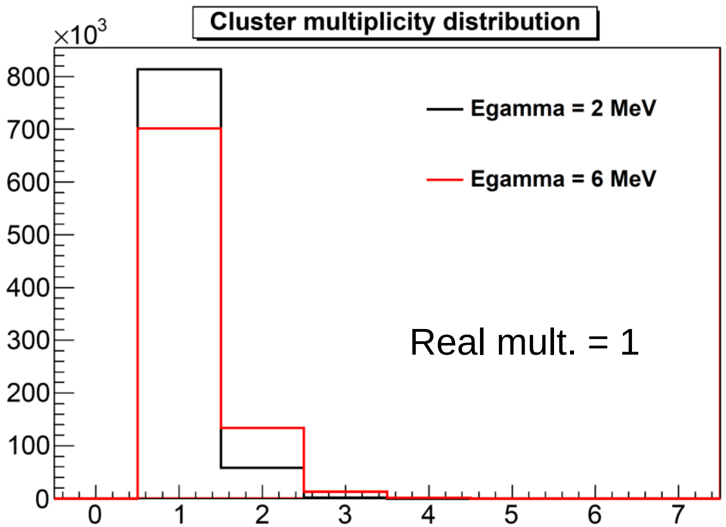
Sum-energy spectra for different multiplicities

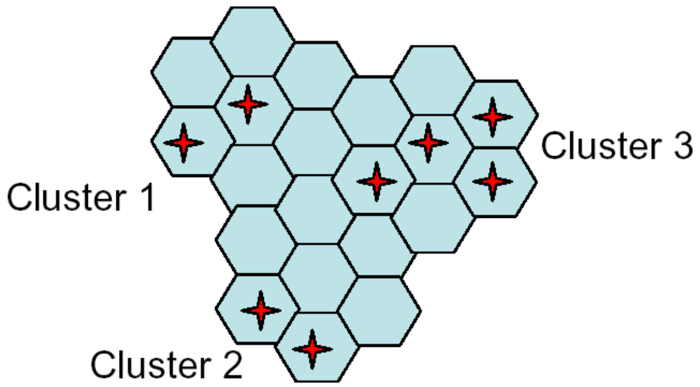


DANCE experiment – data processing





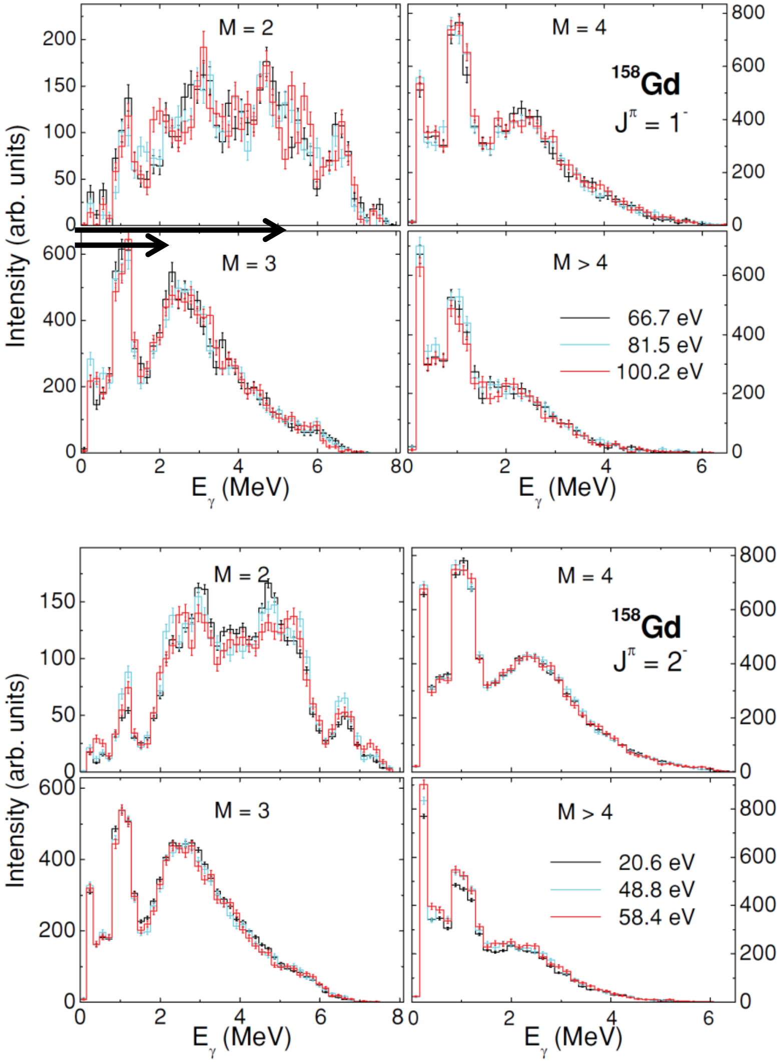




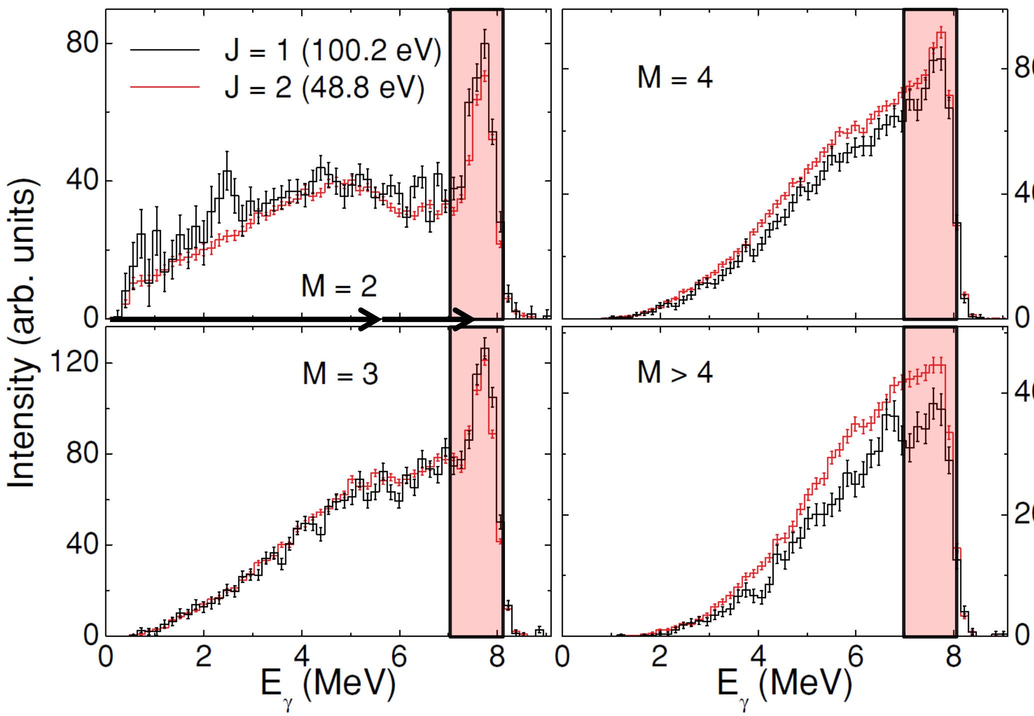
M. Heil *et al.*, Nucl. Instr. Meth. A **459**, 229 (2001).
R. Reifarth *et al.*, Nucl. Instr. Meth. A **531**, 530 (2004).

DANCE experiment – data processing

Experimental MSC spectra



Sum-energy spectra for different multiplicities



Simulations of gamma decay – DICEBOX

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

Simulations of gamma decay – DICEBOX

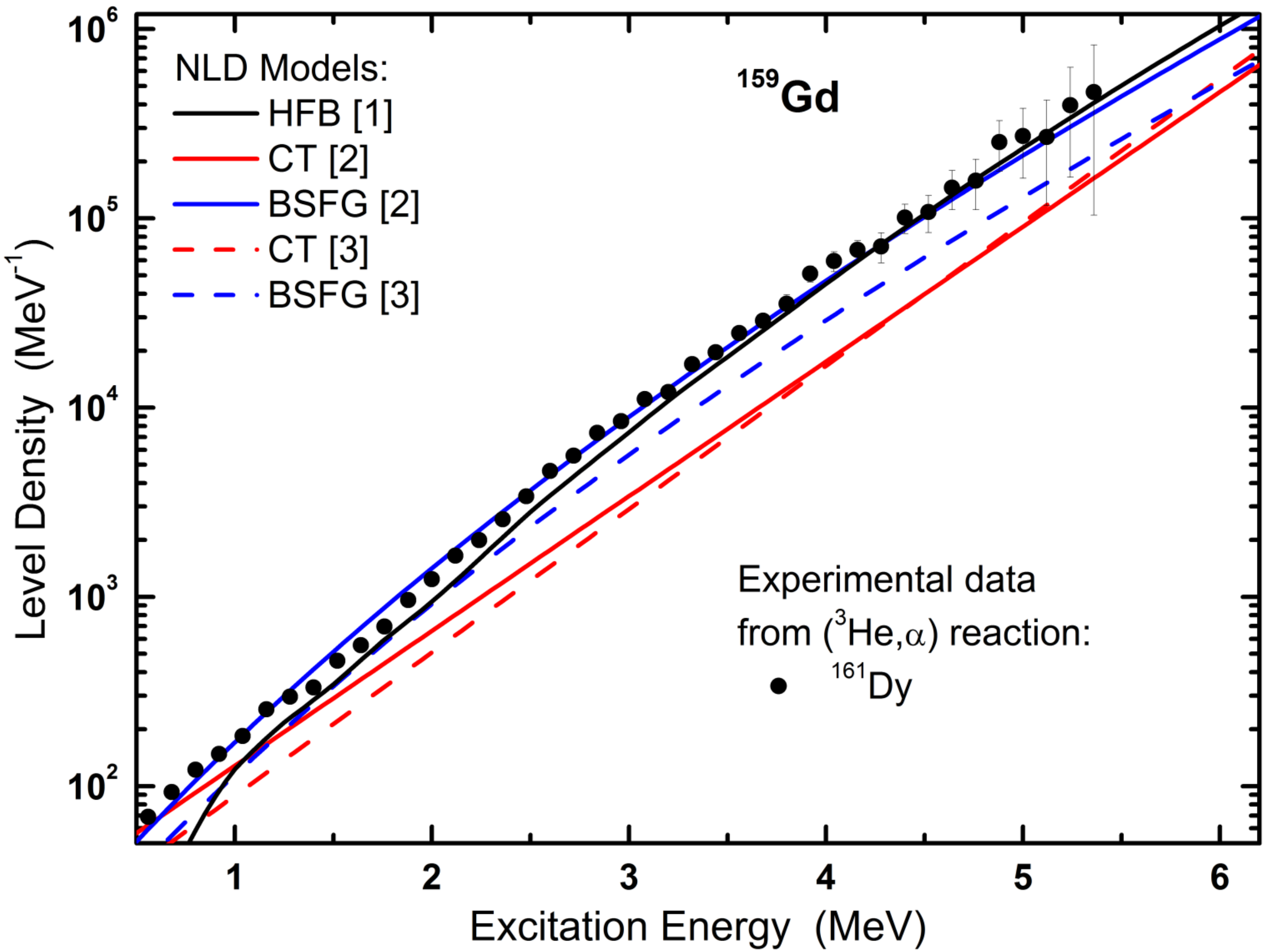
1. Below a **critical energy *E_{crit}*** the energies *E*, spins *J*, parities π and the decay properties of all levels are taken from known data

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

$$\rho(E_i, J_i, \pi_i)$$

Level density

Simulations of gamma decay – NLD



[1] R. Capote *et al.*, Nucl. Data Sheets **110**, 3107 (2009).
[2] T. von Egidy and D. Bucurescu, Phys. Rev. C **72**, 044311 (2005).
[3] T. von Egidy and D. Bucurescu, Phys. Rev. C **80**, 054310 (2009).
^{161}**Dy** data: M. Guttormsen *et al.,* Phys. Rev. C **68**, 064306 (2003).

Simulations of gamma decay – DICEBOX

1. Below a **critical energy** $\boldsymbol{E_{crit}}$ 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

$$\rho(E_i, J_i, \pi_i)$$

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:

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

Simulations of gamma decay – DICEBOX

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

$$\rho(E_i, J_i, \pi_i)$$

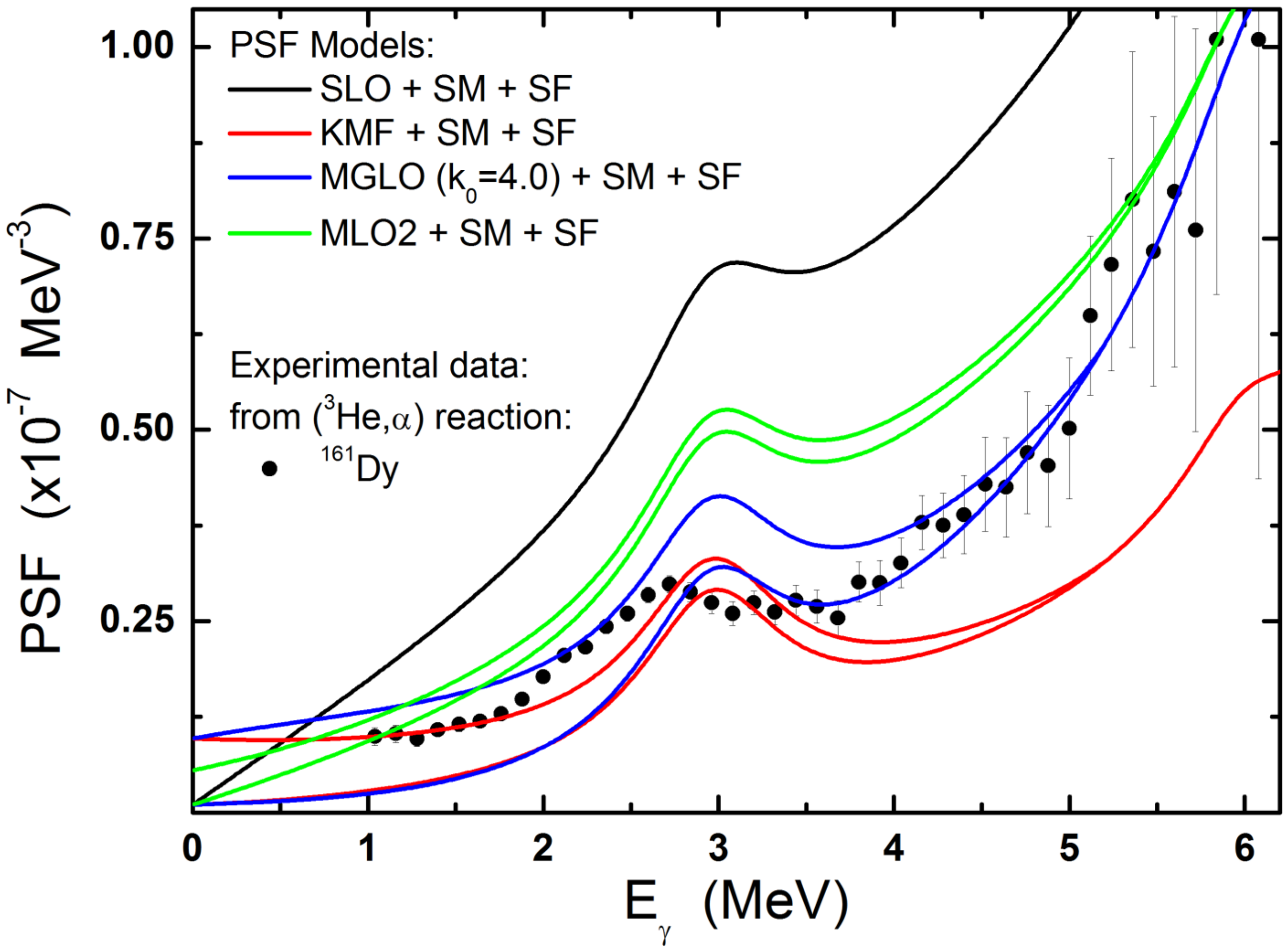
Level density

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

PSFs

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

Simulations of gamma decay – PSFs



The energy of the SM is 3.0 MeV, damping width is 1.0 MeV and the strength $\Sigma B_{tot}(SM)\uparrow \approx 7.46\ \mu_N^{2}$.

^{161}**Dy** data: M. Guttormsen *et al.,* Phys. Rev. C **68**, 064306 (2003).

Simulations of gamma decay – DICEBOX

1. Below a **critical energy** $\boldsymbol{E_{crit}}$ 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

$$\rho(E_i, J_i, \pi_i)$$

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

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

Simulations of gamma decay – DICEBOX

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

$$\rho(E_i, J_i, \pi_i)$$

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:

P-T fluctuations

PSFs

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

Simulations of gamma decay – DICEBOX

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

$$\rho(E_i, J_i, \pi_i)$$

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:

P-T fluctuations

PSFs

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

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

Simulations of gamma decay – DICEBOX

Nuclear Realization:

10^6 energy leves

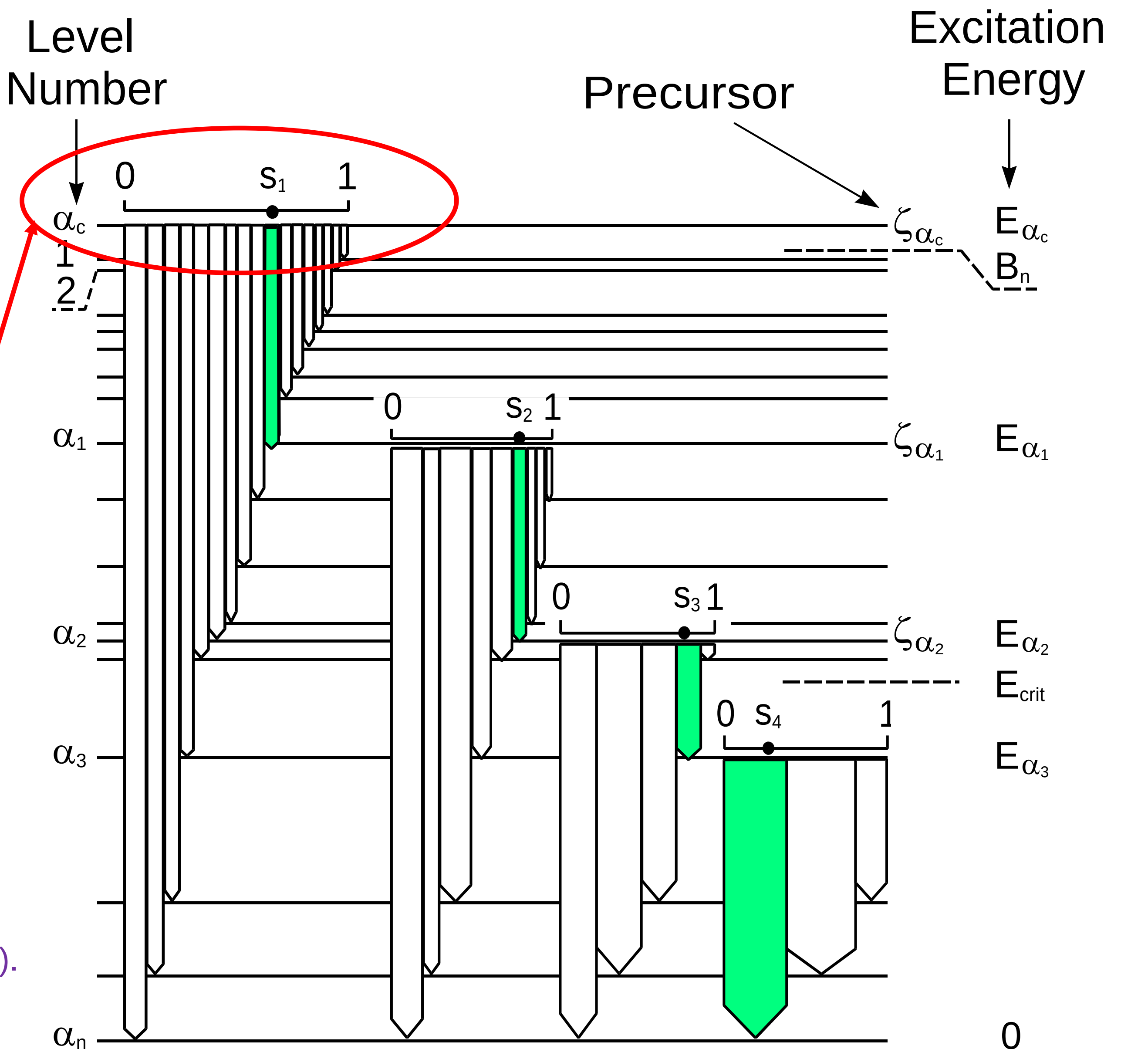
$10^{12}\ \Gamma_{i\gamma f}$

System of precursors

P-T fluctuations

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

$$x = \Gamma_{i\gamma f}/\overline{\Gamma}$$

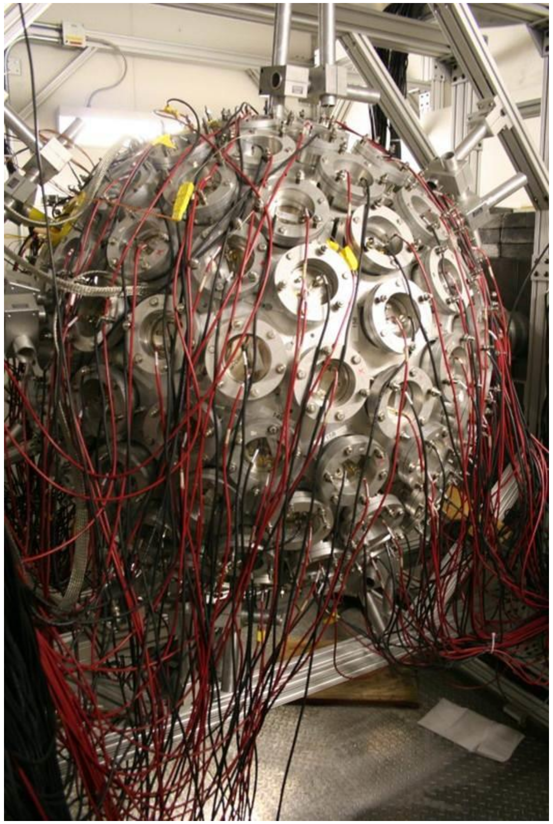


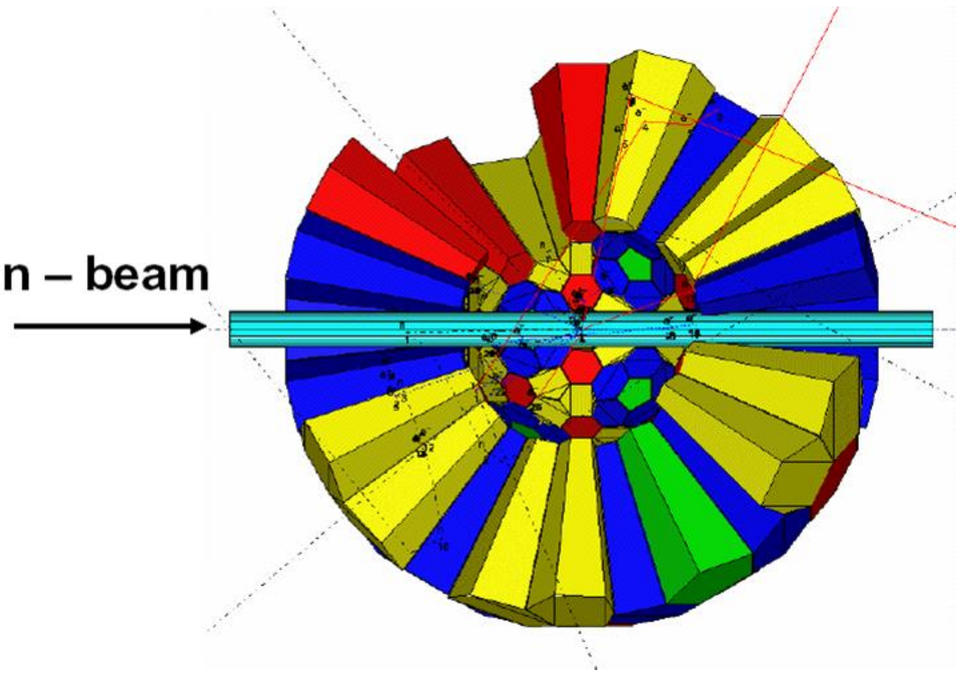
F. Bečvář, NIM A **417**, 434 (1998).

Detector response – Geant4

- The outputs of DICEBOX simulations are transformed to the form of Geant4 input.

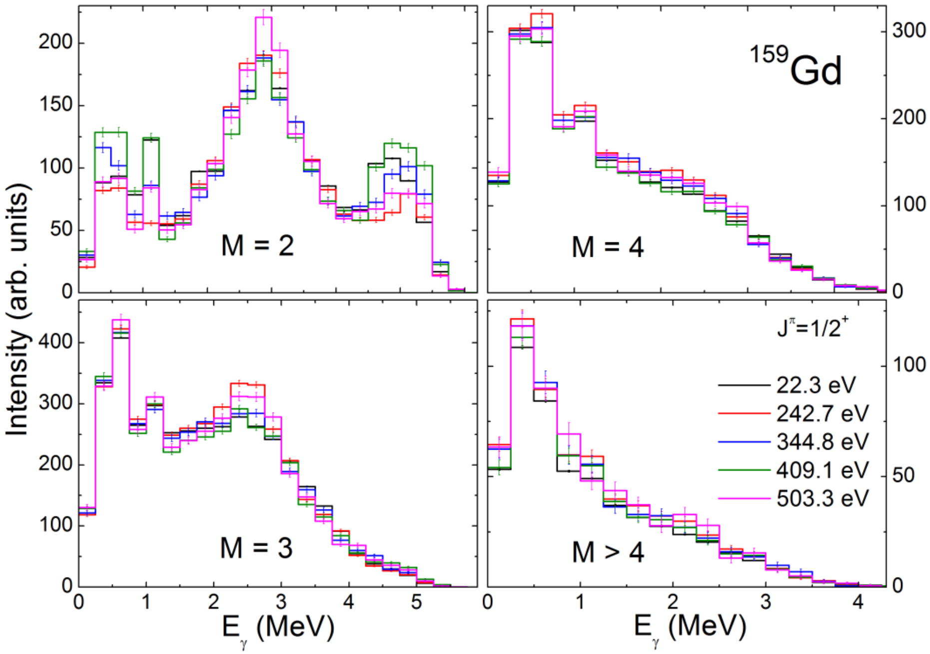
- Simulations of detector response include the exact geometry and chemical composition (regular and irregular pentagonal and hexagonal BaF_2 crystals), all shielding, aluminium beamline, radioactive target holder, etc.



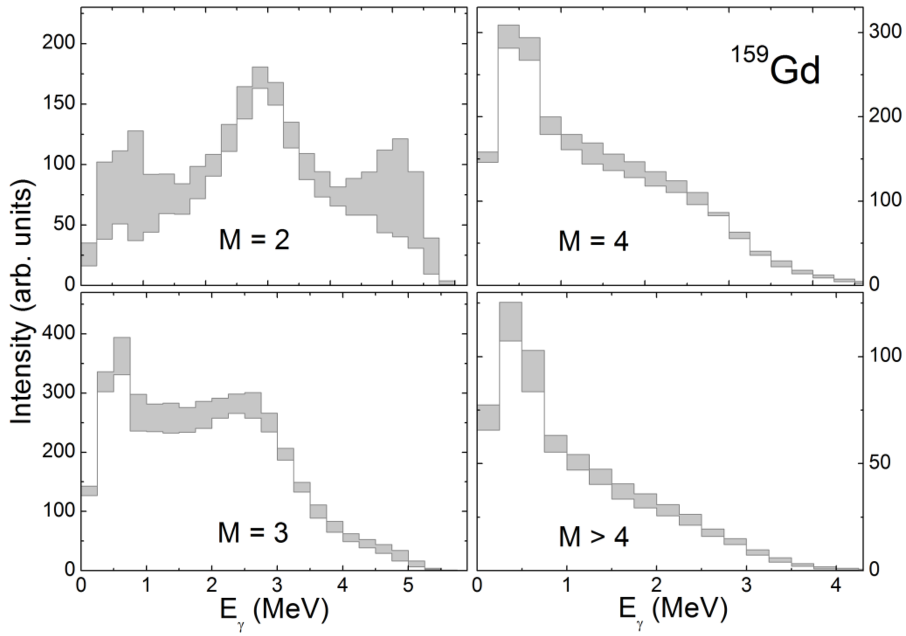


Comparison of experimental MSC spectra with simulations

- To get information on PSFs and LD we compare experimental data with outputs of simulations

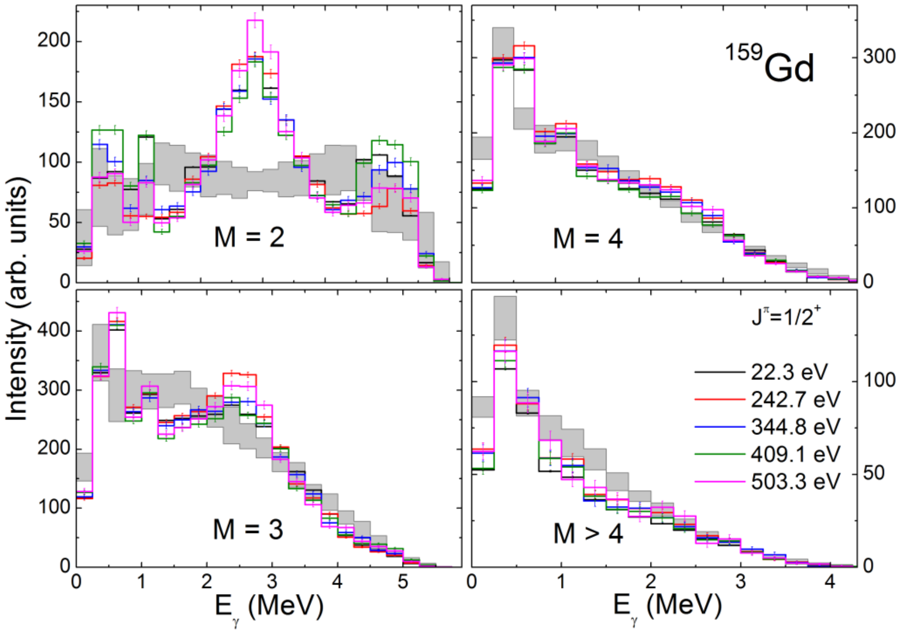


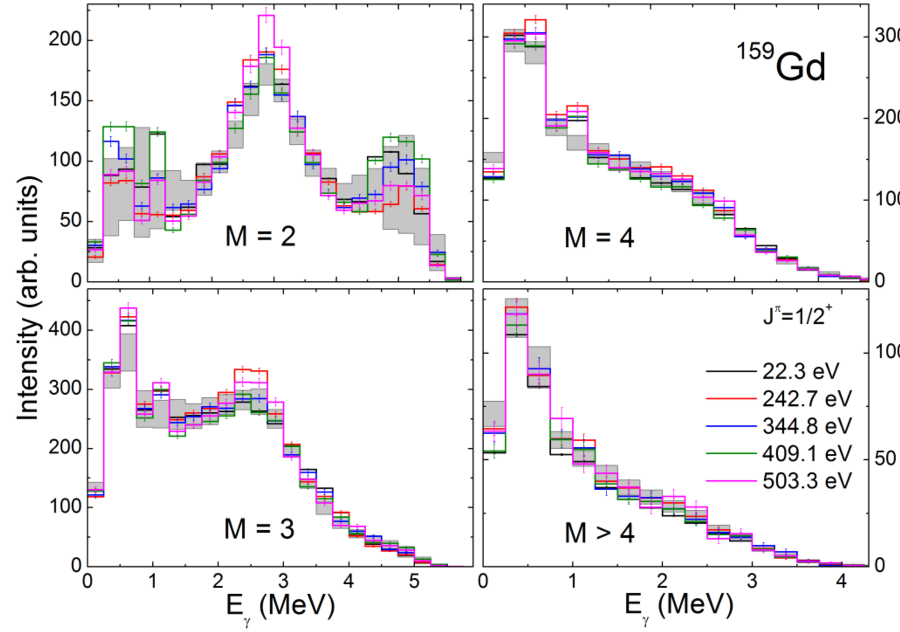
Experimental MSC spectra for five different resonances with $J^{\pi} = ½^{+}$



Simulated MSC spectra produced by DICEBOX and Geant4
(grey corridors are consequence of Porter-Thomas fluctuations)

Comparison of experimental MSC spectra with simulations





Simulation assumptions:

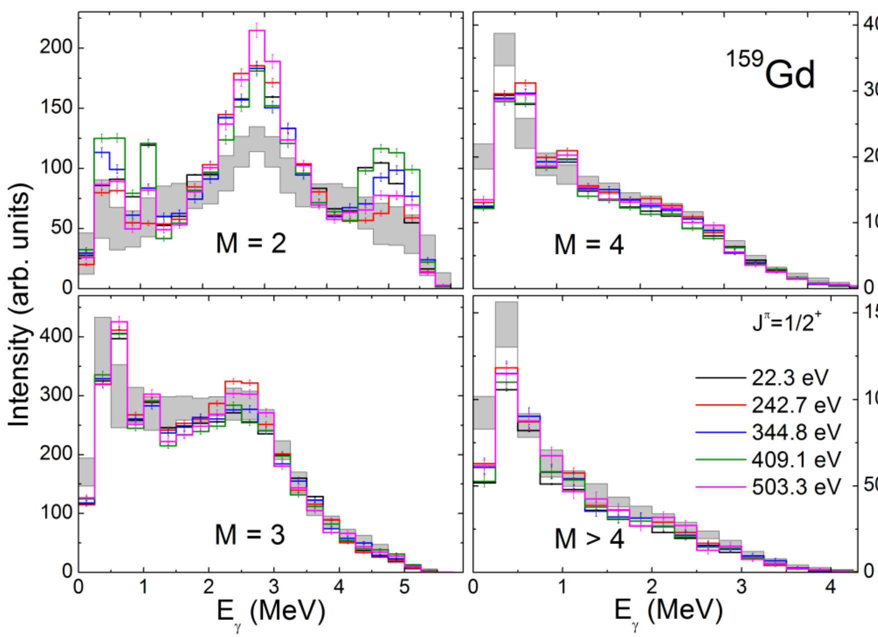
E1: MGLO (k_0 = 4.0, $E_{\gamma 0}$ = 4.5 MeV)
M1: SP + SF
E2: SP
NLD: BSFG

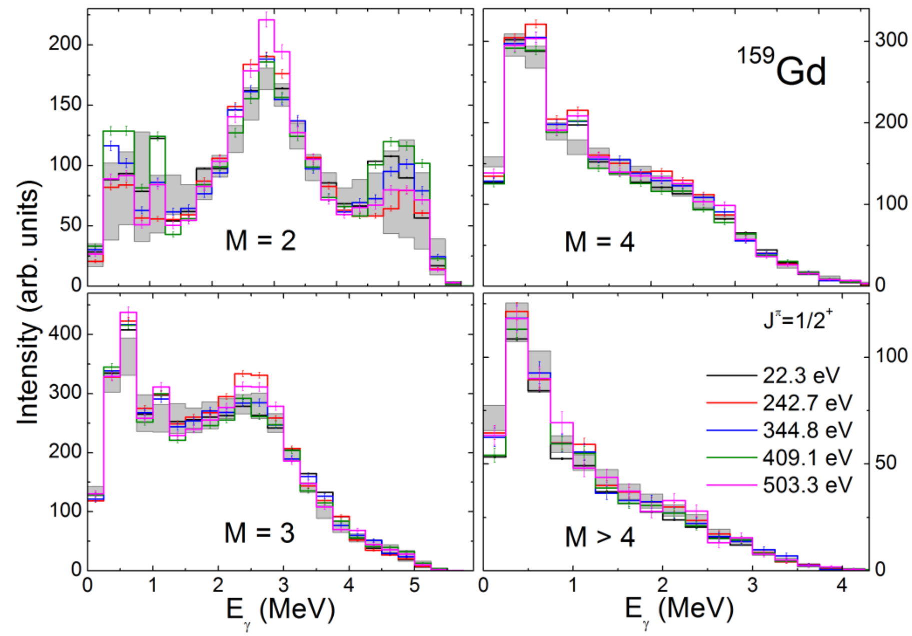
Simulation assumptions:

E1: MGLO (k_0 = 4.0, $E_{\gamma 0}$ = 4.5 MeV)
M1: SP + SF + SM
E2: SP
NLD: BSFG

E_{SM}=3.0 MeV, Γ_{SM}=1.0 MeV,
$\Sigma B_{tot}(SM)\uparrow = 7.46\ \mu_N^2$

Comparison of experimental MSC spectra with simulations





Simulation assumptions:

E1: MGLO (k_0 = 4.0, $E_{\gamma 0}$ = 4.5 MeV) + SR
M1: SP + SF
E2: SP
NLD: BSFG

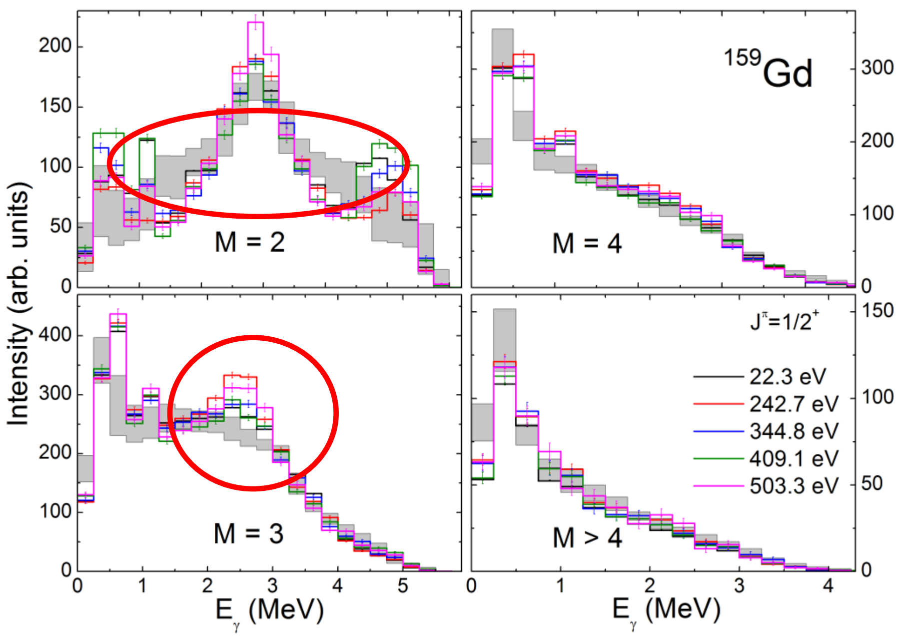
E_{SR}=3.0 MeV, Γ_{SR}=1.0 MeV, σ_{SM}=0.7 mb

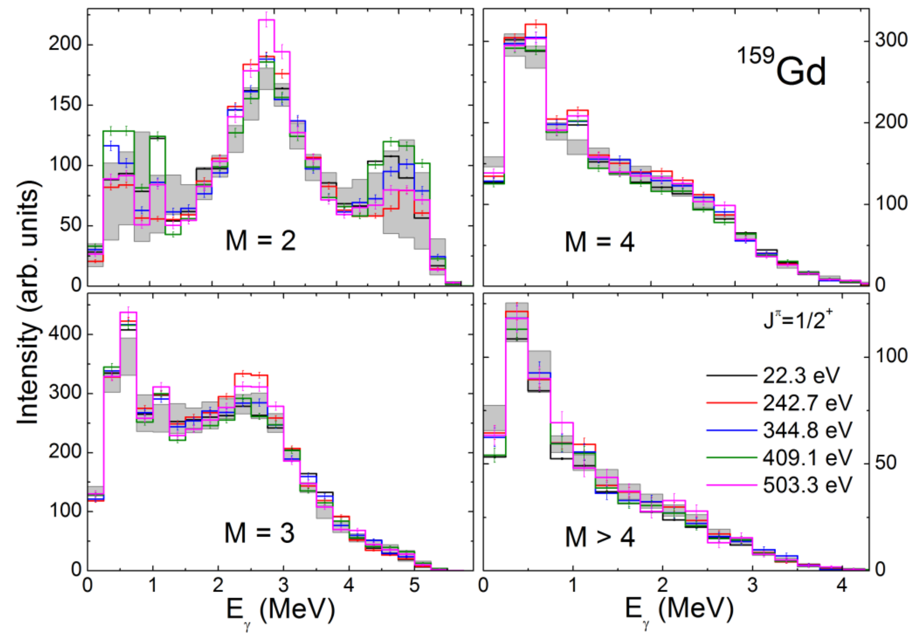
Simulation assumptions:

E1: MGLO (k_0 = 4.0, $E_{\gamma 0}$ = 4.5 MeV)
M1: SP + SF + SM
E2: SP
NLD: BSFG

E_{SM}=3.0 MeV, Γ_{SM}=1.0 MeV,
$\Sigma B_{tot}(SM)\uparrow$ = 7.46 μ_N^2

Comparison of experimental MSC spectra with simulations





Simulation assumptions:

***E*1**: MGLO (k_0 = 4.0, $E_{\gamma 0}$ = 4.5 MeV) + SR
***M*1**: SP + SF + SM **(below 3 MeV)**
***E*2**: SP
NLD: BSFG

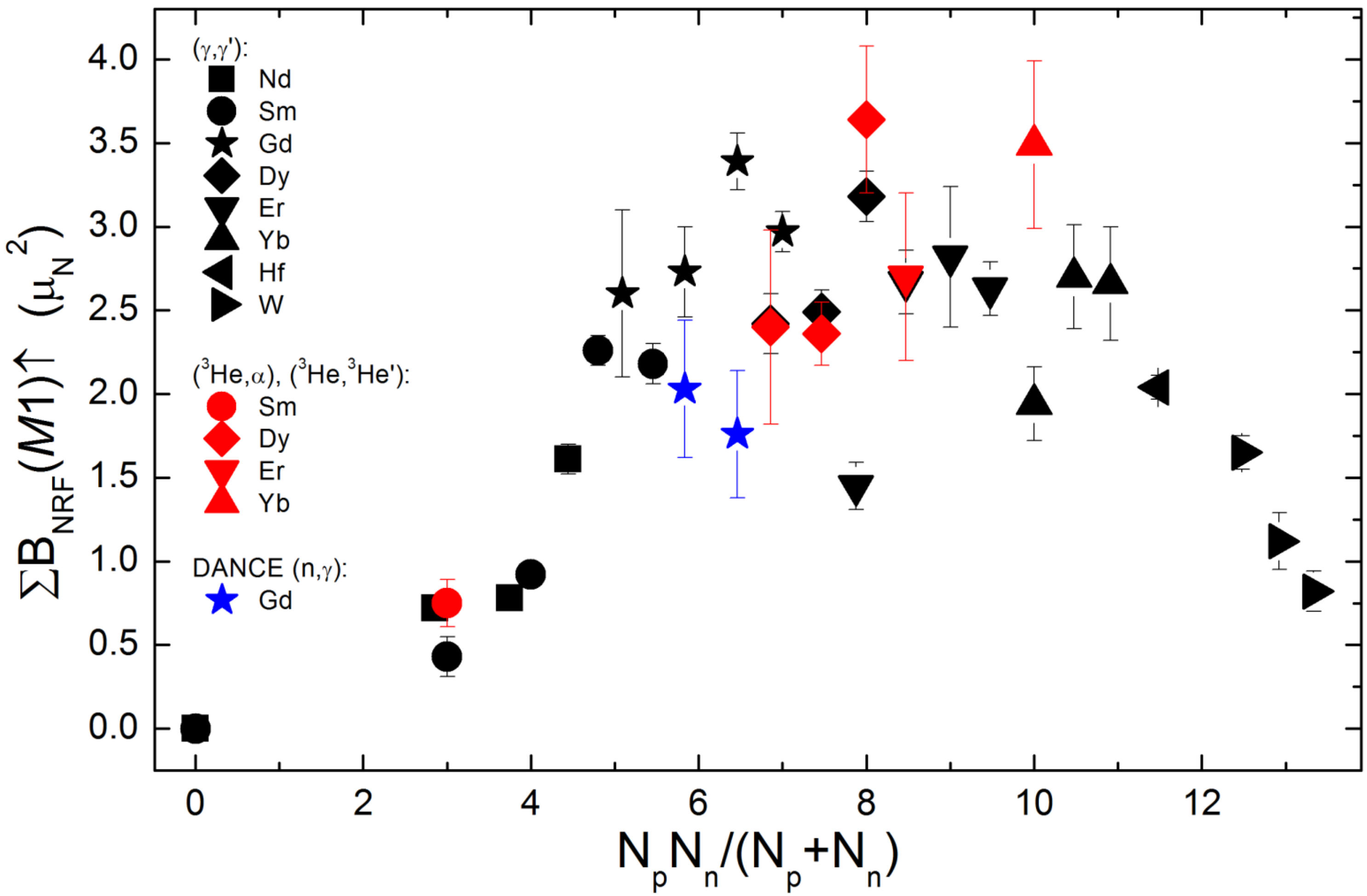
E_{SM}=3.0 MeV, Γ_{SM}=1.0 MeV,
$\Sigma B_{tot}(SM)\uparrow$ = 7.46 μ_N^2

Simulation assumptions:

***E*1**: MGLO (k_0 = 4.0, $E_{\gamma 0}$ = 4.5 MeV)
***M*1**: SP + SF + SM
***E*2**: SP
NLD: BSFG

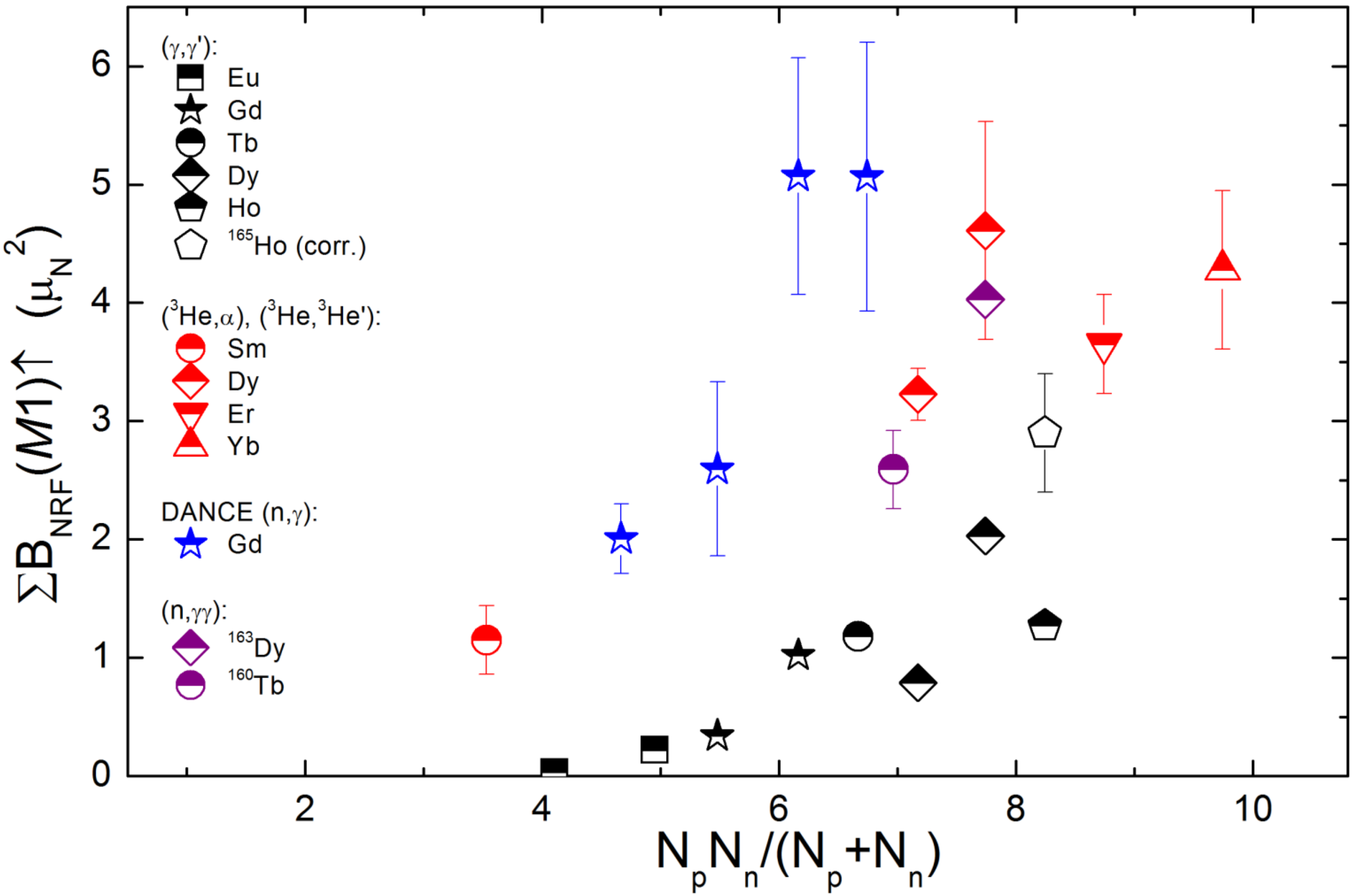
E_{SM}=3.0 MeV, Γ_{SM}=1.0 MeV,
$\Sigma B_{tot}(SM)\uparrow$ = 7.46 μ_N^2

ΣB(*M1*,2.7-3.7)↑ in even nuclei



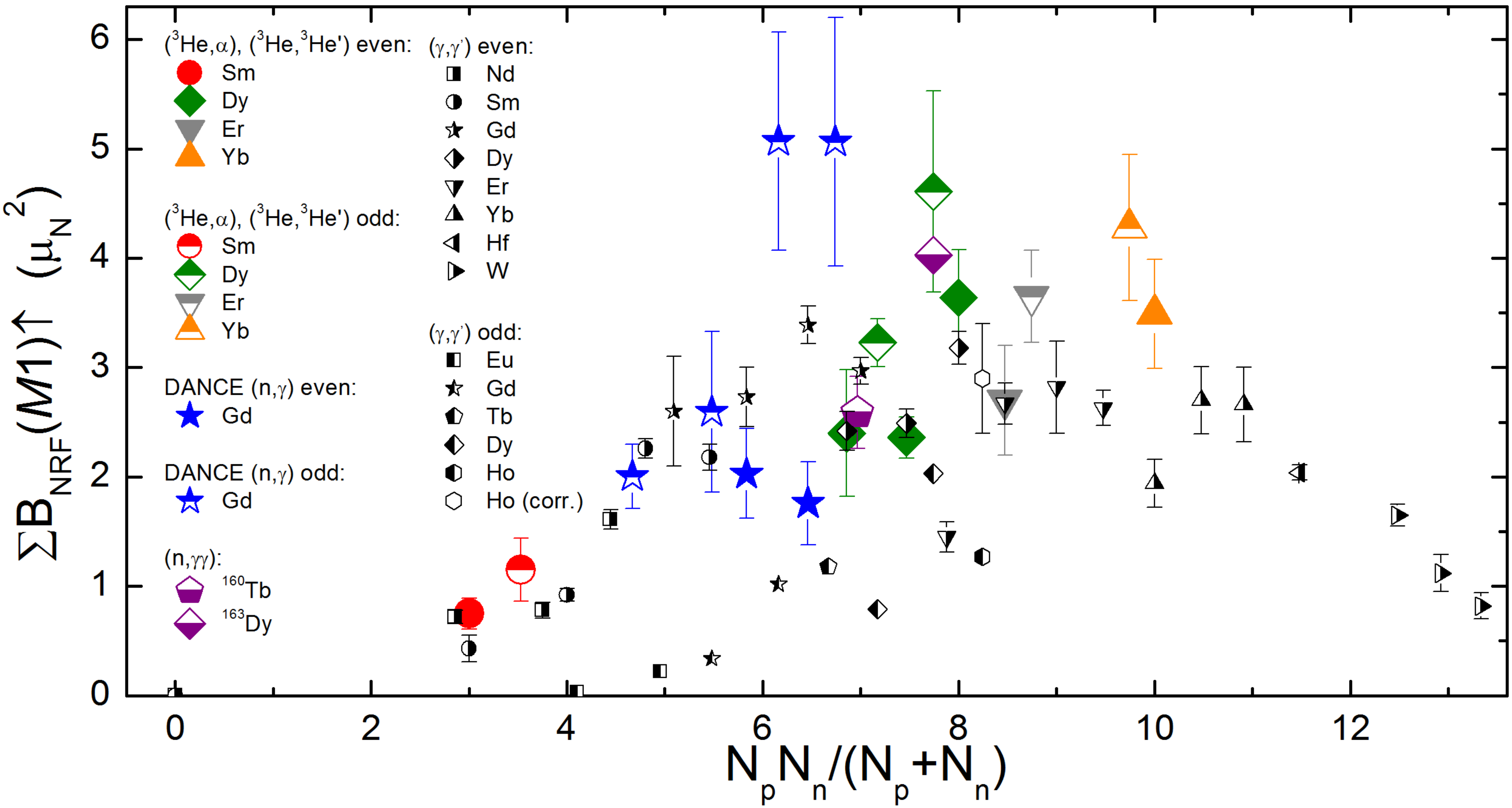
NRF data [black] U. Kneissl *et al.,* Prog. Part. Nucl. Phys. **37**, 349 (1996).
^{148}**Sm** [red] S. Siem *et al.,* PRC **65**, 044314 (2002); ^{160,162}**Dy** [red] M. Guttormsen *et al.,* PRC **68**, 064306 (2003);
^{164}**Dy** [red] H.T. Nyhus *et al.,* PRC **81**, 024325 (2010); ^{166}**Er** [red] E. Melby *et al.,* PRC **63**, 044309 (2001);
^{172}**Yb** [red] A. Voinov *et al.,* PRC **63**, 044313 (2001);
^{158}**Gd** [blue] A. Chyzh *et al.,* PRC **84**, 014306 (2011); ^{156}**Gd** [blue] B. Baramsai *et al.,* PRC **87**, 044609 (2013).

ΣB(*M1*,2.7-3.7)↑ in odd / odd-odd nuclei



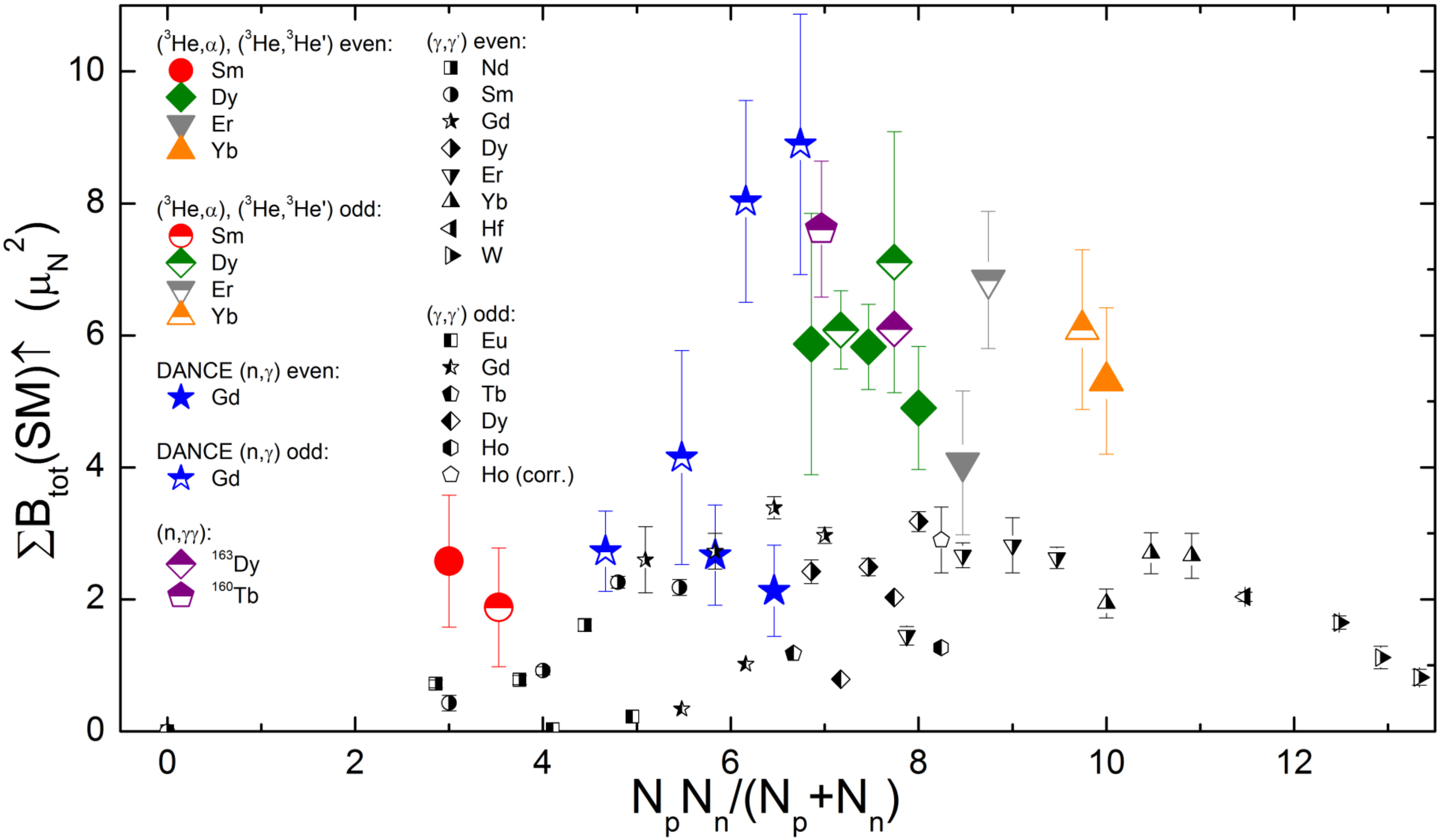
NRF data [black] A. Nord *et al.,* Phys. Rev. C **67,** 034307 (2003).
^{149}**Sm** [red] S. Siem *et al.*, PRC **65**, 044314 (2002); ^{161}**Dy** [red] M. Guttormsen *et al.,* PRC **68**, 064306 (2003);
^{163}**Dy** [red] H.T. Nyhus *et al.,* PRC **81**, 024325 (2010); ^{167}**Er** [red] E. Melby *et al.*, PRC **63**, 044309 (2001);
^{171}**Yb** [red] A. Voinov *et al.*, PRC **63**, 044313 (2001);
^{153,155,157,159}**Gd** [blue] J. Kroll *et al.,* EPJ Web of Conferences 21, 04005 (2012); J. Kroll *et al.,* Phys. Scr. T **154**, 014009 (2013).
^{163}**Dy** [purple] M. Krtička *et al.* PRL 92, 175501 (2004); ^{160}**Tb** [purple] J. Kroll *et al.*, Int. Jour. Mod. Phys. E, V. 20, N. 2, 526 (2011).

ΣB(*M1*,2.7-3.7)↑ all data together



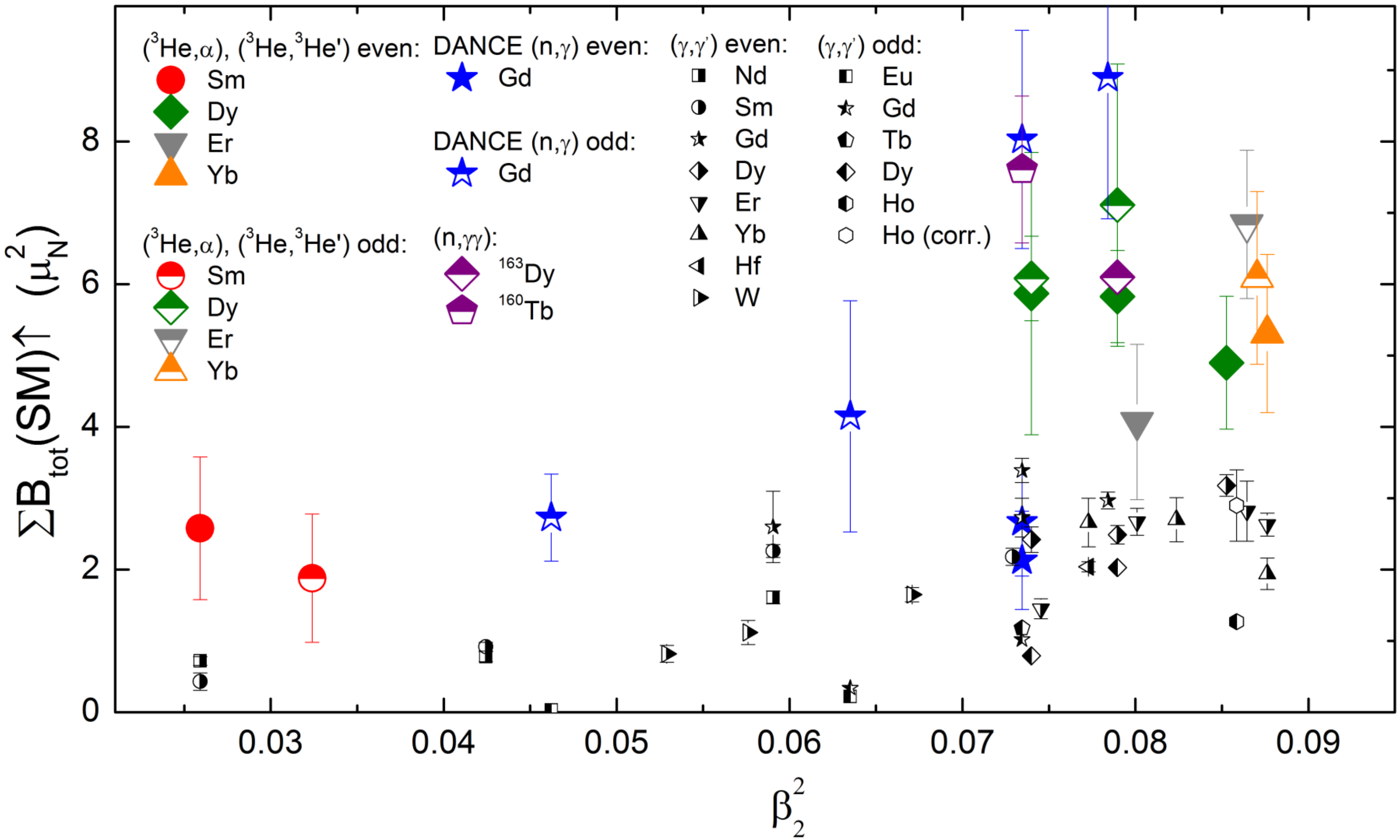
NRF data even [black] U. Kneissl *et al.,* Prog. Part. Nucl. Phys. **37**, 349 (1996).
NRF data odd [black] A. Nord *et al.,* Phys. Rev. C **67,** 034307 (2003).
^{148,149}Sm [red] S. Siem *et al.*, PRC **65**, 044314 (2002); **^{160,161,162}Dy** [red] M. Guttormsen *et al.*, PRC **68**, 064306 (2003);
^{163,164}Dy [red] H.T. Nyhus *et al.,* PRC **81**, 024325 (2010); **^{166,167}Er** [red] E. Melby *et al.*, PRC **63**, 044309 (2001);
^{171,172}Yb [red] A. Voinov *et al.*, PRC **63**, 044313 (2001);
^{158}Gd [blue] A. Chyzh *et al.,* PRC **84**, 014306 (2011); **^{156}Gd** [blue] B. Baramsai *et al.,* PRC **87**, 044609 (2013).
^{153,155,157,159}Gd [blue] J. Kroll *et al.,* EPJ Web of Conferences 21, 04005 (2012); J. Kroll *et al.,* Phys. Scr. T **154**, 014009 (2013).
^{163}Dy [purple] M. Krtička *et al.* PRL 92, 175501 (2004); **^{160}Tb** [purple] J. Kroll *et al.*, Int. Jour. Mod. Phys. E, V. 20, N. 2, 526 (2011).

$\Sigma B_{tot}(SM)\uparrow$ all data together



NRF data even [black] U. Kneissl *et al.,* Prog. Part. Nucl. Phys. **37**, 349 (1996).
NRF data odd [black] A. Nord *et al.,* Phys. Rev. C **67,** 034307 (2003).
^{148,149}Sm [red] S. Siem *et al.*, PRC **65**, 044314 (2002); **^{160,161,162}Dy** [red] M. Guttormsen *et al.,* PRC **68**, 064306 (2003);
^{163,164}Dy [red] H.T. Nyhus *et al.,* PRC **81**, 024325 (2010); **^{166,167}Er** [red] E. Melby *et al.*, PRC **63**, 044309 (2001);
^{171,172}Yb [red] A. Voinov *et al.*, PRC **63**, 044313 (2001);
^{158}Gd [blue] A. Chyzh *et al.,* PRC **84**, 014306 (2011); **^{156}Gd** [blue] B. Baramsai *et al.,* PRC **87**, 044609 (2013).
^{153,155,157,159}Gd [blue] J. Kroll *et al.,* EPJ Web of Conferences 21, 04005 (2012); J. Kroll *et al.,* Phys. Scr. T **154**, 014009 (2013).
^{163}Dy [purple] M. Krtička *et al.* PRL 92, 175501 (2004); **^{160}Tb** [purple] J. Kroll *et al.*, Int. Jour. Mod. Phys. E, V. 20, N. 2, 526 (2011).

$\Sigma B_{tot}(SM)\uparrow$ all data together



NRF data even [black] U. Kneissl *et al.,* Prog. Part. Nucl. Phys. **37**, 349 (1996).
NRF data odd [black] A. Nord *et al.,* Phys. Rev. C **67,** 034307 (2003).
^{148,149}Sm [red] S. Siem *et al.*, PRC **65**, 044314 (2002); **^{160,161,162}Dy** [red] M. Guttormsen *et al.*, PRC **68**, 064306 (2003);
^{163,164}Dy [red] H.T. Nyhus *et al.,* PRC **81**, 024325 (2010); **^{166,167}Er** [red] E. Melby *et al.*, PRC **63**, 044309 (2001);
^{171,172}Yb [red] A. Voinov *et al.*, PRC **63**, 044313 (2001);
^{158}Gd [blue] A. Chyzh *et al.,* PRC **84**, 014306 (2011); **^{156}Gd** [blue] B. Baramsai *et al.,* PRC **87**, 044609 (2013).
^{153,155,157,159}Gd [blue] J. Kroll *et al.,* EPJ Web of Conferences 21, 04005 (2012); J. Kroll *et al.,* Phys. Scr. T **154**, 014009 (2013).
^{163}Dy [purple] M. Krtička *et al.* PRL 92, 175501 (2004); **^{160}Tb** [purple] J. Kroll *et al.*, Int. Jour. Mod. Phys. E, V. 20, N. 2, 526 (2011).

Conclusions

- *M1* SM plays an important role in gamma deexcitation of studied Gd isotopes.
- *M1* SM is observed above the accessible excited states in all studied Gd nuclei.
- Values of $\Sigma B(M1, 2.7\text{-}3.7)\uparrow$ obtained for ^{156,158}Gd are slightly below the results of (γ,γ') experiments.
- We have gotten new results for $\Sigma B(M1)\uparrow$ present in odd rare-earth isotopes ^{153,155,157,159}Gd.
- Odd-even asymmetry of $\Sigma B(M1)\uparrow$ in ^{156,158}Gd and ^{157,159}Gd is in disagreement with the Oslo data for Dy isotopes.

DANCE collaboration

U. Agvaanluvsan[1], B. Baramsai[2], J.A. Becker[3], F. Bečvář[4], T.A. Bredeweg[5], A. Chyzh[2,3], A. Couture[5], D. Dashdorj[2,3], R.C. Haight[5], M. Jandel[5], A.L. Keksis[5], J. Kroll[4], M. Krtička[4], G.E. Mitchell[2], J.M. O'Donnell[5], W. Parker[3], R.S. Rundberg[5], J. L. Ullmann[5], S. Valenta[4], D.J. Vieira[5], C.L. Walker[2], J.B. Wilhelmy[5], J.M. Wouters[5] and C.Y. Wu[3]

[1] MonAme Scientific Research Center, P.O.Box 24-603, Ulaanbaatar, Mongolia

[2] North Carolina State University, Raleigh, North Carolina 27695, USA, and Triangle Universities Nuclear Laboratory, Durham, North Carolina 27708, USA

[3] Lawrence Livermore National laboratory, Livermore, California 94551, USA

[4] Charles University in Prague, Faculty of Mathematics and Physics, V Holešovičkách 2, CZ-180 00 Prague 8, Czech Republic

[5] Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

Prague group

F. Bečvář, M. Krtička, J. Kroll and S. Valenta

Charles University in Prague, Faculty of Mathematics and Physics, V Holešovičkách 2, CZ-180 00 Prague 8, Czech Republic