Candidates for low-lying octupole isovector (mixed-symmetry) excitations

CGS 17 – Grenoble

Marcus Scheck

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Physics Motivation: Low-lying octupole isovector (mixed-symmetry) levels

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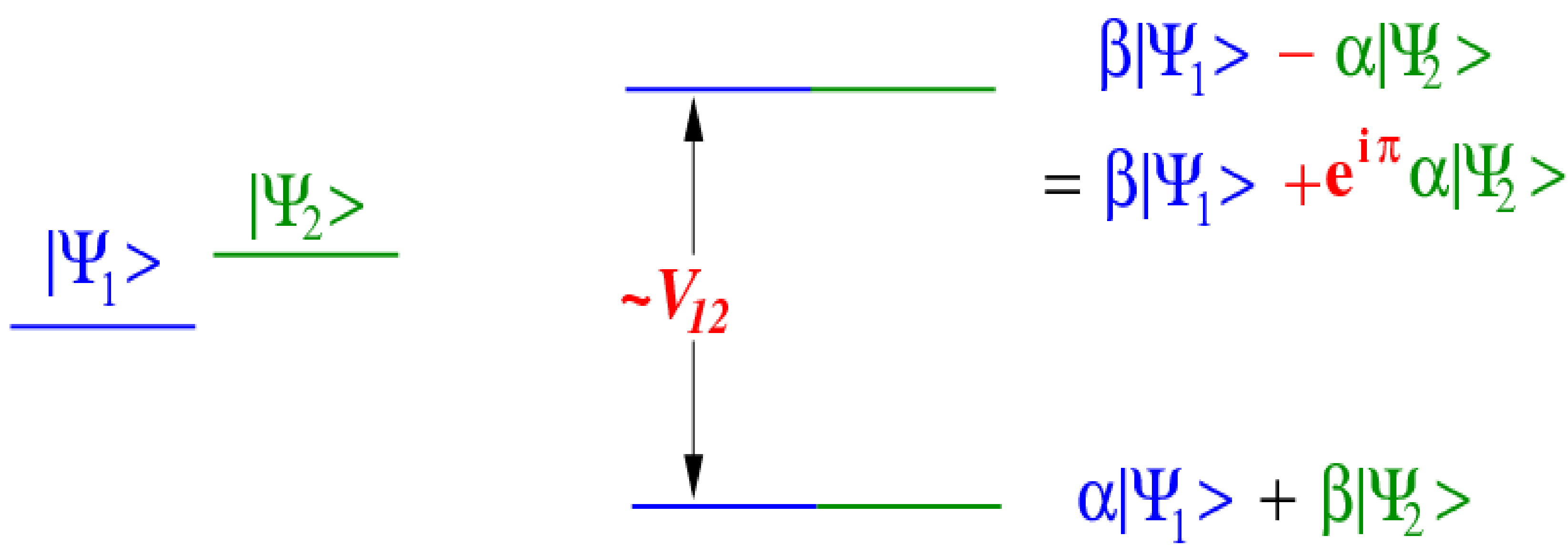
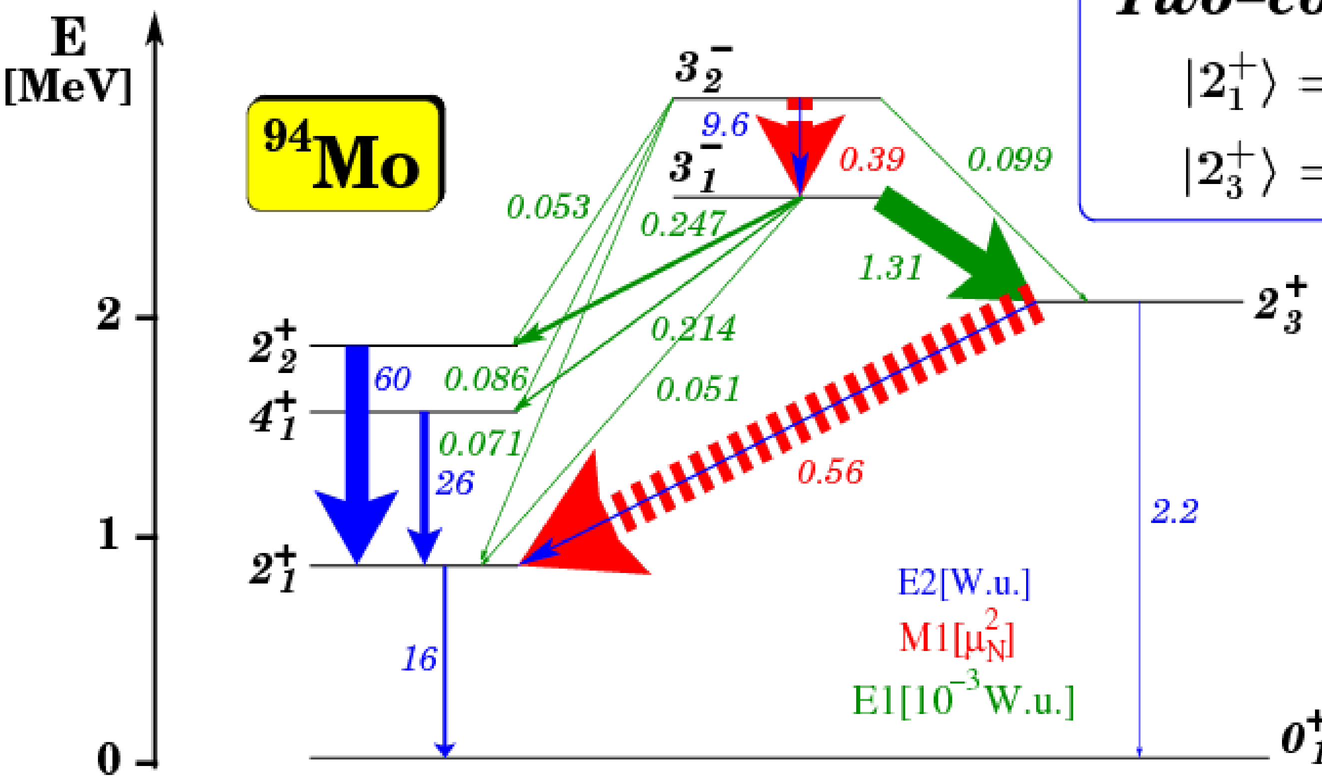
No interaction ***With interaction V_{12}***



$$\begin{pmatrix} H_0 & 0 \\ 0 & H_0 \end{pmatrix} \begin{pmatrix} \Psi_1 \\ \Psi_2 \end{pmatrix} = E_i \begin{pmatrix} \Psi_1 \\ \Psi_2 \end{pmatrix}$$

$$\begin{pmatrix} H_0 & V_{12} \\ V_{12} & H_0 \end{pmatrix} \begin{pmatrix} \Psi_1 \\ \Psi_2 \end{pmatrix} = E_i' \begin{pmatrix} \Psi_1 \\ \Psi_2 \end{pmatrix}$$

Physics Motivation:
Low-lying octupole isovector (mixed-symmetry) levels



Two–component system:

$$|2_1^+\rangle = \alpha|2_\pi^+\rangle + \beta|2_\nu^+\rangle$$

$$|2_3^+\rangle = \beta|2_\pi^+\rangle - \alpha|2_\nu^+\rangle$$

Theory:

proton-neutron octupole-octupole interaction

C.Fransen et al., PRC 67, 024307 (2003)

Physics Motivation: Low-lying octupole isovector (mixed-symmetry) levels

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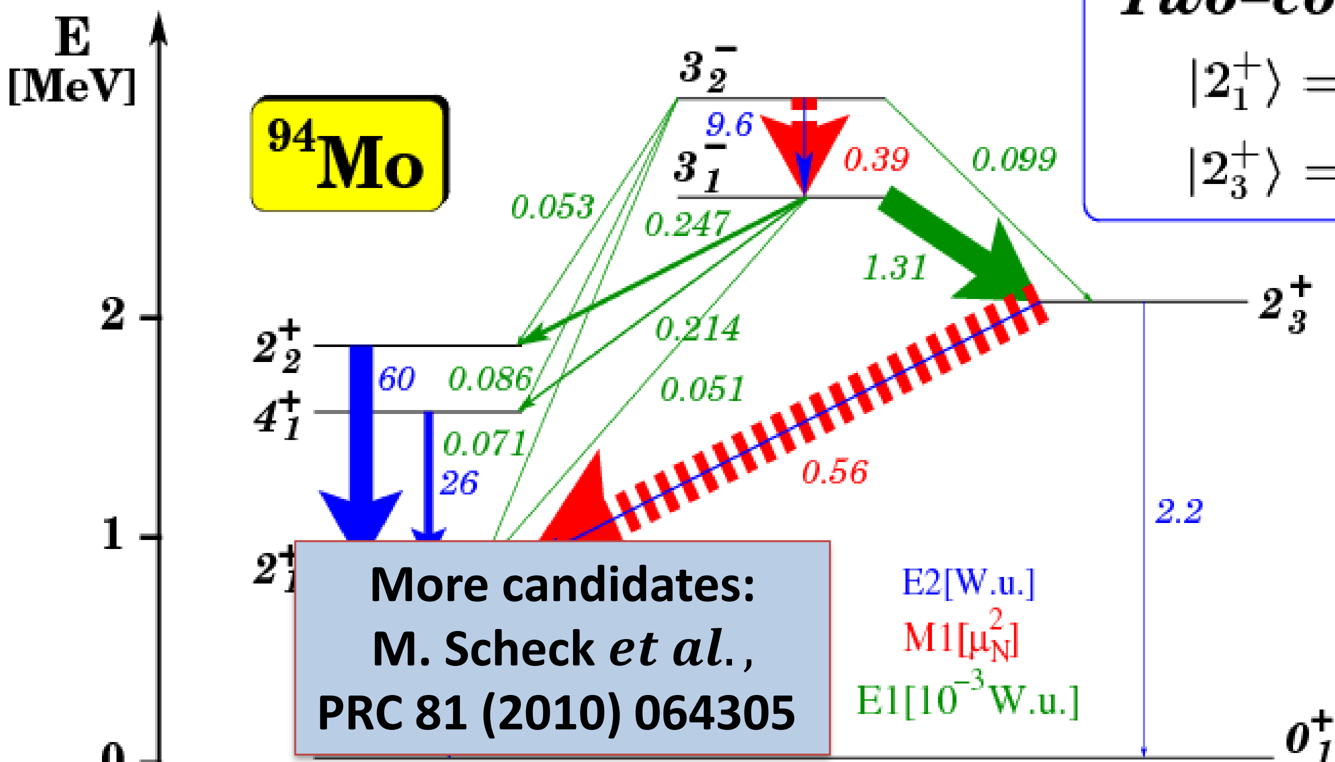

More candidates:
M. Scheck *et al.*,
PRC 81 (2010) 064305

Two–component system:

$$|2_1^+\rangle = \alpha|2_\pi^+\rangle + \beta|2_\nu^+\rangle$$

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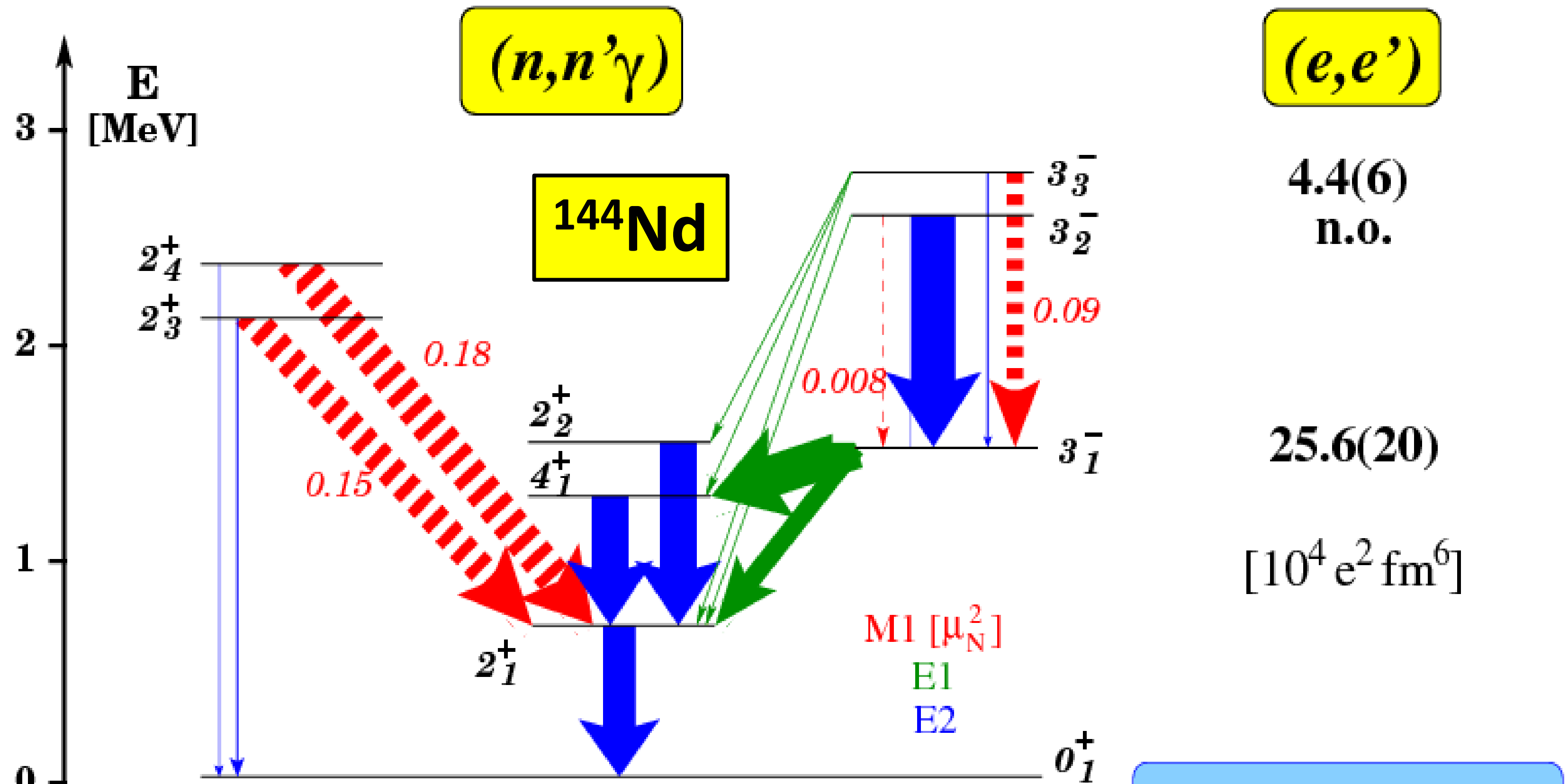

S.F.Hicks et al., PRC 57 (1998) 2264

P.Perini et al., NP A651 (1993) 343

Experimental motivation (uncertainties in data)

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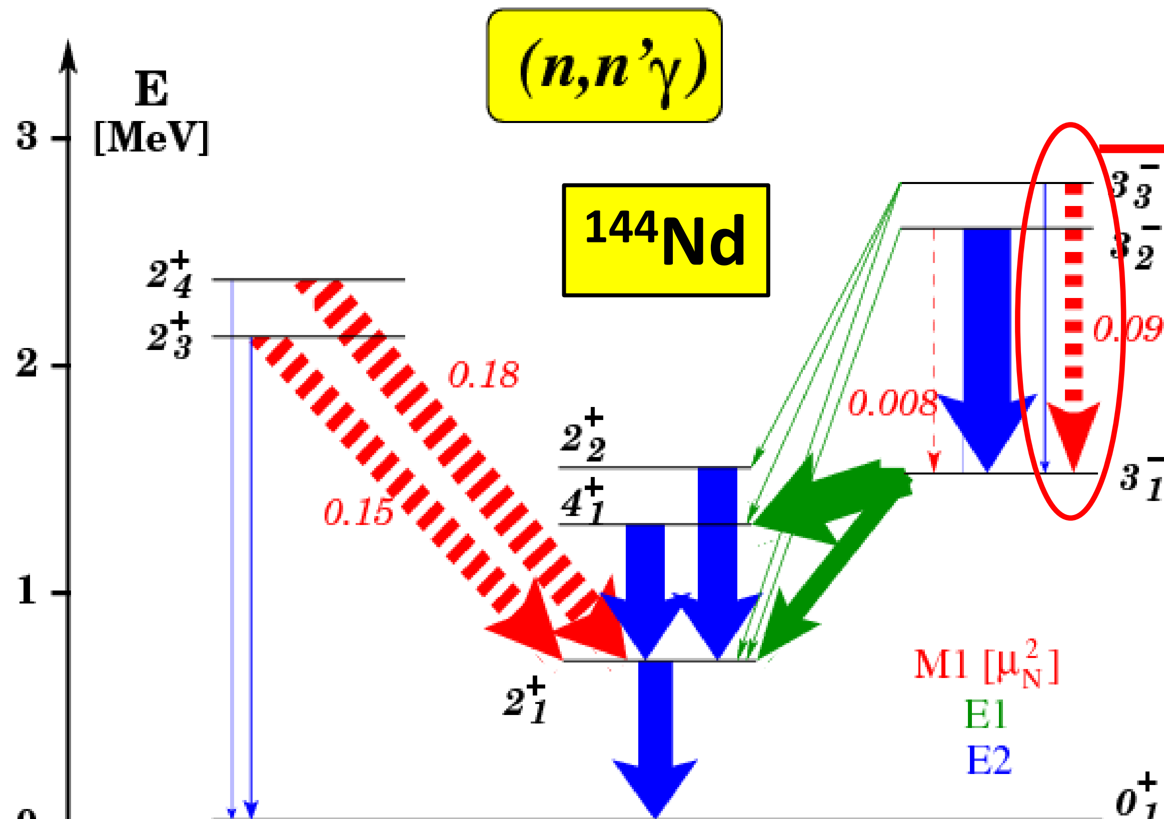


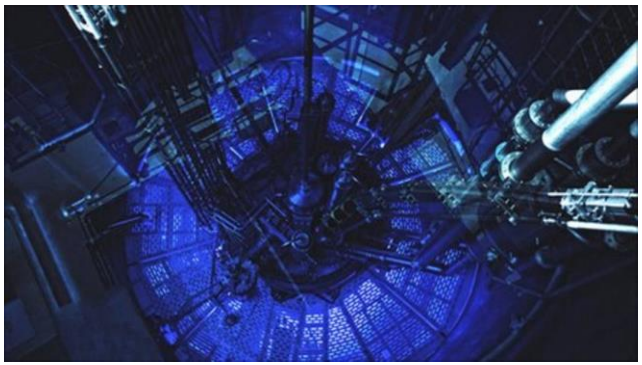
S.F.Hicks et al., PRC 57 (1998) 2264

Doublet with
(2^+) 2828 keV
⇒ (2_2^+) 1560 keV transition

(n,n'γ) data only 'singles' ⇒
How reliable are multipole-mixing ratio δ and relative intensity?

(n,n'γ) 'singles':
heavy open-shell nucleus
⇒ spectra:
high peak density
≈ 3 MeV
upper limit for (n,n'γ)

EXILL (EXogam at ILL): high statistics (n_{th},$\gamma\gamma$)

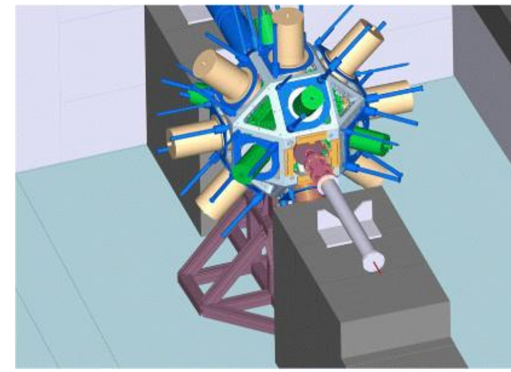


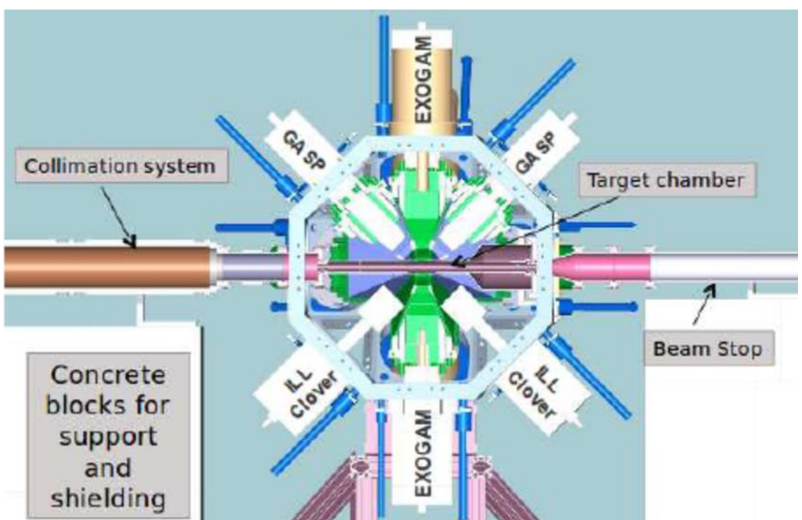
At target:

$$\phi_n \approx 5 \times 10^7 \frac{n}{s \cdot cm^2}$$

$$\sigma_{n_{th}} \cdot m_{target} \approx 250\ mg \cdot b$$

(good HPGe counts rates)



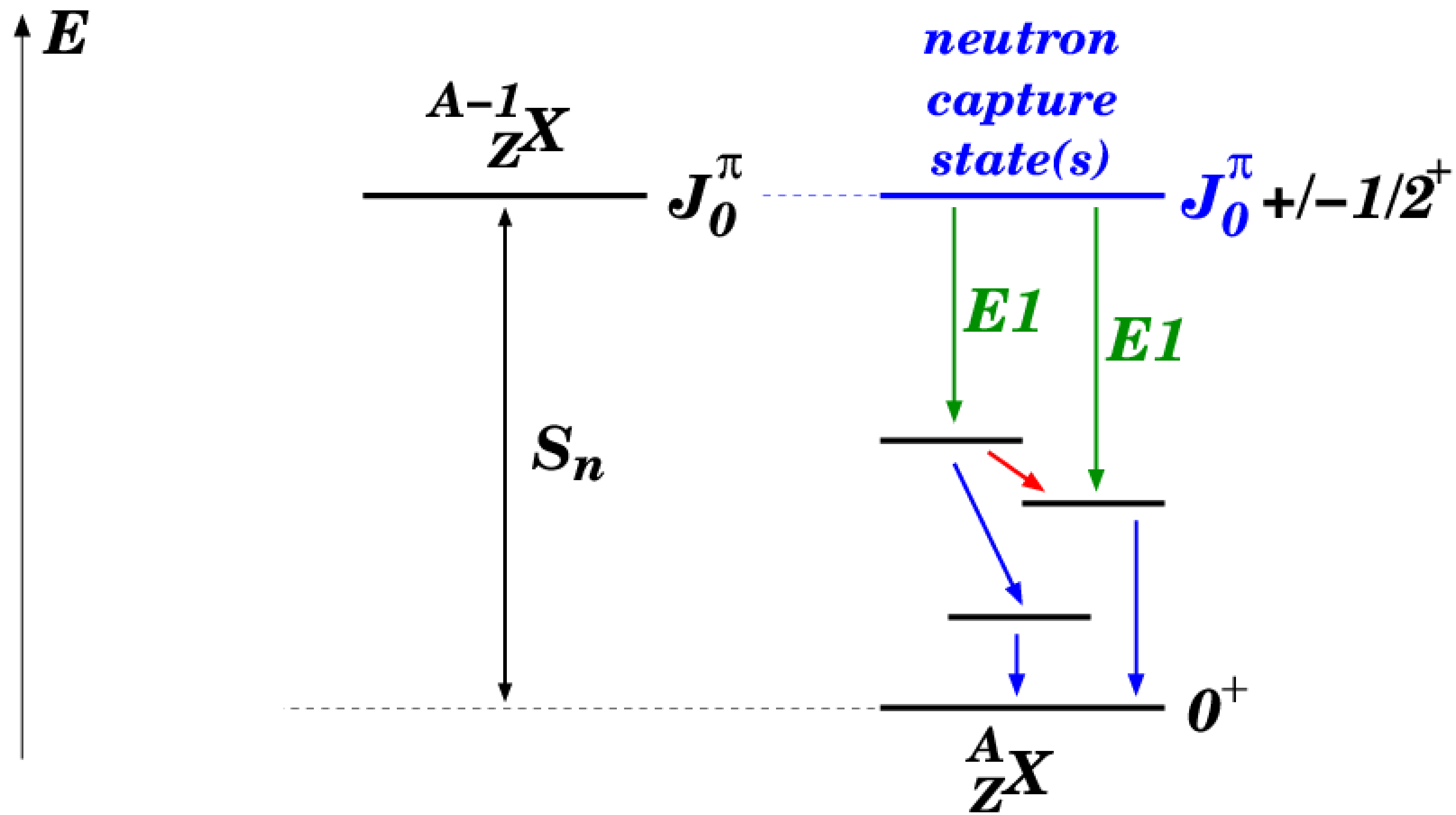


^{143}Nd(n_{th},$\gamma\gamma$) and ^{95}Mo(n_{th},$\gamma\gamma$) :
(only) 8 Clover detectors at $\Theta = 90^o$
octagonal symmetry ⇒ 4 angular groups
$(45^o, 90^o, 135^o$, and $180^o)$

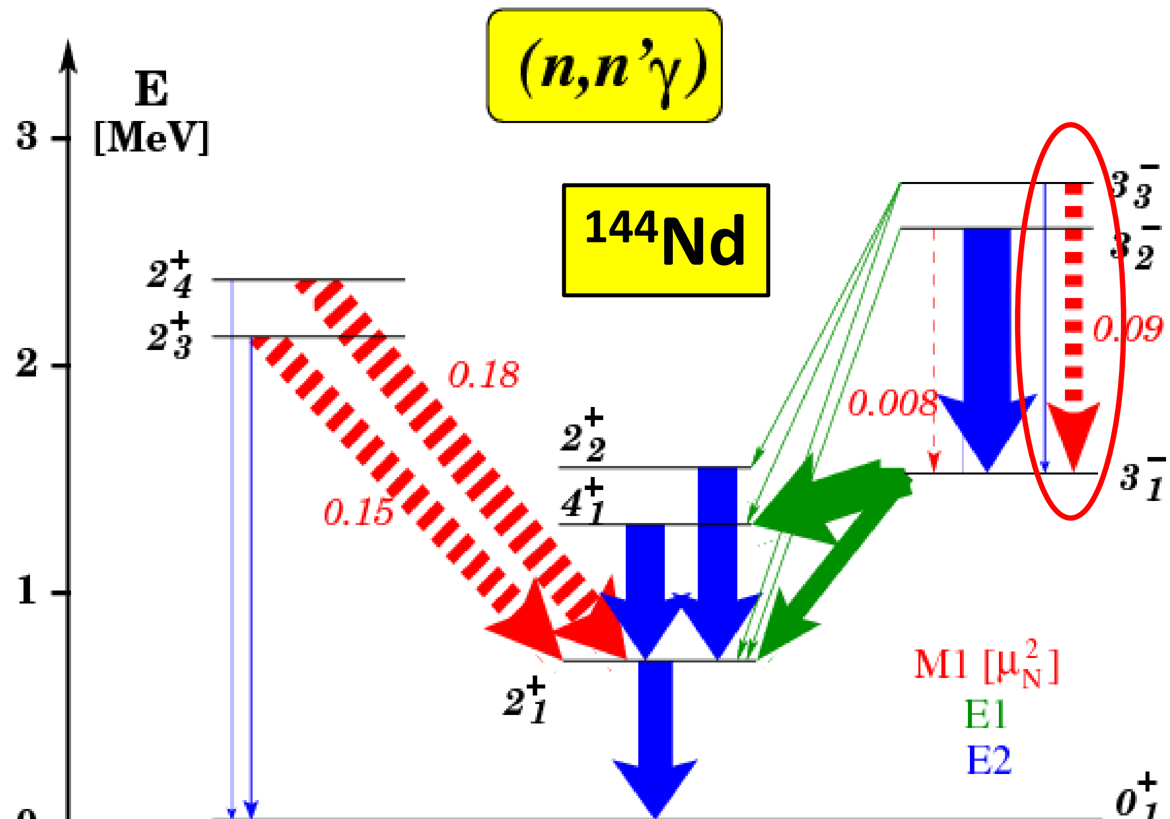
Nucleus	m_{target} [mg]	t_{mess} [hours]
^{95}Mo	17	22
^{143}Nd	0.8	20

A.Blanc et al., Eur. Phys. Jour. Conf. **93** (2015) 01015

${}^{A-1}_{Z}X(\mathrm{n_{th}},\gamma\gamma)$ reaction (in simple terms)



^{144}Nd
3_3^- octupole isovector candidate



S.F.Hicks et al., PRC 57 (1998) 2264

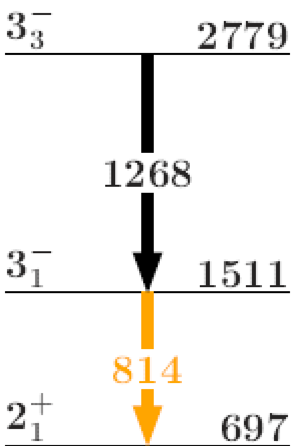
^{143}Nd: $J_0^\pi = 7/2^-$
$\Rightarrow J_{NCS}^\pi = 3^-$ or 4^-

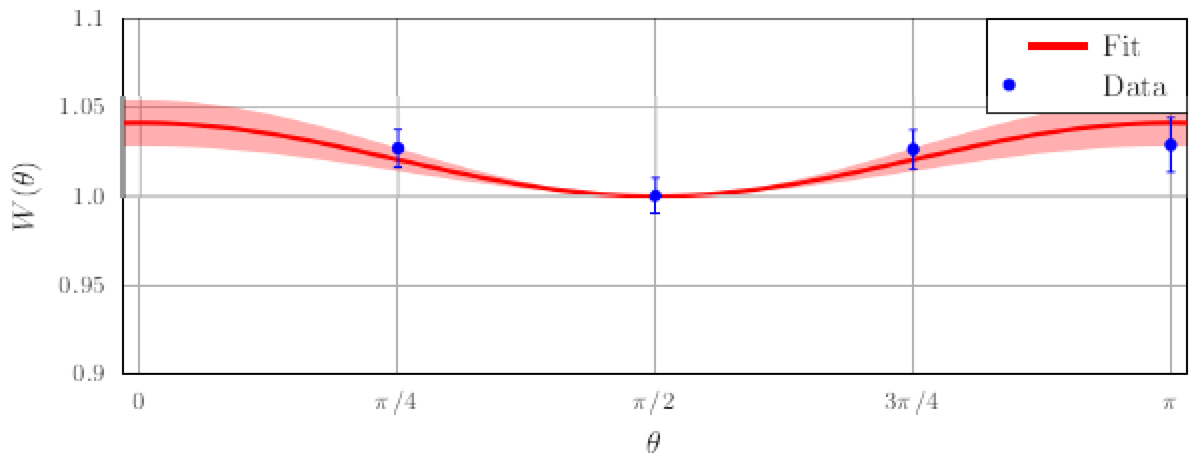
S_n(^{144}Nd): 7817 keV

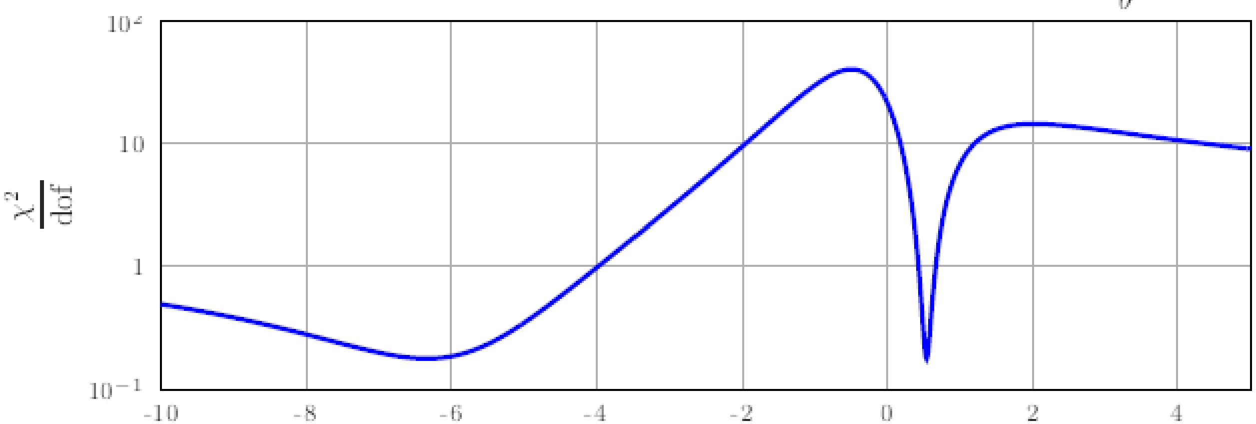
Literature:
$\delta(3_2^- \rightarrow 3_1^-) = 3_{-3}^{+13}$
$\delta(3_3^- \rightarrow 3_1^-) = 0.37_{-11}^{+17}$
$\tau(3_3^-) = 94_{-34}^{+75}$ fs

^{144}Nd
3_3^- octupole isovector candidate

$$W(\theta) = 1 + A_2(\delta)q_2P_2(cos\theta) + A_4(\delta)q_4P_4(cos\theta)$$





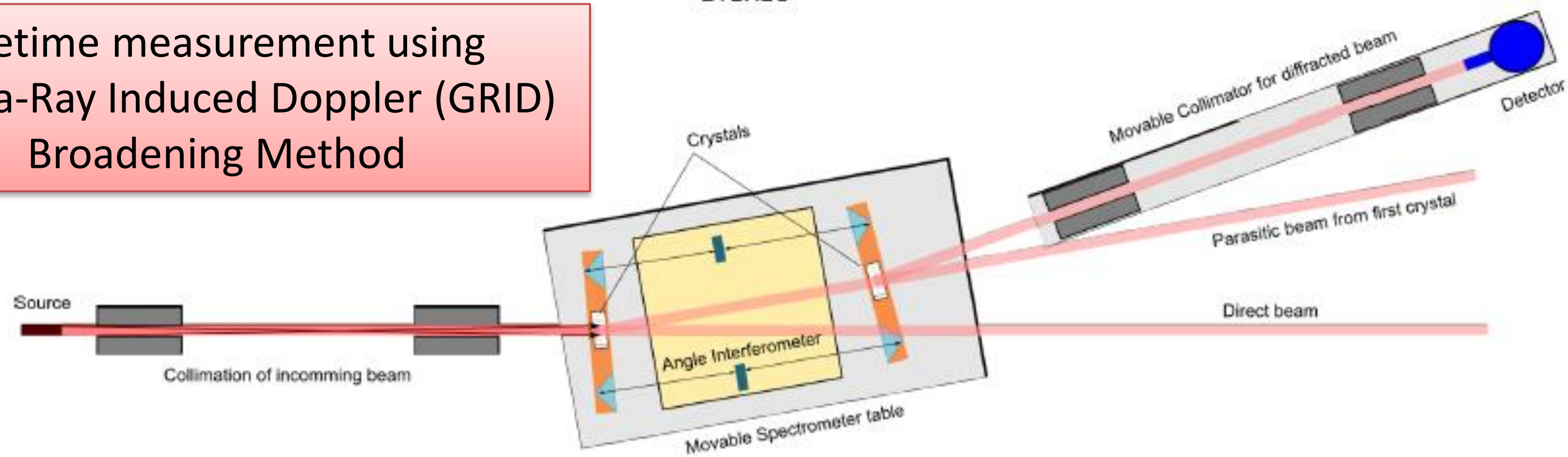


Fit
$$|\delta(3_3^- \rightarrow 3_1^-)| = 0.54(4)$$

Literature:
$$|\delta(3_3^- \rightarrow 3_1^-)| = 0.37^{+17}_{-11}$$

^{144}Nd
3_3^- octupole isovector candidate

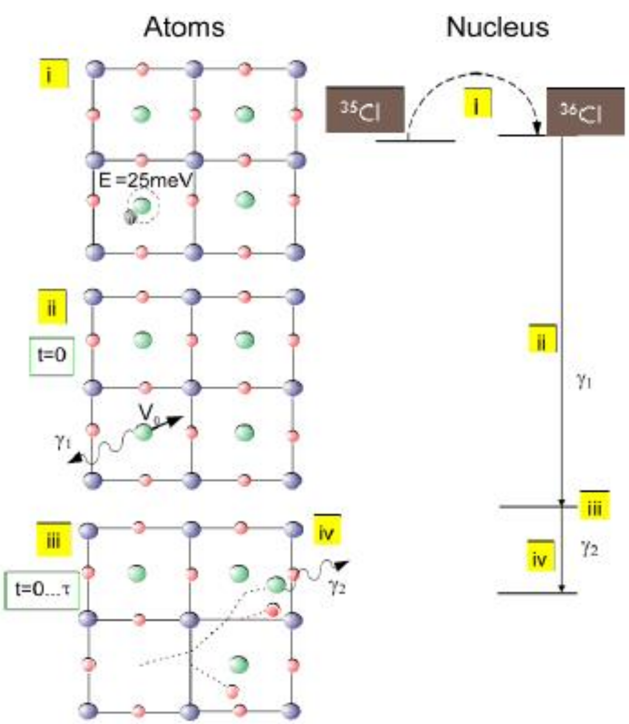
Lifetime measurement using Gamma-Ray Induced Doppler (GRID) Broadening Method

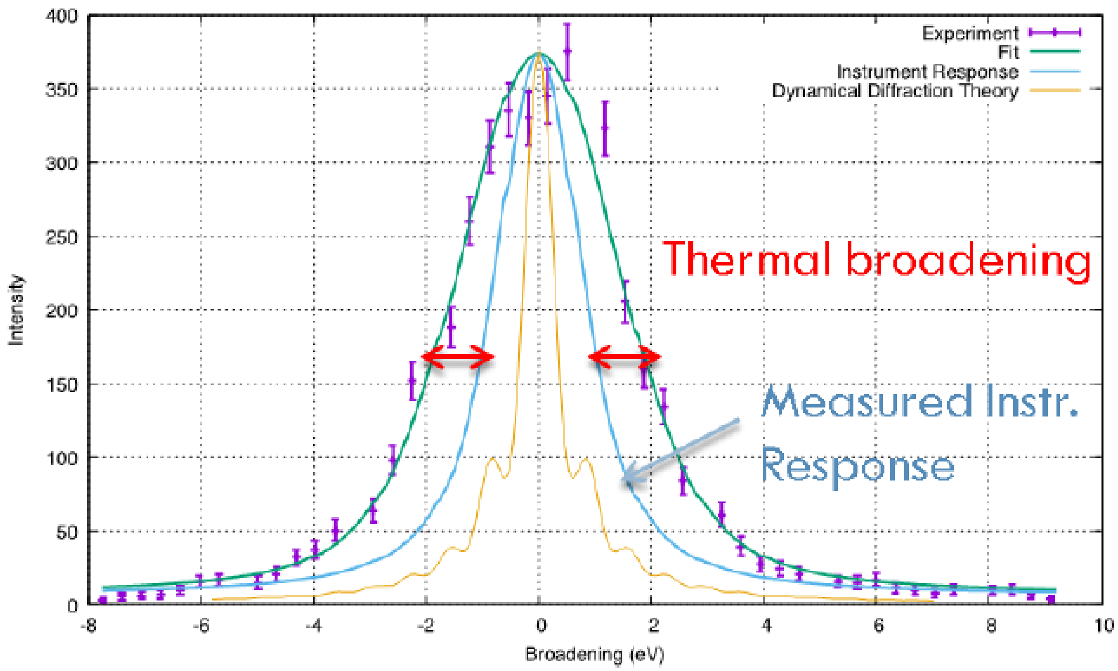


H.G.Boerner and J.Jolie, J.Phys.G. **19** (1993) 217

Literature:
$\boldsymbol{\tau(3_3^-) = 94^{+75}_{-34}}$ **fs**

lifetime measurement: GRID – Gamma-Ray Induced Doppler-broadening method



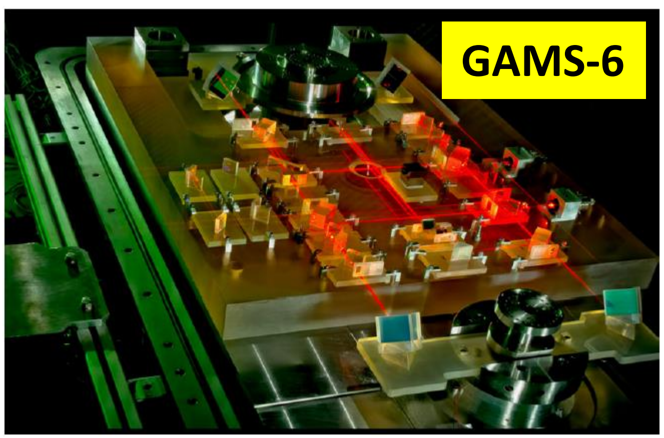


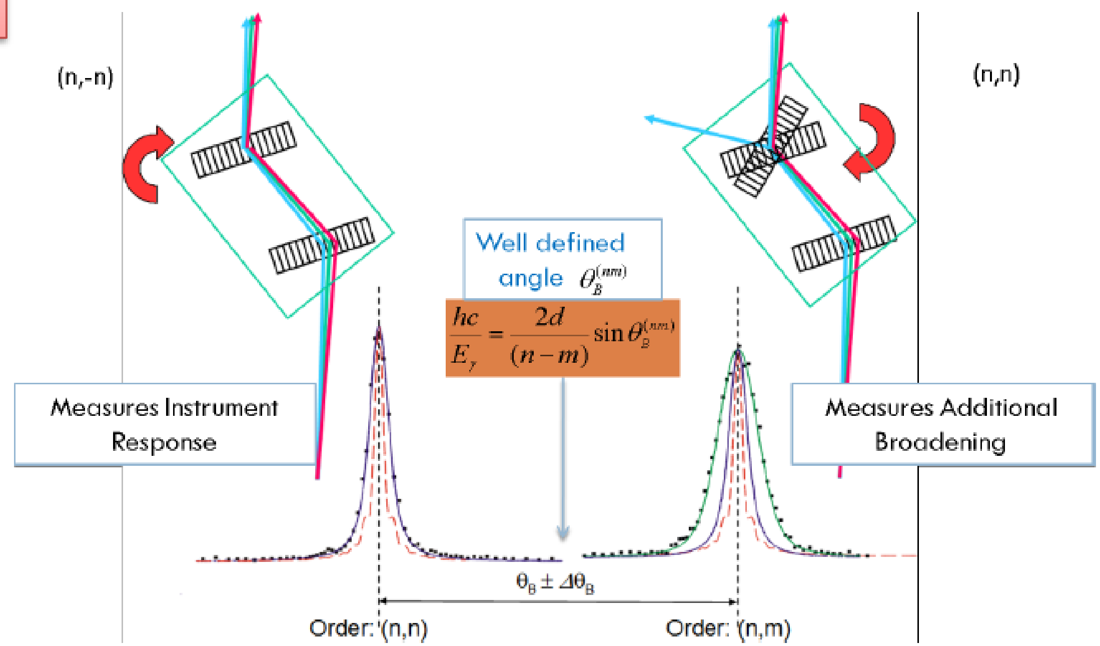
Courtesy: Michael Jentschel, ILL

Literature:
$\tau(2_1^+) = 4.28(7)$**ps**

^{144}Nd
3_3^- octupole isovector candidate

Lifetime measurement using
Gamma-Ray induced Doppler (GRID)
Broadening Method





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^{144}Nd
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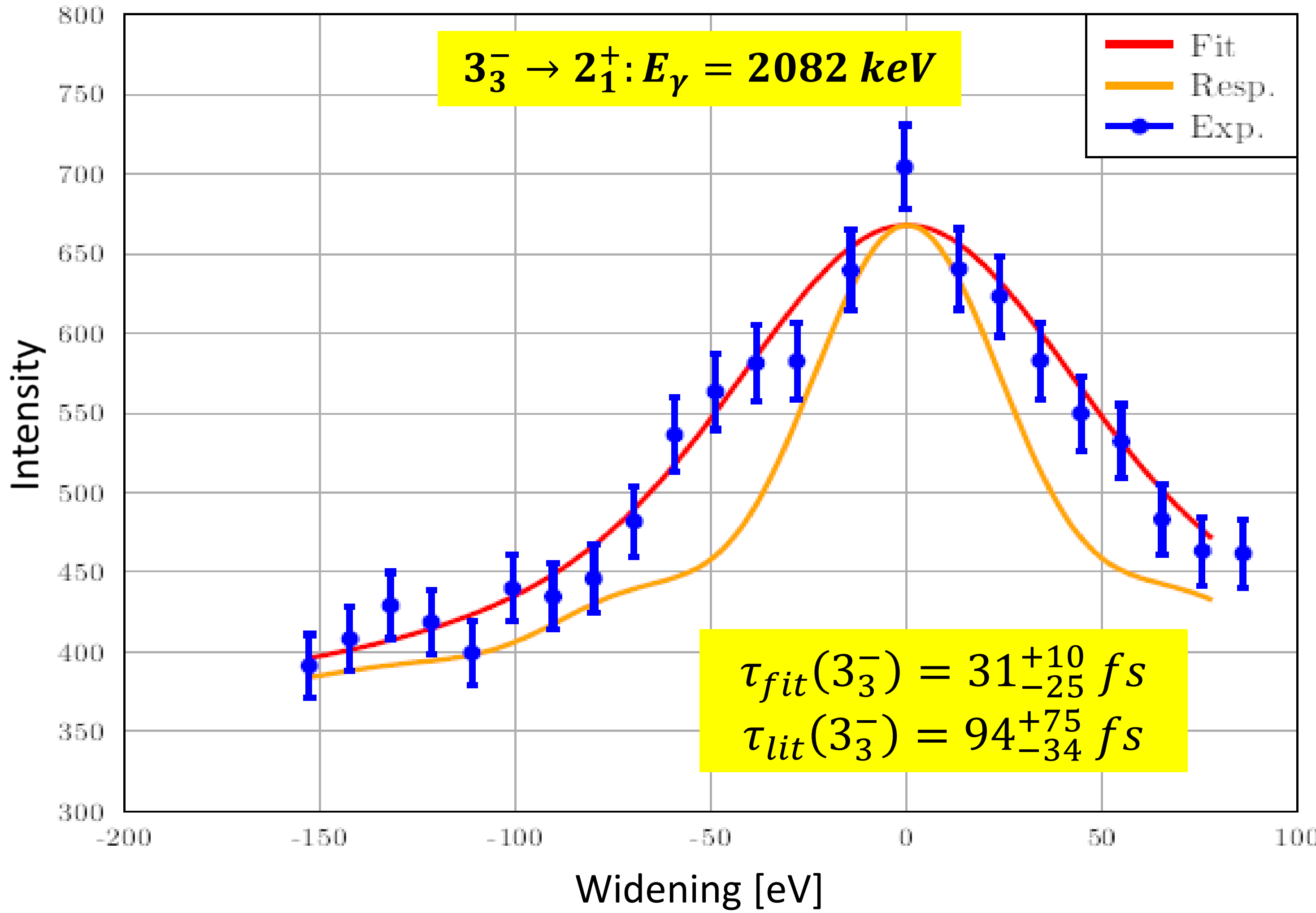


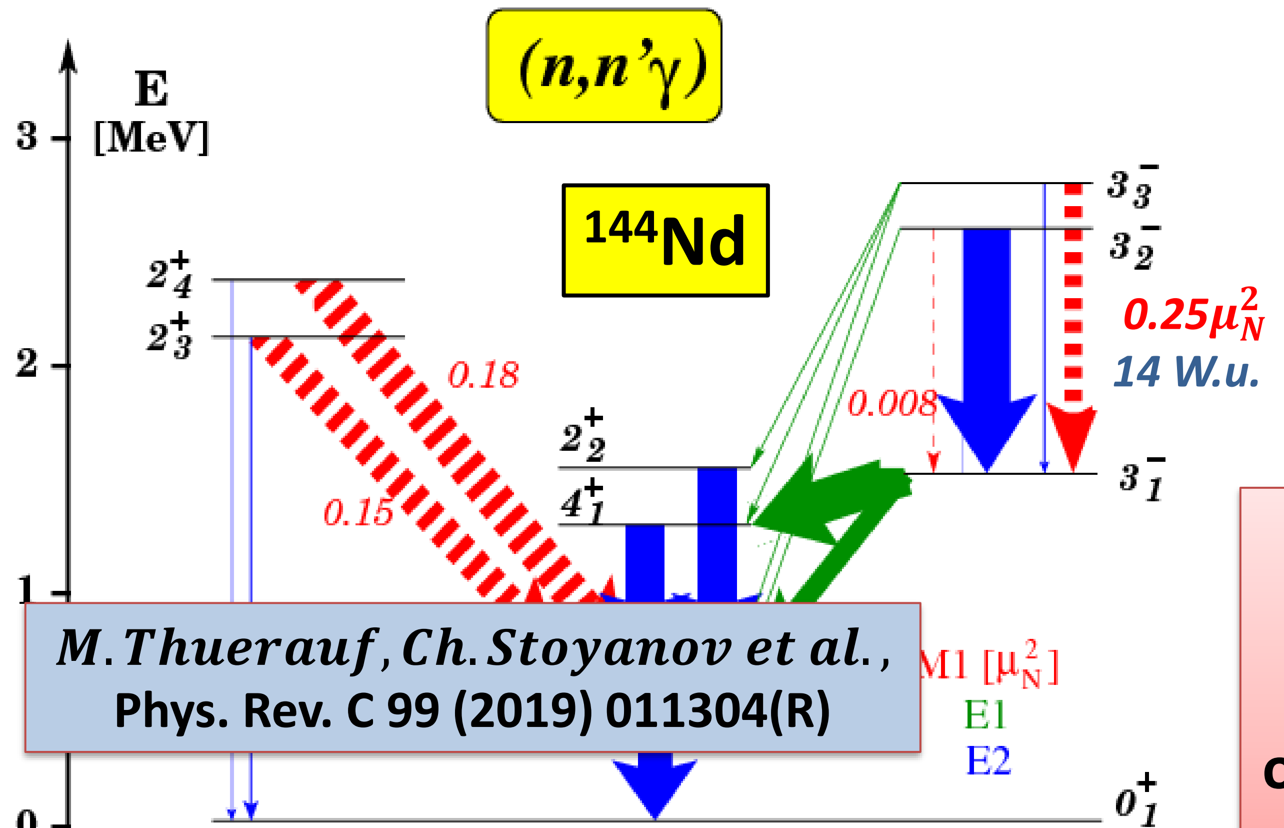
^{144}Nd
3_3^- octupole isovector candidate

$J_i \rightarrow J_f$	E_i	E_γ	$\tau(J_i)$	σL	Expt. – this work			QPM	
					b	δ	$B(\sigma L)$	E_i^{calc}	$B(\sigma L)$
$3_1^- \rightarrow 0_1^+$	1511	1511	[a]810^{+110}_{-90}	$E3$			[b]33.9(17)	1200	21.0
$3_2^- \rightarrow 0_1^+$	2606	2606	[c]153^{+30}_{-16}	$E3$			[d]1.1(1)	2820	2.0
$3_2^- \rightarrow 3_1^-$		1095		$M1$	18.8(3)	2.0^{+25}_{-8}	0.013(11)		0.04
				$E2$			11^{+5}_{-4}		3.2
$3_3^- \rightarrow 0_1^+$	2779	2779	31^{+10}_{-25}	$E3$			[b] 7.3(7)	2904	7.4
$3_3^- \rightarrow 3_1^-$		1268		$M1$	35.4(5)	0.54(4)	$0.25^{+1.09}_{-0.08}$		0.17
				$E2$			14^{+70}_{-5}		19.0

M. Thuerauf, Ch. Stoyanov et al.,
Phys. Rev. C 99 (2019) 011304(R)

QPM (Ch. Stoyanov):
3_3^- state is isovector;
However, calculation indicates
3_3^- state rather two (quasi-)particle

^{144}Nd
3_3^- octupole isovector candidate



M. Thuerauf, Ch. Stoyanov et al.,
Phys. Rev. C 99 (2019) 011304(R)

S.F.Hicks et al., PRC 57 (1998) 2264

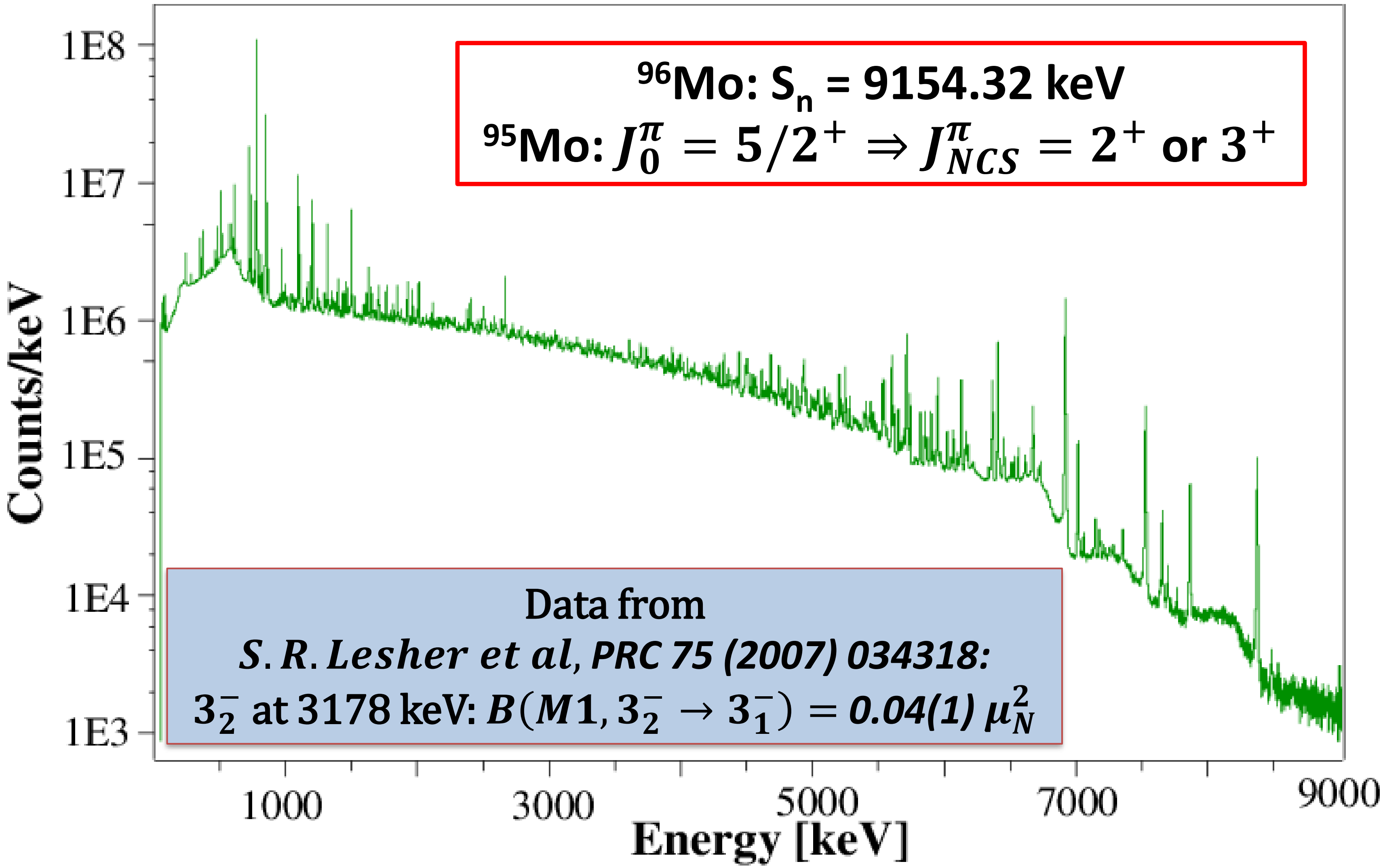
$$\langle 3_1^- \left\| \widehat{M1} \right\| 3_3^- \rangle = 1.32\ \mu_N$$

3_3^- remains a candidate for a low-lying octupole isovector state

$^{95}Mo(n_{th},\gamma\gamma)^{96}Mo$ projection total $\gamma\gamma$ matrix

^{96}Mo: S_n = 9154.32 keV

^{95}Mo: $J_0^\pi = 5/2^+ \Rightarrow J_{NCS}^\pi = 2^+$ or 3^+



Data from

S. R. Lesher et al, PRC 75 (2007) 034318:

3_2^- at 3178 keV: $B(M1, 3_2^- \rightarrow 3_1^-) = 0.04(1)\ \mu_N^2$

^{96}Mo
3_2^- octupole isovector candidate

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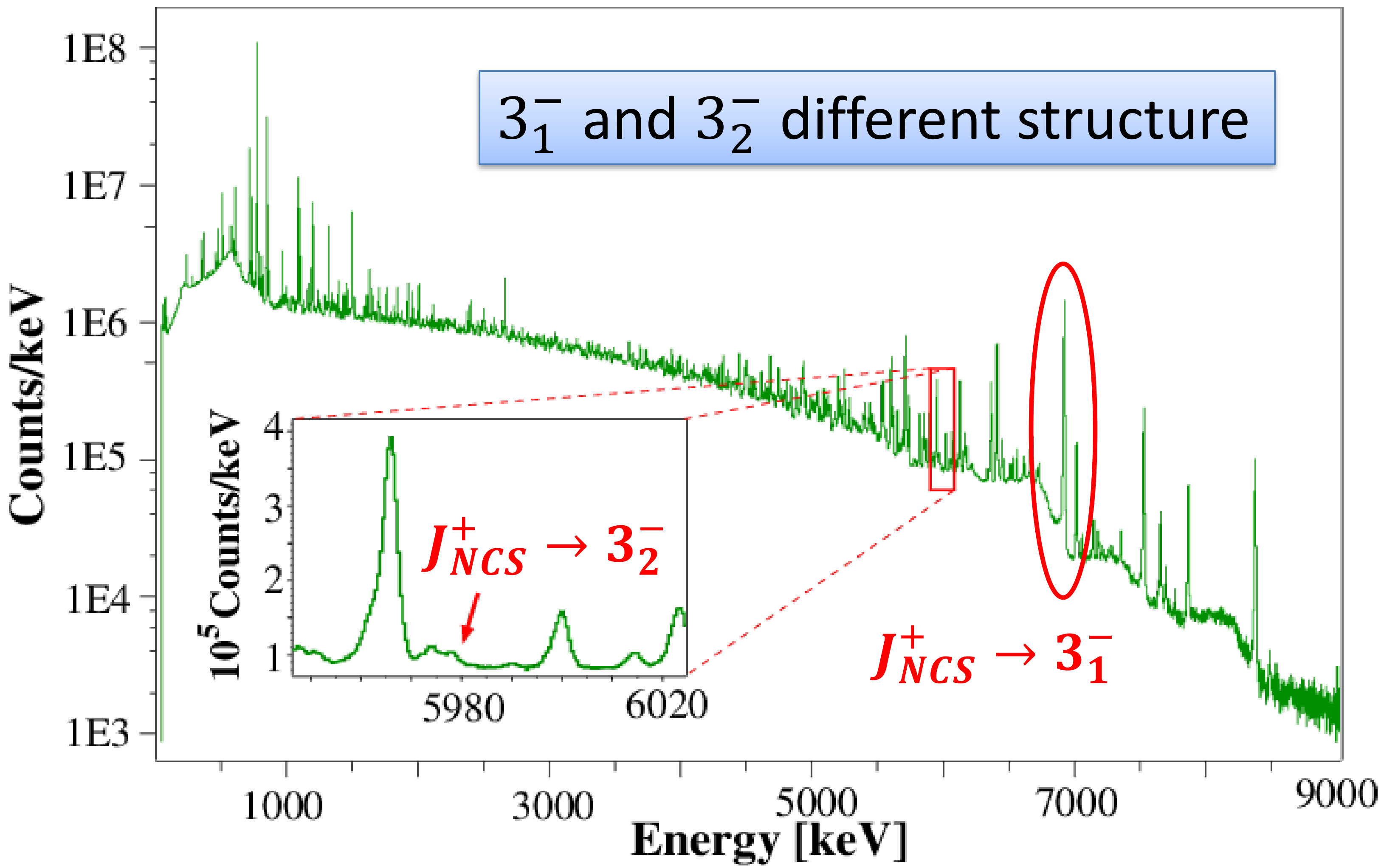
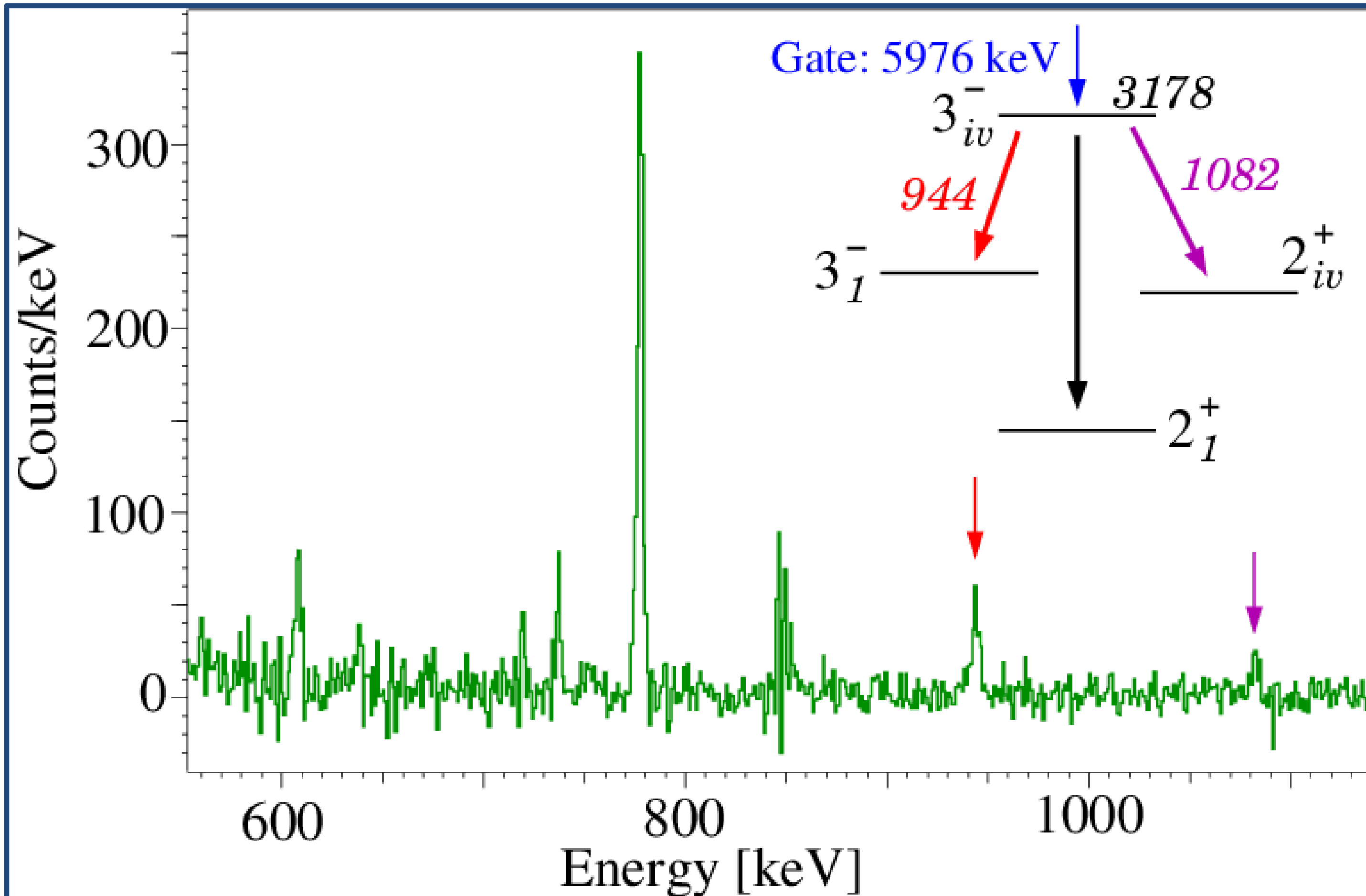
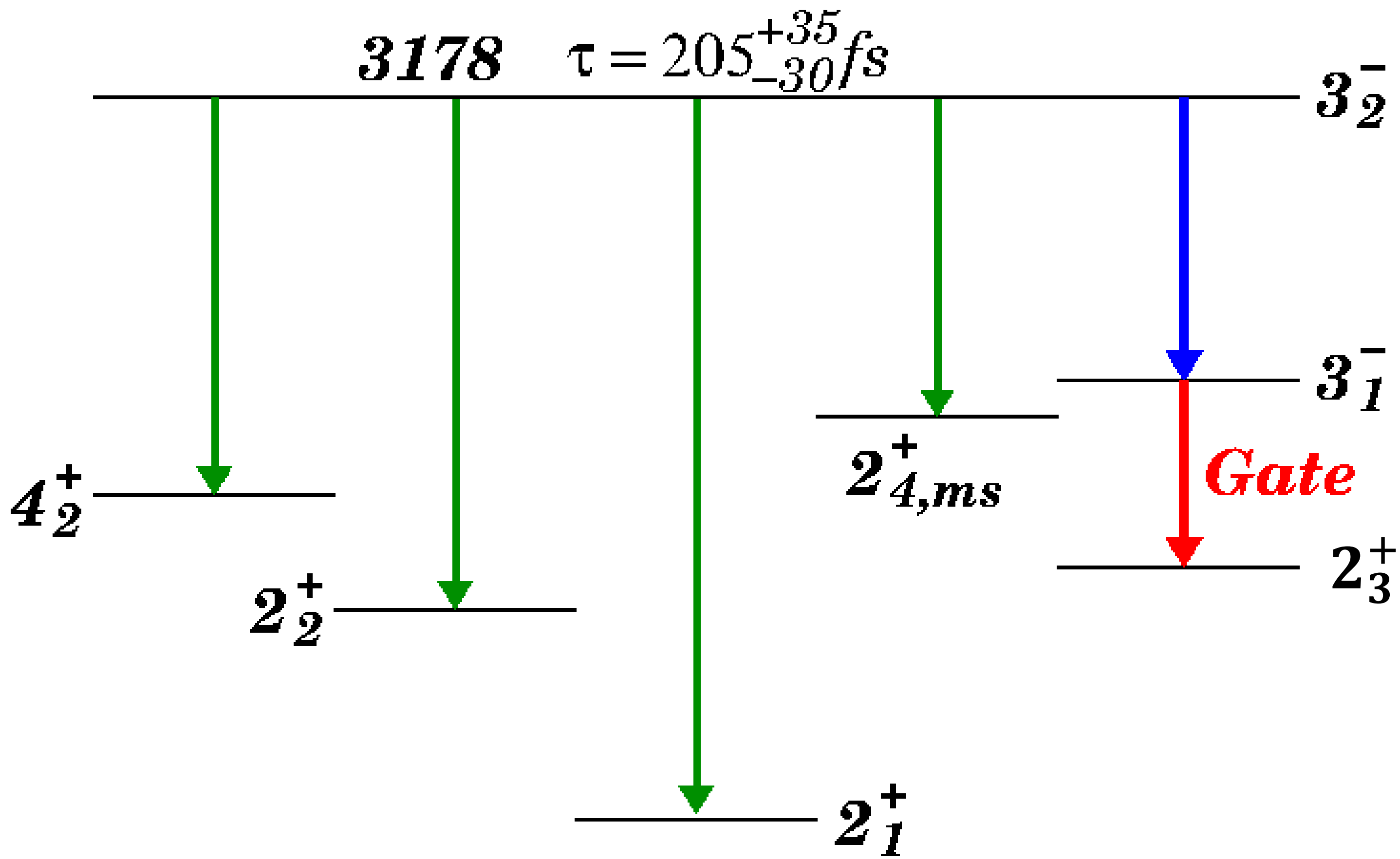


^{96}Mo

3^-_2 octupole isovector candidate

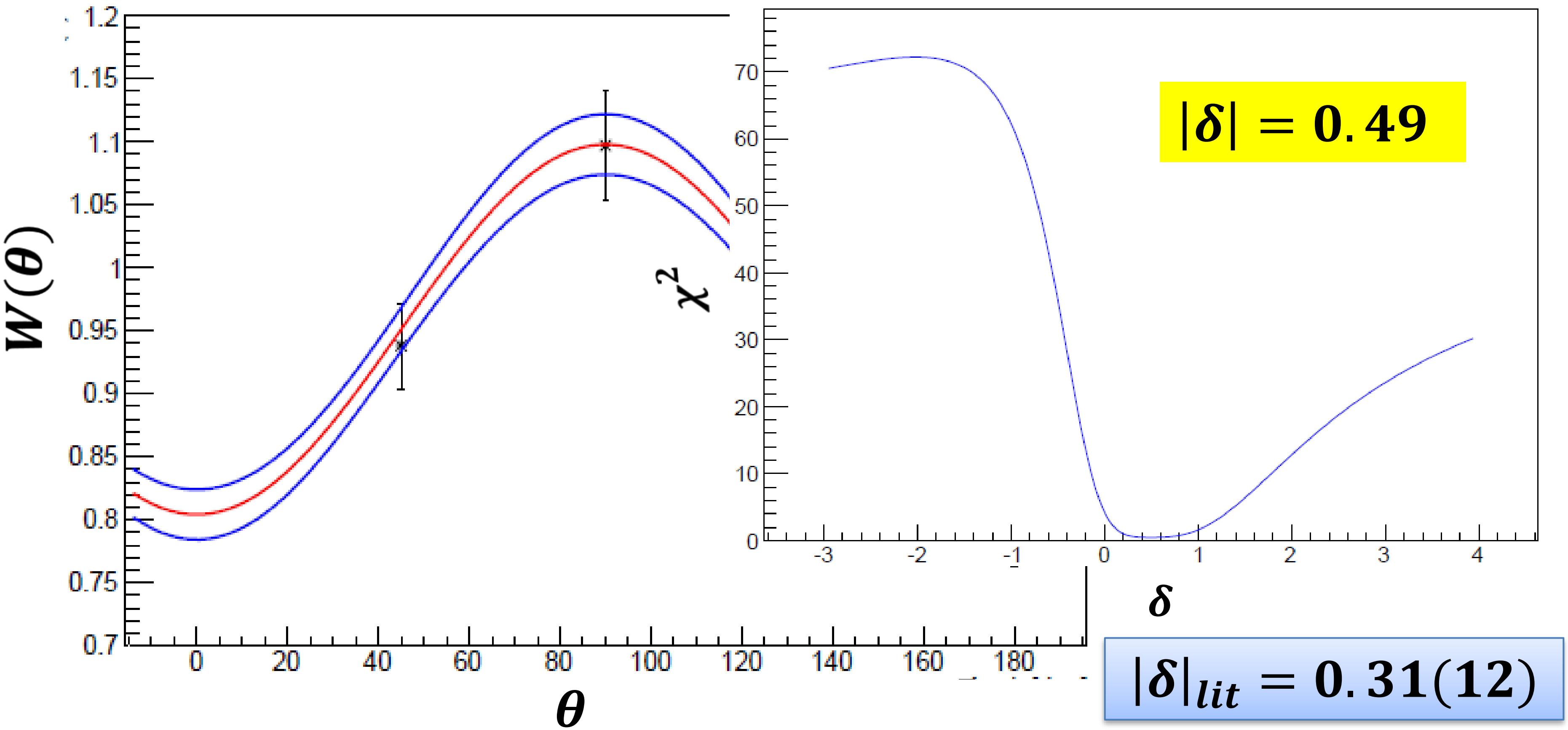


^{96}Mo
3^-_2 octupole isovector candidate
angular distribution 944-keV transition

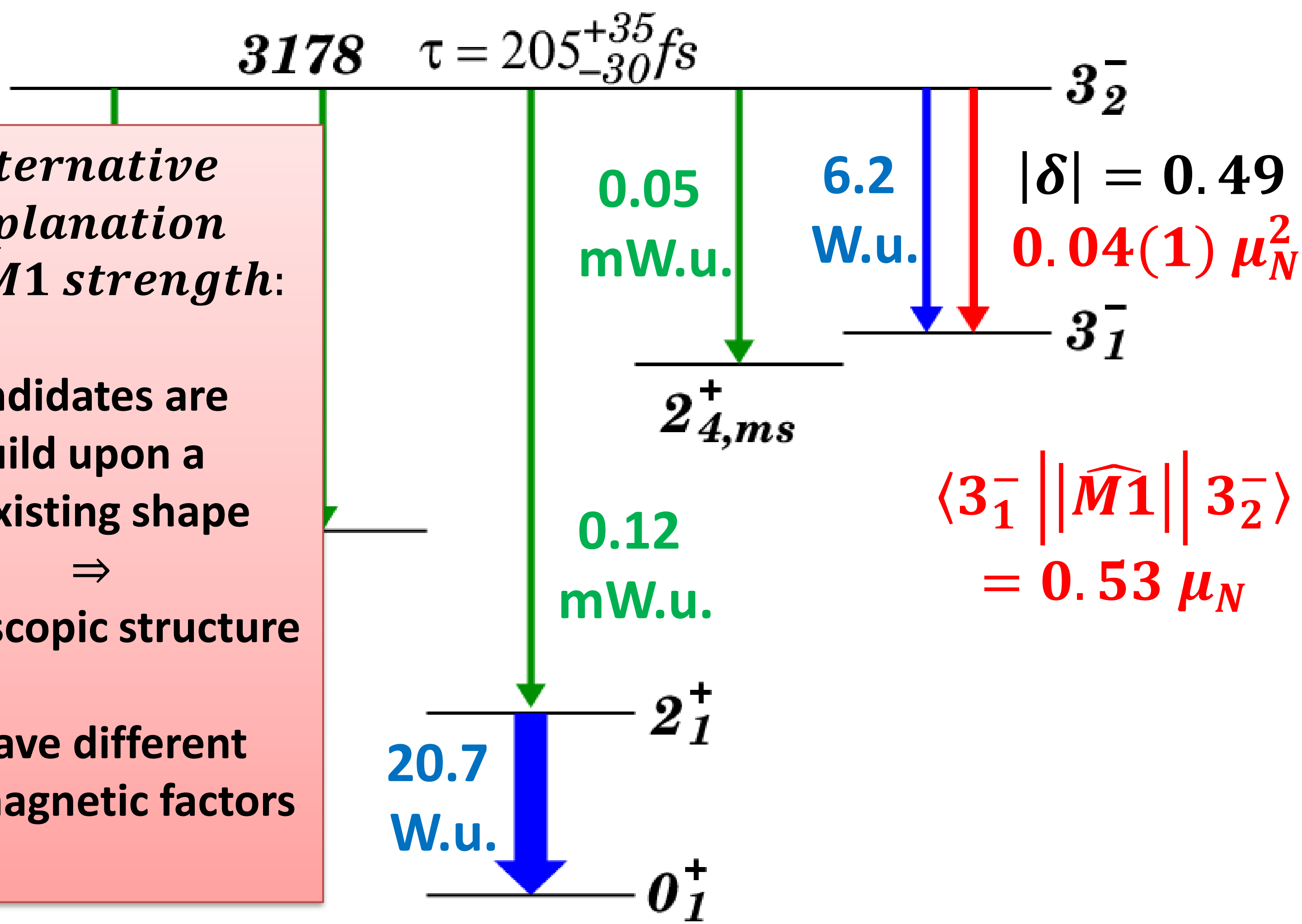


^{96}Mo
3_2^- octupole isovector candidate
angular distribution 944-keV transition

$$W(\theta) = 1 + A_2(\delta)q_2P_2(cos\theta) + A_4(\delta)q_4P_4(cos\theta)$$



^{96}Mo
3^-_2 octupole isovector candidate



Alternative explanation for M1 strength:

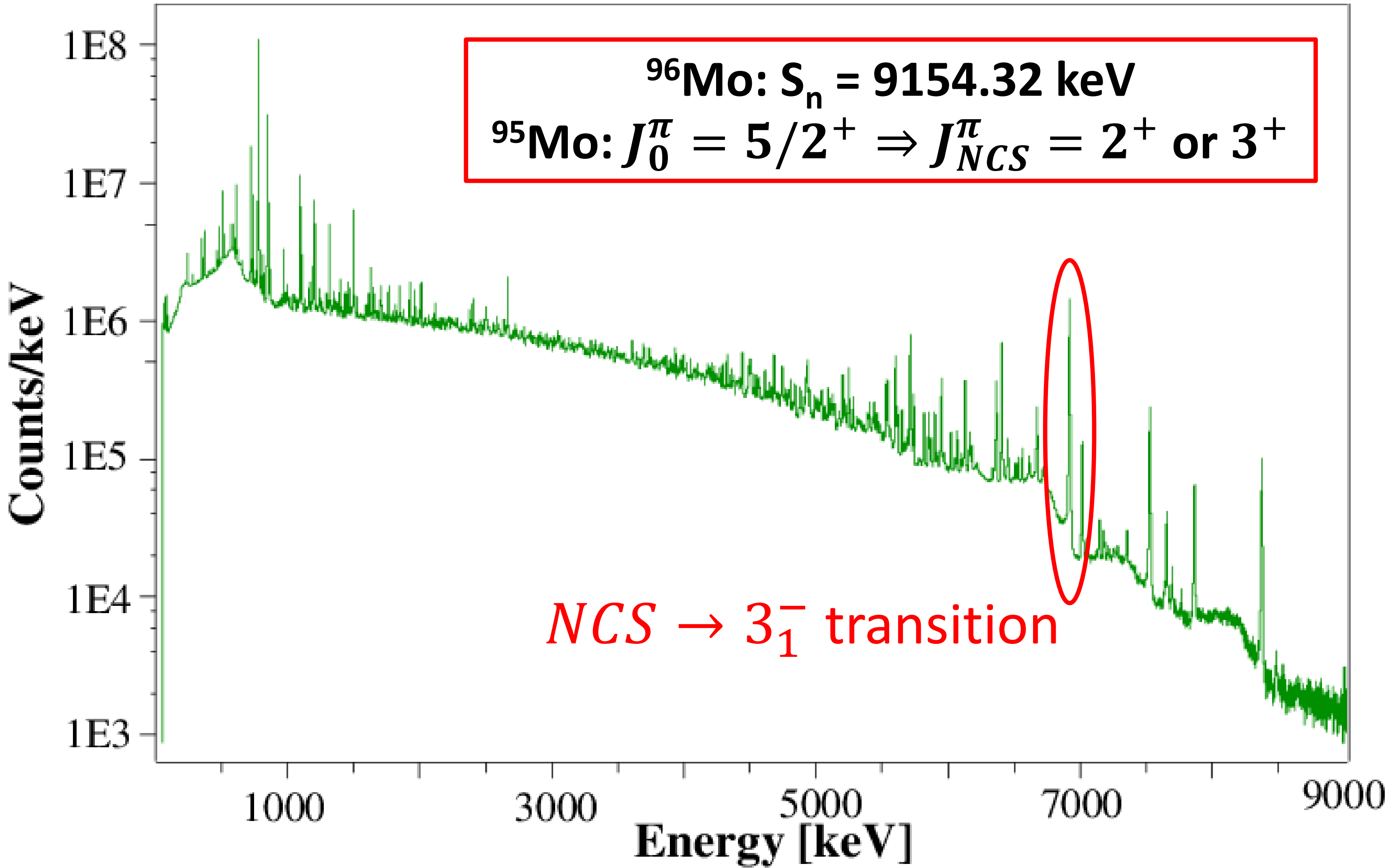
Candidates are build upon a coexisting shape

$\Rightarrow$

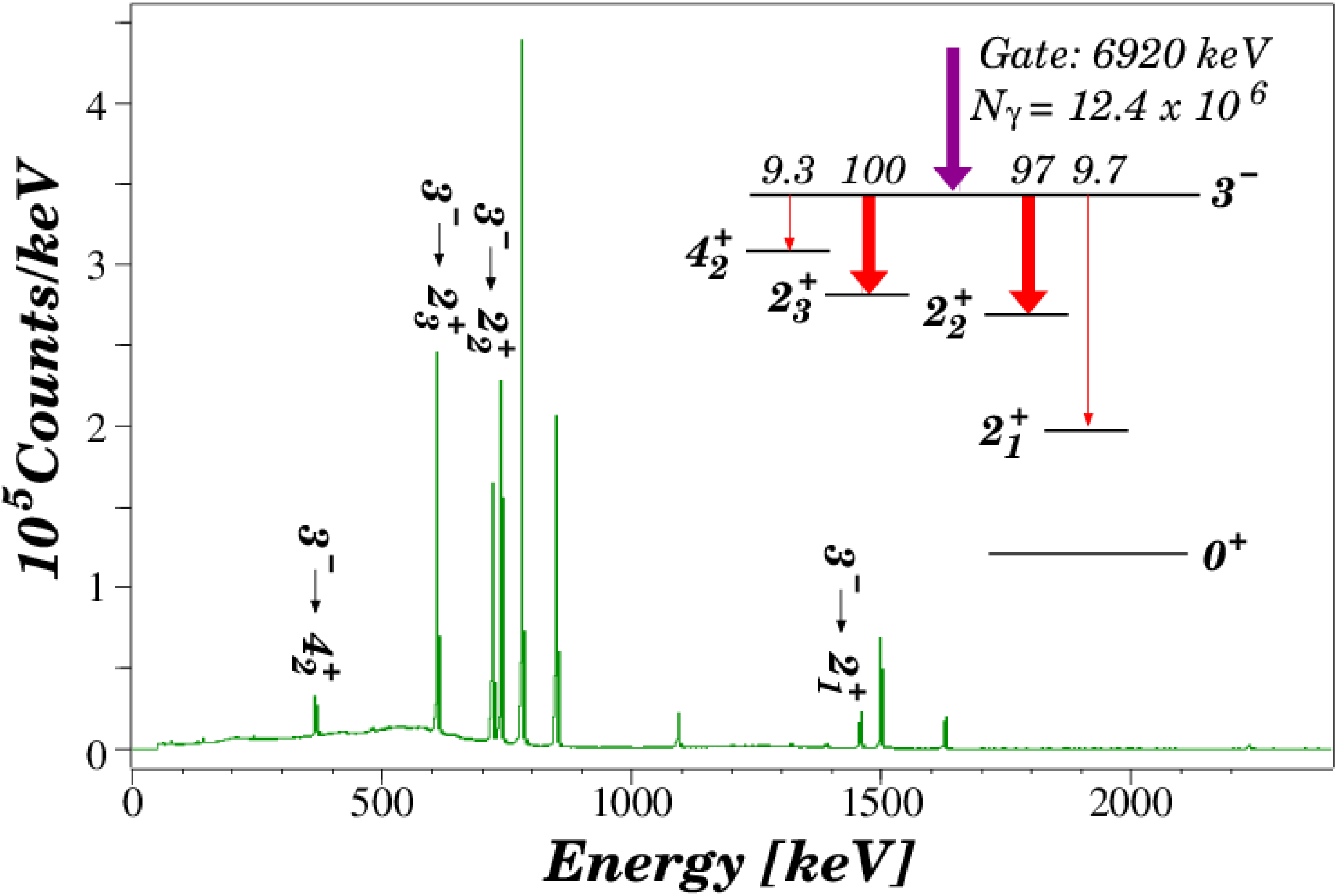
microscopic structure

$\Rightarrow$ have different gyromagnetic factors

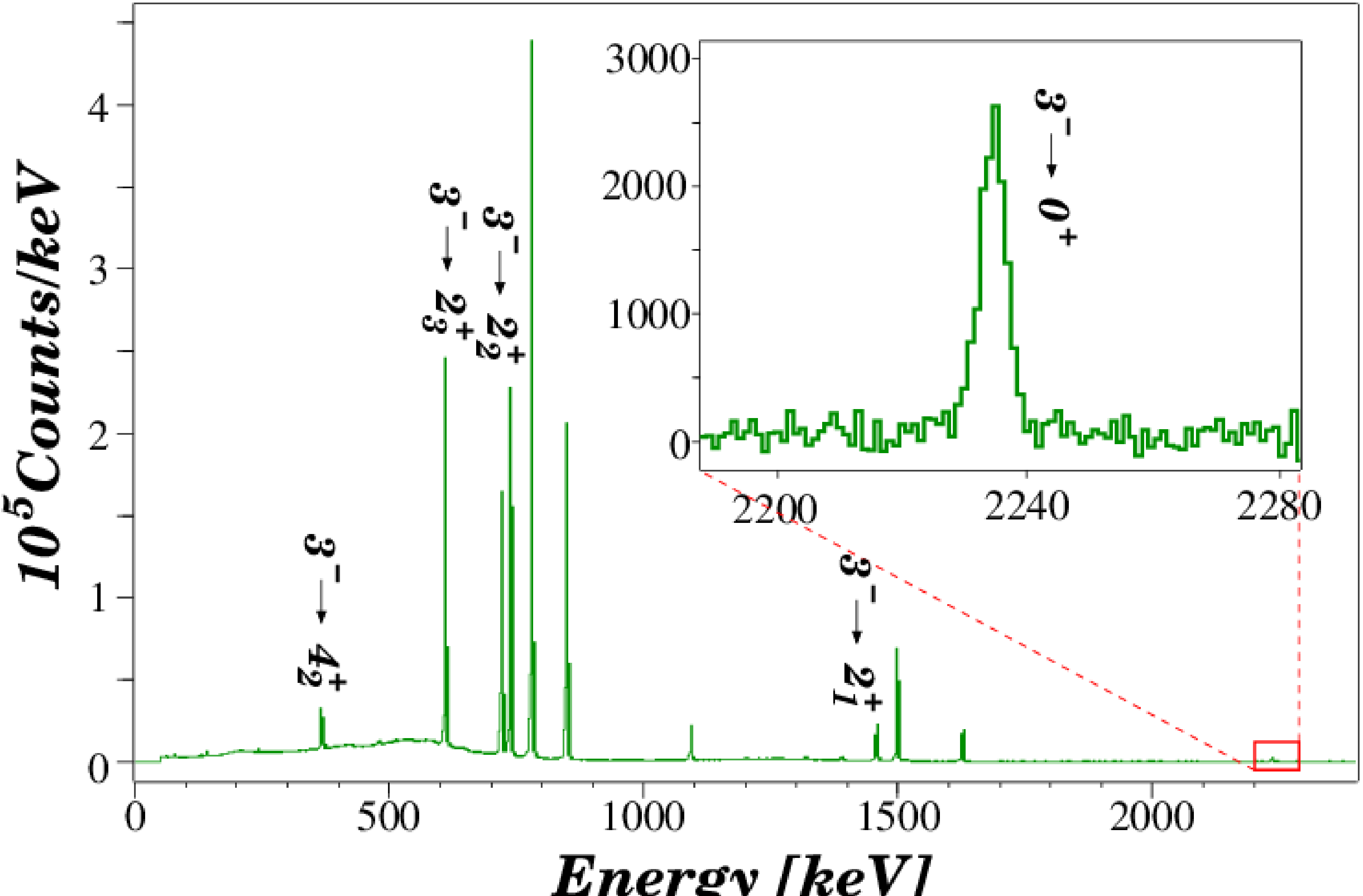
$^{95}Mo(n_{th},\gamma\gamma)^{96}Mo$ projection total $\gamma\gamma$ matrix



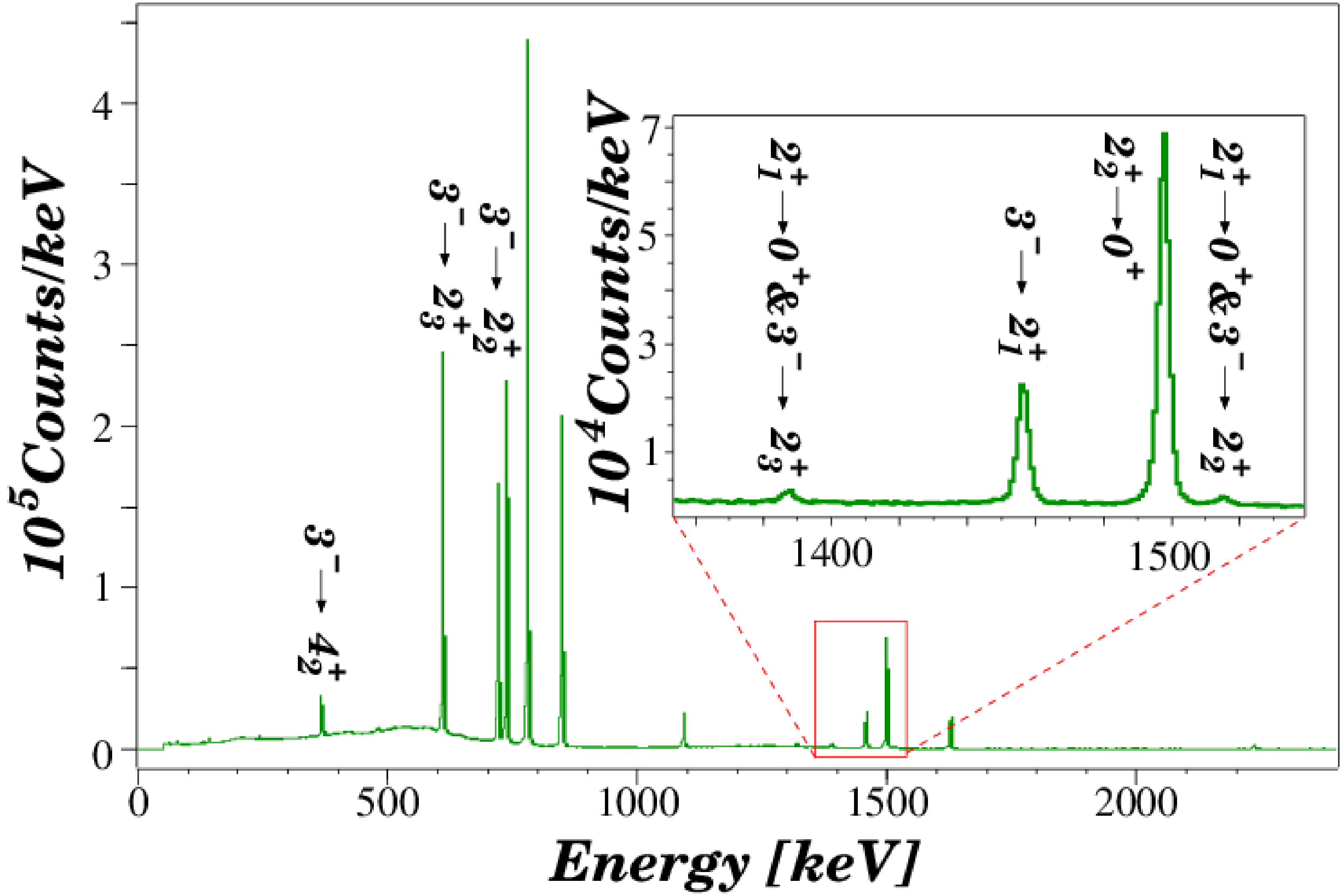
^{96}Mo
3_1^- octupole phonon



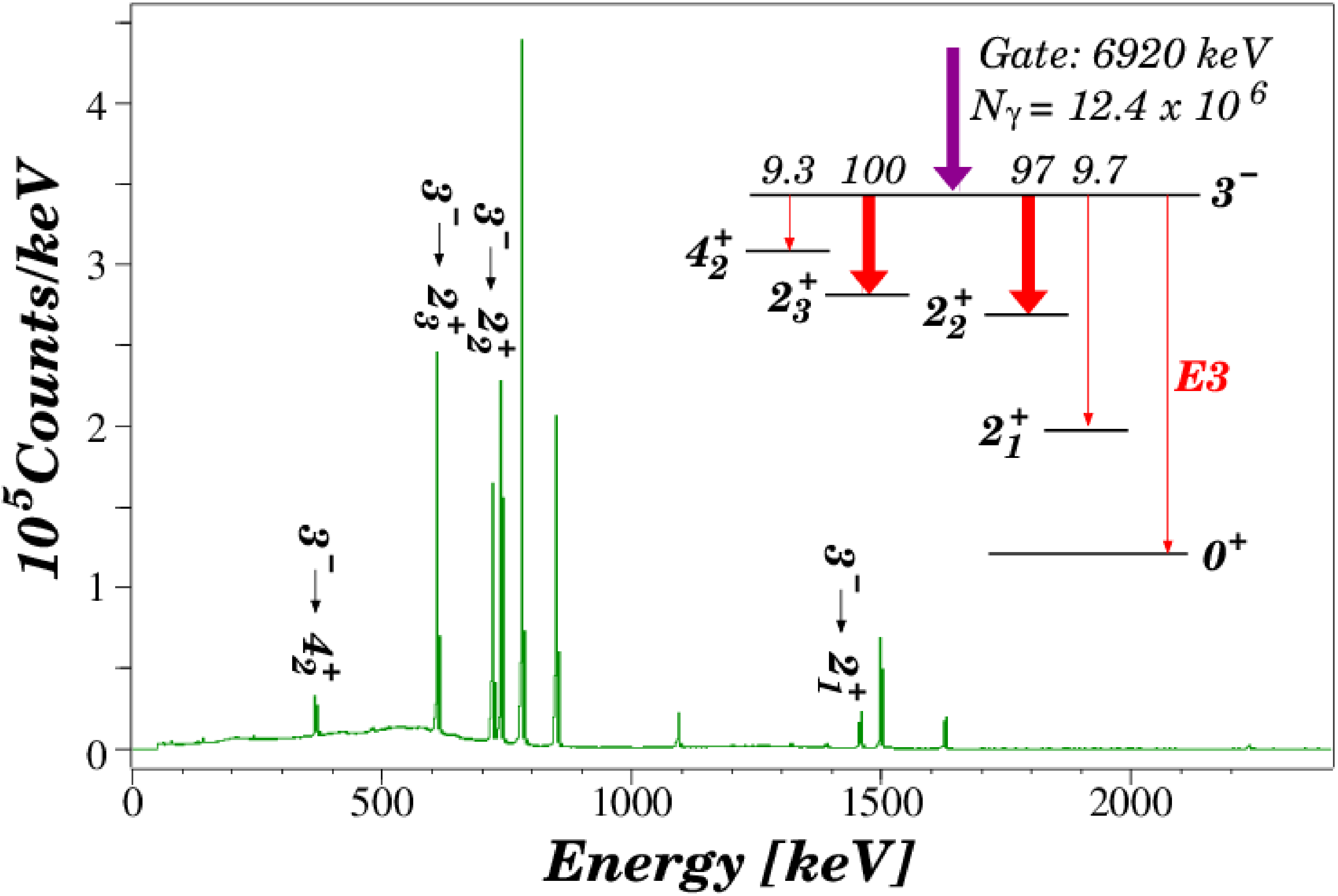
^{96}Mo
3_1^- octupole phonon



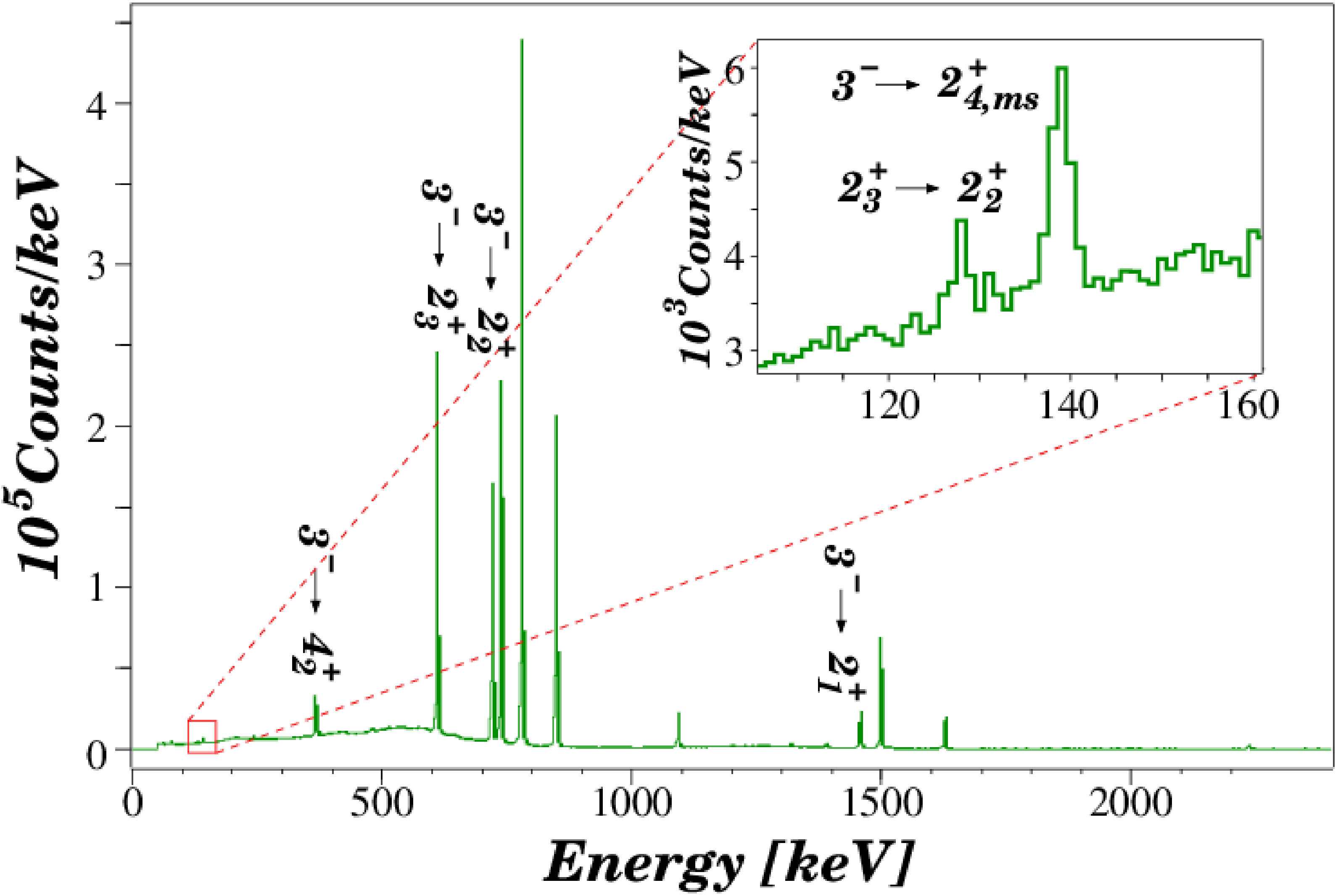
^{96}Mo
3_1^- octupole phonon



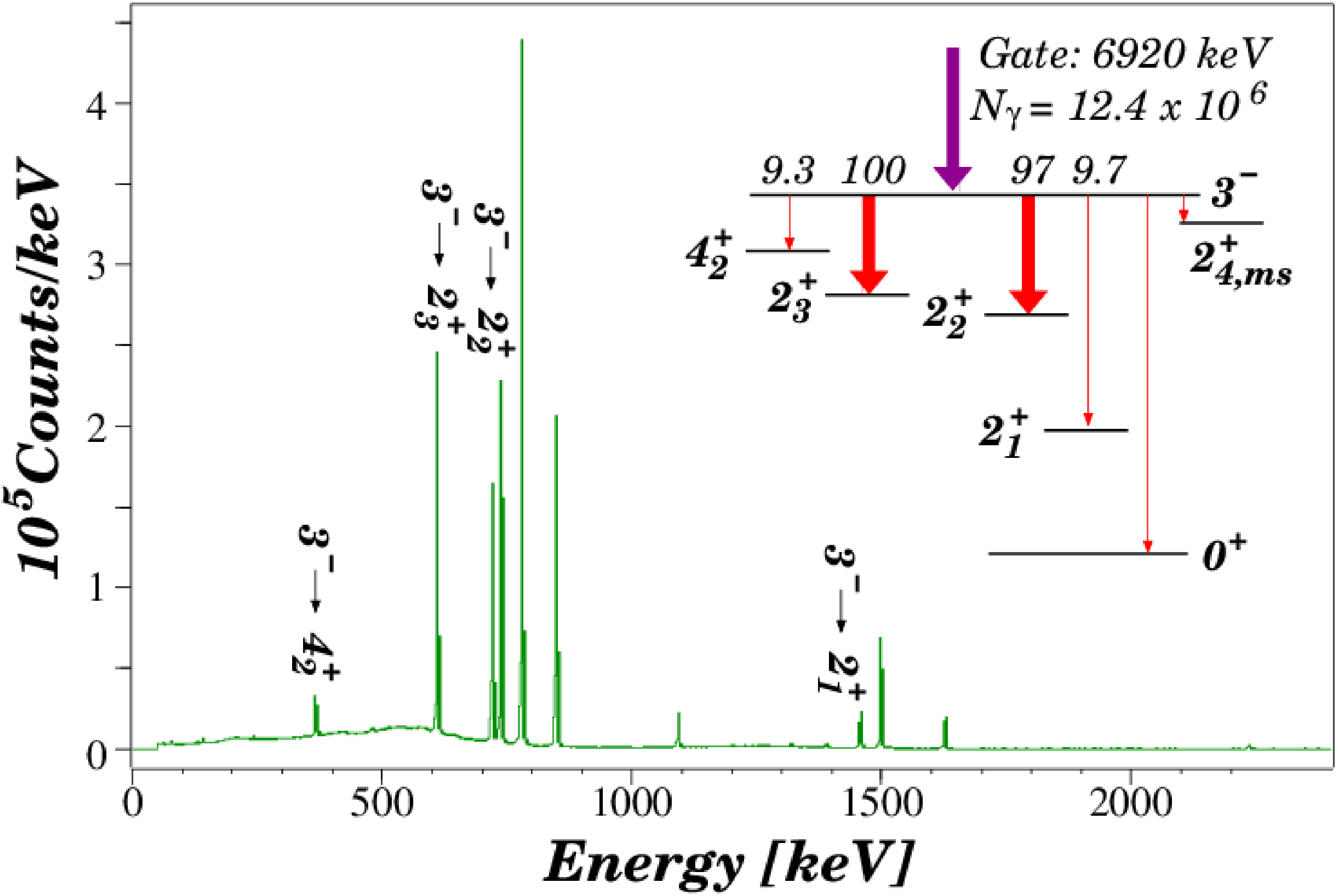
^{96}Mo
3_1^- octupole phonon



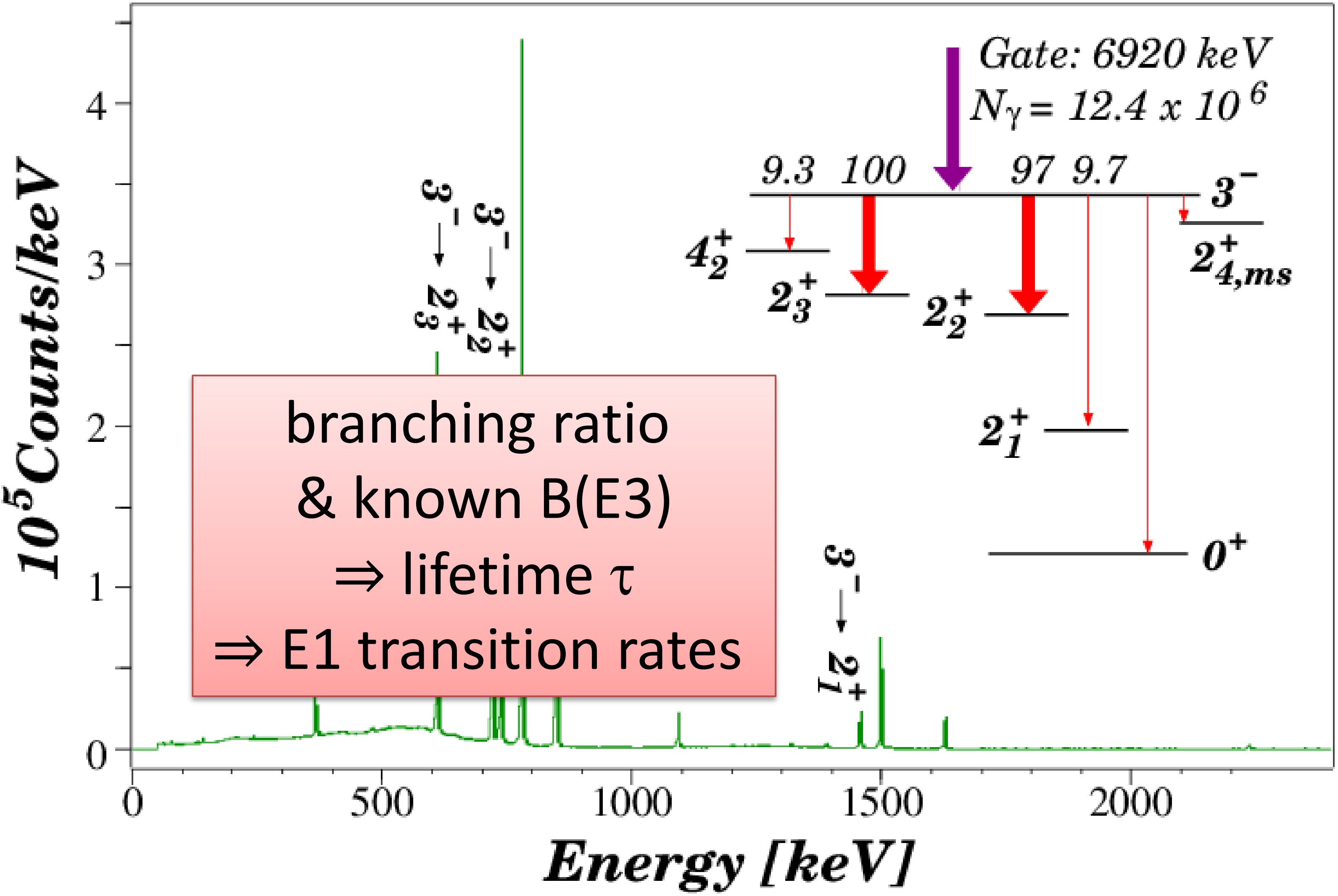
^{96}Mo
3_1^- octupole phonon



^{96}Mo
3_1^- octupole phonon

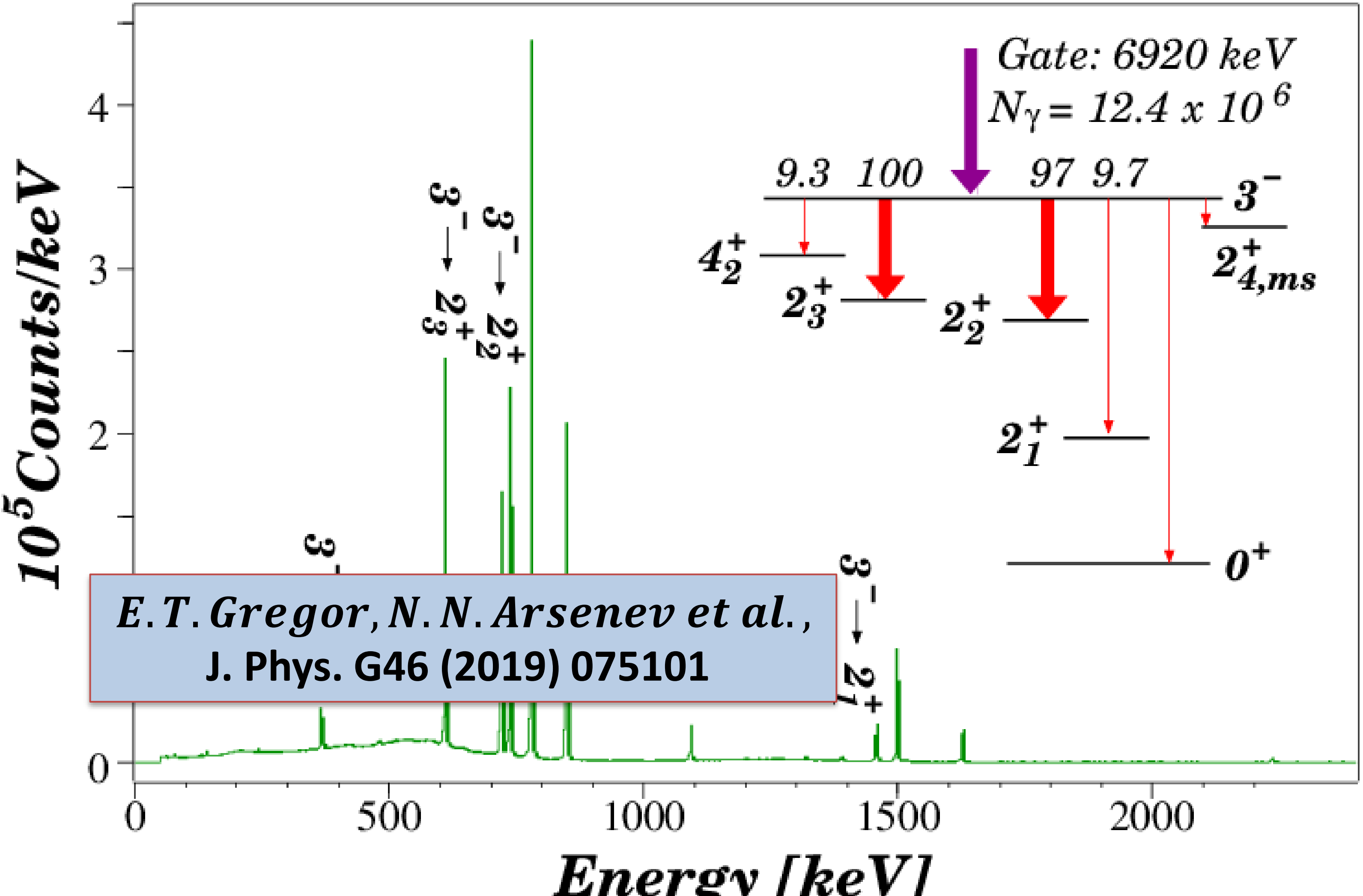


^{96}Mo
3_1^- octupole phonon



branching ratio
& known B(E3)
⇒ lifetime τ
⇒ E1 transition rates

^{96}Mo
3_1^- octupole phonon



E. T. Gregor, N. N. Arsenev et al.,
J. Phys. G46 (2019) 075101

Acknowledgements

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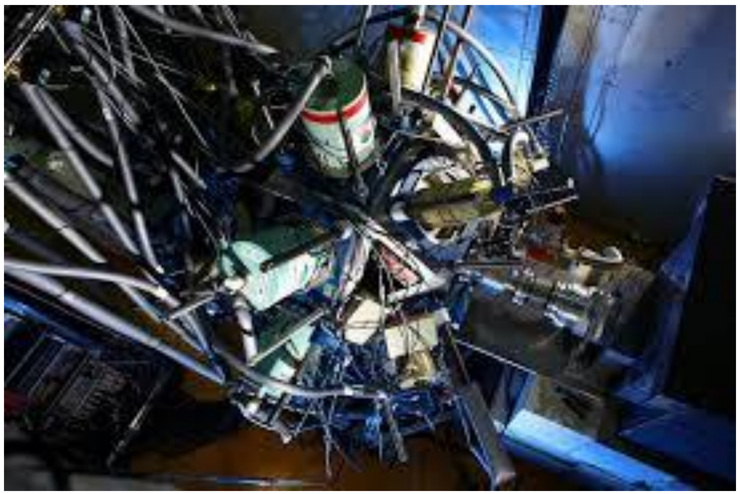

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TECHNISCHE UNIVERSITÄT DARMSTADT

YALE

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Laboratoire de Physique Subatomique et de Cosmologie

GANIL
GRAND ACCELERATEUR NATIONAL D'IONS LOURDS

UNIVERSITAS VARSOVIENSIS

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DFG Deutsche Forschungsgemeinschaft

UKRI Science and Technology Facilities Council