11–15 July, 2022

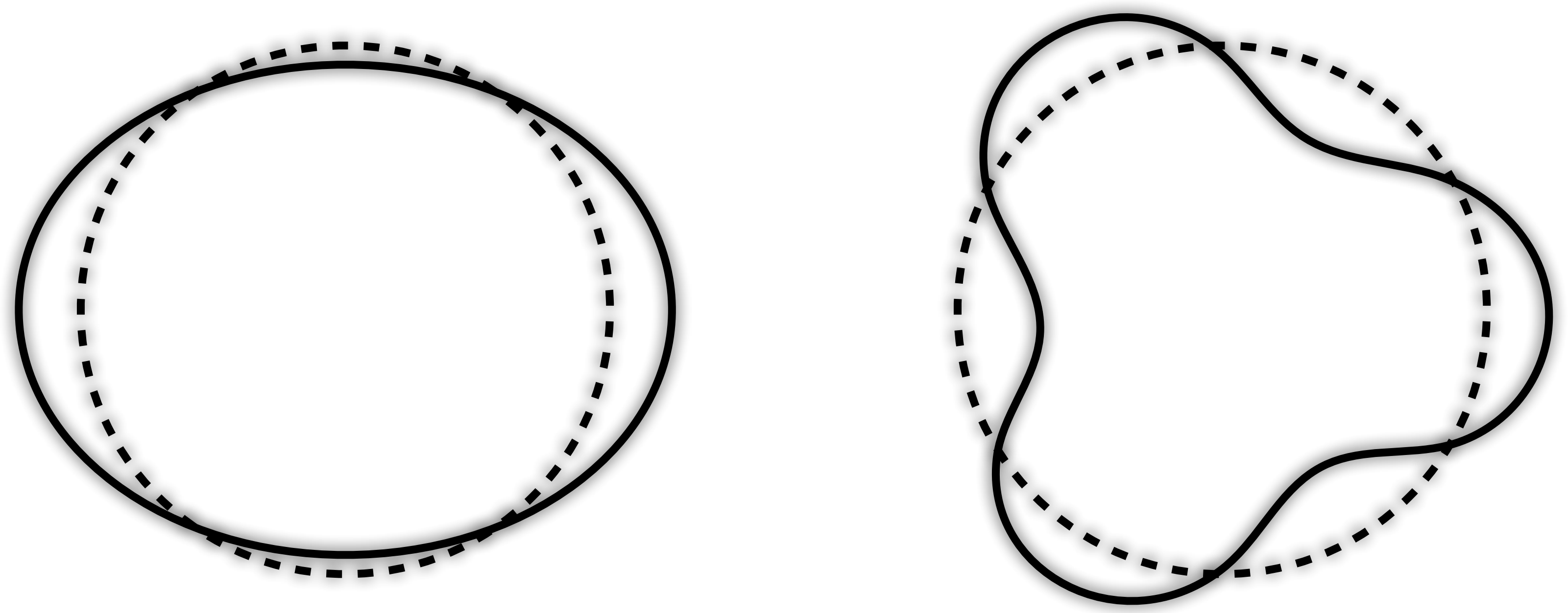
Skyrme-QRPA for monopole modes of excitation

A role of nuclear deformation

K. Yoshida (Kyoto U.)

Giant resonances: collective modes of surface vibration

classical and intuitive picture



L=2: Giant Quadrupole Resonance (GQR)
L=3: High Energy Octupole Resonance (HEOR)

strongly excited by a one-body operator, exhaust a sum-rule value

$$\hat{O} = \sum_{\sigma\sigma'} \sum_{\tau\tau'} \int \vec{r} r^L Y_L(\hat{r}) \hat{\psi}^\dagger(\vec{r}\sigma\tau) \langle\sigma| \begin{Bmatrix} 1 \\ \vec{\sigma} \end{Bmatrix} |\sigma'\rangle \langle\tau| \begin{Bmatrix} 1 \\ \vec{\tau} \end{Bmatrix} |\tau'\rangle \hat{\psi}(\vec{r}\sigma'\tau')$$

space spin isospin

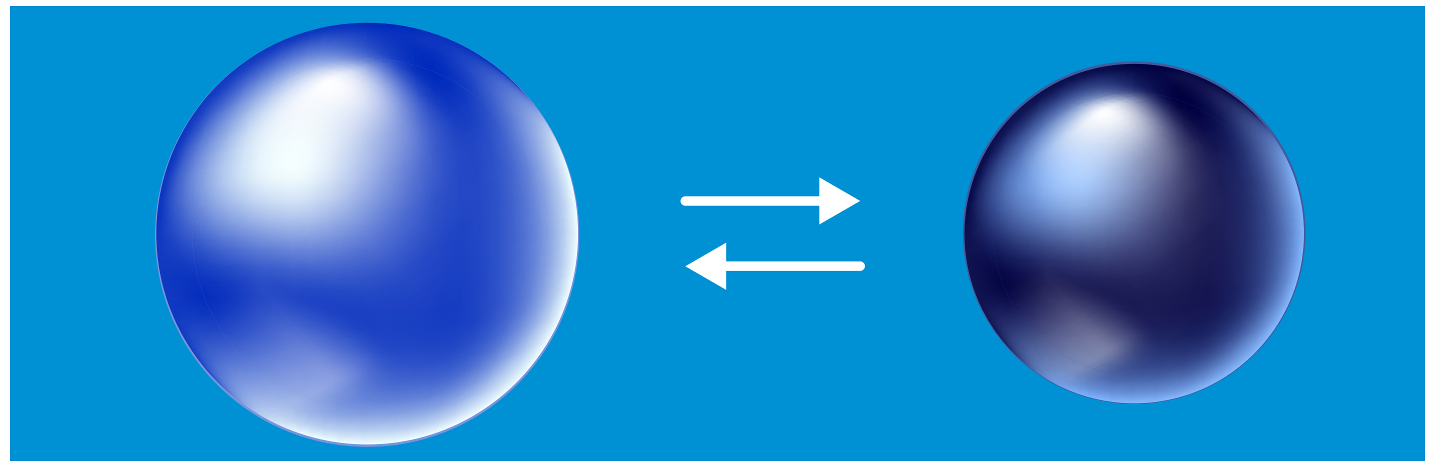
rich variety of modes depending on ΔL, ΔS, ΔT, and ΔN.
affected by many-body correlations (deformation and superfluidity)

Giant Monopole Resonance (GMR)

$$\hat{O} = \sum_{\sigma\tau} \int d\vec{r}\, r^2 \psi^\dagger(\vec{r}\sigma\tau)\psi(\vec{r}\sigma\tau)$$

volume change ⟷ incompressibility of nuclear matter

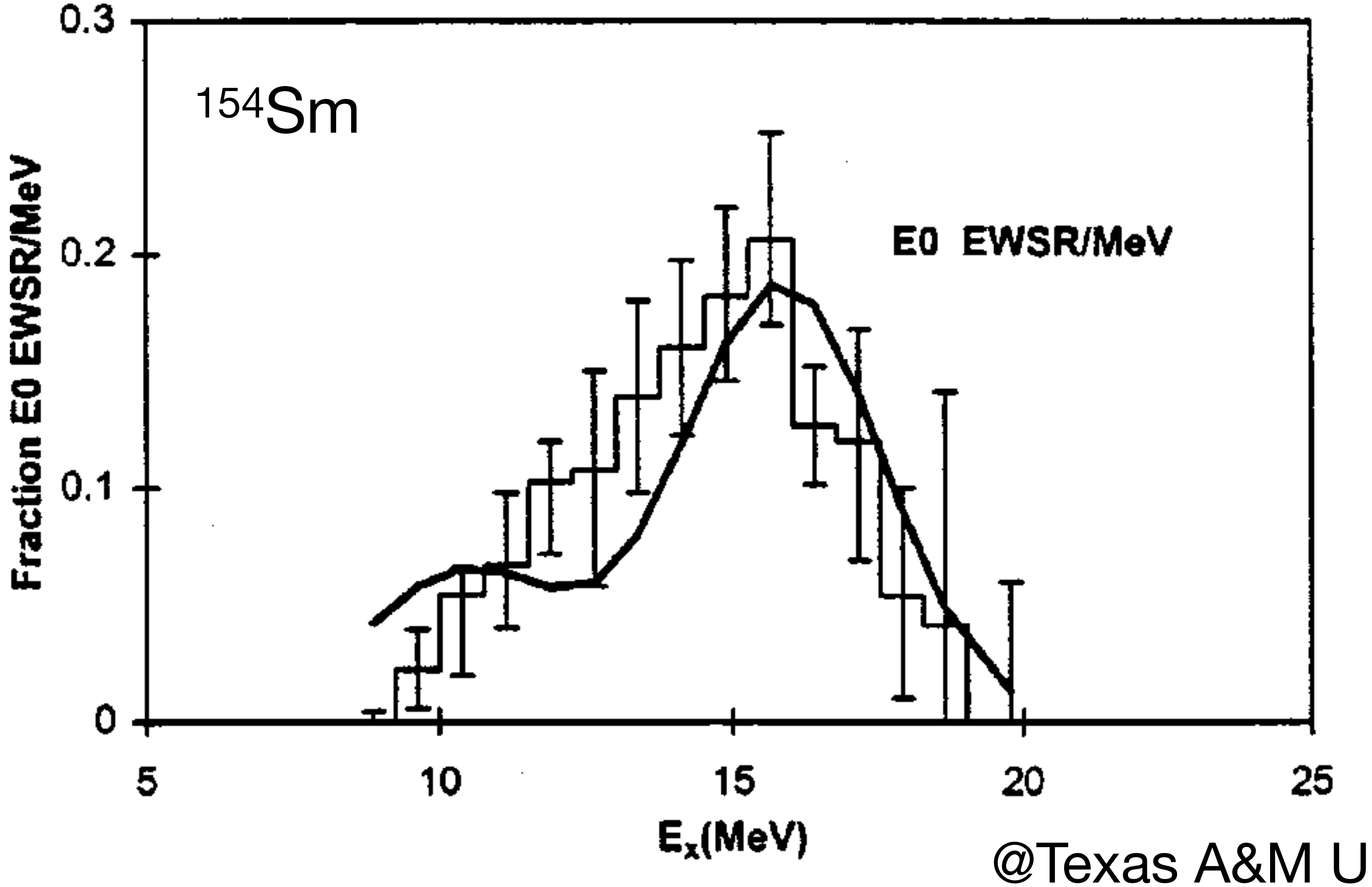
Blaizot ('80)



deformation splitting?

Garg+ ('80)

Youngblood+ ('99)



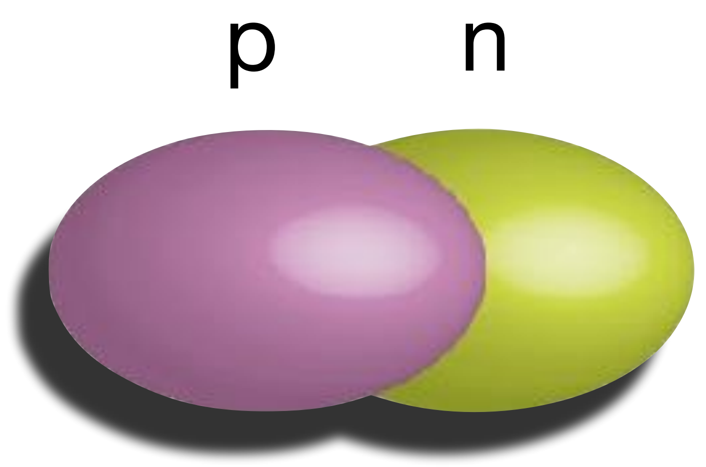
@Texas A&M Univ.

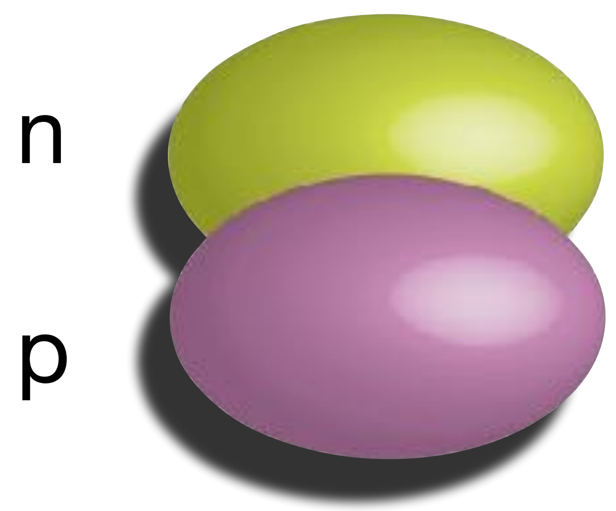
Deformation splitting?

Yoshida–Nakatsukasa ('11)

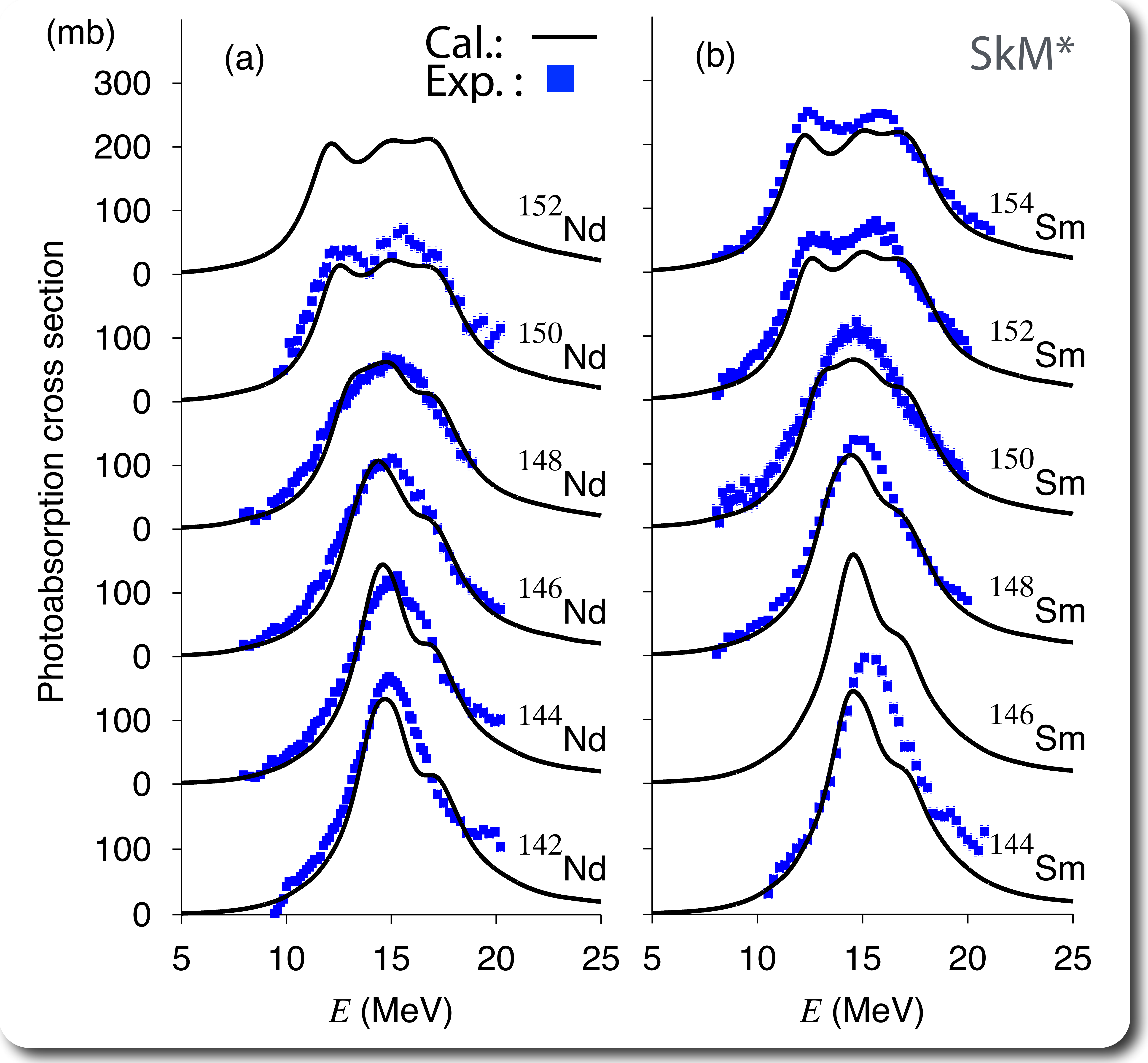
IVGDR

$\omega_{\parallel} \propto \frac{1}{R_{\parallel}}$ $\omega_{\perp} \propto \frac{1}{R_{\perp}}$

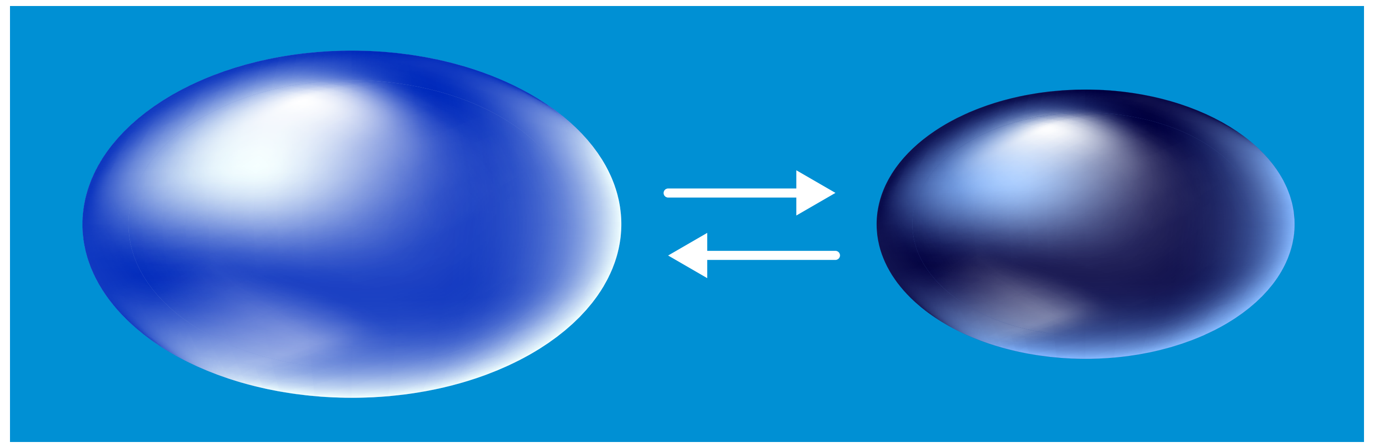




K=0 *K*=1



GMR

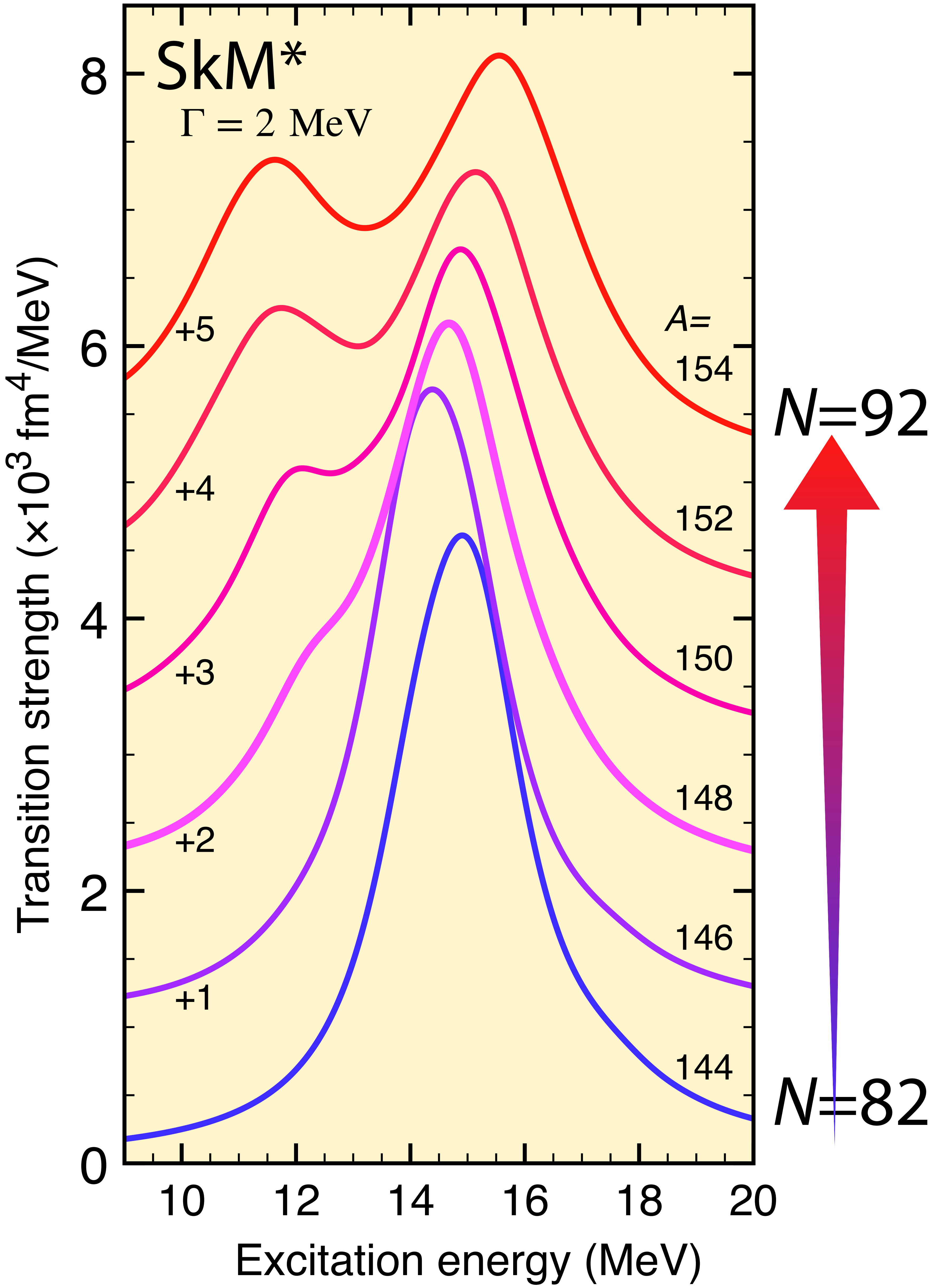


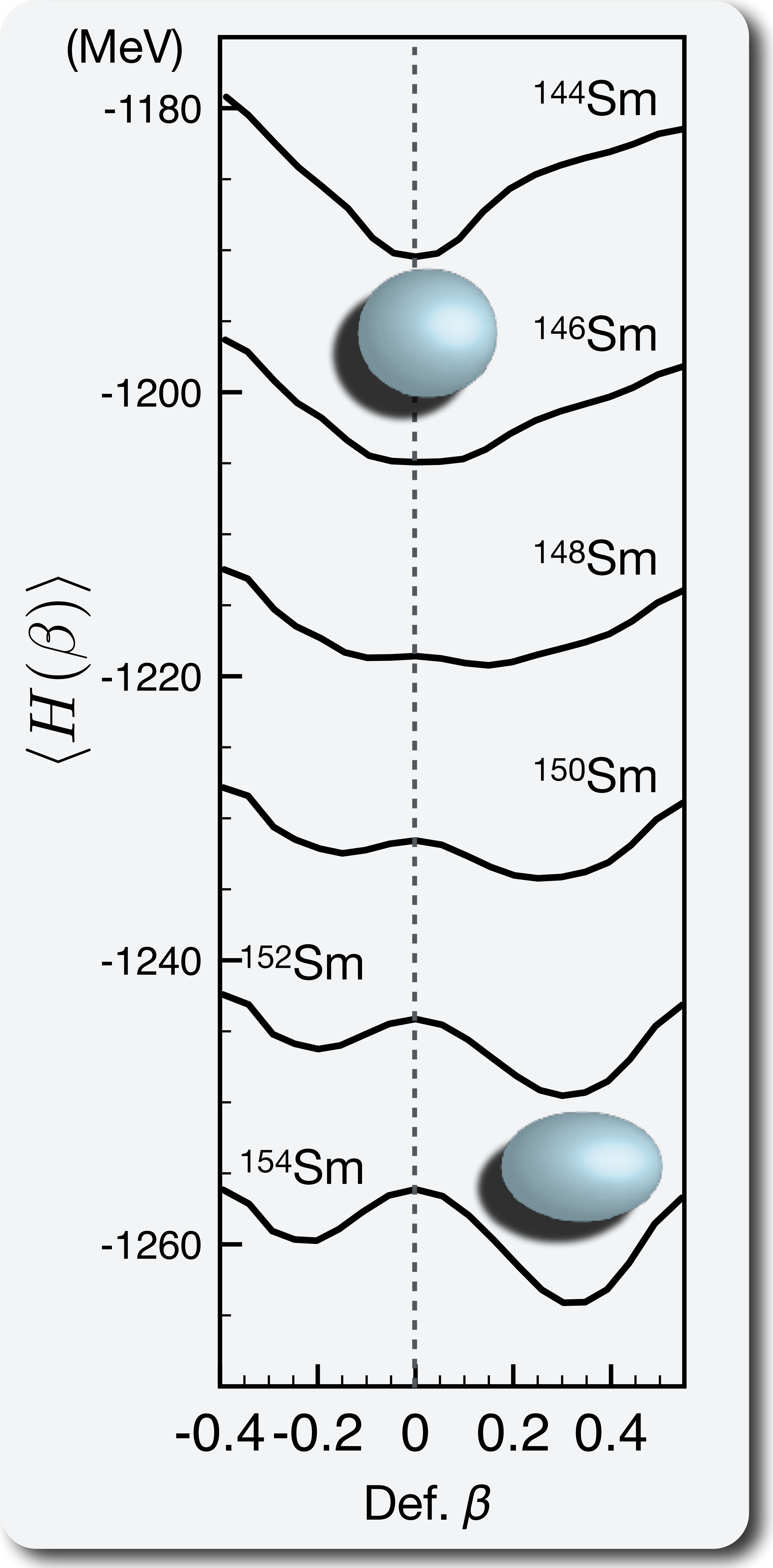
no angle dependence contrary to GDR

$Y_0(\hat{r})$ $Y_{1K}(\hat{r})$

GMR in the Sm isotopes

Yoshida–Nakatsukasa ('13)





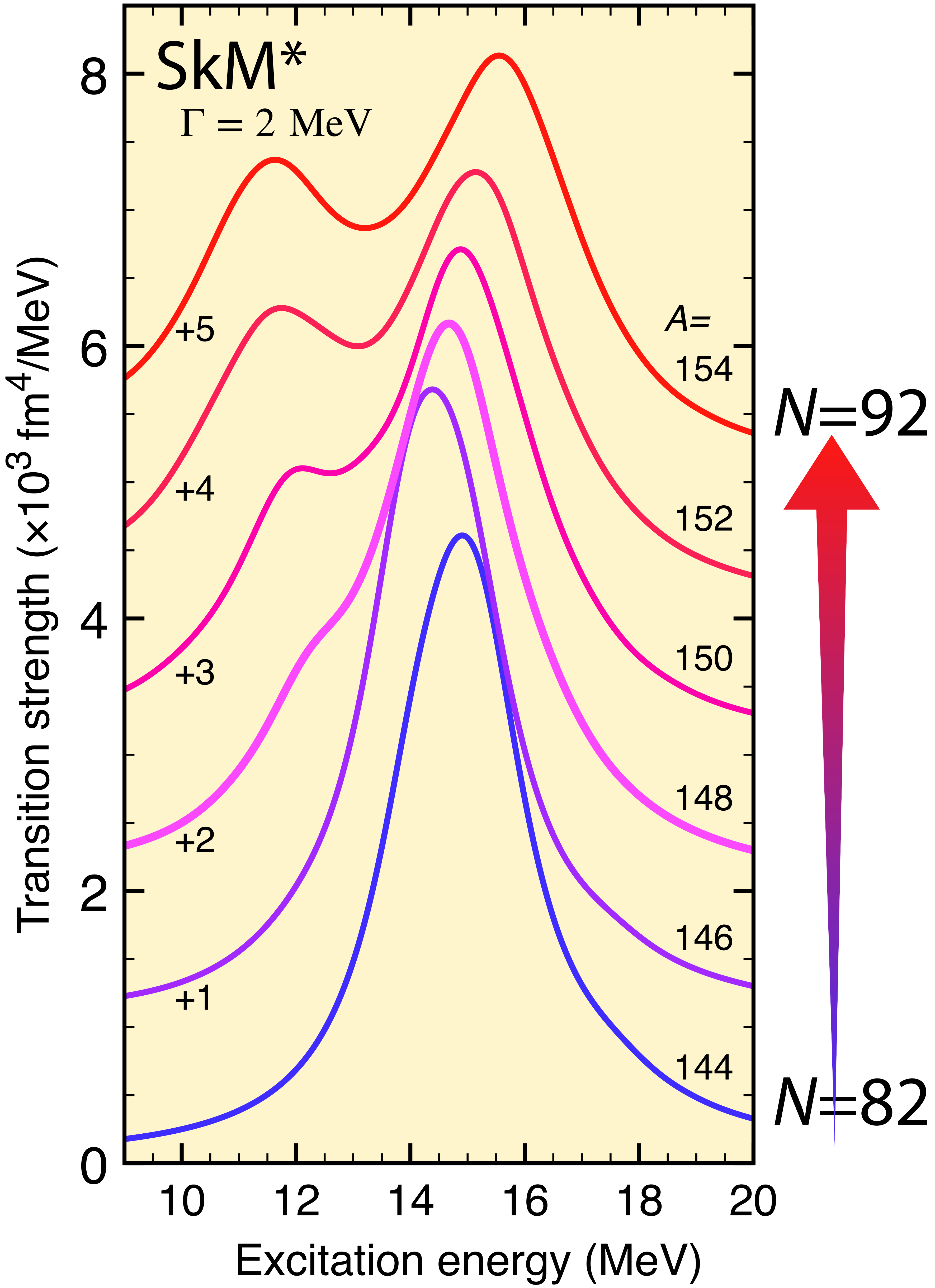
N=82

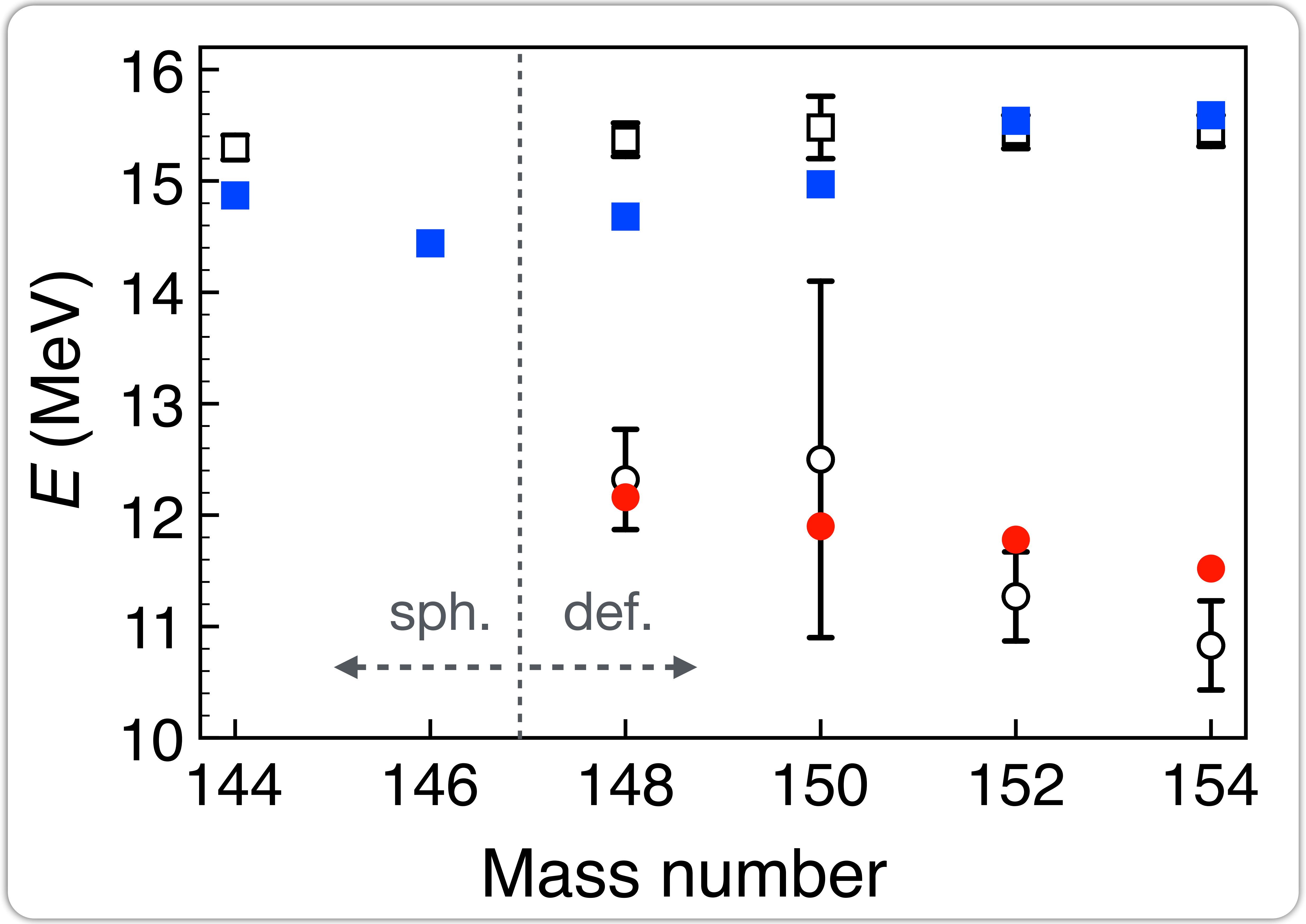
evolution of deformation

N=92

GMR in the Sm isotopes

Yoshida–Nakatsukasa ('13)

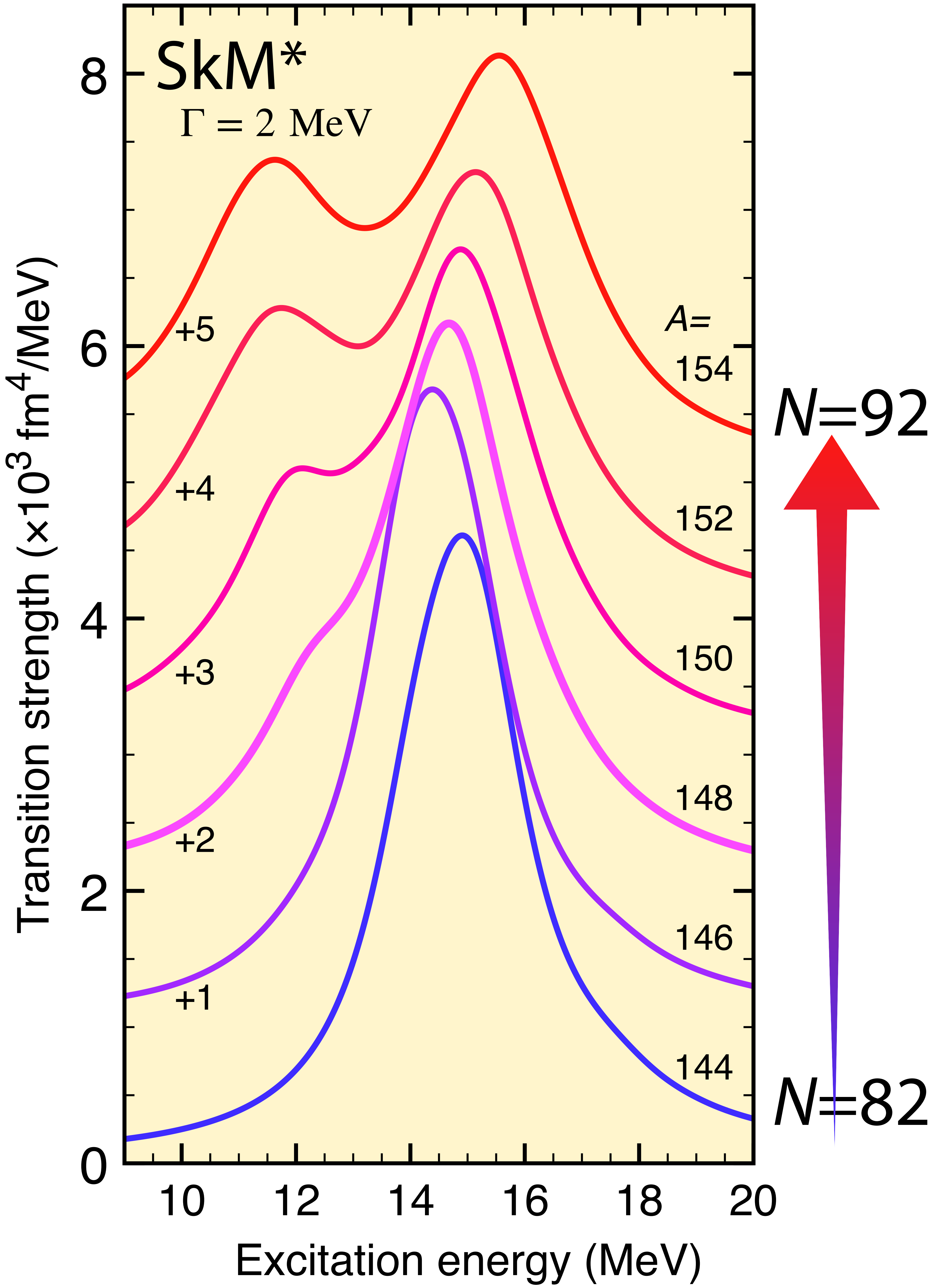




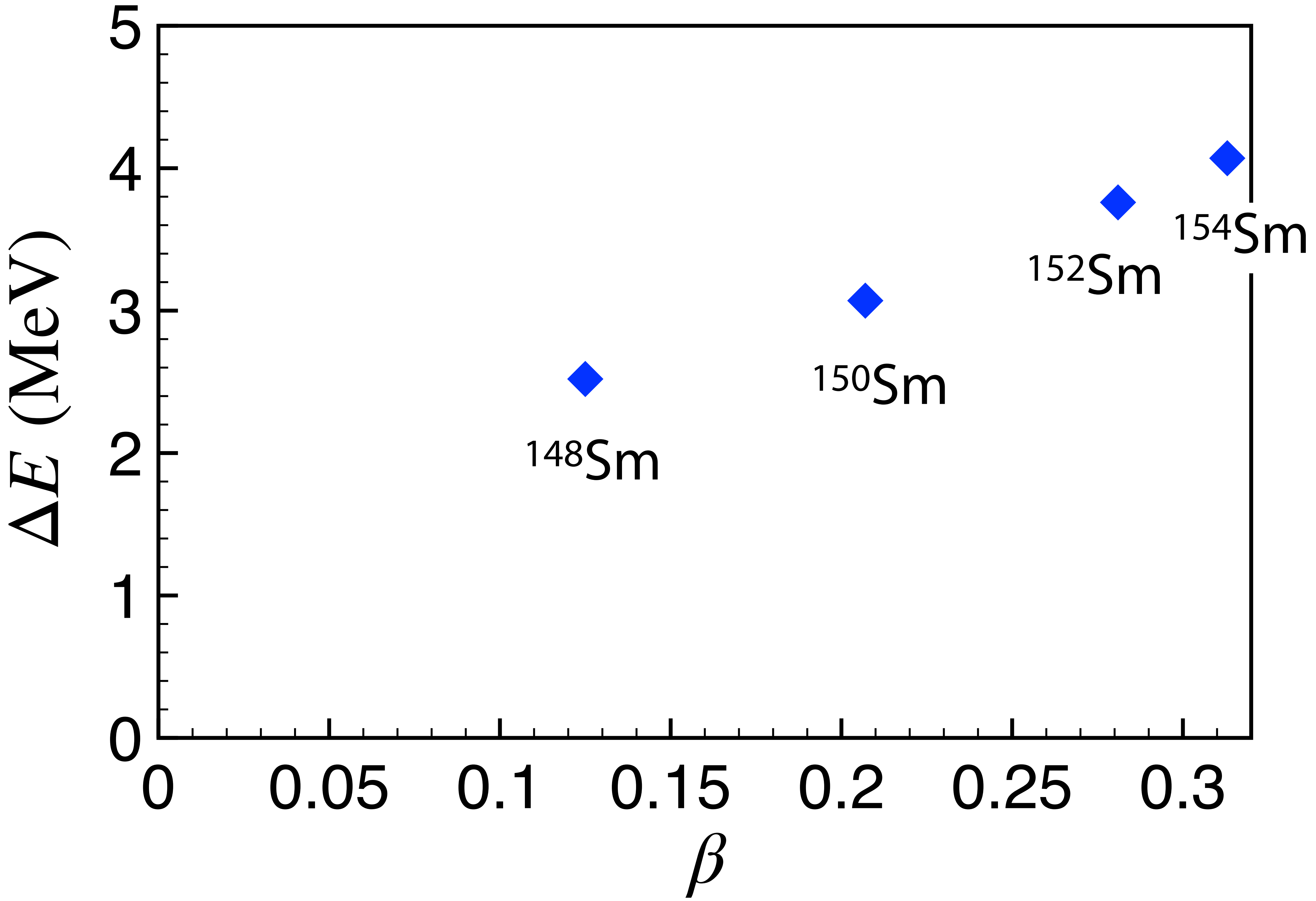
Exp.: Itoh+ ('03)

GMR in the Sm isotopes

Yoshida–Nakatsukasa ('13)

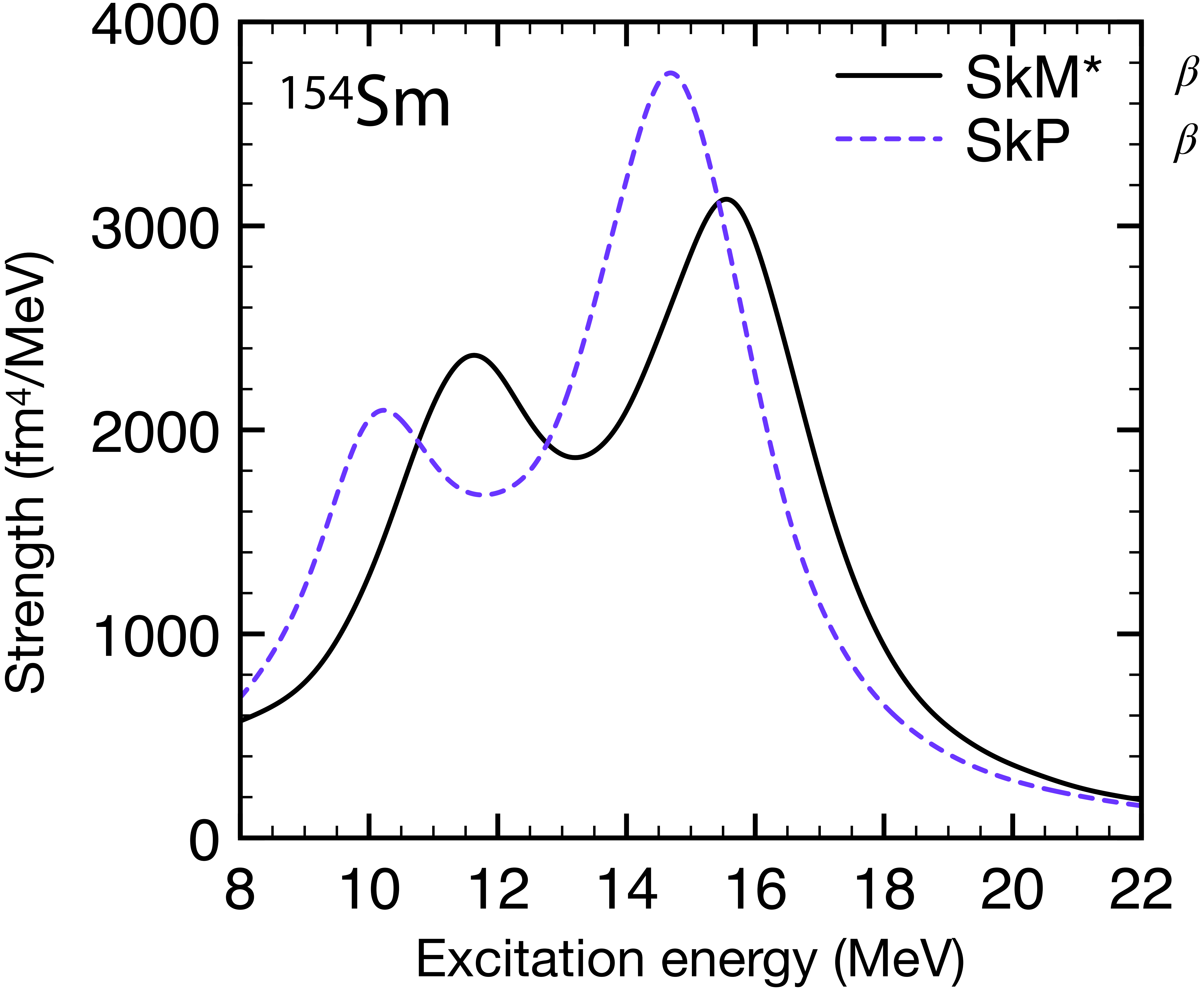


deformation splitting



GMR in the Sm isotopes

Yoshida–Nakatsukasa ('13)



	Ratio of EWS higher/lower
$\beta = 0.31$	1.9
$\beta = 0.29$	3.2

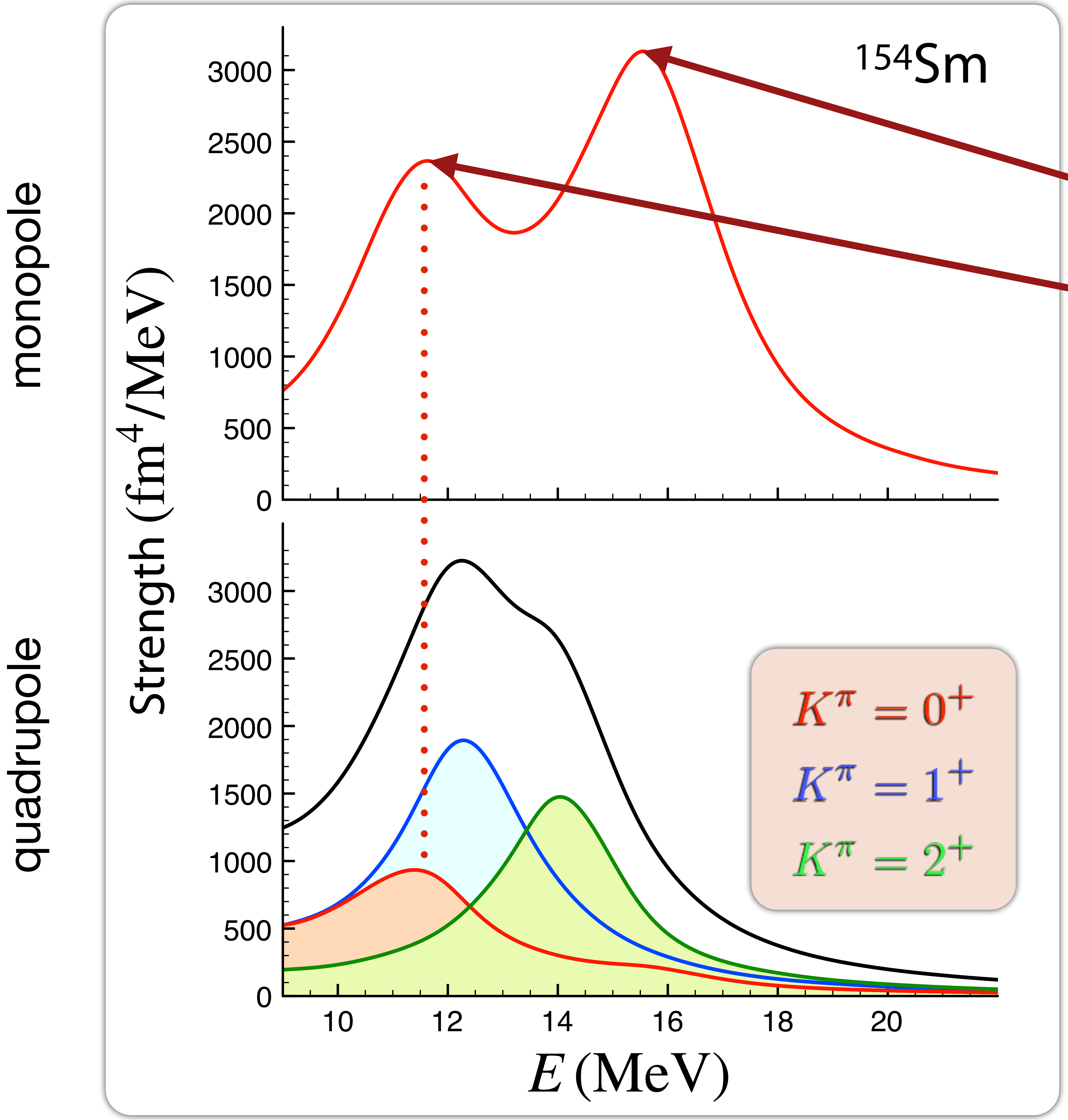
larger strengths in the lower peak in a strongly-deformed nucleus

stronger coupling between GMR and GQR as deformation increases

splitting energy

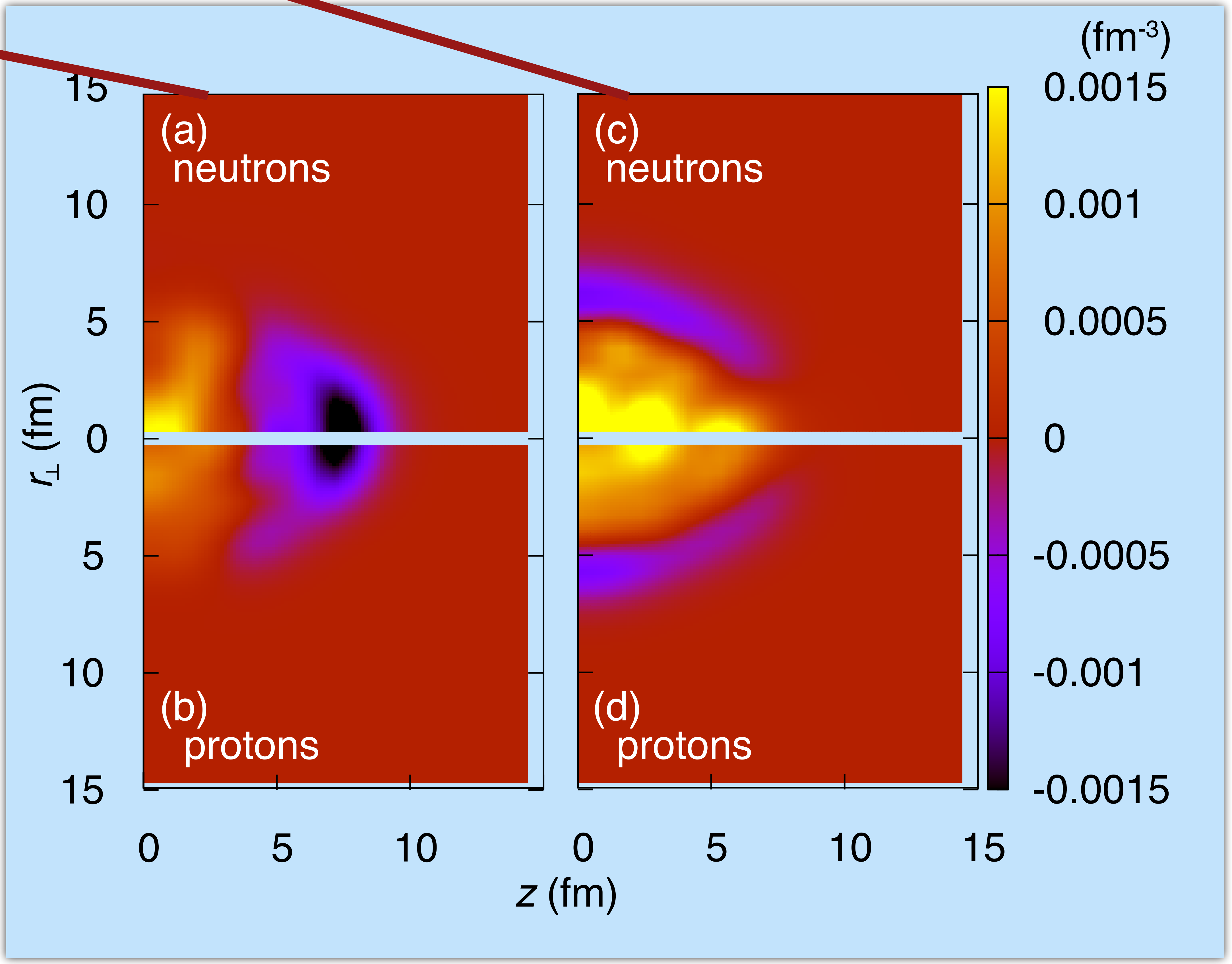
ratio of strengths

Coupling between GMR and GQR

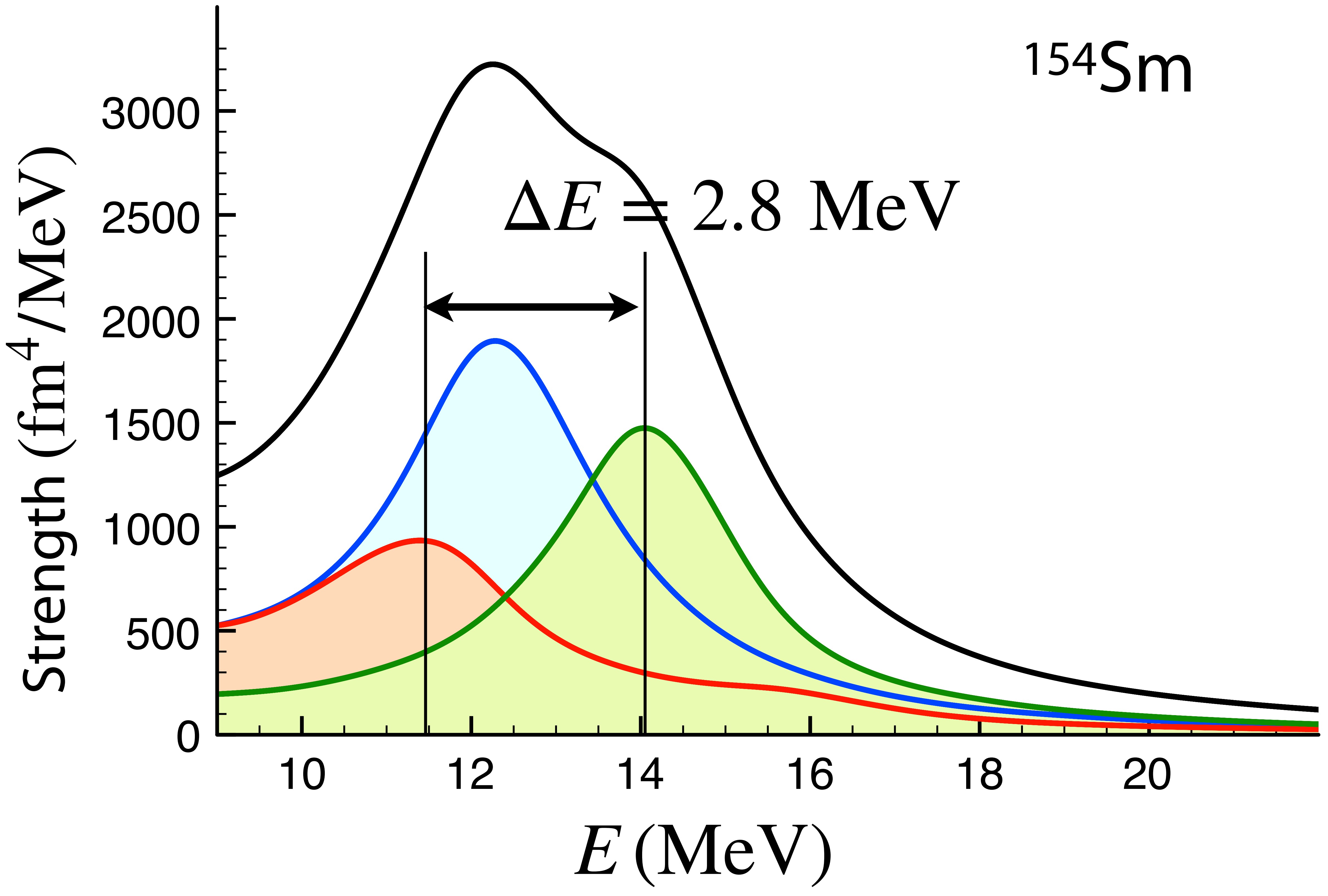


transition density

$$\delta\rho_\lambda(\vec{r}) = \langle \Psi_\lambda | \psi^\dagger(\vec{r})\psi(\vec{r}) | \Psi_0 \rangle$$



Deformation splitting of the GQR

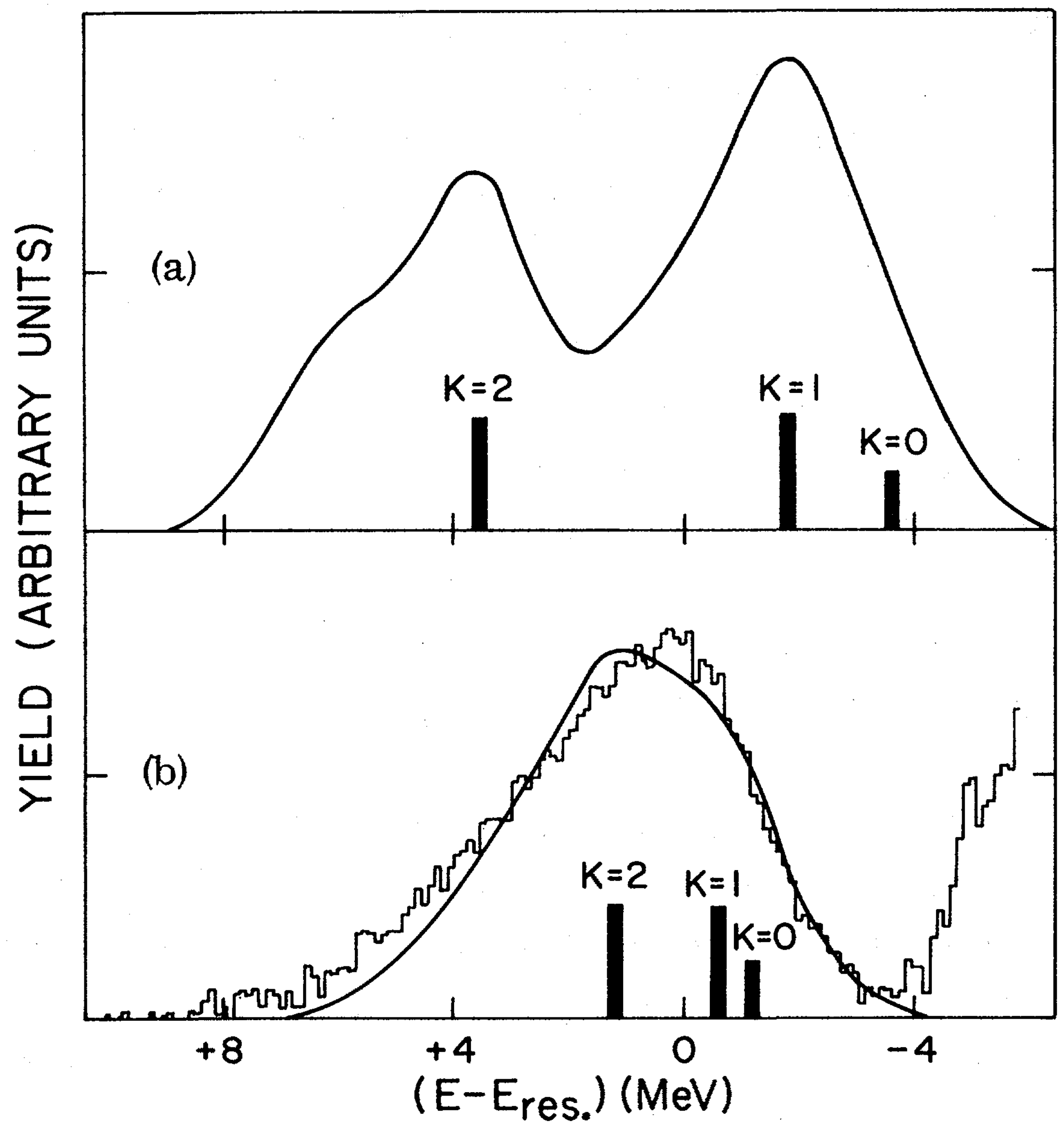


EDF-based QRPA satisfies the nuclear self-consistency

shape (density distribution) and potential

P+Q model

Kishimoto+('75)



$\Delta E \sim 6$ MeV

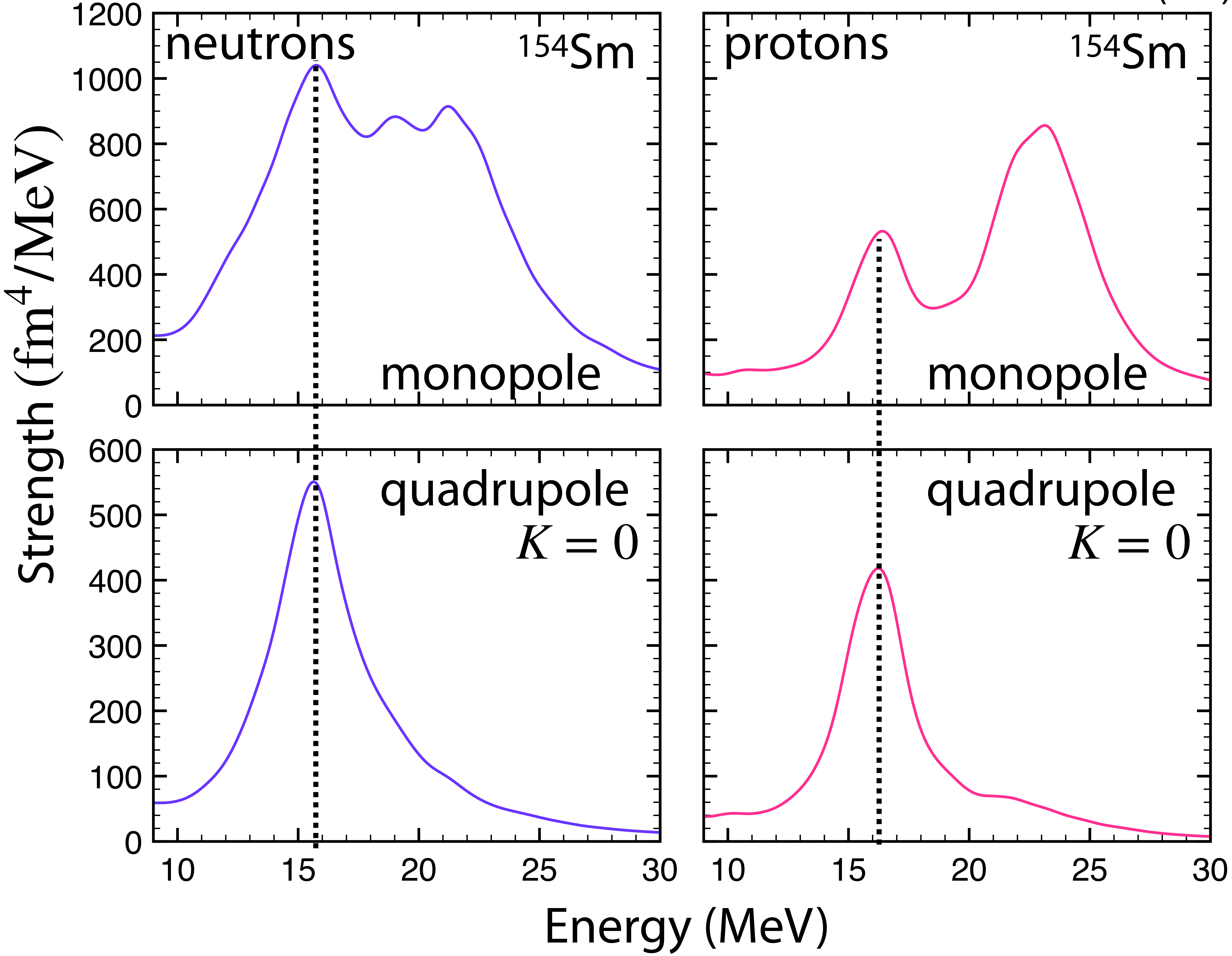
ordinal coordinate

$\Delta E \sim 2$ MeV

doubly-stretched coordinate

Coupling at the static level

Yoshida ('21)



Unperturbed strengths

w/o the RPA (dynamic) correlations

deformation-induced coupling

Peaks

monopole and K=0 quadrupole

coincide in energy

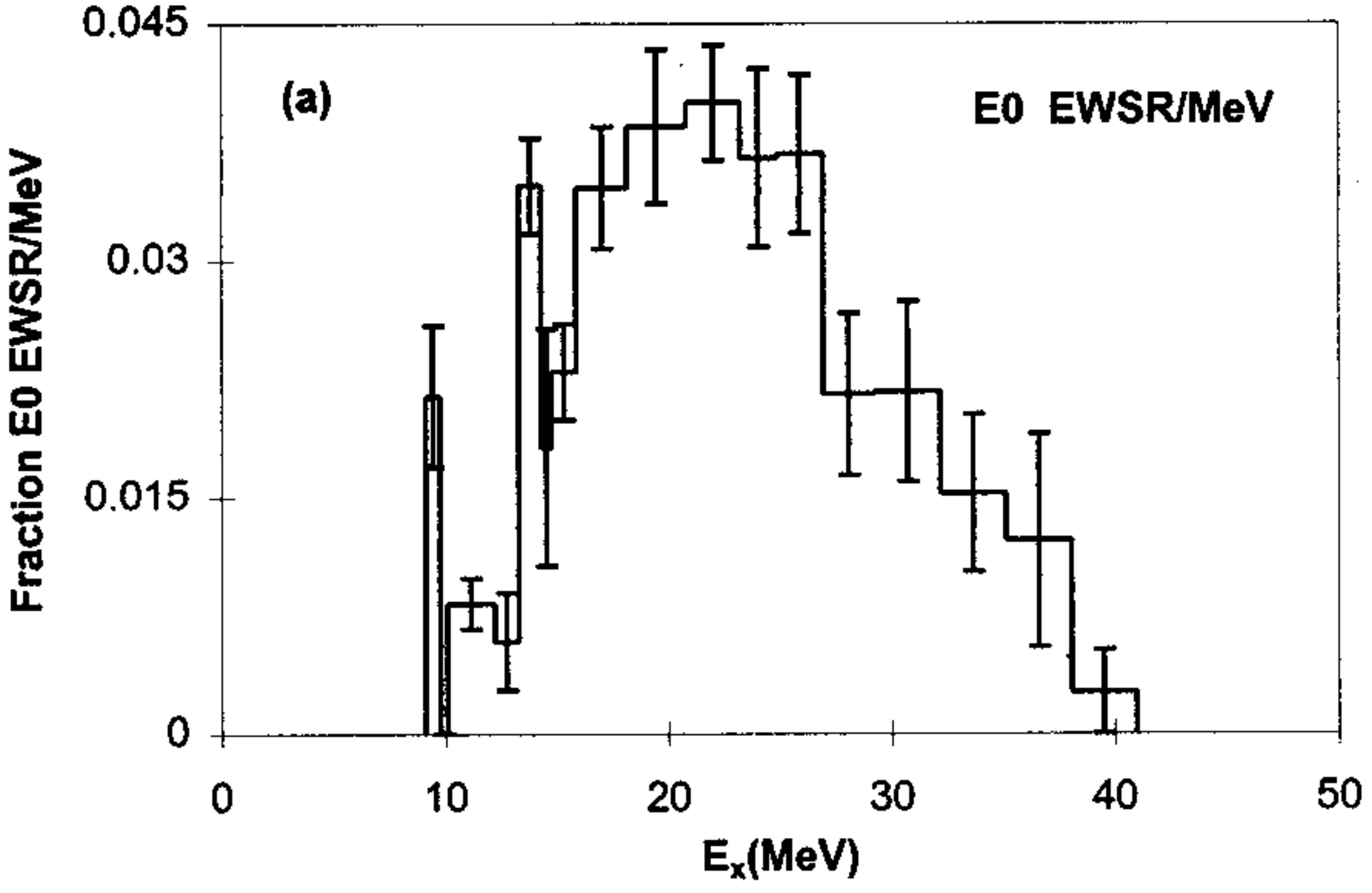
residual interactions

Coexistence persists

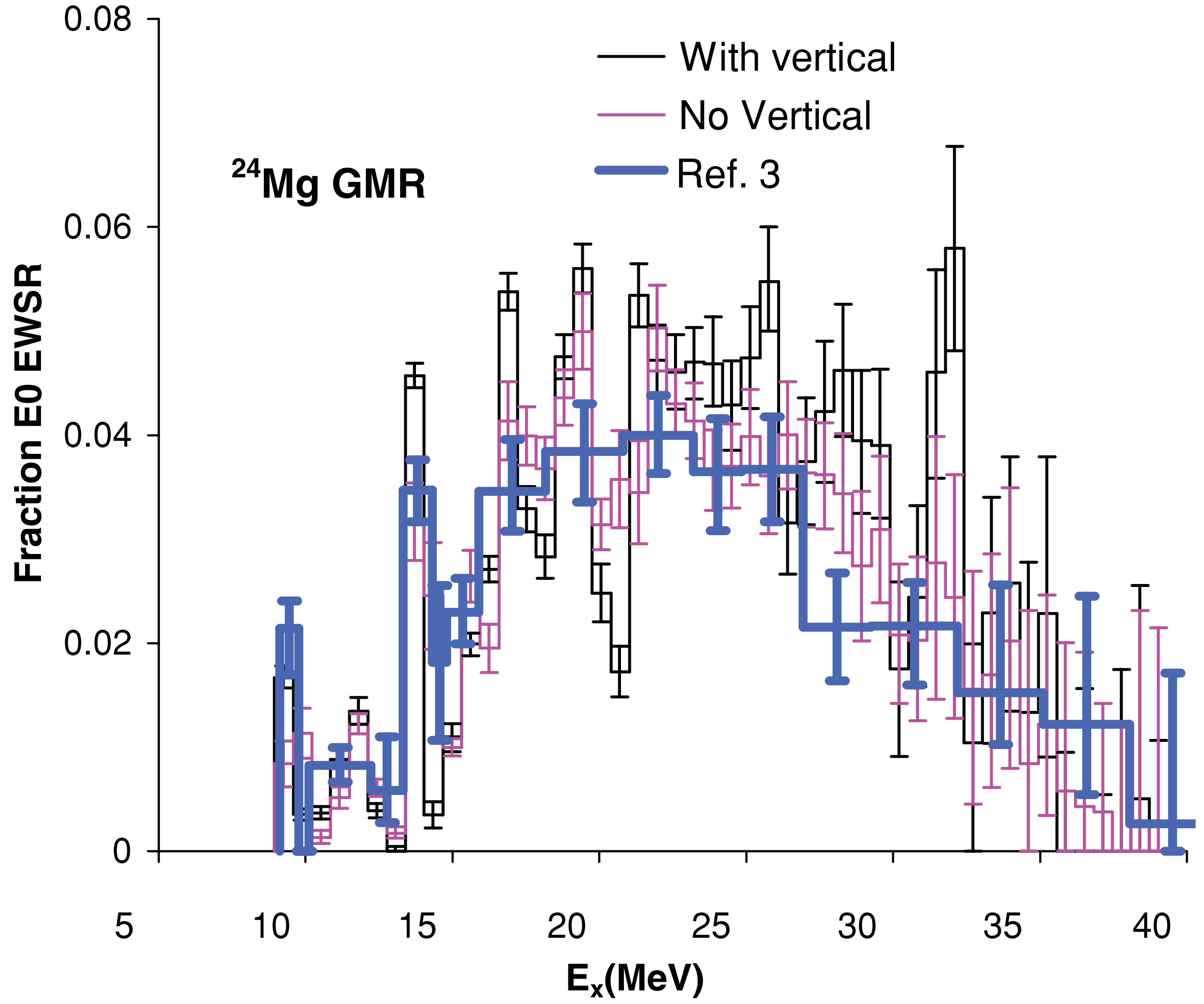
Deformation effect on GMR in light nuclei: universality

^{24}Mg @ TAMU

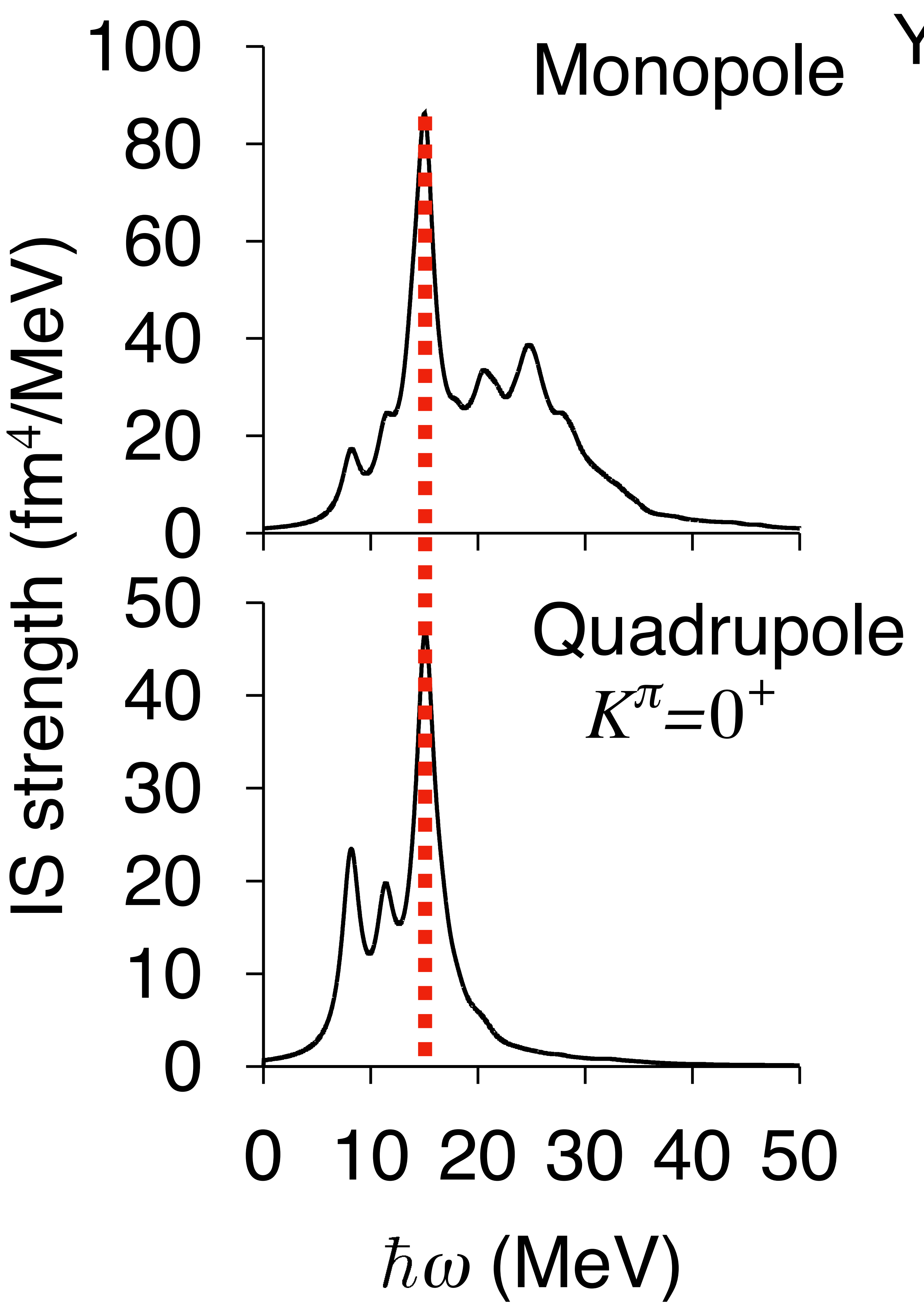
Youngblood+('99)



Youngblood+('09)

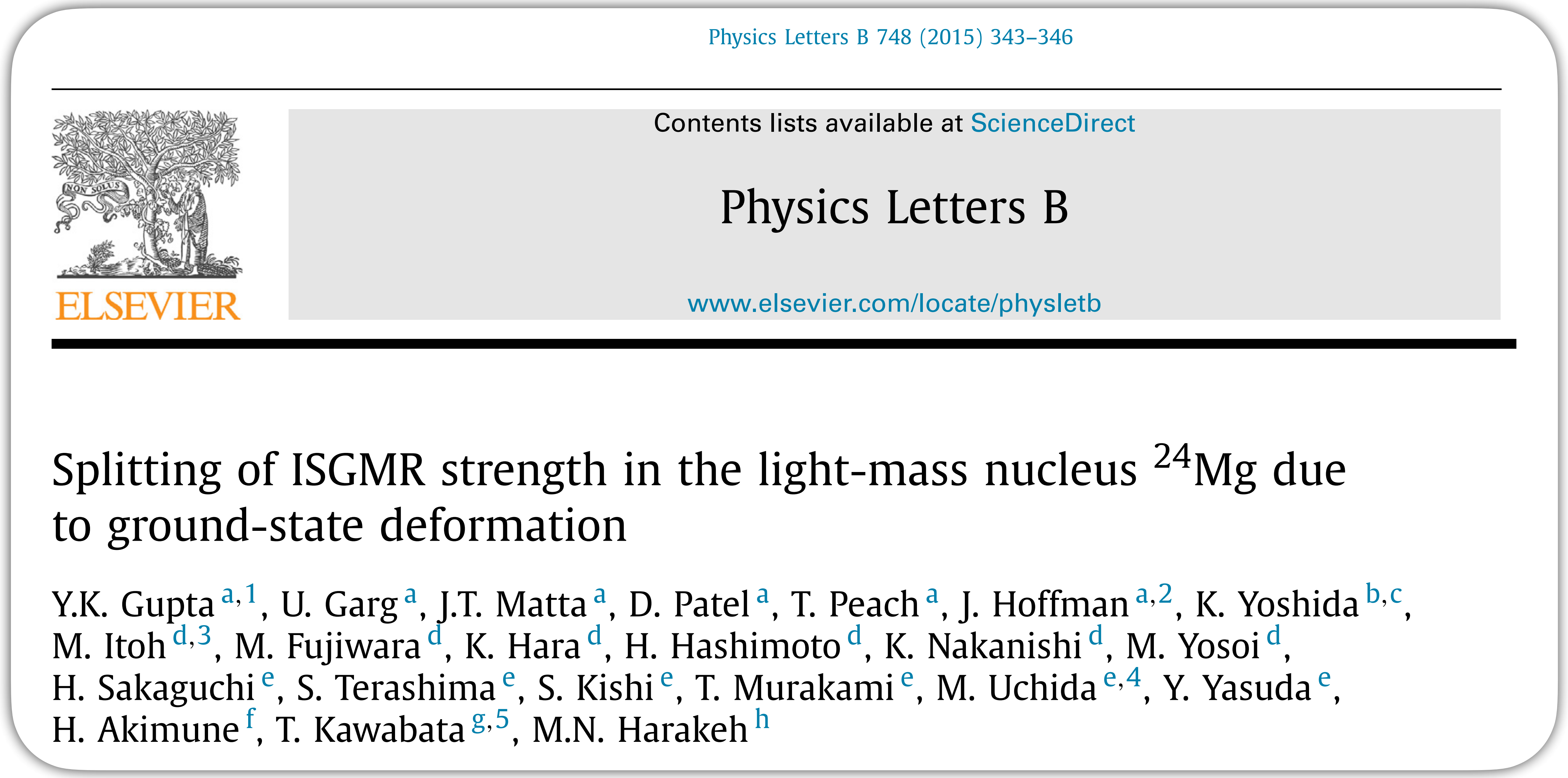


Yoshida('10)



occurrence of the "lower-energy (~15 MeV)" peak due to coupling to the *K*=0 of GQR

Deformation splitting in a light nucleus



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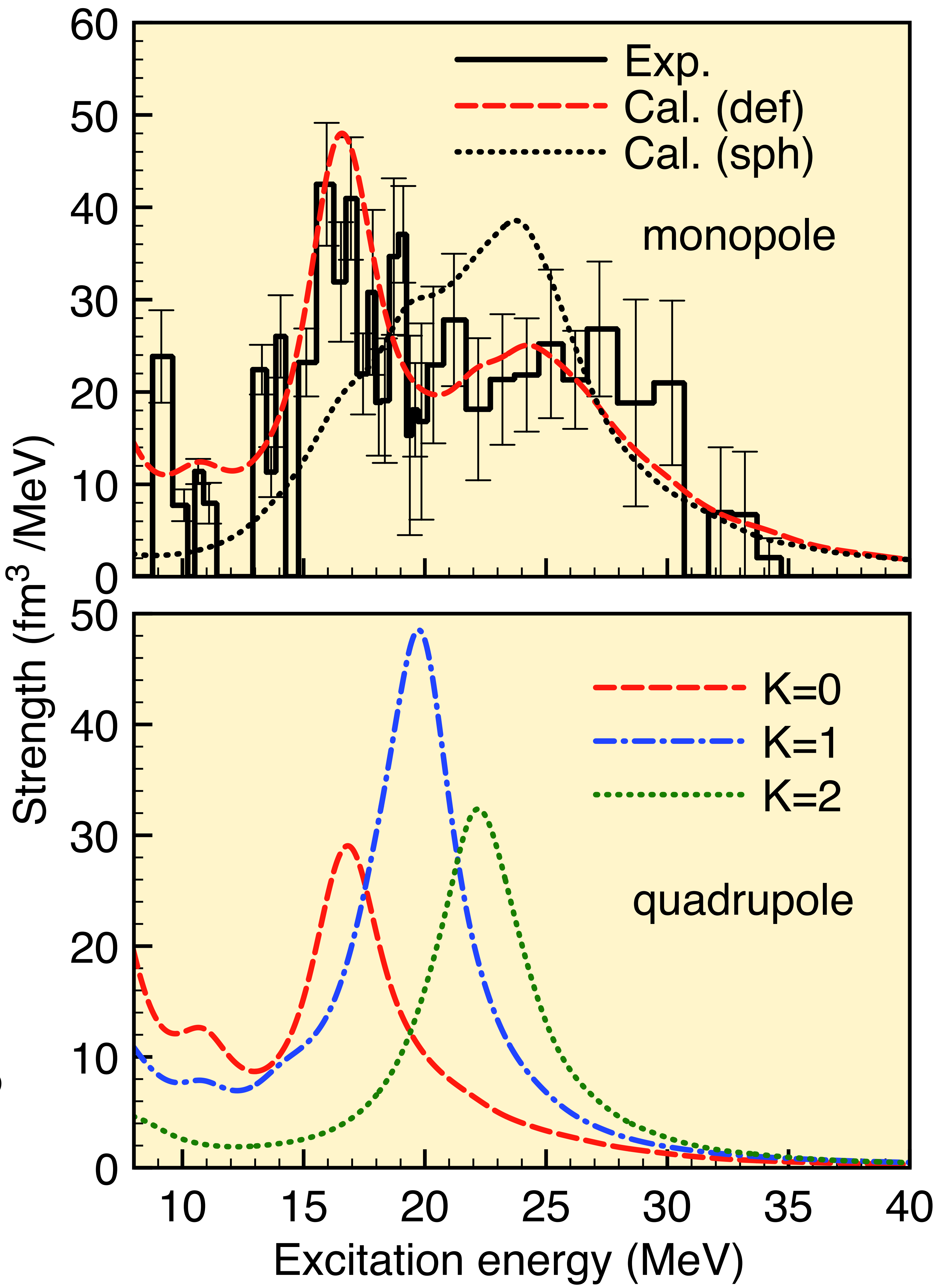
Splitting of ISGMR strength in the light-mass nucleus ^{24}Mg due to ground-state deformation

Y.K. Gupta [a,1], U. Garg [a], J.T. Matta [a], D. Patel [a], T. Peach [a], J. Hoffman [a,2], K. Yoshida [b,c], M. Itoh [d,3], M. Fujiwara [d], K. Hara [d], H. Hashimoto [d], K. Nakanishi [d], M. Yosoi [d], H. Sakaguchi [e], S. Terashima [e], S. Kishi [e], T. Murakami [e], M. Uchida [e,4], Y. Yasuda [e], H. Akimune [f], T. Kawabata [g,5], M.N. Harakeh [h]

First observation of the splitting of GMR strengths in a light system

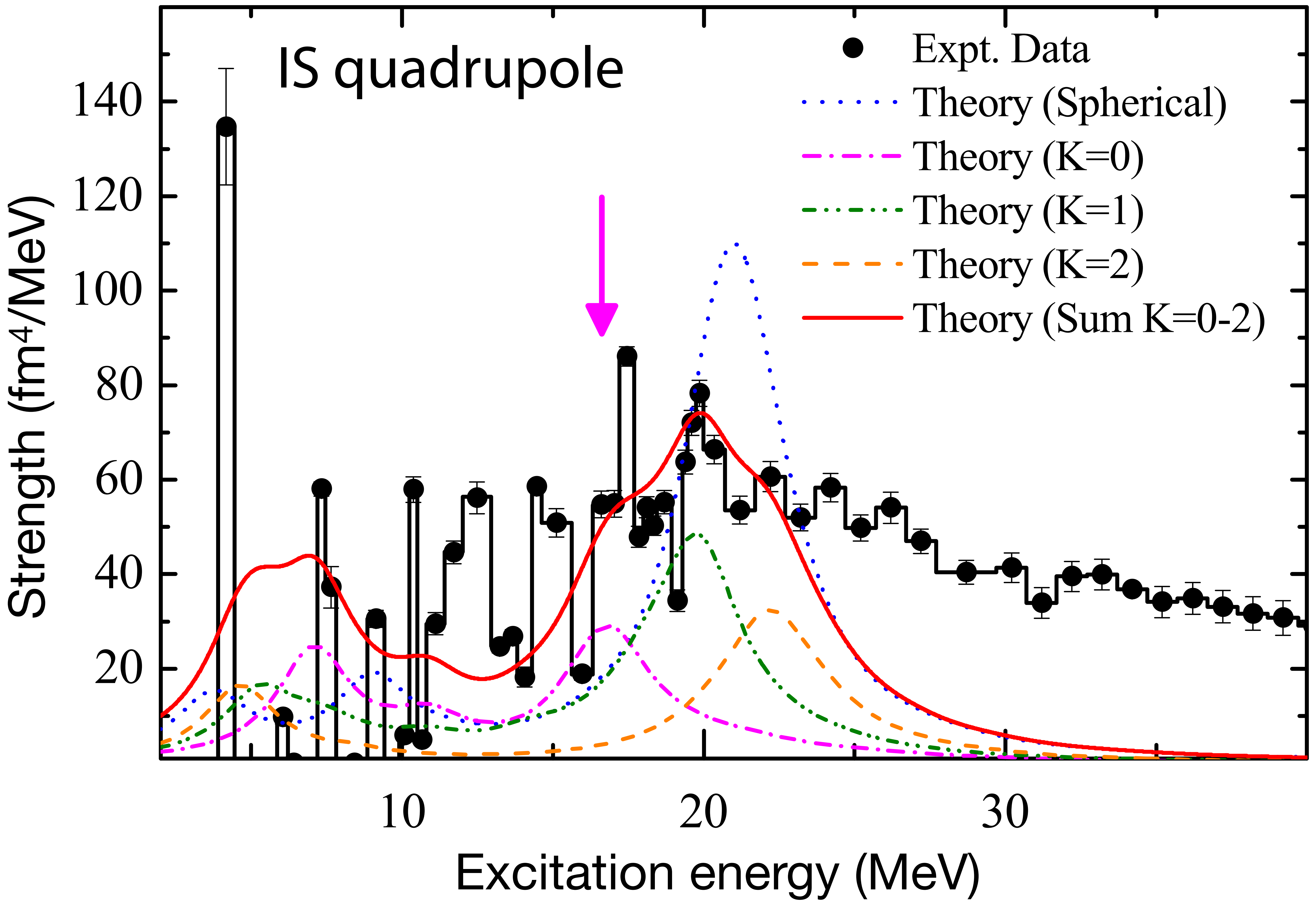


universal feature in deformed nuclei

background-free high-resolution experiment @RCNP

parameter-free nuclear DFT calculation

Strengths: missing in the QRPA

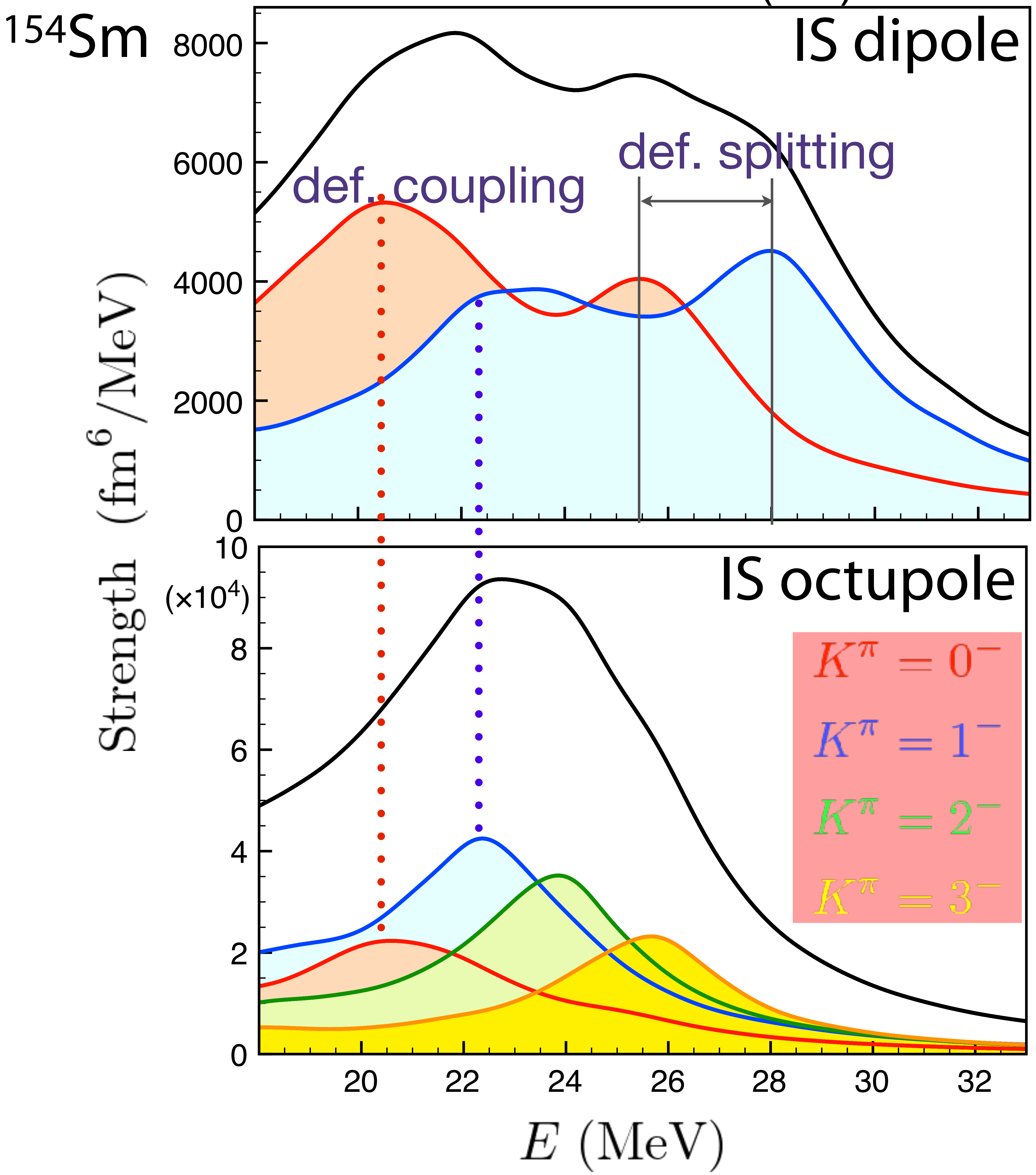


QRPA misses some states around 10–15 MeV

beyond QRPA? clustering degree of freedom?

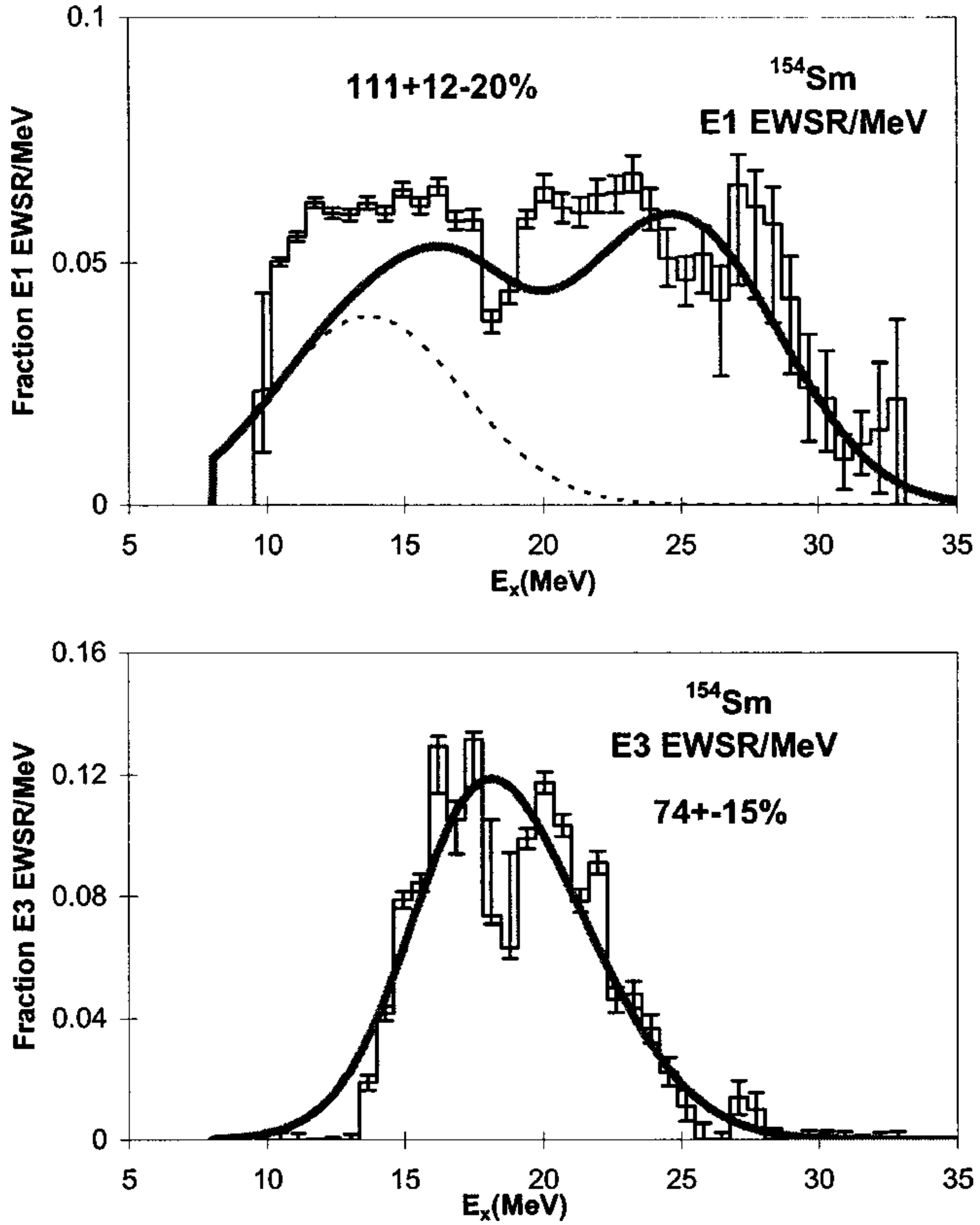
Coupling between $\Delta L = 2$

Yoshida–Nakatsukasa ('13)

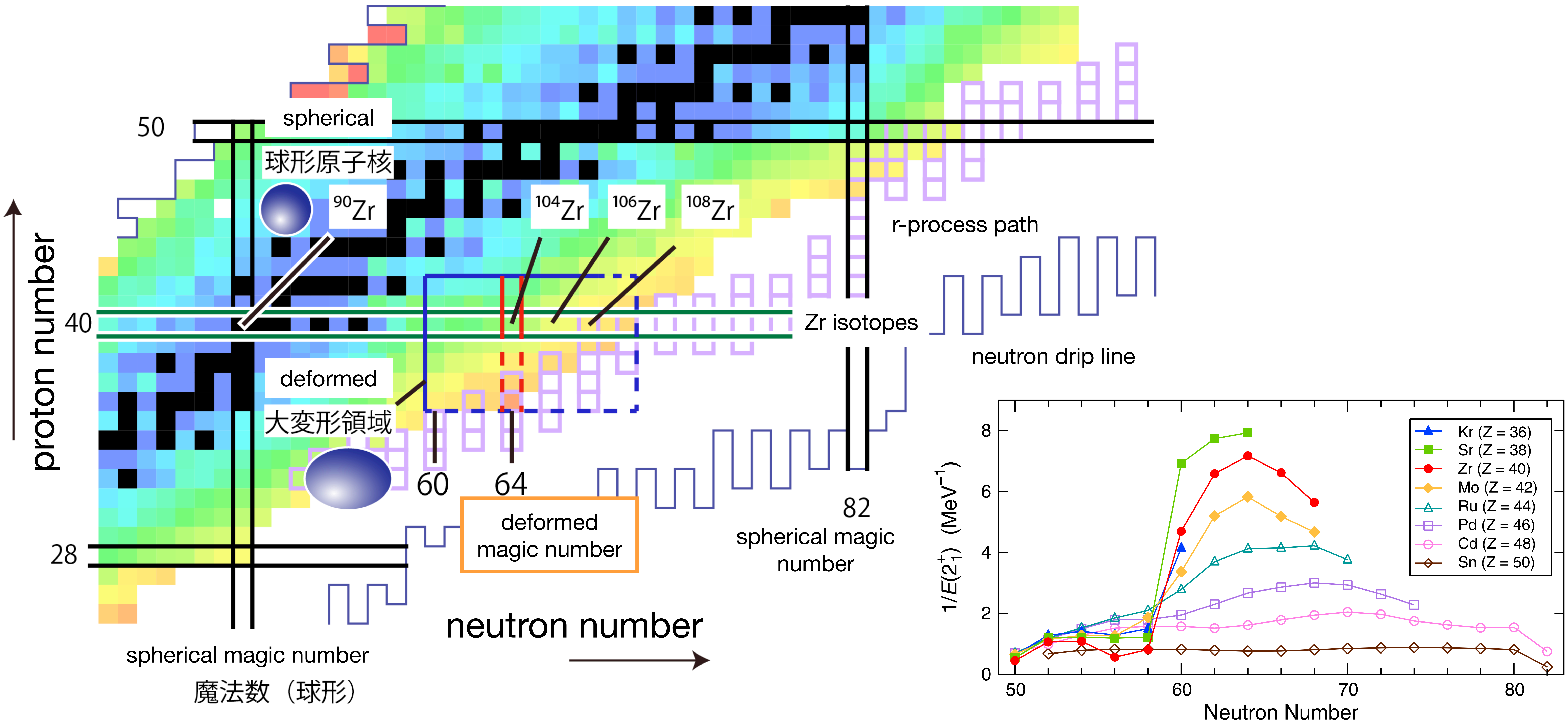


leading to a large width of the ISGDR

Youngblood+ ('04)

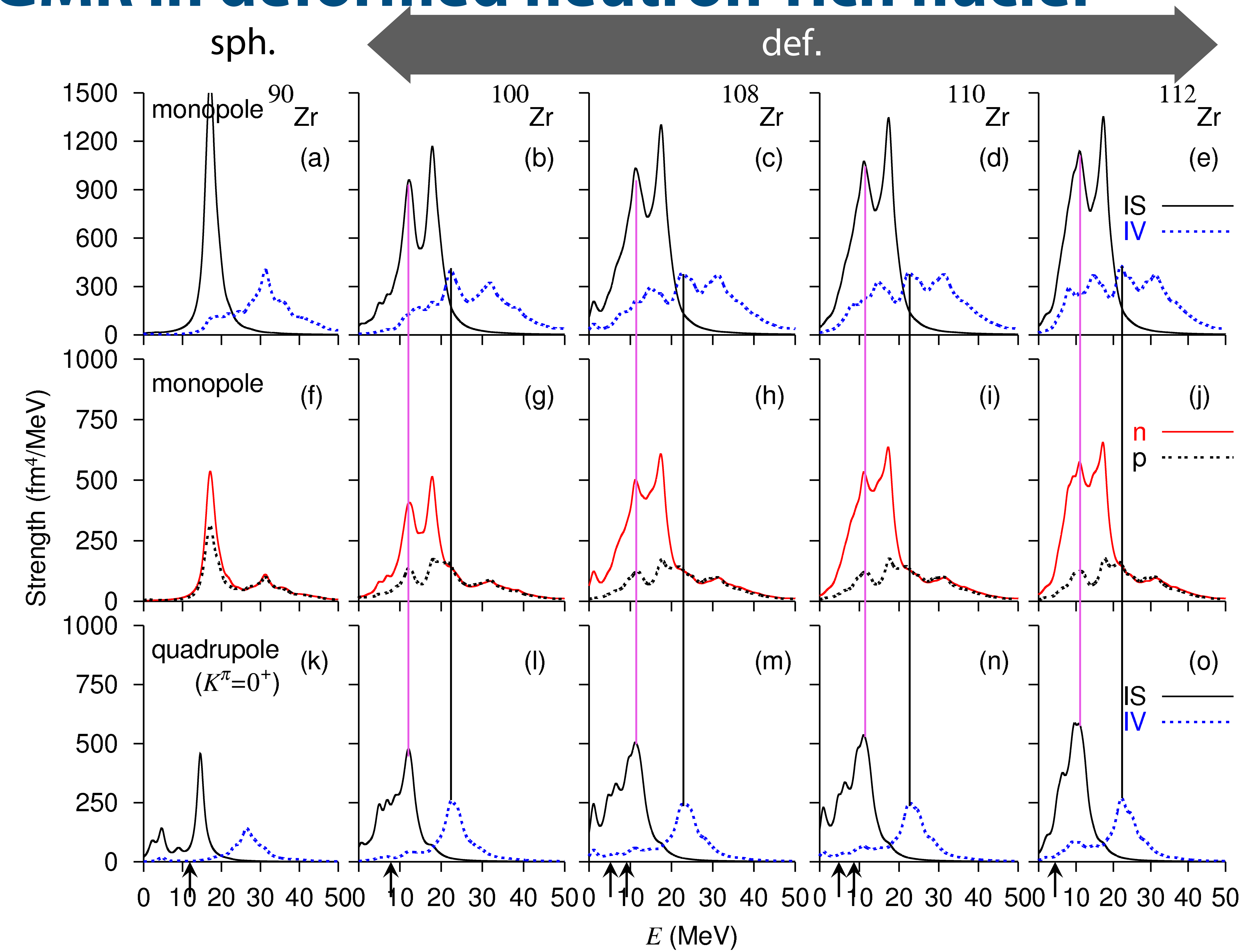


Large deformation of neutron-rich Zr isotopes



Sumikama+ ('11)
Figure taken from RIDAI-RIKEN press release

GMR in deformed neutron-rich nuclei



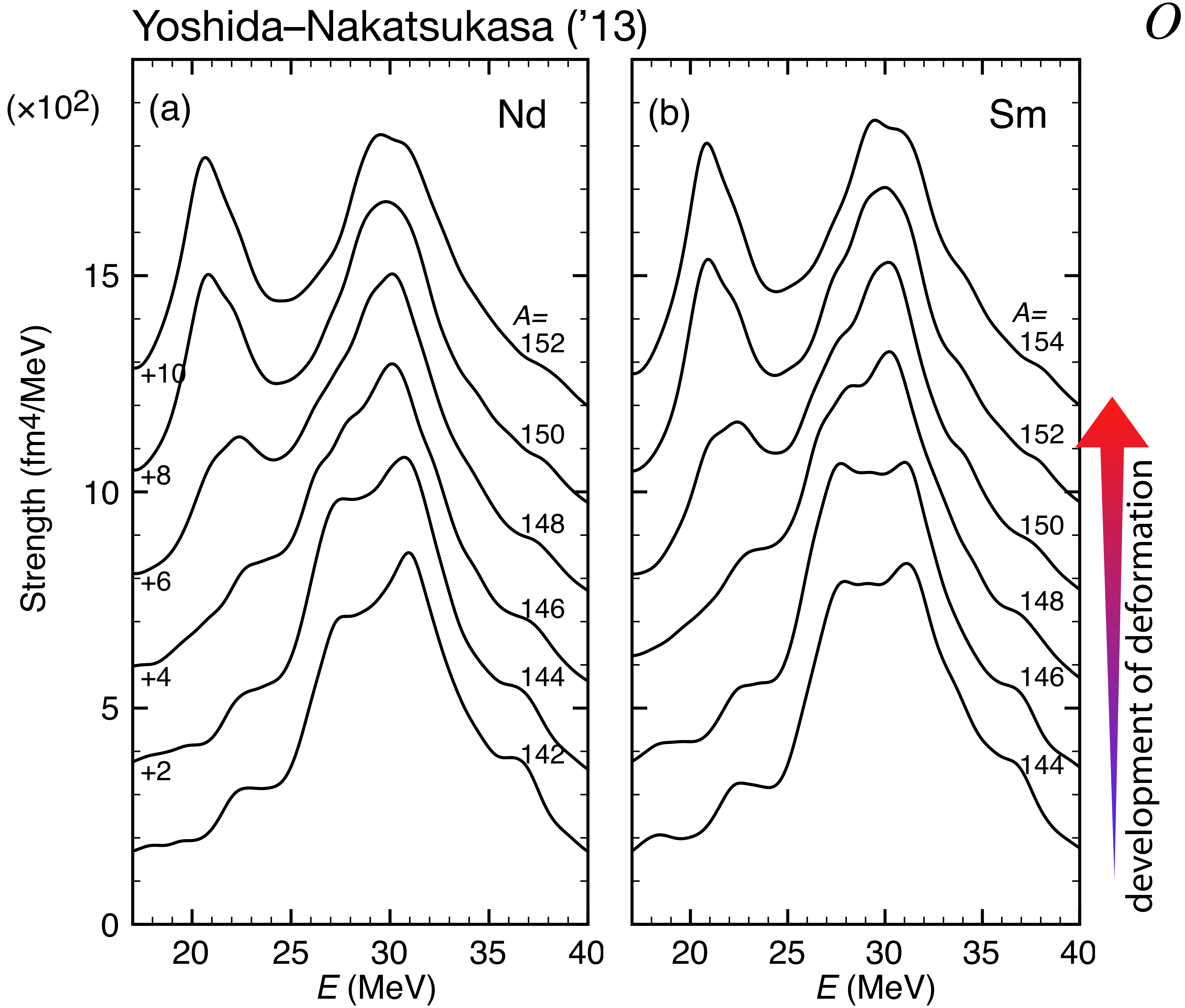
SkM* Yoshida('10)

$\Gamma = 2$ MeV

IV strengths in low energy excitation of neutrons

deformation splitting in IVGMR

Isovector (IV)-GMR in deformed nuclei



$$O = \int d\vec{r}\, r^2 \psi^\dagger(\vec{r}\tau)\langle\tau\,|\,\tau_3\,|\,\tau'\rangle\psi(\vec{r}\tau')$$

emergence of deformation "splitting"

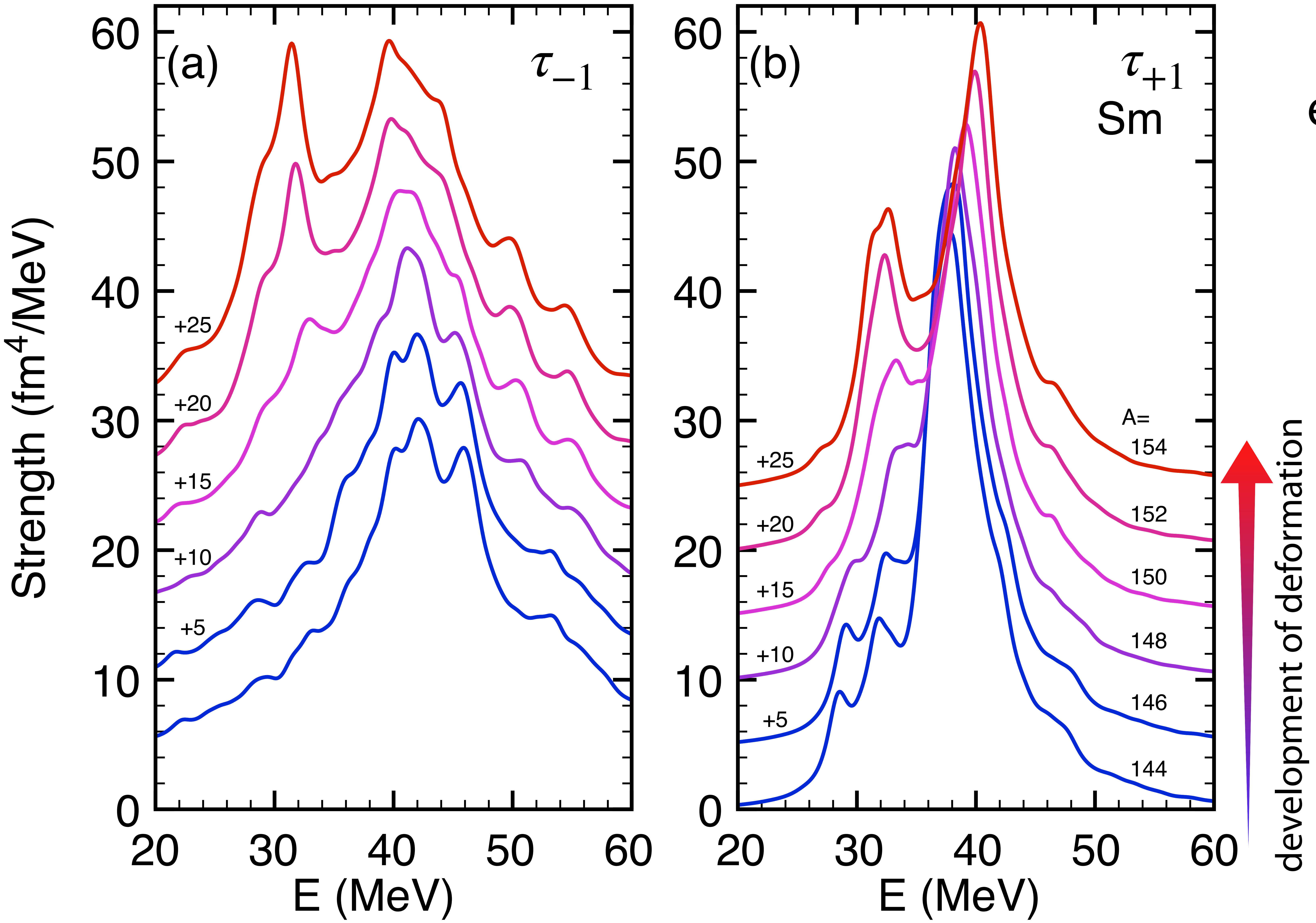
$\Delta E \sim 10\ \mathrm{MeV} @ ^{154}\mathrm{Sm}$

$\sim 2 \times \Delta E(\mathrm{ISGMR})$

due to the coupling to the $K = 0$ of IV-GQR

Isovector (IV)-GMR in deformed nuclei

Yoshida ('21)



$$O = \int d\vec{r} r^2 Y_0(\hat{r}) \psi^\dagger(\vec{r}\tau) \langle \tau | \tau_{\pm 1} | \tau' \rangle \psi(\vec{r}\tau')$$

emergence of
deformation "splitting"
$\Delta E \sim 10$ MeV @ ^{154}Sm

universal in IV excitations
$\mu_\tau = -1, 0, +1$

Summary

Deformation effect in GMR studied by nuclear DFT

appearance of the **deformation splitting**

coupling to the K=0 component of the GQR

deformation splitting of the GQR (K=0,1,2)

taking place at the mean-field level

stronger coupling in well-deformed nuclei

universal in medium-mass and light nuclei, as well as in n-rich nuclei

universal in IS and IV excitations

Coupling between the K=0 component of the dip. and oct. giant resonances

(if the parity is a good quantum number)

References

Yoshida ('10): Mod. Phys. Lett. A 25 (2010), 1783

Yoshida ('10): Phys. Rev. C 82 (2010), 034324

Yoshida–Nakatsukasa ('11): Phys. Rev. C 83 (2011), 021304(R)

Yoshida–Nakatsukasa ('13): Phys. Rev. C 88 (2013), 034309

Yoshida ('21): Phys. Rev. C 104 (2021), 044309