A new analysis of old Saclay data reveals a breaking of axial symmetry in many nuclei.

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Level densities - n-tof data

Quadrupole observables in even nuclei

Splitting of giant dipole resonances

Consequences for their interpretation

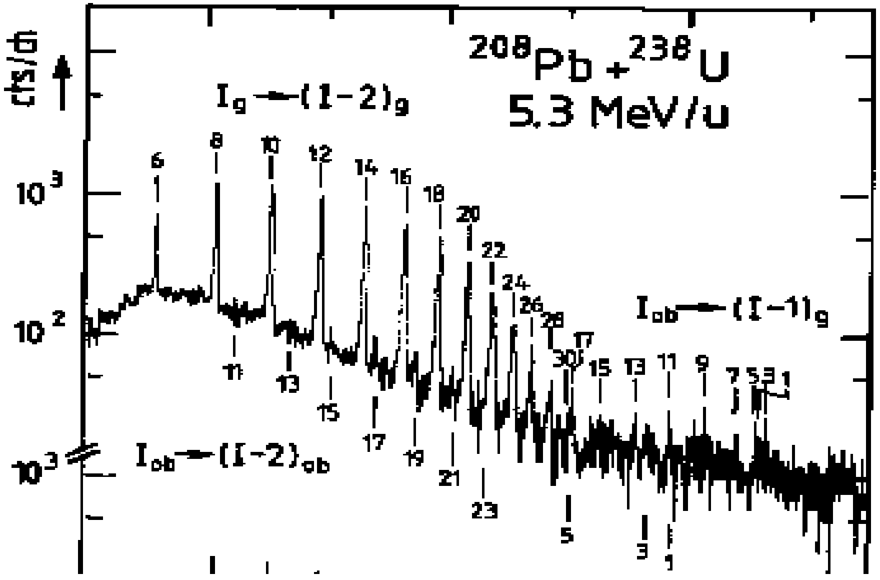
Photon strength and n-capture

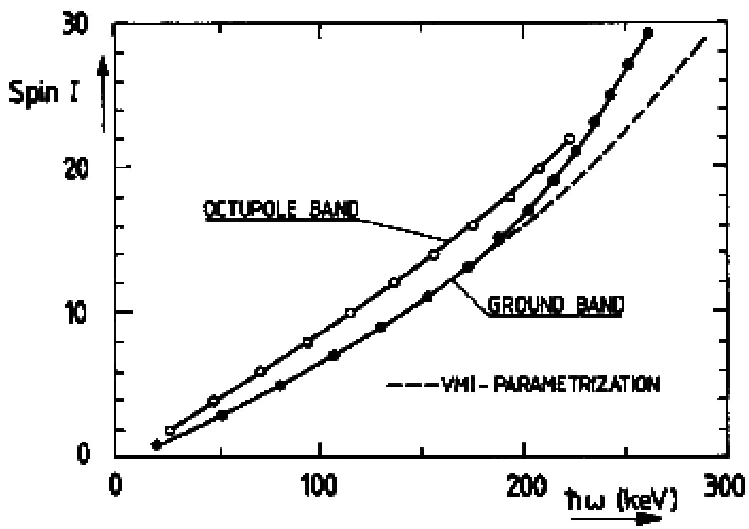
Rotor models and microscopic calculations

Coulomb excitation of actinides and also of 'intermediate' nuclei seems to indicate

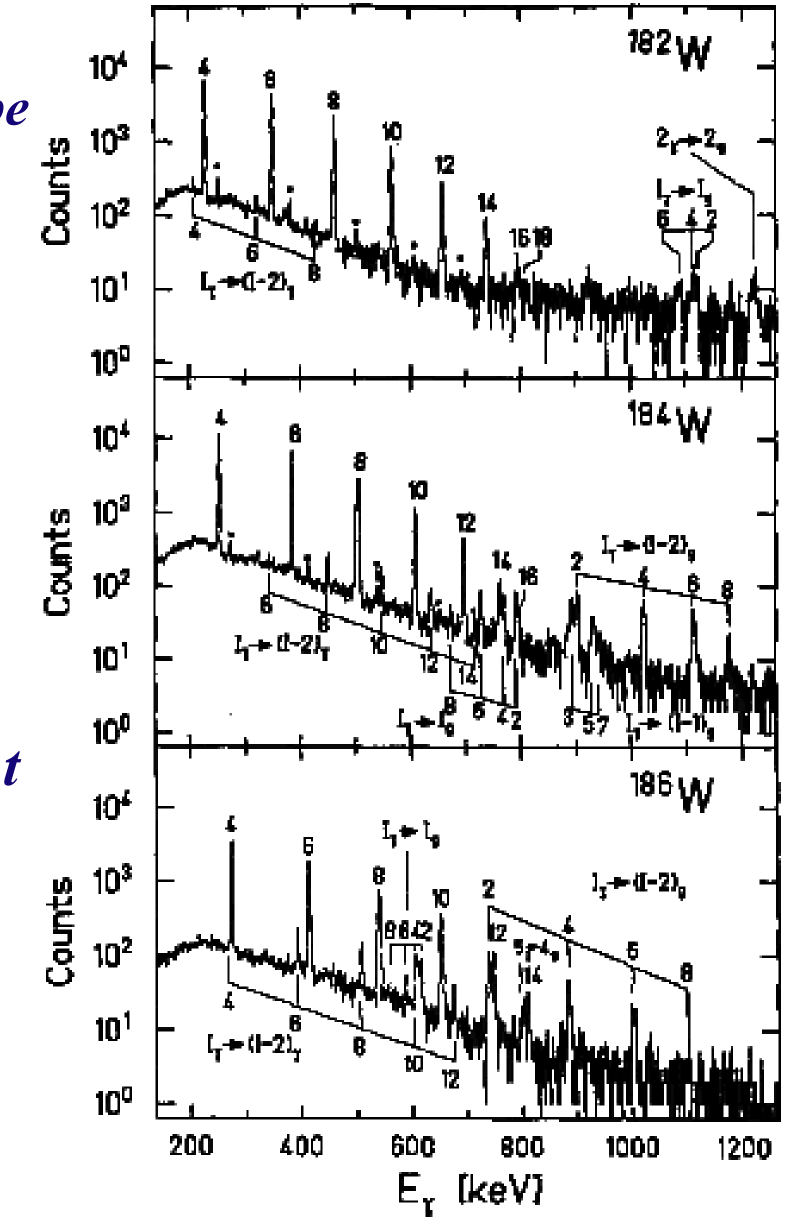
rigid rotation

of <u>axial</u> shape





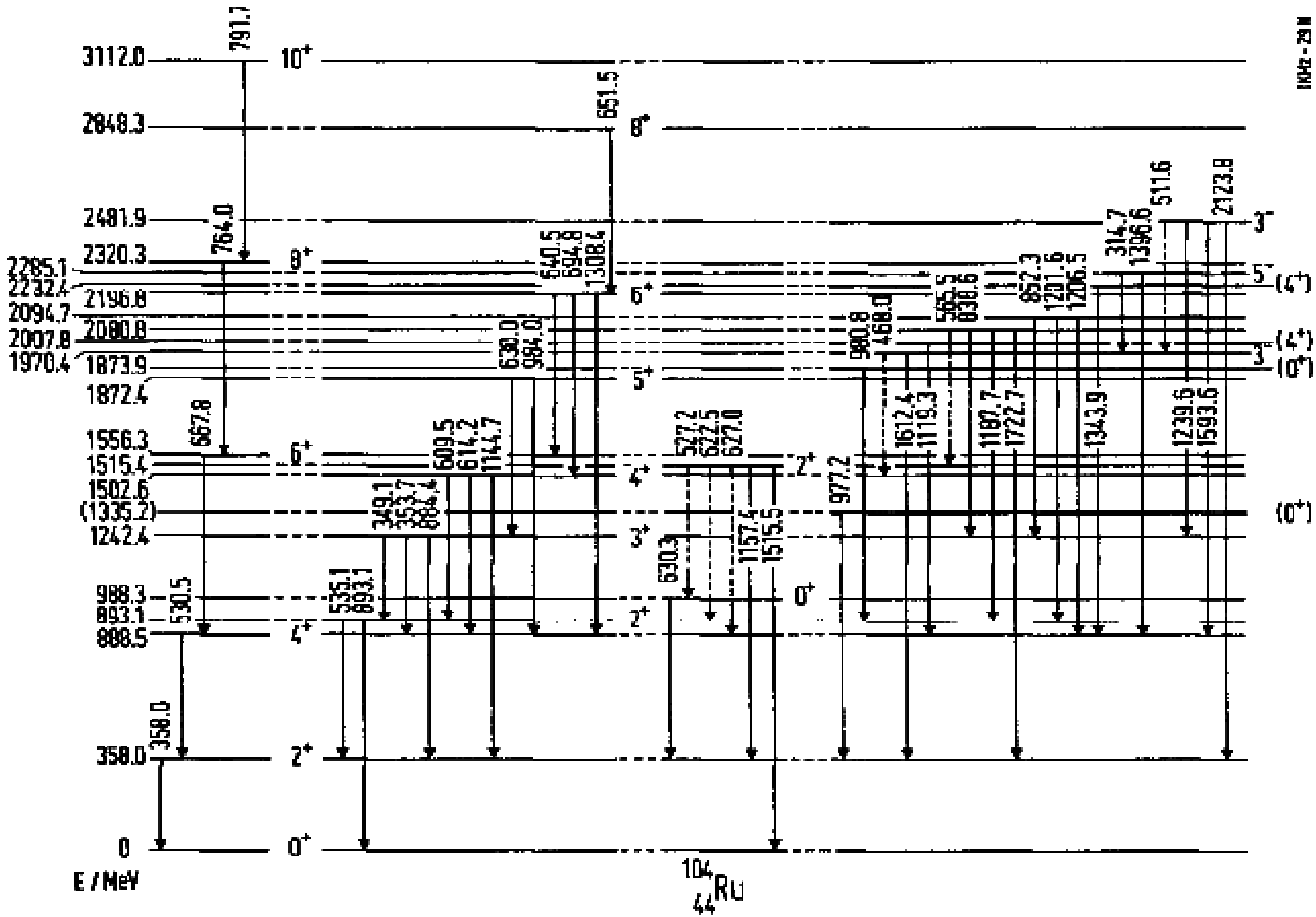
but in general the situation is different



Grosse et al., Physica Scripta 24, 331 (1981)

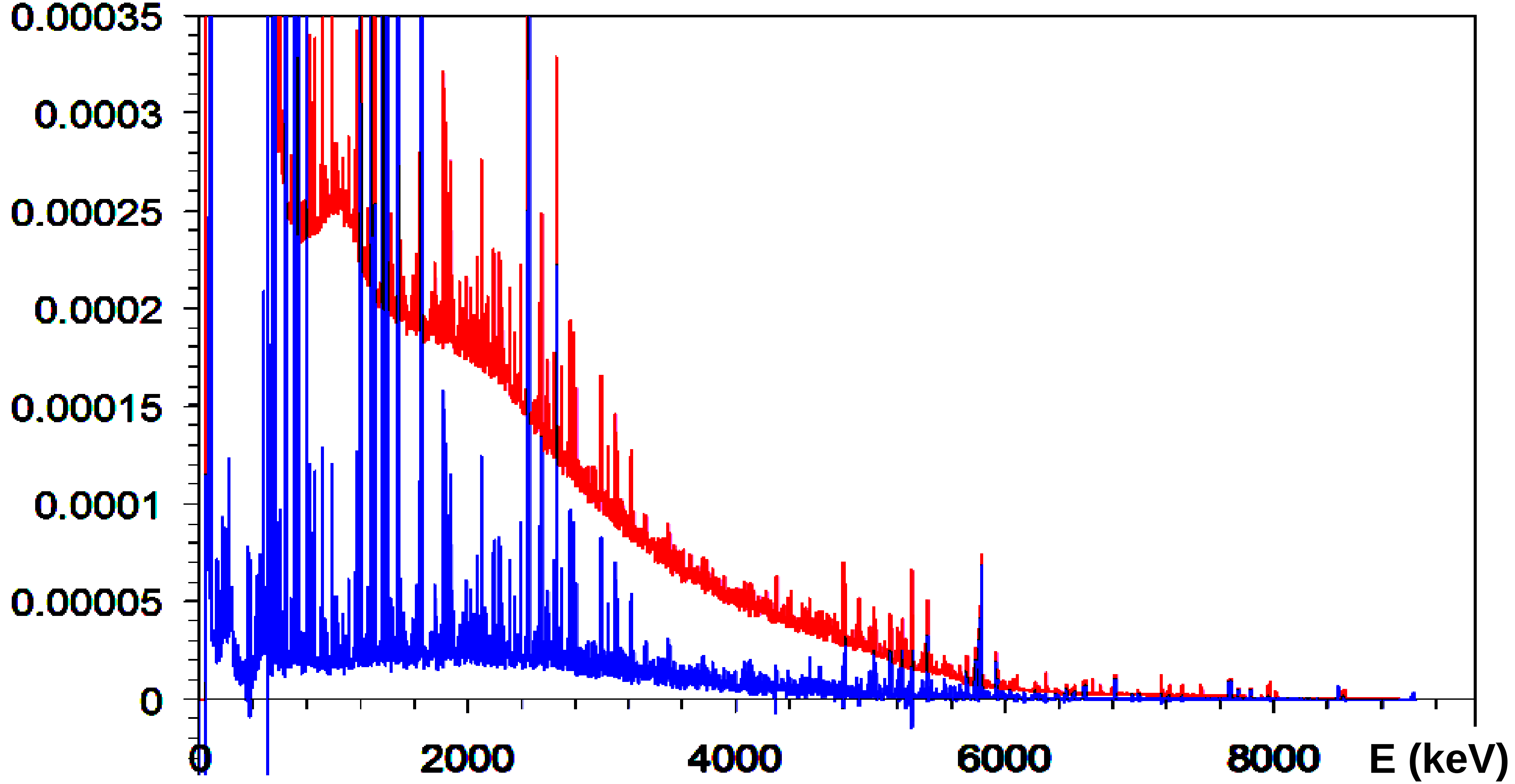
Kulessa et al., PLB 218 (1988) 421

Complex **Coulex data with ^{104}Ru and ^{208}Pb-beams** *indicate broken axial symmetry already at low E_x*



J. Stachel et al., Nuclear Physics A419 (1984) 589

Improved data analysis: Ge-detector spectra from $^{113}Cd(n_{therm},\gamma)$



The deconvoluted, efficiency corrected spectrum shows <u>high level density</u> in quasi-continuous broad distribution peaking at 1 to 3 MeV

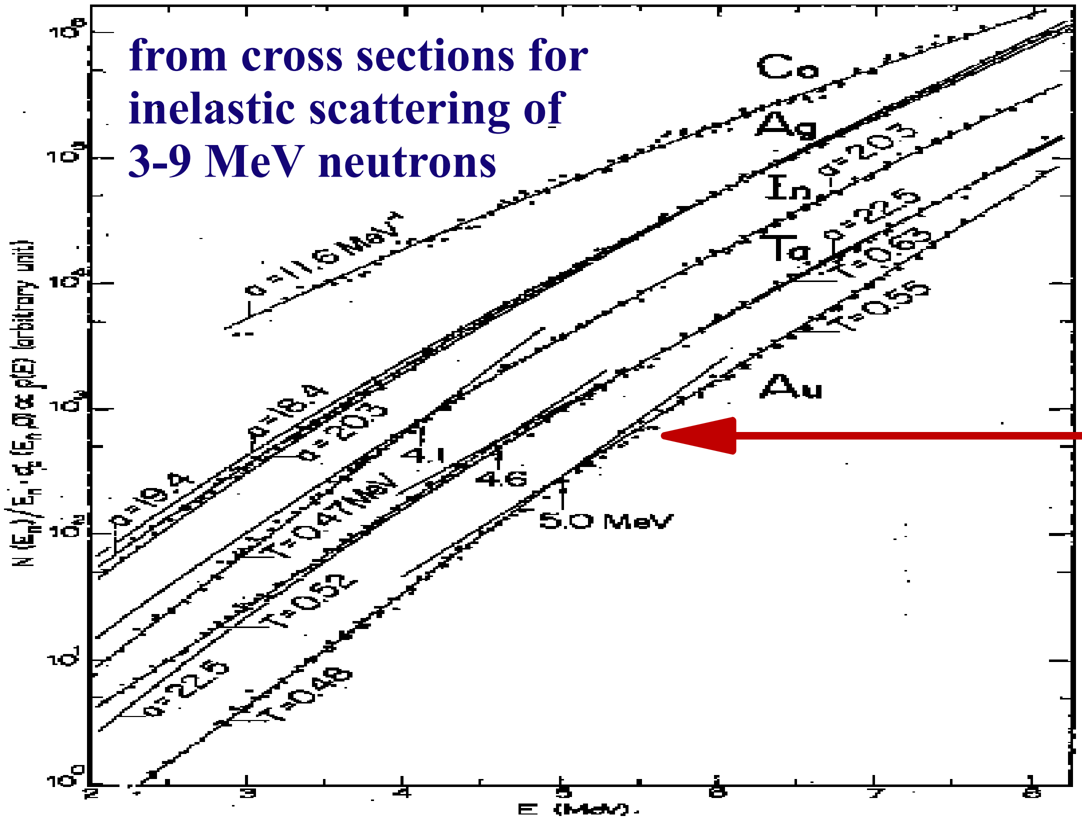
T. Belgya et al., HAS-Budapest-HZDR collaboration

Level densites ρ(E) *in heavy nuclei indicate a phase transition between*

a ***Fermi gas*** *above* $t_c = \Delta_0 \cdot e^C/\pi = 0.567 \cdot \Delta_0$ *(with Euler' constant C)*

and below a regime influenced by ***pairing and shell effects****,*

approximated by an exponential.



phase transition @ t_c

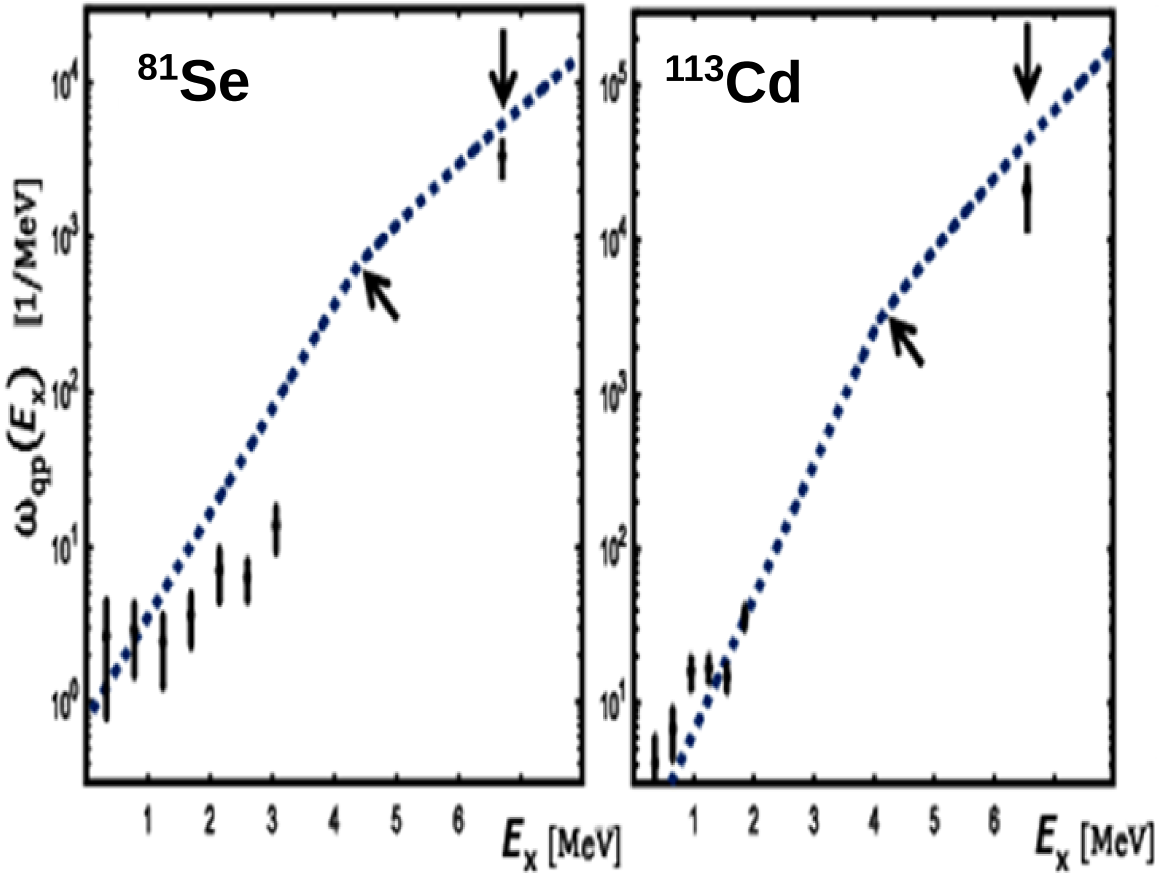
Tsukada et al., NP78 (1966) 369

Fermi gas model

$$\omega_{qp}(E_x) = \frac{\sqrt{\pi}\cdot exp\left(2\sqrt{\tilde{a}(E_x - E_{bs})}\right)}{12\,\tilde{a}^{1/4}(E_x - E_{bs})^{5/4}}$$

Constant temperature model

$$\omega_{qp}(E_x) = \omega_{qp}(0)\, exp\left(\frac{E_x}{T_{ct}}\right)$$



The two-component level density approach has to be complemented by collective rotational enhancement, which is simple for low spins:

$$\rho \rightarrow \frac{2\,J+1}{2\cdot 4}\,\omega_{qp}(E_x)$$

if axial symmetry is <u>not</u> required.

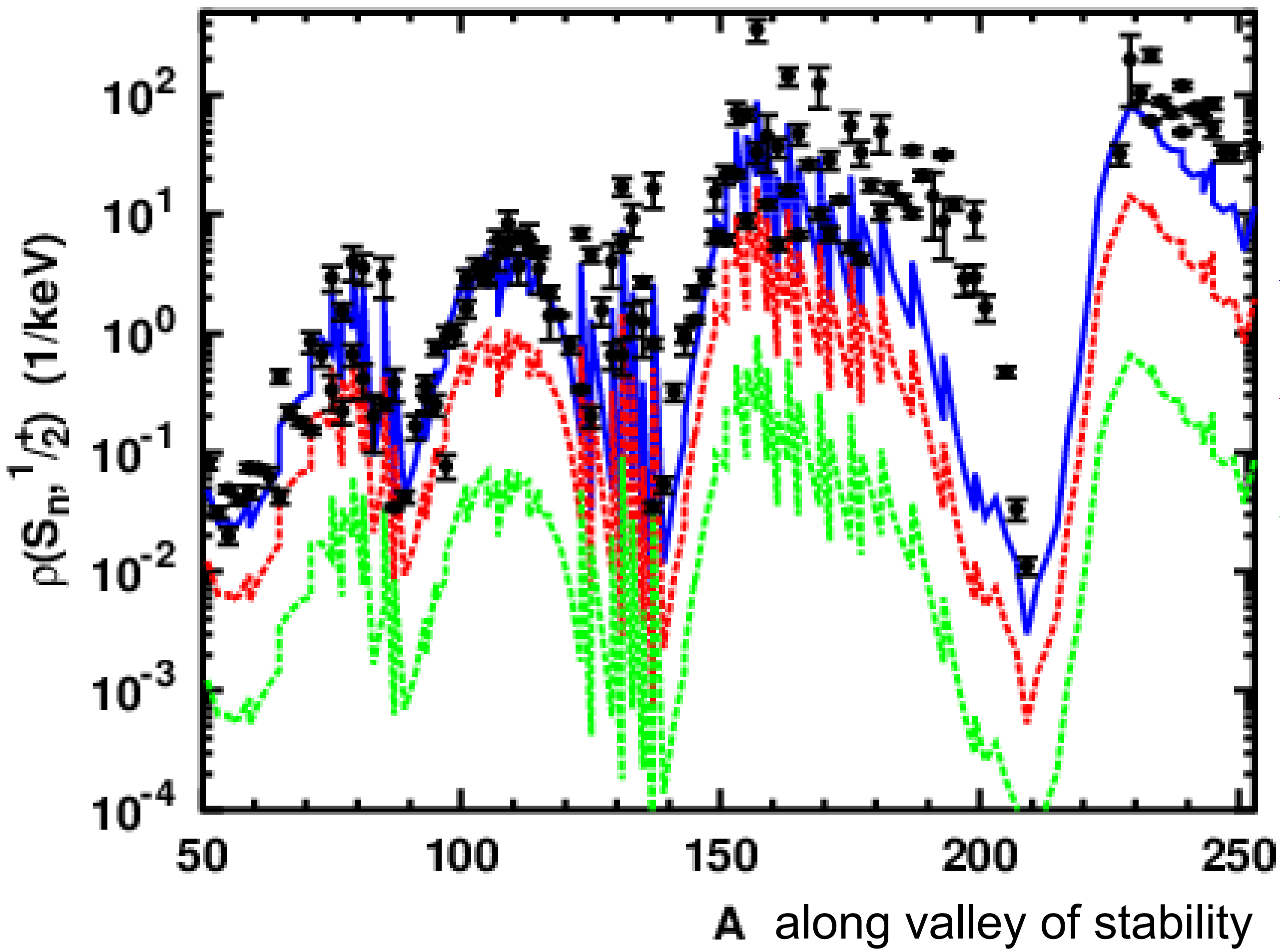
Without fit we get good agreement for states with J = ½ and then also for capture resonances into J=0 targets. *Values for* Δ *and* $\tilde{a}$ *taken from nuclear matter;* E_{bs} *from LD-mass fit.*

Gilbert and Cameron, Can. Journ. of Phys., 43 (1965) 1446

Level densites ρ(E,I) *in heavy nuclei result from collective enhancement (group theory)*

of intrinsic state density ω(E); account for broken axiality allows to use $\tilde{a} = \tilde{a}_{nm} = A/15$

Accurate data stem from n-capture resonances just above S_n*:*



prediction for broken axiality

prediction assuming axiality

prediction for spherical case,

absolute scale,

no parameters adjusted.

Data from RIPL-3 H.Bethe, Rev. Mod. Phys. 9 (1937) 69; S.Bjørnholm, A.Bohr, B.Mottelson; Rochester conf. 1974, IAEA-SM-l74/205

Rotational enhancement of nuclear level density vs. symmetry class

*The intrinsic **quasi-particle state density** in a finite nucleus $\omega_{qp}(E_x)$ is **not** yet the observable density of nuclear levels with **well defined spin** $\rho(E_x, J, \pi)$.*

To fix J the underlying collective symmetry has to be determined by group theory:

small J limit

1. *spherical* ⇒ *only q-p states* $\rho(E_x, J, \pi) \rightarrow \frac{2J+1}{2\cdot\sqrt{8\pi}\,\sigma^3}\,\omega_{qp}(E_x)$

2. *axial* ⇒ *q-p states & rotation ⊥ axis* $\rho \rightarrow \frac{2J+1}{2\cdot\sqrt{8\pi}\,\sigma}\,\omega_{qp}(E_x)$

3. *non-axial (triax)* ⇒ *q-p states & rotation about any axis* $\rho \rightarrow \frac{2J+1}{2\cdot 4}\,\omega_{qp}(E_x)$

4. *no reflection symmetry* ⇒ *q-p states & octupole deform.* $\rho \rightarrow \frac{2J+1}{2}\,\omega_{qp}(E_x)$

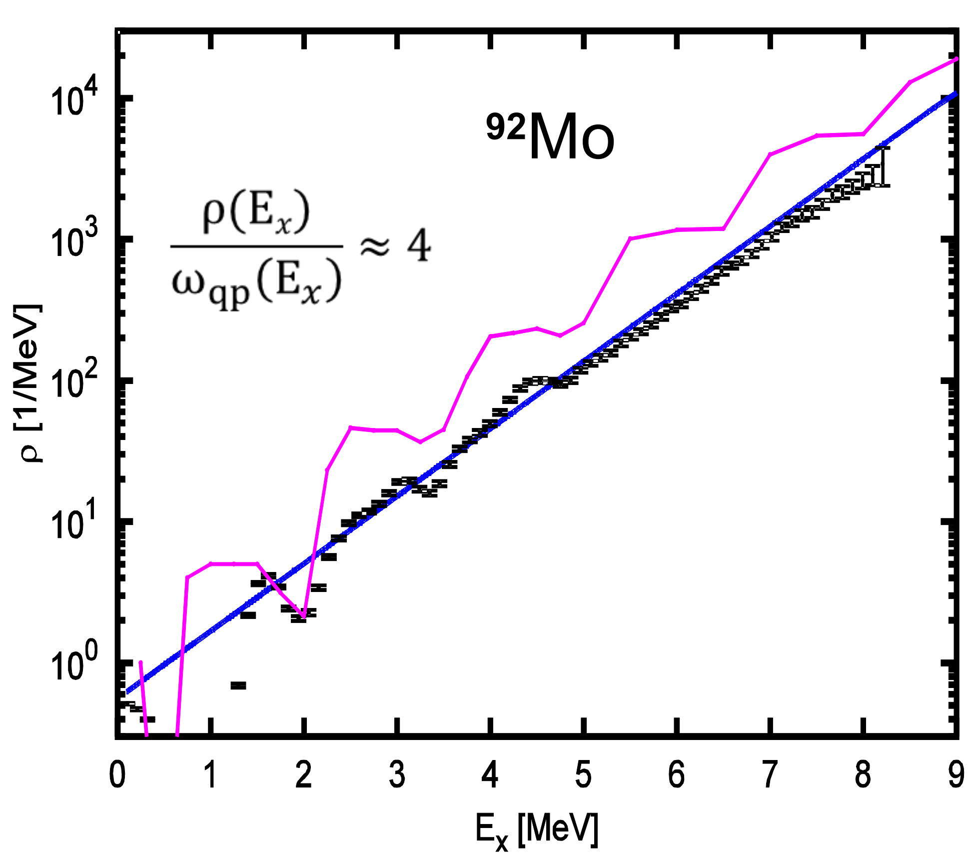
1 parity

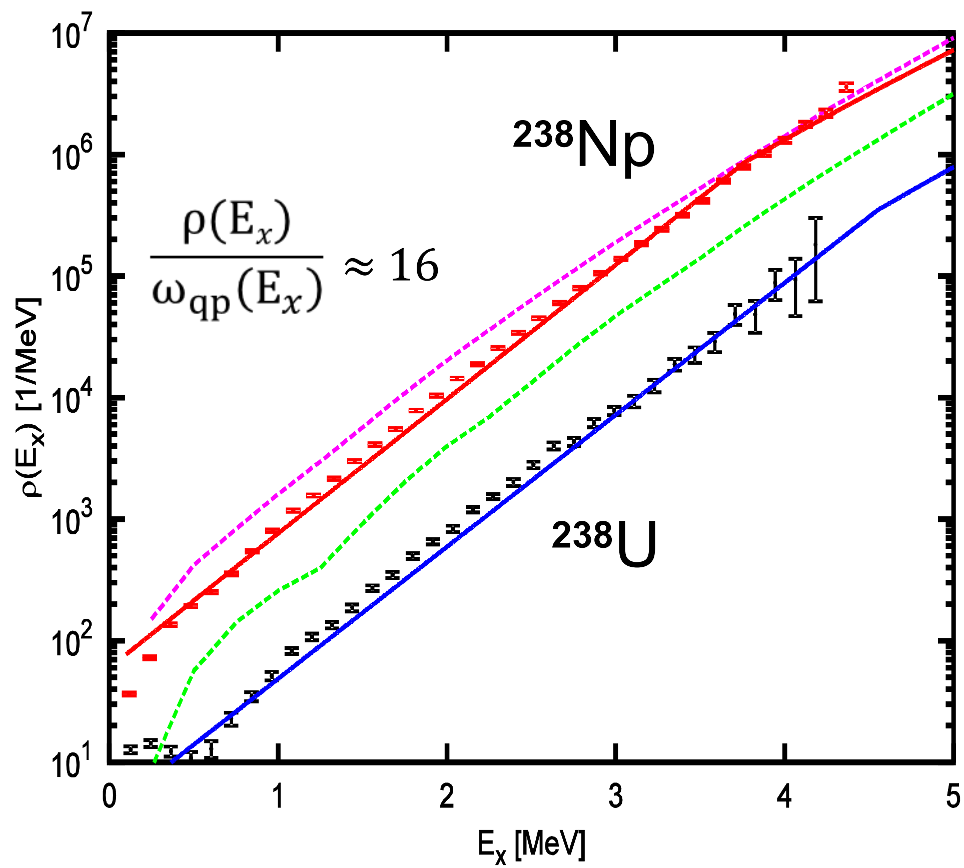
Thomas-Fermi Model ⇒ $\sigma^2 = \frac{\tilde{a}\cdot t}{11} A^{2/3} \approx \frac{A^{5/3}}{143}\cdot t$

Bethe, Rev. Mod. Phys. 9 (1937) 69; Jensen and Luttinger, Phys. Rev. 86 (1952) 907; Bjørnholm et al., Roch. conf.1974, IAEA-SM-l74/205

Collective enhancement for "total" level density $\rho(E_x, I) = \sum_{I=0}^{\infty} \rho(E_x, I)$

$$\frac{\rho(E_x)}{\omega_{qp}(E_x)} = \frac{3}{4} \cdot \sum_{I=0}^{\infty} (2I+1) \cdot e^{-E_{yr}(I)/T_{eff}} \approx 3 \cdot \frac{T_{eff}}{1\text{MeV}} \cdot \sqrt{\frac{\pi \cdot \Im_{app}}{1\text{eV} \cdot \hbar^2}}$$





axiality broken, no parameters adjusted => good agreement on absolute scale.

Goriely, Hilaire, Koning, Phys. Rev. C78 (2008) 064307

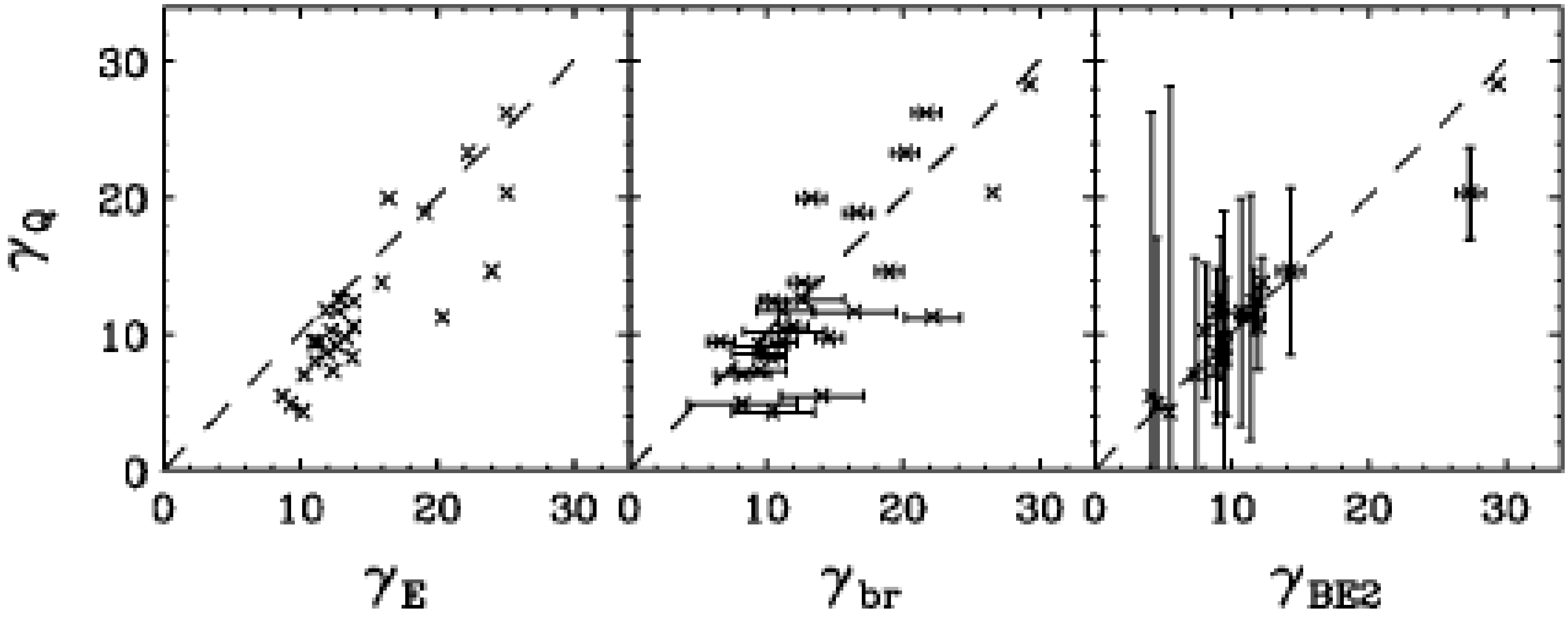
Bjørnholm et al., Roch. cf. 974, IAEA-SM-I74/205

Tveten et al., Phys. Rev. C94, 025804 (2016), Guttormsen et al., Phys. Rev. C88, 024307 (2013), Tornyi et al., Phys. Rev. C89, 044323 (2014)

Comparison of empirical γ-values for nuclei with 50 < Z < 82

The three panels compare γ_Q obtained from IBA-1 fits to the data with γ_E, γ_{br}, and γ_{BE2} values obtained from the Davydov model relating γ to the empirical energy ratio, branching ratio, and B(E2) ratios, respectively.

The uncertainties in γ_Q are the same in each of these panels and shown in only one of them



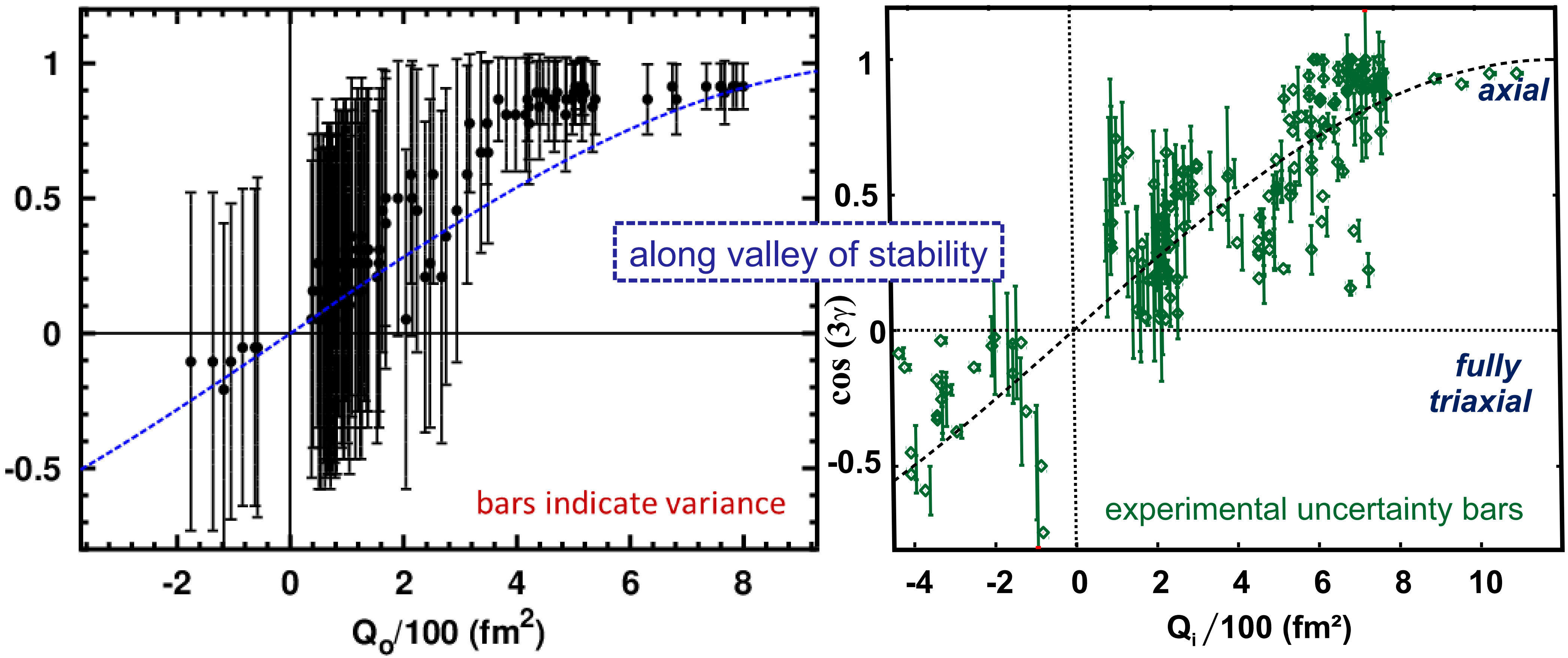
The IBA-1 suggests that axial asymmetry arises from γ-softness

Zhang, Casten, and Zamfir, PRC 60 (99) 021304

*New view on heavy nuclei – **avoiding axial symmetry postulate***

by: newly applied theoretical tools *and* *experimental observations:*

HFB + GCM , projection on I ⇒ β, γ	***level energies***
$Q^3 \cdot \cos(3\gamma)$ ⇒ rotation invariant	***decay properties and Q-moments***
*indicator for **axiality***	***collectively enhanced level density***

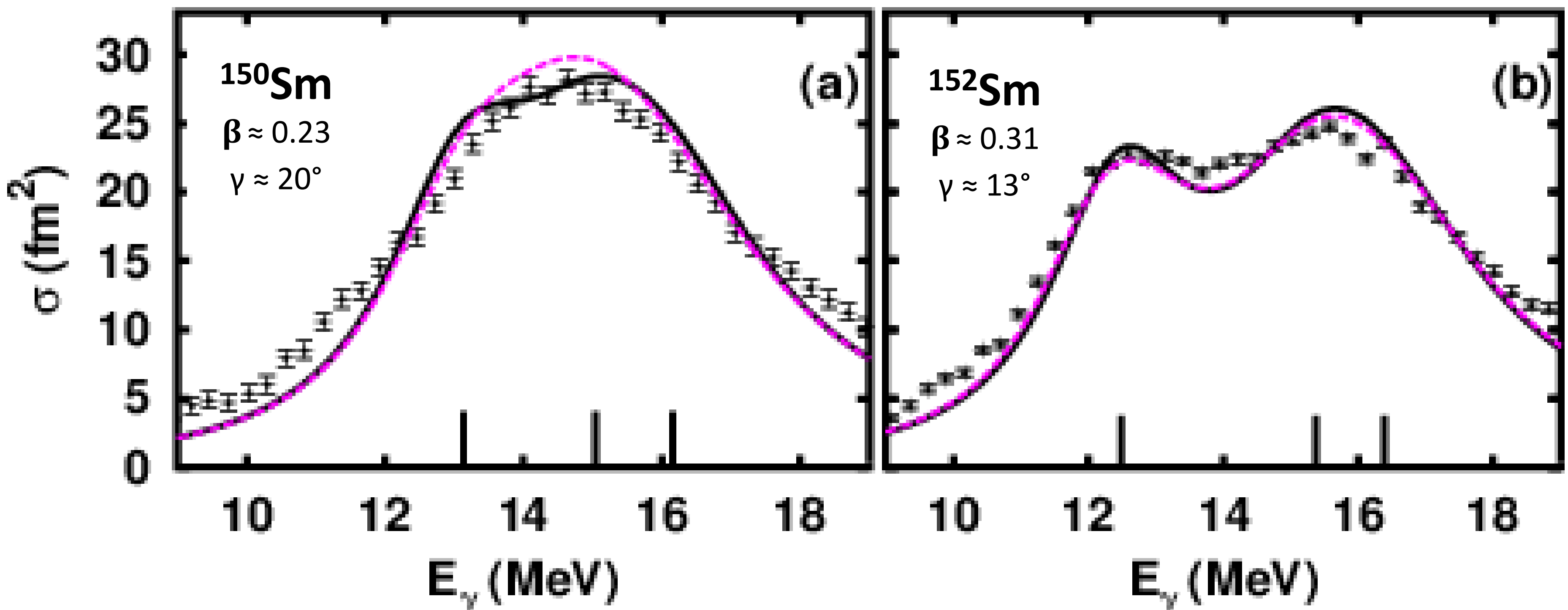


Giant dipole resonances as sensitive to deformation should also recognize it !

Bertsch et al, PRL 99 (2007) 032502; Delaroche et al, Phys. Rev. C 81 (2010) 014303; Warsaw-Rochester collab,, GSI exp'ments

IVGDR's in neighboring nuclei indicate axial symmetry breaking

energies from LDM and widths from surface dissipation model, incl. shape sampling



*with **deformation**-parameters **β,γ** from **QHFB/GCM***

*and **global** fixing of the width* $\Gamma = c_w \cdot E_r^{1.6}$

2-pole fit seems impossible for **^{150}Sm** *but may be possible for* **^{152}Sm**

Carlos et al., Nucl. Phys. A 225, 171 (1974)
Myers et al., Phys. Rev. C 15, 2032 (1977)
Bush and Alhassid, Nucl. Phys. A 531, 27 (1991)
Delaroche et al., Phys. Rev. C 81, 014303 (2010)

^{142}Nd to ^{150}Nd in comparison to the sum of

<u>three</u> Lorentzians (TLO, dashed blue).

The drawn magenta curves show the effect of shape sampling using variances calculated by HFB.

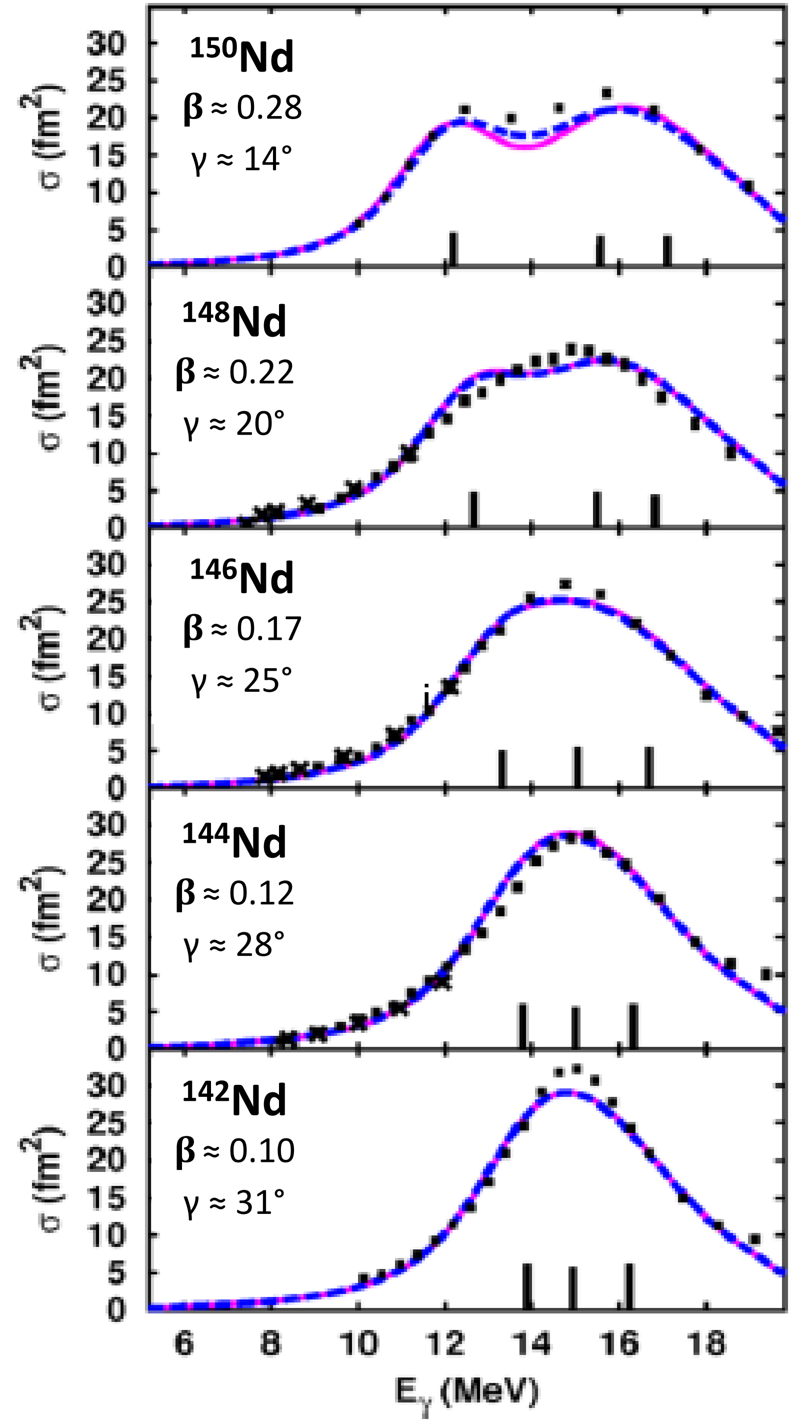
The parameters for central energy and width are the same as for all other nuclides with A>70

$$E_0 = \frac{\hbar c}{R_0}\sqrt{\frac{8J}{m_{eff}} \cdot \frac{A^2}{4NZ}}\left[1 + u - \varepsilon \cdot \frac{1+\varepsilon+3u}{1+\varepsilon+u}\right]^{-1/2}$$

$$\varepsilon = 0.0768, u = (1-\varepsilon)\cdot A^{-1/3}\cdot \frac{3J}{Q}$$

$$E_i = \frac{\omega_i}{\omega_0}\cdot E_0 \quad \text{and} \quad \Gamma_i = c_w E_i^{1.6}$$

Only the 2 parameters m_{eff} = 800 MeV and c_w = 0.045 (3) are adjusted − <u>globally</u> valid for all nuclides with A>70. The ω_i are taken from the HFB/GCM calculations and symmetry energy J = 32.7 MeV and surface stiffness Q = 29.2 MeV are from droplet model fits to masses.

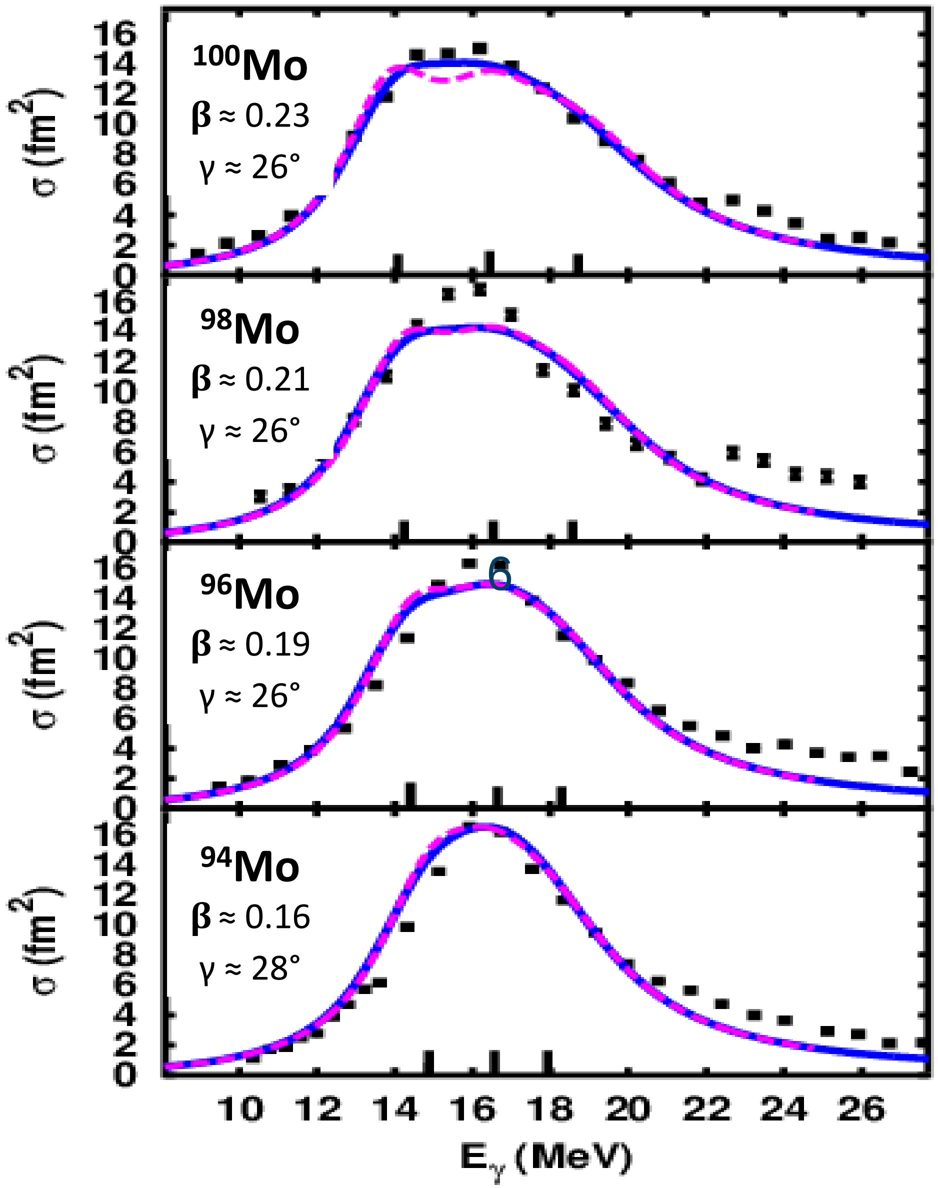


Carlos et al., Nucl. Phys. A172, 437 (1971)

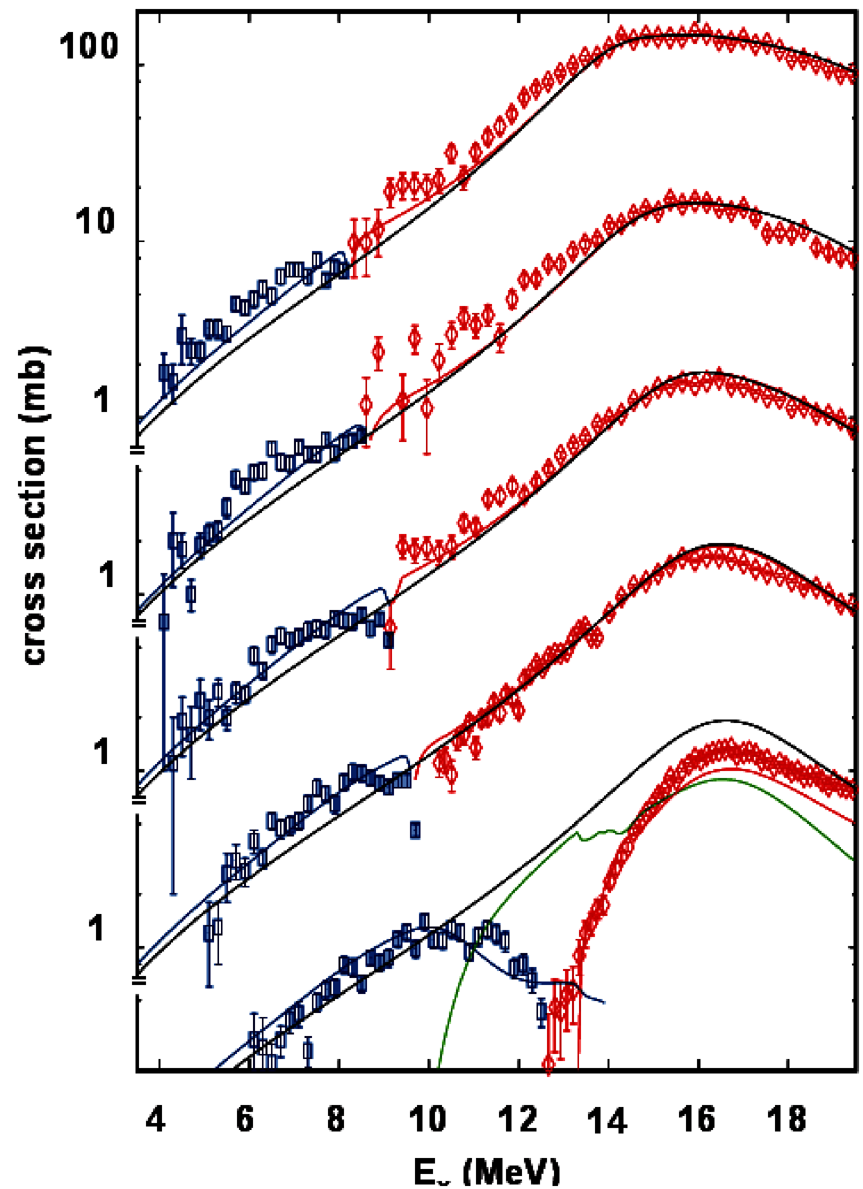
IVGDR's from (γ,n) *and TLO fits with* ***deformation*** *parameters from HFB/GCM*

incl. shape sampling

combined to photon scattering (γ,γ')

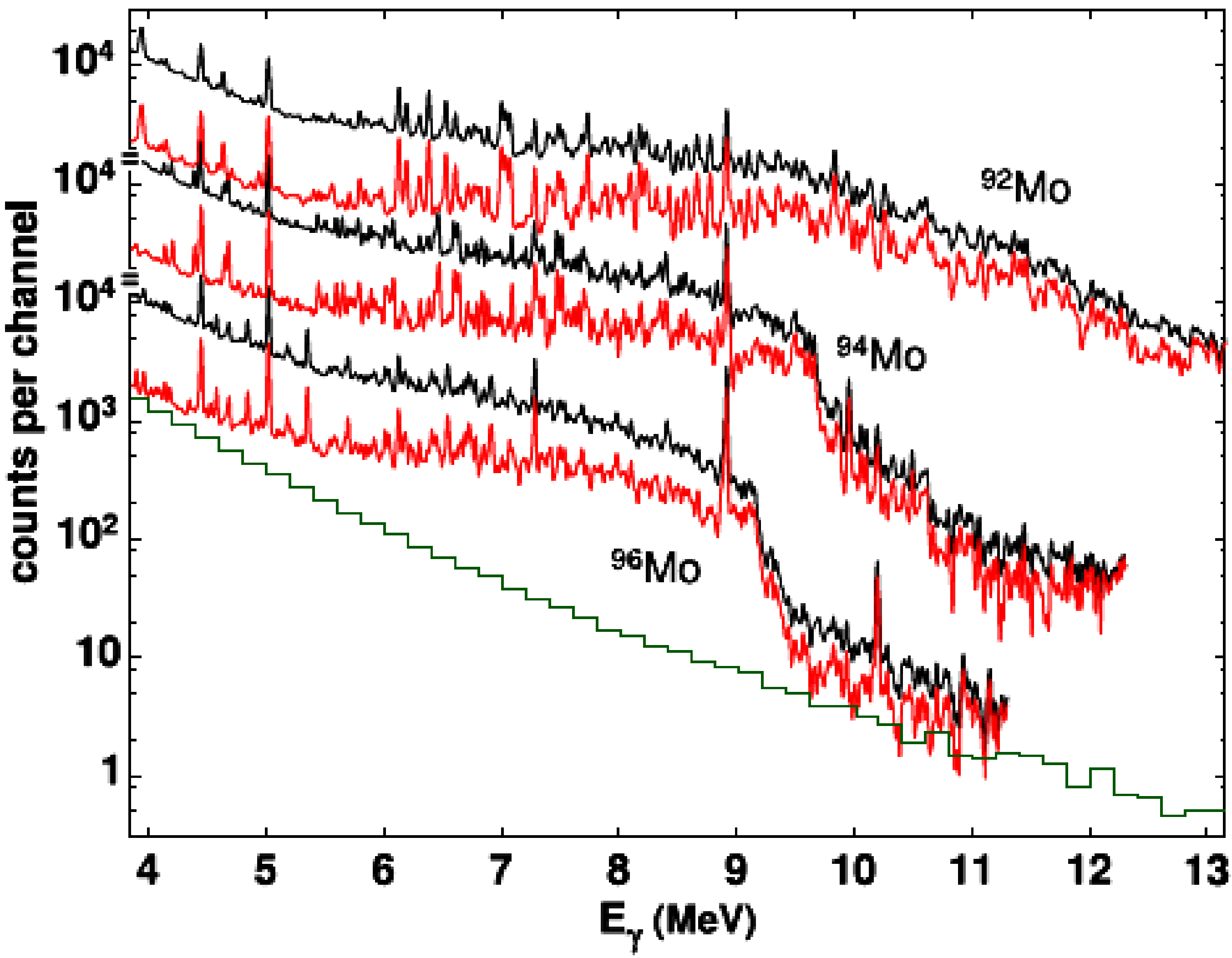


Beil *et al.*, Nucl. Phys. A 227, 427 (1974)



In 92Mo the (γ,p) channel has to be included from Hauser-Feshbach calc.

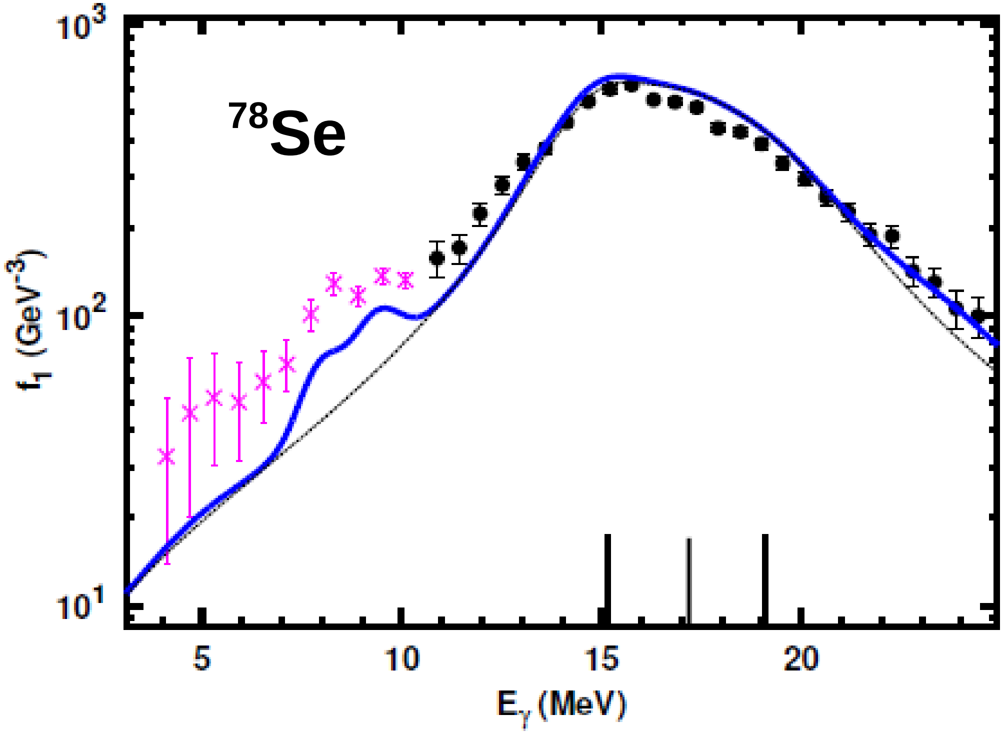
Erhard et al, Phys. Rev. C 81, 034319 (2010)

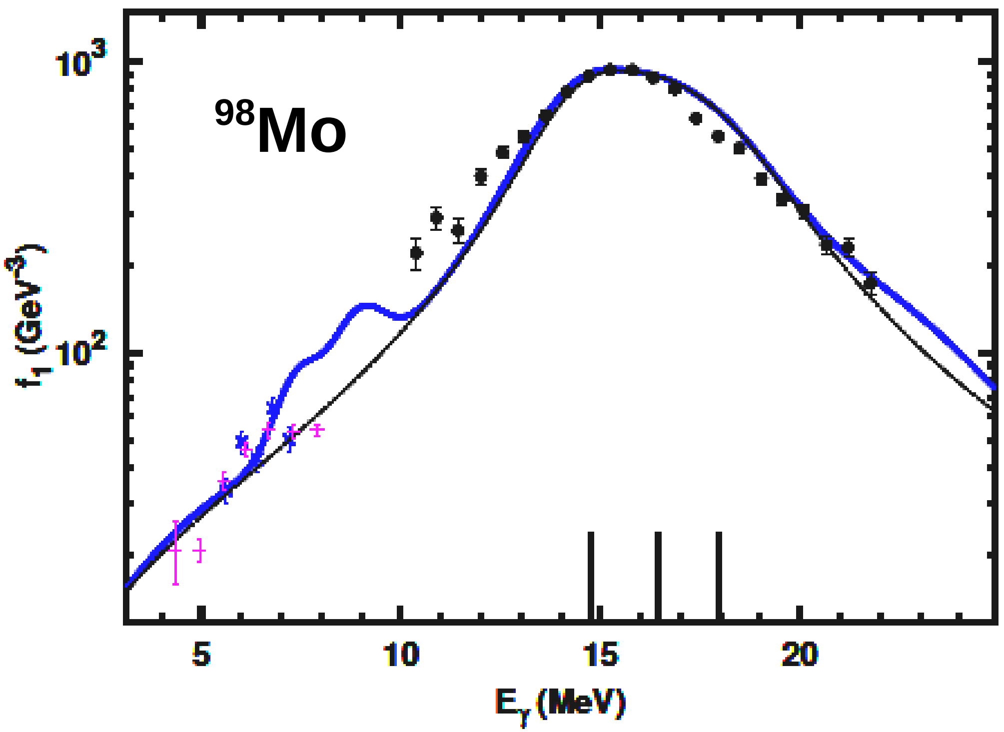


Rusev *et al.*, Phys. Rev. C **79**, 061302 (2009)

HFB/GCM for these nuclei indicates broken axiality --

in agreement to photo-neutron data.

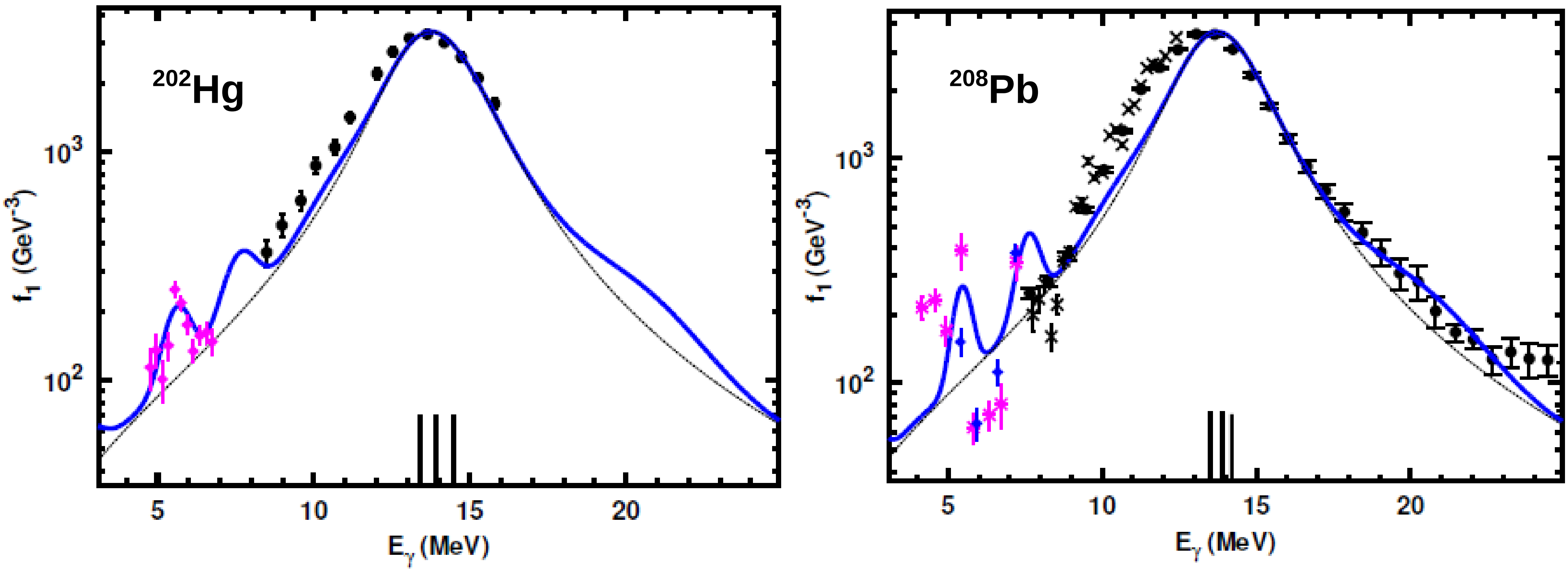




The low energy strength was obtained from absolute scale photon scattering data, partly observed at Duke with a quasi-monochromatic beam from laser back-scattering.

Bertsch et al, PRL 99 (2007) 032502; Delaroche et al, Phys. Rev. C 81 (2010) 014303
Carlos et al., Nucl. Phys. A 258, 365 (1976); Beil et al., Nucl. Phys. A 227, 427 (1974)

Data near shell closure

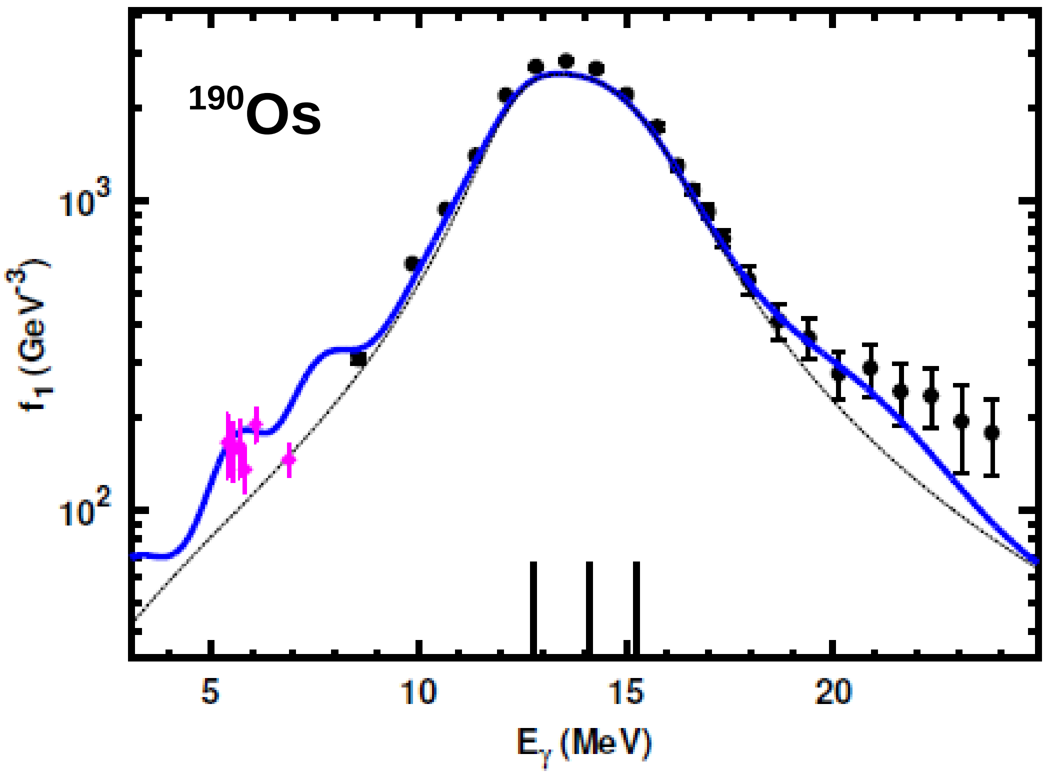


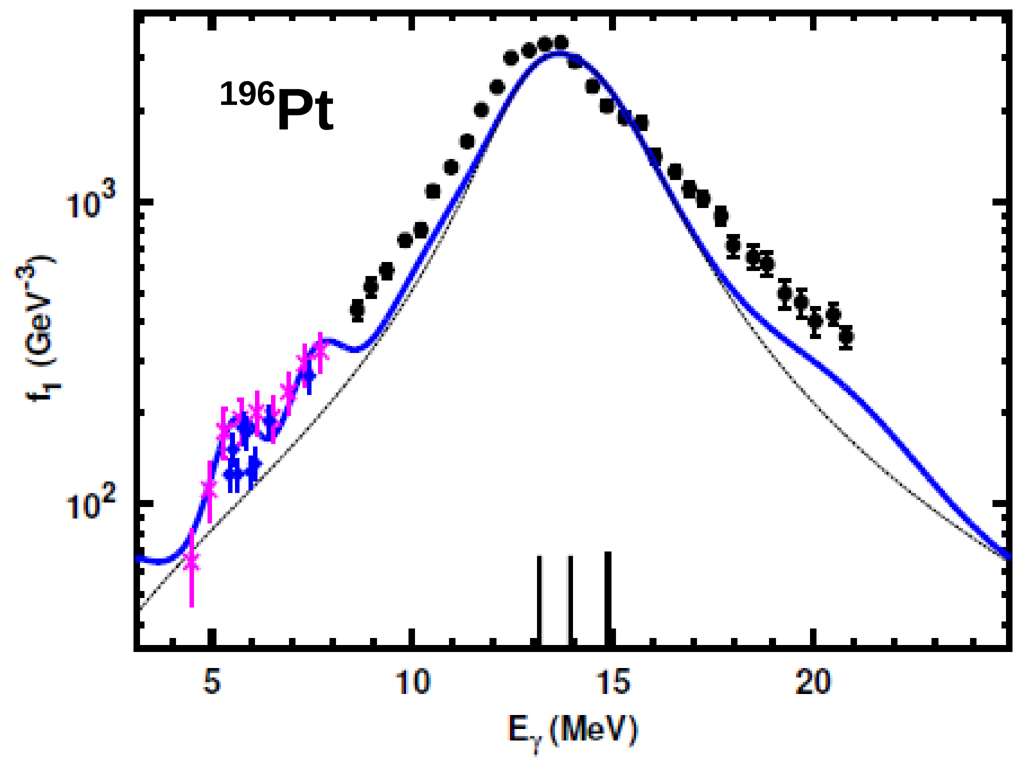
These old data for ^{202}Hg obtained at Urbana with low energy resolution demonstrate a well localized enhancement near 5 MeV.

Data for ^{208}Pb show single peaks indicating Porter-Thomas fluctuations and at 5.2 MeV a strong one, identified with a neutron p-h-state.

Veyssiere et al., Journal de Physique 36, L267 (1975);id., Nucl. Phys. A159, 561 (1970); Vyver et al., Z.Ph. A 284, 91 (1978)

Data for nuclei often assumed to be oblate

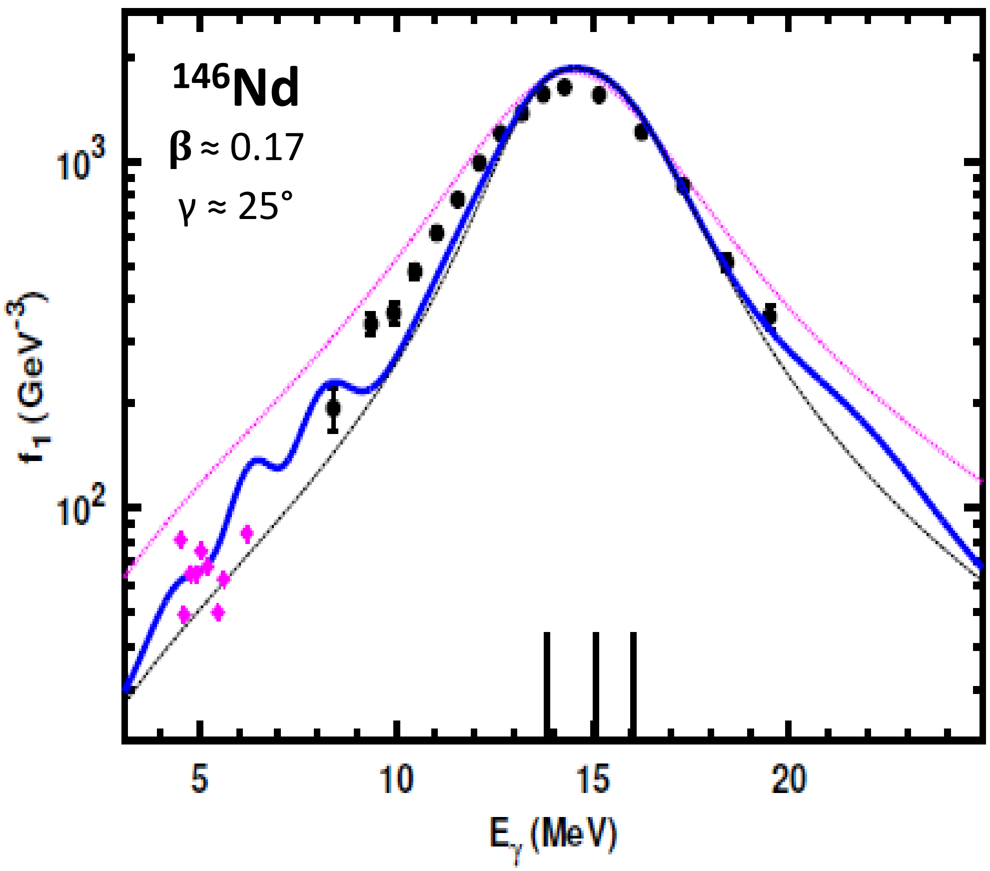


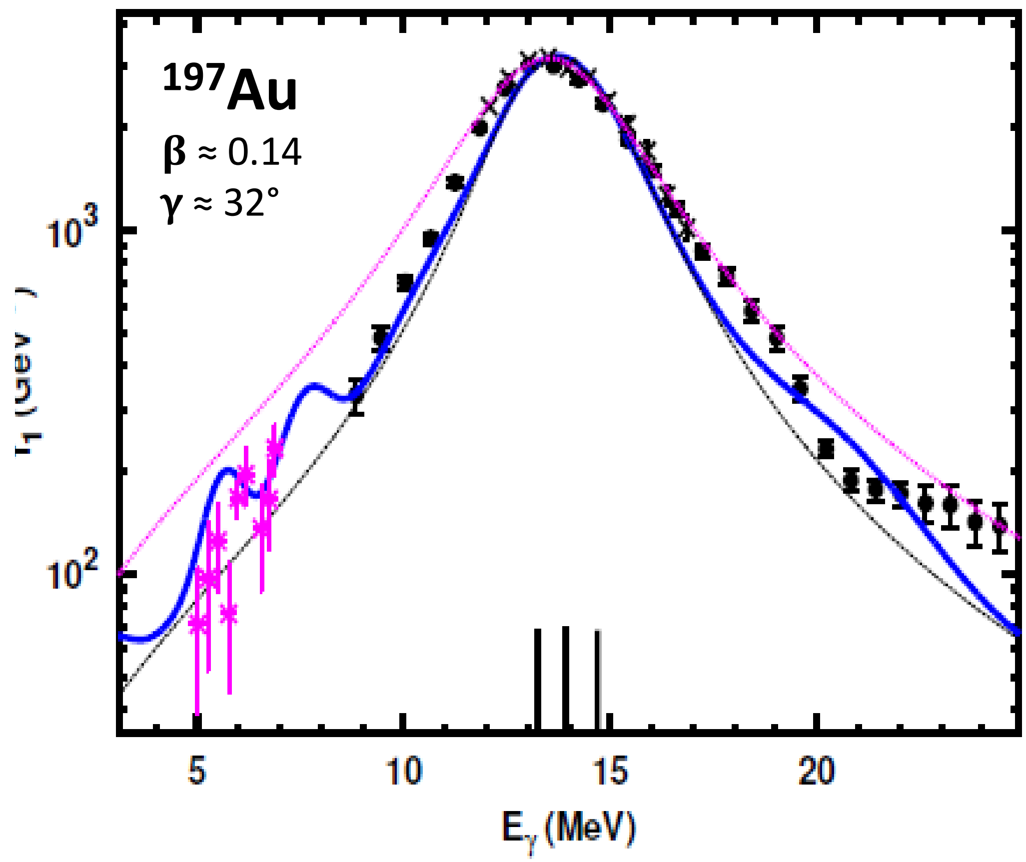


Oblateness is usually seen in near magic nuclei with small Q

Berman, et al., Phys. Rev. C 19, 1205 (1979); Goryachev and Zalesnyy; Sov. J. Nucl. Phys. 27, 779 (1978)

TLO should not be replaced by SLO (single Lorentzian)





The dotted red curve shows the fit made by Plujko et al.

It overpredicts the width and the integral considerably

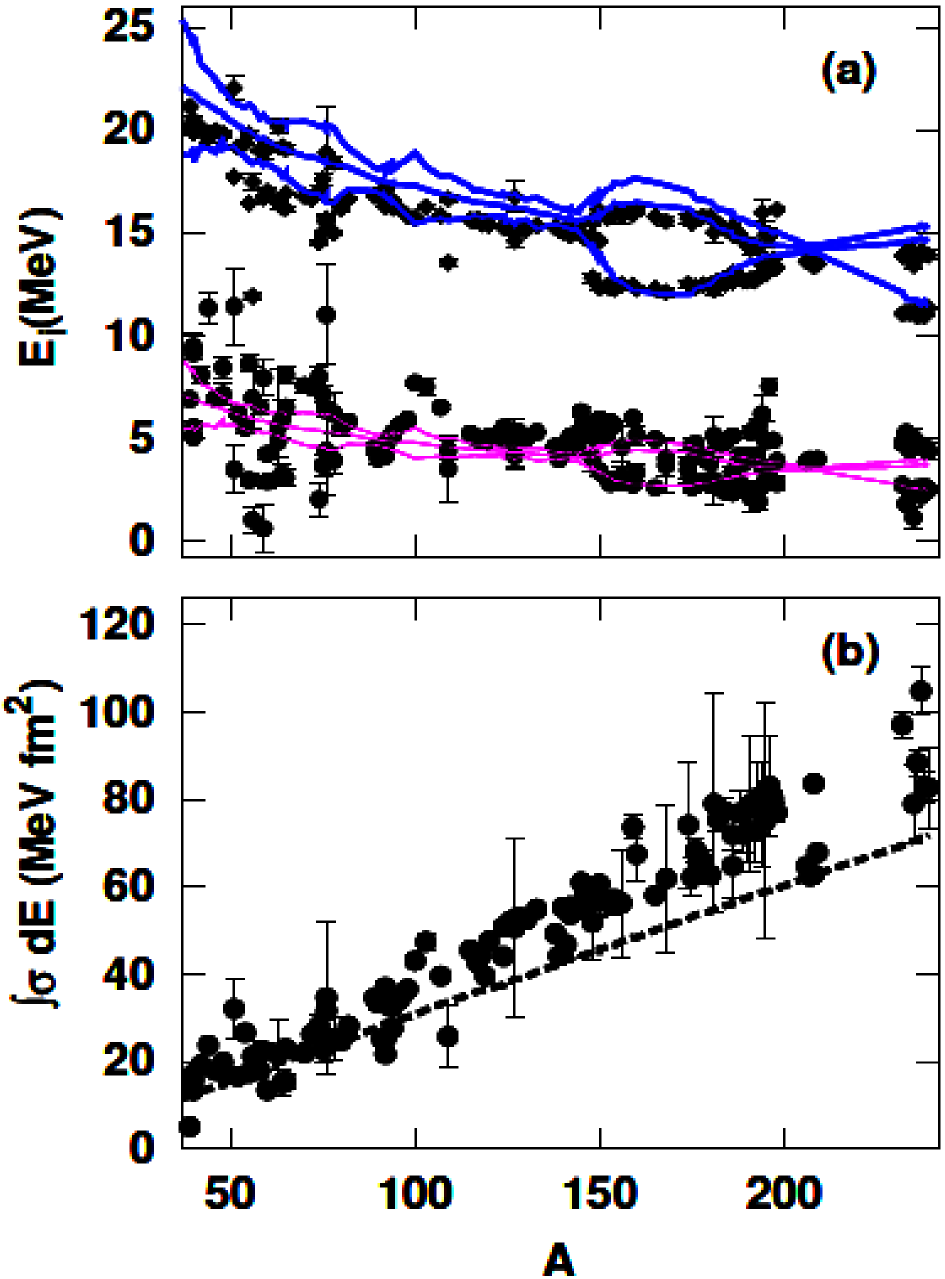
and thus the strength at low energy by a factor of ≈ 3.

Capote et al., Nucl.Data Sh. 110 (2009) 3107; Plujko et al., At.Data & Nucl. Data Tab. 97 (2011) 567;
Carlos et al., Nucl. Phys. A 172, 437 (1971); Veyssiere et al., Nucl. Phys. A159, 561 (1970)

Strength functions shown in RIPL-3, [Pluiko et al.] were obtained from individual fits assuming axiality or shericity.

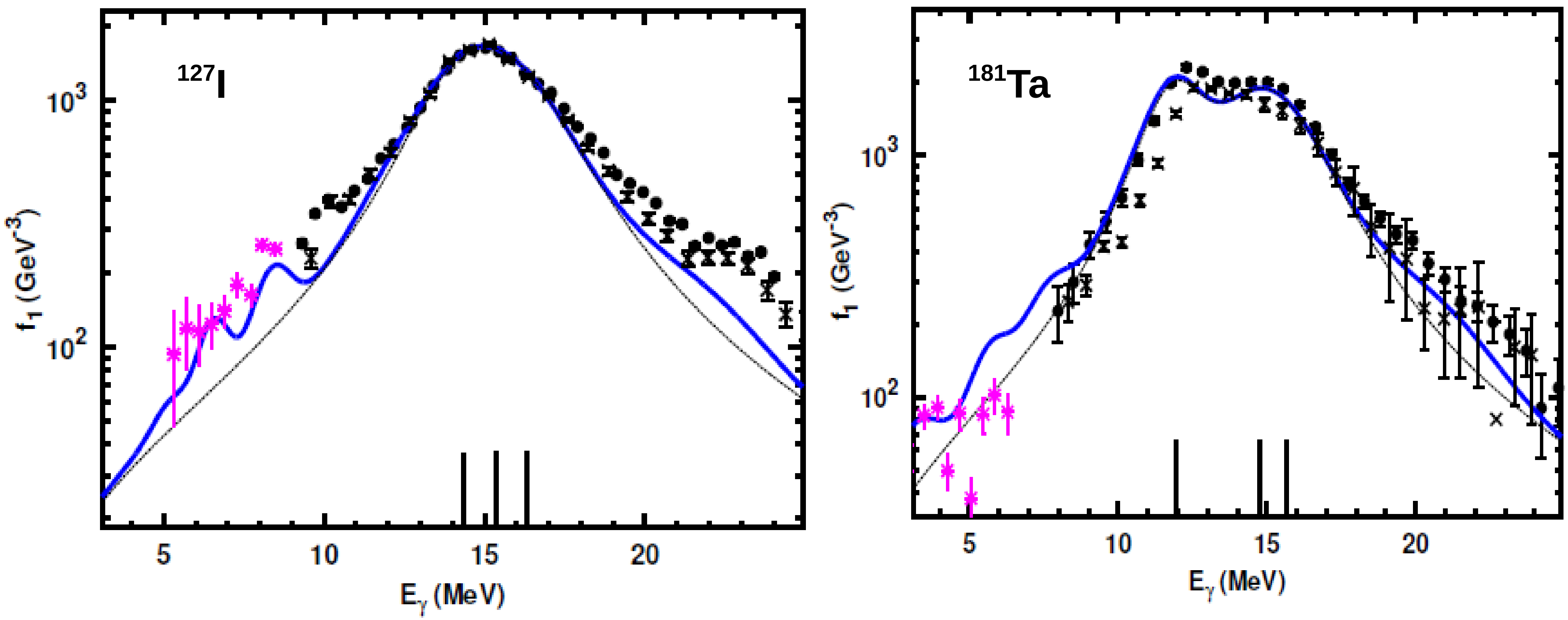
The top figure shows pole energies, which are similar to TLO-predictions but a clear difference in widths is seen.

The bottom figure indicates the difference to TRK-sum-rule, which is integrated in TLO.



From RIPL-3 [Pluiko et al.].

Data for odd nuclei indicate: TLO can be applied as well.



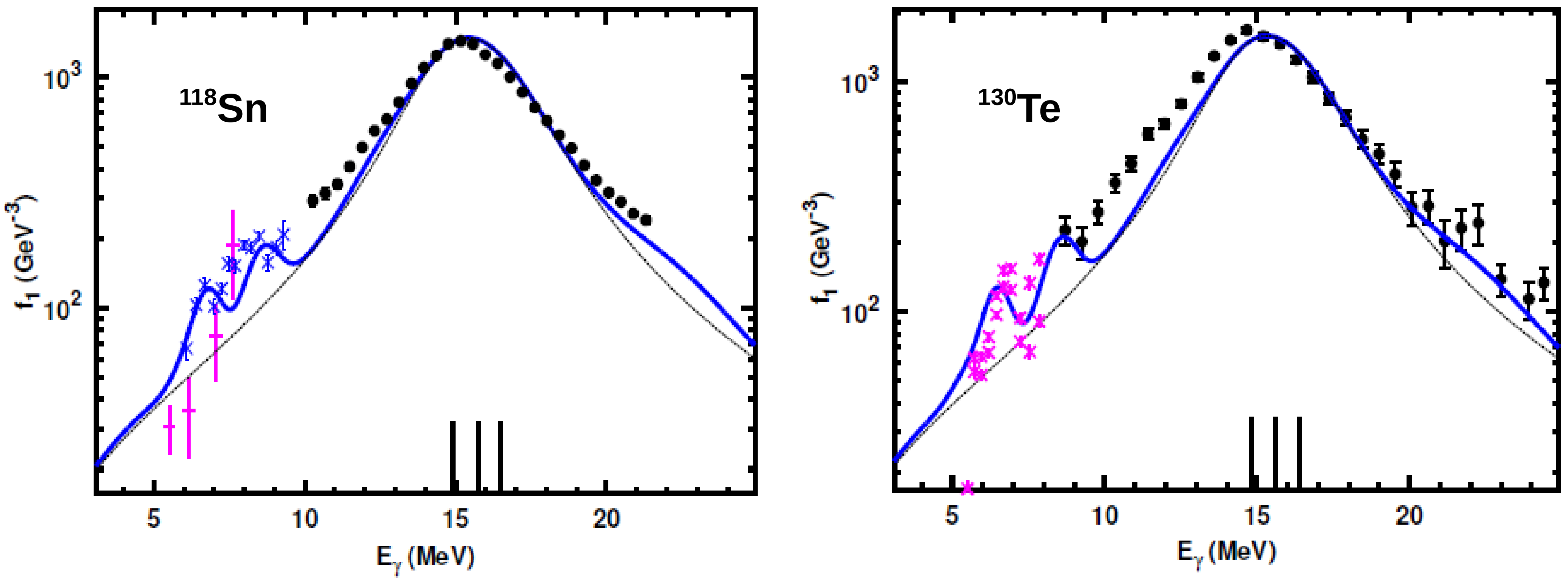
The strength observed corresponds to the cross section summed over a spin multiplet

with m=min(2λ+1, 2J₀+1):

$$g_{eff} = \sum_{r=1,m} \frac{2J_r + 1}{2J_0 + 1} = 2\lambda + 1$$

Bergere et al., Nucl.Phys. A133, 417 (1969); Berman et al., Phys.Rev.C 34, 2201 (1986); id., Phys.Rev.C 36, 1286 (1987)

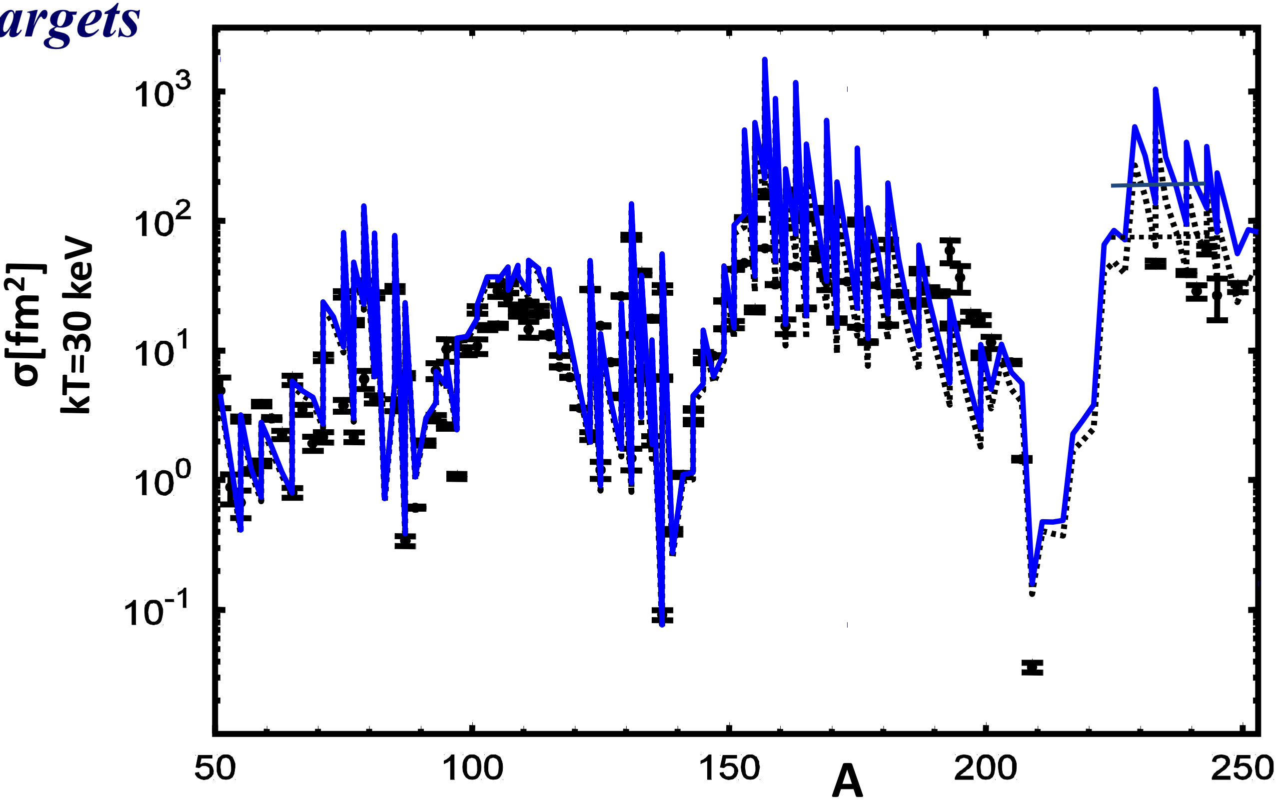
These 'vibrators' may well be triaxial nuclei and are treated as such in TLO.



The data for low energy in these nuclei indicate a separation between 2 pygmy modes and TLO is complemented by adding this to the IVGDR Lorentzians as indicated in blue.

Leprêtre et al., Nucl. Phys. A 219, 39 (1974)

Maxwellian average capture cross-sections, at stellar temperatures of 3·10⁸ K, for J=0 targets



TLO + ***minor strength***

only **E1** *from* ***TLO***

Good agreement for >130 nuclei on absolute scale calculated from global predictions for

average ***level densities ρ(E_r), obtained by admitting broken axiality*** *and*

photon widths *for* ***radiative neutron capture from an extrapolation of TLO-fits to IVGDR's***

=> simultaneous ***test of broken axiality for photon strength*** *and the* ***level density prediction***

Data from: Dillmann et al., PRC 81 (10) 015801; Pritychenko et al., At.D. and Nucl.D. Tabl. 96 (10) 645

Broken axial symmetry indicated by experimental data on:

(a) level densities, *esp. for low spins near S_n*

(b) level energies and transitions,

(c) splitting of giant dipole resonances, resulting in:

if global width is scaled triaxially only one parameter c_w is needed for <u>all</u> heavy nuclei

TRK sum rule agrees to CENS-data, when neutron efficiency is reduced by 10%

GDR pole energies E_o agree well to LDM prediction, when using theoretical def'values

(d) n-capture cross sections*, if* ***TLO*** *is extrapolated to low energies*

Theoretical models assume axiality very often, but:

(a) rigid 3-ax rotor *does not*

(b) cranking of 3-ax body *is possible*

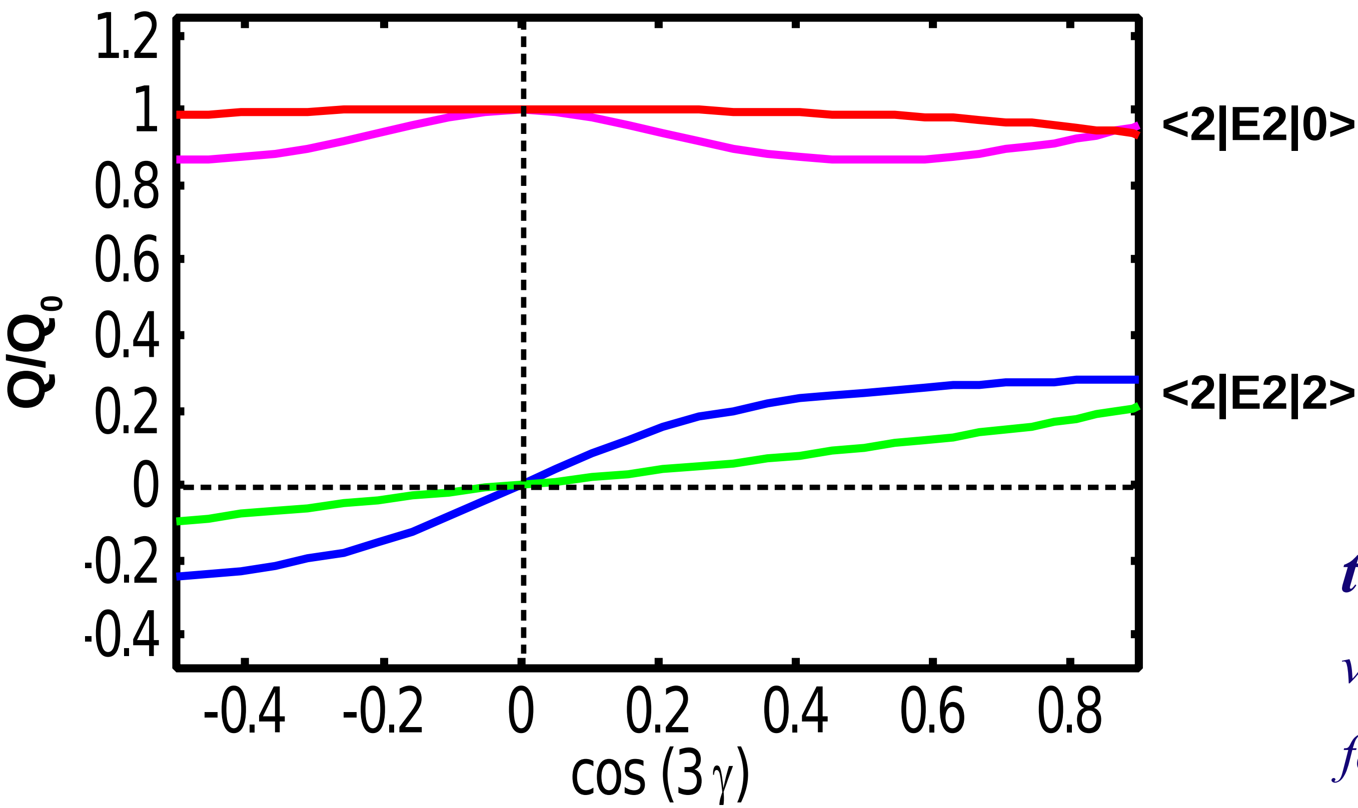
(c) HF-variation after projection <u>enhances</u> broken axiality

(d) QHFB+GCM *(GognyD1S)* ***creates triaxiality; combined to LDM for TLO***

(e) RPA+OM predicts GDR in ^{208}Pb with 3 MeV width; scaled for TLO

(f) RPA+QHFB produce GDR with 1 or 2 poles plus fragments

3-axial rotor, rigid & with cranking



cos(3γ)* ⇒ *indicator for axiality

***Q** is especially sensitive to it*

***the two models** make*
very similar predictions
for the two observables
Q(2⁺)** and **B(E2, 0⁺→2⁺);
this does not help to find
best approach to treat
axial symmetry breaking

Davydov and Fillipov, Nucl. Phys. A 8, 237 (1958)
Ring, Hayashi, Hara, Emling and Grosse, Ph.Lett.B 110, 423 (1982)

Shell model + RPA

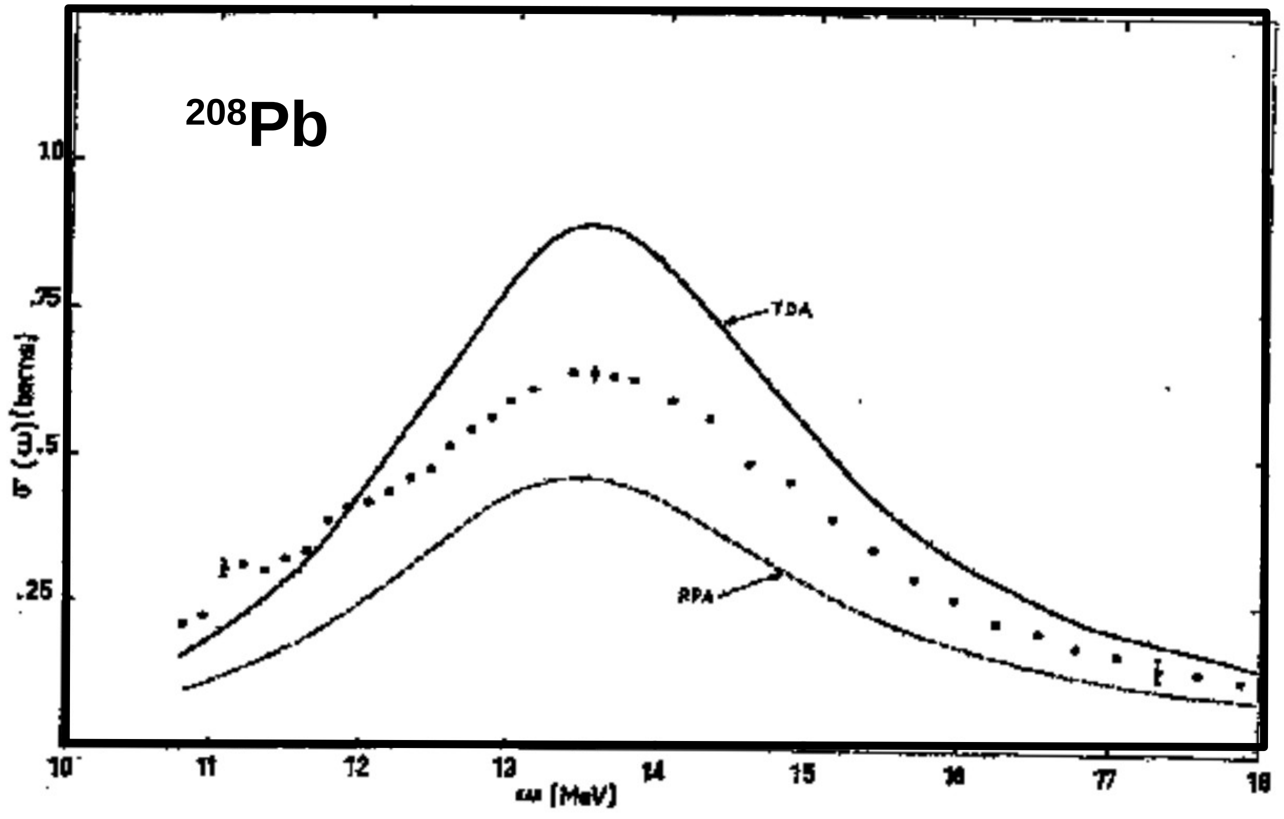
schematic calculation,

for ^{208}Pb, E_r adjusted,

strength integral depends on gs-corr. (RPA),

width is used by TLO

after scaling by $(E/E_{208})^{1.6}$

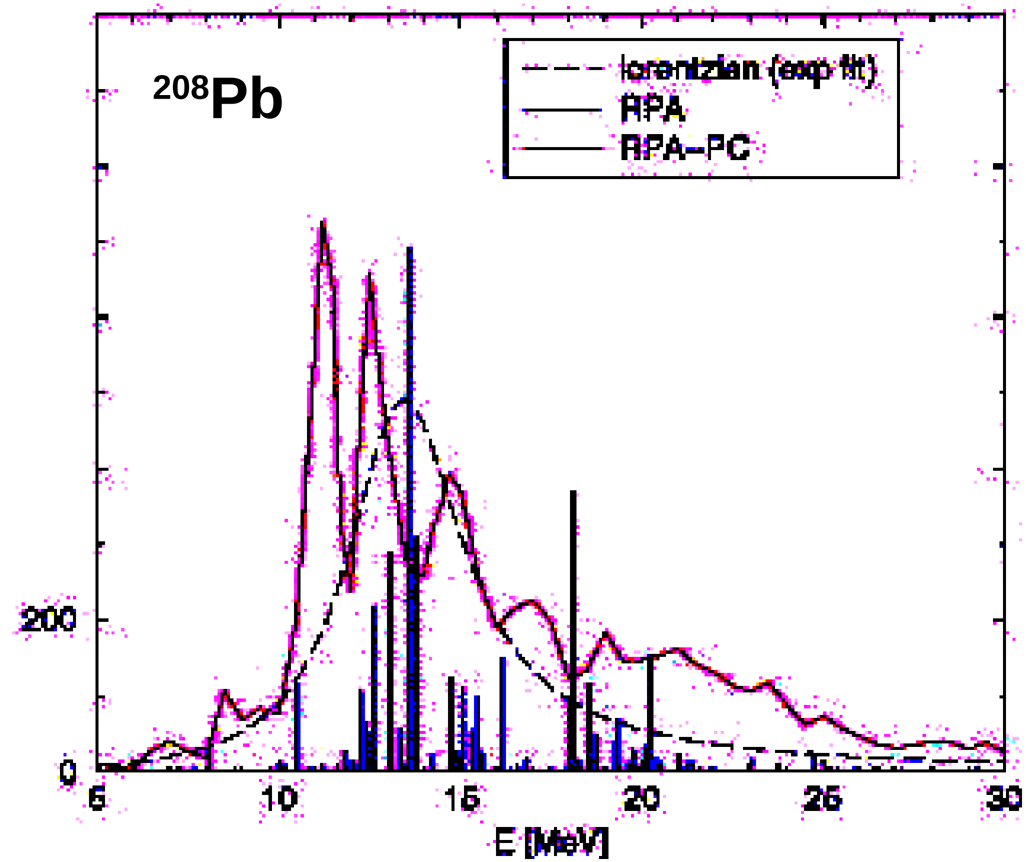


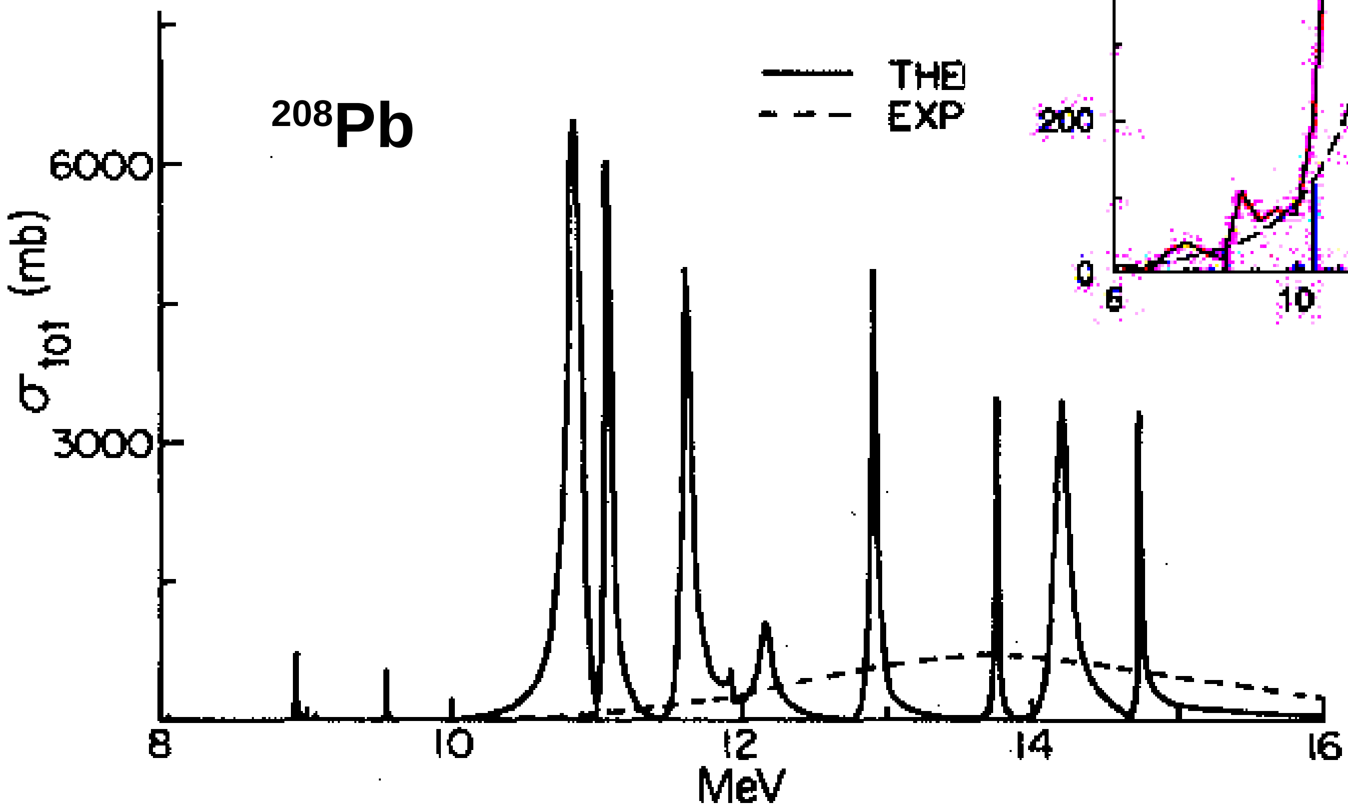
Bush and Alhassid, Nucl. Phys. A 531, 27 (1991)

Dover et al., Ann of Ph (NY) 70 (1972) 458

QRPA-HFB *(Hartree-Fock-Bogolyubov)*

calcul's show distinct fragmentation with spreading clearly exceeding escape widths; often reduced by phonon coupling or smeared by additional broadening



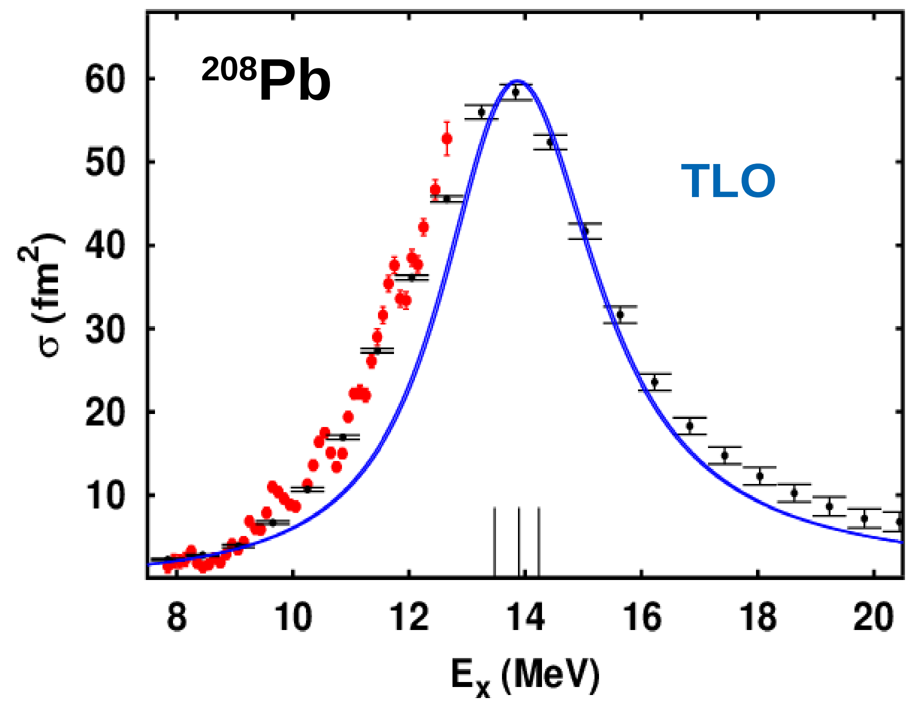


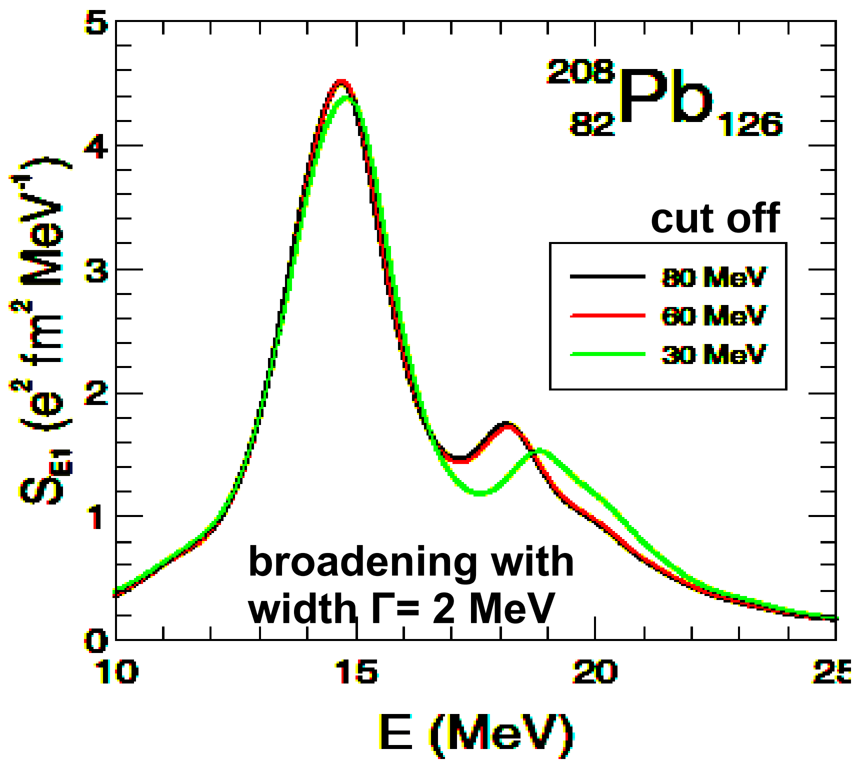
Bertsch et al., Rev. Mod. Phys. 55, 287 (1983)
Shlomo and Bertsch, NPA 243,507(1975)

Sarchi, Bortignon, and Colo, PLB **601**, 27 (2004)

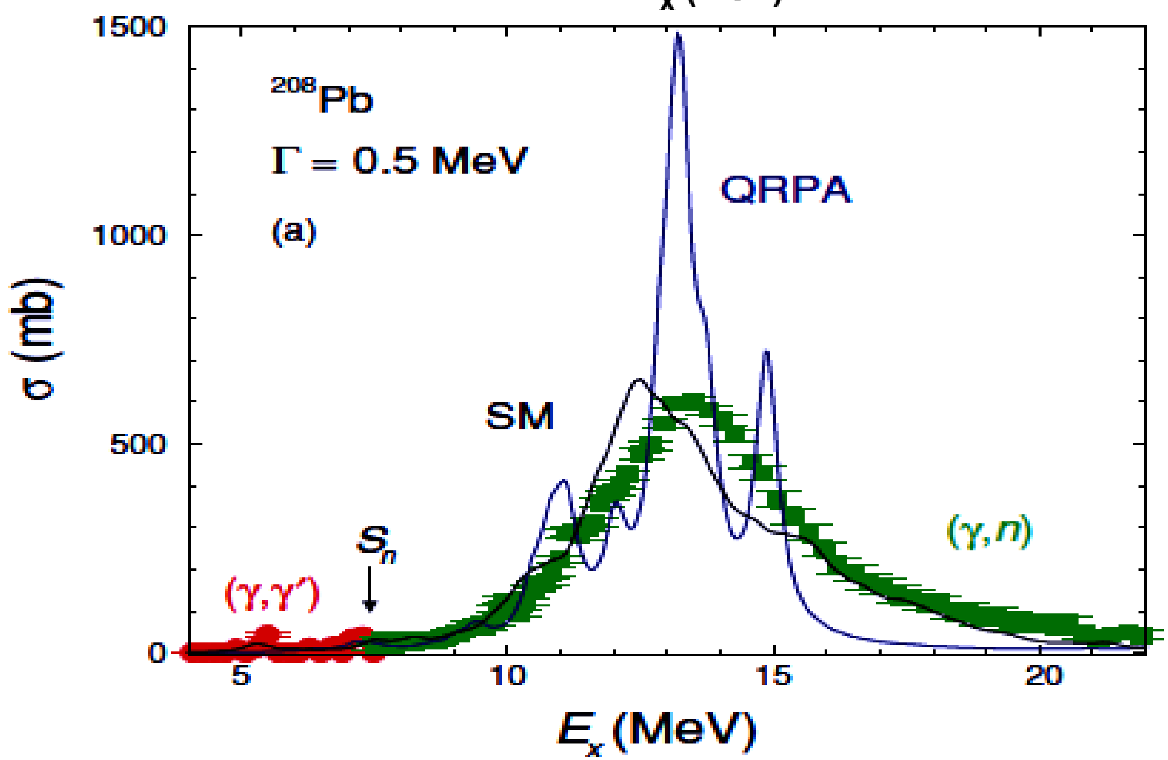
HFB-QRPA-calc's show distinct fragmentation (p-h, Landau damping), many apply additional broadening (2p-2h); experimental data show much less:

(Van de Vyver et al., Z.Phys. A 284, 91 (1978))





Martini et al. , Phys. Rev. C 94, 014304 (2016)



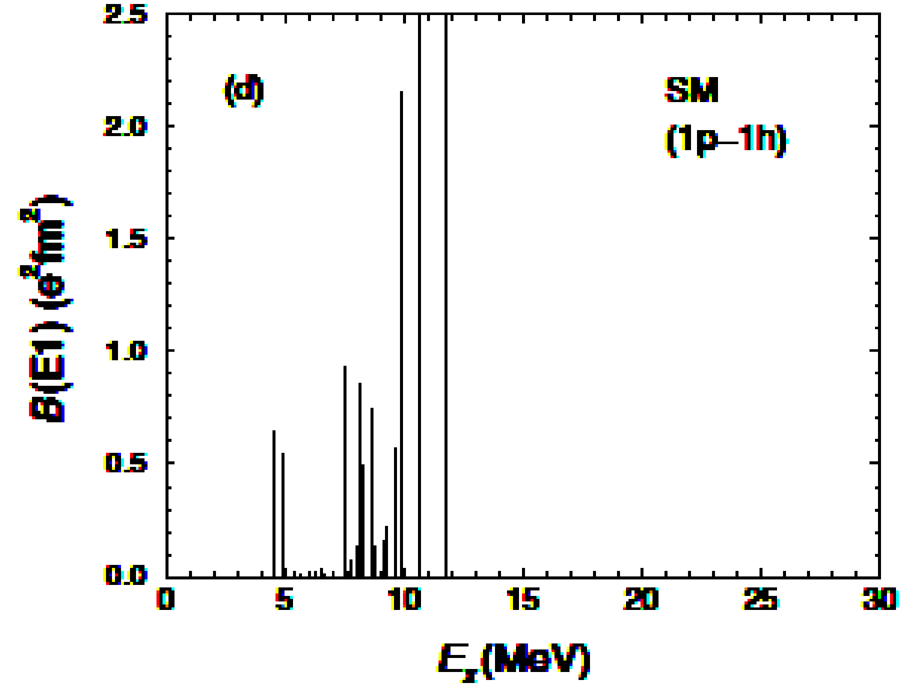
Schwengner et al., PRC **81**, 054315 (2010)

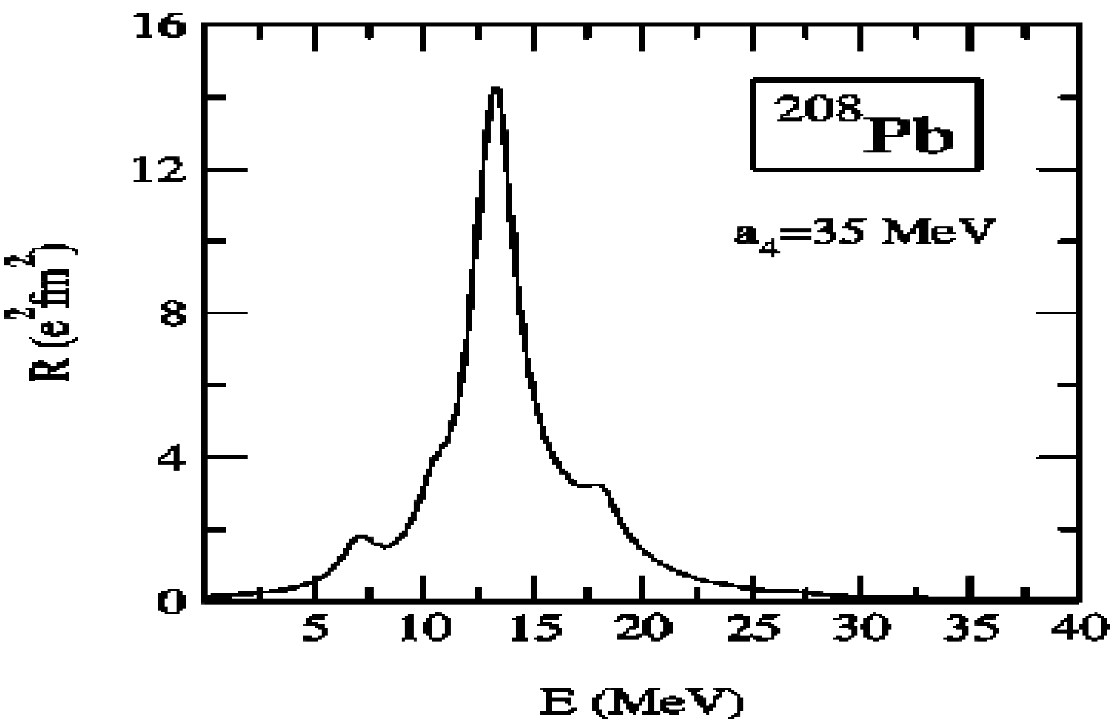
HFB-QRPA-calcul's show distinct fragmentation, indicating strong spreading

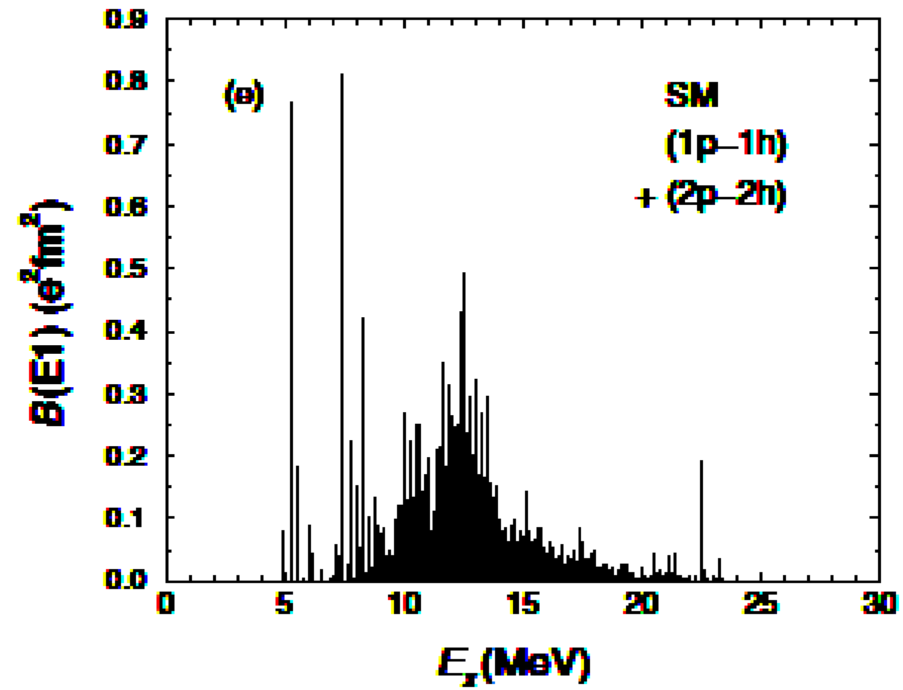
***covariant** (relativistic with meson coupling)*

or shell model calculations

show less of it





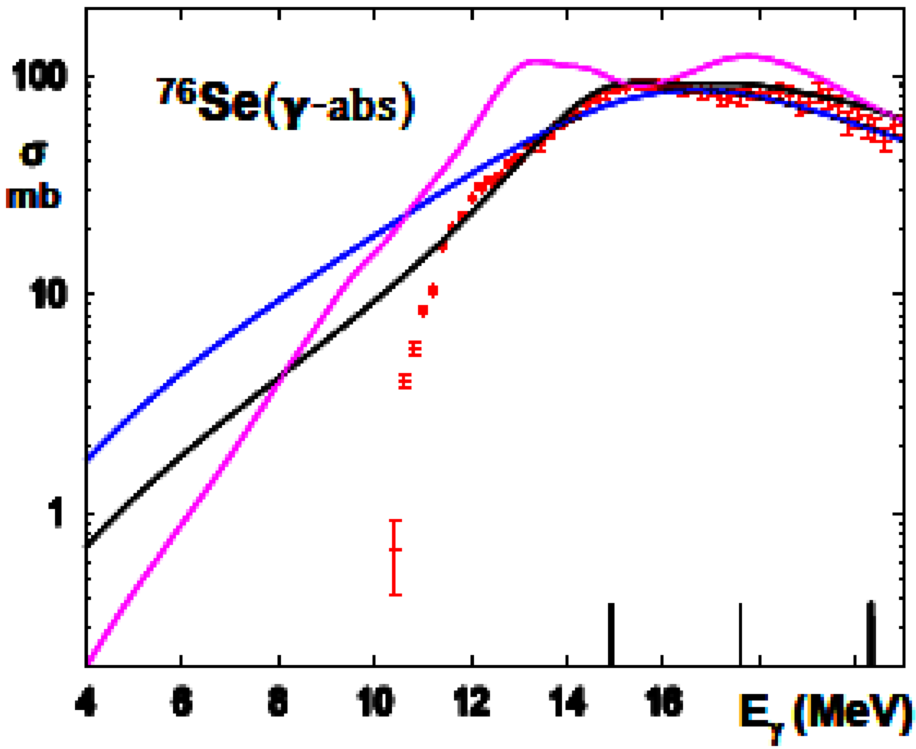


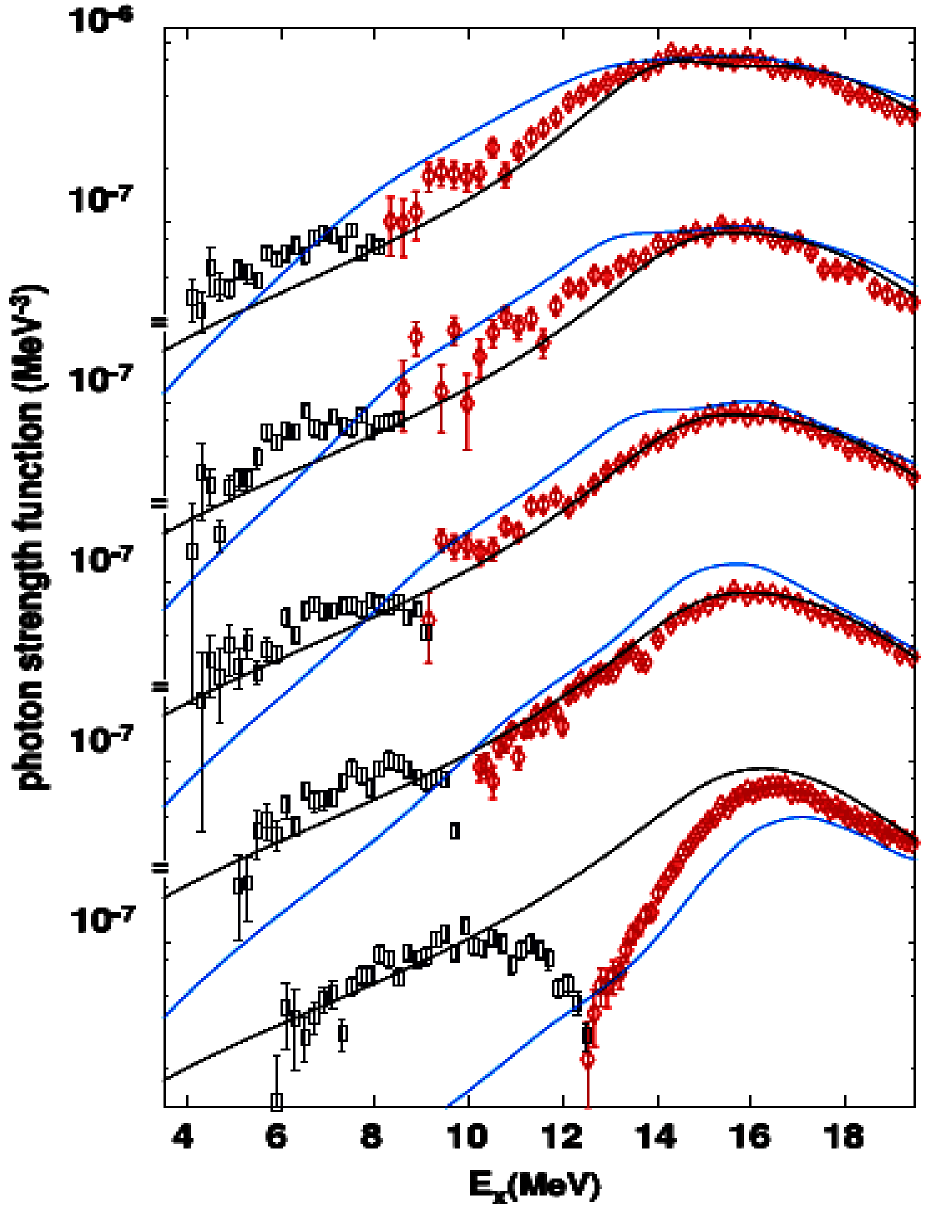
Niksic, Vretenar, and Ring, Phys. Rev. C **66**, 064302 (2002).

Brown, Phys. Rev. Lett. **85**, 5300 (2000).

Schwengner et al., PRC **81**, 054315 (2010)

HF-RPA-calcul's often show less strength in the tail region, which is of importance for radiative neutron capture





Igashira et al., AIP-Conf.proc.1090(08).376

Goriely, Khan, and Samyn, NPA **739**, 331 (2004).

Probabely, the rareness of prediced ***triaxiality***

(e.g. in Hartree-Fock-Bogolyubov calculations)

results from ***not*** *performing the*

angular momentum projection

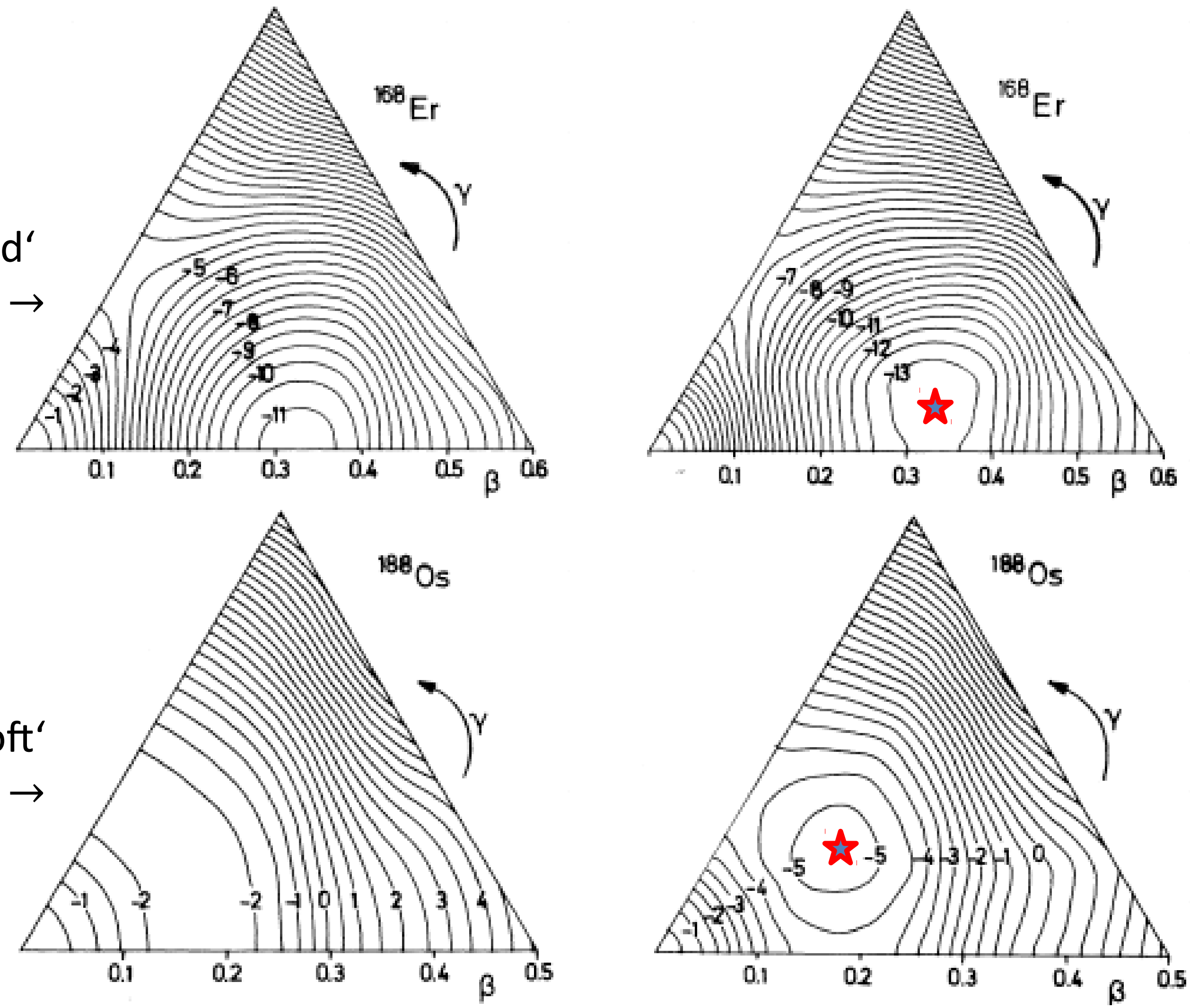
after *the variation.*

PAV **VAP**

‘axially deformed‘ nucleus →

Often the <u>VAP</u>, required by quantum mechanics, is not regarded.

‘-soft‘ nucleus →



Hayashi, Hara, Ring , Phys. Rev. Lett. 53 (1984) 337

Conclusions:

Many experimental facts indicate broken axial symmetry for heavy nuclei :

1. Level densities *predicted on* ***absolute scale***

2. Level sequences and transition rates

3. *Coulomb reorientation and multiple excitation*

4. Triple split *of the* ***giant dipole resonances has interesting consequences for their interpretation***

5. Neutron capture *cross sections (via 1 & 4)*

Theoretical calculations *may impose* ***triaxiality as property of a rotor****, but many assume axiality and predict level densities, photon strength or GDR shapes.*

Axial symmetry breaking is found by

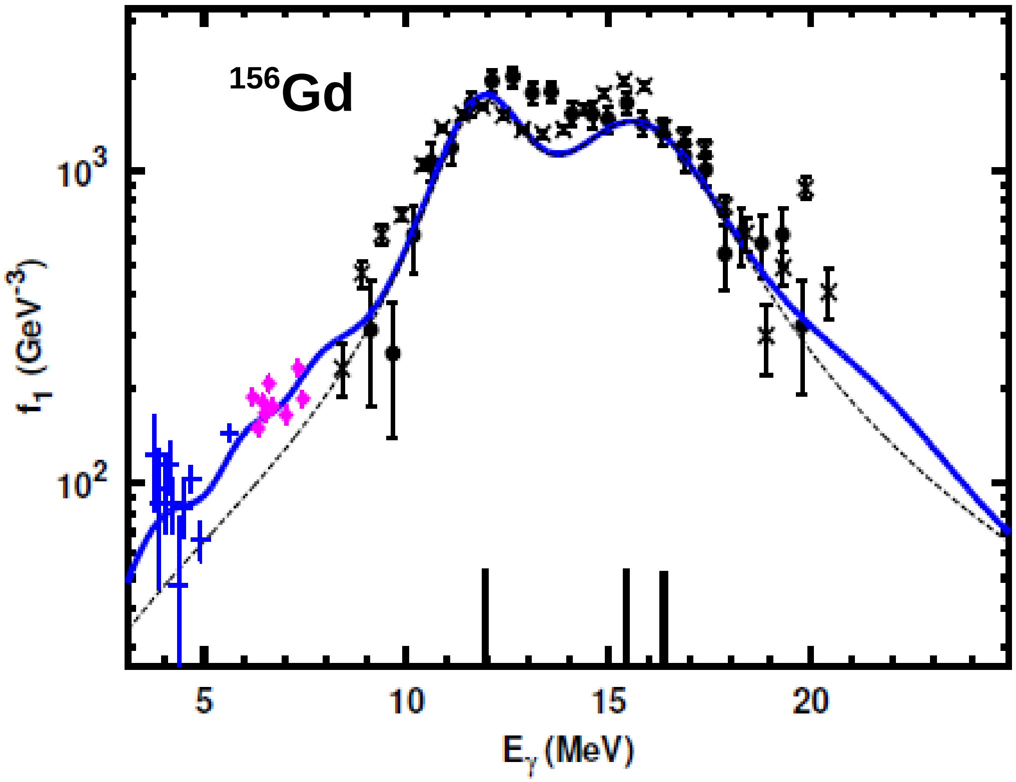
1. Angular momentum projection ***before*** *the Hartree-Fock-Bogolyubov-variation*

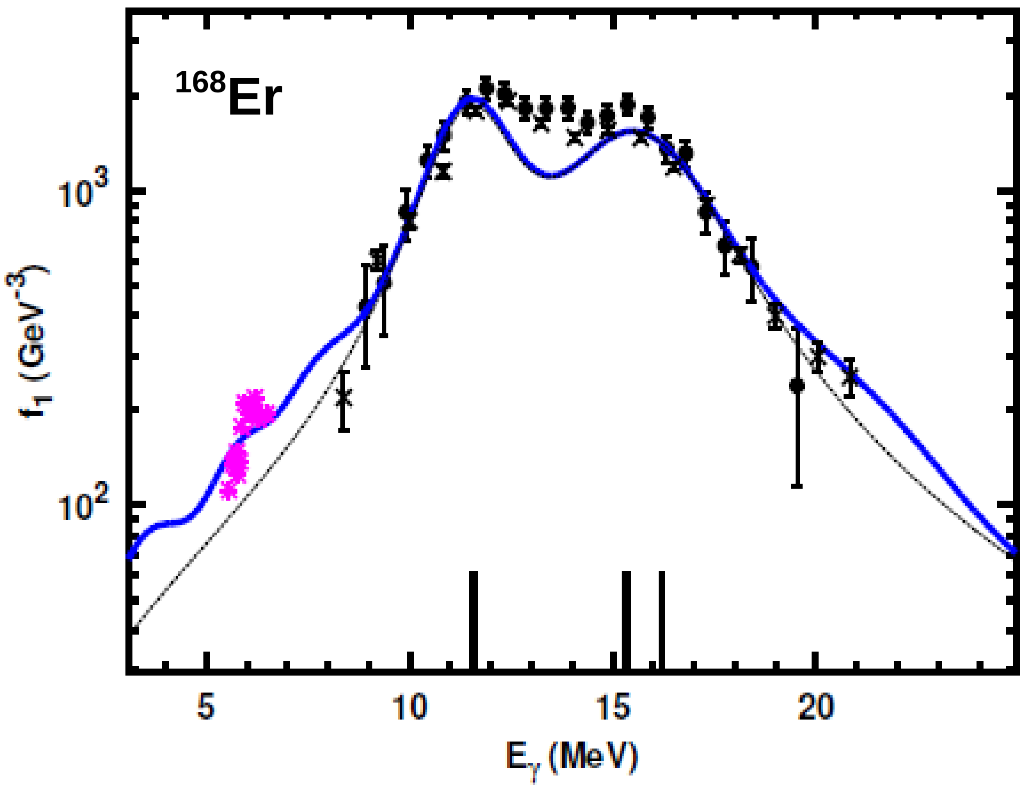
2. HFB *calculations with mapping onto a 5D collective quadrupole Hamiltonian (****GCM****)*

3. *Jahn-Teller effect:****symmetric configurations do not always have the lowest energy***

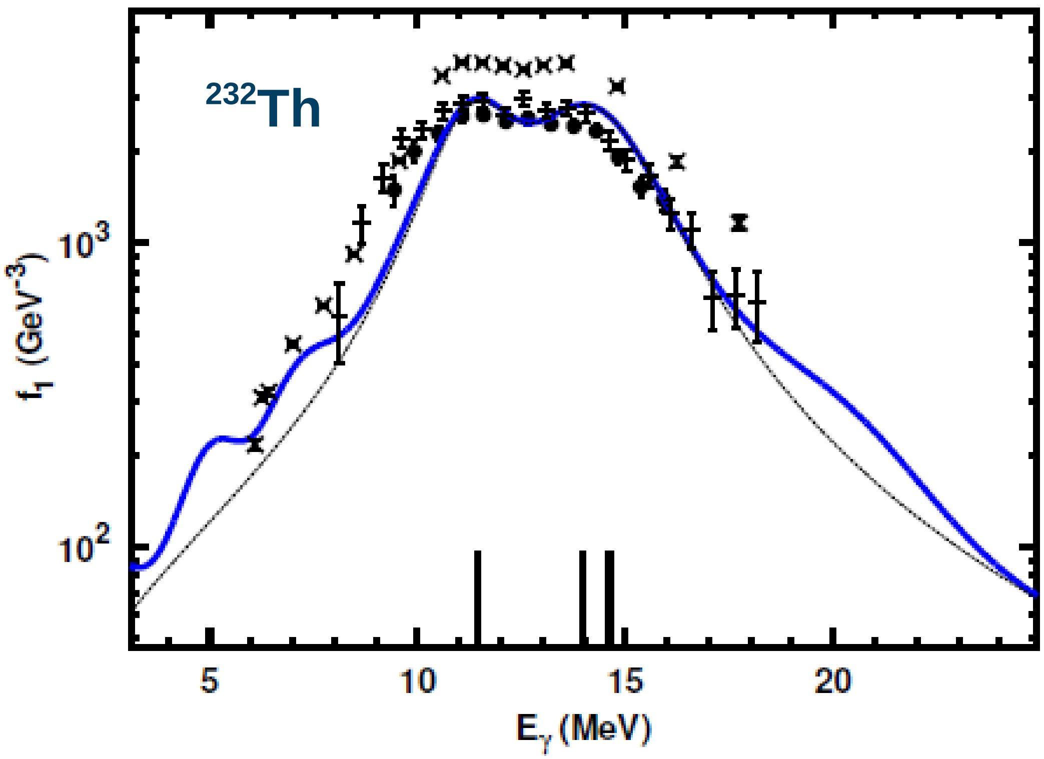
- ***All heavy nuclei are triaxial, some are more deformed and less triaxial than others***

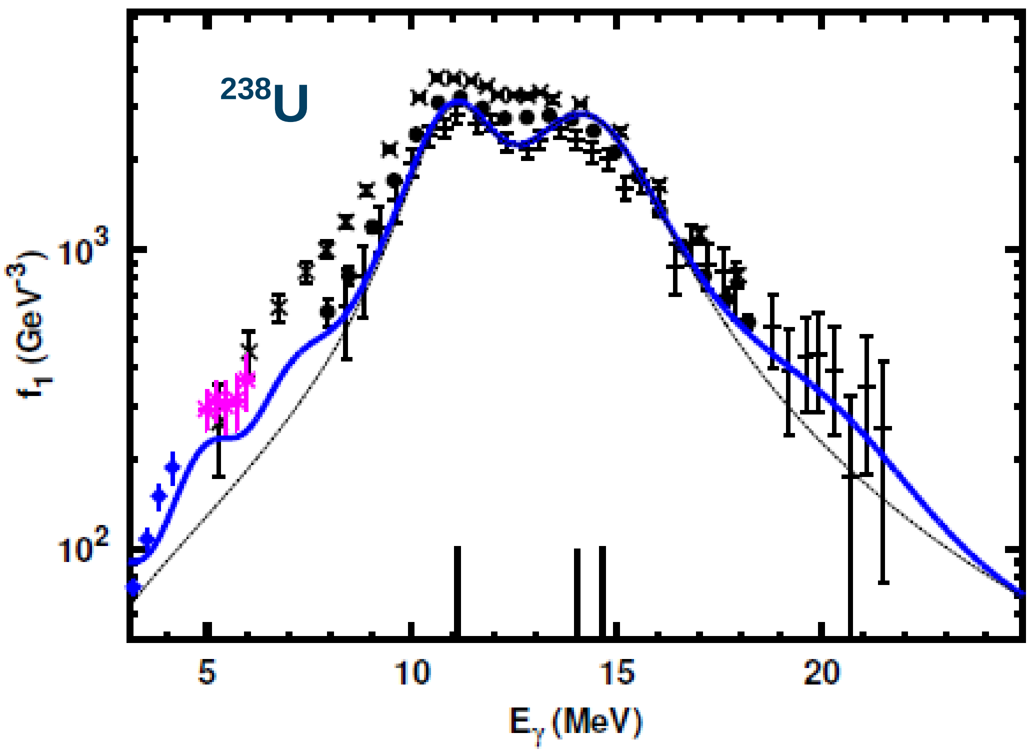
Data and TLO for these nuclei indicate: The top peak can be the smaller one, although it represents 2 components with equal integral but increased width. This has led to some confusion in older RIPL's.





These actinide data show a clear disaccord between different experiments !





The agreement between experiment and TLO is important with respect to the disagreeing data obtained at Livermore [**Caldwell et al., 1980**]. These cross sections for ^{232}Th and ^{238}U are exceptionally large in the sense, that an analysis with TLO indicates an overshoot of 30% as compared to the TRK sum.

Thomas-Fermi (ETFSI) method

used to calculate nuclear masses

(randomly selected in valley of stability).

Z	A	c	h	$\epsilon(\gamma)$	ΔE_{triax}
30	62	0.89	0.04	1.00 (0.0°)	0.0 MeV
32	74	1.16	−0.01	1.05 (9.2°)	−0.1
42	106	1.23	0.01	1.05 (5.8°)	−0.2
56	132	1.11	−0.04	1.05 (16°)	−0.2
58	134	1.11	0.0	1.04 (11°)	−0.2
62	138	1.16	0.02	1.05 (8.2°)	−0.4
68	168	1.18	0.06	1.04 (5.2°)	−0.2
74	186	1.09	0.20	1.05 (7.3°)	−0.3
76	188	1.06	0.22	1.04 (7.0°)	−0.4
76	192	1.04	0.24	1.04 (7.8°)	−0.3
88	222	1.21	−0.27	1.03 (20°)	−0.3
90	233	1.25	−0.21	1.06 (16°)	−0.5
92	236	1.25	−0.21	1.03 (8.3°)	−0.6

When triaxiality is admitted in the calculations, ground state energy is lowered by less than 0.5 MeV.

But axial symmetry is broken anyhow. And it is also broken if triaxiality is only dynamic.

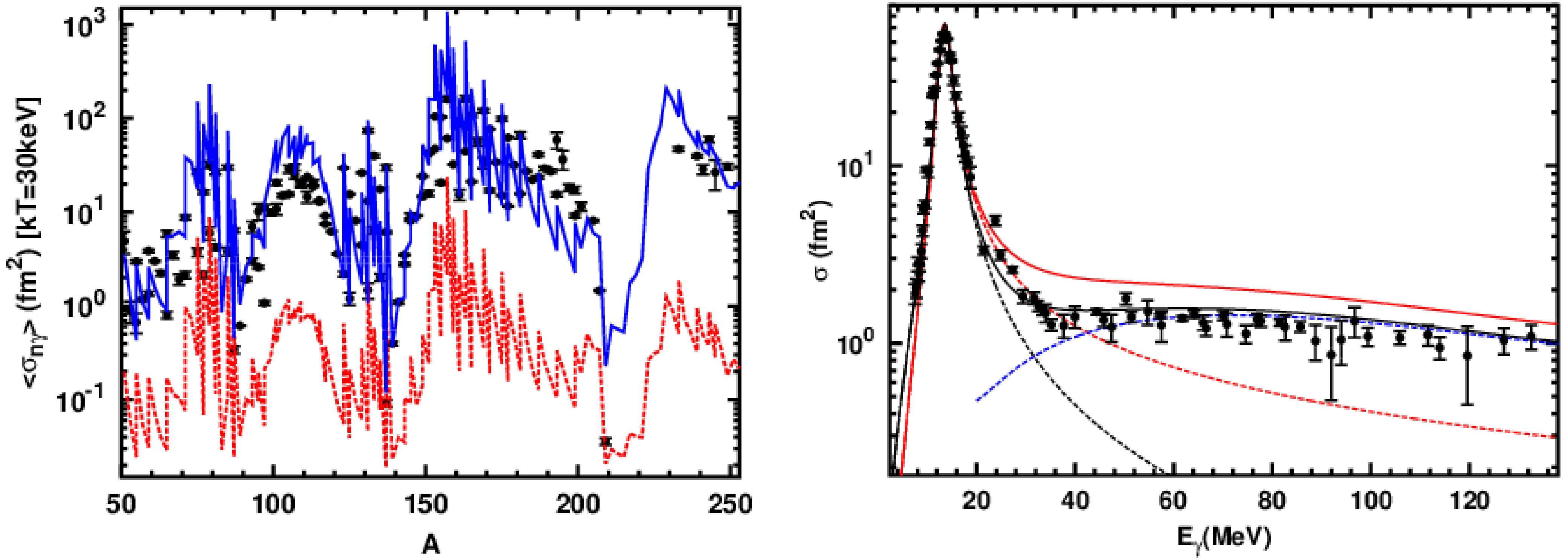
Dutta, Pearson and Tondeur,
PRC 61 054303 (2000)

GDR's, their widths Γ_i and low & high energy tail

As proposed 1983 by Kadmenskii, Markushev and Furmann for n-capture resonances Γ_i vary with E_i .

*A false application often labelled **KMF** proposes to apply this to GDR's with a dependence of Γ_i on E_γ ;*

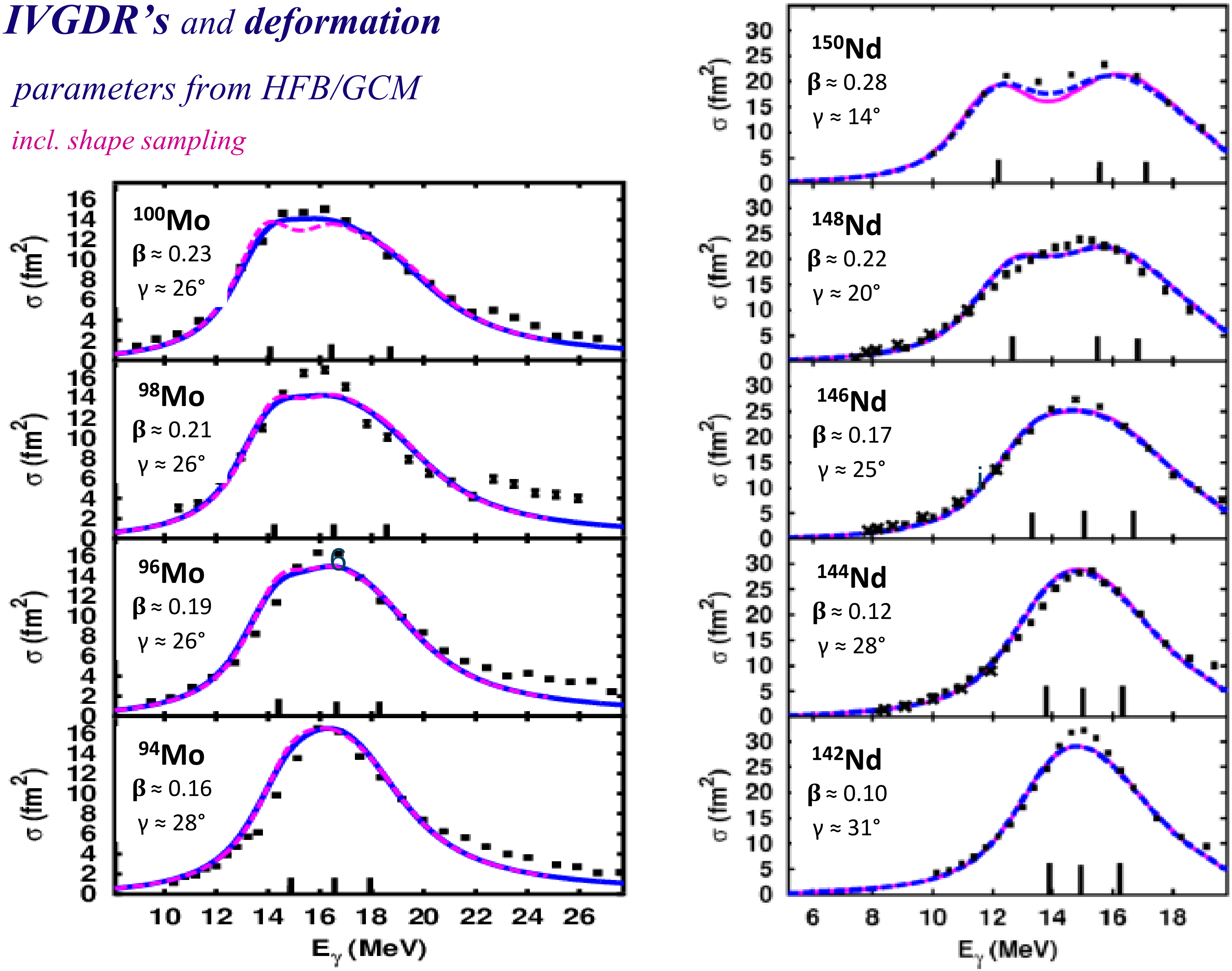
*this results in a **low** prediction for σ(n,γ), if the TLO fit is used [left panel] - and a **surplus** above the GDR, where one sees effect of **quasi-deuteron break up,** calculated 1991 by Chadwick et al [right panel].*



IVGDR's *and* ***deformation***

parameters from HFB/GCM

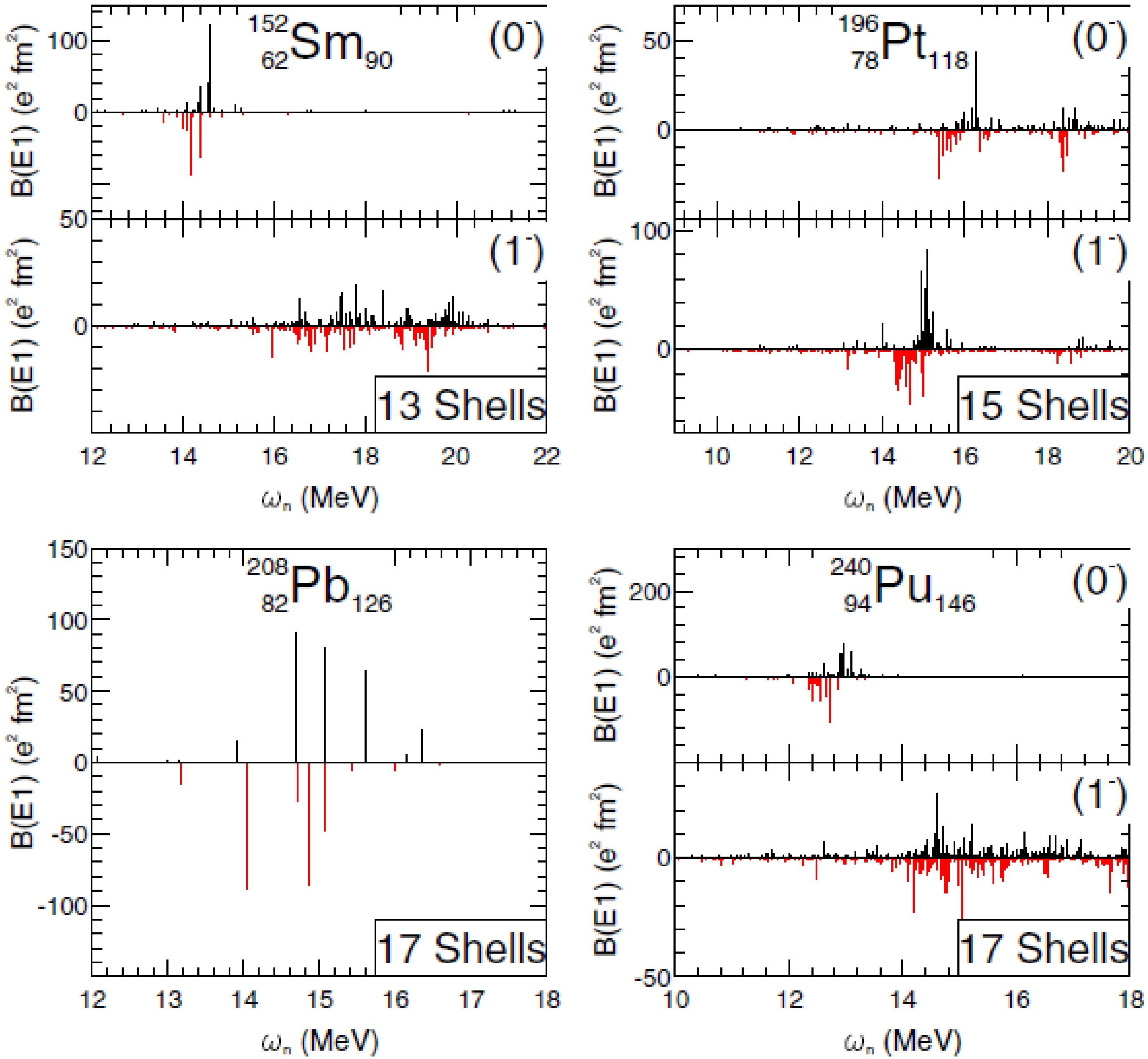
incl. shape sampling



Beil *et al.*, Nucl. Phys. A 227, 427 (1974)

Carlos et al., Nucl. Phys. A172, 437 (1971)

At CEA/DAM an axially symmetric-deformed HFB+QRP is used and a constant width (2.5 MeV) and an energy shift Δ= 2 MeV are adjusted on experimental data.



Martini et al., PRC 94, 014304 (2016)

The calculations performed at CEA-DAM are using large quantities of cpu-time.

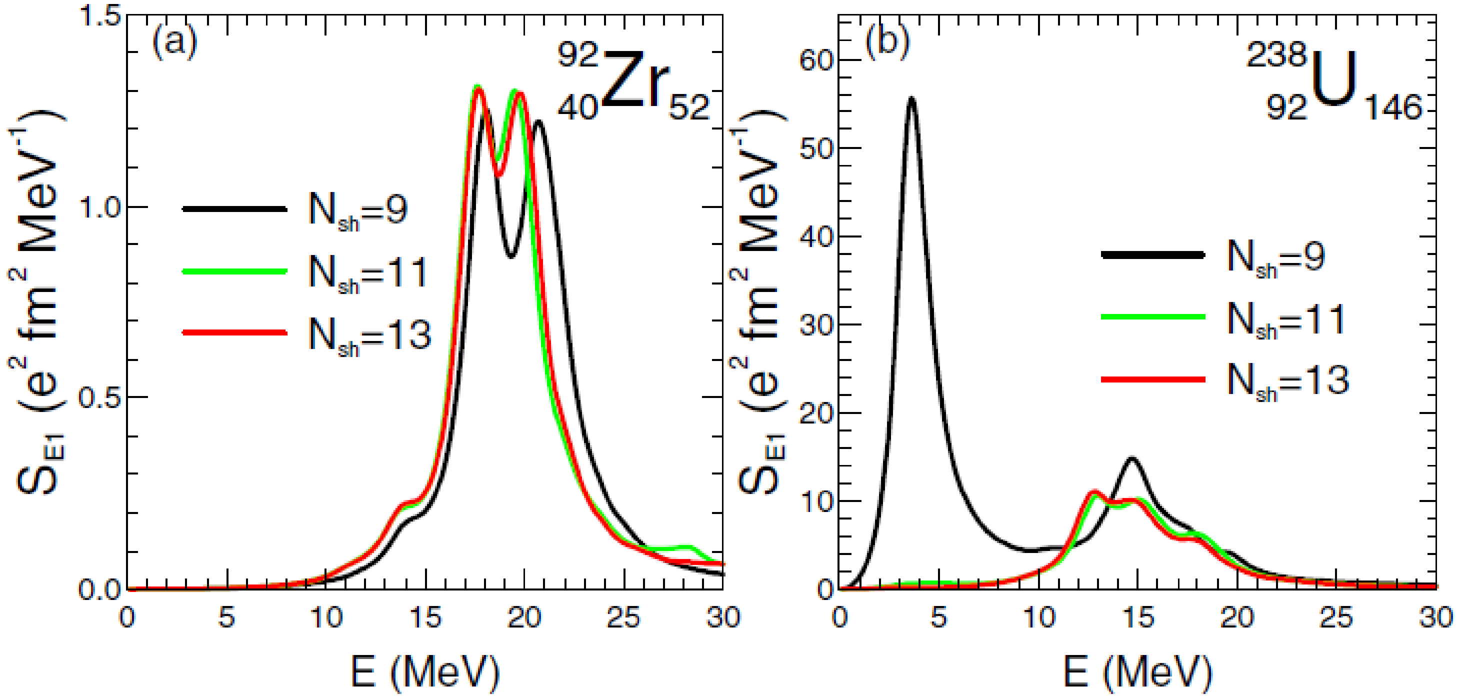


TABLE I. Average computation time for a $K^\pi = 0^-$ of one nucleus for several energy cutoff and basis size combinations using 1024 cpus.

N_{sh}	No cut	$\varepsilon_c = 100$ MeV	$\varepsilon_c = 60$ MeV	$\varepsilon_c = 30$ MeV
9	5 min	5 min	4 min	38 s
11	2 h	2 h	1 h	5 min
13	42 h	26 h	6 h	30 min
15	21 d	8 d	30 h	2 h
17	286 d	63 d	7 d	8 h

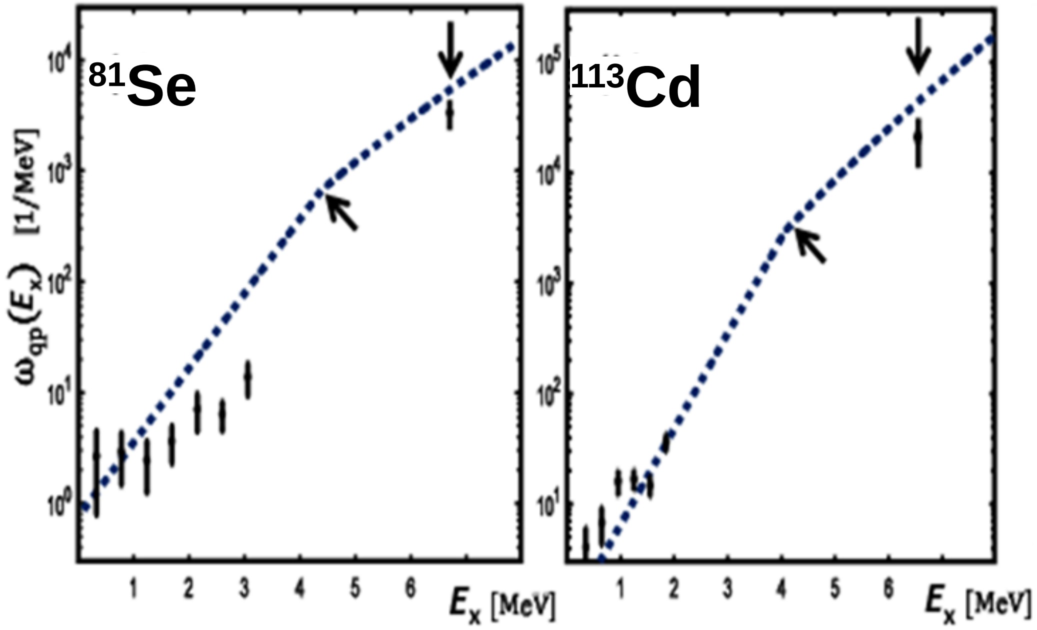
Martini et al., PRC 94, 014304 (2016)

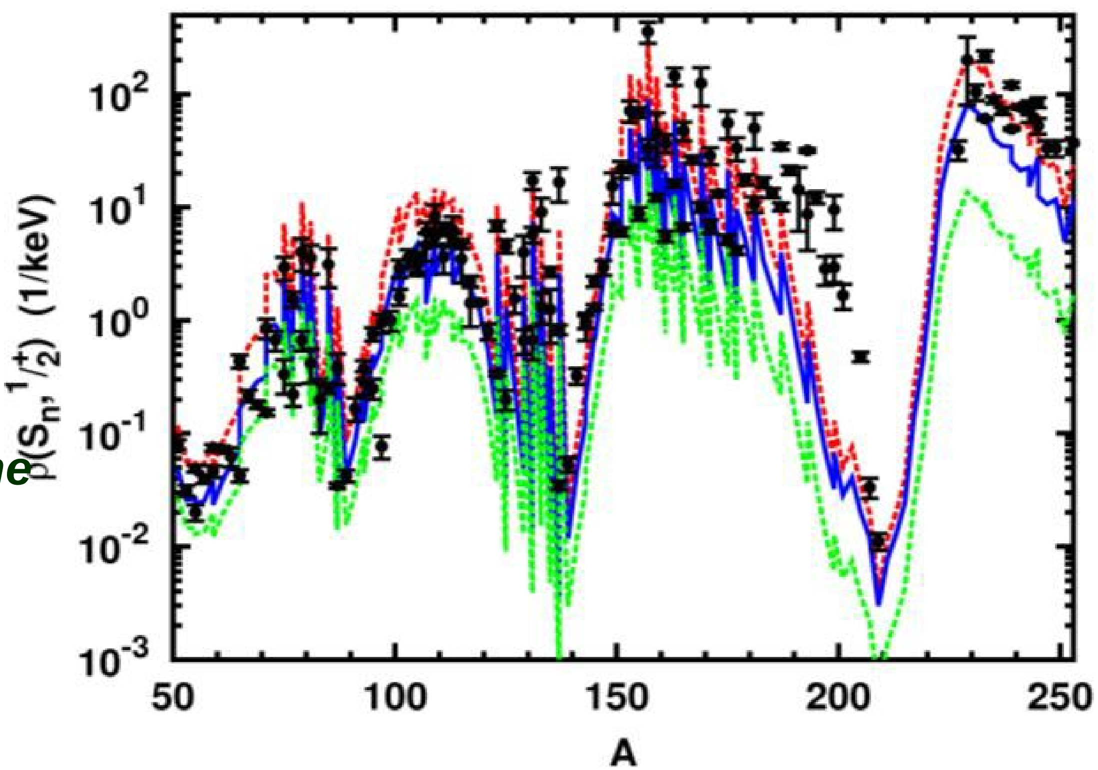
This two-component level density approach has to be complemented by collective rotational enhancement which is very simple for low spins if axial symmetry is not required:

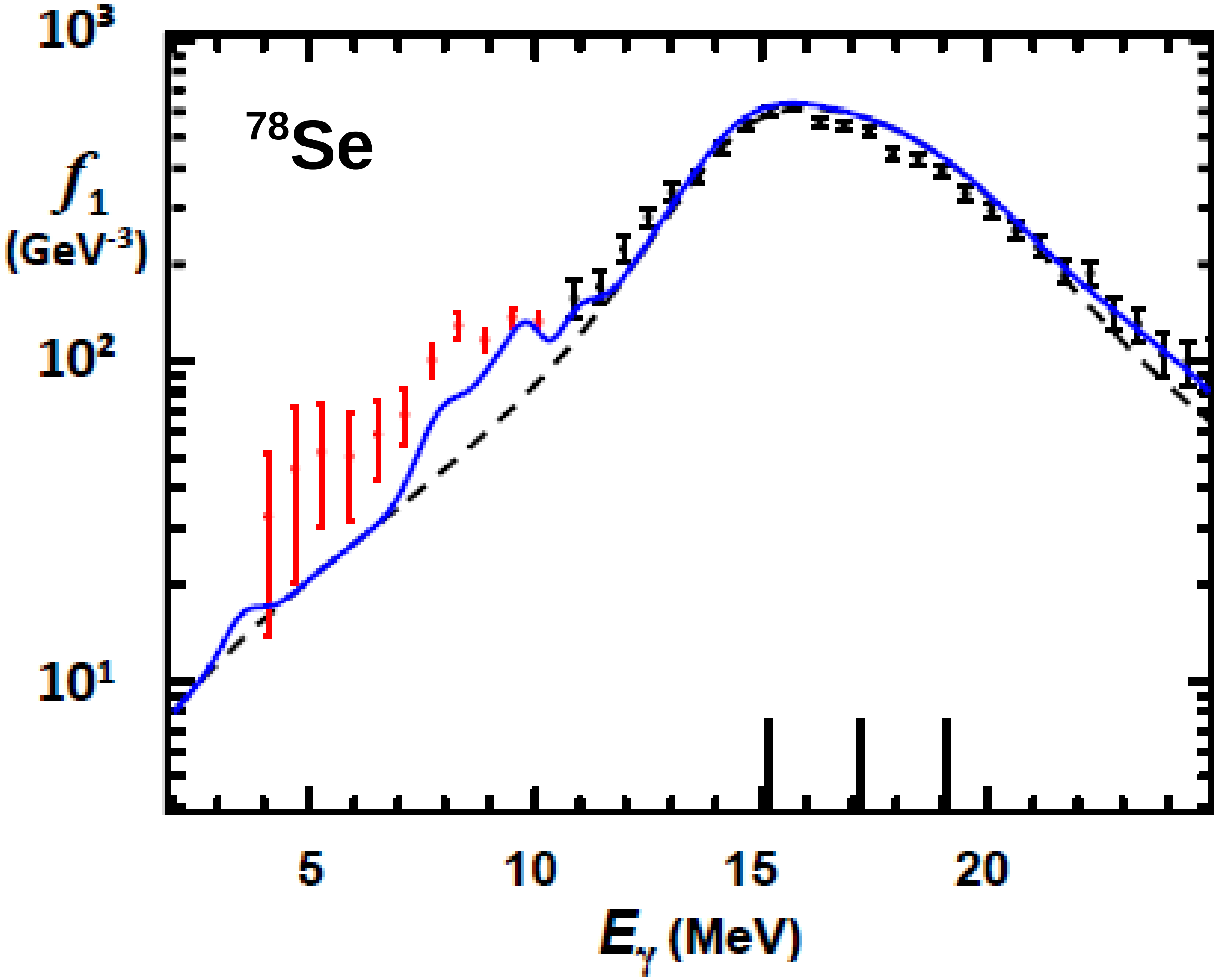
$$\rho \rightarrow \frac{2\,J+1}{2\cdot 4}\,\omega_{qp}(E_x)$$

We get good agreement for states with J = ½ and then also for capture resonances into J=0 targets.

The green curve corresponds to the assumption of axiality.







10³
10²
10¹
f₁
(GeV⁻³)
⁷⁸Se
5
10
15
20
Eγ (MeV)

Rotational enhancement of nuclear level density vs. symmetry class

*The intrinsic **quasi-particle state density** in a finite nucleus* $\boldsymbol{\omega_{qp}(E_x)}$ *is **not** yet the observable density of nuclear levels with **well defined spin*** $\boldsymbol{\rho}(E_x, J = I_{rot}+j, \pi)$.

To fix J the underlying collective symmetry has to be introduced *(group theory)*

small J limit

1. *spherical* ⇒ *only q-p states* $\rho(E_x, J, \pi) \rightarrow \frac{2J+1}{2\cdot\sqrt{8\pi}\,\sigma^3}\,\omega_{qp}(E_x)$

2. *axial* ⇒ *q-p states & rotation ⊥ axis* $\rho \rightarrow \frac{2J+1}{2\cdot\sqrt{8\pi}\,\sigma}\,\omega_{qp}(E_x)$

3. *non-axial (triax)* ⇒ *q-p states & rotation about any axis* $\rho \rightarrow \frac{2J+1}{2\cdot 4}\,\omega_{qp}(E_x)$

4. *no reflection symmetry* ⇒ *q-p states & octupole deform.* $\rho \rightarrow \frac{2J+1}{2}\,\omega_{qp}(E_x)$

1 parity

Thomas-Fermi Model ➡ $\sigma^2 = \frac{\tilde{a}\cdot t}{11}A^{2/3} \approx \frac{A^{5/3}}{143}\cdot t$

H.Bethe, Rev. Mod. Phys. 9 (1937) 69; S.Bjørnholm, A.Bohr, B.Mottelson; Rochester conf. 1974, IAEA-SM-174/205

New view on heavy nuclei – avoiding axial symmetry postulate

by: newly applied theoretical tools *and* *experimental observations:*

HFB + GCM , projection on I ⇒ β, γ

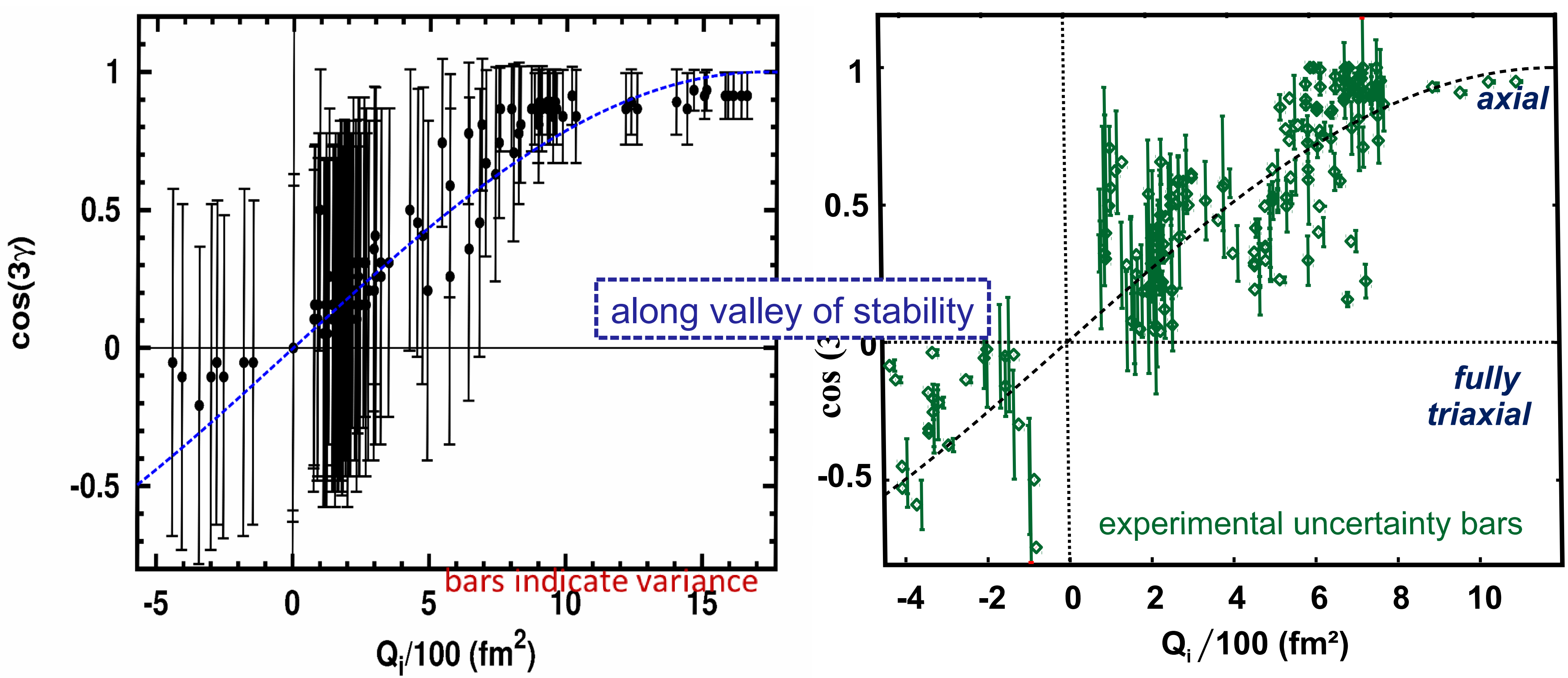
$Q^3 \cdot \cos(3\gamma)$ ⇒ rotation invariant

*indicator for **axiality***

level energies

decay properties and Q-moments

collectively enhanced level density



Giant dipole resonances as sensitive to deformation should also recognize it !

Bertsch et al, PRL 99 (2007) 032502; Delaroche et al, Phys. Rev. C 81 (2010) 014303; Warsaw-Rochester collab,, GSI exp'ments