Radiative neutron capture and photonuclear data in view of global information on electromagnetic strength and level density.

E. Birgerson, E. Grosse, A. Junghans, R. Massarczyk, G. Schramm and R. Schwengner,
FZ Dresden-Rossendorf and TU Dresden

Giant dipole resonances and nuclear shapes

Spreading width and electric dipole transitions

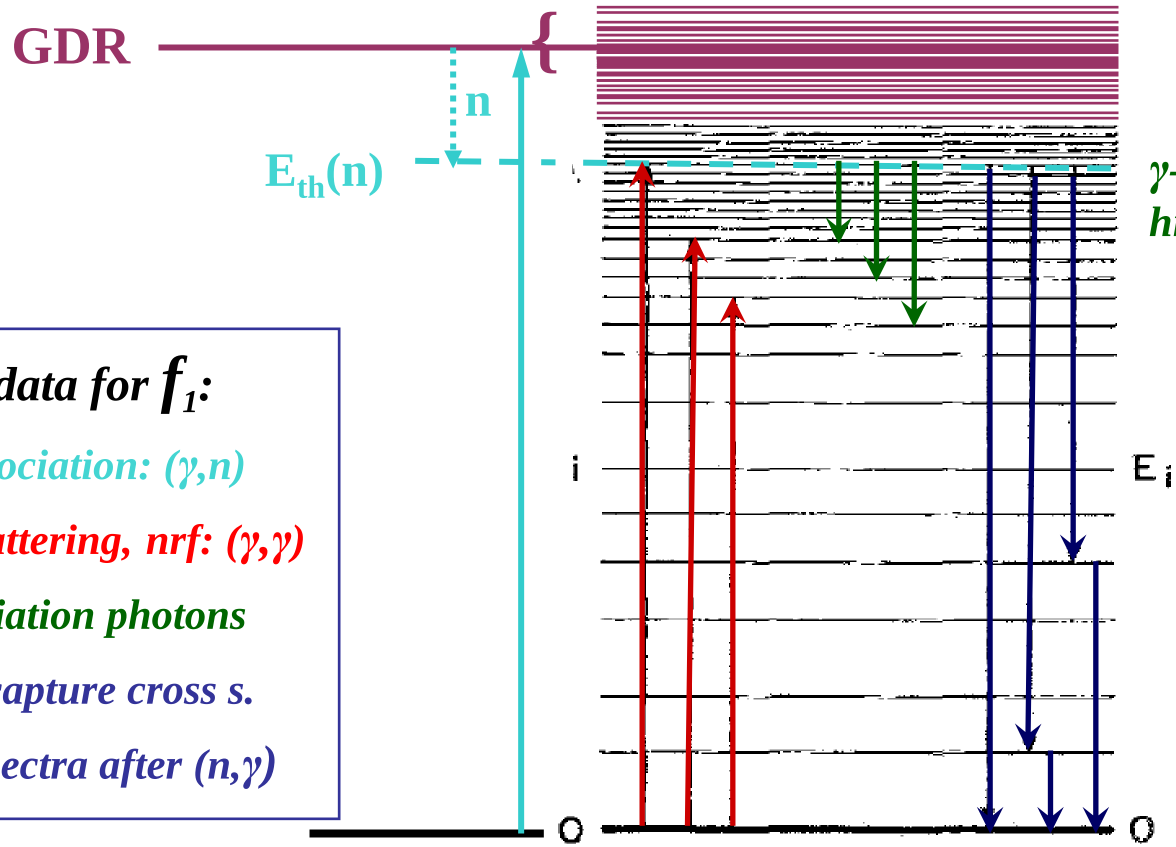
Magnetic dipole transition strength

Level densities and radiative capture

Conclusions

Dipole strength f_1

f_{E1} *is controlled by the isovector giant dipole resonance GDR.*



γ-transitions between high lying states

5 types of data for f_1:

- *photo-dissociation: (γ,n)*
- *photon scattering, nrf: (γ,γ)*
- *pre-dissociation photons*
- *radiative capture cross s.*
- *γ-decay spectra after (n,γ)*

Axel-Brink hypothesis:

dipole strength only depends on E_γ

average width

level density

dipole strength function

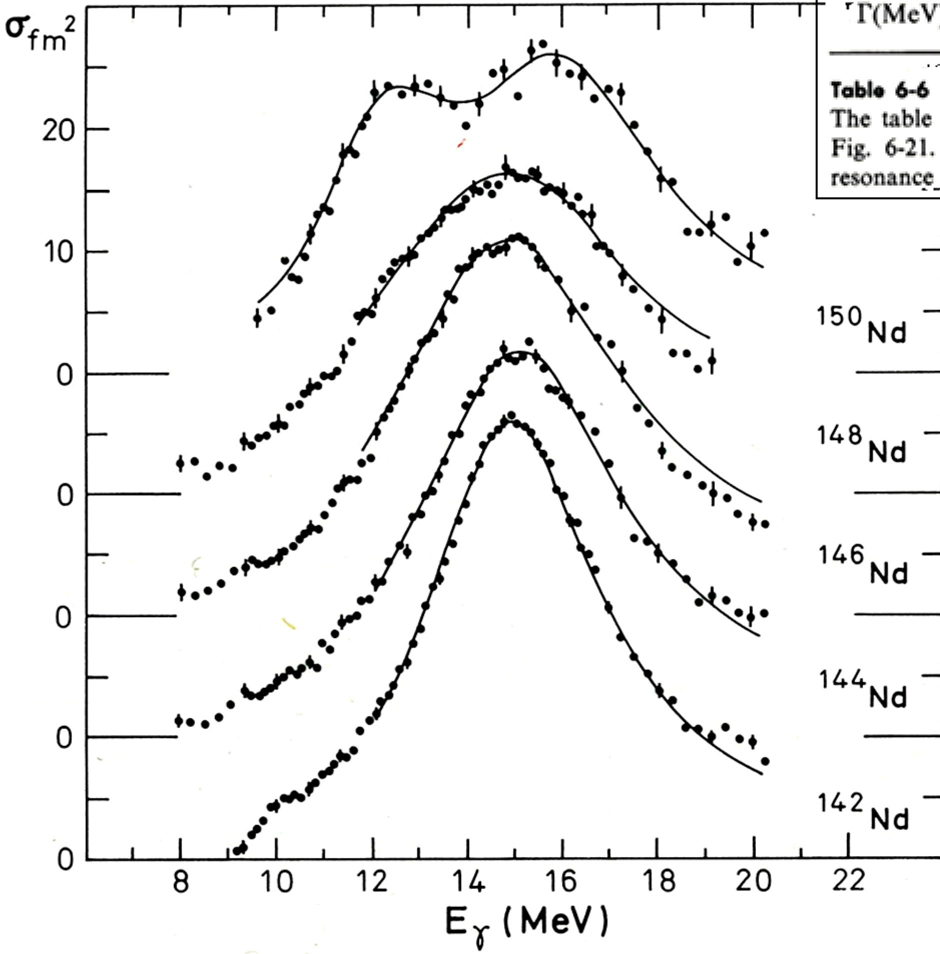
$$f_1 = \frac{\overline{\sigma}_{\gamma\text{-}abs}(0 \rightarrow E_x, \lambda = 1)}{3(\pi\hbar c)^2 E_x} = \frac{\overline{\Gamma}_\gamma(E_u \rightarrow E_l)\,\rho(E_u)}{(E_u - E_l)^3}$$

Bartholomew et al., Advances in Nuclear Physics 7(1973) 229

Axel, Phys. Rev. 126 (1962) 671

Deformation induced GDR splitting –

known since long, but interpreted in various ways



	^{142}Nd	^{144}Nd	^{146}Nd	^{148}Nd	^{150}Nd	
E_0(MeV)	14.9	15.0	14.8	14.7	12.3	16
σ_0(fm^2)	36	32	31	26	17	22
Γ(MeV)	4.4	5.3	6	7.2	3.3	5.2

Table 6-6 Parameters for the dipole resonance in even neodymium isotopes. The table gives the parameters for the Lorentzian resonance curves drawn in Fig. 6-21. The cross section for ^{150}Nd has been fitted to the sum of two resonance functions.

if weakly deformed nuclei are treated as spherical the apparent width is enlarged

simple Lorentzian fits result in widely variing widths

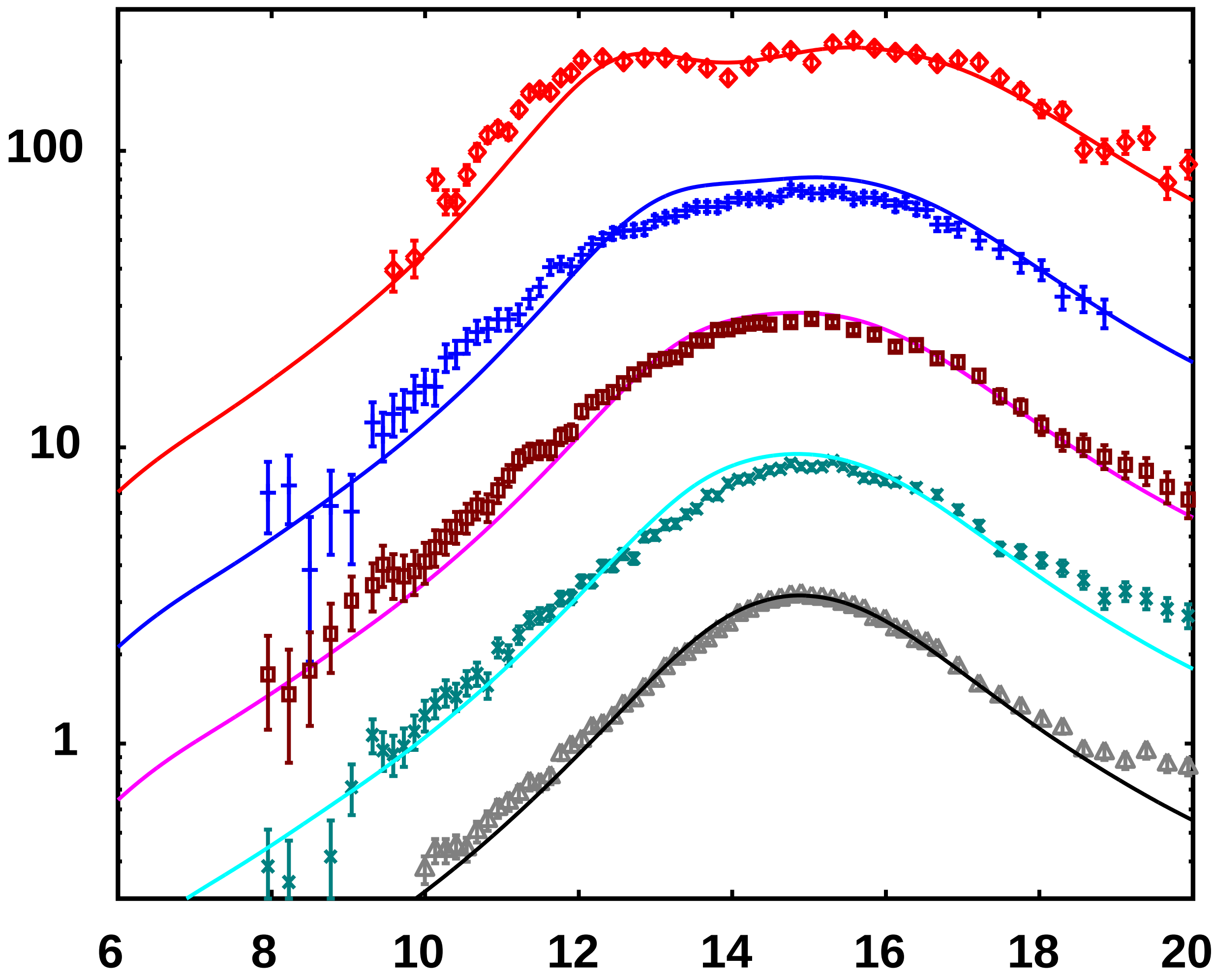
σ_0 seemingly fluctuates with A => deviations from sum rule

The E1-strength at low energy governs radiative capture processes; it is proportional to deviation from sum rule and to GDR width – their determination needs special care !

P.Carlos et al., NPA 172 (1971) 437

Bohr & Mottelson, Nuclear Structure, Vol. II

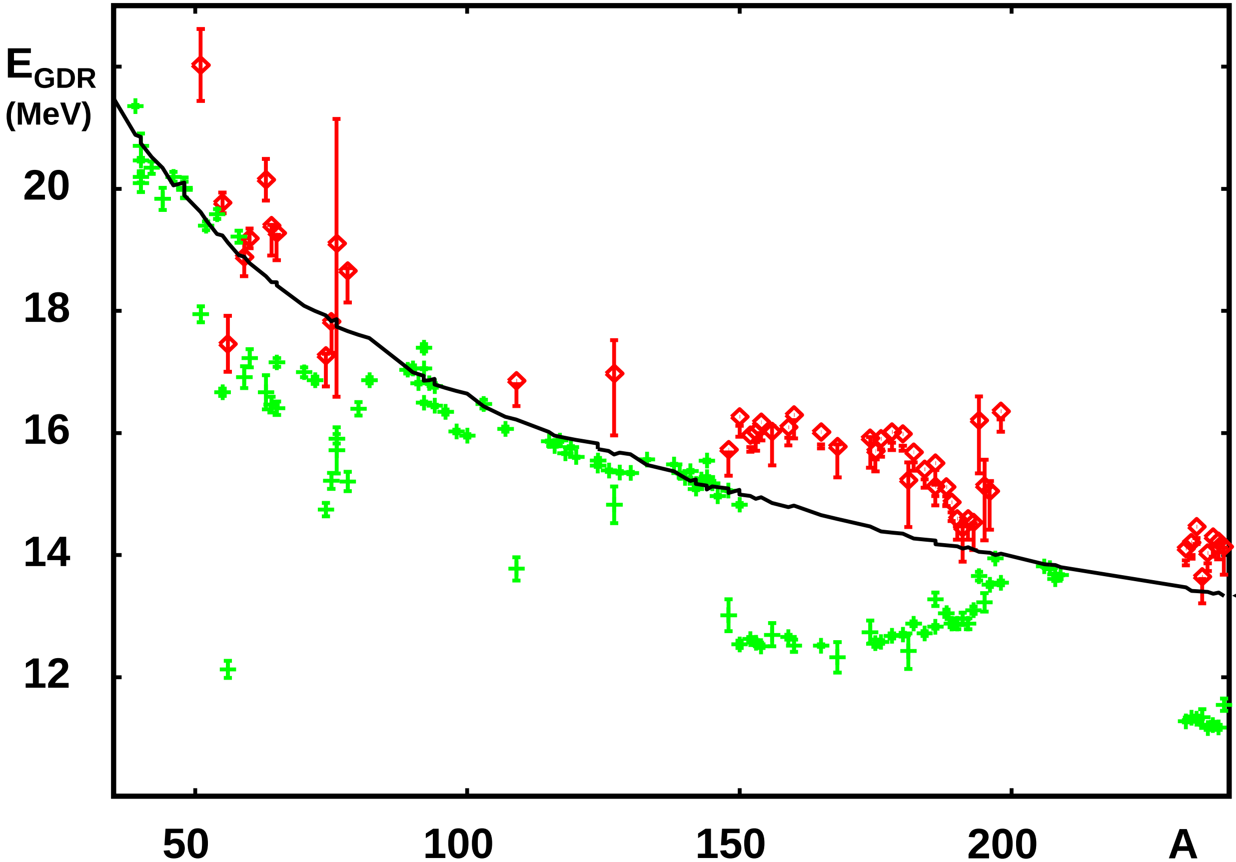
Global parametrization for GDR splitting, width and strength



^{A}Z	B(E2↑) (e^2b^2) exp.	FRDM
^{150}Nd	2.76	2.59
^{148}Nd	1.35	1.67
^{146}Nd	0.76	0.84
^{144}Nd	0.49	0.02
^{142}Nd	0.26	0.01

3 parameters** – in addition to the* **B(E2)-*values *and 2 parameters determined by fit to masses – suffice to describe the GDR not only for the Nd-isotopes, but for **all nuclei with A > 60**.*

GDR-energies as obtained from Lorentzian fits (1 or 2 poles, why not 3?)



average GDR energy E_0 varies only weakly with A

average GDR-energies E_0 are well predicted using mass fits** (FRDM) **and m* = 874 MeV

V.A. Pluiko, www-nds.iaea.org/RIPL-3/gamma/gdrparameters-exp.dat; subm. to ADNDT; R. Capote et al., NDS 110 (2009) 3107

W.D. Myers et al., PR C 15 (1977) 2032
A.Junghans et al., PLB 670 (2008) 200

***Experimental** study (Coulex etc.) of >150 nuclei reveals close correlation between E2-collectivity q_2 and axiality q_3 (both are rotation invariant observables)*

axiality q_3 (eb)$^{3/2}$:

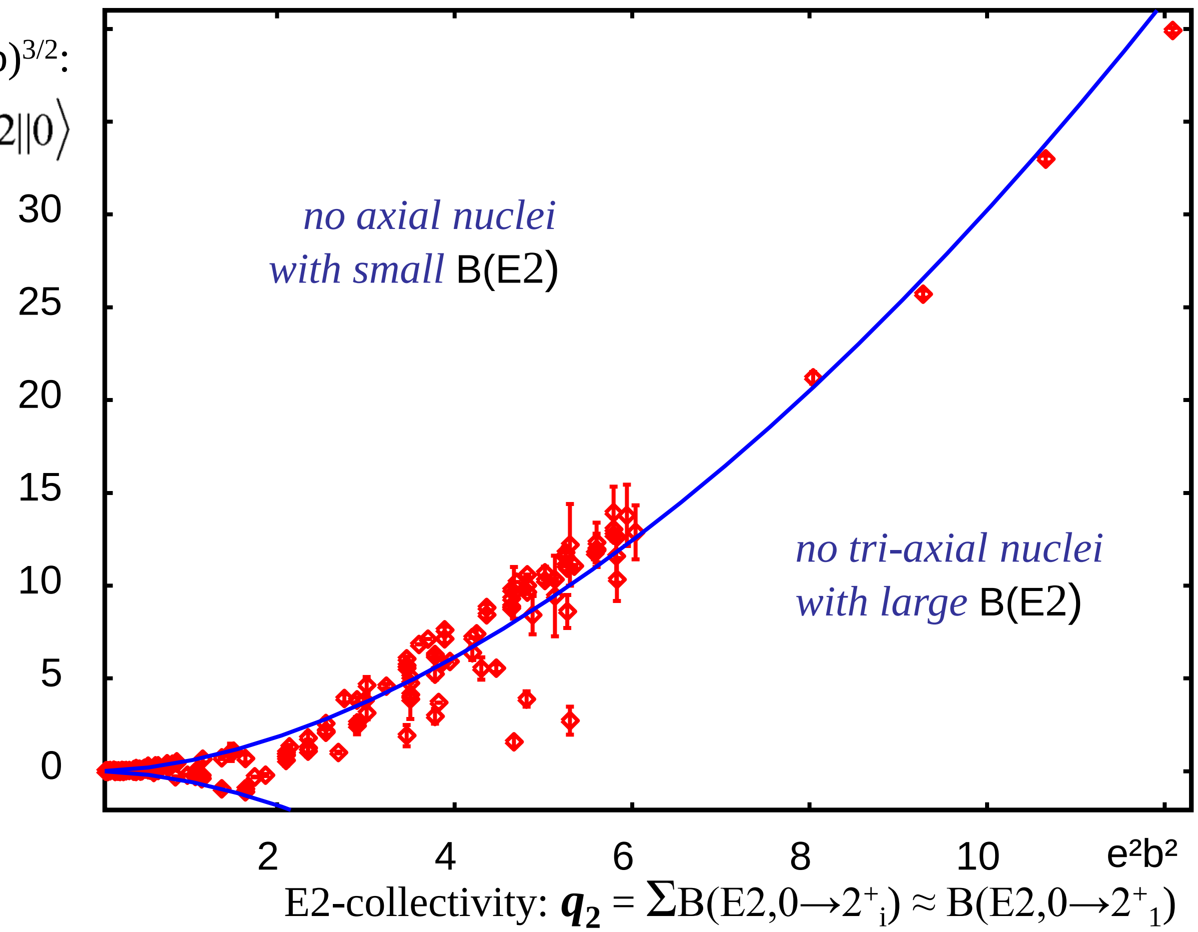
$$\sqrt{\frac{7}{10}}\sum_{r,s}\langle 0\|E2\|2_r\rangle\langle 2_r\|E2\|2_s\rangle\langle 2_s\|E2\|0\rangle$$

systematics:

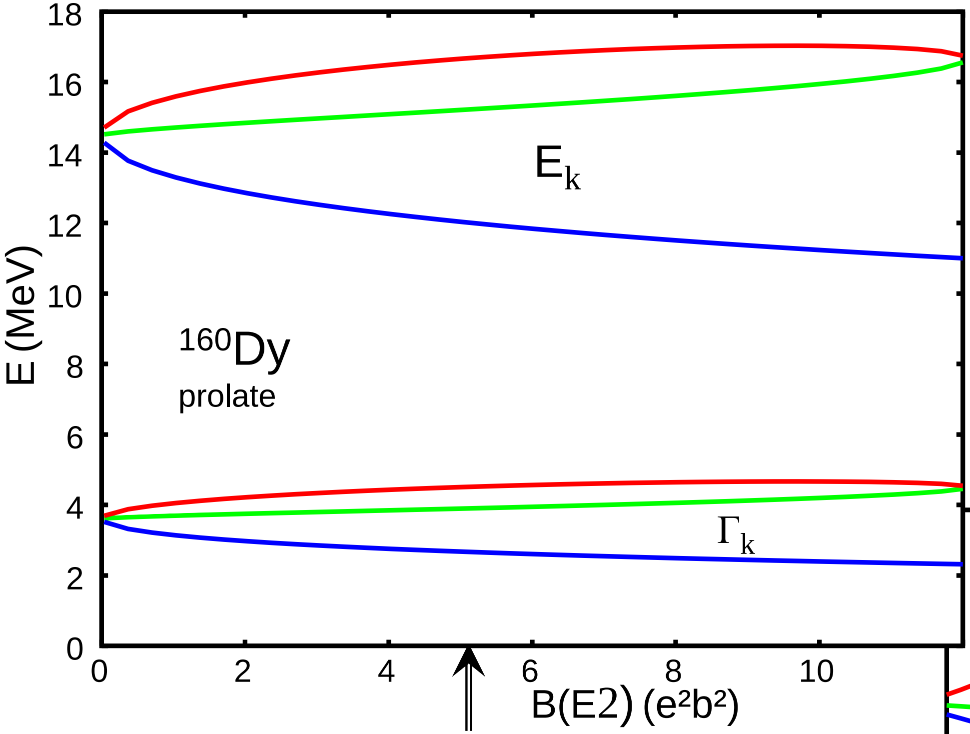
$$-\cos(3\gamma) = q_3/q_2^{3/2}$$

$$= \mathbf{0.55 \cdot B(E2)^{0.24}}$$

2 parameters fixed by spectroscopy data



K. Kumar, PRL **28** (72) 249
S. Raman, ADNDT 42(89)1
M. Zielinska et al., NP **A 712** (02) 3
L. Esser et al., PRC 55 (97) 206
D. Cline, ARNPS 36 (1986) 683
C. Y. Wu and D. Cline, PRC 54 (96) 2356
W. Andrejtscheff and P. Petkov, PRC 48 (93) 2531
V. Werner et al., PRC **71**, 054314 (05)

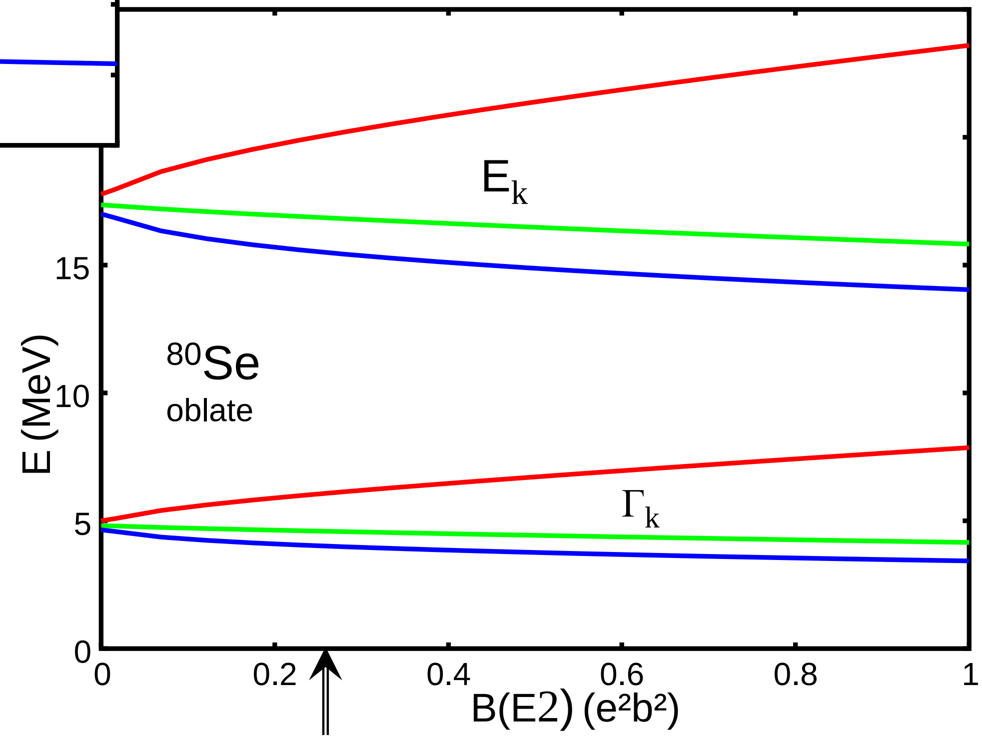


E2-collectivity q_2 ***and axiality*** q_3 ***determine axes of ellipsoid by only assuming reflection symmetry and homogeneous distribution of charge and mass;***

GDR-energies and widths vary accordingly

from systematics:

$-\cos(3\gamma) = q_3/q_2^{3/2} \approx 0.55 \cdot B(E2)^{0.24}$



$$q_2 = \sum_r \langle 0||E2||2_r\rangle\langle 2_r||E2||0\rangle = \sum_r B(E2, 0 \rightarrow 2_r)$$

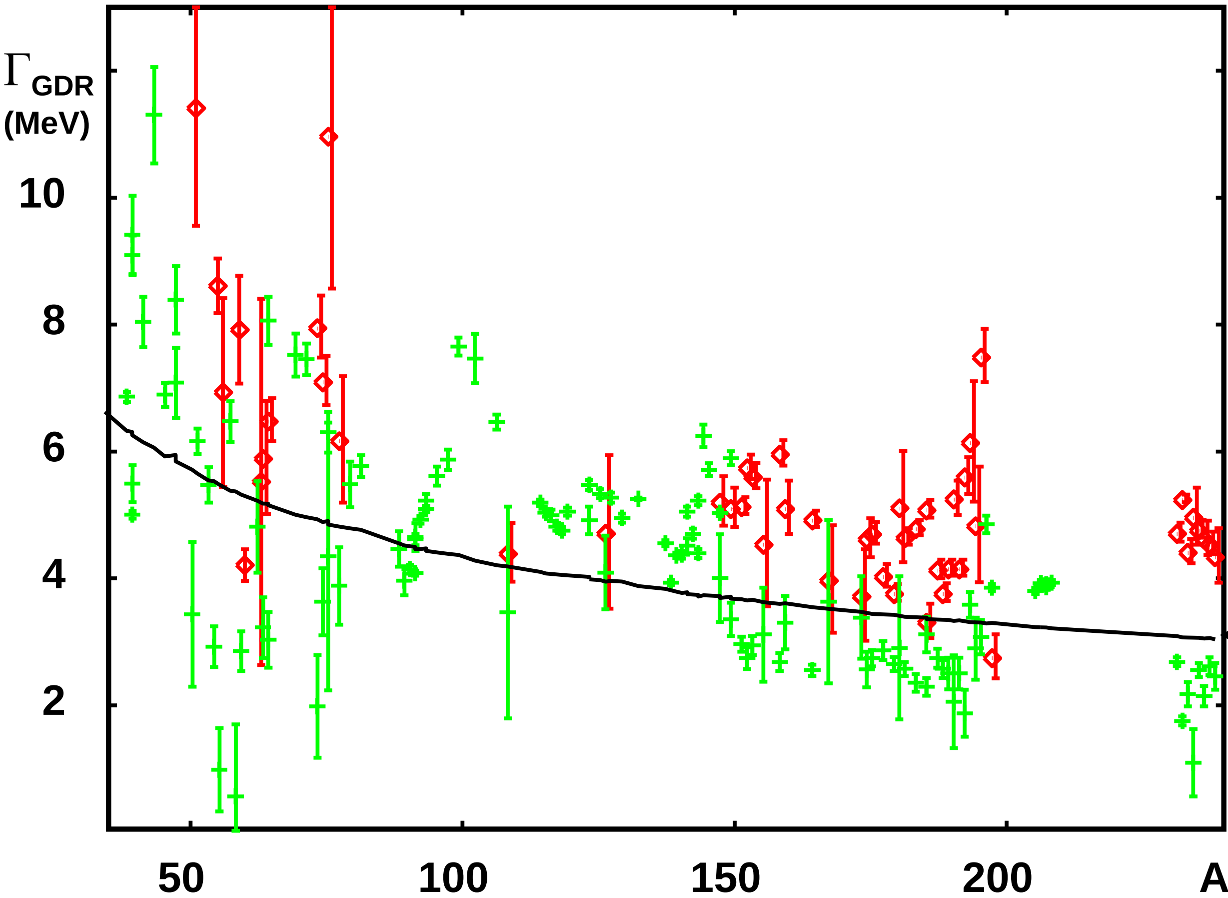
$$q_3 = \sqrt{\frac{7}{10}} \sum_{r,s} \langle 0||E2||2_r\rangle\langle 2_r||E2||2_s\rangle\langle 2_s||E2||0\rangle$$

$$\frac{q_3}{q_2^{3/2}} = -\cos(3\gamma) \qquad d = \frac{4\pi\sqrt{q_2}}{3ZR_0^2} \approx \beta \qquad r_k = \frac{R_k}{R_0} = \frac{E_0}{E_k}$$

$$\sqrt{\frac{45}{\pi}}\, d\cos\gamma = 2r_3^2 - r_1^2 - r_2^2 \qquad \sqrt{\frac{15}{\pi}}\, d\sin\delta = r_1^2 - r_2^2 \qquad r_1 r_2 r_3 = 1$$

K. Kumar, Phys. Rev. Lett. 28, 249 (1972)

GDR-widths as obtained from Lorentzian fits (1 or 2 poles, why not 3?)



average spreading width Γ_0 ***varies only weakly with A; but individual fits yield large scatter; results from neglect of triaxiality.***

average GDR-widths are well predicted by hydrodynamics using wall formula $\Gamma_0 = 0.05 \cdot E_0^{1.6}$;

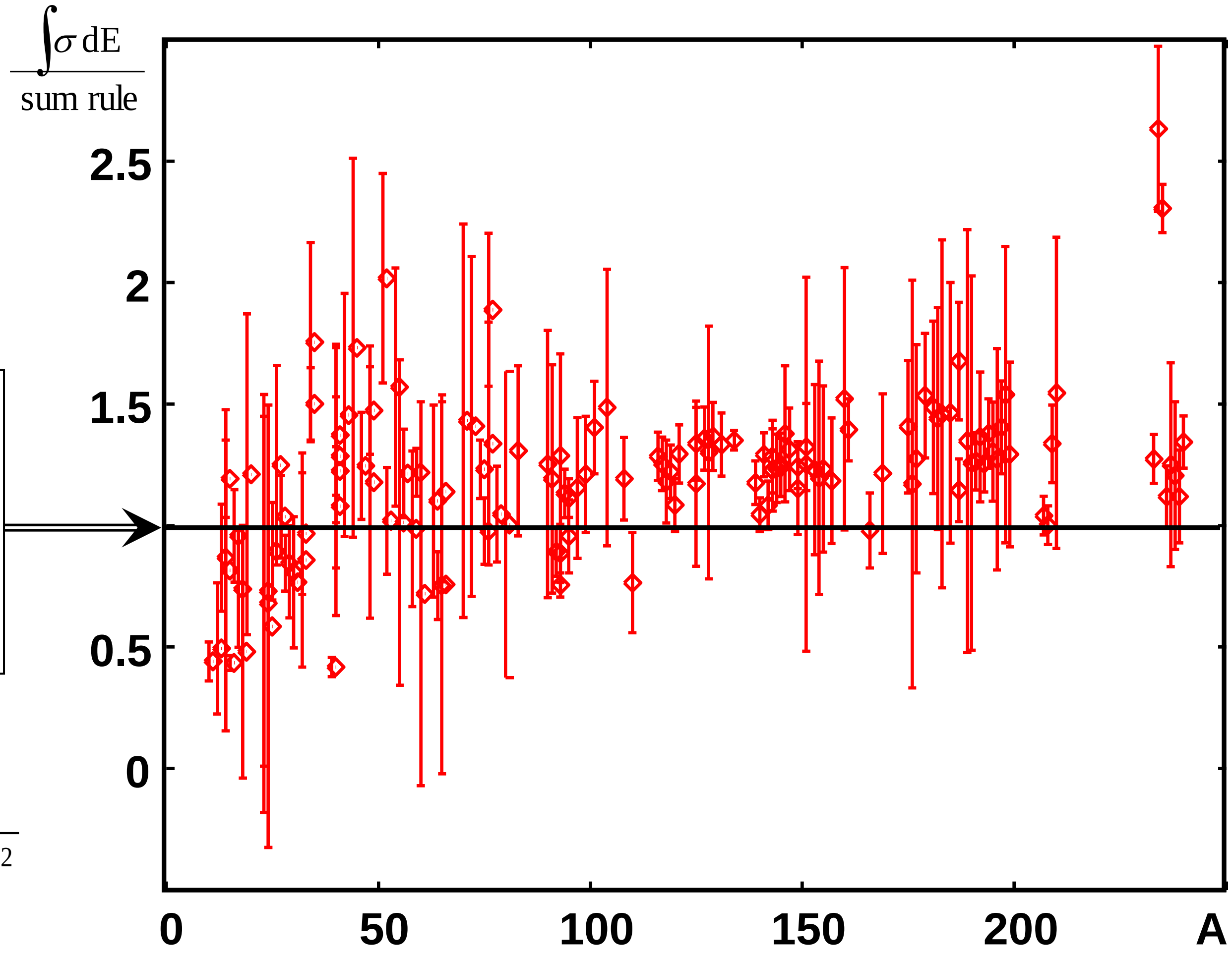
which leads for the 3 components to $\Gamma_k = \underline{0.05} \cdot E_k^{\underline{1.6}}$.

V.A. Pluiko, www-nds.iaea.org/RIPL-3/gamma/gdrparameters-exp.dat; subm. to ADNDT; R. Capote et al., NDS 110 (2009) 3107

A. Junghans et al., PLB 670 (2008) 200

B. Bush and Y. Alhassid, NPA **531** (1991) 27

GDR-integrals as obtained from Lorentzian fits (1 or 2 poles, why not 3?)



GGT sum rule –
derived alone from
unitarity and causality
allows small surplus mainly
for energies above pion mass

$$\sigma_\gamma = \sum_{k=1,2,3} \frac{2I_k}{\pi} \frac{E^2 \Gamma_k}{\left(E_k^2 - E^2\right)^2 + E^2 \Gamma_k^{\,2}}$$

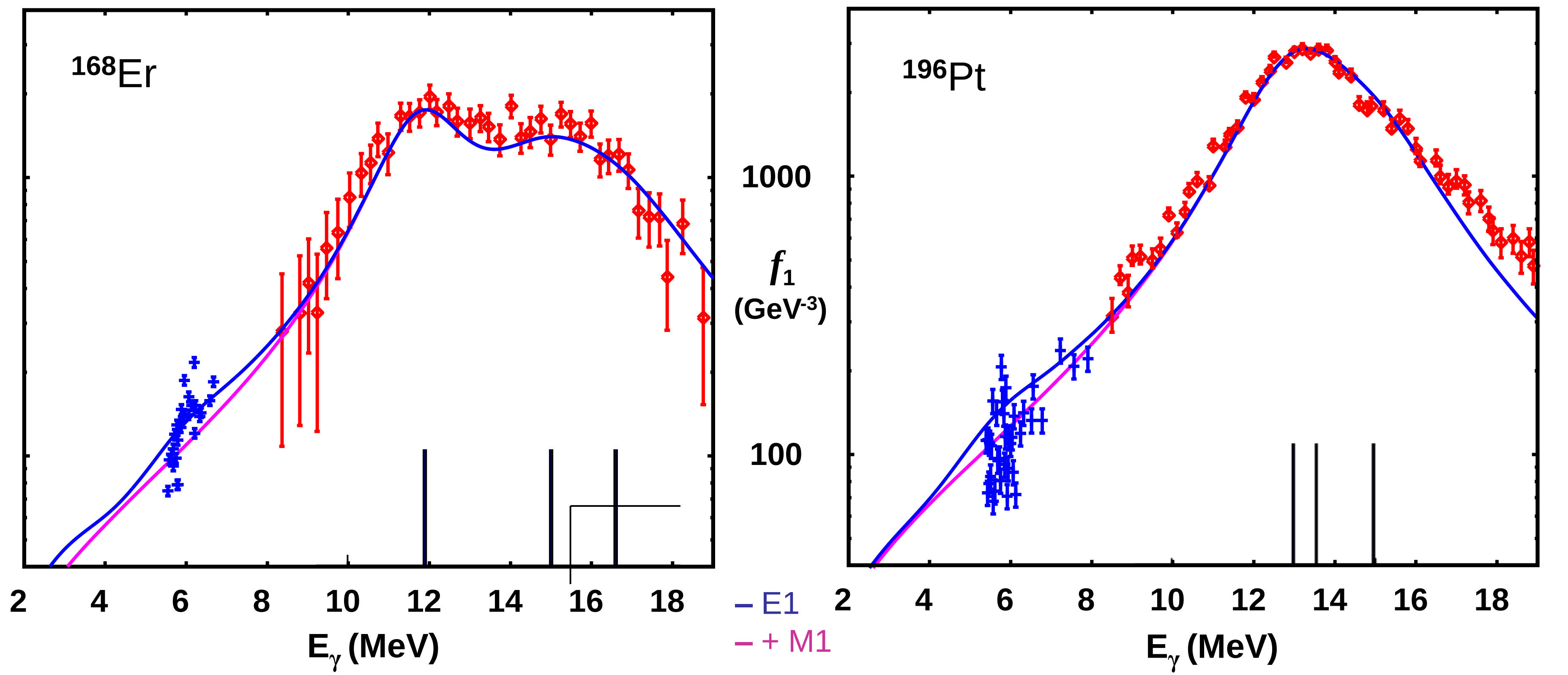
$$I_k = 2\pi^2 \frac{\alpha \hbar^2}{3m_n} \frac{ZN}{A} = 1.99 \frac{ZN}{A} (\text{MeV fm}^2)$$

V.A. Pluiko, www-nds.iaea.org/RIPL-3/gamma/gdrparameters-exp.dat; subm. to ADNDT; R. Capote et al., NDS 110 (2009) 3107

M. Gell-Mann et al., PR 95 (1954) 1612

Triple Lorentzians (TLO) *compared to dipole data for prolate and oblate nucleus*

good description of photon-data in GDR and (n,γ)-data below



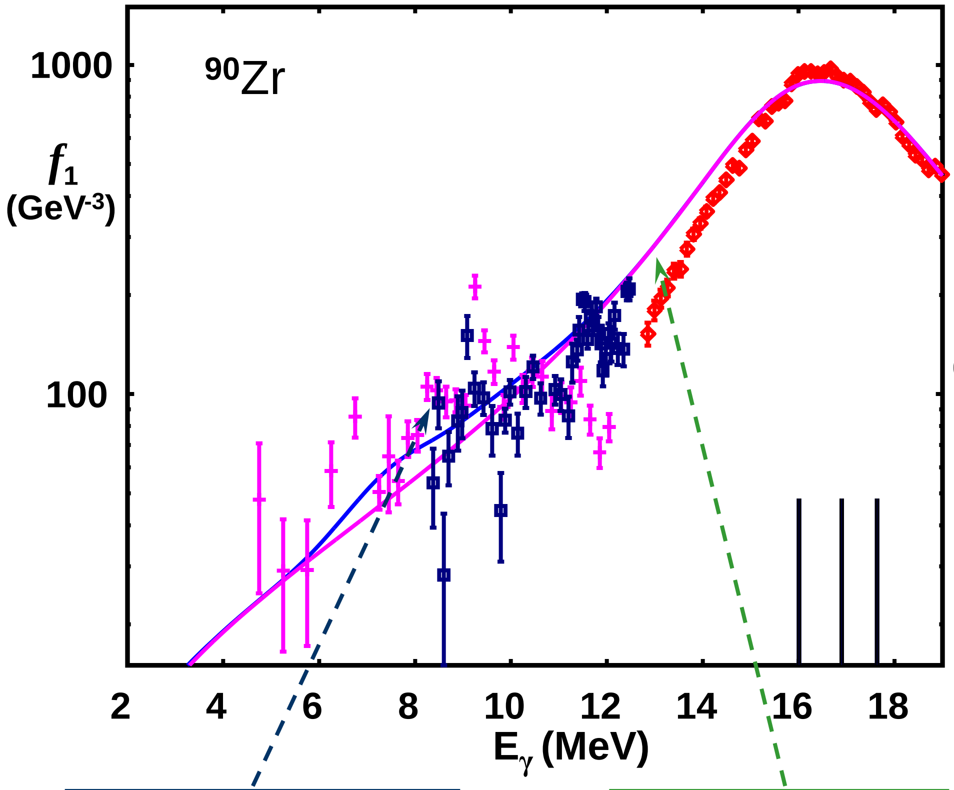
S.F. Mughabghab, C.L. Dunford, PLB 487(00)155

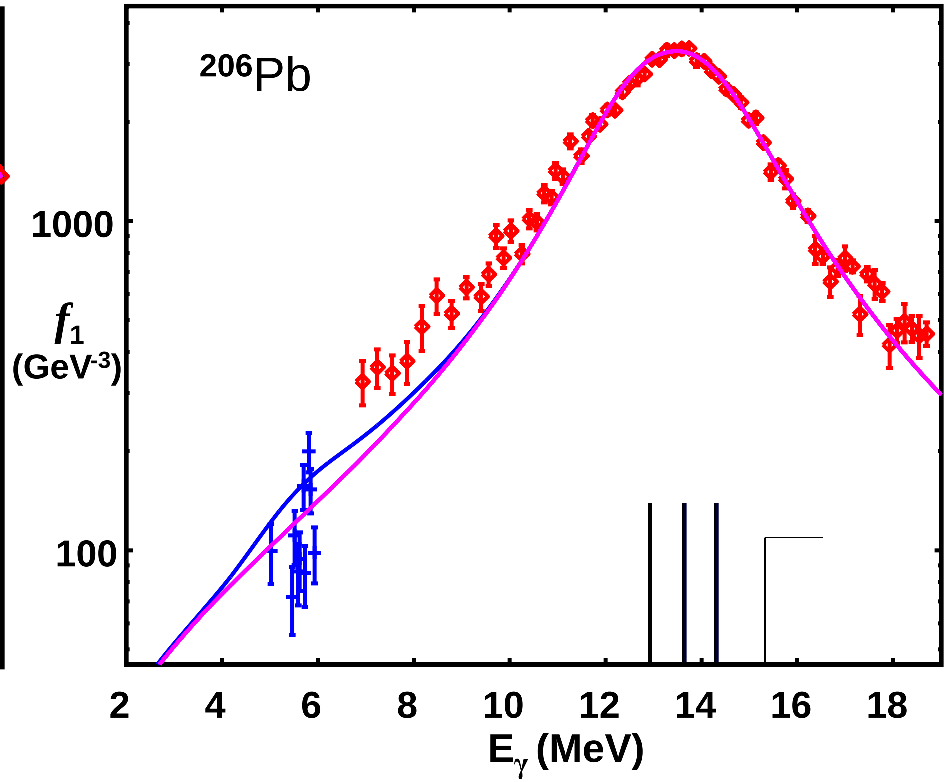
A. Junghans et al., PLB 670 (2008) 200

G.M.Gurevich et al., NPA,351(81) 257
A.M.Goryachev,G.N.Zalesnyy, YF27(78)1479

Triple Lorentzians (TLO) *compared to dipole data for 'quasi-magic' nuclei;*

small B(E2) – i.e. small q_2 – leads to unsignificant deformation induced split.





***ELBE* (γ,γ)-measurements agree well to *Urbana* data**

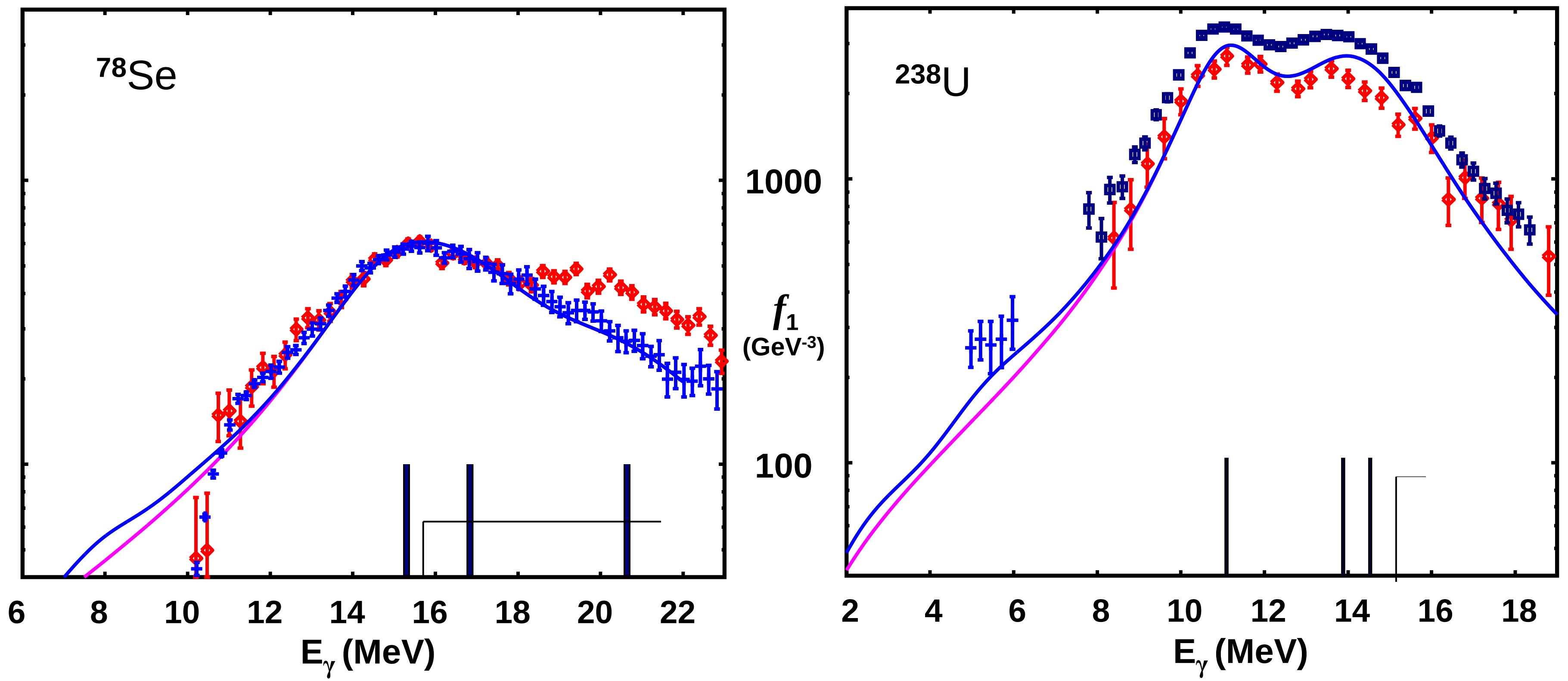
unobserved (γ,p) leads to misssing strength

In 'quasi-magic' nuclei large fluctuations and/or pygmy resonances occur near E_x ~7 MeV.

R. Schwengner et al., PRC78 (08) 064314
P. Axel et al.,PRC 2 (70) 689 A.Lepretre et al., NPA 175 (71) 609
A. Junghans et al., PLB 670 (08) 200
R.D.Starr et al., PRC (82) 25 780
R.R.Harvey et al., PR136 (64) B126

Triple Lorentzians (TLO) *compared to GDR for A=78 and A=238*

with contradicting data



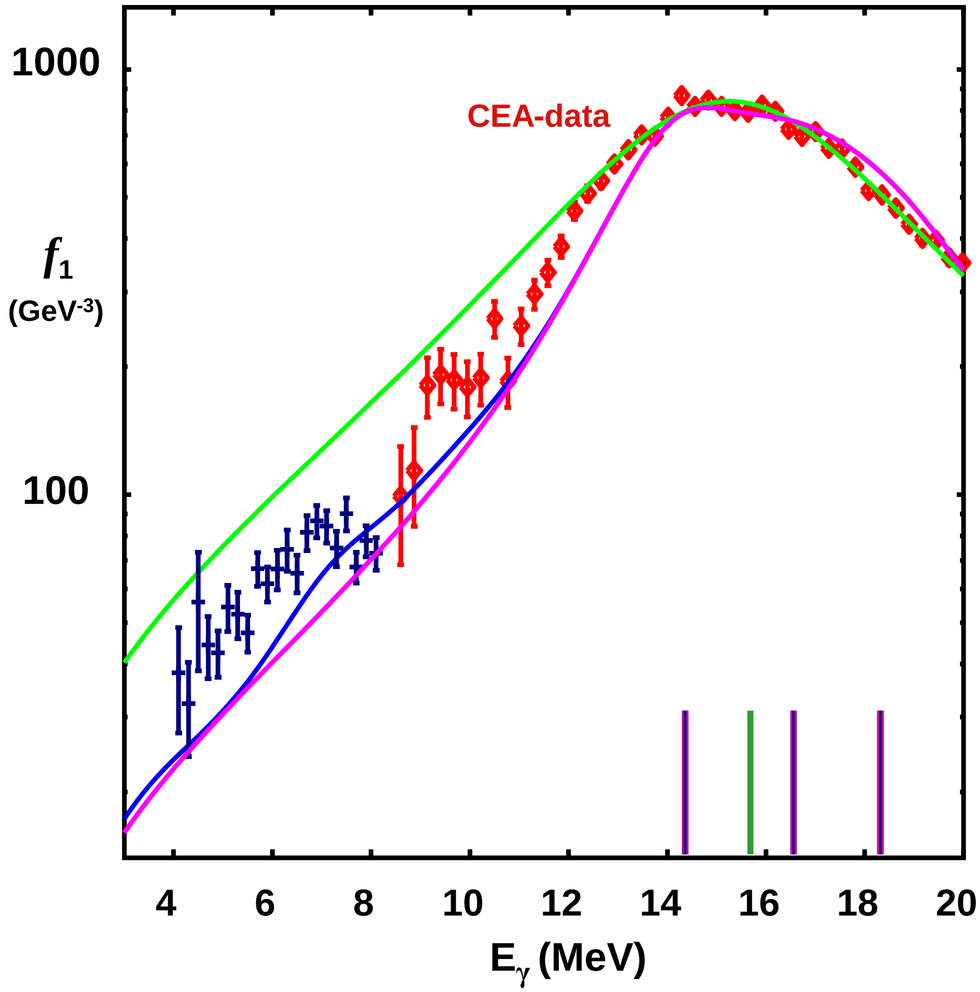
P. Carlos et al., NPA 258 (76) 365
A.M.Goryachev, G.N.Zalesnyy, VTYF 8 (82) 121

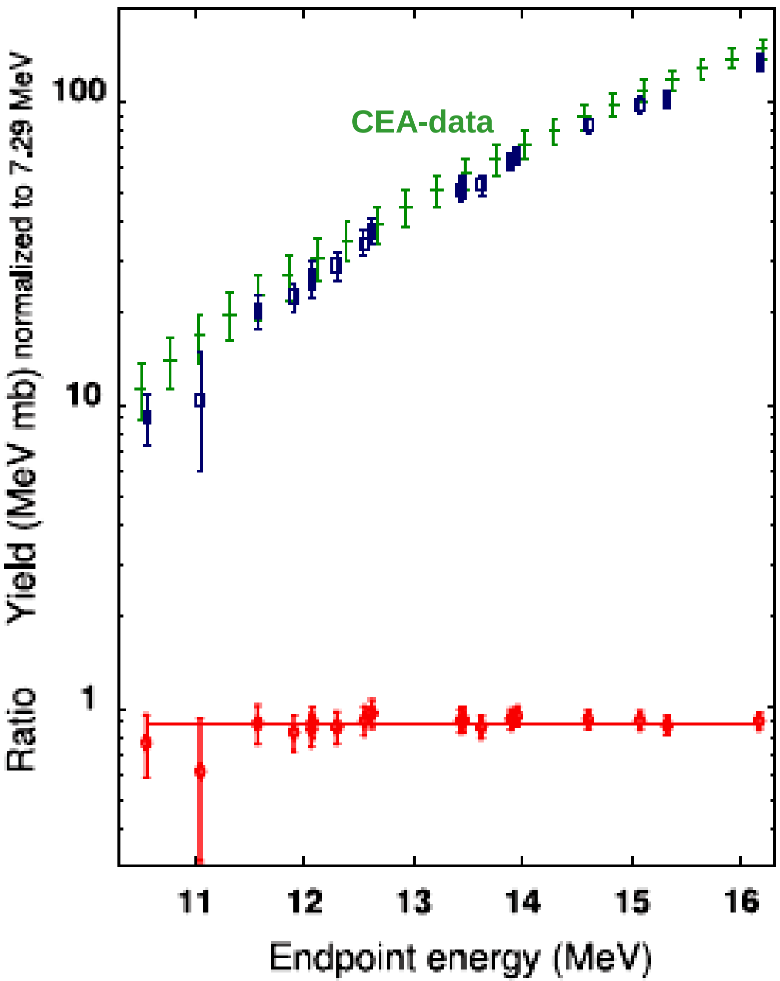
A. Junghans et al., PLB 670 (2008) 200

Y. Birenbaum et al, PRC36(87)1293
A. Veyssière, et al., NPA 199 (73) 45
G.M.Gurevich et al., NPA 273 (76) 326

Simple Lorentzian fits to GDR data may result in too large f_{E1}

because of no deformation induced split – or erroneous normalzation of CEA-data





Rusev et al., PRC 79, 061302 (09);
Pluiko in Capote et al., NDS 110 (2009) 3107 Junghans et al., PLB 670 (08) 200 Beil et al., NP A 227 (74) 427 Erhard et al., PRC81(10)034319

A good global descrption of the GDR shapes is possible *(on absolute scale)*, ***when triaxial nuclei are treated as such*** *(they are not rare)* **=>TLO**.

The global **TLO** ***fit results in a smooth A-dependence of the spreading width and allows to obey the GGT sum rule*** *(no need for pionic effects).*

The resulting **E1** ***strength can thus be considered reliable.***

GDR peak shape does not have an impact on f_{E1} at low E_γ, but it optimizes global fit.

Local fits with 3 resonances would need additional input.

Three questions remain, before this **TLO-f_{E1}** ***is used for radiative processes:***

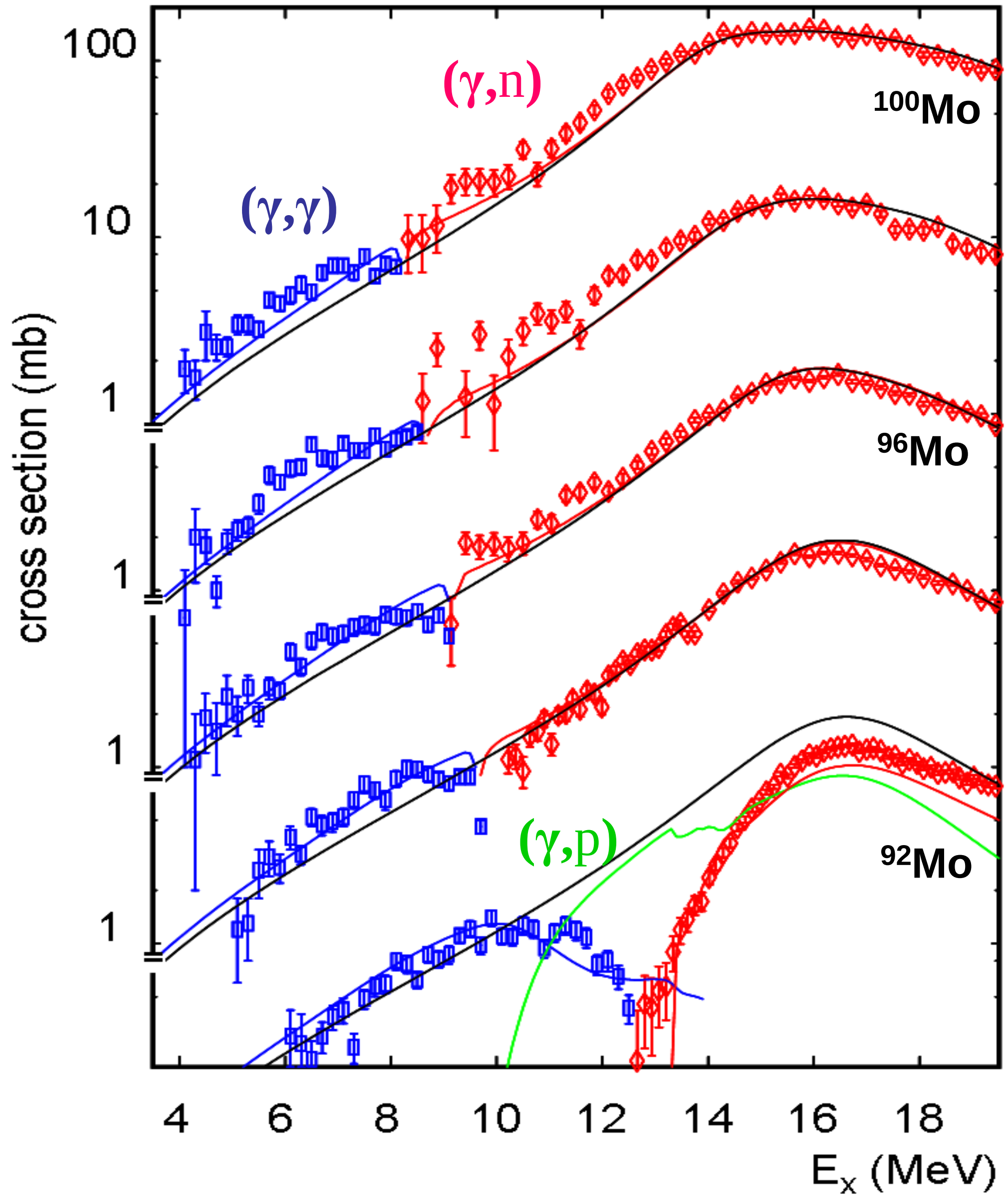
1. ***What role play magnetic dipole transitions*** **(M1)*****?***
2. ***Can it be extrapolated to low energies (2-5 MeV)?***
3. ***Can the effect of f_1 be distinguished from the impact of the level density and its energy dependence?***

***Triple Lorentzian* (TLO)**

– f_{E1} fitted globally to GDR's –

inserted into TALYS

= several exit channels
well described simultaneously



M. Erhard et al., PRC81(10)034319

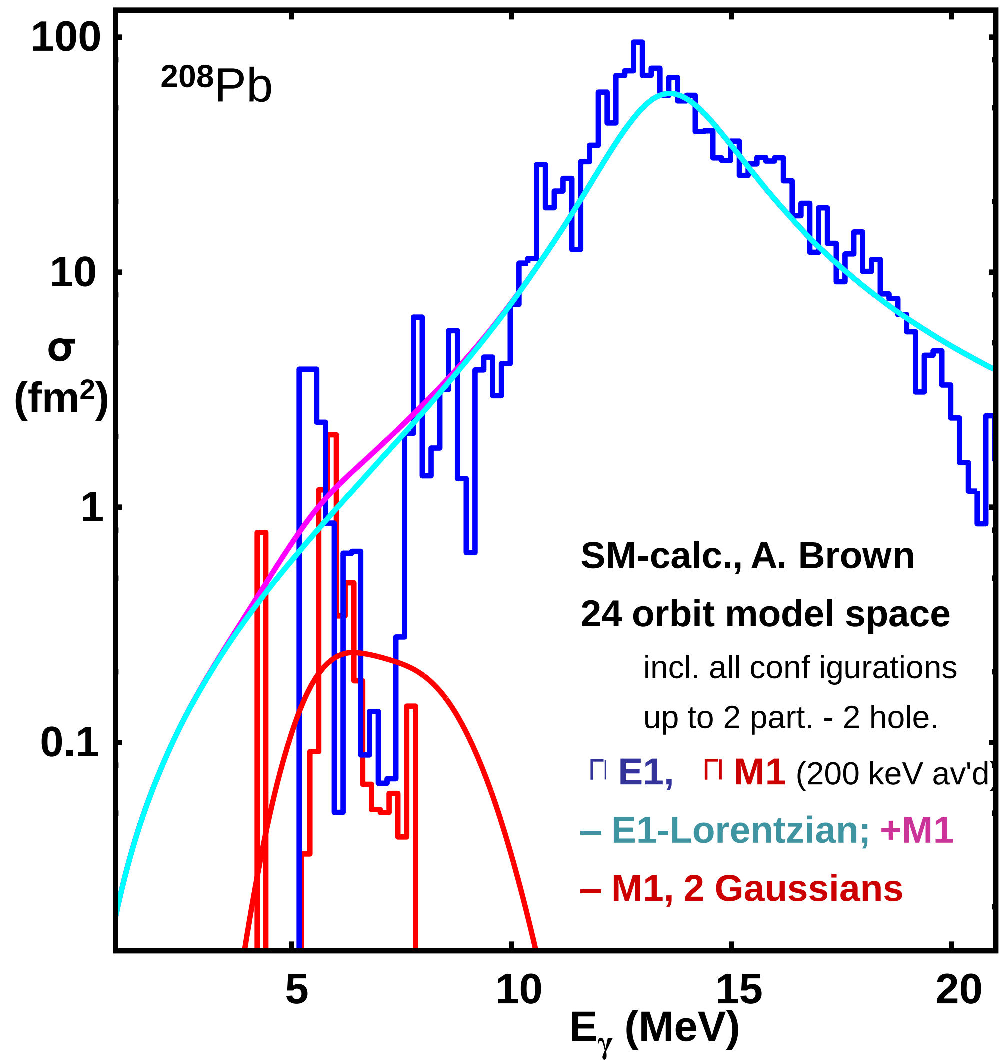
Calculations with TALYS, A.Koning et al. Rusev et al., PRC 79 (09) 061302 A. Junghans et al., PLB 670 (08) 200 H. Beil *et al.*, Nucl. Phys. A **227** (74) 427

E1 *and* **M1** *in the shell model*

For the magic nucleus ^{208}Pb *particle – hole calculations in a shell model basis are feasable. The resulting GDR* (E1) *has a Lorentzian shape.*

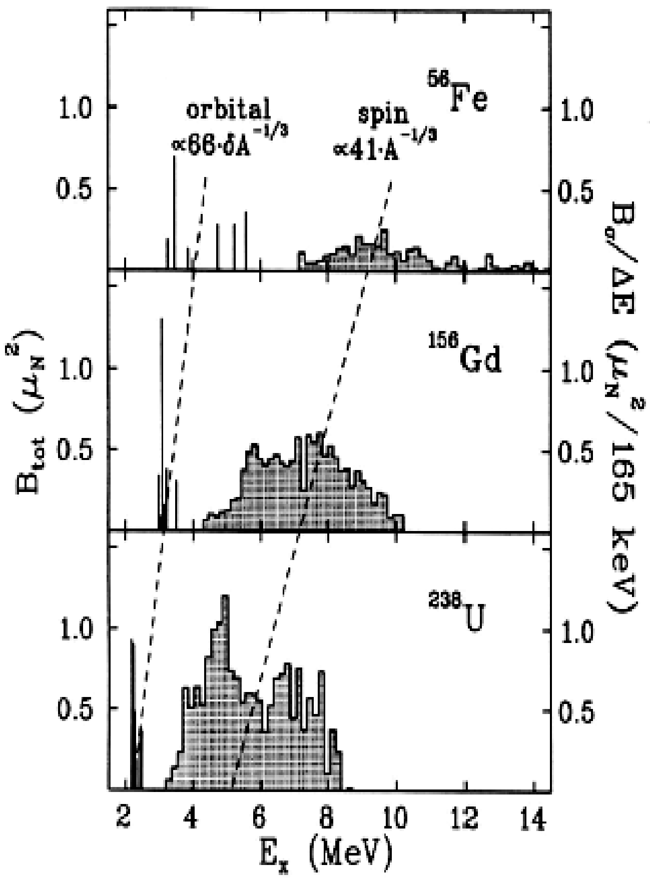
Equivalent calculations of the M1 *strength show a much narrower distribution – more like a Gaussian.*

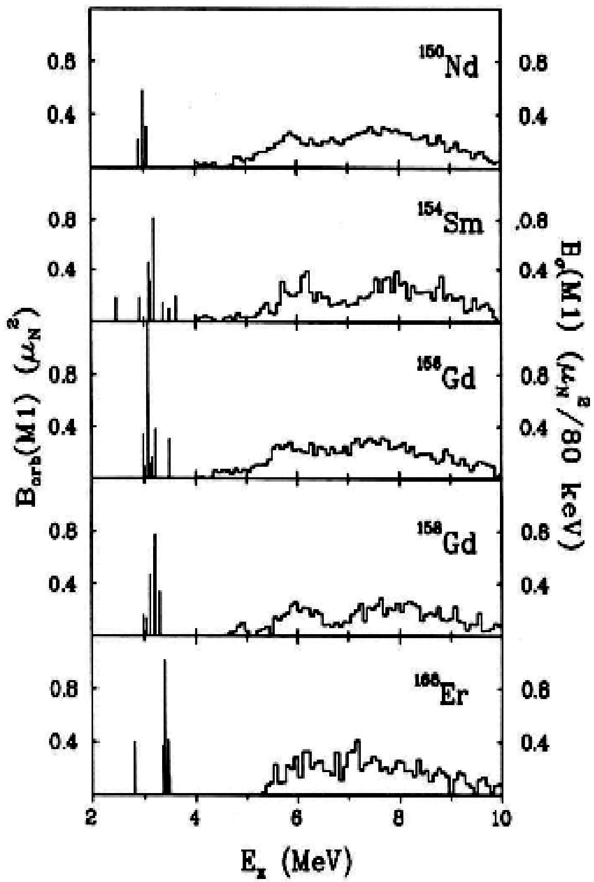
The widespread use of a Lorentzian also for M1 *appears to be justified by analogy only. More* M1 *data are needed.*

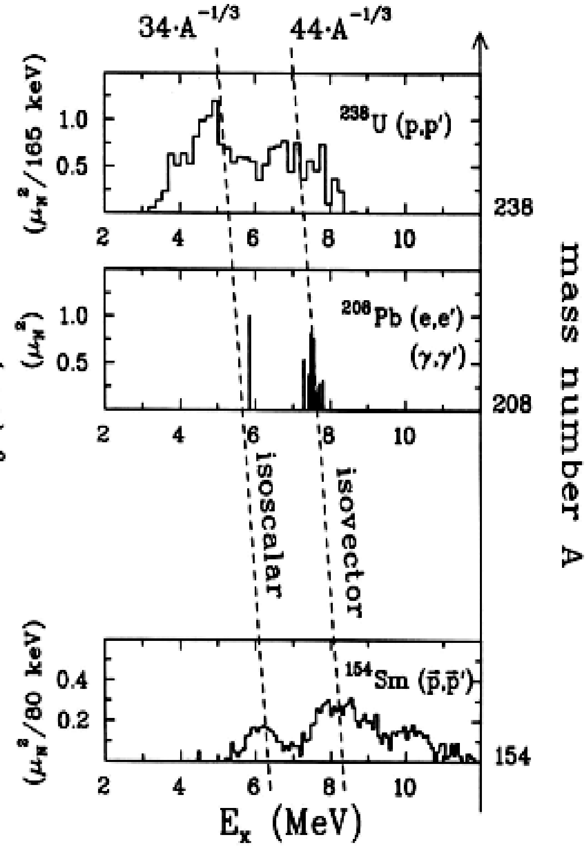


B.A.Brown, PRL 85 (2000) 5300 , cf. R.Schwengner et al., PRC 81, 054315 (2010)

Results for M1 *strength in heavy nuclei newly compiled for Rev. Mod. Phys.*







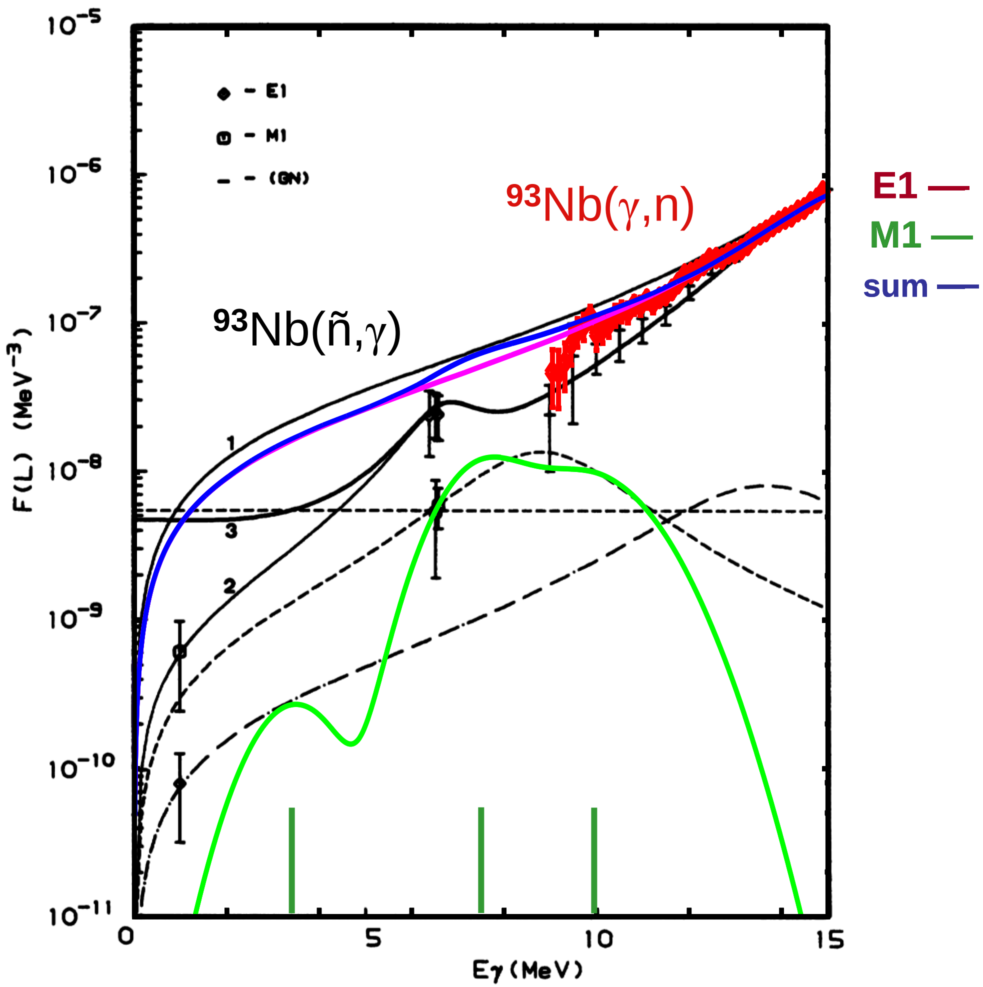
=> In heavy nuclei **M1** *strength has little influence on radiative capture*

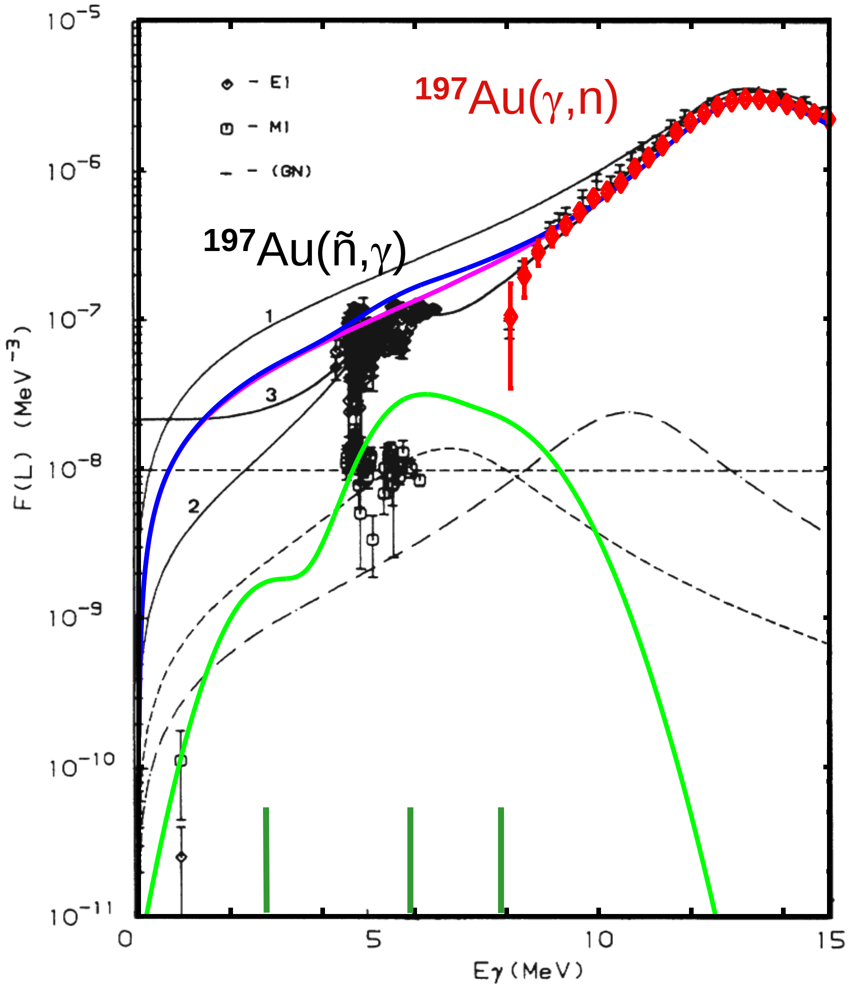
M1 *strength in heavy nuclei well described by 3 Gaussians with a total strength of < 0.2 A μ_N^2.*

A. Richter, Prog. Part. Nucl. Phys. 34 (1995) 261.

K.Heyde et al., arxiv 1004-3429

A sum of 3 Gaussians *(orbital, isoscalar & isovector spin flip)* ***is proposed for*** f_{M1}, ***with their poles and integrals adjusted to experiments specific on magnetic strength; this parametrization is in accord to old polarized neutron data for* M1.**





A.Lepretre et al., NPA 175 (71) 609

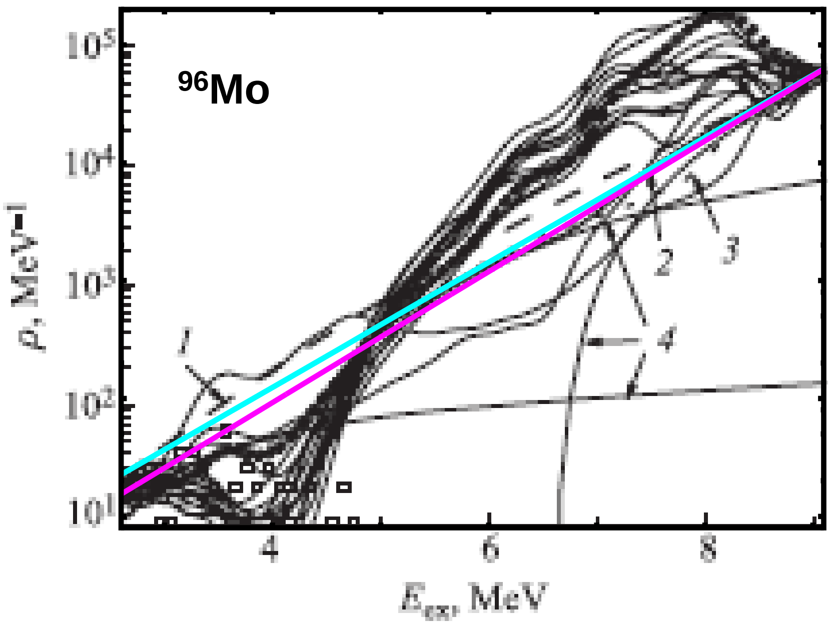
J.Kopecky + M.Uhl, PRC 41 (90) 1941

A. Veyssière et al., NPA 159 (70) 561

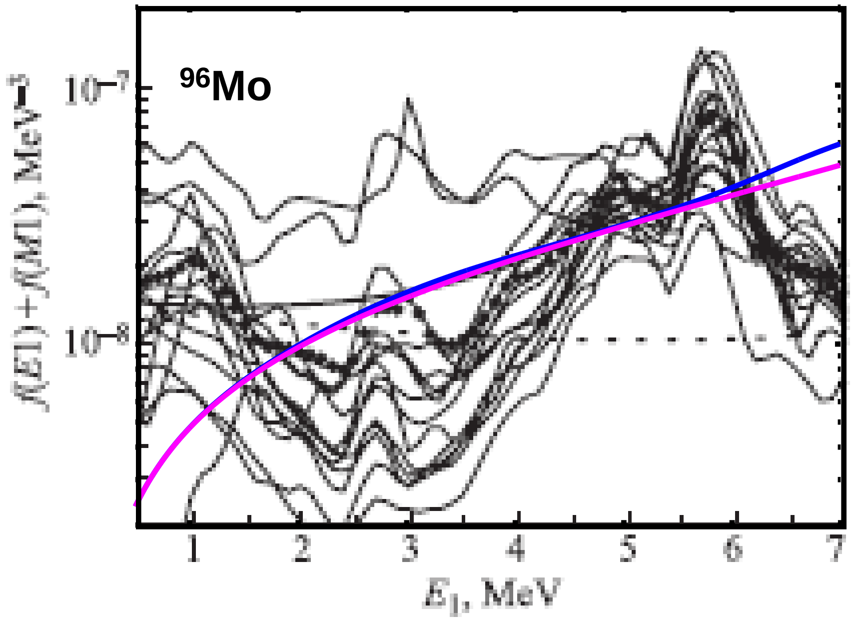
γγ – coincidence data *(two step cascade, TSC)* ***yield information on ρ and f_1 –***

but these two quantities are very strongly anti-correlated!

TLO-dipole strength *(together with CTM)* ***is in reasonable agreement to data***



The thin curves represent the best randomly selected functions of the density of intermediate cascade levels, reproducing Iγγ with the same χ^2 values and are their mean values. Line 2 shows the prediction by Strutinsky's model with the parameter g depending on shell inhomogeneities of one-particle spectrum; line 3 shows the same model for g = const. CTM with T= 783 keV and T= 820 keV using $D(S_n)$ =15 eV.



Thin curves depict the best random functions reproducing Iγγ with the same small χ^2 values and are their mean values.
Solid black curve is the best approximation by model of Sukhovoj et al., dotted curve depicts strength function of KMF model.

"Intensities of the two-step cascades can be reproduced with equal and minimal values of χ^2 by infinite set of different level densities and radiative strength functions".

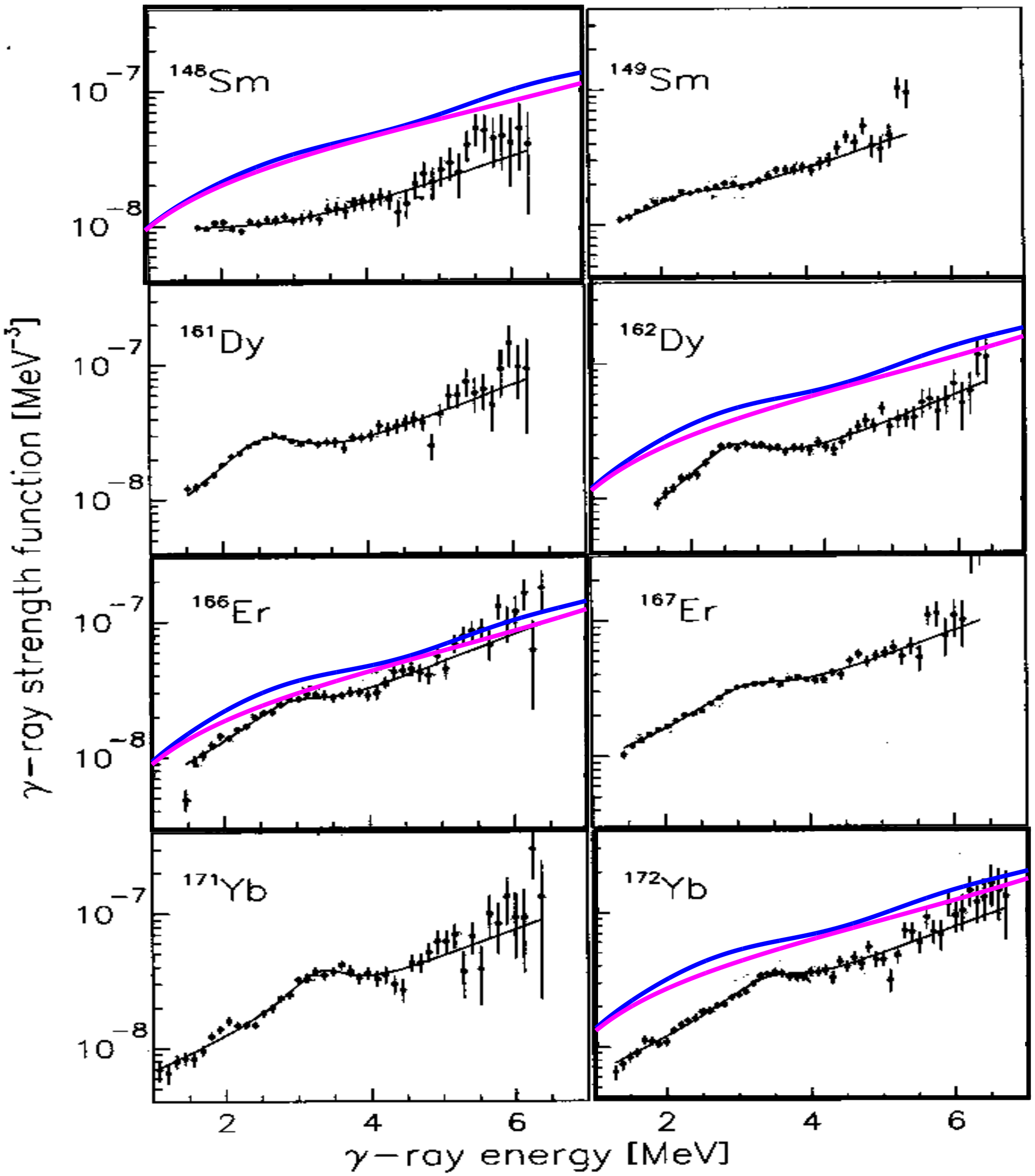
A. M. Sukhovoj, V.A.Khitrov (2008), submitted to Yadernaya Fizika

–-: A. Junghans et al., PLB 670 (2008) 200
–-: id. + M1, K. Heyde et al., RMP (2010)

'Triple' dipole strength is in reasonable agreement to recent JINR-data

for the low energy tail – which determines the radiative capture.

In contrast to ^{96}Mo *no information is given on the correlation between* ρ *and* f_1



β	γ( )
0.21	20
0.33	4
0.35	2
0.34	3

–-: A. Junghans et al., PLB 670 (2008) 200

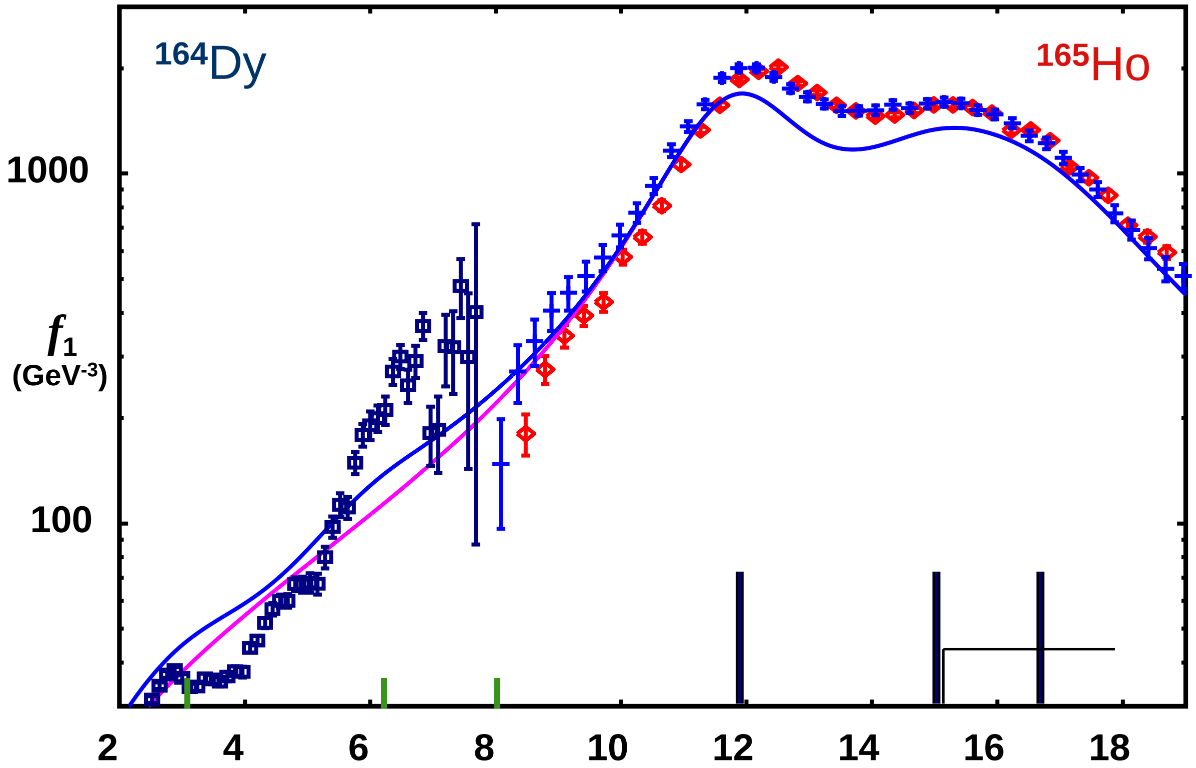
–-: id. + M1, K. Heyde et al., RMP (2010)

data taken from: W. Furman, PSF Praha (07)

Result of triple Lorentzian fits compared to results from 'Oslo method'

Triple electric dipole strength is in average agreement also to new Oslo-data for energies below GDR – radiative capture is determined by f_1 for E_γ< 5 MeV.

Triple magnetic strength may need adjustment – its effect on radiative capture is small.



Oslo data are taken with He-projectiles, which excite nuclei in states with $\ell \approx$ 3-5 $\hbar$

=► thus the extraction of strength for low J depends on the spin dependence of the level density.

H.T. Nyhus et al., PRC 81 (10) 024325;
http://ocl.uio.no/compilation

A. Junghans et al., PLB 670 (08) 200

B.L.Berman et al., PR185 (69) 1576
R.Bergère et al., NPA 121 (68) 463

Average photon width and radiative capture

$$\langle \Gamma_{R\gamma} \rangle = \left\langle \sum_f \Gamma_\gamma (R \rightarrow f) \right\rangle \qquad f_1 E_\gamma^3 = \Gamma_\gamma \rho(E_R)$$

$$= 3 \int_0^{E_R} \frac{\rho(E_f)}{\rho(E_R)} E_\gamma^3 f_1(E_\gamma)\, dE_\gamma \qquad E_R = E_f + E_\gamma$$

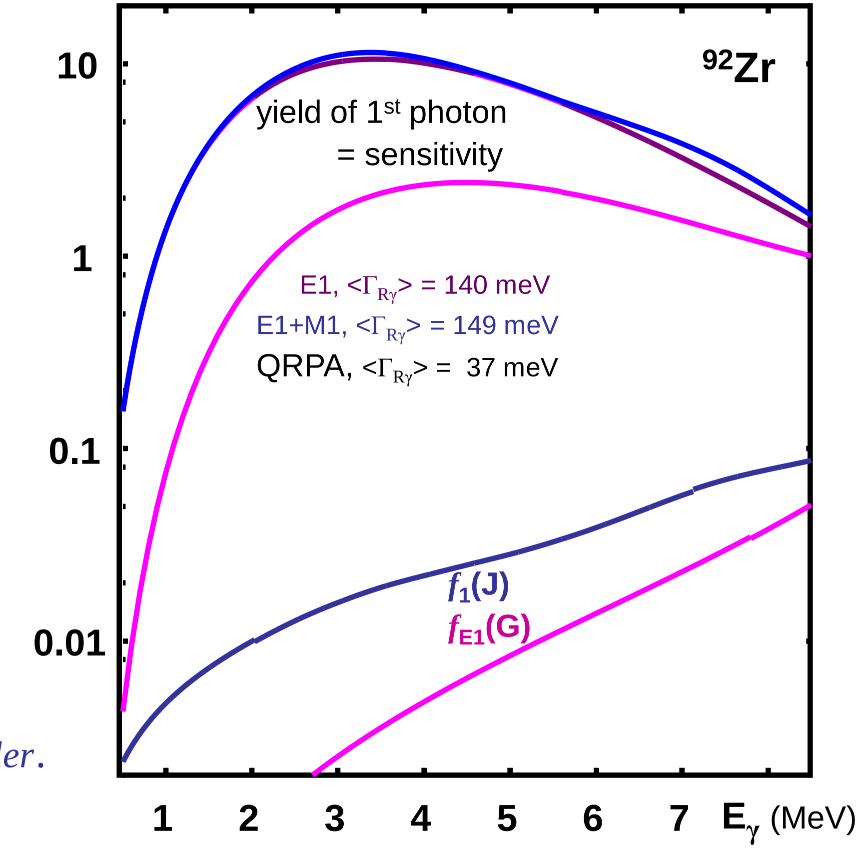
$$= 3 \int_0^{E_R} \frac{E_\gamma^3 f_1(E_\gamma)}{e^{E_\gamma / T}}\, dE_\gamma \qquad E_R = S_n + E_n$$

CTM → *average photon width depends only on* E_γ , f_1 , T *and* not *on* $\rho(S_n)$, *which cancels out* .

The factor **3** *accounts for the decay statistics, it may be smaller*.

$$\langle \sigma_R(n,\gamma) \rangle \approx 2(2\ell + 1)\pi^2 \lambda\!\!\!^{-2}_n \rho(E_R) \langle \Gamma_{R\gamma} \rangle$$

the radiative capture cross section depends also on $\rho(E_R)$.



QRPA *predicts onsiderably smaller* f_1 *and thus also smaller radiative capture*

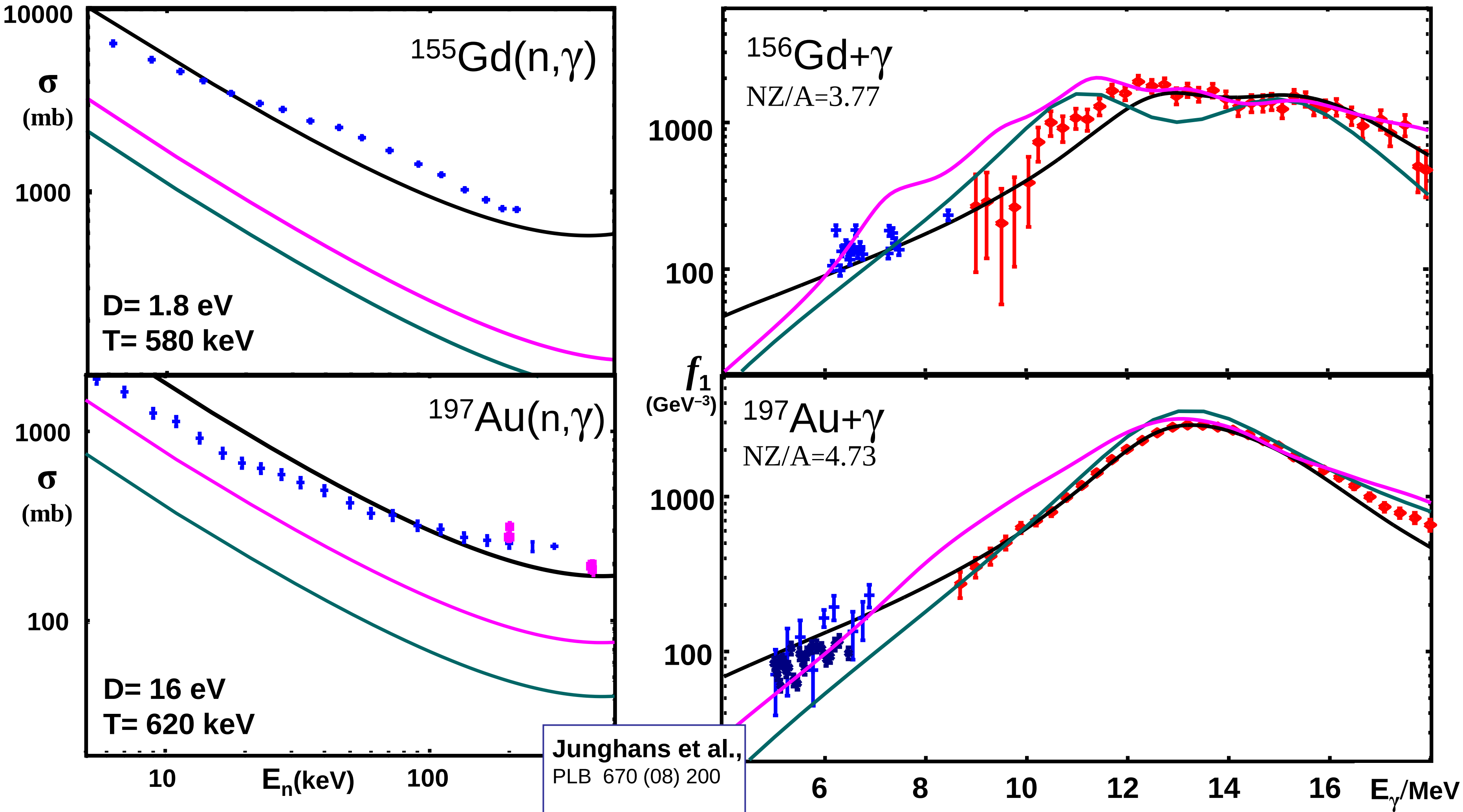
CTM *is good choice for* ρ, *as sensitivity on* E_γ *peaks at* ≈ *4 MeV; it is taken as valid up to* S_n, *even if* $E_M < S_n$.

J: A.Junghans et al., PLB 670 (2008) 200

G: S. Goriely et al., NPA 739 (2004) 331

TLO *gives good description of both: photon absorption and radiative capture*

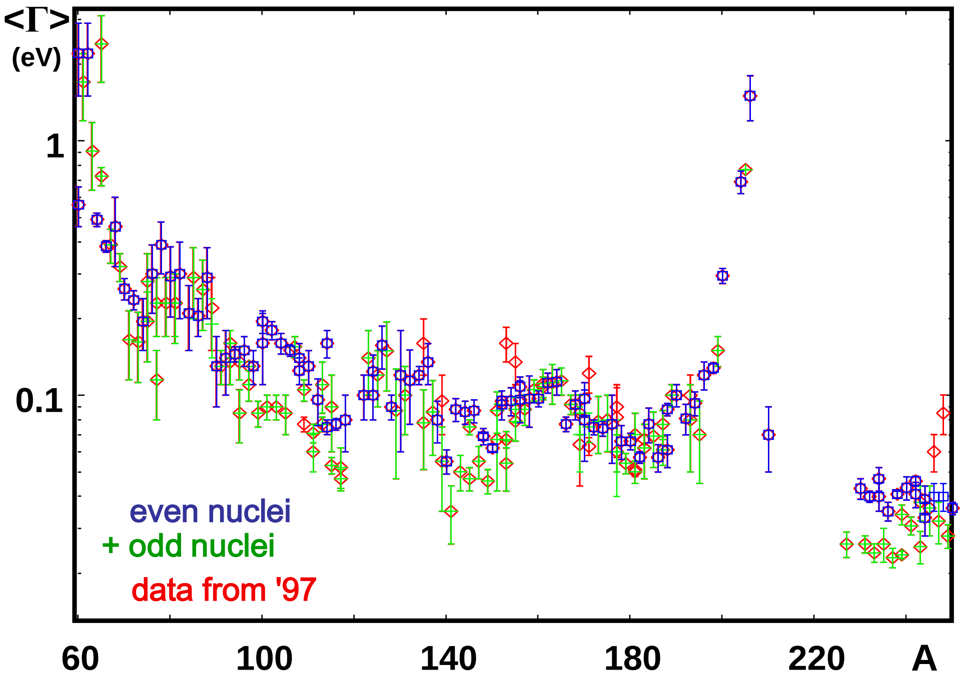
EGLO fails – it starts from 1 or 2 Lorentzians (i.e.large Γ) and reduces low energy strength by setting $\Gamma \sim E_\gamma^2$

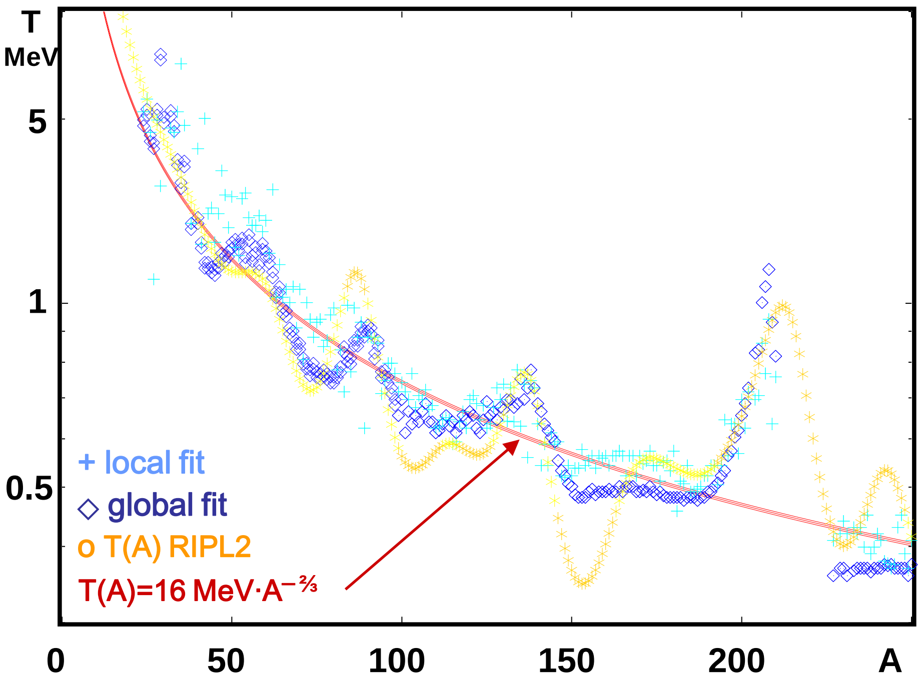


N.Yamamuro et al., NST 20(1983)797
A.N.Davletshin et al., AE 65 (1988) 343
K.Wisshak et al., PRC 52 (1995) 2762

A. Veyssiere et al., Nucl. Phys. A159 (1970) 561
G.M. Gurevich et al., Nucl. Phys. A 338 (1980) 97
S.F. Mughabghab, C.L. Dunford, Phys. Lett. B 487 (2000) 155

Average radiative width ‹Γ› *and temperature* T





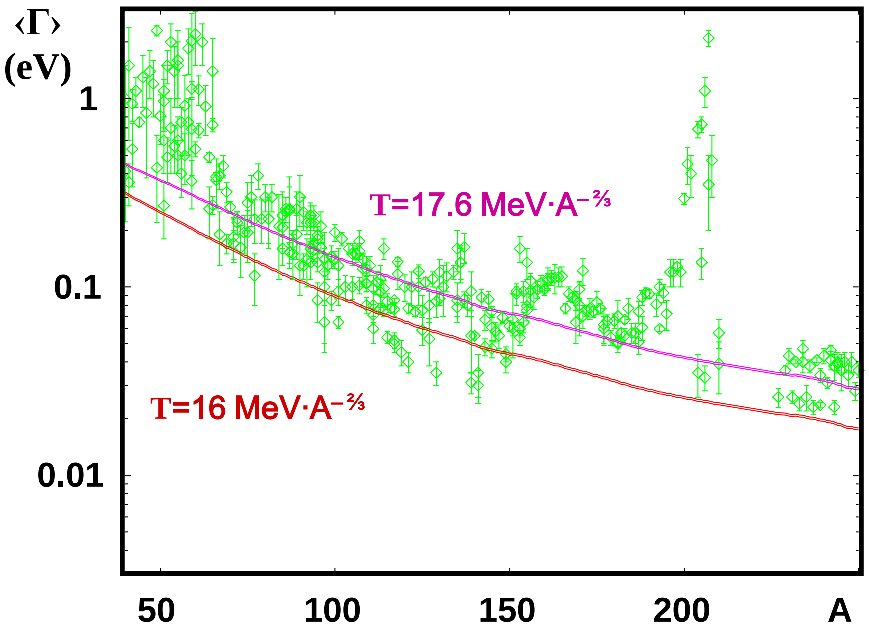
average radiative width ‹Γ› *and energy dependence of level density* T *show surprisingly similar trends in their dependence on mass number* A;
a slowly varying f_1 *is favoured.*

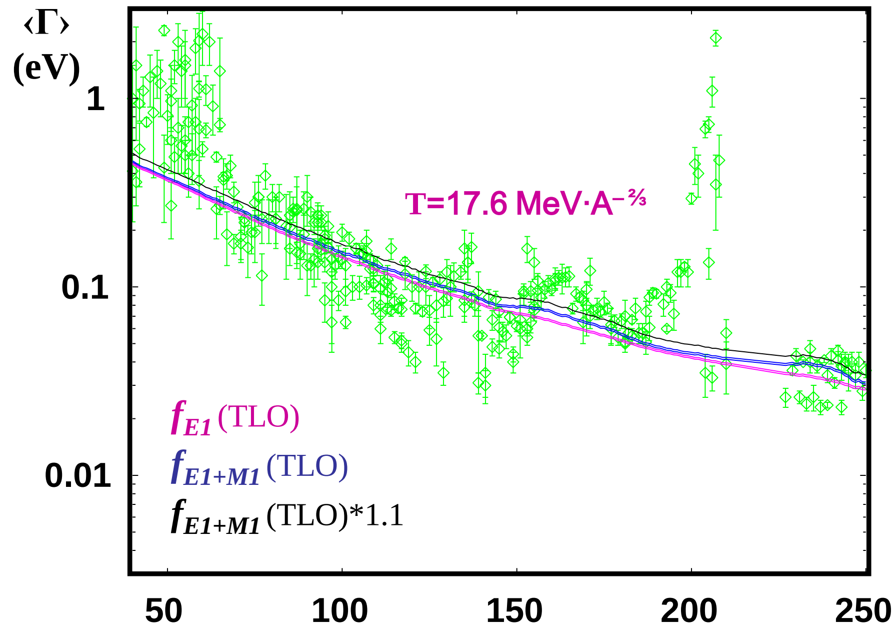
A.Koning *et al.*, Nucl. Phys. A **810** (08) 13

T.Belgya, RIPL2 Handbook (2006) IAEA-TECDOC-1506

A. Ignatyuk, IAEA-TECDOC-1506, RIPL-2

Newly compiled (RIPL-3) *average radiative widths* ⟨Γ⟩ – *compared to prediction of global* TLO-*fit for* f_1 *combined to* T(A) ~$A^{-2/3}$



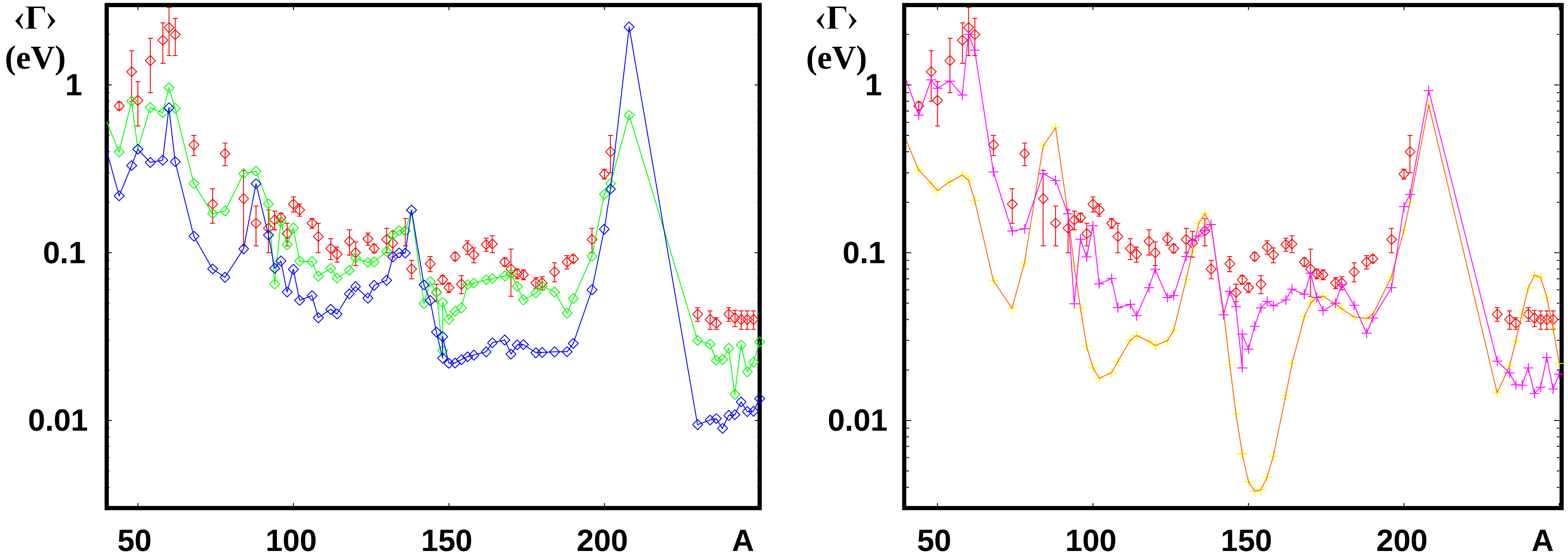


Average radiative widths ⟨Γ⟩ *in heavy nuclei are approximately reproduced in trend and absolute size; local effects like shell closure etc. are not and the influence of M1 is marginal.*

An increase of 10% in T(A) *rises* ⟨Γ⟩ *by 70% – as compared to 10% for 10% change in* f_1 .

A. Ignatyuk in RIPL-3 (09), § 3 Resonances

Average radiative widths ⟨Γ⟩ *as measured in even-even nuclei*
compared to prediction of global TLO *fit for f_1 combined to various* T(A)



TLO *and the local fits for* T *reproduce the data much better than the global* T(A)

Egidy & Bucurescu, PRC80 (09) 054310 local
Koning et al., NPA 810 (08) 13 global

A. Ignatyuk in RIPL-3 (09), § 3 Resonances

Hilaire in RIPL-3 (08) local fit to RIPL-2 resonance data
Belgya, RIPL-2 Handbook (06) IAEA-TECDOC-1506

Conclusions

The E1 strength $\boldsymbol{f_{E1}}$ *as controlled by the isovector giant dipole resonance* ***GDR*** *has at* $E_\gamma \ll E_{GDR}$ *a value proportional to* (1) *the spreading width* Γ_{GDR} *and*

(2) *the ratio to the dipole sum rule.*

To extract both from GDR data the nuclear deformation has to be considered:

The deviation from axial symmetry has an important effect, neglected up to now.

Recent nuclear structure investigations show that triaxiality is

(1) *observed in very many nuclei and*

(2) *anti-correlated to the dynamic quadrupole moment* q_2 *.*

Any use of a Lorentzian for $\boldsymbol{f_{E1}}$ *should be in accord to that; thus*

GDR data do <u>not</u> indicate (1) *a strong deviation from the GMT sum rule (with* m_π*=0)*

(2) *a strong variation of* Γ_{GDR} *with A and Z.*

Radiative neutron capture <u>strongly</u> depends on ***T(E)*** *and <u>less</u> on* $\boldsymbol{f_1}$ – on both *for* $\boldsymbol{E_\gamma \approx 4}$ ***MeV***.

Combined to local ***CTM*** *fits, predictions with the triple Lorentzian* ***TLO*** *compare well to data –*

in dependence of A and on an absolute scale.

M1 *strengh does <u>not</u> have Lorentzian shape – and it has a minor effect on radiative capture .*

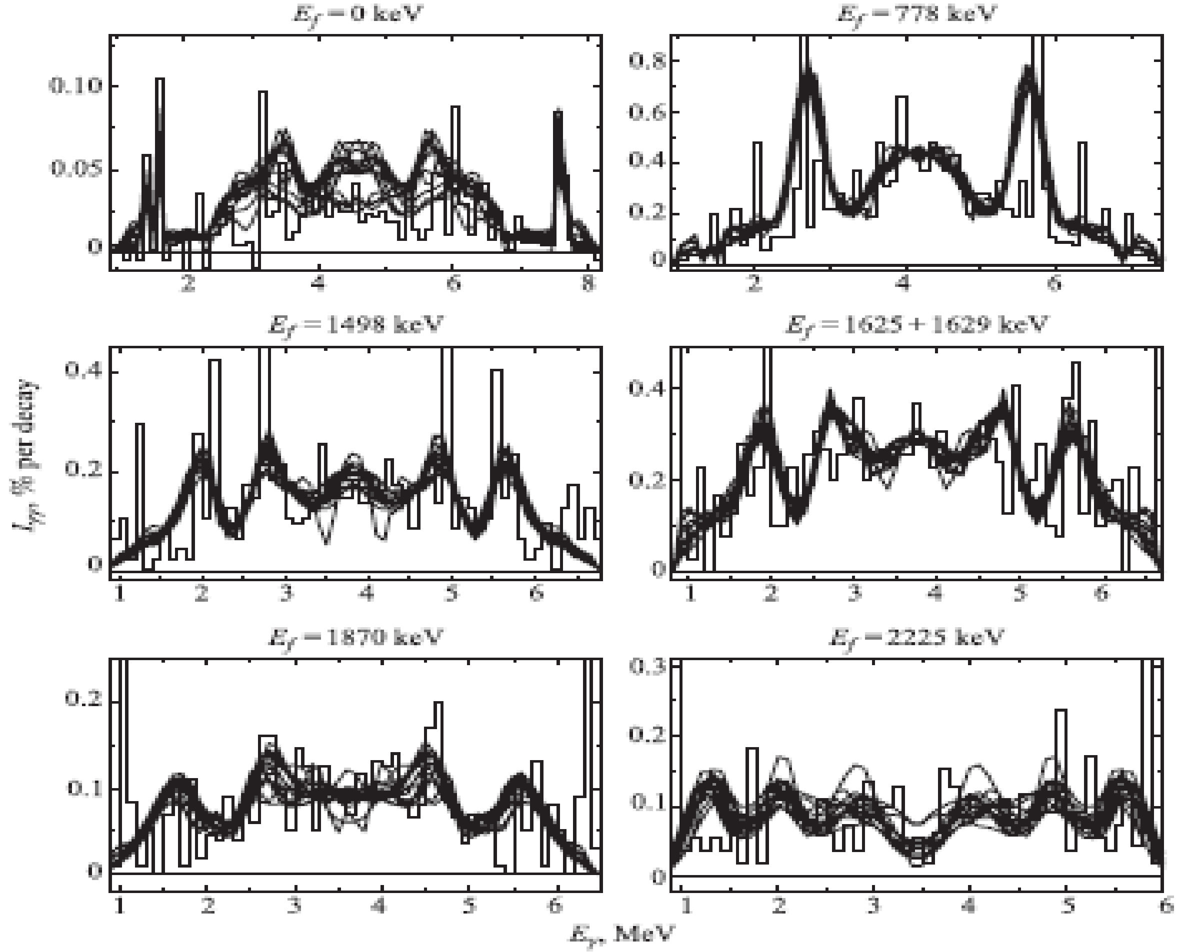


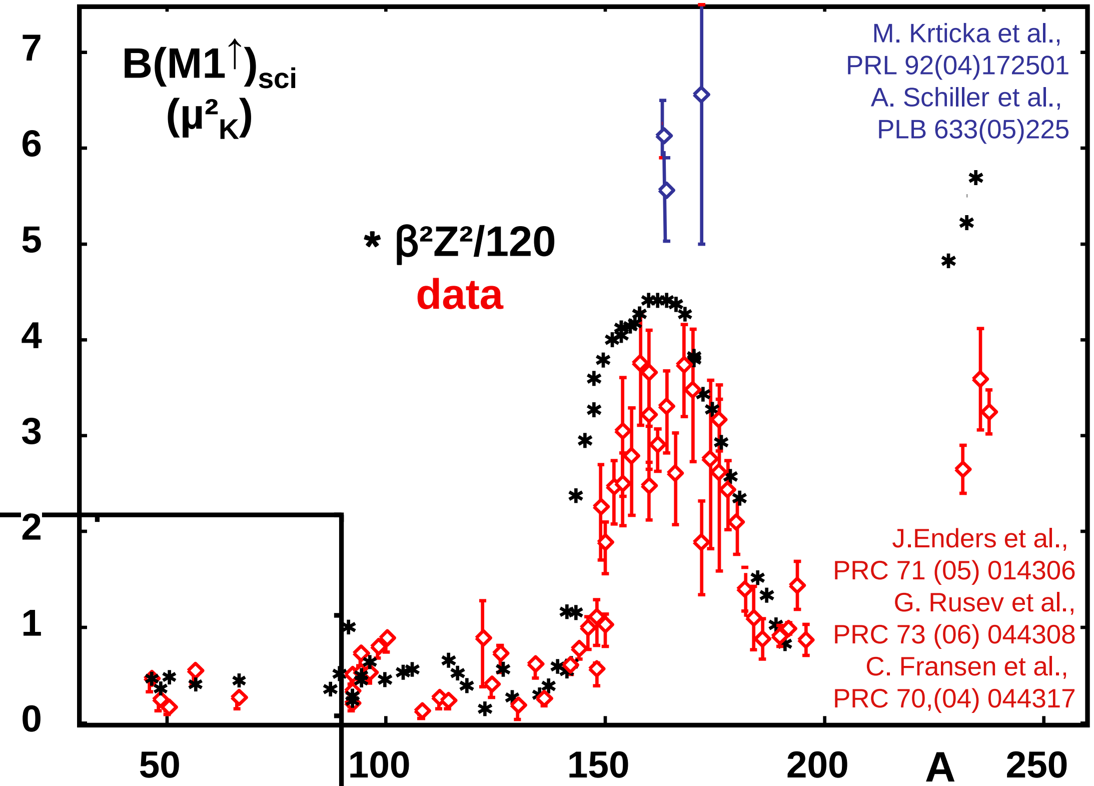
Fig. 1. Histogram — experimental intensity of two-step cascades for the levels E_f (summed over the intervals of 100 keV). Lines — variants of the calculation with random functions of level density and radiative strength functions presented in Figs. 2 and 3

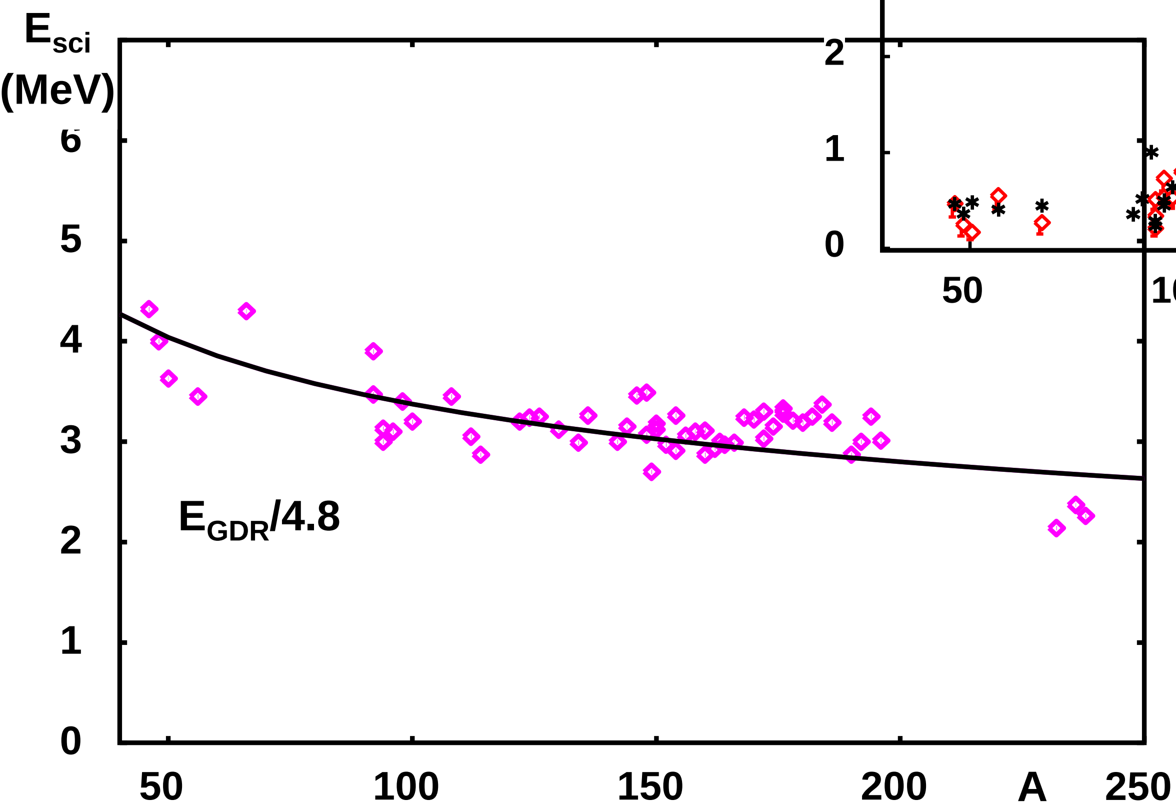
A. M. Sukhovoj, V.A.Khitrov (2008), submitted to Yadernaya Fizika

Orbital* M1 *strength: *"scissors mode"*

Photon scattering lines ⇨ ΣB(M1)

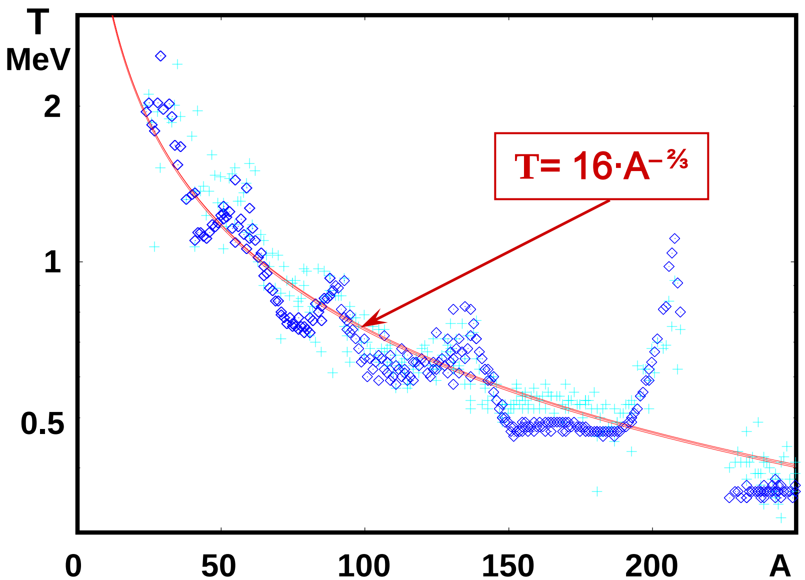
energy of scissors mode is approximately proportional to E_{GDR}

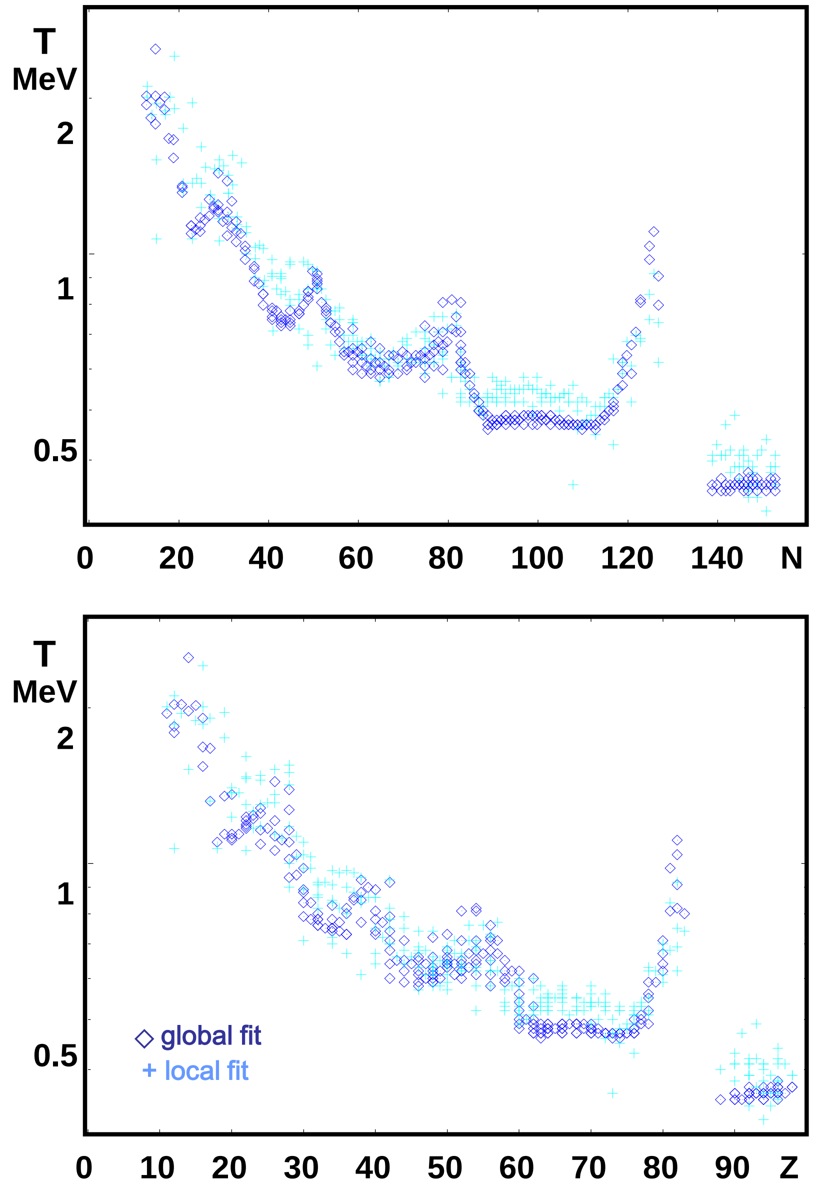




a compromise was searched for between B(M1) *data from elastic scattering γ-lines and data which also contain quasi-continuum*

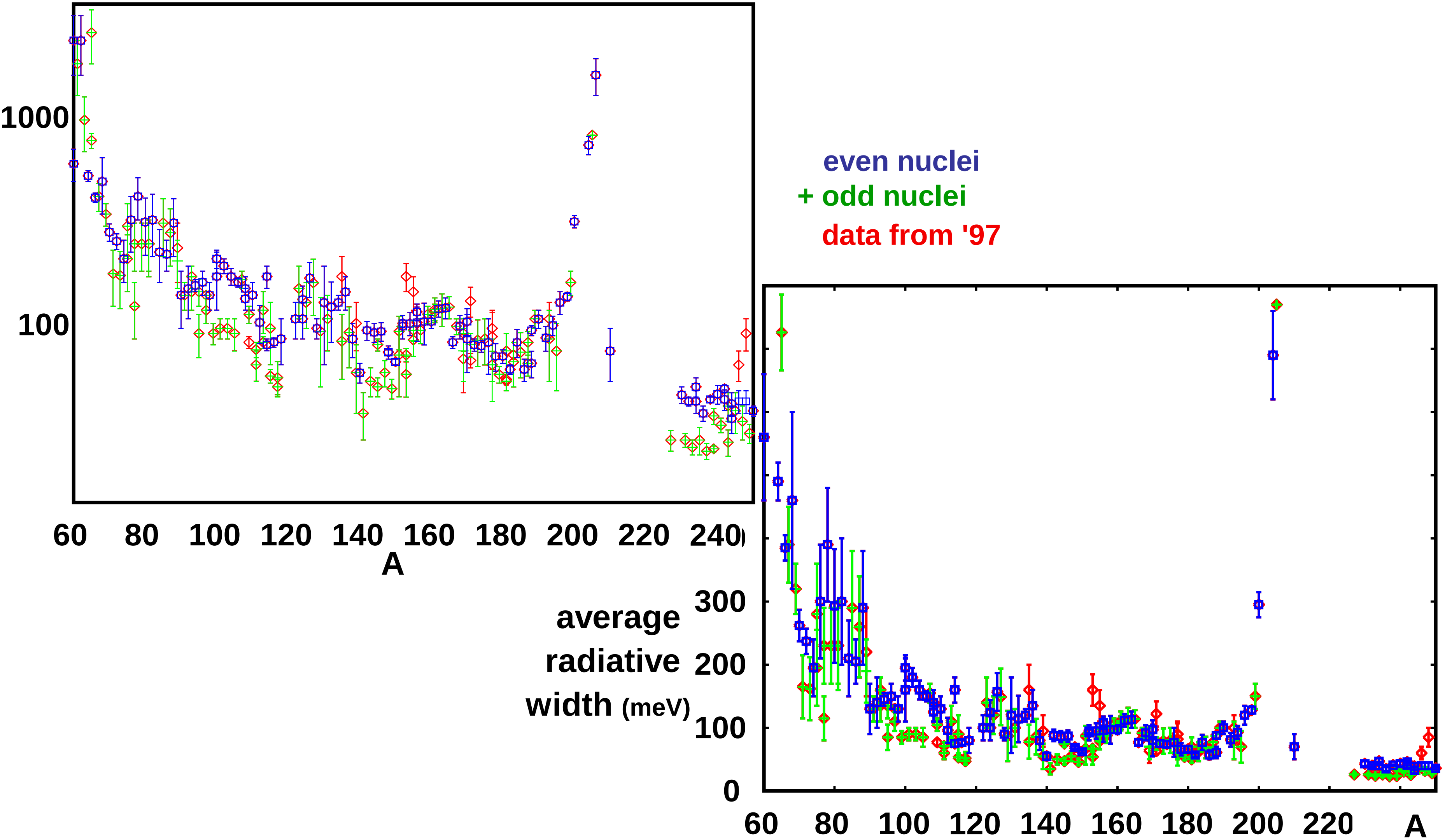
T depends on $A^{-2/3}$ and on shell structure





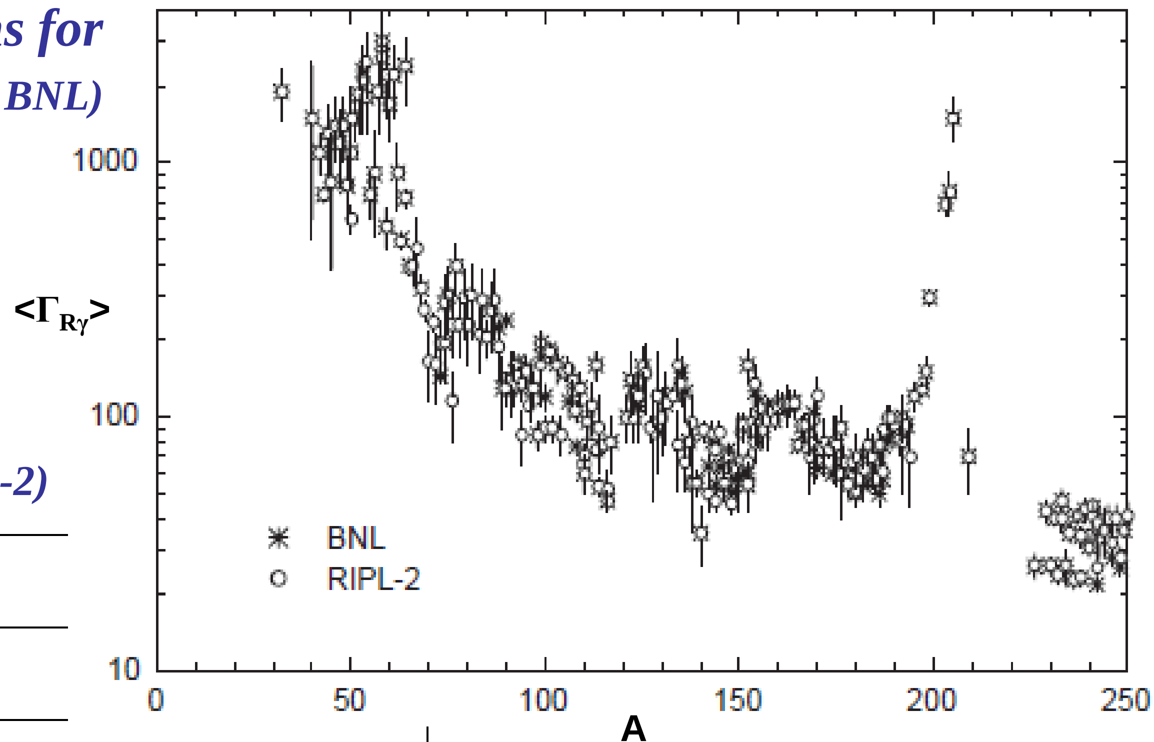
to test dipole strength
for different A, Z and N
the average photon width is
calculated from globally averaged T

A.Koning *et al.*, Nucl. Phys. A **810** (08) 13



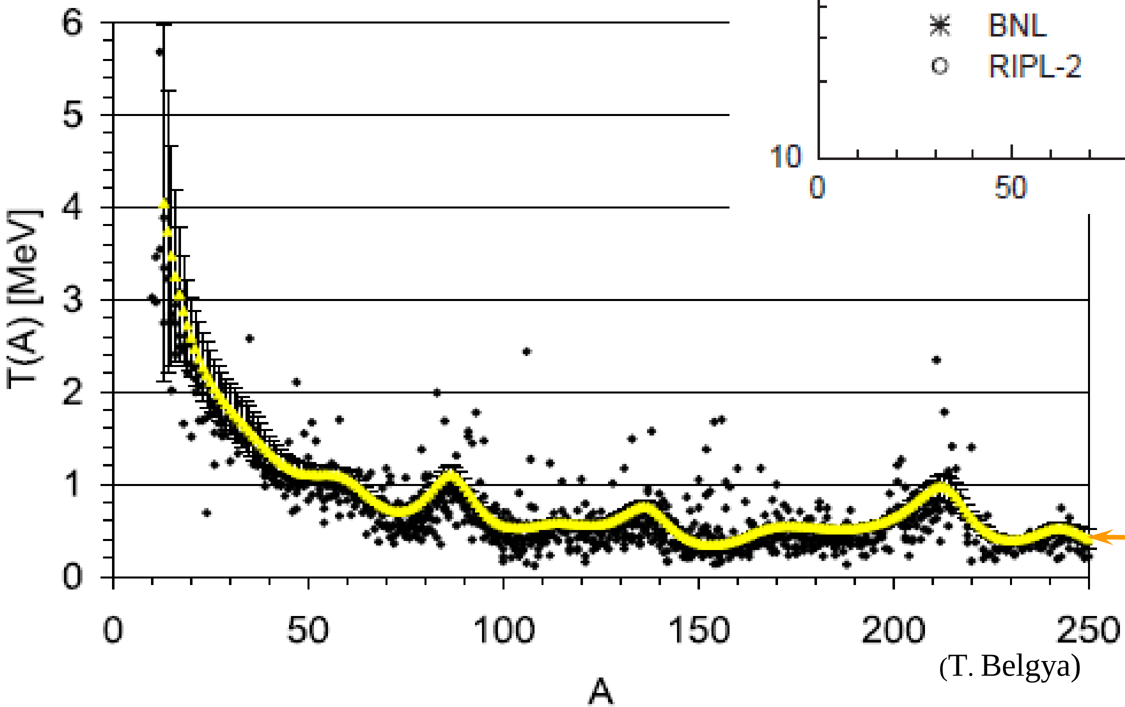
A. Ignatyuk, IAEA-TECDOC-1506, RIPL-2

average radiative widths for s-wave resonances (RIPL-2, BNL)



(A. Ignatyuk)

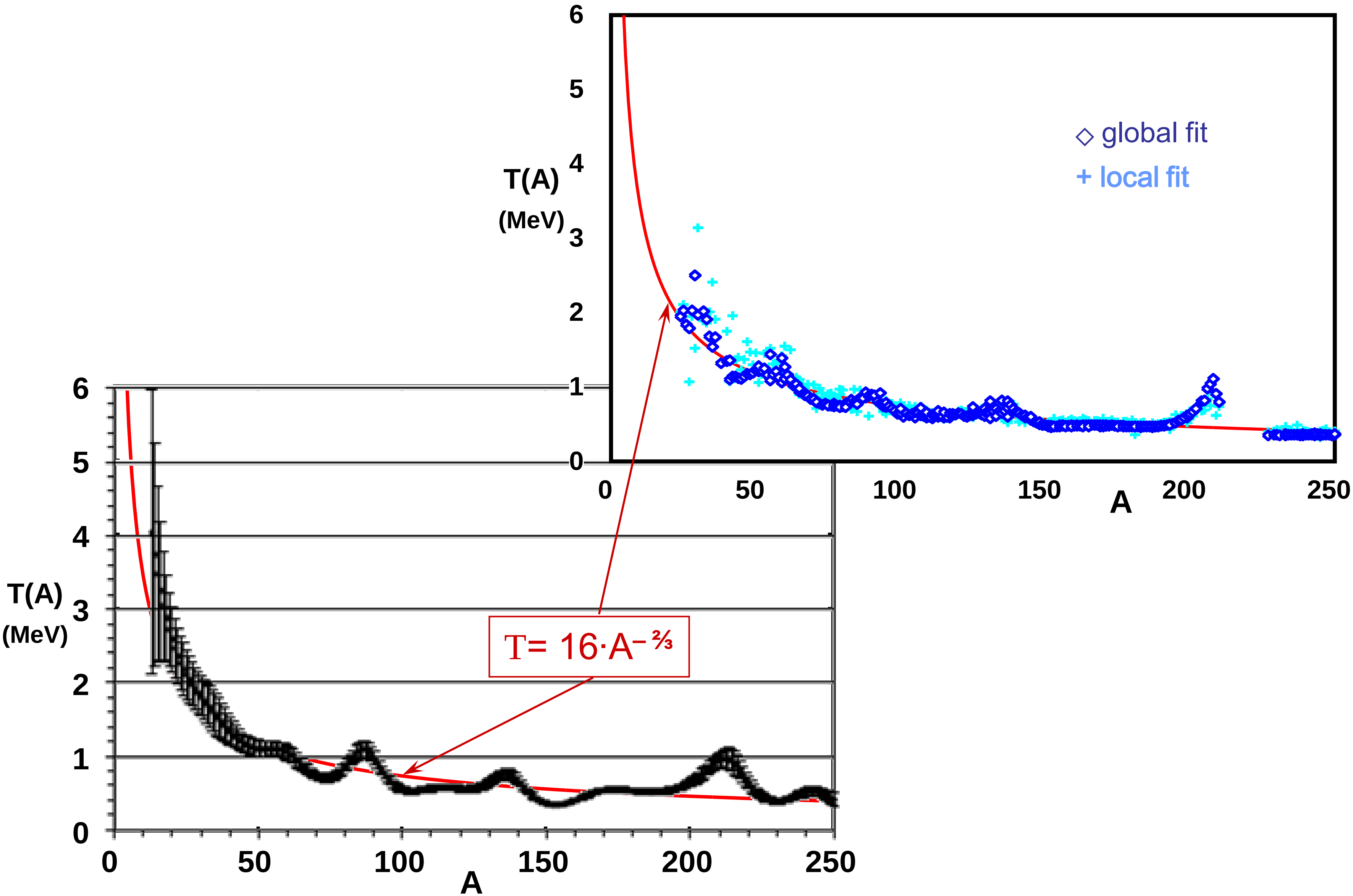
temperature values from 2 different methods (RIPL-2)



(T. Belgya)

global fit T(A) (RIPL-2)

IAEA-TECDOC-1506 , RIPL-2, Library-2

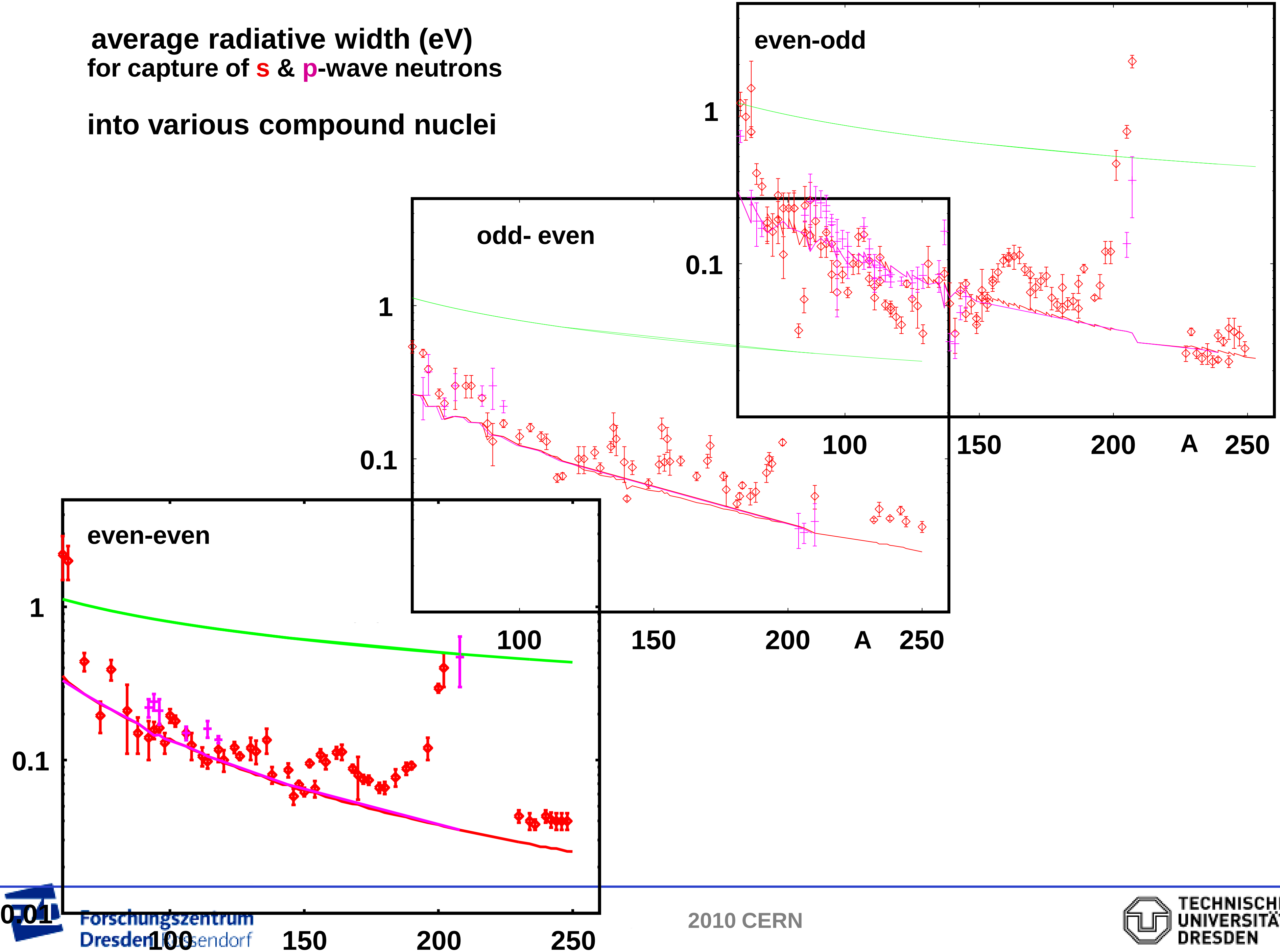


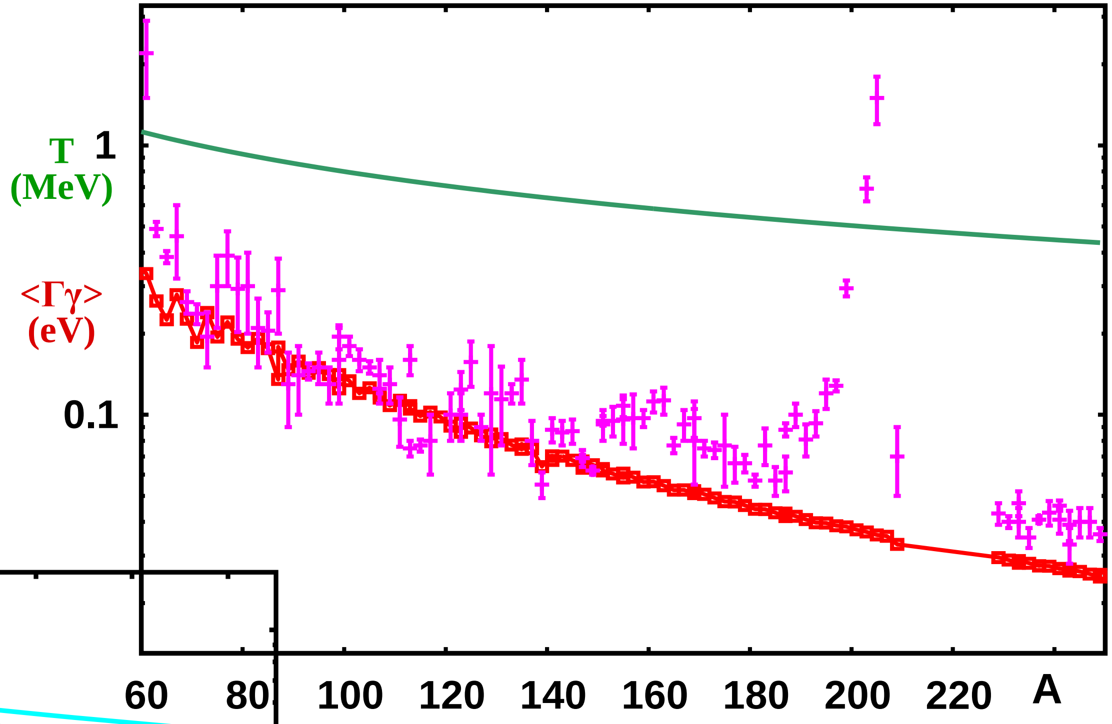
T. Belgya, IAEA-TECDOC-1506 , RIPL-2,

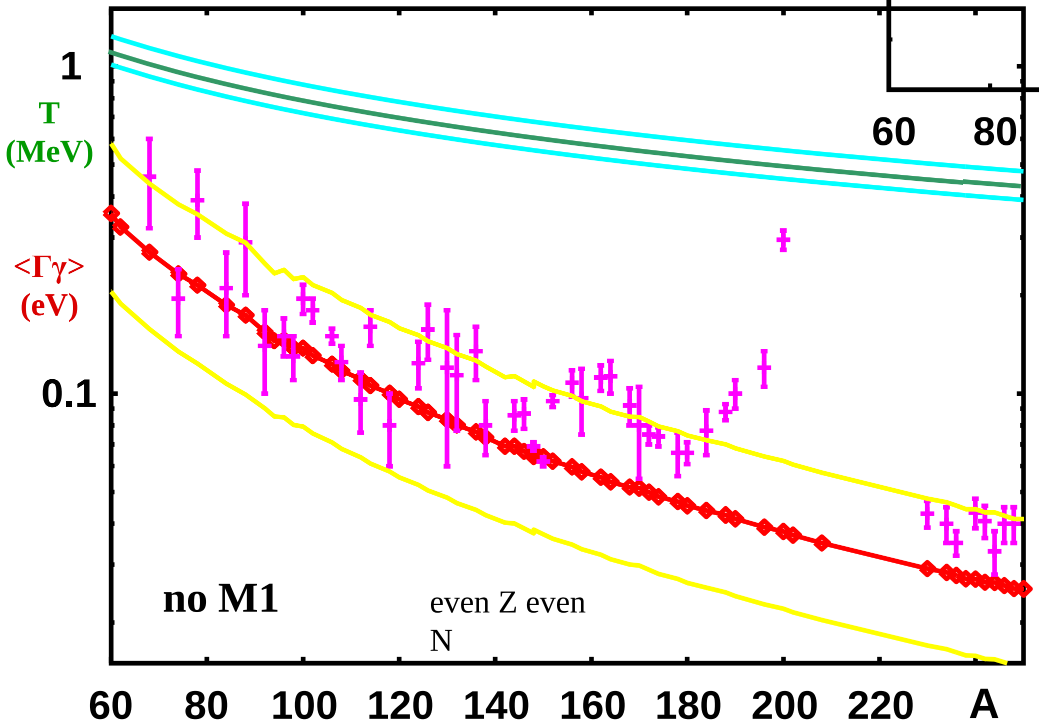
A.Koning *et al.*, Nucl. Phys. A **810** (08) 13

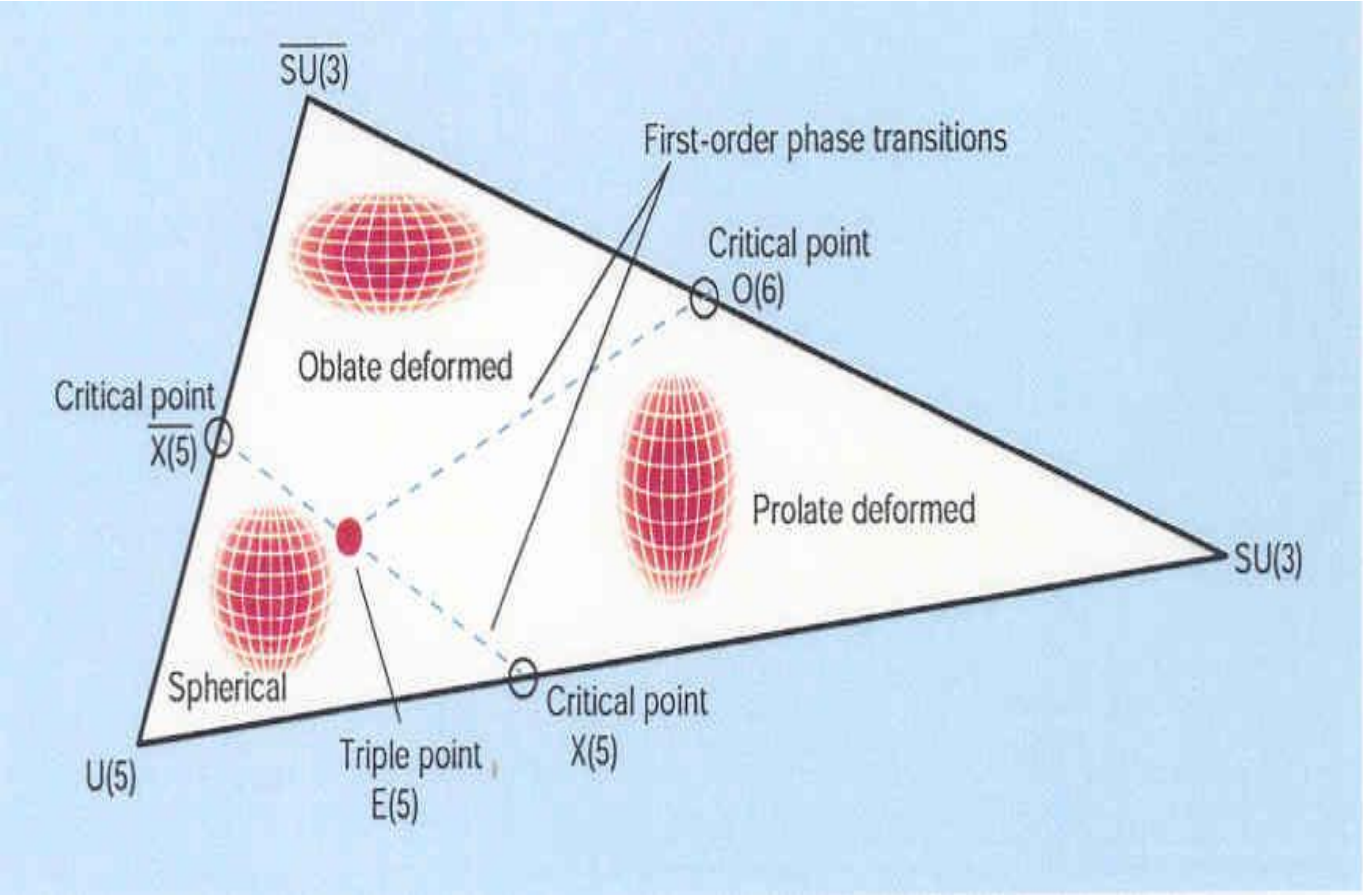
average radiative width (eV)
for capture of s & p-wave neutrons

into various compound nuclei

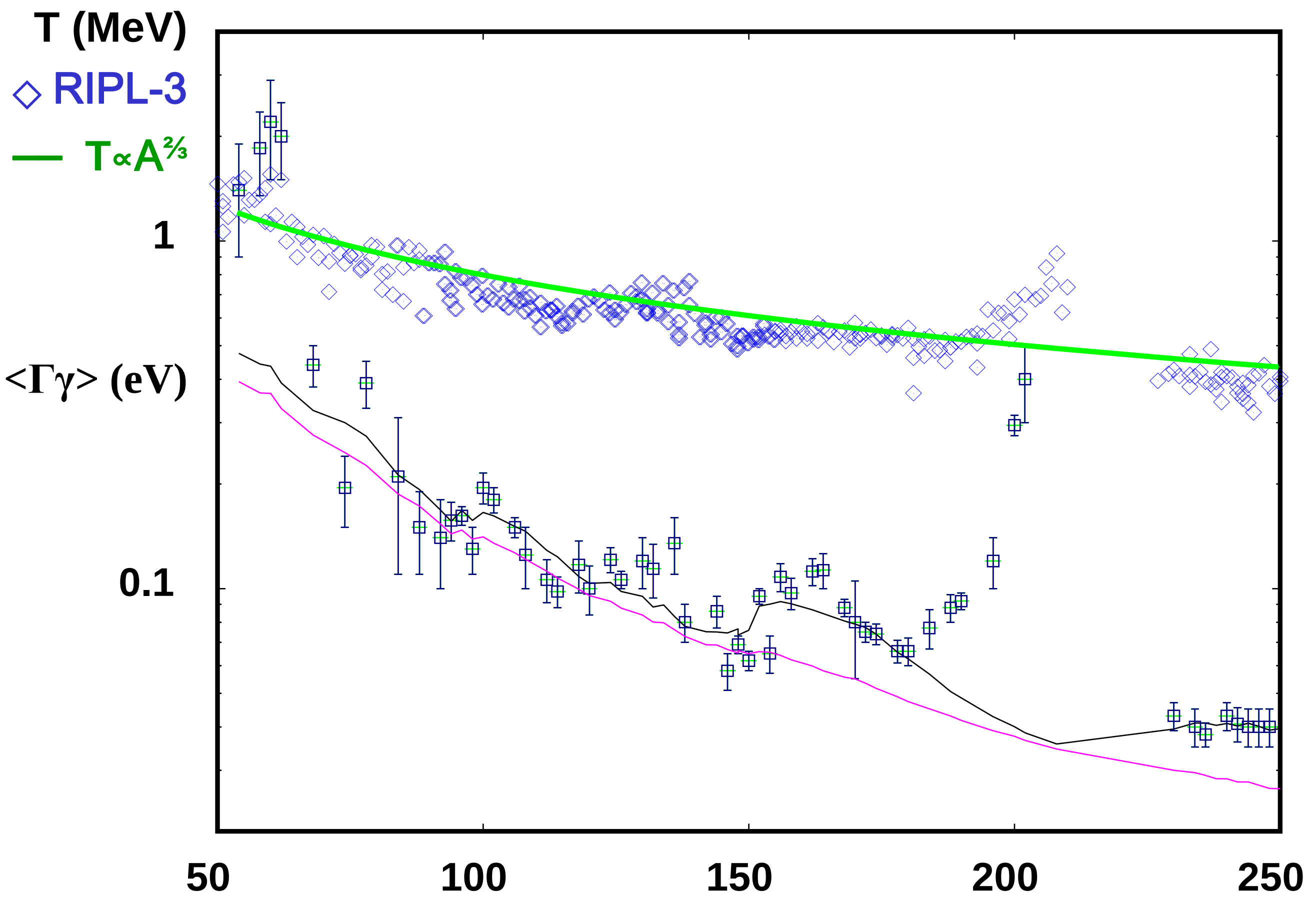


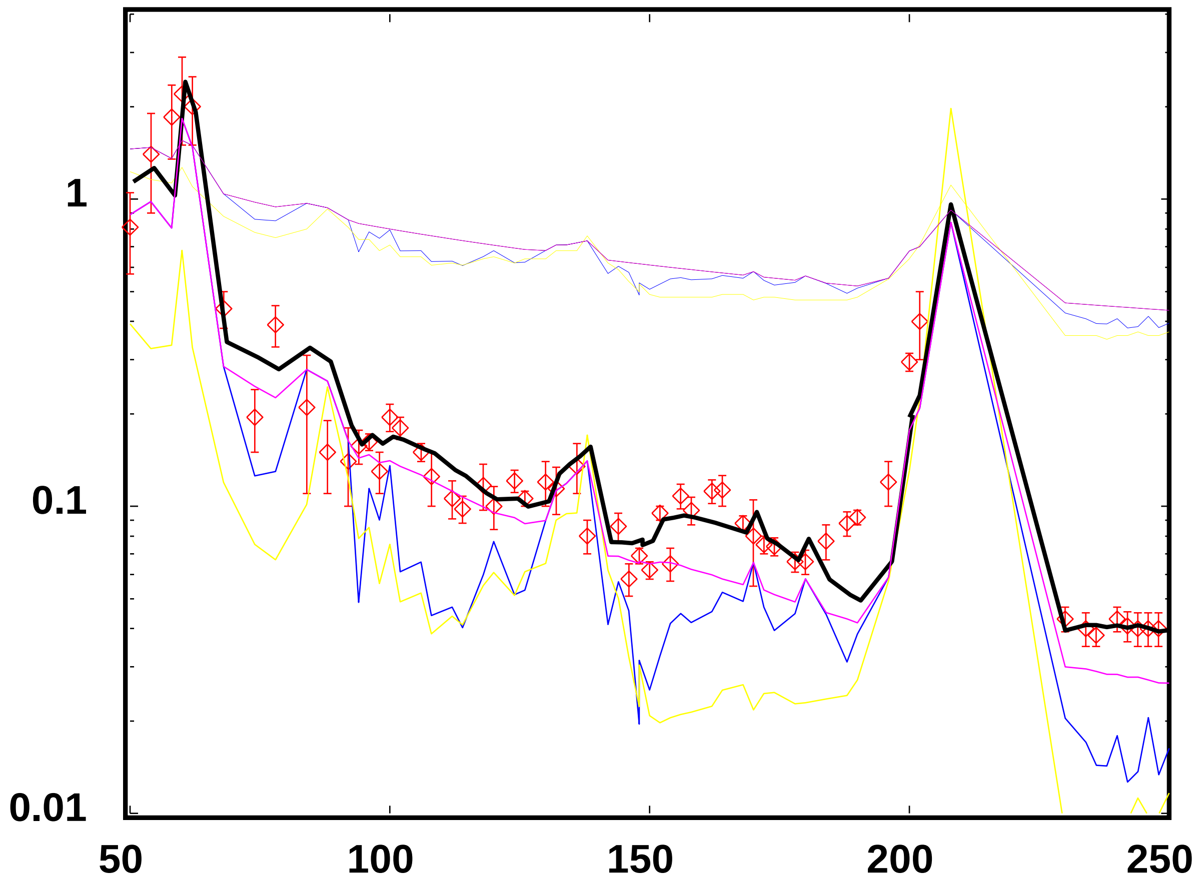

T
(MeV)
1
<Γγ>
(eV)
0.1
60
80
100
120
140
160
180
200
220
A

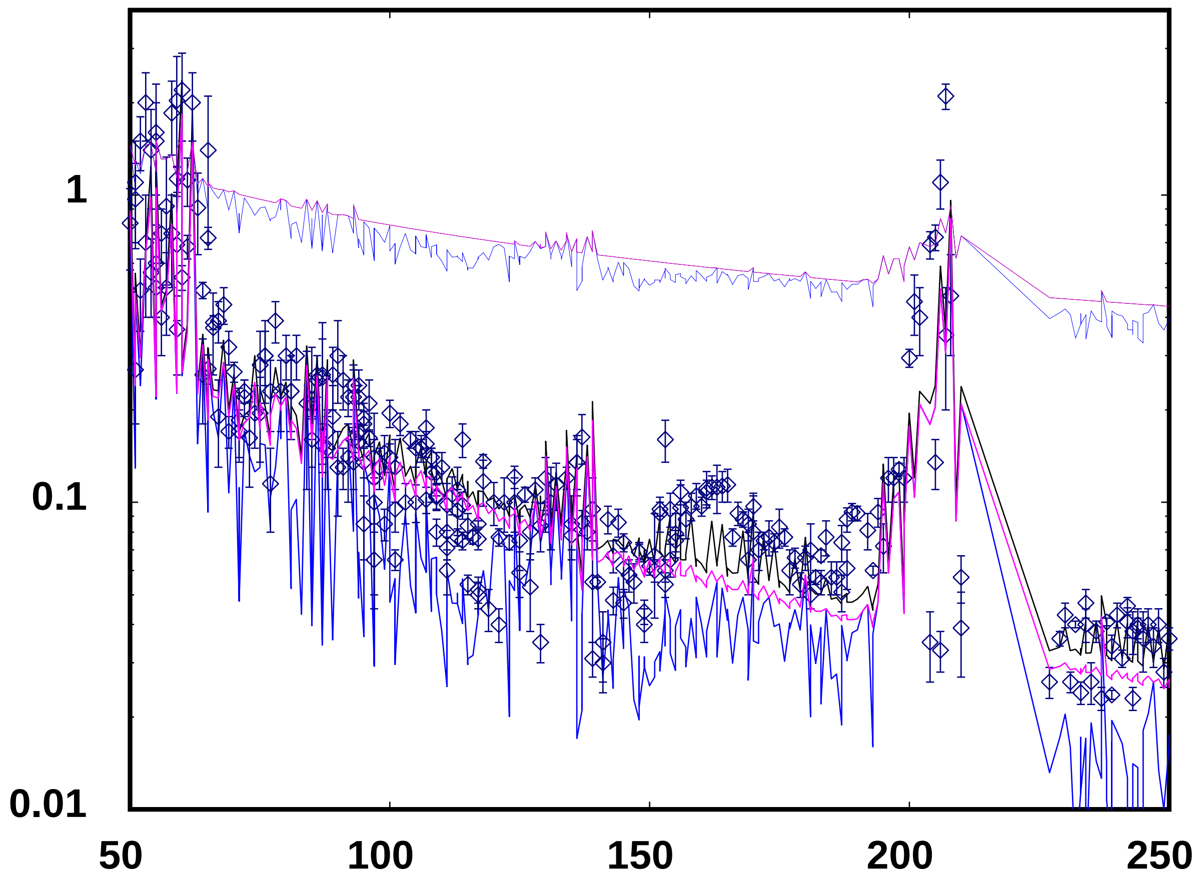

1
T
(MeV)
<Γγ>
(eV)
0.1
no M1
even Z even N
60
80
100
120
140
160
180
200
220
A

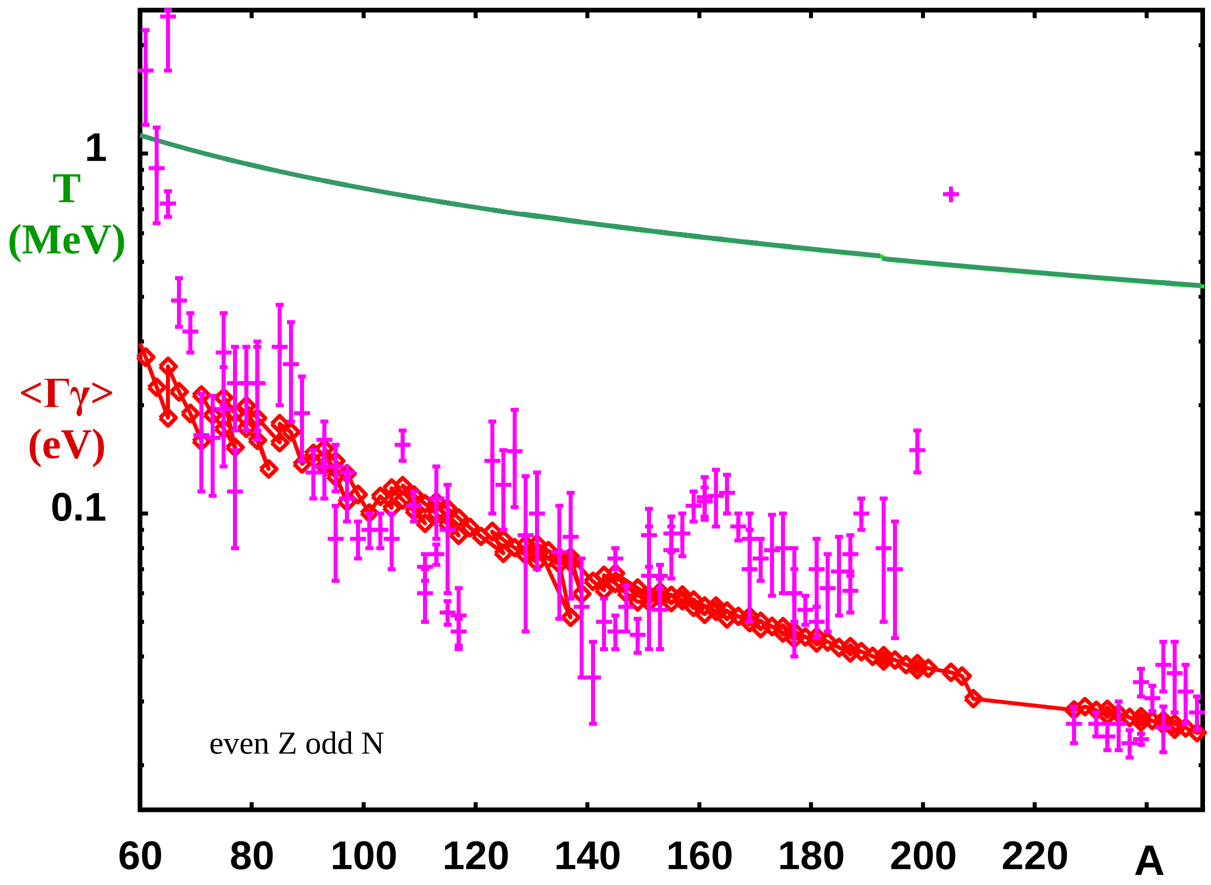


$\overline{SU(3)}$
First-order phase transitions
Critical point
O(6)
Oblate deformed
Critical point
$\overline{X(5)}$
Prolate deformed
SU(3)
Spherical
Critical point
X(5)
U(5)
Triple point
E(5)


T (MeV)
◇ RIPL-3
— T∝A⅔
1
<Γγ> (eV)
0.1
50
100
150
200
250


1
0.1
0.01
50
100
150
200
250


1
0.1
0.01
50
100
150
200
250



1
T
(MeV)
<Γγ>
(eV)
0.1
even Z odd N
60
80
100
120
140
160
180
200
220
A

Conclusions

The E1 strength $\boldsymbol{f_{E1}}$ *is controlled by the isovector giant dipole resonance GDR:*

At $E_\gamma \ll E_{GDR}$ *its value is proportional* (1) *to the spreading width* Γ_{GDR} *and*

(2) *to the excess over the dipole sum rule.*

To extract both from GDR data the nuclear deformation has to be accounted for:

The deviation from axial symmetry has an important effect, neglected up to now.

Modern nuclear structure investigations show that triaxiality is

(1) *observed in very many nuclei and*

(2) *anti-correlated to the quadrupole moment* Q_i .

Any use of a Lorentzian for $\boldsymbol{f_{E1}}$ *has to be in accord to that;*

GDR data do <u>*not*</u> *indicate* (1) *a strong deviation from the GMT sum rule* *(with* m_π*=0)*

(2) *a strong variation of* Γ_{GDR} *with A and Z.*

Radiative neutron capture strongly depends on $\boldsymbol{\rho}$ *and on the dipole strength* $\boldsymbol{f_1}$ *in the region 2 - 6 MeV.*

It is thus influenced by orbital magnetism (scissors mode) and the isoscalar spin flip ***M1*** *strengh.*

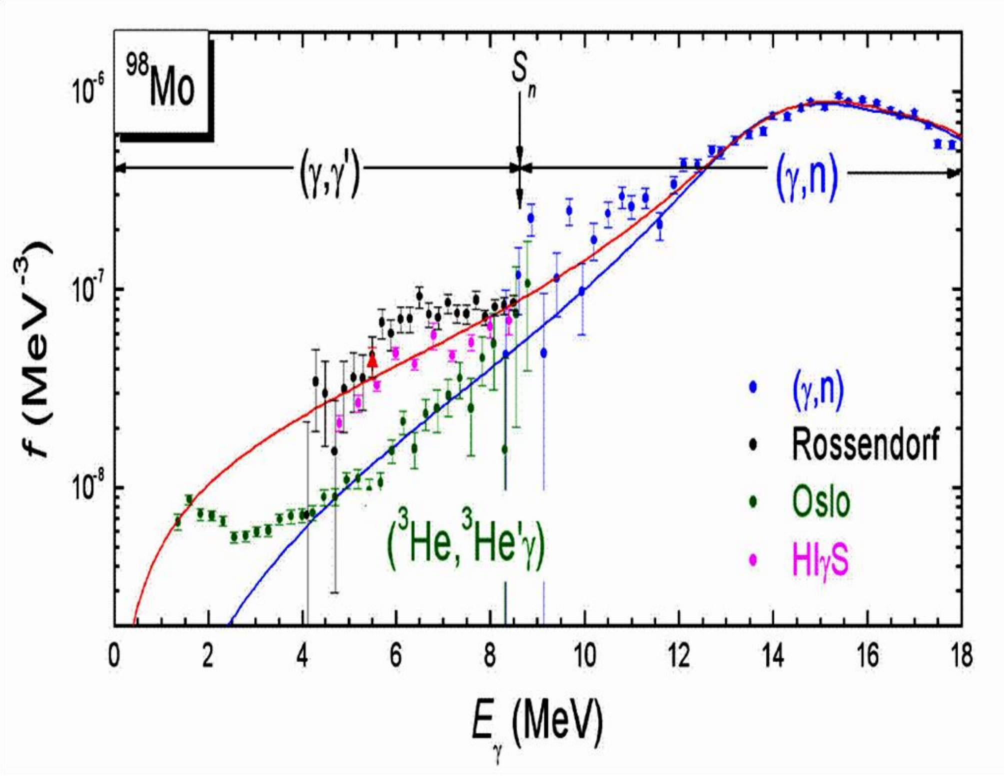
Respective data show that (1) *they do* <u>*not*</u> *have Lorentzian shape* *(with* Γ_{GDR}*)* *and*

(2) *hitherto unobserved continua may increase their strength.*

Very low energy strength *(as predicted by KMF)* *is very difficult to be clearly identified experimentally.*

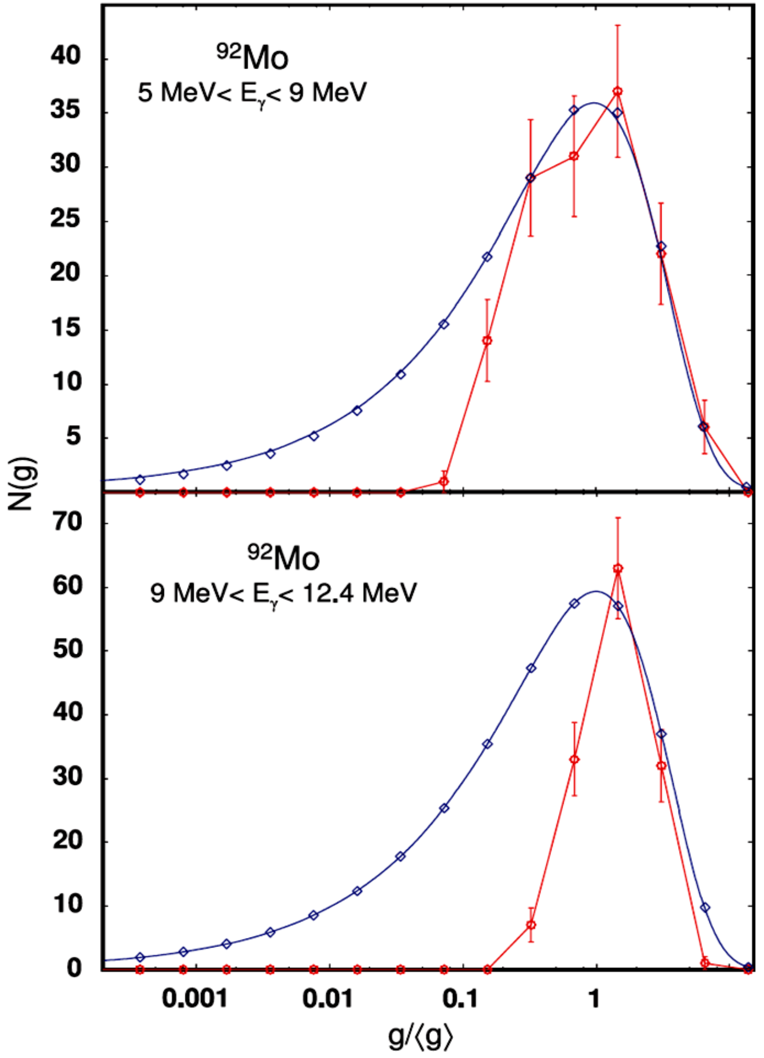
Mo dipole strength studies @ ELBE

agree to ^{98}Mo measurements @ Duke-HIγS



and disagree to (^{3}He,^{3}He)-data from cyclotron @ Oslo.

Tonchev et al.; Siem et al., contrib. to PSF-workshop 2008



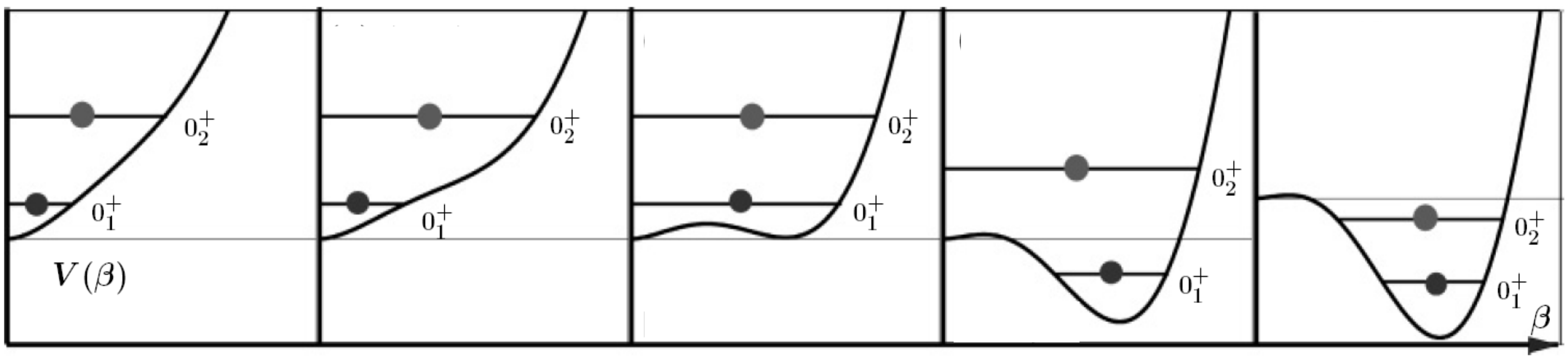
statistical analysis for ^{92}Mo (γ,γ)
shows no collective strength (pigmy?),
only Porter –Thomas fluctuations.

Erhard et al., PRC81(10)034319

Dynamic rms Q-moment vs. static deformation

in relation to

harmonic oscillator *vs.* *winebottle potential (Mexican hat)*



"vibrational" nucleus (γ=0) *vs.* *"rotational" nucleus (γ=0)*

*With the **rotation invariant observables** the the "traditional" mean deformation parameters* $\mathbf{Q_0}$*,* $\boldsymbol{\beta}$ *and* $\boldsymbol{\gamma}$

are replaced by the root mean square (rms) averages $\mathbf{Q_{rms}}$*,* $\mathbf{d}$ *and* $\boldsymbol{\delta}$*.*

*The distiction between **spherical, vibrational, rotational** is lost;*

*quantitative information is used to define **rms-values** and their **variance** instead.*

***Experiment** can only deliver **rms-information** about non-sphericity and non-axiality.*

Fig. from V. Werner et al., PRC **78**, 051303 (2008)

Triaxiality in
Nilsson-Strutinski calculations (FRDM-HFB)

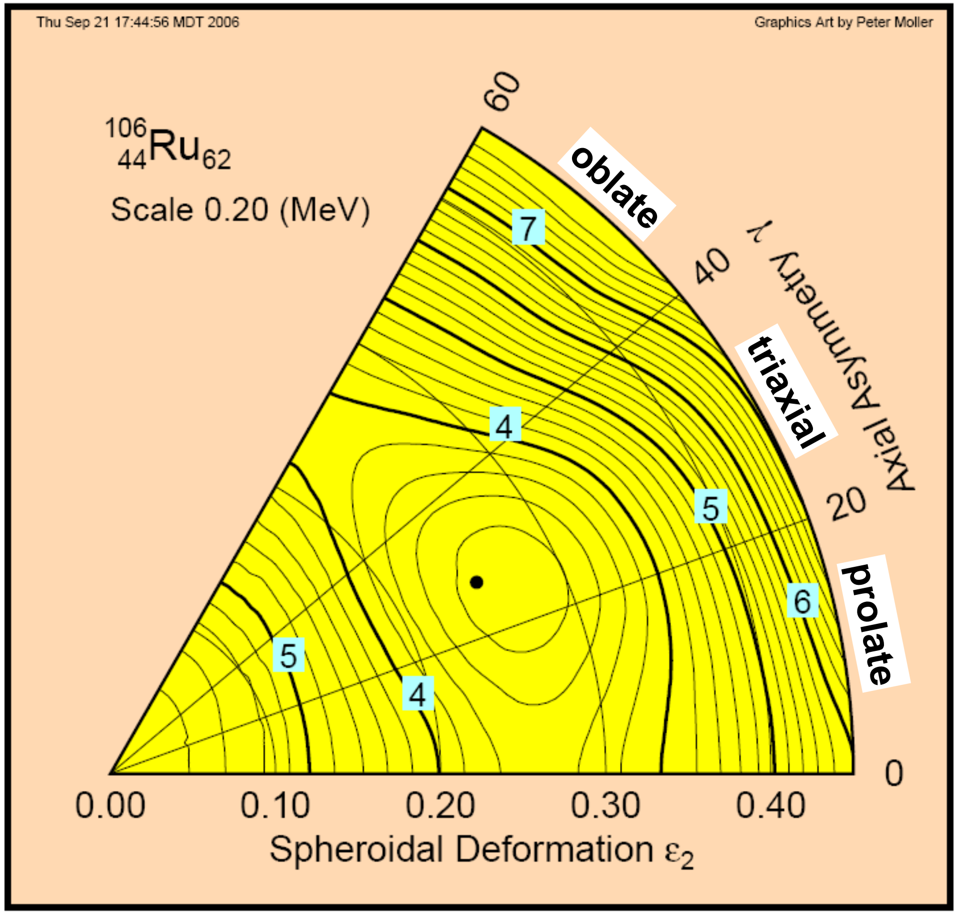


Fig. 4. The calculated ground state shape of ^{106}Ru is triaxial, as is the case for several hundred other nuclei across the nuclear chart out of ~ 9000 studied.

and in calculations with the Thomas-Fermi plus Strutinsky integral (ETFSI) method, saying:

*We are thus inclined to accept the widespread **(>30%)** occurrence of **triaxiality**…as being an essential feature of ETFSI calculations, if not of the **real world** …albeit the associated reduction in energy, …never exceeds 0.7MeV.*

P. Möller et al., PRL 97(06) 162502

A. K. Dutta et al., PRC 61(00)054303

Various contributions to the sum of E2-strengths

- i.e. the quadrupolar deformation

For most nuclei, the e.m. transition $0_1^+ \rightarrow 2_1^+$ *dominates the sum by ~ 95%.*

$$R^{(2)} \equiv \frac{\sum_{r=2,3,..} \left| \langle 2_r \parallel E2 \parallel 0 \rangle \right|^2}{\sum_{r=1,2,3,..} \left| \langle 2_r \parallel E2 \parallel 0 \rangle \right|^2}$$

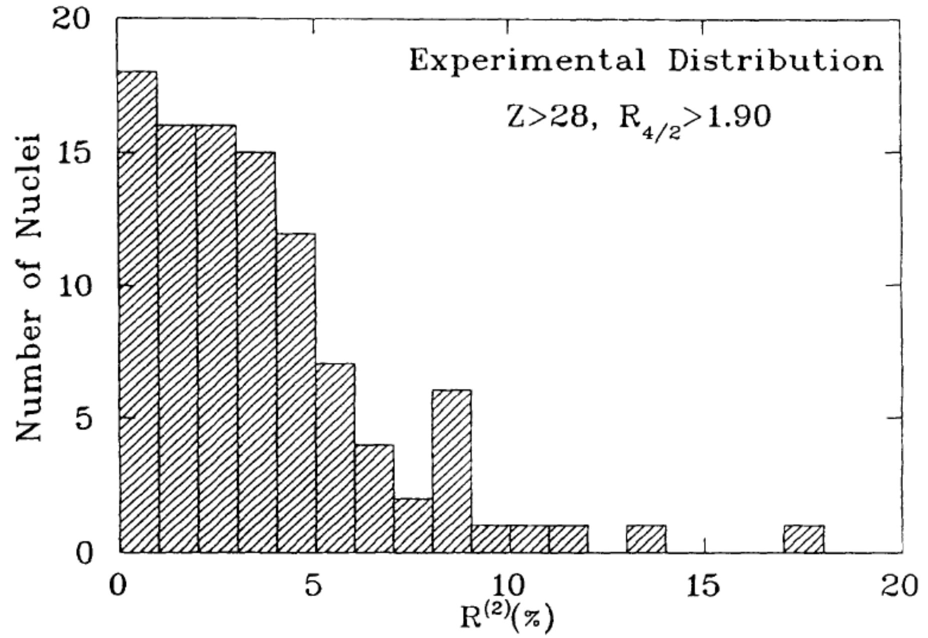


FIG. 1. Histogram of experimental $R^{(2)}$ values for 101 nuclei from Zn to Fm obtained from all known $B(E2{:}0_1^+ \rightarrow 2_i^+)$ values

But: in nearly sperical nuclei the transition from the g.s. to the high energy quadrupole mode GQR is comparable with $0_1^+ \rightarrow 2_1^+$ *.*

It corresponds to a fast oscillation and causes a respective increase of $Q_{rms.}$

N. Pietralla et al.,, Phys. Rev. Lett. 73, 2962 (1994)

Observation vs. theory

The only "theoretical" assumptions to get ***d*** *and* ***δ*** *are:*

reflection symmetry *and*

equal distribution of charge and mass *(i.e. protons and neutrons).*

The radii $\boldsymbol{R_i}$ *of a non-axial ellipsoidal shape (assumed) and the dipole oscillation frequencies* $\boldsymbol{\omega_i}$ *directly result from the observables* $\boldsymbol{K_2}$ *and* $\boldsymbol{K_3}$**.**

The K_3 *are well determined for ~ 100 nuclei only.*
For these the approximations needed have been proven to be OK:

$$K_3 = -\cos(3\delta) = \sqrt{\frac{7}{10K_2^3}} \sum_{r,s=1,\infty} \langle 0\|E2\|\, 2_r\rangle \langle 2_r\|E2\|\, 2_s\rangle \langle 2_s\|E2\|0\rangle$$

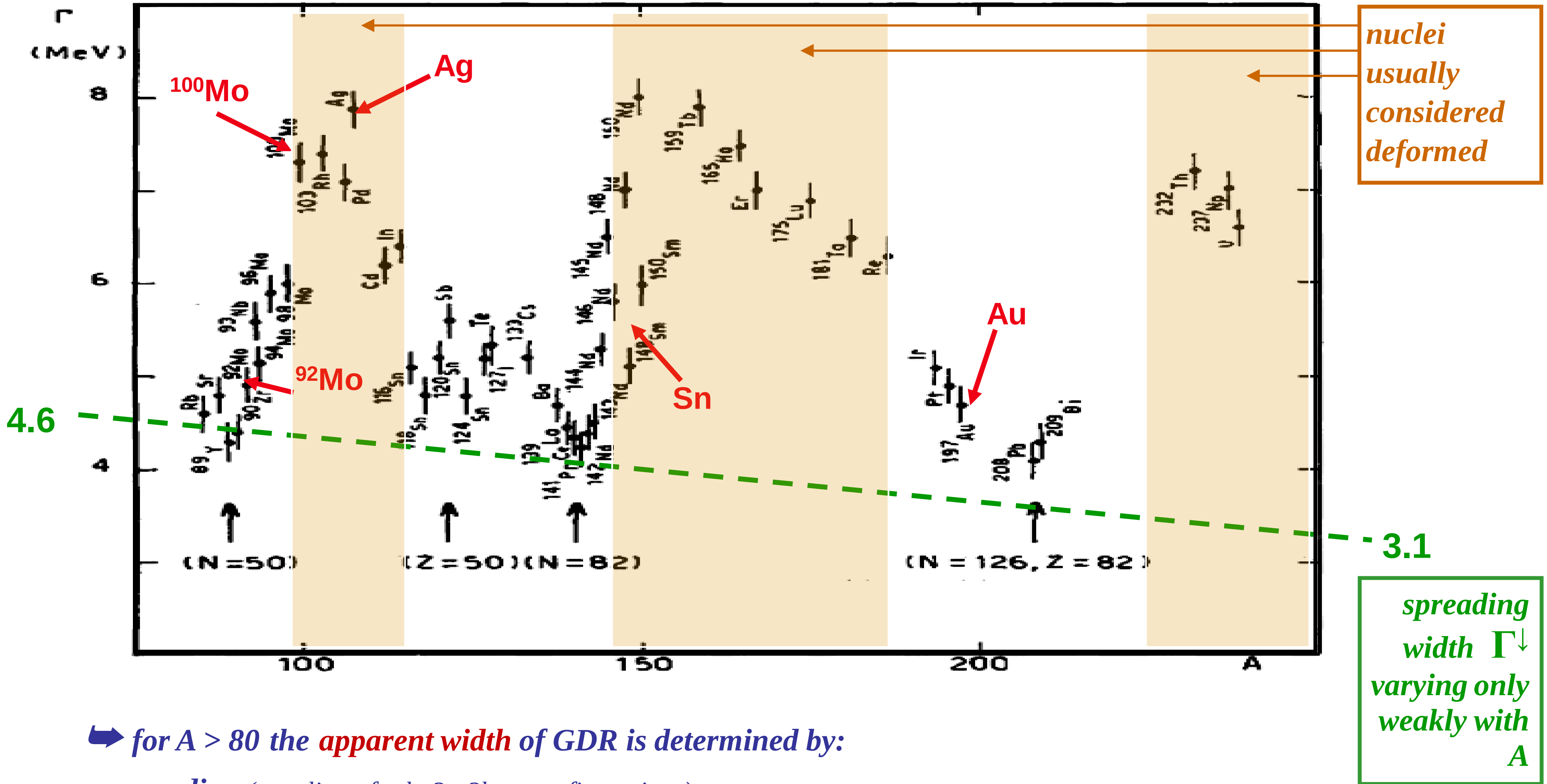
$$\approx \sqrt{\frac{7}{10K_2^3}} \left(\langle 0\|E2\|\, 2_1\rangle \langle 2_1\|E2\|\, 2_1\rangle \langle 2_1\|E2\|0\rangle + 2\,\langle 0\|E2\|\, 2_1\rangle \langle 2_1\|E2\|\, 2_{2,3}\rangle \langle 2_{2,3}\|E2\|\, 0\rangle \right);$$

$$\langle d^3 \cos(3\delta)\rangle \approx \langle d^3\rangle \langle \cos(3\delta)\rangle; \quad \langle d^3\rangle \approx \langle d^2\rangle^{3/2}.$$

K_3 can also be derived from excitation energy information with nearly no experimental uncertainty, but often systematic problems due to theoretical approximations.

W. Andrejtscheff and P. Petkov, PRC 48 (93) 2531 C. Y. Wu and D. Cline, PRC 54 (96) 2356 V. Werner et al., PRC **71**, 054314 (2005)

Apparent GDR-width – from (γ,n)-data taken at CEN Saclay



➡ *for A > 80 the apparent width of GDR is determined by:*

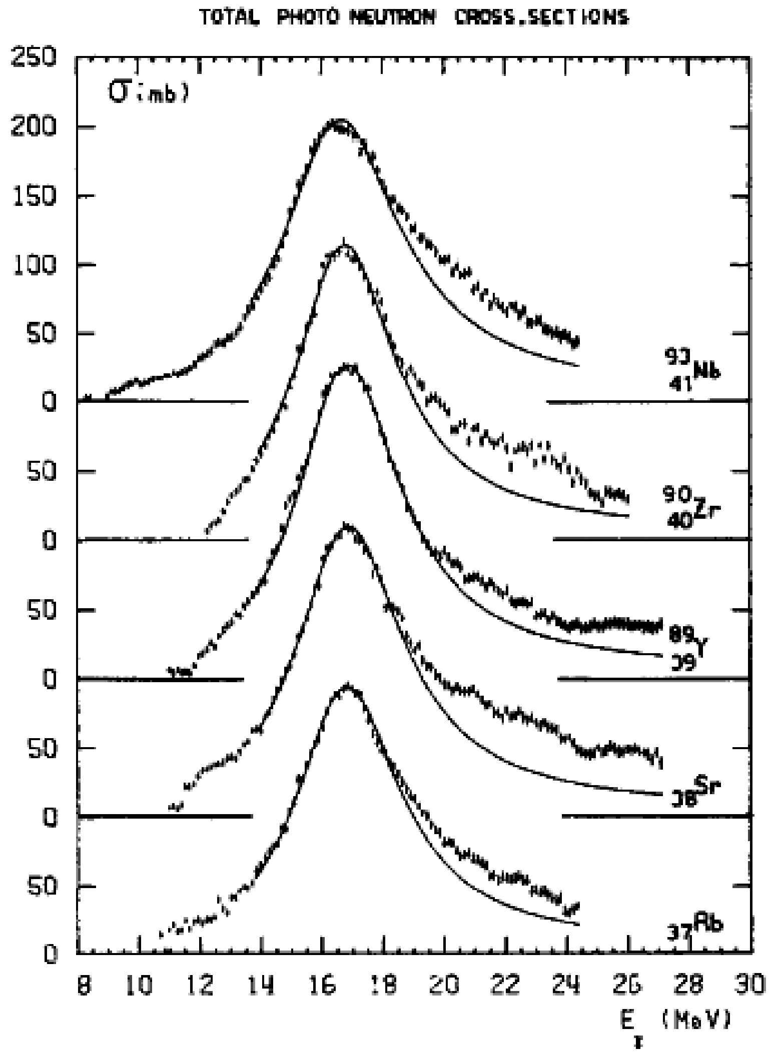
a. spreading (coupling of p-h, 2p-2h,.. -configurations)

b. escape of particles $\Gamma^{\uparrow} \approx 1$ MeV (negligibly small)

c. splitting due to (static & dynamic) deformation not only for well deformed nuclei

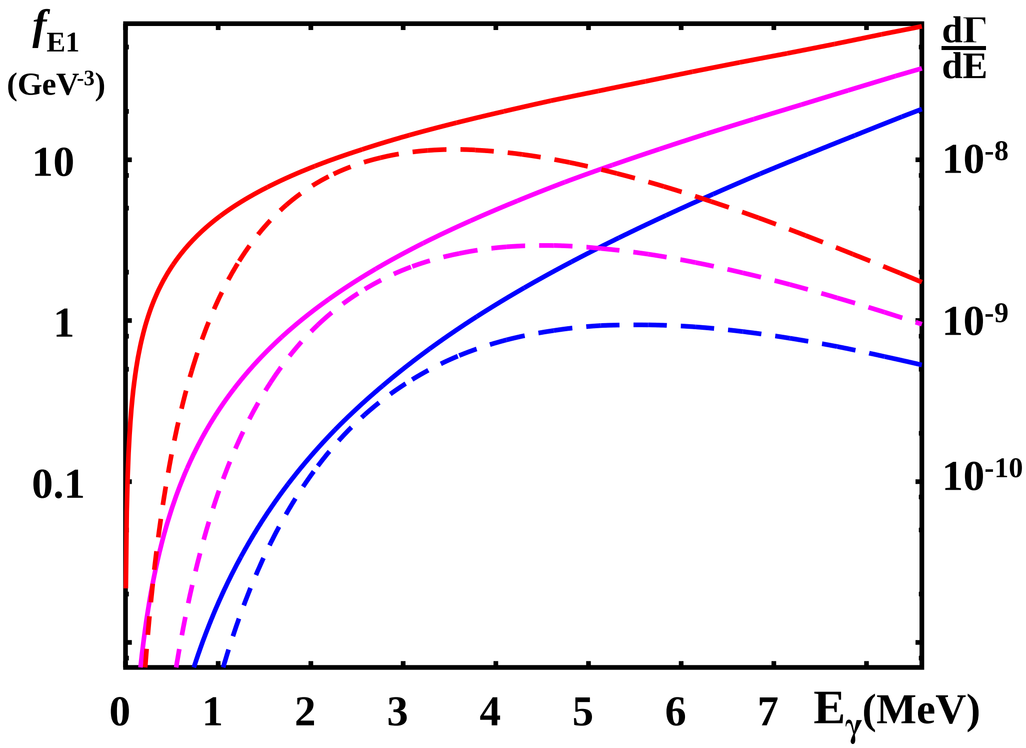
Junghans et al., PLB 670 (2008) 200

Carlos et al., NP A 219 (1974) 61

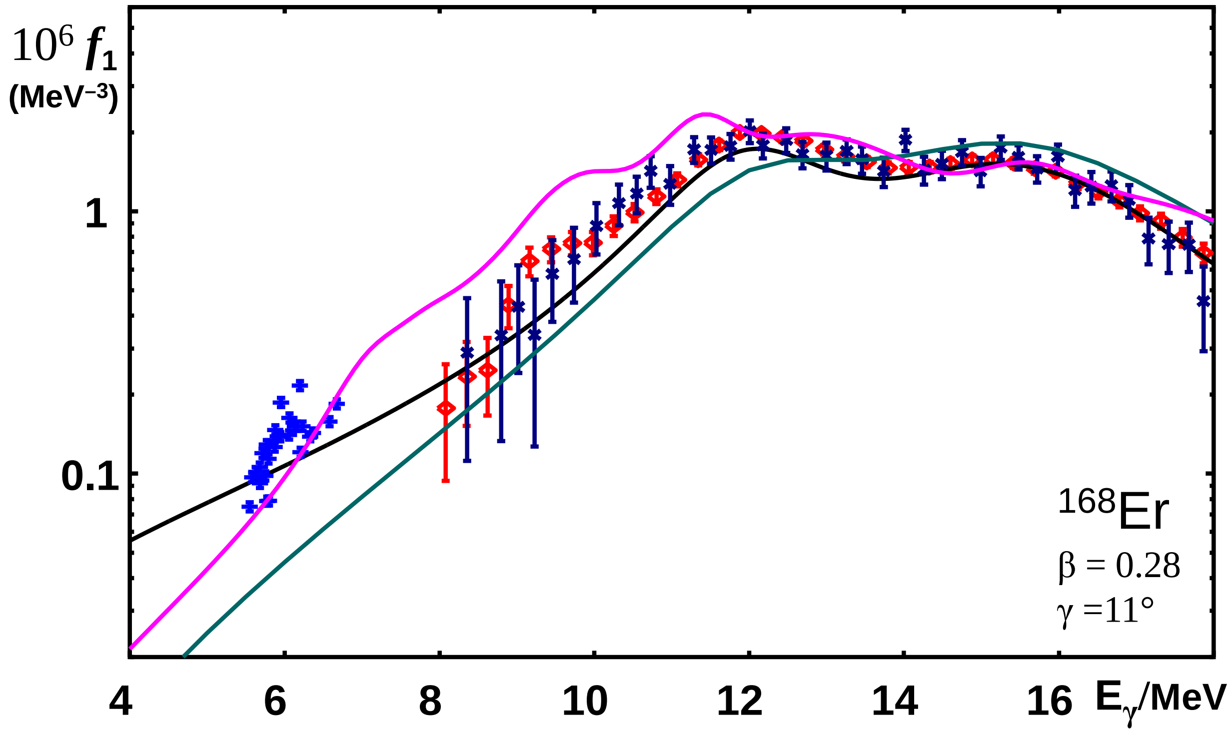


	^{85}Rb	^{88}Sr	^{89}Y	^{90}Zr	^{93}Nb
E_o (MeV)	16.75 (5)	16.70 (5)	16.70 (5)	16.65 (5)	16.55 (5)
σ_{max} (mb)	192 (10)	207 (10)	225 (10)	211 (10)	202 (10)
Γ_{fit} (MeV)	4.1 (2)	4.2 (1)	4.1 (1)	4.0 (1)	4.7 (2)
=> I/I_{GGT}	0.98	1.05	1.10	0.99	1.08

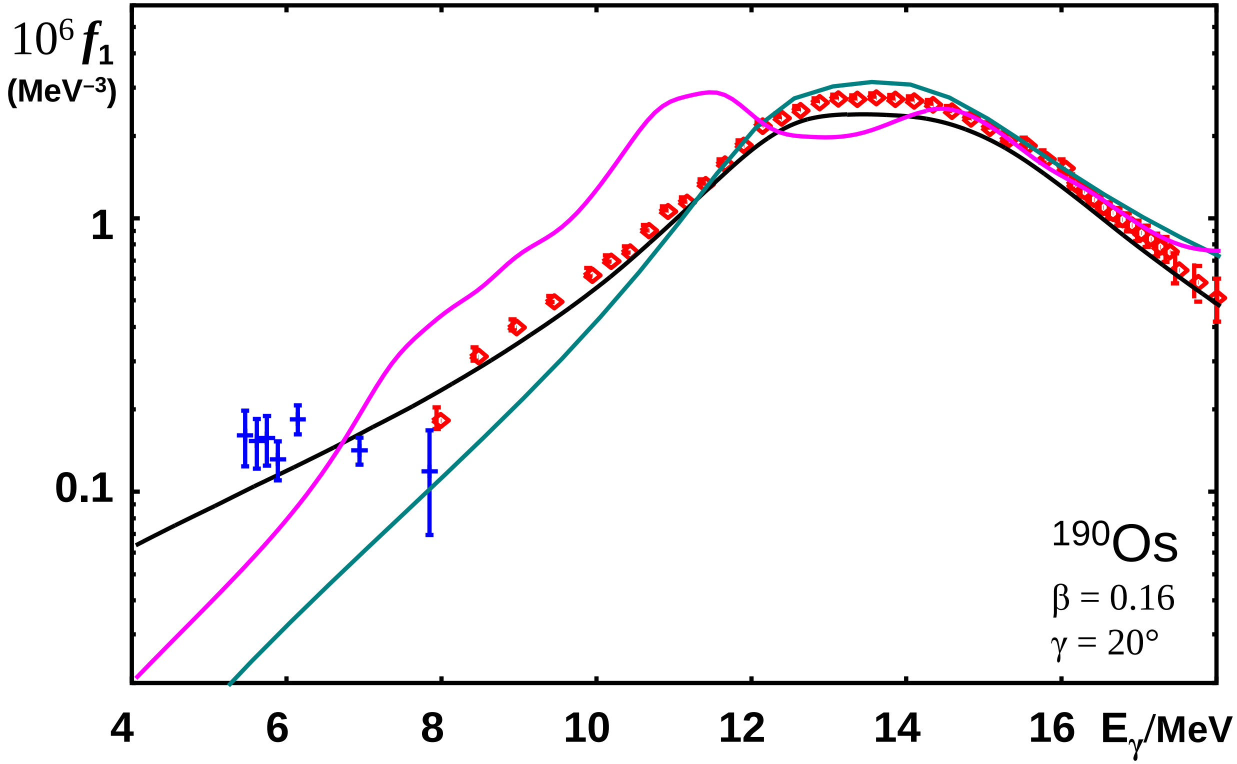
Lepretre et al., NPA175(71)609



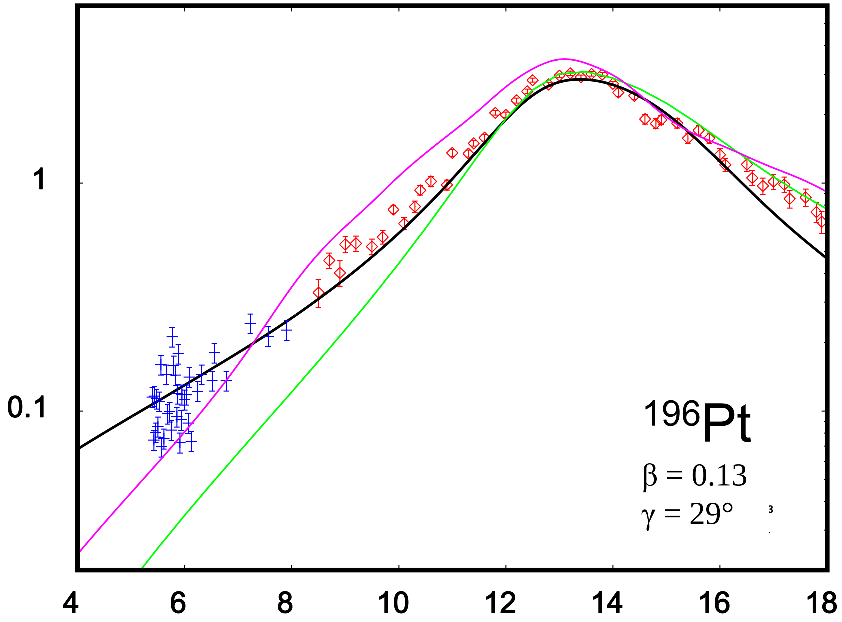
A.Junghans et al., PLB 670 (2008) 200

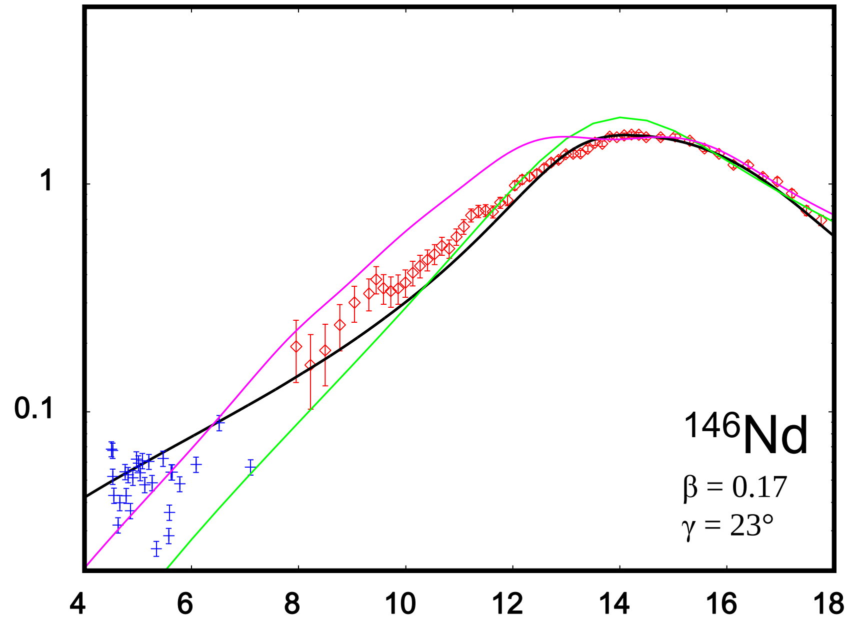


A.Junghans et al., PLB 670 (2008) 200



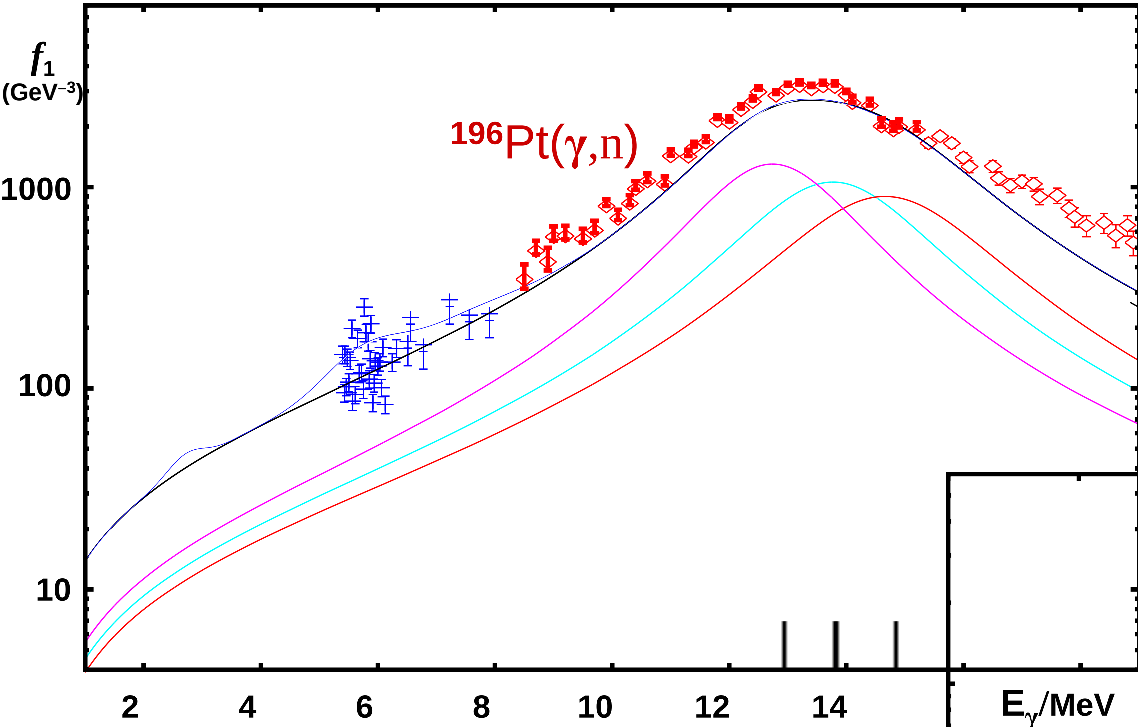
A.Junghans et al., PLB 670 (2008) 200





S. Goriely et al., NPA 739 (2004) 331

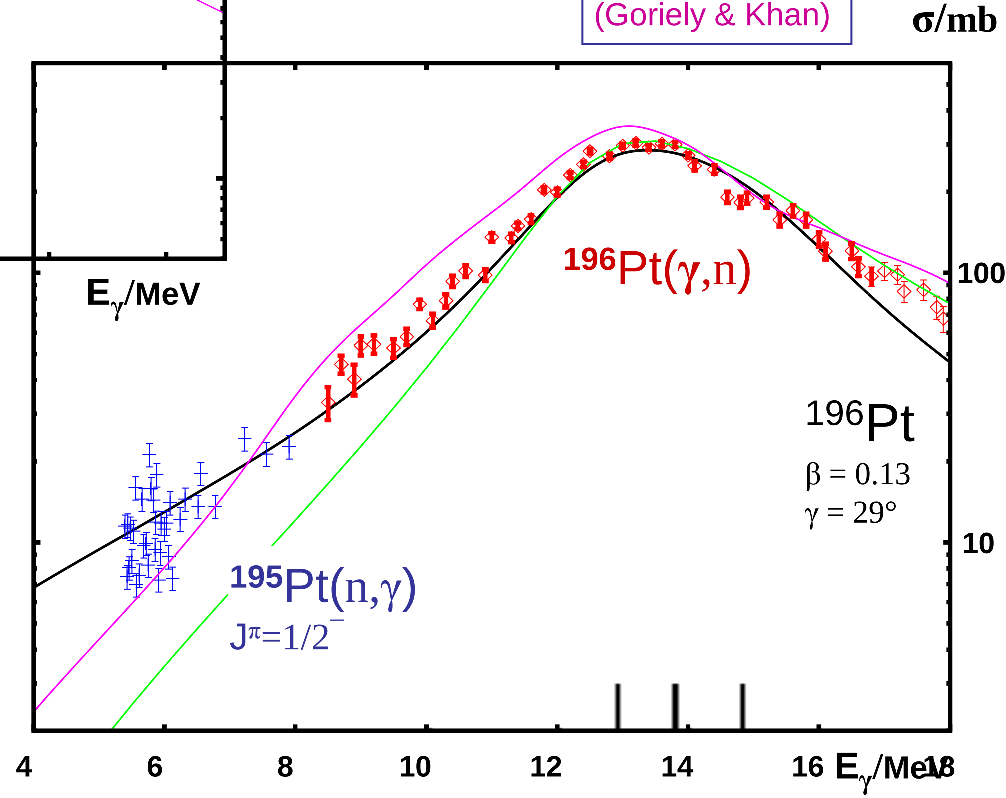
A.Junghans et al., PLB 670 (2008) 200



Axel-Brink
(Junghans et al.)

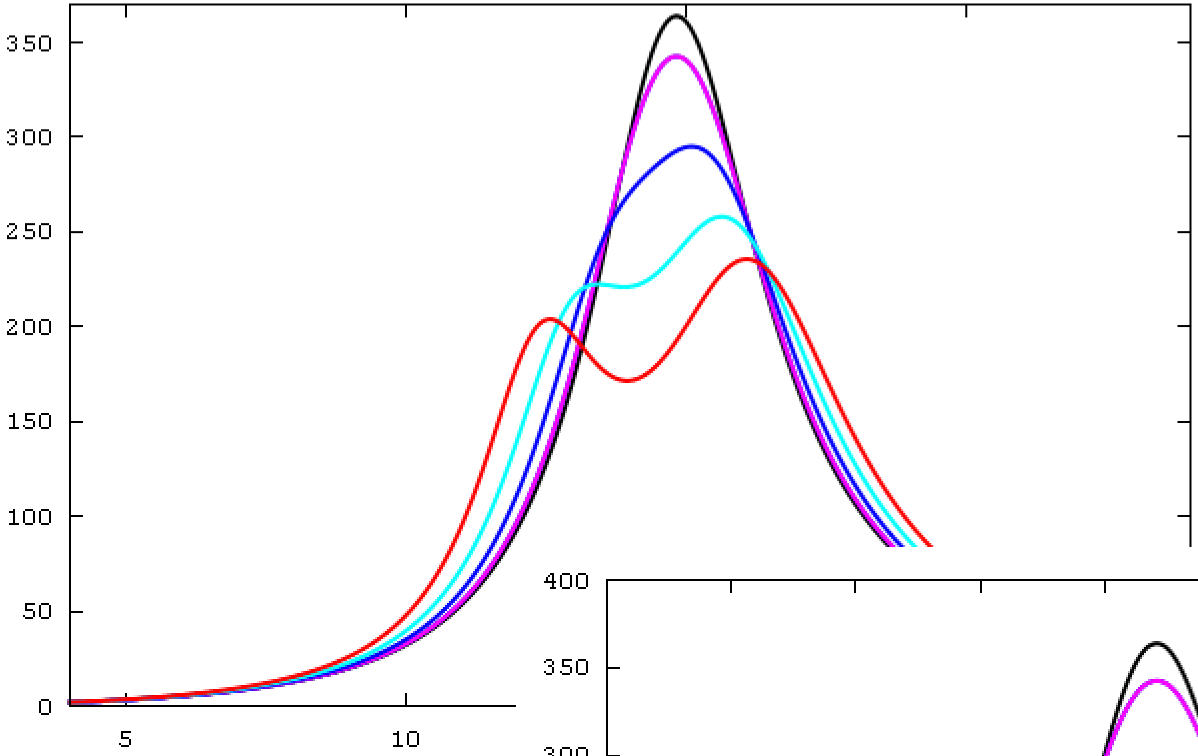
RIPL-2:
EG LO
(Kopecky & Uhl)

QRPA-SLy4
(Goriely & Khan)

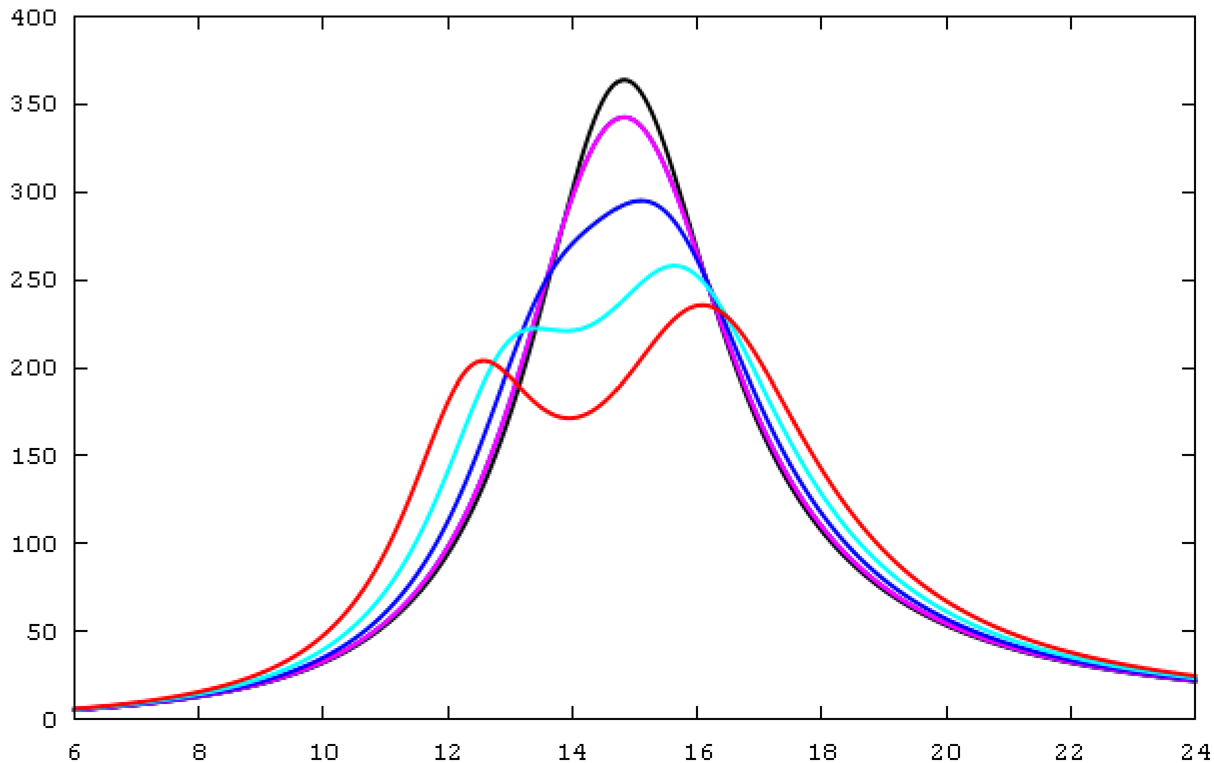


	E_i	Γ_i	%TRK	
^{196}Pt	13.72	4.99	142	ADNDT
	12.89	2.99		Junghans
	13.77	3.32		et al.
	14.81	3.73	100	

Junghans et al., PLB 670 (2008) 200 Mughabghab & Dunford, Phys. Lett. B 487 (2000) 155 Goryachev et al, YF 27 (1978) 1479

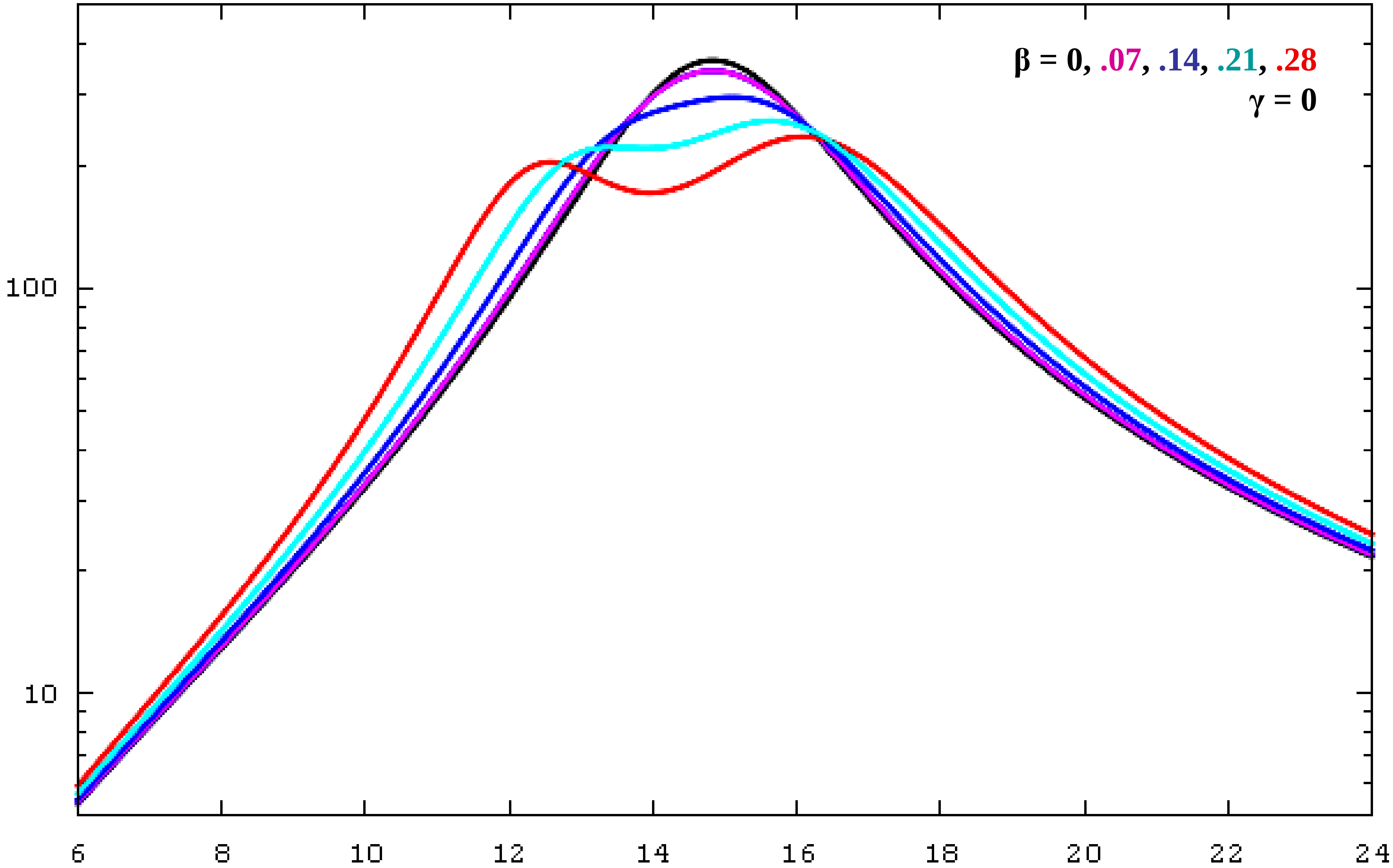


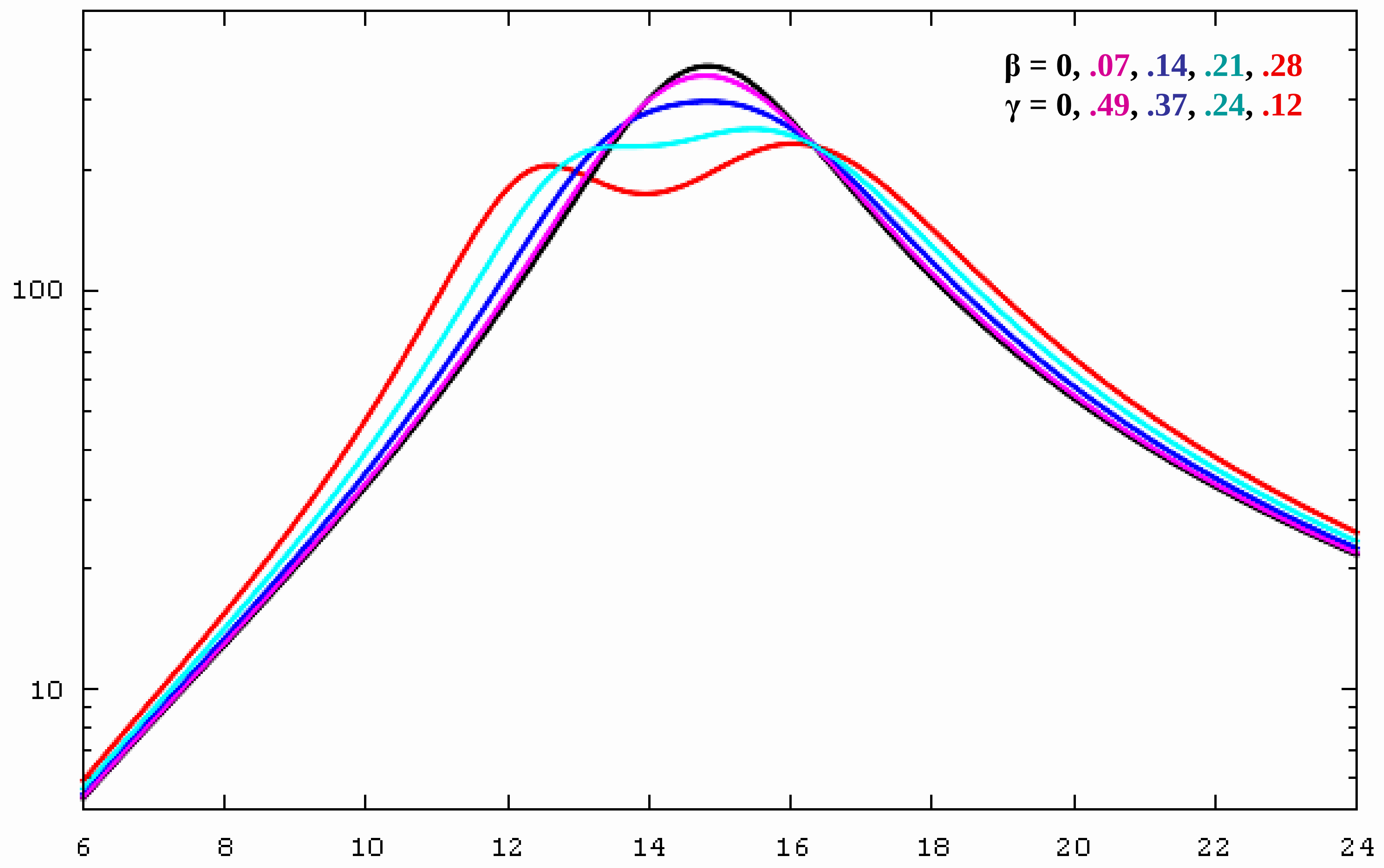
350
300
250
200
150
100
50
0
5
10

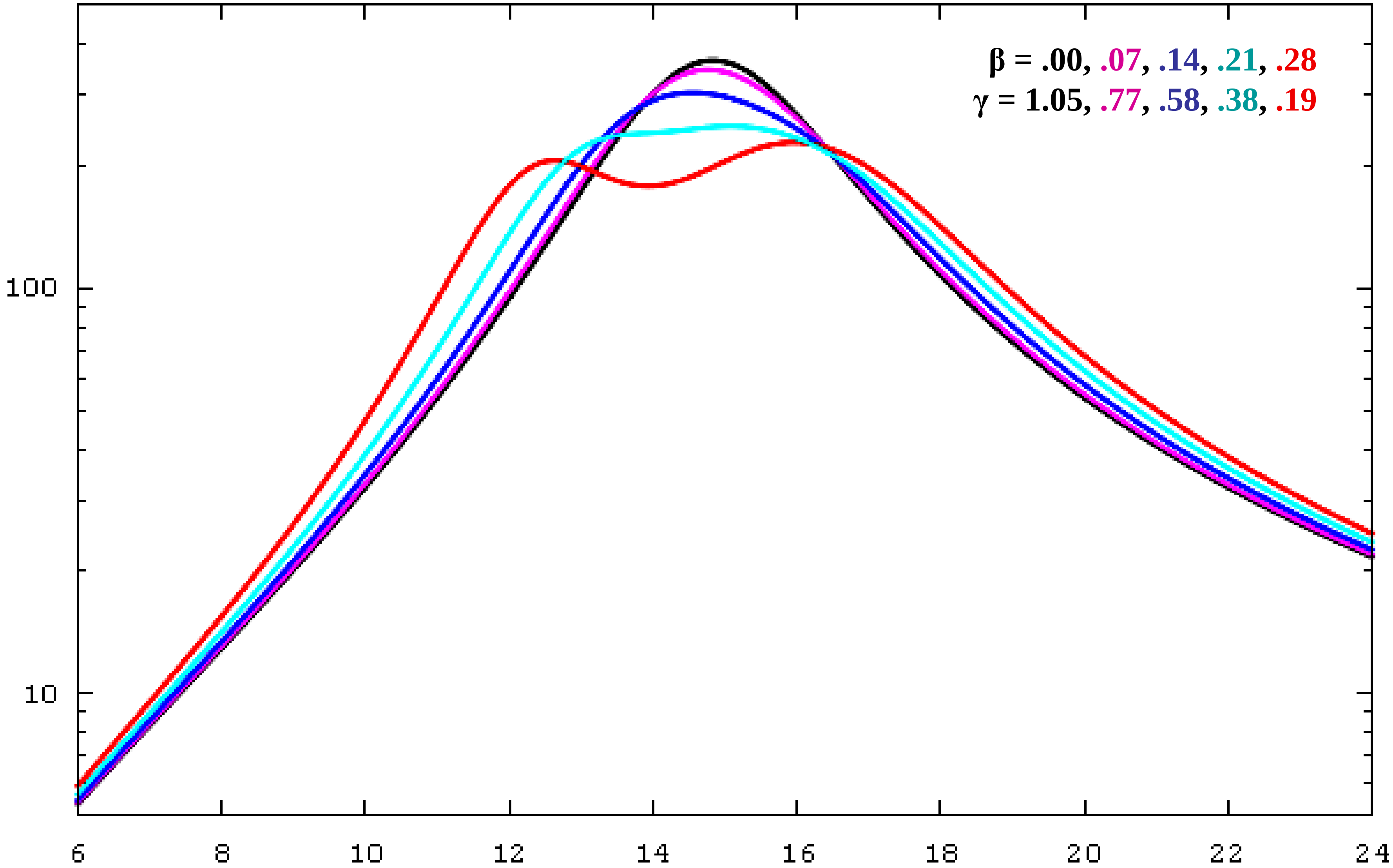


400
350
300
250
200
150
100
50
0
6
8
10
12
14
16
18
20
22
24

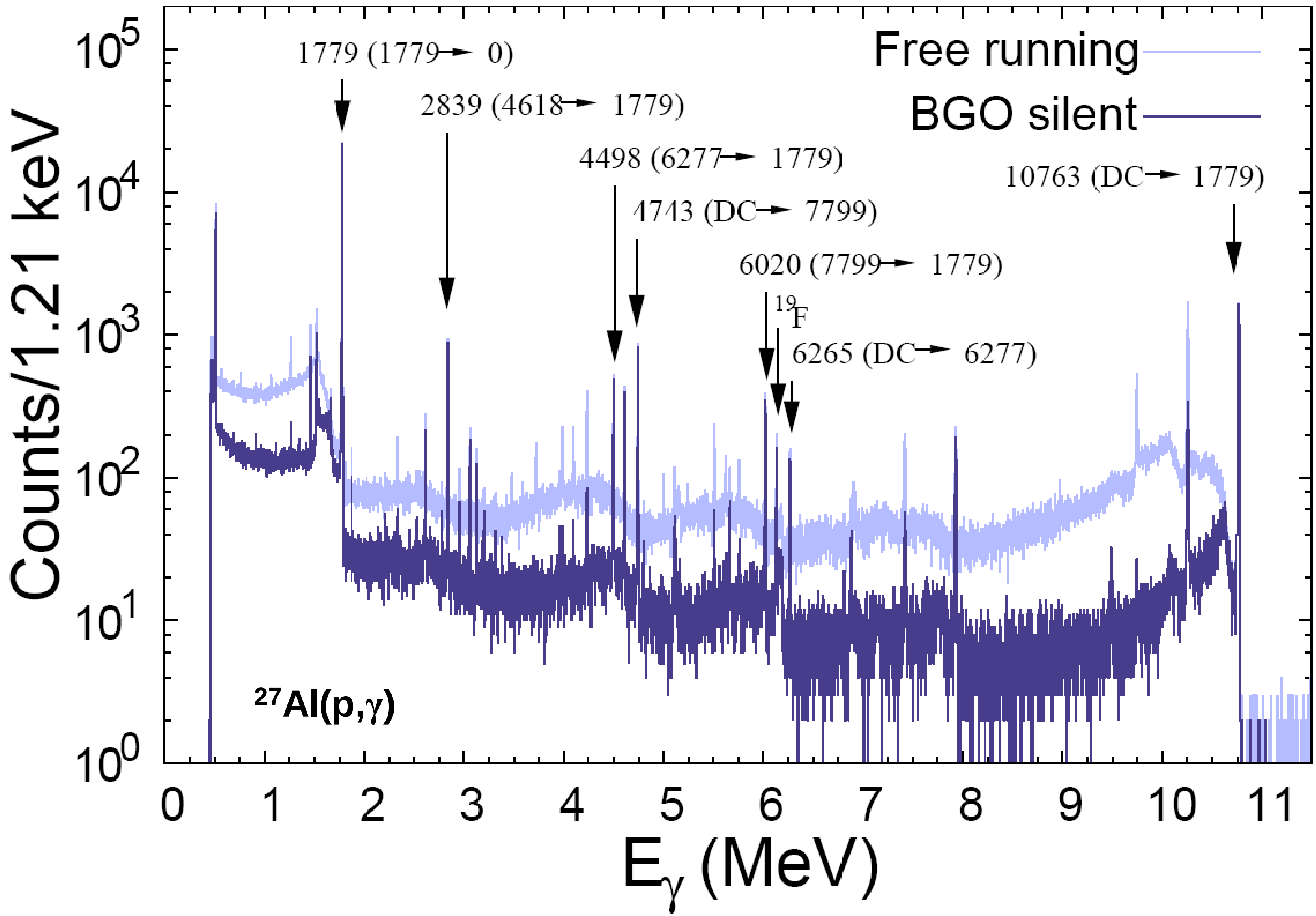
-


β = 0, .07, .14, .21, .28
γ = 0
100
10
6
8
10
12
14
16
18
20
22
24


β = 0, .07, .14, .21, .28
γ = 0, .49, .37, .24, .12
100
10
6
8
10
12
14
16
18
20
22
24



β = .00, .07, .14, .21, .28
γ = 1.05, .77, .58, .38, .19
100
10
6
8
10
12
14
16
18
20
22
24



Counts/1.21 keV
10^0
10^1
10^2
10^3
10^4
10^5
0 1 2 3 4 5 6 7 8 9 10 11
E_γ (MeV)
Free running
BGO silent
1779 (1779→ 0)
2839 (4618→ 1779)
4498 (6277→ 1779)
4743 (DC→ 7799)
6020 (7799→ 1779)
^{19}F
6265 (DC→ 6277)
10763 (DC→ 1779)
^{27}Al(p,γ)