THE NEXT-GENERATION PRACTICAL MODEL OF THE CASCADE GAMMA DECAY OF NEUTRON RESONANCE AND ITS EXPECTED PARAMETERS FOR AN ARBITRARY NUCLEUS

A. M. Sukhovoj, L. V. Mitsyna

Used research methods

a) measurement of the spectra of evaporated nucleons and
b) full spectra of gamma transitions emitted by the nucleus with varied excitation energies

In both methods ρ and Γ are unknown values connected by the equation:

$$I_1 \propto \rho\Gamma / \sum(\rho\Gamma)$$

The main source of a systematical error

The data analysis of both such experiments can not be performed in an accordance with the mathematical requirements for the equations solving, even in principle.

Two-step process:

$$I_{\gamma\gamma}(E_1) = I_1 I_2 = \sum_{\lambda,f} \sum_{i} \frac{\Gamma_{\lambda i}}{\Gamma_{\lambda}} \frac{\Gamma_{if}}{\Gamma_{i}} = \sum_{\lambda,f} \frac{\Gamma_{\lambda i}}{<\Gamma_{\lambda i}> m_{\lambda i}} n_{\lambda i} \frac{\Gamma_{if}}{<\Gamma_{if}> m_{if}}$$

Spectra $I\gamma\gamma = F(E_1)$ as a function of their energy E_1 are actually rolling up the data of two independent experiments:

- the spectrum of the primary transitions of λ resonance decay to the all possible intermediate levels (i)
- and the branching ratios Br for the secondary transition at the final cascade levels (f).

The development of the methodology for measuring the intensity of these cascades and for their analysis is the only way to determine the maximum valid ρ and Γ values.

And it will allow the obtaining the unique possibilities for systematic studies of the nucleus superfluidity.

Possibility of the future experiments:

$$I_2 \propto \Gamma / \sum(\rho\Gamma)$$

The second factor is the branching factor B_r .

It can be determined in case of $I_{\gamma\gamma} \approx 100\%$

from the relation

$B_r = I_{\gamma\gamma} / I_1$

The level density ρ and the strength function K of the radiative widths in principle can be defined from the experiment without using any theoretical nuclear models.

This is not contradict mathematics.

Grounds of the new model

- The $T_{exp}\ \rho_{exp} = T_{om}\ \rho_{es}$ relation has resulted from the form of the spectrum of evaporated nucleons ($T=2\pi\Gamma/D_\lambda$)

$$k_{\mathrm{mod}} = \Gamma/(E_\gamma^3 A^{2/3} D_\lambda)$$

- $K_{exp}=k_{mod}\ \rho_{mod}/\rho_{exp}$ is the interpolation in case of γ-ray emission

The model level density

$$\rho_n = \frac{(2J+1)\exp(-(j+1/2)^2/2\sigma^2}{2\sqrt{(2\pi)}\sigma^3}\Omega_n(U)$$

$$\Omega_n(U) = \frac{g^n(U-E_n)^{n-1}}{((n/2)!)^2(n-1)!}$$

$$C_{coll} = A_l \exp(\sqrt{(E_{ex}-U_l)/E_\nu} - (E_{ex}-U_l)/E_\mu) + \beta$$

$$\rho_{\exp} = C_{coll}\rho_n$$

The model for E1-radiation widths (analogous function – for M1-transitions)

$$k(E1, E_\gamma) = w \frac{1}{3\pi^2\hbar^2 c^2 A^{2/3}} \frac{0.7\sigma_G \Gamma_G^2 (E_\gamma^2 + \kappa 4\pi^2 T^2)}{E_G (E_\gamma^2 - E_G^2)^2} +$$

$$+ P\exp(\alpha(E_\gamma - E_p)) + P\exp(\beta(E_p - E_\gamma)).$$

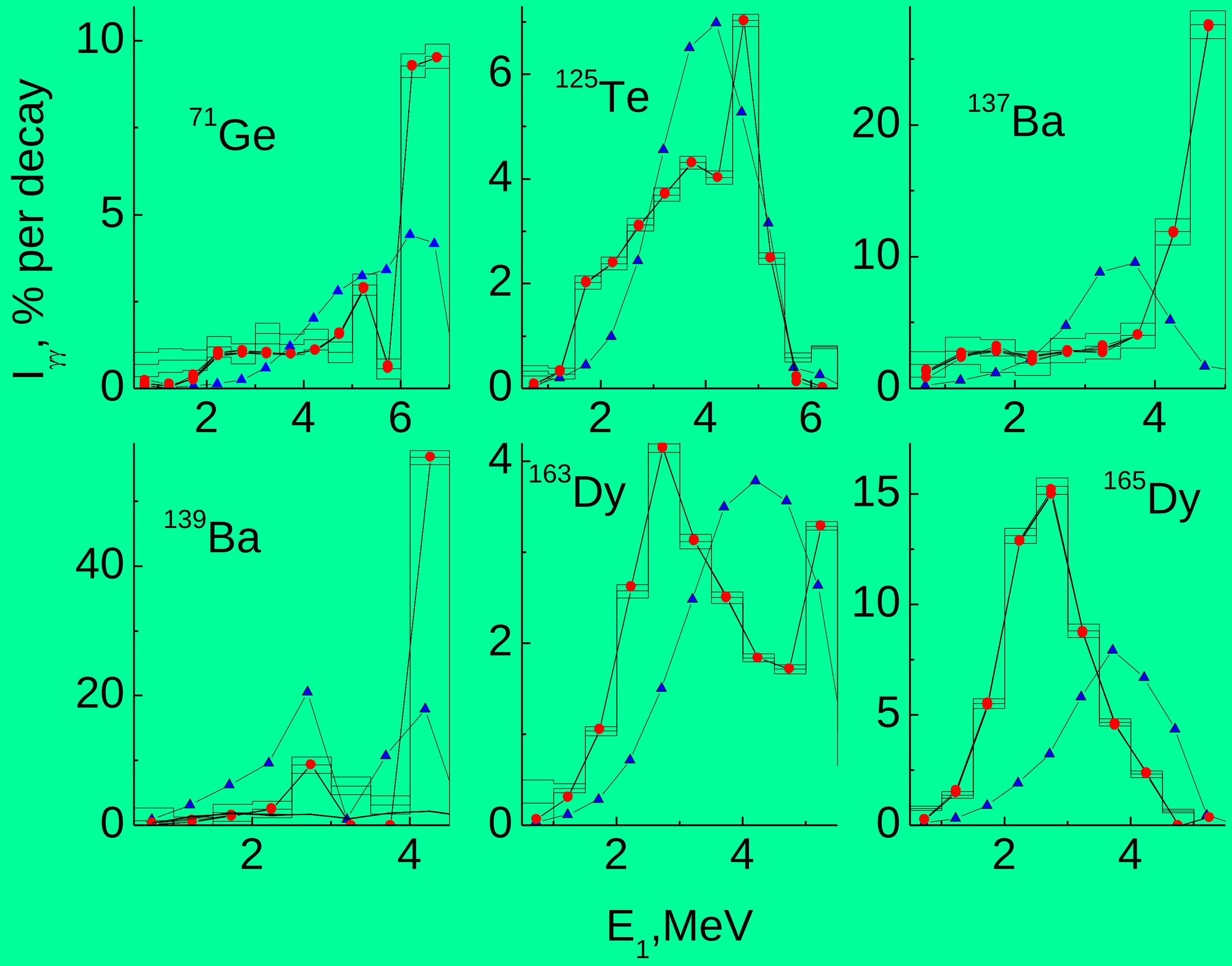
$$T = \sqrt{\kappa U / a}$$

$$w = \Gamma_\gamma^{\exp} / \Gamma_\gamma^{cal}$$

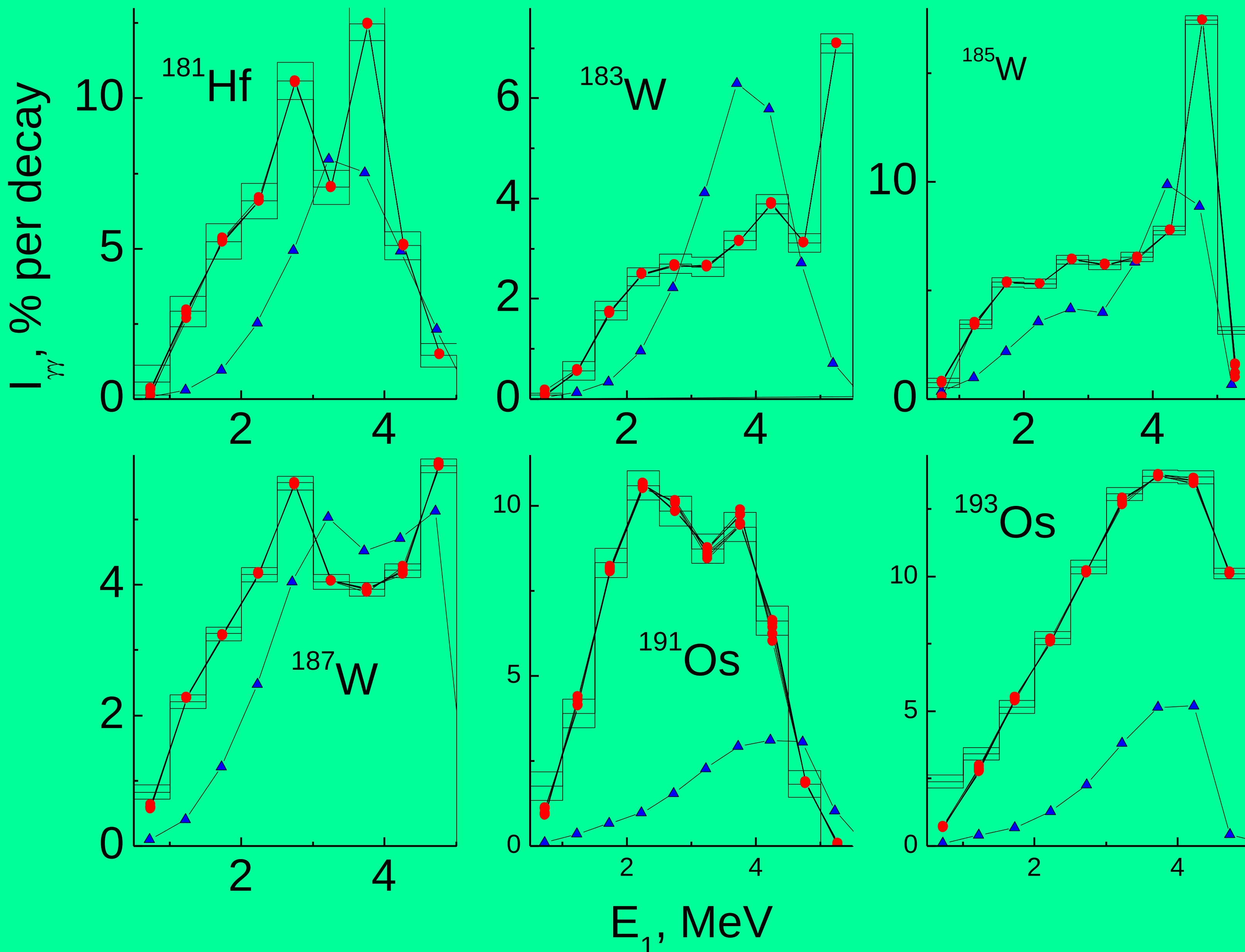
The special cases are also available in the fits:

- Fermi-gas level density – C_{coll} =1
- Strength function - *Kadmenskij S.G., Markushev V.P., Furman W.I.* model,

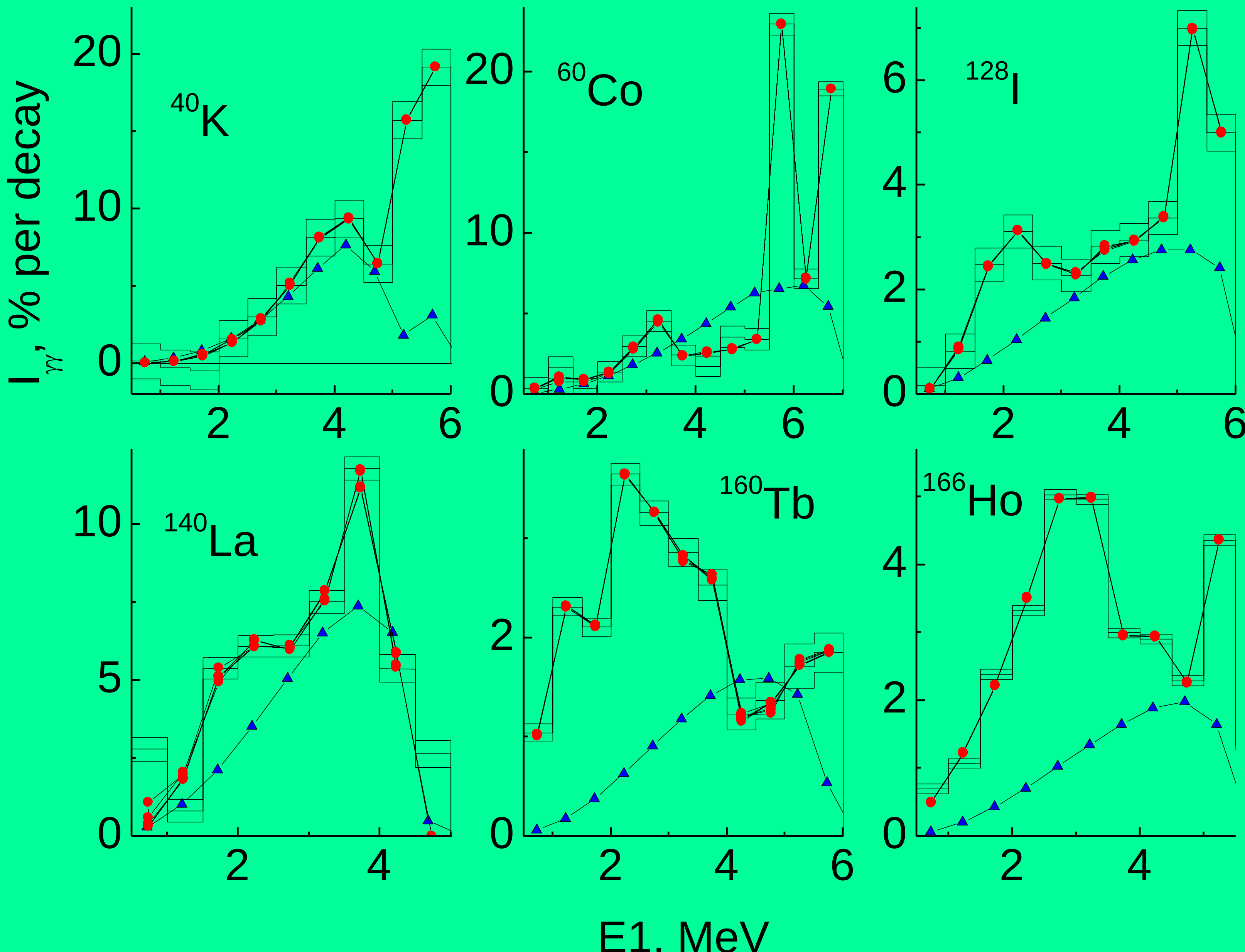
i.e. P=0 and κ=1.



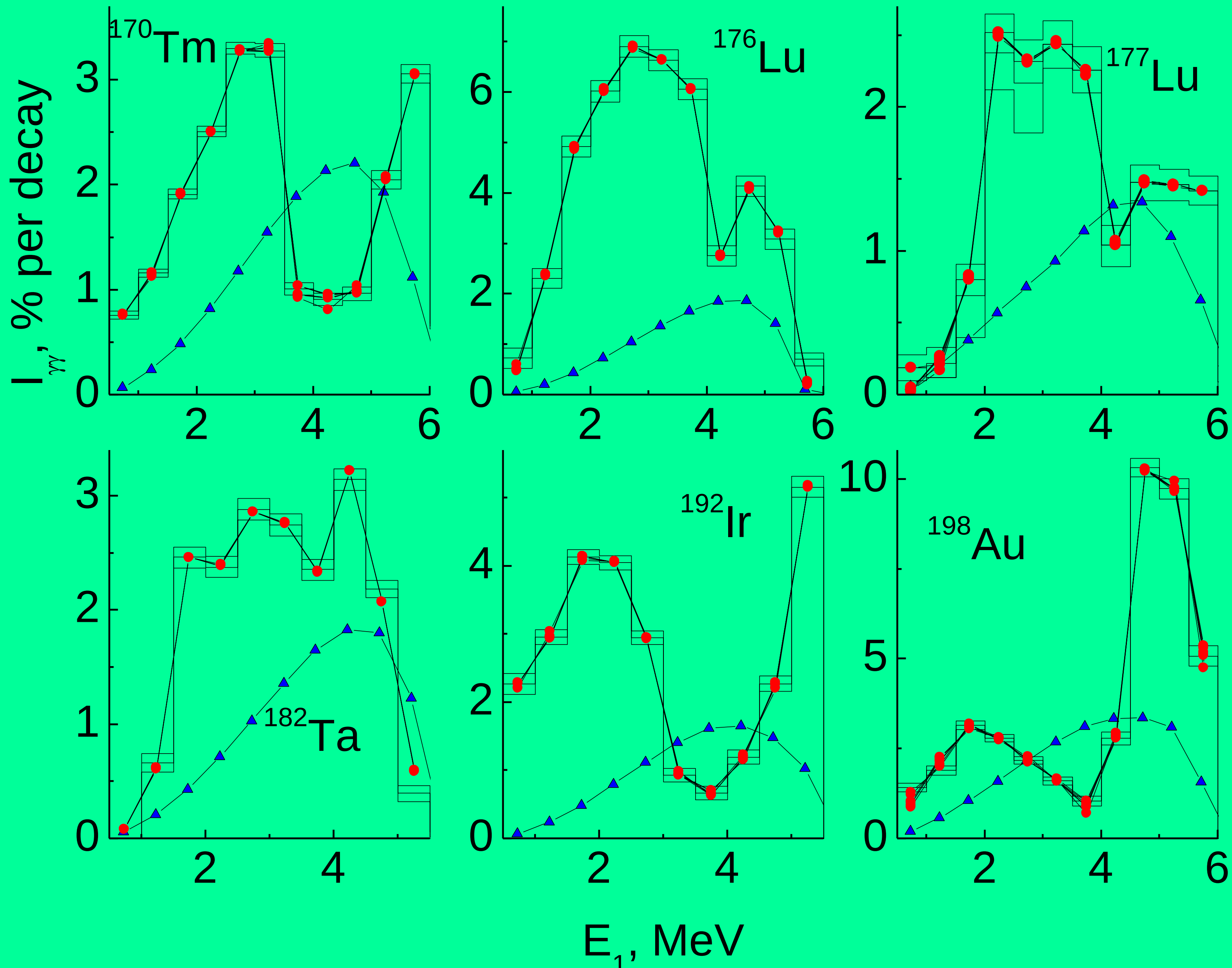
^{71}Ge
^{125}Te
^{137}Ba
^{139}Ba
^{163}Dy
^{165}Dy
$I_{\gamma\gamma}$, % per decay
E_1,MeV



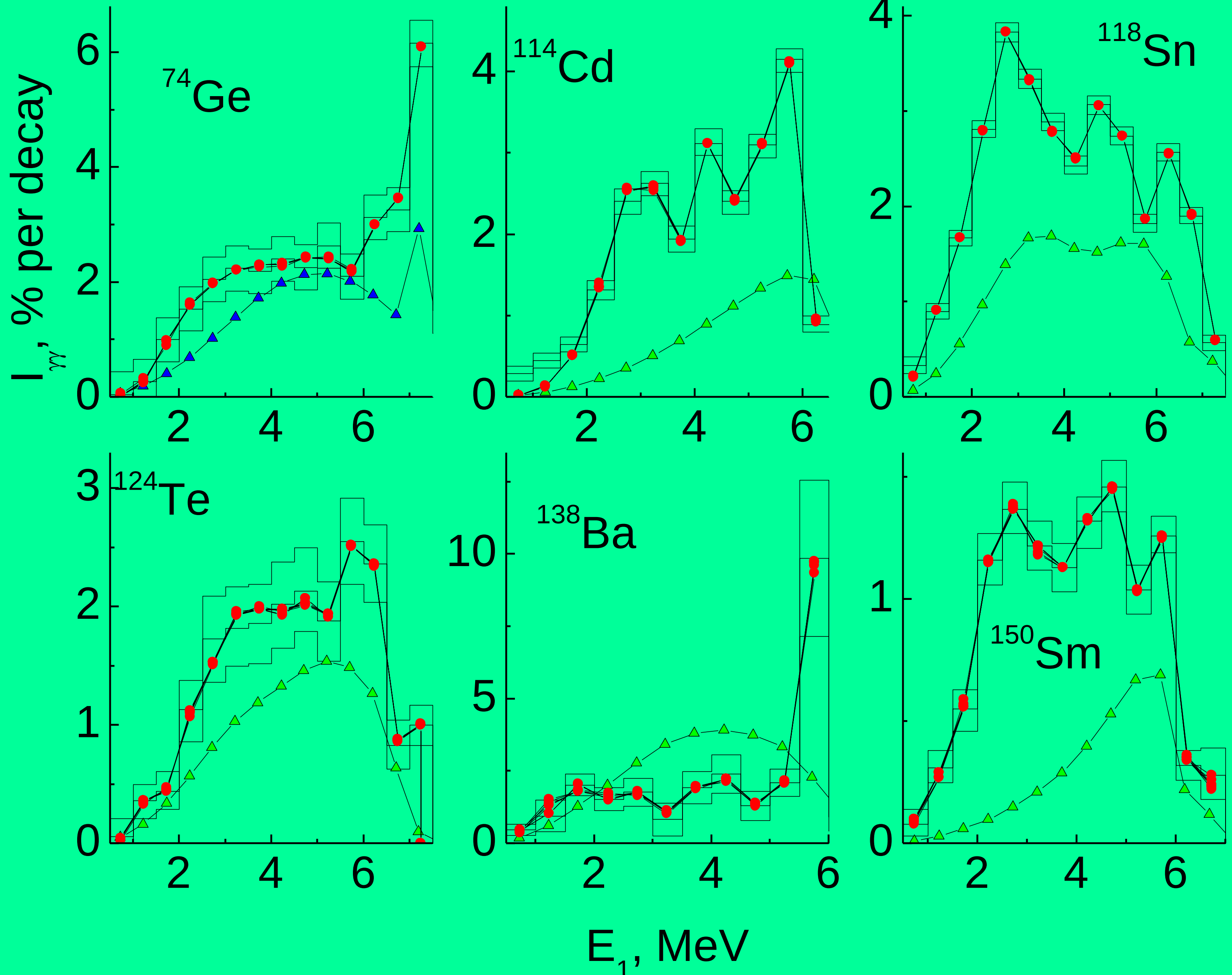
$I_{\gamma\gamma}$, % per decay
^{181}Hf
^{183}W
^{185}W
^{187}W
^{191}Os
^{193}Os
E_1, MeV
0
5
10
2
4
6



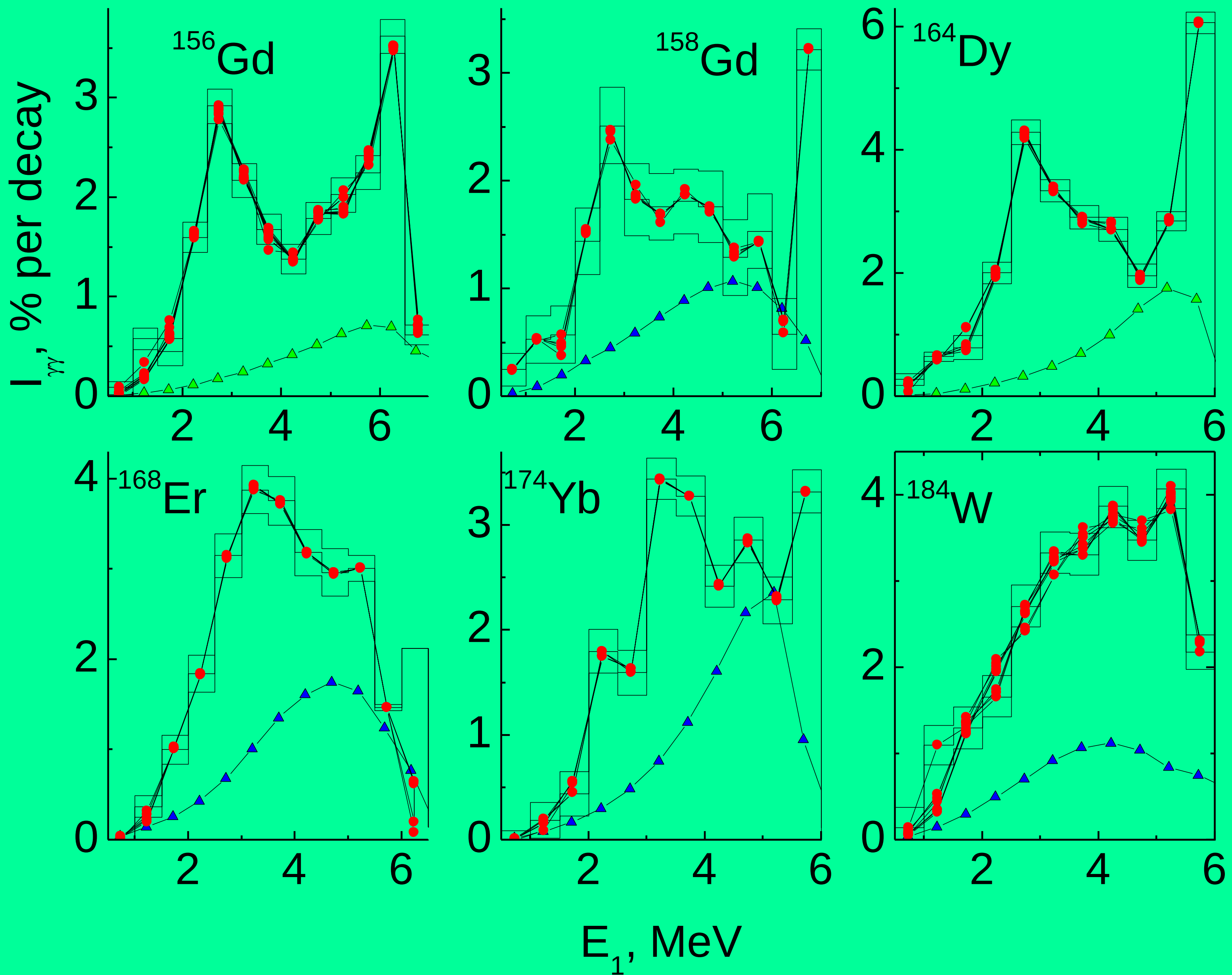
$I_{\gamma\gamma}$, % per decay
E1, MeV
^{40}K
^{60}Co
^{128}I
^{140}La
^{160}Tb
^{166}Ho



170Tm
176Lu
177Lu
182Ta
192Ir
198Au
Iγγ, % per decay
E1, MeV



^{74}Ge
^{114}Cd
^{118}Sn
^{124}Te
^{138}Ba
^{150}Sm
$I_{\gamma\gamma}$, % per decay
E_1, MeV



^{156}Gd
^{158}Gd
^{164}Dy
^{168}Er
^{174}Yb
^{184}W
$I_{\gamma\gamma}$, % per decay
E_1, MeV

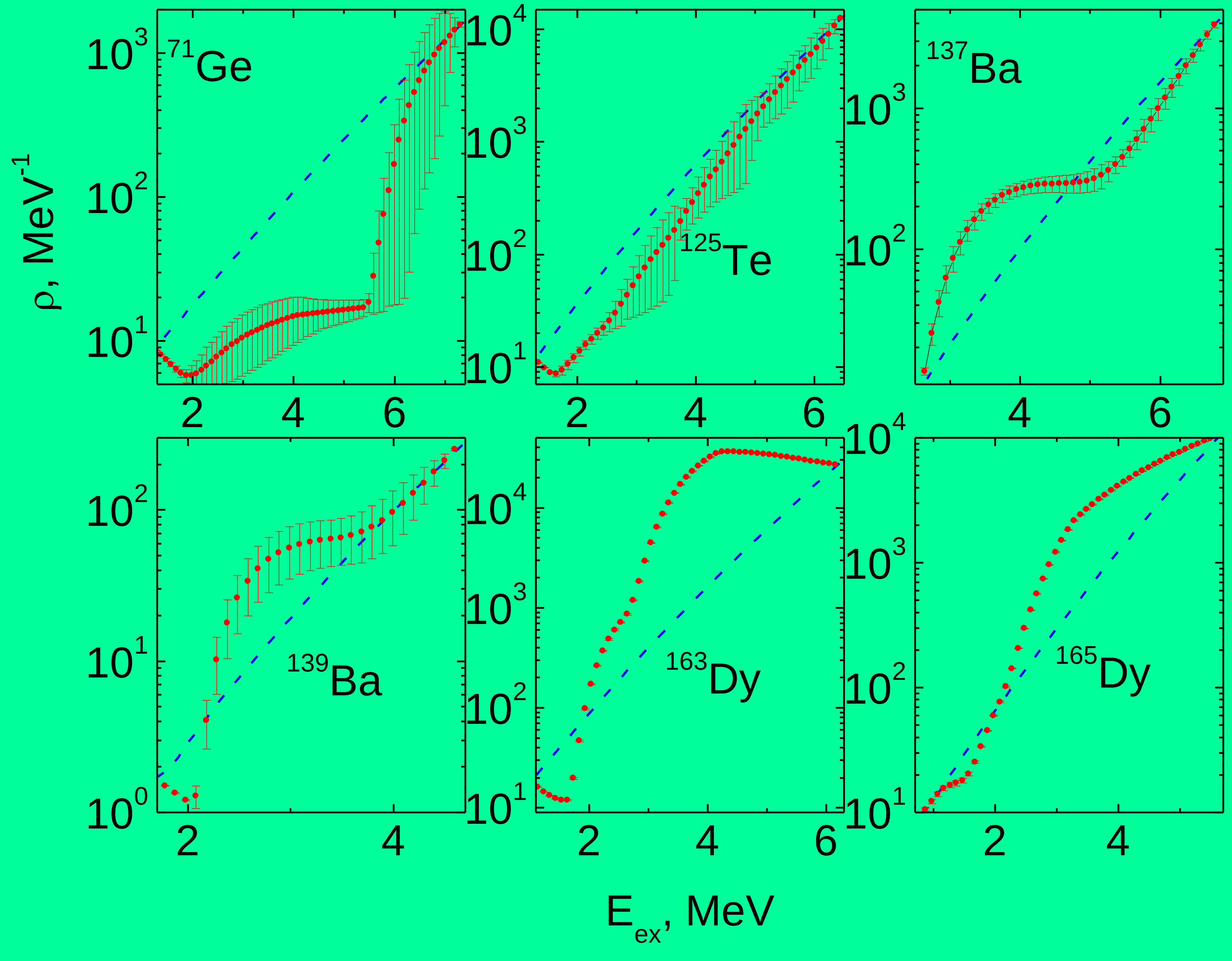
Specific of any experiment

- For all methods of ρ and Γ determination the variations of the spectra δS and of the parameters $\delta\rho$ and $\delta\Gamma$ are connected by equation:

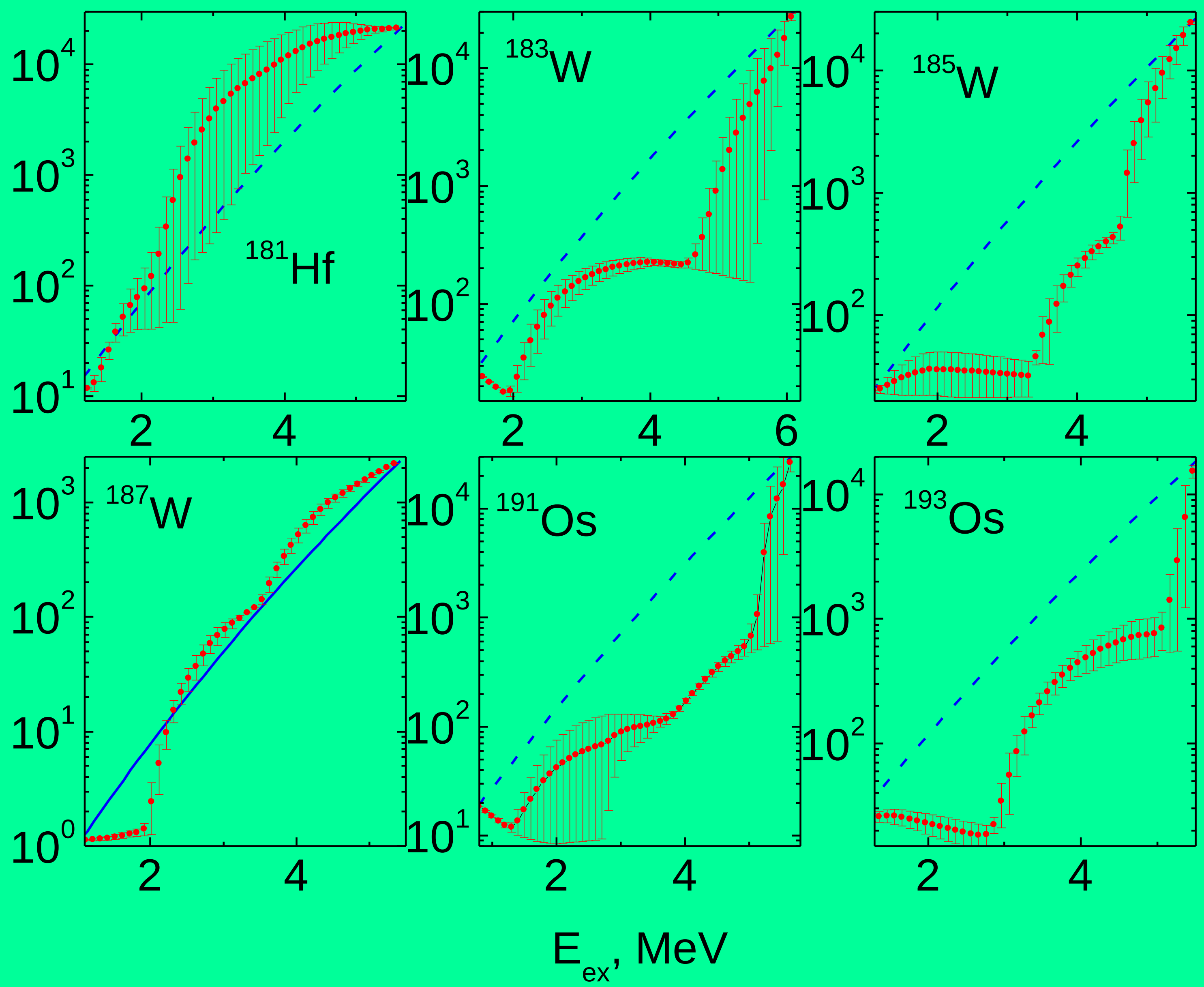
$$\delta S \approx (dS/d\rho)\ \delta\rho \text{ and } \delta S \approx (dS/d\Gamma)\ \delta\Gamma.$$

- All derivations dS/dρ and dS/dΓ here are much less than 1, strongly correlate and depend on excitation energy.

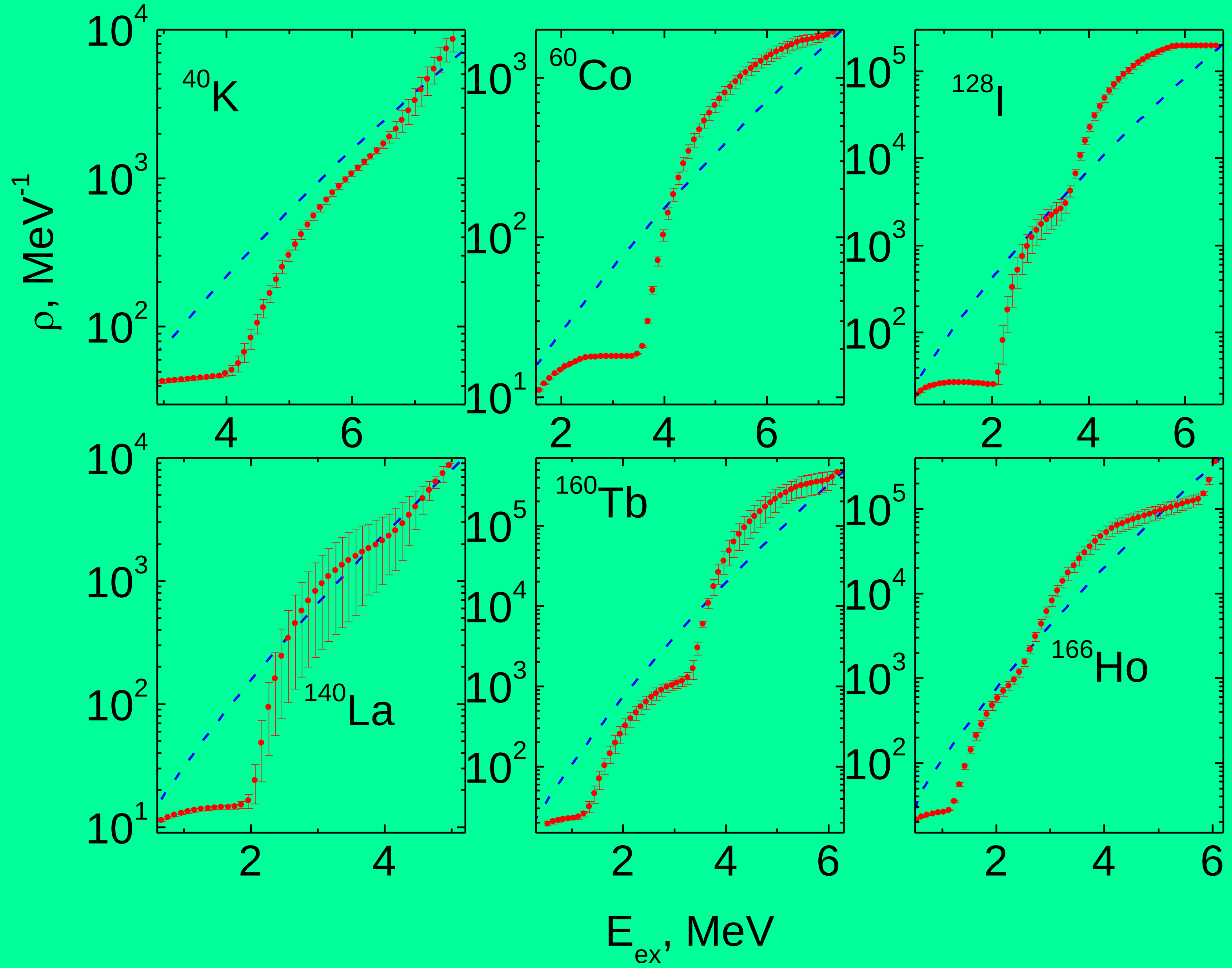
- These values are maximal for registration by the cascade method. As a result, the method provides the minimal errors for ρ and Γ determination.



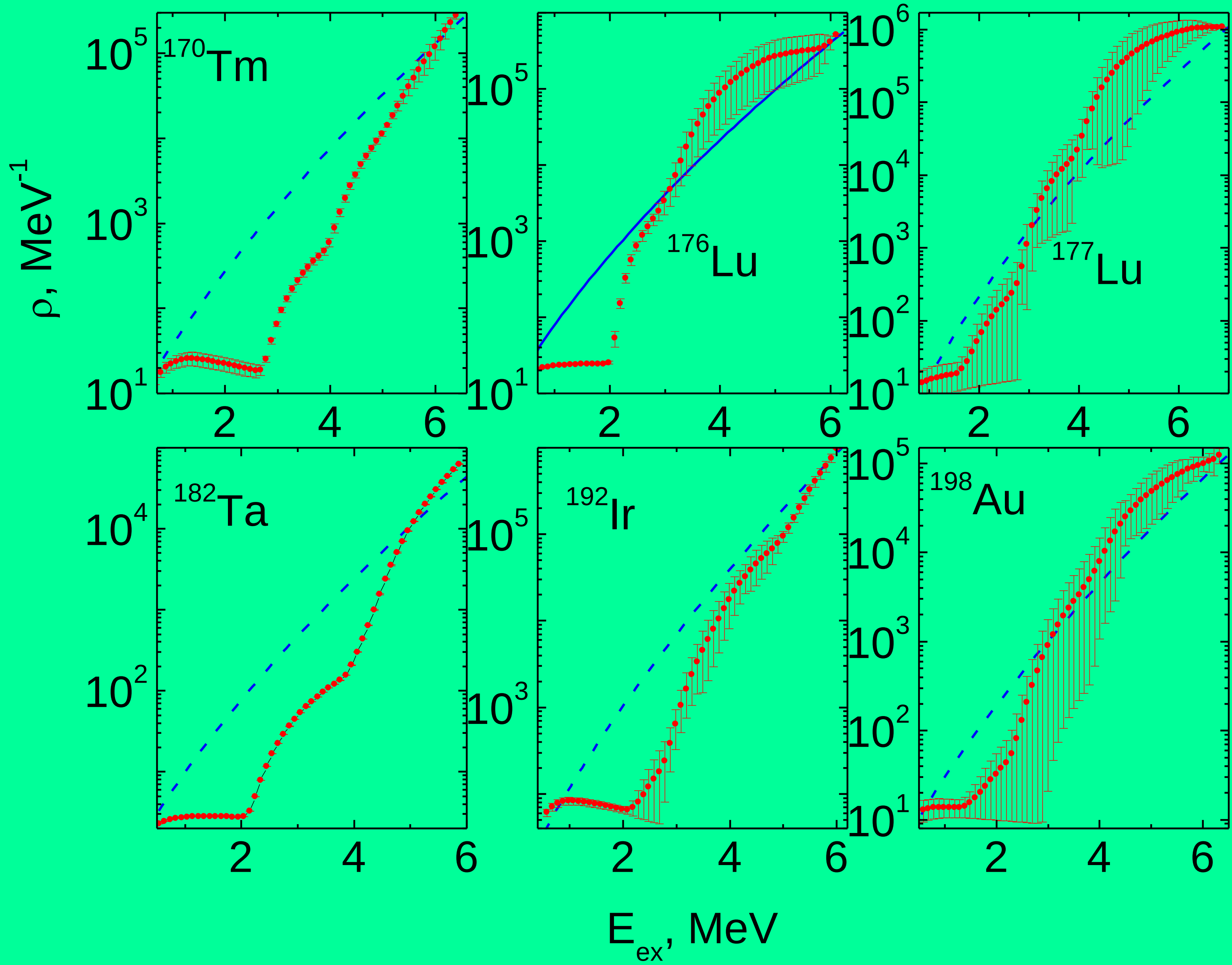
ρ, MeV^-1
E_ex, MeV
71Ge
125Te
137Ba
139Ba
163Dy
165Dy
10^0
10^1
10^2
10^3
10^4
2
4
6



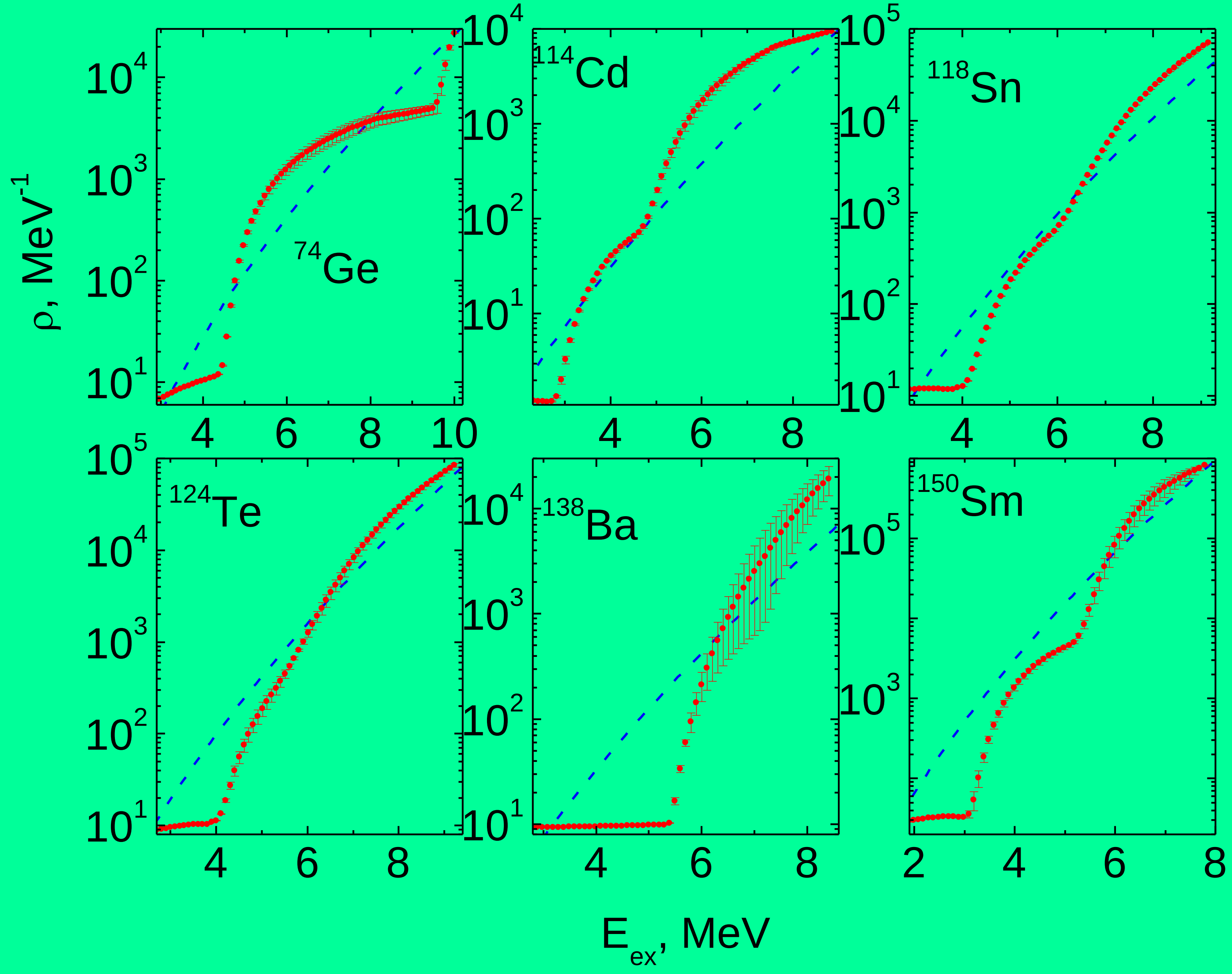
^{181}Hf
^{183}W
^{185}W
^{187}W
^{191}Os
^{193}Os
10^0
10^1
10^2
10^3
10^4
2
4
6
E_{ex}, MeV



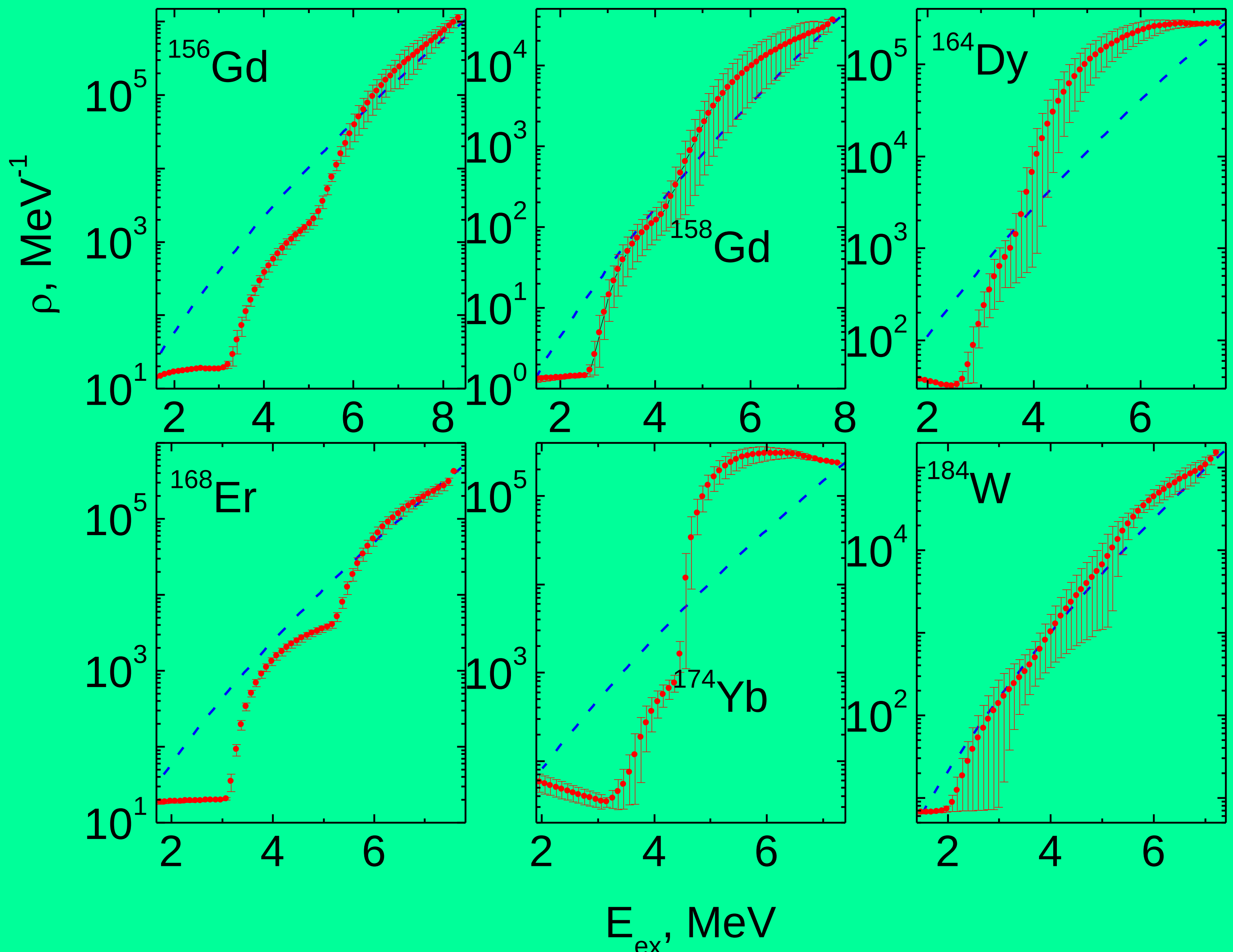
40K
60Co
128I
140La
160Tb
166Ho
ρ, MeV-1
Eex, MeV



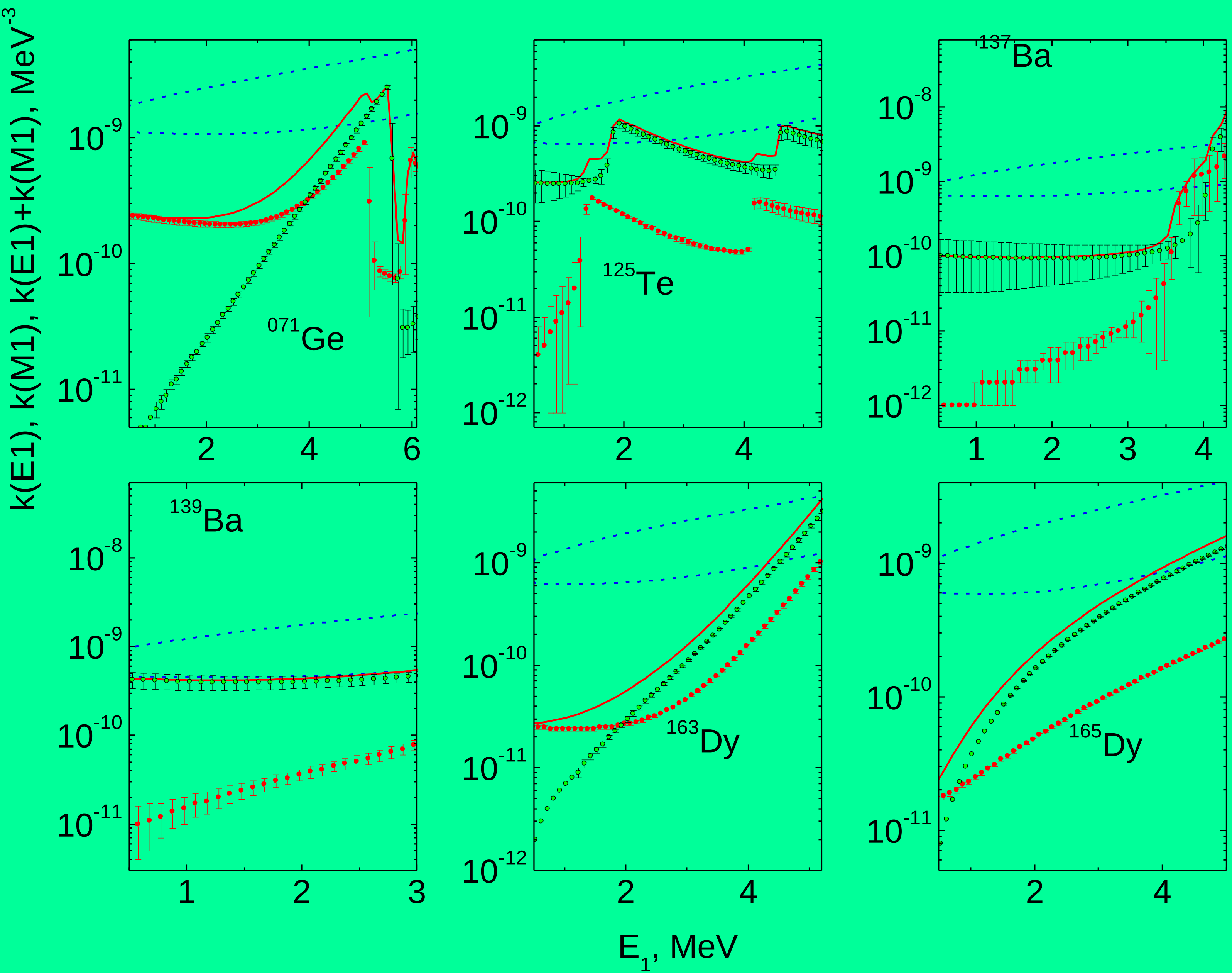
ρ, MeV^{-1}
E$_{ex}$, MeV
^{170}Tm
^{176}Lu
^{177}Lu
^{182}Ta
^{192}Ir
^{198}Au



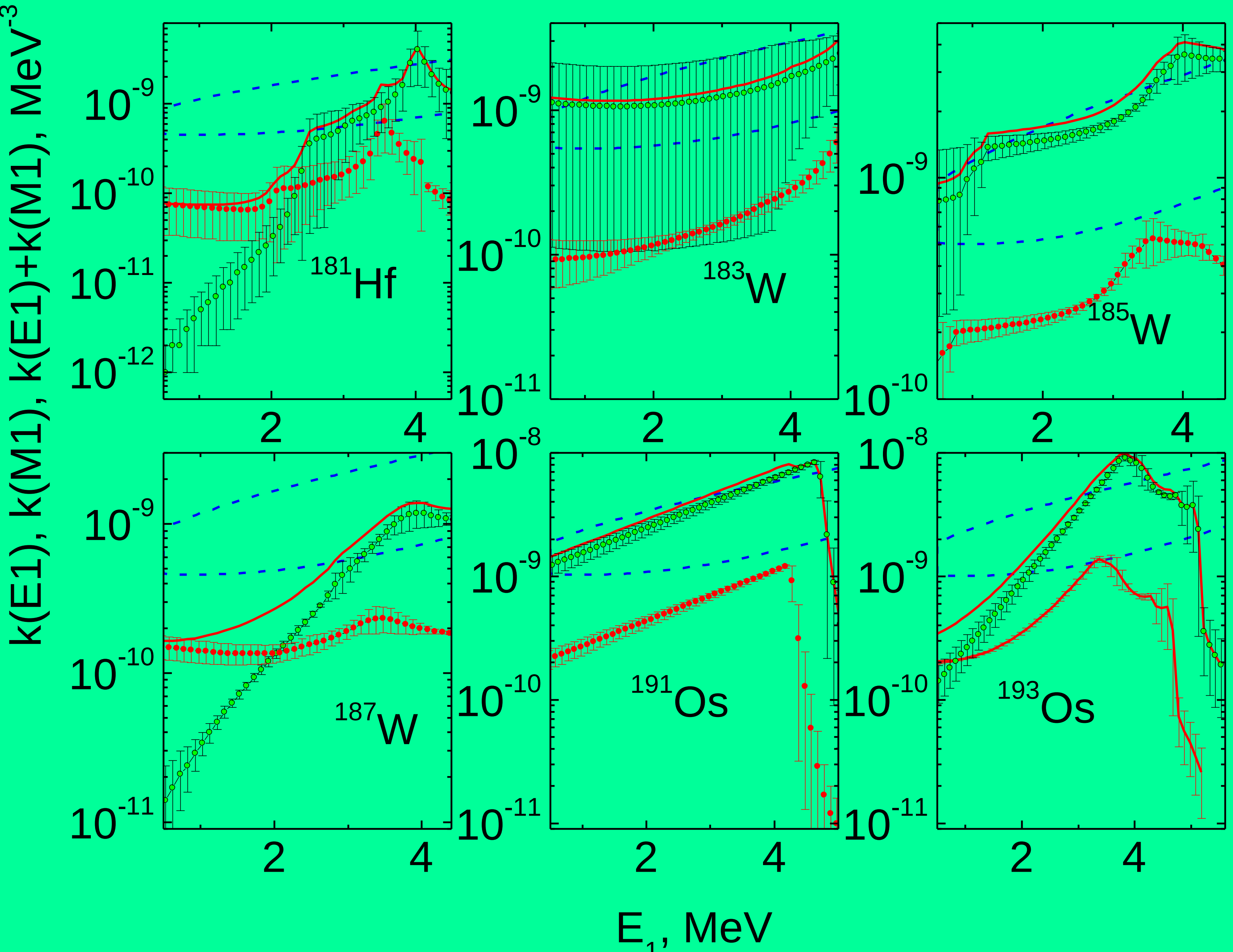
ρ, MeV^-1
E_ex, MeV
74Ge
114Cd
118Sn
124Te
138Ba
150Sm



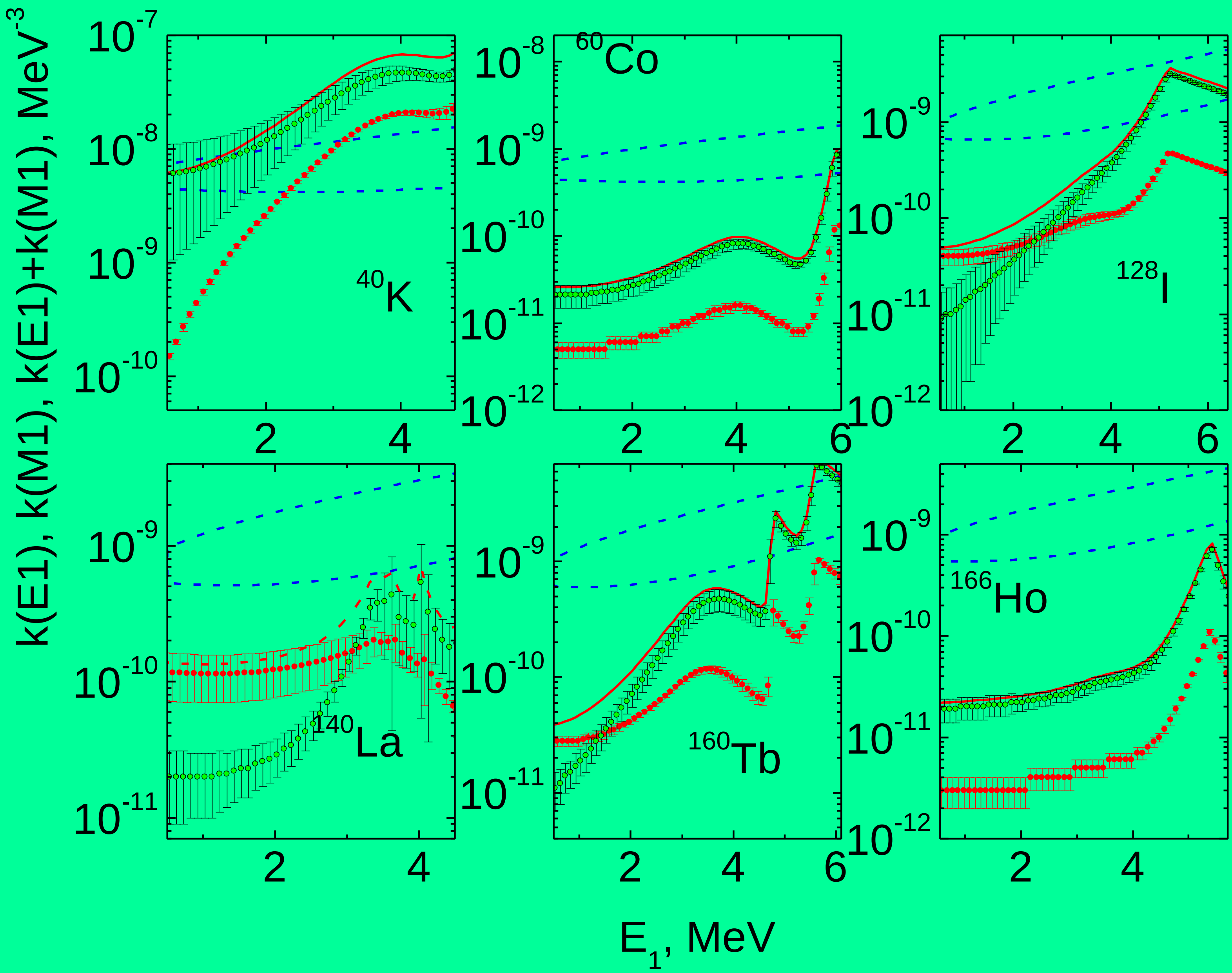
156Gd
158Gd
164Dy
168Er
174Yb
184W
ρ, MeV-1
Ex, MeV

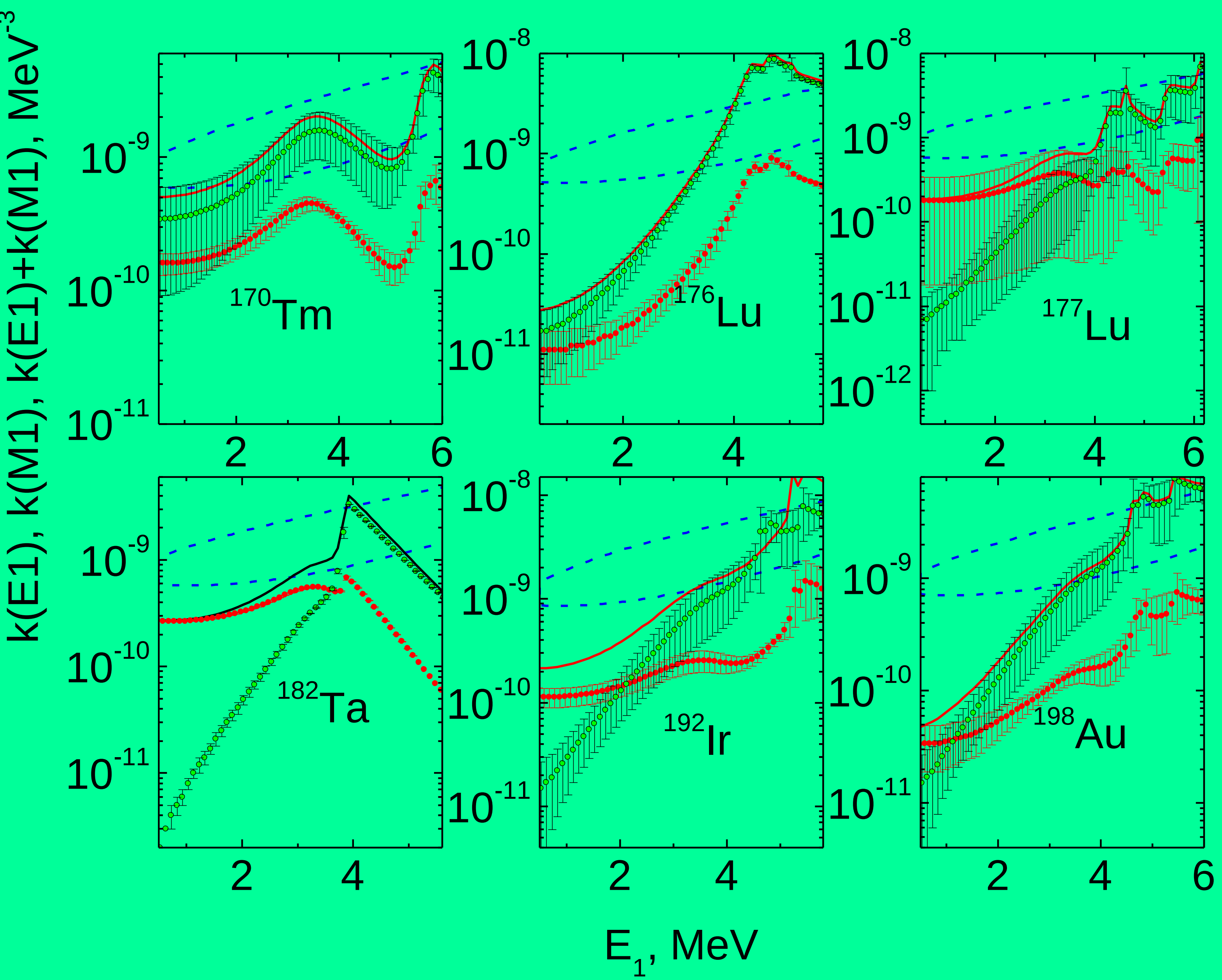


k(E1), k(M1), k(E1)+k(M1), MeV^-3
071Ge
125Te
137Ba
139Ba
163Dy
165Dy
E1, MeV

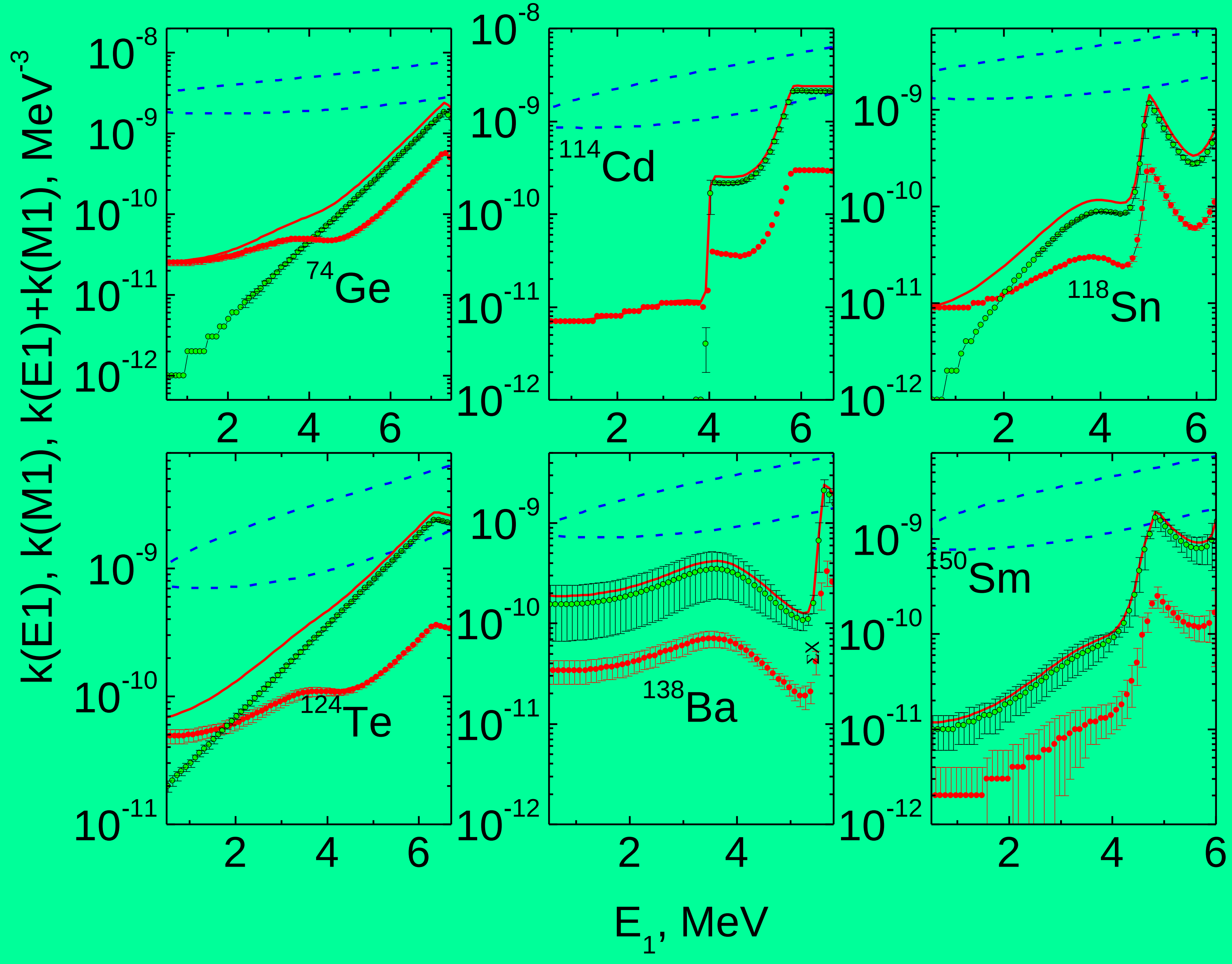


k(E1), k(M1), k(E1)+k(M1), MeV^{-3}
^{181}Hf
^{183}W
^{185}W
^{187}W
^{191}Os
^{193}Os
E$_1$, MeV

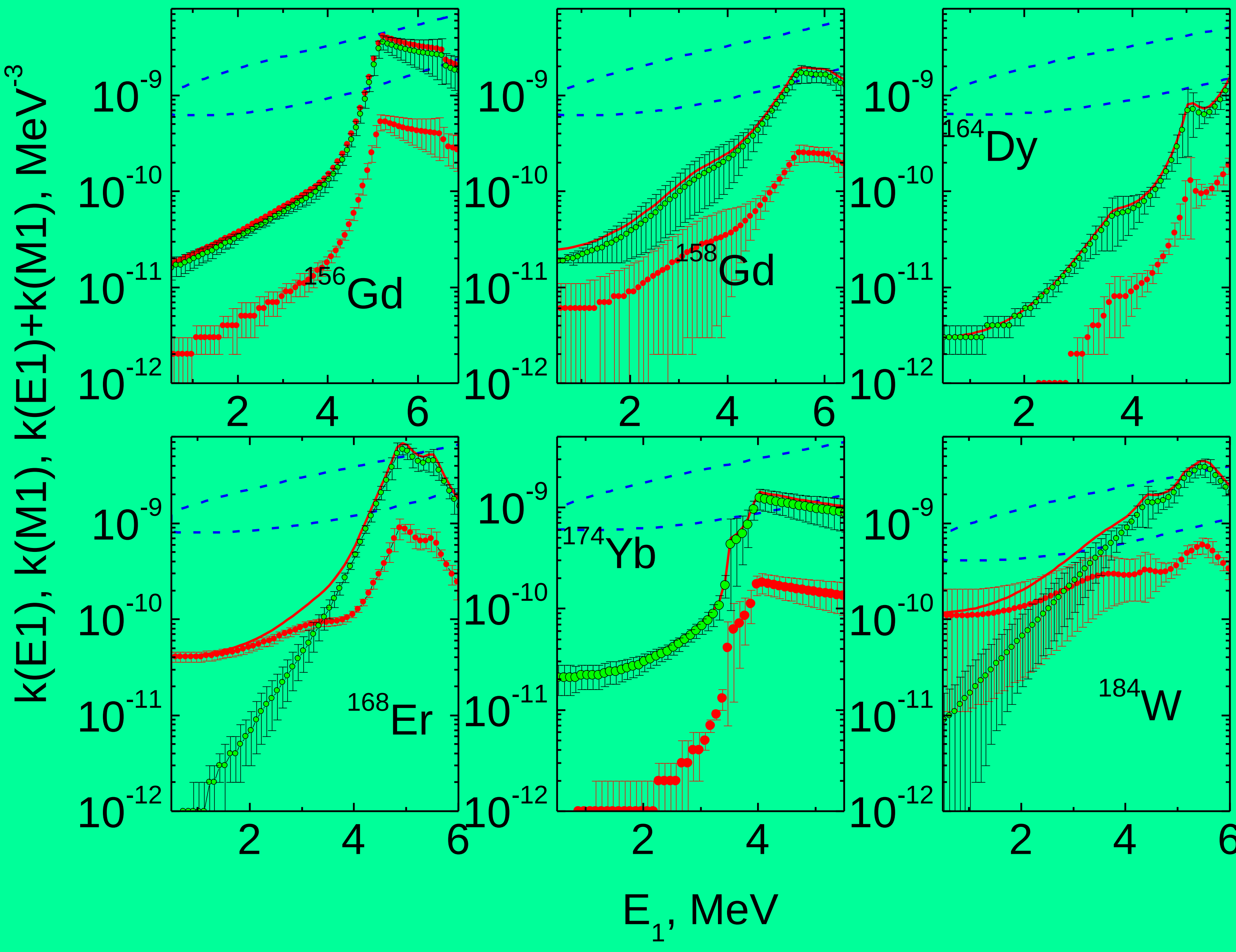

k(E1), k(M1), k(E1)+k(M1), MeV^-3
E_1, MeV
40K
60Co
128I
140La
160Tb
166Ho



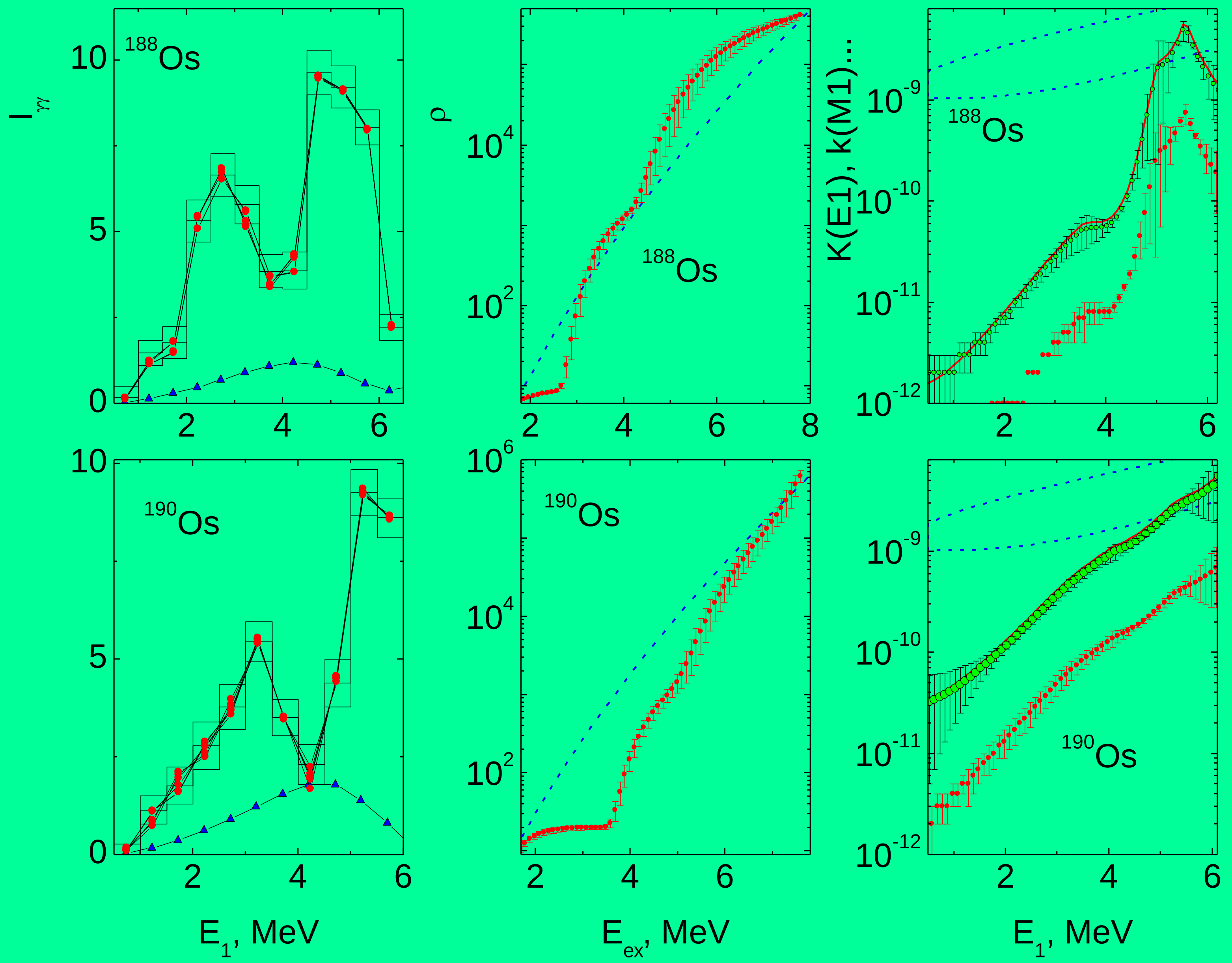
k(E1), k(M1), k(E1)+k(M1), MeV^{-3}
^{170}Tm
^{176}Lu
^{177}Lu
^{182}Ta
^{192}Ir
^{198}Au
E_1, MeV



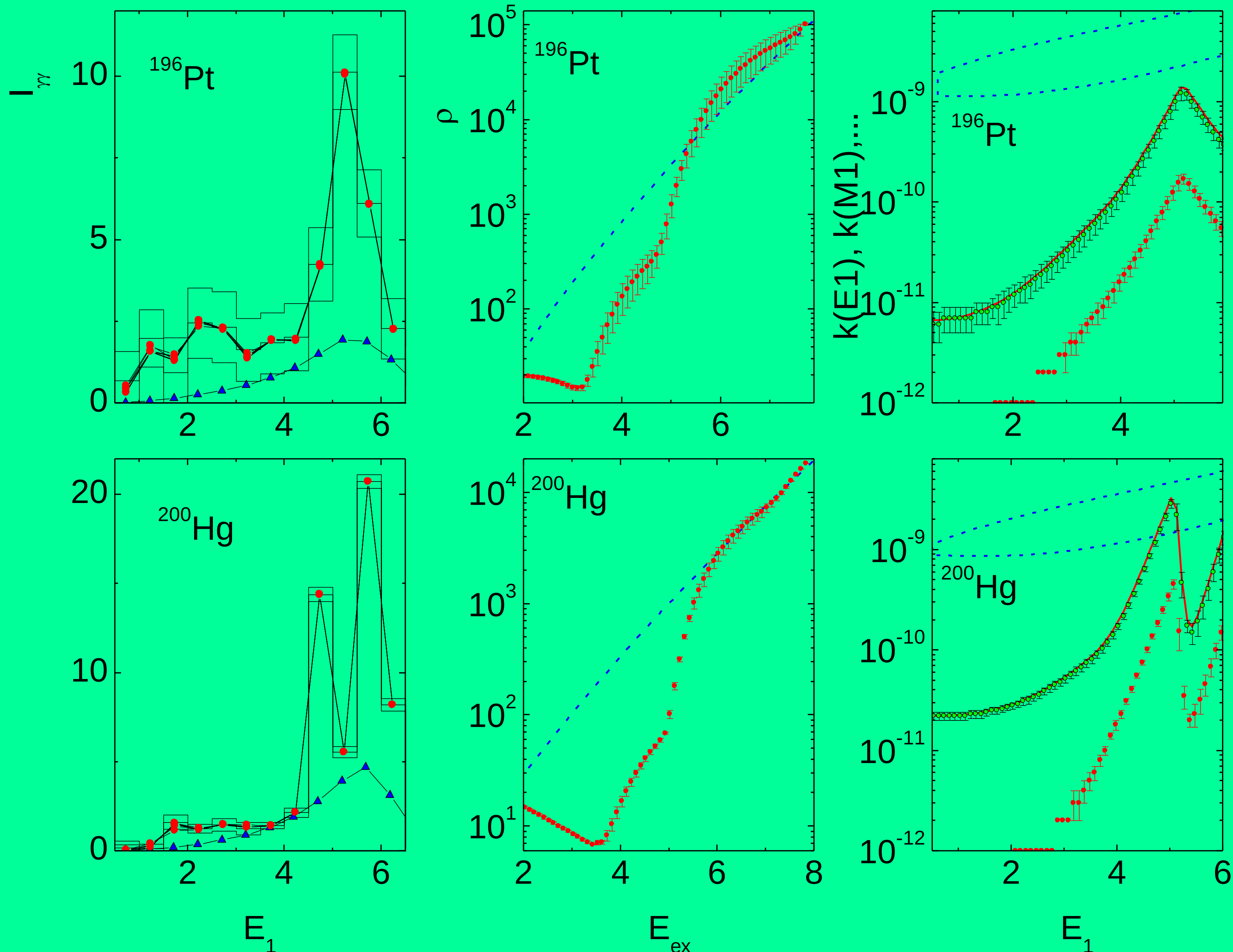
k(E1), k(M1), k(E1)+k(M1), MeV^-3
74Ge
114Cd
118Sn
124Te
138Ba
150Sm
E1, MeV



k(E1), k(M1), k(E1)+k(M1), MeV-3
E1, MeV
156Gd
158Gd
164Dy
168Er
174Yb
184W
10-9
10-10
10-11
10-12
2
4
6

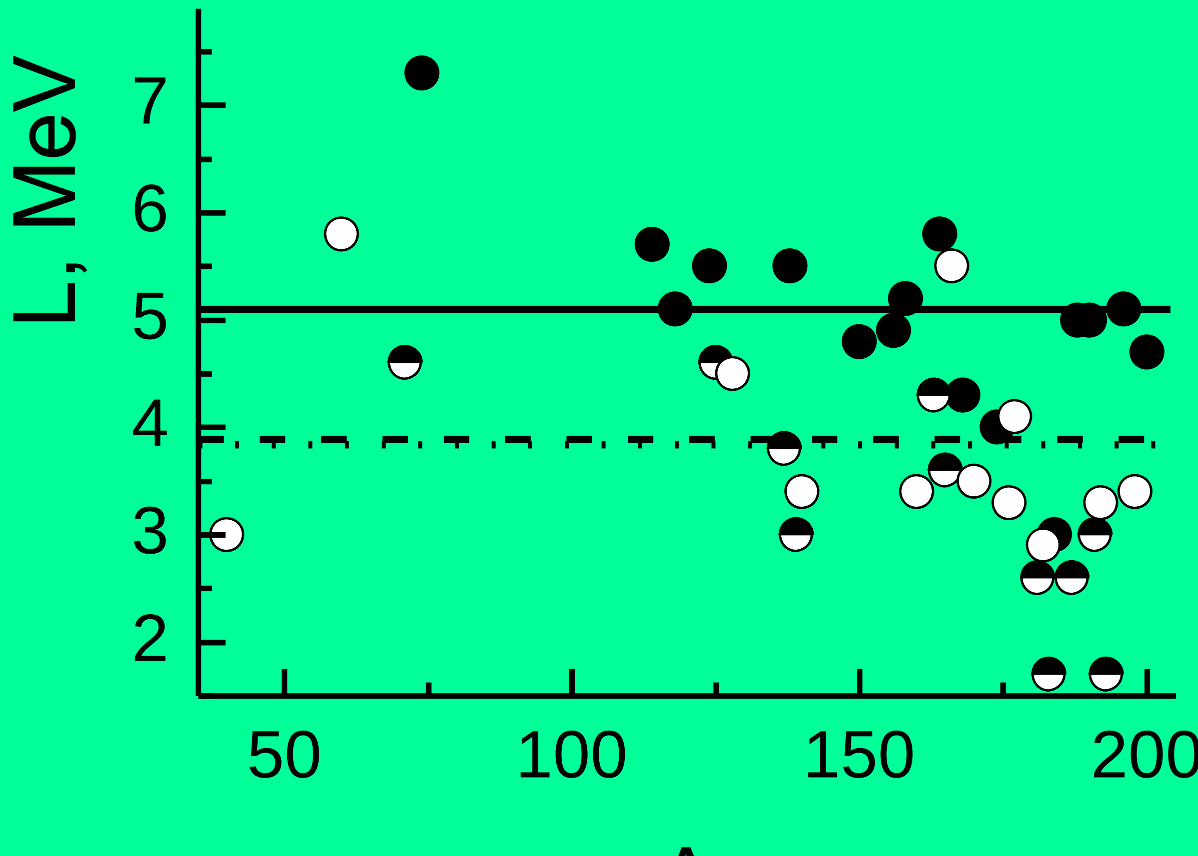


$I_{\gamma\gamma}$
^{188}Os
^{190}Os
E_1, MeV
ρ
E_{ex}, MeV
K(E1), k(M1)...

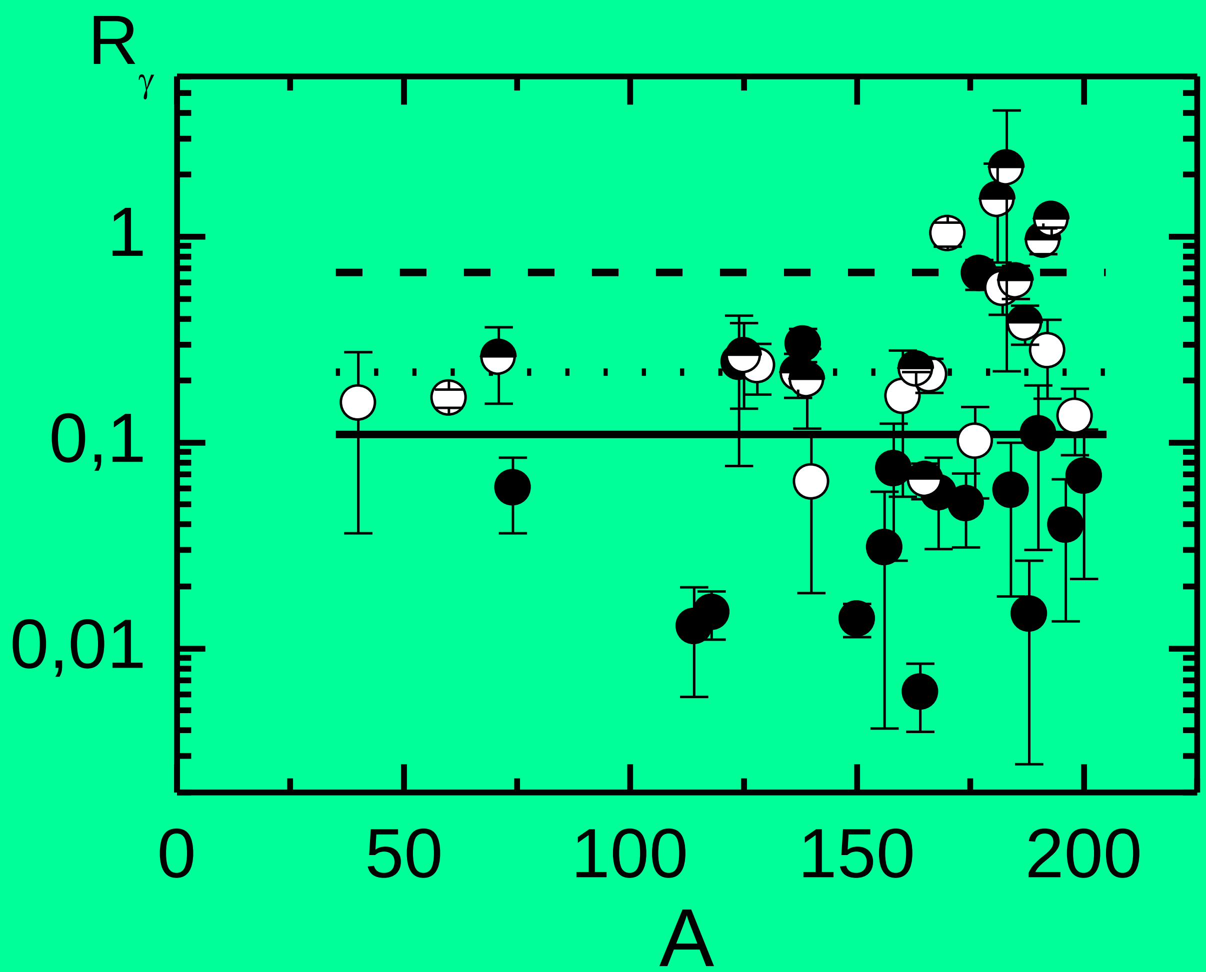


$I_{\gamma\gamma}$
^{196}Pt
^{200}Hg
ρ
E_1
E_{ex}
k(E1), k(M1),...

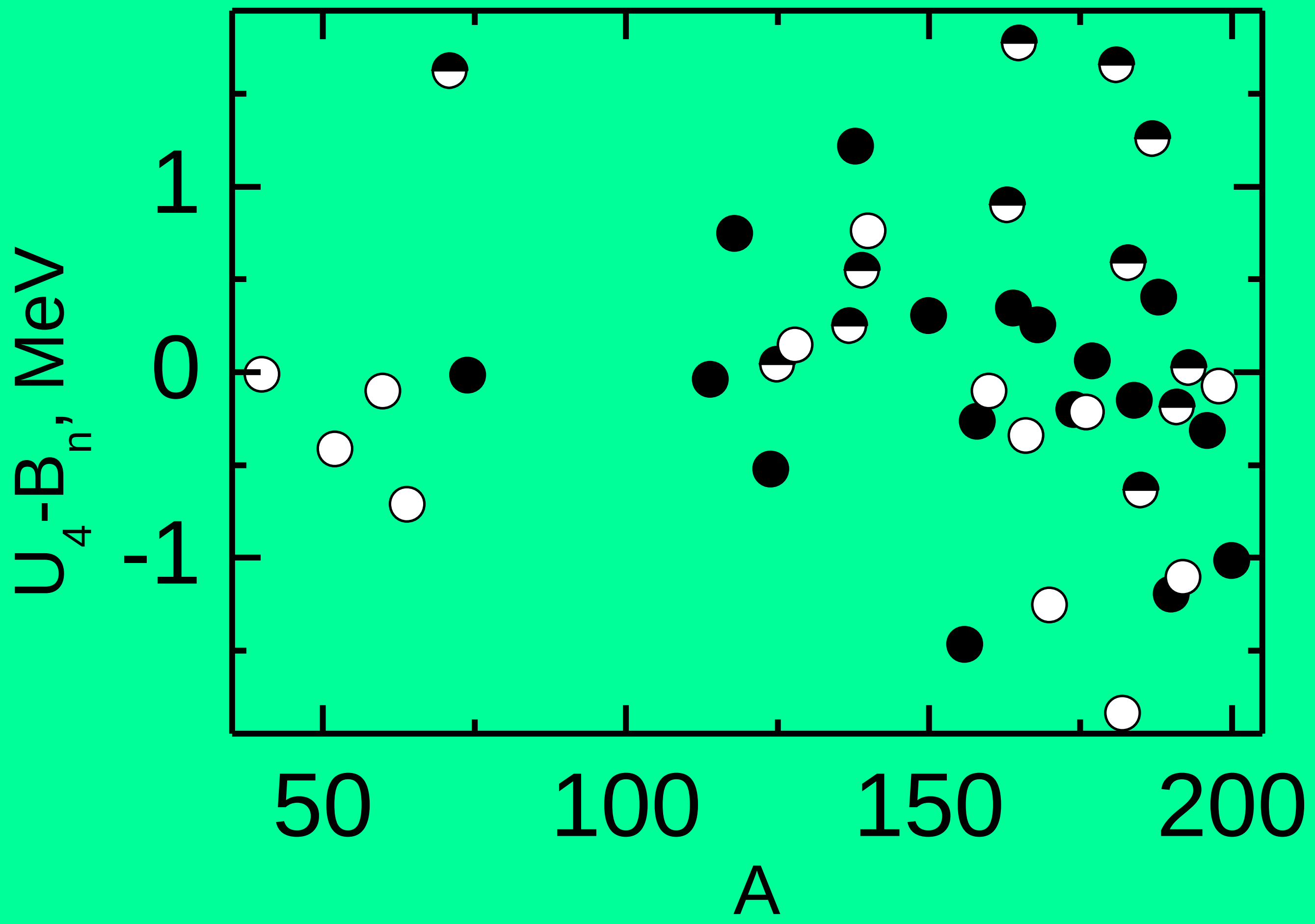
The best fits for the value of the cascade primary gamma-transition energy *L* in the point of equality of the fitting strength functions and ones from [KMF] model

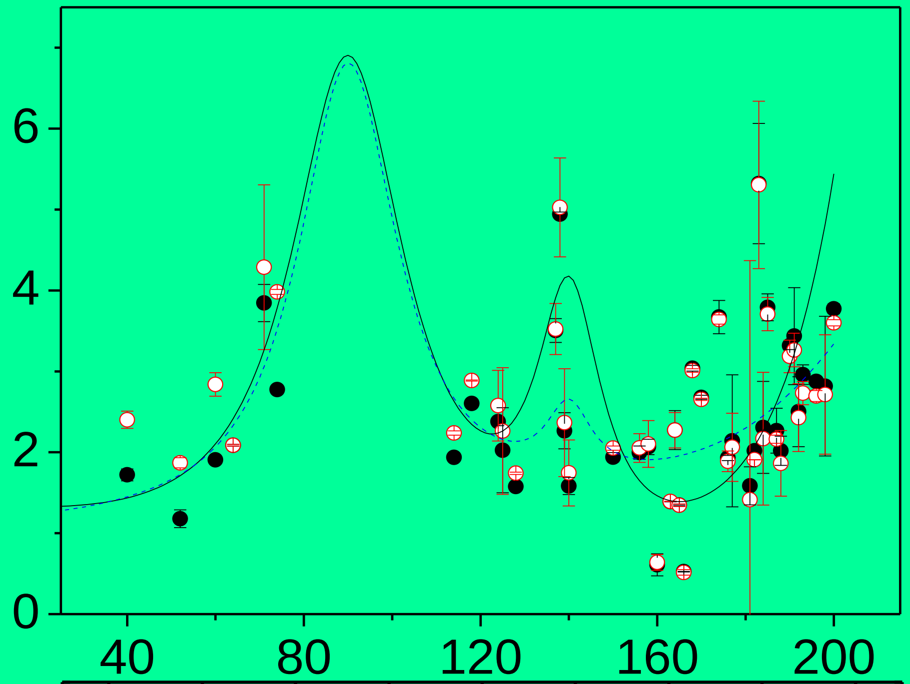


The best ratios of the fitting radiative strength functions to the sum of these functions from [KMF] model for E_1=1 MeV.

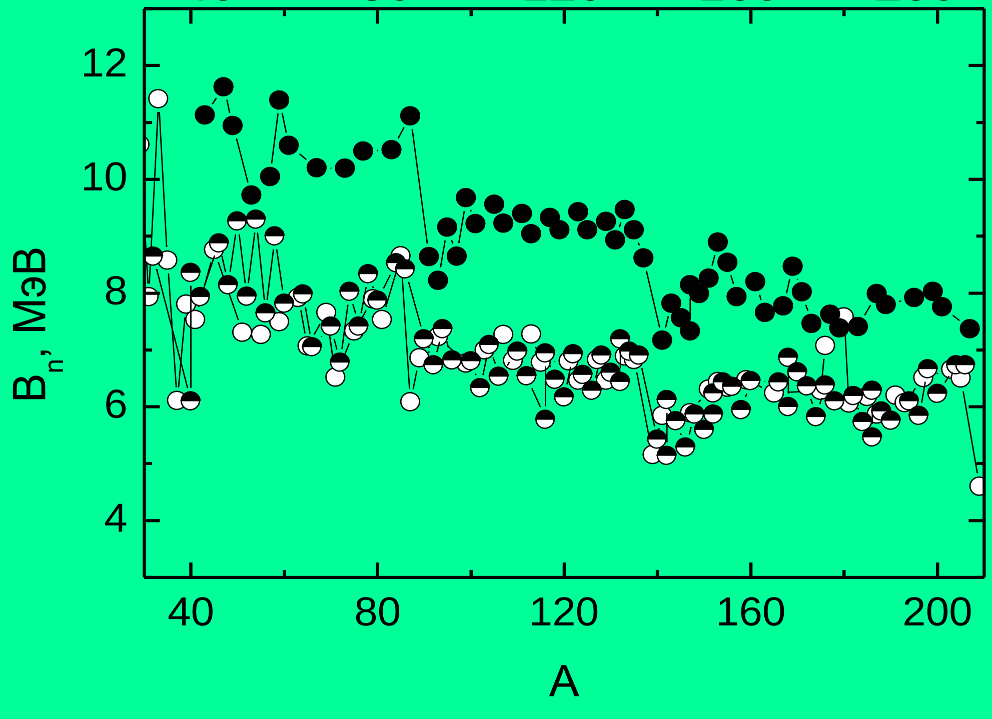


Position of U4-Bn threshold value for the forth pair breaking relative to the mass number of nucleus





Dependence of the thresholds for the second U_2 (black points) and the third U_3 (red open points) Cooper pairs breaking on the nuclear mass *A*. The data of U_2 and U_3 are explored together.

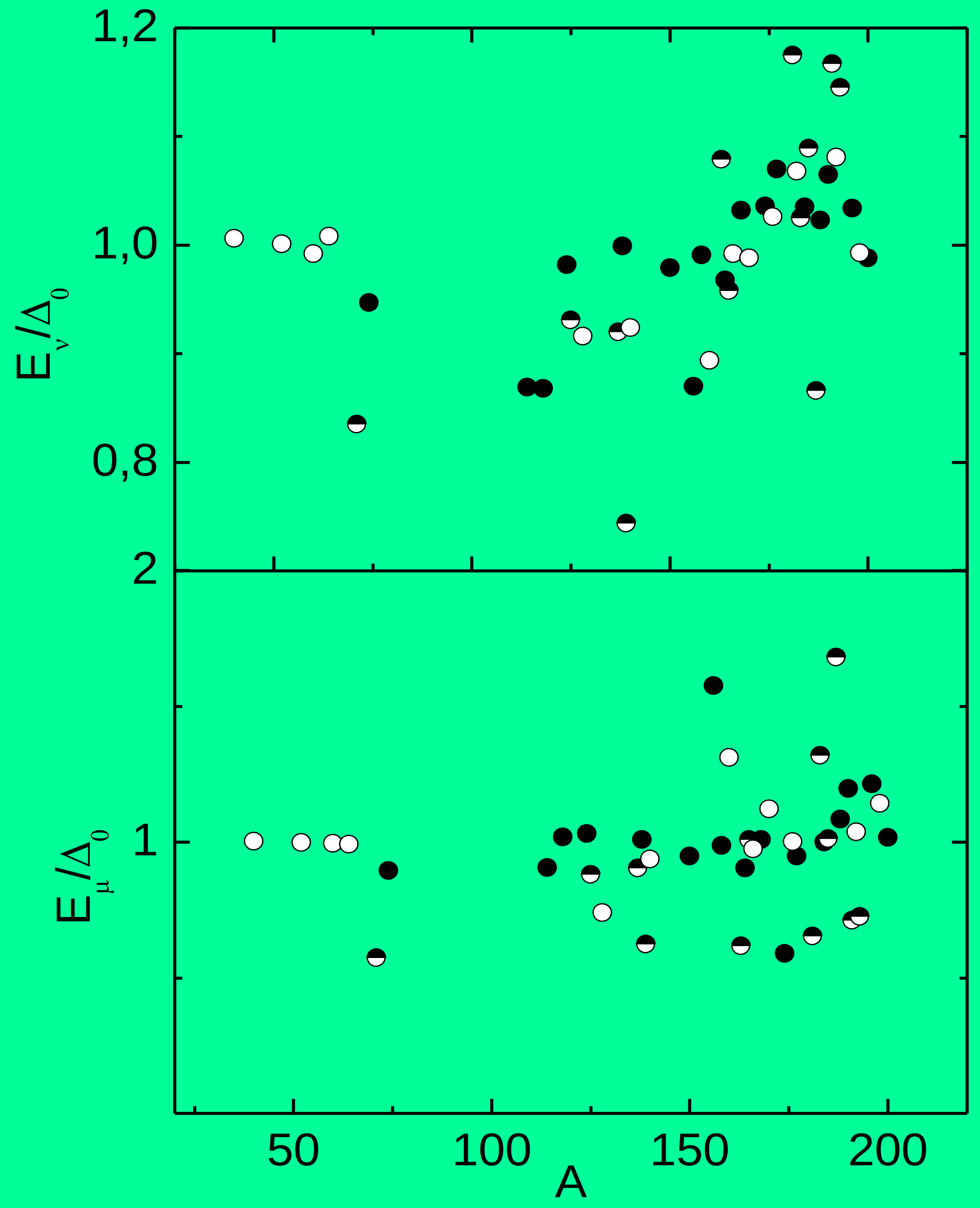


The binding energy for the last neutron for even-even (full circles), even-odd (half open points) and odd-odd (open points) compound nuclei of masses *A*.

Average parameters of Cooper pairs breaking U/δ_0 for the nuclei with even-even (e-e), even-odd (e-o) and odd-odd (o-o) nucleons parities

	Odd-odd nuclei	Even-odd nuclei	Even-even nuclei
Pair number	Average breaking threshold energies for Cooper pairs of nucleons		
2	1.78(68)	2.81(116)	2.71(80)
3	3.27(67)	4.30(118)	4.67(75)
4	5.32(98)	6.41(84)	7.72(55)
Pair number	Averaged coefficient of collective enhancement A_l		
2	30(36)	115(193)	32(52)
3	43(61)	75(84)	88(118)
4	32(34)	86(98)	123(234)
Parameters of vibrational levels contribution			
E_μ	1.02(13)	0.89(32)	1.02(19)
E_ν	0.99(5)	0.99(13)	0.99(5)
Relative part of level density with negative parity of levels			
$P(E_{ex}=E_d)$	0.42(22)	0.32(34)	0.40(32)
$Q(E_{ex}=B_n)$	0.54(50)	0.34(50)	0.24(38)

The best fits of E_μ and E_ν parameters (of phenomenological coefficient C_{coll}) as a function of the nuclear mass



Thank you for your attention