GENERAL TREND AND LOCAL VARIATIONS OF NEUTRON RESONANCE CASCADE GAMMA-DECAY RADIATIVE STRENGTH FUNCTIONS

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Introduction

- Obtain accurate experimental values of **the level density and radiative strength functions is necessary**.
- **It is necessary to develop the method for determination of ρ and Γ**
- Main problem : **FWHM >> D_i**
- Two-step gamma cascade method

- Dependence form of the radiative strength functions (RSF) of electric and magnetic dipole gamma-transitions in heated nucleus on the excited level density
- New hypothesis: modified dependence of RSF on level density

- **The region** of possible values of random **values of the level density and radiative strength functions** which precisely reproduced experimental intensity of **two-step cascades for 41 nuclei from ^{40}K to ^{200}Hg was determined.**

1. Status of modern experiments for determination of radiative strength functions and the level density

- **a) One – step reaction**

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

- the precision of cross sections reproduction is determined **only by the product of these variables but not by absolute values of ρ and Γ**

- **the hypothesis of independence of both, ρ and Γ**, on structure of wave function of nucleus excited levels must be used

- it is necessary to use the model calculated parameters Γ

- **b) Two-step cascade quanta**

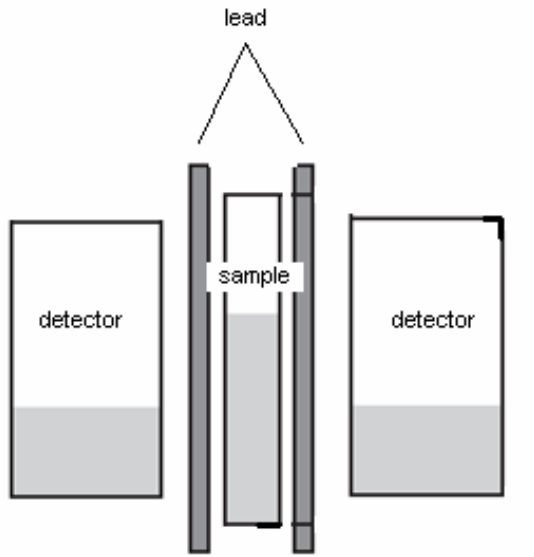
$$I_2 \propto \Gamma / \sum(\rho\Gamma)$$

- detected cascade intensity depends on both, shapes of Γ and ρ parameters energy dependence and absolute value of the level density
- obtaining information of nuclear structure parameters **without introduction of theoretical models in experimental data fitting**
- possibility to obtained information about influence of real nuclear structure to gamma decay parameters

2. Dubna two-step gamma cascade method

Dubna method of nuclear structure parameters estimation using measurements of **two-step gamma cascades following thermal neutron captures**

Using **ordinary HPGe detectors** in **coincidence regime** of measurement



Advantages of Dubna method:

1. ability to **obtained levels scheme**
2. possibility to **test different theoretical prediction**
3. obtaining information of nuclear structure parameters **without introduction of theoretical models in experimental data fitting**
4. obtaining **more reliable and precise values of nuclei structure** parameters (level density, radiative strength function or partial radiative width) than by other methods (smaller systematic errors than in other methods)

2. Dubna Two-step gamma cascade method

Intensity of two-step gamma cascades:

$$I_{\gamma\gamma}(E_1) = \sum_{\lambda,f} \sum_{i} \frac{\Gamma_{\lambda i}}{\Gamma_{\lambda}} \frac{\Gamma_{if}}{\Gamma_{i}} = \sum_{\lambda,f} \frac{\Gamma_{\lambda i}}{<\Gamma_{\lambda i}>} m_{\lambda i} \rho_i \Delta E \frac{\Gamma_{if}}{<\Gamma_{if}>} m_{if}$$

Equation connecting two- step gamma cascade intensity and **ρ and Γ is undoubtedly degenerated.**

N values of experimental cascade intensities always can be converted in ~**2N values of ρ and Γ** which satisfy conditions:

$$\rho_1 \le \rho \le \rho_2 \qquad \Gamma_1 \le \Gamma \le \Gamma_2$$

Using **iterative process** with randomly chosen functions ρ and Γ, it is possible to obtain the most **probable values of level density and radiative width (or radiative strength function).**

3. **Possibilities of development of the effective method for determination of ρ and RSF from $I_{\gamma\gamma}$**

Previous results:

- ^{59}Co*(p,2γ)* ^{60}Ni - reveal very significant increase in mean intensity of the primary *E1*-transition from *p*-resonances to two-phonon level of 2.5 MeV (qualitatively corresponding to predictions of QPMN)
- Significant increase of cascade population of levels in region around $0.5B_n$ for ~ 20 nuclei in mass region from 40 to 200 can be explained at present time only by increase of strength functions values of any cascade gamma-transitions to intermediate levels of, probably, vibration type excitation in energy region of the second (and, possibly, following) nucleons Cooper pairs breakup threshold.
- Evaporation nucleons spectra in reaction ^{181}Ta*(p,n)* ^{181}W showed that the excellent reproduction of the Obninsk experimental data can be achieved at accounting of local significant increase of parameter *T* for excitation energy which does not practically depend on beam protons energy.

3. Possibilities of development of the effective method for determination of ρ and RSF from $I_{\gamma\gamma}$

- **The main defect** of the existing methods for determination of ***ρ*** **and** ***Γ*** is absolute **lack of model ideas on form of functional relation of these parameters** with each other and with real structure of nucleus.
- The level density determined from (n,2γ) reaction, is described in the best way by the **Strutinsky model.**
- Perspective models of ρ and Γ must take in account **coexistence of levels of phonon and quasi-particle types** and inevitable difference between radiative strength functions of gamma-transitions between them.
- Modern models of a nucleus (like QPMN or IBMF) to more or less extent take this difference into account. But, unfortunately, in form which is unfit for practical analysis of the experimental data.
- It is necessary to **develop phenomenological models** for description of experimental set values of nuclear structure parameters.
- At present this can be **partially performed for radiative strength functions** of cascade gamma-transitions.

3. Possibilities of development of the effective method for determination of ρ and RSF from $I_{\gamma\gamma}$

The modified usual strength function *k* of dipole transitions in case of gamma-quantum emission is determined by relation:

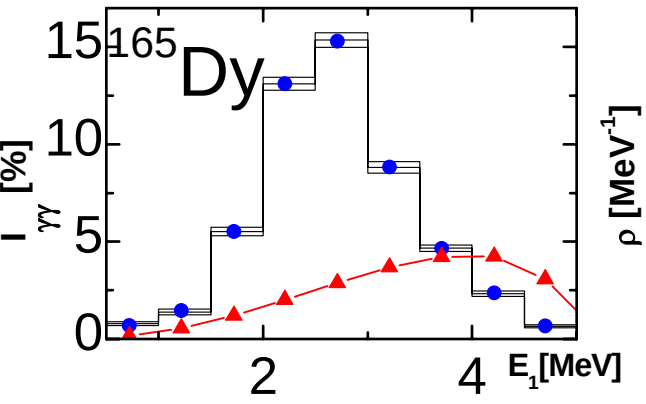
$$K_{\mathrm{modif}} = k_{\mathrm{standard}} \cdot \frac{D_{fg}}{D_i} = \frac{\Gamma_{\lambda i}}{E_\gamma^3 A^{2/3} D_\lambda} \cdot \frac{D_{fg}}{D_i}$$

instead of standard presentation: $k_{standard} = \Gamma_{\lambda i.} / (E_\gamma^3 \; A^{2/3} \; D_\lambda)$

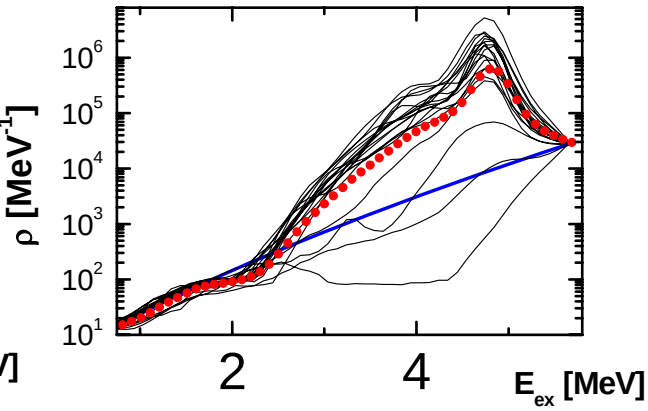
- D_{fg} - spacing between levels of Fermi-Gas model in case of absence of collective type excitations
- D_i fitted (experimental) value

$$K_{\mathrm{modif}} = k_{\mathrm{standard}} \cdot \frac{\rho_{\mathrm{exp}}}{\rho_{fg}}$$

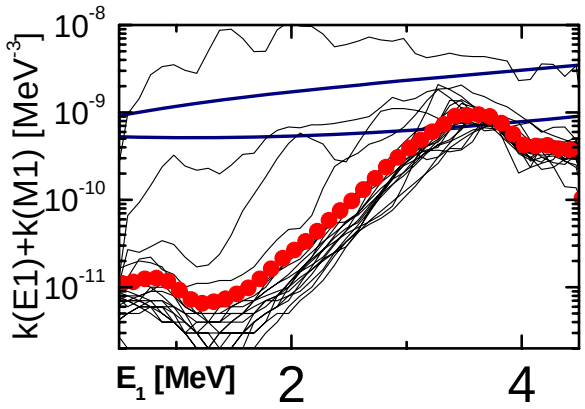
4. Results of practical approximation of two-step cascades intensity for proposed model



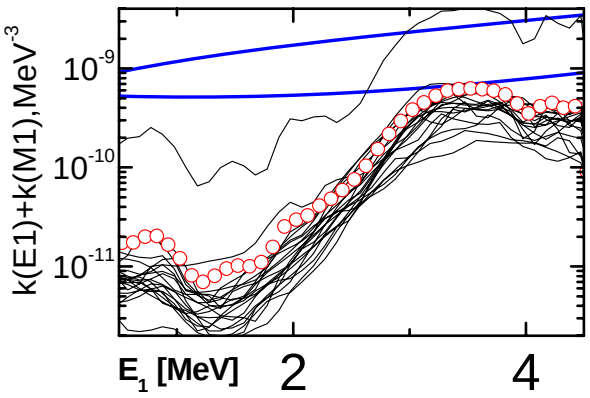
Measured and approximated values of two- step gamma cascade intensity



Level density



Modified RSF

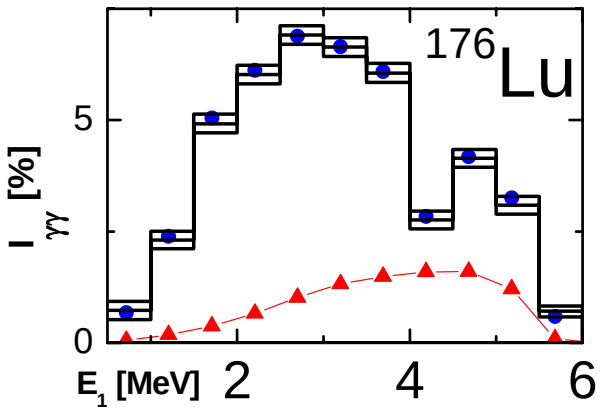


Standard RSF

level density - Fermi-gas model

RSF model– Kadmenskij, Markushev, Furman

4. Results of practical approximation of two-step cascades intensity for proposed model



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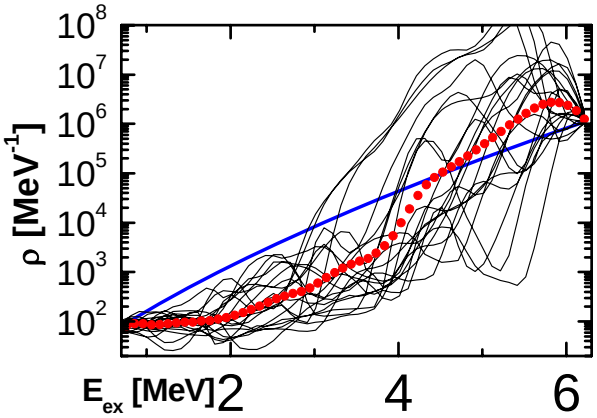
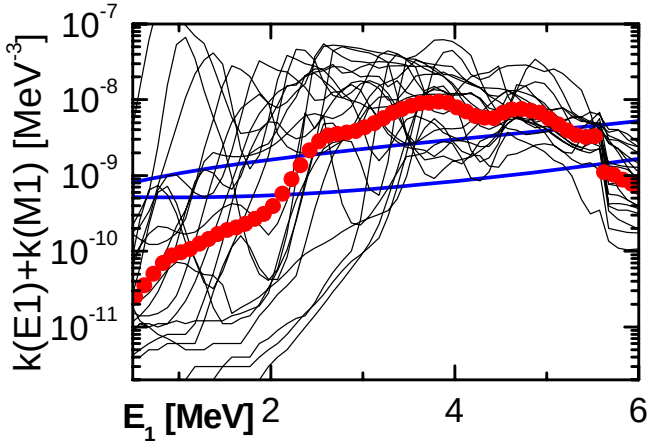
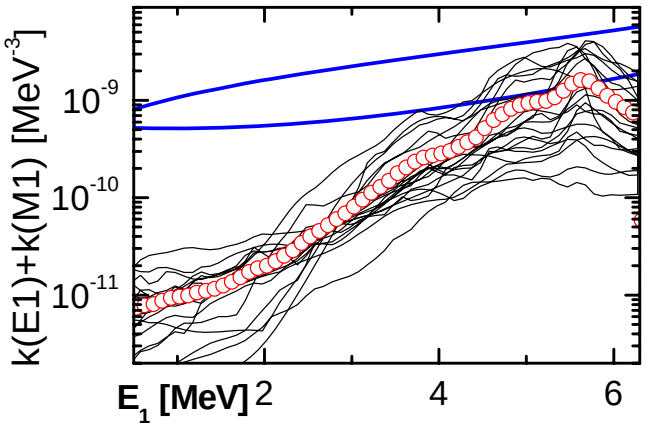


Level density



Modified RSF



Standard RSF

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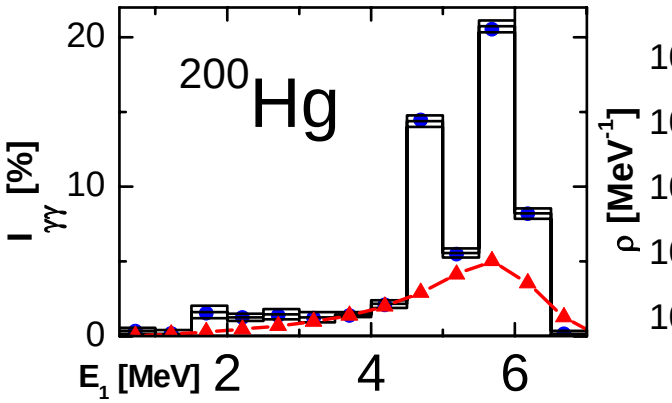
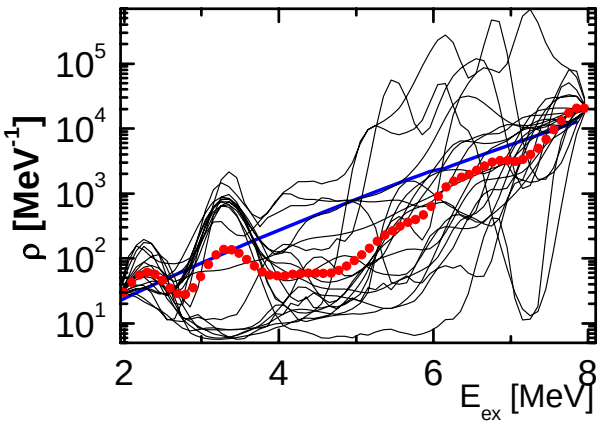
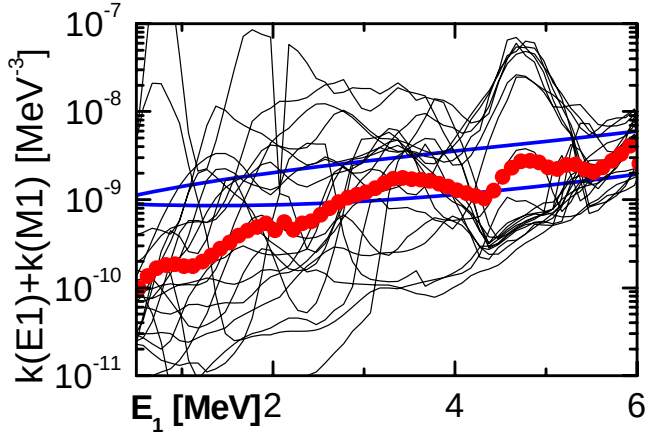


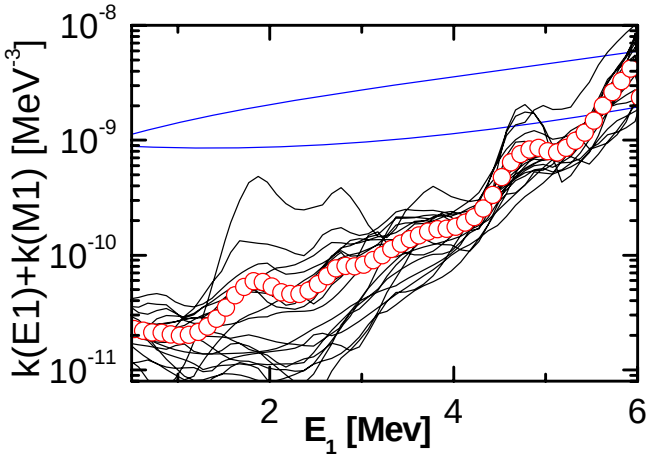
Measured and approximated values of two- step gamma cascade intensity



Level density

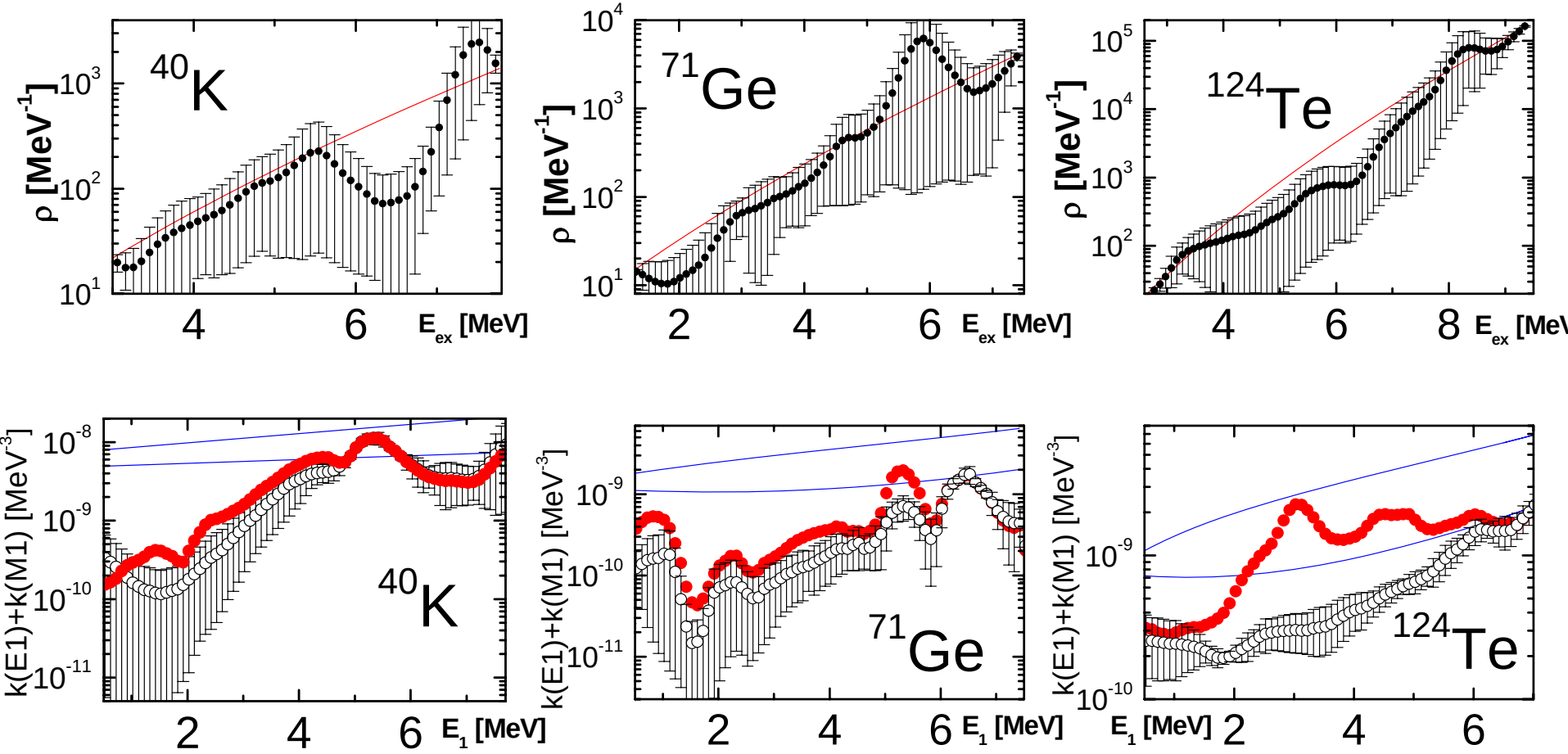


Modified RSF



Standard RSF

4. Results of practical approximation of two-step cascades intensity for proposed model



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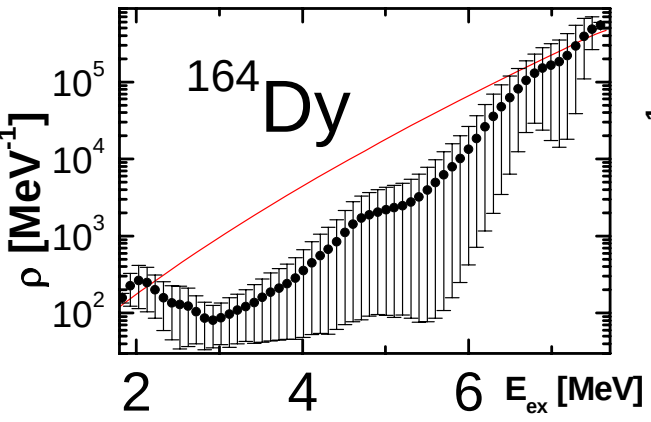
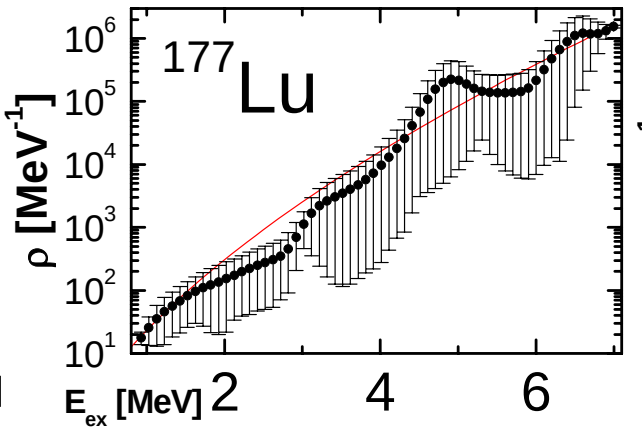
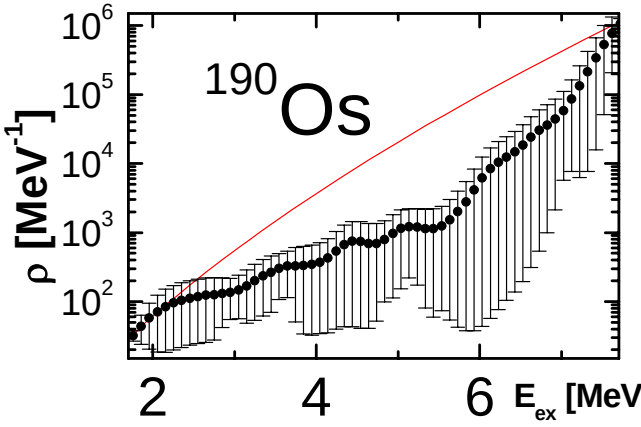
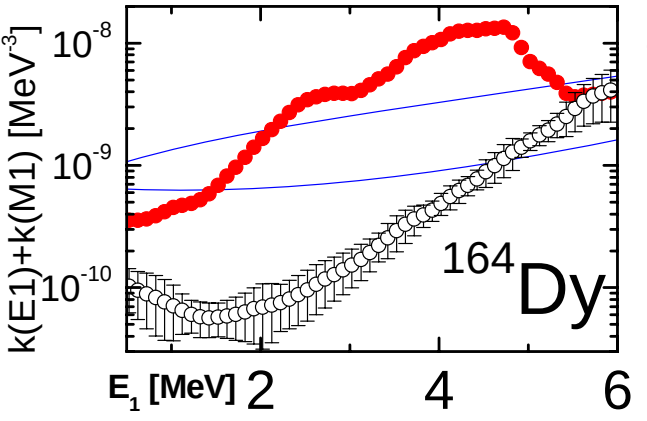
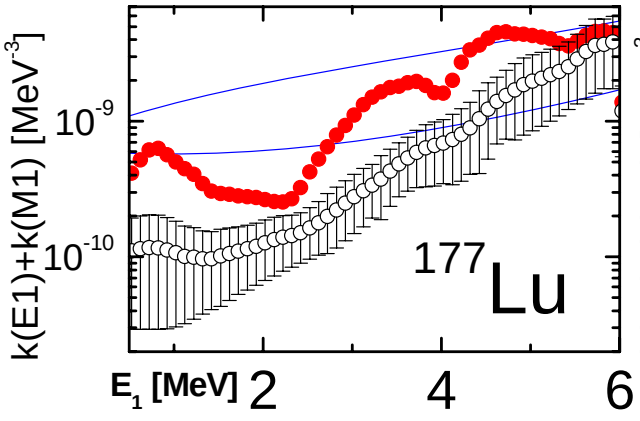
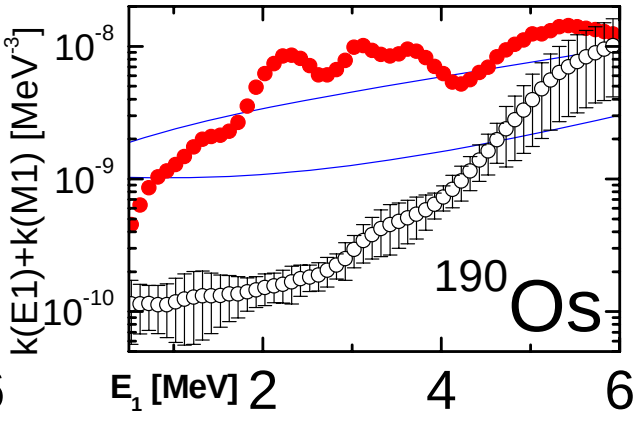












Conclusion

- The use of new hypothesis does not remove **step-like structure in level density** below neutron binding energy. In other words –there is a fact of obvious presence of sharp change in structure of nuclei levels of different type, which at present can be interpreted as **break of Cooper pair of nucleons** in heated nucleus.

- RSF of gamma-transitions between excited levels of heated nucleus also confirm **very strong influence of nucleus structure on their partial widths.**

Conclusion

- Intensity of two-step cascades following thermal neutron capture can be precisely reproduced under condition that the **RSF of cascade transitions are considerably increased because of presence of gamma-transitions between the levels with large vibration components of wave functions.** Respectively, such possibility must be taken into account at both, planning of new experiments and creation of new phenomenological models of radiative strength functions and penetrability coefficients for gamma-quanta or evaporation nucleons and light nuclei.

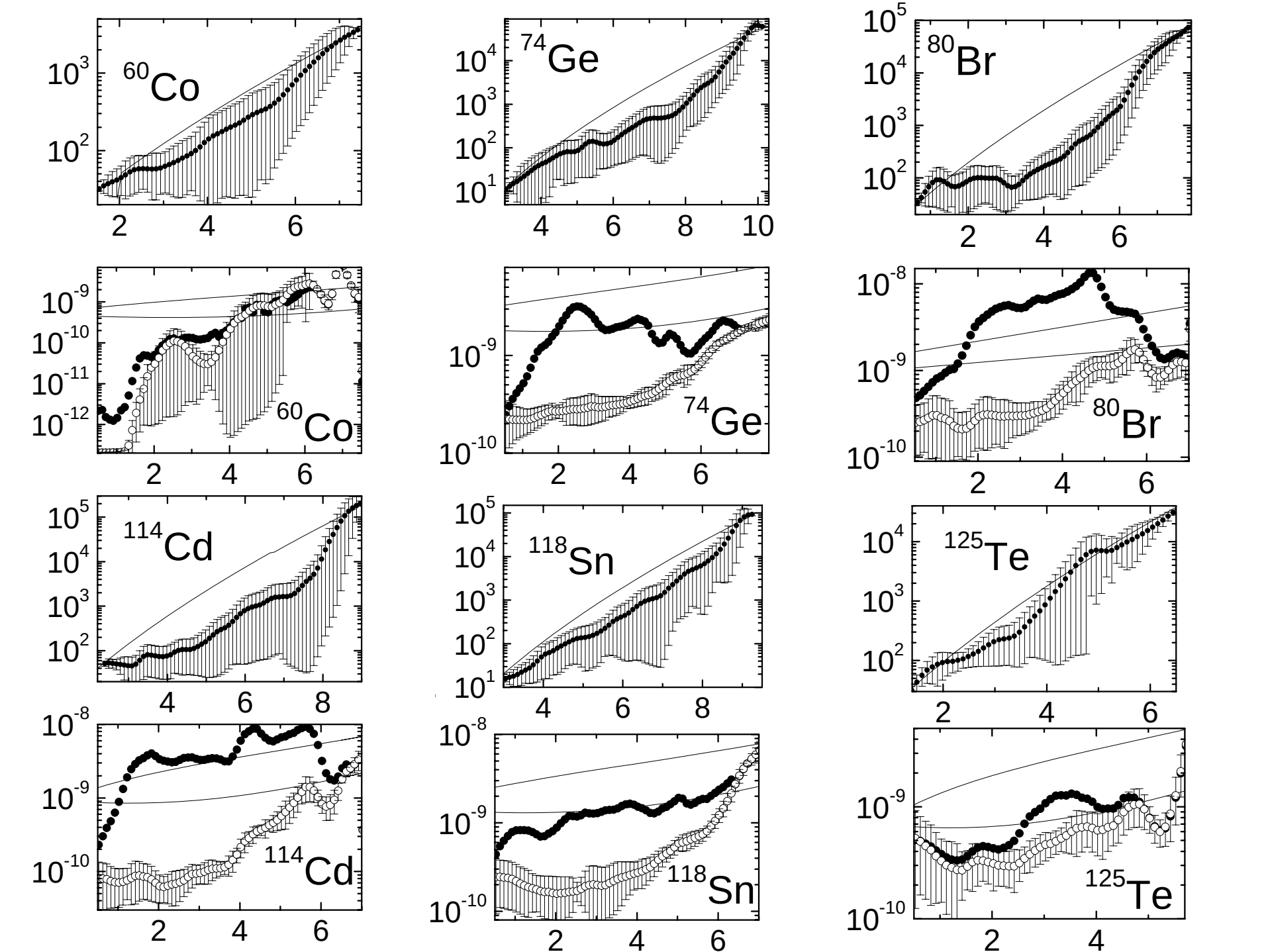
Thank you for your attention

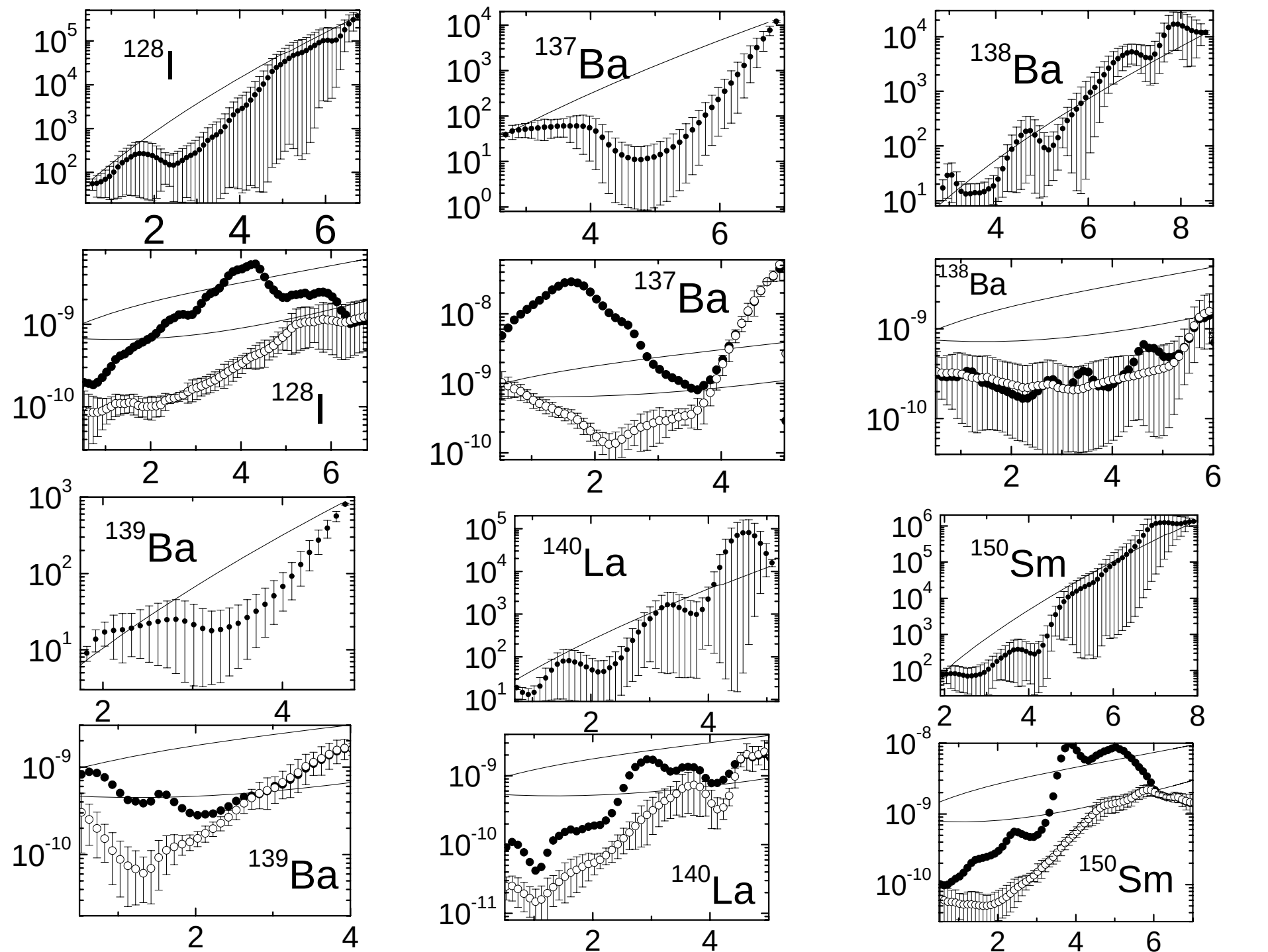
4. Results of practical approximation of two-step cascades intensity for proposed model

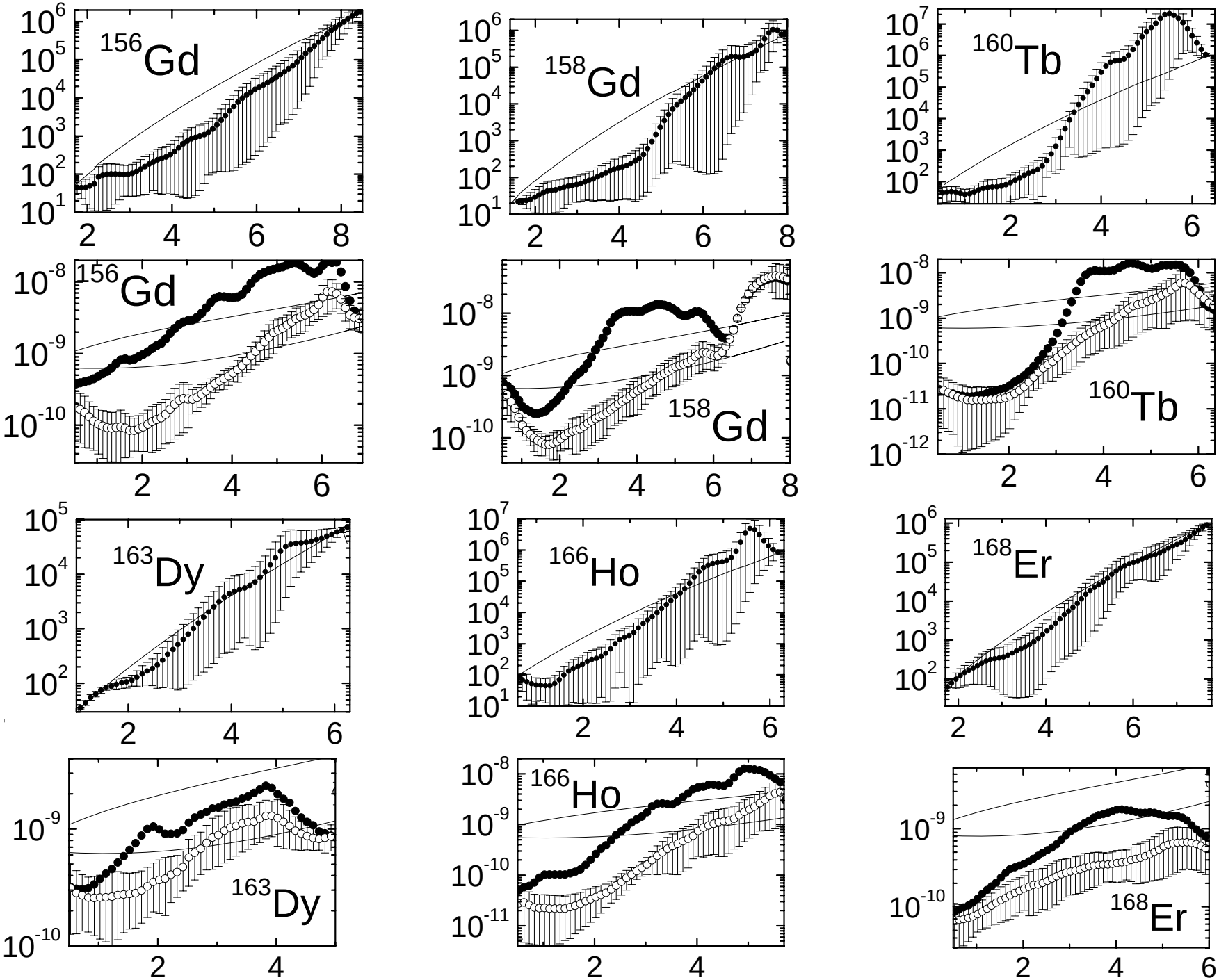
- The unsolved problem is the question on position of points of minimal density (break threshold U_n of the next Cooper pair of nucleons) for levels with parity π=+ and π=-.
- Multipolarities of primary and any next gamma-transitions ending at given nucleus level can be different.
- In region of neutron binding energy, for some nuclei the very strong exceeding of ρ_{exp} above model value ρ_{fg} disappeared or considerably decreased as compared with previous the data.
- Disagreement between ρ_{exp} and ρ_{fg}:

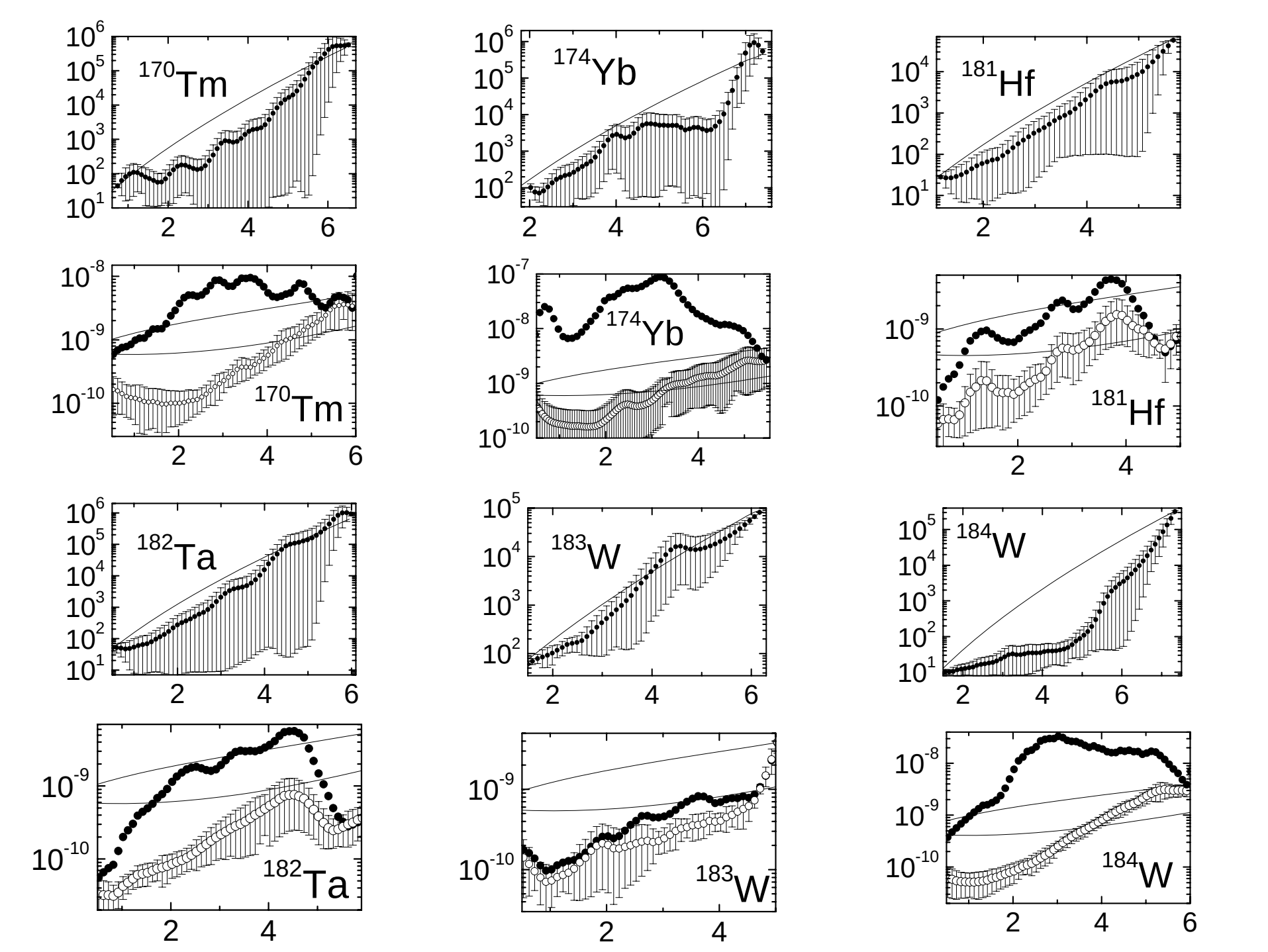
  - the process of energy exchange between quasi-particles and phonons in different isotopes of the same element

  - omission of large amount of very small neutron resonances


^{60}Co
^{74}Ge
^{80}Br
^{60}Co
^{74}Ge
^{80}Br
^{114}Cd
^{118}Sn
^{125}Te
^{114}Cd
^{118}Sn
^{125}Te


128I
137Ba
138Ba
128I
137Ba
138Ba
139Ba
140La
150Sm
139Ba
140La
150Sm


156Gd
158Gd
160Tb
156Gd
158Gd
160Tb
163Dy
166Ho
168Er
163Dy
166Ho
168Er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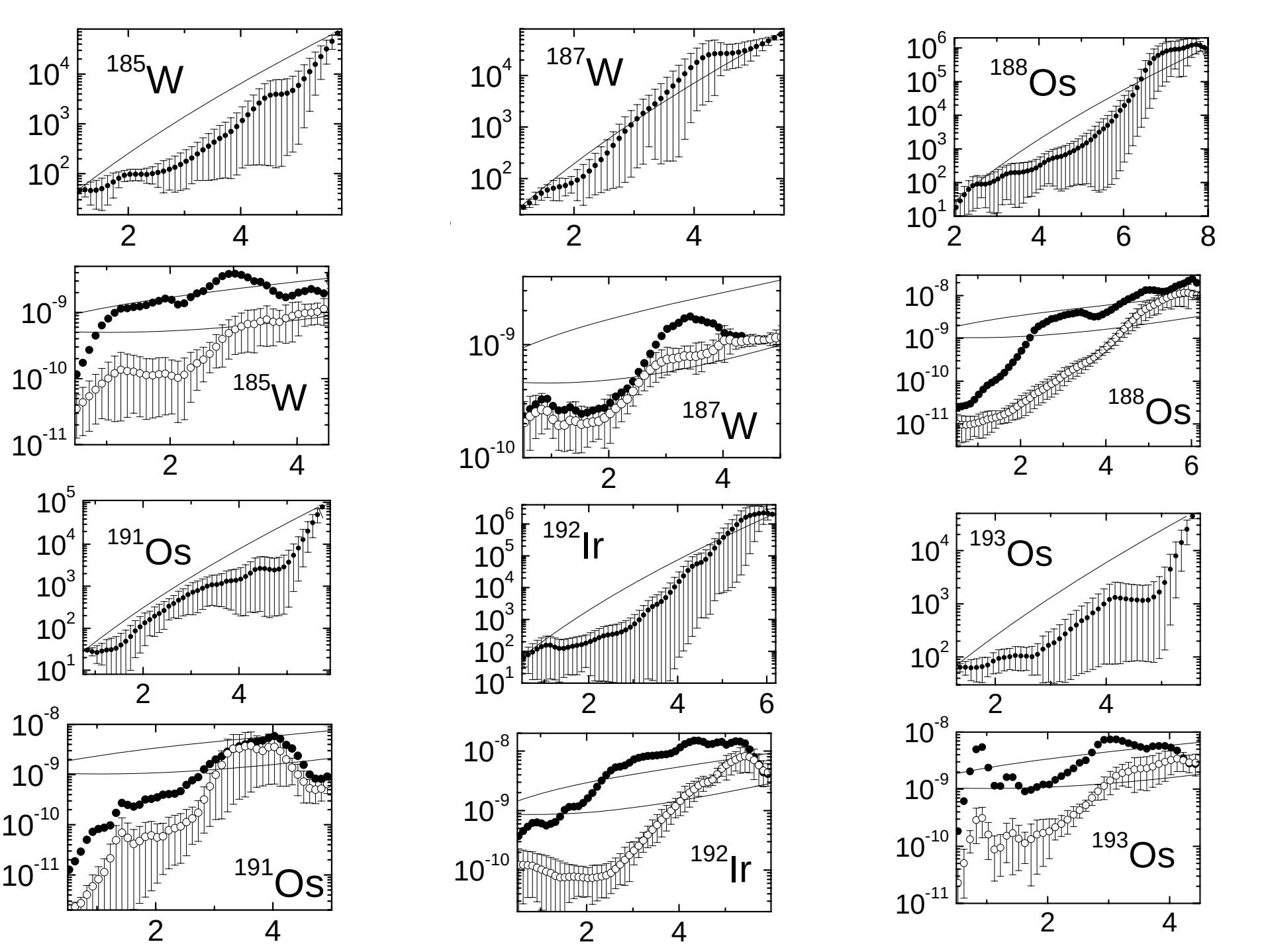
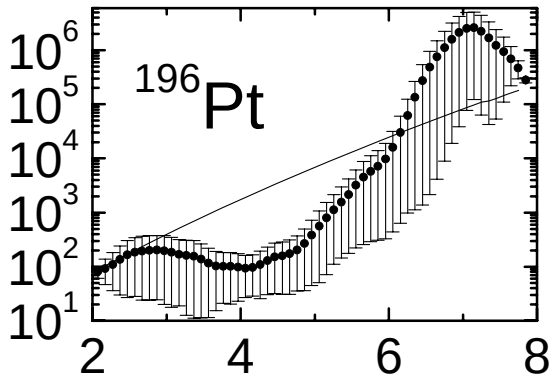
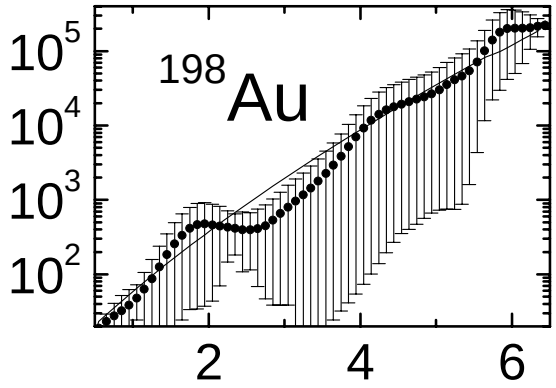
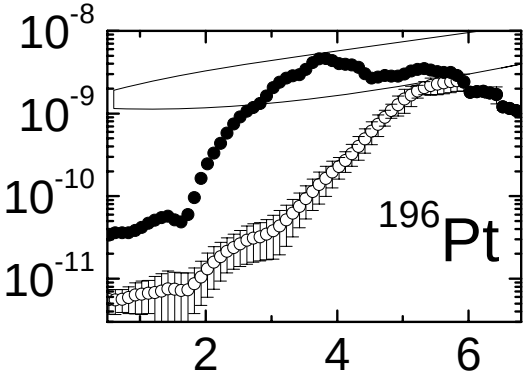
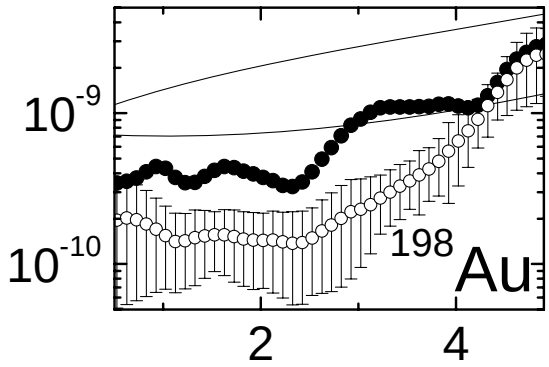
174Yb
181Hf
170Tm
174Yb
181Hf
182Ta
183W
184W
182Ta
183W
184W


185W
187W
188Os
185W
187W
188Os
191Os
192Ir
193Os
191Os
192Ir
193Os


10^6
10^5
10^4
10^3
10^2
10^1
^{196}Pt
2
4
6
8


10^5
10^4
10^3
10^2
^{198}Au
2
4
6


10^{-8}
10^{-9}
10^{-10}
10^{-11}
^{196}Pt
2
4
6


10^{-9}
10^{-10}
^{198}Au
2
4

The observed shape of energy dependence of evaporation nucleon spectrum in ^{181}W and ^{60}Ni can be reproduced by functions $\rho_{cas}=\psi(E_{ex})$ and $\Gamma_{cas}=\varphi(E_1)$ which were obtained from (n,2γ) reaction and satisfy functional dependence:

$$T_{om}\,\rho_{ev}=T_{cas}\,\rho_{cas} \quad \textbf{or}$$

$$\Gamma_{om}/D_{ev}=\Gamma_{cas}/D_{cas}$$