Renewed database of GDR parameters of ground-state photoabsorption

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Experimental database with reliable data for the GDR parameters and their uncertainties is very important for the reliable modeling of E1 gamma-ray cascades in highly excited nuclei, for the study of nuclear reaction mechanisms as well as for verifying different theoretical approaches used to describe the GDR and other nuclear structure properties (deformations, contribution of velocity-dependent forces, shape-transitions, etc), and forms an integral part of modern nuclear reaction computer codes, such as TALYS and EMPIRE.

Method of the GDR parameter's determination

The GDR parameters within SLO&SMLO models were obtained from fitting the theoretical photoabsorption cross sections near GDR range to revised experimental data from EXFOR library with allowance for (γ, p) reaction :

$$\sigma(\gamma, abs) \cong \sigma(\gamma, sn) + \sigma(\gamma, p) + \sigma(\gamma, F)$$

$$\sigma(\gamma, sn) = \sigma(\gamma, 1nx) + \sigma(\gamma, 2nx) + ...$$

Parameters are obtained for 144 isotopes from Li-6 to Pu-239 and 19 elements of natural isotopic composition (475 entries as a whole).

Theoretical photoabsorption cross section $\sigma_{abs}(\varepsilon_\gamma)$:

$$\sigma_{abs}(\varepsilon_\gamma) = \sigma_{GDR}(\varepsilon_\gamma) + \sigma_{QD}(\varepsilon_\gamma),$$

$\sigma_{QD}(\varepsilon_\gamma)$ - quasi-deuteron contribution:

$$\sigma_{QD}(\varepsilon_\gamma) = 397.8\,\frac{NZ}{A}\frac{(\varepsilon_\gamma - 2.224)^{3/2}}{\varepsilon_\gamma^3}\phi(\varepsilon_\gamma)$$

ε_γ (MeV), σ_{QD} (mb).

$\phi(\varepsilon_\gamma)$ accounts for the Pauli-blocking of the excited neutron-proton pair in the nuclear medium:

$$\phi(\varepsilon_\gamma < 20\ \mathrm{MeV}) = \exp(-73.3/\varepsilon_\gamma),$$

$$\phi(20 < \varepsilon_\gamma < 140\ \mathrm{MeV}) = 8.3714\times10^{-2} - 9.8343\times10^{-3}\varepsilon_\gamma + 4.1222\times10^{-4}\varepsilon_\gamma^2 - 3.4762\times10^{-6}\varepsilon_\gamma^3 + 9.3537\times10^{-9}\varepsilon_\gamma^4,$$

$$\phi(\varepsilon_\gamma > 140\ \mathrm{MeV}) = \exp(-24.2/\varepsilon_\gamma).$$

$$\sigma_{GDR}(\varepsilon_\gamma) = \sigma^{\alpha}_{GDR}(\varepsilon_\gamma) = \sum_{j=1}^{j_m} \sigma^{\alpha}_{GDR,j}(\varepsilon_\gamma) = \sigma_{TRK} s^{\alpha}_{j} \cdot F^{\alpha}_{j}(\varepsilon_\gamma),$$

$$F^{\alpha}_{j}(\varepsilon_\gamma) \equiv \frac{2}{\pi} \frac{\varepsilon_\gamma^2 \Gamma^{\alpha}_{j}}{[\varepsilon_\gamma^2 - (E^{\alpha}_{r,j})^2]^2 + [\varepsilon_\gamma \Gamma^{\alpha}_{j}]^2}.$$

$E^{\alpha}_{r,j}$, Γ^{α}_{j} - resonance energy and shape width of the j- mode of the giant dipole excitation for SLO and SMLO models ($\alpha = \mathrm{SLO}$ and SMLO).

s^{α}_{j} - normalized contribution ("weight") of the Lorentzian component F^{α}_{j} of model α to the GDR component of the photoabsorption cross section in terms of the Thomas-Reiche-Kuhn (TRK) sum rule σ_{TRK}

$$\sigma_{TRK} = 60 \frac{NZ}{A} [\mathrm{mb} \times \mathrm{MeV}].$$

$$\Gamma_j^{SLO} = \Gamma_{r,j}^{SLO} = const,$$

$$\Gamma_j^{SMLO}(\varepsilon_\gamma) = a_j\ \varepsilon_\gamma.$$

SLO model: $E_{r,j}^{SLO}$, $\Gamma_j^{SLO} = \Gamma_{r,j}^{SLO}$ and s_j^{SLO} are variables in the fitting procedure.

SMLO model: the parameters $E_{r,j}^{SMLO}$, a_j, s_j^{SMLO} are determined by fitting, and widths $\Gamma_{r,j}^{SMLO}$ are recalculated from a_j :

$$\Gamma_{r,j}^{SMLO} = \Gamma_j^{SMLO}(\varepsilon_\gamma = E_{r,j}^{SMLO}) = a_j E_{r,j}^{SMLO}.$$

The least-squares fitting procedure was employed with χ^2 minimization:

$$\chi^2_{\mathrm{model}} = \frac{1}{N_f}\sum_{i=1}^{N}\frac{\left(\sigma_{\exp}(\varepsilon_i) - \sigma_{abs}^{\mathrm{model}}(\varepsilon_i)\right)^2}{\left(\Delta\sigma(\varepsilon_i)\right)^2},$$

$\sigma_{abs}^{\mathrm{model}}(\varepsilon_i)$ - theoretical cross section at gamma-ray energy ε_i,

$\sigma_{\exp}(\varepsilon_i)$ - measured value for the total photoabsorption cross section with uncertainty $\Delta\sigma(\varepsilon_i)$,

$N_f = N - N_{par}$, N - the number of data points within the fitting interval near GDR,

N_{par} - the number of fitted parameters (3 parameters for each Lorentz-like curve).

The tables of the GDR parameters are prepared and published in

V.A. Plujko, O.M. Gorbachenko, R. Capote, P. Dimitriou, Atomic Data and Nuclear Data Tables, **123-124,** 1-85 (2018); https://doi.org/10.1016/j.adt.2018.03.002; arXiv e-Print – 2018: https://arxiv.org/abs/1804.04445

Table 1
Experimental values and uncertainties of GDR parameters within Standard Lorentzian (SLO) approach.

Nucl	Id	$E_{r,1}$ (MeV)	$\Gamma_{r,1}$ (MeV)	s_1	$E_{r,2}$ (MeV)	$\Gamma_{r,2}$ (MeV)	s_2	s	ε_{min}–ε_{max} (MeV)	Ref
^{6}Li	2	23.69 *16*	5.26 *79*	0.341 *31*				0.341 *31*	21.5–27.0	1986Var
	4	12.18 *5*	11.58 *1*	0.334 *150*				0.334 *4*	5.6–24.7	1965Be1
^{7}Li	0	18.59 *21*	16.28 *116*	0.907 *51*				0.907 *51*	13.2–25.6	1985Ahr
	2a	16.39 *11*	16.03 *42*	0.858 *22*				0.858 *22*	13.5–25.0	1986Var
	2b	16.40 *11*	16.03 *42*	0.858 *22*				0.858 *22*	13.5–25.0	1986Var
	4a	16.34 *7*	10.42 *24*	0.236 *4*				0.236 *4*	10.1–24.7	1973Bra
	4b	16.26 *10*	11.17 *41*	0.248 *7*				0.248 *7*	10.1–24.7	1973Bra
^{9}Be	0	23.75 *10*	9.47 *33*	0.577 *17*				0.577 *17*	17.5–26.0	1975Ahr
^{10}B	4a	21.72 *10*	9.08 *16*	0.441 *8*				0.441 *8*	8.5–24.9	1987Ahs
	4b	22.54 *32*	10.81 *63*	0.518 *26*				0.518 *26*	8.5–24.9	1987Ahs
^{12}C	0	22.86 *2*	3.61 *7*	0.671 *10*				0.671 *10*	20.1–25.0	1969Bez
	1	22.88 *2*	3.06 *1*	0.573 *70*				0.573 *10*	13.2–24.0	1975Ahr
	3a	23.14 *5*	2.89 *11*	0.546 *13*				0.546 *13*	20.2–25.0	2002Ish
	3b	23.09 *7*	2.95 *15*	0.549 *21*				0.549 *21*	20.2–25.0	2002Ish
	4	22.79 *7*	3.62 *28*	0.494 *27*				0.494 *27*	14.0–24.9	1963Bur
^{13}C	3a	24.60 *13*	8.43 *41*	0.868 *22*				0.868 *22*	14.5–29.0	2002Ish
	3b	24.40 *17*	7.70 *63*	0.828 *36*				0.828 *36*	14.5–29.0	2002Ish
^{14}C	3a	15.41 *26*	5.82 *90*	0.333 *47*	26.13 *15*	7.78 *92*	0.483 *46*	0.816 *66*	14.5–30.0	2002Ish
	3b	16.68 *57*	3.10 *67*	0.177 *23*	25.87 *17*	6.84 *84*	0.490 *46*	0.667 *51*	9.0–30.0	2002Ish
^{nat}C	0	23.12 *2*	4.19 *6*	0.705 *7*				0.705 *7*	19.5–25.6	1985Ahr
	0	23.38 *1*	4.17 *4*	0.728 *5*				0.728 *5*	19.0–26.0	1975Ahr
	0	23.14 *2*	4.03 *7*	0.678 *8*				0.678 *8*	19.1–25.8	1972Ahr
	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]	[illegible]

Presented databases update and extend previous compilations in Refs.:

1. S.S.Dietrich, B.L.Berman, At. Data Nucl. Data Tables, 38, 199 (1988).
2. P. Oblozinsky, M.B. Chadwick, T. Fukahori, et.al, Handbook for Calculations of Nuclear Reaction Data: Reference Input Parameter Library), Tech. Rep. IAEA-TECDOC-1034, IAEA, Vienna, Austria, 1998 (http://www-nds.iaea.org/ripl/).
3. T. Belgya, O. Bersillon, R. Capote, et.al, Handbook for calculations of nuclear reaction data, Reference Input Parameter Library- 2, Tech. Rep. IAEA-TECDOC-1506, IAEA, Vienna, Austria, 2006 (http://www-nds.iaea.org/RIPL-2/).
4. R. Capote, M. Herman, P. Oblozinsky, et.al, Nucl. Data Sheets 110, 3107 (2009) (http://www-nds.iaea.org/RIPL-3/).
5. M.B. Chadwick, P. Oblozinsky, A.I. Blokhin, et.al, Handbook on Photonuclear Data for Applications: Cross Sections and Spectra , Tech. Rep. IAEA TECDOC-1178, IAEA Vienna, Austria, 2000 (http://www-nds.iaea.org/reports-new/tecdocs/iaea-tecdoc-1178.pdf).
6. A.V. Varlamov, V.V. Varlamov, D.S. Rudenko, M.E. Stepanov, Atlas of Giant Dipole Resonances. Parameters and Graphs of Photonuclear Reaction Cross Sections, Tech. Rep. INDC(NDS)-394, International Atomic Energy Agency, Vienna, Austria, 1999 (http://www-nds.iaea.org/reports-new/indc-reports/indc-nds/indc-nds-0394.pdf).
7. V.A.Plujko, R.Capote, O.M.Gorbachenko, At. Data Nucl. Data Tables 97, 567 (2011).

Quality of the description of the experimental photonuclear cross sections by the different models is considered by means of the ratious $Rc_i = \langle \chi^2_{\mathrm{smlo}} \rangle / \langle \chi^2_{\mathrm{slo}} \rangle$ in different intervals ($\Delta\varepsilon_i$):

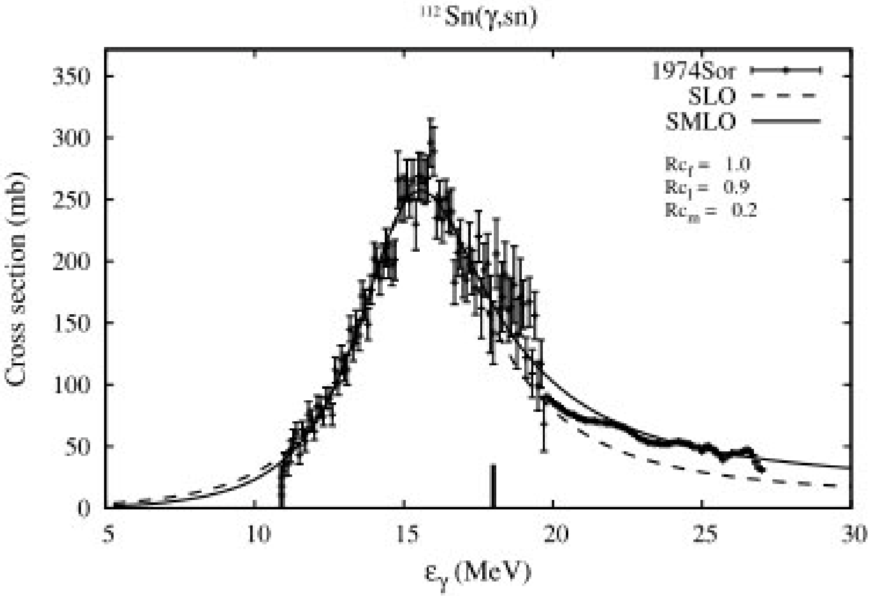
$i = f$ - for fitting intervals;

$i = l$ for intervals of the GDR left tail;

$i = m$ for whole intervals with the experimental data with the energy of the first experimental data-point.

Table of the ratios Rc_i

Intervals	Nuclei		
	Spherical	Spherical+Axially deformed	All
$\Delta\varepsilon_f$	0.96	1.11	1.09
$\Delta\varepsilon_l$	0.71	0.73	0.76
$\Delta\varepsilon_m$	0.70	0.69	0.74



GDR parameter systematics

Systematics of average resonance energies

New GDR data in spherical nuclei and axially deformed nuclei with 150<A<190 , 220<A<253 were used to obtain systematics

The expression for average resonance energy $\overline{E}_r = (E_{r,1} \cdot s_1 + E_{r,2} \cdot s_2)/(s_1 + s_2)$ was adopted in the form

$$\overline{E}_r = e_1 A^{-1/3} \sqrt{\frac{4NZ}{A^2(1+e_2 A^{-1/3})}}.$$

The following values of the factors were determined using GDR data within SLO model:

$$e_1 = 130.28 \pm 0.91 \approx 130.0(9); \quad e_2 = 8.975 \pm 0.194 \approx 9.0(2)$$

The values of the factors using GDR data within SMLO model:

$$e_1 = 128.39 \pm 0.88 \approx 128.0(9); \quad e_2 = 8.454 \pm 0.183 \approx 8.5(2)$$

Systematics of resonance widths and strength parameters

- Systematics for resonance widths

$$\Gamma_r = c\,E_r^{\delta}$$

SLO:

$$c = 0.316 \pm 0.029 \approx 0.32(3); \quad \delta = 0.980 \pm 0.034 \approx 0.98(3)$$

SMLO:

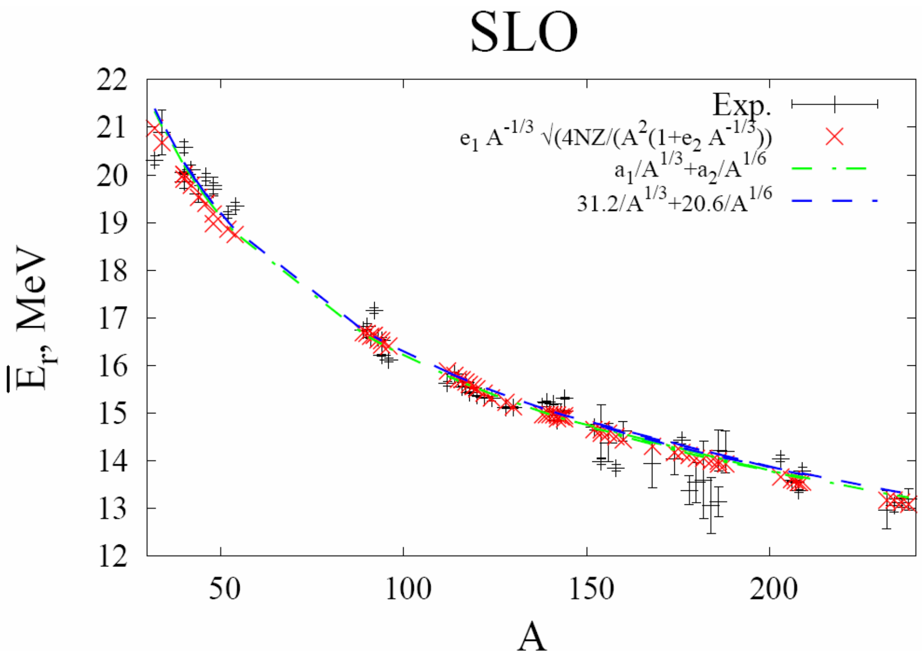
$$c = 0.418 \pm 0.046 \approx 0.42(5); \quad \delta = 0.895 \pm 0.040 \approx 0.90(4)$$

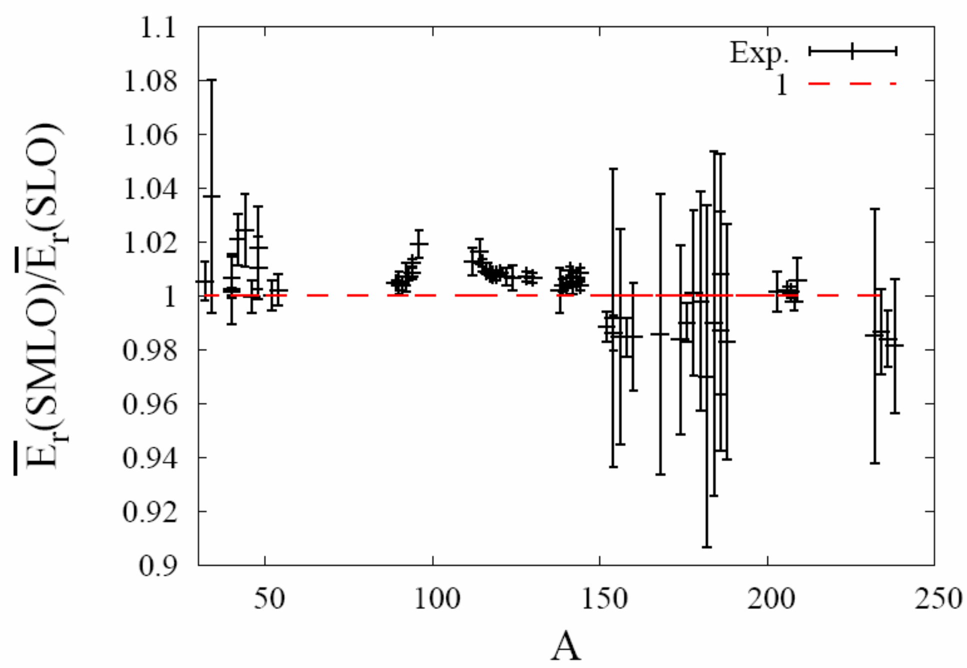
- Systematics of strength parameters $s = s_1 + s_2 = \text{const}$

$$s = 1.166 \pm 0.003 \approx 1.2 \text{ (SLO)}; \quad s = 1.197 \pm 0.003 \approx 1.2 \text{ (SMLO)}$$

Comparisons of new and old GDR systematics

GDR energies





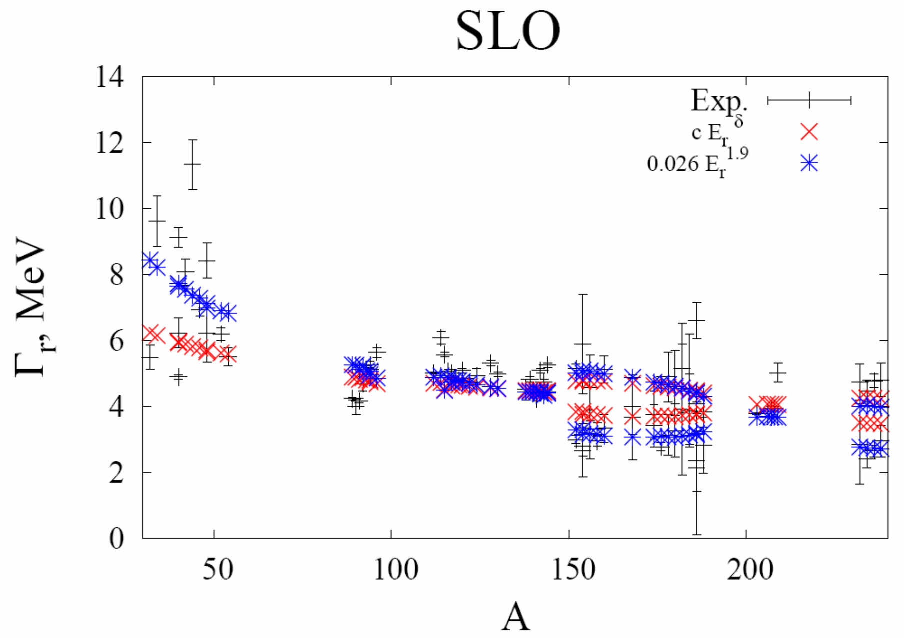
$$\bar{E}_r = 31.2 / A^{1/3} + 20.6 / A^{1/6} \ (MeV)$$

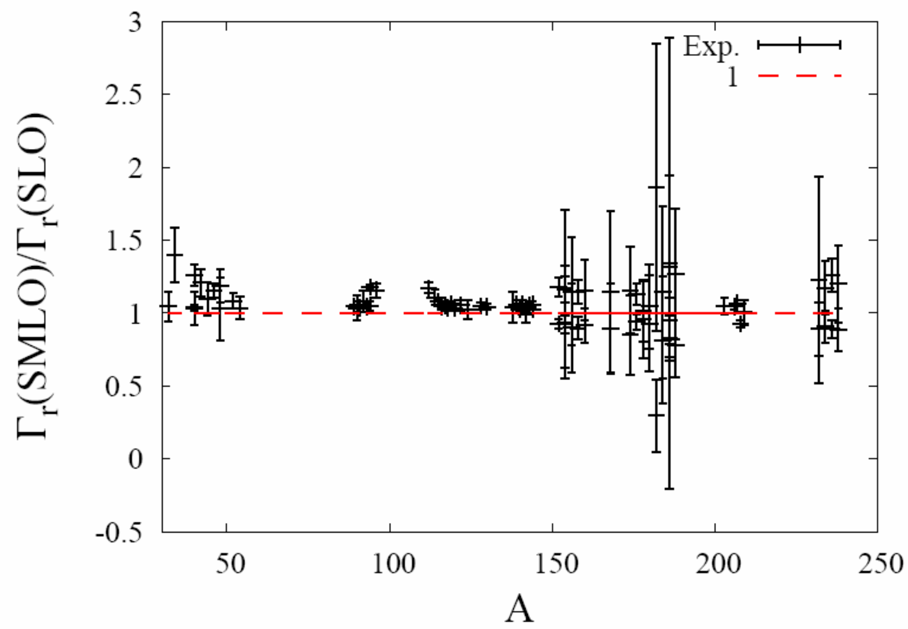
- S. S. Dietrich and B. L. Berman, *At. Data Nucl. Data Tables* 38 (1988) 199.

$$\bar{E}_r = 31.82(36) / A^{1/3} + 20.15(16) / A^{1/6} \ (MeV);\text{new} - \text{SLO model;}$$

$$\bar{E}_r = 32.80(37) / A^{1/3} + 19.85(16) / A^{1/6} \ (MeV);\text{new} - \text{SMLO model.}$$

GDR widths



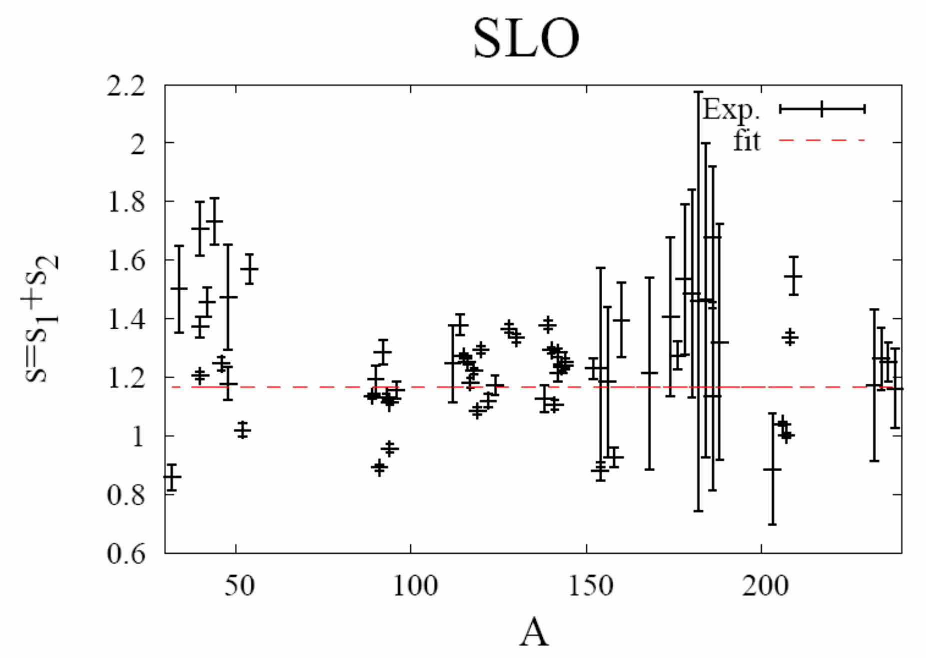


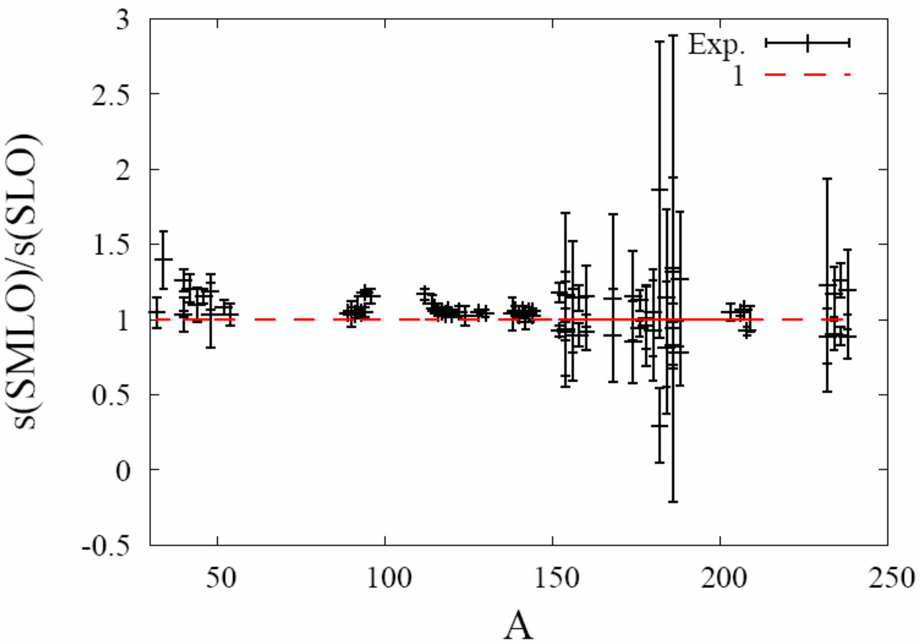
$\Gamma_{r,j} = 0.026\, E_{r,j}^{1.9}$ - P. Carlos, R. Bergere, et al. *Nucl. Phys. A* 219 (1974)61.

$$\Gamma_{r,j} = 0.316(29)\, E_{r,j}^{0.980(34)}$$;new – SLO model;

$$\Gamma_{r,j} = 0.418(46)\, E_{r,j}^{0.895(40)}$$;new – SMLO model.

GDR strength





$s = 1.166(3)$ – SLO model;

$s = 1.197\ (3)$ – SMLO model.

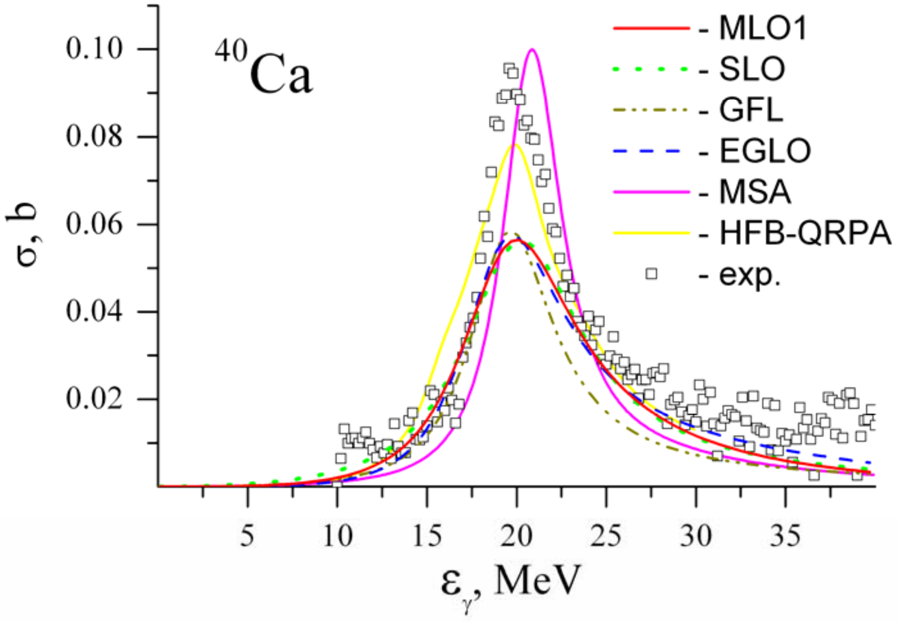
Volume(J) and surface(Q) coefficients of symmetry energy

$$E_{sym} = I^2 \cdot J/(1 + \frac{9J}{4Q} A^{-1/3}), \quad I = \frac{N-Z}{A},$$

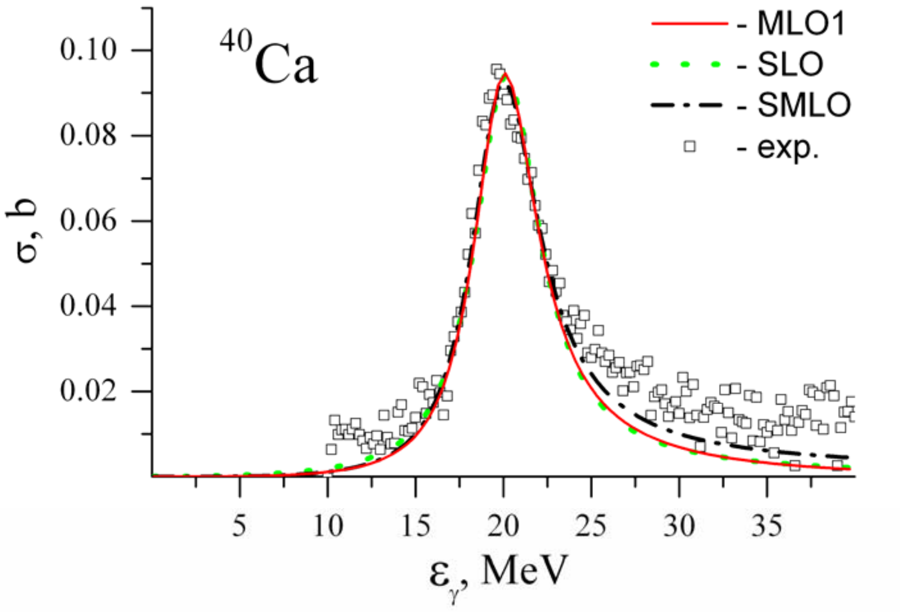
$$\overline{E}_r \equiv c J_1 A^{-1/3} / \sqrt{1 + d \cdot (J/Q) A^{-1/3}}$$

$J, \quad J/Q$	***Myers et al.*** **(c=3)**	***Lipparini et al.*** **(c=15/4)**
Used previously	36.8, 2.18	32.5, 1.00
New (SLO): New (SMLO):	34.7(*4*), 2.08(*4*) 33.1(*4*), 1.97(*4*)	39.7(*5*), 1.67(*3*) 37.9(*4*), 1.58(*3*)
Average values (new)	33.9(*3*), 2.03(*3*)	38.8(*3*), 1.63(*3*)

Comparison of the photoabsorption cross section calculated with different database for GDR parameters



(*a*) - old systematics (Berman&Fultz);



(*b*) - renewed GDR parameters.

HFB-QRPA - microscopic approach by S. Goriely et al, NP A706 (2002) 217; A739 (2004) 331

MSA - semiclassical moving surface method by V.I. Abrosimov, O.I.Davidovskaya,
Izvestiya RAN. 68 (2004)200; Ukrainian Phys. Jour. 51 (2006)234

Exp.data – EXFOR Subent = M0653002,
V.A. Erokhova et al. Izvestiya RAN. Seriya Fiz. **67** (2003) 1479

MAIN RESULTS

1) Renewed GDR parameters for 144 isotopes from Li-6 to Pu-239 and 19 elements of natural isotopic composition (475 entries) are determined. The datatables with figures for photoabsorption CS are prepared and published in: V.A. Plujko, O.M. Gorbachenko, R. Capote, P. Dimitriou, Atomic Data and Nuclear Data Tables, **123-124,** 1-85 (2018); https://doi.org/10.1016/j.adt.2018.03.002; arXiv e-Print – 2018: https://arxiv.org/abs/1804.04445 .
2) Modified systematics of the GDR parameters are obtained.
3) Values of volume and surface coefficients of symmetry energy are determined from new GDR energy systematics.

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Thank you!