Study of nonstatistical effects due to tensor forces

S.I. Sukhoruchkin, M.S. Sukhoruchkina

Petersburg Nuclear Physics Institute, 188300 Gatchina

Abstract

The effect of the linear trend in excitations E^* of near-magic Sb-isotopes found by J.Schiffer and T.Otsuka was checked with the data for other selected nuclei.

1 Introduction

There exists a new outlook on the role of pion-exchange dynamics in nuclear spectroscopy based on the observation by J.Schiffer [1] and T.Otsuka [2] on the interaction of nucleons moving with opposite direction of orbitals ($\nu 1h_{11/2} - \pi 1g_{7/2}$ in case of Sb isotopes). Observed linear trend with the slope 161 keV=$\delta m_N/8$ is shown in Table 1 (boxed values at top are compared with the period $\delta m_N/8$, where δm_N=1293 keV is nucleon mass splitting). Excitations in N-even Sb isotopes (N=72-82) reflect the stable character of the interaction of the $1g_{7/2}$ proton with numbers (N-70)/2 of neutron pairs in $1h_{11/2}$ subshell. The parameter 161 keV corresponding to such stable interaction manifests itself also as a maximum at 160 keV in D-distribution in neighbour isotopes ^{122,124}Sb and as a series of maxima at 161 keV, 483 keV and 644 keV in E^*-distribution of all nuclei with Z=48-60 (Fig.5 in [3], Table 1). The similar effect was observed in Pd isotopes (Table 1).

Table 1. Comparison of E^* (in keV) of $Z = 50, 51$ nuclei with n×1293 keV/8 and ε_o=1022 keV.

^{A}Z	^{133}Sb	^{131}Sb	^{129}Sb	^{127}Sb	^{125}Sb	^{123}Sb	^{116}Sn	^{101}Sn	^{103}Sn	^{117}Sn
N	82	80	78	76	74	72	66	51	53	67
(N-70)/2	6	5	4	3	2	1				
$2J^\pi, J^\pi$	5^+	5^+	5^+	5^+	5^+	5^+	2^+			$1^+, 5^+$
E^*, keV	962	798	645	491	332	160.3	1293	171	170	D=1020
n$\frac{\delta m_N}{8}$	969	808	646	484	323	161	1293	$\varepsilon_o/6$	$\varepsilon_o/6$	ε_o
E^*,D(Sb,Pd)			644-648	483		160-161	1293			512=$\varepsilon_o/2$
D(Sb,Pd) eV			749	572	375					

A stable character of excitations in nuclei ^{101,103}Sn situated over the ^{100}Sn-core manifests itself in a proximity of E^*=170 keV and E^*=168 keV close to $\varepsilon_o/6$ ^{101,103}Sn. The parameter ε_o=$2m_e$=1022 keV corresponds to the stable phonon in nuclei ^{116,117,118}Sn (see Table 3 in [4]). Both parameters D=161 keV=δm_N, D=170 keV=$\varepsilon_o/6$ and combined interval 2×161 keV+170 keV=492 keV were used as *repères* during the analysis of spacing and excitations in all nuclei collected in the recent compilation CRF [5]. Appearance of stable energy intervals related to nucleon mass difference δm_N or m_e was named "tuning effect". The similar effect in particles masses was considered in [6]).

2 Two additional methods of data analysis

Intervals n×161 keV and m×170 keV are seen frequently together (as in Z=50,51 nuclei, Table 1). For example, intervals D=512-682-keV (n=3-4, the period $\varepsilon_o/6$) in the spectrum of ^{55}Co (Fig.2 left) were studied with a special Adjacent Interval Method (AIM). It consists in the fixation in the spectrum of all pairs of levels (E_i^*, E_j^*) forming a maximum in usual spacing distribution (D_{ij}=x) and plotting D-distributions from the fixed levels to all other levels (E_k^*) in the spectrum ($D_{\uparrow}^{AIM}$, $D_{\downarrow}^{AIM}$ or $D_{\uparrow\downarrow}^{AIM}$). Arrows indicate the direction (along E^* axis) from the fixed energies. For example, the interval D=1022 keV=ε_o in ^{55}Co is the distance between the low-lying T=3/2 states. By fixating all intervals x=ε_o, one obtains a distribution with maxima $D_{\uparrow}^{AIM}$=511 keV=$\varepsilon_o/2$ and 324 keV≈ 2 × 161 keV (seen at left in Fig.2, right). These intervals are forming triplets.

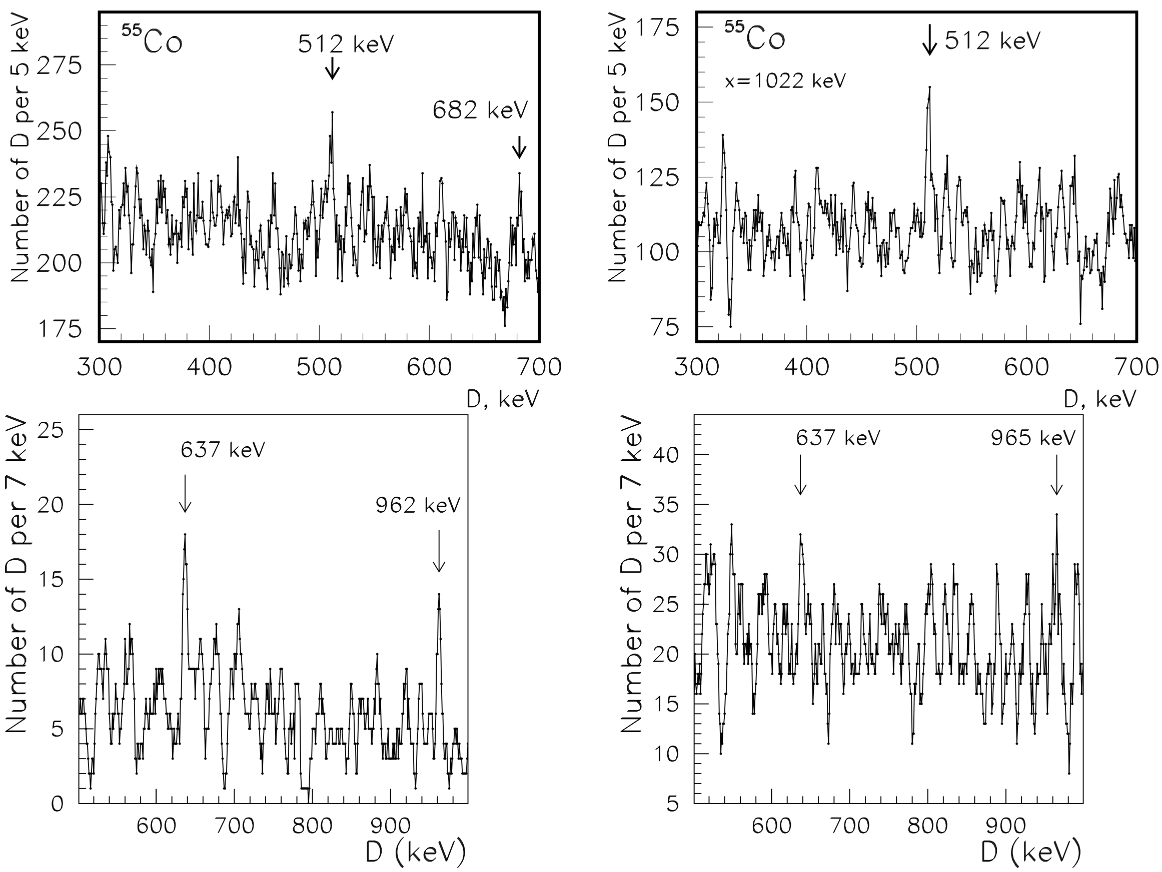

Fig. 1 *Top left:* D-distribution in ^{55}Co. *Top right:* $D_{\uparrow}^{AIM}$-distribution for x=1022 keV, ^{55}Co. *Bottom:* D-distributions in ^{18}F and ^{22}Na, proximity of D=637 keV and D=962-865 keV.

Stable intervals seen as maxima in D-distributions have frequently proximate values in different neighbour nuclei. Such effect exists in the low-lying levels of ^{18}F ($E^* \leq$10 MeV, number of levels n=80) and in levels of ^{22}Na (Fig.1, bottom). To check this result for ^{18}F the AIM-analysis with x=962 keV was performed. The distribution $D_{\uparrow\downarrow}^{AIM}$ with maxima at 324 keV and 636 keV (1:2:3) corresponds to the period 2×161 keV.

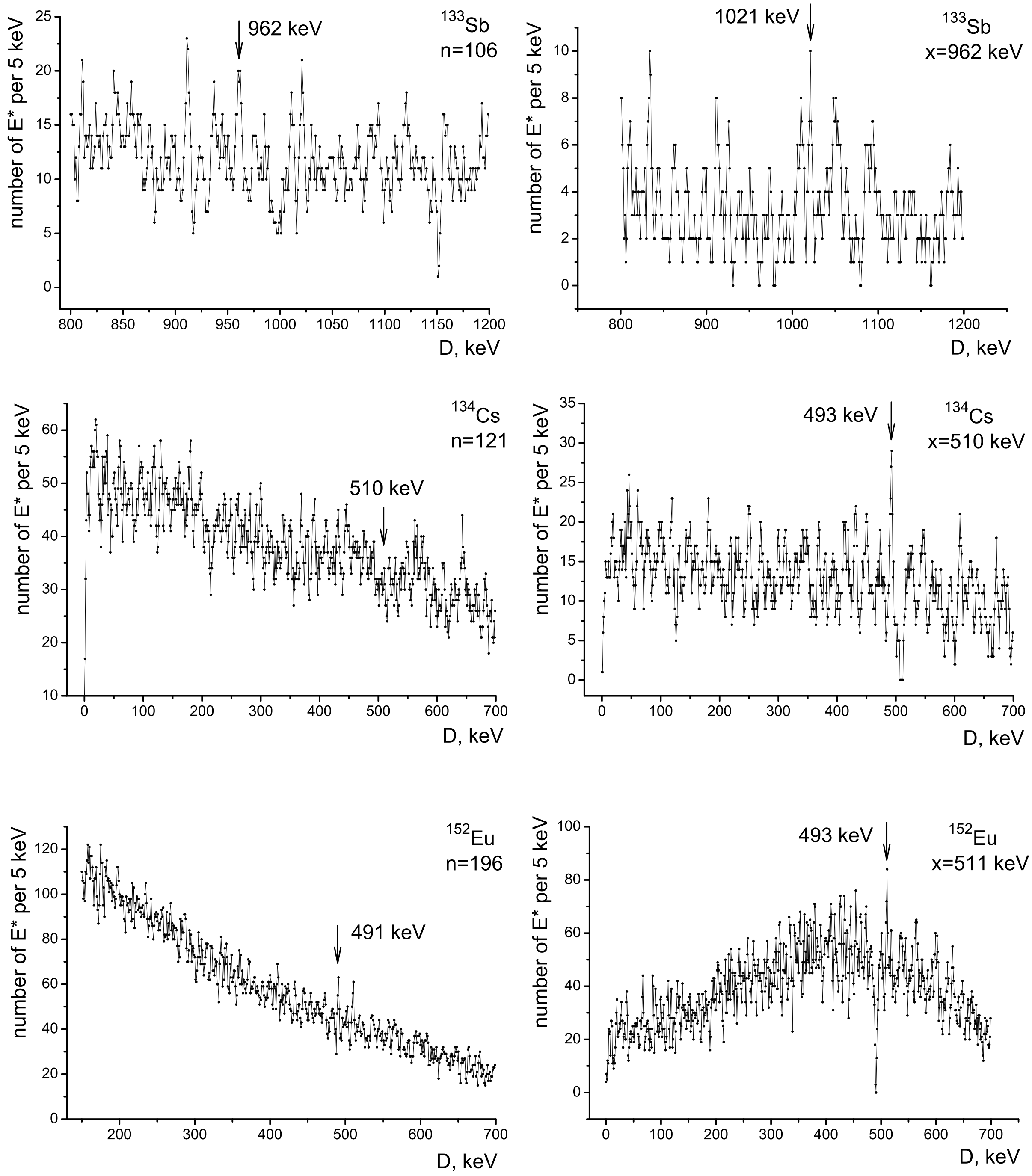

Fig. 2 *Top left and right:* D-distribution in ^{133}Sb and $D_{\uparrow}^{AIM}$-distribution for x=962 keV. *Center left and right:* D-distribution in ^{134}Cs and $D_{\downarrow}^{AIM}$-distribution for x=510 keV. *Bottom left and right:* D-distribution in ^{152}Eu and $D_{\downarrow}^{AIM}$-distribution for x=491 keV.

The second way to check a general character of the pion-exchange dynamics is based on the fact that in highly excited states of the same or neighbour isotopes several close to each other small splitting were observed. For example, intervals D=375-750-1500 eV in ^{124}Sb and D=750-1500 eV in isotopes of Pd and Rh (Fig.8 in [4]) were considered in [6]. Periodicity in positions of neutron resonances in ^{124}Sb found by M.Ohkubo [7] is presented in Fig 3. Resonance positions given at the bottom of Fig 3 are expressed as 312 eV+n×88 eV, or as the period 44 eV due to the ratio 131eV/(88eV/2=44eV)=2.98. The ratio 9:13:17 (in units 44 eV) for position/spacing in resonances concerns strong resonances at 572 eV and 750 eV coinciding with D=572 eV and 373 eV-750 eV observed as maxima in the independent spacing distribution in ^{124}Sb (shown in Fig 8 in [4]).

Two maxima at 44 eV and 572 eV were found independently earlier in sum distritbution of resonance positions in all nuclei with 33–56 (Fig.4 top left). A systematic character of intervals of superfine structure (periods 44 eV) corresponds to the discussed structure of the values (including 492 keV and 644 keV=4×161 keV) if one notices that a ratio between such small intervals and intervals in low-lying levels of the same nuclei are close to QED radiative correction ($\alpha/2\pi$=1.159·10^{-3}). Simultaneously a stable interval/period 161 keV is in the same ratio with the mass of charged pion (161.6 keV/(m_π=130.6 MeV)=1.158·10^{-3} [6]. This SFERC method (Scaling Factor Equal to Radiative Correction) permits to use the observed nonstatistical effects in neutron resonances as an indirect confirmation of the common and universal nuclear dynamics.

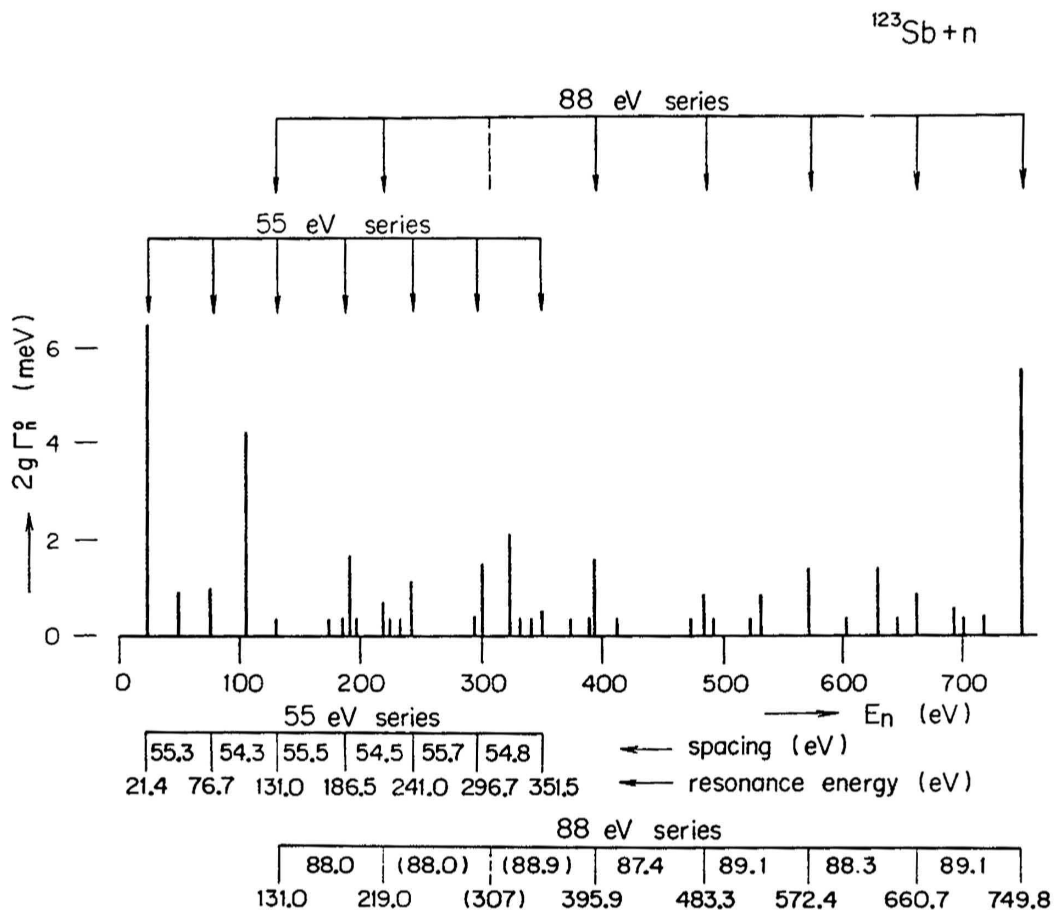

Fig. 3 Positions and neutron widths of resonances in target nucleus ^{123}Sb (by M.Ohkubo [7]).

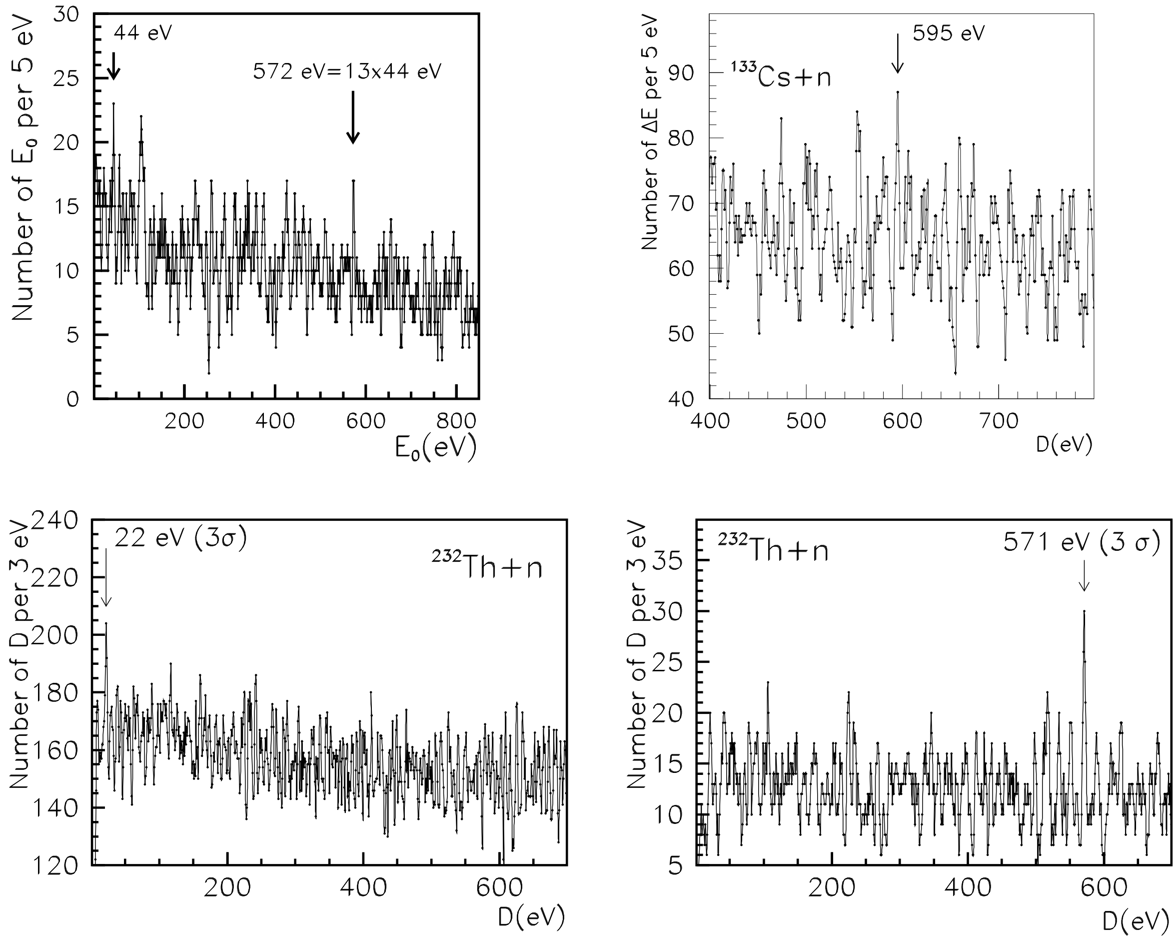

Fig. 4 *Top left:* Distribution of positions of relatively strong neutron resonances in all nuclei with Z=33–56. *Top right:* Spacing distribution of all neutron resonances in ^{134}Cs. *Bottom:* D-distribution for all neutron resonances in ^{233}Th and for strong resonances ($g\Gamma_n^o \geq$1 meV).

Table 2. *Repères* of the periodicity in resonances of ^{124}Sb introduced by M.Ohkubo (boxed) and possible nonstatistical effects (stable D) in neutron resonances of the neighbour isotopes.

^{A}Z	^{122}Sb	^{124}Sb			^{124}Sb			^{128}I	^{130}I		^{134}Cs
Z	51	51			51			53	53		55
N	71	73	73	73	73	73	73	75	77	77	79
E_n,D_{ij},eV	389	$\boxed{396}$	$\boxed{572}$	$\boxed{750}$	198	375	574	88	200	985	396
number/5 eV	20,25				62	64	61	66	141,57	119	24
selection 2gΓ_n^o	l=1,0				all	all	all	l=1	all, l=0	all	2meV
n(44eV)=n4δ''	1meV	$\boxed{9}$	$\boxed{13}$	$\boxed{17}$	9/2	17/2	13	2	9/2	5(9/2)	9

A system in resonance positions introduced by M.Ohkubo as *repères* (fixed intervals) to study nonstatistical effects in other isotopes is shown in Table 2. In this Z,N region the presence of pion-exchange dynamics can be more clearly manifested even at higher excitation. Possible grouping effects are shown in Table 2 and Fig.4 (top right). More accurate data for resonances in ^{122,124}Sb and ^{133,135}Cs are needed for a definite conclusion.

Nonstatistical effect in D-distribution of resonances in ^{232}Th was marked in 60-ties by the Columbia Nevis Cyclotron Group. Recent result is shown in Fig.4 (bottom left). Selection of strong resonances results in a grouping effect at a *repère* n=13 for 571 eV.

3 Spacing distributions in nuclei with Z=5-29

The first step in the analysis of stable nuclear excitations was obtaining a sum E^*-distribution for all nuclei in the first volume of compilation 1/25A (Z=1-29). The maximum at 1291 keV (Fig.3 top) is due to a grouping of E^* in odd-Z nuclei Z=19-29 (Fig.3 bottom). The maximum at 3936 keV=8×492 keV (Fig.5 center) is discussed later.

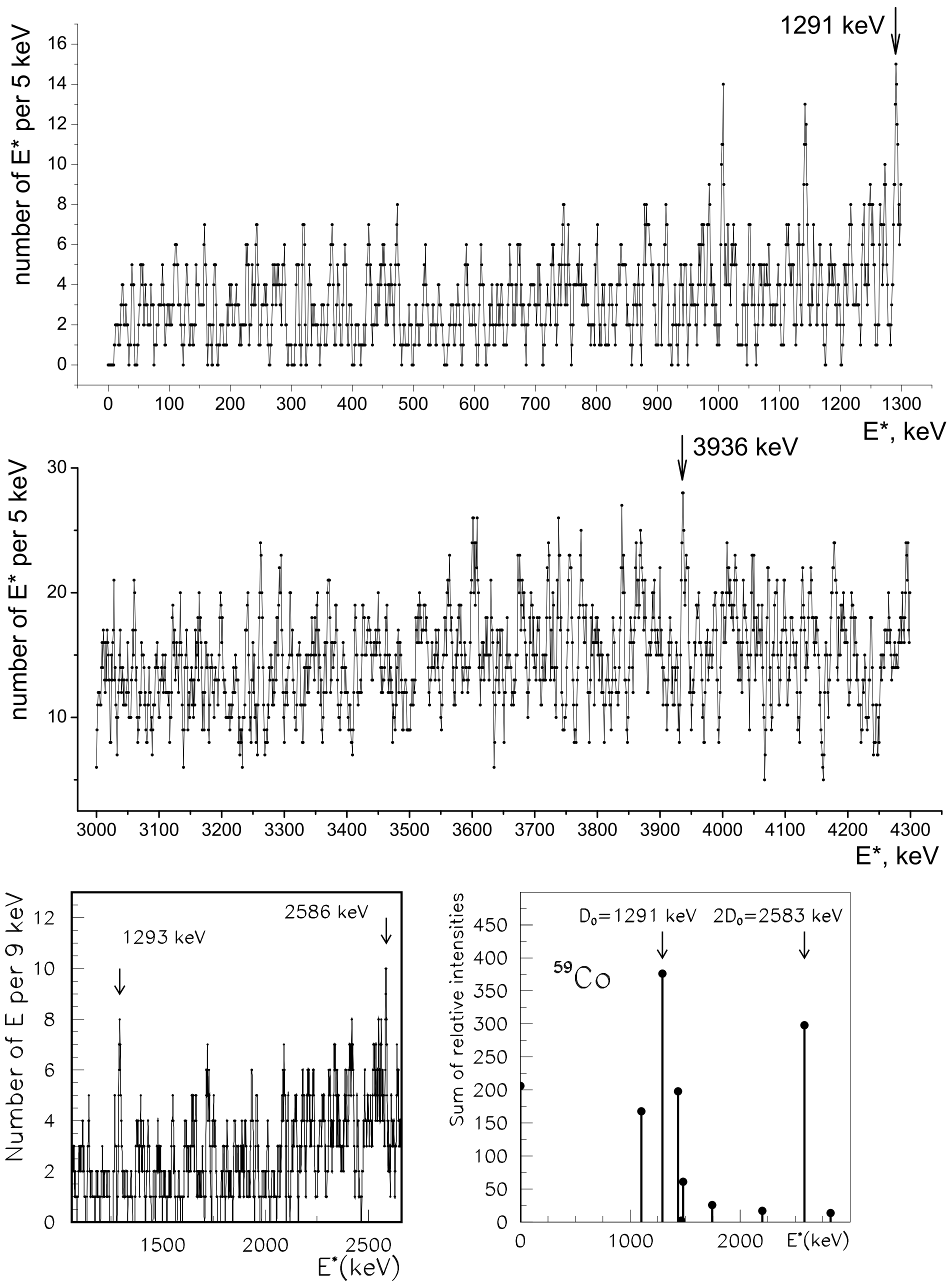

Fig. 5 *Top and center:* E^*-distribution in nuclei with Z=4-29 for energies E^*=<1300 keV and 3000-4300 keV. *Bottom left:* E^*-distribution for Z-odd nuclei (Z≤29). *Bottom right:* Strong transitions from proton resonances in ^{59}Co to low-lying states at $E^*=\delta m_N$ and $2\delta m_N$.

In the lightest nuclei only for ^{18,19,20}F there are a sufficient total numbers of excited states (n=359, 229, 149) to perform the combined correlation analysis. The number of excited states in ^{18}F used for the analysis could be increased from n=359 to n=431 by inclusion E^* known with uncertainty ≈30 keV (this file was not used here).

Stable interval D=1289 keV close to δm_N was found in spacing distribution for all 359 excited states near-magic nucleus ^{18}F (levels are known with the uncertainty 15 keV or less, distribution is shown in Fig.6 (top). This interval is marked with the arrow, and his clear nonstatistical character was checked by the AIM method. Distribution of $D^{AIM}_{\uparrow\downarrow}$ (Fig.6 center) has a clear maximum at the exactly doubled value $D^{AIM}_{\uparrow\downarrow}$=2577 keV. The distribution of the interval $D^{AIM}_{\downarrow}$ (in downwards direction from the upper levels of pairs forming x=1290 keV) contains a maximum at $D^{AIM}_{\downarrow}$=1931 keV=(3/2)x (Fig.6 bottom). It corresponds to a frequent appearance of intervals D=642 keV=x/2 below the fixed intervals x. Another interval D=493 keV was observed in total D-distribution for ^{18}F (Fig.7 top, deviation about 3σ with smaller energy averaging interval ΔE=3 keV, while ΔE=5 keV is the commonly used parameter). For x=493 keV in $D^{AIM}_{\uparrow\downarrow}$-distribution there exists the interval 611 keV=(5/4)x. Intervals 614 keV and 490 keV–984 keV were found also in D-distributions of ^{19}F and ^{20}F. They belong to the system of intervals n×(1/4)492 keV=123 keV (a period) observed also as the above discussed stable intervals 493 keV-611 keV in ^{18}F. Observed in D-distributions for $^{18-20}$F (Fig. 5-7) maxima at D≈492 and 984 keV are rational (1:2:8) to the grouping effect at E^*=3936 keV. Such excitations appear in nuclei with Z=16-20 (Table 3). In the nucleus ^{33}S it corresponds to the exactly equidistant ΔJ=1 excitation (Table 3 left).

Table 3. Excitations in light nuclei (in keV), from ^{33}S up to ^{39}Ca.

^{33}S, 3$^+$			^{38}Cl	^{39}K	^{37}Ar	^{38}Ar	^{39}Ca	D$_{ij}$(^{18}F)	D$_{ij}$(^{20}F)
$2J^\pi$	E^*_{exp}	diff.	E^*_{exp}	E^*_{exp}	E^*_{exp}	E^*_{exp}	E^*_{exp}	493 keV	490 keV
5$^+$	1967	1968	1982	2523	1410	2167	2469		984 keV=
3$^+$	3935		3938	3939	3937	3937	3936	3936/8	3936keV/4

Presence of the exact rational relations in excitations of ^{18}O (the system similar to ^{18}F, two valence nucleons over ^{16}O) can be seen in Table 4 (left). Several excitations are rational to the observed stable interval 1778 keV in spacing distribution Three out of four known 0$^+$, 4$^+$ excitations are in ratios "n" (within Δ=5 keV) to the observed stable interval 1778 keV in spacing distribution. Simultaneously the first 0$^+$ excitation in ^{18}O can be expressed as $E(0^+_1)$=(12/13)3936 keV (the groping at 3936 keV see in Fig.5).

Table 4. Rational relation 1:2:3:4 between spacing and excitation energies E^* (in keV) in ^{18} and relations in spacing D_{ij} (in keV) in light nuclei ^{19}F and ^{19,20}Ne.

^{18}O O^+	2$^+$	4$^+$	0$^+$	0$^+$	4$^+$	^{19}Ne D_{ij}		^{19}F D_{ij}	^{20}Ne D_{ij}
0.0	1982	3555	3634	5336	7117	77(2)	908(2)	339(2)	339(2)
n(1778)		2		3	4	8δ'	12×8δ'	36δ'	36δ'
n×1778		3556	(12/13)3936	5334	7112	76	909	341	341

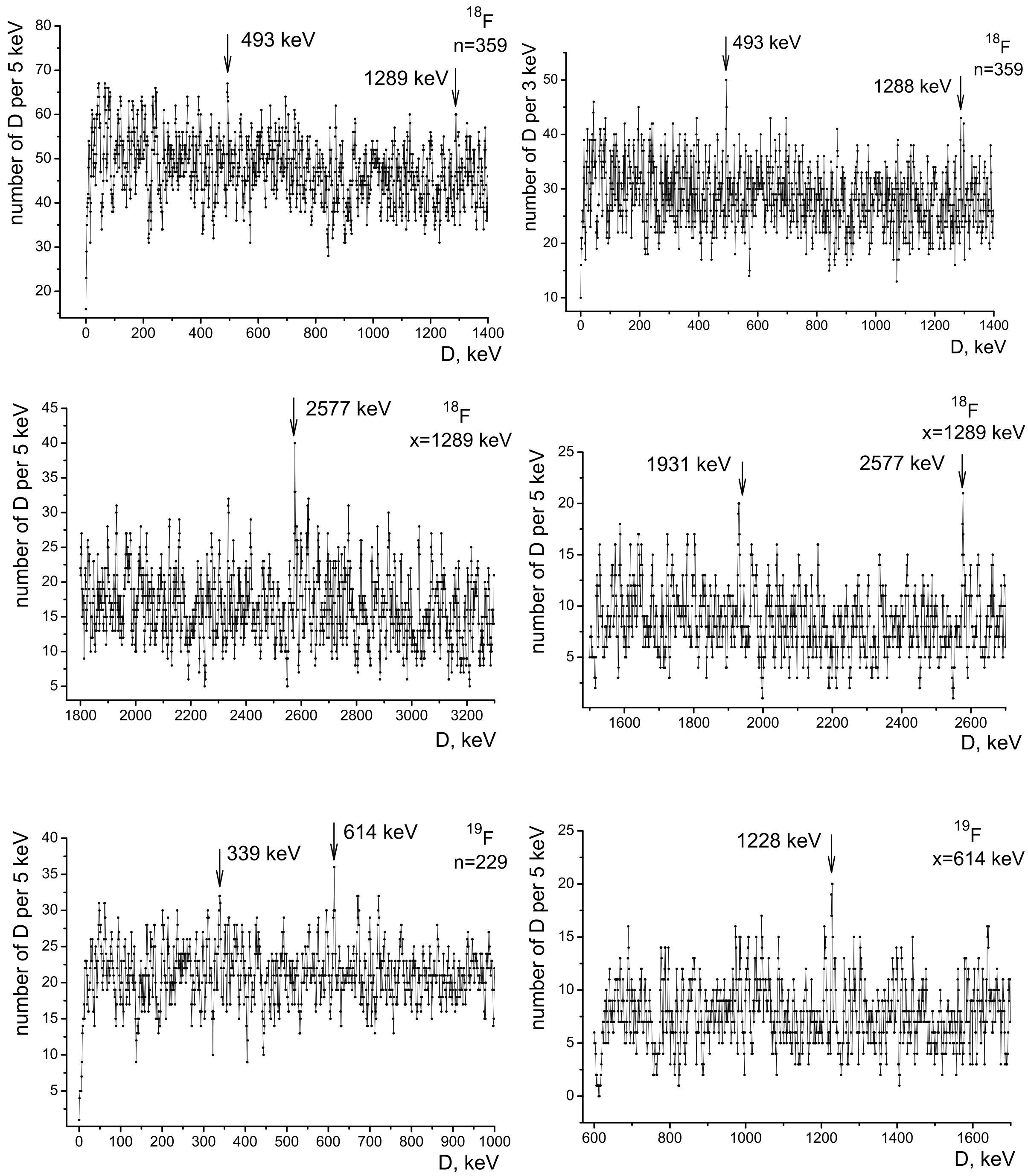

Fig. 6 *Top left:* D-distribution for all levels in ^{18}F, maxima at 493 keV and 1289 keV.
Top right: D-distribution for all levels in ^{18}F with averaging interval ΔE=3 keV, maxima are the same as observed with ΔE=5 keV (at left).
Center: $D_{\updownarrow}^{AIM}$-distribution in ^{18}F x=1289 keV and $D_{\downarrow}^{AIM}$-distribution in ^{18}F x=1289 keV which contains additionally interval 1931 keV=(3/2)x.
Bottom: D-distribution in ^{19}F and $D_{\updownarrow}^{AIM}$-distribution in ^{19}F x=614 keV.

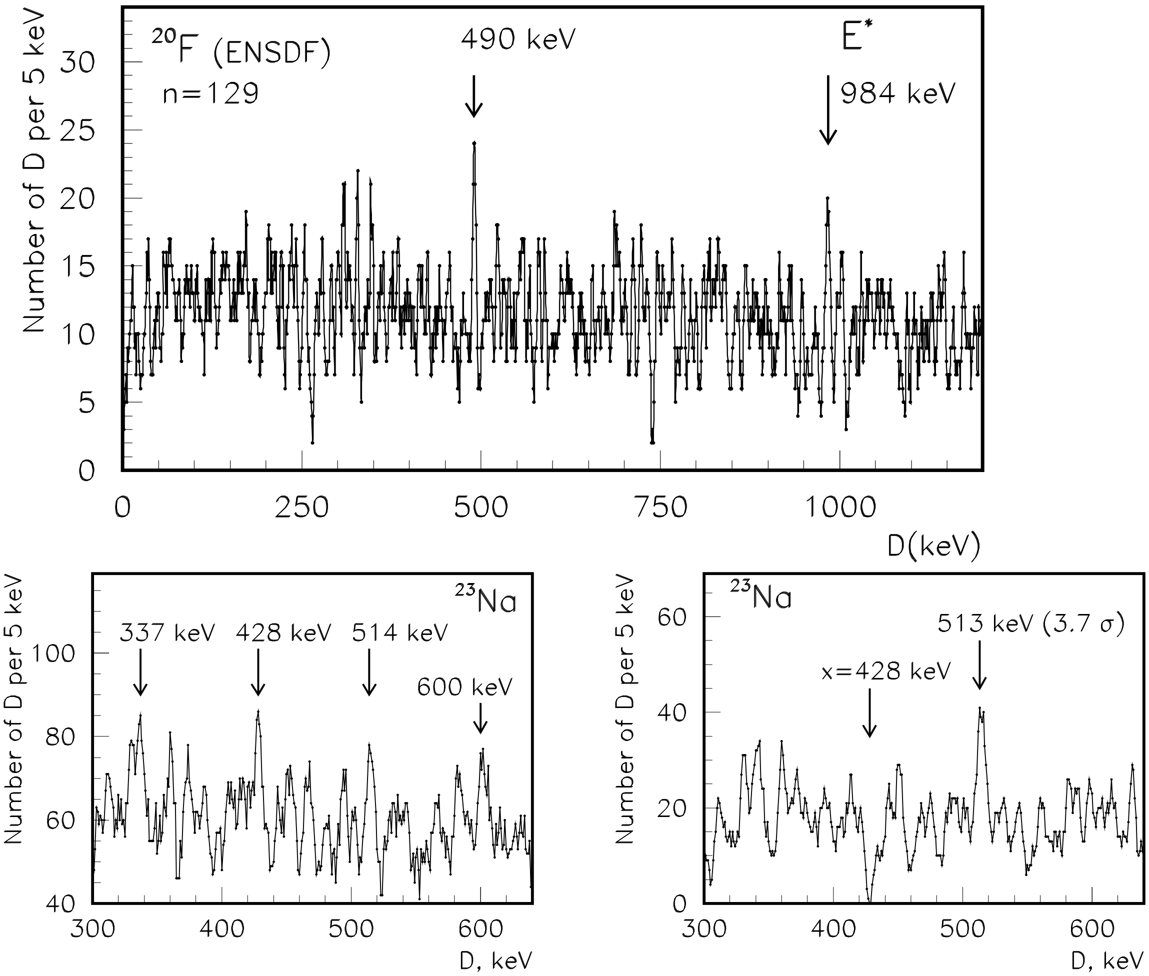

Fig. 7 *Top:* D-distribution for ^{20}F levels in the low-energy regions, stable intervals close to low-lying excitations were noticed, E^* and stable D are marked with arrows. *Bottom:* Spacing distribution in levels of ^{23}Na (n=335) with the maximum at 428 keV and the periodical structure with the parameters of 85 keV checked with the AIM-method (x=428 keV, right).

In spacing distributions of the neighbour N=even isotopes ^{21}Na and ^{23}Na the prominent maxima are located at the same energy 428 keV which in ^{23}Na is a part of the periodical structure with the interval of 85 keV (Fig.7 bottom). The presence of the maximum at the doubled value $D_{\uparrow}^{AIM}$=2x=857 keV corresponds to pairs of such intervals in the spectrum. In the next N=even isotope ^{25}Na (number of known levels n=40) a sequence of three stable intervals D=858(2) keV was noticed. The interval D=x=428 keV itself is composed of intervals 203 keV–226 keV. The interval x=428 keV is adjusted with D=514 keV (seen in the spacing distribution in Fig. 7 left) and with D=247 keV equal to 1/2 of the interval 492 keV in spacing distributions of ^{18,20}F (Table 3, Fig. 6,7.).

The observed rational relations and coincidences in spacing in experimental nuclear spectra of light Z=9-11 nuclei could be used for production of the microscopic nuclear models based on better understanding of nucleon structure.

The tuning effect in particle masses considered in [4,6,8,9] consists in rational relations between the well-know particle masses, namely, masses of muon, pion, neutron, ω-meson, the pion parameter f_π, constant splittng between pseudoscalar mesons, the parameter of residual interaction of constituent quarks (ΔM_Δ) and initial constituent quark mass itself M_q=441 MeV=3ΔM_Δ. They correspond to n=13,17,115,48,16,50,18,54 with the parameter of the discreteness δ=16m_e which is very close to double pion β-decay energy. The initial mass of the baryon in NRCQM has a value about 1320 MeV (three quarks about M_q=436 MeV [10] or M_q=440 MeV from the Ξ-baryon mass [11,12]). Due to the constituent quark interaction this mass becomes the mass of the well-known Δ-baryon (mass 1230 MeV of three quarks with the mass M_q^Δ=410 MeV each). The spin dependent residual interaction is well-known from the nucleon Δ-excitation 2ΔM_Δ=2×147 MeV (close to 2×18δ). Difference m_{Δ^o}–m_n=1233.4(7)–939.57 MeV=293.8(7) MeV=2×146.9(4) MeV coincides with 2×18δ. The mass of nucleons in nuclear medium (m_N^*) is about 8 MeV ($\approx \delta$) less compared with free nucleon mass m_N=115δ (see Fig.9 in [4]). It means that the difference between $m_N^* \approx 114\delta$ and ω-meson mass (6×15δ) accounts about 147 MeV=18δ.

If the preliminary value of scalar field mass M_H=126 GeV [14] will be confirmed, the proximity between ratios in lepton masses $(1/3)m_e/(m_s{=}\Delta M_\Delta{=}147\text{ MeV})/M_H=\alpha/2\pi$ and $m_\mu/M_Z=\alpha/2\pi$ (Table 5) could be connected with the suggestion by V. Belokurov and D. Shirkov that in the electron mass there exists a component proportional to $\alpha/2\pi$ similar to that in the electron magnetic moments (Schwinger term of QED correction). Ratios $(\alpha/2\pi)^{-1}$ in stable nuclear spacing $(\varepsilon_o{=}2m_e)/(\varepsilon'{=}9.5\text{ keV}/8{=}\delta'/8)/(\varepsilon''{=}5.5\text{ eV}/4{=}\delta''/8)$ were introduced in [15]. The parameter of 5.5 eV of superfine structure in spacing of ^{124}Sb was found by K.Ideno and M.Ohkubo [16].

The observed long-range correlations in nuclear data and in nucleon masses themselves are indications on the validity of the common fundamental microscopic approach to the description of results of the nuclear/neutron-resonance spectroscopy.

Table 5 (from [6,8]). Presentation of parameters of tuning effects in particle masses and nuclear data (in lines marked X=-1, 0, 1, 2 at left) by the common expression n·16m$_e(\alpha/2\pi)^X$M with the QED radiative correction $\alpha/2\pi$ (α=137^{-1}). Values m$_\pi$-m$_e$, m$_e$/3, the neutron mass shift N$\delta - m_n - m_e$, m_s and the possible Higgs boson mass [14] are boxed. Stable intervals in excitations (E*, D_{ij}, X=1) and in neutron resonances (X=2) are considered as confirmation of relations in particle masses (X=-1). The value Δ° ≈4 GeV≈ m_b was observed at TEVATRON.

X	M	n = 1	n = 13	n = 16	n = 17	n = 18
-1	3/2			m$_t$=171.2		
GeV	1	2Δ°-2M$_q$	M$_Z$=91.2	M_H=115		M_H=126
0	1	16m$_e$=δ	m$_\mu$ = 105.7	f$_\pi$=131	m$_\pi$-m$_e$	m_s=147-150
MeV	1	2Δ-ε_0	106 = ΔE$_B$	130 = ΔE$_B$	140 = ΔE$_B$	147.2 = ΔE$_B$
	1					m$_\Delta$-m$_n$/2=147
	3			M"$_q$ = m$_\rho$/2	NRCQM	M$_q$=441=ΔE$_B$
1	1				Nδ-m$_n$-m$_e$=161.6(1)	170 = m$_e$/3
keV	1	9.5	123	152	161 (^{18}F, Sb)	512 (Co, Pd)
	4		492		648 (^{97,98}Pd)	682(Co)
	8		984	1212	1293 (Pd), ΣE^*	1360 (Te)
2	1	11	143	176	187, 749 (^{79}Br)	D in neutron
eV	4	44	570 (Sb)		1500 (Sb,Pd,Rh)	resonances

4 Discreteness in parameters of nucleon interaction

Dependence of neutron separation energy S_n on the proton number (shown in Fig.8) in case of near-magic nuclei with N=83 and Z=57-61 (^{140}La-^{142}Pr-^{144}Pm, $\nu 2f_{7/2}$ and $\pi 2d_{5/2}$–$\pi 1g_{7/2}$) has exactly linear character with the parameter $\varepsilon_{n,2p}$=683(1) keV=(2/3)ε_o (boxed values at the bottom of Fig.8. The same $\varepsilon_{n,2p}$=688(4) keV and $\varepsilon_{n,2n}$=339(3) keV=(1/3)ε_o correspond to differences in S_n=7493-6806-6467 keV for nuclei ^{124}I-^{122}Sb-^{124}Sb (N=71, $\nu 1h_{11/2}$, dark triangle and the box in the middle of Fig.8). In Fig.9 it is seen as maxima in distributions of standard parameters ε_{n2n} and ε_{n2p}. In the isotopes under discussion ^{122,124}Sb these parameters are close to maxima of distributions.

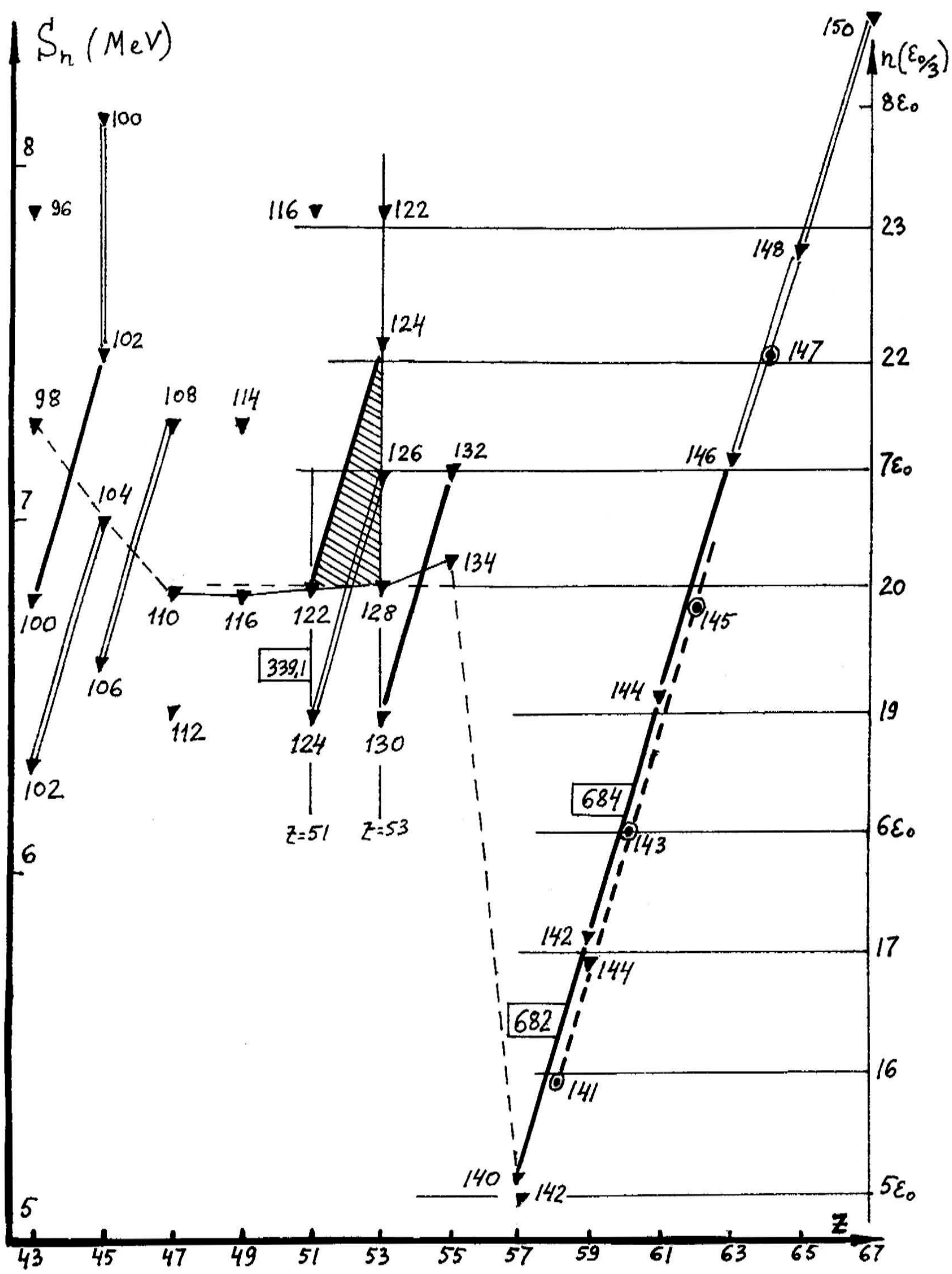

Fig. 8 Dependence of the neutron separation energy S_n on the proton number Z=43-67.

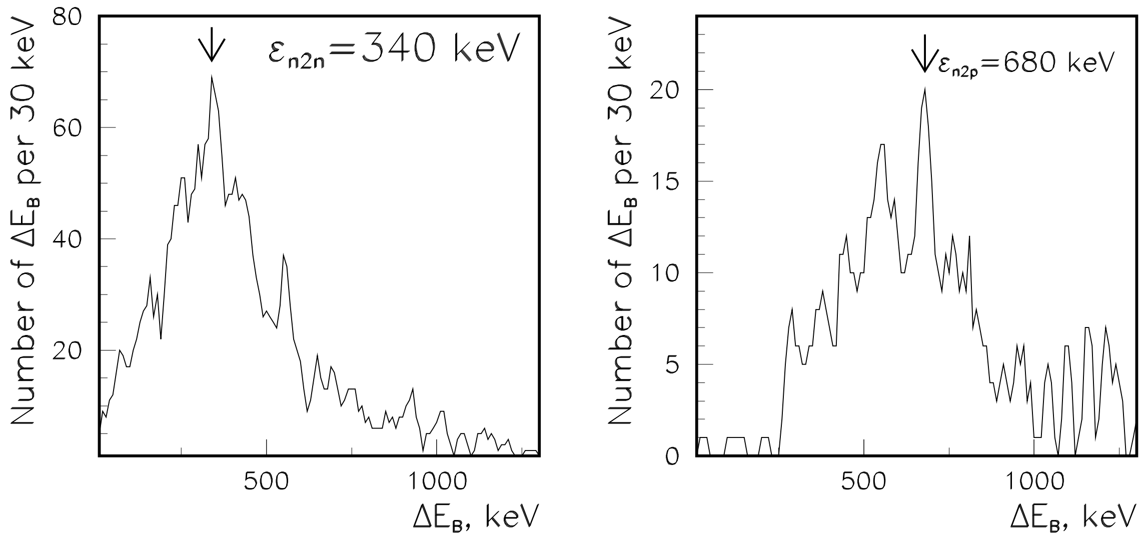

Fig. 9 *Left and right:* Distributions of residual nucleon interaction parameters ε_{n2n} and ε_{n2p}.

5 Conclusions

Presence of stable mass/energy intervals in the regions where the dominance of the pion-exchange dynamics is expected permitted the observation of common tuning effects, the estimation of the common parameters and long-range correlations in nuclear and particle data. Importance of expanding data on highly excited states and the confirmation of the scalar mass SM parameter is outlined.

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